



### GENERAL FEATURES

- Wide supply voltage operation: 2.4 V to 3.7 V
- Internal bipolar switch between regulated and battery inputs
- Ultralow power operation with power saving modes (PSM)
  - Full operation: 4 mA to 1.6 mA (PLL clock dependent)
  - Battery mode: 3.2 mA to 400  $\mu$ A (PLL clock dependent)
  - Sleep mode
    - Real-time clock (RTC) mode: 1.5  $\mu$ A
    - RTC and LCD mode: 38  $\mu$ A (LCD charge pump enabled)
- Reference: 1.2 V  $\pm$  0.1% (10 ppm/ $^{\circ}$ C drift)
- 64-lead RoHS package options
  - Low profile quad flat package (LQFP)
- Operating temperature range:  $-40^{\circ}$ C to  $+85^{\circ}$ C

### ENERGY MEASUREMENT FEATURES

- Proprietary analog-to-digital converters (ADCs) and digital signal processing (DSP) provide high accuracy active (watt), reactive (var), and apparent energy (volt-ampere (VA)) measurement
  - <0.1% error on active energy over a dynamic range of 1000 to 1 @  $25^{\circ}$ C
  - <0.5% error on reactive energy over a dynamic range of 1000 to 1 @  $25^{\circ}$ C (ADE5169 only)
  - <0.5% error on root mean square (rms) measurements over a dynamic range of 500 to 1 for current ( $I_{rms}$ ) and 100 to 1 for voltage ( $V_{rms}$ ) @  $25^{\circ}$ C
- Supports IEC 62053-21, IEC 62053-22, IEC 62053-23, EN 50470-3 Class A, Class B, and Class C, and ANSI C12-16
- Differential input with programmable gain amplifiers (PGAs) supports shunts, current transformers, and di/dt current sensors
- 2 current inputs for antitamper detection in the ADE5169
- High frequency outputs proportional to  $I_{rms}$ , active, reactive, or apparent power (AP)

Table 1. Features Available on Each Part

| Feature                         | Part No.         |
|---------------------------------|------------------|
| Antitamper                      | ADE5166, ADE5169 |
| WATT, VA, $I_{rms}$ , $V_{rms}$ | ADE5166, ADE5169 |
| VAR                             | ADE5169          |
| di/dt Sensor                    | ADE5169          |

### MICROPROCESSOR FEATURES

- 8052-based core
  - Single-cycle 4 MIPS 8052 core
  - 8052-compatible instruction set
  - 32.768 kHz external crystal with on-chip PLL
  - 2 external interrupt sources
  - External reset pin
- Low power battery mode
  - Wake-up from I/O, temperature change, alarm, and universal asynchronous receiver/transmitter (UART)
  - LCD driver operation with automatic scrolling
  - Temperature measurement
- Real-time clock (RTC)
  - Counter for seconds, minutes, hours, days, months, and years
  - Date counter, including leap year compensation
  - Automatic battery switchover for RTC backup
  - Operation down to 2.4 V
  - Ultralow battery supply current: 1.5  $\mu$ A
  - Selectable output frequency: 1 Hz to 16 kHz
  - Embedded digital crystal frequency compensation for calibration and temperature variation of 2 ppm resolution
- Integrated LCD driver
  - 104-segment driver for the ADE5166 and ADE5169
  - 2 $\times$ , 3 $\times$ , or 4 $\times$  multiplexing
  - 4 LCD memory banks for screen scrolling
  - LCD voltages generated internally or with external resistors
  - Internal adjustable drive voltages up to 5 V independent of power supply level
- On-chip peripherals
  - 2 independent UART interfaces
  - SPI or I<sup>2</sup>C
  - Watchdog timer
- Power supply management with user-selectable levels
- Memory: 62 kB flash memory, 2.256 kB RAM
- Development tools
  - Single-pin emulation
  - IDE-based assembly and C-source debugging

### Rev. 0

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## TABLE OF CONTENTS

|   |    |   |    |
|---|----|---|----|
| General Features .....                                | 1  | di/dt Current Sensor and Digital Integrator (ADE5169) ..... | 47 |
| Energy Measurement Features .....                     | 1  | Power Quality Measurements .....                            | 48 |
| Microprocessor Features .....                         | 1  | Phase Compensation .....                                    | 50 |
| Revision History .....                                | 3  | RMS Calculation .....                                       | 51 |
| General Description .....                             | 4  | Active Power Calculation .....                              | 53 |
| Functional Block Diagram .....                        | 4  | Active Energy Calculation .....                             | 55 |
| Specifications .....                                  | 5  | Reactive Power Calculation (ADE5169) .....                  | 58 |
| Energy Metering .....                                 | 5  | Reactive Energy Calculation (ADE5169) .....                 | 60 |
| Analog Peripherals .....                              | 6  | Apparent Power Calculation .....                            | 63 |
| Digital Interface .....                               | 7  | Apparent Energy Calculation .....                           | 63 |
| Timing Specifications .....                           | 9  | Ampere-Hour Accumulation .....                              | 65 |
| Absolute Maximum Ratings .....                        | 14 | Energy-to-Frequency Conversion .....                        | 66 |
| Thermal Resistance .....                              | 14 | Energy Register Scaling .....                               | 66 |
| ESD Caution .....                                     | 14 | Energy Measurement Interrupts .....                         | 67 |
| Pin Configuration and Function Descriptions .....     | 15 | Temperature, Battery, and Supply Voltage Measurements ..... | 68 |
| Typical Performance Characteristics .....             | 17 | Temperature Measurement .....                               | 70 |
| Terminology .....                                     | 21 | Battery Measurement .....                                   | 70 |
| Special Function Register (SFR) Mapping .....         | 22 | External Voltage Measurement .....                          | 71 |
| Power Management .....                                | 24 | 8052 MCU Core Architecture .....                            | 73 |
| Power Management Register Details .....               | 24 | MCU Registers .....   | 73 |
| Power Supply Architecture .....                       | 27 | Basic 8052 Registers .....                                  | 75 |
| Battery Switchover .....                              | 27 | Standard 8052 SFRs .....                                    | 77 |
| Power Supply Management (PSM) Interrupt .....         | 27 | Memory Overview .....                                       | 77 |
| Using the Power Supply Features .....                 | 29 | Addressing Modes .....                                      | 78 |
| Operating Modes .....                                 | 32 | Instruction Set .....                                       | 80 |
| PSM0 (Normal Mode) .....                              | 32 | Read-Modify-Write Instructions .....                        | 82 |
| PSM1 (Battery Mode) .....                             | 32 | Instructions That Affect Flags .....                        | 82 |
| PSM2 (Sleep Mode) .....                               | 32 | Dual Data Pointers .....                                    | 84 |
| 3.3 V Peripherals and Wake-Up Events .....            | 33 | Interrupt System .....                                      | 85 |
| Transitioning Between Operating Modes .....           | 34 | Standard 8052 Interrupt Architecture .....                  | 85 |
| Using the Power Management Features .....             | 34 | Interrupt Architecture .....                                | 85 |
| Energy Measurement .....                              | 35 | Interrupt Registers .....                                   | 85 |
| Access to Energy Measurement SFRs .....               | 35 | Interrupt Priority .....                                    | 86 |
| Access to Internal Energy Measurement Registers ..... | 35 | Interrupt Flags .....                                       | 87 |
| Energy Measurement Registers .....                    | 37 | Interrupt Vectors .....                                     | 89 |
| Energy Measurement Internal Register Details .....    | 38 | Interrupt Latency .....                                     | 89 |
| Interrupt Status/Enable SFRs .....                    | 41 | Context Saving .....  | 89 |
| Analog Inputs .....                                   | 42 | Watchdog Timer .....  | 90 |
| Analog-to-Digital Conversion .....                    | 43 | LCD Driver .....  | 92 |
| Fault Detection .....                                 | 46 | LCD Registers .....   | 92 |

|   |  |
|---|--|
| LCD Setup.....95                          | UART Operation Modes.....123                           |
| LCD Timing and Waveforms .....95          | UART Baud Rate Generation .....124                     |
| Blink Mode.....96                         | UART Additional Features .....126                      |
| Scrolling Mode .....96                    | UART2 Serial Interface.....127                         |
| Display Element Control.....96            | UART2 SFRs .....127                                    |
| Voltage Generation .....97                | UART2 Operation Mode .....129                          |
| LCD External Circuitry.....97             | UART2 Baud Rate Generation .....129                    |
| LCD Function in PSM2.....98               | UART2 Additional Features .....130                     |
| Flash Memory.....99                       | Serial Peripheral Interface (SPI).....131              |
| Flash Memory Overview.....99              | SPI Registers .....131                                 |
| Flash Memory Organization.....99          | SPI Pins.....134                                       |
| Using the Flash Memory .....100           | SPI Master Operating Modes .....135                    |
| Protecting the Flash Memory .....103      | SPI Interrupt and Status Flags .....136                |
| In Circuit Programming .....105           | I <sup>2</sup> C-Compatible Interface .....137         |
| Timers.....106                            | Serial Clock Generation .....137                       |
| Timer Registers.....106                   | Slave Addresses.....137                                |
| Timer 0 and Timer 1.....108               | I <sup>2</sup> C Registers.....137                     |
| Timer 2 .....109                          | Read and Write Operations .....138                     |
| PLL .....111                              | I <sup>2</sup> C Receive and Transmit FIFOs.....139    |
| PLL Registers .....111                    | I/O Ports.....140                                      |
| Real-Time Clock (RTC) .....112            | Parallel I/O .....140                                  |
| Access to RTC SFRs .....112               | I/O Registers .....141                                 |
| Access to Internal RTC Registers .....112 | Port 0.....144   |
| RTC SFRs .....113                         | Port 1.....144   |
| RTC Registers .....116                    | Port 2.....144   |
| RTC Calendar .....117                     | Determining the Version of the ADE5166/ADE5169.....145 |
| RTC Interrupts .....118                   | Outline Dimensions.....146                             |
| RTC Crystal Compensation.....119          | Ordering Guide .....146                                |
| UART Serial Interface.....120             |  |
| UART SFRs .....120                        |  |

## REVISION HISTORY

10/08—Revision 0: Initial Version

# ADE5166/ADE5169

## GENERAL DESCRIPTION

The ADE5166/ADE5169<sup>1</sup> integrate the Analog Devices, Inc., energy (ADE) metering IC analog front end and fixed function DSP solution with an enhanced 8052 MCU core, a full RTC, an LCD driver, and all the peripherals to make an electronic energy meter with an LCD display in a single part.

The ADE measurement core includes active, reactive, and apparent energy calculations, as well as voltage and current rms measurements. This information is accessible for energy billing by using the built-in energy scalars. Many power line supervisory features such as SAG, peak, and zero crossing are included in the energy measurement DSP to simplify energy meter design.

<sup>1</sup> Patents pending.

The microprocessor functionality includes a single-cycle 8052 core, a full RTC with a power supply backup pin, an SPI or I<sup>2</sup>C<sup>®</sup> interface, and two independent UART interfaces. The ready-to-use information from the ADE core reduces the requirement for program memory size, making it easy to integrate complicated design into 62 kB of flash memory.

The ADE5166/ADE5169 include a 104-segment LCD driver with the capability to store up to four LCD screens in memory. This driver generates voltages capable of driving LCDs up to 5 V.

## FUNCTIONAL BLOCK DIAGRAM

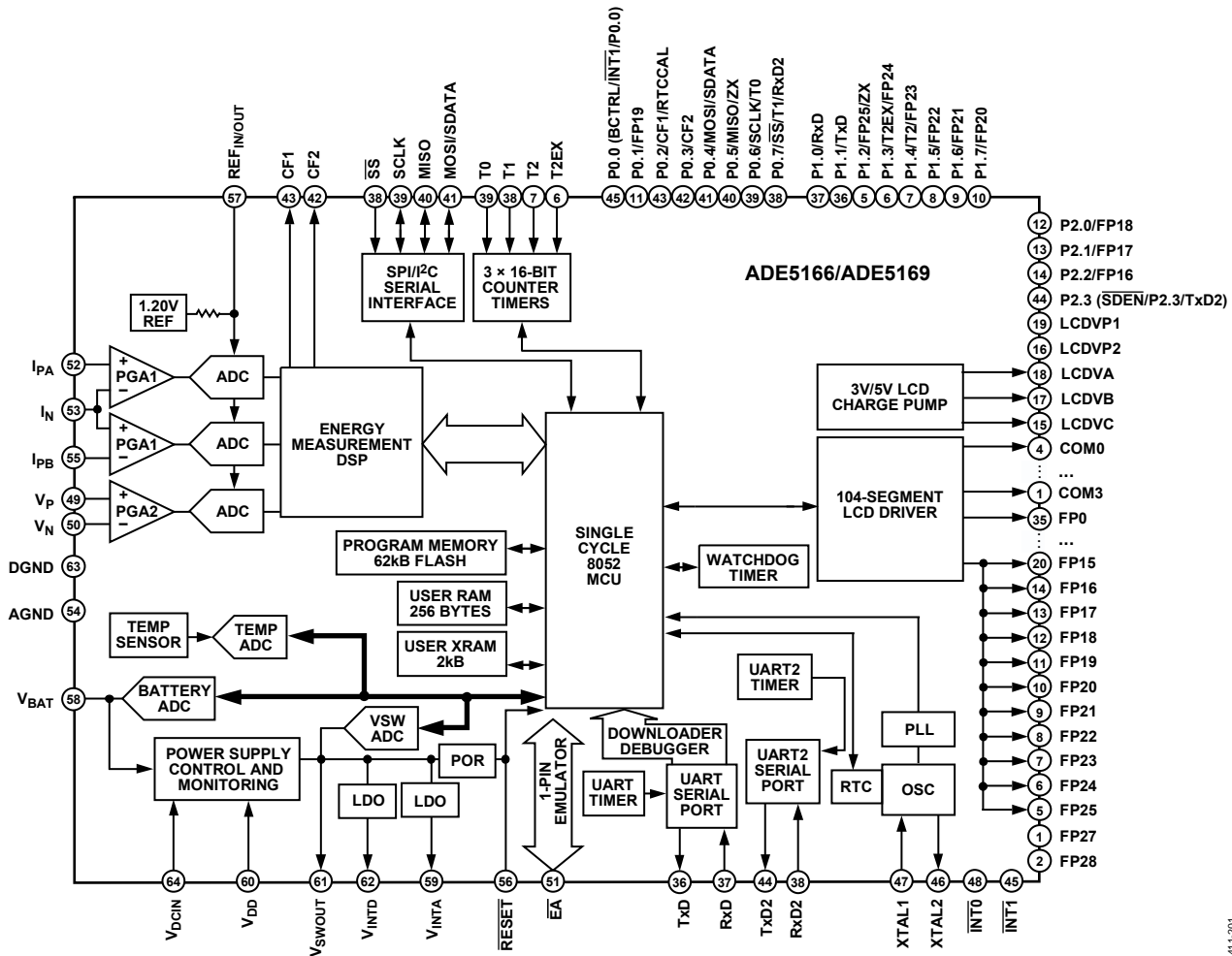


Figure 1.

## SPECIFICATIONS

$V_{DD} = 3.3\text{ V} \pm 5\%$ ,  $AGND = DGND = 0\text{ V}$ , on-chip reference  $XTALx = 32.768\text{ kHz}$ ,  $T_{MIN}$  to  $T_{MAX} = -40^{\circ}\text{C}$  to  $+85^{\circ}\text{C}$ , unless otherwise noted.

### ENERGY METERING

Table 2.

| Parameter  | Min | Typ   | Max          | Unit               | Test Conditions/Comments  |
|--|-----|-------|--------------|--------------------|---|
| <b>MEASUREMENT ACCURACY<sup>1</sup></b>          |     |       |              |                    |   |
| Phase Error Between Channels                     |     |       |              |                    |   |
| PF = 0.8 Capacitive                              |     | ±0.05 |              | Degrees            | Phase lead: 37°   |
| PF = 0.5 Inductive                               |     | ±0.05 |              | Degrees            | Phase lag: 60°  |
| Active Energy Measurement Error <sup>2</sup>     |     | 0.1   |              | % of reading       | Over a dynamic range of 1000 to 1 @ 25°C  |
| AC Power Supply Rejection <sup>2</sup>           |     |       |              |                    | $V_{DD} = 3.3\text{ V} + 100\text{ mV rms}/120\text{ Hz}$                               |
| Output Frequency Variation                       |     | 0.01  |              | %                  | $I_{Px} = V_P = \pm 100\text{ mV rms}$  |
| DC Power Supply Rejection <sup>2</sup>           |     |       |              |                    | $V_{DD} = 3.3\text{ V} \pm 117\text{ mV dc}$  |
| Output Frequency Variation                       |     | 0.01  |              | %                  |   |
| Active Energy Measurement Bandwidth <sup>1</sup> |     | 8     |              | kHz                |   |
| Reactive Energy Measurement Error <sup>2</sup>   |     | 0.5   |              | % of reading       | Over a dynamic range of 1000 to 1 @ 25°C  |
| $V_{rms}$ Measurement Error <sup>2</sup>         |     | 0.5   |              | % of reading       | Over a dynamic range of 100 to 1 @ 25°C   |
| $V_{rms}$ Measurement Bandwidth <sup>1</sup>     |     | 3.9   |              | kHz                |   |
| $I_{rms}$ Measurement Error <sup>2</sup>         |     | 0.5   |              | % of reading       | Over a dynamic range of 500 to 1 @ 25°C   |
| $I_{rms}$ Measurement Bandwidth <sup>1</sup>     |     | 3.9   |              | kHz                |   |
| <b>ANALOG INPUTS</b>                             |     |       |              |                    |   |
| Maximum Signal Levels                            |     |       | ±500<br>±500 | mV peak<br>mV peak | $V_P - V_N$ differential input<br>$I_{PA} - I_N$ and $I_{PB} - I_N$ differential inputs |
| Input Impedance (DC)                             |     | 770   |              | kΩ                 |   |
| ADC Offset Error <sup>2</sup>                    |     | ±10   |              | mV                 | PGA1 = PGA2 = 1   |
|  |     | ±1    |              | mV                 | PGA1 = 16   |
| Gain Error <sup>2</sup>                          |     |       |              |                    |   |
| Current Channel                                  |     | ±3    |              | %                  | $I_{PA} = I_{PB} = 0.5\text{ V dc}$   |
| Voltage Channel                                  |     | ±3    |              | %                  | $V_P - V_N = 0.5\text{ V dc}$   |
| Gain Error Match                                 |     | ±0.2  |              | %                  |   |
| <b>CF1 AND CF2 PULSE OUTPUT</b>                  |     |       |              |                    |   |
| Maximum Output Frequency                         |     | 21.6  |              | kHz                | $V_P - V_N = 500\text{ mV peak}$ , $I_{PA} - I_N = 500\text{ mV}$                       |
| Duty Cycle                                       |     | 50    |              | %                  | If CF1 or CF2 frequency, >5.55 Hz   |
| Active High Pulse Width                          |     | 90    |              | ms                 | If CF1 or CF2 frequency, <5.55 Hz   |
| <b>FAULT DETECTION</b>                           |     |       |              |                    |   |
| Fault Detection Threshold                        |     |       |              |                    |   |
| Inactive Input ≠ Active Input                    |     | 6.25  |              | %, of active       | $I_{PA}$ or $I_{PB}$ active   |
| Input Swap Threshold                             |     |       |              |                    |   |
| Inactive Input > Active Input                    |     | 6.25  |              | %, of active       | $I_{PA}$ or $I_{PB}$ active   |
| Accuracy Fault Mode Operation                    |     |       |              |                    |   |
| $I_{PA}$ Active, $I_{PB} = AGND$                 |     | 0.1   |              | % of reading       | Over a dynamic range of 500 to 1  |
| $I_{PB}$ Active, $I_{PA} = AGND$                 |     | 0.1   |              | % of reading       | Over a dynamic range of 500 to 1  |
| Fault Detection Delay                            |     | 3     |              | Seconds            |   |
| Swap Delay                                       |     | 3     |              | Seconds            |   |

<sup>1</sup> These specifications are not production tested but are guaranteed by design and/or characterization data on production release.

<sup>2</sup> See the Terminology section for definition.

# ADE5166/ADE5169

## ANALOG PERIPHERALS

Table 3.

| Parameter   | Min         | Typ  | Max   | Unit   | Test Conditions/Comments   |   |
|---|-------------|------|-------|--------|--|---|
| <b>INTERNAL ADCs (BATTERY, TEMPERATURE, V<sub>DCIN</sub>)</b> |             |      |       |        |  |   |
| Power Supply Operating Range                                  | 2.4         |      | 3.7   | V      | Measured on V <sub>SWOUT</sub>   |   |
| No Missing Codes <sup>1</sup>                                 | 8           |      |       | Bits   |  |   |
| Conversion Delay <sup>2</sup>                                 |             | 38   |       | μs     |  |   |
| ADC Gain  |             |      |       |        |  |   |
| V <sub>DCIN</sub> Measurement                                 |             | 15.3 |       | mV/LSB |  |   |
| V <sub>BAT</sub> Measurement                                  |             | 14.6 |       | mV/LSB |  |   |
| Temperature Measurement                                       |             | 0.83 |       | °C/LSB |  |   |
| ADC Offset  |             |      |       |        |  |   |
| V <sub>DCIN</sub> Measurement at 3 V                          |             | 200  |       | LSB    |  |   |
| V <sub>BAT</sub> Measurement at 3.7 V                         |             | 246  |       | LSB    |  |   |
| Temperature Measurement at 25°C                               |             | 123  |       | LSB    |  |   |
| <b>V<sub>DCIN</sub> Analog Input</b>                          |             |      |       |        |  |   |
| Maximum Signal Levels   | 0           |      | 3.3   | V      |  |   |
| Input Impedance (DC)  | 1           |      |       | MΩ     |  |   |
| Low V <sub>DCIN</sub> Detection Threshold                     | 1.09        | 1.2  | 1.27  | V      |  |   |
| <b>POWER-ON RESET (POR)</b>                                   |             |      |       |        |  |   |
| <b>V<sub>DD</sub> POR</b>                                     |             |      |       |        |  |   |
| Detection Threshold   | 2.5         |      | 2.95  | V      |  |   |
| POR Active Timeout Period                                     |             | 33   |       | ms     |  |   |
| <b>V<sub>SWOUT</sub> POR</b>                                  |             |      |       |        |  |   |
| Detection Threshold   | 1.8         |      | 2.2   | V      |  |   |
| POR Active Timeout Period                                     |             | 20   |       | ms     |  |   |
| <b>V<sub>INTD</sub> POR</b>                                   |             |      |       |        |  |   |
| Detection Threshold   | 2.0         |      | 2.25  | V      |  |   |
| POR Active Timeout Period                                     |             | 16   |       | ms     |  |   |
| <b>V<sub>INTA</sub> POR</b>                                   |             |      |       |        |  |   |
| Detection Threshold   | 2.0         |      | 2.25  | V      |  |   |
| POR Active Timeout Period                                     |             | 120  |       | ms     |  |   |
| <b>BATTERY SWITCH OVER</b>                                    |             |      |       |        |  |   |
| Voltage Operating Range (V <sub>SWOUT</sub> )                 | 2.4         |      | 3.7   | V      | When V <sub>DD</sub> to V <sub>BAT</sub> switch activated by V <sub>DD</sub><br>When V <sub>DD</sub> to V <sub>BAT</sub> switch activated by V <sub>DCIN</sub>                               |   |
| <b>V<sub>DD</sub> to V<sub>BAT</sub> Switching</b>            |             |      |       |        |  |   |
| Switching Threshold (V <sub>DD</sub> )                        | 2.5         |      | 2.95  | V      |  |   |
| Switching Delay   |             | 10   |       | ns     |  |   |
|   |             | 30   |       | ms     |  |   |
| <b>V<sub>BAT</sub> to V<sub>DD</sub> Switching</b>            |             |      |       |        |  |   |
| Switching Threshold (V <sub>DD</sub> )                        | 2.5         |      | 2.95  | V      |  |   |
| Switching Delay   |             | 30   |       | ms     |  |   |
| V <sub>SWOUT</sub> To V <sub>BAT</sub> Leakage Current        |             | 10   |       | nA     |  |   |
|   |             |      |       |        |  | Based on V <sub>DD</sub> > 2.75 V<br>V <sub>BAT</sub> = 0 V, V <sub>SWOUT</sub> = 3.43 V, T <sub>A</sub> = 25°C |
| <b>LCD, CHARGE PUMP ACTIVE</b>                                |             |      |       |        |  |   |
| Charge Pump Capacitance Between LCDVP1 and LCDVP2             | 100         |      |       | nF     | 1/3 bias mode<br>1/3 bias mode<br>Current on segment line = -2 μA<br>Current on segment line = -2 μA<br>Current on segment line = -2 μA<br>LCDVC – LCDVB, LCDVC – LCDVA, or<br>LCDVB – LCDVA |   |
| LCDVA, LCDVB, LCDVC Decoupling Capacitance                    | 470         |      |       | nF     |  |   |
| LCDVA   | 0           |      | 1.9   | V      |  |   |
| LCDVB   | 0           |      | 3.8   | V      |  |   |
| LCDVC   | 0           |      | 5.8   | V      |  |   |
| V1 Segment Line Voltage                                       | LCDVA – 0.1 |      | LCDVA | V      |  |   |
| V2 Segment Line Voltage                                       | LCDVB – 0.1 |      | LCDVB | V      |  |   |
| V3 Segment Line Voltage                                       | LCDVC – 0.1 |      | LCDVC | V      |  |   |
| DC Voltage Across Segment and COMx Pin                        |             |      | 50    | mV     |  |   |

| Parameter                            | Min         | Typ | Max   | Unit   | Test Conditions/Comments                             |
|--------------------------------------|-------------|-----|-------|--------|--|
| LCD, RESISTOR LADDER ACTIVE          |             |     |       |        |  |
| Leakage Current                      |             | ±20 |       | nA     | 1/2 and 1/3 bias modes, no load                      |
| V1 Segment Line Voltage              | LCDVA – 0.1 |     | LCDVA | V      | Current on segment line = –2 μA                      |
| V2 Segment Line Voltage              | LCDVB – 0.1 |     | LCDVB | V      | Current on segment line = –2 μA                      |
| V3 Segment Line Voltage              | LCDVC – 0.1 |     | LCDVC | V      | Current on segment line = –2 μA                      |
| ON-CHIP REFERENCE                    |             |     |       |        | Nominal 1.2035 V                                     |
| Reference Error                      | –2.2        |     | +2.2  | mV     | T <sub>A</sub> = 25°C, F <sub>core</sub> = 1.024 MHz |
| Power Supply Rejection               |             | 80  |       | dB     |  |
| Temperature Coefficient <sup>1</sup> |             | 10  | 50    | ppm/°C | F <sub>core</sub> = 1.024 MHz                        |

<sup>1</sup> These specifications are not production tested but are guaranteed by design and/or characterization data on production release.

<sup>2</sup> Delay between ADC conversion request and interrupt set.

## DIGITAL INTERFACE

**Table 4.**

| Parameter   | Min    | Typ    | Max  | Unit   | Test Conditions/Comments  |
|---|--------|--------|------|--------|---|
| LOGIC INPUTS <sup>1</sup>   |        |        |      |        |   |
| All Inputs Except XTAL1, XTAL2, BCTRL, $\overline{\text{INT0}}$ , INT1, RESET |        |        |      |        |   |
| Input High Voltage, V <sub>INH</sub>  | 2.0    |        |      | V      |   |
| Input Low Voltage, V <sub>INL</sub>   |        |        | 0.8  | V      |   |
| BCTRL, $\overline{\text{INT0}}$ , INT1, RESET                                 |        |        |      |        |   |
| Input High Voltage, V <sub>INH</sub>  | 1.3    |        |      | V      |   |
| Input Low Voltage, V <sub>INL</sub>   |        |        | 0.8  | V      |   |
| Input Currents  |        |        |      |        |   |
| $\overline{\text{RESET}}$   |        |        | 100  | nA     | $\overline{\text{RESET}} = V_{\text{SWOUT}} = 3.3 \text{ V}$      |
| Port 0, Port 1, Port 2  |        |        | ±100 | nA     | Internal pull-up disabled, input = 0 V or V <sub>SWOUT</sub>      |
|   | –3.75  |        | –8.5 | μA     | Internal pull-up enabled, input = 0 V, V <sub>SWOUT</sub> = 3.3 V |
| Input Capacitance   |        | 10     |      | pF     | All digital inputs  |
| FLASH MEMORY  |        |        |      |        |   |
| Endurance <sup>2</sup>  | 20,000 |        |      | Cycles |   |
| Data Retention <sup>3</sup>   | 20     |        |      | Years  | T <sub>J</sub> = 85°C   |
| CRYSTAL OSCILLATOR <sup>4</sup>   |        |        |      |        |   |
| Crystal Equivalent Series Resistance  | 30     |        | 50   | kΩ     |   |
| Crystal Frequency   | 32     | 32.768 | 33.5 | kHz    |   |
| XTAL1 Input Capacitance   |        | 12     |      | pF     |   |
| XTAL2 Output Capacitance  |        | 12     |      | pF     |   |
| MCU CLOCK RATE (f <sub>core</sub> )   |        | 4.096  |      | MHz    | Crystal = 32.768 kHz and CD[2:0] = 0                              |
|   |        | 32     |      | kHz    | Crystal = 32.768 kHz and CD[2:0] = 0b111                          |
| LOGIC OUTPUTS   |        |        |      |        |   |
| Output High Voltage, V <sub>OH</sub>  | 2.4    |        |      | V      | V <sub>DD</sub> = 3.3 V ± 5%                                      |
| I <sub>SOURCE</sub>   |        |        | 80   | μA     |   |
| Output Low Voltage, V <sub>OL</sub> <sup>5</sup>                              |        |        | 0.4  | V      | V <sub>DD</sub> = 3.3 V ± 5%                                      |
| I <sub>SINK</sub>   |        |        | 2    | mA     |   |
| START-UP TIME <sup>6</sup>  |        |        |      |        |   |
| PSM0 Power-On Time  |        | 880    |      | ms     | V <sub>DD</sub> at 2.75 V to PSM0 code execution                  |
| From Power Saving Mode 1 (PSM1)   |        |        |      |        |   |
| PSM1 to PSM0  |        | 130    |      | ms     | V <sub>DD</sub> at 2.75 V to PSM0 code execution                  |
| From Power Saving Mode 2 (PSM2)   |        |        |      |        |   |
| PSM2 to PSM1  |        | 48     |      | ms     | Wake-up event to PSM1 code execution                              |
| PSM2 to PSM0  |        | 186    |      | ms     | V <sub>DD</sub> at 2.75 V to PSM0 code execution                  |

# ADE5166/ADE5169

| Parameter  | Min  | Typ | Max  | Unit | Test Conditions/Comments   |
|--|------|-----|------|------|--|
| <b>POWER SUPPLY INPUTS</b>                                   |      |     |      |      |  |
| V <sub>DD</sub>  | 3.13 | 3.3 | 3.46 | V    |  |
| V <sub>BAT</sub>   | 2.4  | 3.3 | 3.7  | V    |  |
| <b>INTERNAL POWER SUPPLY SWITCH (V<sub>SWOUT</sub>)</b>      |      |     |      |      |  |
| V <sub>BAT</sub> to V <sub>SWOUT</sub> On Resistance         |      |     | 12   | Ω    | V <sub>BAT</sub> = 2.4 V   |
| V <sub>DD</sub> to V <sub>SWOUT</sub> On Resistance          |      |     | 9    | Ω    | V <sub>DD</sub> = 3.13 V   |
| V <sub>BAT</sub> to/from V <sub>DD</sub> Switching Open Time |      | 40  |      | ns   |  |
| BCTRL State Change and Switch Delay                          |      | 18  |      | μs   |  |
| V <sub>SWOUT</sub> Output Current Drive                      |      |     | 6    | mA   |  |
| <b>POWER SUPPLY OUTPUTS</b>                                  |      |     |      |      |  |
| V <sub>INTA</sub>  | 2.3  |     | 2.70 | V    |  |
| V <sub>INTD</sub>  | 2.3  |     | 2.70 | V    |  |
| V <sub>INTA</sub> Power Supply Rejection                     |      | 60  |      | dB   |  |
| V <sub>INTD</sub> Power Supply Rejection                     |      | 50  |      | dB   |  |
| <b>POWER SUPPLY CURRENTS</b>                                 |      |     |      |      |  |
| Current in Normal Mode (PSM0)                                |      | 4.4 | 5.3  | mA   | f <sub>CORE</sub> = 4.096 MHz, LCD and meter active                  |
|  |      | 2.2 |      | mA   | f <sub>CORE</sub> = 1.024 MHz, LCD and meter active                  |
|  |      | 1.6 |      | mA   | f <sub>CORE</sub> = 32.768 kHz, LCD and meter active                 |
|  |      | 3   | 3.9  | mA   | f <sub>CORE</sub> = 4.096 MHz, metering ADC and DSP powered down     |
| Current in PSM1  |      | 3.3 | 5.05 | mA   | f <sub>CORE</sub> = 4.096 MHz, LCD active, V <sub>BAT</sub> = 3.7 V  |
|  |      | 1   |      | mA   | f <sub>CORE</sub> = 1.024 MHz, LCD active                            |
| Current in PSM2  |      | 38  |      | μA   | LCD active with charge pump at 3.3 V + RTC, V <sub>BAT</sub> = 3.3 V |
|  |      | 1.7 |      | μA   | RTC only, T <sub>A</sub> = 25°C, V <sub>BAT</sub> = 3.3 V            |

<sup>1</sup> Specifications guaranteed by design.

<sup>2</sup> Endurance is qualified as per JEDEC Standard 22 Method A117 and measured at -40°C, +25°C, +85°C, and +125°C.

<sup>3</sup> Retention lifetime equivalent at junction temperature (T<sub>J</sub>) = 85°C as per JEDEC Standard 22 Method A117. Retention lifetime derates with junction temperature.

<sup>4</sup> Recommended crystal specifications.

<sup>5</sup> Test carried out with all the I/Os set to a low output level.

<sup>6</sup> Delay between power supply valid and execution of first instruction by 8052 core.



**TIMING SPECIFICATIONS**

AC inputs during testing were driven at  $V_{SWOUT} - 0.5\text{ V}$  for Logic 1 and at  $0.45\text{ V}$  for Logic 0. Timing measurements were made at  $V_{IH}$  minimum for Logic 1 and at  $V_{IL}$  maximum for Logic 0, as shown in Figure 2.

For timing purposes, a port pin is no longer floating when a  $100\text{ mV}$  change from load voltage occurs. A port pin begins to float when a  $100\text{ mV}$  change from the loaded  $V_{OH}/V_{OL}$  level occurs, as shown in Figure 2.

$C_{LOAD}$  for all outputs =  $80\text{ pF}$ , unless otherwise noted.  $V_{DD} = 2.7\text{ V}$  to  $3.6\text{ V}$ ; all specifications  $T_{MIN}$  to  $T_{MAX}$ , unless otherwise noted.

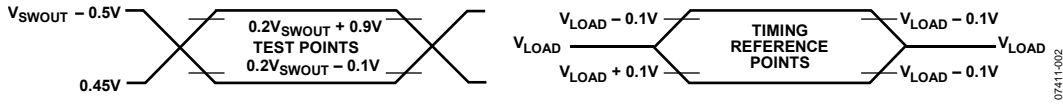


Figure 2. Timing Waveform Characteristics

**Table 5. Clock Input (External Clock Driven XTAL1) Parameter**

| Parameter    | Description                       | 32.768 kHz External Crystal |       |     | Unit          |
|--------------|-----------------------------------|-----------------------------|-------|-----|---------------|
|              |                                   | Min                         | Typ   | Max |               |
| $t_{CK}$     | XTAL1 period                      |                             | 30.52 |     | $\mu\text{s}$ |
| $t_{CKL}$    | XTAL1 width low                   |                             | 6.26  |     | $\mu\text{s}$ |
| $t_{CKH}$    | XTAL1 width high                  |                             | 6.26  |     | $\mu\text{s}$ |
| $t_{CKR}$    | XTAL1 rise time                   |                             | 9     |     | ns            |
| $t_{CKF}$    | XTAL1 fall time                   |                             | 9     |     | ns            |
| $1/t_{CORE}$ | Core clock frequency <sup>1</sup> |                             | 1.024 |     | MHz           |

<sup>1</sup> The ADE5166/ADE5169 internal PLL locks onto a multiple (512x) of the 32.768 kHz external crystal frequency to provide a stable 4.096 MHz internal clock for the system. The core can operate at this frequency or at a binary submultiple defined by the CD[2:0] bits of the POWCON SFR, Address 0xC5 (see Table 25).

**Table 6. I<sup>2</sup>C-Compatible Interface Timing Parameters (400 kHz)**

| Parameter   | Description  | Typ    | Unit          |
|-------------|--|--------|---------------|
| $t_{BUF}$   | Bus-free time between stop condition and start condition | 1.3    | $\mu\text{s}$ |
| $t_L$       | SCLK low pulse width                                     | 1.36   | $\mu\text{s}$ |
| $t_H$       | SCLK high pulse width                                    | 1.14   | $\mu\text{s}$ |
| $t_{SHD}$   | Start condition hold time                                | 251.35 | $\mu\text{s}$ |
| $t_{DSU}$   | Data setup time  | 740    | ns            |
| $t_{DHD}$   | Data hold time   | 400    | ns            |
| $t_{RSU}$   | Setup time for repeated start                            | 12.5   | ns            |
| $t_{PSU}$   | Stop condition setup time                                | 400    | ns            |
| $t_R$       | Rise time of both SCLK and SDATA                         | 200    | ns            |
| $t_F$       | Fall time of both SCLK and SDATA                         | 300    | ns            |
| $t_{SUP}^1$ | Pulse width of spike suppressed                          | 50     | ns            |

<sup>1</sup> Input filtering on both the SCLK and SDATA inputs suppresses noise spikes of  $<50\text{ ns}$ .

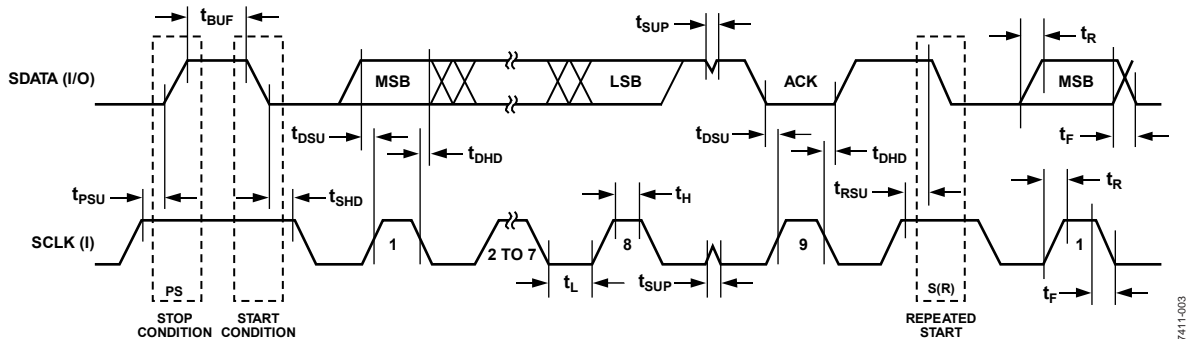


Figure 3. I<sup>2</sup>C-Compatible Interface Timing

# ADE5166/ADE5169

**Table 7. SPI Master Mode Timing (SPICPHA = 1) Parameters**

| Parameter | Description                            | Min                         | Typ | Max                   | Unit |
|-----------|--|-----------------------------|-----|-----------------------|------|
| $t_{SL}$  | SCLK low pulse width                   | $2^{SPR} \times t_{CORE}^1$ |     |                       | ns   |
| $t_{SH}$  | SCLK high pulse width                  | $2^{SPR} \times t_{CORE}^1$ |     |                       | ns   |
| $t_{DAV}$ | Data output valid after SCLK edge      |                             |     | $3 \times t_{CORE}^1$ | ns   |
| $t_{DSU}$ | Data input setup time before SCLK edge | 0                           |     |                       | ns   |
| $t_{DHD}$ | Data input hold time after SCLK edge   | $t_{CORE}^1$                |     |                       | ns   |
| $t_{DF}$  | Data output fall time                  |                             | 19  |                       | ns   |
| $t_{DR}$  | Data output rise time                  |                             | 19  |                       | ns   |
| $t_{SR}$  | SCLK rise time                         |                             | 19  |                       | ns   |
| $t_{SF}$  | SCLK fall time                         |                             | 19  |                       | ns   |

<sup>1</sup>  $t_{CORE}$  depends on the clock divider or CD[2:0] bits of the POWCON SFR, Address 0xC5 (see Table 25);  $t_{CORE} = 2^{CD}/4.096$  MHz.

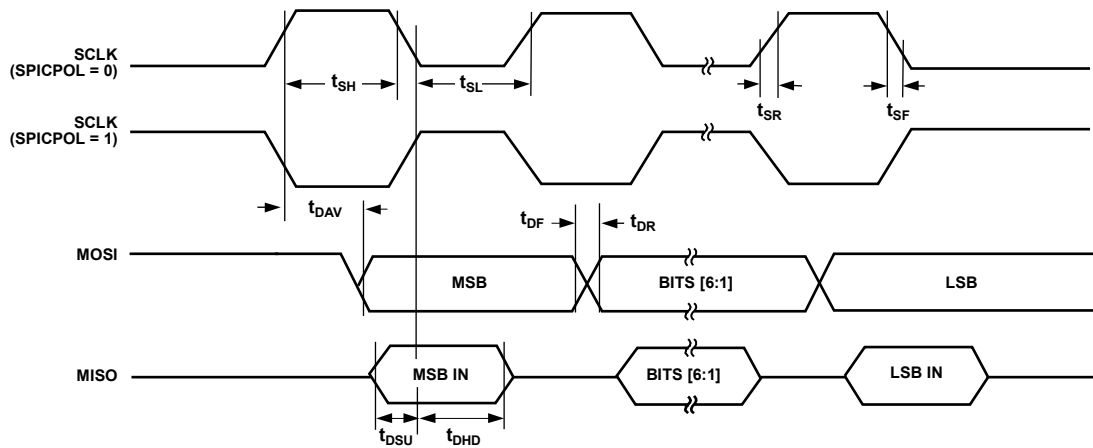


Figure 4. SPI Master Mode Timing (SPICPHA = 1)

07411-004

**Table 8. SPI Master Mode Timing (SPICPHA = 0) Parameters**

| Parameter         | Description                            | Min                          | Typ                            | Max                   | Unit |
|-------------------|--|------------------------------|--------------------------------|-----------------------|------|
| t <sub>SL</sub>   | SCLK low pulse width                   | $2^{SPIR} \times t_{CORE}^1$ | $(SPIR + 1) \times t_{CORE}^1$ |                       | ns   |
| t <sub>SH</sub>   | SCLK high pulse width                  | $2^{SPIR} \times t_{CORE}^1$ | $(SPIR + 1) \times t_{CORE}^1$ |                       | ns   |
| t <sub>DAV</sub>  | Data output valid after SCLK edge      |                              |                                | $3 \times t_{CORE}^1$ | ns   |
| t <sub>DOSU</sub> | Data output setup before SCLK edge     |                              |                                | 75                    | ns   |
| t <sub>DSU</sub>  | Data input setup time before SCLK edge | 0                            |                                |                       | ns   |
| t <sub>DHD</sub>  | Data input hold time after SCLK edge   | $t_{CORE}^1$                 |                                |                       | ns   |
| t <sub>DF</sub>   | Data output fall time                  |                              | 19                             |                       | ns   |
| t <sub>DR</sub>   | Data output rise time                  |                              | 19                             |                       | ns   |
| t <sub>SR</sub>   | SCLK rise time                         |                              | 19                             |                       | ns   |
| t <sub>SF</sub>   | SCLK fall time                         |                              | 19                             |                       | ns   |

<sup>1</sup> t<sub>CORE</sub> depends on the clock divider or CD[2:0] bits of the POWCON SFR, Address 0xC5 (see Table 25); t<sub>CORE</sub> = 2<sup>CD</sup>/4.096 MHz.

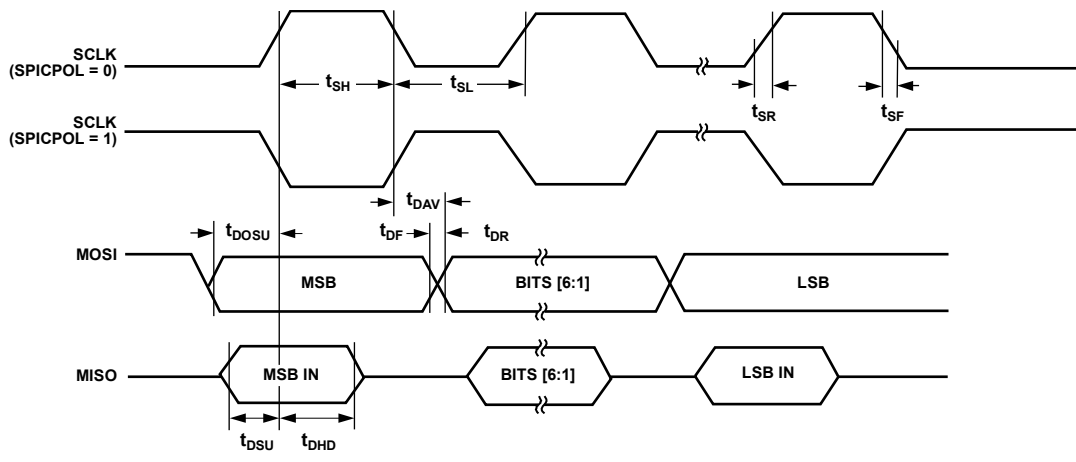


Figure 5. SPI Master Mode Timing (SPICPHA = 0)

07411-905

# ADE5166/ADE5169

**Table 9. SPI Slave Mode Timing (SPICPHA = 1) Parameters**

| Parameter           | Description                            | Min                               | Typ | Max | Unit    |
|---------------------|--|-----------------------------------|-----|-----|---------|
| $t_{\overline{SS}}$ | $\overline{SS}$ to SCLK edge           | 145                               |     |     | ns      |
| $t_{SL}$            | SCLK low pulse width                   | $6 \times t_{CORE}^1$             |     |     | ns      |
| $t_{SH}$            | SCLK high pulse width                  | $6 \times t_{CORE}^1$             |     |     | ns      |
| $t_{DAV}$           | Data output valid after SCLK edge      |                                   |     | 25  | ns      |
| $t_{DSU}$           | Data input setup time before SCLK edge | 0                                 |     |     | ns      |
| $t_{DHD}$           | Data input hold time after SCLK edge   | $2 \times t_{CORE}^1 + 0.5 \mu s$ |     |     | $\mu s$ |
| $t_{DF}$            | Data output fall time                  |                                   | 19  |     | ns      |
| $t_{DR}$            | Data output rise time                  |                                   | 19  |     | ns      |
| $t_{SR}$            | SCLK rise time                         |                                   | 19  |     | ns      |
| $t_{SF}$            | SCLK fall time                         |                                   | 19  |     | ns      |
| $t_{SFS}$           | $\overline{SS}$ high after SCLK edge   | 0                                 |     |     | ns      |

<sup>1</sup>  $t_{CORE}$  depends on the clock divider or CD[2:0] bits of the POWCON SFR, Address 0xC5 (see Table 25);  $t_{CORE} = 2^{CD}/4.096 \text{ MHz}$ .

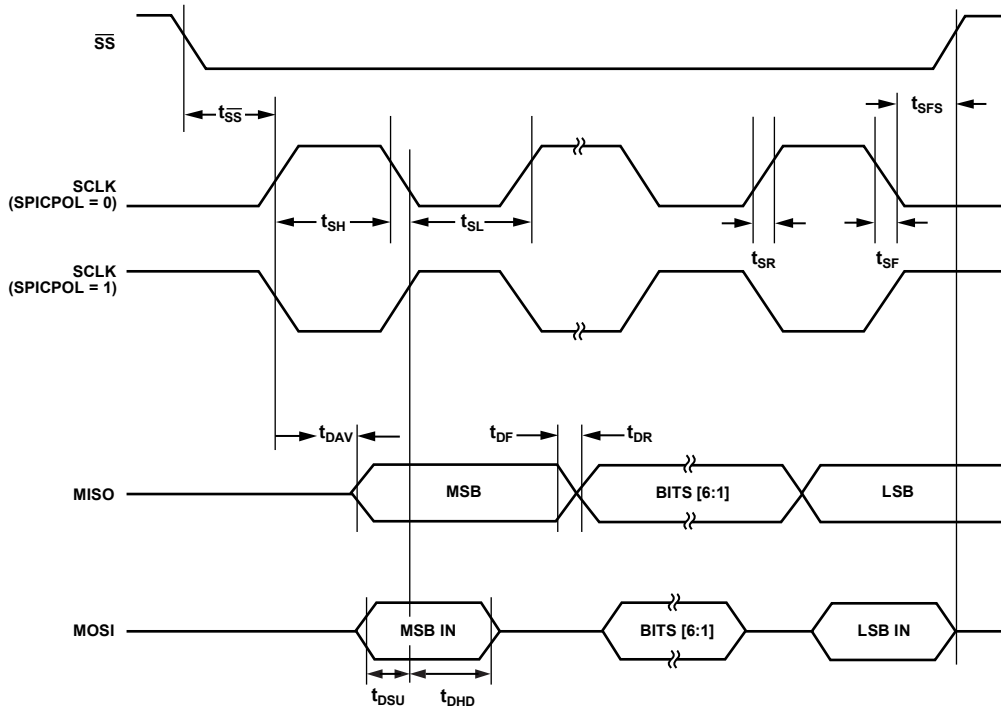


Figure 6. SPI Slave Mode Timing (SPICPHA = 1)

07411-006

**Table 10. SPI Slave Mode Timing (SPICPHA = 0) Parameters**

| Parameter           | Description                                  | Min                               | Typ | Max | Unit    |
|---------------------|--|-----------------------------------|-----|-----|---------|
| $t_{\overline{SS}}$ | $\overline{SS}$ to SCLK edge                 | 145                               |     |     | ns      |
| $t_{SL}$            | SCLK low pulse width                         | $6 \times t_{CORE}^1$             |     |     | ns      |
| $t_{SH}$            | SCLK high pulse width                        | $6 \times t_{CORE}^1$             |     |     | ns      |
| $t_{DAV}$           | Data output valid after SCLK edge            |                                   |     | 25  | ns      |
| $t_{DSU}$           | Data input setup time before SCLK edge       | 0                                 |     |     | ns      |
| $t_{DHD}$           | Data input hold time after SCLK edge         | $2 \times t_{CORE}^1 + 0.5 \mu s$ |     |     | $\mu s$ |
| $t_{DF}$            | Data output fall time                        |                                   | 19  |     | ns      |
| $t_{DR}$            | Data output rise time                        |                                   | 19  |     | ns      |
| $t_{SR}$            | SCLK rise time                               |                                   | 19  |     | ns      |
| $t_{SF}$            | SCLK fall time                               |                                   | 19  |     | ns      |
| $t_{DOSS}$          | Data output valid after $\overline{SS}$ edge | 0                                 |     |     | ns      |
| $t_{SFS}$           | $\overline{SS}$ high after SCLK edge         | 0                                 |     |     | ns      |

<sup>1</sup>  $t_{CORE}$  depends on the clock divider or CD[2:0] bits of the POWCON SFR, Address 0xC5 (see Table 25);  $t_{CORE} = 2^{CD}/4.096$  MHz.

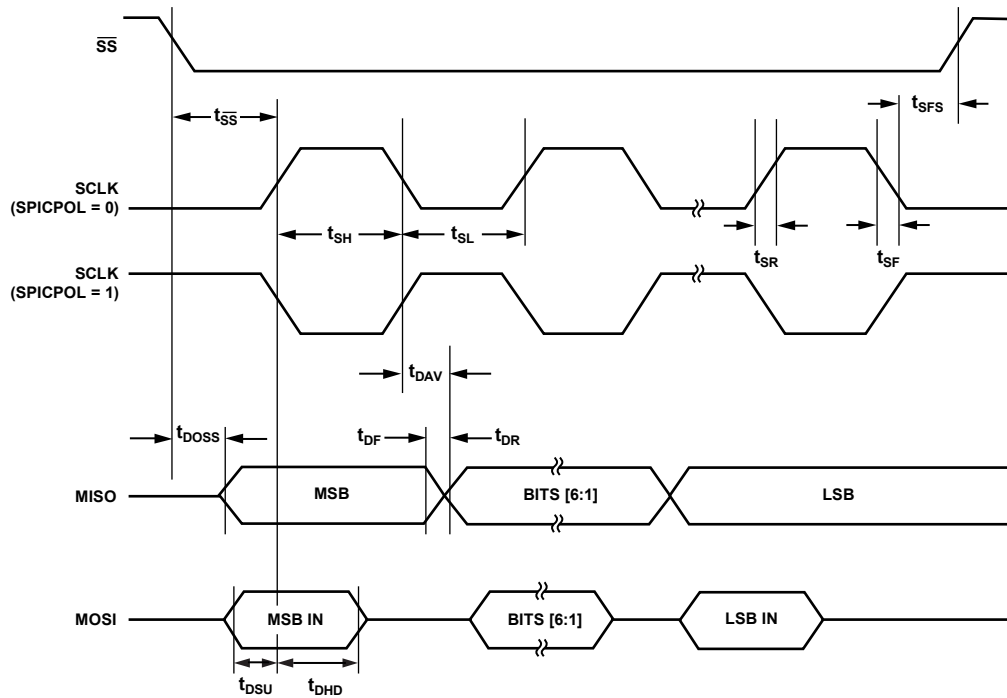


Figure 7. SPI Slave Mode Timing (SPICPHA = 0)

07411-907

## ABSOLUTE MAXIMUM RATINGS

T<sub>A</sub> = 25°C, unless otherwise noted.

**Table 11.**

| Parameter  | Rating                               |
|--|--------------------------------------|
| V <sub>DD</sub> to DGND  | −0.3 V to +3.7 V                     |
| V <sub>BAT</sub> to DGND   | −0.3 V to +3.7 V                     |
| V <sub>DCIN</sub> to DGND  | −0.3 V to V <sub>SWOUT</sub> + 0.3 V |
| Input LCD Voltage to AGND, LCDVA, LCDVB, LCDVC <sup>1</sup>  | −0.3 V to V <sub>SWOUT</sub> + 0.3 V |
| Analog Input Voltage to AGND, V <sub>P</sub> , V <sub>N</sub> , I <sub>PA</sub> , and I <sub>N</sub> | −2 V to +2 V                         |
| Digital Input Voltage to DGND  | −0.3 V to V <sub>SWOUT</sub> + 0.3 V |
| Digital Output Voltage to DGND   | −0.3 V to V <sub>SWOUT</sub> + 0.3 V |
| Operating Temperature Range (Industrial)   | −40°C to +85°C                       |
| Storage Temperature Range  | −65°C to +150°C                      |
| 64-Lead LQFP, Power Dissipation<br>Lead Temperature (Soldering, 30 sec)                              | 300°C                                |

<sup>1</sup> When used with external resistor divider.

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only; functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

### THERMAL RESISTANCE

θ<sub>JA</sub> is specified for the worst-case conditions, that is, a device soldered in a circuit board for surface-mount packages.

**Table 12. Thermal Resistance**

| Package Type | θ <sub>JA</sub> | θ <sub>JC</sub> | Unit |
|--------------|-----------------|-----------------|------|
| 64-Lead LQFP | 60              | 20.5            | °C/W |

### ESD CAUTION



**ESD (electrostatic discharge) sensitive device.** Charged devices and circuit boards can discharge without detection. Although this product features patented or proprietary protection circuitry, damage may occur on devices subjected to high energy ESD. Therefore, proper ESD precautions should be taken to avoid performance degradation or loss of functionality.

# PIN CONFIGURATION AND FUNCTION DESCRIPTIONS

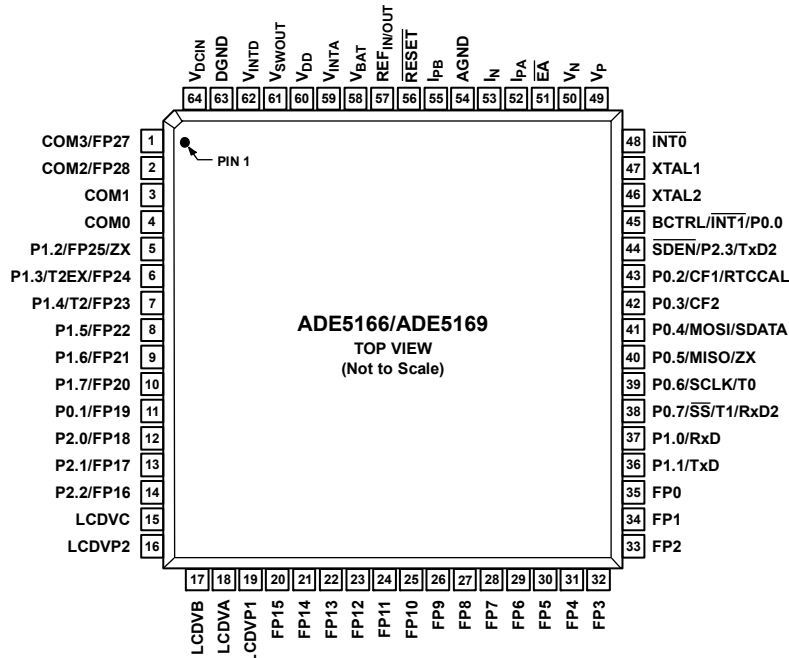


Figure 8. Pin Configuration

Table 13. Pin Function Descriptions

| Pin No.  | Mnemonic        | Description  |
|----------|-----------------|--|
| 1        | COM3/FP27       | Common Output 3/LCD Segment Output 27. COM3 is used for the LCD backplane.   |
| 2        | COM2/FP28       | Common Output 2/LCD Segment Output 28. COM2 is used for the LCD backplane.   |
| 3        | COM1            | Common Output 1. COM1 is used for the LCD backplane.   |
| 4        | COM0            | Common Output 0. COM0 is used for the LCD backplane.   |
| 5        | P1.2/FP25/ZX    | General-Purpose Digital I/O Port 1.2/LCD Segment Output 25/ZX Output.  |
| 6        | P1.3/T2EX/FP24  | General-Purpose Digital I/O Port 1.3/Timer 2 Control Input/LCD Segment Output 24.  |
| 7        | P1.4/T2/FP23    | General-Purpose Digital I/O Port 1.4/Timer 2 Input/LCD Segment Output 23.  |
| 8        | P1.5/FP22       | General-Purpose Digital I/O Port 1.5/LCD Segment Output 22.  |
| 9        | P1.6/FP21       | General-Purpose Digital I/O Port 1.6/LCD Segment Output 21.  |
| 10       | P1.7/FP20       | General-Purpose Digital I/O Port 1.7/LCD Segment Output 20.  |
| 11       | P0.1/FP19       | General-Purpose Digital I/O Port 0.1/LCD Segment Output 19.  |
| 12       | P2.0/FP18       | General-Purpose Digital I/O Port 2.0/LCD Segment Output 18.  |
| 13       | P2.1/FP17       | General-Purpose Digital I/O Port 2.1/LCD Segment Output 17.  |
| 14       | P2.2/FP16       | General-Purpose Digital I/O Port 2.2/LCD Segment Output 16.  |
| 15       | LCDVC           | Output Port for LCD Levels. This pin should be decoupled with a 470 nF capacitor.  |
| 16       | LCDVP2          | Analog Output. A 100 nF capacitor should be connected between this pin and LCDVP1 for the internal LCD charge pump device.     |
| 17, 18   | LCDVB, LCDVA    | Output Port for LCD Levels. These pins should be decoupled with a 470 nF capacitor.  |
| 19       | LCDVP1          | Analog Output. A 100 nF capacitor should be connected between this pin and LCDVP2 for the internal LCD charge pump device.     |
| 20 to 35 | FP15 to FP0     | LCD Segment Output 0 to LCD Segment Output 15.   |
| 36       | P1.1/TxD        | General-Purpose Digital I/O Port 1.1/Transmitter Data Output (Asynchronous).   |
| 37       | P1.0/RxD        | General-Purpose Digital I/O Port 1.0/Receiver Data Input (Asynchronous).   |
| 38       | P0.7/SS/T1/RxD2 | General-Purpose Digital I/O Port 0.7/Slave Select When SPI Is in Slave Mode/Timer 1 Input/Receive Data Input 2 (Asynchronous). |
| 39       | P0.6/SCLK/T0    | General-Purpose Digital I/O Port 0.6/Clock Output for I <sup>2</sup> C or SPI Port/Timer 0 Input.                              |
| 40       | P0.5/MISO/ZX    | General-Purpose Digital I/O Port 0.5/Data Input for SPI Port/ZX Output.  |
| 41       | P0.4/MOSI/SDATA | General-Purpose Digital I/O Port 0.4/Data Output for SPI Port/I <sup>2</sup> C-Compatible Data Line.                           |

# ADE5166/ADE5169

| Pin No. | Mnemonic                       | Description  |
|---------|--------------------------------|--|
| 42      | P0.3/CF2                       | General-Purpose Digital I/O Port 0.3/Calibration Frequency Logic Output 2. The CF2 logic output gives instantaneous active, reactive, $I_{rms}$ , or apparent power information.   |
| 43      | P0.2/CF1/RTCCAL                | General-Purpose Digital I/O Port 0.2/Calibration Frequency Logic Output 1/RTC Calibration Frequency Logic Output. The CF1 logic output gives instantaneous active, reactive, or apparent power or $I_{rms}$ , information. The RTCCAL logic output gives access to the calibrated RTC output.  |
| 44      | $\overline{SDEN}$ /P2.3/TxD2   | Serial Download Mode Enable/General-Purpose Digital Output Port P2.3/Transmitter Data Output 2 (Asynchronous). This pin is used to enable serial download mode through a resistor when pulled low on power-up or reset. On reset, this pin momentarily becomes an input, and the status of the pin is sampled. If there is no pull-down resistor in place, the pin momentarily goes high and then user code is executed. If the pin is pulled down on reset, the embedded serial download/debug kernel executes, and this pin remains low during the internal program execution. After reset, this pin can be used as a digital output port pin (P2.3) or as Transmitter Data Output 2 (asynchronous). |
| 45      | BCTRL/ $\overline{INT1}$ /P0.0 | Digital Input for Battery Control/External Interrupt Input 1/General-Purpose Digital I/O Port 0.0. This logic input connects $V_{DD}$ or $V_{BAT}$ to $V_{SWOUT}$ internally when set to logic high or logic low, respectively. When left open, the connection between $V_{DD}$ or $V_{BAT}$ and $V_{SWOUT}$ is selected internally.   |
| 46      | XTAL2                          | A crystal can be connected across this pin and XTAL1 (see XTAL1 pin description) to provide a clock source for the ADE5166/ADE5169. The XTAL2 pin can drive one CMOS load when an external clock is supplied at XTAL1 or by the gate oscillator circuit. An internal 6 pF capacitor is connected to this pin.  |
| 47      | XTAL1                          | An external clock can be provided at this logic input. Alternatively, a tuning fork crystal can be connected across XTAL1 and XTAL2 to provide a clock source for the ADE5166/ADE5169. The clock frequency for specified operation is 32.768 kHz. An internal 6 pF capacitor is connected to this pin.   |
| 48      | $\overline{INT0}$              | External Interrupt Input 0.  |
| 49, 50  | $V_P, V_N$                     | Analog Inputs for Voltage Channel. These inputs are fully differential voltage inputs with a maximum differential level of $\pm 400$ mV for specified operation. This channel also has an internal PGA.  |
| 51      | $\overline{EA}$                | This pin is used as an input for emulation. When held high, this input enables the device to fetch code from internal program memory locations. The ADE5169 does not support external code memory. This pin should not be left floating.   |
| 52, 53  | $I_{PA}, I_N$                  | Analog Inputs for Current Channel. These inputs are fully differential voltage inputs with a maximum differential level of $\pm 400$ mV for specified operation. This channel also has an internal PGA.  |
| 54      | AGND                           | This pin provides the ground reference for the analog circuitry.   |
| 55      | $I_{PB}$                       | Analog Input for Second Current Channel. This input is fully differential with a maximum differential level of $\pm 400$ mV, referred to $I_N$ for specified operation. This channel also has an internal PGA.   |
| 56      | $\overline{RESET}$             | Reset Input, Active Low.   |
| 57      | $REF_{IN/OUT}$                 | This pin provides access to the on-chip voltage reference. The on-chip reference has a nominal value of $1.2\text{ V} \pm 0.1\%$ and a typical temperature coefficient of 50 ppm/ $^{\circ}\text{C}$ maximum. This pin should be decoupled with a 1 $\mu\text{F}$ capacitor in parallel with a ceramic 100 nF capacitor.   |
| 58      | $V_{BAT}$                      | Power Supply Input from the Battery with a 2.4 V to 3.7 V Range. This pin is connected internally to $V_{DD}$ when the battery is selected as the power supply for the ADE5166/ADE5169.  |
| 59      | $V_{INTA}$                     | This pin provides access to the on-chip 2.5 V analog LDO. No external active circuitry should be connected to this pin. This pin should be decoupled with a 10 $\mu\text{F}$ capacitor in parallel with a ceramic 100 nF capacitor.  |
| 60      | $V_{DD}$                       | 3.3 V Power Supply Input from the Regulator. This pin is connected internally to $V_{SWOUT}$ when the regulator is selected as the power supply for the ADE5166/ADE5169. This pin should be decoupled with a 10 $\mu\text{F}$ capacitor in parallel with a ceramic 100 nF capacitor.   |
| 61      | $V_{SWOUT}$                    | 3.3 V Power Supply Output. This pin provides the supply voltage for the LDOs and internal circuitry of the ADE5166/ADE5169. This pin should be decoupled with a 10 $\mu\text{F}$ capacitor in parallel with a ceramic 100 nF capacitor.  |
| 62      | $V_{INTD}$                     | This pin provides access to the on-chip 2.5 V digital LDO. No external active circuitry should be connected to this pin. This pin should be decoupled with a 10 $\mu\text{F}$ capacitor in parallel with a ceramic 100 nF capacitor.   |
| 63      | DGND                           | This pin provides the ground reference for the digital circuitry.  |
| 64      | $V_{DCIN}$                     | Analog Input for DC Voltage Monitoring. The maximum input voltage on this pin is $V_{SWOUT}$ with respect to AGND. This pin is used to monitor the preregulated dc voltage.  |



# TYPICAL PERFORMANCE CHARACTERISTICS

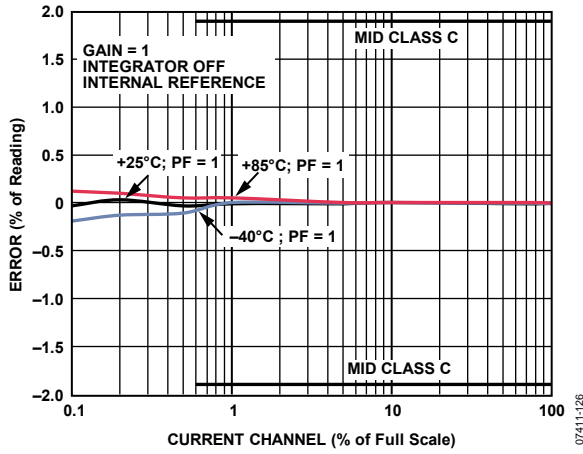


Figure 9. Active Energy Error as a Percentage of Reading (Gain = 1) over Temperature with Internal Reference, Integrator Off

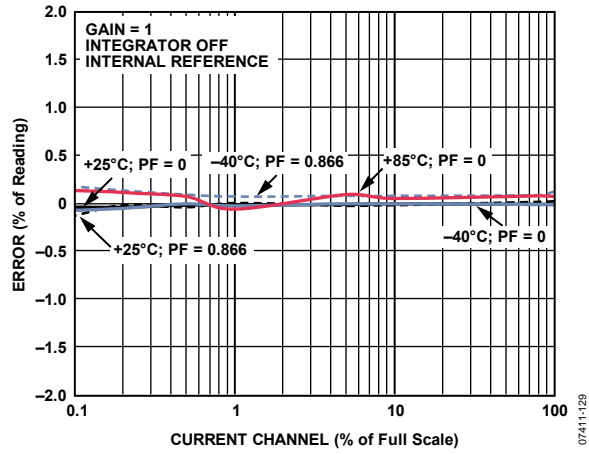


Figure 12. Reactive Energy Error as a Percentage of Reading (Gain = 1) over Power Factor with Internal Reference, Integrator Off

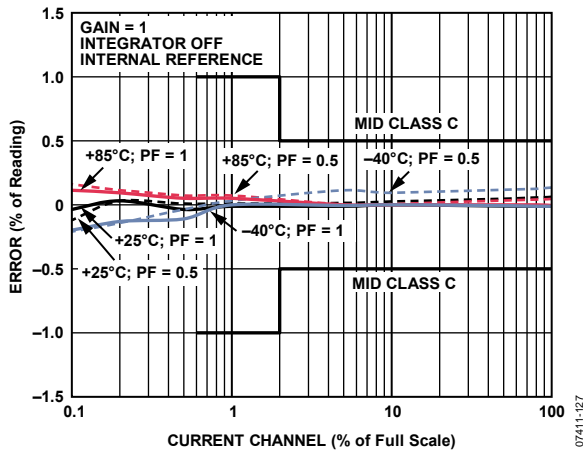


Figure 10. Active Energy Error as a Percentage of Reading (Gain = 1) over Power Factor with Internal Reference, Integrator Off

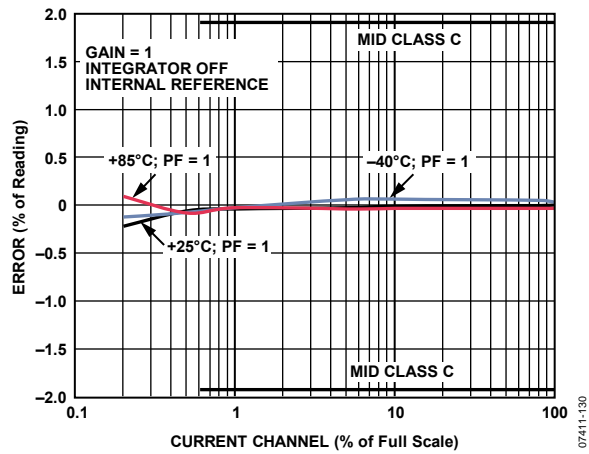


Figure 13. Current RMS Error as a Percentage of Reading (Gain = 1) over Temperature with Internal Reference, Integrator Off

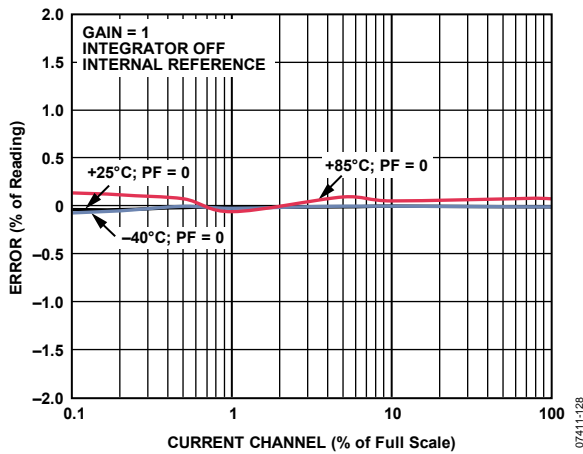


Figure 11. Reactive Energy Error as a Percentage of Reading (Gain = 1) over Temperature with Internal Reference, Integrator Off

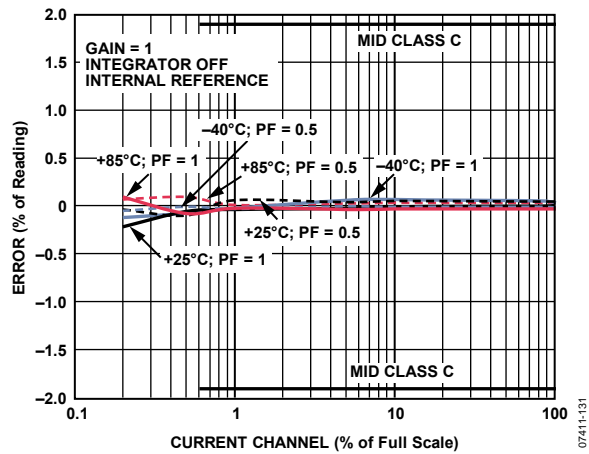


Figure 14. Current RMS Error as a Percentage of Reading (Gain = 1) over Power Factor with Internal Reference, Integrator Off

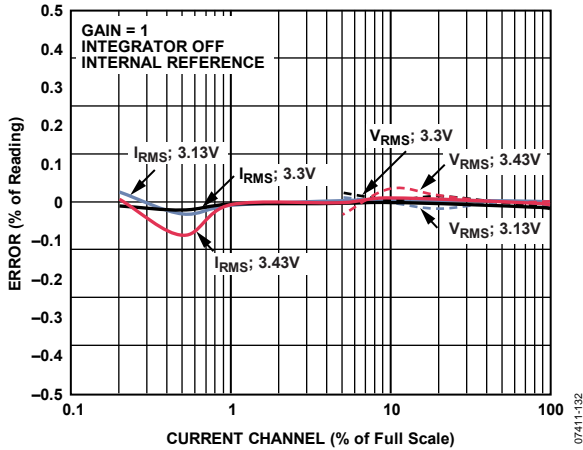


Figure 15. Voltage and Current RMS Error as a Percentage of Reading (Gain = 1) over Power Supply with Internal Reference

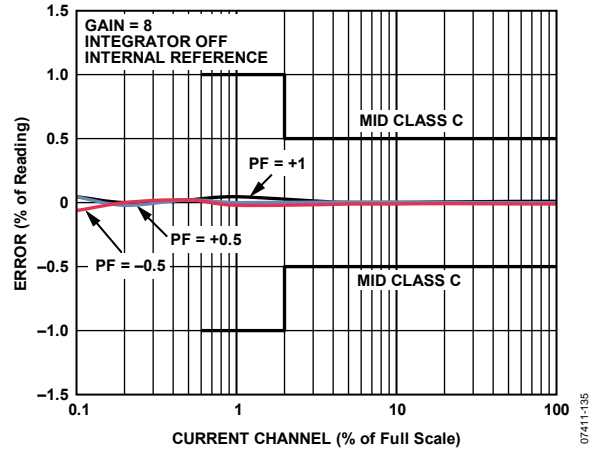


Figure 18. Active Energy Error as a Percentage of Reading (Gain = 8) over Power Factor with Internal Reference, Integrator Off

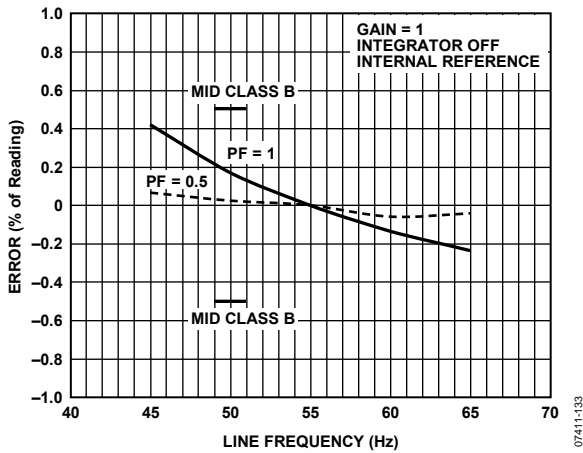


Figure 16. Active Energy Error as a Percentage of Reading (Gain = 1) over Frequency with Internal Reference, Integrator Off

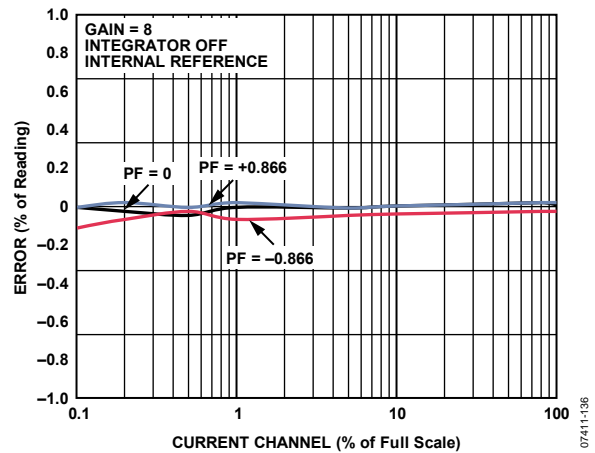


Figure 19. Reactive Energy Error as a Percentage of Reading (Gain = 8) over Power Factor with Internal Reference, Integrator Off

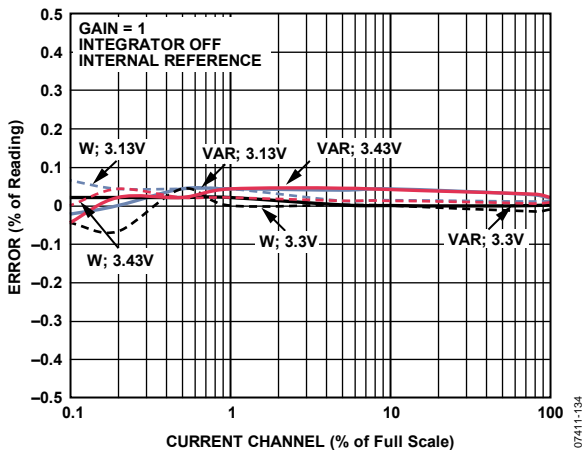


Figure 17. Active and Reactive Energy Error as a Percentage of Reading (Gain = 1) over Power Supply with Internal Reference, Integrator Off

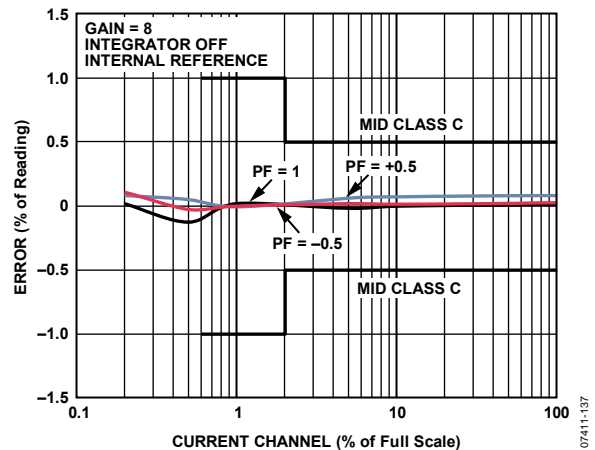


Figure 20. Current RMS Error as a Percentage of Reading (Gain = 8) over Power Factor with Internal Reference, Integrator Off

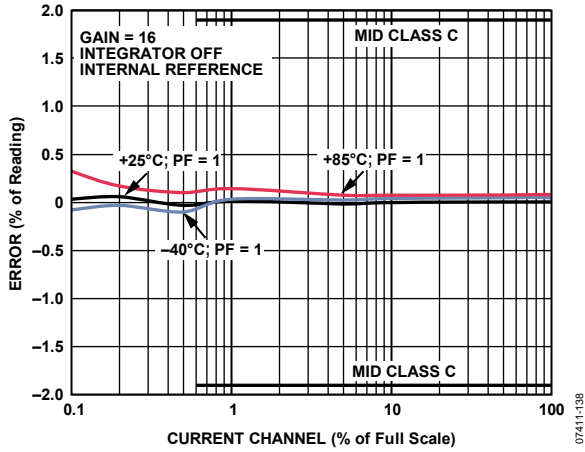


Figure 21. Active Energy Error as a Percentage of Reading (Gain = 16) over Temperature with Internal Reference, Integrator Off

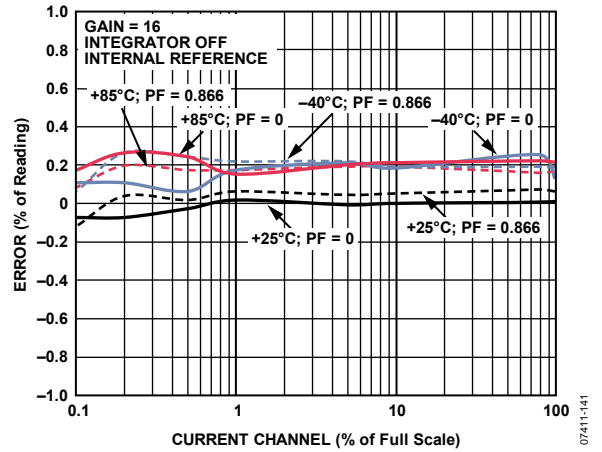


Figure 24. Reactive Energy Error as a Percentage of Reading (Gain = 16) over Power Factor with Internal Reference, Integrator Off

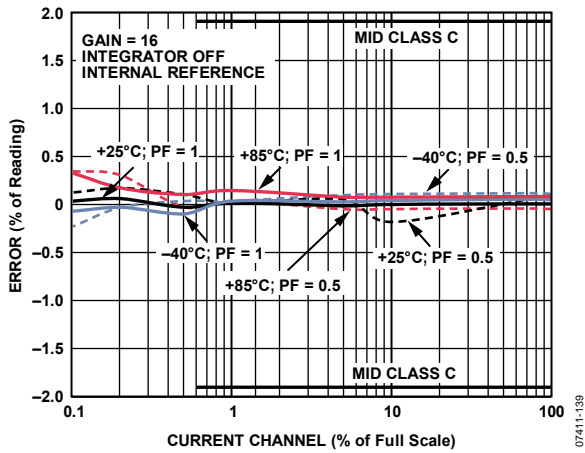


Figure 22. Active Energy Error as a Percentage of Reading (Gain = 16) over Power Factor with Internal Reference, Integrator Off

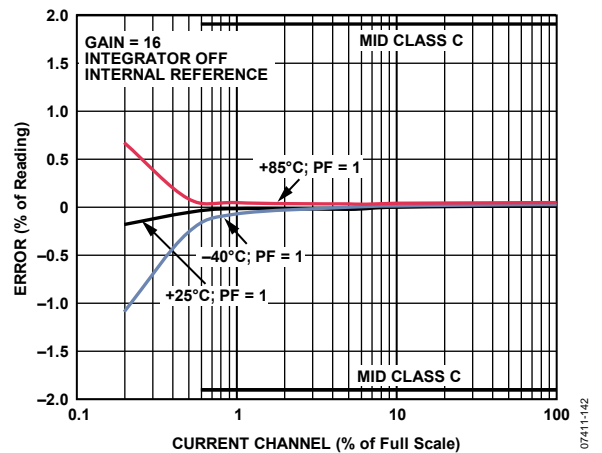


Figure 25. Current RMS Error as a Percentage of Reading (Gain = 16) over Temperature with Internal Reference, Integrator Off

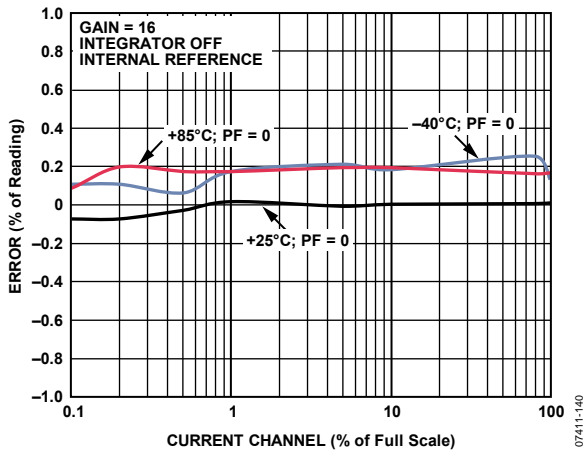


Figure 23. Reactive Energy Error as a Percentage of Reading (Gain = 16) over Temperature with Internal Reference, Integrator Off

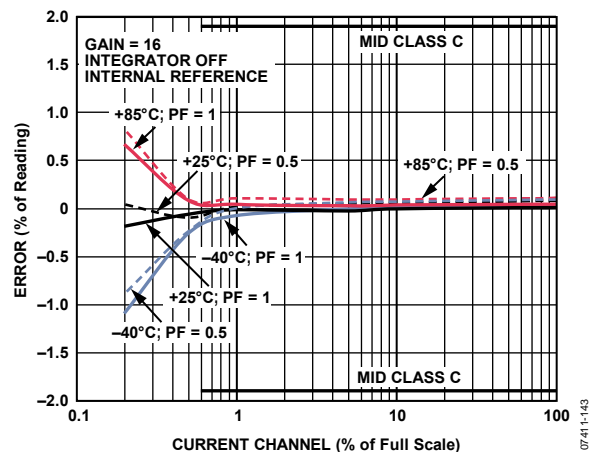


Figure 26. Current RMS Error as a Percentage of Reading (Gain = 16) over Power Factor with Internal Reference, Integrator Off

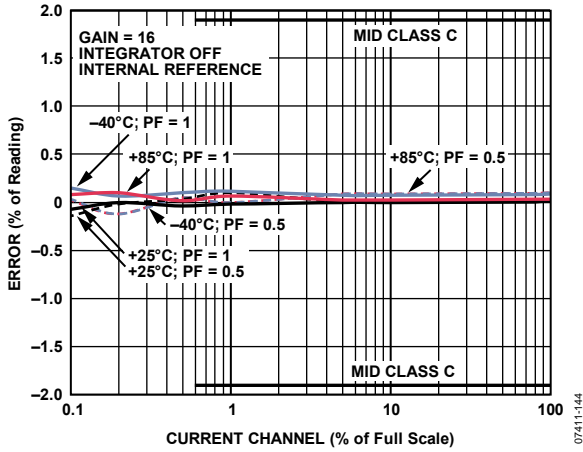


Figure 27. Active Energy Error as a Percentage of Reading (Gain = 16) over Power Factor with Internal Reference, Integrator On

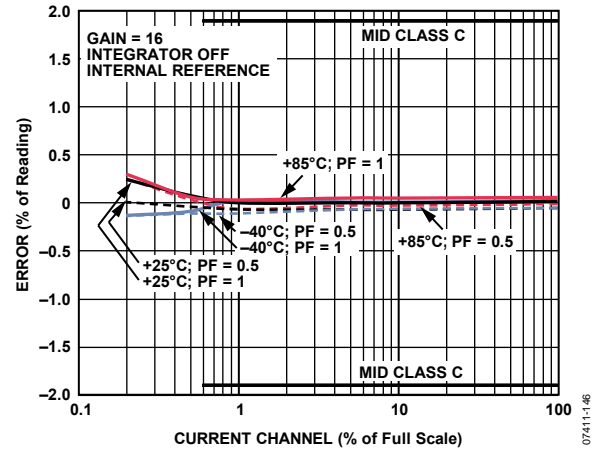


Figure 29. Current RMS Error as a Percentage of Reading (Gain = 16) over Power Factor with Internal Reference, Integrator On

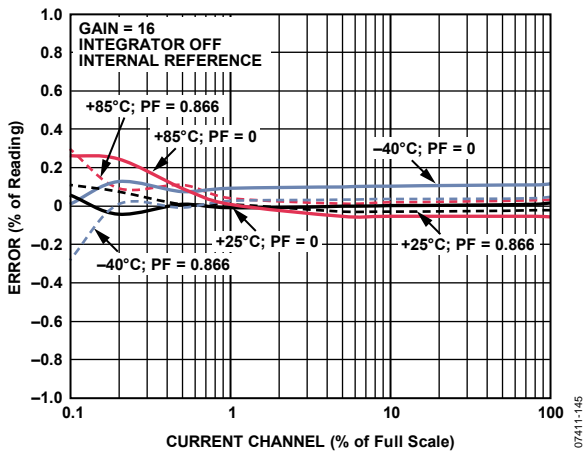


Figure 28. Reactive Energy Error as a Percentage of Reading (Gain = 16) over Power Factor with Internal Reference, Integrator On

## TERMINOLOGY

### Measurement Error

The error associated with the energy measurement made by the ADE5166/ADE5169 is defined by the following formula:

*Percentage Error* =

$$\left( \frac{\text{Energy Register} - \text{True Energy}}{\text{True Energy}} \right) \times 100\%$$

### Phase Error Between Channels

The digital integrator and the high-pass filter (HPF) in the current channel have a nonideal phase response. To offset this phase response and equalize the phase response between channels, two phase correction networks are placed in the current channel: one for the digital integrator and the other for the HPF. The phase correction networks correct the phase response of the corresponding component and ensure a phase match between current channel and voltage channel to within  $\pm 0.1^\circ$  over a range of 45 Hz to 65 Hz with the digital integrator off. With the digital integrator on, the phase is corrected to within  $\pm 0.4^\circ$  over a range of 45 Hz to 65 Hz.

### Power Supply Rejection (PSR)

PSR quantifies the ADE5166/ADE5169 measurement error as a percentage of reading when the power supplies are varied. For the ac PSR measurement, a reading at nominal supplies (3.3 V) is taken. A second reading is obtained with the same input signal

levels when an ac (100 mV rms/120 Hz) signal is introduced onto the supplies. Any error introduced by this ac signal is expressed as a percentage of reading (see the Measurement Error definition).

For the dc PSR measurement, a reading at nominal supplies (3.3 V) is taken. A second reading is obtained with the same input signal levels when the supplies are varied  $\pm 5\%$ . Any error introduced is again expressed as a percentage of the reading.

### ADC Offset Error

ADC offset error is the dc offset associated with the analog inputs to the ADCs. It means that, with the analog inputs connected to AGND, the ADCs still see a dc analog input signal. The magnitude of the offset depends on the gain and input range selection. However, when HPF1 is switched on, the offset is removed from the current channel, and the power calculation is not affected by this offset. The offsets can be removed by performing an offset calibration (see the Analog Inputs section).

### Gain Error

Gain error is the difference between the measured ADC output code (minus the offset) and the ideal output code (see the Current Channel ADC section and the Voltage Channel ADC section). It is measured for each of the gain settings on the current channel (1, 2, 4, 8, and 16). The difference is expressed as a percentage of the ideal code.

## SPECIAL FUNCTION REGISTER (SFR) MAPPING

Table 14. SFR Mapping

| Mnemonic  | Address | Description  | Mnemonic | Address | Description  |
|-----------|---------|--|----------|---------|--|
| INTPR     | 0xFF    | Interrupt pins configuration SFR (see Table 16).     | MIRQENL  | 0xD9    | Interrupt Enable 1 (see Table 43).                       |
| SCRATCH4  | 0xFE    | Scratch Pad 4 (see Table 24).                        | ADCGO    | 0xD8    | Start ADC measurement (see Table 51).                    |
| SCRATCH3  | 0xFD    | Scratch Pad 3 (see Table 23).                        | TEMPADC  | 0xD7    | Temperature ADC value (see Table 55).                    |
| SCRATCH2  | 0xFC    | Scratch Pad 2 (see Table 22).                        | IRMSH    | 0xD6    | I <sub>rms</sub> measurement MSB (see Table 30).         |
| SCRATCH1  | 0xFB    | Scratch Pad 1 (see Table 21).                        | IRMSM    | 0xD5    | I <sub>rms</sub> measurement middle byte (see Table 30). |
| BATVTH    | 0xFA    | Battery detection threshold (see Table 52).          | IRMSL    | 0xD4    | I <sub>rms</sub> measurement LSB (see Table 30).         |
| STRBPER   | 0xF9    | Peripheral ADC strobe period (see Table 49).         | VRMSH    | 0xD3    | V <sub>rms</sub> measurement MSB (see Table 30).         |
| IPSMF     | 0xF8    | Power management interrupt flag (see Table 17).      | VRMSM    | 0xD2    | V <sub>rms</sub> measurement middle byte (see Table 30). |
| TEMPCAL   | 0xF7    | RTC temperature compensation (see Table 132).        | VRMSL    | 0xD1    | V <sub>rms</sub> measurement LSB (see Table 30).         |
| RTCCOMP   | 0xF6    | RTC nominal compensation (see Table 131).            | PSW      | 0xD0    | Program status word (see Table 57).                      |
| BATPR     | 0xF5    | Battery switchover configuration (see Table 18).     | TH2      | 0xCD    | Timer 2 high byte (see Table 119).                       |
| PERIPH    | 0xF4    | Peripheral configuration (see Table 19).             | TL2      | 0xCC    | Timer 2 low byte (see Table 120).                        |
| DIFFPROG  | 0xF3    | Temperature and supply delta (see Table 50).         | RCAP2H   | 0xCB    | Timer 2 reload/capture high byte (see Table 121).        |
| B         | 0xF0    | Auxiliary math (see Table 56).                       | RCAP2L   | 0xCA    | Timer 2 reload/capture low byte (see Table 122).         |
| VDCINADC  | 0xEF    | V <sub>DCIN</sub> ADC value (see Table 53).          | T2CON    | 0xC8    | Timer/Counter 2 control (see Table 114).                 |
| SBAUD2    | 0xEE    | Enhanced Serial Baud Rate Control 2 (see Table 148). | EADRH    | 0xC7    | Flash high byte address (see Table 109).                 |
| LCDSEGE2  | 0xED    | LCD Segment Enable 2 (see Table 100).                | EADRL    | 0xC6    | Flash low byte address (see Table 108).                  |
| IPSME     | 0xEC    | Power management interrupt enable (see Table 20).    | POWCON   | 0xC5    | Power control (see Table 25).                            |
| SBUF2     | 0xEB    | Serial Port 2 buffer (see Table 147).                | KYREG    | 0xC1    | Key (see Table 125).                                     |
| SPISTAT   | 0xEA    | SPI interrupt status (see Table 155).                | WDCON    | 0xC0    | Watchdog timer (see Table 87).                           |
| SPI2CSTAT | 0xEA    | I <sup>2</sup> C interrupt status (see Table 159).   | STCON    | 0xBF    | Stack boundary (see Table 64).                           |
| SPIMOD2   | 0xE9    | SPI Configuration SFR 2 (see Table 154).             | EDATA    | 0xBC    | Flash data (see Table 107).                              |
| I2CADR    | 0xE9    | I <sup>2</sup> C slave address (see Table 158).      | PROTKY   | 0xBB    | Flash protection key (see Table 106).                    |
| SPIMOD1   | 0xE8    | SPI Configuration SFR 1 (see Table 153).             | FLSHKY   | 0xBA    | Flash key (see Table 105).                               |
| I2CMOD    | 0xE8    | I <sup>2</sup> C mode (see Table 157).               | ECON     | 0xB9    | Flash control (see Table 104).                           |
| WAV2H     | 0xE7    | Selection 2 sample MSB (see Table 30).               | IP       | 0xB8    | Interrupt priority (see Table 81).                       |
| WAV2M     | 0xE6    | Selection 2 sample middle byte (see Table 30).       | SPH      | 0xB7    | Stack pointer high (see Table 63).                       |
| WAV2L     | 0xE5    | Selection 2 sample LSB (see Table 30).               | PINMAP2  | 0xB4    | Port 2 weak pull-up enable (see Table 164).              |
| WAV1H     | 0xE4    | Selection 1 sample MSB (see Table 30).               | PINMAP1  | 0xB3    | Port 1 weak pull-up enable (see Table 163).              |
| WAV1M     | 0xE3    | Selection 1 sample middle byte (see Table 30).       | PINMAPO  | 0xB2    | Port 0 weak pull-up enable (see Table 162).              |
| WAV1L     | 0xE2    | Selection 1 sample LSB (see Table 30).               | LCDCONY  | 0xB1    | LCD Configuration Y (see Table 93).                      |
| SCON2     | 0xE1    | Serial communications control (see Table 146).       | CFG      | 0xAF    | Configuration (see Table 65).                            |
| ACC       | 0xE0    | Accumulator (see Table 56).                          | LCDDAT   | 0xAE    | LCD data (see Table 99).                                 |
| BATADC    | 0xDF    | Battery ADC value (see Table 54).                    | LCDPTR   | 0xAC    | LCD pointer (see Table 98).                              |
| MIRQSTH   | 0xDE    | Interrupt Status 3 (see Table 42).                   | IEIP2    | 0xA9    | Interrupt enable and Priority 2 (see Table 82).          |
| MIRQSTM   | 0xDD    | Interrupt Status 2 (see Table 41).                   | IE       | 0xA8    | Interrupt enable (see Table 80).                         |
| MIRQSTL   | 0xDC    | Interrupt Status 1 (see Table 40).                   | DPCON    | 0xA7    | Data pointer control (see Table 78).                     |
| MIRQENH   | 0xDB    | Interrupt Enable 3 (see Table 45).                   | RTCDAT   | 0xA4    | RTC pointer data (see Table 130).                        |
| MIRQENM   | 0xDA    | Interrupt Enable 2 (see Table 44).                   | RTCPtr   | 0xA3    | RTC pointer address (see Table 129).                     |
|           |         |  | TIMECON2 | 0xA2    | RTC Configuration 2 (see Table 128).                     |
|           |         |  | TIMECON  | 0xA1    | RTC configuration (see Table 127).                       |
|           |         |  | P2       | 0xA0    | Port 2 (see Table 167).                                  |
|           |         |  | EPCFG    | 0x9F    | Extended port configuration (see Table 161).             |

| Mnemonic | Address | Description   |
|----------|---------|---|
| SBAUDT   | 0x9E    | Enhanced serial baud rate control (see Table 142).          |
| SBAUDF   | 0x9D    | UART timer fractional divider (see Table 143).              |
| LCDCONX  | 0x9C    | LCD Configuration X (see Table 91).                         |
| SPI2CRx  | 0x9B    | SPI/I <sup>2</sup> C receive buffer (see Table 152).        |
| SPI2CTx  | 0x9A    | SPI/I <sup>2</sup> C transmit buffer (see Table 151).       |
| SBUF     | 0x99    | Serial port buffer (see Table 141).                         |
| SCON     | 0x98    | Serial communications control (see Table 140).              |
| LCDSEGE  | 0x97    | LCD segment enable (see Table 97).                          |
| LCDCLK   | 0x96    | LCD clock (see Table 94).                                   |
| LCDCON   | 0x95    | LCD configuration (see Table 90).                           |
| MDATH    | 0x94    | Energy measurement pointer data MSB (see Table 30).         |
| MDATM    | 0x93    | Energy measurement pointer data middle byte (see Table 30). |
| MDATL    | 0x92    | Energy measurement pointer data LSB (see Table 30).         |

| Mnemonic | Address | Description  |
|----------|---------|--|
| MADDPT   | 0x91    | Energy measurement pointer address (see Table 29).           |
| P1       | 0x90    | Port 1 (see Table 166).                                      |
| TH1      | 0x8D    | Timer 1 high byte (see Table 117).                           |
| TH0      | 0x8C    | Timer 0 high byte (see Table 115).                           |
| TL1      | 0x8B    | Timer 1 low byte (see Table 118).                            |
| TL0      | 0x8A    | Timer 0 low byte (see Table 116).                            |
| TMOD     | 0x89    | Timer/Counter 0 and Timer/Counter 1 mode (see Table 112).    |
| TCON     | 0x88    | Timer/Counter 0 and Timer/Counter 1 control (see Table 113). |
| PCON     | 0x87    | Program control (see Table 58).                              |
| DPH      | 0x83    | Data pointer high (see Table 60).                            |
| DPL      | 0x82    | Data pointer low (see Table 59).                             |
| SP       | 0x81    | Stack pointer (see Table 62).                                |
| P0       | 0x80    | Port 0 (see Table 165).                                      |

# ADE5166/ADE5169

## POWER MANAGEMENT

The ADE5166/ADE5169 have elaborate power management circuitry that manages the regular power supply to battery switchover and power supply failures.

The power management functionalities can be accessed directly through the 8052 SFRs (see Table 15).

**Table 15. Power Management SFRs**

| SFR Address | R/W | Mnemonic | Description                                       |
|-------------|-----|----------|---|
| 0xEC        | R/W | IPSME    | Power management interrupt enable (see Table 20). |
| 0xF5        | R/W | BATPR    | Battery switchover configuration (see Table 18).  |
| 0xF8        | R/W | IPSMF    | Power management interrupt flag (see Table 17).   |
| 0xFF        | R/W | INTPR    | Interrupt pins configuration (see Table 16).      |
| 0xF4        | R/W | PERIPH   | Peripheral configuration (see Table 19).          |
| 0xC5        | R/W | POWCON   | Power control (see Table 25).                     |
| 0xFB        | R/W | SCRATCH1 | Scratch Pad 1 (see Table 21).                     |
| 0xFC        | R/W | SCRATCH2 | Scratch Pad 2 (see Table 22).                     |
| 0xFD        | R/W | SCRATCH3 | Scratch Pad 3 (see Table 23).                     |
| 0xFE        | R/W | SCRATCH4 | Scratch Pad 4 (see Table 24).                     |

## POWER MANAGEMENT REGISTER DETAILS

**Table 16. Interrupt Pins Configuration SFR (INTPR, Address 0xFF)**

| Bit     | Mnemonic                                | Default | Description  |         |  |     |   |     |  |     |   |     |  |
|---------|---|---------|--|---------|--|-----|---|-----|--|-----|---|-----|--|
| 7       | RTCCAL                                  | 0       | Controls RTC calibration output. When set, the RTC calibration frequency selected by FSEL[1:0] is output on the P0.2/CF1/RTCCAL pin.   |         |  |     |   |     |  |     |   |     |  |
| [6:5]   | FSEL                                    | 00      | Sets RTC calibration output frequency and calibration window.<br><table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>FSEL</th> <th>Result (Calibration Window, Frequency)</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>30.5 sec, 1 Hz</td> </tr> <tr> <td>01</td> <td>30.5 sec, 512 Hz</td> </tr> <tr> <td>10</td> <td>0.244 sec, 500 Hz</td> </tr> <tr> <td>11</td> <td>0.244 sec, 16 kHz</td> </tr> </tbody> </table>                          | FSEL    | Result (Calibration Window, Frequency) | 00  | 30.5 sec, 1 Hz                          | 01  | 30.5 sec, 512 Hz                       | 10  | 0.244 sec, 500 Hz                       | 11  | 0.244 sec, 16 kHz                      |
| FSEL    | Result (Calibration Window, Frequency)  |         |  |         |  |     |   |     |  |     |   |     |  |
| 00      | 30.5 sec, 1 Hz                          |         |  |         |  |     |   |     |  |     |   |     |  |
| 01      | 30.5 sec, 512 Hz                        |         |  |         |  |     |   |     |  |     |   |     |  |
| 10      | 0.244 sec, 500 Hz                       |         |  |         |  |     |   |     |  |     |   |     |  |
| 11      | 0.244 sec, 16 kHz                       |         |  |         |  |     |   |     |  |     |   |     |  |
| 4       | Reserved                                | N/A     |  |         |  |     |   |     |  |     |   |     |  |
| [3:1]   | INT1PRG                                 | 000     | Controls the function of $\overline{\text{INT1}}$ .<br><table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>INT1PRG</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>X00</td> <td>GPIO enabled</td> </tr> <tr> <td>X01</td> <td>BCTRL enabled</td> </tr> <tr> <td>01X</td> <td><math>\overline{\text{INT1}}</math> input disabled</td> </tr> <tr> <td>11X</td> <td><math>\overline{\text{INT1}}</math> input enabled</td> </tr> </tbody> </table> | INT1PRG | Result                                 | X00 | GPIO enabled                            | X01 | BCTRL enabled                          | 01X | $\overline{\text{INT1}}$ input disabled | 11X | $\overline{\text{INT1}}$ input enabled |
| INT1PRG | Result                                  |         |  |         |  |     |   |     |  |     |   |     |  |
| X00     | GPIO enabled                            |         |  |         |  |     |   |     |  |     |   |     |  |
| X01     | BCTRL enabled                           |         |  |         |  |     |   |     |  |     |   |     |  |
| 01X     | $\overline{\text{INT1}}$ input disabled |         |  |         |  |     |   |     |  |     |   |     |  |
| 11X     | $\overline{\text{INT1}}$ input enabled  |         |  |         |  |     |   |     |  |     |   |     |  |
| 0       | INTOPRG                                 | 0       | Controls the function of $\overline{\text{INT0}}$ .<br><table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>INTOPRG</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>0</td> <td><math>\overline{\text{INT0}}</math> input disabled</td> </tr> <tr> <td>1</td> <td><math>\overline{\text{INT0}}</math> input enabled</td> </tr> </tbody> </table>  | INTOPRG | Result                                 | 0   | $\overline{\text{INT0}}$ input disabled | 1   | $\overline{\text{INT0}}$ input enabled |     |   |     |  |
| INTOPRG | Result                                  |         |  |         |  |     |   |     |  |     |   |     |  |
| 0       | $\overline{\text{INT0}}$ input disabled |         |  |         |  |     |   |     |  |     |   |     |  |
| 1       | $\overline{\text{INT0}}$ input enabled  |         |  |         |  |     |   |     |  |     |   |     |  |

### Writing to the Interrupt Pins Configuration SFR (INTPR, Address 0xFF)

To protect the RTC from runaway code, a key must be written to the key SFR (KYREG, Address 0xC1) to obtain write access to INTPR. KYREG (see Table 125) should be set to 0xEA to unlock this SFR and reset to 0 after a timekeeping register is written to. The RTC registers can be written using the following 8052 assembly code:

```
MOV    KYREG, #0EAh
MOV    INTPR, #080h
```



**Table 17. Power Management Interrupt Flag SFR (IPSMF, Address 0xF8)**

| Bit | Bit Address | Mnemonic | Default | Description   |
|-----|-------------|----------|---------|---|
| 7   | 0xFF        | FPSR     | 0       | Power supply restored interrupt flag. Set when the $V_{DD}$ power supply has been restored. This occurs when the source of $V_{SWOUT}$ changes from $V_{BAT}$ to $V_{DD}$ . |
| 6   | 0xFE        | FPSM     | 0       | PSM interrupt flag. Set when an enabled PSM interrupt condition occurs.   |
| 5   | 0xFD        | FSAG     | 0       | Voltage SAG interrupt flag. Set when an ADE energy measurement SAG condition occurs.  |
| 4   | 0xFC        | Reserved | 0       | This bit must be kept at 0 for proper operation.  |
| 3   | 0xFB        | FVADC    | 0       | $V_{DCIN}$ ADC monitor interrupt flag. Set when $V_{DCIN}$ changes by $V_{DCIN\_DIFF}$ or when $V_{DCIN}$ measurement is ready.   |
| 2   | 0xFA        | FBAT     | 0       | $V_{BAT}$ monitor interrupt flag. Set when $V_{BAT}$ falls below $BATVTH$ or when $V_{BAT}$ measurement is ready.   |
| 1   | 0xF9        | FBSO     | 0       | Battery switchover interrupt flag. Set when $V_{SWOUT}$ switches from $V_{DD}$ to $V_{BAT}$ .   |
| 0   | 0xF8        | FVDCIN   | 0       | $V_{DCIN}$ monitor interrupt flag. Set when $V_{DCIN}$ falls below 1.2 V.   |

**Table 18. Battery Switchover Configuration SFR (BATPR, Address 0xF5)**

| Bit   | Mnemonic      | Default | Description   |
|-------|---------------|---------|---|
| [7:2] | Reserved      | 0       | These bits must be kept at 0 for proper operation.            |
| [1:0] | BATPRG        | 0       | Control bits for battery switchover.                          |
|       | <b>BATPRG</b> |         | <b>Result</b>   |
|       | 00            |         | Battery switchover enabled on low $V_{DD}$                    |
|       | 01            |         | Battery switchover enabled on low $V_{DD}$ and low $V_{DCIN}$ |
|       | 1X            |         | Battery switchover disabled                                   |

**Table 19. Peripheral Configuration SFR (PERIPH, Address 0xF4)**

| Bit   | Mnemonic      | Default | Description   |
|-------|---------------|---------|---|
| 7     | RX2FLAG       | 0       | If set, indicates that an RxD2 edge event triggered wake-up from PSM2.  |
| 6     | VSWSOURCE     | 1       | Indicates the power supply that is internally connected to $V_{SWOUT}$ (0 $V_{SWOUT} = V_{BAT}$ , 1 $V_{SWOUT} = V_{DD}$ ).   |
| 5     | VDD_OK        | 1       | If set, indicates that $V_{DD}$ power supply is ready for operation.  |
| 4     | PLL_FLT       | 0       | If set, indicates that a PLL fault occurred where the PLL lost lock. Set the PLLACK bit (see Table 51) in the start ADC measurement SFR (ADCGO, Address 0xD8) to acknowledge the fault and clear the PLL_FLT bit. |
| 3     | REF_BAT_EN    | 0       | Set this bit to enable internal voltage reference in PSM2 mode. This bit should be set if LCD is on in PSM1 and PSM2 mode.  |
| 2     | Reserved      | 0       | This bit must be kept at 0 for proper operation.  |
| [1:0] | RXPROG        | 0       | Controls the function of the P0.7/SS/T1/RxD2 pin.   |
|       | <b>RXPROG</b> |         | <b>Result</b>   |
|       | 00            |         | GPIO  |
|       | 01            |         | RxD2 with wake-up disabled  |
|       | 11            |         | RxD2 with wake-up enabled   |

**Table 20. Power Management Interrupt Enable SFR (IPSME, Address 0xEC)**

| Bit | Mnemonic | Default | Description  |
|-----|----------|---------|--|
| 7   | EPSR     | 0       | Enables a PSM interrupt when the power supply restored interrupt flag (FPSR) is set.   |
| 6   | Reserved | 0       | Reserved.  |
| 5   | ESAG     | 0       | Enables a PSM interrupt when the voltage SAG interrupt flag (FSAG) is set.             |
| 4   | Reserved | 0       | This bit must be kept at 0 for proper operation.                                       |
| 3   | EVADC    | 0       | Enables a PSM interrupt when the $V_{DCIN}$ ADC monitor interrupt flag (FVADC) is set. |
| 2   | EBAT     | 0       | Enables a PSM interrupt when the $V_{BAT}$ monitor interrupt flag (FBAT) is set.       |
| 1   | EBSO     | 0       | Enables a PSM interrupt when the battery switchover interrupt flag (FBSO) is set.      |
| 0   | EVDCIN   | 0       | Enables a PSM interrupt when the $V_{DCIN}$ monitor interrupt flag (FVDCIN) is set.    |

**Table 21. Scratch Pad 1 SFR (SCRATCH1, Address 0xFB)**

| Bit    | Mnemonic | Default | Description   |
|--------|----------|---------|---|
| 7 to 0 | SCRATCH1 | 0       | Value can be written/read in this register. This value is maintained in all the power saving modes. |

# ADE5166/ADE5169

**Table 22. Scratch Pad 2 SFR (SCRATCH2, Address 0xFC)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | SCRATCH2 | 0       | Value can be written/read in this register. This value is maintained in all the power saving modes. |

**Table 23. Scratch Pad 3 SFR (SCRATCH3, Address 0xFD)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | SCRATCH3 | 0       | Value can be written/read in this register. This value is maintained in all the power saving modes. |

**Table 24. Scratch Pad 4 SFR (SCRATCH4, Address 0xFE)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | SCRATCH4 | 0       | Value can be written/read in this register. This value is maintained in all the power saving modes. |

## **Clearing the Scratch Pad Registers (SCRATCH1, Address 0xFB to SCRATCH4, Address 0xFE)**

Note that these scratch pad registers are cleared only when the part loses  $V_{DD}$  and  $V_{BAT}$ .

**Table 25. Power Control SFR (POWCON, Address 0xC5)**

| Bit   | Mnemonic                    | Default | Description   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
|-------|-----------------------------|---------|---|----|-----------------------------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|
| 7     | Reserved                    | 1       | Reserved.   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 6     | METER_OF<br>F               | 0       | Set this bit to turn off the modulators and energy metering DSP circuitry to reduce power if metering functions are not needed in PSM0.   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 5     | Reserved                    | 0       | This bit should be kept at 0 for proper operation.  |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 4     | COREOFF                     | 0       | Set this bit to shut down the core and enter PSM2 mode if in the PSM1 operating mode.   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 3     | Reserved                    | 0       | Reserved.   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| [2:0] | CD                          | 010     | Controls the core clock frequency, $f_{CORE}$ . $f_{CORE} = 4.096 \text{ MHz}/2^{CD}$ .   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
|       |                             |         | <table border="1"> <thead> <tr> <th>CD</th> <th>Result (<math>f_{CORE}</math> in MHz)</th> </tr> </thead> <tbody> <tr><td>000</td><td>4.096</td></tr> <tr><td>001</td><td>2.048</td></tr> <tr><td>010</td><td>1.024</td></tr> <tr><td>011</td><td>0.512</td></tr> <tr><td>100</td><td>0.256</td></tr> <tr><td>101</td><td>0.128</td></tr> <tr><td>110</td><td>0.064</td></tr> <tr><td>111</td><td>0.032</td></tr> </tbody> </table> | CD | Result ( $f_{CORE}$ in MHz) | 000 | 4.096 | 001 | 2.048 | 010 | 1.024 | 011 | 0.512 | 100 | 0.256 | 101 | 0.128 | 110 | 0.064 | 111 | 0.032 |
| CD    | Result ( $f_{CORE}$ in MHz) |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 000   | 4.096                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 001   | 2.048                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 010   | 1.024                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 011   | 0.512                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 100   | 0.256                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 101   | 0.128                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 110   | 0.064                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 111   | 0.032                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |

## **Writing to the Power Control SFR (POWCON, Address 0xC5)**

Writing data to the POWCON SFR involves writing 0xA7 into the key SFR (KYREG, Address 0xC1), which is described in Table 125, followed by a write to the POWCON SFR. For example,

```
MOV KYREG,#0A7h      ;Write KYREG to 0xA7 to get write access to the POWCON SFR
MOV POWCON,#10h     ;Shutdown the core
```

**POWER SUPPLY ARCHITECTURE**

The ADE5166/ADE5169 have two power supply inputs,  $V_{DD}$  and  $V_{BAT}$ , and they require only a single 3.3 V power supply at  $V_{DD}$  for full operation. A battery backup, or secondary power supply, with a maximum of 3.7 V can be connected to the  $V_{BAT}$  input. Internally, the ADE5166/ADE5169 connect  $V_{DD}$  or  $V_{BAT}$  to  $V_{SWOUT}$ , which is used to derive power for the ADE5166/ADE5169 circuitry. The  $V_{SWOUT}$  output pin reflects the voltage at the internal power supply ( $V_{SWOUT}$ ) and has a maximum output current of 6 mA. This pin can also be used to power a limited number of peripheral components. The 2.5 V analog supply ( $V_{INTA}$ ) and the 2.5 V supply for the core logic ( $V_{INTD}$ ) are derived by on-chip linear regulators from  $V_{SWOUT}$ . Figure 30 shows the ADE5166/ADE5169 power supply architecture.

The ADE5166/ADE5169 provide automatic battery switchover between  $V_{DD}$  and  $V_{BAT}$  based on the voltage level detected at  $V_{DD}$  or  $V_{DCIN}$ . In addition, the BCTRL input can be used to trigger a battery switchover. The conditions for switching  $V_{SWOUT}$  from  $V_{DD}$  to  $V_{BAT}$  and back to  $V_{DD}$  are described in the Battery Switchover section.  $V_{DCIN}$  is an input pin that can be connected to a 0 V to 3.3 V dc signal. This input is intended for power supply supervisory purposes and does not provide power to the ADE5166/ADE5169 circuitry (see the Battery Switchover section).

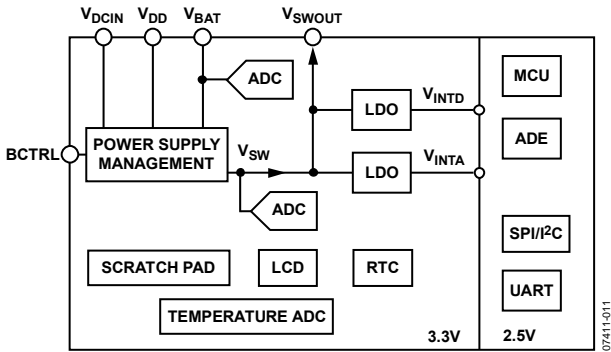


Figure 30. Power Supply Architecture

**BATTERY SWITCHOVER**

The ADE5166/ADE5169 monitor  $V_{DD}$ ,  $V_{BAT}$ , and  $V_{DCIN}$ . Automatic battery switchover from  $V_{DD}$  to  $V_{BAT}$  can be configured based on the status of the  $V_{DD}$ , the  $V_{DCIN}$ , or the BCTRL pin. Battery switchover is enabled by default. Setting Bit 1 in the battery switchover configuration SFR (BATPR, Address 0xF5) disables battery switchover so that  $V_{DD}$  is always connected to  $V_{SWOUT}$  (see Table 18). The source of  $V_{SWOUT}$  is indicated by Bit 6 in the peripheral configuration SFR (PERIPH, Address 0xF4), which is described in Table 19. Bit 6 is set when  $V_{SWOUT}$  is connected to  $V_{DD}$  and cleared when  $V_{SWOUT}$  is connected to  $V_{BAT}$ .

The battery switchover functionality provided by the ADE5166/ADE5169 allows a seamless transition from  $V_{DD}$  to  $V_{BAT}$ . An automatic battery switchover option ensures a stable power supply to the ADE5166/ADE5169, as long as the external battery voltage

is above 2.75 V. It allows continuous code execution even while the internal power supply is switching from  $V_{DD}$  to  $V_{BAT}$  and back. Note that the energy metering ADCs are not available when  $V_{BAT}$  is being used for  $V_{SWOUT}$ .

Power supply management (PSM) interrupts can be enabled to indicate when battery switchover occurs and when the  $V_{DD}$  power supply is restored (see the Power Supply Management (PSM) Interrupt section.)

**$V_{DD}$  to  $V_{BAT}$**

The following three events switch the internal power supply ( $V_{SWOUT}$ ) from  $V_{DD}$  to  $V_{BAT}$ :

- $V_{DCIN} < 1.2$  V. When  $V_{DCIN}$  falls below 1.2 V,  $V_{SWOUT}$  switches from  $V_{DD}$  to  $V_{BAT}$ . This event is enabled when the BATPRG[1:0] bits in the battery switchover configuration SFR (BATPR, Address 0xF5) = 0b01.
- $V_{DD} < 2.75$  V. When  $V_{DD}$  falls below 2.75 V,  $V_{SWOUT}$  switches from  $V_{DD}$  to  $V_{BAT}$ . This event is enabled when BATPRG[1:0] in the BATPR SFR are cleared.
- Falling edge on BCTRL. When the battery control pin, BCTRL, goes low,  $V_{SWOUT}$  switches from  $V_{DD}$  to  $V_{BAT}$ . This external switchover signal can trigger a switchover to  $V_{BAT}$  at any time. Setting the INT1PRG bits to 0bx01 in the interrupt pins configuration SFR (INTPR, Address 0xFF) enables the battery control pin (see Table 16).

**Switching from  $V_{BAT}$  to  $V_{DD}$**

To switch  $V_{SWOUT}$  from  $V_{BAT}$  to  $V_{DD}$ , all of the following events must be true:

- $V_{DD} > 2.75$  V.  $V_{SWOUT}$  switches back to  $V_{DD}$  after  $V_{DD}$  remains above 2.75 V.
- $V_{DCIN} > 1.2$  V and  $V_{DD} > 2.75$  V. If the low  $V_{DCIN}$  condition is enabled,  $V_{SWOUT}$  switches to  $V_{DD}$  after  $V_{DCIN}$  remains above 1.2 V and  $V_{DD}$  remains above 2.75 V.
- Rising edge on BCTRL. If the battery control pin is enabled,  $V_{SWOUT}$  switches back to  $V_{DD}$  after BCTRL is high, and the first or second bullet point is satisfied.

**POWER SUPPLY MANAGEMENT (PSM) INTERRUPT**

The power supply management (PSM) interrupt alerts the 8052 core of power supply events. The PSM interrupt is disabled by default. Setting the EPSM bit in the interrupt enable and Priority 2 SFR (IEIP2, Address 0xA9) enables the PSM interrupt (see Table 82).

The power management interrupt enable SFR (IPSMIE, Address 0xEC) controls the events that result in a PSM interrupt (see Table 20).

Figure 31 illustrates how the PSM interrupt vector is shared among the PSM interrupt sources. The PSM interrupt flags are latched and must be cleared by writing to the IPSMF power management interrupt flag SFR, Address 0xF8 (see Table 17).

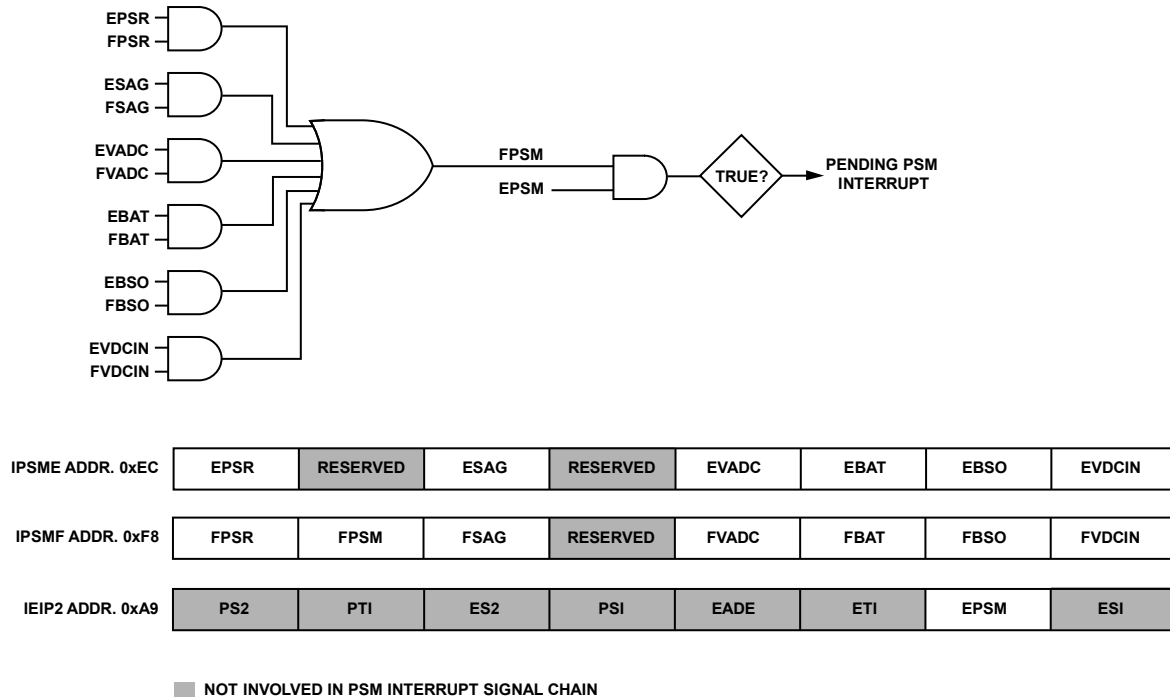


Figure 31. Power Supply Management Interrupt Sources

## Battery Switchover and Power Supply Restored PSM Interrupt

The ADE5166/ADE5169 can be configured to generate a PSM interrupt when the source of  $V_{SWOUT}$  changes from  $V_{DD}$  to  $V_{BAT}$ , indicating battery switchover. Setting the EBSO bit in the power management interrupt enable SFR (IPSME, Address 0xEC) enables this event to generate a PSM interrupt (see Table 20).

The ADE5166/ADE5169 can also be configured to generate an interrupt when the source of  $V_{SWOUT}$  changes from  $V_{BAT}$  to  $V_{DD}$ , indicating that the  $V_{DD}$  power supply has been restored. Setting the EPSR bit in the power management interrupt enable SFR (IPSME, Address 0xEC) enables this event to generate a PSM interrupt.

The flags in the IPSMF SFR for these interrupts, FBSO and FPSR, are set regardless of whether the respective enable bits have been set. The battery switchover and power supply restore event flags, FBSO and FPSR, are latched. These events must be cleared by writing a 0 to these bits. Bit 6 in the peripheral configuration SFR (PERIPH, Address 0xF4), VSWSOURCE, tracks the source of  $V_{SWOUT}$ . The bit is set when  $V_{SWOUT}$  is connected to  $V_{DD}$  and cleared when  $V_{SWOUT}$  is connected to  $V_{BAT}$ .

## $V_{DCIN}$ ADC PSM Interrupt

The ADE5166/ADE5169 can be configured to generate a PSM interrupt when  $V_{DCIN}$  changes magnitude by more than a configurable threshold. This threshold is set in the temperature and supply delta SFR (DIFFPROG, Address 0xF3), which is described in Table 50. See the External Voltage Measurement section for more information. Setting the EVADC bit in the power management interrupt enable SFR (IPSME, Address 0xEC) enables this event to generate a PSM interrupt.

The  $V_{DCIN}$  voltage is measured using a dedicated ADC. These measurements take place in the background at intervals to check the change in  $V_{DCIN}$ . Conversions can also be initiated by writing to the start ADC measurement SFR (ADCGO, Address 0xD8), as described in Table 51. The FVADC flag indicates when a  $V_{DCIN}$  measurement is ready. See the External Voltage Measurement section for details on how  $V_{DCIN}$  is measured.

## $V_{BAT}$ Monitor PSM Interrupt

The  $V_{BAT}$  voltage is measured using a dedicated ADC. These measurements take place in the background at intervals to check the change in  $V_{BAT}$ . The FBAT bit is set when the battery level is lower than the threshold set in the battery detection threshold SFR (BATVTH, Address 0xFA), described in Table 52; or when a new measurement is ready in the battery ADC value SFR (BATADC, Address 0xDF), described in Table 54. See the Battery Measurement section for more information. Setting the EBAT bit in the power management interrupt enable SFR (IPSME, Address 0xEC) enables this event to generate a PSM interrupt.

## $V_{DCIN}$ Monitor PSM Interrupt

The  $V_{DCIN}$  voltage is monitored by a comparator. The FVDCIN bit in the power management interrupt flag SFR (IPSMF, Address 0xF8) is set when the  $V_{DCIN}$  input level is lower than 1.2 V. Setting the EVDCIN bit in the IPSME SFR enables this event to generate a PSM interrupt. This event, which is associated with the SAG monitoring, can be used to detect that a power supply ( $V_{DD}$ ) is compromised and to trigger further actions prior to initiating a switch from  $V_{DD}$  to  $V_{BAT}$ .

**SAG Monitor PSM Interrupt**

The ADE5166/ADE5169 energy measurement DSP monitors the ac voltage input at the  $V_P$  and  $V_N$  input pins. The SAGLVL register (Address 0x14) is used to set the threshold for a line voltage SAG event. The FSAG bit in the power management interrupt flag SFR (IPSMF, Address 0xF8) is set if the line voltage stays below the level set in the SAGLVL register for the number of line cycles set in the SAGCYC register (Address 0x13). See the Line Voltage SAG Detection section for more information. Setting the ESAG bit in the power management interrupt enable SFR (IPSME, Address 0xEC) enables this event to generate a PSM interrupt.

**USING THE POWER SUPPLY FEATURES**

In an energy meter application, the 3.3 V power supply ( $V_{DD}$ ) is typically generated from the ac line voltage and regulated to 3.3 V by a voltage regulator IC. The preregulated dc voltage, typically 5 V to 12 V, can be connected to  $V_{DCIN}$  through a resistor divider. A 3.6 V battery can be connected to  $V_{BAT}$ .

Figure 32 shows how the ADE5166/ADE5169 power supply inputs are set up in this application.

Figure 33 shows the sequence of events that occurs if the main power supply generated by the PSU starts to fail in the power meter application shown in Figure 32. The SAG detection can provide the earliest warning of a potential problem on  $V_{DD}$ . When a SAG event occurs, user code can be configured to back up data and prepare for battery switchover, if desired. The relative spacing of these interrupts depends on the design of the power supply.

Figure 34 shows the sequence of events that occurs if the main power supply starts to fail in the power meter application shown in Figure 32, with battery switchover on low  $V_{DCIN}$  or low  $V_{DD}$  enabled.

Finally, the transition between  $V_{DD}$  and  $V_{BAT}$  and the different power supply modes (see the Operating Modes section) are represented in Figure 35 and Figure 36.

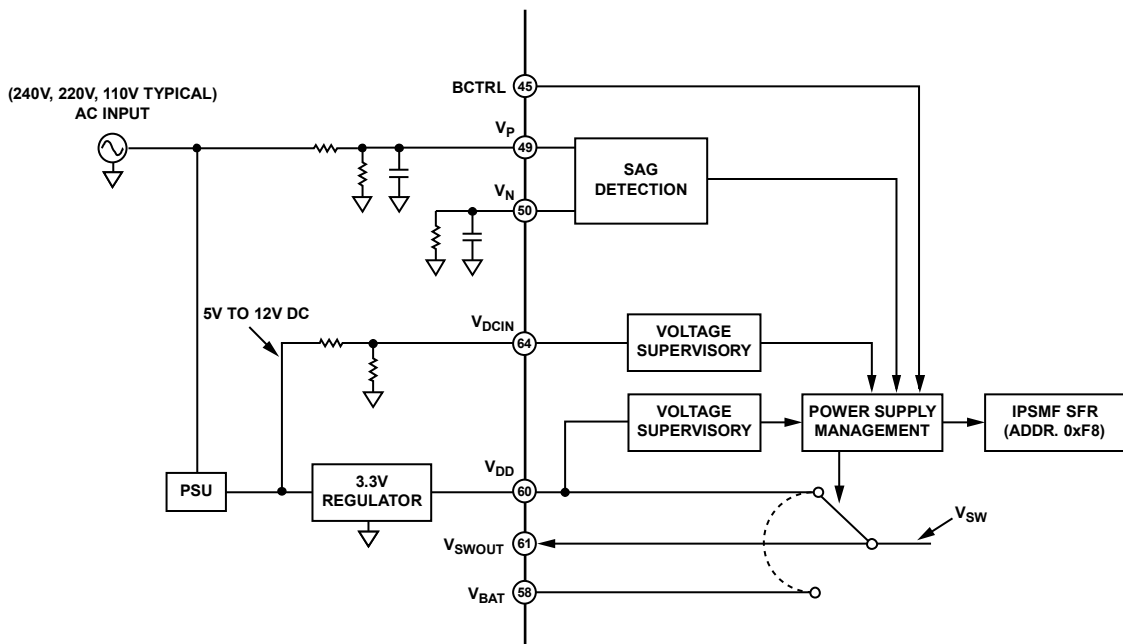


Figure 32. Power Supply Management for Energy Meter Application

07411-013

**Table 26. Power Supply Event Timing Operating Modes**

| Parameter      | Time       | Description  |
|----------------|------------|--|
| t <sub>1</sub> | 10 ns min  | Time between when $V_{DCIN}$ goes below 1.2 V and when FVDCIN is raised.   |
| t <sub>2</sub> | 10 ns min  | Time between when $V_{DD}$ falls below 2.75 V and when battery switchover occurs.  |
| t <sub>3</sub> | 30 ms typ  | Time between when $V_{DCIN}$ falls below 1.2 V and when battery switchover occurs if $V_{DCIN}$ is enabled to cause battery switchover.  |
| t <sub>4</sub> | 130 ms typ | Time between when power supply restore conditions are met ( $V_{DCIN}$ above 1.2 V and $V_{DD}$ above 2.75 V if BATPR[1:0] = 0b01 or $V_{DD}$ above 2.75 V if BATPR[1:0] = 0b00) and when $V_{SWOUT}$ switches to $V_{DD}$ . |

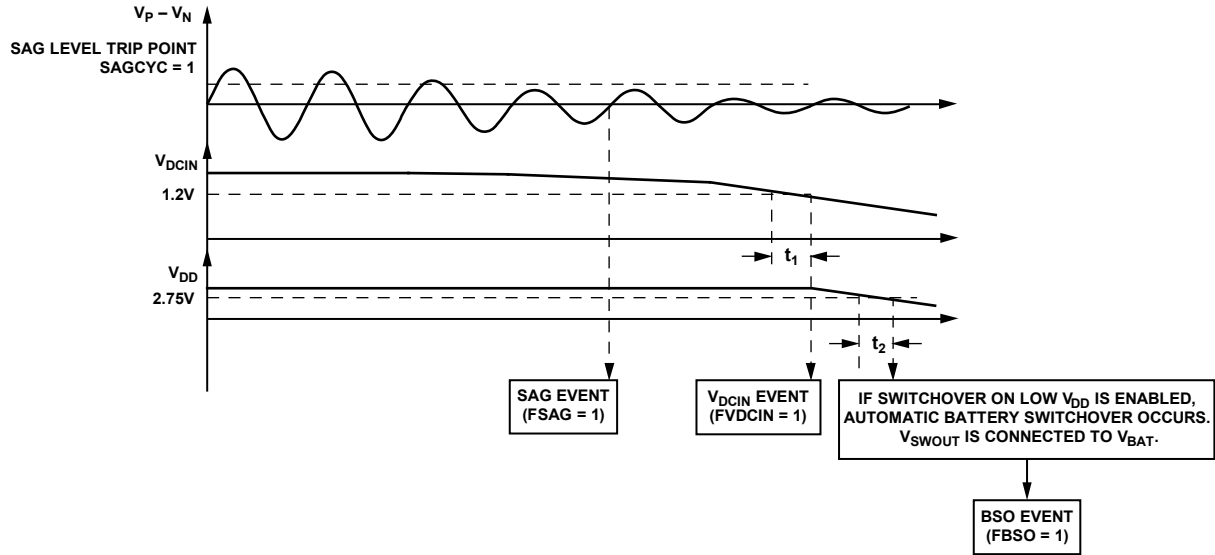


Figure 33. Power Supply Management Interrupts and Battery Switchover with Only  $V_{DD}$  Enabled for Battery Switchover

07411-014

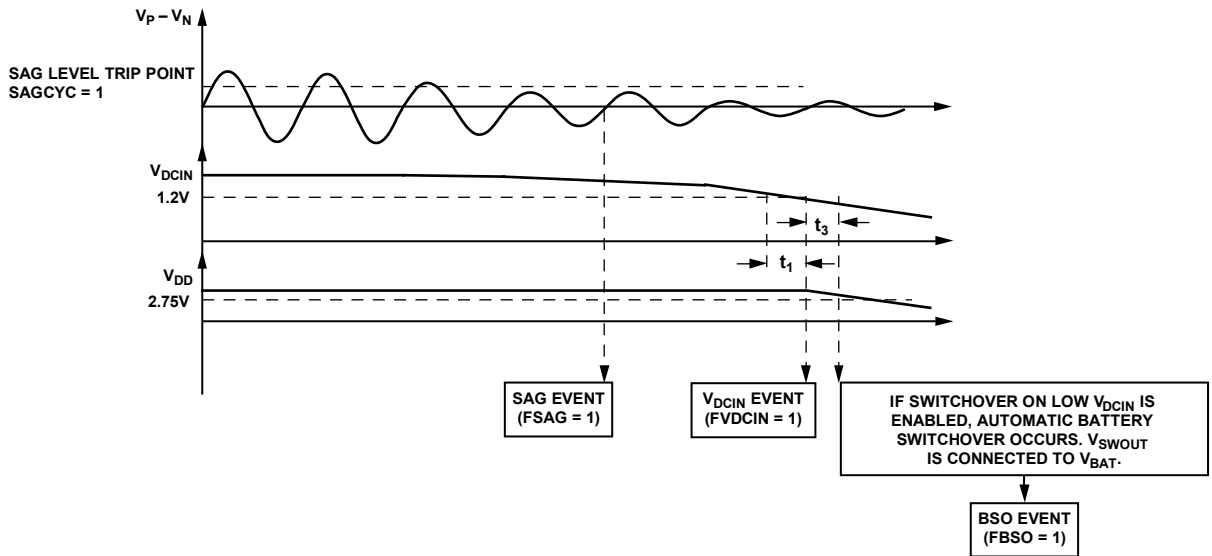


Figure 34. Power Supply Management Interrupts and Battery Switchover with  $V_{DD}$  or  $V_{DCIN}$  Enabled for Battery Switchover

07411-015

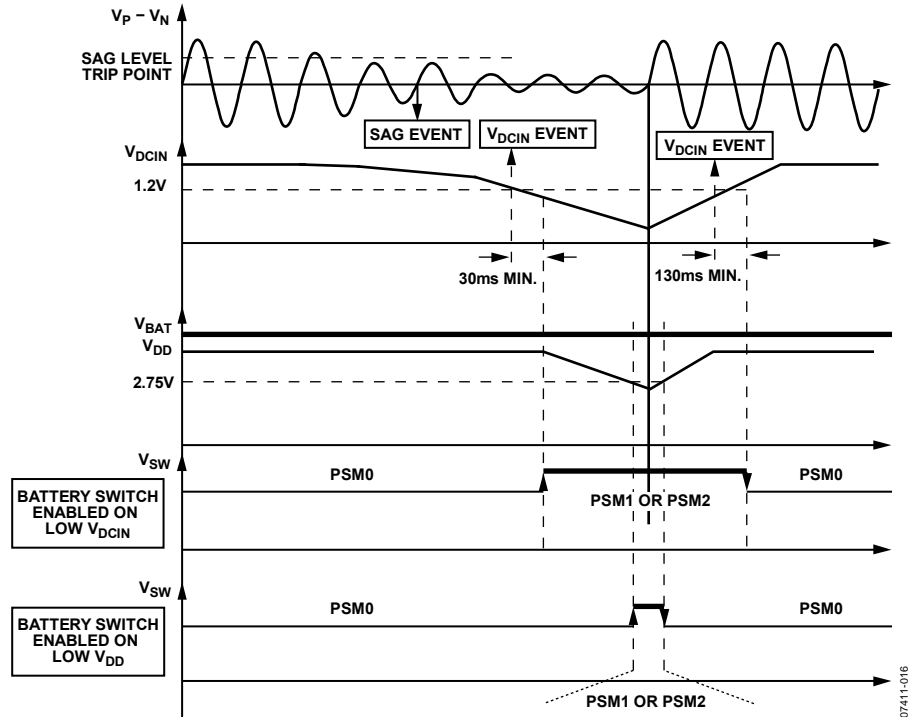


Figure 35. Power Supply Management Transitions Between Modes

07411-016

## OPERATING MODES

### PSM0 (NORMAL MODE)

In PSM0, or normal operating mode,  $V_{SWOUT}$  is connected to  $V_{DD}$ . All of the analog circuitry and digital circuitry powered by  $V_{INTD}$  and  $V_{INTA}$  are enabled by default. In normal mode, the default clock frequency,  $f_{CORE}$ , which is established during a power-on reset or software reset, is 1.024 MHz.

### PSM1 (BATTERY MODE)

In PSM1, or battery mode,  $V_{SWOUT}$  is connected to  $V_{BAT}$ . In this operating mode, the 8052 core and all of the digital circuitry are enabled by default. The analog circuitry for the ADE energy metering DSP powered by  $V_{INTA}$  is disabled. This analog circuitry automatically restarts, and the switch to the  $V_{DD}$  power supply occurs when the  $V_{DD}$  supply is  $>2.75$  V and the PWRDN bit in the MODE1 register (Address 0x0B) is cleared (see Table 32). The default  $f_{CORE}$  for PSM1, established during a power-on reset or software reset, is 1.024 MHz.

### PSM2 (SLEEP MODE)

PSM2 is a low power consumption sleep mode for use in battery operation. In this mode,  $V_{SWOUT}$  is connected to  $V_{BAT}$ . All of the 2.5 V digital and analog circuitry powered through  $V_{INTA}$  and  $V_{INTD}$  is disabled, including the MCU core, resulting in the following:

- The RAM in the MCU is no longer valid.
- The program counter for the 8052, also held in volatile memory, becomes invalid when the 2.5 V supply is shut down. Therefore, the program does not resume from where it left off but always starts from the power-on reset vector when the ADE5166/ADE5169 exit PSM2.

The 3.3 V peripherals (temperature ADC,  $V_{DCIN}$  ADC, RTC, and LCD) are active in PSM2. They can be enabled or disabled to reduce power consumption and are configured for PSM2 operation when the MCU core is active (see Table 28 for more information about the individual peripherals and their PSM2 configuration). The ADE5166/ADE5169 remain in PSM2 until an event occurs to wake them up.

In PSM2, the ADE5166/ADE5169 provide four scratch pad RAM SFRs that are maintained during this mode. These SFRs can be used to save data from PSM0 or PSM1 mode when entering PSM2 mode (see Table 21 to Table 24).

In PSM2 mode, the ADE5166/ADE5169 maintain some SFRs (see Table 27). The SFRs that are not listed in this table should be restored when the part enters PSM0 or PSM1 mode from PSM2 mode.

**Table 27. SFRs Maintained in PSM2**

| I/O Configuration  | Power Supply Management   | RTC Peripherals  | LCD Peripherals   |
|--|---|--|---|
| Interrupt pins configuration SFR (INTPR, Address 0xFF); see Table 16.  | Battery detection threshold SFR (BATVTH, Address 0xFA); see Table 52.     | RTC nominal compensation SFR (RTCCOMP, Address 0xF6); see Table 131.                 | LCD Segment Enable 2 SFR (LCDSEGE2, Address 0xED); see Table 100. |
| Peripheral configuration SFR (PERIPH, Address 0xF4); see Table 19.     | Battery switchover configuration SFR (BATPR, Address 0xF5); see Table 18. | RTC temperature compensation SFR (TEMPCAL, Address 0xF7); see Table 132.             | LCD Configuration Y SFR (LCDCONY, Address 0xB1); see Table 93.    |
| Port 0 weak pull-up enable SFR (PINMAP0, Address 0xB2); see Table 162. | Battery ADC value SFR (BATADC, Address 0xDF); see Table 54.               | RTC configuration SFR (TIMECON, Address 0xA1); see Table 127.                        | LCD Configuration X SFR (LCDCONX, Address 0x9C); see Table 91.    |
| Port 1 weak pull-up enable SFR (PINMAP1, Address 0xB3); see Table 163. | Peripheral ADC strobe period SFR (STRBPER, Address 0xF9); see Table 49.   | RTC Configuration 2 SFR (TIMECON2, Address 0xA2); see Table 128.                     | LCD configuration SFR (LCDCON, Address 0x95); see Table 90.       |
| Port 2 weak pull-up enable SFR (PINMAP2, Address 0xB4); see Table 164. | Temperature and supply delta SFR (DIFFPROG, Address 0xF3); see Table 50.  | All indirectly accessible registers defined in the RTC register list; see Table 134. | LCD clock SFR (LCDCLK, Address 0x96); see Table 94.               |
| Scratch Pad 1 SFR (SCRATCH1, Address 0xFB); see Table 21.              | $V_{DCIN}$ ADC value SFR (VDCINADC, Address 0xEF); see Table 53.          |  | LCD segment enable SFR (LCDSEGE, Address 0x97); see Table 97.     |
| Scratch Pad 2 SFR (SCRATCH2, Address 0xFC); see Table 22.              | Temperature ADC value SFR (TEMPADC, Address 0xD7); see Table 55.          |  | LCD Pointer SFR (LCDPTR, Address 0xAC); see Table 98.             |
| Scratch Pad 3 SFR (SCRATCH3, Address 0xFD); see Table 23.              |   |  | LCD data SFR (LCDDAT, Address 0xAE); see Table 99.                |
| Scratch Pad 4 SFR (SCRATCH4, Address 0xFE); see Table 24.              |   |  |   |



### 3.3 V PERIPHERALS AND WAKE-UP EVENTS

Some of the 3.3 V peripherals are capable of waking the ADE5166/ADE5169 from PSM2 mode. The events that can cause the ADE5166/ADE5169 to wake up from PSM2 mode are listed in the Wake-Up Event column in Table 28. The interrupt flag

associated with these events must be cleared prior to executing instructions that put the ADE5166/ADE5169 in PSM2 mode after wake-up.

**Table 28. 3.3 V Peripherals and Wake-Up Events**

| 3.3 V Peripheral        | Wake-Up Event | Wake-Up Enable Bits | Flag              | Interrupt Vector | Comments  |
|-------------------------|---------------|---------------------|-------------------|------------------|---|
| Temperature ADC         | $\Delta T$    | Maskable            |                   |                  | The temperature ADC can wake up the ADE5166/ADE5169. A pending interrupt is generated according to the description in the Temperature Measurement section. This wake-up event can be disabled by disabling temperature measurements in the temperature and supply delta SFR (DIFFPROG, Address 0xF3) in PSM2 mode. The temperature interrupt needs to be serviced and acknowledged prior to entering PSM2 mode. |
| V <sub>DCIN</sub> ADC   | $\Delta V$    | Maskable            | FVADC             | IPSM             | The V <sub>DCIN</sub> measurement can wake up the ADE5166/ADE5169. FVADC is set according to the description in the External Voltage Measurement section. This wake-up event can be disabled by clearing EVADC in the power management interrupt enable SFR (IPSME, Address 0xEC); see Table 20. The FVADC flag needs to be cleared prior to entering PSM2 mode.  |
| Power Supply Management | PSR           | Nonmaskable         | PSR               | IPSM             | The ADE5166/ADE5169 wake up if the power supply is restored (if V <sub>SWOUT</sub> switches to be connected to V <sub>DD</sub> ). The VSWSOURCE flag, Bit 6 of the peripheral configuration SFR (PERIPH, Address 0xF4), is set to indicate that V <sub>SWOUT</sub> is connected to V <sub>DD</sub> .  |
| RTC                     | Interval      | Maskable            | ITFLAG            | IRTC             | The ADE5166/ADE5169 wake up after the programmable time interval has elapsed. The RTC interrupt needs to be serviced and acknowledged prior to entering PSM2 mode.  |
|                         | Alarm         | Maskable            | Alarm             | IRTC             | An alarm can be set to wake the ADE5166/ADE5169 after the desired amount of time. The RTC alarm is enabled by setting the AL <sub>x</sub> _EN bits in the RTC Configuration 2 SFR (TIMECON2, Address 0xA2). The RTC interrupt needs to be serviced and acknowledged prior to entering PSM2 mode.  |
| I/O Ports <sup>1</sup>  | INT0          | INT0PRG = 1         |                   | IE0              | The edge of the interrupt is selected by the IT0 bit in the TCON SFR (TCON, Address 0x88). The IE0 flag bit in the TCON SFR is not affected. The Interrupt 0 interrupt needs to be serviced and acknowledged prior to entering PSM2 mode.   |
|                         | INT1          | INT1PRG = 11x       |                   | IE1              | The edge of the interrupt is selected by the IT1 bit in the TCON SFR (TCON, Address 0x88). The IE1 flag bit in the TCON SFR is not affected. The Interrupt 1 interrupt needs to be serviced and acknowledged prior to entering PSM2 mode.   |
|                         | Rx2 Edge      | RXPROG[1:0] = 11    | PERIPH[7] (RX2FG) |                  | An Rx edge event occurs if a rising or falling edge is detected on the RxD2 line. The UART2 RxD flag needs to be cleared prior to entering PSM2 mode.   |
| External Reset          | RESET         | Nonmaskable         |                   |                  | If the RESET pin is brought low while the ADE5166/ADE5169 are in PSM2 mode, they wake up to PSM1 mode.  |
| LCD                     |               |                     |                   |                  | The LCD can be enabled/disabled in PSM2 mode. The LCD data memory remains intact.   |
| Scratch Pad             |               |                     |                   |                  | The four SCRATCH <sub>x</sub> registers remain intact in PSM2 mode.   |

<sup>1</sup> All I/O pins are treated as inputs. The weak pull-up on each I/O pin can be disabled individually in the Port 0 weak pull-up enable SFR (PINMAP0, Address 0xB2), Port 1 weak pull-up enable SFR (PINMAP1, Address 0xB3), and Port 2 weak pull-up enable SFR (PINMAP2, Address 0xB4) to decrease current consumption. The interrupts can be enabled or disabled.

## TRANSITIONING BETWEEN OPERATING MODES

The operating mode of the ADE5166/ADE5169 is determined by the power supply connected to  $V_{SWOUT}$ . Therefore, changes in the power supply, such as when  $V_{SWOUT}$  switches from  $V_{DD}$  to  $V_{BAT}$  or when  $V_{SWOUT}$  switches to  $V_{DD}$ , alter the operating mode. This section describes events that change the operating mode.

### Automatic Battery Switchover (PSM0 to PSM1)

If any of the enabled battery switchover events occur (see the Battery Switchover section),  $V_{SWOUT}$  switches to  $V_{BAT}$ . This switchover results in a transition from PSM0 to PSM1 operating mode. When battery switchover occurs, the analog circuitry used in the ADE energy measurement DSP is disabled. To reduce power consumption, the user code can initiate a transition to PSM2.

### Entering Sleep Mode (PSM1 to PSM2)

To reduce power consumption when  $V_{SWOUT}$  is connected to  $V_{BAT}$ , user code can initiate sleep mode, PSM2, by setting Bit 4 in the power control SFR (POWCON, Address 0xC5) to shut down the MCU core. Events capable of waking the MCU can be enabled (see the 3.3 V Peripherals and Wake-Up Events section).

### Servicing Wake-Up Events (PSM2 to PSM1)

The ADE5166/ADE5169 may need to wake up from PSM2 to service wake-up events (see the 3.3 V Peripherals and Wake-Up Events section). PSM1 code execution begins at the power-on reset vector. After servicing the wake-up event, the ADE5166/ADE5169 can return to PSM2 by setting Bit 4 in the power control SFR (POWCON, Address 0xC5) to shut down the MCU core.

### Automatic Switch to $V_{DD}$ (PSM2 to PSM0)

If the conditions to switch  $V_{SWOUT}$  from  $V_{BAT}$  to  $V_{DD}$  occur (see the Battery Switchover section), the operating mode switches to PSM0. When this switch occurs, the MCU core and the analog circuitry used in the ADE energy measurement DSP automatically restart. PSM0 code execution begins at the power-on reset vector.

### Automatic Switch to $V_{DD}$ (PSM1 to PSM0)

If the conditions to switch  $V_{SWOUT}$  from  $V_{BAT}$  to  $V_{DD}$  occur (see the Battery Switchover section), the operating mode switches to PSM0. When this switch occurs, the analog circuitry used in the ADE energy measurement DSP automatically restarts. Note that code execution continues normally. A software reset can be performed to start PSM0 code execution at the power-on reset vector.

## USING THE POWER MANAGEMENT FEATURES

Because program flow is different for each operating mode, the status of  $V_{SWOUT}$  must be known at all times. The VSWSOURCE bit in the peripheral configuration SFR (PERIPH, Address 0xF4) indicates the power supply to which  $V_{SWOUT}$  is connected (see Table 19). This bit can be used to control program flow on wake-up. Because code execution always starts at the power-on reset vector, Bit 6 of the PERIPH SRF can be tested to determine which power supply is being used and to branch to normal code execution or to wake up event code execution. Power supply events can also occur when the MCU core is active. To be aware of the events that change what  $V_{SWOUT}$  is connected to, use the following guidelines:

- Enable the battery switchover interrupt (EBSO) if  $V_{SWOUT} = V_{DD}$  at power-up.
- Enable the power supply restored interrupt (EPSR) if  $V_{SWOUT} = V_{BAT}$  at power-up.

An early warning that battery switchover is about to occur is provided by SAG detection and, possibly, by low  $V_{DCIN}$  detection (see the Battery Switchover section).

For a user-controlled battery switchover, enable automatic battery switchover on low  $V_{DD}$  only. Next, enable the low  $V_{DCIN}$  event to generate the PSM interrupt. When a low  $V_{DCIN}$  event occurs, start data backup. Upon completion of the data backup, enable battery switchover on low  $V_{DCIN}$ . Battery switchover occurs 30 ms later.

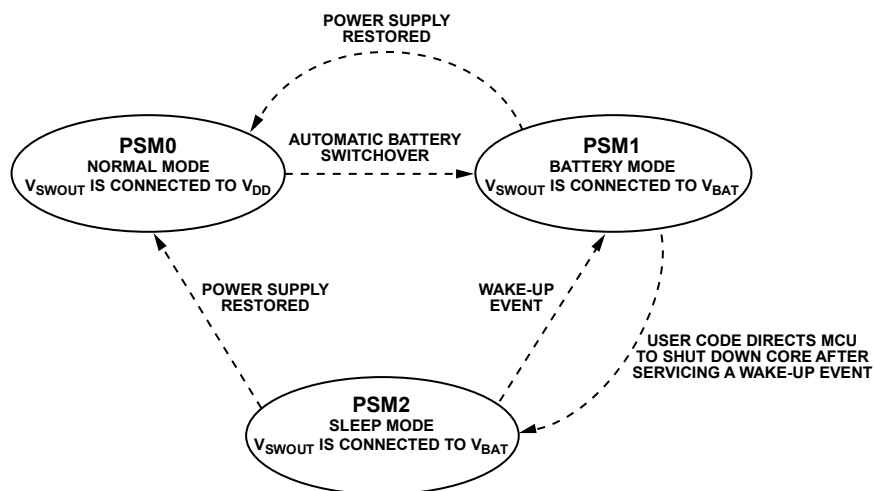


Figure 36. Transitioning Between Operating Modes

07411-017

## ENERGY MEASUREMENT

The ADE5166/ADE5169 offer a fixed function, energy measurement, digital processing core that provides all the information needed to measure energy in single-phase energy meters. The part provides two ways to access the energy measurements: direct access through SFRs for time sensitive information and indirect access through address and data SFRs for the majority of energy measurements. The  $I_{rms}$ ,  $V_{rms}$ , interrupts, and waveform registers are readily available through the SFRs, as shown in Table 30. Other energy measurement information is mapped to a page of memory that is accessed indirectly through the MADDPT, MDATL, MDATM, and MDATH SFRs. The address and data SFRs act as pointers to the energy measurement internal registers.

### ACCESS TO ENERGY MEASUREMENT SFRs

Access to the energy measurement SFRs is achieved by reading or writing to the SFR addresses detailed in Table 30. The internal data for the MIRQx SFRs is latched byte by byte into the SFR when the SFR is read.

The WAV1x, WAV2x, VRMSx, and IRMSx registers are all 3-byte SFRs. The 24-bit data is latched into these SFRs when the high byte is read. Reading the low or medium byte before the high byte results in reading the data from the previous latched sample.

Sample code to read the VRMSx register is as follows:

```
MOV    R1, VRMSH    //latches data in VRMSH,
                   VRMSM, and VRMSL SFRs
MOV    R2, VRMSM
MOV    R3, VRMSL
```

### ACCESS TO INTERNAL ENERGY MEASUREMENT REGISTERS

Access to the internal energy measurement registers is achieved by writing to the energy measurement pointer address SFR (MADDPT, Address 0x91). This SFR selects the energy measurement register to be accessed and determines if a read or a write is performed (see Table 29).

**Table 29. Energy Measurement Pointer Address SFR (MADDPT, Address 0x91)**

| Bit   | Description                                  |
|-------|--|
| 7     | 1 = write, 0 = read                          |
| [6:0] | Energy measurement internal register address |

#### Writing to the Internal Energy Measurement Registers

When Bit 7 of the energy measurement pointer address SFR (MADDPT, Address 0x91) is set, the content of the MDATx SFRs (MDATL, MDATM, and MDATH) is transferred to the

internal energy measurement register designated by the address in the MADDPT SFR. If the internal register is one byte long, only the MDATL SFR content is copied to the internal register, while the MDATM SFR and MDATH SFR contents are ignored.

The energy measurement core functions with an internal clock of 4.096 MHz/5 or 819.2 kHz. Because the 8052 core functions with another clock, 4.096MHz/2<sup>CD</sup>, synchronization between the two clock environments when CD = 0 or 1 is an issue. When data is written to the internal energy measurement registers, a small wait period needs to be implemented before another read or write to these registers can take place.

Sample code to write 0x0155 to the 2-byte SAGLVL register located at 0x14 in the energy measurement memory space is as follows:

```
MOV    MDATM, #01h
MOV    MDATL, #55h
MOV    MADDPT, #SAGLVL_W (Address 0x94)
MOV    A, #05h
DJNZ  ACC, $
      ;Next write or read to energy
      ;measurement SFR can be done after
      ;this.
```

#### Reading the Internal Energy Measurement Registers

When Bit 7 of energy measurement pointer address SFR (MADDPT, Address 0x91) is cleared, the content of the internal energy measurement register designated by the address in MADDPT is transferred to the MDATx SFRs. If the internal register is one byte long, only the MDATL SFR content is updated with a new value, and the MDATM SFR and MDATH SFR contents are reset to 0x00.

The energy measurement core functions with an internal clock of 4.096 MHz/5 or 819.2 kHz. Because the 8052 core functions with another clock, 4.096MHz/2<sup>CD</sup>, synchronization between the two clock environments when CD = 0 or 1 is an issue. When data is read from the internal energy measurement registers, a small wait period needs to be implemented before the MDATx SFRs are transferred to another SFR.

Sample code to read the peak voltage in the 2-byte VPKLVL register located at 0x16 into the data pointer is as follows:

```
MOV    MADDPT, #VPKLVL_R (Address 0x16)
MOV    A, #05h
DJNZ  ACC, $
MOV    DPH, MDATM
MOV    DPL, MDATL
```

# ADE5166/ADE5169

**Table 30. Energy Measurement SFRs**

| Address | R/W | Mnemonic | Description                                      |
|---------|-----|----------|--|
| 0x91    | R/W | MADDPT   | Energy measurement pointer address.              |
| 0x92    | R/W | MDATL    | Energy measurement pointer data LSB.             |
| 0x93    | R/W | MDATM    | Energy measurement pointer data middle byte.     |
| 0x94    | R/W | MDATH    | Energy measurement pointer data MSB.             |
| 0xD1    | R   | VRMSL    | $V_{rms}$ measurement LSB.                       |
| 0xD2    | R   | VRMSM    | $V_{rms}$ measurement middle byte.               |
| 0xD3    | R   | VRMSH    | $V_{rms}$ measurement MSB.                       |
| 0xD4    | R   | IRMSL    | $I_{rms}$ measurement LSB.                       |
| 0xD5    | R   | IRMSM    | $I_{rms}$ measurement middle byte.               |
| 0xD6    | R   | IRMSH    | $I_{rms}$ measurement MSB.                       |
| 0xD9    | R/W | MIRQENL  | Energy measurement interrupt enable LSB.         |
| 0xDA    | R/W | MIRQENM  | Energy measurement interrupt enable middle byte. |
| 0xDB    | R/W | MIRQENH  | Energy measurement interrupt enable MSB.         |
| 0xDC    | R/W | MIRQSTL  | Energy measurement interrupt status LSB.         |
| 0xDD    | R/W | MIRQSTM  | Energy measurement interrupt status middle byte. |
| 0xDE    | R/W | MIRQSTH  | Energy measurement interrupt status MSB.         |
| 0xE2    | R   | WAV1L    | Selection 1 sample LSB.                          |
| 0xE3    | R   | WAV1M    | Selection 1 sample middle byte.                  |
| 0xE4    | R   | WAV1H    | Selection 1 sample MSB.                          |
| 0xE5    | R   | WAV2L    | Selection 2 sample LSB.                          |
| 0xE6    | R   | WAV2M    | Selection 2 sample middle byte.                  |
| 0xE7    | R   | WAV2H    | Selection 2 sample MSB.                          |

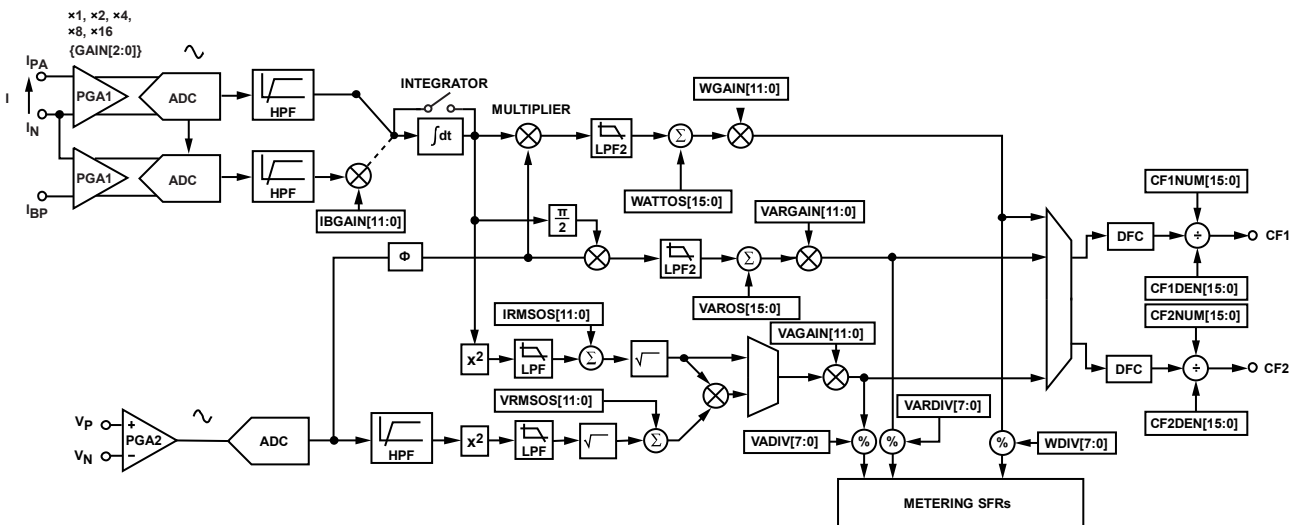


Figure 37. Energy Metering Block Diagram

07411-117

**ENERGY MEASUREMENT REGISTERS**

**Table 31. Energy Measurement Register List**

| Address<br>MADDPT[6:0] | Mnemonic             | R/W | Length<br>(Bits) | Signed/<br>Unsigned | Default | Description  |
|------------------------|----------------------|-----|------------------|---------------------|---------|--|
| 0x01                   | WATTHR               | R   | 24               | S                   | 0       | Reads Wh accumulator without reset.  |
| 0x02                   | RWATTHR              | R   | 24               | S                   | 0       | Reads Wh accumulator with reset.   |
| 0x03                   | LWATTHR              | R   | 24               | S                   | 0       | Reads Wh accumulator synchronous to line cycle.  |
| 0x04                   | VARHR <sup>1</sup>   | R   | 24               | S                   | 0       | Reads VARh accumulator without reset.  |
| 0x05                   | RVARHR <sup>1</sup>  | R   | 24               | S                   | 0       | Reads VARh accumulator with reset.   |
| 0x06                   | LVARHR <sup>1</sup>  | R   | 24               | S                   | 0       | Reads VARh accumulator synchronous to line cycle.  |
| 0x07                   | VAHR                 | R   | 24               | S                   | 0       | Reads VAh accumulator without reset. If the VARMSCFCON bit in the MODE2 register (Address 0x0C) is set, this register accumulates I <sub>rms</sub> .             |
| 0x08                   | RVAHR                | R   | 24               | S                   | 0       | Reads VAh accumulator with reset. If the VARMSCFCON bit in the MODE2 register (Address 0x0C) is set, this register accumulates I <sub>rms</sub> .                |
| 0x09                   | LVAHR                | R   | 24               | S                   | 0       | Reads VAh accumulator synchronous to line cycle. If the VARMSCFCON bit in the MODE2 register (Address 0x0C) is set, this register accumulates I <sub>rms</sub> . |
| 0x0A                   | PER_FREQ             | R   | 16               | U                   | 0       | Reads line period or frequency register depending on Mode2 register.   |
| 0x0B                   | MODE1                | R/W | 8                | U                   | 0x06    | Sets basic configuration of energy measurement (see Table 32).   |
| 0x0C                   | MODE2                | R/W | 8                | U                   | 0x40    | Sets basic configuration of energy measurement (see Table 33).   |
| 0x0D                   | WAVMODE              | R/W | 8                | U                   | 0       | Sets configuration of Waveform Sample 1 and Waveform Sample 2 (see Table 34).  |
| 0x0E                   | NLMODE               | R/W | 8                | U                   | 0       | Sets level of energy no load thresholds (see Table 35).  |
| 0x0F                   | ACCMODE              | R/W | 8                | U                   | 0       | Sets configuration of watt and var accumulation and various tamper alarms (see Table 36).  |
| 0x10                   | PHCAL                | R/W | 8                | S                   | 0x40    | Sets phase calibration register (see the Phase Compensation section).  |
| 0x11                   | ZXTOUT               | R/W | 12               |                     | 0x0FFF  | Sets timeout for zero-crossing timeout detection (see the Zero-Crossing Timeout section).  |
| 0x12                   | LINCYC               | R/W | 16               | U                   | 0xFFFF  | Sets number of half-line cycles for LWATTHR, LVARHR, and LVAHR accumulators.   |
| 0x13                   | SAGCYC               | R/W | 8                | U                   | 0xFF    | Sets number of half-line cycles for SAG detection (see the Line Voltage SAG Detection section).  |
| 0x14                   | SAGLVL               | R/W | 16               | U                   | 0       | Sets detection level for SAG detection (see the Line Voltage SAG Detection section).   |
| 0x15                   | IPKLVL               | R/W | 16               | U                   | 0xFFFF  | Sets peak detection level for current peak detection (see the Peak Detection section).   |
| 0x16                   | VPKLVL               | R/W | 16               | U                   | 0xFFFF  | Sets peak detection level for voltage peak detection (see the Peak Detection section).   |
| 0x17                   | IPEAK                | R   | 24               | U                   | 0       | Reads current peak level without reset (see the Peak Detection section).   |
| 0x18                   | RSTIPEAK             | R   | 24               | U                   | 0       | Reads current peak level with reset (see the Peak Detection section).  |
| 0x19                   | VPEAK                | R   | 24               | U                   | 0       | Reads voltage peak level without reset (see the Peak Detection section).   |
| 0x1A                   | RSTVPEAK             | R   | 24               | U                   | 0       | Reads voltage peak level with reset (see the Peak Detection section).  |
| 0x1B                   | GAIN                 | R/W | 8                | U                   | 0       | Sets PGA gain of analog inputs (see Table 37).   |
| 0x1C                   | IBGAIN               | R/W | 12               | S                   | 0       | Sets matching gain for I <sub>PB</sub> current input.  |
| 0x1D                   | WGAIN                | R/W | 12               | S                   | 0       | Sets watt gain register.   |
| 0x1E                   | VARGAIN <sup>1</sup> | R/W | 12               | S                   | 0       | Sets var gain register.  |
| 0x1F                   | VAGAIN               | R/W | 12               | S                   | 0       | Sets VA gain register.   |
| 0x20                   | WATTOS               | R/W | 16               | S                   | 0       | Sets watt offset register.   |
| 0x21                   | VAROS <sup>1</sup>   | R/W | 16               | S                   | 0       | Sets var offset register.  |
| 0x22                   | IRMSOS               | R/W | 12               | S                   | 0       | Sets current rms offset register.  |
| 0x23                   | VRMSOS               | R/W | 12               | S                   | 0       | Sets voltage rms offset register.  |
| 0x24                   | WDIV                 | R/W | 8                | U                   | 0       | Sets watt energy scaling register.   |
| 0x25                   | VARDIV               | R/W | 8                | U                   | 0       | Sets var energy scaling register.  |
| 0x26                   | VADIV                | R/W | 8                | U                   | 0       | Sets VA energy scaling register.   |
| 0x27                   | CF1NUM               | R/W | 16               | U                   | 0       | Sets CF1 numerator register.   |
| 0x28                   | CF1DEN               | R/W | 16               | U                   | 0x003F  | Sets CF1 denominator register.   |

# ADE5166/ADE5169

| Address<br>MADDPT[6:0] | Mnemonic | R/W | Length<br>(Bits) | Signed/<br>Unsigned | Default | Description  |
|------------------------|----------|-----|------------------|---------------------|---------|--|
| 0x29                   | CF2NUM   | R/W | 16               | U                   | 0       | Sets CF2 numerator register.   |
| 0x2A                   | CF2DEN   | R/W | 16               | U                   | 0x003F  | Sets CF2 denominator register.                                       |
| 0x2B                   | MODE3    | R/W | 8                | U                   | 0       | Enables zero crossing outputs (see Table 38).                        |
| 0x3B                   | Reserved |     |                  |                     | 0       | This register must be set to its default value for proper operation. |
| 0x3C                   | Reserved |     |                  |                     | 0x0300  | This register must be set to its default value for proper operation. |
| 0x3D                   | CALMODE  | R/W | 8                | U                   | 0       | Sets calibration mode (see Table 39).                                |
| 0x3E                   | Reserved |     |                  |                     | 0       | This register must be set to its default value for proper operation. |
| 0x3F                   | Reserved |     |                  |                     | 0       | This register must be set to its default value for proper operation. |

<sup>1</sup> This function is not available in the ADE5166.

## ENERGY MEASUREMENT INTERNAL REGISTER DETAILS

Table 32. Mode 1 Register (MODE1, Address 0x0B)

| Bit | Mnemonic | Default | Description  |
|-----|----------|---------|--|
| 7   | SWRST    | 0       | Setting this bit resets all of the energy measurement registers to their default values. |
| 6   | DISZLFP  | 0       | Setting this bit disables the zero-crossing low-pass filter.                             |
| 5   | INTE     | 0       | Setting this bit enables the digital integrator for use with a di/dt sensor.             |
| 4   | SWAPBITS | 0       | Setting this bit swaps CH1 ADC and CH2 ADC.  |
| 3   | PWRDN    | 0       | Setting this bit powers down voltage and current ADCs.                                   |
| 2   | DISCF2   | 1       | Setting this bit disables Frequency Output CF2.  |
| 1   | DISCF1   | 1       | Setting this bit disables Frequency Output CF1.  |
| 0   | DISHPF   | 0       | Setting this bit disables the HPFs in voltage and current channels.                      |

Table 33. Mode 2 Register (MODE2, Address 0x0C)

| Bit        | Mnemonic   | Default | Description   |            |        |    |  |    |  |    |   |
|------------|--|---------|---|------------|--------|----|--|----|--|----|---|
| [7:6]      | CF2SEL   | 01      | Configuration bits for CF2 output.<br><table border="1"> <thead> <tr> <th>CF2SEL</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>CF2 frequency is proportional to active power.</td> </tr> <tr> <td>01</td> <td>CF2 frequency is proportional to reactive power.<sup>1</sup></td> </tr> <tr> <td>1X</td> <td>CF2 frequency is proportional to apparent power or I<sub>rms</sub>.</td> </tr> </tbody> </table>  | CF2SEL     | Result | 00 | CF2 frequency is proportional to active power.   | 01 | CF2 frequency is proportional to reactive power. <sup>1</sup>  | 1X | CF2 frequency is proportional to apparent power or I <sub>rms</sub> . |
| CF2SEL     | Result   |         |   |            |        |    |  |    |  |    |   |
| 00         | CF2 frequency is proportional to active power.   |         |   |            |        |    |  |    |  |    |   |
| 01         | CF2 frequency is proportional to reactive power. <sup>1</sup>  |         |   |            |        |    |  |    |  |    |   |
| 1X         | CF2 frequency is proportional to apparent power or I <sub>rms</sub> .  |         |   |            |        |    |  |    |  |    |   |
| [5:4]      | CF1SEL   | 00      | Configuration bits for CF1 output.<br><table border="1"> <thead> <tr> <th>CF1SEL</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>CF1 frequency is proportional to active power.</td> </tr> <tr> <td>01</td> <td>CF1 frequency is proportional to reactive power.<sup>1</sup></td> </tr> <tr> <td>1X</td> <td>CF1 frequency is proportional to apparent power or I<sub>rms</sub>.</td> </tr> </tbody> </table>  | CF1SEL     | Result | 00 | CF1 frequency is proportional to active power.   | 01 | CF1 frequency is proportional to reactive power. <sup>1</sup>  | 1X | CF1 frequency is proportional to apparent power or I <sub>rms</sub> . |
| CF1SEL     | Result   |         |   |            |        |    |  |    |  |    |   |
| 00         | CF1 frequency is proportional to active power.   |         |   |            |        |    |  |    |  |    |   |
| 01         | CF1 frequency is proportional to reactive power. <sup>1</sup>  |         |   |            |        |    |  |    |  |    |   |
| 1X         | CF1 frequency is proportional to apparent power or I <sub>rms</sub> .  |         |   |            |        |    |  |    |  |    |   |
| 3          | VARMSCFCON   | 0       | Configuration bits for apparent power or I <sub>rms</sub> for CF1, CF2 outputs, and VA accumulation registers (VAHR, RVAHR, and LVAHR). Note that CF1 cannot be proportional to VA if CF2 is proportional to I <sub>rms</sub> and vice versa.<br><table border="1"> <thead> <tr> <th>VARMSCFCON</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>If CF1SEL[1:0] = 1X, CF1 is proportional to VA<br/>If CF2SEL[1:0] = 1X, CF2 is proportional to VA</td> </tr> <tr> <td>1</td> <td>If CF1SEL[1:0] = 1X, CF1 is proportional to I<sub>rms</sub><br/>If CF2SEL[1:0] = 1X, CF2 is proportional to I<sub>rms</sub></td> </tr> </tbody> </table> | VARMSCFCON | Result | 0  | If CF1SEL[1:0] = 1X, CF1 is proportional to VA<br>If CF2SEL[1:0] = 1X, CF2 is proportional to VA | 1  | If CF1SEL[1:0] = 1X, CF1 is proportional to I <sub>rms</sub><br>If CF2SEL[1:0] = 1X, CF2 is proportional to I <sub>rms</sub> |    |   |
| VARMSCFCON | Result   |         |   |            |        |    |  |    |  |    |   |
| 0          | If CF1SEL[1:0] = 1X, CF1 is proportional to VA<br>If CF2SEL[1:0] = 1X, CF2 is proportional to VA                             |         |   |            |        |    |  |    |  |    |   |
| 1          | If CF1SEL[1:0] = 1X, CF1 is proportional to I <sub>rms</sub><br>If CF2SEL[1:0] = 1X, CF2 is proportional to I <sub>rms</sub> |         |   |            |        |    |  |    |  |    |   |
| 2          | ZXRMS  | 0       | Logic 1 enables update of rms values synchronously to Voltage ZX.   |            |        |    |  |    |  |    |   |
| 1          | FREQSEL  | 0       | Configuration bits to select period or frequency measurement for PER_FREQ register (Address 0x0A).<br><table border="1"> <thead> <tr> <th>FREQSEL</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>PER_FREQ register holds a period measurement</td> </tr> <tr> <td>1</td> <td>PER_FREQ register holds a frequency measurement</td> </tr> </tbody> </table>  | FREQSEL    | Result | 0  | PER_FREQ register holds a period measurement   | 1  | PER_FREQ register holds a frequency measurement  |    |   |
| FREQSEL    | Result   |         |   |            |        |    |  |    |  |    |   |
| 0          | PER_FREQ register holds a period measurement   |         |   |            |        |    |  |    |  |    |   |
| 1          | PER_FREQ register holds a frequency measurement  |         |   |            |        |    |  |    |  |    |   |
| 0          | WAVEN  | 0       | When this bit is set, waveform sampling mode is enabled.  |            |        |    |  |    |  |    |   |

<sup>1</sup> This function is not available in the ADE5166.

**Table 34. Waveform Mode Register (WAVMODE, Address 0x0D)**

| Bit    | Mnemonic             | Default | Description                                   |   |
|--------|----------------------|---------|---|---|
| [7:5]  | WAV2SEL              | 000     | Waveform Sample 2 selection for samples mode. |   |
|        |                      |         | <b>WAV2SEL</b>                                | <b>Source</b>   |
|        |                      |         | 000   | Current   |
|        |                      |         | 001   | Voltage   |
|        |                      |         | 010   | Active power multiplier output                              |
|        |                      |         | 011   | Reactive power multiplier output <sup>1</sup>               |
|        |                      |         | 100   | VA multiplier output  |
|        |                      |         | 101   | I <sub>rms</sub> LPF output                                 |
| Others | Reserved             |         |   |   |
| [4:2]  | WAV1SEL              | 000     | Waveform Sample 1 selection for samples mode. |   |
|        |                      |         | <b>WAV1SEL</b>                                | <b>Source</b>   |
|        |                      |         | 000   | Current   |
|        |                      |         | 001   | Voltage   |
|        |                      |         | 010   | Active power multiplier output                              |
|        |                      |         | 011   | Reactive power multiplier output <sup>1</sup>               |
|        |                      |         | 100   | VA multiplier output  |
|        |                      |         | 101   | I <sub>rms</sub> LPF output (low 24-bit)                    |
| Others | Reserved             |         |   |   |
| [1:0]  | DTRT                 | 00      | Waveform samples output data rate.            |   |
|        |                      |         | <b>DTRT</b>                                   | <b>Update Rate (Clock = f<sub>CORE</sub>/5 = 819.2 kHz)</b> |
|        |                      |         | 00  | 25.6 kSPS (clock/32)  |
|        |                      |         | 01  | 12.8 kSPS (clock/64)  |
|        |                      |         | 10  | 6.4 kSPS (clock/128)  |
| 11     | 3.2 kSPS (clock/256) |         |   |   |

<sup>1</sup> This function is not available in the ADE5166.

**Table 35. No Load Configuration Register (NLMODE, Address 0x0E)**

| Bit   | Mnemonic   | Default | Description   |  |
|-------|--|---------|---|--|
| 7     | DISVARCMP <sup>1</sup>   | 0       | Setting this bit disables fundamental var gain compensation over line frequency.  |  |
| 6     | IRMSNOLOAD   | 0       | Logic 1 enables I <sub>rms</sub> no load threshold detection. The level is defined by the setting of the VANOLOAD bits. |  |
| [5:4] | VANOLOAD   | 00      | Apparent power no load threshold.   |  |
|       |  |         | <b>VANOLOAD</b>   | <b>Result</b>  |
|       |  |         | 00  | No load detection disabled                                       |
|       |  |         | 01  | No load detection enabled with threshold = 0.030% of full scale  |
|       |  |         | 10  | No load detection enabled with threshold = 0.015% of full scale  |
| 11    | No load detection enabled with threshold = 0.0075% of full scale |         |   |  |
| [3:2] | VARNOLOAD <sup>1</sup>   | 00      | Reactive power no load threshold.   |  |
|       |  |         | <b>VARNOLOAD</b>  | <b>Result</b>  |
|       |  |         | 00  | No load detection disabled                                       |
|       |  |         | 01  | No load detection enabled with threshold = 0.015% of full scale  |
|       |  |         | 10  | No load detection enabled with threshold = 0.0075% of full scale |
| 11    | No load detection enabled with threshold = 0.0037% of full scale |         |   |  |
| [1:0] | APNOLOAD   | 00      | Active power no load threshold.   |  |
|       |  |         | <b>APNOLOAD</b>   | <b>Result</b>  |
|       |  |         | 00  | No load detection disabled                                       |
|       |  |         | 01  | No load detection enabled with threshold = 0.015% of full scale  |
|       |  |         | 10  | No load detection enabled with threshold = 0.0075% of full scale |
| 11    | No load detection enabled with threshold = 0.0037% of full scale |         |   |  |

<sup>1</sup> This function is not available in the ADE5166.

# ADE5166/ADE5169

**Table 36. Accumulation Mode Register (ACCMODE, Address 0x0F)**

| Bit | Mnemonic             | Default | Description  |
|-----|----------------------|---------|--|
| 7   | ICHANNEL             | 0       | This bit indicates the current channel used to measure energy in antitampering mode.<br>0 = Channel A (I <sub>PA</sub> ).<br>1 = Channel B (I <sub>PB</sub> ).   |
| 6   | FAULTSIGN            | 0       | Configuration bit to select the event that triggers a fault interrupt.<br>0 = a FAULTSIGN interrupt occurs when the part enters fault mode.<br>1 = a FAULTSIGN interrupt occurs when the part enters normal mode.  |
| 5   | VARSIGN <sup>1</sup> | 0       | Configuration bit to select the event that triggers a reactive power sign interrupt. If cleared to 0, a VARSIGN interrupt occurs when reactive power changes from positive to negative. If set to 1, a VARSIGN interrupt occurs when reactive power changes from negative to positive.   |
| 4   | APSIGN               | 0       | Configuration bit to select event that triggers an active power sign interrupt. If cleared to 0, an APSIGN interrupt occurs when active power changes from positive to negative. If set to 1, an APSIGN interrupt occurs when active power changes from negative to positive.  |
| 3   | ABSVARM <sup>1</sup> | 0       | Logic 1 enables absolute value accumulation of reactive power in energy register and pulse output.   |
| 2   | SAVARM <sup>1</sup>  | 0       | Logic 1 enables reactive power accumulation depending on the sign of the active power. If active power is positive, var is accumulated as it is. If active power is negative, the sign of the var is reversed for the accumulation. This accumulation mode affects both the var registers (VARHR, RVARHR, LVARHR) and the pulse output when connected to VAR. <sup>1</sup> |
| 1   | POAM                 | 0       | Logic 1 enables positive-only accumulation of active power in energy register and pulse output.  |
| 0   | ABSAM                | 0       | Logic 1 enables absolute value accumulation of active power in energy register and pulse output.   |

<sup>1</sup> This function is not available in the ADE5166.

**Table 37. Gain Register (GAIN, Address 0x1B)**

| Bit   | Mnemonic                | Default | Description  |                       |
|-------|-------------------------|---------|--|-----------------------|
| [7:5] | PGA2                    | 000     | These bits define the voltage channel input gain.  |                       |
|       |                         |         | <b>PGA2</b>  | <b>Result</b>         |
|       |                         |         | 000  | Gain = 1              |
|       |                         |         | 001  | Gain = 2              |
|       |                         |         | 010  | Gain = 4              |
|       |                         |         | 011  | Gain = 8              |
| 100   | Gain = 16               |         |  |                       |
| 4     | Reserved                | 0       | Reserved.  |                       |
| 3     | CFSIGN_OPT              | 0       | This bit defines where the CF change of sign detection (APSIGN or VARSIGN) is implemented. |                       |
|       |                         |         | <b>CFSIGN_OPT</b>  | <b>Result</b>         |
|       |                         |         | 0  | Filtered power signal |
| 1     | On a per CF pulse basis |         |  |                       |
| [2:0] | PGA1                    | 000     | These bits define the current channel input gain.  |                       |
|       |                         |         | <b>PGA1</b>  | <b>Result</b>         |
|       |                         |         | 000  | Gain = 1              |
|       |                         |         | 001  | Gain = 2              |
|       |                         |         | 010  | Gain = 4              |
|       |                         |         | 011  | Gain = 8              |
| 100   | Gain = 16               |         |  |                       |

**Table 38. Mode 3 Register (MODE3 Address 0x2B)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:2] | Reserved | 0       | Reserved.   |
| 1     | ZX1      | 0       | Setting this bit enables the zero crossing output signal on P1.2. |
| 0     | ZX2      | 0       | Setting this bit enables the zero crossing output signal on P0.5. |



**Table 39. Calibration Mode Register (CALMODE, Address 0x3D)**

| Bit   | Mnemonic   | Default   | Description   |   |
|-------|------------|---|---|---|
| [7:6] | Reserved   | 0   | These bits must be kept at 0 for proper operation.                  |   |
| [5:4] | SEL_I_CH   | 0   | These bits define the current channel used for energy measurements. |   |
|       |            |   | <b>SEL_I_CH</b>   | <b>Result</b>   |
|       |            |   | 00  | Current channel automatically selected by the tampering condition |
|       |            |   | 01  | Current channel connected to I <sub>PA</sub>                      |
|       |            |   | 10  | Current channel connected to I <sub>PB</sub>                      |
|       | 11         | Current channel automatically selected by the tampering condition |   |   |
| 3     | V_CH_SHORT | 0   | Logic 1 shorts the voltage channel to ground.                       |   |
| 2     | I_CH_SHORT | 0   | Logic 1 shorts the voltage channel to ground.                       |   |
| [1:0] | Reserved   | 0   | These bits must be kept at 0 for proper operation.                  |   |

**INTERRUPT STATUS/ENABLE SFRS**

**Table 40. Interrupt Status 1 SFR (MIRQSTL, Address 0xDC)**

| Bit | Interrupt Flag       | Description  |
|-----|----------------------|--|
| 7   | ADEIRQFLAG           | This bit is set if any of the ADE status flags that are enabled to generate an ADE interrupt is set. This bit is automatically cleared when all of the enabled ADE status flags are cleared. |
| 6   | Reserved             | Reserved.  |
| 5   | FAULTSIGN            | Logic 1 indicates that the fault mode has changed according to the configuration of the ACCMODE register.  |
| 4   | VARSIGN <sup>1</sup> | Logic 1 indicates that the reactive power sign has changed according to the configuration of the ACCMODE register.   |
| 3   | APSIGN               | Logic 1 indicates that the active power sign has changed according to the configuration of the ACCMODE register.   |
| 2   | VANOLOAD             | Logic 1 indicates that an interrupt has been caused by apparent power no load detection. This interrupt is also used to reflect that the part is entering the I <sub>rms</sub> no load mode. |
| 1   | RNOLOAD <sup>1</sup> | Logic 1 indicates that an interrupt has been caused by reactive power no load detection.   |
| 0   | APNOLOAD             | Logic 1 indicates that an interrupt has been caused by active power no load detection.   |

<sup>1</sup> This function is not available in the ADE5166.

**Table 41. Interrupt Status 2 SFR (MIRQSTM, Address 0xDD)**

| Bit | Interrupt Flag    | Description   |
|-----|-------------------|---|
| 7   | CF2               | Logic 1 indicates that a pulse on CF2 has been issued. The flag is set even if the CF2 pulse output is not enabled by clearing Bit 2 of the MODE1 register. |
| 6   | CF1               | Logic 1 indicates that a pulse on CF1 has been issued. The flag is set even if the CF1 pulse output is not enabled by clearing Bit 1 of the MODE1 register. |
| 5   | VAEOF             | Logic 1 indicates that the VAHR register has overflowed.  |
| 4   | REOF <sup>1</sup> | Logic 1 indicates that the VARHR register has overflowed.   |
| 3   | AEOF              | Logic 1 indicates that the WATTHR register has overflowed.  |
| 2   | VAEHF             | Logic 1 indicates that the VAHR register is half full.  |
| 1   | REHF <sup>1</sup> | Logic 1 indicates that the VARHR register is half full.   |
| 0   | AEHF              | Logic 1 indicates that the WATTHR register is half full.  |

<sup>1</sup> This function is not available in the ADE5166.

**Table 42. Interrupt Status 3 SFR (MIRQSTH, Address 0xDE)**

| Bit | Interrupt Flag | Description  |
|-----|----------------|--|
| 7   | RESET          | Indicates the end of a reset (for both software and hardware reset).                                     |
| 6   | Reserved       | Reserved.  |
| 5   | WFSM           | Logic 1 indicates that new data is present in the waveform registers (Address 0xE2 to Address 0xE7).     |
| 4   | PKI            | Logic 1 indicates that the current channel has exceeded the IPKLVL value                                 |
| 3   | PKV            | Logic 1 indicates that the voltage channel has exceeded the VPKLVL value.                                |
| 2   | CYCEND         | Logic 1 indicates the end of the energy accumulation over an integer number of half-line cycles.         |
| 1   | ZXTO           | Logic 1 indicates that no zero crossing on the line voltage happened for the last ZXTO half-line cycles. |
| 0   | ZX             | Logic 1 indicates detection of a zero crossing in the voltage channel.                                   |

# ADE5166/ADE5169

**Table 43. Interrupt Enable 1 SFR (MIRQENL, Address 0xD9)**

| Bit    | Interrupt Enable Bit | Description  |
|--------|----------------------|--|
| 7 to 6 | Reserved             | Reserved.  |
| 5      | FAULTSIGN            | When this bit is set to Logic 1, the FAULTSIGN bit set creates a pending ADE interrupt to the 8052 core. |
| 4      | VARSIGN <sup>1</sup> | When this bit is set to Logic 1, the VARSIGN flag set creates a pending ADE interrupt to the 8052 core.  |
| 3      | APSIGN               | When this bit is set to Logic 1, the APSIGN flag set creates a pending ADE interrupt to the 8052 core.   |
| 2      | VANOLOAD             | When this bit is set to Logic 1, the VANOLOAD flag set creates a pending ADE interrupt to the 8052 core. |
| 1      | RNOLOAD <sup>1</sup> | When this bit is set to Logic 1, the RNOLOAD flag set creates a pending ADE interrupt to the 8052 core.  |
| 0      | APNOLOAD             | When this bit is set to Logic 1, the APNOLOAD flag set creates a pending ADE interrupt to the 8052 core. |

<sup>1</sup> This function is not available in the ADE5166.

**Table 44. Interrupt Enable 2 SFR (MIRQENM, Address 0xDA)**

| Bit | Interrupt Enable Bit | Description   |
|-----|----------------------|---|
| 7   | CF2                  | When this bit is set to Logic 1, a CF2 pulse creates a pending ADE interrupt to the 8052 core.        |
| 6   | CF1                  | When this bit is set to Logic 1, a CF1 pulse creates a pending ADE interrupt to the 8052 core.        |
| 5   | VAEOF                | When this bit is set to Logic 1, the VAEOF flag set creates a pending ADE interrupt to the 8052 core. |
| 4   | REOF <sup>1</sup>    | When this bit is set to Logic 1, the REOF flag set creates a pending ADE interrupt to the 8052 core.  |
| 3   | AEOF                 | When this bit is set to Logic 1, the AEOF flag set creates a pending ADE interrupt to the 8052 core.  |
| 2   | VAEHF                | When this bit is set to Logic 1, the VAEHF flag set creates a pending ADE interrupt to the 8052 core. |
| 1   | REHF <sup>1</sup>    | When this bit is set to Logic 1, the REHF flag set creates a pending ADE interrupt to the 8052 core.  |
| 0   | AEHF                 | When this bit is set to Logic 1, the AEHF flag set creates a pending ADE interrupt to the 8052 core.  |

<sup>1</sup> This function is not available in the ADE5166.

**Table 45. Interrupt Enable 3 SFR (MIRQENH, Address 0xDB)**

| Bit   | Interrupt Enable Bit | Description  |
|-------|----------------------|--|
| [7:6] | Reserved             | Reserved.  |
| 5     | WFSM                 | When this bit is set to Logic 1, the WFSM flag set creates a pending ADE interrupt to the 8052 core.   |
| 4     | PKI                  | When this bit is set to Logic 1, the PKI flag set creates a pending ADE interrupt to the 8052 core.    |
| 3     | PKV                  | When this bit is set to Logic 1, the PKV flag set creates a pending ADE interrupt to the 8052 core.    |
| 2     | CYCEND               | When this bit is set to Logic 1, the CYCEND flag set creates a pending ADE interrupt to the 8052 core. |
| 1     | ZXTO                 | When this bit is set to Logic 1, the ZXTO flag set creates a pending ADE interrupt to the 8052 core.   |
| 0     | ZX                   | When this bit is set to Logic 1, the ZX flag set creates a pending ADE interrupt to the 8052 core.     |

## ANALOG INPUTS

Each ADE5166/ADE5169 has two fully differential voltage input channels. The maximum differential input voltage for the  $V_P/V_N$ , and  $I_{PB}/I_N$  input pairs is  $\pm 0.5$  V.

Each analog input channel has a programmable gain amplifier (PGA) with possible gain selections of 1, 2, 4, 8, and 16. The gain selections are made by writing to the GAIN register (see Table 37 and Figure 38).

Bit 2 to Bit 0 select the gain for the PGA in the current channel, and Bit 7 to Bit 5 select the gain for the PGA in the voltage channel. Figure 39 shows how a gain selection for the current channel is made using the gain register.

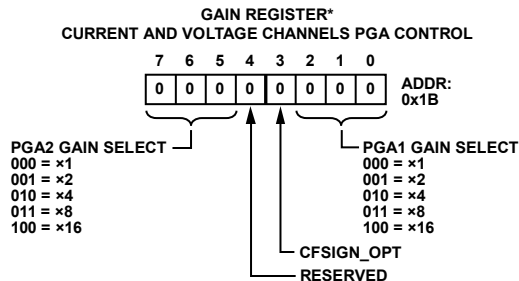


Figure 38. Analog Gain Register

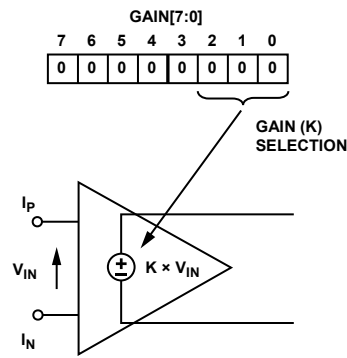


Figure 39. PGA in Current Channel

**ANALOG-TO-DIGITAL CONVERSION**

Each ADE5166/ADE5169 has two  $\Sigma$ - $\Delta$  analog-to digital converters (ADCs). The outputs of these ADCs are mapped directly to waveform sampling SFRs (Address 0xE2 to Address 0xE7) and are used for energy measurement internal digital signal processing. In PSM1 (battery) mode and PSM2 (sleep) mode, the ADCs are powered down to minimize power consumption.

For simplicity, the block diagram in Figure 41 shows a first-order  $\Sigma$ - $\Delta$  ADC. The converter is made up of the  $\Sigma$ - $\Delta$  modulator and the digital low-pass filter (LPF).

A  $\Sigma$ - $\Delta$  modulator converts the input signal into a continuous serial stream of 1s and 0s at a rate determined by the sampling clock. In the ADE5166/ADE5169, the sampling clock is equal to 4.096 MHz/5. The 1-bit DAC in the feedback loop is driven by the serial data stream. The DAC output is subtracted from the input signal. If the loop gain is high enough, the average value of the DAC output (and, therefore, the bit stream) can approach that of the input signal level.

For any given input value in a single sampling interval, the data from the 1-bit ADC is virtually meaningless. Only when a large number of samples are averaged is a meaningful result obtained. This averaging is carried into the second part of the ADC, the digital LPF. By averaging a large number of bits from the modulator, the low-pass filter can produce 24-bit data-words that are proportional to the input signal level.

The  $\Sigma$ - $\Delta$  converter uses two techniques to achieve high resolution from what is essentially a 1-bit conversion technique. The first is oversampling. Oversampling means that the signal is sampled at a rate (frequency) that is many times higher than the bandwidth of interest. For example, the sampling rate in the ADE5166/ADE5169 is 4.096 MHz/5 (819.2 kHz), and the band of interest

is 40 Hz to 2 kHz. Oversampling has the effect of spreading the quantization noise (noise due to sampling) over a wider bandwidth. With the noise spread more thinly over a wider bandwidth, the quantization noise in the band of interest is lowered (see Figure 40).

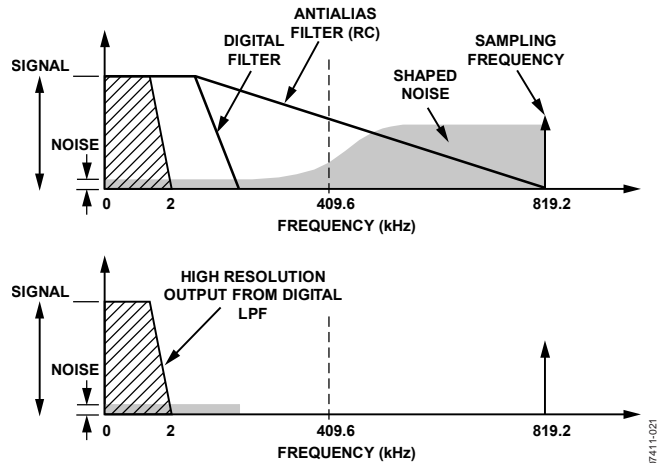


Figure 40. Noise Reduction Due to Oversampling and Noise Shaping in the Analog Modulator

However, oversampling alone is not efficient enough to improve the signal-to-noise ratio (SNR) in the band of interest. For example, an oversampling ratio of four is required to increase the SNR by only 6 dB (1 bit). To keep the oversampling ratio at a reasonable level, it is possible to shape the quantization noise so that the majority of the noise lies at the higher frequencies. In the  $\Sigma$ - $\Delta$  modulator, the noise is shaped by the integrator, which has a high-pass-type response for the quantization noise. The result is that most of the noise is at the higher frequencies where it can be removed by the digital LPF. This noise shaping is shown in Figure 40.

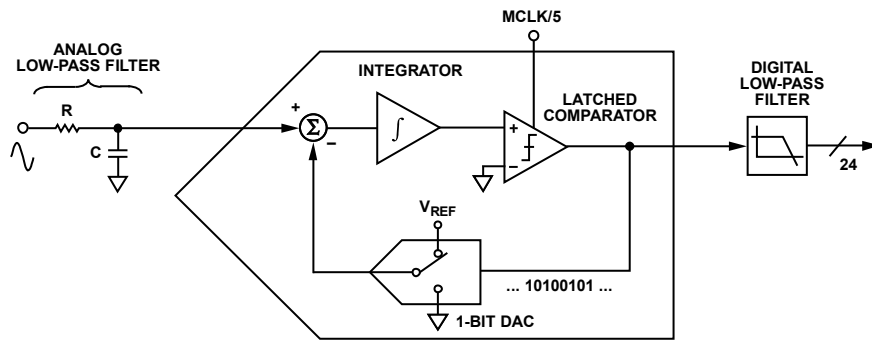


Figure 41. First-Order  $\Sigma$ - $\Delta$  ADC

## Antialiasing Filter

Figure 41 also shows an analog LPF (RC) on the input to the modulator. This filter is present to prevent aliasing, an artifact of all sampled systems. Aliasing means that frequency components in the input signal to the ADC, which are higher than half the sampling rate of the ADC, appear in the sampled signal at a frequency below half the sampling rate. Figure 42 illustrates the effect. Frequency components (the black arrows) above half the sampling frequency (also known as the Nyquist frequency, that is, 409.6 kHz) are imaged or folded back down below 409.6 kHz. This happens with all ADCs, regardless of the architecture. In Figure 42, only frequencies near the sampling frequency (819.2 kHz) move into the band of interest for metering (40 Hz to 2 kHz). This allows the use of a very simple LPF to attenuate high frequency (at approximately 819.2 kHz) noise and prevents distortion in the band of interest.

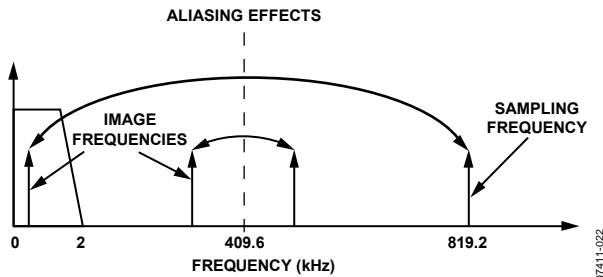


Figure 42. ADC and Signal Processing in Current Channel Outline Dimensions

For conventional current sensors, a simple RC filter (single-pole LPF) with a corner frequency of 10 kHz produces an attenuation of approximately 40 dB at 819.2 kHz (see Figure 42). The 20 dB per decade attenuation is usually sufficient to eliminate the effects of aliasing for conventional current sensors. However, for a di/dt sensor such as a Rogowski coil, the sensor has a 20 dB per decade gain. This neutralizes the -20 dB per decade attenuation produced by one simple LPF. Therefore, when using a di/dt sensor, care should be taken to offset the 20 dB per decade gain. One simple approach is to cascade two RC filters to produce the -40 dB per decade attenuation needed.

## ADC Transfer Function

Both ADCs in the ADE5166/ADE5169 are designed to produce the same output code for the same input signal level. With a full-scale signal on the input of 0.5 V and an internal reference of 1.2 V, the ADC output code is nominally 2,147,483 or 0x20C49B. The maximum code from the ADC is  $\pm 4,194,304$ ; this is equivalent to an input signal level of  $\pm 0.794$  V. However, for specified performance, it is recommended that the full-scale input signal level of 0.5 V not be exceeded.

## Current Channel ADC

Figure 43 shows the ADC and signal processing chain for the current channel. In waveform sampling mode, the ADC outputs a signed, two's complement, 24-bit data-word at a maximum of 25.6 kSPS (4.096 MHz/160).

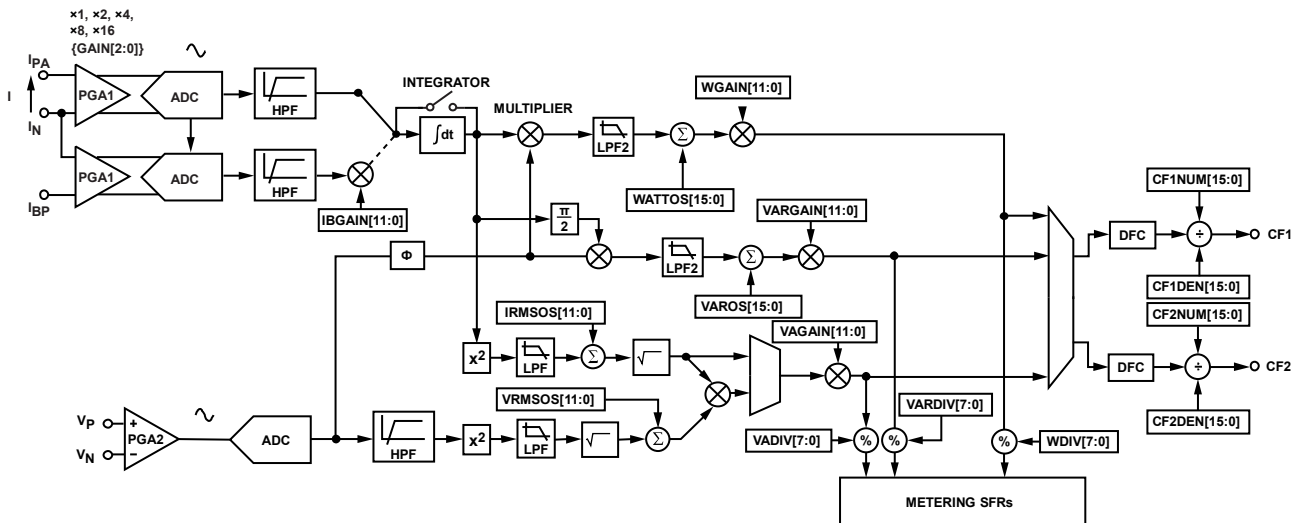


Figure 43. ADC and Signal Processing in Current Channel with PGA1 = 2, 4, 8, or 16

**Voltage Channel ADC**

Figure 44 shows the ADC and signal processing chain for the voltage channel. In waveform sampling mode, the ADC outputs a signed, twos complement, 24-bit data-word at a maximum of 25.6 kSPS (MCLK/160). The ADC produces an output code that is approximately between 0x28F5 (+10,485d) and 0xD70B (-10,485d).

**Channel Sampling**

The waveform samples of the current ADC and voltage ADC can also be routed to the waveform registers to be read by the MCU core. The active, reactive, and apparent power and energy calculation remain uninterrupted during waveform sampling.

When in waveform sampling mode, one of four output sample rates can be chosen by using the DTRT[1:0] bits of the WAVMODE register (see Table 34). The output sample rate can be 25.6 kSPS, 12.8 kSPS, 6.4 kSPS, or 3.2 kSPS. If the WFSM enable bit is set in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB), the 8052 core has a pending ADE interrupt. The sampled signals selected in the WAVMODE register are latched into the waveform SFRs when the waveform high byte (WAV1H or WAV2H) is read.

The ADE interrupt stays active until the WFSM status bit is cleared (see the Energy Measurement Interrupts section).

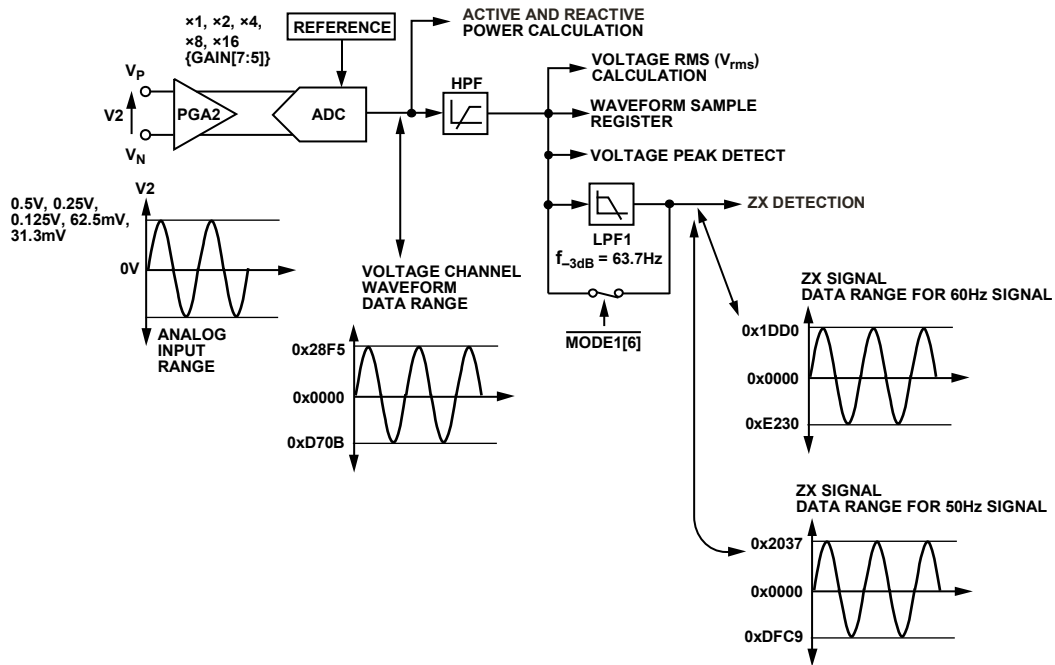


Figure 44. ADC and Signal Processing in Voltage Channel

07411-024

## FAULT DETECTION

The ADE5166/ADE5169 incorporate a fault detection scheme that warns of fault conditions and allows accurate measurement to continue during a fault event. The ADE5166/ADE5169 do this by continuously monitoring both current inputs ( $I_{PA}$  and  $I_{PB}$ ). For ease of understanding, these currents are referred to as phase and neutral (return) currents. In the ADE5166/ADE5169, a fault condition is defined when the difference between  $I_{PA}$  and  $I_{PB}$  is greater than 6.25% of the active channel. If a fault condition is detected and the inactive channel is larger than the active channel, the ADE5166/ADE5169 automatically switch current measurement to the inactive channel. During a fault, the active, reactive, and apparent power and the  $I_{RMS}$  are generated using the larger of the two currents. On power-up,  $I_{PA}$  is the current input selected for active, reactive, and apparent power and  $I_{RMS}$  calculations.

To prevent a false alarm, averaging is done for the fault detection, and a fault condition is detected approximately one second after the event. The fault detection is automatically disabled when the voltage signal is less than 0.3% of the full-scale input range. This eliminates false detection of a fault due to noise at light loads.

Because the ADE5166/ADE5169 look for a difference between the voltage signals on  $I_{PA}$  and  $I_{PB}$ , it is important that both current transducers be closely matched.

### Channel Selection Indication

The current channel selected for measurement is indicated by Bit 7 (ICHANNEL) in the ACCMODE register (Address 0x0F). When this bit is cleared,  $I_{PA}$  is selected and, when it is set,  $I_{PB}$  is selected. The ADE5166/ADE5169 automatically switch from one channel to the other and report the channel configuration in the ACCMODE register.

The current channel selected for measurement can also be forced. Setting the SEL\_I\_CH[5:4] bits in the CALMODE register (Address 0x3D) selects  $I_{PA}$  and  $I_{PB}$ , respectively. When both bits are cleared or set, the current channel used for measurement is selected automatically based on the fault detection.

### Fault Indication

The ADE5166/ADE5169 provide an indication of the part going in or out of a fault condition. The new fault condition is indicated by the FAULTSIGN flag (Bit 5) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC).

When the FAULTSIGN bit (Bit 6) of the ACCMODE register (Address 0x0F) is cleared, the FAULTSIGN flag in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set when the part is entering a fault condition or a normal condition.

When the FAULTSIGN bit (Bit 5) is set in the Interrupt Enable 1 SFR (MIRQENL, Address 0xD9), and the FAULTSIGN flag (Bit 5) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set, the 8052 core has a pending ADE interrupt.

### Fault with Active Input Greater Than Inactive Input

If  $I_{PA}$  is the active current input (that is, being used for billing), and the voltage signal on  $I_{PB}$  (inactive input) falls below 93.75% of  $I_{PA}$ , and the FAULTSIGN bit (Bit 6) of the ACCMODE register (Address 0x0F) is cleared, the FAULTSIGN flag (Bit 5) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set. Both analog inputs are filtered and averaged to prevent false triggering of this logic output. As a consequence of the filtering, there is a time delay of approximately 3 sec on the logic output after the fault event. The FAULTSIGN flag is independent of any activity. Because  $I_{PA}$  is the active input and it is still greater than  $I_{PB}$ , billing is maintained on  $I_{PA}$ ; that is, no swap to the  $I_{PB}$  input occurs.  $I_{PA}$  remains the active input.

### Fault with Inactive Input Greater Than Active Input

If the difference between  $I_{PB}$ , the inactive input, and  $I_{PA}$ , the active input (that is, being used for billing), becomes greater than 6.25% of  $I_{PB}$ , and the FAULTSIGN bit (Bit 6) of the ACCMODE register (Address 0x0F) is cleared, the FAULTSIGN flag (Bit 5) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set. The  $I_{PB}$  analog input becomes the active input. Again, a time constant of about 3 sec is associated with this swap.  $I_{PA}$  does not swap back to the active channel until  $I_{PA}$  is greater than  $I_{PB}$  and the difference between  $I_{PA}$  and  $I_{PB}$ , in this order, becomes greater than 6.25% of  $I_{PB}$ . However, if the FAULTSIGN bit (Bit 6) of the ACCMODE register (Address 0x0F) is set, the FAULTSIGN flag (Bit 5) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set as soon as  $I_{PA}$  is within 6.25% of  $I_{PB}$ . This threshold eliminates concerns about potential chatter between  $I_{PA}$  and  $I_{PB}$  calibration.

Typically, when a meter is calibrated, the voltage and current circuits are separated, as shown in Figure 45. Current passes through only the phase circuit or the neutral circuit. Figure 45 shows current being passed through the phase circuit. This is the preferred option because the ADE5166/ADE5169 start billing on the  $I_{PA}$  input on power-up. The phase circuit CT is connected to  $I_{PA}$  in the diagram. Because the current sensors are not perfectly matched, it is important to match current inputs. The ADE5166/ADE5169 provide a gain calibration register for  $I_{PB}$ , IBGAIN (Address 0x1C). IBGAIN is a 12-bit, signed, two's complement register that provides a gain resolution of 0.0244%/LSB.

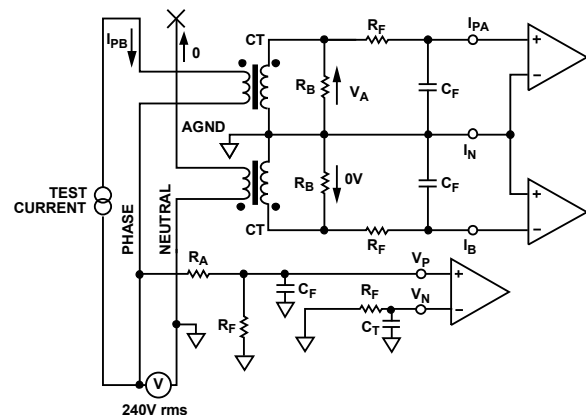


Figure 45. Fault Conditions for Inactive Input Greater Than Active Input

For calibration, a first measurement should be done on  $I_{PA}$  by setting the SEL\_I\_CH bits to 0b01 in the CALMODE register (Address 0x3D). This measurement should be compared to the measurement on  $I_{PB}$ . Measuring  $I_{PB}$  can be forced by setting the SEL\_I\_CH bits to 0b10 in the CALMODE register (Address 0x3D). The gain error between these two measurements can be evaluated using the following equation:

$$Error(\%) = \frac{Measurement(I_B) - Measurement(I_A)}{Measurement(I_A)}$$

The two channels,  $I_{PA}$  and  $I_{PB}$ , can then be matched by writing  $-Error\% / (1 + Error\%) \times 2^{12}$  to the IBGAIN register (Address 0x1C). This matching adjustment is valid for all energy measurements made by the ADE5166/ADE5169, including active power, reactive power (the ADE5169 only), apparent power, and  $I_{rms}$ .

### di/dt CURRENT SENSOR AND DIGITAL INTEGRATOR (ADE5169)

A di/dt sensor, a feature available for the ADE5169, detects changes in the magnetic field caused by ac currents. Figure 46 shows the principle of a di/dt current sensor.

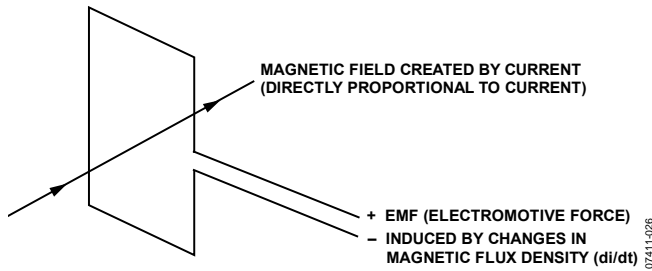


Figure 46. Principle of a di/dt Current Sensor

The flux density of a magnetic field induced by a current is directly proportional to the magnitude of the current. The changes in the magnetic flux density passing through a conductor loop generate an electromotive force (EMF) between the two ends of the loop. The EMF is a voltage signal that is proportional to the di/dt of the current. The voltage output from the di/dt current sensor is determined by the mutual inductance between the current-carrying conductor and the di/dt sensor. The current signal needs to be recovered from the di/dt signal before it can be used. An integrator is, therefore, necessary to restore the signal to its original form.

The ADE5169 has a built-in digital integrator to recover the current signal from the di/dt sensor. The digital integrator on the current channel is switched off by default when the ADE5169 is powered up. Setting the INTE bit (Bit 5) in the MODE1 register (Address 0x0B) turns on the integrator. Figure 47 to Figure 50 show the gain and phase response of the digital integrator.

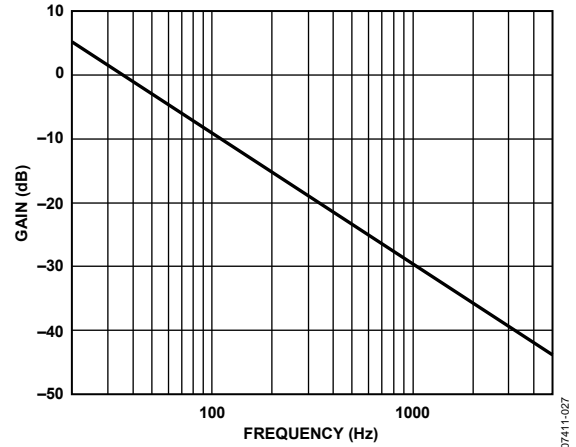


Figure 47. Combined Gain Response of the Digital Integrator and Phase Compensator

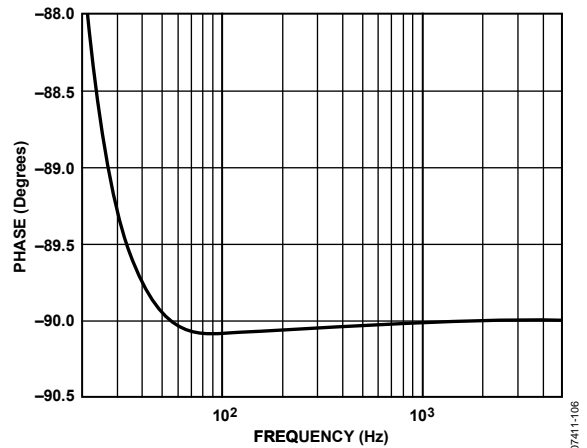


Figure 48. Combined Phase Response of the Digital Integrator and Phase Compensator

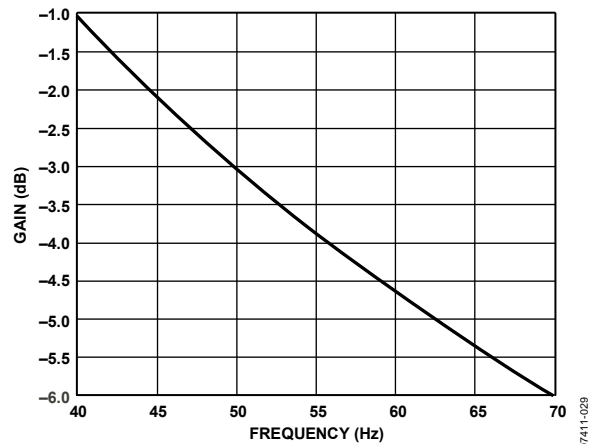


Figure 49. Combined Gain Response of the Digital Integrator and Phase Compensator (40 Hz to 70 Hz)

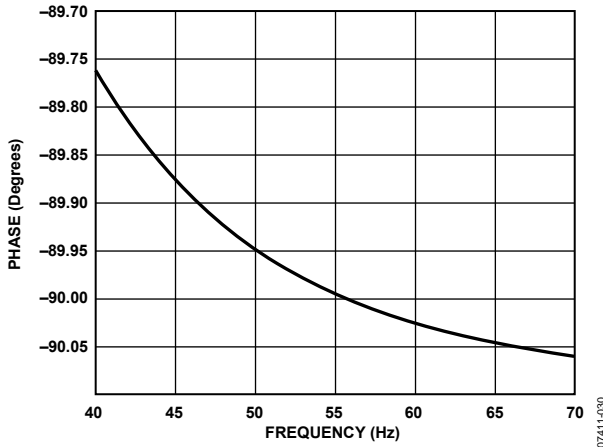


Figure 50. Combined Phase Response of the Digital Integrator and Phase Compensator (40 Hz to 70 Hz)

Note that the integrator has a  $-20$  dB/dec attenuation and an approximately  $-90^\circ$  phase shift. When combined with a di/dt sensor, the resulting magnitude and phase response should be a flat gain over the frequency band of interest. The di/dt sensor has a 20 dB/dec gain associated with it. It also generates significant high frequency noise. Therefore, a more effective antialiasing filter is needed to avoid noise due to aliasing (see the Antialiasing Filter section).

When the digital integrator is switched off, the ADE5169 can be used directly with a conventional current sensor, such as a current transformer (CT), or with a low resistance current shunt.

## POWER QUALITY MEASUREMENTS

### Zero-Crossing Detection

Each ADE5166/ADE5169 has a zero-crossing detection circuit on the voltage channel. This external zero-crossing signal can be output on P0.5 and P1.2 (see Table 38). It is also used in calibration mode.

The zero crossing is generated by default from the output of LPF1. This filter has a low cutoff frequency and is intended for 50 Hz and 60 Hz systems. If needed, this filter can be disabled to allow a higher frequency signal to be detected or to limit the group delay of the detection. If the voltage input fundamental frequency is below 60 Hz, and a time delay in ZX detection is acceptable, it is recommended that LPF1 be enabled. Enabling LPF1 limits the variability in the ZX detection by eliminating the high frequency components. Figure 51 shows how the zero-crossing signal is generated.

The zero-crossing signal, ZX, is generated from the output of LPF1 (bypassed or not). LPF1 has a single pole at 63.7 Hz (at  $MCLK = 4.096$  MHz). As a result, there is a phase lag between

the analog input signal V2 and the output of LPF1. The phase lag response of LPF1 results in a time delay of approximately 2 ms (@ 60 Hz) between the zero crossing on the analog inputs of the voltage channel and ZX detection.

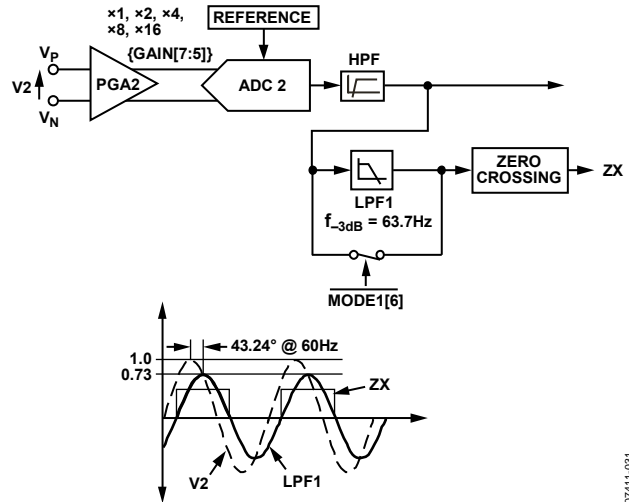


Figure 51. Zero-Crossing Detection on the Voltage Channel

The zero-crossing detection also drives the ZX flag in the Interrupt Status 3 SFR (MIRQSTH, Address 0xDE). If the ZX bit in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB) is set, the 8052 core has a pending ADE interrupt. The ADE interrupt stays active until the ZX status bit is cleared (see the Energy Measurement Interrupts section).

### Zero-Crossing Timeout

The zero-crossing detection also has an associated timeout register, ZXTOUT. This unsigned, 12-bit register is decremented (1 LSB) every  $160/MCLK$  seconds. The register is reset to its user programmed, full-scale value every time a zero crossing is detected on the voltage channel. The default power-on value in this register is 0xFFF. If the internal register decrements to 0 before a zero crossing is detected in the Interrupt Status 3 SFR (MIRQSTH, Address 0xDE), and the ZXTO bit (Bit 1) in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB) is set, the 8052 core has a pending ADE interrupt.

The ADE interrupt stays active until the ZXTO status bit is cleared (see the Energy Measurement Interrupts section). The ZXTOUT register (Address 0x11) can be written to or read by the user (see the Energy Measurement Registers section). The resolution of the register is  $160/MCLK$  seconds per LSB. Thus, the maximum delay for an interrupt is 0.16 seconds ( $1/MCLK \times 2^{12}$ ) when  $MCLK = 4.096$  MHz.



Figure 52 shows the mechanism of the zero-crossing timeout detection when the line voltage stays at a fixed dc level for more than  $MCLK/160 \times ZXTOUT$  seconds.

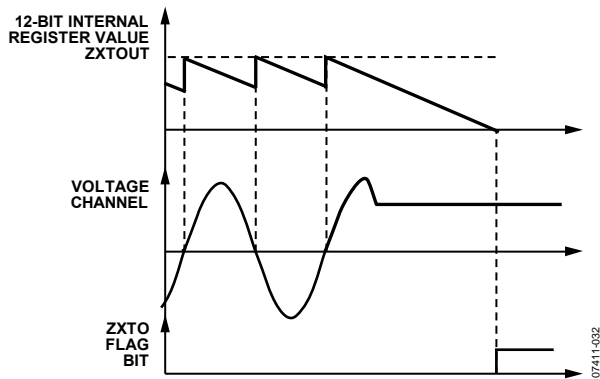


Figure 52. Zero-Crossing Timeout Detection

**Period or Frequency Measurements**

The ADE5166/ADE5169 provide the period or frequency measurement of the line. The period or frequency measurement is selected by clearing or setting the FREQSEL bit (Bit 1) in the MODE2 register (Address 0x0C). The period/frequency register, PER\_FREQ (Address 0x0A), is an unsigned 16-bit register that is updated every period. If LPF1 is enabled, a settling time of 1.8 sec is associated with this filter before the measurement is stable.

When the period measurement is selected, the measurement has a  $2.44 \mu s/LSB$  ( $4.096 \text{ MHz}/10$ ) resolution, which represents 0.014% when the line frequency is 60 Hz. When the line frequency is 60 Hz, the value of the period register is approximately 0d6827. The length of the register enables the measurement of line frequencies as low as 12.5 Hz. The period register is stable at  $\pm 1$  LSB when the line is established, and the measurement does not change.

When the frequency measurement is selected, the measurement has a 0.0625 Hz/LSB resolution when  $MCLK = 4.096 \text{ MHz}$ , which represents 0.104% when the line frequency is 60 Hz. When the line frequency is 60 Hz, the value of the frequency register is 0d960. The frequency register is stable at  $\pm 4$  LSB when the line is established, and the measurement does not change.

**Line Voltage SAG Detection**

In addition to detection of the loss of the line voltage signal (zero crossing), the ADE5166/ADE5169 can also be programmed to detect when the absolute value of the line voltage drops below a certain peak value for a number of line cycles. This condition is illustrated in Figure 53.

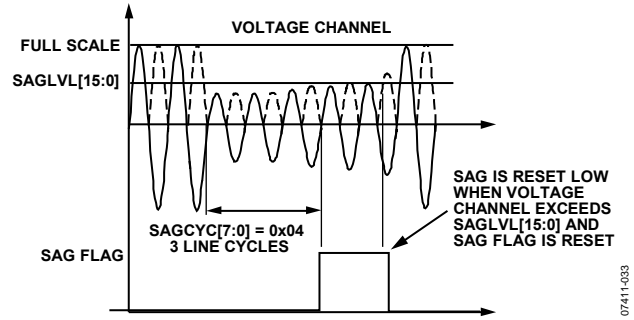


Figure 53. SAG Detection

Figure 53 shows the line voltage falling below a threshold that is set in the SAG level register (SAGLVL[15:0], Address 0x14) for three line cycles. The quantities 0 and 1 are not valid for the SAGCYC register, and the contents represent one more than the desired number of full line cycles. For example, when the SAG cycle (SAGCYC[7:0], Address 0x13) contains 0x04, FSAG (Bit 5) in the power management interrupt flag SFR (IPSMF, Address 0xF8) is set at the end of the third line cycle after the line voltage falls below the threshold. If the SAG enable bit (ESAG, Bit 5) in the power management interrupt enable SFR (IPSME, Address 0xEC) is set, the 8052 core has a pending power supply management interrupt. The PSM interrupt stays active until the ESAG bit is cleared (see the Power Supply Management (PSM) Interrupt section).

In Figure 53, the SAG flag (FSAG) is set on the fifth line cycle after the signal on the voltage channel first dropped below the threshold level.

**SAG Level Set**

The 2-byte contents of the SAG level register (SAGLVL, Address 0x14) are compared to the absolute value of the output from LPF1. Therefore, when LPF1 is enabled, writing 0x2038 to the SAG level register puts the SAG detection level at full scale (see Figure 53). Writing 0x00 or 0x01 puts the SAG detection level at 0. The SAG level register is compared to the input of the ZX detection, and detection is made when the ZX input falls below the contents of the SAG level register.

## Peak Detection

The ADE5166/ADE5169 can also be programmed to detect when the absolute value of the voltage or current channel exceeds a specified peak value. Figure 54 illustrates the behavior of the peak detection for the voltage channel. Both voltage and current channels are monitored at the same time.

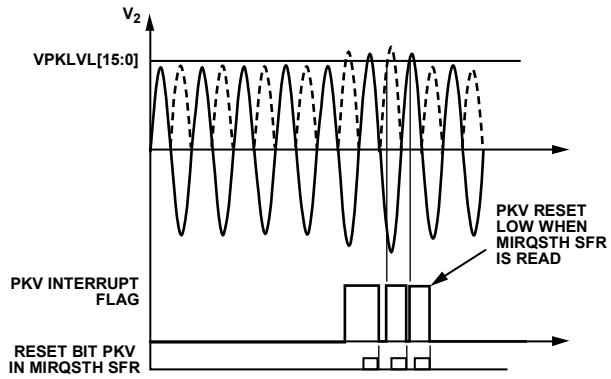


Figure 54. Peak Level Detection

Figure 54 shows a line voltage exceeding a threshold that is set in the voltage peak register (VPKLVL[15:0], Address 0x16). The voltage peak event is recorded by setting the PKV flag in the Interrupt Status 3 SFR (MIRQSTH, Address 0xDE). If the PKV enable bit (Bit 3) is set in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB), the 8052 core has a pending ADE interrupt. Similarly, the current peak event is recorded by setting the PKI flag (Bit 4) in Interrupt Status 3 SFR (MIRQSTH, Address 0xDE). The ADE interrupt stays active until the PKV or PKI status bit is cleared (see the Energy Measurement Interrupts section).

## Peak Level Set

The contents of the VPKLVL (Address 0x16) and IPKLVL (Address 0x15) registers are compared to the absolute value of the voltage and 2 MSBs of the current channel, respectively. Thus, for example, the nominal maximum code from the current channel ADC with a full-scale signal is 0x28F5C2 (see the Current Channel ADC section). Therefore, writing 0x28F5 to the IPKLVL register puts the current channel, peak detection level at full scale and sets the current peak detection to its least sensitive value. Writing 0x00 puts the current channel detection level at 0. The detection is done by comparing the contents of the IPKLVL register to the incoming current channel sample. The PKI flag indicates that the peak level is exceeded. If the PKI or PKV bit is set in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB), the 8052 core has a pending ADE interrupt.

## Peak Level Record

Each ADE5166/ADE5169 records the maximum absolute value reached by the current and voltage channels in two different registers, IPEAK (Address 0x17) and VPEAK (Address 0x19), respectively. Each register is a 24-bit unsigned register that is updated each time the absolute value of the waveform sample

from the corresponding channel is above the value stored in the IPEAK or VPEAK register. The contents of the VPEAK register correspond to the maximum absolute value observed on the voltage channel input. The contents of IPEAK and VPEAK represent the maximum absolute value observed on the current and voltage input, respectively. Reading the RSTIPEAK (Address 0x18) and RSTVPEAK (Address 0x17) registers clears their respective contents after the read operation.

## PHASE COMPENSATION

The ADE5166/ADE5169 must work with transducers that can have inherent phase errors. For example, a phase error of 0.1° to 0.3° is not uncommon for a current transformer (CT). These phase errors can vary from part to part, and they must be corrected to perform accurate power calculations. The errors associated with phase mismatch are particularly noticeable at low power factors. The ADE5166/ADE5169 provide a means of digitally calibrating these small phase errors. The part allows a small time delay or time advance to be introduced into the signal processing chain to compensate for small phase errors. Because the compensation is in time, this technique should be used only for small phase errors in the range of 0.1° to 0.5°. Correcting large phase errors using a time shift technique can introduce significant phase errors at higher harmonics.

The phase calibration register (PHCAL[7:0], Address 0x10) is a two's complement, signed, single-byte register that has values ranging from 0x82 (-126d) to 0x68 (+104d).

The PHCAL register is centered at 0x40, meaning that writing 0x40 to the register gives 0 delay. By changing this register, the time delay in the voltage channel signal path can change from -231.93 μs to +48.83 μs (MCLK = 4.096 MHz). One LSB is equivalent to a 1.22 μs (4.096 MHz/5) time delay or advance. A line frequency of 60 Hz gives a phase resolution of 0.026° at the fundamental (that is, 360° × 1.22 μs × 60 Hz).

Figure 55 illustrates how the phase compensation is used to remove a 0.1° phase lead in the current channel due to the external transducer. To cancel the lead (0.1°) in the current channel, a phase lead must also be introduced into the voltage channel. The resolution of the phase adjustment allows the introduction of a phase lead in increments of 0.026°. The phase lead is achieved by introducing a time advance into the voltage channel. A time advance of 4.88 μs is made by writing -4 (0x3C) to the time delay block, thus reducing the amount of time delay by 4.88 μs, or equivalently, a phase lead of approximately 0.1° at a line frequency of 60 Hz (0x3C represents -4 because the register is centered with 0 at 0x40).

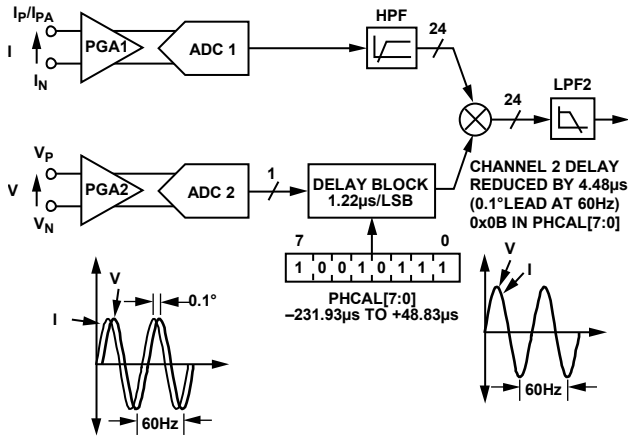


Figure 55. Phase Calibration

**RMS CALCULATION**

The root mean square (rms) value of a continuous signal  $V(t)$  is defined as

$$V_{rms} = \sqrt{\frac{1}{T} \times \int_0^T V^2(t) dt} \tag{1}$$

For time sampling signals, rms calculation involves squaring the signal, taking the average, and obtaining the square root. The ADE5166/ADE5169 implement this method by serially squaring the input, averaging them, and then taking the square root of the average. The averaging part of this signal processing is done by implementing a low-pass filter (LPF3 in Figure 56, Figure 57, and Figure 58).

This LPF has a  $-3$  dB cutoff frequency of 2 Hz when  $MCLK = 4.096$  MHz.

$$V(t) = \sqrt{2} \times V \sin(\omega t) \tag{2}$$

where  $V$  is the rms voltage.

$$V^2(t) = V^2 - V^2 \cos(2\omega t) \tag{3}$$

When this signal goes through LPF3, the  $\cos(2\omega t)$  term is attenuated and only the dc term,  $V_{rms}^2$  (shown as  $V^2$  in Figure 56), goes through.

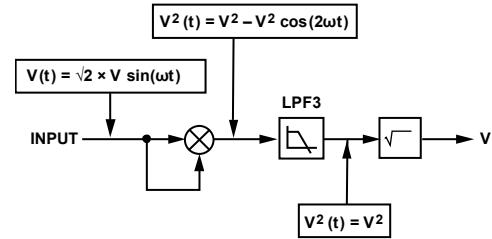


Figure 56. RMS Signal Processing

The  $I_{rms}$  signal can be read from the waveform register by setting the WAVMODE register (Address 0x0D) and setting the WFSM bit (Bit 5) in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB). Like the current and voltage channels waveform sampling modes, the waveform data is available at sample rates of 25.6 kSPS, 12.8 kSPS, 6.4 kSPS, and 3.2 kSPS.

It is important to note that when the current input is larger than 40% of full scale, the  $I_{rms}$  waveform sample register does not represent the true processed rms value. The rms value processed with this level of input is larger than the 24-bit read by the waveform register, making the value read truncated on the high end.

# ADE5166/ADE5169

## Current Channel RMS Calculation

Each ADE5166/ADE5169 simultaneously calculates the rms values for the current and voltage channels in different registers. Figure 57 shows the detail of the signal processing chain for the rms calculation on the current channel. The current channel rms value is processed from the samples used in the current channel waveform sampling mode and is stored in an unsigned 24-bit register ( $I_{rms}$ ). One LSB of the current channel rms register is equivalent to 1 LSB of a current channel waveform sample.

The update rate of the current channel rms measurement is 4.096 MHz/5. To minimize noise in the reading of the register, the  $I_{rms}$  register can also be configured to update only with the zero crossing of the voltage input. This configuration is done by setting the ZXRMS bit (Bit 2) in the MODE2 register (Address 0x0C).

With the different specified full-scale analog input values, the ADC produces an output code that is approximately  $\pm 0d2,684,354$  (see the Current Channel ADC section). Similarly, the equivalent rms value of a full-scale ac signal is  $0d1,898,124$  (0x1CF68C). The current rms measurement provided in the ADE5166/ ADE5169 is

accurate to within 0.5% for signal inputs between full scale and full scale/500. The conversion from the register value to amps must be done externally in the microprocessor using an amps/LSB constant.

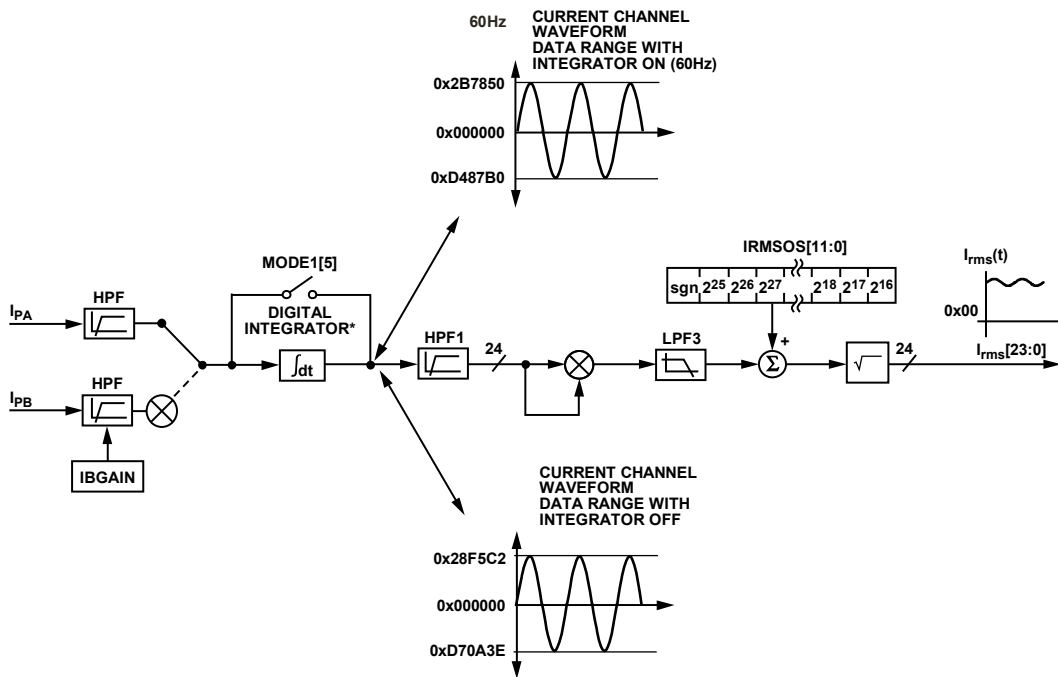
## Current Channel RMS Offset Compensation

The ADE5166/ADE5169 incorporate a current channel rms offset compensation register (IRMSOS). This is a 12-bit signed register that can be used to remove offset in the current channel rms calculation. An offset can exist in the rms calculation due to input noises that are integrated into the dc component of  $V^2(t)$ .

One LSB of the current channel rms offset is equivalent to 16,384 LSBs of the square of the current channel rms register. Assuming that the maximum value from the current channel rms calculation is  $0d1,898,124$  with full-scale ac inputs, then 1 LSB of the current channel rms offset represents 0.23% of measurement error at -60 dB down from full scale.

$$I_{rms} = \sqrt{I_{rms0}^2 + IRMSOS \times 32,768} \quad (4)$$

where  $I_{rms0}$  is the rms measurement without offset correction.



NOTES:  
1. WHEN DIGITAL INTEGRATOR IS ENABLED, FULL-SCALE OUTPUT DATA IS ATTENUATED DEPENDING ON THE SIGNAL FREQUENCY BECAUSE THE INTEGRATOR HAS A -20dB/DECADE FREQUENCY RESPONSE. WHEN DISABLED, THE OUTPUT IS NOT FURTHER ATTENUATED.

Figure 57. Current Channel RMS Signal Processing with PGA1 = 2, 4, 8, or 16

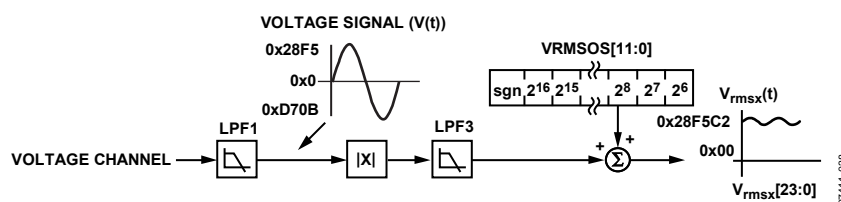


Figure 58. Voltage Channel RMS Signal Processing

**Voltage Channel RMS Calculation**

Figure 58 shows details of the signal processing chain for the rms calculation on the voltage channel. This voltage rms estimation is done in the ADE5166/ADE5169 using the mean absolute value calculation, as shown in Figure 58. The voltage channel rms value is processed from the samples used in the voltage channel waveform sampling mode and is stored in the unsigned 24-bit  $V_{rms}$  register.

The update rate of the voltage channel rms measurement is  $MCLK/5$ . To minimize noise in the reading of the register, the  $V_{rms}$  register can also be configured to update only with the zero crossing of the voltage input. This configuration is done by setting the ZXRMS bit (Bit 2) in the MODE2 register (Address 0x0C).

With the specified full-scale ac analog input signal of 0.5 V, the output from the LPF1 in Figure 58 swings between 0x28F5 and 0xD70B at 60 Hz (see the Voltage Channel ADC section). The equivalent rms value of this full-scale ac signal is approximately 0d1,898,124 (0x1CF68C) in the  $V_{rms}$  register. The voltage rms measurement provided in the ADE5166/ADE5169 is accurate to within  $\pm 0.5\%$  for signal input between full scale and full scale/20. The conversion from the register value to volts must be done externally in the microprocessor using a V/LSB constant.

**Voltage Channel RMS Offset Compensation**

The ADE5166/ADE5169 incorporate a voltage channel rms offset compensation register (VRMSOS). This is a 12-bit signed register that can be used to remove offset in the voltage channel rms calculation. An offset can exist in the rms calculation due to input noises and dc offset in the input samples. One LSB of the voltage channel rms offset is equivalent to 64 LSBs of the rms register. Assuming that the maximum value from the voltage channel rms calculation is 0d1,898,124 with full-scale ac inputs, then 1 LSB of the voltage channel rms offset represents 3.37% of measurement error at -60 dB down of full scale.

$$V_{rms} = V_{rms0} + 64 \times VRMSOS \tag{5}$$

where  $V_{rms0}$  is the rms measurement without offset correction.

**ACTIVE POWER CALCULATION**

Active power is defined as the rate of energy flow from source to load. It is the product of the voltage and current waveforms. The resulting waveform is called the instantaneous power signal and is equal to the rate of energy flow at every instant of time. The unit of power is the watt or joules/second. Equation 8 gives an expression for the instantaneous power signal in an ac system.

$$v(t) = \sqrt{2} \times V \sin(\omega t) \tag{6}$$

$$i(t) = \sqrt{2} \times I \sin(\omega t) \tag{7}$$

where:

$v$  is the rms voltage.

$i$  is the rms current.

$$p(t) = v(t) \times i(t) \tag{8}$$

$$p(t) = VI - VI \cos(2\omega t) \tag{8}$$

The average power over an integral number of line cycles ( $n$ ) is given by the expression in Equation 9.

$$P = \frac{1}{nT} \int_0^{nT} p(t) dt = VI \tag{9}$$

where:

$T$  is the line cycle period.

$P$  is referred to as the active or real power.

Note that the active power is equal to the dc component of the instantaneous power signal  $p(t)$  in Equation 9, that is,  $VI$ . This is the relationship used to calculate active power in the ADE5166/ADE5169. The instantaneous power signal  $p(t)$  is generated by multiplying the current and voltage signals. The dc component of the instantaneous power signal is then extracted by LPF2 (low-pass filter) to obtain the active power information (see Figure 59).

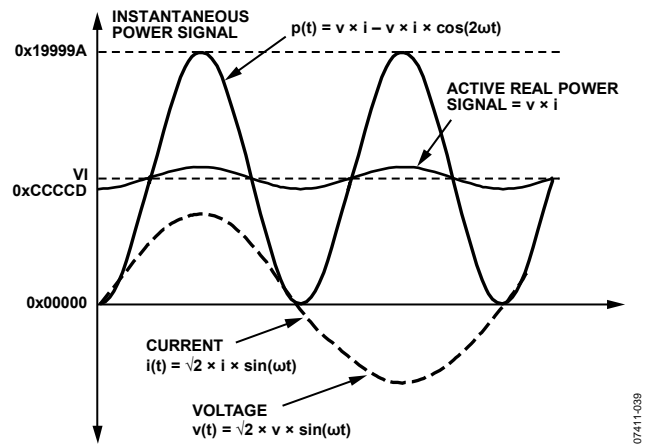


Figure 59. Active Power Calculation

Because LPF2 does not have an ideal brick wall frequency response (see Figure 60), the active power signal has some ripple due to the instantaneous power signal. This ripple is sinusoidal and has a frequency equal to twice the line frequency. Because of its sinusoidal nature, the ripple is removed when the active power signal is integrated to calculate energy (see the Active Energy Calculation section).

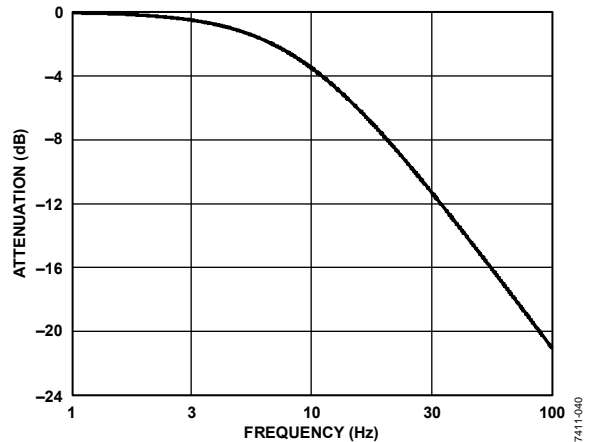


Figure 60. Frequency Response of LPF2

## Active Power Gain Calibration

Figure 61 shows the signal processing chain for the active power calculation in the ADE5166/ADE5169. As explained previously, the active power is calculated by filtering the output of the multiplier with a low-pass filter. Note that, when reading the waveform samples from the output of LPF2, the gain of the active energy can be adjusted by using the multiplier and watt gain register (WGAIN[11:0], Address 0x1D). The gain is adjusted by writing a twos complement 12-bit word to the watt gain register. Equation 10 shows how the gain adjustment is related to the contents of the watt gain register.

$$\text{Output WGAIN} = \left( \text{Active Power} \times \left\{ 1 + \frac{\text{WGAIN}}{2^{12}} \right\} \right) \quad (10)$$

For example, when 0x7FF is written to the watt gain register, the power output is scaled up by 50% (0x7FF = 2047d,  $2047/2^{12} = 0.5$ ). Similarly, 0x800 = -2048d (signed, twos complement) and power output is scaled by -50%. Each LSB scales the power output by 0.0244%. The minimum output range is given when the watt gain register contents are equal to 0x800, and the maximum range is given by writing 0x7FF to the watt gain register. This can be used to calibrate the active power (or energy) calculation in the ADE5166/ADE5169.

## Active Power Offset Calibration

The ADE5166/ADE5169 also incorporate an active power offset register (WATTOS[15:0], Address 0x20). It is a signed, twos complement, 16-bit register that can be used to remove offsets in the active power calculation (see Figure 59). An offset can exist in the power calculation due to crosstalk between channels on the PCB or in the IC itself. The offset calibration allows the contents of the active power register to be maintained at 0 when no power is being consumed.

The 256 LSBs (WATTOS = 0x0100) written to the active power offset register are equivalent to 1 LSB in the waveform sample register. Assuming the average value, output from LPF2 is 0xCCCCD (838,861d) when inputs on the voltage and current channels are both at full scale. At -60 dB down on the current channel (1/1000 of the current channel full-scale input), the average word value output from LPF2 is 838.861 (838,861/1000). One LSB in the LPF2 output has a measurement error of  $1/838.861 \times 100\% = 0.119\%$  of the average value. The active power offset register has a resolution equal to 1/256 LSB of the waveform register. Therefore, the power offset correction resolution is 0.000464%/LSB (0.119%/256) at -60 dB.

## Active Power Sign Detection

The ADE5166/ADE5169 can detect a change of sign in the active power. The APSIGN flag (Bit 3) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) records when a change of sign has occurred according to the APSIGN bit (Bit 4) in the ACCMODE register (Address 0x0F). If the APSIGN flag (Bit 3) is set in the Interrupt Enable 1 SFR (MIRQENL, Address 0xD9), the 8052 core has a pending ADE interrupt. The ADE interrupt stays active until the APSIGN status bit is cleared (see the Energy Measurement Interrupts section).

When APSIGN (Bit 4) in the ACCMODE register (Address 0x0F) is cleared (default), the APSIGN flag (Bit 3) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set when a transition from positive to negative active power occurs.

When the APSIGN bit (Bit 4) in the ACCMODE register (Address 0x0F) is set, the APSIGN flag (Bit 3) in the MIRQSTL SFR (Address 0xDC) is set when a transition from negative to positive active power occurs.

## Active Power No Load Detection

The ADE5166/ADE5169 include a no load threshold feature on the active energy that eliminates any creep effects in the meter. The part accomplishes this by not accumulating energy if the multiplier output is below the no load threshold. When the active power is below the no load threshold, the APNOLOAD flag (Bit 0) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set. If the APNOLOAD bit (Bit 0) is set in the Interrupt Enable 1 SFR (MIRQENL, Address 0xD9), the 8052 core has a pending ADE interrupt. The ADE interrupt stays active until the APNOLOAD status bit is cleared (see the Energy Measurement Interrupts section).

The no load threshold level is selectable by setting the APNOLOAD bits (Bits[1:0]) in the NLMODE register (Address 0x0E). Setting these bits to 0b00 disables the no load detection, and setting them to 0b01, 0b10, or 0b11 sets the no load detection threshold to 0.015%, 0.0075%, or 0.0037% of the multiplier full-scale output frequency, respectively. The IEC 62053-21 specification states that the meter must start up with a load of  $\leq 0.4\% I_{PB}$ , which translates to 0.0167% of the full-scale output frequency of the multiplier.

**ACTIVE ENERGY CALCULATION**

As stated in the Active Power Calculation section, power is defined as the rate of energy flow. This relationship can be expressed mathematically, as shown in Equation 11.

$$P = \frac{dE}{dt} \tag{11}$$

where:

*P* is power.

*E* is energy.

Conversely, energy is given as the integral of power.

$$E = \int P(t)dt \tag{12}$$

The ADE5166/ADE5169 achieve the integration of the active power signal by continuously accumulating the active power signal in an internal, nonreadable, 49-bit energy register. The register (WATTHR[23:0], Address 0x01) represents the upper 24 bits of this internal register. This discrete time accumulation or summation is equivalent to integration in continuous time. Equation 13 expresses the relationship.

$$E = \int p(t)dt = \lim_{t \rightarrow 0} \left\{ \sum_{n=1}^{\infty} p(nT) \times T \right\} \tag{13}$$

where:

*n* is the discrete time sample number.

*T* is the sample period.

The discrete time sample period (*T*) for the accumulation register in the ADE5166/ADE5169 is 1.22 μs (5/MCLK). In addition to calculating the energy, this integration removes any sinusoidal components that may be in the active power signal. Figure 61 shows this discrete time integration or accumulation. The active power signal in the waveform register is continuously added to the internal active energy register.

The active energy accumulation depends on the setting of POAM (Bit 1) and ABSAM (Bit 0) in the ACCMODE register (Address 0x0F). When both bits are cleared, the addition is signed and, therefore, negative energy is subtracted from the active energy contents. When both bits are set, the ADE5166/ADE5169 are set to be in the more restrictive mode, the positive-only accumulation mode.

When POAM (Bit 1) in the ACCMODE register (Address 0x0F) is set, only positive power contributes to the active energy accumulation. When ABSAM (Bit 0) in the ACCMODE register (Address 0x0F) is set, the absolute active power is used for the active energy accumulation (see the Watt-Absolute Accumulation Mode section).

The output of the multiplier is divided by the value in the WDIV register (Address 0x24). If the value in the WDIV register is equal to 0, the internal active energy register is divided by 1. WDIV is an 8-bit, unsigned register. After dividing by WDIV, the active energy is accumulated in a 49-bit internal energy accumulation register. The upper 24 bits of this register are accessible through a read to the active energy register (WATTHR[23:0], Address 0x01). A read to the RWATTHR register (Address 0x02) returns the contents of the WATTHR register, and the upper 24 bits of the internal register are cleared. As shown in Figure 61, the active power signal is accumulated in an internal 49-bit signed register. The active power signal can be read from the waveform register by setting the WAVMODE register (Address 0x0D) and setting the WFSM bit (Bit 5) in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB). Like the current and voltage channels waveform sampling modes, the waveform data is available at sample rates of 25.6 kSPS, 12.8 kSPS, 6.4 kSPS, and 3.2 kSPS.

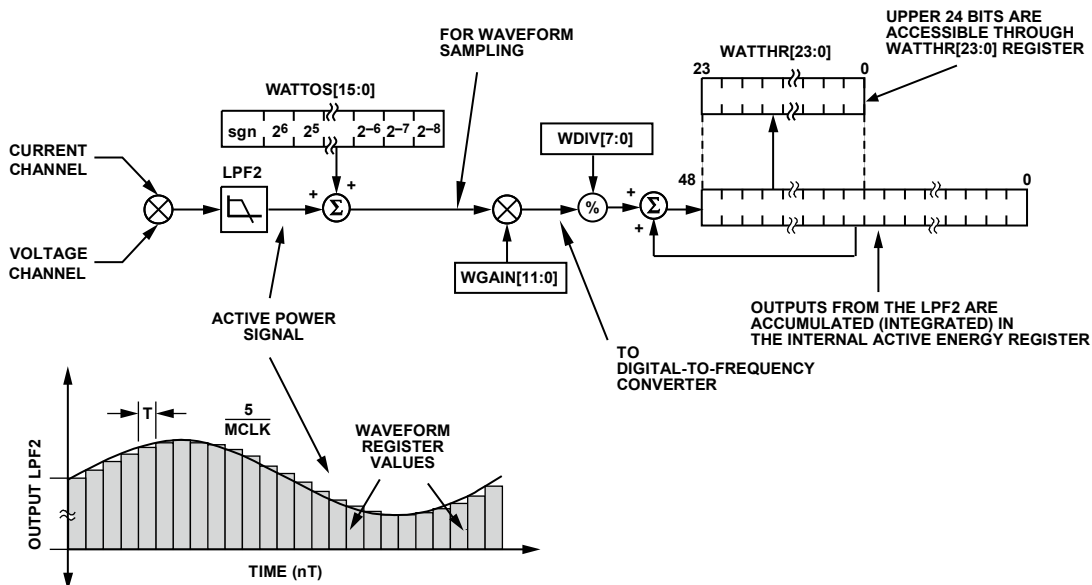


Figure 61. Active Energy Calculation

# ADE5166/ADE5169

Figure 62 shows this energy accumulation for full-scale signals (sinusoidal) on the analog inputs. The three displayed curves illustrate the minimum period of time it takes the energy register to roll over when the active power gain register contents are 0x7FF, 0x000, and 0x800. The watt gain register is used to carry out power calibration in the ADE5166/ADE5169. As shown, the fastest integration time occurs when the watt gain register is set to maximum full scale, that is, 0x7FF.

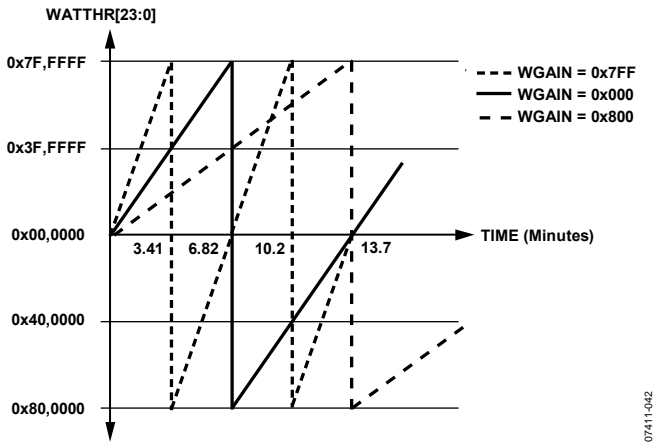


Figure 62. Energy Register Rollover Time for Full-Scale Power (Minimum and Maximum Power Gain)

Note that the energy register contents roll over to full-scale negative (0x800000) and continue to increase in value when the power or energy flow is positive (see Figure 62). Conversely, if the power is negative, the energy register underflows to full-scale positive (0x7FFFFFFF) and continues to decrease in value.

Using the interrupt enable register (MIRQENM, Address 0xDA), the ADE5166/ADE5169 can be configured to issue an ADE interrupt to the 8052 core when the active energy register is half full (positive or negative) or when an overflow or underflow occurs.

## Integration Time Under Steady Load: Active Energy

As mentioned in the Active Energy Calculation section, the discrete time sample period (T) for the accumulation register is 1.22 μs (5/MCLK). With full-scale sinusoidal signals on the analog inputs and the WGAIN register (Address 0x1D) set to 0x000, the average word value from each LPF2 is 0xCCCCD (see Figure 59). The maximum positive value that can be stored in the internal 49-bit register is 2<sup>48</sup> (or 0xFFFF,FFFF,FFF) before it overflows. The integration time under these conditions when WDIV = 0 is calculated in the following equation:

$$Time = \frac{0xFFFF,FFFF,FFF}{0xCCCCD} \times 1.22\mu s = 409.6sec = 6.82min \quad (14)$$

When WDIV is set to a value other than 0, the integration time varies, as shown in Equation 15.

$$Time = Time_{WDIV=0} \times WDIV \quad (15)$$

## Active Energy Accumulation Modes

### Watt-Signed Accumulation Mode

The ADE5166/ADE5169 active energy default accumulation mode is a watt-signed accumulation based on the active power information.

### Watt Positive-Only Accumulation Mode

The ADE5166/ADE5169 are placed in watt positive-only accumulation mode by setting the POAM bit (Bit 1) in the ACCMODE register (Address 0x0F). In this mode, the energy accumulation is done only for positive power, ignoring any occurrence of negative power above or below the no load threshold (see Figure 63). The CF pulse also reflects this accumulation method when in this mode. The default setting for this mode is off. Detection of the transitions in the direction of power flow and detection of no load threshold are active in this mode.

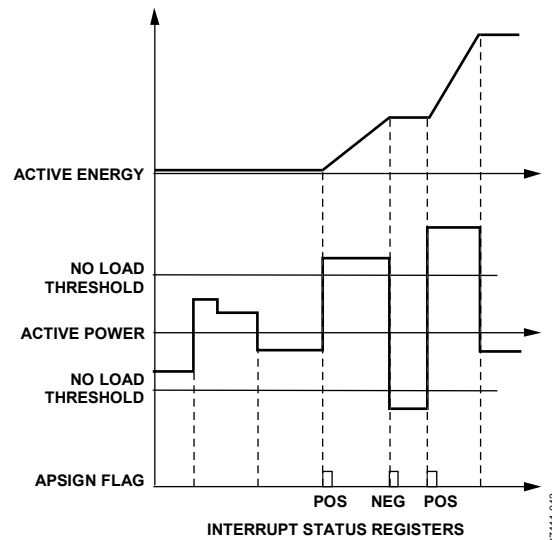


Figure 63. Energy Accumulation in Positive-Only Accumulation Mode

### Watt-Absolute Accumulation Mode

The ADE5166/ADE5169 are placed in watt-absolute accumulation mode by setting the ABSAM bit (Bit 0) in the ACCMODE register (Address 0x0F). In this mode, the energy accumulation is done using the absolute active power, ignoring any occurrence of power below the no load threshold (see Figure 64). The CF pulse also reflects this accumulation method when in this mode. The default setting for this mode is off. Detection of the transitions in the direction of power flow and detection of no load threshold are active in this mode.



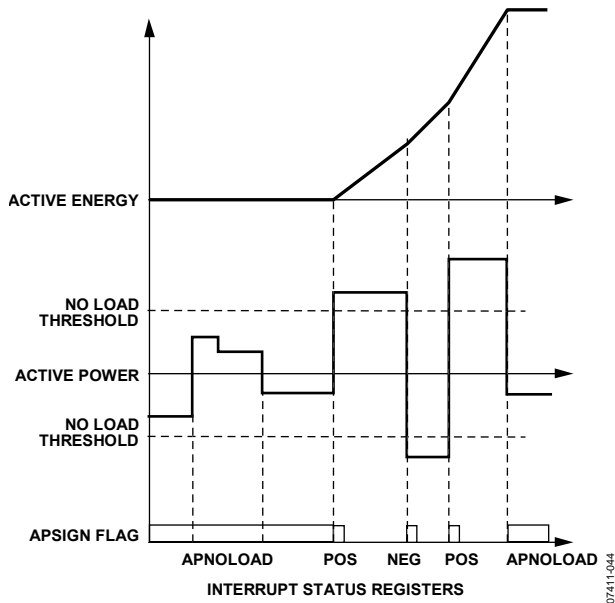


Figure 64. Energy Accumulation in Absolute Accumulation Mode

### Active Energy Pulse Output

All of the ADE5166/ADE5169 circuitry has a pulse output whose frequency is proportional to active power (see the Active Power Calculation section). This pulse frequency output uses the calibrated signal from the WGAIN register (Address 0x1D) output, and its behavior is consistent with the setting of the active energy accumulation mode in the ACCMODE register (Address 0x0F). The pulse output is active low and should preferably be connected to an LED, as shown in Figure 75.

### Line Cycle Active Energy Accumulation Mode

In line cycle active energy accumulation mode, the energy accumulation of the ADE5166/ADE5169 can be synchronized to the voltage channel zero crossing so that active energy can be accumulated over an integral number of half-line cycles. The advantage of summing the active energy over an integer number of line cycles is that the sinusoidal component in the active energy is reduced to 0. This eliminates any ripple in the energy calculation. Energy is calculated more accurately and more quickly because the integration period can be shortened. By using this mode, the energy calibration can be greatly simplified, and the time required to calibrate the meter can be significantly reduced.

In the line cycle active energy accumulation mode, the ADE5166/ADE5169 accumulate the active power signal in the LWATTHR register (Address 0x03) for an integral number of line cycles, as shown in Figure 65. The number of half-line cycles is specified in the LINCYC register (Address 0x12).

The ADE5166/ADE5169 can accumulate active power for up to 65,535 half-line cycles. Because the active power is integrated on an integral number of line cycles, the CYCEND flag (Bit 2) in the Interrupt Status 3 SFR (MIRQSTH, Address 0xDE) is set at the end of an active energy accumulation line cycle. If the CYCEND enable bit (Bit 2) in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB) is set, the 8052 core has a pending ADE interrupt. The ADE interrupt stays active until the CYCEND status bit is cleared (see the Energy Measurement Interrupts section). Another calibration cycle starts as soon as the CYCEND flag is set. If the LWATTHR register (Address 0x03) is not read before a new CYCEND flag is set, the LWATTHR register is overwritten by a new value.

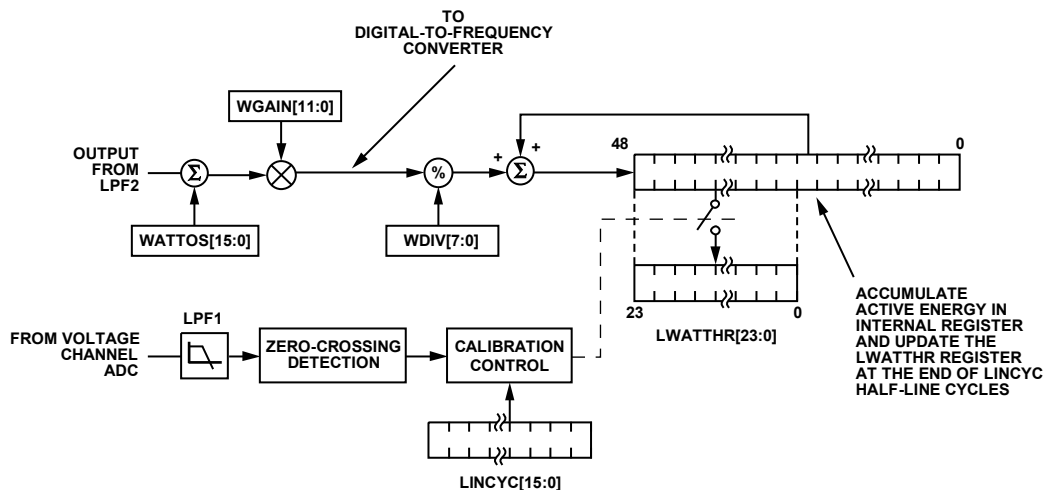


Figure 65. Line Cycle Active Energy Accumulation

When a new half-line cycle is written in the LINCYC register (Address 0x12), the LWATTHR register (Address 0x03) is reset, and a new accumulation starts at the next zero crossing. The number of half-line cycles is then counted until LINCYC is reached. This implementation provides a valid measurement at the first CYCEND interrupt after writing to the LINCYC register (see Figure 66). The line active energy accumulation uses the same signal path as the active energy accumulation. The LSB size of these two registers is equivalent.

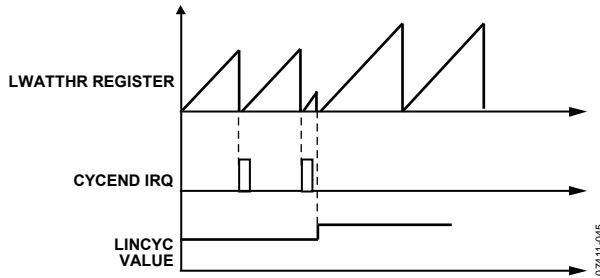


Figure 66. Energy Accumulation When LINCYC Changes

Using the information from Equation 8 and Equation 9

$$E(t) = \int_0^{nT} VI dt - \left\{ \frac{VI}{\sqrt{1 + \left(\frac{f}{8.9}\right)^2}} \right\} \int_0^{nT} \cos(2\pi ft) dt \quad (16)$$

where:

$n$  is an integer.

$T$  is the line cycle period.

Because the sinusoidal component is integrated over an integer number of line cycles, its value is always 0. Therefore,

$$E = \int_0^{nT} VI dt + 0 \quad (17)$$

$$E(t) = VI nT \quad (18)$$

Note that in this mode, the 16-bit LINCYC register can hold a maximum value of 65,535. In other words, the line energy accumulation mode can be used to accumulate active energy for a maximum duration of over 65,535 half-line cycles. At a 60 Hz line frequency, it translates to a total duration of  $65,535/120 \text{ Hz} = 546 \text{ sec}$ .

## REACTIVE POWER CALCULATION (ADE5169)

Reactive power, a function available for the ADE5169, is defined as the product of the voltage and current waveforms when one of these signals is phase-shifted by  $90^\circ$ . The resulting waveform is called the instantaneous reactive power signal. Equation 21 gives an expression for the instantaneous reactive power signal in an ac system when the phase of the current channel is shifted by  $90^\circ$ .

$$v(t) = \sqrt{2} V \sin(\omega t + \theta) \quad (19)$$

$$i(t) = \sqrt{2} I \sin(\omega t)$$

$$i'(t) = \sqrt{2} I \sin\left(\omega t + \frac{\pi}{2}\right) \quad (20)$$

where:

$\theta$  is the phase difference between the voltage and current channel.

$v$  is the rms voltage.

$i$  is the rms current.

$$q(t) = v(t) \times i'(t) \quad (21)$$

$$q(t) = VI \sin(\theta) + VI \sin(2\omega t + \theta)$$

The average reactive power over an integral number of lines ( $n$ ) is given in Equation 22.

$$Q = \frac{1}{nT} \int_0^{nT} q(t) dt = VI \sin(\theta) \quad (22)$$

where:

$T$  is the line cycle period.

$q$  is referred to as the reactive power.

Note that the reactive power is equal to the dc component of the instantaneous reactive power signal,  $q(t)$ , in Equation 21.

The instantaneous reactive power signal,  $q(t)$ , is generated by multiplying the voltage and current channels. In this case, the phase of the current channel is shifted by  $90^\circ$ . The dc component of the instantaneous reactive power signal is then extracted by a low-pass filter to obtain the reactive power information (see Figure 67).

In addition, the phase-shifting filter has a nonunity magnitude response. Because the phase-shifted filter has a large attenuation at high frequency, the reactive power is primarily for calculation at line frequency. The effect of harmonics is largely ignored in the reactive power calculation. Note that, because of the magnitude characteristic of the phase shifting filter, the weight of the reactive power is slightly different from the active power calculation (see the Energy Register Scaling section).

The frequency response of the LPF in the reactive signal path is identical to the one used for LPF2 in the average active power calculation. Because LPF2 does not have an ideal brick wall frequency response (see Figure 60), the reactive power signal has some ripple due to the instantaneous reactive power signal. This ripple is sinusoidal and has a frequency equal to twice the line frequency. Because the ripple is sinusoidal in nature, it is removed when the reactive power signal is integrated to calculate energy.

The reactive power signal can be read from the waveform register by setting the WAVMODE register (Address 0x0D) and the WFSM bit (Bit 5) in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB). Like the current and voltage channels waveform sampling modes, the waveform data is available at sample rates of 25.6 kSPS, 12.8 kSPS, 6.4 kSPS, and 3.2 kSPS.

**Reactive Power Gain Calibration**

Figure 67 shows the signal processing chain for the ADE5169 reactive power calculation. As explained in the Reactive Power Calculation (ADE5169) section, the reactive power is calculated by applying a low-pass filter to the instantaneous reactive power signal. Note that, when reading the waveform samples from the output of LPF2, the gain of the reactive energy can be adjusted by using the multiplier and by writing a twos complement, 12-bit word to the var gain register (VARGAIN[11:0], Address 0x1E). Equation 23 shows how the gain adjustment is related to the contents of the var gain register.

$$\text{Output VARGAIN} = \left( \text{Reactive Power} \times \left\{ 1 + \frac{\text{VARGAIN}}{2^{12}} \right\} \right) \quad (23)$$

The resolution of the VARGAIN register is the same as the WGAIN register (see the Active Power Gain Calibration section). VARGAIN can be used to calibrate the reactive power (or energy) calculation in the ADE5169.

**Reactive Power Offset Calibration**

The ADE5169 also incorporates a reactive power offset register (VAROS[15:0] (Address 0x21). This is a signed, twos complement, 16-bit register that can be used to remove offsets in the reactive power calculation (see Figure 67). An offset can exist in the reactive power calculation due to crosstalk between channels on the PCB or in the IC itself. The offset calibration allows the contents of the reactive power register to be maintained at 0 when no power is being consumed.

The 256 LSBs (VAROS = 0x100) written to the reactive power offset register are equivalent to 1 LSB in the WAVMODE register (Address 0x0D).

**Sign of Reactive Power Calculation**

Note that the average reactive power is a signed calculation. The phase shift filter has  $-90^\circ$  phase shift when the integrator is enabled and  $+90^\circ$  phase shift when the integrator is disabled. Table 46 summarizes the relationship of the phase difference between the voltage and the current and the sign of the resulting var calculation.

**Table 46. Sign of Reactive Power Calculation**

| Angle                            | Integrator | Sign     |
|----------------------------------|------------|----------|
| Between $0^\circ$ to $+90^\circ$ | Off        | Positive |
| Between $-90^\circ$ to $0^\circ$ | Off        | Negative |
| Between $0^\circ$ to $+90^\circ$ | On         | Positive |
| Between $-90^\circ$ to $0^\circ$ | On         | Negative |

**Reactive Power Sign Detection**

The ADE5169 detects a change of sign in the reactive power. The VARSIGN flag (Bit 4) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) records when a change of sign has occurred according to the VARSIGN bit (Bit 5) in the ACCMODE register (Address 0x0F). If the VARSIGN bit is set in the Interrupt Enable 1 SFR (MIRQENL, Address 0xD9), the 8052 core has a pending ADE interrupt. The ADE interrupt stays active until the VARSIGN status bit is cleared (see the Energy Measurement Interrupts section).

When the VARSIGN bit (Bit 5) in the ACCMODE register (Address 0x0F) is cleared (default), the VARSIGN flag (Bit 4) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set when a transition from positive to negative reactive power occurs.

When VARSIGN in the ACCMODE register (Address 0x0F) is set, the VARSIGN flag in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set when a transition from negative to positive reactive power occurs.

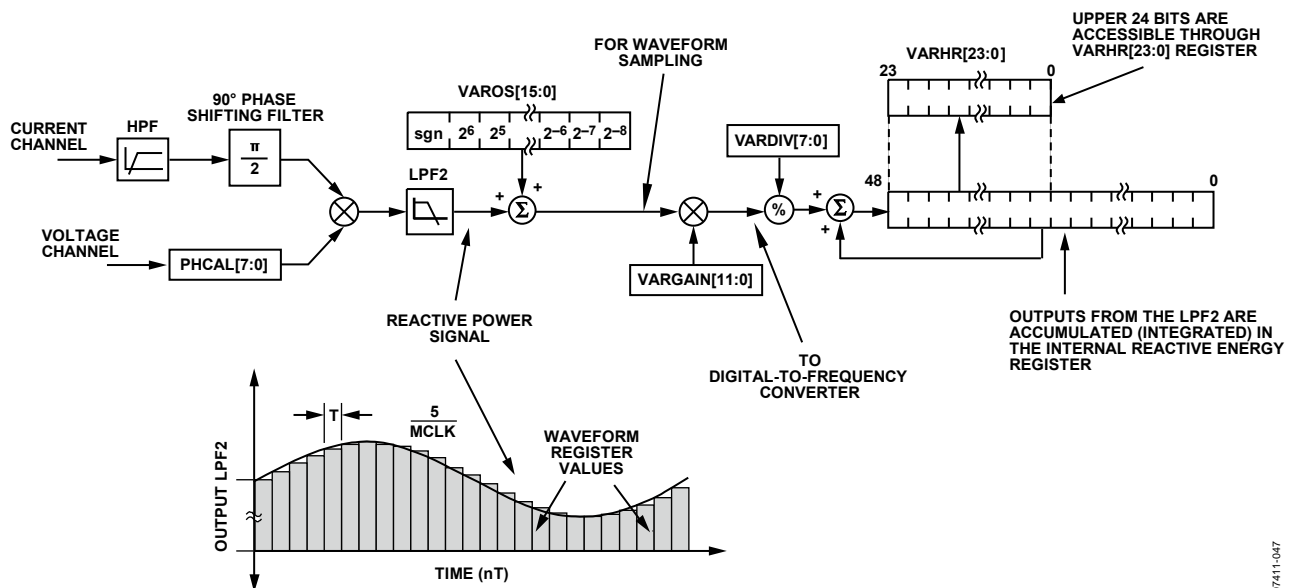


Figure 67. Reactive Energy Calculation

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## Reactive Power No Load Detection

The ADE5169 includes a no load threshold feature on the reactive energy that eliminates any creep effects in the meter. The ADE5169 accomplishes this by not accumulating reactive energy when the multiplier output is below the no load threshold. When the reactive power is below the no load threshold, the RNOLOAD flag (Bit 1) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set. If the RNOLOAD bit (Bit 1) is set in the Interrupt Enable 1 SFR (MIRQENL, Address 0xD9), the 8052 core has a pending ADE interrupt. The ADE interrupt stays active until the RNOLOAD status bit is cleared (see the Energy Measurement Interrupts section).

The no load threshold level can be selected by setting the VARNLOAD bits (Bits[3:2]) in the NLMODE register, located at Address 0x0E. Setting these bits to 0b00 disables the no load detection, and setting them to 0b01, 0b10, or 0b11 sets the no load detection threshold to 0.015%, 0.0075%, and 0.0037% of the full-scale output frequency of the multiplier, respectively.

## REACTIVE ENERGY CALCULATION (ADE5169)

As for active energy, the ADE5169 achieves the integration of the reactive power signal by continuously accumulating the reactive power signal in an internal, nonreadable, 49-bit energy register. The reactive energy register (VARHR[23:0], Address 0x04) represents the upper 24 bits of this internal register. The VARHR register and its function are available for the ADE5169.

The discrete time sample period (T) for the accumulation register in the ADE5169 is 1.22  $\mu$ s (5/MCLK). As well as calculating the energy, this integration removes any sinusoidal components that may be in the active power signal. Figure 67 shows this discrete time integration or accumulation. The reactive power signal in the waveform register is continuously added to the internal reactive energy register.

The reactive energy accumulation depends on the setting of the SAVARM and ABSVARM bits in the ACCMODE register (Address 0x0F). When both bits are cleared, the addition is signed and, therefore, negative energy is subtracted from the reactive energy contents. When both bits are set, the ADE5169 is set to be in the more restrictive mode, which is the absolute accumulation mode.

When the SAVARM bit (Bit 2) in the ACCMODE register (Address 0x0F) is set, the reactive power is accumulated depending on the sign of the active power. When active power is positive, the reactive power is added as it is to the reactive energy register. When active power is negative, the reactive power is subtracted from the reactive energy accumulator (see the Var Antitamber Accumulation Mode section).

When the ABSVARM bit (Bit 3) in the ACCMODE register (Address 0x0F) is set, the absolute reactive power is used for the reactive energy accumulation (see the Var Absolute Accumulation Mode section).

The output of the multiplier is divided by VARDIV. If the value in the VARDIV register (Address 0x25) is equal to 0, the internal reactive energy register is divided by 1. VARDIV is an 8-bit, unsigned register. After dividing by VARDIV, the reactive energy is accumulated in a 49-bit internal energy accumulation register. The upper 24 bits of this register are accessible through a read to the reactive energy register (VARHR[23:0], Address 0x04). A read to the RVAHR register (Address 0x08) returns the content of the VARHR register, and the upper 24 bits of the internal register are cleared.

As shown in Figure 67, the reactive power signal is accumulated in an internal 49-bit, signed register. The reactive power signal can be read from the waveform register by setting the WAVMODE register (Address 0x0D) and setting the WFSM bit (Bit 5) in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB). Like the current and voltage channel waveform sampling modes, the waveform data is available at sample rates of 25.6 kSPS, 12.8 kSPS, 6.4 kSPS, and 3.2 kSPS.

Figure 62 shows this energy accumulation for full-scale signals (sinusoidal) on the analog inputs. These curves also apply for the reactive energy accumulation.

Note that the energy register contents roll over to full-scale negative (0x800000) and continue to increase in value when the power or energy flow is positive. Conversely, if the power is negative, the energy register underflows to full-scale positive (0x7FFFFFFF) and continues to decrease in value.

Using the interrupt enable register (MIRQENM, Address 0xDA), the ADE5169 can be configured to issue an ADE interrupt to the 8052 core when the reactive energy register is half-full (positive or negative) or when an overflow or underflow occurs.

## Integration Time Under Steady Load: Reactive Energy

As mentioned in the Active Energy Calculation section, the discrete time sample period (T) for the accumulation register is 1.22  $\mu$ s (5/MCLK). With full-scale sinusoidal signals on the analog inputs and the VARGAIN register (Address 0x1E) and the VARDIV register (Address 0x25) set to 0x000, the integration time before the reactive energy register overflows is calculated in Equation 24.

$$Time = \frac{0xFFFFFFFF, FFFF, FFFF}{0xCCCCD} \times 1.22 \mu s = 409.6 \text{ sec} = 6.82 \text{ min} \quad (24)$$

When VARDIV is set to a value different from 0, the integration time varies, as shown in Equation 25.

$$Time = Time_{VARDIV=0} \times VARDIV \quad (25)$$

## Reactive Energy Accumulation Modes

### Var Signed Accumulation Mode

The ADE5169 reactive energy default accumulation mode is a signed accumulation based on the reactive power information.

**Var Antitamper Accumulation Mode**

The ADE5169 is placed in var antitamper accumulation mode by setting the SAVARM bit in the ACCMODE register (Address 0x0F). In this mode, the reactive power is accumulated depending on the sign of the active power. When the active power is positive, the reactive power is added as it is to the reactive energy register. When the active power is negative, the reactive power is subtracted from the reactive energy accumulator (see Figure 68). The CF pulse also reflects this accumulation method when in this mode. The default setting for this mode is off. Transitions in the direction of power flow and no load threshold are active in this mode.

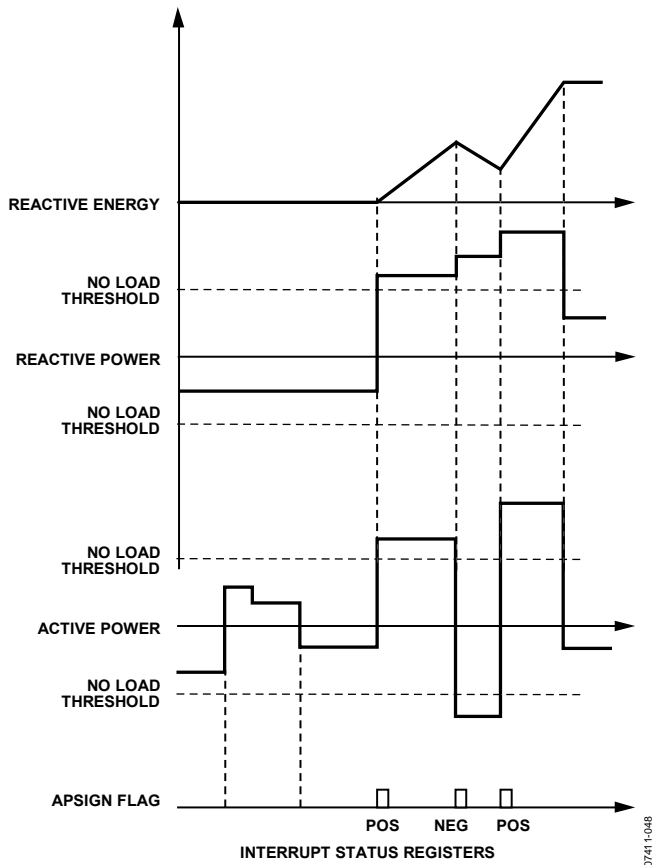


Figure 68. Reactive Energy Accumulation in Antitamper Accumulation Mode

**Var Absolute Accumulation Mode**

The ADE5169 is placed in absolute accumulation mode by setting the ABSVARM bit (Bit 3) in the ACCMODE register (Address 0x0F). In absolute accumulation mode, the reactive energy accumulation is done by using the absolute reactive power and ignoring any occurrence of power below the no load threshold for the reactive energy (see Figure 69). The CF pulse also reflects this accumulation method when in the absolute accumulation mode. The default setting for this mode is off. Transitions in the direction of power flow and no load threshold are active in this mode.

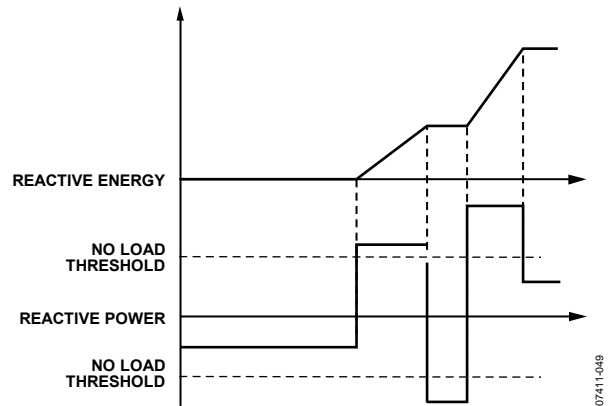


Figure 69. Reactive Energy Accumulation in Absolute Accumulation Mode

**Reactive Energy Pulse Output**

The ADE5169 provides all the circuitry with a pulse output whose frequency is proportional to reactive power (see the Energy-to-Frequency Conversion section). This pulse frequency output uses the calibrated signal after VARGAIN, and its behavior is consistent with the setting of the reactive energy accumulation mode in the ACCMODE register (Address 0x0F). The pulse output is active low and should preferably be connected to an LED, as shown in Figure 75.

# ADE5166/ADE5169

## Line Cycle Reactive Energy Accumulation Mode

In line cycle reactive energy accumulation mode, the energy accumulation of the ADE5169 can be synchronized to the voltage channel zero crossing so that reactive energy can be accumulated over an integral number of half-line cycles. The advantages of this mode are similar to those described in the Line Cycle Active Energy Accumulation Mode section.

In line cycle active energy accumulation mode, the ADE5169 accumulates the reactive power signal in the LVARHR register (Address 0x06) for an integral number of line cycles, as shown in Figure 70. The number of half-line cycles is specified in the LINCYC register (Address 0x12). The ADE5169 can accumulate active power for up to 65,535 half-line cycles.

Because the reactive power is integrated on an integral number of line cycles, the CYCEND flag (Bit 2) in the Interrupt Status 3 SFR (MIRQSTH, Address 0xDE) is set at the end of an active energy accumulation line cycle. If the CYCEND enable bit (Bit 2)

in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB) is set, the 8052 core has a pending ADE interrupt. The ADE interrupt stays active until the CYCEND status bit is cleared (see the Energy Measurement Interrupts section). Another calibration cycle starts as soon as the CYCEND flag is set. If the LVARHR register (Address 0x06) is not read before a new CYCEND flag is set, the LVARHR register is overwritten by a new value.

When a new half-line cycle is written in the LINCYC register (Address 0x12), the LVARHR register is reset, and a new accumulation starts at the next zero crossing. The number of half-line cycles is then counted internally until the value programmed in LINCYC is reached. This implementation provides a valid measurement at the first CYCEND interrupt after writing to the LINCYC register. The line reactive energy accumulation uses the same signal path as the reactive energy accumulation. The LSB size of these two registers is equivalent.

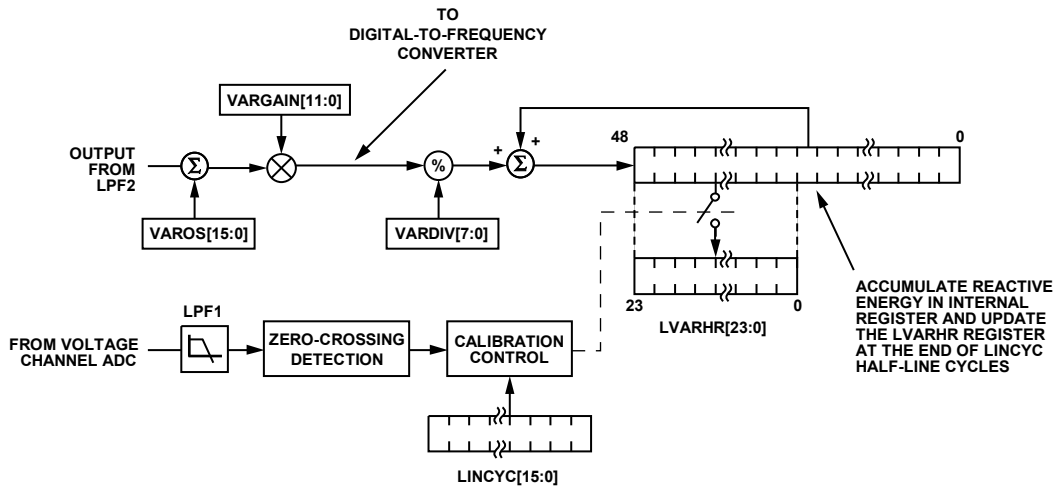


Figure 70. Line Cycle Reactive Energy Accumulation Mode

07411-1050

**APPARENT POWER CALCULATION**

Apparent power is defined as the maximum power that can be delivered to a load.  $V_{rms}$  and  $I_{rms}$  are the effective voltage and current delivered to the load, respectively. Therefore, the apparent power (AP) =  $V_{rms} \times I_{rms}$ . This equation is independent from the phase angle between the current and the voltage.

Equation 29 gives an expression of the instantaneous power signal in an ac system with a phase shift.

$$v(t) = \sqrt{2} V_{rms} \sin(\omega t) \tag{26}$$

$$i(t) = \sqrt{2} I_{rms} \sin(\omega t + \theta) \tag{27}$$

$$p(t) = v(t) \times i(t) \tag{29}$$

$$p(t) = V_{rms} I_{rms} \cos(\theta) - V_{rms} I_{rms} \cos(2\omega t + \theta) \tag{30}$$

Figure 71 illustrates the signal processing for the calculation of the apparent power in the ADE5166/ADE5169.

The apparent power signal can be read from the waveform register by setting the WAVMODE register (Address 0x0D) and setting the WFSM bit (Bit 5) in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB). Like the current and voltage channel waveform sampling modes, the waveform data is available at sample rates of 25.6 kSPS, 12.8 kSPS, 6.4 kSPS, or 3.2 kSPS.

The gain of the apparent energy can be adjusted by using the multiplier and by writing a twos complement, 12-bit word to the VAGAIN register (VAGAIN[11:0], Address 0x1F). Equation 31 shows how the gain adjustment is related to the contents of the VAGAIN register.

$$\text{Output VAGAIN} = \left( \text{Apparent Power} \times \left\{ 1 + \frac{\text{VAGAIN}}{2^{12}} \right\} \right) \tag{31}$$

For example, when 0x7FF is written to the VAGAIN register, the power output is scaled up by 50% ( $0x7FF = 2047d$ ,  $2047/2^{12} = 0.5$ ). Similarly,  $0x800 = -2047d$  (signed twos complement), and power output is scaled by -50%. Each LSB represents 0.0244% of the power output. The apparent power is calculated with the current and voltage rms values obtained in the rms blocks of the ADE5166/ADE5169.

**Apparent Power Offset Calibration**

Each rms measurement includes an offset compensation register to calibrate and eliminate the dc component in the rms value (see the Current Channel RMS Calculation section and the Voltage Channel RMS Calculation section). The voltage and current channels rms values are then multiplied together in the apparent power signal processing. Because no additional offsets are created in the multiplication of the rms values, there is no specific offset compensation in the apparent power signal processing. The offset compensation of the apparent power measurement is done by calibrating each individual rms measurement.

**APPARENT ENERGY CALCULATION**

The apparent energy is given as the integral of the apparent power.

$$\text{Apparent Energy} = \int \text{Apparent Power}(t) dt \tag{32}$$

The ADE5166/ADE5169 achieve the integration of the apparent power signal by continuously accumulating the apparent power signal in an internal 48-bit register. The apparent energy register (VAHR[23:0], Address 0x07) represents the upper 24 bits of this internal register. This discrete time accumulation or summation is equivalent to integration in continuous time. Equation 33 expresses the relationship.

$$\text{Apparent Energy} = \lim_{T \rightarrow 0} \left\{ \sum_{n=0}^{\infty} \text{Apparent Power}(nT) \times T \right\} \tag{33}$$

where:

$n$  is the discrete time sample number.

$T$  is the sample period.

The discrete time sample period ( $T$ ) for the accumulation register in the ADE5166/ADE5169 is 1.22  $\mu s$  ( $5/MCLK$ ).

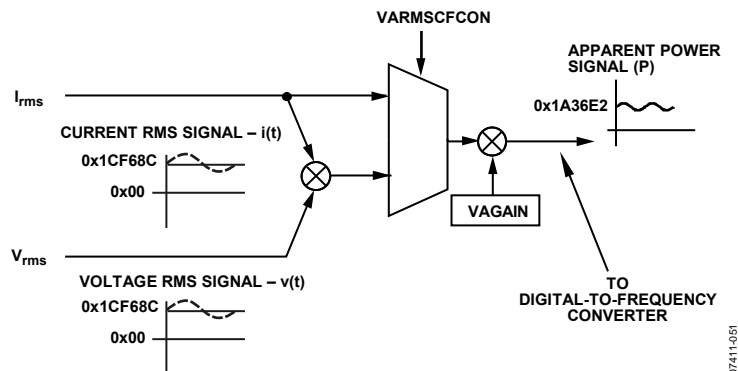


Figure 71. Apparent Power Signal Processing  
Rev. 0 | Page 63 of 148

# ADE5166/ADE5169

Figure 72 shows this discrete time integration or accumulation. The apparent power signal is continuously added to the internal register. This addition is a signed addition even if the apparent energy theoretically remains positive.

The 49 bits of the internal register are divided by VADIV. If the value in the VADIV register (Address 0x26) is 0, the internal apparent energy register is divided by 1. VADIV is an 8-bit, unsigned register. The upper 24 bits are then written in the 24-bit apparent energy register (VAHR[23:0], Address 0x07). The RVAHR register (Address 0x08), which is 24 bits long, is provided to read the apparent energy. This register is reset to 0 after a read operation.

Note that the apparent energy register is unsigned. By setting the VAEHF bit (Bit 2) and the VAEOF bit (Bit 5) in the Interrupt Enable 2 SFR (MIRQENM, Address 0xDA), the ADE5166/ADE5169 can be configured to issue an ADE interrupt to the 8052 core when the apparent energy register is half-full or when an overflow occurs. The half-full interrupt for the unsigned apparent energy register is based on 24 bits, as opposed to 23 bits for the signed active energy register.

### Integration Times Under Steady Load: Apparent Energy

As mentioned in the Apparent Energy Calculation section, the discrete time sample period (T) for the accumulation register is 1.22 μs (5/MCLK). With full-scale sinusoidal signals on the

analog inputs and the VAGAIN register (Address 0x1F) set to 0x000, the average word value from the apparent power stage is 0x1A36E2 (see the Apparent Power Calculation section). The maximum value that can be stored in the apparent energy register before it overflows is 2<sup>24</sup> or 0xFF,FFFF. The average word value is added to the internal register, which can store 2<sup>48</sup> or 0xFFFF,FFFF,FFFF before it overflows. Therefore, the integration time under these conditions with VADIV = 0 is calculated as follows:

$$Time = \frac{0xFFFF,FFFF,FFFF}{0xD055} \times 1.22 \mu s = 199 \text{ sec} = 3.33 \text{ min} \quad (34)$$

When VADIV is set to a value different from 0, the integration time varies, as shown in Equation 35.

$$Time = Time_{VADIV=0} \times VADIV \quad (35)$$

### Apparent Energy Pulse Output

All the ADE5166/ADE5169 circuitry has a pulse output whose frequency is proportional to apparent power (see the Energy-to-Frequency Conversion section). This pulse frequency output uses the calibrated signal after VAGAIN. This output can also be used to output a pulse whose frequency is proportional to I<sub>rms</sub>.

The pulse output is active low and should preferably be connected to an LED, as shown in Figure 75.

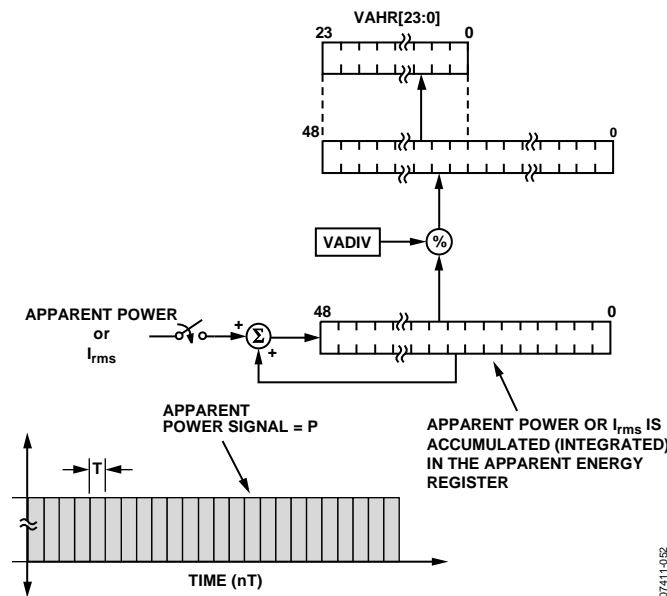


Figure 72. Apparent Energy Calculation



## Line Apparent Energy Accumulation

The ADE5166/ADE5169 are designed with a special apparent energy accumulation mode that simplifies the calibration process. By using the on-chip, zero-crossing detection, the ADE5166/ADE5169 accumulate the apparent power signal in the LVAHR register (Address 0x09) for an integral number of half cycles, as shown in Figure 73. The line apparent energy accumulation mode is always active.

The number of half-line cycles is specified in the LINCYC register (Address 0x12), which is an unsigned 16-bit register. The ADE5166/ADE5169 can accumulate apparent power for up to 65,535 combined half cycles. Because the apparent power is integrated on the same integral number of line cycles as the line active register and reactive energy register, these values can easily be compared. The energies are calculated more accurately because of this precise timing control and provide all the information needed for reactive power and power factor calculation.

At the end of an energy calibration cycle, the CYCEND flag (Bit 2) in the Interrupt Status 3 SFR (MIRQSTH, Address 0xDE) is set. If the CYCEND enable bit (Bit 2) in the Interrupt Enable 3 SFR (MIRQENH, Address 0xDB) is enabled, the 8052 core has a pending ADE interrupt.

As for LWATTHR, when a new half-line cycle is written in the LINCYC register (Address 0x12), the LVAHR register (Address 0x09) is reset and a new accumulation starts at the next zero crossing. The number of half-line cycles is then counted until LINCYC is reached.

This implementation provides a valid measurement at the first CYCEND interrupt after writing to the LINCYC register. The line apparent energy accumulation uses the same signal path as the apparent energy accumulation. The LSB size of these two registers is equivalent.

## Apparent Power No Load Detection

The ADE5166/ADE5169 include a no load threshold feature on the apparent power that eliminates any creep effects in the meter. The ADE5166/ADE5169 accomplish this by not accumulating energy if the multiplier output is below the no load threshold. When the apparent power is below the no load threshold, the VANLOAD flag (Bit 2) in the Interrupt Status 1 SFR (MIRQSTL, Address 0xDC) is set.

If the VANLOAD bit (Bit 2) is set in the Interrupt Enable 1 SFR (MIRQENL, Address 0xD9), the 8052 core has a pending ADE interrupt. The ADE interrupt stays active until the APNOLOAD status bit is cleared (see the Energy Measurement Interrupts section).

The no load threshold level is selectable by setting the VANLOAD bits (Bits[5:4]) in the NLMODE register (Address 0x0E). Setting these bits to 0b00 disables the no load detection, and setting them to 0b01, 0b10, or 0b11 sets the no load detection threshold to 0.030%, 0.015%, and 0.0075% of the full-scale output frequency of the multiplier, respectively.

This no load threshold can also be applied to the  $I_{rms}$  pulse output when selected. In this case, the level of no load threshold is the same as for the apparent energy.

## AMPERE-HOUR ACCUMULATION

In a tampering situation where no voltage is available to the energy meter, the ADE5166/ADE5169 are capable of accumulating the ampere-hour instead of apparent power into the VAHR, RVAHR, and LVAHR. When the VARMSFCFCON bit (Bit 3) of the MODE2 register (Address 0x0C) is set, the VAHR, RVAHR, and LVAHR and the input for the digital-to-frequency converter accumulate  $I_{rms}$  instead of apparent power. All the signal processing and calibration registers available for apparent power and energy accumulation remain the same when ampere-hour accumulation is selected. However, the scaling difference between  $I_{rms}$  and apparent power requires independent values for gain calibration in the VAGAIN (Address 0x1F), VADIV (Address 0x26), CFxNUM (Address 0x27 and Address 0x29), and CFxDEN (Address 0x28 and Address 0x2A) registers.

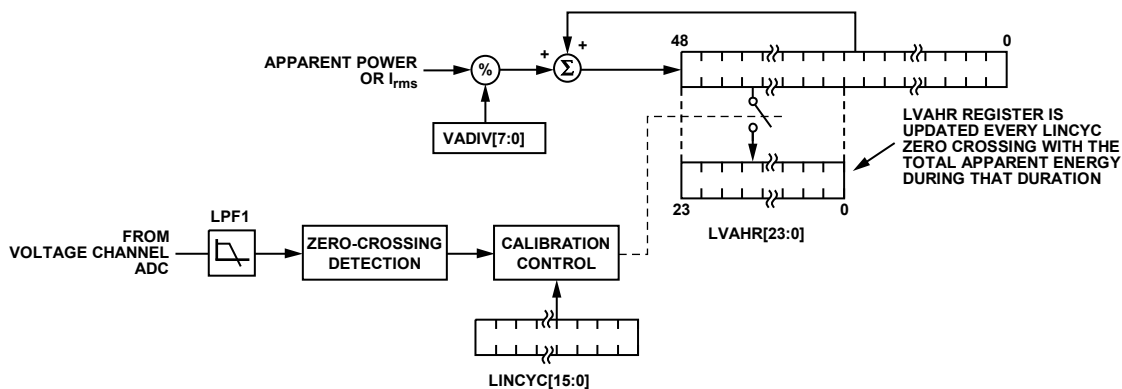


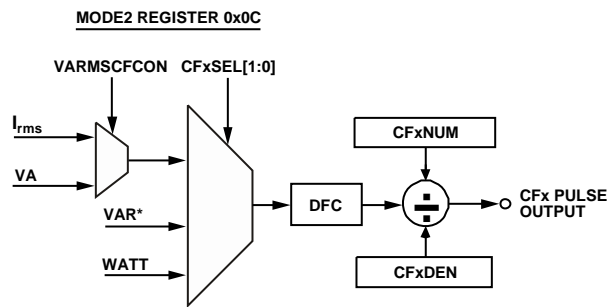
Figure 73. Line Cycle Apparent Energy Accumulation

07411-063

# ADE5166/ADE5169

## ENERGY-TO-FREQUENCY CONVERSION

The ADE5166/ADE5169 also provide two energy-to-frequency conversions for calibration purposes. After initial calibration at manufacturing, the manufacturer or end customer often verifies the energy meter calibration. One convenient way to do this is for the manufacturer to provide an output frequency that is proportional to the active power, reactive power, apparent power, or  $I_{rms}$  under steady load conditions. This output frequency can provide a simple single-wire, optically isolated interface to external calibration equipment. Figure 74 illustrates the energy-to-frequency conversion in the ADE5166/ADE5169.



\*AVAILABLE ONLY IN THE ADE5569 AND ADE5169.

Figure 74. Energy-to-Frequency Conversion

Two digital-to-frequency converters (DFC) are used to generate the pulsed outputs. When  $WDIV = 0$  or  $1$ , the DFC generates a pulse each time 1 LSB in the energy register is accumulated. An output pulse is generated when a  $CFxNUM/CFxDEN$  number of pulses are generated at the DFC output. Under steady load conditions, the output frequency is proportional to the active power, reactive power, apparent power, or  $I_{rms}$ , depending on the  $CFxSEL$  bits in the MODE2 register (Address 0x0C).

Both pulse outputs can be enabled or disabled by clearing or setting the  $DISCF1$  bit (Bit 1) and the  $DISCF2$  bit (Bit 2) in the MODE1 register (Address 0x0B), respectively.

Both pulse outputs set separate flags in the Interrupt Status 2 SFR ( $MIRQSTM$ , Address 0xDD),  $CF1$  (Bit 6) and  $CF2$  (Bit 7). If the  $CF1$  enable bit (Bit 6) and  $CF2$  enable bit (Bit 7) in the Interrupt Enable 2 SFR ( $MIRQENM$ , Address 0xDA) are set, the 8052 core has a pending ADE interrupt. The ADE interrupt stays active until the  $CF1$  or  $CF2$  status bit is cleared (see the Energy Measurement Interrupts section).

### Pulse Output Configuration

The two pulse output circuits have separate configuration bits in the MODE2 register (Address 0x0C). Setting the  $CFxSEL$  bits to 0b00, 0b01, or 0b1x configures the DFC to create a pulse output proportional to active power, reactive power, or apparent power, or  $I_{rms}$ , respectively.

The selection between  $I_{rms}$  and apparent power is done by the  $VARMSCFCON$  bit in the MODE2 register (Address 0x0C). With this selection,  $CF2$  cannot be proportional to apparent power if  $CF1$  is proportional to  $I_{rms}$ , and  $CF1$  cannot be proportional to apparent power if  $CF2$  is proportional to  $I_{rms}$ .

### Pulse Output Characteristic

The pulse output for both DFCs stays low for 90 ms if the pulse period is longer than 180 ms (5.56 Hz). If the pulse period is shorter than 180 ms, the duty cycle of the pulse output is 50%. The pulse output is active low and should preferably be connected to an LED, as shown in Figure 75.

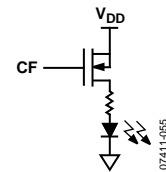


Figure 75. CF Pulse Output

The maximum output frequency with ac input signals at full scale and  $CFxNUM = 0x00$  and  $CFxDEN = 0x00$  is approximately 21.1 kHz.

The ADE5166/ADE5169 incorporate two registers per DFC,  $CFxNUM[15:0]$  and  $CFxDEN[15:0]$ , to set the  $CFx$  frequency. These are unsigned 16-bit registers that can be used to adjust the  $CFx$  frequency to a wide range of values. These frequency scaling registers are 16-bit registers that can scale the output frequency by  $1/2^{16}$  to 1 with a step of  $1/2^{16}$ .

If 0 is written to any of these registers, 1 is applied to the register. The ratio of  $CFxNUM/CFxDEN$  should be less than 1 to ensure proper operation. If the ratio of the  $CFxNUM/CFxDEN$  registers is greater than 1, the register values are adjusted to a ratio of 1. For example, if the output frequency is 1.562 kHz, and the content of  $CFxDEN$  is 0 (0x000), the output frequency can be set to 6.1 Hz by writing 0xFF to the  $CFxDEN$  register.

### ENERGY REGISTER SCALING

The ADE5166/ADE5169 provide measurements of active, reactive, and apparent energies that use separate paths and filtering for calculation. The difference in data paths can result in small differences in LSB weight between active, reactive, and apparent energy registers. These measurements are internally compensated so that the scaling is nearly one to one. The relationship between these registers is shown in Table 47.

Table 47. Energy Registers Scaling

| Line Frequency = 50 Hz            | Line Frequency = 60 Hz            | Integrator |
|-----------------------------------|-----------------------------------|------------|
| $Var = 0.9952 \times \text{watt}$ | $Var = 0.9949 \times \text{watt}$ | Off        |
| $VA = 0.9978 \times \text{watt}$  | $VA = 1.0015 \times \text{watt}$  | Off        |
| $Var = 0.9997 \times \text{watt}$ | $Var = 0.9999 \times \text{watt}$ | On         |
| $VA = 0.9977 \times \text{watt}$  | $VA = 1.0015 \times \text{watt}$  | On         |

**ENERGY MEASUREMENT INTERRUPTS**

The energy measurement part of the ADE5166/ADE5169 has its own interrupt vector for the 8052 core, Vector Address 0x004B (see the Interrupt Vectors section). The bits set in the Interrupt Enable 1 SFR (MIRQENL, Address 0xD9), Interrupt Enable 2 SFR (MIRQENM, Address 0xDA), and Interrupt Enable 3 SFR

(MIRQENH, Address 0xDB) enable the energy measurement interrupts that are allowed to interrupt the 8052 core. If an event is not enabled, it cannot create a system interrupt.

The ADE interrupt stays active until the status bit that has created the interrupt is cleared. The status bit is cleared when a 0 is written to this register bit.

## TEMPERATURE, BATTERY, AND SUPPLY VOLTAGE MEASUREMENTS

The ADE5166/ADE5169 include temperature measurements as well as battery and supply voltage measurements. These measurements enable many forms of compensation. The temperature and supply voltage measurements can be used to compensate external circuitry. The RTC can be calibrated over temperature to ensure that it does not drift. Supply voltage measurements allow the LCD contrast to be maintained despite variations in voltage. Battery measurements allow low battery detection to be performed.

All ADC measurements are configured through the SFRs, as shown in Table 48.

The temperature, battery, and supply voltage measurements can be configured to continue functioning in PSM1 and PSM2. Keeping the temperature measurement active ensures that it is not necessary to wait for the temperature measurement to settle before using it for compensation.

**Table 48. Temperature, Battery, and Supply Voltage Measurement SFRs**

| SFR Address | R/W | Mnemonic | Description                                  |
|-------------|-----|----------|--|
| 0xF9        | R/W | STRBPER  | Peripheral ADC strobe period (see Table 49). |
| 0xF3        | R/W | DIFFPROG | Temperature and supply delta (see Table 50). |
| 0xD8        | R/W | ADCGO    | Start ADC measurement (see Table 51).        |
| 0xFA        | R/W | BATVTH   | Battery detection threshold (see Table 52).  |
| 0xEF        | R/W | VDCINADC | V <sub>DCIN</sub> ADC value (see Table 53).  |
| 0xDF        | R/W | BATADC   | Battery ADC value (see Table 54).            |
| 0xD7        | R/W | TEMPADC  | Temperature ADC value (see Table 55).        |

**Table 49. Peripheral ADC Strobe Period SFR (STRBPER, Address 0xF9)**

| Bit   | Mnemonic     | Default | Description  |                                  |
|-------|--------------|---------|--|----------------------------------|
| [7:6] | Reserved     | 00      | These bits must be kept at 0 for proper operation.   |                                  |
| [5:4] | VDCIN_PERIOD | 0       | Period for background external voltage measurements. |                                  |
|       |              |         | <b>VDCIN_PERIOD</b>                                  | <b>Result</b>                    |
|       |              |         | 00   | No V <sub>DCIN</sub> measurement |
|       |              |         | 01   | 8 min                            |
|       |              |         | 10   | 2 min                            |
| [3:2] | BATT_PERIOD  | 0       | Period for background battery level measurements.    |                                  |
|       |              |         | <b>BATT_PERIOD</b>                                   | <b>Result</b>                    |
|       |              |         | 00   | No battery measurement           |
|       |              |         | 01   | 16 min                           |
|       |              |         | 10   | 4 min                            |
| [1:0] | TEMP_PERIOD  | 0       | Period for background temperature measurements.      |                                  |
|       |              |         | <b>TEMP_PERIOD</b>                                   | <b>Result</b>                    |
|       |              |         | 00   | No temperature measurement       |
|       |              |         | 01   | 8 min                            |
|       |              |         | 10   | 2 min                            |
|       |              |         | 11   | 1 min                            |

**Table 50. Temperature and Supply Delta SFR (DIFFPROG, Address 0xF3)**

| Bit   | Mnemonic                            | Default | Description   |   |
|-------|-------------------------------------|---------|---|---|
| [7:6] | Reserved                            | 0       | Reserved.   |   |
| [5:3] | TEMP_DIFF                           | 0       | Difference threshold between last temperature measurement interrupting 8052 and new temperature measurement that should interrupt 8052.   |   |
|       |                                     |         | <b>TEMP_DIFF</b>  | <b>Result</b>                           |
|       |                                     |         | 000   | No interrupt                            |
|       |                                     |         | 001   | 1 LSB ( $\approx 0.8^{\circ}\text{C}$ ) |
|       |                                     |         | 010   | 2 LSB ( $\approx 1.6^{\circ}\text{C}$ ) |
|       |                                     |         | 011   | 3 LSB ( $\approx 2.4^{\circ}\text{C}$ ) |
|       |                                     |         | 100   | 4 LSB ( $\approx 3.2^{\circ}\text{C}$ ) |
|       |                                     |         | 101   | 5 LSB ( $\approx 4^{\circ}\text{C}$ )   |
|       |                                     |         | 110   | 6 LSB ( $\approx 4.8^{\circ}\text{C}$ ) |
| 111   | Every temperature measurement       |         |   |   |
| [2:0] | VDCIN_DIFF                          | 0       | Difference threshold between last external voltage measurement interrupting 8052 and new external measurement that should interrupt 8052. |   |
|       |                                     |         | <b>VDCIN_DIFF</b>   | <b>Result</b>                           |
|       |                                     |         | 000   | No interrupt                            |
|       |                                     |         | 001   | 1 LSB ( $\approx 120\text{ mV}$ )       |
|       |                                     |         | 010   | 2 LSB ( $\approx 240\text{ mV}$ )       |
|       |                                     |         | 011   | 3 LSB ( $\approx 360\text{ mV}$ )       |
|       |                                     |         | 100   | 4 LSB ( $\approx 480\text{ mV}$ )       |
|       |                                     |         | 101   | 5 LSB ( $\approx 600\text{ mV}$ )       |
|       |                                     |         | 110   | 6 LSB ( $\approx 720\text{ mV}$ )       |
| 111   | Every $V_{\text{DCIN}}$ measurement |         |   |   |

**Table 51. Start ADC Measurement SFR (ADCGO, Address 0xD8)**

| Bit   | Bit Address  | Mnemonic     | Default | Description   |
|-------|--------------|--------------|---------|---|
| 7     | 0xDF         | PLLACK       | 0       | Set this bit to clear the PLL fault bit, PLL_FLT, in the PERIPH register (Address 0xF4). A PLL fault is generated if a reset is caused because the PLL lost lock. |
| [6:3] | 0xDE to 0xDB | Reserved     | 0       | Reserved.   |
| 2     | 0xDA         | VDCIN_ADC_GO | 0       | Set this bit to initiate an external voltage measurement. This bit is cleared when the measurement request is received by the ADC.                                |
| 1     | 0xD9         | TEMP_ADC_GO  | 0       | Set this bit to initiate a temperature measurement. This bit is cleared when the measurement request is received by the ADC.                                      |
| 0     | 0xD8         | BATT_ADC_GO  | 0       | Set this bit to initiate a battery measurement. This bit is cleared when the measurement request is received by the ADC.  |

**Table 52. Battery Detection Threshold SFR (BATVTH, Address 0xFA)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | BATVTH   | 0       | The battery ADC value is compared to this register, the battery threshold register. If BATADC is lower than the threshold, an interrupt is generated. |

**Table 53.  $V_{\text{DCIN}}$  ADC Value SFR (VDCINADC, Address 0xEF)**

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| [7:0] | VDCINADC | 0       | The $V_{\text{DCINADC}}$ value in this register is updated when an ADC interrupt occurs. |

**Table 54. Battery ADC Value SFR (BATADC, Address 0xDF)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | BATADC   | 0       | The battery ADC value in this register is updated when an ADC interrupt occurs. |

**Table 55. Temperature ADC Value SFR (TEMPADC, Address 0xD7)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | TEMPADC  | 0       | The temperature ADC value in this register is updated when an ADC interrupt occurs. |

## TEMPERATURE MEASUREMENT

To provide a digital temperature measurement, each ADE5166/ADE5169 includes a dedicated ADC. An 8-bit temperature ADC value SFR (TEMPADC, Address 0xD7) holds the results of the temperature conversion. The resolution of the temperature measurement is 0.83°C/LSB. There are two ways to initiate a temperature conversion: a single temperature measurement or background temperature measurements.

### Single Temperature Measurement

Set the TEMP\_ADC\_GO bit (Bit 1) in the start ADC measurement SFR (ADCGO, Address 0xD8) to obtain a temperature measurement (see Table 51). An interrupt is generated when the conversion is complete and when the temperature measurement is available in the temperature ADC value SFR (TEMPADC, Address 0xD7).

### Background Temperature Measurements

Background temperature measurements are disabled by default. To configure the background temperature measurement mode, set a temperature measurement interval in the peripheral ADC strobe period SFR (STRBPER, Address 0xF9). Temperature measurements are then performed periodically in the background (see Table 49).

When a temperature conversion completes, the new temperature ADC value is compared to the last temperature ADC value that created an interrupt. If the absolute difference between the two values is greater than the setting in the TEMP\_DIFF bits in the temperature and supply delta SFR (DIFFPROG, Address 0xF3[5:3]), a TEMPADC interrupt is generated (see Table 50). This allows temperature measurements to take place completely in the background, requiring MCU activity only if the temperature changes more than a configurable delta.

To set up background temperature measurement,

1. Initiate a single temperature measurement by setting the TEMP\_ADC\_GO bit in the start ADC measurement SFR (ADCGO, Address 0xD8[1]).
2. Upon completion of this measurement, configure the TEMP\_DIFF bits in the temperature and supply delta SFR (DIFFPROG, Address 0xF3[5:3]) to establish the change in temperature that triggers an interrupt.
3. Set up the interval for background temperature measurements by configuring the TEMP\_PERIOD bits in the peripheral ADC strobe period SFR (STRBPER, Address 0xF9[1:0]).

### Temperature ADC in PSM0, PSM1, and PSM2

Depending on the operating mode of the ADE5166/ADE5169, a temperature conversion is initiated only by certain actions.

- In PSM0 operating mode, the 8052 is active. Temperature measurements are available in the background measurement mode and by initiating a single measurement.
- In PSM1 operating mode, the 8052 is active, and the part is battery powered. Single temperature measurements can be initiated by setting the TEMP\_ADC\_GO bit in the

start ADC measurement SFR (ADCGO, Address 0xD8). Background temperature measurements are not available.

- In PSM2 operating mode, the 8052 is not active. Temperature conversions are available through the background measurement mode only.

The temperature ADC value SFR (TEMPADC, Address 0xD7) is updated with a new value only when a temperature ADC interrupt occurs.

### Temperature ADC Interrupt

The temperature ADC can generate an ADC interrupt when at least one of the following conditions occurs:

- The difference between the new temperature ADC value and the last temperature ADC value generating an ADC interrupt is larger than the value set in the TEMP\_DIFF bits.
- The temperature ADC conversion, initiated by setting start ADC measurement SFR (ADCGO, Address 0xD8), finishes.

When the ADC interrupt occurs, a new value is available in the temperature ADC value SFR (TEMPADC, Address 0xD7). Note that there is no flag associated with this interrupt.

## BATTERY MEASUREMENT

To provide a digital battery measurement, each ADE5166/ADE5169 includes a dedicated ADC. The battery measurement is available in the 8-bit battery ADC value SFR (BATADC, Address 0xDF). The battery measurement has a resolution of 14.6 mV/LSB. A battery conversion can be initiated by two methods: a single battery measurement or background battery measurements.

### Single Battery Measurement

Set the BATT\_ADC\_GO bit (Bit 0) in the start ADC measurement SFR (ADCGO, Address 0xD8) to obtain a battery measurement. An interrupt is generated when the conversion is done and when the battery measurement is available in the battery ADC value SFR (BATADC, Address 0xDF).

### Background Battery Measurements

To configure background measurements for the battery, establish a measurement interval in the peripheral ADC strobe period SFR (STRBPER, Address 0xF9). Battery measurements are then performed periodically in the background (see Table 49).

When a battery conversion completes, the battery ADC value is compared to the low battery threshold, established in the battery detection threshold SFR (BATVTH, Address 0xFA). If the battery ADC value is below this threshold, a low battery flag is set. This low battery flag is the FBAT bit (Bit 2) in the power management interrupt flag SFR (IPSMF, Address 0xF8), used for power supply management. This low battery flag can be enabled to generate the PSM interrupt by setting the EBAT bit (Bit 2) in the power management interrupt enable SFR (IPSMIE, Address 0xEC). This method allows battery measurements to take place completely in the background, requiring MCU activity only if the battery drops below a user-specified threshold.

To set up background battery measurements, follow these steps:

1. Configure the battery detection threshold SFR (BATVTH, Address 0xFA) to establish a low battery threshold. If the BATADC measurement is below this threshold, the FBAT bit (Bit 2) in the power management interrupt flag SFR (IPSMF, Address 0xF8) is set.
2. Set up the interval for background battery measurements by configuring the BATT\_PERIOD bits in the peripheral ADC strobe period SFR (STRBPER, Address 0xF9[3:2]).

### Battery ADC in PSM0, PSM1, and PSM2

Depending on the operating mode, a battery conversion is initiated only by certain actions.

- In PSM0 operating mode, the 8052 is active. Battery measurements are available in the background measurement mode and by initiating a single measurement.
- In PSM1 operating mode, the 8052 is active, and the part is battery powered. Single battery measurements can be initiated by setting the BATT\_ADC\_GO bit (Bit 0) in the start ADC measurement SFR (ADCGO, Address 0xD8). Background battery measurements are not available.
- In PSM2 operating mode, the 8052 is not active. Unlike temperature and  $V_{DCIN}$  measurements, the battery conversions are not available in this mode.

### Battery ADC Interrupt

The battery ADC can generate an ADC interrupt when at least one of the following conditions occurs:

- The new battery ADC value is smaller than the value set in the battery detection threshold SFR (BATVTH, Address 0xFA), indicating a battery voltage loss.
- A single battery measurement initiated by setting the BATT\_ADC\_GO bit in the start ADC measurement SFR (ADCGO, Address 0xD8) finishes.

When the battery flag (FBAT, Bit 2) is set in the power management interrupt flag SFR (IPSMF, Address 0xF8), a new ADC value is available in the battery ADC value SFR (BATADC, Address 0xDF). This battery flag can be enabled as a source of the PSM interrupt to generate a PSM interrupt every time the battery drops below a set voltage threshold or after a single conversion initiated by setting the BATT\_ADC\_GO bit in the start ADC measurement SFR (ADCGO, Address 0xD8) is ready.

The battery ADC value SFR (BATADC, Address 0xDF) is updated with a new value only when the battery flag (FBAT) is set in the power management interrupt flag SFR (IPSMF, Address 0xF8).

## EXTERNAL VOLTAGE MEASUREMENT

The ADE5166/ADE5169 include a dedicated ADC to provide a digital measurement of an external voltage on the  $V_{DCIN}$  pin. An 8-bit SFR, the  $V_{DCIN}$  ADC value SFR (VDCINADC, Address 0xEF),

holds the results of the conversion. The resolution of the external voltage measurement is 15.3 mV/LSB. There are two ways to initiate an external voltage conversion: a single external voltage measurement or background external voltage measurements.

### Single External Voltage Measurement

To obtain an external voltage measurement, set the VDCIN\_ADC\_GO bit (Bit 2) in the start ADC measurement SFR (ADCGO, Address 0xD8). An interrupt is generated when the conversion is done and when the external voltage measurement is available in the  $V_{DCIN}$  ADC value SFR (VDCINADC, Address 0xEF).

### Background External Voltage Measurements

Background external voltage measurements are disabled by default. To configure the background external voltage measurement mode, set an external voltage measurement interval in the peripheral ADC strobe period SFR (STRBPER, Address 0xF9). External voltage measurements are performed periodically in the background (see Table 49).

When an external voltage conversion is complete, the new external voltage ADC value is compared to the last external voltage ADC value that created an interrupt. If the absolute difference between the two values is greater than the setting in the VDCIN\_DIFF[2:0] bits in the temperature and supply delta SFR (DIFFPROG, Address 0xF3), a  $V_{DCIN}$  ADC flag is set. This  $V_{DCIN}$  ADC flag is FVADC (Bit 3) in the power management interrupt flag SFR (IPSMF, Address 0xF8), which is used for power supply management. This  $V_{DCIN}$  ADC flag can be enabled to generate a PSM interrupt by setting the EVADC bit (Bit 3) in the power management interrupt enable SFR (IPSMIE, Address 0xEC).

This method allows external voltage measurements to take place completely in the background, requiring MCU activity only if the external voltage has changed more than a configurable delta.

To set up background external voltage measurements, follow these steps:

1. Initiate a single external voltage measurement by setting the VDCIN\_ADC\_GO bit (Bit 2) in the start ADC measurement SFR (ADCGO, Address 0xD8).
2. Upon completion of this measurement, configure the VDCIN\_DIFF bits in the temperature and supply delta SFR (DIFFPROG, Address 0xF3[2:0]) to establish the change in voltage that sets the FVDCIN (Bit 0) in the power management interrupt flag SFR (IPSMF, Address 0xF8).
3. Set up the interval for background external voltage measurements by configuring the VDCIN\_PERIOD bits in the peripheral ADC strobe period SFR (STRBPER, Address 0xF9[5:4]).

## **External Voltage ADC in the PSM1 and PSM2 Modes**

An external voltage conversion is initiated only by certain actions that depend on the operating mode of the ADE5166/ ADE5169.

- In PSM0 operating mode, the 8052 is active. External voltage measurements are available in the background measurement mode and by initiating a single measurement.
- In PSM1 operating mode, the 8052 is active and the part is powered from battery. Single external voltage measurements can be initiated by setting the VDCIN\_ADC\_GO bit (Bit 2) in the start ADC measurement SFR (ADCGO, Address 0xD8). Background external voltage measurements are not available.
- In PSM2 operating mode, the 8052 is not active. External voltage conversions are available through the background measurement mode only.

The external voltage ADC in the  $V_{DCIN}$  ADC value SFR (VDCINADC, Address 0xEF) is updated with a new value only when an external voltage ADC interrupt occurs.

## **External Voltage ADC Interrupt**

The external voltage ADC can generate an ADC interrupt when at least one of the following conditions occurs:

- The difference between the new external voltage ADC value and the last external voltage ADC value generating an ADC interrupt is larger than the value set in the VDCIN\_DIFF[2:0] bits in the temperature and supply delta SFR (DIFFPROG, Address 0xF3).
- The external voltage ADC conversion, initiated by setting VDCIN\_ADC\_GO in the start ADC measurement SFR (ADCGO, Address 0xD8), finishes.

When the ADC interrupt occurs, a new value is available in the  $V_{DCIN}$  ADC value SFR (VDCINADC, Address 0xEF). Note that there is no flag associated with this interrupt.



## 8052 MCU CORE ARCHITECTURE

The ADE5166/ADE5169 have an 8052 MCU core and use the 8051 instruction set. Some of the standard 8052 peripherals, such as the UART, have been enhanced. This section describes the standard 8052 core and enhancements that have been made to it in the ADE5166/ADE5169.

The special function register (SFR) space is mapped into the upper 128 bytes of internal data memory space and is accessed by direct addressing only. It provides an interface between the CPU and all on-chip peripherals. See Figure 76 for a block diagram showing the programming model of the ADE5166/ADE5169 via the SFR area

All registers except the program counter (PC), instruction register (IR), and the four general-purpose register banks reside in the SFR area. The SFR registers include control, configuration, and data registers that provide an interface between the CPU and all on-chip peripherals.

### MCU REGISTERS

The registers used by the MCU are summarized in Table 56.

Table 56. 8051 SFRs

| SFR   | Address       | Bit Addressable | Description                         |
|-------|---------------|-----------------|-------------------------------------|
| ACC   | 0xE0          | Yes             | Accumulator.                        |
| B     | 0xF0          | Yes             | Auxiliary math.                     |
| PSW   | 0xD0          | Yes             | Program status word (see Table 57). |
| PCON  | 0x87          | No              | Program control (see Table 58).     |
| DPL   | 0x82          | No              | Data pointer low (see Table 59).    |
| DPH   | 0x83          | No              | Data pointer high (see Table 60).   |
| DPTR  | 0x82 and 0x83 | No              | Data pointer (see Table 61).        |
| SP    | 0x81          | No              | Stack pointer (see Table 62).       |
| SPH   | 0xB7          | No              | Stack pointer high (see Table 63).  |
| STCON | 0xBF          | No              | Stack boundary (see Table 64).      |
| CFG   | 0xAF          | No              | Configuration (see Table 65).       |

Table 57. Program Status Word SFR (PSW, Address 0xD0)

| Bit   | Bit Address | Mnemonic      | Description   |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
|-------|-------------|---------------|---|-----|-----|---------------|---|---|---|---|---|---|---|---|---|---|---|---|
| 7     | 0xD7        | CY            | Carry flag. Modified by ADD, ADDC, SUBB, MUL, and DIV instructions.   |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| 6     | 0xD6        | AC            | Auxiliary carry flag. Modified by ADD and ADDC instructions.  |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| 5     | 0xD5        | F0            | General-purpose flag available to the user.   |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| [4:3] | 0xD4, 0xD3  | RS1, RS0      | Register bank select bits.  |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
|       |             |               | <table border="1"> <thead> <tr> <th>RS1</th> <th>RS0</th> <th>Selected Bank</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>0</td> </tr> <tr> <td>0</td> <td>1</td> <td>1</td> </tr> <tr> <td>1</td> <td>0</td> <td>2</td> </tr> <tr> <td>1</td> <td>1</td> <td>3</td> </tr> </tbody> </table> | RS1 | RS0 | Selected Bank | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 0 | 2 | 1 | 1 | 3 |
| RS1   | RS0         | Selected Bank |   |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| 0     | 0           | 0             |   |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| 0     | 1           | 1             |   |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| 1     | 0           | 2             |   |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| 1     | 1           | 3             |   |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| 2     | 0xD2        | OV            | Overflow flag. Modified by ADD, ADDC, SUBB, MUL, and DIV instructions.  |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| 1     | 0xD1        | F1            | General-purpose flag available to the user.   |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |
| 0     | 0xD0        | P             | Parity bit. The number of bits set in the accumulator added to the value of the parity bit is always an even number.  |     |     |               |   |   |   |   |   |   |   |   |   |   |   |   |

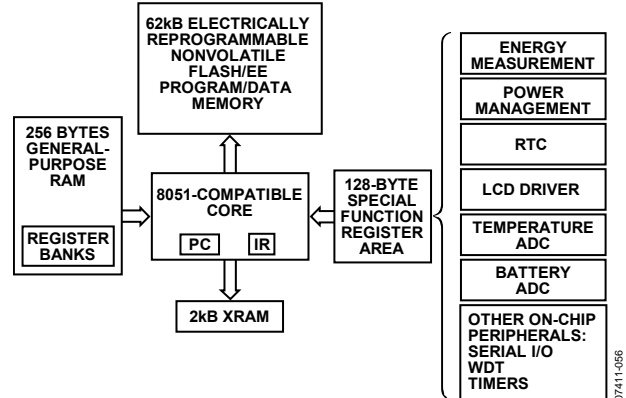


Figure 76. Block Diagram Showing Programming Model via the SFRs

# ADE5166/ADE5169

**Table 58. Program Control SFR (PCON, Address 0x87)**

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| 7     | SMOD     | 0       | Double baud rate control.                                    |
| [6:0] | Reserved | 0       | Reserved. These bits must be kept at 0 for proper operation. |

**Table 59. Data Pointer Low SFR (DPL, Address 0x82)**

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| [7:0] | DPL      | 0       | These bits contain the low byte of the data pointer. |

**Table 60. Data Pointer High SFR (DPH, Address 0x83)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | DPH      | 0       | These bits contain the high byte of the data pointer. |

**Table 61. Data Pointer SFR (DPTR, Address 0x82 and Address 0x83)**

| Bit    | Mnemonic | Default | Description   |
|--------|----------|---------|---|
| [15:0] | DP       | 0       | These bits contain the 2-byte address of the data pointer. DPTR is a combination of the DPH and DPL SFRs. |

**Table 62. Stack Pointer SFR (SP, Address 0x81)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | SP       | 0       | These bits contain the eight LSBs of the pointer for the stack. |

**Table 63. Stack Pointer High SFR (SPH, Address 0xB7)**

| Bit | Mnemonic | Default | Description   |
|-----|----------|---------|---|
| 7   | Reserved | 1       | Reserved. This bit must be set to 1 for proper operation. |
| 6   | SBFLG    | 0       | Stack bottom flag.  |
| 5   | SSA[10]  | 0       | Stack Starting Address Bit 10.                            |
| 4   | SSA[9]   | 0       | Stack Starting Address Bit 9.                             |
| 3   | SSA[8]   | 1       | Stack Starting Address Bit 8.                             |
| 2   | SP[10]   | 0       | Stack Address Bit 10.                                     |
| 1   | SP[9]    | 0       | Stack Address Bit 9.                                      |
| 0   | SP[8]    | 1       | Stack Address Bit 8.                                      |

**Table 64. Stack Boundary SFR (STCON, Address 0xBF)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:3] | WTRLIN   | 0       | Contains the stack waterline setting bits.  |
| 2     | INT_RST  | 0       | Interrupt/reset selection bit.  |
|       |          |         | <b>INT_RST</b> <b>Result</b>  |
|       |          |         | 0                    An interrupt is issued when a stack violation occurs<br>1                    A reset is issued when a stack violation occurs |
| 1     | SBE      | 0       | Stack boundary enable bit.  |
| 0     | WTRLFG   | 0       | Waterline flag.   |

**Table 65. Configuration SFR (CFG, Address 0xAF)**

| Bit | Mnemonic | Default | Description   |
|-----|----------|---------|---|
| 7   | Reserved | 1       | Reserved. This bit should be left set for proper operation.   |
| 6   | EXTEN    | 0       | Enhanced UART enable bit.   |
|     |          |         | <b>EXTEN</b> <b>Result</b>  |
|     |          |         | 0                    Standard 8052 UART without enhanced error checking features<br>1                    Enhanced UART with enhanced error checking (see the UART Additional Features section)  |
| 5   | SCPS     | 0       | Synchronous communication selection bit.  |
|     |          |         | <b>SCPS</b> <b>Result</b>   |
|     |          |         | 0                    I <sup>2</sup> C port is selected for control of the shared I <sup>2</sup> C/SPI (MOSI, MISO, SCLK, and $\overline{SS}$ ) pins and SFRs<br>1                    SPI port is selected for control of the shared I <sup>2</sup> C/SPI (MOSI, MISO, SCLK, and $\overline{SS}$ ) pins and SFRs |

| Bit   | Mnemonic        | Default | Description  |  |
|-------|-----------------|---------|--|--|
| 4     | MOD38EN         | 0       | 38 kHz modulation enable bit.                                  |  |
|       |                 |         | <b>MOD38EN</b>   | <b>Result</b>  |
|       |                 |         | 0  | 38 kHz modulation is disabled  |
|       |                 |         | 1  | 38 kHz modulation is enabled on the pins selected by the MOD38 bits in the EPCFG SFR (Address 0x9F[7:0]) |
| [3:2] | Reserved        | 00      | Reserved. These bits should be kept at 0 for proper operation. |  |
| [1:0] | XREN1,<br>XRENO | 01      | <b>XREN1, XRENO</b>  | <b>Result</b>  |
|       |                 |         | XREN1 or XRENO = 1   | Enable MOVX instruction to use 256 bytes of extended RAM   |
|       |                 |         | XREN1 and XRENO = 0  | Disable MOVX instruction   |

**BASIC 8052 REGISTERS**

**Program Counter (PC)**

The program counter holds the 2-byte address of the next instruction to be fetched. The PC is initialized with 0x00 at reset and is incremented after each instruction is performed. Note that the amount that is added to the PC depends on the number of bytes in the instruction; therefore, the increment can range from one to three bytes. The program counter is not directly accessible to the user but can be directly modified by CALL and JMP instructions that change which part of the program is active.

**Instruction Register (IR)**

The instruction register holds the opcode of the instruction being executed. The opcode is the binary code that results from assembling an instruction. This register is not directly accessible to the user.

**Register Banks**

There are four banks, each containing an 8-byte-wide register, for a total of 32 bytes of registers. These registers are convenient for temporary storage of mathematical operands. An instruction involving the accumulator and a register can be executed in one clock cycle, as opposed to two clock cycles to perform an instruction involving the accumulator and a literal or a byte of general-purpose RAM. The register banks are located in the first 32 bytes of RAM.

The active register bank is selected by the RS0 and RS1 bits in the program status word SFR (PSW, Address 0xD0).

**Accumulator**

The accumulator is a working register, storing the results of many arithmetic or logical operations. The accumulator is used in more than half of the 8052 instructions where it is usually referred to as A. The status register (PSW) constantly monitors the number of bits that are set in the accumulator to determine if it has even or odd parity. The accumulator is stored in the SFR space (see Table 56).

**B Register**

The B register is used by the multiply and divide instructions, MUL AB and DIV AB, to hold one of the operands. Because it is not used for many instructions, it can be used as a scratch pad register like those in the register banks. The B register is stored in the SFR space (see Table 56).

**Program Status Word (PSW)**

The PSW register (PSW, Address 0xD0) reflects the status of arithmetic and logical operations through carry, auxiliary carry, and overflow flags. The parity flag reflects the parity of the contents of the accumulator, which can be helpful for communication protocols. The program status word SFR is bit addressable (see Table 57).

**Data Pointer (DPTR)**

The data pointer SFR (DPTR, Address 0x82 and Address 0x83) is made up of two 8-bit registers: DPL (low byte, Address 0x82), and DPH (high byte, Address 0x83). These SFRs provide memory addresses for internal code and data access. The DPTR can be manipulated as a 16-bit register (DPTR = DPH, DPL) or as two independent 8-bit registers (DPH and DPL) (see Table 59 and Table 60).

The 8052 MCU core architecture supports dual data pointers (see the 8052 MCU Core Architecture section).

**Stack Pointer (SP)**

The stack pointer SFR (SP, Address 0x81) keeps track of the current address of the top of the stack. To push a byte of data onto the stack, the stack pointer is incremented and the data is moved to the new top of the stack. To pop a byte of data off the stack, the top byte of data is moved into the awaiting address and the stack pointer is decremented. The stack is a last in first out (LIFO) method of data storage because the most recent addition to the stack is the first to come off it.

The stack is used during CALL and RET instructions to keep track of the address to move into the PC when returning from the function call. The stack is also manipulated when vectoring for interrupts, to keep track of the prior state of the PC.

The stack resides in the upper part of the extended internal RAM. The SP bits (Bits[7:0]) in the stack pointer SFR (SP, Address 0x81) and the SP bits (Bits[2:0]) in the stack pointer high SFR (SPH, Address 0xB7) hold the address of the stack in the extended RAM. The advantage of this solution is that the use of the general-purpose RAM can be limited to data storage. The use of the extended internal RAM can be limited to the stack or, alternatively, split between the stack and data storage if more space is required. This separation limits the chance of data corruption because the stack can be contained in the upper section of the XRAM and does not overflow into the lower section containing data. Data can still be stored in extended RAM by using the MOVX command.

The default starting address for the stack is 0x100, electing the upper 1792 bytes of XRAM for the stack operation. The starting address can be reconfigured to reduce the stack by writing to the SPH[5:3] bits. These three bits set the value of the three most significant bits of the stack pointer. For example, setting the SPH[5:3] to a value of 110b moves the default starting address of the stack to 0x600, allowing the highest 512 bytes of the XRAM to be used for stack operation. If the situation occurs that the stack reaches the top of the XRAM and overflows, the stack pointer rolls over to the default starting address that is written in SPH[5:3]. Care should be taken if altering the default starting address of the stack because unwanted overwrite operations may occur, should the stack overflow or underflow.

### **Stack Boundary Protection**

As a warning signal that the stack pointer is extending outside the specified range, a stack boundary protection feature is included. This feature is controlled through the stack boundary SFR (STCON, Address 0xBF) and is disabled by default. To enable this feature, the boundary protection enable bit (SBE, Bit 1) should be set in the STCON SFR.

The stack boundary protection works in two ways to protect the remainder of the XRAM from being corrupted. The waterline detection feature monitors the top of the stack and warns the user when the stack pointer is reaching the overflow point. By setting STCON[7:3], the level of the waterline below the top of the XRAM can be set. For example, by setting STCON[7:3] to the maximum value of 0x1F, the waterline is set to its minimum value of 0x7FF - 0x1F = 0x7F0. Similarly, by setting STCON[7:3] to 0x1, the waterline is set at the top of the RAM space, Address 0x7FE. Note that if STCON[7:3] is set to 000b, the feature is effectively disabled and no interrupt or reset is generated.

The bottom of the stack is also preserved by the stack boundary feature. Should the stack pointer be written to a value lower than the default stack starting address defined in SPH[5:3], a warning is issued and the perpetrating command is ignored. The protection for both the waterline and the stack starting address are enabled simultaneously by setting SBE (Bit 1) in the STCON SFR.

When enabled, the stack boundary protection can be configured to either reset the part or trigger an interrupt when a stack violation occurs. The value of the INT\_RST bit (Bit 2) of the STCON SFR (Address 0xBF) determines the response of the part. When STCON[2] is set to 0x1 and the stack pointer exceeds the waterline, the part resets immediately, no matter what other routines are in progress. If an attempt is made to move the stack pointer below the default stack starting address when STCON[2] is high, a reset also occurs. If an interrupt response is selected, the watchdog interrupt service routine is entered, assuming that there is no higher level interrupt currently being serviced. Note that once the SBE bit (Bit 1) of the STCON SFR is enabled, an interrupt (or reset) triggers if the stack boundary is violated, regardless of the status of the EA bit (Bit 7) in the interrupt enable SFR (IE, Address 0xA8). This is because the watchdog interrupt is automatically configured as a high priority interrupt and, therefore, is not disabled by clearing EA. When the SBE bit (Bit 1) of the STCON SFR (Address 0xBF) is low, the feature is completely disabled and no pending interrupts are generated.

There are two separate flags associated with the stack boundary protection, allowing the cause of the violation to be determined. When the waterline is exceeded, a flag is set in WTRLFG (Bit 0) of the stack boundary SFR (STCON, Address 0xBF), indicating that the reset/interrupt was initiated by the stack waterline monitor. This flag remains high until the stack pointer falls below the waterline and the user clears the flag in software. A waterline or watchdog reset alone does not clear the flag. To successfully clear the flag, the software clear must occur while the stack pointer is below the waterline.

Note that the stack pointer should never be altered while in the interrupt service routine because this leads to the program returning to a different section of the program and, therefore, malfunctioning. An external reset also causes the waterline flag to reset.

When an attempt is made to move the stack pointer below the stack starting address, a flag (SBFLG, Bit 0) is set in the stack pointer high SFR (SPH, Address 0xB7), indicating that the reset/interrupt was initiated by the stack bottom monitor. Once again, a boundary or watchdog reset alone does not clear this flag, and the user must clear the flag in software to successfully acknowledge the event. Note that if SPH[5:3] and SPH[2:0] are altered simultaneously to reduce the default stack starting address, when the stack boundary condition is enabled, a stack violation condition occurs and the stack bottom flag, SPH[6], is initiated. To avoid this condition, it is recommended that the default stack starting address remain at 0x100 or be increased to further up the XRAM.

A useful implementation of the waterline feature is to determine the amount of space required for the stack and allow a suitable default starting address to be selected. This optimizes the use of the additional XRAM space, allowing it to be used for data storage. To obtain this information, the waterline should be set to the estimated stack maximum and the interrupt enabled. If the stack exceeds the estimated maximum, the interrupt triggers, and the waterline level should be increased in the interrupt service routine. Before returning to the main program, the waterline interrupt status flag (WTRLFG, Bit 0) of the stack boundary SFR (STCON, Address 0xBF) should be cleared. This program continues to jump to the waterline service routine until the stack no longer exceeds the waterline level and the maximum stack level is determined.

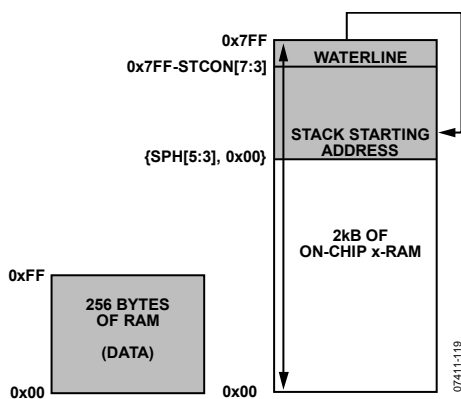


Figure 77. Extended Stack Pointer Operation

## STANDARD 8052 SFRs

The standard 8052 SFRs include the accumulator (ACC), B, PSW, DPTR, and SP SFRs, as described in the Basic 8052 Registers section. The 8052 also defines standard timers, serial port interfaces, interrupts, I/O ports, and power-down modes.

### Timer SFRs

The 8052 contains three 16-bit timers, the identical Timer 0 and Timer 1, as well as a Timer 2. These timers can also function as event counters. Timer 2 has a capture feature in which the value of the timer can be captured in two 8-bit registers upon the assertion of an external input signal (see the Timers section).

### Serial Port SFRs

The two full-duplex serial port peripherals each require two registers, one for setting up the baud rate and other communication parameters, and another byte for the transmit/receive buffer. The ADE5166/ADE5169 also provide enhanced serial port functionality with a dedicated timer for baud rate generation with a fractional divisor and additional error detection (see the UART Serial Interface section and the UART2 Serial Interface section.)

### Interrupt SFR

There is a two-tiered interrupt system standard in the 8052 core. The priority level for each interrupt source is individually selectable as high or low. The ADE5166/ADE5169 enhance this interrupt system by creating, in essence, a third interrupt tier

for a highest priority power supply management interrupt, PSM (see the Interrupt System section).

### I/O Port SFRs

The 8052 core supports four I/O ports, P0 through P3, where Port 0 and Port 2 are typically used for access to external code and data spaces. The ADE5166/ADE5169, unlike standard 8052 products, provide internal nonvolatile flash memory so that an external code space is unnecessary. The on-chip LCD driver requires many pins, some of which are dedicated for LCD functionality and others that can be configured at LCD or general-purpose I/O. Due to the limited number of I/O pins, the ADE5166/ADE5169 do not allow access to external code and data spaces.

The ADE5166/ADE5169 provide 20 pins that can be used for general-purpose I/O. These pins are mapped to Port 0, Port 1, and Port 2 and are accessed through three bit-addressable 8052 SFRs: P0, P1, and P2. Another enhanced feature of the ADE5166/ADE5169 is that the weak pull-ups standard on 8052 Port 1, Port 2, and Port 3 can be disabled to make open-drain outputs, as is standard on Port 0. The weak pull-ups can be enabled on a pin-by-pin basis (see the I/O Ports section).

### Power Control Register (PCON, Address 0x87)

The 8052 core defines two power-down modes: power-down and idle. The ADE5166/ADE5169 enhance the power control capability of the traditional 8052 MCU with additional power management functions. The POWCON register is used to define power control specific functionality for the ADE5166/ADE5169. The program control SFR (PCON, Address 0x87) is not bit addressable (see the Power Management section).

The ADE5166/ADE5169 provide many other peripherals not standard to the 8052 core, for example:

- ADE energy measurement DSP
- Full RTC
- LCD driver
- Battery switchover/power management
- Temperature ADC
- Battery ADC
- SPI/I<sup>2</sup>C communication
- Flash memory controller
- Watchdog timer
- Secondary UART port

## MEMORY OVERVIEW

The ADE5166/ADE5169 contain three memory blocks.

- 62 kB of on-chip Flash/EE program and data memory
- 256 bytes of general-purpose RAM
- 2 kB of internal extended RAM (XRAM)

The 256 bytes of general-purpose RAM share the upper 128 bytes of its address space with the SFRs. All of the memory spaces are shown in Figure 76. The addressing mode specifies which memory space to access.

## General-Purpose RAM

General-purpose RAM resides in Memory Location 0x00 through Memory Location 0xFF. It contains the register banks.

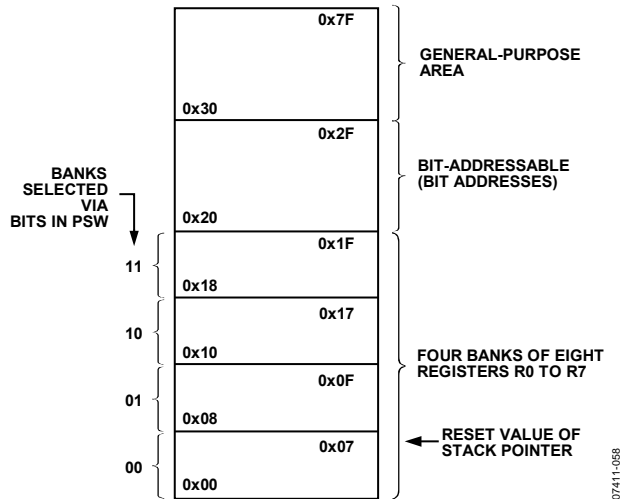


Figure 78. Lower 128 Bytes of Internal Data Memory

Address 0x80 through Address 0xFF of general-purpose RAM are shared with the SFRs. The mode of addressing determines which memory space is accessed, as shown in Figure 79.

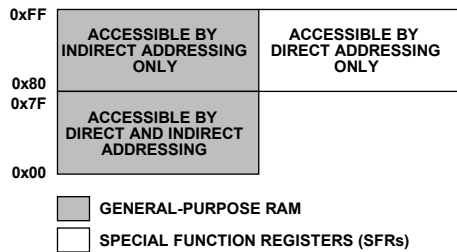


Figure 79. General-Purpose RAM and SFR Memory Address Overlap

Both direct and indirect addressing can be used to access general-purpose RAM from 0x00 through 0x7F, but indirect addressing must be used to access general-purpose RAM with addresses in the range from 0x80 through 0xFF because they share the same address space with the SFRs.

The 8052 core also has the means to access individual bits of certain addresses in the general-purpose RAM and special function memory spaces. The individual bits of general-purpose RAM, Address 0x20 to Address 0x2F, can be accessed through Bit Address 0x00 to Bit Address 0x7F. The benefit of bit addressing is that the individual bits can be accessed quickly, without the need for bit masking, which takes more code memory and execution time. The bit addresses for general-purpose RAM Address 0x20 through Address 0x2F can be seen in Figure 80.

| BYTE ADDRESS | BIT ADDRESSES (HEXA) |    |    |    |    |    |    |    |
|--------------|----------------------|----|----|----|----|----|----|----|
| 0x2F         | 7F                   | 7E | 7D | 7C | 7B | 7A | 79 | 78 |
| 0x2E         | 77                   | 76 | 75 | 74 | 73 | 72 | 71 | 70 |
| 0x2D         | 6F                   | 6E | 6D | 6C | 6B | 6A | 69 | 68 |
| 0x2C         | 67                   | 66 | 65 | 64 | 63 | 62 | 61 | 60 |
| 0x2B         | 5F                   | 5E | 5D | 5C | 5B | 5A | 59 | 58 |
| 0x2A         | 57                   | 56 | 55 | 54 | 53 | 52 | 51 | 50 |
| 0x29         | 4F                   | 4E | 4D | 4C | 4B | 4A | 49 | 48 |
| 0x28         | 47                   | 46 | 45 | 44 | 43 | 42 | 41 | 40 |
| 0x27         | 3F                   | 3E | 3D | 3C | 3B | 3A | 39 | 38 |
| 0x26         | 37                   | 36 | 35 | 34 | 33 | 32 | 31 | 30 |
| 0x25         | 2F                   | 2E | 2D | 2C | 2B | 2A | 29 | 28 |
| 0x24         | 27                   | 26 | 25 | 24 | 23 | 22 | 21 | 20 |
| 0x23         | 1F                   | 1E | 1D | 1C | 1B | 1A | 19 | 18 |
| 0x22         | 17                   | 16 | 15 | 14 | 13 | 12 | 11 | 10 |
| 0x21         | 0F                   | 0E | 0D | 0C | 0B | 0A | 09 | 08 |
| 0x20         | 07                   | 06 | 05 | 04 | 03 | 02 | 01 | 00 |

Figure 80. Bit Addressable Area of General-Purpose RAM

Bit addressing can be used for instructions that involve Boolean variable manipulation and program branching (see the Instruction Set section).

## Special Function Registers (SFRs)

Special function registers are registers that affect the function of the 8051 core or its peripherals. These registers are located in RAM at Address 0x80 through Address 0xFF. They are accessible only through direct addressing, as shown in Figure 79.

The individual bits of some of the SFRs can be accessed for use in Boolean and program branching instructions. These SFRs are labeled as bit addressable, and the bit addresses are given in Table 14.

## Extended Internal RAM (XRAM)

The ADE5166/ADE5169 provide 2 kB of extended on-chip RAM. No external RAM is supported. This RAM is located in Address 0x00 through Address 0x7FF in the extended RAM space. To select the extended RAM memory space, the extended indirect addressing modes are used.

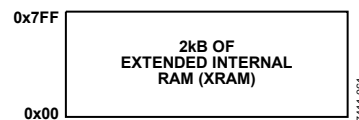


Figure 81. Extended Internal RAM (XRAM) Space

## Code Memory

Code and data memory is stored in the 62 kB flash memory space. No external code memory is supported. To access code memory, code indirect addressing is used.

## ADDRESSING MODES

The 8052 core provides several addressing modes. The addressing mode determines how the core interprets the memory location or data value specified in assembly language code. There are six addressing modes, as shown in Table 66.

**Table 66. 8052 Addressing Modes**

| Addressing Mode   | Example         | Bytes | Core Clock Cycles |
|-------------------|-----------------|-------|-------------------|
| Immediate         | MOV A, #A8h     | 2     | 2                 |
|                   | MOV DPTR, #A8h  | 3     | 3                 |
| Direct            | MOV A, A8h      | 2     | 2                 |
|                   | MOV A, IE       | 2     | 2                 |
|                   | MOV A, R0       | 1     | 1                 |
| Indirect          | MOV A, @R0      | 1     | 2                 |
| Extended Direct   | MOVX A, @DPTR   | 1     | 4                 |
| Extended Indirect | MOVX A, @R0     | 1     | 4                 |
| Code Indirect     | MOVC A, @A+DPTR | 1     | 4                 |
|                   | MOVC A, @A+PC   | 1     | 4                 |
|                   | JMP @A+DPTR     | 1     | 3                 |

### Immediate Addressing

In immediate addressing, the expression entered after the number sign (#) is evaluated by the assembler and stored in the memory address specified. This number is referred to as a literal because it refers only to a value and not to a memory location. Instructions using this addressing mode are slower than those between two registers because the literal must be stored and fetched from memory. The expression can be entered as a symbolic variable or an arithmetic expression; the value is computed by the assembler.

### Direct Addressing

With direct addressing, the value at the source address is moved to the destination address. Direct addressing provides the fastest execution time of all the addressing modes when an instruction is performed between registers using direct addressing. Note that indirect or direct addressing modes can be used to access general-purpose RAM Address 0x00 through Address 0x7F. An instruction with direct addressing that uses an address between 0x80 and 0xFF is referring to a special function memory location.

### Indirect Addressing

With indirect addressing, the value pointed to by the register is moved to the destination address. For example, to move the contents of internal RAM Address 0x82 to the accumulator, use the following two instructions, which require a total of four clock cycles and three bytes of storage in the program memory:

```
MOV    R0, #82h
MOV    A, @R0
```

Indirect addressing allows addresses to be computed and is useful for indexing into data arrays stored in RAM.

Note that an instruction that refers to Address 0x00 through Address 0x7F is referring to internal RAM, and indirect or direct addressing modes can be used. An instruction with indirect addressing that uses an address between 0x80 and 0xFF is referring to internal RAM, not to an SFR.

### Extended Direct Addressing

The DPTR register is used to access internal extended RAM in extended indirect addressing mode. The ADE5166/ADE5169 provide 2 kB of internal extended RAM (XRAM), accessed through MOVX instructions. External memory spaces are not supported on the ADE5166/ADE5169.

In extended direct addressing mode, the DPTR register points to the address of the byte of extended RAM. The following code moves the contents of extended RAM Address 0x100 to the accumulator:

```
MOV    DPTR, #100h
MOVX   A, @DPTR
```

These two instructions require a total of seven clock cycles and four bytes of storage in the program memory.

### Extended Indirect Addressing

The internal extended RAM is accessed through a pointer to the address in indirect addressing mode. The ADE5166/ADE5169 provide 2 kB of internal extended RAM, accessed through MOVX instructions. External memory is not supported on the ADE5166/ADE5169.

In extended indirect addressing mode, a register holds the address of the byte of extended RAM. The following code moves the contents of extended RAM Address 0x80 to the accumulator:

```
MOV    R0, #80h
MOVX   A, @R0
```

These two instructions require six clock cycles and three bytes of storage.

Note that there are 2 kB of extended RAM, so both extended direct and extended indirect addressing can cover the whole address range. There is a storage and speed advantage to using extended indirect addressing because the additional byte of addressing available through the DPTR register that is not needed is not stored.

From the three examples demonstrating the access of internal RAM from 0x80 through 0xFF and extended internal RAM from 0x00 through 0xFF, it can be seen that it is most efficient to use the entire internal RAM accessible through indirect access before moving to extended RAM.

### Code Indirect Addressing

The internal code memory can be accessed indirectly. This can be useful for implementing lookup tables and other arrays of constants that are stored in flash memory. For example, to move the data stored in flash memory at Address 0x8002 into the accumulator,

```
MOV    DPTR, #8002h
CLR    A
MOVX   A, @A+DPTR
```

The accumulator can be used as a variable index into the array of flash memory located at DPTR.

# ADE5166/ADE5169

## INSTRUCTION SET

Table 67 documents the number of clock cycles required for each instruction. Most instructions are executed in one or two clock cycles, resulting in a 4-MIPS peak performance. Note that, throughout this section, A represents the accumulator.

**Table 67. Instruction Set**

| Mnemonic          | Description                                 | Bytes | Cycles |
|-------------------|---|-------|--------|
| <b>Arithmetic</b> |   |       |        |
| ADD A, Rn         | Add register to A                           | 1     | 1      |
| ADD A, @Ri        | Add indirect memory to A                    | 1     | 2      |
| ADD A, dir        | Add direct byte to A                        | 2     | 2      |
| ADD A, #data      | Add Immediate to A                          | 2     | 2      |
| ADDC A, Rn 1 1    | Add register to A with carry                | 1     | 1      |
| ADDC A, @Ri       | Add indirect memory to A with carry         | 1     | 2      |
| ADDC A, dir       | Add direct byte to A with carry             | 2     | 2      |
| ADDC A, #data     | Add immediate to A with carry               | 2     | 2      |
| SUBB A, Rn        | Subtract register from A with borrow        | 1     | 1      |
| SUBB A, @Ri       | Subtract indirect memory from A with borrow | 1     | 2      |
| SUBB A, dir       | Subtract direct from A with borrow          | 2     | 2      |
| SUBB A, #data     | Subtract immediate from A with borrow       | 2     | 2      |
| INC A             | Increment A                                 | 1     | 1      |
| INC Rn            | Increment register                          | 1     | 1      |
| INC @             | Ri increment indirect memory                | 1     | 2      |
| INC dir           | Increment direct byte                       | 2     | 2      |
| INC DPTR          | Increment data pointer                      | 1     | 3      |
| DEC A             | Decrement A                                 | 1     | 1      |
| DEC Rn            | Decrement register                          | 1     | 1      |
| DEC @Ri           | Decrement indirect memory                   | 1     | 2      |
| DEC dir           | Decrement direct byte                       | 2     | 2      |
| MUL AB            | Multiply A by B                             | 1     | 9      |
| DIV AB            | Divide A by B                               | 1     | 9      |
| DA A              | Decimal Adjust A                            | 1     | 2      |
| <b>Logic</b>      |   |       |        |
| ANL A, Rn         | AND register to A                           | 1     | 1      |
| ANL A, @Ri        | AND indirect memory to A                    | 1     | 2      |
| ANL A, dir        | AND direct byte to A                        | 2     | 2      |
| ANL A, #data      | AND immediate to A                          | 2     | 2      |
| ANL dir, A        | AND A to direct byte                        | 2     | 2      |
| ANL dir, #data    | AND immediate data to direct byte           | 3     | 3      |
| ORL A, Rn         | OR register to A                            | 1     | 1      |
| ORL A, @Ri        | OR indirect memory to A                     | 1     | 2      |
| ORL A, dir        | OR direct byte to A                         | 2     | 2      |
| ORL A, #data      | OR immediate to A                           | 2     | 2      |
| ORL dir, A        | OR A to direct byte                         | 2     | 2      |
| ORL dir, #data    | OR immediate data to direct byte            | 3     | 3      |
| XRL A, Rn         | Exclusive-OR register to A                  | 1     | 1      |
| XRL A, @Ri        | Exclusive-OR indirect memory to A           | 2     | 2      |
| XRL A, #data      | Exclusive-OR immediate to A                 | 2     | 2      |
| XRL dir, A        | Exclusive-OR A to direct byte               | 2     | 2      |
| XRL A, dir        | Exclusive-OR indirect memory to A           | 2     | 2      |
| XRL dir, #data    | Exclusive-OR immediate data to direct       | 3     | 3      |
| CLR A             | Clear A                                     | 1     | 1      |
| CPL A             | Complement A                                | 1     | 1      |
| SWAP A            | Swap nibbles of A                           | 1     | 1      |
| RL A              | Rotate A left                               | 1     | 1      |



| Mnemonic             | Description                           | Bytes | Cycles |
|----------------------|---------------------------------------|-------|--------|
| RLC A                | Rotate A left through carry           | 1     | 1      |
| RR A                 | Rotate A right                        | 1     | 1      |
| RRC A                | Rotate A right through carry          | 1     | 1      |
| <b>Data Transfer</b> |                                       |       |        |
| MOV A, Rn            | Move register to A                    | 1     | 1      |
| MOV A, @Ri           | Move indirect memory to A             | 1     | 2      |
| MOV Rn, A            | Move A to register                    | 1     | 1      |
| MOV @Ri, A           | Move A to indirect memory             | 1     | 2      |
| MOV A, dir           | Move direct byte to A                 | 2     | 2      |
| MOV A, #data         | Move immediate to A                   | 2     | 2      |
| MOV Rn, #data        | Move register to immediate            | 2     | 2      |
| MOV dir, A           | Move A to direct byte                 | 2     | 2      |
| MOV Rn, dir          | Move register to direct byte          | 2     | 2      |
| MOV dir, Rn          | Move direct to register               | 2     | 2      |
| MOV @Ri, #data       | Move immediate to indirect memory     | 2     | 2      |
| MOV dir, @Ri         | Move indirect to direct memory        | 2     | 2      |
| MOV @Ri, dir         | Move direct to indirect memory        | 2     | 2      |
| MOV dir, dir         | Move direct byte to direct byte       | 3     | 3      |
| MOV dir, #data       | Move immediate to direct byte         | 3     | 3      |
| MOV DPTR, #data      | Move immediate to data pointer        | 3     | 3      |
| MOVC A, @A+DPTR      | Move code byte relative DPTR to A     | 1     | 4      |
| MOVC A, @A+PC        | Move code byte relative PC to A       | 1     | 4      |
| MOVX A, @Ri          | Move external (A8) data to A          | 1     | 4      |
| MOVX A, @DPTR        | Move external (A16) data to A         | 1     | 4      |
| MOVX @Ri, A          | Move A to external data (A8)          | 1     | 4      |
| MOVX @DPTR, A        | Move A to external data (A16)         | 1     | 4      |
| PUSH dir             | Push direct byte onto stack           | 2     | 2      |
| POP dir              | Pop direct byte from stack            | 2     | 2      |
| XCH A, Rn            | Exchange A and register               | 1     | 1      |
| XCH A, @Ri           | Exchange A and indirect memory        | 1     | 2      |
| XCHD A, @Ri          | Exchange A and indirect memory nibble | 1     | 2      |
| XCH A, dir           | Exchange A and direct byte            | 2     | 2      |
| <b>Boolean</b>       |                                       |       |        |
| CLR C                | Clear carry                           | 1     | 1      |
| CLR bit              | Clear direct bit                      | 2     | 2      |
| SETB C               | Set carry                             | 1     | 1      |
| SETB bit             | Set direct bit                        | 2     | 2      |
| CPL C                | Complement carry                      | 1     | 1      |
| CPL bit              | Complement direct bit                 | 2     | 2      |
| ANL C, bit           | AND direct bit and carry              | 2     | 2      |
| ANL C, /bit          | AND direct bit inverse to carry       | 2     | 2      |
| ORL C, bit           | OR direct bit and carry               | 2     | 2      |
| ORL C, /bit OR       | Direct bit inverse to carry           | 2     | 2      |
| MOV C, bit           | Move direct bit to carry              | 2     | 2      |
| MOV bit, C           | Move carry to direct bit              | 2     | 2      |
| <b>Branching</b>     |                                       |       |        |
| JMP @A+DPTR          | Jump indirect relative to DPTR        | 1     | 3      |
| RET                  | Return from subroutine                | 1     | 4      |
| RETI                 | Return from interrupt                 | 1     | 4      |
| ACALL addr11         | Absolute jump to subroutine           | 2     | 3      |
| AJMP addr11          | Absolute jump unconditional           | 2     | 3      |
| SJMP rel             | Short jump (relative address)         | 2     | 3      |
| JC rel               | Jump on carry equal to 1              | 2     | 3      |

# ADE5166/ADE5169

| Mnemonic             | Description                              | Bytes | Cycles |
|----------------------|--|-------|--------|
| JNC rel              | Jump on carry = 0                        | 2     | 3      |
| JZ rel               | Jump on accumulator = 0                  | 2     | 3      |
| JNZ rel              | Jump on accumulator ≠ 0                  | 2     | 3      |
| DJNZ Rn, rel         | Decrement register, JNZ relative         | 2     | 3      |
| LJMP                 | Long jump unconditional                  | 3     | 4      |
| LCALL addr16         | Long jump to subroutine                  | 3     | 4      |
| JB bit, rel          | Jump on direct bit = 1                   | 3     | 4      |
| JNB bit, rel         | Jump on direct bit = 0                   | 3     | 4      |
| JBC bit, rel         | Jump on direct bit = 1 and clear         | 3     | 4      |
| CJNE A, dir, rel     | Compare A, direct JNE relative           | 3     | 4      |
| CJNE A, #data, rel   | Compare A, immediate JNE relative        | 3     | 4      |
| CJNE Rn, #data, rel  | Compare register, immediate JNE relative | 3     | 4      |
| CJNE @Ri, #data, rel | Compare indirect, immediate JNE relative | 3     | 4      |
| DJNZ dir, rel        | Decrement direct byte, JNZ relative      | 3     | 4      |
| Miscellaneous<br>NOP | No operation                             | 1     | 1      |

## READ-MODIFY-WRITE INSTRUCTIONS

Some 8052 instructions read the latch and others read the pin. The state of the pin is read for instructions that input a port bit. Instructions that read the latch rather than the pins are the ones that read a value, possibly change it, and rewrite it to the latch. Because these instructions involve modifying the port, it is assumed that the pins being modified are outputs, so the output state of the pin is read from the latch. This prevents a possible misinterpretation of the voltage level of a pin. For example, if a port pin is used to drive the base of a transistor, a 1 is written to the bit to turn on the transistor. If the CPU reads the same port bit at the pin rather than the latch, it reads the base voltage of the transistor and interprets it as Logic 0. Reading the latch rather than the pin returns the correct value of 1.

The instructions that read the latch rather than the pins are called read-modify-write instructions and are listed in Table 68. When the destination operand is a port or a port bit, these instructions read the latch rather than the pin.

**Table 68. Read-Modify-Write Instructions**

| Instruction              | Example         | Description                    |
|--------------------------|-----------------|--------------------------------|
| ANL                      | ANL P0, A       | Logic AND                      |
| ORL                      | ORL P1, A       | Logic OR                       |
| XRL                      | XRL P2, A       | Logic XOR                      |
| JBC                      | JBC P1.1, LABEL | Jump if Bit = 1 and clear bit  |
| CPL                      | CPL P2.0        | Complement bit                 |
| INC                      | INC P2          | Increment                      |
| DEC                      | DEC P2          | Decrement                      |
| DJNZ                     | DJNZ P0, LABEL  | Decrement and jump if not zero |
| MOV PX.Y, C <sup>1</sup> | MOV P0.0, C     | Move carry to Bit Y of Port X  |
| CLR PX.Y <sup>1</sup>    | CLR P0.0        | Clear Bit Y of Port X          |
| SETB PX.Y <sup>1</sup>   | SETB P0.0       | Set Bit Y of Port X            |

<sup>1</sup>These instructions read the port byte (all eight bits), modify the addressed bit, and write the new byte back to the latch.

## INSTRUCTIONS THAT AFFECT FLAGS

Many instructions explicitly modify the carry bit, such as the MOV C bit and CLR C instructions. Other instructions that affect status flags are listed in this section.

### ADD A, Source

This instruction adds the source to the accumulator. No status flags are referenced by the instruction.

**Table 69. ADD A (Source) Affected Status Flags**

| Flag | Description   |
|------|---|
| C    | Set if there is a carry out of Bit 7. Cleared otherwise. Used to indicate an overflow if the operands are unsigned.   |
| OV   | Set if there is a carry out of Bit 6 or a carry out of Bit 7, but not if both are set. Used to indicate an overflow for signed addition. This flag is set if two positive operands yield a negative result or if two negative operands yield a positive result. |
| AC   | Set if there is a carry out of Bit 3. Cleared otherwise.  |

### ADDC A, Source

This instruction adds the source and the carry bit to the accumulator. The carry status flag is referenced by the instruction.

**Table 70. ADDC A (Source) Affected Status Flags**

| Flag | Description   |
|------|---|
| C    | Set if there is a carry out of Bit 7. Cleared otherwise. Used to indicate an overflow if the operands are unsigned.   |
| OV   | Set if there is a carry out of Bit 6 or a carry out of Bit 7, but not if both are set. Used to indicate an overflow for signed addition. This flag is set if two positive operands yield a negative result or if two negative operands yield a positive result. |
| AC   | Set if there is a carry out of Bit 3. Cleared otherwise.  |

**SUBB A, Source**

This instruction subtracts the source byte and the carry (borrow) flag from the accumulator. It references the carry (borrow) status flag.

**Table 71. SUBB A (Source) Affected Status Flags**

| Flag | Description  |
|------|--|
| C    | Set if there is a borrow needed for Bit 7. Cleared otherwise. Used to indicate an overflow if the operands are unsigned.   |
| OV   | Set if there is a borrow needed for Bit 6 or Bit 7, but not for both. Used to indicate an overflow for signed subtraction. This flag is set if a negative number subtracted from a positive yields a negative result or if a positive number subtracted from a negative number yields a positive result. |
| AC   | Set if a borrow is needed for Bit 3. Cleared otherwise.  |

**MUL AB**

This instruction multiplies the accumulator by the B SFR. This operation is unsigned. The lower byte of the 16-bit product is stored in the accumulator and the higher byte is left in the B register. No status flags are referenced by the instruction.

**Table 72. MUL AB Affected Status Flags**

| Flag | Description   |
|------|---|
| C    | Cleared   |
| OV   | Set if the result is greater than 255. Cleared otherwise. |

**DIV AB**

This instruction divides the accumulator by the B SFR. This operation is unsigned. The integer part of the quotient is stored in the accumulator and the remainder goes into the B register. No status flags are referenced by the instruction.

**Table 73. DIV AB Affected Status Flags**

| Flag | Description  |
|------|--|
| C    | Cleared  |
| OV   | Cleared unless the B register is equal to 0, in which case the results of the division are undefined and the OV flag is set. |

**DA A**

This instruction adjusts the accumulator to hold two 4-bit digits after the addition of two binary coded decimals (BCDs) with the ADD or ADDC instructions. If the AC bit is set or if the value of Bit 0 to Bit 3 exceeds 9, 0x06 is added to the accumulator

to correct the lower four bits. If the carry bit is set when the instruction begins, or if 0x06 is added to the accumulator in the first step, 0x60 is added to the accumulator to correct the higher four bits.

The carry and AC status flags are referenced by this instruction.

**Table 74. DA A Affected Status Flag**

| Flag | Description  |
|------|--|
| C    | Set if the result is greater than 0x99. Cleared otherwise. |

**RRC A**

This instruction rotates the accumulator to the right through the carry flag. The old LSB of the accumulator becomes the new carry flag, and the old carry flag is loaded into the new MSB of the accumulator.

The carry status flag is referenced by this instruction.

**Table 75. RRC A Affected Status Flag**

| Flag | Description   |
|------|---|
| C    | Equal to the state of ACC[0] before execution of the instruction. |

**RLC A**

This instruction rotates the accumulator to the left through the carry flag. The old MSB of the accumulator becomes the new carry flag, and the old carry flag is loaded into the new LSB of the accumulator.

The carry status flag is referenced by this instruction.

**Table 76. RLC A Affected Status Flag**

| Flag | Description   |
|------|---|
| C    | Equal to the state of ACC[7] before execution of the instruction. |

**CJNE Destination, Source, Relative Jump**

This instruction compares the source value to the destination value and branches to the location set by the relative jump if they are not equal. If the values are equal, program execution continues with the instruction after the CJNE instruction.

No status flags are referenced by this instruction.

**Table 77. CJNE Destination (Source, Relative Jump) Affected Status Flag**

| Flag | Description   |
|------|---|
| C    | Set if the source value is greater than the destination value. Cleared otherwise. |

## DUAL DATA POINTERS

Each ADE5166/ADE5169 incorporates two data pointers. The second data pointer is a shadow data pointer and is selected via the data pointer control SFR (DPCON, Address 0xA7). DPCON features automatic hardware postincrement and postdecrement, as well as an automatic data pointer toggle.

Note that this is the only section of the data sheet where the main and shadow data pointers are distinguished. Whenever the data pointer (DPTR) is mentioned elsewhere in the data sheet, active DPTR is implied.

In addition, only the MOVX/MOVC @DPTR instructions automatically postincrement and postdecrement the DPTR. Other MOVX/MOVC instructions, such as MOVX PC or MOVX @Ri, do not cause the DPTR to automatically postincrement and postdecrement.

To illustrate the operation of DPCON, the following code copies 256 bytes of code memory at Address 0xD000 into XRAM, starting from Address 0x0000:

```

MOV DPTR,#0          ;Main DPTR = 0
MOV DPCON,#55H      ;Select shadow DPTR
                    ;DPTR1 increment mode
                    ;DPTR0 increment mode
                    ;DPTR auto toggling ON
MOV DPTR,#0D000H    ;DPTR = D000H
MOVELOOP: CLR A
MOVX A,@A+DPTR      ;Get data
                    ;Post Inc DPTR
                    ;Swap to Main DPTR(Data)
                    MOVX @DPTR,A      ;Put ACC in XRAM
                    ;Increment main DPTR
                    ;Swap Shadow DPTR(Code)
MOV A, DPL
JNZ MOVELOOP
    
```

**Table 78. Data Pointer Control SFR (DPCON, Address 0xA7)**

| Bit   | Mnemonic        | Default  | Description  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
|-------|-----------------|--|--|-------|-------|--|---|---|----------------|---|---|---|---|---|---|---|---|--|
| 7     |                 | 0  | Not implemented. Write don't care.   |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 6     | DPT             | 0  | Data pointer automatic toggle enable. Cleared by the user to disable autoswapping of the DPTR. Set in user software to enable automatic toggling of the DPTR after each MOVX or MOVC instruction.  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| [5:4] | DP1m1,<br>DP1m0 | 0  | Shadow data pointer mode. These bits enable extra modes of the shadow data pointer operation, allowing more compact and more efficient code size and execution. <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>DP1m1</th> <th>DP1m0</th> <th>Result (Behavior of the Shadow Data Pointer)</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>8052 behavior.</td> </tr> <tr> <td>0</td> <td>1</td> <td>DPTR is postincremented after a MOVX or a MOVC instruction.</td> </tr> <tr> <td>1</td> <td>0</td> <td>DPTR is postdecremented after a MOVX or MOVC instruction.</td> </tr> <tr> <td>1</td> <td>1</td> <td>DPTR LSB is toggled after a MOVX or MOVC instruction. This instruction can be useful for moving 8-bit blocks to/from 16-bit devices.</td> </tr> </tbody> </table> | DP1m1 | DP1m0 | Result (Behavior of the Shadow Data Pointer) | 0 | 0 | 8052 behavior. | 0 | 1 | DPTR is postincremented after a MOVX or a MOVC instruction. | 1 | 0 | DPTR is postdecremented after a MOVX or MOVC instruction. | 1 | 1 | DPTR LSB is toggled after a MOVX or MOVC instruction. This instruction can be useful for moving 8-bit blocks to/from 16-bit devices. |
| DP1m1 | DP1m0           | Result (Behavior of the Shadow Data Pointer)   |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 0     | 0               | 8052 behavior.   |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 0     | 1               | DPTR is postincremented after a MOVX or a MOVC instruction.  |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 1     | 0               | DPTR is postdecremented after a MOVX or MOVC instruction.  |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 1     | 1               | DPTR LSB is toggled after a MOVX or MOVC instruction. This instruction can be useful for moving 8-bit blocks to/from 16-bit devices. |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| [3:2] | DP0m1,<br>DP0m0 | 0  | Main data pointer mode. These bits enable extra modes of the main data pointer operation, allowing more compact and more efficient code size and execution. <table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>DP0m1</th> <th>DP0m0</th> <th>Result (Behavior of the Main Data Pointer)</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>0</td> <td>8052 behavior.</td> </tr> <tr> <td>0</td> <td>1</td> <td>DPTR is postincremented after a MOVX or a MOVC instruction.</td> </tr> <tr> <td>1</td> <td>0</td> <td>DPTR is postdecremented after a MOVX or MOVC instruction.</td> </tr> <tr> <td>1</td> <td>1</td> <td>DPTR LSB is toggled after a MOVX or MOVC instruction. This instruction is useful for moving 8-bit blocks to/from 16-bit devices.</td> </tr> </tbody> </table>           | DP0m1 | DP0m0 | Result (Behavior of the Main Data Pointer)   | 0 | 0 | 8052 behavior. | 0 | 1 | DPTR is postincremented after a MOVX or a MOVC instruction. | 1 | 0 | DPTR is postdecremented after a MOVX or MOVC instruction. | 1 | 1 | DPTR LSB is toggled after a MOVX or MOVC instruction. This instruction is useful for moving 8-bit blocks to/from 16-bit devices.     |
| DP0m1 | DP0m0           | Result (Behavior of the Main Data Pointer)   |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 0     | 0               | 8052 behavior.   |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 0     | 1               | DPTR is postincremented after a MOVX or a MOVC instruction.  |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 1     | 0               | DPTR is postdecremented after a MOVX or MOVC instruction.  |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 1     | 1               | DPTR LSB is toggled after a MOVX or MOVC instruction. This instruction is useful for moving 8-bit blocks to/from 16-bit devices.     |  |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 1     |                 | 0  | Not implemented. Write don't care.   |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |
| 0     | DPSEL           | 0  | Data pointer select. Cleared by the user to select the main data pointer, meaning that the contents of this 16-bit register are placed into the DPL SFR and DPH SFR. Set by the user to select the shadow data pointer, meaning that the contents of a separate 16-bit register appear in the DPL SFR and DPH SFR.   |       |       |  |   |   |                |   |   |   |   |   |   |   |   |  |

## INTERRUPT SYSTEM

The unique power management architecture of the ADE5166/ADE5169 includes an operating mode (PSM2) where the 8052 MCU core is shut down. Events can be configured to wake the 8052 MCU core from the PSM2 operating mode. A distinction is drawn here between events that can trigger the wake-up of the 8052 MCU core and events that can trigger an interrupt when the MCU core is active. Events that can wake the core are referred to as wake-up events, whereas events that can interrupt the program flow when the MCU is active are called interrupts. See the 3.3 V Peripherals and Wake-Up Events section to learn more about events that can wake the 8052 core from PSM2 mode.

The ADE5166/ADE5169 provide 12 interrupt sources with three priority levels. The power management interrupt is at the highest priority level. The other two priority levels are configurable through the interrupt priority SFR (IP, Address 0xB8) and interrupt enable and Priority 2 SFR (IEIP2, Address 0xA9).

### STANDARD 8052 INTERRUPT ARCHITECTURE

The 8052 standard interrupt architecture includes two tiers of interrupts, where some interrupts are assigned a high priority and others are assigned a low priority.

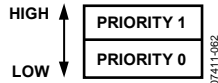


Figure 82. Standard 8052 Interrupt Priority Levels

A Priority 1 interrupt can interrupt the service routine of a Priority 0 interrupt, and if two interrupts of different priorities

Table 79. Interrupt SFRs

| SFR   | Address | Default | Bit Addressable | Description  |
|-------|---------|---------|-----------------|--|
| IE    | 0xA8    | 0x00    | Yes             | Interrupt enable (see Table 80).   |
| IP    | 0xB8    | 0x00    | Yes             | Interrupt priority (see Table 81).   |
| IEIP2 | 0xA9    | 0xA0    | No              | Interrupt enable and Priority 2 (see Table 82).  |
| WDCON | 0xC0    | 0x10    | Yes             | Watchdog timer (see Table 87 and the Writing to the Watchdog Timer SFR (WDCON, Address 0xC0) section). |

Table 80. Interrupt Enable SFR (IE, Address 0xA8)

| Bit | Bit Address | Mnemonic | Description   |
|-----|-------------|----------|---|
| 7   | 0xAF        | EA       | Enables all interrupt sources. Set by the user. Cleared by the user to disable all interrupt sources. |
| 6   | 0xAE        | ETEMP    | Enables the temperature ADC interrupt. Set by the user.   |
| 5   | 0xAD        | ET2      | Enables the Timer 2 interrupt. Set by the user.   |
| 4   | 0xAC        | ES       | Enables the UART serial port interrupt. Set by the user.  |
| 3   | 0xAB        | ET1      | Enables the Timer 1 interrupt. Set by the user.   |
| 2   | 0xAA        | EX1      | Enables the External Interrupt 1 ( $\overline{INT1}$ ). Set by the user.                              |
| 1   | 0xA9        | ET0      | Enables the Timer 0 interrupt. Set by the user.   |
| 0   | 0xA8        | EX0      | Enables External Interrupt 0 ( $\overline{INT0}$ ). Set by the user.                                  |

occur at the same time, the Priority 1 interrupt is serviced first. An interrupt cannot be interrupted by another interrupt of the same priority level. If two interrupts of the same priority level occur simultaneously, a polling sequence is observed (see the Interrupt Priority section).

### INTERRUPT ARCHITECTURE

The ADE5166/ADE5169 possess advanced power supply management features. To ensure a fast response to time-critical power supply issues, such as a loss of line power, the power supply management interrupt should be able to interrupt any interrupt service routine. To enable the user to have full use of the standard 8052 interrupt priority levels, an additional priority level is added for the power supply management (PSM) interrupt. The PSM interrupt is the only interrupt at this highest interrupt priority level.

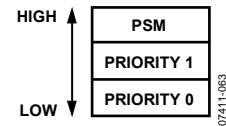


Figure 83. Interrupt Architecture

See the Power Supply Management (PSM) Interrupt section for more information on the PSM interrupt.

### INTERRUPT REGISTERS

The control and configuration of the interrupt system are carried out through four interrupt-related SFRs, discussed in this section.

# ADE5166/ADE5169

**Table 81. Interrupt Priority SFR (IP, Address 0xB8)**

| Bit | Bit Address | Mnemonic | Description   |
|-----|-------------|----------|---|
| 7   | 0xBF        | PADE     | ADE energy measurement interrupt priority (1 = high, 0 = low).                |
| 6   | 0xBE        | PTEMP    | Temperature ADC interrupt priority (1 = high, 0 = low).                       |
| 5   | 0xBD        | PT2      | Timer 2 interrupt priority (1 = high, 0 = low).                               |
| 4   | 0xBC        | PS       | UART serial port interrupt priority (1 = high, 0 = low).                      |
| 3   | 0xBB        | PT1      | Timer 1 interrupt priority (1 = high, 0 = low).                               |
| 2   | 0xBA        | PX1      | $\overline{\text{INT1}}$ (External Interrupt 1) priority (1 = high, 0 = low). |
| 1   | 0xB9        | PT0      | Timer 0 interrupt priority (1 = high, 0 = low).                               |
| 0   | 0xB8        | PX0      | $\overline{\text{INT0}}$ (External Interrupt 0) priority (1 = high, 0 = low). |

**Table 82. Interrupt Enable and Priority 2 SFR (IEIP2, Address 0xA9)**

| Bit | Mnemonic | Description   |
|-----|----------|---|
| 7   | PS2      | UART2 serial port interrupt priority (1 = high, 0 = low).           |
| 6   | PTI      | RTC interrupt priority (1 = high, 0 = low).                         |
| 5   | ES2      | Enables the UART2 serial port interrupt. Set by the user.           |
| 4   | PSI      | SPI/I <sup>2</sup> C interrupt priority (1 = high, 0 = low).        |
| 3   | EADE     | Enables the energy metering interrupt (ADE). Set by the user.       |
| 2   | ETI      | Enables the RTC interval timer interrupt. Set by the user.          |
| 1   | EPSM     | Enables the PSM power supply management interrupt. Set by the user. |
| 0   | ESI      | Enables the SPI/I <sup>2</sup> C interrupt. Set by the user.        |

## INTERRUPT PRIORITY

If two interrupts of the same priority level occur simultaneously, the polling sequence is observed (as shown in Table 83).

**Table 83. Priority Within Interrupt Level**

| Source                 | Priority    | Description                        |
|------------------------|-------------|------------------------------------|
| IPSM                   | 0 (highest) | Power supply management interrupt. |
| IRTC                   | 1           | RTC interval timer interrupt.      |
| IADE                   | 2           | ADE energy measurement interrupt.  |
| WDT                    | 3           | Watchdog timer overflow interrupt. |
| ITEMP                  | 4           | Temperature ADC interrupt.         |
| IE0                    | 5           | External Interrupt 0.              |
| TF0                    | 6           | Timer/Counter 0 interrupt.         |
| IE1                    | 7           | External Interrupt 1.              |
| TF1                    | 8           | Timer/Counter 1 interrupt.         |
| ISPI/I <sup>2</sup> CI | 9           | SPI/I <sup>2</sup> C interrupt.    |
| RI/TI                  | 10          | UART serial port interrupt.        |
| TF2/EXF2               | 11          | Timer/Counter 2 interrupt.         |
| RI2/TI2                | 12 (lowest) | UART2 serial port interrupt.       |

## INTERRUPT FLAGS

The interrupt flags and status flags associated with the interrupt vectors are shown in Table 84 and Table 85, respectively. Most of the interrupts have flags associated with them.

**Table 84. Interrupt Flags**

| Interrupt Source              | Flag      | Bit Name   | Description  |
|-------------------------------|-----------|------------|--|
| IE0                           | TCON.1    | IE0        | External Interrupt 0.  |
| TF0                           | TCON.5    | TF0        | Timer 0.   |
| IE1                           | TCON.3    | IE1        | External Interrupt 1.  |
| TF1                           | TCON.7    | TF1        | Timer 1.   |
| RI + TI                       | SCON.1    | TI         | Transmit interrupt.  |
|                               | SCON.0    | RI         | Receive interrupt.   |
| RI2 + TI2                     | SCON2.1   | TI2        | Transmit 2 interrupt   |
|                               | SCON2.0   | RI2        | Receive 2 interrupt  |
| TF2 + EXF2                    | T2CON.7   | TF2        | Timer 2 overflow flag.   |
|                               | T2CON.6   | EXF2       | Timer 2 external flag.   |
| ITEMP (Temperature ADC)       | N/A       | N/A        | Temperature ADC interrupt. Does not have an interrupt flag associated with it. |
| IPSM (Power Supply)           | IPSMF.6   | FPSM       | PSM interrupt flag.  |
| IADE (Energy Measurement DSP) | MIRQSTL.7 | ADEIRQFLAG | Read MIRQSTH, MIRQSTM, MIRQSTL.  |

**Table 85. Status Flags**

| Interrupt Source          | Flag                   | Bit Address | Description  |
|---------------------------|------------------------|-------------|--|
| ITEMP (Temperature ADC)   | N/A                    | N/A         | Temperature ADC interrupt. Does not have a status flag associated with it. |
| ISPI/I2CI                 | SPI2CSTAT <sup>1</sup> | N/A         | SPI interrupt status register.   |
|                           | SPI2CSTAT              | N/A         | I <sup>2</sup> C interrupt status register.                                |
| IRTC (RTC Interval Timer) | TIMECON.6              | ALFLAG      | RTC alarm flag.  |
|                           | TIMECON.2              | ITFLAG      | RTC interrupt flag.  |
| WDT (Watchdog Timer)      | WDCON.2                | WDS         | Watchdog timeout flag.   |

<sup>1</sup> There is no specific flag for ISPI/I2CI; however, all flags for SPI2CSTAT need to be read to assess the reason for the interrupt.

A functional block diagram of the interrupt system is shown in Figure 84. Note that the PSM interrupt is the only interrupt in the highest priority level.

If an external wake-up event occurs to wake the ADE5166/ADE5169 from PSM2 mode, a pending external interrupt is generated. When the EX0 bit (Bit 0) or the EX1 bit (Bit2) in the interrupt enable SFR (IE, Address 0xA8) is set to enable external interrupts, the program counter is loaded with the IE0 or IE1 interrupt vector. The IE0 and IE1 interrupt flags (Bit 1 and Bit 3, respectively) in the Timer/Counter 0 and Timer/Counter 1 control SFR (TCON, Address 0x88) are not affected by events that occur when the 8052 MCU core is shut down during PSM2 mode (see the Power Supply Management (PSM) Interrupt section).

The temperature ADC and I<sup>2</sup>C/SPI interrupts are latched such that pending interrupts cannot be cleared without entering their respective interrupt service routines. Clearing the I<sup>2</sup>C/SPI status bits in the SPI interrupt status SFR (SPISTAT, Address 0xEA) does not cancel a pending I<sup>2</sup>C/SPI interrupt. These interrupts

remain pending until the I<sup>2</sup>C/SPI interrupt vectors are enabled. Their respective interrupt service routines are entered shortly thereafter.

The RTC interrupts are driven by the alarm and interval flags. Pending RTC interrupts can be cleared without entering the interrupt service routine, by clearing the corresponding RTC flag in software. Entering the interrupt service routine alone does not clear the RTC interrupt.

Figure 84 shows how the interrupts are cleared when the interrupt service routines are entered. Some interrupts with multiple interrupt sources are not automatically cleared; specifically, the PSM, ADE, UART, UART2 and Timer 2 interrupt vectors. Note that the INT0 and INT1 interrupts are cleared only if the external interrupt is configured to be triggered by a falling edge by setting IT0 (Bit 0) in the Timer/Counter 0 and Timer/Counter 1 control SFR (TCON, Address 0x88). If INT0 or INT1 is configured to interrupt on a low level, the interrupt service routine is reentered until the respective pin goes high.

# ADE5166/ADE5169

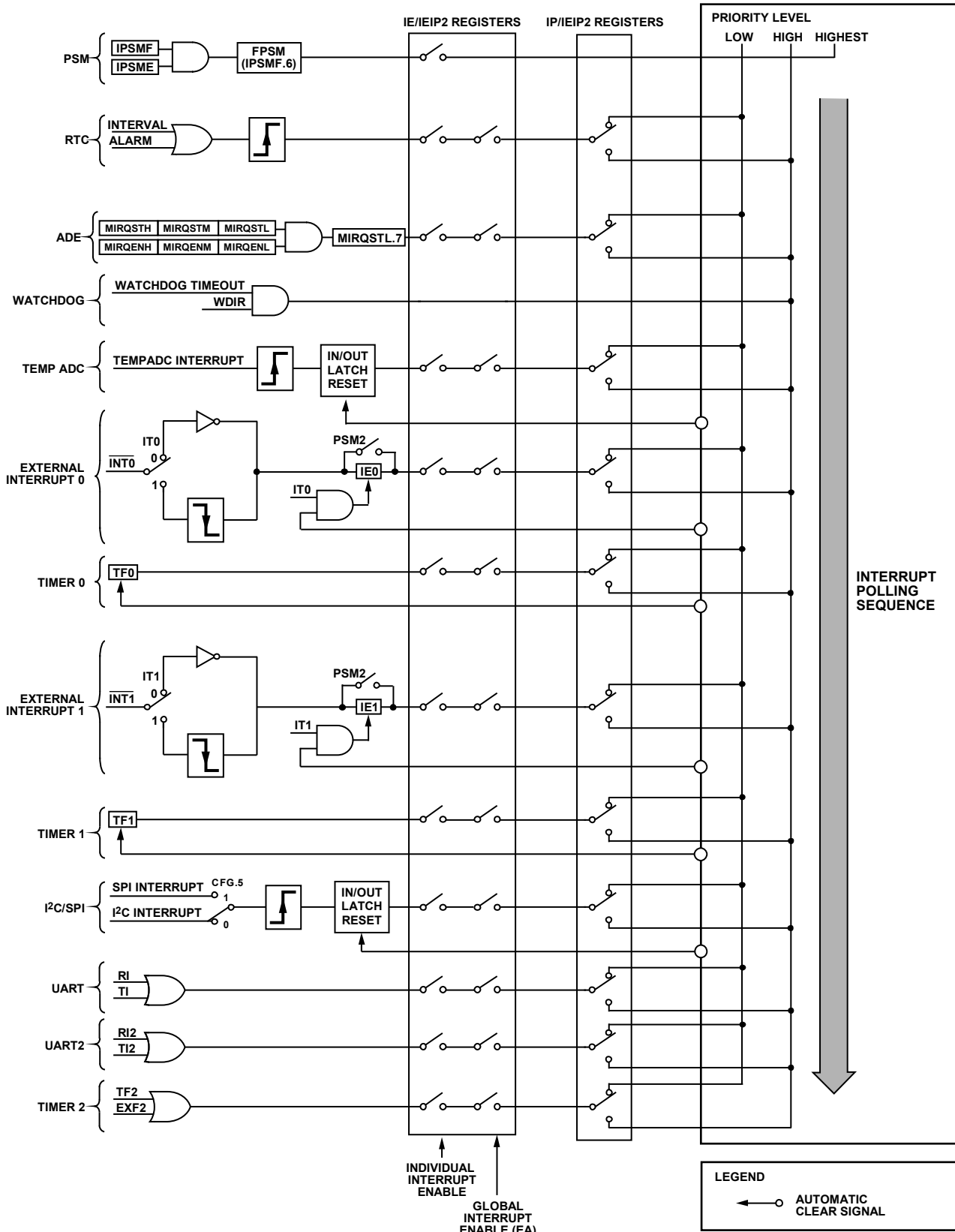


Figure 84. Interrupt System Functional Block Diagram



## INTERRUPT VECTORS

When an interrupt occurs, the program counter is pushed onto the stack, and the corresponding interrupt vector address is loaded into the program counter. When the interrupt service routine is complete, the program counter is popped off the stack by a RETI instruction. This allows program execution to resume from where it was interrupted. The interrupt vector addresses are shown in Table 86.

**Table 86. Interrupt Vector Addresses**

| Source                        | Vector Address |
|-------------------------------|----------------|
| IE0                           | 0x0003         |
| TF0                           | 0x000B         |
| IE1                           | 0x0013         |
| TF1                           | 0x001B         |
| RI + TI                       | 0x0023         |
| TF2 + EXF2                    | 0x002B         |
| ITEMP (Temperature ADC)       | 0x0033         |
| ISPI/I2CI                     | 0x003B         |
| IPSM (Power Supply)           | 0x0043         |
| IADE (Energy Measurement DSP) | 0x004B         |
| IRTC (RTC Interval Timer)     | 0x0053         |
| WDT (Watchdog Timer)          | 0x005B         |
| RI2 + TI2                     | 0x0063         |

## INTERRUPT LATENCY

The 8052 architecture requires that at least one instruction execute between interrupts. To ensure this, the 8052 MCU core hardware prevents the program counter from jumping to an ISR immediately after completing a RETI instruction or an access of the IP and IE SFRs.

The shortest interrupt latency is 3.25 instruction cycles, 800 ns with a clock of 4.096 MHz. The longest interrupt latency for a high priority interrupt results when a pending interrupt is

generated during a low priority interrupt RETI, followed by a multiply instruction. This results in a maximum interrupt latency of 16.25 instruction cycles, 4 μs with a clock of 4.096 MHz.

## CONTEXT SAVING

When the 8052 vectors to an interrupt, only the program counter is saved on the stack. Therefore, the interrupt service routine must be written to ensure that registers used in the main program are restored to their pre-interrupt state. Common SFRs that can be modified in the ISR are the accumulator register and the PSW register. Any general-purpose registers that are used as scratch pads in the ISR should also be restored before exiting the interrupt. The following example 8052 code shows how to restore some commonly used registers:

```
GeneralISR:
; save the current Accumulator value
        PUSH    ACC
; save the current status and register bank
selection
        PUSH    PSW
; service interrupt
...
; restore the status and register bank
selection
        POP     PSW
; restore the accumulator
        POP     ACC
        RETI
```

## WATCHDOG TIMER

The watchdog timer generates a device reset or interrupt within a reasonable amount of time if the ADE5166/ADE5169 enter an erroneous state, possibly due to a programming error or electrical noise. The watchdog is enabled by default with a timeout of two seconds and creates a system reset if not cleared within two seconds. The watchdog function can be disabled by clearing the watchdog enable bit (WDE, Bit 1) in the watchdog timer SFR (WDCON, Address 0xC0).

The watchdog circuit generates a system reset or interrupt (WDS, Bit 2) if the user program fails to set the WDE bit within a predetermined amount of time (set by the PRE bits, Bits[7:4]). The watchdog timer is clocked from the 32.768 kHz external crystal connected between the XTAL1 and XTAL2 pins.

The WDCON SFR can be written to only by user software if the double write sequence described in Table 87 is initiated on every write access to the WDCON SFR.

To prevent any code from inadvertently disabling the watchdog, a watchdog protection can be activated. This watchdog protection locks in the watchdog enable and event settings so they cannot be changed by user code. The protection is activated by clearing a watchdog protection bit in the flash memory. The watchdog protection bit is the most significant bit at Address 0x3FFA of the flash memory. When this bit is cleared, the WDIR bit (Bit 3) is forced to 0, and the WDE bit is forced to 1. Note that the sequence for configuring the flash protection bits must be followed to modify the watchdog protection bit at Address 0x3FFA (see the Protecting the Flash section).

**Table 87. Watchdog Timer SFR (WDCON, Address 0xC0)**

| Bit          | Address                      | Mnemonic | Default | Description   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
|--------------|------------------------------|----------|---------|---|----------|---------------------------|------|---------|------|---------|------|---------|------|--------|------|--------|------|--------|------|-------|------|-------|------|------------------------|------|------------------------------|--------------|-----------------------|
| [7:4]        | 0xC7 to 0xC4                 | PRE      | 7       | Watchdog prescaler. In normal mode, the 16-bit watchdog timer is clocked by the input clock (32.768 kHz). The PRE bits set which of the upper bits of the counter are used as the watchdog output, as follows: $t_{WATCHDOG} = 2^{PRE} \times \frac{2^9}{XTAL1}$  |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
|              |                              |          |         | <table border="1"> <thead> <tr> <th>PRE[3:0]</th> <th>Result (Watchdog Timeout)</th> </tr> </thead> <tbody> <tr><td>0000</td><td>15.6 ms</td></tr> <tr><td>0001</td><td>31.2 ms</td></tr> <tr><td>0010</td><td>62.5 ms</td></tr> <tr><td>0011</td><td>125 ms</td></tr> <tr><td>0100</td><td>250 ms</td></tr> <tr><td>0101</td><td>500 ms</td></tr> <tr><td>0110</td><td>1 sec</td></tr> <tr><td>0111</td><td>2 sec</td></tr> <tr><td>1000</td><td>0 sec, automatic reset</td></tr> <tr><td>1001</td><td>0 sec, serial download reset</td></tr> <tr><td>1010 to 1111</td><td>Not a valid selection</td></tr> </tbody> </table> | PRE[3:0] | Result (Watchdog Timeout) | 0000 | 15.6 ms | 0001 | 31.2 ms | 0010 | 62.5 ms | 0011 | 125 ms | 0100 | 250 ms | 0101 | 500 ms | 0110 | 1 sec | 0111 | 2 sec | 1000 | 0 sec, automatic reset | 1001 | 0 sec, serial download reset | 1010 to 1111 | Not a valid selection |
| PRE[3:0]     | Result (Watchdog Timeout)    |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 0000         | 15.6 ms                      |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 0001         | 31.2 ms                      |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 0010         | 62.5 ms                      |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 0011         | 125 ms                       |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 0100         | 250 ms                       |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 0101         | 500 ms                       |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 0110         | 1 sec                        |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 0111         | 2 sec                        |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 1000         | 0 sec, automatic reset       |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 1001         | 0 sec, serial download reset |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 1010 to 1111 | Not a valid selection        |          |         |   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 3            | 0xC3                         | WDIR     | 0       | Watchdog interrupt response bit. When cleared, the watchdog generates a system reset when the watchdog timeout period has expired. When set, the watchdog generates an interrupt when the watchdog timeout period has expired.  |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 2            | 0xC2                         | WDS      | 0       | Watchdog status bit. This bit is set to indicate that a watchdog timeout has occurred. It is cleared by writing a 0 or by an external hardware reset. A watchdog reset does not clear WDS; therefore, it can be used to distinguish between a watchdog reset and a hardware reset from the RESET pin.   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 1            | 0xC1                         | WDE      | 1       | Watchdog enable bit. When set, this bit enables the watchdog and clears its counter. The watchdog counter is subsequently cleared again whenever WDE is set. If the watchdog is not cleared within its selected timeout period, it generates a system reset or watchdog interrupt, depending on the WDIR bit.   |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |
| 0            | 0xC0                         | WDWR     | 0       | Watchdog write enable bit (see the Writing to the Watchdog Timer SFR (WDCON, Address 0xC0) section).  |          |                           |      |         |      |         |      |         |      |        |      |        |      |        |      |       |      |       |      |                        |      |                              |              |                       |

**Table 88. Watchdog and Flash Protection Byte in Flash (Flash Address = 0x3FFA)**

| Bit   | Mnemonic       | Default | Description  |
|-------|----------------|---------|--|
| 7     | WDPROT_PROTKY7 | 1       | This bit holds the protection for the watchdog timer and the seventh bit of the flash protection key. When this bit is cleared, the watchdog enable and event bits WDE and WDIR cannot be changed by user code. The watchdog configuration is then fixed to WDIR = 0 and WDE = 1. The watchdog timeout in PRE (Bits[7:4]) can still be modified by user code.<br><br>The value of this bit is also used to set the flash protection key. If this bit is cleared to protect the watchdog, then the default value for the flash protection key is 0x7F instead of 0xFF (see the Protecting the Flash section for more information on how to clear this bit). |
| [6:0] | PROTKY[6:0]    | 0xFF    | These bits hold the flash protection key. The content of this flash address is compared to the flash protection key SFR (PROTKY, Address 0xBB) when the protection is being set or changed. If the two values match, the new protection is written to the flash Address 0x3FFF to Address 0x3FFB. See the Protecting the Flash section for more information on how to configure these bits.  |

**Writing to the Watchdog Timer SFR (WDCON, Address 0xC0)**

Writing data to the WDCON SFR involves a double instruction sequence. The WDWR (Bit 0) bit must be set, and the following instruction must be a write instruction to the WDCON SFR.

```

; Disable Watchdog
CLR EA
SETB WDWR
CLR WDE
SETB EA
    
```

This sequence is necessary to protect the WDCON SFR from code execution upsets that may unintentionally modify this SFR. Interrupts should be disabled during this operation due to the consecutive instruction cycles.

**Watchdog Timer Interrupt**

If the watchdog timer is not cleared within the watchdog timeout period, a system reset occurs unless the watchdog timer interrupt is enabled. The watchdog timer interrupt response bit (WDIR, Bit 3) is located in the watchdog timer SFR (WDCON, Address 0xC0). Enabling the WDIR bit allows the program to examine the stack or other variables that may have led the program to execute inappropriate code. The watchdog timer interrupt also allows the watchdog to be used as a long interval timer.

Note that WDIR is automatically configured as a high priority interrupt. This interrupt cannot be disabled by the EA bit (Bit 7) in the interrupt enable SFR (IE, Address 0xA8; see Table 80). Even if all of the other interrupts are disabled, the watchdog is kept active to watch over the program.

## LCD DRIVER

Using shared pins, the LCD module is capable of directly driving an LCD panel of 17 × 4 segments without compromising any ADE5166/ADE5169 functions. It is capable of driving LCDs with 2×, 3×, and 4× multiplexing. The LCD waveform voltages generated through internal charge pump circuitry support up to 5 V LCDs. An external resistor ladder for LCD waveform voltage generation is also supported.

Each ADE5166/ADE5169 has an embedded LCD control circuit, driver, and power supply circuit. The LCD module is functional in all operating modes (see the Operating Modes section) and can store up to four different screens in memory for scrolling purposes.

## LCD REGISTERS

There are six LCD control registers that configure the driver for the specific type of LCD in the end system and set up the user display preferences. The LCD configuration SFR (LCDCON, Address 0x95), LCD Configuration X SFR (LCDCONX, Address 0x9C), and LCD Configuration Y SFR (LCDCONY, Address 0xB1) contain general LCD driver configuration information including the LCD enable and reset, as well as the method of LCD voltage generation and multiplex level. The LCD clock SFR (LCDCLK, Address 0x96) configures timing settings for LCD frame rate and blink rate. LCD pins are configured for LCD functionality in the LCD segment enable SFR (LCDSEGE, Address 0x97) and the LCD Segment Enable 2 SFR (LCDSEGE2, Address 0xED).

**Table 89. LCD Driver SFRs**

| SFR Address | R/W | Mnemonic | Description                           |
|-------------|-----|----------|---------------------------------------|
| 0x95        | R/W | LCDCON   | LCD configuration (see Table 90).     |
| 0x96        | R/W | LCDCLK   | LCD clock (see Table 94).             |
| 0x97        | R/W | LCDSEGE  | LCD segment enable (see Table 97).    |
| 0x9C        | R/W | LCDCONX  | LCD Configuration X (see Table 91).   |
| 0xAC        | R/W | LCDPTR   | LCD pointer (see Table 98).           |
| 0xAE        | R/W | LCDDAT   | LCD data (see Table 99).              |
| 0xB1        | R/W | LCDCONY  | LCD Configuration Y (see Table 93).   |
| 0xED        | R/W | LCDSEGE2 | LCD Segment Enable 2 (see Table 100). |

**Table 90. LCD Configuration SFR (LCDCON, Address 0x95)**

| Bit     | Mnemonic  | Default | Description   |          |        |    |   |    |   |    |   |    |   |
|---------|---|---------|---|----------|--------|----|---|----|---|----|---|----|---|
| 7       | LCDEN   | 0       | LCD enable. If this bit is set, the LCD driver is enabled.  |          |        |    |   |    |   |    |   |    |   |
| 6       | LCDRST  | 0       | LCD data registers reset. If this bit is set, the LCD data registers are reset to 0.  |          |        |    |   |    |   |    |   |    |   |
| 5       | BLINKEN   | 0       | Blink mode enable bit. If this bit is set, blink mode is enabled. The blink mode is configured by BLKMOD (Bits[7:6]) and BLKFREQ (Bits[5:4]) in the LCD clock SFR (LCDCLK, Address 0x96).   |          |        |    |   |    |   |    |   |    |   |
| 4       | LCDPSM2   | 0       | Forces LCD off when in PSM2 (sleep) mode. Note that the internal voltage reference must be enabled by setting the REF_BAT_EN bit in the peripheral configuration SFR (PERIPH, Address 0xF4) to allow LCD operation in PSM2.   |          |        |    |   |    |   |    |   |    |   |
|         |   |         | <table border="1"> <thead> <tr> <th>LCDPSM2</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>The LCD is disabled or enabled in PSM2 by the LCDEN bit</td> </tr> <tr> <td>1</td> <td>The LCD is disabled in PSM2 regardless of LCDEN setting</td> </tr> </tbody> </table>   | LCDPSM2  | Result | 0  | The LCD is disabled or enabled in PSM2 by the LCDEN bit | 1  | The LCD is disabled in PSM2 regardless of LCDEN setting                   |    |   |    |   |
| LCDPSM2 | Result  |         |   |          |        |    |   |    |   |    |   |    |   |
| 0       | The LCD is disabled or enabled in PSM2 by the LCDEN bit                   |         |   |          |        |    |   |    |   |    |   |    |   |
| 1       | The LCD is disabled in PSM2 regardless of LCDEN setting                   |         |   |          |        |    |   |    |   |    |   |    |   |
| 3       | CLKSEL  | 0       | LCD clock selection.  |          |        |    |   |    |   |    |   |    |   |
|         |   |         | <table border="1"> <thead> <tr> <th>CLKSEL</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>0</td> <td><math>f_{LCDCLK} = 2048 \text{ Hz}</math></td> </tr> <tr> <td>1</td> <td><math>f_{LCDCLK} = 128 \text{ Hz}</math></td> </tr> </tbody> </table>   | CLKSEL   | Result | 0  | $f_{LCDCLK} = 2048 \text{ Hz}$                          | 1  | $f_{LCDCLK} = 128 \text{ Hz}$   |    |   |    |   |
| CLKSEL  | Result  |         |   |          |        |    |   |    |   |    |   |    |   |
| 0       | $f_{LCDCLK} = 2048 \text{ Hz}$  |         |   |          |        |    |   |    |   |    |   |    |   |
| 1       | $f_{LCDCLK} = 128 \text{ Hz}$   |         |   |          |        |    |   |    |   |    |   |    |   |
| 2       | BIAS  | 0       | Bias mode.  |          |        |    |   |    |   |    |   |    |   |
|         |   |         | <table border="1"> <thead> <tr> <th>BIAS</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>0</td> <td>1/2</td> </tr> <tr> <td>1</td> <td>1/3</td> </tr> </tbody> </table>  | BIAS     | Result | 0  | 1/2   | 1  | 1/3   |    |   |    |   |
| BIAS    | Result  |         |   |          |        |    |   |    |   |    |   |    |   |
| 0       | 1/2   |         |   |          |        |    |   |    |   |    |   |    |   |
| 1       | 1/3   |         |   |          |        |    |   |    |   |    |   |    |   |
| [1:0]   | LMUX  | 0       | LCD multiplex level.  |          |        |    |   |    |   |    |   |    |   |
|         |   |         | <table border="1"> <thead> <tr> <th>LMUX</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>Reserved</td> </tr> <tr> <td>01</td> <td>2× multiplexing; FP27/COM3 is used as FP27, and FP28/COM2 is used as FP28</td> </tr> <tr> <td>10</td> <td>3× multiplexing; FP27/COM3 is used as FP27, and FP28/COM2 is used as COM2</td> </tr> <tr> <td>11</td> <td>4× multiplexing; FP27/COM3 is used as COM3, and FP28/COM2 is used as COM2</td> </tr> </tbody> </table> | LMUX     | Result | 00 | Reserved  | 01 | 2× multiplexing; FP27/COM3 is used as FP27, and FP28/COM2 is used as FP28 | 10 | 3× multiplexing; FP27/COM3 is used as FP27, and FP28/COM2 is used as COM2 | 11 | 4× multiplexing; FP27/COM3 is used as COM3, and FP28/COM2 is used as COM2 |
|         |   |         | LMUX  | Result   |        |    |   |    |   |    |   |    |   |
|         |   |         | 00  | Reserved |        |    |   |    |   |    |   |    |   |
| 01      | 2× multiplexing; FP27/COM3 is used as FP27, and FP28/COM2 is used as FP28 |         |   |          |        |    |   |    |   |    |   |    |   |
| 10      | 3× multiplexing; FP27/COM3 is used as FP27, and FP28/COM2 is used as COM2 |         |   |          |        |    |   |    |   |    |   |    |   |
| 11      | 4× multiplexing; FP27/COM3 is used as COM3, and FP28/COM2 is used as COM2 |         |   |          |        |    |   |    |   |    |   |    |   |

**Table 91. LCD Configuration X SFR (LCDCONX, Address 0x9C)**

| Bit   | Mnemonic | Default | Description                               |  |
|-------|----------|---------|---|--|
| 7     | Reserved | 0       | Reserved.                                 |  |
| 6     | EXTRES   | 0       | External resistor ladder selection bit.   |  |
|       |          |         | <b>EXTRES</b>                             | <b>Result</b>  |
|       |          |         | 0   | External resistor ladder is disabled. Charge pump is enabled |
|       |          |         | 1   | External resistor ladder is enabled. Charge pump is disabled |
| [5:0] | BIASLVL  | 0       | Bias level selection bits (see Table 92). |  |

**Table 92. LCD Bias Voltage When Contrast Control Is Enabled**

| BIASLVL[5] | V <sub>A</sub> (V)  | 1/2 Bias                        |                                     | 1/3 Bias                            |                                     |
|------------|---|---------------------------------|-------------------------------------|-------------------------------------|-------------------------------------|
|            |   | V <sub>B</sub>                  | V <sub>C</sub>                      | V <sub>B</sub>                      | V <sub>C</sub>                      |
| 0          | $V_{REF} \times \frac{BIASLVL[4:0]}{31}$                  | V <sub>B</sub> = V <sub>A</sub> | V <sub>C</sub> = 2 × V <sub>A</sub> | V <sub>B</sub> = 2 × V <sub>A</sub> | V <sub>C</sub> = 3 × V <sub>A</sub> |
| 1          | $V_{REF} \times \left(1 + \frac{BIASLVL[4:0]}{31}\right)$ | V <sub>B</sub> = V <sub>A</sub> | V <sub>C</sub> = 2 × V <sub>A</sub> | V <sub>B</sub> = 2 × V <sub>A</sub> | V <sub>C</sub> = 3 × V <sub>A</sub> |

**Table 93. LCD Configuration Y SFR (LCDCONY, Address 0xB1)**

| Bit   | Mnemonic         | Default | Description   |
|-------|------------------|---------|---|
| 7     | AUTOSCREENSCROLL | 0       | When set, the four screens scroll automatically. The scrolling item is selected by the BLKFREQ bits in the LCD clock SFR (LCDCLK, Address 0x96). If both BLINKEN in the LCD configuration SFR (LCDCON, Address 0x95) and AUTOSCREENSCROLL are set, this bit preempts the blinking mode.                                       |
| 6     | INV_LVL          | 0       | Frame inversion mode enable bit. If this bit is set, frames are inverted every other frame. If this bit is cleared, frames are not inverted.  |
| [5:4] | Reserved         | 00      | These bits should be kept cleared to 0 for proper operation.  |
| [3:2] | SCREEN_SEL       | 0       | These bits select the screen that is being output on the LCD pins. Values of 0, 1, 2, and 3 select Screen 0, Screen 1, Screen 2, and Screen 3, respectively.  |
| 1     | UPDATEOVER       | 0       | Update finished flag bit. This bit is updated by the LCD driver. When set, this bit indicates that the LCD memory has been updated and a new frame has begun.   |
| 0     | REFRESH          | 0       | Refresh LCD data memory bit. This bit should be set by the user. When set, the LCD driver does not use the data in the LCD data registers to update the display. The LCD data registers can be updated by the 8052. When cleared, the LCD driver uses the data in the LCD data registers to update display at the next frame. |

**Table 94. LCD Clock SFR (LCDCLK, Address 0x96)**

| Bit   | Mnemonic | Default | Description  |  |
|-------|----------|---------|--|--|
| [7:6] | BLKMOD   | 0       | Blink mode clock source configuration bits.  |  |
|       |          |         | <b>BLKMOD</b>  | <b>Result</b>  |
|       |          |         | 00   | The blink rate is controlled by software; the display is off |
|       |          |         | 01   | The blink rate is controlled by software; the display is on  |
|       |          |         | 10   | The blink rate is 2 Hz                                       |
|       |          |         | 11   | The blink rate is set by BLKFREQ[1:0]                        |
| [5:4] | BLKFREQ  | 0       | Blink rate configuration bits. These bits control the LCD blink rate if BLKMOD (Bits[7:6]) = 11. |  |
|       |          |         | <b>BLKFREQ</b>   | <b>Result (Blink Rate)</b>                                   |
|       |          |         | 00   | 1 Hz   |
|       |          |         | 01   | 1/2 Hz   |
|       |          |         | 10   | 1/3 Hz   |
|       |          |         | 11   | 1/4 Hz   |
| [3:0] | FD       | 0       | LCD frame rate selection bits (see Table 95 and Table 96).                                       |  |

# ADE5166/ADE5169

Table 95. LCD Frame Rate Selection for  $f_{LCDCLK} = 2048 \text{ Hz}$  (LCDCON[3] = 0)

| FD3 | FD2 | FD1 | FD0 | 2× Multiplexing |                  | 3× Multiplexing |                    | 4× Multiplexing |                  |
|-----|-----|-----|-----|-----------------|------------------|-----------------|--------------------|-----------------|------------------|
|     |     |     |     | $f_{LCD}$ (Hz)  | Frame Rate (Hz)  | $f_{LCD}$ (Hz)  | Frame Rate (Hz)    | $f_{LCD}$ (Hz)  | Frame Rate (Hz)  |
| 0   | 0   | 0   | 1   | 256             | 128 <sup>1</sup> | 341.3           | 170.7 <sup>1</sup> | 512             | 128 <sup>1</sup> |
| 0   | 0   | 1   | 0   | 170.7           | 85.3             | 341.3           | 113.8 <sup>1</sup> | 341.3           | 85.3             |
| 0   | 0   | 1   | 1   | 128             | 64               | 256             | 85.3               | 256             | 64               |
| 0   | 1   | 0   | 0   | 102.4           | 51.2             | 204.8           | 68.3               | 204.8           | 51.2             |
| 0   | 1   | 0   | 1   | 85.3            | 42.7             | 170.7           | 56.9               | 170.7           | 42.7             |
| 0   | 1   | 1   | 0   | 73.1            | 36.6             | 146.3           | 48.8               | 146.3           | 36.6             |
| 0   | 1   | 1   | 1   | 64              | 32               | 128             | 42.7               | 128             | 32               |
| 1   | 0   | 0   | 0   | 56.9            | 28.5             | 113.8           | 37.9               | 113.8           | 28.5             |
| 1   | 0   | 0   | 1   | 51.2            | 25.6             | 102.4           | 34.1               | 102.4           | 25.6             |
| 1   | 0   | 1   | 0   | 46.5            | 23.25            | 93.1            | 31                 | 93.1            | 23.25            |
| 1   | 0   | 1   | 1   | 42.7            | 21.35            | 85.3            | 28.4               | 85.3            | 21.35            |
| 1   | 1   | 0   | 0   | 39.4            | 19.7             | 78.8            | 26.3               | 78.8            | 19.7             |
| 1   | 1   | 0   | 1   | 36.6            | 18.3             | 73.1            | 24.4               | 73.1            | 18.3             |
| 1   | 1   | 1   | 0   | 34.1            | 17.05            | 68.3            | 22.8               | 68.3            | 17.05            |
| 1   | 1   | 1   | 1   | 32              | 16               | 64              | 21.3               | 64              | 16               |
| 0   | 0   | 0   | 0   | 16              | 8                | 32              | 10.7               | 32              | 8                |

<sup>1</sup> Not within the range of typical LCD frame rates.

Table 96. LCD Frame Rate Selection for  $f_{LCDCLK} = 128 \text{ Hz}$  (LCDCON[3] = 1)

| FD3 | FD2 | FD1 | FD0 | 2× Multiplexing |                 | 3× Multiplexing |                 | 4× Multiplexing |                 |
|-----|-----|-----|-----|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|     |     |     |     | $f_{LCD}$ (Hz)  | Frame Rate (Hz) | $f_{LCD}$ (Hz)  | Frame Rate (Hz) | $f_{LCD}$ (Hz)  | Frame Rate (Hz) |
| 0   | 0   | 0   | 1   | 32              | 16 <sup>1</sup> | 32              | 10.7            | 32              | 8               |
| 0   | 0   | 1   | 0   | 21.3            | 10.6            | 32              | 10.7            | 32              | 8               |
| 0   | 0   | 1   | 1   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 0   | 1   | 0   | 0   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 0   | 1   | 0   | 1   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 0   | 1   | 1   | 0   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 0   | 1   | 1   | 1   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 1   | 0   | 0   | 0   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 1   | 0   | 0   | 1   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 1   | 0   | 1   | 0   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 1   | 0   | 1   | 1   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 1   | 1   | 0   | 0   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 1   | 1   | 0   | 1   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 1   | 1   | 1   | 0   | 16              | 8               | 32              | 10.7            | 32              | 8               |
| 1   | 1   | 1   | 1   | 128             | 64              | 128             | 42.7            | 128             | 32              |
| 0   | 0   | 0   | 0   | 64              | 32              | 64              | 21.3            | 64              | 16              |

<sup>1</sup> Not within the range of typical LCD frame rates.

Table 97. LCD Segment Enable SFR (LCDSEGE, Address 0x97)

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| 7     | FP25EN   | 0       | FP25 function select bit. 0 = general-purpose I/O, 1 = LCD function. |
| 6     | FP24EN   | 0       | FP24 function select bit. 0 = general-purpose I/O, 1 = LCD function. |
| 5     | FP23EN   | 0       | FP23 function select bit. 0 = general-purpose I/O, 1 = LCD function. |
| 4     | FP22EN   | 0       | FP22 function select bit. 0 = general-purpose I/O, 1 = LCD function. |
| 3     | FP21EN   | 0       | FP21 function select bit. 0 = general-purpose I/O, 1 = LCD function. |
| 2     | FP20EN   | 0       | FP20 function select bit. 0 = general-purpose I/O, 1 = LCD function. |
| [1:0] | Reserved | 0       | These bits must be kept at 0 for proper operation.                   |

**Table 98. LCD Pointer SFR (LCDPTR, Address 0xAC)**

| Bit   | Mnemonic   | Default | Description  |
|-------|------------|---------|--|
| 7     | R/W        | 0       | Read or write LCD bit. If this bit is set to 1, the data in the LCD data SFR (LCDDAT, Address 0xAE) is written to the address indicated by the ADDRESS bits (LCDPTR[3:0]). |
| 6     | Reserved   | 0       | Reserved.  |
| [5:4] | RAM2SCREEN | 0       | These bits select the screen recipient of the data memory action.  |
| [3:0] | ADDRESS    | 0       | LCD memory address (see Table 101).  |

**Table 99. LCD Data SFR (LCDDAT, Address 0xAE)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | LCDDATA  | 0       | Data to be written into or read out of the LCD memory SFRs. |

**Table 100. LCD Segment Enable 2 SFR (LCDSEGE2, Address 0xED)**

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| [7:4] | Reserved | 0       | Reserved.  |
| 3     | FP19EN   | 0       | FP19 function select bit. 0 = general-purpose I/O, 1 = LCD function. |
| 2     | FP18EN   | 0       | FP18 function select bit. 0 = general-purpose I/O, 1 = LCD function. |
| 1     | FP17EN   | 0       | FP17 function select bit. 0 = general-purpose I/O, 1 = LCD function. |
| 0     | FP16EN   | 0       | FP16 function select bit. 0 = general-purpose I/O, 1 = LCD function. |

## LCD SETUP

The LCD configuration SFR (LCDCON, Address 0x95) configures the LCD module to drive the type of LCD in the user end system. The BIAS bit (Bit 2) and the LMUX bits (Bits[1:0]) in this SFR should be set according to the LCD specifications.

The COM2/FP28 and COM3/FP27 pins default to LCD segment lines. Selecting the 3× multiplex level in the LCD configuration SFR (LCDCON, Address 0x95) by setting LMUX[1:0] to 10 changes the FP28 pin functionality to COM2. The 4× multiplex level selection, LMUX[1:0] = 11, changes the FP28 pin functionality to COM2 and the FP27 pin functionality to COM3.

The LCD segments of FP0 to FP15 are enabled by default. Additional pins are selected for LCD functionality in the LCD segment enable SFR (LCDSEGE, Address 0x97) and LCD Segment Enable 2 SFR (LCDSEGE2, Address 0xED) where there are individual enable bits for the FP16 to FP25 segment pins. The LCD pins do not have to be enabled sequentially. For example, if the alternate function of FP23, the Timer 2 input, is required, any of the other shared pins, FP16 to FP25, can be enabled instead.

The Display Element Control section contains details about setting up the LCD data memory to turn individual LCD segments on and off. Setting the LCDRST bit (Bit 6) in the LCD configuration SFR (LCDCON, Address 0x95) resets the LCD data memory to its default (0). A power-on reset also clears the LCD data memory.

## LCD TIMING AND WAVEFORMS

An LCD segment acts like a capacitor that is charged and discharged at a certain rate. This rate, the refresh rate, determines the visual characteristics of the LCD. A slow refresh rate results in the LCD blinking on and off between refreshes. A fast refresh rate presents a screen that appears to be continuously lit. In addition, a faster refresh rate consumes more power.

The frame rate, or refresh rate, for the LCD module is derived from the LCD clock,  $f_{LCDCLK}$ . The LCD clock is selected as 2048 Hz or 128 Hz by the CLKSEL bit (Bit 3) in the LCD configuration SFR (LCDCON, Address 0x95). The minimum refresh rate needed for the LCD to appear solid (without blinking) is independent of the multiplex level.

The LCD waveform frequency,  $f_{LCD}$ , is the frequency at which the LCD switches the active common line. Thus, the LCD waveform frequency depends heavily on the multiplex level. The frame rate and LCD waveform frequency are set by  $f_{LCDCLK}$ , the multiplex level, and the FD[3:0] frame rate selection bits in the LCD clock SFR (LCDCLK, Address 0x96).

The LCD module provides 16 different frame rates for  $f_{LCDCLK} = 2048$  Hz, ranging from 8 Hz to 128 Hz for an LCD with 4× multiplexing. Fewer options are available with  $f_{LCDCLK} = 128$  Hz, ranging from 8 Hz to 32 Hz for a 4× multiplexed LCD. The 128 Hz clock is beneficial for battery operation because it consumes less power than the 2048 Hz clock. The frame rate is set by the FD[3:0] bits in the LCD clock SFR (LCDCLK, Address 0x96); see Table 95 and Table 96.

The LCD waveform is inverted at twice the LCD waveform frequency,  $f_{LCD}$ . This way, each frame has an average dc offset of 0. ADC offset degrades the lifetime and performance of the LCD.

## BLINK MODE

Blink mode is enabled by setting the BLINKEN bit (Bit 5) in the LCD configuration SFR (LCDCON, Address 0x95). This mode is used to alternate between the LCD on state and LCD off state so that the LCD screen appears to blink. There are two blinking modes: a software controlled blink mode and an automatic blink mode.

### Software Controlled Blink Mode

The LCD blink rate can be controlled by user code with the BLKMOD bits (Bits[7:6]) in the LCD clock SFR (LCDCLK, Address 0x96) by toggling the bits to turn the display on and off at a rate determined by the MCU code.

### Automatic Blink Mode

There are five blink rates. These blink rates are selected by the BLKMOD bits (Bits[7:6]) and the BLKFREQ bits (Bits[5:4]) bits in the LCD clock SFR (LCDCLK, Address 0x96); see Table 94.

## SCROLLING MODE

The ADE5166/ADE5169 provide the possibility to have four screens in memory. The LCD driver can use any of these screens by setting the SCREEN\_SEL bits in the LCD Configuration Y SFR (LCDCONY, Address 0xB1) and clearing the refresh bit (Bit 0) in the same register. The software scrolling of the screens can then be achieved by a one-command instruction.

### Automatic Scrolling Mode

The ADE5166/ADE5169 also provide an automatic scrolling between the screens using the five available blink rates. This mode is enabled by setting bit AUTOSCREENSCROLL (Bit 7) in the LCD Configuration Y SFR (LCDCONY, Address 0xB1) and also the BLINKEN bit (Bit 5) in the LCD configuration SFR (LCDCON, Address 0x95). To allow the scrolling frequency to be selected, the BLKMOD bits (Bits[7:6]) in the LCD clock SFR (LCDCLK, Address 0x96) should both be set to 1. The scrolling rates are then selected by the BLKFREQ bits (Bits[5:4]) in the LCD clock SFR (LCDCLK, Address 0x96); see Table 94. Automatic scrolling mode is available in all operating modes.

## DISPLAY ELEMENT CONTROL

Four banks of 15 bytes of data memory located in the LCD module control the on or off state of each segment of the LCD. The LCD data memory is stored in Address 0 through Address 14 in the LCD module, with two extra bits defining which one of the four screens is being addressed.

Each byte configures the on and off states of two segment lines. The LSBs store the state of the even numbered segment lines, and the MSBs store the state of the odd numbered segment lines. For example, LCD Data Address 0 refers to segment Line 1 and Line 0 (see Table 101). Note that the LCD data memory is maintained in the PSM2 operating mode.

The LCD data memory is accessed indirectly through the LCD pointer SFR (LCDPTR, Address 0xAC) and LCD data SFR (LCDDAT, Address 0xAE). Moving a value to the LCDPTR SFR selects the LCD screen and data byte to be accessed and initiates a read or write operation (see Table 98).

### Writing to LCD Data Registers

To update the LCD data memory, first set the LSB of the LCD Configuration Y SFR (LCDCONY, Address 0xB1) to freeze the data being displayed on the LCD while updating it. This operation ensures that the data displayed on the screen does not change while the data is being changed. Then, move the data to the LCD data SFR (LCDDAT, Address 0xAE) prior to accessing the LCD pointer SFR (LCDPTR, Address 0xAC). The address of the LCD screen should be consistent with the data changed. When the MSB of the LCD pointer SFR (LCDPTR, Address 0xAC) is set, the content of the LCD data SFR (LCDDAT, Address 0xAE) is transferred to the internal LCD data memory designated by the address in the LCD pointer SFR (LCDPTR, Address 0xAC) and the screen designator. Clear the LSB of the LCD Configuration Y SFR (LCDCONY, Address 0xB1) when all of the data memory has been updated to allow the use of the new LCD setup for display.

Sample 8052 code to update the segments attached to Pin FP10 and Pin FP11 on Screen 1 is as follows:

```
ORL    LCDCONY,#01h ;start updating the data
MOV    LCDDAT,#FFh
MOV    LCDPTR,#80h OR 05h
ANL    LCDCONY,#0FEh ;update finished
```

### Reading LCD Data Registers

When the MSB of the LCD pointer SFR (LCDPTR, Address 0xAC) is cleared, the content of the LCD data memory of the corresponding screen designated by LCDPTR is transferred to the LCD data SFR (LCDDAT, Address 0xAE).

Sample 8052 code to read the contents of LCD Data Memory Address 0x07 on Screen 1, which holds the on and off state of the segments attached to FP14 and FP15, is as follows.

```
MOV    LCDPTR,#07h
MOV    R1, LCDDAT
```



**Table 101. LCD Data Memory Accessed Indirectly Through LCD Pointer SFR (LCDPTR, Address 0xAC) and LCD Data SFR (LCDDAT, Address 0xAE)<sup>1, 2</sup>**

| LCD Memory Address | LCD Pointer SFR (LCDPTR, Address 0xAC) |      |      |      | LCD Pointer SFR (LCDDAT, Address 0xAE) |      |      |      |
|--------------------|--|------|------|------|--|------|------|------|
|                    | COM3                                   | COM2 | COM1 | COM0 | COM3                                   | COM2 | COM1 | COM0 |
| 0x0E               |  |      |      |      | FP28                                   | FP28 | FP28 | FP28 |
| 0x0D               | FP27                                   | FP27 | FP27 | FP27 | N/A                                    | N/A  | N/A  | N/A  |
| 0x0C               | FP25                                   | FP25 | FP25 | FP25 | FP24                                   | FP24 | FP24 | FP24 |
| 0x0B               | FP23                                   | FP23 | FP23 | FP23 | FP22                                   | FP22 | FP22 | FP22 |
| 0x0A               | FP21                                   | FP21 | FP21 | FP21 | FP20                                   | FP20 | FP20 | FP20 |
| 0x09               | FP19                                   | FP19 | FP19 | FP19 | FP18                                   | FP18 | FP18 | FP18 |
| 0x08               | FP17                                   | FP17 | FP17 | FP17 | FP16                                   | FP16 | FP16 | FP16 |
| 0x07               | FP15                                   | FP15 | FP15 | FP15 | FP14                                   | FP14 | FP14 | FP14 |
| 0x06               | FP13                                   | FP13 | FP13 | FP13 | FP12                                   | FP12 | FP12 | FP12 |
| 0x05               | FP11                                   | FP11 | FP11 | FP11 | FP10                                   | FP10 | FP10 | FP10 |
| 0x04               | FP9                                    | FP9  | FP9  | FP9  | FP8                                    | FP8  | FP8  | FP8  |
| 0x03               | FP7                                    | FP7  | FP7  | FP7  | FP6                                    | FP6  | FP6  | FP6  |
| 0x02               | FP5                                    | FP5  | FP5  | FP5  | FP4                                    | FP4  | FP4  | FP4  |
| 0x01               | FP3                                    | FP3  | FP3  | FP3  | FP2                                    | FP2  | FP2  | FP2  |
| 0x00               | FP1                                    | FP1  | FP1  | FP1  | FP0                                    | FP0  | FP0  | FP0  |

<sup>1</sup> COMx designates the common lines.

<sup>2</sup> FPx designates the segment lines.

## VOLTAGE GENERATION

The ADE5166/ADE5169 provide two ways to generate the LCD waveform voltage levels. The on-chip charge pump option can generate 5 V. This makes it possible to use 5 V LCDs with the 3.3 V ADE5166/ADE5169. There is also an option to use an external resistor ladder with a 3.3 V LCD. The EXTRES bit (Bit 6) in the LCD Configuration X SFR (LCDCONX, Address 0x9C) selects the resistor ladder or charge pump option.

When selecting how to generate the LCD waveform voltages, the following should be considered:

- Lifetime performance power consumption
- Contrast control

### Lifetime Performance Power Consumption

In most LCDs, a high amount of current is required when the LCD waveforms change state. The external resistor ladder option draws a constant amount of current, whereas the charge pump circuitry allows dynamic current consumption. If the LCD module is used with the internal charge pump option when the display is disabled, the voltage generation is disabled so that no power is consumed by the LCD function. This feature results in significant power savings if the display is turned off during battery operation.

### Contrast Control

The electrical characteristics of the liquid in the LCD change over temperature. This requires adjustments in the LCD waveform voltages to ensure a readable display. An added benefit of the

internal charge pump voltage generation is a configurable bias voltage that can be compensated over temperature and supply to maintain contrast on the LCD. These compensations can be performed based on the ADE5166/ADE5169 temperature and supply voltage measurements (see the Temperature, Battery, and Supply Voltage Measurements section). This dynamic contrast control is not easily implemented with external resistor ladder voltage generation.

The LCD bias voltage sets the contrast of the display when the charge pump provides the LCD waveform voltages. The ADE5166/ADE5169 provide 64 bias levels selected by the BIASLVL[5:0] bits in the LCD Configuration X SFR (LCDCONX, Address 0x9C). The voltage level on LCDVA, LCDVB, and LCDVC depend on the internal voltage reference value ( $V_{REF}$ ), BIASLVL (Bits[5:0]) selection, and the biasing selected, as described in Table 92.

### Lifetime Performance

DC offset on a segment degrades its performance over time. The voltages generated through the internal charge pump switch faster than those generated by the external resistor ladder, reducing the likelihood of a dc voltage being applied to a segment and increasing the lifetime of the LCD.

## LCD EXTERNAL CIRCUITRY

The voltage generation selection is made by the EXTRES bit (Bit 6) in the LCD configuration X SFR (LCDCONX, Address 0x9C). This bit is cleared by default for charge pump voltage generation, but it can be set to enable an external resistor ladder.

## Charge Pump

Voltage generation through the charge pump requires external capacitors to store charge. The external connections to LCDVA, LCDVB, and LCDVC, as well as to LCDVDP1 and LCDVDP2, are shown in Figure 85.

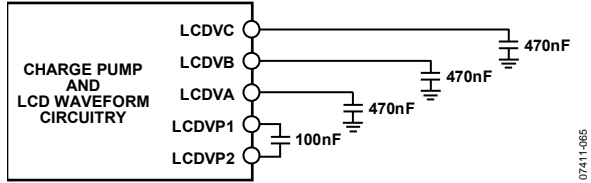


Figure 85. External Circuitry for Charge Pump Option

## External Resistor Ladder

To enable the external resistor ladder option, set the EXTRES bit (Bit 6) in the LCD Configuration X SFR (LCDCONX, Address 0x9C). When EXTRES = 1, the LCD waveform voltages are supplied by the external resistor ladder. Because the LCD voltages are not generated on-chip, the LCD bias compensation implemented to maintain contrast over temperature and supply is not possible.

The external circuitry needed for the resistor ladder option is shown in Figure 86. The resistors required should be in the range of 10 kΩ to 100 kΩ and should be based on the current required by the LCD being used.

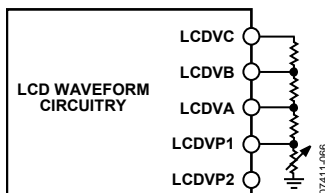


Figure 86. External Circuitry for External Resistor Ladder Option

## LCD FUNCTION IN PSM2

LCDPSM2 (Bit 4) and LCDEN (Bit 7) in the LCD configuration SFR (LCDCON, Address 0x95) control the LCD functionality in the PSM2 operating mode (see Table 102).

Note that the internal voltage reference must be enabled by setting REF\_BAT\_EN (Bit 3) in the peripheral configuration SFR (PERIPH, Address 0xF4) to allow LCD operation in PSM2 mode (see Table 19).

Table 102. Bits Controlling LCD Functionality in PSM2 Mode

| LCDPSM2 | LCDEN | Result                      |
|---------|-------|-----------------------------|
| 0       | 0     | The display is off in PSM2. |
| 0       | 1     | The display is on in PSM2.  |
| 1       | X     | The display is off in PSM2. |

In addition, note that the LCD configuration and data memory is retained when the display is turned off.

## Example LCD Setup

An example of how to set up the LCD peripheral for a specific LCD is described in this section with the following parameters:

- Type of LCD: 5 V, 4× multiplexed with 1/3 bias, 96 segment
- Voltage generation: internal charge pump
- Refresh rate: 64 Hz

A 96-segment LCD with 4× multiplexing requires  $96/4 = 24$  segment lines. Sixteen pins, FP0 to FP15, are automatically dedicated for use as LCD segments. Eight more pins must be chosen for the LCD function. Because the LCD has 4× multiplexing, all four common lines are used. As a result, COM2/FP28 and COM3/FP27 cannot be used as segment lines. Based on the alternate functions of the pins used for FP16 through FP25, FP16 to FP23 are chosen for the eight remaining segment lines. These pins are enabled for LCD functionality in the LCD segment enable SFR (LCDSEGE, Address 0x97) and LCD Segment Enable 2 SFR (LCDSEGE2, Address 0xED).

To determine contrast setting for this 5 V LCD, Table 92 shows the BIASLVL[5:0] setting in the LCD Configuration X SFR (LCDCONX, Address 0x9C) that corresponds to a  $V_C$  of 5 V in 1/3 bias mode. The maximum bias level setting for this LCD is  $\text{BIASLVL}[5:0] = 101110$ .

The LCD is set up with the following 8052 code:

```

; set up LCD pins to have LCD functionality
MOV     LCDSEG, #FP20EN+FP21EN+FP22EN+FP23EN
MOV     LCDSEGX, #FP16EN+FP17EN+FP18EN+FP19EN

; set up LCDCON for fLCDCLK=2048Hz, 1/3 bias
and 4x multiplexing
MOV     LCDCON, #BIAS+LMUX1+LMUX0

; set up LCDCONX for charge pump and
BIASLVL[110111]
MOV     LCDCONX, #BIASLVL5+BIASLVL4+BIASLVL3+BI
ASLVL2+BIASLVL1+BIASLVL0

; set up refresh rate for 64Hz with fLCDCLK =
2048 Hz
MOV     LCDCLK, #FD3+FD2+FD1+FD0

; set up LCD data registers with data to be
displayed using
; LCDPTR and LCDDATA registers
; turn all segments on FP27 ON
ORL     LCDCONY, #01h ; start data memory
refresh
MOV     LCDDAT, #F0h
MOV     LCDPTR, #80h OR 0DH
ANL     LCDCONY, #0FEh ; end of data memory
refresh
ORL     LCDCON, #LCDEN ; enable LCD

To set up the same 3.3 V LCD for use with an external resistor
ladder,

; setup LCDCONX for external resistor ladder
MOV     LCDCONX, #EXTRES
    
```

# FLASH MEMORY

## FLASH MEMORY OVERVIEW

Flash memory is a type of nonvolatile memory that is in-circuit programmable. The default, erased state of a byte of flash memory is 0xFF. When a byte of flash memory is programmed, the required bits change from 1 to 0. The flash memory must be erased to turn the 0s back to 1s. A byte of flash memory cannot, however, be erased individually. The entire segment, or page, of flash memory that contains the byte must be erased.

The ADE5166/ADE5169 provide 62 bytes of flash program/information memory. This memory is segmented into 124 pages that each contain 512 bytes. To reprogram one byte of flash memory, the 511 other bytes in that page must be erased. The flash memory can be erased by page or all at once in a mass erase. There is a command to verify that a flash write operation has completed successfully. The ADE5166/ADE5169 flash memory controller also offers configurable flash memory protection.

The 62 bytes of flash memory are provided on-chip to facilitate code execution without any external discrete ROM device requirements. The program memory can be programmed in-circuit, using the serial download mode provided or using conventional third party memory programmers.

### Flash/EE Memory Reliability

The flash memory arrays on the ADE5166/ADE5169 are fully qualified for two key Flash/EE memory characteristics: Flash/EE memory cycling endurance and Flash/EE memory data retention.

Endurance quantifies the ability of the Flash/EE memory to be cycled through many program, read, and erase cycles. In real terms, a single endurance cycle is composed of four independent, sequential events, as follows:

1. Initial page erase sequence
2. Read/verify sequence
3. Byte program sequence
4. Second read/verify sequence

In reliability qualification, every byte in both the program and data Flash/EE memory is cycled from 0x00 to 0xFF until a first fail is recorded, signifying the endurance limit of the on-chip Flash/EE memory.

As indicated in Table 4, the ADE5166/ADE5169 flash memory endurance qualification has been carried out in accordance with JEDEC Standard 22 Method A117 over the industrial temperature range of -40°C, +25°C, and +85°C. The results allow the specification of a minimum endurance figure over supply and temperature of 100,000 cycles, with a minimum endurance figure of 20,000 cycles of operation at 25°C.

Retention is the ability of the flash memory to retain its programmed data over time. Again, the parts have been qualified in accordance with the formal retention lifetime specification, JEDEC Standard 22 Method A117, at a specific junction temperature ( $T_J = 55^\circ\text{C}$ ). As part of this qualification procedure, the flash memory is cycled to its specified endurance limit, as described previously, before data retention is characterized. This means that the flash memory is guaranteed to retain its data for its full specified retention lifetime every time the flash memory is reprogrammed. It should also be noted that retention lifetime, based on an activation energy of 0.6 eV, derates with  $T_J$ , as shown in Figure 87.

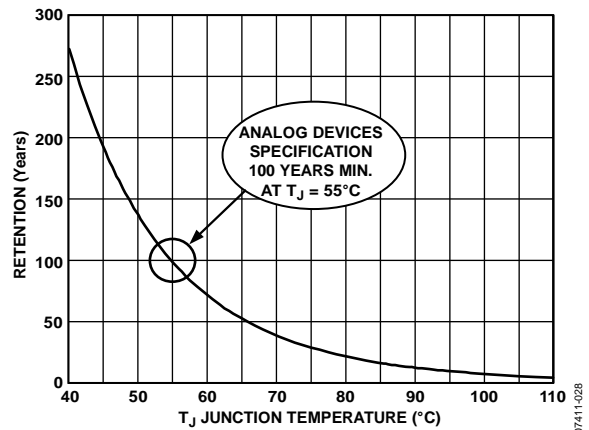


Figure 87. Flash/EE Memory Data Retention

## FLASH MEMORY ORGANIZATION

The ADE5166/ADE5169 contain a 64 kB array of Flash/EE program memory. The upper 2 kB contain permanently embedded firmware, allowing in-circuit serial download, serial debug, and nonintrusive single-pin emulation. The 2 kB of embedded firmware also contains essential coefficients that provide calibration to peripherals such as the ADCs and reference. The embedded firmware contained in the upper 2 kB of Flash/EE memory is not accessible by the user.

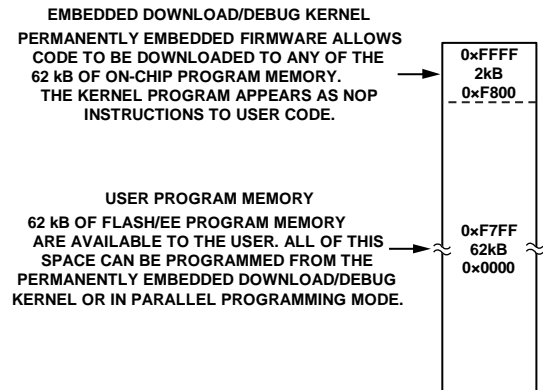


Figure 88. Flash Memory Organization

# ADE5166/ADE5169

The lower 62 bytes are available to the user for program storage or as nonvolatile data memory. They are segmented into 124 pages of 512 bytes each. It is up to the user to decide which flash memory is to be used for data memory. It is recommended that each page be dedicated solely to program or data memory so that an instance does not arise where the program counter is loaded with data memory instead of an opcode from the program memory or where program memory is erased to update a byte of data memory.

The flash memory can be protected from read or write/erase access. The protection is implemented in the upper page of user program memory. The last sixteen bytes from this page are used to configure the write/erase protection for each of the pages. The remaining four bytes are used for configuring read protection of the flash memory. The read protection is selected in groups of four pages. Finally, there is a byte used to store the key required for modifying the protection scheme. If any code protection is required, the page of information memory must be write/erase protected at a minimum.

Thus, it is recommended that if code protection is enabled, the last page of user accessible flash memory should be used only to store data that does not need modification in the field. If the firmware requires protection and may need updating in the future, the last page should be reserved for constants used by the user code that do not require modification during emulation or debug.

Page 0 through Page 122 are, therefore, available for general program and data memory use. It is recommended that Page 123 be used for constants or code that do not require future modifications. Note that the last 20 bytes of page 123 are reserved for the flash memory protection and are, therefore, unavailable to the user.

## USING THE FLASH MEMORY

The 62 bytes of flash memory are configured as 124 pages, each comprising 512 bytes. As with the other ADE5166/ADE5169 peripherals, the interface to this memory space is via a group of registers mapped in the SFR space. The flash data SFR, (EDATA, Address 0xBC) holds the byte of data to be accessed. The byte of flash memory is addressed via the EADRH SFR (Address 0xC7) and the EADRL SFR (Address 0xC6).

**Table 103. Flash SFRs**

| SFR    | Address | Default | Bit Addressable | Description             |
|--------|---------|---------|-----------------|-------------------------|
| ECON   | 0xB9    | 0x00    | No              | Flash control           |
| FLSHKY | 0xBA    | 0xFF    | No              | Flash key               |
| PROTKY | 0xBB    | 0xFF    | No              | Flash protection key    |
| EDATA  | 0xBC    | 0x00    | No              | Flash data              |
| EADRL  | 0xC6    | 0x00    | No              | Flash low byte address  |
| EADRH  | 0xC7    | 0x00    | No              | Flash high byte address |

ECON is an 8-bit flash control SFR (Address 0xB9) that can be written to with one of five flash memory access commands to trigger various read, write, erase, and verify functions. Figure 89 demonstrates the steps required for access to the flash memory.

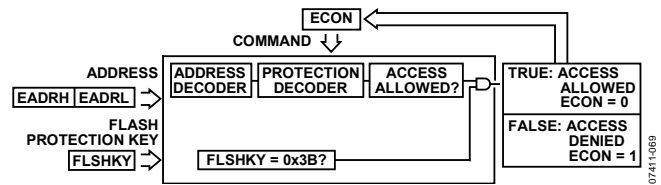


Figure 89. Flash Memory Read/Write/Erase Protection Block Diagram

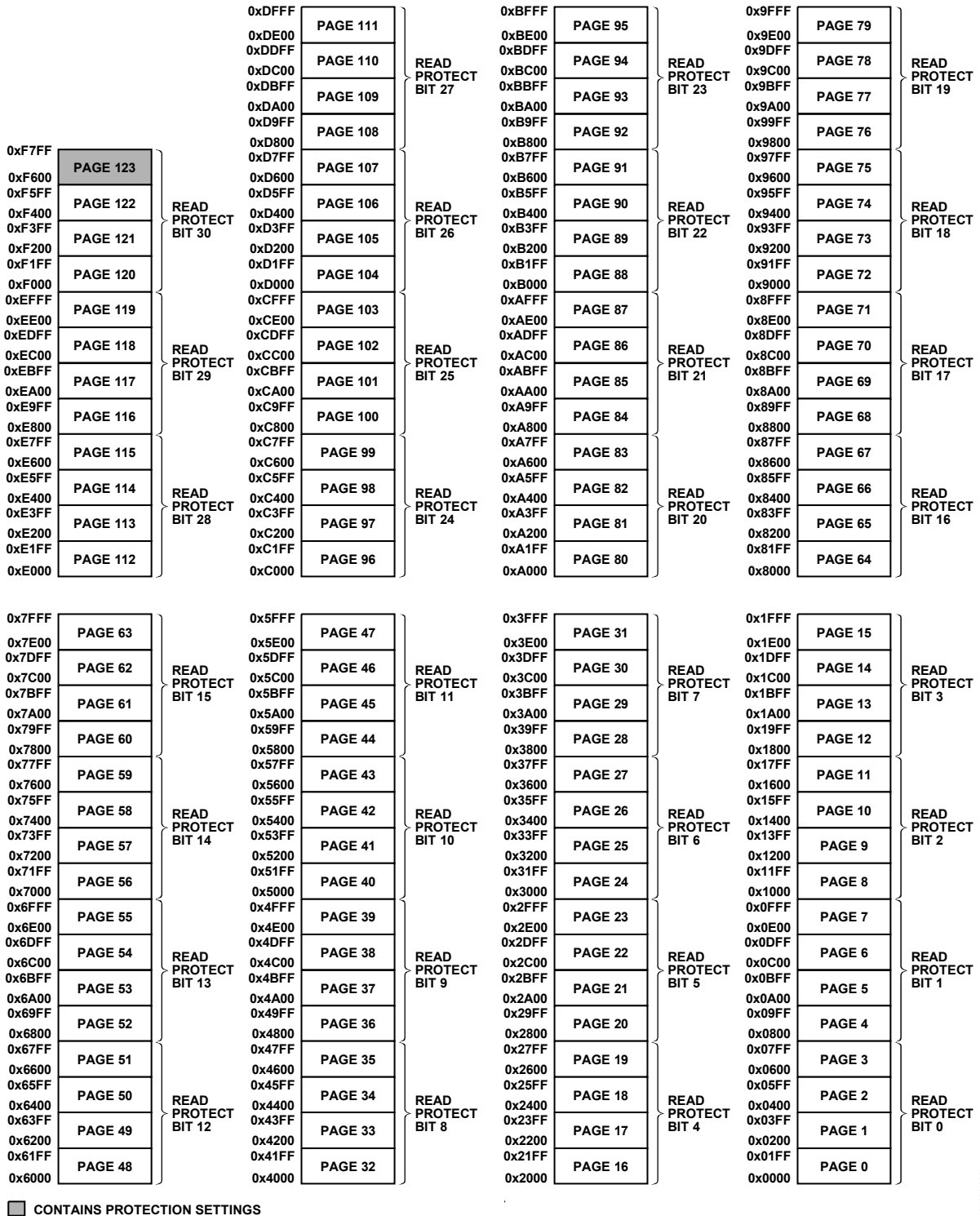


Figure 90. Flash Memory Organization

# ADE5166/ADE5169

## ECON—Flash Control SFR

Programming flash memory is done through the flash control SFR (ECON, Address 0xB9). This SFR allows the user to read, write, erase, or verify the 62 kB of flash memory. As a method of security, a key must be written to the flash key SFR (FLSHKY, Address 0xBA) to initiate any user access to the flash memory. Upon completion of the flash memory operation, the FLSHKY SFR is reset such that it must be written to before another flash memory operation. Requiring the key to be set before an access to the flash memory decreases the likelihood of user code or data being overwritten by a runaway program.

The program counter, PC, is held on the instruction where the ECON SFR is written to until the flash memory controller is done performing the requested operation. Then the PC increments to continue with the next instruction. Any interrupt requests that occur while the flash controller is performing an operation are not handled until the flash operation is complete. All peripherals, such as timers and counters, continue to operate as configured throughout the flash memory access.

**Table 104. Flash Control SFR (ECON, Address 0xB9)**

| Bit   | Mnemonic | Default | Value | Description  |
|-------|----------|---------|-------|--|
| [7:0] | ECON     | 0       | 1     | Write byte. The value in EDATA is written to the flash memory, at the page address given by EADRH (Address 0xC7) and EADRL (Address 0xC6). Note that the byte being addressed must be pre-erased.          |
|       |          |         | 2     | Erase page. A 512-byte page of flash memory address is erased. The page is selected by the address in EADRH and EADRL. Any address in the page can be written to EADRH and EADRL to select it for erasure. |
|       |          |         | 3     | Erase all. All 62 kB of the available flash memory are erased. Note that this command is used during serial mode and parallel download mode but should not be executed by user code.                       |
|       |          |         | 4     | Read byte. The byte in the flash memory, addressed by EADRH and EADRL, is read into EDATA.   |
|       |          |         | 5     | Reserved.  |
|       |          |         | 6     | Reserved.  |
|       |          |         | 7     | Reserved.  |
|       |          |         | 8     | Protect code (see the Protecting the Flash Memory section).  |

**Table 105. Flash Key SFR (FLSHKY, Address 0xBA)**

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| [7:0] | FLSHKY   | 0xFF    | The content of this SFR is compared to the flash key, 0x3B. If the two values match, the next ECON operation is allowed (see the Protecting the Flash Memory section). |

**Table 106. Flash Protection Key SFR (PROTKY, Address 0xBB)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | PROTKY   | 0xFF    | The content of this SFR is compared to the flash memory location at Address 0xF7EA. If the two values match, the update of the write/erase and read protection set up is allowed (see the Protecting the Flash Memory section).<br>If the protection key in the flash is 0xFF, the PROTKY SFR value is not used for comparison. The PROTKY SFR is also used to write the protection key in the flash. This is done by writing the desired value in PROTKY and writing 0x08 in the ECON SFR. This operation can be done only once. |

**Table 107. Flash Data SFR (EDATA, Address 0xBC)**

| Bit   | Mnemonic | Default | Description         |
|-------|----------|---------|---------------------|
| [7:0] | EDATA    | 0       | Flash pointer data. |

**Table 108. Flash Low Byte Address SFR (EADRL, Address 0xC6)**

| Bit   | Mnemonic | Default | Description                     |
|-------|----------|---------|---------------------------------|
| [7:0] | EADRL    | 0       | Flash pointer low byte address. |

**Table 109. Flash High Byte Address SFR (EADRH, Address 0xC7)**

| Bit   | Mnemonic | Default | Description                      |
|-------|----------|---------|----------------------------------|
| [7:0] | EADRH    | 0       | Flash pointer high byte address. |

### Flash Functions

The following sample 8051 code is provided to demonstrate how to use the the flash functions. For these examples, Flash Memory Byte 0x3C00 is accessed.

#### Write Byte

Write 0xF3 into Flash Memory Byte 0x3C00.

```
MOV EDATA, #F3h      ; Data to be written
MOV EADRH, #3Ch     ; Set up byte address
MOV EADRL, #00h
MOV FLSHKY, #3Bh    ; Write Flash security
key.
MOV ECON, #01H      ; Write Byte
```

#### Erase Page

Erase the page containing Flash Memory Byte 0x3C00.

```
MOV EADRH, #3Ch     ; Select page through
byte address
MOV EADRL, #00h
MOV FLSHKY, #3Bh    ; Write Flash security
key.
MOV ECON, #02H      ; Erase Page
```

#### Erase All

Erase all of the 62 kB flash memory.

```
MOV FLSHKY, #3Bh    ; Write Flash security
key.
MOV ECON, #03H      ; Erase All
```

#### Read Byte

Read Flash Memory Byte 0x3C00.

```
MOV EADRH, #3Ch     ; Setup byte address
MOV EADRL, #00h
MOV FLSHKY, #3Bh    ; Write Flash security
key.
MOV ECON, #04H      ; Read Byte
; Data is ready in EDATA register
```

Note that the read byte command can be used to view the status of the protection bytes located in the upper 21 bytes, Page 123. The write byte command is not valid for this area.

### PROTECTING THE FLASH MEMORY

Two forms of protection are offered for this flash memory: read protection and write/erase protection. The read protection ensures that any pages that are read protected cannot be read by the end user. The write protection ensures that the flash memory cannot be erased or written over. This protects the final product from tampering and can prevent the code from being overwritten in the event of a runaway program.

Write/erase protection is individually selectable for all 124 pages. Read protection is selected in groups of four pages (see Figure 90 for the groupings). The protection bits are stored in the last flash memory locations, Address 0xF7EB through Address 0xF7FF (see Figure 91). Sixteen bytes are reserved for write/erase protection, four bytes for read protection, and another byte to set the flash protection key (PROTKY, Address 0xBB). The user must enable write/erase protection for the last page, at a minimum, for the entire protection scheme to work.

Note that the read protection does not prevent MOV C commands from being executed within the code.

There is an additional layer of protection offered by a protection security key (PROTKY). The user can set up a protection security key so that the protection scheme cannot be changed without this key. When the protection key has been configured, it cannot be modified.

#### Enabling Flash Protection by Code

The protection bytes in the flash can be programmed by using the flash controller command and programming ECON to 0x08. Issuing the ECON protection command initiates the programming of one byte of protection data. The EADRL (Address 0xC6) and EDATA (Address 0xBC) data pointers are used to store the least significant address and data bytes, respectively. Note that the EADRH data pointer is not used in this command.

The following sequence should be followed to enable the flash protection:

1. Set the EDATA data pointer with the write/erase or read protection data. When erased, the protection bits default to 1, like any other bit of flash memory. The default protection setting is for no protection. To enable protection, write a 0 to the bits corresponding to the pages that should be protected. Note that when setting the read protection, each protection bit protects four pages.
2. Set the EADRL data pointer with the least significant byte of the protection address. For example, to access the protection on Page 112 through Page 119 (Address 0xF7FE), EADRL should be written to 0xFE.
3. Enable access to the flash by writing 3Bh to the FLSHKY SFR (Address 0xBA).
4. Issue the protection command by writing 08H to the ECON SFR (Address 0xB9).

Step 1 to Step 3 should be repeated for each byte that requires protection. While configuring the final byte of write/read protection, the PROTKY SFR can be enabled for a further level of code security. If enabled, the flash protection key is required to modify the protection scheme. To enable the flash protection key, the Flash Location 0xF7EB where the PROTKY is located should be written to using the flash control SFR (ECON, Address 0xB9). The PROTKY can be written to any 8-bit value; but once configured, it cannot be modified. To enable the PROTKY and activate the flash protection, the part must be reset.

# ADE5166/ADE5169

Note that after the PROTKEY has been activated by a reset, any further changes to the protection require the new 8-bit protection key to be written to the PROTKEY SFR prior to issuing the ECON command. The PROTKEY SFR is cleared automatically when the ECON 0x8 command is issued and, therefore, the user must ensure that the correct value is written to the PROTKEY SFR each time the protection scheme is changed.

The most significant bit of 0xF7FF is used to enable the lock mechanism for the watchdog (see the Watchdog Timer section for more information).

The following code provides an example of how the write/erase protection can be enabled on the first page and the PROTKEY set to 0xA3. Note that to active the following protection, the part requires a reset.

```

; enable write/erase protection on the first
page only
MOV EDATA, #0FEH      ; clear bit WP 0
MOV EADRL, #0F0H      ; write address to F7F0h
MOV FLSHKY, #3BH      ; enable flash access
    
```

```

MOV ECON, #08H        ; issue protection
command
;enable write/erase protection on last page
(this is required for any protection to be
activated)
MOV EDATA, #0F7H      ; clear bit WP123
MOV EADRL, #0FFH      ; write address to F7FFh
MOV FLSHKY, #3BH      ; enable flash access
MOV ECON, #08H        ; issue protection
command
;set up PROTKEY to A3h
MOV EDATA, #0A3H      ; set PROTKEY to A3h
MOV EADRL, #0EBH      ; write address to F7EBh
MOV FLSHKY, #3BH      ; enable flash access
MOV ECON, #08H        ; issue protection
command
    
```

Note that after the PROTKEY is changed to 0xA3, as shown in the preceding example code, all future modifications of the protection scheme require that the PROTKEY SFR to be set to 0xA3 prior to issuing the ECON protection command.

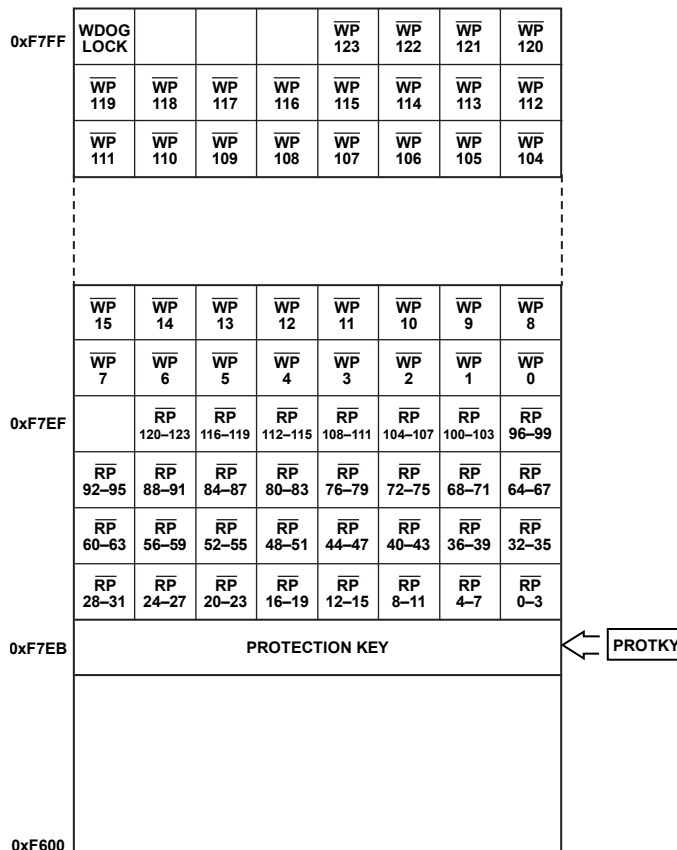


Figure 91. Flash Protection in Page 124



## Enabling Flash Protection by Emulator Commands

Another way to set the flash protection bytes is to use the reserved emulator commands available only in download mode. These commands write directly to the SFRs and can be used to duplicate the operation described in the Enabling Flash Protection by Code section. When these flash bytes are written, the part can exit emulation mode by reset and the protections are effective. This method can be used in production and implemented after downloading the program. The commands used for this operation are an extension of the commands listed in Application Note uC004, *Understanding the Serial Download Protocol*, available at [www.analog.com](http://www.analog.com).

- Command with ASCII Code I or 0x49 writes the data into R0.
- Command with ASCII Code F or 0x46 writes R0 into the SFR address defined in the data of this command.

Omitting the protocol defined in the uC004, the sequence to load protections is similar to the sequence mentioned in the Enabling Flash Protection by Code section, except that two emulator commands are necessary to replace one assembly command. For example, to write the protection value in EADRH (Address 0xC7), the following two commands must be executed:

- Command I with data = value of Protection Byte 0x3FFF
- Command F with data = 0xC7

With this protocol, the protection can be written to the flash memory using the same sequence as described in the Enabling Flash Protection by Code section. When the part is reset, the protection is effective.

### Notes on Flash Protection

The flash protection scheme is disabled by default so that none of the pages of the flash are protected from reading or writing/erasing.

The last page must be write-/erase-protected for the protection scheme to work.

To activate the protection settings, the ADE5166/ADE5169 must be reset after configuring the protection.

After configuring protection on the last page and resetting the part, protections that have been enabled can be removed only by mass erasing the flash memory. The protection bits are never truly write protected. Protection bits can be program modified from a 1 to a 0, even after the last page has been protected. In this way, more protection can be added, but none can be removed.

When the last page is read protected, the protection bits can still be read by the user code. All other bits on this page are not available for reading.

The protection scheme is intended to protect the end system. Protection should be disabled while developing and emulating code.

## Flash Memory Timing

Typical program and erase times for the flash memory are shown in Table 110.

**Table 110. Flash Memory Program and Erase Times**

| Command    | Bytes Affected | Flash Memory Timing |
|------------|----------------|---------------------|
| Write Byte | 1 byte         | 30 μs               |
| Erase Page | 512 bytes      | 20 ms               |
| Erase All  | 62 kB          | 2.5 sec             |
| Read Byte  | 1 byte         | 100 ns              |

Note that the core microcontroller operation is idled until the requested flash memory operation is complete. In practice, this means that even though the flash operation is typically initiated with a two-machine-cycle MOV instruction (to write to the flash control SFR (ECON, Address 0xB9), the next instruction is not executed until the Flash/EE operation is complete. This means that the core cannot respond to interrupt requests until the Flash/EE operation is complete, although the core peripheral functions such as counters/timers continue to count, as configured, throughout this period.

## IN CIRCUIT PROGRAMMING

### Serial Downloading

The ADE5166/ADE5169 facilitate code download via the standard UART serial port. The parts enter serial download mode after a reset or a power cycle if the  $\overline{SDEN}$  pin is pulled low through an external 1 kΩ resistor. Once in serial download mode, the hidden embedded download kernel executes. This allows the user to download code to the full 62 kB of flash memory while the device is in circuit in its target application hardware.

Protection configured in the last page of the ADE5166/ADE5169 affects whether flash memory can be accessed in serial download mode. Read protected pages cannot be read. Write/erase protected pages cannot be written or erased. The configuration bits cannot be programmed in serial download mode.

## TIMERS

Each ADE5166/ADE5169 has three 16-bit timers/counters: Timer/Counter 0, Timer/Counter 1, and Timer/Counter 2. The timer/counter hardware is included on-chip to relieve the processor core of overhead inherent in implementing timer/counter functionality in software. Each timer/counter consists of two 8-bit registers: TH<sub>x</sub> and TL<sub>x</sub> (x = 0, 1, or 2). All three timers can be configured to operate as timers or as event counters.

When functioning as a timer, the TL<sub>x</sub> SFR is incremented every machine cycle. Thus, it can be thought of as counting machine cycles. Because a machine cycle on a single cycle core consists of one core clock period, the maximum count rate is the core clock frequency.

When functioning as a counter, the TL<sub>x</sub> register is incremented by a 1-to-0 transition at its corresponding external input pin: T0, T1, or T2. When the samples show a high in one cycle and a low in the next cycle, the count is incremented. Because it takes two machine cycles (two core clock periods) to recognize a 1-to-0 transition, the maximum count rate is half the core clock frequency.

There are no restrictions on the duty cycle of the external input signal, but to ensure that a given level is sampled at least once before it changes, it must be held for a minimum of one full machine cycle. User configuration and control of all timer operating modes is achieved via the SFRs listed in Table 111.

**Table 111. Timer SFRs**

| SFR    | Address | Bit Addressable | Description  |
|--------|---------|-----------------|--|
| TCON   | 0x88    | Yes             | Timer/Counter 0 and Timer/Counter 1 control (see Table 113). |
| TMOD   | 0x89    | No              | Timer/Counter 0 and Timer/Counter 1 mode (see Table 112).    |
| TL0    | 0x8A    | No              | Timer 0 low byte (see Table 116).                            |
| TL1    | 0x8B    | No              | Timer 1 low byte (see Table 118).                            |
| TH0    | 0x8C    | No              | Timer 0 high byte (see Table 115).                           |
| TH1    | 0x8D    | No              | Timer 1 high byte (see Table 117).                           |
| T2CON  | 0xC8    | Yes             | Timer/Counter 2 control (see Table 114).                     |
| RCAP2L | 0xCA    | No              | Timer 2 reload/capture low byte (see Table 122).             |
| RCAP2H | 0xCB    | No              | Timer 2 reload/capture high byte (see Table 121).            |
| TL2    | 0xCC    | No              | Timer 2 low byte (see Table 120).                            |
| TH2    | 0xCD    | No              | Timer 2 high byte (see Table 119).                           |

## TIMER REGISTERS

**Table 112. Timer/Counter 0 and Timer/Counter 1 Mode SFR (TMOD, Address 0x89)**

| Bit          | Mnemonic   | Default | Description  |              |        |    |  |    |  |    |   |    |  |
|--------------|--|---------|--|--------------|--------|----|--|----|--|----|---|----|--|
| 7            | Gate1  | 0       | Timer 1 gating control. Set by software to enable Timer/Counter 1 only when the INT1 pin is high and the TR1 control bit (Address 0x88[6]) is set. Cleared by software to enable Timer 1 whenever the TR1 control bit is set.  |              |        |    |  |    |  |    |   |    |  |
| 6            | C/T1   | 0       | Timer 1 timer or counter select bit. Set by software to select counter operation (input from T1 pin). Cleared by software to select the timer operation (input from internal system clock).  |              |        |    |  |    |  |    |   |    |  |
| [5:4]        | T1/M1, T1/M0   | 00      | Timer 1 mode select bits.<br><table border="1"> <thead> <tr> <th>T1/M1, T1/M0</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>TH1 (Address 0x8D) operates as an 8-bit timer/counter. TL1 (Address 0x8B) serves as a 5-bit prescaler.</td> </tr> <tr> <td>01</td> <td>16-bit timer/counter. TH1 and TL1 are cascaded; there is no prescaler.</td> </tr> <tr> <td>10</td> <td>8-bit autoreload timer/counter. TH1 holds a value to reload into TL1 each time it overflows.</td> </tr> <tr> <td>11</td> <td>Timer/Counter 1 stopped.</td> </tr> </tbody> </table>  | T1/M1, T1/M0 | Result | 00 | TH1 (Address 0x8D) operates as an 8-bit timer/counter. TL1 (Address 0x8B) serves as a 5-bit prescaler. | 01 | 16-bit timer/counter. TH1 and TL1 are cascaded; there is no prescaler. | 10 | 8-bit autoreload timer/counter. TH1 holds a value to reload into TL1 each time it overflows.  | 11 | Timer/Counter 1 stopped.   |
| T1/M1, T1/M0 | Result   |         |  |              |        |    |  |    |  |    |   |    |  |
| 00           | TH1 (Address 0x8D) operates as an 8-bit timer/counter. TL1 (Address 0x8B) serves as a 5-bit prescaler.   |         |  |              |        |    |  |    |  |    |   |    |  |
| 01           | 16-bit timer/counter. TH1 and TL1 are cascaded; there is no prescaler.   |         |  |              |        |    |  |    |  |    |   |    |  |
| 10           | 8-bit autoreload timer/counter. TH1 holds a value to reload into TL1 each time it overflows.   |         |  |              |        |    |  |    |  |    |   |    |  |
| 11           | Timer/Counter 1 stopped.   |         |  |              |        |    |  |    |  |    |   |    |  |
| 3            | Gate0  | 0       | Timer 0 gating control. Set by software to enable Timer/Counter 0 only when the INT0 pin is high and the TR0 control bit (Address 0x88[4]) is set. Cleared by software to enable Timer 0 whenever the TR0 control bit is set in the Timer/Counter 0 and Timer/Counter 1 control SFR (TCON, Address 0x88).  |              |        |    |  |    |  |    |   |    |  |
| 2            | C/T0   | 0       | Timer 0 timer or counter select bit. Set by software to the select counter operation (input from the T0 pin). Cleared by software to the select timer operation (input from internal system clock).  |              |        |    |  |    |  |    |   |    |  |
| [1:0]        | T0/M1, T0/M0   | 00      | Timer 0 mode select bits.<br><table border="1"> <thead> <tr> <th>T0/M1, T0/M0</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>TH0 operates as an 8-bit timer/counter. TL0 serves as a 5-bit prescaler.</td> </tr> <tr> <td>01</td> <td>16-bit timer/counter. TH0 and TL0 are cascaded; there is no prescaler.</td> </tr> <tr> <td>10</td> <td>8-bit autoreload timer/counter. TH0 holds a value to reload into TL0 each time TL0 overflows.</td> </tr> <tr> <td>11</td> <td>TL0 is an 8-bit timer/counter controlled by the standard Timer 0 control bits. TH0 is an 8-bit timer only, controlled by Timer 1 control bits.</td> </tr> </tbody> </table> | T0/M1, T0/M0 | Result | 00 | TH0 operates as an 8-bit timer/counter. TL0 serves as a 5-bit prescaler.                               | 01 | 16-bit timer/counter. TH0 and TL0 are cascaded; there is no prescaler. | 10 | 8-bit autoreload timer/counter. TH0 holds a value to reload into TL0 each time TL0 overflows. | 11 | TL0 is an 8-bit timer/counter controlled by the standard Timer 0 control bits. TH0 is an 8-bit timer only, controlled by Timer 1 control bits. |
| T0/M1, T0/M0 | Result   |         |  |              |        |    |  |    |  |    |   |    |  |
| 00           | TH0 operates as an 8-bit timer/counter. TL0 serves as a 5-bit prescaler.   |         |  |              |        |    |  |    |  |    |   |    |  |
| 01           | 16-bit timer/counter. TH0 and TL0 are cascaded; there is no prescaler.   |         |  |              |        |    |  |    |  |    |   |    |  |
| 10           | 8-bit autoreload timer/counter. TH0 holds a value to reload into TL0 each time TL0 overflows.  |         |  |              |        |    |  |    |  |    |   |    |  |
| 11           | TL0 is an 8-bit timer/counter controlled by the standard Timer 0 control bits. TH0 is an 8-bit timer only, controlled by Timer 1 control bits. |         |  |              |        |    |  |    |  |    |   |    |  |

**Table 113. Timer/Counter 0 and Timer/Counter 1 Control SFR (TCON, Address 0x88)**

| Bit | Bit Address | Mnemonic         | Default | Description   |
|-----|-------------|------------------|---------|---|
| 7   | 0x8F        | TF1              | 0       | Timer 1 overflow flag. Set by hardware on a Timer/Counter 1 overflow. Cleared by hardware when the program counter (PC) vectors to the interrupt service routine.   |
| 6   | 0x8E        | TR1              | 0       | Timer 1 run control bit. Set by the user to turn on Timer/Counter 1. Cleared by the user to turn off Timer/Counter 1.   |
| 5   | 0x8D        | TF0              | 0       | Timer 0 overflow flag. Set by hardware on a Timer/Counter 0 overflow. Cleared by hardware when the PC vectors to the interrupt service routine.   |
| 4   | 0x8C        | TR0              | 0       | Timer 0 run control bit. Set by the user to turn on Timer/Counter 0. Cleared by the user to turn off Timer/Counter 0.   |
| 3   | 0x8B        | IE1 <sup>1</sup> | 0       | External Interrupt 1 ( $\overline{INT1}$ ) flag. Set by hardware by a falling edge or by a zero level applied to the external interrupt pin, $\overline{INT1}$ , depending on the state of Bit IT1. Cleared by hardware when the PC vectors to the interrupt service routine only if the interrupt was transition activated. If level activated, the external requesting source, rather than the on-chip hardware, controls the request flag.       |
| 2   | 0x8A        | IT1 <sup>1</sup> | 0       | External Interrupt 1 (IE1) trigger type. Set by software to specify edge sensitive detection, that is, a 1-to-0 transition. Cleared by software to specify level sensitive detection, that is, zero level.  |
| 1   | 0x89        | IE0 <sup>1</sup> | 0       | External Interrupt 0 ( $\overline{INT0}$ ) flag. Set by hardware by a falling edge or by a zero level being applied to the external interrupt pin, $\overline{INT0}$ , depending on the state of Bit IT0. Cleared by hardware when the PC vectors to the interrupt service routine only if the interrupt was transition activated. If level activated, the external requesting source, rather than the on-chip hardware, controls the request flag. |
| 0   | 0x88        | IT0 <sup>1</sup> | 0       | External Interrupt 0 (IE0) trigger type. Set by software to specify edge sensitive detection, that is, 1-to-0 transition. Cleared by software to specify level sensitive detection, that is, zero level.  |

<sup>1</sup> These bits are not used to control Timer/Counter 0 and Timer/Counter 1 but are instead used to control and monitor the external  $\overline{INT0}$  and  $\overline{INT1}$  interrupt pins.

**Table 114. Timer/Counter 2 Control SFR (T2CON, Address 0xC8)**

| Bit | Bit Address | Mnemonic | Default | Description   |
|-----|-------------|----------|---------|---|
| 7   | 0xCF        | TF2      | 0       | Timer 2 overflow flag. Set by hardware on a Timer 2 overflow. TF2 cannot be set when either RCLK = 1 or TCLK = 1. Cleared by user software.   |
| 6   | 0xCE        | EXF2     | 0       | Timer 2 external flag. Set by hardware when either a capture or reload is caused by a negative transition on the T2EX pin and EXEN2 = 1. Cleared by user software.  |
| 5   | 0xCD        | RCLK     | 0       | Receive clock enable bit. Set by the user to enable the serial port to use Timer 2 overflow pulses for its receive clock in Serial Port Mode 1 and Serial Port Mode 3. Cleared by the user to enable Timer 1 overflow to be used for the receive clock.   |
| 4   | 0xCC        | TCLK     | 0       | Transmit clock enable bit. Set by the user to enable the serial port to use Timer 2 overflow pulses for its transmit clock in Serial Port Mode 1 and Serial Port Mode 3. Cleared by the user to enable Timer 1 overflow to be used for the transmit clock.  |
| 3   | 0xCB        | EXEN2    | 0       | Timer 2 external enable flag. Set by the user to enable a capture or reload to occur as a result of a negative transition on the T2EX pin if Timer 2 is not being used to clock the serial port. Cleared by the user for Timer 2 to ignore events at T2EX.  |
| 2   | 0xCA        | TR2      | 0       | Timer 2 start/stop control bit. Set by the user to start Timer 2. Cleared by the user to stop Timer 2.  |
| 1   | 0xC9        | C/T2     | 0       | Timer 2 timer or counter function select bit. Set by the user to select the counter function (input from the external T2 pin). Cleared by the user to select the timer function (input from the on-chip core clock).  |
| 0   | 0xC8        | CAP2     | 0       | Timer 2 capture/reload select bit. Set by the user to enable captures on negative transitions at the T2EX pin if EXEN2 = 1. Cleared by the user to enable autoreloads with Timer 2 overflows or negative transitions at the T2EX pin when EXEN2 = 1. When either RCLK = 1 or TCLK = 1, this bit is ignored and the timer is forced to autoreload on Timer 2 overflow. |

# ADE5166/ADE5169

**Table 115. Timer 0 High Byte SFR (TH0, Address 0x8C)**

| Bit   | Mnemonic | Default | Description             |
|-------|----------|---------|-------------------------|
| [7:0] | TH0      | 0       | Timer 0 data high byte. |

**Table 116. Timer 0 Low Byte SFR (TL0, Address 0x8A)**

| Bit   | Mnemonic | Default | Description            |
|-------|----------|---------|------------------------|
| [7:0] | TL0      | 0       | Timer 0 data low byte. |

**Table 117. Timer 1 High Byte SFR (TH1, Address 0x8D)**

| Bit   | Mnemonic | Default | Description             |
|-------|----------|---------|-------------------------|
| [7:0] | TH1      | 0       | Timer 1 data high byte. |

**Table 118. Timer 1 Low Byte SFR (TL1, Address 0x8B)**

| Bit   | Mnemonic | Default | Description            |
|-------|----------|---------|------------------------|
| [7:0] | TL1      | 0       | Timer 1 data low byte. |

**Table 119. Timer 2 High Byte SFR (TH2, Address 0xCD)**

| Bit   | Mnemonic | Default | Description             |
|-------|----------|---------|-------------------------|
| [7:0] | TH2      | 0       | Timer 2 data high byte. |

**Table 120. Timer 2 Low Byte SFR (TL2, Address 0xCC)**

| Bit   | Mnemonic | Default | Description            |
|-------|----------|---------|------------------------|
| [7:0] | TL2      | 0       | Timer 2 data low byte. |

**Table 121. Timer 2 Reload/Capture High Byte SFR (RCAP2H, Address 0xCB)**

| Bit   | Mnemonic | Default | Description                       |
|-------|----------|---------|-----------------------------------|
| [7:0] | TH2      | 0       | Timer 2 reload/capture high byte. |

**Table 122. Timer 2 Reload/Capture Low Byte SFR (RCAP2L, Address 0xCA)**

| Bit   | Mnemonic | Default | Description                      |
|-------|----------|---------|----------------------------------|
| [7:0] | TL2      | 0       | Timer 2 reload/capture low byte. |

## TIMER 0 AND TIMER 1

### Timer 0 High/Low and Timer 1 High/Low Data Registers

Each timer consists of two 8-bit SFRs. For Timer 0, they are Timer 0 high byte (TH0, Address 0x8C) and Timer 0 low byte (TL0, Address 0x8A). For Timer 1, they are Timer 1 high byte (TH1, Address 0x8D) and Timer 1 low byte (TL1, Address 0x8B). These SFRs can be used as independent registers or combined into a single 16-bit register, depending on the timer mode configuration (see Table 115 to Table 118).

### Timer/Counter 0 and Timer/Counter 1 Operating Modes

This section describes the operating modes for Timer/Counter 0 and Timer/Counter 1. Unless otherwise noted, these modes of operation are the same for both Timer 0 and Timer 1.

## Mode 0 (13-Bit Timer/Counter)

Mode 0 configures an 8-bit timer/counter. Figure 92 shows Mode 0 operation. Note that the divide-by-12 prescaler is not present on the single cycle core.

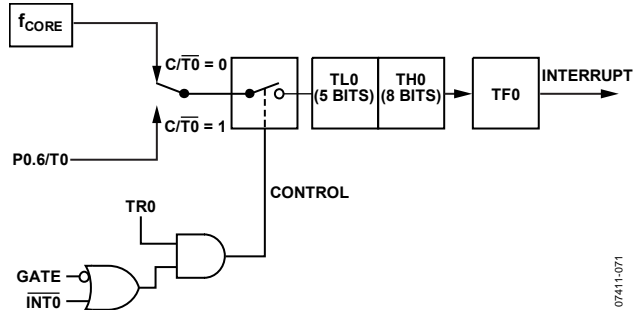


Figure 92. Timer/Counter 0, Mode 0

In this mode, the timer register is configured as a 13-bit register. As the count rolls over from all 1s to all 0s, it sets the timer overflow flag, TF0 (Address 0x88[5]). TF0 can then be used to request an interrupt. The counted input is enabled to the timer when  $TR0 = 1$  and either  $\overline{Gate0} = 0$  or  $\overline{INT0} = 1$ . Setting  $\overline{Gate0} = 1$  allows the timer to be controlled by the external input,  $\overline{INT0}$ , to facilitate pulse width measurements. TR0 is a control bit located in the Timer/Counter 0 and Timer/Counter 1 control SFR (TCON, Address 0x88[4]); the Gate0/Gate1 bits are in Timer/Counter 0 and Timer/Counter 1 mode SFR (TMOD, Address 0x89, Bit 3 and Bit 7, respectively). The 13-bit register consists of all eight bits of Timer 0 high byte SFR (TH0, Address 0x8C) and the lower five bits of Timer 0 low byte SFR (TL0, Address 0x8A). The upper three bits of TL0 SFR are indeterminate and should be ignored. Setting the run flag (TR0) does not clear the registers.

## Mode 1 (16-Bit Timer/Counter)

Mode 1 is the same as Mode 0 except that the Mode 1 timer register runs with all 16 bits. Mode 1 is shown in Figure 93.

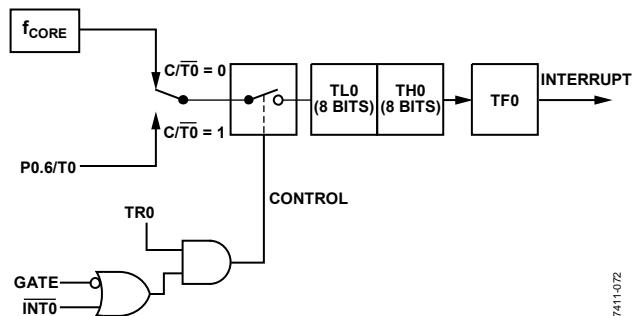


Figure 93. Timer/Counter 0, Mode 1

**Mode 2 (8-Bit Timer/Counter with Autoreload)**

Mode 2 configures the timer register as an 8-bit counter (TL0) with automatic reload, as shown in Figure 94. Overflow from TL0 not only sets TF0 but also reloads TL0 with the contents of TH0, which is preset by software. The reload leaves TH0 unchanged.

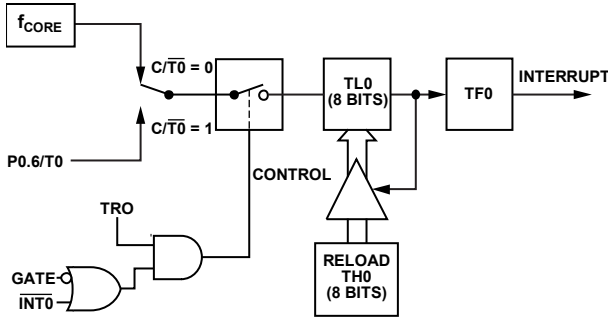


Figure 94. Timer/Counter 0, Mode 2

**Mode 3 (Two 8-Bit Timer/Counters)**

Mode 3 has different effects on Timer 0 and Timer 1. Timer 1 in Mode 3 simply holds its count. The effect is the same as setting TR1 = 0. Timer 0 in Mode 3 establishes TL0 and TH0 as two separate counters. This configuration is shown in Figure 95. TL0 uses the Timer 0 control bits,  $\overline{C/T0}$ , Gate0 (see Table 112), TR0, TF0 (see Table 113), and the  $\overline{INT0}$  pin. TH0 is locked into a timer function (counting machine cycles) and takes over the use of TR1 and TF1 from Timer 1. Therefore, TH0 controls the Timer 1 interrupt. Mode 3 is provided for applications requiring an extra 8-bit timer or counter.

When Timer 0 is in Mode 3, Timer 1 can be turned on and off by switching it out of and into its own Mode 3, or it can be used by the serial interface as a baud rate generator. In fact, Timer 1 can be used in any application not requiring an interrupt from Timer 1 itself.

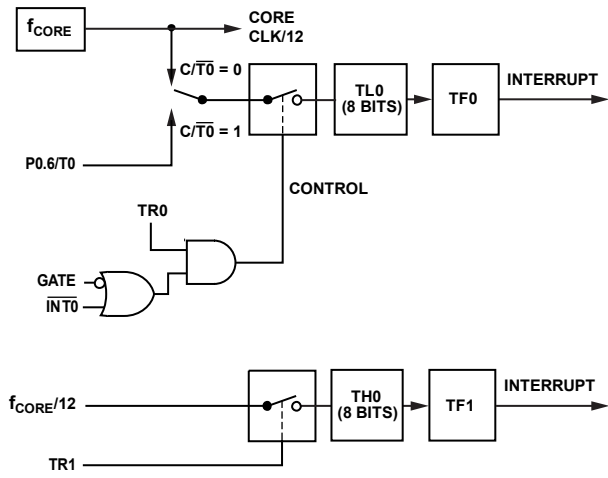


Figure 95. Timer/Counter 0, Mode 3

**TIMER 2**

**Timer/Counter 2 Data Registers**

Timer/Counter 2 also has two pairs of 8-bit data registers associated with it: Timer 2 high byte SFR (TH2, Address 0xCD), Timer 2 low byte SFR (TL2, Address 0xCC), Timer 2 reload/capture high byte SFR (RCAP2H, Address 0xCB), and Timer 2 reload/capture low byte SFR (RCAP2L, Address 0xCA). These are used both as timer data registers and as timer capture/reload registers (see Table 119 to Table 122).

**Timer/Counter 2 Operating Modes**

The following sections describe the operating modes for Timer/Counter 2. The operating modes are selected by bits in the Timer/Counter 2 control SFR (T2CON, Address 0xC8), as shown in Table 114 and Table 123.

Table 123. T2CON Operating Modes

| RCLK or TCLK | CAP2 | TR2 | Mode              |
|--------------|------|-----|-------------------|
| 0            | 0    | 1   | 16-bit autoreload |
| 0            | 1    | 1   | 16-bit capture    |
| 1            | X    | 1   | Baud rate         |
| X            | X    | 0   | Off               |

**16-Bit Autoreload Mode**

The 16-bit autoreload mode has two options that are selected by EXEN2 (Bit 3) in the Timer/Counter 2 control SFR (T2CON, Address 0xC8). If EXEN2 = 0 when Timer 2 rolls over, it not only sets TF2 but also causes the Timer 2 SFRs to be reloaded with the 16-bit value in both the Timer 2 reload/capture high byte SFR (RCAP2H, Address 0xCB) and Timer 2 reload/capture low byte SFR (RCAP2L, Address 0xCA) registers, which are preset by software. If EXEN2 = 1, Timer 2 performs the same events as when EXEN2 = 0 but adds a 1-to-0 transition at the external input pin, T2EX, which triggers the 16-bit reload and sets EXF2. Autoreload mode is shown in Figure 96.

**16-Bit Capture Mode**

The 16-bit capture mode has two options that are selected by EXEN2 (Bit 3) in the Timer/Counter 2 control SFR (T2CON, Address 0xC8). If EXEN2 = 0, Timer 2 is a 16-bit timer or counter that, upon overflowing, sets the Timer 2 overflow bit (TF2, Bit 7). This bit can be used to generate an interrupt. If EXEN2 = 1, then Timer 2 performs the same events as when EXEN2 = 0, but it adds a 1-to-0 transition on the T2E external input, causing the current value in the Timer 2 SFRs, TL2 (Address 0xCC) and TH2 (Address 0xCD) to be captured into the RCAP2L (Address 0xCA) and RCAP2H (Address 0xCB) SFRs, respectively. In addition, the transition at T2EX causes the EXF2 bit (Bit 6) in the T2CON SFR (Address 0xC8) to be set, and EXF2, like TF2, can generate an interrupt. Capture mode is shown in Figure 97. The baud rate generator mode is selected by RCLK = 1 and/or TCLK = 1.

In either case, if Timer 2 is used to generate the baud rate, the TF2 interrupt flag does not occur. Therefore, Timer 2 interrupts do not occur and do not have to be disabled. In this mode, the EXF2 flag

can, however, still cause interrupts that can be used as a third external interrupt. Baud rate generation is described as part of the UART serial port operation in the UART Serial Interface section.

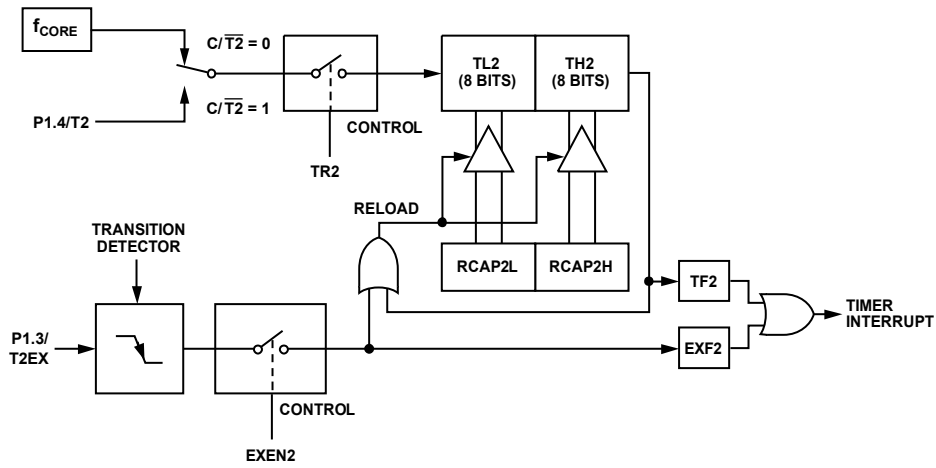


Figure 96. Timer/Counter 2, 16-Bit Autoreload Mode

07411-075

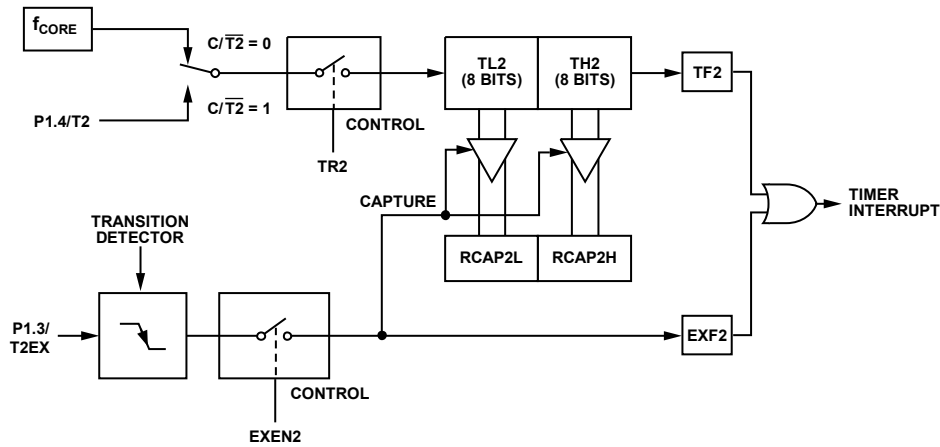


Figure 97. Timer/Counter 2, 16-Bit Capture Mode

07411-076

## PLL

The ADE5166/ADE5169 are intended for use with a 32.768 kHz watch crystal. A PLL locks onto a multiple of this frequency to provide a stable 4.096 MHz clock for the system. The core can operate at this frequency or at binary submultiples of it to allow power savings when maximum core performance is not required. The default core clock is the PLL clock divided by 4, or 1.024 MHz. The ADE energy measurement clock is derived from the PLL clock and is maintained at 4.096 MHz/5 MHz (or 819.2 kHz) across all CD settings.

The PLL is controlled by the CD[2:0] bits in the power control SFR (POWCON, Address 0xC5). To protect erroneous changes to the POWCON SFR, a key is required to modify the register. First, the key SFR (KYREG, Address 0xC1) is written with the key, 0xA7, and then a new value is written to the POWCON SFR.

If the PLL loses lock, the MCU is reset and the PLL\_FLT bit (Bit 4) is set in the peripheral configuration SFR (PERIPH, Address 0xF4). Set the PLLACK bit in the start ADC measurement SFR (ADCGO, Address 0xD8) to acknowledge the PLL fault, clearing the PLL\_FLT bit.

## PLL REGISTERS

**Table 124. Power Control SFR (POWCON, Address 0xC5)**

| Bit   | Mnemonic                    | Default | Description   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
|-------|-----------------------------|---------|---|----|-----------------------------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|-----|-------|
| 7     | Reserved                    | 1       | Reserved.   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 6     | METER_OFF                   | 0       | Set this bit to 1 to turn off the modulators and energy metering DSP circuitry to reduce power if metering functions are not needed in PSM0.  |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 5     | Reserved                    | 0       | This bit should be kept at 0 for proper operation.  |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 4     | COREOFF                     | 0       | Set this bit to 1 to shut down the core if in the PSM1 operating mode.  |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 3     | Reserved                    |         | Reserved.   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| [2:0] | CD                          | 010     | Controls the core clock frequency ( $f_{CORE}$ ). $f_{CORE} = 4.096 \text{ MHz}/2^{CD}$ .   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
|       |                             |         | <table border="1"> <thead> <tr> <th>CD</th> <th>Result (<math>f_{CORE}</math> in MHz)</th> </tr> </thead> <tbody> <tr> <td>000</td> <td>4.096</td> </tr> <tr> <td>001</td> <td>2.048</td> </tr> <tr> <td>010</td> <td>1.024</td> </tr> <tr> <td>011</td> <td>0.512</td> </tr> <tr> <td>100</td> <td>0.256</td> </tr> <tr> <td>101</td> <td>0.128</td> </tr> <tr> <td>110</td> <td>0.064</td> </tr> <tr> <td>111</td> <td>0.032</td> </tr> </tbody> </table> | CD | Result ( $f_{CORE}$ in MHz) | 000 | 4.096 | 001 | 2.048 | 010 | 1.024 | 011 | 0.512 | 100 | 0.256 | 101 | 0.128 | 110 | 0.064 | 111 | 0.032 |
| CD    | Result ( $f_{CORE}$ in MHz) |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 000   | 4.096                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 001   | 2.048                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 010   | 1.024                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 011   | 0.512                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 100   | 0.256                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 101   | 0.128                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 110   | 0.064                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |
| 111   | 0.032                       |         |   |    |                             |     |       |     |       |     |       |     |       |     |       |     |       |     |       |     |       |

### Writing to the Power Control SFR (POWCON, Address 0xC5)

Note that writing data to the POWCON SFR involves writing 0xA7 into the key SFR (KYREG, Address 0xC1), followed by a write to the POWCON SFR.

**Table 125. Key SFR (KYREG, Address 0xC1)**

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| [7:0] | KYREG    | 0       | Write 0xA7 to the KYREG SFR before writing to the POWCON SFR to unlock it.<br>Write 0xEA to the KYREG SFR before writing to the INTPR, HTHSEC, SEC, MIN, or HOUR timekeeping registers to unlock them (see the RTC Registers section). |

## REAL-TIME CLOCK (RTC)

The ADE5166/ADE5169 have an embedded RTC (see Figure 98). The external 32.768 kHz crystal is used as the clock source for the RTC. Calibration is provided to compensate the nominal crystal frequency and for variations in the external crystal frequency over temperature. By default, the RTC is active in all the power saving modes. The RTC counters retain their values through watchdog resets and external resets and are reset only during a power-on reset.

The ADE5166/ADE5169 provide two ways to access the RTC data: by direct access through SFRs for configuration and by indirect access through address and data SFRs for the timekeeping registers and some other configurations. The address and data SFRs act as pointers to the RTC internal registers.

### ACCESS TO RTC SFRs

Access to the RTC SFRs is achieved by reading or writing to the SFR addresses that are detailed in the Access to Internal RTC Registers section. Writing to the indirect registers is protected by a key, as explained in the Writing to Internal RTC Registers section. Reading is not protected.

### ACCESS TO INTERNAL RTC REGISTERS

Access to the internal RTC measurement registers is achieved by writing to the RTC pointer address SFR (RTCPTR, Address 0xA3). The RTCPTR register selects the RTC register to be accessed and determines if a read or a write is performed (see Table 129).

#### Writing to Internal RTC Registers

The RTC circuitry runs off a 32.768 kHz clock. The timekeeping registers, HTHSEC, SEC, MIN, HOUR, DAY, DATE, MONTH, and YEAR are updated with a 32.768 kHz clock. However, the TIMECON (Address 0xA1) and TIMECON2 (Address 0xA2) SFRs and the INTVAL register (Address 0x09) are updated with a 128 Hz clock. It takes up to two 128 Hz clock cycles from when the MCU writes the TIMECON, TIMECON2, or INTVAL SFRs until they are successfully updated in the RTC.

When the RTCW\_RB bit of the RTCPTR SFR (Address 0xA3) is set, the content of the RTCDAT SFR (Address 0xA4) is transferred to the internal RTC register designated by the address in the RTCPTR SFR. To protect the RTC timekeeping registers from runaway code, a key must be written to the KYREG SFR (Address 0xC1) to obtain write access to any of the RTC indirect registers. The KYREG should be set to 0xEA to unlock the timekeeping registers and is reset to zero after a timekeeping register is written.

The RTC registers can be written using the following 8052 assembly code:

```
MOV    RTCKey, #0EAh
CALL   UpdateRTC
...
UpdateRTC:
MOV    KYREG, RTCKey
MOV    RTCDAT, #30
MOV    RTCPTR, #82h
MOV    KYREG, RTCKey
MOV    RTCDAT, #05
MOV    RTCPTR, #83h
MOV    KYREG, RTCKey
MOV    RTCDAT, #04
MOV    RTCPTR, #84h
MOV    RTCKey, #00h
RET
```

#### Reading Internal Energy Measurement Registers

When Bit 7 of the RTCPTR SFR is cleared, the content of the internal RTC data register designated by the address in RTCPTR is transferred to the RTCDAT SFR. The RTC cannot be stopped to read the current time because stopping the RTC introduces an error in its timekeeping. Therefore, the RTC is read on-the-fly, and the counter registers must be checked for overflow. This can be accomplished using the following 8052 assembly code:

```
ReadAgain:
MOV    RTCPTR #01    ; Read HTHSEC using Bank
0
MOV    R0, RTCDAT
MOV    RTCPTR, #02    ; Read SEC
MOV    R1, RTCDAT
MOV    RTCPTR, #03    ; Read MIN
MOV    R2, RTCDAT
MOV    RTCPTR, #04    ; Read HOUR
MOV    R3, RTCDAT
MOV    RTCPTR, #01    ; Read HTHSEC
MOV    A, RTCDAT
CJNE  A, 00h, ReadAgain    ; 00h is R0 in
Bank 0
```



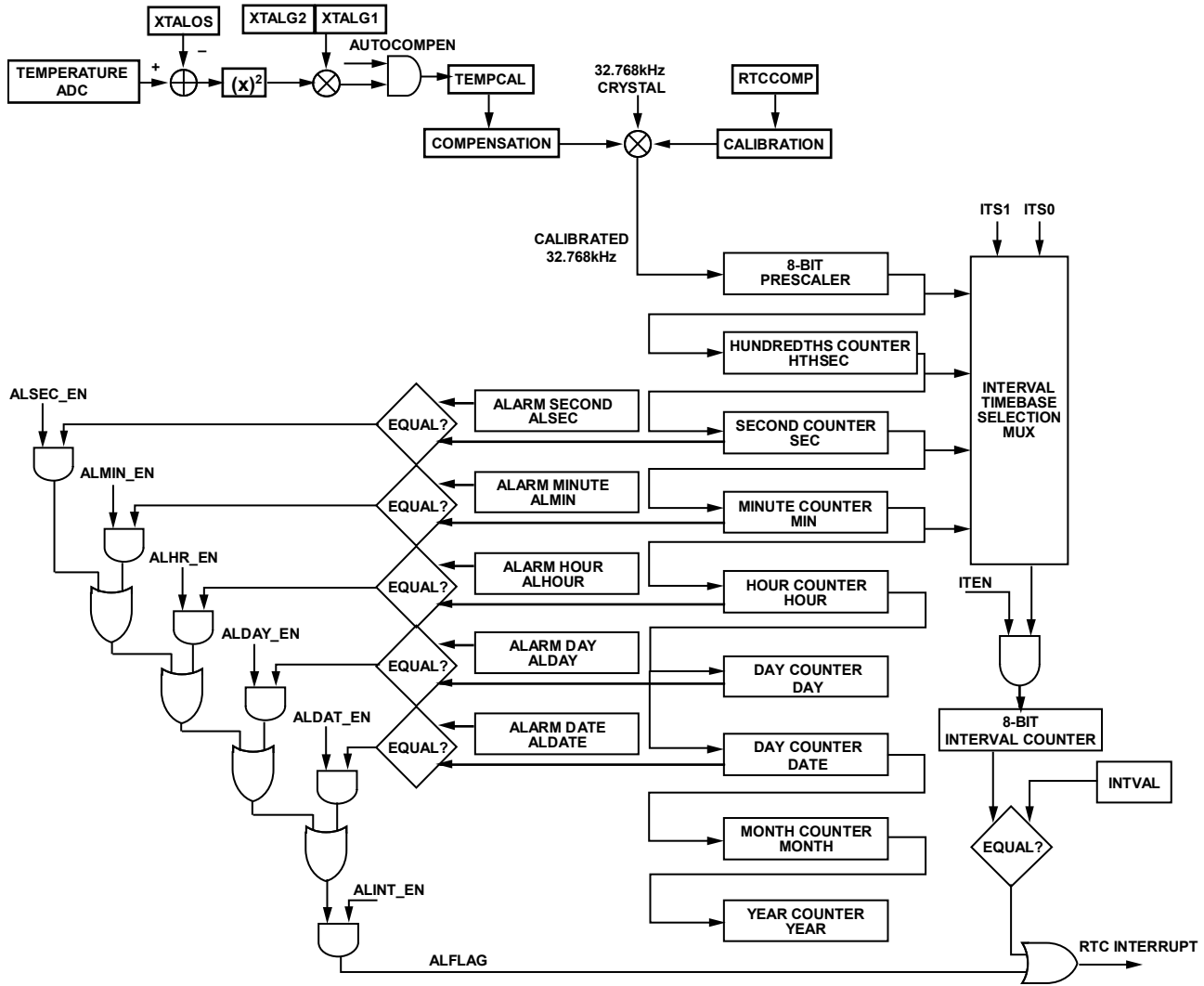


Figure 98. RTC Implementation

**RTC SFRs**

Table 126. List of RTC SFRs

| SFR      | Address | Bit Addressable | Description   |
|----------|---------|-----------------|---|
| TIMECON  | 0xA1    | No              | RTC configuration (see Table 127).  |
| TIMECON2 | 0xA2    | No              | RTC Configuration 2 (see Table 128).  |
| RTCPTR   | 0xA3    | No              | RTC pointer address (see Table 129).  |
| RTCDAT   | 0xA4    | No              | RTC pointer data (see Table 130).   |
| KYREG    | 0xC1    | No              | Key (see Table 133).  |
| RTCCOMP  | 0xF6    | No              | RTC nominal compensation (see Table 131).                                   |
| TEMPCAL  | 0xF7    | No              | RTC temperature compensation (see Table 132). This is a read only register. |

# ADE5166/ADE5169

**Table 127. RTC Configuration SFR (TIMECON, Address 0xA1)**

| Bit   | Mnemonic   | Default | Description   |  |
|-------|------------|---------|---|--|
| 7     | Reserved   | N/A     | Reserved.   |  |
| 6     | ALFLAG     | 0       | Alarm flag. This bit is set when the RTC registers match the enabled alarm registers. It can be cleared by the user to indicate that the alarm has been serviced.     |  |
| [5:4] | ITS1, ITS0 | 0       | INTVAL timebase select bits.  |  |
|       |            |         | <b>ITS1, ITS0</b>   | <b>Timebase</b>  |
|       |            |         | 00  | 1/128 sec  |
|       |            |         | 01  | Second   |
|       |            |         | 10  | Minute   |
|       |            |         | 11  | Hour   |
| 3     | SIT        | 0       | Interval timer one-time alarm.  |  |
|       |            |         | <b>SIT</b>  | <b>Result</b>  |
|       |            |         | 0   | The ITFLAG flag is set after INTVAL counts, and then another interval count starts |
|       |            |         | 1   | The ITFLAG flag is set after one time interval                                     |
| 2     | ITFLAG     | 0       | Interval timer flag. This bit is set when the configured time interval has elapsed. It can be cleared by the user to indicate that the alarm event has been serviced. |  |
| 1     | ITEN       | 0       | Interval timer enable.  |  |
|       |            |         | <b>ITEN</b>   | <b>Result</b>  |
|       |            |         | 0   | The interval timer is disabled, and the 8-bit interval timer counter is reset      |
|       |            |         | 1   | Set this bit to 1 to enable the interval timer                                     |
| 0     | Unused     | N/A     | Unused.   |  |

**Table 128. RTC Configuration 2 SFR (TIMECON2, Address 0xA2)**

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| [7:5] | Reserved | N/A     | Reserved.  |
| 4     | ALDAT_EN | 0       | Alarm date enable. When this bit is set, the data in the AL_DATE register (Address 0x0E) is compared to the data in the RTC DATE register (Address 0x06). If the two values match and any other enabled RTC alarms also match, the ALFLAG in the TIMECON SFR (Address 0xA1) is set. If enabled, an RTC interrupt occurs. |
| 3     | ALDAY_EN | 0       | Alarm day enable. When this bit is set, the data in the AL_DAY (Address 0x0D) register is compared to the data in the RTC DAY register (Address 0x05). If the two values match and any other enabled RTC alarms also match, the ALFLAG in the TIMECON SFR (Address 0xA1) is set. If enabled, an RTC interrupt occurs.    |
| 2     | ALHR_EN  | 0       | Alarm hour enable. When this bit is set, the data in the AL_HOUR register (Address 0x0C) is compared to the data in the RTC HOUR register (Address 0x04). If the two values match and any other enabled RTC alarms also match, the ALFLAG in the TIMECON SFR (Address 0xA1) is set. If enabled, an RTC interrupt occurs. |
| 1     | ALMIN_EN | 0       | Alarm minute enable. When set, the data in the AL_MIN register (Address 0x0B) is compared to the data in the RTC MIN register (Address 0x03). If the two values match and any other enabled RTC alarms also match, the ALFLAG in the TIMECON SFR (Address 0xA1) is set. If enabled, an RTC interrupt occurs.             |
| 0     | ALSEC_EN | 0       | Alarm second enable. When this bit is set, the data in the AL_SEC register (Address 0x0A) is compared to the data in the RTC SEC register (Address 0x02). If the two values match and any other enabled RTC alarms also match, the ALFLAG in the TIMECON SFR (Address 0xA1) is set. If enabled, an RTC interrupt occurs. |

**Table 129. RTC Pointer Address SFR (RTCPTN, Address 0xA3)**

| Bit   | Mnemonic    | Default | Description                              |  |
|-------|-------------|---------|--|--|
| 7     | RTCW_RB     | 0       | Read/write selection.                    |  |
|       |             |         | <b>RTCW_RB</b>                           | <b>Results</b>   |
|       |             |         | 0  | The RTC register at RTC_ADDRESS (Bits[4:0]) is read into the RTCDAT SFR (Address 0xA4).  |
|       |             |         | 1  | The data in the RTCDAT SFR is written in the RTC register at RTC_ADDRESS (Bits[4:0]). This operation is completed only if the KYREG SFR (Address 0xC1) is set to 0xEA, the instruction before writing to the RTCDAT SFR. |
| [6:5] | Reserved    | N/A     | Reserved.                                |  |
| [4:0] | RTC_ADDRESS | 0       | Target address for read/write operation. |  |

**Table 130. RTC Pointer Data SFR (RTCDAT, Address 0xA4)**

| Bit   | Mnemonic | Default | Description                                    |
|-------|----------|---------|--|
| [7:0] | RTC_DATA | 0       | Location of data for read/write RTC operation. |

**Table 131. RTC Nominal Compensation SFR (RTCCOMP, Address 0xF6)**

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| [7:0] | RTCCOMP  | 0       | The RTCCOMP SFR holds the nominal RTC compensation value at 25°C. Note that this register is reset after a watchdog reset, an external reset, or a power-on reset (POR). |

**Table 132. RTC Temperature Compensation SFR (TEMPCAL, Address 0xF7)**

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| [7:0] | TEMPCAL  | 0       | The TEMPCAL SFR is used to calibrate the RTC over temperature. This allows the external crystal shift to be compensated over temperature. Note that this register is reset after a watchdog reset, an external reset, or a power-on reset (POR). |

**Table 133. Key SFR (KYREG, Address 0xC1)**

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | KYREG    | 0       | To unlock the POWCON SFR (Address 0xC5) and enable a write operation, 0xA7 should be written to the KYREG SFR (Address 0xC1). To unlock the HTHSEC, SEC, MIN or HOUR time-keeping registers or the RTCCAL register and enable a write operation, 0xEA should be written to KYREG. |

# ADE5166/ADE5169

## RTC REGISTERS

Table 134. RTC Register List

| Address<br>RTCPTR[4:0] | Mnemonic | R/W | Length | Signed/<br>Unsigned | Default<br>Value | Description   |
|------------------------|----------|-----|--------|---------------------|------------------|---|
| 0x00                   | Reserved | N/A | N/A    | N/A                 | N/A              | Reserved.   |
| 0x01                   | HTHSEC   | R/W | 8      | U                   | 0                | This counter updates every 1/128 second, referenced from the calibrated 32.768 kHz clock. It overflows from 127 to 00, incrementing the seconds counter, SEC.   |
| 0x02                   | SEC      | R/W | 8      | U                   | 0                | This counter updates every second, referenced from the calibrated 32.768 kHz clock. It overflows from 59 to 00, incrementing the minutes counter, MIN.  |
| 0x03                   | MIN      | R/W | 8      | U                   | 0                | This counter updates every minute, referenced from the calibrated 32.768 kHz clock. It overflows from 59 to 00, incrementing the hours counter, HOUR.   |
| 0x04                   | HOUR     | R/W | 8      | U                   | 0                | This counter updates every hour, referenced from the calibrated 32.768 kHz clock. It overflows from 23 to 00, incrementing the DAY and DATE counters.   |
| 0x05                   | DAY      | R/W | 8      | U                   | 0                | This counter updates every day, referenced from the calibrated 32.768 kHz clock. It overflows from 6 to 0.  |
| 0x06                   | DATE     | R/W | 8      | U                   | 1                | This counter updates every day, referenced from the calibrated 32.768 kHz clock. It overflows from 28/29/30 or 31 to 01, depending on the month, incrementing the month counter, MONTH.   |
| 0x07                   | MONTH    | R/W | 8      | U                   | 1                | This counter starts at 1 and updates every month, referenced from the calibrated 32.768 kHz clock. It overflows from 12 to 01, incrementing the year counter, YEAR.   |
| 0x08                   | YEAR     | R/W | 8      | U                   | 0                | This counter updates every year, referenced from the calibrated 32.768 kHz clock.   |
| 0x09                   | INTVAL   | R/W | 8      | U                   | 0                | The interval timer counts according to the timebase established in the ITS bits of the RTC Configuration SFR (TIMECON, Address 0xA1[5:4]). When the number of counts is equal to INTVAL, the ITFLAG flag is set and a pending RTC interrupt is created, if enabled. Note that the interval counter is eight bits, so it could count up to 255 sec, for example. |
| 0x0A                   | AL_SEC   | R/W | 8      | U                   | 0                | Alarm second register. When this register matches the SEC register and the ALSEC_EN bit (TIMECON2, Address 0xA2[0]) is set, the ALFLAG is issued if all other enabled alarms match their corresponding timekeeping register. If enabled, a pending RTC interrupt is generated.  |
| 0x0B                   | AL_MIN   | R/W | 8      | U                   | 0                | Alarm minute register. When this register matches the MIN register and the ALMIN_EN bit (TIMECON2, Address 0xA2[1]) is set, the ALFLAG is issued if all other enabled alarms match their corresponding timekeeping register. If enabled, a pending RTC interrupt is generated.  |
| 0x0C                   | AL_HOUR  | R/W | 8      | U                   | 0                | Alarm hour register. When this register matches the HOUR register and the ALHR_EN bit (TIMECON2, Address 0xA2[2]) is set, the ALFLAG is issued if all other enabled alarms match their corresponding timekeeping register. If enabled, a pending RTC interrupt is generated.  |
| 0x0D                   | AL_DAY   | R/W | 8      | U                   | 0                | Alarm day register. When this register matches the DAY register and the ALDAY_EN bit (TIMECON2, Address 0xA2[3]) is set, the ALFLAG is issued if all other enabled alarms match their corresponding timekeeping registers. If enabled, a pending RTC interrupt is generated.  |
| 0x0E                   | AL_DATE  | R/W | 8      | U                   | 0                | Alarm date register. When this register matches the DATE register and the ALDAT_EN bit (TIMECON2, Address 0xA2[4]) is set, the ALFLAG is issued if all other enabled alarms match their corresponding timekeeping registers. If enabled, a pending RTC interrupt is generated.  |
| 0x0F                   | RTC_CAL  | R/W | 8      | U                   | 0                | Configuration of the RTC calibration output (see Table 135).  |

**Table 135. RTC Calibration Configuration Register (RTC\_CAL, Address 0x0F)**

| Bit   | Mnemonic    | Default | Description   |   |                           |
|-------|-------------|---------|---|---|---------------------------|
| 7     | CAL_EN_PSM2 | 0       | When this bit is set and the CAL_EN bit is set, the RTC output is present on P0.5/MISO/ZX in PSM2 mode. The RTC output is disabled on all other pins in PSM2. |   |                           |
| 6     | CAL_EN      | 0       | RTC calibration enable output.  |   |                           |
|       |             |         | <b>CAL_EN</b>   | <b>Result</b>                                 |                           |
|       |             |         | 0   | The RTC calibration output signal is disabled |                           |
|       |             | 1       | The RTC calibration output signal is enabled and present on the pins selected by the RTC_CAL[3:0] bits  |   |                           |
| [5:4] | FSEL[1:0]   | 0       | RTC calibration output frequency selection.   |   |                           |
|       |             |         | <b>FSEL[1:0]</b>  | <b>Frequency</b>                              | <b>Calibration window</b> |
|       |             |         | 00  | 1 Hz  | 30.5 seconds              |
|       |             |         | 01  | 512 Hz  | 30.5 seconds              |
|       |             |         | 10  | 500 Hz  | 0.244 second              |
|       |             | 11      | 16 kHz  | 0.244 second                                  |                           |
| 3     | RTC_P2P3    | 0       | When this bit is set and the CAL_EN bit is set, the RTC output is present on the P2.3/SDEN/TxD2 pin.  |   |                           |
| 2     | RTC_P1P2    | 0       | When this bit is set and the CAL_EN bit is set, the RTC output is present on the P1.2/FP25/ZX pin.  |   |                           |
| 1     | RTC_P0P7    | 0       | When this bit is set and the CAL_EN bit is set, the RTC output is present on the P0.7/SS/T1/RxD2 pin.   |   |                           |
| 0     | RTC_P0P5    | 0       | When this bit is set and the CAL_EN bit is set, the RTC output is present on the P0.5/MISO/ZX pin.  |   |                           |

**RTC CALENDAR**

The RTC has a full calendar, taking into account leap years. The rollover of the date to increment the month is implemented according to the parameters shown in Table 136.

**Table 136. Month Rollover**

| MONTH Register | Rollover Value                | Estimated Month |
|----------------|-------------------------------|-----------------|
| 0x01           | 31                            | January         |
| 0x02           | 28 or 29 days (see Table 137) | February        |
| 0x03           | 31                            | March           |
| 0x04           | 30                            | April           |
| 0x05           | 31                            | May             |
| 0x06           | 30                            | June            |
| 0x07           | 31                            | July            |
| 0x08           | 31                            | August          |
| 0x09           | 30                            | September       |
| 0x0A           | 31                            | October         |
| 0x0B           | 30                            | November        |
| 0x0C           | 31                            | December        |

**Table 137. Leap Years—Rollover After 29 Days**

| Year Register | Estimated Year |
|---------------|----------------|
| 0d04          | 2004           |
| 0d08          | 2008           |
| 0d12          | 2012           |
| 0d16          | 2016           |
| 0d20          | 2020           |
| 0d24          | 2024           |
| 0d28          | 2028           |
| 0d32          | 2032           |
| 0d36          | 2036           |
| 0d40          | 2040           |
| 0d44          | 2044           |
| 0d48          | 2048           |
| 0d52          | 2052           |
| 0d56          | 2056           |
| 0d60          | 2060           |
| 0d64          | 2064           |
| 0d68          | 2068           |
| 0d72          | 2072           |
| 0d76          | 2076           |
| 0d80          | 2080           |
| 0d84          | 2084           |
| 0d88          | 2088           |
| 0d92          | 2092           |
| 0d96          | 2096           |

## RTC INTERRUPTS

The RTC alarm and interval timer interrupts are enabled by setting the ETI bit in the interrupt enable and Priority 2 SFR (IEIP2, Address 0xA9). When an alarm or interval timer event occurs, the corresponding flag is set and a pending RTC interrupt is generated. If the RTC interrupt is enabled, the program vectors to the RTC interrupt address, and the corresponding RTC flag can be cleared in software. Moving to the RTC interrupt address alone does not automatically clear the flag. To successfully acknowledge the interrupt event, the flag has to be cleared by software. If the RTC interrupt is disabled when the event occurs, the pending interrupt remains until the corresponding RTC flag is cleared. The ALFLAG and ITFLAG flags, therefore, drive the RTC interrupt and should be managed by the user to keep track of the RTC events.

Note that, if the ADE5166/ADE5169 are awakened by an RTC event, either the ALFLAG or ITFLAG, then the pending RTC interrupt must be serviced before the ADE5166/ADE5169 can go back to sleep again. The ADE5166/ADE5169 keep waking up until this interrupt has been serviced.

## Interval Timer Alarm

The RTC can be used as an interval timer. When the interval timer is enabled by setting the ITEN bit in the RTC configuration SFR (TIMECON, Address 0xA1[1]), the interval timer clock source selected by the ITS1 and ITS0 bits (TIMECON, Bits[5:4]) is passed through to an 8-bit counter. This counter increments on every interval timer clock pulse until the 8-bit counter is equal to the value in the alarm interval register. Then an alarm event is generated, setting the ITFLAG bit (TIMECON, Address 0xA1[2]) and creating a pending RTC interrupt. If the SIT bit (TIMECON, Address 0xA1[3]) is clear, the 8-bit counter is cleared and starts counting again. If the SIT bit is set, the 8-bit counter is held in reset after the alarm occurs.

Take care when changing the interval timer timebase. The recommended procedure is as follows:

1. If the INTVAL register is going to be modified, write to the INTVAL register first. Then wait for one 128 Hz clock cycle to synchronize with the RTC, 64,000 cycles at a 4.096 MHz instruction cycle clock.
2. Disable the interval timer by clearing the ITEN bit (Bit 1) in the TIMECON SFR. Then wait for one 128 Hz clock cycle to synchronize with the RTC, 64,000 cycles at a 4.096 MHz instruction cycle clock.
3. Read the TIMECON SFR to ensure that the ITEN bit is clear. If it is not, wait for another 128 Hz clock cycle.
4. Set the timebase bits, ITS1 and ITS0 (Bits 5:4) in the TIMECON SFR to configure the interval. Wait for a 128 Hz clock cycle for this change to take effect.

## Alarm

The RTC can be used with an alarm to wake up periodically. The alarm registers (AL\_SEC, AL\_MIN, AL\_HOUR, AL\_DAY, and AL\_DATE) should be set to the specific time that the alarm event is required, and the corresponding Alxx\_EN bits set in the TIMECON2 SFR (Address 0xA2). The enabled alarm registers are then compared to their respective RTC registers (SEC, MIN, HOUR, DAY, and DATE) and when all enabled alarms match their corresponding RTC registers, the alarm flag is set and a pending interrupt is generated. The alarm flag is located in Bit 6 of the TIMECON SFR (Address 0xA1). If enabled, an RTC interrupt occurs and the program vectors to the RTC interrupt address.

**RTC CRYSTAL COMPENSATION**

The RTC provides registers to compensate for the tolerance of the crystal frequency and its variation over temperature. Up to ±248 ppm frequency error can be calibrated out by the RTC circuitry. The compensation is fully digital and implemented by adding or subtracting pulses from the crystal clock signal.

The resolution of the RTC nominal compensation SFR (RTCCOMP, Address 0xF6) is ±2 ppm/LSB, or 0.17 sec/day/LSB. The RTC compensation circuitry adds the RTC temperature compensation SFR (TEMPCAL, Address 0xF7) and the RTC nominal compensation SFR (RTCCOMP, Address 0xF6) to determine how much compensation is required. The sum of these two registers is limited to ±248 ppm, or 42.85 sec/day.

**RTC Calibration**

The nominal crystal frequency can be calibrated by adjusting the RTCCOMP SFR so that the clock going into the RTC is precisely 32.768 kHz at 25°C.

**Calibration Flow**

An RTC calibration pulse output is on up to four pins configured by the four LSBs in the RTC calibration configuration register (RTC\_CAL, Address 0x0F). Enable the RTC output by setting the CAL\_EN bit (Bit 6) in the RTC calibration configuration register (RTC\_CAL, Address 0x0F).

The RTC calibration is accurate to within ±2 ppm over a 30.5 sec window in all operational modes: PSM0, PSM1, and PSM2. Two output frequencies are offered for the normal RTC mode: 1 Hz with FSEL[1:0] = 00 and 512 Hz with FSEL[1:0] = 01 in the RTC calibration configuration register (RTC\_CAL, Address 0x0F).

A shorter window of 0.244 sec is offered for fast calibration during PSM0 or PSM1 mode. Two output frequencies are offered for this RTC calibration output mode: 500 Hz with FSEL[1:0] = 10 and 16 kHz with FSEL[1:0] = 11 in the RTC calibration configuration

register (RTC\_CAL, Address 0x0F). Note that for the 0.244 sec calibration window, the RTC is clocked 125 times faster than in the normal mode, resulting in timekeeping registers that represent seconds/125, minutes/125, and hours/125, instead of seconds, minutes, and hours. Therefore, this mode should be used for calibration only.

**Table 138. RTC Calibration Options**

| Option             | FSEL[1:0] | Calibration Window (sec) | f <sub>RTCCAL</sub> (Hz) |
|--------------------|-----------|--------------------------|--------------------------|
| Normal Mode 0      | 00        | 30.5                     | 1                        |
| Normal Mode 1      | 01        | 30.5                     | 512                      |
| Calibration Mode 0 | 10        | 0.244                    | 500                      |
| Calibration Mode 1 | 11        | 0.244                    | 16000                    |

When no RTC compensation is applied, with RTCCOMP and TEMPCAL equal to zero, the nominal compensation required to account for the error in the external crystal can be determined. In this case, it is not necessary to wait for an entire calibration window to determine the error in the pulse output. Calculating at the error in frequency between two consecutive pulses on the RTC calibration pin is sufficient.

The value to write to the RTCCOMP SFR is calculated from the % error or seconds per day error on the frequency output. Each LSB of the RTCCOMP SFR represents 2 ppm of correction where 1 sec/day error is equal to 11.57 ppm.

$$RTCCOMP = 5000 \times (\% \text{ Error})$$

$$RTCCOMP = \frac{1}{2 \times 11.57} \times (\text{sec/day Error})$$

During calibration, user software writes the current time to the RTC. Refer to the Access to Internal RTC Registers section for more information on how to read and write to the RTC time-keeping registers.

# ADE5166/ADE5169

## UART SERIAL INTERFACE

The ADE5166/ADE5169 UART can be configured in one of four modes.

- Shift register with baud rate fixed at  $f_{CORE}/12$
- 8-bit UART with variable baud rate
- 9-bit UART with baud rate fixed at  $f_{CORE}/64$  or  $f_{CORE}/32$
- 9-bit UART with variable baud rate

Variable baud rates are defined by using an internal timer to generate any rate between 300 bauds/sec and 115,200 bauds/sec.

The UART serial interface provided in the ADE5166/ADE5169 is a full-duplex serial interface. It is also receive buffered by storing the first received byte in a receive buffer until the reception of the second byte is complete. The physical interface to the UART is provided via the Rx/D (P1.0/RxD) and Tx/D (P1.1/TxD) pins,

and the firmware interface is through the SFRs presented in Table 139.

Both the serial port receive and transmit registers are accessed through the serial port buffer SFR (SBUF, Address 0x99). Writing to SBUF loads the transmit register, and reading SBUF accesses a physically separate receive register.

An enhanced UART mode is offered by using the UART timer and by providing enhanced frame error, break error, and overwrite error detection. This mode is enabled by setting the EXTEN bit in the configuration SFR (CFG, Address 0xAF) (see the UART Additional Features section). The enhanced serial baud rate control SFR (SBAUDT, Address 0x9E) and UART timer fractional divider SFR (SBAUFD, Address 0x9D) are used to configure the UART timer and to indicate the enhanced UART errors.

### UART SFRs

Table 139. Serial Port SFRs

| SFR    | Address | Bit Addressable | Description  |
|--------|---------|-----------------|--|
| SCON   | 0x98    | Yes             | Serial communications control (see Table 140).     |
| SBUF   | 0x99    | No              | Serial port buffer (see Table 141).                |
| SBAUDT | 0x9E    | No              | Enhanced serial baud rate control (see Table 142). |
| SBAUFD | 0x9D    | No              | UART timer fractional divider (see Table 143).     |

Table 140. Serial Communications Control SFR (SCON, Address 0x98)

| Bit      | Bit Address  | Mnemonic | Default | Description   |          |                                  |    |   |    |  |    |  |    |  |
|----------|--|----------|---------|---|----------|----------------------------------|----|---|----|--|----|--|----|--|
| [7:6]    | 0x9F, 0x9E   | SM0, SM1 | 00      | UART serial mode select bits. These bits select the serial port operating mode.<br><table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>SM0, SM1</th> <th>Result (Selected Operating Mode)</th> </tr> </thead> <tbody> <tr> <td>00</td> <td>Mode 0, shift register, fixed baud rate (<math>f_{CORE}/12</math>)</td> </tr> <tr> <td>01</td> <td>Mode 1, 8-bit UART, variable baud rate</td> </tr> <tr> <td>10</td> <td>Mode 2, 9-bit UART, fixed baud rate (<math>f_{CORE}/32</math>) or (<math>f_{CORE}/16</math>)</td> </tr> <tr> <td>11</td> <td>Mode 3, 9-bit UART, variable baud rate</td> </tr> </tbody> </table> | SM0, SM1 | Result (Selected Operating Mode) | 00 | Mode 0, shift register, fixed baud rate ( $f_{CORE}/12$ ) | 01 | Mode 1, 8-bit UART, variable baud rate | 10 | Mode 2, 9-bit UART, fixed baud rate ( $f_{CORE}/32$ ) or ( $f_{CORE}/16$ ) | 11 | Mode 3, 9-bit UART, variable baud rate |
| SM0, SM1 | Result (Selected Operating Mode)   |          |         |   |          |                                  |    |   |    |  |    |  |    |  |
| 00       | Mode 0, shift register, fixed baud rate ( $f_{CORE}/12$ )                  |          |         |   |          |                                  |    |   |    |  |    |  |    |  |
| 01       | Mode 1, 8-bit UART, variable baud rate                                     |          |         |   |          |                                  |    |   |    |  |    |  |    |  |
| 10       | Mode 2, 9-bit UART, fixed baud rate ( $f_{CORE}/32$ ) or ( $f_{CORE}/16$ ) |          |         |   |          |                                  |    |   |    |  |    |  |    |  |
| 11       | Mode 3, 9-bit UART, variable baud rate                                     |          |         |   |          |                                  |    |   |    |  |    |  |    |  |
| 5        | 0x9D   | SM2      | 0       | Multiprocessor communication enable bit. Enables multiprocessor communication in Mode 2 and Mode 3, and framing error detection in Mode 1.<br>In Mode 0, SM2 should be cleared.<br>In Mode 1, if SM2 is set, RI is not activated if a valid stop bit was not received.<br>If SM2 is cleared, RI is set as soon as the byte of data is received.<br>In Mode 2 or Mode 3, if SM2 is set, RI is not activated if the received ninth data bit in RB8 is 0. If SM2 is cleared, RI is set as soon as the byte of data is received.  |          |                                  |    |   |    |  |    |  |    |  |
| 4        | 0x9C   | REN      | 0       | Serial port receive enable bit. Set by user software to enable serial port reception. Cleared by user software to disable serial port reception.  |          |                                  |    |   |    |  |    |  |    |  |
| 3        | 0x9B   | TB8      | 0       | Serial port transmit (Bit 9). The data loaded into TB8 is the ninth data bit transmitted in Mode 2 and Mode 3.  |          |                                  |    |   |    |  |    |  |    |  |
| 2        | 0x9A   | RB8      | 0       | Serial port receiver (Bit 9). The ninth data bit received in Mode 2 and Mode 3 is latched into RB8. For Mode 1, the stop bit is latched into RB8.   |          |                                  |    |   |    |  |    |  |    |  |
| 1        | 0x99   | TI       | 0       | Serial port transmit interrupt flag. Set by hardware at the end of the eighth bit in Mode 0 or at the beginning of the stop bit in Mode 1, Mode 2, and Mode 3. TI must be cleared by user software.   |          |                                  |    |   |    |  |    |  |    |  |
| 0        | 0x98   | RI       | 0       | Serial port receive interrupt flag. Set by hardware at the end of the eighth bit in Mode 0 or halfway through the stop bit in Mode 1, Mode 2, and Mode 3. RI must be cleared by user software.  |          |                                  |    |   |    |  |    |  |    |  |



**Table 141. Serial Port Buffer SFR (SBUF, Address 0x99)**

| Bit   | Mnemonic | Default | Description              |
|-------|----------|---------|--------------------------|
| [7:0] | SBUF     | 0       | Serial port data buffer. |

**Table 142. Enhanced Serial Baud Rate Control SFR (SBAUDT, Address 0x9E)**

| Bit   | Mnemonic      | Default | Description   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
|-------|---------------|---------|---|-----|--------|-----|-------------|-----|-------------|-----|-------------|-----|-------------|-----|--------------|-----|--------------|-----|--------------|-----|---------------|
| 7     | OWE           | 0       | Overwrite error. This bit is set when new data is received and RI = 1 (Bit 0 in the SCON SFR, Address 0x98). It indicates that SBUF was not read before the next character was transferred in, causing the prior SBUF data to be lost. Write a 0 to this bit to clear it.   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 6     | FE            | 0       | Frame error. This bit is set when the received frame does not have a valid stop bit. This bit is read only and is updated every time a frame is received.   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 5     | BE            | 0       | Break error. This bit is set whenever the receive data line (Rx) is low for longer than a full transmission frame, which is the time required for a start bit, eight data bits, a parity bit, and half a stop bit. This bit is updated every time a frame is received.  |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| [4:3] | SBTH          | 0       | Extended divider ratio for baud rate setting, as shown in Table 144.  |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| [2:0] | DIV           | 0       | Binary divider (see Table 144).   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
|       |               |         | <table border="1" style="width: 100%;"> <thead> <tr> <th>DIV</th> <th>Result</th> </tr> </thead> <tbody> <tr><td>000</td><td>Divide by 1</td></tr> <tr><td>001</td><td>Divide by 2</td></tr> <tr><td>010</td><td>Divide by 4</td></tr> <tr><td>011</td><td>Divide by 8</td></tr> <tr><td>100</td><td>Divide by 16</td></tr> <tr><td>101</td><td>Divide by 32</td></tr> <tr><td>110</td><td>Divide by 64</td></tr> <tr><td>111</td><td>Divide by 128</td></tr> </tbody> </table> | DIV | Result | 000 | Divide by 1 | 001 | Divide by 2 | 010 | Divide by 4 | 011 | Divide by 8 | 100 | Divide by 16 | 101 | Divide by 32 | 110 | Divide by 64 | 111 | Divide by 128 |
| DIV   | Result        |         |   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 000   | Divide by 1   |         |   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 001   | Divide by 2   |         |   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 010   | Divide by 4   |         |   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 011   | Divide by 8   |         |   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 100   | Divide by 16  |         |   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 101   | Divide by 32  |         |   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 110   | Divide by 64  |         |   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |
| 111   | Divide by 128 |         |   |     |        |     |             |     |             |     |             |     |             |     |              |     |              |     |              |     |               |

**Table 143. UART Timer Fractional Divider SFR (SBAUDF, Address 0x9D)**

| Bit   | Mnemonic        | Default | Description  |
|-------|-----------------|---------|--|
| 7     | UARTBAUDEN      | 0       | UART baud rate enable. Set to enable UART timer to generate the baud rate. When set, the SMOD bit (PCON, Address 0x87[7]), the TCLK bit (T2CON, Address 0x88[4]), and the RCLK bit (T2CON, Address 0xC8[5]) are ignored. Cleared to let the baud rate be generated as per a standard 8052. |
| 6     | Not implemented |         | Not implemented, write don't care.   |
| [5:0] | SBAUDF          | 0       | UART timer fractional divider.   |

# ADE5166/ADE5169

Table 144. Common Baud Rates Using the UART Timer with a 4.096 MHz PLL Clock

| Ideal Baud | CD | SBTH | DIV | SBAUDT | SBAUDF | % Error |
|------------|----|------|-----|--------|--------|---------|
| 115,200    | 0  | 0    | 1   | 0x01   | 0x87   | +0.16   |
| 115,200    | 1  | 0    | 0   | 0x00   | 0x87   | +0.16   |
| 57,600     | 0  | 0    | 2   | 0x02   | 0x87   | +0.16   |
| 57,600     | 1  | 0    | 1   | 0x01   | 0x87   | +0.16   |
| 38,400     | 0  | 0    | 2   | 0x02   | 0xAB   | -0.31   |
| 38,400     | 1  | 0    | 1   | 0x01   | 0xAB   | -0.31   |
| 38,400     | 2  | 0    | 0   | 0x00   | 0xAB   | -0.31   |
| 19,200     | 0  | 0    | 3   | 0x03   | 0xAB   | -0.31   |
| 19,200     | 1  | 0    | 2   | 0x02   | 0xAB   | -0.31   |
| 19,200     | 2  | 0    | 1   | 0x01   | 0xAB   | -0.31   |
| 19,200     | 3  | 0    | 0   | 0x00   | 0xAB   | -0.31   |
| 9600       | 0  | 0    | 4   | 0x04   | 0xAB   | -0.31   |
| 9600       | 1  | 0    | 3   | 0x03   | 0xAB   | -0.31   |
| 9600       | 2  | 0    | 2   | 0x02   | 0xAB   | -0.31   |
| 9600       | 3  | 0    | 1   | 0x01   | 0xAB   | -0.31   |
| 9600       | 4  | 0    | 0   | 0x00   | 0xAB   | -0.31   |
| 4800       | 0  | 0    | 5   | 0x05   | 0xAB   | -0.31   |
| 4800       | 1  | 0    | 4   | 0x04   | 0xAB   | -0.31   |
| 4800       | 2  | 0    | 3   | 0x03   | 0xAB   | -0.31   |
| 4800       | 3  | 0    | 2   | 0x02   | 0xAB   | -0.31   |
| 4800       | 4  | 0    | 1   | 0x01   | 0xAB   | -0.31   |
| 4800       | 5  | 0    | 0   | 0x00   | 0xAB   | -0.31   |
| 2400       | 0  | 0    | 6   | 0x06   | 0xAB   | -0.31   |
| 2400       | 1  | 0    | 5   | 0x05   | 0xAB   | -0.31   |
| 2400       | 2  | 0    | 4   | 0x04   | 0xAB   | -0.31   |
| 2400       | 3  | 0    | 3   | 0x03   | 0xAB   | -0.31   |
| 2400       | 4  | 0    | 2   | 0x02   | 0xAB   | -0.31   |
| 2400       | 5  | 0    | 1   | 0x01   | 0xAB   | -0.31   |
| 2400       | 6  | 0    | 0   | 0x00   | 0xAB   | -0.31   |
| 300        | 0  | 2    | 7   | 0x17   | 0xAB   | -0.31   |
| 300        | 1  | 1    | 7   | 0x0F   | 0xAB   | -0.31   |
| 300        | 2  | 0    | 7   | 0x07   | 0xAB   | -0.31   |
| 300        | 3  | 0    | 6   | 0x06   | 0xAB   | -0.31   |
| 300        | 4  | 0    | 5   | 0x05   | 0xAB   | -0.31   |
| 300        | 5  | 0    | 4   | 0x04   | 0xAB   | -0.31   |
| 300        | 6  | 0    | 3   | 0x03   | 0xAB   | -0.31   |
| 300        | 7  | 0    | 2   | 0x02   | 0xAB   | -0.31   |

**UART OPERATION MODES**

**Mode 0 (Shift Register with Baud Rate Fixed at  $f_{CORE}/12$ )**

Mode 0 is selected when the SM0 and SM1 bits in the serial communications control register SFR (SCON, Address 0x98) are cleared. In this shift register mode, serial data enters and exits through the RxD pin. The TxD pin outputs the shift clock. The baud rate is fixed at  $f_{CORE}/12$ . Eight data bits are transmitted or received.

Transmission is initiated by any instruction that writes to the serial port buffer SFR (SBUF, Address 0x99). The data is shifted out of the Pin RxD line. The eight bits are transmitted with the least significant bit (LSB) first.

Reception is initiated when the serial port receive enable bit (Bit REN, Address 0x98[4]) is 1, and the serial port receive interrupt bit (Bit RI, Address 0x98[0]) is 0. When RI is cleared, the data is clocked into the Pin RxD line, and the clock pulses are output from the Pin TxD line as shown in Figure 99.

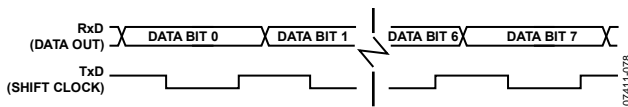


Figure 99. 8-Bit Shift Register Mode

**Mode 1 (8-Bit UART, Variable Baud Rate)**

Mode 1 is selected by clearing the SM0 bit (Address 0x98[7]) and setting the SM1 bit (Address 0x98[6]). Each data byte (LSB first) is preceded by a start bit (0) and followed by a stop bit (1). Therefore, each frame consists of 10 bits transmitted on the TxD pin or received on the RxD pin.

The baud rate is set by a timer overflow rate. Timer 1 or Timer 2 can be used to generate baud rates, or both timers can be used simultaneously where one generates the transmit rate and the other generates the receive rate. There is also a dedicated timer for baud rate generation, the UART timer, which has a fractional divisor to precisely generate any baud rate (see the UART Timer Generated Baud Rates section).

Transmission is initiated by a write to the serial port buffer SFR (SBUF, Address 0x99). Next, a stop bit (1) is loaded into the ninth bit position of the internal serial port shift register. The data is output bit by bit until the stop bit appears on the TxD pin and the transmit interrupt flag, TI (Address 0x98[1]), is automatically set, as shown in Figure 100.

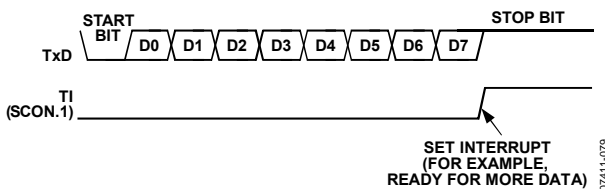


Figure 100. 8-Bit Variable Baud Rate

Reception is initiated when a 1-to-0 transition is detected on the RxD pin. Assuming that a valid start bit is detected, character reception continues. The eight data bits are clocked into the internal serial port shift register.

All of the following conditions must be met at the time the final shift pulse is generated to receive a character:

- If the extended UART is disabled (EXTEN = 0 in the CFG SFR, Address 0xAF), RI must be 0 to receive a character. This ensures that the data in the SBUF SFR is not overwritten if the last received character has not been read.
- If frame error checking is enabled by setting SM2 (Bit 5 of the SCON SFR, Address 0x98), the received stop bit must be set to receive a character. This ensures that every character received comes from a valid frame, with both a start bit and a stop bit.

If any of these conditions is not met, the received frame is irretrievably lost, and the receive interrupt flag (Bit RI in the SCON SFR, Address 0x98[0]) is not set.

If the received frame has met these conditions, the following events occur:

- The eight bits in the receive shift register are latched into the SBUF SFR.
- The ninth bit (stop bit) is clocked into RB8 in the SCON SFR.
- The receiver interrupt flag (RI in the SCON SFR) is set.

**Mode 2 (9-Bit UART with Baud Fixed at  $f_{CORE}/64$  or  $f_{CORE}/32$ )**

Mode 2 is selected by setting SM0 and clearing SM1. In this mode, the UART operates in 9-bit mode with a fixed baud rate. The baud rate is fixed at  $f_{CORE}/64$  by default, although setting the SMOD bit in the program control SFR (PCON, Address 0x87) doubles the frequency to  $f_{CORE}/32$ . Eleven bits are transmitted or received: a start bit (0), eight data bits, a programmable ninth bit, and a stop bit (1). The ninth bit is most often used as a parity bit or as part of a multiprocessor communication protocol, although it can be used for anything, including a ninth data bit, if required.

To use the ninth data bit as part of a communication protocol for a multiprocessor network such as RS-485, the ninth bit is set to indicate that the frame contains the address of the device with which the master wants to communicate. The devices on the network are always listening for a packet with the ninth bit set and are configured such that if the ninth bit is cleared, the frame is not valid, and a receive interrupt is not generated. If the ninth bit is set, all devices on the network receive the address and obtain a receive character interrupt. The devices examine the address and, if it matches one of the preprogrammed addresses of the device, that device configures itself to listen to all incoming frames, even those with the ninth bit cleared. Because the master has initiated communication with that device, all the following packets with the ninth bit cleared are intended specifically for that addressed device until another packet with the ninth bit set is received. If the address does not match, the device continues to listen for address packets.

To transmit, the eight data bits must be written into the serial port buffer SFR (SBUF, Address 0x99). The ninth bit must be written to TB8 (Bit 3) in the serial communications control SFR (SCON, Address 0x98). When transmission is initiated, the eight data bits from SBUF are loaded into the transmit shift register (LSB first). The ninth data bit, held in TB8, is loaded into the ninth bit position of the transmit shift register. The transmission starts at the next valid baud rate clock. The serial port transmit interrupt flag (TI, Bit 1 in the SCON SFR) is set as soon as the transmission completes, when the stop bit appears on TxD.

All of the following conditions must be met at the time the final shift pulse is generated to receive a character:

- If the extended UART is disabled (EXTEN = 0 in the CFG SFR), RI in the SCON SFR must be 0 to receive a character. This ensures that the data in SBUF is not overwritten if the last received character has not been read.
- If multiprocessor communication is enabled by setting SM2 in the SCON SFR, the received ninth bit must be set to receive a character. This ensures that only frames with the ninth bit set, which are frames that contain addresses, generate a receive interrupt.

If any of these conditions is not met, the received frame is irretrievably lost, and the receive interrupt flag (RI in the SCON SFR) is not set.

Reception for Mode 2 is similar to that of Mode 1. The eight data bytes are input at RxD (LSB first) and loaded onto the receive shift register. If the received frame has met the previous criteria, the following events occur:

- The eight bits in the receive shift register are latched into the SBUF SFR.
- The ninth data bit is latched into RB8 in the SCON SFR.
- The receiver interrupt flag (RI in the SCON SFR) is set.

### Mode 3 (9-Bit UART with Variable Baud Rate)

Mode 3 is selected by setting both SM0 and SM1 in the SCON SFR. In this mode, the 8052 UART serial port operates in 9-bit mode with a variable baud rate. The baud rate is set by a timer overflow rate. Timer 1 or Timer 2 can be used to generate baud rates, or both timers can be used simultaneously where one generates the transmit rate and the other generates the receive rate. There is also a dedicated timer for baud rate generation, the UART timer, which has a fractional divisor to precisely generate any baud rate (see the UART Timer Generated Baud Rates section). The operation of the 9-bit UART is the same as for Mode 2, but the baud rate can be varied.

In all four modes, transmission is initiated by any instruction that uses SBUF as a destination register. Reception is initiated in Mode 0 when RI = 0 and REN = 1 in the SCON SFR. Reception is initiated in the other modes by the incoming start bit if REN = 1.

## UART BAUD RATE GENERATION

### Mode 0 Baud Rate Generation

The baud rate in Mode 0 is fixed.

$$\text{Mode 0 Baud Rate} = \left( \frac{f_{\text{CORE}}}{12} \right)$$

### Mode 2 Baud Rate Generation

The baud rate in Mode 2 depends on the value of the SMOD bit in the program control SFR (PCON, Address 0x87[7]). If SMOD = 0, the baud rate is 1/32 of the core clock. If SMOD = 1, the baud rate is 1/16 of the core clock.

$$\text{Mode 2 Baud Rate} = \frac{2^{\text{SMOD}}}{32} \times f_{\text{CORE}}$$

### Mode 1 and Mode 3 Baud Rate Generation

The baud rates in Mode 1 and Mode 3 are determined by the overflow rate of the timer generating the baud rate, that is, Timer 1, Timer 2, or the dedicated baud rate generator, UART timer, which has an integer and a fractional divisor.

#### Timer 1 Generated Baud Rates

When Timer 1 is used as the baud rate generator, the baud rates in Mode 1 and Mode 3 are determined by the Timer 1 overflow rate. The value of SMOD is as follows:

$$\text{Mode 1 or Mode 3 Baud Rate} = \frac{2^{\text{SMOD}}}{32} \times \text{Timer 1 Overflow Rate}$$

The Timer 1 interrupt should be disabled in this application. The timer itself can be configured for either timer or counter operation and in any of its three running modes. In the most typical application, it is configured for timer operation in auto-reload mode (high nibble of TMOD = 0010 binary, see Table 12). In that case, the baud rate is given by the following formula:

$$\text{Mode 1 or Mode 3 Baud Rate} = \frac{2^{\text{SMOD}}}{32} \times \frac{f_{\text{CORE}}}{(256 - \text{TH1})}$$

#### Timer 2 Generated Baud Rates

Baud rates can also be generated by using Timer 2. Using Timer 2 is similar to using Timer 1 in that the timer must overflow 16 times before a bit is transmitted or received. Because Timer 2 has a 16-bit autoreload mode, a wider range of baud rates is possible.

$$\text{Mode 1 or Mode 3 Baud Rate} = \frac{1}{16} \times \text{Timer 2 Overflow Rate}$$

Therefore, when Timer 2 is used to generate baud rates, the timer increments every two clock cycles rather than every core machine cycle as before. It increments six times faster than Timer 1, and, therefore, baud rates six times faster are possible.

Because Timer 2 has 16-bit autoreload capability, very low baud rates are still possible. Timer 2 is selected as the baud rate generator by setting TCLK and/or RCLK in Timer/Counter 2 control SFR (T2CON, Address 0xC8). The baud rates for transmit and receive can be simultaneously different. Setting RCLK and/or TCLK puts Timer 2 into its baud rate generator mode, as shown in Figure 102.

In this case, the baud rate is given by the following formula:

$$\text{Mode 1 or Mode 3 Baud Rate} = \frac{f_{CORE}}{16 \times [65536 - (RCAP2H : RCAP2L)]}$$

**UART Timer Generated Baud Rates**

The high integer dividers in a UART block mean that high speed baud rates are not always possible. In addition, generating baud rates requires the exclusive use of a timer, rendering it unusable for other applications when the UART is required. To address this problem, each ADE5166/ADE5169 has a dedicated baud rate timer (UART timer) specifically for generating highly accurate baud rates. The UART timer can be used instead of Timer 1 or Timer 2 for generating very accurate high speed UART baud rates, including 115,200 bps. This timer also allows a much wider range of baud rates to be obtained. In fact, every desired bit rate from 12 bps to 393,216 bps can be generated to within an error of ±0.8%. The UART timer also frees up the other three timers, allowing them to be used for different applications. A block diagram of the UART timer is shown in Figure 101.

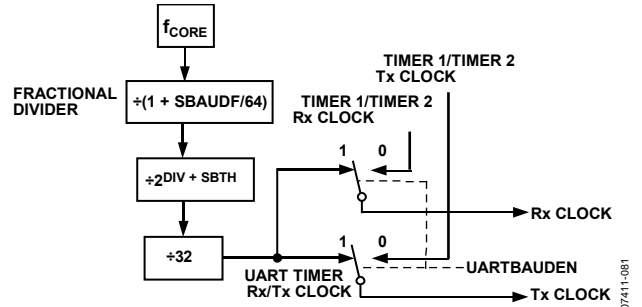


Figure 101. UART Timer, UART Baud Rate

Two SFRs, enhanced serial baud rate control SFR (SBAUDT, Address 0x9E) and UART timer fractional divider SFR (SBAUDEF, Address 0x9D), are used to control the UART timer. SBAUDT is the baud rate control SFR; it sets up the integer divider (DIV) and the extended divider (SBTH) for the UART timer.

The appropriate value to write to DIV (Bits[2:0]) and SBTH (Bits[4:3]) can be calculated using the following formula, where f<sub>CORE</sub> is defined in the POWCON SFR (see Table 25). Note that the DIV value must be rounded down to the nearest integer.

$$DIV + SBTH = \frac{\log\left(\frac{f_{CORE}}{16 \times \text{Baud Rate}}\right)}{\log(2)}$$

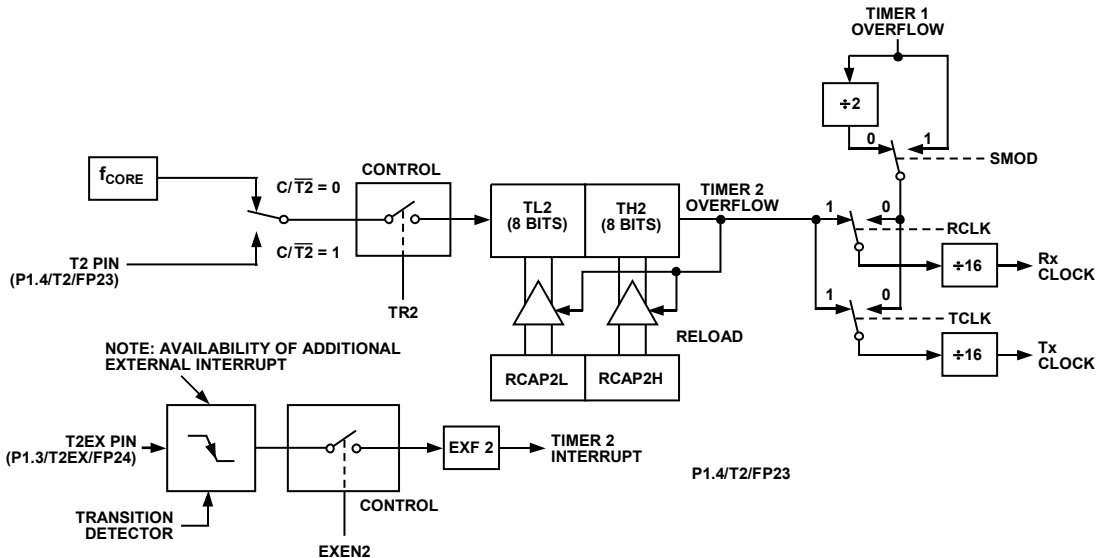


Figure 102. Timer 2, UART Baud Rates

SBAUDF is the fractional divider ratio required to achieve the required baud rate. The appropriate value for SBAUDF can be calculated with the following formula:

$$SBAUDF = 64 \times \left( \frac{f_{CORE}}{16 \times 2^{DIV+SBTH} \times \text{Baud Rate}} - 1 \right)$$

Note that SBAUDF should be rounded to the nearest integer. After the values for DIV and SBAUDF are calculated, the actual baud rate can be calculated with the following formula:

$$\text{Actual Baud Rate} = \frac{f_{CORE}}{16 \times 2^{DIV+SBTH} \times \left( 1 + \frac{SBAUDF}{64} \right)}$$

For example, to obtain a baud rate of 9600 bps while operating at a core clock frequency of 4.096 MHz and with the PLL CD bits equal to 0,

$$DIV + SBTH = \frac{\log\left(\frac{4,096,000}{16 \times 9600}\right)}{\log(2)} = 4.74 = 4$$

Note that the DIV result is rounded down.

$$SBAUDF = 64 \times \left( \frac{4,096,000}{16 \times 2^3 \times 9600} - 1 \right) = 42.67 = 0x2B$$

Thus, the actual baud rate is 9570 bps, resulting in a 0.31% error.

## UART ADDITIONAL FEATURES

### Enhanced Error Checking

The extended UART provides frame error, break error, and overwrite error detection. Framing errors occur when a stop bit is not present at the end of the frame. A missing stop bit implies that the data in the frame may not have been received properly. Break error detection indicates whether the RxD line has been low for longer than a 9-bit frame. It indicates that the data just received, a 0 or null character, is not valid because the master has disconnected. Overwrite error detection indicates when the received data has not been read fast enough and, as a result, a byte of data has been lost.

The 8052 standard UART offers frame-error checking for an 8-bit UART through the SM2 and RB8 bits in the SCON SFR. Setting the SM2 bit prevents frames without a stop bit from being received. The stop bit is latched into the RB8 bit in the serial communications control SFR (SCON, Address 0x98). This bit can be examined to determine if a valid frame was received. The 8052 does not,

however, provide frame error checking for a 9-bit UART. This enhanced error checking functionality is available through the frame error bit, FE, in the enhanced serial baud rate control SFR (SBAUDT, Address 0x9E). The FE bit is set on framing errors for both 8-bit and 9-bit UARTs.

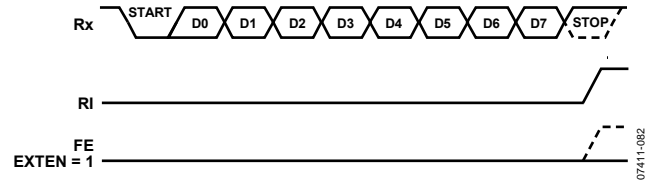


Figure 103. UART Timing in Mode 1

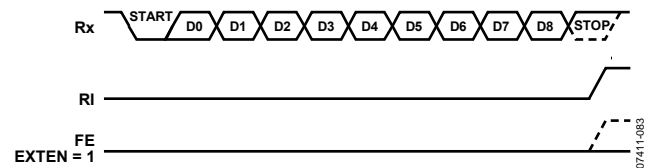


Figure 104. UART Timing in Mode 2 and Mode 3

The 8052 standard UART does not provide break error detection. However, for an 8-bit UART, a break error can be detected when the received character is 0, a null character, and when there is a no stop bit because the RB8 bit is low. Break error detection is not possible for a 9-bit 8052 UART because the stop bit is not recorded. The ADE5166/ADE5169 enhanced break error detection is available through the BE bit in the SBAUDT SFR.

The 8052 standard UART prevents overwrite errors by not allowing a character to be received when the RI, receive interrupt flag, is set. However, it does not indicate if a character has been lost because the RI bit in the SCON SFR is set when the frame is received. The enhanced UART overwrite error detection provides this information. When the enhanced 8052 UART is enabled, a frame is received regardless of the state of the RI flag. If RI = 1 when a new byte is received, the byte in SCON is overwritten, and the overwrite error flag is set. The overwrite error flag is cleared when SBUF is read.

The extended UART is enabled by setting the EXTEN bit in the configuration SFR (CFG, Address 0xAF).

### UART TxD Signal Modulation

There is an internal 38 kHz signal that can be OR'ed with the UART transmit signal for use in remote control applications (see the 38 kHz Modulation section).

## UART2 SERIAL INTERFACE

The ADE5166/ADE5169 UART2 is an 8-bit or 9-bit UART with variable baud rate.

Variable baud rates are defined by using an internal timer to generate any rate between 300 bauds/sec and 115,200 bauds/sec.

The UART2 serial interface provided in the ADE5166/ADE5169 is a full-duplex serial interface. It is also receive buffered by storing the first received byte in a receive buffer until the reception of the second byte is complete. The physical interface to the UART is provided via the RxD2 (P0.7/SS/T1/RxD2) pin and the TxD2 (SDEN/P2.3/TxD2) pin, whereas the firmware interface is through the SFRs presented in Table 145.

### UART2 SFRs

Table 145. Serial Port 2 SFRs

| SFR    | Address | Bit Addressable | Description                                       |
|--------|---------|-----------------|---|
| SCON2  | 0xE1    | No              | Serial communications control (see Table 146).    |
| SBUF2  | 0xEB    | No              | Serial Port 2 buffer (see Table 147).             |
| SBAUD2 | 0xEE    | No              | Enhance serial baud rate control (see Table 148). |

Table 146. Serial Communications Control SFR (SCON2, Address 0xE1)

| Bit | Mnemonic | Default | Description   |
|-----|----------|---------|---|
| 7   | N/A      | N/A     | Reserved  |
| 6   | EN-T8    | 0       | 9-bit UART, variable baud rate enable bit. When set, the UART2 is in 9-bit mode.  |
| 5   | OWE2     | 0       | Overwrite error. This bit is set when new data is received and RI = 1 in the SCON SFR. It indicates that SBUF2 was not read before the next character was transferred in, causing the prior SBUF2 data to be lost. Write a 0 to this bit to clear it.           |
| 4   | FE2      | 0       | Frame error. This bit is set when the received frame does not have a valid stop bit. This bit is read only and updated every time a frame is received.  |
| 3   | BE2      | 0       | Break error. This bit is set whenever the receive data line (RxD2) is low for longer than a full transmission frame, the time required for a start bit, eight data bits, a parity bit, and half a stop bit. This bit is updated every time a frame is received. |
| 2   | REN2     | 0       | Serial Port 2 receive enable bit. Set by user software to enable serial port reception. Cleared by user software to disable serial port reception.  |
| 1   | TI2      | 0       | Serial Port 2 transmit interrupt flag. Set by hardware at the end of the eighth bit, TI2 must be cleared by user software.  |
| 0   | RI2      | 0       | Serial Port 2 receive interrupt flag. Set by hardware at the end of the eighth bit, RI2 must be cleared by user software.   |

Table 147. Serial Port 2 Buffer SFR (SBUF2, Address 0xEB)

| Bit   | Mnemonic | Default | Description                |
|-------|----------|---------|----------------------------|
| [7:0] | SBUF2    | 0       | Serial Port 2 data buffer. |

Table 148. Enhanced Serial Baud Rate Control 2 SFR (SBAUD2, Address 0xEE)

| Bit   | Mnemonic | Default | Description  |
|-------|----------|---------|--|
| 7     | TB8      | 0       | Serial port transmit (Bit 9). The data loaded into TB8 is the ninth data bit transmitted in 9-bit mode.  |
| 6     | RB9      | 0       | Serial port receiver (Bit 9). The ninth data bit received in 9-bit mode is latched into RB8. For 8-bit mode, the stop bit is latched into RB8. |
| 5     | SBF2     |         | Fractional divider Boolean: when set, SBAUDF2 = 0x2B when clear, SBAUDF2 = 0x07.   |
| [4:3] | SBTH2    | 0       | Extended divider ratio for baud rate setting (see Table 144).  |

Both the serial port receive and transmit registers are accessed through the SBUF2 SFR (Address 0xEB). Writing to SBUF2 loads the transmit register, and reading SBUF2 accesses a physically separate receive register.

An enhanced UART mode is offered by using the UART timer and providing enhanced frame error, break error, and overwrite error detection. The SBAUD2 SFR (Address 0xEE) is used to configure the UART2 timer and to indicate the enhanced UART2 errors.

# ADE5166/ADE5169

| Bit   | Mnemonic | Default | Description     |                               |
|-------|----------|---------|-----------------|-------------------------------|
| [2:0] | DIV2     | 0       | Binary divider. |                               |
|       |          |         | <b>DIV2</b>     | <b>Result</b>                 |
|       |          |         | 000             | Divide by 1 (see Table 144)   |
|       |          |         | 001             | Divide by 2 (see Table 144)   |
|       |          |         | 010             | Divide by 4 (see Table 144)   |
|       |          |         | 011             | Divide by 8 (see Table 144)   |
|       |          |         | 100             | Divide by 16 (see Table 144)  |
|       |          |         | 101             | Divide by 32 (see Table 144)  |
|       |          |         | 110             | Divide by 164 (see Table 144) |
|       |          |         | 111             | Divide by 128 (see Table 144) |

**Table 149. Common Baud Rates Using the UART2 Timer with a 4.096 MHz PLL Clock**

| Ideal Baud | CD | SBTH2 | DIV2 | SBAUDT | SBF2 | SBAUDF2 | % Error |
|------------|----|-------|------|--------|------|---------|---------|
| 115,200    | 0  | 0     | 1    | 0x01   | 0    | 0x07    | + 0.16  |
| 115,200    | 1  | 0     | 0    | 0x00   | 0    | 0x07    | + 0.16  |
| 57,600     | 0  | 0     | 2    | 0x02   | 0    | 0x07    | + 0.16  |
| 57,600     | 1  | 0     | 1    | 0x01   | 0    | 0x07    | + 0.16  |
| 38,400     | 0  | 0     | 2    | 0x02   | 1    | 0x2B    | -0.31   |
| 38,400     | 1  | 0     | 1    | 0x01   | 1    | 0x2B    | -0.31   |
| 38,400     | 2  | 0     | 0    | 0x00   | 1    | 0x2B    | -0.31   |
| 19,200     | 0  | 0     | 3    | 0x03   | 1    | 0x2B    | -0.31   |
| 19,200     | 1  | 0     | 2    | 0x02   | 1    | 0x2B    | -0.31   |
| 19,200     | 2  | 0     | 1    | 0x01   | 1    | 0x2B    | -0.31   |
| 19,200     | 3  | 0     | 0    | 0x00   | 1    | 0x2B    | -0.31   |
| 9600       | 0  | 0     | 4    | 0x04   | 1    | 0x2B    | -0.31   |
| 9600       | 1  | 0     | 3    | 0x03   | 1    | 0x2B    | -0.31   |
| 9600       | 2  | 0     | 2    | 0x02   | 1    | 0x2B    | -0.31   |
| 9600       | 3  | 0     | 1    | 0x01   | 1    | 0x2B    | -0.31   |
| 9600       | 4  | 0     | 0    | 0x00   | 1    | 0x2B    | -0.31   |
| 4800       | 0  | 0     | 5    | 0x05   | 1    | 0x2B    | -0.31   |
| 4800       | 1  | 0     | 4    | 0x04   | 1    | 0x2B    | -0.31   |
| 4800       | 2  | 0     | 3    | 0x03   | 1    | 0x2B    | -0.31   |
| 4800       | 3  | 0     | 2    | 0x02   | 1    | 0x2B    | -0.31   |
| 4800       | 4  | 0     | 1    | 0x01   | 1    | 0x2B    | -0.31   |
| 4800       | 5  | 0     | 0    | 0x00   | 1    | 0x2B    | -0.31   |
| 2400       | 0  | 0     | 6    | 0x06   | 1    | 0x2B    | -0.31   |
| 2400       | 1  | 0     | 5    | 0x05   | 1    | 0x2B    | -0.31   |
| 2400       | 2  | 0     | 4    | 0x04   | 1    | 0x2B    | -0.31   |
| 2400       | 3  | 0     | 3    | 0x03   | 1    | 0x2B    | -0.31   |
| 2400       | 4  | 0     | 2    | 0x02   | 1    | 0x2B    | -0.31   |
| 2400       | 5  | 0     | 1    | 0x01   | 1    | 0x2B    | -0.31   |
| 2400       | 6  | 0     | 0    | 0x00   | 1    | 0x2B    | -0.31   |
| 300        | 0  | 2     | 7    | 0x17   | 1    | 0x2B    | -0.31   |
| 300        | 1  | 1     | 7    | 0x0F   | 1    | 0x2B    | -0.31   |
| 300        | 2  | 0     | 7    | 0x07   | 1    | 0x2B    | -0.31   |
| 300        | 3  | 0     | 6    | 0x06   | 1    | 0x2B    | -0.31   |
| 300        | 4  | 0     | 5    | 0x05   | 1    | 0x2B    | -0.31   |
| 300        | 5  | 0     | 4    | 0x04   | 1    | 0x2B    | -0.31   |
| 300        | 6  | 0     | 3    | 0x03   | 1    | 0x2B    | -0.31   |
| 300        | 7  | 0     | 2    | 0x02   | 1    | 0x2B    | -0.31   |



### UART2 OPERATION MODE

The UART2 has two operation modes where each data byte (LSB first) is preceded by a start bit (0), followed by a stop bit (1). Therefore, each frame consists of 10 bits transmitted on the TxD2 pin or received on the RxD2 pin.

The baud rate is set by a dedicated timer for baud rate generation, the UART2 timer, which has a fractional divisor to precisely generate any baud rate.

Transmission is initiated by a write to the Serial Port 2 SFR (SBUF2, Address 0xEB). Next, a stop bit (1) is loaded into the ninth bit position of the serial port shift register. The data is output bit by bit until the stop bit appears on the TxD2 pin and the Serial Port 2 transmit interrupt flag, TI2 (Bit 1 of the SCON2 SFR) is automatically set, as shown in Figure 105.

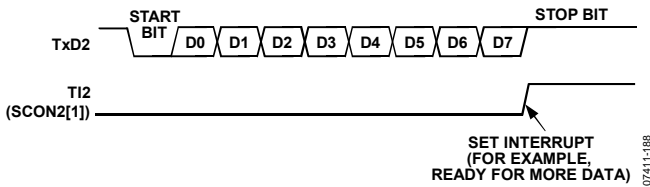


Figure 105. 8-Bit Variable Baud Rate

Reception is initiated when a 1-to-0 transition is detected on the RxD2 pin. Assuming that a valid start bit is detected, character reception continues. The eight data bits are clocked into the serial port shift register.

All of the following conditions must be met at the time the final shift pulse is generated to receive a character:

- If the extended UART is disabled (EXTEN = 0 in the CFG SFR), RI (Bit 0 in the SCON SFR) must be 0 to receive a character. This ensures that the data in the SBUF SFR is not overwritten if the last received character has not been read.
- If frame error checking is enabled by setting SM2 (Bit 5 in the SCON SFR), the received stop bit must be set to receive a character. This ensures that every character received comes from a valid frame, with both a start bit and a stop bit.

If any of these conditions is not met, the received frame is irretrievably lost, and the Serial Port 2 receive interrupt flag, RI2, is not set.

If the received frame meets the preceding conditions, the following events occur:

- The eight bits in the receive shift register are latched into SBUF2.
- The Serial Port 2 receiver interrupt flag (RI2) is set.

Transmission is initiated by any instruction that uses SBUF2 as a destination register. Reception is initiated by the incoming start bit if REN2 = 1 in the SCON2 SFR, Address 0xE1[2].

### 9-Bit UART 2 with Variable Baud Rate

Setting EN-T8 in the serial communications control SFR (SCON2, Address 0xE1[6]) selects the 9-bit mode. In this mode, the UART2 serial port operates in 9-bit mode with a variable baud rate. The baud rate is set by a dedicated timer for baud rate generation, the UART2 timer, which has a fractional divisor to precisely generate any baud rate (see the UART Timer Generated Baud Rates section). The operation of the 9-bit UART2 is the same as for the 9-bit mode of the UART.

In both modes, transmission is initiated by any instruction that uses SBUF2 as a destination register. Reception is initiated in 8-bit mode when RI = 0 and REN = 1 in the SCON SFR. Reception is initiated in the 9-bit mode by the incoming start bit if REN = 1.

### UART2 BAUD RATE GENERATION

The baud rate is determined by the overflow rate of the dedicated baud rate generator, the UART2 timer, which has an integer and fractional divisor.

#### UART2 Timer Generated Baud Rates

The enhanced Serial Baud Rate Control 2 SFR (SBAUD2, Address 0xEE) is used to control the UART2 timer. SBAUD2 is the baud rate control SFR; it sets up the integer divider (DIV2) and the extended divider (SBTH2) for the UART2 timer.

The desired value to write to DIV2 (Bits[2:0]) and to SBTH2 (Bits[4:3]) can be calculated using the following formula, where  $f_{core}$  is defined in the POWCON SFR. Note that the DIV2 value must be rounded down to the nearest integer.

$$DIV2 + SBTH2 = \frac{\log\left(\frac{f_{core}}{16 \times \text{Baud Rate}}\right)}{\log(2)}$$

SBAUDF2 is the fractional divider ratio required to achieve the required baud rate. The appropriate value for SBAUDF2 can be calculated with the following formula:

$$SBAUDF2 = 64 \times \left( \frac{f_{core}}{16 \times 2^{DIV2+SBTH2} \times \text{Baud Rate}} - 1 \right)$$

Note that the SBAUDF2 can only take two values, 0x87 or 0xAB, by clearing or by setting the SBF2 bit (Bit 5), respectively, in the SBAUD2 SFR. These values were chosen to provide an accurate baud rate for 300, 2400, 4800, 9600, 19,200, 38,400, 57,600, and 115,200 bps. Once DIV2 and SBAUDF2 are calculated, the actual baud rate can be calculated, using the following formula:

$$\text{Actual Baud Rate} = \frac{f_{core}}{16 \times 2^{DIV2+SBTH2} \times \left(1 + \frac{SBAUDF2}{64}\right)}$$

## ADE5166/ADE5169

For example, to get a baud rate of 9600 while operating at a core clock frequency of 4.096 MHz, with the PLL CD bits equal to 0,

$$DIV2 + SBTH2 = \log(4,096,000 / (16 \times 9600)) / \log 2 = 4.74 = 4$$

Note that the DIV result is rounded down.

$$SBAUDF2 = 64 \times (4,096,000 / (16 \times 2^3 \times 9600) - 1) = 42.67 = 0x2B$$

Therefore, the actual baud rate is 9570 bps, which gives an error of 0.31%.

### UART2 ADDITIONAL FEATURES

#### **Enhanced Error Checking**

The extended UART2 provides frame error, break error, and overwrite error detection. Framing errors occur when a stop bit is not present at the end of the frame. A missing stop bit implies

that the data in the frame may not have been received properly. Break error detection indicates whether the RxD2 line is low for longer than a 9-bit frame. It indicates that the data just received, a 0 or NULL character, is not valid because the master has disconnected. Overwrite error detection indicates whether the received data isn't read fast enough and, as result, a byte of data is lost.

#### **UART2 Tx/D2 Signal Modulation**

There is an internal 38 kHz signal that can be read with the UART2 transmit signal for use in remote control applications.

One of the events that can wake the MCU from sleep mode is activity on the RxD2 (P0.7/ $\overline{SS}$ /T1/RxD2) pin. See the 3.3 V Peripherals and Wake-Up Events section for more information.

## SERIAL PERIPHERAL INTERFACE (SPI)

The ADE5166/ADE5169 integrate a complete hardware serial peripheral interface on-chip. The SPI is full duplex so that eight bits of data are synchronously transmitted and simultaneously received. This SPI implementation is double buffered, allowing users to read the last byte of received data while a new byte is shifted in. The next byte to be transmitted can be loaded while the current byte is shifted out.

The SPI port can be configured for master or slave operation. The physical interface to the SPI is via the MISO (P0.5/MISO/ZX), MOSI (P0.4/MOSI/SDATA), SCLK (P0.6/SCLK/T0), and  $\overline{SS}$

(P0.7/ $\overline{SS}$ /T1/RxD2) pins, while the firmware interface is via the SPI Configuration SFR 1 (SPIMOD1, Address 0xE8), the SPI Configuration SFR 2 (SPIMOD2, Address 0xE9), the SPI interrupt status SFR (SPISTAT, Address 0xEA), the SPI/I<sup>2</sup>C transmit buffer SFR (SPI2CTx, Address 0x9A), and the SPI/I<sup>2</sup>C receive buffer SFR (SPI2CRx, Address 0x9B).

Note that the SPI pins are shared with the I<sup>2</sup>C pins. Therefore, the user can enable only one interface at a time. The SCPS bit in the configuration SFR (CFG, Address 0xAF) selects which peripheral is active.

### SPI REGISTERS

Table 150. SPI SFR List

| SFR Address | Mnemonic | R/W | Length (Bits) | Default | Description   |
|-------------|----------|-----|---------------|---------|---|
| 0x9A        | SPI2CTx  | W   | 8             | 0       | SPI/I <sup>2</sup> C transmit buffer (see Table 151). |
| 0x9B        | SPI2CRx  | R   | 8             | 0       | SPI/I <sup>2</sup> C receive buffer (see Table 152).  |
| 0xE8        | SPIMOD1  | R/W | 8             | 0x10    | SPI Configuration SFR 1 (see Table 153).              |
| 0xE9        | SPIMOD2  | R/W | 8             | 0       | SPI Configuration SFR 2 (see Table 154).              |
| 0xEA        | SPISTAT  | R/W | 8             | 0       | SPI interrupt status (see Table 155).                 |

Table 151. SPI/I<sup>2</sup>C Transmit Buffer SFR (SPI2CTx, Address 0x9A)

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | SPI2CTx  | 0       | SPI or I <sup>2</sup> C transmit buffer. When the SPI2CTx SFR is written, its content is transferred to the transmit FIFO input. When a write is requested, the FIFO output is sent on the SPI or I <sup>2</sup> C bus. |

Table 152. SPI/I<sup>2</sup>C Receive Buffer SFR (SPI2CRx, Address 0x9B)

| Bit   | Mnemonic | Default | Description   |
|-------|----------|---------|---|
| [7:0] | SPI2CRx  | 0       | SPI or I <sup>2</sup> C receive buffer. When SPI2CRx SFR is read, one byte from the receive FIFO output is transferred to the SPI2CRx SFR. A new data byte from the SPI or I <sup>2</sup> C bus is written to the FIFO input. |

# ADE5166/ADE5169

Table 153. SPI Configuration SFR 1 (SPIMOD1, Address 0xE8)

| Bit   | Bit Address  | Mnemonic | Default | Description   |   |
|-------|--------------|----------|---------|---|---|
| [7:6] | 0xEF to 0xEE | Reserved | 0       | Reserved.   |   |
| 5     | 0xED         | INTMOD   | 0       | SPI interrupt mode.   |   |
|       |              |          |         | <b>INTMOD</b>   | <b>Result</b>   |
|       |              |          |         | 0   | SPI interrupt is set when the SPI Rx buffer is full   |
|       |              |          |         | 1   | SPI interrupt is set when the SPI Tx buffer is empty  |
| 4     | 0xEC         | AUTO_SS  | 1       | Master mode, $\overline{SS}$ output control (see Figure 106).   |   |
|       |              |          |         | <b>AUTO_SS</b>  | <b>Result</b>   |
|       |              |          |         | 0   | The $\overline{SS}$ pin is held low while this bit is cleared, allowing manual chip select control using the $\overline{SS}$ pin  |
|       |              |          |         | 1   | Single byte read or write; the $\overline{SS}$ pin goes low during a single byte transmission and then returns high<br>Continuous transfer; the $\overline{SS}$ pin goes low during the duration of the multibyte continuous transfer and then returns high |
| 3     | 0xEB         | SS_EN    | 0       | Slave mode, $\overline{SS}$ input enable.<br>When this bit is set to Logic 1, the $\overline{SS}$ pin is defined as the slave select input pin for the SPI slave interface. |   |
| 2     | 0xEA         | RxOFW    | 0       | Receive buffer overflow write enable.   |   |
|       |              |          |         | <b>RxOFW</b>  | <b>Result</b>   |
|       |              |          |         | 0   | If the SPI2CRx SFR has not been read when a new data byte is received, the new byte is discarded  |
|       |              |          |         | 1   | If the SPI2CRx SFR has not been read when a new data byte is received, the new byte overwrites the old data   |
| [1:0] | 0xE9 to 0xE8 | SPIR     | 0       | Master mode, SPI SCLK frequency.  |   |
|       |              |          |         | <b>SPIR</b>   | <b>Result</b>   |
|       |              |          |         | 00  | $f_{\text{CORE}}/8 = 512 \text{ kHz}$ (if $f_{\text{CORE}} = 4.096 \text{ MHz}$ )   |
|       |              |          |         | 01  | $f_{\text{CORE}}/16 = 256 \text{ kHz}$ (if $f_{\text{CORE}} = 4.096 \text{ MHz}$ )  |
|       |              |          |         | 10  | $f_{\text{CORE}}/32 = 128 \text{ kHz}$ (if $f_{\text{CORE}} = 4.096 \text{ MHz}$ )  |
|       |              |          |         | 11  | $f_{\text{CORE}}/64 = 64 \text{ kHz}$ (if $f_{\text{CORE}} = 4.096 \text{ MHz}$ )   |

Table 154. SPI Configuration SFR 2 (SPIMOD2, Address 0xE9)

| Bit | Mnemonic | Default | Description  |   |
|-----|----------|---------|--|---|
| 7   | SPICONT  | 0       | Master mode, SPI continuous transfer mode enable bit.  |   |
|     |          |         | <b>SPICONT</b>   | <b>Result</b>   |
|     |          |         | 0  | The SPI interface stops after one byte is transferred and $\overline{SS}$ is deasserted. A new data transfer can be initiated after a stalled period.   |
|     |          |         | 1  | The SPI interface continues to transfer data until no valid data is available in the SPI2CTx SFR. $\overline{SS}$ remains asserted until the SPI2CTx SFR and the transmit shift registers are empty.  |
| 6   | SPIEN    | 0       | SPI interface enable bit.                              |   |
|     |          |         | <b>SPIEN</b>   | <b>Result</b>   |
|     |          |         | 0  | The SPI interface is disabled.  |
|     |          |         | 1  | The SPI interface is enabled.   |
| 5   | SPIODO   | 0       | SPI open-drain output configuration bit.               |   |
|     |          |         | <b>SPIODO</b>  | <b>Result</b>   |
|     |          |         | 0  | Internal pull-up resistors are connected to the SPI outputs.  |
|     |          |         | 1  | The SPI outputs are open drain and need external pull-up resistors. The pull-up voltage should not exceed the specified operating voltage.  |
| 4   | SPIMS_b  | 0       | SPI master mode enable bit.                            |   |
|     |          |         | <b>SPIMS_b</b>   | <b>Result</b>   |
|     |          |         | 0  | The SPI interface is defined as a slave.  |
|     |          |         | 1  | The SPI interface is defined as a master.   |
| 3   | SPICPOL  | 0       | SPI clock polarity configuration bit (see Figure 108). |   |
|     |          |         | <b>SPICPOL</b>   | <b>Result</b>   |
|     |          |         | 0  | The default state of SCLK is low, and the first SCLK edge is rising. Depending on the SPICPHA bit, the SPI data output changes state on the falling or rising edge of SCLK while the SPI data input is sampled on the rising or falling edge of SCLK.   |
|     |          |         | 1  | The default state of SCLK is high, and the first SCLK edge is falling. Depending on the SPICPHA bit, the SPI data output changes state on the rising or falling edge of SCLK while the SPI data input is sampled on the falling or rising edge of SCLK. |
| 2   | SPICPHA  | 0       | SPI clock phase configuration bit (see Figure 108).    |   |
|     |          |         | <b>SPICPHA</b>   | <b>Result</b>   |
|     |          |         | 0  | The SPI data output changes state when $\overline{SS}$ goes low at the second edge of SCLK and then every two subsequent edges, whereas the SPI data input is sampled at the first SCLK edge and then every two subsequent edges.                       |
|     |          |         | 1  | The SPI data output changes state at the first edge of SCLK and then every two subsequent edges, whereas the SPI data input is sampled at the second SCLK edge and then every two subsequent edges.   |
| 1   | SPILSBF  | 0       | Master mode, LSB first configuration bit.              |   |
|     |          |         | <b>SPILSBF</b>   | <b>Result</b>   |
|     |          |         | 0  | The MSB of the SPI outputs is transmitted first.  |
|     |          |         | 1  | The LSB of the SPI outputs is transmitted first.  |
| 0   | TIMODE   | 1       | Transfer and interrupt mode of the SPI interface.      |   |
|     |          |         | <b>TIMODE</b>  | <b>Result</b>   |
|     |          |         | 1  | This bit must be set to 1 for proper operation.   |

# ADE5166/ADE5169

Table 155. SPI Interrupt Status SFR (SPISTAT, Address 0xEA)

| Bit | Mnemonic | Default | Description   |  |  |
|-----|----------|---------|---|--|--|
| 7   | BUSY     | 0       | SPI peripheral busy flag.   |  |  |
|     |          |         | <b>BUSY</b>   | <b>Result</b>  |  |
|     |          |         | 0   | The SPI peripheral is idle.  |  |
|     |          |         | 1   | The SPI peripheral is busy transferring data in slave or master mode.  |  |
| 6   | MMERR    | 0       | SPI multimaster error flag.   |  |  |
|     |          |         | <b>MMERR</b>  | <b>Result</b>  |  |
|     |          |         | 0   | A multiple master error has not occurred.  |  |
|     |          |         | 1   | If the SS_EN bit (SPIMOD1, Address 0xE8) is set, enabling the slave select input and asserting the SS pin while the SPI peripheral is transferring data as a master, this flag is raised to indicate the error. Write a 0 to this bit to clear it.   |  |
| 5   | SPIRxOF  | 0       | SPI receive overflow error flag. Reading the SPI2CRx SFR clears this bit.   |  |  |
|     |          |         | <b>SPIRxOF</b>  | <b>TIMODE</b>  | <b>Result</b>  |
|     |          |         | 0   | X  | The SPI2CRx SFR (Address 0x9B) contains valid data.  |
|     |          |         | 1   | This bit is set if the SPI2CRx SFR is not read before the end of the next byte transfer. If the RxOFW bit (SPIMOD1, Address 0xE8) is set and this condition occurs, SPI2CRx is overwritten.  |  |
| 4   | SPIRxIRQ | 0       | SPI receive mode interrupt flag. Reading the SPI2CRx SFR clears this bit.   |  |  |
|     |          |         | <b>SPIRxIRQ</b>   | <b>TIMODE</b>  | <b>Result</b>  |
|     |          |         | 0   | X  | The SPI2CRx register does not contain new data.  |
|     |          |         | 1   | 0  | This bit is set when the SPI2CRx register contains new data. If the SPI/I <sup>2</sup> C interrupt is enabled, an interrupt is generated when this bit is set. If the SPI2CRx register is not read before the end of the current byte transfer, the transfer stops and the SS pin is deasserted. |
|     |          |         | 1   | The SPI2CRx register contains new data.  |  |
| 3   | SPIRxBF  | 0       | Status bit for SPI Rx buffer. When set, the Rx FIFO is full. A read of the SPI2CRx clears this flag.  |  |  |
| 2   | SPITxUF  | 0       | Status bit for SPI Tx buffer. When set, the Tx FIFO is underflowing and data can be written into SPI2CTx (Address 0x9A). Write a 0 to this bit to clear it. |  |  |
| 1   | SPITxIRQ | 0       | SPI transmit mode interrupt flag. Writing new data to the SPI2CTx SFR clears this bit.  |  |  |
|     |          |         | <b>SPITxIRQ</b>   | <b>TIMODE</b>  | <b>Result</b>  |
|     |          |         | 0   | X  | The SPI2CTx SFR is full.   |
|     |          |         | 1   | 0  | The SPI2CTx SFR is empty.  |
|     |          |         | 1   | This bit is set when the SPI2CTx SFR is empty. If the SPI/I <sup>2</sup> C interrupt is enabled, an interrupt is generated when this bit is set. If new data is not written into the SPI2CTx SFR before the end of the current byte transfer, the transfer stops, and the SS pin is deasserted. Write a 0 to this bit to clear it. |  |
| 0   | SPITxBF  | 0       | Status bit for the SPI Tx buffer. When set, the SPI Tx buffer is full. Write a 0 to this bit to clear it.   |  |  |

## SPI PINS

### MISO (Master In, Slave Out Data I/O Pin)

The MISO (P0.5/MISO/ZX) pin is configured as an input line in master mode and as an output line in slave mode. The MISO line on the master (data in) should be connected to the MISO line in the slave device (data out). The data is transferred as byte-wide (8-bit) serial data, MSB first.

### MOSI (Master Out, Slave In Pin)

The MOSI (P0.4/MOSI/SDATA) pin is configured as an output line in master mode and as an input line in slave mode. The MOSI line on the master (data out) should be connected to the MOSI line in the slave device (data in). The data is transferred as byte-wide (8-bit) serial data, MSB first.

### SCLK (Serial Clock I/O Pin)

The master serial clock (SCLK) is used to synchronize the data being transmitted and received through the MOSI and MISO data lines. The SCLK (P0.6/SCLK/T0) pin is configured as an output in master mode and as an input in slave mode.

In master mode, the bit rate, polarity, and phase of the clock are controlled by SPI Configuration SFR 1 (SPIMOD1, Address 0xE8) and SPI Configuration SFR 2 (SPIMOD2, Address 0xE9).

In slave mode, the SPI Configuration SFR 2 (SPIMOD2, Address 0xE9) must be configured with the phase and polarity of the expected input clock.

In both master and slave modes, the data is transmitted on one edge of the SCLK signal and sampled on the other. It is important, therefore, that the SPICPHA and SPICPOL bits be configured the same for the master and slave devices.

**$\overline{SS}$  (Slave Select Pin)**

In SPI slave mode, a transfer is initiated by the assertion of  $\overline{SS}$  low. The SPI port then transmits and receives 8-bit data until the data is concluded by the deassertion of  $\overline{SS}$  according to the SPICON bit setting. In slave mode,  $\overline{SS}$  is always an input.

In SPI master mode, the  $\overline{SS}$  (P0.7/ $\overline{SS}$ /T1/RxD2) pin can be used to control data transfer to a slave device. In the automatic slave select control mode, the  $\overline{SS}$  is asserted low to select the slave device and then raised to deselect the slave device after the transfer is complete. Automatic slave select control is enabled by setting the AUTO\_SS bit (Bit 4) in the SPI Configuration SFR 1 (SPIMOD1, Address 0xE8).

In a multimaster system, the  $\overline{SS}$  can be configured as an input so that the SPI peripheral can operate as a slave in some situations and as a master in others. In this case, the slave selects for the slaves controlled by this SPI peripheral should be generated with general I/O pins.

**SPI MASTER OPERATING MODES**

The double-buffered receive and transmit registers can be used to maximize the throughput of the SPI peripheral by continuously streaming out data in master mode. The continuous transmit mode is designed to use the full capacity of the SPI. In this mode, the master transmits and receives data until the SPI/I2C transmit buffer SFR (SPI2CTx, Address 0x9A) is empty at the start of a byte transfer. Continuous mode is enabled by setting the SPICONT bit (Bit 7) in the SPI Configuration SFR 2 (SPIMOD2, Address 0xE9). The SPI peripheral also offers a single byte read/write function.

In master mode, the type of transfer is handled automatically, depending on the configuration of the SPICONT bit in the SPI Configuration SFR 2 (SPIMOD2, Address 0xE9). The following procedures show the sequence of events that should be performed for each master operating mode. Based on the  $\overline{SS}$  configuration, some of these events take place automatically.

**Procedures for Using SPI as a Master**

**Single Byte Write Mode, SPICONT (SPIMOD2[7]) = 0**

1. Write to the SPI2CTx SFR.
2.  $\overline{SS}$  is asserted low, and a write routine is initiated.
3. The SPITxIRQ interrupt flag is set when the SPI2CTx register is empty.
4.  $\overline{SS}$  is deasserted high.
5. Write to SPI2CTx SFR to clear the SPITxIRQ interrupt flag.

**Continuous Mode, SPICONT (SPIMOD2[7]) = 1**

1. Write to the SPI2CTx SFR.
2.  $\overline{SS}$  is asserted low, and a write routine is initiated.
3. Wait for the SPITxIRQ interrupt flag to write to SPI2CTx SFR.
4. Transfer continues until the SPI2CTx register and transmit shift registers are empty.
5. The SPITxIRQ interrupt flag is set when the SPI2CTx register is empty.
6.  $\overline{SS}$  is deasserted high.
7. Write to SPI2CTx SFR to clear the SPITxIRQ interrupt flag.

Figure 106 shows the SPI output for certain automatic chip select and continuous mode selections. Note that if the continuous mode is not used, a short delay is inserted between transfers.

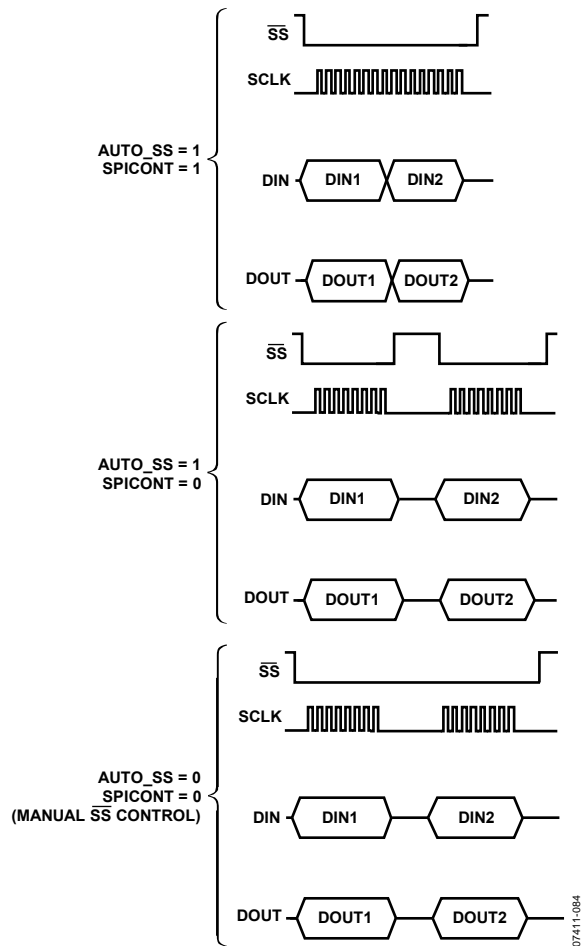


Figure 106. Automatic Chip Select and Continuous Mode Output

Note that reading the content of the SPI/I<sup>2</sup>C receive buffer SFR (SPI2CRx, Address 0x9B) should be done using a 2-cycle instruction set, such as MOV A or SPI2CRX. Using a 3-cycle instruction, such as MOV 0x3D or SPI2CRX, does not transfer the right information into the target register.

## SPI INTERRUPT AND STATUS FLAGS

The SPI interface has several status flags that indicate the status of the double-buffered receive and transmit registers. Figure 107 shows when the status and interrupt flags are raised. The transmit interrupt occurs when the transmit shift register is loaded with the data in the SPI/I<sup>2</sup>C transmit buffer SFR (SPI2CTx, Address 0x9A) register. If the SPI master is in transmit operating mode, and the SPI/I<sup>2</sup>C transmit buffer SFR (SPI2CTx, Address 0x9A) register has not been written with new data by the beginning of the next byte transfer, the transmit operation stops.

When a new byte of data is received in the SPI/I<sup>2</sup>C receive buffer SFR (SPI2CRx, Address 0x9B), the SPI receive interrupt flag is raised. If the data in the SPI/I<sup>2</sup>C receive buffer SFR (SPI2CRx,

Address 0x9B) is not read before new data is ready to be loaded into the SPI/I<sup>2</sup>C receive buffer SFR (SPI2CRx, Address 0x9B), an overflow condition has occurred. This overflow condition, indicated by the SPIRxOF flag, forces the new data to be discarded or overwritten if the RxOFW bit (SPIMOD1, Address 0xE8) is set.

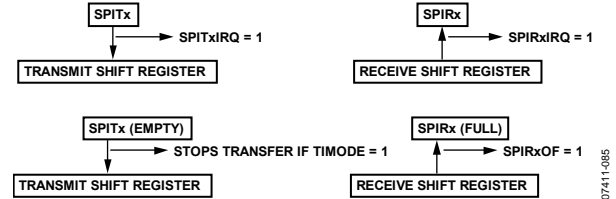


Figure 107. SPI Receive and Transmit Interrupt and Status Flags

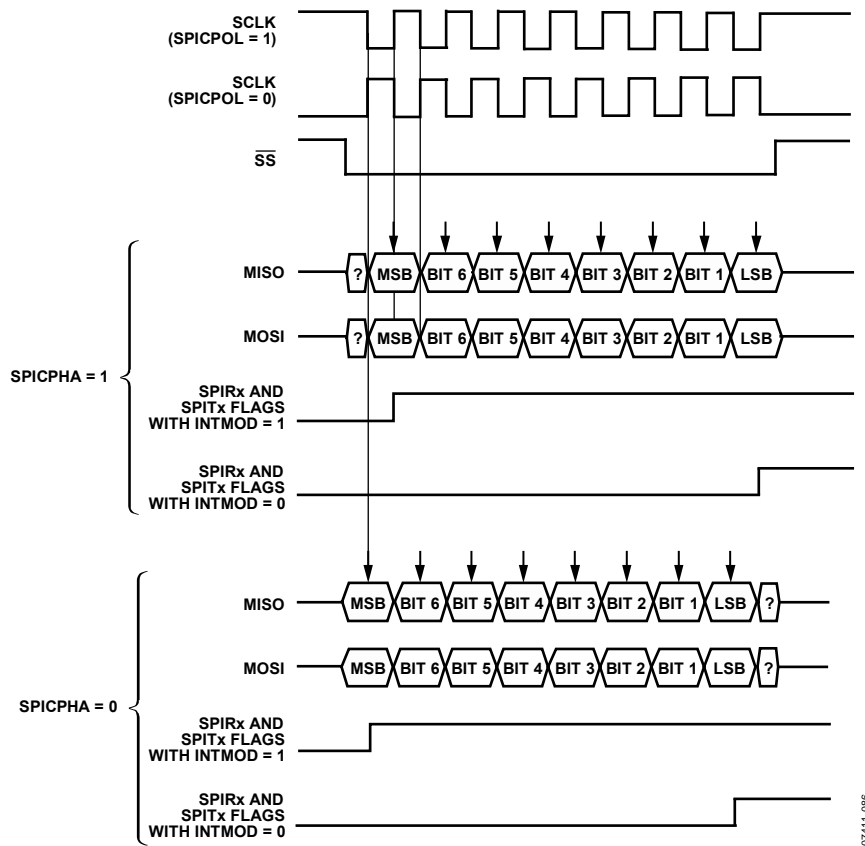


Figure 108. SPI Timing Configurations



## I<sup>2</sup>C-COMPATIBLE INTERFACE

The ADE5166/ADE5169 support a fully licensed I<sup>2</sup>C interface. The I<sup>2</sup>C interface is implemented as a full hardware master.

SDATA (P0.4/MOSI/SDATA) is the data I/O pin, and SCLK (P0.6/SCLK/T0) is the serial clock. These two pins are shared with the MOSI and SCLK pins of the on-chip SPI interface. Therefore, the user can enable only one interface or the other on these pins at any given time. The SCPS bit (Bit 5) in the configuration SFR (CFG, Address 0xAF) selects which peripheral is active.

The two pins used for data transfer, SDATA and SCLK, are configured in a wire-AND format that allows arbitration in a multimaster system.

The transfer sequence of an I<sup>2</sup>C system consists of a master device initiating a transfer by generating a start condition while the bus is idle. The master transmits the address of the slave device and the direction of the data transfer in the initial address transfer. If the slave acknowledges, the data transfer is initiated. This continues until the master issues a stop condition and the bus becomes idle.

### SERIAL CLOCK GENERATION

The I<sup>2</sup>C master in the system generates the serial clock for a transfer. The master channel can be configured to operate in fast mode (256 kHz) or standard mode (32 kHz).

The bit rate is defined in the I2CMOD SFR as follows:

$$f_{SCLK} = \frac{f_{CORE}}{16 \times 2^{I2CR[1:0]}}$$

### SLAVE ADDRESSES

The I<sup>2</sup>C slave address SFR (I2CADR, Address 0xE9) contains the slave device ID. The LSB of this register contains a read/write request. A write to this SFR starts the I<sup>2</sup>C communication.

### I<sup>2</sup>C REGISTERS

The I<sup>2</sup>C peripheral interface consists of five SFRs.

- I2CMOD
- SPI2CSTAT
- I2CADR
- SPI2CTx
- SPI2CRx

Because the SPI and I<sup>2</sup>C serial interfaces share the same pins, they also share the same SFRs, such as the SPI2CTx and SPI2CRx SFRs. In addition, the I2CMOD, I2CADR, and SPI2CSTAT SFRs are shared with the SPIMOD1, SPIMOD2, and SPISTAT SFRs, respectively.

Table 156. I<sup>2</sup>C SFR List

| SFR Address | Mnemonic  | R/W | Length | Default | Description   |
|-------------|-----------|-----|--------|---------|---|
| 0x9A        | SPI2CTx   | W   | 8      |         | SPI/I <sup>2</sup> C transmit buffer (see Table 151).       |
| 0x9B        | SPI2CRx   | R   | 8      | 0       | SPI/I <sup>2</sup> C receive buffer (see Table 152).        |
| 0xE8        | I2CMOD    | R/W | 8      | 0       | I <sup>2</sup> C mode (see Table 157).                      |
| 0xE9        | I2CADR    | R/W | 8      | 0       | I <sup>2</sup> C slave address (see Table 158).             |
| 0xEA        | SPI2CSTAT | R/W | 8      | 0       | I <sup>2</sup> C interrupt status register (see Table 159). |

Table 157. I<sup>2</sup>C Mode SFR (I2CMOD, Address 0xE8)

| Bit   | Bit Address   | Mnemonic | Default | Description   |      |        |    |   |    |   |    |  |    |   |
|-------|---|----------|---------|---|------|--------|----|---|----|---|----|--|----|---|
| 7     | 0xEF  | I2CEN    | 0       | I <sup>2</sup> C enable bit. When this bit is set to Logic 1, the I <sup>2</sup> C interface is enabled. A write to the I2CADR SFR (Address 0xE9) starts a communication.   |      |        |    |   |    |   |    |  |    |   |
| [6:5] | 0xEE to 0xED  | I2CR     | 0       | I <sup>2</sup> C SCLK frequency.<br><table border="1" style="width: 100%; border-collapse: collapse;"> <thead> <tr> <th>I2CR</th> <th>Result</th> </tr> </thead> <tbody> <tr> <td>00</td> <td><math>f_{CORE}/16 = 256 \text{ kHz}</math> if <math>f_{CORE} = 4.096 \text{ MHz}</math></td> </tr> <tr> <td>01</td> <td><math>f_{CORE}/32 = 128 \text{ kHz}</math> if <math>f_{CORE} = 4.096 \text{ MHz}</math></td> </tr> <tr> <td>10</td> <td><math>f_{CORE}/64 = 64 \text{ kHz}</math> if <math>f_{CORE} = 4.096 \text{ MHz}</math></td> </tr> <tr> <td>11</td> <td><math>f_{CORE}/128 = 32 \text{ kHz}</math> if <math>f_{CORE} = 4.096 \text{ MHz}</math></td> </tr> </tbody> </table> | I2CR | Result | 00 | $f_{CORE}/16 = 256 \text{ kHz}$ if $f_{CORE} = 4.096 \text{ MHz}$ | 01 | $f_{CORE}/32 = 128 \text{ kHz}$ if $f_{CORE} = 4.096 \text{ MHz}$ | 10 | $f_{CORE}/64 = 64 \text{ kHz}$ if $f_{CORE} = 4.096 \text{ MHz}$ | 11 | $f_{CORE}/128 = 32 \text{ kHz}$ if $f_{CORE} = 4.096 \text{ MHz}$ |
| I2CR  | Result  |          |         |   |      |        |    |   |    |   |    |  |    |   |
| 00    | $f_{CORE}/16 = 256 \text{ kHz}$ if $f_{CORE} = 4.096 \text{ MHz}$ |          |         |   |      |        |    |   |    |   |    |  |    |   |
| 01    | $f_{CORE}/32 = 128 \text{ kHz}$ if $f_{CORE} = 4.096 \text{ MHz}$ |          |         |   |      |        |    |   |    |   |    |  |    |   |
| 10    | $f_{CORE}/64 = 64 \text{ kHz}$ if $f_{CORE} = 4.096 \text{ MHz}$  |          |         |   |      |        |    |   |    |   |    |  |    |   |
| 11    | $f_{CORE}/128 = 32 \text{ kHz}$ if $f_{CORE} = 4.096 \text{ MHz}$ |          |         |   |      |        |    |   |    |   |    |  |    |   |
| [4:0] | 0xEC to 0xE8  | I2CRCT   | 0       | Configures the length of the I <sup>2</sup> C received FIFO buffer. The I <sup>2</sup> C peripheral stops when I2CRCT[4:0] + 1 byte have been read, or if an error occurs.  |      |        |    |   |    |   |    |  |    |   |

Table 158. I<sup>2</sup>C Slave Address SFR (I2CADR, Address 0xE9)

| Bit   | Mnemonic  | Default | Description   |
|-------|-----------|---------|---|
| [7:1] | I2CSLVADR | 0       | Address of the I <sup>2</sup> C slave being addressed. Writing to this register starts the I <sup>2</sup> C transmission (read or write).   |
| 0     | I2CR_W    | 0       | Command bit for read or write. When this bit is set to Logic 1, a read command is transmitted on the I <sup>2</sup> C bus. Data from the slave in the SPI2CRx SFR (Address 0x9B) is expected after a command byte. When this bit is set to Logic 0, a write command is transmitted on the I <sup>2</sup> C bus. Data to slave is expected in the SPI2CTx SFR. |

**Table 159. I<sup>2</sup>C Interrupt Status Register SFR (SPI2CSTAT, Address 0xEA)**

| Bit   | Mnemonic           | Default | Description   |
|-------|--------------------|---------|---|
| 7     | I2CBUSY            | 0       | This bit is set to Logic 1 when the I <sup>2</sup> C interface is used. When set, the Tx FIFO is emptied.   |
| 6     | I2CNOACK           | 0       | I <sup>2</sup> C no acknowledgement transmit interrupt. This bit is set to Logic 1 when the slave device does not send an acknowledgement. The I <sup>2</sup> C communication is stopped after this event. Write a 0 to this bit to clear it. |
| 5     | I2CRxIRQ           | 0       | I <sup>2</sup> C receive interrupt. This bit is set to Logic 1 when the receive FIFO is not empty. Write a 0 to this bit to clear it.   |
| 4     | I2CTxIRQ           | 0       | I <sup>2</sup> C transmit interrupt. This bit is set to Logic 1 when the transmit FIFO is empty. Write a 0 to this bit to clear it.   |
| [3:2] | I2CFIFOSTAT        | 0       | Status bits for 3- or 4-byte deep I <sup>2</sup> C FIFO. The FIFO monitored in these two bits is the one currently used in I <sup>2</sup> C communication (receive or transmit) because only one FIFO is active at a time.                    |
|       | <b>I2CFIFOSTAT</b> |         | <b>Result</b>   |
|       | 00                 |         | FIFO empty  |
|       | 01                 |         | Reserved  |
|       | 10                 |         | FIFO half full  |
|       | 11                 |         | FIFO full   |
| 1     | I2CACC_ERR         | 0       | Set when trying to write and read at the same time. Write a 0 to this bit to clear it.  |
| 0     | I2CTxWR_ERR        | 0       | Set when a write was attempted when the I <sup>2</sup> C transmit FIFO was full. Write a 0 to this bit to clear it.   |

## READ AND WRITE OPERATIONS

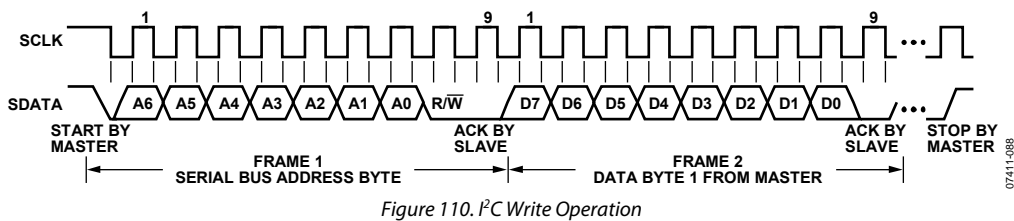
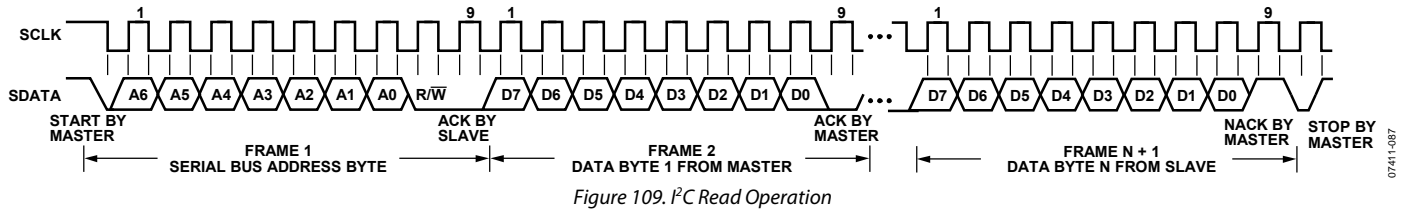


Figure 109 and Figure 110 depict I<sup>2</sup>C read and write operations, respectively. Note that the LSB of the I2CADR SFR (Address 0xE9) is used to select whether a read or write operation is performed on the slave device. During the read operation, the master acknowledges are generated automatically by the I<sup>2</sup>C peripheral. The master generated no acknowledge (NACK) before the end of a read operation is also automatically generated after the I2CRCT bits in the I2CMOD SFR (Address 0xE8[4:0]) have been read from the slave. If the I2CADR register is updated during a transmission, instead of generating a stop at the end of the read or write operation, the master generates a start condition and continues with the next communication.

### Reading the SPI/I<sup>2</sup>C Receive Buffer SFR (SPI2CRx, Address 0x9B)

Reading the SPI2CRx SFR should be done with a 2-cycle instruction, such as

```
Mov a, spi2crx or Mov R0, spi2crx.
```

A 3-cycle instruction, such as

```
Mov 3dh, spi2crx
```

does not transfer the right data into RAM Address 0x3D.

### I<sup>2</sup>C RECEIVE AND TRANSMIT FIFOS

The I<sup>2</sup>C peripheral has a 4-byte receive FIFO and a 4-byte transmit FIFO. The buffers reduce the overhead associated with using the I<sup>2</sup>C peripheral. Figure 111 shows the operation of the I<sup>2</sup>C receive and transmit FIFOs.

The Tx FIFO can be loaded with four bytes to be transmitted to the slave at the beginning of a write operation. When the transmit FIFO is empty, the I<sup>2</sup>C transmit interrupt flag is set, and the PC vectors to the I<sup>2</sup>C interrupt vector if this interrupt is enabled. If a new byte is not loaded into the Tx FIFO before it is needed in the transmit shift register, the communication stops. An error, such as not receiving an acknowledge, also causes the communication to terminate. In case of an error during a write operation, the Tx FIFO is flushed.

The Rx FIFO allows four bytes to be read in from the slave before the MCU has to read the data. A receive interrupt can

be generated after each byte is received or when the Rx FIFO is full. If the peripheral is reading from a slave address, the communication stops when the number of received bytes equals the number set in I2CRCT in the I2CMOD SFR (Address 0xE8[4:0]). An error, such as not receiving an acknowledge, also causes the communication to terminate.

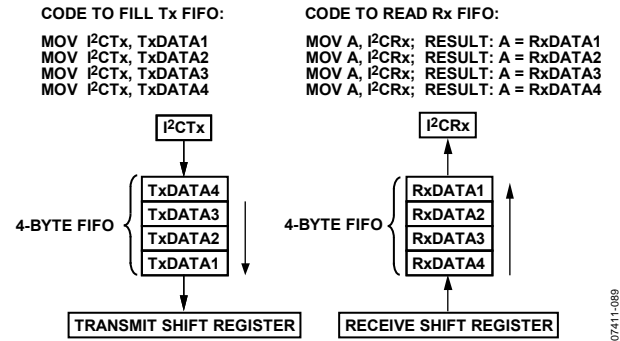


Figure 111. I<sup>2</sup>C FIFO Operation

07411-089

## I/O PORTS

### PARALLEL I/O

The ADE5166/ADE5169 use three input/output ports to exchange data with external devices. In addition to performing general-purpose I/O, some are capable of driving an LCD or performing alternate functions for the peripherals available on-chip. In general, when a peripheral is enabled, the pins associated with it cannot be used as a general-purpose I/O. The I/O port can be configured through the SFRs listed in Table 160.

**Table 160. I/O Port SFRs**

| SFR     | Address | Bit Addressable | Description                 |
|---------|---------|-----------------|-----------------------------|
| P0      | 0x80    | Yes             | Port 0 register             |
| P1      | 0x90    | Yes             | Port 1 register             |
| P2      | 0xA0    | Yes             | Port 2 Register             |
| EPCFG   | 0x9F    | No              | Extended port configuration |
| PINMAP0 | 0xB2    | No              | Port 0 weak pull-up enable  |
| PINMAP1 | 0xB3    | No              | Port 1 weak pull-up enable  |
| PINMAP2 | 0xB4    | No              | Port 2 weak pull-up enable  |

The three bidirectional I/O ports have internal pull-ups that can be enabled or disabled individually for each pin. The internal pull-ups are enabled by default. Disabling an internal pull-up causes a pin to become open drain. Weak internal pull-ups are configured through the PINMAPx SFRs.

Figure 112 shows a typical bit latch and I/O buffer for an I/O pin. The bit latch (one bit in the SFR of each port) is represented as a Type D flip-flop, which clocks in a value from the internal bus in response to a write-to-latch signal from the CPU. The Q output of the flip-flop is placed on the internal bus in response to a read latch signal from the CPU. The level of the port pin itself is placed on the internal bus in response to a read pin signal from the CPU. Some instructions that read a port activate the read latch signal, and others activate the read pin signal. See the Read-Modify-Write Instructions section for details.

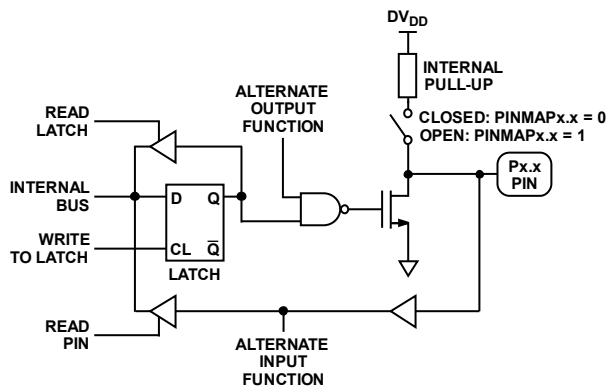


Figure 112. Port 0 Bit Latch and I/O Buffer

### Weak Internal Pull-Ups Enabled

A pin with weak internal pull-up enabled is used as an input by writing a 1 to the pin. The pin is pulled high by the internal pull-ups, and the pin is read using the circuitry shown in Figure 112. If the pin is driven low externally, it sources current because of the internal pull-ups.

A pin with internal pull-up enabled is used as an output by writing a 1 or a 0 to the pin to control the level of the output. If a 0 is written to the pin, it drives a logic low output voltage ( $V_{OL}$ ) and is capable of sinking 1.6 mA.

### Open Drain (Weak Internal Pull-Ups Disabled)

When the weak internal pull-up on a pin is disabled, the pin becomes open drain. Use this open-drain pin as a high impedance input by writing a 1 to the pin. The pin is read using the circuitry shown in Figure 112. The open-drain option is preferable for inputs because it draws less current than the internal pull-ups that were enabled.

### 38 kHz Modulation

Every ADE5166/ADE5169 provides a 38 kHz modulation signal. The 38 kHz modulation is accomplished by internally XOR'ing the level written to the I/O pin with a 38 kHz square wave. Then, when a 0 is written to the I/O pin, it is modulated as shown in Figure 113.

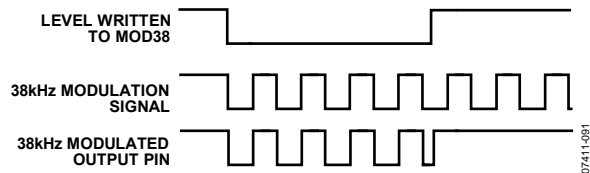


Figure 113. 38 kHz Modulation

Uses for this 38 kHz modulation include IR modulation of a UART transmit signal or a low power signal to drive an LED. The modulation can be enabled or disabled with the MOD38EN bit (Bit 4) in the CFG SFR (Address 0xAF). The 38 kHz modulation is available on eight pins, selected by the MOD38[7:0] bits in the extended port configuration SFR (EPCFG, Address 0x9F).

**I/O REGISTERS**

**Table 161. Extended Port Configuration SFR (EPCFG, Address 0x9F)**

| Bit | Mnemonic   | Default | Description  |
|-----|------------|---------|--|
| 7   | MOD38_FP21 | 0       | This bit enables 38 kHz modulation on the P1.6/FP21 pin.       |
| 6   | MOD38_FP22 | 0       | This bit enables 38 kHz modulation on the P1.5/FP22 pin.       |
| 5   | MOD38_FP23 | 0       | This bit enables 38 kHz modulation on the P1.4/T2/FP23 pin.    |
| 4   | MOD38_TxD  | 0       | This bit enables 38 kHz modulation on the P1.1/TxD pin.        |
| 3   | MOD38_CF1  | 0       | This bit enables 38 kHz modulation on the P0.2/CF1/RTCCAL pin. |
| 2   | MOD38_S5b  | 0       | This bit enables 38 kHz modulation on the P0.7/S5/T1/RxD2 pin. |
| 1   | MOD38_MISO | 0       | This bit enables 38 kHz modulation on the P0.5/MISO/ZX pin.    |
| 0   | MOD38_CF2  | 0       | This bit enables 38 kHz modulation on the P0.3/CF2 pin.        |

**Table 162. Port 0 Weak Pull-Up Enable SFR (PINMAP0, Address 0xB2)**

| Bit | Mnemonic  | Default | Description  |
|-----|-----------|---------|--|
| 7   | PINMAP0.7 | 0       | The weak pull-up on P0.7 is disabled when this bit is set. |
| 6   | PINMAP0.6 | 0       | The weak pull-up on P0.6 is disabled when this bit is set. |
| 5   | PINMAP0.5 | 0       | The weak pull-up on P0.5 is disabled when this bit is set. |
| 4   | PINMAP0.4 | 0       | The weak pull-up on P0.4 is disabled when this bit is set. |
| 3   | PINMAP0.3 | 0       | The weak pull-up on P0.3 is disabled when this bit is set. |
| 2   | PINMAP0.2 | 0       | The weak pull-up on P0.2 is disabled when this bit is set. |
| 1   | PINMAP0.1 | 0       | The weak pull-up on P0.1 is disabled when this bit is set. |
| 0   | PINMAP0.0 | 0       | The weak pull-up on P0.0 is disabled when this bit is set. |

**Table 163. Port 1 Weak Pull-Up Enable SFR (PINMAP1, Address 0xB3)**

| Bit | Mnemonic  | Default | Description  |
|-----|-----------|---------|--|
| 7   | PINMAP1.7 | 0       | The weak pull-up on P1.7 is disabled when this bit is set. |
| 6   | PINMAP1.6 | 0       | The weak pull-up on P1.6 is disabled when this bit is set. |
| 5   | PINMAP1.5 | 0       | The weak pull-up on P1.5 is disabled when this bit is set. |
| 4   | PINMAP1.4 | 0       | The weak pull-up on P1.4 is disabled when this bit is set. |
| 3   | PINMAP1.3 | 0       | The weak pull-up on P1.3 is disabled when this bit is set. |
| 2   | PINMAP1.2 | 0       | The weak pull-up on P1.2 is disabled when this bit is set. |
| 1   | PINMAP1.1 | 0       | The weak pull-up on P1.1 is disabled when this bit is set. |
| 0   | PINMAP1.0 | 0       | The weak pull-up on P1.0 is disabled when this bit is set. |

**Table 164. Port 2 Weak Pull-Up Enable SFR (PINMAP2, Address 0xB4)**

| Bit   | Mnemonic  | Default | Description   |
|-------|-----------|---------|---|
| [7:6] | Reserved  | 0       | Reserved. Should be left cleared.                           |
| 5     | PINMAP2.5 | 0       | The weak pull-up on RESET is disabled when this bit is set. |
| 4     | Reserved  | 0       | Reserved. Should be left cleared.                           |
| 3     | PINMAP2.3 | 0       | Reserved. Should be left cleared.                           |
| 2     | PINMAP2.2 | 0       | The weak pull-up on P2.2 is disabled when this bit is set.  |
| 1     | PINMAP2.1 | 0       | The weak pull-up on P2.1 is disabled when this bit is set.  |
| 0     | PINMAP2.0 | 0       | The weak pull-up on P2.0 is disabled when this bit is set.  |

# ADE5166/ADE5169

**Table 165. Port 0 SFR (P0, Address 0x80)**

| Bit | Bit Address | Mnemonic | Default | Description <sup>1</sup>   |
|-----|-------------|----------|---------|--|
| 7   | 0x87        | T1       | 1       | This bit reflects the state of the P0.7/ $\overline{SS}$ /T1/RxD2 pin. It can be written to or read. |
| 6   | 0x86        | T0       | 1       | This bit reflects the state of the P0.6/SCLK/T0 pin. It can be written to or read.                   |
| 5   | 0x85        | ZX       | 1       | This bit reflects the state of the P0.5/MISO/ZX pin. It can be written to or read.                   |
| 4   | 0x84        |          | 1       | This bit reflects the state of the P0.4/MOSI/SDATA pin. It can be written to or read.                |
| 3   | 0x83        | CF2      | 1       | This bit reflects the state of the P0.3/CF2 pin. It can be written to or read.                       |
| 2   | 0x82        | CF1      | 1       | This bit reflects the state of the P0.2/CF1/RTCCAL pin. It can be written to or read.                |
| 1   | 0x81        |          | 1       | This bit reflects the state of the P0.1/FP19/RTCCAL pin. It can be written to or read.               |
| 0   | 0x80        | INT1     | 1       | This bit reflects the state of the BCTRL/INT1/P0.0 pin. It can be written to or read.                |

<sup>1</sup> When an alternate function is chosen for a pin of this port, the bit controlling this pin should always be set.

**Table 166. Port 1 SFR (P1, Address 0x90)**

| Bit | Bit Address | Mnemonic | Default | Description <sup>1</sup>   |
|-----|-------------|----------|---------|--|
| 7   | 0x97        |          | 1       | This bit reflects the state of the P1.7/FP20 pin. It can be written to or read.      |
| 6   | 0x96        |          | 1       | This bit reflects the state of the P1.6/FP21 pin. It can be written to or read.      |
| 5   | 0x95        |          | 1       | This bit reflects the state of the P1.5/FP22 pin. It can be written to or read.      |
| 4   | 0x94        | T2       | 1       | This bit reflects the state of the P1.4/T2/FP23 pin. It can be written to or read.   |
| 3   | 0x93        | T2EX     | 1       | This bit reflects the state of the P1.3/T2EX/FP24 pin. It can be written to or read. |
| 2   | 0x92        | ZX1      | 1       | This bit reflects the state of the P1.2/FP25/ZX pin. It can be written to or read.   |
| 1   | 0x91        | TxD      | 1       | This bit reflects the state of the P1.1/TxD pin. It can be written to or read.       |
| 0   | 0x90        | RxD      | 1       | This bit reflects the state of the P1.0/RxD pin. It can be written to or read.       |

<sup>1</sup> When an alternate function is chosen for a pin of this port, the bit controlling this pin should always be set.

**Table 167. Port 2 SFR (P2, Address 0xA0)**

| Bit   | Bit Address  | Mnemonic | Default | Description <sup>1</sup>   |
|-------|--------------|----------|---------|--|
| [7:4] | 0x97 to 0x94 |          | 0x1F    | These bits are unused and should remain set.   |
| 3     | 0x93         | P2.3     | 1       | This bit reflects the state of the $\overline{SDEN}$ /P2.3/TxD2 pin. It can be written only. |
| 2     | 0x92         | P2.2     | 1       | This bit reflects the state of the P2.2/FP16 pin. It can be written to or read.              |
| 1     | 0x91         | P2.1     | 1       | This bit reflects the state of the P2.1/FP17 pin. It can be written to or read.              |
| 0     | 0x90         | P2.0     | 1       | This bit reflects the state of the P2.0/FP18 pin. It can be written to or read.              |

<sup>1</sup> When an alternate function is chosen for a pin of this port, the bit controlling this pin should always be set.

**Table 168. Port 0 Alternate Functions**

| Pin No. | Alternate Function   | Alternate Function Enable   |
|---------|--|---|
| P0.0    | BCTRL external battery control input<br>$\overline{\text{INT1}}$ external interrupt<br>$\overline{\text{INT1}}$ wake-up from PSM2 operating mode   | Set INT1PRG = X01 in the interrupt pins configuration SFR (INTPR, Address 0xFF[3:1]).<br>Set EX1 in the interrupt enable SFR (IE, Address 0xA8).<br>Set INT1PRG = 11x in the interrupt pins configuration SFR (INTPR, Address 0xFF[3:1]).   |
| P0.1    | FP19 LCD segment pin   | Set FP19EN in the LCD Segment Enable 2 SFR (LCDSEGE2, Address 0xED).  |
| P0.2    | CF1 ADE calibration frequency output   | Clear the DISCF1 bit in the ADE energy measurement internal MODE1 register (Address 0x0B).  |
| P0.3    | CF2 ADE calibration frequency output   | Clear the DISCF2 bit in the ADE energy measurement internal MODE1 register (Address 0x0B).  |
| P0.4    | MOSI SPI data line<br>SDATA I <sup>2</sup> C data line   | Set the SCPS bit in the configuration SFR (CFG, Address 0xAF), and set the SPIEN bit in SPI Configuration SFR 2 (SPIMOD2, Address 0xE9).<br>Clear the SCPS bit in the configuration SFR (CFG, Address 0xAF), and set the I2CEN bit in the I <sup>2</sup> C mode SFR (I2CMOD, Address 0xE8).   |
| P0.5    | MISO SPI data line<br>Zero Crossing Detection 2  | Set the SCPS bit in the configuration SFR (CFG, Address 0xAF), and set the SPIEN bit in SPI Configuration SFR 2 (SPIMOD2, Address 0xE9).<br>Set the ZX2 bit in the MODE3 energy measurement SFR (MODE3, Address 0x2B)   |
| P0.6    | SCLK serial clock for I <sup>2</sup> C or SPI<br>T0 Timer 0 input  | Set the I2CEN bit in the I <sup>2</sup> C mode SFR (I2CMOD, Address 0xE8) or the SPIEN bit in SPI Configuration SFR 2 (SPIMOD2, Address 0xE9) to enable the I <sup>2</sup> C or SPI interface.<br>Set the C/ $\overline{\text{T0}}$ bit in the Timer/Counter 0 and Timer/Counter 1 mode SFR (TMOD, Address 0x89) to enable T0 as an external event counter.   |
| P0.7    | $\overline{\text{SS}}$ SPI slave select input for SPI in slave mode<br>$\overline{\text{SS}}$ SPI slave select output for SPI in master mode<br>T1 Timer 1 input<br>Rx/D2 receiver data input for UART2<br>Rx/D2 edge wake-up from PSM2 operating mode | Set the SS_EN bit in SPI Configuration SFR 1 (SPIMOD1, Address 0xE8).<br>Set the SPIMS_b bit in SPI Configuration SFR 2 (SPIMOD2, Address 0xE9).<br>Set the C/ $\overline{\text{T1}}$ bit in the Timer/Counter 0 and Timer/Counter 1 mode SFR (TMOD, Address 0x89) to enable T1 as an external event counter.<br>Set the REN2 bit in the serial communications control SFR (SCON2, Address 0xE1).<br>Set RXPROG[1:0] = 11 in the peripheral configuration SFR (PERIPH, Address 0xF4). |

**Table 169. Port 1 Alternate Functions**

| Pin No. | Alternate Function                                 | Alternate Function Enable  |
|---------|--|--|
| P1.0    | RxD receiver data input for UART                   | Set the REN bit in the serial communications control register SFR (SCON, Address 0x98).  |
| P1.1    | TxD transmitter data output for UART               | This pin becomes TxD as soon as data is written into SBUF.   |
| P1.2    | FP25 LCD segment pin<br>Zero-Crossing Detection 1  | Set FP25EN in the LCD segment enable SFR (LCDSEGE, Address 0x97).<br>Set the ZX1 bit in the MODE3 energy measurement SFR (MODE3, Address 0x2B)   |
| P1.3    | FP24 LCD segment pin<br>T2EX Timer 2 control input | Set FP24EN in the LCD segment enable SFR (LCDSEGE, Address 0x97).<br>Set EXEN2 in the Timer/Counter 2 control SFR (T2CON, Address 0xC8).   |
| P1.4    | FP23 LCD segment pin<br>T2 Timer 2 input           | Set FP23EN in the LCD segment enable SFR (LCDSEGE, Address 0x97).<br>Set the C/ $\overline{\text{T2}}$ bit in the Timer/Counter 2 control SFR (T2CON, Address 0xC8) to enable T2 as an external event counter. |
| P1.5    | FP22 LCD segment pin                               | Set FP22EN in the LCD segment enable SFR (LCDSEGE, Address 0x97).  |
| P1.6    | FP21 LCD segment pin                               | Set FP21EN in the LCD segment enable SFR (LCDSEGE, Address 0x97).  |
| P1.7    | FP20 LCD segment pin                               | Set FP20EN in the LCD segment enable SFR (LCDSEGE, Address 0x97).  |

**Table 170. Port 2 Alternate Functions**

| Pin No. | Alternate Function   | Alternate Function Enable   |
|---------|--|---|
| P2.0    | FP18 LCD segment pin   | Set FP18EN in the LCD Segment Enable 2 SFR (LCDSEGE2, Address 0xED).              |
| P2.1    | FP17 LCD segment pin   | Set FP17EN in the LCD Segment Enable 2 SFR (LCDSEGE2, Address 0xED).              |
| P2.2    | FP16 LCD segment pin   | Set FP16EN in the LCD Segment Enable 2 SFR (LCDSEGE2, Address 0xED).              |
| P2.3    | $\overline{\text{SDEN}}$ serial download pin sampled on reset;<br>P2.3 is an output only; Tx/D2 is the transmitter data output for UART2 | Enabled by default. This pin becomes Tx/D2 as soon as data is written into SBUF2. |

## PORT 0

Port 0 is controlled directly through the bit-addressable Port 0 SFR (P0, Address 0x80). The weak internal pull-ups for Port 0 are configured through the Port 0 weak pull-up enable SFR (PINMAP0, Address 0xB2); they are enabled by default. The weak internal pull-up is disabled by writing a 1 to PINMAP0.x.

Port 0 pins also have various secondary functions, as described in Table 168. The alternate functions of Port 0 pins can be activated only if the corresponding bit latch in the Port 0 SFR contains a 1. Otherwise, the port pin remains at 0.

## PORT 1

Port 1 is an 8-bit bidirectional port controlled directly through the bit-addressable Port 1 SFR (P1, Address 0x90). The weak internal pull-ups for Port 1 are configured through the Port 1 weak pull-up enable SFR (PINMAP1, Address 0xB3); they are enabled by default. The weak internal pull-up is disabled by writing a 1 to PINMAP1.x.

Port 1 pins also have various secondary functions, as described in Table 169. The alternate functions of Port 1 pins can be activated only if the corresponding bit latch in the Port 1 SFR contains a 1. Otherwise, the port pin remains at 0.

## PORT 2

Port 2 is a 4-bit bidirectional port controlled directly through the bit-addressable Port 2 SFR (P2, Address 0xA0). Note that P2.3 can be used as an output only. Consequently, any read operation, such as a CPL P2.3, cannot be executed on this I/O. The weak internal pull-ups for Port 2 are configured through the Port 2 weak pull-up enable SFR (PINMAP2, Address 0xB4); they are enabled by default. The weak internal pull-up is disabled by writing a 1 to PINMAP2.x.

Port 2 pins also have various secondary functions as described in Table 170. The alternate functions of Port 2 pins can be activated only if the corresponding bit latch in the Port 2 SFR contains a 1. Otherwise, the port pin remains at 0.



## **DETERMINING THE VERSION OF THE ADE5166/ADE5169**

Each ADE5166/ADE5169 holds in its internal flash registers a value that defines its version. This value helps to determine if users have the latest version of the part.

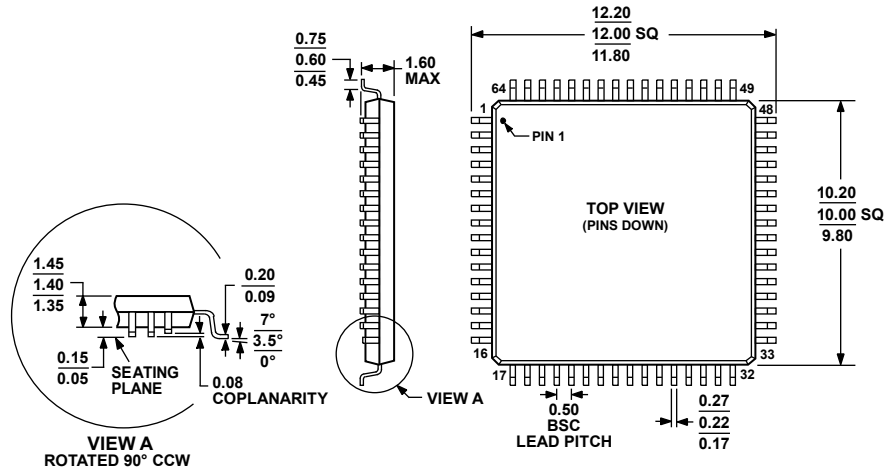
This value can be accessed as follows:

1. Launch HyperTerminal with a 9600 baud rate.
2. Put the part in serial download mode by first holding  $\overline{\text{SDEN}}$  to logic low, then resetting the part.
3. Hold the  $\overline{\text{SDEN}}$  pin. \_\_\_\_\_
4. Press and release the RESET pin.

A string should appear on the HyperTerminal containing the part name and version number.

# ADE5166/ADE5169

## OUTLINE DIMENSIONS



COMPLIANT TO JEDEC STANDARDS MS-026-BCD

Figure 114. 64-Lead Low Profile Quad Flat Package [LQFP] (ST-64-2)

Dimensions shown in millimeters

051706-A

## ORDERING GUIDE

| Model <sup>1</sup>               | Antitamper | di/dt Sensor Interface | VAR | Flash (kB) | Temperature Range | Package Description           | Package Option |
|----------------------------------|------------|------------------------|-----|------------|-------------------|-------------------------------|----------------|
| ADE5166ASTZF62 <sup>2</sup>      | Yes        | No                     | Yes | 62         | -40°C to +85°C    | 64-Lead LQFP                  | ST-64-2        |
| ADE5166ASTZF62-RL <sup>2</sup>   | Yes        | No                     | Yes | 62         | -40°C to +85°C    | 64-Lead LQFP, 13" Tape & Reel | ST-64-2        |
| ADE5169ASTZF62 <sup>2</sup>      | Yes        | Yes                    | Yes | 62         | -40°C to +85°C    | 64-Lead LQFP                  | ST-64-2        |
| ADE5169ASTZF62-RL <sup>2</sup>   | Yes        | Yes                    | Yes | 62         | -40°C to +85°C    | 64-Lead LQFP, 13" Tape & Reel | ST-64-2        |
| ADE8052Z-PRG1                    |            |                        |     |            |                   | ADE Programmer                |                |
| ADE8052Z-DWDL1                   |            |                        |     |            |                   | ADE Downloader                |                |
| ADE8052Z-EMUL1                   |            |                        |     |            |                   | ADE Emulator                  |                |
| EVAL- ADE5169F62EBZ <sup>2</sup> |            |                        |     |            |                   | Evaluation Board              |                |

<sup>1</sup> All models have W + VA + rms, 5 V LCD, and RTC.

<sup>2</sup> Z = RoHS Compliant Part.

**NOTES**

**NOTES**

Purchase of licensed I<sup>2</sup>C components of Analog Devices or one of its sublicensed Associated Companies conveys a license for the purchaser under the Philips I<sup>2</sup>C Patent Rights to use these components in an I<sup>2</sup>C system, provided that the system conforms to the I<sup>2</sup>C Standard Specification as defined by Philips.

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