National Semiconductor

**PRELIMINARY**
November 2000

# COP8SA Family
# 8-Bit CMOS ROM Based and One-Time Programmable (OTP) Microcontroller with 1k to 4k Memory, Power On Reset, and Very Small Packaging

## General Description

**Note: COP8SAx devices are instruction set and pin compatible supersets of the COP800 Family devices, and are replacements for these in new designs when possible.**

The COPSAx Rom based and OTP microcontrollers are highly integrated COP8™ feature core devices, with 1k to 4k memory and advanced features including low EMI. These single-chip CMOS devices are suited for low cost applications requiring a full featured controller, low EMI, and POR. 100% form-fit-function compatible OTP versions are available with 1k, 2k, and 4k memory, and in a variety of packages including 28-pin CSP. Erasable windowed versions are available for use with a range of COP8 software and hardware development tools.

Family features include an 8-bit memory mapped architecture, 10 MHz CKI with 1 µs instruction cycle, one multi-function 16-bit timer/counter with PWM output, MICROWIRE/PLUS™ serial I/O, two power saving HALT/IDLE modes, MIWU, idle timer, on-chip R/C oscillator, 12 high current outputs, user selectable options (WATCHDOG™, 4 clock/oscillator modes, power-on-reset), low EMI 2.7V to 5.5V operation, and 16/20/28/40/44 pin packages.

Devices included in this datasheet are:

| Device | Memory (bytes) | RAM (bytes) | I/O Pins | Packages | Temperature |
|---|---|---|---|---|---|
| COP8SAA5 | 1k ROM | 64 | 12/16/24 | 16/20/28 DIP/SOIC, 28 CSP | 0 to +70˚C, -40 to +85˚C, -40 to +125˚C |
| COP8SAB5 | 2k ROM | 128 | 16/24 | 20/28 DIP/SOIC, 28 CSP | 0 to +70˚C, -40 to +85˚C, -40 to +125˚C |
| COP8SAC5 | 4k ROM | 128 | 16/24/36/40 | 20/28 DIP/SOIC, 28 CSP, 40 DIP, 44 PLCC/QFP | 0 to +70˚C, -40 to +85˚C, -40 to +125˚C |
| COP8SAA7 | 1k OTP EPROM | 64 | 12/16/24 | 16/20/28 DIP/SOIC, 28 CSP | 0 to +70˚C, -40 to +85˚C, -40 to +125˚C |
| COP8SAB7 | 2k OTP EPROM | 128 | 16/24 | 20/28 DIP/SOIC, 28 CSP | 0 to +70˚C, -40 to +85˚C, -40 to +125˚C |
| COP8SAC7 | 4k OTP EPROM | 128 | 16/24 | 20/28 DIP/SOIC, 28 CSP, 40 DIP, 44 PLCC/QFP | 0 to +70˚C, -40 to +85˚C, -40 to +125˚C |
| COP8SAC7-Q3 | 4k EPROM | 128 | 16/24/36 | 20/28/40 DIP | Room Temp. Only |
| COP8SAC7-J3 | 4k EPROM | 128 | 40 | 44 PLCC | Room Temp. Only |

## Key Features

- Low cost 8-bit OTP microcontroller
- OTP program space with read/write protection (fully secured)
- Quiet Design (low radiated emissions)
- Multi-Input Wakeup pins with optional interrupts (4 to 8 pins)
- 8 bytes of user storage space in EPROM
- User selectable clock options
  - — Crystal/Resonator options
  - — Crystal/Resonator option with on-chip bias resistor
  - — External oscillator
  - — Internal R/C oscillator
- Internal Power-On Reset — user selectable
- WATCHDOG and Clock Monitor Logic — user selectable
- Up to 12 high current outputs



COP8SA Family, 8-Bit CMOS ROM Based and One-Time Programmable (OTP) Microcontroller with 1k to 4k Memory, Power On Reset, and Very Small Packaging

## CPU Features

- Versatile easy to use instruction set
- 1 µs instruction cycle time
- Eight multi-source vectored interrupts servicing
  - — External interrupt
  - — Idle Timer T0
  - — One Timer (with 2 interrupts)
  - — MICROWIRE/PLUS Serial Interface
  - — Multi-Input Wake Up
  - — Software Trap
  - — Default VIS (default interrupt)
- 8-bit Stack Pointer SP (stack in RAM)
- Two 8-bit Register Indirect Data Memory Pointers
- True bit manipulation
- Memory mapped I/O
- BCD arithmetic instructions

## Peripheral Features

- Multi-Input Wakeup Logic
- One 16-bit timer with two 16-bit registers supporting:
  - — Processor Independent PWM mode
  - — External Event counter mode
  - — Input Capture mode
- Idle Timer
- MICROWIRE/PLUS Serial Interface (SPI Compatible)

## I/O Features

- Software selectable I/O options
  - — TRI-STATE® Output
  - — Push-Pull Output
  - — Weak Pull Up Input
  - — High Impedance Input
- Schmitt trigger inputs on ports G and L
- Up to 12 high current outputs
- Pin efficient (i.e., 40 pins in 44-pin package are devoted to useful I/O)

## Fully Static CMOS Design

- Low current drain (typically < 4 µA)
- Single supply operation: 2.7V to 5.5V
- Two power saving modes: HALT and IDLE

## Temperature Ranges

0˚C to +70˚C, −40˚C to +85˚C, and −40˚C to +125˚C

## Development Support

- Windowed packages for DIP and PLCC
- Real time emulation and full program debug offered by MetaLink Development System

## Block Diagram

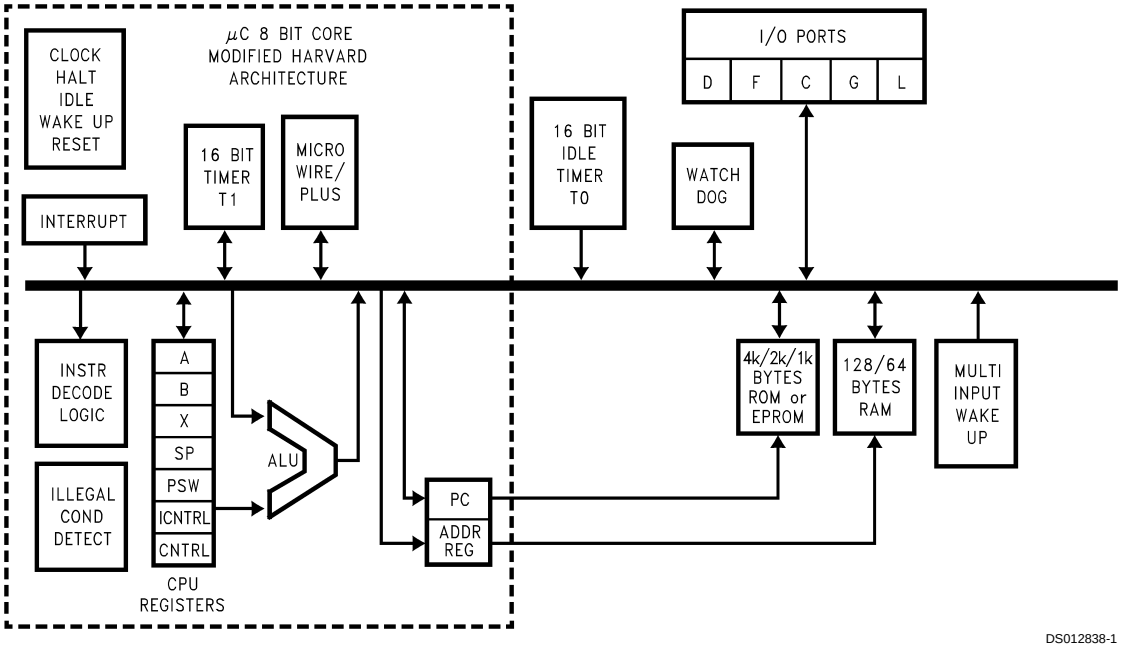



**FIGURE 1. COP8SAx Block Diagram**

## General Description (Continued)

Key features include an 8-bit memory mapped architecture, a 16-bit timer/counter with two associated 16-bit registers supporting three modes (Processor Independent PWM generation, External Event counter, and Input Capture capabilities), two power saving HALT/IDLE modes with a multi-sourced wakeup/interrupt capability, on-chip R/C oscillator, high current outputs, user selectable options such as WATCHDOG, Oscillator configuration, and power-on-reset.

### 1.1 EMI REDUCTION

The COP8SAx family of devices incorporates circuitry that guards against electromagnetic interference — an increasing problem in today's microcontroller board designs. National's patented EMI reduction technology offers low EMI clock circuitry, gradual turn-on output drivers (GTOs) and internal $I_{CC}$ smoothing filters, to help circumvent many of the EMI issues influencing embedded control designs. National has achieved 15 dB–20 dB reduction in EMI transmissions when designs have incorporated its patented EMI reducing circuitry.

### 1.2 ARCHITECTURE

The COP8SAx family is based on a modified Harvard architecture, which allows data tables to be accessed directly from program memory. This is very important with modern microcontroller-based applications, since program memory is usually ROM or EPROM, while data memory is usually RAM. Consequently data tables usually need to be contained in ROM or EPROM, so they are not lost when the microcontroller is powered down. In a modified Harvard architecture, instruction fetch and memory data transfers can be overlapped with a two stage pipeline, which allows the next instruction to be fetched from program memory while the current instruction is being executed using data memory. This is not possible with a Von Neumann single-address bus architecture.

The COP8SAx family supports a software stack scheme that allows the user to incorporate many subroutine calls. This capability is important when using High Level Languages. With a hardware stack, the user is limited to a small fixed number of stack levels.

### 1.3 INSTRUCTION SET

In today's 8-bit microcontroller application arena cost/performance, flexibility and time to market are several of the key issues that system designers face in attempting to build well-engineered products that compete in the marketplace. Many of these issues can be addressed through the manner in which a microcontroller's instruction set handles processing tasks. And that's why COP8 family offers a unique and code-efficient instruction set — one that provides the flexibility, functionality, reduced costs and faster time to market that today's microcontroller based products require.

Code efficiency is important because it enables designers to pack more on-chip functionality into less program memory space (ROM/OTP). Selecting a microcontroller with less program memory size translates into lower system costs, and the added security of knowing that more code can be packed into the available program memory space.

#### 1.3.1 Key Instruction Set Features

The COP8SAx family incorporates a unique combination of instruction set features, which provide designers with optimum code efficiency and program memory utilization.

**Single Byte/Single Cycle Code Execution**

The efficiency is due to the fact that the majority of instructions are of the single byte variety, resulting in minimum program space. Because compact code does not occupy a substantial amount of program memory space, designers can integrate additional features and functionality into the microcontroller program memory space. Also, the majority instructions executed by the device are single cycle, resulting in minimum program execution time. In fact, 77% of the instructions are single byte single cycle, providing greater code and I/O efficiency, and faster code execution.

#### 1.3.2 Many Single-Byte, Multifunction Instructions

The COP8SAx instruction set utilizes many single-byte, multifunction instructions. This enables a single instruction to accomplish multiple functions, such as DRSZ, DCOR, JID, and LOAD/EXCHANGE instructions with post-incrementing and post-decrementing, to name just a few examples. In many cases, the instruction set can simultaneously execute as many as three functions with the same single-byte instruction.

JID: (Jump Indirect); Single byte instruction; decodes external events and jumps to corresponding service routines (analogous to "DO CASE" statements in higher level languages).

LAID: (Load Accumulator-Indirect); Single byte look up table instruction provides efficient data path from the program memory to the CPU. This instruction can be used for table lookup and to read the entire program memory for checksum calculations.

RETSK: (Return Skip); Single byte instruction allows return from subroutine and skips next instruction. Decision to branch can be made in the subroutine itself, saving code.

AUTOINC/DEC: (Auto-Increment/Auto-Decrement); These instructions use the two memory pointers B and X to efficiently process a block of data (analogous to "FOR NEXT" in higher level languages).

#### 1.3.3 Bit-Level Control

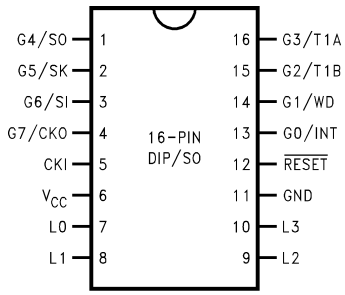
Bit-level control over many of the microcontroller's I/O ports provides a flexible means to ease layout concerns and save board space. All members of the COP8 family provide the ability to set, reset and test any individual bit in the data memory address space, including memory-mapped I/O ports and associated registers. Three memory-mapped pointers handle register indirect addressing and software stack pointer functions. The memory data pointers allow the option of post-incrementing or post-decrementing with the data movement instructions (LOAD/EXCHANGE). And 15 memory-maped registers allow designers to optimize the precise implementation of certain specific instructions.

### 1.4 PACKAGING/PIN EFFICIENCY

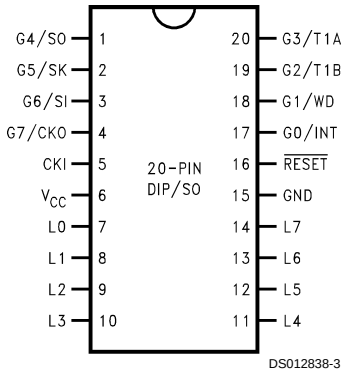
Real estate and board configuration considerations demand maximum space and pin efficiency, particularly given today's high integration and small product form factors. Microcontroller users try to avoid using large packages to get the I/O needed. Large packages take valuable board space and increases device cost, two trade-offs that microcontroller designs can ill afford.

The COP8 family offers a wide range of packages and do not waste pins: up to 90.9% (or 40 pins in the 44-pin package) are devoted to useful I/O.

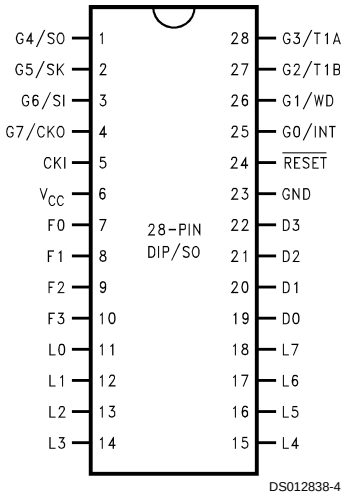
## Connection Diagrams



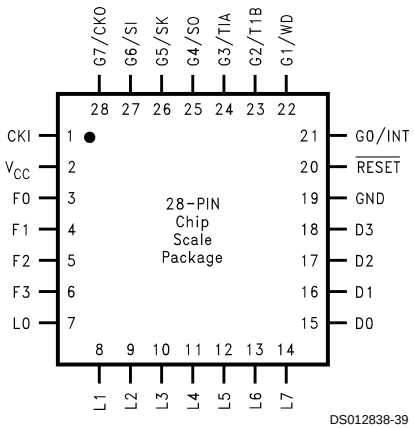

**Top View**



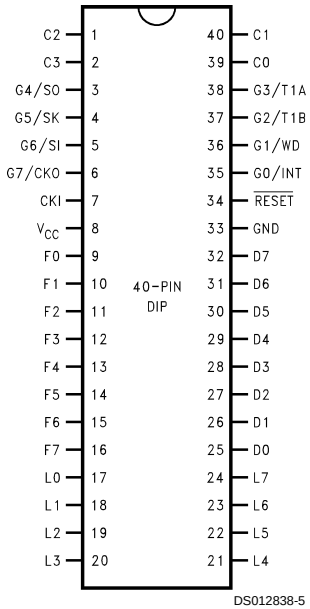

**Top View**



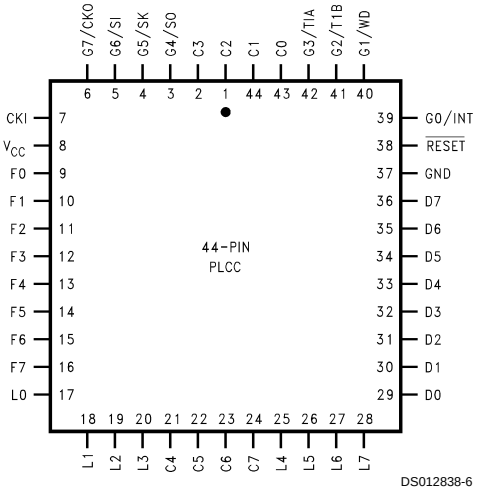

**Top View**




**Top View**




**Top View**




**Top View**

**FIGURE 2. Connection Diagrams**

## Ordering Information

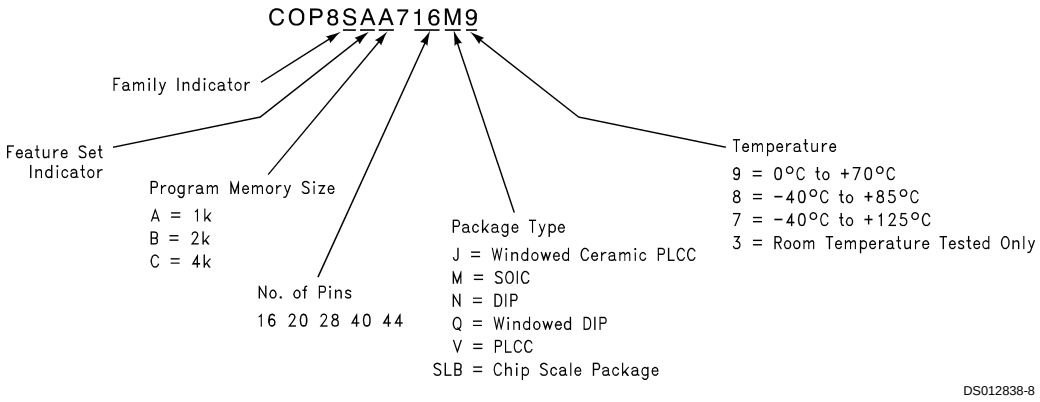



**FIGURE 3. Part Numbering Scheme**

| | 1k EPROM | | 2k EPROM | | 4k EPROM | | 4k EPROM | |
|---|---|---|---|---|---|---|---|---|
| Temperature | Order Number | Package | Order Number | Package | Order Number | Package | Windowed Device Order Number | Package |
| 0˚C to +70˚C | COP8SAA716M9 | 16M | | | | | | |
| | COP8SAA720M9 | 20M | COP8SAB720M9 | 20M | COP8SAC720M9 | 20M | | |
| | COP8SAA728M9 | 28M | COP8SAB728M9 | 28M | COP8SAC728M9 | 28M | | |
| | COP8SAA716N9 | 16N | | | | | | |
| | COP8SAA720N9 | 20N | COP8SAB720N9 | 20N | COP8SAC720N9 | 20N | COP8SAC720Q3 | 20Q |
| | COP8SAA728N9 | 28N | COP8SAB728N9 | 28N | COP8SAC728N9 | 28N | COP8SAC728Q3 | 28Q |
| | | | | | COP8SAC740N9 | 40N | COP8SAC740Q3 | 40Q |
| | | | | | COP8SAC744V9 | 44V | COP8SAC744J3 | 44J |
| −40˚C to +85˚C | COP8SAA716M8 | 16M | | | | | | |
| | COP8SAA720M8 | 20M | COP8SAB720M8 | 20M | COP8SAC720M8 | 20M | | |
| | COP8SAA728M8 | 28M | COP8SAB728M8 | 28M | COP8SAC728M8 | 28M | | |
| | COP8SAA716N8 | 16N | | | | | | |
| | COP8SAA720N8 | 20N | COP8SAB720N8 | 20N | COP8SAC720N8 | 20N | | |
| | COP8SAA728N8 | 28N | COP8SAB728N8 | 28N | COP8SAC728N8 | 28N | | |
| | | | | | COP8SAC740N8 | 40N | | |
| | | | | | COP8SAC744V8 | 44V | | |
| | COP8SAA7SLB8 | SLB | COP8SAB7SLB8 | SLB | COP8SAC7SLB8 | SLB | | |
| −40˚C to +125˚C | | | | | COP8SAC720M7 | 20M | | |
| | | | | | COP8SAC728M7 | 28M | | |
| | | | | | COP8SAC720N7 | 20N | | |
| | | | | | COP8SAC728N7 | 28N | | |
| | | | | | COP8SAC740N7 | 40N | | |
| | | | | | COP8SAC744V7 | 44V | | |

# 4.0 Electrical Characteristics

## Absolute Maximum Ratings (Note 1)

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.**

| | |
|---|---|
| Supply Voltage ($V_{CC}$) | 7V |
| Voltage at Any Pin | −0.6V to $V_{CC}$ +0.6V |
| ESD Protection Level | 2 kV (Human Body Model) |
| Total Current into $V_{CC}$ Pin (Source) | 80 mA |
| Total Current out of GND Pin (Sink) | 100 mA |
| Storage Temperature Range | −65˚C to +140˚C |

**Note 1:** *Absolute maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications are not ensured when operating the device at absolute maximum ratings.*

## DC Electrical Characteristics

0˚C ≤ $T_A$ ≤ +70˚C unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Operating Voltage | (Note 8) | 2.7 | | 5.5 | V |
| Power Supply Rise Time from 0.0V | | | | | |
| (On-Chip Power-On Reset Selected) | | 10 ns | | 50 ms | |
| $V_{CC}$ Start Voltage to Guarantee POR | | | | 0.25 | V |
| Power Supply Ripple (Note 3) | Peak-to-Peak | | | 0.1 $V_{CC}$ | V |
| Supply Current (Note 4) | | | | | |
| CKI = 10 MHz | $V_{CC}$ = 5.5V, $t_C$ = 1 µs | | | 6 | mA |
| CKI = 4 MHz | $V_{CC}$ = 4.5V, $t_C$ = 2.5 µs | | | 2.1 | mA |
| HALT Current (Note 5) —WATCHDOG Disabled | $V_{CC}$ = 5.5V, CKI = 0 MHz | | <4 | 8 | µA |
| IDLE Current (Note 4) | | | | | |
| CKI = 10 MHz | $V_{CC}$ = 5.5V, $t_C$ = 1 µs | | | 1.5 | mA |
| CKI = 4 MHz | $V_{CC}$ = 4.5V, $t_C$ = 2.5 µs | | | 0.8 | mA |
| Input Levels ($V_{IH}$, $V_{IL}$) | | | | | |
| $\overline{\text{RESET}}$ | | | | | |
| Logic High | | 0.8 $V_{CC}$ | | | V |
| Logic Low | | | | 0.2 $V_{CC}$ | V |
| CKI, All Other Inputs | | | | | |
| Logic High | | 0.7 $V_{CC}$ | | | V |
| Logic Low | | | | 0.2 $V_{CC}$ | V |
| Value of the Internal Bias Resistor for the Crystal/Resonator Oscillator | | 0.5 | 1.0 | 2.0 | MΩ |
| CKI Resistance to $V_{CC}$ or GND when R/C Oscillator is Selected | $V_{CC}$ = 5.5V | 5 | 8 | 11 | kΩ |
| Hi-Z Input Leakage (same as TRI-STATE output) | $V_{CC}$ = 5.5V | −2 | | +2 | µA |
| Input Pullup Current | $V_{CC}$ = 5.5V, $V_{IN}$ = 0V | −40 | | −250 | µA |
| G and L Port Input Hysteresis | | 0.25 $V_{CC}$ | | | V |

## DC Electrical Characteristics (Continued)

$0^{\circ}C \le T_A \le +70^{\circ}C$ unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Output Current Levels | | | | | |
| D Outputs | | | | | |
| Source | $V_{CC}$ = 4.5V, $V_{OH}$ = 3.3V | −0.4 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −0.2 | | | mA |
| Sink | $V_{CC}$ = 4.5V, $V_{OL}$ = 1.0V | 10 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OL}$ = 0.4V | 2 | | | mA |
| L Port | | | | | |
| Source (Weak Pull-Up) | $V_{CC}$ = 4.5V, $V_{OH}$ = 2.7V | −10 | | −110 | µA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −2.5 | | −33 | µA |
| Source (Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OH}$ = 3.3V | −0.4 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −0.2 | | | mA |
| Sink (L0–L3, Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OL}$ = 1.0V | 10 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OL}$ = 0.4V | 2 | | | mA |
| Sink (L4–L7, Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OL}$ = 0.4V | 1.6 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OL}$ = 0.4V | 0.7 | | | mA |
| All Others | | | | | |
| Source (Weak Pull-Up Mode) | $V_{CC}$ = 4.5V, $V_{OH}$ = 2.7V | −10 | | −110 | µA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −2.5 | | −33 | µA |
| Source (Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OH}$ = 3.3V | −0.4 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −0.2 | | | mA |
| Sink (Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OL}$ = 0.4V | 1.6 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OL}$ = 0.4V | 0.7 | | | mA |
| Allowable Sink Current per Pin (Note 8) | | | | | |
| D Outputs and L0 to L3 | | | | 15 | mA |
| All Others | | | | 3 | mA |
| Maximum Input Current without Latchup (Note 6) | | | | ±200 | mA |
| RAM Retention Voltage, Vr | | 2.0 | | | V |
| $V_{CC}$ Rise Time from a $V_{CC} \ge 2.0V$ | (Note 9) | 12 | | | µs |
| Input Capacitance | (Note 8) | | | 7 | pF |
| Load Capacitance on D2 | (Note 8) | | | 1000 | pF |

## AC Electrical Characteristics

$0^{\circ}C \le T_A \le +70^{\circ}C$ unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Instruction Cycle Time ($t_C$) | | | | | |
| Crystal/Resonator, External | $4.5V \le V_{CC} \le 5.5V$ | 1.0 | | DC | μs |
| | $2.7V \le V_{CC} < 4.5V$ | 2.0 | | DC | μs |
| Internal R/C Oscillator | $4.5V \le V_{CC} \le 5.5V$ | | 1.667 | | μs |
| | $2.7V \le V_{CC} < 4.5V$ | | TBD | | μs |
| R/C Oscillator Frequency Variation | $4.5V \le V_{CC} \le 5.5V$ | | | ±35 | % |
| (Note 8) | $2.7V \le V_{CC} < 4.5V$ | | | TBD | % |
| External CKI Clock Duty Cycle (Note 8) | fr = Max | 45 | | 55 | % |
| Rise Time (Note 8) | fr = 10 MHz Ext Clock | | | 12 | ns |
| Fall Time (Note 8) | fr = 10 MHz Ext Clock | | | 8 | ns |
| Inputs | | | | | |
| $t_{SETUP}$ | $4.5V \le V_{CC} \le 5.5V$ | 200 | | | ns |
| | $2.7V \le V_{CC} < 4.5V$ | 500 | | | ns |
| $t_{HOLD}$ | $4.5V \le V_{CC} \le 5.5V$ | 60 | | | ns |
| | $2.7V \le V_{CC} < 4.5V$ | 150 | | | ns |
| Output Propagation Delay (Note 7) | $R_L$ = 2.2k, $C_L$ = 100 pF | | | | |
| $t_{PD1}$, $t_{PD0}$ | | | | | |
| SO, SK | $4.5V \le V_{CC} \le 5.5V$ | | | 0.7 | μs |
| | $2.7V \le V_{CC} < 4.5V$ | | | 1.75 | μs |
| All Others | $4.5V \le V_{CC} \le 5.5V$ | | | 1.0 | μs |
| | $2.7V \le V_{CC} < 4.5V$ | | | 2.5 | μs |
| MICROWIRE Setup Time ($t_{UWS}$) (Note 7) | | 20 | | | ns |
| MICROWIRE Hold Time ($t_{UWH}$) (Note 7) | | 56 | | | ns |
| MICROWIRE Output Propagation Delay ($t_{UPD}$) | | | | 220 | ns |
| MICROWIRE Maximum Shift Clock | | | | | |
| Master Mode | | | | 500 | kHz |
| Slave Mode | | | | 1 | MHz |
| Input Pulse Width (Note 7) | | | | | |
| Interrupt Input High Time | | 1 | | | $t_C$ |
| Interrupt Input Low Time | | 1 | | | $t_C$ |
| Timer 1 Input High Time | | 1 | | | $t_C$ |
| Timer 1 Input Low Time | | 1 | | | $t_C$ |
| Reset Pulse Width | | 1 | | | μs |

**Note 2:** $t_C$ = Instruction cycle time (Clock input frequency divided by 10).

**Note 3:** Maximum rate of voltage change must be < 0.5 V/ms.

**Note 4:** Supply and IDLE currents are measured with CKI driven with a square wave Oscillator, CKO driven 180° out of phase with CKI, inputs connected to $V_{CC}$ and outputs driven low but not connected to a load.

**Note 5:** The HALT mode will stop CKI from oscillating in the R/C and the Crystal configurations. In the R/C configuration, CKI is forced high internally. In the crystal or external configuration, CKI is TRI-STATE. Measurement of $I_{DD}$ HALT is done with device neither sourcing nor sinking current; with L. F, C, G0, and G2–G5 programmed as low outputs and not driving a load; all outputs programmed low and not driving a load; all inputs tied to $V_{CC}$; WATCHDOG and clock monitor disabled. Parameter refers to HALT mode entered via setting bit 7 of the G Port data register.

**Note 6:** Pins G6 and $\overline{\text{RESET}}$ are designed with a high voltage input network. These pins allow input voltages > $V_{CC}$ and the pins will have sink current to $V_{CC}$ when biased at voltages > $V_{CC}$ (the pins do not have source current when biased at a voltage below $V_{CC}$). The effective resistance to $V_{CC}$ is 750Ω (typical). These two pins will not latch up. The voltage at the pins must be limited to < 14V. **WARNING: Voltages in excess of 14V will cause damage to the pins. This warning excludes ESD transients.**

**Note 7:** The output propagation delay is referenced to the end of the instruction cycle where the output change occurs.

**Note 8:** Parameter characterized but not tested.

**Note 9:** Rise times faster than this specification may reset the device if POR is enabled and may affect the value of Idle Timer T0 if POR is not enabled.

## Absolute Maximum Ratings (Note 10)

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.**

| | |
|---|---|
| Supply Voltage ($V_{CC}$) | 7V |
| Voltage at Any Pin | −0.6V to $V_{CC}$ +0.6V |
| ESD Protection Level | 2 kV (Human Body Model) |
| Total Current into $V_{CC}$ Pin (Source) | 80 mA |
| Total Current out of GND Pin (Sink) | 100 mA |
| Storage Temperature Range | −65˚C to +140˚C |

**Note 10:** *Absolute maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications are not ensured when operating the device at absolute maximum ratings.*

## DC Electrical Characteristics

−40˚C ≤ $T_A$ ≤ +85˚C unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Operating Voltage | | 2.7 | | 5.5 | V |
| Power Supply Rise Time from 0.0V | (Note 17) | | | | |
| (On-Chip Power-On Reset Selected) | | 10 ns | | 50 ms | |
| $V_{CC}$ Start Voltage to Guarantee POR | | | | 0.25 | V |
| Power Supply Ripple (Note 12) | Peak-to-Peak | | | 0.1 $V_{CC}$ | V |
| Supply Current (Note 13) | | | | | |
| CKI = 10 MHz | $V_{CC}$ = 5.5V, $t_C$ = 1 µs | | | 6.0 | mA |
| HALT Current (Note 14) —WATCHDOG Disabled | $V_{CC}$ = 5.5V, CKI = 0 MHz | | <4 | 10.0 | µA |
| IDLE Current (Note 13) | | | | | |
| CKI = 10 MHz | $V_{CC}$ = 5.5V, $t_C$ = 1 µs | | | 1.5 | mA |
| Input Levels ($V_{IH}$, $V_{IL}$) | | | | | |
| $\overline{\text{RESET}}$ | | | | | |
| Logic High | | 0.8 $V_{CC}$ | | | V |
| Logic Low | | | | 0.2 $V_{CC}$ | V |
| CKI, All Other Inputs | | | | | |
| Logic High | | 0.7 $V_{CC}$ | | | V |
| Logic Low | | | | 0.2 $V_{CC}$ | V |
| Value of the Internal Bias Resistor for the Crystal/Resonator Oscillator | | 0.5 | 1.0 | 2.0 | MΩ |
| CKI Resistance to $V_{CC}$ or GND when R/C Oscillator is Selected | $V_{CC}$ = 5.5V | 5 | 8 | 11 | kΩ |
| Hi-Z Input Leakage (same as TRI-STATE output) | $V_{CC}$ = 5.5V | −2 | | +2 | µA |
| Input Pullup Current | $V_{CC}$ = 5.5V, $V_{IN}$ = 0V | −40 | | −250 | µA |
| G and L Port Input Hysteresis | | 0.25 $V_{CC}$ | | | V |

## DC Electrical Characteristics (Continued)

$-40^{\circ}C \le T_A \le +85^{\circ}C$ unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Output Current Levels | | | | | |
| D Outputs | | | | | |
| Source | $V_{CC}$ = 4.5V, $V_{OH}$ = 3.3V | −0.4 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −0.2 | | | mA |
| Sink | $V_{CC}$ = 4.5V, $V_{OL}$ = 1.0V | 10 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OL}$ = 0.4V | 2 | | | mA |
| L Port | | | | | |
| Source (Weak Pull-Up) | $V_{CC}$ = 4.5V, $V_{OH}$ = 2.7V | −10.0 | | −110 | µA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −2.5 | | −33 | µA |
| Source (Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OH}$ = 3.3V | −0.4 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −0.2 | | | mA |
| Sink (L0–L3, Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OL}$ = 1.0V | 10.0 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OL}$ = 0.4V | 2 | | | mA |
| Sink (L4–L7, Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OL}$ = 0.4V | 1.6 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OL}$ = 0.4V | 0.7 | | | mA |
| All Others | | | | | |
| Source (Weak Pull-Up Mode) | $V_{CC}$ = 4.5V, $V_{OH}$ = 2.7V | −10.0 | | −110 | µA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −2.5 | | −33 | µA |
| Source (Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OH}$ = 3.3V | −0.4 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OH}$ = 1.8V | −0.2 | | | mA |
| Sink (Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OL}$ = 0.4V | 1.6 | | | mA |
| | $V_{CC}$ = 2.7V, $V_{OL}$ = 0.4V | 0.7 | | | mA |
| Allowable Sink Current per Pin (Note 17) | | | | | |
| D Outputs and L0 to L3 | | | | 15 | mA |
| All Others | | | | 3 | mA |
| Maximum Input Current without Latchup (Note 15) | | | | ±200 | mA |
| RAM Retention Voltage, Vr | | 2.0 | | | V |
| $V_{CC}$ Rise Time from a $V_{CC} \ge 2.0V$ | (Note 18) | 12 | | | µs |
| Input Capacitance | (Note 17) | | | 7 | pF |
| Load Capacitance on D2 | (Note 17) | | | 1000 | pF |

## AC Electrical Characteristics

$-40^{\circ}C \le T_A \le +85^{\circ}C$ unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Instruction Cycle Time ($t_C$) | | | | | |
| Crystal/Resonator, External | $4.5V \le V_{CC} \le 5.5V$ | 1.0 | | DC | µs |
| | $2.7V \le V_{CC} < 4.5V$ | 2.0 | | DC | µs |
| Internal R/C Oscillator | $4.5V \le V_{CC} \le 5.5V$ | | 1.667 | | µs |
| | $2.7V \le V_{CC} < 4.5V$ | | TBD | | µs |
| R/C Oscillator Frequency Variation | $4.5V \le V_{CC} \le 5.5V$ | | | ±35 | % |
| (Note 17) | $2.7V \le V_{CC} < 4.5V$ | | | TBD | % |
| External CKI Clock Duty Cycle (Note 17) | fr = Max | 45 | | 55 | % |
| Rise Time (Note 17) | fr = 10 MHz Ext Clock | | | 12 | ns |
| Fall Time (Note 17) | fr = 10 MHz Ext Clock | | | 8 | ns |

## AC Electrical Characteristics (Continued)

$-40^{\circ}C \le T_A \le +85^{\circ}C$ unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Inputs | | | | | |
| $t_{SETUP}$ | $4.5V \le V_{CC} \le 5.5V$ | 200 | | | ns |
| | $2.7V \le V_{CC} < 4.5V$ | 500 | | | ns |
| $t_{HOLD}$ | $4.5V \le V_{CC} \le 5.5V$ | 60 | | | ns |
| | $2.7V \le V_{CC} < 4.5V$ | 150 | | | ns |
| Output Propagation Delay (Note 16) | $R_L$ = 2.2k, $C_L$ = 100 pF | | | | |
| $t_{PD1}$, $t_{PD0}$ | | | | | |
| SO, SK | $4.5V \le V_{CC} \le 5.5V$ | | | 0.7 | µs |
| | $2.7V \le V_{CC} < 4.5V$ | | | 1.75 | µs |
| All Others | $4.5V \le V_{CC} \le 5.5V$ | | | 1.0 | µs |
| | $2.7V \le V_{CC} < 4.5V$ | | | 2.5 | µs |
| MICROWIRE Setup Time ($t_{UWS}$) (Note 16) | | 20 | | | ns |
| MICROWIRE Hold Time ($t_{UWH}$) (Note 16) | | 56 | | | ns |
| MICROWIRE Output Propagation Delay ($t_{UPD}$) | | | | 220 | ns |
| MICROWIRE Maximum Shift Clock | | | | | |
| Master Mode | | | | 500 | kHz |
| Slave Mode | | | | 1 | MHz |
| Input Pulse Width (Note 17) | | | | | |
| Interrupt Input High Time | | 1 | | | $t_C$ |
| Interrupt Input Low Time | | 1 | | | $t_C$ |
| Timer 1 Input High Time | | 1 | | | $t_C$ |
| Timer 1 Input Low Time | | 1 | | | $t_C$ |
| Reset Pulse Width | | 1 | | | µs |

**Note 11:** $t_C$ = Instruction cycle time (Clock input frequency divided by 10).

**Note 12:** Maximum rate of voltage change must be < 0.5 V/ms.

**Note 13:** Supply and IDLE currents are measured with CKI driven with a square wave Oscillator, CKO driven 180˚ out of phase with CKI, inputs connected to $V_{CC}$ and outputs driven low but not connected to a load.

**Note 14:** The HALT mode will stop CKI from oscillating in the R/C and the Crystal configurations. In the R/C configuration, CKI is forced high internally. In the crystal or external configuration, CKI is TRI-STATE. Measurement of $I_{DD}$ HALT is done with device neither sourcing nor sinking current; with L. F, C, G0, and G2–G5 programmed as low outputs and not driving a load; all outputs programmed low and not driving a load; all inputs tied to $V_{CC}$; clock monitor disabled. Parameter refers to HALT mode entered via setting bit 7 of the G Port data register.

**Note 15:** Pins G6 and $\overline{\text{RESET}}$ are designed with a high voltage input network. These pins allow input voltages > $V_{CC}$ and the pins will have sink current to $V_{CC}$ when biased at voltages > $V_{CC}$ (the pins do not have source current when biased at a voltage below $V_{CC}$). The effective resistance to $V_{CC}$ is 750Ω (typical). These two pins will not latch up. The voltage at the pins must be limited to < 14V. WARNING: Voltages in excess of 14V will cause damage to the pins. This warning excludes ESD transients.

**Note 16:** The output propagation delay is referenced to the end of the instruction cycle where the output change occurs.

**Note 17:** Parameter characterized but not tested.

**Note 18:** Rise times faster than this specification may reset the device if POR is enabled and may affect the value of Idle Timer T0 if POR is not enabled.

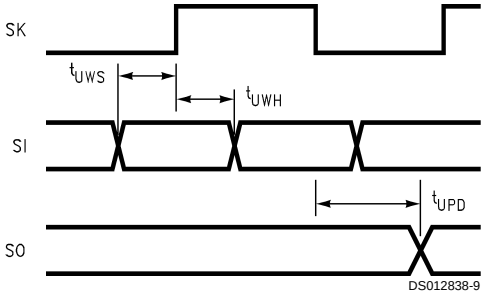



**FIGURE 4. MICROWIRE/PLUS Timing**

## Absolute Maximum Ratings (Note 19)

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.**

| | |
|---|---|
| Supply Voltage ($V_{CC}$) | 7V |
| Voltage at Any Pin | −0.6V to $V_{CC}$ +0.6V |
| ESD Protection Level | 2 kV (Human Body Model) |
| Total Current into $V_{CC}$ Pin (Source) | 80 mA |
| Total Current out of GND Pin (Sink) | 100 mA |
| Storage Temperature Range | −65˚C to +140˚C |

**Note 19:** *Absolute maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications are not ensured when operating the device at absolute maximum ratings.*

## DC Electrical Characteristics

−40˚C ≤ $T_A$ ≤ +125˚C unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Operating Voltage | | 4.5 | | 5.5 | V |
| Power Supply Rise Time from 0.0V | (Note 17) | | | | |
| (On-Chip Power-On Reset Selected) | | 10 ns | | 50 ms | |
| $V_{CC}$ Start Voltage to Guarantee POR | | | | 0.25 | V |
| Power Supply Ripple (Note 12) | Peak-to-Peak | | | 0.1 $V_{CC}$ | V |
| Supply Current (Note 13) | | | | | |
| CKI = 10 MHz | $V_{CC}$ = 5.5V, $t_C$ = 1 µs | | | 6.0 | mA |
| HALT Current (Note 14) —WATCHDOG Disabled | $V_{CC}$ = 5.5V, CKI = 0 MHz | | <10 | 30 | µA |
| IDLE Current (Note 13) | | | | | |
| CKI = 10 MHz | $V_{CC}$ = 5.5V, $t_C$ = 1 µs | | | 1.5 | mA |
| Input Levels ($V_{IH}$, $V_{IL}$) | | | | | |
| $\overline{\text{RESET}}$ | | | | | |
| Logic High | | 0.8 $V_{CC}$ | | | V |
| Logic Low | | | | 0.2 $V_{CC}$ | V |
| CKI, All Other Inputs | | | | | |
| Logic High | | 0.7 $V_{CC}$ | | | V |
| Logic Low | | | | 0.2 $V_{CC}$ | V |
| Value of the Internal Bias Resistor for the Crystal/Resonator Oscillator | | 0.5 | 1.0 | 2.0 | MΩ |
| CKI Resistance to $V_{CC}$ or GND when R/C Oscillator is Selected | $V_{CC}$ = 5.5V | 5 | 8 | 11 | kΩ |
| Hi-Z Input Leakage | $V_{CC}$ = 5.5V | −5 | | +5 | µA |
| Input Pullup Current | $V_{CC}$ = 5.5V, $V_{IN}$ = 0V | −35 | | −400 | µA |
| G and L Port Input Hysteresis | | 0.25 $V_{CC}$ | | | V |
| Output Current Levels | | | | | |
| D Outputs | | | | | |
| Source | $V_{CC}$ = 4.5V, $V_{OH}$ = 3.3V | −0.4 | | | mA |
| Sink | $V_{CC}$ = 4.5V, $V_{OL}$ = 1.0V | 9 | | | mA |
| L Port | | | | | |
| Source (Weak Pull-Up) | $V_{CC}$ = 4.5V, $V_{OH}$ = 2.7V | −9 | | −140 | µA |
| Source (Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OH}$ = 3.3V | −0.4 | | | mA |
| Sink (L0–L3, Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OL}$ = 1.0V | 9 | | | mA |
| Sink (L4–L7, Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OL}$ = 0.4V | 1.4 | | | mA |
| All Others | | | | | |
| Source (Weak Pull-Up Mode) | $V_{CC}$ = 4.5V, $V_{OH}$ = 2.7V | −9 | | −140 | µA |
| Source (Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OH}$ = 3.3V | −0.4 | | | mA |
| Sink (Push-Pull Mode) | $V_{CC}$ = 4.5V, $V_{OL}$ = 0.4V | 1.4 | | | mA |
| TRI-STATE Leakage | $V_{CC}$ = 5.5V | −5 | | +5 | µA |

## DC Electrical Characteristics (Continued)

$-40^{\circ}C \le T_A \le +125^{\circ}C$ unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Allowable Sink Current per Pin (Note 17) | | | | | |
| D Outputs and L0 to L3 | | | | 15 | mA |
| All Others | | | | 3 | mA |
| Maximum Input Current without Latchup (Note 15) | Room Temp | | | ±200 | mA |
| RAM Retention Voltage, Vr | | 2.0 | | | V |
| $V_{CC}$ Rise Time from a $V_{CC} \ge 2.0V$ | (Note 18) | 12 | | | µs |
| Input Capacitance | (Note 17) | | | 7 | pF |
| Load Capacitance on D2 | (Note 17) | | | 1000 | pF |

## AC Electrical Characteristics

$-40^{\circ}C \le T_A \le +125^{\circ}C$ unless otherwise specified.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|
| Instruction Cycle Time ($t_C$) | | | | | |
| Crystal/Resonator, External | $4.5V \le V_{CC} \le 5.5V$ | 1.0 | | DC | µs |
| Internal R/C Oscillator | $4.5V \le V_{CC} \le 5.5V$ | | 1.667 | DC | µs |
| R/C Oscillator Frequency Variation (Note 6) | $4.5V \le V_{CC} \le 5.5V$ | | | TBD | % |
| External CKI Clock Duty Cycle (Note 6) | fr = Max | 45 | | 55 | % |
| Rise Time (Note 6) | fr = 10 MHz Ext Clock | | | 12 | ns |
| Fall Time (Note 6) | fr = 10 MHz Ext Clock | | | 8 | ns |
| Inputs | | | | | |
| $t_{SETUP}$ | $4.5V \le V_{CC} \le 5.5V$ | 200 | | | ns |
| $t_{HOLD}$ | $4.5V \le V_{CC} \le 5.5V$ | 60 | | | ns |
| Output Propagation Delay (Note 5) | $R_L$ = 2.2k, $C_L$ = 100 pF | | | | |
| $t_{PD1}$, $t_{PD0}$ | | | | | |
| SO, SK | $4.5V \le V_{CC} \le 5.5V$ | | | 0.7 | µs |
| All Others | $4.5V \le V_{CC} \le 5.5V$ | | | 1.0 | µs |
| MICROWIRE Setup Time ($t_{UWS}$) (Note 5) | | 20 | | | ns |
| MICROWIRE Hold Time ($t_{UWH}$) (Note 5) | | 56 | | | ns |
| MICROWIRE Output Propagation Delay ($t_{UPD}$) | | | | 220 | ns |
| MICROWIRE Maximum Shift Clock | | | | | |
| Master Mode | | | | 500 | kHz |
| Slave Mode | | | | 1 | MHz |
| Input Pulse Width (Note 6) | | | | | |
| Interrupt Input High Time | | 1 | | | $t_C$ |
| Interrupt Input Low Time | | 1 | | | $t_C$ |
| Timer 1, 2, 3 Input High Time | | 1 | | | $t_C$ |
| Timer 1, 2, 3 Input Low Time | | 1 | | | $t_C$ |
| Reset Pulse Width | | 1 | | | µs |

# 5.0 Pin Descriptions

COP8SAx I/O structure minimizes external component requirements. Software-switchable I/O enables designers to reconfigure the microcontroller's I/O functions with a single instruction. Each individual I/O pin can be independently configured as an output pin low, an output high, an input with high impedance or an input with a weak pull-up device. A typical example is the use of I/O pins as the keyboard matrix input lines. The input lines can be programmed with internal weak pull-ups so that the input lines read logic high when the keys are all up. With a key closure, the corresponding input line will read a logic zero since the weak pull-up can easily be overdriven. When the key is released, the internal weak pullup will pull the input line back to logic high. This flexibility eliminates the need for external pull-up resistors. The High current options are available for driving LEDs, motors and speakers. This flexibility helps to ensure a cleaner design, with less external components and lower costs. Below is the general description of all available pins.

$V_{CC}$ and GND are the power supply pins. All $V_{CC}$ and GND pins must be connected.

CKI is the clock input. This can come from the Internal R/C oscillator, external, or a crystal oscillator (in conjunction with CKO). See Oscillator Description section.

$\overline{\text{RESET}}$ is the master reset input. See Reset description section.

The device contains four bidirectional 8-bit I/O ports (C, G, L and F), where each individual bit may be independently configured as an input (Schmitt trigger inputs on ports L and G), output or TRI-STATE under program control. Three data memory address locations are allocated for each of these I/O ports. Each I/O port has two associated 8-bit memory mapped registers, the CONFIGURATION register and the output DATA register. A memory mapped address is also reserved for the input pins of each I/O port. (See the memory map for the various addresses associated with the I/O ports.) *Figure 5* shows the I/O port configurations. The DATA and CONFIGURATION registers allow for each port bit to be individually configured under software control as shown below:

| CONFIGURATION Register | DATA Register | Port Set-Up |
|---|---|---|
| 0 | 0 | Hi-Z Input (TRI-STATE Output) |
| 0 | 1 | Input with Weak Pull-Up |
| 1 | 0 | Push-Pull Zero Output |
| 1 | 1 | Push-Pull One Output |

Port L is an 8-bit I/O port. All L-pins have Schmitt triggers on the inputs.

Port L supports the Multi-Input Wake Up feature on all eight pins. The 16-pin device does not have a full complement of Port L pins. The unavailable pins are not terminated. A read operation these unterminated pins are not terminated. A read operation these unterminated pins will return unpredictable values. To minimize current drain, the unavailable pins must be programmed as outputs.

Port G is an 8-bit port. Pin G0, G2–G5 are bi-directional I/O ports. Pin G6 is always a general purpose Hi-Z input. All pins have Schmitt Triggers on their inputs. **Pin G1 serves as the dedicated WDOUT WATCHDOG output with weak pullup if WATCHDOG feature is selected by the ECON register. The pin is a general purpose I/O if WATCHDOG feature is not selected.** If WATCHDOG feature is selected, bit 1 of the Port G configuration and data register does not have any effect on Pin G1 setup. Pin G7 is either input or output depending on the oscillator option selected. With the crystal oscillator option selected, G7 serves as the dedicated output pin for the CKO clock output. With the internal R/C or the external oscillator option selected, G7 serves as a general purpose Hi-Z input pin and is also used to bring the device out of HALT mode with a low to high transition on G7. There are two registers associated with Port G, a data register and a configuration register. Using these registers, each of the 5 I/O pins (G0, G2–G5) can be individually configured under software control.

Since G6 is an input only pin and G7 is the dedicated CKO clock output pin (crystal clock option) or general purpose input (R/C or external clock option), the associated bits in the data and configuration registers for G6 and G7 are used for special purpose functions as outlined below. Reading the G6 and G7 data bits will return zeroes.

The device will be placed in the HALT mode by writing a "1" to bit 7 of the Port G Data Register. Similarly the device will be placed in the IDLE mode by writing a "1" to bit 6 of the Port G Data Register.

Writing a "1" to bit 6 of the Port G Configuration Register enables the MICROWIRE/PLUS to operate with the alternate phase of the SK clock. The G7 configuration bit, if set high, enables the clock start up delay after HALT when the R/C clock configuration is used.

| | Config. Reg. | Data Reg. |
|---|---|---|
| G7 | CLKDLY | HALT |
| G6 | Alternate SK | IDLE |

Port G has the following alternate features:

G6 SI (MICROWIRE Serial Data Input)

G5 SK (MICROWIRE Serial Clock)

G4 SO (MICROWIRE Serial Data Output)

G3 T1A (Timer T1 I/O)

G2 T1B (Timer T1 Capture Input)

G0 INTR (External Interrupt Input)

Port G has the following dedicated functions:

G7 CKO Oscillator dedicated output or general purpose input

G1 WDOUT WATCHDOG and/or CLock Monitor if WATCHDOG enabled, otherwise it is a general purpose I/O

Port C is an 8-bit I/O port. The 40-pin device does not have a full complement of Port C pins. The unavailable pins are not terminated. A read operation on these unterminated pins will return unpredictable values. Only the COP8SAC7 device contains Port C. The 20/28 pin devices do not offer Port C. On these devices, the associated Port C Data and Configuration registers should not be used.

Port F is an 8-bit I/O port. The 28-pin device does not have a full complement of Port F pins. The unavailable pins are not terminated. A read operation on these unterminated pins will return unpredictable values.

## 5.0 Pin Descriptions (Continued)

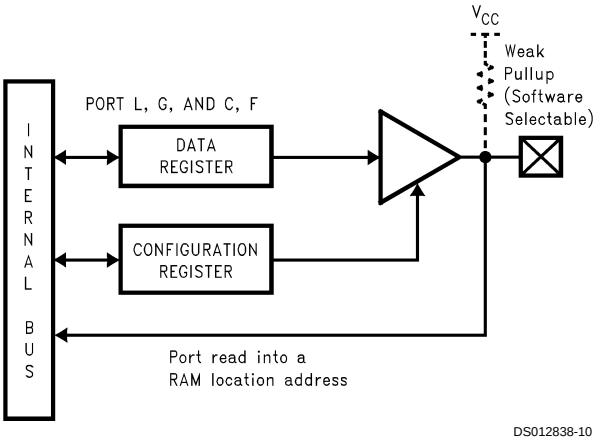



**FIGURE 5. I/O Port Configurations**

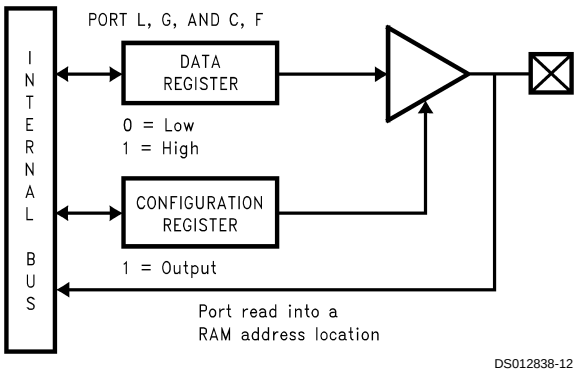



**FIGURE 6. I/O Port Configurations—Output Mode**

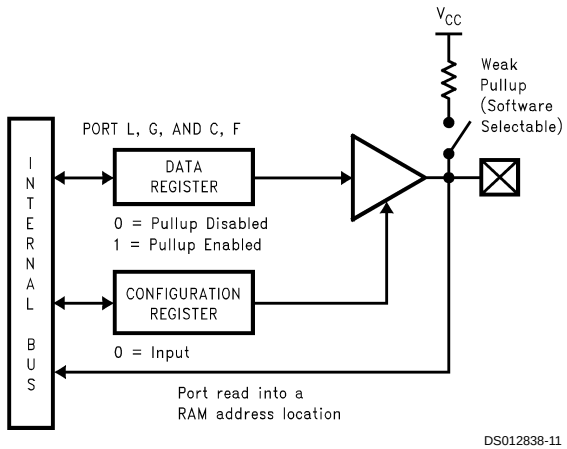



**FIGURE 7. I/O Port Configurations—Input Mode**

Port D is an 8-bit output port that is preset high when $\overline{\text{RESET}}$ goes low. The user can tie two or more D port outputs (except D2) together in order to get a higher drive.

**Note:** Care must be exercised with the D2 pin operation. At RESET, the external loads on this pin must ensure that the output voltages stay above 0.7 $V_{CC}$ to prevent the chip from entering special modes. Also keep the external loading on D2 to less than 1000 pF.

## 6.0 Functional Description

The architecture of the device is a modified Harvard architecture. With the Harvard architecture, the program memory EPROM is separated from the data store memory (RAM). Both EPROM and RAM have their own separate addressing space with separate address buses. The architecture, though based on the Harvard architecture, permits transfer of data from EPROM to RAM.

### 6.1 CPU REGISTERS

The CPU can do an 8-bit addition, subtraction, logical or shift operation in one instruction ($t_C$) cycle time.

There are six CPU registers:

A is the 8-bit Accumulator Register

PC is the 15-bit Program Counter Register

PU is the upper 7 bits of the program counter (PC)

PL is the lower 8 bits of the program counter (PC)

B is an 8-bit RAM address pointer, which can be optionally post auto incremented or decremented.

X is an 8-bit alternate RAM address pointer, which can be optionally post auto incremented or decremented.

SP is the 8-bit stack pointer, which points to the subroutine/interrupt stack (in RAM). With reset the SP is initialized to RAM address 02F Hex (devices with 64 bytes of RAM), or initialized to RAM address 06F Hex (devices with 128 bytes of RAM).

All the CPU registers are memory mapped with the exception of the Accumulator (A) and the Program Counter (PC).

### 6.2 PROGRAM MEMORY

The program memory consists of 1024, 2048, or 4096 bytes of EPROM or ROM. *Table 1* shows the program memory sizes for the different devices. These bytes may hold program instructions or constant data (data tables for the LAID instruction, jump vectors for the JID instruction, and interrupt vectors for the VIS instruction). The program memory is addressed by the 15-bit program counter (PC). All interrupts in the device vector to program memory location 0FF Hex. The program memory reads 00 Hex in the erased state.

### 6.3 DATA MEMORY

The data memory address space includes the on-chip RAM and data registers, the I/O registers (Configuration, Data and Pin), the control registers, the MICROWIRE/PLUS SIO shift register, and the various registers, and counters associated with the timers (with the exception of the IDLE timer). Data memory is addressed directly by the instruction or indirectly by the B, X and SP pointers.

The data memory consists of 64 or 128 bytes of RAM. *Table 1* shows the data memory sizes for the different devices. Fifteen bytes of RAM are mapped as “registers” at addresses 0F0 to 0FE Hex. These registers can be loaded immediately, and also decremented and tested with the DRSZ (decrement register and skip if zero) instruction. The memory pointer registers X, SP and B are memory mapped into this space at address locations 0FC to 0FE Hex respectively, with the other registers (except 0FF) being available for general usage. Address location 0FF is reserved for future RAM expansion. If compatibility with future devices (with more RAM) is not desired, this location can be used as a general purpose RAM location.

The instruction set permits any bit in memory to be set, reset or tested. All I/O and registers (except A and PC) are

# 6.0 Functional Description (Continued)

memory mapped; therefore, I/O bits and register bits can be directly and individually set, reset and tested. The accumulator (A) bits can also be directly and individually tested.

RAM contents are undefined upon power-up.

**TABLE 1. Program/Data Memory Sizes**

| Device | Program Memory (Bytes) | Data Memory (Bytes) | User Storage (Bytes) |
|---|---|---|---|
| COP8SAA7 | 1024 | 64 | 8 |
| COP8SAB7 | 2048 | 128 | 8 |
| COP8SAC7 | 4096 | 128 | 8 |

### 6.4 ECON (CONFIGURATION) REGISTER

The ECON register is used to configure the user selectable clock, security, power-on reset, WATCHDOG, and HALT options. The register can be programmed and read only in EPROM programming mode. Therefore, the register should be programmed at the same time as the program memory. The contents of the ECON register shipped from the factory read 00 Hex (windowed device), 80 Hex (OTP device) or as specified by the customer (ROM device).

The format of the ECON register is as follows:

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |
|---|---|---|---|---|---|---|---|
| X | POR | SECURITY | CKI 2 | CKI 1 | WATCH DOG | Reserved | HALT |

Bit 7 = x This is for factory test. The polarity is always 0.

Bit 6 = 1 Power-on reset enabled.

= 0 Power-on reset disabled.

Bit 5 = 1 Security enabled. EPROM read and write are not allowed.

= 0 Security disabled. EPROM read and write are allowed.

Bits 4, 3 = 0, 0 External CKI option selected. G7 is available as a HALT restart and/or general purpose input. CKI is clock input.

= 0, 1 R/C oscillator option selected. G7 is available as a HALT restart and/or general purpose input. CKI clock input. Internal R/C components are supplied for maximum R/C frequency.

= 1, 0 Crystal oscillator with on-chip crystal bias resistor disabled. G7 (CKO) is the clock generator output to crystal/resonator.

= 1, 1 Crystal oscillator with on-chip crystal bias resistor enabled. G7 (CKO) is the clock generator output to crystal/resonator.

Bit 2 = 1 WATCHDOG feature disabled. G1 is a general purpose I/O.

= 0 WATCHDOG feature enabled. G1 pin is WATCHDOG output with waek pullup.

Bit 1 = Reserved.

Bit 0 = 1 HALT mode disabled.

= 0 HALT mode enabled.

### 6.5 USER STORAGE SPACE IN EPROM

In addition to the ECON register, there are 8 bytes of EPROM available for “user information”. ECON and these 8 bytes are outside of the code area and are not protected by the security bit of the ECON register. Even when security is set, information in the 8-byte USER area is both read and write enabled allowing the user to read from and write into the area at all times while still protecting the code from unauthorized access.

Both ECON and USER area, 9 bytes total, are outside of the normal address range of the EPROM and can not be accessed by the executing software. This allows for the storage of non-secured information. Typical uses are for storage of serial numbers, data codes, version numbers, copyright information, lot numbers, etc.

The COP8 assembler defines a special ROM section type, CONF, into which the ECON and USER data may be coded. Both ECON and User Data are programmed automatically by programmers that are certified by National.

The following examples illustrate the declaration of ECON and the User information.

Syntax:

```
[label:] .sect econ, conf
         .db   value  ;1 byte,
                      ;configures options
         .db
         .endsect<user information>
                      ;up to 8 bytes
```

Example: The following sets a value in the ECON register and User Identification for a COP8SAC728M7. The ECON bit values shown select options: Power-on enabled, Security disabled, Crystal oscillator with on-chip bias disabled, WATCHDOG enabled and HALT mode enabled.

```
.chip 8SAC
.sect econ, conf
.db  0x55        ;por, extal, wd, halt
.db  'my v1.00'  ;user data declaration
.endsect
...
.end start
```

**Note:** All programmers certified for programming this family of parts will support programming of the CONFiguration section. Please contact National or your device programmer supplier for more information.

### 6.6 OTP SECURITY

The device has a security feature that, when enabled, prevents external reading of the OTP program memory. The security bit in the ECON register determines, whether security is enabled or disabled. If the security feature is disabled, the contents of the internal EPROM may be read.

**If the security feature is enabled, then any attempt to externally read the contents of the EPROM will result in the value FF Hex being read from all program locations. Under no circumstances can a secured part be read.** In addition, with the security feature enabled, the write operation to the EPROM program memory and ECON register is inhibited. The ECON register is readable regardless of the state of the security bit. The security bit, when set, **cannot** be erased, **even in windowed packages**. If the security bit is set in a device in a windowed package, that device may be erased but will not be further programmable.

If security is being used, it is recommended that all other bits in the ECON register be programmed first. Then the security bit can be programmed.

# 6.0 Functional Description (Continued)

## 6.7 RESET

The device is initialized when the $\overline{\text{RESET}}$ pin is pulled low or the On-chip Power-On Reset is enabled.

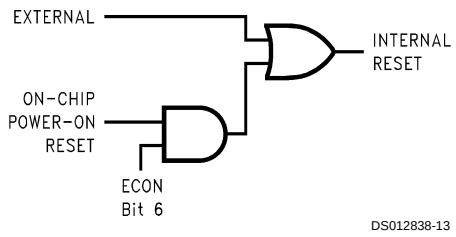



**FIGURE 8. Reset Logic**

The following occurs upon initialization:

Port L: TRISTATE
Port C: TRISTATE
Port G: TRISTATE
Port F: TRISTATE
Port D: HIGH
PC: CLEARED to 0000
PSW, CNTRL and ICNTRL registers: CLEARED
SIOR: UNAFFECTED after RESET with power already applied
RANDOM after RESET at power-on
T1CNTRL: CLEARED
Accumulator, Timer 1:
RANDOM after RESET with crystal clock option (power already applied)
UNAFFECTED after RESET with R/C clock option (power already applied)
RANDOM after RESET at power-on
WKEN, WKEDG: CLEARED
WKPND: RANDOM
SP (Stack Pointer):
Initialized to RAM address 02F Hex (devices with 64 bytes of RAM), or initialized to RAM address 06F Hex (devices with 128 bytes of RAM).
B and X Pointers:
UNAFFECTED after RESET with power already applied
RANDOM after RESET at power-on
RAM:
UNAFFECTED after RESET with power already applied
RANDOM after RESET at power-on
WATCHDOG (if enabled):

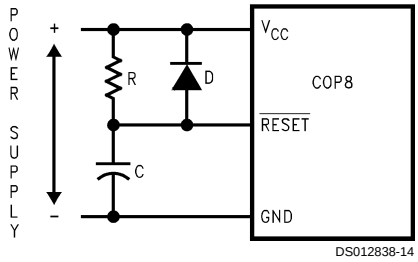
The device comes out of reset with both the WATCHDOG logic and the Clock Monitor detector armed, with the WATCHDOG service window bits set and the Clock Monitor bit set. The WATCHDOG and Clock Monitor circuits are inhibited during reset. The WATCHDOG service window bits being initialized high default to the maximum WATCHDOG service window of 64k $t_C$ clock cycles. The Clock Monitor bit being initialized high will cause a Clock Monitor error following reset if the clock has not reached the minimum specified frequency at the termination of reset. A Clock Monitor error will cause an active low error output on pin G1. This error output will continue until 16 $t_C$–32 $t_C$ clock cycles following the clock frequency reaching the minimum specified value, at which time the G1 output will go high.

### 6.7.1 External Reset

The $\overline{\text{RESET}}$ input when pulled low initializes the device. The $\overline{\text{RESET}}$ pin must be held low for a minimum of one instruction cycle to guarantee a valid reset. During Power-Up initialization, the user must ensure that the $\overline{\text{RESET}}$ pin is held low until the device is within the specified $V_{CC}$ voltage. An R/C circuit on the $\overline{\text{RESET}}$ pin with a delay 5 times (5x) greater than the power supply rise time or 15 µs whichever is greater, is recommended. Reset should also be wide enough to ensure crystal start-up upon Power-Up.

$\overline{\text{RESET}}$ may also be used to cause an exit from the HALT mode.

A recommended reset circuit for this deviced is shown in *Figure 9*.




RC >5x power supply rise time or 15 µs, whichever is greater.

**FIGURE 9. Reset Circuit Using External Reset**

### 6.7.2 On-Chip Power-On Reset

The on-chip reset circuit is selected by a bit in the ECON register. When enabled, the device generates an internal reset as $V_{CC}$ rises to a voltage level above 2.0V. The on-chip reset circuitry is able to detect both fast and slow rise times on $V_{CC}$ ($V_{CC}$ rise time between 10 ns and 50 ms).

Under no circumstances should the $\overline{\text{RESET}}$ pin be allowed to float. If the on-chip Power-On Reset feature is being used, $\overline{\text{RESET}}$ pin should be connected directly to $V_{CC}$. The output of the power-on reset detector will **always** preset the Idle timer to 0FFF(4096 $t_C$). At this time, the internal reset will be generated.

If the Power-On Reset feature is enabled, the internal reset will not be turned off until the Idle timer underflows. The internal reset will perform the same functions as external reset. The user is responsible for ensuring that $V_{CC}$ is at the minimum level for the operating frequency within the 4096 $t_C$. After the underflow, the logic is designed such that no additional internal resets occur as long as $V_{CC}$ remains above 2.0V.

**Note:** While the POR feature of the COP8SAx was never intended to function as a brownout detector, there are certain constraints of this block that the system designer must address to properly recover from a brownout condition. This is true regardless of whether the internal POR or the external reset feature is used.

A brownout condition is reached when $V_{CC}$ of the device goes below the minimum operating conditions of the device. The minimum guaranteed operating conditions are defined as $V_{CC}$ = 4.5V @ 10 MHz CKI, $V_{CC}$ = 2.7V @ 4 MHz, or $V_{CC}$ = 2.0V during HALT mode (or when CKI is stopped) operation.

When using either the external reset or the POR feature to recover from a brownout condition, $V_{CC}$ must be lowered to 0.25V or an external reset must be applied whenever it goes below the minimum operating conditions as stated above.

## 6.0 Functional Description (Continued)

The contents of data registers and RAM are unknown following the on-chip reset.

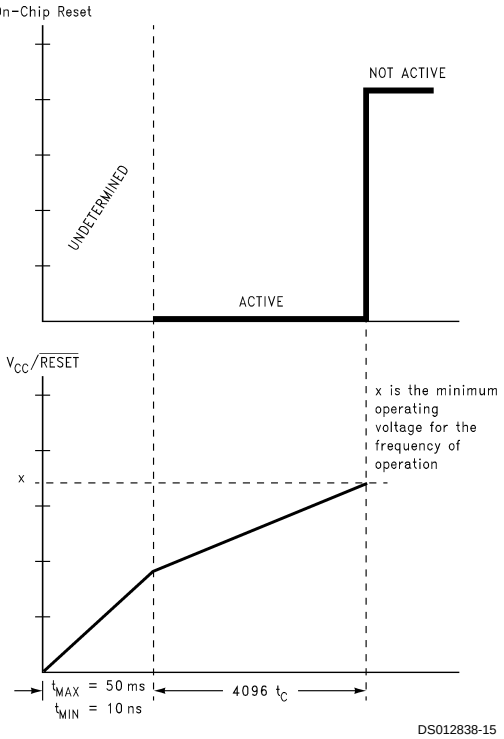



**FIGURE 10. Reset Timing (Power-On Reset Enabled) with $V_{CC}$ Tied to $\overline{RESET}$**

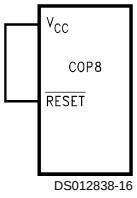



**FIGURE 11. Reset Circuit Using Power-On Reset**

### 6.8 OSCILLATOR CIRCUITS

There are four clock oscillator options available: Crystal Oscillator with or without on-chip bias resistor, R/C Oscillator with on-chip resistor and capacitor, and External Oscillator. The oscillator feature is selected by programming the ECON register, which is summarized in *Table 2*.

**TABLE 2. Oscillator Option**

| ECON4 | ECON3 | Oscillator Option |
|---|---|---|
| 0 | 0 | External Oscillator |
| 1 | 0 | Crystal Oscillator without Bias Resistor |
| 0 | 1 | R/C Oscillator |
| 1 | 1 | Crystal Oscillator with Bias Resistor |

#### 6.8.1 Crystal Oscillator

The crystal Oscillator mode can be selected by programming ECON Bit 4 to 1. CKI is the clock input while G7/CKO is the clock generator output to the crystal. An on-chip bias resistor connected between CKI and CKO can be enabled by programming ECON Bit 3 to 1 with the crystal oscillator option selection. The value of the resistor is in the range of 0.5M to 2M (typically 1.0M). *Table 3* shows the component values required for various standard crystal values. Resistor R2 is only used when the on-chip bias resistor is disabled. *Figure 12* shows the crystal oscillator connection diagram.

**TABLE 3. Crystal Oscillator Configuration, $T_A$ = 25˚C, $V_{CC}$ = 5V**

| R1 (kΩ) | R2 (MΩ) | C1 (pF) | C2 (pF) | CKI Freq. (MHz) |
|---|---|---|---|---|
| 0 | 1 | 30 | 30 | 15 |
| 0 | 1 | 32 | 32 | 10 |
| 0 | 1 | 45 | 30–36 | 4 |
| 5.6 | 1 | 100 | 100–156 | 0.455 |

#### 6.8.2 External Oscillator

The External Oscillator mode can be selected by programming ECON Bit 3 to 0 and ECON Bit 4 to 0. CKI can be driven by an external clock signal provided it meets the specified duty cycle, rise and fall times, and input levels. G7/CKO is available as a general purpose input G7 and/or Halt control. *Figure 13* shows the external oscillator connection diagram.

#### 6.8.3 R/C Oscillator

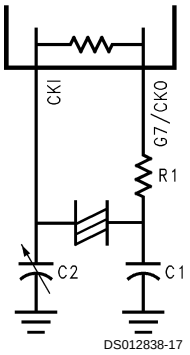
The R/C Oscillator mode can be selected by programming ECON Bit 3 to 1 and ECON Bit 4 to 0. In R/C oscillation mode, CKI is left floating, while G7/CKO is available as a general purpose input G7 and/or HALT control. The R/C controlled oscillator has on-chip resistor and capacitor for maximum R/C oscillator frequency operation. The maximum frequency is 6 MHz ± 35% for $V_{CC}$ between 4.5V to 5.5V and temperature range of −40˚C to +85˚C. For max frequency operation, the CKI pin should be left floating. For lower frequencies, an external capacitor should be connected between CKI and either $V_{CC}$ or GND. Immunity of the R/C oscillator to external noise can be improved by connecting one half the external capacitance to $V_{CC}$ and one half to GND. PC board trace length on the CKI pin should be kept as short as possible. *Table 4* shows the oscillator frequency as a function of approximate external capacitance on the CKI pin. *Figure 14* shows the R/C oscillator configuration.

**TABLE 4. R/C Oscillator Configuration, −40˚C to +85˚C, $V_{CC}$ = 4.5V to 5.5V, OSC Freq. Variation of ± 35%**

| External Capacitor (pF) | R/C OSC Freq (MHz) | Instr. Cycle (µs) |
|---|---|---|
| 0 | 6 | 1.667 |
| 13 | 4 | 2.5 |
| 62 | 2 | 5.0 |
| 120 | 1 | 10 |
| 5600 | 32 kHz | 312.5 |

## 6.0 Functional Description (Continued)

**With On-Chip Bias Resistor**




**Without On-Chip Bias Resistor**

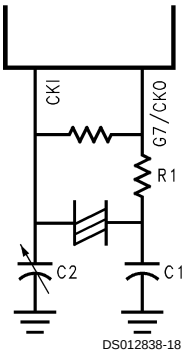



**FIGURE 12. Crystal Oscillator**

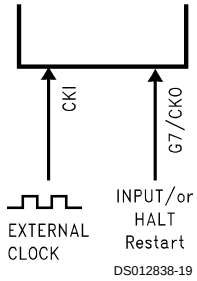
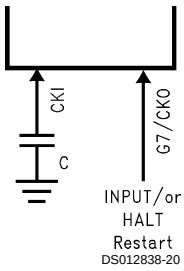
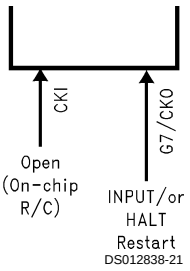



**FIGURE 13. External Oscillator**




For operation at lower than maximum R/C oscillator frequency.




For operation at maximum R/C oscillator frequency.

**FIGURE 14. R/C Oscillator**

# 6.0 Functional Description (Continued)

## 6.9 CONTROL REGISTERS

### CNTRL Register (Address X'00EE)

| T1C3 | T1C2 | T1C1 | T1C0 | MSEL | IEDG | SL1 | SL0 |
|---|---|---|---|---|---|---|---|
| Bit 7 | | | | | | | Bit 0 |

The Timer1 (T1) and MICROWIRE/PLUS control register contains the following bits:

- T1C3 Timer T1 mode control bit
- T1C2 Timer T1 mode control bit
- T1C1 Timer T1 mode control bit
- T1C0 Timer T1 Start/Stop control in timer modes 1 and 2, T1 Underflow Interrupt Pending Flag in timer mode 3
- MSEL Selects G5 and G4 as MICROWIRE/PLUS signals SK and SO respectively
- IEDG External interrupt edge polarity select (0 = Rising edge, 1 = Falling edge)
- SL1 & SL0 Select the MICROWIRE/PLUS clock divide by (00 = 2, 01 = 4, 1x = 8)

### PSW Register (Address X'00EF)

| HC | C | T1PNDA | T1ENA | EXPND | BUSY | EXEN | GIE |
|---|---|---|---|---|---|---|---|
| Bit 7 | | | | | | | Bit 0 |

The PSW register contains the following select bits:

- HC Half Carry Flag
- C Carry Flag
- T1PNDA Timer T1 Interrupt Pending Flag (Autoreload RA in mode 1, T1 Underflow in Mode 2, T1A capture edge in mode 3)
- T1ENA Timer T1 Interrupt Enable for Timer Underflow or T1A Input capture edge
- EXPND External interrupt pending
- BUSY MICROWIRE/PLUS busy shifting flag
- EXEN Enable external interrupt
- GIE Global interrupt enable (enables interrupts)

The Half-Carry flag is also affected by all the instructions that affect the Carry flag. The SC (Set Carry) and R/C (Reset Carry) instructions will respectively set or clear both the carry flags. In addition to the SC and R/C instructions, ADC, SUBC, RRC and RLC instructions affect the Carry and Half Carry flags.

### ICNTRL Register (Address X'00E8)

| Reserved | LPEN | T0PND | T0EN | µWPND | µWEN | T1PNDB | T1ENB |
|---|---|---|---|---|---|---|---|
| Bit 7 | | | | | | | Bit 0 |

The ICNTRL register contains the following bits:

- Reserved This bit is reserved and should to zero
- LPEN L Port Interrupt Enable (Multi-Input Wakeup/ Interrupt)
- T0PND Timer T0 Interrupt pending
- T0EN Timer T0 Interrupt Enable (Bit 12 toggle)
- µWPND MICROWIRE/PLUS interrupt pending
- µWEN Enable MICROWIRE/PLUS interrupt
- T1PNDB Timer T1 Interrupt Pending Flag for T1B capture edge
- T1ENB Timer T1 Interrupt Enable for T1B Input capture edge

# 7.0 Timers

The device contains a very versatile set of timers (T0, T1). Timer T1 and associated autoreload/capture registers power up containing random data.

## 7.1 TIMER T0 (IDLE TIMER)

The device supports applications that require maintaining real time and low power with the IDLE mode. This IDLE mode support is furnished by the IDLE timer T0. The Timer T0 runs continuously at the fixed rate of the instruction cycle clock, $t_C$. The user cannot read or write to the IDLE Timer T0, which is a count down timer.

The Timer T0 supports the following functions:

- Exit out of the Idle Mode (See Idle Mode description)
- WATCHDOG logic (See WATCHDOG description)
- Start up delay out of the HALT mode
- Timing the width of the internal power-on-reset

The IDLE Timer T0 can generate an interrupt when the twelfth bit toggles. This toggle is latched into the T0PND pending flag, and will occur every 4.096 ms at the maximum clock frequency ($t_C$ = 1 µs). A control flag T0EN allows the interrupt from the twelfth bit of Timer T0 to be enabled or disabled. Setting T0EN will enable the interrupt, while resetting it will disable the interrupt.

## 7.2 TIMER T1

One of the main functions of a microcontroller is to provide timing and counting capability for real-time control tasks. The COP8 family offers a very versatile 16-bit timer/counter structure, and two supporting 16-bit autoreload/capture registers (R1A and R1B), optimized to reduce software burdens in real-time control applications. The timer block has two pins associated with it, T1A and T1B. Pin T1A supports I/O required by the timer block, while pin T1B is an input to the timer block.

The timer block has three operating modes: Processor Independent PWM mode, External Event Counter mode, and Input Capture mode.

The control bits T1C3, T1C2, and T1C1 allow selection of the different modes of operation.

### 7.2.1 Mode 1. Processor Independent PWM Mode

One of the timer's operating modes is the Processor Independent PWM mode. In this mode, the timer generates a "Processor Independent" PWM signal because once the timer is setup, no more action is required from the CPU which translates to less software overhead and greater throughput. The user software services the timer block only when the PWM parameters require updating. This capability is provided by the fact that the timer has two separate 16-bit reload registers. One of the reload registers contains the "ON" timer while the other holds the "OFF" time. By contrast, a microcontroller that has only a single reload register requires an additional software to update the reload value (alternate between the on-time/off-time).

The timer can generate the PWM output with the width and duty cycle controlled by the values stored in the reload registers. The reload registers control the countdown values and the reload values are automatically written into the timer when it counts down through 0, generating interrupt on each reload. Under software control and with minimal overhead,

## 7.0 Timers (Continued)

the PMW outputs are useful in controlling motors, triacs, the intensity of displays, and in providing inputs for data acquisition and sine wave generators.

In this mode, the timer T1 counts down at a fixed rate of $t_C$. Upon every underflow the timer is alternately reloaded with the contents of supporting registers, R1A and R1B. The very first underflow of the timer causes the timer to reload from the register R1A. Subsequent underflows cause the timer to be reloaded from the registers alternately beginning with the register R1B.

The T1 Timer control bits, T1C3, T1C2 and T1C1 set up the timer for PWM mode operation.

*Figure 15* shows a block diagram of the timer in PWM mode.

The underflows can be programmed to toggle the T1A output pin. The underflows can also be programmed to generate interrupts.

Underflows from the timer are alternately latched into two pending flags, T1PNDA and T1PNDB. The user must reset these pending flags under software control. Two control enable flags, T1ENA and T1ENB, allow the interrupts from the timer underflow to be enabled or disabled. Setting the timer enable flag T1ENA will cause an interrupt when a timer underflow causes the R1A register to be reloaded into the timer. Setting the timer enable flag T1ENB will cause an interrupt when a timer underflow causes the R1B register to be reloaded into the timer. Resetting the timer enable flags will disable the associated interrupts.

Either or both of the timer underflow interrupts may be enabled. This gives the user the flexibility of interrupting once per PWM period on either the rising or falling edge of the PWM output. Alternatively, the user may choose to interrupt on both edges of the PWM output.

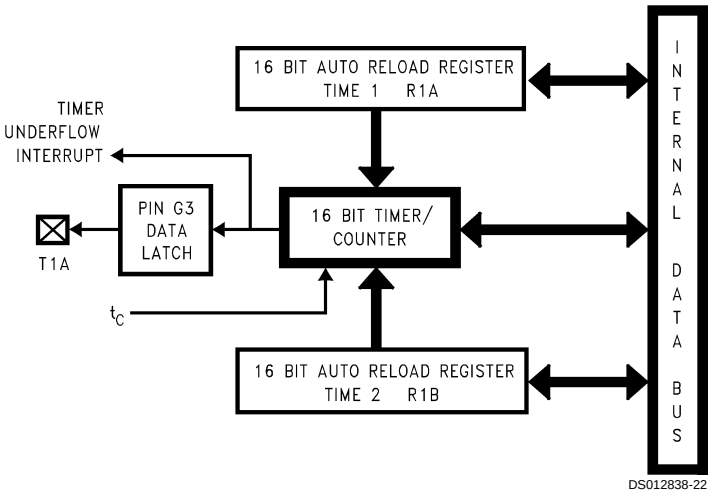



**FIGURE 15. Timer in PWM Mode**

### 7.2.2 Mode 2. External Event Counter Mode

This mode is quite similar to the processor independent PWM mode described above. The main difference is that the timer, T1, is clocked by the input signal from the T1A pin. The T1 timer control bits, T1C3, T1C2 and T1C1 allow the timer to be clocked either on a positive or negative edge from the T1A pin. Underflows from the timer are latched into the T1PNDA pending flag. Setting the T1ENA control flag will cause an interrupt when the timer underflows.

In this mode the input pin T1B can be used as an independent positive edge sensitive interrupt input if the T1ENB control flag is set. The occurrence of a positive edge on the T1B input pin is latched into the T1PNDB flag.

*Figure 16* shows a block diagram of the timer in External Event Counter mode.

**Note:** The PWM output is not available in this mode since the T1A pin is being used as the counter input clock.

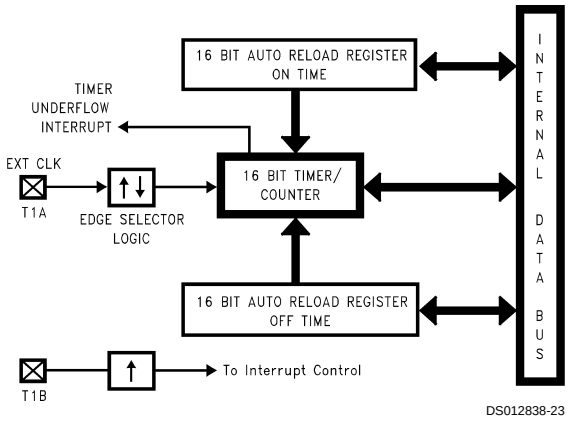



**FIGURE 16. Timer in External Event Counter Mode**

# 7.0 Timers (Continued)

### 7.2.3 Mode 3. Input Capture Mode

The device can precisely measure external frequencies or time external events by placing the timer block, T1, in the input capture mode. In this mode, the reload registers serve as independent capture registers, capturing the contents of the timer when an external event occurs (transition on the timer input pin). The capture registers can be read while maintaining count, a feature that lets the user measure elapsed time and time between events. By saving the timer value when the external event occurs, the time of the external event is recorded. Most microcontrollers have a latency time because they cannot determine the timer value when the external event occurs. The capture register eliminates the latency time, thereby allowing the applications program to retrieve the timer value stored in the capture register.

In this mode, the timer T1 is constantly running at the fixed $t_C$ rate. The two registers, R1A and R1B, act as capture registers. Each register acts in conjunction with a pin. The register R1A acts in conjunction with the T1A pin and the register R1B acts in conjunction with the T1B pin.

The timer value gets copied over into the register when a trigger event occurs on its corresponding pin. Control bits, T1C3, T1C2 and T1C1, allow the trigger events to be specified either as a positive or a negative edge. The trigger condition for each input pin can be specified independently.

The trigger conditions can also be programmed to generate interrupts. The occurrence of the specified trigger condition on the T1A and T1B pins will be respectively latched into the pending flags, T1PNDA and T1PNDB. The control flag T1ENA allows the interrupt on T1A to be either enabled or disabled. Setting the T1ENA flag enables interrupts to be generated when the selected trigger condition occurs on the T1A pin. Similarly, the flag T1ENB controls the interrupts from the T1B pin.

Underflows from the timer can also be programmed to generate interrupts. Underflows are latched into the timer T1C0 pending flag (the T1C0 control bit serves as the timer underflow interrupt pending flag in the Input Capture mode). Consequently, the T1C0 control bit should be reset when entering the Input Capture mode. The timer underflow interrupt is enabled with the T1ENA control flag. When a T1A interrupt occurs in the Input Capture mode, the user must check both the T1PNDA and T1C0 pending flags in order to determine whether a T1A input capture or a timer underflow (or both) caused the interrupt.

*Figure 17* shows a block diagram of the timer in Input Capture mode.

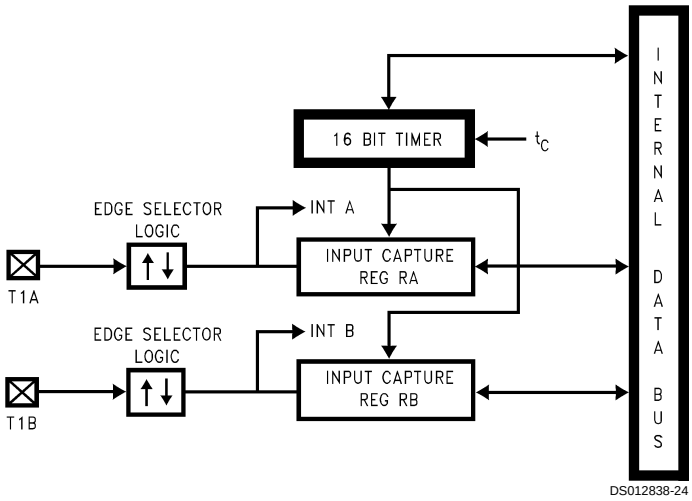



**FIGURE 17. Timer in Input Capture Mode**

# 7.0 Timers (Continued)

### 7.3 TIMER CONTROL FLAGS

The control bits and their functions are summarized below.

T1C3 Timer mode control

T1C2 Timer mode control

T1C1 Timer mode control

T1C0 Timer Start/Stop control in Modes 1 and 2 (Processor Independent PWM and External Event Counter), where 1 = Start, 0 = Stop
Timer Underflow Interrupt Pending Flag in Mode 3 (Input Capture)

T1PNDA Timer Interrupt Pending Flag

T1ENA Timer Interrupt Enable Flag
1 = Timer Interrupt Enabled
0 = Timer Interrupt Disabled

T1PNDB Timer Interrupt Pending Flag

T1ENB Timer Interrupt Enable Flag
1 = Timer Interrupt Enabled
0 = Timer Interrupt Disabled

The timer mode control bits (T1C3, T1C2 and T1C1) are detailed below:

| Mode | T1C3 | T1C2 | T1C1 | Description | Interrupt A Source | Interrupt B Source | Timer Counts On |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | PWM: T1A Toggle | Autoreload RA | Autoreload RB | $t_C$ |
| | 1 | 0 | 0 | PWM: No T1A Toggle | Autoreload RA | Autoreload RB | $t_C$ |
| 2 | 0 | 0 | 0 | External Event Counter | Timer Underflow | Pos. T1B Edge | Pos. T1A Edge |
| | 0 | 0 | 1 | External Event Counter | Timer Underflow | Pos. T1B Edge | Pos. T1A Edge |
| 3 | 0 | 1 | 0 | Captures: T1A Pos. Edge T1B Pos. Edge | Pos. T1A Edge or Timer Underflow | Pos. T1B Edge | $t_C$ |
| | 1 | 1 | 0 | Captures: T1A Pos. Edge T1B Neg. Edge | Pos. T1A Edge or Timer Underflow | Neg. T1B Edge | $t_C$ |
| | 0 | 1 | 1 | Captures: T1A Neg. Edge T1B Neg. Edge | Neg. T1A Edge or Timer Underflow | Neg. T1B Edge | $t_C$ |
| | 1 | 1 | 1 | Captures: T1A Neg. Edge T1B Neg. Edge | Neg. T1A Edge or Timer Underflow | Neg. T1B Edge | $t_C$ |

# 8.0 Power Save Modes

Today, the proliferation of battery-operated based applications has placed new demands on designers to drive power consumption down. Battery-operated systems are not the only type of applications demanding low power. The power budget constraints are also imposed on those consumer/industrial applications where well regulated and expensive power supply costs cannot be tolerated. Such applications rely on low cost and low power supply voltage derived directly from the "mains" by using voltage rectifier and passive components. Low power is demanded even in automotive applications, due to increased vehicle electronics content. This is required to ease the burden from the car battery. Low power 8-bit microcontrollers supply the smarts to control battery-operated, consumer/industrial, and automotive applications.

The COP8SAx devices offer system designers a variety of low-power consumption features that enable them to meet the demanding requirements of today's increasing range of low-power applications. These features include low voltage operation, low current drain, and power saving features such as HALT, IDLE, and Multi-Input wakeup (MIWU).

The devices offer the user two power save modes of operation: HALT and IDLE. In the HALT mode, all microcontroller activities are stopped. In the IDLE mode, the on-board oscillator circuitry and timer T0 are active but all other microcontroller activities are stopped. In either mode, all on-board RAM, registers, I/O states, and timers (with the exception of T0) are unaltered.

Clock Monitor if enabled can be active in both modes.

## 8.1 HALT MODE

The device can be placed in the HALT mode by writing a "1" to the HALT flag (G7 data bit). All microcontroller activities, including the clock and timers, are stopped. The WATCHDOG logic on the device is disabled during the HALT mode. However, the clock monitor circuitry, if enabled, remains active and will cause the WATCHDOG output pin (WDOUT) to go low. If the HALT mode is used and the user does not want to activate the WDOUT pin, the Clock Monitor should be disabled after the device comes out of reset (resetting the Clock Monitor control bit with the first write to the WDSVR register). In the HALT mode, the power requirements of the device are minimal and the applied voltage ($V_{CC}$) may be decreased to $V_r$ ($V_r$ = 2.0V) without altering the state of the machine.

The device supports three different ways of exiting the HALT mode. The first method of exiting the HALT mode is with the Multi-Input Wakeup feature on Port L. The second method is with a low to high transition on the CKO (G7) pin. This method precludes the use of the crystal clock configuration (since CKO becomes a dedicated output), and so may only be used with an R/C clock configuration. The third method of exiting the HALT mode is by pulling the $\overline{\text{RESET}}$ pin low.

Since a crystal or ceramic resonator may be selected as the oscillator, the Wakeup signal is not allowed to start the chip running immediately since crystal oscillators and ceramic resonators have a delayed start up time to reach full amplitude and frequency stability. The IDLE timer is used to generate a fixed delay to ensure that the oscillator has indeed stabilized before allowing instruction execution. In this case, upon detecting a valid Wakeup signal, only the oscillator circuitry is enabled. The IDLE timer is loaded with a value of 256 and is clocked with the $t_C$ instruction cycle clock. The $t_C$ clock is derived by dividing the oscillator clock down by a factor of 10. The Schmitt trigger following the CKI inverter on the chip ensures that the IDLE timer is clocked only when the oscillator has a sufficiently large amplitude to meet the Schmitt trigger specifications. This Schmitt trigger is not part of the oscillator closed loop. The start-up time-out from the IDLE timer enables the clock signals to be routed to the rest of the chip.

If an R/C clock option is being used, the fixed delay is introduced optionally. A control bit, CLKDLY, mapped as configuration bit G7, controls whether the delay is to be introduced or not. The delay is included if CLKDLY is set, and excluded if CLKDLY is reset. The CLKDLY bit is cleared on reset.

The device has two options associated with the HALT mode. The first option enables the HALT mode feature, while the second option disables the HALT mode selected through bit 0 of the ECON register. With the HALT mode enable option, the device will enter and exit the HALT mode as described above. With the HALT disable option, the device cannot be placed in the HALT mode (writing a "1" to the HALT flag will have no effect, the HALT flag will remain "0").

The WATCHDOG detector circuit is inhibited during the HALT mode. However, the clock monitor circuit if enabled remains active during HALT mode in order to ensure a clock monitor error if the device inadvertently enters the HALT mode as a result of a runaway program or power glitch.

If the device is placed in the HALT mode, with the R/C oscillator selected, the clock input pin (CKI) is forced to a logic high internally. With the crystal or external oscillator the CKI pin is TRI-STATE.

## 8.0 Power Save Modes (Continued)

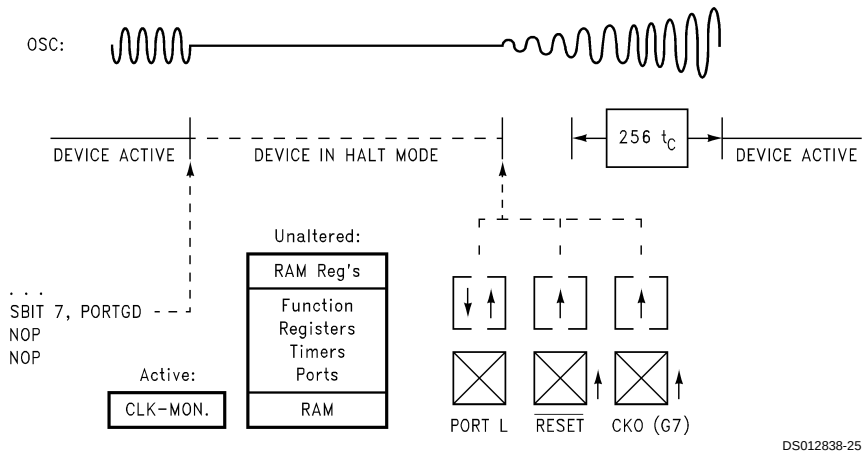



**FIGURE 18. Wakeup from HALT**

### 8.2 IDLE MODE

The device is placed in the IDLE mode by writing a "1" to the IDLE flag (G6 data bit). In this mode, all activities, except the associated on-board oscillator circuitry and the IDLE Timer T0, are stopped.

As with the HALT mode, the device can be returned to normal operation with a reset, or with a Multi-Input Wakeup from the L Port. Alternately, the microcontroller resumes normal operation from the IDLE mode when the twelfth bit (representing 4.096 ms at internal clock frequency of 10 MHz, $t_C$ = 1 µs) of the IDLE Timer toggles.

This toggle condition of the twelfth bit of the IDLE Timer T0 is latched into the T0PND pending flag.

The user has the option of being interrupted with a transition on the twelfth bit of the IDLE Timer T0. The interrupt can be enabled or disabled via the T0EN control bit. Setting the T0EN flag enables the interrupt and vice versa.

The user can enter the IDLE mode with the Timer T0 interrupt enabled. In this case, when the T0PND bit gets set, the device will first execute the Timer T0 interrupt service routine and then return to the instruction following the "Enter Idle Mode" instruction.

Alternatively, the user can enter the IDLE mode with the IDLE Timer T0 interrupt disabled. In this case, the device will resume normal operation with the instruction immediately following the "Enter IDLE Mode" instruction.

**Note:** It is necessary to program two NOP instructions following both the set HALT mode and set IDLE mode instructions. These NOP instructions are necessary to allow clock resynchronization following the HALT or IDLE modes.

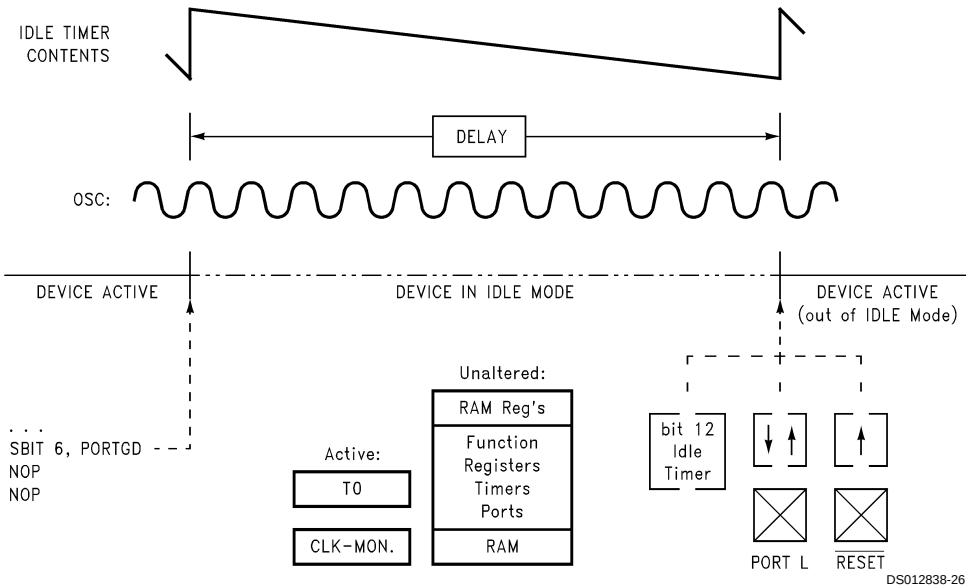



**FIGURE 19. Wakeup from IDLE**

# 8.0 Power Save Modes (Continued)

### 8.3 MULTI-INPUT WAKEUP

The Multi-Input Wakeup feature is used to return (wakeup) the device from either the HALT or IDLE modes. Alternately Multi-Input Wakeup/Interrupt feature may also be used to generate up to 8 edge selectable external interrupts.

*Figure 20* shows the Multi-Input Wakeup logic.

The Multi-Input Wakeup feature utilizes the L Port. The user selects which particular L port bit (or combination of L Port bits) will cause the device to exit the HALT or IDLE modes. The selection is done through the register WKEN. The register WKEN is an 8-bit read/write register, which contains a control bit for every L port bit. Setting a particular WKEN bit enables a Wakeup from the associated L port pin.

The user can select whether the trigger condition on the selected L Port pin is going to be either a positive edge (low to high transition) or a negative edge (high to low transition). This selection is made via the register WKEDG, which is an 8-bit control register with a bit assigned to each L Port pin. Setting the control bit will select the trigger condition to be a negative edge on that particular L Port pin. Resetting the bit selects the trigger condition to be a positive edge. Changing an edge select entails several steps in order to avoid a Wakeup condition as a result of the edge change. First, the associated WKEN bit should be reset, followed by the edge select change in WKEDG. Next, the associated WKPND bit should be cleared, followed by the associated WKEN bit being re-enabled.

An example may serve to clarify this procedure. Suppose we wish to change the edge select from positive (low going high) to negative (high going low) for L Port bit 5, where bit 5 has previously been enabled for an input interrupt. The program would be as follows:

```
RBIT  5, WKEN   ; Disable MIWU
SBIT  5, WKEDG  ; Change edge polarity
RBIT  5, WKPND  ; Reset pending flag
SBIT  5, WKEN   ; Enable MIWU
```

If the L port bits have been used as outputs and then changed to inputs with Multi-Input Wakeup/Interrupt, a safety procedure should also be followed to avoid wakeup conditions. After the selected L port bits have been changed from output to input but before the associated WKEN bits are enabled, the associated edge select bits in WKEDG should be set or reset for the desired edge selects, followed by the associated WKPND bits being cleared.

This same procedure should be used following reset, since the L port inputs are left floating as a result of reset.

The occurrence of the selected trigger condition for Multi-Input Wakeup is latched into a pending register called WKPND. The respective bits of the WKPND register will be set on the occurrence of the selected trigger edge on the corresponding Port L pin. The user has the responsibility of clearing these pending flags. Since WKPND is a pending register for the occurrence of selected wakeup conditions, the device will not enter the HALT mode if any Wakeup bit is both enabled and pending. Consequently, the user must clear the pending flags before attempting to enter the HALT mode.

WKEN and WKEDG are all read/write registers, and are cleared at reset. WKPND register contains random value after reset.

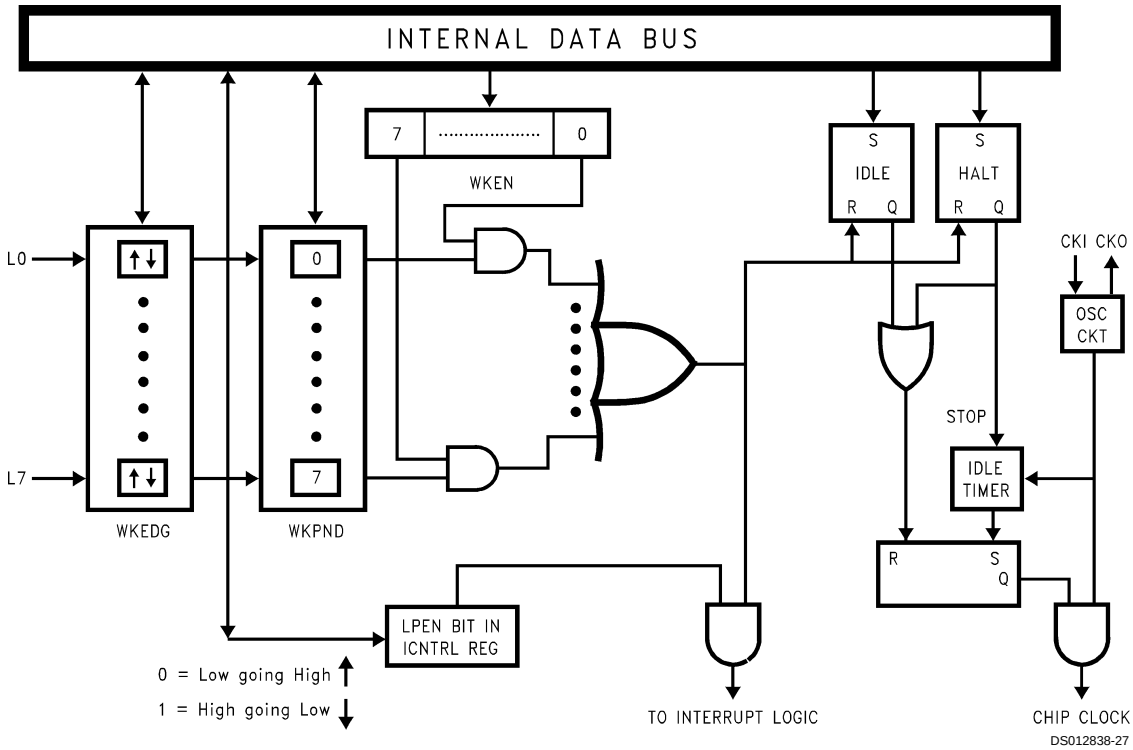



**FIGURE 20. Multi-Input Wake Up Logic**

# 9.0 Interrupts

## 9.1 INTRODUCTION

The device supports eight vectored interrupts. Interrupt sources include Timer 1, Timer T0, Port L Wakeup, Software Trap, MICROWIRE/PLUS, and External Input.

All interrupts force a branch to location 00FF Hex in program memory. The VIS instruction may be used to vector to the appropriate service routine from location 00FF Hex.

The Software trap has the highest priority while the default VIS has the lowest priority.

Each of the six maskable inputs has a fixed arbitration ranking and vector.

*Figure 21* shows the Interrupt Block Diagram.

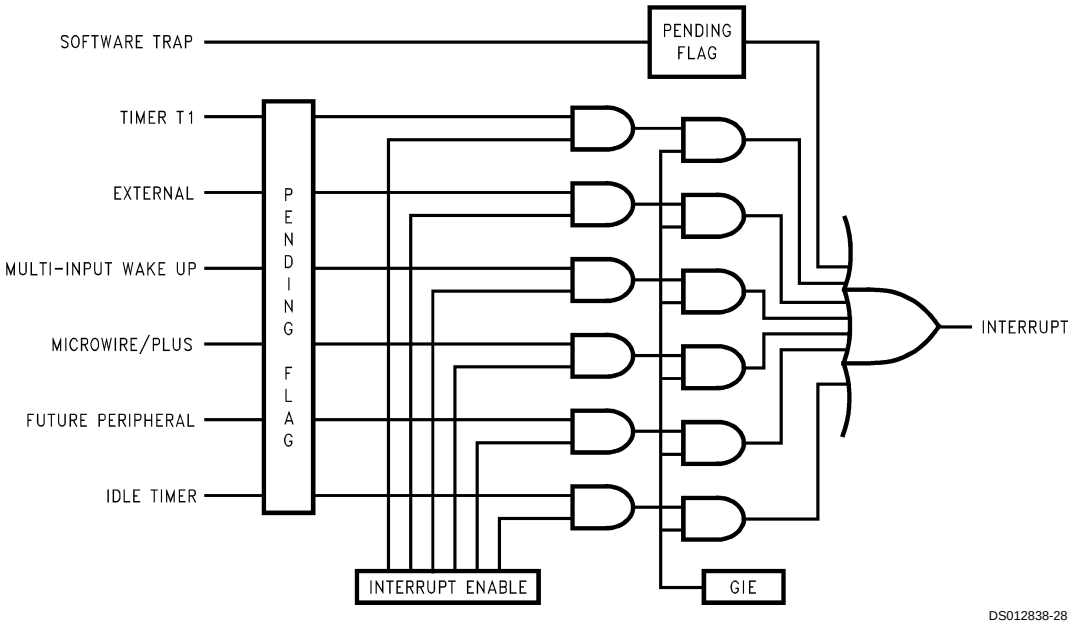



**FIGURE 21. Interrupt Block Diagram**

# 9.0 Interrupts (Continued)

## 9.2 MASKABLE INTERRUPTS

All interrupts other than the Software Trap are maskable. Each maskable interrupt has an associated enable bit and pending flag bit. The pending bit is set to 1 when the interrupt condition occurs. The state of the interrupt enable bit, combined with the GIE bit determines whether an active pending flag actually triggers an interrupt. All of the maskable interrupt pending and enable bits are contained in mapped control registers, and thus can be controlled by the software.

A maskable interrupt condition triggers an interrupt under the following conditions:

1. The enable bit associated with that interrupt is set.
2. The GIE bit is set.
3. The device is not processing a non-maskable interrupt. (If a non-maskable interrupt is being serviced, a maskable interrupt must wait until that service routine is completed.)

An interrupt is triggered only when all of these conditions are met at the beginning of an instruction. If different maskable interrupts meet these conditions simultaneously, the highest priority interrupt will be serviced first, and the other pending interrupts must wait.

Upon Reset, all pending bits, individual enable bits, and the GIE bit are reset to zero. Thus, a maskable interrupt condition cannot trigger an interrupt until the program enables it by setting both the GIE bit and the individual enable bit. When enabling an interrupt, the user should consider whether or not a previously activated (set) pending bit should be acknowledged. If, at the time an interrupt is enabled, any previous occurrences of the interrupt should be ignored, the associated pending bit must be reset to zero prior to enabling the interrupt. Otherwise, the interrupt may be simply enabled; if the pending bit is already set, it will immediately trigger an interrupt. A maskable interrupt is active if its associated enable and pending bits are set.

An interrupt is an asychronous event which may occur before, during, or after an instruction cycle. Any interrupt which occurs during the execution of an instruction is not acknowledged until the start of the next normally executed instruction is to be skipped, the skip is performed before the pending interrupt is acknowledged.

At the start of interrupt acknowledgment, the following actions occur:

1. The GIE bit is automatically reset to zero, preventing any subsequent maskable interrupt from interrupting the current service routine. This feature prevents one maskable interrupt from interrupting another one being serviced.
2. The address of the instruction about to be executed is pushed onto the stack.
3. The program counter (PC) is loaded with 00FF Hex, causing a jump to that program memory location.

The device requires seven instruction cycles to perform the actions listed above.

If the user wishes to allow nested interrupts, the interrupts service routine may set the GIE bit to 1 by writing to the PSW register, and thus allow other maskable interrupts to interrupt the current service routine. If nested interrupts are allowed, caution must be exercised. The user must write the program in such a way as to prevent stack overflow, loss of saved context information, and other unwanted conditions.

The interrupt service routine stored at location 00FF Hex should use the VIS instruction to determine the cause of the interrupt, and jump to the interrupt handling routine corresponding to the highest priority enabled and active interrupt. Alternately, the user may choose to poll all interrupt pending and enable bits to determine the source(s) of the interrupt. If more than one interrupt is active, the user's program must decide which interrupt to service.

Within a specific interrupt service routine, the associated pending bit should be cleared. This is typically done as early as possible in the service routine in order to avoid missing the next occurrence of the same type of interrupt event. Thus, if the same event occurs a second time, even while the first occurrence is still being serviced, the second occurrence will be serviced immediately upon return from the current interrupt routine.

An interrupt service routine typically ends with an RETI instruction. This instruction sets the GIE bit back to 1, pops the address stored on the stack, and restores that address to the program counter. Program execution then proceeds with the next instruction that would have been executed had there been no interrupt. If there are any valid interrupts pending, the highest-priority interrupt is serviced immediately upon return from the previous interrupt.

## 9.3 VIS INSTRUCTION

The general interrupt service routine, which starts at address 00FF Hex, must be capable of handling all types of interrupts. The VIS instruction, together with an interrupt vector table, directs the device to the specific interrupt handling routine based on the cause of the interrupt.

VIS is a single-byte instruction, typically used at the very beginning of the general interrupt service routine at address 00FF Hex, or shortly after that point, just after the code used for context switching. The VIS instruction determines which enabled and pending interrupt has the highest priority, and causes an indirect jump to the address corresponding to that interrupt source. The jump addresses (vectors) for all possible interrupts sources are stored in a vector table.

The vector table may be as long as 32 bytes (maximum of 16 vectors) and resides at the top of the 256-byte block containing the VIS instruction. However, if the VIS instruction is at the very top of a 256-byte block (such as at 00FF Hex), the vector table resides at the top of the next 256-byte block. Thus, if the VIS instruction is located somewhere between 00FF and 01DF Hex (the usual case), the vector table is located between addresses 01E0 and 01FF Hex. If the VIS instruction is located between 01FF and 02DF Hex, then the vector table is located between addresses 02E0 and 02FF Hex, and so on.

Each vector is 15 bits long and points to the beginning of a specific interrupt service routine somewhere in the 32 kbyte memory space. Each vector occupies two bytes of the vector table, with the higher-order byte at the lower address. The vectors are arranged in order of interrupt priority. The vector of the maskable interrupt with the lowest rank is located to 0yE0 (higher-order byte) and 0yE1 (lower-order byte). The next priority interrupt is located at 0yE2 and 0yE3, and so forth in increasing rank. The Software Trap has the highest rank and its vector is always located at 0yFE and 0yFF. The number of interrupts which can become active defines the size of the table.

*Table 5* shows the types of interrupts, the interrupt arbitration ranking, and the locations of the corresponding vectors in the vector table.

The vector table should be filled by the user with the memory locations of the specific interrupt service routines. For ex-

## 9.0 Interrupts (Continued)

ample, if the Software Trap routine is located at 0310 Hex, then the vector location 0yFE and -0yFF should contain the data 03 and 10 Hex, respectively. When a Software Trap interrupt occurs and the VIS instruction is executed, the program jumps to the address specified in the vector table.

The interrupt sources in the vector table are listed in order of rank, from highest to lowest priority. If two or more enabled and pending interrupts are detected at the same time, the one with the highest priority is serviced first. Upon return from the interrupt service routine, the next highest-level pending interrupt is serviced.

If the VIS instruction is executed, but no interrupts are enabled and pending, the lowest-priority interrupt vector is used, and a jump is made to the corresponding address in the vector table. This is an unusual occurrence, and may be the result of an error. It can legitimately result from a change in the enable bits or pending flags prior to the execution of the VIS instruction, such as executing a single cycle instruction which clears an enable flag at the same time that the pending flag is set. It can also result, however, from inadvertent execution of the VIS command outside of the context of an interrupt.

The default VIS interrupt vector can be useful for applications in which time critical interrupts can occur during the servicing of another interrupt. Rather than restoring the program context (A, B, X, etc.) and executing the RETI instruction, an interrupt service routine can be terminated by returning to the VIS instruction. In this case, interrupts will be serviced in turn until no further interrupts are pending and the default VIS routine is started. After testing the GIE bit to ensure that execution is not erroneous, the routine should restore the program context and execute the RETI to return to the interrupted program.

This technique can save up to fifty instruction cycles ($t_c$), or more, (50 µs at 10 MHz oscillator) of latency for pending interrupts with a penalty of fewer than ten instruction cycles if no further interrupts are pending.

To ensure reliable operation, the user should always use the VIS instruction to determine the source of an interrupt. Although it is possible to poll the pending bits to detect the source of an interrupt, this practice is not recommended. The use of polling allows the standard arbitration ranking to be altered, but the reliability of the interrupt system is compromised. The polling routine must individually test the enable and pending bits of each maskable interrupt. If a Software Trap interrupt should occur, it will be serviced last, even though it should have the highest priority. Under certain conditions, a Software Trap could be triggered but not serviced, resulting in an inadvertent "locking out" of all maskable interrupts by the Software Trap pending flag. Problems such as this can be avoided by using VIS instruction.

**TABLE 5. Interrupt Vector Table**

| **Arbitration Ranking** | **Source** | **Description** | **Vector** (Note 20) **Address (Hi-Low Byte)** |
|---|---|---|---|
| (1) Highest | Software | INTR Instruction | 0yFE–0yFF |
| (2) | Reserved | Future | 0yFC–0yFD |
| (3) | External | G0 | 0yFA–0yFB |
| (4) | Timer T0 | Underflow | 0yF8–0yF9 |
| (5) | Timer T1 | T1A/Underflow | 0yF6–0yF7 |
| (6) | Timer T1 | T1B | 0yF4–0yF5 |
| (7) | MICROWIRE/PLUS | BUSY Low | 0yF2–0yF3 |
| (8) | Reserved | Future | 0yF0–0yF1 |
| (9) | Reserved | Future | 0yEE–0yEF |
| (10) | Reserved | Future | 0yEC–0yED |
| (11) | Reserved | Future | 0yEA–0yEB |
| (12) | Reserved | Future | 0yE8–0yE9 |
| (13) | Reserved | Future | 0yE6–0yE7 |
| (14) | Reserved | Future | 0yE4–0yE5 |
| (15) | Port L/Wakeup | Port L Edge | 0yE2–0yE3 |
| (16) Lowest | Default | VIS Instruction Execution without any interrupts | 0yE0–0yE1 |

**Note 20:** y is a variable which represents the VIS block. VIS and the vector table must be located in the same 256-byte block except if VIS is located at the last address of a block. In this case, the table must be in the next block.

# 9.0 Interrupts (Continued)

### 9.3.1 VIS Execution

When the VIS instruction is executed it activates the arbitration logic. The arbitration logic generates an even number between E0 and FE (E0, E2, E4, E6 etc...) depending on which active interrupt has the highest arbitration ranking at the time of the 1st cycle of VIS is executed. For example, if the software trap interrupt is active, FE is generated. If the external interrupt is active and the software trap interrupt is not, then FA is generated and so forth. If the only active interrupt is software trap, than E0 is generated. This number replaces the lower byte of the PC. The upper byte of the PC remains unchanged. The new PC is therefore pointing to the vector of the active interrupt with the highest arbitration ranking. This vector is read from program memory and placed into the PC which is now pointed to the 1st instruction of the service routine of the active interrupt with the highest arbitration ranking.

*Figure 22* illustrates the different steps performed by the VIS instruction. *Figure 23* shows a flowchart for the VIS instruction.

The non-maskable interrupt pending flag is cleared by the RPND (Reset Non-Maskable Pending Bit) instruction (under certain conditions) and upon RESET.

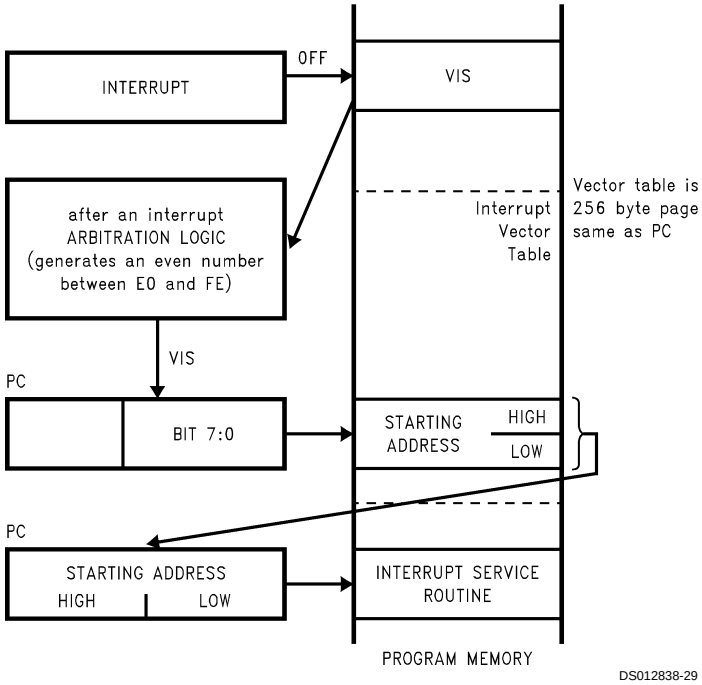



**FIGURE 22. VIS Operation**

## 9.0 Interrupts (Continued)

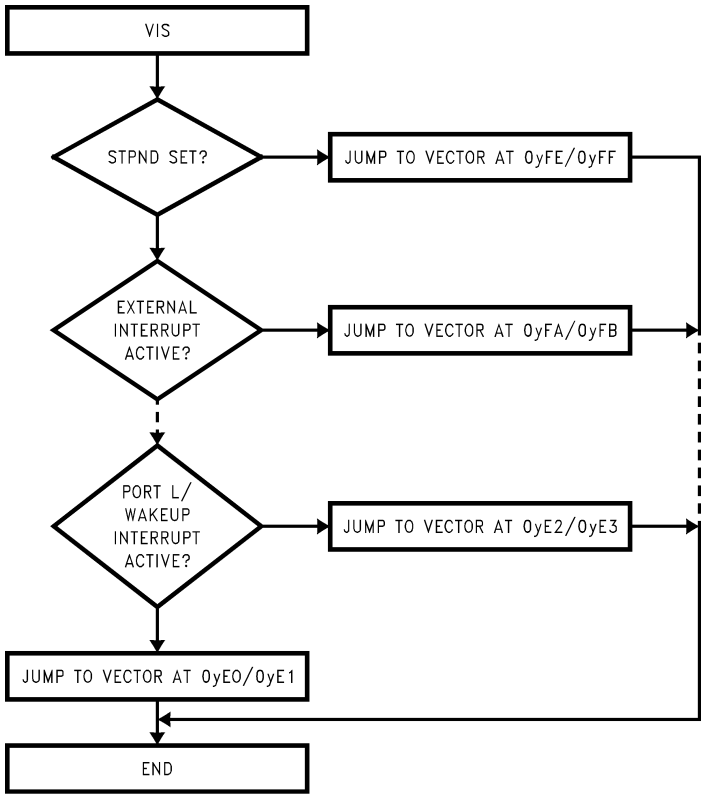



**FIGURE 23. VIS Flowchart**

## 9.0 Interrupts (Continued)

**Programming Example: External Interrupt**

```
            PSW             =00EF
            CNTRL           =00EE
            RBIT            0,PORTGC
            RBIT            0,PORTGD        ; G0 pin configured Hi-Z
            SBIT            IEDG, CNTRL     ; Ext interrupt polarity; falling edge
            SBIT            GIE, PSW        ; Set the GIE bit
            SBIT            EXEN, PSW       ; Enable the external interrupt
WAIT:       JP              WAIT            ; Wait for external interrupt
            .
            .
            .
            .=0FF                           ; The interrupt causes a
            VIS                             ; branch to address 0FF
                                            ;The VIS causes a branch to
                                            ;interrupt vector table
            .
            .
            .
            .=01FA                          ; Vector table (within 256 byte
            .ADDRW SERVICE                  ; of VIS inst.) containing the ext
                                            ;interrupt service routine
            .
            .
            .
SERVICE:                                    ; Interrupt Service Routine
            RBIT, EXPND, PSW                ; Reset ext interrupt pend. bit
            .
            .
            .
            RET                          ; Return, set the GIE bit
```

# 9.0 Interrupts (Continued)

## 9.4 NON-MASKABLE INTERRUPT

### 9.4.1 Pending Flag

There is a pending flag bit associated with the non-maskable interrupt, called STPND. This pending flag is not memory-mapped and cannot be accessed directly by the software.

The pending flag is reset to zero when a device Reset occurs. When the non-maskable interrupt occurs, the associated pending bit is set to 1. The interrupt service routine should contain an RPND instruction to reset the pending flag to zero. The RPND instruction always resets the STPND flag.

### 9.4.2 Software Trap

The Software Trap is a special kind of non-maskable interrupt which occurs when the INTR instruction (used to acknowledge interrupts) is fetched from program memory and placed in the instruction register. This can happen in a variety of ways, usually because of an error condition. Some examples of causes are listed below.

If the program counter incorrectly points to a memory location beyond the available program memory space, the non-existent or unused memory location returns zeroes which is interpreted as the INTR instruction.

If the stack is popped beyond the allowed limit (address 02F or 06F Hex), a Software Trap is triggered.

A Software Trap can be triggered by a temporary hardware condition such as a brownout or power supply glitch.

The Software Trap has the highest priority of all interrupts. When a Software Trap occurs, the STPND bit is set. The GIE bit is not affected and the pending bit (not accessible by the user) is used to inhibit other interrupts and to direct the program to the ST service routine with the VIS instruction. Nothing can interrupt a Software Trap service routine except for another Software Trap. The STPND can be reset only by the RPND instruction or a chip Reset.

The Software Trap indicates an unusual or unknown error condition. Generally, returning to normal execution at the point where the Software Trap occurred cannot be done reliably. Therefore, the Software Trap service routine should reinitialize the stack pointer and perform a recovery procedure that restarts the software at some known point, similar to a device Reset, but not necessarily performing all the same functions as a device Reset. The routine must also execute the RPND instruction to reset the STPND flag. Otherwise, all other interrupts will be locked out. To the extent possible, the interrupt routine should record or indicate the context of the device so that the cause of the Software Trap can be determined.

If the user wishes to return to normal execution from the point at which the Software Trap was triggered, the user must first execute RPND, followed by RETSK rather than RETI or RET. This is because the return address stored on the stack is the address of the INTR instruction that triggered the interrupt. The program must skip that instruction in order to proceed with the next one. Otherwise, an infinite loop of Software Traps and returns will occur.

Programming a return to normal execution requires careful consideration. If the Software Trap routine is interrupted by another Software Trap, the RPND instruction in the service routine for the second Software Trap will reset the STPND flag; upon return to the first Software Trap routine, the STPND flag will have the wrong state. This will allow maskable interrupts to be acknowledged during the servicing of the first Software Trap. To avoid problems such as this, the user program should contain the Software Trap routine to perform a recovery procedure rather than a return to normal execution.

Under normal conditions, the STPND flag is reset by a RPND instruction in the Software Trap service routine. If a programming error or hardware condition (brownout, power supply glitch, etc.) sets the STPND flag without providing a way for it to be cleared, all other interrupts will be locked out. To alleviate this condition, the user can use extra RPND instructions in the main program and in the WATCHDOG service routine (if present). There is no harm in executing extra RPND instructions in these parts of the program.

## 9.5 PORT L INTERRUPTS

Port L provides the user with an additional eight fully selectable, edge sensitive interrupts which are all vectored into the same service subroutine.

The interrupt from Port L shares logic with the wake up circuitry. The register WKEN allows interrupts from Port L to be individually enabled or disabled. The register WKEDG specifies the trigger condition to be either a positive or a negative edge. Finally, the register WKPND latches in the pending trigger conditions.

The GIE (Global Interrupt Enable) bit enables the interrupt function.

A control flag, LPEN, functions as a global interrupt enable for Port L interrupts. Setting the LPEN flag will enable interrupts and vice versa. A separate global pending flag is not needed since the register WKPND is adequate.

Since Port L is also used for waking the device out of the HALT or IDLE modes, the user can elect to exit the HALT or IDLE modes either with or without the interrupt enabled. If he elects to disable the interrupt, then the device will restart execution from the instruction immediately following the instruction that placed the microcontroller in the HALT or IDLE modes. In the other case, the device will first execute the interrupt service routine and then revert to normal operation. (See HALT MODE for clock option wakeup information.)

## 9.6 INTERRUPT SUMMARY

The device uses the following types of interrupts, listed below in order of priority:

1. The Software Trap non-maskable interrupt, triggered by the INTR (00 opcode) instruction. The Software Trap is acknowledged immediately. This interrupt service routine can be interrupted only by another Software Trap. The Software Trap should end with two RPND instructions followed by a restart procedure.
2. Maskable interrupts, triggered by an on-chip peripheral block or an external device connected to the device. Under ordinary conditions, a maskable interrupt will not interrupt any other interrupt routine in progress. A maskable interrupt routine in progress can be interrupted by the non-maskable interrupt request. A maskable interrupt routine should end with an RETI instruction.

# 10.0 WATCHDOG/Clock Monitor

The devices contain a user selectable WATCHDOG and clock monitor. The following section is applicable only if WATCHDOG feature has been selected in the ECON register. The WATCHDOG is designed to detect the user program getting stuck in infinite loops resulting in loss of program control or "runaway" programs.

The WATCHDOG logic contains two separate service windows. While the user programmable upper window selects the WATCHDOG service time, the lower window provides protection against an infinite program loop that contains the WATCHDOG service instruction.

The COP8SAx devices provide the added feature of a software trap that provides protection against stack overpops and addressing locations outside valid user program space.

The Clock Monitor is used to detect the absence of a clock or a very slow clock below a specified rate on the CKI pin.

The WATCHDOG consists of two independent logic blocks: WD UPPER and WD LOWER. WD UPPER establishes the upper limit on the service window and WD LOWER defines the lower limit of the service window.

Servicing the WATCHDOG consists of writing a specific value to a WATCHDOG Service Register named WDSVR which is memory mapped in the RAM. This value is composed of three fields, consisting of a 2-bit Window Select, a 5-bit Key Data field, and the 1-bit Clock Monitor Select field. *Table 6* shows the WDSVR register.

**TABLE 6. WATCHDOG Service Register (WDSVR)**

| Window Select | | Key Data | | | | | Clock Monitor |
|---|---|---|---|---|---|---|---|
| X | X | 0 | 1 | 1 | 0 | 0 | Y |

The lower limit of the service window is fixed at 256 instruction cycles. Bits 7 and 6 of the WDSVR register allow the user to pick an upper limit of the service window.

*Table 7* shows the four possible combinations of lower and upper limits for the WATCHDOG service window. This flexibility in choosing the WATCHDOG service window prevents any undue burden on the user software.

Bits 5, 4, 3, 2 and 1 of the WDSVR register represent the 5-bit Key Data field. The key data is fixed at 01100. Bit 0 of the WDSVR Register is the Clock Monitor Select bit.

**TABLE 7. WATCHDOG Service Window Select**

| WDSVR Bit 7 | WDSVR Bit 6 | Clock Monitor | Service Window (Lower-Upper Limits) |
|---|---|---|---|
| 0 | 0 | x | 2048–8k $t_C$ Cycles |
| 0 | 1 | x | 2048–16k $t_C$ Cycles |
| 1 | 0 | x | 2048–32k $t_C$ Cycles |
| 1 | 1 | x | 2048–64k $t_C$ Cycles |
| x | x | 0 | Clock Monitor Disabled |
| x | x | 1 | Clock Monitor Enabled |

### 10.1 CLOCK MONITOR

The Clock Monitor aboard the device can be selected or deselected under program control. The Clock Monitor is guaranteed not to reject the clock if the instruction cycle clock ($1/t_C$) is greater or equal to 10 kHz. This equates to a clock input rate on CKI of greater or equal to 100 kHz.

### 10.2 WATCHDOG/CLOCK MONITOR OPERATION

The WATCHDOG is enabled by bit 2 of the ECON register. When this ECON bit is 0, the WATCHDOG is enabled and pin G1 becomes the WATCHDOG output with a weak pullup.

The WATCHDOG and Clock Monitor are disabled during reset. The device comes out of reset with the WATCHDOG armed, the WATCHDOG Window Select bits (bits 6, 7 of the WDSVR Register) set, and the Clock Monitor bit (bit 0 of the WDSVR Register) enabled. Thus, a Clock Monitor error will occur after coming out of reset, if the instruction cycle clock frequency has not reached a minimum specified value, including the case where the oscillator fails to start.

The WDSVR register can be written to only once after reset and the key data (bits 5 through 1 of the WDSVR Register) must match to be a valid write. This write to the WDSVR register involves two irrevocable choices: (i) the selection of the WATCHDOG service window (ii) enabling or disabling of the Clock Monitor. Hence, the first write to WDSVR Register involves selecting or deselecting the Clock Monitor, select the WATCHDOG service window and match the WATCHDOG key data. Subsequent writes to the WDSVR register will compare the value being written by the user to the WATCHDOG service window value and the key data (bits 7 through 1) in the WDSVR Register. *Table 8* shows the sequence of events that can occur.

The user must service the WATCHDOG at least once before the upper limit of the service window expires. The WATCHDOG may not be serviced more than once in every lower limit of the service window. The user may service the WATCHDOG as many times as wished in the time period between the lower and upper limits of the service window. The first write to the WDSVR Register is also counted as a WATCHDOG service.

The WATCHDOG has an output pin associated with it. This is the WDOUT pin, on pin 1 of the port G. WDOUT is active low and must be externally connected to the RESET pin or to some other external logic which handles WATCHDOG event. The WDOUT pin has a weak pullup in the inactive state. This pull-up is sufficient to serve as the connection to $V_{CC}$ for systems which use the internal Power On Reset. Upon triggering the WATCHDOG, the logic will pull the WDOUT (G1) pin low for an additional 16 $t_C$–32 $t_C$ cycles after the signal level on WDOUT pin goes below the lower Schmitt trigger threshold. After this delay, the device will stop forcing the WDOUT output low. The WATCHDOG service window will restart when the WDOUT pin goes high.

A WATCHDOG service while the WDOUT signal is active will be ignored. The state of the WDOUT pin is not guaranteed on reset, but if it powers up low then the WATCHDOG will time out and WDOUT will go high.

The Clock Monitor forces the G1 pin low upon detecting a clock frequency error. The Clock Monitor error will continue until the clock frequency has reached the minimum specified value, after which the G1 output will go high following 16 $t_C$–32 $t_C$ clock cycles. The Clock Monitor generates a continual Clock Monitor error if the oscillator fails to start, or fails to reach the minimum specified frequency. The specification for the Clock Monitor is as follows:

$1/t_C > 10$ kHz — No clock rejection.

$1/t_C < 10$ Hz — Guaranteed clock rejection.

# 10.0 WATCHDOG/Clock Monitor (Continued)

**TABLE 8. WATCHDOG Service Actions**

| Key Data | Window Data | Clock Monitor | Action |
|---|---|---|---|
| Match | Match | Match | Valid Service: Restart Service Window |
| Don't Care | Mismatch | Don't Care | Error: Generate WATCHDOG Output |
| Mismatch | Don't Care | Don't Care | Error: Generate WATCHDOG Output |
| Don't Care | Don't Care | Mismatch | Error: Generate WATCHDOG Output |

### 10.3 WATCHDOG AND CLOCK MONITOR SUMMARY

The following salient points regarding the WATCHDOG and CLOCK MONITOR should be noted:

- Both the WATCHDOG and CLOCK MONITOR detector circuits are inhibited during RESET.
- Following RESET, the WATCHDOG and CLOCK MONITOR are both enabled, with the WATCHDOG having the maximum service window selected.
- The WATCHDOG service window and CLOCK MONITOR enable/disable option can only be changed once, during the initial WATCHDOG service following RESET.
- The initial WATCHDOG service must match the key data value in the WATCHDOG Service register WDSVR in order to avoid a WATCHDOG error.
- Subsequent WATCHDOG services must match all three data fields in WDSVR in order to avoid WATCHDOG errors.
- The correct key data value cannot be read from the WATCHDOG Service register WDSVR. Any attempt to read this key data value of 01100 from WDSVR will read as key data value of all 0's.
- The WATCHDOG detector circuit is inhibited during both the HALT and IDLE modes.
- The CLOCK MONITOR detector circuit is active during both the HALT and IDLE modes. Consequently, the device inadvertently entering the HALT mode will be detected as a CLOCK MONITOR error (provided that the CLOCK MONITOR enable option has been selected by the program).
- With the single-pin R/C oscillator option selected and the CLKDLY bit reset, the WATCHDOG service window will resume following HALT mode from where it left off before entering the HALT mode.
- With the crystal oscillator option selected, or with the single-pin R/C oscillator option selected and the CLKDLY bit set, the WATCHDOG service window will be set to its selected value from WDSVR following HALT. Consequently, the WATCHDOG should not be serviced for at least 256 instruction cycles following HALT, but must be serviced within the selected window to avoid a WATCHDOG error.
- The IDLE timer T0 is not initialized with external RESET.
- The user can sync in to the IDLE counter cycle with an IDLE counter (T0) interrupt or by monitoring the T0PND flag. The T0PND flag is set whenever the twelfth bit of the IDLE counter toggles (every 4096 instruction cycles). The user is responsible for resetting the T0PND flag.
- A hardware WATCHDOG service occurs just as the device exits the IDLE mode. Consequently, the WATCHDOG should not be serviced for at least 256 instruction cycles following IDLE, but must be serviced within the selected window to avoid a WATCHDOG error.
- Following RESET, the initial WATCHDOG service (where the service window and the CLOCK MONITOR enable/disable must be selected) may be programmed anywhere within the maximum service window (65,536 instruction cycles) initialized by RESET. Note that this initial WATCHDOG service may be programmed within the initial 256 instruction cycles without causing a WATCHDOG error.
- In order to RESET the device on the occurrence of a WATCH event, the user must connect the WDOUT pin (G1) pin to the RESET external to the device. The weak pull-up on the WDOUT pin is sufficient to provide the RESET connection to $V_{CC}$ for devices which use both Power On Reset and WATCHDOG.

### 10.4 DETECTION OF ILLEGAL CONDITIONS

The device can detect various illegal conditions resulting from coding errors, transient noise, power supply voltage drops, runaway programs, etc.

Reading of undefined ROM gets zeroes. The opcode for software interrupt is 00. If the program fetches instructions from undefined ROM, this will force a software interrupt, thus signaling that an illegal condition has occurred.

The subroutine stack grows down for each call (jump to subroutine), interrupt, or PUSH, and grows up for each return or POP. The stack pointer is initialized to RAM location 06F Hex during reset. Consequently, if there are more returns than calls, the stack pointer will point to addresses 070 and 071 Hex (which are undefined RAM). Undefined RAM from addresses 070 to 07F (Segment 0), and all other segments (i.e., Segments 4 … etc.) is read as all 1's, which in turn will cause the program to return to address 7FFF Hex. This is an undefined ROM location and the instruction fetched (all 0's) from this location will generate a software interrupt signaling an illegal condition.

Thus, the chip can detect the following illegal conditions:

1. Executing from undefined ROM
2. Over "POP"ing the stack by having more returns than calls.

When the software interrupt occurs, the user can re-initialize the stack pointer and do a recovery procedure before restarting (this recovery program is probably similar to that following reset, but might not contain the same program initialization procedures). The recovery program should reset the software interrupt pending bit using the RPND instruction.

# 11.0 MICROWIRE/PLUS

MICROWIRE/PLUS is a serial SPI compatible synchronous communications interface. The MICROWIRE/PLUS capability enables the device to interface with MICROWIRE/PLUS or SPI peripherals (i.e. A/D converters, display drivers, EEPROMs etc.) and with other microcontrollers which support the MICROWIRE/PLUS or SPI interface. It consists of an 8-bit serial shift register (SIO) with serial data input (SI), serial data output (SO) and serial shift clock (SK). *Figure 24* shows a block diagram of the MICROWIRE/PLUS logic.

The shift clock can be selected from either an internal source or an external source. Operating the MICROWIRE/PLUS arrangement with the internal clock source is called the Master mode of operation. Similarly, operating the MICROWIRE/PLUS arrangement with an external shift clock is called the Slave mode of operation.

The CNTRL register is used to configure and control the MICROWIRE/PLUS mode. To use the MICROWIRE/PLUS, the MSEL bit in the CNTRL register is set to one. In the master mode, the SK clock rate is selected by the two bits, SL0 and SL1, in the CNTRL register. *Table 9* details the different clock rates that may be selected.

**TABLE 9. MICROWIRE/PLUS Master Mode Clock Select**

| SL1 | SL0 | SK Period |
|---|---|---|
| 0 | 0 | 2 x $t_C$ |
| 0 | 1 | 4 x $t_C$ |
| 1 | x | 8 x $t_C$ |

Where $t_C$ is the instruction cycle clock

## 11.1 MICROWIRE/PLUS OPERATION

Setting the BUSY bit in the PSW register causes the MICROWIRE/PLUS to start shifting the data. It gets reset when eight data bits have been shifted. The user may reset the BUSY bit by software to allow less than 8 bits to shift. If enabled, an interrupt is generated when eight data bits have been shifted. The device may enter the MICROWIRE/PLUS mode either as a Master or as a Slave. *Figure 24* shows how two microcontroller devices and several peripherals may be interconnected using the MICROWIRE/PLUS arrangements.

**WARNING**

The SIO register should only be loaded when the SK clock is in the idle phase. Loading the SIO register while the SK clock is in the active phase, will result in undefined data in the SIO register.

Setting the BUSY flag when the input SK clock is in the active phase while in the MICROWIRE/PLUS is in the slave mode may cause the current SK clock for the SIO shift register to be narrow. For safety, the BUSY flag should only be set when the input SK clock is in the idle phase.

### 11.1.1 MICROWIRE/PLUS Master Mode Operation

In the MICROWIRE/PLUS Master mode of operation the shift clock (SK) is generated internally. The MICROWIRE Master always initiates all data exchanges. The MSEL bit in the CNTRL register must be set to enable the SO and SK functions onto the G Port. The SO and SK pins must also be selected as outputs by setting appropriate bits in the Port G configuration register. In the slave mode, the shift clock stops after 8 clock pulses. *Table 10* summarizes the bit settings required for Master mode of operation.

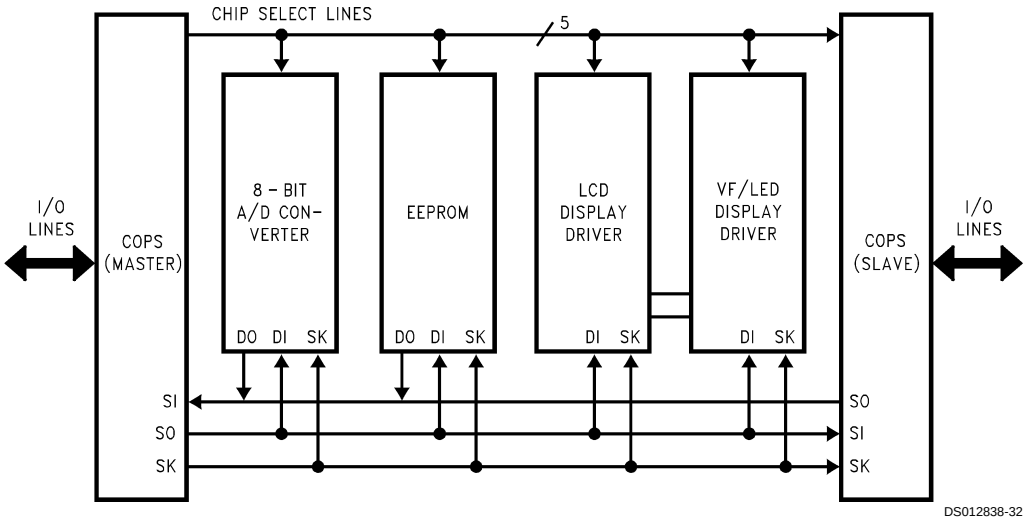



**FIGURE 24. MICROWIRE/PLUS Application**

# 11.0 MICROWIRE/PLUS (Continued)

### 11.1.2 MICROWIRE/PLUS Slave Mode Operation

In the MICROWIRE/PLUS Slave mode of operation the SK clock is generated by an external source. Setting the MSEL bit in the CNTRL register enables the SO and SK functions onto the G Port. The SK pin must be selected as an input and the SO pin is selected as an output pin by setting and resetting the appropriate bits in the Port G configuration register. *Table 10* summarizes the settings required to enter the Slave mode of operation.

This table assumes that the control flag MSEL is set.

**TABLE 10. MICROWIRE/PLUS Mode Settings**

| G4 (SO) Config. Bit | G5 (SK) Config. Bit | G4 Fun. | G5 Fun. | Operation |
|---|---|---|---|---|
| 1 | 1 | SO | Int. SK | MICROWIRE/PLUS Master |
| 0 | 1 | TRI-STATE | Int. SK | MICROWIRE/PLUS Master |
| 1 | 0 | SO | Ext. SK | MICROWIRE/PLUS Slave |
| 0 | 0 | TRI-STATE | Ext. SK | MICROWIRE/PLUS Slave |

The user must set the BUSY flag immediately upon entering the Slave mode. This ensures that all data bits sent by the Master is shifted properly. After eight clock pulses the BUSY flag is clear, the shift clock is stopped, and the sequence may be repeated.

### 10.1.3 Alternate SK Phase Operation and SK Idle Polarity

The device allows either the normal SK clock or an alternate phase SK clock to shift data in and out of the SIO register. In both the modes the SK idle polarity can be either high or low. The polarity is selected by bit 5 of Port G data register. In the normal mode data is shifted in on the rising edge of the SK clock and the data is shifted out on the falling edge of the SK clock. The SIO register is shifted on each falling edge of the SK clock. In the alternate SK phase operation, data is shifted in on the falling edge of the SK clock and shifted out on the rising edge of the SK clock. Bit 6 of Port G configuration register selects the SK edge.

A control flag, SKSEL, allows either the normal SK clock or the alternate SK clock to be selected. Resetting SKSEL causes the MICROWIRE/PLUS logic to be clocked from the normal SK signal. Setting the SKSEL flag selects the alternate SK clock. The SKSEL is mapped into the G6 configuration bit. The SKSEL flag will power up in the reset condition, selecting the normal SK signal.

**TABLE 11. MICROWIRE/PLUS Shift Clock Polarity and Sample/Shift Phase**

| SK Phase | Port G | | SO Clocked Out On: | SI Sampled On: | SK Idle Phase |
|---|---|---|---|---|---|
| | G6 (SKSEL) Config. Bit | G5 Data Bit | | | |
| Normal | 0 | 0 | SK Falling Edge | SK Rising Edge | Low |
| Alternate | 1 | 0 | SK Rising Edge | SK Falling Edge | Low |
| Alternate | 0 | 1 | SK Rising Edge | SK Falling Edge | High |
| Normal | 1 | 1 | SK Falling Edge | SK Rising Edge | High |

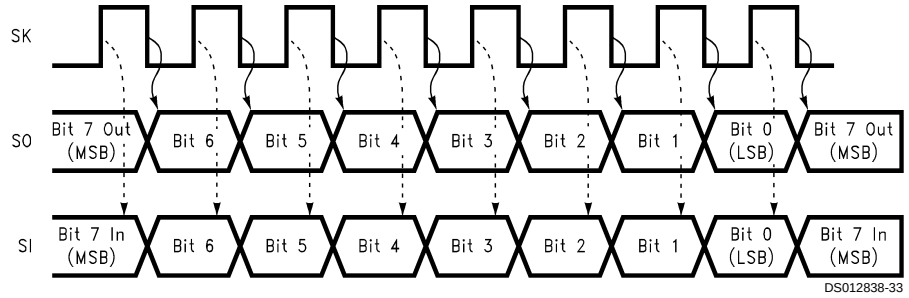



**FIGURE 25. MICROWIRE/PLUS SPI Mode Interface Timing, Normal SK Mode, SK Idle Phase being Low**

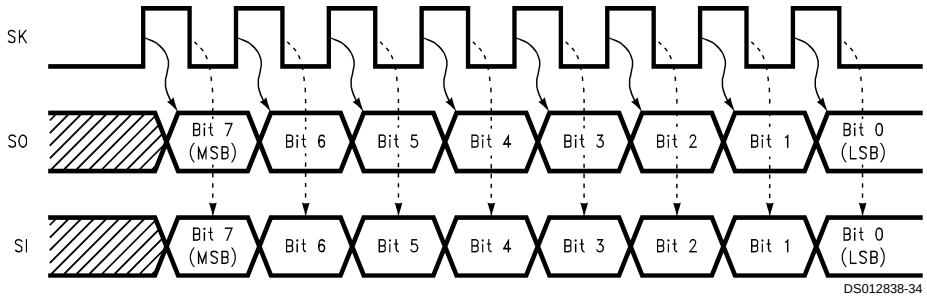



**FIGURE 26. MICROWIRE/PLUS SPI Mode Interface Timing, Alternate SK Mode, SK Idle Phase being Low**

## 11.0 MICROWIRE/PLUS (Continued)

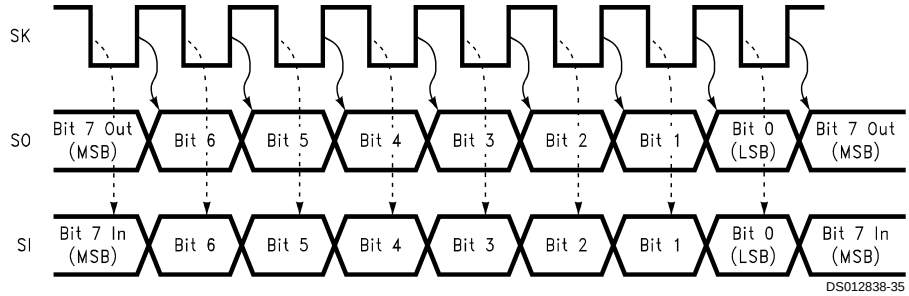



**FIGURE 27. MICROWIRE/PLUS SPI Mode Interface Timing, Alternate SK Mode, SK Idle Phase being High**

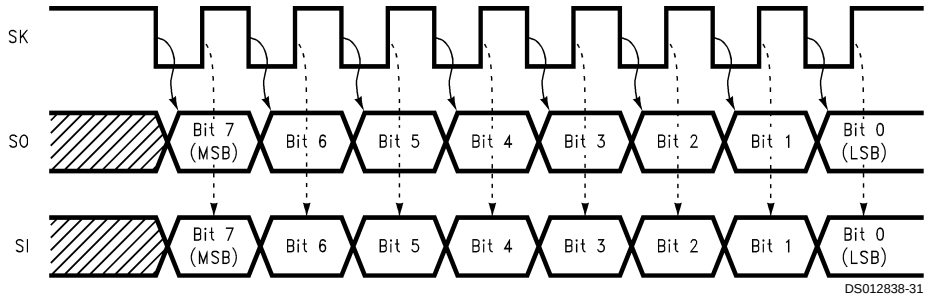



**FIGURE 28. MICROWIRE/PLUS SPI Mode Interface Timing, Normal SK Mode, SK Idle Phase being High**

## 12.0 Memory Map

All RAM, ports and registers (except A and PC) are mapped into data memory address space.

| RAM Select | Address ADD REG | Contents |
|---|---|---|
| 64 On-Chip RAM Bytes. | 02 to 2F | On-Chip RAM (48 Bytes) |
| (COP8SAAx) | 30 to 7F | Unused RAM (Reads as all ones) |
| 128 On-Chip RAM Bytes | 00 to 6F | On-Chip RAM (112 Bytes) |
| (COP8SABx/SACx) | 70 to 7F | Unused RAM (Reads as all ones) |
| | 80 to 93 | Reserved |
| | 94 | Port F Data Register |
| | 95 | Port F Configuration Register |
| | 96 | Port F Input Pins (Read Only) |
| | 97 | Reserved |
| | A0 to C6 | Reserved |
| | C7 | WATCHDOG Service Register (Reg: WDSVR) |
| | C8 | MIWU Edge Select Register (Reg: WKEDG) |
| | C9 | MIWU Enable Register (Reg: WKEN) |
| | CA | MIWU Pending Register (Reg: WKPND) |
| | CB to CF | Reserved |
| | D0 | Port L Data Register |
| | D1 | Port L Configuration Register |
| | D2 | Port L Input Pins (Read Only) |
| | D3 | Reserved |
| | D4 | Port G Data Register |
| | D5 | Port G Configuration Register |
| | D6 | Port G Input Pins (Read Only) |
| | D7 | Reserved |
| | D8 | Port C Data Register |
| | D9 | Port C Configuration Register |
| | DA | Port C Input Pins (Read Only) |
| | DB | Reserved |
| | DC | Port D |
| | DD to DF | Reserved |
| | E0 to E5 | Reserved |
| | E6 | Timer T1 Autoload Register T1RB Lower Byte |
| | E7 | Timer T1 Autoload Register T1RB Upper Byte |
| | E8 | ICNTRL Register |
| | E9 | MICROWIRE/PLUS Shift Register |
| | EA | Timer T1 Lower Byte |
| | EB | Timer T1 Upper Byte |
| | EC | Timer T1 Autoload Register T1RA Lower Byte |
| | ED | Timer T1 Autoload Register T1RA Upper Byte |
| | EE | CNTRL Control Register |
| | EF | PSW Register |
| | F0 to FB | On-Chip RAM Mapped as Registers |
| | FC | X Register |
| | FD | SP Register |
| | FE | B Register |
| | FF | Reserved (Segment Register) |

Reading any undefined memory location in the address range of 0080H–00FFH will return undefined data.

# 13.0 Instruction Set

## 13.1 INTRODUCTION

This section defines the instruction set of the COP8SAx Family members. It contains information about the instruction set features, addressing modes and types.

## 13.2 INSTRUCTION FEATURES

The strength of the instruction set is based on the following features:

- Mostly single-byte opcode instructions minimize program size.
- One instruction cycle for the majority of single-byte instructions to minimize program execution time.
- Many single-byte, multiple function instructions such as DRSZ.
- Three memory mapped pointers: two for register indirect addressing, and one for the software stack.
- Sixteen memory mapped registers that allow an optimized implementation of certain instructions.
- Ability to set, reset, and test any individual bit in data memory address space, including the memory-mapped I/O ports and registers.
- Register-Indirect LOAD and EXCHANGE instructions with optional automatic post-incrementing or decrementing of the register pointer. This allows for greater efficiency (both in cycle time and program code) in loading, walking across and processing fields in data memory.
- Unique instructions to optimize program size and throughput efficiency. Some of these instructions are DRSZ, IFBNE, DCOR, RETSK, VIS and RRC.

## 12.3 ADDRESSING MODES

The instruction set offers a variety of methods for specifying memory addresses. Each method is called an addressing mode. These modes are classified into two categories: operand addressing modes and transfer-of-control addressing modes. Operand addressing modes are the various methods of specifying an address for accessing (reading or writing) data. Transfer-of-control addressing modes are used in conjunction with jump instructions to control the execution sequence of the software program.

### 13.3.1 Operand Addressing Modes

The operand of an instruction specifies what memory location is to be affected by that instruction. Several different operand addressing modes are available, allowing memory locations to be specified in a variety of ways. An instruction can specify an address directly by supplying the specific address, or indirectly by specifying a register pointer. The contents of the register (or in some cases, two registers) point to the desired memory location. In the immediate mode, the data byte to be used is contained in the instruction itself.

Each addressing mode has its own advantages and disadvantages with respect to flexibility, execution speed, and program compactness. Not all modes are available with all instructions. The Load (LD) instruction offers the largest number of addressing modes.

The available addressing modes are:

- Direct
- Register B or X Indirect
- Register B or X Indirect with Post-Incrementing/ Decrementing
- Immediate
- Immediate Short
- Indirect from Program Memory

The addressing modes are described below. Each description includes an example of an assembly language instruction using the described addressing mode.

**Direct.** The memory address is specified directly as a byte in the instruction. In assembly language, the direct address is written as a numerical value (or a label that has been defined elsewhere in the program as a numerical value).

Example: Load Accumulator Memory Direct

LD A,05

| Reg/Data Memory | Contents Before | Contents After |
|---|---|---|
| Accumulator | XX Hex | A6 Hex |
| Memory Location 0005 Hex | A6 Hex | A6 Hex |

**Register B or X Indirect.** The memory address is specified by the contents of the B Register or X register (pointer register). In assembly language, the notation [B] or [X] specifies which register serves as the pointer.

Example: Exchange Memory with Accumulator, B Indirect

X A,[B]

| Reg/Data Memory | Contents Before | Contents After |
|---|---|---|
| Accumulator | 01 Hex | 87 Hex |
| Memory Location 0005 Hex | 87 Hex | 01 Hex |
| B Pointer | 05 Hex | 05 Hex |

**Register B or X Indirect with Post-Incrementing/ Decrementing.** The relevant memory address is specified by the contents of the B Register or X register (pointer register). The pointer register is automatically incremented or decremented after execution, allowing easy manipulation of memory blocks with software loops. In assembly language, the notation [B+], [B−], [X+], or [X−] specifies which register serves as the pointer, and whether the pointer is to be incremented or decremented.

Example: Exchange Memory with Accumulator, B Indirect with Post-Increment

X A,[B+]

| Reg/Data Memory | Contents Before | Contents After |
|---|---|---|
| Accumulator | 03 Hex | 62 Hex |
| Memory Location 0005 Hex | 62 Hex | 03 Hex |
| B Pointer | 05 Hex | 06 Hex |

**Intermediate.** The data for the operation follows the instruction opcode in program memory. In assembly language, the number sign character (#) indicates an immediate operand.

# 13.0 Instruction Set (Continued)

Example: Load Accumulator Immediate
LD A,#05

| Reg/Data Memory | Contents Before | Contents After |
|---|---|---|
| Accumulator | XX Hex | 05 Hex |

**Immediate Short.** This is a special case of an immediate instruction. In the “Load B immediate” instruction, the 4-bit immediate value in the instruction is loaded into the lower nibble of the B register. The upper nibble of the B register is reset to 0000 binary.

Example: Load B Register Immediate Short
LD B,#7

| Reg/Data Memory | Contents Before | Contents After |
|---|---|---|
| B Pointer | 12 Hex | 07 Hex |

**Indirect from Program Memory.** This is a special case of an indirect instruction that allows access to data tables stored in program memory. In the “Load Accumulator Indirect” (LAID) instruction, the upper and lower bytes of the Program Counter (PCU and PCL) are used temporarily as a pointer to program memory. For purposes of accessing program memory, the contents of the Accumulator and PCL are exchanged. The data pointed to by the Program Counter is loaded into the Accumulator, and simultaneously, the original contents of PCL are restored so that the program can resume normal execution.

Example: Load Accumulator Indirect
LAID

| Reg/Data Memory | Contents Before | Contents After |
|---|---|---|
| PCU | 04 Hex | 04 Hex |
| PCL | 35 Hex | 36 Hex |
| Accumulator | 1F Hex | 25 Hex |
| Memory Location 041F Hex | 25 Hex | 25 Hex |

### 13.3.2 Tranfer-of-Control Addressing Modes

Program instructions are usually executed in sequential order. However, Jump instructions can be used to change the normal execution sequence. Several transfer-of-control addressing modes are available to specify jump addresses.

A change in program flow requires a non-incremental change in the Program Counter contents. The Program Counter consists of two bytes, designated the upper byte (PCU) and lower byte (PCL). The most significant bit of PCU is not used, leaving 15 bits to address the program memory.

Different addressing modes are used to specify the new address for the Program Counter. The choice of addressing mode depends primarily on the distance of the jump. Farther jumps sometimes require more instruction bytes in order to completely specify the new Program Counter contents.

The available transfer-of-control addressing modes are:

- Jump Relative
- Jump Absolute
- Jump Absolute Long
- Jump Indirect

The transfer-of-control addressing modes are described below. Each description includes an example of a Jump instruction using a particular addressing mode, and the effect on the Program Counter bytes of executing that instruction.

**Jump Relative.** In this 1-byte instruction, six bits of the instruction opcode specify the distance of the jump from the current program memory location. The distance of the jump can range from −31 to +32. A JP+1 instruction is not allowed. The programmer should use a NOP instead.

Example: Jump Relative
JP 0A

| Reg | Contents Before | Contents After |
|---|---|---|
| PCU | 02 Hex | 02 Hex |
| PCL | 05 Hex | 0F Hex |

**Jump Absolute.** In this 2-byte instruction, 12 bits of the instruction opcode specify the new contents of the Program Counter. The upper three bits of the Program Counter remain unchanged, restricting the new Program Counter address to the same 4 kbyte address space as the current instruction.

(This restriction is relevant only in devices using more than one 4 kbyte program memory space.)

Example: Jump Absolute
JMP 0125

| Reg | Contents Before | Contents After |
|---|---|---|
| PCU | 0C Hex | 01 Hex |
| PCL | 77 Hex | 25 Hex |

**Jump Absolute Long.** In this 3-byte instruction, 15 bits of the instruction opcode specify the new contents of the Program Counter.

Example: Jump Absolute Long
JMP 03625

| Reg/ Memory | Contents Before | Contents After |
|---|---|---|
| PCU | 42 Hex | 36 Hex |
| PCL | 36 Hex | 25 Hex |

## 13.0 Instruction Set (Continued)

**Jump Indirect.** In this 1-byte instruction, the lower byte of the jump address is obtained from a table stored in program memory, with the Accumulator serving as the low order byte of a pointer into program memory. For purposes of accessing program memory, the contents of the Accumulator are written to PCL (temporarily). The data pointed to by the Program Counter (PCH/PCL) is loaded into PCL, while PCH remains unchanged.

Example: Jump Indirect

JID

| Reg/ Memory | Contents Before | Contents After |
|---|---|---|
| PCU | 01 Hex | 01 Hex |
| PCL | C4 Hex | 32 Hex |
| Accumulator | 26 Hex | 26 Hex |
| Memory Location 0126 Hex | 32 Hex | 32 Hex |

The VIS instruction is a special case of the Indirect Transfer of Control addressing mode, where the double-byte vector associated with the interrupt is transferred from adjacent addresses in program memory into the Program Counter in order to jump to the associated interrupt service routine.

### 13.4 INSTRUCTION TYPES

The instruction set contains a wide variety of instructions. The available instructions are listed below, organized into related groups.

Some instructions test a condition and skip the next instruction if the condition is not true. Skipped instructions are executed as no-operation (NOP) instructions.

#### 13.4.1 Arithmetic Instructions

The arithmetic instructions perform binary arithmetic such as addition and subtraction, with or without the Carry bit.

- Add (ADD)
- Add with Carry (ADC)
- Subtract (SUB)
- Subtract with Carry (SUBC)
- Increment (INC)
- Decrement (DEC)
- Decimal Correct (DCOR)
- Clear Accumulator (CLR)
- Set Carry (SC)
- Reset Carry (RC)

#### 13.4.2 Transfer-of-Control Instructions

The transfer-of-control instructions change the usual sequential program flow by altering the contents of the Program Counter. The Jump to Subroutine instructions save the Program Counter contents on the stack before jumping; the Return instructions pop the top of the stack back into the Program Counter.

- Jump Relative (JP)
- Jump Absolute (JMP)
- Jump Absolute Long (JMPL)
- Jump Indirect (JID)
- Jump to Subroutine (JSR)
- Jump to Subroutine Long (JSRL)
- Return from Subroutine (RET)
- Return from Subroutine and Skip (RETSK)
- Return from Interrupt (RETI)
- Software Trap Interrupt (INTR)
- Vector Interrupt Select (VIS)

#### 13.4.3 Load and Exchange Instructions

The load and exchange instructions write byte values in registers or memory. The addressing mode determines the source of the data.

- Load (LD)
- Load Accumulator Indirect (LAID)
- Exchange (X)

#### 13.4.4 Logical Instructions

The logical instructions perform the operations AND, OR, and XOR (Exclusive OR). Other logical operations can be performed by combining these basic operations. For example, complementing is accomplished by exclusiveORing the Accumulator with FF Hex.

- Logical AND (AND)
- Logical OR (OR)
- Exclusive OR (XOR)

#### 13.4.5 Accumulator Bit Manipulation Instructions

The Accumulator bit manipulation instructions allow the user to shift the Accumulator bits and to swap its two nibbles.

- Rotate Right Through Carry (RRC)
- Rotate Left Through Carry (RLC)
- Swap Nibbles of Accumulator (SWAP)

#### 13.4.6 Stack Control Instructions

- Push Data onto Stack (PUSH)
- Pop Data off of Stack (POP)

#### 13.4.7 Memory Bit Manipulation Instructions

The memory bit manipulation instructions allow the user to set and reset individual bits in memory.

- Set Bit (SBIT)
- Reset Bit (RBIT)
- Reset Pending Bit (RPND)

#### 13.4.8 Conditional Instructions

The conditional instruction test a condition. If the condition is true, the next instruction is executed in the normal manner; if the condition is false, the next instruction is skipped.

- If Equal (IFEQ)
- If Not Equal (IFNE)
- If Greater Than (IFGT)
- If Carry (IFC)
- If Not Carry (IFNC)
- If Bit (IFBIT)
- If B Pointer Not Equal (IFBNE)
- And Skip if Zero (ANDSZ)
- Decrement Register and Skip if Zero (DRSZ)

# 13.0 Instruction Set (Continued)

### 13.4.9 No-Operation Instruction

The no-operation instruction does nothing, except to occupy space in the program memory and time in execution.

No-Operation (NOP)

**Note:** The VIS is a special case of the Indirect Transfer of Control addressing mode, where the double byte vector associated with the interrupt is transferred from adjacent addresses in the program memory into the program counter (PC) in order to jump to the associated interrupt service routine.

### 13.5 REGISTER AND SYMBOL DEFINITION

The following abbreviations represent the nomenclature used in the instruction description and the COP8 cross-assembler.

| Registers | |
|---|---|
| A | 8-Bit Accumulator Register |
| B | 8-Bit Address Register |
| X | 8-Bit Address Register |
| SP | 8-Bit Stack Pointer Register |
| PC | 15-Bit Program Counter Register |
| PU | Upper 7 Bits of PC |
| PL | Lower 8 Bits of PC |
| C | 1 Bit of PSW Register for Carry |
| HC | 1 Bit of PSW Register for Half Carry |
| GIE | 1 Bit of PSW Register for Global Interrupt Enable |
| VU | Interrupt Vector Upper Byte |
| VL | Interrupt Vector Lower Byte |

| Symbols | |
|---|---|
| [B] | Memory Indirectly Addressed by B Register |
| [X] | Memory Indirectly Addressed by X Register |
| MD | Direct Addressed Memory |
| Mem | Direct Addressed Memory or [B] |
| Meml | Direct Addressed Memory or [B] or Immediate Data |
| Imm | 8-Bit Immediate Data |
| Reg | Register Memory: Addresses F0 to FF (Includes B, X and SP) |
| Bit | Bit Number (0 to 7) |
| ← | Loaded with |
| ↔ | Exchanged with |

# 13.0 Instruction Set (Continued)

## 13.6 INSTRUCTION SET SUMMARY

| | | | |
|---|---|---|---|
| ADD | A,Meml | ADD | A←A + Meml |
| ADC | A,Meml | ADD with Carry | A←A + Meml + C, C←Carry, HC←Half Carry |
| SUBC | A,Meml | Subtract with Carry | A←A − $\overline{\text{Meml}}$ + C, C←Carry, HC←Half Carry |
| AND | A,Meml | Logical AND | A←A and $\overline{\text{Meml}}$ |
| ANDSZ | A,Imm | Logical AND Immed., Skip if Zero | Skip next if (A and Imm) = 0 |
| OR | A,Meml | Logical OR | A←A or Meml |
| XOR | A,Meml | Logical EXclusive OR | A←A xor Meml |
| IFEQ | MD,Imm | IF EQual | Compare MD and Imm, Do next if MD = Imm |
| IFEQ | A,Meml | IF EQual | Compare A and Meml, Do next if A = Meml |
| IFNE | A,Meml | IF Not Equal | Compare A and Meml, Do next if A ≠ Meml |
| IFGT | A,Meml | IF Greater Than | Compare A and Meml, Do next if A > Meml |
| IFBNE | # | If B Not Equal | Do next if lower 4 bits of B ≠ Imm |
| DRSZ | Reg | Decrement Reg., Skip if Zero | Reg←Reg − 1, Skip if Reg = 0 |
| SBIT | #,Mem | Set BIT | 1 to bit, Mem (bit = 0 to 7 immediate) |
| RBIT | #,Mem | Reset BIT | 0 to bit, Mem |
| IFBIT | #,Mem | IF BIT | If bit #, A or Mem is true do next instruction |
| RPND | | Reset PeNDing Flag | Reset Software Interrupt Pending Flag |
| X | A,Mem | EXchange A with Memory | A↔Mem |
| X | A,[X] | EXchange A with Memory [X] | A↔[X] |
| LD | A,Meml | LoaD A with Memory | A←Meml |
| LD | A,[X] | LoaD A with Memory [X] | A←[X] |
| LD | B,Imm | LoaD B with Immed. | B←Imm |
| LD | Mem,Imm | LoaD Memory Immed. | Mem←Imm |
| LD | Reg,Imm | LoaD Register Memory Immed. | Reg←Imm |
| X | A, [B ±] | EXchange A with Memory [B] | A↔[B], (B←B ±1) |
| X | A, [X ±] | EXchange A with Memory [X] | A↔[X], (X←X ±1) |
| LD | A, [B±] | LoaD A with Memory [B] | A←[B], (B←B ±1) |
| LD | A, [X±] | LoaD A with Memory [X] | A←[X], (X←X±1) |
| LD | [B±],Imm | LoaD Memory [B] Immed. | [B]←Imm, (B←B±1) |
| CLR | A | CLeaR A | A←0 |
| INC | A | INCrement A | A←A + 1 |
| DEC | A | DECrement A | A←A − 1 |
| LAID | | Load A InDirect from ROM | A←ROM (PU,A) |
| DCOR | A | Decimal CORrect A | A←BCD correction of A (follows ADC, SUBC) |
| RRC | A | Rotate A Right thru C | C→A7→…→A0→C |
| RLC | A | Rotate A Left thru C | C←A7←…←A0←C, HC←A0 |
| SWAP | A | SWAP nibbles of A | A7…A4↔A3…A0 |
| SC | | Set C | C←1, HC←1 |
| RC | | Reset C | C←0, HC←0 |
| IFC | | IF C | IF C is true, do next instruction |
| IFNC | | IF Not C | If C is not true, do next instruction |
| POP | A | POP the stack into A | SP←SP + 1, A←[SP] |
| PUSH | A | PUSH A onto the stack | [SP]←A, SP←SP − 1 |
| VIS | | Vector to Interrupt Service Routine | PU←[VU], PL←[VL] |
| JMPL | Addr. | Jump absolute Long | PC←ii (ii = 15 bits, 0 to 32k) |
| JMP | Addr. | Jump absolute | PC9…0←i (i = 12 bits) |
| JP | Disp. | Jump relative short | PC←PC + r (r is −31 to +32, except 1) |

# 13.0 Instruction Set (Continued)

| | | | |
|---|---|---|---|
| JSRL | Addr. | Jump SubRoutine Long | [SP]←PL, [SP−1]←PU,SP−2, PC←ii |
| JSR | Addr. | Jump SubRoutine | [SP]←PL, [SP−1]←PU,SP−2, PC9…0←i |
| JID | | Jump InDirect | PL←ROM (PU,A) |
| RET | | RETurn from subroutine | SP + 2, PL←[SP], PU←[SP−1] |
| RETSK | | RETurn and SKip | SP + 2, PL←[SP],PU←[SP−1], skip next instruction |
| RETI | | RETurn from Interrupt | SP + 2, PL ←[SP],PU←[SP−1],GIE←1 |
| INTR | | Generate an Interrupt | [SP]←PL, [SP−1]←PU, SP−2, PC←0FF |
| NOP | | No OPeration | PC←PC + 1 |

### 13.7 INSTRUCTION EXECUTION TIME

Most instructions are single byte (with immediate addressing mode instructions taking two bytes).

Most single byte instructions take one cycle time to execute.

Skipped instructions require x number of cycles to be skipped, where x equals the number of bytes in the skipped instruction opcode.

See the BYTES and CYCLES per INSTRUCTION table for details.

**Bytes and Cycles per Instruction**

The following table shows the number of bytes and cycles for each instruction in the format of byte/cycle.

**Arithmetic and Logic Instructions**

| | [B] | Direct | Immed. |
|---|---|---|---|
| ADD | 1/1 | 3/4 | 2/2 |
| ADC | 1/1 | 3/4 | 2/2 |
| SUBC | 1/1 | 3/4 | 2/2 |
| AND | 1/1 | 3/4 | 2/2 |
| OR | 1/1 | 3/4 | 2/2 |
| XOR | 1/1 | 3/4 | 2/2 |
| IFEQ | 1/1 | 3/4 | 2/2 |
| IFGT | 1/1 | 3/4 | 2/2 |
| IFBNE | 1/1 | | |
| DRSZ | | 1/3 | |
| SBIT | 1/1 | 3/4 | |
| RBIT | 1/1 | 3/4 | |
| IFBIT | 1/1 | 3/4 | |

| | |
|---|---|
| RPND | 1/1 |

**Instructions Using A & C**

| | |
|---|---|
| CLRA | 1/1 |
| INCA | 1/1 |
| DECA | 1/1 |
| LAID | 1/3 |
| DCORA | 1/1 |
| RRCA | 1/1 |
| RLCA | 1/1 |
| SWAPA | 1/1 |
| SC | 1/1 |
| RC | 1/1 |
| IFC | 1/1 |
| IFNC | 1/1 |
| PUSHA | 1/3 |
| POPA | 1/3 |
| ANDSZ | 2/2 |

**Transfer of Control Instructions**

| | |
|---|---|
| JMPL | 3/4 |
| JMP | 2/3 |
| JP | 1/3 |
| JSRL | 3/5 |
| JSR | 2/5 |
| JID | 1/3 |
| VIS | 1/5 |
| RET | 1/5 |
| RETSK | 1/5 |
| RETI | 1/5 |
| INTR | 1/7 |
| NOP | 1/1 |

## 13.0 Instruction Set (Continued)

### Memory Transfer Instructions

| | Register Indirect | | Direct | Immed. | Register Indirect Auto Incr. & Decr. | | |
|---|---|---|---|---|---|---|---|
| | [B] | [X] | | | [B+, B−] | [X+, X−] | |
| X A, (Note 21) | 1/1 | 1/3 | 2/3 | | 1/2 | 1/3 | |
| LD A, (Note 21) | 1/1 | 1/3 | 2/3 | 2/2 | 1/2 | 1/3 | |
| LD B, Imm | | | | 1/1 | | | (If B < 16) |
| LD B, Imm | | | | 2/2 | | | (If B > 15) |
| LD Mem, Imm | 2/2 | | 3/3 | | 2/2 | | |
| LD Reg, Imm | | | 2/3 | | | | |
| IFEQ MD, Imm | | | 3/3 | | | | |

**Note 21:** = > Memory location addressed by B or X or directly.

## 13.8 Opcode Table

| Upper Nibble | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| F | E | D | C | B | A | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | |
| JP−15 | JP−31 | LD 0F0, #i | DRSZ 0F0 | RRCA | RC | ADC A,#i | ADC A,[B] | IFBIT 0,[B] | ANDSZ A, #i | LD B,#0F | IFBNE 0 | JSR x000–x0FF | JMP x000–x0FF | JP+17 | INTR | 0 |
| JP−14 | JP−30 | LD 0F1, #i | DRSZ 0F1 | * | SC | SUBC A, #i | SUBC A,[B] | IFBIT 1,[B] | * | LD B,#0E | IFBNE 1 | JSR x100–x1FF | JMP x100–x1FF | JP+18 | JP+2 | 1 |
| JP−13 | JP−29 | LD 0F2, #i | DRSZ 0F2 | X A,[X+] | X A,[B+] | IFEQ A,#i | IFEQ A,[B] | IFBIT 2,[B] | * | LD B,#0D | IFBNE 2 | JSR x200–x2FF | JMP x200–x2FF | JP+19 | JP+3 | 2 |
| JP−12 | JP−28 | LD 0F3, #i | DRSZ 0F3 | X A,[X−] | X A,[B−] | IFGT A,#i | IFGT A,[B] | IFBIT 3,[B] | * | LD B,#0C | IFBNE 3 | JSR x300–x3FF | JMP x300–x3FF | JP+20 | JP+4 | 3 |
| JP−11 | JP−27 | LD 0F4, #i | DRSZ 0F4 | VIS | LAID | ADD A,#i | ADD A,[B] | IFBIT 4,[B] | CLRA | LD B,#0B | IFBNE 4 | JSR x400–x4FF | JMP x400–x4FF | JP+21 | JP+5 | 4 |
| JP−10 | JP−26 | LD 0F5, #i | DRSZ 0F5 | RPND | JID | AND A,#i | AND A,[B] | IFBIT 5,[B] | SWAPA | LD B,#0A | IFBNE 5 | JSR x500–x5FF | JMP x500–x5FF | JP+22 | JP+6 | 5 |
| JP−9 | JP−25 | LD 0F6, #i | DRSZ 0F6 | X A,[X] | X A,[B] | XOR A,#i | XOR A,[B] | IFBIT 6,[B] | DCORA | LD B,#09 | IFBNE 6 | JSR x600–x6FF | JMP x600–x6FF | JP+23 | JP+7 | 6 |
| JP−8 | JP−24 | LD 0F7, #i | DRSZ 0F7 | * | * | OR A,#i | OR A,[B] | IFBIT 7,[B] | PUSHA | LD B,#08 | IFBNE 7 | JSR x700–x7FF | JMP x700–x7FF | JP+24 | JP+8 | 7 |
| JP−7 | JP−23 | LD 0F8, #i | DRSZ 0F8 | NOP | RLCA | LD A,#i | IFC | SBIT 0,[B] | RBIT 0,[B] | LD B,#07 | IFBNE 8 | JSR x800–x8FF | JMP x800–x8FF | JP+25 | JP+9 | 8 |
| JP−6 | JP−22 | LD 0F9, #i | DRSZ 0F9 | IFNE A,[B] | IFEQ Md,#i | IFNE A,#i | IFNC | SBIT 1,[B] | RBIT 1,[B] | LD B,#06 | IFBNE 9 | JSR x900–x9FF | JMP x900–x9FF | JP+26 | JP+10 | 9 |
| JP−5 | JP−21 | LD 0FA, #i | DRSZ 0FA | LD A,[X+] | LD A,[B+] | LD [B+],#i | INCA | SBIT 2,[B] | RBIT 2,[B] | LD B,#05 | IFBNE 0A | JSR xA00–xAFF | JMP xA00–xAFF | JP+27 | JP+11 | A |
| JP−4 | JP−20 | LD 0FB, #i | DRSZ 0FB | LD A,[X−] | LD A,[B−] | LD [B−],#i | DECA | SBIT 3,[B] | RBIT 3,[B] | LD B,#04 | IFBNE 0B | JSR xB00–xBFF | JMP xB00–xBFF | JP+28 | JP+12 | B |
| JP−3 | JP−19 | LD 0FC, #i | DRSZ 0FC | LD Md,#i | JMPL | X A,Md | POPA | SBIT 4,[B] | RBIT 4,[B] | LD B,#03 | IFBNE 0C | JSR xC00–xCFF | JMP xC00–xCFF | JP+29 | JP+13 | C |
| JP−2 | JP−18 | LD 0FD, #i | DRSZ 0FD | DIR | JSRL | LD A,Md | RETSK | SBIT 5,[B] | RBIT 5,[B] | LD B,#02 | IFBNE 0D | JSR xD00–xDFF | JMP xD00–xDFF | JP+30 | JP+14 | D |
| JP−1 | JP−17 | LD 0FE, #i | DRSZ 0FE | LD A,[X] | LD A,[B] | LD [B],#i | RET | SBIT 6,[B] | RBIT 6,[B] | LD B,#01 | IFBNE 0E | JSR xE00–xEFF | JMP xE00–xEFF | JP+31 | JP+15 | E |
| JP−0 | JP−16 | LD 0FF, #i | DRSZ 0FF | * | * | LD B,#i | RETI | SBIT 7,[B] | RBIT 7,[B] | LD B,#00 | IFBNE 0F | JSR xF00–xFFF | JMP xF00–xFFF | JP+32 | JP+16 | F |

Lower Nibble

Where,

i is the immediate data

Md is a directly addressed memory location

* is an unused opcode

The opcode 60 Hex is also the opcode for IFBIT #i,A

# 14.0 Mask Options

For mask options information on COP8SAx5 devices, please refer to Section 6.4 ECON (CONFIGURATION) REGISTER.

# 15.0 Development Tools Support

## 15.1 OVERVIEW

National is engaged with an international community of independent 3rd party vendors who provide hardware and software development tool support. Through National's interaction and guidance, these tools cooperate to form a choice of solutions that fits each developer's needs.

This section provides a summary of the tool and development kits currently available. Up-to-date information, selection guides, free tools, demos, updates, and purchase information can be obtained at our web site at: www.national.com/cop8.

## 15.2 SUMMARY OF TOOLS

**COP8 Evaluation Tools**

- **COP8–NSEVAL:** Free Software Evaluation package for Windows. A fully integrated evaluation environment for COP8, including versions of WCOP8 IDE (Integrated Development Environment), COP8-NSASM, COP8-MLSIM, COP8C, DriveWay™ COP8, Manuals, and other COP8 information.
- **COP8–MLSIM:** Free Instruction Level Simulator tool for Windows. For testing and debugging software instructions only (No I/O or interrupt support).
- **COP8–EPU:** Very Low cost COP8 Evaluation & Programming Unit. Windows based evaluation and hardware-simulation tool, with COP8 device programmer and erasable samples. Includes COP8-NSDEV, Driveway COP8 Demo, MetaLink Debugger, I/O cables and power supply.
- **COP8–EVAL-HIxx:** Low cost target application evaluation and development board for COP8Sx Families, from Hilton Inc. Real-time environment with integrated A/D, Temp Sensor, and Peripheral I/O.
- **COP8–EVAL-ICUxx:** Very Low cost evaluation and design test board for COP8ACC and COP8SGx Families, from ICU. Real-time environment with add-on A/D, D/A, and EEPROM. Includes software routines and reference designs.
- **Manuals, Applications Notes, Literature:** Available free from our web site at: www.national.com/cop8.

**COP8 Integrated Software/Hardware Design Development Kits**

- **COP8-EPU:** Very Low cost Evaluation & Programming Unit. Windows based development and hardware-simulation tool for COPSx/xG families, with COP8 device programmer and samples. Includes COP8-NSDEV, Driveway COP8 Demo, MetaLink Debugger, cables and power supply.
- **COP8-DM:** Moderate cost Debug Module from MetaLink. A Windows based, real-time in-circuit emulation tool with COP8 device programmer. Includes COP8-NSDEV, DriveWay COP8 Demo, MetaLink Debugger, power supply, emulation cables and adapters.

**COP8 Development Languages and Environments**

- **COP8-NSASM:** Free COP8 Assembler v5 for Win32. Macro assembler, linker, and librarian for COP8 software development. Supports all COP8 devices. (DOS/Win16 v4.10.2 available with limited support). (Compatible with WCOP8 IDE, COP8C, and DriveWay COP8).
- **COP8-NSDEV:** Very low cost Software Development Package for Windows. An integrated development environment for COP8, including WCOP8 IDE, COP8C (limited version), COP8-NSASM, COP8-MLSIM.
- **COP8C:** Moderately priced C Cross-Compiler and Code Development System from Byte Craft (no code limit). Includes BCLIDE (Byte Craft Limited Integrated Development Environment) for Win32, editor, optimizing C Cross-Compiler, macro cross assembler, BC-Linker, and MetaLink tools support. (DOS/SUN versions available; Compiler is installable under WCOP8 IDE; Compatible with DriveWay COP8).
- **EWCOP8-KS:** Very Low cost ANSI C-Compiler and Embedded Workbench from IAR (Kickstart version: COP8Sx/Fx only with 2k code limit; No FP). A fully integrated Win32 IDE, ANSI C-Compiler, macro assembler, editor, linker, Liberian, C-Spy simulator/debugger, PLUS MetaLink EPU/DM emulator support.
- **EWCOP8-AS:** Moderately priced COP8 Assembler and Embedded Workbench from IAR (no code limit). A fully integrated Win32 IDE, macro assembler, editor, linker, librarian, and C-Spy high-level simulator/debugger with I/O and interrupts support. (Upgradeable with optional C-Compiler and/or MetaLink Debugger/Emulator support).
- **EWCOP8-BL:** Moderately priced ANSI C-Compiler and Embedded Workbench from IAR (Baseline version: All COP8 devices; 4k code limit; no FP). A fully integrated Win32 IDE, ANSI C-Compiler, macro assembler, editor, linker, librarian, and C-Spy high-level simulator/debugger. (Upgradeable; CWCOP8-M MetaLink tools interface support optional).
- **EWCOP8:** Full featured ANSI C-Compiler and Embedded Workbench for Windows from IAR (no code limit). A fully integrated Win32 IDE, ANSI C-Compiler, macro assembler, editor, linker, librarian, and C-Spy high-level simulator/debugger. (CWCOP8-M MetaLink tools interface support optional).
- **EWCOP8-M:** Full featured ANSI C-Compiler and Embedded Workbench for Windows from IAR (no code limit). A fully integrated Win32 IDE, ANSI C-Compiler, macro assembler, editor, linker, librarian, C-Spy high-level simulator/debugger, PLUS MetaLink debugger/hardware interface (CWCOP8-M).

**COP8 Productivity Enhancement Tools**

- **WCOP8 IDE:** Very Low cost IDE (Integrated Development Environment) from KKD. Supports COP8C, COP8-NSASM, COP8-MLSIM, DriveWay COP8, and MetaLink debugger under a common Windows Project Management environment. Code development, debug, and emulation tools can be launched from the project window framework.
- **DriveWay-COP8:** Low cost COP8 Peripherals Code Generation tool from Aisys Corporation. Automatically generates tested and documented C or Assembly source code modules containing I/O drivers and interrupt handlers for each on-chip peripheral. Application specific code can be inserted for customization using the integrated editor. (Compatible with COP8-NSASM, COP8C, and WCOP8 IDE.)

# 15.0 Development Tools Support

(Continued)

- **COP8-UTILS:** Free set of COP8 assembly code examples, device drivers, and utilities to speed up code development.
- **COP8-MLSIM:** Free Instruction Level Simulator tool for Windows. For testing and debugging software instructions only (No I/O or interrupt support).

**COP8 Real-Time Emulation Tools**

- **COP8-DM:** MetaLink Debug Module. A moderately priced real-time in-circuit emulation tool, with COP8 device programmer. Includes MetaLink Debugger, power supply, emulation cables and adapters.
- **IM-COP8:** MetaLink iceMASTER®. A full featured, real-time in-circuit emulator for COP8 devices. Includes COP8-NSDEV, Driveway COP8 Demo, MetaLink Windows Debugger, and power supply. Package-specific probes and surface mount adaptors are ordered separately.

**COP8 Device Programmer Support**

- MetaLink's EPU and Debug Module include development device programming capability for COP8 devices.
- Third-party programmers and automatic handling equipment cover needs from engineering prototype and pilot production, to full production environments.
- Factory programming available for high-volume requirements.

### 15.3 TOOLS ORDERING NUMBERS FOR THE COP8SAx FAMILY DEVICES

Note: The following order numbers apply to the COP8 devices in this datasheet only.

| Vendor | Tools | Order Number | Cost | Notes |
|---|---|---|---|---|
| | COP8-NSEVAL | COP8-NSEVAL | VL | Order from web site. |
| | COP8-NSDEV | COP8-NSDEV | L | Included in EM. Order CD from web site |
| | COP8-REF | None | | |
| | COP8-EVAL | COP8-EVAL-COB1 | VL | Order from web site |
| | COP8-EM | COP8-EM-SA | M | Included p/s, 20/28/40 pin DIP target cable, manuals, software |
| | EM Target Cables and Adapters | COP8-EMC-44P | VL | 44 PLCC Target Cable |
| | | COP8-EMC-28CSP | L | 28 CSP Target Cable |
| | | COP8-EMA-16D | L | 20 DIP to 16 DIP Adapter |
| | | COP8-EMA-xxSO | L | DIP to SOIC Cable Converter |
| | | COP8-EMA-44QFP | L | 44 pin PLCC to 44 QFP Cable Converter |
| | Development Devices | COP8SAC7Q | VL | 4k Eraseable/OTP devices |
| | COP8-PM | COP8-PM-00 | L | Included p/s, manuals, software, 16/20/28/40 DIP/SO and 44 PLCC programming socket; add OTP adapter (if needed) |
| | OTP Programming Adapters | COP8-PGMA-44QFP | L | For programming 44 QFP on any programmer |
| | | COP8-PGMA-28CSP | L | For programming 28 CSP on any programmer |
| | | COP8-PGMA-44CSP | L | For programming 44 CSP on any programmer |
| | | COP8-PGMA-28SO | VL | For programming 16/20/28 SOIC on any programmer |

## 15.0 Development Tools Support (Continued)

| | | | | |
|---|---|---|---|---|
| MetaLink | COP8-DM | DM5-KCOP8-SA | M | Included p/s (PS-10), target cables (DIP and PLCC), 16/20/28/40 DIP/SO and 44 PLCC programming sockets. Add OTP adapter (if needed) and target adapter (if needed) |
| | DM Target Adapters | MHW-CNVxx (xx = 33, 34 etc.) | L | DM target converters for 16DIP/20SO/28SO/44QFP/28CSP; (i.e. MHW-CNV38 for 20 pin DIP to SO package converter) |
| | OTP Programming Adapters | MHW-COP8-PGMA-DS | L | For programming 16/20/28 SOIC and 44 PLCC on the EPU |
| | | MHW-COP8-PGMA-44QFP | L | For programming 44 QFP on any programmer |
| | | MHW-COP8-PGMA-28CSP | L | For programming 28 CSP on any programmer |
| | COP8-IM | IM-COP8-AD-464 (-220) (10 MHz maximum) | H | Base unit 10 MHz; -220 = 220V; add probe card (required) and target adapter (if needed); included software and manuals |
| | IM Probe Card | PC-COP8SA44PW-AD-10 | M | 10 MHz 44 PLCC probe card; 2.5V to 6.0V |
| | | PC-COP8SA40DW-AD-10 | M | 10 MHz 40 DIP probe card; 2.5V to 6.0V |
| | IM Probe Target Adapters | MHW-SOICxx (xx = 16, 20, 28) | L | 16 or 20 or 28 pin SOIC adapter for probe card |
| | | MHW-CONV33 | L | 44 pin QFP adapter for 44 PLCC probe card |
| KKD | WCOP8-IDE | WCOP8-IDE | VL | Included in DM and EM |
| IAR | EWCOP8-xx | See summary above | L - H | Included all software and manuals |
| Byte Craft | COP8C | COP8C COP8CWIN | M | Included all software and manuals |
| Aisys | DriveWay COP8 | DriveWay COP8 | L | Included all software and manuals |
| OTP Programmers | | Go to: www.national.com/cop8 | L - H | A wide variety world-wide |
| Cost: Free; VL =< $100; L = $100 - $300; M = $300 - $1k; H = $1k - $3k; VH = $3k - $5k | | | | |

# 15.0 Development Tools Support (Continued)

### 15.4 WHERE TO GET TOOLS

Tools are ordered directly from the following vendors. Please go to the vendor's web site for current listings of distributors.

| Vendor | Home Office | Electronic Sites | Other Main Offices |
|---|---|---|---|
| Aisys | U.S.A.: Santa Clara, CA<br>1-408-327-8820<br>fax: 1-408-327-8830 | www.aisysinc.com<br>info@aisysinc.com | Distributors |
| Byte Craft | U.S.A.<br>1-519-888-6911<br>fax: 1-519-746-6751 | www.bytecraft.com<br>info@bytecraft.com | Distributors |
| IAR | Sweden: Uppsala<br>+46 18 16 78 00<br>fax: +46 18 16 78 38 | www.iar.se<br>info@iar.se<br>info@iar.com<br>info@iarsys.co.uk<br>info@iar.de | U.S.A.: San Francisco<br>1-415-765-5500<br>fax: 1-415-765-5503<br>U.K.: London<br>+44 171 924 33 34<br>fax: +44 171 924 53 41<br>Germany: Munich<br>+49 89 470 6022<br>fax: +49 89 470 956 |
| ICU | Sweden: Polygonvaegen<br>+46 8 630 11 20<br>fax: +46 8 630 11 70 | www.icu.se<br>support@icu.se<br>support@icu.ch | Switzeland: Hoehe<br>+41 34 497 28 20<br>fax: +41 34 497 28 21 |
| KKD | Denmark: | www.kkd.dk | |
| MetaLink | U.S.A.: Chandler, AZ<br>1-800-638-2423<br>fax: 1-602-926-1198 | www.metaice.com<br>sales@metaice.com<br>support@metaice.com<br>bbs: 1-602-962-0013<br>www.metalink.de | Germany: Kirchseeon<br>80-91-5696-0<br>fax: 80-91-2386<br>islanger@metalink.de<br>Distributors Worldwide |
| National | U.S.A.: Santa Clara, CA<br>1-800-272-9959<br>fax: 1-800-737-7018 | www.national.com/cop8<br>support@nsc.com<br>europe.support@nsc.com | Europe: +49 (0) 180 530 8585<br>fax: +49 (0) 180 530 8586<br>Distributors Worldwide |

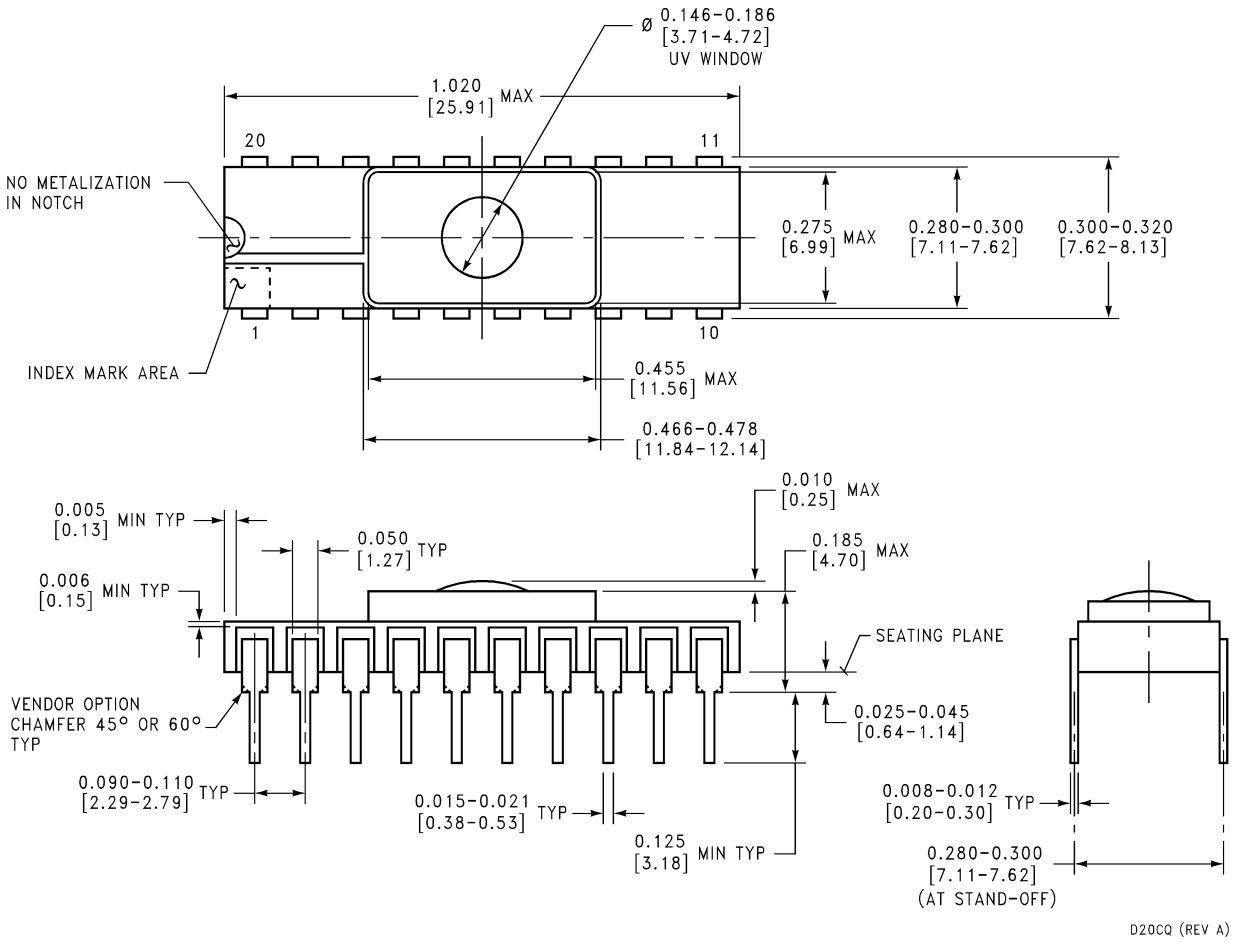
The following companies have approved COP8 programmers in a variety of configurations. Contact your local office or distributor. You can link to their web sites and get the latest listing of approved programmers from National's COP8 OTP Support page at: www.national.com/cop8.

Advantech; Dataman; EE Tools; Minato; BP Microsystems; Data I/O; Hi-Lo Systems; ICE Technology; Lloyd Research; Logical Devices; MQP; Needhams; Phyton; SMS; Stag Programmers; System General; Tribal Microsystems; Xeltek.

### 15.5 CUSTOMER SUPPORT

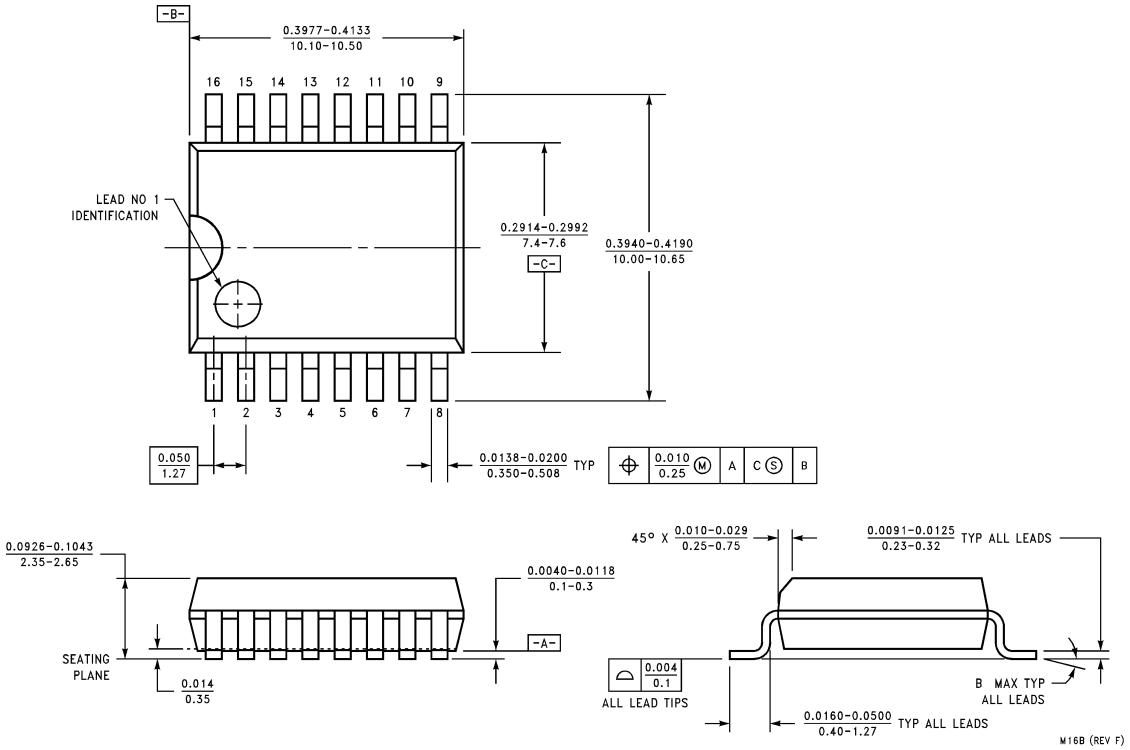
Complete product information and technical support is available from National's customer response centers, and from our on-line COP8 customer support sites.

## Physical Dimensions inches (millimeters) unless otherwise noted

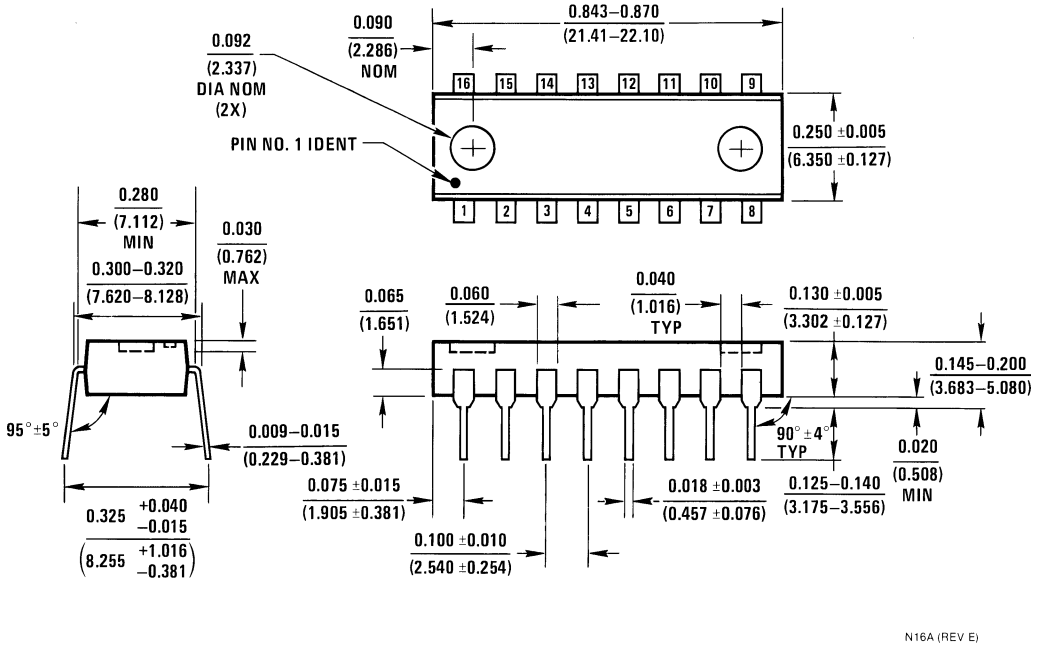



**20-Lead Hermetic Dual-In-Line Package, EPROM (D)**
**Order Number COP8SAC720Q3**
**NS Package Number D20CQ**

## Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

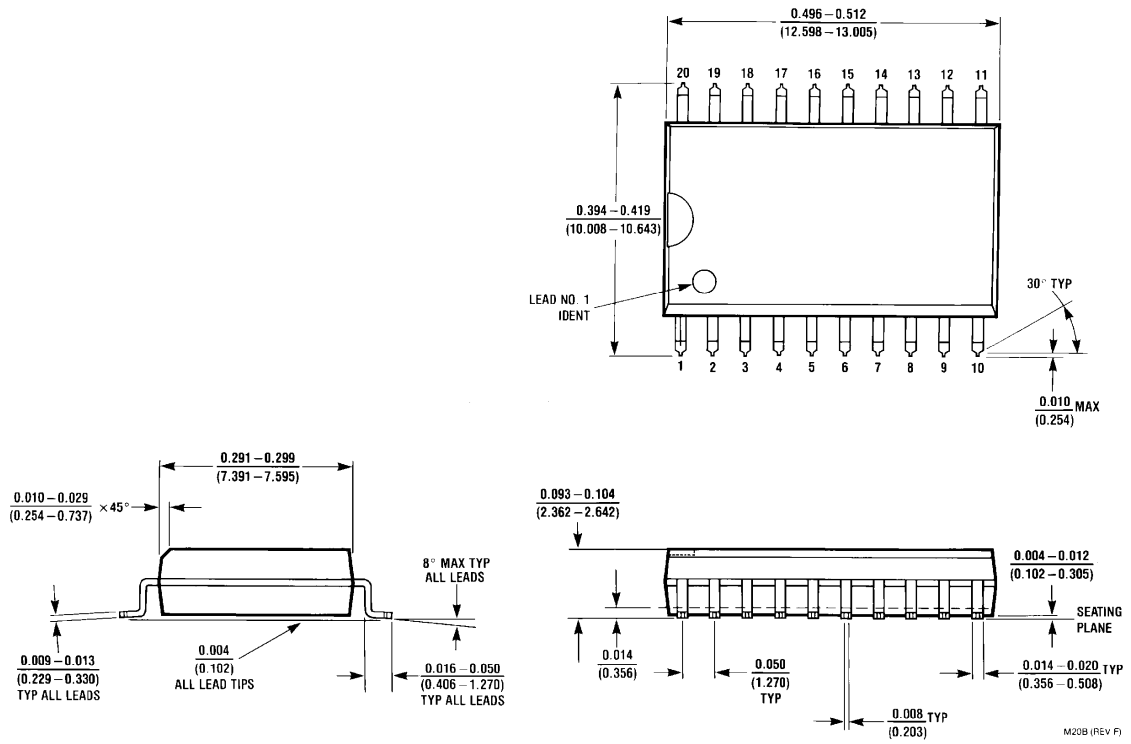



**Molded Small Outline Package (WM)**
**Order Number COP8SAA716M8 or COP8SAA716M9**
**NS Package Number M16B**

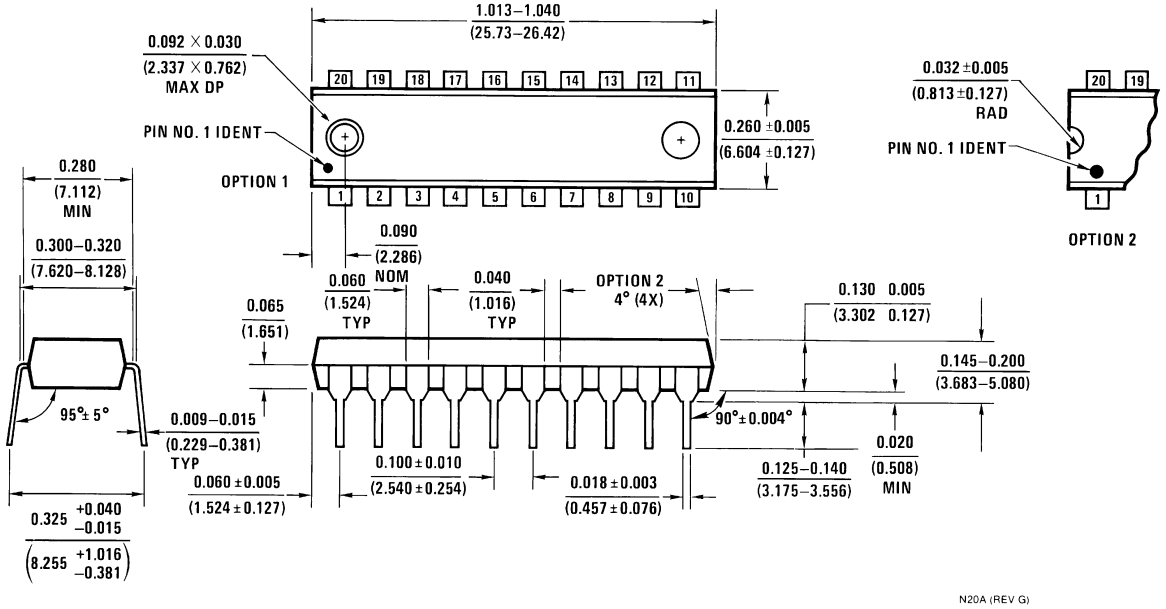



**Molded Dual-In-Line Package (N)**
**Order Number COP8SAA716N8 or COP8SAA716N9**
**NS Package Number N16A**

## Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

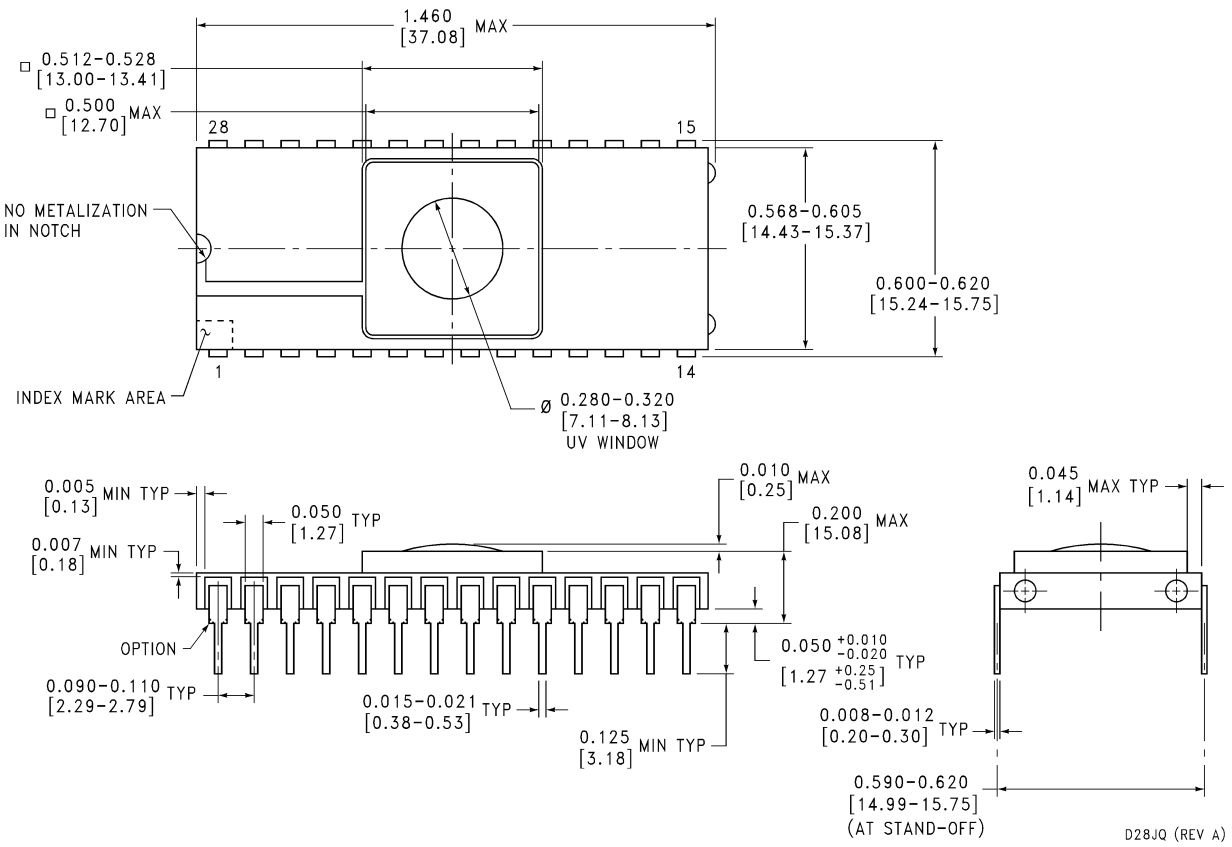



**Molded SO Wide Body Package (WM)**
**Order Number COP8SAA720M9, COP8SAB720M9, COP8SAC720M9**
**COP8SAA720M8, COP8SAB720M8 or COP8SAC720M8**
**NS Package Number M20B**



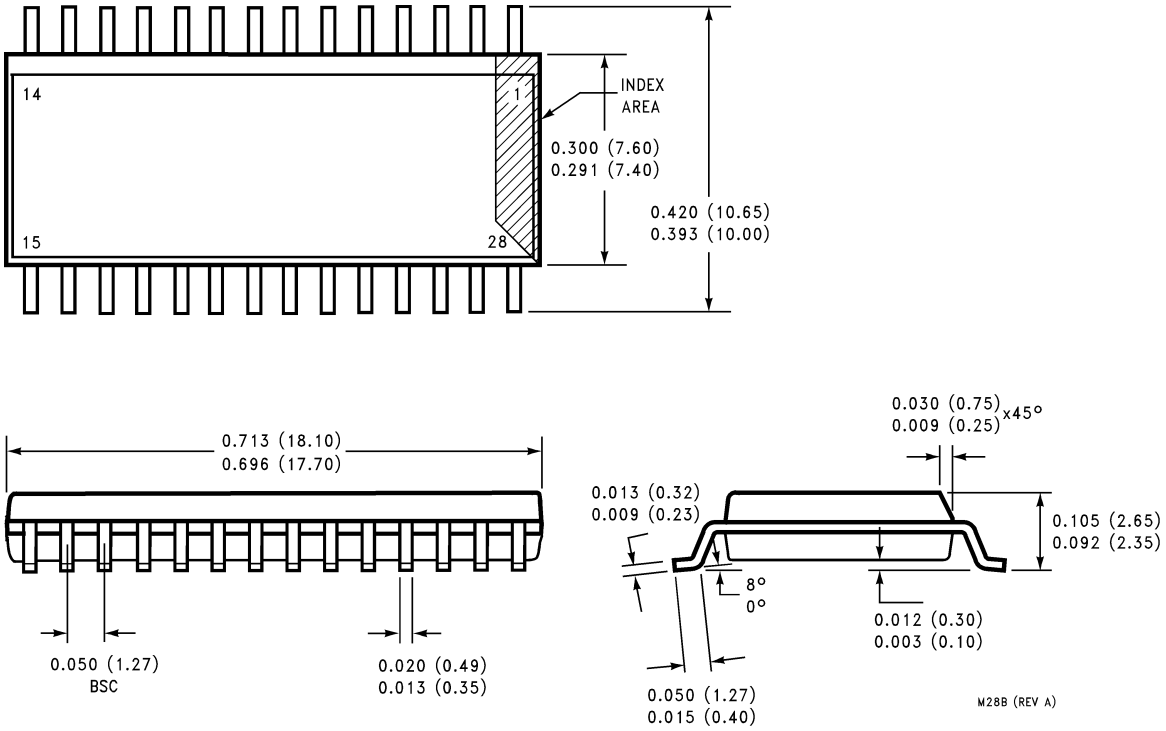

**Molded Dual-In-Line Package (N)**
**Order Number COP8SAA720N9, COP8SAB720N9, COP8SAC720N9,**
**COP8SAA720N8, COP8SAB720N8 or COP8SAC720N8**
**NS Package Number N20A**

## Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

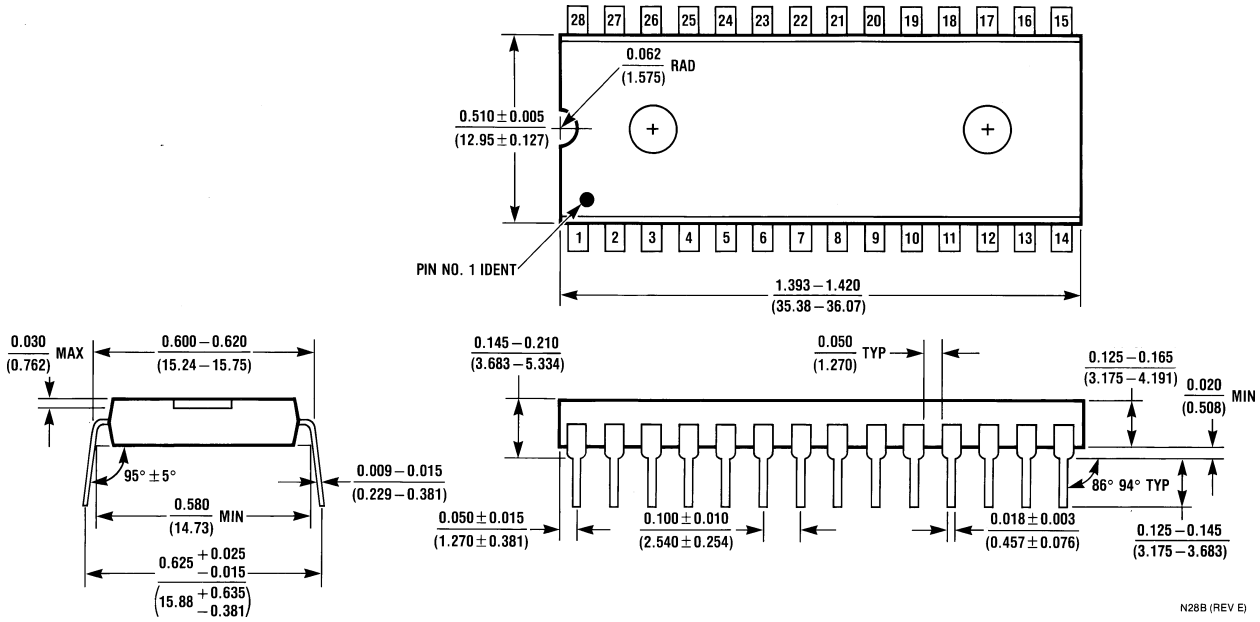



**28-Lead Hermetic Dual-In-Line Package EPROM (D)**
**Order Number COP8SAC728Q3**
**NS Package Number D28JQ**

## Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

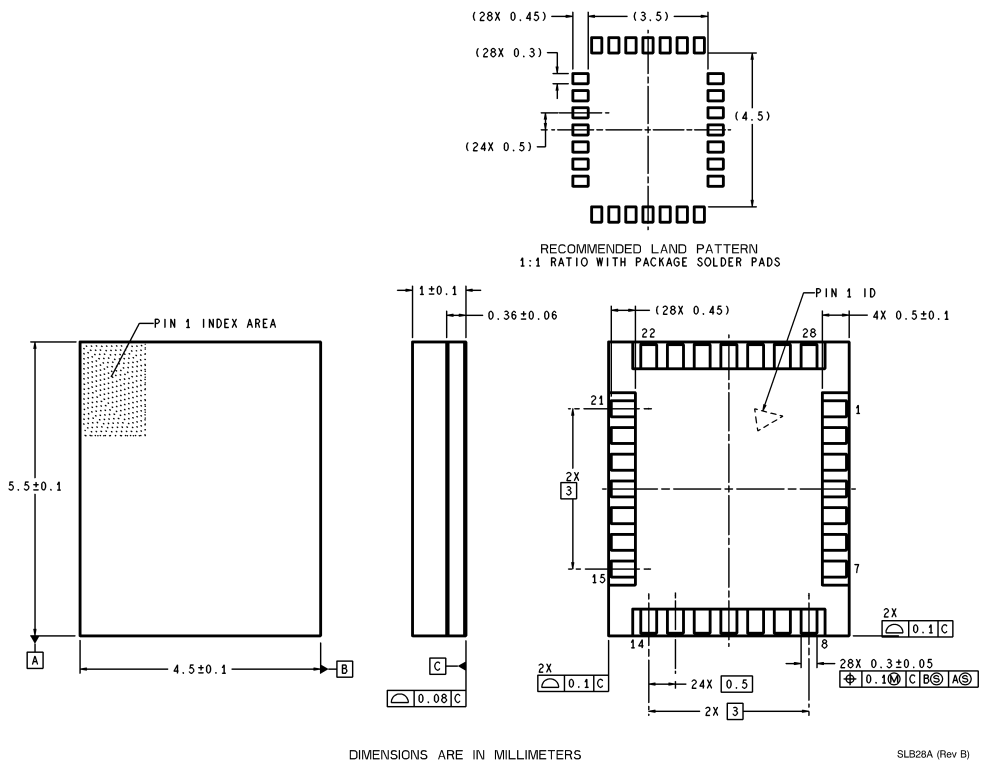



**Molded SO Wide Body Package (WM)**
**Order Number COP8SAA728M9, COP8SAB728M9, COP8SAC728M9,**
**COP8SAA728M8, COP8SAB728M8 or COP8SAC728M8**
**NS Package Number M28B**



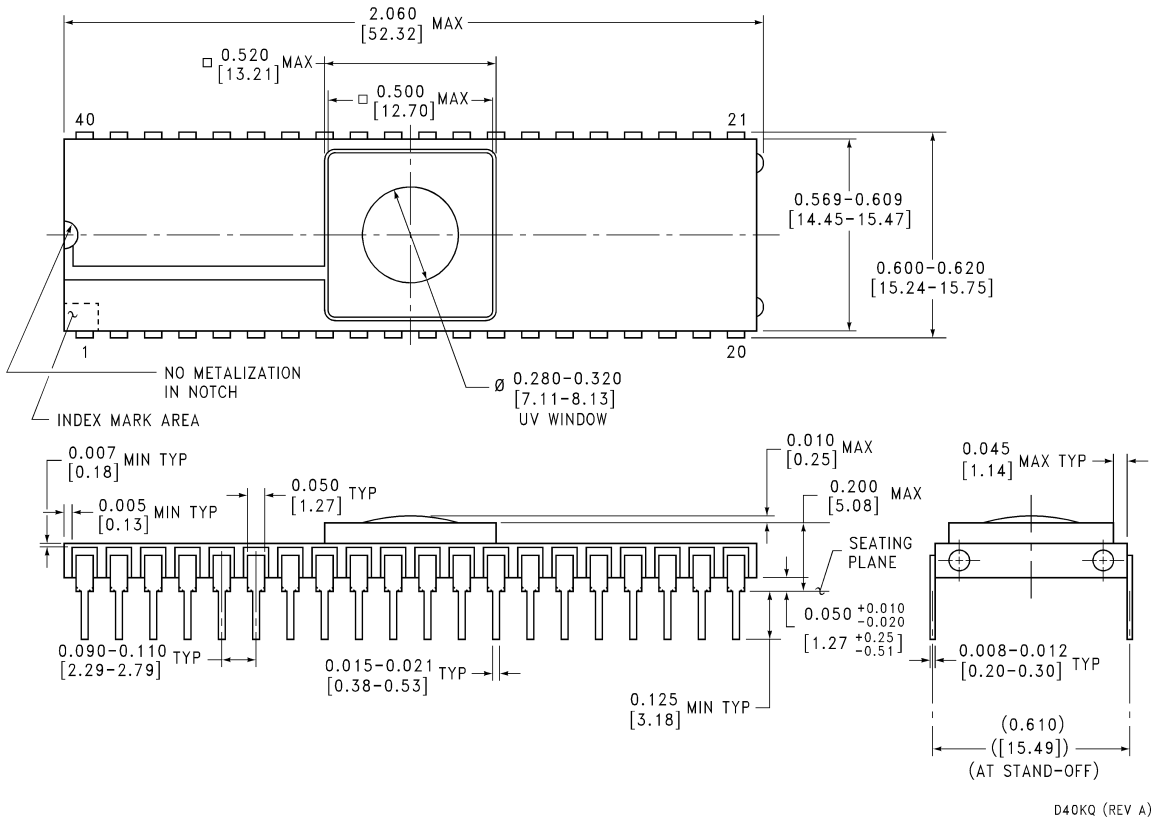

**Molded Dual-In-Line Package (N),**
**Order Number COP8SAA728N9, COP8SAB728N9, COP8SAC728N9,**
**COP8SAA728N8, COP8SAB728N8 or COP8SAC728N8**
**NS Package Number N28B**

## Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

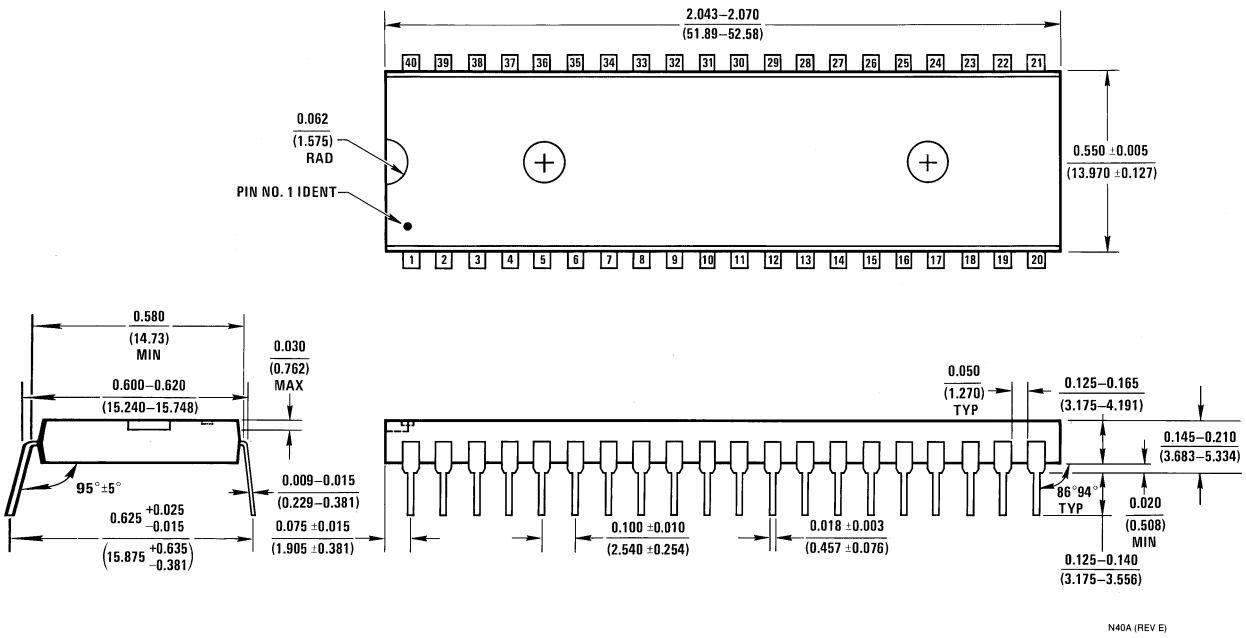



**28 Lead Chip Scale Package (SLB)**
**Order Number COP8SAA7SLB9, COP8SAB7SLB9 or COP8SAC7SLB9**
**NS Package Number SLB28A**

## Physical Dimensions inches (millimeters) unless otherwise noted (Continued)

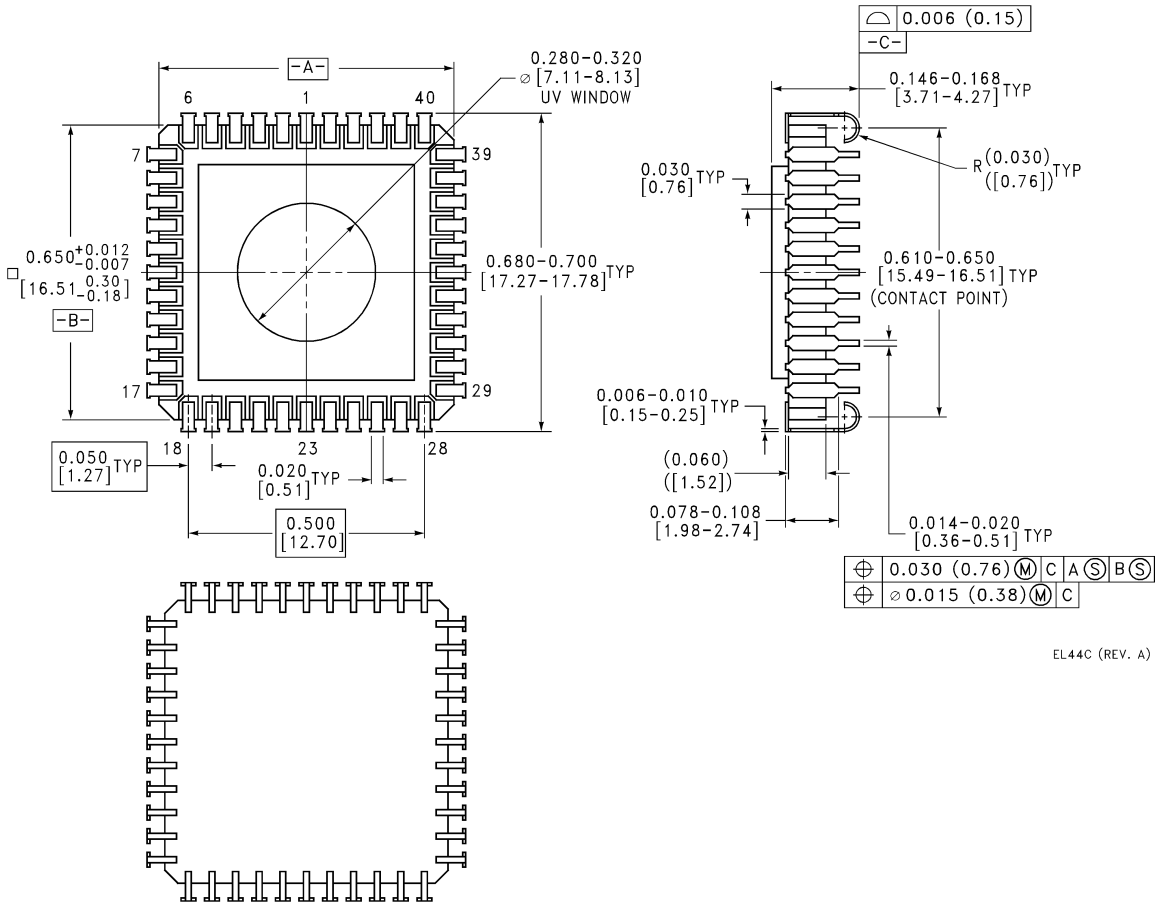



**40-Lead Hermetic DIP EPROM (D)**
**Order Number COP8SAC740Q3**
**NS Package Number D40KQ**



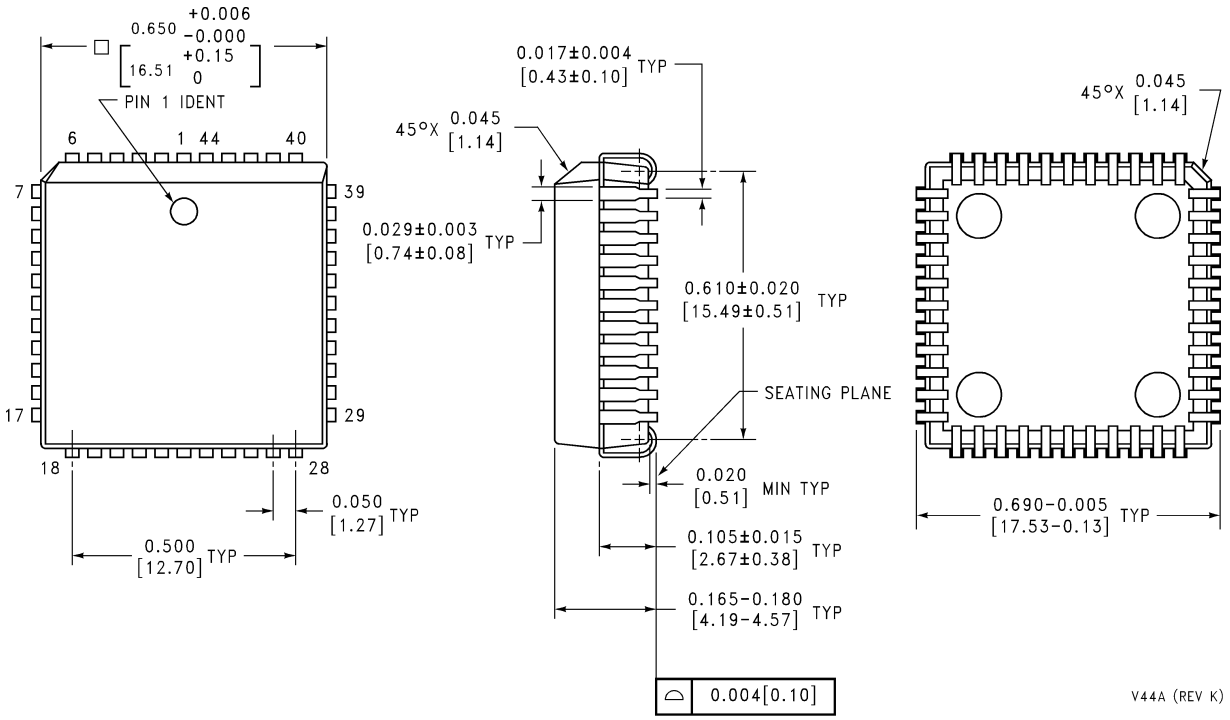

**Molded Dual-In-Line Package (N)**
**Order Number COP8SAC740N9 or COP8SAC740N8**
**NS Package Number N40A**

## Physical Dimensions inches (millimeters) unless otherwise noted (Continued)




**44-Lead EPROM Leaded Chip Carrier (EL)**
**Order Number COP8SAC744Q3**
**NS Package Number EL44C**

## Physical Dimensions inches (millimeters) unless otherwise noted (Continued)




**Molded Dual-In-Line Package (N)**
**Order Number COP8SAC744V9 or COP8SAC744V8**
**NS Package Number V44A**

### LIFE SUPPORT POLICY

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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