

## Sensorless Motor Control IC for Appliances

### Features

- **MCE™ (Motion Control Engine) - Hardware based computation engine for high efficiency sinusoidal sensorless control of permanent magnet AC motor**
- **Support Induction motor sensorless FOC control**
- **Supports both interior and surface permanent magnet motors**
- **Built-in hardware peripheral for single shunt current feedback reconstruction**
- **No external current or voltage sensing operational amplifier required**
- **Three/two-phase Space Vector PWM**
- **Analog output (PWM)**
- **Embedded 8-bit high speed microcontroller (8051) for flexible I/O and man-machine control**
- **JTAG programming port for emulation/debugger**
- **Serial communication interface (UART)**
- **I<sup>2</sup>C/SPI serial interface**
- **Watchdog timer with independent analog clock**
- **Three general purpose timers/counters**
- **Two special timers: periodic timer, capture timer**
- **Internal 'One-Time Programmable' (OTP) memory and internal RAM for final production usage**
- **Pin compatible with IRMCF371, RAM version**
- **1.8V/3.3V CMOS**

### Product Summary

Maximum crystal frequency	60 MHz
Maximum internal clock (SYSCLK) frequency	128 MHz
Maximum 8051 clock frequency	33 MHz
Sensorless control computation time	11 µsec typ
MCE™ computation data range	16 bit signed
8051 OTP Program memory	64K bytes
MCE program and Data RAM	8K bytes
GateKill latency (digital filtered)	2 µsec
PWM carrier frequency counter	16 bits/ SYSCLK
A/D input channels	4
A/D converter resolution	12 bits
A/D converter conversion speed	2 µsec
8051 instruction execution speed	2 SYSCLK
Analog output (PWM) resolution	8 bits
UART baud rate (typ)	57.6K bps
Number of I/O (max)	13
Package (lead-free)	QFP48
Operating temperature	-40°C ~ 85°C

### Description

IRMCK371 is a high performance OTP based motion control IC designed primarily for appliance applications. IRMCK371 is designed to achieve low cost and high performance control solutions for advanced inverterized appliance motor control. IRMCK371 contains two computation engines. One is Motion Control Engine (MCE™) for sensorless control of permanent magnet motors; the other is an 8-bit high-speed microcontroller (8051). Both computation engines are integrated into one monolithic chip. The MCE™ contains a collection of control elements such as Proportional plus Integral, Vector rotator, Angle estimator, Multiply/Divide, Low loss SVPWM, Single Shunt IFB. The user can program a motion control algorithm by connecting these control elements using a graphic compiler. Key components of the sensorless control algorithms, such as the Angle Estimator, are provided as complete pre-defined control blocks implemented in hardware. A unique analog/digital circuit and algorithm to fully support single shunt current reconstruction is also provided. The 8051 microcontroller performs 2-cycle instruction execution (16MIPS at 33MHz). The MCE and 8051 microcontroller are connected via dual port RAM to process signal monitoring and command input. An advanced graphic compiler for the MCE™ is seamlessly integrated into the MATLAB/Simulink environment, while third party JTAG based emulator tools are supported for 8051 developments. IRMCK371 comes with a small QFP48 pin lead-free package..

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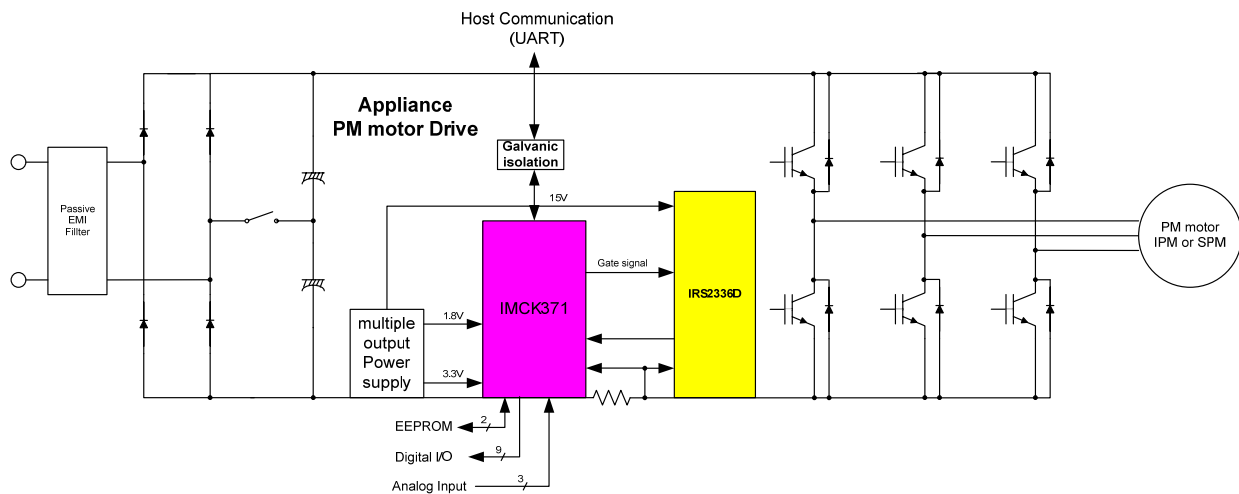
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# 1 Overview

IRMCK371 is a new International Rectifier integrated circuit device primarily designed as a one-chip solution for complete inverter controlled appliance motor control applications. Unlike a traditional microcontroller or DSP, the IRMCK371 provides a built-in closed loop sensorless control algorithm using the unique Motion Control Engine (MCE™) for permanent magnet motors. The MCE™ consists of a collection of control elements, motion peripherals, a dedicated motion control sequencer and dual port RAM to map internal signal nodes. IRMCK371 also employs a unique single shunt current reconstruction circuit to eliminate additional analog/digital circuitry and enables a direct shunt resistor interface to the IC. Motion control programming is achieved using a dedicated graphical compiler integrated into the MATLAB/Simulink™ development environment. Sequencing, user interface, host communication, and upper layer control tasks can be implemented in the 8051 high-speed 8-bit microcontroller. The 8051 microcontroller is equipped with a JTAG port to facilitate emulation and debugging tools. Figure 1 shows a typical application schematic using the IRMCK371.

IRMCF371 is intended for development purpose and contains 48K bytes of RAM, which can be loaded from external EEPROM for 8051 program execution. For high volume production, IRMCK371 contains OTP ROM in place of program RAM to reduce the cost. Both IRMCK371 and IRMCK371 come in the same 48-pin QFP package with identical pin configuration to facilitate PC board layout and transition to mass production



**Figure 1. Typical Application Block Diagram Using IRMCK371**

## 2 IRMCK371 Block Diagram and Main Functions

IRMCK371 block diagram is shown in Figure 2.

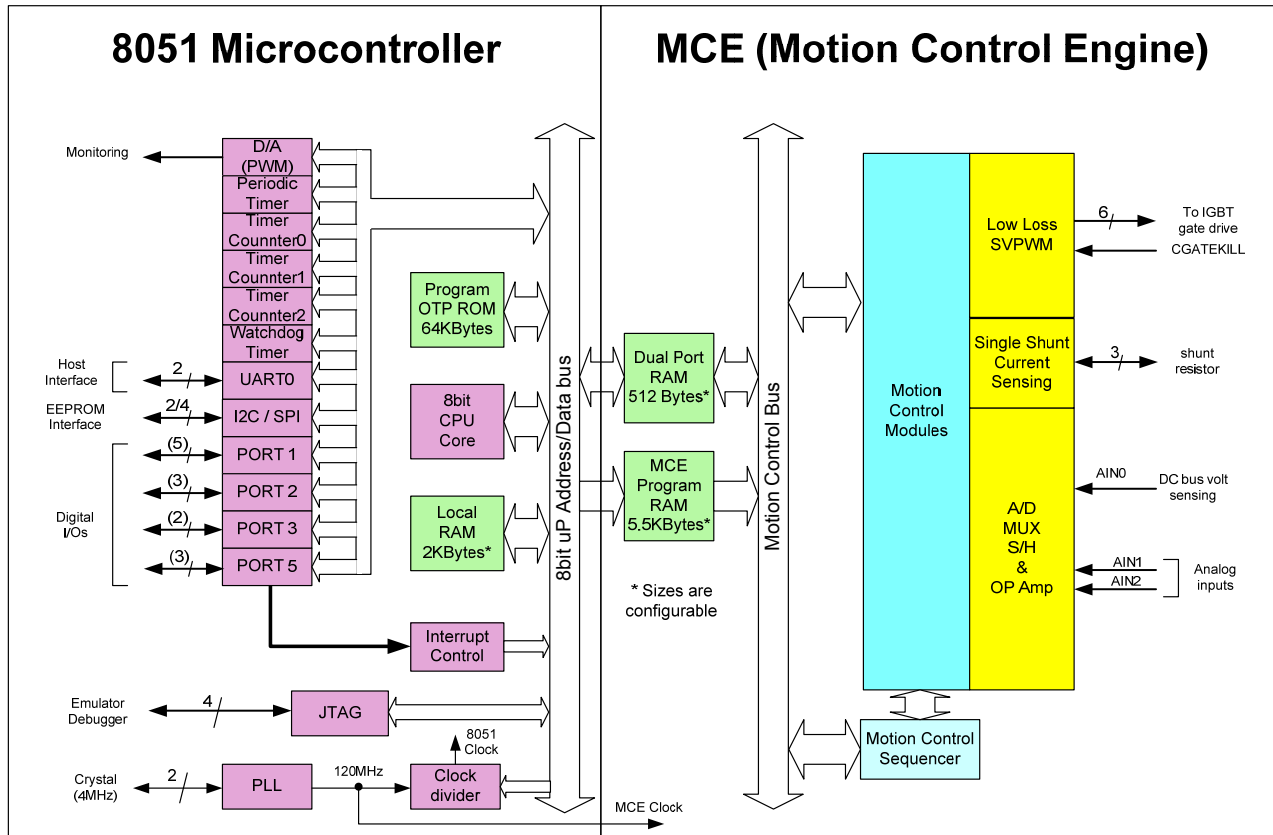


Figure 2. IRMCK371 Internal Block Diagram

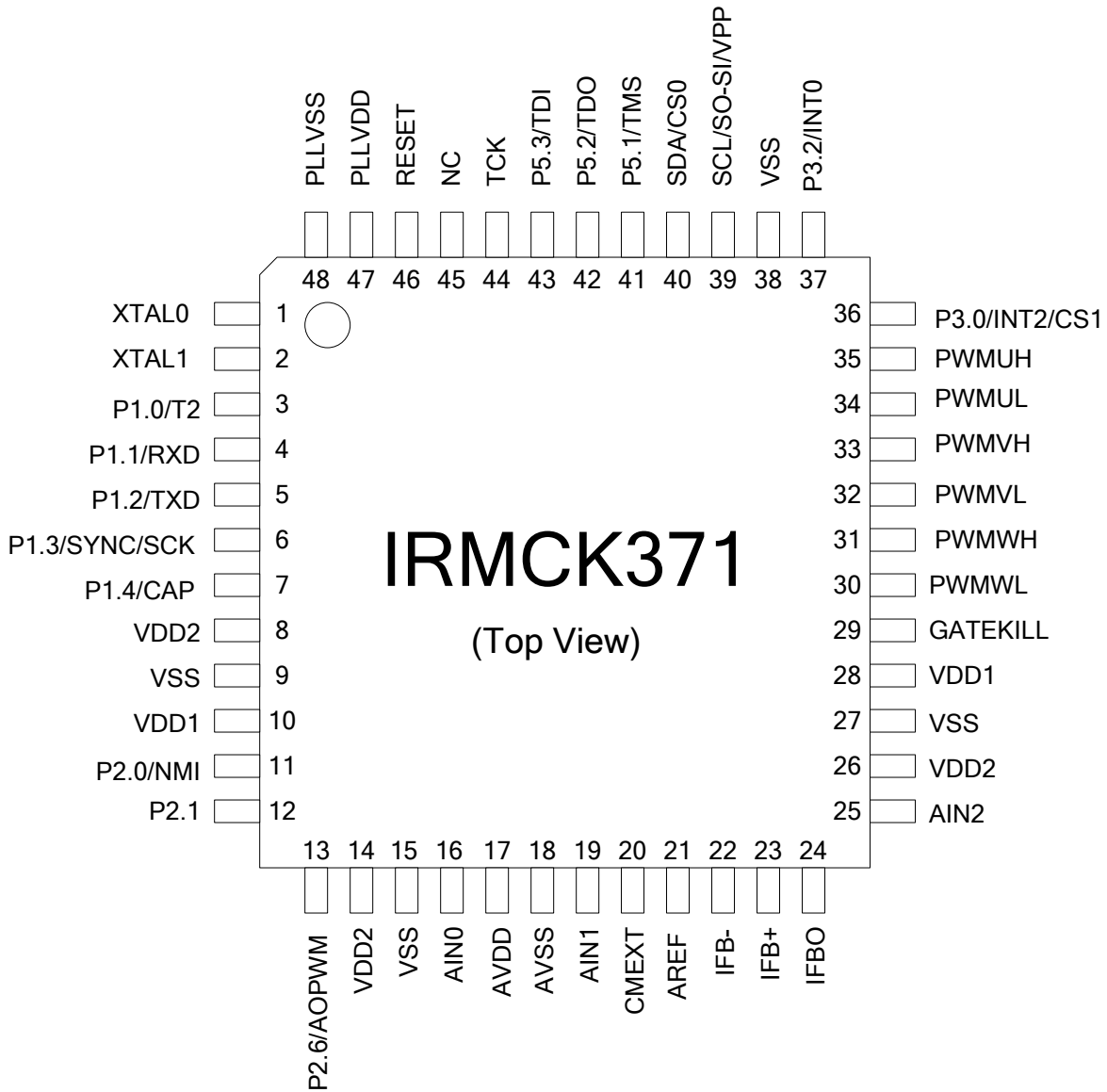
IRMCK371 contains the following functions for sensorless AC motor control applications:

- Motion Control Engine (MCE™)
  - Proportional plus Integral block
  - Low pass filter
  - Differentiator and lag (high pass filter)
  - Ramp
  - Limit
  - Angle estimate (sensorless control)
  - Inverse Clark transformation
  - Vector rotator
  - Bit latch
  - Peak detect
  - Transition
  - Multiply-divide (signed and unsigned)

- Divide (signed and unsigned)
- Adder
- Subtractor
- Comparator
- Counter
- Accumulator
- Switch
- Shift
- ATAN (arc tangent)
- Function block (any curve fitting, nonlinear function)
- 16-bit wide Logic operations (AND, OR, XOR, NOT, NEGATE)
- MCE™ program and data memory (6K byte). <sup>Note 1</sup>
- MCE™ control sequencer
  
- 8051 microcontroller
  - Three 16-bit timer/counters
  - 16-bit periodic timer
  - 16-bit analog watchdog timer
  - 16-bit capture timer
  - Up to 13 discrete I/Os
  - Four-channel 12-bit A/D
    - One buffered channel for current sensing (0 – 1.2V input)
    - Three unbuffered channels (0 – 1.2V input)
  - JTAG port (4 pins)
  - One channel of analog output (8-bit PWM)
  - UART
  - I<sup>2</sup>C/SPI port
  - 64K byte program OTP
  - 2K byte data RAM. <sup>Note 1</sup>

Note 1: Total size of RAM is 8K byte including MCE program, MCE data, and 8051 data. Different sizes can be allocated depending on applications.

### 3 Pinout



**Figure 3. IRMCK371 Pin Configuration**



## 4 Input/Output of IRMCK371

All I/O signals of IRMCK371 are shown in Figure 4. All I/O pins are 3.3V logic interface except A/D interface pins.

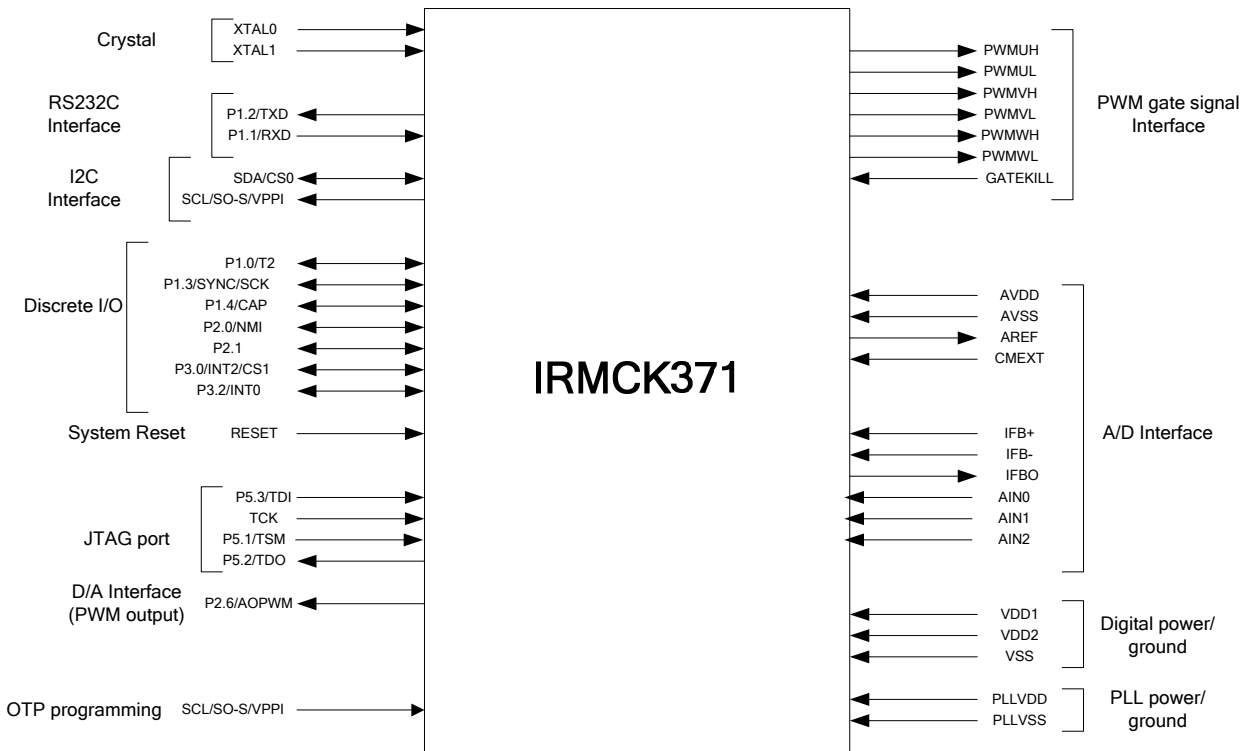


Figure 4. Input/Output of IRMCK371

## 4.1 8051 Peripheral Interface Group

### UART Interface

P1.2/TXD	Output, Transmit data from IRMCK371, can be configured as P1.2
P1.1/RXD	Input, Receive data to IRMCK371, can be configured as P1.1

### Discrete I/O Interface

P1.0/T2	Input/output port 1.0, can be configured as Timer 2 input
P1.1/RXD	Input/output port 1.1, can be configured as RXD input
P1.2/TXD	Input/output port 1.2, can be configured as TXD output
P1.3/SYNC/SCK	Input/output port 1.3, can be configured as SYNC output or SPI clock
P1.4/CAP	Input/output port 1.4, can be configured as Capture Timer input
P2.0/NMI	Input/output port 2.0, can be configured as non-maskable interrupt input
P2.1	Input/output port 2.1
P3.0/INT2/CS1	Input/output port 3.0, can be configured as INT2 input or SPI chip select 1
P3.2/INT0	Input/output port 3.2, can be configured as INT0 input

### Analog Output Interface

AOPWM	Output, PWM output 0, 8-bit resolution, configurable carrier frequency
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### Crystal Interface

XTAL0	Input, connected to crystal
XTAL1	Output, connected to crystal

### Reset Interface

RESET	Inout, system reset, needs to be pulled up to VDD1 but doesn't require external RC time constant
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### I<sup>2</sup>C/SPI Interface

SCL/SO-SI	Input/output, I <sup>2</sup> C clock output or SPI data
SDA/CS0	Input/output, I <sup>2</sup> C Data line or SPI chip select 0
P3.0/INT2/CS1	Input/output, INT2 or SPI chip select 1
P1.3/SYNC/SCK	Input/output, SYNC output or SPI clock, needs to be pulled up to VDD1 in order to boot from I <sup>2</sup> C EEPROM

## 4.2 Motion Peripheral Interface Group

### PWM

PWMUH	Output, PWM phase U high side gate signal
PWMUL	Output, PWM phase U low side gate signal
PWMVH	Output, PWM phase V high side gate signal
PWMVL	Output, PWM phase V low side gate signal
PWMWH	Output, PWM phase W high side gate signal
PWMWL	Output, PWM phase W low side gate signal

### Fault

GATEKILL	Input, upon assertion, this negates all six PWM signals, programmable logic sense
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### 4.3 Analog Interface Group

AVDD	Analog power (1.8V)
AVSS	Analog power return
AREF	0.6V buffered output
CMEXT	Unbuffered 0.6V, input to the AREF buffer, capacitor needs to be connected.
IFB+	Input, Operational amplifier positive input for shunt resistor current sensing
IFB-	Input, Operational amplifier negative input for shunt resistor current sensing
IFBO	Output, Operational amplifier output for shunt resistor current sensing
AIN0	Input, Analog input channel 0 (0 – 1.2V), typically configured for DC bus voltage input
AIN1	Input, Analog input channel 1 (0 – 1.2V), needs to be pulled down to AVSS if unused
AIN2	Input, Analog input channel 2 (0 – 1.2V), needs to be pulled down to AVSS if unused

### 4.4 Power Interface Group

VDD1	Digital power for I/O (3.3V)
VDD2	Digital power for core logic (1.8V)
VSS	Digital common
PLLVD	PLL power (1.8V)
PLLSS	PLL ground return

### 4.5 Test Interface Group

TSTMOD	Must be tied to VSS, used only for factory testing.
P5.1/TSM	Input/output port 5.1, configured as JTAG port by default
P5.2/TDO	Input/output port 5.2, configured as JTAG port by default
P5.3/TDI	Input/output port 5.3, configured as JTAG port by default
TCK	Input, JTAG test clock

## 5 Application Connections

Typical application connection is shown in Figure 5. All components necessary to implement a complete sensorless drive control algorithm are shown connected to IRMCK371.

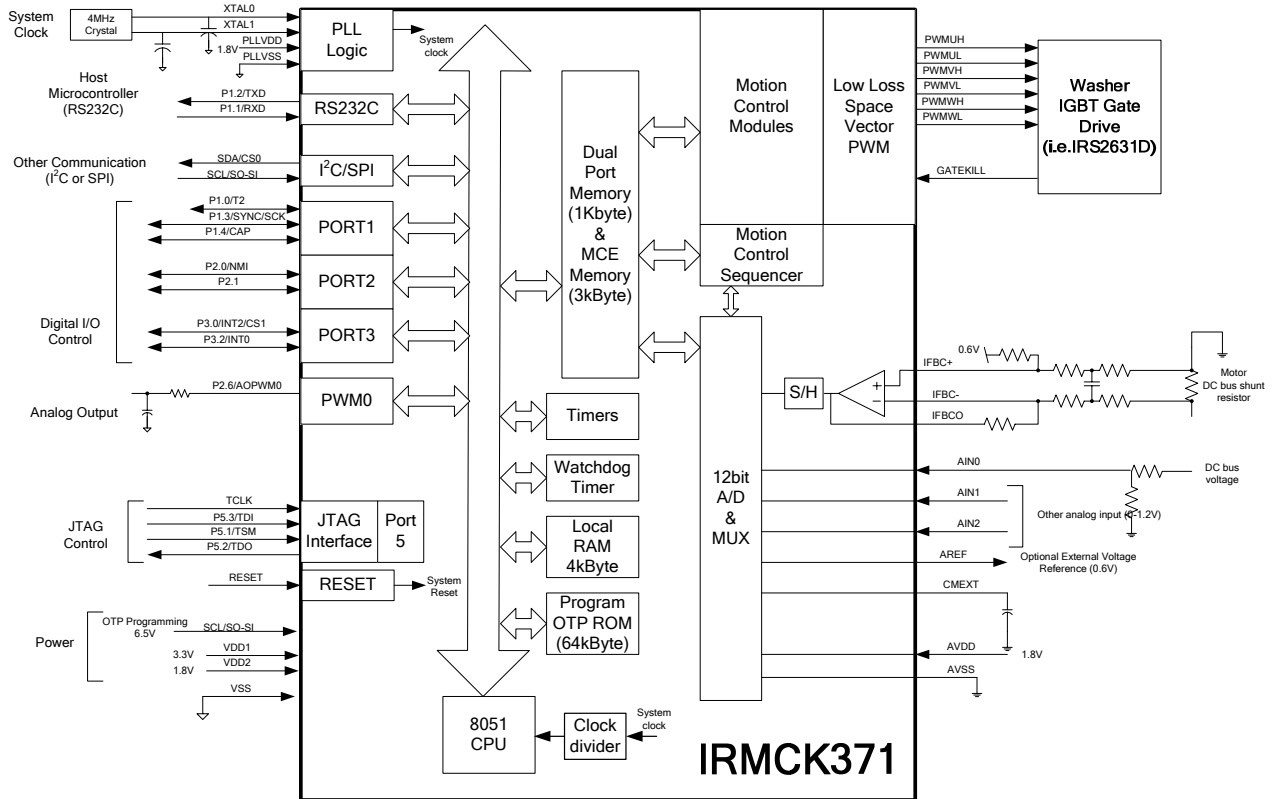


Figure 5. Application Connection of IRMCK371

## 6 DC Characteristics

### 6.1 Absolute Maximum Ratings

Symbol	Parameter	Min	Typ	Max	Condition
V <sub>DD1</sub>	Supply Voltage	-0.3 V	-	3.6 V	Respect to VSS
V <sub>DD2</sub>	Supply Voltage	-0.3 V	-	1.98 V	Respect to VSS
V <sub>IA</sub>	Analog Input Voltage	-0.3 V	-	1.98 V	Respect to AVSS
V <sub>ID</sub>	Digital Input Voltage	-0.3 V	-	3.65 V	Respect to VSS
T <sub>A</sub>	Ambient Temperature	-40 °C	-	85 °C	
T <sub>S</sub>	Storage Temperature	-65 °C	-	150 °C	

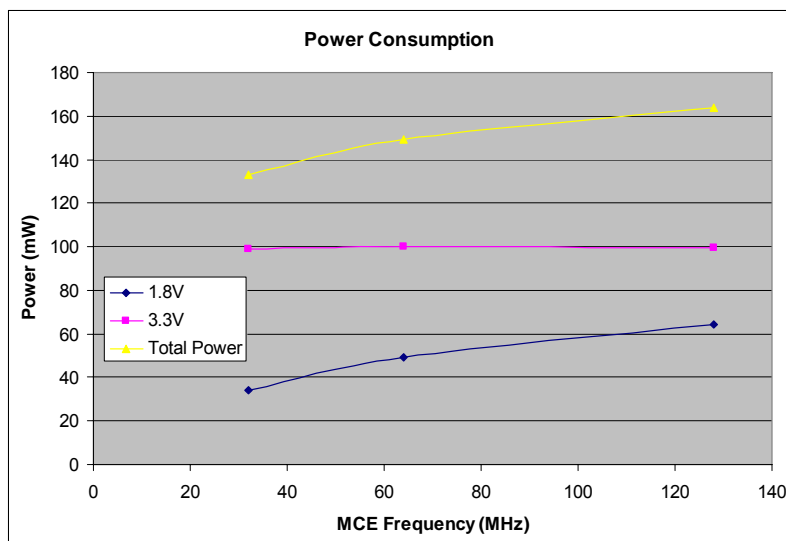
**Table 1. Absolute Maximum Ratings**

**Caution:** Stresses beyond those listed in “Absolute Maximum Ratings” may cause permanent damage to the device. These are stress ratings only and function of the device at these or any other conditions beyond those indicated in the operational sections of the specifications are not implied.

### 6.2 System Clock Frequency and Power Consumption

Symbol	Parameter	Min	Typ	Max	Unit
SYSCLK	System Clock	32	-	128	MHz
8051CLK	8051 Clock	-	-	32	MHz

**Table 2. System Clock Frequency**



### 6.3 Digital I/O DC Characteristics

Symbol	Parameter	Min	Typ	Max	Condition
V <sub>DD1</sub>	Supply Voltage	3.0 V	3.3 V	3.6 V	Recommended
V <sub>DD2</sub>	Supply Voltage	1.62 V	1.8 V	1.98 V	Recommended
V <sub>IL</sub>	Input Low Voltage	-0.3 V	-	0.8 V	Recommended
V <sub>IH</sub>	Input High Voltage	2.0 V		3.6 V	Recommended
C <sub>IN</sub>	Input capacitance	-	3.6 pF	-	(1)
I <sub>L</sub>	Input leakage current		±10 nA	±1 µA	V <sub>O</sub> = 3.3 V or 0 V
I <sub>OL1</sub> <sup>(2)</sup>	Low level output current	8.9 mA	13.2 mA	15.2 mA	V <sub>OL</sub> = 0.4 V (1)
I <sub>OH1</sub> <sup>(2)</sup>	High level output current	12.4 mA	24.8 mA	38 mA	V <sub>OH</sub> = 2.4 V (1)
I <sub>OL2</sub> <sup>(3)</sup>	Low level output current	17.9 mA	26.3 mA	33.4 mA	V <sub>OL</sub> = 0.4 V (1)
I <sub>OH2</sub> <sup>(3)</sup>	High level output current	24.6 mA	49.5 mA	81 mA	V <sub>OH</sub> = 2.4 V (1)

**Table 3. Digital I/O DC Characteristics**

Note:

- (1) Data guaranteed by design.
- (2) Applied to SCL/SO-SI, SDA/CS0 pins.
- (3) Applied to P1.0/T2, P1.1/RXD, P1.2/TXD, P1.3/SYNC/SCK, P1.4/CAP, P2.0/NMI, P2.1, P2.6/AOPWM0, P3.0/INT2/CS1, P3.2/INT0, P5.1/TMS, P5.2/TDO, P5.3/TDI, GATEKILL, PWMUL, PWMUH, PWMVL, PWMVH, PWMWL, PWMWH pins.

### 6.4 PLL and Oscillator DC characteristics

Symbol	Parameter	Min	Typ	Max	Condition
V <sub>PLLVD</sub>	Supply Voltage	1.62 V	1.8 V	1.92 V	Recommended
V <sub>IL OSC</sub>	Oscillator Input Low Voltage	V <sub>PLLSS</sub>	-	0.2* V <sub>PLLVD</sub>	V <sub>PLLVD</sub> = 1.8 V (1)
V <sub>IH OSC</sub>	Oscillator Input High Voltage	0.8* V <sub>PLLVD</sub>		V <sub>PLLVD</sub>	V <sub>PLLVD</sub> = 1.8 V (1)

**Table 4. PLL DC Characteristics**

Note:

- (1) Data guaranteed by design.

### 6.5 Analog I/O DC Characteristics

- OP amp for current sensing (IFB+, IFB-, IFBO)

$C_{AREF} = 1nF$ ,  $C_{MEXT} = 100nF$ . Unless specified,  $T_a = 25^{\circ}C$ .

Symbol	Parameter	Min	Typ	Max	Condition
$V_{AVDD}$	Supply Voltage	1.71 V	1.8 V	1.89 V	Recommended
$V_{OFFSET}$	Input Offset Voltage	-	-	26 mV	$V_{AVDD} = 1.8 V$
$V_I$	Input Voltage Range	0 V		1.2 V	Recommended
$V_{OUTSW}$	OP amp output operating range	50 mV <sup>(1)</sup>	-	1.2 V	$V_{AVDD} = 1.8 V$
$C_{IN}$	Input capacitance	-	3.6 pF	-	(1)
$R_{FDBK}$	OP amp feedback resistor	5 k $\Omega$	-	20 k $\Omega$	Requested between IFBO and IFB-
$OP_{GAINCL}$	Operating Close loop Gain	80 db	-	-	(1)
CMRR	Common Mode Rejection Ratio	-	80 db	-	(1)
$I_{SRC}$	Op amp output source current	-	1 mA	-	$V_{OUT} = 0.6 V$ (1)
$I_{SNK}$	Op amp output sink current	-	100 $\mu A$	-	$V_{OUT} = 0.6 V$ (1)

**Table 5. Analog I/O DC Characteristics**

Note:

(1) Data guaranteed by design.

### 6.6 Under Voltage Lockout DC characteristics

Unless specified,  $T_a = 25^{\circ}C$ ,  $AVDD (1.8V)$

Symbol	Parameter	Min	Typ	Max	Condition
$UV_{CC+}$	UVcc positive going Threshold <sup>(1)</sup>	1.53 V	1.66 V	1.71 V	$V_{DD1} = 3.3 V$
$UV_{CC-}$	UVcc negative going Threshold	1.52 V	1.62 V	1.71 V	$V_{DD1} = 3.3 V$
$UV_{CCH}$	UVcc Hysteresys	-	40 mV	-	

**Table 6. UVcc DC Characteristics**

Note:

(1) Data guaranteed by design.

### 6.7 AREF Characteristics

$C_{AREF} = 1nF$ ,  $C_{MEXT} = 100nF$ . Unless specified,  $T_a = 25^{\circ}C$ .

Symbol	Parameter	Min	Typ	Max	Condition
$V_{AREF}$	AREF Output Voltage	495 mV	600 mV	700 mV	$V_{AVDD} = 1.8 V$
$\Delta V_o$	Load regulation ( $V_{DC}-0.6$ )	-	1 mV	-	(1)
PSRR	Power Supply Rejection Ratio	-	75 db	-	(1)

**Table 7. AREF DC Characteristics**

Note: (1) Data guaranteed by design.

## 7 AC Characteristics

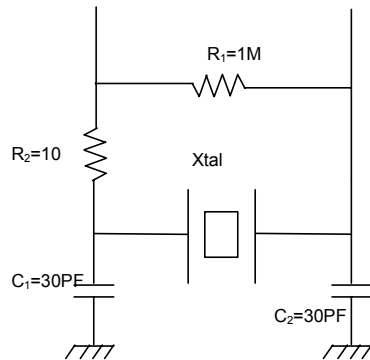
### 7.1 PLL AC Characteristics

Symbol	Parameter	Min	Typ	Max	Condition
$F_{CLKIN}$	Crystal input frequency	3.2 MHz	4 MHz	60 MHz	<sup>(1)</sup> (see figure below)
$F_{PLL}$	Internal clock frequency	32 MHz	50 MHz	128 MHz	<sup>(1)</sup>
$F_{LWPM}$	Sleep mode output frequency	$F_{CLKIN} \div 256$	-	-	<sup>(1)</sup>
$J_S$	Short time jitter	-	200 psec	-	<sup>(1)</sup>
$D$	Duty cycle	-	50 %	-	<sup>(1)</sup>
$T_{LOCK}$	PLL lock time	-	-	500 $\mu$ sec	<sup>(1)</sup>

**Table 8. PLL AC Characteristics**

Note:

(1) Data guaranteed by design.



**Figure 7 Crystal oscillator circuit**



## 7.2 Analog to Digital Converter AC Characteristics

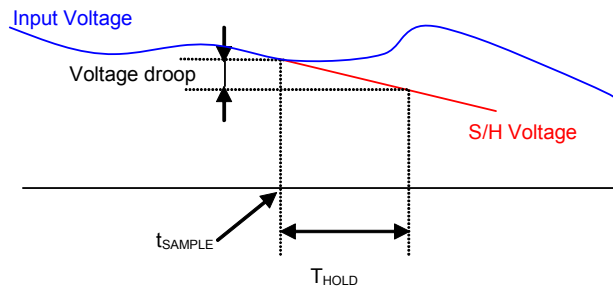
Unless specified,  $T_a = 25^\circ\text{C}$ .

Symbol	Parameter	Min	Typ	Max	Condition
$T_{\text{CONV}}$	Conversion time	-	-	2.05 $\mu\text{sec}$	<sup>(1)</sup>
$T_{\text{HOLD}}$	Sample/Hold maximum hold time	-	-	10 $\mu\text{sec}$	Voltage droop $\leq$ 15 LSB (see figure below)

**Table 9. A/D Converter AC Characteristics**

Note:

(1) Data guaranteed by design.



**Figure 8 Voltage droop of sample and hold**

## 7.3 Op Amp AC Characteristics

- OP amps for current sensing (IFB+, IFB-, IFBO)

Unless specified,  $T_a = 25^\circ\text{C}$ .

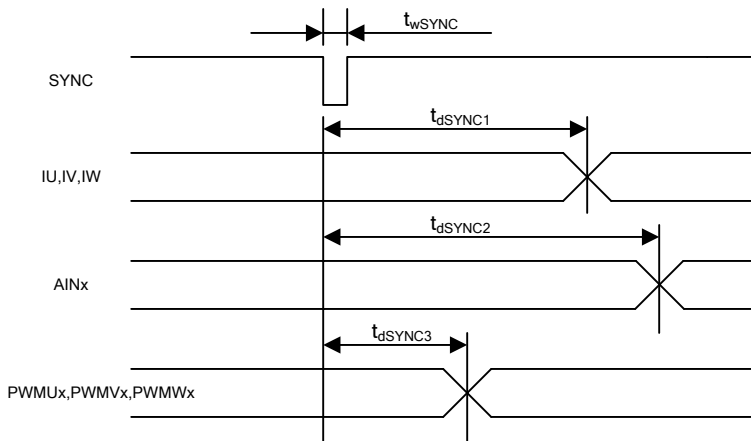
Symbol	Parameter	Min	Typ	Max	Condition
$OP_{\text{SR}}$	OP amp slew rate	-	10 V/ $\mu\text{sec}$	-	$V_{\text{AVDD}} = 1.8 \text{ V}$ , $CL = 33 \text{ pF}$ <sup>(1)</sup>
$OP_{\text{IMP}}$	OP input impedance	-	$10^8 \Omega$	-	<sup>(1)</sup>
$T_{\text{SET}}$	Settling time	-	400 ns	-	$V_{\text{AVDD}} = 1.8 \text{ V}$ , $CL = 33 \text{ pF}$ <sup>(1)</sup>

**Table 10. Current Sensing OP amp Amp AC Characteristics**

Note:

(1) Data guaranteed by design.

### 7.4 SYNC to SVPWM and A/D Conversion AC Timing



**Figure 9 SYNC to SVPWM and A/D Conversion AC Timing**

Unless specified,  $T_a = 25^\circ\text{C}$ .

Symbol	Parameter	Min	Typ	Max	Unit
$t_{wSYNC}$	SYNC pulse width	-	32	-	SYSClk
$t_{dSYNC1}$	SYNC to current feedback conversion time	-	-	100	SYSClk
$t_{dSYNC2}$	SYNC to AIN0-6 analog input conversion time	-	-	200	SYSClk <sup>(1)</sup>
$t_{dSYNC3}$	SYNC to PWM output delay time	-	-	2	SYSClk

**Table 11. SYNC AC Characteristics**

Note:

(1) AIN1 through AIN6 channels are converted once every 6 SYNC events

### 7.5 GATEKILL to SVPWM AC Timing

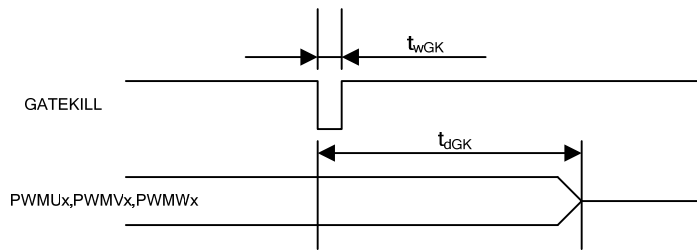


Figure 10 GATEKILL to SVPWM AC Timing

Unless specified, Ta = 25°C.

Symbol	Parameter	Min	Typ	Max	Unit
t <sub>wGK</sub>	GATEKILL pulse width	32	-	-	SYCLK
t <sub>dGK</sub>	GATEKILL to PWM output delay	-	-	100	SYCLK

Table 12. GATEKILL to SVPWM AC Timing

### 7.6 Interrupt AC Timing

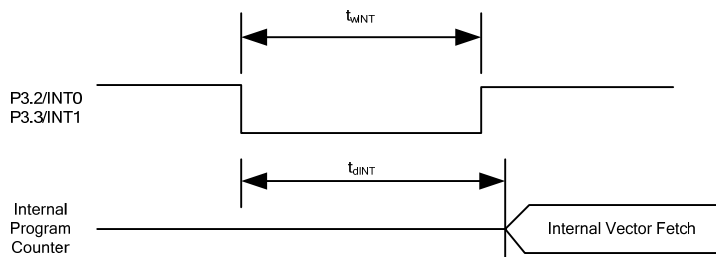


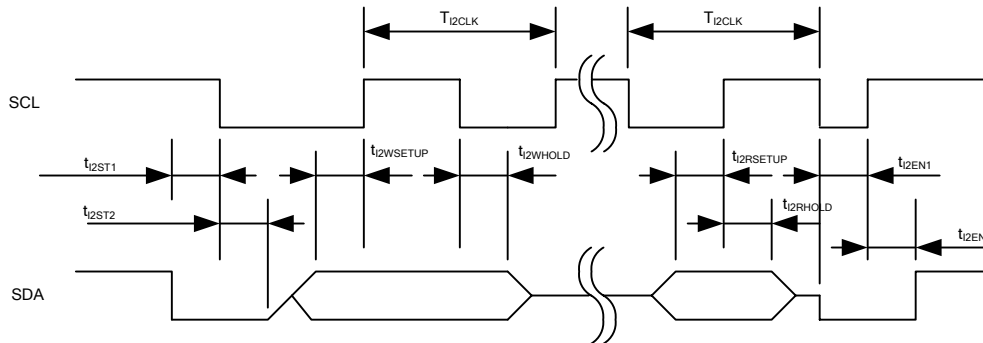
Figure 11 Interrupt AC Timing

Unless specified, Ta = 25°C.

Symbol	Parameter	Min	Typ	Max	Unit
t <sub>wINT</sub>	INT0, INT1 Interrupt Assertion Time	4	-	-	SYCLK
t <sub>dINT</sub>	INT0, INT1 latency	-	-	4	SYCLK

Table 13. Interrupt AC Timing

## 7.7 I<sup>2</sup>C AC Timing



**Figure 12 I<sup>2</sup>C AC Timing**

Unless specified, Ta = 25°C.

Symbol	Parameter	Min	Typ	Max	Unit
T <sub>I2CLK</sub>	I <sup>2</sup> C clock period	10	-	8192	SYSCLK
t <sub>I2ST1</sub>	I <sup>2</sup> C SDA start time	0.25	-	-	T <sub>I2CLK</sub>
t <sub>I2ST2</sub>	I <sup>2</sup> C SCL start time	0.25	-	-	T <sub>I2CLK</sub>
t <sub>I2WSETUP</sub>	I <sup>2</sup> C write setup time	0.25	-	-	T <sub>I2CLK</sub>
t <sub>I2WHOLD</sub>	I <sup>2</sup> C write hold time	0.25	-	-	T <sub>I2CLK</sub>
t <sub>I2RSETUP</sub>	I <sup>2</sup> C read setup time	I <sup>2</sup> C filter time <sup>(1)</sup>	-	-	SYSCLK
t <sub>I2RHOLD</sub>	I <sup>2</sup> C read hold time	1	-	-	SYSCLK

**Table 14. I<sup>2</sup>C AC Timing**

Note:

- (1) I<sup>2</sup>C read setup time is determined by the programmable filter time applied to I<sup>2</sup>C communication.

## 7.8 SPI AC Timing

### 7.8.1 SPI Write AC timing

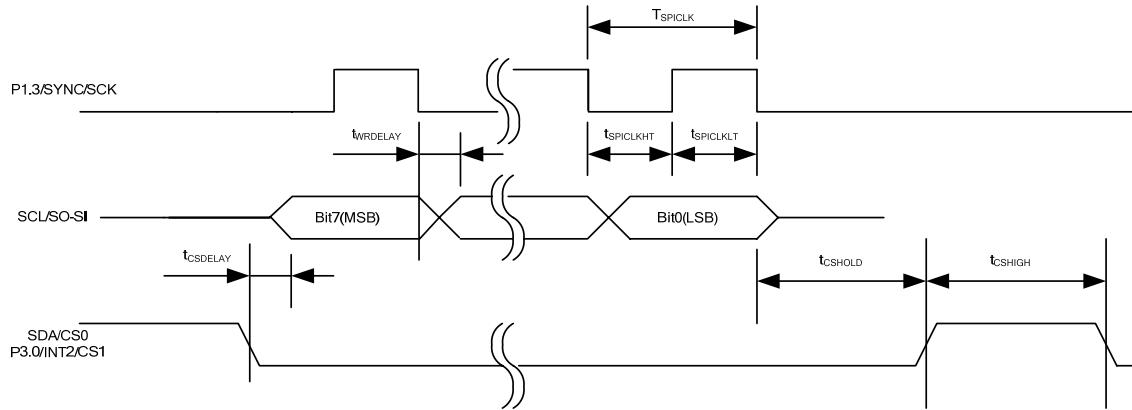


Figure 13 SPI write AC Timing

Unless specified,  $T_a = 25^\circ\text{C}$ .

Symbol	Parameter	Min	Typ	Max	Unit
$T_{\text{SPICLK}}$	SPI clock period	4	-	-	SYSCLOCK
$t_{\text{SPICLKHT}}$	SPI clock high time	-	1/2	-	$T_{\text{SPICLK}}$
$t_{\text{SPICLKLT}}$	SPI clock low time	-	1/2	-	$T_{\text{SPICLK}}$
$t_{\text{CSDELAY}}$	CS to data delay time	-	-	10	nsec
$t_{\text{WRDELAY}}$	CLK falling edge to data delay time	-	-	10	nsec
$t_{\text{CSHIGH}}$	CS high time between two consecutive byte transfer	1	-	-	$T_{\text{SPICLK}}$
$t_{\text{CSHOLD}}$	CS hold time	-	1	-	$T_{\text{SPICLK}}$

Table 15. SPI Write AC Timing

7.8.2 SPI Read AC Timing

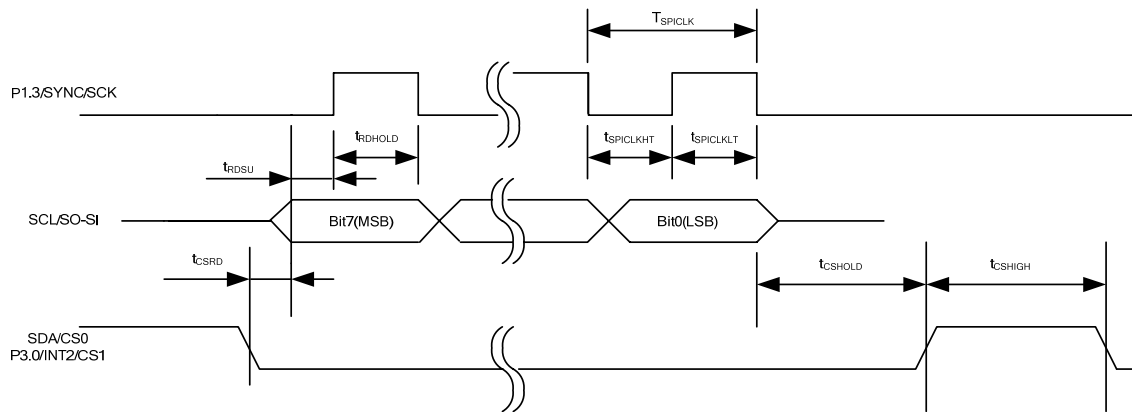


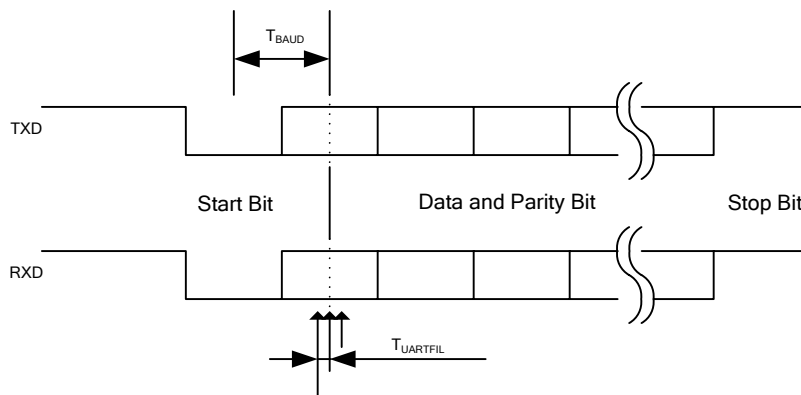
Figure 14 SPI read AC Timing

Unless specified, Ta = 25°C.

Symbol	Parameter	Min	Typ	Max	Unit
T <sub>SPICLK</sub>	SPI clock period	4	-	-	SYSCLK
t <sub>SPICLKHT</sub>	SPI clock high time	-	1/2	-	T <sub>SPICLK</sub>
t <sub>SPICLKLT</sub>	SPI clock low time	-	1/2	-	T <sub>SPICLK</sub>
t <sub>CSRDL</sub>	CS to data delay time	-	-	10	nsec
t <sub>RDSU</sub>	SPI read data setup time	10	-	-	nsec
t <sub>RDHOLD</sub>	SPI read data hold time	10	-	-	nsec
t <sub>CSHIGH</sub>	CS high time between two consecutive byte transfer	1	-	-	T <sub>SPICLK</sub>
t <sub>CSHOLD</sub>	CS hold time	-	1	-	T <sub>SPICLK</sub>

Table 16. SPI Read AC Timing

## 7.9 UART AC Timing



**Figure 15 UART AC Timing**

Unless specified,  $T_a = 25^\circ\text{C}$ .

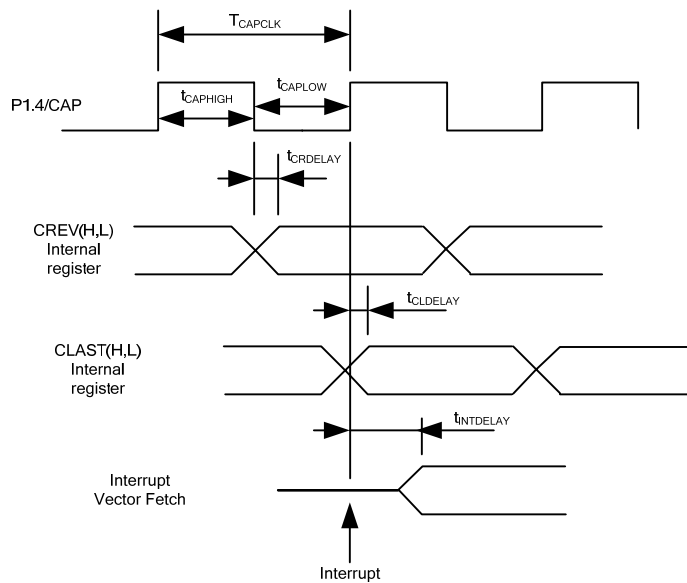
Symbol	Parameter	Min	Typ	Max	Unit
$T_{BAUD}$	Baud Rate Period	-	57600	-	bit/sec
$T_{UARTFIL}$	UART sampling filter period <sup>(1)</sup>	-	1/16	-	$T_{BAUD}$

**Table 17. UART AC Timing**

Note:

- (1) Each bit including start and stop bit is sampled three times at center of a bit at an interval of  $1/16 T_{BAUD}$ . If three sampled values do not agree, then UART noise error is generated.

### 7.10 CAPTURE Input AC Timing



**Figure 16 CAPTURE Input AC Timing**

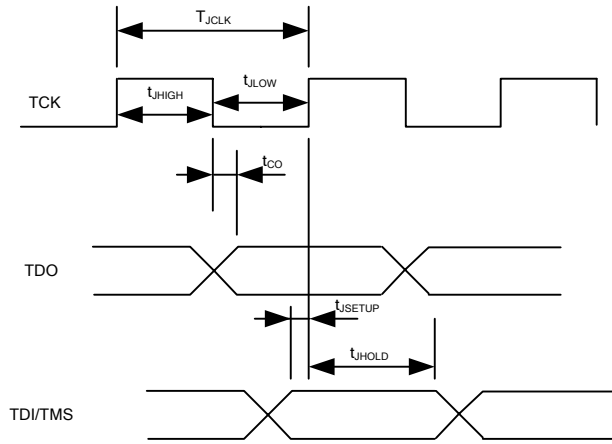
Unless specified,  $T_a = 25^\circ\text{C}$ .

Symbol	Parameter	Min	Typ	Max	Unit
$T_{CAPCLK}$	CAPTURE input period	8	-	-	SYSCLK
$t_{CAPHIGH}$	CAPTURE input high time	4	-	-	SYSCLK
$t_{CAPLOW}$	CAPTURE input low time	4	-	-	SYSCLK
$t_{CRDELAY}$	CAPTURE falling edge to capture register latch time	-	-	4	SYSCLK
$t_{CLDELAY}$	CAPTURE rising edge to capture register latch time	-	-	4	SYSCLK
$t_{INTDELAY}$	CAPTURE input interrupt latency time	-	-	4	SYSCLK

**Table 18. CAPTURE AC Timing**



### 7.11 JTAG AC Timing



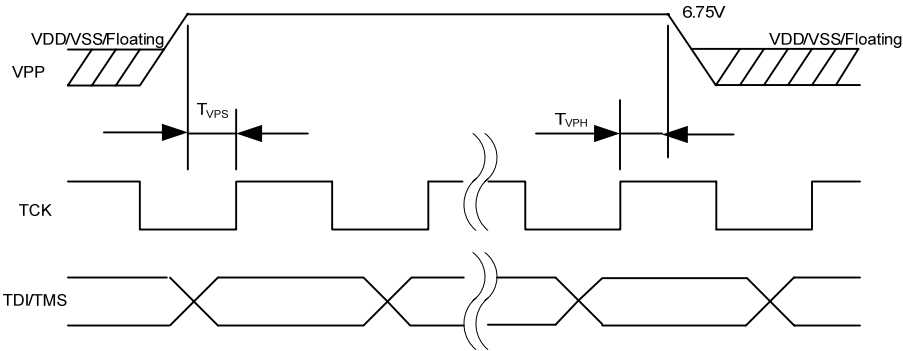
**Figure 17 JTAG AC Timing**

Unless specified,  $T_a = 25^\circ\text{C}$ .

Symbol	Parameter	Min	Typ	Max	Unit
$T_{JCLK}$	TCK Period	-	-	50	MHz
$t_{JHIGH}$	TCK High Period	10	-	-	nsec
$t_{JLOW}$	TCK Low Period	10	-	-	nsec
$t_{CO}$	TCK to TDO propagation delay time	0	-	5	nsec
$t_{JSETUP}$	TDI/TMS setup time	4	-	-	nsec
$t_{JHOLD}$	TDI/TMS hold time	0	-	-	nsec

**Table 19. JTAG AC Timing**

## 7.12 OTP Programming Timing



**Figure 18 OTP Programming Timing**

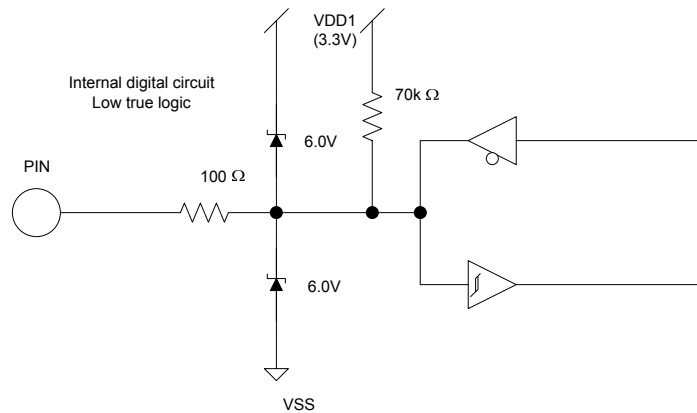
Unless specified,  $T_a = 25^\circ\text{C}$ .

Symbol	Parameter	Min	Typ	Max	Unit
$T_{VPS}$	VPP Setup Time	10	-	-	nsec
$T_{VPH}$	VPP Hold Time	15	-	-	nsec

**Table 20. OTP Programming Timing**

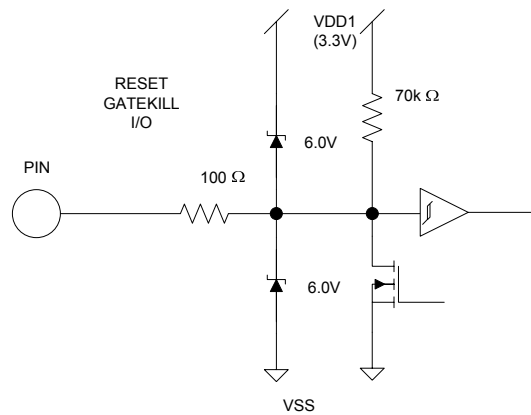
## 8 I/O Structure

The following figure shows the motor PWM and digital I/O structure



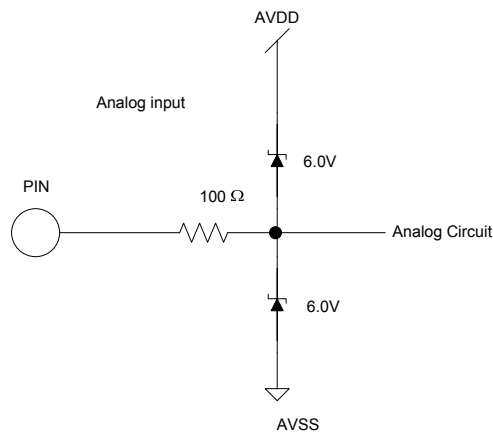
**Figure 19 All digital I/O except motor PWM output**

The following figure shows RESET and GATEKILL I/O structure.



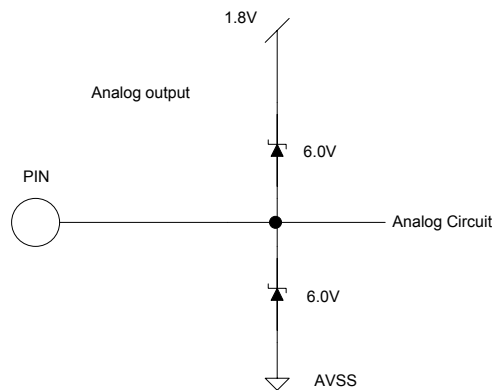
**Figure 20 RESET, GATEKILL I/O**

The following figure shows the analog input structure.



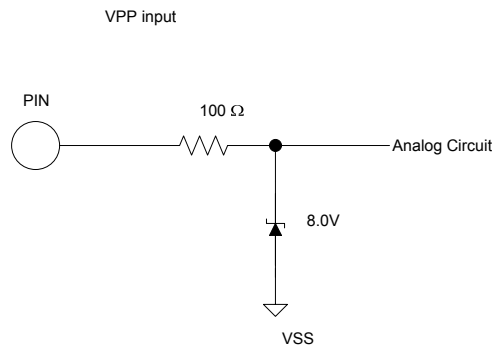
**Figure 21 Analog input**

The following figure shows all analog operational amplifier output pins and AREF pin I/O structure.



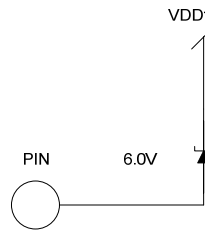
**Figure 22 Analog operational amplifier output and AREF I/O structure**

The following figure shows the VPP pin I/O structure



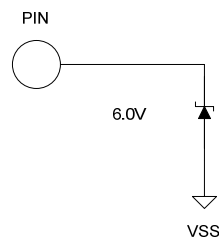
**Figure 23 VPP programming pin I/O structure**

The following figure shows the VSS, AVSS and PLLVSS pin structure



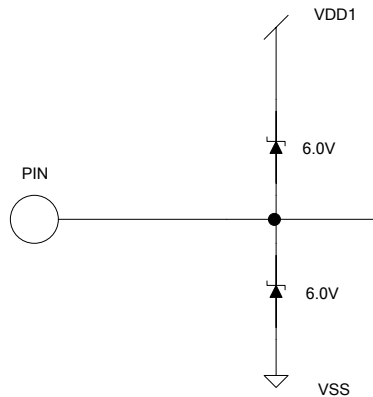
**Figure 24 VSS, AVSS and PLLVSS pin structure**

The following figure shows the VDD1, VDD2, AVDD and PLLVDD pin structure



**Figure 25 VDD1, VDD2, AVDD and PLLVDD pin structure**

The following figure shows the XTAL0 and XTAL1 pins structure



**Figure 26 XTAL0/XTAL1 pins structure**

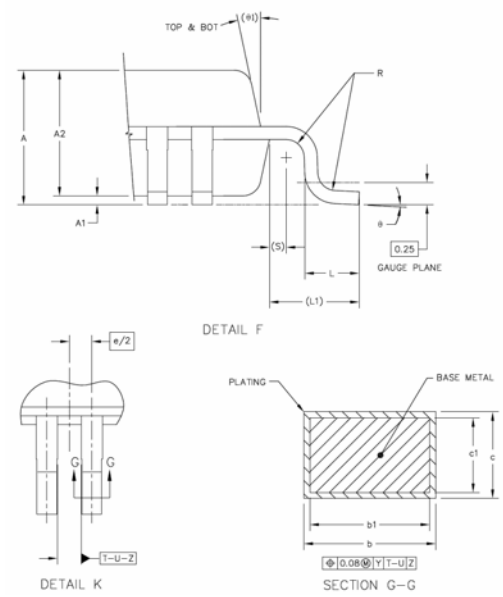
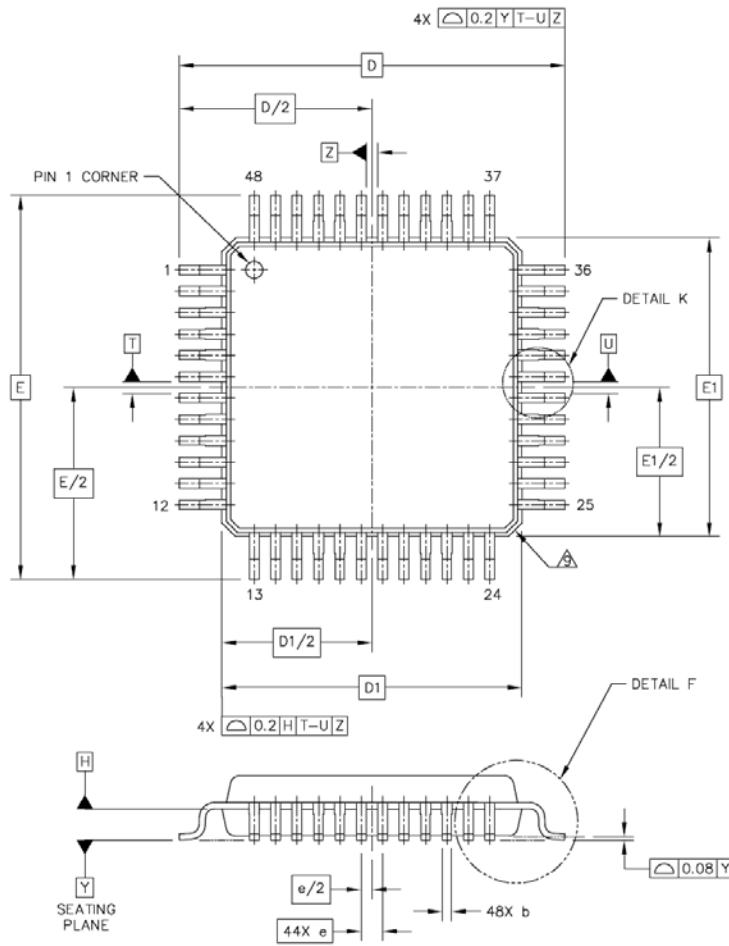
## 9 Pin List

Pin Number	Pin Name	Internal Pull-up /Pull-down	Pin Type	Description
1	XTAL0		I	Crystal input
2	XTAL1		O	Crystal output
3	P1.0/T2		I/O	Discrete programmable I/O or Timer/Counter 2 input
4	P1.1/RXD		I/O	Discrete programmable I/O or UART receive input
5	P1.2/TXD		I/O	Discrete programmable I/O or UART transmit output
6	P1.3/SYNC/SCK		I/O	Discrete programmable I/O or SYNC output or SPI clock output
7	P1.4/CAP		I/O	Discrete programmable I/O or Capture Timer input
8	VDD2		P	1.8V digital power
9	VSS		P	Digital common
10	VDD1		P	3.3V digital power
11	P2.0/NMI		I/O	Discrete I/O or Non Maskable Interrupt
12	P2.1		I/O	Discrete I/O
13	P2.6/AOPWM		I/O	Discrete I/O or PWM digital output
14	VDD2		P	1.8V digital power
15	VSS		P	Digital common
16	AIN0		I	Analog input channel 0, 0-1.2V range, needs to be pulled down to AVSS if unused
17	AVDD		P	1.8V analog power
18	AVSS		P	Analog common
19	AIN1		I	Analog input channel 1, 0-1.2V range, needs to be pulled down to AVSS if unused
20	CMEXT		O	Unbuffered 0.6V output. Capacitor needs to be connected.
21	AREF		O	Analog reference voltage output (0.6V)
22	IFB-		I	Single shunt current sensing OP amp input (-)
23	IFB+		I	Single shunt current sensing OP amp input (+)
24	IFBO		O	Single shunt current sensing OP amp output
25	AIN2		I	Analog input channel 2, 0-1.2V range, needs to be pulled down to AVSS if unused
26	VDD2		P	1.8V digital power
27	VSS		P	Digital common
28	VDD1		P	3.3V digital power
29	GATEKILL		I	PWM shutdown input, 2- $\mu$ sec digital filter, configurable either high or low true.
30	PWMWL	70 k $\Omega$ Pull up	O	PWM gate drive for phase W low side, configurable either high or low true
31	PWMWH	70 k $\Omega$ Pull up	O	PWM gate drive for phase W high side, configurable either high or low true

Pin Number	Pin Name	Internal Pull-up /Pull-down	Pin Type	Description
32	PWMVL	70 kΩ Pull up	O	PWM gate drive for phase V low side, configurable either high or low true
33	PWMVH	70 kΩ Pull up	O	PWM gate drive for phase V high side, configurable either high or low true
34	PWMUL	70 kΩ Pull up	O	PWM gate drive for phase U low side, configurable either high or low true
35	PWMUH	70 kΩ Pull up	O	PWM gate drive for phase U high side, configurable either high or low true
36	P3.0/INT2/C S1		I/O	Discrete programmable I/O or external interrupt 2 input or SPI chip select 1
37	P3.2/NINT0		I/O	Discrete programmable I/O or external interrupt 0 input
38	VSS		P	Digital common
39	SCL/SO-SI		I/O	I2C clock or SPI data
40	SDA/CS0		I/O	I2C data or SPI chip select 0
41	P5.1/TMS		I/O	Discrete I/O or JTAG test mode select
42	P5.2/TDO		I/O	Discrete I/O or JTAG test data output
43	P5.3/TDI		I/O	Discrete I/O or JTAG test data input
44	TCK		I	JTAG test clock input
45	TSTMOD	58 kΩ pull down	I	Test mode input, must be tied to VSS
46	RESET		I/O	Reset, low true, Schmitt trigger input
47	PLLVDD		P	1.8V PLL power
48	PLLVSS		P	PLL ground

**Table 21. Pin List**

# 10 Package Dimensions



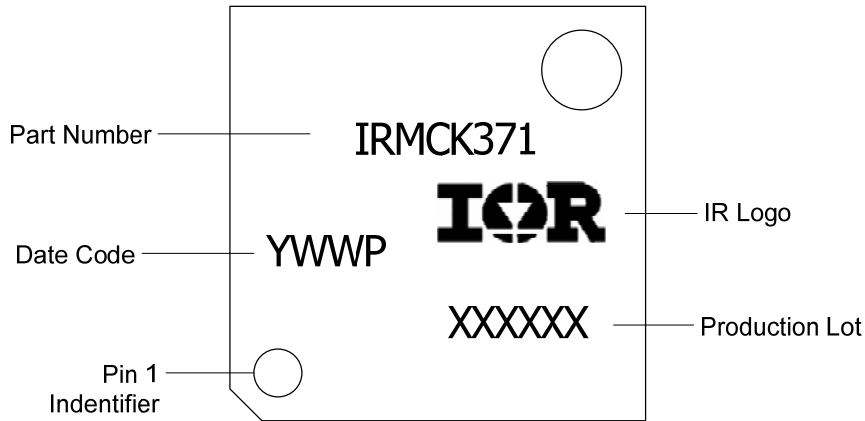
NOTES:

1. DIMENSIONS ARE IN MILLIMETERS.
  2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
  3. DATUM PLANE H IS LOCATED AT BOTTOM OF LEAD AND IS COINCIDENT WITH THE LEAD WHERE THE LEAD EXITS THE PLASTIC BODY AT THE BOTTOM OF THE PARTING LINE.
  4. DATUM T, U AND Z TO BE DETERMINED AT DATUM PLANE H.
  5. DIMENSIONS D AND E TO BE DETERMINED AT SEATING PLANE Y.
  6. DIMENSIONS D1 AND E1 DO NOT INCLUDE MOLD PROTRUSION. ALLOWABLE PROTRUSION IS 0.25 PER SIDE. DIMENSIONS D1 AND E1 DO INCLUDE MOLD MISMATCH AND ARE DETERMINED AT DATUM PLANE H.
  7. DIMENSION b DOES NOT INCLUDE DAM BAR PROTRUSION. DAM BAR PROTRUSION SHALL NOT CAUSE THE b DIMENSION TO EXCEED 0.35.
  8. MINIMUM SOLDER PLATE THICKNESS SHALL BE 0.0076.
- △ EXACT SHAPE OF EACH CORNER IS OPTIONAL.

DIM	MIN	MAX	DIM	MIN	MAX	DIM	MIN	MAX
A	1.4	1.6	L1	1 REF				
A1	0.05	0.15	R	0.15	0.25			
A2	1.35	1.45	S	0.2 REF				
b	0.17	0.27	θ	1°	5°			
b1	0.17	0.23	θ1	12° REF				
c	0.09	0.2						
c1	0.09	0.16						
D	9 BSC							
D1	7 BSC							
e	0.5 BSC							
E	9 BSC							
E1	7 BSC							
L	0.5	0.7						



## 11 Part Marking Information



## 12 Order Information

**Lead-Free Part in 48-lead QFP**  
**Moisture Sensitivity Rating – MSL3**

Part number	Order quantities
IRMCK371TR	2000 parts on tape and reel in dry pack
IRMCK371TY	2500 parts on trays (160 parts per tray) in dry pack

International  
**IOR** Rectifier

The LQFP-48 is MSL3 qualified  
 This product has been designed and qualified for the industrial level  
 Qualification standards can be found at [www.irf.com](http://www.irf.com) <<http://www.irf.com>>  
 IR WORLD HEADQUARTERS: 233 Kansas St., El Segundo, California 90245, Tel: (310) 252-7105  
 Data and specifications subject to change without notice. 12/25/2007

[www.irf.com](http://www.irf.com)