iMOTION™

High Performance Sensorless Motor Control IC

Description

IRMCF188 is a high performance Flash based motion control IC designed and optimized for complete air conditioner control which contains two computation engines integrated into one monolithic chip. One is the Flexible Motion Control Engine (MCE™) for sensorless control of permanent magnet motors or induction motors; the other is an 8-bit high-speed microcontroller (8051). The user can program a motion control algorithm by connecting these control elements using a graphic compiler. Key components of the complex sensorless control algorithms, such as the Angle Estimator, are provided as complete pre-defined control blocks. A unique analog/digital circuit and algorithm fully supports single shunt or leg shunt current reconstruction. IRMCF188 performs a PFC (Power Factor Correction) function in addition to the motor control. IRMCF188 comes in a 64 pin QFP package.

Features

- MCE™ (Flexible Motion Control Engine) - Dedicated computation engine for high efficiency sinusoidal sensorless motor control
- Built-in hardware peripheral for single or two shunt current feedback reconstruction and analog circuits
- Supports induction machine and both interior and surface permanent magnet motor sensorless control
- Dedicated PFC PWM for digital PFC control
- Loss minimization Space Vector PWM
- Three-channel 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)
- I2C/SPI serial interface
- Three general purpose timers/counters
- Two special timers: periodic timer, capture timer
- Watchdog timer with independent internal clock
- Internal 64 Kbyte flash memory
- 3.3V single supply

Product Summary

Maximum clock input ($f_{crystal}$)	60 MHz
Maximum Internal clock (SYSCLK)	120MHz
Maximum 8051 clock (8051CLK)	30MHz
MCE™ computation data range	16 bit signed
8051 Program Flash	52KB
8051/MCE Data RAM	4KB
MCE Program RAM	12KB
GateKill latency (digital filtered)	2 µsec
PWM carrier frequency	20 bits/ SYSCLK
A/D input channels	10
A/D converter resolution	12 bits
A/D converter conversion speed	2 µsec
Analog output (PWM) resolution	8 bits
UART baud rate (typ)	57.6 Kbps
Number of digital I/O (max)	24
Package (lead free)	QFP64
Typical 3.3V operating current	30mA

Base Part Number	Package Type	Standard Pack		Orderable Part Number
		Form	Quantity	
IRMCF188	LQFP64	Tape and Reel	1500	IRMCF188TR
IRMCF188	LQFP64	Tray	1600	IRMCF188TY

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1 Overview

IRMCF188 is a new generation International Rectifier integrated circuit device primarily designed as a one-chip solution for complete inverterized appliance motor control applications. Unlike a traditional microcontroller or DSP, the IRMCF188 provides a built-in closed loop sensorless control algorithm using the unique Flexible Motion Control Engine (MCE™) for permanent magnet motors as well as induction 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. IRMCF188 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, while still supporting leg shunt current sensing. 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. Figure 1 shows a typical application schematic using the IRMCF188 in leg shunt mode.

IRMCF188 contains 64K bytes of Flash program memory and comes in a 64-pin QFP package.

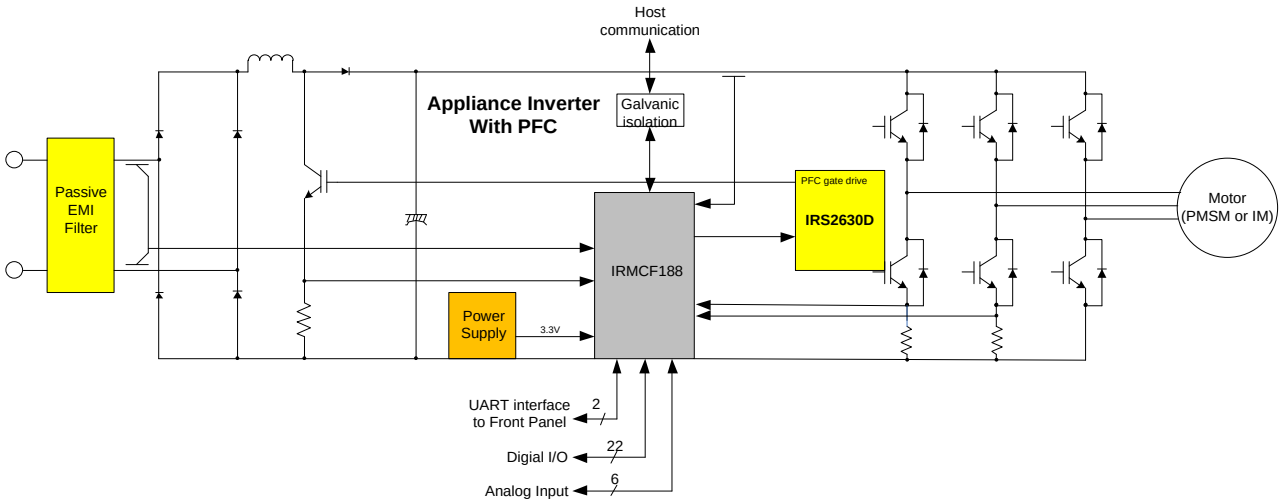

Figure 1. Typical Application Block Diagram Using IRMCF188

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2 Pinout

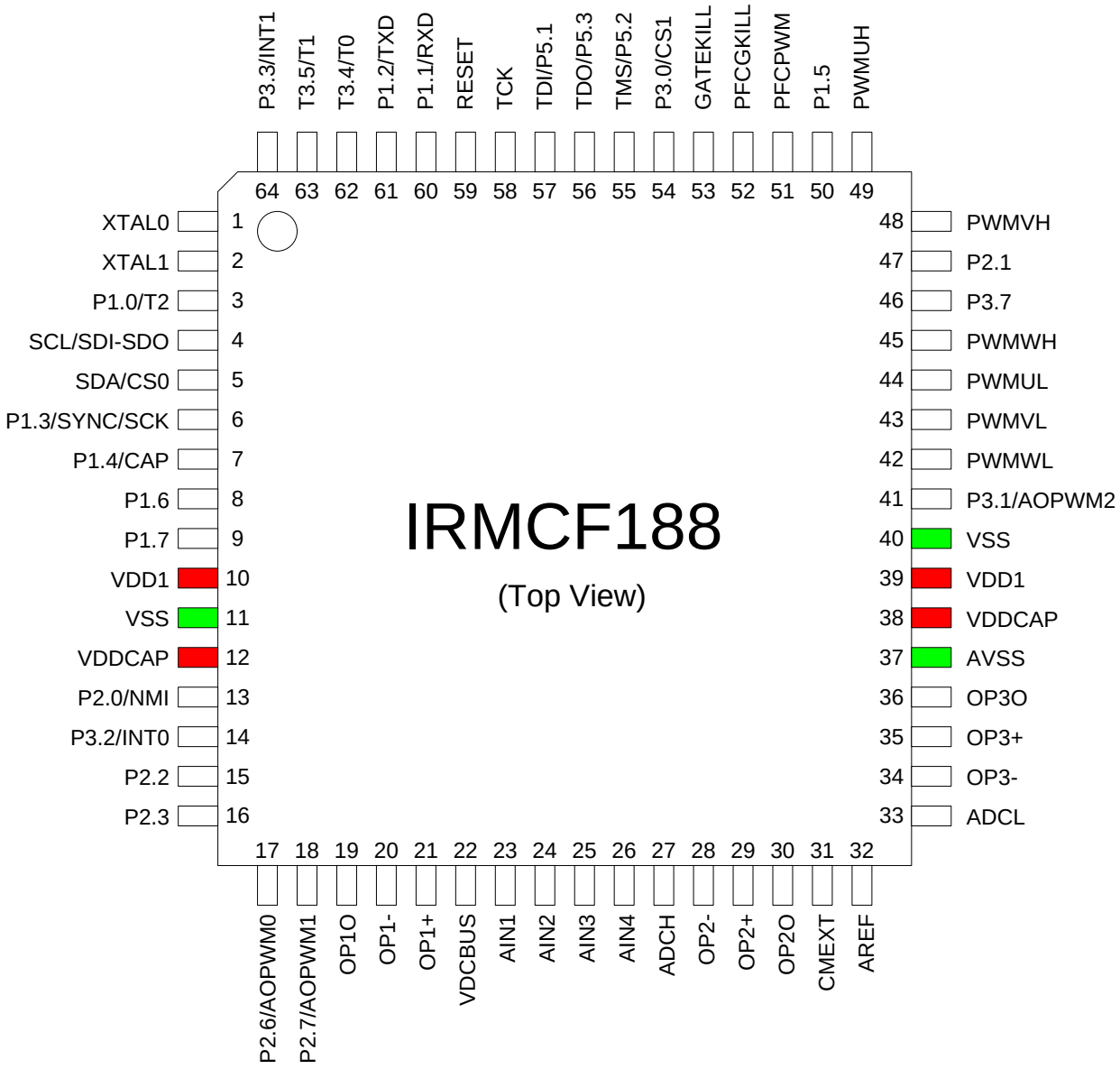

Figure 2. Pinout of IRMCF188

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3 IRMCF188 Block Diagram and Main Functions

IRMCF188 block diagram for leg shunt mode is shown in Figure 3.

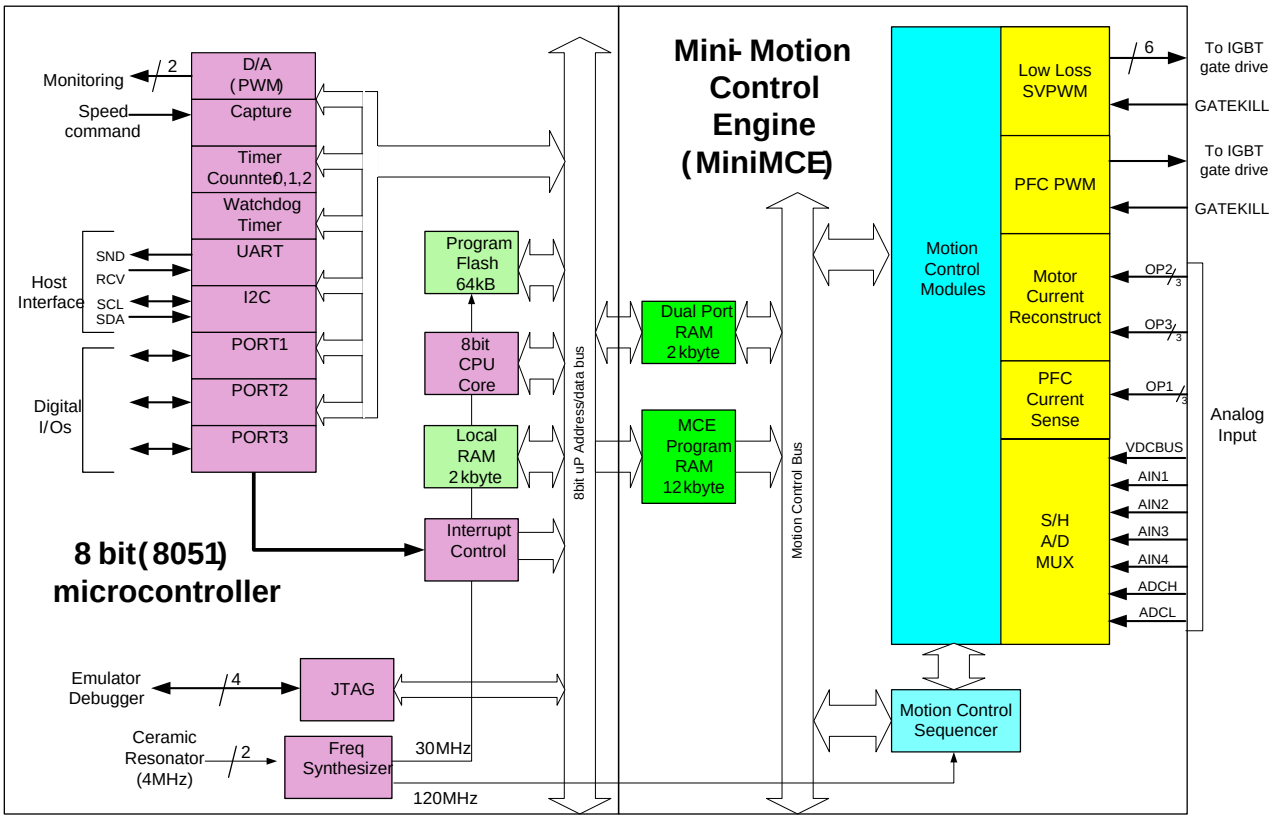

Figure 3. IRMCF188 Block Diagram

IRMCF188 contains the following functions for sensorless AC motor control applications:

Motion Control Engine (MCE™)

- Sensorless FOC (complete sensorless field oriented control)
- 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)
- Adder

8051 microcontroller

- Two 16 bit timer/counters
- One 16 bit periodic timer
- One 16 bit watchdog timer
- One 16 bit capture timer
- Up to 24 discrete digital I/Os
- Ten-channel 12 bit A/D
  - Buffered (current sensing) three channels (0 – 1.2V input)
  - Unbuffered seven channels (0 – 1.2V input)
- JTAG port (4 pins)
- Up to three channels of analog output (8 bit PWM)
- UART
- I^2C/SPI port

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- Divide (signed and unsigned)
- 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 memory and dual port RAM (6K byte)
- MCE™ control sequencer
- 64K byte Flash memory
- 2K byte data RAM

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4 Application connection and Pin function

Figure 4 shows the application connections in leg shunt mode. Figure 5 shows the application connections in single shunt mode.

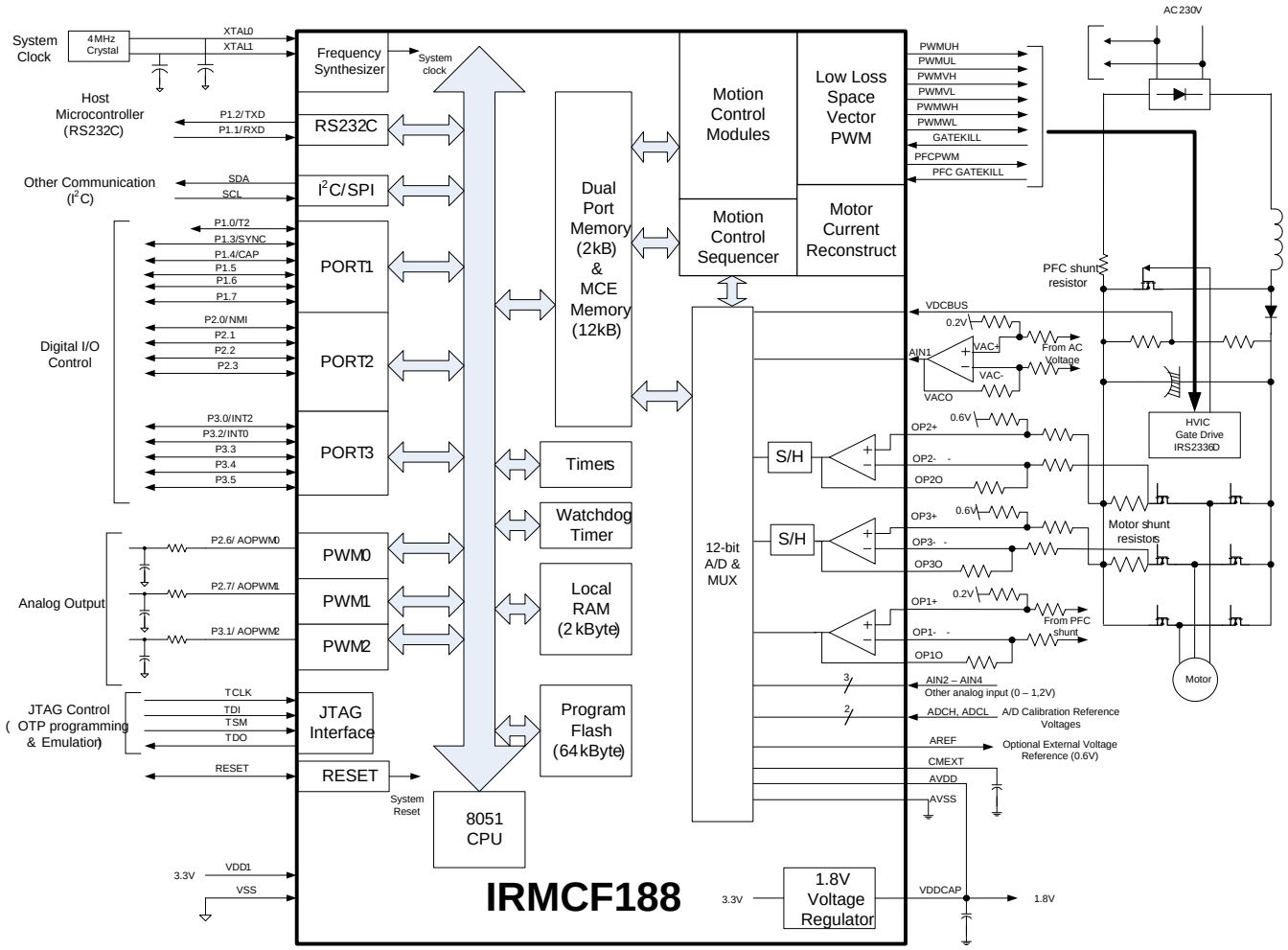

Figure 4. IRMCF188 Leg Shunt Connection Diagram

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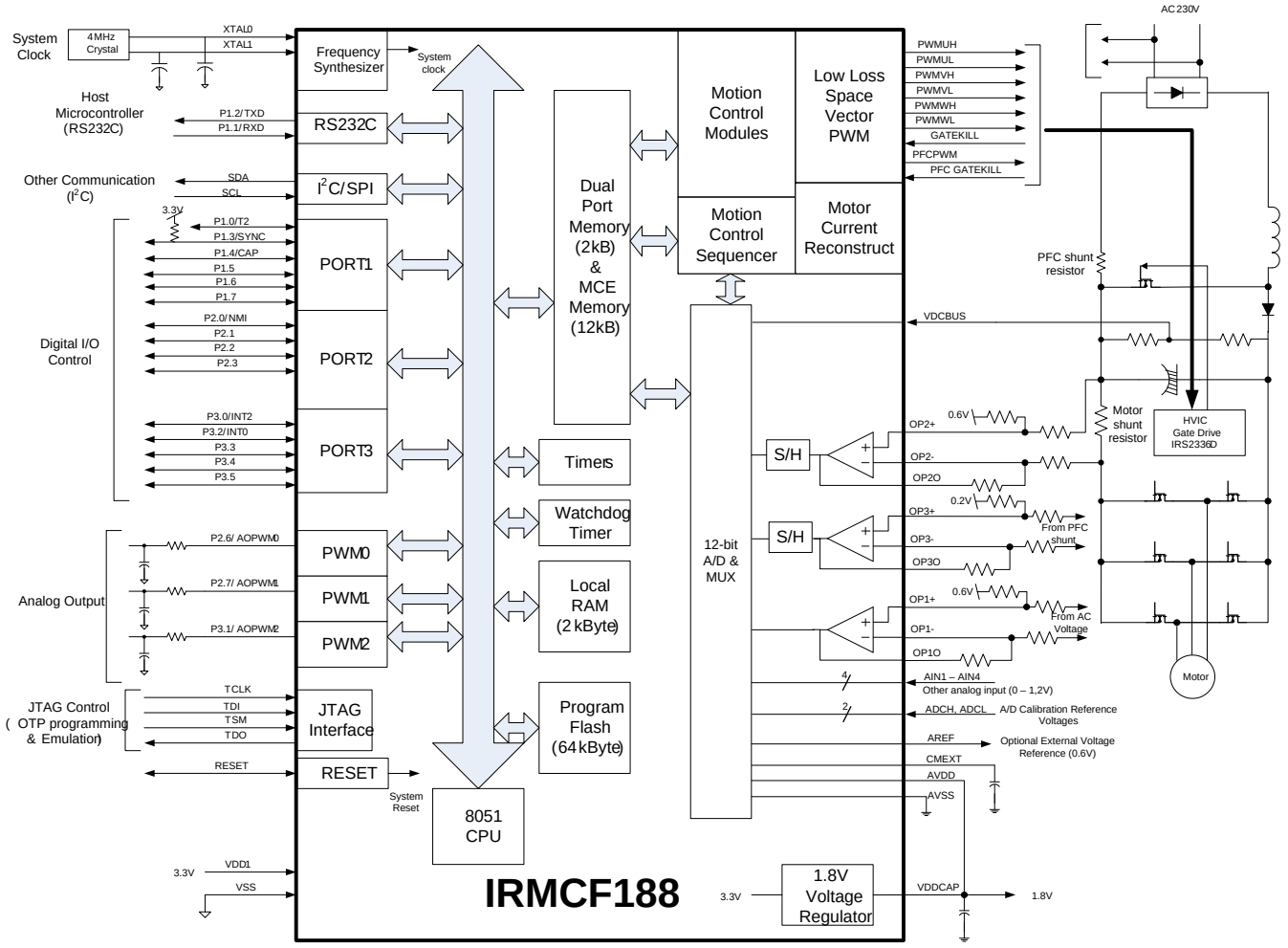

Figure 5. IRMCF188 Single Shunt Connection Diagram

4.1 8051 Peripheral Interface Group

UART Interface

P1.2/TXD	Output, Transmit data from IRMCF188
P1.1/RXD	Input, Receive data to IRMCF188

Discrete I/O Interface

P1.0/T2	Input/output port 1.0, can be configured as Timer/Counter 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 output
P1.4/CAP	Input/output port 1.4, can be configured as Capture Timer input
P1.5	Input/output port 1.5
P1.6	Input/output port 1.6
P1.7	Input/output port 1.6
P2.0/NMI	Input/output port 2.0, can be configured as non-maskable interrupt input
P2.2	Input/output port 2.2
P2.3	Input/output port 2.3
P2.6/AOPWM0	Input/output port 2.6, can be configured as AOPWM0 output

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P2.7/AOPWM1	Input/output port 2.7, can be configured as AOPWM1 output
P3.0/INT2/CS1	Input/output port 3.0, can be configured as INT2 input or SPI chip select 1
P3.1/AOPWM2	Input/output port 3.1, can be configured as AOPWM2 output
P3.2/NINT0	Input/output port 3.2, can be configured as INT0 input
P3.3/NINT1	Input/output port 3.3, can be configured as INT1 input
P3.4/T0	Input/output port 3.4, can be configured as T0 input for counter mode
P3.5/T1	Input/output port 3.5, can be configured as T1 input for counter mode
P3.7	Input/output port 3.7
P5.1/TDI	Input port 5.1, configured as JTAG port by default
P5.2/TMS	Input port 5.2, configured as JTAG port by default

Analog Output Interface

P2.6/AOPWM0	Input/output, can be configured as 8-bit PWM output 0 with programmable carrier frequency
P2.7/AOPWM1	Input/output, can be configured as 8-bit PWM output 1 with programmable carrier frequency
P3.1/AOPWM2	Input/output, can be configured as 8-bit PWM output 2 with programmable carrier frequency

Crystal Interface

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

Reset Interface

RESET	Input and Output, system reset, doesn't require external RC time constant

I^2C Interface

SCL/SO-SI	Output, I^2C clock output, or SPI data
SDA/CS0	Input/output, I^2C Data line or SPI chip select 0

I^2C/SPI Interface

SCL/SO-SI	Output, I^2C clock output, or SPI data
SDA/CS0	Input/output, I^2C data line or SPI chip select 0
P1.3/SYNC/SCK	Input/output port 1.3, can be configured as SYNC output or SPI clock output
P3.0/INT2/CS1	Input/output port 3.0, can be configured as INT2 input or SPI chip select 1

4.2 Motion Peripheral Interface Group

PWM

PWMUH	Output, PWM phase U high side gate signal, internally pulled down by 58kΩ, configured high true at a power up
PWMUL	Output, PWM phase U low side gate signal, internally pulled down by 58kΩ, configured high true at a power up
PWMVH	Output, PWM phase V high side gate signal, internally pulled down by 58kΩ, configured high true at a power up
PWMVL	Output, PWM phase V low side gate signal, internally pulled down by 58kΩ, configured high true at a power up
PWMWH	Output, PWM phase W high side gate signal, internally pulled down by 58kΩ, configured high true at a power up
PWMWL	Output, PWM phase W low side gate signal, internally pulled down by 58kΩ, configured high true at a power up
PFCPWM	Output, PFCPWM output signal, internally pulled up by 70kΩ, configured low true at a power up

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Fault

GATEKILL	Input, upon assertion this negates all six PWM signals, active low, internally pulled up by 70kΩ
PFCGKILL	Input, upon assertion, this negates PFCPWM signal, active low, internally pulled up by 70kΩ

4.3 Analog Interface Group

AVSS	Analog power return, (analog internal 1.8V power is shared with VDDCAP)
AREF	0.6V buffered output
CMEXT	Unbuffered 0.6V, input to the AREF buffer, capacitor needs to be connected.
OP1+	Input, Operational amplifier positive input for application sensing
OP1-	Input, Operational amplifier negative input for application sensing
OP1O	Output, Operational amplifier output for application sensing
OP2+	Input, Operational amplifier positive input for application sensing
OP2-	Input, Operational amplifier negative input for application sensing
OP2O	Output, Operational amplifier output for application sensing
OP3+	Input, Operational amplifier positive input for application sensing
OP3-	Input, Operational amplifier negative input for application sensing
OP3O	Output, Operational amplifier output for application sensing
VDCBUS	Input, Analog input channel (0 – 1.2V), allocated 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
AIN3	Input, Analog input channel 3 (0 – 1.2V), needs to be pulled down to AVSS if unused
AIN4	Input, Analog input channel 4 (0 – 1.2V), needs to be pulled down to AVSS if unused
ADCH	Input, Analog input channel dedicated for A/D compensation (0 – 1.2V), needs to be pulled down to AVSS if unused
ADCL	Input, Analog input channel dedicated for A/D compensation (0 – 1.2V), internally biased to 0.6V, see Figure 23 for internal structure

Analog Channel	Leg Shunt Mode	Single Shunt Mode	Pin number(s)
OP1	PFC Current	AC Voltage	19, 20, 21
OP2	Motor U Phase Current	Motor Shunt Current	28, 29, 30
OP3	Motor V Phase Current	PFC Current	34, 35, 36
AIN1	AC Voltage	*Unallocated*	23

Table 1. Analog channel sensing functions in Leg and Single Shunt Modes

4.4 Power Interface Group

VDD1	Digital power (3.3V)
VDDCAP	Internal 1.8V output, requires capacitors to the pin. Shared with analog power pad internally **Note:** The internal 1.8V supply is not designed to power any external circuits or devices. Only capacitors should be connected to this pin.
VSS	Digital common

4.5 Test Interface Group

P5.2/TMS	JTAG test mode input or input digital port

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TDO	JTAG data output
P5.1/TDI	JTAG data input, or input digital port
TCK	JTAG test clock

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5 DC Characteristics

5.1 Absolute Maximum Ratings

Symbol	Parameter	Min	Typ	Max	Condition
V_{DD1}	Supply Voltage	-0.3 V	-	3.6 V	Respect to VSS
V_{IA}	Analog Input Voltage	-0.3 V	-	1.98 V	Respect to AVSS
V_{ID}	Digital Input Voltage	-0.3 V	-	6.0 V	Respect to VSS
T_A	Ambient Temperature	-40 ˚C	-	85 ˚C	
T_S	Storage Temperature	-65 ˚C	-	150 ˚C	

Table 2. 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.

5.2 System Clock Frequency and Power Consumption

C_{AREF} = 1nF, C_{MEXT}= 100nF. VDD1=3.3V, Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Unit
SYSCLK	System Clock	32	-	120	**MHz**
P_D	Power consumption		100[1)]	-	**mW**

Table 3. System Clock Frequency

Note 1) The value is based on the condition of MCE clock=100MHz, 8051 clock 20MHz with a actual motor and PFC running by a typical MCE application program and 8051 code.

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5.3 Digital I/O DC Characteristics

Symbol	Parameter	Min	Typ	Max	Condition
V_{DD1}	Supply Voltage	3.0 V	3.3 V	3.6 V	Recommended
V_{IL}	Input Low Voltage	-0.3 V	-	0.8 V	Recommended
V_{IH}	Input High Voltage	2.0 V		3.6 V	Recommended
C_{IN}	Input capacitance	-	3.6 pF	-	(1)
I_L	Input leakage current		±10 nA	±1 µA	V_O = 3.3 V or 0 V
I_{OL1} (2)	Low level output current	8.9 mA	13.2 mA	15.2 mA	V_{OL} = 0.4 V (1)
I_{OH1} (2)	High level output current	12.4 mA	24.8 mA	38 mA	V_{OH} = 2.4 V (1)
I_{OL2} (3)	Low level output current	17.9 mA	26.3 mA	33.4 mA	V_{OL} = 0.4 V (1)
I_{OH2} (3)	High level output current	24.6 mA	49.5 mA	81 mA	V_{OH} = 2.4 V (1)

Table 4. Digital I/O DC Characteristics

Note:
(1) Data guaranteed by design.
(2) Applied to SCL/SO-SI, SDA/CS0 pins.
(3) Applied to all digital I/O pins except SCL/SO-SI and SDA/CS0 pins.

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5.4 Analog I/O DC Characteristics

- OP amps for application sensing (OP1+, OP1-, OP1O, OP2+, OP2-, OP2O, OP3+, OP3-, OP3O)

C_{AREF} = 1nF, C_{MEXT}= 100nF. VDD1=3.3V, Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Condition
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 (1)	-	1.2 V	V_{AVDD} = 1.8 V
C_{IN}	Input capacitance	-	3.6 pF	-	(1)
R_{FDBK}	OP amp feedback resistor	5 kΩ	-	20 kΩ	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 µA	-	V_{OUT} = 0.6 V (1)

Table 5. Analog I/O DC Characteristics

Note:

(1) Data guaranteed by design.

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5.5 Under Voltage Lockout DC characteristics

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Condition
UV_{CC+}	UVcc positive going Threshold	2.78 V	3.04 V	3.23 V	(1)
UV_{CC-}	UVcc negative going Threshold	2.78 V	2.97 V	3.23 V	
$UV_{CC}H$	UVcc Hysteresys	-	73 mV	-	(1)

Table 6. UVcc DC Characteristics

Note:

(1) Data guaranteed by design.

5.6 Itrip comparator DC characteristics

Unless specified, VDD1=3.3V, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Condition
$Itrip_{+}$	Itrip positive going Threshold	-	1.22V	-	V_{DD1} = 3.3 V
$Itrip_{-}$	Itrip negative going Threshold	-	1.10V	-	V_{DD1} = 3.3 V
ItripH	Itrip Hysteresys	-	120mV	-	

Table 7. Itrip DC Characteristics

5.7 CMEXT and AREF Characteristics

C_{AREF} = 1nF, C_{MEXT}= 100nF. Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Condition
V_{CM}	CMEXT voltage	495 mV	600 mV	700 mV	V_{VDD1} = 3.3 V
V_{AREF}	Buffer Output Voltage	495 mV	600 mV	700 mV	V_{VDD1} = 3.3 V
ΔV_o	Load regulation (V_{DC}-0.6)	-	1 mV	-	(1)
PSRR	Power Supply Rejection Ratio	-	75 db	-	(1)

Table 8. CMEXT and AREF DC Characteristics

Note:

(1) Data guaranteed by design.

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6 AC Characteristics

6.1 Digital PLL AC Characteristics

Symbol	Parameter	Min	Typ	Max	Condition
F_{CLKIN}	Crystal input frequency	3.2 MHz	4 MHz	60 MHz	(1) (see figure below)
F_{PLL}	Internal clock frequency	32 MHz	50 MHz	128 MHz	(1)
F_{LWPW}	Sleep mode output frequency	F_{CLKIN} ÷ 256	-	-	(1)
J_S	Short time jitter	-	200 psec	-	(1)
D	Duty cycle	-	50 %	-	(1)
T_{LOCK}	PLL lock time	-	-	500 µsec	(1)

Table 9. PLL AC Characteristics

Note:
(1) Data guaranteed by design.

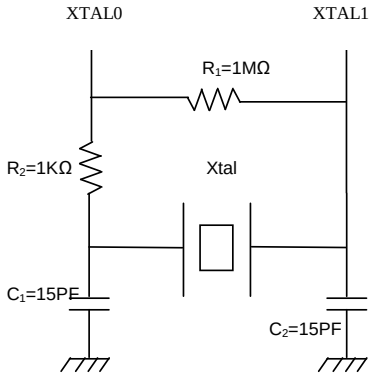

Figure 6. Crystal circuit example

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6.2 Analog to Digital Converter AC Characteristics

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Condition
T_{CONV}	Conversion time	-	-	2.05 µsec	(1)
T_{HOLD}	Sample/Hold maximum hold time	-	-	10 µsec	Voltage droop ≤ 15 LSB (see figure below)

Table 10 . A/D Converter AC Characteristics

Note:

(1) Data guaranteed by design.

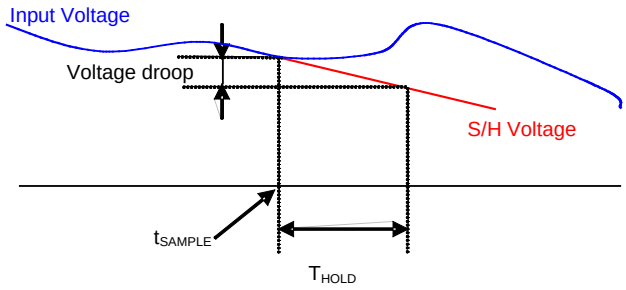

Figure 7. Voltage droop and S/H hold time

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6.3 Op amp AC Characteristics

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Condition
OP_{SR}	OP amp slew rate	-	10 V/µsec	-	VDD1 = 3.3 V, CL = 33 pF (1)
OP_{IMP}	OP input impedance	-	10^8 Ω	-	(1) (2)
T_{SET}	Settling time	-	400 ns	-	VDD1 = 3.3 V, CL = 33 pF (1)

Table 11 Current Sensing OP Amp AC Characteristics

Note:

(1) Data guaranteed by design.

(2) To guarantee stability of the operational amplifier, it is recommended to load the output pin by a capacitor of 47pF, see Figure 8. Here only Op-amp 1 is shown but all op amp outputs should be loaded with this capacitor value.

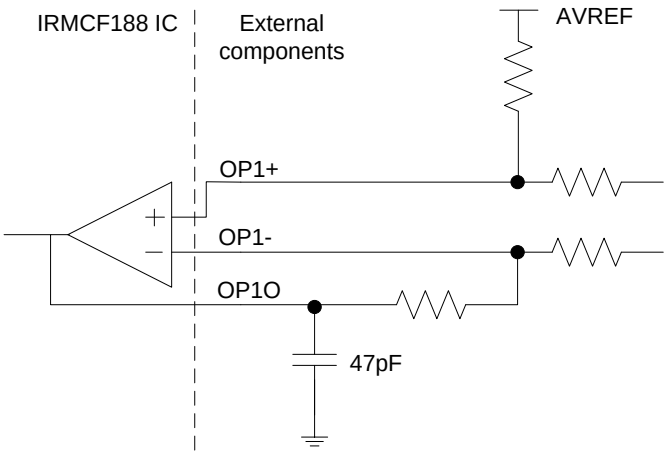

Figure 8 Op amp output capacitor

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6.4 SYNC to SVPWM and A/D Conversion AC Timing

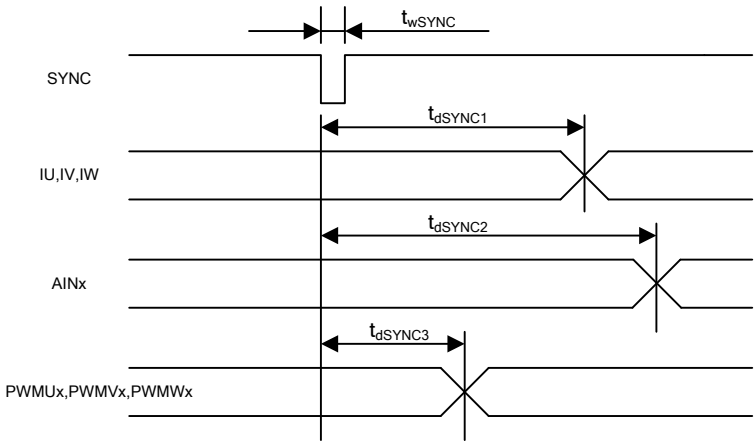

Figure 9. SYNC timing

Unless specified, Ta = 25˚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 AIN0-4, ADCH, ADCL analog input conversion time	-	-	200	SYSCLK (1)
t_{dSYNC3}	SYNC to PWM output delay time	-	-	2	SYSCLK

Table 12. SYNC AC Characteristics

Note:

(1) AIN2 – AIN4, ADCH, ADCL channels are converted once every 5 SYNC events

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6.5 GATEKILL to SVPWM AC Timing

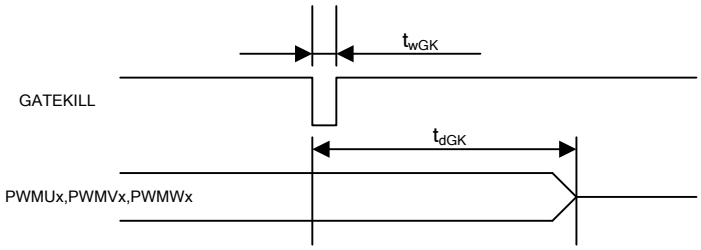

Figure 10. Gatekill timing

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Unit
t_{wGK}	GATEKILL pulse width	32	-	-	SYSCLK
t_{dGK}	GATEKILL to PWM output delay	-	-	100	SYSCLK

Table 13. GATEKILL to SVPWM AC Timing

6.6 Itrip AC Timing

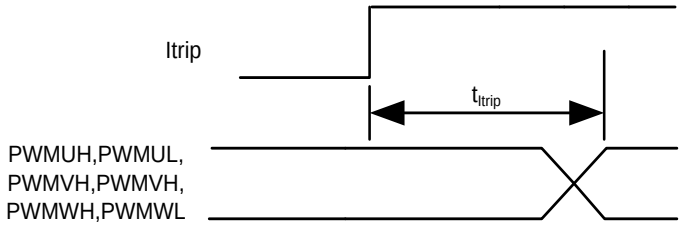

Figure 11. ITRIP timing

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Unit
t_{ITRIP}	Itrip propagation delay	-	-	100(sysclk)+1.0usec	SYSCLK+usec

Table 14. Itrip AC Timing

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6.7 Interrupt AC Timing

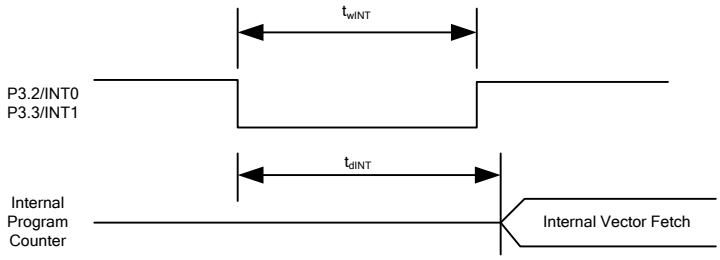

Figure 12. Interrupt timing

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Unit
t_{wINT}	INT0, INT1 Interrupt Assertion Time	4	-	-	SYSCLK
t_{dINT}	INT0, INT1 latency	-	-	4	SYSCLK

Table 15. Interrupt AC Timing

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6.8 I²C AC Timing

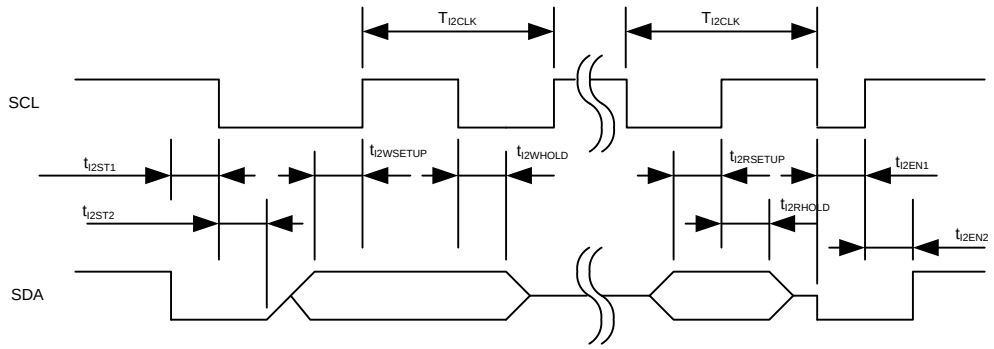

Figure 13. I²C Timing

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Unit
T_{I2CLK}	I²C clock period	10	-	8192	SYSCLK
t_{I2ST1}	I²C SDA start time	0.25	-	-	T_{I2CLK}
t_{I2ST2}	I²C SCL start time	0.25	-	-	T_{I2CLK}
$t_{I2WSETUP}$	I²C write setup time	0.25	-	-	T_{I2CLK}
$t_{I2WHOLD}$	I²C write hold time	0.25	-	-	T_{I2CLK}
$t_{I2RSETUP}$	I²C read setup time	I²C filter time(1)	-	-	SYSCLK
$t_{I2RHOLD}$	I²C read hold time	1	-	-	SYSCLK

Table 16. I²C AC Timing

Note:

(1) I²C read setup time is determined by the programmable filter time applied to I²C communication.

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6.9 SPI AC Timing

6.9.1.1 SPI Write AC timing

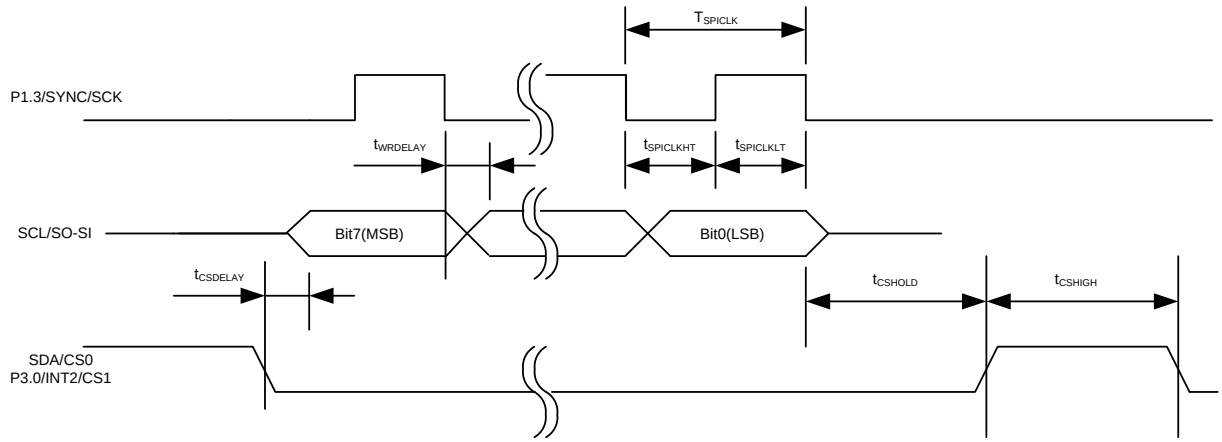

Figure 14. SPI write timing

Unless specified, Ta = 25˚C.

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

Table 17. SPI Write AC Timing

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6.9.1.2 SPI Read AC Timing

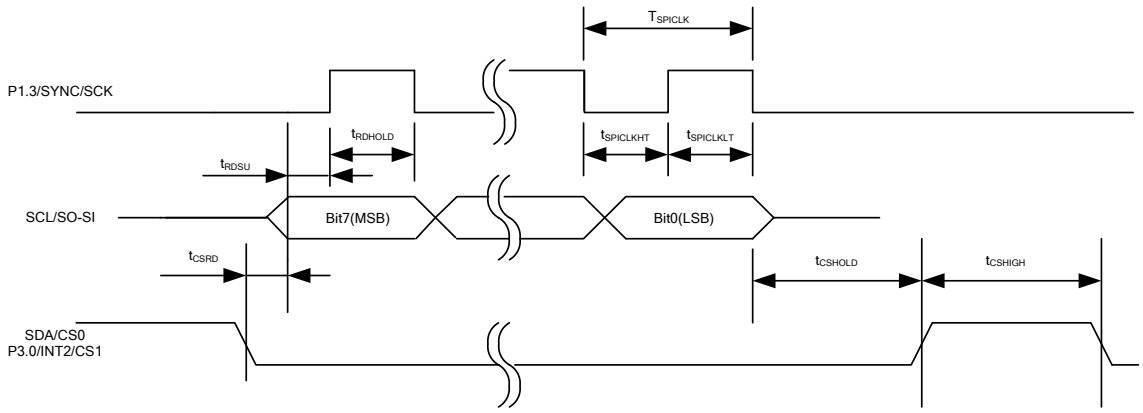

Figure 15. SPI read timing

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Unit
T_{SPICLK}	SPI clock period	4	-	-	SYSCLK
$t_{SPICLKHT}$	SPI clock high time	-	1/2	-	T_{SPICLK}
$t_{SPICLKLT}$	SPI clock low time	-	1/2	-	T_{SPICLK}
t_{CSRD}	CS to data delay time	-	-	10	nsec
t_{RDSU}	SPI read data setup time	10	-	-	nsec
t_{RDHOLD}	SPI read data hold time	10	-	-	nsec
t_{CSHIGH}	CS high time between two consecutive byte transfer	1	-	-	T_{SPICLK}
t_{CSHOLD}	CS hold time	-	1	-	T_{SPICLK}

Table 18. SPI Read AC Timing

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6.10 UART AC Timing

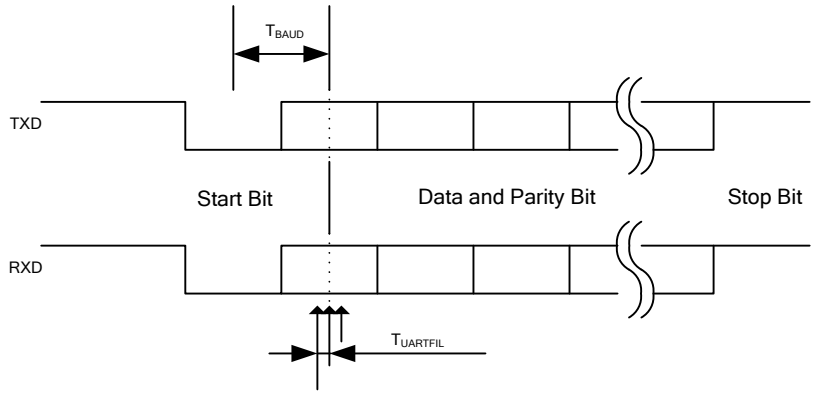

Figure 16. UART timing

Unless specified, Ta = 25˚C.

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

Table 19. 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.

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6.11 CAPTURE Input AC Timing

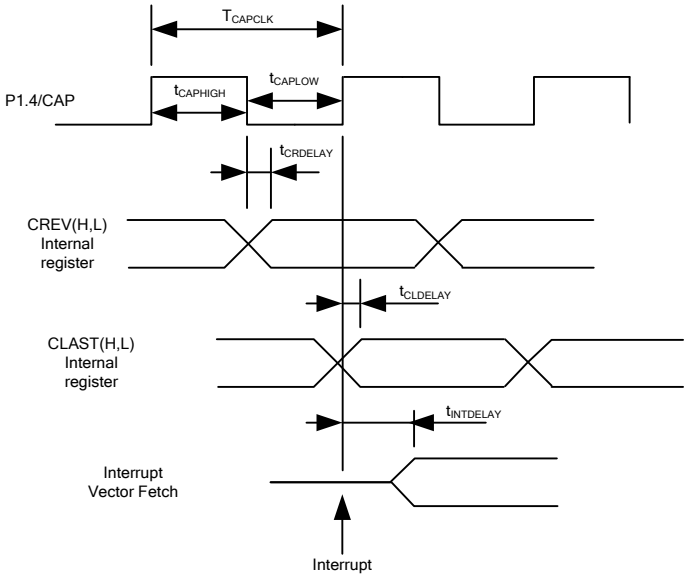

Figure 17. CAPTURE timing

Unless specified, Ta = 25˚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 20. CAPTURE AC Timing

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6.12 JTAG AC Timing

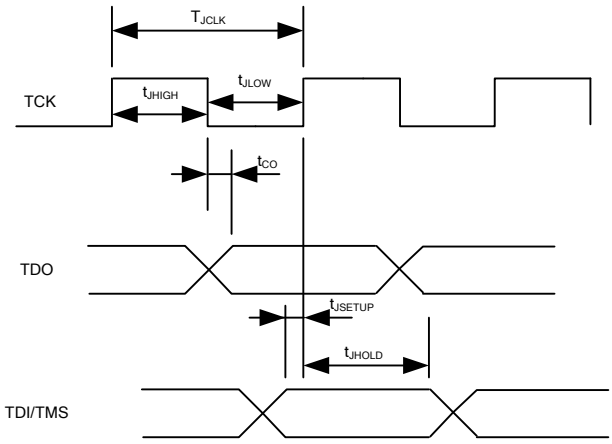

Figure 18. JTAG timing

Unless specified, Ta = 25˚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 21. JTAG AC Timing

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7 I/O Structure

The following figure shows the PWM output (PWMUH/PWMUL/PWMVH/PWMVL/PWMWH/PWMWL/PFCPWM)

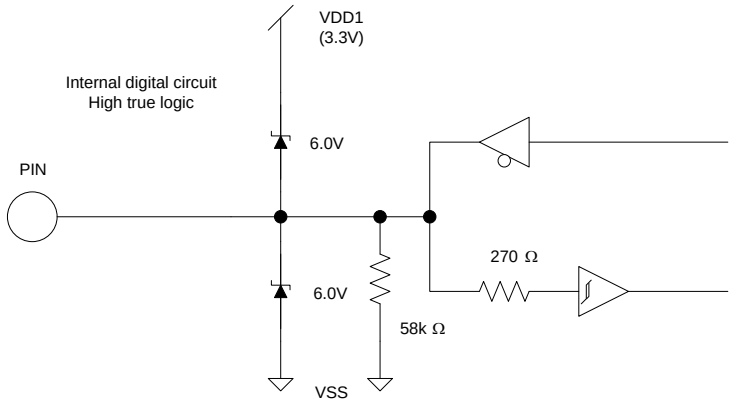

Figure 19. PWMUL/PWMUH/PWMVL/PWMVH/PWMWL/PWMWH/PFCPWM output

The following figure shows the digital I/O structure except the PWM output

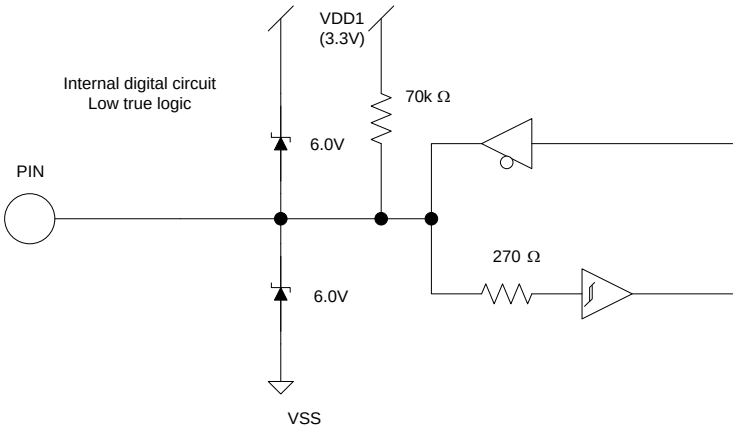

Figure 20. All digital I/O except PWM output

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

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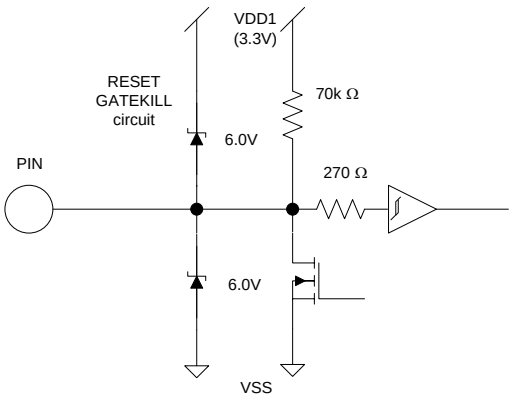

Figure 21. RESET, GATEKILL I/O

The following figure shows the analog input structure, except for ADCL.

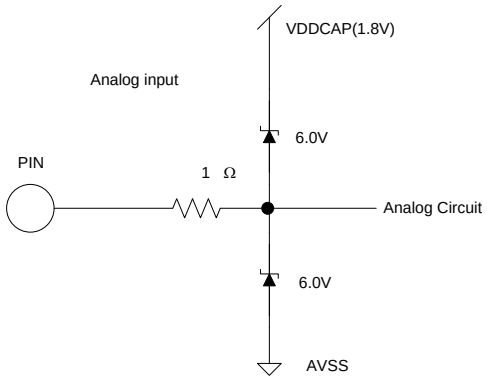

Figure 22. Analog input

The following figure shows the ADCL input structure.

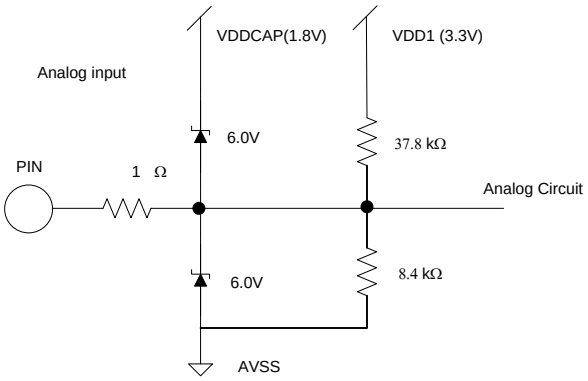

Figure 23. ADCL pin input structure

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

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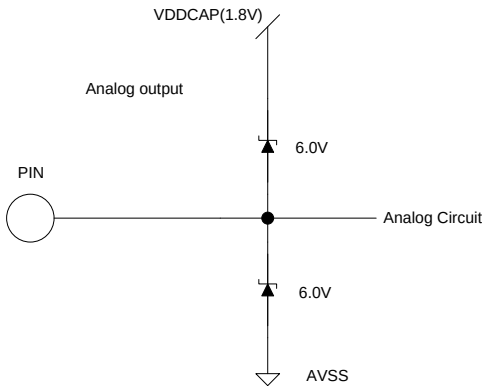

Figure 24 Analog operational amplifier output and AREF I/O structure

The following figure shows the VSS,AVSS pin I/O structure

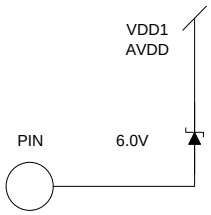

Figure 25. VSS,AVSS pin I/O structure

The following figure shows the VDD1,VDDCAP pin I/O structure

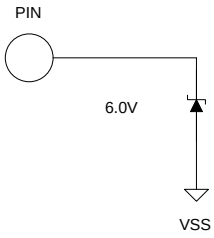

Figure 26. VDD1,VDDCAP pin I/O structure

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The following figure shows the XTAL0 and XTAL1 pins structure

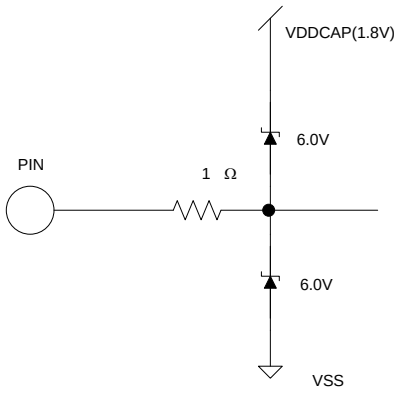

Figure 27. XTAL0/XTAL1 pins structure

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8 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	SCL/SO-SI		I/O	I^2C clock output (open drain, need pull up) or SPI data
5	SDA/CS0		I/O	I^2C data (open drain, need pull up) or SPI Chip Select 0
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	P1.6		I/O	Discrete programmable I/O
9	P1.7			Discrete programmable I/O
10	VDD1		P	3.3V digital power
11	VSS		P	Digital common
12	VDDCAP		P	Internal 1.8V output, Capacitor(s) to be connected
13	P2.0/NMI		I/O	Discrete programmable I/O or Non-maskable Interrupt input
14	P3.2/INT0		I/O	Discrete programmable I/O or Interrupt 0 input
15	P2.2		I/O	Discrete programmable I/O
16	P2.3		I/O	Discrete programmable I/O
17	P2.6/AOPWM0		I/O	Discrete programmable I/O or PWM 0 digital output
18	P2.7/AOPWM1		I/O	Discrete programmable I/O or PWM 1 digital output
19	OP1O		O	Op amp output for application sensing, 0-1.2V range
20	OP1-		I	Op amp negative input for application sensing, 0-1.2V range, needs to be pulled down to AVSS if unused
21	OP1+		I	Op amp positive input for application sensing, 0-1.2V range, needs to be pulled down to AVSS if unused
22	VDCBUS		I	Analog input channel (0 – 1.2V), allocated for DC bus voltage input, needs to be pulled down to AVSS if unused
23	AIN1		I	Analog input channel 1, 0-1.2V range, needs to be pulled down to AVSS if unused
24	AIN2		I	Analog input channel 2, 0-1.2V range, needs to be pulled down to AVSS if unused
25	AIN3		I	Analog input channel 3, 0-1.2V range, needs to be pulled down to AVSS if unused
26	AIN4		I	Analog input channel 4, 0-1.2V range, needs to be pulled down to AVSS if unused
27	ADCH		I	Input, Analog input channel dedicated for A/D compensation (0 – 1.2V), needs to be pulled down to AVSS if unused
28	OP2-		I	Op amp negative input for application sensing, 0-1.2V range, needs to be pulled down to AVSS if unused
29	OP2+		I	Op amp positive input for application sensing, 0-1.2V range, needs to be pulled down to AVSS if unused
30	OP2O		O	Op amp output for application sensing, 0-1.2V range
31	CMEXT		O	Unbuffered 0.6V output. Capacitor needs to be connected.
32	AREF		O	Analog reference voltage output (0.6V)

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Pin Number	Pin Name	Internal Pull-up /Pull-down	Pin Type	Description
33	ADCL		I	Input, Analog input channel dedicated for A/D compensation (0 – 1.2V), internally biased to 0.6V, see Figure 23 for internal structure
34	OP3-		I	Op amp negative input for application sensing, 0-1.2V range, needs to be pulled down to AVSS if unused
35	OP3+		I	Op amp positive input for application sensing, 0-1.2V range, needs to be pulled down to AVSS if unused
36	OP3O		O	Op amp output for application sensing, 0-1.2V range
37	AVSS		P	Analog common
38	VDDCAP		P	Internal 1.8V output, Capacitor(s) to be connected
39	VDD1		P	3.3V digital power
40	VSS		P	Digital common
41	P3.1/AOPWM2		I/O	Discrete programmable I/O or PWM 2 digital output
42	PWMWL	58 kΩ Pull down	O	PWM gate drive for phase W low side, configurable either high or low true.
43	PWMVL	58 kΩ Pull down	O	PWM gate drive for phase V low side, configurable either high or low true
44	PWMUL	58 kΩ Pull down	O	PWM gate drive for phase U low side, configurable either high or low true
45	PWMWH	58 kΩ Pull down	O	PWM gate drive for phase W high side, configurable either high or low true
46	P3.7		I/O	Discrete programmable I/O
47	P2.1		I/O	Discrete programmable I/O
48	PWMVH	58 kΩ Pull down	O	PWM gate drive for phase V high side, configurable either high or low true
49	PWMUH	58 kΩ Pull down	O	PWM gate drive for phase U high side, configurable either high or low true
50	P1.5		I/O	Discrete programmable I/O.
51	PFCPWM		I/O	PFC PWM gate drive , configurable either high or low
52	PFCGKILL	70 kΩ Pull up	I	PFCPWM shutdown input, active low input.
53	GATEKILL	70 kΩ Pull up	I	PWM shutdown input, configurable digital filter, active low input.
54	P3.0/INT2/CS1	70 kΩ Pull up	I/O	Discrete programmable I/O or external interrupt 2 input or SPI Chip Select 1
55	P5.2/TMS		I	JTAG test mode select or digital input port
56	TDO		O	JTAG test data output
57	P5.1/TDI		I	JTAG test data input or digital input port
58	TCK		I	JTAG test clock
59	RESET		I	Reset, low true, Schmitt trigger input
60	P1.1/RXD		I/O	UART receiver input or Discrete programmable I/O
61	P1.2/TXD		I/O	UART transmitter output or Discrete programmable I/O
62	P3.4/T0		I/O	Discrete programmable I/O or Timer/Counter 2 input
63	P3.5/T1		I/O	Discrete programmable I/O or Timer/Counter 2 input
64	P3.3/INT1		I/O	Interrupt 1 input or Discrete I/O

Table 22. Pin List

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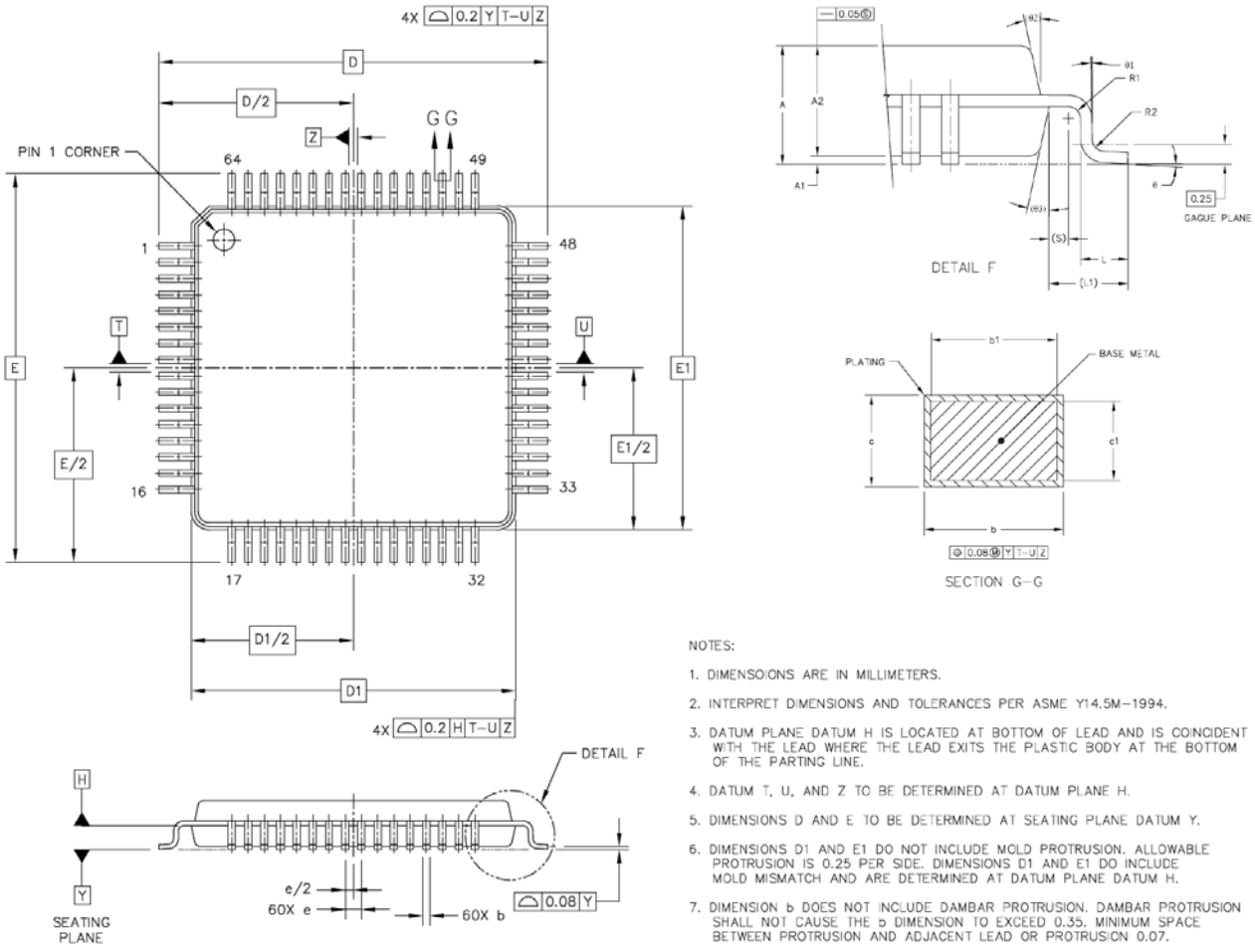
9 Package Dimensions



NOTES:

1. DIMENSOIONS ARE IN MILLIMETERS.
2. INTERPRET DIMENSIONS AND TOLERANCES PER ASME Y14.5M-1994.
3. DATUM PLANE DATUM 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 DATUM 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 DATUM H.
7. DIMENSION b DOES NOT INCLUDE DAMBAR PROTRUSION. DAMBAR PROTRUSION SHALL NOT CAUSE THE b DIMENSION TO EXCEED 0.35. MINIMUM SPACE BETWEEN PROTRUSION AND ADJACENT LEAD OR PROTRUSION 0.07.

DIM	MIN	MAX	DIM	MIN	MAX	DIM	MIN	MAX
A	---	1.6	L1	1 REF				
A1	0.05	0.15	R1	0.1	0.2			
A2	1.35	1.45	R2	0.1	0.2			
b	0.17	0.27	S	0.2 REF				
b1	0.17	0.23	θ	0°	7°			
c	0.09	0.2	θ1	0°	---			
c1	0.09	0.16	θ2	12° REF				
D	12 BSC		θ3	12° REF				
D1	10 BSC							
e	0.5 BSC							
E	12 BSC							
E1	10 BSC							
L	0.45	0.75						

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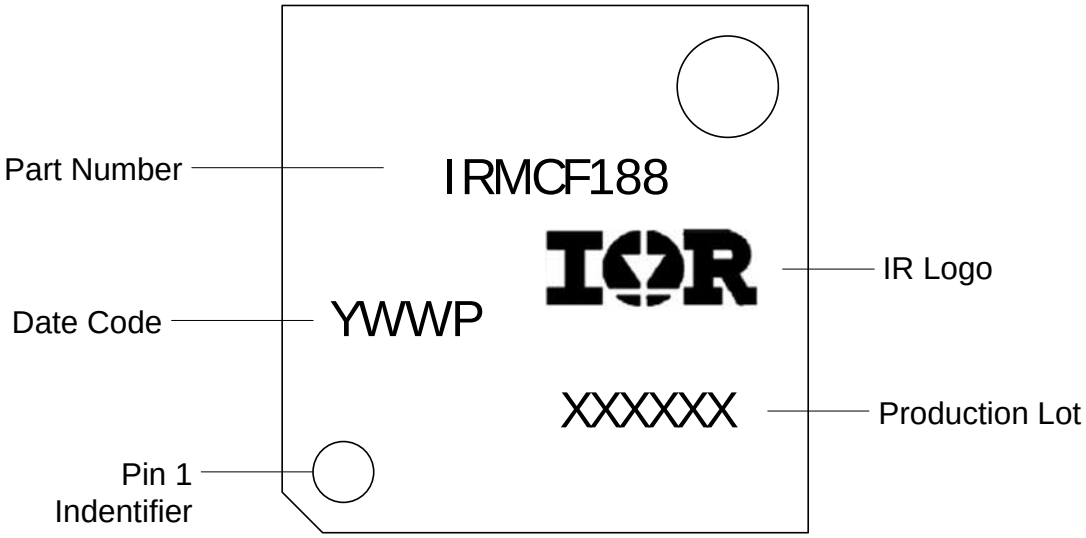
10 Part Marking Information



11 Qualification Information

Qualification Level		Industrial[††] (per JEDEC JESD 47E)
Moisture Sensitivity Level		MSL3[†††] (per IPC/JEDEC J-STD-020C)
ESD	**Machine Model**	Class B (per JEDEC standard JESD22-A114D)
	Human Body Model	Class 2 (per EIA/JEDEC standard EIA/JESD22-A115-A)
RoHS Compliant		Yes

† Qualification standards can be found at International Rectifier's web site http://www.irf.com/

†† Higher qualification ratings may be available should the user have such requirements. Please contact your International Rectifier sales representative for further information.

††† Higher MSL ratings may be available for the specific package types listed here. Please contact your International Rectifier sales representative for further information.

Note: Test condition for Temperature Cycling test is -40C to 125C.

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