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International
IOR Rectifier

Data Sheet No. PD60338

IRMCK311

Dual Channel 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**
- **Integrated Power Factor Correction 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**
- **Dual channel three/two-phase 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**
- **Two serial communication interface (UART)**
- **I²C/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 IRMCF311 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	56K 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	6
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)	14
Package (lead-free)	QFP64
Operating temperature	-40°C ~ 85°C

Description

IRMCK311 is a high performance OTP based motion control IC designed primarily for appliance applications. IRMCK311 is designed to achieve low cost and high performance control solutions for advanced inverterized appliance motor control. IRMCK311 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. IRMCK311 comes with a small QFP64 pin lead-free package.

TABLE OF CONTENTS

1 Overview 5
2 IRMCK311 Block Diagram and Main Functions 6
3 Pinout 8
4 Input/Output of IRMCK311 9
4.1 8051 Peripheral Interface Group 10
4.2 Motion Peripheral Interface Group 10
4.3 Analog Interface Group 11
4.4 Power Interface Group 11
4.5 Test Interface 12
5 Application Connections 13
6 DC Characteristics 14
6.1 Absolute Maximum Ratings 14
6.2 System Clock Frequency and Power Consumption 14
6.3 Digital I/O DC Characteristics 15
6.4 PLL and Oscillator DC Characteristics 15
6.5 Analog I/O DC Characteristics 16
6.6 Under Voltage Lockout DC Characteristics 17
6.7 AREF Characteristics 17
7 AC Characteristics 18
7.1 PLL AC Characteristics 18
7.2 Analog to Digital Converter AC Characteristics 19
7.3 Op Amp AC Characteristics 19
7.4 SYNC to SVPWM and A/D Conversion AC Timing 20
7.5 GATEKILL to SVPWM AC Timing 21
7.6 Interrupt AC Timing 21
7.7 I^2C AC Timing 22
7.8 SPI AC Timing 23
7.8.1 SPI Write AC timing 23
7.8.2 SPI Read AC Timing 24
7.9 UART AC Timing 25
7.10 CAPTURE Input AC Timing 26
7.11 JTAG AC Timing 27
7.12 OTP Programming Timing 28
8 I/O Structure 29
9 Pin List 32
10 Package Dimensions 35
11 Part Marking Information 36
12 Ordering Information 36

TABLE OF FIGURES

Figure 1. Typical Application Block Diagram Using IRMCK311 5
Figure 2. IRMCK311 Internal Block Diagram 6
Figure 3. IRMCK311 Pin Configuration 8
Figure 4. Input/Output of IRMCK311 9
Figure 5. Application Connection of IRMCK311 13
Figure 6. Clock Frequency vs. Power Consumption 14
Figure 7 Crystal oscillator circuit 18
Figure 8 Voltage droop of sample and hold 19
Figure 9 SYNC to SVPWM and A/D conversion AC Timing 20
Figure 10 GATEKILL to SVPWM AC Timing 21
Figure 11 Interrupt AC Timing 21
Figure 12 I^2C AC Timing 22
Figure 13 SPI AC Timing 23
Figure 14 SPI Read AC Timing 24
Figure 15 UART AC Timing 25
Figure 16 CAPTURE Input AC Timing 26
Figure 17 JTAG AC Timing 27
Figure 18 OTP Programming Timing 28
Figure 19 All digital I/O except motor PWM output 29
Figure 20 RESET, GATEKILL I/O 29
Figure 21 Analog input 30
Figure 22 Analog operational amplifier output and AREF I/O structure 30
Figure 23 VPP programming pin I/O structure 30
Figure 24 VSS and AVSS pin structure 31
Figure 25 VDD1 and VDDCAP pin structure 31
Figure 26 XTAL0/XTAL1 pins structure 31

TABLE OF TABLES

Table 1. Absolute Maximum Ratings 14
Table 2. System Clock Frequency 14
Table 3. Digital I/O DC Characteristics 15
Table 4. PLL DC Characteristics 15
Table 5. Analog I/O DC Characteristics 16
Table 6. UVcc DC Characteristics 17
Table 7. AREF DC Characteristics 17
Table 8. PLL AC Characteristics 18
Table 9. A/D Converter AC Characteristics 19
Table 10. Current Sensing OP Amp AC Characteristics 19
Table 11. SYNC AC Characteristics 20
Table 12. GATEKILL to SVPWM AC Timing 21
Table 13. Interrupt AC Timing 21
Table 14. I^2C AC Timing 22
Table 15. SPI Write AC Timing 23
Table 16. SPI Read AC Timing 24
Table 17. UART AC Timing 25
Table 18. CAPTURE AC Timing 26
Table 19. JTAG AC Timing 27
Table 20. OTP Programming Timing 28
Table 21. Pin List 32

1 Overview

IRMCK311 is a new International Rectifier integrated circuit device primarily designed as a one-chip solution for complete inverter controlled appliance dual motor control applications. Unlike a traditional microcontroller or DSP, the IRMCK311 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. IRMCK311 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. The sensorless control is the same for both motors with a single shunt current sensing capability. 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 IRMCK311.

IRMCK311 is intended for volume production purpose and contains 64K bytes of OTP (One Time Programming) ROM, which can be programmed through a JTAG port. For a development purpose use, IRMCF311 contains a 48k byte of RAM in place of program OTP to facilitate an application development work. Both IRMCF311 and IRMCK311 come in the same 64-pin QFP package with identical pin configuration to facilitate PC board layout and transition to mass production

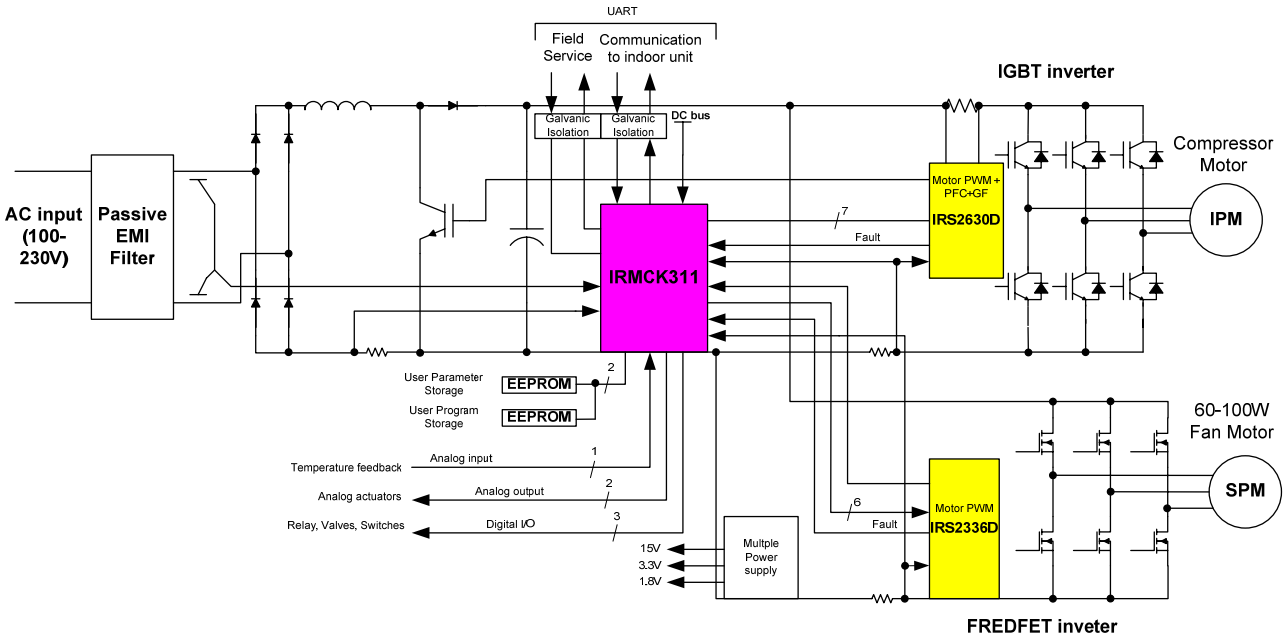

Figure 1. Typical Application Block Diagram Using IRMCK311

2 IRMCK311 Block Diagram and Main Functions

IRMCK311 block diagram is shown in Figure 2.

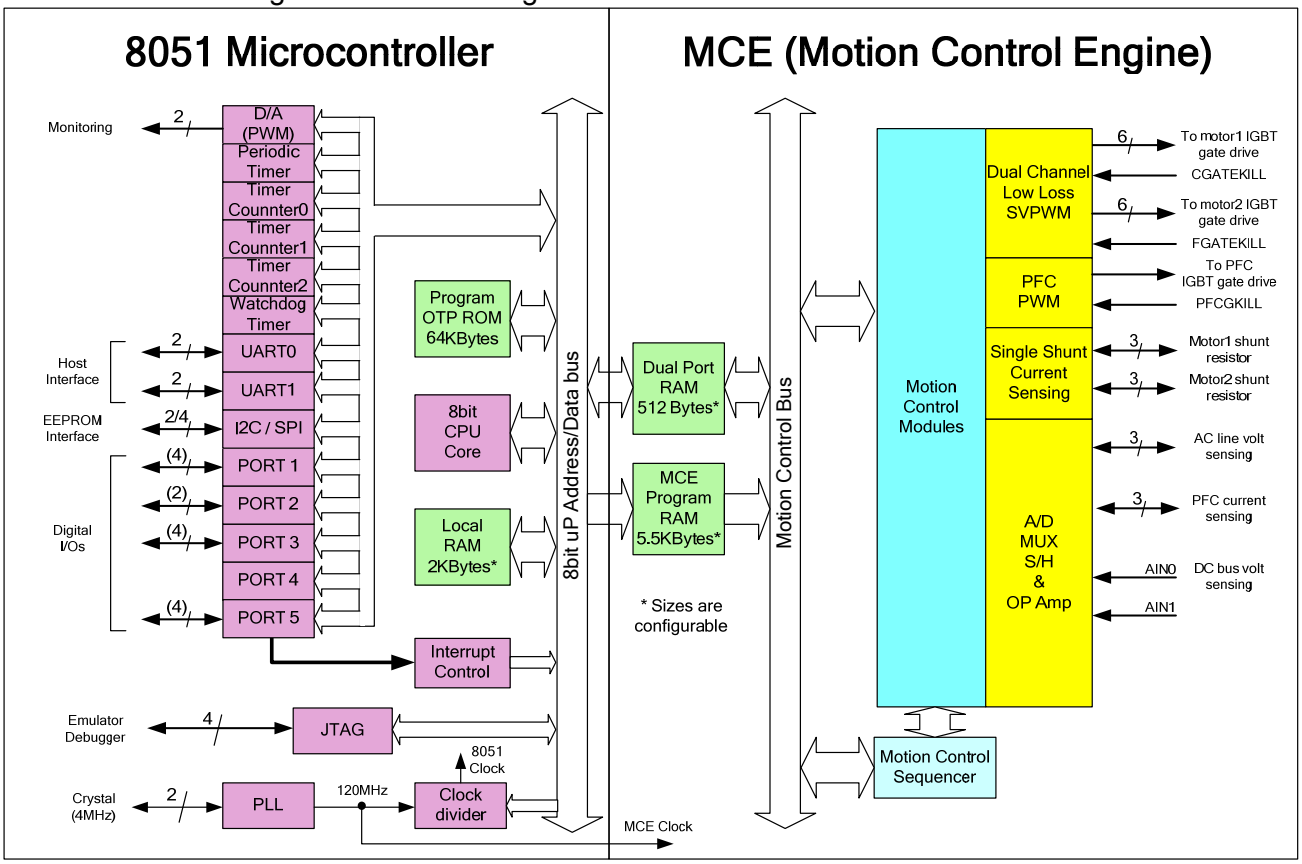

Figure 2. IRMCK311 Internal Block Diagram

IRMCK311 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). Note 1
- 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 36 discrete I/Os
  - Eleven-channel 12-bit A/D
    - Five buffered channels (0 – 1.2V input)
    - One unbuffered channel (0 – 1.2V input)
  - JTAG port (4 pins)
  - Up to three channels of analog output (8-bit PWM)
  - Two UART
  - I^2C/SPI port
  - 64K byte Note 1 program One-Time Programmable memory
  - 2K byte data RAM. Note 2

Note 1: Total size of OTP memory is 64K byte, however MCE program occupies maximum 8K byte which will be loaded into internal RAM at a powerup/boot process. Therefore only 56K byte OTP memory area is usable for 8051 microcontroller.
Note 2: 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

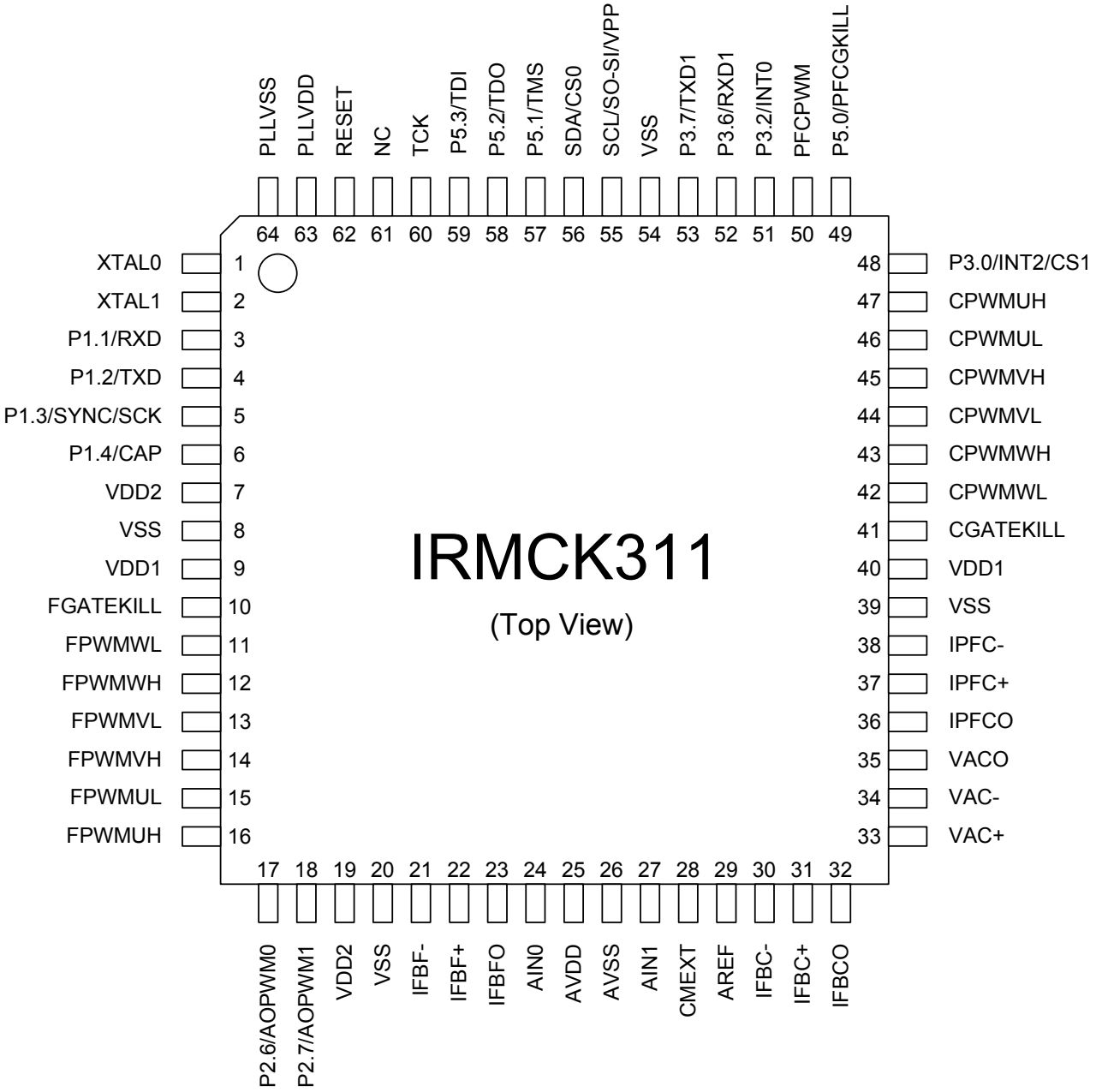

Figure 3. IRMCK311 Pin Configuration

4 Input/Output of IRMCK311

All I/O signals of IRMCK311 are shown in Figure 4. All I/O pins are 3.3V logic interface except A/D interface pins.

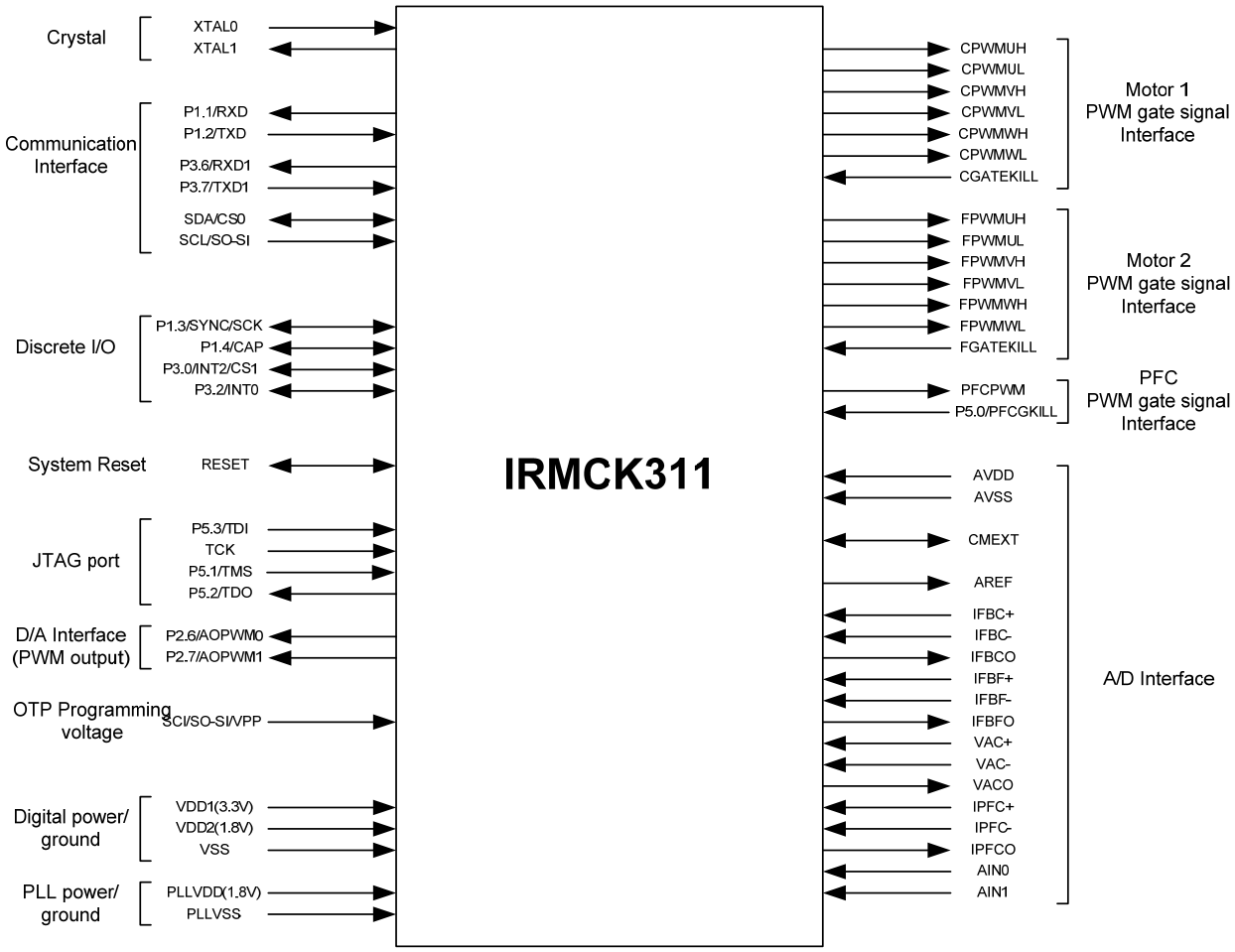

Figure 4. Input/Output of IRMCK311

4.1 8051 Peripheral Interface Group

UART Interface

P1.1/RXD	Input, Receive data to IRMCK311, can be configured as P1.1
P1.2/TXD	Output, Transmit data from IRMCK311, can be configured as P1.2
P3.6/RXD1	Input, 2nd channel Receive data to IRMCK311, can be configured as P3.6
P3.7/TXD1	Output, 2nd channel Transmit data from IRMCK311, can be configured as P3.7

Discrete I/O Interface

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
P3.0/INT2/CS1	Input/output port 3.0, can be configured as external interrupt 2 or SPI chip select 1
P3.2/INT0	Input/output port 3.2, can be configured as external interrupt 0

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

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

I^2C/SPI Interface

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

4.2 Motion Peripheral Interface Group

PWM

CPWMUH	Output, motor 1 PWM phase U high side gate signal
CPWMUL	Output, motor 1 PWM phase U low side gate signal
CPWMVH	Output, motor 1 PWM phase V high side gate signal
CPWMVL	Output, motor 1 PWM phase V low side gate signal
CPWMWH	Output, motor 1 PWM phase W high side gate signal
CPWMWL	Output, motor 1 PWM phase W low side gate signal
FPWMUH	Output, motor 2 PWM phase U high side gate signal
FPWMUL	Output, motor 2 PWM phase U low side gate signal

FPWMVH	Output, motor 2 PWM phase V high side gate signal
FPWMVL	Output, motor 2 PWM phase V low side gate signal
FPWMWH	Output, motor 2 PWM phase W high side gate signal
FPWMWL	Output, motor 2 PWM phase W low side gate signal
PFCPWM	Output, PFC PWM

Fault

CGATEKILL	Input, upon assertion, this negates all six PWM signals for motor 1, programmable logic sense
P5.0/PFCGKILL	Input, upon assertion, this negates PFCPWM signal, programmable logic sense, can be configured as discrete I/O in which case CGATEKILL negates PFCPWM
FGATEKILL	Input, upon assertion, this negates all six PWM signals for motor 2, programmable logic sense

4.3 Analog Interface Group

AVDD	Analog power (1.8V)
AVSS	Analog power return
AREF	Buffered 0.6V output
CMEXT	Unbuffered 0.6V, input to the AREF buffer, capacitor needs to be connected.
IFBC+	Input, Operational amplifier positive input for shunt resistor current sensing of motor 1
IFBC-	Input, Operational amplifier negative input for shunt resistor current sensing of motor 1
IFBCO	Output, Operational amplifier output for shunt resistor current sensing of motor 1
IFBF+	Input, Operational amplifier positive input for shunt resistor current sensing of motor 2
IFBF-	Input, Operational amplifier negative input for shunt resistor current sensing of motor 2
IFBFO	Output, Operational amplifier output for shunt resistor current sensing of motor 2
IPFC+	Input, Operational amplifier positive input for PFC current sensing
IPFC-	Input, Operational amplifier negative input for PFC current sensing
IPFO	Output, Operational amplifier output for PFC current sensing
VAC+	Input, Operational amplifier positive input for PFC AC voltage sensing
VAC-	Input, Operational amplifier negative input for PFC AC voltage sensing
VACO	Output, Operational amplifier output for PFC AC voltage sensing
VDC+	Input, Operational amplifier positive input for DC bus voltage sensing
VDC-	Input, Operational amplifier negative input for DC bus voltage sensing
AIN0/VDCO	Input/Output, Analog input channel 0 or Operational amplifier output for DC bus voltage sensing
AIN1	Input, Analog input channel 1 (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
PLLVDD	PLL power (1.8V)
PLLVSS	PLL ground return
SCL/SO-SI/VPP	OTP programming supply. Can be left open in OTP read mode (normal)

4.5 Test Interface

P5.3/TDI	Input, JTAG test data input
P5.1/TMS	Input, JTAG test mode select
TCK	Input, JTAG test clock
P5.2/TDO	Output, JTAG test data output

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 IRMCK311.

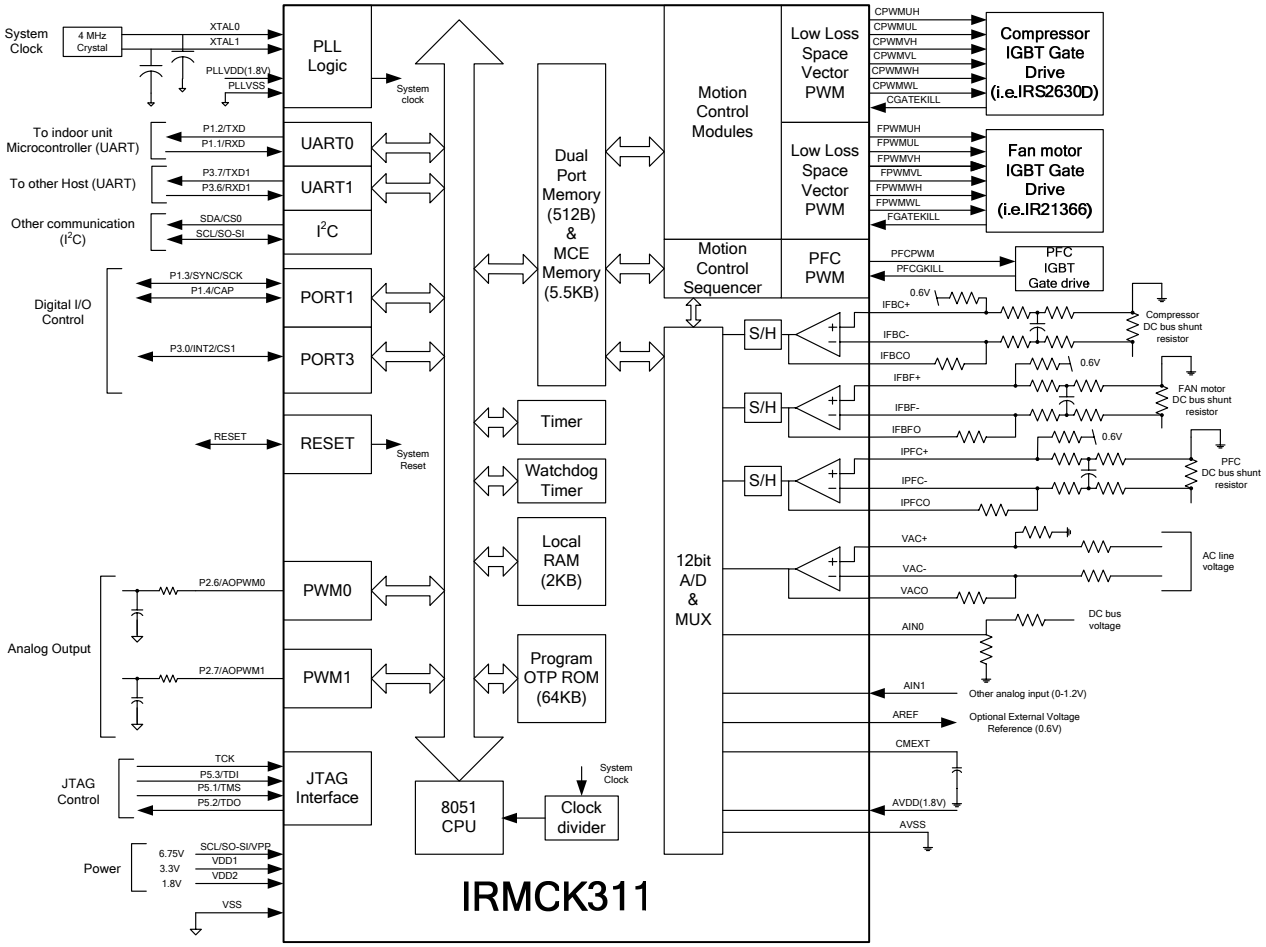

Figure 5. Application Connection of IRMCK311

6 DC Characteristics

6.1 Absolute Maximum Ratings

Symbol	Parameter	Min	Typ	Max	Condition
V_{DD1}	Supply Voltage	-0.3 V	-	3.6 V	Respect to VSS
V_{DD2}	Supply Voltage	-0.3 V	-	1.98 V	Respect to VSS
V_{PP}	OTP Programming Voltage	-0.3V	-	7.0V	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	-	3.65 V	Respect to VSS
T_A	Ambient Temperature	-40 ˚C	-	85 ˚C	
T_S	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

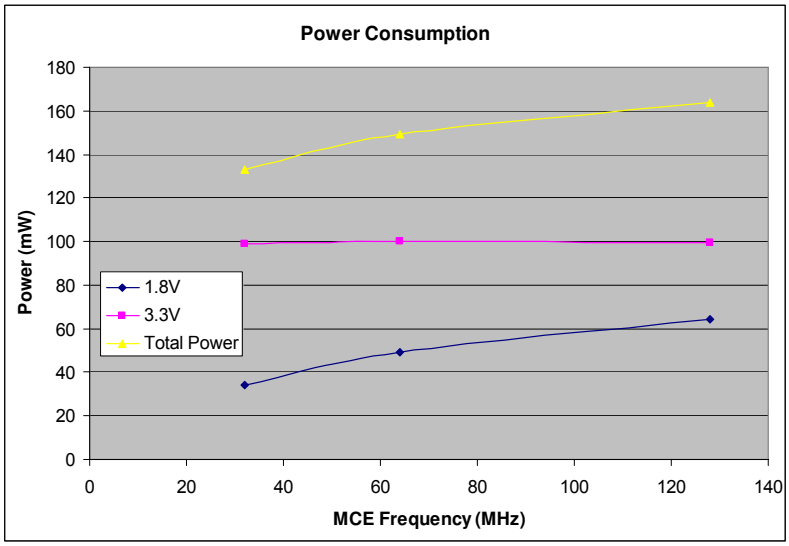

Figure 6. Clock Frequency vs. Power Consumption

6.3 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_{DD2}	Supply Voltage	1.62 V	1.8 V	1.98 V	Recommended
V_{PP}	OTP Programming voltage	6.50V	6.75V	7.0V	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 3. Digital I/O DC Characteristics

Note:
(1) Data guaranteed by design.
(2) Applied to SCL/SO-SI, SDA/CS0 pins.
(3) Applied to P1.1/RXD, P1.2/TXD, P1.3/SYNC/SCK, P1.4/CAP, P2.6/AOPWM0, P2.7/AOPWM1, P3.0/INT2/CS1, P3.2/INT0, P3.6/RXD1, P3.7/TXD1, P5.0/PFCGKILL, P5.1/TMS, P5.2/TDO, P5.3/TDI, CGATEKILL, FGATEKILL, CPWMUL, CPWMUH, CPWMVL, CPWMVH, CPWMWL, CPWMWH, FPWMUL, FPWMUH, FPWMVL, FPWMVH, FPWMWL, FPWMWH, and PFCPWM pins.

6.4 PLL and Oscillator DC Characteristics

Symbol	Parameter	Min	Typ	Max	Condition
V_{PLLVDD}	Supply Voltage	1.62 V	1.8 V	1.92 V	Recommended
$V_{IL\ OSC}$	Oscillator Input Low Voltage	V_{PLLVSS}	-	0.2* V_{PLLVDD}	V_{PLLVDD} = 1.8 V (1)
$V_{IH\ OSC}$	Oscillator Input High Voltage	0.8* V_{PLLVDD}		V_{PLLVDD}	V_{PLLVDD} = 1.8 V (1)

Table 4. PLL DC Characteristics

Note:
(1) Data guaranteed by design.

6.5 Analog I/O DC Characteristics

- OP amps for current sensing (IFBC+, IFBC-, IFBCO, IFBF+, IFBF-, IFBFO, IPFC+, IPFC-, IPFCO)

C_{AREF} = 1nF, C_{MEXT}= 100nF. Unless specified, Ta = 25˚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 (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 op amp output and negative input
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.

6.6 Under Voltage Lockout DC Characteristics

- Based on AVDD (1.8V)

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Condition
UV_{CC+}	UVcc positive going Threshold[1)]	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
$UV_{CC}H$	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, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Condition
V_{AREF}	AREF Output Voltage	495 mV	600 mV	700 mV	V_{AVDD} = 1.8 V
ΔV_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	(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 8. PLL AC Characteristics

Note:
(1) Data guaranteed by design.

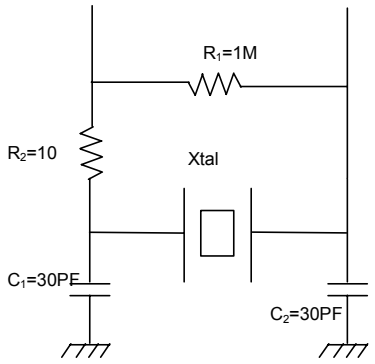

Figure 7 Crystal oscillator circuit

7.2 Analog to Digital Converter AC Characteristics

Unless specified, 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 9. A/D Converter AC Characteristics

Note:
(1) Data guaranteed by design.

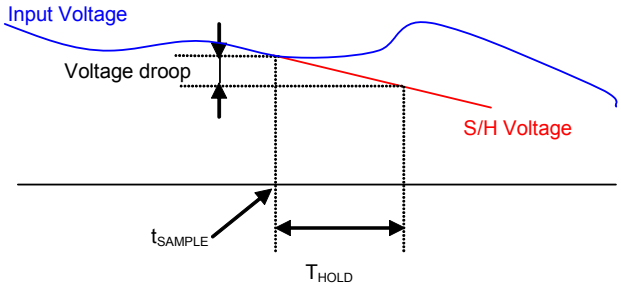

Figure 8 Voltage droop of sample and hold

7.3 Op Amp AC Characteristics

- OP amps for current sensing (IFBC+, IFBC-, IFBCO, IFBF+, IFBF-, IFBFO, IPFC+, IPFC-, IPFCO)

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Condition
OP_{SR}	OP amp slew rate	-	10 V/µsec	-	V_{AVDD} = 1.8 V, CL = 33 pF (1)
OP_{IMP}	OP input impedance	-	10^8 Ω	-	(1)
T_{SET}	Settling time	-	400 ns	-	V_{AVDD} = 1.8 V, CL = 33 pF (1)

Table 10. Current Sensing OP Amp AC Characteristics

Note:
(1) Data guaranteed by design.

7.4 SYNC to SVPWM and A/D Conversion AC Timing

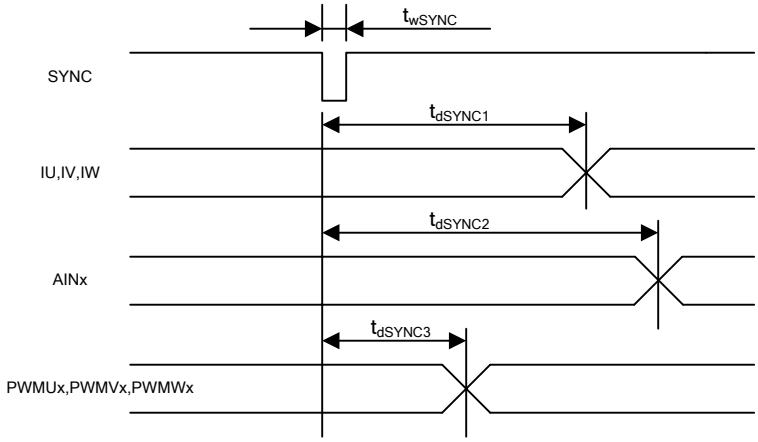

Figure 9 SYNC to SVPWM and A/D conversion AC Timing

Unless specified, 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 AIN0-6 analog input conversion time	-	-	200	SYSCLK (1)
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

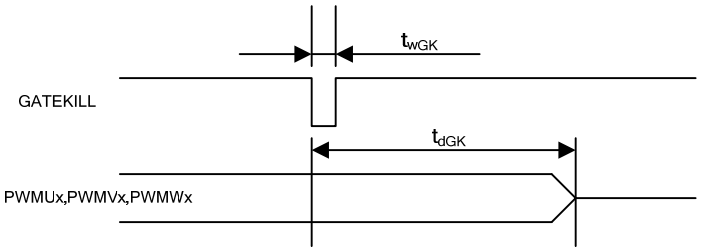

Figure 10 GATEKILL to SVPWM AC Timing

Unless specified, Ta = 25˚C.

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

Table 12. GATEKILL to SVPWM AC Timing

7.6 Interrupt AC Timing

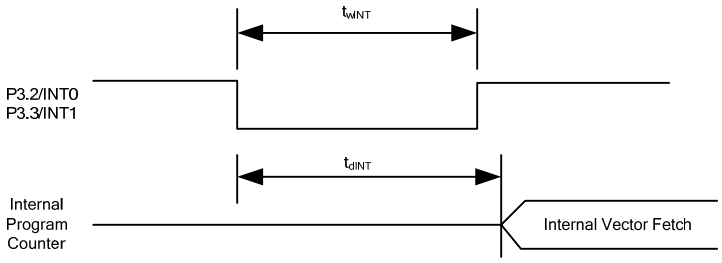

Figure 11 Interrupt AC Timing

Unless specified, Ta = 25˚C.

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

Table 13. Interrupt AC Timing

7.7 I²C AC Timing

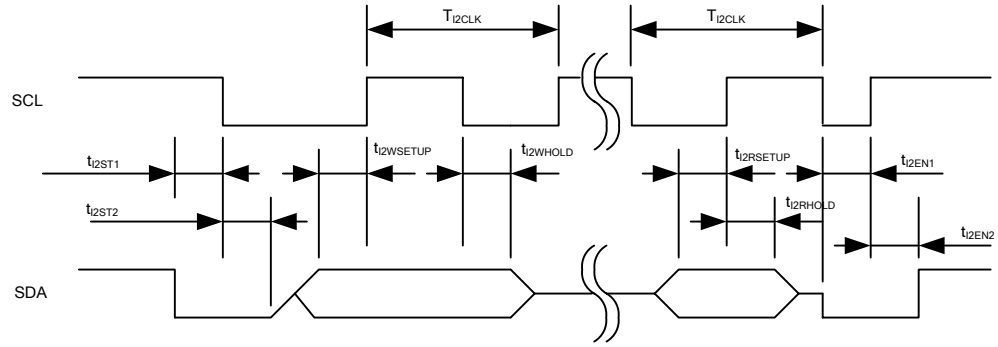

Figure 12 I²C AC Timing

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 14. I²C AC Timing

Note:

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

7.8 SPI AC Timing

7.8.1 SPI Write AC timing

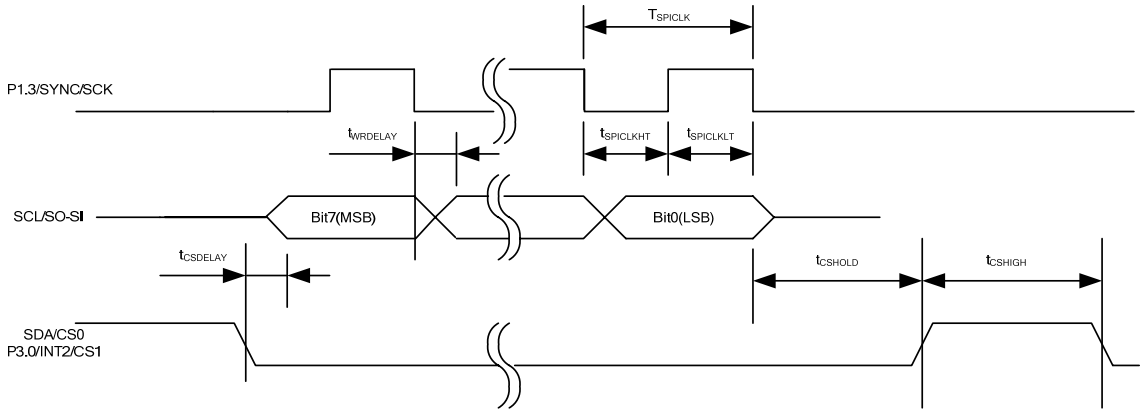

Figure 13 SPI AC Timing

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 15. SPI Write AC Timing

7.8.2 SPI Read AC Timing

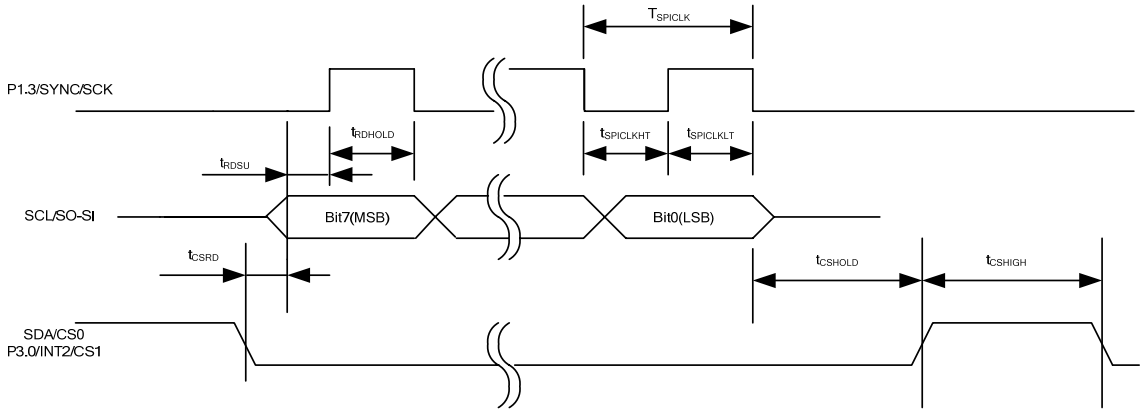

Figure 14 SPI Read AC Timing

Unless specified, Ta = 25˚C.

Symbol	Parameter	Min	Typ	Max	Unit
T_{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 16. SPI Read AC Timing

7.9 UART AC Timing

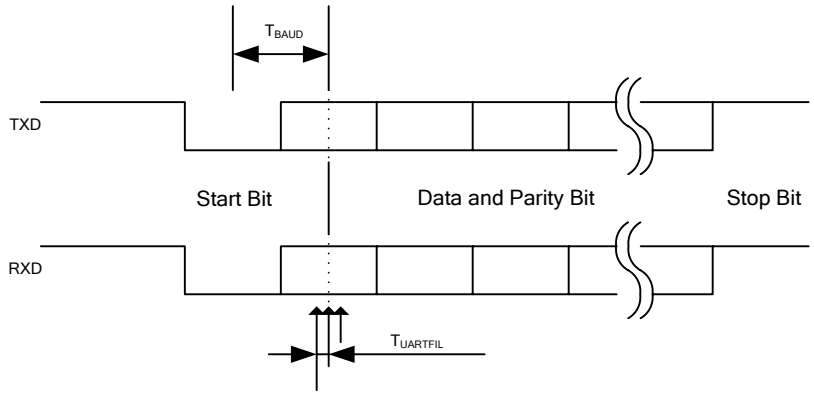

Figure 15 UART AC Timing

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 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.