

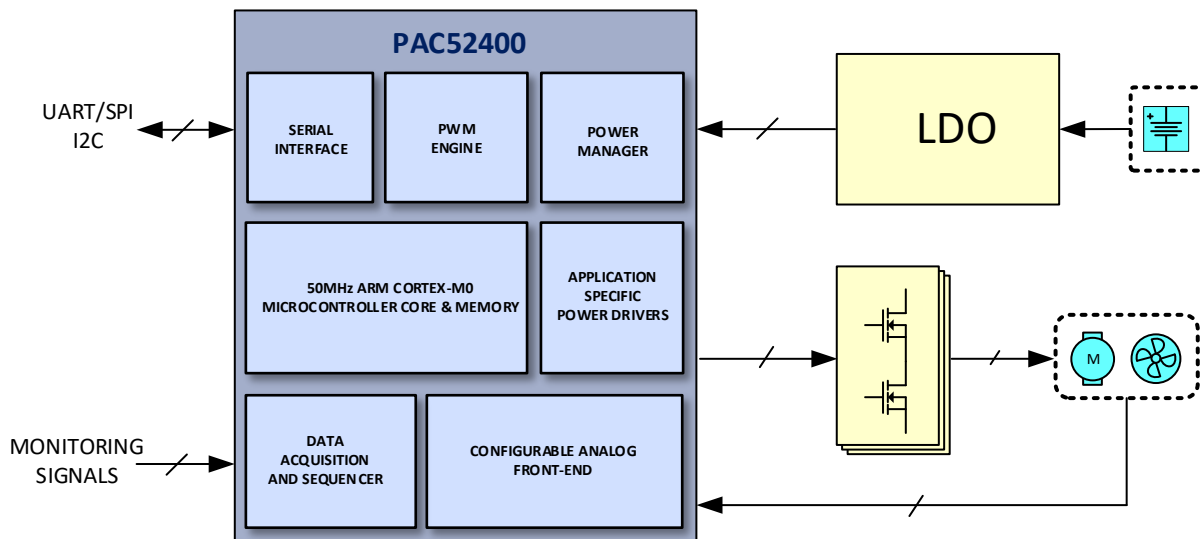
1 PRODUCT OVERVIEW

The PAC52400 belongs to Qorvo's broad portfolio of full-featured Power Application Controller® (PAC) products that are highly optimized for controlling and powering next generation smart energy appliances, devices, and equipment. These application controllers integrate a 50MHz Arm® Cortex®-M0 32-bit microcontroller core with Qorvo's proprietary and patent-pending Multi-Mode Power Manager™, Configurable Analog Front End™, and Application Specific Power Drivers™ to form the most compact microcontroller-based power and general purpose application systems ranging from digital power supply to motor control. The PAC52400 microcontroller features up to 32kB of embedded FLASH and 8kB of SRAM memory, a high-speed 10-bit 1μs analog-to-digital converter (ADC) with dual auto-sampling sequencers, 5V/3.3V I/Os, flexible clock sources, timers, a versatile 14-channel PWM engine, and several serial interfaces.

The Multi-Mode Power Manager (MPPM) provides a power management solution for a simple power source topology. It integrates linear regulated voltage supplies to power the internal analog and digital blocks. The Application Specific Power Drivers (ASPD) are medium-voltage power drivers designed for each target set of control applications, including half bridge, H-bridge, 3-phase, intelligent power module (IPM), and general purpose driving. The Configurable Analog Front End (CAFE) comprises differential programmable gain amplifiers, single-ended programmable gain amplifiers, comparators, digital-to-analog converters, and I/Os for programmable and inter-connectible signal sampling, feedback amplification, and sensor monitoring of multiple analog input signals. Together, these modules and microcontroller enable a wide range of compact applications with highly integrated power management, driving, feedback, and control for DC supply up to 44V.

APPLICATIONS

- Power Tools (up to 24V)
- 12V Server Fans
- Embedded Speed Controllers (ESCs)



The PAC52400 is available in a 48-pin, 6x6 mm TQFN package. The PAC family includes a range of part numbers optimized to work with different targeted primary applications.

KEY FEATURES

- Proprietary Multi-Mode Power Manager
 - ◆ Direct DC supply up to 20V
 - ◆ 4 linear regulators with power and hibernate management
 - ◆ Power and temperature monitor, warning, and fault detection
- Proprietary Configurable Analog Front End
 - ◆ 6 analog front end I/O pins
 - ◆ 1 differential programmable gain amplifiers
 - ◆ 4 single-ended programmable gain amplifiers
 - ◆ 6 comparators
 - ◆ 2 DACs (10-bit and 8-bit)
 - ◆ Low-speed clock output for optimizing UL/IEC60730 Class B Safety Applications
- Proprietary Application Specific Power Drivers
 - ◆ 3 low-side and 3 high-side gate drivers with 0.75A gate driving capability
 - ◆ Configurable delays and fast fault protection
- 50MHz Arm® Cortex®-M0 32-bit microcontroller core
 - ◆ Fast single cycle 32-bit x 32-bit multiplier
 - ◆ 24-bit SysTick timer
 - ◆ Nested vectored interrupt controller (NVIC) with 20 external interrupts
 - ◆ Wake-up interrupt controller allowing power-saving sleep modes
 - ◆ Clock-gating allowing low power operation
- 32kB FLASH and 8kB SRAM memory
- 10-bit 1 μ s ADC with multi-input/multi-sample control engine
 - ◆ 9 ADC inputs including input from configurable analog front end
- 3.3V I/Os
 - ◆ 3 general purpose I/Os with tri-state and dedicated analog input to ADC
- True 5V I/Os
 - ◆ 12 general purpose I/Os with tri-state, pull-up and pull-down and dedicated I/O supply
 - ◆ Configurable as true 5V or 3.3V I/Os
- Flexible clock and PLL from internal 2% oscillator, ring oscillator, external clock, or crystal
- 9 timing generators
 - ◆ Four 16-bit timers with up to 15 PWM/CC blocks and 7 independent dead-time controllers
 - ◆ 24-bit watchdog timer
 - ◆ 4s or 8s watchdog timer
 - ◆ 24-bit real time clock
 - ◆ 24-bit SysTick timer
 - ◆ Wake-up timer for sleep modes from 0.125s to 8s
- SPI, I²C, and UART communication interfaces
- SWD debug interface with interface disable function

TABLE OF CONTENTS

1	Product Overview	1
APPLICATIONS		1
Key Features		2
2	Product Selection Summary	9
3	Ordering Information	9
4	Absolute Maximum Ratings	10
5	Architectural Block Diagram	11
6	Pin Configuration	12
6.1	PAC52400QM	12
7	Pin Description	13
8	Power manager	19
8.1	Features	19
8.2	Block Diagram	19
8.3	Functional Description	19
8.3.1	Linear Regulators	20
8.3.2	Power Up Sequence	20
8.3.3	Hibernate Mode	21
8.3.4	Power and Temperature Monitor	21
8.3.5	Voltage Reference	22
8.4	Electrical Characteristics	23
9	Configurable Analog Front End (CAFE)	25
9.1	Block Diagram	25
9.2	Functional Description	26
9.2.1	Differential Programmable Gain Amplifier (DA10)	26
9.2.2	Single-Ended Programmable Gain Amplifier (AMP)	26
9.2.3	General Purpose Comparator (CMP)	26
9.2.4	Phase Comparator (PHC)	26
9.2.5	Protection Comparator (PCMP)	27
9.2.6	Analog Output Buffer (BUF)	27
9.2.7	Analog Front End I/O (AIO)	27
9.2.8	Push Button (PBTN)	27
9.2.9	HP DAC and LP DAC	28
9.2.10	CLKOUT	28

9.2.11	ADC Pre-Multiplexer.....	28
9.2.12	Configurable Analog Signal Matrix (CASM)	28
9.2.13	Configurable Digital Signal Matrix (CDSM)	29
9.3	Electrical Characteristics	29
9.4	Typical Performance Characteristics	34
10	Application Specific Power Drivers (ASPD)	36
10.1	Features.....	36
10.2	Block Diagram	36
10.3	Functional Description	36
10.3.1	Low-Side Gate Driver	38
10.3.2	High-Side Gate Driver	38
10.3.3	High-Side Switching Transients	38
10.3.4	Power Drivers Control	39
10.3.5	Gate Driver Fault Protection.....	39
10.4	Electrical Characteristics	40
10.5	Typical Performance Characteristics.....	41
	Typical Performance Characteristics (Continued)	42
11	ADC With Auto-Sampling Sequencer	43
11.1	Block Diagram	43
11.2	Functional Description	43
11.2.1	ADC	43
11.2.2	Auto-Sampling Sequencer	43
11.2.3	EMUX Control	44
11.3	Electrical Characteristics	44
12	Memory System	45
12.1	Features.....	45
12.2	Block Diagram	45
12.3	Functional Description	45
12.3.1	Program and Data FLASH	45
12.3.2	SRAM	45
12.4	Electrical Characteristics	46
13	Clock Control System.....	47
13.1	Features.....	47
13.2	Block Diagram	47
13.3	Functional Description	48

13.3.1	Free Running Clock (FRCLK)	48
13.3.2	Fast Clock (FCLK)	48
13.3.3	High-Speed Clock (HCLK)	48
13.3.4	Auxiliary Clock (ACLK)	48
13.3.5	Clock Gating	48
13.3.6	Ring Oscillator (ROSC)	48
13.3.7	Trimmed 4MHz RC Oscillator	48
13.3.8	Internal Slow RC Oscillator	49
13.3.9	Crystal Oscillator Driver	49
13.3.10	External Clock Input	49
13.3.11	PLL	49
13.4	Electrical Characteristics	50
14	ARM® CORTEX®-M0 Microcontroller Core	51
14.1	Features	51
14.2	Block Diagram	51
14.3	Functional Description	51
14.4	Electrical Characteristics	52
14.5	Typical Performance Characteristics	52
15	I/O Controller	53
15.1	Features	53
15.2	Block Diagram	53
15.3	Functional Description	54
15.4	GPIO Current Injection	54
15.5	Electrical Characteristics	55
16	Serial Interface	56
16.1	Block Diagram	56
16.2	Functional Description	56
16.2.1	I ² C Controller	57
16.3	UART Controller	57
16.4	SPI Controller	57
16.5	Dynamic Characteristics	58
17	Timers	62
17.1	Block Diagram	62
17.2	Functional Description	63
17.2.1	Timer A	63



17.2.2 Timer B 63

17.2.3 Timer C 64

17.2.4 Timer D 64

17.2.5 Watchdog Timer 64

17.2.6 CAFE Watchdog Timer 64

17.2.7 Wake-Up Timer 64

17.2.8 Real-Time Clock 64

18 Thermal Characteristics 65

19 Application Examples 66

20 PACKAGE OUTLINE AND DIMENSIONS 67

21 Handling Precautions 67

22 Solderability 67

23 Product Compliance 68

LIST OF TABLES

Table 2-1 Product Selection Summary	9
Table 3-1 Ordering Information	9
Table 4-1 Absolute Maximum Ratings	10
Table 7-1 Multi-Mode Power Manager and System Pin Description	13
Table 7-2 Configurable Analog Front End Pin Description	14
Table 7-3 Application Specific Power Drivers Pin Description.....	15
Table 7-4 I/O Ports Pin Description	15
Table 7-5 I/O Ports Pin Description (Continued).....	16
Table 7-6 I/O Ports Pin Description (Continued).....	17
Table 8-1 Linear Regulators Electrical Characteristics	23
Table 8-2 Power System Electrical Characteristics	24
Table 9-1 Differential Programmable Gain Amplifier (DA) Electrical Characteristics	29
Table 9-2 Single-Ended Programmable Gain Amplifier (AMP) Electrical Characteristics	30
Table 9-3 General Purpose Comparator (CMP) Electrical Characteristics.....	30
Table 9-4 Phase Comparator (PHC) Electrical Characteristics	31
Table 9-5 Protection Comparator (PCMP) Electrical Characteristics	31
Table 9-6 Analog Output Buffer (BUF) Electrical Characteristics	31
Table 9-7 Analog Front End I/O (AIO) Electrical Characteristics.....	32
Table 9-8 Push Button (PBTN) Electrical Characteristics.....	32
Table 9-9 HP DAC and LP DAC Electrical Characteristics.....	32
Table 9-10 CLKOUT Electrical Characteristics	33
Table 10-1 Power Driver Resources by Part Numbers.....	37
Table 10-2 Microcontroller Port and PWM to Power Driver Mapping	39
Table 10-3 Power Driver Propagation Delay	39
Table 10-4 Gate Drivers Electrical Characteristics	40
Table 11-1 ADC and Auto-Sampling Sequencer Electrical Characteristics	44
Table 12-1 Memory System Electrical Characteristics	46
Table 13-1 Clock Control System Electrical Characteristics.....	50
Table 14-1 Microcontroller and Clock Control System Electrical Characteristics.....	52
Table 15-1 I/O Controller Electrical Characteristics	55
Table 16-1 Serial Interface Dynamic Characteristics	58
Table 16-2 I ² C Dynamic Characteristics	59
Table 16-3 SPI Dynamic Characteristics	61
Table 18-1 Thermal Characteristics	65

LIST OF FIGURES

Figure 5-1 Architectural Block Diagram	11
Figure 6-1 PAC52400QM Pin Configuration (TQFN66-48 Package)	12
Figure 7-1 Power Supply Bypass Capacitor Routing	18
Figure 8-1 Power Manager	19
Figure 8-2 Linear Regulators	20
Figure 8-3 Power Up Sequence	21
Figure 9-1 Configurable Analog Front End	25
Figure 10-1 Application Specific Power Drivers	36
Figure 10-2 Typical Gate Driver Connections	38
Figure 10-3 High-Side Switching Transients and Optional Circuitry	39
Figure 11-1 ADC with Auto-Sampling Sequencer	43
Figure 12-1 Memory System	45
Figure 13-1 Clock Control System	47
Figure 14-1 Arm Cortex-M0 Microcontroller Core	51
Figure 15-1 I/O Controller	53
Figure 16-1 Serial Interface	56
Figure 16-2 I ² C Timing Diagram	60
Figure 16-3 SPI Timing Diagram	61
Figure 17-1 Timers A, B, C, and D	62
Figure 17-2 AFE Watchdog and Wake-Up Timer	63
Figure 17-3 Real-Time Clock and Watchdog Timer	63
Figure 19-1 3-Phase Motor Drive Using PAC52400 (Simplified Diagram)	66
Figure 20-1 TQFN66-48 Package Outline and Dimensions	67

2 PRODUCT SELECTION SUMMARY

Table 2-1 Product Selection Summary

PART NUMBER	PIN PKG	POWER MANAGER		CONFIGURABLE ANALOG FRONT END					APPLICATION SPECIFIC POWER DRIVERS			MICROCONTROLLER						PRIMARY APPLICATION
		INPUT VOLTAGE	MULTI-MODE SW	DIFF-PGA	PGA	COMPARATOR	DAC	ADC CHANNEL	POWER DRIVER	PWM CHANNEL	FAULT PROTECT	SPEED (MHz)	FLASH (kB)	SRAM (kB)	GPIO	INTERFACE	XTAL	
PAC52400	48-pin 6x6 TQFN	5.2-44V	Y	1	4	6	2	8	3 LS (0.75A/0.75A) 3 HS (0.75A/0.75A)	6	Int	50	32	8	22	SPI I ² C UART SWD	N	3 half bridge, 3-phase control

Notes: DIFF-PGA = differential programmable gain amplifier, PGA = programmable gain amplifier HS = high-side , LS = low-side

3 ORDERING INFORMATION

Table 3-1 Ordering Information

PART NUMBER ⁽¹⁾	TEMPERATURE RANGE	PACKAGE	PINS	PACKING
PAC52400QM-T	-40°C to 105°C	TQFN66-48	48 + Exposed Pad	Tape & Reel (3K Units)
PAC52400QMSR	-40°C to 105°C	TQFN66-48	48 + Exposed Pad	Tape & Reel (100 Units)

⁽¹⁾ See Product Selection Summary for product features for each part number.

4 ABSOLUTE MAXIMUM RATINGS

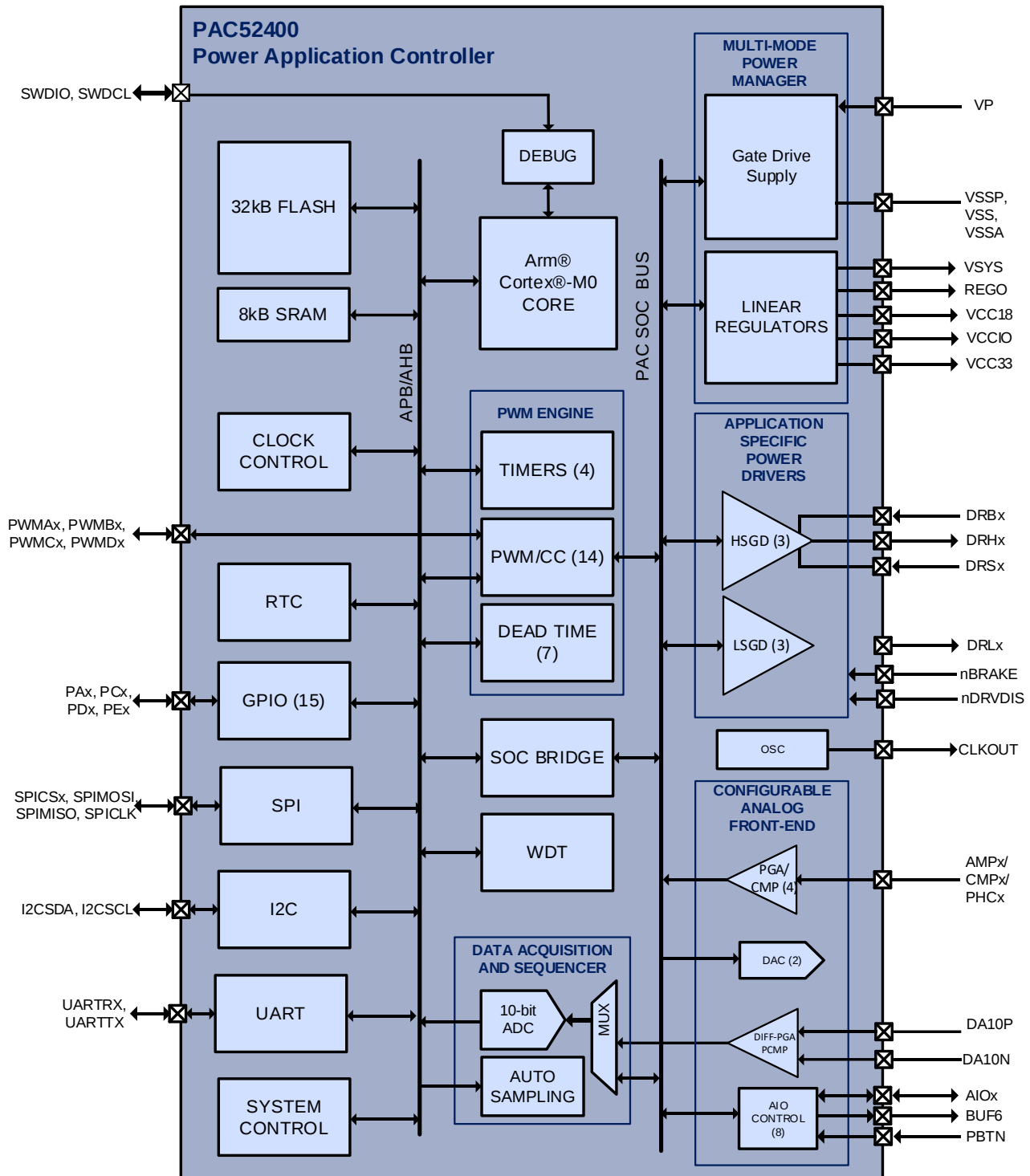
Table 4-1 Absolute Maximum Ratings

(Do not exceed these limits to prevent damage to the device. Exposure to absolute maximum rating conditions for long periods may affect device reliability.)

PARAMETER		VALUE	UNIT
VP to VSS		-0.3 to 20	V
REGO to VSS		-0.3 to VP + 0.3	V
VSYs, AIO6 to VSS		-0.3 to 6	V
VCC33 to VSS		-0.3 to 4.1	V
VCC18 to VSS		-0.3 to 2.5	V
AIO[9:7, 1:0], VCCIO to VSS		-0.3 to V _{SYs} + 0.3	V
PAX, PDx, PEX to VSS		-0.3 to V _{CCIO} + 0.3	V
PCx.. to VSSA		-0.3 to V _{CC33} + 0.3	V
PAX/.., PBx/.., PCx/.., PDx/.., PEX/.. pin injection current		7.5	mA
PAX/.., PBx/.., PCx/.., PDx/.., PEX/.. sum of all pin injection current		25	mA
DRLx to VSSP		-0.3 to V _P + 0.3	V
DRBx to VSSP		-0.3 to 56	V
DRSx to VSSP		-6 to 44	V
DRSx allowable offset slew rate (dV _{DRSx} /dt)		5	V/ns
DRBx, DRHx to respective DRSx		-0.3 to 20	V
VSSP, VSSA to VSS		-0.3 to 0.3	V
VSS, VSYs, DRLx, DRHx, REGO RMS current		0.2	A _{RMS}
VSSP RMS current ⁽¹⁾		0.4	A _{RMS}
VP RMS current ⁽¹⁾		0.6	A _{RMS}
Operating temperature range		-40 to 105	°C
Electrostatic discharge (ESD)	Human body model (JEDEC)	2	kV
	Charge device model (JEDEC)	1	kV

5 ARCHITECTURAL BLOCK DIAGRAM

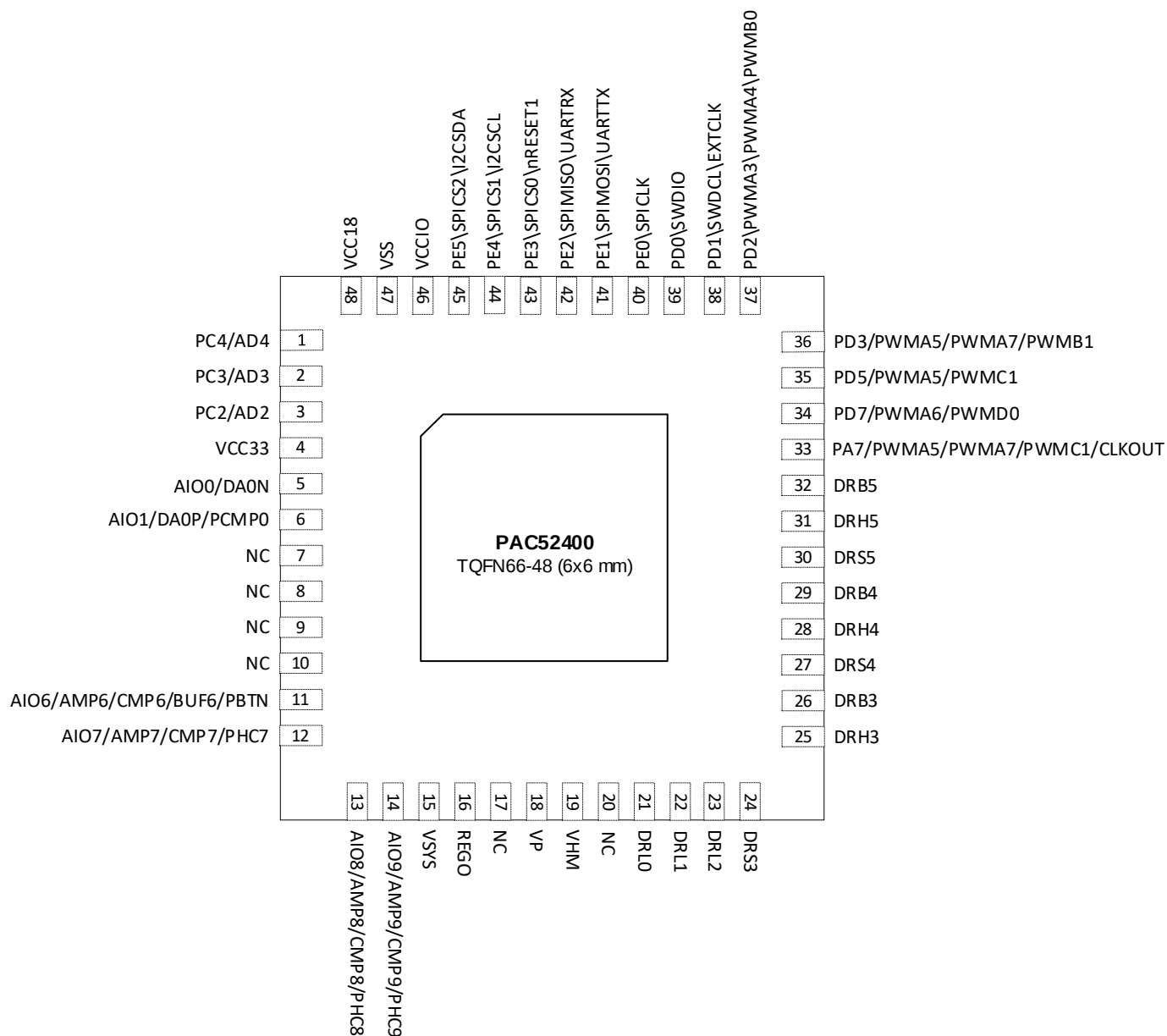
Figure 5-1 Architectural Block Diagram



6 PIN CONFIGURATION

6.1 PAC52400QM

Figure 6-1 PAC52400QM Pin Configuration (TQFN66-48 Package)



7 PIN DESCRIPTION

Table 7-1 Multi-Mode Power Manager and System Pin Description

PIN NAME	PIN NUMBER	TYPE	DESCRIPTION
EP (VSS)	EP	Power	Exposed pad. Must be connected to V _{SS} in a star ground configuration. Connect to a large PCB copper area for power dissipation heat sinking.
VSS	47	Power	Ground.
REGO	16	Power	System regulator output. Connect to V _{sys} directly or through an external power-dissipating resistor.
VCC18	48	Power	Internally generated 1.8V core power supply. Connect a 2.2μF or higher value ceramic capacitor from V _{CC18} to V _{SSA} . See Figure 9-1. Power Supply Bypass Capacitor Routing below.
VCC33	4	Power	Internally generated 3.3V power supply. Connect a 2.2μF or higher value ceramic capacitor from V _{CC33} to V _{SSA} . See PCB layout note below.
VCCIO	46	Power	Internally generated digital I/O power supply. Connect a 4.7μF or higher value ceramic capacitor from V _{CCIO} to V _{SSA} . See Figure 9-1. Power Supply Bypass Capacitor Routing below.
VHM	19	Power	Main power supply. Connect a 1μF or higher value ceramic capacitor, or a 0.1μF ceramic capacitor in parallel with a 10μF or higher electrolytic capacitor from V _{HM} to V _{SSP} . This pin requires good capacitive bypassing to V _{SSP} , so the ceramic capacitor must be connected with a shorter than 10mm trace from the pin. See Figure 9-1. Power Supply Bypass Capacitor Routing below. Can be connected directly to VP if input voltage is less than 20V.
VP	18	Power	Main power supply. Provides power to the power drivers as well as voltage feedback path for the switching supply. Connect a properly sized supply bypass capacitor in parallel with a 0.1μF ceramic capacitor from V _P pin to V _{SS} . This pin requires good capacitive bypassing to V _{SS} , so the ceramic capacitor must be connected with a shorter than 10mm trace from the pin. See Figure 9-1. Power Supply Bypass Capacitor Routing below.
VSYS	15	Power	5V system power supply. Connect a 4.7μF or higher value ceramic capacitor from V _{sys} to V _{SSP} . See Figure 9-1. Power Supply Bypass Capacitor Routing below.

Table 7-2 Configurable Analog Front End Pin Description

PIN NAME	PIN NUMBER	FUNCTION	TYPE	DESCRIPTION
AIO0/DA0N	5	AIO0	I/O	Analog front end I/O 0.
		DA0N	Analog	Differential PGA 0 negative input.
AIO1/DA0P/PCMP0	6	AIO1	I/O	Analog front end I/O 1.
		DA0P	Analog	Differential PGA 0 positive input.
		PCMP0	Analog	Protection comparator input 0.
AIO6/AMP6/CMP6/BUF6/PBTN	11	AIO6	I/O	Analog front end I/O 6.
		AMP6	Analog	PGA input 6.
		CMP6	Analog	Comparator input 6.
		BUF6	Analog	Buffer output 6.
		PBTN	Analog	Push button input.
AIO7/AMP7/CMP7/PHC7	12	AIO7	I/O	Analog front end I/O 7.
		AMP7	Analog	PGA input 7.
		CMP7	Analog	Comparator input 7.
		PHC7	Analog	Phase comparator input 7.
AIO8/AMP8/CMP8/PHC8	13	AIO8	I/O	Analog front end I/O 8.
		AMP8	Analog	PGA input 8.
		CMP8	Analog	Comparator input 8.
		PHC8	Analog	Phase comparator input 8.
AIO9/AMP9/CMP9/PHC9	14	AIO9	I/O	Analog front end I/O 9.
		AMP9	Analog	PGA input 9.
		CMP9	Analog	Comparator input 9.
		PHC9	Analog	Phase comparator input 9.

Table 7-3 Application Specific Power Drivers Pin Description

PIN NAME	PIN NUMBER	TYPE	DESCRIPTION
DRB3	26	Analog	High-side gate driver bootstrap 3.
DRB4	29	Analog	High-side gate driver bootstrap 4.
DRB5	32	Analog	High-side gate driver bootstrap 5.
DRH3	25	Analog	High-side gate driver 3.
DRH4	28	Analog	High-side gate driver 4.
DRH5	31	Analog	High-side gate driver 5.
DRL0	21	Analog	Low-side gate driver 0.
DRL1	22	Analog	Low-side gate driver 1.
DRL2	23	Analog	Low-side gate driver 2.
DRS3	24	Analog	High-side gate driver source 3.
DRS4	27	Analog	High-side gate driver source 4.
DRS5	30	Analog	High-side gate driver source 5.

Table 7-4 I/O Ports Pin Description

PIN NAME	PIN NUMBER	FUNCTION	TYPE	DESCRIPTION
PC2/AD2	3	PC2	I/O	I/O port C2.
		AD2	Analog	ADC input 2.
PC3/AD3	2	PC3	I/O	I/O port C3.
		AD3	Analog	ADC input 3.
PC4/AD4	1	PC4	I/O	I/O port C4.
		AD4	Analog	ADC input 4.

Table 7-5 I/O Ports Pin Description (Continued)

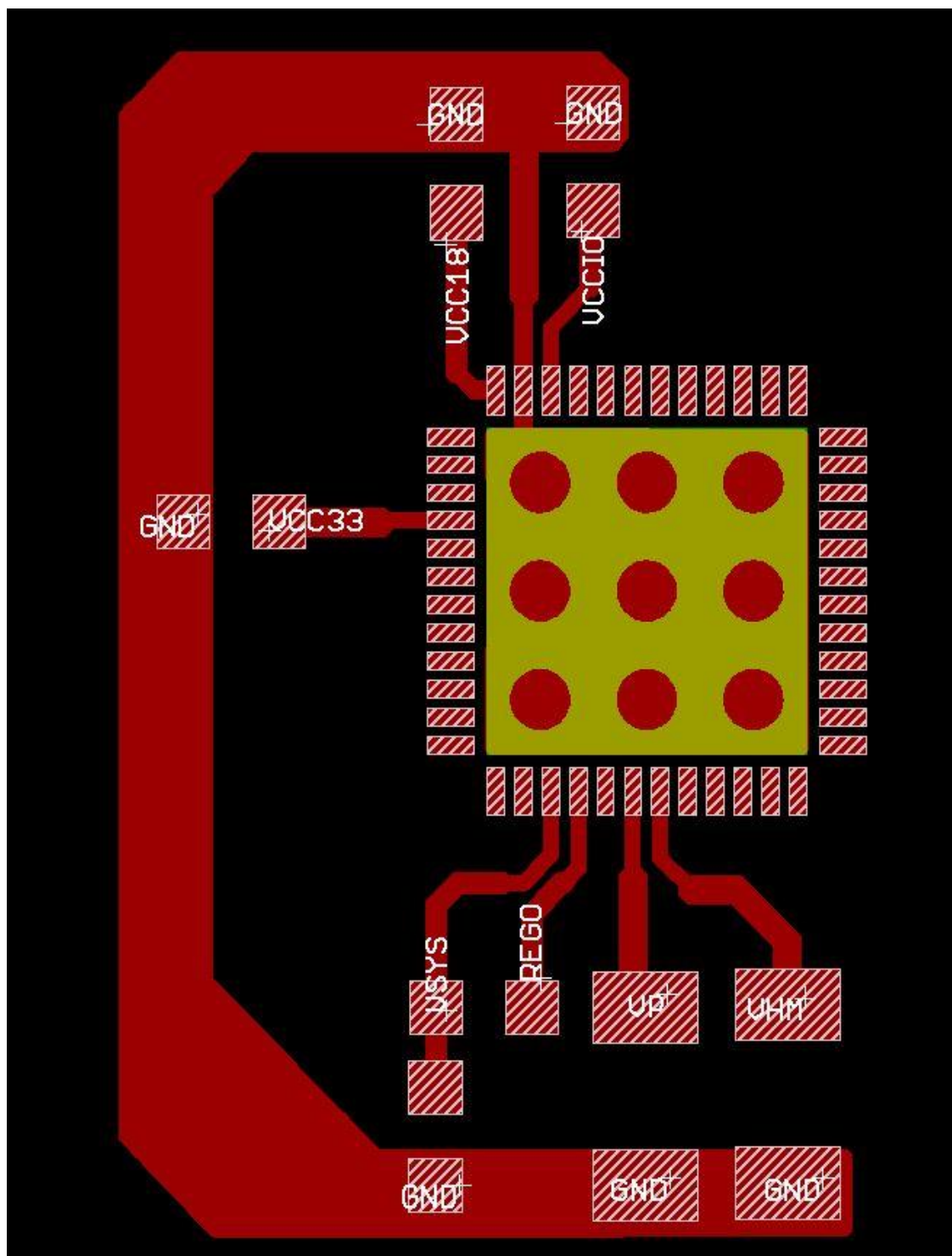
PIN NAME	PIN NUMBER	FUNCTION	TYPE	DESCRIPTION
PA7/PWMA5/PWMA7/PAMC1/CLKOUT	33	PA7	Digital	I/O port A7.
		PWMA5	Digital	Timer A PWM/Capture 5.
		PWMA7	Digital	Timer A PWM/Capture 7.
		PWMC1	Digital	Timer C PWM/Capture 1.
		CLKOUT	Digital	Low-speed clock output
PD0/SWDIO	39	PD0	I/O	I/O port D0.
		SWDIO	I/O	Serial wire debug I/O.
PD1/SWDCL/EXTCLK	38	PD1	I/O	I/O port D1.
		SWDCL	I	Serial wire debug clock.
		EXTCLK	I	External clock.
PD2/PWMA3/PWMA4/PWMB0	37	PD2	I/O	I/O port D2.
		PWMA3	I/O	Timer A PWM/capture 3.
		PWMA4	I/O	Timer A PWM/capture 4.
		PWMB0	I/O	Timer B PWM/capture 0.
PD3/PWMA5/PWMA7/PWMB1	36	PD3	I/O	I/O port D3.
		PWMA5	I/O	Timer A PWM/capture 5.
		PWMA7	I/O	Timer A PWM/capture 7.
		PWMB1	I/O	Timer B PWM/capture 1.
PD5/PWMA5/PWMC1	35	PD5	I/O	I/O port D5.
		PWMA5	I/O	Timer A PWM/capture 5.
		PWMC1	I/O	Timer C PWM/capture 1.
PD7/PWMA6/PWMD0	34	PD7	I/O	I/O port D7.
		PWMA6	I/O	Timer A PWM/capture 6.
		PWMD0	I/O	Timer D PWM/capture 0.
PE0/SPICLK	40	PE0	I/O	I/O port E0.
		SPICLK	I/O	SPI clock.
PE1/SPIMOSI/UARTTX	41	PE1	I/O	I/O port E1.
		SPIMOSI	I/O	SPI master out slave in (MOSI).
		UARTTX	O	UART transmit output.
PE2/SPIMISO/UARTRX	42	PE2	I/O	I/O port E2.
		SPIMISO	I/O	SPI master in slave out (MISO).
		UARTRX	I	UART receive input.



Table 7-6 I/O Ports Pin Description (Continued)

PIN NAME	PIN NUMBER	FUNCTION	TYPE	DESCRIPTION
PE3/SPICS0/nRESET1	43	PE3	I/O	I/O port E3.
		SPICS0	O	SPI chip select 0.
		nRESET1	I	Reset input 1 (active low).
PE4/SPICS1/I2CSCL	44	PE4	I/O	I/O port E4.
		SPICS1	O	SPI chip select 1.
		I2CSCL	I/O	I2C clock.
PE5/SPICS2/I2CSDA	45	PE5	I/O	I/O port E5.
		SPICS2	O	SPI chip select 2.
		I2CSDA	I/O	I2C data.

Figure 7-1 Power Supply Bypass Capacitor Routing



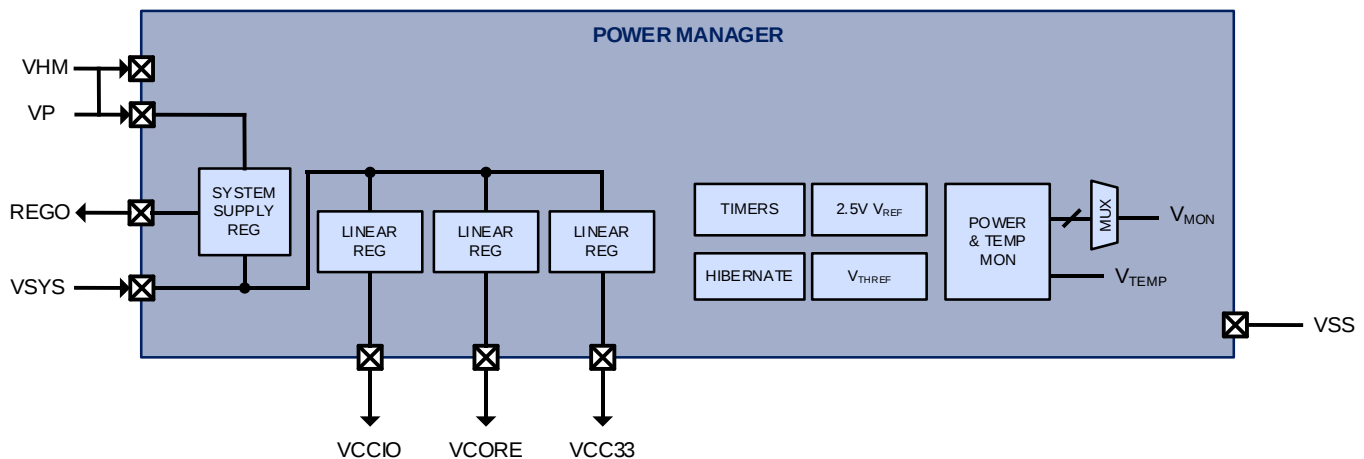
8 POWER MANAGER

8.1 Features

- Direct DC supply up to 20V
- 4 linear regulators with power and hibernate management
- Power and temperature monitor, warning, and fault detection

8.2 Block Diagram

Figure 8-1 Power Manager



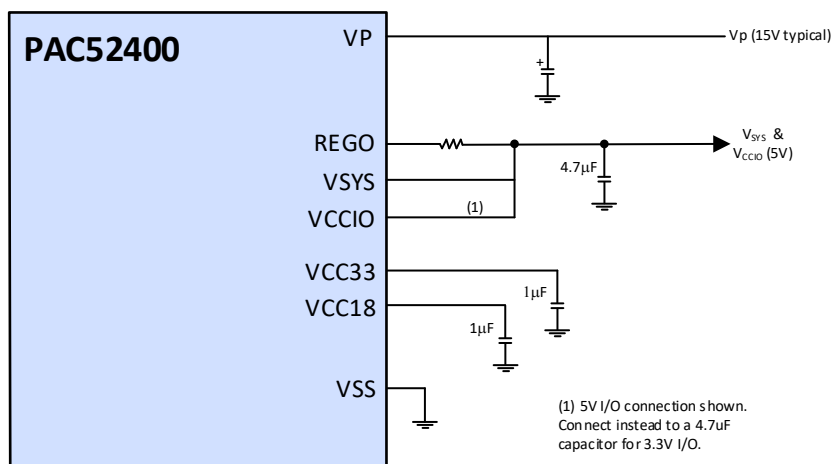
8.3 Functional Description

The Power Manager ([Figure 10-1](#)) is optimized to efficiently provide "all-in-one" power management required by the PAC and associated application circuitry from a simple regulated input power source. Application provides main supply input V_P , from which four linear regulators are derived. V_{SYS} , V_{CCIO} , V_{CC33} , and V_{CC18} LDO outputs can be employed for 5V system, 5V or 3.3V I/O, 3.3V mixed signal, and 1.8V microcontroller core circuitry. The power manager also handles system functions including internal reference generation, timers, hibernate mode management, and power and temperature monitoring.

8.3.1 Linear Regulators

The Power Manager includes up to four linear regulators. The system supply regulator is a medium voltage regulator that takes the V_P supply and sources up to 100mA at REGO until V_{SYS} , externally coupled to REGO, reaches 5V. This allows a properly rated external resistor to be connected from REGO to V_{SYS} to close the current loop and offload power dissipation between V_P and V_{SYS} . Once V_{SYS} is above 4.3V, the three additional 40mA linear regulators for V_{CCIO} , V_{CC33} , and V_{CC18} supplies sequentially power up. [Figure 10-4](#) shows typical circuit connections for the linear regulators. For 5V I/O systems, short the V_{CCIO} pin to V_{SYS} to bypass the V_{CCIO} regulator. For 3.3V I/O systems, the V_{CCIO} regulator generates 3.3V. The V_{CC33} and V_{CC18} regulators generate 3.3V and 1.8V, respectively. When V_{SYS} , V_{CCIO} , V_{CC33} , and V_{CC18} are all above their respective power good thresholds, and the configurable power on reset duration has expired, the microcontroller is initialized.

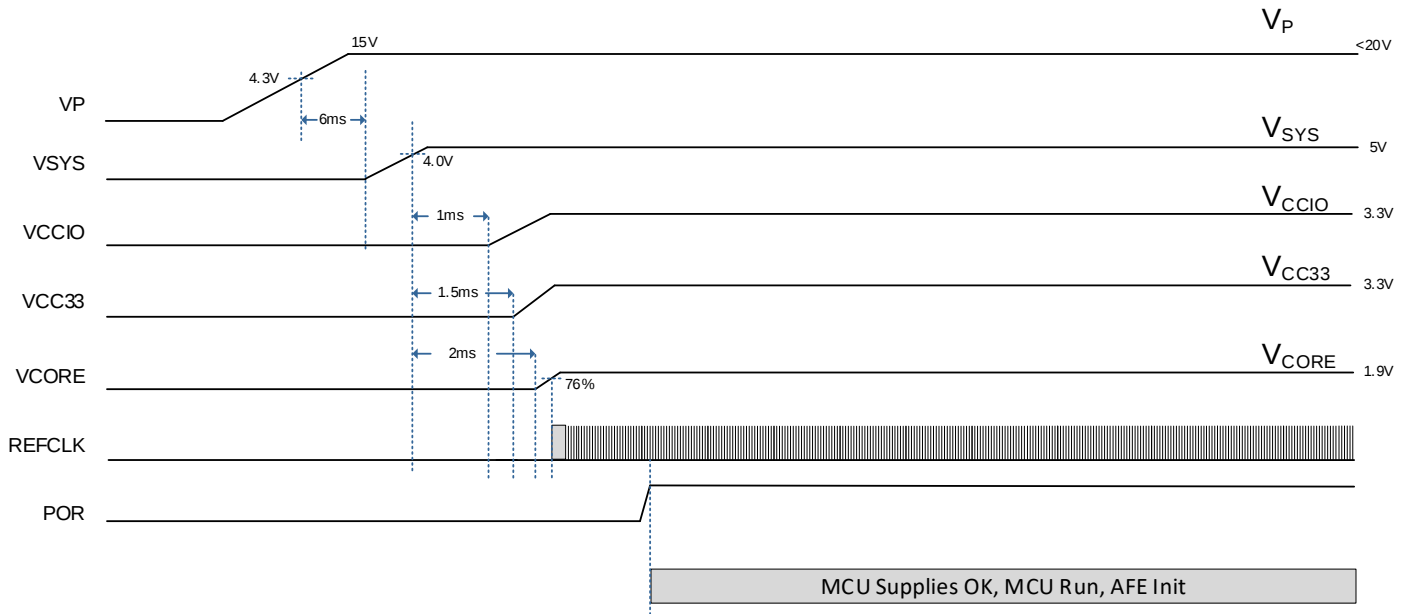
Figure 8-2 Linear Regulators



8.3.2 Power Up Sequence

The Power Manager follows a typical power up sequence as in the [Figure 10-5](#) below. A typical sequence begins with V_P ramping up to the applied, less than 20V, regulated voltage, before the linear regulators are enabled. When all the supplies are ready, the internal clocks become available, and the microcontroller starts executing from the program memory.

Figure 8-3 Power Up Sequence



8.3.3 Hibernate Mode

The IC can go into an ultra-low power hibernate mode via the microcontroller firmware (see device's User Guide for more information on how to enter hibernate mode). In hibernate mode, only a minimal amount (typically 13 μ A) of current is used by V_{HM} , and all internal regulators are shut down to eliminate power drain from the output supplies. The system exits hibernate mode after a wake-up timer duration (configurable from 125ms to 8s or infinite) has expired or, if push button enabled, after an additional push button event has been detected. When exiting the hibernate mode, the power manager goes through the start up cycle and the microcontroller is reinitialized. Only the persistent power manager status bits (resets and faults) are retained during hibernation.

8.3.4 Power and Temperature Monitor

Whenever any of the V_{SYS} , V_{CCIO} , V_{CC33} , or V_{CC18} power supplies falls below their respective power good threshold voltage, a fault event is detected and the microcontroller is reset. The microcontroller stays in the reset state until V_{SYS} , V_{CCIO} , V_{CC33} , and V_{CC18} supply rails are all good again and the reset time has expired. A microcontroller reset can also be initiated by a non maskable temperature fault event that occurs when the IC temperature reaches 170°C. The fault status bits are persistent during reset, and can be read by the microcontroller upon re-initialization to determine the cause of previous reset.

A power monitoring signal V_{MON} is provided onto the ADC pre-multiplexer for monitoring various internal power supplies. V_{MON} can be set to be V_{CC18} , $0.4 \cdot V_{CC33}$, $0.4 \cdot V_{CCIO}$, $0.4 \cdot V_{SYS}$, $0.1 \cdot V_{REGO}$, $0.1 \cdot V_P$, or the internal compensation voltage V_{COMP} for switching supply power monitoring.

For temperature warning, an IC temperature warning event at 140°C is provided as maskable interrupts to the microcontroller. This condition will assert an interrupt on IRQ1 (pin PB0).

These warnings allow the microcontroller to safely power down the system.

In addition to the temperature warning interrupt and fault reset, a temperature monitor signal $V_{TEMP} = 1.5 + 5.04e-3 \cdot (T - 25^{\circ}C)$ (V) is provided onto the ADC pre-multiplexer for IC temperature measurement.

8.3.5 Voltage Reference

The reference block includes a 2.5V high precision reference voltage that provides the 2.5V reference voltage for the ADC, the DACs, and the 4-level programmable threshold voltage V_{THREF} (0.1V, 0.2V, 0.5V, and 1.25V).

8.4 Electrical Characteristics

Table 8-1 Linear Regulators Electrical Characteristics

($V_P = 12V$ and $T_A = -40^\circ C$ to $105^\circ C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$V_{OP;VP}$	V_P operating voltage range		4.7		18	V
$V_{UVLO;VP}$	V_P under-voltage-lockout threshold	V_P rising, hysteresis = 0.2V	4	4.3	4.7	V
$I_{Q;VP}$	V_P quiescent supply current	Power manager only, including $I_{Q;V_{SYS}}$		400	750	μA
$I_{Q;V_{SYS}}$	V_{SYS} quiescent supply current	V_{CCIO} , V_{CC33} , and V_{CC18} regulators only		350	600	μA
V_{SYS}	V_{SYS} output voltage	Load = 10 μA to 200mA	4.8	5	5.18	V
V_{CCIO}	V_{CCIO} output voltage	Load = 10mA				V
		V_{CCIO} shorted to V_{SYS} V_{CCIO} from regulator		V_{SYS} 3.152		
V_{CC33}	V_{CC33} output voltage	Load = 10mA	3.185	3.3	3.415	V
V_{CC18}	V_{CC18} output voltage	Load = 10mA	1.834	1.9	1.975	V
$I_{LIM;V_{SYS}}$	V_{SYS} regulator current limit		110	125		mA
$I_{LIM;V_{CCIO}}$	V_{CCIO} regulator current limit		45	80		mA
$I_{LIM;V_{CC33}}$	V_{CC33} regulator current limit		45	80		mA
$I_{LIM;V_{CC18}}$	V_{CC18} regulator current limit		45	80		mA
k_{SCFB}	Short circuit current fold back			50		%
$V_{DO;V_{SYS}}$	V_{SYS} dropout voltage	$V_P = 5V$, $I_{SYS} = 100mA$		350	680	mV
$V_{UVLO;V_{SYS}}$	V_{SYS} under-voltage-lockout threshold	V_{SYS} rising, hysteresis = 0.5V	4.1	4.3	4.5	V
k_{POKIO}	V_{CCIO} Power OK threshold	V_{CCIO} rising, hysteresis = 10%	80	86	92	%
k_{POK33}	V_{CC33} Power OK threshold	V_{CC33} rising, hysteresis = 10%	80	86	92	%
k_{POK18}	V_{CC18} Power OK threshold	V_{CC18} rising, hysteresis = 10%	80	86	92	%

Table 8-2 Power System Electrical Characteristics

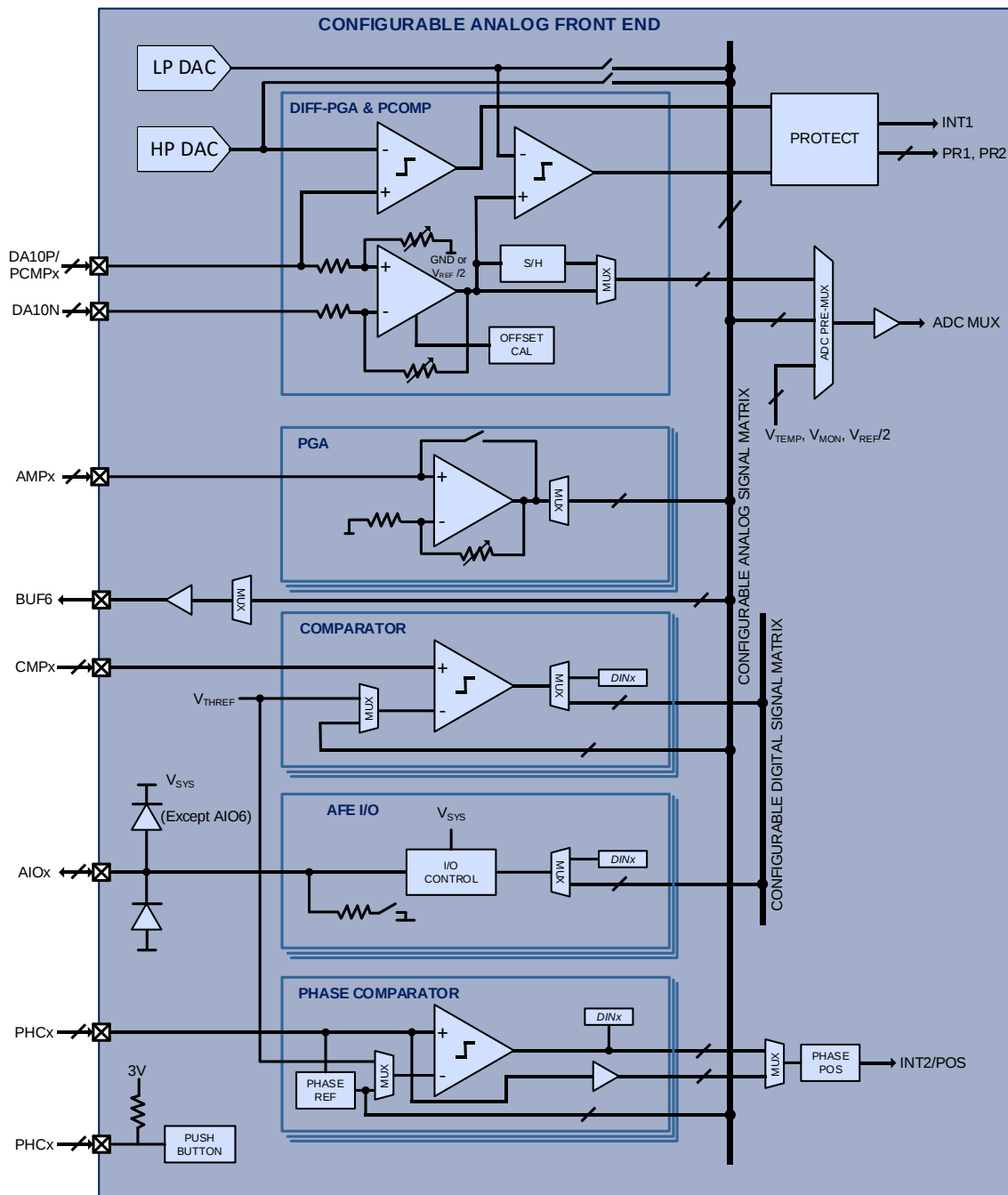
($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
V_{REF}	Reference voltage	$T_A = 25^{\circ}C$	2.487	2.5	2.513	V
		$T_A = -40^{\circ}C$ to $105^{\circ}C$	2.463	2.5	2.537	
k_{MON}	Power monitoring voltage (V_{MON}) coefficient	V_{CC18}	0.92	1	1.02	V/V
		V_{SYS} , V_{CCIO} , V_{CC33}	0.36	0.4	0.43	
		V_P , V_{REGO}	0.09	0.1	0.11	
V_{TEMP}	Temperature monitor voltage at $25^{\circ}C$	$T_A = 25^{\circ}C$, at ADC	1.475	1.5	1.540	V
k_{TEMP}	Temperature monitor coefficient	At ADC		6		mV/K
T_{WARN}	Over-temperature warning threshold	Hysteresis = $10^{\circ}C$		140		$^{\circ}C$
T_{FAULT}	Over-temperature fault threshold	Hysteresis = $10^{\circ}C$		170		$^{\circ}C$

9 CONFIGURABLE ANALOG FRONT END (CAFE)

9.1 Block Diagram

Figure 9-1 Configurable Analog Front End



9.2 Functional Description

The device includes a Configurable Analog Front End (CAFE, [Figure 11-1](#)) accessible through up to 6 analog and I/O pins. These pins can be configured to form flexible interconnected circuitry made up of 1 differential programmable gain amplifier, 4 single-ended programmable gain amplifiers, 4 general purpose comparators, 3 phase comparators, 2 protection comparators, and one buffer output. These pins can also be programmed as analog feed-through pins, or as analog front end I/O pins that can function as digital inputs or digital open-drain outputs. The PAC proprietary configurable analog signal matrix (CASM) and configurable digital signal matrix (CDSM) allow real time asynchronous analog and digital signals to be routed in flexible circuit connections for different applications. A push button function is provided for optional push button on, hibernate, and off power management function. A low speed clock output is provided for optimizing system design for UL/IEC60730 Class B Safety Applications.

9.2.1 Differential Programmable Gain Amplifier (DA10)

The DA10P and DA10N pin pair are positive and negative inputs, respectively, to a differential programmable gain amplifier. The differential gain can be programmable to be 1x, 2x, 4x, 8x, 16x, 32x, and 48x for zero ohm signal source impedance. The differential programmable gain amplifier has -0.3V to 2.5V input common mode range, and its output can be configured for routing directly to the ADC pre-multiplexer, or through a sample-and-hold circuit synchronized with the ADC auto-sampling mechanism. Each differential amplifier is accompanied by offset calibration circuitry, and two protection comparators for protection event monitoring. The programmable gain differential amplifier is optimized for use with signal source impedance lower than 500Ω and with matched source impedance on both positive and negative inputs for minimal offset. The effective gain is scaled by $13.5k / (13.5k + R_{SOURCE})$, where R_{SOURCE} is the matched source impedance of each input.

9.2.2 Single-Ended Programmable Gain Amplifier (AMP)

Each AMPx input goes to a single-ended programmable gain amplifier with signal relative to V_{SSA} . The amplifier gain can be programmed to be 1x, 2x, 4x, 8x, 16x, 32x, and 48x, or as analog feed-through. The programmable gain amplifier output is routed via a multiplexer to the configurable analog signal matrix CASM.

9.2.3 General Purpose Comparator (CMP)

The general purpose comparator takes the CMPx input and compares it to either the programmable threshold voltage (V_{THREF}) or a signal from the configurable analog signal matrix CASM. The comparator has 0V to V_{SYS} input common mode range, and its polarity-selectable output is routed via a multiplexer to either a data input bit or the configurable digital signal matrix CDSM. Each general purpose comparator has two mask bits to prevent or allow rising or falling edge of its output to trigger second microcontroller interrupt INT2, where INT2 can be configured to active protection event PR1.

9.2.4 Phase Comparator (PHC)

The phase comparator takes the PHCx input and compares it to either the programmable threshold voltage (V_{THREF}) or a signal from the configurable analog signal matrix CASM. The comparison signal can be set to a phase reference signal generated by averaging the PHCx input voltages. In a three-phase motor control application, the phase reference signal acts as a virtual center tap for BEMF detection. The PHCx inputs are optionally fed through to the CASM. The phase comparator has 0V to V_{SYS} input common mode range, and its polarity-selectable output is routed to a data input bit and to the phase/position multiplexer synchronized with the auto-sampling sequencers. The PHC inputs can be compared to the

virtual center-tap, or phase to phase for the most efficient BEMF zero-cross detection. The phase comparators have configurable asymmetric hysteresis.

The phase comparator has 0V to V_{SYS} input common mode range, and its polarity-selectable output is routed to a data input bit and to the phase/position multiplexer synchronized with the auto-sampling sequencers.

9.2.5 Protection Comparator (PCMP)

Two protection comparators are provided in association with the differential programmable gain amplifier, with outputs available to trigger protection events and accessible as read-back output bits. The high-speed protection (HP) comparator compares the PCMPx pin to the 8-bit HP DAC output voltage, with full scale voltage of 2.5V. The limit protection (LP) comparator compares the differential programmable gain amplifier output to the 10-bit LP DAC output voltage, with full scale voltage of 2.5V.

Each protection comparator has a mask bit to prevent or allow it to trigger the main microcontroller interrupt INT1. Each protection comparator also has one mask bit to prevent or allow it to activate protection event PR1, and another mask bit to prevent or allow it to activate protection event PR2. These two protection events can be used directly by protection circuitry in the Application Specific Power Drivers (ASPD) to protect devices being driven.

9.2.6 Analog Output Buffer (BUF)

A subset of the signals from the configurable analog signal matrix CASM can be multiplexed to the BUF6 pin for external use. The buffer offset voltage can be minimized with the built-in swap function.

9.2.7 Analog Front End I/O (AIO)

Up to 6 AIOx pins are available in the device. In the analog front end I/O mode, the pin can be configured to be a digital input or digital open-drain output. The AIOx input or output signal can be set to a data input or output register bit, or multiplexed to one of the signals in the configurable digital signal matrix CDSM. The signal can be set to active high (default) or active low, with V_{SYS} supply rail. Where AIO_{6,7,8,9} supports microcontroller interrupt for external signals. Each has two mask bits to prevent or allow rising or falling edge of its corresponding digital input to trigger second microcontroller interrupt INT2.

9.2.8 Push Button (PBTN)

The push button PBTN, when enabled, can be used by the microcontroller to detect a user active-low push button event. Once the system is in hibernate mode, PBTN can be used to wake up the system. In addition, PBTN can also be used as a hardware reset for the microcontroller when it is held low for longer than 8s during normal operation. The PBTN input is active low and has a 55k Ω pull-up resistor to 3V.

9.2.9 HP DAC and LP DAC

The 8-bit HP DAC can be used as the comparison voltage for the high-speed protection (HP) comparators, or routed for general purpose use via the AB2 signal in the CASM. The HP DAC output full scale voltage is 2.5V.

The 10-bit LP DAC can be used as the comparison voltage for the limit protection (LP) comparators, or routed for general purpose use via the AB3 signal in the CASM. The LP DAC output full scale voltage is 2.5V.

9.2.10 CLKOUT

There is a low-speed clock output that may be enabled and configured on this device. The clock output is disabled by default and may be enabled or disabled through a register bit. The clock output may be configured for 250 Hz, 500 Hz, or 1kHz.

This clock output is useful for generating a second clock source that is needed by UL or IEC60730 Class B Safety standards. This output may be connected to a digital input on the PCB on this device so that the MCU firmware may detect any issues with the clock such as failure, or drifting of the frequency.

The CLKOUT pin is shared with PA7, as an open-drain output. If the CLKOUT pin is enabled, then PA7 may be configured as a weak-pull up or a high-impedance input, with a 100k pull-up resistor that connects PA7 to VCCIO. The digital input functions will still be enabled, but no output functions are allowed.

9.2.11 ADC Pre-Multiplexer

The ADC pre-multiplexer is a 16-to-1 multiplexer that selects between the differential programmable gain amplifier output, AB1 through AB9, temperature monitor signal (V_{TEMP}), power monitor signal (V_{MON}), and offset calibration reference ($V_{REF} / 2$). The ADC pre-multiplexer can be directly controlled or automatically scanned by the auto-sampling sequencer.

When the ADC pre-multiplexer is automatically scanned, the unbuffered or sensitive signals should be masked by setting appropriate register bits.

9.2.12 Configurable Analog Signal Matrix (CASM)

The CASM has 9 general purpose analog signals labeled AB1 through AB9 that can be used for:

- Routing the single-ended programmable gain amplifier or analog feed-through output to AB1 through AB9
- Routing an analog signal via AB1, AB2, or AB3 to the negative input of a general purpose comparator or phase comparator
- Routing the 8-bit HP DAC output to AB2
- Routing the 10-bit LP DAC output to AB3
- Routing analog signals via AB1 through AB12 to the ADC pre-multiplexer
- Routing phase comparator feed-through signals to AB7, AB8, and AB9, and averaged voltage to AB1

9.2.13 Configurable Digital Signal Matrix (CDSM)

The CDSM has 7 general purpose bi-directional digital signals labeled DB1 through DB7 that can be used for:

- Routing the AIOx input to or output signals from DB1 through DB7
- Routing the general purpose comparator output signals to DB1 through DB7

9.3 Electrical Characteristics

Table 9-1 Differential Programmable Gain Amplifier (DA) Electrical Characteristics

(V_{sys} = V_{CCIO} = 5V, V_{CC33} = 3.3V, and T_A = -40°C to 105°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
I _{CC,DA}	Operating supply current	Enabled amplifier		150	300	μA
V _{ICMR,DA}	Input common mode range		-0.3		2.5	V
V _{OLR,DA}	Output linear range		0.1		V _{sys} – 0.1	V
V _{SHR,DA}	Sample and hold range		0.1		3.5	V
V _{OS,DA}	Input offset voltage	Gain = 48x, V _{DA10P} = V _{DA10N} = 0V, T _A = 25°C	-8		8	mV
A _{VZI,DA}	Differential amplifier gain (zero ohm source impedance)	Gain = 1x	-2%	1	2%	
		Gain = 2x		2		
		Gain = 4x		4		
		Gain = 8x, V _{DAxP} = 125mV, V _{DAxN} = 0V, T _A = 25°C		8		
		Gain = 16x		16		
		Gain = 32x		32		
		Gain = 48x		48		
K _{CMRR,DA}	Common mode rejection ratio	Gain = 8x, V _{DA10P} = V _{DA10N} = 0V, T _A = 25°C		55		dB
R _{INDIF,DA}	Differential input impedance			27		kΩ
	Slew rate ⁽¹⁾	Gain = 8x	7	10		V/μs
t _{ST,DA}	Settling time ⁽¹⁾	To 1% of final value		200	400	ns

⁽¹⁾ Guaranteed by design.

Table 9-2 Single-Ended Programmable Gain Amplifier (AMP) Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$I_{CC,AMP}$	Operating supply current	Each enabled amplifier		80	140	μA
$V_{ICMR,AMP}$	Input common mode range		0		V_{SYS}	V
$V_{OLR,AMP}$	Output linear range		0.1		$V_{SYS} - 0.1$	V
$V_{OS,AMP}$	Input offset voltage	Gain = 1x, $T_A = 25^{\circ}C$, $V_{AMPX} = 2.5V$	-10		10	mV
$A_{V,AMP}$	Amplifier gain	Gain = 1x	-2%	1	2%	
		Gain = 2x		2		
		Gain = 4x		4		
		Gain = 8x, $V_{AMPX} = 125mV$, $T_A = 25^{\circ}C$		8		
		Gain = 16x		16		
		Gain = 32x		32		
		Gain = 48x		48		
$I_{IN,AMP}$	Input current			0	1	μA
	Slew rate ⁽¹⁾	Gain = 8x	8	12		V/ μs
$t_{ST,AMP}$	Settling time ⁽¹⁾	To 1% of final value		150	300	ns

⁽¹⁾ Guaranteed by design.

Table 9-3 General Purpose Comparator (CMP) Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$I_{CC,CMP}$	Operating supply current	Each enabled comparator		35	110	μA
$V_{ICMR,CMP}$	Input common mode range		0		V_{SYS}	V
$V_{OS,CMP}$	Input offset voltage	$V_{CMPX} = 2.5V$, $T_A = 25^{\circ}C$	-10		10	mV
$V_{HYS,CMP}$	Hysteresis	HYSMODE = 0; HYS[1:0] = 10b		23		mV
$I_{IN,CMP}$	Input current			0	1	μA
$t_{DEL,CMP}$	Comparator delay ⁽¹⁾				100	ns

⁽¹⁾ Guaranteed by design.

Table 9-4 Phase Comparator (PHC) Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$I_{CC,PHC}$	Operating supply current	Each enabled comparator		35	110	μA
$V_{ICMR,PHC}$	Input common mode range		0		V_{SYS}	V
$V_{OS,PHC}$	Input offset voltage	$V_{PHCx} = 2.5V$, $T_A = 25^{\circ}C$	-10		10	mV
$V_{HYS,PHC}$	Hysteresis	$HYSMODE = 0$; $HYS[1:0] = 10b$		23		mV
$I_{IN,PHC}$	Input current			0	1	μA
$t_{DEL,PHC}$	Comparator delay ⁽¹⁾				100	ns

⁽¹⁾ Guaranteed by design.

Table 9-5 Protection Comparator (PCMP) Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$I_{CC,PCMP}$	Operating supply current	Each enabled comparator		35	100	μA
$V_{ICMR,PCMP}$	Input common mode range		0.3		$V_{SYS} - 1$	V
$V_{OS,PCMP}$	Input offset voltage	$V_{PCMPx} = 2.5V$, $T_A = 25^{\circ}C$	-10		10	mV
$V_{HYS,PCMP}$	Hysteresis			20		mV
$I_{IN,PCMP}$	Input current			0	1	μA
$t_{DEL,PCMP}$	Comparator delay ⁽¹⁾				100	ns

⁽¹⁾ Guaranteed by design.

Table 9-6 Analog Output Buffer (BUF) Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$I_{CC,BUF}$	Operating supply current	No load		35	100	μA
$V_{ICMR,BUF}$	Input common mode range		0		3.5	V
$V_{OLR,AMP}$	Output linear range		0.1		3.5	V
$V_{OS,BUF}$	Offset voltage	$V_{BUF} = 2.5V$, $T_A = 25^{\circ}C$	-18		18	mV
I_{OMAX}	Maximum output current	$C_L = 0.1nF$	0.8	1.3		mA

Table 9-7 Analog Front End I/O (AIO) Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
V_{AIO}	Pin voltage range		0		5	V
$V_{IH,AIO}$	High-level input voltage		2.2			V
$V_{IL,AIO}$	Low-level input voltage				0.8	V
$R_{PD,AIO}$	Pull-down resistance	Input mode	0.5	1	1.8	MΩ
$V_{OL,AIO}$	Low-level output voltage	$I_{AIOx} = 7mA$, open-drain output mode			0.4	V
$I_{OL,AIO}$	Low-level output sink current	$V_{AIOx} = 0.4V$, open-drain output mode	6	14		mA
$I_{LK,AIO}$	High-level output leakage current	$V_{AIOx} = 5V$, open-drain output mode		0	10	μA

Table 9-8 Push Button (PBTN) Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$V_{I,PBTN}$	Input voltage range		0		5	V
$V_{IH,PBTN}$	High-level input voltage		2			V
$V_{IL,PBTN}$	Low-level input voltage				0.35	V
$R_{PU,PBTN}$	Pull-up resistance	To 3V, push-button input mode	40	55	95	kΩ

Table 9-9 HP DAC and LP DAC Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
V_{DACREF}	DAC reference voltage	$T_A = 25^{\circ}C$	2.480	2.5	2.520	V
		$T_A = -40^{\circ}C$ to $105^{\circ}C$	2.453	2.5	2.547	
	HP 8-bit DAC INL ⁽¹⁾		-1		1	LSB
	HP 8-bit DAC DNL ⁽¹⁾		-0.5		0.5	LSB
	LP 10-bit DAC INL ⁽¹⁾		-2		2	LSB
	LP 10-bit DAC DNL ⁽¹⁾		-1		1	LSB

⁽¹⁾ Guaranteed by design and characterization.

Table 9-10 CLKOUT Electrical Characteristics

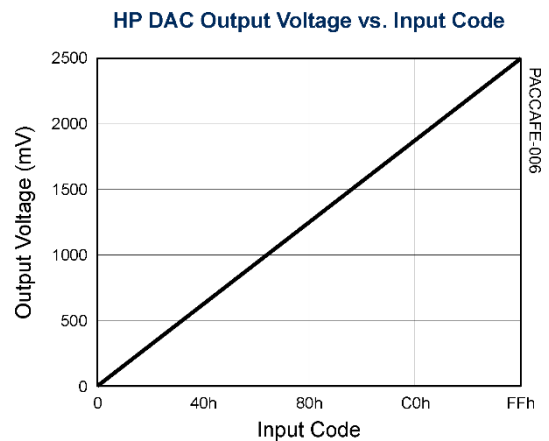
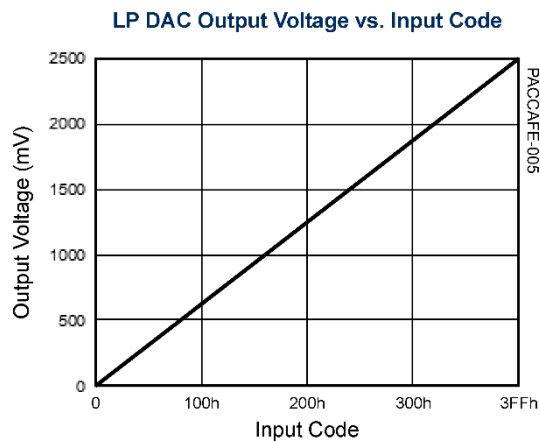
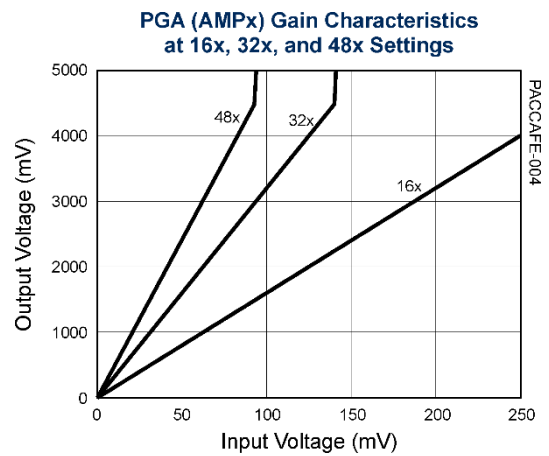
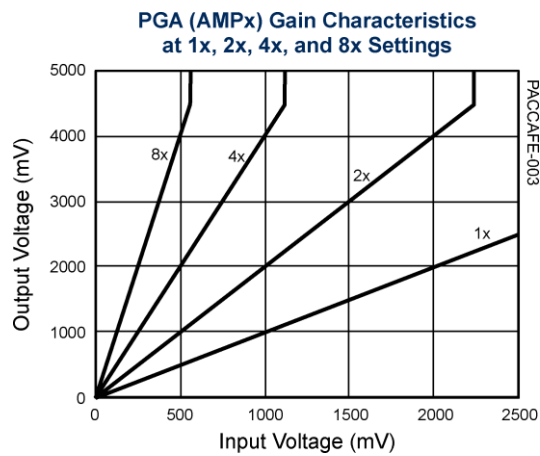
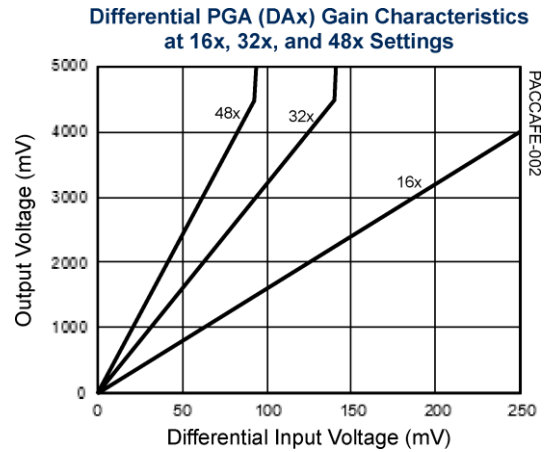
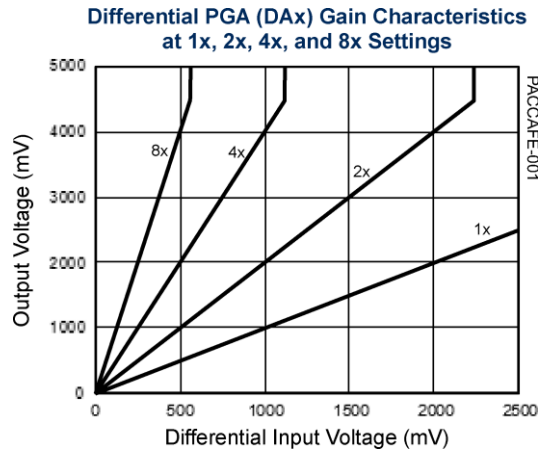
($V_{SYS} = V_{CCIO} = 5V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

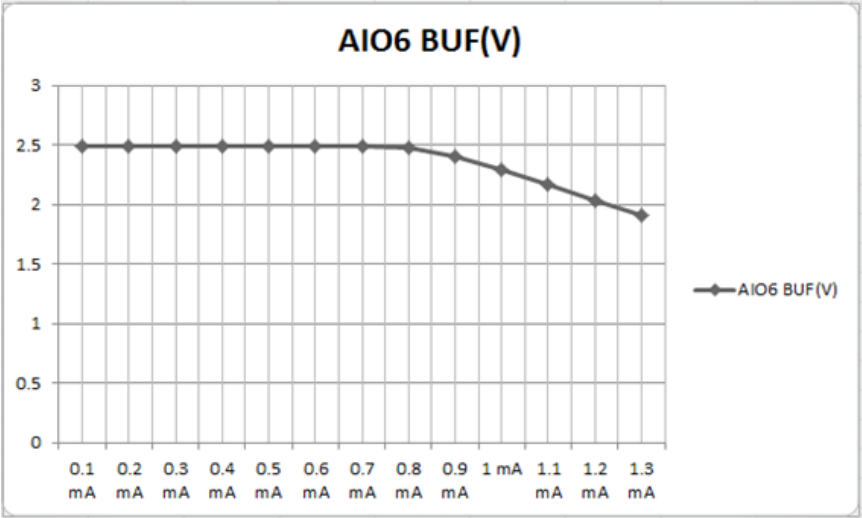
SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
F_{CLKOUT}	Low-speed clock output frequency		450	500	550	Hz
F_{CLKOUT_ERR}	Low-speed clock output frequency error ¹	$T_A = 25^{\circ}C$, F_{CLKOUT} reference from stored value in INFO FLASH.	-10		10	%
		$T_A = -40^{\circ}C$ to $105^{\circ}C$, F_{CLKOUT} reference from stored value in INFO FLASH.	-25		25	%

¹ To improve the accuracy tolerance, the user may use calibrated values for CLKOUT measurements available in INFO FLASH. See the PAC52400 User Guide for more information.

9.4 Typical Performance Characteristics

($V_{SYS} = 5V$ and $T_A = 25^\circ C$ unless otherwise specified.)





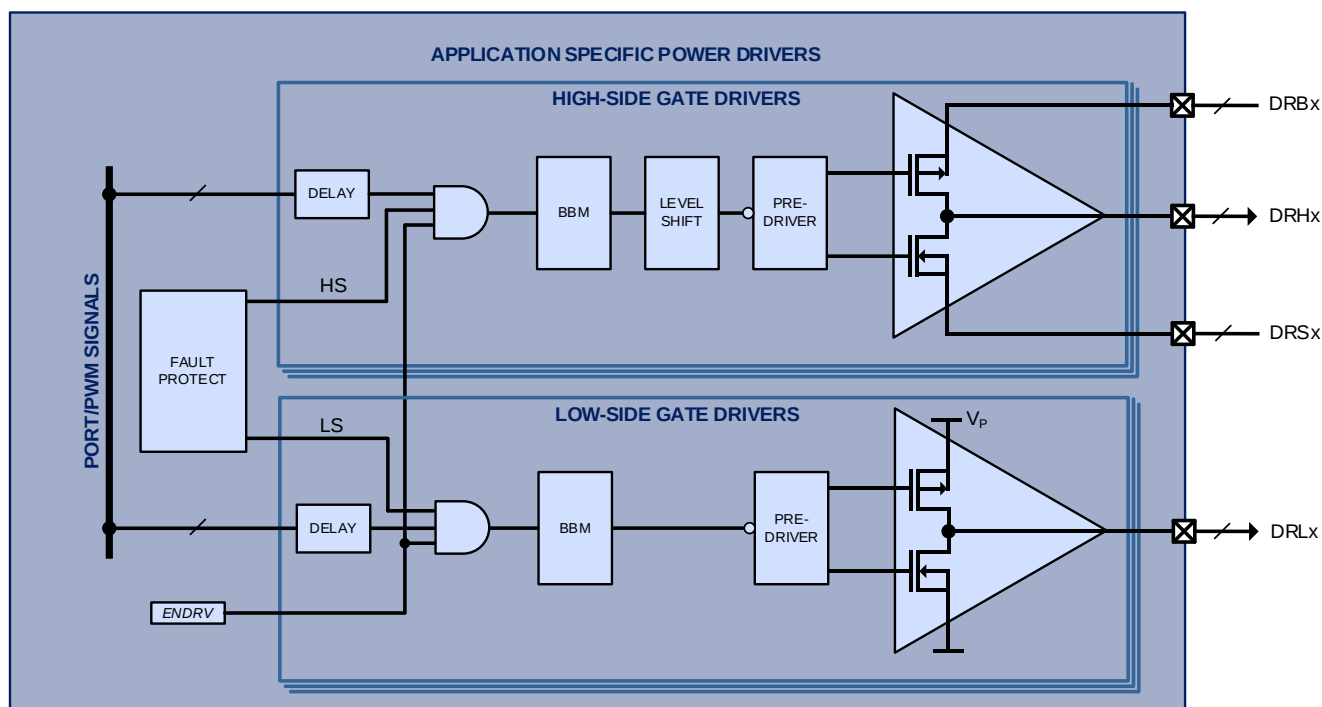
10 APPLICATION SPECIFIC POWER DRIVERS (ASPD)

10.1 Features

- 3 low-side and 3 high-side gate drivers
- 0.75A sink/source gate driving capability
- Configurable delays and fast fault protection

10.2 Block Diagram

Figure 10-1 Application Specific Power Drivers



10.3 Functional Description

The Application Specific Power Drivers (ASPD, [Figure 12-1](#)) module handles power driving for power control applications. The PAC52400 has three low-side gate drivers (DRLx), three high-side gate drivers (DRHx). Each gate driver can drive an external MOSFET or IGBT switch in response to high-speed control signals from the microcontroller ports, and a pair of high-side and low-side gate drivers can form a half-bridge driver.

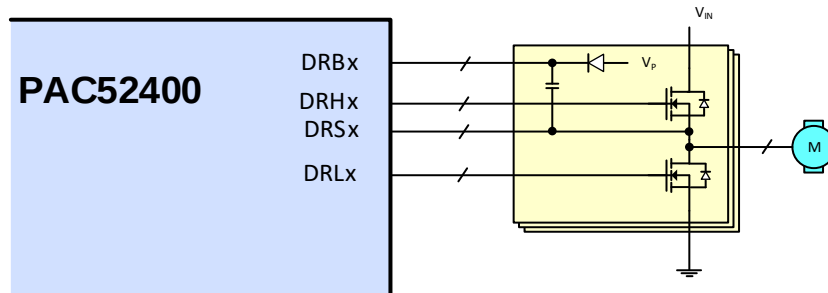
[Figure 12-2](#) below shows typical gate driver connections and [Table 12-1](#) shows the ASPD available resources. The PAC52400 gate drivers support up to a 56V boot-strap supply.



Table 10-1 Power Driver Resources by Part Numbers

PART NUMBER	LOW-SIDE GATE DRIVER		HIGH-SIDE GATE DRIVER		
	DRLx	SOURCE /SINK CURRENT	DRHx	MAX SUPPLY	SOURCE/ SINK CURRENT
PAC52400	3	0.75A/0.75A	3	56V	0.75A/0.75A

Figure 10-2 Typical Gate Driver Connections



The ASPD includes built-in configurable fault protection for the internal gate drivers.

10.3.1 Low-Side Gate Driver

The DRLx low-side gate driver drives the gate of an external MOSFET or IGBT switch between the low-level V_{SSP} power ground rail and high-level V_P supply rail. The DRLx output pin has sink and source output current capability of 0.75A. Each low-side gate driver is controlled by a microcontroller port signal with 4 configurable levels of propagation delay.

10.3.2 High-Side Gate Driver

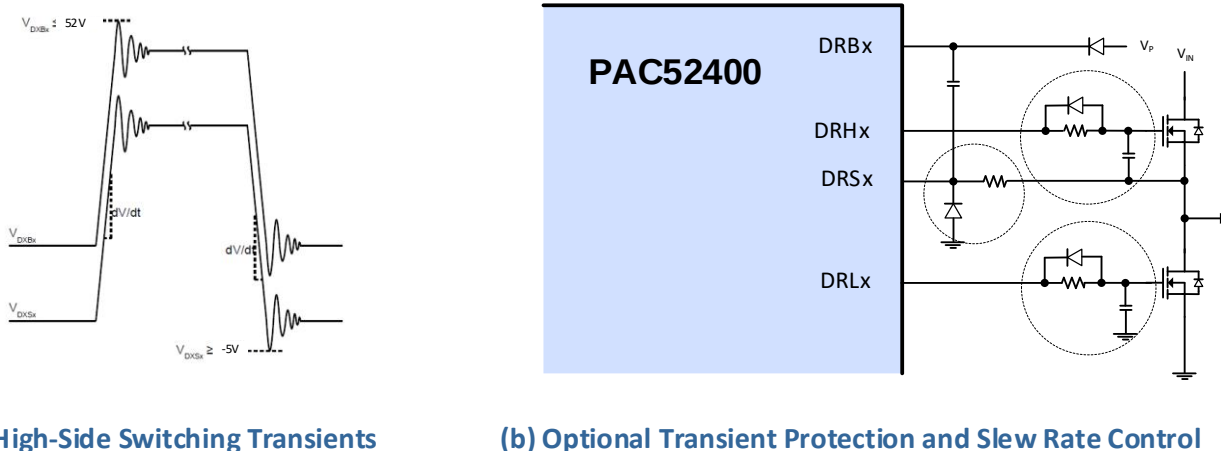
The DRHx high-side gate driver drives the gate of an external MOSFET or IGBT switch between its low-level DRSx driver source rail and its high-level DRBx bootstrap rail. The DRSx pin can go up to 40V steady state. The DRHx output pin has sink and source output current capability of 0.75A. The DRBx bootstrap pin can have a maximum operating voltage of 16V relative to the DRSx pin, and up to 52V steady state. The DRSx pin is designed to tolerate momentary switching negative spikes down to -5V without affecting the DRHx output state. Each high-side gate driver is controlled by a microcontroller port signal with 4 configurable levels of propagation delay.

For bootstrapped high-side operation, connect an appropriate capacitor between DRBx and DRSx and a properly rated bootstrap diode from V_P to DRBx. To operate the DRHx output as a low-side gate driver, connect its DRBx pin to V_P and its DRSx pin to V_{SSP} .

10.3.3 High-Side Switching Transients

Typical high-side switching transients are shown in [Figure 12-3\(a\)](#). To ensure functionality and reliability, the DRSx and DRBx pins must not exceed the peak and undershoot limit values shown. This should be verified by probing the DRBx and DRSx pins directly relative to VSS pin. A small resistor and diode clamp for the DRSx pin can be used to make sure that the pin voltage stays within the negative limit value. In addition, the high-side slew rate dV/dt must be kept within $\pm 5V/ns$ for DRSx. This can be achieved by adding a resistor-diode pair in series, and an optional capacitor in parallel with the power switch gate. The parallel capacitor also provides a low impedance and close gate shunt against coupling from the switch drain. These optional protection and slew rate control are shown in [Figure 12-3\(b\)](#).

Figure 10-3 High-Side Switching Transients and Optional Circuitry



10.3.4 Power Drivers Control

All power drivers are initially disabled from power-on-reset. To enable the power drivers, the microprocessor must first set the driver enable bit to '1'. The gate drivers are controlled by the microcontroller ports and/or PWM signals according to [Table 12-2](#), with configurable delays as shown in [Table 12-3](#). Refer to the PAC Application Notes and User Guide for additional information on power drivers control programming.

Table 10-2 Microcontroller Port and PWM to Power Driver Mapping

PART NUMBER	PWMA0	PWMA1	PWMA2	PWMA3/PWMA4/ PWMB0	PWMA5/PWMC0	PWMA6/PWMD0
	PA0	PA1	PA2	PA3	PA4	PA5
PAC52400	DRL0	DRL1	DRL2	DRH3	DRH4	DRH5

Table 10-3 Power Driver Propagation Delay

DRLx		DRHx	
RISING	FALLING	RISING	FALLING
130ns	140ns	160ns	140ns

10.3.5 Gate Driver Fault Protection

The ASPD incorporates a configurable fault protection mechanism using protection signal from the Configurable Analog Front End (CAFE), designated as protection event 1 (PR1) signal. The DRL0/DRL1/DRL2 drivers are designated as low-side group 1. The DRH3/DRH4/DRH5 gate drivers are designated as high-side group 1. The PR1 signal from the CAFE can be used to disable low-side group 1, high-side group 1, or both depending on the PR1 mask bit settings.

10.4 Electrical Characteristics

Table 10-4 Gate Drivers Electrical Characteristics

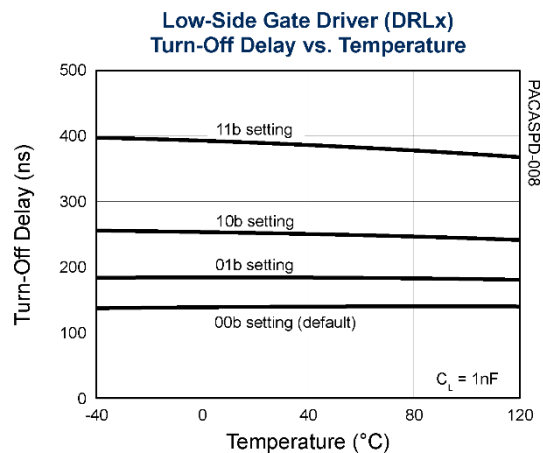
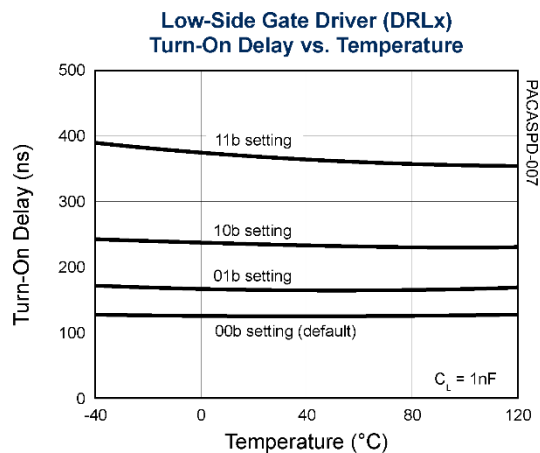
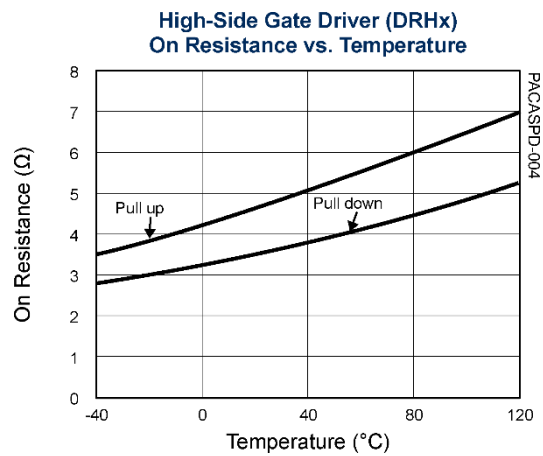
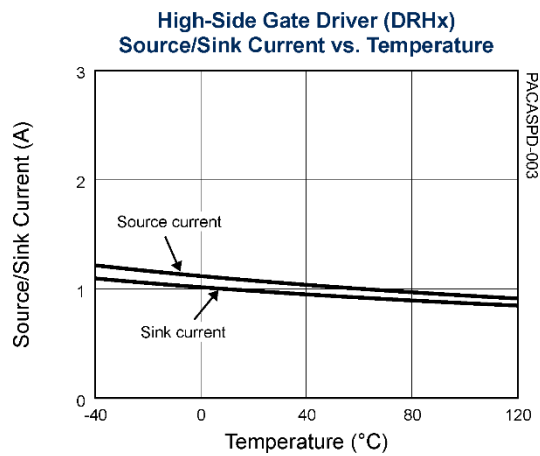
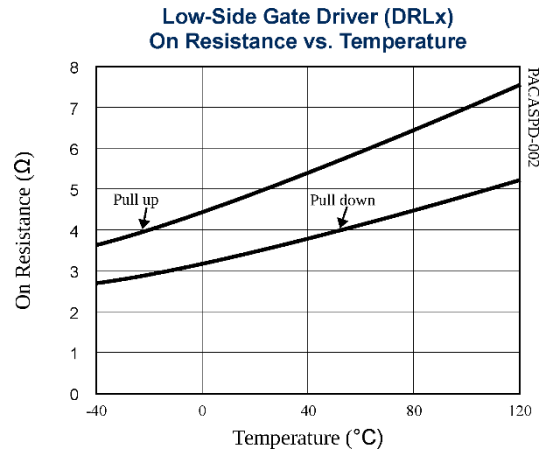
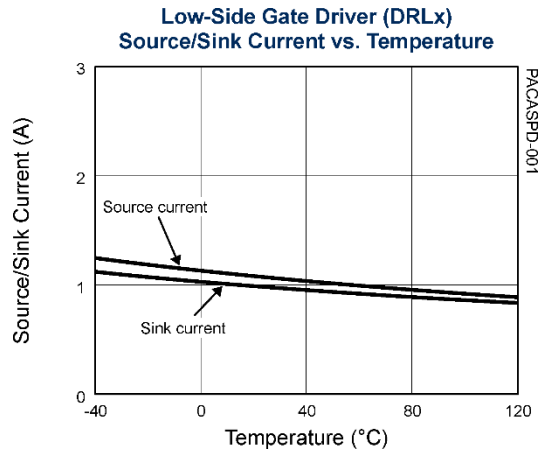
($V_P = 12V$, $V_{SYS} = 5V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
Low-Side Gate Drivers (DRLx Pins)						
$V_{OH,DRL}$	High-level output voltage	$I_{DRLx} = -50mA$	$V_P - 0.3$			V
$V_{OL,DRL}$	Low-level output voltage	$I_{DRLx} = 50mA$			0.2	V
$I_{OHPK,DRL}$	High-level pulsed peak source current	10 μs pulse		-0.75		A
$I_{OLPK,DRL}$	Low-level pulsed peak sink current	10 μs pulse		0.75		A
High-Side Gate Drivers (DRHx, DRBx and DRSx Pins)						
V_{DRS}	Level-shift driver source voltage range	Repetitive, 10 μs pulse	-5		40	V
		Steady state	0		40	
V_{DRB}	Bootstrap pin voltage range	Repetitive, 10 μs pulse	3		52	V
		Steady state	5.2		52	
$V_{BS,DRB}$	Bootstrap supply voltage range	V_{DRBx} , relative to respective V_{DRSx}	5.2		16	V
$V_{UVLO,DRB}$	Bootstrap UVLO threshold	V_{DRBx} rising, relative to respective V_{DRSx} , hysteresis= 0.5V	3.5		4.6	V
$I_{BS,DRB}$	Bootstrap circuit supply current	Gate Driver Disabled		27	50	μA
		Gate Driver Enabled		38	60	
$I_{OS,DRB}$	Offset supply current	Gate Driver Disabled		0.5	10	μA
		Gate Driver Enabled		0.5	10	
$V_{OH,DRH}$	High-level output voltage	$I_{DRHx} = -50mA$	$V_{DRBx} - 0.3$			V
$V_{OL,DRH}$	Low-level output voltage	$I_{DRHx} = 50mA$			$V_{DRSx} + 0.2$	V
$I_{OHPK,DRH}$	High-level pulsed peak source current	10 μs pulse		-0.75		A
$I_{OLPK,DRH}$	Low-level pulsed peak sink current	10 μs pulse		0.75		A
High-Side and Low-Side Gate Driver Propagation Delay						
t_{PD}	Propagation Delay ²	Delay setting 00b		Delay + 0		ns
		Delay setting 01b		Delay + 50		ns
		Delay setting 10b		Delay + 100		ns
		Delay setting 11b		Delay + 200		ns

² Delay from [Power Driver Propagation Delay](#)

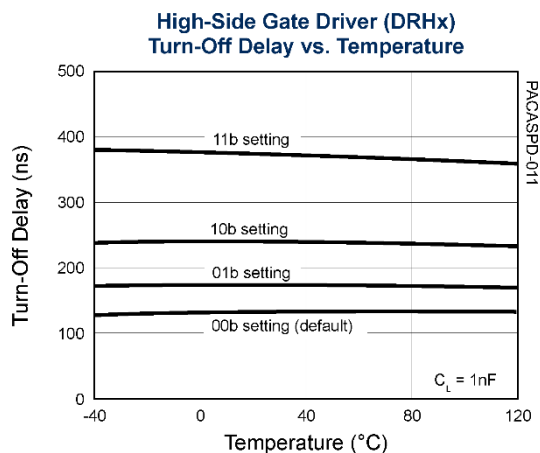
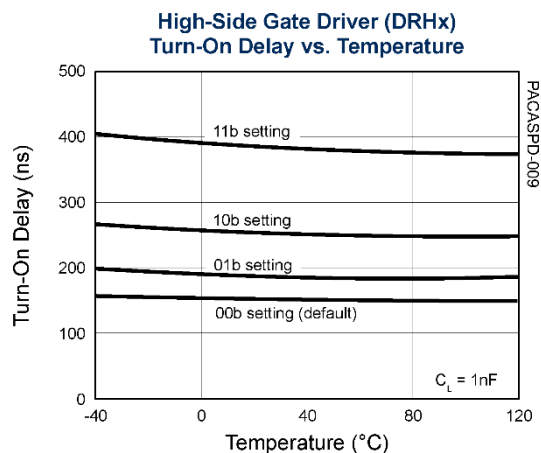
10.5 Typical Performance Characteristics

($V_P = 12V$, $V_{SYS} = 5V$ and $T_A = 25^\circ C$ unless otherwise specified.)



Typical Performance Characteristics (Continued)

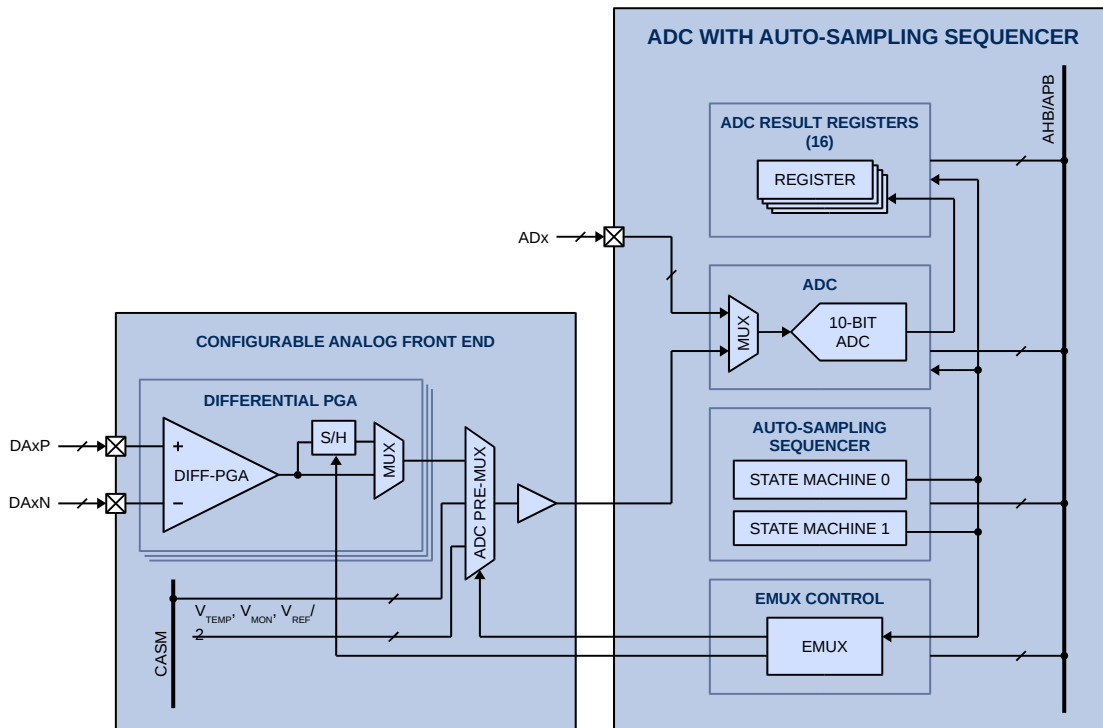
($V_P = 12V$, $V_{SYS} = 5V$ and $T_A = 25^\circ C$ unless otherwise specified.)



11 ADC WITH AUTO-SAMPLING SEQUENCER

11.1 Block Diagram

Figure 11-1 ADC with Auto-Sampling Sequencer



11.2 Functional Description

11.2.1 ADC

The analog-to-digital converter (ADC) is a 10-bit successive approximation register (SAR) ADC with 1 μ s conversion time and up to 1MSPS capability. The ADC input clock has a user-configurable divider from /1 to /8 of the system clock. The integrated analog multiplexer allows selection from up to 6 direct ADx inputs, and from up to 10 analog inputs signals in the Configurable Analog Front End (CAFE), including up to 3 differential input pairs. The ADC can be configured for repeating or non-repeating conversions and can interrupt the microcontroller when a conversion is finished.

11.2.2 Auto-Sampling Sequencer

Two independent and flexible auto-sampling sequencer state machines allow signal sampling using the ADC without interaction from microcontroller core. Each auto-sampling sequencer state machine can be programmed to take and store up to 8 samples each in the ADC result register from different analog inputs, able to control the ADC MUX and ADC Premux as well as the precise timing of the S/H in the Configurable analog front end. The sampling start of the auto-sampling sequencer can be precisely triggered using timers A, B, C, or D or any of their associated PWM edges (high-to-low or low-

to-high). It also supports manual start or a ping-pong-scheme, where one auto-sampling sequencer state machine triggers the other when it finishes sampling.

The auto-sampling sequencer can interrupt the microcontroller when either conversion sequence is finished.

11.2.3 EMUX Control

A dedicated low latency interface controllable by the auto-sampling sequencer or register control allows changing the ADC premultiplexer and asserting/deasserting the S/H circuit in the configurable analog front end, allowing back to back conversions of multiple analog inputs without microcontroller interaction.

11.3 Electrical Characteristics

Table 11-1 ADC and Auto-Sampling Sequencer Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, $V_{CC18} = 1.8V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
ADC						
f_{ADCLK}	ADC conversion clock input				16	MHz
t_{ADCONV}	ADC conversion time	$f_{ADCLK} = 16MHz$			1	μs
	ADC resolution			10		bits
	ADC effective resolution		9.2			bits
	ADC differential non-linearity (DNL)			± 0.5		LSB
	ADC integral non-linearity (INL)			± 1		LSB
	ADC offset error			0.6		%FS
	ADC gain error			0.12		%FS
Reference Voltage						
V_{REFADC}	ADC reference voltage input			2.5		V
Sample and Hold						
t_{ADCSH}	ADC sample and hold time	$f_{ADCLK} = 16MHz$		188		ns
C_{ADCIC}	ADC input capacitance			1.3		pF
Input Voltage Range						
V_{ADCIN}	ADC input voltage range	ADC multiplexer input	0		V_{REFADC}	V
EMUX Clock Speed						
$f_{EMUXCLK}$	EMUX engine clock input				50	MHz
PLL Clock Speed						
f_{OUTPLL}	PLL output frequency	$T_A = -40^{\circ}C$ to $85^{\circ}C$	3.5		100	MHz
		$T_A = 85^{\circ}C$ to $105^{\circ}C$	3.5		80	MHz

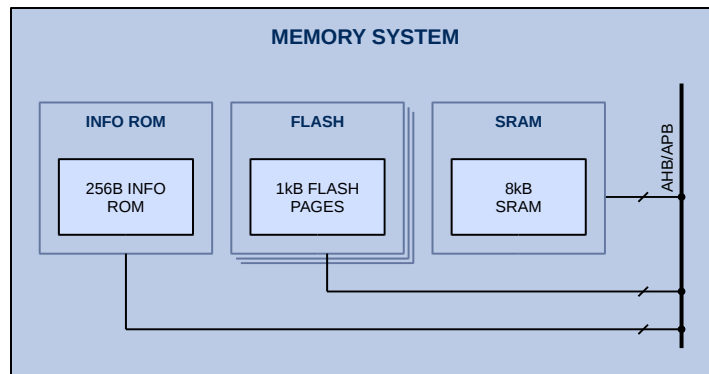
12 MEMORY SYSTEM

12.1 Features

- 32kB embedded FLASH
 - ◆ 100,000 program/erase cycles
 - ◆ 10 years data retention
- 8kB SRAM

12.2 Block Diagram

Figure 12-1 Memory System



12.3 Functional Description

The device has multiple banks of embedded FLASH memory, SRAM memory, as well as peripheral control registers that are all program-accessible in a flat memory map.

12.3.1 Program and Data FLASH

32kB in 32 pages of 1kB each is available for program or data memory. Each of them can be individually erased or written to while the microcontroller is executing a program from SRAM.

12.3.2 SRAM

Up to 8kB contiguous array of SRAM is available for non-persistent data storage. The SRAM memory supports word (4-byte), half-word (2-byte) and byte address aligned access. The microcontroller may execute code out of SRAM for time-critical applications, or when modifying the contents of FLASH memory.

12.4 Electrical Characteristics

Table 12-1 Memory System Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, $V_{CC18} = 1.8V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
Embedded FLASH						
$t_{READ;FLASH}$	FLASH read time		40			ns
$t_{WRITE;FLASH}$	FLASH write time		20			μs
$t_{PERASE;FLASH}$	FLASH page erase time				10	ms
$N_{PERASE;FLASH}$	FLASH program/erase cycles			100k		cycles
$t_{DR;FLASH}$	FLASH data retention		10			years
SRAM						
t_{SRAM}	SRAM access cycle time		20			ns

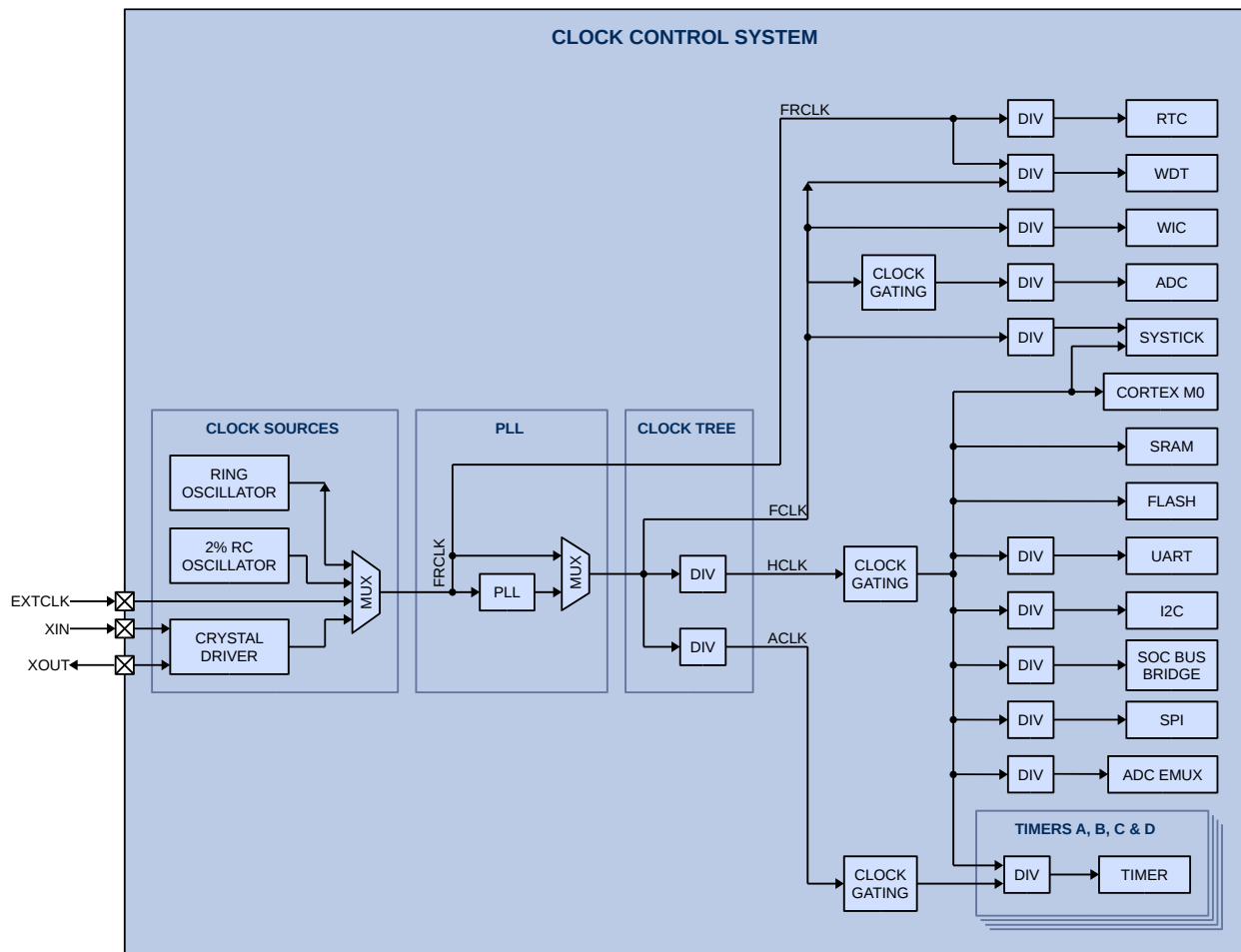
13 CLOCK CONTROL SYSTEM

13.1 Features

- Ring oscillator with 7.5MHz, 9.6MHz, 13.8MHz, and 25.7MHz settings
- High accuracy 2% trimmed 4MHz RC oscillator
- Crystal oscillator driver supporting 2MHz to 10MHz crystals
- External clock input up to 40MHz
- PLL with 1MHz to 25MHz input, and 3.5MHz to 100MHz output
- /1 to /8 clock divider for HCLK
- /1 to /128 clock divider for ACLK

13.2 Block Diagram

Figure 13-1 Clock Control System



13.3 Functional Description

The PAC clock control system covers a wide range of applications.

13.3.1 Free Running Clock (FRCLK)

The free running clock (FRCLK) is generated from one of the 4 clock sources: ring oscillator, trimmed RC oscillator, crystal driver or external clock input. The FRCLK is used for the real-time clock (RTC), watchdog timer (WDT), input to the PLL, or FCLK source to clock the system in low power and sleep mode.

13.3.2 Fast Clock (FCLK)

The fast clock (FCLK) is generated from the PLL or supplied by the FRCLK directly. The FCLK supplies the watchdog timer (WDT), ADC, wake-up interrupt controller (WIC), SysTick timer, Arm® Cortex®-M0 peripheral high speed clock (HCLK) and low speed clock (LSCLK).

13.3.3 High-Speed Clock (HCLK)

The high-speed clock (HCLK) is derived from the FCLK with a /1, /2, /4 or /8 divider. It supplies the peripheral AHB/APB bus, Timers A to D, dead-time controllers, SPI interface, I2C interface, UART interface, EMUX interface, SOC bus bridge and memory subsystem, and can go as high as 50MHz.

13.3.4 Auxiliary Clock (ACLK)

The auxiliary clock (ACLK) is derived from FCLK with a /1, /2, to /128 divider, and supplies the timer and dead-time blocks. It can be clocked faster or slower than HCLK and can go as high as 100MHz.

13.3.5 Clock Gating

The clock tree supports clock gating in deep-sleep mode for the timer block, ADC, SPI interface, I²C interface, UART interface, memory subsystem and the Arm® Cortex®-M0 itself.

13.3.6 Ring Oscillator (ROSC)

The integrated ring oscillator provides 4 different clocks with 7.5MHz, 9.6MHz, 13.8MHz, and 25.7MHz settings. After reset, the clock tree always defaults to this clock input with the lowest frequency setting.

13.3.7 Trimmed 4MHz RC Oscillator

The 2% trimmed 4MHz RC oscillator provides an accurate clock suitable for many applications. It is also used to derive the clock for the Multi-Mode Power Manager.

13.3.8 Internal Slow RC Oscillator

An internal 32kHz RC oscillator is used during start up to provide an initial clock to analog circuitry. It is not used as a clock input to the clock tree.

13.3.9 Crystal Oscillator Driver

The optional crystal oscillator driver can drive crystals from 2MHz to 10MHz to provide a highly accurate and stable clock into the system.

13.3.10 External Clock Input

The clock tree can be supplied with an external clock up to 10MHz.

13.3.11 PLL

The integrated PLL input clock is supplied by the FRCLK with an input frequency range of 1MHz to 25MHz. The PLL output frequency is adjustable from 3.5MHz to 100MHz.

13.4 Electrical Characteristics

Table 13-1 Clock Control System Electrical Characteristics

($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, $V_{CC18} = 1.8V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
Clock Tree (FRCLK, FCLK, HCLK, and ACLK)						
f _{FRCLK}	Free running clock frequency			50		MHz
f _{FCLK}	Fast clock frequency			100		MHz
f _{HCLK}	High-speed clock frequency			50		MHz
f _{ACLK}	Auxiliary clock frequency			100		MHz
Internal Oscillators						
f _{ROSC}	Ring oscillator frequency	Frequency setting = 11b		7.5		MHz
		Frequency setting = 10b		9.6		
		Frequency setting = 01b		13.8		
		Frequency setting = 00b		25.7		
f _{TRIM}	Trimmed RC oscillator frequency	T _A = 25°C	-2%	4	2%	MHz
		T _A = -40°C to 105°C	-3%	4	3%	
	Trimmed RC oscillator clock jitter	T _A = -40°C to 85°C		0.5		%
Crystal Oscillator Driver						
V _{IH;XIN}	XIN high-level input voltage		0.65•V _{CC18}			V
V _{IL;XIN}	XIN low-level input voltage		0.35•V _{CC18}			V
f _{XTAL}	Crystal oscillator frequency range		2	10		MHz
	Recommended capacitive load	f _{XTAL} = 2MHz to 3MHz		25		pF
		f _{XTAL} = 3MHz to 6MHz		20		
		f _{XTAL} = 6MHz to 10MHz		16		
	External circuit ESR	f _{XTAL} = 2MHz to 3MHz		1000		Ω
		f _{XTAL} = 3MHz to 6MHz		400		
		f _{XTAL} = 6MHz to 10MHz		100		
External Clock Input						
f _{EXTCLK}	External clock input frequency range			40		MHz
t _{HIGH;EXTCLK}	External clock high time		10			ns
t _{LOW;EXTCLK}	External clock low time		10			ns
PLL						
f _{INPLL}	PLL input frequency range		2	25		MHz
f _{OUTPLL}	PLL output frequency range		3.5	100		MHz
	PLL settling time			0.5		ns
	PLL period jitter	RMS		30		ps
		Peak to peak		±150		

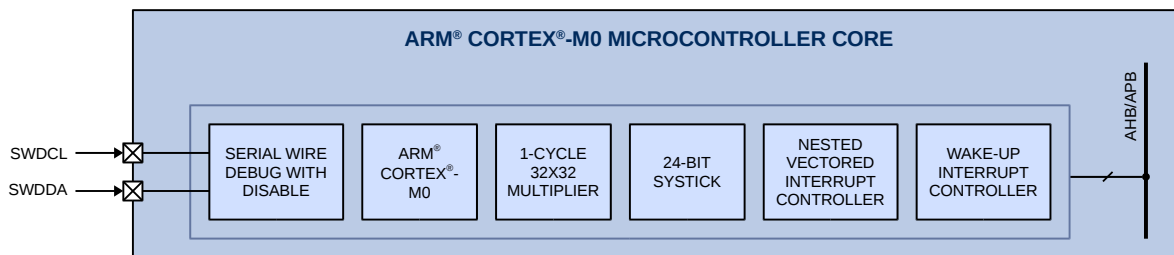
14 ARM® CORTEX®-M0 MICROCONTROLLER CORE

14.1 Features

- Arm® Cortex®-M0 core
- Fast single-cycle 32-bit x 32-bit multiplier
- 24-bit SysTick timer
- Up to 50MHz operation
- Serial wire debug (SWD), with 4 break-point and 2 watch-point unit comparators
- Nested vectored interrupt controller (NVIC) with 25 external interrupts
- Wake-up interrupt controller (WIC) with GPIO, real-time clock (RTC) and watchdog timer (WDT) interrupts enabled
- Sleep and deep-sleep mode with clock gating

14.2 Block Diagram

Figure 14-1 Arm Cortex-M0 Microcontroller Core



14.3 Functional Description

The Arm® Cortex®-M0 microcontroller core is configured for little endian operation and includes the fast single-cycle 32-bit multiplier and 24-bit SysTick timer and can operate at a frequency of up to 50MHz.

The microcontroller nested vectored interrupt controller (NVIC) supports 25 external interrupts for the device's peripherals and sub-systems. For low-latency interrupt processing, the NVIC also supports interrupt tail-chaining. The wake-up interrupt controller (WIC) is able to wake up the device from low-power modes using any GPIO interrupt, as well as from the RTC or WDT. The Arm® Cortex®-M0 supports both sleep and deep-sleep low-power modes. The deep-sleep mode supports clock gating to limit standby power even further.

Firmware debug support includes 4 break-point and 2 watch-point unit comparators using the serial wire debug (SWD) protocol. The serial wire debug mechanism can be disabled to prevent device access to the firmware in the field.

14.4 Electrical Characteristics

Table 14-1 Microcontroller and Clock Control System Electrical Characteristics

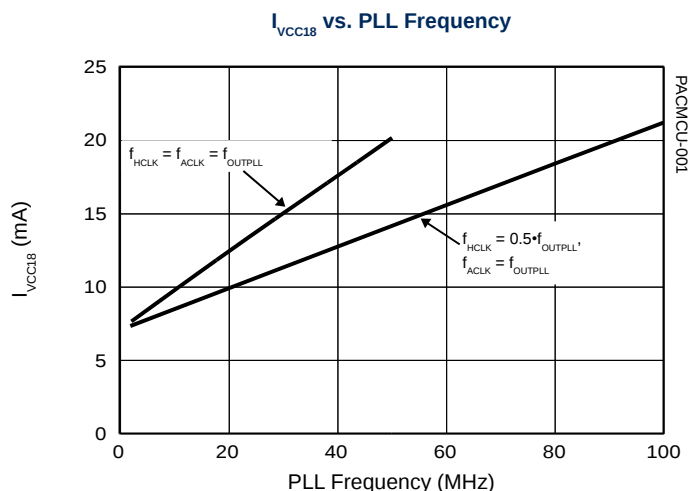
($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, $V_{CC18} = 1.8V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
f_{HCLK}	Microcontroller clock	HCLK			50	MHz
$I_{OP;V_{SYS}}$	V_{SYS} operating supply current	$f_{FRCLK} = f_{HCLK} = f_{ACLK} = \text{ROSC 11b}$, PLL disabled, CPU halt; other clock sources, ADC, timers, and serial interface disabled	2.5 ⁽¹⁾	3.4	7	mA
		$f_{FRCLK} = f_{HCLK} = f_{ACLK} = \text{ROSC 10}$, PLL disabled, CPU halt; other clock sources, ADC, timers, and serial interface disabled	3.0 ⁽¹⁾	4	7.8	
		$f_{FRCLK} = f_{HCLK} = f_{ACLK} = \text{ROSC 01}$, PLL disabled, CPU halt; other clock sources, ADC, timers, and serial interface disabled	4.1 ⁽¹⁾	5.3	9.5	
		$f_{FRCLK} = f_{HCLK} = f_{ACLK} = \text{ROSC 00}$, PLL disabled, CPU halt; other clock sources, ADC, timers, and serial interface disabled	7.4 ⁽¹⁾	9	15	
		$f_{FRCLK} = f_{HCLK} = f_{ACLK} = \text{CLKREF}$, PLL disabled, CPU halt; other clock sources, ADC, timers, and serial interface disabled	1.5 ⁽¹⁾	2.3	4.4	
		$f_{FRCLK} = f_{HCLK} = f_{ACLK} = 10\text{MHz XTAL}$, PLL disabled, CPU halt; other clock sources, ADC, timers, and serial interface disabled	3.6 ⁽¹⁾	4.5	6.7	
		$f_{FRCLK} = 4\text{MHz CLKREF}$, $f_{HCLK} = 50\text{MHz}$, $f_{ACLK} = f_{OUTPLL} = 100\text{MHz}$, CPU halt; other clock sources, ADC, timers, and serial interface disabled	20.9 ⁽¹⁾	23.3	26.5	

⁽¹⁾ All minimum operating supply current values are for room temperature only

14.5 Typical Performance Characteristics

($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, $V_{CC18} = 1.8V$, and $T_A = 25^{\circ}C$ unless otherwise specified.)



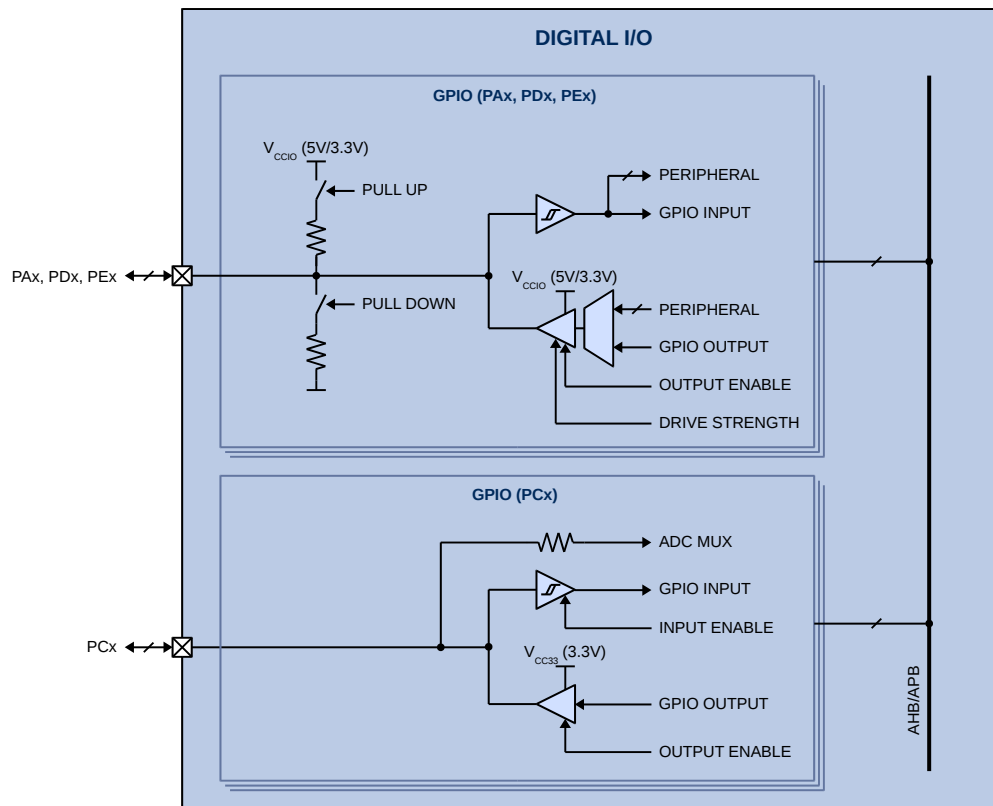
15 I/O CONTROLLER

15.1 Features

- 5V-compliant I/O PAX, PDx, PEx
- 3.3V-compliant I/O PCx
- Configurable drive strength on PAX, PDx, PEx
- Configurable pull-up or pull-down on PAX, PDx, PEx

15.2 Block Diagram

Figure 15-1 I/O Controller



15.3 Functional Description

The PAC can support up to 4 ports with 8 I/Os each from PAX, PCx, PDx, and PEx, in addition to the I/Os on the analog front end. All PAX, PCx, PDx, and PEx ports have interrupt capability with configurable interrupt edge.

PAX, PDx, and PEx I/Os use VCCIO as the I/O supply voltage that is 5V on default parts (and 3.3V available from factory). The drive current can be configured as 8mA or 16mA. They also support weak pull-up and pull-down to save external components.

PCx uses VCC33 as its I/O supply voltage. The drive current is fixed to 8mA. PC0 to PC5 are also associated with analog inputs AD0 to AD5 to the ADC.

15.4 GPIO Current Injection

Under normal operation, there should not be current injected into the GPIOs on the device due to the GPIO voltage below ground or above the GPIO supply.³ Current injected occurs when the GPIO pin voltage is less than -0.3V or when greater than GPIO supply + 0.3V.

In order provide a robust solution when this situation occurs, this device allows a small amount of injected current into the GPIO pins, to avoid excessive leakage or device damage.

For information on the GPIO current injection thresholds, see the absolute maximum parameters for this device.

Sustained operation with the GPIO pin voltage greater than the GPIO supply or when the GPIO pin voltage is less than -0.3V may result in reduced lifetime of the device. GPIO current injection should only be a temporary condition.

³ VCC33 is the supply for any PC GPIO pin and VCCIO is the supply for any other GPIO pins.

15.5 Electrical Characteristics

Table 15-1 I/O Controller Electrical Characteristics

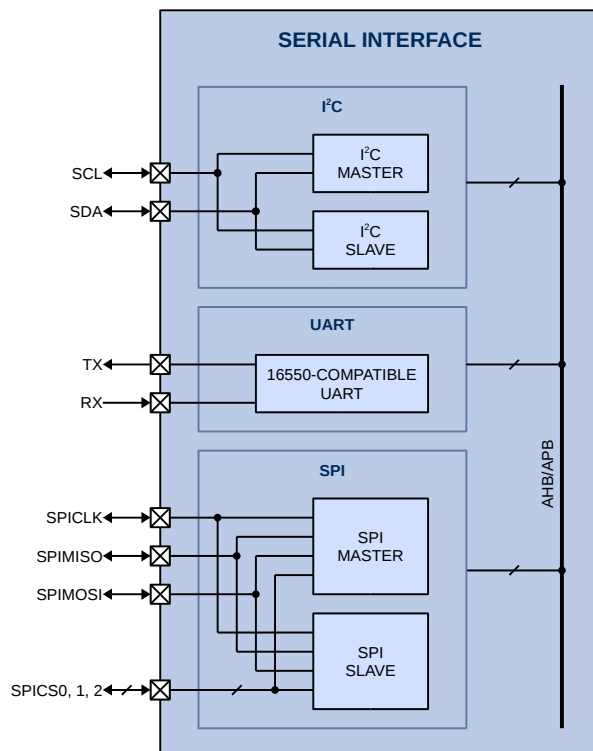
($V_{SYS} = V_{CCIO} = 5V$, $V_{CC33} = 3.3V$, $V_{CC18} = 1.8V$, and $T_A = -40^{\circ}C$ to $105^{\circ}C$ unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNIT
PAX, PDx, PEx (5V Operation)							
V _{IH}	High-level input voltage	V _{CCIO} = 5V		3			V
V _{IL}	Low-level input voltage	V _{CCIO} = 5V		0.8			V
I _{OL}	Low-level output sink current	V _{CCIO} = 5V, V _{OL} = 0.4V	Drive strength setting = 0b	7			mA
			Drive strength setting = 1b	15			
I _{OH}	High-level output source current	V _{CCIO} = 5V, V _{OH} = 2.4V	Drive strength setting = 0b	-7			mA
			Drive strength setting = 1b	-15			
R _{PU}	Weak pull-up resistance	V _{CCIO} = 5V		53	66	87	kΩ
R _{PD}	Weak pull-down resistance	V _{CCIO} = 5V		63	108	244	kΩ
I _{IL}	Input leakage current	T _A = 125°C		-10	0	10	μA
PAX, PDx, PEx (3.3V Operation)							
V _{IH}	High-level input voltage	V _{CCIO} = 3.3V		2			V
V _{IL}	Low-level input voltage	V _{CCIO} = 3.3V		0.8			V
I _{OL}	Low-level output sink current	V _{CCIO} = 3.3V, V _{OL} = 0.4V	Drive strength setting = 0b	4			mA
			Drive strength setting = 1b	8			
I _{OH}	High-level output source current	V _{CCIO} = 3.3V, V _{OH} = 2.4V	Drive strength setting = 0b	-4			mA
			Drive strength setting = 1b	-8			
R _{PU}	Weak pull-up resistance	V _{CCIO} = 3.3V		47	74	104	kΩ
R _{PD}	Weak pull-down resistance	V _{CCIO} = 3.3V		50	84	121	kΩ
I _{IL}	Input leakage current	T _A = 125°C		-10	0	10	μA
PCx (3.3V Operation)							
V _{IH}	High-level input voltage	V _{CC33} = 3.3V		2			V
V _{IL}	Low-level input voltage	V _{CC33} = 3.3V		0.8			V
I _{OL}	Low-level output sink current	V _{CC33} = 3.3V, V _{OL} = 0.4V		7			mA
I _{OH}	High-level output source current	V _{CC33} = 3.3V, V _{OH} = 2.4V		-7			mA
I _{IL}	Input leakage current	T _A = 125°C		-10	0	10	μA

16 SERIAL INTERFACE

16.1 Block Diagram

Figure 16-1 Serial Interface



16.2 Functional Description

The device has up to three serial interfaces: I²C, UART, and SPI.

16.2.1 I²C Controller

The I²C controller is a configurable peripheral that can support various modes of operation:

- I²C master operation
 - ◆ Normal mode (100kHz), fast mode (400kHz), or fast mode plus (1MHz)
 - ◆ Single and multi-master
 - ◆ Synchronization (multi-master)
 - ◆ Arbitration (multi-master)
 - ◆ 7-bit or 10-bit slave addressing
- I²C slave operation
 - ◆ Normal mode (100kHz), fast mode (400kHz), or fast mode plus (1MHz)
 - ◆ Clock stretching
 - ◆ 7-bit or 10-bit slave addressing

The I²C peripheral may operate either by polling, or can be configured to be interrupt driven for both receive and transmit data.

16.3 UART Controller

The UART peripheral is a configurable peripheral that can support various features and modes of operation:

- Programmable clock selection
- National Instruments PC16550D compatible
- 16-deep transmit and receive FIFO and fractional clock divisor
- Up to 3.125Mbps communication speed (with HCLK = 50MHz)

The UART peripheral may operate either by polling, or can be configured to be interrupt driven for both receive and transmit data.

16.4 SPI Controller

The device contains an SPI controller that can each be used in either master or slave operation, with the following features:

- SPI master operation
 - ◆ Control of up to three different SPI slaves
 - ◆ Operation up to 25MHz
 - ◆ Flexible multiple transmit mode for variable-size SPI data with user-defined chip-select behavior
 - ◆ Chip select “shaping” through programmable additional delay for chip-select setup, hold and wait time for back-to-back transfers

- SPI master or slave operation
 - ◆ Supports clock phase and polarity control
 - ◆ Data transmission/reception can be on 8-, 16-, 24- or 32-bit boundary
 - ◆ Selectable data bit ordering (LSB or MSB first)
 - ◆ Programmable chip select polarity
 - ◆ Selectable “auto-retransmit” mode

The SPI peripheral may operate either by polling, or can be configured to be interrupt driven for both receive and transmit data.

16.5 Dynamic Characteristics

Table 16-1 Serial Interface Dynamic Characteristics

(V_{SYS} = V_{CCIO} = 5V, V_{CC33} = 3.3V, V_{CC18} = 1.8V, and T_A = -40°C to 105°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
I ² C						
f _{I2CCLK}	I ² C input clock frequency	Standard mode (100kHz)	2.8			MHz
		Fast mode (400kHz)	2.8			MHz
		Fast mode plus (1MHz)	6.14			MHz
UART						
f _{UARTCLK}	UART input clock frequency			f _{HCLK} /16		MHz
	UART baud rate	f _{HCLK} = 50MHz		3.125		Mbps
SPI						
f _{SPICLK}	SPI input clock frequency	Master mode		f _{HCLK} /2		MHz
		Slave mode		f _{HCLK} /2		MHz

Table 16-2 I²C Dynamic Characteristics

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
f _{SCL}	SCL clock frequency	Standard mode	0		100	kHz
		Fast mode	0		400	
		Fast mode plus	0		1000	
t _{LOW}	SCL clock low	Standard mode	4.7			μs
		Fast mode	1.3			
		Fast mode plus	0.5			
t _{HIGH}	SCL clock high	Standard mode	4.0			μs
		Fast mode	0.6			
		Fast mode plus	0.26			
t _{HD;STA}	Hold time for a repeated START condition	Standard mode	4.0			μs
		Fast mode	0.6			
		Fast mode plus	0.26			
t _{SU;STA}	Set-up time for a repeated START condition	Standard mode	4.7			μs
		Fast mode	0.6			
		Fast mode plus	0.26			
t _{HD;DAT}	Data hold time	Standard mode	0		3.45	μs
		Fast mode	0		0.9	
		Fast mode plus	0			
t _{SU;DAT}	Data set-up time	Standard mode	250			ns
		Fast mode	100			
		Fast mode plus	50			
t _{SU;STO}	Set-up time for STOP condition	Standard mode	4.0			μs
		Fast mode	0.6			
		Fast mode plus	0.26			
t _{BUF}	Bus free time between a STOP and START condition	Standard mode	4.7			μs
		Fast mode	1.3			
		Fast mode plus	0.5			
t _r	Rise time for SDA and SCL	Standard mode			1000	ns
		Fast mode	20		300	
		Fast mode plus			120	
t _f	Fall time for SDA and SCL	Standard mode			300	ns
		Fast mode			300	
		Fast mode plus			120	
C _b	Capacitive load for each bus line	Standard mode, Fast mode			400	pF
		Fast mode plus			550	pF

Figure 16-2 I²C Timing Diagram

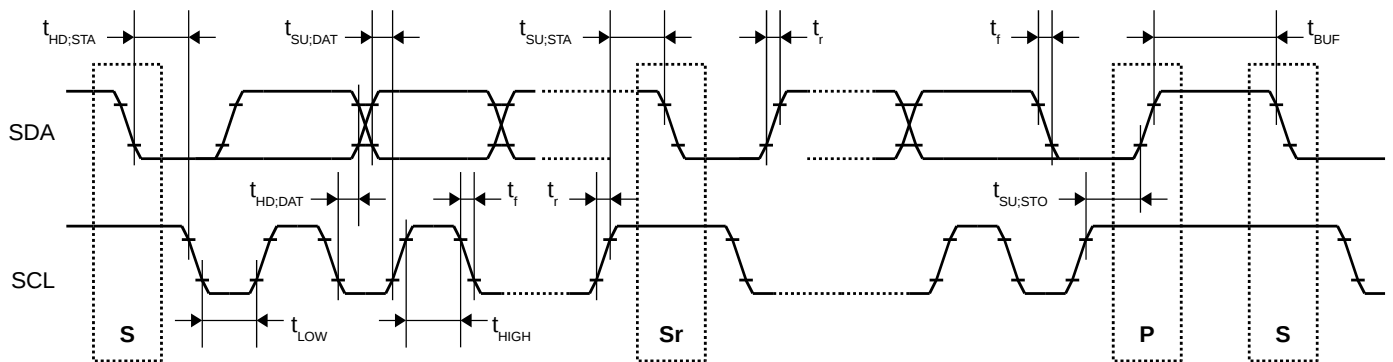
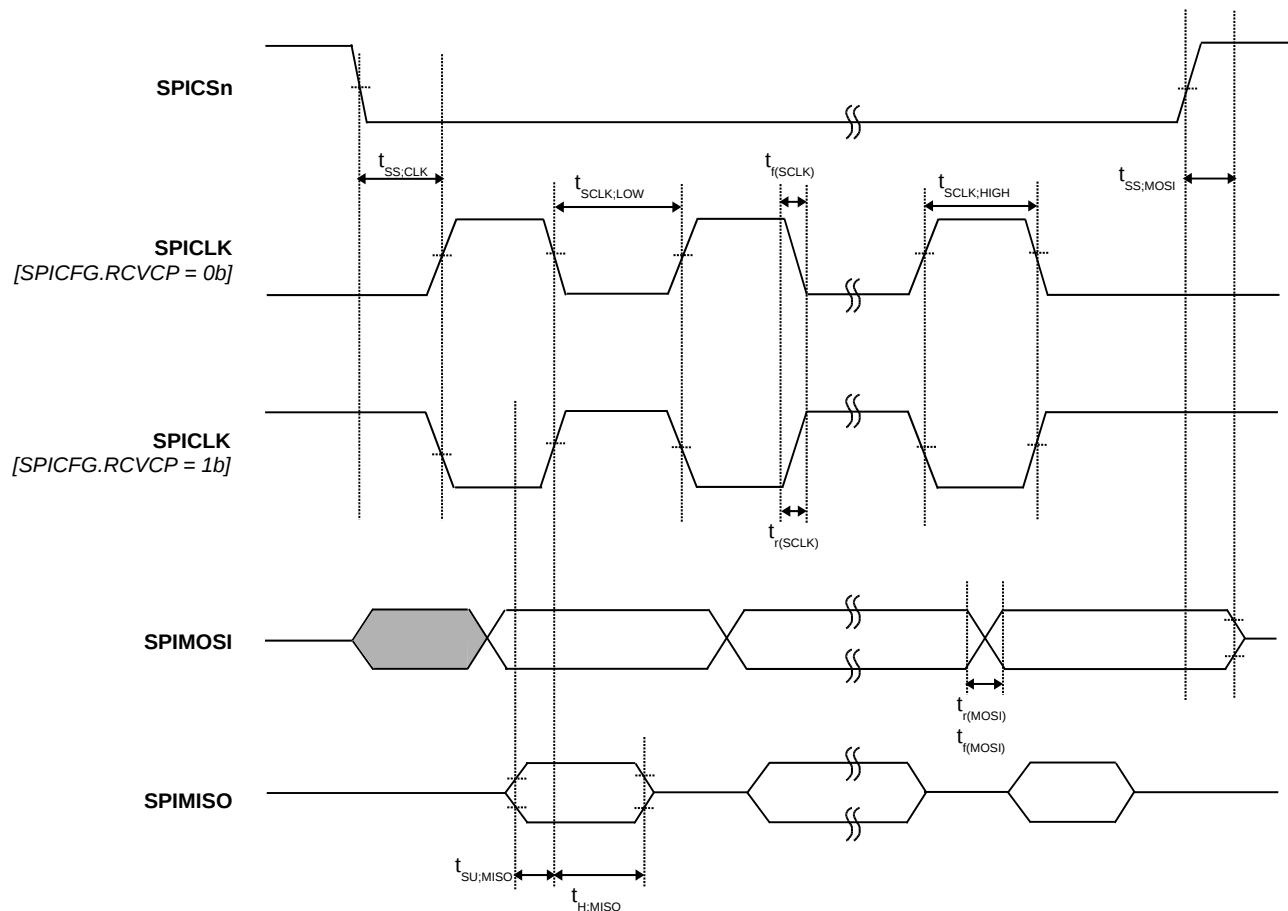


Table 16-3 SPI Dynamic Characteristics

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$t_{SCLK;HIGH}$	SPICLK Input High Time	SPICLK = 25MHz	30			ns
$t_{SCLK;LOW}$	SPICLK Input Low Time		30			ns
$t_{SS;SCLK}$	SPICSn to SPICLK Time		120			ns
$t_{SS;MOSI}$	SPICSn to SPIMISO High-impedance time		10		50	ns
$t_r(SCLK)$	SPICLK Rise Time			10	25	ns
$t_f(SCLK)$	SPICLK Fall Time			10	25	ns
$t_r(MOSI)$	SPIMISO Rise Time			10	25	ns
$t_f(SMOSI)$	SPIMISO Fall Time			10	25	ns
$t_{SU;MISO}$	SPIMISO Setup Time		20			ns
$t_{H;MISO}$	SPIMISO Hold Time		20			ns

Figure 16-3 SPI Timing Diagram



17 TIMERS

17.1 Block Diagram

Figure 17-1 Timers A, B, C, and D

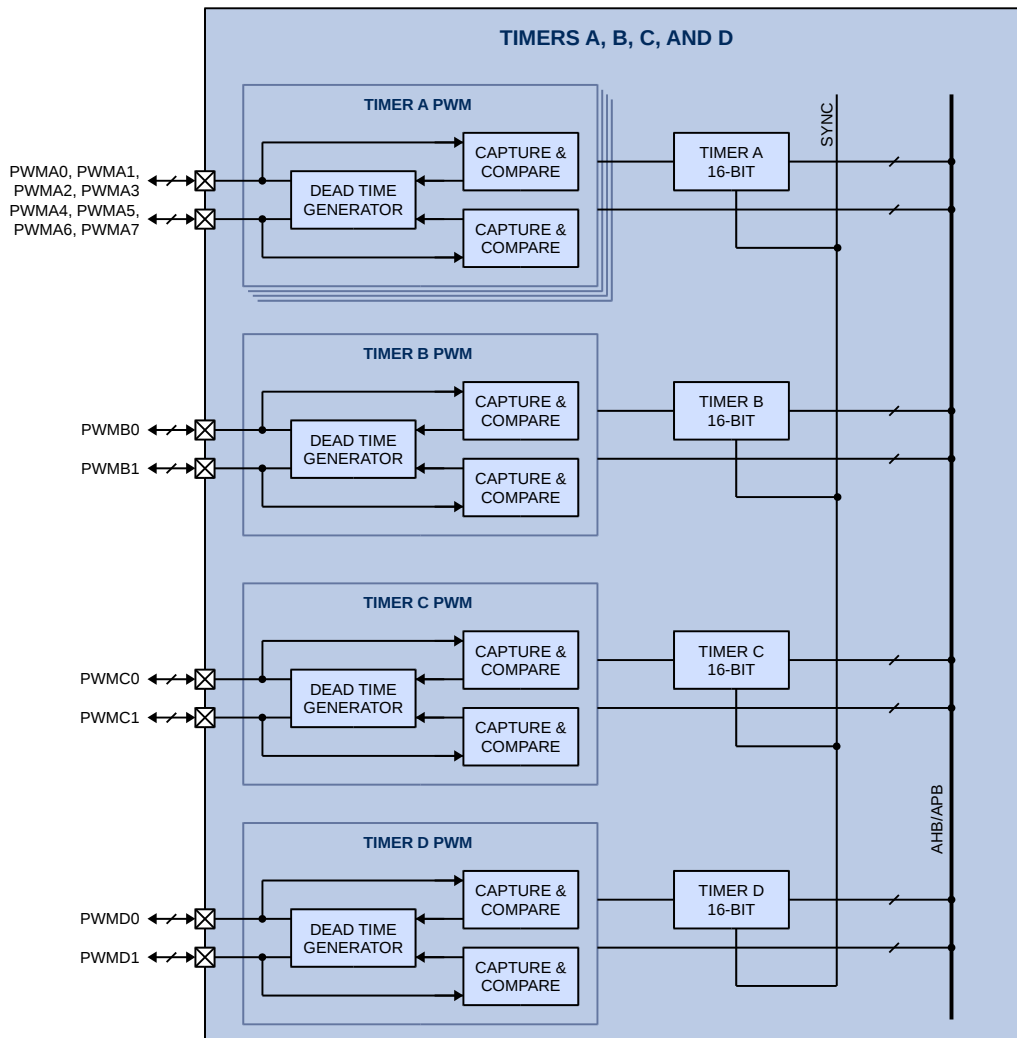


Figure 17-2 AFE Watchdog and Wake-Up Timer

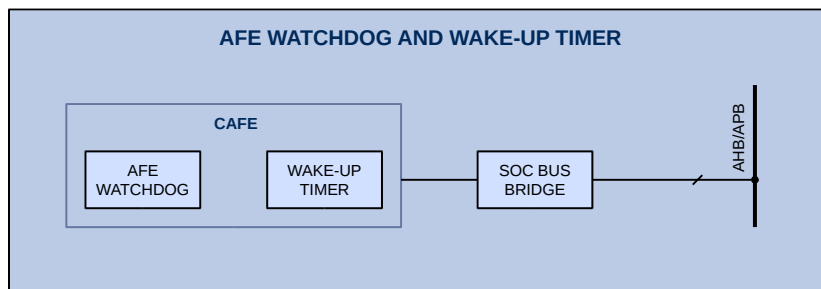
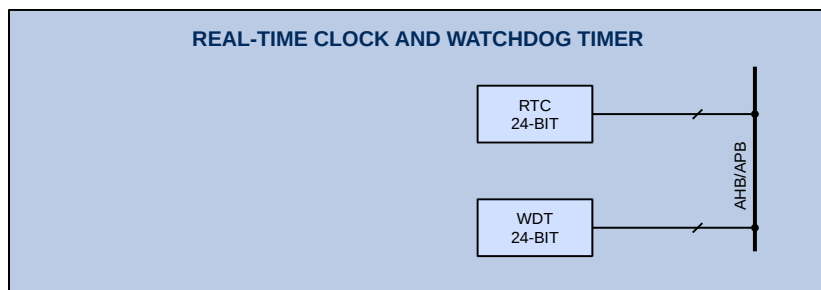


Figure 17-3 Real-Time Clock and Watchdog Timer



17.2 Functional Description

The device includes 9 timers: timer A, timer B, timer C, timer D, watchdog timer 1 (WDT), watchdog timer 2, wake-up timer, real-time clock (RTC), and SysTick timer. The device supports up to 14 different PWM signals and has up to 7 dead-time controllers. Timers A, B, C and D can be concatenated to synchronize to a single clock and start/stop signal for applications that require a synchronized timer period between timers.

17.2.1 Timer A

Timer A is a general purpose 16-bit timer with 8 PWM/capture and compare units. It has 4 pairs of PWM signals going into 4 dead-time controllers. Timer A can be concatenated with timers B, C, and D to synchronize the PWM/capture and compare units. It can use either ACLK or HCLK as clock input with an additional clock divider from /1 to /128.

17.2.2 Timer B

Timer B is a general purpose 16-bit timer with 2 PWM/capture and compare units. It has one pair of PWM signals going into one dead-time controller, as well as 2 additional compare units that can be used for additional system time bases for interrupts. Timer B can be concatenated with timers A, C, and D to synchronize the PWM/capture and compare units. It can use either ACLK or HCLK as clock input with an additional clock divider from /1 to /128.

17.2.3 Timer C

Timer C is a general purpose 16-bit timer with 2 PWM/capture and compare units. It has one pair of PWM signals going into one dead-time controller. Timer C can be concatenated with timers A, B, and D to synchronize the PWM/capture and compare units. It can use either ACLK or HCLK as clock input with an additional clock divider from /1 to /128.

17.2.4 Timer D

Timer D is a general purpose 16-bit timer with 2 PWM/capture and compare units. It has one pair of PWM signals going into one dead-time controller. Timer D can be concatenated with timers A, B, and C to synchronize the PWM/capture and compare units. It can use either ACLK or HCLK as clock input with an additional clock divider from /1 to /128.

17.2.5 Watchdog Timer

The 24-bit watchdog timer (WDT) can be used for long time period measurements or periodic wake up from sleep mode. The watchdog timer can be used as a system watchdog, or as an interval timer, or both. The watchdog timer can use either FRCLK or FCLK as clock input with an additional clock divider from /2 to /65536.

17.2.6 CAFE Watchdog Timer

There is a second watchdog timer in the AFE that can be used to monitor communication between the MCU and AFE on the PAC SOC bus. If this timer expires, it will trigger a device reset when there is no communication for a period of either 4s or 8s.

17.2.7 Wake-Up Timer

The wake-up timer can be used for very low power hibernate and sleep modes to wake up the micro controller periodically. It can be configured to be 125ms, 250ms, 500ms, 1s, 2s, 4, or 8s.

17.2.8 Real-Time Clock

The 24-bit real-time clock (RTC) can be used for time measurements when an accurate clock source is used. This timer can also be used for periodic wake up from sleep mode. The RTC uses FRCLK as clock input with an additional clock divider from /2 to /65536.

18 THERMAL CHARACTERISTICS

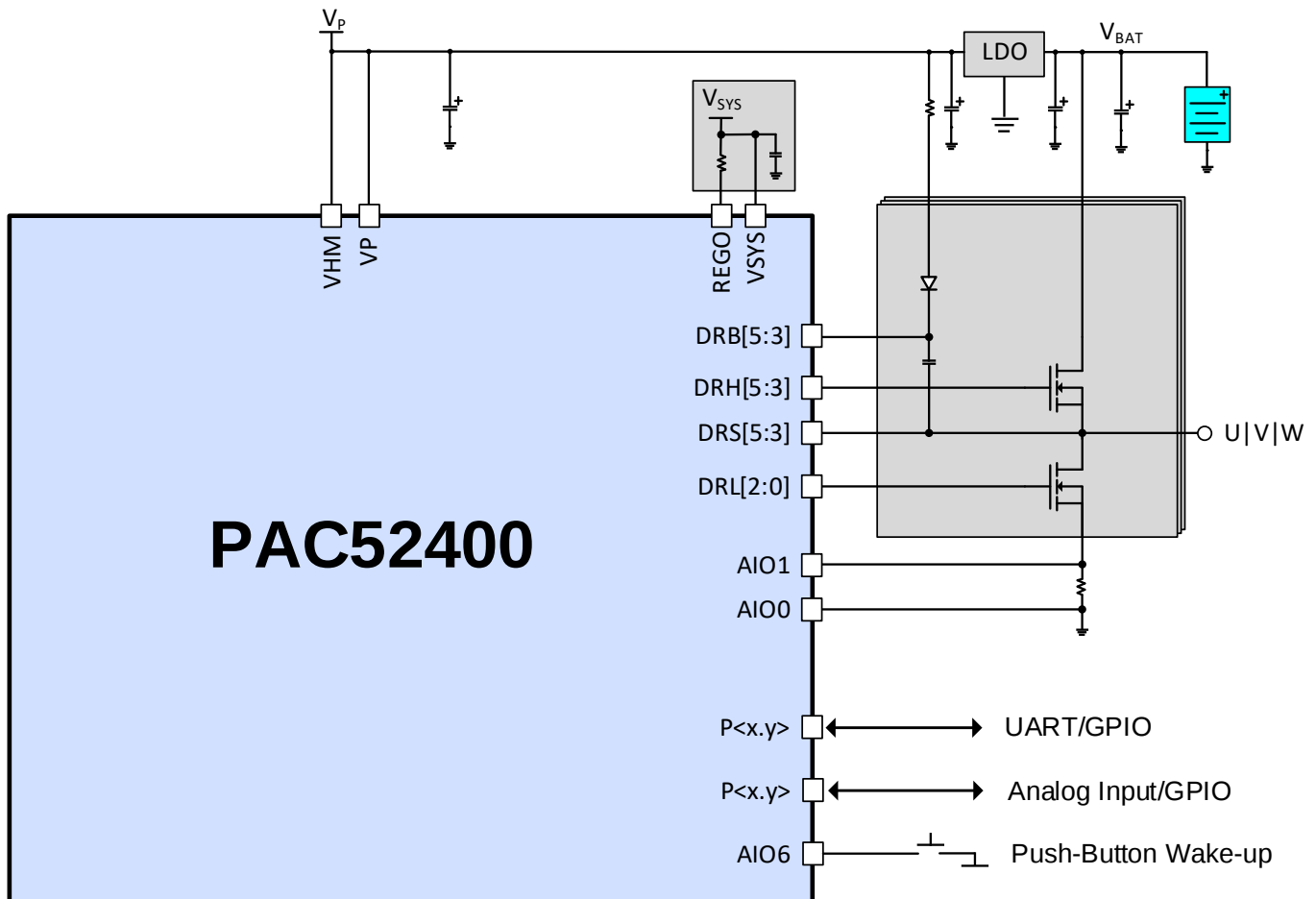
Table 18-1 Thermal Characteristics

PARAMETER	VALUE	UNIT
Operating ambient temperature range	-40 to 105	°C
Operating junction temperature range	-40 to 125	°C
Storage temperature range	-55 to 150	°C
Lead temperature (Soldering, 10 seconds)	300	°C
Junction-to-case thermal resistance (θ_{JC})	2.897	°C/W
Junction-to-ambient thermal resistance (θ_{JA})	23.36	°C/W

19 APPLICATION EXAMPLES

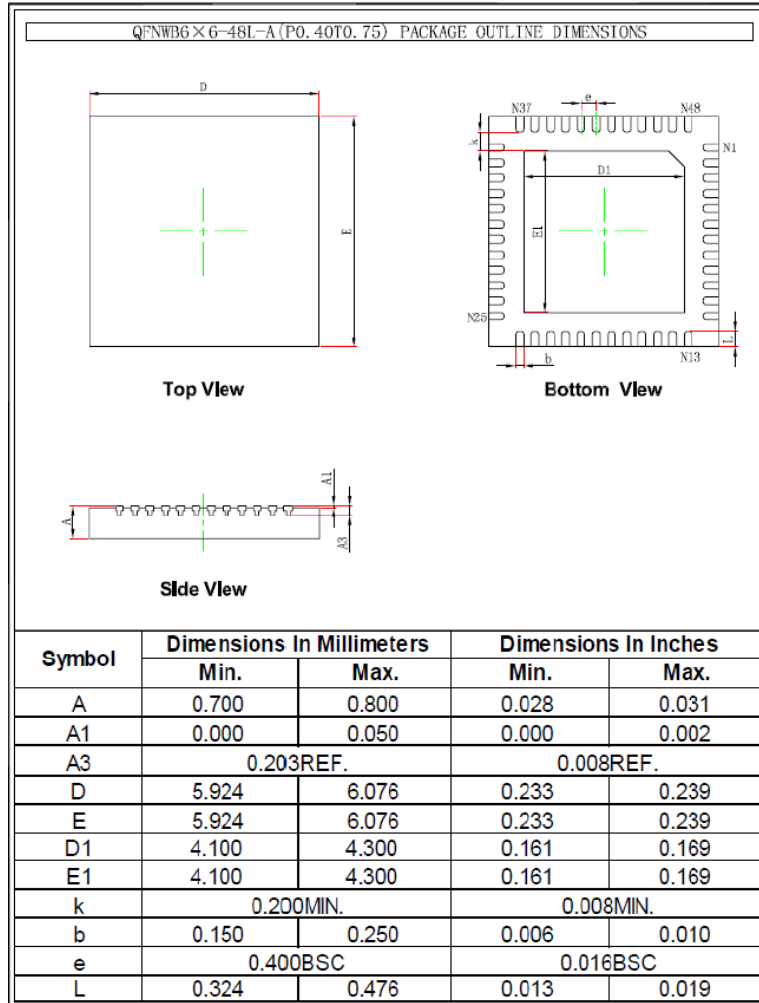
The following simplified diagrams show different examples of PAC applications. Refer to application notes for detailed design description.

Figure 19-1 3-Phase Motor Drive Using PAC52400 (Simplified Diagram)



20 PACKAGE OUTLINE AND DIMENSIONS

Figure 20-1 TQFN66-48 Package Outline and Dimensions



21 HANDLING PRECAUTIONS

PARAMETER	RATING	STANDARD
ESD – Human Body Model (HBM)	Class 1A	ESDA/JEDEC JS-001-2012
ESD – Charged Device Model (CDM)	Class C3	JEDEC JESD22-C101F
MSL – Moisture Sensitivity Level	Level 3	IPC/JEDEC J-STD-020



Caution!

ESD sensitive device

22 SOLDERABILITY

Compatible with both lead-free (260 °C max. reflow temperature) and tin/lead (245 °C max. reflow temperature) soldering processes.

23 PRODUCT COMPLIANCE

This part complies with RoHS directive 2011/65/EU as amended by (EU) 2015/863.

This part also has the following attributes:

- Lead Free
- Halogen Free (Chlorine, Bromine)
- Antimony Free
- PFOS Free
- SVHC Free



Contact Information

For the latest specifications, additional product information, worldwide sales and distribution locations:

Web: www.qorvo.com

Tel: 1-844-890-8163

Email: customer.support@qorvo.com

For technical questions and application information:

Email: appsupport@qorvo.com

Important Notice

The information contained herein is believed to be reliable; however, Qorvo makes no warranties regarding the information contained herein and assumes no responsibility or liability whatsoever for the use of the information contained herein. All information contained herein is subject to change without notice. Customers should obtain and verify the latest relevant information before placing orders for Qorvo products. The information contained herein or any use of such information does not grant, explicitly or implicitly, to any party any patent rights, licenses, or any other intellectual property rights, whether with regard to such information itself or anything described by such information. **THIS INFORMATION DOES NOT CONSTITUTE A WARRANTY WITH RESPECT TO THE PRODUCTS DESCRIBED HEREIN, AND QORVO HEREBY DISCLAIMS ANY AND ALL WARRANTIES WITH RESPECT TO SUCH PRODUCTS WHETHER EXPRESS OR IMPLIED BY LAW, COURSE OF DEALING, COURSE OF PERFORMANCE, USAGE OF TRADE OR OTHERWISE, INCLUDING THE IMPLIED WARRANTIES OF MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE.**

Without limiting the generality of the foregoing, Qorvo products are not warranted or authorized for use as critical components in medical, life-saving, or life-sustaining applications, or other applications where a failure would reasonably be expected to cause severe personal injury or death.

Copyright 2022 © Qorvo, Inc. | Qorvo®, Active-Semi®, Power Application Controller®, Multi-Mode Power Manager™, Configurable Analog Front End™ and Application Specific Power Drivers™ are trademarks of Qorvo, Inc.

Arm® and Cortex® are registered trademarks of Arm Limited. All referenced brands and trademarks are the property of their respective owners.

Mouser Electronics

Authorized Distributor

Click to View Pricing, Inventory, Delivery & Lifecycle Information:

[Qorvo:](#)

[PAC52400QM-T](#) [PAC52400QMSR](#)