PAC5523 Data Sheet

Power Application Controller®

Multi-Mode Power Manager™

Configurable Analog Front End™

Application Specific Power Drivers™

ARM© Cortex®-M4F Controller Core

www.active-semi.com

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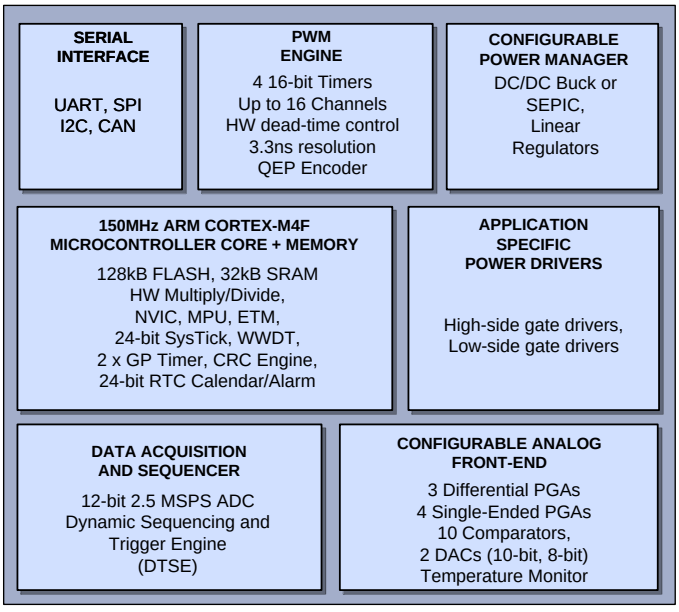
GENERAL DESCRIPTION

The PAC5523 is a custom Power Application Controller© (PAC) product that is optimized for high-speed BLDC motor control. The PAC5523 integrates a 150MHz ARM Cortex-M4F 32-bit microcontroller core with Active-Semi'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 motor control solution available.

The PAC5523 microcontroller features 128kB of embedded FLASH and 32kB of SRAM memory, a 2.5MSPS analog-to-digital converter (ADC) with programmable auto-sampling of up to 24 conversion sequences, 3.3V IO, flexible clock control system, PWM and general-purpose timers and several serial communications interfaces.

The Multi-Mode Power Manager (MMPM) provides "all-in-one" efficient power management solution for multiple types of power sources. It features a configurable multi-mode switching supply controller capable of operating a buck or SEPIC converter and up to four linear regulated voltage supplies. The Application Specific Power Drivers (ASPD) are power drivers designed for 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.

Figure 1-1. PAC5523 Power Application Controller

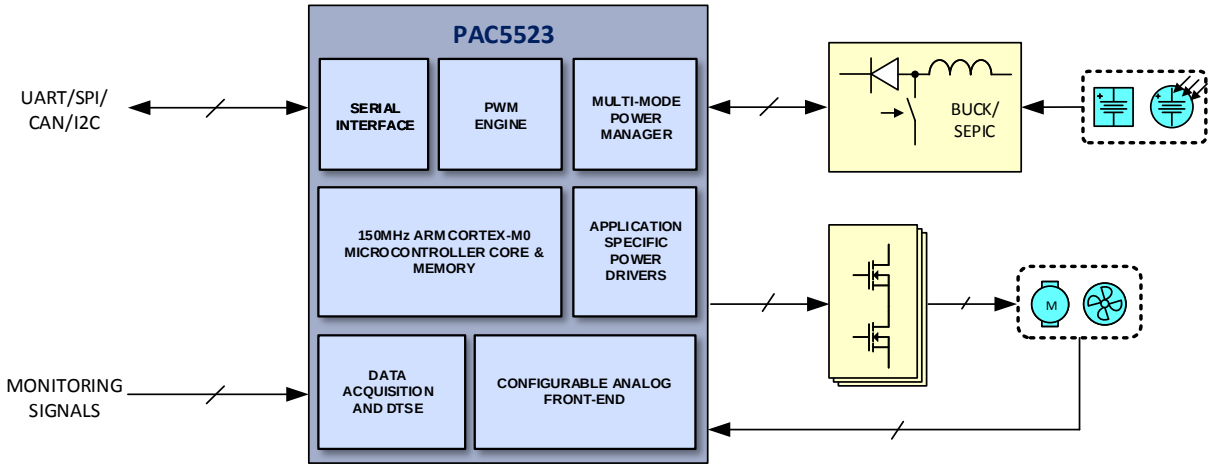


The PAC5523 is available in a 48-pin, 6x6mm TQFN package.

1 PAC FAMILY APPLICATIONS

- General-purpose high-voltage system controllers
- Home appliances
- Ceiling Fans
- Standing Fans
- Compressors
- Power Tools
- Garden Tools
- Motor Controllers
- Industrial Applications
- Drone/RC

Figure 1-1 Simplified Application Diagram



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	VSRC	POWER DRIVER	PWM CHANNEL	SPEED (MHz)	FLASH (kB)	SRAM (kB)	GPIO	COMM	XTAL	
PAC5523	48-pin 6x6 TQFN	5.2 – 70V	Y	3	4	10	2	15	70V	3 LS (1.5A/1.5A) 3 HS (1.5A/1.5A)	6@VP 15@VCCIO	150	128	32	10@VSYS 3 @ VP 15@VCCIO	UART SPI I2C CAN SWD JTAG ETM	N	3 half-bridge 3 phase control BEMF Trapezoidal or FOC

Notes: DIFF-PGA = differential programmable gain amplifier; HS = high-side, LS = low-side, PGA = programmable gain amplifier, VSRC = Bootstrap Voltage Source

3 ORDERING INFORMATION

Table 3-1 Ordering Information

PART NUMBER[1]	TEMPERATURE RANGE	PACKAGE	PINS	PACKING
PAC5523QM	-40°C to 125°C	TQFN66-48	48 + Exposed Pad	Tray

[1] See *Product Selection Summary* for product features for each part number

4 FEATURES

4.1 Feature Overview

- **Proprietary Multi-Mode Power Manager**
  - Multi-mode switching supply controller configurable for DC/DC Buck or SEPIC topologies
  - Direct battery supply from 5V – 20V
  - 4 Linear regulators with power and hibernate management
  - Power and temperature monitor, warning, fault detection
- **Proprietary Configurable Analog Front-End**
  - 10 Analog Front-End IO pins
  - 3 Differential Programmable Gain Amplifiers
  - 4 Single-ended Programmable Gain Amplifiers
  - Programmable Over-Current Protection
  - 10 Comparators
  - 2 DACs (10-bit and 8-bit)
  - Integrated BEMF comparator mode with virtual center-tap
- **Proprietary Application Specific Power Drivers**
  - 3 Low-side and 3 High-Side gate drivers with 1.5A gate driving capacity
  - Configurable propagation delay and fault protection
- **150MHz ARM Cortex-M4F 32-bit Microcontroller Core**
  - Single-cycle 32-bit x 32-bit hardware multiplier
  - 32-bit hardware divider
  - DSP Instructions and Saturation Arithmetic Support
  - Integrated sleep and deep sleep modes
  - Single-precision Floating Point Unit (FPU)
  - 8-region Memory Protection Unit (MPU)
  - Nested Vectored Interrupt Controller (NVIC) with 32 Interrupts with 8 levels of priority
  - 24-Bit SysTick Timer
  - Wake-up Interrupt Controller (WIC) allowing power-saving sleep modes
  - Clock-gating allowing low-power operation
  - Embedded Trace Macrocell (ETM) for in-system debugging at real-time without breakpoints
- **Memory**
  - 128kB FLASH
  - 32kB SRAM with ECC
  - 2 x 1kB INFO FLASH area for manufacturing information
  - 1 x 1kB INFO FLASH area for user parameter storage and application configuration or code
  - Code Protection

- **Analog to Digital Converter (ADC)**
  - 12-bit resolution
  - 2.5MSPS
  - Programmable Dynamic Triggering and Sampling Engine (DTSE)
- **I/O**
  - 3.3V Digital Input/Output or Analog Input for ADC
  - Configurable weak pull-up and pull-down
  - Configurable drive strength (6mA to 25mA minimum)
  - Dedicated Integrated IO power supply (3.3V)
  - Flexible peripheral MUX allowing each IO pin to be configured with one of up to 8 peripheral functions
  - Flexible Interrupt Controller
- **Flexible Clock Control System (CCS)**
  - 300MHz PLL from internal 2% oscillator
  - 20MHz Ring Oscillator
  - 20MHz External Clock Input
- **Timing Generators**
  - Four 16-bit timers with up to 32 PWM/CC blocks
    - 16 Programmable Hardware Dead-time generators
    - Up to 300MHz input clock for high-resolution PWM
  - 16-bit Windowed Watchdog Timer (WWDT)
  - 24-bit Real-time Clock (RTC) with Calendar and Alarm Functions
  - 24-bit SysTick Timer
  - 2 x 24-bit General-purpose count-down timers with interrupt
  - Wake-up timer for sleep modes from 0.125s to 8s
- **Communication Peripherals**
  - 3 x USART
    - SPI or UART modes
    - SPI Master/Slave, up to 25MHz
    - UART, up to 1Mbps
  - I2C Master/Slave
  - CAN 2.0A/B Controller
  - Single Wire Debugger (SWD)/JTAG
  - Embedded Trace Macrocell (ETM)
- **4-Level User-Configurable Code Protection**
- **96-bit Unique ID**
- **CRC Engine**
  - Offloads software for communications and safety protocol through hardware acceleration
  - Configurable Polynomial (CRC-16 or CRC-8)
  - Configurable Input Data Width, Input and Output Reflection
  - Programmable Seed Value

5 ABSOLUTE MAXIMUM RATINGS

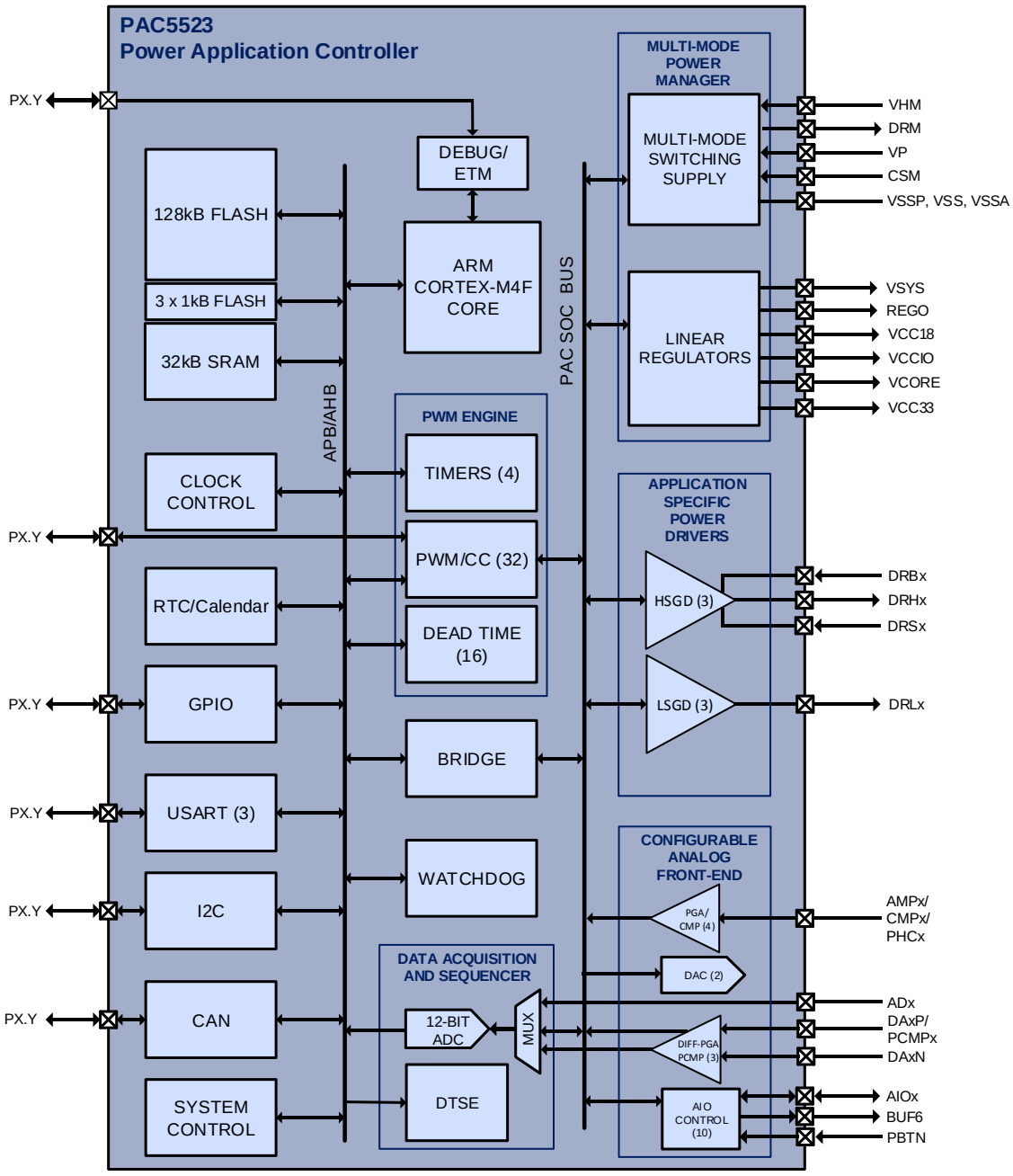
Table 5-1 Absolute Maximum Ratings[2]

PARAMETER		VALUE	UNIT
VHM, DRM to VSSP		-0.3 to 72	V
VP to VSS		-0.3 to 20	V
CSM, REGO to VSS		-0.3 to V_P + 0.3	V
VSYS, VCCIO, AIO6 to VSS		-0.3 to 6	V
VCC33 to VSS		-0.3 to 4.1	V
VCORE to VSS		-0.3 to 1.44	V
VCC18 to VSS		-0.3 to 2.5	V
AIO[0..5, 7..9] to VSS		-0.3 to V_{SYS} + 0.3	V
PD[0..7], PE[0..7]		-0.3 to 4.6	V
DRLx to VSSP		-0.3 to VP + 0.3	V
DRBx to VSSP		-0.3 to 84	V
DRSx to VSSP		-6 to 72	V
DRSx allowable offset slew rate (dVDRSx/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, VSYSSW RMS current[3]		0.2	A_{RMS}
VSSP RMS current[3]		0.4	A_{RMS}
VP RMS current[3]		0.6	A_{RMS}
Operating temperature range		-40 to 125	°C
Electrostatic Discharge (ESD)	Human body model (JEDEC)	2	kV
	Charge device model (JEDEC)	1	kV

[2] Do not exceed these limits to prevent damage to the device. Exposure to absolute maximum rating conditions for long periods may affect device reliability.
[3] Peak current can be 10 times higher than RMS value for pulses shorter than 10μs

6 ARCHITECTURAL BLOCK DIAGRAM

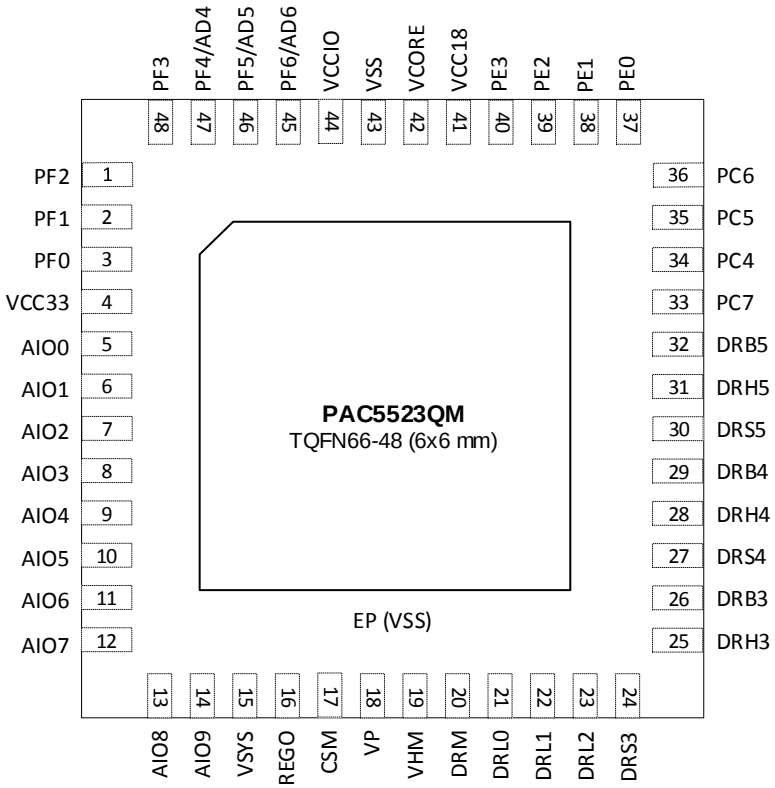
Figure 6-1 Architectural Block Diagram



7 PIN CONFIGURATION

7.1 PAC5523QM

Figure 7-1 PAC5523QM Pin Configuration (TQFN66-48 Package)



8 PIN DESCRIPTION

Table 8-1 Multi-Mode Power Manager (MMPM) and System Pin Description

PIN NAME	PIN NUMBER	TYPE	DESCRIPTION
VCC33	4	Power	Internally generated 3.3V power supply. Connect to a 2.2µF or higher value ceramic capacitor from V_{CC33} to V_{SSA}.
VSYS	15	Power	5V System power supply. Connect to a 6.8µF (20%) or higher ceramic capacitor from V_{SYS} to V_{SS}.
REGO	16	Power	System regulator output. Connect to V_{SYS} directly or through an external power-dissipating resistor.
CSM	17	Power	Switching supply current sense input. Connect to the positive side of the current sense resistor.
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 to V_{SS} for voltage loop stabilization. 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.
VHM	19	Power	Switching supply controller supply input. 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.
DRM	20	Power	Switching supply driver output. Connect to the base or gate of the external power NPN or n-channel MOSFET. See User Guide and application notes.
VCC18	41	Power	Internally generated 1.8V power supply. Connect a 2.2µF or higher value ceramic capacitor from V_{CC18} to V_{SSA}.
VCORE	42	Power	Internally generated 1.2V core power supply. Connect a 2.2µF or higher value ceramic capacitor from V_{CORE} to V_{SSA}.
VSS	43	Power	Ground.
VCCIO	44	Power	Internally generated digital I/O 3.3V power supply. Connect a 4.7µF or higher value ceramic capacitor from V_{CCIO} to V_{SSA}.
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.

Table 8-2 Configurable Analog Front End (CAFE) Pin Description

PIN NAME	PIN NUMBER	FUNCTION	TYPE	DESCRIPTION
AIO0	5	AIO0	I/O	Analog front end I/O 0.
		DA0N	Analog	Differential PGA 0 negative input.
AIO1	6	AIO1	I/O	Analog front end I/O 1.
		DA0P	Analog	Differential PGA 0 positive input.
AIO2	7	AIO2	I/O	Analog front end I/O 2.
		DA1N	Analog	Differential PGA 1 negative input.
AIO3	8	AIO3	I/O	Analog front end I/O 3.
		DA1P	Analog	Differential PGA 1 positive input.
AIO4	9	AIO4	I/O	Analog front end I/O 4.
		DA2N	Analog	Differential PGA 2 negative input.
AIO5	10	AIO5	I/O	Analog front end I/O 5.
		DA2P	Analog	Differential PGA 2 positive input.
AIO6	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	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	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	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 8-3 Application Specific Power Drivers (ASPD) Pin Description

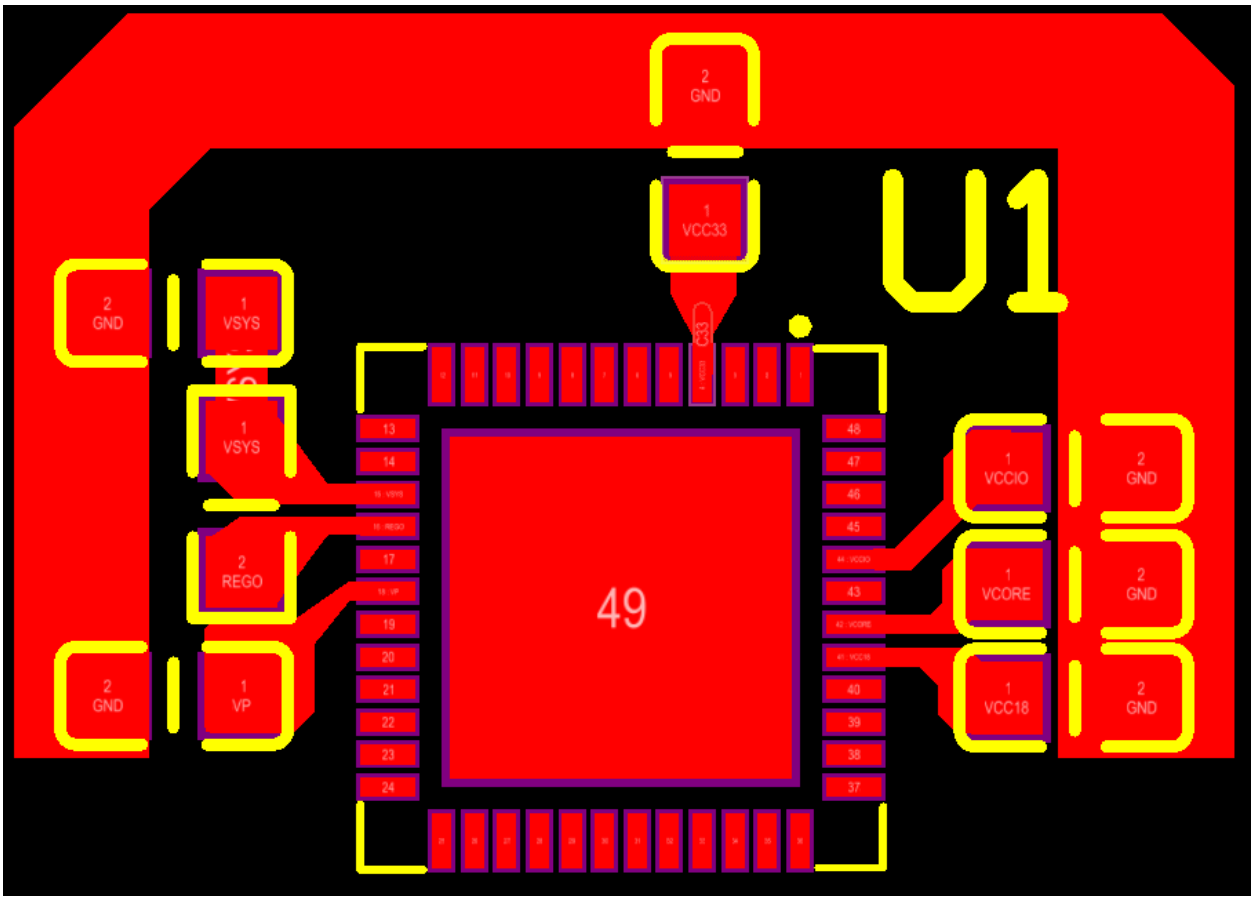
PIN NAME	PIN NUMBER	TYPE	DESCRIPTION
DRL0	21	Analog	Low-side gate driver 0.
DRL1	22	Analog	Low-side gate driver 1.
DRL2	23	Analog	Low-side gate driver 2.
DRS3	24	Analog	High-side gate driver source 3.
DRH3	25	Analog	High-side gate driver 3.
DRB3	26	Analog	High-side gate driver bootstrap 3.
DRS4	27	Analog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

Table 8-4 I/O Ports Pin Description

PIN NAME	PIN NUMBER	FUNCTION	TYPE	DESCRIPTION[4]
PF2	1	PF2	I/O	I/O port PF2.
PF1	2	PF1	I/O	I/O port PF1.
PF0	3	PF0	I/O	I/O port PF0.
PC7	33	PC7	I/O	I/O port PC7.
PC4	34	PC4	I/O	I/O port PC4.
PC5	35	PC5	I/O	IO port PC5.
PC6	36	PC6	I/O	I/O port PC6.
PE0	37	PE0	I/O	I/O port PE0.
PE1	38	PE1	I/O	I/O port PE1.
PE2	39	PE2	I/O	I/O port PE2.
PE3	40	PE3	I/O	I/O port PE3.
PF6	45	PF6	I/O	I/O port PF6.
		AD6	Analog Input	ADC channel ADC6.
PF5	46	PF5	I/O	I/O port PF5.
		AD5	Analog Input	ADC channel ADC5.
PF4	47	PF4	I/O	I/O port PF4.
		AD4	Analog Input	ADC channel ADC4.
PF3	48	PF3	I/O	I/O port PF3.

[4] For a full description of all of the pin configurations for each digital I/O, see the PAC55XX Family User Guide for the Peripheral MUX.

Figure 8-1 Power Supply Bypass Capacitor Routing

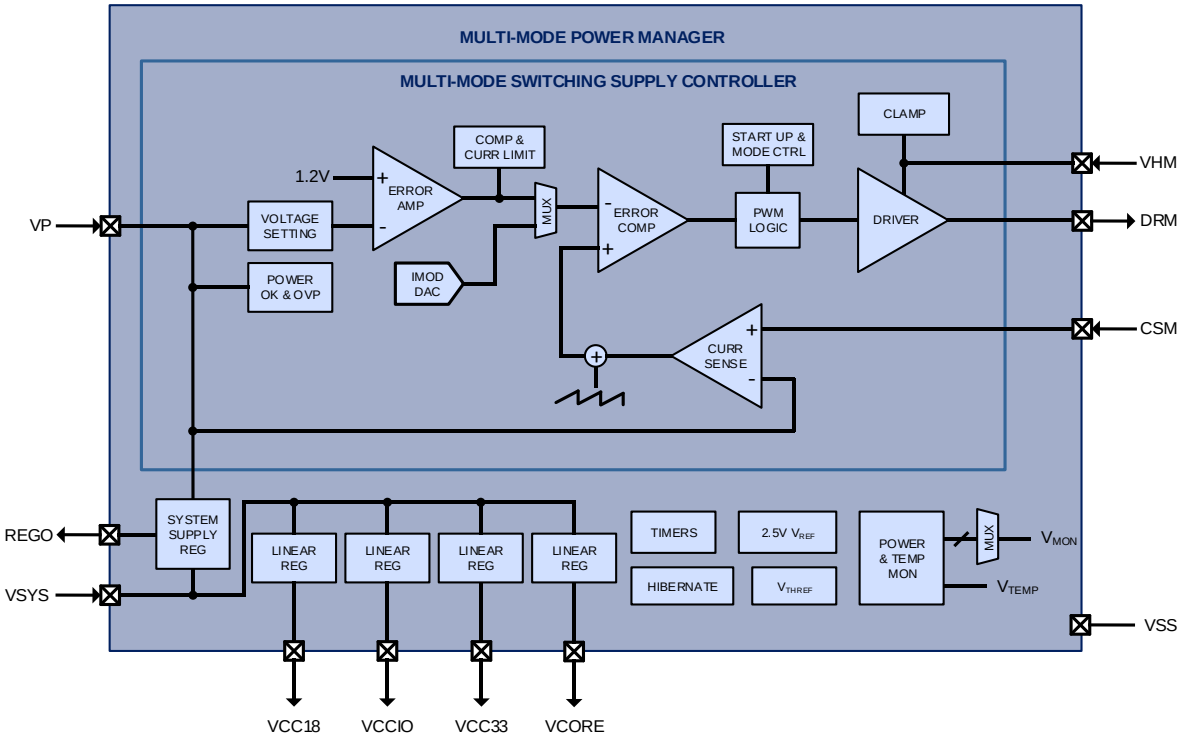


9 MULTI-MODE POWER MANAGER (MMPM)

9.1 Features

- Multi-mode switching supply controller configurable as buck or SEPIC
- DC supply up to 70V input
- Direct DC input of up to 20V with no DC/DC
- 5 linear regulators with power and hibernate management, including V_{REF} for ADC
- Power and temperature monitor, warning, and fault detection

Figure 9-1 MMPM Block Diagram



9.2 Functional Description

The Multi-Mode Power Manager (Figure 9-1) is optimized to efficiently provide “all-in-one” power management required by the PAC and associated application circuitry. It incorporates a dedicated multi-mode switching supply (MMSS) controller operable as a Buck or SEPIC converter to efficiently convert power from a DC input source to generate a main supply output V_P. Five linear regulators provide V_{CC18}, V_{SYS}, V_{CCIO}, V_{CC33}, and V_{CORE} supplies for MCU FLASH, 5V system, 3.3V I/O, 3.3V mixed signal, and 1.2V microcontroller core circuitry. The power manager also handles system functions including internal reference generation, timers, hibernate mode management, and power and temperature monitoring.

9.3 Multi-Mode Switching Supply (MMSS) Controller

The MMSS controller drives an external power transistor for pulse-width modulation switching of an inductor or transformer for power conversion. The DRM output drives the gate of the N-CH MOSFET or the base of the NPN between the V_{HM} on state and V_{SSP} off state at proper duty cycle and switching frequency to ensure that the main supply voltage V_P is regulated. The V_P regulation voltage is initially set to 15V during start up, and can be reconfigured to be 9V or 12V by the microcontroller after initialization. When V_P is lower than the target regulation voltage, the internal feedback control circuitry causes the inductor current to increase to raise V_P. Conversely, when V_P is higher than the regulation voltage, the feedback loop control causes the inductor current to decrease to lower V_P. The feedback loop is internally stabilized. The output current capability of the switching supply is determined by the external current sense resistor. In the high-side current sense buck or SEPIC mode, the inductor current signal is sensed differentially between the CSM pin and V_P, and has a peak current limit threshold of 0.26V.

The MMSS controller is flexible and configurable as a buck or SEPIC converter. Input sources include battery supply for buck mode (Figure 9-2) or SEPIC mode (Figure 9-3). The MMSS controller operational mode is determined by external configuration and register settings from the microcontroller after power up. It can operate in either high-side or low-side current sense mode, and does not require external feedback loop compensation circuitry.

Figure 9-2 Buck Mode

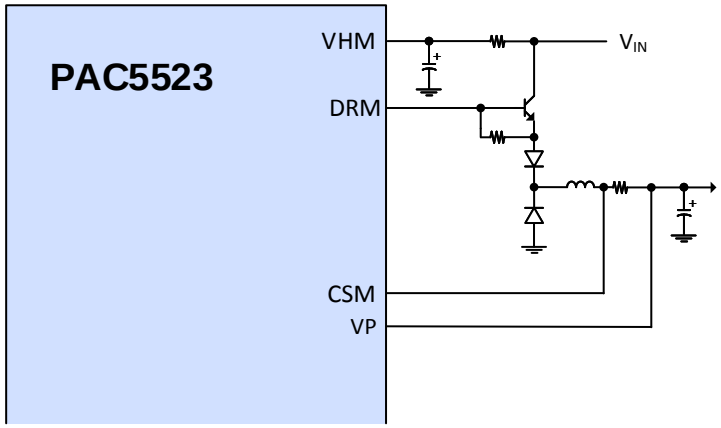
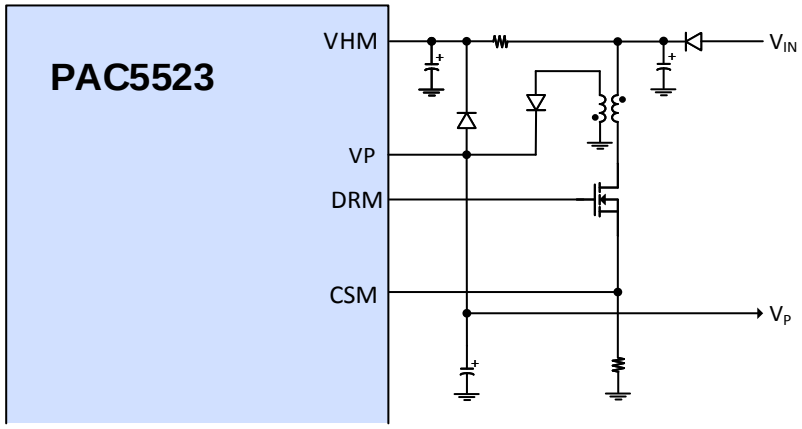


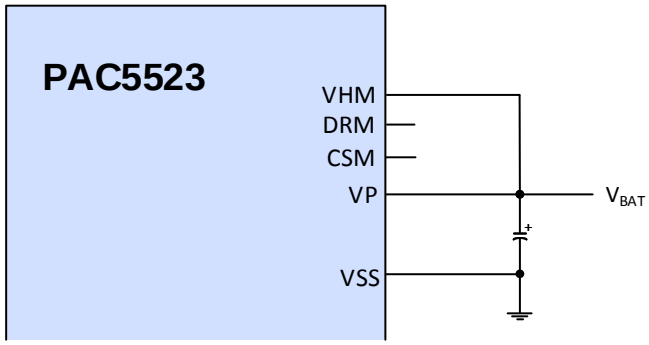
Figure 9-3 SEPIC Mode



The MMSS detects and selects between high-side and low-side mode during start up based on the placement of the current sense resistor and the CSM pin voltage. It employs a safe start up mode with a 9.5kHz switching frequency until V_P exceeds 4.3V under-voltage-lockout threshold, then transitions to the 45kHz default switching frequency for at least 6ms to bring V_P close to the target voltage, before enabling the linear regulators. Any extra load should only be applied after the supplies are available and the microprocessor has initialized. The switching frequency can be reconfigured by the microprocessor to be 181kHz to 500kHz in the high switching frequency mode for battery-based applications, and to be 45kHz to 125kHz in the low switching frequency mode. Upon initialization, the microcontroller must reconfigure the MMSS to the desired settings for V_P regulation voltage, switching mode, switching frequency, and V_{HM} clamp. Refer to the PAC application notes and user guide for MMSS controller design and programming.

If a stable external 5V to 20V power source is available, it can power the V_P main supply and all the linear regulators directly without requiring the MMSS controller to operate. In such applications, V_{HM} can be connected directly to V_P and the microcontroller should disable the MMSS upon initialization to reduce power loss.

Figure 9-4 Direct Battery Supply

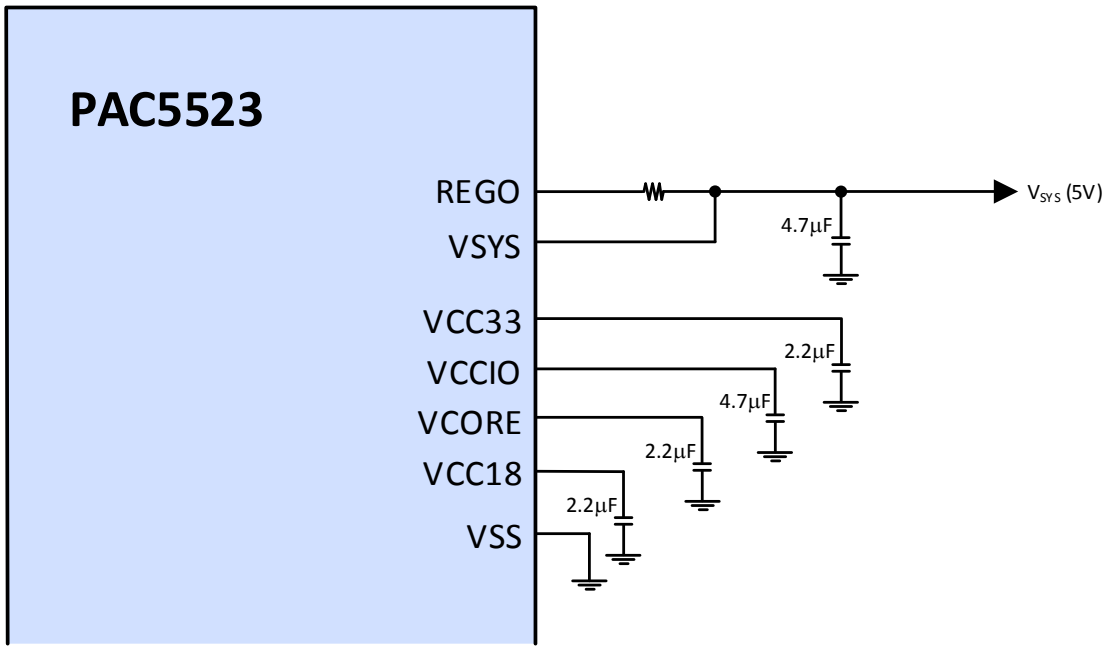


9.4 Linear Regulators

The MMPM includes four linear regulators. The system supply regulator (VSYS) is a medium voltage regulator that takes the V_P supply and sources up to 200mA 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 loop and offload power dissipation between V_P and V_{SYS}.

Once VSYS is above 4V, the four additional linear regulators for VCC18, VCCIO, VCC33, and VCORE supplies sequentially power up. Figure 9-5 shows typical circuit connections for the linear regulators. The VCC18 regulator generates a dedicated 1.8V supply for FLASH on the MCU. The VCCIO regulator generates a dedicated 3.3V supply for IO. The VCC33 and VCORE regulators generate 3.3V and 1.2V, respectively. When VSYS, VCCIO, VCC33, and VCORE are all above their respective power good thresholds, and the configurable power on reset duration has expired, the microcontroller is initialized.

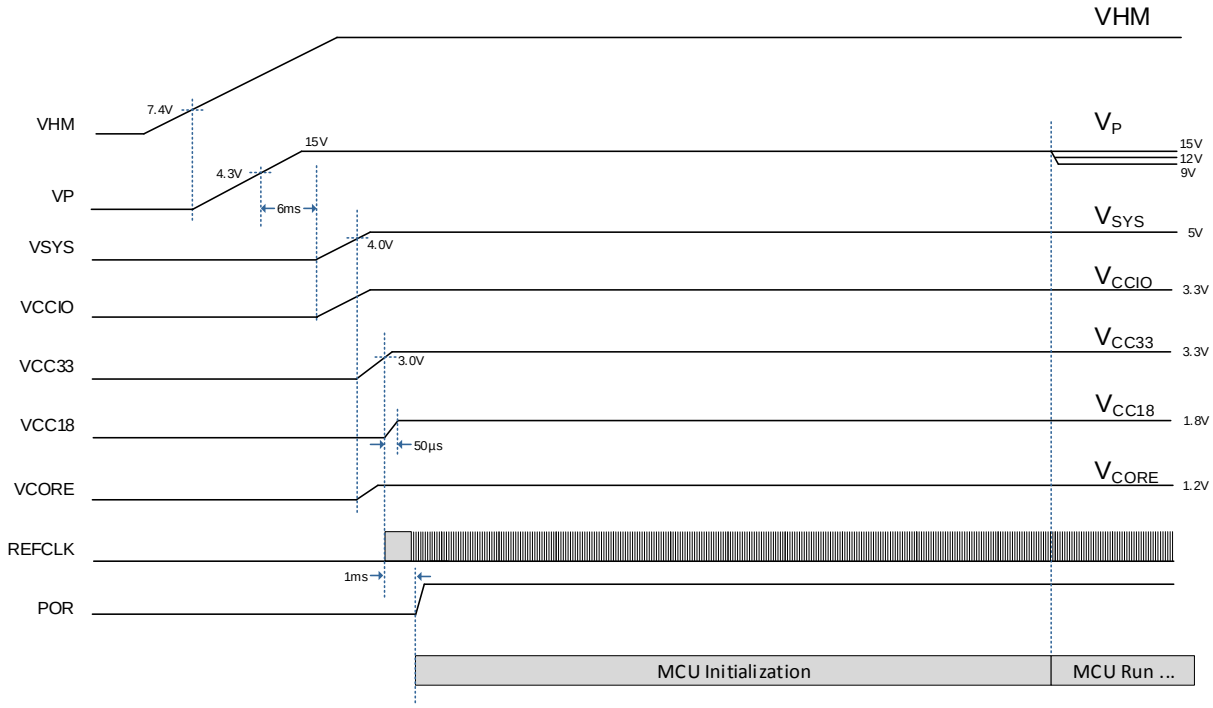
Figure 9-5 Linear Regulators



9.5 Power-up Sequence

The MMPM follows a typical power up sequence as in the Figure 9-6 below. A typical sequence begins with input power supply being applied, followed by the safe start up and start up durations to bring the switching supply output V_P to 15V, 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. During initialization, the microcontroller can reconfigure the switching supply to a different V_P regulation voltage such as 9V or 12V and to an appropriate switching frequency and switching mode. The total loading on the switching supply must be kept below 25% of the maximum output current until after the reconfiguration of the switching supply is complete.

Figure 9-6 Power-Up Sequence



9.6 Hibernate Mode

The IC can go into an ultra-low power hibernate mode via the microcontroller firmware or via the optional push button (PBTN, see *Push Button* description in *Configurable Analog Front End*). In hibernate mode, only a minimal amount (typically 18µA) of current is used by V_P, and the MMSS controller 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.

9.7 Power and Temperature Monitor

Whenever any of the V_{SYS}, V_{CCIO}, V_{CC33}, or V_{CORE} 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_{CORE} supply rails are all good again and the reset time has expired. A microcontroller reset can also be initiated by a 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_{CORE}, 0.4•V_{CC33}, 0.4•V_{CCIO}, 0.4•V_{SYS}, 0.1•VREGO, 0.1•$V_{P,}$ or the internal compensation voltage V_{COMP} for switching supply power monitoring.

For power and temperature warning, an IC temperature warning event at 140°C are provided as a maskable interrupt to the microcontroller. This warning allows 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 • (T - 25°C) (V) is provided onto the ADC pre-multiplexer for IC temperature measurement.

9.8 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).

9.9 Electrical Characteristics

Table 9-1 Multi-Mode Switching Supply Controller Electrical Characteristics

(V_{HM} = 24V, V_P = 12V and T_A = -40°C to 125°C unless otherwise specified)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
Input Supply (V_{HM})						
$I_{HIB;VHM}$	V_{HM} hibernate mode supply current	V_{HM}, hibernate mode		18	36	µA
$I_{SU;VHM}$	V_{HM} start-up supply current	V_{HM} < $V_{UVLOR;VHM}$		75	120	µA
$I_{OP;VHM}$	V_{HM} operating supply current	DRM floating		0.3	0.5	mA
$V_{OP;VHM}$	V_{HM} operating voltage range		5		70	V
$V_{UVLOR;VHM}$	V_{HM} under-voltage lockout rising		6.8	7.4	8	V
$V_{UVLOF;VHM}$	V_{HM} under-voltage lockout falling		6	6.6	7	V
$V_{CLAMP;VHM}$	V_{HM} clamp voltage	Clamp enabled, sink current = 100 µA	14.5	16.9	19.5	V
$I_{CLAMP;VHM}$	V_{HM} clamp sink current limit	Clamp enabled		4		mA
Output Supply and Feedback (V_P)						
$V_{REG;VP}$	V_P output regulation voltage	Programmable to 9V, 12V or 15V, Load = 0 to 500mA	-7	-1	5	%
$k_{POK;VP}$	V_P power OK threshold	V_P rising, hysteresis = 10%	82	87	92	%
$k_{OVP;VP}$	V_P over-voltage protection threshold	V_P rising, hysteresis = 15%, MMPM Controller enabled		136		%
Switching Control						
$f_{SWM;DRM}$	Switching frequency programmable range	High-frequency mode, 8 settings	181		500	kHz
		Low-frequency mode, 8 settings	45		125	kHz
$f_{SSU;DRM}$	Safe start-up switching frequency			9.5		kHz
$t_{ONMIN;DRM}$	Minimum on-time			440		ns
$t_{OFFMIN;DRM}$	Minimum off-time	Low duty-cycle and low-frequency mode		25		%
		Low duty-cycle and high-frequency mode		440		ns
		High duty-cycle mode		820		ns
Current Sense (CSM pin)						
$V_{DET;CSM}$	CSM mode detection threshold	Rising, hysteresis = 50mV	0.40	0.55	0.69	V
$V_{HSLIM;CSM}$	High-side current limit threshold	181kHz, duty = 25%, relative to V_P	0.17	0.26	0.35	V
$V_{LSLIM;CSM}$	Low-side current limit threshold	45kHz, duty = 25%	0.7	1	1.48	V
$t_{BLANK;CSM}$	Current sense blanking time			200		ns
$V_{PROT;CSM}$	Low-side abnormal current sense protection threshold	V_P < 4.3V		0.8		V
		V_P > 4.3V		1.9		
Gate Driver Output (DRM pin)						

$V_{OH;DRM}$	High-level output voltage	5% I_{OH}, relative to VHM	V_{HM} – 1			V
$V_{OL;DRM}$	Low-level output voltage	5% I_{OL}			0.6	V
$I_{OH;DRM}$	High-level output source current	$V_{DRM} = V_{HM} – 5V$		-0.3		A
$I_{OL;DRM}$	Low-level output sink current	$V_{DRM} = 5V$		0.5		A
$t_{PD;DRM}$	Strong pull-down pulse width	High-side current sense mode		240		ns

Table 9-2 Linear Regulators Electrical Characteristics

(V_P = 12V and T_A = -40°C to 125°C unless otherwise specified)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$V_{OP;VP}$	V_P operating voltage range		4.5		20	V
$V_{UVLO;VP}$	V_P under-voltage lockout threshold	V_P rising, hysteresis = 0.2V	4	4.3	4.6	V
$I_{Q;VP}$	V_P quiescent supply current	Power manager only, including $I_Q;V_{SYS}$		400	750	µA
$I_{Q;VSYS}$	V_{SYS} quiescent supply current	V_{CCIO}, V_{CC33} and V_{CORE} regulators only		350	600	µA
V_{SYS}	V_{SYS} output voltage	Load = 10µA to 200mA	4.8	5	5.18	V
V_{CCIO}	V_{CCIO} output voltage	Load = 10mA	3.15	3.3	3.4	V
V_{CC33}	V_{CC33} output voltage	Load = 10mA	3.15	3.3	3.4	V
V_{CORE}	V_{CORE} output voltage	Load = 10mA	1.14	1.2	1.26	V
$I_{LIM;VSYS}$	V_{SYS} regulator current limit		220	330		mA
$I_{LIM;VCCIO}$	V_{CCIO} regulator current limit		45	80		mA
$I_{LIM;VCC33}$	V_{CC33} regulator current limit		45	80		mA
$I_{LIM;VCORE}$	V_{CORE} regulator current limit		45	80		mA
k_{SCFB}	Short-circuit current fold-back			50		%
$V_{DO;VSYS}$	V_{SYS} dropout voltage	V_P = 5V, I_{SYS} = 100mA		350	680	mV
$V_{UVLO;VSYS}$	V_{SYS} under-voltage lockout threshold	V_{SYS} rising, hysteresis = 0.2V	3.5	4	4.4	V
$k_{POK;VCCIO}$	V_{CCIO} power OK threshold	V_{CCIO} rising, hysteresis = 10%	79	85	91	%
$k_{POK;VCC33}$	V_{CC33} power OK threshold	V_{CC33} rising, hysteresis = 10%	79	85	91	%
$k_{POK;VCORE}$	V_{CORE} power OK threshold	V_{CORE} falling, hysteresis = 10%	79	85	91	%
$t_{POK;VCC18}$	V_{CC18} power OK time	C_{VCC18} = 1µF			50	µs

Table 9-3. Power System Electrical Characteristics

(T_A = -40°C to 125°C unless otherwise specified)

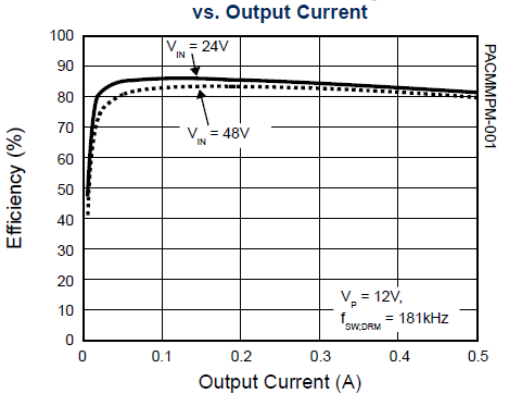
SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
V_{REF}	Reference Voltage	T_A = 25°C	2.487	2.5	2.513	V

		T_A = -40°C to 125°C	2.463	2.5	2.537	V
k_{MON}	Power monitoring voltage (V_{MON}) coefficient	V_{CORE}		1		V/V
		V_{SYS}, V_{CCIO}, V_{CC33}		0.4		
		V_P, V_{REGO}		0.1		
V_{TEMP}	Temperature monitor voltage at 25°C	T_A = 25°C, at ADC	1.475	1.5	1.54	V
k_{TEMP}	Temperature monitor coefficient	At ADC		5.04		mV/K
T_{WARN}	Over-temperature warning threshold	Hysteresis = 10°C		140		°C
T_{FAULT}	Over-temperature fault threshold	Hysteresis = 10°C		170		°C

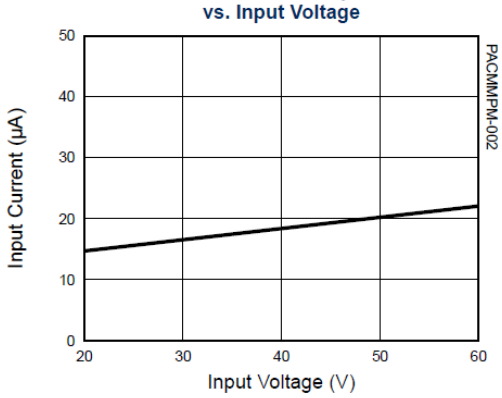
9.10 Typical Performance Characteristics

(V_P = 12V and T_A = 25°C unless otherwise specified)

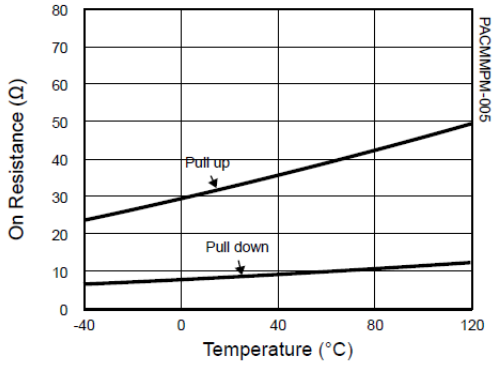
Buck Mode Efficiency vs. Output Current



Buck Mode Hibernate Input Current vs. Input Voltage



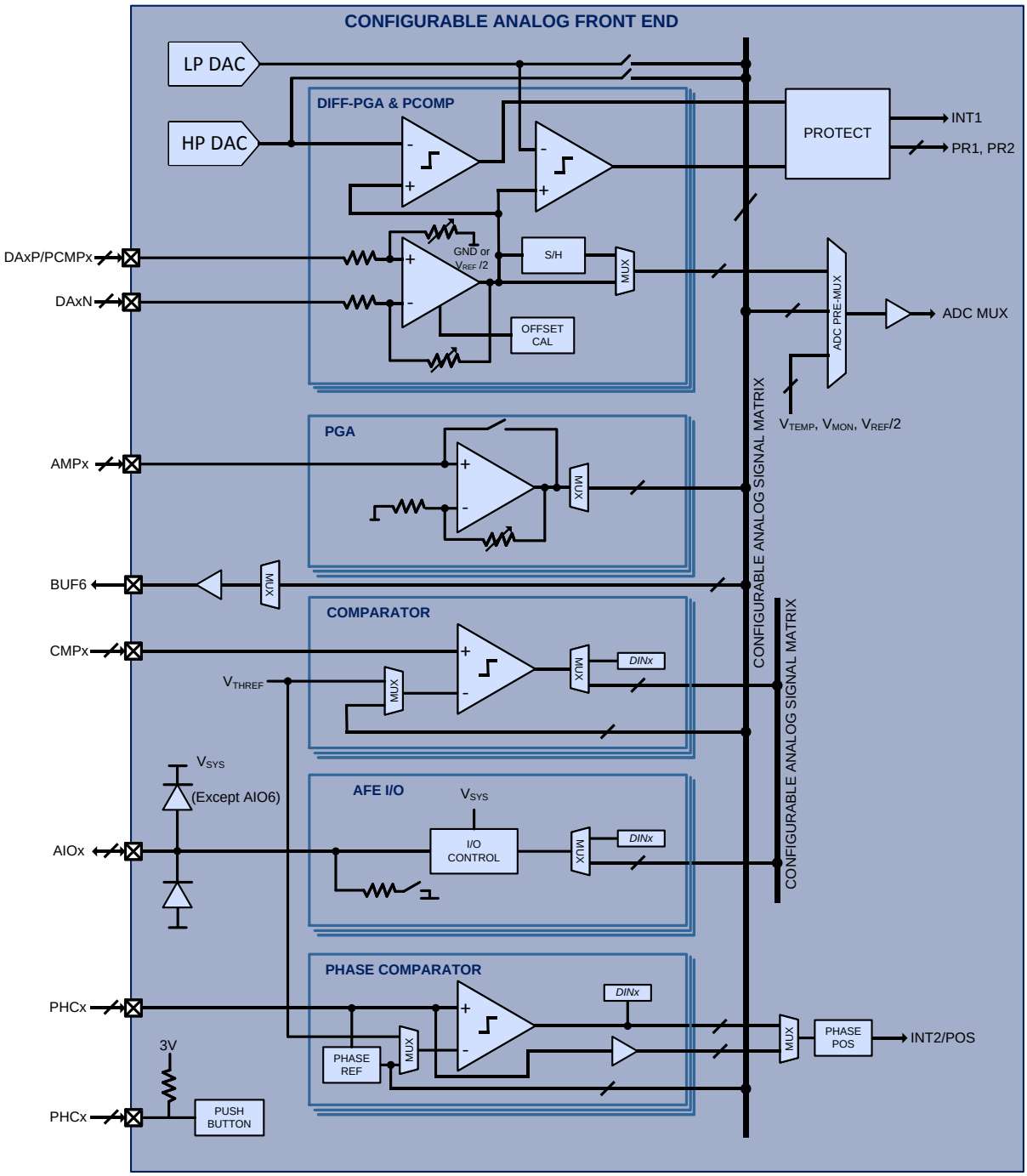
DRM Driver Output On Resistance vs. Temperature



10 CONFIGURABLE ANALOG FRONT END (CAFE)

10.1 Block Diagram

Figure 10-1 Configurable Analog Front End



10.2 Functional Description

The device includes a Configurable Analog Front End (CAFE, Figure 10-1) accessible through 10 analog and I/O pins. These pins can be configured to form flexible interconnected circuitry made up of 3 differential programmable gain amplifiers, 4 single-ended programmable gain amplifiers, 4 general purpose comparators, 3 phase comparators, 10 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.

10.3 Differential Programmable Gain Amplifier (DA)

The DAxP and DAxN 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 3.5V 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.

10.4 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.

10.5 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.

10.6 Phase Comparator (PHC)

The phase comparator takes the PHCx input and compares it to either the programmable threshold voltage (VTHREF) 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 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.

10.7 Protection Comparator (PCMP)

Two protection comparators are provided in association with each 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.

10.8 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.

10.9 Analog Front End I/O (AIO)

Up to 10 AIOx pins are available in the device, depending on the product[5]. 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

[5] See the pin configuration and description for specific information on which pins are available in this product.

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.

10.10 Push Button (PBTN)

The push button PBTN, when enabled, can be used by the MCU to detect a user active-low push button event and to put the system into an ultra-low-power hibernate mode. 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 55kΩ pull-up resistor to 3V.

10.11 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.

10.12 ADC Pre-Multiplexer

The ADC pre-multiplexer is a 16-to-1 multiplexer that selects between the 3 differential programmable gain amplifier outputs, 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.

10.13 Configurable Analog Signal Matrix (CASM)

The CASM has 12 general purpose analog signals labeled AB1 through AB12 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

10.14 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

10.15 Electrical Characteristics

Table 10-1 Differential Programmable Gain Amplifier (DA) Electrical Characteristics

(V_{SYS} = 5V, V_{CCIO} = 3.3V and T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$I_{CC;DA}$	Operating supply current	Each enabled amplifier		150	300	µA
$V_{ICMR;DA}$	Input common mode range		-0.3		3.5	V
$V_{OLR;DA}$	Output linear range		0.1		3.5	V
$V_{OS;DA}$	Input offset voltage	Gain = 48x, V_{DAxP}=V_{DAxN}=0V, T_A=25°C	-8		8	mV
$A_{VZI;DA}$	Differential amplifier gain (zero ohm source impedance)	Gain = 1x		1		
		Gain = 2x		2		
		Gain = 4x		4		
		Gain = 8x, V_{DAxP}=V_{DAxN}=0V, T_A = 25°C		8		
			-2		2	%
		Gain = 16x		16		
		Gain = 32x		32		
		Gain = 48x		48		
$k_{CMRR;DA}$	Common mode rejection ratio	Gain = 8x, V_{DAxP}=V_{DAxN}=0V, T_A = 25°C		55		dB
$R_{INDIF;DA}$	Differential input impedance			27		kΩ
	Slew rate[6]	Gain = 8x	7	10		V/µs
$t_{ST;DA}$	Settling time[6]	To 1% of final value		200	400	ns

Table 10-2 Single-Ended Programmable Gain Amplifier (AMP) Electrical Characteristics

(V_{SYS} = 5V, V_{CCIO} = 3.3V and T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$I_{CC;AMP}$	Operating supply current	Each enabled amplifier		80	140	µA
$V_{OLR;AMP}$	Output linear range		0.1		3.5	V
$V_{OS;AMP}$	Input offset voltage	Gain = 1x, T_A=25°C, V_{AMPX}=2.5V	-10		10	mV
$A_{V;AMP}$	Amplifier gain	Gain = 1x		1		
		Gain = 2x		2		
		Gain = 4x		4		
		Gain = 8x, V_{AMPx}=125mV, T_A = 25°C	-2		2	%
		Gain = 16x		16		

[6] Guaranteed by design

		Gain = 32x		32		
		Gain = 48x		48		
$I_{IN;AMP}$	Input current			0	1	µA
	Slew rate[6]	Gain = 8x	8	12		V/µs
$t_{ST;AMP}$	Settling time[6]	To 1% of final value		150	300	ns

Table 10-3 General Purpose Comparator (CMP) Electrical Characteristics

(V_{SYS} = 5V, V_{CC33} = 3.3V and T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$I_{CC;CMP}$	Operating supply current	Each enabled amplifier		35	110	µA
$V_{ICMR;CMP}$	Input common mode range		0		V_{SYS}	V
$V_{OS;CMP}$	Input offset voltage	VCMPx=2.5V, TA=25C	-10		10	mV
$V_{HYS;CMP}$	Hysteresis			20		mV
$I_{IN;CMP}$	Input current			0	1	µA
$t_{DEL;CMP}$	Comparator delay[6]				100	ns

Table 10-4 Phase Comparator (PHC) Electrical Characteristics

(V_{SYS} = 5V, V_{CC33} = 3.3V and T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
$I_{CC;PHC}$	Operating supply current	Each enabled amplifier		35	110	µA
$V_{ICMR;PHC}$	Input common mode range		0		V_{SYS}	V
$V_{OS;PHC}$	Input offset voltage	V_{PCMPx}=2.5V, T_A=25°C	-10		10	mV
$V_{HYS;PHC}$	Hysteresis			20		mV
$I_{IN;PHC}$	Input current			0	1	µA
$t_{DEL;PHC}$	Comparator delay[6]				100	ns

Table 10-5 Protection Comparator (PCMP) Electrical Characteristics

(V_{SYS} = 5V, V_{CC33} = 3.3V and T_A = -40°C to 125°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_{CMPx}=2.5V, T_A=25°C	-10		10	mV
$V_{HYS;PCMP}$	Hysteresis			20		mV
$I_{IN;PCMP}$	Input current			0	1	µA

$t_{DEL;PCMP}$	Comparator delay[6]			100	ns

Table 10-6 Analog Output Buffer (BUF) Electrical Characteristics

(V_{SYS} = 5V, V_{CCIO} = 3.3V, and T_A = -40°C to 125°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°C	-18		18	mV
I_{OMAX}	Maximum output current	C_L = 0.1nF	0.8	1.3		mA

Table 10-7 Analog Front End (AIO) Electrical Characteristics

(V_{SYS} = 5V, V_{CCIO} = 3.3V, and T_A = -40°C to 125°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	$I_{AIO<9:7,3:1>}$=7mA, open-drain output mode			0.4	V
		$I_{AIO<6,0>}$=7mA, open-drain output mode			0.5	
$I_{OL;AIO}$	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 10-8 Push Button (PBTN) Electrical Characteristics

(V_{SYS} = 5V, V_{CCIO} = 3.3V, and T_A = -40°C to 125°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 10-9 HP DAC and LP DAC Electrical Characteristics

(V_{SYS} = 5V, V_{CCIO} = 3.3V, and T_A = -40°C to 125°C unless otherwise specified.)

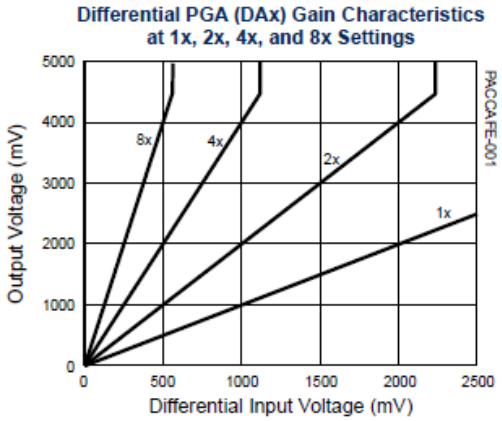
SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
VDACREF	DAC reference voltage	TA = 25°C	2.48	2.5	2.52	V
		TA = -40°C to 125°C	2.453	2.5	2.547	
	HP 8-bit DAC INL[7]		-1		1	LSB
	HP 8-bit DAC DNL[7]		-0.5		0.5	LSB
	LP 10-bit DAC INL[7]		-2		2	LSB
	LP 10-bit DAC DNL[7]		-1		1	LSB

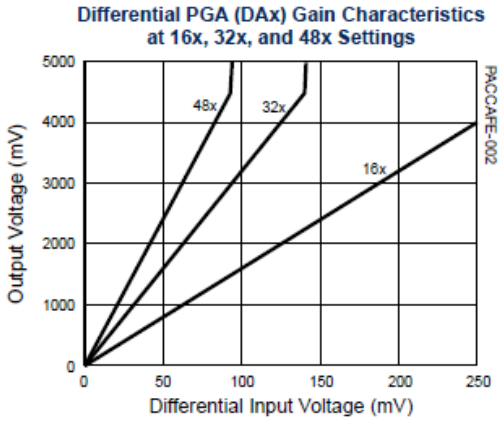
[7] Guaranteed by design and characterization

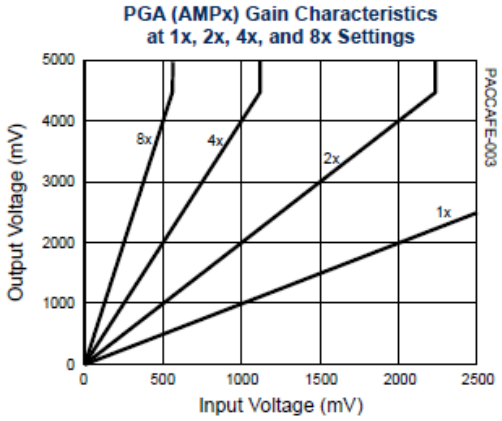
10.16 Typical Performance Characteristics

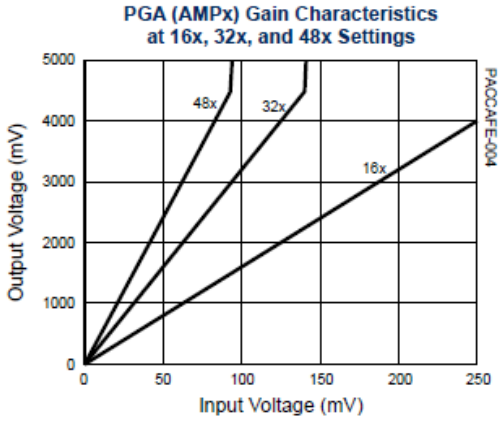
Figure 10-2 PGA Typical Performance Characteristics

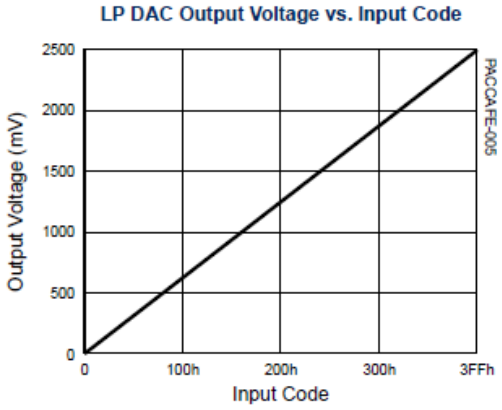
(V_{SYS} = 5V and T_A = 25°C unless otherwise specified)

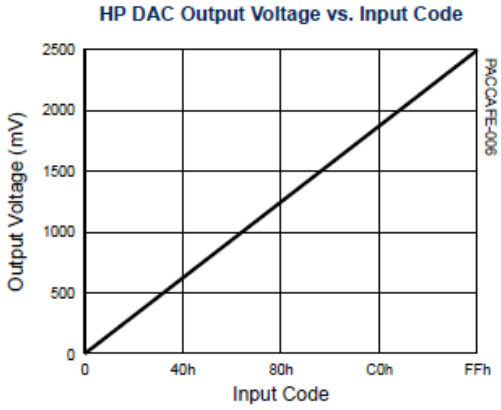












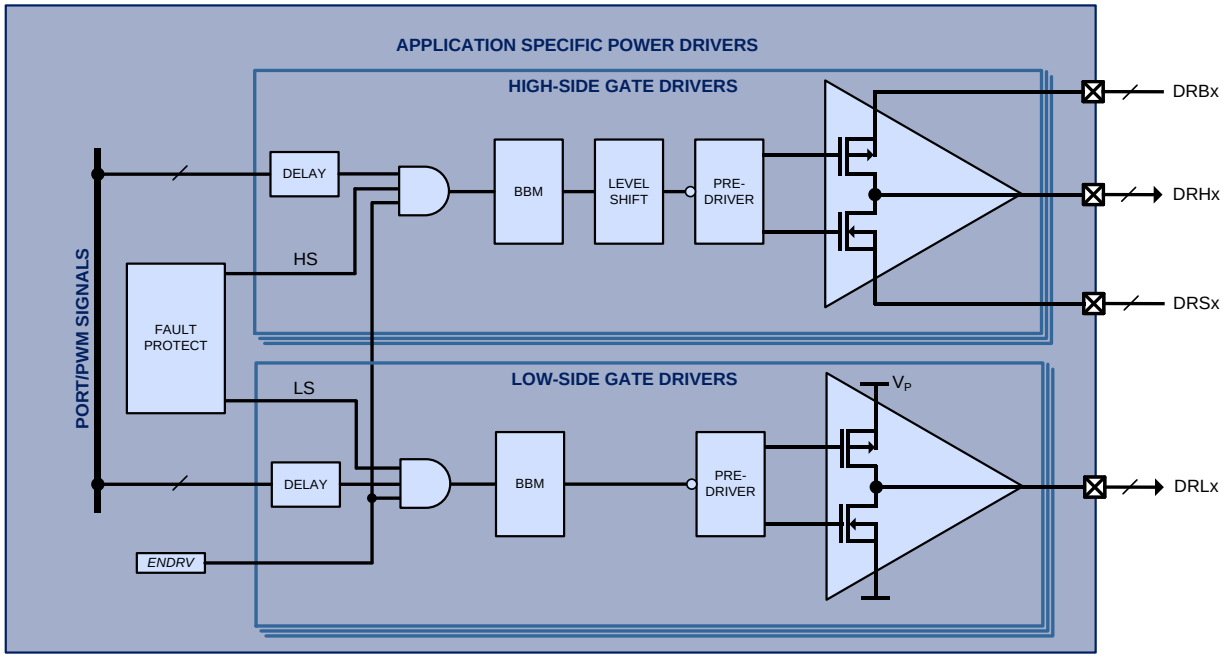
11 APPLICATION SPECIFIC POWER DRIVERS (ASPD)

11.1 Features

- 3 low-side and 3 high-side gate drivers
- 1.5A gate driving capability
- Configurable delays and fast fault protection

11.2 Block Diagram

Figure 11-1 Application Specific Power Drivers



11.3 Functional Description

The Application Specific Power Drivers (ASPD, Figure 11-1) module handles power driving for power and motor control applications. The ASPD contains 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 11-2 below shows typical gate driver connections and Table 11-1 shows the ASPD available resources. The ASPD gate drivers support up to a 70V supply.

Figure 11-2 Typical Gate Driver Connections

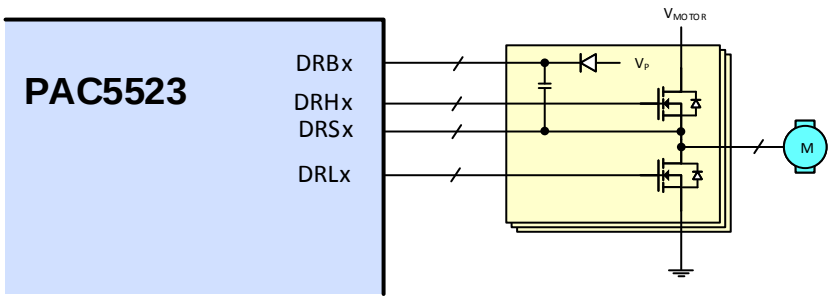


Table 11-1 Power Driver Resources by Part Numbers

PART NUMBER	LOW-SIDE GATE DRIVER		HIGH-SIDE GATE DRIVER		
	DRLx	SOURCE/SINK CURRENT	DRHx	MAX SUPPLY	SOURCE/SINK CURRENT
PAC5523	3	1.5A/1.5A	3	70V	1.5A/1.5A

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

11.4 Low-Side Gate Driver

The DRLx low-side gate driver drives the gate of an external MOSFET or IGBT switch between the low-level VSSP power ground rail and high-level VP supply rail. The DRLx output pin has sink and source output current capability of 1.5A. Each low-side gate driver is controlled by a microcontroller port signal with 4 configurable levels of propagation delay.

11.5 High-Side Gate Driver

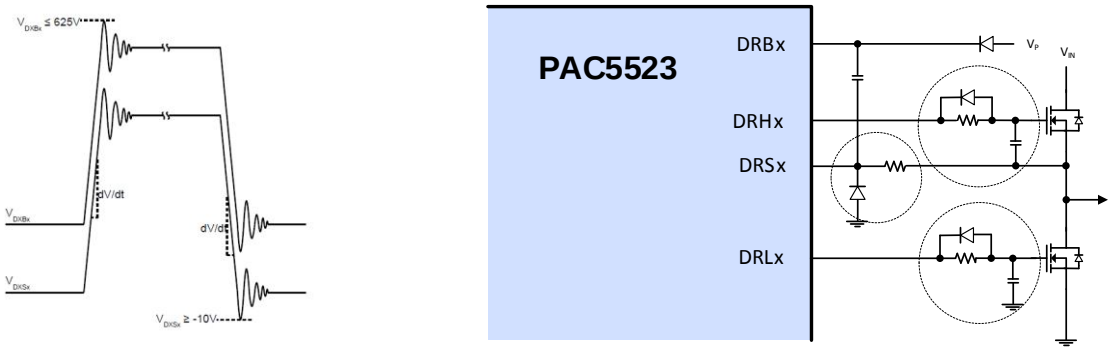
The DRHx high-side gate driver drives the gate of an external MOSFET or IGBT switch between its low-level DRSx driver source rail and its high-level DRBx bootstrap rail. The DRSx pin can go up to 70V steady state. The DRHx output pin has sink and source output current capability of 1.5A. The DRBx bootstrap pin can have a maximum operating voltage of 16V relative to the DRSx pin, and up to 82V 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}.

11.6 High-Side Switching Transients

Typical high-side switching transients are shown in Figure 11-3(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 ±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 11-3(b).

Figure 11-3 High-Side Switching Transients and Optional Circuitry



(a) High-Side Switching Transients (b) Optional Transient Protection and Slew Rate Control

11.7 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 as shown in SOC CONTROL SIGNALS. The drivers have configurable delays as shown in Table 11-2 Power Driver Delay Configuration. Refer to the PAC application notes and user guide for additional information on power drivers control programming.

Table 11-2 Power Driver Delay Configuration

DELAY SETTING	DRLx		DRHx	
	RISING	FALLING	RISING	FALLING
00b (default)	130ns	140ns	160ns	140ns
01b	170ns	180ns	200ns	180ns
10b	230ns	250ns	260ns	240ns
11b	360ns	380ns	380ns	370ns

11.8 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.

11.9 Electrical Characteristics

Table 11-3 Gate Driver Electrical Characteristics

(V_P = 12V, V_{SYS} = 5V and T_A = -40°C to 125°C unless otherwise specified.)

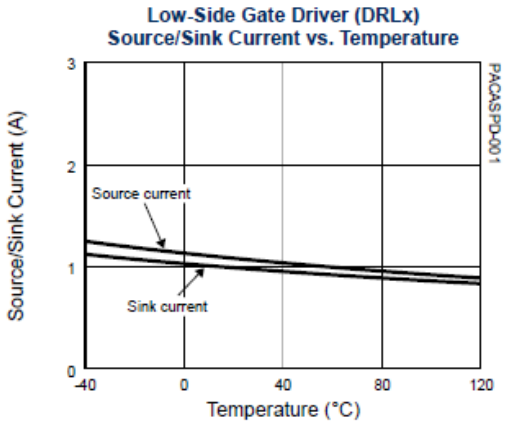
SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
Low-Side Gate Drivers (DRLx pins)						
$V_{OH;DRL}$	High-level output voltage	I_{DRLx} = -50mA	V_P-0.5	V_P-0.25		V
$V_{OL;DRL}$	Low-level output voltage	I_{DRLx} = 50mA		0.175	0.35	V
$I_{OHPK;DRL}$	High-level pulsed peak source current	10µs pulse		-1.5		A
$I_{OLPK;DRL}$	Low-level pulsed peak sink current	10µs pulse		1.5		A
High-Side Gate Drivers (DRHx, DRBx and DRSx pins)						
V_{DRS}	Level-shift driver source voltage range	Repetitve, 10µs pulse	-5		71	V
		Steady state	0		66	V
V_{DRB}	Bootstrap pin voltage range	Repetitive, 10µs pulse	3		83	V
		Steady state	5.2		78	V
$V_{BS;DRB}$	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 = 1V		3.5	4.5	V
$I_{BS;DRB}$	Bootstrap circuit supply current	Gate Driver Disabled		23	35	µA
		Gate Driver Enabled		30	45	
$I_{OS;DRB}$	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}-0.6	V_{DRBx}-0.2		V
$V_{OL;DRH}$	Low-level output voltage	I_{DRHx} = 50mA		V_{DRSx}+0.175	V_{DRSx}+0.35	V
$I_{OHPK;DRH}$	High-level pulsed peak source current	10µs pulse		-1.5		A
$I_{OLPK;DRL}$	Low-level pulsed peak sink current	10µs pulse		1.5		A
High-Side and Low-Side Gate Driver Propagation Delay						
t_{PD}	Propagation Delay	Delay setting 00b		10		ns
		Delay setting 01b		50		ns

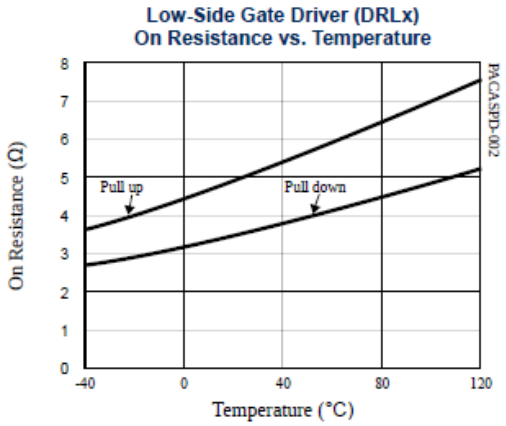
		Delay setting 10b		120		ns
		Delay setting 11b		250		ns

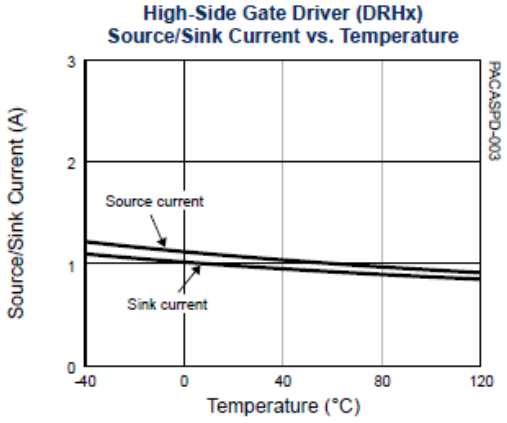
11.10 Typical Performance Characteristics

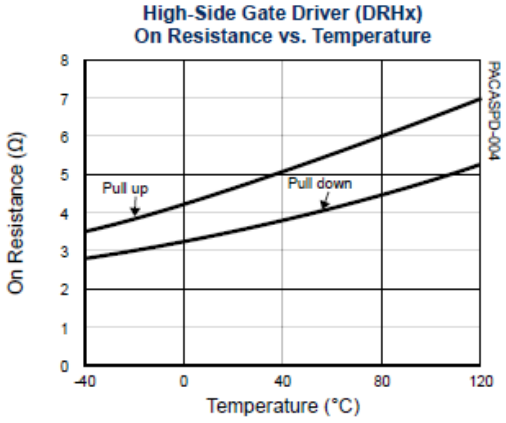
Figure 11-4 ASPD Gate Driver Typical Performance Characteristics

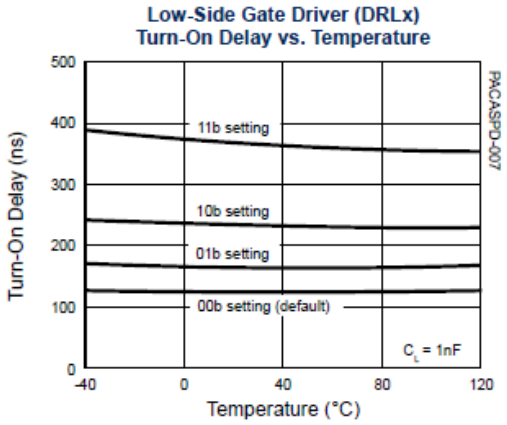
(V_P = 12V, V_{SYS} = 5V and T_A = -40°C to 125°C unless otherwise specified.)











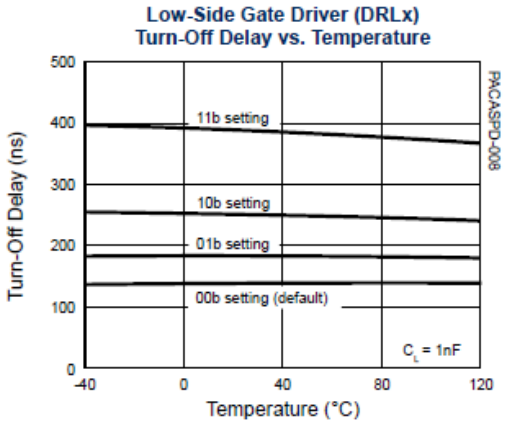
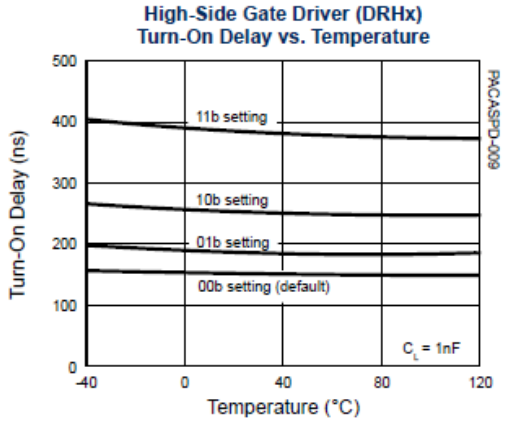
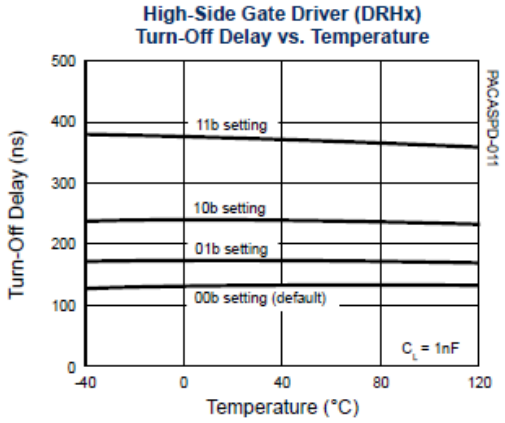


Figure 11-5 ASPD Gate Driver Typical Performance Characteristics (cont)

(V_P = 12V, V_{SYS} = 5V and T_A = -40°C to 125°C unless otherwise specified.)





12 SOC CONTROL SIGNALS

The MCU has access to the Analog Sub-system on the PAC5523 through certain digital peripherals. The functions that the MCU may access from the Analog Sub-System are:

- High-side and Low-side Gate Drivers
- SPI Interface for Analog Register Access
- ADC EMUX
- Analog Sub-system Interrupts

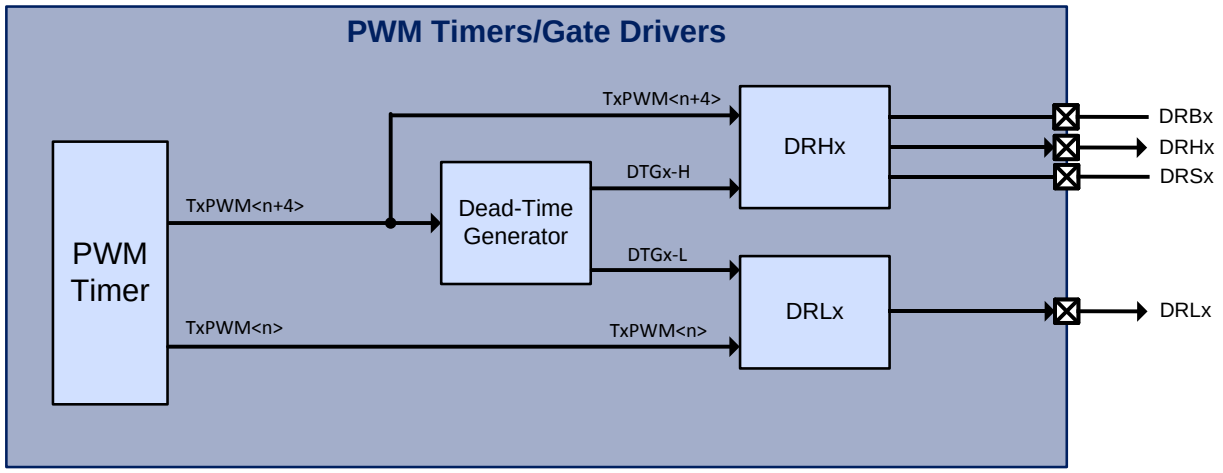
12.1 High-side and Low-Side Gate Drivers

The high-side and low-side gate drivers on the PAC5523 are controlled by PWM outputs of the timer peripherals on the MCU. The timer peripheral generates the PWM output. The PWM timer may be configured to generate a complementary PWM output (high-side and low-side gate drive signals) with hardware controlled dead-time.

These signals are sent to the gate drivers in the Analog Sub-system that create the high and low side gate drivers for the external inverter.

The user may choose to enable or not enable the DTG (Dead-time Generator). The diagram below shows the block diagram of the PWM timer, DTG and ASPD gate drivers.

Figure 12-1 SOC Signals for Gate Drivers



Each timer peripheral that drives the DTG and ASPD Gate Drivers has two PWM outputs that are connected to the gate drivers: TxPWM<n> and TxPWM<n+4>. If the Dead-Time Generator is disabled TxPWM<n> is connected to the DRLx gate driver output and TxPWM<n+4> is connected to the DRHx gate driver output.

If the DTG is enabled, the TxPWM<n+4> is used to generate the complementary high-side and low-side output (DTGx-H and DTGx-L). DTGx-H is connected to the DRHx output and DTGx-L is connected to the DRLx output.

The MCU allows flexibility the assignment of PWM outputs to ASPD gate drivers. The tables below shows which PWM outputs are available for each gate driver.

For applications that drive half-bridge or full-bridge topologies, the DTG will be enabled to allow a complementary output with dead-time insertion.

Table 12-1 PWM to ASPD Gate Driver Options (DTG Enabled)

Gate Driver	PWM Input Options
DRH3/ DRL0	TAPWM4 TBPWM4 TCPWM0 TCPWM4 TDPWM4
DRH4/ DRL1	TAPWM5 TBPWM5 TCPWM1 TCPWM5 TDPWM5
DRH5/ DRL0	TAPWM6 TBPWM6 TCPWM2 TCPWM6 TDPWM6

For applications that are not driving half-bridge topologies, the DTG is disabled and the PWM outputs are directly connected to the gate drivers.

Table 12-2 PWM to ASPD Gate Driver Options (DTG Disabled)

Gate Driver	PWM Input Options
DRH3	TAPWM4 TBPWM4 TCPWM0 TCPWM4 TDPWM4
DRH4	TAPWM5 TBPWM5

	TCPWM1 TCPWM5 TDPWM5
DRH5	TAPWM6 TBPWM6 TCPWM2 TCPWM6 TDPWM6
DRL0	TAPWM0 TBPWM0 TCPWM0 TDPWM0
DRL1	TAPWM1 TBPWM1 TCPWM1 TDPWM1
DRL2	TAPWM2 TBPWM2 TCPWM2 TDPWM2

12.2 SPI SOC Bus

The SPI SOC bus is used for reading and writing registers in the Analog Sub-System. The PAC5523 allows both USARTA and USARTB to be used as the SPI master to read and write registers in the Analog Sub-System.

The table below shows which peripherals and which IO pins should be used for this interface.

Table 12-3 SPI SOC Bus Connections

SPI Signal	USART Signal	IO Pin
SCLK	USASCLK	PA3
	USBSCLK	PA3
MOSI	USAMOSI	PA4
	USBMOSI	PA4
MISO	USAMISO	PA5
	USBMISO	PA5

SS	USASS	PA6
	USBSS	PA6

12.3 ADC EMUX

The ADC EMUX is a write-only serial bus that the ADC DTSE uses for instructing the CAFE to perform MUX changes, activate Sample and Hold, etc.

The table below shows the MCU pins that are used by the ADC EMUX in the PAC5523.

Table 12-4 SPI SOC Bus Connections

EMUX Signal	Description	IO Pin
EMUXC	EMUX Clock	PA2
EMUXD	EMUX Data	PA1

12.4 Analog Interrupts

The Analog sub-system has two interrupts that it can generate for different conditions. The table below shows the two different interrupts, the interrupt conditions and the IO pin that the interrupts are connected to.

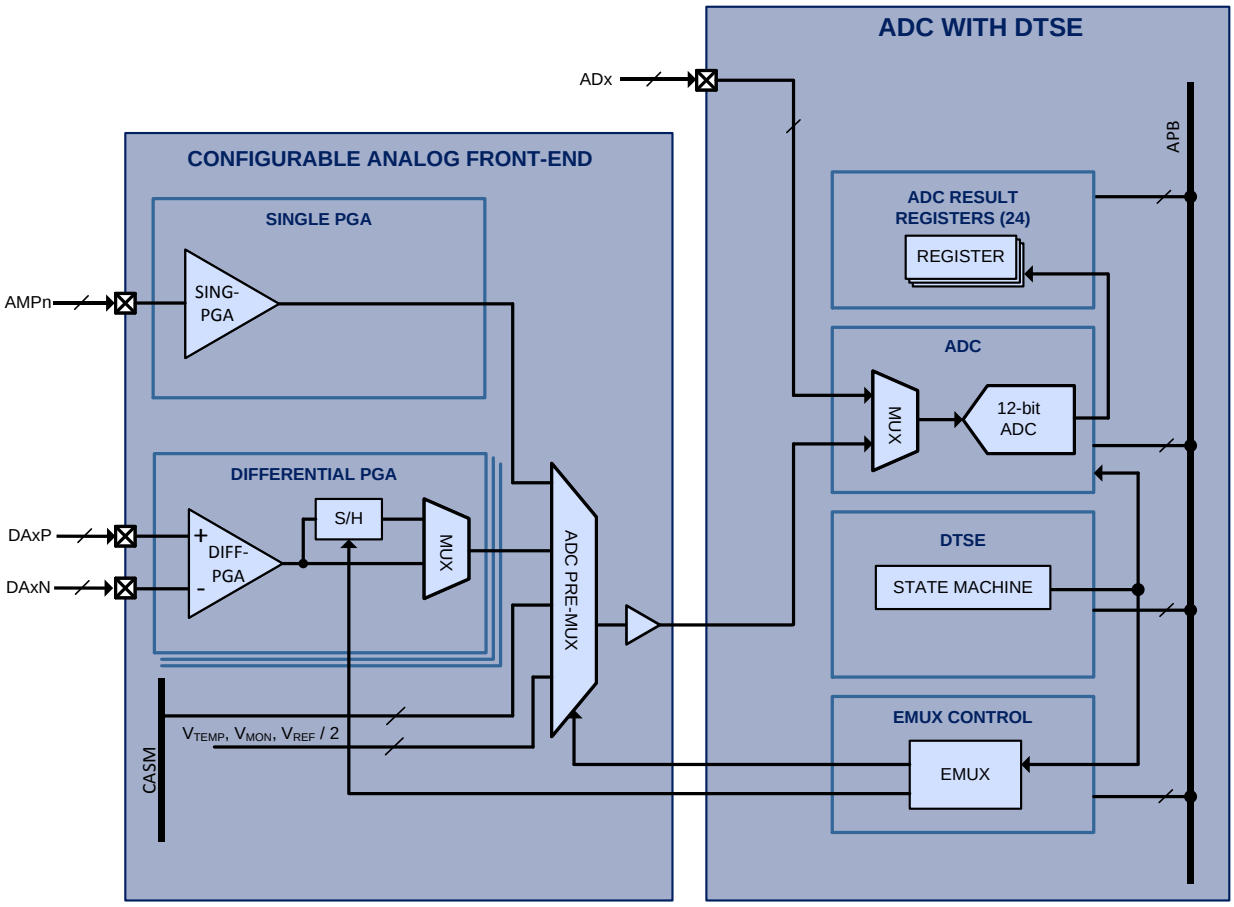
Table 12-5 Analog Interrupts

Analog IRQ	Interrupt Conditions	IO Pin
nIRQ1	HPCOMP/LPCOMP Comparator Protection for Over-current and Over-Voltage events	PA7
nIRQ2	BEMF and Special Mode Comparator, including phase to phase comparator, AIO6/AIO7/AIO8/AIO9 interrupt	PA0

13 ADC/DTSE

13.1 ADC Block Diagram

Figure 13-1 ADC with DTSE



13.2 Functional Description

13.2.1 ADC

The analog-to-digital converter (ADC) is a 12-bit successive approximation register (SAR) ADC with 400ns conversion time and up to 2.5 MSPS capability. The integrated analog multiplexer allows selection from up to 8 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 as well as temperature and V_{REF} / 2.

The ADC contains a power down mode, and the user may configure the ADC to interrupt the MCU for the completion of a conversion when in manual mode. The ADC may be configured for either repeating or non-repeating conversions or conversion sequences.

13.2.2 Dynamic Triggering and Sample Engine

The Dynamic Triggering and Sample Engine (DTSE) is a highly-configurable automatic sequencer that allows the user to configure automatic sampling of their application-specific analog signals without any interaction from the micro-controller core. The DTSE also contains a pseudo-DMA engine that copies each of up to 24 conversion results to dedicated memory space and can interrupt the MCU when complete.

The DTSE has up to 32 input triggers, from PWM Timers A, B, C and D for either the rising, falling or rising and falling PWM edges. The user may also force any trigger sequence by writing a register via firmware. The user can configure the DTSE to chain from 1 to 24 conversions to any PWM trigger.

The DTSE has a flexible interrupt structure that allows up to 24 interrupts to be configured at the completion of any individual conversion. The user may configure one of four different IRQ signals wen generating an interrupt during sequence conversions. The IRQ may be generated at the end of a conversion sequence, or at the end of series of conversions. The user may select one of four IRQs for conversions, and each may be assigned a different interrupt priority.

Each of the 24 conversions has dedicated results registers, so that the pseudo-DMA engine has dedicated storage for each of the conversion results.

13.2.3 EMUX Control

A dedicated low latency interface controllable by the DTSE or register control allows changing the ADC pre-multiplexer and asserting/de-asserting the S/H circuit in the Configurable Analog Front-End (CAFE), allowing back to back conversions of multiple analog inputs without microcontroller interaction.

For more information on the ADC and DTSE, see the PAC55XX Family User Guide.

13.3 Electrical Characteristics

Table 13-1 ADC and DTSE Electrical Characteristics

(V_P = 12V, V_{SYS} = 5V and T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
ADC						
f_{ADCCLK}	ADC conversion clock input				40	MHz
$f_{ADCCONV}$	ADC conversion time	f_{ADCCLK} = 40MHz			400	ns
	ADC resolution			12		bits
	ADC effective resolution		10.5			bits
	ADC differential non-linearity (DNL)	F_{ADCCLK} = 25MHz		±0.5		LSB
		F_{ADCCLK} = 40MHz		±0.75		LSB
	ADC integral non-linearity (INL)	F_{ADCCLK} = 25MHz		±0.5		LSB
		F_{ADCCLK} = 40MHz		±0.75		LSB
	ADC offset error			0.6		%FS
	ADC gain error			0.12		%FS
REFERENCE VOLTAGE						
V_{REFADC}	ADC reference input voltage[8]	VREF = 2.5V		2.5		V
SAMPLE AND HOLD						
t_{ADCSH}	ADC sample and hold time	f_{ADCCLK} = 40MHz		188		µs
C_{ADCIC}	ADC input capacitance	ADC MUX input		1		pF
EMUX CLOCK SPEED						
$f_{EMUXCLK}$	EMUX engine clock input				50	MHz

[8] The ADC supports two discrete VREF voltages: 2.5V and 3.0V. Values between 2.5V and 3.0V are not supported. These can be configured in the CAFE. See the PAC55XX Family User Guide for more information.

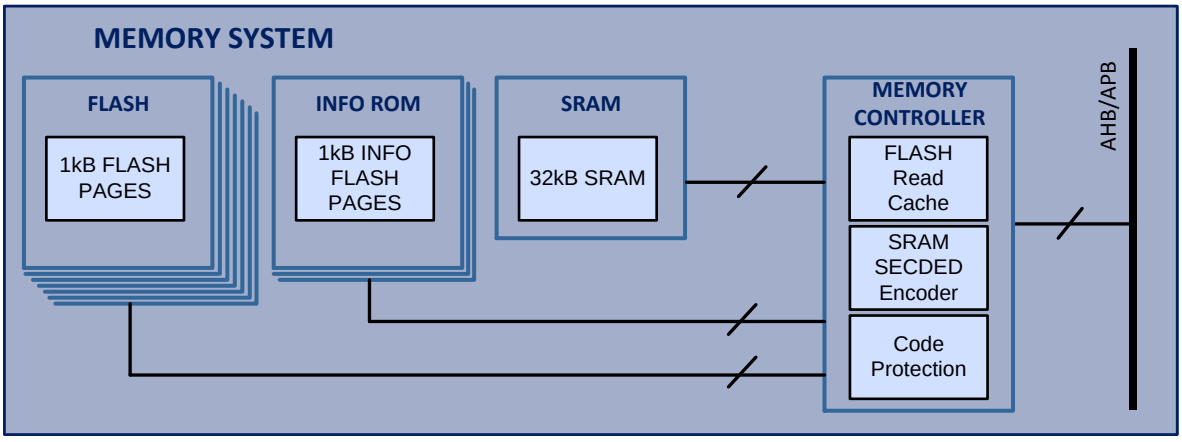
14 MEMORY SYSTEM

14.1 Features

- 128kB Embedded FLASH
  - 30,000 program/erase cycles
  - 10 years data retention
  - FLASH look-ahead buffer for optimizing access
- 1kB INFO-1 Embedded FLASH
- 1kB INFO-2 Embedded FLASH
  - Device ID, Unique ID, trim and manufacturing data
- 1kB INFO-3 Embedded FLASH
  - User data storage, configuration or parameter storage
  - Data or code
- 32kB SRAM
  - 150MHz access for code or data
  - SECDED for read/write operations
- User-configurable code protection

14.2 Memory System Block Diagram

Figure 14-1 Memory System



14.3 Functional Description

The PAC55XX has multiple banks of embedded FLASH memory, SRAM memory as well as peripheral control registers that are program-accessible in a flat memory map.

14.4 Program FLASH

The PAC55XX Memory Controller provides access to 128 1kB pages of main program FLASH for a total of 128kB of FLASH through the system AHB bus. Each page may be individually erased or written while the MCU is executing instructions from SRAM or from INFO-2 or INFO-3 FLASH memory.

The PAC55XX Memory Controller provides a FLASH read buffer that optimizes access from the MCU to the FLASH memory. This look ahead buffer monitors the program execution and fetches instructions from FLASH before they are needed to optimize access to this memory.

14.5 INFO FLASH

The PAC55XX Memory Controller provides access to the INFO-1, INFO-2 and INFO-3 FLASH memories, which are each a single 1kB page for a total of 3kB or memory.

INFO-1 and INFO-2 are read-only memories that contains device-specific information such as the device ID, a unique ID, trimming and calibration data that may be used by programs executing on the PAC55XX.

INFO-3 is available to the user for data or program storage.

14.6 SRAM

The PAC55XX Memory Controller provides access to the 32kB SRAM for non-persistent data storage. The SRAM memory supports word (4B), half-word (2B) and byte addresses with aligned access.

The PAC55XX Memory Controller can read or write data from RAM up to 150MHz. This can be a benefit for time-critical applications. This memory can also be used for program execution when modifying the contents of FLASH, INFO-1 or INFO-2 FLASH.

The PAC55XX Memory Controller also has an SECDED encoder, capable of detecting and correcting single-bit errors, and detecting double-bit errors. The user may read the status of the encoder, to see if a single-bit error has occurred. The user may also enable an interrupt upon

detection of single-bit errors. Dual-bit errors can be configured to generate an interrupt in the PAC55XX.[9]

For more information on the PAC55XX Memory Controller, see the PAC55XX Family User Guide.

14.7 Code Protection

The PAC55XX allows user configurable code protection, to secure code from being read from the device.

There are four levels of code protection available as shown in the table below.

Table 14-1 Code Protection Level Description

LEVEL	NAME	FEATURES
0	UNLOCKED	• No restrictions
1	RW PROTECTION	• SWD/JTAG enabled • Programmable protection of up to 128 regions of FLASH • User-specified Read or Write protection per region
2	SWD DISABLED	• SWD/JTAG disabled • Programmable protection of up to 128 regions of FLASH • User-specified Read or Write protection per region
3	SWD/JTAG PERMANENTLY DISABLED	• SWD/JTAG disabled • Programmable protection of up to 128 regions of FLASH • User-specified Read or Write protection per region • No recovery

[9] Note that when writing half-word or single bytes to SRAM, the memory controller must perform a read-modify write to memory to perform the SECDED calculation. These operations will take more than one clock cycle to perform for this reason.

14.8 Electrical Characteristics

Table 14-2 Memory System Electrical Characteristics

(T_A = -40°C to 125°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		30			µs
$t_{PERASE;FLASH}$	FLASH page erase time			2		ms
$t_{MERASE;FLASH}$	FLASH full erase time			10		ms
$N_{PERASE;FLASH}$	FLASH program/erase cycles		30k			cycles
$t_{DR;FLASH}$	FLASH data retention		10			Years
SRAM						
$t_{ACC;SRAM}$	SRAM access time	HCLK = 150MHz; Word (32-bits), aligned	6.67			ns
		HCLK = 150MHz; Half-word (16-bits), byte (8-bits), aligned	6.67			ns

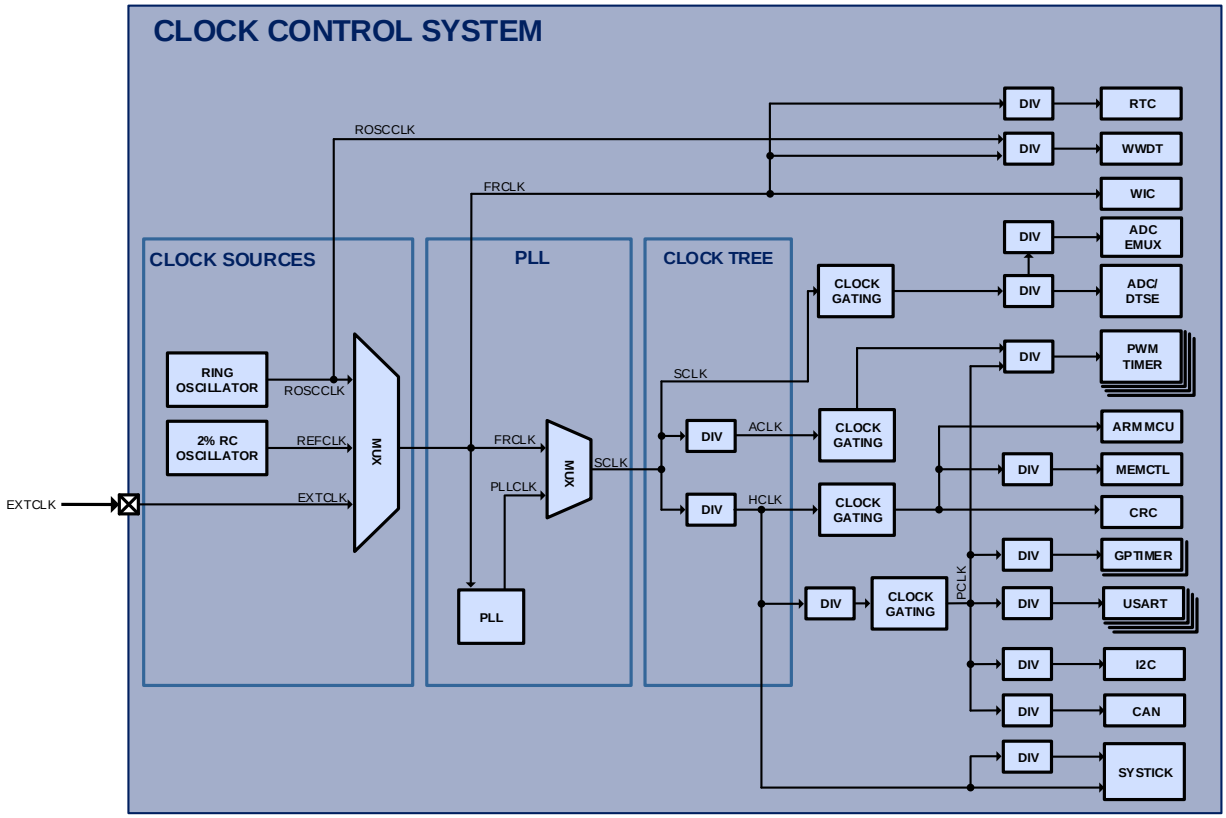
15 SYSTEM AND CLOCK CONTROL

15.1 Features

- 20MHz Ring Oscillator
- High accuracy 2% trimmed 4MHz RC oscillator
- External Clock Input for External Clocks up to 20MHz
- PLL with 1MHz to 50MHz input, 62.5MHz to 300MHz output
- Clock dividers for all system clocks
- Clock gating for power conservation during low-power operation

15.2 Block Diagram

Figure 15-1 Clock Control System



15.3 Clock Sources

15.3.1 Ring Oscillator

The Ring Oscillator (ROSC) is an integrated 20MHz clock oscillator that is the default system clock, and is available by default when the PAC55XX comes out of reset. The output of the ROSC is the ***ROSCCLK*** clock. The ***ROSCLK*** may be selected as the ***FRCLK*** clock and may supply the WWDT, for applications that need an independent clock source or need to continue to be clocked when the system is in a low-power mode.

The ROSC may be disabled by the user by a configuration register.

15.3.2 Reference Clock

The Reference Clock (***REFCLK***) is an integrated 2% trimmed 4MHz RC clock. This clock is suitable for many applications. This clock may be selected as the ***FRCLK*** and can be used as the input to the PLL and is used to derive the clock for the MMPM.

15.3.3 External Clock Input

The External Clock Input (EXTCLK) is a clock input available through the digital peripheral MUX, and allows the drive the clock system by a 50% duty cycle clock of up to 20MHz. This clock may be selected as FRCLK and can be used as the input the PLL (as long as the accuracy is better than +/- 2%).

15.4 PLL

The PAC55XX contains a Phase Lock Loop (PLL) that can generate very high clock frequencies up to 300MHz for the peripherals and timers in the device. The input to the PLL is the ***FRCLK*** and must be from the ***EXTCLK*** or ***REFCLK*** clock sources

The input to the PLL must be between 1MHz – 50MHz and the output can be configured to be from 62.5MHz to 300MHz. The user can configure the PLL to generate the desired clock output based on a set of configuration registers in the CCS. The output of the PLL is the ***PLLCLK*** clock. The user may configure a MUX to generate the SCLK clock from ***PLLCLK*** or from ***FRCLK***.

In addition to configuring the PLL output frequency, the PLL may be enabled, disabled and bypassed through a set of configuration registers in the CCS.

15.5 Clock Tree

The following are of the system clocks available in the clock tree. See the section below to see which clocks are available for each of the digital peripherals in the system.

15.5.1 FRCLK

The free-running clock (***FRCLK***) is generated from one of the four clock sources (***ROSCCLK***, ***EXTCLK*** or ***REFCLK***). This clock may be used by the WWDT and the RTC, for configurations that turn off all other system clocks during low power operation.

The ***FRCLK*** or ***PLLCLK*** is selected via a MUX and the output becomes ***SCLK***.

15.5.2 SCLK

The System Clock (***SCLK***) generates two system clocks: ***ACLK*** and ***HCLK***. Each of these system clocks has their own 3b clock divider and is described below.

15.5.3 PCLK

The Peripheral Clock (***PCLK***) is used by most of the digital peripherals in the PAC55XX. This clock has a 3b clock divider and also has clock gating support, which allows this clock output to be disabled before the system is put into the ARM Cortex-M4's deep sleep mode to conserve energy.

As shown above, most of the peripherals that use ***PCLK*** also have their own clock dividers so that this clock can be further divided down to meet the application's needs.

15.5.4 ACLK

The Auxiliary Clock (***ACLK***) may be optionally used by the PWM timer block in the PAC55XX in order to generate a very fast clock for PWM output to generate the best possible accuracy and edge generation.

This clock has a 3b clock divider and also has clock gating support, which disables this clock output when the system is put into the ARM Cortex-M4's deep sleep mode to conserve energy.

As shown above, the ***ACLK*** is an optional input for just the PWM timer block in the PAC55XX.

15.5.5 HCLK

The AHB Clock (***HCLK***) is used by the ARM Cortex-M4 MCU and Memory Controller peripheral. This clock has a 3b divider and also has clock gating support, which allows this clock output to be disabled before the system is put into the ARM Cortex-M4's deep sleep mode to conserve energy.

HCLK supplies PCLK with its clock source.

15.6 Electrical Characteristics

Table 15-1 CCS Electrical Characteristics

(T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
Clock Tree (FRCLK, FCLK, PCLK, ACLK, HCLK)						
f_{FRCLK}	Free-running clock frequency				25	MHz
f_{SCLK}	System clock frequency				300	MHz
f_{PCLK}	Peripheral clock frequency	After divider			150	MHz
f_{ACLK}	Auxiliary clock frequency	After divider			300	MHz
f_{HCLK}	High-speed clock frequency	After divider			150	MHz
Internal Oscillators						
$f_{ROSCCLK}$	Ring oscillator frequency			20		MHz
$f_{TRIM;REFCLK}$	Trimmed RC oscillator frequency	T_A = 25°C	-2%	4	2%	MHz
		T_A = -40°C to 125°C	-3%	4	3%	
$f_{JITTER;REFCLK}$	Trimmed RC oscillator clock jitter	T_A = -40°C to 85°C		0.5		%
External Clock Input (EXTCLK)						
f_{EXTCLK}	External Clock Input Frequency				20	MHz
	External Clock Input Duty Cycle		40		60	%
$V_{IH;EXTCLK}$	External Clock Input high-level input voltage		2.1			V
$V_{IL;EXTCLK}$	External Clock Input low-level input voltage				0.825	V
PLL						
$f_{IN;PLL}$	PLL input frequency range		1		50	MHz
$f_{OUT;PLL}$	PLL output frequency range		62.5		300	MHz
$t_{SETTLE;PLL}$	PLL setting time	T_A = 25°C, PLL settled			15	µs
		T_A = 25°C, **PLLLOCK** = 1		200	500	µs
$t_{JITTER;PLL}$	PLL period jitter	RMS		25		ps
		Peak to peak			100	ps
	PLL duty cycle		40	50	60	%

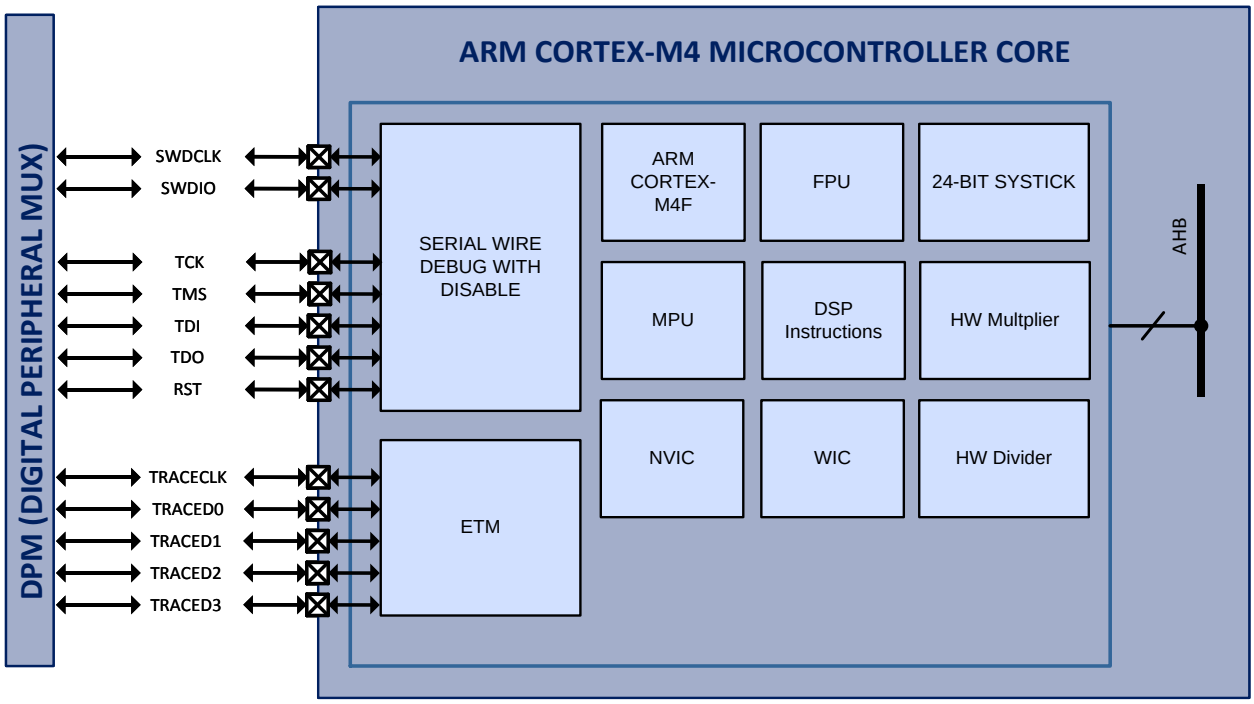
16 ARM CORTEX-M4F MCU CORE

16.1 Features

- ARM Cortex-M4F core
- SWD or JTAG Debug
- SWD/JTAG code security
- Embedded Trace Module (ETM) for instruction tracing
- Memory Protection Unit (MPU)
- Nested Vectored Interrupt Controller (NVIC) with 29 user interrupts and 8 levels of priority
- Floating Point Unit (FPU)
- Wakeup Interrupt Controller (WIC)
- 24-bit SysTick Count-down Timer
- Hardware Multiply and Divide Instructions

16.2 Block Diagram

Figure 16-1 ARM Cortex-M4F Microcontroller Core



16.3 Functional Description

The ARM Cortex-M4F microcontroller core is configured for little endian operation and includes hardware support for multiplication and division, DSP instructions as well as an IEEE754 single-precision Floating Point Unit (FPU).

The MCU also contains an 8-region Memory Protection Unit (MPU), as well as a Nested Vector Interrupt Controller (NVIC) that supports 29 user interrupts with 8 levels of priority. There is a 24-bit SysTick count-down timer.

The ARM Cortex-M4F supports sleep and deep sleep modes for low power operation. In sleep mode, the ARM Cortex-M4F is disabled. In deep sleep mode, the MCU as well as many peripherals are disabled. The Wakeup Interrupt Controller (WIC) can wake up the MCU when in deep sleep mode by using any GPIO interrupt, the Real-Time Clock (RTC) or Windowed Watchdog Timer (WWDT). The PAC55XX also supports clock gating to reduce power during deep sleep operation.

The debugger supports 4 breakpoint and 2 watch-point unit comparators using the SWD or JTAG protocols. The debug serial interfaces may be disabled to prevent memory access to the firmware during customer production.

For more information on the detailed operation of the Microcontroller Core in the PAC55XX, see the PAC55XX Family User Guide.

16.4 Application Typical Current Consumption

The MCU clock configuration and peripheral configuration have a large influence on the amount of load that the power supplies in the PAC55XX will have.

The table below shows a number of popular configurations and what the typical power consumption will be on the VSYS and VCORE power supplies in the PAC55XX.

Table 16-1 PAC55XX Application Typical Current Consumption

CLOCK CONFIGURATION	MCU PERIPHERALS	MCU STATE	I_{VSYS}	I_{VCORE}	I_{VCC33}
CLKREF = 4MHz PLL Disabled ACLK=HCLK=PCLK=SCLK=MCLK = 16MHz ROSCCLK Enabled FRCLK MUX = ROSCCLK	All peripherals disabled	Halted	9.5mA	2.3mA	n/a
CLKREF = 4MHz PLLCLK = 30MHz ACLK=HCLK=PCLK=SCLK= 16MHz MCLK = 30MHz ROSCCLK Enabled FRCLK MUX = PLLCLK	All peripherals disabled	Halted	10.5mA	3.5mA	n/a
CLKREF = 4MHz PLLCLK = 150MHz ACLK=HCLK=PCLK=SCLK= 150MHz MCLK = 30MHz ROSCCLK Enabled FRCLK MUX = PLLCLK	All peripherals disabled	Halted	20mA	13.5mA	n/a
CLKREF = 4MHz PLLCLK = 300MHz ACLK=HCLK=PCLK=SCLK= 150MHz MCLK = 30MHz ROSCCLK Enabled FRCLK MUX = PLLCLK	All peripherals disabled	Halted	22mA	15mA	n/a
CLKREF = 4MHz PLLCLK = 300MHz ACLK=HCLK=PCLK=SCLK= 150MHz MCLK = 30MHz ROSCCLK Enabled FRCLK MUX = PLLCLK ADCCLK = 40MHz	ADC enabled (repeated conversions)	Halted	36mA	16mA	13.5mA
CLKREF = 4MHz PLLCLK = 300MHz ACLK=HCLK=PCLK=SCLK= 150MHz MCLK = 30MHz ROSCCLK Enabled FRCLK MUX = PLLCLK	All peripherals disabled	CPU Executes instructions from FLASH	8.5mA	2.2mA	n/a
CLKREF = 4MHz PLLCLK = 300MHz ACLK=HCLK=PCLK=SCLK= 150MHz MCLK = 30MHz ROSCCLK Enabled FRCLK MUX = PLLCLK	Timer A enabled; TAPWM[7:0] enabled; Fs = 100kHz; 50% duty cycle	Halted	22mA	15mA	n/a

16.5 Electrical Characteristics

Table 16-2 MCU and Clock Control System Electrical Characteristics

(T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
f_{HCLK}	Microcontroller Clock				150	MHz
$I_{Q;VCORE}$	V_{CORE} quiescent current	ARM Cortex-M4F Sleep/Deep Sleep Modes			2	mA
		PAC5523 Hibernate Mode			0	mA
$I_{Q;VSYS}$	V_{SYS} quiescent current	ARM Cortex-M4F Sleep/Deep Sleep Modes			8	mA
		PAC5523 Hibernate Mode			15	µA
$I_{Q;VCCIO}$	VCCIO quiescent current	ARM Cortex-M4F Sleep/Deep Sleep Modes			0.15	mA
		PAC5523 Hibernate Mode			0	mA
$I_{Q;VCC33}$	VCC33 quiescent current	ARM Cortex-M4F Sleep/Deep Sleep Modes			0.4	mA
		PAC5523 Hibernate Mode			0	mA

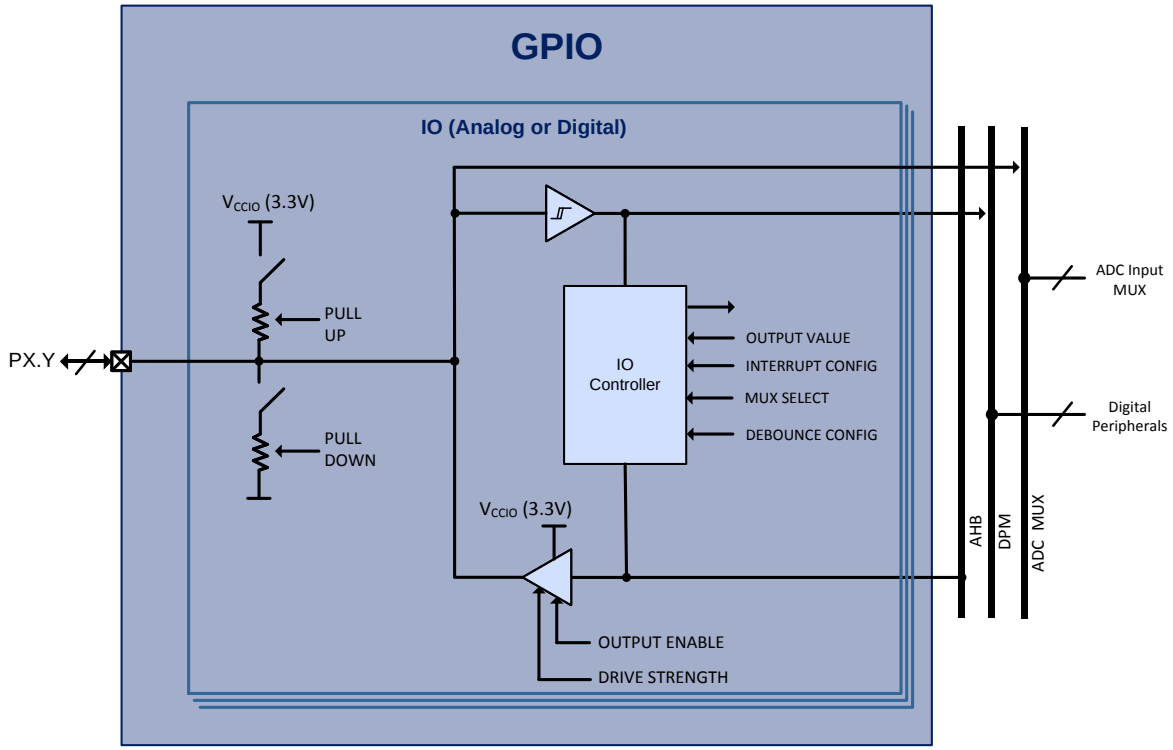
17 IO CONTROLLER

17.1 Features

- 3.3V Input/Output, 4.6V input tolerant
- Push-Pull Output, Open-Drain Output or High-Impedance Input for each IO
- Configurable Pull-up and Pull-down for each IO (60k)
- Configurable Drive Strength for each IO (up to 24mA)
- Analog Input for some IOs
- Edge-sensitive or level-sensitive interrupts
- Rising edge, falling edge or both edge interrupts
- Peripheral MUX allowing up to 8 peripheral selections for each IO
- Configurable De-bouncing Circuit for each IO

17.2 Block Diagram

Figure 17-1 IO Controller Block Diagram



17.3 Functional Description

The PAC55XX IO cells can be used for digital input/output and analog input for the ADC. All IOs are supplied by the V_{CCIO} (3.3V) power supply.

Each IO can be configured for digital push-pull output, open-drain output or high-impedance input. Each IO also has a configurable 60k weak pull-up or weak pull-down that can be enabled.

NOTE: Configuring both pull-up and pull-down at the same time may cause device damage and should be avoided.

Each IO has a configurable de-bouncing filter that can be enabled or disabled, to help filter out noise.

All IO have interrupt capability. Each pin can be configured for either level or edge sensitive interrupts, and can select between rising edge, falling edge and both edges for interrupts. Each pin has a separate interrupt enable and interrupt flag.

Some of the IO on the PAC5523 can be configured as an analog input to the ADC.

17.4 Peripheral MUX

The following table shows the available pin MUX options for this device. Note that if the pin is configured for analog input, the peripheral MUX is bypassed.

Table 17-1 PAC5523 Peripheral Pin MUX

PIN	Peripheral MUX Selection								ADC CH
	S0	S1	S2	S3	S4	S5	S6	S7	
PC7	GPIOC7	TBPWM7	TCPWM7		USBSS	USCMISO	FRCLK	EMUXC	
PC4	GPIOC4	TBPWM4	TCPWM4	TCIDX	USBMOSI	USCSCLK	CANRXD	I2CSDL	
PC5	GPIOC5	TBPWM5	TCPWM5	TCPHA	USBMISO	USCSS	CANTXD	I2CSDA	
PC6	GPIOC6	TBPWM6	TCPWM6	TCPHB	USBSCLK	USCMOSI		EMUXD	
PE0	GPIOE0	TCPWM4	TDPWM0	TAIDX	TBIDX	USCCLK	I2CSCL	EMUXC	
PE1	GPIOE1	TCPWM5	TDPWM1	TAPHA	TBPHA	USCSS	I2CSDA	EMUXD	
PE2	GPIOE2	TCPWM6	TDPWM2	TAPHB	TBPHB	USCMOSI	CANRXD	EXTCLK	
PE3	GPIOE3	TCPWM7	TDPWM3	FRCLK		USCMISO	CANTXD		
PF0	GPIOF0	TCPWM0	TDPWM0	TCK/SWDCL	TBIDX	USBSCLK	TRACED2	TRACECLK	
PF1	GPIOF1	TCPWM1	TDPWM1	TMS/SWDIO	TBPHA	USBSS	TRACED1	TRACED0	
PF2	GPIOF2	TCPWM2	TDPWM2	TDI	TBPHB	USBMOSI	TRACED0	TRACED1	
PF3	GPIOF3	TCPWM3	TDPWM3	TDO	FRCLK	USBMISO	TRACECLK	TRACED2	
PF4	GPIOF4	TCPWM4	TDPWM4	TCK/SWDCL	TCIDX	USDSCLK	TRACED3	EMUXC	ADC4
PF5	GPIOF5	TCPWM5	TDPWM5	TMS/SWDIO	TCPHA	USDSS		EMUXD	ADC5
PF6	GPIOF6	TCPWM6	TDPWM6	TDI	TCPHB	USDMOSI	CANRXD	I2CSCL	ADC6

17.5 Electrical Characteristics

Table 17-2 IO Controller Electrical Characteristics

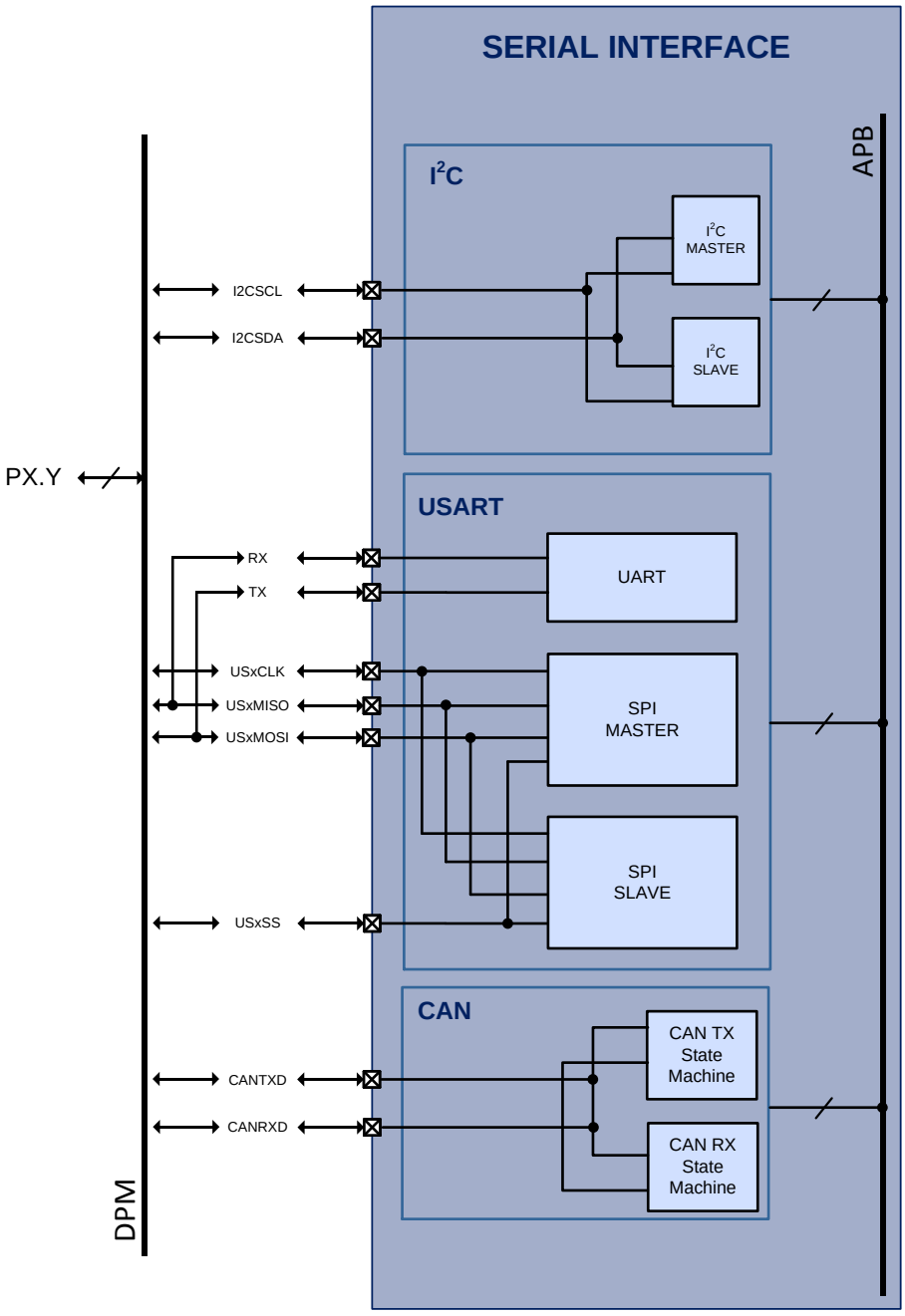
(V_{CCIO} = 3.3V, V_{SYS} = 5V, V_{CORE} = 1.2V, and T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS		MIN	TYP	MAX	UNIT
All other IO pins (Digital IO)							
V_{IH}	High-level input voltage			2.1			V
V_{IL}	Low-level input voltage					0.825	V
I_{OL}	Low-level output sink current (Limited by I_{VSYS} and I_{VCCIO})	V_{OL} = 0.4V	DS = 6mA	6			mA
			DS = 8mA	8			
			DS = 11mA	11			
			DS = 14mA	14			
			DS = 17mA	17			
			DS = 20mA	20			
			DS = 22mA	22			
			DS = 25mA	25			
I_{OH}	High-level output source current (Limited by I_{VSYS} and I_{VCCIO})	V_{OH} = 2.4V	DS = 6mA			-6	mA
			DS = 8mA			-8	
			DS = 11mA			-11	
			DS = 14mA			-14	
			DS = 17mA			-17	
			DS = 20mA			-20	
			DS = 22mA			-22	
			DS = 25mA			-25	
I_{IL}	Input leakage current			-2		0.95	µA
R_{PU}	Weak pull-up resistance	When pull-up enabled		45	60	100	kΩ
R_{PD}	Weak pull-down resistance	When pull-down enabled		45	60	115	kΩ

18 SERIAL INTERFACE

18.1 Block Diagram

Figure 18-1 Serial Interface Block Diagram



18.2 Functional Description

The PAC55XX has three types of serial interfaces: I^{2}C, USART and CAN. The PAC55XX has one I^{2}C controller, one CAN controller and up to 3 USARTs.

18.3 I^{2}C Controller

The PAC55XX contains one I^{2}C controller. This is a configurable APB peripheral and the clock input is PCLK. This peripheral has an input clock divider that can be used to generate various master clock frequencies. The I^{2}C controller can support various modes of operation:

- I^{2}C master operation
  - Standard (100kHz), full-speed (400kHz), fast (1MHz) or high-speed modes (3.4MHz)
  - Single and multi-master
  - Synchronization (multi-master)
  - Arbitration (multi-master)
  - 7-bit or 10-bit slave addressing
- I^{2}C slave operation
  - Standard (100kHz), full-speed (400kHz), fast (1MHz) or high-speed modes (3.4MHz)
  - Clock stretching
  - 7-bit or 10-bit slave addressing

The I^{2}C peripheral may operate either by polling, or can be configured to be interrupt driven for both receive and transmit operations.

18.4 USART

The PAC55XX contains up to 2 Universal Synchronous Receive Transmit (USART) peripherals. Each USART is a configurable APB bus client and input clock is PCLK. These peripherals have a configurable clock divider that can be used to produce various frequencies for the UART or SPI master peripheral.

The number of these peripherals depends on the peripheral MUX configuration. See the IO Controller section on information on how to configure the peripheral MUX with the USART peripheral.

The USART peripheral supports two main modes: SPI mode and UART mode.

18.4.1 USART SPI Mode

- Master or slave mode operation
- 8-bit, 16-bit or 32-bit word transfers
- Configurable clock polarity (active high or active low)
- Configurable data phase (setup/sample or sample/setup)

- Interrupts and status flags for RX and TX operations
- Support for up to 25MHz SPI clock

18.4.2 USART UART Mode

- 8-bit data
- Programmable data bit rate
- Maximum baud rate of 1Mbaud
- RX and TX FIFOs
- Configurable stop bits (1 or 2)
- Configurable parity: even, odd, none
  - Mark/space support for 9-bit addressing protocols
- Interrupt and status flags for RX and TX operations

18.5 CAN

The PAC55XX contains one Controller Area Network (CAN) peripheral. The CAN peripheral is a configurable APB bus client and input clock is PCLK. This peripheral has a configurable clock divider that can be used to produce various frequencies for the CAN peripheral.

- CAN 2.0B support
- 1Mb/s data rate
- 64-byte receive FIFO
- 16-byte transmit buffer
- Standard and extended frame support
- Arbitration
- Overload frame generated on FIFO overflow
- Normal and Listen Only modes supported
- Interrupt and status flags for RX and TX operations

18.6 Dynamic Characteristics

Table 18-1 Serial Interface Dynamic Characteristics

(V_{CCIO} = 3.3V, V_{SYS} = 5V, V_{CORE} = 1.2V, and T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
I²C						
f_{I2CCLK}	I²C input clock frequency	Standard mode (100kHz)	2.8			MHz
		Full-speed mode (400kHz)	2.8			MHz
		Fast mode (1MHz)	6.14			MHz
		High-speed mode (3.4MHz)	20.88			MHz
USART (UART mode)						
$f_{UARTCLK}$	USART input clock frequency				f_{PCLK}/16	MHz
$f_{UARTBAUD}$	UART baud rate	$f_{USARTCLK}$ = 7.1825MHz			1	Mbps
USART (SPI mode)						
f_{SPICLK}	USART input clock frequency	Master mode			50	MHz
		Slave mode			50	MHz
$f_{USARTSPICLK}$	USART SPI clock frequency	Master mode			25	MHz
		Slave mode			25	MHz
CAN						
f_{CANCLK}	CAN input clock frequency				50	MHz
f_{CANTX}	CAN transmit clock frequency				1	Mbps
f_{CANRX}	CAN receive clock frequency				1	Mbps

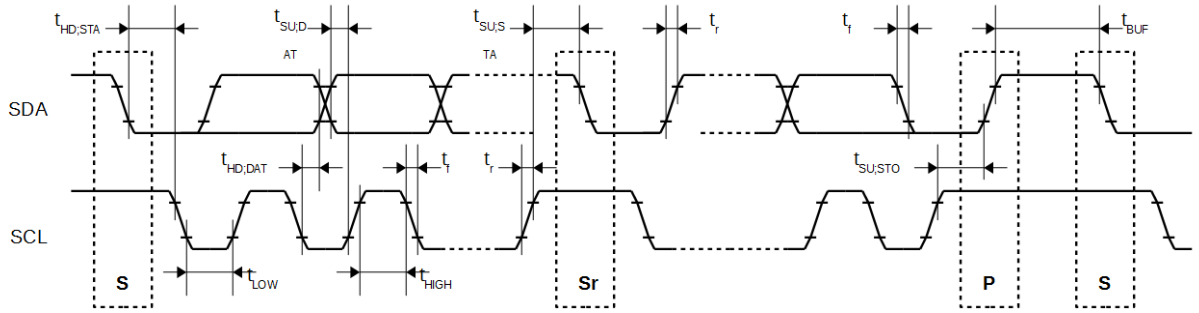
Table 18-2 I²C Dynamic Characteristics

(V_{CCIO} = 3.3V, V_{SYS} = 5V, V_{CORE} = 1.2V, and T_A = -40°C to 125°C unless otherwise specified.)

SYMBOL	PARAMETER	CONDITIONS	MIN	TYP	MAX	UNIT
f_{SCL}	SCL clock frequency	Standard mode	0		100	kHz
		Full-speed mode	0		400	kHz
		Fast mode	0		1	MHz
t_{LOW}	SCL clock low	Standard mode	4.7			µs
		Full-speed mode	1.3			µs
		Fast mode	0.5			µs
t_{HIGH}	SCL clock high	Standard mode	4.0			µs
		Full-speed mode	0.6			µs
		Fast mode	0.26			µs

$t_{HD;STA}$	Hold time for a repeated START condition	Standard mode	4.0		µs
		Full-speed mode	0.6		µs
		Fast mode	0.26		µs
$t_{SU;STA}$	Set-up time for a repeated START condition	Standard mode	4.7		µs
		Full-speed mode	0.6		µs
		Fast mode	0.26		µs
$t_{HD;DAT}$	Data hold time	Standard mode	0	3.45	µs
		Full-speed mode	0	0.9	µs
		Fast mode	0		µs
$t_{SU;DAT}$	Data setup time	Standard mode	250		ns
		Full-speed mode	100		ns
		Fast mode	50		ns
$t_{SU;STO}$	Set-up time for STOP condition	Standard mode	4.0		µs
		Full-speed mode	0.6		µs
		Fast mode	0.26		µs
t_{BUF}	Bus free time between a STOP and START condition	Standard mode	4.7		µs
		Full-speed mode	1.3		µs
		Fast mode	0.5		µs
t_r	Rise time for SDA and SCL	Standard mode		1000	ns
		Full-speed mode	20	300	ns
		Fast mode		120	ns
t_f	Fall time for SDA and SCL	Standard mode		300	ns
		Full-speed mode		300	ns
		Fast mode		120	ns
C_b	Capacitive load for each bus line	Standard mode, full-speed mode		400	pF
		Fast mode		550	pF

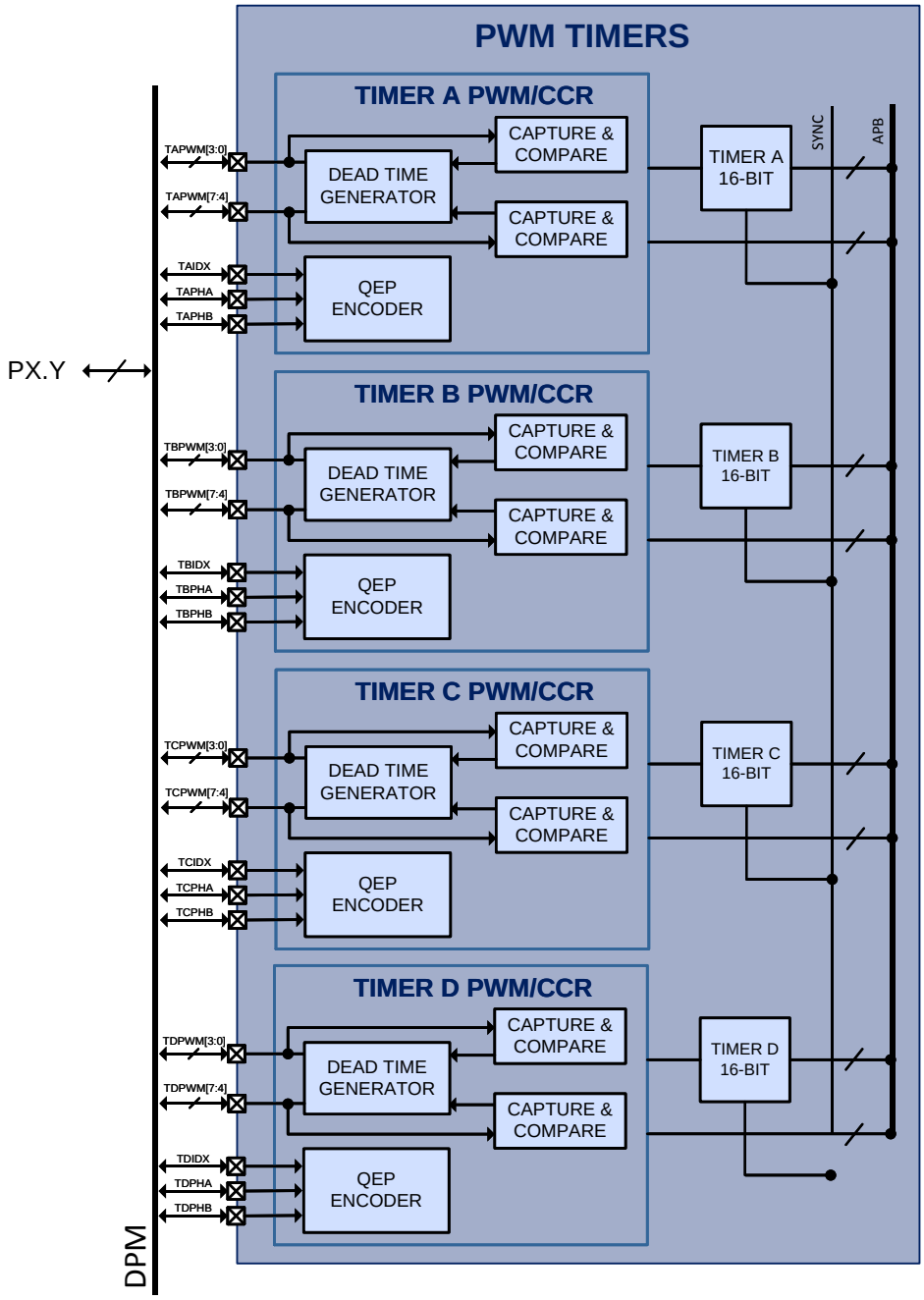
Figure 18-2 I²C Timing Diagram


$t_{HD;STA}$
$t_{SU;DAT}$
$t_{SU;STA}$
t_r
t_f
t_{BUF}
SDA
$t_{HD;DAT}$
t_f
t_r
$t_{SU;STO}$
SCL
S
t_{LOW}
t_{HIGH}
Sr
P
S

19 PWM TIMERS

19.1 Block Diagram

Figure 19-1 PWM Timers Block Diagram



19.2 Timer Features

- Configurable input clock source: PCLK or ACLK
- Up to 300MHz input clock
- 3-bit Input clock divider
- Timer counting modes
  - up, up/down and asymmetric
- Timer latch modes
  - Latch when counter = 0
  - Latch when counter = period
  - Latch when CCR value written
  - Latch all CCR values at same time
- Base timer interrupts
- Single shot or auto-reload

19.2.1 CCR/PWM Timer

- PWM output or capture input
- CCR interrupt enable
- CCR interrupt skips
- SW force CCR interrupt
- CCR interrupt type
  - Rising, falling or both
- CCR compare latch modes
  - Latch when counter = 0
  - Latch when counter = period
  - Latch immediate
- CCR capture latch modes
  - Latch on rising edge
  - Latch on falling edge
  - Latch on both rising and falling edges
- Invert CCR output
- CCR phase delay for phase shifted drive topologies
- ADC trigger outputs
  - PWM rising edge or falling edge

19.2.2 Dead-time Generators (DTG)

- DTG enabled
- 12-bit rising edge delay

- 12-bit falling edge delay

19.2.3 QEP Decoder

- QEP encoder enabled
- Direction status
- Configurable Interrupts:
  - Phase A rising edge
  - Phase B rising edge
  - Index event
  - Counter wrap
- 4 different counting modes for best resolution, range and speed performance

20 GENERAL PURPOSE TIMERS

20.1 Block Diagram

Figure 20-1 SOC Bus Watchdog and Wake-up Timer

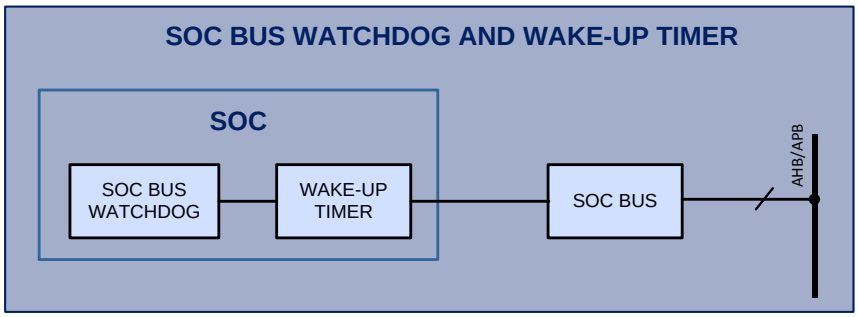
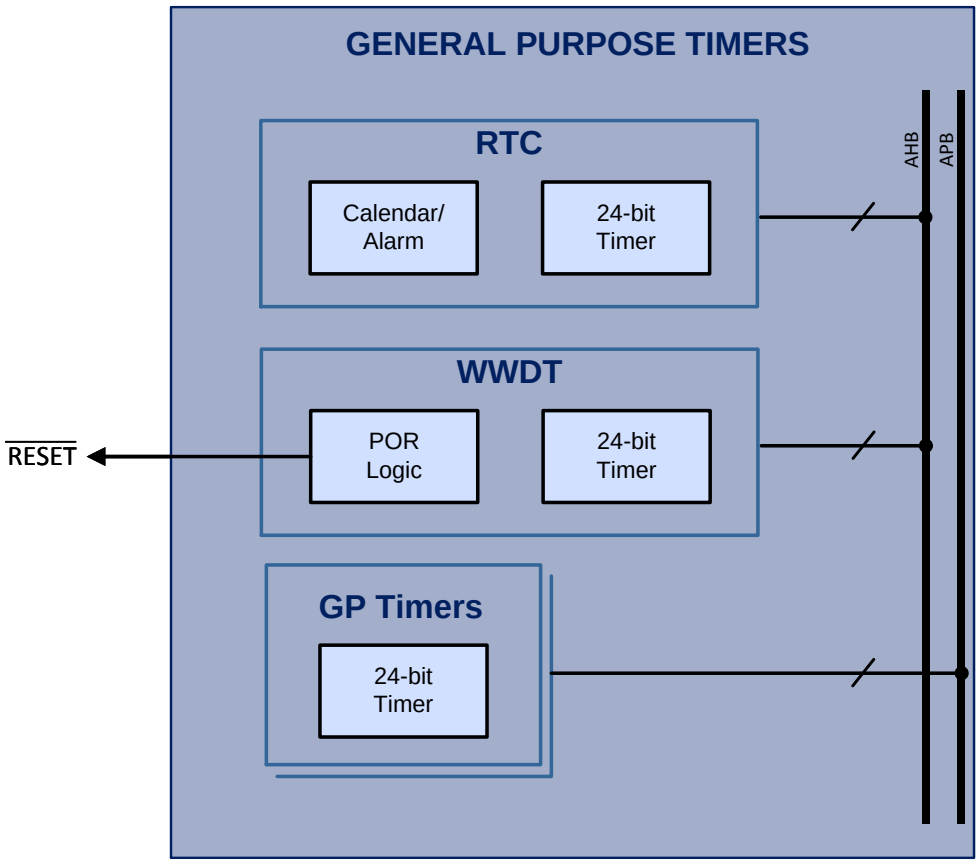


Figure 20-2 General Purpose Timers



20.2 Functional Description

20.2.1 SOC Bus Watchdog Timer

The SOC Bus Watchdog Timer is used to monitor internal SOC Bus communication. It will trigger a device reset if there is no SOC Bus communication to the AFE for 4s or 8s.

20.2.2 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.

20.2.3 Real-time Clock with Calendar (RTC)

The 24-bit real-time clock with calendar (RTC) is an AHB bus client and may also be used to measure long time periods and periodic wake up from sleep mode.

The RTC uses FRCLK as its clock source and has a divider that can be configured up to a /65536 input clock divider. In order to count accurately, the input clock divider must be configured to generate a 1MHz clock to the RTC.

The RTC counts the time (seconds, minutes, hours, days) since enabled. It also allows the user to set a calendar date to set an alarm function that can be configured to generate an interrupt to the NVIC when it counts to that value.

20.2.4 Windowed Watchdog Timer (WWDT)

The 24-bit windowed watchdog timer (WWDT) is an AHB bus client and can be used for long time period measurements or periodic wake up from sleep mode. Its primary use is to reset the system via a POR if it is not reset at a certain periodic interval.

The WWDT can be configured to use FRCLK or ROSCCLK as its clock source and has a divider that be configured up to a /65536 input clock divider.

The WWDT can be configured to allow only a small window when it is valid to reset the timer, to maximize application security and catch any stray code operating on the MCU.

The WWDT may be configured to enable an interrupt for the MCU, and the timer can be disabled when unused to save energy for low power operations.

20.2.5 GP Timer (GPT)

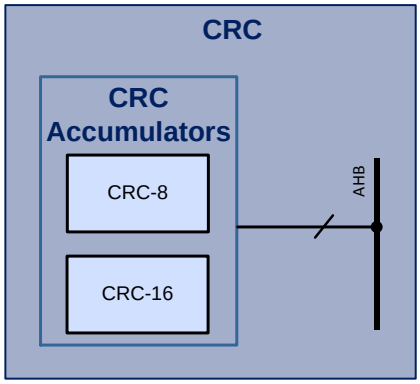
The PAC55XX contains two General Purpose (GP) Timers.

These timers are 24-bit timers and are both APB bus clients. These count-down timers use PCLK as their input clock and have a configurable divider of up to /65536. Each of the GPT can be configured to interrupt the MCU when they count down to 0.

21 CRC

21.1 Block Diagram

Figure 21-1 CRC Block Diagram



21.2 Functional Description

The CRC peripheral can perform CRC calculation on data into through registers from the MCU to accelerate the calculation or validation of a CRC for communications protocols or data integrity checks.

The CRC peripheral allows the calculation of both CRC-8 and CRC-16 on data. The CRC peripheral also allows the user to specify a seed value, select the data input to be 8b or 32b and to reflect the final output for firmware efficiency.

The CRC peripheral is an AHB slave and has the following features:

- Polynomial selection via configuration register:
  - CCITT CRC-16 (0x1021)
  - IBM/ANSI CRC-16 (0x8005)
  - Dallas/Maxim CRC-8 (0x31)
- Input data width: 8b, 32b
- Reflect input
- Reflect output
- Specify seed value

22 THERMAL CHARACTERISTICS

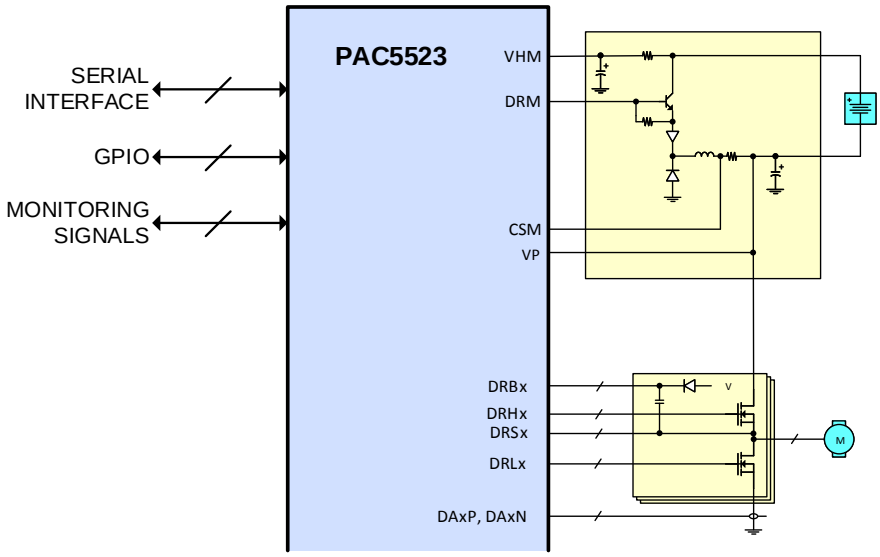
Table 22-1 Thermal Characteristics

PARAMETER	VALUE	UNIT
Operating ambient temperature range	-40 to 125	°C
Operating junction temperature range	-40 to 150	°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

23 APPLICATION EXAMPLES

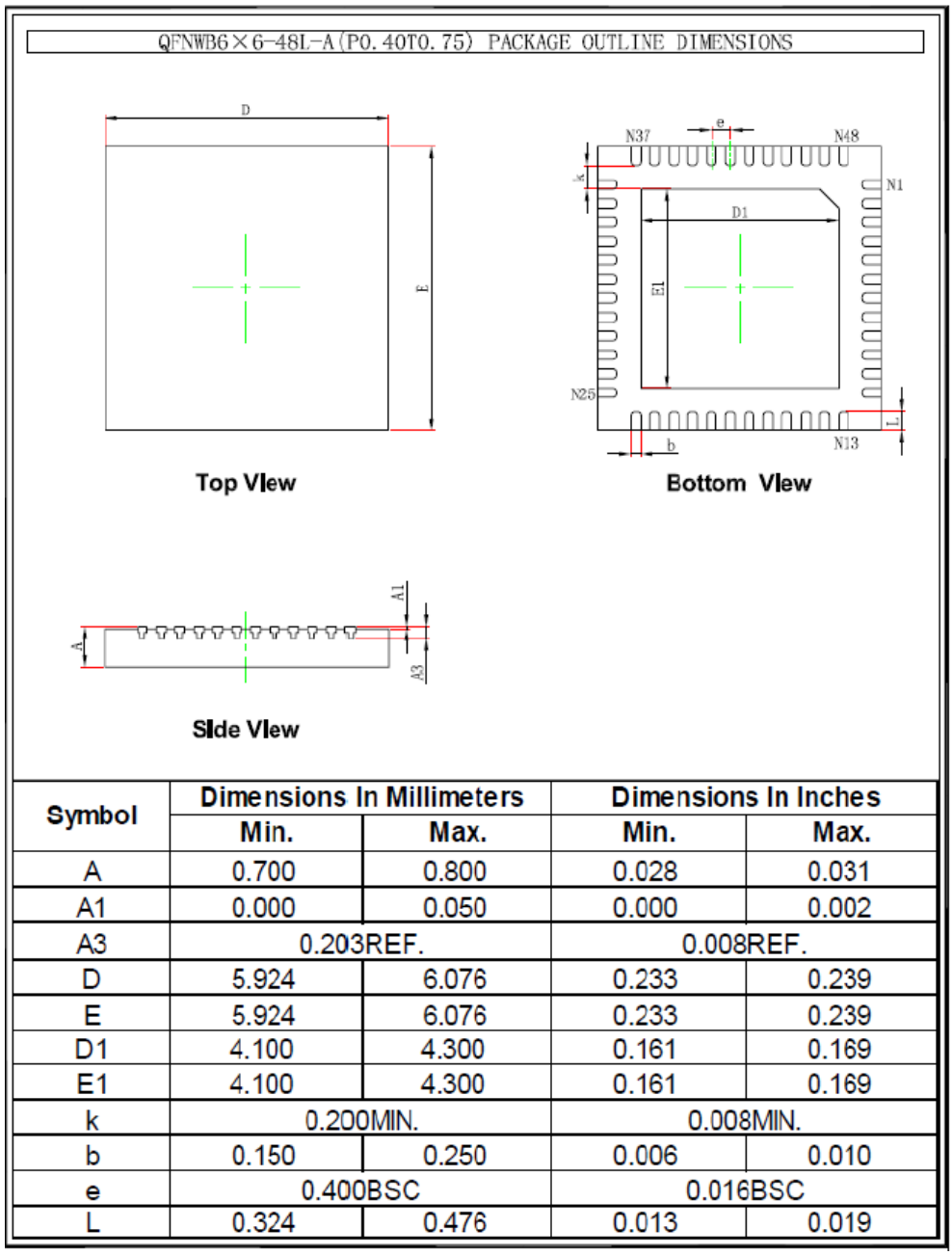
The following simplified diagram shows an example of a single-motor, low-voltage application using the PAC5523 device.

Figure 23-1 Sensorless FOC/BEMF Motor Drive Using PAC5523 (Simplified Diagram)



24 PACKAGE OUTLINE AND DIMENSIONS

Figure 24-1 TQFN66-48 Package Outline and Dimensions



Symbol	Dimensions In Millimeters		Dimensions In Inches	
	Min.	Max.	Min.	Max.
A	0.700	0.800	0.028	0.031
A1	0.000	0.050	0.000	0.002
A3	0.203REF.		0.008REF.	
D	5.924	6.076	0.233	0.239
E	5.924	6.076	0.233	0.239
D1	4.100	4.300	0.161	0.169
E1	4.100	4.300	0.161	0.169
k	0.200MIN.		0.008MIN.	
b	0.150	0.250	0.006	0.010
e	0.400BSC		0.016BSC	
L	0.324	0.476	0.013	0.019

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