

# PAC5523 Data Sheet

*Power Application Controller*<sup>®</sup>

Multi-Mode Power Manager<sup>™</sup>

Configurable Analog Front End<sup>™</sup>

Application Specific Power Drivers<sup>™</sup>

ARM<sup>®</sup> Cortex<sup>®</sup>-M4F Controller Core



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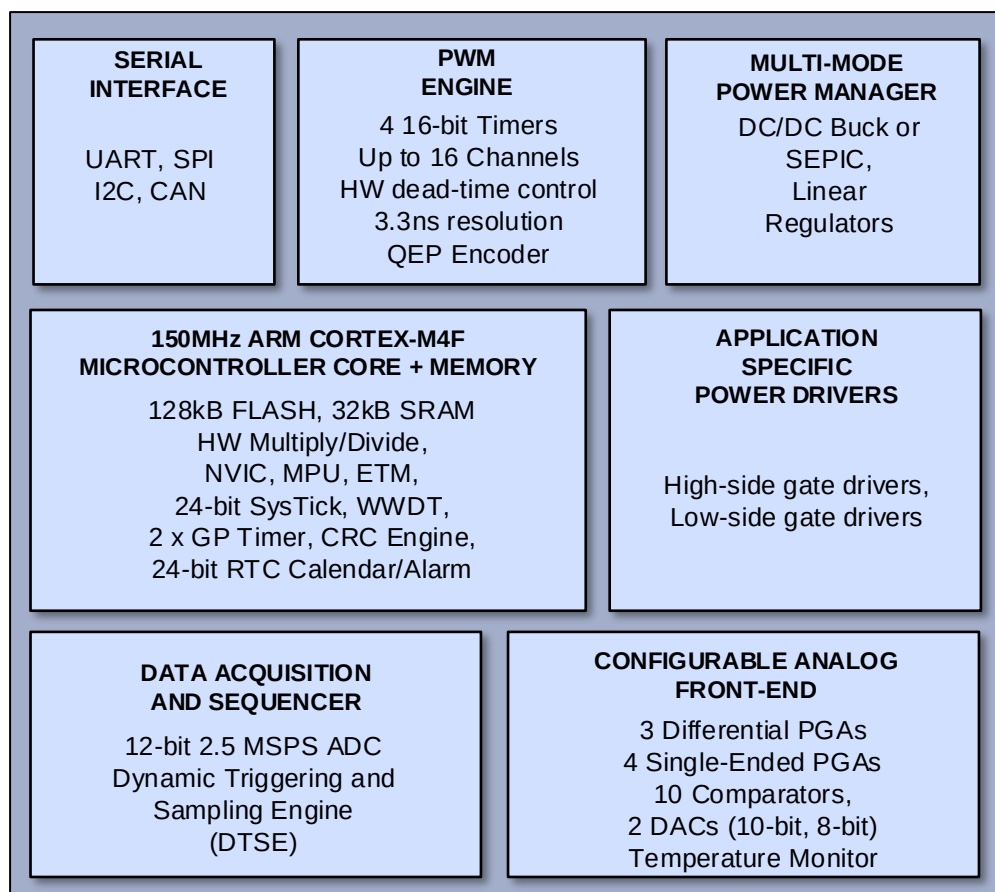
# 1 GENERAL DESCRIPTION

The PAC5523 is a Power Application Controller<sup>®</sup> (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<sup>™</sup>, Configurable Analog Front-End<sup>™</sup> and Application Specific Power Drivers<sup>™</sup> 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**

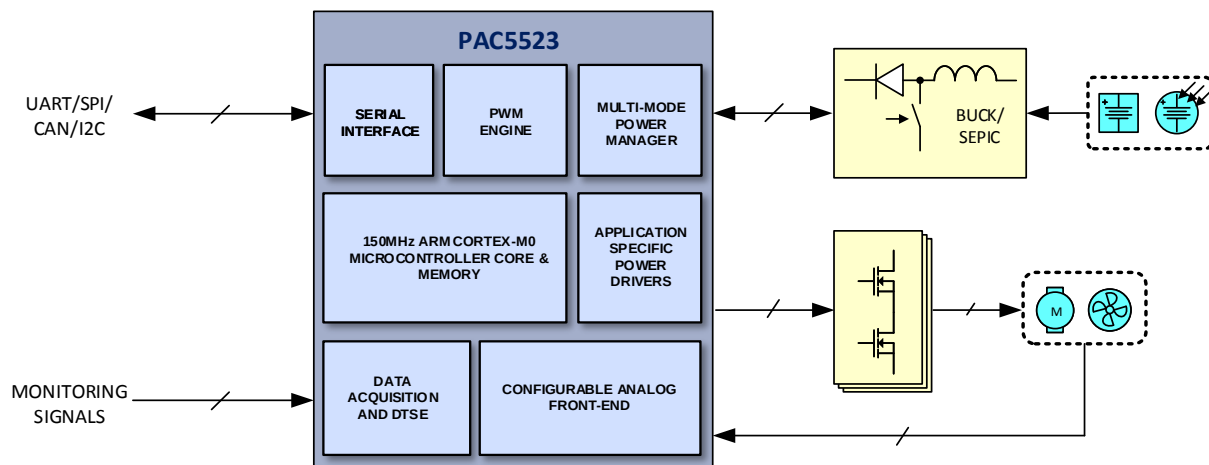


The PAC5523 is available in a 48-pin, 6x6mm TQFN package.

## 2 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 2-1 Simplified Application Diagram



### 3 PRODUCT SELECTION SUMMARY

Table 3-1 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<br>6x6<br>TQFN | 5.2 –<br>70V  | Y             | 3                             | 4   | 10         | 2   | 15          | 70V                                | 3 LS<br>(1.5A/1.5A)<br>3 HS<br>(1.5A/1.5A) | 6@VP<br>15@VCCIO | 150             | 128        | 32        | 10@VSYS<br>3 @ VP<br>15@VCCIO | UART<br>SPI<br>I2C<br>CAN<br>SWD<br>JTAG<br>ETM | N    | 3 half-bridge<br>3 phase control<br><br>BEMF Trapezoidal<br>or FOC |

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

## 4 ORDERING INFORMATION

Table 4-1 Ordering Information

| PART NUMBER <sup>1</sup> | TEMPERATURE RANGE | PACKAGE   | PINS             | PACKING |
|--------------------------|-------------------|-----------|------------------|---------|
| PAC5523QM                | -40°C to 125°C    | TQFN66-48 | 48 + Exposed Pad | Tray    |

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<sup>1</sup> See *Product Selection Summary* for product features for each part number

## 5 FEATURES

### 5.1 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

## 6 ABSOLUTE MAXIMUM RATINGS

 Table 6-1 Absolute Maximum Ratings<sup>2</sup>

| 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 $V_P + 0.3$     | 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 <sup>3</sup> |                             | 0.2                     | A <sub>RMS</sub> |
| VSSP RMS current <sup>3</sup>                          |                             | 0.4                     | A <sub>RMS</sub> |
| VP RMS current <sup>3</sup>                            |                             | 0.6                     | A <sub>RMS</sub> |
| Operating temperature range                            |                             | -40 to 125              | °C               |
| Electrostatic Discharge (ESD)                          | Human body model (JEDEC)    | 2                       | kV               |
|  | Charge device model (JEDEC) | 1                       | kV               |

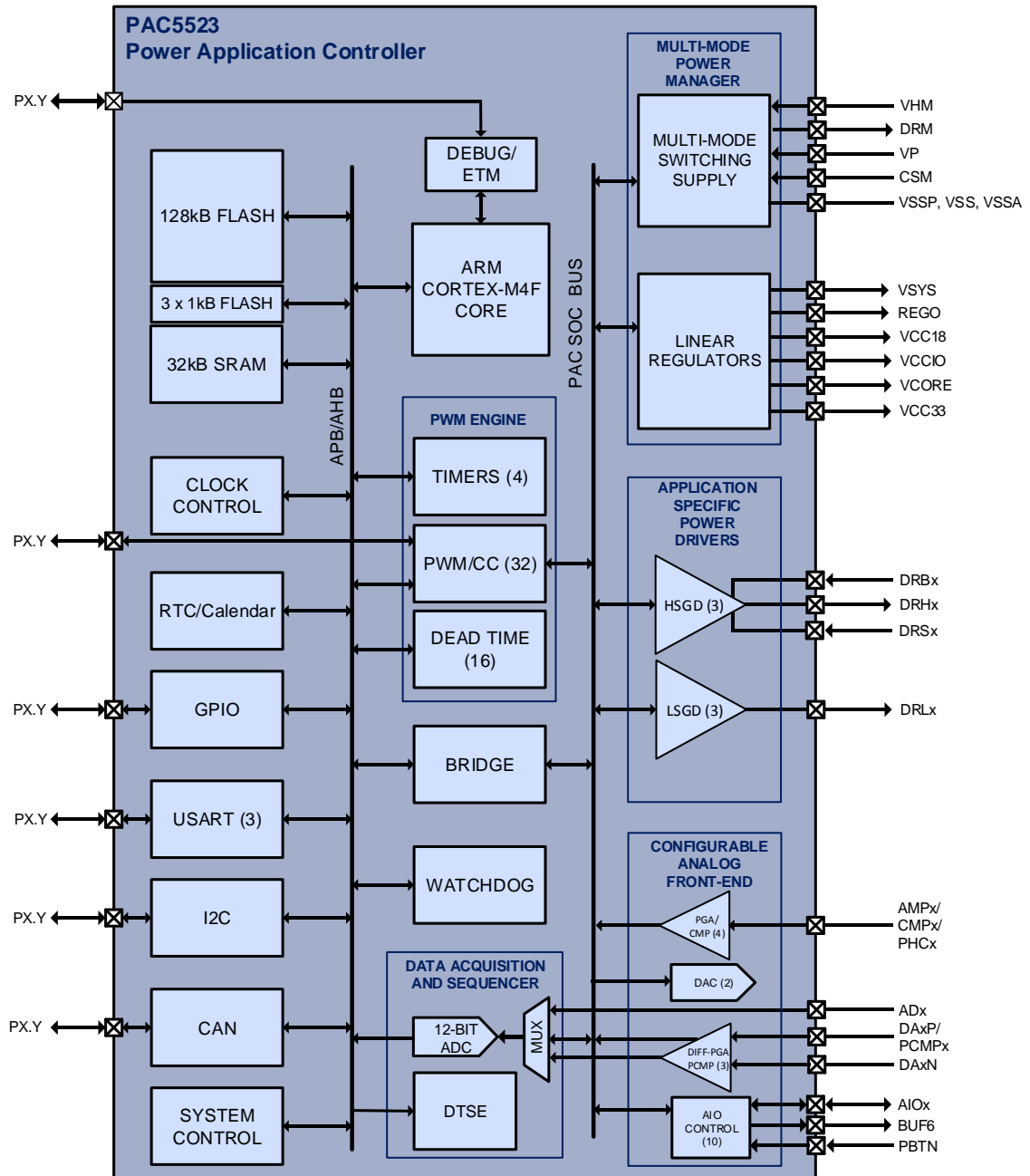
<sup>2</sup> Do not exceed these limits to prevent damage to the device. Exposure to absolute maximum rating conditions for long periods may affect device reliability.

<sup>3</sup> Peak current can be 10 times higher than RMS value for pulses shorter than 10μs



## 7 ARCHITECTURAL BLOCK DIAGRAM

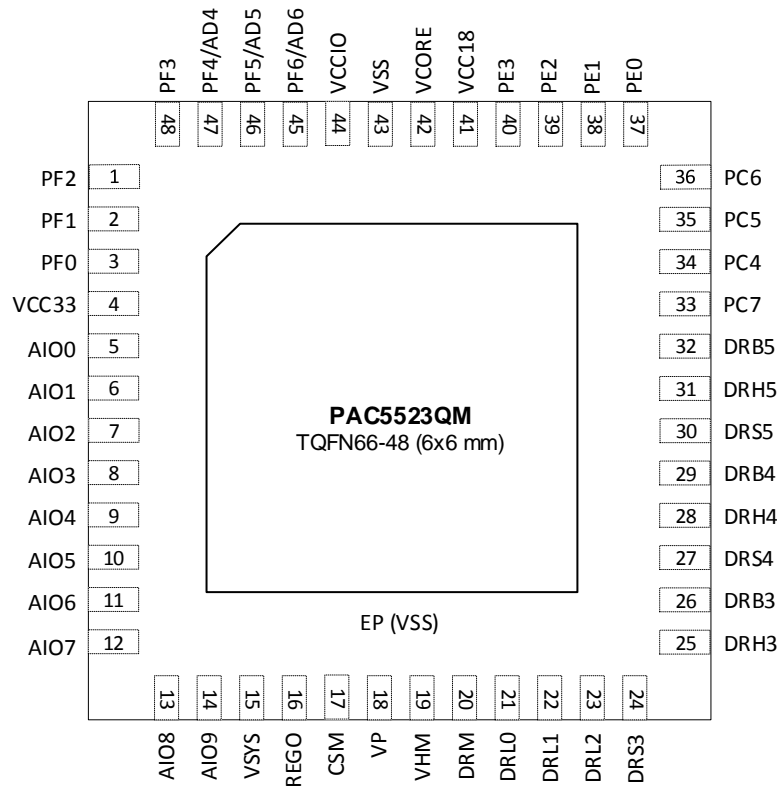
Figure 7-1 Architectural Block Diagram



## 8 PIN CONFIGURATION

### 8.1 PAC5523QM

Figure 8-1 PAC5523QM Pin Configuration (TQFN66-48 Package)



## 9 PIN DESCRIPTION

**Table 9-1 Multi-Mode Power Manager (MPPM) 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 <sub>CC33</sub> to V <sub>SSA</sub> .   |
| VSYS     | 15         | Power | 5V System power supply. Connect to a 6.8μF (20%) or higher ceramic capacitor from V <sub>SYS</sub> to V <sub>SS</sub> .   |
| REGO     | 16         | Power | System regulator output. Connect to V <sub>SYS</sub> 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 <sub>P</sub> to V <sub>SS</sub> for voltage loop stabilization. This pin requires good capacitive bypassing to V <sub>SS</sub> , 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 <sub>HM</sub> to V <sub>SSP</sub> . This pin requires good capacitive bypassing to V <sub>SSP</sub> , 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 <sub>CC18</sub> to V <sub>SSA</sub> .  |
| VCORE    | 42         | Power | Internally generated 1.2V core power supply. Connect a 2.2μF or higher value ceramic capacitor from V <sub>CORE</sub> to V <sub>SSA</sub> .   |
| 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 <sub>CCIO</sub> to V <sub>SSA</sub> .  |
| EP (VSS) | EP         | Power | Exposed pad. Must be connected to V <sub>SS</sub> in a star ground configuration. Connect to a large PCB copper area for power dissipation heat sinking.  |

**Table 9-2 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 9-3 Application Specific Power Drivers (ASPD) Pin Description**

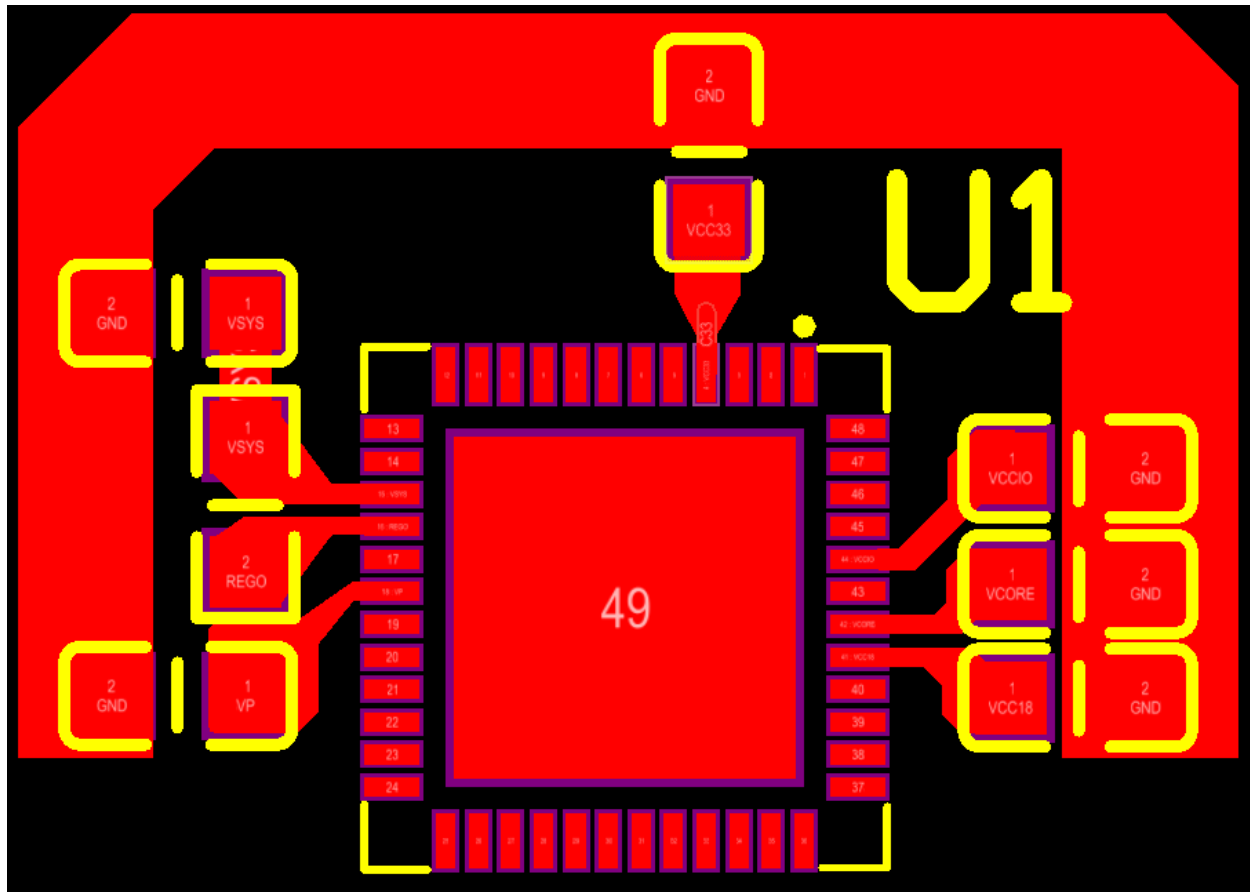
| PIN NAME | PIN NUMBER | TYPE   | DESCRIPTION                        |
|----------|------------|--------|------------------------------------|
| DRL0     | 21         | Analog | Low-side gate driver 0.            |
| DRL1     | 22         | Analog | Low-side gate driver 1.            |
| DRL2     | 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 9-4 I/O Ports Pin Description**

| PIN NAME | PIN NUMBER | FUNCTION | TYPE         | DESCRIPTION <sup>4</sup> |
|----------|------------|----------|--------------|--------------------------|
| 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          | I/O 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.            |

<sup>4</sup> 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 9-1 Power Supply Bypass Capacitor Routing

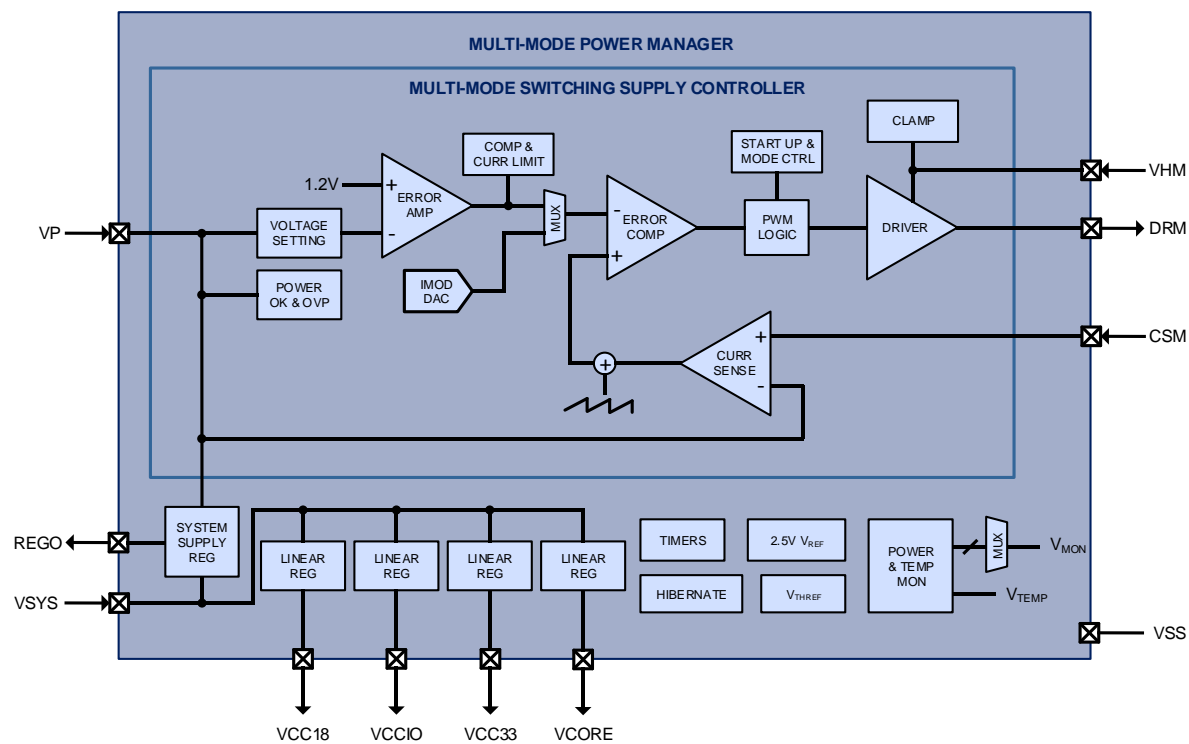


## 10 MULTI-MODE POWER MANAGER (MMPM)

### 10.1 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 10-1 MMPM Block Diagram



### 10.2 Functional Description

The Multi-Mode Power Manager (Figure 10-1) 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.



### 10.3 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 10-2) or SEPIC mode (Figure 10-3). 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 10-2 Buck Mode

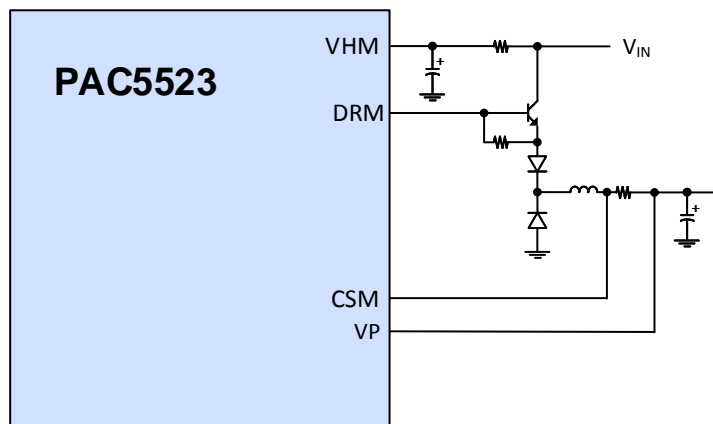
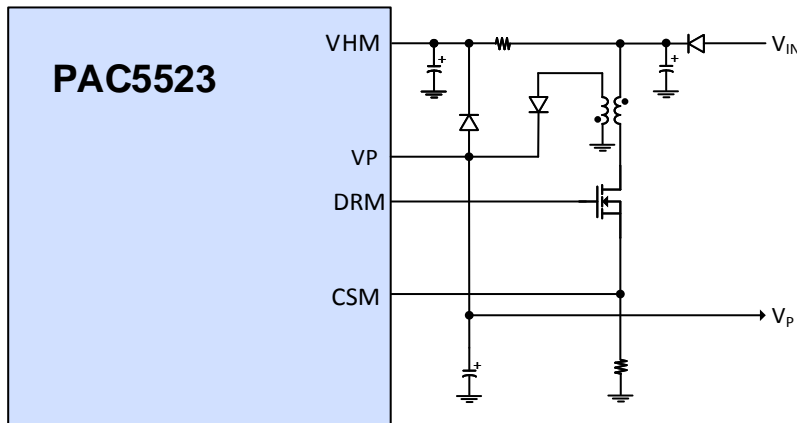


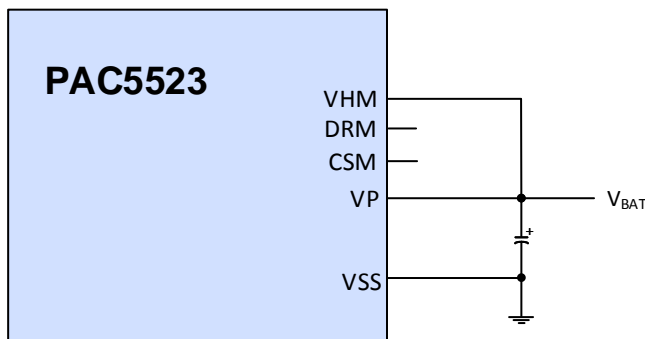
Figure 10-3 SEPIC Mode



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 10-4 Direct Battery Supply

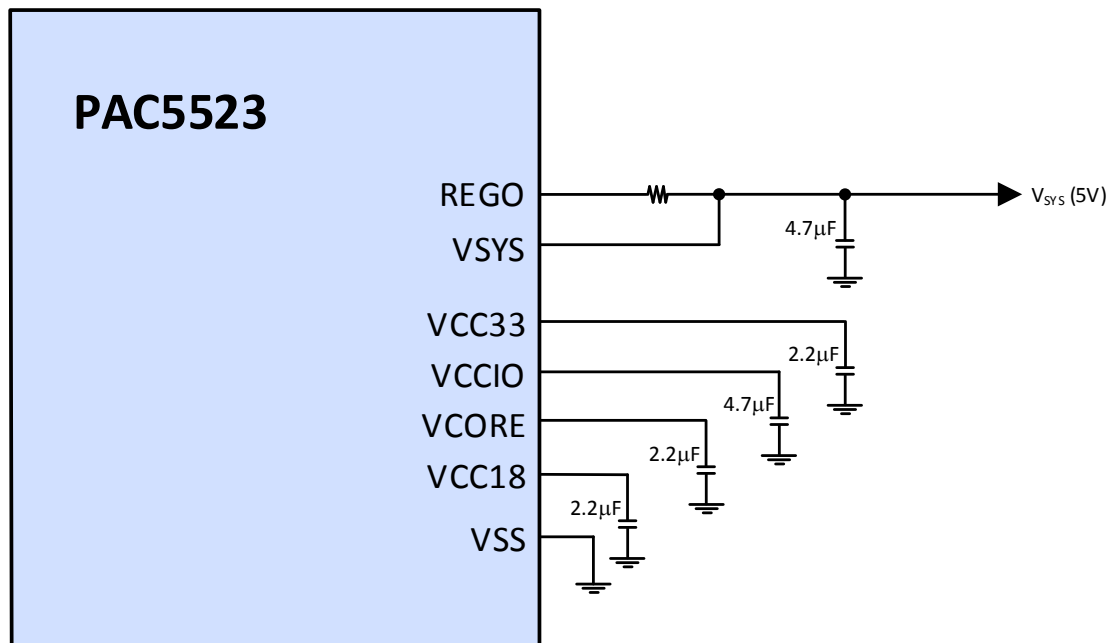


## 10.4 Linear Regulators

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 10-5 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.

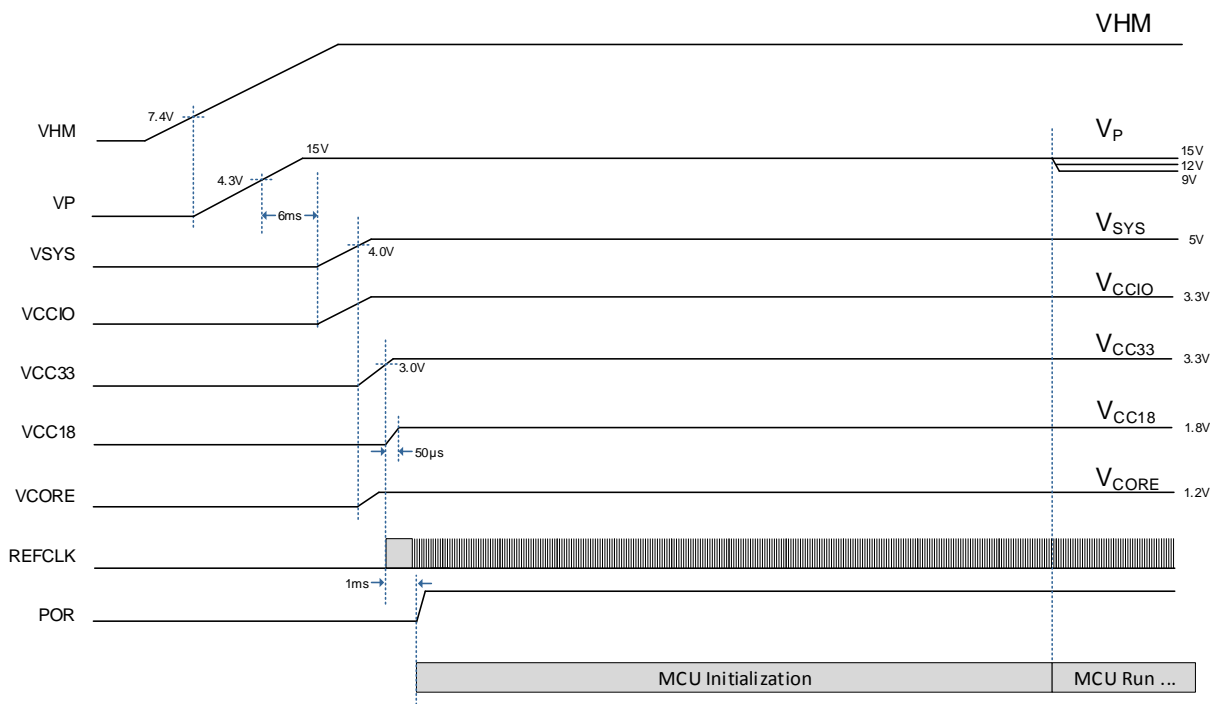
Figure 10-5 Linear Regulators



## 10.5 Power-up Sequence

The MMPM follows a typical power up sequence as in the Figure 10-6 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 10-6 Power-Up Sequence



## 10.6 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.

## 10.7 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  $V_{CORE}$ ,  $0.4 \cdot V_{CC33}$ ,  $0.4 \cdot V_{CCIO}$ ,  $0.4 \cdot V_{SYS}$ ,  $0.1 \cdot V_{REGO}$ ,  $0.1 \cdot V_P$ , or the internal compensation voltage  $V_{COMP}$  for switching supply power monitoring.

For 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  $V_{TEMP} = 1.5 + 5.04e-3 \cdot (T - 25^\circ\text{C})$  (V) is provided onto the ADC pre-multiplexer for IC temperature measurement.

## 10.8 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).

## 10.9 Electrical Characteristics

**Table 10-1 Multi-Mode Switching Supply Controller Electrical Characteristics**

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

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

|              |                                  |                                    |              |      |     |    |
|--------------|----------------------------------|------------------------------------|--------------|------|-----|----|
| $V_{OH,DRM}$ | High-level output voltage        | 5% $I_{OH}$ , relative to $V_{HM}$ | $V_{HM} - 1$ |      |     | 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 10-2 Linear Regulators Electrical Characteristics**

( $V_P = 12V$  and  $T_A = -40^\circ C$  to  $125^\circ C$  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 $I_{Q,VSYS}$             |      | 400 | 750  | $\mu A$ |
| $I_{Q,VSYS}$    | $V_{SYS}$ quiescent supply current        | $V_{CCIO}$ , $V_{CC33}$ and $V_{CORE}$ regulators only |      | 350 | 600  | $\mu A$ |
| $V_{SYS}$       | $V_{SYS}$ output voltage                  | Load = 10 $\mu A$ 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                  | $C_{VCC18} = 1\mu F$                                   |      |     | 50   | $\mu s$ |

**Table 10-3. Power System Electrical Characteristics**

( $T_A = -40^\circ C$  to  $125^\circ C$  unless otherwise specified)

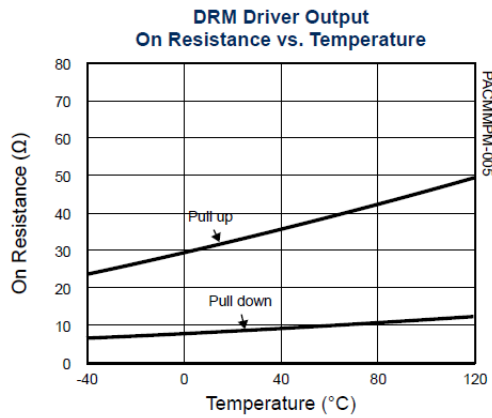
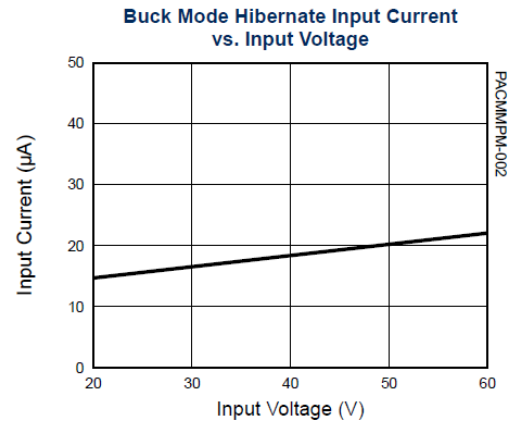
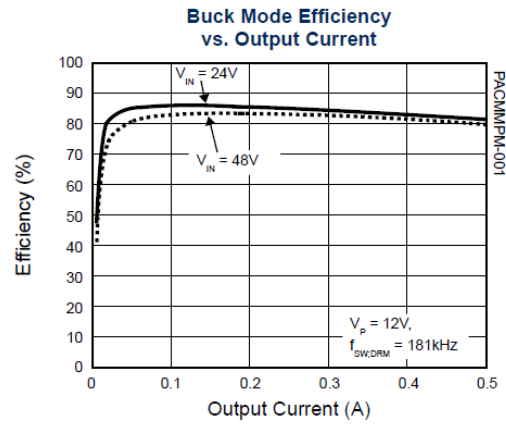
| SYMBOL    | PARAMETER         | CONDITIONS         | MIN   | TYP | MAX   | UNIT |
|-----------|-------------------|--------------------|-------|-----|-------|------|
| $V_{REF}$ | Reference Voltage | $T_A = 25^\circ C$ | 2.487 | 2.5 | 2.513 | V    |

|                    |  |  |       |     |       |      |
|--------------------|--|--|-------|-----|-------|------|
|                    |  | T <sub>A</sub> = -40°C to 125°C                          | 2.463 | 2.5 | 2.537 | V    |
| k <sub>MON</sub>   | Power monitoring voltage (V <sub>MON</sub> ) coefficient | V <sub>CORE</sub>  | 1     |     |       | V/V  |
|                    |  | V <sub>SYS</sub> , V <sub>CCIO</sub> , V <sub>CC33</sub> | 0.4   |     |       |      |
|                    |  | V <sub>P</sub> , V <sub>REGO</sub>                       | 0.1   |     |       |      |
| V <sub>TEMP</sub>  | Temperature monitor voltage at 25°C                      | T <sub>A</sub> = 25°C, at ADC                            | 1.475 | 1.5 | 1.54  | V    |
| k <sub>TEMP</sub>  | Temperature monitor coefficient                          | At ADC   | 5.04  |     |       | mV/K |
| T <sub>WARN</sub>  | Over-temperature warning threshold                       | Hysteresis = 10°C  | 140   |     |       | °C   |
| T <sub>FAULT</sub> | Over-temperature fault threshold                         | Hysteresis = 10°C  | 170   |     |       | °C   |



## 10.10 Typical Performance Characteristics

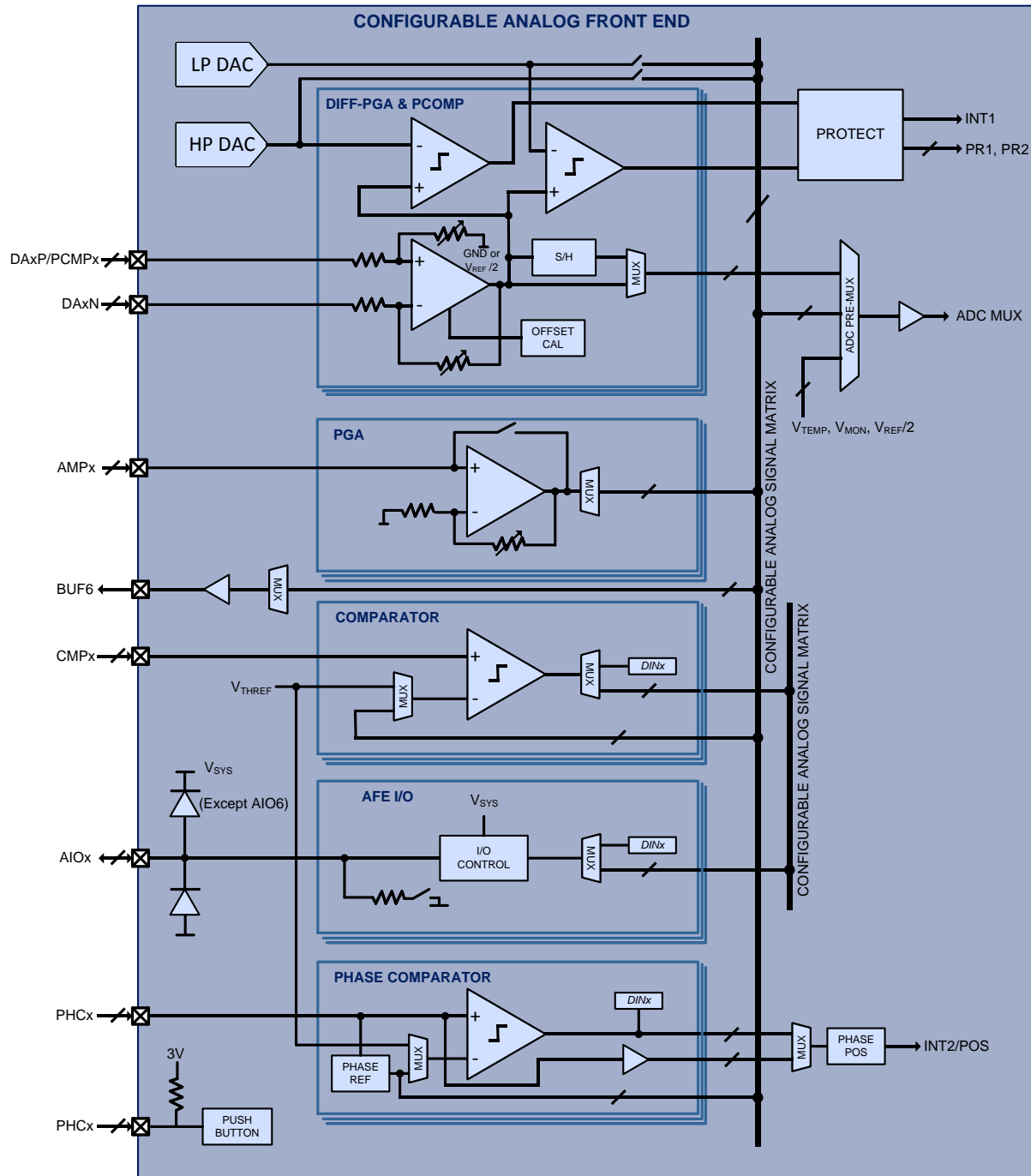
( $V_P = 12V$  and  $T_A = 25^\circ C$  unless otherwise specified)



# 11 CONFIGURABLE ANALOG FRONT END (CAFE)

## 11.1 Block Diagram

Figure 11-1 Configurable Analog Front End



## 11.2 Functional Description

The device includes a Configurable Analog Front End (CAFE, Figure 11-1) 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.

### 11.3 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.

### 11.4 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.

### 11.5 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.

## 11.6 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.

## 11.7 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.

## 11.8 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.

## 11.9 Analog Front End I/O (AIO)

Up to 10 AIOx pins are available in the device, depending on the product<sup>5</sup>. 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

<sup>5</sup> 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.

### 11.10 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 55k $\Omega$  pull-up resistor to 3V.

### 11.11 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.

### 11.12 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.

### 11.13 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

#### **11.14 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

## 11.15 Electrical Characteristics

**Table 11-1 Differential Programmable Gain Amplifier (DA) Electrical Characteristics**

(V<sub>SYS</sub> = 5V, V<sub>CCIO</sub> = 3.3V and T<sub>A</sub> = -40°C to 125°C unless otherwise specified.)

| SYMBOL                | PARAMETER  | CONDITIONS   | MIN  | TYP | MAX | UNIT |
|-----------------------|--|--|------|-----|-----|------|
| I <sub>CC,DA</sub>    | Operating supply current                                   | Each enabled amplifier   |      | 150 | 300 | μA   |
| V <sub>ICMR,DA</sub>  | Input common mode range                                    |  | -0.3 |     | 3.5 | V    |
| V <sub>OLR,DA</sub>   | Output linear range  |  | 0.1  |     | 3.5 | V    |
| V <sub>OS,DA</sub>    | Input offset voltage                                       | Gain = 48x, V <sub>DAXP</sub> =V <sub>DAXN</sub> =0V, T <sub>A</sub> =25°C | -8   |     | 8   | mV   |
| A <sub>VZI,DA</sub>   | Differential amplifier gain<br>(zero ohm source impedance) | Gain = 1x  |      | 1   |     |      |
|                       |  | Gain = 2x  |      | 2   |     |      |
|                       |  | Gain = 4x  |      | 4   |     |      |
|                       |  | Gain = 8x, V <sub>DAXP</sub> =V <sub>DAXN</sub> =0V, T <sub>A</sub> = 25°C |      | 8   |     |      |
|                       |  |  | -2   |     | 2   | %    |
|                       |  | Gain = 16x   |      | 16  |     |      |
|                       |  | Gain = 32x   |      | 32  |     |      |
|                       |  | Gain = 48x   |      | 48  |     |      |
| K <sub>CMRR,DA</sub>  | Common mode rejection ratio                                | Gain = 8x, V <sub>DAXP</sub> =V <sub>DAXN</sub> =0V, T <sub>A</sub> = 25°C |      | 55  |     | dB   |
| R <sub>INDIF,DA</sub> | Differential input impedance                               |  |      | 27  |     | kΩ   |
|                       | Slew rate <sup>6</sup>                                     | Gain = 8x  | 7    | 10  |     | V/μs |
| t <sub>ST,DA</sub>    | Settling time <sup>6</sup>                                 | To 1% of final value   |      | 200 | 400 | ns   |

**Table 11-2 Single-Ended Programmable Gain Amplifier (AMP) Electrical Characteristics**

(V<sub>SYS</sub> = 5V, V<sub>CCIO</sub> = 3.3V and T<sub>A</sub> = -40°C to 125°C unless otherwise specified.)

| SYMBOL               | PARAMETER                | CONDITIONS   | MIN | TYP | MAX | UNIT |
|----------------------|--------------------------|--|-----|-----|-----|------|
| I <sub>CC,AMP</sub>  | Operating supply current | Each enabled amplifier                                     |     | 80  | 140 | μA   |
| V <sub>OLR,AMP</sub> | Output linear range      |  | 0.1 |     | 3.5 | V    |
| V <sub>OS,AMP</sub>  | Input offset voltage     | Gain = 1x, T <sub>A</sub> =25°C, V <sub>AMPX</sub> =2.5V   | -10 |     | 10  | mV   |
| A <sub>V,AMP</sub>   | Amplifier gain           | Gain = 1x  |     | 1   |     |      |
|                      |                          | Gain = 2x  |     | 2   |     |      |
|                      |                          | Gain = 4x  |     | 4   |     |      |
|                      |                          | Gain = 8x, V <sub>AMPX</sub> =125mV, T <sub>A</sub> = 25°C | -2  |     | 2   | %    |
|                      |                          |  |     | 16  |     |      |

<sup>6</sup> Guaranteed by design

|              |                            |                      |         |            |
|--------------|----------------------------|----------------------|---------|------------|
|              |                            | Gain = 32x           | 32      |            |
|              |                            | Gain = 48x           | 48      |            |
| $I_{IN,AMP}$ | Input current              |                      | 0 1     | $\mu A$    |
|              | Slew rate <sup>6</sup>     | Gain = 8x            | 8 12    | V/ $\mu s$ |
| $t_{ST,AMP}$ | Settling time <sup>6</sup> | To 1% of final value | 150 300 | ns         |

**Table 11-3 General Purpose Comparator (CMP) Electrical Characteristics**

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

| SYMBOL         | PARAMETER                     | CONDITIONS                          | MIN | TYP | MAX       | UNIT    |
|----------------|-------------------------------|-------------------------------------|-----|-----|-----------|---------|
| $I_{CC,CMP}$   | Operating supply current      | Each enabled amplifier              |     | 35  | 110       | $\mu A$ |
| $V_{ICMR,CMP}$ | Input common mode range       |                                     | 0   |     | $V_{SYS}$ | V       |
| $V_{OS,CMP}$   | Input offset voltage          | $V_{CMPx}=2.5V$ , $T_A=25^{\circ}C$ | -10 |     | 10        | mV      |
| $V_{HYS,CMP}$  | Hysteresis                    |                                     |     | 20  |           | mV      |
| $I_{IN,CMP}$   | Input current                 |                                     |     | 0   | 1         | $\mu A$ |
| $t_{DEL,CMP}$  | Comparator delay <sup>6</sup> |                                     |     |     | 100       | ns      |

**Table 11-4 Phase Comparator (PHC) Electrical Characteristics**

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

| SYMBOL         | PARAMETER                     | CONDITIONS                           | MIN | TYP | MAX       | UNIT    |
|----------------|-------------------------------|--------------------------------------|-----|-----|-----------|---------|
| $I_{CC,PHC}$   | Operating supply current      | Each enabled amplifier               |     | 35  | 110       | $\mu A$ |
| $V_{ICMR,PHC}$ | Input common mode range       |                                      | 0   |     | $V_{SYS}$ | V       |
| $V_{OS,PHC}$   | Input offset voltage          | $V_{PCMPx}=2.5V$ , $T_A=25^{\circ}C$ | -10 |     | 10        | mV      |
| $V_{HYS,PHC}$  | Hysteresis                    |                                      |     | 20  |           | mV      |
| $I_{IN,PHC}$   | Input current                 |                                      |     | 0   | 1         | $\mu A$ |
| $t_{DEL,PHC}$  | Comparator delay <sup>6</sup> |                                      |     |     | 100       | ns      |

**Table 11-5 Protection Comparator (PCMP) Electrical Characteristics**

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

| SYMBOL          | PARAMETER                | CONDITIONS                          | MIN | TYP | MAX         | UNIT    |
|-----------------|--------------------------|-------------------------------------|-----|-----|-------------|---------|
| $I_{CC,PCMP}$   | Operating supply current | Each enabled comparator             |     | 35  | 100         | $\mu A$ |
| $V_{ICMR,PCMP}$ | Input common mode range  |                                     | 0.3 |     | $V_{SYS}-1$ | V       |
| $V_{OS,PCMP}$   | Input offset voltage     | $V_{CMPx}=2.5V$ , $T_A=25^{\circ}C$ | -10 |     | 10          | mV      |
| $V_{HYS,PCMP}$  | Hysteresis               |                                     |     | 20  |             | mV      |
| $I_{IN,PCMP}$   | Input current            |                                     |     | 0   | 1           | $\mu A$ |



|                       |                               |  |     |    |
|-----------------------|-------------------------------|--|-----|----|
| $t_{\text{DEL,PCMP}}$ | Comparator delay <sup>6</sup> |  | 100 | ns |
|-----------------------|-------------------------------|--|-----|----|

**Table 11-6 Analog Output Buffer (BUF) Electrical Characteristics**

(V<sub>SYS</sub> = 5V, V<sub>CCIO</sub> = 3.3V, and T<sub>A</sub> = -40°C to 125°C unless otherwise specified.)

| SYMBOL                | PARAMETER                | CONDITIONS                                     | MIN | TYP | MAX | UNIT |
|-----------------------|--------------------------|--|-----|-----|-----|------|
| I <sub>CC,BUF</sub>   | Operating supply current | No load  |     | 35  | 100 | μA   |
| V <sub>ICMR,BUF</sub> | Input common mode range  |  | 0   |     | 3.5 | V    |
| V <sub>OLR,AMP</sub>  | Output linear range      |  | 0.1 |     | 3.5 | V    |
| V <sub>OS,BUF</sub>   | Offset voltage           | V <sub>BUF</sub> = 2.5V, T <sub>A</sub> = 25°C | -18 |     | 18  | mV   |
| I <sub>OMAX</sub>     | Maximum output current   | C <sub>L</sub> = 0.1nF                         | 0.8 | 1.3 |     | mA   |

**Table 11-7 Analog Front End (AIO) Electrical Characteristics**

(V<sub>SYS</sub> = 5V, V<sub>CCIO</sub> = 3.3V, and T<sub>A</sub> = -40°C to 125°C unless otherwise specified.)

| SYMBOL              | PARAMETER                         | CONDITIONS  | MIN | TYP | MAX | UNIT |
|---------------------|-----------------------------------|---|-----|-----|-----|------|
| V <sub>AIO</sub>    | Pin voltage range                 |   | 0   |     | 5   | V    |
| V <sub>IH,AIO</sub> | High-level input voltage          |   | 2.2 |     |     | V    |
| V <sub>IL,AIO</sub> | Low-level input voltage           |   |     |     | 0.8 | V    |
| R <sub>PD,AIO</sub> | Pull-down resistance              | Input mode  | 0.5 | 1   | 1.8 | MΩ   |
| V <sub>OL,AIO</sub> | Low-level output voltage          | I <sub>AIO&lt;9,7,3,1&gt;</sub> = 7mA, open-drain output mode |     |     | 0.4 | V    |
|                     |                                   | I <sub>AIO&lt;6,0&gt;</sub> = 7mA, open-drain output mode     |     |     | 0.5 |      |
| I <sub>OL,AIO</sub> | Low-level output sink current     | V <sub>AIOx</sub> = 0.4V, open-drain output mode              | 6   | 14  |     | mA   |
| I <sub>LK,AIO</sub> | High-level output leakage current | V <sub>AIOx</sub> = 5V, open-drain output mode                |     | 0   | 10  | μA   |

**Table 11-8 Push Button (PBTN) Electrical Characteristics**

(V<sub>SYS</sub> = 5V, V<sub>CCIO</sub> = 3.3V, and T<sub>A</sub> = -40°C to 125°C unless otherwise specified.)

| SYMBOL               | PARAMETER                | CONDITIONS                    | MIN | TYP | MAX  | UNIT |
|----------------------|--------------------------|-------------------------------|-----|-----|------|------|
| V <sub>I,PBTN</sub>  | Input voltage range      |                               | 0   |     | 5    | V    |
| V <sub>IH,PBTN</sub> | High-level input voltage |                               | 2   |     |      | V    |
| V <sub>IL,PBTN</sub> | Low-level input voltage  |                               |     |     | 0.35 | V    |
| R <sub>PU,PBTN</sub> | Pull-up resistance       | To 3V, push-button input mode | 40  | 55  | 95   | kΩ   |

**Table 11-9 HP DAC and LP DAC Electrical Characteristics**

(V<sub>sys</sub> = 5V, V<sub>CCIO</sub> = 3.3V, and T<sub>A</sub> = -40°C to 125°C unless otherwise specified.)

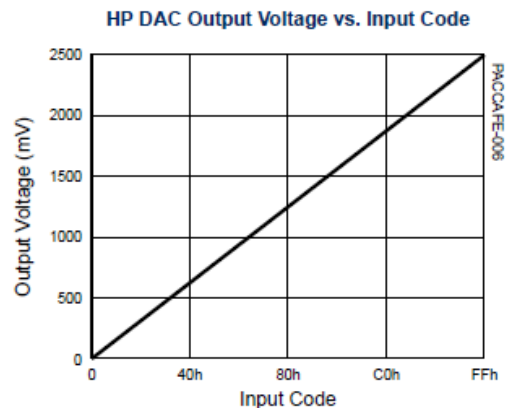
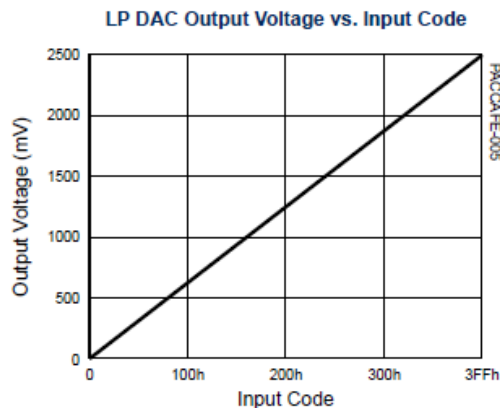
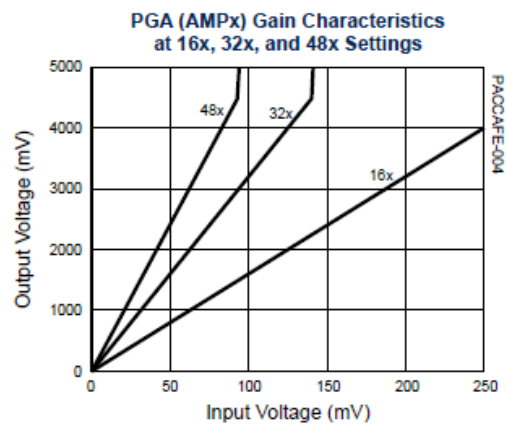
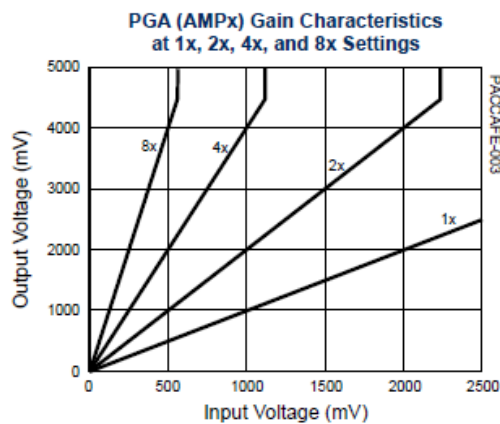
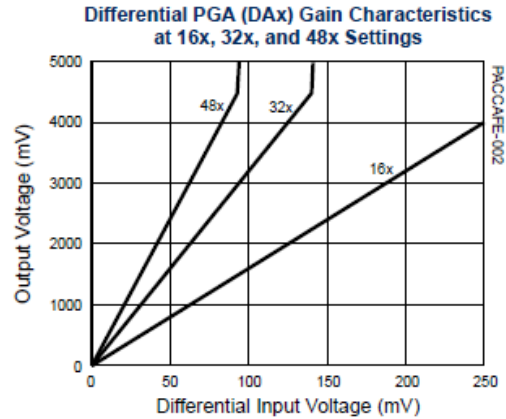
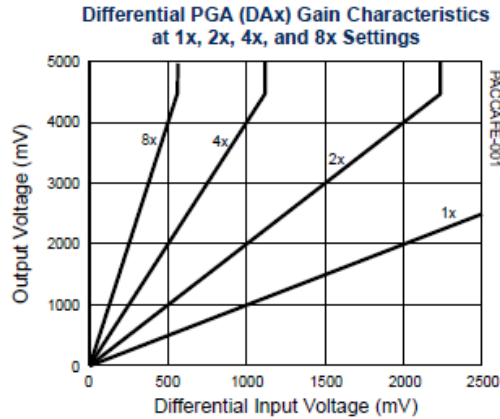
| SYMBOL  | PARAMETER                      | CONDITIONS          | MIN   | TYP | MAX   | UNIT |
|---------|--------------------------------|---------------------|-------|-----|-------|------|
| VDACREF | DAC reference voltage          | TA = 25°C           | 2.48  | 2.5 | 2.52  | V    |
|         | 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

<sup>7</sup> Guaranteed by design and characterization

## 11.16 Typical Performance Characteristics

Figure 11-2 PGA Typical Performance Characteristics

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



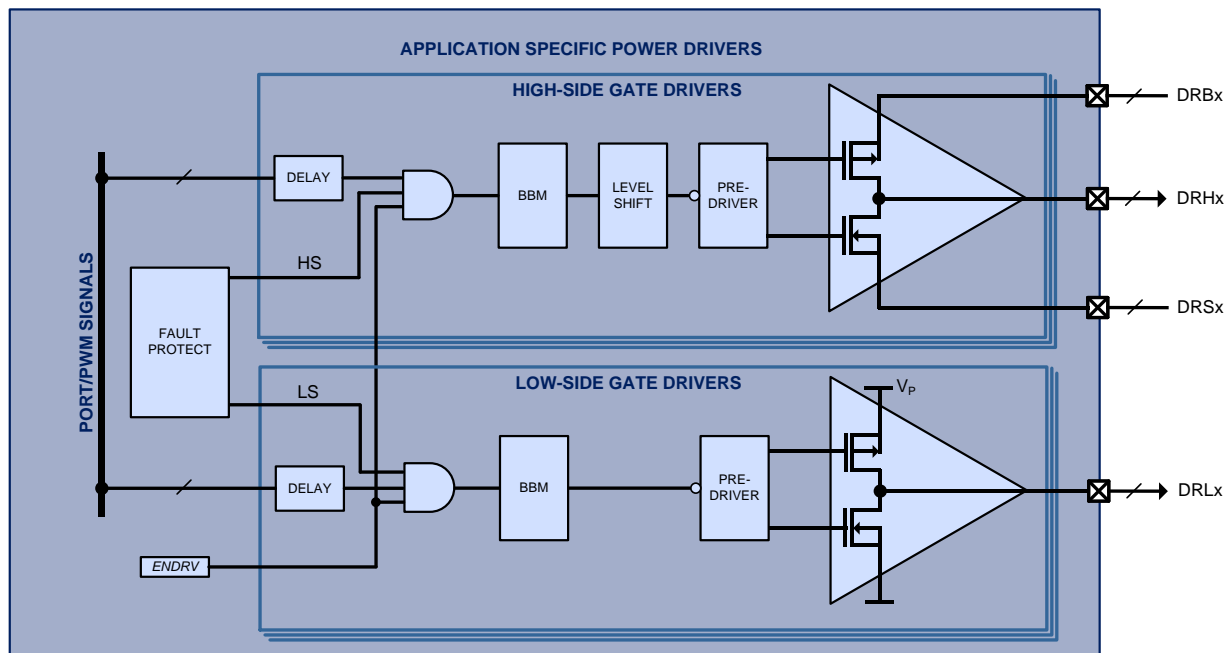
## 12 APPLICATION SPECIFIC POWER DRIVERS (ASPD)

### 12.1 Features

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

### 12.2 Block Diagram

Figure 12-1 Application Specific Power Drivers



### 12.3 Functional Description

The Application Specific Power Drivers (ASPD, Figure 12-1) 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 12-2 below shows typical gate driver connections and Table 12-1 shows the ASPD available resources. The ASPD gate drivers support up to a 70V supply.

Figure 12-2 Typical Gate Driver Connections

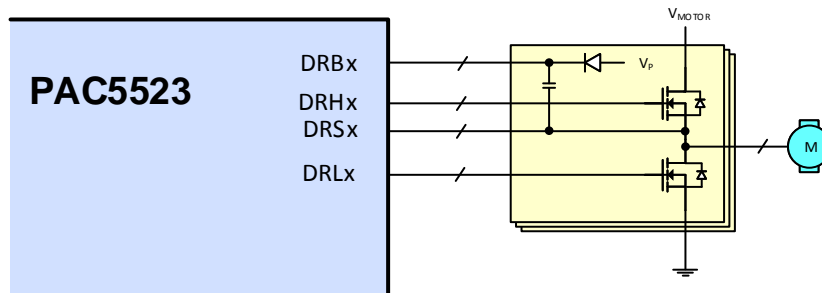


Table 12-1 Power Driver Resources by Part Numbers

| 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.

## 12.4 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.

## 12.5 High-Side Gate Driver

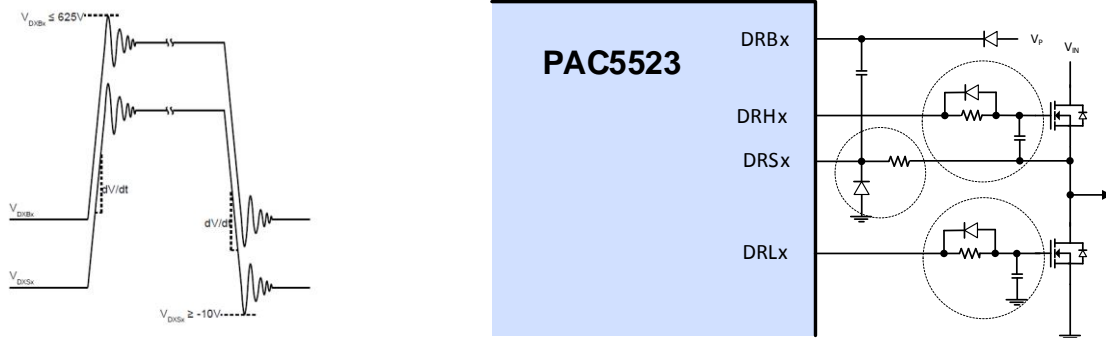
The DRHx high-side gate driver drives the gate of an external MOSFET or IGBT switch between its low-level DRSx driver source rail and its high-level DRBx bootstrap rail. The DRSx pin can go up to 70V steady state. The DRHx output pin has sink and source output current capability of 1.5A. The DRBx bootstrap 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 VP to DRBx. To operate the DRHx output as a low-side gate driver, connect its DRBx pin to VP and its DRSx pin to VSSP.

## 12.6 High-Side Switching Transients

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

Figure 12-3 High-Side Switching Transients and Optional Circuitry



(a) High-Side Switching Transients

(b) Optional Transient Protection and Slew Rate Control

## 12.7 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 12-2 Power Driver Delay Configuration. Refer to the PAC application notes and user guide for additional information on power drivers control programming.

Table 12-2 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   |

## 12.8 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.

## 12.9 Electrical Characteristics

**Table 12-3 Gate Driver Electrical Characteristics**

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

| SYMBOL  | PARAMETER                               | CONDITIONS   | MIN              | TYP                | MAX               | UNIT    |
|---|---|--|------------------|--------------------|-------------------|---------|
| <b>Low-Side Gate Drivers (DRLx pins)</b>                    |   |  |                  |                    |                   |         |
| $V_{OH;DRL}$  | 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   | 10 $\mu s$ pulse   |                  | -1.5               |                   | A       |
| $I_{OLPK;DRL}$  | Low-level pulsed peak sink current      | 10 $\mu s$ pulse   |                  | 1.5                |                   | A       |
| <b>High-Side Gate Drivers (DRHx, DRBx and DRSx pins)</b>    |   |  |                  |                    |                   |         |
| $V_{DRS}$   | Level-shift driver source voltage range | Repetitive, 10 $\mu s$ pulse   | -5               |                    | 71                | V       |
|   |   | Steady state   | 0                |                    | 66                | V       |
| $V_{DRB}$   | Bootstrap pin voltage range             | Repetitive, 10 $\mu s$ 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                | $\mu A$ |
|   |   | Gate Driver Enabled  |                  | 30                 | 45                |         |
| $I_{OS;DRB}$  | Offset supply current                   | Gate Driver Disabled   |                  | 0.5                | 10                | $\mu A$ |
|   |   | 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   | 10 $\mu s$ pulse   |                  | -1.5               |                   | A       |
| $I_{OLPK;DRL}$  | Low-level pulsed peak sink current      | 10 $\mu s$ pulse   |                  | 1.5                |                   | A       |
| <b>High-Side and Low-Side Gate Driver Propagation Delay</b> |   |  |                  |                    |                   |         |
| $t_{PD}$  | Propagation Delay                       | Delay setting 00b  |                  | 10                 |                   | ns      |
|   |   | Delay setting 01b  |                  | 50                 |                   | ns      |

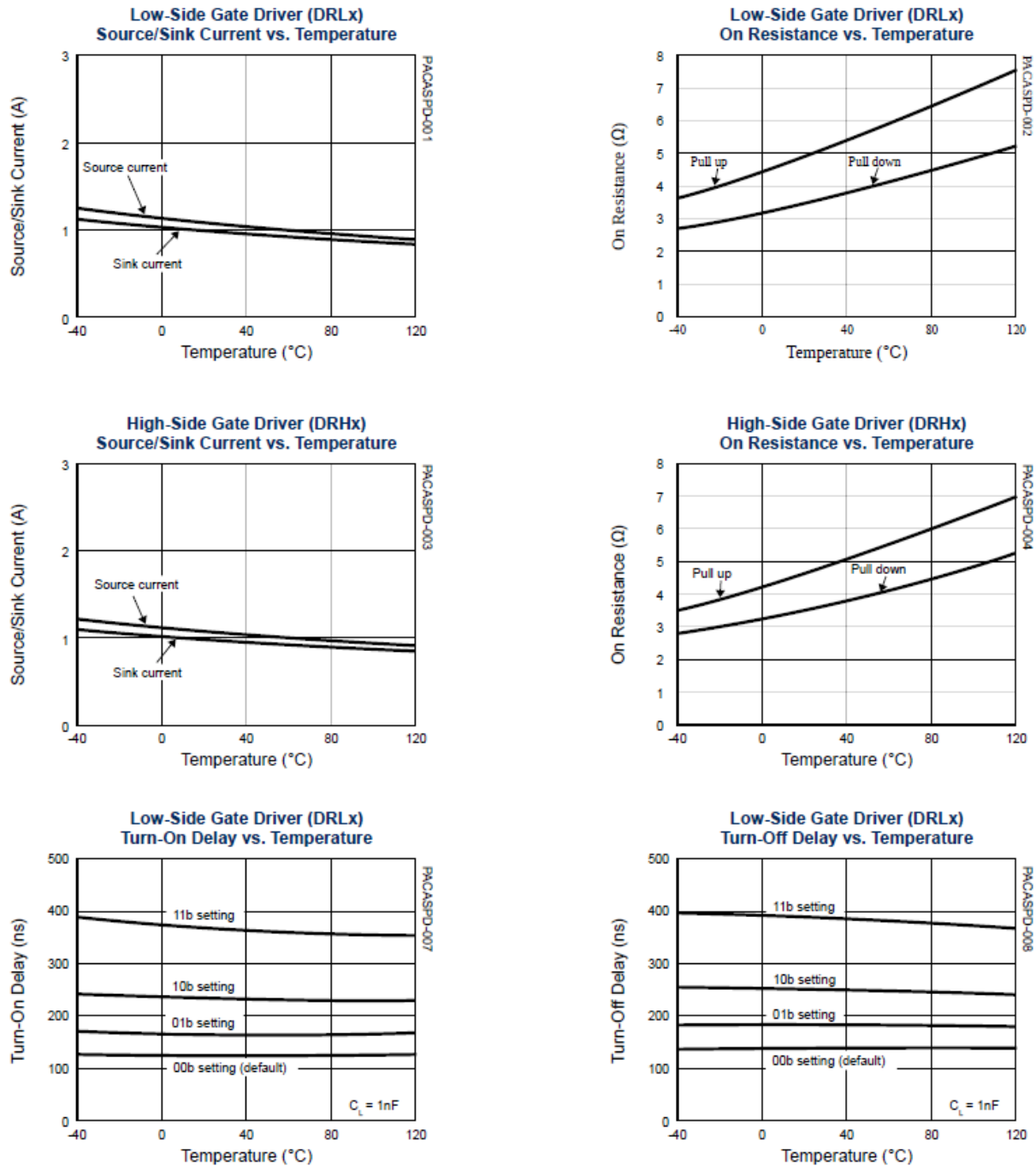
|  |  |                   |  |     |  |    |
|--|--|-------------------|--|-----|--|----|
|  |  | Delay setting 10b |  | 120 |  | ns |
|  |  | Delay setting 11b |  | 250 |  | ns |



## 12.10 Typical Performance Characteristics

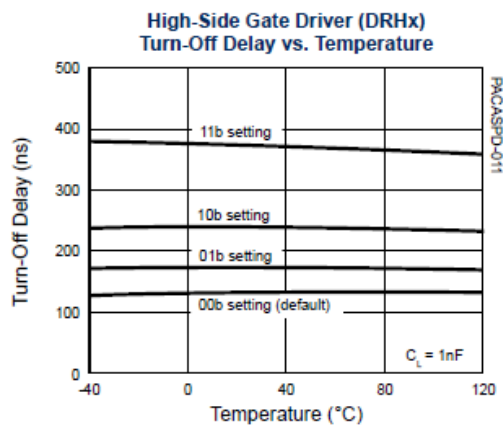
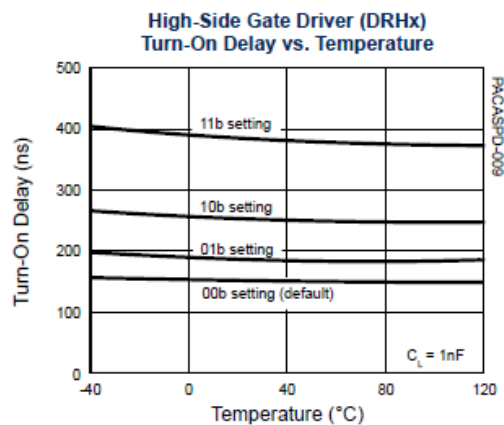
Figure 12-4 ASPD Gate Driver Typical Performance Characteristics

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



**Figure 12-5 ASPD Gate Driver Typical Performance Characteristics (cont)**

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



## 13 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

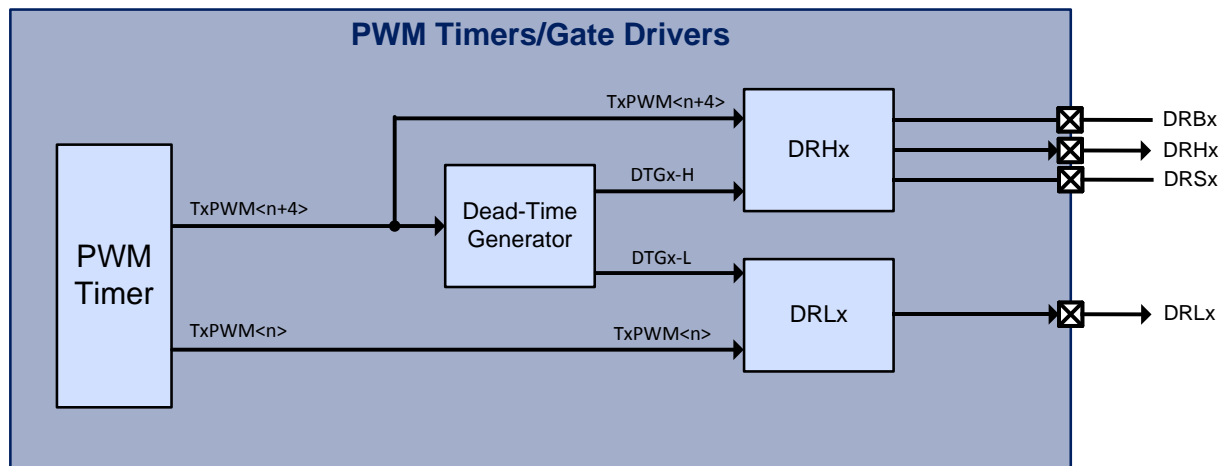
### 13.1 High-side and Low-Side Gate Drivers

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 13-1 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 13-1 PWM to ASPD Gate Driver Options (DTG Enabled)**

| Gate Driver   | PWM Input Options                              |
|---------------|--|
| DRH3/<br>DRL0 | TAPWM4<br>TBPWM4<br>TCPWM0<br>TCPWM4<br>TDPWM4 |
| DRH4/<br>DRL1 | TAPWM5<br>TBPWM5<br>TCPWM1<br>TCPWM5<br>TDPWM5 |
| DRH5/<br>DRL0 | TAPWM6<br>TBPWM6<br>TCPWM2<br>TCPWM6<br>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 13-2 PWM to ASPD Gate Driver Options (DTG Disabled)**

| Gate Driver | PWM Input Options                              |
|-------------|--|
| DRH3        | TAPWM4<br>TBPWM4<br>TCPWM0<br>TCPWM4<br>TDPWM4 |
| DRH4        | TAPWM5<br>TBPWM5                               |

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

### 13.2 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 13-3 SPI SOC Bus Connections**

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

|    |       |     |
|----|-------|-----|
| SS | USASS | PA6 |
|    | USBSS | PA6 |

### 13.3 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 13-4 SPI SOC Bus Connections**

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

### 13.4 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.

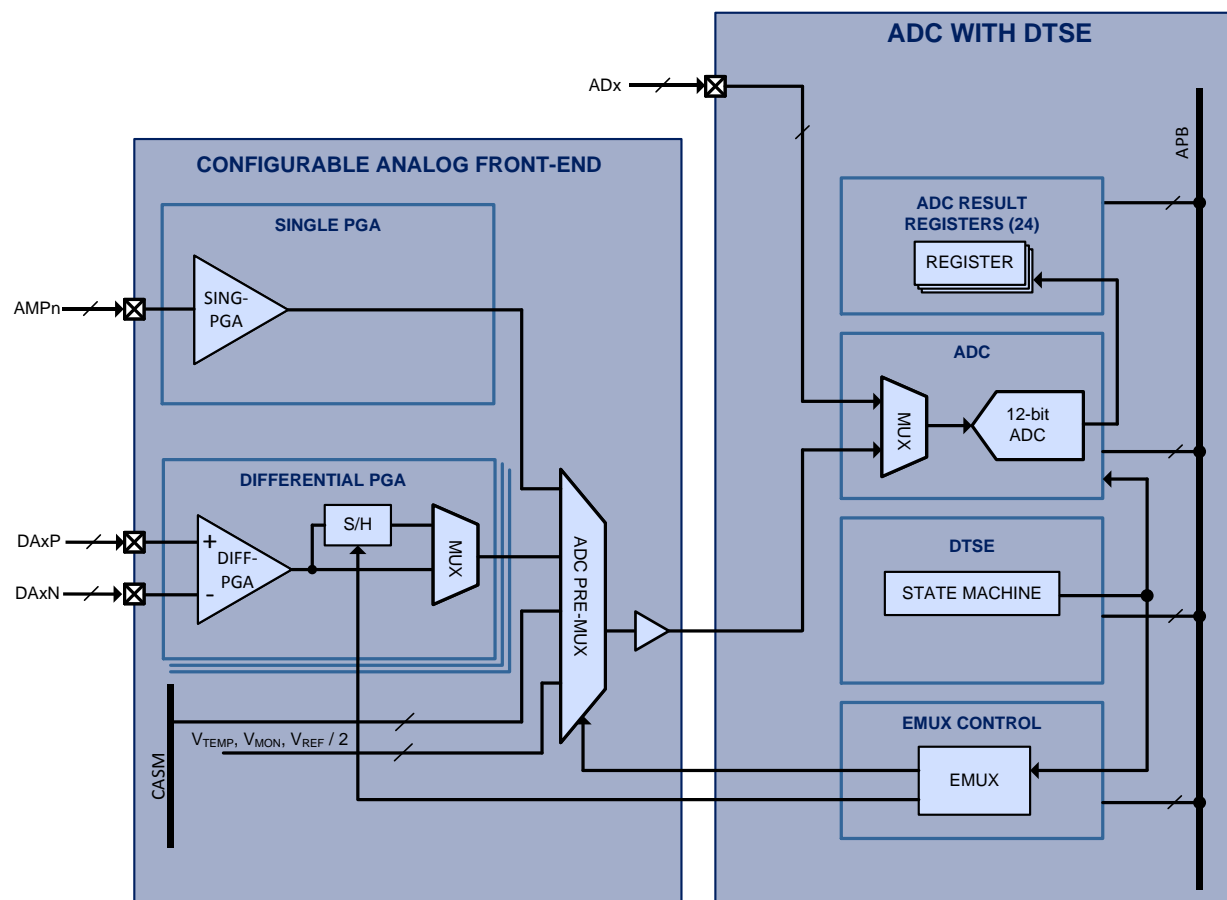
**Table 13-5 Analog Interrupts**

| 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    |

## 14 ADC/DTSE

### 14.1 ADC Block Diagram

Figure 14-1 ADC with DTSE



### 14.2 Functional Description

#### 14.2.1 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.

#### 14.2.2 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 when generating an interrupt during sequence conversions. The IRQ may be generated at the end of a conversion sequence, or at the end of a 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.

#### 14.2.3 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.



## 14.3 Electrical Characteristics

**Table 14-1 ADC and DTSE Electrical Characteristics**

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

| SYMBOL                   | PARAMETER                                | CONDITIONS           | MIN  | TYP        | MAX | UNIT    |
|--------------------------|--|----------------------|------|------------|-----|---------|
| <b>ADC</b>               |  |                      |      |            |     |         |
| $f_{ADCCLK}$             | 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)     | $F_{ADCCLK} = 25MHz$ |      | $\pm 0.5$  |     | LSB     |
|                          |  | $F_{ADCCLK} = 40MHz$ |      | $\pm 0.75$ |     | LSB     |
|                          | ADC integral non-linearity (INL)         | $F_{ADCCLK} = 25MHz$ |      | $\pm 0.5$  |     | LSB     |
|                          |  | $F_{ADCCLK} = 40MHz$ |      | $\pm 0.75$ |     | LSB     |
|                          | ADC offset error                         |                      |      | 0.6        |     | %FS     |
|                          | ADC gain error                           |                      |      | 0.12       |     | %FS     |
| <b>REFERENCE VOLTAGE</b> |  |                      |      |            |     |         |
| $V_{REFADC}$             | ADC reference input voltage <sup>8</sup> | $VREF = 2.5V$        |      | 2.5        |     | V       |
| <b>SAMPLE AND HOLD</b>   |  |                      |      |            |     |         |
| $t_{ADCSH}$              | ADC sample and hold time                 | $f_{ADCCLK} = 40MHz$ |      | 188        |     | $\mu s$ |
| $C_{ADCIC}$              | ADC input capacitance                    | ADC MUX input        |      | 1          |     | pF      |
| <b>EMUX CLOCK SPEED</b>  |  |                      |      |            |     |         |
| $f_{EMUXCLK}$            | EMUX engine clock input                  |                      |      |            | 50  | MHz     |

<sup>8</sup> 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.

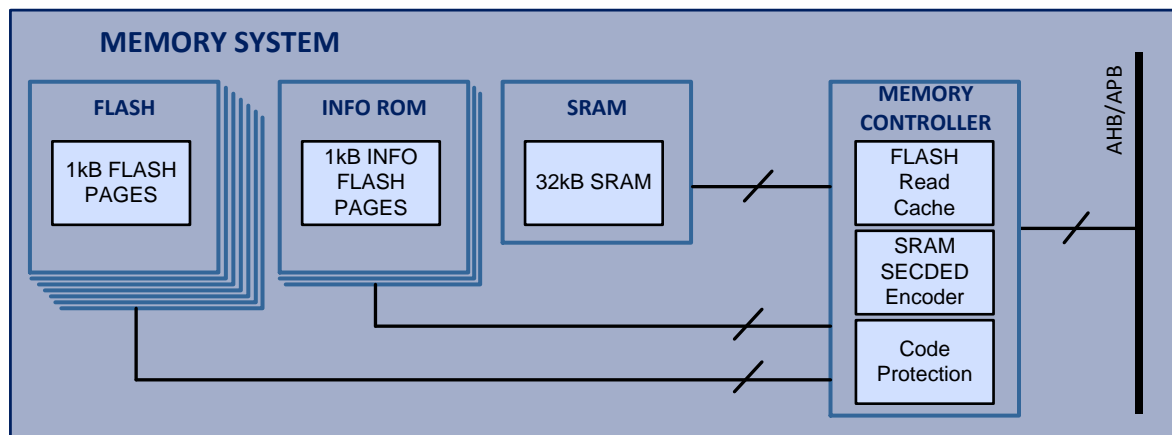
## 15 MEMORY SYSTEM

### 15.1 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
  - SECEDED for read/write operations
- User-configurable code protection

### 15.2 Memory System Block Diagram

Figure 15-1 Memory System



### 15.3 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.

### 15.4 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.

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.

### 15.5 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 of 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.

### 15.6 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.

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.<sup>9</sup>

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<sup>9</sup> 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.

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

## 15.7 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 15-1 Code Protection Level Description

| LEVEL | NAME                          | FEATURES   |
|-------|-------------------------------|--|
| 0     | UNLOCKED                      | <ul style="list-style-type: none"><li>No restrictions</li></ul>  |
| 1     | RW PROTECTION                 | <ul style="list-style-type: none"><li>SWD/JTAG enabled</li><li>Programmable protection of up to 128 regions of FLASH</li><li>User-specified Read or Write protection per region</li></ul>                      |
| 2     | SWD DISABLED                  | <ul style="list-style-type: none"><li>SWD/JTAG disabled</li><li>Programmable protection of up to 128 regions of FLASH</li><li>User-specified Read or Write protection per region</li></ul>                     |
| 3     | SWD/JTAG PERMANENTLY DISABLED | <ul style="list-style-type: none"><li>SWD/JTAG disabled</li><li>Programmable protection of up to 128 regions of FLASH</li><li>User-specified Read or Write protection per region</li><li>No recovery</li></ul> |

## 15.8 Electrical Characteristics

**Table 15-2 Memory System Electrical Characteristics**

(T<sub>A</sub> = -40°C to 125°C unless otherwise specified.)

| SYMBOL                    | PARAMETER                  | CONDITIONS  | MIN  | TYP | MAX | UNIT   |
|---------------------------|----------------------------|---|------|-----|-----|--------|
| <b>Embedded FLASH</b>     |                            |   |      |     |     |        |
| t <sub>READ;FLASH</sub>   | FLASH read time            |   | 40   |     |     | ns     |
| t <sub>WRITE;FLASH</sub>  | FLASH write time           |   | 30   |     |     | μs     |
| t <sub>PERASE;FLASH</sub> | FLASH page erase time      |   |      | 2   |     | ms     |
| t <sub>MERASE;FLASH</sub> | FLASH full erase time      |   |      | 10  |     | ms     |
| N <sub>PERASE;FLASH</sub> | FLASH program/erase cycles |   | 30k  |     |     | cycles |
| t <sub>DR;FLASH</sub>     | FLASH data retention       |   | 10   |     |     | Years  |
| <b>SRAM</b>               |                            |   |      |     |     |        |
| t <sub>ACC;SRAM</sub>     | SRAM access time           | HCLK = 150MHz;<br>Word (32-bits), aligned                     | 6.67 |     |     | ns     |
|                           |                            | HCLK = 150MHz;<br>Half-word (16-bits), byte (8-bits), aligned | 6.67 |     |     | ns     |

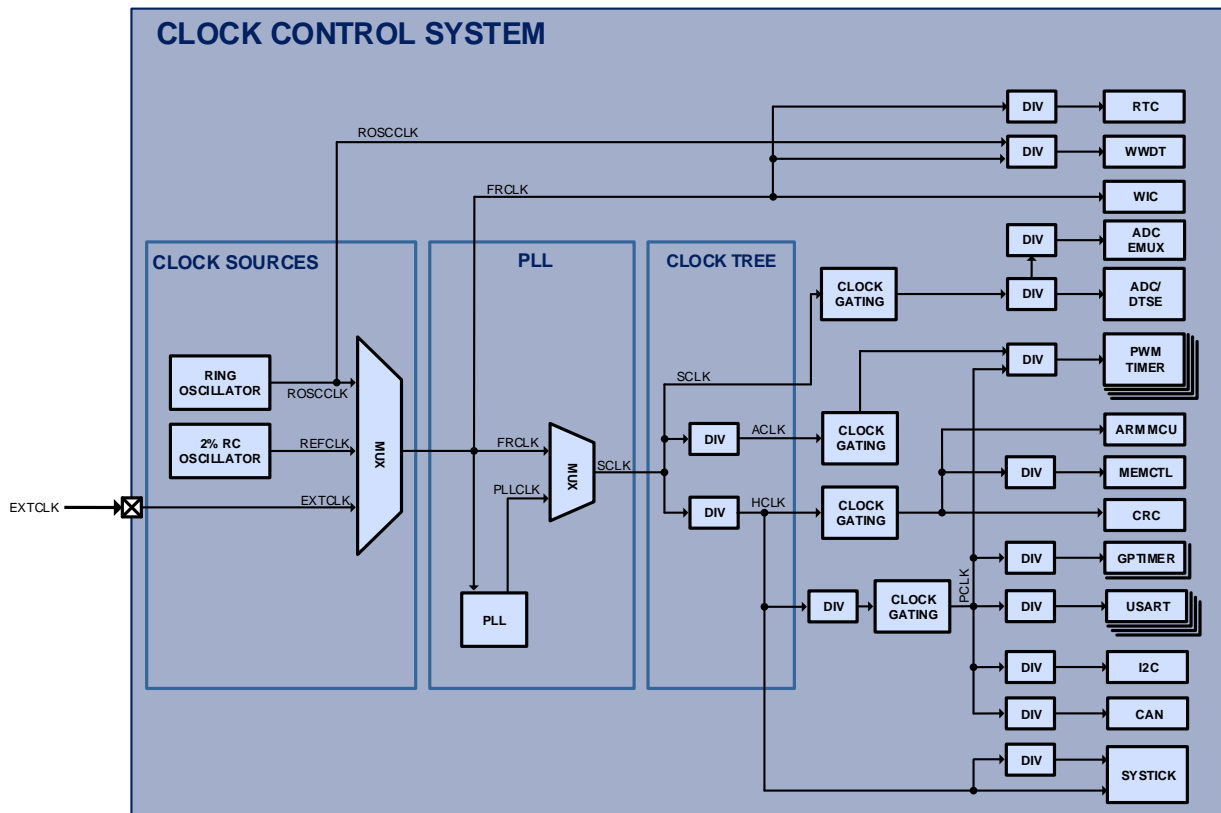
## 16 SYSTEM AND CLOCK CONTROL

### 16.1 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

### 16.2 Block Diagram

Figure 16-1 Clock Control System



## 16.3 Clock Sources

### 16.3.1 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 **ROSCCLK** 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.

### 16.3.2 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.

### 16.3.3 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%).

## 16.4 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.

## 16.5 Clock Tree

The following are 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.

### 16.5.1 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**.

### 16.5.2 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.

### 16.5.3 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.

### 16.5.4 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.

### 16.5.5 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.



## 16.6 Electrical Characteristics

Table 16-1 CCS Electrical Characteristics

(T<sub>A</sub> = -40°C to 125°C unless otherwise specified.)

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

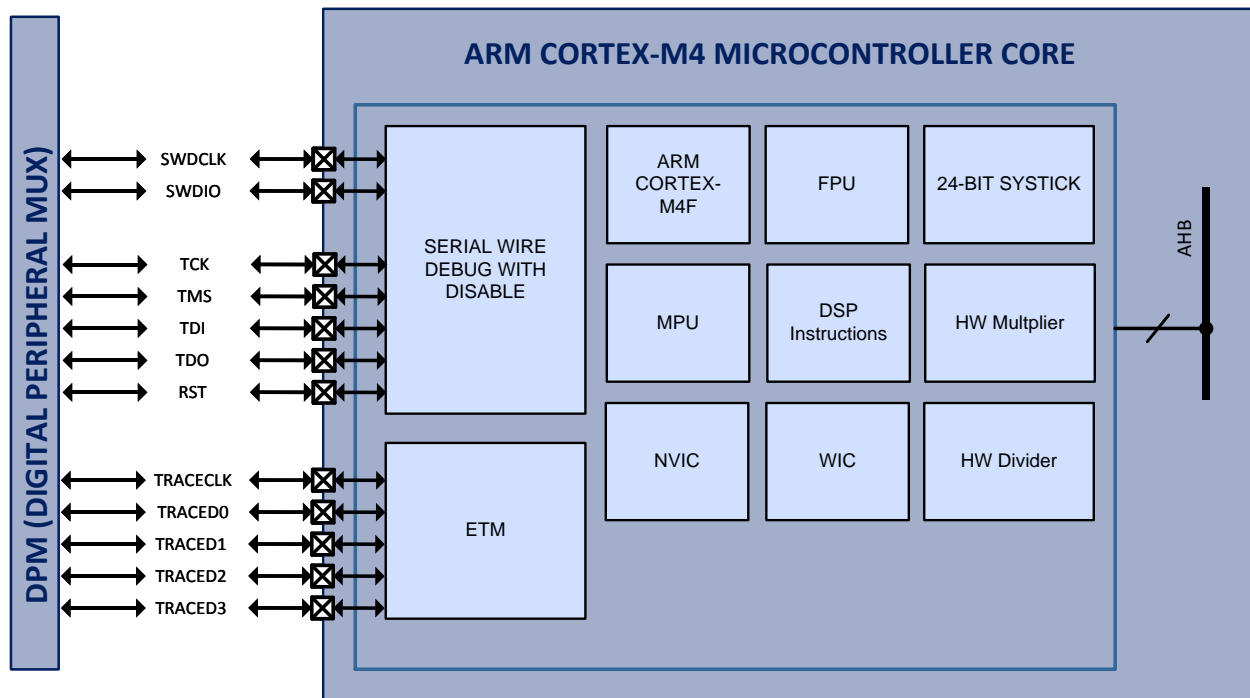
## 17 ARM CORTEX-M4F MCU CORE

### 17.1 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

### 17.2 Block Diagram

Figure 17-1 ARM Cortex-M4F Microcontroller Core



### 17.3 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.

## 17.4 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 17-1 PAC55XX Application Typical Current Consumption**

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

## 17.5 Electrical Characteristics

**Table 17-2 MCU and Clock Control System Electrical Characteristics**

(T<sub>A</sub> = -40°C to 125°C unless otherwise specified.)

| SYMBOL                          | PARAMETER                           | CONDITIONS                            | MIN | TYP | MAX  | UNIT |
|---------------------------------|-------------------------------------|---------------------------------------|-----|-----|------|------|
| f <sub>HCLK</sub>               | Microcontroller Clock               |                                       |     |     | 150  | MHz  |
| I <sub>Q:V<sub>CORE</sub></sub> | V <sub>CORE</sub> quiescent current | ARM Cortex-M4F Sleep/Deep Sleep Modes |     |     | 2    | mA   |
|                                 |                                     | PAC5523 Hibernate Mode                |     |     | 0    | mA   |
| I <sub>Q:V<sub>SYS</sub></sub>  | V <sub>SYS</sub> quiescent current  | ARM Cortex-M4F Sleep/Deep Sleep Modes |     |     | 8    | mA   |
|                                 |                                     | PAC5523 Hibernate Mode                |     |     | 15   | μA   |
| I <sub>Q:V<sub>CCIO</sub></sub> | V <sub>CCIO</sub> quiescent current | ARM Cortex-M4F Sleep/Deep Sleep Modes |     |     | 0.15 | mA   |
|                                 |                                     | PAC5523 Hibernate Mode                |     |     | 0    | mA   |
| I <sub>Q:V<sub>CC33</sub></sub> | V <sub>CC33</sub> quiescent current | ARM Cortex-M4F Sleep/Deep Sleep Modes |     |     | 0.4  | mA   |
|                                 |                                     | PAC5523 Hibernate Mode                |     |     | 0    | mA   |

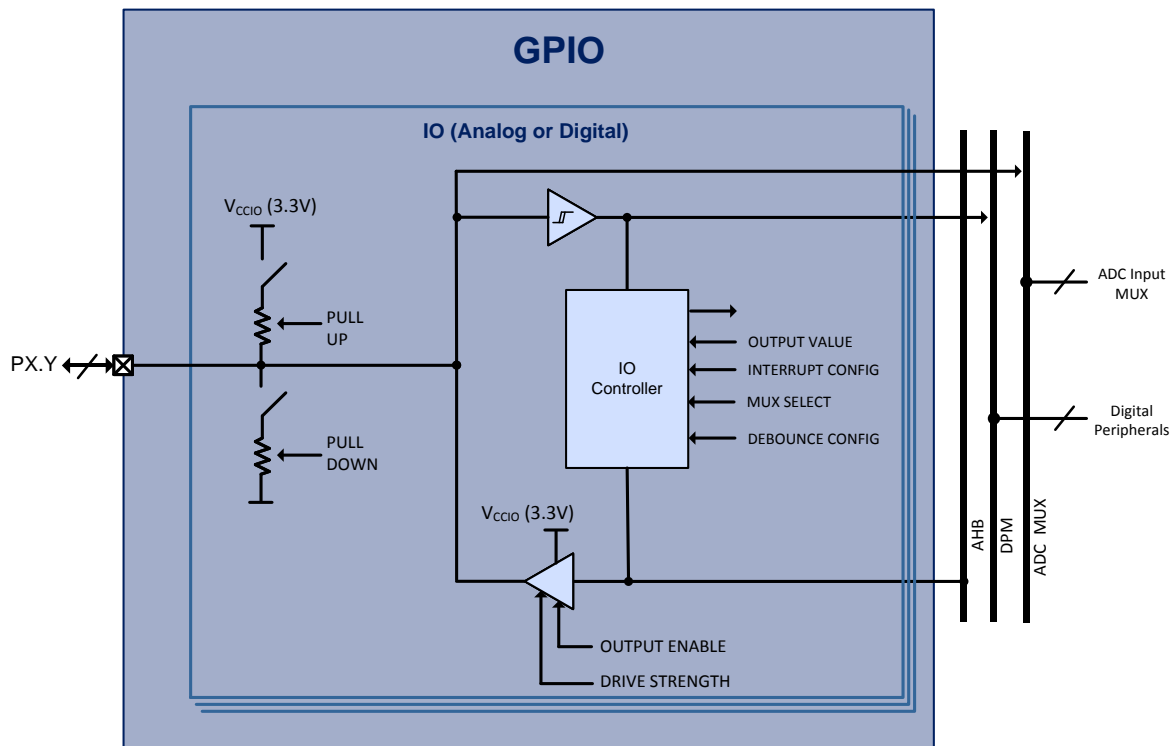
## 18 IO CONTROLLER

### 18.1 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

### 18.2 Block Diagram

Figure 18-1 IO Controller Block Diagram



### 18.3 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.

## 18.4 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 18-1 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   | USDCLK  | TRACED3  | EMUXC    | ADC4   |
| PF5 | GPIOF5                   | TCPWM5 | TDPWM5 | TMS/SWDIO | TCPHA   | USDSS   |          | EMUXD    | ADC5   |
| PF6 | GPIOF6                   | TCPWM6 | TDPWM6 | TDI       | TCPHB   | USDMOSI | CANRXD   | I2CSCL   | ADC6   |



## 18.5 Electrical Characteristics

Table 18-2 IO Controller Electrical Characteristics

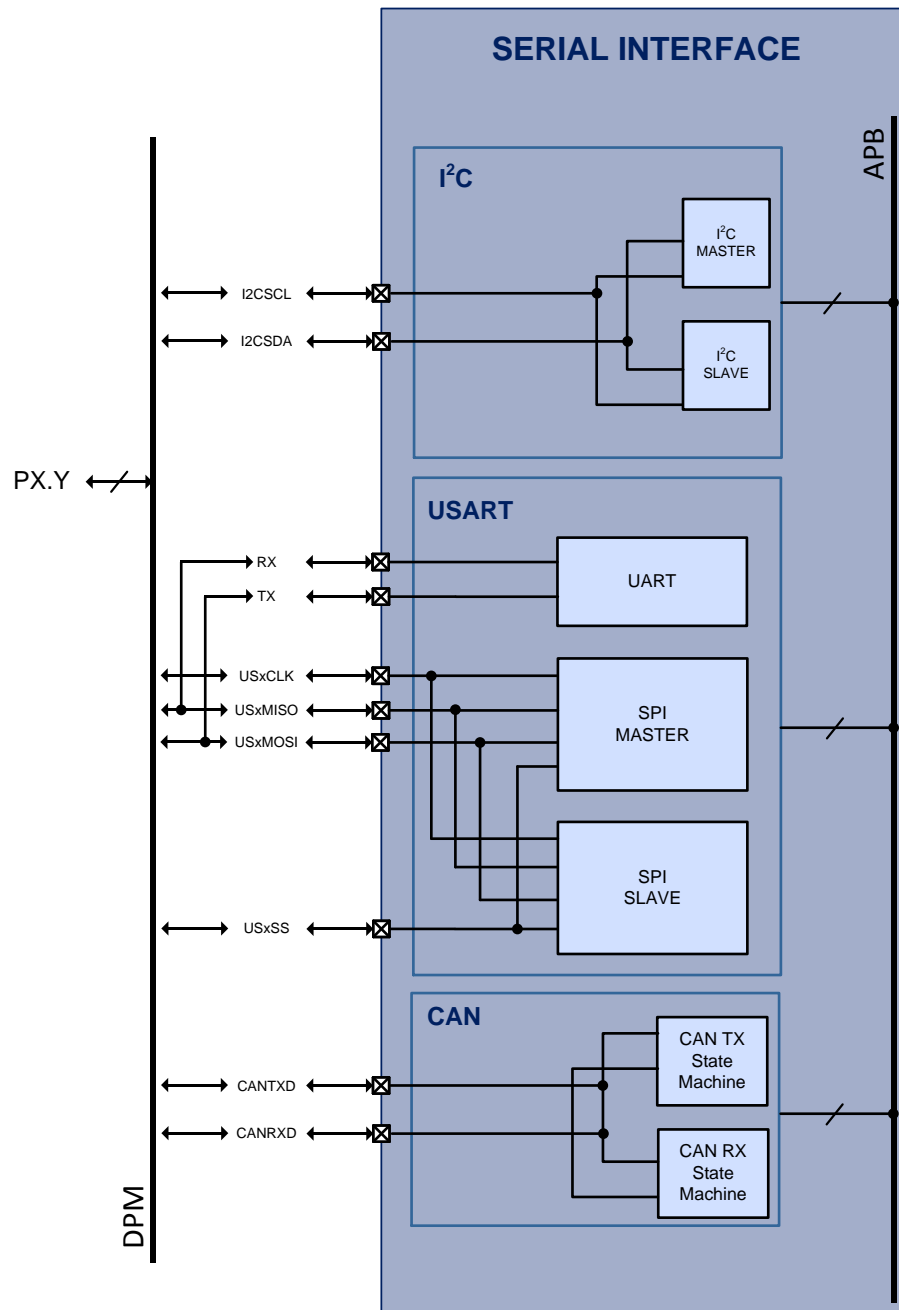
( $V_{CCIO} = 3.3V$ ,  $V_{SYS} = 5V$ ,  $V_{CORE} = 1.2V$ , and  $T_A = -40^{\circ}C$  to  $125^{\circ}C$  unless otherwise specified.)

| SYMBOL                                | PARAMETER  | CONDITIONS             | MIN       | TYP | MAX   | UNIT       |
|---------------------------------------|--|------------------------|-----------|-----|-------|------------|
| <b>All other IO pins (Digital IO)</b> |  |                        |           |     |       |            |
| $V_{IH}$                              | High-level input voltage   |                        | 2.1       |     |       | V          |
| $V_{IL}$                              | Low-level input voltage  |                        |           |     | 0.825 | V          |
| $I_{OL}$                              | Low-level output sink current<br>(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<br>(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  | $\mu A$    |
| $R_{PU}$                              | Weak pull-up resistance  | When pull-up enabled   | 45        | 60  | 100   | k $\Omega$ |
| $R_{PD}$                              | Weak pull-down resistance  | When pull-down enabled | 45        | 60  | 115   | k $\Omega$ |

## 19 SERIAL INTERFACE

### 19.1 Block Diagram

Figure 19-1 Serial Interface Block Diagram



## 19.2 Functional Description

The PAC55XX has three types of serial interfaces: I<sup>2</sup>C, USART and CAN. The PAC55XX has one I<sup>2</sup>C controller, one CAN controller and up to 3 USARTs.

### 19.3 I<sup>2</sup>C Controller

The PAC55XX contains one I<sup>2</sup>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<sup>2</sup>C controller can support various modes of operation:

- I<sup>2</sup>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<sup>2</sup>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<sup>2</sup>C peripheral may operate either by polling, or can be configured to be interrupt driven for both receive and transmit operations.

### 19.4 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.

#### 19.4.1 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

#### 19.4.2 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

### 19.5 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

## 19.6 Dynamic Characteristics

**Table 19-1 Serial Interface Dynamic Characteristics**

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

| SYMBOL                   | PARAMETER                              | CONDITIONS                        | MIN   | TYP                   | MAX | UNIT |
|--------------------------|--|-----------------------------------|-------|-----------------------|-----|------|
| I <sup>2</sup> C         |  |                                   |       |                       |     |      |
| f <sub>I2CCLK</sub>      | I <sup>2</sup> C 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 <sub>UARTCLK</sub>     | USART input clock frequency            |                                   |       | f <sub>PCLK</sub> /16 |     | MHz  |
| f <sub>UARTBAUD</sub>    | UART baud rate                         | f <sub>USARTCLK</sub> = 7.1825MHz |       | 1                     |     | Mbps |
| USART (SPI mode)         |  |                                   |       |                       |     |      |
| f <sub>SPICLK</sub>      | USART input clock frequency            | Master mode                       |       | 50                    |     | MHz  |
|                          |  | Slave mode                        |       | 50                    |     | MHz  |
| f <sub>USARTSPICLK</sub> | USART SPI clock frequency              | Master mode                       |       | 25                    |     | MHz  |
|                          |  | Slave mode                        |       | 25                    |     | MHz  |
| CAN                      |  |                                   |       |                       |     |      |
| f <sub>CANCLK</sub>      | CAN input clock frequency              |                                   |       | 50                    |     | MHz  |
| f <sub>CANTX</sub>       | CAN transmit clock frequency           |                                   |       | 1                     |     | Mbps |
| f <sub>CANRX</sub>       | CAN receive clock frequency            |                                   |       | 1                     |     | Mbps |

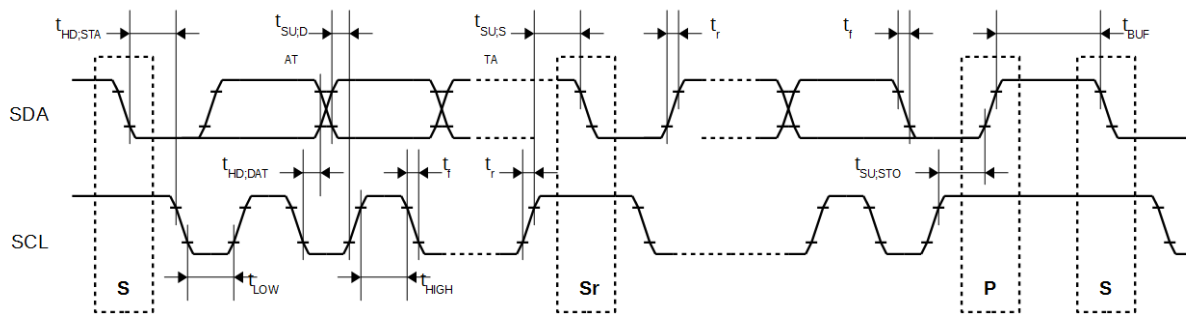
**Table 19-2 I<sup>2</sup>C Dynamic Characteristics**

( $V_{CCIO} = 3.3V$ ,  $V_{SYS} = 5V$ ,  $V_{CORE} = 1.2V$ , and  $T_A = -40^{\circ}C$  to  $125^{\circ}C$  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  |     |     | $\mu s$ |
|            |                     | Full-speed mode | 1.3  |     |     | $\mu s$ |
|            |                     | Fast mode       | 0.5  |     |     | $\mu s$ |
| $t_{HIGH}$ | SCL clock high      | Standard mode   | 4.0  |     |     | $\mu s$ |
|            |                     | Full-speed mode | 0.6  |     |     | $\mu s$ |
|            |                     | Fast mode       | 0.26 |     |     | $\mu s$ |

|              |  |                                |                             |         |
|--------------|--|--------------------------------|-----------------------------|---------|
| $t_{HD,STA}$ | Hold time for a repeated START condition         | Standard mode                  | 4.0                         | $\mu s$ |
|              |  | Full-speed mode                | 0.6                         | $\mu s$ |
|              |  | Fast mode                      | 0.26                        | $\mu s$ |
| $t_{SU,STA}$ | Set-up time for a repeated START condition       | Standard mode                  | 4.7                         | $\mu s$ |
|              |  | Full-speed mode                | 0.6                         | $\mu s$ |
|              |  | Fast mode                      | 0.26                        | $\mu s$ |
| $t_{HD,DAT}$ | Data hold time                                   | Standard mode                  | 0                      3.45 | $\mu s$ |
|              |  | Full-speed mode                | 0                      0.9  | $\mu s$ |
|              |  | Fast mode                      | 0                           | $\mu s$ |
| $t_{SU,DAT}$ | 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                         | $\mu s$ |
|              |  | Full-speed mode                | 0.6                         | $\mu s$ |
|              |  | Fast mode                      | 0.26                        | $\mu s$ |
| $t_{BUF}$    | Bus free time between a STOP and START condition | Standard mode                  | 4.7                         | $\mu s$ |
|              |  | Full-speed mode                | 1.3                         | $\mu s$ |
|              |  | Fast mode                      | 0.5                         | $\mu s$ |
| $t_r$        | 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      |

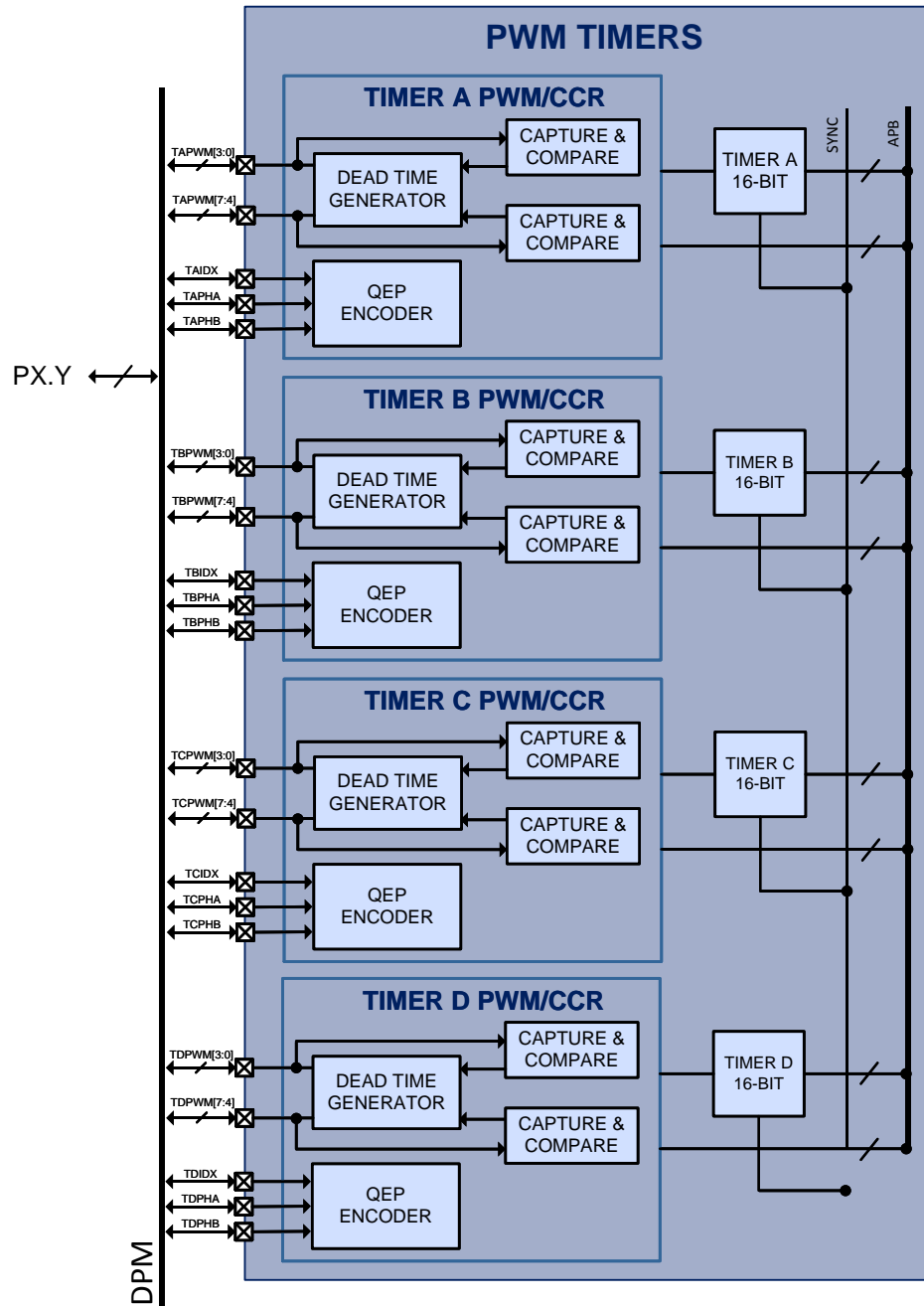
**Figure 19-2 I<sup>2</sup>C Timing Diagram**



## 20 PWM TIMERS

### 20.1 Block Diagram

Figure 20-1 PWM Timers Block Diagram





## 20.2 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

### 20.2.1 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

### 20.2.2 Dead-time Generators (DTG)

- DTG enabled
- 12-bit rising edge delay

- 12-bit falling edge delay

#### 20.2.3 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

## 21 GENERAL PURPOSE TIMERS

### 21.1 Block Diagram

Figure 21-1 SOC Bus Watchdog and Wake-up Timer

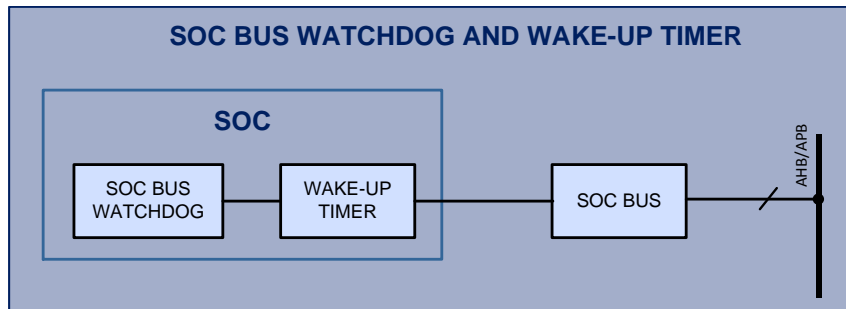
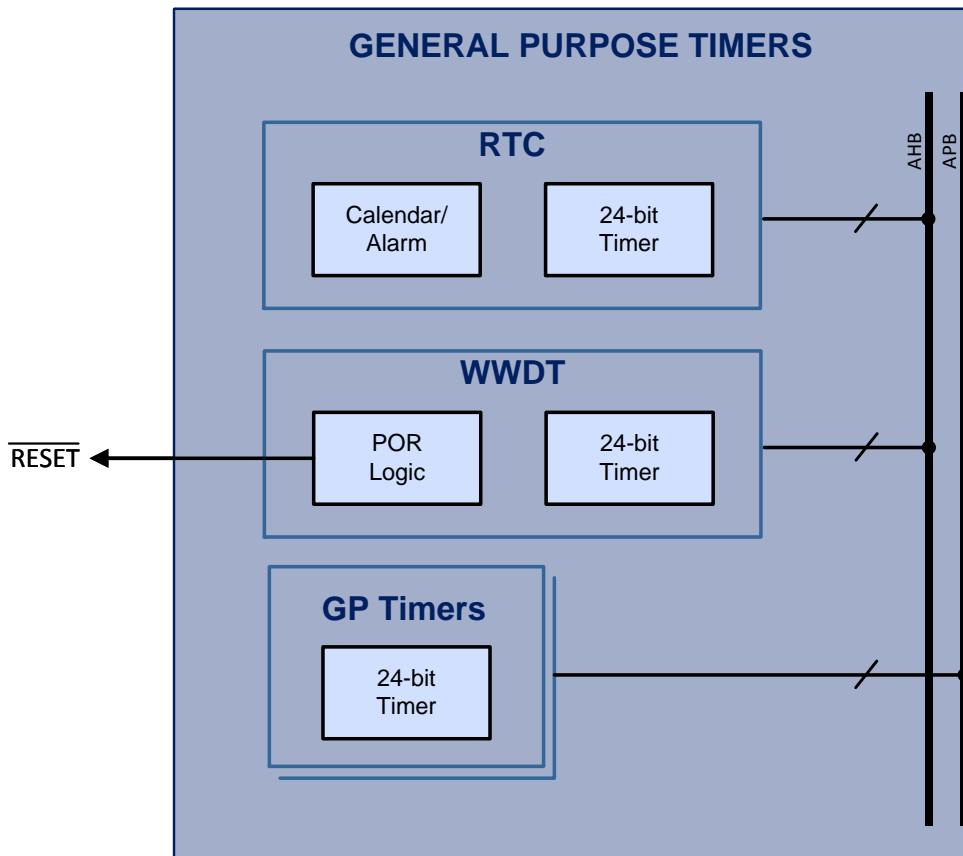


Figure 21-2 General Purpose Timers



## 21.2 Functional Description

### 21.2.1 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.

### 21.2.2 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.

### 21.2.3 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.

### 21.2.4 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.

### 21.2.5 GP Timer (GPT)

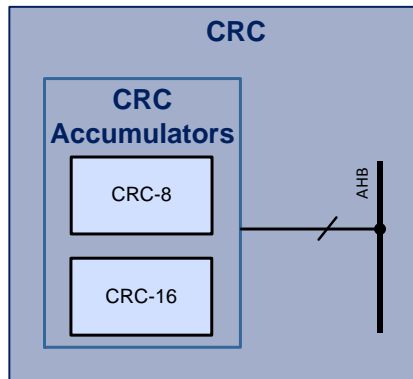
The PAC55XX contains two General Purpose (GP) Timers.

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 /32768. Each of the GPT can be configured to interrupt the MCU when they count down to 0.

## 22 CRC

### 22.1 Block Diagram

Figure 22-1 CRC Block Diagram



### 22.2 Functional Description

The CRC peripheral can perform CRC calculation on data 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

## 23 THERMAL CHARACTERISTICS

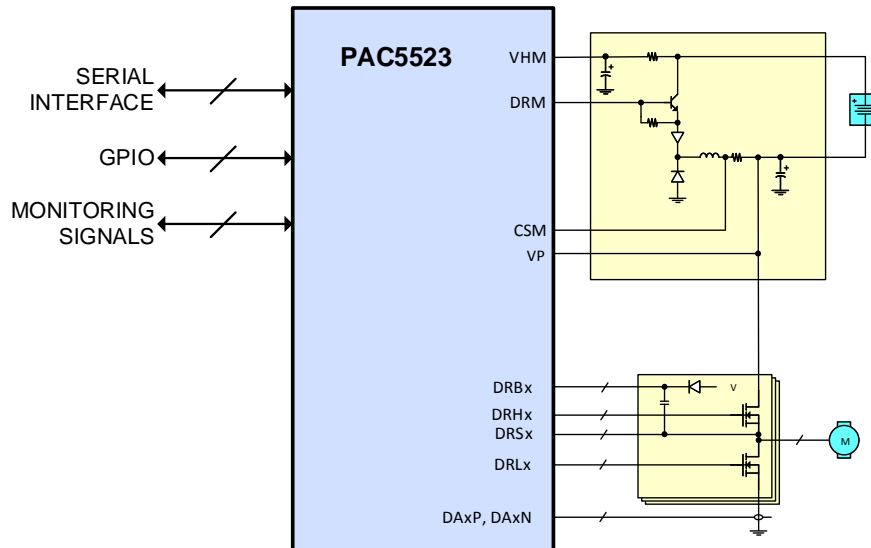
Table 23-1 Thermal Characteristics

| 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 ( $\Theta_{JC}$ )    | 2.897      | °C/W |
| Junction-to-ambient thermal resistance ( $\Theta_{JA}$ ) | 23.36      | °C/W |

## 24 APPLICATION EXAMPLES

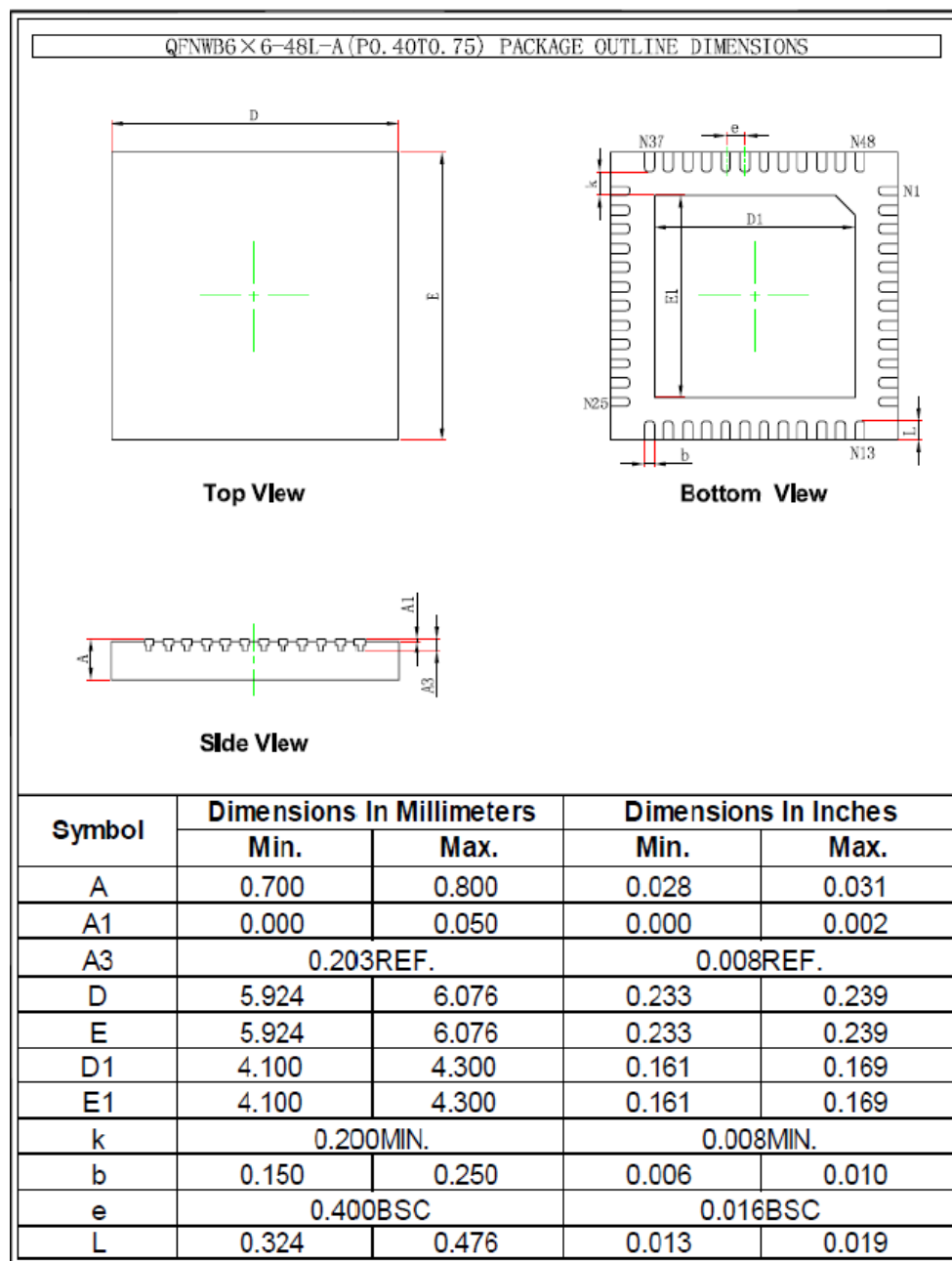
The following simplified diagram shows an example of a single-motor, low-voltage application using the PAC5523 device.

**Figure 24-1 Sensorless FOC/BEMF Motor Drive Using PAC5523 (Simplified Diagram)**



## 25 PACKAGE OUTLINE AND DIMENSIONS

Figure 25-1 TQFN66-48 Package Outline and Dimensions





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