# Si8250/1/2UM

## Digital Power Controller User's Manual

### Single-Chip, Flash Digital Controller
- Supports isolated and non-isolated applications
- Supports AC/DC, DC/DC and PFC applications
- Enables new system capabilities
  - Adaptive dead-time control
  - Nonlinear control response
  - Efficiency optimization
  - Self diagnostics/status reporting

### Dedicated DSP-Based Control Processor
- Update rate up to 10 MHz (independent of firmware)
- Differential input ADC
- Loop filter DSP engine
  - PID + 2nd stage low-pass filter
  - Selectable discrete time or SINC 2nd stage low-pass filter
- Highly flexible DPWM with up to 6 output phases
  - 50 kHz to greater than 1 MHz output
  - Less than 5 ns dithered resolution
- Hardware pulse-by-pulse current limiting with programmable leading-edge blanking
- Programmable hardware overcurrent protection

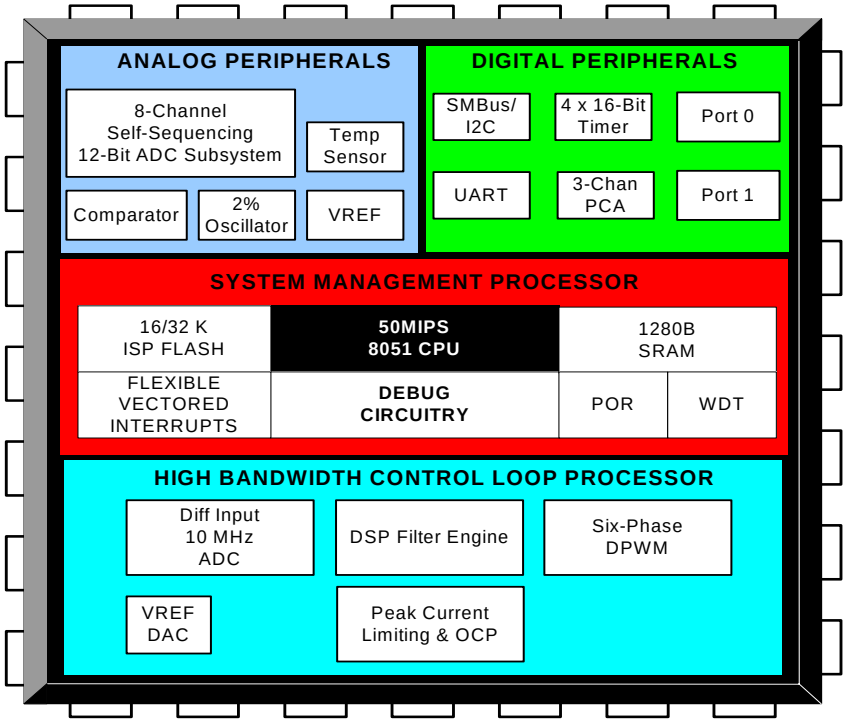
### Typical Applications
- DC/DC converters
- AC/DC converters
- PFC circuits
- DC motor control

### Packages
- 32-pin LQFP
- 28-pin 5 x 5 mm QFN

### 50 MIPS Flash System Management Processor
- 16 or 32 kB of Flash
  - Flash can be used as EEPROM
- On-board 2% oscillator
- Self-sequencing, 8-channel 12-bit ADC
  - Supports firmware-programmable safeguards (UVLO, OTP, OVP)
  - Individual hardware limit detectors with vectored interrupts
  - On-board temperature sensor and VREF
- High-speed, programmable general-purpose comparator
- SMBus hardware interface
- Enhanced UART for isolated control data link
- Four 16-bit timers
- 3-Channel PCA for general-purpose timing or additional PWM outputs
- High-current, fully-programmable I/O port lines

### Comprehensive, Low-Cost Development Kit
- Minimizes learning curve and speeds time-to-market
- Real-time firmware kernel
  - greatly reduces firmware development
- Intuitive compensator design tool
- GUI-based waveform designer/simulator
- System configuration wizards
- Intuitive IDE with real-time debug
  - Standard and on-line debug modes

### Temperature Range
- –40 to +125 ºC



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# 1. System Overview

Digital power supply control offers system performance, cost, and flexibility advantages over traditional analog approaches. Performance gains are made possible through complex adaptive and nonlinear control response and efficiency optimization algorithms. External functions can be implemented in firmware, reducing external component count and its related size and cost. In-system programmability enables system behavior to be changed quickly and easily.

The Si8250/1/2 digital switching power supply controllers address a wide range of switch mode power topologies. These products consist of dedicated, high-speed hardware control hardware that operates under the supervision of an integrated Flash system management processor. As such, they offer the fast control response, ease-of-use and economies of a hardware solution, and the flexibility of a programmable solution.

Si8250/1/2 devices are useful in both isolated and non-isolated complex systems such as bridge and multiphase topologies. They can operate from the primary or secondary-side of the supply. They provide all necessary system functions including analog data conversion, full digital voltage or phase angle regulation, fault monitoring and recovery, and communications interface in a single chip. Critical control and fault detection functions are implemented in hardware and operate autonomously, even while the CPU is disabled.

As shown in the lower portion of Figure 1.1, the cycle-by-cycle hardware control path extends from the VSENSE input, through the 10 MHz ADC, loop filter, and six-phase DPWM. The ADC and loop filter together generate frequency-compensated duty cycle term u(n), which directly modulates the DPWM hardware. The system management processor provides functions such as system initialization, control optimization, fault detection/recovery, system maintenance and communication interface, soft-start/stop management, and other user-defined functions.

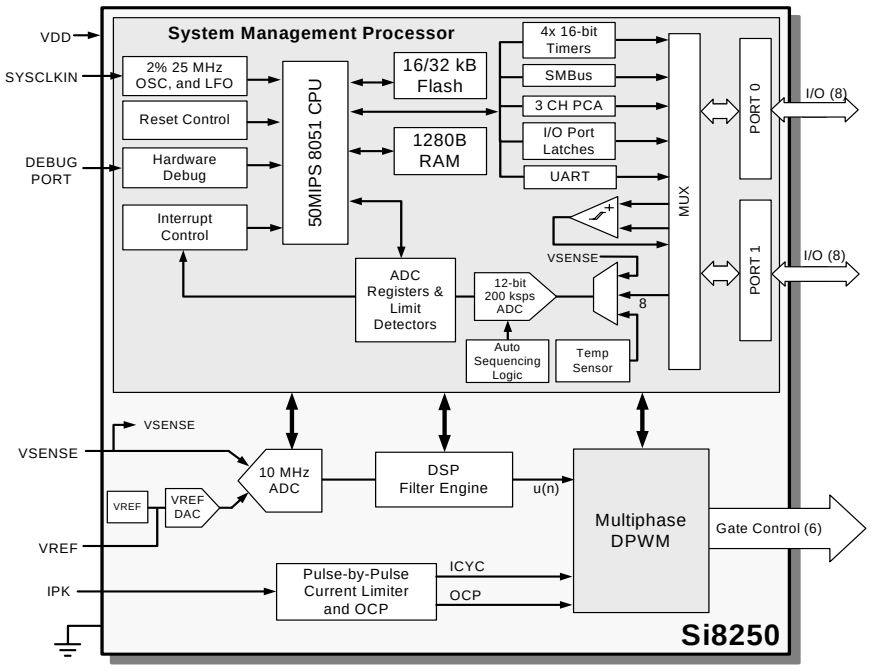


**Figure 1.1. Si8250/1/2 Block Diagram**

**Table 1.1. Product Selection Guide**

| Product Ordering Number | Flash Memory | Number of PWM phases | UART | Package |
|---|---|---|---|---|
| Si8250-IQ | 32 kB | 6 | ✔ | LQFP-32 |
| Si8250-IM | 32 kB | 6 | ✔ | QFN-28 |
| Si8251-IQ | 16 kB | 6 | ✔ | LQFP-32 |
| Si8251-IM | 16 kB | 6 | ✔ | QFN-28 |
| Si8252-IQ | 16 kB | 3 | — | LQFP-32 |
| Si8252-IM | 16 kB | 3 | — | QFN-28 |

## 1.1. 10 MHz Control Processor ADC

The 6-bit, 10 MHz ADC is enabled during steady-state power supply operation. It digitizes the difference between the supply output voltage (VSENSE), and a programmable voltage reference level supplied by the 9-bit voltage reference DAC (REFDAC). The ADC has a built-in, programmable transient detector that asserts an interrupt when the ADC output suddenly deviates outside of the programmed range. Programmable LSB size provides a means to avoid limit cycle oscillation.

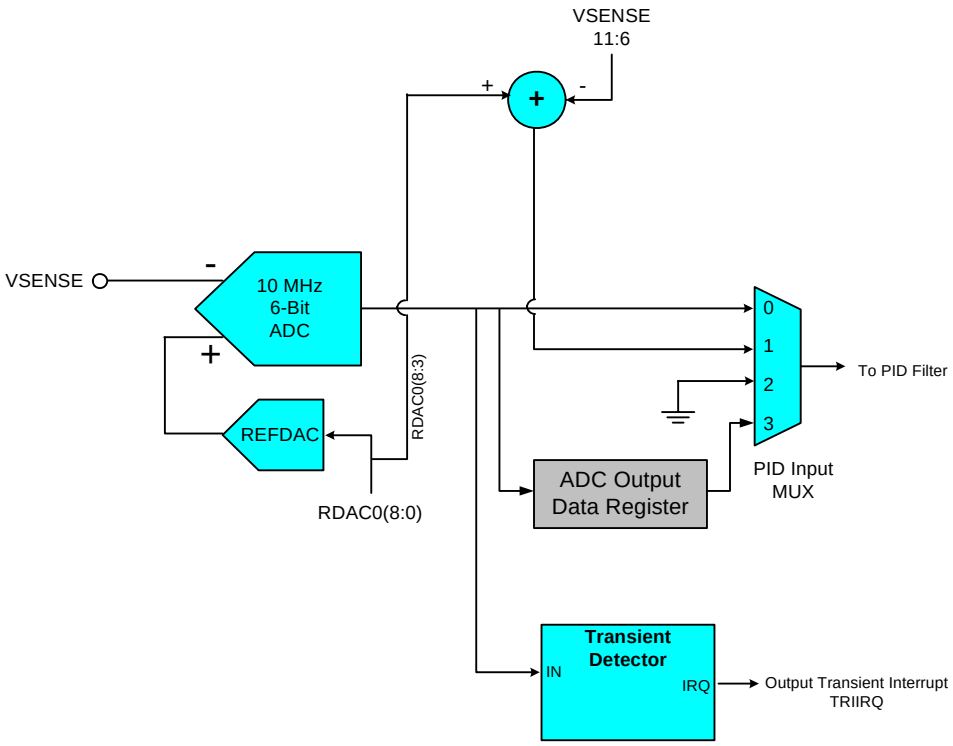


**Figure 1.2. 10 MHz Control Processor ADC**

## 1.2. DSP Filter Engine

The DSP filter engine consists of a first-stage PID filter and second stage low-pass filter. All coefficients are dynamically programmable enabling the system management processor to optimize loop response as load conditions change. The PID integrator has anti-wind-out logic that is automatically enabled during peak current limiting. One of two second-stage low-pass filters can be selected by software: a two-pole low pass that is updated at 10 MHz or a single switching cycle "quiet mode" SINC decimation filter that generates zeros at frequency intervals equal to fs/(2 x Decimation Ratio). The decimation ratio should be chosen to place a zero at the PWM frequency for the maximum attenuation of the PWM frequency component.

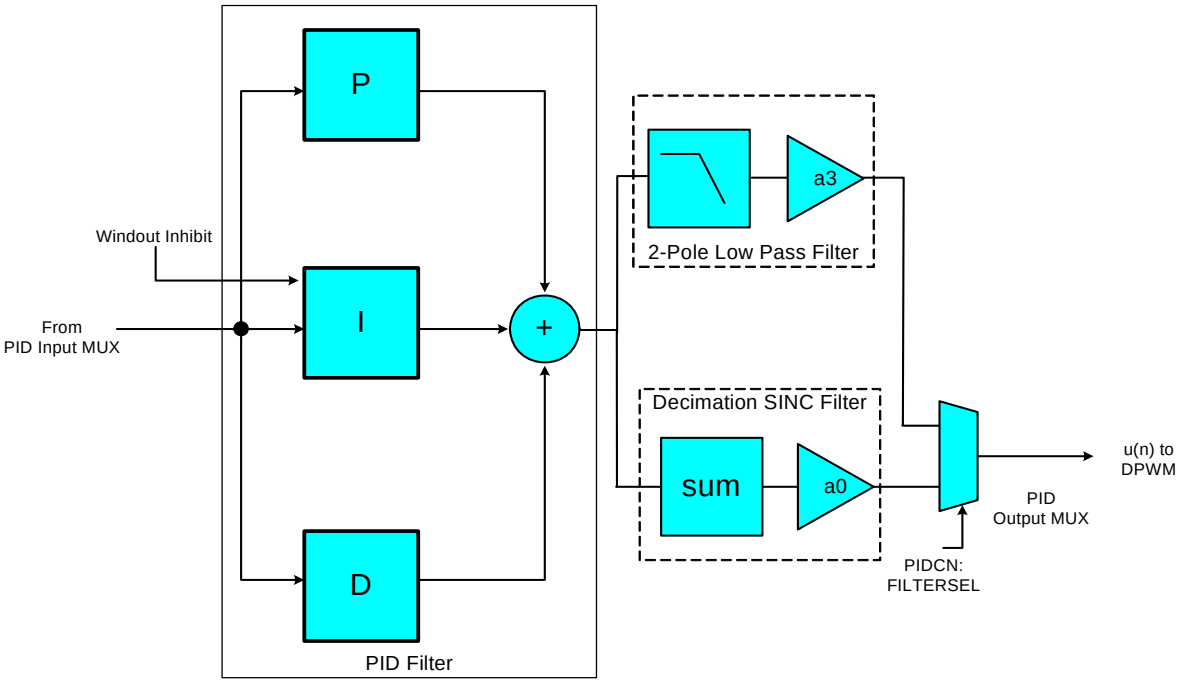


**Figure 1.3. DSP Filter Engine**

## 1.3. Six-Channel DPWM

The DPWM is a highly flexible timing generator that supports up to six modulation phases. Fixed or dynamically-adjustable dead times are supported. PWM and phase modulation are also supported. Output timing resolution is 5 ns (undithered). The DPWM is initialized by the system management processor and can be directly modulated in hardware or by the system management processor. A Trim and Limit subsystem enables the system management processor to program u(n) upper and lower limits for each output phase. It also provides the means for the system management processor to apply a time bias to u(n) for each timing phase to compensate for system power stage anomalies.

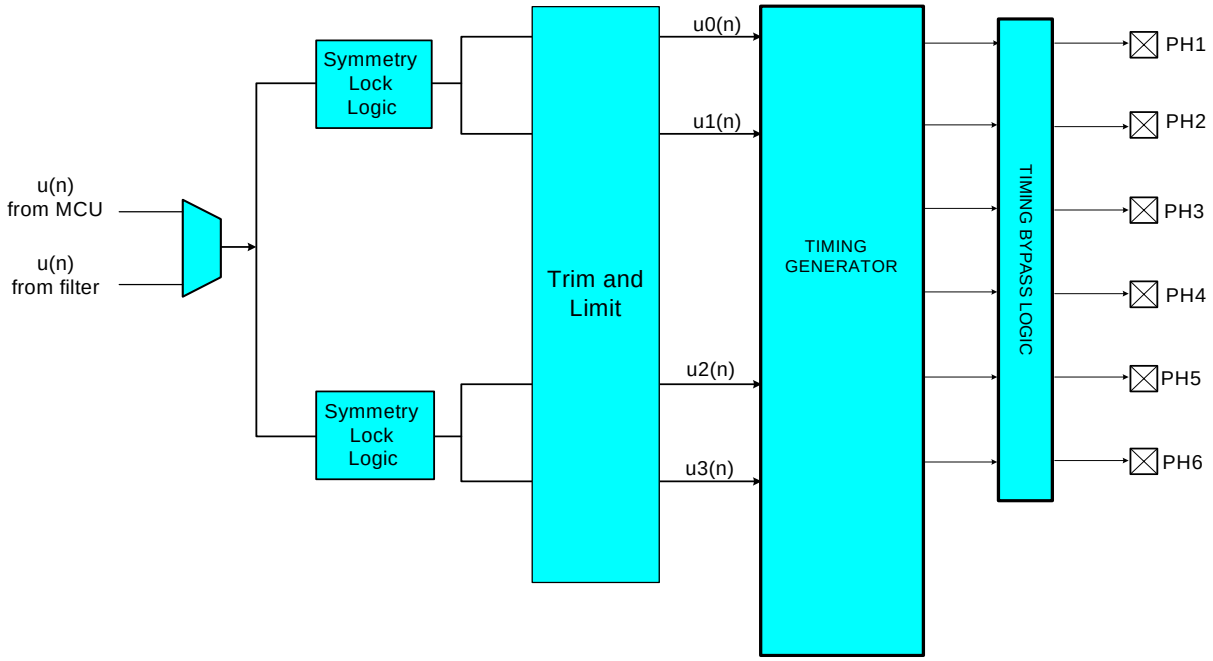


**Figure 1.4. Six-Channel DPWM**

## 1.4. Peak Current Limit Comparator

Cycle-by-cycle current limiting and overcurrent protection are provided by this subsystem. The output of the Peak Current Limit Comparator is asserted when the inductor current waveform applied to the IPK input exceeds the comparator threshold setting. Programmable leading edge blanking is provided to guard against false triggers. An overcurrent protection accumulator asserts an OCP interrupt when the number of consecutive current limit cycle interrupts equals a programmed maximum.

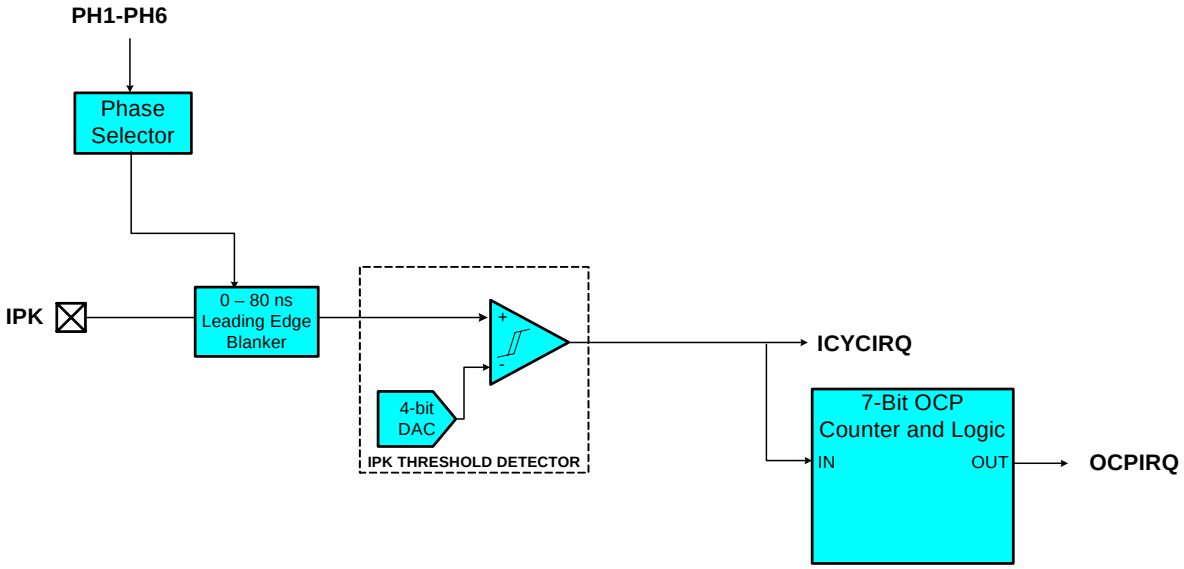


**Figure 1.5. Peak Current Limit Comparator**

## 1.5. Self-Sequencing 12-Bit ADC

Other system parameters, such as the supply input voltage, are digitized by a self-sequencing 12-bit, 200 ksps ADC. This ADC has individual result registers with programmable limit detectors for each ADC input MUX channel. A vectored interrupt is generated when the measured parameter exceeds the programmed limits. This monitoring mechanism enables fast response to system fault conditions and facilitates efficient interrupt-driven systems.

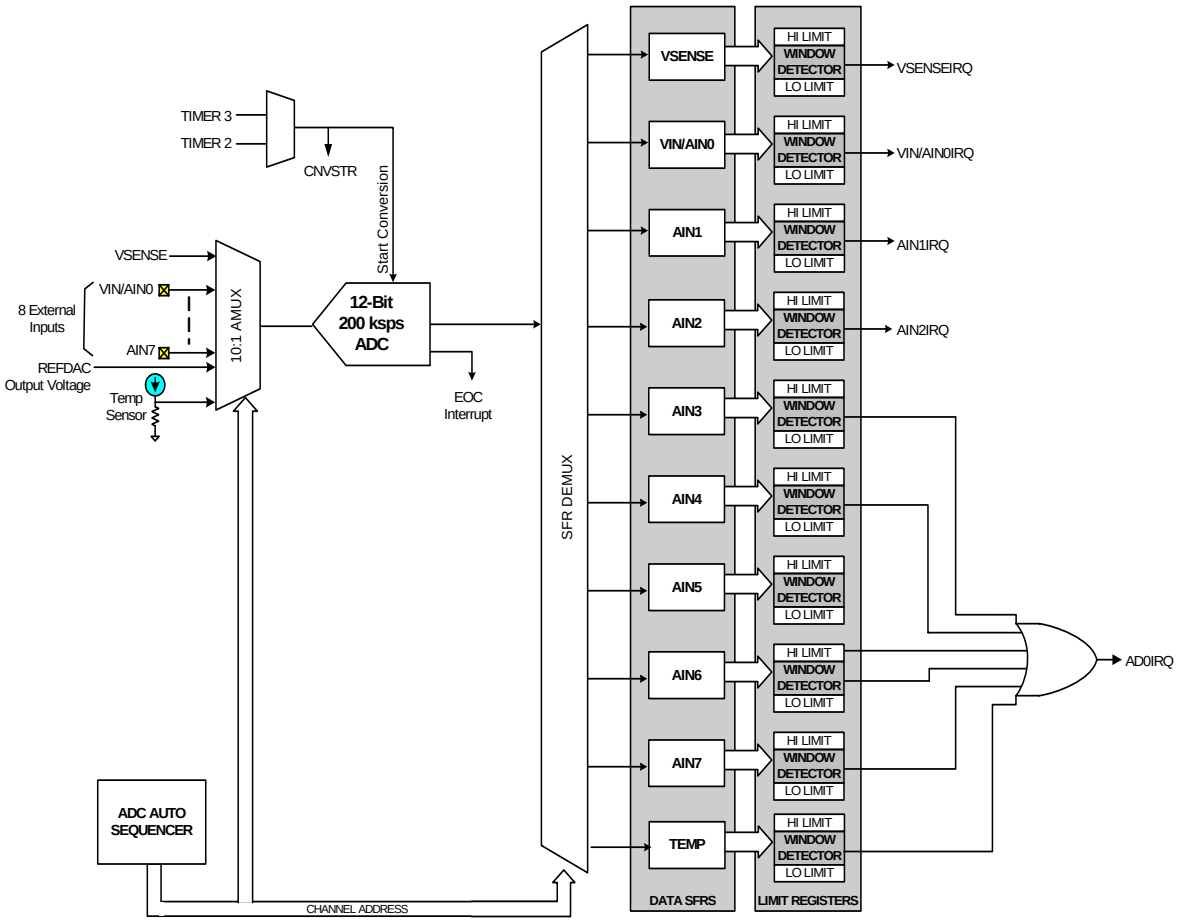


**Figure 1.6. Self Sequencing ADC Overview Diagram**

## 1.6. System Management Processor

The Si8250/1/2 devices use Silicon Laboratories' proprietary CIP-51 microcontroller core. The CIP-51 is fully compatible with the MCS-51™ instruction set. Standard 803x/805x assemblers and compilers can be used to develop software. The CIP-51 employs a pipelined architecture that greatly increases its instruction throughput over the standard 8051 architecture. In a standard 8051, all instructions except for MUL and DIV take 12 or 24 system clock cycles to execute and usually have a maximum system clock of 12–24 MHz. By contrast, the CIP-51 core executes 70% of its instructions in one or two system clock cycles, with no instructions taking more than eight system clock cycles.

With the CIP-51's system clock running at 50 MHz, it has a peak throughput of 50 MIPS. The CIP-51 has a total of 109 instructions. The table below shows the total number of instructions that require each execution time.

| Clocks to Execute | 1 | 2 | 2/4 | 3 | 3/5 | 4 | 5 | 4/6 | 6 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of Instructions | 26 | 50 | 5 | 10 | 7 | 5 | 2 | 1 | 2 | 1 |

The Si8250/1/2 includes several key enhancements to the CIP-51 core and peripherals to improve performance and ease-of-use in end applications. An extended interrupt handler allows the numerous analog and digital peripherals to operate independently of the controller core and interrupt the controller only when necessary. By requiring less intervention from the microcontroller core, an interrupt-driven system is more efficient and allows for easier implementation of multi-tasking, real-time systems.

Eight reset sources are available: power-on reset circuitry (POR), an on-chip VDD monitor, a watchdog timer, a Missing Clock Detector, a voltage level detection from Comparator0, a forced software reset, an external reset pin, and an illegal Flash access protection circuit. Each reset source except for the POR, Reset Input Pin, or Flash error may be disabled by the user in software. The WDT may be permanently enabled in software after a power-on reset during system management processor initialization. The internal oscillator is factory calibrated to 24.5 MHz ±2%. A clock multiplier allows for operation at up to 50 MHz.

## 1.7. Development Tools

Si8250/1/2 devices include on-chip Silicon Laboratories 2-Wire (C2) debug circuitry that provides non-intrusive, full-speed, in-circuit debugging of the production part installed in the end application. Silicon Labs' debugging system supports inspection and modification of memory and registers, breakpoints, and single stepping. No additional target RAM, program memory, timers, or communications channels are required. All the digital and analog peripherals are functional and work correctly while debugging. All the peripherals (except for the ADC and SMBus) are stalled when the system management processor is halted, during single stepping, or at a breakpoint in order to keep them synchronized.

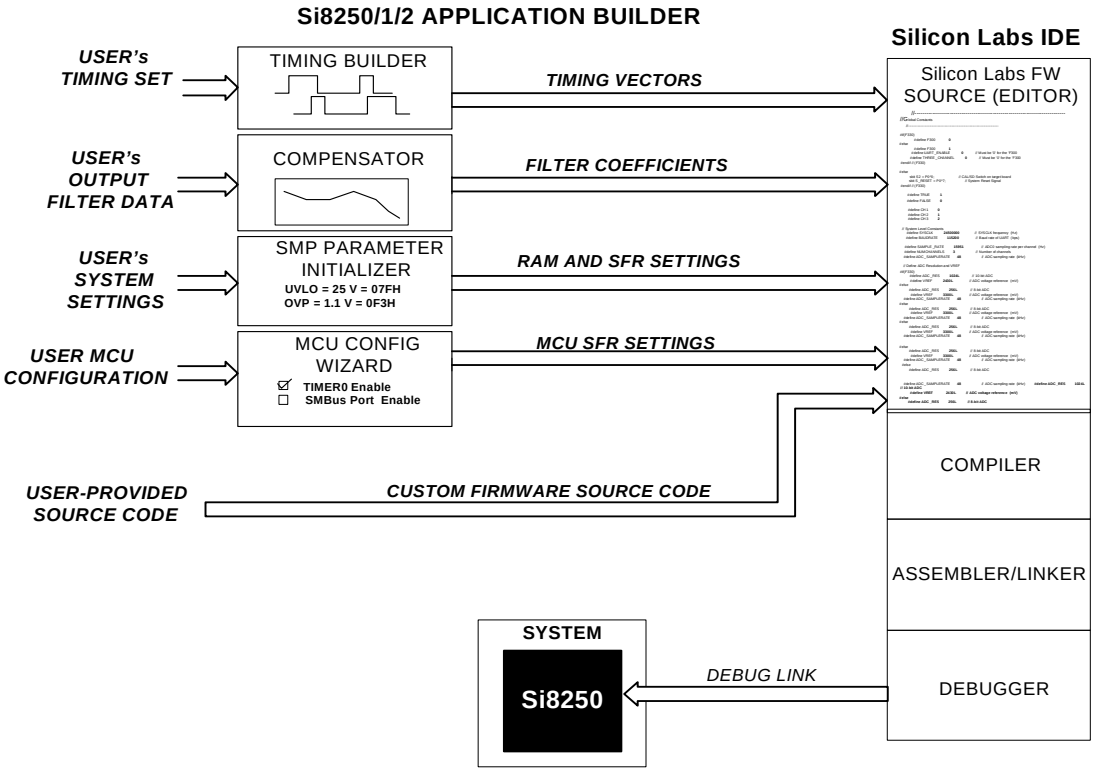


**Figure 1.7. Development/In-System Debug Diagram**

The Si8250DK development kit consists of a standard Silicon Labs IDE (editor, macro-assembler/linker, demo C compiler and real-time, in-system debugger) and a SMPS Application Builder and real-time firmware kernel. With the power supply hardware design as a starting point, the user enters system-specific parameters, such as minimum PWM duty cycle waveforms, system operating points, protection limits, and system management processor configuration, into the SMPS Builder.

Compensation can be done in the familiar S-domain, allowing the user to apply proven design techniques while fully deriving all of the benefits of a Z-domain solution. Using GUI-based design tools (examples shown in Figure 1.8 and Figure 1.9), the user inputs his system timing, pole/zero locations, and system parameters. With this input, the SMPS Application Builder software calculates and loads the required initialization parameters into the real-time kernel, dramatically simplifying design and speeding time-to-market. The kernel is then compiled into a downloadable firmware program and loaded into the Flash memory of the Si8250/1/2. This development methodology minimizes the amount of code the designer must generate, lowering design risk and speeding time-to-market.

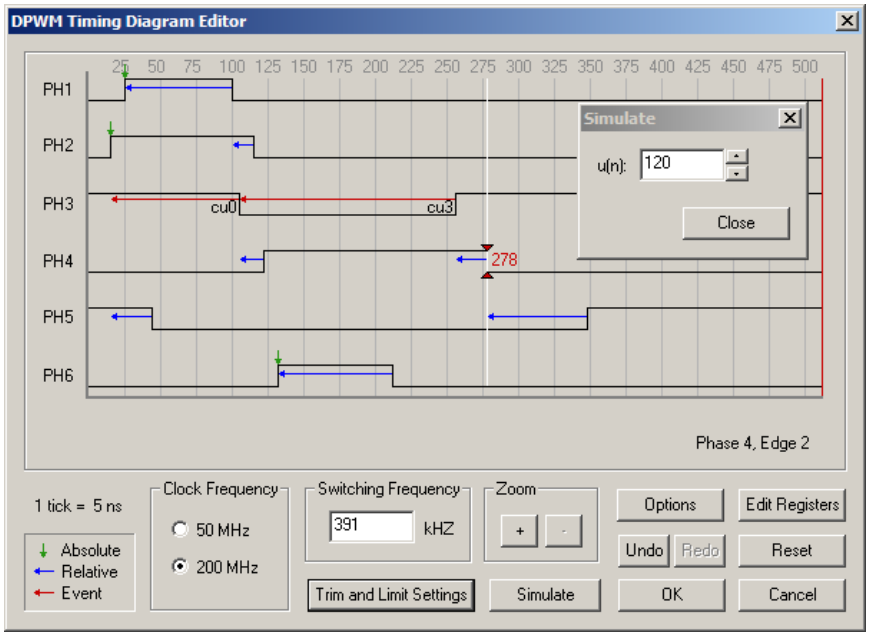


**Figure 1.8. System Waveform Builder Tool**

The System Waveform Builder Tool (Figure 1.8) generates DPWM initialization code directly from timing waveforms drawn by the user.

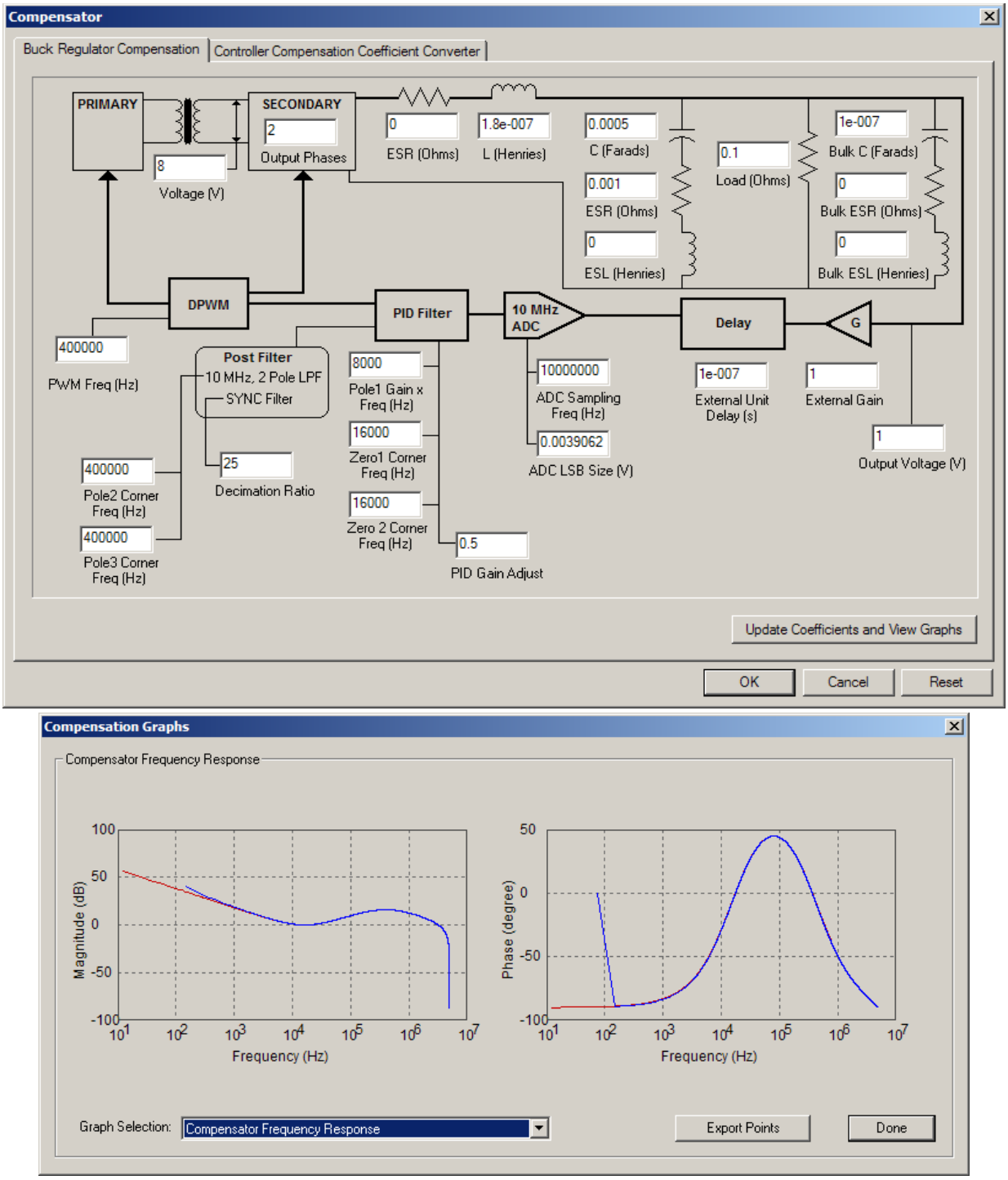


**Figure 1.9. Buck Regulator Compensation Tool**

Compensation tools automatically generate filter coefficients based on the user's system parameters and desired pole/zero frequencies. Controller and loop magnitude and frequency plots allow the user to fine-tune his design.

## 1.8. Memory Map

The CIP-51 has a standard 8051 program and data address configuration. It includes 256 bytes of data RAM, with the upper 128 bytes dual-mapped. Indirect addressing accesses the upper 128 bytes of general purpose RAM, and direct addressing accesses the 128 byte SFR address space. The lower 128 bytes of RAM are accessible via direct and indirect addressing. The first 32 bytes are addressable as four banks of general purpose registers, and the next 16 bytes can be byte addressable or bit addressable.

Program memory consists of up to 32 kB of Flash. This memory may be reprogrammed in-system in 512 byte sectors and requires no special off-chip programming voltage.

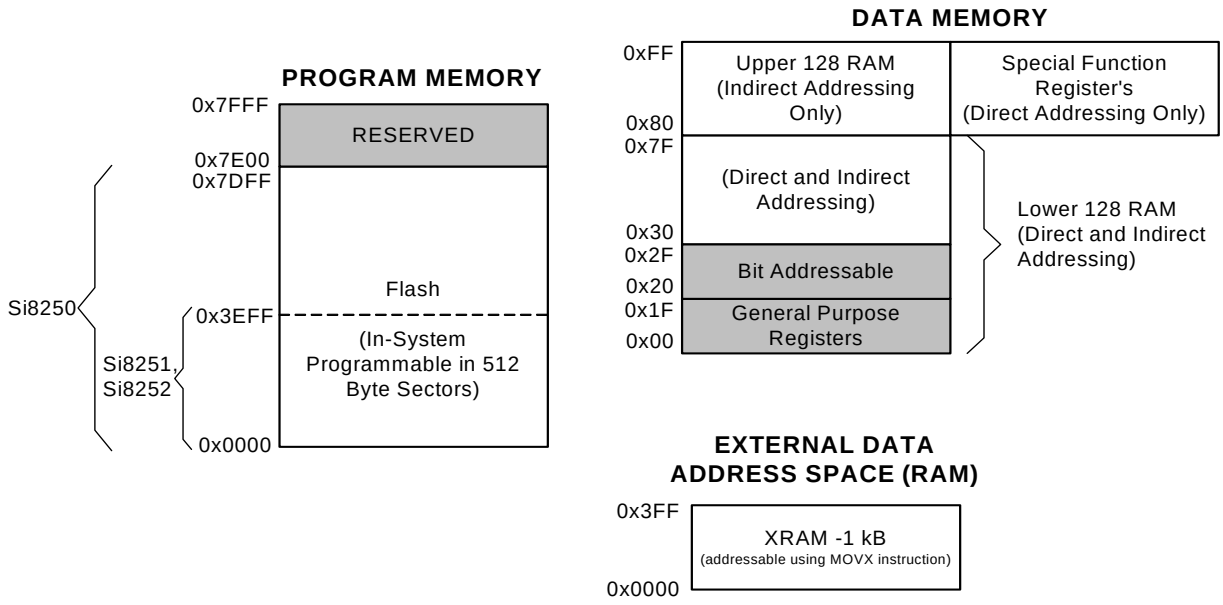


**Figure 1.10. Memory Map Diagram**

## 1.9. Comparator 0

Si8250/1/2 devices include a software-configurable voltage comparator with an input multiplexer. The comparator offers programmable response time and hysteresis and two outputs that are optionally available at the Port pins: a synchronous "latched" output (CP0) or an asynchronous "raw" output (CP0A). Comparator interrupts may be generated on rising, falling, or both edges. When in IDLE or suspend mode, the CP0 interrupt may be used as a "wake-up" source for the processor. Comparator0 may also be configured as a reset source.

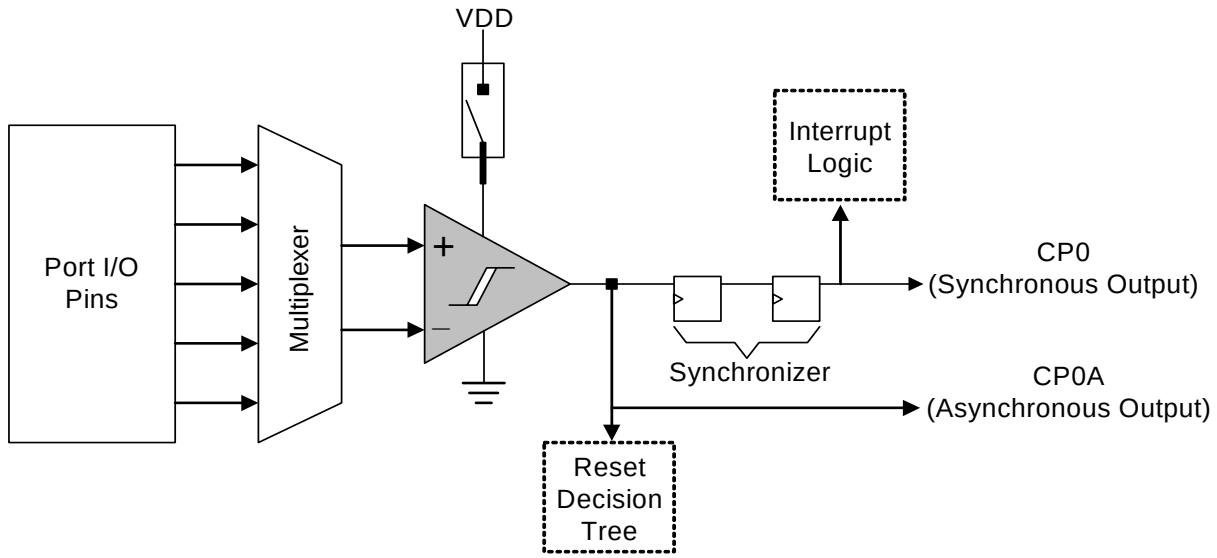


**Figure 1.11. Comparator 0**

## 1.10. Serial Ports

The Si8250/1/2 family includes an SMBus/$I^2C$ interface and a full-duplex UART with enhanced baud rate configuration. The UART is typically used to transmit data across the isolation barrier in isolated supplies while the SMBus port is used as a system communication interface and can operate as a master or slave. Each of the serial buses is fully implemented in hardware and makes extensive use of the CIP-51's interrupts, thus requiring very little CPU intervention.

## 1.11. Port I/O

Si8250/1/2 family devices include 16 port I/O pins. Port pins are organized as two byte-wide ports. The port pins behave like typical 8051 ports with a few enhancements. Port 0 can be configured as a digital I/O and Port 1 can be configured as a digital or analog I/O. Pins selected as digital I/O can be configured for push-pull or open-drain operation. The "weak pullups" that are fixed on typical 8051 devices may be globally disabled to save power.

The Digital Crossbar allows mapping of internal digital system resources to port I/O pins. On-chip counter/timers, serial buses, hardware interrupts, and other digital signals can be configured to appear on the port pins using the Crossbar control registers. This allows the user to select the exact mix of general-purpose port I/O, digital, and analog resources needed for the application.

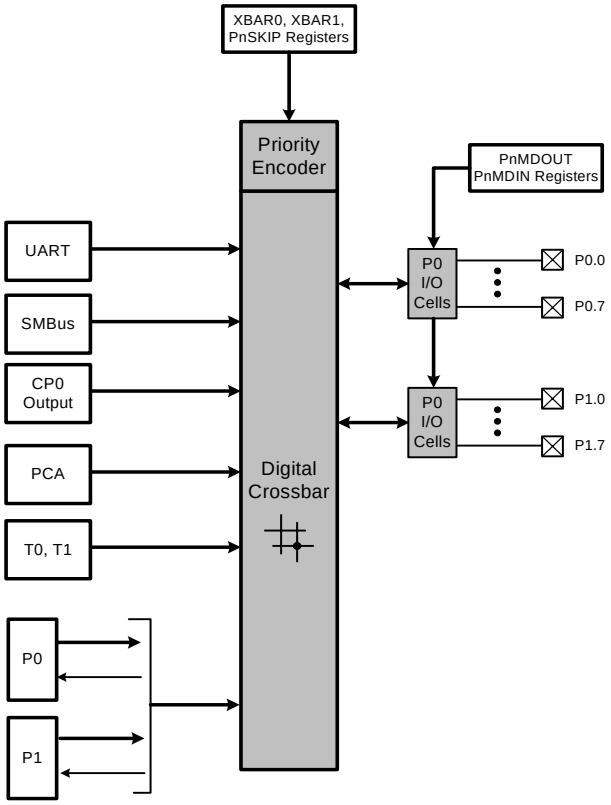


**Figure 1.12. Port I/O Block Diagram**

## 1.12. Programmable Counter Array

The 3-channel Programmable Counter Array (PCA0) provides enhanced timer functionality while requiring less CPU intervention than the standard 8051 counter/timers. The PCA consists of a dedicated 16-bit counter/timer and three 16-bit capture/compare modules. The counter/timer is driven by a programmable time base that can select between six sources: system clock, system clock divided by four, system clock divided by twelve, the external oscillator clock source divided by 8, real-time clock source divided by 8, Timer 0 overflow, or an external clock signal on the External Clock input (ECI) input pin.

Each capture/compare module may be configured to operate independently in one of six modes: Edge-Triggered Capture, Software Timer, High-Speed Output, Frequency Output, 8-Bit PWM, or 16-Bit PWM. Additionally, PCA Module 2 may be used as a watchdog timer (WDT), and is enabled in this mode following a system reset. The PCA Capture/Compare Module I/O and the External Clock Input may be routed to Port I/O using the digital crossbar.

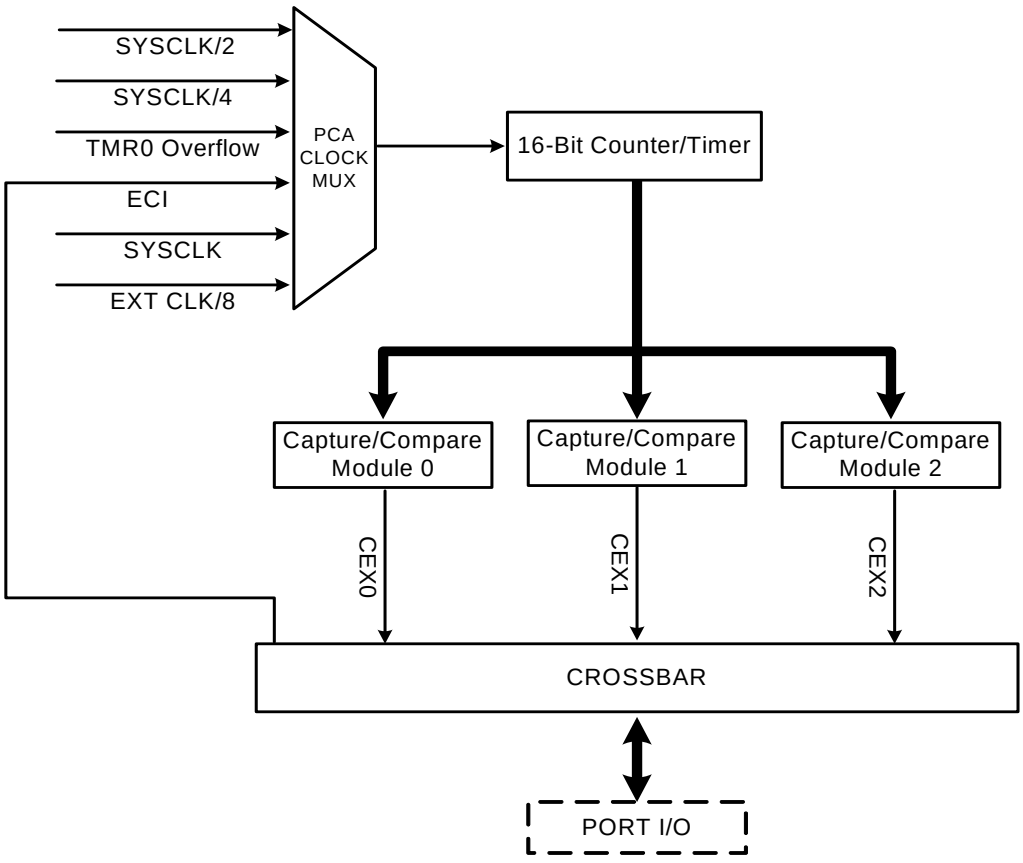


**Figure 1.13. Programmable Counter Array**

## NOTES:

# 2. System Operation

## 2.1. Power Up Initialization

When reset, the Si8250 enters lockout mode (minimum current consumption state) as specified in Table 2.1. During power up, all I/O pins of the Si8250/1/2 are at high impedance (except PH1–PH6, which are low) until device hardware is in its starting state. When this occurs, the I/O pins transition to the user's programmed states. The PH1–PH6 outputs remain low until either initialized to some other state by the system management processor or until DPWM switching begins. The system management processor is enabled and operating at 80 kHz. Typically, the system management processor will remain enabled long enough for firmware to initialize operating parameters, then will enter Stop mode if VIN is below the UVLO threshold. The system management processor can be restored to operating mode by any of four wake-up sources: a Comparator0 interrupt; the falling edge of the UART RX input (for isolated applications); a VIN0/VIN level interrupt (non-isolated applications), or a system management processor reset.

**Table 2.1. Si825x Power-Up State**

| Si8250 Peripheral | Power-Up State |
|---|---|
| VREF Generator | Disabled |
| Reference Scaling DAC | Disabled, output = 0 V |
| 10 MHz ADC (ADC1) | Disabled |
| ADC0 Input MUX | Channel 1 (ADC0) selected |
| DSP Filter | Disabled |
| DPWM Input Control MUX | Channel 0 (filter output) selected |
| DPWM | Disabled, PH outputs = 00 |
| Leading Edge Blanker | Disabled |
| Blanker VT DAC | Disabled |
| Current Limit Comparator | Disabled |
| OCP Detector | Disabled |
| ADC0 | Disabled |
| Port 0 I/O | All I/O = input mode, open drain configuration |
| Port 1 I/O | All I/O = input mode, open drain configuration |
| Interrupts | Individually and globally disabled |
| POR/Brown-out detector | Enabled |
| System Management Processor Clock | 80 kHz LFO enabled |
| GP Comparator | Disabled |
| Serial Ports and Timers | Disabled |

## 2.2. Isolated Applications

An isolated supply example is shown in Figure 2.1. Critical primary-side voltages (e.g., VIN) are digitized and transmitted to the UART on-board the Si8250/1/2 by a Silicon Labs C8051F30x MCU. All secondary-side voltages are measured and converted directly by the ADC0 on the Si8250/1/2. Primary-side gate control signals are isolated using a Silicon Labs Si840x quad-channel, high-speed isolator. Secondary side gate control lines connect directly to the inputs of the corresponding external driver ICs.

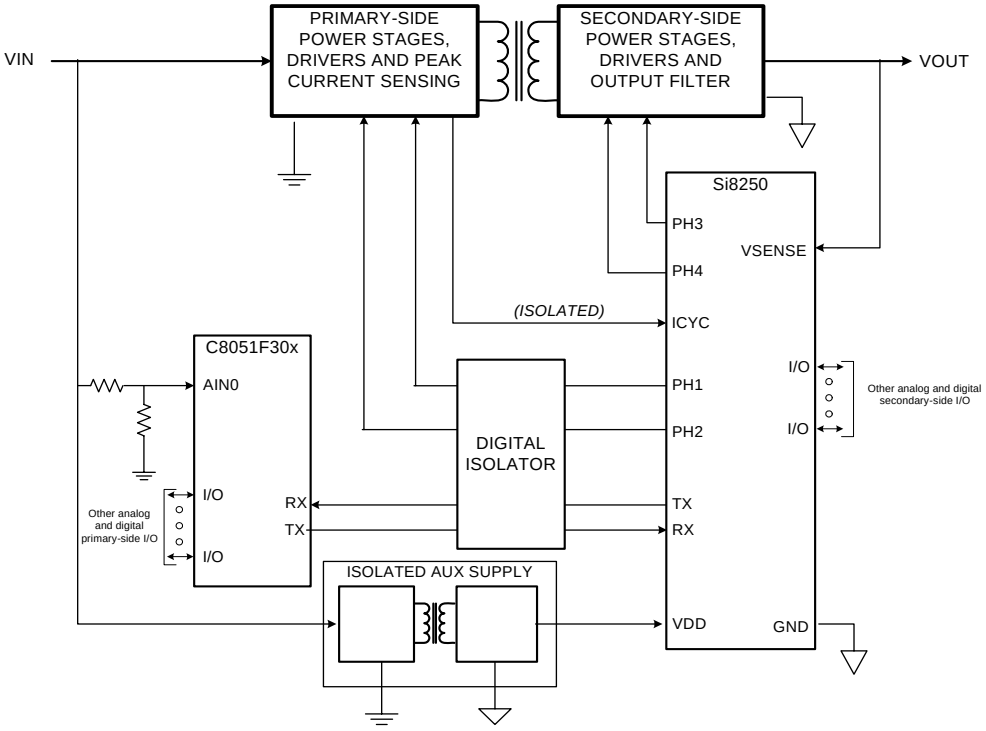


**Figure 2.1. Isolated SMPS Application**

## 2.3. Non-Isolated (POL) Applications

The non-isolated application differs from the isolated case in that the UART is not used. In the non-isolated case, the VIN/AIN0 channel of the 12-bit ADC connects directly to the VIN/AIN0 input of ADC0 as shown in Figure 2.2. A local regulator biases the Si8250/1/2 and all gate control signals connect directly to the external MOSFET driver ICs.

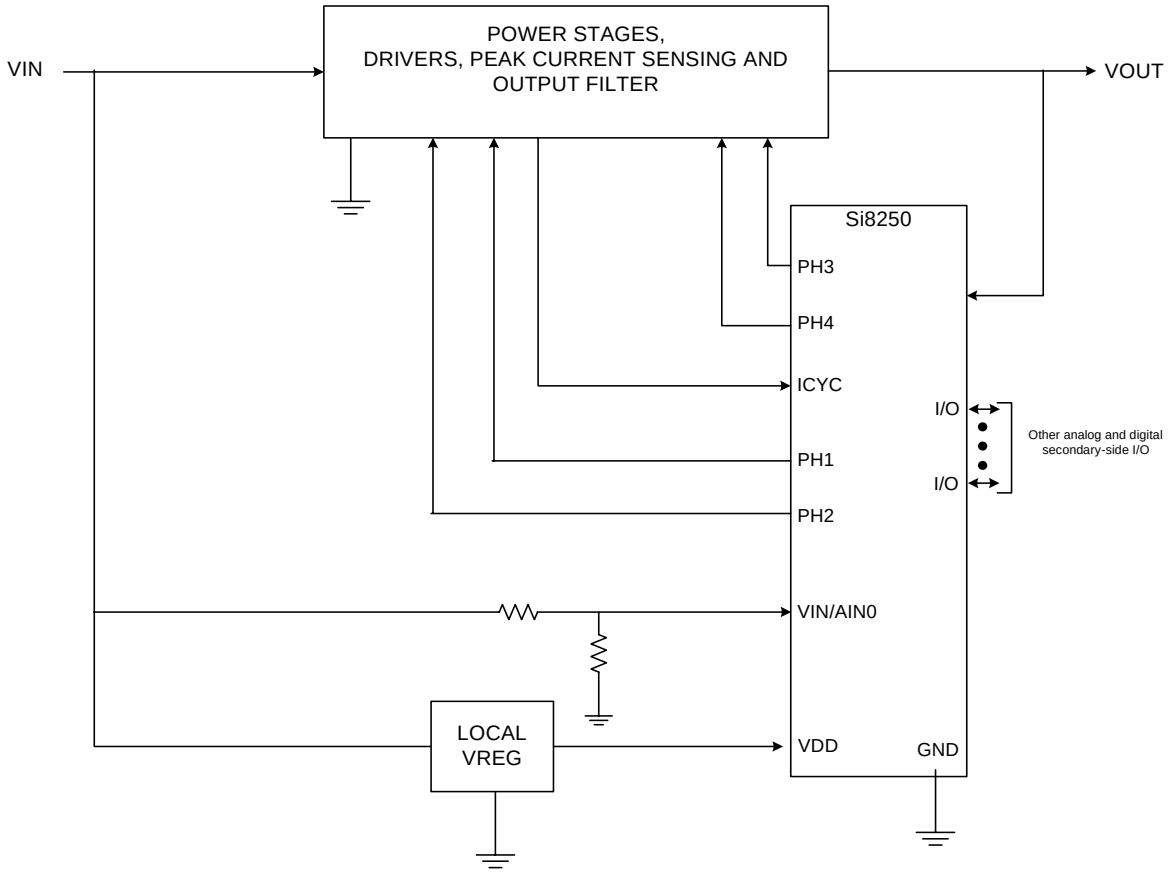


**Figure 2.2. Non Isolated Converter**

## 2.4. Clock Source

The Si8250/1/2 is clocked internally from the low-frequency oscillator (LFO), 25 MHz oscillator, or external clock source. A SYNC function is provided to synchronize the Si8250/1/2 and external hardware.

## 2.5. PWM Limits, Protection and Operating Point Settings

The minimum and maximum PWM duty cycle limits are programmed in firmware and loaded into hardware registers during by the system management processor during initialization. The PWM duty cycle increases in a linear fashion from programmed minimum to programmed maximum as u(n) varies from zero to full scale (0x1FF). System safeguard settings (e.g., over-voltage protection threshold) and operating point settings (e.g., output voltage) are also firmware-programmable and loaded to hardware registers during initialization.

## NOTES:

# 3. Pinout and Package Definitions

**Table 3.1. Pin Descriptions**

| Name | QFN-28 Pin # | LQFP-32 Pin# | Type | Description |
|---|---|---|---|---|
| $\overline{\text{RST}}$/C2CK | 1 | 1 | D I/O | Reset input or bidirect debug clock |
| IPK | 2 | 2 | AIN | Inductor current input |
| VSENSE | 3 | 3 | AIN | Output voltage feedback input |
| GND | 4 | — | AIN | Ground |
| GNDA | — | 4 | AIN | Ground |
| VDD | 5 | — | AIN | Power supply input |
| VDDA | — | 5 | AIN | Power supply input |
| VREF | 6 | 6 | AIN | External voltage reference input |
| P1.0/VIN or AIN0 | 7 | 7 | D I/O or AIN | Port 1 I/O or scaled power supply input voltage |
| P1.1/AIN1 | 8 | 8 | D I/O or AIN | Port 1 I/O or ADC input 1 |
| P1.2/AIN2 | 9 | 9 | D I/O or AIN | Port 1 I/O or ADC input 2 |
| P1.3/AIN3 | 10 | 10 | D I/O or AIN | Port 1 I/O or ADC input 3 |
| P1.4/AIN4 | 11 | 11 | D I/O or AIN | Port 1 I/O or ADC input 4 |
| GND | — | 12 | AIN | Ground |
| VDD | — | 13 | AIN | Power supply input |
| P1.5/AIN5 | 12 | 14 | D I/O or AIN | Port 1 I/O or ADC input 5 |
| P1.6/AIN6 | 13 | 15 | D I/O or AIN | Port 1 I/O or ADC input 6 |
| P1.7/ AIN7/C2D | 14 | 16 | D I/O, DIN or AIN | Port 1 I/O or ADC input 7 or C2 Data |
| P0.7 | 15 | 17 | D I/O | Port 0 I/O |
| P0.6 | 16 | 18 | D I/O | Port 0 I/O |
| P0.5 | 17 | 19 | D I/O | Port 0 I/O |
| P0.4 | 18 | 20 | D I/O | Port 0 I/O |
| P0.3/XCLK | 19 | 21 | D I/O | Port 0 I/O |
| P0.2 | 20 | 22 | D I/O | Port 0 I/O |
| P0.1 | 21 | 23 | D I/O | Port 0 I/O |
| P0.0 | 22 | 24 | D I/O | Port 0 I/O or bidirectional debug data |
| PH6 | 23 | 25 | DOUT | Phase 6 switch control output |
| PH5 | 24 | 26 | DOUT | Phase 5 switch control output |
| PH4 | 25 | 27 | DOUT | Phase 4 switch control output |
| VDD | — | 28 | AIN | Power supply input |
| GND | — | 29 | AIN | Ground |
| PH3 | 26 | 30 | DOUT | Phase 3 switch control output |
| PH2 | 27 | 31 | DOUT | Phase 2 switch control output |
| PH1 | 28 | 32 | DOUT | Phase 1 switch control output |

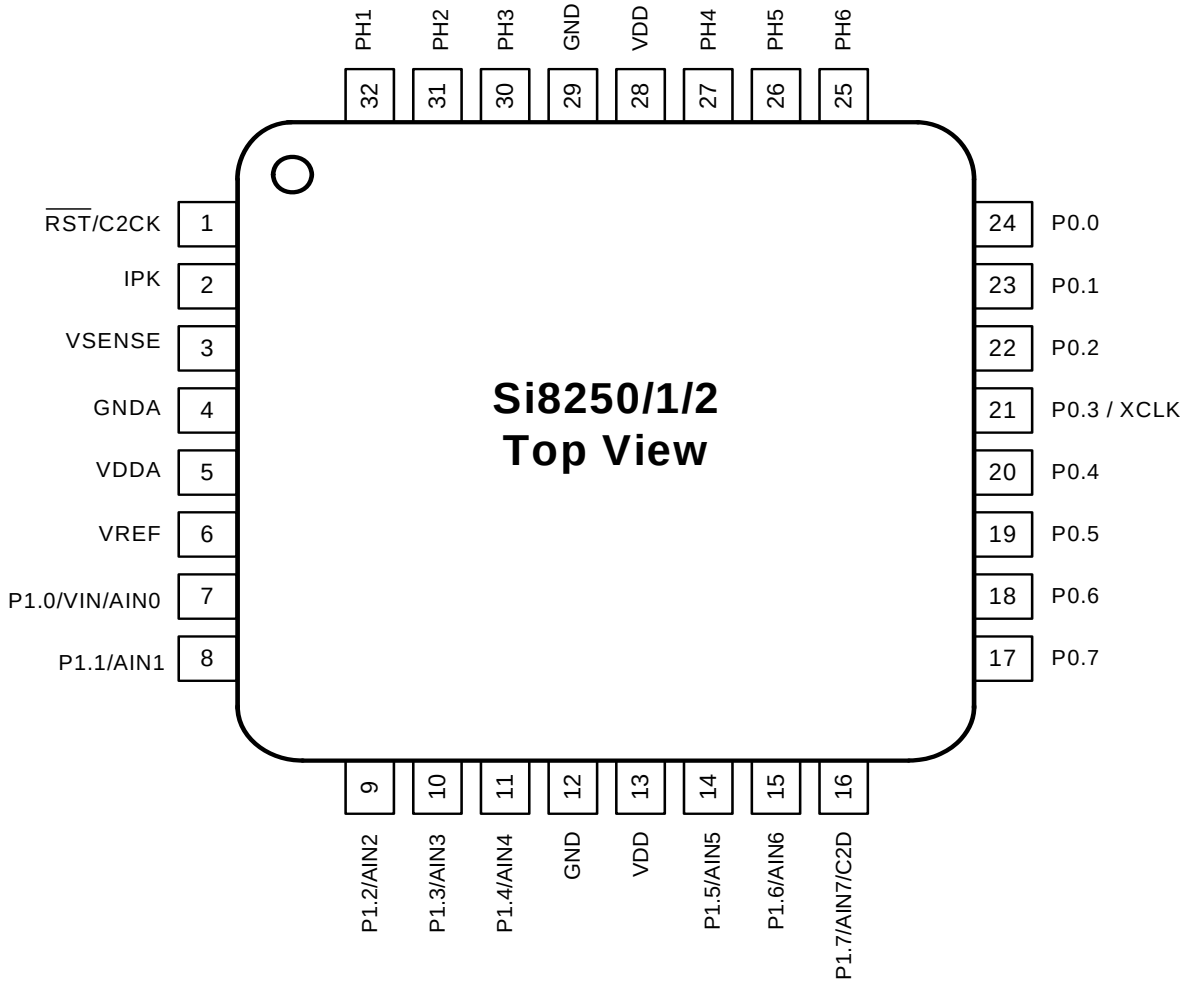


**Figure 3.1. LQFP-32 Pinout Diagram (Top View)**

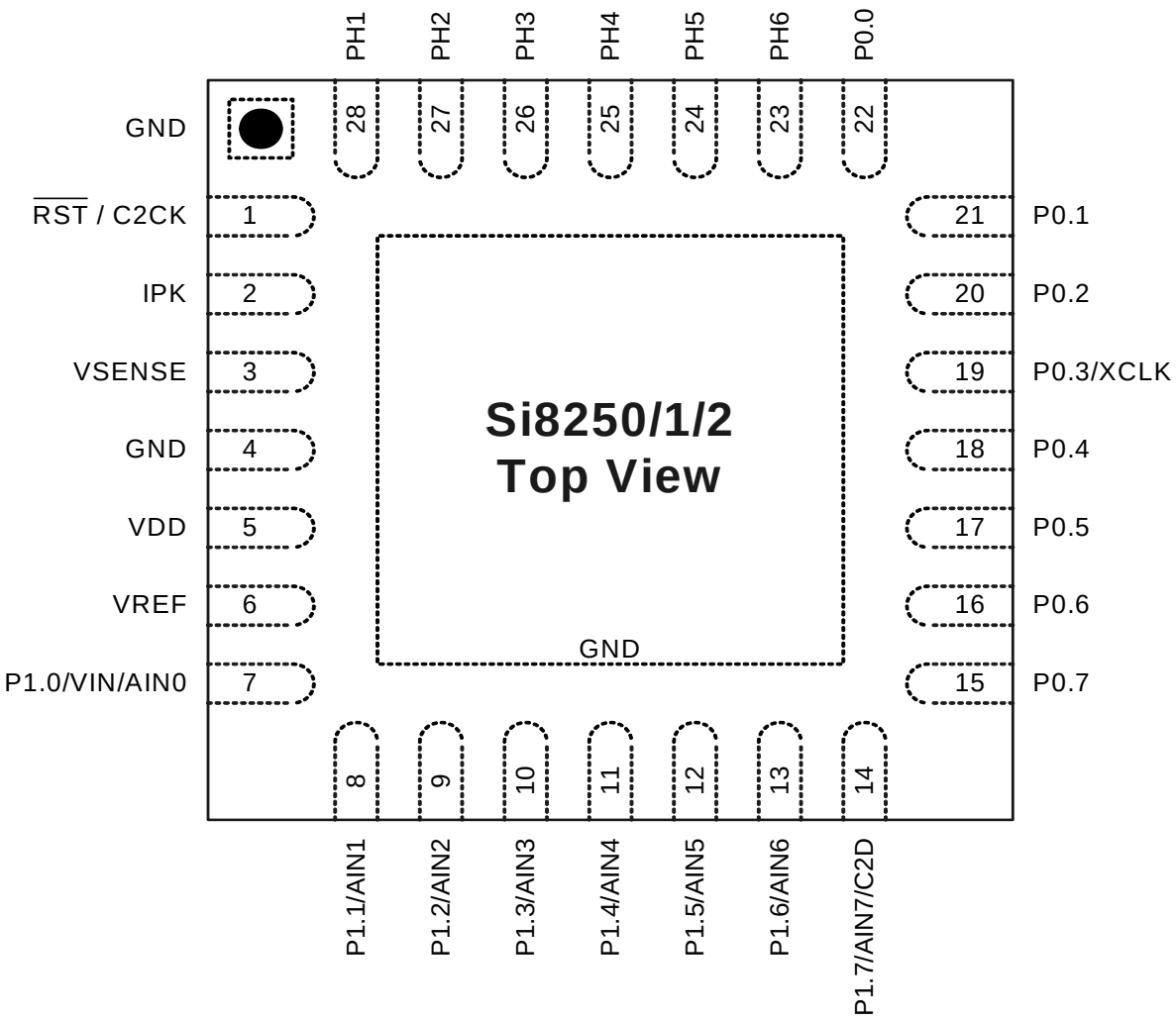


**Figure 3.2. QFN-28 Pinout Diagram (Top View)**

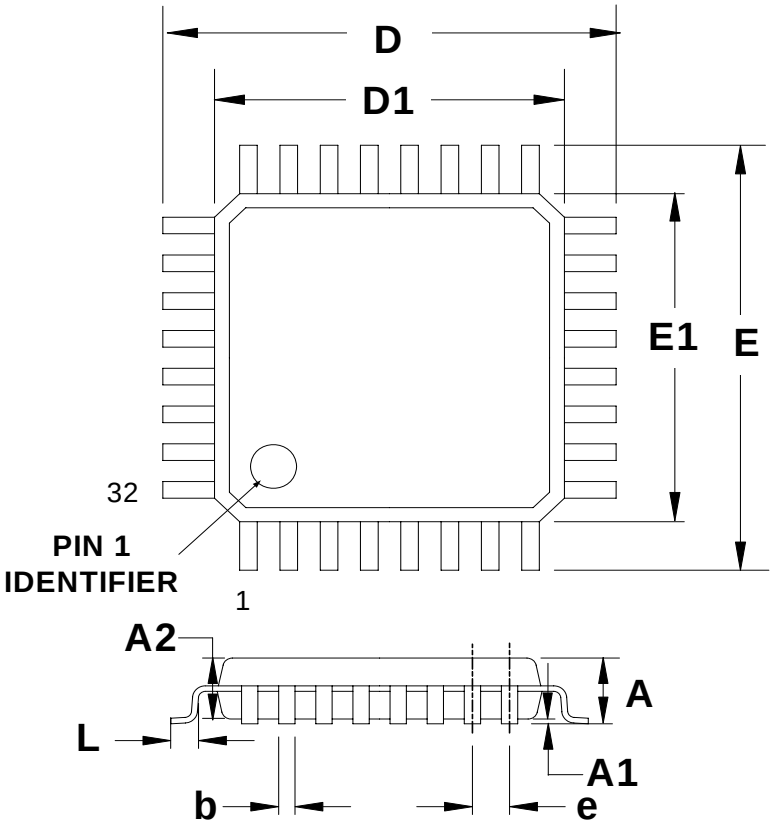


**Table 3.2. LQFP-32 Package Dimensions**

| | MM | | |
|---|---|---|---|
| | MIN | TYP | MAX |
| A | — | — | 1.60 |
| A1 | 0.05 | — | 0.15 |
| A2 | 1.35 | 1.40 | 1.45 |
| b | 0.30 | 0.37 | 0.45 |
| D | — | 9.00 | — |
| D1 | — | 7.00 | — |
| e | — | 0.80 | — |
| E | — | 9.00 | — |
| E1 | — | 7.00 | — |
| L | 0.45 | 0.60 | 0.75 |

**Figure 3.3. LQFP-32 Package Diagram**

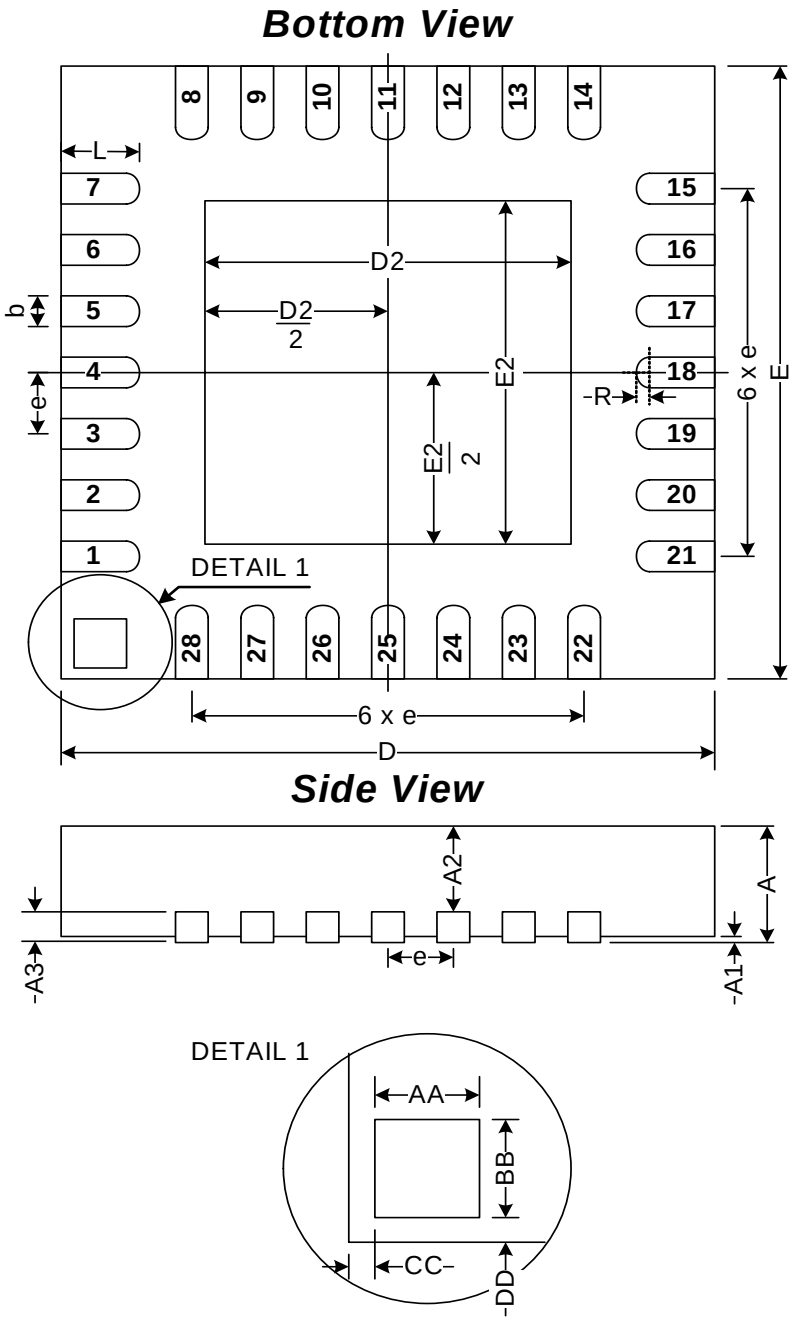


**Figure 3.4. QFN-28 Package Drawing**

**Table 3.3. QFN-28 Package Dimensions**

| | MM | | |
|---|---|---|---|
| | MIN | TYP | MAX |
| A | 0.80 | 0.90 | 1.00 |
| A1 | 0 | 0.02 | 0.05 |
| A2 | 0 | 0.65 | 1.00 |
| A3 | — | 0.25 | — |
| b | 0.18 | 0.23 | 0.30 |
| D | — | 5.00 | — |
| D2 | 2.90 | 3.15 | 3.35 |
| E | — | 5.00 | — |
| E2 | 2.90 | 3.15 | 3.35 |
| e | — | 0.5 | — |
| L | 0.45 | 0.55 | 0.65 |
| N | — | 28 | — |
| ND | — | 7 | — |
| NE | — | 7 | — |
| R | 0.09 | — | — |
| AA | — | 0.435 | — |
| BB | — | 0.435 | — |
| CC | — | 0.18 | — |
| DD | — | 0.18 | — |

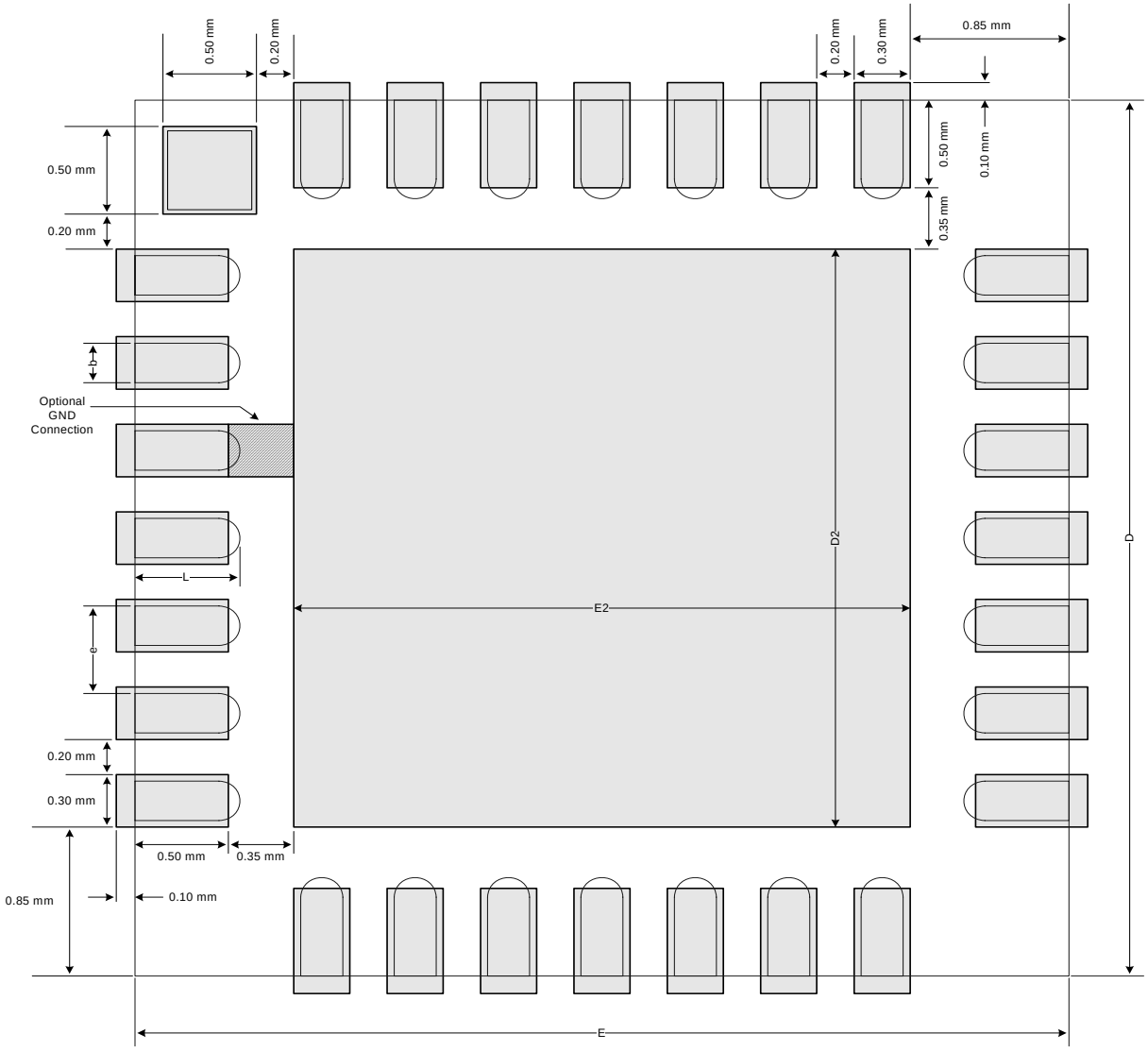


**Figure 3.5. Typical QFN-28 Landing Diagram**

***Top View***

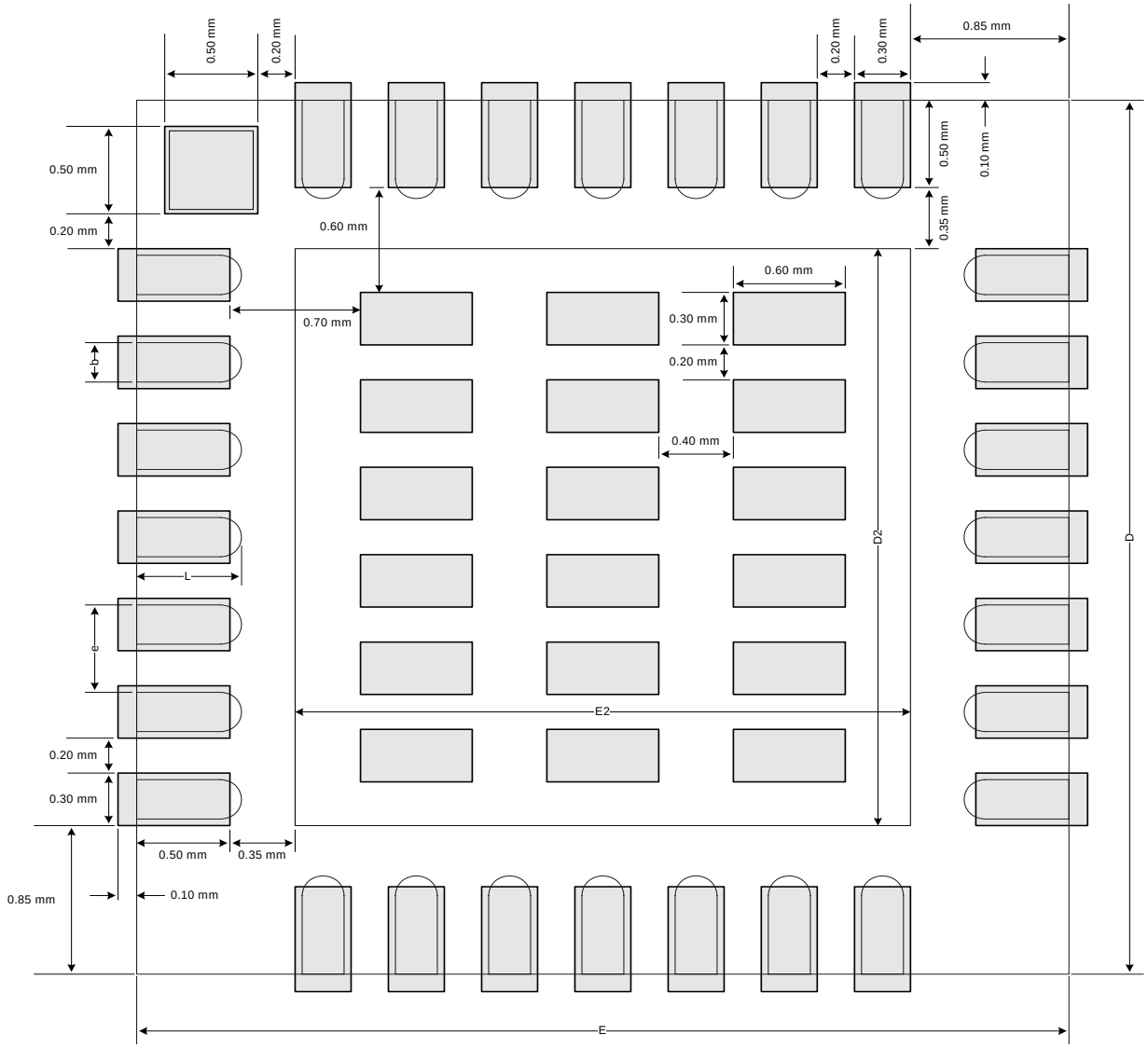


**Figure 3.6. Typical QFN-28 Solder Paste Mask**

## NOTES:

# 4. ADC1 (10 MHz Loop ADC)

ADC1 is a differential input, programmable sampling rate (10, 5, 2.5, or 1.25 MHz) analog-to-digital converter with programmable LSB size. It digitizes the difference between sensed output voltage, VSENSE, and the programmable voltage reference into a 6-bit signed value. The resolution of ADC1 can be programmed over an LSB range from 4 to 20 mV. The programmable LSB size allows the ADC resolution to be adjusted to prevent limit cycle oscillation. For more information, see Section "**4.1. Adjustable LSB Size**" on page **48**. To minimize power during Lockout mode, ADC1 is disabled when power is initially applied and when reset. Once enabled, it continuously converts at programmed sampling rate with the converted 2's complement result stored in the ADC1DAT register.

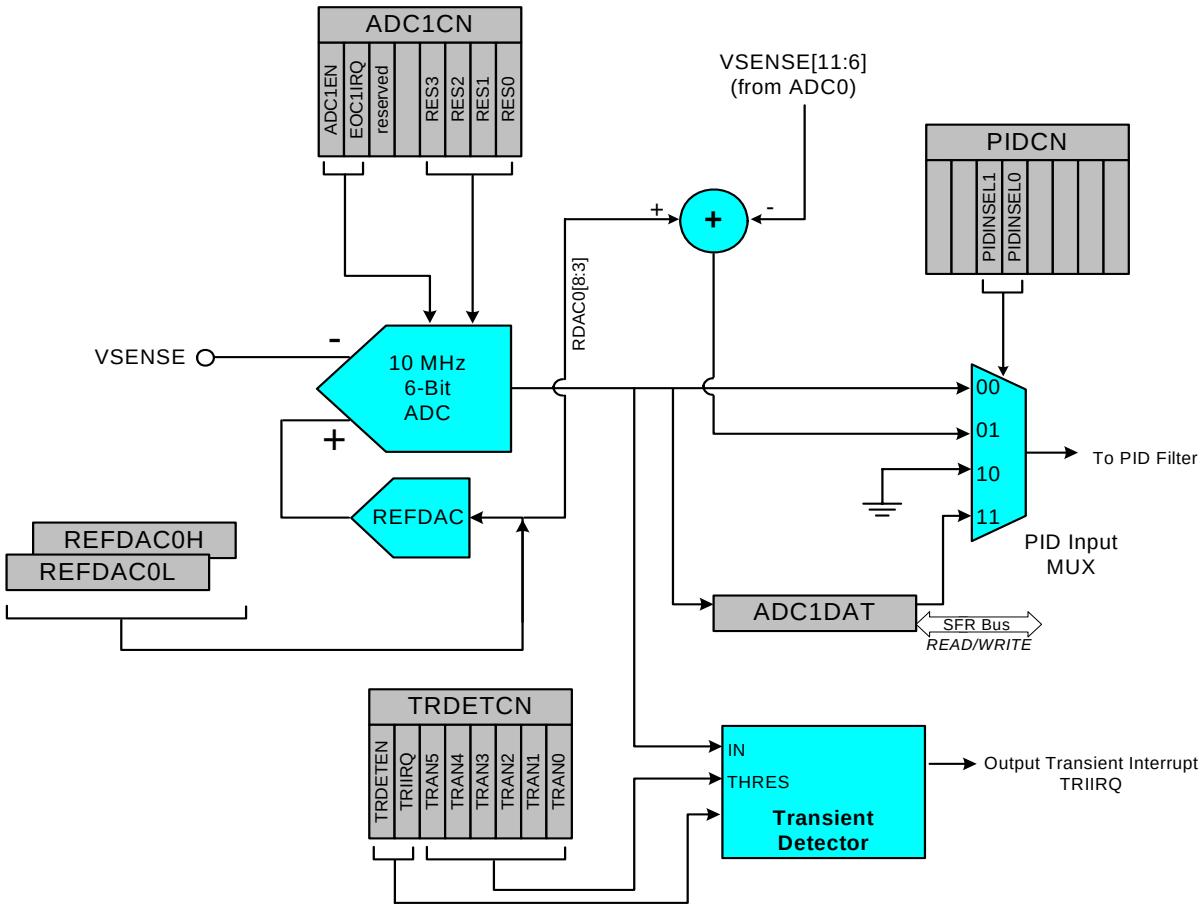


**Figure 4.1. ADC1 Functional Block Diagram**

ADC1 is enabled by setting ADCEN to '1'. Once enabled, ADC1 converts continuously and asserts EOCIRQ at the end of each conversion. The resolution of ADC1 is programmed by RES[3:0] in ADC1CN, and the sampling frequency is selected by the combination of ADCSP1 bit in PLLCN<2> and the ADCSP2 bit in the PIDDECCN<7> register (Section "**17.3. SINC Decimation Low-Pass Filter (Option 2)**" on page **150**).

The settings are described in the following table.

**Table 4.1. Settings for the ADC1 Sampling Rate**

| Bit ADCSP1 in Register PLLCN<2> | Bit ADCSP2 in Register PIDDECCN<7> | ADC1 Sampling Rate |
|---|---|---|
| 0 | 0 | 10 MHz |
| 1 | 0 | 5 MHz |
| 0 | 1 | 2.5 MHz |
| 1 | 1 | 1.25 MHz |

## 4.1. Adjustable LSB Size

Limit cycle oscillation produces unwanted tones in the power supply output frequency spectrum. It is typically caused by the lack of an integration term in the compensator, and/or too coarse a DPWM resolution relative to that of the ADC. The Si8250/1/2 family offers two ways to address limit cycle oscillation:

- **Adjust ADC1 LSB size**: This action changes the voltage threshold between adjacent ADC output states. The ADC LSB size is adjusted to be larger than the DPWM LSB size. This allows the DPWM LSB to fit within the zero bin of the ADC, eliminating the possibility of limit cycle oscillation.
- **Controlled dither**: The DPWM effective resolution can be increased by dithering using the on-board pseudo-random noise source. See Section "**17. DSP Filter Engine**" on page **147** for more details.

## 4.2. PID Input MUX

The PIDINSEL bits in the PIDCN register control the address selection for the PID input MUX. This MUX provides the means for the system management processor to route one of four different inputs to the PID filter:

- Channel 0: The output of ADC1.
- Channel 1: The difference between VSENSE (as measured by ADC0) and REFDAC input data.
- Channel 2: Ground.
- Channel 3: The difference between VSENSE and the reference setting as calculated by the system management processor. This feature supports PFC applications where the system management processor performs phase angle control, and the 10 MHz hardware loop of the Si8250 provides boost regulator control.

The PID input MUX typically operates in Channel 0 mode during steady-state operation. When the PID input MUX is set to address 0, ADC1 is selected and ADC1DAT acts as a read-only register. Channel 1 is selected during soft-start because the 12-bit resolution provided by ADC0 results in small step sizes during the soft-start ramp. MUX Channel 2 mode is provided to facilitate system debug. MUX Channel 3 mode the ADC1DAT register acts as a read/write register, providing the means for the system management processor calculate and write the difference term directly into the control loop to support low control bandwidth applications such as power factor correction. In this mode, ADC1DAT becomes a read/write register.

## 4.3. Transient Detector

Due to the high dc gain provided by the PID filter integrator term, the output of ADC1 typically deviates by ±1 LSB during normal system operation. A sudden voltage transient forces ADC1 output beyond this range due to the relatively slower response of the filter. The Transient Detector monitors the output of ADC1 and asserts a TRIIRQ interrupt when the output of ADC1 exceeds a user-specified range. The Transient Detector is enabled when the TRDETEN bit in the TRDETCN register is set to 1. The TRIIRQ interrupt is asserted when the absolute value of ADC1 output exceeds the limits programmed by TRAN[4:0] in the TRDETCN register. The typical response to a transient detector interrupt is an increase to the loop gain as outlined in Section "**17. DSP Filter Engine**" on page **147**.

## SFR Definition 4.1. ADC1CN: ADC1 Control

| R/W | R | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ADC1EN | EOC1IRQ | reserved | — | RES3 | RES2 | RES1 | RES0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xFE

Bit 7: ADC1EN: ADC1 Enable Bit
0: ADC1 disabled.
1: ADC1 enabled.

Bit 6 EOC1IRQ: ADC1 End-of-Conversion Interrupt Bit
0: ADC1 has not completed a data conversion since the last time EOC1IRQ was cleared.
1: ADC1 has completed a data conversion.

Bit 5 Reserved, must be maintained ‘0’.

Bit 4 Unused.

Bits 3–0: RES[3:0]: ADC1 Resolution Control Bits (LSB size)
0000: Resistor ladder disable
0001: Reserved
0010: 4 mV (default)
0011: 6 mV
0100: 8 mV
0101: 10 mV
0110: 12 mV
0111: 14 mV
1000: 16 mV
1001: 18 mV
1010: 20 mV
1011–1111: Reserved

## SFR Definition 4.2. ADC1DAT: ADC1 Data

| — | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xFD

Bits 7–6: Unused.

Bits 5–0: ADC1DAT[5:0]: ADC1 2s complement output data.
**Note**: This register is read-only except when PIDINSEL is set to ‘11’ (system management

## SFR Definition 4.3. TRDETCN: ADC1 Transient Detector Control

| R/W | R/W | — | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TRDETEN | TRIIRQ | — | TRAN4 | TRAN3 | TRAN2 | TRAN1 | TRAN0 | 00011111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x3D

Bit 7: TRDETEN: PID Input Transient Detector Enable Bit
0: Transient detector disabled.
1: Transient detector enabled.

Bit 6: TRIIRQ: Transient Detector Interrupt Flag
0: No transient detected.
1: Transient detected.

Bit 5: Not used.

Bits 4–0: TRAN[4:0]: Transient Magnitude Detector Threshold
These bits set the magnitude of the change on the output of ADC1 that will trigger a transient interrupt (TRIIRQ). For example, if TRAN[4:0] = 00110b, TRIIRQ will be asserted for all positive ADC1 output values at or greater than 000110b or less than 111010b.

## 5. Peak Current Limit Detector

The output of the user's inductor or transformer current-sensing circuit connects to the IPK input pin of the Si8250/1/2. The peak current limit detector provides cycle-by-cycle current limiting by automatically truncating the ongoing portion of the PWM switching phase when peak current exceeds a preset threshold value. This event is defined as a current cycle interrupt (ICYCIRQ).

Leading edge blanking prevents false current limit triggers that may occur at the start of each switching cycle. The programmable phase selector circuit specifies the output switching edge(s) that trigger the leading edge blanking circuit (bits LEBPHn in LEBCN). When triggered, the leading edge blanker inhibits the peak current comparator input for up to 16 cycles of the DPWM clock source (bits LEB[1:0] in the LEBCN SFR). For example, when the DPWM clock is 200 MHz a blanking time of up to 80 ns is possible. The resulting current waveform is applied to a threshold detector, which consists of a high-speed comparator and 4-bit DAC threshold reference generator. A current limit interrupt (ICYCIRQ) is generated when the amplitude of the peak current waveform exceeds the programmed threshold value.

A system overcurrent protection fault (OCPIRQ) is automatically generated by dedicated counting logic. This circuit consists of a 7-bit counter/digital comparator combination that asserts an OCPIRQ when the number of consecutive ICYCIRQ events equals the programmed limit of the OCP[6:0] bits in OCPCN.

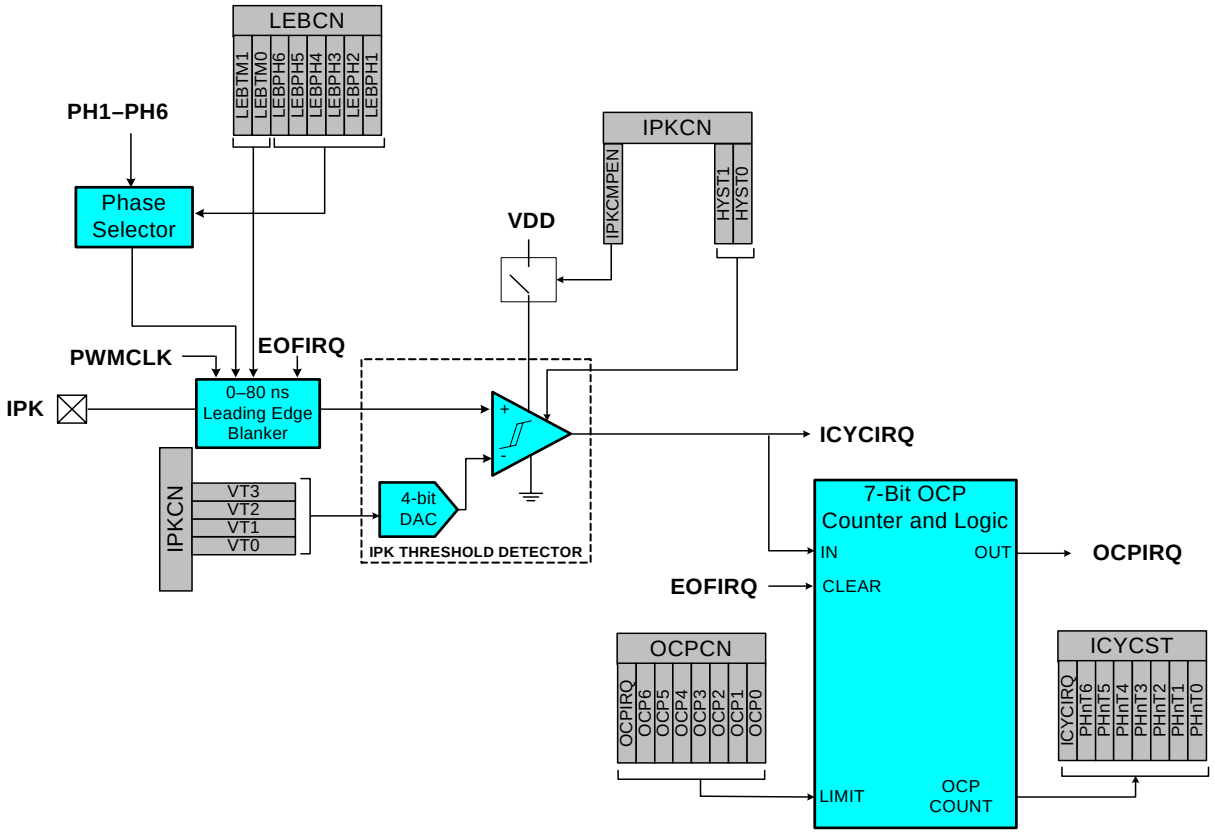


**Figure 5.1. Peak Current Limit Detector Block Diagram**

## 5.1. Leading Edge Blanker

The leading-edge blanking circuit inhibits the peak current threshold detector for a fixed time period (tBLANK) determined by the settings in LEBCN. Blanking is triggered on the rising edge of the PHn outputs specified by bits LEBPH1–LEBPH6 in LEBCN. Any combination of PHn outputs may be designated as triggers by setting the corresponding LEBPH1-LEBPHn bit to 1. The blanking time is programmed by LEBTM0, LEBTM1 in LEBCN. (See Section "**SFR Definition 5.2. LEBCN: Leading-Edge Blanking Control**" on page **55** for programming details.) As shown in Figure 5.2, the peak current detector input is shut-off for tBLANK when triggered by the states of LEBPH1–LEBPH6.

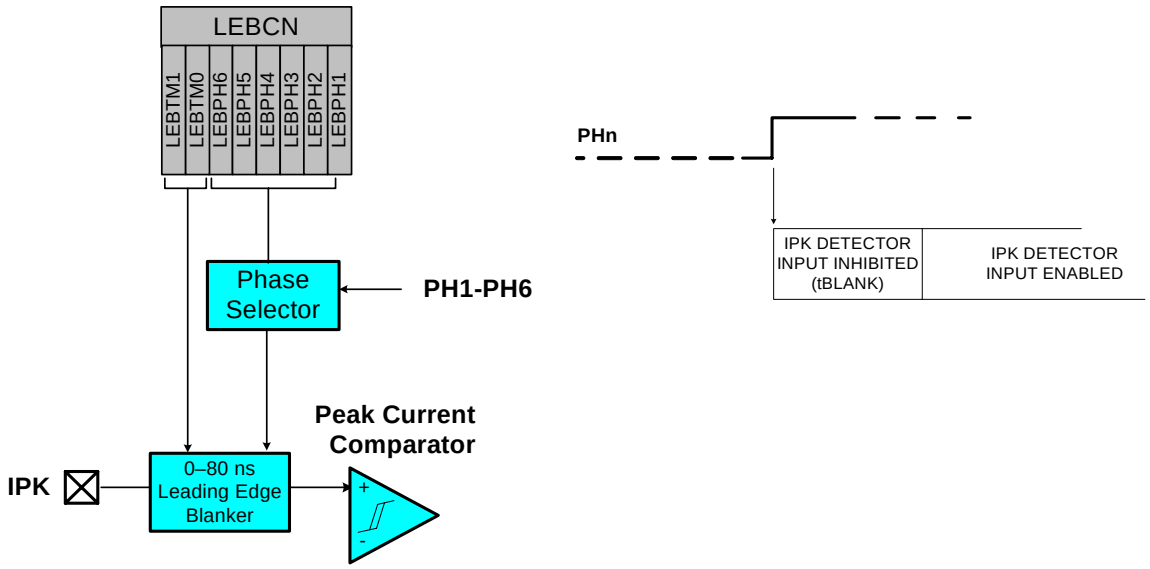


**Figure 5.2. Leading Edge Blanker Operation**

## 5.2. Peak Current Threshold Detector

The peak current detector consists of a 12 ns comparator with programmable hysteresis and a 4-bit DAC to set the threshold. Detector hysteresis is programmable from 0 mV to 20 mV in 5 mV steps. The peak current detector threshold is programmable from 50 to 800 mV in 50 mV increments.

## 5.3. Overcurrent Count and Compare

The overcurrent count and compare logic consists of 7-bit counting hardware and a digital comparator that compares the number of consecutive current limit cycles (ICYCIRQ) to a user-programmed maximum; an OCP interrupt is issued when the programmed count limit is reached. The count limit is programmed in overcurrent protection control SFR (OCPCN). In addition, the current number of consecutive current limit cycles can be read by the system management processor at any time in the Cycle Status SFR (ICYCST).

The ICYCIRQ cycle counter is reset to zero by hardware when a normal (non-current-limit) cycle occurs. For example, OCP[6:0] = 0001111b will result in an OCPIRQ being asserted on the 16th consecutive ICYCIRQ event. If a switching cycle is completed through the voltage feedback path (i.e., a normal, "non-current limit" cycle), the OCP count is immediately reset to zero. There must be 16 current limit cycles in a row for an OCPIRQ to be asserted in this example. If the OCP count reaches the user-programmed limit, the OCP count is reset, and the DPWM bypass is initiated if enabled. For more information, see Section "**6.6. DPWM Bypass**" on page **66**.

A graphical example of OCP detector action is shown in Figure 5.3. In this example, there are two phases per switching cycle. The OCP detector is programmed to assert the OCPIRQ when six consecutive current limit events occur. As shown, the peak current detector asserts ICYCIRQ each time peak current exceeds the threshold. At first, there are three consecutive ICYCIRQs, followed by a non-current-limit cycle (i.e., normal loop action), which causes the ICYCIRQ count to be cleared at the end of the normal cycle. The accumulation of ICYCIRQ events resumes when peak current is again above the detector threshold setting, and OCPIRQ is asserted at the completion of the sixth ICYCIRQ. The EOF interrupt is asserted by hardware at the end of each switching cycle and is shown here for reference only.

**Note:** The OCP hardware shutdown may be disabled by setting HWBP in the DPWMCN to 0.

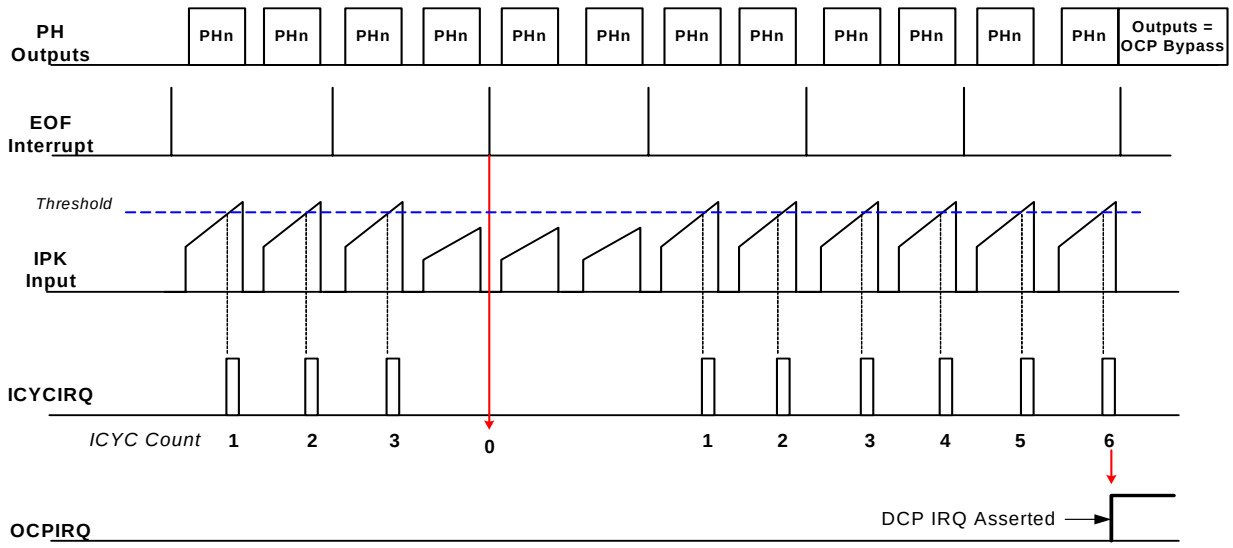


**Figure 5.3. Hardware OCP Circuit Action**

## SFR Definition 5.1. IPKCN: Peak Current Comparator Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| IPKEN | ICYCIRQ | VT3 | VT2 | VT1 | VT0 | HYST1 | HYST0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xA0

Bit 7: IPKEN: Peak Current Comparator Enable Bit
0: Peak current comparator disabled
1: Peak current comparator enabled

Bit 6: ICYCIRQ: Peak Current Comparator Interrupt Output
0: Normal operation—no cycle current limit in progress
1: Current limit cycle in progress

Bits 5–2: VT[3:0]: Peak Current Comparator Voltage Threshold Control
0000: 50 mV
0001: 100 mV
0010: 150 mV
0011: 200 mV (default)
0100: 250 mV
0101: 300 mV
0110: 350 mV
0111: 400 mV
1000: 450 mV
1001: 500 mV
1010: 550 mV
1011: 600 mV
1100: 650 mV
1101: 700 mV
1110: 750 mV
1111: 800 mV

Bits 1–0: HYST[1:0]: Peak Comparator Hysteresis Control Bits
00: 0 mV
01: 5 mV
10: 10 mV
11: 20 mV

## SFR Definition 5.2. LEBCN: Leading-Edge Blanking Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| LEBTM1 | LEBTM0 | LEBPH6 | LEBPH5 | LEBPH4 | LEBPH3 | LEBPH2 | LEBPH1 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xD6

Bits 7–6: LEBTM[1:0]: Leading-Edge Blanking Period
00: 0 cycles of the DPWM clock (i.e., 0 ns blanking time)
01: 4 cycles of the DPWM clock (i.e., 20 ns blanking time at 200 MHz)
10: 8 cycles of the DPWM clock (i.e., 40 ns blanking time at 200 MHz)
11: 16 cycles of the DPWM clock (i.e., 80 ns blanking time at 200 MHz)

Bits 5–0: LEBPHn: Leading-Edge Blanking Phase Select
0: The leading edge of phase n is passed through with no leading-edge blanking added.
1: The leading edge of phase n is blanked for the time period specified by the LEBTM[1:0] bits.

## SFR Definition 5.3. ICYCST: Cycle-by-Cycle Peak Current Limit Status

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| reserved | ICYCCNT6 | ICYCCNT5 | ICYCCNT4 | ICYCCNT3 | ICYCCNT2 | ICYCCNT1 | ICYCCNT0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xD2

Bit 7: Reserved; must be maintained ‘0’.

Bits 6–0: ICYCCNT[6:0]: Overcurrent Protection Counter Data Bits 6–0.

## SFR Definition 5.4. OCPCN: Overcurrent Protection Control

| R | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| OCPIRQ | OCP6 | OCP5 | OCP4 | OCP3 | OCP2 | OCP1 | OCP0 | 01111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xD7

Bit 7: OCPIRQ: Overcurrent Protection Counter Interrupt Flag
0: Normal system operation—no OCP fault.
1: Overcurrent protection counter at count limit—OCP active.

Bits 6–0: OCP[6:0]: Overcurrent Protection Counter Limit Bits
These determine the number of consecutive ICYCIRQ events required to assert an overcurrent protection fault interrupt (OCPIRQ). That is, OCPIRQ is asserted when (OCP[6:0]) = (ICYCCNT[6:0]).

## NOTES:

# 6. Digital PWM (DPWM)

The digital pulse width modulation (DPWM) module is an advanced segment of digital hardware that provides the diverse gate control options necessary to drive many switch-mode power supply configurations. The module can generate up to six signals (phases) accommodating pulse width and phase modulation schemes that can be modulated by hardware (output from the DSP filter engine) as well as by firmware (writing a register). Phase-to-phase timing can be fully programmed to prevent typical system problems, such as shoot-through. In addition, the DPWM may be clocked at 200 MHz, 50 MHz, or 25 MHz from the internal oscillator (or external clock), thus achieving signal resolutions as low as 5 ns (undithered). With this resolution and 9-bit cycle length control, the DPWM can easily achieve typical power supply switching frequencies beyond 1 MHz. A block diagram of the DPWM appears in Figure 6.1.

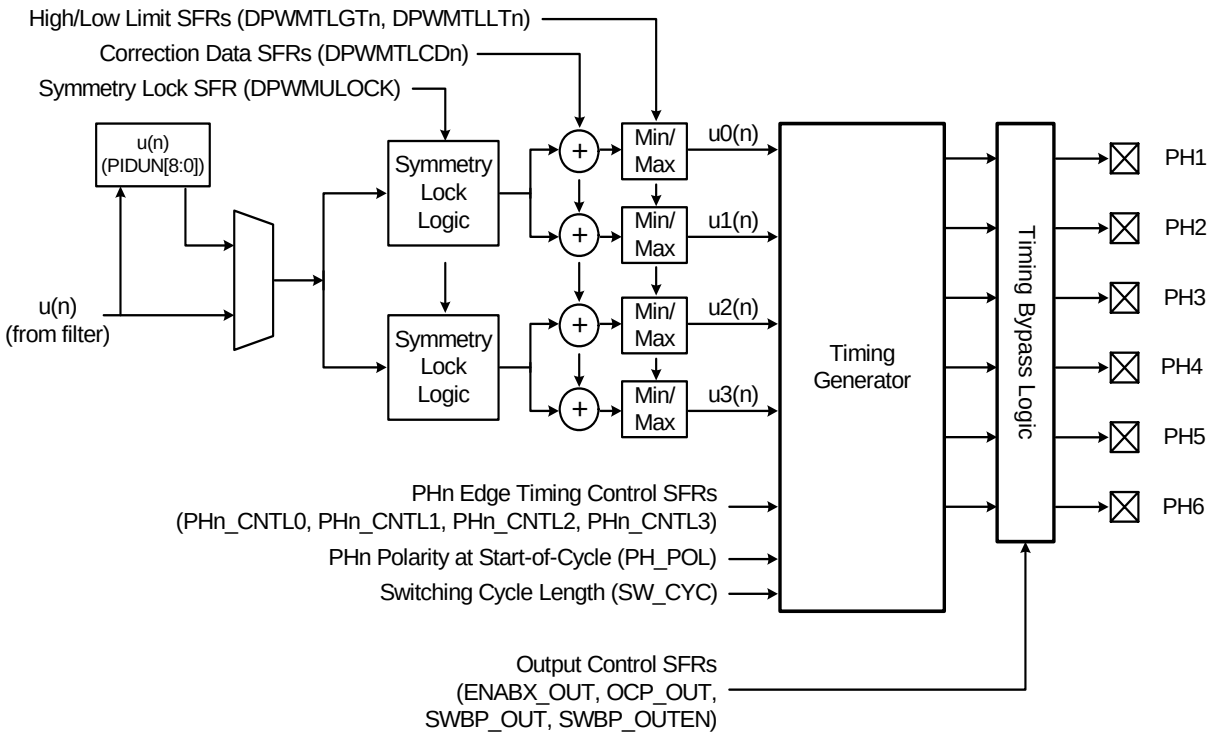


**Figure 6.1. DPWM Functional Block Diagram**

As shown, the compensated duty cycle modulation variable u(n) is applied to the input of the DPWM through the DPWM input MUX. This MUX selects the DSP filter engine output or system management processor as the DPWM modulation source. The MUX output is connected to a pair of programmable symmetry lock circuits that can be used to latch the value of u(n) at a specified time, thereby maintaining it constant for the remainder of the switching cycle. The output from each symmetry lock circuit is connected to a pair of trim and limit circuits that allow the system management processor to bias and limit the value of u(n). This results in up to four individual u(n) functions, each of which can differ in their offset and min/max limits. For more information see Section "**6.4. Trim and Limit Subsystem**" on page **60**.

The Timing Generator creates the desired phases to drive the power circuit. The timing generator must be initialized by firmware, and it can be initialized to produce up to six phases. Once initialized, it is modulated by up to four u(n) functions. Flexible multiplexing circuitry allows any PHn output to be modulated by any of the four u(n) functions. For more information see Section "**6.5. DPWM Timing Generator**" on page **61**.

Timing Bypass logic provides safe stop states for all PHn outputs. Bypass can be programmed to occur automatically during OCP or when the ENABLE input is forced to its off state. Bypass can also be initiated by the system management processor in firmware. Each of these three bypass conditions have an associated programmable stop pattern. For more information see Section "**6.6. DPWM Bypass**" on page **66**.

## 6.1. Writing to the DPWM SFRs

There are many registers used to setup and control the DPWM module; most of these registers are accessed in indirect SFR space. A DPWM SFR is accessed by writing the SFR address to DPWMADDR, then reading or writing the data in DPWMDATA. Bit 2 of DPWMCNTL is the address Auto-Increment bit; when set to 1, this bit causes DPWMADDR to increment automatically on each access of DPWMDATA for fast sequential SFR accesses.

## 6.2. DPWM Input MUX

The DPWM input MUX selects hardware or system management processor modulation. (Refer to Figure 6.2.) The DPWM input MUX is controlled by the DPWMINPUT bit in the DPWMCNTL register. When channel 1 of the DPWM input MUX is selected, the last u(n) update written to the PIDUN register is latched, and further updates from the filter are inhibited. While in this state the system management processor can directly modulate the DPWM by writing to PIDUN[8:0]. Hardware modulation resumes when the MUX is again set to channel 0.

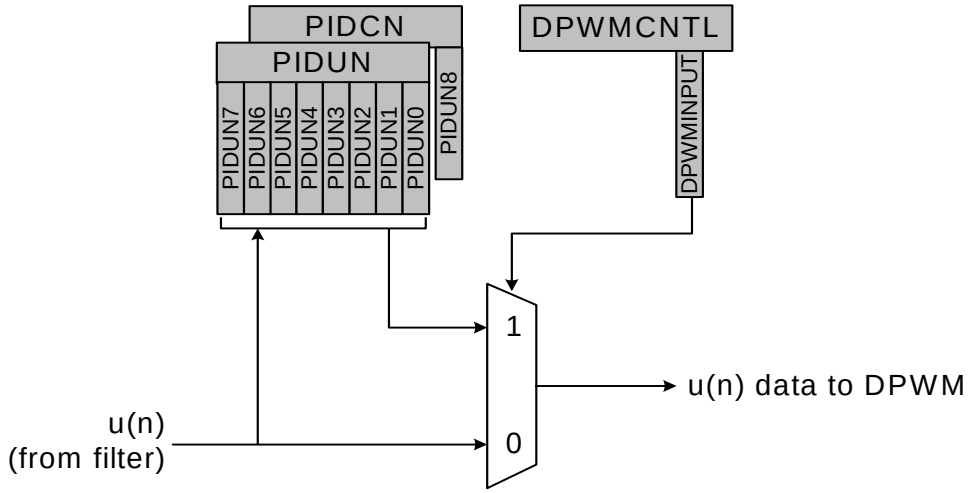


**Figure 6.2. DPWM Input MUX**

## 6.3. Symmetry Lock

Duty cycle variable u(n) is updated at a maximum rate of 10 MHz. As such, the value of u(n) can typically change many times within a given switching cycle. This may be problematic for circuits requiring symmetrical modulation timing (e.g., driving complementary switching pairs). To satisfy these requirements, the Symmetry Lock circuit latches the value of u(n) at a specific time of the switching cycle, guaranteeing equal pulse widths. Symmetry Lock latch timing is firmware programmable.

The block diagram for the Symmetry Lock circuit is shown in Figure 6.3. When enabled, the two Symmetry Lock latches store the value of u(n) once per switching cycle at a time specified by DPWMULOCK. The two latched u(n) values are paired with two trim and limit functions, resulting in four unique u(n) functions that can be mapped to any PHn output in any combination using the PHn_CNTL0 registers in the Timing Generator (please see “6.5.3. Programming Timing Patterns” on page 62).

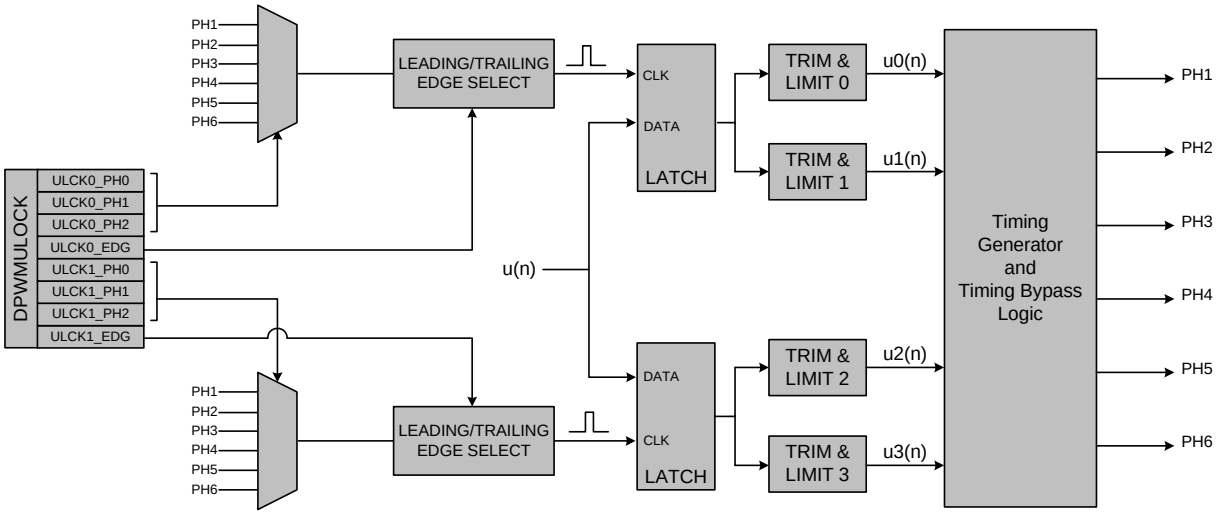


**Figure 6.3. Symmetry Lock Architecture**

## 6.4. Trim and Limit Subsystem

The Trim and Limit subsystem enables the system management processor to set minimum and maximum limits and/or bias each u(n). As shown in Figure 6.4, each of the two u(n) outputs from the Symmetry Lock circuit are applied to a pair of two's complement adders, providing the means to apply a positive or negative bias to each u(n) value by writing the offset value to the trim-and-limit correction data register (DPWMTLCDn). The min/max range of each adder output is determined by the limiter settings in the associated low limit register (DPWMTLLTn) and high limit register (DPWMTLGTn).

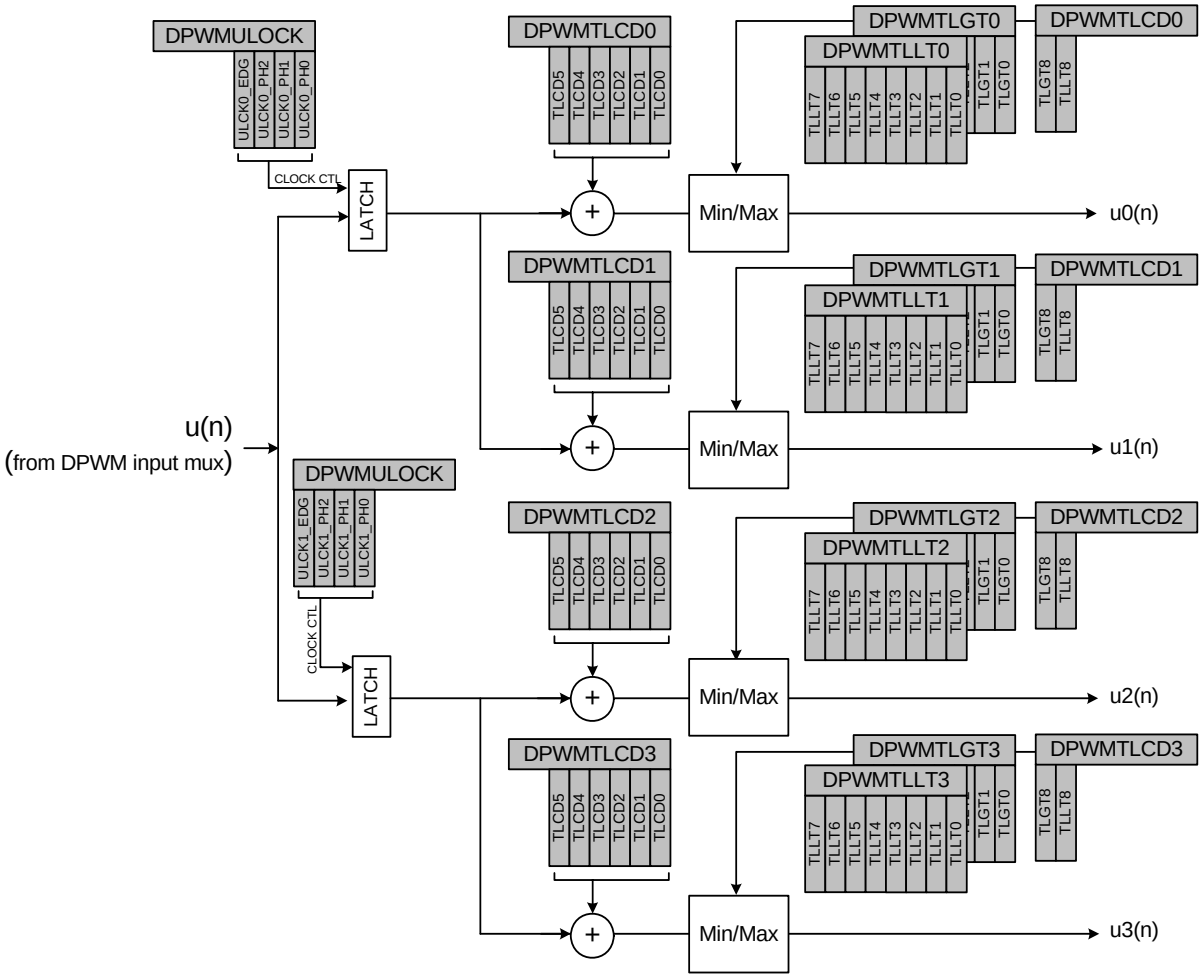


**Figure 6.4. Trim and Limit Programming Model**

## 6.5. DPWM Timing Generator

The DPWM timing generator provides up to six highly flexible PWM or phase-shift modulated timing phases referred to as PH1 through PH6. Positive, negative, or system management processor-controlled dead times can be implemented. As shown in Figure 6.5, each PHn output has its own pattern generator that can be programmed to select any one of the four compensated control variables, u0(n) through u3(n), as its modulation source. This mapping provides complete flexibility allowing any PHn output to be modulated by any u(n) source. It also allows Symmetry Lock to be applied to any combination of PHn outputs.

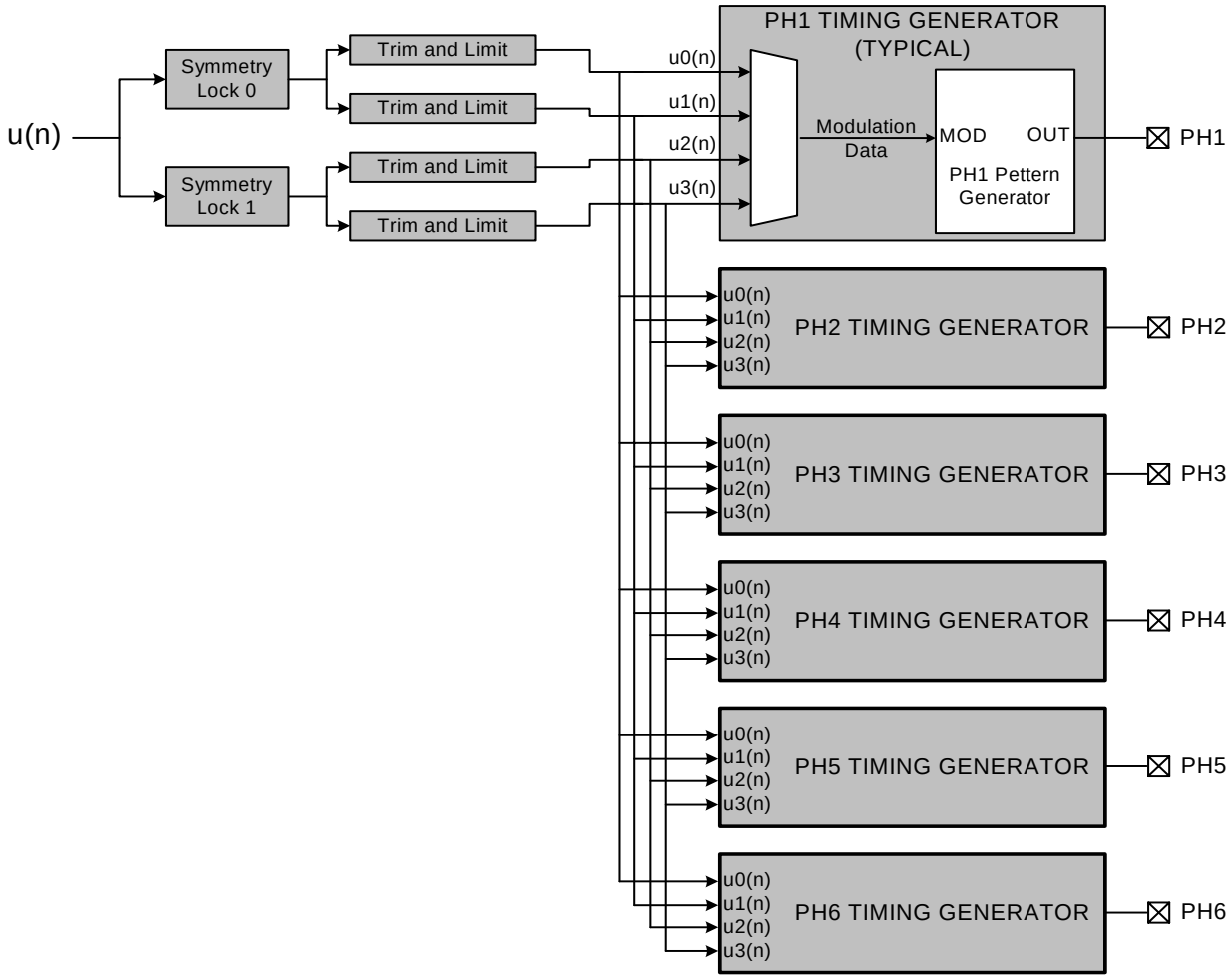


**Figure 6.5. DPWM Timing Generator Block Diagram**

### 6.5.1. Initializing the Module

The DPWM module should be initialized prior to being enabled to minimize the chance of generating undesired modulation. First, the desired switching period, timing patterns, bypass control, limits, and offsets should be set to the desired startup conditions. Then the module should be enabled by setting the DPWM_EN bit in the DPWMCNTL SFR.

### 6.5.2. Setting the Switching Period

The switching cycle period is controlled by the SW_CYC[8:0] bits where the switching frequency is equal to the clock into the DPWM divided by SW_CYC[8:0] plus one as shown in the following equation:

$$F_{switch} = \frac{F_{DPWM}}{\text{SW\_CYC[8:0]} + 1}$$

With the internal oscillator being the typical clock source, the DPWM module can be clocked by one of three clock options from the PLL; refer to the DPWMSP bits in the PLLCN special function register. Thus the minimum switching frequency from the module is slightly less than 50 kHz with DPWMSP[1:0] set to '10' (about 25 MHz into the DPWM module); likewise, the minimum switching frequency from the module is slightly less than 400 kHz with DPWMSP[1:0] set to '00' (about 200 MHz into the DPWM module).

The switching frequency is not the only characteristic affected by the SW_CYC[8:0] setting. With 9 bits of control there is a maximum possible of 512 ticks per switching cycle allowed for phase formation. Each phase (set by PHn_CNTL0, PHn_CNTL1, PHnCNTL2, and PHn_CNTL3) can be no longer than SW_CYC[8:0] + 1 ticks. Thus it is also important to note that you get a full 9 bits of modulation control when the SW_CYC[8:0] is at its maximum; however, the dynamic range is decreased as the switching period is decreased, SW_CYC[8:0] + 1 < 512.

### 6.5.3. Programming Timing Patterns

Programming the timing patterns is the most complex setup required for this module primarily because the module is highly configurable for almost any power control application. Fortunately, there is a graphical tool available to ease timing pattern setup, the Waveform Builder. The Waveform Builder included in the Si8250DK automatically generates all DPWM register initialization values based on the user's waveform drawings. The designer only needs to draw the waveforms in the Waveform Builder's unique and easy-to-use graphical environment, and the tool will generate the setup data.

If the use of the Waveform Builder is not desired, the module can still be setup manually. The timing of each phase (PH1, PH2,... PH6) is controlled by the programmed settings in its control registers PHn_CNTL0 through PHn_CNTL3. Each timing phase is allowed to have a maximum of two transitions per switching cycle. The programming model for a single PHn output is shown in Figure 6.6.

Essentially there is no single setup procedure for timing patterns because the setup for each application is unique; however, there are just three general steps that should be followed to successfully setup a valid timing pattern:

Step 1. Determine the desired switching period. This information will set the maximum ticks per cycle. Generally speaking more ticks means more dynamic range, thus best effort should be made to maximize this.
Step 2. Draw a single cycle of all the phases needed for the design. There should only be at most two transitions per phase and at most six total phases.
Step 3. Determine all the edge dependencies, which usually constitutes determining what portions of each phase is modulated and not modulated.

Once these three steps are completed the timing pattern should be relatively straight forward. Refer to Section "**6.5.4. Timing Programming Example, Pulse-Width and Phase-Shift Modulation**" on page **64** for an example.

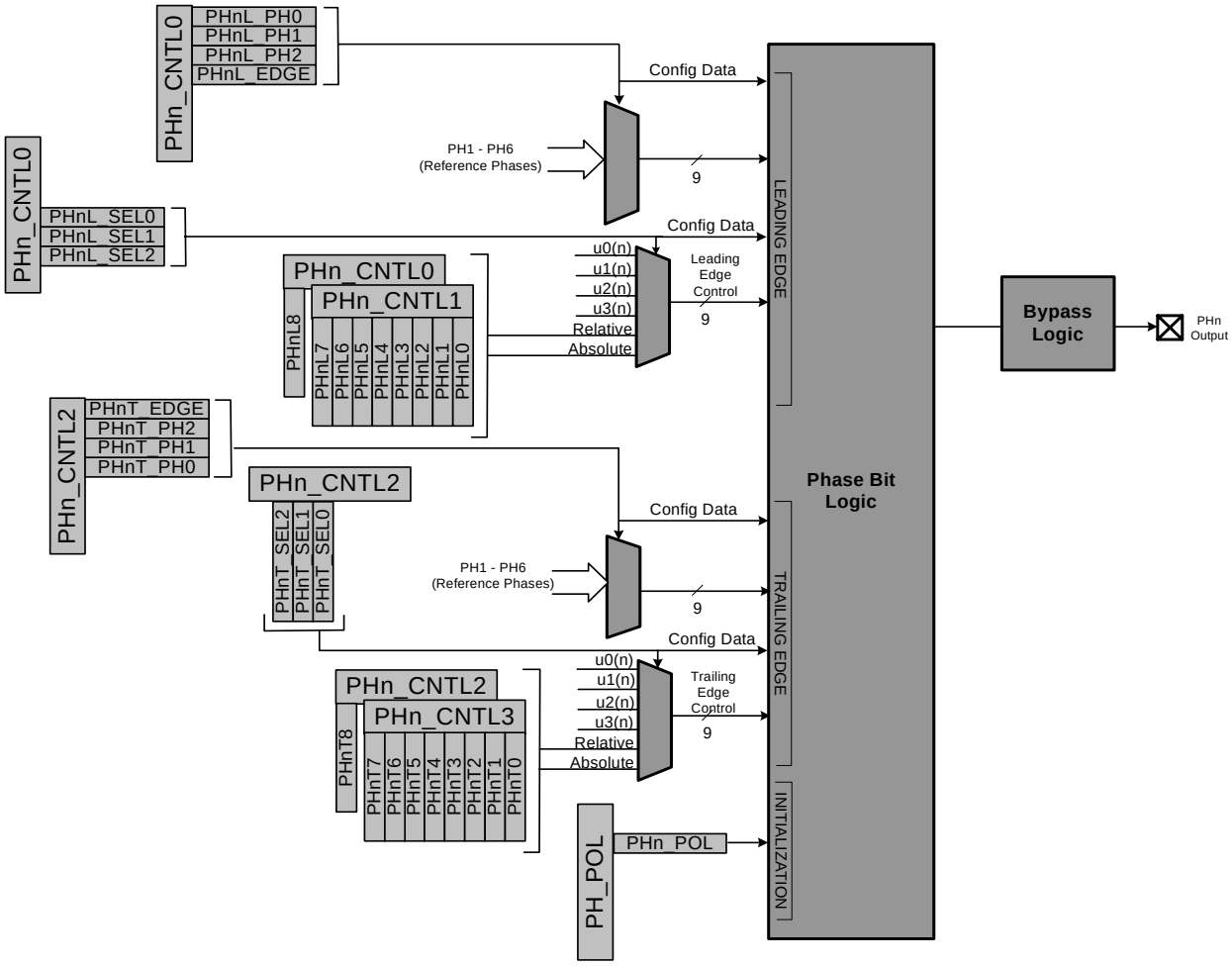


**Figure 6.6. DPWM Timing Register Programming Model**

### 6.5.4. Timing Programming Example, Pulse-Width and Phase-Shift Modulation

The following is a combined example of both pulse-width and phase-shift modulation on phases PH1 and PH2 consecutively. As shown in Figure 6.7 the total period is 320 ticks. For Phase 1 the pulse width is simply modulated by u0(n). For Phase 2 the modulation is slightly different. In this case the pulse width is fixed at 160 ticks of the input clock; however, its position relative to tick time 0 is modulated by u1(n).

There are three basic steps to setting up timing in this example:

Step 1. Determine the period. The desired frequency is about 156 kHz or about 320 ticks at 20 ns per tick.
Step 2. Draw the desired timing; see Figure 6.7.
Step 3. Determine all dependencies. Phase 1 starts at absolute time 0 and is modulated by u0(n), so its trailing edge is relative to its leading edge. The leading edge in Phase 2 is modulated relative to Phase 1. Since the pulse width is fixed the trailing edge width is set to 160 ticks relative to its leading edge. Table 6.1 shows the setup.

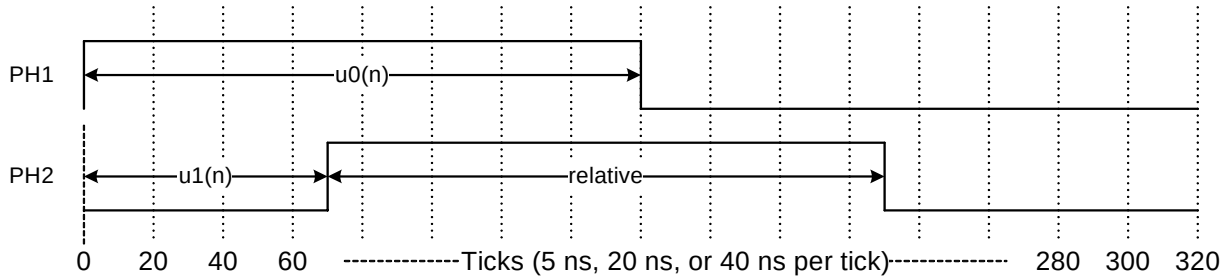


**Figure 6.7. DPWM Timing Example—PWM and PSM**

**Table 6.1. DPWM Timing Example—PWM and PSM**

| Description | Register Name | Hex | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---|---|---|---|---|---|---|---|---|---|---|
| Switching Period (320 ticks) | SWCYC | 0x40 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| | PH_POL | 0x80 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phase 1 Control Leading transition at tick 0, trailing transition relative to leading transition and modulated by u0(n) | PH1_CNTL0 | 0x70 | 0 | 1 | 1 | 1 | X | X | X | X |
| | PH1_CNTL1 | 0x00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | PH1_CNTL2 | 0x01 | X | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | PH1_CNTL3 | 0x00 | X | X | X | X | X | X | X | X |
| Phase 2 Control Leading transition relative to PH1 leading, trailing transition relative to leading by 160 ticks | PH2_CNTL0 | 0x09 | X | 0 | 0 | 0 | 1 | 0 | 0 | 1 |
| | PH2_CNTL1 | 0x00 | X | X | X | X | X | X | X | X |
| | PH2_CNTL2 | 0x42 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 |
| | PH2_CNTL3 | 0xA0 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |

**Note:** “X” = Don’t care.

### 6.5.5. Timing Programming Example, Dead-time

The following is an example setup for a simple Synchronous Buck converter operating in continuous conduction mode with one additional phase providing a pulse every frame for synchronizing other circuitry. This example demonstrates how dead-time can be inserted between the phases, and as seen in the timing diagram, Figure 6.8, there is built-in dead-time between transitions of Phase 1 and Phase 2.

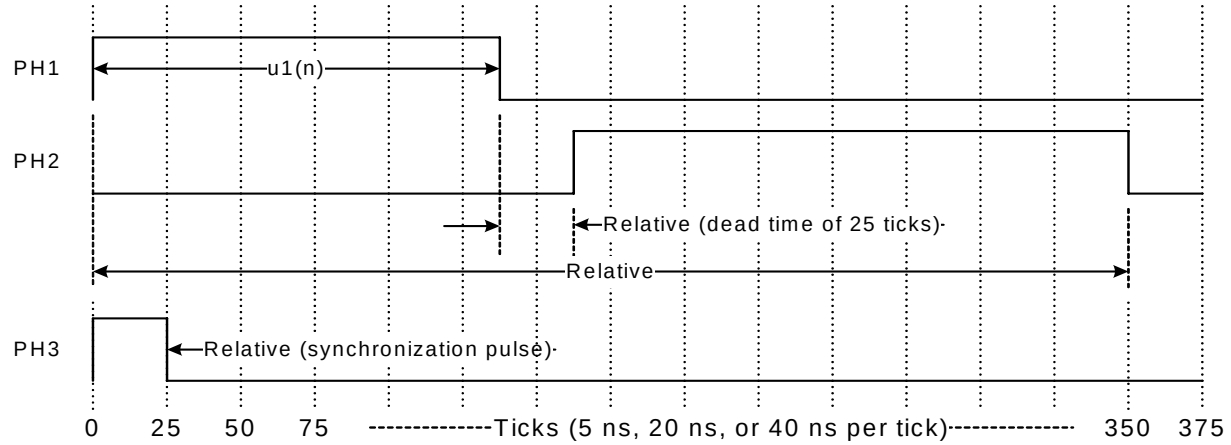


**Figure 6.8. DPWM Timing Example, Dead-time**

**Table 6.2. DPWM Timing Example, Dead-time**

| Description | Register Name | Hex | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 |
|---|---|---|---|---|---|---|---|---|---|---|
| Switching Period (375 ticks) | SWCYC | 0x77 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 |
| | PH_POL | 0x80 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Phase 1 Control Leading transition at tick 0, trailing transition relative to leading transition and modulated by u1(n) | PH1_CNTL0 | 0x70 | 0 | 1 | 1 | 1 | X | X | X | X |
| | PH1_CNTL1 | 0x00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | PH1_CNTL2 | 0x01 | X | 0 | 0 | 0 | 0 | 0 | 0 | 1 |
| | PH1_CNTL3 | 0x00 | X | X | X | X | X | X | X | X |
| Phase 2 Control Leading transition relative to PH1 trailing, trailing transition relative to PH1 leading | PH2_CNTL0 | 0x12 | X | 1 | 0 | 0 | 1 | 0 | 0 | 1 |
| | PH2_CNTL1 | 0x00 | X | X | X | X | X | X | X | X |
| | PH2_CNTL2 | 0x42 | 0 | 1 | X | X | 0 | 0 | 1 | 0 |
| | PH2_CNTL3 | 0x44 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 |
| Phase 3 Control Absolute on both transitions | PH3_CNTL0 | 0x70 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | PH3_CNTL1 | 0x00 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | PH3_CNTL2 | 0x70 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| | PH3_CNTL3 | 0x19 | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 1 |

**Note:** “X” = Don’t care.

## 6.6. DPWM Bypass

The DPWM bypass safeguards the power supply system by forcing each PHn output into user-defined 'safe' states during supply shutdown. Figure 6.9 shows the bypass logic that is included on each PHn output (the PH1 output is shown as a typical case). As shown, the PH1 output MUX selects DPWM generator output (default) or one of three static, pre-defined states contained in the software bypass (SWBP_OUT), overcurrent protection fault (OCP_OUT), or Enable (ENABX_OUT) bypass registers.

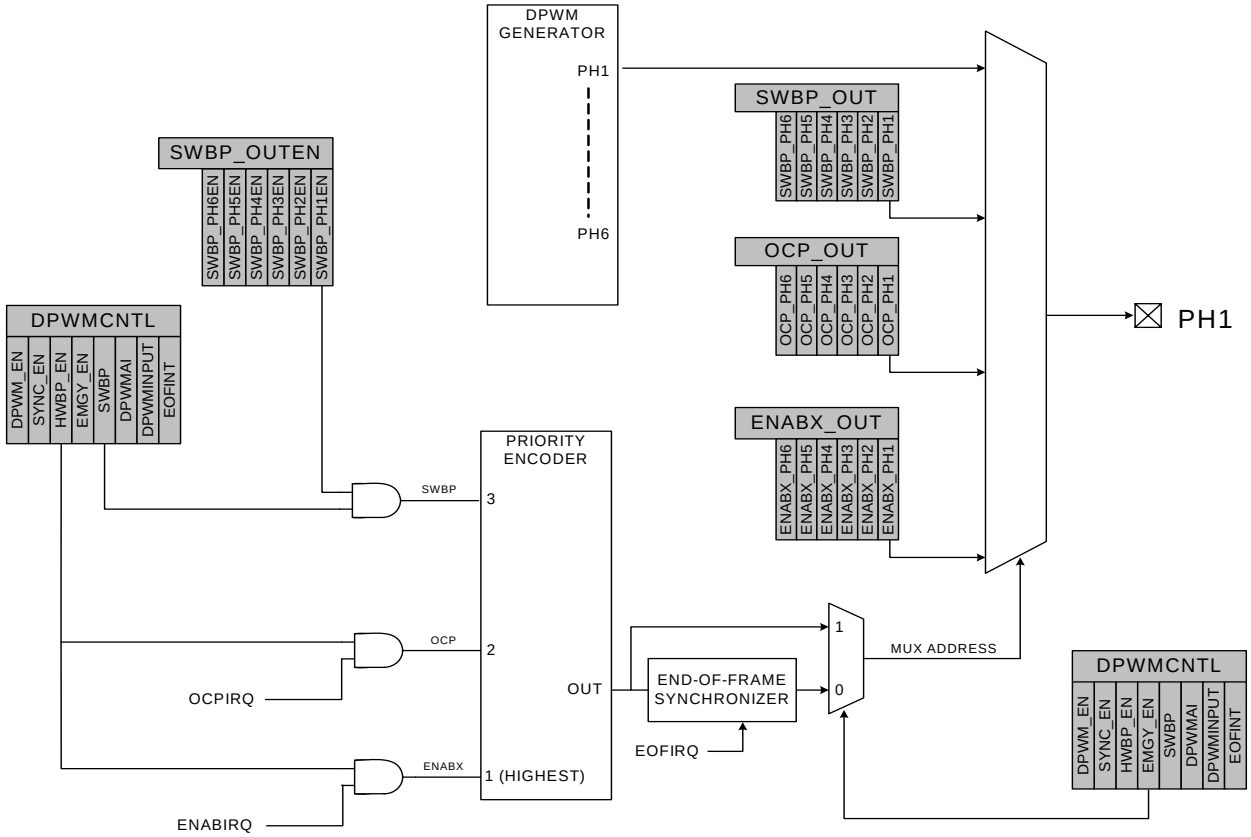


**Figure 6.9. DPWM Bypass Programming Model**

The three shutdown sources (in priority order) are as follows:

- Overcurrent protection fault
- ENABLE input
- Software bypass (initiated by the system management processor)

Both the ENABLE input and OCP are hardware shutdowns and are enabled by setting the HWBP_EN bit in the DPWMCNTL register to logic 1. When enabled, a supply shutdown occurs when either the ENABIRQ (ENABLE input pin forced to its OFF state) or OCPIRQ interrupts are asserted. If both occur simultaneously, the higher priority ENABLE interrupt will prevail. The lowest priority shutdown source is the software bypass, which is invoked by the system management processor by setting the SWBP bit DPWMCNTL to 1. The corresponding SWBP_OUTEN bit must be set to 1 to be bypassed. The transition from DPWM output to any of the three pre-defined states can be programmed to occur on switching frame boundaries or instantaneously by setting the EMGY_EN bit in DPWMCNTL to 1.

## 6.7. Sync Mode

This mode allows the start of each switching cycle to be synchronized with an external clock. The user enables sync mode by assigning the SYNC input to the port I/O pins by setting SYNCEN in XBAR0 and SYNC_EN bit in DPWMCNTL to 1. A logic level sync pulse is applied to the SYNC input, the positive edge of which triggers (or re-triggers) the start of a new switching as shown in Figure 6.10. The SYNC pulse must return low a minimum of 3 DPWM clock cycles prior to the next positive transition as shown.

**Important Note about Sync Mode:** The switching cycle in execution is unconditionally terminated and a new switching cycle initiated on the positive edge of the SYNC pulse. In this mode, the programmed switching cycle is ignored. If the SYNC clock is a substantially higher frequency, the switching cycle may be prematurely restarted resulting in damage to the power stages of the supply.

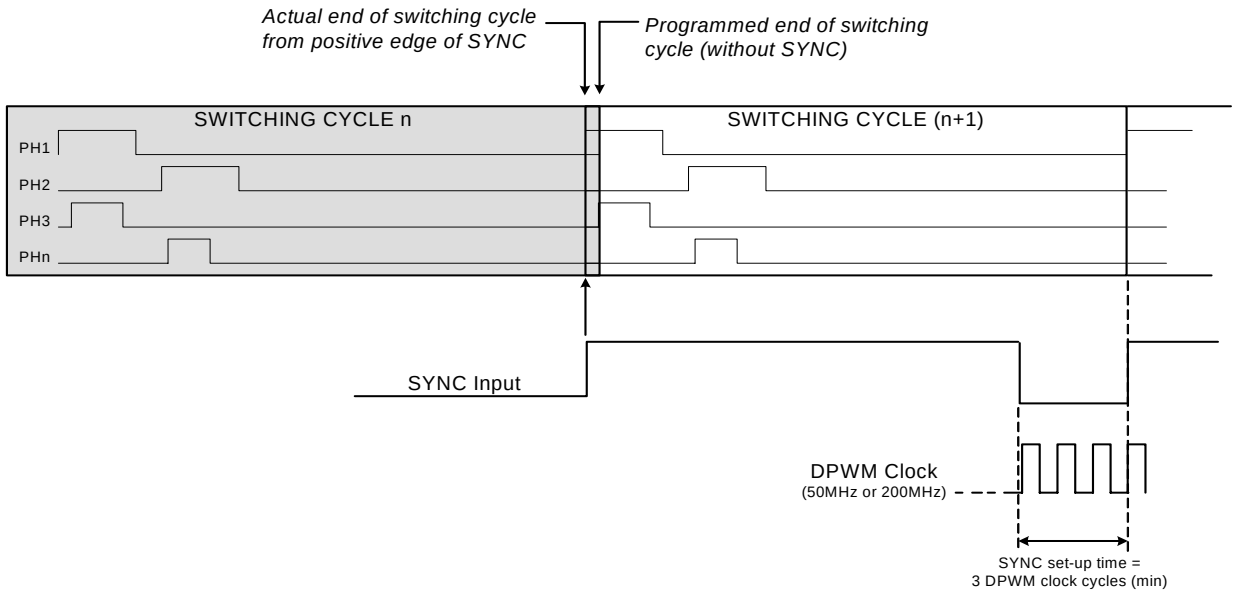


**Figure 6.10. DPWM Sync Mode Example**

## 6.8. Frame Skipping

Even at minimum PWM duty cycle, system losses at minimum load may be insufficient to prevent VOUT from rising above its specified maximum. Frame skipping reduces the effective energy transferred to the load by occasionally skipping switching cycles. It is analogous to pulse skipping, but applies to the full switching cycle. Frame Skipping is illustrated in Figure 6.11.

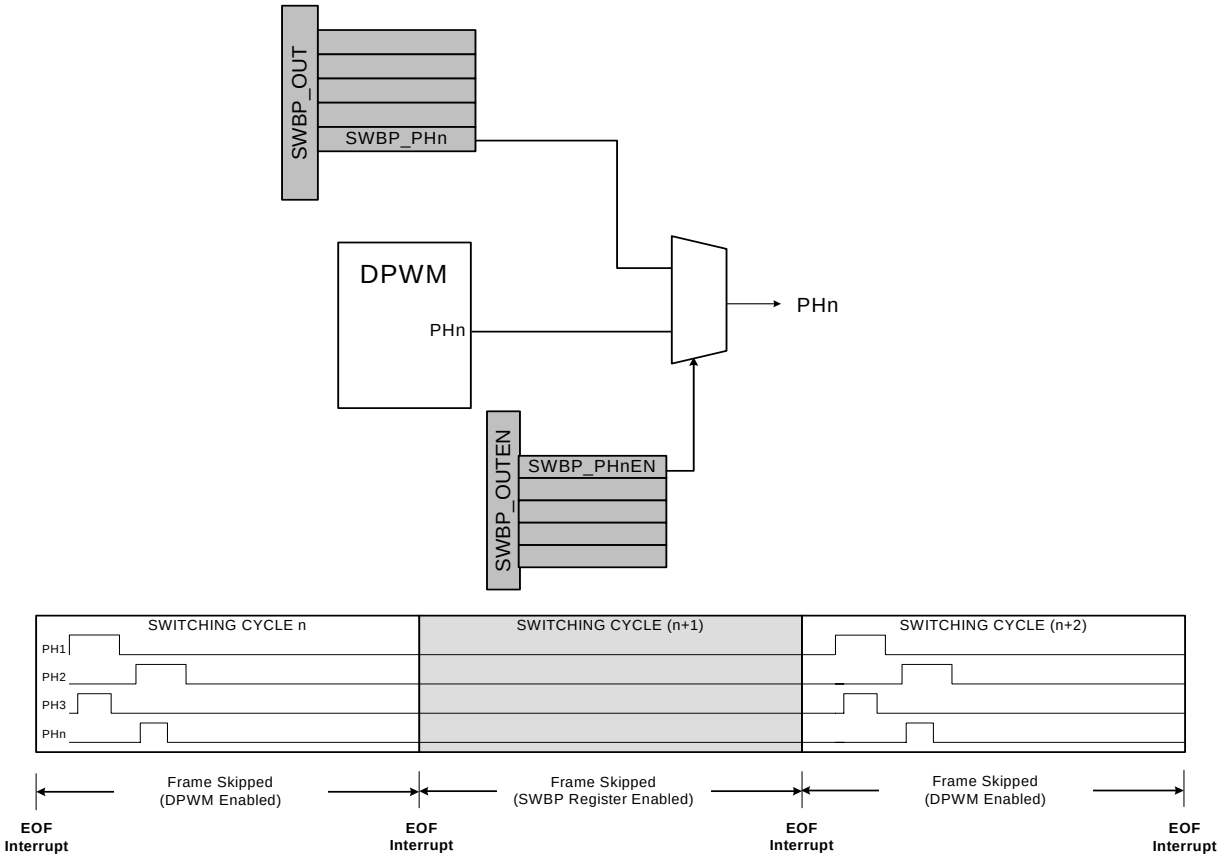


**Figure 6.11. Frame Skipping**

Each PHn bit has a corresponding PHn enable bit in SWBP_OUTEN and a state bit in SWBP_OUT. The end-of-frame (EOF) interrupt interrupts the system management processor at the end of each switching cycle. When this occurs, the system management processor sets or clears the SWBP bit in the DPWM-CNTL register, forcing the output MUX for each PH output to pass either the DPWM output (active switching cycle) or the OFF state contained in SWBP_OUT. Firmware can be configured to skip any number of cycles. Normal (continuous active frame) mode resumes when firmware detects an increase in output loading.

### SFR Definition 6.1. DPWMOUT: Output Data

| Same register as DPWMOUT at Address 0x2C | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |

SFR Address: 0xA6

This register is also addressable in the direct SFR space for fast access.

### SFR Definition 6.2. DPWMCN: DPWM Control

| Same register as DPWMCN at Address 0x00 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |

SFR Address: 0xF8

This register is also addressable in the direct SFR space for fast access.

### SFR Definition 6.3. DPWMULOCK: DPWM Symmetry Lock Control

| Same register as DPWMULOCK at Address 0x27 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |

SFR Address: 0x9E

This register is also addressable in the direct SFR space for fast access.

### SFR Definition 6.4. DPWMTLCD0: DPWM Trim & Limit Correction Data Register 0

| Same register as DPWMTLDC0 at Address 0x28 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |

SFR Address: 0xA1

This register is also addressable in the direct SFR space for fast access.

### SFR Definition 6.5. DPWMTLCD1: DPWM Trim & Limit Correction Data Register 1

| Same register as DPWMTLDC1 at Address 0x29 | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |

SFR Address: 0xA2

This register is also addressable in the direct SFR space for fast access.

### SFR Definition 6.6. DPWMTLCD2: DPWM Trim & Limit Correction Data Register 2

| Same register as DPWMTLDC2 at Address 0x2A | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |

SFR Address: 0xA3

This register is also addressable in the direct SFR space for fast access.

### SFR Definition 6.7. DPWMTLCD3: DPWM Trim & Limit Correction Data Register 3

| Same register as DPWMTLDC3 at Address 0x2B | | | | | | | |
|---|---|---|---|---|---|---|---|
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 |

SFR Address: 0x9A

This register is also addressable in the direct SFR space for fast access.

### SFR Definition 6.8. DPWMADDR: DPWM Indirect Address

| — | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | Auto inc Bit | DPWMA5 | DPWMA4 | DPWMA3 | DPWMA2 | DPWMA1 | DPWMA0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xAD

Bits 7–6: Unused.

Bits 5–0: DPWMA[5:0]: DPWM indirect address bits.

### SFR Definition 6.9. DPWMDATA: DPWM Indirect Address Data

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| DPWMD7 | DPWMD6 | DPWMD5 | DPWMD4 | DPWMD3 | DPWMD2 | DPWMD1 | DPWMD0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xAE

Bits 7–0: DPWMDATA[7:0]: Indirect address DPWM data bits.

## SFR Definition 6.10. DPWMCN: DPWM Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| DPWM_EN | SYNC_EN | HWBP_EN | EMGY_EN | SWBP | DPWMAI | DPWMINPUT | EOFINT | 00000100 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x00

Bit 7: DPWM_EN: DPWM Enable Bit
0: DPWM Disabled.
1: DPWM Enabled.

Bit 6: SYNC_EN: Sync Input Function Enable Bit
0: Sync Input Function Disabled.
1: Sync Input Function Enabled.

Bit 5: HWBP_EN: Hardware DPWM Bypass Enable (ENABLE or OCP interrupt asserted)
0: Hardware DPWM Bypass Disabled.
1: Hardware DPWM Bypass Enabled.

Bit 4: EMGY_EN: Emergency Shutdown Mode Enable Bit
0: Emergency Shutdown Mode Disabled (wait for end-of-frame to switch to bypass mode).
1: Emergency Shutdown Mode Enabled (switch to bypass mode immediately).

Bit 3: SWBP: Software DPWM Bypass Control
0: Software DPWM Bypass Off.
1: Software DPWM Bypass On.

Bit 2: DPWMAI: Address Auto Increment Bit.
0: Auto increment disabled.
1: Auto increment enabled.

Bit 1: DPWMINPUT: DPWM Input MUX Control Bit
0: Filter output selected (high-speed hardware modulates DPWM).
1: System management processor selected (system management processor directly modulates DPWM).

Bit 0: EOFINT: End-of-Frame Interrupt Status Bit
0: Switching Frame in Progress.
1: Switching Frame Completed.
This bit is set by hardware when switching frame is completed. This bit is not automatically cleared by hardware and must be cleared by software.

### SFR Definition 6.11. SW_CYC: Switching Cycle Length Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| SW_CYC7 | SW_CYC6 | SW_CYC5 | SW_CYC4 | SW_CYC3 | SW_CYC2 | SW_CYC1 | SW_CYC0 | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x01

Bits 7–0: SW_CYC[7:0]: Switching Cycle Clock Length Data Bits
This register contains the lower 8 bits of a 9-bit word. This word specifies the desired length of a complete switching cycle in unit clocks. The most significant bit (SW_CYC8) of this word is located in PH_POL. For example, if the user's timing requires only 128 of the 512 clock period, the user would program bits SW_CYC[8:0] to 0b001111111.

### SFR Definition 6.12. PH_POL: Phase Polarity Control

| R/W | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| SW_CYC8 | — | PH6_POL | PH5_POL | PH4_POL | PH3_POL | PH2_POL | PH1_POL | 10000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x02

Bit 7: SW_CYC8: Switching Cycle Clock Length Data Bit 8
This is the most significant bit of the 9-bit switching cycle clock length control word. The least significant 8 bits of this word are located in SW_CYC.

Bit 6: Unused.

Bits 5–0: PHn_POL: DPWM PHn Initial Output State
0: Output PHn is logic low at the beginning of the switching cycle.
1: Output PHn is logic high at the beginning of the switching cycle.

### SFR Definition 6.13. ENABX_OUT: ENABX Bypass Control

| — | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | ENABX_PH6 | ENABX_PH5 | ENABX_PH4 | ENABX_PH3 | ENABX_PH2 | ENABX_PH1 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x03

Bit 7: Unused.

Bit 6: Unused.

Bits 5–0: ENABX_PHn: Enable Control Input Bypass State for PH1:PH6
This register sets the default output states of PH1 to PH6 when the ENABLE input is used to turn the power supply off. For example, if the ENABX_PH6 through ENABX_PH1 are set to zero, all six PH outputs will be forced low when the supply is turned-off using the Enable control input.

### SFR Definition 6.14. OCP_OUT: Overcurrent Protection Bypass Control

| — | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | OCP_PH6 | OCP_PH5 | OCP_PH4 | OCP_PH3 | OCP_PH2 | OCP_PH1 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x04

Bit 7: Unused

Bit 6: Unused

Bits 5–0: OCP _PHn: Overcurrent Protection Bypass State for PH1:PH6
This register sets the default output states of PH1 to PH6 when the supply is shut-off due to an overcurrent protection fault. For example, if the OCP_PH6 through OCP_PH1 are all zero, all six PH outputs will be forced low when the supply enters an overcurrent protection fault condition.

### SFR Definition 6.15. SWBP_OUT: Software Bypass Control

| — | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | SWBP_PH6 | SWBP_PH5 | SWBP_PH4 | SWBP_PH3 | SWBP_PH2 | SWBP_PH1 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x05

Bit 7: Unused

Bit 6: Unused

Bits 5–0: SWBP_PHn: Software Bypass State for PH1:PH6
This register sets the default output states of PH1 to PH6 when the supply is shut-off by firmware. For example, if the SWBP_PH6 through SWBP_PH1 are all set to zero, all six PH outputs will be forced low when firmware shuts the supply down.

## SFR Definition 6.16. SWBP_OUTEN: Software Bypass Output Enable

| — | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | SWBP_PH6EN | SWBP_PH5EN | SWBP_PH4EN | SWBP_PH3EN | SWBP_PH2EN | SWBP_PH1EN | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x06

Bit 7: Unused.

Bit 6: Unused.

Bits 5–0: SWBP_PHnEN: Software Bypass Enable for PH1:PH6
This register selects the output phases that will be affected by the states specified in the SWBP_OUT register during software-invoked power supply shutdown. For example, if SWBP_PH1EN and SWBP_PH2EN are set to 1 and SWBP_PH3EN through SWBP_PH6EN are set to zero, the PH1 and PH2 outputs will be forced to the states specified by the SWBP_PH1 and SWBP_PH2 bits in the SWBP_OUT register when a software bypass is initiated. The remaining and output phases PH3 through PH6 will continue unaffected under the control of the DPWM.

## SFR Definition 6.17. PH1_CNTL0: Phase 1 Leading Edge Control Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH1L8 | PH1L_SEL2 | PH1L_SEL1 | PH1L_SEL0 | PH1L_EDGE | PH1L_PH2 | PH1L_PH1 | PH1L_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x07

Bit 7: PH1L8: Leading Edge Timing Data Bit 8
This is bit 9 (MSB) of the PH1_CTL1 register.

Bits 6–4: PH1L_SEL[2:0]: Leading Edge Control Bits
000: PH1 Leading Edge Timing Determined by u0(n)
001: PH1 Leading Edge Timing Determined by u1(n)
010: PH1 Leading Edge Timing Determined by u2(n)
011: PH1 Leading Edge Timing Determined by u3(n)
100: PH1 Leading Edge Timing is Relative to Another Timing Edge
101: PH1 Leading Edge Timing is Relative to Another Timing Edge
110: PH1 Leading Edge Timing is Relative to Another Timing Edge
111: PH1 Leading Edge Timing is Absolute

Bit 3: PH1L_EDGE: Relative Timing Reference Edge Leading/Trailing Edge Select
0: Relative Timing is Referenced to Leading Edge.
1: Relative Timing is Referenced to Trailing Edge.

Bits 2–0: PH1L_PH[2:0]: Leading Edge Relative Timing Reference Edge
000: reserved
001: PH1 Leading Edge Timing Relative to PH1
010: PH1 Leading Edge Timing Relative to PH2
011: PH1 Leading Edge Timing Relative to PH3
100: PH1 Leading Edge Timing Relative to PH4
101: PH1 Leading Edge Timing Relative to PH5
110: PH1 Leading Edge Timing Relative to PH6
111: reserved

## SFR Definition 6.18. PH1_CNTL1: Phase 1 Leading Edge Control Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH1L7 | PH1L6 | PH1L5 | PH1L4 | PH1L3 | PH1L2 | PH1L1 | PH1L0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x08

Bits 7–0: PH1L[7:0]: Leading Edge Timing Control Bits
A 9-bit word composed of these 8 bits plus PH1L8 in PH1_CTL0 specify the time at which the leading edge of PH1 changes state.

### SFR Definition 6.19. PH1_CNTL2: Phase 1 Trailing Edge Control Register 2

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH1T8 | PH1T_SEL2 | PH1T_SEL1 | PH1T_SEL0 | PH1T_EDGE | PH1T_PH2 | PH1T_PH1 | PH1T_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x09

Bit 7: PH1T8: Trailing Edge Timing Data Bit 8
This is bit 9 (MSB) of the PH1_CTL1 register.

Bits 6–4: PH1T_SEL[2:0]: Trailing Edge Control Bits
000: PH1 Trailing Edge Timing Determined by u0(n)
001: PH1 Trailing Edge Timing Determined by u1(n)
010: PH1 Trailing Edge Timing Determined by u2(n)
011: PH1 Trailing Edge Timing Determined by u3(n)
100: PH1 Trailing Edge Timing is Relative to Another Timing Edge
101: PH1 Trailing Edge Timing is Relative to Another Timing Edge
110: PH1 Trailing Edge Timing is Relative to Another Timing Edge
111: PH1 Trailing Edge Timing is Absolute

Bit 3: PH1T_EDGE: Relative Timing Reference Edge Leading/Trailing Edge Select
0: Relative Timing is Referenced to Leading Edge.
1: Relative Timing is Referenced to Trailing Edge.

Bits 2–0: PH1T_PH[2:0]: Trailing Edge Relative Timing Reference Edge
000: reserved
001: PH1 Trailing Edge Timing Relative to PH1
010: PH1 Trailing Edge Timing Relative to PH2
011: PH1 Trailing Edge Timing Relative to PH3
100: PH1 Trailing Edge Timing Relative to PH4
101: PH1 Trailing Edge Timing Relative to PH5
110: PH1 Trailing Edge Timing Relative to PH6
111: reserved

### SFR Definition 6.20. PH1_CNTL3: Phase 1 Trailing Edge Control Register 3

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH1T7 | PH1T6 | PH1T5 | PH1T4 | PH1T3 | PH1T2 | PH1T1 | PH1T0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0A

Bits 7–0: PH1T[7:0]: Trailing Edge Timing Control Bits
A 9-bit word composed of these 8 bits plus PH1T8 in PH1_CNTL2 specify the time at which the trailing edge of PH1 changes state.

### SFR Definition 6.21. PH2_CNTL0: Phase 2 Leading Edge Control Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH2L8 | PH2L_SEL2 | PH2L_SEL1 | PH2L_SEL0 | PH2L_EDGE | PH2L_PH2 | PH2L_PH1 | PH2L_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0B

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 2 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.22. PH2_CNTL1: Phase 2 Leading Edge Control Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH2L7 | PH2L6 | PH2L5 | PH2L4 | PH2L3 | PH2L2 | PH2L1 | PH2L0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0C

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 2 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.23. PH2_CNTL2: Phase 2 Trailing Edge Control Register 2

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH2T8 | PH2T_SEL2 | PH2T_SEL1 | PH2T_SEL0 | PH2T_EDGE | PH2T_PH2 | PH2T_PH1 | PH2T_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0D

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 2 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.24. PH2_CNTL3: Phase 2 Trailing Edge Control Register 3

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH2T7 | PH2T6 | PH2T5 | PH2T4 | PH2T3 | PH2T2 | PH2T1 | PH2T0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0E

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 2 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.25. PH3_CNTL0: Phase 3 Leading Edge Control Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH3L8 | PH3L_SEL2 | PH3L_SEL1 | PH3L_SEL0 | PH3L_EDGE | PH3L_PH2 | PH3L_PH1 | PH3L_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0F

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 3 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.26. PH3_CNTL1: Phase 3 Leading Edge Control Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH3L7 | PH3L6 | PH3L5 | PH3L4 | PH3L3 | PH3L2 | PH3L1 | PH3L0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x10

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 3 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.27. PH3_CNTL2: Phase 3 Trailing Edge Control Register 2

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH3T8 | PH3T_SEL2 | PH3T_SEL1 | PH3T_SEL0 | PH3T_EDGE | PH3T_PH2 | PH3T_PH1 | PH3T_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x11

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 3 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.28. PH3_CNTL3: Phase 3 Trailing Edge Control Register 3

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH3T7 | PH3T6 | PH3T5 | PH3T4 | PH3T3 | PH3T2 | PH3T1 | PH3T0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x12

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 3 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.29. PH4_CNTL0: Phase 4 Leading Edge Control Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH4L8 | PH4L_SEL2 | PH4L_SEL1 | PH4L_SEL0 | PH4L_EDGE | PH4L_PH2 | PH4L_PH1 | PH4L_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x13

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 4 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.30. PH4_CNTL1: Phase 4 Leading Edge Control Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH4L7 | PH4L6 | PH4L5 | PH4L4 | PH4L3 | PH4L2 | PH4L1 | PH4L0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x14

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 4 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.31. PH4_CNTL2: Phase 4 Trailing Edge Control Register 2

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH4T8 | PH4T_SEL2 | PH4T_SEL1 | PH4T_SEL0 | PH4T_EDGE | PH4T_PH2 | PH4T_PH1 | PH4T_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x15

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 4 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.32. PH4_CNTL3: Phase 4 Trailing Edge Control Register 3

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH4T7 | PH4T6 | PH4T5 | PH4T4 | PH4T3 | PH4T2 | PH4T1 | PH4T0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x16

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 4 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.33. PH5_CNTL0: Phase 5 Leading Edge Control Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH5L8 | PH5L_SEL2 | PH5L_SEL1 | PH5L_SEL0 | PH5L_EDGE | PH5L_PH2 | PH5L_PH1 | PH5L_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x17

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 5 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.34. PH5_CNTL1: Phase 5 Leading Edge Control Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH5L7 | PH5L6 | PH5L5 | PH5L4 | PH5L3 | PH5L2 | PH5L1 | PH5L0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x18

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 5 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.35. PH5_CNTL2: Phase 5 Trailing Edge Control Register 2

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH5T8 | PH5T_SEL2 | PH5T_SEL1 | PH5T_SEL0 | PH5T_EDGE | PH5T_PH2 | PH5T_PH1 | PH5T_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x19

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 5 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.36. PH5_CNTL3: Phase 5 Trailing Edge Control Register 3

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH5T7 | PH5T6 | PH5T5 | PH5T4 | PH5T3 | PH5T2 | PH5T1 | PH5T0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1A

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 5 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.37. PH6_CNTL0: Phase 6 Leading Edge Control Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH6L8 | PH6L_SEL2 | PH6L_SEL1 | PH6L_SEL0 | PH6L_EDGE | PH6L_PH2 | PH6L_PH1 | PH6L_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1B

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 6 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.38. PH6_CNTL1: Phase 6 Leading Edge Control Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH6L7 | PH6L6 | PH6L5 | PH6L4 | PH6L3 | PH6L2 | PH6L1 | PH65L0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1C

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 6 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.39. PH6_CNTL2: Phase 6 Trailing Edge Control Register 2

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH6T8 | PH6T_SEL2 | PH6T_SEL1 | PH6T_SEL0 | PH6T_EDGE | PH6T_PH2 | PH6T_PH1 | PH6T_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1D

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 6 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.40. PH6_CNTL3: Phase 6 Trailing Edge Control Register 3

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PH6T7 | PH6T6 | PH6T5 | PH6T4 | PH6T3 | PH6T2 | PH6T1 | PH6T0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1E

**Note**: The Phase 1 SFR definitions are essentially the same for this Phase except Phase 6 is the reference. Refer to Phase 1 SFR bit definitions.

### SFR Definition 6.41. DPWMTLLT0: Trim/Limit Low Limit Control Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLLT7 | TLLT6 | TLLT5 | TLLT4 | TLLT3 | TLLT2 | TLLT1 | TLLT0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1F

Bits 7–0: TLLT[7:0]: u0(n) Trim and Limit Low Limit Data
This register sets the lower limit of compensated duty cycle modulation variable u0(n).

### SFR Definition 6.42. DPWMTLGT0: Trim/Limit High Limit Control Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLGT7 | TLGT6 | TLGT5 | TLGT4 | TLGT3 | TLGT2 | TLGT1 | TLGT0 | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x20

Bits 7–0: TLGT[7:0]: u0(n) Trim and Limit High Limit Data
This register sets the upper limit of compensated duty cycle modulation variable u0(n).

### SFR Definition 6.43. DPWMTLLT1: Trim/Limit Low Limit Control Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLLT7 | TLLT6 | TLLT5 | TLLT4 | TLLT3 | TLLT2 | TLLT1 | TLLT0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x21

Bits 7–0: TLLT[7:0]: u1(n) Trim and Limit Low Limit Data
This register sets the lower limit of compensated duty cycle modulation variable u1(n).

### SFR Definition 6.44. DPWMTLGT1: Trim/Limit High Limit Control Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLGT7 | TLGT6 | TLGT5 | TLGT4 | TLGT3 | TLGT2 | TLGT1 | TLGT0 | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x22

Bits 7–0: TLGT[7:0]: u1(n) Trim and Limit High Limit Data
This register sets the upper limit of compensated duty cycle modulation variable u1(n).

### SFR Definition 6.45. DPWMTLLT2: Trim/Limit Low Limit Control Register 2

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLLT7 | TLLT6 | TLLT5 | TLLT4 | TLLT3 | TLLT2 | TLLT1 | TLLT0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x23

Bits 7–0: TLLT[7:0]: u2(n) Trim and Limit Low Limit Data
This register sets the lower limit of compensated duty cycle modulation variable u2(n).

### SFR Definition 6.46. DPWMTLGT2: Trim/Limit High Limit Control Register 2

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLGT7 | TLGT6 | TLGT5 | TLGT4 | TLGT3 | TLGT2 | TLGT1 | TLGT0 | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x24

Bits 7–0: TLGT[7:0]: u2(n) Trim and Limit High Limit Data
This register sets the upper limit of compensated duty cycle modulation variable u2(n).

### SFR Definition 6.47. DPWMTLLT3: Trim/Limit Low Limit Control Register 3

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLLT7 | TLLT6 | TLLT5 | TLLT4 | TLLT3 | TLLT2 | TLLT1 | TLLT0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x25

Bits 7–0: TLLT[7:0]: u3(n) Trim and Limit Low Limit Data
This register sets the lower limit of compensated duty cycle modulation variable u3(n).

### SFR Definition 6.48. DPWMTLGT3: Trim/Limit High Limit Control Register 3

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLGT7 | TLGT6 | TLGT5 | TLGT4 | TLGT3 | TLGT2 | TLGT1 | TLGT0 | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x26

Bits 7–0: TLGT[7:0]: u3(n) Trim and Limit High Limit Data
This register sets the upper limit of compensated duty cycle modulation variable u3(n).

### SFR Definition 6.49. DPWMULOCK: Symmetry Lock Control Register

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ULCK1_EDG | ULCK1_PH2 | ULCK1_PH1 | ULCK1_PH0 | ULCK0_EGD | ULCK0_PH2 | ULCK0_PH1 | ULCK0_PH0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x27

Bit 7: ULCK1_EDG: Symmetry Lock Reference Edge for u0(n) and u1(n)
0: Symmetry Lock Occurs on Leading Edge of Reference Phase.
1: Symmetry Lock Occurs on Trailing Edge of Reference Phase.

Bits 6–4: ULCK1_PH[2:0]: Reference Phase Select Bits
001: Phase 1 Selected
010: Phase 2 Selected
011: Phase 3 Selected
100: Phase 4 Selected
101: Phase 5 Selected
110: Phase 6 Selected

Bit 3: ULCK0_EDG: Symmetry Lock Reference Edge for u2(n) and u3(n)
0: Symmetry lock occurs on leading edge of reference phase.
1: Symmetry lock occurs on trailing edge of reference phase.

Bits 2–0: ULCK0_PH[2:0]: Reference Phase Select Bits
001: Phase 1 Selected
010: Phase 2 Selected
011: Phase 3 Selected
100: Phase 4 Selected
101: Phase 5 Selected
110: Phase 6 Selected

### SFR Definition 6.50. DPWMTLCD0: Trim & Limit Correction Data Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLGT8 | TLLT8 | TLCD5 | TLCD4 | TLCD3 | TLCD2 | TLCD1 | TLCD0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x28

Bit 7: TLGT8: DPWMTLGT0 High Limit Register Data Bit 8

Bit 6: TLLT8: DPWMTLLT0 Low Limit Register Data Bit 8

Bits 5–0: TLDC[5:0]: u0(n) Correction Data
The data in this register applies a positive or negative offset to u0(n). It is two's-complement format.

### SFR Definition 6.51. DPWMTLCD1: Trim & Limit Correction Data Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLGT8 | TLLT8 | TLCD5 | TLCD4 | TLCD3 | TLCD2 | TLCD1 | TLCD0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x29

Bit 7: TLGT8: DPWMTLGT1 High Limit Register Data Bit 8

Bit 6: TLLT8: DPWMTLLT1 Low Limit Register Data Bit 8

Bits 5–0: TLDC[5:0]: u1(n) Correction Data
The data in this register applies a positive or negative offset to u1(n). It is 2s complement format.

### SFR Definition 6.52. DPWMTLCD2: Trim & Limit Correction Data Register 2

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLGT8 | TLLT8 | TLCD5 | TLCD4 | TLCD3 | TLCD2 | TLCD1 | TLCD0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x2A

Bit 7: TLGT8: DPWMTLGT2 High Limit Register Data Bit 8

Bit 6: TLLT8: DPWMTLLT2 Low Limit Register Data Bit 8

Bits 5–0: TLDC[5:0]: u2(n) Correction Data
The data in this register applies a positive or negative offset to u2(n). It is 2s complement format.

### SFR Definition 6.53. DPWMTLCD3: Trim & Limit Correction Data Register 3

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TLGT8 | TLLT8 | TLCD5 | TLCD4 | TLCD3 | TLCD2 | TLCD1 | TLCD0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x2B

Bit 7: TLGT8: DPWMTLGT3 High Limit Register Data Bit 8

Bit 6: TLLT8: DPWMTLLT3 Low Limit Register Data Bit 8

Bits 5–0: TLDC[5:0]: u3(n) Correction Data
The data in this register applies a positive or negative offset to u3(n). It is 2s complement format.

### SFR Definition 6.54. DPWMOUT: DPWM Output Register

| — | — | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | PH6 | PH5 | PH4 | PH3 | PH2 | PH1 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x2C

Bits 7–6 Unused.

Bits 5–0: PH6–1: These read-only register bits show the present state of the PH1:PH6 DPWM outputs.

## 7. Rev. 0.7Voltage Reference

The Voltage reference MUX on Si8250/1/2 devices is configurable to use an externally-connected voltage reference, the internal reference voltage generator, or the VDD power supply voltage (see Figure 7.1). An external voltage reference may be connected to the VREF pin, and the internal reference is disabled by clearing the REFBE bit in the Reference Control register (REF0CN), which selects the reference source.

The BIASE bit enables the internal voltage bias generator, which is used by the ADC, Temperature Sensor, and internal oscillators. This bit is forced to logic 1 when any of the aforementioned peripherals are enabled. The bias generator may be enabled manually by writing a '1' to the BIASE bit in register REF0CN; see REF0CN register details.

The internal voltage reference circuit consists of a 1.20 V, temperature stable bandgap voltage reference generator and output buffer amplifier. The internal voltage reference can be driven out on the VREF pin by setting the REFBE bit in register REF0CN to a '1'. The maximum load seen by the VREF pin must be less than 200 µA to GND. When using the internal voltage reference, bypass capacitors of 0.1 µF and 4.7 µF are recommended from the VREF pin to GND. If the internal reference is not used, the REFBE bit should be cleared to '0'.

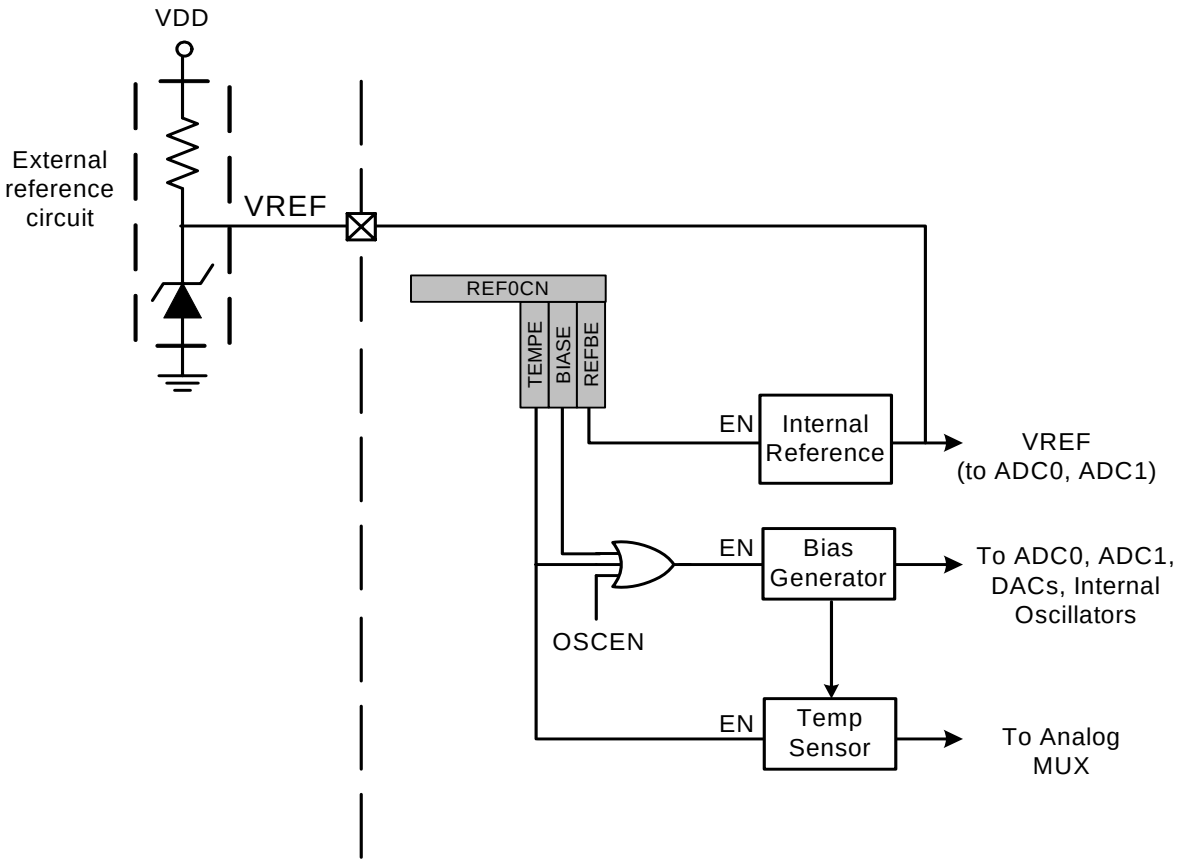


**Figure 7.1. Voltage Reference Functional Block Diagram**

### SFR Definition 7.1. REF0CN: Reference Control

| — | — | — | — | — | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | — | TEMPE | BIASE | REFBE | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xD1

Bits 7–3: Unused.

Bit 2: TEMPE: Temperature Sensor Enable Bit
0: Temperature Sensor Off
1: Temperature Sensor On

Bit 1: BIASE: Internal Analog Bias Generator Enable Bit
0: Internal analog bias generator automatically enabled when needed
1: Internal analog bias generator on

Bit 0: REFBE: Internal Reference Buffer Enable Bit
0: Internal reference buffer disabled
1: Internal reference buffer enabled.

# 8. Comparator 0

Si8250/1/2 devices include an on-chip programmable voltage comparator shown in Figure 8.1. Comparator0 offers programmable response time and hysteresis, an analog input multiplexer, and two outputs that are optionally available at the Port pins: a synchronous "latched" output (CP0), or an asynchronous "raw" output (CP0A). The asynchronous CP0A signal is available even when the system clock is not active. This allows the Comparator to operate and generate an output with the device in STOP mode. When assigned to a Port pin, the Comparator output may be configured as open drain or push-pull. The Comparator0 inputs are selected in the CPT0MX register. The CMX0P[3:0] bits select the Comparator0 positive input, which may be assigned to even port pins (P1.0, P1.2, P1.4, P1.6). The CMX0N[3:0] bits select the Comparator0 negative input, which may be assigned to odd port pins (P1.1, P1.3, P1.5, P1.7).

**Important Note About Comparator Inputs:** The Port pins selected as Comparator inputs should be configured as analog inputs in their associated Port configuration register, and configured to be skipped by the Crossbar.

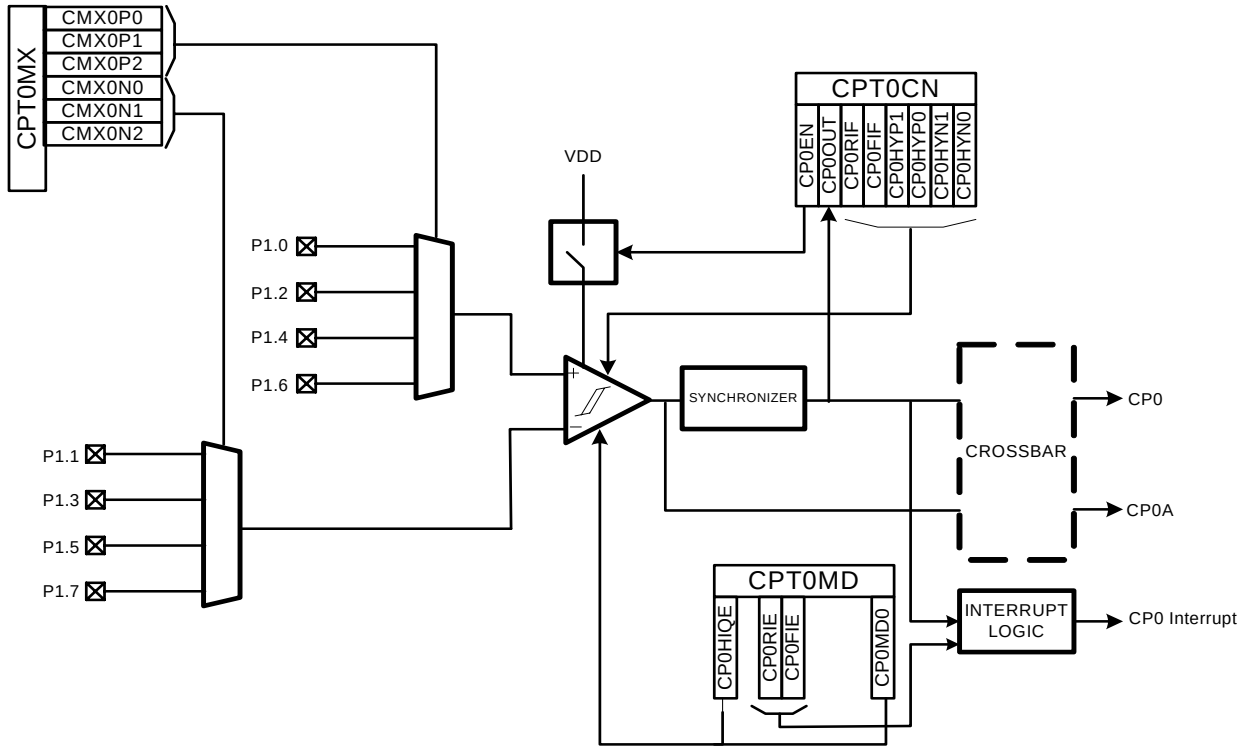


**Figure 8.1. Comparator0 Functional Block Diagram**

Comparator0 has two programmable response modes: 40 ns and 750 ns. The fast 40 ns response time is useful for pulse or ring detection applications while the lower power 750 ns response time is useful for threshold monitoring applications. Response time is selected by the CP0MD0 bit in CPT0MD.

The Comparator output can be polled in software, used as an interrupt source, internal oscillator suspend awakening source and/or routed to a Port pin. When routed to a Port pin, the Comparator output is available asynchronous or synchronous to the system clock; the asynchronous output is available even in STOP mode (with no system clock active). When disabled, the Comparator output (if assigned to a Port I/O pin via the Crossbar) defaults to the logic low state, and its supply current falls to less than 100 nA. See

Section "19.1. Priority Crossbar Decoder" on page 197 for details on configuring Comparator outputs via the digital Crossbar. Comparator inputs can be externally driven from –0.25 V to (VDD) + 0.25 V without damage or upset.

Comparator 0 hysteresis is software-programmable via its Comparator Control register CPT0CN (for n = 0 or 1). The user can program both the amount of hysteresis voltage (referred to the input voltage) and the positive and negative-going symmetry of this hysteresis around the threshold voltage (see Figure 8.2).

The Comparator hysteresis is programmed using bits CP0HYP[1:0] and bits CP0HYN[1:0] in the Comparator Control Register CPT0CN. The amount of negative hysteresis voltage is determined by the settings of the CP0HYN[1:0] bits. Settings of 20, 10 or 5 mV of negative hysteresis can be programmed, or negative hysteresis can be disabled. In a similar way, the amount of positive hysteresis is determined by the setting the CP0HYP[1:0] bits.

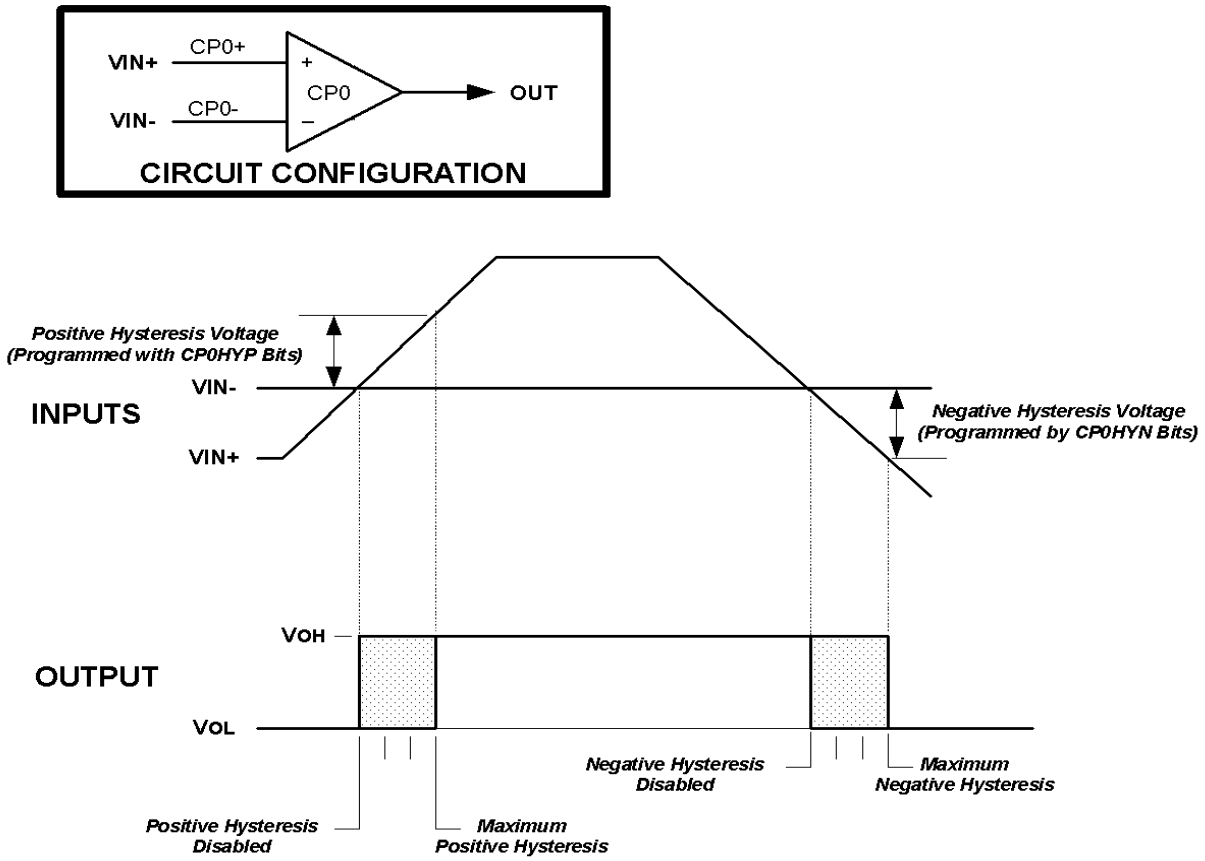


**Figure 8.2. Comparator Hysteresis Plot**

Comparator interrupts can be generated on both rising-edge and falling-edge output transitions. The CP0FIF flag is set to logic 1 upon a Comparator falling-edge interrupt, and the CP0RIF flag is set to logic 1 upon the Comparator rising-edge interrupt. Once set, these bits remain set until cleared by software. The output state of the Comparator can be obtained at any time by reading the CP0OUT bit. The Comparator is enabled by setting the CP0N bit to logic 1, and is disabled by clearing this bit to logic 0.

The output state of the Comparator can be obtained at any time by reading the CP0OUT bit. The Comparator is enabled by setting the CP0EN bit to logic 1, and is disabled by clearing this bit to logic 0. When the Comparator is enabled, the internal oscillator is awakened from suspend mode if the Comparator output is logic 0.

Note that false rising edges and falling edges can be detected when the comparator is first powered-on or if changes are made to the hysteresis or response time control bits. Therefore, it is recommended that the rising-edge and falling-edge flags be explicitly cleared to logic 0 after the comparator is enabled and after its mode bits have been changed.

The Comparator0 interrupt may be used as a wake-up source from Stop Mode and is typically configured in low-power mode for this application.

### SFR Definition 8.1. CPT0CN: Comparator0 Control

| R/W | R | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| CP0EN | CP0OUT | CP0RIF | CP0FIF | CP0HYP1 | CP0HYP0 | CP0HYN1 | CP0HYN0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |
| | | | | | | SFR Address: | | 0x9B |

Bit 7: CP0EN: Comparator 0 Enable bit
0: Comparator 0 disabled
1: Comparator 0 enabled

Bit 6: CP0OUT: Comparator 0 Output
0: Voltage on CP0+ < CP0-
1: Voltage on CP0+ > CP0-.

Bit 5: CP0RIF: Comparator Rising-Edge Interrupt Flag
0: No Comparator0 rising edge interrupt has occurred since this flag was last cleared.
1: Comparator0 rising edge interrupt has occurred.

Bit 4: CP0FIF: Comparator0 Falling-Edge Interrupt Flag
0: No Comparator0 falling edge interrupt has occurred since this flag was last cleared.
1: Comparator0 falling edge interrupt has occurred.

Bits 3–2: CP0HYP[1:0]: Comparator0 Positive Hysteresis Control Bits.
00: Positive hysteresis disabled
01: Positive hysteresis = 5 mV
10: Positive hysteresis = 10 mV
11: Positive hysteresis = 20 mV

Bits 1-0: CP0HYN[1:0]: Comparator0 Negative Hysteresis Control Bits.
00: Negative hysteresis disabled
01: Negative hysteresis = 5 mV
10: Negative hysteresis = 10 mV
11: Negative hysteresis = 20 mV

### SFR Definition 8.2. CPT0MD: Comparator0 Mode Selection

| R/W | — | R/W | R/W | — | — | — | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| CP0HIQE | — | CP0RIE | CP0FIE | — | — | — | CP0MD0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x9D

Bit 7: CP0HIQE: High-Speed Analog Mode Enable Bit
0: Comparator0 input configured in Low Speed Analog Mode.
1: Comparator0 input configured in High Speed Analog Mode.

Bit 6: Unused

Bit 5: CP0RIE: Comparator0 Rising Edge Interrupt Enable
0: Rising edge interrupt disabled.
1: Rising edge interrupt enabled.

Bit 4: CP0FIE: Comparator0 Falling-Edge Interrupt Enable
0: Falling edge interrupt disabled.
1: Falling edge interrupt enabled.

Bits 3–1: Unused

Bit 0: CP0MD0: Comparator 0 Mode Select Bits
0: Response time = 750 ns
1: Response time = 40 ns

### SFR Definition 8.3. CPT0MX: Comparator0 MUX Selection

| — | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | CMX0N2 | CMX0N1 | CMX0N0 | — | CMX0P2 | CMX0P1 | CMX0P0 | 01000100 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x9F

Bit 7: Unused.

Bit 6–4: CMX0N[2:0]: Comparator0 Negative Input MUX Select
These bits select which port pin is used as Comparator0 negative input.
000: P1.1
001: P1.3
010: P1.5
011: P1.7
1xx: None

Bit 3: Unused.

Bit 2–0: CMX0P[2:0]: Comparator0 Positive Input MUX Select
These bits select which port pin is used as Comparator0 positive input.
000: P1.0
001: P1.2
010: P1.4
011: P1.6
1xx: None

# 9. CIP-51 CPU

MCS-51™ instruction set. Standard 803x/805x assemblers and compilers can be used to develop software. The Si8250/1/2 family has a superset of all the peripherals included with a standard 8051. See Section "**1. System Overview**" on page **19** for more information about the available peripherals. The CIP-51 includes on-chip debug hardware, which interfaces directly with the analog and digital subsystems, providing a complete data acquisition or control-system solution in a single integrated circuit.

The CIP-51 Microcontroller core implements the standard 8051 organization and peripherals as well as additional custom peripherals and functions to extend its capability. The CIP-51 core includes the following features:

- Fully Compatible with MCS-51 Instruction Set
- 256 Bytes of Internal RAM
- Reset Input
- Integrated Debug Logic
- 50 MIPS Peak Throughput
- Extended Interrupt Handler
- Power Management Modes
- Program and Data Memory Security

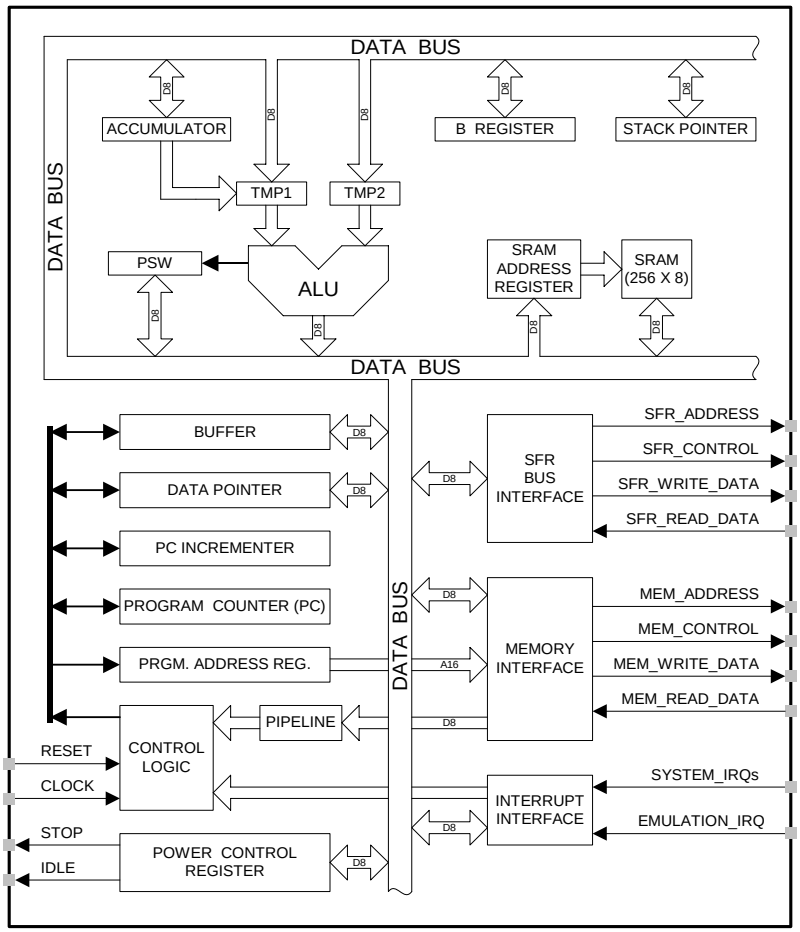


**Figure 9.1. CIP-51 Block Diagram**

**Performance**
The CIP-51 employs a pipelined architecture that greatly increases its instruction throughput over the standard 8051 architecture. In a standard 8051, all instructions except for MUL and DIV take 12 or 24 system clock cycles to execute, and usually have a maximum system clock of 12 MHz. By contrast, the CIP-51 core executes 70% of its instructions in one or two system clock cycles, with no instructions taking more than eight system clock cycles.

With the CIP-51's system clock running at 50 MHz, it has a peak throughput of 50 MIPS. The CIP-51 has a total of 109 instructions. The table below shows the total number of instructions that require each execution time.

| Clocks to Execute | 1 | 2 | 2/4 | 3 | 3/5 | 4 | 5 | 4/6 | 6 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| Number of Instructions | 26 | 50 | 5 | 10 | 7 | 5 | 2 | 1 | 2 | 1 |

**Programming and Debugging Support**
In-system programming of the Flash program memory and communication with on-chip debug support logic is accomplished via the Silicon Labs 2-Wire (C2) interface. Note that the re-programmable Flash can also be read and written a single byte at a time by the application software using the MOVC and MOVX instructions. This feature allows program memory to be used for non-volatile data storage as well as updating program code under software control.

The on-chip debug support logic facilitates full speed in-circuit debugging, allowing the setting of hardware breakpoints, starting, stopping and single stepping through program execution (including interrupt service routines), examination of the program's call stack, and reading/writing the contents of registers and memory. This method of on-chip debugging is completely non-intrusive, requiring no RAM, Stack, timers, or other on-chip resources.

The CIP-51 is supported by development tools from Silicon Laboratories, Inc. and third party vendors. Silicon Laboratories provides an integrated development environment (IDE) including editor, evaluation compiler, assembler, debugger and programmer. The IDE's debugger and programmer interface to the CIP-51 via the on-chip debug logic to provide fast and efficient in-system device programming and debugging. Third party macro assemblers and C compilers are also available.

## 9.1. Instruction Set

The instruction set of the CIP-51 System Controller is fully compatible with the standard MCS-51™ instruction set. Standard 8051 development tools can be used to develop software for the CIP-51. All CIP-51 instructions are the binary and functional equivalent of their MCS-51™ counterparts, including opcodes, addressing modes and effect on PSW flags. However, instruction timing is different than that of the standard 8051.

### 9.1.1. Instruction and CPU Timing

In many 8051 implementations, a distinction is made between machine cycles and clock cycles, with machine cycles varying from 2 to 12 clock cycles in length. However, the CIP-51 implementation is based solely on clock cycle timing. All instruction timings are specified in terms of clock cycles.

Due to the pipelined architecture of the CIP-51, most instructions execute in the same number of clock cycles as there are program bytes in the instruction. Conditional branch instructions take two less clock cycles to complete when the branch is not taken as opposed to when the branch is taken. Table 9.1 is the CIP-51 Instruction Set Summary, which includes the mnemonic, number of bytes, and number of clock cycles for each instruction.

### 9.1.2. MOVX Instruction and Program Memory

The MOVX instruction is typically used to access data stored in XDATA memory space. In the CIP-51, the MOVX instruction can also be used to write or erase on-chip program memory space implemented as re-programmable Flash memory. The Flash access feature provides a mechanism for the CIP-51 to update program code and use the program memory space for non-volatile data storage. Refer to **Section "13. Flash Memory" on page 115** for further details.

**Table 9.1. CIP-51 Instruction Set Summary[1]**

| Mnemonic | Description | Bytes | Clock Cycles |
|---|---|---|---|
| **Arithmetic Operations** | | | |
| ADD A, Rn | Add register to A | 1 | 1 |
| ADD A, direct | Add direct byte to A | 2 | 2 |
| ADD A, @Ri | Add indirect RAM to A | 1 | 2 |
| ADD A, #data | Add immediate to A | 2 | 2 |
| ADDC A, Rn | Add register to A with carry | 1 | 1 |
| ADDC A, direct | Add direct byte to A with carry | 2 | 2 |
| ADDC A, @Ri | Add indirect RAM to A with carry | 1 | 2 |
| ADDC A, #data | Add immediate to A with carry | 2 | 2 |
| SUBB A, Rn | Subtract register from A with borrow | 1 | 1 |
| SUBB A, direct | Subtract direct byte from A with borrow | 2 | 2 |
| SUBB A, @Ri | Subtract indirect RAM from A with borrow | 1 | 2 |
| SUBB A, #data | Subtract immediate from A with borrow | 2 | 2 |
| INC A | Increment A | 1 | 1 |
| INC Rn | Increment register | 1 | 1 |
| INC direct | Increment direct byte | 2 | 2 |
| INC @Ri | Increment indirect RAM | 1 | 2 |
| DEC A | Decrement A | 1 | 1 |
| DEC Rn | Decrement register | 1 | 1 |
| DEC direct | Decrement direct byte | 2 | 2 |
| DEC @Ri | Decrement indirect RAM | 1 | 2 |
| INC DPTR | Increment Data Pointer | 1 | 1 |
| MUL AB | Multiply A and B | 1 | 4 |
| DIV AB | Divide A by B | 1 | 8 |
| DA A | Decimal adjust A | 1 | 1 |
| **Logical Operations** | | | |
| ANL A, Rn | AND Register to A | 1 | 1 |
| ANL A, direct | AND direct byte to A | 2 | 2 |
| ANL A, @Ri | AND indirect RAM to A | 1 | 2 |
| ANL A, #data | AND immediate to A | 2 | 2 |
| ANL direct, A | AND A to direct byte | 2 | 2 |
| ANL direct, #data | AND immediate to direct byte | 3 | 3 |
| ORL A, Rn | OR Register to A | 1 | 1 |
| ORL A, direct | OR direct byte to A | 2 | 2 |
| ORL A, @Ri | OR indirect RAM to A | 1 | 2 |
| ORL A, #data | OR immediate to A | 2 | 2 |
| ORL direct, A | OR A to direct byte | 2 | 2 |

**Table 9.1. CIP-51 Instruction Set Summary[1] (Continued)**

| Mnemonic | Description | Bytes | Clock Cycles |
|---|---|---|---|
| ORL direct, #data | OR immediate to direct byte | 3 | 3 |
| XRL A, Rn | Exclusive-OR Register to A | 1 | 1 |
| XRL A, direct | Exclusive-OR direct byte to A | 2 | 2 |
| XRL A, @Ri | Exclusive-OR indirect RAM to A | 1 | 2 |
| XRL A, #data | Exclusive-OR immediate to A | 2 | 2 |
| XRL direct, A | Exclusive-OR A to direct byte | 2 | 2 |
| XRL direct, #data | Exclusive-OR immediate to direct byte | 3 | 3 |
| CLR A | Clear A | 1 | 1 |
| CPL A | Complement A | 1 | 1 |
| RL A | Rotate A left | 1 | 1 |
| RLC A | Rotate A left through Carry | 1 | 1 |
| RR A | Rotate A right | 1 | 1 |
| RRC A | Rotate A right through Carry | 1 | 1 |
| SWAP A | Swap nibbles of A | 1 | 1 |
| **Data Transfer** | | | |
| MOV A, Rn | Move Register to A | 1 | 1 |
| MOV A, direct | Move direct byte to A | 2 | 2 |
| MOV A, @Ri | Move indirect RAM to A | 1 | 2 |
| MOV A, #data | Move immediate to A | 2 | 2 |
| MOV Rn, A | Move A to Register | 1 | 1 |
| MOV Rn, direct | Move direct byte to Register | 2 | 2 |
| MOV Rn, #data | Move immediate to Register | 2 | 2 |
| MOV direct, A | Move A to direct byte | 2 | 2 |
| MOV direct, Rn | Move Register to direct byte | 2 | 2 |
| MOV direct, direct | Move direct byte to direct byte | 3 | 3 |
| MOV direct, @Ri | Move indirect RAM to direct byte | 2 | 2 |
| MOV direct, #data | Move immediate to direct byte | 3 | 3 |
| MOV @Ri, A | Move A to indirect RAM | 1 | 2 |
| MOV @Ri, direct | Move direct byte to indirect RAM | 2 | 2 |
| MOV @Ri, #data | Move immediate to indirect RAM | 2 | 2 |
| MOV DPTR, #data16 | Load DPTR with 16-bit constant | 3 | 3 |
| MOVC A, @A+DPTR | Move code byte relative DPTR to A | 1 | 4 to 7[2] |
| MOVC A, @A+PC | Move code byte relative PC to A | 1 | 4 to 7[2] |
| MOVX A, @Ri | Move external data (8-bit address) to A | 1 | 3 |
| MOVX @Ri, A | Move A to external data (8-bit address) | 1 | 3 |
| MOVX A, @DPTR | Move external data (16-bit address) to A | 1 | 3 |
| MOVX @DPTR, A | Move A to external data (16-bit address) | 1 | 3 |
| PUSH direct | Push direct byte onto stack | 2 | 2 |
| POP direct | Pop direct byte from stack | 2 | 2 |
| XCH A, Rn | Exchange Register with A | 1 | 1 |
| XCH A, direct | Exchange direct byte with A | 2 | 2 |
| XCH A, @Ri | Exchange indirect RAM with A | 1 | 2 |
| XCHD A, @Ri | Exchange low nibble of indirect RAM with A | 1 | 2 |

**Table 9.1. CIP-51 Instruction Set Summary[1] (Continued)**

| Mnemonic | Description | Bytes | Clock Cycles |
|---|---|---|---|
| **Boolean Manipulation** | | | |
| CLR C | Clear Carry | 1 | 1 |
| CLR bit | Clear direct bit | 2 | 2 |
| SETB C | Set Carry | 1 | 1 |
| SETB bit | Set direct bit | 2 | 2 |
| CPL C | Complement Carry | 1 | 1 |
| CPL bit | Complement direct bit | 2 | 2 |
| ANL C, bit | AND direct bit to Carry | 2 | 2 |
| ANL C, /bit | AND complement of direct bit to Carry | 2 | 2 |
| ORL C, bit | OR direct bit to carry | 2 | 2 |
| ORL C, /bit | OR complement of direct bit to Carry | 2 | 2 |
| MOV C, bit | Move direct bit to Carry | 2 | 2 |
| MOV bit, C | Move Carry to direct bit | 2 | 2 |
| JC rel | Jump if Carry is set | 2 | 2/4 |
| JNC rel | Jump if Carry is not set | 2 | 2/4 |
| JB bit, rel | Jump if direct bit is set | 3 | 3/5 |
| JNB bit, rel | Jump if direct bit is not set | 3 | 3/5 |
| JBC bit, rel | Jump if direct bit is set and clear bit | 3 | 3/5 |
| **Program Branching** | | | |
| ACALL addr11 | Absolute subroutine call | 2 | 4 |
| LCALL addr16 | Long subroutine call | 3 | 5 |
| RET | Return from subroutine | 1 | 6 |
| RETI | Return from interrupt | 1 | 6 |
| AJMP addr11 | Absolute jump | 2 | 4 |
| LJMP addr16 | Long jump | 3 | 5 |
| SJMP rel | Short jump (relative address) | 2 | 4 |
| JMP @A+DPTR | Jump indirect relative to DPTR | 1 | 4 |
| JZ rel | Jump if A equals zero | 2 | 2/4 |
| JNZ rel | Jump if A does not equal zero | 2 | 2/4 |
| CJNE A, direct, rel | Compare direct byte to A and jump if not equal | 3 | 3/5 |
| CJNE A, #data, rel | Compare immediate to A and jump if not equal | 3 | 3/5 |
| CJNE Rn, #data, rel | Compare immediate to Register and jump if not equal | 3 | 3/5 |
| CJNE @Ri, #data, rel | Compare immediate to indirect and jump if not equal | 3 | 4/6 |
| DJNZ Rn, rel | Decrement Register and jump if not zero | 2 | 2/4 |
| DJNZ direct, rel | Decrement direct byte and jump if not zero | 3 | 3/5 |
| NOP | No operation | 1 | 1 |

**Notes:**

1. Assumes PFEN = 1 for all instruction timing.
2. MOVC instructions take 4 to 7 clock cycles depending on instruction alignment and the FLRT setting (SFR Definition 13.3. “FLSCL: Flash Scale” on page 120).

**Notes on Registers, Operands and Addressing Modes:**

**Rn**: Register R0–R7 of the currently selected register bank.

**@Ri**: Data RAM location addressed indirectly through R0 or R1.

**rel**: 8-bit, signed (2s complement) offset relative to the first byte of the following instruction. Used by SJMP and all conditional jumps.

**direct**: 8-bit internal data location's address. This could be a direct-access Data RAM location (0x00–0x7F) or an SFR (0x80–0xFF).

**#data**: 8-bit constant

**#data16**: 16-bit constant

**bit**: Direct-accessed bit in Data RAM or SFR

**addr11**: 11-bit destination address used by ACALL and AJMP. The destination must be within the same 2 kB page of program memory as the first byte of the following instruction.

**addr16**: 16-bit destination address used by LCALL and LJMP. The destination may be anywhere within the 8 kB program memory space.

There is one unused opcode (0xA5) that performs the same function as NOP.

## 9.2. Register Descriptions

Following are descriptions of SFRs related to the operation of the CIP-51 System Controller. Reserved bits should not be set to logic 1. Future product versions may use these bits to implement new features in which case the reset value of the bit will be logic 0, selecting the feature's default state. Detailed descriptions of the remaining SFRs are included in the sections of the data sheet associated with their corresponding system function.

### SFR Definition 9.1. SP: Stack Pointer

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x81

Bits 7–0: SP: Stack Pointer.
The Stack Pointer holds the location of the top of the stack. The stack pointer is incremented before every PUSH operation. The SP register defaults to 0x07 after reset.

### SFR Definition 9.2. DPL: Data Pointer Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x82

Bits 7–0: DPL: Data Pointer Low.
The DPL register is the low byte of the 16-bit DPTR. DPTR is used to access indirectly addressed XRAM and Flash memory.

### SFR Definition 9.3. DPH: Data Pointer High Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x83

Bits 7–0: DPH: Data Pointer High.
The DPH register is the high byte of the 16-bit DPTR. DPTR is used to access indirectly addressed XRAM and Flash memory.

## SFR Definition 9.4. PSW: Program Status Word

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| CY | AC | F0 | RS1 | RS0 | OV | F1 | PARITY | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0xD0

Bit 7: CY: Carry Flag
This bit is set when the last arithmetic operation resulted in a carry (addition) or a borrow (subtraction). It is cleared to 0 by all other arithmetic operations.

Bit 6: AC: Auxiliary Carry Flag
This bit is set when the last arithmetic operation resulted in a carry into (addition) or a borrow from (subtraction) the high order nibble. It is cleared to 0 by all other arithmetic operations.

Bit 5: F0: User Flag 0
This is a bit-addressable, general purpose flag for use under software control.

Bits 4–3: RS[1:0]: Register Bank Select
These bits select which register bank is used during register accesses.

| RS1 | RS0 | Register Bank | Address |
|---|---|---|---|
| 0 | 0 | 0 | 0x00–0x07 |
| 0 | 1 | 1 | 0x08–0x0F |
| 1 | 0 | 2 | 0x10–0x17 |
| 1 | 1 | 3 | 0x18–0x1F |

Bit 2: OV: Overflow Flag
This bit is set to 1 under the following circumstances:
- An ADD, ADDC, or SUBB instruction causes a sign-change overflow.
- A MUL instruction results in an overflow (result is greater than 255).
- A DIV instruction causes a divide-by-zero condition.

The OV bit is cleared to 0 by the ADD, ADDC, SUBB, MUL, and DIV instructions in all other cases.

Bit 1: F1: User Flag 1
This is a bit-addressable, general purpose flag for use under software control.

Bit 0: PARITY: Parity Flag
This bit is set to 1 if the sum of the eight bits in the accumulator is odd and cleared if the sum is even.

### SFR Definition 9.5. ACC: Accumulator

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ACC.7 | ACC.6 | ACC.5 | ACC.4 | ACC.3 | ACC.2 | ACC.1 | ACC.0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0xE0

Bits 7–0: ACC: Accumulator
This register is the accumulator for arithmetic operations.

### SFR Definition 9.6. B: B Register

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| B.7 | B.6 | B.5 | B.4 | B.3 | B.2 | B.1 | B.0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0xF0

Bits 7–0: B: B Register
This register serves as a second accumulator for certain arithmetic operations.

## 9.3. Power Management Modes

The CIP-51 core has two software programmable power management modes: idle and stop. Idle mode halts the CPU while leaving the peripherals and internal clocks active. In stop mode, the CPU is halted, all interrupts and timers (except the Missing Clock Detector) are inactive, and the internal oscillator is stopped (analog peripherals remain in their selected states; the external oscillator is not affected). Since clocks are running in idle mode, power consumption is dependent upon the system clock frequency and the number of peripherals left in active mode before entering idle. Stop mode consumes the least power. SFR Definition 9.7 describes the Power Control Register (PCON) used to control the CIP-51's power management modes.

Although the CIP-51 has Idle and Stop modes built in (as with any standard 8051 architecture), power management of the entire system management processor is better accomplished by enabling/disabling individual peripherals as needed. Each analog peripheral can be disabled when not in use and placed in low power mode. Digital peripherals, such as timers or serial buses, draw little power when they are not in use. Turning off the oscillators lowers power consumption considerably; however a reset is required to restart the system management processor.

The Si8250/1/2 devices feature a very low-power SUSPEND mode that stops the internal oscillator until a wakening event occurs. See **Section “20. Oscillators**” on page **207**.

### 9.3.1. Idle Mode

Setting the Idle Mode Select bit (PCON.0) causes the CIP-51 to halt the CPU and enter idle mode as soon as the instruction that sets the bit completes execution. All internal registers and memory maintain their original data. All analog and digital peripherals can remain active during idle mode.

Idle mode is terminated when an enabled interrupt is asserted or a reset occurs. The assertion of an enabled interrupt will cause the Idle Mode Selection bit (PCON.0) to be cleared and the CPU to resume operation. The pending interrupt will be serviced and the next instruction to be executed after the return from interrupt (RETI) will be the instruction immediately following the one that set the Idle Mode Select bit. If idle mode is terminated by an internal or external reset, the CIP-51 performs a normal reset sequence and begins program execution at address 0x0000.

If enabled, the watchdog timer (WDT) will eventually cause an internal watchdog reset and thereby terminate the idle mode. This feature protects the system from an unintended permanent shutdown in the event of an inadvertent write to the PCON register. If this behavior is not desired, the WDT may be disabled by software prior to entering the Idle mode if the WDT was initially configured to allow this operation. This provides the opportunity for additional power savings, allowing the system to remain in the Idle mode indefinitely, waiting for an external stimulus to wake up the system.

### 9.3.2. Stop Mode

Setting the Stop Mode Select bit (PCON.1) causes the CIP-51 to enter Stop mode as soon as the instruction that sets the bit completes execution. In stop mode the internal oscillator, CPU, and all digital peripherals are stopped; the state of the external oscillator circuit is not affected. Each analog peripheral (including the external oscillator circuit) may be shut down individually prior to entering Stop Mode. Stop mode can only be terminated by an internal or external reset. On reset, the CIP-51 performs the normal reset sequence and begins program execution at address 0x0000.

If enabled, the Missing Clock Detector will cause an internal reset and thereby terminate the stop mode. The Missing Clock Detector should be disabled if the CPU is to be put to in stop mode for longer than the MCD timeout period of 100 µs.

**SFR Definition 9.7. PCON: Power Control**

| — | — | — | — | — | — | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | — | — | STOP | IDLE | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x87

Bits 7–3: Reserved.

Bit 1: STOP: STOP Mode Select
Writing a ‘1’ to this bit will place the CIP-51 into STOP mode. This bit will always read ‘0’.
1: CIP-51 forced into powerdown mode. (Turns off internal oscillator).

Bit 0: IDLE: IDLE Mode Select
Writing a ‘1’ to this bit will place the CIP-51 into IDLE mode. This bit will always read ‘0’.
1: CIP-51 forced into IDLE mode. (Shuts off clock to CPU, but clock to Timers, Interrupts, and all peripherals remain active.)

## 10. Prefetch Engine

The Si8250/1/2 family of devices incorporate a 2-byte prefetch engine. Due to Flash access time specifications, the prefetch engine is necessary for full-speed (50 MHz) code execution. Instructions are read from Flash memory two bytes at a time by the prefetch engine, and given to the CIP-51 processor core to execute. When running linear code (code without any jumps or branches), the prefetch engine allows instructions to be executed at full speed. When a code branch occurs, the processor may be stalled for up to two clock cycles while the next set of code bytes is retrieved from Flash memory. The FLRT bit (FLSCL.4) determines how many clock cycles are used to read each set of two code bytes from Flash. When operating from a system clock of 25 MHz or less, the FLRT bit should be set to '0' so that the prefetch engine takes only one clock cycle for each read. When operating with a system clock of greater than 25 MHz (up to 50 MHz), the FLRT bit should be set to '1' so that each prefetch code read lasts for two clock cycles.

### SFR Definition 10.1. PFE0CN: Prefetch Engine Control

| — | — | R/W | — | — | — | — | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | PFEN | — | — | — | — | FLBWE | 00100000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xE3

Bits 7-6: Unused. Read = 00b; Write = Don't Care

Bit 5: PFEN: Prefetch Enable.
This bit enables the prefetch engine.
0: Prefetch engine is disabled.
1: Prefetch engine is enabled.

Bits 4-1: Unused. Read = 0000b; Write = Don't Care

Bit 0: FLBWE: Flash Block Write Enable.
This bit allows block writes to Flash memory from software.
0: Each byte of a software Flash write is written individually.
1: Flash bytes are written in groups of two.

Note: The prefetch engine should be disabled when changes to FLRT are made. See **Section "13. Flash Memory" on page 115**.

## NOTES:

# 11. Cyclic Redundancy Check Unit (CRC0)

Si8250/1/2 devices include a cyclic redundancy check unit (CRC0) that can perform a CRC using a 16-bit or 32-bit polynomial. CRC0 accepts a stream of 8-bit data written to the CRC0IN register. CRC0 posts the 16-bit or 32-bit result to an internal register. The internal result register may be accessed indirectly using the CRC0PNT bits and CRC0DAT register, as shown in Figure 11.1. CRC0 also has a bit reverse register for quick data manipulation.

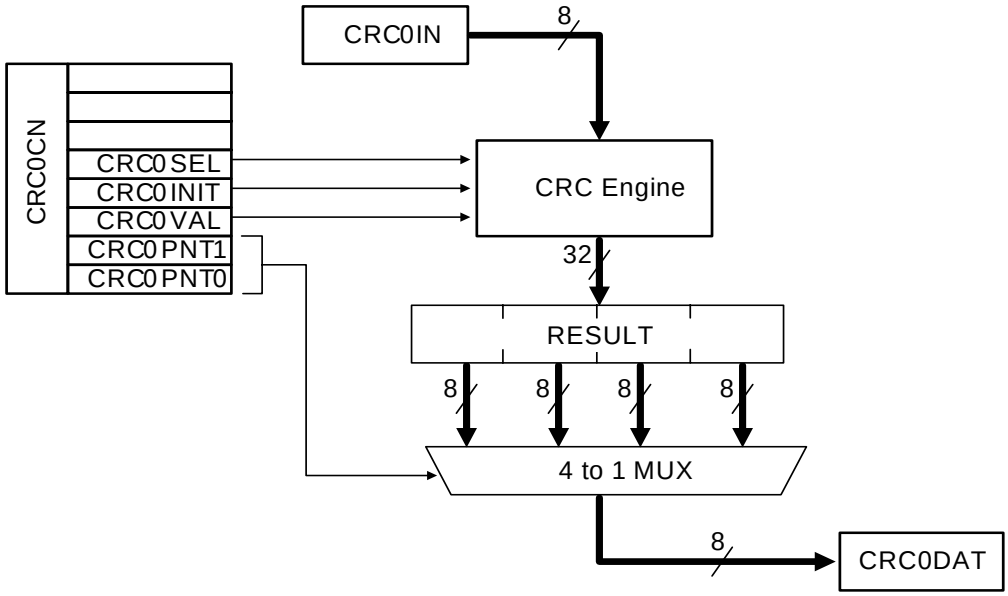


**Figure 11.1. CRC0 Block Diagram**

## 11.1. Preparing for a CRC Calculation

To prepare CRC0 for a CRC calculation, software should select the desired polynomial and set the initial value of the result. Two polynomials are available: 0x1021 (16-bit) and 0x04C11DB7 (32-bit). The CRC0 result may be initialized to one of two values: 0x00000000 or 0xFFFFFFFF. The following steps can be used to initialize CRC0:

Step 1. Step 1. Select a polynomial (Set CRC0SEL to '0' for 16-bit or '1' for 32-bit).
Step 2. Step 2. Select the initial result value (Set CRC0VAL to '0' for 0x00000000 or '1' for 0xFFFFFFFF).
Step 3. Step 3. Set the result to its initial value (Write '1' to CRC0INIT).

## 11.2. Performing a CRC Calculation

Once CRC0 is initialized, the input data stream is sequentially written to CRC0IN, one byte at a time. The CRC0 result is automatically updated after each byte is written.

## 11.3. Accessing the CRC0 Result

The internal CRC0 result is 16-bits (CRC0SEL = 0b) or 32-bits (CRC0SEL = 1b). The CRC0PNT bits select the byte that is targeted by read and write operations on CRC0DAT. The calculation result will remain in the internal CR0 result register until it is set, overwritten, or additional data is written to CRC0IN.

## 11.4. CRC0 Bit Reverse Feature

CRC0 includes hardware to reverse the bit order of each bit in a byte as shown in Figure 11.2. Each byte of data written to CRC0FLIP is read back bit reversed. For example, if 0xC0 is written to CRC0FLIP, the data read back is 0x03. Bit reversal is a useful mathematical function used in algorithms such as the FFT.

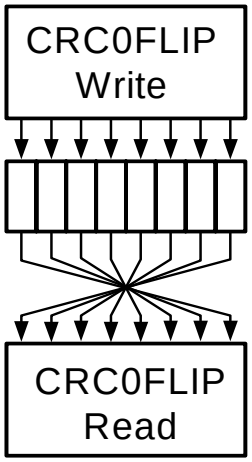


**Figure 11.2. Bit Reverse Register**

## SFR Definition 11.1. CRC0CN: CRC0 Control

| — | — | — | R/W | W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | CRC0SEL | CRC0INIT | CRC0VAL | CRC0PNT1 | CRC0PNT0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x84

Bits 7–5: UNUSED. Read = 0b. Write = don't care.

Bit 4: CRC0SEL: CRC0 Polynomial Select Bit
0: CRC0 uses the 16-bit polynomial 0x1021 for calculating the CRC result.
1: CRC0 uses the 32-bit polynomial 0x04C11DB7 for calculating the CRC result.

Bit 3: CRC0INIT: CRC0 Result Initialization Bit
Writing a '1' to this bit initializes the entire CRC result based on CRC0VAL.

Bit 2: CRC0VAL: CRC0 Set Value Select Bit
This bit selects the set value of the CRC result.
0: CRC result is set to 0x00000000 on write of '1' to CRC0INIT.
1: CRC result is set to 0xFFFFFFFF on write of '1' to CRC0INIT.

Bits 1–0: CRC0PNT[1:0]: CRC0 Result Pointer
These bits specify which byte of the CRC result will be read/written on the next access to CRC0DAT.
When CRC0SEL = 0:
00: CRC0DAT accesses bits 7-0 of the 16-bit CRC result.
01: CRC0DAT accesses bits 15-8 of the 16-bit CRC result.
10: CRC0DAT accesses bits 7-0 of the 16-bit CRC result.
11: CRC0DAT accesses bits 15-8 of the 16-bit CRC result.
When CRC0SEL = 1:
00: CRC0DAT accesses bits 7-0 of the 32-bit CRC result.
01: CRC0DAT accesses bits 15-8 of the 32-bit CRC result.
10: CRC0DAT accesses bits 23-16 of the 32-bit CRC result.
11: CRC0DAT accesses bits 31-24 of the 32-bit CRC result.

### SFR Definition 11.2. CRC0IN: CRC0 Data Input

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x85

Bits 7–0: CRC0IN[7:0]: CRC Data Input
Each write to CRCIN results in the written data being computed into the existing CRC result.

### SFR Definition 11.3. CRC0DAT: CRC0 Data Output

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x86

Bits 7–0: CRC0DAT[7:0]: Indirect CRC Result Data Bits.
Each operation performed on CRC0DAT targets the CRC result bits pointed to by CRC0PNT.

### SFR Definition 11.4. CRC0FLIP: CRC0 Bit Flip

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xDF

Bits 7–0: CRC0FLIP[7:0]: CRC Bit Flip.
Any byte written to CRC0FLIP is read back in a bit-reversed order, i.e., the written LSB becomes the MSB. For example, if 0x05 is written to CRC0FLIP, the data read back will be 0xA0.

## 12. Reset Sources

Reset circuitry allows the controller to be easily placed in a predefined default condition. On entry to this reset state, the following occur:

- CIP-51 halts program execution.
- Special Function Registers (SFRs) are initialized to their defined reset values.
- External Port pins are forced to a known state.
- Interrupts and timers are disabled.

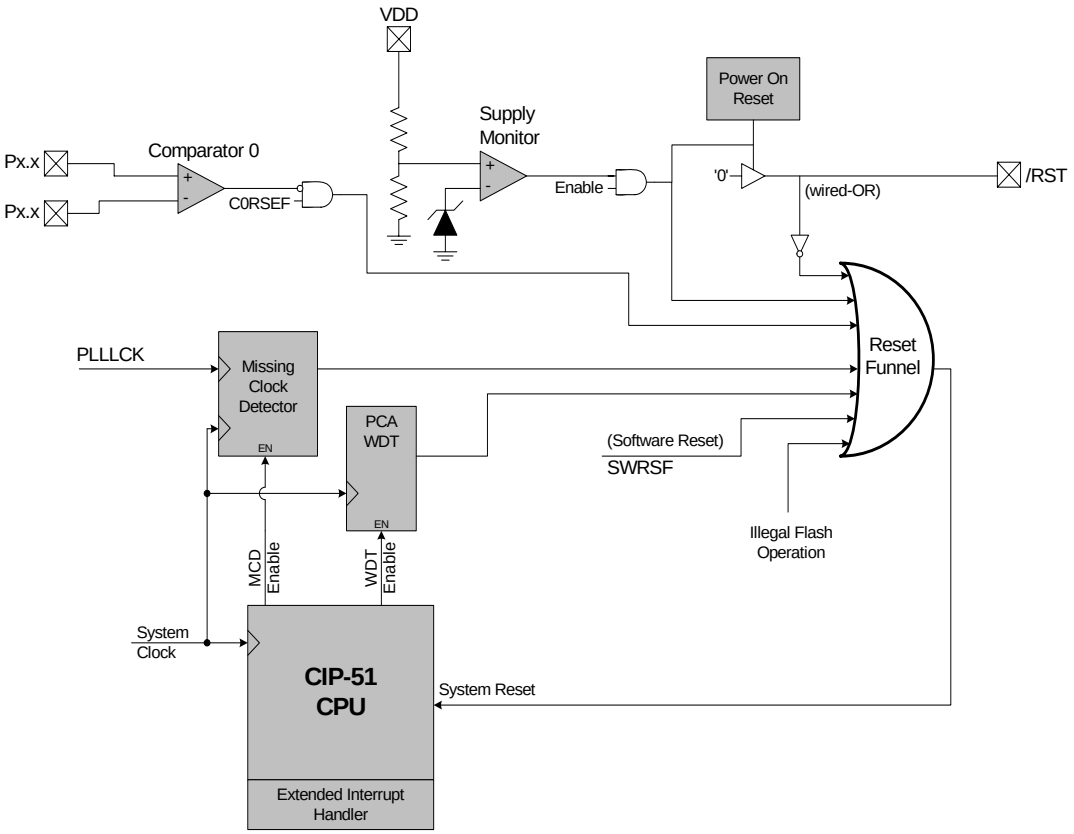


**Figure 12.1. Reset Sources**

All SFRs are reset to the predefined values noted in the SFR detailed descriptions. The contents of internal data memory are unaffected during a reset; any previously stored data is preserved. However, since the stack pointer SFR is reset, the stack is effectively lost, even though the data on the stack is not altered.

The Port I/O latches are reset to 0xFF (all logic ones) in open-drain mode. Weak pullups are enabled during and after the reset. For VDD Monitor and power-on resets, the $\overline{\text{RST}}$ pin is driven low until the device exits the reset state. On exit from the reset state, the program counter (PC) is reset, and the system clock defaults to the internal oscillator. Refer to Section "**20. Oscillators**" on page **207** for information on selecting and configuring the system clock source. The Watchdog Timer is enabled with the system clock divided by 12 as its clock source (Section "**24.2. Watchdog Timer Mode**" on page **270** details the use of the Watchdog Timer). Program execution begins at location 0x0000.

## 12.1. Power-On Reset

During power-up, the device is held in a reset state and the $\overline{\text{RST}}$ pin is driven low until VDD settles above VRST. A delay occurs before the device is released from reset; the delay decreases as the VDD ramp time increases (VDD ramp time is defined as how fast VDD ramps from 0 V to VRST). Figure 12.2 plots the power-on and VDD monitor reset timing. The maximum VDD ramp time is 1 ms; slower ramp times may cause the device to be released from reset before VDD reaches the VRST level. For ramp times less than 1 ms, the power-on reset delay (TPORDelay) is typically less than 0.3 ms.

On exit from a power-on reset, the PORSF flag (RSTSRC.1) is set by hardware to logic 1. When PORSF is set, all of the other reset flags in the RSTSRC Register are indeterminate (PORSF is cleared by all other resets). Since all resets cause program execution to begin at the same location (0x0000), software can read the PORSF flag to determine if a powerup was the cause of reset. The contents of internal data memory should be assumed to be undefined after a power-on reset. The VDD monitor is enabled following a power-on reset.

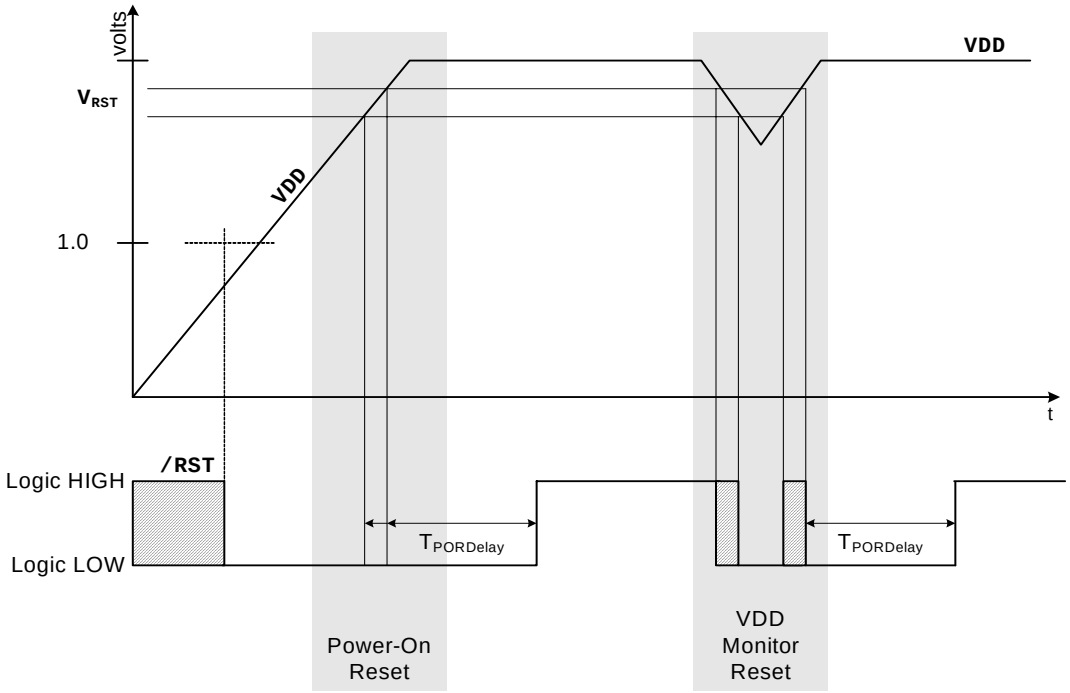


**Figure 12.2. Power-On and $V_{DD}$ Monitor Reset Timing**

## 12.2. Power-Fail Reset / $V_{DD}$ Monitor

When a powerdown transition or power irregularity causes $V_{DD}$ to drop below VRST, the power supply monitor will drive the $\overline{RST}$ pin low and hold the CIP-51 in a reset state (see Figure 12.2). When $V_{DD}$ returns to a level above VRST, the CIP-51 will be released from the reset state. Note that even though internal data memory contents are not altered by the power-fail reset, it is impossible to determine if $V_{DD}$ dropped below the level required for data retention. If the PORSF flag reads '1', the data may no longer be valid. The $V_{DD}$ monitor is enabled and selected as a reset source after power-on resets; however its defined state (enabled/disabled) is not altered by any other reset source. For example, if the $V_{DD}$ monitor is disabled by software, and a software reset is performed, the $V_{DD}$ monitor will still be disabled after the reset. **To protect the integrity of Flash contents, it is strongly recommended that the $V_{DD}$ monitor remain enabled and selected as a reset source if software contains routines that erase or write Flash memory**.

The $V_{DD}$ monitor must be enabled before it is selected as a reset source. Selecting the $V_{DD}$ monitor as a reset source before it is enabled and stabilized may cause a system reset. The procedure for re-enabling the $V_{DD}$ monitor and configuring the $V_{DD}$ monitor as a reset source is shown below:

Step 1. Enable the $V_{DD}$ monitor (VDMEN bit in VDM0CN = '1').
Step 2. Wait for the $V_{DD}$ monitor to stabilize (see the Si8250 Data Sheet for the $V_{DD}$ Monitor turn-on time). **Note: This delay should be omitted if software contains routines that erase or write Flash memory.**
Step 3. Select the $V_{DD}$ monitor as a reset source (PORSF bit in RSTSRC = '1').

### SFR Definition 12.1. VDM0CN: $V_{DD}$ Monitor Control

| R/W | R | — | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| VDMEN | VDDSTAT | — | reserved | reserved | reserved | reserved | reserved | 1v000000* |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xFF

Bit 7: VDMEN: $V_{DD}$ Monitor Enable.
This bit turns the $V_{DD}$ monitor circuit on/off. The $V_{DD}$ Monitor cannot generate system resets until it is also selected as a reset source in register RSTSRC (SFR Definition 12.2). The $V_{DD}$ Monitor must be allowed to stabilize before it is selected as a reset source. **Selecting the $V_{DD}$ monitor as a reset source before it has stabilized may generate a system reset.** See the Si8250 Data Sheet for the minimum $V_{DD}$ Monitor turn-on time.
0: $V_{DD}$ Monitor Disabled (default).
1: $V_{DD}$ Monitor Enabled.

Bit 6: VDDSTAT: $V_{DD}$ Status.
This bit indicates the current power supply status ($V_{DD}$ Monitor output).
0: $V_{DD}$ is at or below the $V_{DD}$ monitor threshold.
1: $V_{DD}$ is above the $V_{DD}$ monitor threshold.

Bit 5: Unused.

Bits 4–0: Reserved. Read = Variable. Write = don't care.

***Note:** Bit 6 will be initialized to 1 or 0 depending on the state of the VDD monitor output.

## 12.3. External Reset

The external RST pin provides a means for external circuitry to force the device into a reset state. Asserting an active-low signal on the RST pin generates a reset; an external pullup and/or decoupling of the RST pin may be necessary to avoid erroneous noise-induced resets. See Table 16.1 on page 129 for complete RST pin specifications. The PINRSF flag (RSTSRC.0) is set on exit from an external reset.

## 12.4. Missing Clock Detector Reset

The missing clock detector reset is asserted when SYSCLK is absent for a specified period or when the PLL loses lock. Thus if the missing clock reset is enabled and PLL is not locked, the Si825x will reset. Therefore it is important to enable the missing clock detector source after the PLL is locked. The following steps show the sequence:

1. Enable the PLL.
2. Wait for PLL being locked.
3. Enable missing clock reset source.

After a MCD reset, the MCDRSF flag (RSTSRC.2) will read '1', signifying the MCD as the reset source; otherwise, this bit reads '0'. Writing a '1' to the MCDRSF bit enables the Missing Clock Detector; writing a '0' disables it. The state of the RST pin is unaffected by this reset.

## 12.5. Comparator0 Reset

Comparator0 can be configured as a reset source by writing a '1' to the C0RSF flag (RSTSRC.5). Comparator0 should be enabled and allowed to settle prior to writing to C0RSF to prevent any turn-on chatter on the output from generating an unwanted reset. The Comparator0 reset is active-low: if the non-inverting input voltage (on CP0+) is less than the inverting input voltage (on CP0-), the device is put into the reset state. After a Comparator0 reset, the C0RSF flag (RSTSRC.5) will read '1' signifying Comparator0 as the reset source; otherwise, this bit reads '0'. The state of the RST pin is unaffected by this reset.

## 12.6. PCA Watchdog Timer Reset

The programmable Watchdog Timer (WDT) function of the Programmable Counter Array (PCA) can be used to prevent software from running out of control during a system malfunction. The PCA WDT function can be enabled or disabled by software as described in Section "**24.2. Watchdog Timer Mode**" on page **270**; the WDT is enabled and clocked by SYSCLK/12 following any reset. If a system malfunction prevents user software from updating the WDT, a reset is generated and the WDTRSF bit (RSTSRC.5) is set to '1'. The state of the $\overline{\text{RST}}$ pin is unaffected by this reset.

## 12.7. Flash Error Reset

If a Flash read/write/erase or program read targets an illegal address, a system reset is generated. This may occur due to any of the following:

- Flash write or erase is attempted above user code space. This occurs when PSWE is set to '1' and a MOVX write operation targets an address above address 0x7DFF.
- Flash read is attempted above user code space. This occurs when a MOVC operation targets an address above address 0x7DFF.
- Program read is attempted above user code space. This occurs when user code attempts to branch to an address above 0x7DFF.
- Flash read, write or erase attempt is restricted due to a Flash security setting.

The FERROR bit (RSTSRC.6) is set following a Flash error reset. The state of the $\overline{\text{RST}}$ pin is unaffected by this reset.

## 12.8. Software Reset

Software may force a reset by writing a '1' to the SWRSF bit (RSTSRC.4). The SWRSF bit will read '1' following a software forced reset. The state of the $\overline{\text{RST}}$ pin is unaffected by this reset.

## SFR Definition 12.2. RSTSRC: Reset Source

| — | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | FERROR | C0RSF | SWRSF | WDTRSF | MCDRSF | PORSF | PINRSF | Variable |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xEF

**Note:** Software should avoid read modify write instructions when writing values to RSTSRC.

Bit 7: Unused.

Bit 6: FERROR: Flash Error Indicator
0: Source of last reset was not a Flash read/write/erase error.
1: Source of last reset was a Flash read/write/erase error.

Bit 5: C0RSF: Comparator0 Reset Enable and Flag
**Read:**
0: Source of last reset was not Comparator0.
1: Source of last reset was Comparator0.
**Write:**
0: Comparator0 is disabled as a reset source.
1: Comparator0 is enabled as a reset source.

Bit 4: SWRSF: Software Reset Force and Flag
**Read:**
0: Source of last reset was not a write to the SWRSF bit.
1: Source of last reset was a write to the SWRSF bit.
**Write:**
0: No Effect
1: Forces a system reset

Bit 3: WDTRSF: Watchdog Timer Reset Flag
0: Source of last reset was not a watchdog timer timeout.
1: Source of last reset was a watchdog timer timeout.

Bit 2: MCDRSF: Missing Clock Detector
**Read:**
0: Source of last reset was not a missing clock detector timeout.
1: Source of last reset was a missing clock detector timeout.
**Write:**
0: Missing clock detector disabled.
1: Missing clock detector is enabled; forces a reset if a missing clock condition is detected.

Bit 1: PORSF: Power-On Reset Force and Flag
This bit is set any time a power-on reset occurs. Writing this bit enables or disables the $V_{DD}$ monitor as a reset source. **Note: Writing 1 to this bit before the VDD monitor is enabled and stabilized may cause a system reset. See register VDM0CN definition.**
**Read:**
0: Last reset was not a power on or Vdd monitor reset.
1: Last reset was a power on or Vdd monitor reset.
**Write:**
0: VDD monitor is not a reset source.
1: VDD monitor is a reset source.

Bit 0: PINRSF: HW Reset Pin Flag
0: Source of last reset was not $\overline{\text{RST}}$.
1: Source of last reset was not $\overline{\text{RST}}$.

# 13. Flash Memory

On-chip, re-programmable Flash memory is included for program code and non-volatile data storage. The Flash memory can be programmed in-system through the C2 interface or by software using the MOVX instruction. Once cleared to logic 0, a Flash bit must be erased to set it back to logic 1. Flash bytes would typically be erased (set to 0xFF) before being reprogrammed. The write and erase operations are automatically timed by hardware for proper execution; data polling to determine the end of the write/erase operation is not required. Code execution is stalled during a Flash write/erase operation.

## 13.1. Programming The Flash Memory

The simplest means of programming the Flash memory is through the C2 interface using programming tools provided by Silicon Laboratories or a third party vendor. This is the only means for programming a non-initialized device. For details on the C2 commands to program Flash memory, see Section "**25. C2 Interface**" on page **277**.

To ensure the integrity of Flash contents, it is strongly recommended that the on-chip $V_{DD}$ Monitor be enabled in any system that includes code that writes and/or erases Flash memory from software.

### 13.1.1. Flash Lock and Key Functions

Flash writes and erases by user software are protected with a lock and key function. The Flash Lock and Key Register (FLKEY) must be written with the correct key codes, in sequence, before Flash operations may be performed. The key codes are: 0xA5, 0xF1. The timing does not matter, but the codes must be written in order. If the key codes are written out of order, or the wrong codes are written, Flash writes and erases will be disabled until the next system reset. Flash writes and erases will also be disabled if a Flash write or erase is attempted before the key codes have been written properly. The Flash lock resets after each write or erase; the key codes must be written again before a following Flash operation can be performed.

### 13.1.2. FLASH Erase Procedure

The Flash memory can be programmed by software using the MOVX write instruction with the address and data byte to be programmed provided as normal operands. Before writing to Flash memory using MOVX, Flash write operations must be enabled by setting the PSWE Program Store Write Enable bit (PSCTL.0) to logic 1 (this directs the MOVX writes to target Flash memory) and writing the Flash key codes in sequence to the Flash Lock register (FLKEY). The PSWE bit remains set until cleared by software.

A write to Flash memory can clear bits to logic 0 but cannot set them; only an erase operation can set bits to logic 1 in Flash. A byte location to be programmed should be erased before a new value is written. The Flash memory is organized in 512-byte pages. The erase operation applies to an entire page (setting all bytes in the page to 0xFF). To erase an entire 512-byte page, perform the following steps:

Step 1. Disable interrupts (recommended).
Step 2. Set the PSEE bit (register PSCTL).
Step 3. Set the PSWE bit (register PSCTL).
Step 4. Write the first key code to FLKEY: 0xA5.
Step 5. Write the second key code to FLKEY: 0xF1.
Step 6. Using the MOVX instruction, write a data byte to any location within the 512-byte page to be erased.
Step 7. Clear the PSWE and PSEE bits.
Step 8. Re-enable interrupts.

### 13.1.3. Flash Write Procedure

Bytes in Flash memory can be written one byte at a time, or in groups of two. The FLBWE bit in register PFE0CN controls whether a single byte or a block of two bytes is written to Flash during a write operation. When FLBWE is cleared to '0', the Flash will be written one byte at a time. When FLBWE is set to '1', the Flash will be written in two-byte blocks. Block writes are performed in the same amount of time as single-byte writes, which can save time when storing large amounts of data to Flash memory.

During a single-byte write to Flash, bytes are written individually, and a Flash write will be performed after each MOVX write instruction. The recommended procedure for writing Flash in single bytes is as follows:

Step 1. Disable interrupts.
Step 2. Clear the FLBWE bit (register PFE0CN) to select single-byte write mode.
Step 3. Set the PSWE bit (register PSCTL).
Step 4. Clear the PSEE bit (register PSCTL).
Step 5. Write the first key code to FLKEY: 0xA5.
Step 6. Write the second key code to FLKEY: 0xF1.
Step 7. Using the MOVX instruction, write a single data byte to the desired location within the 512-byte sector.
Step 8. Clear the PSWE bit.
Step 9. Re-enable interrupts.

Steps 5–7 must be repeated for each byte to be written. For block Flash writes, the Flash write procedure is only performed after the last byte of each block is written with the MOVX write instruction. A Flash write block is two bytes long, from even addresses to odd addresses. Writes must be performed sequentially (i.e., addresses ending in 0b and 1b must be written in order). The Flash write will be performed following the MOVX write that targets the address ending in 1b. If a byte in the block does not need to be updated in Flash, it should be written to 0xFF. The recommended procedure for writing Flash in blocks is:

Step 1. Disable interrupts.
Step 2. Set the FLBWE bit (register PFE0CN) to select block write mode.
Step 3. Set the PSWE bit (register PSCTL).
Step 4. Clear the PSEE bit (register PSCTL).
Step 5. Write the first key code to FLKEY: 0xA5.
Step 6. Write the second key code to FLKEY: 0xF1.
Step 7. Using the MOVX instruction, write the first data byte to the even block location (ending in 0b).
Step 8. Write the first key code to FLKEY: 0xA5.
Step 9. Write the second key code to FLKEY: 0xF1.
Step 10. Using the MOVX instruction, write the second data byte to the odd block location (ending in 1b).
Step 11. Clear the PSWE bit.
Step 12. Re-enable interrupts.

Steps 5–10 must be repeated for each block to be written.

## 13.2. Non-volatile Data Storage

The Flash memory can be used for non-volatile data storage as well as program code. This allows data such as calibration coefficients to be calculated and stored at run time. Data is written using the MOVX write instruction and read using the MOVC instruction. Note: MOVX read instructions always target XRAM.

## 13.3. Security Options

The CIP-51 provides security options to protect the Flash memory from inadvertent modification by software as well as to prevent the viewing of proprietary program code and constants. The Program Store Write Enable (bit PSWE in register PSCTL) and the Program Store Erase Enable (bit PSEE in register PSCTL) bits protect the Flash memory from accidental modification by software. PSWE must be explicitly set to '1' before software can modify the Flash memory; both PSWE and PSEE must be set to '1' before software can erase Flash memory. Additional security features prevent proprietary program code and data constants from being read or altered across the C2 interface.

A Security Lock Byte located at the last byte of Flash user space offers protection of the Flash program memory from access (reads, writes, or erases) by unprotected code or the C2 interface. The Flash security mechanism allows the user to lock n 512-byte Flash pages, starting at page 0 (addresses 0x0000 to 0x01FF), where n is the 1's complement number represented by the Security Lock Byte. Note that the page containing the Flash Security Lock Byte is unlocked when no other Flash pages are locked (all bits of the Lock Byte are '1') and locked when any other Flash pages are locked (any bit of the Lock Byte is '0'). See example below.

| | |
|---|---|
| Security Lock Byte: | 11111101b |
| 1s Complement: | 00000010b |
| Flash pages locked: | 3 (First two Flash pages + Lock Byte Page) |
| Addresses locked: | 0x0000 to 0x03FF (first two Flash pages) and 0x7C00 to 0x7DFF (Lock Byte Page) |

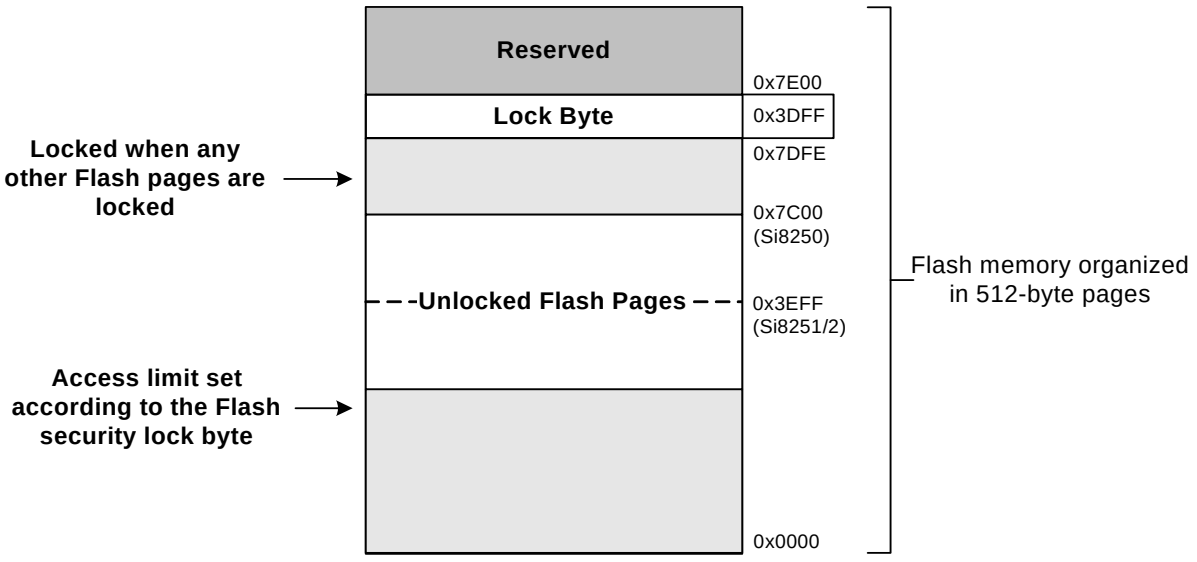


**Figure 13.1. Flash Program Memory Map**

The level of Flash security depends on the Flash access method. The three Flash access methods that can be restricted are reads, writes, and erases from the C2 debug interface, user firmware executing on unlocked pages, and user firmware executing on locked pages.

Accessing Flash from the C2 debug interface:

Step 1. Any unlocked page may be read, written, or erased.
Step 2. Locked pages cannot be read, written, or erased.
Step 3. The page containing the Lock Byte may be read, written, or erased if it is unlocked.
Step 4. Reading the contents of the Lock Byte is always permitted.
Step 5. Locking additional pages (changing '1's to '0's in the Lock Byte) is always permitted.
Step 6. Unlocking Flash pages (changing '0's to '1's in the Lock Byte) requires the C2 Device Erase command,
Step 7. which erases all Flash pages including the page containing the Lock Byte and the Lock Byte itself.
Step 8. The Reserved Area cannot be read, written, or erased.

Accessing Flash from user firmware executing on an unlocked page:

Step 1. Any unlocked page except the page containing the Lock Byte may be read, written, or erased.
Step 2. Locked pages cannot be read, written, or erased.
Step 3. The page containing the Lock Byte cannot be erased. It may be read or written only if it is unlocked.
Step 4. Reading the contents of the Lock Byte is always permitted.
Step 5. Locking additional pages (changing '1's to '0's in the Lock Byte) is always permitted.
Step 6. Unlocking Flash pages (changing '0's to '1's in the Lock Byte) is not permitted.
Step 7. The Reserved Area cannot be read, written, or erased.

Any attempt to access the reserved area, or any other locked page, will result in a Flash Error device reset.
Accessing Flash from user firmware executing on a locked page:

Step 1. Any unlocked page except the page containing the Lock Byte may be read, written, or erased.
Step 2. Any locked page except the page containing the Lock Byte may be read, written, or erased.
Step 3. The page containing the Lock Byte cannot be erased. It may only be read or written.
Step 4. Reading the contents of the Lock Byte is always permitted.
Step 5. Locking additional pages (changing '1's to '0's in the Lock Byte) is always permitted.
Step 6. Unlocking Flash pages (changing '0's to '1's in the Lock Byte) is not permitted.
Step 7. The Reserved Area cannot be read, written, or erased.

Any attempt to access the reserved area, or any other locked page, will result in a Flash Error device reset.

### SFR Definition 13.1. PSCTL: Program Store R/W Control

| — | — | — | — | — | — | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | — | — | PSEE | PSWE | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x8F

Bits 7-2: Unused

Bit 1: PSEE: Program Store Erase Enable
Setting this bit (in combination with PSWE) allows an entire page of Flash program memory to be erased. If this bit is logic 1 and Flash writes are enabled (PSWE is logic 1), a write to Flash memory using the MOVX instruction will erase the entire page that contains the location addressed by the MOVX instruction. The value of the data byte written does not matter.
0: Flash program memory erasure disabled.
1: Flash program memory erasure enabled.

Bit 0: PSWE: Program Store Write Enable
Setting this bit allows writing a byte of data to the Flash program memory using the MOVX write instruction. The Flash location should be erased before writing data.
0: Writes to Flash program memory disabled.
1: Writes to Flash program memory enabled; the MOVX write instruction targets Flash memory.

### SFR Definition 13.2. FLKEY: Flash Lock and Key

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xB7

Bits 7–0: FLKEY: Flash Lock and Key Register
**Write:** This register provides a lock and key function for Flash erasures and writes. Flash writes and erases are enabled by writing 0xA5 followed by 0xF1 to the FLKEY register. Flash writes and erases are automatically disabled after the next write or erase is complete. If any writes to FLKEY are performed incorrectly, or if a Flash write or erase operation is attempted while these operations are disabled, the Flash will be permanently locked from writes or erasures until the next device reset. If an application never writes to Flash, it can intentionally lock the Flash by writing a non-0xA5 value to FLKEY from software.

**Read:** When read, bits 1:0 indicate the current Flash lock state.
00: Flash is write/erase locked.
01: The first key code has been written (0xA5).
10: Flash is unlocked (writes/erases allowed).
11: Flash writes/erases disabled until the next reset.

## 13.4. Flash Timing

On reset, the Si8250/1/2 Flash timing is configured for operation with system clocks up to 25 MHz. If the system clock will not be increased above 25 MHz, then the Flash timing registers may be left at their reset value. For every Flash read or fetch, the system provides an internal Flash read strobe to the Flash memory. The Flash read strobe lasts for one or two system clock cycles, based on FLRT (FLSCL.4). **If the system clock is greater than 25 MHz, the FLRT bit must be set to logic 1, otherwise data read or fetched from Flash may not represent the actual contents of Flash.** When the Flash read strobe is asserted, Flash memory is active. When it is de-asserted, Flash memory is in a low power state. The Flash read strobe does not need to be asserted for longer than 80 ns in order for Flash reads and fetches to be reliable. For system clocks greater than 12.5 MHz (but less than 25 MHz), the Flash read strobe width is limited by the system clock period. For system clocks less than 12.5 MHz, the Flash read strobe is limited by a programmable one shot with a default period of 80 ns (1/12.5 MHz). This is a power saving feature that is very beneficial for very slow system clocks (e.g., 32.768 kHz where the system clock period is greater than 30,000 ns). For additional power savings, the one shot can be programmed to values less than 80 ns. The one shot can be trimmed according the equation in the ONESHOT register description.

### SFR Definition 13.3. FLSCL: Flash Scale

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| Reserved | Reserved | Reserved | FLRT | Reserved | Reserved | Reserved | Reserved | 00000011 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xB6

Bits 7–5: Reserved; must be maintained ‘0’.

Bit 4: FLRT: Flash Read Time Control
This bit should be programmed to the smallest allowed value, according to the system clock speed.
0: SYSCLK $\leq$ 25 MHz (Flash read strobe is one system clock).
1: SYSCLK $\leq$ 50 MHz (Flash read strobe is two system clocks).

Bits 3–0: Reserved; must be maintained ‘0’.

## SFR Definition 13.4. ONESHOT: Flash Oneshot Period

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | PERIOD3 | PERIOD2 | PERIOD1 | PERIOD0 | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xAF

Bits 7–4: Unused.

Bits 3–0: PERIOD[3:0]: Oneshot Period Control Bits.
These bits limit the internal Flash read strobe width as follows. When the Flash read strobe is de-asserted, the Flash memory enters a low-power state for the remainder of the system clock cycle. These bits have no effect when the system clocks is greater than 12.5 MHz and FLRT = 0.

$$FLASH_{RDMAX} = 5ns + (PERIOD \times 5ns)$$

## NOTES:

# 14. External RAM

The Si8250/1/2 devices include RAM mapped into the external data memory space. The Si8250/1/2 have 2048 bytes of XRAM. All of these address locations may be accessed using the external move instruction (MOVX) and the data pointer (DPTR), or using MOVX indirect addressing mode. If the MOVX instruction is used with an 8-bit address operand (such as @R1), then the high byte of the 16-bit address is provided by the External Memory Interface Control Register (EMI0CN as shown in SFR Definition 14.1).

**Note**: The MOVX instruction is also used for writes to the Flash memory. See **Section "13. Flash Memory" on page 115** for details. The MOVX instruction accesses XRAM by default.

For a 16-bit MOVX operation (@DPTR), the upper 5-bits of the 16-bit external data memory address word are "don't cares." As a result, the RAM is mapped modulo style over the entire 64 kB external data memory address range. For example, the XRAM byte at address 0x0000 is shadowed at addresses 0x0800, 0x1000, 0x1800, 0x2000, etc. for a Si8250/1/2 device. This is a useful feature when performing a linear memory fill, because the address pointer does not have to be reset when reaching the RAM block boundary.

### SFR Definition 14.1. EMI0CN: External Memory Interface Control

| — | — | — | — | — | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | — | PGSEL2 | PGSEL1 | PGSEL0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xAA

Bits 7–3: Unused. Read = 00000b. Write = don't care.

Bits 2–0: PGSEL[2:0]: XRAM Page Select.
The EMI0CN register provides the high byte of the 16-bit external data memory address when using an 8-bit MOVX command, effectively selecting a 256-byte page of RAM. Since the upper (unused) bits of the register are always zero, the PGSEL determines which page of XRAM is accessed.
For Example: If EMI0CN = 0x01, addresses 0x0100 through 0x01FF will be accessed.

## NOTES:

## 15. Reference Scaling DAC (REFDAC)

The 9-bit reference scaling DAC supplies a 0 to 1.25 V variable voltage reference to ADC1. To minimize power consumption during Lockout mode, the REFDAC and associated reference generator is disabled on power-up and reset and must be enabled by firmware. The voltage reference must be enabled for the REFDAC to operate (see Section "**7. Rev. 0.7Voltage Reference**" on page **87**). The REFDAC is enabled or disabled via the RDACEN bit in the REFDACMD register. REFDAC output voltage is controlled by RDAC[8:0] in REFDAC0L and REFDAC0H. The REFDAC output is updated when the REFDAC0L register is written.

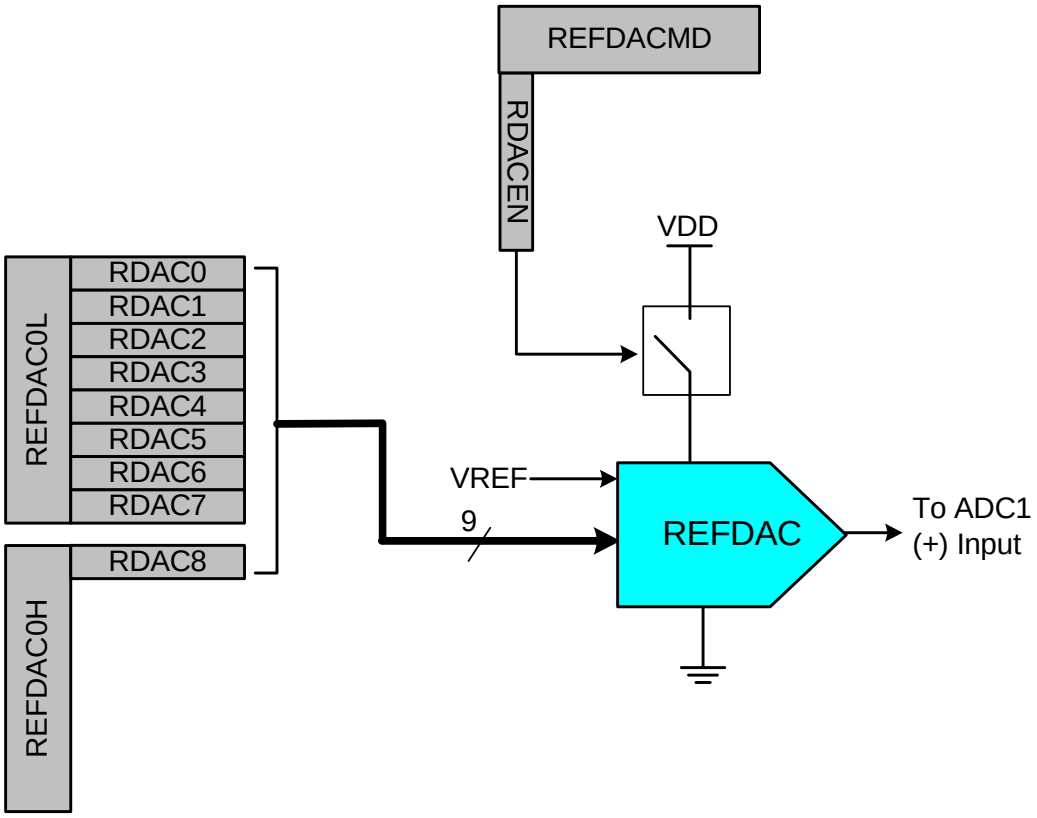


**Figure 15.1. REFDAC Block Diagram**

### SFR Definition 15.1. REFDAC0H: Reference DAC High Byte Data

| — | — | — | — | — | — | — | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | — | — | — | RDAC8 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x97

Bits 7–1: Unused

Bit 0: RDAC8: Reference DAC data bit 8
Refout = Vref x RDAC[8:0]/512

### SFR Definition 15.2. REFDAC0L: Reference DAC Low Byte Data

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| RDAC7 | RDAC6 | RDAC5 | RDAC4 | RDAC3 | RDAC2 | RDAC1 | RDAC0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x96

Bits 7–0: RDAC[7:0]: Reference DAC Data Bits
Refout = Vref x RDAC[8:0]/512

### SFR Definition 15.3. REFDACMD: Reference DAC Mode Control

| R/W | — | — | — | — | — | — | — | Reset Value |
|---|---|---|---|---|---|---|---|---|
| RDACEN | — | — | — | — | — | — | — | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xF1

Bit 7: RDACEN: Reference DAC Enable
0: Reference DAC disabled.
1: Reference DAC enabled.

Bits 6–0: Unused.

# 16. Memory Organization and SFRs

The memory organization of the Si8250/1/2 is similar to that of a standard 8051. There are two separate memory spaces: program memory and data memory. Program and data memory share the same address space but are accessed via different instruction types. The memory map is shown in Figure 16.1.

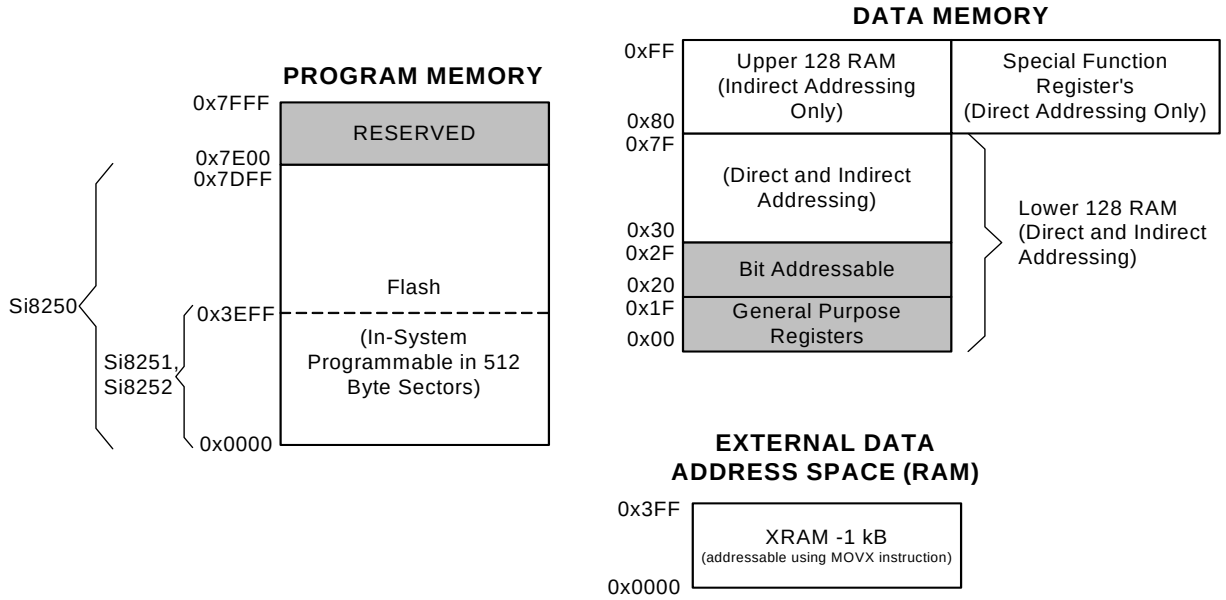


**Figure 16.1. Memory Map**

## 16.1. Program Memory

The CIP-51 core has a 64k-byte program memory space. The Si8250/1/2 implements up to 32 kB of this program memory space as in-system, re-programmable Flash memory, organized in a contiguous block from addresses 0x0000 to max address 0x7DFF. Addresses above 0x7DFF are reserved.Program memory is normally assumed to be read-only. However, the Si8250/1/2 can write to program memory by setting the Program Store Write Enable bit (PSCTL.0) and using the MOVX write instruction. This feature provides a mechanism for updates to program code and use of the program memory space for non-volatile data storage. Refer to **Section “13. Flash Memory” on page 115** for further details.

## 16.2. Data Memory

The Si8250 includes 256 bytes of internal RAM mapped into the data memory space from 0x00 through 0xFF. The lower 128 bytes of data memory are used for general purpose registers and scratch pad memory. Either direct or indirect addressing may be used to access the lower 128 bytes of data memory. Locations 0x00 through 0x1F are addressable as four banks of general purpose registers, each bank consisting of eight byte-wide registers. The next 16 bytes, locations 0x20 through 0x2F, may either be addressed as bytes or as 128-bit locations accessible with the direct addressing mode.

The upper 128 bytes of data memory are accessible only by indirect addressing. This region occupies the same address space as the Special Function Registers (SFRs) but is physically separate from the SFR space. The addressing mode used by an instruction when accessing locations above 0x7F determines whether the CPU accesses the upper 128 bytes of data memory space or the SFRs. Instructions that use direct addressing will access the SFR space. Instructions using indirect addressing above 0x7F access the

upper 128 bytes of data memory. The Si8250/1/2 family also includes 1024 bytes of on-chip RAM mapped into the external memory (XDATA) space. This RAM can be accessed using the CIP-51 core's MOVX instruction. More information on the XRAM memory can be found in **Section “14. External RAM” on page 123**.

## 16.3. General Purpose Registers

The lower 32 bytes of data memory (locations 0x00 through 0x1F) may be addressed as four banks of general-purpose registers. Each bank consists of eight byte-wide registers designated R0 through R7. Only one of these banks may be enabled at a time. Two bits in the program status word, RS0 (PSW.3) and RS1 (PSW.4), select the active register bank (see description of the PSW in **Section “19. Port Input/Output” on page 195**). This allows fast context switching when entering subroutines and interrupt service routines. Indirect addressing modes use registers R0 and R1 as index registers.

## 16.4. Bit Addressable Locations

In addition to direct access to data memory organized as bytes, the sixteen data memory locations at 0x20 through 0x2F are also accessible as 128 individually addressable bits. Each bit has a bit address from 0x00 to 0x7F. Bit 0 of the byte at 0x20 has bit address 0x00 while bit 7 of the byte at 0x20 has bit address 0x07. Bit 7 of the byte at 0x2F has bit address 0x7F. A bit access is distinguished from a full byte access by the type of instruction used (bit source or destination operands as opposed to a byte source or destination). The MCS-51™ assembly language allows an alternate notation for bit addressing of the form XX.B where XX is the byte address and B is the bit position within the byte. For example, the instruction:

MOV C, 22.3h moves the Boolean value at 0x13 (bit 3 of the byte at location 0x22) into the Carry flag.

## 16.5. Stack

A programmer's stack can be located anywhere in the 256-byte data memory. The stack area is designated using the Stack Pointer (SP, 0x81) SFR. The SP will point to the last location used. The next value pushed on the stack is placed at SP+1 and then SP is incremented. A reset initializes the stack pointer to location 0x07. Therefore, the first value pushed on the stack is placed at location 0x08, which is also the first register (R0) of register bank 1. Thus, if more than one register bank is to be used, the SP should be initialized to a location in the data memory not being used for data storage. The stack depth can extend up to 256 bytes.

## 16.6. Special Function Registers

The direct-access data memory locations from 0x80 to 0xFF constitute the special function registers (SFRs). The SFRs provide control and data exchange with the CIP-51's resources and peripherals. The CIP-51 duplicates the SFRs found in a typical 8051 implementation as well as implementing additional SFRs used to configure and access the sub-systems unique to the system management processor. This allows the addition of new functionality while retaining compatibility with the MCS-51™ instruction set. Table 16.1 lists the SFRs implemented in the CIP-51 System Controller.

The SFR registers are accessed anytime the direct addressing mode is used to access memory locations from 0x80 to 0xFF. SFRs with addresses ending in 0x0 or 0x8 (e.g., P0, TCON, IE, etc.) are bit-addressable as well as byte-addressable. All other SFRs are byte-addressable only. Unoccupied addresses in the SFR space are reserved for future use. Accessing these areas will have an indeterminate effect and should be avoided. Table 16.1 summarizes all directly-addressable registers.

## Table 16.1. Special Function Register (SFR) Memory Map

| | 0(8) | 1(9) | 2(A) | 3(B) | 4(C) | 5(D) | 6(E) | 7(F) |
|---|---|---|---|---|---|---|---|---|
| F8 | DPWMCNTL | PCA0L | PCA0H | PCA0CPL0 | PCA0CPH0 | ADC1DAT | **ADC1CN** | VDM0CN |
| F0 | B | **REFDACMD** | P1MDIN | **PIDKPCN** | **PIDKICN** | **PIDKDCN** | EIP1 | EIP2 |
| E8 | ADC0CN | PCA0CPL1 | PCA0CPH1 | PCA0CPL2 | PCA0CPH2 | **PIDA1CN** | **PIDA2CN** | RSTSRC |
| E0 | ACC | XBR0 | XBR1 | PFE0CN | IT01CF | **PIDA3CN** | EIE1 | EIE2 |
| D8 | PCA0CN | PCA0MD | PCA0CPM0 | PCA0CPM1 | PCA0CPM2 | **PIDA0CN** | **DECCN** | CRCFLIP |
| D0 | PSW | REF0CN | **ICYCST** | **TRDETCN** | P0SKIP | P1SKIP | **LEBCN** | **OCPCN** |
| C8 | TMR2CN | ADC0LM1 | TMR2RLL | TMR2RLH | TMR2L | TMR2H | **PIDCN** | **PIDUN** |
| C0 | SMB0CN | SMB0CF | SMB0DAT | **ADC0GTL** | **ADC0GTH** | **ADC0LTL** | **ADC0TH** | **ADC0LMO** |
| B8 | IP | **PLLCN** | ADC0TK | ADC0MX | ADC0CF | **ADC0L** | **ADC0H** | **ADC0STA1** |
| B0 | P0ODEN | **OSCXCN** | OSCICN | OSCICL | | **ADC0STA0** | FLSCL | FLKEY |
| A8 | IE | CLKSEL | EMI0CN | **ADC0ADDR** | **ADC0DATA** | **DPWMADDR** | **DPWMDATA** | ONESHOT |
| A0 | IPKCN | **DPWMTLCD0** | **DPWMTLCD1** | **DPWMTLCD2** | P0MDOUT | P1MDOUT | **DPWMOUT** | SFRPAGE |
| 98 | SCON0 | SBUF0 | **DPWMTLCD3** | CPT0CN | **OSCLCN** | CPT0MD | **DPWMULOCK** | CPT0MX |
| 90 | P1 | TMR3CN | TMR3LL | TMR3RLH | TMR3L | TMR3H | **REFDAC0L** | **REFDAC0H** |
| 88 | TCON | TMOD | TL0 | TL1 | TH0 | TH1 | CKCON | PSCTL |
| 80 | P0 | SP | DPL | DPH | CRCCN | CRCIN | CRCREG | PCON |
| | | 1(9) | 2(A) | 3(B) | 4(C) | 5(D) | 6(E) | 7(F) |

## Table 16.2. Special Function Register List

| Register | Address | Description | Page |
|---|---|---|---|
| ACC | 0xE0 | Accumulator | 101 |
| ADC0ADDR | 0xAB | ADC0 Indirect Address | 170 |
| ADC0CF | 0xBC | ADC0 Configuration | 172 |
| ADC0CN | 0xE8 | ADC0 Control | 173 |
| ADC0DATA | 0xAC | ADC0 Indirect Data | 171 |
| ADC0GTH | 0xC4 | ADC0 Greater-Than Data High Byte | 177 |
| ADC0GTL | 0xC3 | ADC0 Greater-Than Data Low Byte | 177 |
| ADC0H | 0xBE | ADC0 | 176 |
| ADC0L | 0xBD | ADC0 | 176 |
| ADC0LM0 | 0xC7 | ADC0 Limit Interrupt Flag 0 | 175 |
| ADC0LM1 | 0xC9 | ADC0 Limit Interrupt Flag 1 | 176 |
| ADC0LTH | 0xC6 | ADC0 Less-Than Data High Byte | 177 |
| ADC0LTL | 0xC5 | ADC0 Less-Than Data Low Byte | 177 |

**Table 16.2. Special Function Register List (Continued)**

| Register | Address | Description | Page |
|---|---|---|---|
| ADC0MX | 0xBB | ADC0 AMUX Channel Select | 170 |
| ADC0STA0 | 0xB5 | ADC0 Status 0 | 171 |
| ADC0TK | 0xBA | ADC0 Tracking Mode Select | 174 |
| ADC1CN | 0xFD | ADC1 Control | 49 |
| ADC1DAT | 0xFD | ADC1 Data | 49 |
| B | 0xF0 | B Register | 101 |
| CKCON | 0x8E | Clock Control | 250 |
| CLKSEL | 0xA9 | Clock Select | 211 |
| CPT0CN | 0x9B | Comparator0 Control | 91 |
| CPT0MD | 0x9D | Comparator0 Mode Selection | 92 |
| CPT0MX | 0x9F | Comparator0 MUX Selection | 92 |
| CRC0CN | 0x84 | CRC0 Control | 107 |
| CRC0DAT | 0x86 | CRC0 Data Output | 108 |
| CRC0FLIP | 0xDF | CRC0 Bit Flip | 108 |
| CRC0IN | 0x85 | CRC0 Data Input | 108 |
| DPH | 0x83 | Data Pointer High | 99 |
| DPL | 0x82 | Data Pointer Low | 99 |
| DPWMADDR | 0xAD | DPWM Indirect Address | 70 |
| DPWMCN | 0xF8 | DPWM Control | 69 |
| DPWMDATA | 0xAE | DPWM Indirect Data | 70 |
| DPWMOUT | 0xA6 | DPWM Output Data | 69 |
| DPWMTLCD0 | 0xA1 | DPWM Trim and Limit Data 0 | 69 |
| DPWMTLCD1 | 0xA2 | DPWM Trim and Limit Data 1 | 69 |
| DPWMTLCD2 | 0xA3 | DPWM Trim and Limit Data 2 | 70 |
| DPWMTLCD3 | 0x9A | DPWM Trim and Limit Data 3 | 70 |
| DPWMULOCK | 0x9E | DPWM Symmetry Lock Control | 69 |
| EIE1 | 0xE6 | Extended Interrupt Enable | 141 |
| EIE2 | 0xE7 | Extended Interrupt Enable | 143 |
| EIP1 | 0xF6 | Extended Interrupt Priority | 142 |
| EIP2 | 0xF7 | Extended Interrupt Priority | 144 |
| EMI0CN | 0xAA | External Memory Interface Control | 123 |
| FLKEY | 0xB7 | Flash Lock and Key | 119 |
| FLSCL | 0xB6 | Flash Scale | 120 |
| ICYCST | 0xD2 | Current Limiter Status | 55 |
| IE | 0xA8 | Interrupt Enable | 139 |
| IP | 0xB8 | Interrupt Priority | 140 |
| IPKCN | 0xA0 | Peak Current Detector Control | 54 |
| IT01CF | 0xE4 | INT0/ENABLE Configuration | 145 |
| LEBCN | 0xD6 | Leading Edge Blanking Control | 55 |

**Table 16.2. Special Function Register List (Continued)**

| Register | Address | Description | Page |
|---|---|---|---|
| OCPCN | 0xD7 | Overcurrent Protection Control | 55 |
| ONESHOT | 0xAF | Flash Oneshot Period | 121 |
| OSCICL | 0xB3 | Internal Oscillator Calibration | 212 |
| OSCICN | 0xB2 | Internal Oscillator Control | 212 |
| OSCLCN | 0x9C | Low Frequency Oscillator Control | 211 |
| OSCXCN | 0xB1 | External Oscillator Control | 213 |
| P0 | 0x80 | Port 0 Latch | 203 |
| P0MDOUT | 0xA4 | Port 0 Output Mode Configuration | 203 |
| P0ODEN | 0xB0 | Port 0 Overdrive | 202 |
| P0SKIP | 0xD4 | Port 0 Skip | 204 |
| P1 | 0x90 | Port 1 Latch | 204 |
| P1MDIN | 0xF2 | Port 1 Input Mode Configuration | 205 |
| P1MDOUT | 0xA5 | Port 1 Output Mode Configuration | 204 |
| P1SKIP | 0xD5 | Port 1 Skip | 204 |
| PCA0CN | 0xD8 | PCA 0 Control | 273 |
| PCA0CPH0 | 0xFC | PCA Capture 0 | 276 |
| PCA0CPH1 | 0xEA | PCA Capture 1 | 276 |
| PCA0CPH2 | 0xEC | PCA Capture 2 | 276 |
| PCA0CPL0 | 0xFB | PCA Capture 0 | 276 |
| PCA0CPL1 | 0xE9 | PCA Capture 1 Low | 276 |
| PCA0CPL2 | 0xEB | PCA Capture 2 | 276 |
| PCA0CPM0 | 0xDA | PCA Module 0 Mode | 275 |
| PCA0CPM1 | 0xDB | PCA Module 1 Mode | 275 |
| PCA0CPM2 | 0xDC | PCA Module 2 Mode | 275 |
| PCA0H | 0xFA | PCA Counter High | 276 |
| PCA0L | 0xF9 | PCA Counter Low | 276 |
| PCA0MD | 0xD9 | PCA Mode | 274 |
| PCON | 0x87 | Power Control | 102 |
| PFE0CN | 0xE3 | Prefetch Engine Control | 103 |
| PIDA0CN | 0xDD | PID Filter Coefficient A0 | 154 |
| PIDA1CN | 0xED | PID Filter Coefficient A1 | 153 |
| PIDA2CN | 0xEE | PID Filter Coefficient A2 | 154 |
| PIDA3CN | 0xE5 | PID Filter Coefficient A3 | 154 |
| PIDCN | 0xCE | PID Filter Control | 156 |
| PIDDECCN | 0xDE | SINC Filter Decimation Ratio | 155 |
| PIDKDCN | 0xF5 | PID Filter Coefficient KD | 153 |
| PIDKICN | 0xF4 | PID Filter Coefficient KI | 153 |
| PIDKPCN | 0xF3 | PID Filter Coefficient KP | 153 |
| PIDUN | 0xCF | DSP Filter Output u(n) | 156 |

**Table 16.2. Special Function Register List (Continued)**

| Register | Address | Description | Page |
|---|---|---|---|
| PLLCN | 0xB9 | PLL Control | 213 |
| PSCTL | 0x8F | Program Store R/W Control | 119 |
| PSW | 0xD0 | Program Status Word | 100 |
| REF0CN | 0xD1 | Voltage Reference Control | 88 |
| REFDAC0H | 0x97 | REFDAC High Byte Data | 126 |
| REFDAC0L | 0x96 | REFDAC Low Byte Data | 126 |
| REFDACMD | 0xF1 | REFDAC Mode | 126 |
| RSTSRC | 0xEF | Reset Source Configuration/Status | 114 |
| SBUF0 | 0x99 | UART0 Data Buffer | 239 |
| SCON0 | 0x98 | UART0 Control | 238 |
| SMB0CF | 0xC1 | SMBus Configuration | 221 |
| SMB0CN | 0xC0 | SMBus Control | 223 |
| SMB0DAT | 0xC2 | SMBus Data | 225 |
| SP | 0x81 | SP 0x81 Stack Pointer117 | 99 |
| TCON | 0x88 | Timer/Counter Control | 248 |
| TH0 | 0x8C | Timer/Counter 0 High | 251 |
| TH1 | 0x8D | Timer/Counter 1 High | 251 |
| TL0 | 0x8A | Timer/Counter 0 Low | 251 |
| TL1 | 0x8B | Timer/Counter 1 Low | 251 |
| TMOD | 0x89 | Timer/Counter Mode | 249 |
| TMR2CN | 0xC8 | Timer/Counter 2 Control | 254 |
| TMR2H | 0xCD | Timer/Counter 2 High | 255 |
| TMR2L | 0xCC | Timer/Counter 2 Low | 255 |
| TMR2RLH | 0xCB | Timer/Counter 2 Reload High | 255 |
| TMR2RLL | 0xCA | Timer/Counter 2 Reload Low | 255 |
| TMR3CN | 0x91 | Timer/Counter 3Control | 258 |
| TMR3H | 0x95 | Timer/Counter 3 High | 259 |
| TMR3L | 0x94 | Timer/Counter 3 Low | 259 |
| TMR3RLH | 0x93 | Timer/Counter 3 Reload High | 259 |
| TMR3RLL | 0x92 | Timer/Counter 3 Reload Low | 259 |
| TRDETCN | 0xD3 | Transient Detector Control | 50 |
| VDM0CN | 0xFF | VDD Monitor Control | 111 |
| XBAR0 | 0xE1 | Port I/O Crossbar Control | 200 |
| XBAR1 | 0xE2 | Port I/O Crossbar Control | 201 |

**Table 16.3. Special Function Indirect Register List**

| Register | Address | Description | Page |
|---|---|---|---|
| **ADC0 SFRs** | | | |
| ADC0ASCN | 0x40 | Autoscan Control | 194 |
| AIN0/VINGTH | 0x0C | AIN0/VIN High Limit Detector High Byte | 181 |
| AIN0/VINGTL | 0x0D | AIN0/VIN High Limit Detector Low Byte | 181 |
| AIN0/VINH | 0x0A | AIN0/VIN Data High Byte | 180 |
| AIN0/VINL | 0x0B | AIN0/VIN Data Low Byte | 181 |
| AIN0/VINLTH | 0x0E | AIN0/VIN Low Limit Detector High Byte | 181 |
| AIN0/VINLTL | 0x0F | AIN0/VIN Low Limit Detector Low Byte | 182 |
| AIN1GTH | 0x12 | AIN1 High Limit Detector High Byte | 182 |
| AIN1GTL | 0x13 | AIN1 High Limit Detector Low Byte | 183 |
| AIN1H | 0x10 | AIN1 Data High Byte | 182 |
| AIN1L | 0x11 | AIN1 Data Low Byte | 182 |
| AIN1LTH | 0x14 | AIN1 Low Limit Detector High Byte | 183 |
| AIN1LTL | 0x15 | AIN1 Low Limit Detector Low Byte | 183 |
| AIN2GTH | 0x18 | AIN2 High Limit Detector High Byte | 184 |
| AIN2GTL | 0x19 | AIN2 High Limit Detector Low Byte | 184 |
| AIN2H | 0x16 | AIN2 Data High Byte | 183 |
| AIN2L | 0x17 | AIN2 Data Low Byte | 184 |
| AIN2LTH | 0x1A | AIN2 Low Limit Detector High Byte | 184 |
| AIN2LTL | 0x1B | AIN2 Low Limit Detector Low Byte | 185 |
| AIN3GTH | 0x1E | AIN3 High Limit Detector High Byte | 185 |
| AIN3GTL | 0x1F | AIN3 High Limit Detector Low Byte | 186 |
| AIN3H | 0x1C | AIN3 Data High Byte | 185 |
| AIN3L | 0x1D | AIN3 Data Low Byte | 185 |
| AIN3LTH | 0x20 | AIN3 Low Limit Detector High Byte | 186 |
| AIN3LTL | 0x21 | AIN3 Low Limit Detector Low Byte | 186 |
| AIN4GTH | 0x24 | AIN4 High Limit Detector High Byte | 187 |
| AIN4GTL | 0x25 | AIN4 High Limit Detector Low Byte | 187 |
| AIN4H | 0x22 | AIN4 Data High Byte | 186 |
| AIN4L | 0x23 | AIN4 Data Low Byte | 187 |
| AIN4LTH | 0x26 | AIN4 Low Limit Detector High Byte | 187 |
| AIN4LTL | 0x27 | AIN4 Low Limit Detector Low Byte | 188 |
| AIN5GTH | 0x2A | AIN5 High Limit Detector High Byte | 188 |
| AIN5GTL | 0x2B | AIN5 High Limit Detector Low Byte | 189 |
| AIN5H | 0x28 | AIN5 Data High Byte | 188 |
| AIN5L | 0x29 | AIN5 Data Low Byte | 188 |
| AIN5LTH | 0x2C | AIN5 Low Limit Detector High Byte | 189 |
| AIN5LTL | 0x2D | AIN5 Low Limit Detector Low Byte | 189 |

**Table 16.3. Special Function Indirect Register List (Continued)**

| Register | Address | Description | Page |
|---|---|---|---|
| AIN6GTH | 0x30 | AIN6 High Limit Detector High Byte | 190 |
| AIN6GTL | 0x31 | AIN6 High Limit Detector Low Byte | 190 |
| AIN6H | 0x2E | AIN6 Data High Byte | 189 |
| AIN6L | 0x2F | AIN6 Data Low Byte | 190 |
| AIN6LTH | 0x32 | AIN6 Low Limit Detector High Byte | 190 |
| AIN6LTL | 0x33 | AIN6 Low Limit Detector Low Byte | 191 |
| AIN7GTH | 0x36 | AIN7 High Limit Detector High Byte | 191 |
| AIN7GTL | 0x37 | AIN7 High Limit Detector Low Byte | 192 |
| AIN7H | 0x34 | AIN7 Data High Byte | 191 |
| AIN7L | 0x35 | AIN7 Data Low Byte | 191 |
| AIN7LTH | 0x38 | AIN7 Low Limit Detector High Byte | 192 |
| AIN7LTL | 0x39 | AIN7 Low Limit Detector Low Byte | 192 |
| TEMPGTH | 0x3C | TEMP High Limit Detector High Byte | 193 |
| TEMPGTL | 0x3D | TEMP High Limit Detector Low Byte | 193 |
| TEMPH | 0x3A | TEMP Data High Byte | 192 |
| TEMPL | 0x3B | TEMP Data Low Byte | 193 |
| TEMPLTH | 0x3E | TEMP Low Limit Detector High Byte | 193 |
| TEMPLTL | 0x3F | TEMP Low Limit Detector Low Byte | 194 |
| TS01CN | 0x00 | Timeslot 0,1 Control | 178 |
| TS23CN | 0x01 | Timeslot 2,3 Control | 178 |
| TS45CN | 0x02 | Timeslot 4,5 Control | 178 |
| TS67CN | 0x03 | Timeslot 6,7 Control | 179 |
| VSENSEGTH | 0x06 | VSENSE High Limit Detector High Byte | 179 |
| VSENSEGTL | 0x07 | VSENSE High Limit Detector Low Byte | 180 |
| VSENSEH | 0x04 | VSENSE Data High Byte | 179 |
| VSENSEL | 0x05 | VSENSE Data Low Byte | 179 |
| VSENSELTH | 0x08 | VSENSE Low Limit Detector High Byte | 180 |
| VSENSELTL | 0x09 | VSENSE Low Limit Detector Low Byte | 180 |
| **DPWM SFRs** | | | |
| DPWMCN | 0x00 | DPWM Control | 69 |
| DPWMOUT | 0x2C | DPWM PH Output States | 69 |
| DPWMTLCD0 | 0x28 | Trim and Limit Data 0 | 69 |
| DPWMTLCD1 | 0x29 | Trim and Limit Data 1 | 69 |
| DPWMTLCD2 | 0x2A | Trim and Limit Data 2 | 70 |
| DPWMTLCD3 | 0x2B | Trim and Limit Data 3 | 70 |
| DPWMTLGT0 | 0x20 | Trim and Limit High Limit 0 | 82 |
| DPWMTLGT1 | 0x22 | Trim and Limit High Limit 1 | 82 |
| DPWMTLGT2 | 0x24 | Trim and Limit High Limit 2 | 83 |
| DPWMTLGT3 | 0x26 | Trim and Limit High Limit 3 | 83 |

**Table 16.3. Special Function Indirect Register List (Continued)**

| Register | Address | Description | Page |
|---|---|---|---|
| DPWMTLLT0 | 0x1F | Trim and Limit Low Limit 0 | 82 |
| DPWMTLLT1 | 0x21 | Trim and Limit Low Limit 1 | 82 |
| DPWMTLLT2 | 0x23 | Trim and Limit Low Limit 2 | 83 |
| DPWMTLLT3 | 0x25 | Trim and Limit Low Limit 3 | 83 |
| DPWMULOCK | 0x27 | Symmetry Lock Control | 69 |
| ENABX_OUT | 0x03 | ENABLE Input OFF PH Shutdown States | 72 |
| OCP_OUT | 0x04 | OCP PH Shutdown States | 73 |
| PH_POL | 0x02 | Initial Phase Polarity Control | 72 |
| PH1_CNTL0 | 0x07 | PH1 Leading Edge Control 1 | 75 |
| PH1_CNTL1 | 0x08 | PH1 Leading Edge Control 2 | 75 |
| PH1_CNTL2 | 0x09 | PH1 Trailing Edge Control 1 | 76 |
| PH1_CNTL3 | 0x0A | PH1 Trailing Edge Control 2 | 76 |
| PH2_CNTL0 | 0x0B | PH2 Leading Edge Control 1 | 77 |
| PH2_CNTL1 | 0x0C | PH2 Leading Edge Control 2 | 77 |
| PH2_CNTL2 | 0x0D | PH2Trailing Edge Control 1 | 77 |
| PH2_CNTL3 | 0x0E | PH2 Trailing Edge Control 2 | 77 |
| PH3_CNTL0 | 0x0F | PH3 Leading Edge Control 1 | 78 |
| PH3_CNTL1 | 0x10 | PH3 Leading Edge Control 2 | 78 |
| PH3_CNTL2 | 0x11 | PH3 Trailing Edge Control 1 | 78 |
| PH3_CNTL3 | 0x12 | PH3 Trailing Edge Control 2 | 78 |
| PH4_CNTL0 | 0x13 | PH4 Leading Edge Control 1 | 79 |
| PH4_CNTL1 | 0x14 | PH4 Leading Edge Control 2 | 79 |
| PH4_CNTL2 | 0x15 | PH4 Trailing Edge Control 1 | 79 |
| PH4_CNTL3 | 0x16 | PH4 Trailing Edge Control 2 | 79 |
| PH5_CNTL0 | 0x17 | PH5 Leading Edge Control 1 | 80 |
| PH5_CNTL1 | 0x18 | PH5 Leading Edge Control 2 | 80 |
| PH5_CNTL2 | 0x19 | PH5 Trailing Edge Control 1 | 80 |
| PH5_CNTL3 | 0x1A | PH5 Trailing Edge Control 2 | 80 |
| PH6_CNTL0 | 0x1B | PH6 Leading Edge Control 1 | 81 |
| PH6_CNTL1 | 0x1C | PH6 Leading Edge Control 2 | 81 |
| PH6_CNTL2 | 0x1D | PH6 Trailing Edge Control 1 | 81 |
| PH6_CNTL3 | 0x1E | PH6 Trailing Edge Control 2 | 81 |
| SW_CYC | 0x01 | Switching Cycle Length Control | 72 |
| SWBP_OUT | 0x05 | Software Bypass PH Shutdown States | 73 |
| SWBP_OUTEN | 0x06 | Software Bypass PH Enables | 74 |

## 16.7. Interrupt Handler

The Si8250/1/2 family includes an extended interrupt system supporting a total of 23 interrupt sources with two priority levels. The allocation of interrupt sources between on-chip peripherals and external input pins varies according to the specific version of the device. Each interrupt source has one or more associated interrupt-pending flag(s) located in an SFR. When a peripheral or external source meets a valid interrupt condition, the associated interrupt-pending flag is set to logic 1.

If interrupts are enabled for the source, an interrupt request is generated when the interrupt-pending flag is set. As soon as execution of the current instruction is complete, the CPU generates an LCALL to a predetermined address to begin execution of an interrupt service routine (ISR). Each ISR must end with an RETI instruction, which returns program execution to the next instruction that would have been executed if the interrupt request had not occurred. If interrupts are not enabled, the interrupt-pending flag is ignored by the hardware and program execution continues as normal. (The interrupt-pending flag is set to logic 1 regardless of the interrupt's enable/disable state.)

Each interrupt source can be individually enabled or disabled through the use of an associated interrupt enable bit in the Interrupt Enable and Extended Interrupt Enable SFRs. However, interrupts must first be globally enabled by setting the EA bit (IE.7) to logic 1 before the individual interrupt enables are recognized. Setting the EA bit to logic 0 disables all interrupt sources regardless of the individual interrupt-enable settings. Note that interrupts which occur when the EA bit is set to logic 0 will be held in a pending state and will not be serviced until the EA bit is set back to logic 1.

Some interrupt-pending flags are automatically cleared by the hardware when the CPU vectors to the ISR. However, most are not cleared by the hardware and must be cleared by software before returning from the ISR. If an interrupt-pending flag remains set after the CPU completes the return-from-interrupt (RETI) instruction, a new interrupt request will be generated immediately and the CPU will re-enter the ISR after the completion of the next instruction.

## 16.8. System Management Processor Interrupt Sources and Vectors

Software can simulate an interrupt by setting any interrupt-pending flag to logic 1. If interrupts are enabled for the flag, an interrupt request will be generated and the CPU will vector to the ISR address associated with the interrupt-pending flag. Interrupt sources, associated vector addresses, priority order and control bits are summarized in Table 16.4. Refer to the data sheet section associated with a particular on-chip peripheral for information regarding valid interrupt conditions for the peripheral and the behavior of its interrupt-pending flag(s).

## 16.9. Interrupt Priorities

Each interrupt source can be individually programmed to one of two priority levels: low or high. A low priority interrupt service routine can be preempted by a high priority interrupt. A high priority interrupt cannot be preempted. Each interrupt has an associated interrupt priority bit in an SFR (IP or EIP1) used to configure its priority level. Low priority is the default. If two interrupts are recognized simultaneously, the interrupt with the higher priority is serviced first. If both interrupts have the same priority level, a fixed priority order is used to arbitrate. (See Table 16.4.)

## Table 16.4. Interrupt Summary

| Interrupt Source | Interrupt Vector | Priority Order | Pending Flag | Bit Addressable? | Cleared by HW? | Enable Flag | Priority Control |
|---|---|---|---|---|---|---|---|
| Reset | 0x0000 | Top | None | N/A | N/A | N/A | N/A |
| External ($\overline{INT0}$) | 0x0003 | 0 | IE0 (TCON.1) | Y | Y | EX0 (IE.0) | PX0 (IP.0) |
| OCP | 0x000B | 1 | OCPIRQ (OCPCN.7) | N | Y | EOCP (IE.1) | POCP (IP.1) |
| AIN0/VIN | 0x0013 | 2 | AIN0VINIRQ (ADC0LM0.0) | N | Y | EAIN0/VIN (IE.2) | PAIN0/VIN (IP.2) |
| UART0* | 0x001B | 3 | RI0 (SCON0.0)<br>TI0 (SCON0.1) | Y | N | ES0 (IE.3) | PS0 (IP.3) |
| Transient Detector | 0x0023 | 4 | TRIIRQ (TRDETCN.6) | N | N | ETRDET (IE.4) | PTRDET (IP.4) |
| Comparator0* | 0x002B | 5 | CP0FIF (CPT0CN.4)<br>CP0RIF (CPT0CN.5) | N | N | ECP0 (IE.5) | PCP0 (IP.5) |
| ENABLE | 0x0033 | 6 | ENABX (TCON.3) | Y | Y | EEN (IE.6) | PEN(IP.6) |
| ICYC Limit | 0x003B | 7 | ICYCIRQ (IPKCN.6) | N | | EICYC (EIE1.0) | PICYC (EIP1.0) |
| ADC0WINT | 0x0043 | 8 | ADC0WINT (ADC0CN.3) | Y | N | EWADC0 (EIE1.1) | PWADC0 (EIP1.1) |
| End of Switching Frame | 0x004B | 9 | EOFINT (DPWMCNTL.0) | Y | Y | EEOF (EIE1.2) | PEOF (EIP1.2) |
| ADC0 End of Conversion | 0x0053 | 10 | ADC0INT (ADCOCN.5) | Y | N | EADC0 (EIE1.3) | PADC0 (EIP1.3) |
| Scheduler (Timer0) | 0x005B | 11 | TF0 (TCON.5) | Y | Y | ET0 (EIE1.4) | PT0 (EIP1.4) |
| VSENSE | 0x0063 | 12 | VSENSEIRQ (ADC0LM1.0) | N | N | EVSENSE (EIE1.5) | PVSENSE (EIP1.5) |
| AIN1 | 0x006B | 13 | AIN1IRQ (ADC0LM0.0) | N | N | EAIN1 (EIE1.6) | PAIN1 (EIP1.6) |
| Programmable Counter Array | 0x0073 | 14 | CF (PCA0CN.7)<br>CCFn (PCA0CN.n) | Y | N | EPCA0 (EIE1.7) | PPCA0 (EIP1.7) |
| Timer 1 | 0x007B | 15 | TF1 (TCON.7) | Y | Y | ET1 (EIE2.0) | PT1 (EIP2.0) |
| AIN2 | 0x0083 | 16 | AIN2IRQ (ADC0LM0.2) | N | N | EAIN2 (EIE2.1) | PAIN2 (EIP2.1) |
| Timer 3 | 0x008B | 17 | TF3H (TMR3CN.7)<br>TF3L (TMR3CN.6) | N | Y | ET3 (EIE2.2) | PT3 (EIP2.2) |
| AIN3- AIN7,<br>Temp Sensor | 0x0093 | 18 | AIN3IRQ–AIN7IRQ (ADC0LM0.7–.3)<br>TEMPIRQ (ADC0LM1.1) | N | N | EAIN37TMP (EIE2.3) | PAIN37TMP (EIP2.3) |
| ADC1 End of Conversion | 0x009B | 19 | EOC1IRQ (ADC1CN.6) | N | N | EADC1 (EIE2.4) | PADC1 (EIP2.4) |
| Timer 2 | 0x00A3 | 20 | TF2H (TMR2CN.7)<br>TF2L (TMR2CN.6) | Y | Y | ET2 (EIE2.5) | PT2 (EIP2.5) |
| $I^2C$ Port | 0x00AB | 21 | SI (SMB0CN.0) | Y | N | ESMB0 (EIE2.6) | PSMB0 (EIP2.6) |

***Note:** These interrupts also act as wake-up sources from Stop mode.

## 16.10. Interrupt Latency

Interrupt response time depends on the state of the CPU when the interrupt occurs. Pending interrupts are sampled and priority decoded each system clock cycle. Therefore, the fastest possible response time is 7 system clock cycles: 1 clock cycle to detect the interrupt, 1 clock cycle to execute a single instruction, and 5 clock cycles to complete the LCALL to the ISR. If an interrupt is pending when a RETI is executed, a single instruction is executed before an LCALL is made to service the pending interrupt. Therefore, the maximum response time for an interrupt (when no other interrupt is currently being serviced or the new interrupt is of greater priority) occurs when the CPU is performing an RETI instruction followed by a DIV as the next instruction. In this case, the response time is 19 system clock cycles: 1 clock cycle to detect the interrupt, 5 clock cycles to execute the RETI, 8 clock cycles to complete the DIV instruction and 5 clock cycles to execute the LCALL to the ISR. If the CPU is executing an ISR for an interrupt with equal or higher priority, the new interrupt will not be serviced until the current ISR completes, including the RETI and following instruction.

## 16.11. External ($\overline{\text{INT0}}$) and ENABLE Interrupts

The $\overline{\text{INT0}}$ and ENABLE interrupts interrupt sources are configurable as active high or low, edge or level sensitive. The IN0PL ($\overline{\text{INT0}}$ Polarity) and ENINTPL (ENABLE Input Polarity) bits in the IT01CF register select active high or active low; the IT0 and IT1 bits in TCON select level or edge sensitive. The table below lists the possible configurations.

| IT0 | IN0PL | $\overline{\text{INT0}}$ Interrupt |
|---|---|---|
| 1 | 0 | Active Low, Edge Sensitive |
| 1 | 1 | Active High, Edge Sensitive |
| 0 | 0 | Active Low, Level Sensitive |
| 0 | 1 | Active High, Level Sensitive |

| IT1 | ENINTPL | ENABLE Input Interrupt |
|---|---|---|
| 1 | 0 | Active Low, Edge Sensitive |
| 1 | 1 | Active High, Edge Sensitive |
| 0 | 0 | Active Low, Level Sensitive |
| 0 | 1 | Active High, Level Sensitive |

$\overline{\text{INT0}}$ and ENABLE are assigned to Port pins as defined in the IT01CF register. Note that $\overline{\text{INT0}}$ and ENBLINT Port pin assignments are independent of any Crossbar assignments. $\overline{\text{INT0}}$ and ENABLE will monitor their assigned Port pins without disturbing the peripheral that was assigned the Port pin via the Crossbar. To assign a Port pin only to $\overline{\text{INT0}}$ and/or ENABLE, configure the Crossbar to skip the selected pin(s). This is accomplished by setting the associated bit in register XBR0 (see Section "**19.1. Priority Crossbar Decoder**" on page **197** for complete details on configuring the Crossbar).

IE0 (TCON.1) and ENABX (TCON.3) serve as the interrupt-pending flags for the $\overline{\text{INT0}}$ and ENABLE interrupts, respectively. If an $\overline{\text{INT0}}$ or ENABLE interrupt is configured as edge-sensitive, the corresponding interrupt-pending flag is automatically cleared by the hardware when the CPU vectors to the ISR. When configured as level sensitive, the interrupt-pending flag remains logic 1 while the input is active as defined by the corresponding polarity bit (IN0PL or ENINTPL); the flag remains logic 0 while the input is inactive. The interrupt source must hold the input active until the interrupt request is recognized. It must then deactivate the interrupt request before execution of the ISR completes or another interrupt request will be generated.

## 16.12. Interrupt Register Descriptions

The SFRs used to enable the interrupt sources and set their priority levels are described below. Refer to the data sheet section associated with a particular on-chip peripheral for information regarding valid interrupt conditions for the peripheral and the behavior of its interrupt-pending flag(s).

### SFR Definition 16.1. IE: Interrupt Enable

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| EA | ENINT | ECP0 | ETRDET | ES0 | EAIN0/VIN | EOCP | EX0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0xA8

Bit 7: EA: Enable All. This bit globally enables/disables all interrupts. It overrides the individual interrupt mask settings.
0: Global interrupts disabled.
1: Enable each interrupt according to its mask setting.

Bit 6: ENINT: External Interrupt (ENABLE) Enable
0: External interrupt disabled.
1: External interrupt enabled.

Bit 5: ECP0: Comparator0 Interrupt Enable
0: Comparator0 interrupt disabled.
1: Comparator0 interrupt enabled.

Bit 4: ETRDET: Transient Detector Interrupt Enable
0: Transient Detector interrupt disabled.
1: Transient Detector interrupt enabled.

Bit 3: ES0: Enable UART Interrupt
0: UART interrupt requests disabled.
1: Enable UART interrupt enabled.

Bit 2: EAIN0/VIN: AIN0/VIN Window Detector Interrupt Enable
0: AIN0/VIN window detector interrupt disabled.
1: AIN0/VIN window detector interrupt enabled.

Bit 1: EOCP: Enable Overcurrent Protection Fault Interrupt
0: Overcurrent protection fault interrupt requests disabled.
1: Overcurrent protection fault interrupt requests enabled.

Bit 0: EX0: External Interrupt (INT0) Enable
0: External interrupt disabled.
1: External interrupt enabled.

## SFR Definition 16.2. IP: Interrupt Priority

| — | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | PENAB | PCP0 | PTRDET | PS0 | PAIN0/VIN | POCP | PINT0 | 10000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0xB8

Bit 7: Unused.

Bit 6: PENAB: External Interrupt (ENABLE) Priority Control
0: External interrupt is set to low priority level.
1: External interrupt is set to high priority level.

Bit 5: PCP0: Comparator0 Interrupt Priority Control.
0: Comparator0 interrupt is set to low priority level.
1: Comparator0 interrupt is set to high priority level.

Bit 4: PTRDET: Transient Detector Interrupt Priority Control
0: Transient Detector interrupt is set to low priority level.
1: Transient Detector interrupt is set to high priority level.

Bit 3: PS0: Enable UART Interrupt Priority Control
0: UART interrupt is set to low priority level.
1: UART interrupt is set to high priority level.

Bit 2: PAIN0/VIN: AIN0/VIN Window Detector Interrupt Priority Control
0: AIN0/VIN window detector interrupt is set to low priority level.
1: AIN0/VIN window detector interrupt is set to high priority level.

Bit 1: POCP: Enable Overcurrent Protection Fault Interrupt Priority Control
0: Disable overcurrent protection fault is set to low priority level.
1: Enable overcurrent protection fault interrupt is set to high priority level.

Bit 0: PINT0: Enable External Interrupt (INT0) Interrupt Priority Control
0: External Interrupt is set to low priority level.
1: External Interrupt is set to high priority level.

## SFR Definition 16.3. EIE1: Extended Interrupt Enable 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| EPCA0 | EAIN1 | EVSENSE | ET0 | EADC0 | EEOF | EWADC0 | EICYC | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xE6

Bit 7: EPCA0: Enable PCA0 Interrupt Enable
0: PCA0 interrupt disabled.
1: PCA0 interrupt enabled.

Bit 6: EAIN1: Enable AIN0 Window Detector Interrupt Enable
0: AIN1 window detector interrupt disabled.
1: AIN1 window detector interrupt enabled.

Bit 5: EVSENSE: VSENSE Window Detector Interrupt Enable
0: VSENSE window detector interrupt disabled.
1: VSENSE window detector interrupt enabled.

Bit 4: ET0: Timer0 Interrupt Enable
0: Timer0 interrupt disabled.
1: Timer0 interrupt enabled.

Bit 3: EADC0: ADC0 End-of-Conversion Interrupt Enable
0: ADC0 EOC interrupt disabled.
1: ADC0 EOC interrupt enabled.

Bit 2: EEOF: DPWM End-of-Frame Interrupt Enable
0: DPWM End-of-frame interrupt disabled.
1: DPWM End-of-frame interrupt enabled.

Bit 1: EWADC0: ADC0 Window Detector Enable
0: ADC0 Window detector disabled.
1: ADC0 Window detector enabled.

Bit 0: EICYC: Peak Current Detector Interrupt Enable
0: Peak current detector interrupt disabled.
1: Peak current detector interrupt enabled.

## SFR Definition 16.4. EIP1: Extended Interrupt Priority 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PPCA0 | PAIN1 | PVSENSE | PT0 | PADC0 | PEOF | PWADC0 | PICYC | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xF6

Bit 7: PPCA0: Enable PCA0 Interrupt Priority Control
0: PCA0 interrupt is set to low priority.
1: PCA0 interrupt is set to high priority.

Bit 6: PAIN1: Enable AIN0 Window Detector Interrupt Priority Control
0: AIN1 window detector interrupt is set to low priority.
1: AIN1 window detector interrupt is set to high priority.

Bit 5: PVSENSE: VSENSE Window Detector Interrupt Priority Control
0: VSENSE window detector interrupt is set to low priority.
1: VSENSE window detector interrupt is set to high priority.

Bit 4: PT0: Timer0 Interrupt Priority Control
0: Timer0 interrupt is set to low priority.
1: Timer0 interrupt is set to high priority.

Bit 3: PADC0: ADC0 End-of-Conversion Interrupt Priority Control
0: ADC0 EOC interrupt is set to low priority.
1: ADC0 EOC interrupt is set to high priority.

Bit 2: PEOF: DPWM End-of-Frame Interrupt Priority Control
0: DPWM End-of-frame interrupt is set to low priority.
1: DPWM End-of-frame interrupt is set to high priority.

Bit 1: PWADC0: ADC0 Window Detector Interrupt Priority Control
0: ADC0 Window detector is set to low priority.
1: ADC0 Window detector is set to high priority.

Bit 0: PICYC: Peak Current Detector Interrupt Priority Control
0: Peak current detector interrupt is set to low priority.
1: Peak current detector interrupt is set to high priority.

## SFR Definition 16.5. EIE2: Extended Interrupt Enable 2

| — | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | ESMB0 | ET2 | EADC1 | EAIN37TMP | ET3 | EAIN2 | ET1 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xE7

Bit 7: Unused

Bit 6: ESMB0: SMBus Interrupt Enable
0: SMBus interrupt disabled.
1: SMBus interrupt enabled.

Bit 5: ET2: Timer 2 Interrupt Enable
0: Timer 2 interrupt disabled.
1: Timer 2 interrupt enabled.

Bit 4: EADC1: ADC1 End-of-Conversion Interrupt Enable
0: ADC1 End-of-conversion interrupt disabled.
1: ADC1 End-of-conversion interrupt enabled.

Bit 3: EAIN37TMP: Enable AIN3 to AIN7 and Temperature Sensor Interrupt
0: AIN37TMP interrupt disabled.
1: AIN37TMP interrupt enabled.

Bit 2: ET3: Timer 3 Interrupt Enable
0: Timer 3 interrupt disabled.
1: Timer 3 interrupt enabled.

Bit 1: EAIN2: AIN2 Window Interrupt Enable
0: AIN2 window interrupt disabled.
1: AIN2 window interrupt enabled.

Bit 0: ET1: Timer 1 Interrupt Enable
0: Timer 1 interrupt disabled.
1: Timer 1 interrupt enabled.

## SFR Definition 16.6. EIP2: Extended Interrupt Priority 2

| — | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | PSMB0 | PT2 | PADC1 | PAIN37TMP | PT3 | PAIN2 | PT1 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xF7

Bit 7: Unused.

Bit 6: PSMB0: SMBus Interrupt Priority Control
0: SMBus interrupt set to low priority.
1: SMBus interrupt set to high priority.

Bit 5: PT2: Timer 2 Interrupt Priority Control
0: Timer 2 interrupt set to low priority.
1: Timer 2 interrupt set to high priority.

Bit 4: PADC1: ADC1 End-of-Conversion Interrupt Priority Control
0: ADC1 End-of-conversion interrupt set to low priority.
1: ADC1 End-of-conversion interrupt set to high priority.

Bit 3: PAIN37TMP: Enable AIN3 to AIN7 and Temperature Sensor Interrupt Priority Control
0: AIN37TMP interrupt set to low priority.
1: AIN37TMP interrupt set to high priority.

Bit 2: PT3: Timer 3 Interrupt Priority Control
0: Timer 3 interrupt set to low priority.
1: Timer 3 interrupt set to high priority.

Bit 1: PAIN2: AIN2 Window Interrupt Priority Control
0: AIN2 window interrupt set to low priority.
1: AIN2 window interrupt set to high priority.

Bit 0: PT1: Timer 1 Interrupt Priority Control
0: Timer 1 interrupt set to low priority.
1: Timer 1 interrupt set to high priority.

## SFR Definition 16.7. IT01CF: $\overline{\text{INT0}}$/ENABLE Input Configuration

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ENINTPL | ENINTSL2 | ENINTSL1 | ENINTSL0 | IN0PL | IN0SL2 | IN0SL1 | IN0SL0 | 00000001 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xE4

Note: Refer to SFR Definition 23.1. “TCON: Timer Control” on page 248 for INT0/ENABLE edge- or level-sensitive interrupt selection.

Bit 7: ENINTPL: ENABLE Input Interrupt Polarity
0: ENABLE Input is active low.
1: ENABLE input is active high.

Bits 6-4: ENINTSL[2:0]: ENINT Port Pin Selection Bits
These bits select which Port pin is assigned to ENABLE. Note that this pin assignment is independent of the Crossbar; ENABLE will monitor the assigned Port pin without disturbing the peripheral that has been assigned the Port pin via the Crossbar. The Crossbar will not assign the Port pin to a peripheral if it is configured to skip the selected pin (accomplished by setting to '1' the corresponding bit in register P0SKIP).

| ENINTSL[2:0] | ENABLE Port Pin |
|---|---|
| 000 | P0.0 |
| 001 | P0.1 |
| 010 | P0.2 |
| 011 | P0.3 |
| 100 | P0.4 |
| 101 | P0.5 |
| 110 | P0.6 |
| 111 | P0.7 |

Bit 3: IN0PL: $\overline{\text{INT0}}$ Polarity
0: $\overline{\text{INT0}}$ interrupt is active low.
1: $\overline{\text{INT0}}$ interrupt is active high.

Bits 2-0: INT0SL[2:0]: $\overline{\text{INT0}}$ Port Pin Selection baksheesh bits select which Port pin is assigned to $\overline{\text{INT0}}$. Note that this pin assignment is independent of the Crossbar; $\overline{\text{INT0}}$ will monitor the assigned Port pin without disturbing the peripheral that has been assigned the Port pin via the Crossbar. The Crossbar will not assign the Port pin to a peripheral if it is configured to skip the selected pin (accomplished by setting to '1' the corresponding bit in register P0SKIP).

| INT0SL[2:0] | $\overline{\text{INT0}}$ Port Pin |
|---|---|
| 000 | P0.0 |
| 001 | P0.1 |
| 010 | P0.2 |
| 011 | P0.3 |
| 100 | P0.4 |
| 101 | P0.5 |
| 110 | P0.6 |
| 111 | P0.7 |

## NOTES:

# 17. DSP Filter Engine

The output of the ADC is applied to the input of the DSP filter engine, which provides the phase compensation necessary to stabilize the control loop. The CPU can adjust filter coefficients to tune control response as system load conditions vary. The DSP filter engine consists of two stages: a first stage proportional-integral-derivative (PID) filter and a selectable second stage low-pass (LPF) or sinc filter (SINC). The composite filter (PID and LPF) provides up to three poles and three zeros, while the composite filter (PID and SINC) provides one pole and multiple zeros. Figure 17.1 is a block diagram of the DSP filter engine, and Table 17.1 shows the ranges of coefficients.

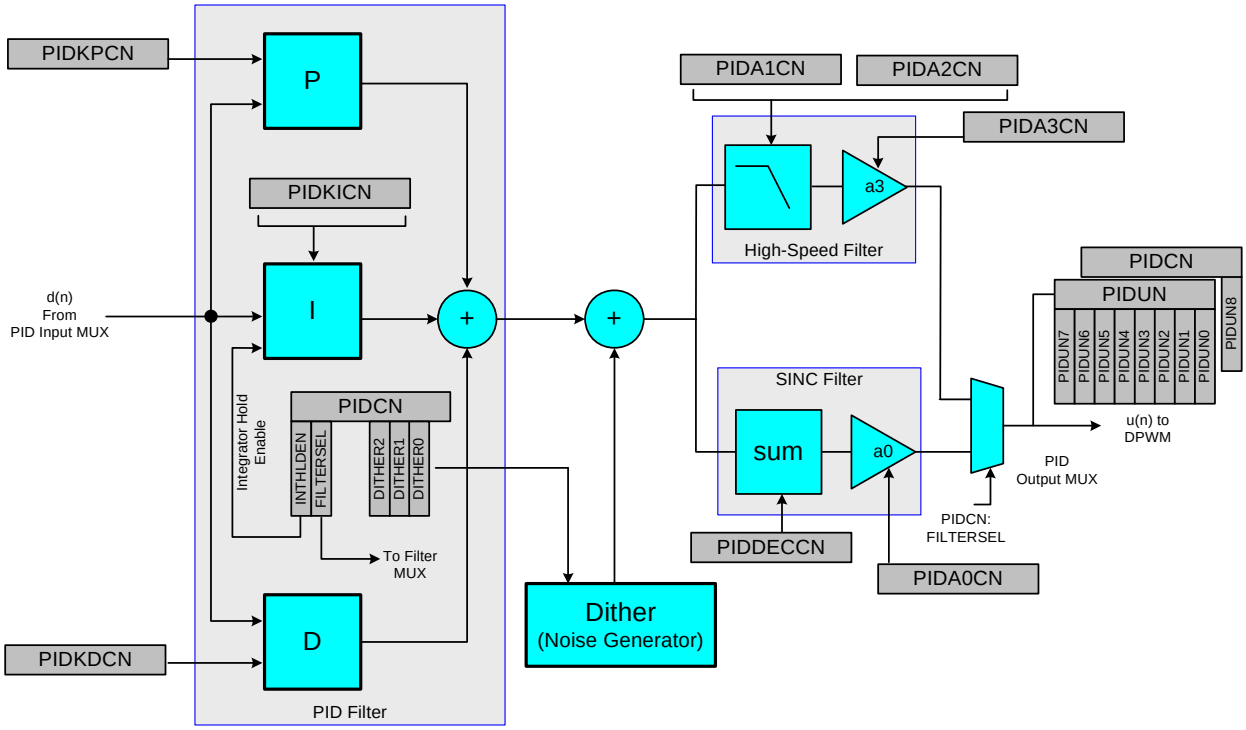


**Figure 17.1. DSP Filter Engine Block Diagram**

## 17.1. PID Filter

The PID filter output is the sum of a proportional gain term, P, integration gain term, I, and derivative gain term, D, derived from the error signal of control-loop ADC. Each transfer function for each component is determined by its coefficient, as summarized in Table 17.1.

The gain of P is set by the kP coefficient in PIDKPCN register. The range of kP is 00000000b to 00111111b and provides a gain adjustment range of 0 (i.e., P component disabled) to 3.9375. This term applies a proportional gain to the error d(n). As the gain term is increased, the power supply responds faster to changes in d(n), but decreases system damping and stability. Step response overshoot and ringing could be caused by too large a value of the gain term.

The integral gain of I is set by the kI coefficient in the PIDKICN register. The range of kI is 00000000b to 01111111b and provides an integrator gain adjustment range of 0 to 0.248047. Unlike proportional gain (which reduces instantaneous error), integral gain reduces steady state error to zero. The integrator has infinite dc gain, and consequently adjusts the mean supply output voltage to drive its input to zero. The

amount of time power supply takes to reach its steady state is inversely proportional to the integral gain kI. Instability and oscillation can also be caused by too large value of the integral term. Too small of an integral gain can result in limit cycle oscillation. Should the integrator input not achieve a zero value, integration will continue until the integrator output saturated at maximum or minimum (integrator wind out). Wind out adversely affects control loop response because the integrator requires additional recovery time to return to its normal operating range as the loop attempts recovery. One cause of wind-out is cycle-by-cycle current limiting (i.e., PWM duty cycle truncated by the peak current comparator prior to the output voltage achieving its nominal value). The Si8250/1/2 devices have anti-wind out circuitry that inhibits integrator updates during current limiting, thereby holding integrator output constant. However should integrator wind out occur, the integrator can be reset to zero by setting the integrator clear bit in the PIDKICN register. Please see Section "**17.8. Integrator Anti-Wind Out**" on page **152** on Integrator anti-wind out for details.

The derivative gain of D is set by the kD coefficient in the PIDKDCN register. The range of kD is 00000000b to 00111111b and provides a derivative gain adjustment range of 0 to 63. The derivative term can improve stability, reduce step-response overshoot (damping) and reduce step-response time. The derivative term is proportional to the rate of change of the error signal d(n) and therefore improves controller reaction time by predicting changes in the error. Following an output disturbance, the supply output will return to its nominal value faster as kD is increased; however, output overshoot can be caused by excessive damping from the derivative term.

The P, I, and D terms are summed as follows:

$$kP + (kI)\left(\frac{1}{1 - Z^{-1}}\right) + kD(1 - Z^{-1}) = \frac{(kP + kI + kD) - (kP + 2kD)Z^{-1} + kDZ^{-2}}{1 - Z^{-1}}$$

**Equation 17.1. PID Transfer Function**

The transfer function provides one pole and two zeros. The output of the PID filter is passed to one of two second-stage filters (high-speed, low-pass filter or decimation SINC filter).

In summary, increasing kP decreases stability, improves response time, and decreases steady-state error. Increasing kI decreases stability, improves response time, but worsens settling time. Increasing kD decreases step-response overshoot and response time. The user should utilize the Compensator tool in the Application Builder tool suite to build an initial design then apply the guidelines above to "fine tune" the power supply performance.

Open and closed-loop PID response is illustrated in Figure 17.2. The open-loop case is shown on the left side of the figure, where the loop is opened and disturbance voltage V (which is slightly less than REF) is introduced. When this happens, the following actions take place:

1. The P output is immediately driven to a level determined by kP and magnitude of (VREF – V).
2. The I output integrates at a rate determined by the value of kI and the magnitude of (V – VREF)
3. The D output goes positive by an amount determined by the value of kD and the PID input rate-of-change.

The composite PID output sums these three actions as shown in the bottom trace. Note the P and D terms provide immediate response, while the I term provides longer-term corrective loop action.

**Table 17.1. DSP Filter Engine Coefficients**

| Coefficient | SFR | Data Format | Register Format | | | | | | | | Range (Base 10) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | D7 | D6 | D5 | D4 | D3 | D2 | D1 | D0 | |
| kP | PIDKPCN | xx.xxxx | | | x | x | x | x | x | x | 0 to 3.9375 |
| kI | PIDKICN | .00xxxxxx | Clear | x | x | x | x | x | x | x | 0 to 0.248047 |
| kD | PIDKDCN | xxxxxx. | | | x | x | x | x | x | x | 0 to 63 |
| A0 | PIDA0CN | .xxxxxxxx | x | x | x | x | x | x | x | x | 0 to 0.996094 |
| A1 | PIDA1CN | Sx.xxxxxx | s | x | x | x | x | x | x | x | –2 to 1.984375 |
| A2 | PIDA2CN | .xxxxxxx | | x | x | x | x | x | x | x | 0 to 0.9921875 |
| A3 | PIDA3CN | .xxxxxxx | | x | x | x | x | x | x | x | 0 to 0.9921875 |
| DEC | PIDDECCN | xxxxxxxx. | x | x | x | x | x | x | x | x | 1 to 256 |

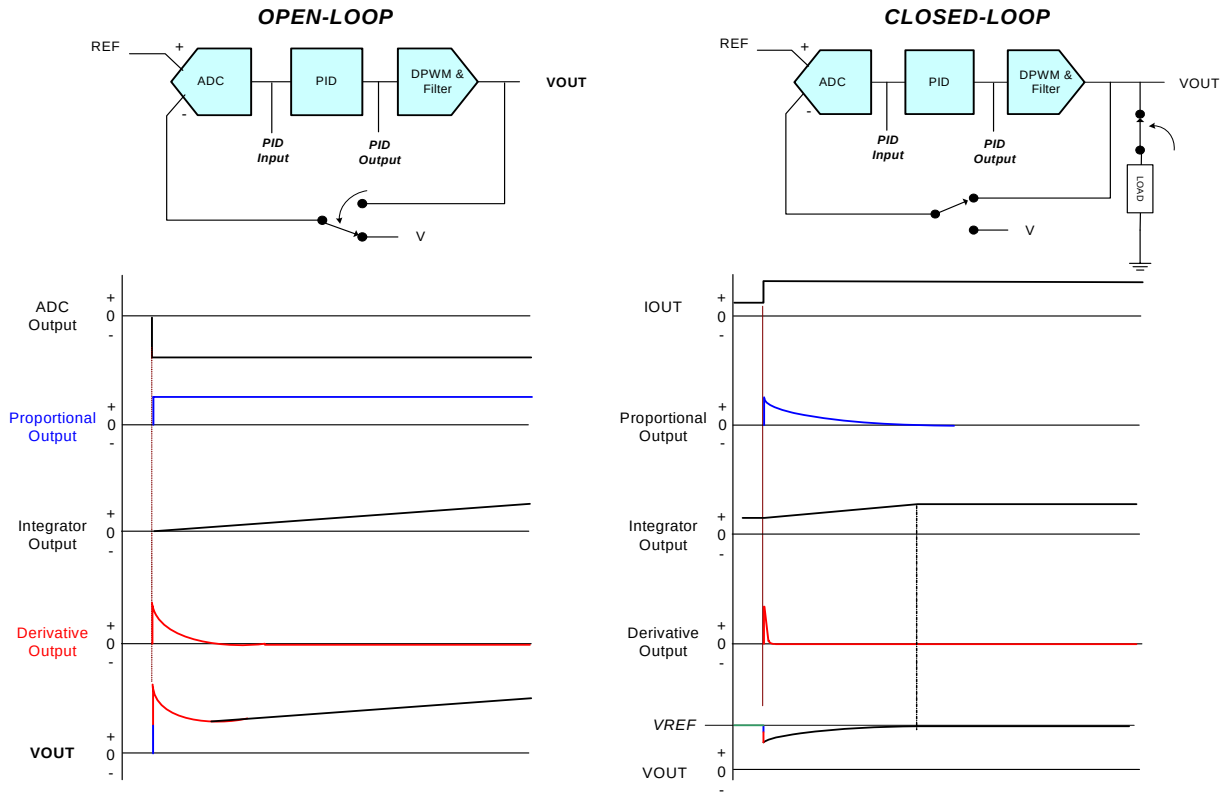


**Figure 17.2. PID Output Sums**

In the closed-loop case shown on the right in Figure 17.2, an output disturbance is introduced when the load is suddenly connected to the supply output, causing an increase in output current and decrease in output voltage. The P and D outputs again react immediately to correct the error. By comparison, the I output moves slower, but provides precise control to return VOUT to its nominal value.

## 17.2. High-Speed Low-Pass Filter (Option 1)

The second-stage high-speed filter has a sampling frequency of 5 MHz or 10 MHz. It is a two-pole filter with pole coefficients of A1 in PIDA1CN register and A2 in PIDA2CN register plus a gain term with coefficient of A3 in PIDA3CN register (the transfer function is shown in Equation 17.2). The range of A1 is 10000000b to 01111111b (in 2s complement) and provides a pole adjustment range of –2 to 1.984375. The range of A2 is 00000000b to 01111111b and provides a pole adjustment range of 0 to 0.9921875. The range of A3 is 00000000b to 01111111b and provides a gain adjustment range of 0 to 0.9921875. This filter's high sampling rate updates u(n) multiple times in a given switching cycle for fast transient response. Coefficients A1 and A2 control the cutoff frequency of the two poles. The frequency of the first zero is located at one-half of sampling rate. Gain term A3 adjusts the dc gain of the low-pass filter. This coefficient can be used by the transient interrupt routine to temporarily boost loop gain for faster recovery. The compensator tool should be used to place the actual poles locations.

$$\frac{A3(1+Z^{-1})}{1+A1Z^{-1}+A2Z^{-2}}$$

**Equation 17.2. Transfer Function of Low-Pass Filter**

## 17.3. SINC Decimation Low-Pass Filter (Option 2)

The SINC filter has an input sampling frequency of 10 MHz and an programmable output frequency ranging from 39 KHz to 10 MHz (because of its down-sampling action, this filter is also known as the "decimation filter"). The SINC filter is an all zeros filter plus gain term. The gain term A0 has a coefficient range of 0 to 0.996094. The zeros are evenly distributed along the sampling frequency and defined by the decimation ratio, DEC, which provides an adjustable range of 1 to 127 in the PIDDECCN[6:0] register. It has DEC/2 spectral zeros if DEC is even, or DEC/2 – 1 if DEC is odd. The decimation ratio is defined as the filter input frequency divided by the filter output frequency (i.e., fin/fout). The resulting output of SINC filter is an averaged value of PID controller output when coefficient DEC is equal to the ratio of 10 MHz/PWM switching frequency. Control variable u(n) is applied to the DPWM only at the start of every switching cycle and maintains a constant value until the start of the next switching cycle. Zeros should be located at the switching frequency and its harmonics. While this filter does not provide fast response to transient conditions, it offers reduced switching noise in the control loop and minimum PWM edge jitter for quieter system operation. (When using the SINC filter, transient response can still be enhanced using the transient detector interrupt and adjusting gain term A0.) Therefore, decimation ratio allows filter throughput (system response time) to be traded for noise attenuation.

$$\frac{A0(1-Z^{-DEC})}{1-Z^{-1}} = A0(1+Z^{-1}+Z^{-2}+\ldots+Z^{DEC+1})$$

**Equation 17.3. Transfer Function of SINC Decimation Filter**

## 17.4. Dither

Dithering provides a means to increase DPWM resolution to avoid limit cycle oscillation. The Si8250 contains a digital pseudo-random noise generator with six amplitude options programmed by the DITHER[2:0] bits in the PIDCN register. Output of this noise source is injected into the control loop just after the PID and before the low-pass and SINC filters. With the added noise it is possible to increase the theoretical DPWM resolution.

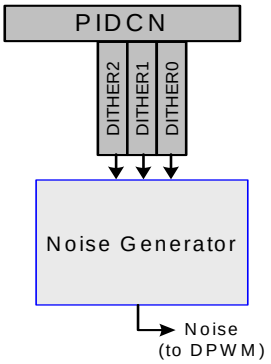


**Figure 17.3. Dither Control**

## 17.5. Output Filter Select MUX

The user's choice of the two-pole low-pass or decimation SINC filter will depend on the application. At its fastest setting the two-pole low-pass filter provides faster transient response than the SINC filter. However, the SINC filter provides a ‘quieter’ modulation.

## 17.6. Placing Poles and Zeros

Software supplied with the Si8250/1/2DK simplifies design by automatically populating coefficient values into the appropriate registers. The user provides specifications for converter's input and output voltages, pole and zero location of compensator, and external loading. The filter design tool will display compensator, converter and open-loop frequency responses, along with load and line regulation.

## 17.7. Compensation Design Strategy

The Si8250/1/2 DSP filter engine can implement traditional compensation schemes (Type 1, 2 3) or other functions to a maximum of 3-poles and 3-zeros. The principles of digital compensation are similar to those of analog compensation, so traditional analog design techniques are applicable. The maximum closed-loop gain crossover frequency should be less than the minimum switching frequency of the power supply. For example, a traditional Type 3 compensator may be implemented by placing two compensating zeros around output filter corner frequency, a high-frequency pole to compensate for the induced zero caused by capacitor ESR, and another pole at a very high frequency to guarantee sufficient gain and phase margins. These parameters can be written into the Compensator tool contained in the development kit software suite. Once specified, the compensator tool calculates all filter coefficients and allows user to review gain response, loop bandwidth and phase margin, and make fine adjustments.

## 17.8. Integrator Anti-Wind Out

When enabled, the integrator anti-wind out circuit automatically inhibits integrator updates during current limit cycles. As shown in Figure 17.4, the integrator updates are blocked during current limit cycles (ICYCIRQ = 1) when the integrator hold enable bit (INTHLDEN) bit is set to 1. While blocked, the integrator holds it last updated value. Normal integrator action resumes when ICYCIRQ interrupts cease at the end-of-switching interrupt (EOFIRQ).

## 17.9. Integrator Clear

When the CLEAR bit in PIDKICN is set to 1, the content of integrator is reset to zero. The reset can be useful after the power supply is shut down due to overcurrent protection fault (OCP) and other conditions that may cause a residual integrator output. In most cases, reset is not needed because the integrator will gradually integrate to zero when REFDAC is set to zero.

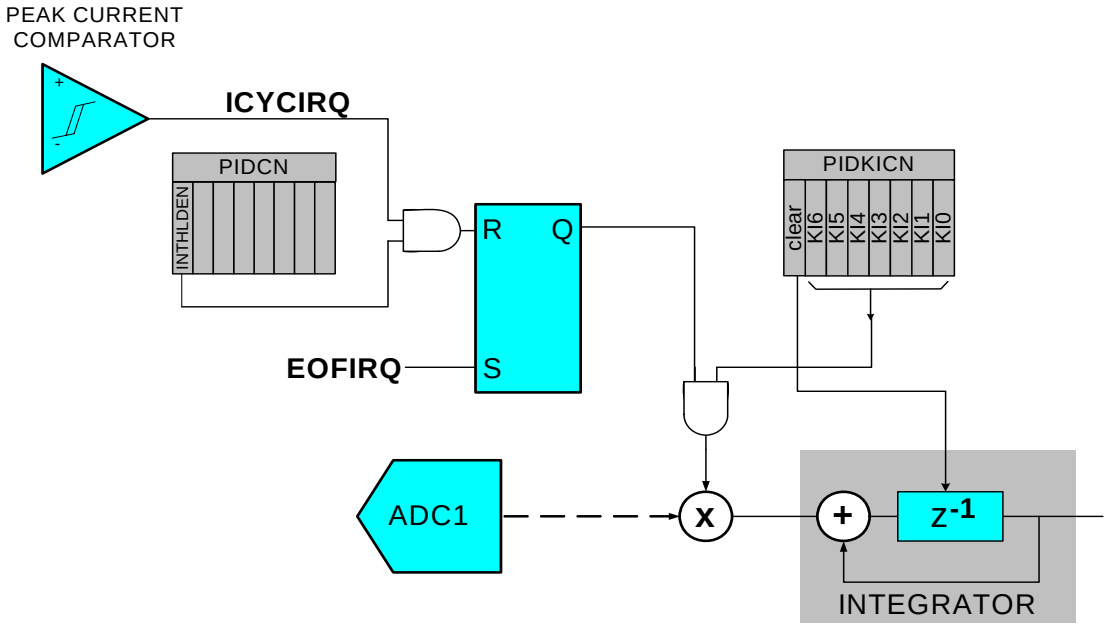


**Figure 17.4. Integrator Anti-Windout**

### SFR Definition 17.1. PIDKPCN: PID Filter Proportional Coefficient

| — | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xF3

Bits 7–6: Unused.

Bits 5–0: kP[5:0] Proportional coefficient bits 5:0. Format is xx.xxxx

### SFR Definition 17.2. PIDKICN: PID Filter Integration Coefficient

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ICLR | kI6 | kI5 | kI4 | kI3 | kI2 | kI1 | kI0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xF4

Bit 7: ICLR: Integrator clear.

Bits 6–0: kI[6:0]: Integration coefficient bits 6:0. Format is _ _xxxxxxx

### SFR Definition 17.3. PIDKDCN: PID Filter Differentiation Coefficient

| — | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xF5

Bits 7–6: Unused.

Bits 5–0: kD[5:0]: Differentiation coefficient bits 5:0. Format is xxxxxx

### SFR Definition 17.4. PIDA1CN: PID Low-Pass Filter Pole 1 Coefficient

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xED

Bits 7–0: A1[7:0]: Pole 1 coefficient bits 7:0. Format is sx.xxxxxx (2s complement).

### SFR Definition 17.5. PIDA2CN: PID Low-Pass Filter Pole 2 Coefficient

| — | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xEE

Bit 7: Unused.

Bits 6–0: A2[6:0]: Pole 2 coefficient bits 6:0. Format is .xxxxxxx

### SFR Definition 17.6. PIDA3CN: PID Low-Pass Filter Gain

| — | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xE5

Bit 7: Unused.

Bits 6–0: A3[6:0]: Low-pass filter gain coefficient bits 6:0. Format is .xxxxxxx

### SFR Definition 17.7. PIDA0CN: PID SINC Filter Gain

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xDD

Bits 7–0: A0[7:0]: SINC filter gain coefficient bits 7:0. Format is .xxxxxxxx

## SFR Definition 17.8. PIDDECCN: SINC Filter Decimation Ratio Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ADCSP2 | DEC6 | DEC5 | DEC4 | DEC3 | DEC2 | DEC1 | DEC0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xDE

Bit7 ADCSP2: in combination with bit ADCSP1 from Register PLLCN<2>, the sampling frequency of ADC1 can be selected. The settings are:

| Bit ADCSP1 in Register PLLCN<2> | Bit ADCSP2 in Register PIDDECCN<7> | ADC1 Sampling Rate |
|---|---|---|
| 0 | 0 | 10 MHz |
| 1 | 0 | 5 MHz |
| 0 | 1 | 2.5 MHz |
| 1 | 1 | 1.25 MHz |

Bits 6–0: DEC[6:0]: Decimation ratio coefficient bits 6:0. Decimation ratio = DEC[6:0] + 1.

### SFR Definition 17.9. PIDCN: PID Filter Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| INTHLDEN | FILTERSEL | PIDINPUT1 | PIDINPUT0 | DITHER2 | DITHER1 | DITHER0 | PIDUN8 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xCE

Bit 7: INTHLDEN: Integrator Hold Enable
0: Integrator unconditionally responds to input changes.
1: Integrator output value holds when an ICYCIRQ occurs.

Bit 6: FILTERSEL: Filter Select Bit
0: Second order low-pass filter selected.
1: SINC filter selected.

Bits 5–4: PIDINPUT[1:0]: PID Filter Input Select Bits
00: PID filter input = ADC1 conversion output.
01: PID filter input = ($V_{REFDAC} - V_{SENSE}$).
10: PID filter input = ground.
11: PID filter input = ADC1 data register.

Bits 3–1: DITHER[2:0]: Dither Amplitude Control
000: Dither disable
001: _ _._ _ _D
010: _ _._ _ D_
011: _ _._ D _ _
100: _ _.D _ _ _
101: _D ._ _ _ _
110: D _._ _ _ _
111: Reserved

Bit 0: PIDUN8: PID Output bit 8

### SFR Definition 17.10. PIDUN: PID Output (u(n)) LSB

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PIDUN7 | PIDUN6 | PIDUN5 | PIDUN4 | PIDUN3 | PIDUN2 | PIDUN1 | PIDUN0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xCF

Bits 7–0: PIDUN[7:0]: PID compensator (PIDUN8 resides at bit 0 of PIDCN)

# 18. ADC0 (12-Bit, Self-Sequencing ADC)

ADC0 consists of a 12-bit, 200 ksps ADC and associated auto-sequencing logic, limit registers, and temperature sensor. Each AMUX channel has a corresponding SFR and hardware limit detector. The limit detectors compare the converted parameter to user-programmed limits and generate a vectored interrupt when these limits are exceeded. ADC0 is equipped with auto-sequencing logic, which completely eliminates the need for system management processor supervision during data conversion. Auto sequencing automates the analog data conversion process and enables system protection functions to be implemented in firmware. When in auto-sequencing mode, ADC0 self-manages AMUX addressing, start-of-conversion, parametric limit tests, and data storage. ADC0 can also be operated in modes typical of Silicon Laboratories' MCUs, including timer or firmware start-of-conversion triggers and firmware-controlled AMUX addressing.

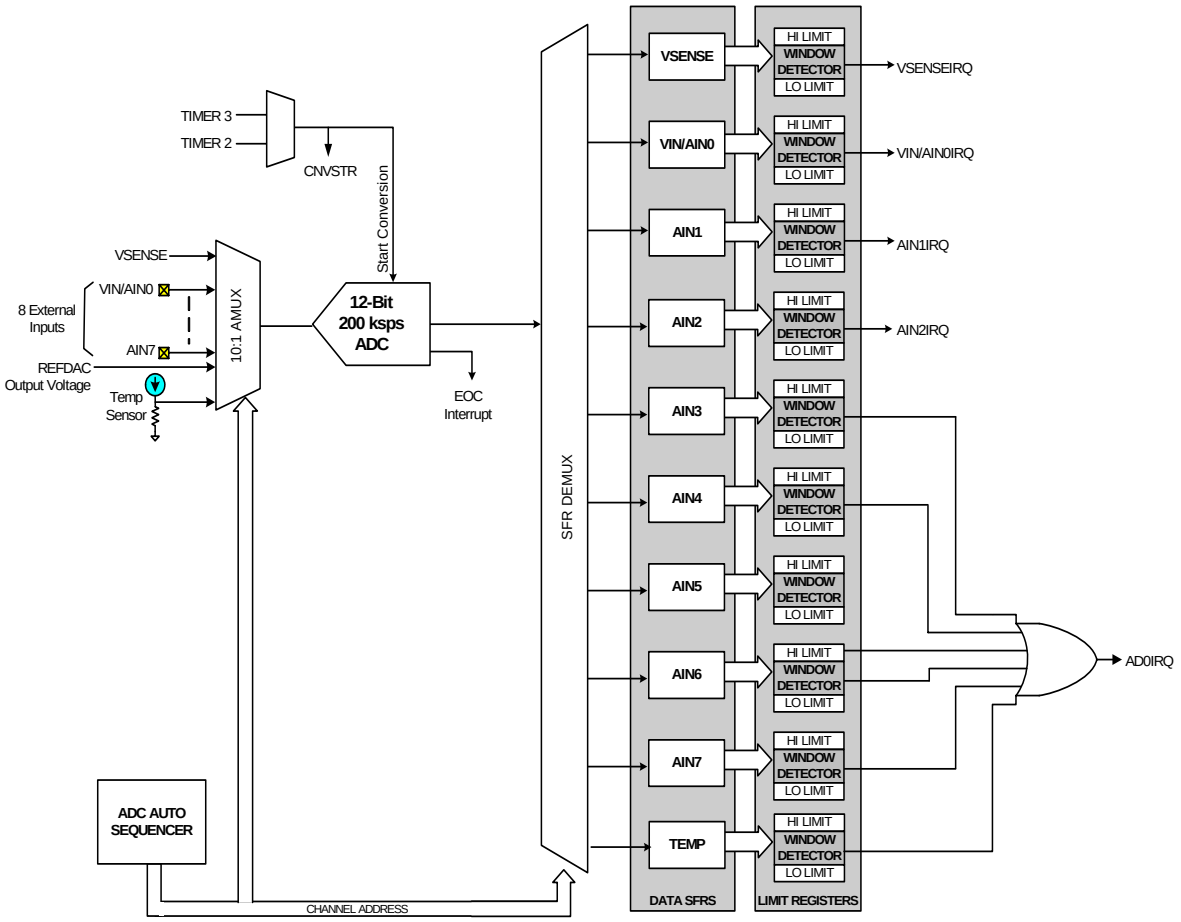


**Figure 18.1. ADC0 Functional Block Diagram**

## 18.1. ADC0 Indirect Addressing

There are many registers used to set up and control ADC0; most of these registers are accessed in indirect SFR space. An indirect ADC0 SFR is accessed by writing the SFR address to ADC0ADDR, then reading or writing the data in ADC0DATA. Note that ADC0AI is the address auto-increment bit; when set to '1', this bit causes ADC0ADDR to increment automatically on each access of ADC0DATA for fast sequential SFR accesses.

## 18.2. Analog Multiplexer (AMUX)

The AD0MX[3:0] bits select the input channel to the ADC. Any of the following may be selected as an input: P1.0–P1.7, the on-chip temperature sensor, ground, the REFDAC output, and the scaled power supply output voltage (VSENSE). ADC0 is single-ended, and all signals measured are with respect to GND. The ADC0 inputs channels are selected using the ADC0MX register as described in the register definition at the end of this chapter.

**Important Note About ADC0 Input Configuration:** Port pins selected as ADC0 inputs should be configured as analog inputs and should be skipped by the Digital Crossbar. To configure a Port pin for analog input, set the corresponding bit in register P1MDIN to “0”. To force the Crossbar to skip a Port pin, set the corresponding bit in register P1SKIP to “1”.

As shown in Figure 18.2, the MUX channel address and the SFR demultiplexer operate in parallel such that the converted result for a given analog input is stored in its associated SFR. As shown, the ADC0ASCN bit selects either the AMUX channel address from either AD0MX or the auto-sequencing logic. This address selects both the AMUX channel and output SFR addresses, ensuring the converted result is stored in its designated SFR and level-checked by the associated limit detector.

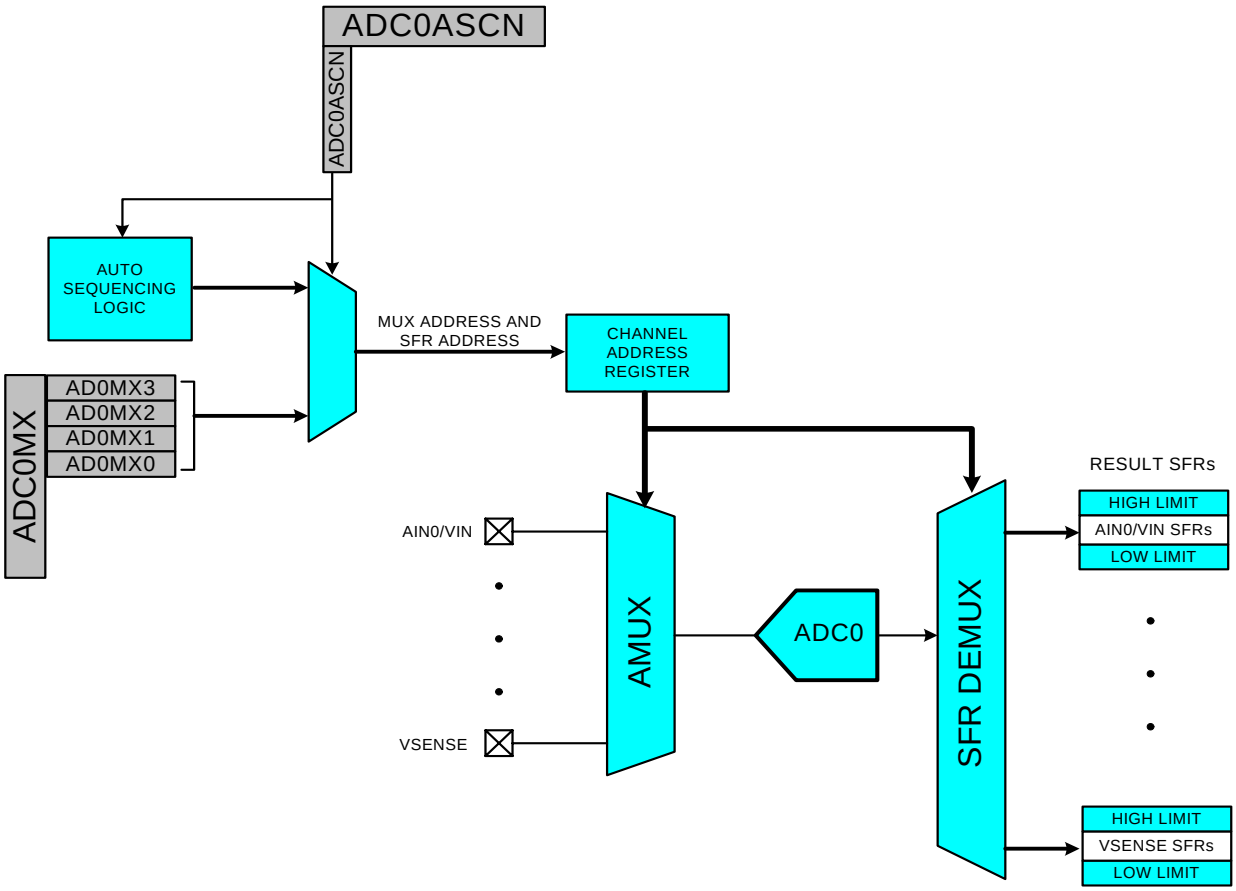


**Figure 18.2. 12-Bit ADC Auto Sequencing Detail**

## 18.3. Temperature Sensor

The typical temperature sensor transfer function is shown in Figure 18.3. The output voltage (VTEMP) is the positive ADC input when the temperature sensor is selected by bits AD0MX[3:0] in register ADC0MX.

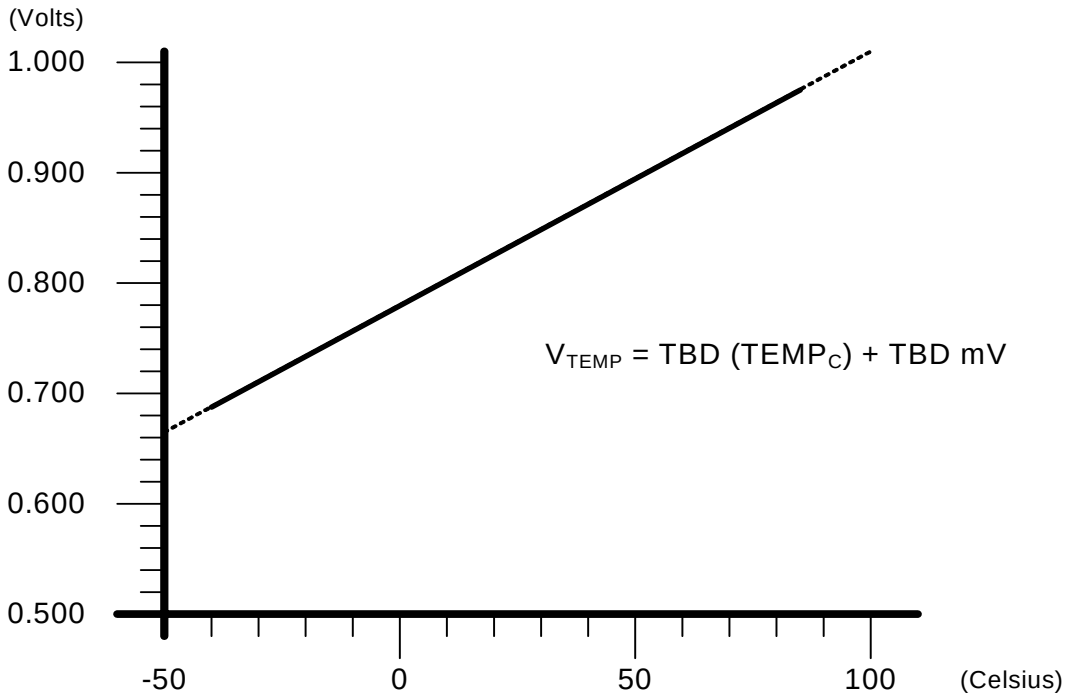


**Figure 18.3. Typical Temperature Sensor Transfer Function**

### 18.3.1. Starting a Conversion

Referring to the Figure 18.4, an ADC0 conversion can be initiated in one of three ways depending on the programmed states of the ADC0 Start of Conversion Mode bits (AD0CM[1:0]) in register ADC0CN. Conversions may be initiated by one of the following:

- Writing a '1' to the AD0BUSY bit of register ADC0CN
- Non-auto-sequencing mode Timer 2 or Timer 3 overflow (timed continuous supervised conversions)
- Auto-Sequencing mode Timer 2 or Timer 3 overflow (timed continuous automatic conversions)

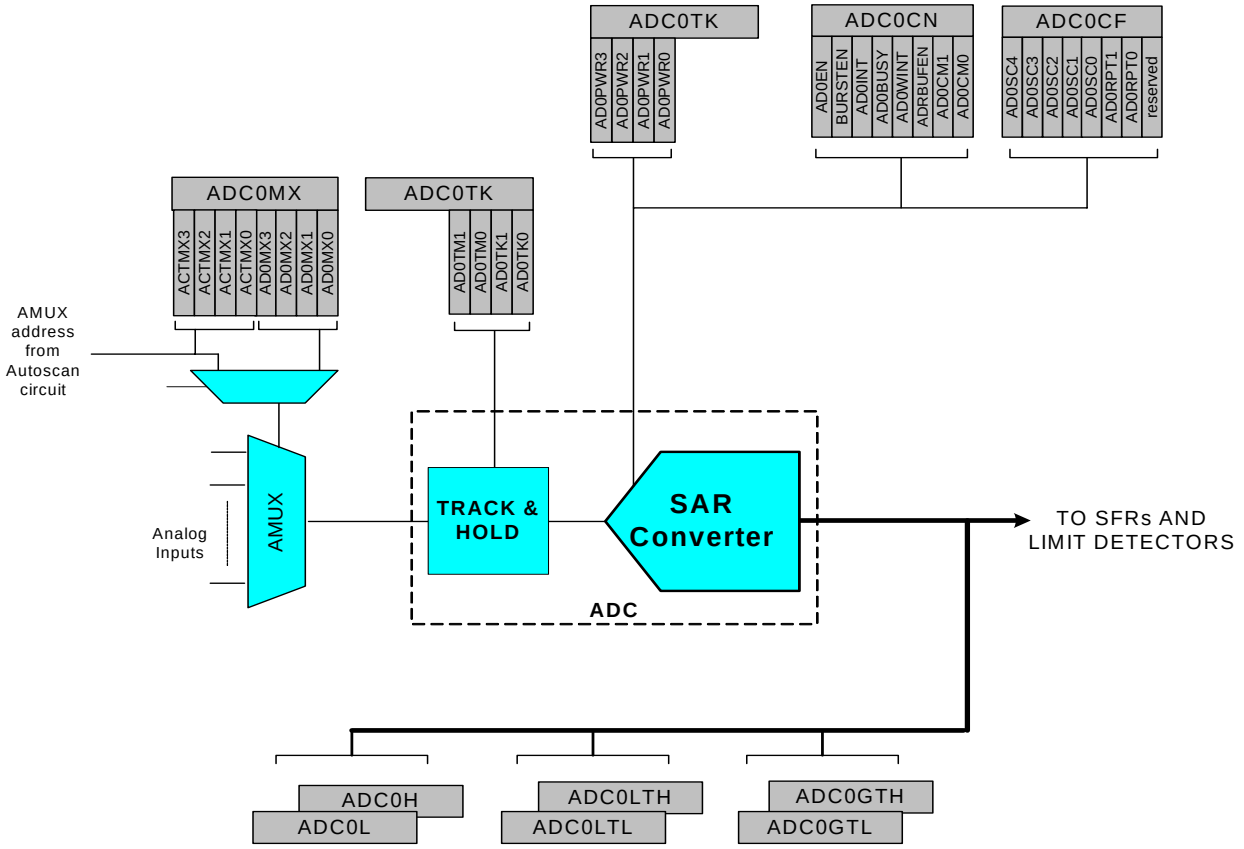


**Figure 18.4. ADC0 Programming Model**

Writing a '1' to AD0BUSY provides software control of ADC0 whereby conversions are performed "on-demand". During conversion, the AD0BUSY bit is set to logic 1 and reset to logic 0 when the conversion is complete. The falling edge of AD0BUSY triggers an interrupt (when enabled) and sets the conversion complete ADC0 interrupt flag (AD0INT).

**Note:** When polling for ADC conversion completions, the ADC0 interrupt flag (AD0INT) should be used. Converted data is available in the ADC0 data registers, ADC0H:ADC0L, when bit AD0INT is logic 1. When Timer 2 or Timer 3 overflows are used as the conversion source, Low Byte overflows are used if Timer 2/3 is in 8-bit mode; High byte overflows are used if Timer 2/3 is in 16-bit mode.

### 18.3.2. Tracking Modes

Each ADC0 conversion must be preceded by a minimum tracking time for the converted result to be accurate. ADC0 has three tracking modes: Pre-Tracking, Post-Tracking, and Dual-Tracking. Pre-Tracking Mode provides the minimum delay between the convert start signal and end of conversion by tracking before the convert start signal. This mode requires software management in order to meet minimum tracking requirements. In Post-Tracking Mode, a programmable tracking time starts after the convert start signal and is managed by hardware. Dual-Tracking Mode maximizes tracking time by tracking before and after the convert start signal. Figure 18.5 shows examples of the three tracking modes.

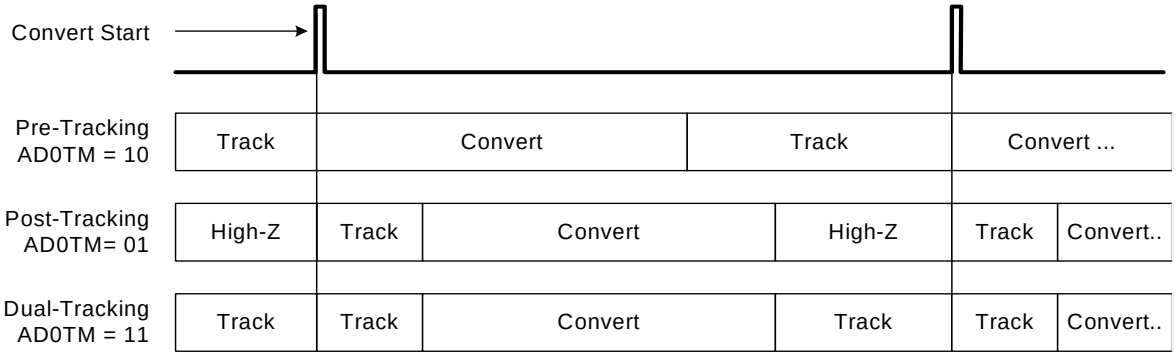


**Figure 18.5. ADC0 Tracking Modes**

Pre-Tracking Mode is selected when AD0TM is set to 00b. Conversions are started immediately following the convert start signal. ADC0 is tracking continuously when not performing a conversion. Software must allow at least the minimum tracking time between each end of conversion and the next convert start signal. The minimum tracking time must also be met after ADC0 is enabled, before the first convert start signal.

Post-Tracking Mode is selected when AD0TM is set to 11b. A programmable tracking time based on AD0TK is started immediately following the convert start signal. Conversions are started after the programmed tracking time ends. After a conversion is complete, ADC0 does not track the input. Rather, the sampling capacitor remains disconnected from the input making the input pin high-impedance until the next convert start signal.

Dual-Tracking Mode is selected when AD0TM is set to 01b. A programmable tracking time based on AD0TK is started immediately following the convert start signal. Conversions are started after the programmed tracking time ends. After a conversion is complete, ADC0 tracks continuously until the next conversion is started.

More tracking time than is specified in the Si8250 Data Sheet may be required after changing MUX settings. See the settling time requirements described in Section “**18.4.1. Settling Time Requirements**” on page **168**.

### 18.3.3. Timing

ADC0 has a maximum conversion speed specified in the Si8250 Data Sheet. ADC0 is clocked from the ADC0 Subsystem Clock ($F_{CLK}$). The source of $F_{CLK}$ is selected based on the BURSTEN bit. When BURSTEN is logic 0, $F_{CLK}$ is derived from the current system clock. When BURSTEN is logic 1, $F_{CLK}$ is derived from the Burst Mode Oscillator, an independent clock source with a maximum frequency of 25 MHz.

When ADC0 is performing a conversion, it requires a clock source that is typically slower than $F_{CLK}$. The ADC0 SAR conversion clock (SAR clock) is a divided version of $F_{CLK}$. The divide ratio can be configured using the AD0SC bits in the AD0CF register. The maximum SAR clock frequency is listed in the Si8250 Data Sheet.

ADC0 can be in one of three states at any given time: tracking, converting, or idle. Tracking time depends on the tracking mode selected. For Pre-Tracking Mode, tracking is managed by software and ADC0 starts conversions immediately following the convert start signal. For Post-Tracking and Dual-Tracking Modes, the tracking time after the convert start signal is equal to the value determined by the AD0TK bits plus 2 $F_{CLK}$ cycles. Tracking is immediately followed by a conversion. The ADC0 conversion time is always 13 SAR clock cycles plus an additional 2 $F_{CLK}$ cycles to start and complete a conversion. Figure 18.6 shows timing diagrams for a conversion in Pre-Tracking Mode and tracking plus conversion in Post-Tracking or Dual-Tracking Mode. In this example, repeat count is set to one.

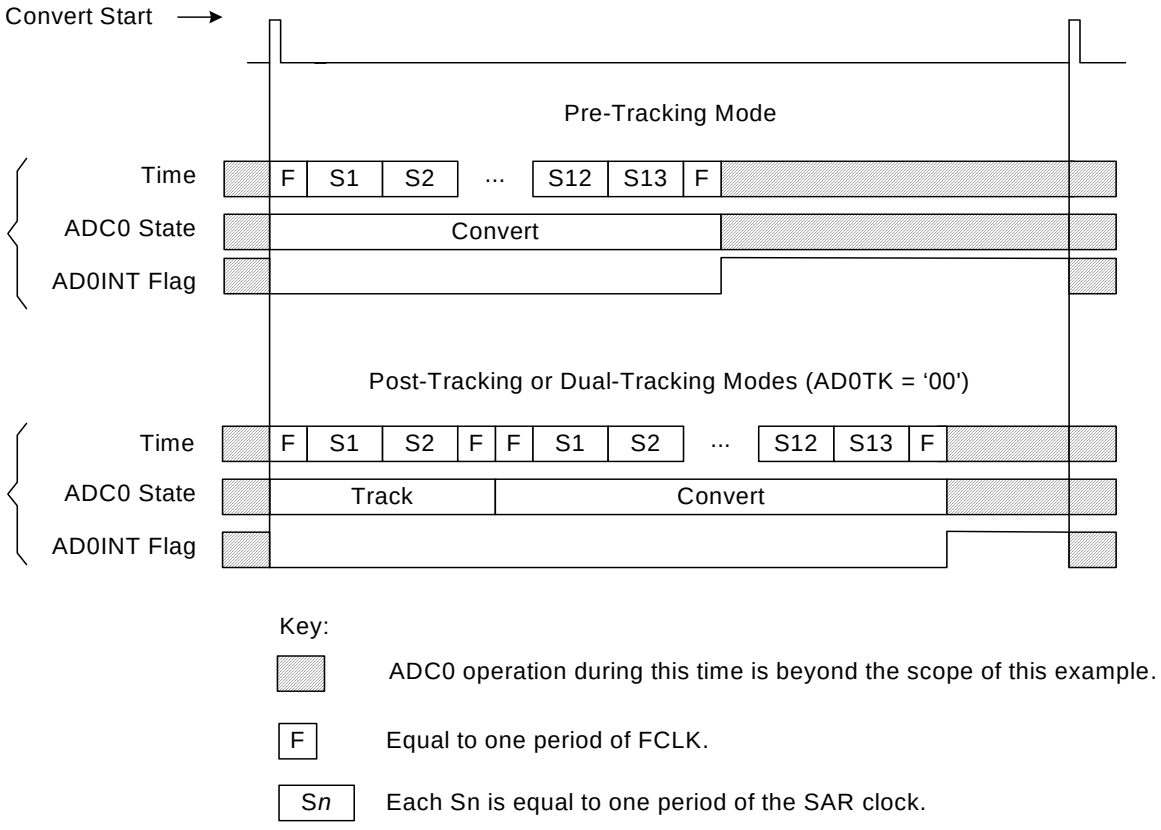


**Figure 18.6. 12-Bit ADC Tracking Mode Example**

### 18.3.4. Burst Mode

Burst Mode is a power saving feature that allows ADC0 to remain in a very low power state between conversions. When Burst Mode is enabled, ADC0 wakes from a very low power state, accumulates 1, 4, 8, or 16 samples using an internal Burst Mode clock (approximately 25 MHz), and then re-enters a very low power state. Since the Burst Mode clock is independent of the system clock, ADC0 can perform multiple conversions then enter a very low power state within a single system clock cycle, if the system clock is slow or suspended.

Burst Mode is enabled by setting BURSTEN to logic 1. When in Burst Mode, AD0EN controls the ADC0 idle power state (i.e., the state ADC0 enters when not tracking or performing conversions). If AD0EN is set to logic 0, ADC0 is powered down after each burst. If AD0EN is set to logic 1, ADC0 remains enabled after each burst. On each convert start signal, ADC0 is awakened from its Idle Power State. If ADC0 is powered down, it will automatically power up and wait the programmable Power-Up Time controlled by the AD0PWR bits. Otherwise, ADC0 will start tracking and converting immediately. Figure 18.7 shows Burst Mode Operation with a slow system clock and a repeat count of 4.

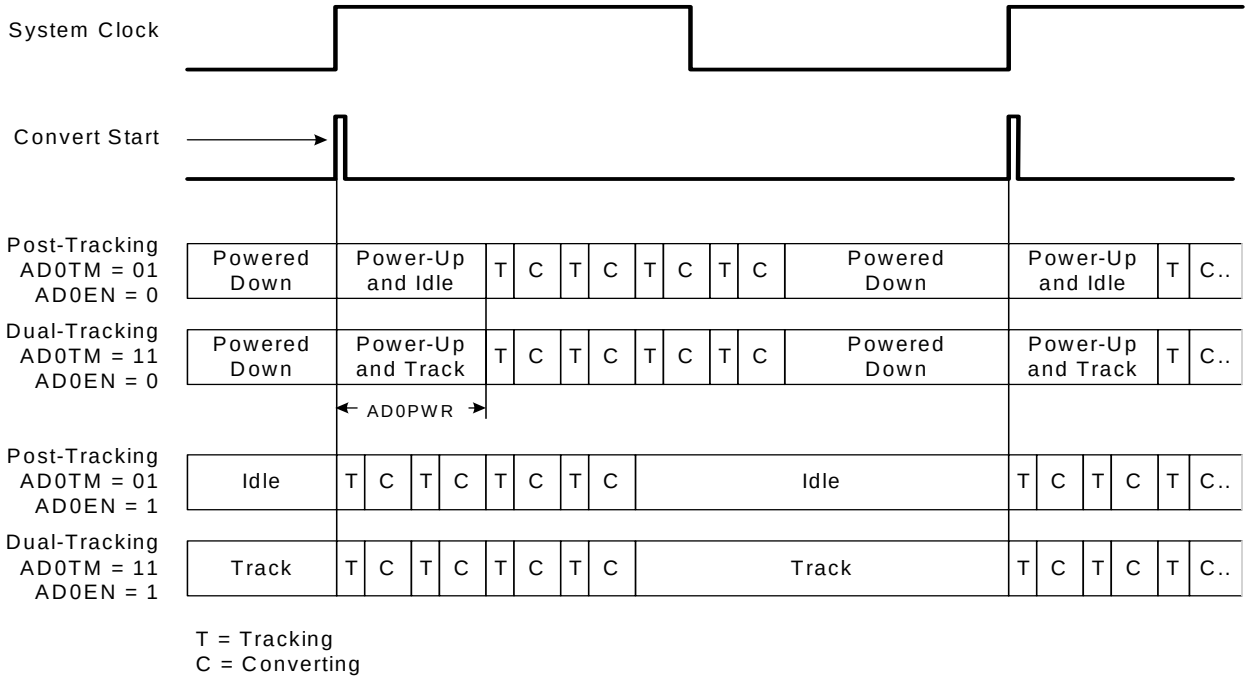


**Figure 18.7. 12-Bit ADC Burst Mode Example with Repeat Count Set to 4**

**Important Note:** When Burst Mode is enabled, only Post-Tracking and Dual-Tracking modes can be used.

When Burst Mode is enabled, a single convert start will initiate a number of conversions equal to the repeat count. When it is disabled, a convert start is required to initiate each conversion. In both modes, the ADC0 End of Conversion Interrupt Flag (AD0INT) will be set after repeat count conversions have been accumulated. Similarly, the Window Comparator will not compare the result to the greater-than and less-than registers until repeat count conversions have been accumulated.

The registers ADC0H and ADC0L contain the high and low bytes of the output conversion code. When the repeat count is set to 1, conversion codes are represented in 12-bit unsigned integer format and the output conversion code is updated after each conversion. Inputs are measured from '0' to VREF x 4095/4096.

Data can be right-justified or left-justified, depending on the setting of the AD0RJST bit (ADC0CN.2). Unused bits in the ADC0H and ADC0L registers are set to '0'. Example codes are shown below for both right-justified and left-justified data.

When the ADC0 Repeat Count is greater than 1, the output conversion code represents the accumulated result of the conversions performed and is updated after the last conversion in the series is finished. The output value can be 14-bit (4 samples), 15-bit (8 samples), or 16-bit (16 samples) in unsigned integer format based on the selected repeat count. The repeat count can be selected using the AD0RPT bits in the ADC0CF register.

When the ADC0 input configuration is changed (i.e., a different AMUX0 selection is made), a minimum tracking time is required before an accurate conversion can be performed. This tracking time is determined by the AMUX0 resistance, the ADC0 sampling capacitance, any external source resistance, and the accuracy required for the conversion.

### 18.3.5. Auto-Sequencing Mode

As shown in Figure 18.8, ADC0 auto-sequencing mode is enabled by setting the ADC0ASCN bit in the ADC0ADDR register to 1 and selecting Timer 2 or Timer 3 as the start-of-conversion trigger. The analog inputs are converted in a sequence specified by the contents of the Timeslot registers (TS01CN, TS23CN, TS45CN, TS67CN), which must be initialized prior to engaging auto-sequencing. When a timer interrupt occurs, the AMUX is sequenced to the next address specified in the timeslot register, the track-and-hold is placed in hold mode, and ADC0 is triggered. At the end of conversion, data is stored in a dedicated SFR where hardware limit detectors compare the data to prescribed upper and lower limits. An interrupt is generated if the data is outside of these limits.

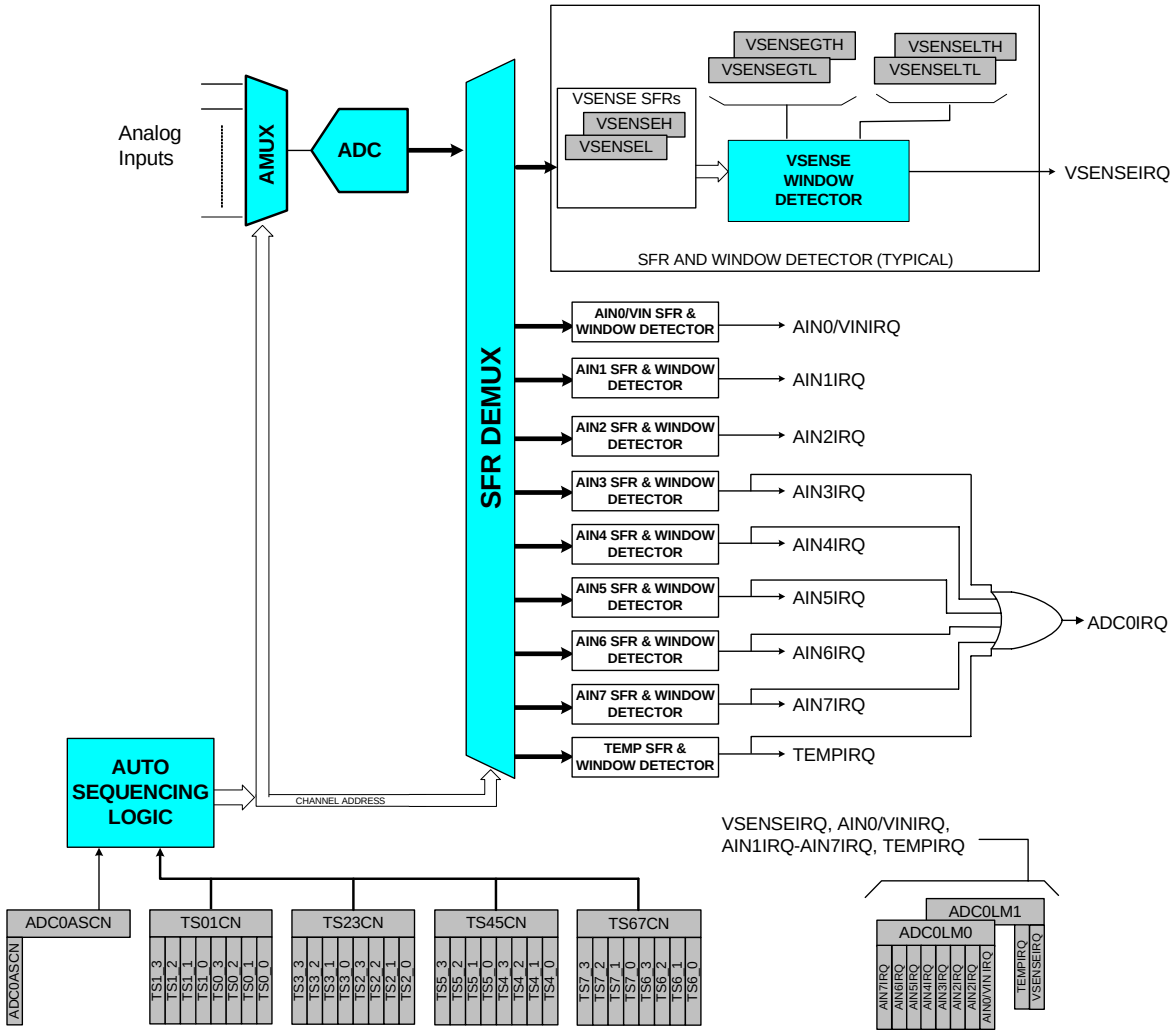


**Figure 18.8. ADC0 Limit Detectors**

**Important Notes about Auto Sequence Mode:**

1. The temperature sensor and REFDAC outputs cannot be read using autoscan mode. These values can only be read while ADC0 is under firmware control.

2. The ADC0 window detector interrupt and ADC0EOL interrupt should be disabled during autose-quencing.

An ADC auto-sequencing frame is composed of eight timeslots, each containing an AMUX address. Any of the analog in (AINn) input channels and VSENSE can be assigned to any timeslot as shown in Figure 18.9.

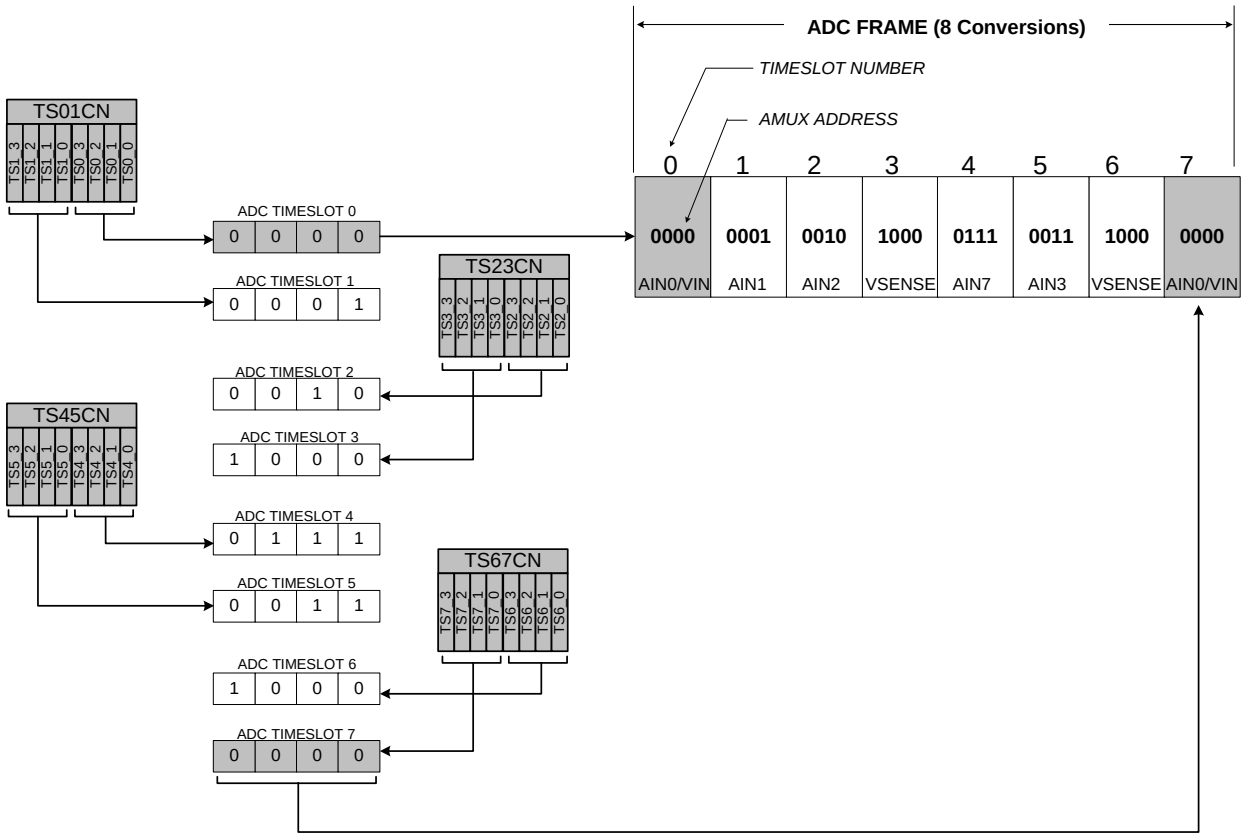


**Figure 18.9. Programming ADC Auto Sequencer Timeslots**

As shown, register TS01CN is the timeslot 0 and timeslot 1 assignment register. The lower nibble of this register contains 0000b, which corresponds to AMUX channel 0 (i.e., AIN0/VIN input). The next nibble of TS01CN contains 0001b corresponding to AIN 1 and so forth. Any given variable can be assigned more than once, effectively increasing the update rate for that variable.

## 18.4. Output Conversion Code

The registers ADC0H and ADC0L (or the AMUX channel-specific SFR in auto-sequencing mode) contain the high and low bytes of the output conversion code. When the repeat count is set to 1, conversion codes are represented in 12-bit unsigned integer format and the output conversion code is updated after each conversion. Inputs are measured from '0' to VREF x 4095/4096. Unused bits in the result registers are set to '0'.

When the ADC0 Repeat Count is greater than 1, the output conversion code represents the accumulated result of the conversions performed and is updated after the last conversion in the series is finished. The output value can be 14-bit (4 samples), 15-bit (8 samples), or 16-bit (16 samples) in unsigned integer for-

mat based on the selected repeat count. The repeat count can be selected using the AD0RPT bits in the ADC0CF register.

### 18.4.1. Settling Time Requirements

When the ADC0 input configuration is changed (i.e., a different AMUX0 selection is made), a minimum tracking time is required before an accurate conversion can be performed. This tracking time is determined by the AMUX0 resistance, the ADC0 sampling capacitance, any external source resistance, and the accuracy required for the conversion. Figure 18.10 shows the equivalent ADC0 input circuit.

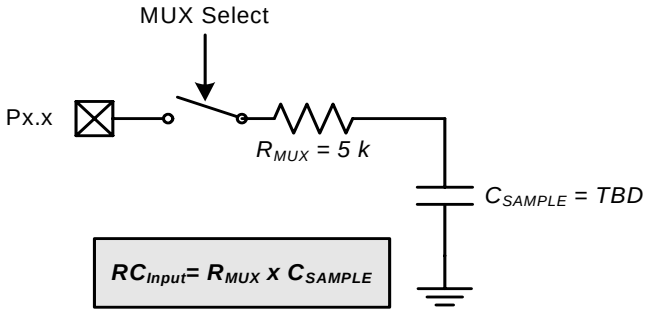


**Figure 18.10. ADC0 Equivalent Input Circuits**

The required ADC0 settling time for a given settling accuracy (SA) may be approximated by Equation 18.1. When measuring the Temperature Sensor output or VDD with respect to GND, RTOTAL reduces to RMUX.

$$t = \ln\left(\frac{2^n}{SA}\right) \times R_{TOTAL} C_{SAMPLE}$$

**Equation 18.1. ADC0 Settling Time Requirements**

Where:

- SA is the settling accuracy, given as a fraction of an LSB (for example, 0.25 to settle within 1/4 LSB).
- t is the required settling time in seconds.
- RTOTAL is the sum of the AMUX0 resistance and any external source resistance.
- n is the ADC resolution in bits (12).

### 18.4.2. ADC0 Operation

In a typical system, ADC0 is configured using the following steps:

Step 1. Initialize auto-sequencing mode timeslot assignments.
Step 2. Choose the start of conversion source.
Step 3. Choose Normal Mode or Burst Mode operation.
Step 4. If Burst Mode, choose the ADC0 Idle Power State and set the Power-Up Time.
Step 5. Choose the tracking mode. Note that Pre-Tracking Mode can only be used with Normal Mode.
Step 6. Calculate required settling time and set the post convert-start tracking time using the AD0TK bits.
Step 7. Choose the repeat count.
Step 8. Enable auto-sequencing mode (if used), enable or disable the End of Conversion and Window Comparator Interrupts.

### 18.4.3. Window Detectors

ADC0 contains a dedicated window detector (for use in software-supervised conversion mode) and ten individual limit detectors for use in autosequencing mode. Each detector operates as described in this section.

Figure 18.11 shows two example window comparisons for data with ADC0LTH:ADC0LTL = 0x0200 (512d) and ADC0GTH:ADC0GTL = 0x0100 (256d). The input voltage can range from '0' to $V_{REF}$ x (4095/4096) with respect to GND, and is represented by a 12-bit unsigned integer value. The repeat count is set to one. In the left example, an interrupt will be generated if the ADC0 conversion word (ADC0H:ADC0L) is within the range defined by measured parameter limit registers (e.g., AINIGTH, GTL and AINILTH, LTL) (if 0x0100 < ADC0H:ADC0L < 0x0200). In the right example, an interrupt will be generated if the ADC0 conversion word is outside of the range defined by the limit registers (if ADC0H:ADC0L < 0x0100 or ADC0H:ADC0L > 0x0200).

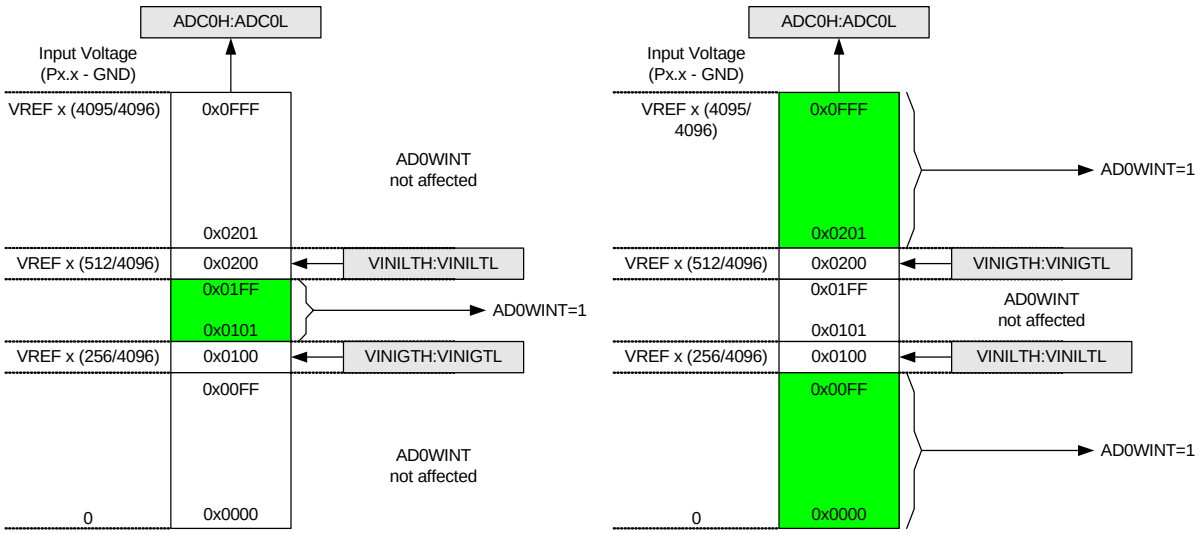


**Figure 18.11. ADC Window Compare Examples**

### SFR Definition 18.1. ADC0MX: ADC0 Channel Select

| R | R | R | R | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ACTMX3 | ACTMX2 | ACTMX1 | ACTMX0 | AD0MX3 | AD0MX2 | AD0MX1 | AD0MX0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xBB

Bits 7–4: ACTMX[3:0]: AMUX status bits
These read-only bits allow the system management processor to read the current AMUX address during auto-sequencing operation. The states of these bits are identical to those of ADC0MX[3:0].

Bits 3-0: AD0MX[3:0]: ADC0 input MUX channel select bits
These bits select ADC0 MUX input channel 0 to 7 when the MUX is not in auto-sequencing mode.
0000: P1.0 or AIN0/VIN
0001: P1.1 or AIN1
0010: P1.2 or AIN2
0011: P1.3 or AIN3
0100: P1.4 or AIN4
0101: P1.5 or AIN5
0110: P1.6 or AIN6
0111: P1.7 or AIN7
1000: VSENSE
1001: GND
1010: GND
1011: GND
1100: GND
1101: GND
1110: Reference DAC
1111: Temperature sensor

### SFR Definition 18.2. ADC0ADDR: ADC0 Indirect Address Pointer

| — | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xAB

Bit 7: Unused.

Bits 6–0: ADC0ADDR[6:0]: Indirect address bits.

### SFR Definition 18.3. ADC0DATA: ADC0 Indirect Data Pointer

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xAC

Bits 7–0: ADC0DATA[7:0]: Indirect SFR data

### SFR Definition 18.4. ADC0STA0: ACD0 SFR Flag Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| AIN7EOC | AIN6EOC | AIN5EOC | AIN4EOC | AIN3EOC | AIN2EOC | AIN1EOC | AIN0VINEOC | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xB5

Bit 7: AIN7EOC: AIN7 Analog Input End of Conversion
0: The data in the AIN7 SFR has not been updated since it was last read.
1: New data is available in the AIN7 SFR.

Bit 6: AIN6EOC: AIN6 Analog Input End of Conversion
0: The data in the AIN6 SFR has not been updated since it was last read.
1: New data is available in the AIN6 SFR.

Bit 5: AIN5EOC: AIN5 Analog Input End of Conversion
0: The data in the AIN5 SFR has not been updated since it was last read.
1: New data is available in the AIN5 SFR.

Bit 4: AIN4EOC: AIN4 Analog Input End of Conversion
0: The data in the AIN4 SFR has not been updated since it was last read.
1: New data is available in the AIN4 SFR.

Bit 3: AIN3EOC: AIN3 Analog Input End of Conversion
0: The data in the AIN3 SFR has not been updated since it was last read.
1: New data is available in the AIN3 SFR.

Bit 2: AIN2EOC: AIN2 Analog Input End of Conversion
0: The data in the AIN2 SFR has not been updated since it was last read.
1: New data is available in the AIN2 SFR.

Bit 1: AIN1EOC: AIN1 Analog Input End of Conversion
0: The data in the AIN1 SFR has not been updated since it was last read.
1: New data is available in the AIN1 SFR.

Bit 0: AIN0VINEOC: AIN0/VIN Analog Input End of Conversion
0: The data in the AIN0/VIN SFR has not been updated since it was last read.
1: New data is available in the AIN0/VIN SFR.

### SFR Definition 18.5. ADC0STA1: ADC0 SFR Flag Register 1

| — | — | — | — | — | — | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | — | — | TEMPEOC | VSENSEEOC | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xBF

Bits 7–2: Unused.

Bit 1: TEMPEOC: Temperature Sensor End of Conversion
0: The data in the Temp Sensor SFR has not been updated since it was last read.
1: New data is available in the Temp Sensor SFR.

Bit 0: VSENSEEOC: VSENSE Analog Input End of Conversion
0: The data in the VSENSE SFR has not been updated since it was last read.
1: New data is available in the VSENSE SFR.

### SFR Definition 18.6. ADC0CF: ADC0 Configuration

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | — | Reset Value |
|---|---|---|---|---|---|---|---|---|
| AD0SC4 | AD0SC3 | AD0SC2 | AD0SC1 | AD0SC0 | AD0RPT1 | AD0RPT0 | reserved | 11111000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xBC

Bits 7–3: AD0SC[4:0]: ADC0 SAR Conversion Clock Period Bits
SAR conversion clock is derived from $F_{CLK}$ by the following equation, where ADC0SC refers to the 5-bit value held in ADC0SC[4:0]: ADC0SC = ($F_{CLK}$/CLKSAR) – 1.

Bits 2–1: AD0RPT[1:0]: ADC0 Repeat Count
00: 1 conversion is performed.
01: 4 conversions are performed and accumulated.
10: 8 conversions are performed and accumulated.
11: 16 conversions are performed and accumulated.

Bit 0: Reserved; must be maintained ‘0’.

## SFR Definition 18.7. ADC0CN: ADC0 Control

| R/W | R/W | R | R/W | R | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| AD0EN | BURSTEN | AD0INT | AD0BUSY | AD0WINT | AD0RBUFEN | AD0CM1 | AD0CM0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xE8

Bit 7: AD0EN: ADC0 Enable bit
0: ADC0 disabled and in low-power shutdown.
1: ADC0 enabled and ready for data conversions.

Bit 6: BURSTEN: ADC0 Burst Mode Enable Bit
0: ADC0 burst mode disabled.
1: ADC0 burst mode enabled.

Bit 5: AD0INT: ADC0 Conversion Complete Flag
0: ADC0 has not completed a data conversion since the last time ADC0INT was cleared.
1: ADC0 has completed a data conversion.

Bit 4: AD0BUSY:
READ:
0: ADC0 conversion is complete or a conversion is not in progress. Note that ADC0INT is set to logic ‘1’ on the falling edge of AD0BUSY.
1: ADC0 conversion is in progress.
WRITE:
0: No effect.
1: Initiates AD0 conversion if ADC0CM[1:0] = 00b; otherwise, no effect.

Bit 3: AD0WINT: ADC0 Window Interrupt
0: ADC0 window interrupt not active.
1: ADC0 window interrupt asserted.

Bit 2: AD0RBUFEN: ADC0 SAR Buffer Enable Bit
0: ADC0 SAR buffer disabled.
1: ADC0 SAR buffer enabled.

Bits 1–0: AD0CM[1:0]
00: AD0 conversion initiated on every write of ‘1’ to ADC0BUSY.
01: AD0 conversion initiated on overflow of Timer 3.
10: Reserved.
11: Timer 2 - If split, T2 low, else high.

## SFR Definition 18.8. ADC0TK: ADC0 Tracking Mode

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| AD0PWR3 | AD0PWR2 | AD0PWR1 | AD0PWR0 | AD0TM1 | AD0TM0 | AD0TK1 | AD0TK0 | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xBA

Bits 7–4: AD0PWR[3:0]: ADC0 Burst Mode Power-up Time
For BURSTEN = 0: ADC0 power state controlled by ADC0EN.
For BURSTEN = 1 and ADC0EN = 1: ADC0 remains enabled and does not enter the low power state.
For BURSTEN = 1 and ADC0EN = 0: ADC0 enters the low power state and is enabled after each start-of-conversion. The power-up time is programmed according to the following equation: ADC0PWR = (TSTARTUP/200 ns) – 1.

Bits 3–2: AD0TM[1:0]: ADC0 Tracking Mode Bits
00: Reserved.
01: ADC0 is configured to Post-Tracking Mode.
10: ADC0 is configured to Pre-Tracking Mode.
11: ADC0 is configured to Dual-Tracking Mode.

Bits 1–0: AD0TK[1:0]: ADC0 Post-Track Time
00: Post-Tracking time is equal to 2 SAR clock cycles + 2 $F_{CLK}$ cycles.
01: Post-Tracking time is equal to 4 SAR clock cycles + 2 $F_{CLK}$ cycles.
10: Post-Tracking time is equal to 8 SAR clock cycles + 2 $F_{CLK}$ cycles.
11: Post-Tracking time is equal to 16 SAR clock cycles + 2 $F_{CLK}$ cycles.

## SFR Definition 18.9. ADC0LM0: ADC0 Analog Channel Limit Interrupt Flag Register 0

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| AIN7IRQ | AIN6IRQ | AIN5IRQ | AIN4IRQ | AIN3IRQ | AIN2IRQ | AIN1IRQ | AIN0VINIRQ | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xC7

Bit 7: AIN7IRQ: Analog Input 7 Limit Interrupt
0: Analog input AIN7 is within programmed limits - interrupt not asserted.
1: Analog input AIN7 is outside programmed limits - interrupt asserted.

Bit 6: AIN6IRQ: Analog Input 6 Limit Interrupt
0: Analog input AIN6 is within programmed limits - interrupt not asserted.
1: Analog input AIN6 is outside programmed limits - interrupt asserted.

Bit 5: AIN5IRQ: Analog Input 5 Limit Interrupt
0: Analog input AIN5 is within programmed limits - interrupt not asserted.
1: Analog input AIN5 is outside programmed limits - interrupt asserted.

Bit 4: AIN4IRQ: Analog Input 4 Limit Interrupt
0: Analog input AIN4 is within programmed limits - interrupt not asserted.
1: Analog input AIN4 is outside programmed limits - interrupt asserted.

Bit 3: AIN3IRQ: Analog Input 3 Limit Interrupt
0: Analog input AIN3 is within programmed limits - interrupt not asserted.
1: Analog input AIN3 is outside programmed limits - interrupt asserted.

Bit 2: AIN2IRQ: Analog Input 2 Limit Interrupt
0: Analog input AIN2 is within programmed limits - interrupt not asserted.
1: Analog input AIN2 is outside programmed limits - interrupt asserted.

Bit 1: AIN1IRQ: Analog Input 1 Limit Interrupt
0: Analog input AIN1 is within programmed limits - interrupt not asserted.
1: Analog input AIN1 is outside programmed limits - interrupt asserted.

Bit 0: AIN0VINIRQ: Analog Input 0/VIN Limit Interrupt
0: Analog input AIN0/VIN is within programmed limits - interrupt not asserted.
1: Analog input AIN0/VIN is outside programmed limits - interrupt asserted.

### SFR Definition 18.10. ADC0LM1: ADC0 Analog Channel Limit Interrupt Flag Register 1

| — | — | — | — | — | — | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | — | — | TEMPIRQ | VSENSEIRQ | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xC9

Bits 7–2: Unused.

Bit 1: TEMPIRQ: Temperature Sensor High Limit Interrupt
0: Measured temperature is within programmed limits—interrupt not asserted.
1: Measured temperature is outside programmed limits—interrupt asserted.

Bit 0: VSENSEIRQ: VSENSE limit interrupt
0: VSENSE is within programmed limits—interrupt not asserted.
1: VSENSE is outside programmed limits—interrupt asserted.

### SFR Definition 18.11. ADC0H: ADC0 High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xBE

Bits 7–4: Unused.

Bits 3–0: ADC0[11:8]: ADC0 high byte output data.

### SFR Definition 18.12. ADC0L: ADC0 Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xBD

Bits 7–0: ADC0[7:0]: ADC0 low byte output data.

### SFR Definition 18.13. ADC0GTH: ADC0 High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xC4

Bits 7–4: Unused.

Bits 3–0: ADC0GTH[11:8]: ADC0 High limit detector high byte.

### SFR Definition 18.14. ADC0GTL: ADC0 High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xC3

Bits 7–0: ADC0GTL[7:0]: ADC0 High limit detector low byte.

### SFR Definition 18.15. ADC0LTH: ADC0 Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xC6

Bits 7–4: Unused.

Bits 3–0: ADC0LTH[11:8]: ADC0 low limit detector high byte.

### SFR Definition 18.16. ADC0LTL: ADC0 Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit7 | Bit6 | Bit5 | Bit4 | Bit3 | Bit2 | Bit1 | Bit0 | |

SFR Address: 0xC5

Bits 7–0: ADC0LTL[7:0]: ADC0 low limit detector low byte.

### SFR Definition 18.17. TS01CN: ADC0 Timeslot 0 and 1 Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TS1_3 | TS1_2 | TS1_1 | TS1_0 | TS2_3 | TS0_2 | TS0_1 | TS0_0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x00

Bits 7–4: TS1[3:0]: Timeslot 1 assignment bits: this binary code specifies the AMUX input channel to be converted in timeslot 1.

Bits 3–0: TS0[3:0]: Timeslot 0 assignment bits: this binary code specifies the AMUX input channel to be converted in timeslot 0.

### SFR Definition 18.18. TS23CN: ADC0 Timeslot 2 and 3 Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TS3_3 | TS3_2 | TS3_1 | TS3_0 | TS2_3 | TS2_2 | TS2_1 | TS2_0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x01

Bits 7–4: TS3[3:0]: Timeslot 3 assignment bits: this binary code specifies the AMUX input channel to be converted in timeslot 3.

Bits 3–0: TS2[3:0]: Timeslot 2 assignment bits: this binary code specifies the AMUX input channel to be converted in timeslot 2.

### SFR Definition 18.19. TS45CN: ADC0 Timeslot 4 and 5 Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TS5_3 | TS5_2 | TS5_1 | TS5_0 | TS4_3 | TS4_2 | TS4_1 | TS4_0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bi t2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x02

Bits 7–4: TS5[3:0]: Timeslot 5 assignment bits: this binary code specifies the AMUX input channel to be converted in timeslot 5.

Bits 3–0: TS4[3:0]: Timeslot 4 assignment bits: this binary code specifies the AMUX input channel to be converted in timeslot 4.

### SFR Definition 18.20. TS67CN: ADC0 Timeslot 6 and 7 Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TS7_3 | TS7_2 | TS7_1 | TS7_0 | TS6_3 | TS6_2 | TS6_1 | TS6_0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x03

Bits 7–4: TS7[3:0]: Timeslot 7 assignment bits: this binary code specifies the AMUX input channel to be converted in timeslot 7.

Bits 3–0: TS6[3:0]: Timeslot 6 assignment bits: this binary code specifies the AMUX input channel to be converted in timeslot 6.

### SFR Definition 18.21. VSENSEH: Power Supply Output Voltage High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | VSENSE11 | VSENSE10 | VSENSE9 | VSENSE8 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x04

Bits 7–4: Unused

Bits 3–0: VSENSE[11:8]: Power supply output voltage high byte data.

### SFR Definition 18.22. VSENSEL: Power Supply Output Voltage Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x05

Bits 7–0: VSENSE[7:0]: Power supply output voltage low byte data.

### SFR Definition 18.23. VSENSEGTH: $V_{SENSE}$ High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x06

Bits 7–4: Unused.

Bits 3–0: VSENSEGTH[11:8]: $V_{SENSE}$ high limit detector high byte data.

### SFR Definition 18.24. VSENSEGTL: $V_{SENSE}$ High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x07

Bits7–0: VSENSEGTL[7:0]: $V_{SENSE}$ high limit detector low byte data.

### SFR Definition 18.25. VSENSELTH: $V_{SENSE}$ Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x08

Bits 7–4: Unused.

Bits 3–0: VSENSELTH [11:8]: $V_{SENSE}$ low limit detector high byte data.

### SFR Definition 18.26. VSENSELTL: $V_{SENSE}$ Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x09

Bits 7–0: VSENSELTL[7:0]: $V_{SENSE}$ low limit detector low byte data.

### SFR Definition 18.27. AIN0/VINH: AIN0/Power Supply Input Voltage High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0A

Bits 7–4: Unused.

Bits 3–0: AIN0/VIN [11:8]: Power supply Input voltage high byte data.

### SFR Definition 18.28. AIN0/VINL: AIN0/Power Supply Input Voltage Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0B

Bits 7–0: AIN0/VIN [7:0]: Power supply Input voltage low byte data.

### SFR Definition 18.29. AIN0/VINGTH: AIN0/VIN High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0C

Bits 7–4: Unused.

Bits 3–0: AIN0/VINGTH [11:8]: AIN0/VIN high limit detector high byte data.

### SFR Definition 18.30. AIN0/VINGTL: AIN0/VIN High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0D

Bits 7–0: AIN0/VINGTL[7:0]: AIN0/VIN high limit detector low byte data.

### SFR Definition 18.31. AIN0/VINLTH: AIN0/VIN Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0E

Bits 7–4: Unused.

Bits 3–0: AIN0/VINLTH [11:8]: AIN0/VIN low limit detector high byte data.

### SFR Definition 18.32. AIN0/VINLTL: AIN0/VIN Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x0F

Bits 7–0: AIN0/VINLTL[7:0]: AIN0/VIN low limit detector low byte data.

### SFR Definition 18.33. AIN1H: ADC0 MUX Channel 1 High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x10

Bits 7–4: Unused.

Bits 3–0: AIN1[11:8]: Power supply input voltage high byte data.

### SFR Definition 18.34. AIN1L: ADC0 MUX Channel 1 Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x11

Bits 7–0: AIN1[7:0]: Power supply input voltage low byte data.

### SFR Definition 18.35. AIN1GTH: AIN1 High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x12

Bits 7–4: Unused.

Bits 3–0: AIN1GTH [11:8]: AIN1 high limit detector high byte data.

### SFR Definition 18.36. AIN1GTL: AIN1 High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x13

Bits 7–0: AIN1GTL[7:0]: AIN1 high limit detector low byte data.

### SFR Definition 18.37. AIN1LTH: AIN1 Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x14

Bits 7–4: Unused.

Bits 3–0: AIN1LTH[11:8]: AIN1 low limit detector high byte data.

### SFR Definition 18.38. AIN1LTL: AIN1 Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x15

Bits 7–0: AIN1LTL[7:0]: AIN1 low limit detector low byte data.

### SFR Definition 18.39. AIN2H: ADC0 MUX Channel 2 High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x16

Bits 7–4: Unused.

Bits 3–0: AIN2 [11:8]: Power supply input voltage high byte data.

### SFR Definition 18.40. AIN2L: ADC0 MUX Channel 2 Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x17

Bits 7–0: AIN2[7:0]: Power supply input voltage low byte data.

### SFR Definition 18.41. AIN2GTH: AIN2 High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x18

Bits 7–4: Unused.

Bits 3–0: AIN2GTH[11:8]: AIN2 high limit detector high byte data.

### SFR Definition 18.42. AIN2GTL: AIN2 High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x19

Bits 7–0: AIN2GTL[7:0]: AIN2 high limit detector low byte data.

### SFR Definition 18.43. AIN2LTH: AIN2 Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1A

Bits 7–4: Unused.

Bits 3–0: AIN2LTH[11:8]: AIN2 low limit detector high byte data.

### SFR Definition 18.44. AIN2LTL: AIN2 Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1B

Bits 7–0: AIN2LTL[7:0]: AIN2 low limit detector low byte data.

### SFR Definition 18.45. AIN3H: ADC0 MUX Channel 3 High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1C

Bits 7–4: Unused.

Bits 3–0: AIN3[11:8]: Power supply input voltage high byte data.

### SFR Definition 18.46. AIN3L: ADC0 MUX Channel 3 Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1D

Bits 7–0: AIN3[7:0]: Power supply input voltage low byte data.

### SFR Definition 18.47. AIN3GTH: AIN3 High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1E

Bits 7–4: Unused.

Bits 3–0: AIN3GTH[11:8]: AIN3 high limit detector high byte data.

### SFR Definition 18.48. AIN3GTL: AIN3 High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x1F

Bits 7–0: AIN3GTL[7:0]: AIN3 high limit detector low byte data.

### SFR Definition 18.49. AIN3LTH: AIN3 Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x20

Bits 7–4: Unused.

Bits 3–0: AIN3LTH[11:8]: AIN3 low limit detector high byte data.

### SFR Definition 18.50. AIN3LTL: AIN3 Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x21

Bits 7–0: AIN3LTL[7:0]: AIN3 low limit detector low byte data.

### SFR Definition 18.51. AIN4H: ADC0 MUX Channel 4 High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x22

Bits 7–4: Unused.

Bits 3–0: AIN4[11:8]: Power supply input voltage high byte data.

### SFR Definition 18.52. AIN4L: ADC0 MUX Channel 4 Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x23

Bits 7–0: AIN4[7:0]: Power supply input voltage low byte data.

### SFR Definition 18.53. AIN4GTH: AIN4 High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x24

Bits 7–4: Unused.

Bits 3–0: AIN4GTH[11:8]: AIN4 high limit detector high byte data.

### SFR Definition 18.54. AIN4GTL: AIN4 High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x25

Bits 7–0: AIN4GTL[7:0]: AIN4 high limit detector low byte data.

### SFR Definition 18.55. AIN4LTH: AIN4 Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x26

Bits 7–4: Unused.

Bits 3–0: AIN4LTH[11:8]: AIN4 low limit detector high byte data.

### SFR Definition 18.56. AIN4LTL: AIN4 Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x27

Bits 7–0: AIN4LTL[7:0]: AIN4 low limit detector low byte data.

### SFR Definition 18.57. AIN5H: ADC0 MUX Channel 5 High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x28

Bits 7–4: Unused.

Bits 3–0: AIN5[11:8]: Power supply input voltage high byte data.

### SFR Definition 18.58. AIN5L: ADC0 MUX Channel 5 Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x29

Bits 7–0: AIN5[7:0]: Power supply input voltage low byte data.

### SFR Definition 18.59. AIN5GTH: AIN5 High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x2A

Bits 7–4: Unused.

Bits 3–0: AIN5GTH[11:8]: AIN5 high limit detector high byte data.

### SFR Definition 18.60. AIN5GTL: AIN5 High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x2B

Bits 7–0: AIN5GTL[7:0]: AIN5 high limit detector low byte data.

### SFR Definition 18.61. AIN5LTH: AIN5 Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x2C

Bits 7–4: Unused.

Bits 3–0: AIN5LTH[11:8]: AIN5 low limit detector high byte data.

### SFR Definition 18.62. AIN5LTL: AIN5 Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x2D

Bits 7–0: AIN5LTL[7:0]: AIN5 low limit detector low byte data.

### SFR Definition 18.63. AIN6H: ADC0 MUX Channel 6 High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x2E

Bits 7–4: Unused.

Bits 3–0: AIN6[11:8]: Power supply input voltage high byte data.

### SFR Definition 18.64. AIN6L: ADC0 MUX Channel 6 Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x2F

Bits 7–0: AIN6[7:0]: Power supply input voltage low byte data.

### SFR Definition 18.65. AIN6GTH: AIN6 High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x30

Bits 7–4: Unused.

Bits 3–0: AIN6GTH[11:8]: AIN6 high limit detector high byte data.

### SFR Definition 18.66. AIN6GTL: AIN6 High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x31

Bits 7–0: AIN6GTL[7:0]: AIN6 high limit detector low byte data.

### SFR Definition 18.67. AIN6LTH: AIN6 Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x32

Bits 7–4: Unused.

Bits 3–0: AIN6LTH[11:8]: AIN6 low limit detector high byte data.

### SFR Definition 18.68. AIN6LTL: AIN6 Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x33

Bits 7–0: AIN6LTL[7:0]: AIN6 low limit detector low byte data.

### SFR Definition 18.69. AIN7H: ADC0 MUX Channel 7 High Byte Data

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x34

Bits 7–4: Unused.

Bits 3–0: AIN7[11:8]: Power supply input voltage high byte data.

### SFR Definition 18.70. AIN7L: ADC0 MUX Channel 7 Low Byte Data

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x35

Bits 7–0: AIN6LTL[7:0]: AIN7 voltage low byte data.

### SFR Definition 18.71. AIN7GTH: AIN7 High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x36

Bits 7–4: Unused.

Bits 3–0: AIN7GTH[11:8]: AIN7 high limit detector high byte data.

### SFR Definition 18.72. AIN7GTL: AIN7 High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x37

Bits 7–0: AIN7GTL[7:0]: AIN7 high limit detector low byte data.

### SFR Definition 18.73. AIN7LTH: AIN7 Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x38

Bits 7–4: Unused.

Bits 3–0: AIN7LTH[11:8]: AIN7 low limit detector high byte data.

### SFR Definition 18.74. AIN7LTL: AIN7 Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x39

Bits 7–0: AIN7LTL[7:0]: AIN7 low limit detector low byte data.

### SFR Definition 18.75. TEMPH: Temp Sensor High Byte Data Register

| — | — | — | — | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x3A

Bits 7–4: Unused.

Bits 3–0: TEMPH[11:8]: Temp sensor high byte data.

### SFR Definition 18.76. TEMPL: Temp Sensor Low Byte Data Register

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x3B

Bits 7–0: TEMPL[7:0]: Temp sensor low byte data.

### SFR Definition 18.77. TEMPGTH: Temp Sensor High Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00001111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x3C

Bits 7–4: Unused.

Bits 3–0: TEMPGTH[11:8]: Temp sensor high limit detector high byte data.

### SFR Definition 18.78. TEMPGTL: Temp Sensor High Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x3D

Bits 7–0: TEMPGTL[7:0]: Temp sensor high limit detector low byte data.

### SFR Definition 18.79. TEMPLTH: Temp Sensor Low Limit Detector High Byte

| — | — | — | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x3E

Bits 7–4: Unused.

Bits 3–0: TEMPLTH[11:8]: Temp sensor low limit detector high byte data.

### SFR Definition 18.80. TEMPLTL: Temp Sensor Low Limit Detector Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x3F

Bits 7–0: TEMPLTL[7:0]: Temp sensor low limit detector low byte data.

### SFR Definition 18.81. ADC0ASCN: ADC0 Auto Sequencing Control

| R | R/W | — | — | — | — | — | — | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ADC0ASCN | ADC0AI | — | — | — | — | — | — | 01000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address (indirect): 0x40

Bit 7: ADC0ASCN: ADC0 Auto Sequencing Enable Bit
0: Auto sequencing disabled.
1: Auto sequencing enabled.

Bit 6: ADC0AI: ADC0 Indirect Register Pointer Auto-Increment Enable
0: Auto-increment disabled—SFR address pointer does not increment after SFR access.
1: Auto-increment enabled—SFR pointer automatically increments after SFR access.

Bits 5–0: Unused.

## 19. Port Input/Output

Internal resources are available through 16 I/O pins. Port pins are organized as two byte-wide Ports. Each of the Port pins can be defined as general-purpose I/O (GPIO); Port pins P0.0–P1.7 can be assigned to the internal digital resources as shown below. The designer has complete control over which functions are assigned, limited only by the number of physical I/O pins. This resource assignment flexibility is achieved through the use of a Priority Crossbar Decoder. Note that the state of a Port I/O pin can always be read in the corresponding Port latch, regardless of the Crossbar settings. The Crossbar assigns the selected internal digital resources to the I/O pins based on the Priority Decoder. Registers XBAR0 and XBAR1 are used to select internal digital functions. Analog functions can be assigned to P1.0–P1.7 only. Port 0 pins are 5 V tolerant over the operating range of $V_{DD}$ when configured as open-drain. The Port I/O cells are configured as either push-pull or open-drain in the Port Output Mode registers (Registers P0MDOUT and P1MDOUT).

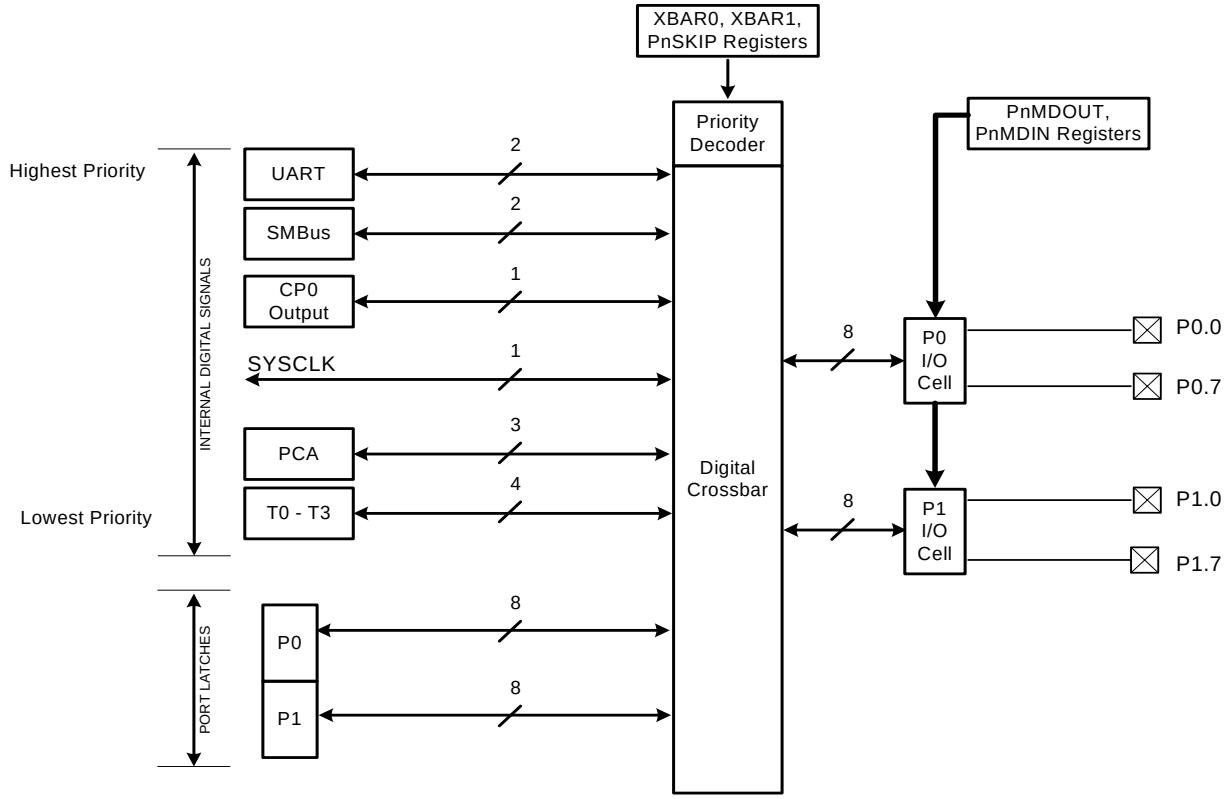


**Figure 19.1. Port I/O Functional Block Diagram**

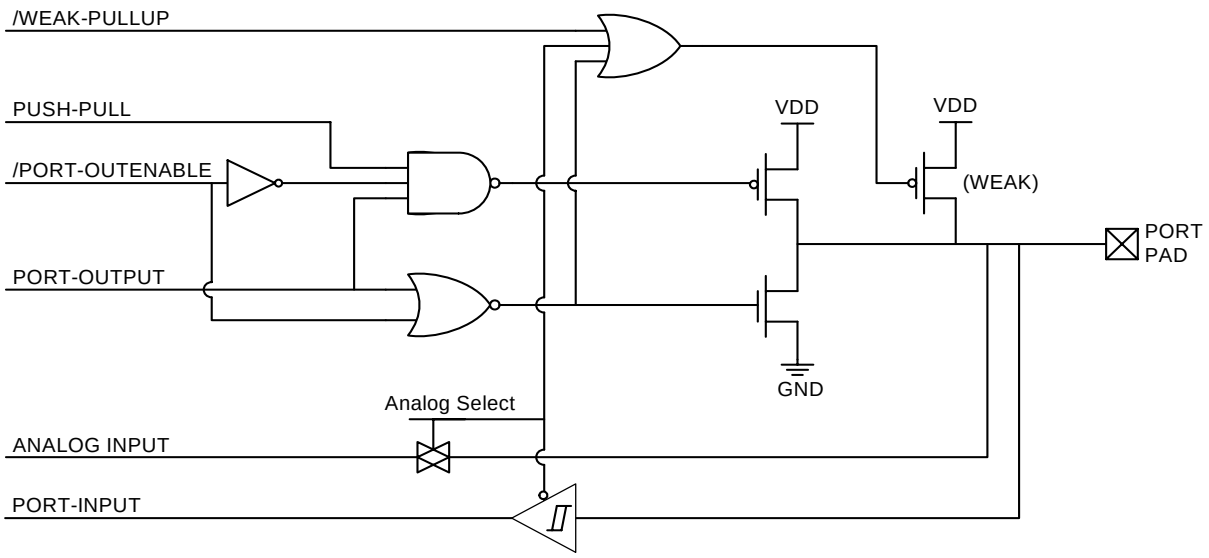


**Figure 19.2. Port I/O Cell Block Diagram**

## 19.1. Priority Crossbar Decoder

The Priority Crossbar Decoder assigns a priority to each I/O function, starting at the top with UART0. When a digital resource is selected, the least-significant unassigned Port pin is assigned to that resource (excluding UART0, which will be assigned to pins P0.4 and P0.5). If a Port pin is assigned, the Crossbar skips that pin when assigning the next selected resource. Additionally, the Crossbar will skip Port pins whose associated bits in the PnSKIP registers are set. The PnSKIP registers allow software to skip Port pins that are to be used for analog input (Port 1 only), dedicated functions, or GPIO.

**Important Note on Crossbar Configuration:** If a Port pin is claimed by a peripheral without use of the Crossbar, its corresponding PnSKIP bit should be set. This applies to any selected ADC or comparator inputs. The Crossbar skips selected pins as if they were already assigned, and moves to the next unassigned pin. Figure 19.3 shows the Crossbar Decoder priority with no Port pins skipped (P0SKIP, P1SKIP = 0x00); Figure 19.4 shows the Crossbar Decoder priority with the XTAL1 (P1.0) and XTAL2 (P1.1) pins skipped (P1SKIP = 0x03).

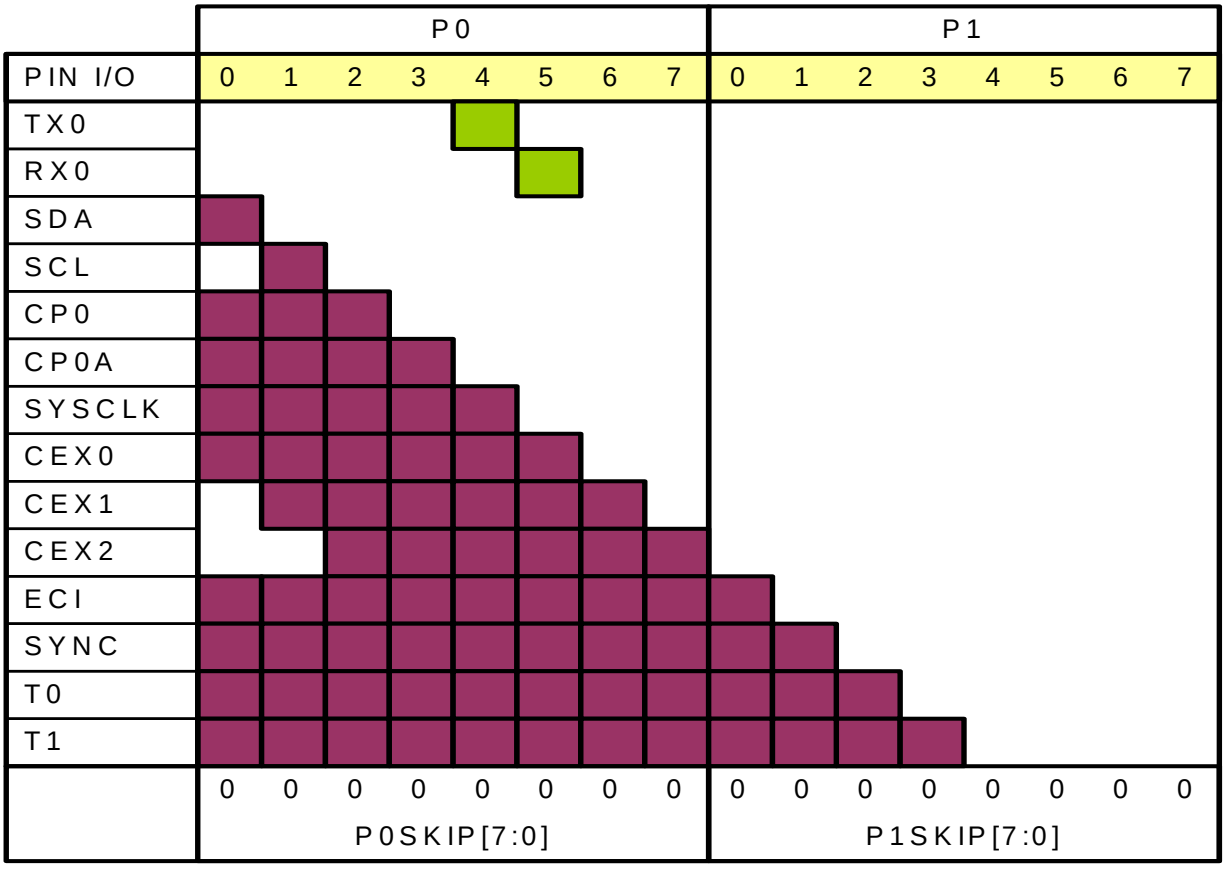


**Figure 19.3. Crossbar Priority Decoder with No Pins Skipped**

Registers XBR0 and XBR1 are used to assign the digital I/O resources to the physical I/O Port pins. When the SMBus is selected, the Crossbar assigns both pins associated with the SMBus (SDA and SCL); when the UART is selected, the Crossbar assigns both pins associated with the UART (TX and RX). UART0 pin assignments are fixed for boot loading purposes: UART TX0 is always assigned to P0.4; UART RX0 is always assigned to P0.5. Standard Port I/Os appear contiguously starting at P0.0 after prioritized functions and skipped pins are assigned.

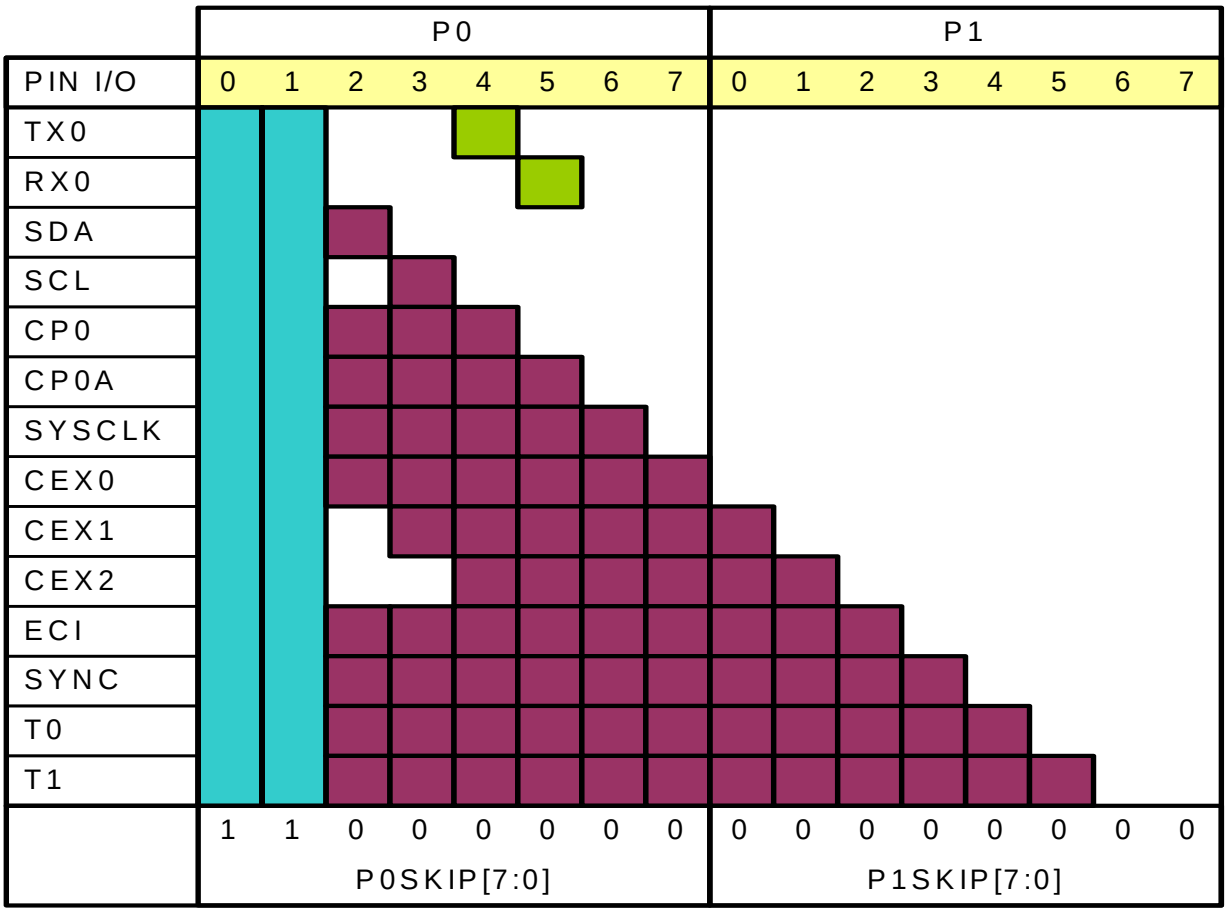


**Figure 19.4. Crossbar Priority Decoder with Crystal Pins Skipped**

## 19.2. Port I/O Initialization

Port I/O initialization consists of the following steps:

Step 1. Select the input mode (analog or digital) for all Port pins, using the Port Input Mode register (PnMDIN).
Step 2. Select the output mode (open-drain or push-pull) for all Port pins, using the Port Output Mode register (PnMDOUT).
Step 3. Select any pins to be skipped by the I/O Crossbar using the Port Skip registers (PnSKIP).
Step 4. Assign Port pins to desired peripherals using XBAR0 and XBAR1.
Step 5. Enable the Crossbar (XBARE = '1').

All Port pins must be configured as either analog or digital inputs. Any pins to be used as Comparator or ADC inputs should be configured as an analog input. When a pin is configured as an analog input, its weak pullup, digital driver, and digital receiver are disabled. This process saves power and reduces noise on the analog input. Pins configured as digital inputs may still be used by analog peripherals; however, this practice is not recommended.

Additionally, all analog input pins should be configured to be skipped by the Crossbar (accomplished by setting the associated bits in PnSKIP). Port input mode is set in the PnMDIN register, where a '1' indicates a digital input, and a '0' indicates an analog input. All pins default to digital inputs on reset.

**Important Note:** Port 0 pins are 5 V tolerant across the operating range of $V_{DD}$. Figure 19.5 shows the input current range of P0 pins when overdriven above $V_{DD}$ (when $V_{DD}$ is 2.7 V nominal). There are two overdrive modes for Port 0: Normal and High-Impedance. When the corresponding bit in P0ODEN is logic 0, Normal Overdrive Mode is selected and the port pin requires 150 µA peak overdrive current when its voltage reaches approximately $V_{DD}$ + 0.7 V. When the corresponding bit in P0ODEN is logic 1, High-Impedance Overdrive Mode is selected and the port pin does not require any additional overdrive current. Pins configured to High-Impedance Overdrive Mode consume slightly more power from $V_{DD}$ than pins configured to Normal Overdrive Mode. Port 1 pins cannot be overdriven above $V_{DD}$.

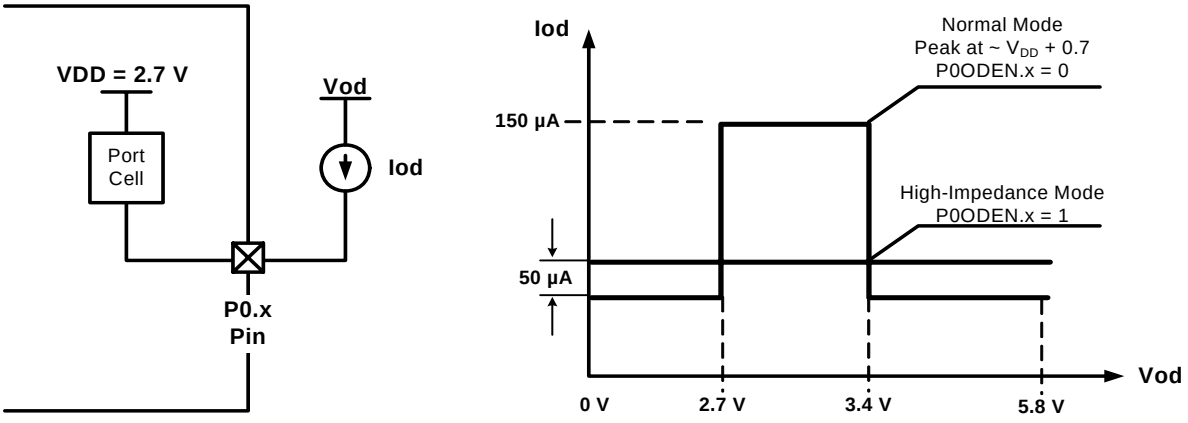


**Figure 19.5. Port 0 Input Overdrive Current Range**

The output driver characteristics of the I/O pins are defined using the Port Output Mode registers (PnMDOUT). Each Port Output driver can be configured as either open drain or push-pull. This selection is required even for the digital resources selected in the XBRn registers, and is not automatic. The only exception to this is the SMBus (SDA, SCL) pins, which are configured as open-drain regardless of the PnMDOUT settings. When the WEAKPUD bit in XBR1 is '0', a weak pullup is enabled for all Port I/O configured as open-drain. WEAKPUD does not affect the push-pull Port I/O. Furthermore, the weak pullup is turned off on an output that is driving a '0' to avoid unnecessary power dissipation.

Registers XBR0 and XBR1 must be loaded with the appropriate values to select the digital I/O functions required by the design. Setting the XBARE bit in XBR1 to '1' enables the Crossbar. Until the Crossbar is enabled, the external pins remain as standard Port I/O (in input mode), regardless of the XBRn Register settings. For given XBRn Register settings, one can determine the I/O pin-out using the Priority Decode Table.

The Crossbar must be enabled to use Port pins as standard Port I/O in output mode. Port output drivers are disabled while the Crossbar is disabled.

### SFR Definition 19.1. XBAR0: Port I/O Crossbar Register 0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | CP0AE | CP0E | SYSCKE | SMB0E | SYNCE | UART0E | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xE1

Bits 7–6: Unused

Bit 5: CP0AE: Comparator0 Asynchronous Output Enable
0: Asynchronous CP0 output unavailable on port pin.
1: Asynchronous CP0 output available on port pin.

Bit 4: CP0E: Comparator0 Synchronous Output Enable
0: Synchronous CP0 output unavailable on port pin.
1: Synchronous CP0 output available on port pin.

Bit 3: SYSCKE: /SYSCLK Output Enable
0: SYSCLK unavailable at port pin.
1: SYSCLK available at port pin.

Bit 2: SMB0E: SMBus I/O Enable
0: SMBus I/O unavailable at Port pins.
1: SMBus I/O available at Port pins.

Bit 1: SYNCE: DPWM Sync Input Enable
0: SYNC unavailable at port pins.
1: SYNC available at port pins.

Bit 0: UART0E: UART I/O Enable
0: UART unavailable at port pins.
1: UART available at port pins.

## SFR Definition 19.2. XBAR1: Port I/O Crossbar Register 1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| WEAKPUD | XBARE | T1E | T0E | ECIE | PCA0ME2 | PCA0ME1 | PCA0ME0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xE2

Bit 7: WEAKPUD: Port I/O Weak Pullup Disable
0: Weak Pullups enabled (except for Ports whose I/O are configured as analog input).
1: Weak pullups disabled.

Bit 6: XBARE: Crossbar Enable
0: Crossbar disabled.
1: Crossbar enabled.

Bit 5: T1E: Timer1 I/O Enable
0: T1 unavailable at port pins.
1: T1 available at port pins.

Bit 4: T0E: Timer1 I/O Enable
0: T0 unavailable at port pins.
1: T0 available at port pins.

Bit 3: ECIE: PCA0 External Counter Input Enable
0: ECI unavailable on port pin.
1: ECI available on port pin.

Bits 2–0: PCA0ME[2:0]: PCA Module I/O Enable Bits
000: All PCA I/O unavailable at Port pins.
001: CEX0 routed to Port pin.
010: CEX0, CEX1 routed to Port pins.
011: CEX0, CEX1, CEX2 routed to Port pins.
1xx: CEX0, CEX1, CEX2 routed to Port pins.

## 19.3. General Purpose Port I/O

Port pins that remain unassigned by the Crossbar and are not used by analog peripherals can be used for general purpose I/O. Ports P0 and P1 are accessed through corresponding special function registers (SFRs) that are both byte addressable and bit addressable. When writing to a Port, the value written to the SFR is latched to maintain the output data value at each pin. When reading, the logic levels of the Port's input pins are returned regardless of the XBRn settings (i.e., even when the pin is assigned to another signal by the Crossbar, the Port register can always read its corresponding Port I/O pin). The exception to this is the execution of the read-modify-write instructions that target a Port Latch register as the destination. The read-modify-write instructions when operating on a Port SFR are the following: ANL, ORL, XRL, JBC, CPL, INC, DEC, DJNZ and MOV, CLR or SETB, when the destination is an individual bit in a Port SFR. For these instructions, the value of the register (not the pin) is read, modified, and written back to the SFR.

### SFR Definition 19.3. P0ODEN: Port0 Overdrive Mode

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ODEN7 | ODEN6 | ODEN5 | ODEN4 | ODEN3 | ODEN2 | ODEN1 | ODEN0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xB0

Bits 7–0: High Impedance Overdrive Mode Enable Bits for P0.7–P0.0 (respectively).
Port pins configured to High-Impedance Overdrive Mode do not require additional overdrive current. Port pins configured to Normal Overdrive Mode require approximately 150 µA of input overdrive current when the voltage at the pin reaches $V_{IO}$ + 0.7 V.
0: Corresponding P0.n pin is configured to Normal Overdrive Mode.
1: Corresponding P0.n pin is configured to High-Impedance Overdrive Mode.

### SFR Definition 19.4. P0SKIP: Port0 Skip

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| P0SKIP7 | P0SKIP6 | P0SKIP5 | P0SKIP4 | P0SKIP3 | P0SKIP2 | P0SKIP1 | P0SKIP0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xD4

Bits 7–0: P0SKIP[7:0]: Port0 Crossbar Skip Enable Bits
These bits select Port pins to be skipped by the Crossbar Decoder. Port pins used as analog inputs (for ADC or Comparator) or used as special functions ($V_{REF}$ input, external oscillator circuit, CNVSTR input) should be skipped by the Crossbar.
0: Corresponding P0.n pin is not skipped by the Crossbar.
1: Corresponding P0.n pin is skipped by the Crossbar.

### SFR Definition 19.5. P0MDOUT: Port0 Output Mode

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| P0MDOUT7 | P0MDOUT6 | P0MDOUT5 | P0MDOUT4 | P0MDOUT3 | P0MDOUT2 | P0MDOUT1 | P0MDOUT0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xA4

Bits 7–0: P1MDOUT[7:0]: Output Configuration Bits for P0.7–P0.0 (respectively): ignored if corresponding bit in register P0MDIN is logic 0.
0: Corresponding P0.n Output is open-drain.
1: Corresponding P0.n Output is push-pull.

(Note: When SDA and SCL appear on any of the Port I/O, each are open-drain regardless of the value of P0MDOUT).

### SFR Definition 19.6. P0: Port0

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| P0.7 | P0.6 | P0.5 | P0.4 | P0.3 | P0.2 | P0.1 | P0.0 | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0x80

Bits 7–0: P0.[7:0]
Write—Output appears on I/O pins per Crossbar Registers.
0: Logic Low Output.
1: Logic High Output (high impedance if corresponding P0MDOUT.n bit = 0).
Read—Always reads ‘0’ if selected as analog input in register P0MDIN. Directly reads Port pin when configured as digital input.
0: P0.n pin is logic low.
1: P0.n pin is logic high.

### SFR Definition 19.7. P1: Port1

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| P1.7 | P1.6 | P1.5 | P1.4 | P1.3 | P1.2 | P1.1 | P1.0 | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0x90

Bits 7–0: P1.[7:0]
Write—Output appears on I/O pins per Crossbar Registers.
0: Logic Low Output.
1: Logic High Output (high impedance if corresponding P1MDOUT.n bit = 0).
Read—Always reads '0' if selected as analog input in register P1MDIN. Directly reads Port pin when configured as digital input.
0: P1.n pin is logic low.
1: P1.n pin is logic high.

### SFR Definition 19.8. P1MDOUT: Port1 Output Mode

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| P1MDOUT7 | P1MDOUT6 | P1MDOUT5 | P1MDOUT4 | P1MDOUT3 | P1MDOUT2 | P1MDOUT1 | P1MDOUT0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xA5

Bits 7–0: P1MDOUT[7:0]: Output Configuration Bits for P1.7–P1.0 (respectively): ignored if corresponding bit in register P1MDIN is logic 0.
0: Corresponding P1.n Output is open-drain.
1: Corresponding P1.n Output is push-pull.

### SFR Definition 19.9. P1SKIP: Port1 Skip

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| P1SKIP7 | P1SKIP6 | P1SKIP5 | P1SKIP4 | P1SKIP3 | P1SKIP2 | P1SKIP1 | P1SKIP0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xD5

Bits 7–0: P1SKIP[7:0]: Port1 Crossbar Skip Enable Bits
These bits select Port pins to be skipped by the Crossbar Decoder. Port pins used as analog inputs (for ADC or Comparator) or used as special functions ($V_{REF}$ input, external oscillator circuit, CNVSTR input) should be skipped by the Crossbar.
0: Corresponding P1.n pin is not skipped by the Crossbar.
1: Corresponding P1.n pin is skipped by the Crossbar.

## SFR Definition 19.10. P1MDIN: Port1 Input Mode

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| P1MDIN7 | P1MDIN6 | P1MDIN5 | P1MDIN4 | P1MDIN3 | P1MDIN2 | P1MDIN1 | P1MDIN0 | 11111111 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xF2

Bits 7–0: P1MDIN[7:0]: Analog Input Configuration Bits for P1.7–P1.0 (respectively).
Port pins configured as analog inputs have their weak pullup, digital driver, and digital receiver disabled.
0: Corresponding P1.n pin is configured as an analog input.
1: Corresponding P1.n pin is not configured as an analog input.

## NOTES:

# 20. Oscillators

The Si8250/1/2 devices provide multiple clocking options to accommodate a diverse set of power control application requirements. Essentially there are four major clocking options, and the CLKSEL[1:0] bits in CLKSEL register select the oscillator source that is used as the system clock:

- Low-frequency internal oscillator
- Clock multiply via the PLL
- High-frequency internal oscillator
- External clock

In addition to the four major clocking options, there are several other options that control other aspects of the oscillator block. Some of these options include clock dividers, power management, as well as clock selection to the digital power controller peripherals. The system oscillator is controlled through a set of registers introduced here and shown functionally in Figure 20.1:

- CLKSEL: System Clock Select
- OSCXCN: External Oscillator Control
- OSCICN: Internal Oscillator Control
- OSCICL: Internal Oscillator Calibration
- OSCLCN: Low-Frequency Oscillator Control
- PLLCN: Phase-Locked Loop Control

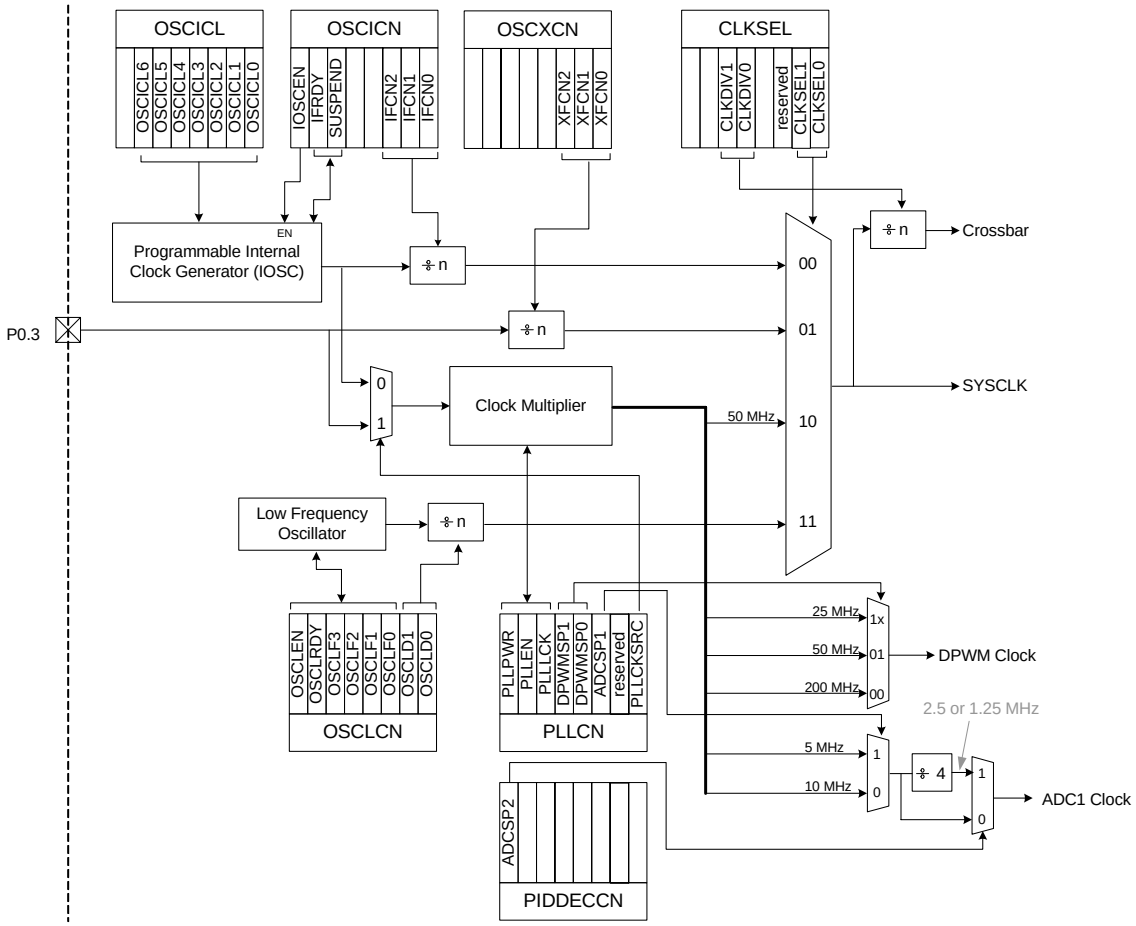


**Figure 20.1. Oscillator Diagram**

**Table 20.1. Clock Selection Frequencies**

| IFCN[2:0] | XFCN[2:0] | OSCLD[1:0] | CLKSEL[1:0] | SYSCLK Frequency | Notes |
|---|---|---|---|---|---|
| 000 | xxx | xx | 00 | 24.5 MHz | The internal oscillator is typically used for the active Digital Power Controller. The frequency can be adjusted to achieve higher or lower than nominal values. |
| 001 | | | | 12.25 MHz | |
| 010 | | | | 6.13 MHz | |
| 011 | | | | 3.06 MHz | |
| 100 | | | | 1.53 MHz | |
| 101 | | | | 766 kHz | |
| 110 | | | | 383 kHz | |
| 111 | | | | 191 kHz | |
| xxx | 000 | xx | 01 | clock | The system clock frequency is a function of the clock source. This would not be used for most power applications since an external clock source is required in this mode. |
| | 001 | | | clock/2 | |
| | 010 | | | clock/4 | |
| | 011 | | | clock/8 | |
| | 100 | | | clock/16 | |
| | 101 | | | clock/32 | |
| | 110 | | | clock/64 | |
| | 111 | | | clock/128 | |
| xxx | xxx | 00 | 11 | 10 kHz | This option is ideal for low-power operation when the Digital Power Controller is not actively regulating. |
| | | 01 | | 20 kHz | |
| | | 10 | | 40 kHz | |
| | | 11 | | 80 kHz | |
| xxx | xxx | xx | 10 | ~ 50 MHz | An output of 50 MHz depends on the clock source (external or internal) and their operating frequency. Using the internal oscillator, the nominal frequency is 49 MHz. Note: The PLL must be enabled for the Digital Power Controller; however, choosing the PLL as the system clock is not required. |

## 20.1. Clock Switching

The system clock may be switched on the fly between any of the available clocks; however, the selected clock source must be enabled and settled into its operating region. If the selected clock is not present, the missing clock detector will trigger a reset if enabled.

## 20.2. Low-Frequency Oscillator

The internal low-frequency oscillator (LFO) has a nominal frequency of 80 kHz. When running from this oscillator the supply current to the Si8250/1/2 is minimized. It is therefore the default oscillator following a power-on or reset. It is enabled and disabled under firmware control using the OSCLEN bit in the OSCLCN register. The LFO can be adjusted by firmware using the OSCLF[3:0] bits in OSCLCN. In addition, the LFO output frequency can be divided by 1, 2, 4 or 8, depending on the settings of the OSCLD[1:0] bits in OSCLCN.

## 20.3. Programmable Internal Oscillator

The Programmable Internal Oscillator is factory calibrated to obtain a 24.5 MHz nominal frequency; this is within the desired operating frequency used to drive the PLL and thus can be used to drive the Digital Power Controller. The internal oscillator is typically enabled by firmware just prior to initiating soft-start, and remains enabled throughout steady-state power supply operation. During supply powerdown a more suitable clock like the LFO may be selected to achieve low power, or the device may be placed in an IDLE or STOP mode.

The factory calibration of the Programmable Internal Oscillator can be overridden by writing the OSCICL register. Also, to achieve lower operating frequencies, the IFCN[2:0] bits can be modified to select a divided variation of the internal oscillator.

The internal oscillator requires very little start-up time; therefore, it may be selected as the system clock immediately after enabling the internal oscillator. It is enabled by setting the IOSCEN bit in the OSCICN register.

When firmware sets the SUSPEND bit in the OSCICN register, the internal oscillator is suspended. If the system is clocked from the Programmable Internal Oscillator, the input clock to the peripheral and the CIP-51 will be stopped until one of the following events occur:

- Comparator 0 is enabled and its output is logic 0.
- UART RX falling edge.

When one of these events occur and the internal oscillator awakens, the CIP-51 and any affected peripherals resume normal operation.

## 20.4. External Clock Input

The Si8250/1/2 devices provide an external clock input for clocking the microcontroller core, peripherals, and the Digital Power Controller as shown in Figure 20.1. The XFCN[2:0] bits in the OSCXCN register configure a divider for lower frequency operation. To use the external clock as an input source port pin, P0.3 should be skipped in the crossbar and configured as open-drain.

When the external clock is not selected as the system clock, it may still clock other peripherals such as timers and the PCA.

## 20.5. PLL Clock Multiplier

The PLL Clock Multiplier generates a time base that is eight times that of the input thus providing a possible 200 MHz clock source for the Digital Power Controller. For the system clock, which drives the system management processor and most peripherals, the PLL output is divided to achieve up to 50 MHz. The Digital Power Controller can also be selected to run from the 50 MHz or 25 MHz signal sources for lower frequency power control applications. Also note that the PLL must be enabled for power control; however, it does not have to be selected as the system clock. To enable the PLL Clock Multiplier, the PLLEN and PLLPWR bits in the PLLCN register must be set.

**Important Note:** Although the management processor can be selected to run at a higher frequency than the DPWM, this should not be done. When the DPWM is running at 25 MHz, DPWMSP = ‘1x', the system should be selected to run at 25 MHz or less.

## 20.6. Reference Clock Output

The Si8250/1/2 devices provide an option to drive out a reference clock to a pin through the Crossbar. By adjusting the CLKDIV[1:0] bits the SYSCLK or a division of the SYSCLK can be put out to the Crossbar as a clock reference for other external circuitry.

### SFR Definition 20.1. CLKSEL: System Clock Select

| — | — | R/W | R/W | — | — | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | CLKDIV1 | CLKDIV0 | — | — | CLKSEL1 | CLKSEL0 | 00000011 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xA9

Bits 7–6: Unused

Bits 5–4: CLKDIV[1:0]: Output SYSCLK Frequency Divider Bits.
00: SYSCLK output to the Crossbar equals the system clock
01: SYSCLK output to the Crossbar equals the system clock/2
10: SYSCLK output to the Crossbar equals the system clock/4
11: SYSCLK output to the Crossbar equals the system clock/8

Bit 3: Unused.

Bit 2: Reserved; must be maintained ‘0’.

Bits 1–0: CLKSEL[1:0]: System Clock Source Select Bits.
00: SYSCLK derived from internal oscillator (frequency determined by OSCICN)
01: SYSCLK derived from external clock source (frequency determined by OSCXCN)
10: SYSCLK derived from PLL clock multiplier (frequency determined by PLLCN)
11: SYSCLK derived from low-frequency oscillator (frequency determined by OSCLCN)

### SFR Definition 20.2. OSCLCN: Low-Frequency Oscillator Control

| R/W | R | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| OSCLEN | OSCLRDY | OSCLF3 | OSCLF2 | OSCLF1 | OSCLF0 | OSCLD1 | OSCLD0 | 11xxxx11 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x9C

Bit 7: OSCLEN: Low-Frequency Oscillator Enable
0: Low-frequency oscillator disabled.
1: Low-frequency oscillator enabled.

Bit 6: OSCLRDY: Internal Low-Frequency Oscillator Ready
0: internal low-frequency oscillator frequency not stabilized.
1: internal low-frequency oscillator frequency stabilized.

Bits 5–2: OSCLF[3:0]: Internal Low-Frequency Oscillator Frequency Fine-Tune Control Bits
0000: Oscillator operating at its highest frequency
...
...
...
1111: Oscillator operating at its lowest frequency

Bits 1–0: OSCLD[1:0]: Internal Low-Frequency Oscillator Divider Select
00: Divide by 8 selected
01: Divide by 4 selected
10: Divide by 2 selected
11: Divide by 1 selected

## SFR Definition 20.3. OSCICN: Internal Oscillator Control

| R/W | R | R/W | — | — | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| IOSCEN | IFRDY | SUSPEND | — | — | IFCN2 | IFCN1 | IFCN0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xB2

Bit 7: IOSCEN: Internal Oscillator Enable
0: Internal oscillator disabled.
1: Internal oscillator enabled.

Bit 6: IFRDY: Internal Oscillator Frequency Ready Flag
0: Internal oscillator is not running at programmed frequency.
1: Internal oscillator is running at programmed frequency.

Bit 5: SUSPEND: Internal Oscillator Suspend Enable Bit
Setting this bit to 1 places the internal oscillator in suspend mode. The internal oscillator resumes operation when one of the suspend mode awakening events occur.

Bits 4–3: Unused.

Bits 2–0: IFCN[2:0]: Interface clock divide-by-n control.
000: divide-by-128
001: divide-by-64
010: divide-by-32
011: divide-by-16
100: divide-by-8
101: divide-by-4
110: divide-by-2
111: divide-by-1

## SFR Definition 20.4. OSCICL: Internal Oscillator Calibration

| — | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | OSCICL6 | OSCICL5 | OSCICL4 | OSCICL3 | OSCICL2 | OSCICL1 | OSCICL0 | Variable |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xB3

Bit 7: Unused

Bits 6–0: OSCICL[6:0]: Internal Oscillator Calibration Bits
0x00: Minimum operating frequency
...
...
...
0x7F: Maximum operating frequency

## SFR Definition 20.5. OSCXCN: External Oscillator Control

| — | — | — | — | — | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| — | — | — | — | — | XFCN2 | XFCN1 | XFCN0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xB1

Bits 7–3: Unused

Bits 2–0: XFCN[2:0]: External Oscillator Control Bits
000: divide-by-1
001: divide-by-2
010: divide-by-4
011: divide-by-8
100: divide-by-16
101: divide-by-32
110: divide-by-64
111: divide-by-128

## SFR Definition 20.6. PLLCN: Phase-Locked Loop Control

| R/W | R/W | R | R/W | R/W | — | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PLLPWR | PLLEN | PLLLCK | DPWMSP1 | DPWMSP0 | ADCSP1 | reserved | PLLCKSRC | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xB9

Bit 7: PLLPWR: PLL Power Enable
0: PLL bias generator is de-activated. No static power is consumed.
1: PLL bias generator is active. Must be set for PLL to operate.

Bit 6: PLLEN: PLL Enable Bit.
0: PLL is held in reset
1: PLL is enabled. PLLPWR must be '1'.

Bit 5: PLLLCK: PLL Lock Status
0: PLL frequency is not locked.
1: PLL frequency is locked.

Bit 4–3: DPWMSP[1:0]: DPWM clock speed
00: DPWM clock = 200 MHz, Resolution = 5 ns
01: DPWM clock = 50 MHz, Resolution = 20 ns
1x: DPWM clock = 25 MHz, Resolution = 40 ns

Bit 2: ADCSP1: ADC1 Clock Select
ADCSP1, along with ADCSP2 bit from Register PIDDECCN, determines the sampling rate of ADC1.

Bit 1: Reserved, must be maintained ‘0’

Bit 0: PLLCKSRC: PLL Clock Source
0: Internal clock source selected.
1: External clock source selected.

## NOTES:

## 21. SMBus

The SMBus I/O interface is a two-wire, bi-directional serial bus. The SMBus is compliant with the System Management Bus Specification, version 2, and compatible with the $I^2C$ serial bus. Reads and writes to the interface by the system controller are byte oriented with the SMBus interface autonomously controlling the serial transfer of the data. Data can be transferred at up to 1/10th of the system clock as a master or slave. (This can be faster than allowed by the SMBus specification, depending on the system clock used.) A method of extending the clock-low duration is available to accommodate devices with different speed capabilities on the same bus.

The SMBus interface may operate as a master and/or slave, and may function on a bus with multiple masters. The SMBus provides control of SDA (serial data), SCL (serial clock) generation and synchronization, arbitration logic, and START/STOP control and generation. Three SFRs are associated with the SMBus: SMB0CF configures the SMBus; SMB0CN controls the status of the SMBus; and SMB0DAT is the data register, used for both transmitting and receiving SMBus data and slave addresses.

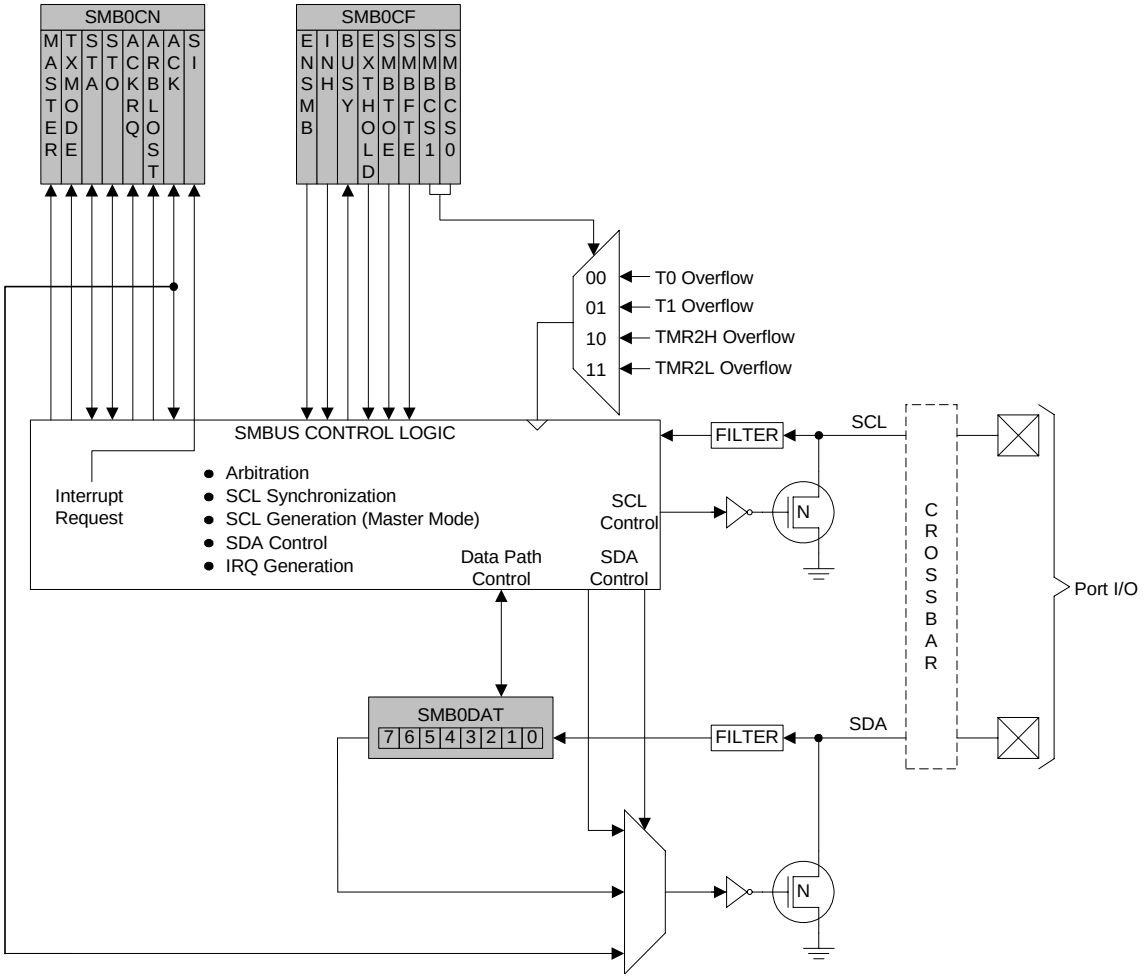


**Figure 21.1. SMBus Block Diagram**

## 21.1. Supporting Documents

It is assumed the reader is familiar with or has access to the following supporting documents:

- The $I^2C$ Manual (AN10216-01), Philips Semiconductor
- System Management Bus Specification—Version 2, SBS Implementers Forum

## 21.2. SMBus Configuration

Figure 21.2 shows a typical SMBus configuration. The SMBus specification allows any recessive voltage between 3.0 V and 5.0 V; different devices on the bus may operate at different voltage levels. The bi-directional SCL (serial clock) and SDA (serial data) lines must be connected to a positive power supply voltage through a pullup resistor or similar circuit. Every device connected to the bus must have an open-drain or open-collector output for both the SCL and SDA lines, so that both are pulled high (recessive state) when the bus is free. The maximum number of devices on the bus is limited only by the requirement that the rise and fall times on the bus not exceed 300 ns and 1000 ns, respectively.

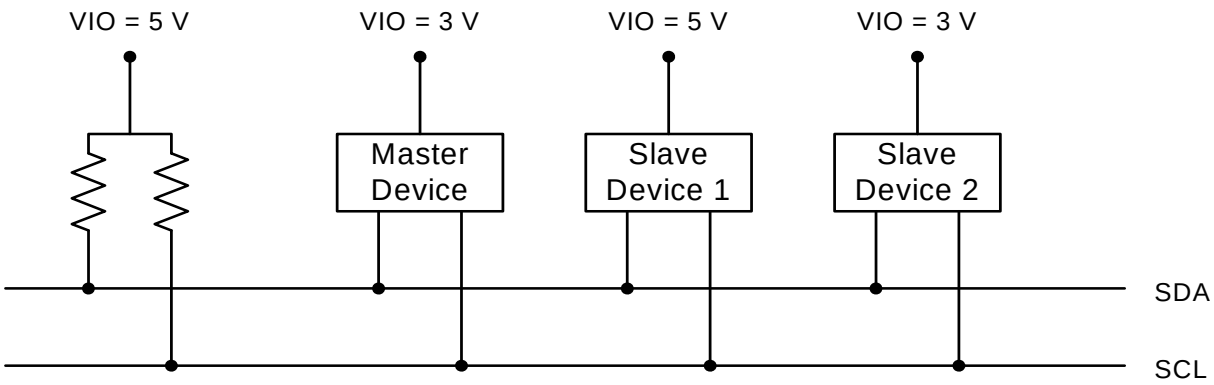


**Figure 21.2. Typical SMBus Configuration**

**Note:** It is recommended that the SDA and SCL pins be configured for high impedance overdrive mode. See Section "**19. Port Input/Output**" on page **195** for more information.

## 21.3. SMBus Operation

Two types of data transfers are possible: data transfers from a master transmitter to an addressed slave receiver (WRITE), and data transfers from an addressed slave transmitter to a master receiver (READ). The master device initiates both types of data transfers and provides the serial clock pulses on SCL. The SMBus interface may operate as a master or a slave, and multiple master devices on the same bus are supported. If two or more masters attempt to initiate a data transfer simultaneously, an arbitration scheme is employed with a single master always winning the arbitration. It is not necessary to specify one device as the Master in a system; any device who transmits a START and a slave address becomes the master for the duration of that transfer.

A typical SMBus transaction consists of a START condition followed by an address byte (Bits7-1: 7-bit slave address; Bit0: R/W direction bit), one or more bytes of data, and a STOP condition. Each byte that is received (by a master or slave) must be acknowledged (ACK) with a low SDA during a high SCL (see Figure 21.3). If the receiving device does not ACK, the transmitting device will read a NACK (not acknowledge), which is a high SDA during a high SCL.

The direction bit (R/W) occupies the least-significant bit position of the address byte. The direction bit is set to logic 1 to indicate a "READ" operation and cleared to logic 0 to indicate a "WRITE" operation.

All transactions are initiated by a master, with one or more addressed slave devices as the target. The master generates the START condition and then transmits the slave address and direction bit. If the transaction is a WRITE operation from the master to the slave, the master transmits the data a byte at a time waiting for an ACK from the slave at the end of each byte. For READ operations, the slave transmits the data waiting for an ACK from the master at the end of each byte. At the end of the data transfer, the master generates a STOP condition to terminate the transaction and free the bus. Figure 21.3 illustrates a typical SMBus transaction.

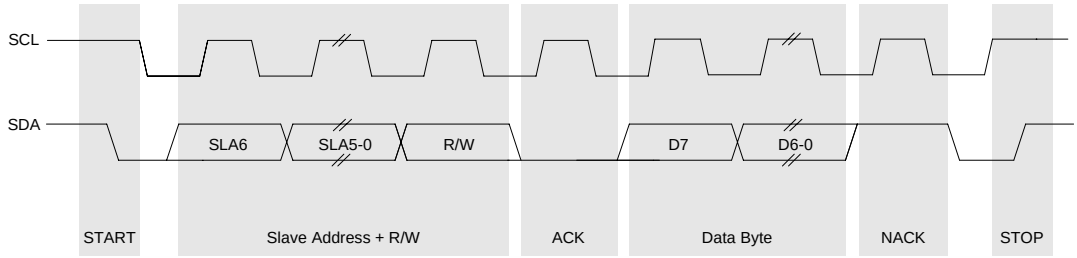


**Figure 21.3. SMBus Transaction**

### 21.3.1. Arbitration

A master may start a transfer only if the bus is free. The bus is free after a STOP condition or after the SCL and SDA lines remain high for a specified time (see **Section "21.3.4. SCL High (SMBus Free) Timeout" on page 218**). In the event that two or more devices attempt to begin a transfer at the same time, an arbitration scheme is employed to force one master to give up the bus. The master devices continue transmitting until one attempts a HIGH while the other transmits a LOW. Since the bus is open-drain, the bus will be pulled LOW. The master attempting the HIGH will detect a LOW SDA and lose the arbitration. The winning master continues its transmission without interruption; the losing master becomes a slave and receives the rest of the transfer if addressed. This arbitration scheme is non-destructive: one device always wins, and no data is lost.

### 21.3.2. Clock Low Extension

SMBus provides a clock synchronization mechanism, similar to $I^2C$, which allows devices with different speed capabilities to coexist on the bus. A clock-low extension is used during a transfer in order to allow slower slave devices to communicate with faster masters. The slave may temporarily hold the SCL line LOW to extend the clock low period, effectively decreasing the serial clock frequency.

### 21.3.3. SCL Low Timeout

If the SCL line is held low by a slave device on the bus, no further communication is possible. Furthermore, the master cannot force the SCL line high to correct the error condition. To solve this problem, the SMBus protocol specifies that devices participating in a transfer must detect any clock cycle held low longer than 25 ms as a “timeout” condition. Devices that have detected the timeout condition must reset the communication no later than 10 ms after detecting the timeout condition.

When the SMBTOE bit in SMB0CF is set, Timer 3 is used to detect SCL low timeouts. Timer 3 is forced to reload when SCL is high, and allowed to count when SCL is low. With Timer 3 enabled and configured to overflow after 25 ms (and SMBTOE set), the Timer 3 interrupt service routine can be used to reset (disable and re-enable) the SMBus in the event of an SCL low timeout.

### 21.3.4. SCL High (SMBus Free) Timeout

The SMBus specification stipulates that if the SCL and SDA lines remain high for more that 50 µs, the bus is designated as free. When the SMBFTE bit in SMB0CF is set, the bus will be considered free if SCL and SDA remain high for more than 10 SMBus clock source periods. If the SMBus is waiting to generate a Master START, the START will be generated following this timeout. A clock source is required for free timeout detection, even in a slave-only implementation. **Enabling the Bus Free Timeout is recommended.**

## 21.4. Using the SMBus

The SMBus can operate in both Master and Slave modes. The interface provides timing and shifting control for serial transfers; higher level protocol is determined by user software. The SMBus interface provides the following application-independent features:

- Byte-wise serial data transfers
- Clock signal generation on SCL (Master Mode only) and SDA data synchronization
- Timeout/bus error recognition, as defined by the SMB0CF configuration register
- START/STOP timing, detection, and generation
- Bus arbitration
- Interrupt generation
- Status information

SMBus interrupts are generated for each data byte or slave address that is transferred. When transmitting, this interrupt is generated after the ACK cycle so that software may read the received ACK value; when receiving data, this interrupt is generated before the ACK cycle so that software may define the outgoing ACK value. See **Section “21.5. SMBus Transfer Modes” on page 226** for more details on transmission sequences.

Interrupts are also generated to indicate the beginning of a transfer when a master (START generated), or the end of a transfer when a slave (STOP detected). Software should read the SMB0CN (SMBus Control register) to find the cause of the SMBus interrupt. The SMB0CN register is described in **Section “21.4.1. SMB0CN Control Register” on page 222**; Table 21.4 provides a quick SMB0CN decoding reference.

SMBus configuration options include:

- Timeout detection (SCL Low Timeout and/or Bus Free Timeout)
- SDA setup and hold time extensions
- Slave event enable/disable
- Clock source selection

These options are selected in the SMB0CF register, as described in **Section "21.4.0.1. SMBus Configuration Register" on page 219**.

#### 21.4.0.1.SMBus Configuration Register

The SMBus Configuration register (SMB0CF) is used to enable the SMBus Master and/or Slave modes, select the SMBus clock source, and select the SMBus timing and timeout options. When the ENSMB bit is set, the SMBus is enabled for all master and slave events. Slave events may be disabled by setting the INH bit. With slave events inhibited, the SMBus interface will still monitor the SCL and SDA pins; however, the interface will NACK all received addresses and will not generate any slave interrupts. When the INH bit is set, all slave events will be inhibited following the next START (interrupts will continue for the duration of the current transfer).

**Table 21.1. SMBus Clock Source Selection**

| SMBCS1 | SMBCS0 | SMBus Clock Source |
|---|---|---|
| 0 | 0 | Timer 0 Overflow |
| 0 | 1 | Timer 1 Overflow |
| 1 | 0 | Timer 2 High Byte Overflow |
| 1 | 1 | Timer 2 Low Byte Overflow |

The SMBCS1-0 bits select the SMBus clock source, which is used only when operating as a master or when the Bus Free Timeout detection is enabled. When operating as a master, overflows from the selected source determine the absolute minimum SCL low and high times as defined in Equation 21.1. The selected clock source may be shared by other peripherals so long as the timer is left running at all times. For example, Timer 1 overflows may generate the SMBus and UART baud rates simultaneously. Timer configuration is covered in **Section "23. Timers" on page 243**.

$$T_{HighMin} = T_{LowMin} = \frac{1}{f_{ClockSourceOverflow}}$$

**Equation 21.1. Minimum SCL High and Low Times**

The selected clock source should be configured to establish the minimum SCL High and Low times as per Equation 21.1. When the interface is operating as a master (and SCL is not driven or extended by any other devices on the bus), the typical SMBus bit rate is approximated by Equation 21.2.

$$BitRate = \frac{f_{ClockSourceOverflow}}{3}$$

**Equation 21.2. Typical SMBus Bit Rate**

Figure 21.4 shows the typical SCL generation described by Equation 21.2. Notice that $T_{HIGH}$ is typically twice as large as $T_{LOW}$. The actual SCL output may vary due to other devices on the bus (SCL may be extended low by slower slave devices, or driven low by contending master devices). The bit rate when operating as a master will never exceed the limits defined by equation Equation 21.1.

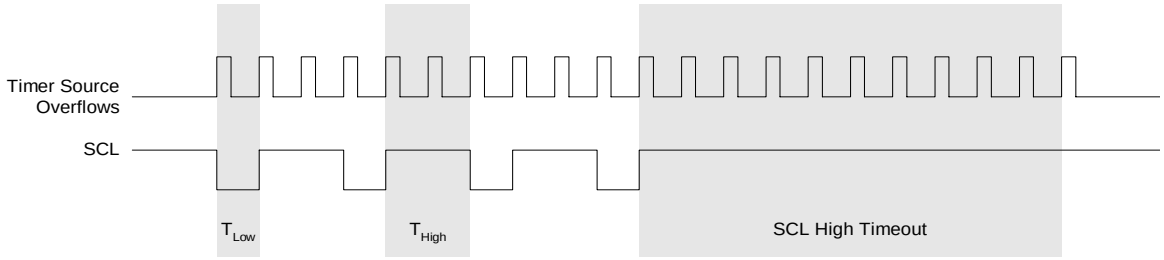


**Figure 21.4. Typical SMBus SCL Generation**

Setting the EXTHOLD bit extends the minimum setup and hold times for the SDA line. The minimum SDA setup time defines the absolute minimum time that SDA is stable before SCL transitions from low-to-high. The minimum SDA hold time defines the absolute minimum time that the current SDA value remains stable after SCL transitions from high-to-low. EXTHOLD should be set so that the minimum setup and hold times meet the SMBus Specification requirements of 250 ns and 300 ns, respectively. Table 21.2 shows the minimum setup and hold times for the two EXTHOLD settings. Setup and hold time extensions are typically necessary when SYSCLK is above 10 MHz.

**Note**: For SCL operation above 100 kHz, EXTHOLD should be cleared to ‘0’.

**Table 21.2. Minimum SDA Setup and Hold Times**

| EXTHOLD | Minimum SDA Setup Time | Minimum SDA Hold Time |
|---|---|---|
| 0 | $T_{low}$ - 4 system clocks<br>OR<br>1 system clock + s/w delay* | 3 system clocks |
| 1 | 11 system clocks | 12 system clocks |
| ***Note:** Setup Time for ACK bit transmissions and the MSB of all data transfers. The s/w delay occurs between the time SMB0DAT or ACK is written and when SI is cleared. Note that if SI is cleared in the same write that defines the outgoing ACK value, s/w delay is zero. | | |

With the SMBTOE bit set, Timer 3 should be configured to overflow after 25 ms in order to detect SCL low timeouts (see **Section “21.3.3. SCL Low Timeout” on page 218**). The SMBus interface will force Timer 3 to reload while SCL is high, and allow Timer 3 to count when SCL is low. The Timer 3 interrupt service routine should be used to reset SMBus communication by disabling and re-enabling the SMBus.

SMBus Free Timeout detection can be enabled by setting the SMBFTE bit. When this bit is set, the bus will be considered free if SDA and SCL remain high for more than 10 SMBus clock source periods (see Figure 21.4). When a Free Timeout is detected, the interface will respond as if a STOP was detected (an interrupt will be generated, and STO will be set). **Enabling the Bus Free Timeout is recommended.**

## SFR Definition 21.1. SMB0CF: SMBus Clock/Configuration

| R/W | R/W | R | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| ENSMB | INH | BUSY | EXTHOLD | SMBTOE | SMBFTE | SMBCS1 | SMBCS0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xC1

Bit 7: ENSMB: SMBus Enable
This bit enables/disables the SMBus interface. When enabled, the interface constantly monitors the SDA and SCL pins.
0: SMBus interface disabled.
1: SMBus interface enabled.

Bit 6: INH: SMBus Slave Inhibit
When this bit is set to logic 1, the SMBus does not generate an interrupt when slave events occur. This effectively removes the SMBus slave from the bus. Master Mode interrupts are not affected.
0: SMBus Slave Mode enabled.
1: SMBus Slave Mode inhibited.

Bit 5: BUSY: SMBus Busy Indicator
This bit is set to logic 1 by hardware when a transfer is in progress. It is cleared to logic 0 when a STOP or free-timeout is sensed.

Bit 4: EXTHOLD: SMBus Setup and Hold Time Extension Enable
This bit controls the SDA setup and hold times according to Table 21.2.
0: SDA Extended Setup and Hold Times disabled.
1: SDA Extended Setup and Hold Times enabled.

Bit 3: SMBTOE: SMBus SCL Timeout Detection Enable
This bit enables SCL low timeout detection. If set to logic 1, the SMBus forces Timer 3 to reload while SCL is high and allows Timer 3 to count when SCL goes low. Timer 3 should be programmed to generate interrupts at 25 ms, and the Timer 3 interrupt service routine should reset SMBus communication.

Bit 2: SMBFTE: SMBus Free Timeout Detection Enable
When this bit is set to logic 1, the bus will be considered free if SCL and SDA remain high for more than 10 SMBus clock source periods.

Bits 1–0: SMBCS[1:0]: SMBus Clock Source Selection
These two bits select the SMBus clock source, which is used to generate the SMBus bit rate. The selected device should be configured according to Equation 21.1.

| SMBCS1 | SMBCS0 | SMBus Clock Source |
|---|---|---|
| 0 | 0 | Timer 0 Overflow |
| 0 | 1 | Timer 1 Overflow |
| 1 | 0 | Timer 2 High Byte Overflow |
| 1 | 1 | Timer 2 Low Byte Overflow |

### 21.4.1. SMB0CN Control Register

SMB0CN is used to control the interface and to provide status information (see SFR Definition 21.2). The higher four bits of SMB0CN (MASTER, TXMODE, STA, and STO) form a status vector that can be used to jump to service routines. MASTER and TXMODE indicate the master/slave state and transmit/receive modes, respectively.

STA and STO indicate that a START and/or STOP has been detected or generated since the last SMBus interrupt. STA and STO are also used to generate START and STOP conditions when operating as a master. Writing a ‘1’ to STA will cause the SMBus interface to enter Master Mode and generate a START when the bus becomes free (STA is not cleared by hardware after the START is generated). Writing a ‘1’ to STO while in Master Mode will cause the interface to generate a STOP and end the current transfer after the next ACK cycle. If STO and STA are both set (while in Master Mode), a STOP followed by a START will be generated.

As a receiver, writing the ACK bit defines the outgoing ACK value; as a transmitter, reading the ACK bit indicates the value received on the last ACK cycle. ACKRQ is set each time a byte is received, indicating that an outgoing ACK value is needed. When ACKRQ is set, software should write the desired outgoing value to the ACK bit before clearing SI. A NACK will be generated if software does not write the ACK bit before clearing SI. SDA will reflect the defined ACK value immediately following a write to the ACK bit; however SCL will remain low until SI is cleared. If a received slave address is not acknowledged, further slave events will be ignored until the next START is detected.

The ARBLOST bit indicates that the interface has lost an arbitration. This may occur anytime the interface is transmitting (master or slave). A lost arbitration while operating as a slave indicates a bus error condition. ARBLOST is cleared by hardware each time SI is cleared.

The SI bit (SMBus Interrupt Flag) is set at the beginning and end of each transfer, after each byte frame, or when an arbitration is lost; see Table 21.3 for more details.

**Important Note About the SI Bit:** The SMBus interface is stalled while SI is set; thus SCL is held low, and the bus is stalled until software clears SI.

Table 21.3 lists all sources for hardware changes to the SMB0CN bits. Refer to Table 21.4 for SMBus status decoding using the SMB0CN register.

## SFR Definition 21.2. SMB0CN: SMBus Control

| R | R | R/W | R/W | R | R | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| MASTER | TXMODE | STA | STO | ACKRQ | ARBLOST | ACK | SI | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0xC0

Bit 7: MASTER: SMBus Master/Slave Indicator
This read-only bit indicates when the SMBus is operating as a master.
0: SMBus operating in Slave Mode.
1: SMBus operating in Master Mode.

Bit 6: TXMODE: SMBus Transmit Mode Indicator
This read-only bit indicates when the SMBus is operating as a transmitter.
0: SMBus in Receiver Mode.
1: SMBus in Transmitter Mode.

Bit 5: STA: SMBus Start Flag
Write:
0: No Start generated.
1: When operating as a master, a START condition is transmitted if the bus is free (If the bus is not free, the START is transmitted after a STOP is received or a timeout is detected). If STA is set by software as an active Master, a repeated START will be generated after the next ACK cycle.
Read:
0: No Start or repeated Start detected.
1: Start or repeated Start detected.

Bit 4: STO: SMBus Stop Flag. **If set by hardware, this bit must be cleared by software.**
Write:
0: No STOP condition is transmitted.
1: Setting STO to logic 1 causes a STOP condition to be transmitted after the next ACK cycle. When the STOP condition is generated, hardware clears STO to logic 0. If both STA and STO are set, a STOP condition is transmitted followed by a START condition.
Read:
0: No Stop condition detected.
1: Stop condition detected (if in Slave Mode) or pending (if in Master Mode).

Bit 3: ACKRQ: SMBus Acknowledge Request
This read-only bit is set to logic 1 when the SMBus has received a byte and needs the ACK bit to be written with the correct ACK response value.

Bit 2: ARBLOST: SMBus Arbitration Lost Indicator
This read-only bit is set to logic 1 when the SMBus loses arbitration while operating as a transmitter. A lost arbitration while a slave indicates a bus error condition.

Bit 1: ACK: SMBus Acknowledge Flag
This bit defines the out-going ACK level and records incoming ACK levels. It should be written each time a byte is received (when ACKRQ=1), or read after each byte is transmitted.
0: A "not acknowledge" has been received (if in Transmitter Mode) OR will be transmitted (if in Receiver Mode).
1: An "acknowledge" has been received (if in Transmitter Mode) OR will be transmitted (if in Receiver Mode).

Bit 0: SI: SMBus Interrupt Flag
This bit is set by hardware under the conditions listed in Table 21.3. SI must be cleared by software. While SI is set, SCL is held low and the SMBus is stalled.

**Table 21.3. Sources for Hardware Changes to SMB0CN**

| Bit | Set by Hardware When: | Cleared by Hardware When: |
|---|---|---|
| MASTER | | • A STOP is generated.<br>• Arbitration is lost. |
| TXMODE | | • A START is detected.<br>• Arbitration is lost.<br>• SMB0DAT is not written before the start of an SMBus frame. |
| STA | | • Must be cleared by software. |
| STO | | • A pending STOP is generated.<br>• If STO is set by hardware, it must be cleared by software. |
| ACKRQ | | • After each ACK cycle. |
| ARBLOST | | • Each time SI is cleared. |
| ACK | | • The incoming ACK value is high (NOT ACKNOWLEDGE). |
| SI | | • Must be cleared by software. |

### 21.4.2. Data Register

The SMBus Data register SMB0DAT holds a byte of serial data to be transmitted or one that has just been received. Software may safely read or write to the data register when the SI flag is set. Software should not attempt to access the SMB0DAT register when the SMBus is enabled and the SI flag is cleared to logic 0, as the interface may be in the process of shifting a byte of data into or out of the register.

Data in SMB0DAT is always shifted out MSB first. After a byte has been received, the first bit of received data is located at the MSB of SMB0DAT. While data is being shifted out, data on the bus is simultaneously being shifted in. SMB0DAT always contains the last data byte present on the bus. In the event of lost arbitration, the transition from master transmitter to slave receiver is made with the correct data or address in SMB0DAT.

**SFR Definition 21.3. SMB0DAT: SMBus Data**

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xC2

Bits 7–0: SMB0DAT: SMBus Data
The SMB0DAT register contains a byte of data to be transmitted on the SMBus serial interface or a byte that has just been received on the SMBus serial interface. The CPU can read from or write to this register whenever the SI serial interrupt flag (SMB0CN.0) is set to logic 1. The serial data in the register remains stable as long as the SI flag is set. When the SI flag is not set, the system may be in the process of shifting data in/out and the CPU should not attempt to access this register.

## 21.5. SMBus Transfer Modes

The SMBus interface may be configured to operate as master and/or slave. At any particular time, it will be operating in one of the following four modes: Master Transmitter, Master Receiver, Slave Transmitter, or Slave Receiver. The SMBus interface enters Master Mode any time a START is generated, and remains in Master Mode until it loses an arbitration or generates a STOP. An SMBus interrupt is generated at the end of all SMBus byte frames; however, note that the interrupt is generated before the ACK cycle when operating as a receiver, and after the ACK cycle when operating as a transmitter.

### 21.5.1. Master Transmitter Mode

Serial data is transmitted on SDA while the serial clock is output on SCL. The SMBus interface generates the START condition and transmits the first byte containing the address of the target slave and the data direction bit. In this case the data direction bit (R/W) will be logic 0 (WRITE). The master then transmits one or more bytes of serial data. After each byte is transmitted, an acknowledge bit is generated by the slave. The transfer is ended when the STO bit is set and a STOP is generated. Note that the interface will switch to Master Receiver Mode if SMB0DAT is not written following a Master Transmitter interrupt. Figure 21.5 shows a typical Master Transmitter sequence. Two transmit data bytes are shown, though any number of bytes may be transmitted. Notice that the ‘data byte transferred’ interrupts occur **after** the ACK cycle in this mode.

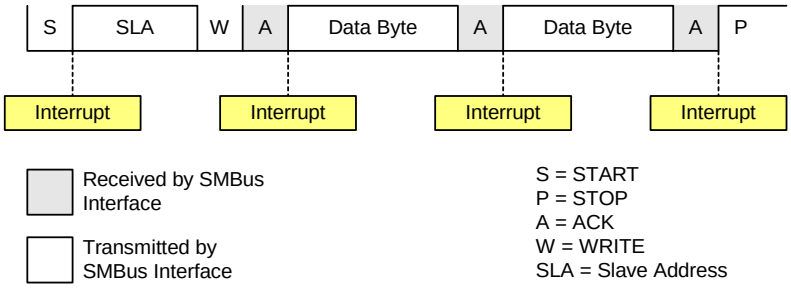


**Figure 21.5. Typical Master Transmitter Sequence**

### 21.5.2. Master Receiver Mode

Serial data is received on SDA while the serial clock is output on SCL. The SMBus interface generates the START condition and transmits the first byte containing the address of the target slave and the data direction bit. In this case the data direction bit (R/W) will be logic 1 (READ). Serial data is then received from the slave on SDA while the SMBus outputs the serial clock. The slave transmits one or more bytes of serial data. After each byte is received, ACKRQ is set to ‘1’ and an interrupt is generated. Software must write the ACK bit (SMB0CN.1) to define the outgoing acknowledge value. (Writing a ‘1’ to the ACK bit generates an ACK; writing a ‘0’ generates a NACK.) Software should write a ‘0’ to the ACK bit after the last byte is received, to transmit a NACK. The interface exits Master Receiver Mode after the STO bit is set and a STOP is generated. Note that the interface will switch to Master Transmitter Mode if SMB0DAT is written while an active Master Receiver. Figure 21.6 shows a typical Master Receiver sequence. Two received data bytes are shown, though any number of bytes may be received. Notice that the ‘data byte transferred’ interrupts occur **before** the ACK cycle in this mode.

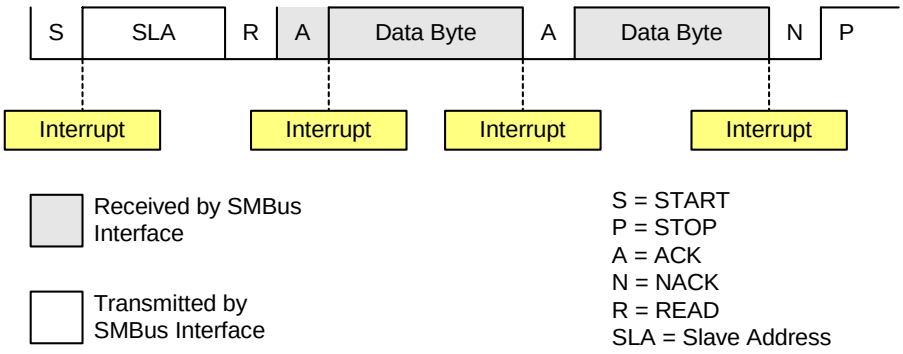


**Figure 21.6. Typical Master Receiver Sequence**

### 21.5.3. Slave Receiver Mode

Serial data is received on SDA and the clock is received on SCL. When slave events are enabled (INH = 0), the interface enters Slave Receiver Mode when a START followed by a slave address and direction bit (WRITE in this case) is received. Upon entering Slave Receiver Mode, an interrupt is generated and the ACKRQ bit is set. Software responds to the received slave address with an ACK, or ignores the received slave address with a NACK. If the received slave address is ignored, slave interrupts will be inhibited until the next START is detected. If the received slave address is acknowledged, zero or more data bytes are received. Software must write the ACK bit after each received byte to ACK or NACK the received byte. The interface exits Slave Receiver Mode after receiving a STOP. Note that the interface will switch to Slave Transmitter Mode if SMB0DAT is written while an active Slave Receiver. Figure 21.7 shows a typical Slave Receiver sequence. Two received data bytes are shown, though any number of bytes may be received. Notice that the 'data byte transferred' interrupts occur **before** the ACK cycle in this mode.

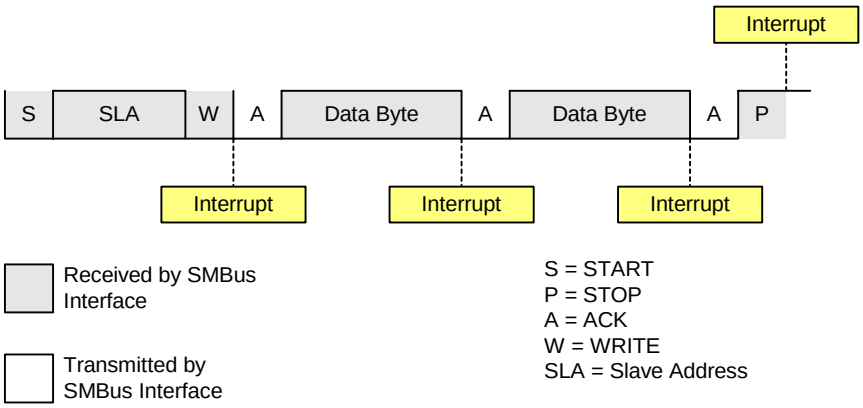


**Figure 21.7. Typical Slave Receiver Sequence**

### 21.5.4. Slave Transmitter Mode

Serial data is transmitted on SDA and the clock is received on SCL. When slave events are enabled (INH = 0), the interface enters Slave Receiver Mode (to receive the slave address) when a START followed by a slave address and direction bit (READ in this case) is received. Upon entering Slave Transmitter Mode, an interrupt is generated and the ACKRQ bit is set. Software responds to the received slave address with an ACK, or ignores the received slave address with a NACK. If the received slave address is ignored, slave interrupts will be inhibited until a START is detected. If the received slave address is acknowledged, data should be written to SMB0DAT to be transmitted. The interface enters Slave Transmitter Mode, and transmits one or more bytes of data. After each byte is transmitted, the master sends an acknowledge bit; if the acknowledge bit is an ACK, SMB0DAT should be written with the next data byte. If the acknowledge bit is a NACK, SMB0DAT should not be written to before SI is cleared (Note: an error condition may be generated if SMB0DAT is written following a received NACK while in Slave Transmitter Mode). The interface exits Slave Transmitter Mode after receiving a STOP. Note that the interface will switch to Slave Receiver Mode if SMB0DAT is not written following a Slave Transmitter interrupt. Figure 21.8 shows a typical Slave Transmitter sequence. Two transmitted data bytes are shown, though any number of bytes may be transmitted. Notice that the 'data byte transferred' interrupts occur **after** the ACK cycle in this mode.

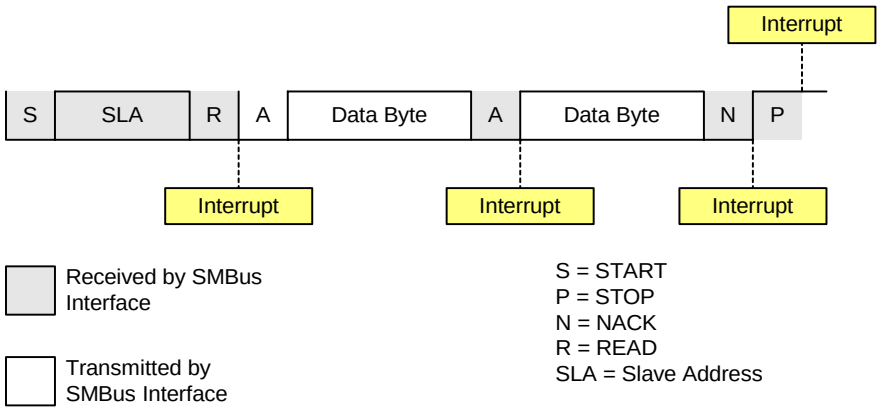


**Figure 21.8. Typical Slave Transmitter Sequence**

## 21.6. SMBus Status Decoding

The current SMBus status can be easily decoded using the SMB0CN register. In Table 21.4, STATUS VECTOR refers to the four upper bits of SMB0CN: MASTER, TXMODE, STA, and STO. The shown response options are only the typical responses; application-specific procedures are allowed as long as they conform to the SMBus specification. Highlighted responses are allowed but do not conform to the SMBus specification.

**Table 21.4. SMBus Status Decoding**

| Mode | Values Read | | | | Current SMbus State | Typical Response Options | Values Written | | |
|---|---|---|---|---|---|---|---|---|---|
| | Status Vector | ACKRQ | ARBLOST | ACK | | | STA | STO | ACK |
| Master Transmitter | 1110 | 0 | 0 | X | A master START was generated. | Load slave address + R/W into SMB0DAT. | 0 | 0 | X |
| | 1100 | 0 | 0 | 0 | A master data or address byte was transmitted; NACK received. | Set STA to restart transfer. | 1 | 0 | X |
| | | | | | | Abort transfer. | 0 | 1 | X |
| | | 0 | 0 | 1 | A master data or address byte was transmitted; ACK received. | Load next data byte into SMB0DAT. | 0 | 0 | X |
| | | | | | | End transfer with STOP. | 0 | 1 | X |
| | | | | | | End transfer with STOP and start another transfer. | 1 | 1 | X |
| | | | | | | Send repeated START. | 1 | 0 | X |
| | | | | | | Switch to Master Receiver Mode (clear SI without writing new data to SMB0DAT). | 0 | 0 | X |
| Master Receiver | 1000 | 1 | 0 | X | A master data byte was received; ACK requested. | Acknowledge received byte; Read SMB0DAT. | 0 | 0 | 1 |
| | | | | | | Send NACK to indicate last byte, and send STOP. | 0 | 1 | 0 |
| | | | | | | Send NACK to indicate last byte, and send STOP followed by START. | 1 | 1 | 0 |
| | | | | | | Send ACK followed by repeated START. | 1 | 0 | 1 |
| | | | | | | Send NACK to indicate last byte, and send repeated START. | 1 | 0 | 0 |
| | | | | | | Send ACK and switch to Master Transmitter Mode (write to SMB0DAT before clearing SI). | 0 | 0 | 1 |
| | | | | | | Send NACK and switch to Master Transmitter Mode (write to SMB0DAT before clearing SI). | 0 | 0 | 0 |

**Table 21.4. SMBus Status Decoding (Continued)**

| Mode | Values Read | | | | Current SMbus State | Typical Response Options | Values Written | | |
|---|---|---|---|---|---|---|---|---|---|
| | Status Vector | ACKRQ | ARBLOST | ACK | | | STA | STO | ACK |
| Slave Transmitter | 0100 | 0 | 0 | 0 | A slave byte was transmitted; NACK received. | No action required (expecting STOP condition). | 0 | 0 | X |
| | | 0 | 0 | 1 | A slave byte was transmitted; ACK received. | Load SMB0DAT with next data byte to transmit. | 0 | 0 | X |
| | | 0 | 1 | X | A Slave byte was transmitted; error detected. | No action required (expecting Master to end transfer). | 0 | 0 | X |
| | 0101 | 0 | X | X | A STOP was detected while an addressed Slave Transmitter. | No action required (transfer complete). | 0 | 0 | X |
| Slave Receiver | 0010 | 1 | 0 | X | A slave address was received; ACK requested. | Acknowledge received address. | 0 | 0 | 1 |
| | | | | | | Do not acknowledge received address. | 0 | 0 | 0 |
| | | 1 | 1 | X | Lost arbitration as master; slave address received; ACK requested. | Acknowledge received address. | 0 | 0 | 1 |
| | | | | | | Do not acknowledge received address. | 0 | 0 | 0 |
| | | | | | | Reschedule failed transfer; do not acknowledge received address. | 1 | 0 | 0 |
| | 0010 | 0 | 1 | X | Lost arbitration while attempting a repeated START. | Abort failed transfer. | 0 | 0 | X |
| | | | | | | Reschedule failed transfer. | 1 | 0 | X |
| | 0001 | 1 | 1 | X | Lost arbitration while attempting a STOP. | No action required (transfer complete/aborted). | 0 | 0 | 0 |
| | | 0 | 0 | X | A STOP was detected while an addressed slave receiver. | No action required (transfer complete). | 0 | 0 | X |
| | | 0 | 1 | X | Lost arbitration due to a detected STOP. | Abort transfer. | 0 | 0 | X |
| | | | | | | Reschedule failed transfer. | 1 | 0 | X |
| | 0000 | 1 | 0 | X | A slave byte was received; ACK requested. | Acknowledge received byte; Read SMB0DAT. | 0 | 0 | 1 |
| | | | | | | Do not acknowledge received byte. | 0 | 0 | 0 |
| | | 1 | 1 | X | Lost arbitration while transmitting a data byte as master. | Abort failed transfer. | 0 | 0 | 0 |
| | | | | | | Reschedule failed transfer. | 1 | 0 | 0 |

## NOTES:

# 22. UART0

UART0 is an asynchronous, full duplex serial port offering modes 1 and 3 of the standard 8051 UART. Enhanced baud rate support allows a wide range of clock sources to generate standard baud rates (details in **Section "22.1. Enhanced Baud Rate Generation" on page 234**). Received data buffering allows UART0 to start reception of a second incoming data byte before software has finished reading the previous data byte.

UART0 has two associated SFRs: Serial Control Register 0 (SCON0) and Serial Data Buffer 0 (SBUF0). The single SBUF0 location provides access to both transmit and receive registers. **Writes to SBUF0 always access the Transmit register. Reads of SBUF0 always access the buffered Receive register; it is not possible to read data from the Transmit register.**

With UART0 interrupts enabled, an interrupt is generated each time a transmit is completed (TI0 is set in SCON0), or a data byte has been received (RI0 is set in SCON0). The UART0 interrupt flags are not cleared by hardware when the CPU vectors to the interrupt service routine. They must be cleared manually by software, allowing software to determine the cause of the UART0 interrupt (transmit complete or receive complete).

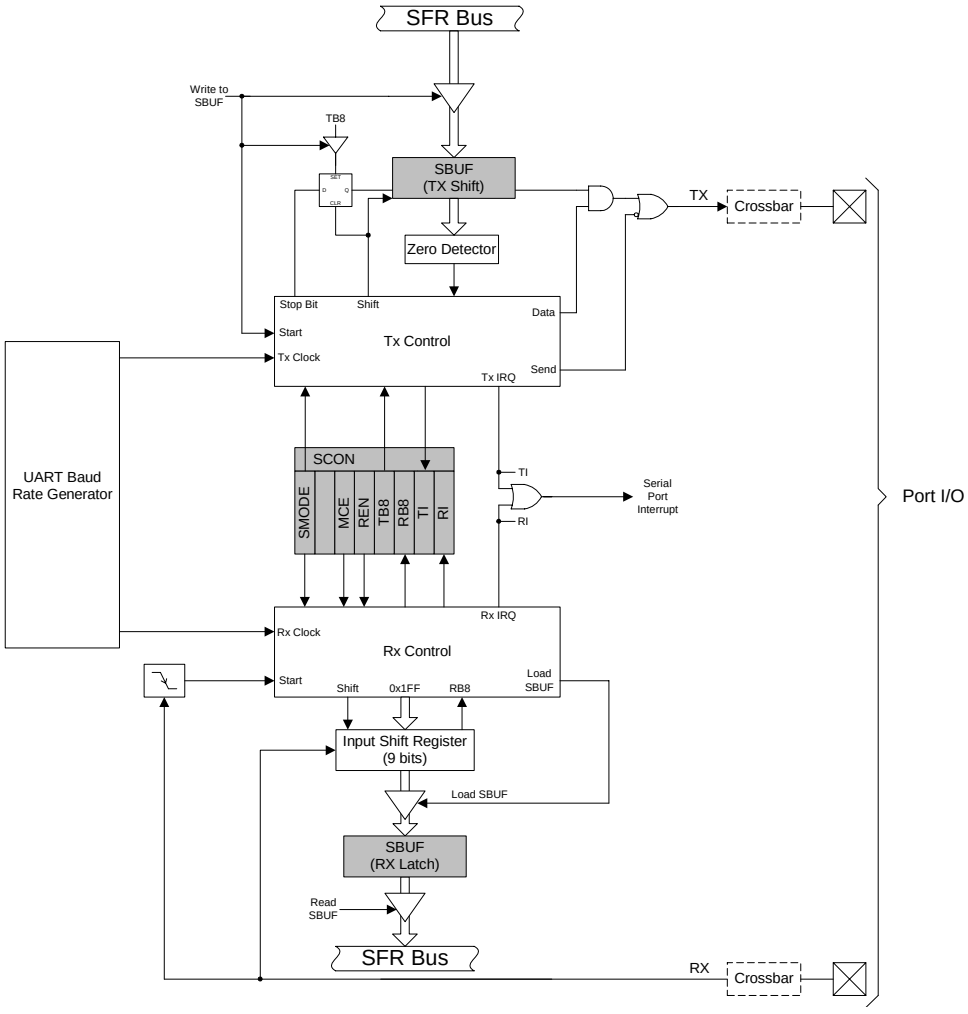


**Figure 22.1. UART0 Block Diagram**

## 22.1. Enhanced Baud Rate Generation

The UART0 baud rate is generated by Timer 1 in 8-bit auto-reload mode. The TX clock is generated by TL1; the RX clock is generated by a copy of TL1 (shown as RX Timer in Figure 22.2), which is not user-accessible. Both TX and RX Timer overflows are divided by two to generate the TX and RX baud rates. The RX Timer runs when Timer 1 is enabled, and uses the same reload value (TH1). However, an RX Timer reload is forced when a START condition is detected on the RX pin. This allows a receive to begin any time a START is detected, independent of the TX Timer state.

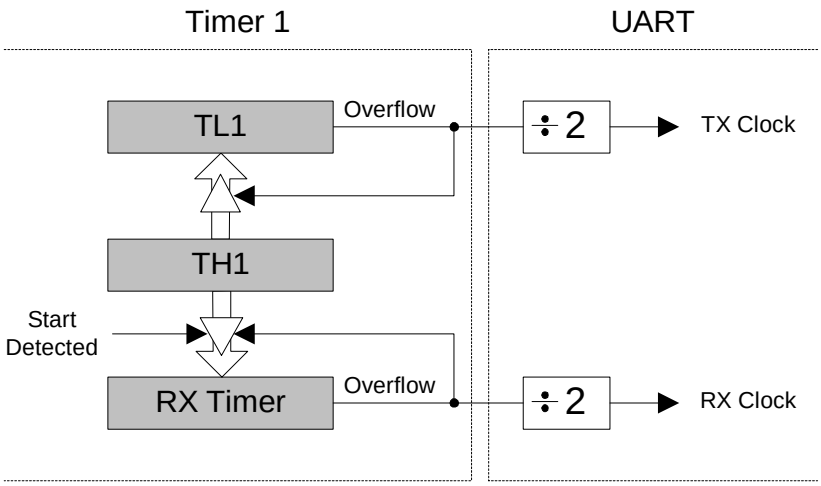


**Figure 22.2. UART0 Baud Rate Logic**

Timer 1 should be configured for Mode 2, 8-bit auto-reload (see **Section "23.2.2. Mode 2: 8-bit Counter/Timer with Auto-Reload" on page 245**). The Timer 1 reload value should be set so that overflows will occur at two times the desired UART baud rate frequency. Timer 1 may be clocked by one of six sources: SYSCLK, SYSCLK/4, SYSCLK/12, SYSCLK/48, the external oscillator clock/8, or an external input T1. The UART0 baud rate is determined by Equation 22.1-A and Equation 22.1-B.

A) $$\text{UartBaudRate} = \frac{1}{2} \times \text{T1\_Overflow\_Rate}$$

B) $$\text{T1\_Overflow\_Rate} = \frac{\text{T1}_{\text{CLK}}}{256 - \text{TH1}}$$

**Equation 22.1. UART0 Baud Rate**

Where $T1_{CLK}$ is the frequency of the clock supplied to Timer 1, and *T1H* is the high byte of Timer 1 (8-bit auto-reload mode reload value). Timer 1 clock frequency is selected as described in **Section "23. Timers" on page 243**. A quick reference for typical baud rates and system clock frequencies is given in Table 22.1 through Table 22.6. Note that the internal oscillator may still generate the system clock when the external oscillator is driving Timer 1.

## 22.2. Operational Modes

UART0 provides standard asynchronous, full duplex communication. The UART mode (8-bit or 9-bit) is selected by the S0MODE bit (SCON0.7). Typical UART connection options are shown in Figure 22.3.

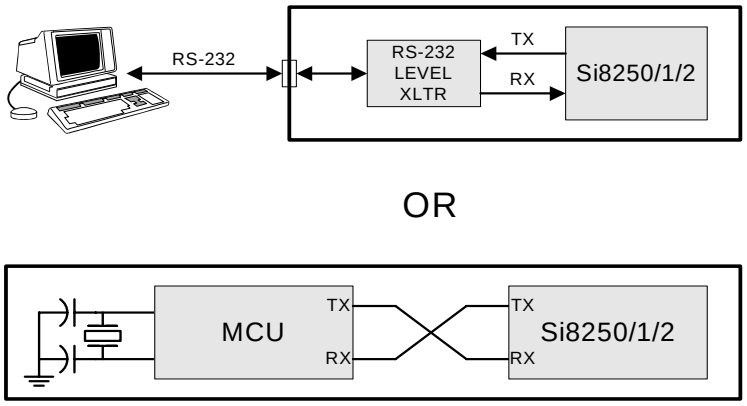


**Figure 22.3. UART Interconnect Diagram**

### 22.2.1. 8-Bit UART

8-Bit UART mode uses a total of 10 bits per data byte: one start bit, eight data bits (LSB first), and one stop bit. Data are transmitted LSB first from the TX0 pin and received at the RX0 pin. On receive, the eight data bits are stored in SBUF0 and the stop bit goes into RB80 (SCON0.2).

Data transmission begins when software writes a data byte to the SBUF0 register. The TI0 Transmit Interrupt Flag (SCON0.1) is set at the end of the transmission (the beginning of the stop-bit time). Data reception can begin any time after the REN0 Receive Enable bit (SCON0.4) is set to logic 1. After the stop bit is received, the data byte will be loaded into the SBUF0 receive register if the following conditions are met: RI0 must be logic 0, and if MCE0 is logic 1, the stop bit must be logic 1. In the event of a receive data overrun, the first received 8 bits are latched into the SBUF0 receive register and the following overrun data bits are lost.

If these conditions are met, the eight bits of data is stored in SBUF0, the stop bit is stored in RB80 and the RI0 flag is set. If these conditions are not met, SBUF0 and RB80 will not be loaded and the RI0 flag will not be set. An interrupt will occur if enabled when either TI0 or RI0 is set.

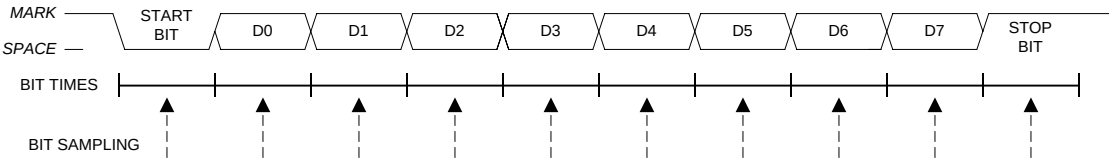


**Figure 22.4. 8-Bit UART Timing Diagram**

### 22.2.2. 9-Bit UART

9-bit UART mode uses a total of eleven bits per data byte: a start bit, 8 data bits (LSB first), a programmable ninth data bit, and a stop bit. The state of the ninth transmit data bit is determined by the value in TB80 (SCON0.3), which is assigned by user software. It can be assigned the value of the parity flag (bit P in register PSW) for error detection, or used in multiprocessor communications. On receive, the ninth data bit goes into RB80 (SCON0.2) and the stop bit is ignored.

Data transmission begins when an instruction writes a data byte to the SBUF0 register. The TI0 Transmit Interrupt Flag (SCON0.1) is set at the end of the transmission (the beginning of the stop-bit time). Data reception can begin any time after the REN0 Receive Enable bit (SCON0.4) is set to '1'. After the stop bit is received, the data byte will be loaded into the SBUF0 receive register if the following conditions are met: (1) RI0 must be logic 0, and (2) if MCE0 is logic 1, the 9th bit must be logic 1 (when MCE0 is logic 0, the state of the ninth data bit is unimportant). If these conditions are met, the eight bits of data are stored in SBUF0, the ninth bit is stored in RB80, and the RI0 flag is set to '1'. If the above conditions are not met, SBUF0 and RB80 will not be loaded and the RI0 flag will not be set to '1'. A UART0 interrupt will occur if enabled when either TI0 or RI0 is set to '1'.

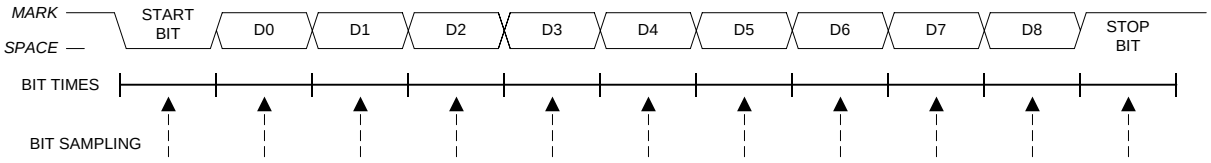


**Figure 22.5. 9-Bit UART Timing Diagram**

## 22.3. Multiprocessor Communications

9-Bit UART mode supports multiprocessor communication between a master processor and one or more slave processors by special use of the ninth data bit. When a master processor wants to transmit to one or more slaves, it first sends an address byte to select the target(s). An address byte differs from a data byte in that its ninth bit is logic 1; in a data byte, the ninth bit is always set to logic 0.

Setting the MCE0 bit (SCON0.5) of a slave processor configures its UART such that when a stop bit is received, the UART will generate an interrupt only if the ninth bit is logic 1 (RB80 = 1) signifying an address byte has been received. In the UART interrupt handler, software will compare the received address with the slave's own assigned 8-bit address. If the addresses match, the slave will clear its MCE0 bit to enable interrupts on the reception of the following data byte(s). Slaves that weren't addressed leave their MCE0 bits set and do not generate interrupts on the reception of the following data bytes, thereby ignoring the data. Once the entire message is received, the addressed slave resets its MCE0 bit to ignore all transmissions until it receives the next address byte.

Multiple addresses can be assigned to a single slave and/or a single address can be assigned to multiple slaves, thereby enabling "broadcast" transmissions to more than one slave simultaneously. The master processor can be configured to receive all transmissions or a protocol can be implemented such that the master/slave role is temporarily reversed to enable half-duplex transmission between the original master and slave(s).

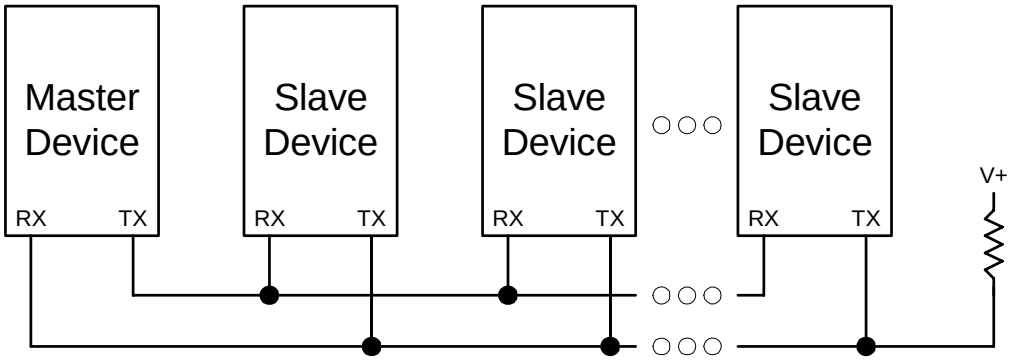


**Figure 22.6. UART Multi-Processor Mode Interconnect Diagram**

## SFR Definition 22.1. SCON0: Serial Port 0 Control

| R/W | — | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| S0MODE | — | MCE0 | REN0 | TB80 | RB80 | TI0 | RI0 | 01000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0x98

Bit 7: S0MODE: Serial Port 0 Operation Mode
This bit selects the UART0 Operation Mode.
0: 8-bit UART with Variable Baud Rate.
1: 9-bit UART with Variable Baud Rate.

Bit 6: Unused. Read = 1b. Write = don't care.

Bit 5: MCE0: Multiprocessor Communication Enable
The function of this bit is dependent on the Serial Port 0 Operation Mode.
S0MODE = 0: Checks for valid stop bit.
0: Logic level of stop bit is ignored.
1: RI0 will only be activated if stop bit is logic level 1.
S0MODE = 1: Multiprocessor Communications Enable.
0: Logic level of ninth bit is ignored.
1: RI0 is set and an interrupt is generated only when the ninth bit is logic 1.

Bit 4: REN0: Receive Enable
This bit enables/disables the UART receiver.
0: UART0 reception disabled.
1: UART0 reception enabled.

Bit 3: TB80: Ninth Transmission Bit
The logic level of this bit will be assigned to the ninth transmission bit in 9-bit UART Mode. It is not used in 8-bit UART Mode. Set or cleared by software as required.

Bit 2: RB80: Ninth Receive Bit
RB80 is assigned the value of the STOP bit in Mode 0; it is assigned the value of the 9th data bit in Mode 1.

Bit 1: TI0: Transmit Interrupt Flag
Set by hardware when a byte of data has been transmitted by UART0 (after the 8th bit in 8-bit UART Mode, or at the beginning of the STOP bit in 9-bit UART Mode). When the UART0 interrupt is enabled, setting this bit causes the CPU to vector to the UART0 interrupt service routine. This bit must be cleared manually by software.

Bit 0: RI0: Receive Interrupt Flag
Set to '1' by hardware when a byte of data has been received by UART0 (set at the STOP bit sampling time). When the UART0 interrupt is enabled, setting this bit to '1' causes the CPU to vector to the UART0 interrupt service routine. This bit must be cleared manually by software.

## SFR Definition 22.2. SBUF0: Serial (UART0) Port Data Buffer

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x99

Bits 7–0: SBUF0[7:0]: Serial Data Buffer Bits 7–0 (MSB-LSB)
This SFR accesses two registers; a transmit shift register and a receive latch register. When data is written to SBUF0, it goes to the transmit shift register and is held for serial transmission. Writing a byte to SBUF0 initiates the transmission. A read of SBUF0 returns the contents of the receive latch.

### Table 22.1. Timer Settings for Standard Baud Rates Using the Internal Oscillator

| | Frequency: 24.5 MHz | | | | | | |
|---|---|---|---|---|---|---|---|
| | Target Baud Rate (bps) | Baud Rate % Error | Oscilla-tor Divide Factor | Timer Clock Source | SCA1-SCA0 (pre-scale select)* | T1M* | Timer 1 Reload Value (hex) |
| | 230400 | -0.32% | 106 | SYSCLK | XX | 1 | 0xCB |
| | 115200 | -0.32% | 212 | SYSCLK | XX | 1 | 0x96 |
| | 57600 | 0.15% | 426 | SYSCLK | XX | 1 | 0x2B |
| | 28800 | -0.32% | 848 | SYSCLK / 4 | 01 | 0 | 0x96 |
| | 14400 | 0.15% | 1704 | SYSCLK / 12 | 00 | 0 | 0xB9 |
| | 9600 | -0.32% | 2544 | SYSCLK / 12 | 00 | 0 | 0x96 |
| | 2400 | -0.32% | 10176 | SYSCLK / 48 | 10 | 0 | 0x96 |
| | 1200 | 0.15% | 20448 | SYSCLK / 48 | 10 | 0 | 0x2B |

X = Don't care

***Note:** SCA1-SCA0 and T1M bit definitions can be found in **Section 23.1**.

### Table 22.2. Timer Settings for Standard Baud Rates Using an External 25.0 MHz Oscillator

| | Frequency: 25.0 MHz | | | | | | |
|---|---|---|---|---|---|---|---|
| | Target Baud Rate (bps) | Baud Rate % Error | Oscilla-tor Divide Factor | Timer Clock Source | SCA1-SCA0 (pre-scale select)* | T1M* | Timer 1 Reload Value (hex) |
| | 230400 | -0.47% | 108 | SYSCLK | XX | 1 | 0xCA |
| | 115200 | 0.45% | 218 | SYSCLK | XX | 1 | 0x93 |
| | 57600 | -0.01% | 434 | SYSCLK | XX | 1 | 0x27 |
| | 28800 | 0.45% | 872 | SYSCLK / 4 | 01 | 0 | 0x93 |
| | 14400 | -0.01% | 1736 | SYSCLK / 4 | 01 | 0 | 0x27 |
| | 9600 | 0.15% | 2608 | EXTCLK / 8 | 11 | 0 | 0x5D |
| | 2400 | 0.45% | 10464 | SYSCLK / 48 | 10 | 0 | 0x93 |
| | 1200 | -0.01% | 20832 | SYSCLK / 48 | 10 | 0 | 0x27 |
| | 57600 | -0.47% | 432 | EXTCLK / 8 | 11 | 0 | 0xE5 |
| | 28800 | -0.47% | 864 | EXTCLK / 8 | 11 | 0 | 0xCA |
| | 14400 | 0.45% | 1744 | EXTCLK / 8 | 11 | 0 | 0x93 |
| | 9600 | 0.15% | 2608 | EXTCLK / 8 | 11 | 0 | 0x5D |

X = Don't care

***Note:** SCA1-SCA0 and T1M bit definitions can be found in **Section 23.1**.

### Table 22.3. Timer Settings for Standard Baud Rates Using an External 22.1184 MHz Oscillator

| | Frequency: 22.1184 MHz | | | | | | |
|---|---|---|---|---|---|---|---|
| | Target Baud Rate (bps) | Baud Rate % Error | Oscilla-tor Divide Factor | Timer Clock Source | SCA1-SCA0 (pre-scale select)* | T1M* | Timer 1 Reload Value (hex) |
| | 230400 | 0.00% | 96 | SYSCLK | XX | 1 | 0xD0 |
| | 115200 | 0.00% | 192 | SYSCLK | XX | 1 | 0xA0 |
| | 57600 | 0.00% | 384 | SYSCLK | XX | 1 | 0x40 |
| | 28800 | 0.00% | 768 | SYSCLK / 12 | 00 | 0 | 0xE0 |
| | 14400 | 0.00% | 1536 | SYSCLK / 12 | 00 | 0 | 0xC0 |
| | 9600 | 0.00% | 2304 | SYSCLK / 12 | 00 | 0 | 0xA0 |
| | 2400 | 0.00% | 9216 | SYSCLK / 48 | 10 | 0 | 0xA0 |
| | 1200 | 0.00% | 18432 | SYSCLK / 48 | 10 | 0 | 0x40 |
| | 230400 | 0.00% | 96 | EXTCLK / 8 | 11 | 0 | 0xFA |
| | 115200 | 0.00% | 192 | EXTCLK / 8 | 11 | 0 | 0xF4 |
| | 57600 | 0.00% | 384 | EXTCLK / 8 | 11 | 0 | 0xE8 |
| | 28800 | 0.00% | 768 | EXTCLK / 8 | 11 | 0 | 0xD0 |
| | 14400 | 0.00% | 1536 | EXTCLK / 8 | 11 | 0 | 0xA0 |
| | 9600 | 0.00% | 2304 | EXTCLK / 8 | 11 | 0 | 0x70 |

X = Don't care

***Note:** SCA1-SCA0 and T1M bit definitions can be found in **Section 23.1**.

### Table 22.4. Timer Settings for Standard Baud Rates Using an External 18.432 MHz Oscillator

| | Frequency: 18.432 MHz | | | | | | |
|---|---|---|---|---|---|---|---|
| | Target Baud Rate (bps) | Baud Rate % Error | Oscilla-tor Divide Factor | Timer Clock Source | SCA1-SCA0 (pre-scale select)* | T1M* | Timer 1 Reload Value (hex) |
| | 230400 | 0.00% | 80 | SYSCLK | XX | 1 | 0xD8 |
| | 115200 | 0.00% | 160 | SYSCLK | XX | 1 | 0xB0 |
| | 57600 | 0.00% | 320 | SYSCLK | XX | 1 | 0x60 |
| | 28800 | 0.00% | 640 | SYSCLK / 4 | 01 | 0 | 0xB0 |
| | 14400 | 0.00% | 1280 | SYSCLK / 4 | 01 | 0 | 0x60 |
| | 9600 | 0.00% | 1920 | SYSCLK / 12 | 00 | 0 | 0xB0 |
| | 2400 | 0.00% | 7680 | SYSCLK / 48 | 10 | 0 | 0xB0 |
| | 1200 | 0.00% | 15360 | SYSCLK / 48 | 10 | 0 | 0x60 |
| | 230400 | 0.00% | 80 | EXTCLK / 8 | 11 | 0 | 0xFB |
| | 115200 | 0.00% | 160 | EXTCLK / 8 | 11 | 0 | 0xF6 |
| | 57600 | 0.00% | 320 | EXTCLK / 8 | 11 | 0 | 0xEC |
| | 28800 | 0.00% | 640 | EXTCLK / 8 | 11 | 0 | 0xD8 |
| | 14400 | 0.00% | 1280 | EXTCLK / 8 | 11 | 0 | 0xB0 |
| | 9600 | 0.00% | 1920 | EXTCLK / 8 | 11 | 0 | 0x88 |

X = Don't care

***Note:** SCA1-SCA0 and T1M bit definitions can be found in **Section 23.1**.

**Table 22.5. Timer Settings for Standard Baud Rates Using an External 11.0592 MHz Oscillator**

| | Frequency: 11.0592 MHz | | | | | | |
|---|---|---|---|---|---|---|---|
| | Target Baud Rate (bps) | Baud Rate % Error | Oscilla-tor Divide Factor | Timer Clock Source | SCA1-SCA0 (pre-scale select)* | T1M* | Timer 1 Reload Value (hex) |
| | 230400 | 0.00% | 48 | SYSCLK | XX | 1 | 0xE8 |
| | 115200 | 0.00% | 96 | SYSCLK | XX | 1 | 0xD0 |
| | 57600 | 0.00% | 192 | SYSCLK | XX | 1 | 0xA0 |
| | 28800 | 0.00% | 384 | SYSCLK | XX | 1 | 0x40 |
| | 14400 | 0.00% | 768 | SYSCLK / 12 | 00 | 0 | 0xE0 |
| | 9600 | 0.00% | 1152 | SYSCLK / 12 | 00 | 0 | 0xD0 |
| | 2400 | 0.00% | 4608 | SYSCLK / 12 | 00 | 0 | 0x40 |
| | 1200 | 0.00% | 9216 | SYSCLK / 48 | 10 | 0 | 0xA0 |
| | 230400 | 0.00% | 48 | EXTCLK / 8 | 11 | 0 | 0xFD |
| | 115200 | 0.00% | 96 | EXTCLK / 8 | 11 | 0 | 0xFA |
| | 57600 | 0.00% | 192 | EXTCLK / 8 | 11 | 0 | 0xF4 |
| | 28800 | 0.00% | 384 | EXTCLK / 8 | 11 | 0 | 0xE8 |
| | 14400 | 0.00% | 768 | EXTCLK / 8 | 11 | 0 | 0xD0 |
| | 9600 | 0.00% | 1152 | EXTCLK / 8 | 11 | 0 | 0xB8 |

X = Don't care

***Note:** SCA1-SCA0 and T1M bit definitions can be found in **Section 23.1**.

**Table 22.6. Timer Settings for Standard Baud Rates Using an External 3.6864 MHz Oscillator**

| | Frequency: 3.6864 MHz | | | | | | |
|---|---|---|---|---|---|---|---|
| | Target Baud Rate (bps) | Baud Rate % Error | Oscilla-tor Divide Factor | Timer Clock Source | SCA1-SCA0 (pre-scale select)* | T1M* | Timer 1 Reload Value (hex) |
| | 230400 | 0.00% | 16 | SYSCLK | XX | 1 | 0xF8 |
| | 115200 | 0.00% | 32 | SYSCLK | XX | 1 | 0xF0 |
| | 57600 | 0.00% | 64 | SYSCLK | XX | 1 | 0xE0 |
| | 28800 | 0.00% | 128 | SYSCLK | XX | 1 | 0xC0 |
| | 14400 | 0.00% | 256 | SYSCLK | XX | 1 | 0x80 |
| | 9600 | 0.00% | 384 | SYSCLK | XX | 1 | 0x40 |
| | 2400 | 0.00% | 1536 | SYSCLK / 12 | 00 | 0 | 0xC0 |
| | 1200 | 0.00% | 3072 | SYSCLK / 12 | 00 | 0 | 0x80 |
| | 230400 | 0.00% | 16 | EXTCLK / 8 | 11 | 0 | 0xFF |
| | 115200 | 0.00% | 32 | EXTCLK / 8 | 11 | 0 | 0xFE |
| | 57600 | 0.00% | 64 | EXTCLK / 8 | 11 | 0 | 0xFC |
| | 28800 | 0.00% | 128 | EXTCLK / 8 | 11 | 0 | 0xF8 |
| | 14400 | 0.00% | 256 | EXTCLK / 8 | 11 | 0 | 0xF0 |
| | 9600 | 0.00% | 384 | EXTCLK / 8 | 11 | 0 | 0xE8 |

X = Don't care

***Note:** SCA1-SCA0 and T1M bit definitions can be found in **Section 23.1**.

# 23. Timers

Each Si825x includes four counter/timers: two are 16-bit counter/timers compatible with those found in the standard 8051, and two are 16-bit auto-reload timers for use with other device peripherals or for general purpose use. These timers can be used to measure time intervals, count external events, and generate periodic interrupt requests. Timer 0 and Timer 1 are nearly identical and have four primary modes of operation. Timer 2 and Timer 3 offer 16-bit and split 8-bit timer functionality with auto-reload.

**Table 23.1. Timer Modes**

| Timer 0 and Timer 1 Modes: | Timer 2 Modes: | Timer 3 Modes: |
|---|---|---|
| 13-bit counter/timer | 16-bit timer with auto-reload | 16-bit timer with auto-reload |
| 10-bit counter/timer | | |
| 8-bit counter/timer with auto-reload | Two 8-bit timers with auto-reload | Two 8-bit timers with auto-reload |
| Two 8-bit counter/timers (Timer 0 only) | | |

Timers 0 and 1 may be clocked by one of five sources, determined by the Timer Mode Select bits (T1M-T0M) and the Clock Scale bits (SCA1-SCA0). The Clock Scale bits define a pre-scaled clock from which Timer 0 and/or Timer 1 may be clocked. (See SFR Definition 23.3 for pre-scaled clock selection.)

Timer 0/1 may then be configured to use this pre-scaled clock signal or the system clock. Timer 2 and Timer 3 may be clocked by the system clock, the system clock divided by 12, or the external oscillator clock source divided by 8.

Timer 0 and Timer 1 may also be operated as counters. When functioning as a counter, a counter/timer register is incremented on each high-to-low transition at the selected input pin (T0 or T1). Events with a frequency of up to one-fourth the system clock's frequency can be counted. The input signal need not be periodic, but it must be held at a given level for at least two full system clock cycles to ensure the level is properly sampled.

## 23.1. Timer 0 and Timer 1

Each timer is implemented as a 16-bit register accessed as two separate bytes: a low byte (TL0 or TL1) and a high byte (TH0 or TH1). The Counter/Timer Control register (TCON) is used to enable Timer 0 and Timer 1 as well as indicate status. Timer 0 interrupts can be enabled by setting the ET0 bit in the IE register (Section "**16.12. Interrupt Register Descriptions**" on page **139**); Timer 1 interrupts can be enabled by setting the ET1 bit in the IE register (**Section 16.12**). Both counter/timers operate in one of four primary modes selected by setting the Mode Select bits T1M1-T0M0 in the Counter/Timer Mode register (TMOD). Each timer can be configured independently. Each operating mode is described below.

## 23.2. Mode 0 13-bit Counter/Timer

Timer 0 and Timer 1 operate as 13-bit counter/timers in Mode 0. The following describes the configuration and operation of Timer 0. However, both timers operate identically, and Timer 1 is configured in the same manner as described for Timer 0.

The TH0 register holds the eight MSBs of the 13-bit counter/timer. TL0 holds the five LSBs in bit positions TL0.4-TL0.0. The three upper bits of TL0 (TL0.7–TL0.5) are indeterminate and should be masked out or ignored when reading. As the 13-bit timer register increments and overflows from 0x1FFF (all ones) to 0x0000, the timer overflow flag TF0 (TCON.5) is set and an interrupt will occur if Timer 0 interrupts are enabled.

The C/T0 bit (TMOD.2) selects the counter/timer's clock source. When C/T0 is set to logic 1, high-to-low transitions at the selected Timer 0 input pin (T0) increment the timer register (Refer to Section "**19.1. Priority Crossbar Decoder**" on page **197** for information on selecting and configuring external I/O pins). Clearing C/T selects the clock defined by the T0M bit (CKCON.3). When T0M is set, Timer 0 is clocked by the system clock. When T0M is cleared, Timer 0 is clocked by the source selected by the Clock Scale bits in CKCON (see Figure 22.6).

Setting the TR0 bit (TCON.4) enables the timer when either GATE0 (TMOD.3) is logic 0 or the input signal INT0 is active as defined by bit IN0PL in register IT01CF (see SFR Definition 16.7). Setting GATE0 to '1' allows the timer to be controlled by the external input signal INT0 (see Section "**16.12. Interrupt Register Descriptions**" on page **139**), facilitating pulse width measurements.

| TR0 | GATE0 | $\overline{\text{INT0}}$ | Counter/Timer |
|---|---|---|---|
| 0 | X | X | Disabled |
| 1 | 0 | X | Enabled |
| 1 | 1 | 0 | Disabled |
| 1 | 1 | 1 | Enabled |
| **Note:** X = Don't care. | | | |

Setting TR0 does not force the timer to reset. The timer registers should be loaded with the desired initial value before the timer is enabled.

TL1 and TH1 form the 13-bit register for Timer 1 in the same manner as described above for TL0 and TH0. Timer 1 is configured and controlled using the relevant TCON and TMOD bits just as with Timer 0. The input signal ENABLE is used with Timer 1; the ENABLE polarity is defined by bit IN1PL in register IT01CF (see SFR Definition 16.7).

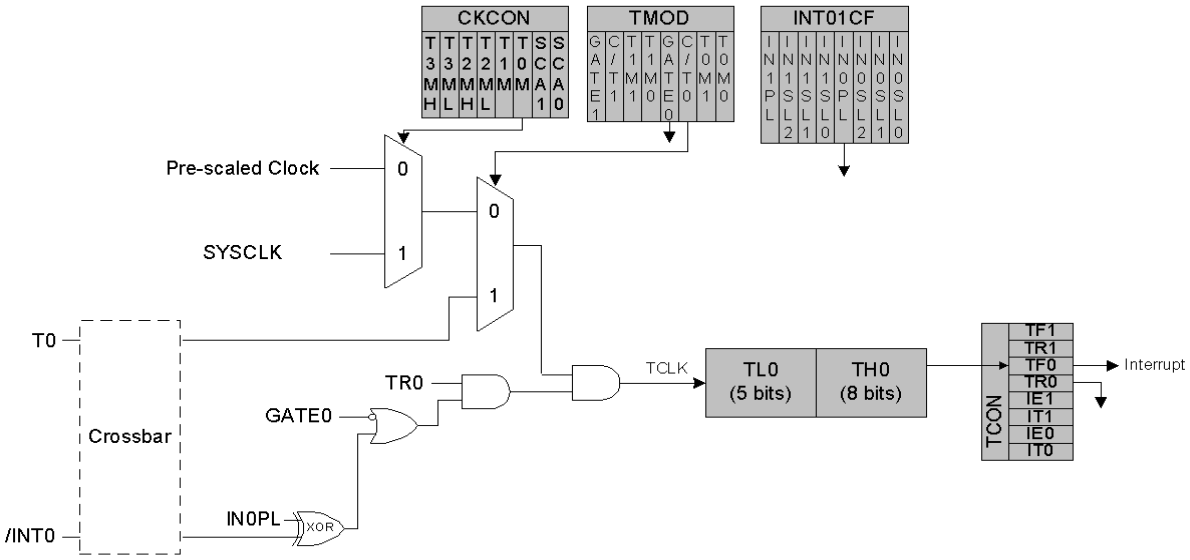


**Figure 23.1. T0 Mode 0 Block Diagram**

### 23.2.1. Mode 1: 16-bit Counter/Timer

Mode 1 operation is the same as Mode 0, except that the counter/timer registers use all 16 bits. The counter/timers are enabled and configured in Mode 1 in the same manner as for Mode 0.

### 23.2.2. Mode 2: 8-bit Counter/Timer with Auto-Reload

Mode 2 configures Timer 0 and Timer 1 to operate as 8-bit counter/timers with automatic reload of the start value. TL0 holds the count and TH0 holds the reload value. When the counter in TL0 overflows from all ones to 0x00, the timer overflow flag TF0 (TCON.5) is set and the counter in TL0 is reloaded from TH0. If Timer 0 interrupts are enabled, an interrupt will occur when the TF0 flag is set. The reload value in TH0 is not changed. TL0 must be initialized to the desired value before enabling the timer for the first count to be correct. When in Mode 2, Timer 1 operates identically to Timer 0. Both counter/timers are enabled and configured in Mode 2 in the same manner as Mode 0. Setting the TR0 bit (TCON.4) enables the timer when either GATE0 (TMOD.3) is logic 0 or when the input signal INT0 is active as defined by bit IN0PL in register IT01CF (see Section "**16.11. External (INT0) and ENABLE Interrupts**" on page **138** for details on the external input signals INT0 and ENABLE).

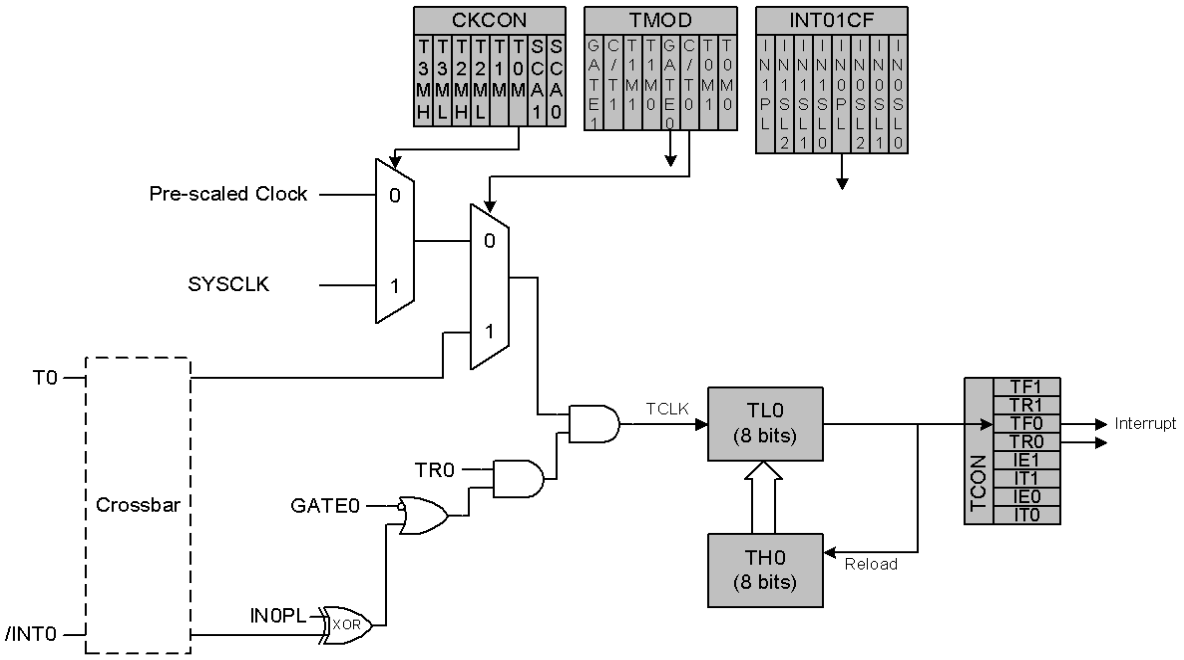


**Figure 23.2. T0 Mode 2 Block Diagram**

### 23.2.3. Mode 3: Two 8-bit Counter/Timers (Timer 0 Only)

In Mode 3, Timer 0 is configured as two separate 8-bit counter/timers held in TL0 and TH0. The counter/timer in TL0 is controlled using the Timer 0 control/status bits in TCON and TMOD: TR0, C/T0, GATE0 and TF0. TL0 can use either the system clock or an external input signal as its time base. The TH0 register is restricted to a timer function sourced by the system clock or pre-scaled clock. TH0 is enabled using the Timer 1 run control bit TR1. TH0 sets the Timer 1 overflow flag TF1 on overflow and thus controls the Timer 1 interrupt. Timer 1 is inactive in Mode 3.

When Timer 0 is operating in Mode 3, Timer 1 can be operated in Modes 0, 1 or 2, but cannot be clocked by external signals nor set the TF1 flag and generate an interrupt. However, the Timer 1 overflow can be used to generate baud rates for the SMBus and UART. While Timer 0 is operating in Mode 3, Timer 1 run control is handled through its mode settings. To run Timer 1 while Timer 0 is in Mode 3, set the Timer 1 Mode as 0, 1, or 2. To disable Timer 1, configure it for Mode 3.

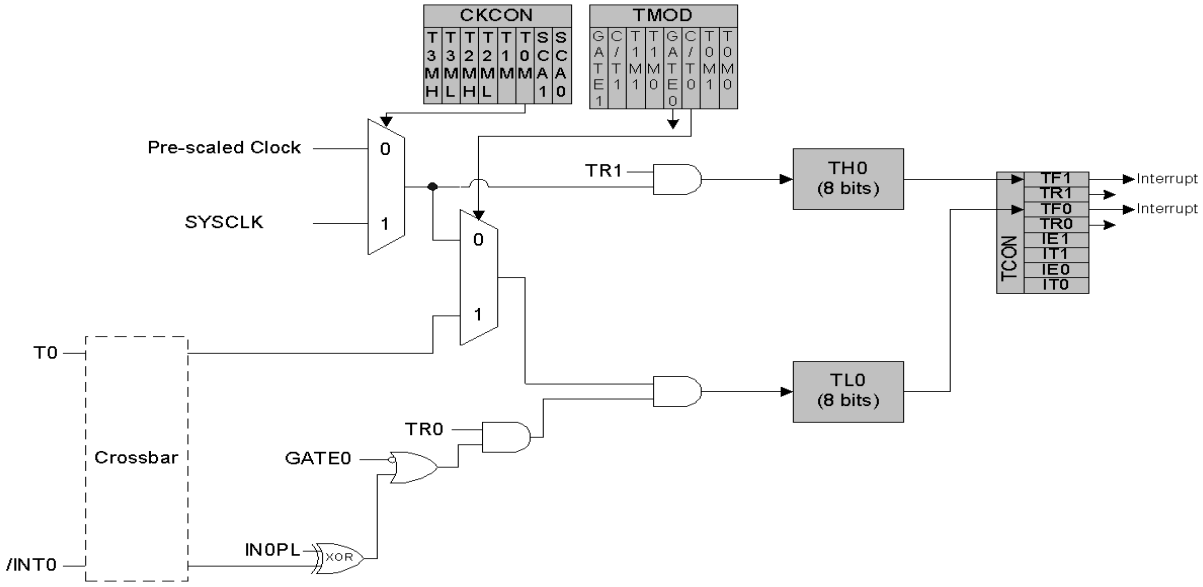


**Figure 23.3. T0 Mode 3 Block Diagram**

## SFR Definition 23.1. TCON: Timer Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TF1 | TR1 | TF0 | TR0 | ENABX | IT1 | IE0 | IT0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0x88

Bit 7: TF1: Timer 1 Overflow Flag
Set by hardware when Timer 1 overflows. This flag can be cleared by software but is automatically cleared when the CPU vectors to the Timer 1 interrupt service routine.
0: No Timer 1 overflow detected.
1: Timer 1 has overflowed.

Bit 6: TR1: Timer 1 Run Control
0: Timer 1 disabled.
1: Timer 1 enabled.

Bit 5: TF0: Timer 0 Overflow Flag
Set by hardware when Timer 0 overflows. This flag can be cleared by software but is automatically cleared when the CPU vectors to the Timer 0 interrupt service routine.
0: No Timer 0 overflow detected.
1: Timer 0 has overflowed.

Bit 4: TR0: Timer 0 Run Control
0: Timer 0 disabled.
1: Timer 0 enabled.

Bit 3: ENABX: External ENABLE Interrupt
This flag is set by hardware when an edge/level of type defined by IT1 is detected. It can be cleared by software but is automatically cleared when the CPU vectors to the External Interrupt 1 service routine if IT1 = 1. When IT1 = 0, this flag is set to '1' when ENABLE is active as defined by bit IN1PL in register IT01CF (see SFR Definition 16.7. "IT01CF: INT0/ENABLE Input Configuration" on page 145).

Bit 2: IT1: ENABLE Interrupt Type Select
This bit selects whether the configured ENABLE interrupt will be edge or level sensitive. ENABLE is configured active low or high by the IN1PL bit in the IT01CF register (see SFR Definition 16.7. "IT01CF: INT0/ENABLE Input Configuration" on page 145).
0: ENABLE is level triggered.
1: ENABLE is edge triggered.

Bit 1: IE0: External Interrupt 0
This flag is set by hardware when an edge/level of type defined by IT0 is detected. It can be cleared by software but is automatically cleared when the CPU vectors to the External Interrupt 0 service routine if IT0 = 1. When IT0 = 0, this flag is set to '1' when $\overline{\text{INT0}}$ is active as defined by bit IN0PL in register IT01CF (see SFR Definition 16.7. "IT01CF: INT0/ENABLE Input Configuration" on page 145).

Bit 0: IT0: Interrupt 0 Type Select
This bit selects whether the configured $\overline{\text{INT0}}$ interrupt will be edge or level sensitive. $\overline{\text{INT0}}$ is configured active low or high by the IN0PL bit in register IT01CF (see SFR Definition 16.7. "IT01CF: INT0/ENABLE Input Configuration" on page 145).
0: $\overline{\text{INT0}}$ is level triggered.
1: $\overline{\text{INT0}}$ is edge triggered.

## SFR Definition 23.2. TMOD: Timer Mode

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| GATE1 | C/T1 | T1M1 | T1M0 | GATE0 | C/T0 | T0M1 | T0M0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x89

Bit 7: GATE1: Timer 1 Gate Control
0: Timer 1 enabled when TR1 = 1 irrespective of ENABLE logic level.
1: Timer 1 enabled only when TR1 = 1 AND ENABLE is active as defined by bit IN1PL in register IT01CF (see SFR Definition 16.7. “IT01CF: INT0/ENABLE Input Configuration” on page 145).

Bit 6: C/T1: Counter/Timer 1 Select
0: Timer Function: Timer 1 incremented by clock defined by T1M bit (CKCON.4).
1: Counter Function: Timer 1 incremented by high-to-low transitions on external input pin (T1).

Bits 5–4: T1M[1:0]: Timer 1 Mode Select
These bits select the Timer 1 operation mode.

| T1M1 | T1M0 | Mode |
|---|---|---|
| 0 | 0 | Mode 0: 13-bit counter/timer |
| 0 | 1 | Mode 1: 16-bit counter/timer |
| 1 | 0 | Mode 2: 8-bit counter/timer with auto-reload |
| 1 | 1 | Mode 3: Timer 1 inactive |

Bit 3: GATE0: Timer 0 Gate Control
0: Timer 0 enabled when TR0 = 1 irrespective of $\overline{\text{INT0}}$ logic level.
1: Timer 0 enabled only when TR0 = 1 AND $\overline{\text{INT0}}$ is active as defined by bit IN0PL in register IT01CF (see SFR Definition 16.7. “IT01CF: INT0/ENABLE Input Configuration” on page 145).

Bit 2: C/T0: Counter/Timer Select
0: Timer Function: Timer 0 incremented by clock defined by T0M bit (CKCON.3).
1: Counter Function: Timer 0 incremented by high-to-low transitions on external input pin (T0).

Bits 1–0: T0M[1:0]: Timer 0 Mode Select
These bits select the Timer 0 operation mode.

| T0M1 | T0M0 | Mode |
|---|---|---|
| 0 | 0 | Mode 0: 13-bit counter/timer |
| 0 | 1 | Mode 1: 16-bit counter/timer |
| 1 | 0 | Mode 2: 8-bit counter/timer with auto-reload |
| 1 | 1 | Mode 3: Two 8-bit counter/timers |

## SFR Definition 23.3. CKCON: Clock Control

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| T3MH | T3ML | T2MH | T2ML | T1M | T0M | SCA1 | SCA0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x8E

Bit 7: T3MH: Timer 3 High Byte Clock Select
This bit selects the clock supplied to the Timer 3 high byte if Timer 3 is configured in split 8-bit timer mode. T3MH is ignored if Timer 3 is in any other mode.
0: Timer 3 high byte uses the clock defined by the T3XCLK bit in TMR3CN.
1: Timer 3 high byte uses the system clock.

Bit 6: T3ML: Timer 3 Low Byte Clock Select
This bit selects the clock supplied to Timer 3. If Timer 3 is configured in split 8-bit timer mode, this bit selects the clock supplied to the lower 8-bit timer.
0: Timer 3 low byte uses the clock defined by the T3XCLK bit in TMR3CN.
1: Timer 3 low byte uses the system clock.

Bit 5: T2MH: Timer 2 High Byte Clock Select
This bit selects the clock supplied to the Timer 2 high byte if Timer 2 is configured in split 8-bit timer mode. T2MH is ignored if Timer 2 is in any other mode.
0: Timer 2 high byte uses the clock defined by the T2XCLK bit in TMR2CN.
1: Timer 2 high byte uses the system clock.

Bit 4: T2ML: Timer 2 Low Byte Clock Select
This bit selects the clock supplied to Timer 2. If Timer 2 is configured in split 8-bit timer mode, this bit selects the clock supplied to the lower 8-bit timer.
0: Timer 2 low byte uses the clock defined by the T2XCLK bit in TMR2CN.
1: Timer 2 low byte uses the system clock.

Bit 3: T1M: Timer 1 Clock Select
This select the clock source supplied to Timer 1. T1M is ignored when C/T1 is set to logic 1.
0: Timer 1 uses the clock defined by the prescale bits, SCA[1:0].
1: Timer 1 uses the system clock.

Bit 2: T0M: Timer 0 Clock Select
This bit selects the clock source supplied to Timer 0. T0M is ignored when C/T0 is set to logic 1.
0: Counter/Timer 0 uses the clock defined by the prescale bits, SCA[1:0].
1: Counter/Timer 0 uses the system clock.

Bits 1–0: SCA[1:0]: Timer 0/1 Prescale Bits
These bits control the division of the clock supplied to Timer 0 and Timer 1 if configured to use prescaled clock inputs.

| SCA1 | SCA0 | Prescaled Clock |
|---|---|---|
| 0 | 0 | System clock divided by 12 |
| 0 | 1 | System clock divided by 4 |
| 1 | 0 | System clock divided by 48 |
| 1 | 1 | External clock divided by 8 |

**Note:** External clock divided by 8 is synchronized with the system clock.

### SFR Definition 23.4. TL0: Timer 0 Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x8A

Bits 7–0: TL0: Timer 0 Low Byte
The TL0 register is the low byte of the 16-bit Timer 0.

### SFR Definition 23.5. TL1: Timer 1 Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x8B

Bits 7–0: TL1: Timer 1 Low Byte
The TL1 register is the low byte of the 16-bit Timer 1.

### SFR Definition 23.6. TH0: Timer 0 High Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x8C

Bits 7–0: TH0: Timer 0 High Byte
The TH0 register is the high byte of the 16-bit Timer 0.

### SFR Definition 23.7. TH1: Timer 1 High Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x8D

Bits 7–0: TH1: Timer 1 High Byte
The TH1 register is the high byte of the 16-bit Timer 1.

## 23.3. Timer 2

Timer 2 is a 16-bit timer formed by two 8-bit SFRs: TMR2L (low byte) and TMR2H (high byte). Timer 2 may operate in 16-bit auto-reload mode or (split) 8-bit auto-reload mode. The T2SPLIT bit (TMR2CN.3) defines the Timer 2 operation mode. Timer 2 can also be used in Capture Mode to measure the LFO frequency with respect to another.

Timer 2 may be clocked by the system clock, the system clock divided by 12, or the external oscillator source divided by 8. Note that the external oscillator source divided by 8 is synchronized with the system clock.

### 23.3.1. 16-bit Timer with Auto-Reload

When T2SPLIT (TMR2CN.3) is zero, Timer 2 operates as a 16-bit timer with auto-reload. Timer 2 can be clocked by SYSCLK, SYSCLK divided by 12, or the external oscillator clock source divided by 8. As the 16-bit timer register increments and overflows from 0xFFFF to 0x0000, the 16-bit value in the Timer 2 reload registers (TMR2RLH and TMR2RLL) is loaded into the Timer 2 register as shown in Figure 23.4, and the Timer 2 High Byte Overflow Flag (TMR2CN.7) is set. If Timer 2 interrupts are enabled (if IE.5 is set), an interrupt will be generated on each Timer 2 overflow. Additionally, if Timer 2 interrupts are enabled and the TF2LEN bit is set (TMR2CN.5), an interrupt will be generated each time the lower 8 bits (TMR2L) overflow from 0xFF to 0x00.

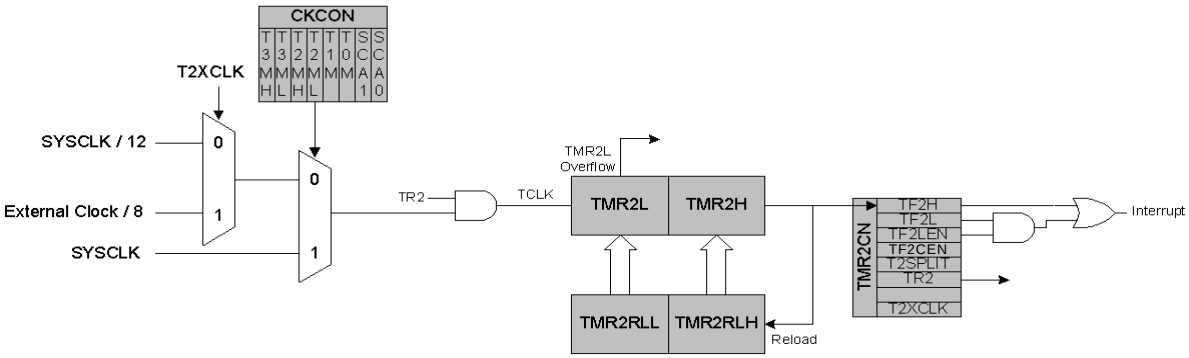


**Figure 23.4. Timer 2 16-Bit Mode Block Diagram**

### 23.3.2. 8-bit Timers with Auto-Reload

When T2SPLIT is set, Timer 2 operates as two 8-bit timers (TMR2H and TMR2L). Both 8-bit timers operate in auto-reload mode as shown in Figure 23.5. TMR2RLL holds the reload value for TMR2L; TMR2RLH holds the reload value for TMR2H. The TR2 bit in TMR2CN handles the run control for TMR2H. TMR2L is always running when configured for 8-bit Mode.

Each 8-bit timer may be configured to use SYSCLK, SYSCLK divided by 12, or the external oscillator clock source divided by 8. The Timer 2 Clock Select bits (T2MH and T2ML in CKCON) select either SYSCLK or the clock defined by the Timer 2 External Clock Select bit (T2XCLK in TMR2CN), as follows:

| T2MH | T2XCLK | TMR2H Clock Source |
|---|---|---|
| 0 | 0 | SYSCLK / 12 |
| 0 | 1 | External Clock / 8 |
| 1 | X | SYSCLK |

| T2ML | T2XCLK | TMR2L Clock Source |
|---|---|---|
| 0 | 0 | SYSCLK / 12 |
| 0 | 1 | External Clock / 8 |
| 1 | X | SYSCLK |

The TF2H bit is set when TMR2H overflows from 0xFF to 0x00; the TF2L bit is set when TMR2L overflows from 0xFF to 0x00. When Timer 2 interrupts are enabled (IE.5), an interrupt is generated each time TMR2H overflows. If Timer 2 interrupts are enabled and TF2LEN (TMR2CN.5) is set, an interrupt is generated each time either TMR2L or TMR2H overflows. When TF2LEN is enabled, software must check the TF2H and TF2L flags to determine the source of the Timer 2 interrupt. The TF2H and TF2L interrupt flags are not cleared by hardware and must be manually cleared by software.

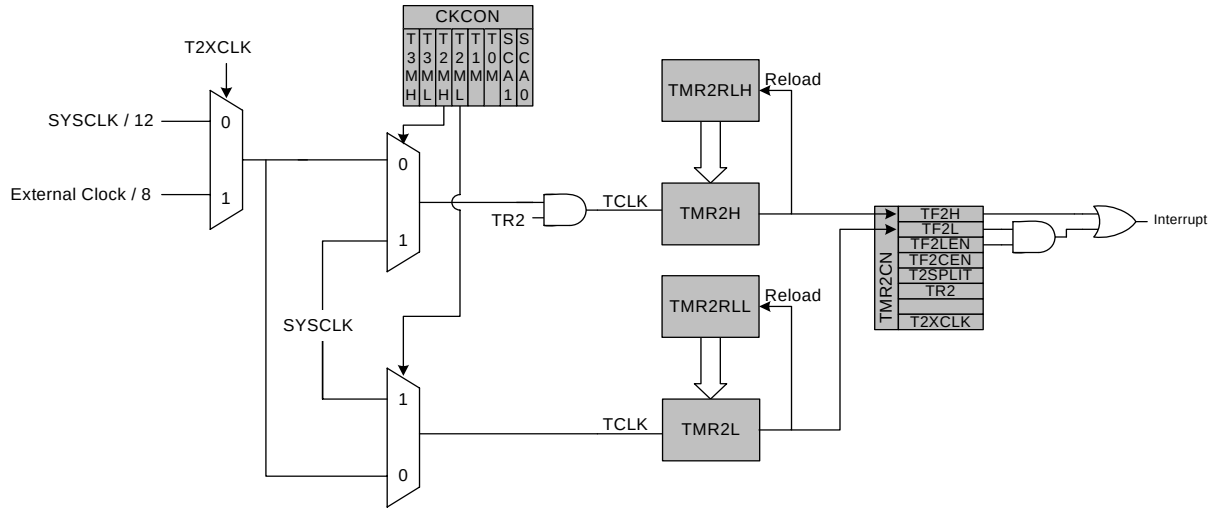


**Figure 23.5. Timer 2 8-Bit Mode Block Diagram**

## SFR Definition 23.8. TMR2CN: Timer 2 Control

| R/W | R/W | R/W | R/W | R/W | R/W | — | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TF2H | TF2L | TF2LEN | TF2CEN | T2SPLIT | TR2 | — | T2XCLK | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0xC8

Bit 7: TF2H: Timer 2 High Byte Overflow Flag
Set by hardware when the Timer 2 high byte overflows from 0xFF to 0x00. In 16 bit mode, this will occur when Timer 2 overflows from 0xFFFF to 0x0000. When the Timer 2 interrupt is enabled, setting this bit causes the CPU to vector to the Timer 2 interrupt service routine. TF2H is not automatically cleared by hardware and must be cleared by software.

Bit 6: TF2L: Timer 2 Low Byte Overflow Flag
Set by hardware when the Timer 2 low byte overflows from 0xFF to 0x00. When this bit is set, an interrupt will be generated if TF2LEN is set and Timer 2 interrupts are enabled. TF2L will set when the low byte overflows regardless of the Timer 2 mode. This bit is not automatically cleared by hardware.

Bit 5: TF2LEN: Timer 2 Low Byte Interrupt Enable
This bit enables/disables Timer 2 Low Byte interrupts. If TF2LEN is set and Timer 2 interrupts are enabled, an interrupt will be generated when the low byte of Timer 2 overflows. This bit should be cleared when operating Timer 2 in 16-bit mode.
0: Timer 2 Low Byte interrupts disabled.
1: Timer 2 Low Byte interrupts enabled.

Bit 4: TF2CEN. Timer 2 Capture Enable
0: Timer 2 capture mode disabled.
1: Timer 2 capture mode enabled. Capture the LFO on every rising edge.

Bit 3: T2SPLIT: Timer 2 Split Mode Enable
When this bit is set, Timer 2 operates as two 8-bit timers with auto-reload.
0: Timer 2 operates in 16-bit auto-reload mode.
1: Timer 2 operates as two 8-bit auto-reload timers.

Bit 2: TR2: Timer 2 Run Control
This bit enables/disables Timer 2. In 8-bit mode, this bit enables/disables TMR2H only; TMR2L is always enabled in this mode.
0: Timer 2 disabled.
1: Timer 2 enabled.

Bit 1: Not implemented

Bit 0: T2XCLK: Timer 2 External Clock Select
This bit selects the external clock source for Timer 2. If Timer 2 is in 8-bit mode, this bit selects the external oscillator clock source for both timer bytes. However, the Timer 2 Clock Select bits (T2MH and T2ML in register CKCON) may still be used to select between the external clock and the system clock for either timer.
0: Timer 2 external clock selection is the system clock divided by 12.
1: Timer 2 external clock uses the clock defined by the T2RCLK bit.

### SFR Definition 23.9. TMR2RLL: Timer 2 Reload Register Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xCA

Bits 7–0: TMR2RLL: Timer 2 Reload Register Low Byte
TMR2RLL holds the low byte of the reload value for Timer 2.

### SFR Definition 23.10. TMR2RLH: Timer 2 Reload Register High Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xCB

Bits 7–0: TMR2RLH: Timer 2 Reload Register High Byte
The TMR2RLH holds the high byte of the reload value for Timer 2.

### SFR Definition 23.11. TMR2L: Timer 2 Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xCC

Bits 7–0: TMR2L: Timer 2 Low Byte
In 16-bit mode, the TMR2L register contains the low byte of the 16-bit Timer 2. In 8-bit mode, TMR2L contains the 8-bit low byte timer value.

### SFR Definition 23.12. TMR2H Timer 2 High Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xCD

Bits 7–0: TMR2H: Timer 2 High Byte
In 16-bit mode, the TMR2H register contains the high byte of the 16-bit Timer 2. In 8-bit mode, TMR2H contains the 8-bit high byte timer value.

## 23.4. Timer 3

Timer 3 is a 16-bit timer formed by two 8-bit SFRs: TMR3L (low byte) and TMR3H (high byte). Timer 3 may operate in 16-bit auto-reload mode or (split) 8-bit auto-reload mode. The T3SPLIT bit (TMR3CN.3) defines the Timer 3 operation mode. Timer 3 can also be used in Capture Mode to measure the LFO clock frequency.

Timer 3 may be clocked by the system clock, the system clock divided by 12, or the external oscillator source divided by 8. Note that the external oscillator source divided by 8 is synchronized with the system clock.

### 23.4.1. 16-bit Timer with Auto-Reload

When T3SPLIT (TMR3CN.3) is zero, Timer 3 operates as a 16-bit timer with auto-reload. Timer 3 can be clocked by SYSCLK, SYSCLK divided by 12, or the external oscillator clock source divided by 8. As the 16-bit timer register increments and overflows from 0xFFFF to 0x0000, the 16-bit value in the Timer 3 reload registers (TMR3RLH and TM3RLL) is loaded into the Timer 3 register as shown in Figure 23.4, and the Timer 3 High Byte Overflow Flag (TMR3CN.7) is set. If Timer 3 interrupts are enabled, an interrupt will be generated on each Timer 3 overflow. Additionally, if Timer 3 interrupts are enabled and the TF3LEN bit is set (TMR3CN.5), an interrupt will be generated each time the lower 8 bits (TMR3L) overflow from 0xFF to 0x00.

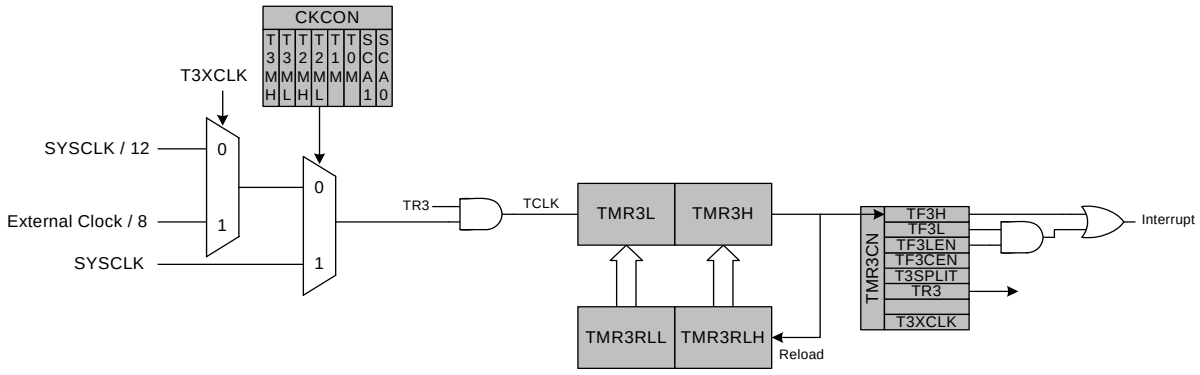


**Figure 23.6. Timer 3 16-Bit Mode Block Diagram**

### 23.4.2. 8-bit Timers with Auto-Reload

When T3SPLIT is set, Timer 3 operates as two 8-bit timers (TMR3H and TMR3L). Both 8-bit timers operate in auto-reload mode as shown in Figure 23.5. TMR3RLL holds the reload value for TMR3L; TMR3RLH holds the reload value for TMR3H. The TR3 bit in TMR3CN handles the run control for TMR3H. TMR3L is always running when configured for 8-bit Mode.

Each 8-bit timer may be configured to use SYSCLK, SYSCLK divided by 12, or the external oscillator clock source divided by 8. The Timer 3 Clock Select bits (T3MH and T3ML in CKCON) select either SYSCLK or the clock defined by the Timer 3 External Clock Select bit (T3XCLK in TMR3CN), as follows:

| T3MH | T3XCLK | TMR3H Clock Source |
|---|---|---|
| 0 | 0 | SYSCLK / 12 |
| 0 | 1 | External Clock / 8 |
| 1 | X | SYSCLK |

| T3ML | T3XCLK | TMR3L Clock Source |
|---|---|---|
| 0 | 0 | SYSCLK / 12 |
| 0 | 1 | External Clock / 8 |
| 1 | X | SYSCLK |

The TF3H bit is set when TMR3H overflows from 0xFF to 0x00; the TF3L bit is set when TMR3L overflows from 0xFF to 0x00. When Timer 3 interrupts are enabled, an interrupt is generated each time TMR3H overflows. If Timer 3 interrupts are enabled and TF3LEN (TMR3CN.5) is set, an interrupt is generated each time either TMR3L or TMR3H overflows. When TF3LEN is enabled, software must check the TF3H and TF3L flags to determine the source of the Timer 3 interrupt. The TF3H and TF3L interrupt flags are not cleared by hardware and must be manually cleared by software.

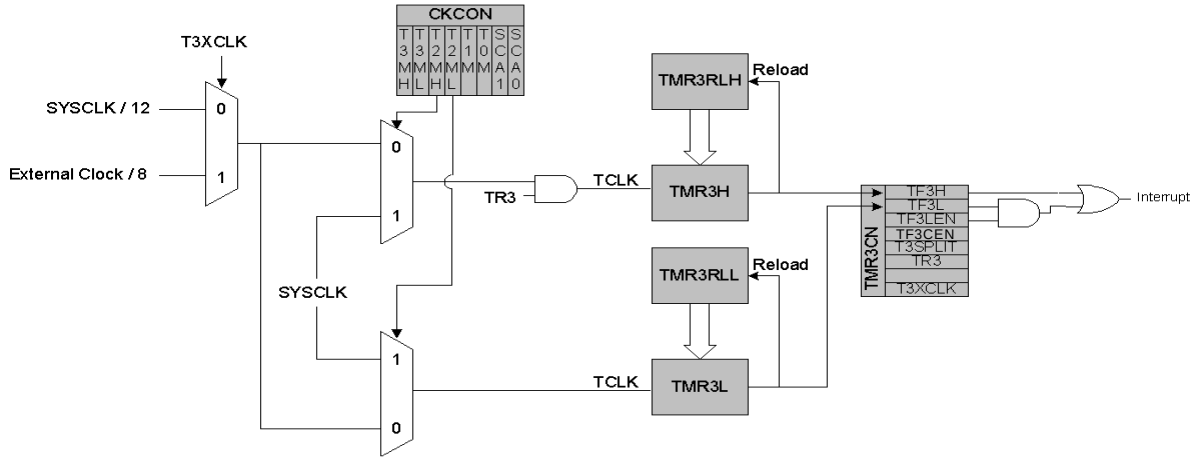


**Figure 23.7. Timer 3 8-Bit Mode Block Diagram**

## SFR Definition 23.13. TMR3CN: Timer 3 Control

| R/W | R/W | R/W | R/W | R/W | R/W | — | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| TF3H | TF3L | TF3LEN | TF3CEN | T3SPLIT | TR3 | — | T3XCLK | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x91

Bit 7: TF3H: Timer 3 High Byte Overflow Flag
Set by hardware when the Timer 3 high byte overflows from 0xFF to 0x00. In 16 bit mode, this will occur when Timer 3 overflows from 0xFFFF to 0x0000. When the Timer 3 interrupt is enabled, setting this bit causes the CPU to vector to the Timer 3 interrupt service routine. TF3H is not automatically cleared by hardware and must be cleared by software.

Bit 6: TF3L: Timer 3 Low Byte Overflow Flag
Set by hardware when the Timer 3 low byte overflows from 0xFF to 0x00. When this bit is set, an interrupt will be generated if TF3LEN is set and Timer 3 interrupts are enabled. TF3L will set when the low byte overflows regardless of the Timer 3 mode. This bit is not automatically cleared by hardware.

Bit 5: TF3LEN: Timer 3 Low Byte Interrupt Enable
This bit enables/disables Timer 3 Low Byte interrupts. If TF3LEN is set and Timer 3 interrupts are enabled, an interrupt will be generated when the low byte of Timer 3 overflows. This bit should be cleared when operating Timer 3 in 16-bit mode.
0: Timer 3 Low Byte interrupts disabled.
1: Timer 3 Low Byte interrupts enabled.

Bit 4: TF3CEN: Timer 3 Capture Enable
0: Timer 3 capture mode disabled.
1: Timer 3 capture mode enabled. Capture the LFO on every rising edge.

Bit 3: T3SPLIT: Timer 3 Split Mode Enable
When this bit is set, Timer 3 operates as two 8-bit timers with auto-reload.
0: Timer 3 operates in 16-bit auto-reload mode.
1: Timer 3 operates as two 8-bit auto-reload timers.

Bit 2: TR3: Timer 3 Run Control
This bit enables/disables Timer 3. In 8-bit mode, this bit enables/disables TMR3H only; TMR3L is always enabled in this mode.
0: Timer 3 disabled.
1: Timer 3 enabled.

Bit 1: Not implemented

Bit 0: T3XCLK: Timer 3 External Clock Select
This bit selects the external clock source for Timer 3. If Timer 3 is in 8-bit mode, this bit selects the external oscillator clock source for both timer bytes. However, the Timer 3 Clock Select bits (T3MH and T3ML in register CKCON) may still be used to select between the external clock and the system clock for either timer.
0: Timer 3 external clock selection is the system clock divided by 12.
1: Timer 3 external clock uses the clock defined by the T3RCLK bit.

### SFR Definition 23.14. TMR3RLL: Timer 3 Reload Register Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x92

Bits 7–0: TMR3RLL: Timer 3 Reload Register Low Byte
TMR3RLL holds the low byte of the reload value for Timer 3.

### SFR Definition 23.15. TMR3RLH: Timer 3 Reload Register High Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x93

Bits 7–0: TMR3RLH: Timer 3 Reload Register High Byte
The TMR3RLH holds the high byte of the reload value for Timer 3.

### SFR Definition 23.16. TMR3L: Timer 3 Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x94

Bits 7–0: TMR3L: Timer 3 Low Byte
In 16-bit mode, the TMR3L register contains the low byte of the 16-bit Timer 3. In 8-bit mode, TMR3L contains the 8-bit low byte timer value.

### SFR Definition 23.17. TMR3H: Timer 3 High Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0x95

Bits 7–0: TMR3H: Timer 3 High Byte
In 16-bit mode, the TMR3H register contains the high byte of the 16-bit Timer 3. In 8-bit mode, TMR3H contains the 8-bit high byte timer value.

## NOTES:

# 24. Programmable Counter Array (PCA0)

The Programmable Counter Array (PCA0) provides enhanced timer functionality while requiring less CPU intervention than the standard 8051 counter/timers. The PCA consists of a dedicated 16-bit counter/timer and three 16-bit capture/compare modules. Each capture/compare module has its own associated I/O line (CEXn) that is routed through the Crossbar to Port I/O when enabled. (See Section "**19.1. Priority Crossbar Decoder**" on page **197** for details on configuring the Crossbar.) The counter/timer is driven by a programmable timebase that can select between seven sources: system clock, system clock divided by four, system clock divided by twelve, the external oscillator clock source divided by 8, Timer 0 overflow, or an external clock signal on the ECI input pin. Each of the three capture/compare module may be configured to operate independently in one of six modes: Edge-Triggered Capture, Software Timer, High-Speed Output, Frequency Output, 8-Bit PWM, or 16-Bit PWM. (Each mode is described in Section "**24.1.1. Capture/Compare Modules**" on page **263**.) The PCA is configured and controlled through the system controller's Special Function Registers. The PCA block diagram is shown in Figure 24.1.

**Important Note:** The PCA Module 2 may be used as a watchdog timer (WDT), and is enabled in this mode following a system reset. Access to certain PCA registers is restricted while WDT mode is enabled. See Section "**24.2. Watchdog Timer Mode**" on page **270** for details.

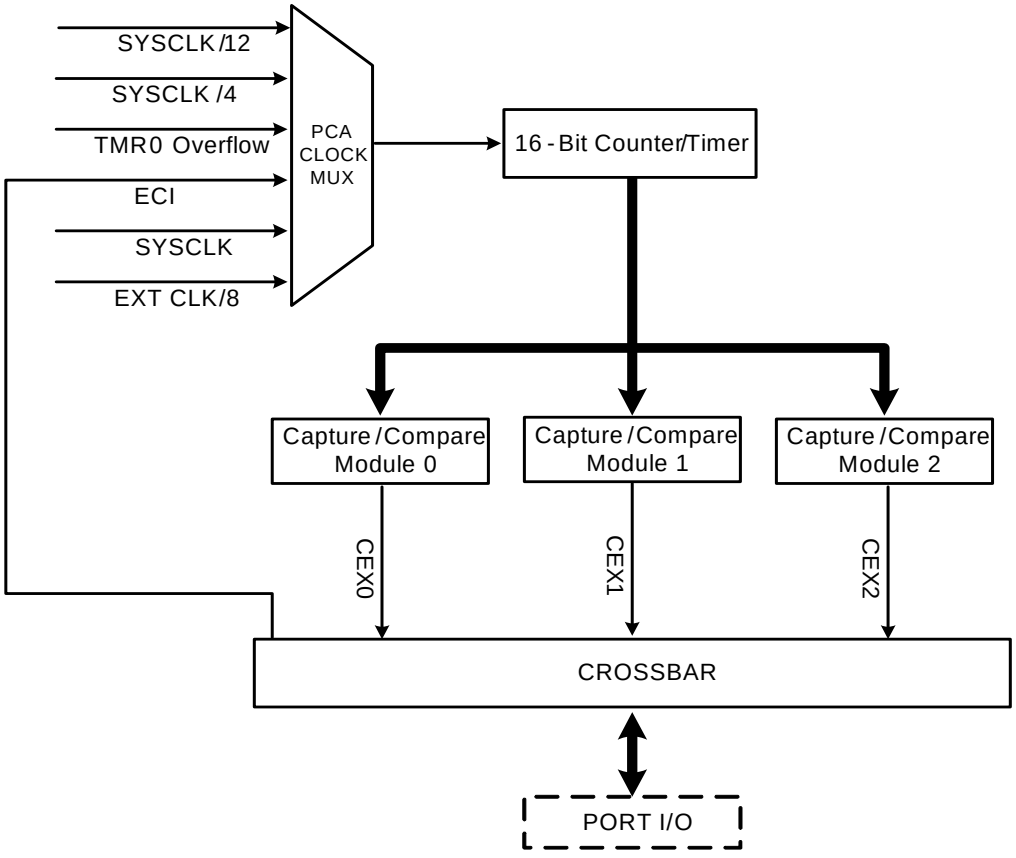


**Figure 24.1. PCA Block Diagram**

## 24.1. PCA Counter/Timer

The 16-bit PCA counter/timer consists of two 8-bit SFRs: PCA0L and PCA0H. PCA0H is the high byte (MSB) of the 16-bit counter/timer and PCA0L is the low byte (LSB). Reading PCA0L automatically latches the value of PCA0H into a "snapshot" register; the following PCA0H read accesses this "snapshot" register. **Reading the PCA0L Register first guarantees an accurate reading of the entire 16-bit PCA0 counter.** Reading PCA0H or PCA0L does not disturb the counter operation. The CPS2–CPS0 bits in the PCA0MD register select the timebase for the counter/timer as shown in Table 24.1.

**Table 24.1. PCA Timebase Input Options**

| CPS2 | CPS1 | CPS0 | Timebase |
|---|---|---|---|
| 0 | 0 | 0 | System clock divided by 12 |
| 0 | 0 | 1 | System clock divided by 4 |
| 0 | 1 | 0 | Timer 0 overflow |
| 0 | 1 | 1 | High-to-low transitions on ECI (max rate = system clock divided by 4) |
| 1 | 0 | 0 | System clock |
| 1 | 0 | 1 | External oscillator source divided by 8* |
| ***Note:** External clock divided by 8 is synchronized with the system clock. | | | |

When the counter/timer overflows from 0xFFFF to 0x0000, the Counter Overflow Flag (CF) in PCA0MD is set to logic 1 and an interrupt request is generated if CF interrupts are enabled. Setting the ECF bit in PCA0MD to logic 1 enables the CF flag to generate an interrupt request. The CF bit is not automatically cleared by hardware when the CPU vectors to the interrupt service routine, and must be cleared by software (Note: PCA0 interrupts must be globally enabled before CF interrupts are recognized. PCA0 interrupts are globally enabled by setting the EA bit (IE.7) and the EPCA0 bit in EIE1 to logic 1). Clearing the CIDL bit in the PCA0MD register allows the PCA to continue normal operation while the CPU is in Idle mode.

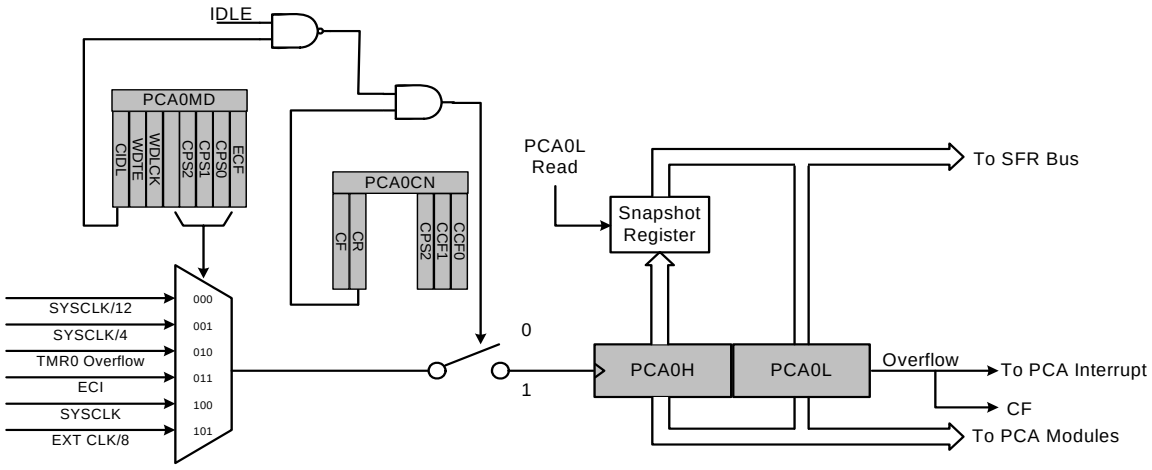


**Figure 24.2. PCA Module Block Diagram**

### 24.1.1. Capture/Compare Modules

Each module can be configured to operate independently in one of six operation modes: Edge-triggered Capture, Software Timer, High Speed Output, Frequency Output, 8-Bit Pulse Width Modulator, or 16-Bit Pulse Width Modulator. Each module has Special Function Registers (SFRs) associated with it in the CIP-51 system controller. These registers are used to exchange data with a module and configure the module's mode of operation.

Table 24.2 summarizes the bit settings in the PCA0CPMn registers used to select the PCA capture/compare module's operating modes. Setting the ECCFn bit in a PCA0CPMn register enables the module's CCFn interrupt.

**Note**: PCA0 interrupts must be globally enabled before individual CCFn interrupts are recognized. PCA0 interrupts are globally enabled by setting the EA bit and the EPCA0 bit to logic 1. See Figure 24.3 for details on the PCA interrupt configuration.

**Table 24.2. PCA0CPM Register Settings for PCA Capture/Compare Modules**

| PWM16 | ECOM | CAPP | CAPN | MAT | TOG | PWM | ECCF | Operation Mode |
|---|---|---|---|---|---|---|---|---|
| X | X | 1 | 0 | 0 | 0 | 0 | X | Capture triggered by positive edge on CEXn |
| X | X | 0 | 1 | 0 | 0 | 0 | X | Capture triggered by negative edge on CEXn |
| X | X | 1 | 1 | 0 | 0 | 0 | X | Capture triggered by transition on CEXn |
| X | 1 | 0 | 0 | 1 | 0 | 0 | X | Software Timer |
| X | 1 | 0 | 0 | 1 | 1 | 0 | X | High Speed Output |
| X | 1 | 0 | 0 | X | 1 | 1 | X | Frequency Output |
| 0 | 1 | 0 | 0 | X | 0 | 1 | X | 8-Bit Pulse Width Modulator |
| 1 | 1 | 0 | 0 | X | 0 | 1 | X | 16-Bit Pulse Width Modulator |
| X = Don’t Care | | | | | | | | |

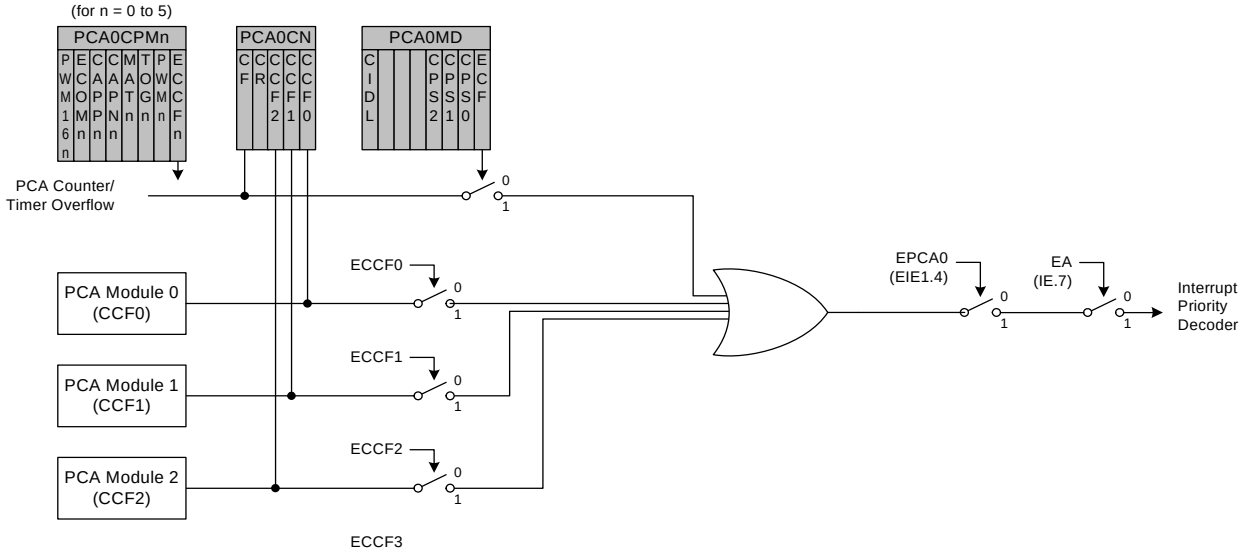


**Figure 24.3. PCA Interrupt Block Diagram**

### 24.1.2. Edge-triggered Capture Mode

In this mode, a valid transition on the CEXn pin causes the PCA to capture the value of the PCA counter/timer and load it into the corresponding module's 16-bit capture/compare register (PCA0CPLn and PCA0CPHn). The CAPPn and CAPNn bits in the PCA0CPMn register are used to select the type of transition that triggers the capture: low-to-high transition (positive edge), high-to-low transition (negative edge), or either transition (positive or negative edge). When a capture occurs, the Capture/Compare Flag (CCFn) in PCA0CN is set to logic 1 and an interrupt request is generated if CCF interrupts are enabled. The CCFn bit is not automatically cleared by hardware when the CPU vectors to the interrupt service routine, and must be cleared by software. If both CAPPn and CAPNn bits are set to logic 1, then the state of the Port pin associated with CEXn can be read directly to determine whether a rising-edge or falling-edge caused the capture.

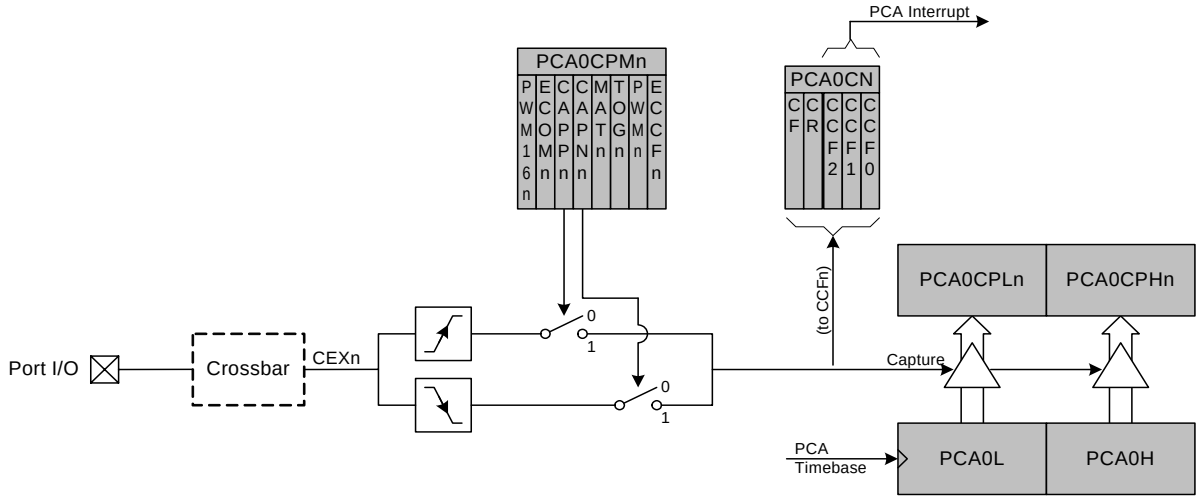


**Figure 24.4. PCA Capture Mode Diagram**

**Note:** The CEXn input signal must remain high or low for at least 2 system clock cycles to be recognized by the hardware.

### 24.1.3. Software Timer (Compare) Mode

In Software Timer mode, the PCA counter/timer value is compared to the module's 16-bit capture/compare register (PCA0CPHn and PCA0CPLn). When a match occurs, the Capture/Compare Flag (CCFn) in PCA0CN is set to logic 1 and an interrupt request is generated if CCF interrupts are enabled. The CCFn bit is not automatically cleared by hardware when the CPU vectors to the interrupt service routine, and must be cleared by software. Setting the ECOMn and MATn bits in the PCA0CPMn register enables Software Timer mode.

**Important Note About Capture/Compare Registers:** When writing a 16-bit value to the PCA0 Capture/Compare registers, the low byte should always be written first. Writing to PCA0CPLn clears the ECOMn bit to '0'; writing to PCA0CPHn sets ECOMn to '1'.

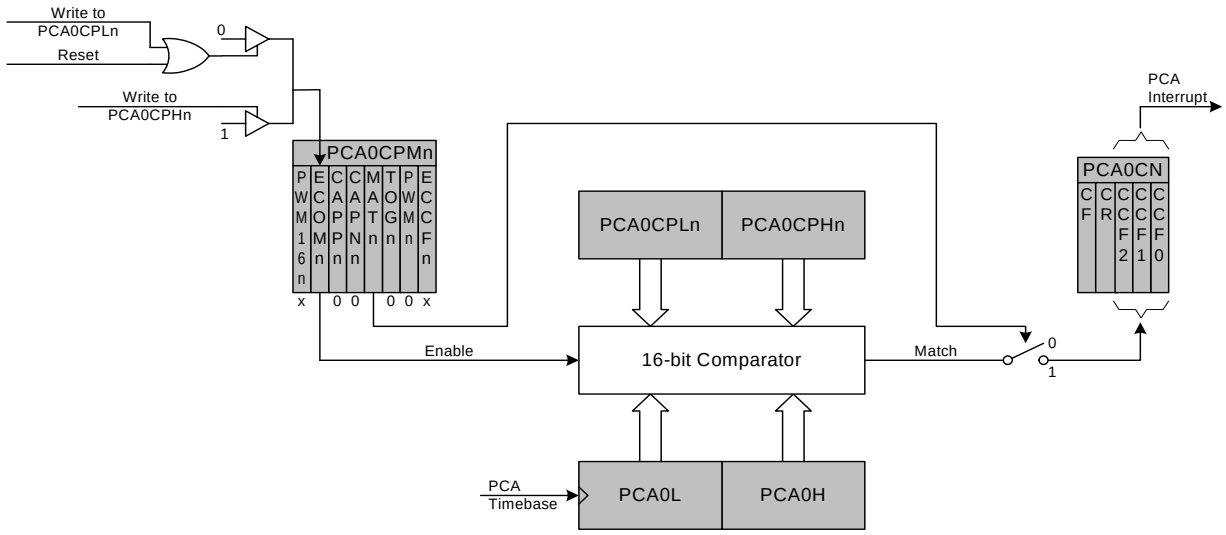


**Figure 24.5. PCA Software Timer Mode Diagram**

### 24.1.4. High Speed Output Mode

In High Speed Output mode, a module's associated CEXn pin is toggled each time a match occurs between the PCA Counter and the module's 16-bit capture/compare register (PCA0CPHn and PCA0CPLn) Setting the TOGn, MATn, and ECOMn bits in the PCA0CPMn register enables the High-Speed Output mode.

**Important Note About Capture/Compare Registers:** When writing a 16-bit value to the PCA0 Capture/Compare registers, the low byte should always be written first. Writing to PCA0CPLn clears the ECOMn bit to '0'; writing to PCA0CPHn sets ECOMn to '1'.

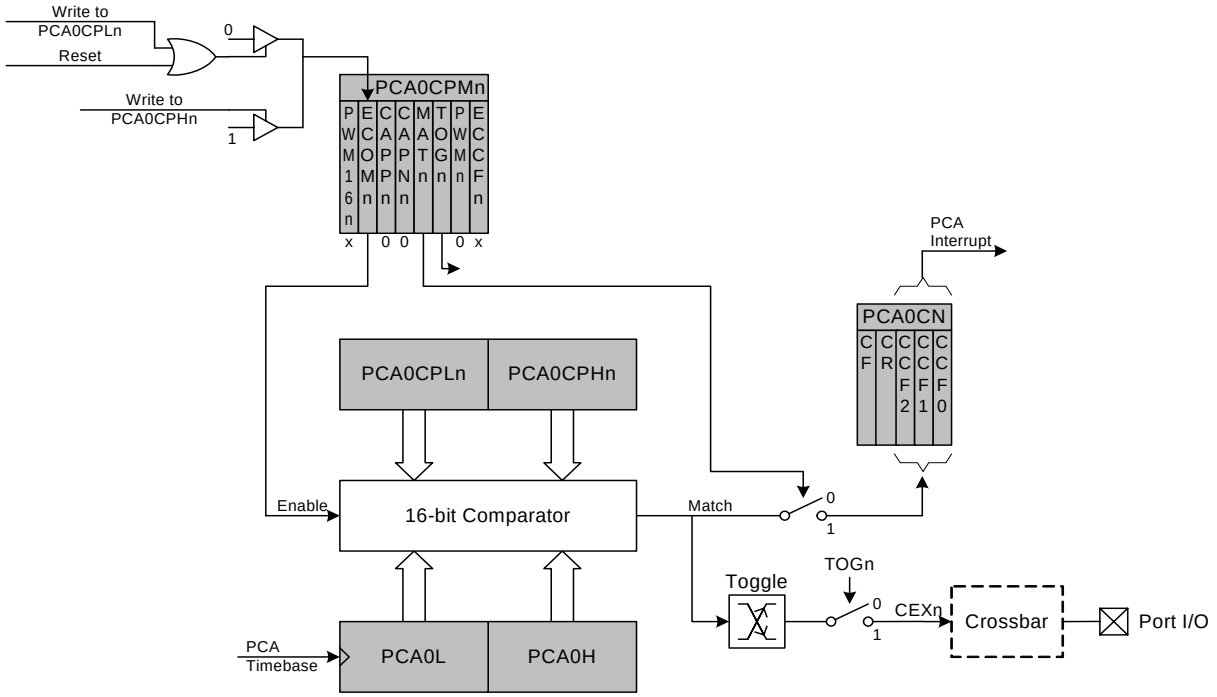


**Figure 24.6. PCA High-Speed Output Mode Diagram**

**Note:** The initial state of the Toggle output is logic 1 and is initialized to this state when the module enters High Speed Output Mode.

### 24.1.5. Frequency Output Mode

Frequency Output Mode produces a programmable-frequency square wave on the module's associated CEXn pin. The capture/compare module high byte holds the number of PCA clocks to count before the output is toggled. The frequency of the square wave is then defined by Equation 24.1.

$$F_{CEXn} = \frac{F_{PCA}}{2 \times PCA0CPHn}$$

**Note:** A value of 0x00 in the PCA0CPHn register is equal to 256 for this equation.

**Equation 24.1. Square Wave Frequency Output**

Where $F_{PCA}$ is the frequency of the clock selected by the CPS2-0 bits in the PCA mode register, PCA0MD. The lower byte of the capture/compare module is compared to the PCA counter low byte; on a match, CEXn is toggled and the offset held in the high byte is added to the matched value in PCA0CPLn. Frequency Output Mode is enabled by setting the ECOMn, TOGn, and PWMn bits in the PCA0CPMn register.

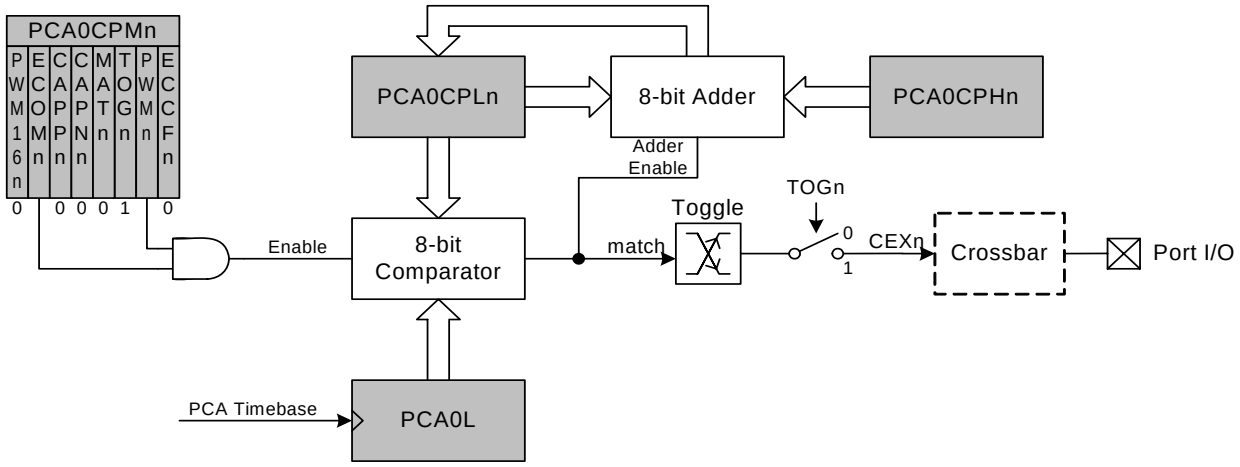


**Figure 24.7. PCA Frequency Output Mode**

### 24.1.6. 8-Bit Pulse Width Modulator Mode

Each module can be used independently to generate a pulse width modulated (PWM) output on its associated CEXn pin. The frequency of the output is dependent on the timebase for the PCA counter/timer. The duty cycle of the PWM output signal is varied using the module's PCA0CPHn capture/compare register. When the value in the low byte of the PCA counter/timer (PCA0L) is equal to the value in PCA0CPLn, the output on the CEXn pin will be set. When the count value in PCA0L overflows, the CEXn output will be reset (see Figure 24.8). Also, when the counter/timer low byte (PCA0L) overflows from 0xFF to 0x00, PCA0CPLn is reloaded automatically with the value stored in the module's capture/compare high byte (PCA0CPHn) without software intervention. Setting the ECOMn and PWMn bits in the PCA0CPMn register enables 8-Bit Pulse Width Modulator mode. The duty cycle for 8-Bit PWM Mode is given by Equation 24.2.

**Important Note About Capture/Compare Registers**: When writing a 16-bit value to the PCA0 Capture/Compare registers, the low byte should always be written first. Writing to PCA0CPLn clears the ECOMn bit to '0'; writing to PCA0CPHn sets ECOMn to '1'.

$$DutyCycle = \frac{(256 - PCA0CPHn)}{256}$$

**Equation 24.2. 8-Bit PWM Duty Cycle**

Using Equation 24.2, the largest duty cycle is 100% (PCA0CPHn = 0), and the smallest duty cycle is 0.39% (PCA0CPHn = 0xFF). A 0% duty cycle may be generated by clearing the ECOMn bit to '0'.

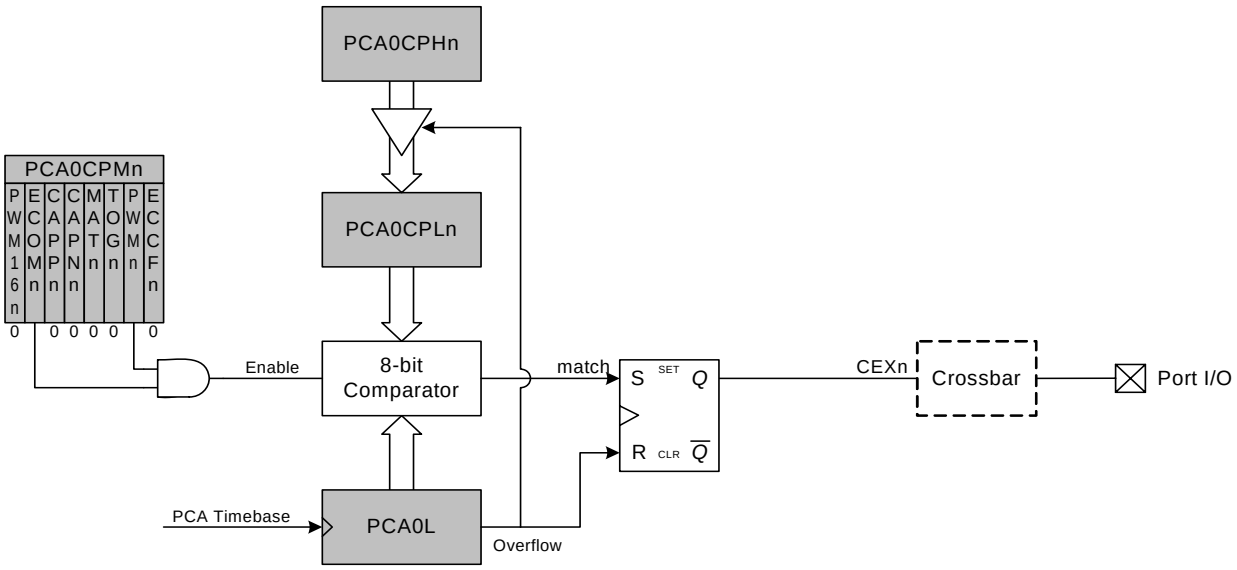


**Figure 24.8. PCA 8-Bit PWM Mode Diagram**

### 24.1.7. 16-Bit Pulse Width Modulator Mode

A PCA module may also be operated in 16-Bit PWM mode. In this mode, the 16-bit capture/compare module defines the number of PCA clocks for the low time of the PWM signal. When the PCA counter matches the module contents, the output on CEXn is asserted high; when the counter overflows, CEXn is asserted low. To output a varying duty cycle, new value writes should be synchronized with PCA CCFn match interrupts. 16-Bit PWM Mode is enabled by setting the ECOMn, PWMn, and PWM16n bits in the PCA0CPMn register. For a varying duty cycle, match interrupts should be enabled (ECCFn = 1 AND MATn = 1) to help synchronize the capture/compare register writes. The duty cycle for 16-Bit PWM Mode is given by Equation 24.3.

**Important Note About Capture/Compare Registers**: When writing a 16-bit value to the PCA0 Capture/Compare registers, the low byte should always be written first. Writing to PCA0CPLn clears the ECOMn bit to '0'; writing to PCA0CPHn sets ECOMn to '1'.

$$DutyCycle = \frac{(65536 - PCA0CPn)}{65536}$$

**Equation 24.3. 16-Bit PWM Duty Cycle**

Using Equation 24.3, the largest duty cycle is 100% (PCA0CPn = 0), and the smallest duty cycle is 0.0015% (PCA0CPn = 0xFFFF). A 0% duty cycle may be generated by clearing the ECOMn bit to '0'.

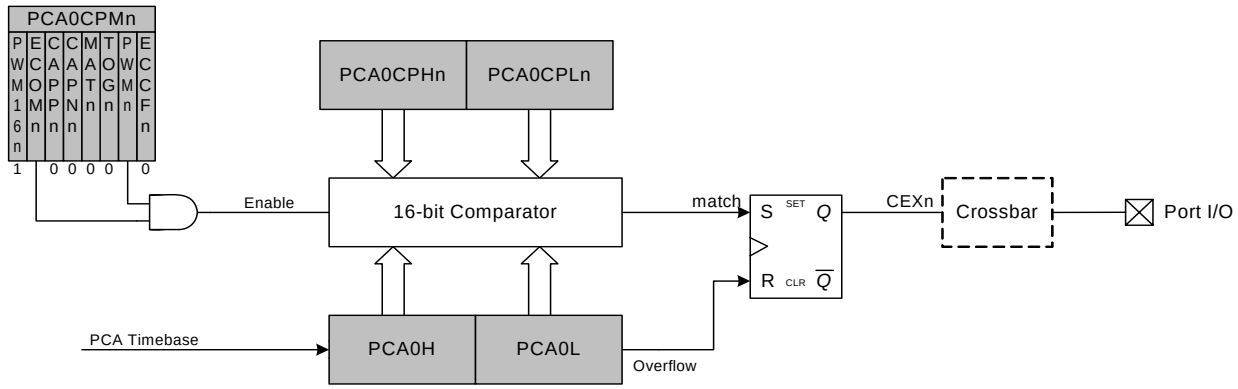


**Figure 24.9. PCA 16-Bit PWM Mode**

## 24.2. Watchdog Timer Mode

A programmable watchdog timer (WDT) function is available through the PCA Module 2. The WDT is used to generate a reset if the time between writes to the WDT update register (PCA0CPH2) exceed a specified limit. The WDT can be configured and enabled/disabled as needed by software. With the WDTE bit set in the PCA0MD register, Module 2 operates as a watchdog timer (WDT). The Module 2 high byte is compared to the PCA counter high byte; the Module 2 low byte holds the offset to be used when WDT updates are performed. **The Watchdog Timer is enabled on reset. Writes to some PCA registers are restricted while the Watchdog Timer is enabled.**

### 24.2.1. Watchdog Timer Operation

While the WDT is enabled:

- PCA counter is forced on.
- Writes to PCA0L and PCA0H are not allowed.
- PCA clock source bits (CPS2-CPS0) are frozen.
- PCA Idle control bit (CIDL) is frozen.
- Module 2 is forced into software timer mode.
- Writes to the Module 2 mode register (PCA0CPM2) are disabled.

While the WDT is enabled, writes to the CR bit will not change the PCA counter state; the counter will run until the WDT is disabled. The PCA counter run control (CR) will read zero if the WDT is enabled but user software has not enabled the PCA counter. If a match occurs between PCA0CPH2 and PCA0H while the WDT is enabled, a reset will be generated. To prevent a WDT reset, the WDT may be updated with a write of any value to PCA0CPH2. Upon a PCA0CPH2 write, PCA0H plus the offset held in PCA0CPL2 is loaded into PCA0CPH2 (See Figure 24.10).

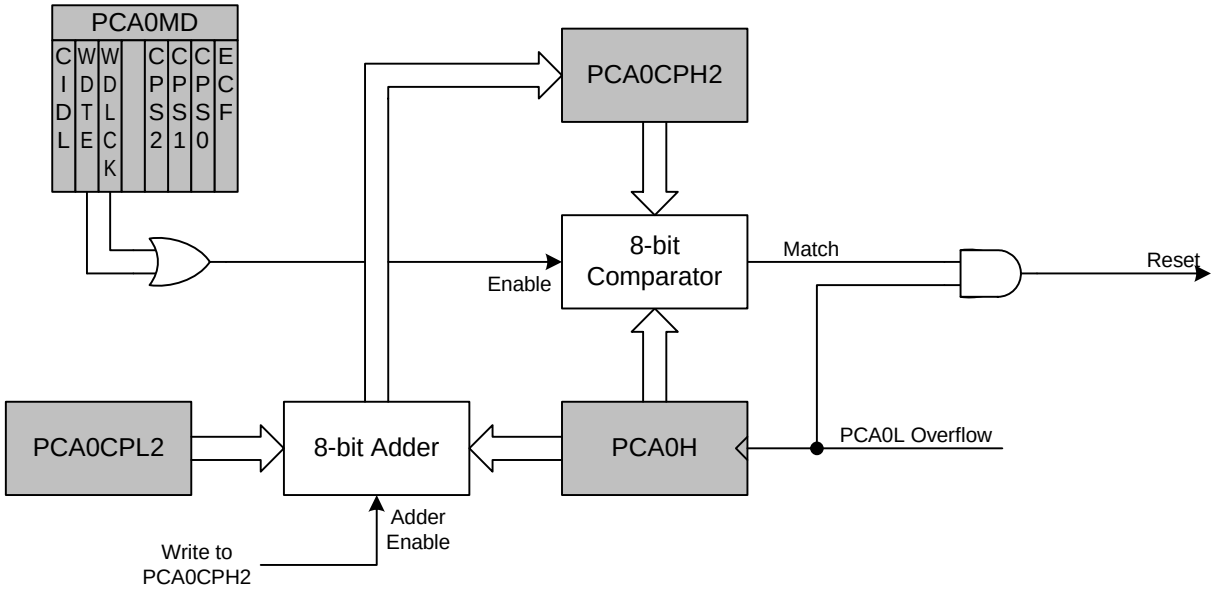


**Figure 24.10. PCA Module 5 with Watchdog Timer Enabled**

Note that the 8-bit offset held in PCA0CPH2 is compared to the upper byte of the 16-bit PCA counter. This offset value is the number of PCA0L overflows before a reset. Up to 256 PCA clocks may pass before the first PCA0L overflow occurs, depending on the value of the PCA0L when the update is performed. The total offset is then given (in PCA clocks) by Equation 24.4, where PCA0L is the value of the PCA0L register at the time of the update.

$$Offset = (256 \times PCA0CPL2) + (256 - PCA0L)$$

**Equation 24.4. Watchdog Timer Offset in PCA Clocks**

The WDT reset is generated when PCA0L overflows while there is a match between PCA0CPH2 and PCA0H. Software may force a WDT reset by writing a '1' to the CCF2 flag (PCA0CN.2) while the WDT is enabled.

### 24.2.2. Watchdog Timer Usage

To configure the WDT, perform the following tasks:

- Disable the WDT by writing a '0' to the WDTE bit.
- Select the desired PCA clock source (with the CPS2-CPS0 bits).
- Load PCA0CPL2 with the desired WDT update offset value.
- Configure the PCA Idle mode (set CIDL if the WDT should be suspended while the CPU is in Idle mode).
- Enable the WDT by setting the WDTE bit to '1'.

The PCA clock source and Idle mode select cannot be changed while the WDT is enabled. The watchdog timer is enabled by setting the WDTE or WDLCK bits in the PCA0MD register. When WDLCK is set, the WDT cannot be disabled until the next system reset. If WDLCK is not set, the WDT is disabled by clearing the WDTE bit. The WDT is enabled following any reset. The PCA0 counter clock defaults to the system clock divided by 12, PCA0L defaults to 0x00, and PCA0CPL2 defaults to 0x00. Using Equation 24.4, this results in a WDT timeout interval of 3072 system clock cycles. Table 24.3 lists some example timeout intervals for typical system clocks.

**Table 24.3. Watchdog Timer Timeout Intervals[1]**

| System Clock (Hz) | PCA0CPL2 | Timeout Interval (ms) |
|---|---|---|
| 24,500,000 | 255 | 32.1 |
| 24,500,000 | 128 | 16.2 |
| 24,500,000 | 32 | 4.1 |
| 18,432,000 | 255 | 42.7 |
| 18,432,000 | 128 | 21.5 |
| 18,432,000 | 32 | 5.5 |
| 11,059,200 | 255 | 71.1 |
| 11,059,200 | 128 | 35.8 |
| 11,059,200 | 32 | 9.2 |
| 3,060,000 | 255 | 257 |
| 3,060,000 | 128 | 129.5 |
| 3,060,000 | 32 | 33.1 |
| 191,406[2] | 255 | 4109 |
| 191,406[2] | 128 | 2070 |
| 191,406[2] | 32 | 530 |
| 32,000 | 255 | 24576 |
| 32,000 | 128 | 12384 |
| 32,000 | 32 | 3168 |

**Notes:**

1. Assumes SYSCLK / 12 as the PCA clock source, and a PCA0L value of 0x00 at the update time.
2. Internal oscillator reset frequency.

## 24.3. Register Descriptions for PCA

Following are detailed descriptions of the special function registers related to the operation of the PCA.

### SFR Definition 24.1. PCA0CN: PCA Control

| R/W | R/W | — | — | — | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| CF | CR | — | — | — | CCF2 | CCF1 | CCF0 | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Bit Addressable |

SFR Address: 0xD8

Bit 7: CF: PCA Counter/Timer Overflow Flag
Set by hardware when the PCA counter/timer overflows from 0xFFF to 0x0000. When the counter/timer overflow (CF) interrupt is enabled, setting this bit causes the CPU to vector to the PCA interrupt service routine. This bit is not automatically cleared by hardware and must be cleared by software.

Bit 6: CR: PCA Counter/Timer Run Control
This bit enables/disables the PCA Counter/Timer
0: PCA counter/timer disabled
1: PCA counter/timer enabled

Bit 5–3: Unused.

Bit 2: CCF2: PCA Module 2 Capture/Compare Flag
This bit is set by hardware when a match or capture occurs. When the CCF2 interrupt is enabled, setting this bit causes the CPU to vector to the PCA interrupt service routine. This bit is not automatically cleared by hardware and must be cleared by software.

Bit 1: CCF1: PCA Module 1 Capture/Compare Flag
This bit is set by hardware when a match or capture occurs. When the CCF1 interrupt is enabled, setting this bit causes the CPU to vector to the PCA interrupt service routine. This bit is not automatically cleared by hardware and must be cleared by software.

Bit 0: CCF0: PCA Module 0 Capture/Compare Flag
This bit is set by hardware when a match or capture occurs. When the CCF0 interrupt is enabled, setting this bit causes the CPU to vector to the PCA interrupt service routine. This bit is not automatically cleared by hardware and must be cleared by software.

## SFR Definition 24.2. PCA0MD: PCA0 Mode

| R/W | R/W | R/W | — | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| CIDL | WDTE | WDLCK | — | CPS2 | CPS1 | CPS0 | ECF | 01000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xD9

Bit 7: CIDL: PCA Counter/Timer Idle Control
Specifies PCA behavior when CPU is in Idle Mode.
0: PCA continues to function normally while the system controller is in idle mode.
1: PCA operation is suspended while the system controller is in idle mode.

Bit 6: WDTE: Watchdog Timer Enable
If this bit is set, PCA Module 2 is used as the watchdog timer.
0: Watchdog Timer disabled
1: PCA Module 2 enabled as Watchdog Timer.

Bit 5: WDLCK: Watchdog Timer Lock
This bit locks/unlocks the Watchdog Timer Enable. When WDLCK is set, the Watchdog Timer may not be disabled until the next system reset.
0: Watchdog Timer Enable unlocked.
1: Watchdog Timer Enable locked.

Bit 4: Unused.

Bits 3–1: CPS[2:0]: PCA Counter/Timer Pulse Select. These bits select the timebase source for the PCA counter.

| CPS2 | CPS1 | CPS0 | Timebase |
|---|---|---|---|
| 0 | 0 | 0 | System clock divided by 12 |
| 0 | 0 | 1 | System clock divided by 4 |
| 0 | 1 | 0 | Timer 0 overflow |
| 0 | 1 | 1 | High-to-low transitions on ECI (max rate = system clock divided by 4) |
| 1 | 0 | 0 | System clock |
| 1 | 0 | 1 | External clock divided by 8* |
| 1 | 1 | 0 | Reserved |
| 1 | 1 | 1 | Reserved |

***Note:** External clock divided by 8 is synchronized with the system clock.

Bit 0: ECF: PCA Counter/Timer Overflow Interrupt Enable. This bit sets the masking of the PCA Counter/Timer Overflow (CF) interrupt.
0: Disable the CF interrupt.
1: Enable a PCA Counter/Timer Overflow interrupt request when CF (PCA0CN.7) is set.

**Note: When the WDTE bit is set to '1', the PCA0MD register cannot be modified. To change the contents of the PCA0MD register, the Watchdog Timer must first be disabled.**

## SFR Definition 24.3. PCA0CPMn: PCA Capture/Compare Mode

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| PWM16n | ECOMn | CAPPn | CAPNn | MATn | TOGn | PWMn | ECCFn | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: PCA0CPM0: 0xDA
PCA0CPM1: 0xDB
PCA0CPM2: 0xDC

Bit 7: PWM16n: 16-bit Pulse Width Modulation Enable
This bit selects 16-bit mode when Pulse Width Modulation mode is enabled (PWMn = 1).
0: 8-bit PWM selected.
1: 16-bit PWM selected.

Bit 6: ECOMn: Comparator Function Enable
This bit enables/disables the comparator function for PCA module n.
0: Disabled.
1: Enabled.

Bit 5: CAPPn: Capture Positive Function Enable
This bit enables/disables the positive edge capture for PCA module n.
0: Disabled.
1: Enabled.

Bit 4: CAPNn: Capture Negative Function Enable
This bit enables/disables the negative edge capture for PCA module n.
0: Disabled.
1: Enabled.

Bit 3: MATn: Match Function Enable
This bit enables/disables the match function for PCA module n. When enabled, matches of the PCA counter with a module's capture/compare register cause the CCFn bit in PCA0MD register to be set to logic 1.
0: Disabled.
1: Enabled.

Bit 2: TOGn: Toggle Function Enable
This bit enables/disables the toggle function for PCA module n. When enabled, matches of the PCA counter with a module's capture/compare register cause the logic level on the CEXn pin to toggle. If the PWMn bit is also set to logic 1, the module operates in Frequency Output Mode.
0: Disabled.
1: Enabled.

Bit 1: PWMn: Pulse Width Modulation Mode Enable
This bit enables/disables the PWM function for PCA module n. When enabled, a pulse width modulated signal is output on the CEXn pin. 8-bit PWM is used if PWM16n is cleared; 16-bit mode is used if PWM16n is set to logic 1. If the TOGn bit is also set, the module operates in Frequency Output Mode.
0: Disabled.
1: Enabled.

Bit 0: ECCFn: Capture/Compare Flag Interrupt Enable
This bit sets the masking of the Capture/Compare Flag (CCFn) interrupt.
0: Disable CCFn interrupts.
1: Enable a Capture/Compare Flag interrupt request when CCFn is set.

### SFR Definition 24.4. PCA0L: PCA Counter/Timer Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xF9

Bits 7–0: PCA0L: PCA Counter/Timer Low Byte
The PCA0L register holds the low byte (LSB) of the 16-bit PCA Counter/Timer.

### SFR Definition 24.5. PCA0H: PCA Counter/Timer High Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: 0xFA

Bits 7–0: PCA0H: PCA Counter/Timer High Byte
The PCA0H register holds the high byte (MSB) of the 16-bit PCA Counter/Timer.

### SFR Definition 24.6. PCA0CPLn: PCA Capture Module Low Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: PCA0CPL0: 0xFB
PCA0CPL1: 0xE9
PCA0CPL2: 0xEB

Bits 7–0: PCA0CPLn: PCA Capture Module Low Byte
The PCA0CPLn register holds the low byte (LSB) of the 16-bit capture module n.

### SFR Definition 24.7. PCA0CPHn: PCA Capture Module High Byte

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

SFR Address: PCA0CPH0: 0xFC
PCA0CPH1: 0xE9
PCA0CPH2: 0xEC

Bits 7–0: PCA0CPHn: PCA Capture Module High Byte. The PCA0CPHn register holds the high byte (MSB) of the 16-bit capture module n.

# 25. C2 Interface

Si8250/1/2 devices include an on-chip Silicon Laboratories 2-Wire (C2) debug interface to allow Flash programming, boundary scan functions, and in-system debugging with the production part installed in the end application. The C2 interface uses a clock signal (C2CK) and a bi-directional C2 data signal (C2D) to transfer information between the device and a host system. See the C2 Interface Specification for details on the C2 protocol.

## 25.1. C2 Interface Registers

The following describes the C2 registers necessary to perform Flash programming and boundary scan functions through the C2 interface. All C2 registers are accessed through the C2 interface as described in the C2 Interface Specification.

### C2 Register Definition 25.1. C2ADD: C2 Address

| R/W | R/W | R/W | R/W | R/W | R/W | R/W | R/W | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

Bits7–0: The C2ADD register is accessed via the C2 interface to select the target Data register for C2 Data Read and Data Write commands.

| Address | Description |
|---|---|
| 0x00 | Selects the Device ID register for Data Read instructions (DEVICEID) |
| 0x01 | Selects the Revision ID register for Data Read instructions (REVID) |
| 0x02 | Selects the C2 Flash Programming Control register for Data Read/Write instructions (FPCTL) |
| 0xB4 | Selects the C2 Flash Programming Data register for Data Read/Write instructions (FPDAT) |

### C2 Register Definition 25.2. DEVICEID: C2 Device ID

| R | R | R | R | R | R | R | R | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00001011 |
| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | |

This read-only register returns the 8-bit device ID: 0x0B (Si8250/1/2).

### C2 Register Definition 25.3. REVID: C2 Revision ID

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |

This read-only register returns the 8-bit revision ID: 0x01 (Revision B).

### C2 Register Definition 25.4. FPCTL: C2 Flash Programming Control

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |

Bits 7–0 FPCTL[7:0]: Flash Programming Control Register.
This register is used to enable Flash programming via the C2 interface. To enable C2 Flash programming, the following codes must be written in order: 0x02, 0x01. Note that once C2 Flash programming is enabled, a system reset must be issued to resume normal operation.

### C2 Register Definition 25.5. FPDAT: C2 Flash Programming Data

| Bit 7 | Bit 6 | Bit 5 | Bit 4 | Bit 3 | Bit 2 | Bit 1 | Bit 0 | Reset Value |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 00000000 |

Bits 7–0: FPDAT[7:0]: C2 Flash Programming Data Register.
This register is used to pass Flash commands, addresses, and data during C2 Flash accesses. Valid commands are listed below.

| Code | Command |
|---|---|
| 0x06 | Flash Block Read |
| 0x07 | Flash Block Write |
| 0x08 | Flash Page Erase |
| 0x03 | Device Erase |

## 25.2. C2 Pin Sharing

The C2 protocol allows the C2 pins to be shared with user functions so that in-system debugging, Flash programming, and boundary scan functions may be performed. This is possible because C2 communication is typically performed when the device is in the halt state, where all on-chip peripherals and user software are stalled. In this halted state, the C2 interface can safely 'borrow' the C2CK (RST) and C2D (P2.7) pins. In most applications, external resistors are required to isolate C2 interface traffic from the user application. A typical isolation configuration is shown in Figure 25.1.

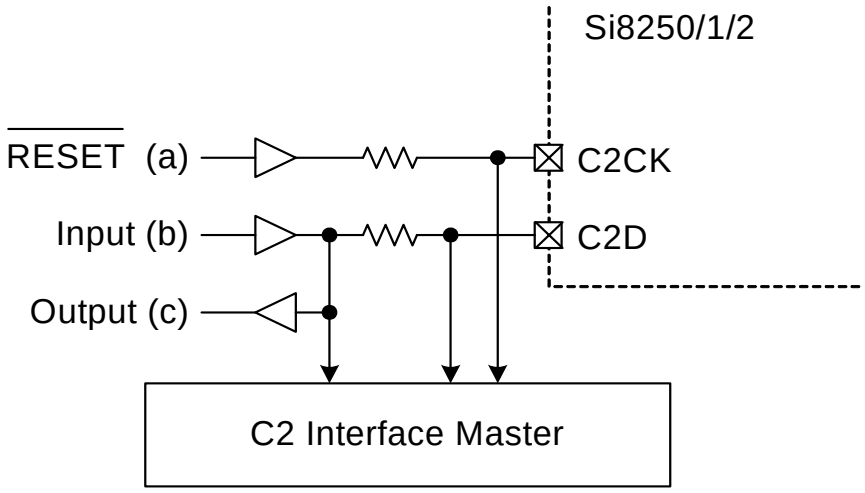


**Figure 25.1. Typical C2 Pin Sharing**

The configuration in Figure 25.1 assumes the following:

1. The user input (b) cannot change state while the target device is halted.
2. The RST pin on the target device is used as an input only.

Additional resistors may be necessary depending on the specific application.

# DOCUMENT CHANGE LIST

## Revision 0.6 to Revision 0.7

- Detection of PLL unlock is tied with Missing Clock detector reset.
- Addition of 2.5 MHz and 1.25 MHz sampling rate for ADC1.
- REV C layout.
- Updated “Contact Information” on page 282.
  - Updated disclaimer.

## NOTES:

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