

July 1999

COP888xG/CS Family

8-Bit CMOS ROM Based Microcontrollers with 4k to 24k Memory, Comparators and USART

General Description

Note: COP888xG devices are form-fit-function compatible supersets of the COP888xG/CL/CS Family devices, and are replacements for these in new designs, and design upgrades with minimum effort.

The COP888xG ROM based microcontrollers are highly integrated COP8™ Feature core devices with larger memory (4k to 24k) and advanced features including two Analog comparators. These single-chip CMOS devices are suited for more complex applications requiring a full featured controller with a range of memory sizes, low EMI (except EG), comparators, and a full-duplex USART. Pin and software compatible (different V_{CC} range) 8k to 32k OTP (One Time

Programmable) versions are available (COP8SGx7 Family). Erasable windowed versions are available for use with a range of software and hardware development tools.

Family features include an 8-bit memory mapped architecture, 10 MHz CKI with 1 μ s instruction cycle, three multi-function 16-bit timer/counters, full-duplex USART, MICROWIRE/PLUS™ serial I/O, two Analog comparators, two power saving HALT/IDLE modes, idle timer, MIWU, high current outputs, software selectable I/O options, WATCHDOG™ timer and Clock Monitor, low EMI 2.5V to 5.5V operation, and 28/40/44 pin packages.

Devices included in this datasheet are:

| Device | Memory (bytes) | RAM (bytes) | I/O Pins | Packages | Temperature | Comments |
|----------|----------------|-------------|----------|----------------------|---------------|------------------------------|
| COP684CS | 4k ROM | 192 | 24 | 28 DIP/SOIC | -55 to +125°C | 4.5V - 5.5V |
| COP884CS | 4k ROM | 192 | 24 | 28 DIP/SOIC | -40 to +85°C | |
| COP984CS | 4k ROM | 192 | 24 | 28 DIP/SOIC | -0 to +70°C | 2.5V - 4.0V, CSH=4.0V - 6.0V |
| COP688CS | 4k ROM | 192 | 36/40 | 40 DIP, 44 PLCC | -55 to +125°C | 4.5V - 5.5V |
| COP888CS | 4k ROM | 192 | 36/40 | 40 DIP, 44 PLCC | -40 to +85°C | |
| COP988CS | 4k ROM | 192 | 36/40 | 40 DIP, 44 PLCC | -0 to +70°C | 2.5V - 4.0V, CSH=4.0V - 6.0V |
| COP884CG | 4k ROM | 128 | 24 | 28 DIP/SOIC | -40 to +85°C | 2.5V - 6.0V |
| COP888CG | 4k ROM | 128 | 34/38 | 40 DIP, 44 PLCC | -40 to +85°C | 2.5V - 6.0V |
| COP684EG | 4k ROM | 256 | 24 | 28 DIP, SOIC | -55 to +125°C | 4.5V - 5.5V |
| COP884EG | 4k ROM | 256 | 24 | 28 DIP, SOIC | -40 to +85°C | |
| COP984EG | 4k ROM | 256 | 24 | 28 DIP, SOIC | 0 to +70°C | 2.5V - 4.0V, EGH=4.0 - 6.0V |
| COP688EG | 8k ROM | 256 | 36/40 | 40 DIP, 44 PLCC | -55 to +125°C | 4.5V - 5.5V |
| COP888EG | 8k ROM | 256 | 36/40 | 40 DIP, 44 PLCC/PQFP | -40 to +85°C | |
| COP988EG | 8k ROM | 256 | 36/40 | 40 DIP, 44 PLCC | 0 to +70°C | 2.5V - 4.0V, EGH=4.0 - 6.0V |
| COP688GG | 16k ROM | 512 | 36/40 | 40 DIP, 44 PLCC/PQFP | -55 to +125°C | 4.5V - 5.5V |
| COP888GG | 16k ROM | 512 | 36/40 | 40 DIP, 44 PLCC/PQFP | -40 to +85°C | |
| COP688HG | 20k ROM | 512 | 36/40 | 40 DIP, 44 PLCC | -55 to +125°C | 4.5V - 5.5V |
| COP888HG | 20k ROM | 512 | 36/40 | 40 DIP, 44 PLCC | -40 to +85°C | |
| COP688KG | 24k ROM | 512 | 36/40 | 40 DIP, 44 PLCC | -55 to +125°C | 4.5V - 5.5V |
| COP888KG | 24k ROM | 512 | 36/40 | 40 DIP, 44 PLCC | -40 to +85°C | |

Key Features

- Full duplex USART
- Three 16-bit timers, each with two 16-bit registers supporting:
 - Processor Independent PWM mode
 - External Event counter mode
 - Input Capture mode
- Quiet design (low radiated emissions)
- 4 to 24 kbytes on-board ROM
- 128 to 512 bytes on-board RAM

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iceMASTER® is a registered trademark of MetaLink Corporation.

COP888xG/CS Family, 8-Bit CMOS ROM Based Microcontrollers with 4k to 24k Memory, Comparators and USART

Key Features (Continued)

Additional Peripheral Features

- Idle Timer
- Multi-Input Wake-Up (MIWU) with optional interrupts (8)
- Two analog comparators (one for the CS series)
- WATCHDOG and Clock Monitor logic
- MICROWIRE/PLUS serial I/O

I/O Features

- Memory mapped I/O
- Software selectable I/O options (TRI-STATE® Output, Push-Pull Output, Weak Pull-Up Input, High Impedance Input)
- Up to 8 high current outputs
- Schmitt trigger inputs on ports G and L
- Packages:
 - 44 PQFP with 40 I/O pins
 - 44 PLCC with 40 I/O pins
 - 40 DIP with 36 I/O pins
 - 28 DIP/SOIC with 24 I/O pins

CPU/Instruction Set Features

- 1 μ s instruction cycle time
- Versatile and easy to use instruction set

- Up to fourteen multi-source vectored interrupts servicing
 - External Interrupt with selectable edge
 - Idle Timer T0
 - Three Timers (one timer for the CS series)(each with 2 interrupts)
 - MICROWIRE/PLUS
 - Multi-Input Wake-Up
 - Software Trap
 - USART (2)
 - Default VIS (default interrupt)
- 8-bit Stack Pointer SP — (stack in RAM)
- Two 8-bit Register Indirect Data Memory Pointers (B and X)

Fully Static CMOS

- Two power saving modes: HALT and IDLE
- Low current drain (typically $<1 \mu$ A)
- Single supply operation: 2.5V–5.5V (COP88x)
- Temperature ranges:
 - 0°C to +70°C, –40°C to +85°C, and –55°C to +125°C

Development Support

- Emulation and OTP devices
- Real time emulation and full program debug offered by MetaLink's Development System

Block Diagram

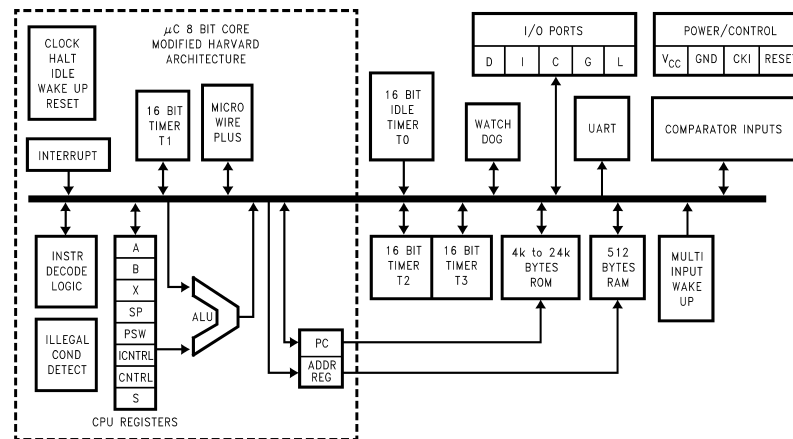
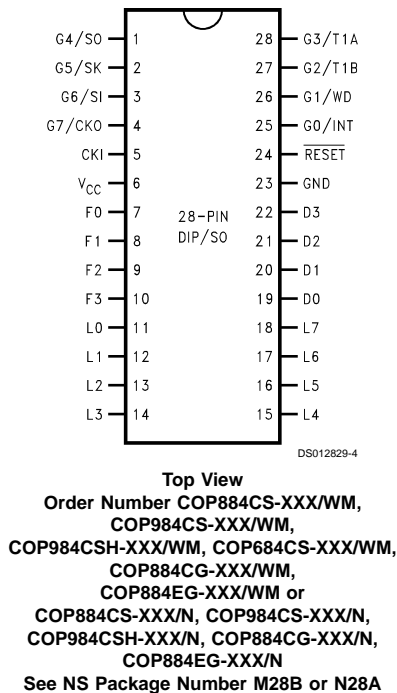


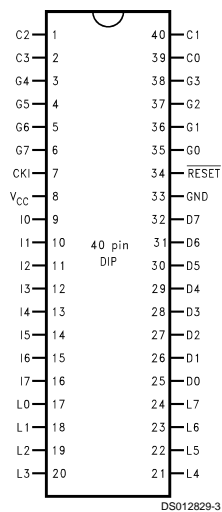
FIGURE 1. COP88xG Block Diagram

DS012829-1

Connection Diagrams



Dual-In-Line Package



Plastic Chip Carrier

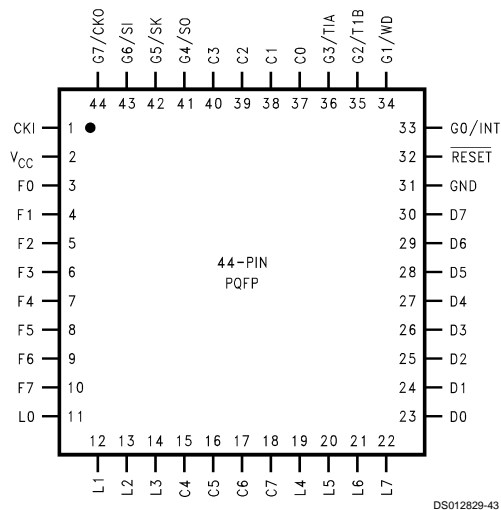
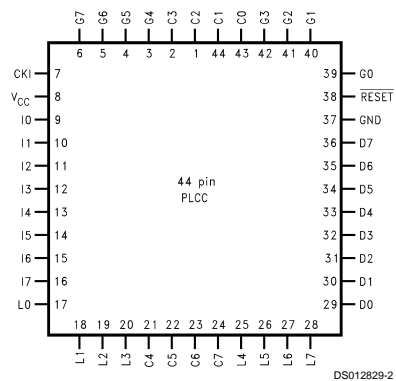


FIGURE 2. Connection Diagrams

Connection Diagrams (Continued)

Pinouts for 28-, 40- and 44-Pin Packages

| Port | Type | Alt. Fun | Alt. Fun | 28-Pin DIP/SO | 40-Pin DIP | 44-Pin PLCC | 44-Pin PQFP |
|-----------------|-------|--------------|----------|------------------|---------------|----------------|----------------|
| L0 | I/O | MIWU | | 11 | 17 | 17 | 11 |
| L1 | I/O | MIWU | CKX | 12 | 18 | 18 | 12 |
| L2 | I/O | MIWU | TDX | 13 | 19 | 19 | 13 |
| L3 | I/O | MIWU | RDX | 14 | 20 | 20 | 14 |
| L4 | I/O | MIWU | T2A* | 15 | 21 | 25 | 19 |
| L5 | I/O | MIWU | T2B* | 16 | 22 | 26 | 20 |
| L6 | I/O | MIWU | T3A* | 17 | 23 | 27 | 21 |
| L7 | I/O | MIWU | T3B* | 18 | 24 | 28 | 22 |
| G0 | I/O | INT | | 25 | 35 | 39 | 33 |
| G1 | WDOUT | | | 26 | 36 | 40 | 34 |
| G2 | I/O | T1B | | 27 | 37 | 41 | 35 |
| G3 | I/O | T1A | | 28 | 38 | 42 | 36 |
| G4 | I/O | SO | | 1 | 3 | 3 | 41 |
| G5 | I/O | SK | | 2 | 4 | 4 | 42 |
| G6 | I | SI | | 3 | 5 | 5 | 43 |
| G7 | I/CKO | HALT Restart | | 4 | 6 | 6 | 44 |
| D0 | O | | | 19 | 25 | 29 | 23 |
| D1 | O | | | 20 | 26 | 30 | 24 |
| D2 | O | | | 21 | 27 | 31 | 25 |
| D3 | O | | | 22 | 28 | 32 | 26 |
| D4 | O | | | | 29 | 33 | 7 |
| D5 | O | | | | 30 | 34 | 8 |
| D6 | O | | | | 31 | 35 | 9 |
| D7 | O | | | | 32 | 36 | 10 |
| I0 | I | | | 7 | 9 | 9 | 27 |
| I1 | I | COMP1IN- | | 8 | 10 | 10 | 28 |
| I2 | I | COMP1IN+ | | 9 | 11 | 11 | 29 |
| I3 | I | COMP1OUT | | 10 | 12 | 12 | 30 |
| I4 | I | COMP2IN* | | | 13 | 13 | 3 |
| I5 | I | COMP2IN+* | | | 14 | 14 | 4 |
| I6 | I | COMP2OUT* | | | 15 | 15 | 5 |
| I7 | I | | | | 16 | 16 | 6 |
| C0 | I/O | | | | 39 | 43 | 37 |
| C1 | I/O | | | | 40 | 44 | 38 |
| C2 | I/O | | | | 1 | 1 | 39 |
| C3 | I/O | | | | 2 | 2 | 40 |
| C4 | I/O | | | | | 21 | 15 |
| C5 | I/O | | | | | 22 | 16 |
| C6 | I/O | | | | | 23 | 17 |
| C7 | I/O | | | | | 24 | 18 |
| V _{CC} | | | | 6 | 8 | 8 | 2 |
| GND | | | | 23 | 33 | 37 | 31 |
| CKI | | | | 5 | 7 | 7 | 1 |
| RESET | | | | 24 | 34 | 38 | 32 |

Note 1: * Not available on the CS series

Absolute Maximum Ratings (Note 4)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage (V_{CC}) 7V
Voltage at Any Pin $-0.3V$ to $V_{CC} + 0.3V$

Total Current into V_{CC} Pin (Source) 100 mA
Total Current out of GND Pin (Sink) 110 mA
Storage Temperature Range $-65^{\circ}C$ to $+140^{\circ}C$

Note 2: Absolute maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications are not ensured when operating the device at absolute maximum ratings.

DC Electrical Characteristics 98xEG and 98xCS:

$0^{\circ}C \leq T_A \leq +70^{\circ}C$ unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|---------------------------------------|----------------------------------|--------------|--------|---------------|---------|
| Operating Voltage | | | | | |
| COP98xCS, COP98xEG | | 2.5 | | 4.0 | V |
| COP98xCSS, COP98xEGH | | 4.0 | | 6.0 | V |
| Power Supply Ripple (Note 6) | Peak-to-Peak | | | $0.1 V_{CC}$ | V |
| Supply Current (Note 7) | | | | | |
| CKI = 10 MHz | $V_{CC} = 6.0V, t_c = 1 \mu s$ | | | 12.5 | mA |
| CKI = 4 MHz | $V_{CC} = 6.0V, t_c = 2.5 \mu s$ | | | 5.5 | mA |
| CKI = 4 MHz | $V_{CC} = 4V, t_c = 2.5 \mu s$ | | | 2.5 | mA |
| CKI = 1 MHz | $V_{CC} = 4V, t_c = 10 \mu s$ | | | 1.4 | mA |
| HALT Current (Note 8) | $V_{CC} = 6.0V, CKI = 0 MHz$ | | <0.7 | 8 | μA |
| | $V_{CC} = 4V, CKI = 0 MHz$ | | <0.3 | 4 | μA |
| IDLE Current | | | | | |
| CKI = 10 MHz | $V_{CC} = 6.0V, t_c = 1 \mu s$ | | | 3.5 | mA |
| CKI = 4 MHz | $V_{CC} = 6.0V, t_c = 2.5 \mu s$ | | | 2.5 | mA |
| CKI = 1 MHz | $V_{CC} = 4V, t_c = 10 \mu s$ | | | 0.7 | mA |
| Input Levels (V_{IH}, V_{IL}) | | | | | |
| RESET | | | | | |
| Logic High | | $0.8 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| CKI (External and Crystal Osc. Modes) | | | | | |
| Logic High | | $0.7 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| All Other Inputs | | | | | |
| Logic High | | $0.7 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| Hi-Z Input Leakage | $V_{CC} = 6.0V, V_{IN} = 0V$ | -1 | | +1 | μA |
| Input Pullup Current | $V_{CC} = 6.0V, V_{IN} = 0V$ | -40 | | -250 | μA |
| G and L Port Input Hysteresis | (Note 10) | | | $0.35 V_{CC}$ | V |
| Output Current Levels | | | | | |
| D Outputs | | | | | |
| Source | $V_{CC} = 4V, V_{OH} = 3.3V$ | -0.4 | | | mA |
| | $V_{CC} = 2.5V, V_{OH} = 1.8V$ | -0.2 | | | mA |
| Sink | $V_{CC} = 4V, V_{OL} = 1V$ | 10 | | | mA |
| | $V_{CC} = 2.5V, V_{OL} = 0.4V$ | 2.0 | | | mA |
| All Others | | | | | |
| Source (Weak Pull-Up Mode) | $V_{CC} = 4V, V_{OH} = 2.7V$ | -10 | | -100 | μA |
| | $V_{CC} = 2.5V, V_{OH} = 1.8V$ | -2.5 | | -33 | μA |
| Source (Push-Pull Mode) | $V_{CC} = 4V, V_{OH} = 3.3V$ | -0.4 | | | mA |
| | $V_{CC} = 2.5V, V_{OH} = 1.8V$ | -0.2 | | | mA |
| Sink (Push-Pull Mode) | $V_{CC} = 4V, V_{OL} = 0.4V$ | 1.6 | | | mA |
| | $V_{CC} = 2.5V, V_{OL} = 0.4V$ | 0.7 | | | mA |

DC Electrical Characteristics 98xEG and 98xCS: (Continued)

0°C ≤ T_A ≤ +70°C unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---------------------------------|-----|-----|------|-------|
| TRI-STATE Leakage | V _{CC} = 6.0V | -1 | | +1 | μA |
| Allowable Sink/Source Current per Pin | | | | | |
| D Outputs (Sink) | | | | 15 | mA |
| All others | | | | 3 | mA |
| Maximum Input Current without Latchup (Notes 9, 10) | T _A = 25° | | | ±100 | mA |
| RAM Retention Voltage, V _r | 500 ns Rise and Fall Time (min) | 2 | | | V |
| Input Capacitance | | | | 7 | pF |
| Load Capacitance on D2 | | | | 1000 | pF |

AC Electrical Characteristics 98xEG and 98xCS:

0°C ≤ T_A ≤ +70°C unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|--|--|-----|-----|------|----------------|
| Instruction Cycle Time (t _c) | | | | | |
| Crystal, Resonator | 4V ≤ V _{CC} ≤ 6.0V | 2.5 | | DC | μs |
| | 2.5V ≤ V _{CC} < 4V | 1.0 | | DC | μs |
| R/C Oscillator | 4V ≤ V _{CC} ≤ 6.0V | 7.5 | | DC | μs |
| | 2.5V ≤ V _{CC} < 4V | 3.0 | | DC | μs |
| Inputs | | | | | |
| t _{SETUP} | 4V ≤ V _{CC} ≤ 6.0V | 200 | | | ns |
| | 2.5V ≤ V _{CC} < 4V | 500 | | | ns |
| t _{HOLD} | 4V ≤ V _{CC} ≤ 6.0V | 60 | | | ns |
| | 2.5V ≤ V _{CC} < 4V | 150 | | | ns |
| Output Propagation Delay | R _L = 2.2k, C _L = 100 pF | | | | |
| t _{PD1} , t _{PD0} | 4V ≤ V _{CC} ≤ 6.0V | | | 0.7 | μs |
| SO, SK | 2.5V ≤ V _{CC} < 4V | | | 1.75 | μs |
| All Others | 4V ≤ V _{CC} ≤ 6.0V | | | 1 | μs |
| | 2.5V ≤ V _{CC} < 4V | | | 2.5 | μs |
| MICROWIRE Setup Time (t _{UWS}) (Note 10) | | 20 | | | ns |
| MICROWIRE Hold Time (t _{UWH}) (Note 10) | | 56 | | | ns |
| MICROWIRE Output Propagation Delay (t _{UPD}) | | | | 220 | ns |
| Input Pulse Width (Note 11) | | | | | |
| Interrupt Input High Time | | 1 | | | t _c |
| Interrupt Input Low Time | | 1 | | | t _c |
| Timer 1, 2, 3 Input High Time | | 1 | | | t _c |
| Timer 1, 2, 3 Input Low Time | | 1 | | | t _c |
| Reset Pulse Width | | 1 | | | μs |

Absolute Maximum Ratings (Note 4)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

Supply Voltage (V_{CC}) 7V
Voltage at Any Pin $-0.3V$ to $V_{CC} + 0.3V$

Total Current into V_{CC} Pin (Source) 100 mA
Total Current out of GND Pin (Sink) 110 mA
Storage Temperature Range $-65^{\circ}C$ to $+140^{\circ}C$

Note 3: Absolute maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications are not ensured when operating the device at absolute maximum ratings.

DC Electrical Characteristics 88xCG, 88xCS, and 88xEG:

$-40^{\circ}C \leq T_A \leq +85^{\circ}C$ unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|---------------------------------------|----------------------------------|--------------|------|---------------|---------|
| Operating Voltage | | | | | |
| Power Supply Ripple (Note 6) | Peak-to-Peak | | | $0.1 V_{CC}$ | V |
| Supply Current (Note 7) | | | | | |
| CKI = 10 MHz | $V_{CC} = 6.0V, t_c = 1 \mu s$ | | | 12.5 | mA |
| CKI = 4 MHz | $V_{CC} = 6.0V, t_c = 2.5 \mu s$ | | | 5.5 | mA |
| CKI = 4 MHz (88xCG & 88xEG only) | $V_{CC} = 4V, t_c = 2.5 \mu s$ | | | 2.5 | mA |
| CKI = 1 MHz (88xCG & 88xEG only) | $V_{CC} = 4V, t_c = 10 \mu s$ | | | 1.4 | mA |
| HALT Current (Note 8) | $V_{CC} = 6.0V, CKI = 0$ MHz | | <1.0 | 8 | μA |
| (88xCG & 88xEG only) | $V_{CC} = 4V, CKI = 0$ MHz | | <0.5 | 4 | μA |
| IDLE Current | | | | | |
| CKI = 10 MHz | $V_{CC} = 6.0V, t_c = 1 \mu s$ | | | 3.5 | mA |
| CKI = 4 MHz | $V_{CC} = 6.0V, t_c = 2.5 \mu s$ | | | 2.5 | mA |
| CKI = 1 MHz (88xCG & 88xEG only) | $V_{CC} = 4V, t_c = 10 \mu s$ | | | 0.7 | mA |
| Input Levels (V_{IH}, V_{IL}) | | | | | |
| RESET | | | | | |
| Logic High | | $0.8 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| CKI (External adn Crystal Osc. Modes) | | | | | |
| Logic High | | $0.7 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| All Other Inputs | | | | | |
| Logic High | | $0.7 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| Hi-Z Input Leakage | $V_{CC} = 6.0V$ | -2 | | +2 | μA |
| Input Pullup Current | $V_{CC} = 6.0V, V_{IN} = 0V$ | -40 | | -250 | μA |
| G and L Port Input Hysteresis | (Note 10) | | | $0.35 V_{CC}$ | V |
| Output Current Levels | | | | | |
| D Outputs | | | | | |
| Source | $V_{CC} = 4V, V_{OH} = 3.3V$ | -0.4 | | | mA |
| | $V_{CC} = 2.5V, V_{OH} = 1.8V$ | -0.2 | | | mA |
| Sink | $V_{CC} = 4V, V_{OL} = 1V$ | 10 | | | mA |
| | $V_{CC} = 2.5V, V_{OL} = 0.4V$ | 2.0 | | | mA |
| All Others | | | | | |
| Source (Weak Pull-Up Mode) | $V_{CC} = 4V, V_{OH} = 2.7V$ | -10 | | -100 | μA |
| | $V_{CC} = 2.5V, V_{OH} = 1.8V$ | -2.5 | | -33 | μA |
| Source (Push-Pull Mode) | $V_{CC} = 4V, V_{OH} = 3.3V$ | -0.4 | | | mA |
| | $V_{CC} = 2.5V, V_{OH} = 1.8V$ | -0.2 | | | mA |
| Sink (Push-Pull Mode) | $V_{CC} = 4V, V_{OL} = 0.4V$ | 1.6 | | | mA |

DC Electrical Characteristics 88xCG, 88xCS, and 88xEG: (Continued)

–40°C ≤ T_A ≤ +85°C unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|--|--|-----|-----|------|-------|
| | V _{CC} = 2.5V, V _{OL} = 0.4V | 0.7 | | | mA |
| TRI-STATE Leakage | V _{CC} = 6.0V | –1 | | +1 | μA |
| Allowable Sink/Source Current per Pin | | | | | |
| D Outputs (Sink) | | | | 15 | mA |
| All others | | | | 3 | mA |
| Maximum Input Current without Latchup (Notes 9, 10) | T _A = 25° | | | ±100 | mA |
| RAM Retention Voltage, V _r | 500 ns Rise and Fall Time (min) | 2 | | | V |
| Input Capacitance | | | | 7 | pF |
| Load Capacitance on D2 | | | | 1000 | pF |

AC Electrical Characteristics 888EG, 88xCS, and 88xCG:

–40°C ≤ T_A ≤ +85°C unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|--|--|-----|-----|------|----------------|
| Instruction Cycle Time (t _c) | | | | | |
| Crystal, Resonator | 4V ≤ V _{CC} ≤ 6.0V | 1.0 | | DC | μs |
| | 2.5V ≤ V _{CC} < 4V | 2.5 | | DC | μs |
| R/C Oscillator | 4V ≤ V _{CC} ≤ 6.0V | 3.0 | | DC | μs |
| | 2.5V ≤ V _{CC} < 4V | 7.5 | | DC | μs |
| Inputs | | | | | |
| t _{SETUP} | 4V ≤ V _{CC} ≤ 6.0V | 200 | | | ns |
| | 2.5V ≤ V _{CC} < 4V | 500 | | | ns |
| t _{HOLD} | 4V ≤ V _{CC} ≤ 6.0V | 60 | | | ns |
| | 2.5V ≤ V _{CC} < 4V | 150 | | | ns |
| Output Propagation Delay | R _L = 2.2k, C _L = 100 pF | | | | |
| t _{PD1} , t _{PD0} | 4V ≤ V _{CC} ≤ 6.0V | | | 0.7 | μs |
| SO, SK | 2.5V ≤ V _{CC} < 4V | | | 1.75 | μs |
| All Others | 4V ≤ V _{CC} ≤ 6.0V | | | 1 | μs |
| | 2.5V ≤ V _{CC} < 4V | | | 2.5 | μs |
| MICROWIRE Setup Time (t _{UWS}) (Note 10) | | 20 | | | ns |
| MICROWIRE Hold Time (t _{UWH}) (Note 10) | | 56 | | | ns |
| MICROWIRE Output Propagation Delay (t _{UPD}) | | | | 220 | ns |
| Input Pulse Width (Note 11) | | | | | |
| Interrupt Input High Time | | 1 | | | t _c |
| Interrupt Input Low Time | | 1 | | | t _c |
| Timer 1, 2, 3 Input High Time | | 1 | | | t _c |
| Timer 1, 2, 3 Input Low Time | | 1 | | | t _c |
| Reset Pulse Width | | 1 | | | μs |

Absolute Maximum Ratings (Note 4)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage (V_{CC}) 7V
Voltage at Any Pin $-0.3V$ to $V_{CC} + 0.3V$

Total Current into V_{CC} Pin (Source) 100 mA
Total Current out of GND Pin (Sink) 110 mA
Storage Temperature Range -65°C to $+140^{\circ}\text{C}$

Note 4: Absolute maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications are not ensured when operating the device at absolute maximum ratings.

DC Electrical Characteristics 888GG, 888HG, and 888KG:

$-40^{\circ}\text{C} \leq T_A \leq +85^{\circ}\text{C}$ unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|---------------------------------------|--------------------------------------|--------------|--------|---------------|---------|
| Operating Voltage | | 2.5 | | 5.5 | V |
| Power Supply Ripple (Note 6) | Peak-to-Peak | | | $0.1 V_{CC}$ | V |
| Supply Current (Note 7) | | | | | |
| CKI = 10 MHz | $V_{CC} = 5.5V, t_c = 1 \mu s$ | | | 12.5 | mA |
| CKI = 4 MHz | $V_{CC} = 5.5V, t_c = 2.5 \mu s$ | | | 5.5 | mA |
| CKI = 4 MHz | $V_{CC} = 4V, t_c = 2.5 \mu s$ | | | 2.5 | mA |
| CKI = 1 MHz | $V_{CC} = 4V, t_c = 10 \mu s$ | | | 1.4 | mA |
| HALT Current (Note 8) | $V_{CC} = 5.5V, CKI = 0 \text{ MHz}$ | | <1 | 10 | μA |
| | $V_{CC} = 4V, CKI = 0 \text{ MHz}$ | | <0.5 | 6 | μA |
| IDLE Current | | | | | |
| CKI = 10 MHz | $V_{CC} = 5.5V, t_c = 1 \mu s$ | | | 3.5 | mA |
| CKI = 4 MHz | $V_{CC} = 5.5V, t_c = 2.5 \mu s$ | | | 2.5 | mA |
| CKI = 1 MHz | $V_{CC} = 4V, t_c = 10 \mu s$ | | | 0.7 | mA |
| Input Levels (V_{IH}, V_{IL}) | | | | | |
| RESET | | | | | |
| Logic High | | $0.8 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| CKI, All Other Inputs | | | | | |
| Logic High | | $0.7 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| Hi-Z Input Leakage | $V_{CC} = 5.5V, V_{IN} = 0V$ | -2 | | +2 | μA |
| Input Pullup Current | $V_{CC} = 5.5V, V_{IN} = 0V$ | -40 | | -250 | μA |
| G and L Port Input Hysteresis | (Note 10) | | | $0.35 V_{CC}$ | V |
| Output Current Levels | | | | | |
| D Outputs | | | | | |
| Source | $V_{CC} = 4V, V_{OH} = 3.3V$ | -0.4 | | | mA |
| | $V_{CC} = 2.5V, V_{OH} = 1.8V$ | -0.2 | | | mA |
| Sink | $V_{CC} = 4V, V_{OL} = 1V$ | 10 | | | mA |
| | $V_{CC} = 2.5V, V_{OL} = 0.4V$ | 2.0 | | | mA |
| All Others | | | | | |
| Source (Weak Pull-Up Mode) | $V_{CC} = 4V, V_{OH} = 2.7V$ | -10 | | -100 | μA |
| | $V_{CC} = 2.5V, V_{OH} = 1.8V$ | -2.5 | | -33 | μA |
| Source (Push-Pull Mode) | $V_{CC} = 4V, V_{OH} = 3.3V$ | -0.4 | | | mA |
| | $V_{CC} = 2.5V, V_{OH} = 1.8V$ | -0.2 | | | mA |
| Sink (Push-Pull Mode) | $V_{CC} = 4V, V_{OL} = 0.4V$ | 1.6 | | | mA |
| | $V_{CC} = 2.5V, V_{OL} = 0.4V$ | 0.7 | | | mA |
| TRI-STATE Leakage | $V_{CC} = 5.5V$ | -2 | | +2 | μA |
| Allowable Sink/Source Current per Pin | | | | | |
| D Outputs (Sink) | | | | 15 | mA |
| All others | | | | 3 | mA |
| Maximum Input Current | | | | | |

DC Electrical Characteristics 888GG, 888HG, and 888KG: (Continued)-40°C ≤ T_A ≤ +85°C unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|---------------------------------------|---------------------------------|-----|-----|------|-------|
| without Latchup (Notes 9, 10) | Room Temperature | | | ±100 | mA |
| RAM Retention Voltage, V _r | 500 ns Rise and Fall Time (min) | 2 | | | V |
| Input Capacitance | | | | 7 | pF |
| Load Capacitance on D2 | (Note 10) | | | 1000 | pF |

AC Electrical Characteristics 888GG, 888HG, and 888KG:-40°C ≤ T_A ≤ +85°C unless otherwise specified

| Parameter (88xCG & 88xEG only) | Conditions | Min | Typ | Max | Units |
|--|--|-----|-----|------|----------------|
| Instruction Cycle Time (t _c) | | | | | |
| Crystal, Resonator | 2.5V ≤ V _{CC} < 4V | 1.0 | | DC | μs |
| | 4V ≤ V _{CC} ≤ 5.5V | 2.5 | | DC | μs |
| R/C Oscillator | 2.5V ≤ V _{CC} < 4V | 3.0 | | DC | μs |
| | 4V ≤ V _{CC} ≤ 5.5V | 7.5 | | DC | μs |
| Inputs | | | | | |
| t _{SETUP} | 4V ≤ V _{CC} ≤ 5.5V | 200 | | | ns |
| | 2.5V ≤ V _{CC} < 4V | 500 | | | ns |
| t _{HOLD} | 4V ≤ V _{CC} ≤ 5.5V | 60 | | | ns |
| | 2.5V ≤ V _{CC} < 4V | 150 | | | ns |
| Output Propagation Delay | R _L = 2.2k, C _L = 100 pF | | | | |
| t _{PD1} , t _{PD0} | | | | | |
| SO, SK | 4V ≤ V _{CC} ≤ 5.5V | | | 0.7 | μs |
| | 2.5V ≤ V _{CC} < 4V | | | 1.75 | μs |
| All Others | 4V ≤ V _{CC} ≤ 5.5V | | | 1 | μs |
| | 2.5V ≤ V _{CC} < 4V | | | 2.5 | μs |
| MICROWIRE Setup Time (t _{UWS}) (Note 10) | V _{CC} ≥ 4V | 20 | | | ns |
| MICROWIRE Hold Time (t _{UWH}) (Note 10) | V _{CC} ≥ 4V | 56 | | | ns |
| MICROWIRE Output Propagation Delay (t _{UPD}) | V _{CC} ≥ 4V | | | 220 | ns |
| Input Pulse Width (Note 11) | | | | | |
| Interrupt Input High Time | | 1 | | | t _c |
| Interrupt Input Low Time | | 1 | | | t _c |
| Timer 1, 2, 3 Input High Time | | 1 | | | t _c |
| Timer 1, 2, 3 Input Low Time | | 1 | | | t _c |
| Reset Pulse Width | | 1 | | | μs |

Absolute Maximum Ratings (Note 5)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.

Supply Voltage (V_{CC}) 7V
Voltage at Any Pin $-0.3V$ to $V_{CC} + 0.3V$

Total Current into V_{CC} Pin (Source) 100 mA
Total Current out of GND Pin (Sink) 110 mA
Storage Temperature Range -65°C to $+140^{\circ}\text{C}$

Note 5: Absolute maximum ratings indicate limits beyond which damage to the device may occur. DC and AC electrical specifications are not ensured when operating the device at absolute maximum ratings.

DC Electrical Characteristics 68xCS and 68xxG:

$-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$ unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|---|-------------------------------------|--------------|-----|---------------|---------|
| Operating Voltage | | 4.5 | | 5.5 | V |
| Power Supply Ripple (Note 6) | Peak-to-Peak | | | $0.1 V_{CC}$ | V |
| Supply Current (Note 7) | | | | | |
| CKI = 10 MHz | $V_{CC} = 5.5V$, $t_c = 1 \mu s$ | | | 12.5 | mA |
| CKI = 4 MHz | $V_{CC} = 5.5V$, $t_c = 2.5 \mu s$ | | | 5.5 | mA |
| HALT Current (Note 8) | $V_{CC} = 5.5V$, CKI = 0 MHz | | <10 | 30 | μA |
| IDLE Current | | | | | |
| CKI = 10 MHz | $V_{CC} = 5.5V$, $t_c = 1 \mu s$ | | | 3.5 | mA |
| CKI = 4 MHz | $V_{CC} = 5.5V$, $t_c = 2.5 \mu s$ | | | 2.5 | mA |
| Input Levels (V_{IH} , V_{IL}) | | | | | |
| RESET | | | | | |
| Logic High | | $0.8 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| CKI (68xCS & 68xEG only) | | | | | |
| Logic High | | $0.7 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| All Other Inputs | | | | | |
| Logic High | | $0.7 V_{CC}$ | | | V |
| Logic Low | | | | $0.2 V_{CC}$ | V |
| Hi-Z Input Leakage | $V_{CC} = 5.5V$, $V_{IN} = 0V$ | -5 | | +5 | μA |
| Input Pullup Current | $V_{CC} = 5.5V$, $V_{IN} = 0V$ | -35 | | -400 | μA |
| G and L Port Input Hysteresis | (Note 10) | | | $0.35 V_{CC}$ | V |
| Output Current Levels | | | | | |
| D Outputs | | | | | |
| Source | $V_{CC} = 4.5V$, $V_{OH} = 3.3V$ | -0.4 | | | mA |
| Sink | $V_{CC} = 4.5V$, $V_{OL} = 1V$ | 9 | | | mA |
| All Others | | | | | |
| Source (Weak Pull-Up Mode) | $V_{CC} = 4.5V$, $V_{OH} = 2.7V$ | -9 | | -140 | μA |
| Source (Push-Pull Mode) | $V_{CC} = 4.5V$, $V_{OH} = 3.3V$ | -0.4 | | | mA |
| Sink (Push-Pull Mode) | $V_{CC} = 4.5V$, $V_{OL} = 0.4V$ | 1.4 | | | mA |
| TRI-STATE Leakage | $V_{CC} = 5.5V$ | -5 | | +5 | μA |
| Allowable Sink/Source Current per Pin | | | | | |
| D Outputs (Sink) | | | | 12 | mA |
| All others | | | | 2.5 | mA |
| Maximum Input Current without Latchup (Notes 9, 10) | Room Temp | | | ± 100 | mA |
| RAM Retention Voltage, V_r | 500 ns Rise and Fall Time (min) | 2 | | | V |
| Input Capacitance | (Note 10) | | | 7 | pF |
| Load Capacitance on D2 | (Note 10) | | | 1000 | pF |

AC Electrical Characteristics 68xCS and 68xxG:

–55°C ≤ T_A ≤ +125°C unless otherwise specified

| Parameter | Conditions | Min | Typ | Max | Units |
|--|--|-----|-----|-----|----------------|
| Instruction Cycle Time (t _c) | | | | | |
| Crystal, Resonator | V _{CC} ≥ 4.5V | 1.0 | | DC | μs |
| R/C Oscillator | V _{CC} ≥ 4.5V | 3.0 | | DC | μs |
| 68xCS & 68xEG only) | | | | | |
| Inputs | | | | | |
| t _{SETUP} | V _{CC} ≥ 4.5V | 200 | | | ns |
| t _{HOLD} | V _{CC} ≥ 4.5V | 60 | | | ns |
| Output Propagation Delay | R _L = 2.2k, C _L = 100 pF | | | | |
| t _{PD1} , t _{PD0} | | | | | |
| SO, SK | V _{CC} ≥ 4.5V | | | 0.7 | μs |
| All Others | V _{CC} ≥ 4.5V | | | 1 | μs |
| MICROWIRE™ Setup Time (t _{UWS}) (Note 10) | | 20 | | | ns |
| MICROWIRE Hold Time (t _{UWH}) (Note 10) | | 56 | | | ns |
| MICROWIRE Output Propagation Delay (t _{UPD}) | | | | 220 | ns |
| Input Pulse Width (Note 11) | | | | | |
| Interrupt Input High Time | | 1 | | | t _c |
| Interrupt Input Low Time | | 1 | | | t _c |
| Timer 1, 2, 3 Input High Time | | 1 | | | t _c |
| Timer 1, 2, 3 Input Low Time | | 1 | | | t _c |
| Reset Pulse Width | | 1 | | | μs |

Note 6: Maximum rate of voltage change must be less than 0.5 V/ms.

Note 7: Supply current is measured after running 2000 cycles with a square wave CKI input, CKO open, inputs at rails and outputs open.

Note 8: The HALT mode will stop CKI from oscillating in the RC and the Crystal configurations. Measurement of IDD HALT is done with device neither sourcing or sinking current; with L, C, and G0–G5 programmed as low outputs and not driving a load; all outputs programmed low and not driving a load; all inputs tied to V_{CC}; clock monitor and comparators disabled. Parameter refers to HALT mode entered via setting bit 7 of the G Port data register. Part will pull up CKI during HALT in crystal clock mode.

Note 9: Pins G6 and RESET are designed with a high voltage input network. These pins allow input voltages greater than V_{CC} and the pins will have sink current to V_{CC} when biased at voltages greater than V_{CC} (the pins do not have source current when biased at a voltage below V_{CC}). The effective resistance to V_{CC} is 750Ω (typical). These two pins will not latch up. The voltage at the pins must be limited to less than 14V. WARNING: Voltages in excess of 14V will cause damage to the pins. This warning excludes ESD transients.

Note 10: Parameter characterized but not tested.

Note 11: t_c = Instruction Cycle Time

Comparators AC and DC Characteristics

V_{CC} = 5V, –40°C ≤ T_A ≤ +85°C.

| Parameter | Conditions | Min | Typ | Max | Units |
|---|---|-----|------|-----------------------|-------|
| Input Offset Voltage | 0.4V ≤ V _{IN} ≤ V _{CC} – 1.5V | | ±10 | ±25 | mV |
| Input Common Mode Voltage Range | | 0.4 | | V _{CC} – 1.5 | V |
| Voltage Gain | | | 300k | | V/V |
| Low Level Output Current | V _{OL} = 0.4V | 1.6 | | | mA |
| High Level Output Current | V _{OH} = 4.6V | 1.6 | | | mA |
| DC Supply Current per Comparator (When Enabled) | | | | 250 | μA |
| Response Time | 100 mV Overdrive, 100 pF Load | | | 1 | μs |

Comparators AC and DC Characteristics (Continued)

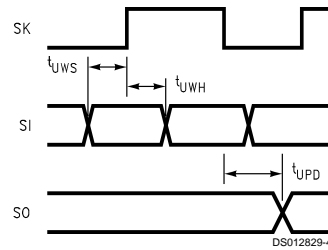
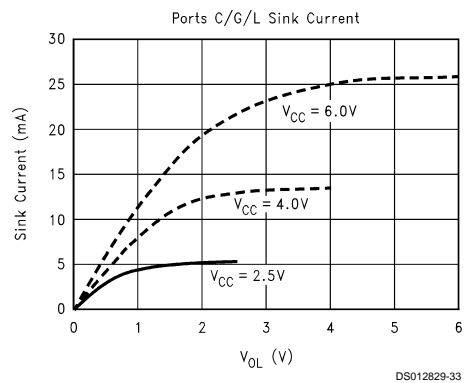
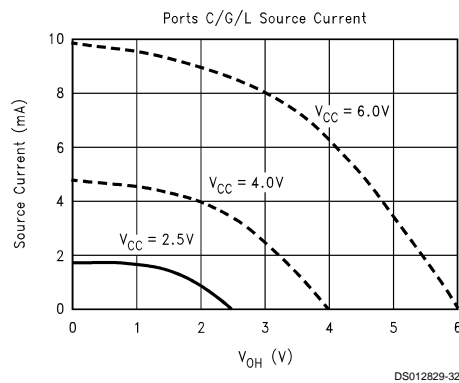
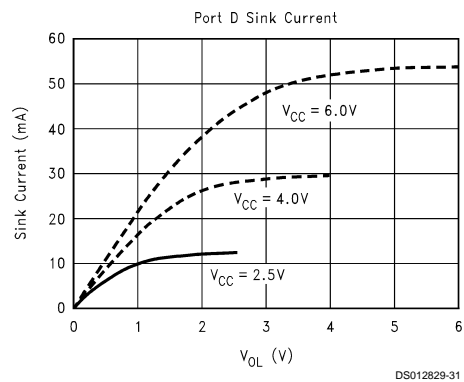
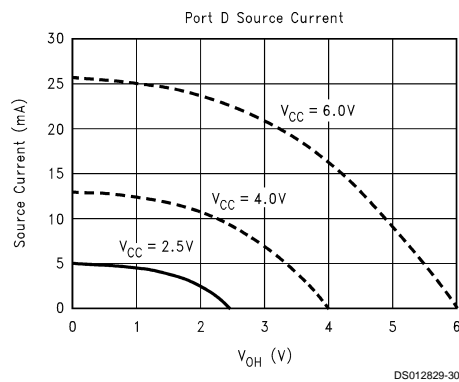
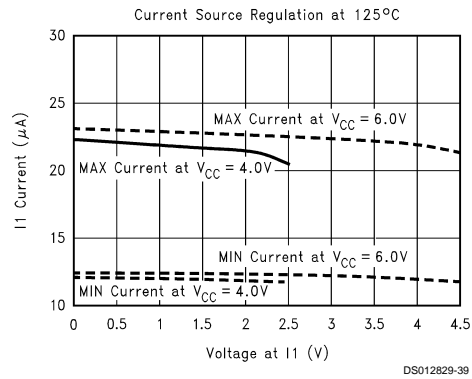
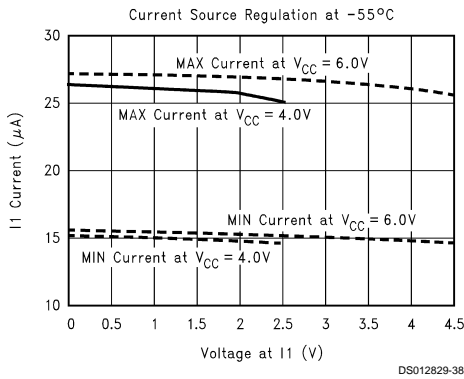
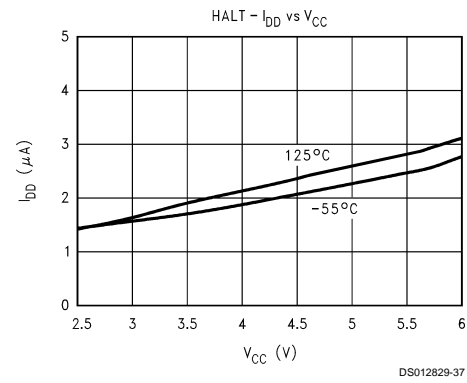
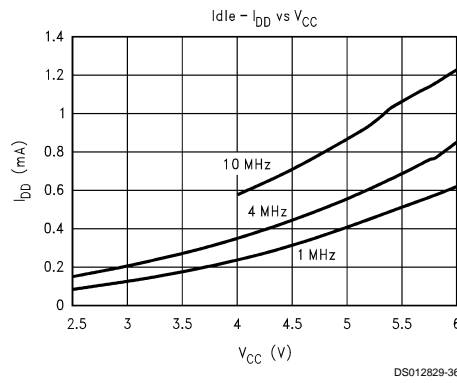
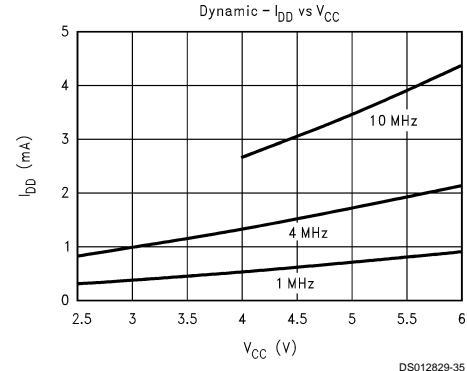
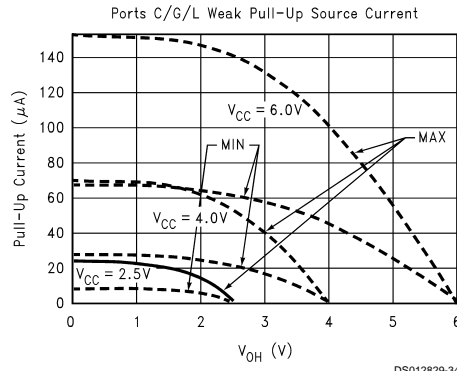


FIGURE 3. MICROWIRE/PLUS Timing

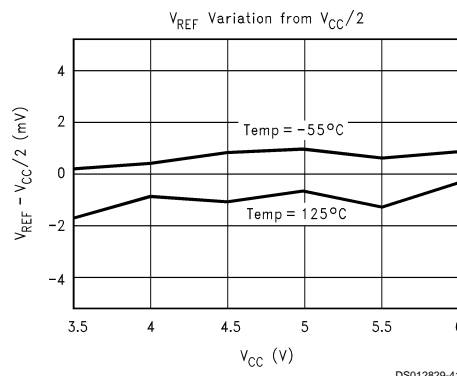
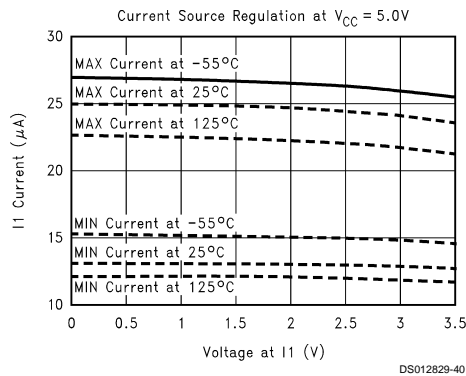
Typical Performance Characteristics ($-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$)



Typical Performance Characteristics ($-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$) (Continued)



Typical Performance Characteristics ($-55^{\circ}\text{C} \leq T_A \leq +125^{\circ}\text{C}$) (Continued)



Pin Descriptions

V_{CC} and GND are the power supply pins. All V_{CC} and GND pins must be connected.

CKI is the clock input. This can come from an R/C generated oscillator, or a crystal oscillator (in conjunction with CKO). See Oscillator Description section.

RESET is the master reset input. See Reset Description section.

The device contains three bidirectional 8-bit I/O ports (C, G and L), where each individual bit may be independently configured as an input (Schmitt Trigger inputs on ports L and G), output or TRI-STATE under program control. Three data memory address locations are allocated for each of these I/O ports. Each I/O port has two associated 8-bit memory mapped registers, the CONFIGURATION register and the output DATA register. A memory mapped address is also reserved for the input pins of each I/O port. (See the memory map for the various addresses associated with the I/O ports.) Figure 4 shows the I/O port configurations. The DATA and CONFIGURATION registers allow for each port bit to be individually configured under software control as shown below:

| CONFIGURATION Register | DATA Register | Port Set-Up |
|------------------------|---------------|-------------------------------|
| 0 | 0 | Hi-Z Input (TRI-STATE Output) |
| 0 | 1 | Input with Weak Pull-Up |
| 1 | 0 | Push-Pull Zero Output |
| 1 | 1 | Push-Pull One Output |

PORT L is an 8-bit I/O port. All L-pins have Schmitt triggers on the inputs.

The Port L supports Multi-Input Wake Up on all eight pins. L1 is used for the USART external clock. L2 and L3 are used for the USART transmit and receive. L4 and L5 are used for the timer input functions T2A and T2B. L6 and L7 are used for the timer input functions T3A and T3B (except on the CS series).

The Port L has the following alternate features:

- L7 MIWU or T3B
- L6 MIWU or T3A
- L5 MIWU or T2B
- L4 MIWU or T2A
- L3 MIWU or RDX

L2 MIWU or TDX

L1 MIWU or CKX

L0 MIWU

Port G is an 8-bit port with 5 I/O pins (G0, G2–G5), an input pin (G6), and a dedicated output pin (G1). Pins G0 and G2–G6 all have Schmitt Triggers on their inputs. Pin G1 serves as the dedicated WDOUT WATCHDOG output, while pin G7 is either input or output depending on the oscillator mask option selected. With the crystal oscillator option selected, G7 serves as the dedicated output pin for the CKO clock output. With the single-pin R/C oscillator mask option selected, G7 serves as a general purpose input pin but is also used to bring the device out of HALT mode with a low to high transition on G7. There are two registers associated with the G Port, a data register and a configuration register. Therefore, each of the 5 I/O bits (G0, G2–G5) can be individually configured under software control.

Since G6 is an input only pin and G7 is the dedicated CKO clock output pin (crystal clock option) or general purpose input (R/C clock option), the associated bits in the data and configuration registers for G6 and G7 are used for special purpose functions as outlined on the next page. Reading the G6 and G7 data bits will return zeros.

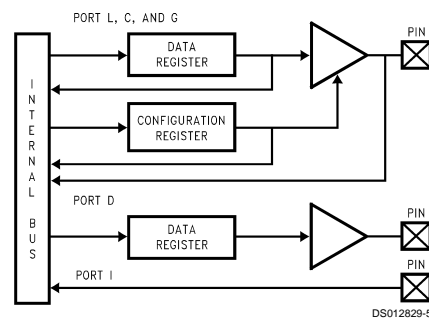


FIGURE 4. I/O Port Configurations

Note that the chip will be placed in the HALT mode by writing a "1" to bit 7 of the Port G Data Register. Similarly the chip will be placed in the IDLE mode by writing a "1" to bit 6 of the Port G Data Register.

Writing a "1" to bit 6 of the Port G Configuration Register enables the MICROWIRE/PLUS to operate with the alternate

Pin Descriptions (Continued)

phase of the SK clock. The G7 configuration bit, if set high, enables the clock start up delay after HALT when the R/C clock configuration is used.

| | Config Reg. | Data Reg. |
|----|--------------|-----------|
| G7 | CLKDLY | HALT |
| G6 | Alternate SK | IDLE |

Port G has the following alternate features:

- G6 SI (MICROWIRE Serial Data Input)
- G5 SK (MICROWIRE Serial Clock)
- G4 SO (MICROWIRE Serial Data Output)
- G3 T1A (Timer T1 I/O)
- G2 T1B (Timer T1 Capture Input)
- G0 INTR (External Interrupt Input)

Port G has the following dedicated functions:

- G7 CKO Oscillator dedicated output or general purpose input
- G1 WDOUT WATCHDOG and/or Clock Monitor dedicated output

Port C is an 8-bit I/O port. The 40-pin device does not have a full complement of Port C pins. The unavailable pins are not terminated. A read operation for these unterminated pins will return unpredictable values.

Port I is an eight-bit Hi-Z input port.

Port I1–I3 are used for Comparator 1. Port I4–I6 are used for Comparator 2.

The Port I has the following alternate features:

- I6 COMP2OUT (Comparator 2 Output)
- I5 COMP2+IN (Comparator 2 Positive Input)
- I4 COMP2–IN (Comparator 2 Negative Input)
- I3 COMP1OUT (Comparator 1 Output)
- I2 COMP1+IN (Comparator 1 Positive Input)
- I1 COMP1–IN (Comparator 1 Negative Input)

Port D is an 8-bit output port that is preset high when $\overline{\text{RESET}}$ goes low. The user can tie two or more D port outputs (except D2) together in order to get a higher drive.

Functional Description

The architecture of the device is modified Harvard architecture. With the Harvard architecture, the control store program memory (ROM) is separated from the data store memory (RAM). Both ROM and RAM have their own separate addressing space with separate address buses. The architecture, though based on Harvard architecture, permits transfer of data from ROM to RAM.

CPU REGISTERS

The CPU can do an 8-bit addition, subtraction, logical or shift operation in one instruction (t_c) cycle time.

There are six CPU registers:

A is the 8-bit Accumulator Register

PC is the 15-bit Program Counter Register

PU is the upper 7 bits of the program counter (PC)

PL is the lower 8 bits of the program counter (PC)

B is an 8-bit RAM address pointer, which can be optionally post auto incremented or decremented.

X is an 8-bit alternate RAM address pointer, which can be optionally post auto incremented or decremented.

SP is the 8-bit stack pointer, which points to the subroutine/interrupt stack (in RAM). The SP is initialized to RAM address 06F with reset.

S is the 8-bit Data Segment Address Register used to extend the lower half of the address range (00 to 7F) into 256 data segments of 128 bytes each.

All the CPU registers are memory mapped with the exception of the Accumulator (A) and the Program Counter (PC).

PROGRAM MEMORY

The program memory consists of up to 24 kbytes of ROM. These bytes may hold program instructions or constant data (data tables for the LAID instruction, jump vectors for the JID instruction, and interrupt vectors for the VIS instruction). The program memory is addressed by the 15-bit program counter (PC). All interrupts in the devices vector to program memory location 0FF Hex.

DATA MEMORY

The data memory address space includes the on-chip RAM and data registers, the I/O registers (Configuration, Data and Pin), the control registers, the MICROWIRE/PLUS SIO shift register, and the various registers, and counters associated with the timers (with the exception of the IDLE timer). Data memory is addressed directly by the instruction or indirectly by the B, X, SP pointers and S register.

The data memory consists of up to 512 bytes of RAM. Sixteen bytes of RAM are mapped as "registers" at addresses 0F0 to 0FF Hex. These registers can be loaded immediately, and also decremented and tested with the DRSZ (decrement register and skip if zero) instruction. The memory pointer registers X, SP, B and S are memory mapped into this space at address locations 0FC to 0FF Hex respectively, with the other registers being available for general usage.

The instruction set permits any bit in memory to be set, reset or tested. All I/O and registers (except A and PC) are memory mapped; therefore, I/O bits and register bits can be directly and individually set, reset and tested. The accumulator (A) bits can also be directly and individually tested.

Note: RAM contents are undefined upon power-up.

Data Memory Segment RAM Extension

Data memory address 0FF is used as a memory mapped location for the Data Segment Address Register (S).

The data store memory is either addressed directly by a single byte address within the instruction, or indirectly relative to the reference of the B, X, or SP pointers (each contains a single-byte address). This single-byte address allows an addressing range of 256 locations from 00 to FF hex. The upper bit of this single-byte address divides the data store memory into two separate sections as outlined previously. With the exception of the RAM register memory from address locations 00F0 to 00FF, all RAM memory is memory mapped with the upper bit of the single-byte address being equal to zero. This allows the upper bit of the single-byte address to determine whether or not the base address range (from 0000 to 00FF) is extended. If this upper bit equals one (representing address range 0080 to 00FF), then address extension does not take place. Alternatively, if this upper bit equals zero, then the data segment extension register S is used to extend the base address range (from 0000 to 007F) from XX00 to XX7F, where XX represents the 8 bits from the S register. Thus the 128-byte data segment extensions are located from addresses 0100 to 017F for data segment 1,

Data Memory Segment RAM Extension (Continued)

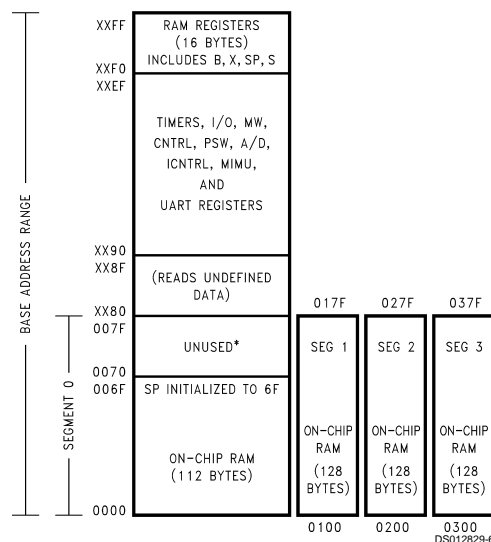
0200 to 027F for data segment 2, etc., up to FF00 to FF7F for data segment 255. The base address range from 0000 to 007F represents data segment 0.

Figure 5 illustrates how the S register data memory extension is used in extending the lower half of the base address range (00 to 7F hex) into 256 data segments of 128 bytes each, with a total addressing range of 32 kbytes from XX00 to XX7F. This organization allows a total of 256 data segments of 128 bytes each with an additional upper base segment of 128 bytes. Furthermore, all addressing modes are available for all data segments. The S register must be changed under program control to move from one data segment (128 bytes) to another. However, the upper base segment (containing the 16 memory registers, I/O registers, control registers, etc.) is always available regardless of the contents of the S register, since the upper base segment (address range 0080 to 00FF) is independent of data segment extension.

The instructions that utilize the stack pointer (SP) always reference the stack as part of the base segment (Segment 0), regardless of the contents of the S register. The S register is not changed by these instructions. Consequently, the stack (used with subroutine linkage and interrupts) is always located in the base segment. The stack pointer will be initialized to point at data memory location 006F as a result of reset.

The 128 bytes of RAM contained in the base segment are split between the lower and upper base segments. The first 112 bytes of RAM are resident from address 0000 to 006F in the lower base segment, while the remaining 16 bytes of RAM represent the 16 data memory registers located at addresses 00F0 to 00FF of the upper base segment. No RAM is located at the upper sixteen addresses (0070 to 007F) of the lower base segment.

Additional RAM beyond these initial 128 bytes, however, will always be memory mapped in groups of 128 bytes (or less) at the data segment address extensions (XX00 to XX7F) of the lower base segment. The additional bytes of RAM are memory mapped from segment 1 up through segment 3 (see Figure 5).



*Reads as all ones.

FIGURE 5. RAM Organization

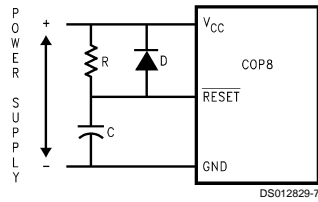
Reset

The **RESET** input when pulled low initializes the microcontroller. Initialization will occur whenever the **RESET** input is pulled low. Upon initialization, the data and configuration registers for ports L, G and C are cleared, resulting in these Ports being initialized to the TRI-STATE mode. Pin G1 of the G Port is an exception (as noted below) since pin G1 is dedicated as the WATCHDOG and/or Clock Monitor error output pin. Port D is set high. The PC, PSW, ICNTRL, CNTRL, T2CNTRL and T3CNTRL control registers are cleared. The USART registers PSR, ENU (except that TBMT bit is set), ENUR and ENUI are cleared. The Comparator Select Register is cleared. The S register is initialized to zero. The Multi-Input Wakeup registers WKEN and WKEDG are cleared. Wakeup register WKPND is unknown. The stack pointer, SP, is initialized to 6F hex.

The device comes out of reset with both the WATCHDOG logic and the Clock Monitor detector armed, with the WATCHDOG service window bits set and the Clock Monitor bit set. The WATCHDOG and Clock Monitor circuits are inhibited during reset. The WATCHDOG service window bits being initialized high default to the maximum WATCHDOG service window of 64k t_C clock cycles. The Clock Monitor bit being initialized high will cause a Clock Monitor error following reset if the clock has not reached the minimum specified frequency at the termination of reset. A Clock Monitor error will cause an active low error output on pin G1. This error output will continue until 16 t_C –32 t_C clock cycles following the clock frequency reaching the minimum specified value, at which time the G1 output will enter the TRI-STATE mode.

The external RC network shown in Figure 6 should be used to ensure that the **RESET** pin is held low until the power supply to the chip stabilizes.

Reset (Continued)



$RC > 5 \times \text{Power Supply Rise Time}$

FIGURE 6. Recommended Reset Circuit

Oscillator Circuits

The chip can be driven by a clock input on the CKI input pin which can be between DC and 10 MHz. The CKO output clock is on pin G7 (crystal configuration). The CKI input frequency is divided down by 10 to produce the instruction cycle clock ($1/t_c$).

Figure 7 shows the Crystal and R/C oscillator diagrams.

CRYSTAL OSCILLATOR

CKI and CKO can be connected to make a closed loop crystal (or resonator) controlled oscillator.

Table 1 shows the component values required for various standard crystal values.

R/C OSCILLATOR

By selecting CKI as a single pin oscillator input, a single pin R/C oscillator circuit can be connected to it. CKO is available as a general purpose input, and/or HALT restart input.

Table 2 shows the variation in the oscillator frequencies as functions of the component (R and C) values.

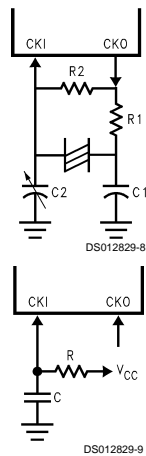


FIGURE 7. Crystal and R/C Oscillator Diagrams

TABLE 1. Crystal Oscillator Configuration, $T_A = 25^\circ\text{C}$

| R1 (k Ω) | R2 (M Ω) | C1 (pF) | C2 (pF) | CKI Freq (MHz) | Conditions |
|---------------------|---------------------|------------|------------|-------------------|---------------|
| 0 | 1 | 30 | 30–36 | 10 | $V_{CC} = 5V$ |

| R1 (k Ω) | R2 (M Ω) | C1 (pF) | C2 (pF) | CKI Freq (MHz) | Conditions |
|---------------------|---------------------|------------|------------|-------------------|-----------------|
| 0 | 1 | 30 | 30–36 | 4 | $V_{CC} = 5V$ |
| 0 | 1 | 200 | 100–150 | 0.455 | $V_{CC} = 2.5V$ |

TABLE 2. RC Oscillator Configuration, $T_A = 25^\circ\text{C}$

| R (k Ω) | C (pF) | CKI Freq (MHz) | Instr. Cycle (μs) | Conditions |
|--------------------|-----------|-------------------|-----------------------------------|---------------|
| 3.3 | 82 | 2.2 to 2.7 | 3.7 to 4.6 | $V_{CC} = 5V$ |
| 5.6 | 100 | 1.1 to 1.3 | 7.4 to 9.0 | $V_{CC} = 5V$ |
| 6.8 | 100 | 0.9 to 1.1 | 8.8 to 10.8 | $V_{CC} = 5V$ |

Note: $3k \leq R \leq 200k$

$50 \text{ pF} \leq C \leq 200 \text{ pF}$

CONTROL REGISTERS

CNTRL Register (Address X'00EE)

| T1C3 | T1C2 | T1C1 | T1C0 | MSEL | IEDG | SL1 | SL0 |
|-------|------|------|------|------|------|-----|-------|
| Bit 7 | | | | | | | Bit 0 |

The Timer1 (T1) and MICROWIRE/PLUS control register contains the following bits:

- T1C3 Timer T1 mode control bit
- T1C2 Timer T1 mode control bit
- T1C1 Timer T1 mode control bit
- T1C0 Timer T1 Start/Stop control in timer modes 1 and 2, T1 Underflow Interrupt Pending Flag in timer mode 3
- MSEL Selects G5 and G4 as MICROWIRE/PLUS signals SK and SO respectively
- IEDG External interrupt edge polarity select (0 = Rising edge, 1 = Falling edge)
- SL1 & SL0 Select the MICROWIRE/PLUS clock divide by (00 = 2, 01 = 4, 1x = 8)

PSW Register (Address X'00EF)

| HC | C | T1PNDA | T1ENA | EXPND | BUSY | EXEN | GIE |
|-------|---|--------|-------|-------|------|------|-------|
| Bit 7 | | | | | | | Bit 0 |

The PSW register contains the following select bits:

- HC Half Carry Flag
- C Carry Flag
- T1PNDA Timer T1 Interrupt Pending Flag (Autoreload RA in mode 1, T1 Underflow in Mode 2, T1A capture edge in mode 3)
- T1ENA Timer T1 Interrupt Enable for Timer Underflow or T1A Input capture edge
- EXPND External interrupt pending
- BUSY MICROWIRE/PLUS busy shifting flag
- EXEN Enable external interrupt
- GIE Global interrupt enable (enables interrupts)

The Half-Carry flag is also affected by all the instructions that affect the Carry flag. The SC (Set Carry) and R/C (Reset Carry) instructions will respectively set or clear both the carry flags. In addition to the SC and R/C instructions, ADC, SUBC, RRC and RLC instructions affect the Carry and Half Carry flags.

CONTROL REGISTERS (Continued)

ICNTRL Register (Address X'00E8)

| Reserved | LPEN | T0PND | T0EN | μ WPND | μ WEN | T1PNDB | T1ENB |
|----------|------|-------|------|------------|-----------|--------|-------|
| Bit 7 | | | | | | | Bit 0 |

The ICNTRL register contains the following bits:

| | |
|------------|--|
| Reserved | This bit is reserved and should be zero |
| LPEN | L Port Interrupt Enable (Multi-Input Wakeup/Interrupt) |
| T0PND | Timer T0 Interrupt pending |
| T0EN | Timer T0 Interrupt Enable (Bit 12 toggle) |
| μ WPND | MICROWIRE/PLUS interrupt pending |
| μ WEN | Enable MICROWIRE/PLUS interrupt |
| T1PNDB | Timer T1 Interrupt Pending Flag for T1B capture edge |
| T1ENB | Timer T1 Interrupt Enable for T1B Input capture edge |

T2CNTRL Register (Address X'00C6)

| T2C3 | T2C2 | T2C1 | T2C0 | T2PNDA | T2ENA | T2PNDB | T2ENB |
|-------|------|------|------|--------|-------|--------|-------|
| Bit 7 | | | | | | | Bit 0 |

The T2CNTRL control register contains the following bits:

| | |
|--------|---|
| T2C3 | Timer T2 mode control bit |
| T2C2 | Timer T2 mode control bit |
| T2C1 | Timer T2 mode control bit |
| T2C0 | Timer T2 Start/Stop control in timer modes 1 and 2, T2 Underflow Interrupt Pending Flag in timer mode 3 |
| T2PNDA | Timer T2 Interrupt Pending Flag (Autoreload RA in mode 1, T2 Underflow in mode 2, T2A capture edge in mode 3) |
| T2ENA | Timer T2 Interrupt Enable for Timer Underflow or T2A Input capture edge |
| T2PNDB | Timer T2 Interrupt Pending Flag for T2B capture edge |
| T2ENB | Timer T2 Interrupt Enable for Timer Underflow or T2B Input capture edge |

Note: The T2CNTRL register is not available on the CS series.

T3CNTRL Register (Address X'00B6)

| T3C3 | T3C2 | T3C1 | T3C0 | T3PNDA | T3ENA | T3PNDB | T3ENB |
|-------|------|------|------|--------|-------|--------|-------|
| Bit 7 | | | | | | | Bit 0 |

The T3CNTRL control register contains the following bits:

| | |
|--------|---|
| T3C3 | Timer T3 mode control bit |
| T3C2 | Timer T3 mode control bit |
| T3C1 | Timer T3 mode control bit |
| T3C0 | Timer T3 Start/Stop control in timer modes 1 and 2, T3 Underflow Interrupt Pending Flag in timer mode 3 |
| T3PNDA | Timer T3 Interrupt Pending Flag (Autoreload RA in mode 1, T3 Underflow in mode 2, T3A capture edge in mode 3) |
| T3ENA | Timer T3 Interrupt Enable for Timer Underflow or T3A Input capture edge |
| T3PNDB | Timer T3 Interrupt Pending Flag for T3B capture edge |
| T3ENB | Timer T3 Interrupt Enable for Timer Underflow or T3B Input capture edge |

Note: The T3CNTRL register is not available on the CS series.

Timers

These devices contain a very versatile set of timers (T0, T1, T2, T3 for all except the CS series, which only use T0 and T1). All timers and associated autoreload/capture registers power up containing random data.

TIMER T0 (IDLE TIMER)

The device supports applications that require maintaining real time and low power with the IDLE mode. This IDLE mode support is furnished by the IDLE timer T0, which is a 16-bit timer. The Timer T0 runs continuously at the fixed rate of the instruction cycle clock, t_c . The user cannot read or write to the IDLE Timer T0, which is a count down timer.

The Timer T0 supports the following functions:

- Exit out of the Idle Mode (See Idle Mode description)
- WATCHDOG logic (See WATCHDOG description)
- Start up delay out of the HALT mode

The IDLE Timer T0 can generate an interrupt when the thirteenth bit toggles. This toggle is latched into the T0PND pending flag, and will occur every 4 ms at the maximum clock frequency ($t_c = 1 \mu s$). A control flag T0EN allows the interrupt from the thirteenth bit of Timer T0 to be enabled or disabled. Setting T0EN will enable the interrupt, while resetting it will disable the interrupt.

TIMER T1, TIMER T2 AND TIMER T3

These devices can have a set of up to three powerful timer/counter blocks, T1, T2 and T3. The associated features and functioning of a timer block are described by referring to the timer block Tx. Since the three timer blocks, T1, T2 and T3 are identical, all comments are equally applicable to any of the three timer blocks.

Each timer block consists of a 16-bit timer, Tx, and two supporting 16-bit autoreload/capture registers, RxA and RxB. Each timer block has two pins associated with it, TxA and TxB. The pin TxA supports I/O required by the timer block, while the pin TxB is an input to the timer block. The powerful and flexible timer block allows the device to easily perform all timer functions with minimal software overhead. The timer block has three operating modes: Processor Independent PWM mode, External Event Counter mode, and Input Capture mode.

The control bits TxC3, TxC2, and TxC1 allow selection of the different modes of operation.

Mode 1. Processor Independent PWM Mode

As the name suggests, this mode allows the device to generate a PWM signal with very minimal user intervention. The user only has to define the parameters of the PWM signal (ON time and OFF time). Once begun, the timer block will continuously generate the PWM signal completely independent of the microcontroller. The user software services the timer block only when the PWM parameters require updating.

In this mode the timer Tx counts down at a fixed rate of t_c . Upon every underflow the timer is alternately reloaded with the contents of supporting registers, RxA and RxB. The very first underflow of the timer causes the timer to reload from the register RxA. Subsequent underflows cause the timer to be reloaded from the registers alternately beginning with the register RxB.

The Tx Timer control bits, TxC3, TxC2 and TxC1 set up the timer for PWM mode operation.

Figure 8 shows a block diagram of the timer in PWM mode.

Timers (Continued)

The underflows can be programmed to toggle the TxA output pin. The underflows can also be programmed to generate interrupts.

Underflows from the timer are alternately latched into two pending flags, TxPND A and TxPND B. The user must reset these pending flags under software control. Two control enable flags, TxENA and TxENB, allow the interrupts from the timer underflow to be enabled or disabled. Setting the timer enable flag TxENA will cause an interrupt when a timer underflow causes the Rx A register to be reloaded into the timer. Setting the timer enable flag TxENB will cause an interrupt when a timer underflow causes the Rx B register to be reloaded into the timer. Resetting the timer enable flags will disable the associated interrupts.

Either or both of the timer underflow interrupts may be enabled. This gives the user the flexibility of interrupting once per PWM period on either the rising or falling edge of the PWM output. Alternatively, the user may choose to interrupt on both edges of the PWM output.

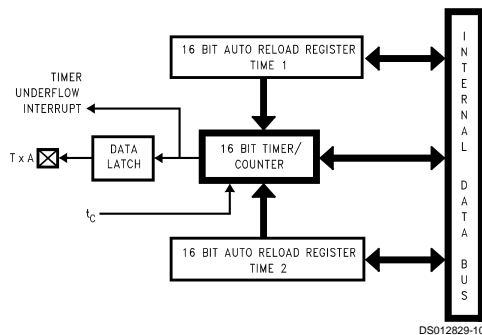


FIGURE 8. Timer in PWM Mode

Mode 2. External Event Counter Mode

This mode is quite similar to the processor independent PWM mode described above. The main difference is that the timer, Tx, is clocked by the input signal from the Tx A pin. The Tx timer control bits, Tx C3, Tx C2 and Tx C1 allow the timer to be clocked either on a positive or negative edge from the Tx A pin. Underflows from the timer are latched into the TxPND A pending flag. Setting the TxENA control flag will cause an interrupt when the timer underflows.

In this mode the input pin Tx B can be used as an independent positive edge sensitive interrupt input if the TxENB control flag is set. The occurrence of a positive edge on the Tx B input pin is latched into the TxPND B flag.

Figure 9 shows a block diagram of the timer in External Event Counter mode.

Note: The PWM output is not available in this mode since the Tx A pin is being used as the counter input clock.

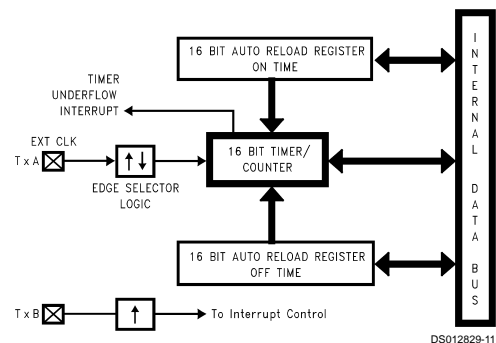


FIGURE 9. Timer in External Event Counter Mode

Mode 3. Input Capture Mode

The device can precisely measure external frequencies or time external events by placing the timer block, Tx, in the input capture mode.

In this mode, the timer Tx is constantly running at the fixed t_c rate. The two registers, Rx A and Rx B, act as capture registers. Each register acts in conjunction with a pin. The register Rx A acts in conjunction with the Tx A pin and the register Rx B acts in conjunction with the Tx B pin.

The timer value gets copied over into the register when a trigger event occurs on its corresponding pin. Control bits, Tx C3, Tx C2 and Tx C1, allow the trigger events to be specified either as a positive or a negative edge. The trigger condition for each input pin can be specified independently.

The trigger conditions can also be programmed to generate interrupts. The occurrence of the specified trigger condition on the Tx A and Tx B pins will be respectively latched into the pending flags, TxPND A and TxPND B. The control flag TxENA allows the interrupt on Tx A to be either enabled or disabled. Setting the TxENA flag enables interrupts to be generated when the selected trigger condition occurs on the Tx A pin. Similarly, the flag TxENB controls the interrupts from the Tx B pin.

Underflows from the timer can also be programmed to generate interrupts. Underflows are latched into the timer Tx C0 pending flag (the Tx C0 control bit serves as the timer underflow interrupt pending flag in the Input Capture mode). Consequently, the Tx C0 control bit should be reset when entering the Input Capture mode. The timer underflow interrupt is enabled with the TxENA control flag. When a Tx A interrupt occurs in the Input Capture mode, the user must check both the TxPND A and Tx C0 pending flags in order to determine whether a Tx A input capture or a timer underflow (or both) caused the interrupt.

Figure 10 shows a block diagram of the timer in Input Capture mode.

Timers (Continued)

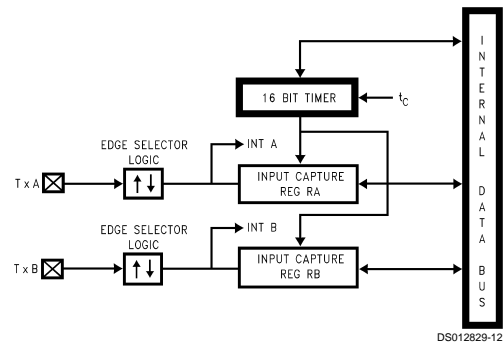


FIGURE 10. Timer in Input Capture Mode

TIMER CONTROL FLAGS

The control bits and their functions are summarized below.

| | |
|---------|---|
| TxC3 | Timer mode control |
| TxC2 | Timer mode control |
| TxC1 | Timer mode control |
| TxC0 | Timer Start/Stop control in Modes 1 and 2 (Processor Independent PWM and External Event Counter), where 1 = Start, 0 = Stop Timer Underflow Interrupt Pending Flag in Mode 3 (Input Capture) |
| TxPND A | Timer Interrupt Pending Flag |
| TxENA | Timer Interrupt Enable Flag 1 = Timer Interrupt Enabled 0 = Timer Interrupt Disabled |
| TxPND B | Timer Interrupt Pending Flag |
| TxENB | Timer Interrupt Enable Flag 1 = Timer Interrupt Enabled 0 = Timer Interrupt Disabled |

Timers (Continued)

The timer mode control bits (TxC3, TxC2 and TxC1) are detailed below:

| Mode | TxC3 | TxC2 | TxC1 | Description | Interrupt A Source | Interrupt B Source | Timer Counts On |
|------|------|------|------|--|-----------------------------------|--------------------|-----------------|
| 1 | 1 | 0 | 1 | PWM: Tx A Toggle | Autoreload RA | Autoreload RB | t_c |
| | 1 | 0 | 0 | PWM: No Tx A Toggle | Autoreload RA | Autoreload RB | t_c |
| 2 | 0 | 0 | 0 | External Event Counter | Timer Underflow | Pos. Tx B Edge | Pos. Tx A Edge |
| | 0 | 0 | 1 | External Event Counter | Timer Underflow | Pos. Tx B Edge | Pos. Tx A Edge |
| 3 | 0 | 1 | 0 | Captures: Tx A Pos. Edge Tx B Pos. Edge | Pos. Tx A Edge or Timer Underflow | Pos. Tx B Edge | t_c |
| | 1 | 1 | 0 | Captures: Tx A Pos. Edge Tx B Neg. Edge | Pos. Tx A Edge or Timer Underflow | Neg. Tx B Edge | t_c |
| | 0 | 1 | 1 | Captures: Tx A Neg. Edge Tx B Neg. Edge | Neg. Tx A Edge or Timer Underflow | Neg. Tx B Edge | t_c |
| | 1 | 1 | 1 | Captures: Tx A Neg. Edge Tx B Neg. Edge | Neg. Tx A Edge or Timer Underflow | Neg. Tx B Edge | t_c |

Power Save Modes

The device offers the user two power save modes of operation: HALT and IDLE. In the HALT mode, all microcontroller activities are stopped. In the IDLE mode, the on-board oscillator circuitry and timer T0 are active but all other microcontroller activities are stopped. In either mode, all on-board RAM, registers, I/O states, and timers (with the exception of T0) are unaltered.

HALT MODE

The device can be placed in the HALT mode by writing a "1" to the HALT flag (G7 data bit). All microcontroller activities, including the clock and timers, are stopped. The WATCHDOG logic on the device is disabled during the HALT mode. However, the clock monitor circuitry if enabled remains active and will cause the WATCHDOG output pin (WDOUT) to go low. If the HALT mode is used and the user does not want to activate the WDOUT pin, the Clock Monitor should be disabled after the device comes out of reset (resetting the Clock Monitor control bit with the first write to the WDSVR register). In the HALT mode, the power requirements of the device are minimal and the applied voltage (V_{CC}) may be decreased to V_i ($V_i = 2.0V$) without altering the state of the machine.

The device supports three different ways of exiting the HALT mode. The first method of exiting the HALT mode is with the Multi-Input Wakeup feature on the L port. The second method is with a low to high transition on the CKO (G7) pin. This method precludes the use of the crystal clock configuration (since CKO becomes a dedicated output), and so may only be used with an RC clock configuration. The third method of exiting the HALT mode is by pulling the RESET pin low.

Since a crystal or ceramic resonator may be selected as the oscillator, the Wakeup signal is not allowed to start the chip

running immediately since crystal oscillators and ceramic resonators have a delayed start up time to reach full amplitude and frequency stability. The IDLE timer is used to generate a fixed delay to ensure that the oscillator has indeed stabilized before allowing instruction execution. In this case, upon detecting a valid Wakeup signal, only the oscillator circuitry is enabled. The IDLE timer is loaded with a value of 256 and is clocked with the t_c instruction cycle clock. The t_c clock is derived by dividing the oscillator clock down by a factor of 10. The Schmitt trigger following the CKI inverter on the chip ensures that the IDLE timer is clocked only when the oscillator has a sufficiently large amplitude to meet the Schmitt trigger specifications. This Schmitt trigger is not part of the oscillator closed loop. The startup timeout from the IDLE timer enables the clock signals to be routed to the rest of the chip.

If an RC clock option is being used, the fixed delay is introduced optionally. A control bit, CLKDLY, mapped as configuration bit G7, controls whether the delay is to be introduced or not. The delay is included if CLKDLY is set, and excluded if CLKDLY is reset. The CLKDLY bit is cleared on reset.

The device has two mask options associated with the HALT mode. The first mask option enables the HALT mode feature, while the second mask option disables the HALT mode. With the HALT mode enable mask option, the device will enter and exit the HALT mode as described above. With the HALT disable mask option, the device cannot be placed in the HALT mode (writing a "1" to the HALT flag will have no effect, the HALT flag will remain "0").

IDLE MODE

The device is placed in the IDLE mode by writing a "1" to the IDLE flag (G6 data bit). In this mode, all activities, except the associated on-board oscillator circuitry and the IDLE Timer T0, are stopped. The power supply requirements of the

Power Save Modes (Continued)

micro-controller in this mode of operation are typically around 30% of normal power requirement of the micro-controller.

As with the HALT mode, the device can be returned to normal operation with a reset, or with a Multi-Input Wakeup from the L Port. Alternately, the microcontroller resumes normal operation from the IDLE mode when the thirteenth bit (representing 4.096 ms at internal clock frequency of 10 MHz, $t_c = 1 \mu s$) of the IDLE Timer toggles.

This toggle condition of the thirteenth bit of the IDLE Timer T0 is latched into the T0PND pending flag.

The user has the option of being interrupted with a transition on the thirteenth bit of the IDLE Timer T0. The interrupt can be enabled or disabled via the T0EN control bit. Setting the T0EN flag enables the interrupt and vice versa.

The user can enter the IDLE mode with the Timer T0 interrupt enabled. In this case, when the T0PND bit gets set, the

device will first execute the Timer T0 interrupt service routine and then return to the instruction following the "Enter Idle Mode" instruction.

Alternatively, the user can enter the IDLE mode with the IDLE Timer T0 interrupt disabled. In this case, the device will resume normal operation with the instruction immediately following the "Enter IDLE Mode" instruction.

Note: It is necessary to program two NOP instructions following both the set HALT mode and set IDLE mode instructions. These NOP instructions are necessary to allow clock resynchronization following the HALT or IDLE modes.

Multi-Input Wakeup

The Multi-Input Wakeup feature is used to return (wakeup) the device from either the HALT or IDLE modes. Alternately Multi-Input Wakeup/Interrupt feature may also be used to generate up to 8 edge selectable external interrupts.

Figure 11 shows the Multi-Input Wakeup logic.

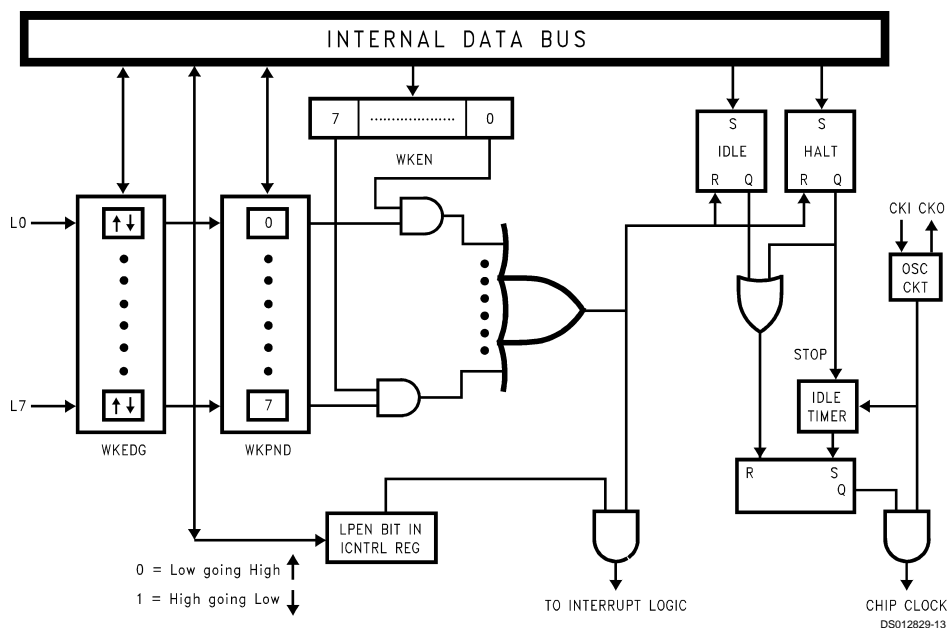


FIGURE 11. Multi-Input Wake Up Logic

The Multi-Input Wakeup feature utilizes the L Port. The user selects which particular L port bit (or combination of L Port bits) will cause the device to exit the HALT or IDLE modes. The selection is done through the Register WKEN. The Register WKEN is an 8-bit read/write register, which contains a control bit for every L port bit. Setting a particular WKEN bit enables a Wakeup from the associated L port pin.

The user can select whether the trigger condition on the selected L Port pin is going to be either a positive edge (low to high transition) or a negative edge (high to low transition). This selection is made via the Register WKEDG, which is an 8-bit control register with a bit assigned to each L Port pin. Setting the control bit will select the trigger condition to be a negative edge on that particular L Port pin. Resetting the bit selects the trigger condition to be a positive edge. Changing

an edge select entails several steps in order to avoid a Wakeup condition as a result of the edge change. First, the associated WKEN bit should be reset, followed by the edge select change in WKEDG. Next, the associated WKPND bit should be cleared, followed by the associated WKEN bit being re-enabled.

An example may serve to clarify this procedure. Suppose we wish to change the edge select from positive (low going high) to negative (high going low) for L Port bit 5, where bit 5 has previously been enabled for an input interrupt. The program would be as follows:

```

RBIT 5, WKEN ; Disable MIWU
SBIT 5, WKEDG ; Change edge polarity
RBIT 5, WKPND ; Reset pending flag
SBIT 5, WKEN ; Enable MIWU
    
```


Multi-Input Wakeup (Continued)

If the L port bits have been used as outputs and then changed to inputs with Multi-Input Wakeup/Interrupt, a safety procedure should also be followed to avoid wakeup conditions. After the selected L port bits have been changed from output to input but before the associated WKEN bits are enabled, the associated edge select bits in WKEDG should be set or reset for the desired edge selects, followed by the associated WKPND bits being cleared.

This same procedure should be used following reset, since the L port inputs are left floating as a result of reset.

The occurrence of the selected trigger condition for Multi-Input Wakeup is latched into a pending register called WKPND. The respective bits of the WKPND register will be set on the occurrence of the selected trigger edge on the corresponding Port L pin. The user has the responsibility of clearing these pending flags. Since WKPND is a pending register for the occurrence of selected wakeup conditions, the device will not enter the HALT mode if any Wakeup bit is both enabled and pending. Consequently, the user must clear the pending flags before attempting to enter the HALT mode.

WKEN, WKPND and WKEDG are all read/write registers, and are cleared at reset.

PORT L INTERRUPTS

Port L provides the user with an additional eight fully selectable, edge sensitive interrupts which are all vectored into the same service subroutine.

The interrupt from Port L shares logic with the wake up circuitry. The register WKEN allows interrupts from Port L to be individually enabled or disabled. The register WKEDG specifies the trigger condition to be either a positive or a negative edge. Finally, the register WKPND latches in the pending trigger conditions.

The GIE (Global Interrupt Enable) bit enables the interrupt function.

A control flag, LPEN, functions as a global interrupt enable for Port L interrupts. Setting the LPEN flag will enable interrupts and vice versa. A separate global pending flag is not needed since the register WKPND is adequate.

Since Port L is also used for waking the device out of the HALT or IDLE modes, the user can elect to exit the HALT or IDLE modes either with or without the interrupt enabled. If he elects to disable the interrupt, then the device will restart execution from the instruction immediately following the instruction that placed the microcontroller in the HALT or IDLE modes. In the other case, the device will first execute the interrupt service routine and then revert to normal operation. (See HALT MODE for clock option wakeup information.)

The Wakeup signal will not start the chip running immediately since crystal oscillators or ceramic resonators have a finite start up time. The IDLE Timer (T0) generates a fixed delay to ensure that the oscillator has indeed stabilized before allowing the device to execute instructions. In this case, upon detecting a valid Wakeup signal, only the oscillator circuitry and the IDLE Timer T0 are enabled. The IDLE Timer is loaded with a value of 256 and is clocked from the t_c instruction cycle clock. The t_c clock is derived by dividing down the oscillator clock by a factor of 10. A Schmitt trigger following the CKI on-inverter ensures that the IDLE timer is clocked only when the oscillator has a sufficiently large amplitude to meet the Schmitt trigger specifications. This Schmitt trigger is not part of the oscillator closed loop. The start-up time-out from the IDLE timer enables the clock signals to be routed to the rest of the chip.

If the RC clock option is used, the fixed delay is under software control. A control flag, CLKDLY, in the G7 configuration bit allows the clock start up delay to be optionally inserted. Setting CLKDLY flag high will cause clock start up delay to be inserted and resetting it will exclude the clock start up delay. The CLKDLY flag high will cause clock start up delay. The CLKDLY flag is cleared during reset, so the clock start up delay is not present following reset with the RC clock options.

USART

The device contains a full-duplex software programmable USART. The USART (*Figure 12*) consists of a transmit shift register, a receive shift register and seven addressable registers, as follows: a transmit buffer register (TBUF), a receiver buffer register (RBUF), a USART control and status register (ENU), a USART receive control and status register (ENUR), a USART interrupt and clock source register (ENUI), a prescaler select register (PSR) and baud (BAUD) register. The ENU register contains flags for transmit and receive functions; this register also determines the length of the data frame (7, 8 or 9 bits), the value of the ninth bit in transmission, and parity selection bits. The ENUR register flags framing, data overrun and parity errors while the USART is receiving.

Other functions of the ENUR register include saving the ninth bit received in the data frame, enabling or disabling the USART's attention mode of operation and providing additional receiver/transmitter status information via RCVG and XMTG bits. The determination of an internal or external clock source is done by the ENUI register, as well as selecting the number of stop bits and enabling or disabling transmit and receive interrupts. A control flag in this register can also select the USART mode of operation: asynchronous or synchronous.

USART (Continued)

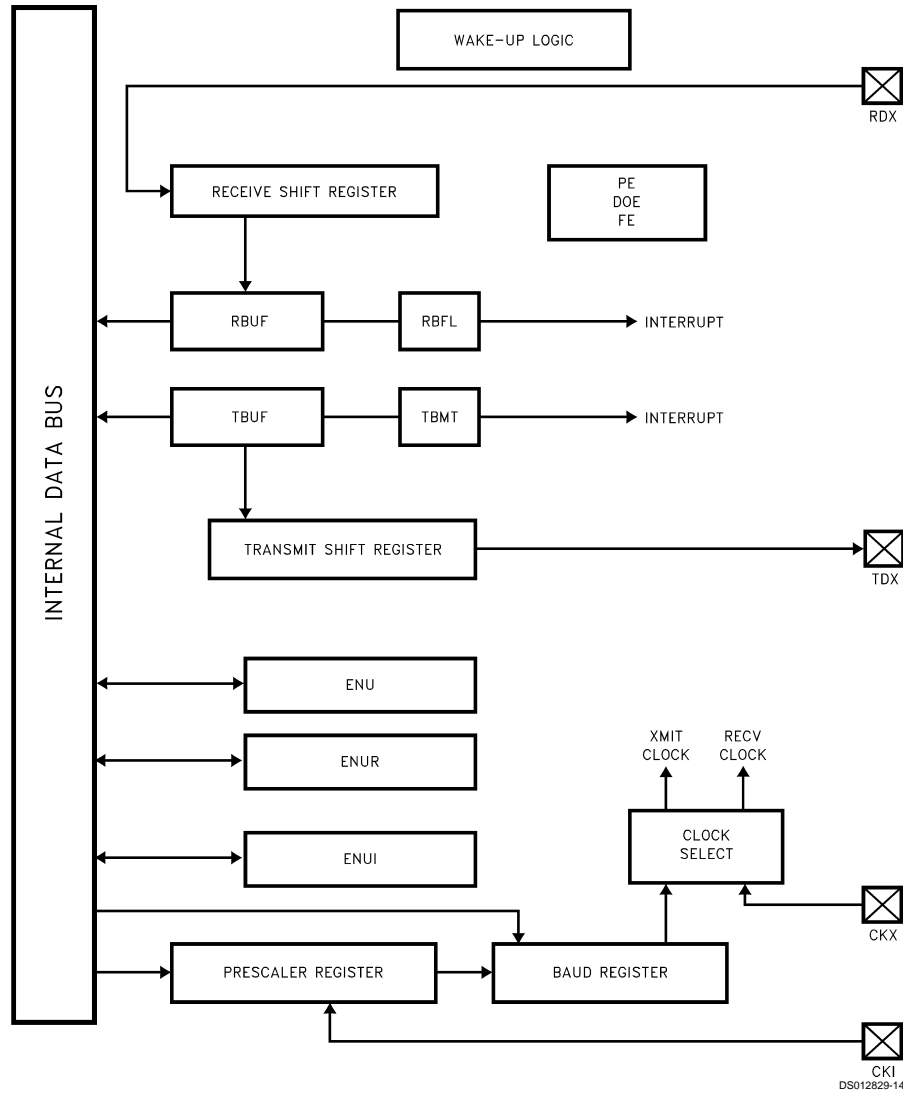


FIGURE 12. USART Block Diagram

USART CONTROL AND STATUS REGISTERS

The operation of the USART is programmed through three registers: ENU, ENUR and ENUI.

DESCRIPTION OF USART REGISTER BITS

ENU-USART Control and Status Register (Address at 0BA)

| PEN | PSEL1 | XBIT9/ PSEL0 | CHL1 | CHL0 | ERR | RBFL | TBMT |
|-------|-------|-----------------|------|------|-----|------|-------|
| Bit 7 | | | | | | | Bit 0 |

PEN: This bit enables/disables Parity (7- and 8-bit modes only). Read/Write, cleared on reset.

PEN = 0 Parity disabled.

PEN = 1 Parity enabled.

PSEL1, PSEL0: Parity select bits. Read/Write, cleared on reset.

PSEL1 = 0, PSEL0 = 0 Odd Parity (if Parity enabled)

PSEL1 = 0, PSEL0 = 1 Even Parity (if Parity enabled)

PSEL1 = 1, PSEL0 = 0 Mark(1) (if Parity enabled)

PSEL1 = 1, PSEL0 = 1 Space(0) (if Parity enabled)

XBIT9/PSEL0: Programs the ninth bit for transmission when the USART is operating with nine data bits per frame. For seven or eight data bits per frame, this bit in conjunction with PSEL1 selects parity. Read/Write, cleared on reset.

USART (Continued)

CHL1, CHL0: These bits select the character frame format. Parity is not included and is generated/verified by hardware. Read/Write, cleared on reset.

CHL1 = 0, CHL0 = 0 The frame contains eight data bits.
CHL1 = 0, CHL0 = 1 The frame contains seven data bits.

CHL1 = 1, CHL0 = 0 The frame contains nine data bits.
CHL1 = 1, CHL0 = 1 Loopback Mode selected. Transmitter output internally looped back to receiver input. Nine bit framing format is used.

ERR: This bit is a global USART error flag which gets set if any or a combination of the errors (DOE, FE, PE) occur. Read only; it cannot be written by software, cleared on reset.

RBFL: This bit is set when the USART has received a complete character and has copied it into the RBUF register. It is automatically reset when software reads the character from RBUF. Read only; it cannot be written by software, cleared on reset.

TBMT: This bit is set when the USART transfers a byte of data from the TBUF register into the TSFT register for transmission. It is automatically reset when software writes into the TBUF register. Read only, bit is set to "one" on reset; it cannot be written by software.

ENUR-USART Receive Control and Status Register
(Address at 0BB)

| DOE | FE | PE | Reserved (Note 12) | RBIT9 | ATTN | XMTG | RCVG |
|-------|----|----|-----------------------|-------|------|------|-------|
| Bit 7 | | | | | | | Bit 0 |

Note 12: Bit is reserved for future use. User must set to zero.

DOE: Flags a Data Overrun Error. Read only, cleared on read, cleared on reset.

DOE = 0 Indicates no Data Overrun Error has been detected since the last time the ENUR register was read.

DOE = 1 Indicates the occurrence of a Data Overrun Error.

FE: Flags a Framing Error. Read only, cleared on read, cleared on reset.

FE = 0 Indicates no Framing Error has been detected since the last time the ENUR register was read.

FE = 1 Indicates the occurrence of a Framing Error.

PE: Flags a Parity Error. Read only, cleared on read, cleared on reset.

PE = 0 Indicates no Parity Error has been detected since the last time the ENUR register was read.

PE = 1 Indicates the occurrence of a Parity Error.

SPARE: Reserved for future use. Read/Write, cleared on reset.

RBIT9: Contains the ninth data bit received when the USART is operating with nine data bits per frame. Read only, cleared on reset.

ATTN: ATTENTION Mode is enabled while this bit is set. This bit is cleared automatically on receiving a character with data bit nine set. Read/Write, cleared on reset.

XMTG: This bit is set to indicate that the USART is transmitting. It gets reset at the end of the last frame (end of last Stop bit). Read only, cleared on reset.

RCVG: This bit is set high whenever a framing error occurs and goes low when RDX goes high. Read only, cleared on reset.

ENUI-USART Interrupt and Clock Source Register
(Address at 0BC)

| STP2 | STP78 | ETDX | SSEL | XRCLK | XTCLK | ERI | ETI |
|-------|-------|------|------|-------|-------|-----|-------|
| Bit 7 | | | | | | | Bit 0 |

STP2: This bit programs the number of Stop bits to be transmitted. Read/Write, cleared on reset.

STP2 = 0 One Stop bit transmitted.

STP2 = 1 Two Stop bits transmitted.

STP78: This bit is set to program the last Stop bit to be 7/8th of a bit in length. Read/Write, cleared on reset.

ETDX: TDX (USART Transmit Pin) is the alternate function assigned to Port L pin L2; it is selected by setting ETDX bit. To simulate line break generation, software should reset ETDX bit and output logic zero to TDX pin through Port L data and configuration registers. Read/Write, cleared on reset.

SSEL: USART mode select. Read/Write, cleared on reset.

SSEL = 0 Asynchronous Mode.

SSEL = 1 Synchronous Mode.

XRCLK: This bit selects the clock source for the receiver section. Read/Write, cleared on reset.

XRCLK = 0 The clock source is selected through the PSR and BAUD registers.

XRCLK = 1 Signal on CKX (L1) pin is used as the clock.

XTCLK: This bit selects the clock source for the transmitter section. Read/Write, cleared on reset.

XTCLK = 0 The clock source is selected through the PSR and BAUD registers.

XTCLK = 1 Signal on CKX (L1) pin is used as the clock.

ERI: This bit enables/disables interrupt from the receiver section. Read/Write, cleared on reset.

ERI = 0 Interrupt from the receiver is disabled.

ERI = 1 Interrupt from the receiver is enabled.

ETI: This bit enables/disables interrupt from the transmitter section. Read/Write, cleared on reset.

ETI = 0 Interrupt from the transmitter is disabled.

ETI = 1 Interrupt from the transmitter is enabled.

Associated I/O Pins

Data is transmitted on the TDX pin and received on the RDX pin. TDX is the alternate function assigned to Port L pin L2; it is selected by setting ETDX (in the ENUI register) to one. RDX is an inherent function of Port L pin L3, requiring no setup.

The baud rate clock for the USART can be generated on-chip, or can be taken from an external source. Port L pin L1 (CKX) is the external clock I/O pin. The CKX pin can be either an input or an output, as determined by Port L Configuration and Data registers (Bit 1). As an input, it accepts a clock signal which may be selected to drive the transmitter and/or receiver. As an output, it presents the internal Baud Rate Generator output.

USART Operation

The USART has two modes of operation: asynchronous mode and synchronous mode.

ASYNCHRONOUS MODE

This mode is selected by resetting the SSEL (in the ENUI register) bit to zero. The input frequency to the USART is 16 times the baud rate.

The TSFT and TBUF registers double-buffer data for transmission. While TSFT is shifting out the current character on the TDX pin, the TBUF register may be loaded by software with the next byte to be transmitted. When TSFT finishes transmitting the current character the contents of TBUF are transferred to the TSFT register and the Transmit Buffer Empty Flag (TBMT in the ENU register) is set. The TBMT flag is automatically reset by the USART when software loads a new character into the TBUF register. There is also the XMTG bit which is set to indicate that the USART is transmitting. This bit gets reset at the end of the last frame (end of last Stop bit). TBUF is a read/write register.

The RSFT and RBUF registers double-buffer data being received. The USART receiver continually monitors the signal on the RDX pin for a low level to detect the beginning of a Start bit. Upon sensing this low level, it waits for half a bit time and samples again. If the RDX pin is still low, the receiver considers this to be a valid Start bit, and the remaining bits in the character frame are each sampled a single time, at the mid-bit position. Serial data input on the RDX pin is shifted into the RSFT register. Upon receiving the complete character, the contents of the RSFT register are copied into the RBUF register and the Received Buffer Full Flag (RBFL) is set. RBFL is automatically reset when software reads the character from the RBUF register. RBUF is a read only register. There is also the RCVG bit which is set high when a framing error occurs and goes low once RDX goes high. TBMT, XMTG, RBFL and RCVG are read only bits.

SYNCHRONOUS MODE

In this mode data is transferred synchronously with the clock. Data is transmitted on the rising edge and received on the falling edge of the synchronous clock.

This mode is selected by setting SSEL bit in the ENUI register. The input frequency to the USART is the same as the baud rate.

When an external clock input is selected at the CKX pin, data transmit and receive are performed synchronously with this clock through TDX/RDX pins.

If data transmit and receive are selected with the CKX pin as clock output, the device generates the synchronous clock

output at the CKX pin. The internal baud rate generator is used to produce the synchronous clock. Data transmit and receive are performed synchronously with this clock.

FRAMING FORMATS

The USART supports several serial framing formats (*Figure 13*). The format is selected using control bits in the ENU, ENUR and ENUI registers.

The first format (1, 1a, 1b, 1c) for data transmission (CHL0 = 1, CHL1 = 0) consists of Start bit, seven Data bits (excluding parity) and 7/8, one or two Stop bits. In applications using parity, the parity bit is generated and verified by hardware.

The second format (CHL0 = 0, CHL1 = 0) consists of one Start bit, eight Data bits (excluding parity) and 7/8, one or two Stop bits. Parity bit is generated and verified by hardware.

The third format for transmission (CHL0 = 0, CHL1 = 1) consists of one Start bit, nine Data bits and 7/8, one or two Stop bits. This format also supports the USART "ATTENTION" feature. When operating in this format, all eight bits of TBUF and RBUF are used for data. The ninth data bit is transmitted and received using two bits in the ENU and ENUR registers, called XBIT9 and RBIT9. RBIT9 is a read only bit. Parity is not generated or verified in this mode.

For any of the above framing formats, the last Stop bit can be programmed to be 7/8th of a bit in length. If two Stop bits are selected and the 7/8th bit is set (selected), the second Stop bit will be 7/8th of a bit in length.

The parity is enabled/disabled by PEN bit located in the ENU register. Parity is selected for 7- and 8-bit modes only. If parity is enabled (PEN = 1), the parity selection is then performed by PSEL0 and PSEL1 bits located in the ENU register.

Note that the XBIT9/PSEL0 bit located in the ENU register serves two mutually exclusive functions. This bit programs the ninth bit for transmission when the USART is operating with nine data bits per frame. There is no parity selection in this framing format. For other framing formats XBIT9 is not needed and the bit is PSEL0 used in conjunction with PSEL1 to select parity.

The frame formats for the receiver differ from the transmitter in the number of Stop bits required. The receiver only requires one Stop bit in a frame, regardless of the setting of the Stop bit selection bits in the control register. Note that an implicit assumption is made for full duplex USART operation that the framing formats are the same for the transmitter and receiver.

USART Operation (Continued)

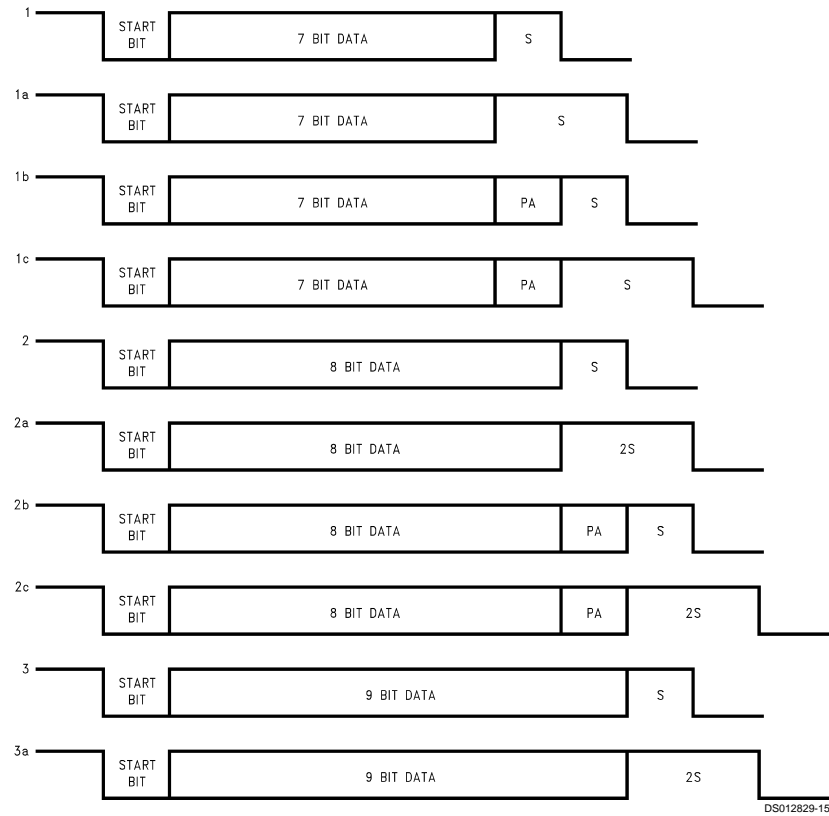


FIGURE 13. Framing Formats

USART INTERRUPTS

The USART is capable of generating interrupts. Interrupts are generated on Receive Buffer Full and Transmit Buffer Empty. Both interrupts have individual interrupt vectors. Two bytes of program memory space are reserved for each interrupt vector. The two vectors are located at addresses 0xEC to 0xEF Hex in the program memory space. The interrupts can be individually enabled or disabled using Enable Transmit Interrupt (ETI) and Enable Receive Interrupt (ERI) bits in the ENUI register.

The interrupt from the Transmitter is set pending, and remains pending, as long as both the TBMT and ETI bits are set. To remove this interrupt, software must either clear the ETI bit or write to the TBUF register (thus clearing the TBMT bit).

The interrupt from the receiver is set pending, and remains pending, as long as both the RBFL and ERI bits are set. To remove this interrupt, software must either clear the ERI bit or read from the RBUF register (thus clearing the RBFL bit).

Baud Clock Generation

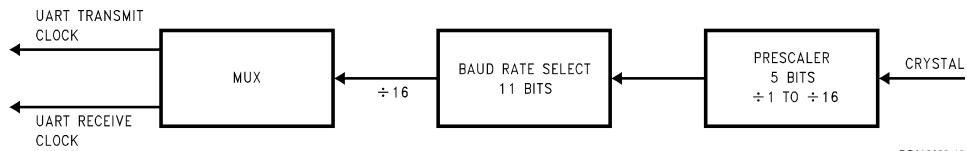
The clock inputs to the transmitter and receiver sections of the USART can be individually selected to come either from an external source at the CKX pin (port L, pin L1) or from a source selected in the PSR and BAUD registers. Internally,

the basic baud clock is created from the oscillator frequency through a two-stage divider chain consisting of a 1–16 (increments of 0.5) prescaler and an 11-bit binary counter. (Figure 14). The divide factors are specified through two read/write registers shown in Figure 15. Note that the 11-bit Baud Rate Divisor spills over into the Prescaler Select Register (PSR). PSR is cleared upon reset.

As shown in Table 6, a Prescaler Factor of 0 corresponds to NO CLOCK. This condition is the USART power down mode where the USART clock is turned off for power saving purpose. The user must also turn the USART clock off when a different baud rate is chosen.

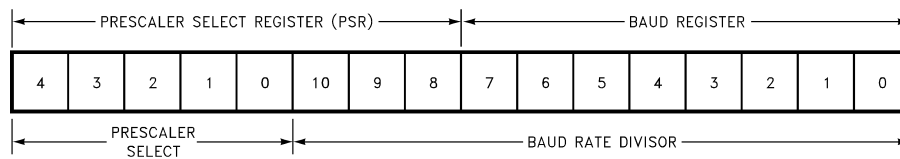
The correspondences between the 5-bit Prescaler Select and Prescaler factors are shown in Table 6. There are many ways to calculate the two divisor factors, but one particularly effective method would be to achieve a 1.8432 MHz frequency coming out of the first stage. The 1.8432 MHz prescaler output is then used to drive the software programmable baud rate counter to create a 16x clock for the following baud rates: 110, 134.5, 150, 300, 600, 1200, 1800, 2400, 3600, 4800, 7200, 9600, 19200 and 38400 (Table 1). Other baud rates may be created by using appropriate divisors. The 16x clock is then divided by 16 to provide the rate for the serial shift registers of the transmitter and receiver.

Baud Clock Generation (Continued)



DS012829-16

FIGURE 14. USART BAUD Clock Generation



DS012829-17

FIGURE 15. USART BAUD Clock Divisor Registers

TABLE 3. Baud Rate Divisors
(1.8432 MHz Prescaler Output)

| Baud Rate | Baud Rate Divisor – 1 (N-1) |
|----------------|-----------------------------|
| 110 (110.03) | 1046 |
| 134.5 (134.58) | 855 |
| 150 | 767 |
| 300 | 383 |
| 600 | 191 |
| 1200 | 95 |
| 1800 | 63 |
| 2400 | 47 |
| 3600 | 31 |
| 4800 | 23 |
| 7200 | 15 |
| 9600 | 11 |
| 19200 | 5 |
| 38400 | 2 |

Note: The entries in Table 4 assume a prescaler output of 1.8432 MHz. In the asynchronous mode the baud rate could be as high as 625k.

TABLE 4. Prescaler Factors

| Prescaler Select | Prescaler Factor |
|------------------|------------------|
| 00000 | NO CLOCK |
| 00001 | 1 |
| 00010 | 1.5 |
| 00011 | 2 |
| 00100 | 2.5 |
| 00101 | 3 |
| 00110 | 3.5 |
| 00111 | 4 |

| Prescaler Select | Prescaler Factor |
|------------------|------------------|
| 01000 | 4.5 |
| 01001 | 5 |
| 01010 | 5.5 |
| 01011 | 6 |
| 01100 | 6.5 |
| 01101 | 7 |
| 01110 | 7.5 |
| 01111 | 8 |
| 10000 | 8.5 |
| 10001 | 9 |
| 10010 | 9.5 |
| 10011 | 10 |
| 10100 | 10.5 |
| 10101 | 11 |
| 10110 | 11.5 |
| 10111 | 12 |
| 11000 | 12.5 |
| 11001 | 13 |
| 11010 | 13.5 |
| 11011 | 14 |
| 11100 | 14.5 |
| 11101 | 15 |
| 11110 | 15.5 |
| 11111 | 16 |

Baud Clock Generation (Continued)

As an example, considering Asynchronous Mode and a CKI clock of 4.608 MHz, the prescaler factor selected is:

$$4.608/1.8432 = 2.5$$

The 2.5 entry is available in *Table 4*. The 1.8432 MHz prescaler output is then used with proper Baud Rate Divisor (*Table 3*) to obtain different baud rates. For a baud rate of 19200 e.g., the entry in *Table 3* is 5.

$N - 1 = 5$ ($N - 1$ is the value from *Table 3*)

$N = 6$ (N is the Baud Rate Divisor)

$$\text{Baud Rate} = 1.8432 \text{ MHz}/(16 \times 6) = 19200$$

The divide by 16 is performed because in the asynchronous mode, the input frequency to the USART is 16 times the baud rate. The equation to calculate baud rates is given below.

The actual Baud Rate may be found from:

$$\text{BR} = \text{Fc}/(16 \times N \times P)$$

Where:

BR is the Baud Rate

Fc is the CKI frequency

N is the Baud Rate Divisor (*Table 3*).

P is the Prescaler Divide Factor selected by the value in the Prescaler Select Register (*Table 4*)

Note: In the Synchronous Mode, the divisor 16 is replaced by two.

Example:

Asynchronous Mode:

Crystal Frequency = 5 MHz

Desired baud rate = 9600

Using the above equation $N \times P$ can be calculated first.

$$N \times P = (5 \times 10^6)/(16 \times 9600) = 32.552$$

Now 32.552 is divided by each Prescaler Factor (*Table 4*) to obtain a value closest to an integer. This factor happens to be 6.5 ($P = 6.5$).

$$N = 32.552/6.5 = 5.008 \text{ (} N = 5 \text{)}$$

The programmed value (from *Table 3*) should be 4 ($N - 1$).

Using the above values calculated for N and P:

$$\text{BR} = (5 \times 10^6)/(16 \times 5 \times 6.5) = 9615.384$$

$$\% \text{ error} = (9615.385 - 9600)/9600 \times 100 = 0.16\%$$

Effect of HALT/IDLE

The USART logic is reinitialized when either the HALT or IDLE modes are entered. This reinitialization sets the TBMT flag and resets all read only bits in the USART control and status registers. Read/Write bits remain unchanged. The Transmit Buffer (TBUF) is not affected, but the Transmit Shift register (TSFT) bits are set to one. The receiver registers RBUF and RSFT are not affected.

The device will exit from the HALT/IDLE modes when the Start bit of a character is detected at the RDX (L3) pin. This feature is obtained by using the Multi-Input Wakeup scheme provided on the device.

Before entering the HALT or IDLE modes the user program must select the Wakeup source to be on the RDX pin. This selection is done by setting bit 3 of WKEN (Wakeup Enable) register. The Wakeup trigger condition is then selected to be high to low transition. This is done via the WKEDG register (Bit 3 is one.)

If the device is halted and crystal oscillator is used, the Wakeup signal will not start the chip running immediately be-

cause of the finite start up time requirement of the crystal oscillator. The idle timer (T0) generates a fixed ($256 t_c$) delay to ensure that the oscillator has indeed stabilized before allowing the device to execute code. The user has to consider this delay when data transfer is expected immediately after exiting the HALT mode.

Diagnostic

Bits CHARL0 and CHARL1 in the ENU register provide a loopback feature for diagnostic testing of the USART. When these bits are set to one, the following occur: The receiver input pin (RDX) is internally connected to the transmitter output pin (TDX); the output of the Transmitter Shift Register is "looped back" into the Receive Shift Register input. In this mode, data that is transmitted is immediately received. This feature allows the processor to verify the transmit and receive data paths of the USART.

Note that the framing format for this mode is the nine bit format; one Start bit, nine data bits, and 7/8, one or two Stop bits. Parity is not generated or verified in this mode.

Attention Mode

The USART Receiver section supports an alternate mode of operation, referred to as ATTENTION Mode. This mode of operation is selected by the ATTN bit in the ENUR register. The data format for transmission must also be selected as having nine Data bits and either 7/8, one or two Stop bits.

The ATTENTION mode of operation is intended for use in networking the device with other processors. Typically in such environments the messages consists of device addresses, indicating which of several destinations should receive them, and the actual data. This Mode supports a scheme in which addresses are flagged by having the ninth bit of the data field set to a 1. If the ninth bit is reset to a zero the byte is a Data byte.

While in ATTENTION mode, the USART monitors the communication flow, but ignores all characters until an address character is received. Upon receiving an address character, the USART signals that the character is ready by setting the RBFL flag, which in turn interrupts the processor if USART Receiver interrupts are enabled. The ATTN bit is also cleared automatically at this point, so that data characters as well as address characters are recognized. Software examines the contents of the RBUF and responds by deciding either to accept the subsequent data stream (by leaving the ATTN bit reset) or to wait until the next address character is seen (by setting the ATTN bit again).

Operation of the USART Transmitter is not affected by selection of this Mode. The value of the ninth bit to be transmitted is programmed by setting XBIT9 appropriately. The value of the ninth bit received is obtained by reading RBIT9. Since this bit is located in ENUR register where the error flags reside, a bit operation on it will reset the error flags.

Comparators

The device contains two differential comparators, each with a pair of inputs (positive and negative) and an output. Ports I1–I3 and I4–I6 are used for the comparators. The following is the Port I assignment:

- I6 Comparator2 output
- I5 Comparator2 positive input
- I4 Comparator2 negative input
- I3 Comparator1 output

Comparators (Continued)

- I2 Comparator1 positive input
- I1 Comparator1 negative input

Only Comparator 1 is available on the CS series.

A Comparator Select Register (CMPSL) is used to enable the comparators, read the outputs of the comparators internally, and enable the outputs of the comparators to the pins. Two control bits (enable and output enable) and one result

bit are associated with each comparator. The comparator result bits (CMP1RD and CMP2RD) are read only bits which will read as zero if the associated comparator is not enabled. The Comparator Select Register is cleared with reset, resulting in the comparators being disabled. The comparators should also be disabled before entering either the HALT or IDLE modes in order to save power. The configuration of the CMPSL register is as follows:

CMPSL REGISTER (ADDRESS X'00B7)

| Reserved | CMP20E | CMP2RD | CMP2EN | CMP10E | CMP1RD | CMP1EN | Reserved |
|----------|--------|--------|--------|--------|--------|--------|----------|
| Bit 7 | | | | | | | Bit 0 |

The CMPSL register contains the following bits:

Reserved These bits are reserved and must be zero

CMP20E Selects pin I6 as comparator 2 output provided that CMP2EN is set to enable the comparator

CMP2RD Comparator 2 result (this is a read only bit, which will read as 0 if the comparator is not enabled)

CMP2EN Enable comparator 2

CMP10E Selects pin I3 as comparator 1 output provided that CMP1EN is set to enable the comparator

CMP1RD Comparator 1 result (this is a read only bit, which will read as 0 if the comparator is not enabled)

CMP1EN Enable comparator 1

Note: For compatibility with existing code and with existing Mask ROMMed devices the bits of the CMPSL register will take precedence over the associated Port F configuration and data output bits.

Interrupts

INTRODUCTION

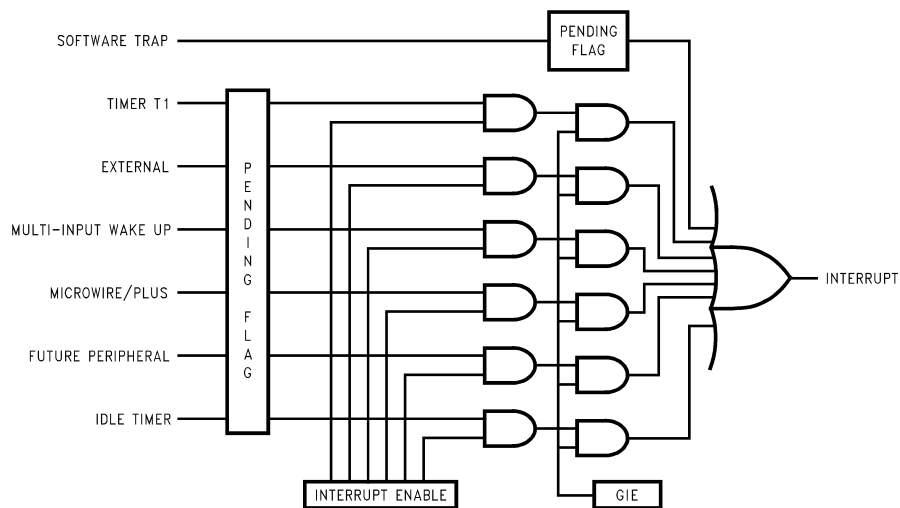
Each device supports thirteen vectored interrupts. Interrupt sources include Timer 0, Timer 1, Timer 2, Timer 3, Port L Wakeup, Software Trap, MICROWIRE/PLUS, and External Input.

All interrupts force a branch to location 00FF Hex in program memory. The VIS instruction may be used to vector to the appropriate service routine from location 00FF Hex.

The Software trap has the highest priority while the default VIS has the lowest priority.

Each of the 13 maskable inputs has a fixed arbitration ranking and vector.

Figure 16 shows the Interrupt Block Diagram.



DS012829-28

FIGURE 16. Interrupt Block Diagram

Interrupts (Continued)

MASKABLE INTERRUPTS

All interrupts other than the Software Trap are maskable. Each maskable interrupt has an associated enable bit and pending flag bit. The pending bit is set to 1 when the interrupt condition occurs. The state of the interrupt enable bit, combined with the GIE bit determines whether an active pending flag actually triggers an interrupt. All of the maskable interrupt pending and enable bits are contained in mapped control registers, and thus can be controlled by the software.

A maskable interrupt condition triggers an interrupt under the following conditions:

1. The enable bit associated with that interrupt is set.
2. The GIE bit is set.
3. The device is not processing a non-maskable interrupt. (If a non-maskable interrupt is being serviced, a maskable interrupt must wait until that service routine is completed.)

An interrupt is triggered only when all of these conditions are met at the beginning of an instruction. If different maskable interrupts meet these conditions simultaneously, the highest priority interrupt will be serviced first, and the other pending interrupts must wait.

Upon Reset, all pending bits, individual enable bits, and the GIE bit are reset to zero. Thus, a maskable interrupt condition cannot trigger an interrupt until the program enables it by setting both the GIE bit and the individual enable bit. When enabling an interrupt, the user should consider whether or not a previously activated (set) pending bit should be acknowledged. If, at the time an interrupt is enabled, any previous occurrences of the interrupt should be ignored, the associated pending bit must be reset to zero prior to enabling the interrupt. Otherwise, the interrupt may be simply enabled; if the pending bit is already set, it will immediately trigger an interrupt. A maskable interrupt is active if its associated enable and pending bits are set.

An interrupt is an asynchronous event which may occur before, during, or after an instruction cycle. Any interrupt which occurs during the execution of an instruction is not acknowledged until the start of the next normally executed instruction is to be skipped, the skip is performed before the pending interrupt is acknowledged.

At the start of interrupt acknowledgment, the following actions occur:

1. The GIE bit is automatically reset to zero, preventing any subsequent maskable interrupt from interrupting the current service routine. This feature prevents one maskable interrupt from interrupting another one being serviced.
2. The address of the instruction about to be executed is pushed onto the stack.
3. The program counter (PC) is loaded with 00FF Hex, causing a jump to that program memory location.

The device requires seven instruction cycles to perform the actions listed above.

If the user wishes to allow nested interrupts, the interrupts service routine may set the GIE bit to 1 by writing to the PSW register, and thus allow other maskable interrupts to interrupt the current service routine. If nested interrupts are allowed, caution must be exercised. The user must write the program in such a way as to prevent stack overflow, loss of saved context information, and other unwanted conditions.

The interrupt service routine stored at location 00FF Hex should use the VIS instruction to determine the cause of the

interrupt, and jump to the interrupt handling routine corresponding to the highest priority enabled and active interrupt. Alternately, the user may choose to poll all interrupt pending and enable bits to determine the source(s) of the interrupt. If more than one interrupt is active, the user's program must decide which interrupt to service.

Within a specific interrupt service routine, the associated pending bit should be cleared. This is typically done as early as possible in the service routine in order to avoid missing the next occurrence of the same type of interrupt event. Thus, if the same event occurs a second time, even while the first occurrence is still being serviced, the second occurrence will be serviced immediately upon return from the current interrupt routine.

An interrupt service routine typically ends with an RETI instruction. This instruction sets the GIE bit back to 1, pops the address stored on the stack, and restores that address to the program counter. Program execution then proceeds with the next instruction that would have been executed had there been no interrupt. If there are any valid interrupts pending, the highest-priority interrupt is serviced immediately upon return from the previous interrupt.

VIS INSTRUCTION

The general interrupt service routine, which starts at address 00FF Hex, must be capable of handling all types of interrupts. The VIS instruction, together with an interrupt vector table, directs the device to the specific interrupt handling routine based on the cause of the interrupt.

VIS is a single-byte instruction, typically used at the very beginning of the general interrupt service routine at address 00FF Hex, or shortly after that point, just after the code used for context switching. The VIS instruction determines which enabled and pending interrupt has the highest priority, and causes an indirect jump to the address corresponding to that interrupt source. The jump addresses (vectors) for all possible interrupts sources are stored in a vector table.

The vector table may be as long as 32 bytes (maximum of 16 vectors) and resides at the top of the 256-byte block containing the VIS instruction. However, if the VIS instruction is at the very top of a 256-byte block (such as at 00FF Hex), the vector table resides at the top of the next 256-byte block. Thus, if the VIS instruction is located somewhere between 00FF and 01DF Hex (the usual case), the vector table is located between addresses 01E0 and 01FF Hex. If the VIS instruction is located between 01FF and 02DF Hex, then the vector table is located between addresses 02E0 and 02FF Hex, and so on.

Each vector is 15 bits long and points to the beginning of a specific interrupt service routine somewhere in the 32 kbyte memory space. Each vector occupies two bytes of the vector table, with the higher-order byte at the lower address. The vectors are arranged in order of interrupt priority. The vector of the maskable interrupt with the lowest rank is located to 0yE0 (higher-order byte) and 0yE1 (lower-order byte). The next priority interrupt is located at 0yE2 and 0yE3, and so forth in increasing rank. The Software Trap has the highest rank and its vector is always located at 0yFE and 0yFF. The number of interrupts which can become active defines the size of the table.

Table 5 shows the types of interrupts, the interrupt arbitration ranking, and the locations of the corresponding vectors in the vector table.

The vector table should be filled by the user with the memory locations of the specific interrupt service routines. For ex-

Interrupts (Continued)

ample, if the Software Trap routine is located at 0310 Hex, then the vector location 0yFE and -0yFF should contain the data 03 and 10 Hex, respectively. When a Software Trap interrupt occurs and the VIS instruction is executed, the program jumps to the address specified in the vector table.

The interrupt sources in the vector table are listed in order of rank, from highest to lowest priority. If two or more enabled and pending interrupts are detected at the same time, the one with the highest priority is serviced first. Upon return from the interrupt service routine, the next highest-level pending interrupt is serviced.

If the VIS instruction is executed, but no interrupts are enabled and pending, the lowest-priority interrupt vector is used, and a jump is made to the corresponding address in the vector table. This is an unusual occurrence, and may be the result of an error. It can legitimately result from a change in the enable bits or pending flags prior to the execution of the VIS instruction, such as executing a single cycle instruction which clears an enable flag at the same time that the pending flag is set. It can also result, however, from inadvertent execution of the VIS command outside of the context of an interrupt.

The default VIS interrupt vector can be useful for applications in which time critical interrupts can occur during the servicing of another interrupt. Rather than restoring the pro-

gram context (A, B, X, etc.) and executing the RETI instruction, an interrupt service routine can be terminated by returning to the VIS instruction. In this case, interrupts will be serviced in turn until no further interrupts are pending and the default VIS routine is started. After testing the GIE bit to ensure that execution is not erroneous, the routine should restore the program context and execute the RETI to return to the interrupted program.

This technique can save up to fifty instruction cycles (t_p), or more, (50 μ s at 10 MHz oscillator) of latency for pending interrupts with a penalty of fewer than ten instruction cycles if no further interrupts are pending.

To ensure reliable operation, the user should always use the VIS instruction to determine the source of an interrupt. Although it is possible to poll the pending bits to detect the source of an interrupt, this practice is not recommended. The use of polling allows the standard arbitration ranking to be altered, but the reliability of the interrupt system is compromised. The polling routine must individually test the enable and pending bits of each maskable interrupt. If a Software Trap interrupt should occur, it will be serviced last, even though it should have the highest priority. Under certain conditions, a Software Trap could be triggered but not serviced, resulting in an inadvertent "locking out" of all maskable interrupts by the Software Trap pending flag. Problems such as this can be avoided by using VIS instruction.

TABLE 5. Interrupt Vector Table

| Arbitration Ranking | Source | Description | Vector Address (Note *NO TARGET FOR FNxref NS7955*) (Hi-Low Byte) |
|---------------------|----------------|------------------|---|
| (1) Highest | Software | INTR Instruction | 0yFE–0yFF |
| (2) | Reserved | | 0yFC–0yFD |
| (3) | External | G0 | 0yFA–0yFB |
| (4) | Timer T0 | Underflow | 0yF8–0yF9 |
| (5) | Timer T1 | T1A/Underflow | 0yF6–0yF7 |
| (6) | Timer T1 | T1B | 0yF4–0yF5 |
| (7) | MICROWIRE/PLUS | BUSY Low | 0yF2–0yF3 |
| (8) | Reserved | | 0yF0–0yF1 |
| (9) | UART | Receive | 0yEE–0yEF |
| (10) | UART | Transmit | 0yEC–0yED |
| (11) | Timer T2 * | T2A/Underflow | 0yEA–0yEB |
| (12) | Timer T2 * | T2B | 0yE8–0yE9 |
| (13) | Timer T3 * | T2A/Underflow | 0yE6–0yE7 |
| (14) | Timer T3 * | T3B | 0yE4–0yE5 |
| (15) | Port L/Wakeup | Port L Edge | 0yE2–0yE3 |
| (16) Lowest | Default VIS | Reserved | 0yE0–0yE1 |

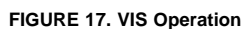
Note 13: y is a variable which represents the VIS block. VIS and the vector table must be located in the same 256-byte block except if VIS is located at the last address of a block. In this case, the table must be in the next block.

* Reserved on the CS series.

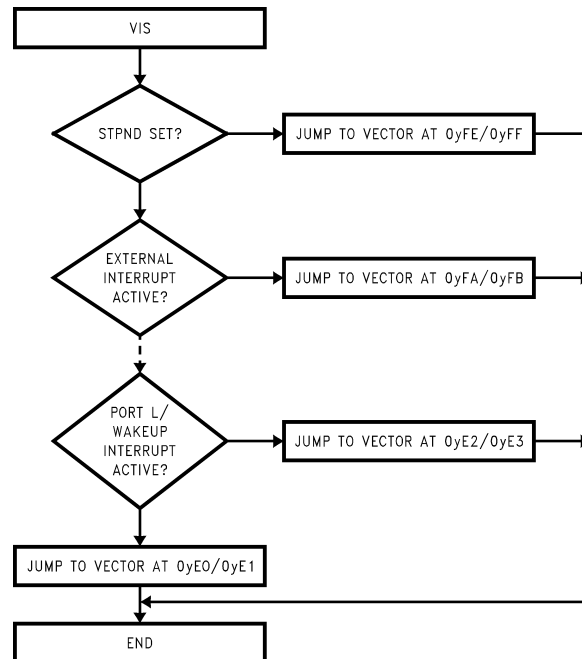
VIS Execution

ing. This vector is read from program memory and placed into the PC which is now pointed to the 1st instruction of the service routine of the active interrupt with the highest arbitration ranking.

The non-maskable interrupt pending flag is cleared by the RPND (Reset Non-Maskable Pending Bit) instruction (under certain conditions) and upon RESET.



Interrupts (Continued)



DS012829-30

FIGURE 18. VIS Flowchart

Interrupts (Continued)

Programming Example: External Interrupt

```
        PSW          =00EF
        CNTRL        =00EE
        RBIT         0,PORTGC
        RBIT         0,PORTGD      ; G0 pin configured Hi-Z
        SBIT         IEDG, CNTRL    ; Ext interrupt polarity; falling edge
        SBIT         EXEN, PSW      ; Enable the external interrupt
        SBIT         GIE, PSW       ; Set the GIE bit
WAIT:    JP          WAIT          ; Wait for external interrupt
        .
        .
        .=0FF                      ; The interrupt causes a
VIS      ; branch to address 0FF
        ; The VIS causes a branch to
        ; interrupt vector table
        .
        .
        .=01FA                      ; Vector table (within 256 byte
        .ADDRW SERVICE              ; of VIS inst.) containing the ext
        ; interrupt service routine
        .
        .
INT_EXIT: RETI
        .
        .
SERVICE: RBIT      EXPND, PSW       ; Interrupt Service Routine
        ; Reset ext interrupt pend. bit
        .
        .
        .
        JP    INT_EXIT              ; Return, set the GIE bit
```

Interrupts (Continued)

NON-MASKABLE INTERRUPT

Pending Flag

There is a pending flag bit associated with the non-maskable interrupt, called STPND. This pending flag is not memory-mapped and cannot be accessed directly by the software.

The pending flag is reset to zero when a device Reset occurs. When the non-maskable interrupt occurs, the associated pending bit is set to 1. The interrupt service routine should contain an RPND instruction to reset the pending flag to zero. The RPND instruction always resets the STPND flag.

Software Trap

The Software Trap is a special kind of non-maskable interrupt which occurs when the INTR instruction (used to acknowledge interrupts) is fetched from program memory and placed in the instruction register. This can happen in a variety of ways, usually because of an error condition. Some examples of causes are listed below.

If the program counter incorrectly points to a memory location beyond the available program memory space, the non-existent or unused memory location returns zeroes which is interpreted as the INTR instruction.

If the stack is popped beyond the allowed limit (address 06F Hex), a 7FFF will be loaded into the PC, if this last location in program memory is unprogrammed or unavailable, a Software Trap will be triggered.

A Software Trap can be triggered by a temporary hardware condition such as a brownout or power supply glitch.

The Software Trap has the highest priority of all interrupts. When a Software Trap occurs, the STPND bit is set. The GIE bit is not affected and the pending bit (not accessible by the user) is used to inhibit other interrupts and to direct the program to the ST service routine with the VIS instruction. Nothing can interrupt a Software Trap service routine except for another Software Trap. The STPND can be reset only by the RPND instruction or a chip Reset.

The Software Trap indicates an unusual or unknown error condition. Generally, returning to normal execution at the point where the Software Trap occurred cannot be done reliably. Therefore, the Software Trap service routine should reinitialize the stack pointer and perform a recovery procedure that restarts the software at some known point, similar to a device Reset, but not necessarily performing all the same functions as a device Reset. The routine must also execute the RPND instruction to reset the STPND flag. Otherwise, all other interrupts will be locked out. To the extent possible, the interrupt routine should record or indicate the context of the device so that the cause of the Software Trap can be determined.

If the user wishes to return to normal execution from the point at which the Software Trap was triggered, the user must first execute RPND, followed by RETSK rather than RETI or RET. This is because the return address stored on the stack is the address of the INTR instruction that triggered the interrupt. The program must skip that instruction in order to proceed with the next one. Otherwise, an infinite loop of Software Traps and returns will occur.

Programming a return to normal execution requires careful consideration. If the Software Trap routine is interrupted by another Software Trap, the RPND instruction in the service routine for the second Software Trap will reset the STPND

flag; upon return to the first Software Trap routine, the STPND flag will have the wrong state. This will allow maskable interrupts to be acknowledged during the servicing of the first Software Trap. To avoid problems such as this, the user program should contain the Software Trap routine to perform a recovery procedure rather than a return to normal execution.

Under normal conditions, the STPND flag is reset by a RPND instruction in the Software Trap service routine. If a programming error or hardware condition (brownout, power supply glitch, etc.) sets the STPND flag without providing a way for it to be cleared, all other interrupts will be locked out. To alleviate this condition, the user can use extra RPND instructions in the main program and in the WATCHDOG service routine (if present). There is no harm in executing extra RPND instructions in these parts of the program.

PORT L INTERRUPTS

Port L provides the user with an additional eight fully selectable, edge sensitive interrupts which are all vectored into the same service subroutine.

The interrupt from Port L shares logic with the wake up circuitry. The register WKEN allows interrupts from Port L to be individually enabled or disabled. The register WKEDG specifies the trigger condition to be either a positive or a negative edge. Finally, the register WKPND latches in the pending trigger conditions.

The GIE (Global Interrupt Enable) bit enables the interrupt function.

A control flag, LPEN, functions as a global interrupt enable for Port L interrupts. Setting the LPEN flag will enable interrupts and vice versa. A separate global pending flag is not needed since the register WKPND is adequate.

Since Port L is also used for waking the device out of the HALT or IDLE modes, the user can elect to exit the HALT or IDLE modes either with or without the interrupt enabled. If he elects to disable the interrupt, then the device will restart execution from the instruction immediately following the instruction that placed the microcontroller in the HALT or IDLE modes. In the other case, the device will first execute the interrupt service routine and then revert to normal operation. (See HALT MODE for clock option wakeup information.)

INTERRUPT SUMMARY

The device uses the following types of interrupts, listed below in order of priority:

1. The Software Trap non-maskable interrupt, triggered by the INTR (00 opcode) instruction. The Software Trap is acknowledged immediately. This interrupt service routine can be interrupted only by another Software Trap. The Software Trap should end with two RPND instructions followed by a restart procedure.
2. Maskable interrupts, triggered by an on-chip peripheral block or an external device connected to the device. Under ordinary conditions, a maskable interrupt will not interrupt any other interrupt routine in progress. A maskable interrupt routine in progress can be interrupted by the non-maskable interrupt request. A maskable interrupt routine should end with an RETI instruction or, prior to restoring context, should return to execute the VIS instruction. This is particularly useful when exiting long interrupt service routines if the time between interrupts is short. In this case the RETI instruction would only be executed when the default VIS routine is reached.

WATCHDOG

The device contains a WATCHDOG and clock monitor. The WATCHDOG is designed to detect the user program getting stuck in infinite loops resulting in loss of program control or "runaway" programs. The Clock Monitor is used to detect the absence of a clock or a very slow clock below a specified rate on the CKI pin.

The WATCHDOG consists of two independent logic blocks: WD UPPER and WD LOWER. WD UPPER establishes the upper limit on the service window and WD LOWER defines the lower limit of the service window.

Servicing the WATCHDOG consists of writing a specific value to a WATCHDOG Service Register named WDSVR which is memory mapped in the RAM. This value is composed of three fields, consisting of a 2-bit Window Select, a 5-bit Key Data field, and the 1-bit Clock Monitor Select field. Table 6 shows the WDSVR register.

TABLE 6. WATCHDOG Service Register (WDSVR)

| Window Select | | Key Data | | | | | Clock Monitor |
|---------------|---|----------|---|---|---|---|---------------|
| X | X | 0 | 1 | 1 | 0 | 0 | Y |
| 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 |

The lower limit of the service window is fixed at 2048 instruction cycles. Bits 7 and 6 of the WDSVR register allow the user to pick an upper limit of the service window.

Table 7 shows the four possible combinations of lower and upper limits for the WATCHDOG service window. This flexibility in choosing the WATCHDOG service window prevents any undue burden on the user software.

Bits 5, 4, 3, 2 and 1 of the WDSVR register represent the 5-bit Key Data field. The key data is fixed at 01100. Bit 0 of the WDSVR Register is the Clock Monitor Select bit.

TABLE 7. WATCHDOG Service Window Select

| WDSVR Bit 7 | WDSVR Bit 6 | Clock Monitor | Service Window (Lower-Upper Limits) |
|-------------|-------------|---------------|-------------------------------------|
| 0 | 0 | x | 2048–8k t_c Cycles |
| 0 | 1 | x | 2048–16k t_c Cycles |
| 1 | 0 | x | 2048–32k t_c Cycles |
| 1 | 1 | x | 2048–64k t_c Cycles |
| x | x | 0 | Clock Monitor Disabled |
| x | x | 1 | Clock Monitor Enabled |

Clock Monitor

The Clock Monitor aboard the device can be selected or de-selected under program control. The Clock Monitor is guaranteed not to reject the clock if the instruction cycle clock ($1/t_c$) is greater or equal to 10 kHz. This equates to a clock input rate on CKI of greater or equal to 100 kHz.

WATCHDOG Operation

The WATCHDOG and Clock Monitor are disabled during reset. The device comes out of reset with the WATCHDOG armed, the WATCHDOG Window Select bits (bits 6, 7 of the WDSVR Register) set, and the Clock Monitor bit (bit 0 of the WDSVR Register) enabled. Thus, a Clock Monitor error will

occur after coming out of reset, if the instruction cycle clock frequency has not reached a minimum specified value, including the case where the oscillator fails to start.

The WDSVR register can be written to only once after reset and the key data (bits 5 through 1 of the WDSVR Register) must match to be a valid write. This write to the WDSVR register involves two irrevocable choices: (i) the selection of the WATCHDOG service window (ii) enabling or disabling of the Clock Monitor. Hence, the first write to WDSVR Register involves selecting or deselecting the Clock Monitor, select the WATCHDOG service window and match the WATCHDOG key data. Subsequent writes to the WDSVR register will compare the value being written by the user to the WATCHDOG service window value and the key data (bits 7 through 1) in the WDSVR Register. Table 8 shows the sequence of events that can occur.

The user must service the WATCHDOG at least once before the upper limit of the service window expires. The WATCHDOG may not be serviced more than once in every lower limit of the service window. The user may service the WATCHDOG as many times as wished in the time period between the lower and upper limits of the service window. The first write to the WDSVR Register is also counted as a WATCHDOG service.

The WATCHDOG has an output pin associated with it. This is the WDOUT pin, on pin 1 of the port G. WDOUT is active low. The WDOUT pin is in the high impedance state in the inactive state. Upon triggering the WATCHDOG, the logic will pull the WDOUT (G1) pin low for an additional $16 t_c$ – $32 t_c$ cycles after the signal level on WDOUT pin goes below the lower Schmitt trigger threshold. After this delay, the device will stop forcing the WDOUT output low.

The WATCHDOG service window will restart when the WDOUT pin goes high. It is recommended that the user tie the WDOUT pin back to V_{CC} through a resistor in order to pull WDOUT high.

A WATCHDOG service while the WDOUT signal is active will be ignored. The state of the WDOUT pin is not guaranteed on reset, but if it powers up low then the WATCHDOG will time out and WDOUT will enter high impedance state.

The Clock Monitor forces the G1 pin low upon detecting a clock frequency error. The Clock Monitor error will continue until the clock frequency has reached the minimum specified value, after which the G1 output will enter the high impedance TRI-STATE mode following $16 t_c$ – $32 t_c$ clock cycles. The Clock Monitor generates a continual Clock Monitor error if the oscillator fails to start, or fails to reach the minimum specified frequency. The specification for the Clock Monitor is as follows:

$1/t_c > 10 \text{ kHz}$ — No clock rejection.

$1/t_c < 10 \text{ Hz}$ — Guaranteed clock rejection.

WATCHDOG AND CLOCK MONITOR SUMMARY

The following salient points regarding the WATCHDOG and CLOCK MONITOR should be noted:

- Both the WATCHDOG and CLOCK MONITOR detector circuits are inhibited during RESET.
- Following RESET, the WATCHDOG and CLOCK MONITOR are both enabled, with the WATCHDOG having the maximum service window selected.
- The WATCHDOG service window and CLOCK MONITOR enable/disable option can only be changed once, during the initial WATCHDOG service following RESET.

WATCHDOG Operation (Continued)

- The initial WATCHDOG service must match the key data value in the WATCHDOG Service register WDSVR in order to avoid a WATCHDOG error.
- Subsequent WATCHDOG services must match all three data fields in WDSVR in order to avoid WATCHDOG errors.
- The correct key data value cannot be read from the WATCHDOG Service register WDSVR. Any attempt to read this key data value of 01100 from WDSVR will read as key data value of all 0's.
- The WATCHDOG detector circuit is inhibited during both the HALT and IDLE modes.
- The CLOCK MONITOR detector circuit is active during both the HALT and IDLE modes. Consequently, the device inadvertently entering the HALT mode will be detected as a CLOCK MONITOR error (provided that the CLOCK MONITOR enable option has been selected by the program).
- With the single-pin R/C oscillator mask option selected and the CLKDLY bit reset, the WATCHDOG service window will resume following HALT mode from where it left off before entering the HALT mode.
- With the crystal oscillator mask option selected, or with the single-pin R/C oscillator mask option selected and the CLKDLY bit set, the WATCHDOG service window will be set to its selected value from WDSVR following HALT. Consequently, the WATCHDOG should not be serviced for at least 2048 instruction cycles following HALT, but must be serviced within the selected window to avoid a WATCHDOG error.
- The IDLE timer T0 is not initialized with RESET.
- The user can sync in to the IDLE counter cycle with an IDLE counter (T0) interrupt or by monitoring the T0PND flag. The T0PND flag is set whenever the thirteenth bit of the IDLE counter toggles (every 4096 instruction cycles). The user is responsible for resetting the T0PND flag.
- A hardware WATCHDOG service occurs just as the device exits the IDLE mode. Consequently, the WATCHDOG should not be serviced for at least 2048 instruction cycles following IDLE, but must be serviced within the selected window to avoid a WATCHDOG error.
- Following RESET, the initial WATCHDOG service (where the service window and the CLOCK MONITOR enable/disable must be selected) may be programmed anywhere within the maximum service window (65,536 instruction cycles) initialized by RESET. Note that this initial WATCHDOG service may be programmed within the initial 2048 instruction cycles without causing a WATCHDOG error.

Detection of Illegal Conditions

The device can detect various illegal conditions resulting from coding errors, transient noise, power supply voltage drops, runaway programs, etc.

Reading of undefined ROM gets zeros. The opcode for software interrupt is zero. If the program fetches instructions from undefined ROM, this will force a software interrupt, thus signaling that an illegal condition has occurred.

The subroutine stack grows down for each call (jump to subroutine), interrupt, or PUSH, and grows up for each return or POP. The stack pointer is initialized to RAM location 06F Hex during reset. Consequently, if there are more returns than calls, the stack pointer will point to addresses 070 and 071 Hex (which are undefined RAM). Undefined RAM from addresses 070 to 07F (Segment 0), and all other segments (i.e., Segments 4 ... etc.) is read as all 1's, which in turn will cause the program to return to address 7FFF Hex. This is an undefined ROM location and the instruction fetched (all 0's) from this location will generate a software interrupt signaling an illegal condition.

Thus, the chip can detect the following illegal conditions:

1. Executing from undefined ROM
2. Over "POP"ing the stack by having more returns than calls.

When the software interrupt occurs, the user can re-initialize the stack pointer and do a recovery procedure before restarting (this recovery program is probably similar to that following reset, but might not contain the same program initialization procedures). The recovery program should reset the software interrupt pending bit using the RPND instruction.

MICROWIRE/PLUS

MICROWIRE/PLUS is a serial synchronous communications interface. The MICROWIRE/PLUS capability enables the device to interface with any of National Semiconductor's MICROWIRE peripherals (i.e. A/D converters, display drivers, E²PROMs etc.) and with other microcontrollers which support the MICROWIRE interface. It consists of an 8-bit serial shift register (SIO) with serial data input (SI), serial data output (SO) and serial shift clock (SK). Figure 19 shows a block diagram of the MICROWIRE/PLUS logic.

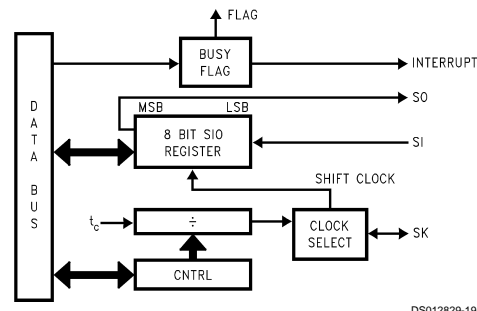


FIGURE 19. MICROWIRE/PLUS Block Diagram

The shift clock can be selected from either an internal source or an external source. Operating the MICROWIRE/PLUS arrangement with the internal clock source is called the Master mode of operation. Similarly, operating the MICROWIRE/PLUS arrangement with an external shift clock is called the Slave mode of operation.

The CNTRL register is used to configure and control the MICROWIRE/PLUS mode. To use the MICROWIRE/PLUS, the MSEL bit in the CNTRL register is set to one. In the master mode, the SK clock rate is selected by the two bits, SL0 and SL1, in the CNTRL register. Table 9 details the different clock rates that may be selected.

MICROWIRE/PLUS (Continued)

TABLE 8. WATCHDOG Service Actions

| Key Data | Window Data | Clock Monitor | Action |
|------------|-------------|---------------|---------------------------------------|
| Match | Match | Match | Valid Service: Restart Service Window |
| Don't Care | Mismatch | Don't Care | Error: Generate WATCHDOG Output |
| Mismatch | Don't Care | Don't Care | Error: Generate WATCHDOG Output |
| Don't Care | Don't Care | Mismatch | Error: Generate WATCHDOG Output |

TABLE 9. MICROWIRE/PLUS Master Mode Clock Select

| SL1 | SL0 | SK |
|-----|-----|-----------|
| 0 | 0 | 2 x t_c |
| 0 | 1 | 4 x t_c |
| 1 | x | 8 x t_c |

Where t_c is the instruction cycle clock

MICROWIRE/PLUS OPERATION

Setting the BUSY bit in the PSW register causes the MICROWIRE/PLUS to start shifting the data. It gets reset when eight data bits have been shifted. The user may reset the BUSY bit by software to allow less than 8 bits to shift. If enabled, an interrupt is generated when eight data bits have been shifted. The device may enter the MICROWIRE/PLUS mode either as a Master or as a Slave. *Figure 20* shows how two microcontroller devices and several peripherals may be interconnected using the MICROWIRE/PLUS arrangements.

Warning:

The SIO register should only be loaded when the SK clock is low. Loading the SIO register while the SK clock is high will result in undefined data in the SIO register. SK clock is normally low when not shifting.

Setting the BUSY flag when the input SK clock is high in the MICROWIRE/PLUS slave mode may cause the current SK clock for the SIO shift register to be narrow. For safety, the BUSY flag should only be set when the input SK clock is low.

MICROWIRE/PLUS Master Mode Operation

In the MICROWIRE/PLUS Master mode of operation the shift clock (SK) is generated internally by the device. The MICROWIRE Master always initiates all data exchanges. The MSEL bit in the CNTRL register must be set to enable the SO and SK functions onto the G Port. The SO and SK pins must also be selected as outputs by setting appropriate bits in the Port G configuration register. *Table 10* summarizes the bit settings required for Master mode of operation.

MICROWIRE/PLUS Slave Mode Operation

In the MICROWIRE/PLUS Slave mode of operation the SK clock is generated by an external source. Setting the MSEL bit in the CNTRL register enables the SO and SK functions

onto the G Port. The SK pin must be selected as an input and the SO pin is selected as an output pin by setting and resetting the appropriate bits in the Port G configuration register. *Table 10* summarizes the settings required to enter the Slave mode of operation.

The user must set the BUSY flag immediately upon entering the Slave mode. This will ensure that all data bits sent by the Master will be shifted properly. After eight clock pulses the BUSY flag will be cleared and the sequence may be repeated.

Alternate SK Phase Operation

The device allows either the normal SK clock or an alternate phase SK clock to shift data in and out of the SIO register. In both the modes the SK is normally low. In the normal mode data is shifted in on the rising edge of the SK clock and the data is shifted out on the falling edge of the SK clock. The SIO register is shifted on each falling edge of the SK clock. In the alternate SK phase operation, data is shifted in on the falling edge of the SK clock and shifted out on the rising edge of the SK clock.

A control flag, SKSEL, allows either the normal SK clock or the alternate SK clock to be selected. Resetting SKSEL causes the MICROWIRE/PLUS logic to be clocked from the normal SK signal. Setting the SKSEL flag selects the alternate SK clock. The SKSEL is mapped into the G6 configuration bit. The SKSEL flag will power up in the reset condition, selecting the normal SK signal.

TABLE 10. MICROWIRE/PLUS Mode Settings

This table assumes that the control flag MSEL is set.

| G4 (SO) Config. Bit | G5 (SK) Config. Bit | G4 Fun. | G5 Fun. | Operation |
|---------------------|---------------------|-----------|---------|-----------------------|
| 1 | 1 | SO | Int. SK | MICROWIRE/PLUS Master |
| 0 | 1 | TRI-STATE | Int. SK | MICROWIRE/PLUS Master |
| 1 | 0 | SO | Ext. SK | MICROWIRE/PLUS Slave |
| 0 | 0 | TRI-STATE | Ext. SK | MICROWIRE/PLUS Slave |

MICROWIRE/PLUS (Continued)

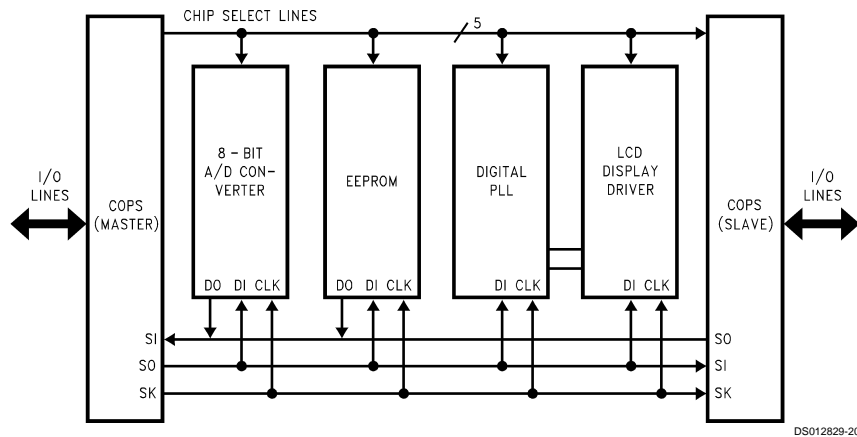


FIGURE 20. MICROWIRE/PLUS Application

Memory Map

All RAM, ports and registers (except A and PC) are mapped into data memory address space.

| Address S/ADD REG | Contents | Address S/ADD REG | Contents |
|----------------------|---|----------------------|---|
| 0000 to 006F | On-Chip RAM bytes (112 bytes) | xxBC | UART Interrupt and Clock Source Register (Reg:ENUI) |
| 0070 to 007F | Unused RAM Address Space (Reads As All Ones) | xxBD | UART Baud Register (Reg:BAUD) |
| xx80 to xx93 | Unused RAM Address Space (Reads Undefined Data) | xxBE | UART Prescale Select Register (Reg:PSR) |
| xx94 | Port F data register, PORTFD | xxBF | Reserved for UART |
| xx95 | Port F configuration register, PORTFC | xxC0 | Timer T2 Lower Byte |
| xx96 | Port F input pins (read only), PORTFP | xxC1 | Timer T2 Upper Byte |
| xx97 to xxAF | Unused address space (Reads Undefined Data) | xxC2 | Timer T2 Autoload Register T2RA Lower Byte |
| xxB0 | Timer T3 Lower Byte | xxC3 | Timer T2 Autoload Register T2RA Upper Byte |
| xxB1 | Timer T3 Upper Byte | xxC4 | Timer T2 Autoload Register T2RB Lower Byte |
| xxB2 | Timer T3 Autoload Register T3RA Lower Byte | xxC5 | Timer T2 Autoload Register T2RB Upper Byte |
| xxB3 | Timer T3 Autoload Register T3RA Upper Byte | xxC6 | Timer T2 Control Register |
| xxB4 | Timer T3 Autoload Register T3RB Lower Byte | xxC7 | WATCHDOG Service Register (Reg:WDSVR) |
| xxB5 | Timer T3 Autoload Register T3RB Upper Byte | xxC8 | MIWU Edge Select Register (Reg:WKEDG) |
| xxB6 | Timer T3 Control Register | xxC9 | MIWU Enable Register (Reg:WKEN) |
| xxB7 | Comparator Select Register (Reg:CMPSL) | xxCA | MIWU Pending Register (Reg:WKPND) |
| xxB8 | UART Transmit Buffer (Reg:TBUF) | xxCB to xxCF | Reserved |
| xxB9 | UART Receive Buffer (Reg:RBUF) | xxD0 | Port L Data Register |
| xxBA | UART Control and Status Register (Reg:ENU) | xxD1 | Port L Configuration Register |
| xxBB | UART Receive Control and Status Register (Reg:ENUR) | xxD2 | Port L Input Pins (Read Only) |
| | | xxD3 | Reserved for Port L |
| | | xxD4 | Port G Data Register |
| | | xxD5 | Port G Configuration Register |

Memory Map (Continued)

| Address S/ADD REG | Contents |
|----------------------|--|
| xxD6 | Port G Input Pins (Read Only) |
| xxD7 | Port I Input Pins (Read Only) (Actually reads Port F input pins) |
| xxD8 | Port C Data Register |
| xxD9 | Port C Configuration Register |
| xxDA | Port C Input Pins (Read Only) |
| xxDB | Reserved for Port C |
| xxDC | Port D |
| xxDD to xxDF | Reserved for Port D |
| xxE0 to xxE5 | Reserved for EE Control Registers |
| xxE6 | Timer T1 Autoload Register T1RB Lower Byte |
| xxE7 | Timer T1 Autoload Register T1RB Upper Byte |
| xxE8 | ICNTRL Register |
| xxE9 | MICROWIRE/PLUS Shift Register |
| xxEA | Timer T1 Lower Byte |
| xxEB | Timer T1 Upper Byte |

| Address S/ADD REG | Contents |
|----------------------|--|
| xxEC | Timer T1 Autoload Register T1RA Lower Byte |
| xxED | Timer T1 Autoload Register T1RA Upper Byte |
| xxEE | CNTRL Control Register |
| xxEF | PSW Register |
| xxF0 to xxFB | On-Chip RAM Mapped as Registers |
| xxFC | X Register |
| xxFD | SP Register |
| xxFE | B Register |
| xxFF | S Register |
| 0100–017F | On-Chip 128 RAM Bytes |
| 0200–027F | On-Chip 128 RAM Bytes (Reads as undefined data on COP8SGE) |
| 0300–037F | On-Chip 128 RAM Bytes (Reads as undefined data on COP8SGE) |

Note: Reading memory locations 0070H–007FH (Segment 0) will return all ones. Reading unused memory locations 0080H–00AFH (Segment 0) will return undefined data. Reading memory locations from other Segments (i.e., Segment 2, Segment 3, ... etc.) will return undefined data.

Addressing Modes

There are ten addressing modes, six for operand addressing and four for transfer of control.

OPERAND ADDRESSING MODES

Register Indirect

This is the “normal” addressing mode. The operand is the data memory addressed by the B pointer or X pointer.

Register Indirect (with auto post increment or decrement of pointer)

This addressing mode is used with the LD and X instructions. The operand is the data memory addressed by the B pointer or X pointer. This is a register indirect mode that automatically post increments or decrements the B or X register after executing the instruction.

Direct

The instruction contains an 8-bit address field that directly points to the data memory for the operand.

Immediate

The instruction contains an 8-bit immediate field as the operand.

Short Immediate

This addressing mode is used with the Load B Immediate instruction. The instruction contains a 4-bit immediate field as the operand.

Indirect

This addressing mode is used with the LAID instruction. The contents of the accumulator are used as a partial address (lower 8 bits of PC) for accessing a data operand from the program memory.

TRANSFER OF CONTROL ADDRESSING MODES

Relative

This mode is used for the JP instruction, with the instruction field being added to the program counter to get the new program location. JP has a range from –31 to +32 to allow a 1-byte relative jump (JP + 1 is implemented by a NOP instruction). There are no “pages” when using JP, since all 15 bits of PC are used.

Absolute

This mode is used with the JMP and JSR instructions, with the instruction field of 12 bits replacing the lower 12 bits of the program counter (PC). This allows jumping to any location in the current 4k program memory segment.

Absolute Long

This mode is used with the JMPL and JSRL instructions, with the instruction field of 15 bits replacing the entire 15 bits of the program counter (PC). This allows jumping to any location up to 32k in the program memory space.

Indirect

This mode is used with the JID instruction. The contents of the accumulator are used as a partial address (lower 8 bits of PC) for accessing a location in the program memory. The contents of this program memory location serve as a partial address (lower 8 bits of PC) for the jump to the next instruction.

Note: The VIS is a special case of the Indirect Transfer of Control addressing mode, where the double byte vector associated with the interrupt is transferred from adjacent addresses in the program memory into the program counter (PC) in order to jump to the associated interrupt service routine.

Instruction Set

Register and Symbol Definition

| Registers | |
|-----------|---|
| A | 8-Bit Accumulator Register |
| B | 8-Bit Address Register |
| X | 8-Bit Address Register |
| S | 8-Bit Segment Register |
| SP | 8-Bit Stack Pointer Register |
| PC | 15-Bit Program Counter Register |
| PU | Upper 7 Bits of PC |
| PL | Lower 8 Bits of PC |
| C | 1 Bit of PSW Register for Carry |
| HC | 1 Bit of PSW Register for Half Carry |
| GIE | 1 Bit of PSW Register for Global Interrupt Enable |
| VU | Interrupt Vector Upper Byte |
| VL | Interrupt Vector Lower Byte |

| Symbols | |
|---------|--|
| [B] | Memory Indirectly Addressed by B Register |
| [X] | Memory Indirectly Addressed by X Register |
| MD | Direct Addressed Memory |
| Mem | Direct Addressed Memory or [B] |
| Meml | Direct Addressed Memory or [B] or Immediate Data |
| Imm | 8-Bit Immediate Data |
| Reg | Register Memory: Addresses F0 to FF (Includes B, X and SP) |
| Bit | Bit Number (0 to 7) |
| ← | Loaded with |
| ↔ | Exchanged with |

Instruction Set (Continued)

INSTRUCTION SET

| | | | |
|-------|----------------|-------------------------------------|--|
| ADD | A,Meml | ADD | $A \leftarrow A + \text{Meml}$ |
| ADC | A,Meml | ADD with Carry | $A \leftarrow A + \text{Meml} + C$, $C \leftarrow \text{Carry}$ $HC \leftarrow \text{Half Carry}$ |
| SUBC | A,Meml | Subtract with Carry | $A \leftarrow A - \overline{\text{Meml}} + C$, $C \leftarrow \text{Carry}$ $HC \leftarrow \text{Half Carry}$ |
| AND | A,Meml | Logical AND | $A \leftarrow A \text{ and Meml}$ |
| ANDSZ | A,Imm | Logical AND Immed., Skip if Zero | Skip next if $(A \text{ and Imm}) = 0$ |
| OR | A,Meml | Logical OR | $A \leftarrow A \text{ or Meml}$ |
| XOR | A,Meml | Logical EXclusive OR | $A \leftarrow A \text{ xor Meml}$ |
| IFEQ | MD,Imm | IF Equal | Compare MD and Imm, Do next if $MD = \text{Imm}$ |
| IFEQ | A,Meml | IF Equal | Compare A and Meml, Do next if $A = \text{Meml}$ |
| IFNE | A,Meml | IF Not Equal | Compare A and Meml, Do next if $A \neq \text{Meml}$ |
| IFGT | A,Meml | IF Greater Than | Compare A and Meml, Do next if $A > \text{Meml}$ |
| IFBNE | # | If B Not Equal | Do next if lower 4 bits of $B \neq \text{Imm}$ |
| DRSZ | Reg | Decrement Reg., Skip if Zero | $\text{Reg} \leftarrow \text{Reg} - 1$, Skip if $\text{Reg} = 0$ |
| SBIT | #,Mem | Set BIT | 1 to bit, Mem (bit = 0 to 7 immediate) |
| RBIT | #,Mem | Reset BIT | 0 to bit, Mem |
| IFBIT | #,Mem | IF BIT | If bit in A or Mem is true do next instruction |
| RPND | | Reset PeNDing Flag | Reset Software Interrupt Pending Flag |
| X | A,Mem | EXchange A with Memory | $A \leftrightarrow \text{Mem}$ |
| X | A,[X] | EXchange A with Memory [X] | $A \leftrightarrow [X]$ |
| LD | A,Meml | LoaD A with Memory | $A \leftarrow \text{Meml}$ |
| LD | A,[X] | LoaD A with Memory [X] | $A \leftarrow [X]$ |
| LD | B,Imm | LoaD B with Immed. | $B \leftarrow \text{Imm}$ |
| LD | Mem,Imm | LoaD Memory Immed | $\text{Mem} \leftarrow \text{Imm}$ |
| LD | Reg,Imm | LoaD Register Memory Immed. | $\text{Reg} \leftarrow \text{Imm}$ |
| X | A, [B \pm] | EXchange A with Memory [B] | $A \leftrightarrow [B]$, $(B \leftarrow B \pm 1)$ |
| X | A, [X \pm] | EXchange A with Memory [X] | $A \leftrightarrow [X]$, $(X \leftarrow X \pm 1)$ |
| LD | A, [B \pm] | LoaD A with Memory [B] | $A \leftarrow [B]$, $(B \leftarrow B \pm 1)$ |
| LD | A, [X \pm] | LoaD A with Memory [X] | $A \leftarrow [X]$, $(X \leftarrow X \pm 1)$ |
| LD | [B \pm],Imm | LoaD Memory [B] Immed. | $[B] \leftarrow \text{Imm}$, $(B \leftarrow B \pm 1)$ |
| CLR | A | CLear A | $A \leftarrow 0$ |
| INC | A | INCRement A | $A \leftarrow A + 1$ |
| DEC | A | DECrement A | $A \leftarrow A - 1$ |
| LAID | | Load A InDirect from ROM | $A \leftarrow \text{ROM (PU,A)}$ |
| DCOR | A | Decimal CORrect A | $A \leftarrow \text{BCD correction of A (follows ADC, SUBC)}$ |
| RRC | A | Rotate A Right thru C | $C \rightarrow A7 \rightarrow \dots \rightarrow A0 \rightarrow C$ |
| RLC | A | Rotate A Left thru C | $C \leftarrow A7 \leftarrow \dots \leftarrow A0 \leftarrow C$ |
| SWAP | A | SWAP nibbles of A | $A7 \dots A4 \leftrightarrow A3 \dots A0$ |
| SC | | Set C | $C \leftarrow 1$, $HC \leftarrow 1$ |
| RC | | Reset C | $C \leftarrow 0$, $HC \leftarrow 0$ |
| IFC | | IF C | If C is true, do next instruction |
| IFNC | | IF Not C | If C is not true, do next instruction |
| POP | A | POP the stack into A | $\text{SP} \leftarrow \text{SP} + 1$, $A \leftarrow [\text{SP}]$ |
| PUSH | A | PUSH A onto the stack | $[\text{SP}] \leftarrow A$, $\text{SP} \leftarrow \text{SP} - 1$ |
| VIS | | Vector to Interrupt Service Routine | $\text{PU} \leftarrow [\text{VU}]$, $\text{PL} \leftarrow [\text{VL}]$ |
| JMPL | Addr. | Jump absolute Long | $\text{PC} \leftarrow \text{ii}$ (ii = 15 bits, 0 to 32k) |
| JMP | Addr. | Jump absolute | $\text{PC9} \dots 0 \leftarrow i$ (i = 12 bits) |
| JP | Disp. | Jump relative short | $\text{PC} \leftarrow \text{PC} + r$ (r is -31 to +32, except 1) |

Instruction Set (Continued)

INSTRUCTION SET (Continued)

| | | | |
|-------|-------|------------------------|--|
| JSRL | Addr. | Jump SubRoutine Long | $[SP] \leftarrow PL, [SP-1] \leftarrow PU, SP-2, PC \leftarrow ii$ |
| JSR | Addr | Jump SubRoutine | $[SP] \leftarrow PL, [SP-1] \leftarrow PU, SP-2, PC9...0 \leftarrow i$ |
| JID | | Jump InDirect | $PL \leftarrow ROM(PU, A)$ |
| RET | | RETurn from subroutine | $SP + 2, PL \leftarrow [SP], PU \leftarrow [SP-1]$ |
| RETSK | | RETurn and SKip | $SP + 2, PL \leftarrow [SP], PU \leftarrow [SP-1],$ skip next instruction |
| RETI | | RETurn from Interrupt | $SP + 2, PL \leftarrow [SP], PU \leftarrow [SP-1], GIE \leftarrow 1$ |
| INTR | | Generate an Interrupt | $[SP] \leftarrow PL, [SP-1] \leftarrow PU, SP-2, PC \leftarrow 0FF$ |
| NOP | | No OPeration | $PC \leftarrow PC + 1$ |

Instruction Execution Time

Most instructions are single byte (with immediate addressing mode instructions taking two bytes).

Most single byte instructions take one cycle time to execute.

Skipped instructions require x number of cycles to be skipped, where x equals the number of bytes in the skipped instruction opcode.

Bytes and Cycles per Instruction

The following table shows the number of bytes and cycles for each instruction in the format of byte/cycle.

Arithmetic and Logic Instructions

| | [B] | Direct | Immed. |
|-------|-----|--------|--------|
| ADD | 1/1 | 3/4 | 2/2 |
| ADC | 1/1 | 3/4 | 2/2 |
| SUBC | 1/1 | 3/4 | 2/2 |
| AND | 1/1 | 3/4 | 2/2 |
| OR | 1/1 | 3/4 | 2/2 |
| XOR | 1/1 | 3/4 | 2/2 |
| IFEQ | 1/1 | 3/4 | 2/2 |
| IFNE | 1/1 | 3/4 | 2/2 |
| IFGT | 1/1 | 3/4 | 2/2 |
| IFBNE | 1/1 | | |
| DRSZ | | 1/3 | |
| SBIT | 1/1 | 3/4 | |
| RBIT | 1/1 | 3/4 | |
| IFBIT | 1/1 | 3/4 | |
| RPND | 1/1 | | |

Instructions Using A & C

| | |
|-------|-----|
| CLRA | 1/1 |
| INCA | 1/1 |
| DECA | 1/1 |
| LAID | 1/3 |
| DCOR | 1/1 |
| RRCA | 1/1 |
| RLCA | 1/1 |
| SWAPA | 1/1 |
| SC | 1/1 |
| RC | 1/1 |
| IFC | 1/1 |
| IFNC | 1/1 |
| PUSHA | 1/3 |
| POPA | 1/3 |
| ANDSZ | 2/2 |

Transfer of Control Instructions

| | |
|-------|-----|
| JMPL | 3/4 |
| JMP | 2/3 |
| JP | 1/3 |
| JSRL | 3/5 |
| JSR | 2/5 |
| JID | 1/3 |
| VIS | 1/5 |
| RET | 1/5 |
| RETSK | 1/5 |
| RETI | 1/5 |
| INTR | 1/7 |
| NOP | 1/1 |

Memory Transfer Instructions

| | Register Indirect | | Direct | Immed. | Register Indirect Auto Incr. & Decr. | | |
|-----------------|-------------------|-----|--------|--------|--------------------------------------|----------|----------------------------|
| | [B] | [X] | | | [B+, B-] | [X+, X-] | |
| X A, (Note 14) | 1/1 | 1/3 | 2/3 | | 1/2 | 1/3 | (IF B < 16) (IF B > 15) |
| LD A, (Note 14) | 1/1 | 1/3 | 2/3 | 2/2 | 1/2 | 1/3 | |
| LD B, Imm | | | | 1/1 | | | |
| LD B, Imm | | | | 2/2 | | | |
| LD Mem, Imm | 2/2 | | 3/3 | | 2/2 | | |
| LD Reg, Imm | | | 2/3 | | | | |
| IFEQ MD, Imm | | | 3/3 | | | | |

Note 14: = > Memory location addressed by B or X or directly.

Instruction Execution Time (Continued)

Opcode Table

| Upper Nibble | | | | | | | | | | | | | | | | Lower Nibble | | | | | | | | | | | | | | | |
|--------------|-------|------------|----------|-----------|--------------|-------------|-----------|------------|-------------|-----------|----------|---------------|---------------|-------|---------|--------------|--|--|--|--|--|--|--|--|--|--|--|--|--|--|--|
| F | E | D | C | B | A | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 0 | | | | | | | | | | | | | | | | |
| JP-15 | JP-31 | LD 0F0, #i | DRSZ 0F0 | RRCA | RC | ADC A, #i | ADC A[B] | IFBIT 0[B] | ANDSZ A, #i | LD B, #0F | IFBNE 0 | JSR x000-x0FF | JMP x000-x0FF | JP+17 | INTR 0 | | | | | | | | | | | | | | | | |
| JP-14 | JP-30 | LD 0F1, #i | DRSZ 0F1 | * | SC | SUBC A, #i | SUBC A[B] | IFBIT 1[B] | * | LD B, #0E | IFBNE 1 | JSR x100-x1FF | JMP x100-x1FF | JP+18 | JP+2 1 | | | | | | | | | | | | | | | | |
| JP-13 | JP-29 | LD 0F2, #i | DRSZ 0F2 | X A[X+] | X A[B+] | IFEQ A, #i | IFEQ A[B] | IFBIT 2[B] | * | LD B, #0D | IFBNE 2 | JSR x200-x2FF | JMP x200-x2FF | JP+19 | JP+3 2 | | | | | | | | | | | | | | | | |
| JP-12 | JP-28 | LD 0F3, #i | DRSZ 0F3 | X A[X-] | X A[B-] | IFGT A, #i | IFGT A[B] | IFBIT 3[B] | * | LD B, #0C | IFBNE 3 | JSR x300-x3FF | JMP x300-x3FF | JP+20 | JP+4 3 | | | | | | | | | | | | | | | | |
| JP-11 | JP-27 | LD 0F4, #i | DRSZ 0F4 | VIS | LAID | ADD A, #i | ADD A[B] | IFBIT 4[B] | CLRA | LD B, #0B | IFBNE 4 | JSR x400-x4FF | JMP x400-x4FF | JP+21 | JP+5 4 | | | | | | | | | | | | | | | | |
| JP-10 | JP-26 | LD 0F5, #i | DRSZ 0F5 | RPND | JID | AND A, #i | AND A[B] | IFBIT 5[B] | SWAPA | LD B, #0A | IFBNE 5 | JSR x500-x5FF | JMP x500-x5FF | JP+22 | JP+6 5 | | | | | | | | | | | | | | | | |
| JP-9 | JP-25 | LD 0F6, #i | DRSZ 0F6 | X A[X] | X A[B] | XOR A, #i | XOR A[B] | IFBIT 6[B] | DCORA | LD B, #09 | IFBNE 6 | JSR x600-x6FF | JMP x600-x6FF | JP+23 | JP+7 6 | | | | | | | | | | | | | | | | |
| JP-8 | JP-24 | LD 0F7, #i | DRSZ 0F7 | * | * | OR A, #i | OR A[B] | IFBIT 7[B] | PUSHA | LD B, #08 | IFBNE 7 | JSR x700-x7FF | JMP x700-x7FF | JP+24 | JP+8 7 | | | | | | | | | | | | | | | | |
| JP-7 | JP-23 | LD 0F8, #i | DRSZ 0F8 | NOP | RLCA | LD A, #i | IFC | SBIT 0[B] | RBIT 0[B] | LD B, #07 | IFBNE 8 | JSR x800-x8FF | JMP x800-x8FF | JP+25 | JP+9 8 | | | | | | | | | | | | | | | | |
| JP-6 | JP-22 | LD 0F9, #i | DRSZ 0F9 | IFNE A[B] | IFEQ Md, #i | IFNE A, #i | IFNC | SBIT 1[B] | RBIT 1[B] | LD B, #06 | IFBNE 9 | JSR x900-x9FF | JMP x900-x9FF | JP+26 | JP+10 9 | | | | | | | | | | | | | | | | |
| JP-5 | JP-21 | LD 0FA, #i | DRSZ 0FA | LD A[X+] | LD A[B+] | LD [B+], #i | INCA | SBIT 2[B] | RBIT 2[B] | LD B, #05 | IFBNE 0A | JSR xA00-xAFF | JMP xA00-xAFF | JP+27 | JP+11 A | | | | | | | | | | | | | | | | |
| JP-4 | JP-20 | LD 0FB, #i | DRSZ 0FB | LD A[X-] | LD A[B-] | LD [B-], #i | DECA | SBIT 3[B] | RBIT 3[B] | LD B, #04 | IFBNE 0B | JSR xB00-xBFF | JMP xB00-xBFF | JP+28 | JP+12 B | | | | | | | | | | | | | | | | |
| JP-3 | JP-19 | LD 0FC, #i | DRSZ 0FC | Md, #i | JMPL X A, Md | X A, Md | POPA | SBIT 4[B] | RBIT 4[B] | LD B, #03 | IFBNE 0C | JSR xC00-xCFF | JMP xC00-xCFF | JP+29 | JP+13 C | | | | | | | | | | | | | | | | |
| JP-2 | JP-18 | LD 0FD, #i | DRSZ 0FD | DIR | JSRL | LD A, Md | RETSK | SBIT 5[B] | RBIT 5[B] | LD B, #02 | IFBNE 0D | JSR xD00-xDFF | JMP xD00-xDFF | JP+30 | JP+14 D | | | | | | | | | | | | | | | | |
| JP-1 | JP-17 | LD 0FE, #i | DRSZ 0FE | LD A[X] | LD A[B] | LD [B], #i | RET | SBIT 6[B] | RBIT 6[B] | LD B, #01 | IFBNE 0E | JSR xE00-xEFF | JMP xE00-xEFF | JP+31 | JP+15 E | | | | | | | | | | | | | | | | |
| JP-0 | JP-16 | LD 0FF, #i | DRSZ 0FF | * | * | LD B, #i | RETI | SBIT 7[B] | RBIT 7[B] | LD B, #00 | IFBNE 0F | JSR xF00-xFFF | JMP xF00-xFFF | JP+32 | JP+16 F | | | | | | | | | | | | | | | | |

Where,
i is the immediate data
Md is a directly addressed memory location
* is an unused opcode
The opcode 60 Hex is also the opcode for IFBIT #i.A

Mask Options

The mask programmable options are shown below. The options are programmed at the same time as the ROM pattern submission.

OPTION 1: CLOCK CONFIGURATION

- = 1 Crystal Oscillator (CKI/10)
G7 (CKO) is clock generator output to crystal/resonator with CKI being the clock input
- = 2 Single-pin RC controlled oscillator (CKI/10)
G7 is available as a HALT restart and/or general purpose input

OPTION 2: HALT

- = 1 Enable HALT mode
- = 2 Disable HALT mode

OPTION 3: BONDING OPTIONS

- = 1 44-Pin PLCC
- = 2 40-Pin DIP
- = 3 N/A
- = 4 28-DIP
- = 5 28-Pin SO

Some device can be driven by a clock input on the CKI input pin which can be between DC and 10 MHz. The CKO output clock is on pin G7 (if clock option=1 has been selected). The CKI input frequency is divided down by 10 to produce the instruction cycle clock (1/tc).

Not all packages are available for all devices, please check order information.

Development Support

OVERVIEW

National is engaged with an international community of independent 3rd party vendors who provide hardware and software development tool support. Through National's interaction and guidance, these tools cooperate to form a choice of tools that fits each developer's needs.

This section provides a summary of the tool and development kits currently available. Up-to-date information, selection guides, free tools, demos, updates, and purchase information can be obtained at our web site at: www.national.com/cop8.

SUMMARY OF TOOLS

COP8 Evaluation Tools

- **COP8-NSEVAL:** Free Software Evaluation package for Windows. A fully integrated evaluation environment for COP8, including versions of WCOP8 IDE (Integrated Development Environment), COP8-NSASM, COP8-MLSIM, COP8C, DriveWay™ COP8, Manuals, and other COP8 information.
- **COP8-MLSIM:** Free Instruction Level Simulator tool for Windows. For testing and debugging software instructions only (No I/O or interrupt support).
- **COP8-EPU:** Very Low cost COP8 Evaluation & Programming Unit. Windows based evaluation and hardware-simulation tool, with COP8 device programmer and erasable samples. Includes COP8-NSDEV, DriveWay COP8 Demo, MetaLink Debugger, I/O cables and power supply.

- **COP8-EVAL-ICUxx:** Very Low cost evaluation and design test board for COP8ACC and COP8SGx Families, from ICU. Real-time environment with add-on A/D, D/A, and EEPROM. Includes software routines and reference designs.
- **Manuals, Applications Notes, Literature:** Available free from our web site at: www.national.com/cop8.

COP8 Integrated Software/Hardware Design Development Kits

- **COP8-EPU:** Very Low cost Evaluation & Programming Unit. Windows based development and hardware-simulation tool for COPSx/xG families, with COP8 device programmer and samples. Includes COP8-NSDEV, DriveWay COP8 Demo, MetaLink Debugger, cables and power supply.
- **COP8-DM:** Moderate cost Debug Module from MetaLink. A Windows based, real-time in-circuit emulation tool with COP8 device programmer. Includes COP8-NSDEV, DriveWay COP8 Demo, MetaLink Debugger, power supply, emulation cables and adapters.

COP8 Development Languages and Environments

- **COP8-NSASM:** Free COP8 Assembler v5 for Win32. Macro assembler, linker, and librarian for COP8 software development. Supports all COP8 devices. (DOS/Win16 v4.10.2 available with limited support). (Compatible with WCOP8 IDE, COP8C, and DriveWay COP8).
- **COP8-NSDEV:** Very low cost Software Development Package for Windows. An integrated development environment for COP8, including WCOP8 IDE, COP8-NSASM, COP8-MLSIM.
- **COP8C:** Moderately priced C Cross-Compiler and Code Development System from Byte Craft (no code limit). Includes BCLIDE (Byte Craft Limited Integrated Development Environment) for Win32, editor, optimizing C Cross-Compiler, macro cross assembler, BC-Linker, and MetaLink tools support. (DOS/SUN versions available; Compiler is installable under WCOP8 IDE; Compatible with DriveWay COP8).
- **EW COP8-KS:** Very Low cost ANSI C-Compiler and Embedded Workbench from IAR (Kickstart version: COP8Sx/Fx only with 2k code limit; No FP). A fully integrated Win32 IDE, ANSI C-Compiler, macro assembler, editor, linker, Librarian, C-Spy simulator/debugger, PLUS MetaLink EPU/DM emulator support.
- **EW COP8-AS:** Moderately priced COP8 Assembler and Embedded Workbench from IAR (no code limit). A fully integrated Win32 IDE, macro assembler, editor, linker, librarian, and C-Spy high-level simulator/debugger with I/O and interrupts support. (Upgradeable with optional C-Compiler and/or MetaLink Debugger/Emulator support).
- **EW COP8-BL:** Moderately priced ANSI C-Compiler and Embedded Workbench from IAR (Baseline version: All COP8 devices; 4k code limit; no FP). A fully integrated Win32 IDE, ANSI C-Compiler, macro assembler, editor, linker, librarian, and C-Spy high-level simulator/debugger. (Upgradeable; CW COP8-M MetaLink tools interface support optional).
- **EW COP8:** Full featured ANSI C-Compiler and Embedded Workbench for Windows from IAR (no code limit). A fully integrated Win32 IDE, ANSI C-Compiler, macro assembler, editor, linker, librarian, and C-Spy high-level simulator/debugger. (CW COP8-M MetaLink tools interface support optional).

Development Support (Continued)

- **EW COP8-M:** Full featured ANSI C-Compiler and Embedded Workbench for Windows from IAR (no code limit). A fully integrated Win32 IDE, ANSI C-Compiler, macro assembler, editor, linker, librarian, C-Spy high-level simulator/debugger, PLUS MetaLink debugger/hardware interface (CWCOP8-M).

COP8 Productivity Enhancement Tools

- **WCOP8 IDE:** Very Low cost IDE (Integrated Development Environment) from KKD. Supports COP8C, COP8-NSASM, COP8-MLSIM, DriveWay COP8, and MetaLink debugger under a common Windows Project Management environment. Code development, debug, and emulation tools can be launched from the project window framework.
- **DriveWay-COP8:** Low cost COP8 Peripherals Code Generation tool from Aisys Corporation. Automatically generates tested and documented C or Assembly source code modules containing I/O drivers and interrupt handlers for each on-chip peripheral. Application specific code can be inserted for customization using the integrated editor. (Compatible with COP8-NSASM, COP8C, and WCOP8 IDE.)
- **COP8-UTILS:** Free set of COP8 assembly code examples, device drivers, and utilities to speed up code development.
- **COP8-MLSIM:** Free Instruction Level Simulator tool for Windows. For testing and debugging software instructions only (No I/O or interrupt support).

COP8 Real-Time Emulation Tools

- **COP8-DM:** MetaLink Debug Module. A moderately priced real-time in-circuit emulation tool, with COP8 device programmer. Includes MetaLink Debugger, power supply, emulation cables and adapters.
- **IM-COP8:** MetaLink iceMASTER®. A full featured, real-time in-circuit emulator for COP8 devices. Includes COP8-NSDEV, Driveway COP8 Demo, MetaLink Windows Debugger, and power supply. Package-specific probes and surface mount adaptors are ordered separately.

COP8 Device Programmer Support

- MetaLink's EPU and Debug Module include development device programming capability for COP8 devices.
- Third-party programmers and automatic handling equipment cover needs from engineering prototype and pilot production, to full production environments.
- Factory programming available for high-volume requirements.

TOOLS ORDERING NUMBERS FOR THE COP888xG/CS FAMILY DEVICES

The COP888xG/CS devices are compatible with the COP8SGx devices, and the SGx tools can be also used for development.

| Vendor | Tools | Order Number | Cost | Notes |
|----------|--------------------------|--|------|---|
| National | COP8-NSEVAL | COP8-NSEVAL | Free | Web site download |
| | COP8-NSASM | COP8-NSASM | Free | Included in EPU and DM. Web site download |
| | COP8-MLSIM | COP8-MLSIM | Free | Included in EPU and DM. Web site download |
| | COP8-NSDEV | COP8-NSDEV | VL | Included in EPU and DM. Order CD from website |
| | COP8-EPU | COP8SG-EPU (-1 or -2) | VL | -1 = 110V, -2 = 220V; Included p/s, 40 pin DIP target cable, manuals, software, 16/20/28/40 DIP OTP programming socket; add DM target adapter or OTP adapter (if needed) |
| | COP8-DM | COP8SG-DM (10 MHz) | M | Included p/s, 28/40/44 pin DIP/SO/PLCC target cables, manuals, software, 16/20/28/40 DIP/SO and 44 PLCC programming socket; add OTP adapter or target adapter (if needed) |
| | DM Target Adapters | DM-COP8/28D-SO | VL | 28 pin DIP to SO converter |
| | | DM-COP8/44P-44Q | L | 44 pin PLCC to 44 QFP converter |
| | Development Devices | COP8FGx7 (15 MHz) COP8SGx7 (10 MHz) | VL | 8k or 32k Eraseable or OTP devices |
| | OTP Programming Adapters | COP8SA-PGMA | L | For programming 28 SOIC and 44 PLCC on the EPU |
| | | COP8-PGMA-44QFP | L | For programming 44 QFP on any programmer |
| | | COP8-PGMA-28SO | VL | For programming 16/20/28 SOIC on any programmer |
| | IM-COP8 | Call MetaLink | | |

Development Support (Continued)

| | | | | |
|---|--------------------------|--|-------|--|
| MetaLink | COP8-EPU | EPU-8SGx (-1 or -2) | VL | 1 = 110V, 2 = 220V; included p/s, 40 pin DIP target cable, manuals, software, 16/20/28/40 DIP OTP programming socket; add DM target adapter or OTP adapter (if needed) |
| | COP8-DM | DM4-COP8-888xG (x = C, E, G, H, K) or DM5-COP8-FGx (15 MHz) or DM4-COP8-SGx (10 MHz), plus PS-10, plus DM-COP8/xxx (ie. 28D) | M | Included p/s (PS-10), target cable of choice (DIP or PLCC; i.e. DM-COP8/28D), 16/20/28/40 DIP/SO and 44 PLCC programming sockets. Add OTP adapter (if needed) and target adapter (if needed) |
| | DM Target Adapters | MHW-CNVxx (xx = 33, 34 etc.) | L | DM target converters for 16DIP/20SO/28SO/44QFP/28CSP; (i.e. MHW-CNV38 for 20 pin DIP to SO package converter) |
| | OTP Programming Adapters | MHW-COP8-PGMA-DS | L | For programming 16/20/28 SOIC and 44 PLCC on the EPU |
| | | MHW-COP8-PGMA-44QFP | L | For programming 44 QFP on any programmer |
| | | MHW-COP8-PGMA-28CSP | L | For programming 28 CSP on any programmer |
| | IM-COP8 | IM-COP8-AD-464 (-220) (10 MHz maximum) | H | Base unit 10 MHz; -220 = 220V; add probe card (required) and target adapter (if needed); included software and manuals |
| | IM Probe Card | PC-8884xG28DW-AD-10 (x = C, E, G, K) | M | 10 MHz 28 DIP probe card; 2.5V to 6.0V |
| | | PC-888xG40DW-AD-10 (x = C, E, G, K) | M | 10 MHz 40 DIP probe card; 2.5V to 6.0V |
| | | PC-888xG44PW-AD-10 (x = C, E, G, K) | M | 10 MHz 44 PLCC probe card; 2.5V to 6.0V |
| | IM Probe Target Adapters | MHW-SOICxx (xx = 16, 20, 28) | L | 16 or 20 or 28 pin SOIC adapter for probe card |
| | | MHW-CONV33 | L | 44 pin QFP adapter for 44 PLCC probe card |
| ICU or National | COP8-EVAL-ICUxx | ICU-303 | L | No power supply |
| | | COP8-EVAL-ICUSG | L | No power supply |
| KKD | WCOP8-IDE | WCOP8-IDE | VL | Included in EPU and DM |
| IAR | EWOP8-xx | See summary above | L - H | Included all software and manuals |
| Byte Craft | COP8C | COP8C | M | Included all software and manuals |
| Aisys | DriveWay COP8 | DriveWay COP8 | L | Included all software and manuals |
| OTP Programmers | | Contact vendors | L - H | For approved programmer listings and vendor information go to our OTP support page at: www.national.com/cop8 |
| Cost: Free; VL =< \$100; L = \$100 - \$300; M = \$300 - \$1k; H = \$1k - \$3k; VH = \$3k - \$5k | | | | |

Development Support (Continued)

WHERE TO GET TOOLS

Tools are ordered directly from the following vendors. Please go to the vendor's web site for current listings of distributors.

| Vendor | Home Office | Electronic Sites | Other Main Offices |
|------------|--|---|--|
| Aisys | U.S.A.: Santa Clara, CA 1-408-327-8820 fax: 1-408-327-8830 | www.aisysinc.com info@aisysinc.com | Distributors |
| Byte Craft | U.S.A. 1-519-888-6911 fax: 1-519-746-6751 | www.bytecraft.com info@bytecraft.com | Distributors |
| IAR | Sweden: Uppsala +46 18 16 78 00 fax: +46 18 16 78 38 | www.iar.se info@iar.se info@iar.com info@iarsys.co.uk info@iar.de | U.S.A.: San Francisco 1-415-765-5500 fax: 1-415-765-5503 U.K.: London +44 171 924 33 34 fax: +44 171 924 53 41 Germany: Munich +49 89 470 6022 fax: +49 89 470 956 |
| ICU | Sweden: Polygonvaegen +46 8 630 11 20 fax: +46 8 630 11 70 | www.icu.se support@icu.se support@icu.ch | Switzerland: Hoehe +41 34 497 28 20 fax: +41 34 497 28 21 |
| KKD | Denmark: | www.kkd.dk | |
| MetaLink | U.S.A.: Chandler, AZ 1-800-638-2423 fax: 1-602-926-1198 | www.metaice.com sales@metaice.com support@metaice.com bbs: 1-602-962-0013 www.metalink.de | Germany: Kirchseeon 80-91-5696-0 fax: 80-91-2386 islanger@metalink.de Distributors Worldwide |
| National | U.S.A.: Santa Clara, CA 1-800-272-9959 fax: 1-800-737-7018 | www.national.com/cop8 support@nsc.com europe.support@nsc.com | Europe: +49 (0) 180 530 8585 fax: +49 (0) 180 530 8586 Distributors Worldwide |

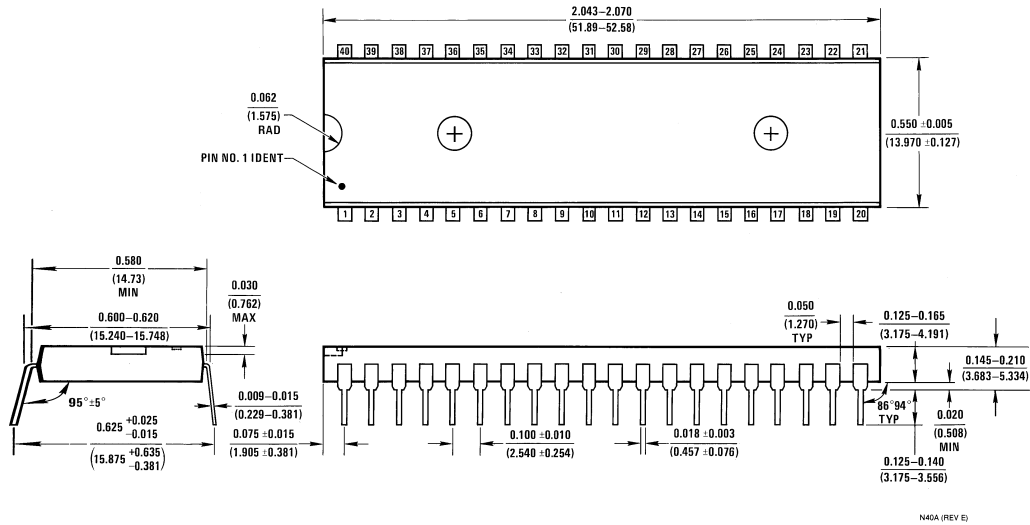
The following companies have approved COP8 programmers in a variety of configurations. Contact your local office or distributor. You can link to their web sites and get the latest listing of approved programmers from National's COP8 OTP Support page at: www.national.com/cop8.

Advantech; Advin; BP Microsystems; Data I/O; Hi-Lo Systems; ICE Technology; Lloyd Research; Logical Devices; MQP; Needhams; Phytion; SMS; Stag Programmers; System General; Tribal Microsystems; Xeltek.

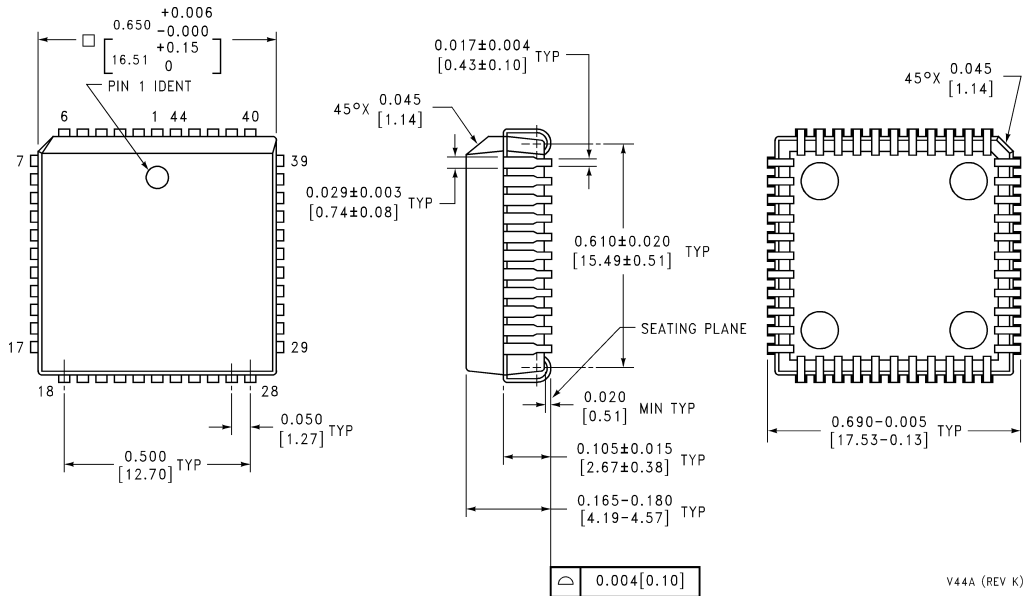
CUSTOMER SUPPORT

Complete product information and technical support is available from National's customer response centers, and from our on-line COP8 customer support sites.

Physical Dimensions inches (millimeters) unless otherwise noted



Molded Dual-In-Line Package (N)
Order Number COP688KG-XXX/N, COP888KG-XXX/N
NS Package Number N40A



Plastic Leaded Chip Carrier (V)
Order Number COP688KG-XXXV, COP888KG-XXX/V
NS Package Number V44A

Notes

LIFE SUPPORT POLICY

NATIONAL'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT AND GENERAL COUNSEL OF NATIONAL SEMICONDUCTOR CORPORATION. As used herein:

1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, and whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in a significant injury to the user.
2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.



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