National Semiconductor

PRELIMINARY

COP8788EG/COP8784EG microCMOS One-Time Programmable (OTP) Microcontrollers

General Description

The COP8788EG/COP8784EG programmable microcontrollers are members of the COPS™ microcontroller family. Each device is a two chip system in a plastic package. Within the package is the COP888EG and an 8k EPROM with port recreation logic. The code executes out of the EPROM. The device is offered in four packages: 44-pin PLCC, 40-pin DIP, 28-pin DIP and 28-pin SO.

The COP8788EG/COP8784EG are fully static, fabricated using double-metal silicon gate microCMOS technology. Features include an 8-bit memory mapped architecture, MICROWIRE/PLUS™ serial I/O, three 16-bit timer/counters supporting three modes (Processor Independent PWM generation, External Event counter, and Input Capture mode capabilities), full duplex UART and two comparators. Each I/O pin has software selectable configurations. The devices operates over a voltage range of 4.5V to 5.5V. High throughput is achieved with an efficient, regular instruction set operating at a maximum of 1 μs per instruction rate.

The COP8788EG/COP8784EG devices can be used to provide form fit and function emulation for the COP888EG/COP884EG, COP888CG/COP884CG and COP888CS/COP884CS family of mask programmable devices. The user must pay special attention, since the COP8788EG/COP8784EG devices contain additional features and are supersets of COP888CG/COP884CG and COP888CS/COP884CS. The following table shows the differences between the various devices.

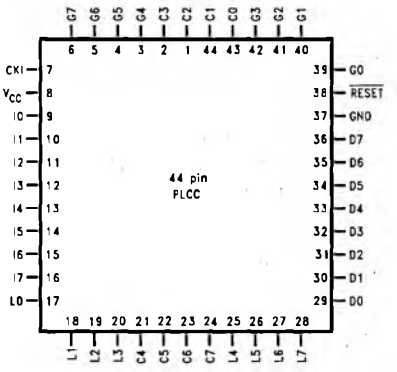
	ROM (Bytes)	RAM (Bytes)	Timers	# of Comparators
COP8788EG/ COP8784EG	8k	256	T0, T1, T2, T3	2
COP888EG/ COP884EG	8k	256	T0, T1, T2, T3	2
COP888CG/ COP884CG	4k	192	T0, T1, T2, T3	2
COP888CS/ COP884CS	4k	192	T0, T1	1

Features

- Low cost 8-bit microcontroller
- Fully static CMOS, with low current drain
- 1 μs instruction cycle time
- 8192 bytes on-board EPROM
- 256 bytes on-board RAM
- Single supply operation: 4.5V–5.5V
- Full duplex UART
- Two analog comparators
- MICROWIRE/PLUS™ serial I/O
- WATCHDOG™ and Clock monitor logic
- Idle Timer
- Multi-Input Wake Up (MIWU) with optional interrupts (8)
- Fourteen multi-source vectored interrupts servicing
  - — External interrupt
  - — Idle Timer T0
  - — Two Timers (each with 2 interrupts)
  - — MICROWIRE/PLUS
  - — Multi-Input Wake up
  - — Software Trap
  - — UART (2)
  - — Default VIS
- Three 16-bit timers, each with two 16-bit registers supporting:
  - — Processor Independent PWM mode
  - — External Event counter mode
  - — Input Capture mode
- 8-bit Stack Pointer SP (stack in RAM)
- Two 8-bit Register Indirect Data Memory Pointers (B and X)
- Versatile instruction set with true bit manipulation
- Memory mapped I/O
- BCD arithmetic instructions
- Package:
  - — 44 PLCC with 39 I/O pins
  - — 40 DIP with 35 I/O pins
  - — 28 DIP with 23 I/O pins
  - — 28 SO with 23 I/O pins (contact local sales office for availability)
- Software selectable I/O options
  - — TRI-STATE® Output
  - — Push-Pull Output
  - — Weak Pull Up Input
  - — High Impedance Input
- Schmitt trigger inputs on ports G and L
- Form fit and function emulation device for the COP888EG/COP884EG, COP888CG/COP884CG and COP888CS/COP884CS
- Real time emulation and full program debug offered by MetaLink's Development Systems

Connection Diagrams

Plastic Chip Carrier

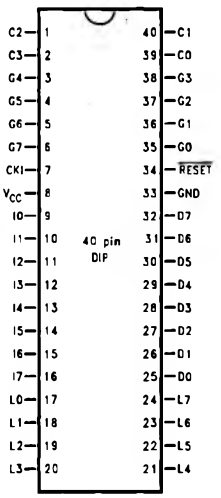


TL/DD12064-1

Top View

Order Number COP8788EGV-X, COP8788EGFV-R
See NS Package Number V44A

Dual-In-Line Package

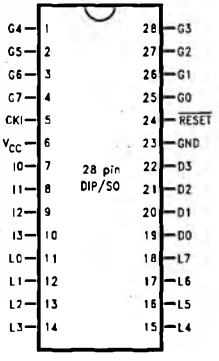


TL/DD12064-2

Top View

Order Number COP8788EGN-X, COP8788EGN-R
See NS Package Number N40A

Dual-In-Line Package



TL/DD12064-3

Top View

Order Number COP8784EGN-X, COP8784EGN-R,
COP8784EGWM-X or COP8784EGWM-R
See NS Package Number M28B or N28A

FIGURE 1. COP8788EG/COP8784EG Connection Diagrams

Connection Diagrams (Continued)

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

Port	Type	Alt. Fun	Alt. Fun	28-Pin Pkg.	40-Pin Pkg.	44-Pin Pkg.
L0	I/O	MIWU		11	17	17
L1	I/O	MIWU	CKX	12	18	18
L2	I/O	MIWU	TDX	13	19	19
L3	I/O	MIWU	RDX	14	20	20
L4	I/O	MIWU	T2A	15	21	25
L5	I/O	MIWU	T2B	16	22	26
L6	I/O	MIWU	T3A	17	23	27
L7	I/O	MIWU	T3B	18	24	28
G0	I/O	INT	ALE	25	35	39
G1	WDOUT			26	36	40
G2	I/O	T1B	$\overline{WR}$	27	37	41
G3	I/O	T1A	$\overline{RD}$	28	38	42
G4	I/O	SO		1	3	3
G5	I/O	SK		2	4	4
G6	I	SI	ME	3	5	5
G7	I/CKO	HALT Restart		4	6	6
D0	O		AD0	19	25	29
D1	O		AD1	20	26	30
D2	O		AD2	21	27	31
D3	O		AD3	22	28	32
I0	I			7	9	9
I1	I	COMP1IN−		8	10	10
I2	I	COMP1IN+		9	11	11
I3	I	COMP1OUT		10	12	12
I4	I	COMP2IN−			13	13
I5	I	COMP2IN+			14	14
I6	I	COMP2OUT			15	15
I7	I				16	16
D4	O		AD4		29	33
D5	O		AD5		30	34
D6	O		AD6		31	35
D7	O		AD7		32	36
C0	I/O				39	43
C1	I/O				40	44
C2	I/O				1	1
C3	I/O				2	2
C4	I/O					21
C5	I/O					22
C6	I/O					23
C7	I/O					24
V_{CC}				6	8	8
GND				23	33	37
CKI				5	7	7
$\overline{RESET}$			V_{PP}	24	34	38

Absolute Maximum Ratings (Note)

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°C

Note: *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 $-40°C \le T_A \le +85°C$ unless otherwise specified

Parameter	Conditions	Min	Typ	Max	Units
Operating Voltage		4.5		5.5	V
Power Supply Ripple (Note 1)	Peak-to-Peak			0.1 V_{CC}	V
Supply Current (Note 2)					
CKI = 10 MHz	V_{CC} = 5.5V, t_c = 1 μs			25	mA
HALT Current (Note 3)	V_{CC} = 5.5V, CKI = 0 MHz		250		μA
IDLE Current					
CKI = 10 MHz	V_{CC} = 5.5V, t_c = 1 μs			15	mA
Input Levels					
$\overline{\text{RESET}}$					
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} = 5.5V	−2		+2	μA
Input Pullup Current	V_{CC} = 5.5V	40		250	μA
G and L Port Input Hysteresis			0.05 V_{CC}	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	10			mA
All Others					
Source (Weak Pull-Up Mode)	V_{CC} = 4.5V, V_{OH} = 2.7V	10		100	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	1.6			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 without Latchup (Note 4)	T_A = 25°C			±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

Note 1: Rate of voltage change must be less then 0.5 V/ms.

Note 2: Supply current is measured after running 2000 cycles with a square wave CKI input, CKO open, inputs at rails and outputs open.

Note 3: The HALT mode will stop CKI from oscillating in the RC and the Crystal configurations. Test conditions: All inputs tied to V_{CC}, L and G ports in the TRI-STATE mode and tied to ground, all outputs low and tied to ground. The clock monitor is disabled.

Note 4: Pins G6 and $\overline{\text{RESET}}$ are designed with a high voltage input network for factory testing. 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.

AC Electrical Characteristics $-40°C \le T_A \le +85°C$ unless otherwise specified

Parameter	Conditions	Min	Typ	Max	Units
Instruction Cycle Time (t_C)					
Crystal, Resonator,		1		DC	μs
R/C Oscillator		3		DC	μs
CKI Clock Duty Cycle (Note 5)	f_r = Max	40		60	%
Rise Time (Note 5)	f_r = 10 MHz Ext Clock			5	ns
Fall Time (Note 5)	f_r = 10 MHz Ext Clock			5	ns
Inputs					
t_{SETUP}		200			ns
t_{HOLD}		60			ns
Output Propagation Delay	R_L = 2.2k, C_L = 100 pF				
t_{PD1}, t_{PD0}					
SO, SK				0.7	μs
All Others				1	μs
MICROWIRE™ Setup Time (t_{UWS})		20			ns
MICROWIRE Hold Time (t_{UWH})		56			ns
MICROWIRE Output Propagation Delay (t_{UPD})				220	ns
Input Pulse Width					
Interrupt Input High Time		1			t_C
Interrupt Input Low Time		1			t_C
Timer Input High Time		1			t_C
Timer Input Low Time		1			t_C
Reset Pulse Width		1			μs

Note 5: Parameter sample (not 100% tested).

Comparators AC and DC Characteristics V_{CC} = 5V, T_A = 25°C

Parameter	Conditions	Min	Typ	Max	Units
Input Offset Voltage	$0.4V \le V_{IN} \le V_{CC} - 1.5V$		±10	±25	mV
Input Common Mode Voltage Range		0.4		$V_{CC} - 1.5$	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	TBD mV Step, TBD mV Overdrive, 100 pF Load		1		μs

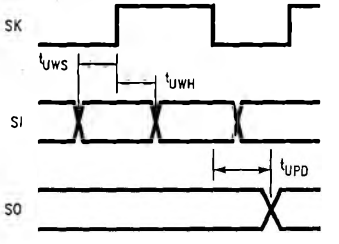


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FIGURE 2. MICROWIRE/PLUS Timing

Pin Descriptions

V_{CC} and GND are the power supply pins.

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.

$\overline{\text{RESET}}$ 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 3* 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.

Port L supports Multi-Input Wake Up (MIWU) on all eight pins. L1 is used for the UART external clock. L2 and L3 are used for the UART 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.

Port L has the following alternate features:

- L0 MIWU
- L1 MIWU or CKX
- L2 MIWU or TDX
- L3 MIWU or RDX
- L4 MIWU or T2A
- L5 MIWU or T2B
- L6 MIWU or T3A
- L7 MIWU or T3B

Port G is an 8-bit port with 5 I/O pins (G0, G2–G5), an input pin (G6), and two dedicated output pins (G1 and G7). 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.

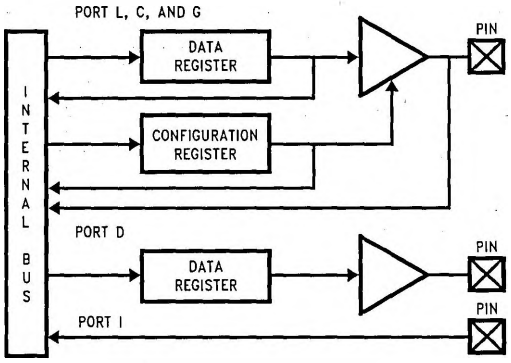

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FIGURE 3. I/O Port Configurations

Pin Descriptions (Continued)

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 below. Reading the G6 and G7 data bits will return zeros.

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 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:

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

Port G has the following dedicated functions:

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

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. The 28-pin device does not have a full complement of Port I pins. The unavailable pins are not terminated i.e., they are floating. A read operation for these unterminated pins will return unpredictable values. The user must ensure that the software takes this into account by either masking or restricting the accesses to bit operations. The unterminated Port I pins will draw power only when addressed. The I port leakage may be higher in 28-pin devices.

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

The Port I has the following alternate features.

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

Port D is a recreated 8-bit output port that is preset high when $\overline{\text{RESET}}$ goes low. D port recreation is one clock cycle behind normal port timing. 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 8092 bytes 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 256 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.

Data Memory Segment RAM Extension

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

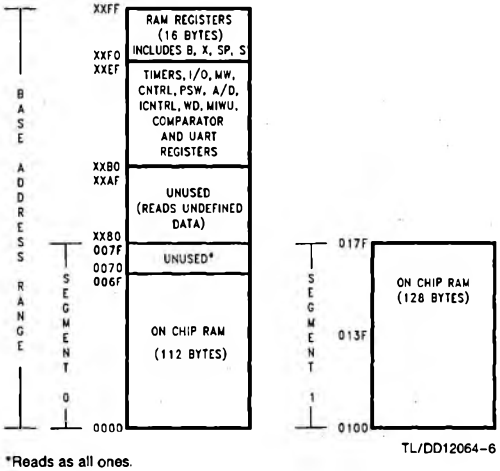
The data store memory is either addressed directly by a single byte address within the instruction, or indirectly relative to the reference of the B, X, or SP pointers (each contains a single-byte address). This single-byte address allows an addressing range of 256 locations from 00 to FF hex. The upper 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, 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 4 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 116 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 128 bytes of RAM are memory mapped at address locations 0100 to 017F hex.



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*Reads as all ones.

FIGURE 4. RAM Organization

Reset

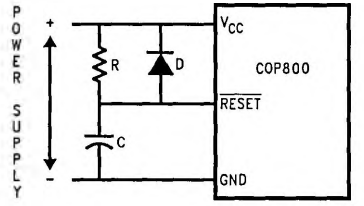
The $\overline{\text{RESET}}$ input when pulled low initializes the microcontroller. Initialization will occur whenever the $\overline{\text{RESET}}$ input is pulled low. Upon initialization, the data and configuration registers for ports L, G and C are cleared, resulting in these Ports being initialized 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 UART 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 Wake Up registers WKEN, WKEDG and WKPND are cleared. 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 5* should be used to ensure that the $\overline{\text{RESET}}$ pin is held low until the power supply to the chip stabilizes.

Note: Continual state of reset will cause the device to draw excessive current.

Reset (Continued)



TL/DD/12064-7

RC > 5 × Power Supply Rise Time

FIGURE 5. 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 6 shows the Crystal and R/C diagrams.

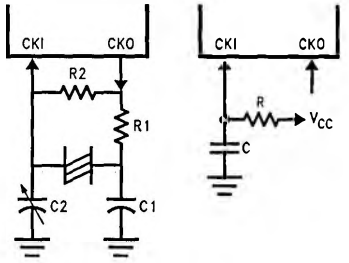


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FIGURE 6. Crystal and R/C Oscillator Diagrams

CRYSTAL OSCILLATOR

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

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

TABLE I. Crystal Oscillator Configuration, T_A = 25°C

R1 (kΩ)	R2 (MΩ)	C1 (pF)	C2 (pF)	CKI Freq (MHz)	Conditions
0	1	30	30-36	10	V_{CC} = 5V
0	1	30	30-36	4	V_{CC} = 5V
0	1	200	100-150	0.455	V_{CC} = 5V

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 pin.

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

TABLE II. R/C Oscillator Configuration, T_A = 25°C

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

Note: 3k ≤ R ≤ 200k

50 pF ≤ C ≤ 200 pF

Current Drain

The total current drain of the chip depends on:

1. Oscillator operation mode—I1
2. Internal switching current—I2
3. Internal leakage current—I3
4. Output source current—I4
5. DC current caused by external input not at V_{CC} or GND—I5
6. Clock Monitor current when enabled—I6
7. Clock Monitor current when enabled—I7

Thus the total current drain, It, is given as

$$It = I1 + I2 + I3 + I4 + I5 + I6 + I7$$

The chip will draw more current as the CKI input frequency increases up to the maximum 10 MHz value. Operating with a crystal network will draw more current than an external square-wave. Switching current, governed by the equation below, can be reduced by lowering voltage and frequency. Leakage current can be reduced by lowering voltage and temperature. The other two items can be reduced by carefully designing the end-user's system.

$$I2 = C \times V \times f$$

where C = equivalent capacitance of the chip
V = operating voltage
f = CKI frequency

Control Registers

CNTRL Register (Address X'00EE)

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

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

T1C3	T1C2	T1C1	T1C0	MSEL	IEDG	SL1	SL0

Bit 7 Bit 0

Control Registers (Continued)

PSW Register (Address X'00EF)

The PSW register contains the following select bits:

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

HC	C	T1PNDA	T1ENA	EXPND	BUSY	EXEN	GIE

Bit 7 Bit 0

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

ICNTRL Register (Address X'00E8)

The ICNTRL register contains the following bits:

- T1ENB Timer T1 Interrupt Enable for T1B Input capture edge
- T1PNDB Timer T1 Interrupt Pending Flag for T1B capture edge
- WEN Enable MICROWIRE/PLUS interrupt
- WPND MICROWIRE/PLUS interrupt pending
- T0EN Timer T0 Interrupt Enable (Bit 12 toggle)
- T0PND Timer T0 Interrupt pending
- LPEN L Port Interrupt Enable (Multi-Input Wake Up/ Interrupt)

  Bit 7 could be used as a flag

Unused	LPEN	T0PND	T0EN	WPND	WEN	T1PNDB	T1ENB

Bit 7 Bit 0

T2CNTRL Register (Address X'00C6)

The T2CNTRL register contains the following bits:

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

T2C3	T2C2	T2C1	T2C0	T2PNDA	T2ENA	T2PNDB	T2ENB

Bit 7 Bit 0

T3CNTRL Register (Address X'00B6)

The T3CNTRL register contains the following bits:

- T3ENB Timer T3 Interrupt Enable for T3B
- T3PNDB Timer T3 Interrupt Pending Flag for T3B pin (T3B capture edge)
- T3ENA Timer T3 Interrupt Enable for Timer Underflow or T3A pin
- T3PNDA Timer T3 Interrupt Pending Flag (Autoload RA in mode 1, T3 Underflow in mode 2, T3a capture edge in mode 3)
- T3C0 Timer T3 Start/Stop control in timer modes 1 and 2

  Timer T3 Underflow Interrupt Pending Flag in timer mode 3
- T3C1 Timer T3 mode control bit
- T3C2 Timer T3 mode control bit
- T3C3 Timer T3 mode control bit

T3C3	T3C2	T3C1	T3C0	T3PNDA	T3ENA	T3PNDB	T3ENB

Bit 7 Bit 0

Timers

The device contains a very versatile set of timers (T0, T1, T2, T3). All timers and associated autoreload/capture registers power up containing random data.

TIMER T0 (IDLE TIMER)

The devices support 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 μs). 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.

Timers (Continued)

TIMER T1, TIMER T2 AND TIMER T3

The devices have a set of 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 7 shows a block diagram of the timer in PWM mode. 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, TxPNDA and TxPNDB. 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 RxA register to be reloaded into the timer. Setting the timer enable flag TxENB will cause an interrupt when a timer underflow causes the RxB 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.

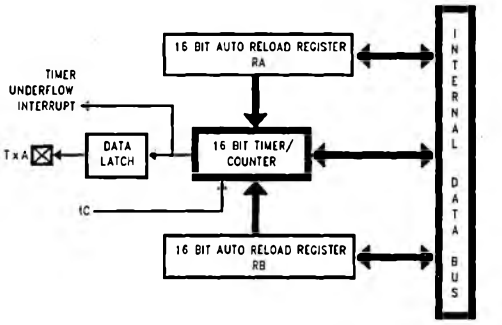

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FIGURE 7. Timer in PWM Mode

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 TxA pin. The Tx timer control bits, TxC3, TxC2 and TxC1 allow the timer to be clocked either on a positive or negative edge from the TxA pin. Underflows from the timer are latched into the TxPNDA pending flag. Setting the TxENA control flag will cause an interrupt when the timer underflows.

In this mode the input pin TxB 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 TxB input pin is latched into the TxPNDB flag.

Figure 8 shows a block diagram of the timer in External Event Counter mode.

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

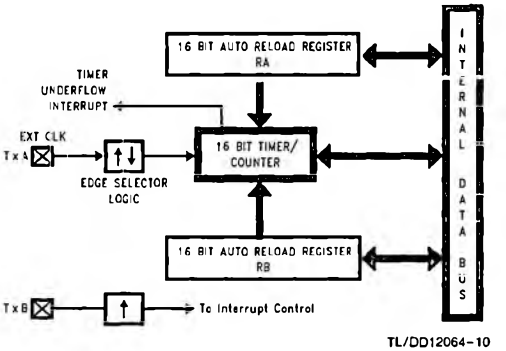

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FIGURE 8. Timer in External Event Counter Mode

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, RxA and RxB, act as capture registers. Each register acts in conjunction with a pin. The register RxA acts in conjunction with the TxA pin and the register RxB acts in conjunction with the TxB pin.

Timers (Continued)

The timer value gets copied over into the register when a trigger event occurs on its corresponding pin. Control bits, TxC3, TxC2 and TxC1, 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 TxA and TxB pins will be respectively latched into the pending flags, TxPNDA and TxPNDB. The control flag TxENA allows the interrupt on TxA to be either enabled or disabled. Setting the TxENA flag enables interrupts to be generated when the selected trigger condition occurs on the TxA pin. Similarly, the flag TxENB controls the interrupts from the TxB pin.

Underflows from the timer can also be programmed to generate interrupts. Underflows are latched into the timer TxC0 pending flag (the TxC0 control bit serves as the timer underflow interrupt pending flag in the Input Capture mode). Consequently, the TxC0 control bit should be reset when entering the Input Capture mode. The timer underflow interrupt is enabled with the TxENA control flag. When a TxA interrupt occurs in the Input Capture mode, the user must check both the TxPNDA and TxC0 pending flags in order to determine whether a TxA input capture or a timer underflow (or both) caused the interrupt.

Figure 9 shows a block diagram of the timer in Input Capture mode.

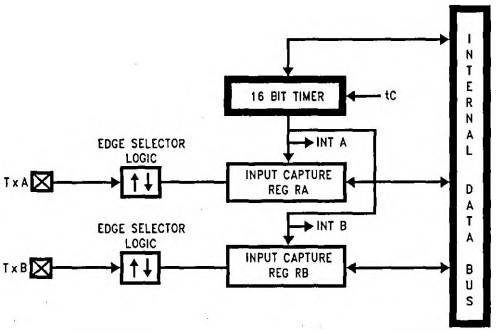

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FIGURE 9. Timer in Input Capture Mode

TIMER CONTROL FLAGS

The timers T1, T2 and T3 have indentical control structures. The control bits and their functions are summarized below.

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)
TxPNDA	Timer Interrupt Pending Flag
TxPNDB	Timer Interrupt Pending Flag
TxENA	Timer Interrupt Enable Flag
TxENB	Timer Interrupt Enable Flag 1 = Timer Interrupt Enabled 0 = Timer Interrupt Disabled
TxC3	Timer mode control
TxC2	Timer mode control
TxC1	Timer mode control

Timers (Continued)

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

TxC3	TxC2	TxC1	Timer Mode	Interrupt A Source	Interrupt B Source	Timer Counts On
0	0	0	MODE 2 (External Event Counter)	Timer Underflow	Pos. TxB Edge	TxA Pos. Edge
0	0	1	MODE 2 (External Event Counter)	Timer Underflow	Pos. TxB Edge	TxA Neg. Edge
1	0	1	MODE 1 (PWM) TxA Toggle	Autoreload RA	Autoreload RB	t_C
1	0	0	MODE 1 (PWM) No TxA Toggle	Autoreload RA	Autoreload RB	t_C
0	1	0	MODE 3 (Capture) Captures: TxA Pos. Edge TxB Pos. Edge	Pos. TxA Edge or Timer Underflow	Pos. TxB Edge	t_C
1	1	0	MODE 3 (Capture) Captures: TxA Pos. Edge TxB Neg. Edge	Pos. TxA Edge or Timer Underflow	Neg. TxB Edge	t_C
0	1	1	MODE 3 (Capture) Captures: TxA Neg. Edge TxB Pos. Edge	Neg. TxB Edge or Timer Underflow	Pos. TxB Edge	t_C
1	1	1	MODE 3 (Capture) Captures: TxA Neg. Edge TxB Neg. Edge	Neg. TxA Edge or Timer Underflow	Neg. TxB Edge	t_C

Power Save Modes

The devices offer 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 the WATCHDOG logic, the Clock Monitor 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 devices 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_r (V_r = 2.0V) without altering the state of the machine.

The devices support three different ways of exiting the HALT mode. The first method of exiting the HALT mode is with the Multi-Input Wake Up 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 be used with an RC clock configuration. The third method of exiting the HALT mode is by pulling the $\overline{\text{RESET}}$ pin low.

Since a crystal or ceramic resonator may be selected as the oscillator, the Wake Up 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 Wake Up 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.

Power Save Modes (Continued)

The WATCHDOG detector circuit is inhibited during the HALT mode. However, the clock monitor circuit if enabled remains active during HALT mode in order to ensure a clock monitor error if the device inadvertently enters the HALT mode as a result of a runaway program or power glitch.

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, the WATCHDOG logic, the clock monitor and the IDLE Timer T0, are stopped. The power supply requirements of the micro-controller in this mode of operation are typically around 30% of normal power requirement of the microcontroller.

As with the HALT mode, the device can be returned to normal operation with a reset, or with a Multi-Input Wake Up 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 1 MHz, t_c = 1 μs) 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.

Due to the on-board 8k EPROM with port recreation logic, the HALT/IDLE current is much higher compared to the equivalent masked port.

Multi-Input Wake Up

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

Figure 10 shows the Multi-Input Wake Up logic. The Multi-Input Wake Up 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 Reg: WKEN. The Reg: WKEN

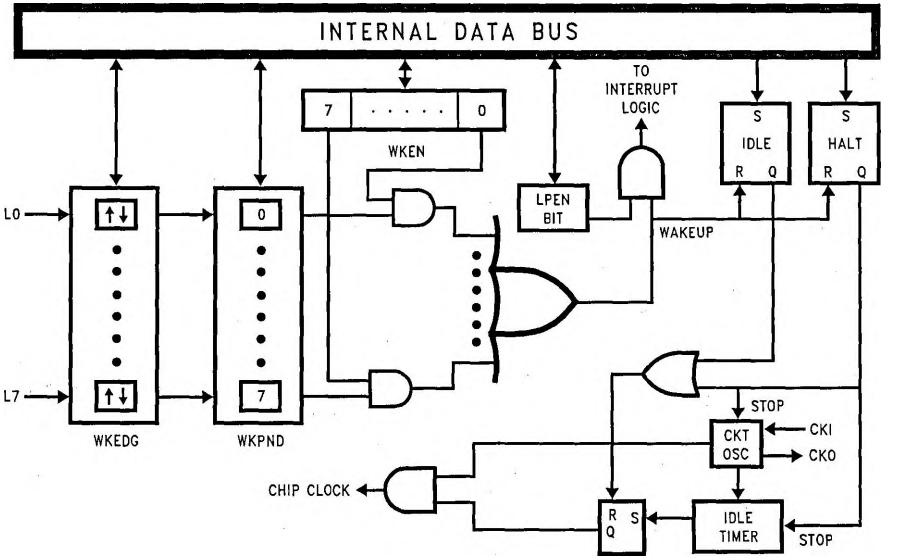

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FIGURE 10. Multi-Input Wake Up Logic

Multi-Input Wake Up (Continued)

is an 8-bit read/write register, which contains a control bit for every L port bit. Setting a particular WKEN bit enables a Wake Up 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 Reg: 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 pseudo Wake Up 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:

```
RMRBIT  5, WKEN
RMSBIT  5, WKEDG
RMRBIT  5, WKPND
RMSBIT  5, WKEN
```

If the L port bits have been used as outputs and then changed to inputs with Multi-Input Wake Up/Interrupt, a safety procedure should also be followed to avoid inherited pseudo 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 Wake Up 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 Wake Up conditions, the device will not enter the HALT mode if any Wake Up bit is both enabled and pending. Consequently, the user has the responsibility of clearing 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.

The Wake Up 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 Wake Up 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-chip 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 startup timeout 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 is cleared during reset, so the clock start up delay is not present following reset with the RC clock options.

UART

The device contains a full-duplex software programmable UART. The UART *(Figure 11)* consists of a transmit shift register, a receiver shift register and seven addressable registers, as follows: a transmit buffer register (TBUF), a receiver buffer register (RBUF), a UART control and status register (ENU), a UART receive control and status register (ENUR), a UART 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 UART is receiving.

Other functions of the ENUR register include saving the ninth bit received in the data frame, enabling or disabling the UART'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 UART mode of operation: asynchronous or synchronous.

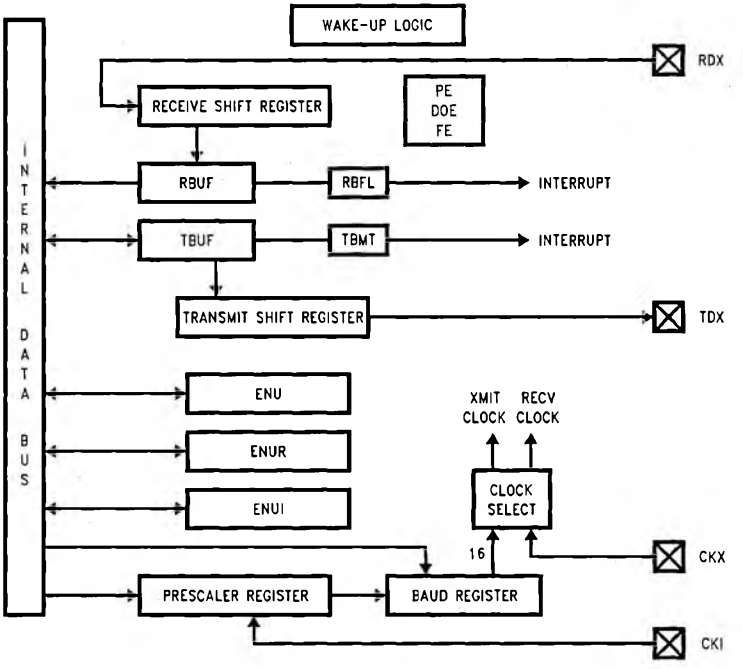

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FIGURE 11. UART Block Diagram

UART (Continued)

UART CONTROL AND STATUS REGISTERS

The operation of the UART is programmed through three registers: ENU, ENUR and ENUI. The function of the individual bits in these registers is as follows:

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

PEN	PSEL1	XBIT9/ PSEL0	CHL1	CHL0	ERR	RBFL	TBMT
0RW	0RW	0RW	0RW	0RW	0R	0R	1R

Bit 7 Bit 0

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

DOE	FE	PE	SPARE	RBIT9	ATTN	XMTG	RCVG
0RD	0RD	0RD	0RW*	0R	0RW	0R	0R

Bit7 Bit0

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

STP2	STP78	ETDX	SSEL	XRCLK	XTCLK	ERI	ETI
0RW	0RW	0RW	0RW	0RW	0RW	0RW	0RW

Bit7 Bit0

*Bit is not used.

0 Bit is cleared on reset.

1 Bit is set to one on reset.

R Bit is read-only; it cannot be written by software.

RW Bit is read/write.

D Bit is cleared on read; when read by software as a one, it is cleared automatically. Writing to the bit does not affect its state.

DESCRIPTION OF UART REGISTER BITS

ENU—UART CONTROL AND STATUS REGISTER

TBMT: This bit is set when the UART 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.

RBFL: This bit is set when the UART has received a complete character and has copied it into the RBUF register. It is automatically reset when software reads the character from RBUF.

ERR: This bit is a global UART error flag which gets set if any or a combination of the errors (DOE, FE, PE) occur.

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

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.

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

PSEL1, PSEL0: Parity select bits.

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

PEN: This bit enables/disables Parity (7- and 8-bit modes only).

PEN = 0 Parity disabled.
PEN = 1 Parity enabled.

ENUR—UART RECEIVE CONTROL AND STATUS REGISTER

RCVG: This bit is set high whenever a framing error occurs and goes low when RDX goes high.

XMTG: This bit is set to indicate that the UART is transmitting. It gets reset at the end of the last frame (end of last Stop bit).

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

RBIT9: Contains the ninth data bit received when the UART is operating with nine data bits per frame.

SPARE: Reserved for future use.

PE: Flags a Parity Error.

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.

FE: Flags a Framing Error.

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.

DOE: Flags a Data Overrun Error.

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.

ENUI—UART INTERRUPT AND CLOCK SOURCE REGISTER

ETI: This bit enables/disables interrupt from the transmitter section.

ETI = 0 Interrupt from the transmitter is disabled.
ETI = 1 Interrupt from the transmitter is enabled.

ERI: This bit enables/disables interrupt from the receiver section.

ERI = 0 Interrupt from the receiver is disabled.
ERI = 1 Interrupt from the receiver is enabled.

XTCLK: This bit selects the clock source for the transmitter section.

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.

XRCLK: This bit selects the clock source for the receiver section.

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.

SSEL: UART mode select.

SSEL = 0 Asynchronous Mode.
SSEL = 1 Synchronous Mode.

UART (Continued)

ETDX: TDX (UART 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.

STP78: This bit is set to program the last Stop bit to be 7/8th of a bit in length.

STP2: This bit programs the number of Stop bits to be transmitted.

STP2 = 0 One Stop bit transmitted.
STP2 = 1 Two Stop bits transmitted.

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 UART 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.

UART Operation

The UART 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 UART 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 UART when software loads a new character into the TBUF register. There is also the XMTG bit which is set to indicate that the UART 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 UART 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 UART 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 UART supports several serial framing formats *(Figure 12)*. 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 UART "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 UART 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 UART operation that the framing formats are the same for the transmitter and receiver.

UART Operation (Continued)

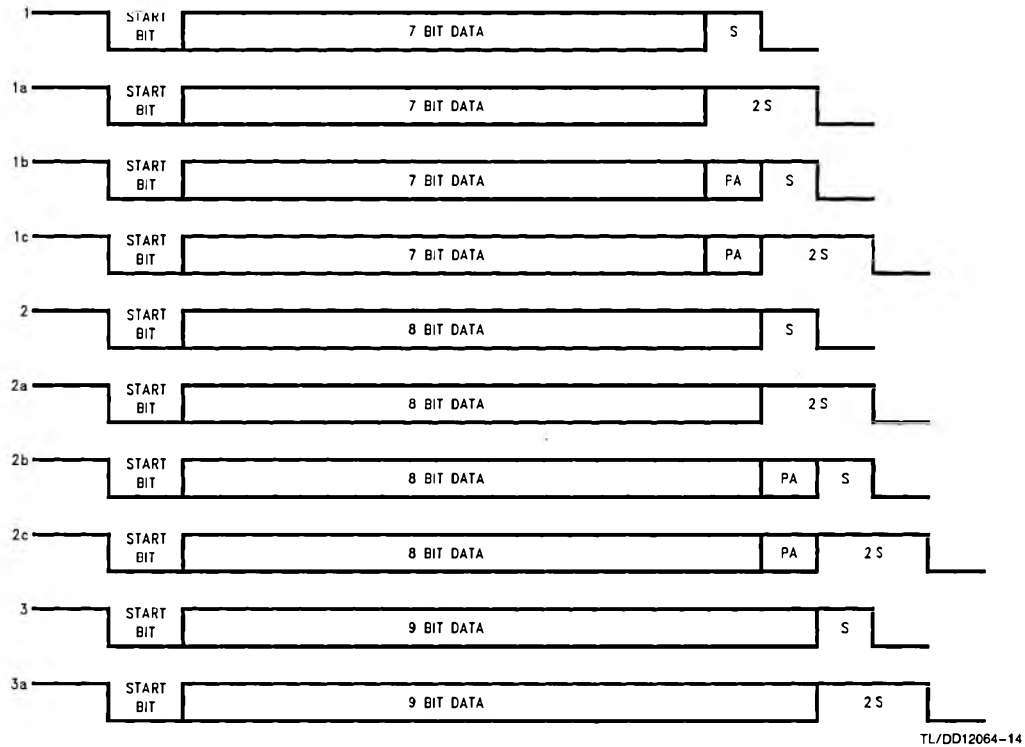

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FIGURE 12. Framing Formats

UART INTERRUPTS

The UART 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 UART 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 13)* The divide factors are specified through two read/write registers shown in *Figure 14*. 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 III, a Prescaler Factor of 0 corresponds to NO CLOCK. NO CLOCK condition is the UART power down mode where the UART clock is turned off for power saving purpose. The user must also turn the UART clock off when a different baud rate is chosen.

The correspondences between the 5-bit Prescaler Select and Prescaler factors are shown in Table III. 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 x16 clock for the following baud rates: 110, 134.5, 150, 300, 600, 1200, 1800, 2400, 3600, 4800, 7200, 9600, 19200 and 38400 (Table IV). Other baud rates may be created by using appropriate divisors. The x16 clock is then divided by 16 to provide the rate for the serial shift registers of the transmitter and receiver.

Baud Clock Generation (Continued)

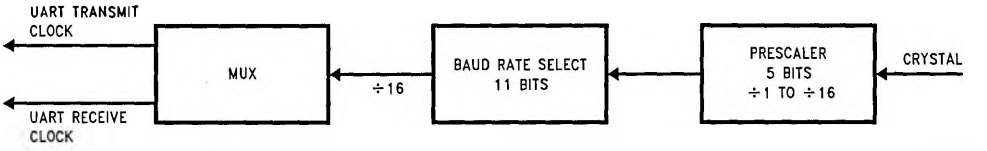

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FIGURE 13. UART BAUD Clock Generation

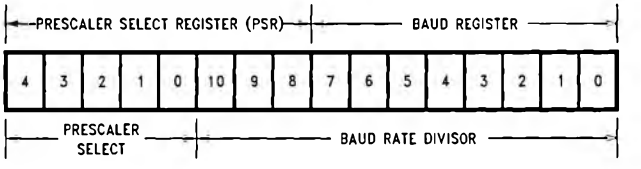

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FIGURE 14. UART BAUD Clock Divisor Registers

TABLE III. Prescaler Factors

Prescaler Select	Prescaler Factor	Prescaler Select	Prescaler Factor
00000	NO CLOCK	10000	8.5
00001	1	10001	9
00010	1.5	10010	9.5
00011	2	10011	10
00100	2.5	10100	10.5
00101	3	10101	11
00110	3.5	10110	11.5
00111	4	10111	12
01000	4.5	11000	12.5
01001	5	11001	13
01010	5.5	11010	13.5
01011	6	11011	14
01100	6.5	11100	14.5
01101	7	11101	15
01110	7.5	11110	15.5
01111	8	11111	16

TABLE IV. 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 IV assume a prescaler output of 1.8432 MHz. In the asynchronous mode the baud rate could be as high as 625k.

As an example, considering the 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 III. The 1.8432 MHz prescaler output is then used with proper Baud Rate Divisor (Table II) to obtain different baud rates. For a baud rate of 19200 e.g., the entry in Table IV is V.

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

$N = 6$ (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 UART is 16 times the baud rate. The equation to calculate baud rates is given below.

The actual Baud Rate may be found from:

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

Baud Clock Generation (Continued)

Where:

BR is the Baud Rate

Fc is the CKI frequency

N is the Baud Rate Divisor (Table IV).

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

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 × 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 III) to obtain a value closest to an integer. This factor happens to be 6.5 (P = 6.5).

$$N = 32.552/6.5 = 5.008 \ (N = 5)$$

The programmed value (from Table IV) should be 4 (N − 1).

Using the above values calculated for N and P:

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

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

Effect of HALT/IDLE

The UART 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 UART 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 Wake Up scheme provided on the device.

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

If the device is halted and crystal oscillator is used, the Wake Up signal will not start the chip running immediately because of the finite start up time requirement of the crystal oscillator. The idle timer (T0) generates a fixed 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 UART. 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 UART.

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 UART 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 UART monitors the communication flow, but ignores all characters until an address character is received. Upon receiving an address character, the UART signals that the character is ready by setting the RBFL flag, which in turn interrupts the processor if UART 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 UART 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 devices contain 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:

- I1 Comparator1 negative input
- I2 Comparator1 positive input
- I3 Comparator1 output
- I4 Comparator2 negative input
- I5 Comparator2 positive input
- I6 Comparator2 output

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:

Comparators (Continued)

CMPSL REGISTER (ADDRESS X'00B7)

The CMPSL register contains the following bits:

CMP1EN Enable comparator 1

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

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

CMP2EN Enable comparator 2

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

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

Unused	CMP20E	CMP2RD	CMP2EN	CMP10E	CMP1RD	CMP1EN	Unused

Bit 7 Bit 0

Note that the two unused bits of CMPSL may be used as software flags.

Comparator outputs have the same spec as Ports L and G except that the rise and fall times are symmetrical.

Interrupts

The devices support a vectored interrupt scheme. It supports a total of fourteen interrupt sources. The following table lists all the possible device interrupt sources, their arbitration ranking and the memory locations reserved for the interrupt vector for each source.

Two bytes of program memory space are reserved for each interrupt source. All interrupt sources except the software interrupt are maskable. Each of the maskable interrupts have an Enable bit and a Pending bit. A maskable interrupt is active if its associated enable and pending bits are set. If GIE = 1 and an interrupt is active, then the processor will be interrupted as soon as it is ready to start executing an instruction except if the above conditions happen during the Software Trap service routine. This exception is described in the Software Trap sub-section.

The interruption process is accomplished with the INTR instruction (opcode 00), which is jammed inside the Instruction Register and replaces the opcode about to be executed. The following steps are performed for every interrupt:

1. The GIE (Global Interrupt Enable) bit is reset.
2. The address of the instruction about to be executed is pushed into the stack.
3. The PC (Program Counter) branches to address 00FF. This procedure takes 7 t_C cycles to execute.

Arbitration Ranking	Source	Description	Vector Address Hi-Low Byte
(1) Highest	Software	INTR Instruction	0yFE–0yFF
	Reserved	for Future Use	0yFC–0yFD
(2)	External	Pin G0 Edge	0yFA–0yFB
(3)	Timer T0	Underflow	0yF8–0yF9
(4)	Timer T1	T1A/Underflow	0yF6–0yF7
(5)	Timer T1	T1B	0yF4–0yF5
(6)	MICROWIRE/PLUS	BUSY Goes Low	0yF2–0yF3
	Reserved	for Future Use	0yF0–0yF1
(7)	UART	Receive	0yEE–0yEF
(8)	UART	Transmit	0yEC–0yED
(9)	Timer T2	T2A/Underflow	0yEA–0yEB
(10)	Timer T2	T2B	0yE8–0yE9
(11)	Timer T3	T3A/Underflow	0yE6–0yE7
(12)	Timer T3	T3B	0yE4–0yE5
(13)	Port L/Wake Up	Port L Edge	0yE2–0yE3
(14) Lowest	Default	VIS Instr. Execution without Any Interrupts	0yE0–0yE1

y is VIS page, y ≠ 0.

Interrupts (Continued)

At this time, since GIE = 0, other maskable interrupts are disabled. The user is now free to do whatever context switching is required by saving the context of the machine in the stack with PUSH instructions. The user would then program a VIS (Vector Interrupt Select) instruction in order to branch to the interrupt service routine of the highest priority interrupt enabled and pending at the time of the VIS. Note that this is not necessarily the interrupt that caused the branch to address location 00FF Hex prior to the context switching.

Thus, if an interrupt with a higher rank than the one which caused the interruption becomes active before the decision of which interrupt to service is made by the VIS, then the interrupt with the higher rank will override any lower ones and will be acknowledged. The lower priority interrupt(s) are still pending, however, and will cause another interrupt immediately following the completion of the interrupt service routine associated with the higher priority interrupt just serviced. This lower priority interrupt will occur immediately following the RETI (Return from Interrupt) instruction at the end of the interrupt service routine just completed.

Inside the interrupt service routine, the associated pending bit has to be cleared by software. The RETI (Return from Interrupt) instruction at the end of the interrupt service routine will set the GIE (Global Interrupt Enable) bit, allowing the processor to be interrupted again if another interrupt is active and pending.

The VIS instruction looks at all the active interrupts at the time it is executed and performs an indirect jump to the beginning of the service routine of the one with the highest rank.

The addresses of the different interrupt service routines, called vectors, are chosen by the user and stored in ROM in a table starting at 01E0 (assuming that VIS is located between 00FF and 01DF). The vectors are 15-bit wide and therefore occupy 2 ROM locations.

VIS and the vector table must be located in the same 256-byte block (0y00 to 0yFF) except if VIS is located at the last address of a block. In this case, the table must be in the next block. The vector table cannot be inserted in the first 256-byte block ($y \neq 0$).

The vector of the maskable interrupt with the lowest rank is located at 0yE0 (Hi-Order byte) and 0yE1 (Lo-Order byte) and so forth in increasing rank number. The vector of the maskable interrupt with the highest rank is located at 0yFA (Hi-Order byte) and 0yFB (Lo-Order byte).

The Software Trap has the highest rank and its vector is located at 0yFE and 0yFF.

If, by accident, a VIS gets executed and no interrupt is active, then the PC (Program Counter) will branch to a vector located at 0yE0–0yE1. This vector can point to the Software Trap (ST) interrupt service routine, or to another special service routine as desired.

Figure 15 shows the Interrupt block diagram.

SOFTWARE TRAP

The Software Trap (ST) is a special kind of non-maskable interrupt which occurs when the INTR instruction (used to acknowledge interrupts) is fetched from ROM and placed inside the instruction register. This may happen when the PC is pointing beyond the available ROM address space or when the stack is over-popped.

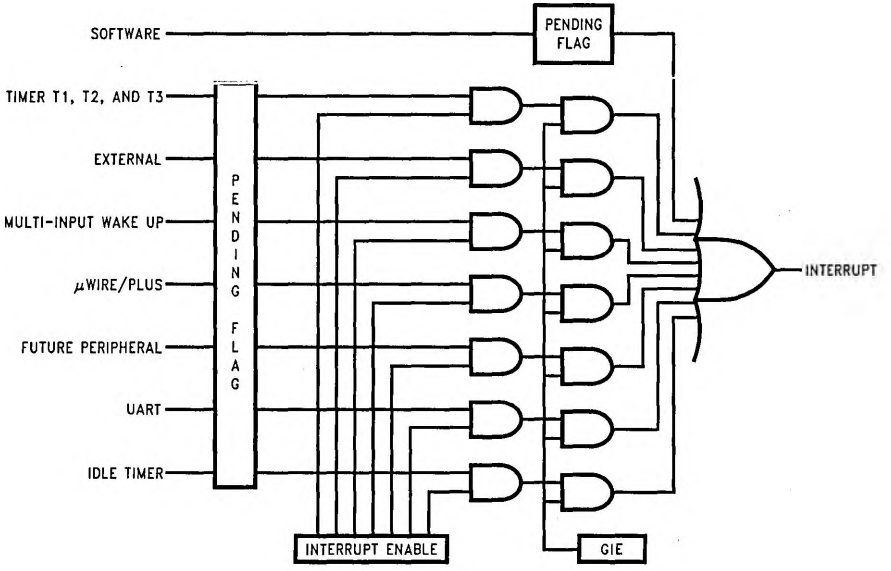

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FIGURE 15. Interrupt Block Diagram

Interrupts (Continued)

When an ST occurs, the user can re-initialize the stack pointer and do a recovery procedure (similar to reset, but not necessarily containing all of the same initialization procedures) before restarting.

The occurrence of an ST is latched into the ST pending bit. The GIE bit is not affected and the ST 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. The RPND instruction is used to clear the software interrupt pending bit. This pending bit is also cleared on reset.

The ST has the highest rank among all interrupts.

Nothing (except another ST) can interrupt an ST being serviced.

WATCHDOG

The devices contain 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 V shows the WDSVR register.

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 VI 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 V. 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

TABLE VI. WATCHDOG Service Window Select

WDSVR Bit 7	WDSVR Bit 6	Service Window (Lower-Upper Limits)
0	0	2k–8k t_C Cycles
0	1	2k–16k t_C Cycles
1	0	2k–32k t_C Cycles
1	1	2k–64k t_C Cycles

Clock Monitor

The Clock Monitor aboard the device can be selected or deselected 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 VII 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.

TABLE VII. 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

WATCHDOG Operation (Continued)

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:

$1/t_c > 10$ kHz—No clock rejection.

$1/t_c < 10$ 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.
- 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 COP888 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), 140 to 17F (Segment 1), and all other segments (i.e., Segments 3 . . . 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, E^2PROMs 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 16* shows a block diagram of the MICROWIRE/PLUS logic.

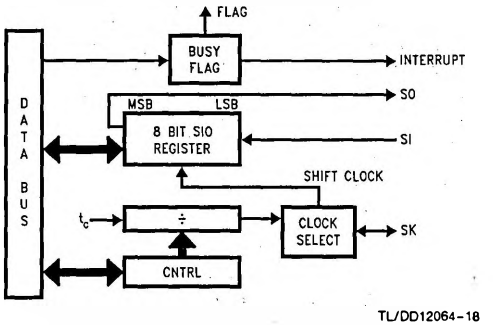

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FIGURE 16. MICROWIRE/PLUS Block Diagram

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 VIII details the different clock rates that may be selected.

TABLE VIII. MICROWIRE/PLUS Master Mode Clock Select

SL1	SL0	SK
0	0	$2 \times t_c$
0	1	$4 \times t_c$
1	x	$8 \times t_c$

Where t_c is the instruction cycle clock

MICROWIRE/PLUS (Continued)

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 17* shows how two devices, microcontrollers 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 IX 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 bit in the Port G configuration register. Table IX 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 IX. MICROWIRE/PLUS Mode Selection

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

Note: This table assumes that the control flag MSEL is set.

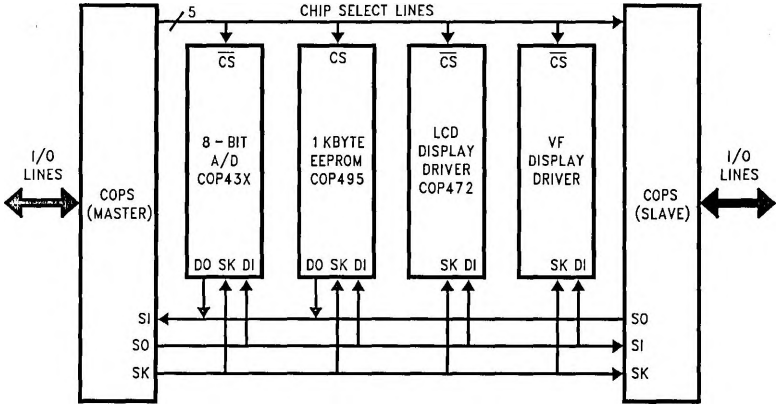

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FIGURE 17. MICROWIRE/PLUS Application

Memory Map

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

Address S/ADD REG	Contents
0000 to 006F	On-Chip RAM bytes (112 bytes)
0070 to 007F	Unused RAM Address Space (Reads As All Ones)
xx80 to xxAF	Unused RAM Address Space (Reads Undefined Data)
xxB0	Timer T3 Lower Byte
xxB1	Timer T3 Upper Byte
xxB2	Timer T3 Autoload Register T3RA Lower Byte
xxB3	Timer T3 Autoload Register T3RA Upper Byte
xxB4	Timer T3 Autoload Register T3RB Lower Byte
xxB5	Timer T3 Autoload Register T3RB Upper Byte
xxB6	Timer T3 Control Register
xxB7	Comparator Select Register (CMPSL)
xxB8	UART Transmit Buffer (TBUF)
xxB9	UART Receive Buffer (RBUF)
xxBA	UART Control and Status Register (ENU)
xxBB	UART Receive Control and Status Register (ENUR)
xxBC	UART Interrupt and Clock Source Register (ENUI)
xxBD	UART Baud Register (BAUD)
xxBE	UART Prescale Select Register (PSR)
xxBF	Reserved for UART
xxC0	Timer T2 Lower Byte
xxC1	Timer T2 Upper Byte
xxC2	Timer T2 Autoload Register T2RA Lower Byte
xxC3	Timer T2 Autoload Register T2RA Upper Byte
xxC4	Timer T2 Autoload Register T2RB Lower Byte
xxC5	Timer T2 Autoload Register T2RB Upper Byte
xxC6	Timer T2 Control Register
xxC7	WATCHDOG Service Register (Reg:WDSVR)
xxC8	MIWU Edge Select Register (Reg:WKEDG)
xxC9	MIWU Enable Register (Reg:WKEN)
xxCA	MIWU Pending Register (Reg:WKPND)
xxCB	Reserved
xxCC	Reserved
xxCD to xxCF	Reserved

Address S/ADD REG	Contents
xxD0	Port L Data Register
xxD1	Port L Configuration Register
xxD2	Port L Input Pins (Read Only)
xxD3	Reserved for Port L
xxD4	Port G Data Register
xxD5	Port G Configuration Register
xxD6	Port G Input Pins (Read Only)
xxD7	Port I Input Pins (Read Only)
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 DF	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
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 FB	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

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 all ones.

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 in the current 4k 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
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)
Æ	Loaded with
'	Exchanged with

Instruction Set (Continued)

INSTRUCTION SET

ADD	A,Meml	ADD	A ← A + Meml
ADC	A,Meml	ADD with Carry	A ← A + Meml + C, C ← Carry, HC ← Half Carry
SUBC	A,Meml	Subtract with Carry	A ← A − Meml + C, C ← Carry, HC ← Half Carry
AND	A,Meml	Logical AND	A ← A and Meml
ANDSZ	A,Imm	Logical AND Immed., Skip if Zero	Skip next if (A and Imm) = 0
OR	A,Meml	Logical OR	A ← A or Meml
XOR	A,Meml	Logical EXclusive OR	A ← A xor Meml
IFEQ	MD,Imm	IF EQual	Compare MD and Imm, Do next if MD = Imm
IFEQ	A,Meml	IF EQual	Compare A and Meml, Do next if A = Meml
IFNE	A,Meml	IF Not Equal	Compare A and Meml, Do next if A ≠ Meml
IFGT	A,Meml	IF Greater Than	Compare A and Meml, Do next if A > Meml
IFBNE	#	If B Not Equal	Do next if lower 4 bits of B ≠ Imm
DRSZ	Reg	Decrement Reg., Skip if Zero	Reg ← Reg − 1, Skip if 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 ⟷ Mem
X	A,[X]	EXchange A with Memory [X]	A ⟷ [X]
LD	A,Meml	LoaD A with Memory	A ← Meml
LD	A,[X]	LoaD A with Memory [X]	A ← [X]
LD	B,Imm	LoaD B with Immed.	B ← Imm
LD	Mem,Imm	LoaD Memory Immed.	Mem ← Imm
LD	Reg,Imm	LoaD Register Memory Immed.	Reg ← Imm
X	A, [B ±]	EXchange A with Memory [B]	A ⟷ [B], (B ← B ±1)
X	A, [X ±]	EXchange A with Memory [X]	A ⟷ [X], (X ← ±1)
LD	A, [B±]	LoaD A with Memory [B]	A ← [B], (B ← B ±1)
LD	A, [X±]	LoaD A with Memory [X]	A ← [X], (X ← X±1)
LD	[B±],Imm	LoaD Memory [B] Immed.	[B] ← Imm, (B ← B±1)
CLR	A	CLeaR A	A ← 0
INC	A	INCrement A	A ← A + 1
DEC	A	DECrementA	A ← A − 1
LAID		Load A InDirect from ROM	A ← ROM (PU,A)
DCOR	A	Decimal CORrect A	A ← BCD correction of A (follows ADC, SUBC)
RRC	A	Rotate A Right thru C	C → A7 → . . . → A0 → C
RLC	A	Rotate A Left thru C	C ← A7 ← . . . ← A0 ← C
SWAP	A	SWAP nibbles of A	A7 . . . A4 ⟷ A3 . . . A0
SC		Set C	C ← 1, HC ← 1
RC		Reset C	C ← 0, HC ← 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	SP ← SP + 1, A ← [SP]
PUSH	A	PUSH A onto the stack	[SP] ← A, SP ← SP − 1
VIS		Vector to Interrupt Service Routine	PU ← [VU], PL ← [VL]
JMPL	Addr.	Jump absolute Long	PC ← ii (ii = 15 bits, 0k to 32k)
JMP	Addr.	Jump absolute	PC9 . . . 0 ← i (i = 12 bits)
JP	Disp.	Jump relative short	PC ← PC + r (r is −31 to +32, except 1)
JSRL	Addr.	Jump SubRoutine Long	[SP] ← PL, [SP−1] ← PU,SP−2, PC ← ii
JSR	Add.	Jump SubRoutine	[SP] ← PL, [SP−1] ← PU,SP−2, PC9 . . . 0 ← i
JID		Jump InDirect	PL ← ROM (PU,A)
RET		RETurn from subroutine	SP + 2, PL ← [SP], PU ← [SP−1]
RETSK		RETurn and SKip	SP + 2, PL ← [SP],PU ← [SP−1]
RETI		RETurn from Interrupt	SP + 2, PL ← [SP],PU ← [SP−1],GIE ← 1
INTR		Generate an Interrupt	[SP] ← PL, [SP−1] ← PU, SP−2, PC ← 0FF
NOP		No OPeration	PC ← 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.

See the BYTES and CYCLES per INSTRUCTION table for details.

Bytes and Cycles per Instruction

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

Logic and Arithmetic 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
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 and C

CLRA	1/1
INCA	1/1
DECA	1/1
LAID	1/3
DCORA	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. and Decr.		
	[B]	[X]			[B+, B−]	[X+, X−]	
X A,*	1/1	1/3	2/3		1/2	1/3	
LD A,*	1/1	1/3	2/3	2/2	1/2	1/3	
LD B, Imm				1/1			(IF B < 16)
LD B, Imm				2/3			(IF B > 15)
LD Mem, Imm	2/2	2/2	3/3		2/2		
LD Reg, Imm			2/3				
IFEQ MD, Imm			3/3				

* = > Memory location addressed by B or X or directly.

COP8788EG/COP8784EG 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	JP − 15	0
JP −14	JP −30	LD 0F1, #i	DRSZ 0F1	*	SC	SUBC A, #i	SUB A,[B]	IFBIT 1,[B]	*	LD B,#0E	IFBNE 1	JSR x100–x1FF	JMP x100–x1FF	JP + 18	JP − 14	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 − 13	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 − 12	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 − 11	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 − 10	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 − 9	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 − 7	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 − 6	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 − 5	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 − 4	B
JP −3	JP −19	LD 0FC, #i	DRSZ 0FC	LD Md,#i	JMPL	X A,Md	POPA	SBIT 4,[B]	RBIT 4,[B]	LD B,#03	IFBNE 0C	JSR xC00–xCFF	JMP xC00–xCFF	JP + 29	JP − 3	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 − 2	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 − 1	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 − 0	F

where,

i is the immediate data

Md is a directly addressed memory location

* is an unused opcode

Note: The opcode 60 Hex is also the opcode for IFBIT #i,A

Ordering Information and Development Support

COP8788EG/COP8784EG Ordering Information

Device Number	Clock Option	Package	Emulates
COP8788EGV-X COP8788EGV-R*	Crystal R/C	44 PLCC	COP888EG
COP8788EGN-X COP8788EGN-R*	Crystal R/C	40 DIP	COP888EG
COP8784EGN-X COP8784EGN-R*	Crystal R/C	28 DIP	COP884EG
COP8784EGWM-X* COP8784EGWM-R*	Crystal R/C	28 SO	COP884EG

*Check with the local sales office about the availability.

PROGRAMMING SUPPORT

Programming of these emulator devices is supported by different sources. The following programmers are certified for programming these One-Time Programmable emulator devices:

EPROM Programmer Information

Manufacturer and Product	U.S. Phone Number	Europe Phone Number	Asia Phone Number
MetaLink-Debug Module	(602) 926-0797	Germany: +49-8141-1030	Hong Kong: 852-737-1800
Xeltek-Superpro	(408) 745-7974	Germany: +49-20-41-684758	Singapore: 65-276-6433
BP Microsystems-Turpro	(800) 225-2102	Germany: +49-89-85-76667	Hong Kong: 852-388-0629
Data I/O-Unisite -System 29 -System 39	(800) 322-8246	Europe: +31-20-622866 Germany: +49-89-85-8020	Japan: +33-432-6991
Abcom-COP8 Programmer		Europe: +49-89-808707	
System General-Turpro-1-FX -APRO	(408) 263-6667	Switzerland: +41-31-921-7844	Taiwan: +2-917-3005

Development Support

IN-CIRCUIT EMULATOR

The MetaLink iceMASTER™-COP8 Model 400 In-Circuit Emulator for the COP8 family of microcontrollers features high-performance operation, ease of use, and an extremely flexible user-interface or maximum productivity. Interchangeable probe cards, which connect to the standard common base, support the various configurations and packages of the COP8 family.

The iceMASTER provides real time, full speed emulation up to 10 MHz, 32 kbytes of emulation memory and 4k frames of trace buffer memory. The user may define as many as 32k trace and break triggers which can be enabled, disabled, set or cleared. They can be simple triggers based on code address, direct address, opcode value, opcode class or immediate operand. Complex breakpoints can be ANDed and ORed together. Trace information consists of address bus values, opcodes and user selectable probe clips status (external event lines). The trace buffer can be viewed as raw hex or as disassembled instructions. The probe clip bit values can be displayed in binary, hex or digital waveform formats.

During single-step operation the dynamically annotated code feature displays the contents of all accessed (read and write) memory locations and registers, as well as flow-of-control direction change markers next to each instruction executed.

The iceMASTER's performance analyzer offers a resolution of better than 6 μs. The user can easily monitor the time spent executing specific portions of code and find "hot spots" or "dead code". Up to 15 independent memory areas based on code address or label ranges can be defined. Analysis results can be viewed in bar graph format or as actual frequency count.

Emulator memory operations for program memory include single line assembler, disassembler, view, change and write to file. Data memory operations include fill, move, compare, dump to file, examine and modify. The contents of any memory space can be directly viewed and modified from the corresponding window.

The iceMASTER comes with an easy to use window interface. Each window can be sized, highlighted, color-controlled, added, or removed completely. Commands can be accessed via pull-down-menus and/or redefinable hot keys. A context sensitive hypertext/hyperlinked on-line help system explains clearly the options the user has from within any window.

The iceMASTER connects easily to a PC® via the standard COMM port and its 115.2 kBaud serial link keeps typical program download time to under 3 seconds.

The following tables list the emulator and probe cards ordering information.

Emulator Ordering Information

Part Number	Description	Current Version
IM-COP8/400/1‡	MetaLink base unit in-circuit emulator for all COP8 devices, symbolic debugger software and RS 232 serial interface cable, with 110V @ 60 Hz Power Supply.	Host Software: Ver. 3.3 Rev. 5, Model File Rev 3.050.
IM-COP8/400/2‡	MetaLink base unit in-circuit emulator for all COP8 devices, symbolic debugger software and RS 232 serial interface cable, with 220V @ 50 Hz Power Supply.	
DM-COP8/888EG‡	MetaLink IceMaster Debug Modul. This is the low cost version of the MetaLink IceMaster. Firmware: Ver. 6.07	

‡These parts include National's COP8 Assembler/Linker/Librarian Package (COP8-DEV-IBMA).

Development Support (Continued)

Probe Card Ordering Information

Part Number	Package	Voltage Range	Emulates
MHW-884EG28D5PC	28 DIP	4.5V–5.5V	COP884EG
MHW-884EG28DWPC	28 DIP	2.5V–6.0V	COP884EG
MHW-888EG40D5PC	40 DIP	4.5V–5.5V	COP888EG
MHW-888EG40DWPC	40 DIP	2.5V–6.0V	COP888EG
MWH-888EG44D5PC	44 PLCC	4.5V–5.5V	COP888EG
MHW-888EG44DWPC	44 PLCC	2.5V–6.0V	COP888EG

MACRO CROSS ASSEMBLER

National Semiconductor offers a relocatable COP8 macro cross assembler. It runs on industry standard compatible PCs and supports all of the full-symbolic debugging features of the MetaLink iceMASTER emulators.

Assembler Ordering Information

Part Number	Description	Manual
COP8-DEV-IBMA	COP8 Assembler/ Linker/Librarian for IBM® PC/XT®, AT® or compatible.	424410632-001

DIAL-A-HELPER

Dial-A-Helper is a service provided by the Microcontroller Applications group. The Dial-A-Helper is an Electronic Bulletin Board Information system.

INFORMATION SYSTEM

The Dial-A-Helper system provides access to an automated information storage and retrieval system that may be accessed over standard dial-up telephone lines 24 hours a day. The system capabilities include a MESSAGE SECTION (electronic mail) for communications to and from the Microcontroller Applications Group and a FILE SECTION which consists of several file areas where valuable application software and utilities could be found. The minimum requirement for accessing the Dial-A-Helper is a Hayes compatible modem.

If the user has a PC with a communications package then files from the FILE SECTION can be down loaded to disk for later use.

ORDER P/N: MOLE-DIAL-A-HLP

Information System Package contains:
Dial-A-Helper Users Manual
Public Domain Communications Software

FACTORY APPLICATIONS SUPPORT

Dial-A-Helper also provides immediate factor applications support. If a user has questions, he can leave messages on our electronic bulletin board, which we will respond to.

Voice: (800) 272-9959
Modem: CANADA/U.S.: (800) NSC-MICRO
(800) 672-6427
Baud: 14.4k
Set-Up: Length: 8-Bit
Parity: None
Stop Bit: 1
Operation: 24 Hrs., 7 Days

National Semiconductor

COP472-3 Liquid Crystal Display Controller

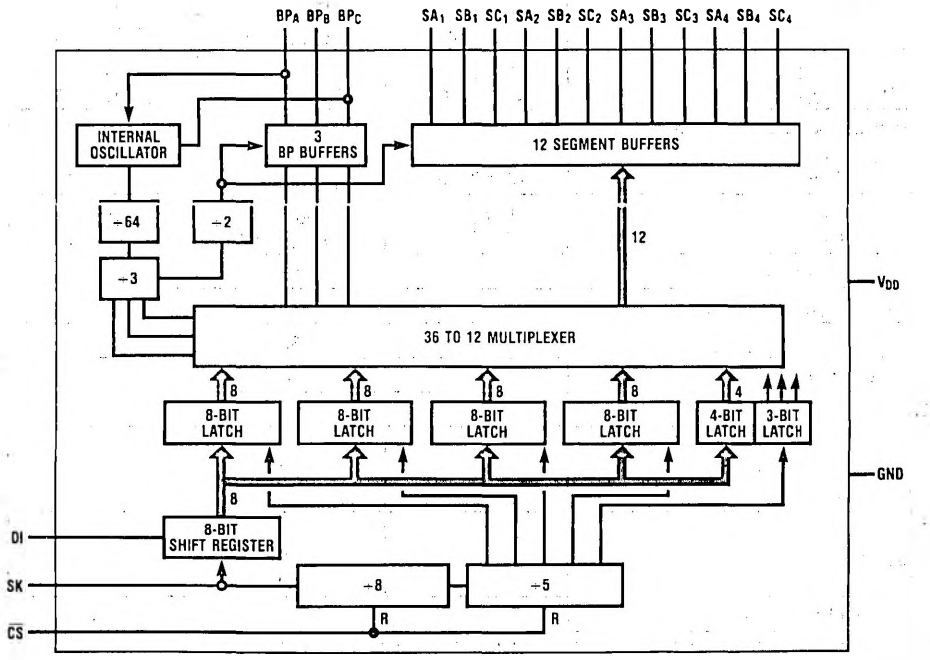
General Description

The COP472–3 Liquid Crystal Display (LCD) Controller is a peripheral member of the COPS™ family, fabricated using CMOS technology. The COP472-3 drives a multiplexed liquid crystal display directly. Data is loaded serially and is held in internal latches. The COP472-3 contains an on-chip oscillator and generates all the multi-level waveforms for backplanes and segment outputs on a triplex display. One COP472-3 can drive 36 segments multiplexed as 3 x 12 (4½ digit display). Two COP472-3 devices can be used together to drive 72 segments (3 x 24) which could be an 8½ digit display.

Features

- Direct interface to TRIPLEX LCD
- Low power dissipation (100 μW typ.)
- Low cost
- Compatible with all COPS processors
- Needs no refresh from processor
- On-chip oscillator and latches
- Expandable to longer displays
- Operates from display voltage
- MICROWIRE™ compatible serial I/O
- 20-pin Dual-In-Line package and 20-pin SO

Block Diagram



TL/DD/6932–1

Absolute Maximum Ratings

Voltage at CS, DI, SK pins	−0.3V to +9.5V	Storage Temperature	−65°C to +150°C
Voltage at all other Pins	−0.3V to V_{DD}+0.3V	Lead Temp. (Soldering, 10 Seconds)	300°C
Operating Temperature Range	0°C to 70°C		

DC Electrical Characteristics

GND = 0V, V_{DD} = 3.0V to 5.5V, T_A = 0°C to 70°C (depends on display characteristics)

Parameter	Conditions	Min	Max	Units
Power Supply Voltage, V_{DD}		3.0	5.5	Volts
Power Supply Current, I_{DD} (Note 1)	V_{DD}=5.5V		250	μA
	V_{DD}=3V		100	μA
Input Levels				
DI, SK, CS				
V_{IL}			0.8	Volts
V_{IH}		0.7 V_{DD}	9.5	Volts
BPA (as Osc. in)				
V_{IL}			0.6	Volts
V_{IH}		V_{DD}−0.6	V_{DD}	Volts
Output Levels, BPC (as Osc. Out)				
V_{OL}			0.4	Volts
V_{OH}		V_{DD}−0.4	V_{DD}	Volts
Backplane Outputs (BPA, BPB, BPC)				
$V_{BPA, BPB, BPC}$ ON	During	$V_{DD}-\Delta V$	V_{DD}	Volts
$V_{BPA, BPB, BPC}$ OFF	BP+ Time	$\frac{1}{3} V_{DD}-\Delta V$	$\frac{1}{3} V_{DD}+\Delta V$	Volts
$V_{BPA, BPB, BPC}$ ON	During	0	ΔV	Volts
$V_{BPA, BPB, BPC}$ OFF	BP− Time	$\frac{2}{3} V_{DD}-\Delta V$	$\frac{2}{3} V_{DD}+\Delta V$	Volts
Segment Outputs (SA_1 ~ SA_4)				
V_{SEG} ON	During	0	ΔV	Volts
V_{SEG} OFF	BP+ Time	$\frac{2}{3} V_{DD}-\Delta V$	$\frac{2}{3} V_{DD}+\Delta V$	Volts
V_{SEG} ON	During	$V_{DD}-\Delta V$	V_{DD}	Volts
V_{SEG} OFF	BP− Time	$\frac{1}{3} V_{DD}-\Delta V$	$\frac{1}{3} V_{DD}+\Delta V$	Volts
Internal Oscillator Frequency		15	80	kHz
Frame Time (Int. Osc. ÷ 192)		2.4	12.8	ms
Scan Frequency ($1/T_{SCAN}$)		39	208	Hz
SK Clock Frequency		4	250	kHz
SK Width		1.7		μs
DI				
Data Setup, t_{SETUP}		1.0		μs
Data Hold, t_{HOLD}		100		ns
$\overline{CS}$				
t_{SETUP}		1.0		μs
t_{HOLD}		1.0		μs
Output Loading Capacitance			100	pF

Note 1: Power supply current is measured in stand-alone mode with all outputs open and all inputs at V_{DD}.

Note 2: $\Delta V = 0.05 V_{DD}$.

Absolute Maximum Ratings

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

Voltage at CS, DI, SK Pins	−0.3V to +9.5V
Voltage at All Other Pins	−0.3V to V_{DD}+0.3V
Operating Temperature Range	−40°C to +85°C
Storage Temperature	−65°C to +150°C
Lead Temperature (Soldering, 10 seconds)	300°C

DC Electrical Characteristics

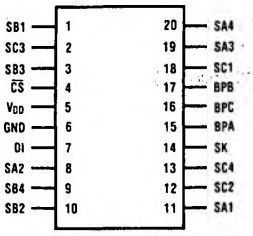
GND = 0V, V_{DD} = 3.0V to 5.5V, T_A = −40°C to +85°C (depends on display characteristics)

Parameter	Conditions	Min	Max	Units
Power Supply Voltage, V_{DD}		3.0	5.5	Volts
Power Supply Current, I_{DD} (Note 1)	V_{DD}=5.5V		300	μA
	V_{DD}=3V		120	μA
Input Levels				
DI, SK, CS				
V_{IL}			0.8	Volts
V_{IH}		0.7 V_{DD}	9.5	Volts
BPA (as Osc. In)				
V_{IL}			0.6	Volts
V_{IH}		V_{DD}−0.6	V_{DD}	Volts
Output Levels, BPC (as Osc. Out)				
V_{OL}			0.4	Volts
V_{OH}		V_{DD}−0.4	V_{DD}	Volts
Backplane Outputs (BPA, BPB, BPC)				
$V_{BPA, BPB, BPC}$ ON	During	V_{DD}−ΔV	V_{DD}	Volts
$V_{BPA, BPB, BPC}$ OFF	BP+ Time	⅓ V_{DD}−ΔV	⅓ V_{DD}+ΔV	Volts
$V_{BPA, BPB, BPC}$ ON	During	0	ΔV	Volts
$V_{BPA, BPB, BPC}$ OFF	BP− Time	⅔ V_{DD}−ΔV	⅔ V_{DD}+ΔV	Volts
Segment Outputs (SA_1 ~ SA_4)				
V_{SEG} ON	During	0	ΔV	Volts
V_{SEG} OFF	BP+ Time	⅔ V_{DD}−ΔV	⅔ V_{DD}+ΔV	Volts
V_{SEG} ON	During	V_{DD}−ΔV	V_{DD}	Volts
V_{SEG} OFF	BP− Time	⅓ V_{DD}−ΔV	⅓ V_{DD}+ΔV	Volts
Internal Oscillator Frequency		15	80	kHz
Frame Time (Int. Osc. ÷ 192)		2.4	12.8	ms
Scan Frequency ($1/T_{SCAN}$)		39	208	Hz
SK Clock Frequency		4	250	kHz
SK Width		1.7		μs
DI				
Data Setup, t_{SETUP}		1.0		μs
Data Hold, t_{HOLD}		100		ns
$\overline{CS}$				
t_{SETUP}		1.0		μs
t_{HOLD}		1.0		μs
Output Loading Capacitance			100	pF

Note 1: Power supply current is measured in stand-alone mode with all outputs open and all inputs at V_{DD}.

Note 2: ΔV = 0.05 V_{DD}.

Dual-In-Line Package



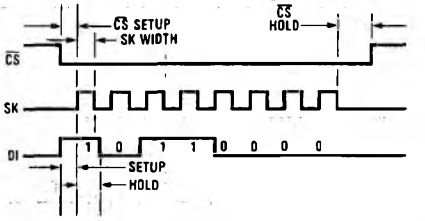
Top View

TL/DD/6932-2

Pin	Description
$\overline{CS}$	Chip select
V_{DD}	Power supply (display voltage)
GND	Ground
DI	Serial data input
SK	Serial clock input
BP_A	Display backplane A (or oscillator in)
BP_B	Display backplane B
BP_C	Display backplane C (or oscillator out)
SA1 ~ SC4	12 multiplexed outputs

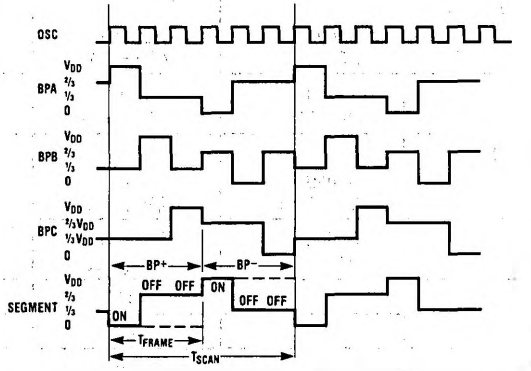
Order Number COP472MW-3 or COP472N-3
See NS Package Number M20A or N20A

FIGURE 2. Connection Diagram



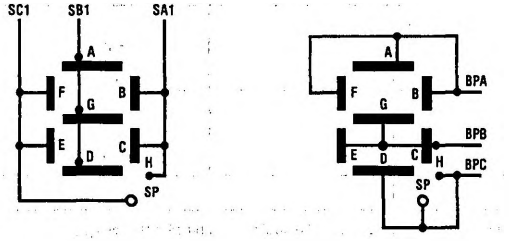
TL/DD/6932-3

FIGURE 3. Serial Load Timing Diagram



TL/DD/6932-4

FIGURE 4. Backplane and Segment Waveforms



TL/DD/6932-5

FIGURE 5. Typical Display Internal Connections Epson LD-370

Functional Description

The COP472-3 drives 36 bits of display information organized as twelve segments and three backplanes. The COP472-3 requires 40 information bits: 36 data and 4 control. The function of each control bit is described below. Display information format is a function of the LCD interconnections. A typical segment/backplane configuration is illustrated in *Figure 5*, with this configuration the COP472-3 will drive 4 digits of 9 segments.

To adapt the COP472-3 to any LCD display configuration, the segment/backplane multiplex scheme is illustrated in Table I.

Two or more COP472-3 chips can be cascaded to drive additional segments. There is no limit to the number of COP472-3's that can be used as long as the output loading capacitance does not exceed specification.

TABLE I. COP472-3 Segment/Backplane Multiplex Scheme

Bit Number	Segment, Backplane	Data to Numeric Display	
1	SA1, BPC	SH	
2	SB1, BPB	SG	
3	SC1, BPA	SF	
4	SC1, BPB	SE	Digit 1
5	SB1, BPC	SD	
6	SA1, BPB	SC	
7	SA1, BPA	SB	
8	SB1, BPA	SA	
9	SA2, BPC	SH	
10	SB2, BPB	SG	
11	SC2, BPA	SF	
12	SC2, BPB	SE	Digit 2
13	SB2, BPC	SD	
14	SA2, BPB	SC	
15	SA2, BPA	SB	
16	SB2, BPA	SA	
17	SA3, BPC	SH	
18	SB3, BPB	SG	
19	SC3, BPA	SF	
20	SC3, BPB	SE	Digit 3
21	SB3, BPC	SD	
22	SA3, BPB	SC	
23	SA3, BPA	SB	
24	SB3, BPA	SA	
25	SA4, BPC	SH	
26	SB4, BPB	SG	
27	SC4, BPA	SF	
28	SC4, BPB	SE	Digit 4
29	SB4, BPC	SD	
30	SA4, BPB	SC	
31	SA4, BPA	SB	
32	SB4, BPA	SA	
33	SC1, BPC	SPA	Digit 1
34	SC2, BPC	SP2	Digit 2
35	SC3, BPC	SP3	Digit 3
36	SC4, BPC	SP4	Digit 4
37	not used		
38	Q6		
39	Q7		
40	SYNC		

SEGMENT DATA BITS

Data is loaded in serially, in sets of eight bits. Each set of segment data is in the following format:

SA	SB	SC	SD	SE	SF	SG	SH

Data is shifted into an eight bit shift register. The first bit of the data is for segment H, digit 1. The eighth bit is segment A, digit 1. A set of eight bits is shifted in and then loaded into the digit one latches. The second set of 8 bits is loaded into digit two latches. The third set into digit three latches, and the fourth set is loaded into digit four latches.

CONTROL BITS

The fifth set of 8 data bits contains special segment data and control data in the following format:

SYNC	Q7	Q6	X	SP4	SP3	SP2	SP1

The first four bits shifted in contain the special character segment data. The fifth bit is not used. The sixth and seventh bits program the COP472-3 as a stand alone LCD driver or as a master or slave for cascading COP472-3's. BPC of the master is connected to BPA of each slave. The following table summarizes the function of bits six and seven:

Q7	Q6	Function	BPC Output	BPA Output
1	1	Slave	Backplane Output	Oscillator Input
0	1	Stand Alone	Backplane Output	Backplane Output
1	0	Not Used	Internal Osc. Output	Oscillator Input
0	0	Master	Internal Osc. Output	Backplane Output

The eighth bit is used to synchronize two COP472-3's to drive an 8½-digit display.

LOADING SEQUENCE TO DRIVE A 4½-DIGIT DISPLAY

Steps:

1. Turn $\overline{CE}$ low.
2. Clock in 8 bits of data for digit 1.
3. Clock in 8 bits of data for digit 2.
4. Clock in 8 bits of data for digit 3.
5. Clock in 8 bits of data for digit 4.
6. Clock in 8 bits of data for special segment and control function of BPC and BPA.

0	0	1	1	SP4	SP3	SP2	SP1

7. Turn $\overline{CS}$ high.

Note: $\overline{CS}$ may be turned high after any step. For example to load only 2 digits of data, do steps 1, 2, 3, and 7.

$\overline{CS}$ must make a high to low transition before loading data in order to reset internal counters.

LOADING SEQUENCE TO DRIVE AN 8½-DIGIT DISPLAY

Two or more COP472-3's may be connected together to drive additional segments. An eight digit multiplexed display is shown in *Figure 7*. The following is the loading sequence to drive an eight digit display using two COP472-3's. The right chip is the master and the left the slave.

Steps:

1. Turn $\overline{CS}$ low on both COP472-3's.
2. Shift in 32 bits of data for the slave's four digits.
3. Shift in 4 bits of special segment data: a zero and three ones.

1	1	1	0	SP4	SP3	SP2	SP1

   This synchronizes both the chips and BPA is oscillator input. Both chips are now stopped.

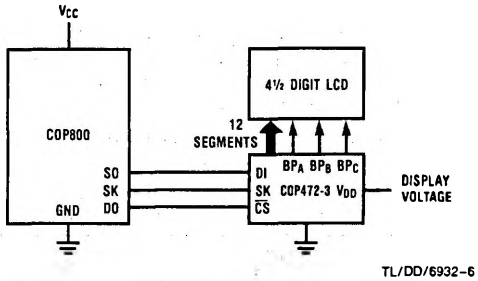
4. Turn CS high to both chips.
5. Turn CS low to master COP472-3.
6. Shift in 32 bits of data for the master's 4 digits.
7. Shift in four bits of special segment data, a one and three zeros.

0	0	0	1	SP4	SP3	SP2	SP1

   This sets the master COP472-3 to BPA as a normal backplane output and BPC as oscillator output. Now both the chips start and run off the same oscillator.

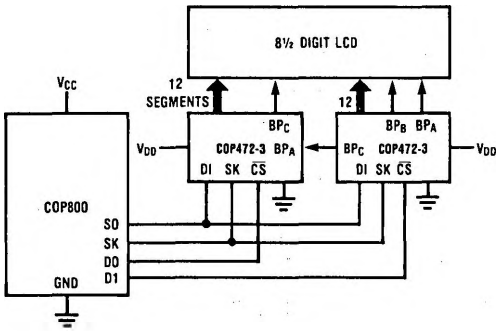
8. Turn $\overline{CS}$ high.

The chips are now synchronized and driving 8 digits of display. To load new data simply load each chip separately in the normal manner, keeping the correct status bits to each COP472-3 (0110 or 0001).



TL/DD/6932–6

FIGURE 6. System Diagram – 4½ Digit Display



TL/DD/6932–7

FIGURE 7. System Diagram – 8½ Digit Display