

DATA SHEET

89C51/89C52/89C54/89C58
80C51 8-bit microcontroller family
4K/8K/16K/32K Flash

Product data
Supersedes data of 1999 Oct 27
IC28 Data Handbook

2002 Jan 15

80C51 8-bit microcontroller family 4K/8K/16K/32K Flash

89C51/89C52/89C54/89C58

DESCRIPTION

The 89C51/89C52/89C54/89C58 contain a non-volatile FLASH program memory that is parallel programmable. For devices that are serial programmable (In-System Programmable (ISP) and In-Application Programmable (IAP) with a boot loader), see the 89C51Rx2 or 89C66x datasheets.

All three families are Single-Chip 8-bit Microcontrollers manufactured in advanced CMOS process and are derivatives of the 80C51 microcontroller family. All the devices have the same instruction set as the 80C51.

SELECTION TABLE FOR FLASH DEVICES

	MTP devices (this data sheet)		ISP/IAP devices (see separate data sheets)	
	89C51	89C52/54/58	89C51Rx2	89C66x
ROM/EPROM memory size	4K	8K/16K/32K	16K–64K	16K–64K
RAM size (byte)	128	256	512–1K	512–8K
Parallel programming	yes	yes	yes	yes
In-System Programming (ISP)	no	no	yes	yes
In-Application Programming (IAP)	no	no	yes	yes
PWM	no	no	yes	yes
Programmable Timer/Counter (PCA)	no	no	yes	yes
Hardware Watchdog Timer	no	no	yes	yes
Serial Channels	UART	UART	UART	UART + I ² C

MTP = Multi-Time Programming (via parallel programmer)

ISP = In-System Programming (via serial interface)

IAP = In-Application Programming

Please note that the FLASH programming algorithm for these parts has been modified. Please see the Device Comparison table for details.

DEVICE COMPARISON TABLE

Item	Old devices	New devices	Reason for change
Type description	P89C5xUBxx / P89C5xUFxx	P89C5xBx	Letter U dropped for shorter type descriptions (formerly designated speed (0–33 MHz))
Programming algorithm	When using parallel programmer, be sure to select P89C5xUxxx devices	When using a parallel programmer, be sure to select P89C5xBx devices (no more letter U). IF DEVICES ARE NOT YET SELECTABLE, ASK YOUR VENDOR FOR A SOFTWARE UPDATE.	Programming algorithm modification required by process change!
Quad Flat Package type	PQFP package (P89C5xUxBB)	PQFP package replaced by LQFP package (P89C5xBBD). SEE NEW DIMENSIONS AT THE END OF THIS DATA SHEET.	Reduction in package height
Package identifiers	PLCC = AA PQFP = BB PDIP = PN	PLCC = A LQFP = BD PDIP = P	Shorter type descriptions
Flash memory program and erase cycles	100 program and erase cycles	10,000 program and erase cycles	Process change allows more program and erase cycles
Power consumption	Active mode: $I_{CC(MAX)} = (0.9 \times \text{FREQ.} + 20)\text{mA}$ Idle mode: $I_{CC(MAX)} = (0.37 \times \text{FREQ.} + 1.0)\text{mA}$	Active mode: $I_{CC(MAX)} = (0.55 \times \text{FREQ.} + 8.0)\text{mA}$ Idle mode: $I_{CC(MAX)} = (0.3 \times \text{FREQ.} + 2.0)\text{mA}$	Process change allows lower power consumption

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FEATURES

- 80C51 Central Processing Unit
- On-chip FLASH Program Memory
- Speed up to 33 MHz
- Fully static operation
- RAM expandable externally up to 64 kbytes
- 4 interrupt priority levels
- 6 interrupt sources
- Four 8-bit I/O ports
- Full-duplex enhanced UART
 - Framing error detection
 - Automatic address recognition
- Three 16-bit timers/counters T0, T1 (standard 80C51) and additional T2 (capture and compare)
- Power control modes
 - Clock can be stopped and resumed
 - Idle mode
 - Power down mode
- Programmable clock out
- Second DPTR register
- Asynchronous port reset
- Low EMI (inhibit ALE)
- Wake up from power down by an external interrupt

ORDERING INFORMATION

Type number				Package			Temperature Range ³ (°C)	Voltage Range (V)	Frequency (MHz)
4K Flash version	8K Flash version	16K Flash version	32K Flash version	Name	Description	Version			
P89C51BA	P89C52BA	P89C54BA	P89C58BA	PLCC44	plastic leaded chip carrier; 44 leads	SOT187-2	0 to +70	5	0 to 33
P89C51BP ¹ P89C51BN ²	P89C52BP ¹ P89C52BN ²	P89C54BP ¹ P89C54BN ²	P89C58BP ¹ P89C58BN ²	DIP40	plastic dual in-line package; 40 leads	SOT129-1	0 to +70	5	0 to 33
P89C51BBD	P89C52BBD	P89C54BBD	P89C58BBD	LQFP44	plastic low profile quad flat package; 44 leads; body 10 x 10 x 1.4 mm	SOT389-1	0 to +70	5	0 to 33

NOTES:

1. Philips (except North America) Part Order Number
2. Philips North America Part Order Number. Note that parts will be marked "P89C5xBP", respectively (x = 1, 2, 4, 8)
3. Industrial temperatures will be released with P89C5x2 devices (see separate data sheet)

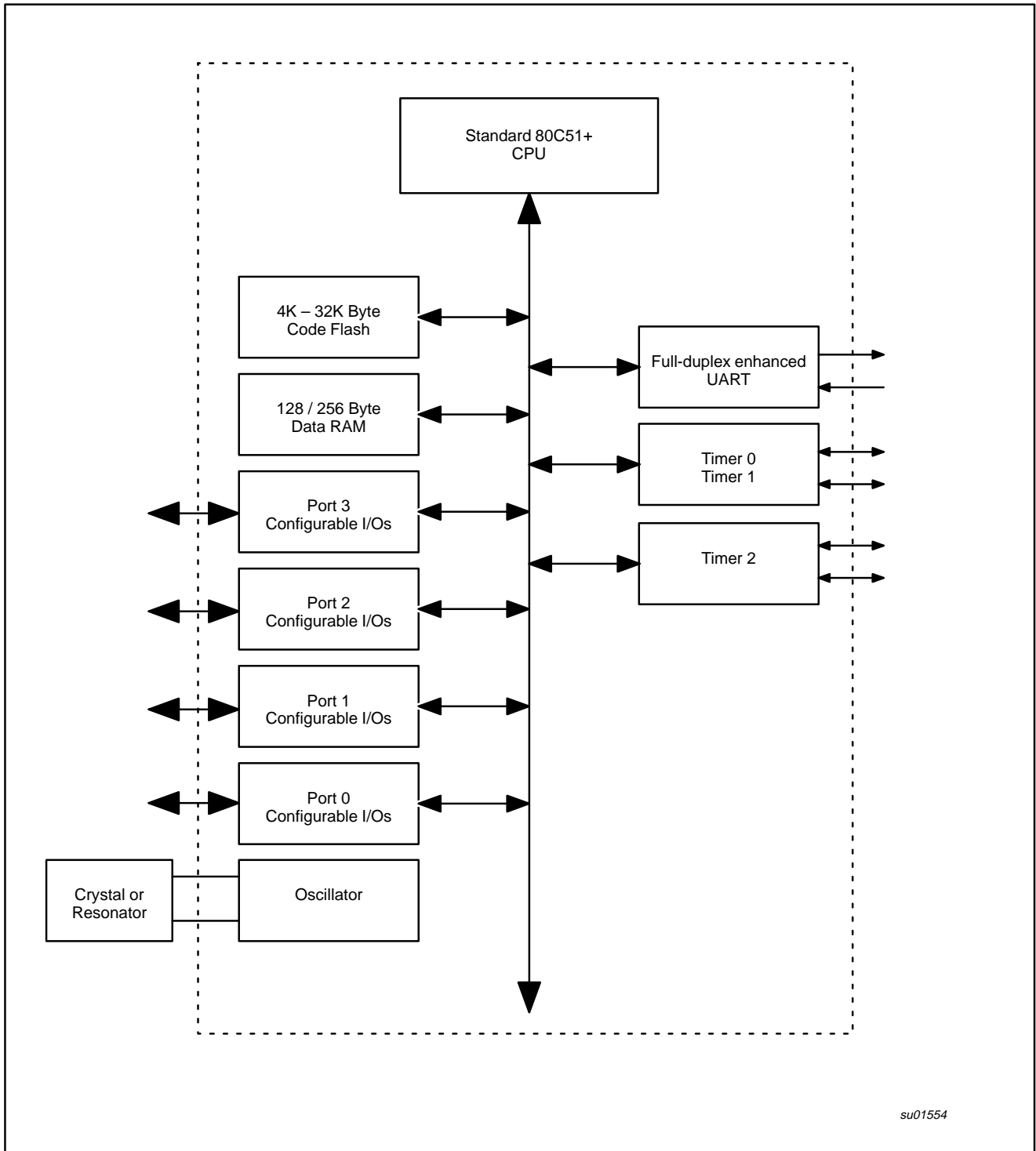
PART NUMBER DERIVATION

Device number (P89C5x)	Temperature range	Package
P89C51 P89C52 P89C54 P89C58	B = 0 °C to 70 °C	BD = LQFP A = PLCC P = PDIP

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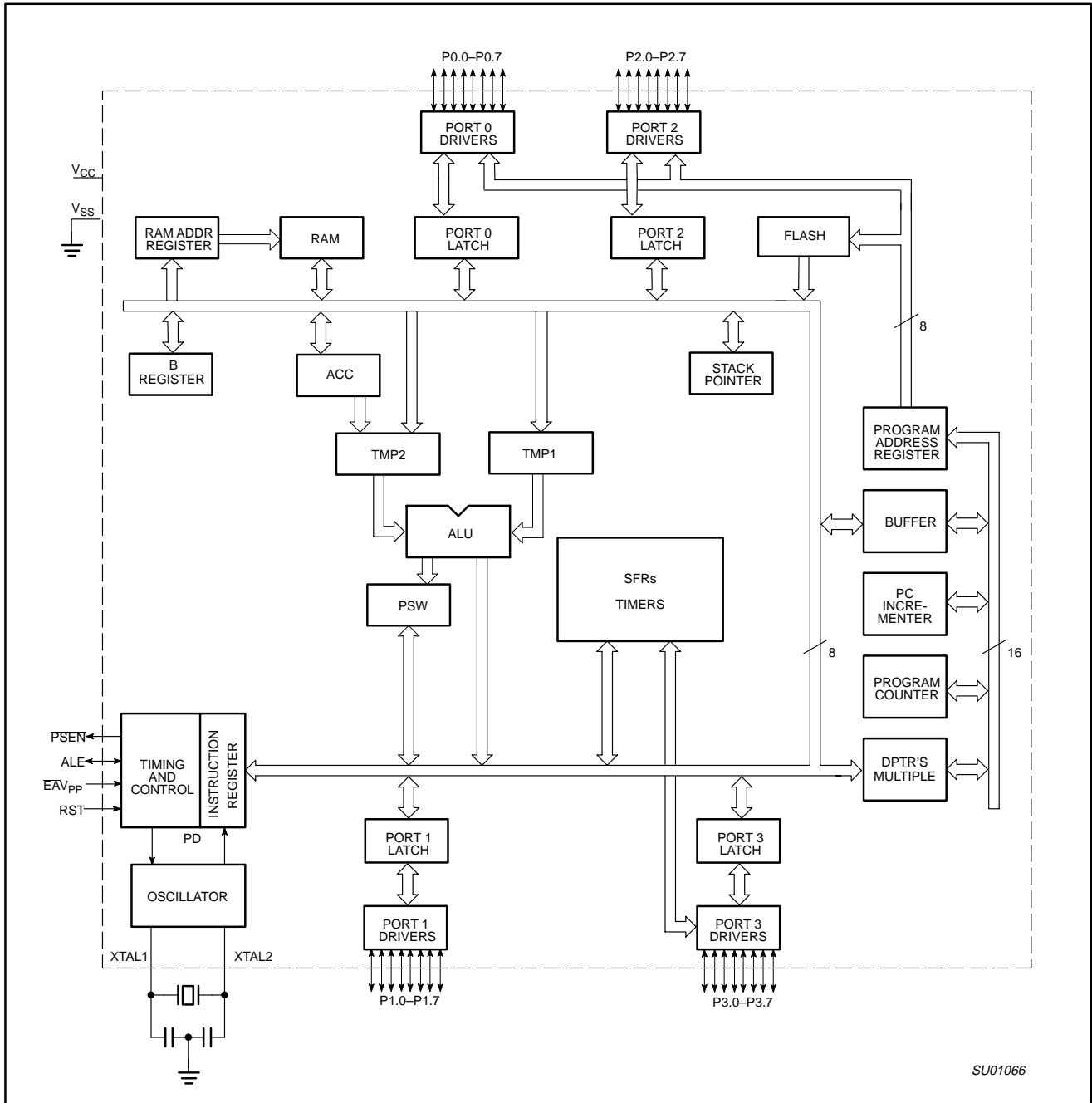
BLOCK DIAGRAM 1



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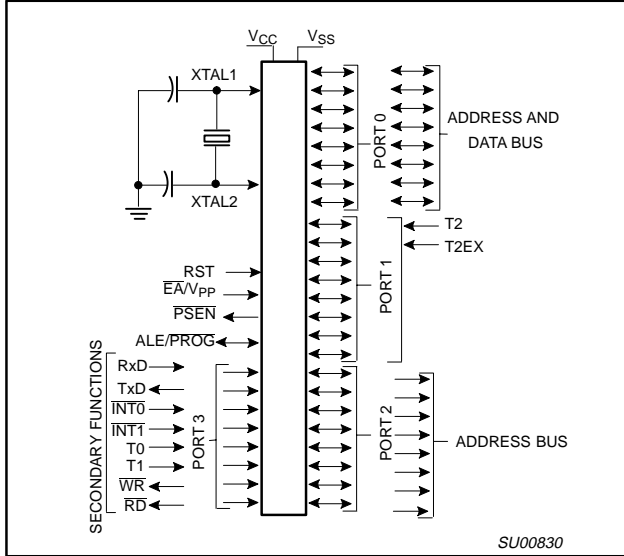
BLOCK DIAGRAM 2 (CPU ORIENTED)



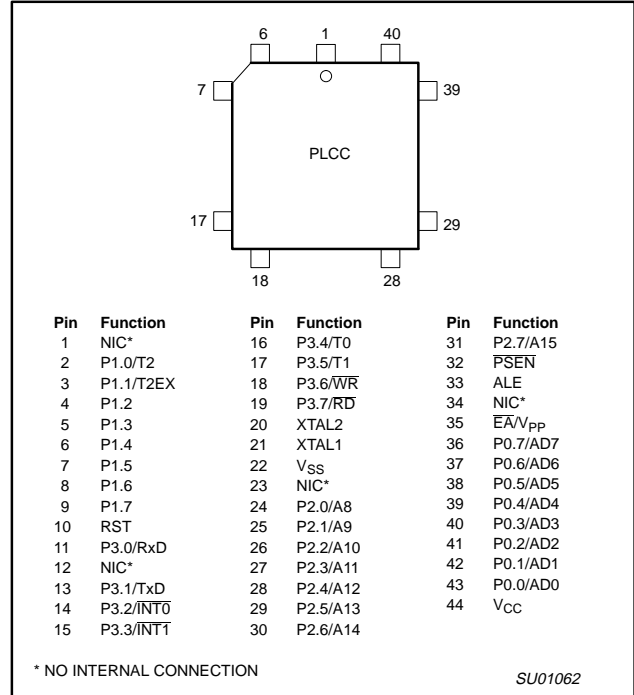
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LOGIC SYMBOL

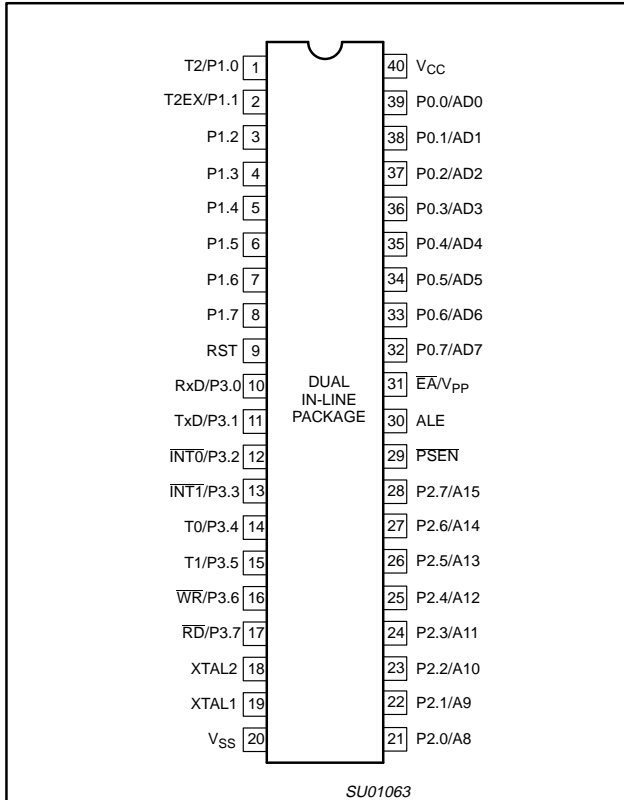


Ceramic and Plastic Leaded Chip Carrier Pin Functions

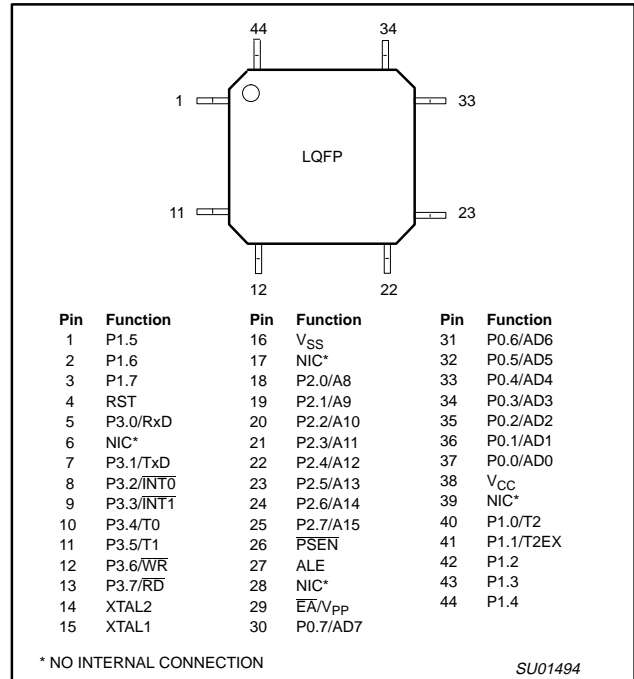


PIN CONFIGURATIONS

Dual In-Line Package Pin Functions



Low Profile Quad Flat Pack Pin Functions



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PIN DESCRIPTIONS

MNEMONIC	PIN NUMBER			TYPE	NAME AND FUNCTION
	DIP	LCC	QFP		
V _{SS}	20	22	16	I	Ground: 0 V reference.
V _{CC}	40	44	38	I	Power Supply: This is the power supply voltage for normal, idle, and power-down operation.
P0.0–0.7	39–32	43–36	37–30	I/O	Port 0: Port 0 is an open-drain, bidirectional I/O port. Port 0 pins that have 1s written to them float and can be used as high-impedance inputs. Port 0 is also the multiplexed low-order address and data bus during accesses to external program and data memory. In this application, it uses strong internal pull-ups when emitting 1s.
P1.0–P1.7	1–8	2–9	40–44, 1–3	I/O	Port 1: Port 1 is an 8-bit bidirectional I/O port with internal pull-ups. Port 1 pins that have 1s written to them are pulled high by the internal pull-ups and can be used as inputs. As inputs, port 1 pins that are externally pulled low will source current because of the internal pull-ups. (See DC Electrical Characteristics: I _{IL}). Alternate function for Port 1:
	1	2	40	I/O	T2 (P1.0): Timer/Counter2 external count input/clockout (see Programmable Clock-Out).
	2	3	41	I	T2EX (P1.1): Timer/Counter2 reload/capture/direction control.
P2.0–P2.7	21–28	24–31	18–25	I/O	Port 2: Port 2 is an 8-bit bidirectional I/O port with internal pull-ups. Port 2 pins that have 1s written to them are pulled high by the internal pull-ups and can be used as inputs. As inputs, port 2 pins that are externally being pulled low will source current because of the internal pull-ups. (See DC Electrical Characteristics: I _{IL}). Port 2 emits the high-order address byte during fetches from external program memory and during accesses to external data memory that use 16-bit addresses (MOVX @DPTR). In this application, it uses strong internal pull-ups when emitting 1s. During accesses to external data memory that use 8-bit addresses (MOV @Ri), port 2 emits the contents of the P2 special function register.
P3.0–P3.7	10–17	11, 13–19	5, 7–13	I/O	Port 3: Port 3 is an 8-bit bidirectional I/O port with internal pull-ups. Port 3 pins that have 1s written to them are pulled high by the internal pull-ups and can be used as inputs. As inputs, port 3 pins that are externally being pulled low will source current because of the pull-ups. (See DC Electrical Characteristics: I _{IL}). Port 3 also serves the special features of the 89C51/89C52/89C54/89C58, as listed below:
	10	11	5	I	RxD (P3.0): Serial input port
	11	13	7	O	TxD (P3.1): Serial output port
	12	14	8	I	INT0 (P3.2): External interrupt
	13	15	9	I	INT1 (P3.3): External interrupt
	14	16	10	I	T0 (P3.4): Timer 0 external input
	15	17	11	I	T1 (P3.5): Timer 1 external input
	16	18	12	O	WR (P3.6): External data memory write strobe
	17	19	13	O	RD (P3.7): External data memory read strobe
	RST	9	10	4	I
ALE	30	33	27	O	Address Latch Enable: Output pulse for latching the low byte of the address during an access to external memory. In normal operation, ALE is emitted at a constant rate of 1/6 the oscillator frequency, and can be used for external timing or clocking. Note that one ALE pulse is skipped during each access to external data memory. ALE can be disabled by setting SFR auxiliary.0. With this bit set, ALE will be active only during a MOVX instruction.
PSEN	29	32	26	O	Program Store Enable: The read strobe to external program memory. When executing code from the external program memory, PSEN is activated twice each machine cycle, except that two PSEN activations are skipped during each access to external data memory. PSEN is not activated during fetches from internal program memory.
E _A /V _{PP}	31	35	29	I	External Access Enable/Programming Supply Voltage: E _A must be externally held low to enable the device to fetch code from external program memory locations 0000H to the maximum internal memory boundary. If E _A is held high, the device executes from internal program memory unless the program counter contains an address greater than 0FFFH for 4 k devices, 1FFFFH for 8 k devices, 3FFFFH for 16 k devices, and 7FFFFH for 32 k devices. The value on the E _A pin is latched when RST is released and any subsequent changes have no effect. This pin also receives the 5V/12V (±10%) programming supply voltage (V _{PP}) during FLASH programming.
XTAL1	19	21	15	I	Crystal 1: Input to the inverting oscillator amplifier and input to the internal clock generator circuits.
XTAL2	18	20	14	O	Crystal 2: Output from the inverting oscillator amplifier.

NOTE: To avoid "latch-up" effect at power-on, the voltage on any pin (other than V_{PP}) at any time must not be higher than V_{CC} + 0.5 V or V_{SS} – 0.5 V, respectively.

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Table 1. 89C51/89C52/89C54/89C58 Special Function Registers

SYMBOL	DESCRIPTION	DIRECT ADDRESS	BIT ADDRESS, SYMBOL, OR ALTERNATIVE PORT FUNCTION								RESET VALUE
			MSB				LSB				
ACC*	Accumulator	E0H	E7	E6	E5	E4	E3	E2	E1	E0	00H
AUXR#	Auxiliary	8EH	-	-	-	-	-	-	-	AO	xxxxxxx0B
AUXR1#	Auxiliary 1	A2H	-	-	-	-	GF2	0	-	DPS	xxxx00x0B
B*	B register	F0H	F7	F6	F5	F4	F3	F2	F1	F0	00H
DPTR:	Data Pointer (2 bytes)										
DPH	Data Pointer High	83H									00H
DPL	Data Pointer Low	82H									00H
			AF	AE	AD	AC	AB	AA	A9	A8	
IE*	Interrupt Enable	A8H	EA	-	ET2	ES	ET1	EX1	ET0	EX0	0x000000B
			BF	BE	BD	BC	BB	BA	B9	B8	
IP*	Interrupt Priority	B8H	-	-	PT2	PS	PT1	PX1	PT0	PX0	xx000000B
			B7	B6	B5	B4	B3	B2	B1	B0	
IPH#	Interrupt Priority High	B7H	-	-	PT2H	PSH	PT1H	PX1H	PT0H	PX0H	xx000000B
			87	86	85	84	83	82	81	80	
P0*	Port 0	80H	AD7	AD6	AD5	AD4	AD3	AD2	AD1	AD0	FFH
			97	96	95	94	93	92	91	90	
P1*	Port 1	90H	-	-	-	-	-	-	T2EX	T2	FFH
			A7	A6	A5	A4	A3	A2	A1	A0	
P2*	Port 2	A0H	AD15	AD14	AD13	AD12	AD11	AD10	AD9	AD8	FFH
			B7	B6	B5	B4	B3	B2	B1	B0	
P3*	Port 3	B0H	RD	WR	T1	T0	INT1	INT0	TxD	RxD	FFH
PCON# ¹	Power Control	87H	SMOD1	SMOD0	-	POF ²	GF1	GF0	PD	IDL	00xxx000B
			D7	D6	D5	D4	D3	D2	D1	D0	
PSW*	Program Status Word	D0H	CY	AC	F0	RS1	RS0	OV	-	P	000000x0B
RACAP2H#	Timer 2 Capture High	CBH									00H
RACAP2L#	Timer 2 Capture Low	CAH									00H
SADDR#	Slave Address	A9H									00H
SADEN#	Slave Address Mask	B9H									00H
SBUF	Serial Data Buffer	99H									xxxxxxxxxB
			9F	9E	9D	9C	9B	9A	99	98	
SCON*	Serial Control	98H	SM0/FE	SM1	SM2	REN	TB8	RB8	TI	RI	00H
SP	Stack Pointer	81H									07H
			8F	8E	8D	8C	8B	8A	89	88	
TCON*	Timer Control	88H	TF1	TR1	TF0	TR0	IE1	IT1	IE0	IT0	00H
			CF	CE	CD	CC	CB	CA	C9	C8	
T2CON*	Timer 2 Control	C8H	TF2	EXF2	RCLK	TCLK	EXEN2	TR2	C/T2	CP/RL2	00H
T2MOD#	Timer 2 Mode Control	C9H	-	-	-	-	-	-	T2OE	DCEN	xxxxxxx00B
TH0	Timer High 0	8CH									00H
TH1	Timer High 1	8DH									00H
TH2#	Timer High 2	CDH									00H
TL0	Timer Low 0	8AH									00H
TL1	Timer Low 1	8BH									00H
TL2#	Timer Low 2	CCH									00H
TMOD	Timer Mode	89H	GATE	C/T	M1	M0	GATE	C/T	M1	M0	00H

* SFRs are bit addressable.
SFRs are modified from or added to the 80C51 SFRs.
- Reserved bits.
1. Reset value depends on reset source.
2. Bit will not be affected by reset.

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89C51/89C52/89C54/89C58**FLASH EPROM MEMORY****General Description**

The 89C51/89C52/89C54/89C58 FLASH reliably stores memory contents even after 10,000 erase and program cycles. The cell is designed to optimize the erase and programming mechanisms. In addition, the combination of advanced tunnel oxide processing and low internal electric fields for erase and programming operations produces reliable cycling.

Features

- FLASH EPROM internal program memory with Chip Erase
- Up to 64 k byte external program memory if the internal program memory is disabled ($\overline{EA} = 0$)
- Programmable security bits
- 10,000 minimum erase/program cycles for each byte
- 10 year minimum data retention
- Programming support available from many popular vendors

OSCILLATOR CHARACTERISTICS

XTAL1 and XTAL2 are the input and output, respectively, of an inverting amplifier. The pins can be configured for use as an on-chip oscillator.

To drive the device from an external clock source, XTAL1 should be driven while XTAL2 is left unconnected. There are no requirements on the duty cycle of the external clock signal, because the input to the internal clock circuitry is through a divide-by-two flip-flop. However, minimum and maximum high and low times specified in the data sheet must be observed.

RESET

A reset is accomplished by holding the RST pin high for at least two machine cycles (24 oscillator periods), while the oscillator is running. To insure a good power-on reset, the RST pin must be high long enough to allow the oscillator time to start up (normally a few milliseconds) plus two machine cycles. At power-on, the voltage on V_{CC} and RST must come up at the same time for a proper start-up. Ports 1, 2, and 3 will asynchronously be driven to their reset condition when a voltage above V_{IH1} (min.) is applied to RST.

The value on the \overline{EA} pin is latched when RST is deasserted and has no further effect.

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LOW POWER MODES

Stop Clock Mode

The static design enables the clock speed to be reduced down to 0 MHz (stopped). When the oscillator is stopped, the RAM and Special Function Registers retain their values. This mode allows step-by-step utilization and permits reduced system power consumption by lowering the clock frequency down to any value. For lowest power consumption the Power Down mode is suggested.

Idle Mode

In the idle mode (see Table 2), the CPU puts itself to sleep while all of the on-chip peripherals stay active. The instruction to invoke the idle mode is the last instruction executed in the normal operating mode before the idle mode is activated. The CPU contents, the on-chip RAM, and all of the special function registers remain intact during this mode. The idle mode can be terminated either by any enabled interrupt (at which time the process is picked up at the interrupt service routine and continued), or by a hardware reset which starts the processor in the same manner as a power-on reset.

Power-Down Mode

To save even more power, a Power Down mode (see Table 2) can be invoked by software. In this mode, the oscillator is stopped and the instruction that invoked Power Down is the last instruction executed. The on-chip RAM and Special Function Registers retain their values down to 2.0 V and care must be taken to return V_{CC} to the minimum specified operating voltages before the Power Down Mode is terminated.

Either a hardware reset or external interrupt can be used to exit from Power Down. Reset redefines all the SFRs but does not change the on-chip RAM. An external interrupt allows both the SFRs and the on-chip RAM to retain their values.

To properly terminate Power Down the reset or external interrupt should not be executed before V_{CC} is restored to its normal operating level and must be held active long enough for the oscillator to restart and stabilize (normally less than 10ms).

With an external interrupt, INT0 and INT1 must be enabled and configured as level-sensitive. Holding the pin low restarts the oscillator but bringing the pin back high completes the exit. Once the interrupt is serviced, the next instruction to be executed after RETI will be the one following the instruction that put the device into Power Down.

Design Consideration

When the idle mode is terminated by a hardware reset, the device normally resumes program execution, from where it left off, up to

two machine cycles before the internal reset algorithm takes control. On-chip hardware inhibits access to internal RAM in this event, but access to the port pins is not inhibited. To eliminate the possibility of an unexpected write when Idle is terminated by reset, the instruction following the one that invokes Idle should not be one that writes to a port pin or to external memory.

ONCE™ Mode

The ONCE ("On-Circuit Emulation") Mode facilitates testing and debugging of systems without the device having to be removed from the circuit. The ONCE Mode is invoked by:

1. Pull ALE low while the device is in reset and \overline{PSEN} is high;
2. Hold ALE low as RST is deactivated.

While the device is in ONCE Mode, the Port 0 pins go into a float state, and the other port pins and ALE and \overline{PSEN} are weakly pulled high. The oscillator circuit remains active. While the device is in this mode, an emulator or test CPU can be used to drive the circuit. Normal operation is restored when a normal reset is applied.

Programmable Clock-Out

A 50% duty cycle clock can be programmed to come out on P1.0. This pin, besides being a regular I/O pin, has two alternate functions. It can be programmed:

1. to input the external clock for Timer/Counter 2, or
2. to output a 50% duty cycle clock ranging from 61Hz to 4MHz at a 16MHz operating frequency.

To configure the Timer/Counter 2 as a clock generator, bit $C/\overline{T}2$ (in T2CON) must be cleared and bit T2OE in T2MOD must be set. Bit TR2 (T2CON.2) also must be set to start the timer.

The Clock-Out frequency depends on the oscillator frequency and the reload value of Timer 2 capture registers (RCAP2H, RCAP2L) as shown in this equation:

$$\frac{\text{Oscillator Frequency}}{4 \times (65536 - \text{RCAP2H, RCAP2L})}$$

Where (RCAP2H,RCAP2L) = the content of RCAP2H and RCAP2L taken as a 16-bit unsigned integer.

In the Clock-Out mode Timer 2 roll-overs will not generate an interrupt. This is similar to when it is used as a baud-rate generator. It is possible to use Timer 2 as a baud-rate generator and a clock generator simultaneously. Note, however, that the baud-rate and the Clock-Out frequency will be the same.

Table 2. External Pin Status During Idle and Power-Down Mode

MODE	PROGRAM MEMORY	ALE	\overline{PSEN}	PORT 0	PORT 1	PORT 2	PORT 3
Idle	Internal	1	1	Data	Data	Data	Data
Idle	External	1	1	Float	Data	Address	Data
Power-down	Internal	0	0	Data	Data	Data	Data
Power-down	External	0	0	Float	Data	Data	Data

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TIMER 0 AND TIMER 1 OPERATION

Timer 0 and Timer 1

The "Timer" or "Counter" function is selected by control bits C/T in the Special Function Register TMOD. These two Timer/Counters have four operating modes, which are selected by bit-pairs (M1, M0) in TMOD. Modes 0, 1, and 2 are the same for both Timers/Counters. Mode 3 is different. The four operating modes are described in the following text.

Mode 0

Putting either Timer into Mode 0 makes it look like an 8048 Timer, which is an 8-bit Counter with a divide-by-32 prescaler. Figure 2 shows the Mode 0 operation as it applies to Timer 1.

In this mode, the Timer register is configured as a 13-bit register. As the count rolls over from all 1s to all 0s, it sets the Timer interrupt flag TF1. The counted input is enabled to the Timer when TR1 = 1 and either GATE = 0 or INT1 = 1. (Setting GATE = 1 allows the Timer to be controlled by external input INT1, to facilitate pulse width measurements). TR1 is a control bit in the Special Function Register TCON (Figure 3). GATE is in TMOD.

The 13-bit register consists of all 8 bits of TH1 and the lower 5 bits of TL1. The upper 3 bits of TL1 are indeterminate and should be ignored. Setting the run flag (TR1) does not clear the registers.

Mode 0 operation is the same for the Timer 0 as for Timer 1. Substitute TR0, TF0, and INT0 for the corresponding Timer 1 signals in Figure 2. There are two different GATE bits, one for Timer 1 (TMOD.7) and one for Timer 0 (TMOD.3).

Mode 1

Mode 1 is the same as Mode 0, except that the Timer register is being run with all 16 bits.

Mode 2

Mode 2 configures the Timer register as an 8-bit Counter (TL1) with automatic reload, as shown in Figure 4. Overflow from TL1 not only sets TF1, but also reloads TL1 with the contents of TH1, which is preset by software. The reload leaves TH1 unchanged.

Mode 2 operation is the same for Timer/Counter 0.

Mode 3

Timer 1 in Mode 3 simply holds its count. The effect is the same as setting TR1 = 0.

Timer 0 in Mode 3 establishes TL0 and TH0 as two separate counters. The logic for Mode 3 on Timer 0 is shown in Figure 5. TL0 uses the Timer 0 control bits: C/T, GATE, TR0, and TF0, as well as the INT0 pin. TH0 is locked into a timer function (counting machine cycles) and takes over the use of TR1 and TF1 from Timer 1. Thus, TH0 now controls the "Timer 1" interrupt.

Mode 3 is provided for applications requiring an extra 8-bit timer on the counter. With Timer 0 in Mode 3, an 80C51 can look like it has three Timer/Counters. When Timer 0 is in Mode 3, Timer 1 can be turned on and off by switching it out of and into its own Mode 3, or can still be used by the serial port as a baud rate generator, or in fact, in any application not requiring an interrupt.

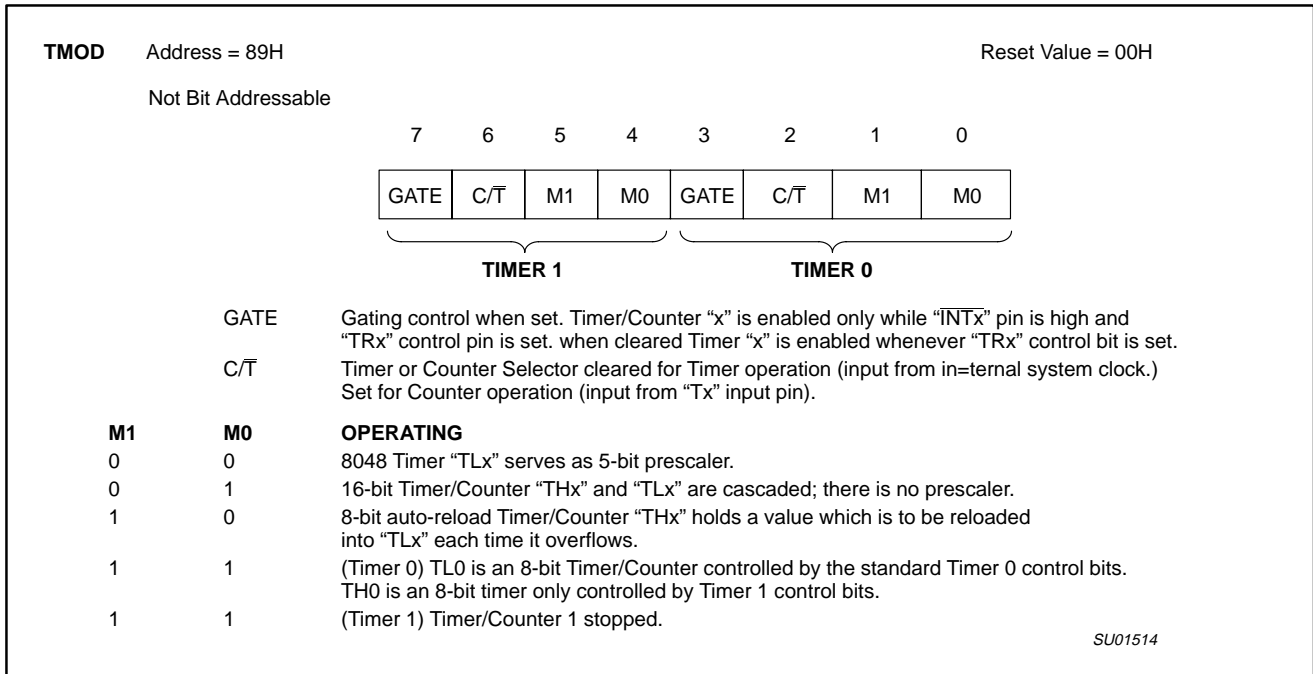


Figure 1. Timer/Counter 0/1 Mode Control (TMOD) Register

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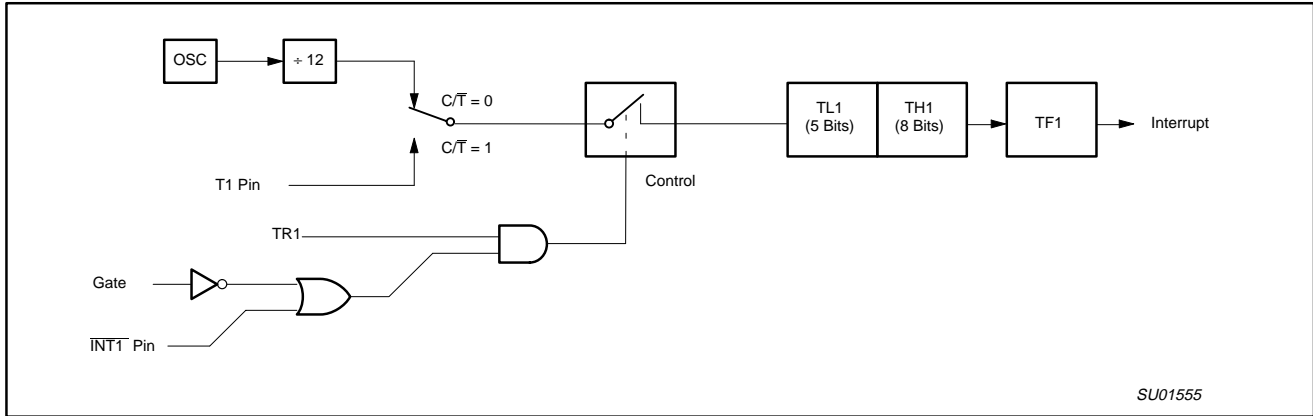


Figure 2. Timer/Counter 0/1 Mode 0: 13-Bit Counter (Timer 1 shown)

TCON Address = 88H Reset Value = 00H
Bit Addressable

	7	6	5	4	3	2	1	0
	TF1	TR1	TF0	TR0	IE1	IT1	IE0	IT0

BIT	SYMBOL	FUNCTION
TCON.7	TF1	Timer 1 overflow flag. Set by hardware on Timer/Counter overflow. Cleared by hardware when processor vectors to interrupt routine, or clearing the bit in software.
TCON.6	TR1	Timer 1 Run control bit. Set/cleared by software to turn Timer/Counter on/off.
TCON.5	TF0	Timer 0 overflow flag. Set by hardware on Timer/Counter overflow. Cleared by hardware when processor vectors to interrupt routine, or by clearing the bit in software.
TCON.4	TR0	Timer 0 Run control bit. Set/cleared by software to turn Timer/Counter on/off.
TCON.3	IE1	Interrupt 1 Edge flag. Set by hardware when external interrupt edge detected. Cleared when interrupt processed.
TCON.2	IT1	Interrupt 1 type control bit. Set/cleared by software to specify falling edge/low level triggered external interrupts.
TCON.1	IE0	Interrupt 0 Edge flag. Set by hardware when external interrupt edge detected. Cleared when interrupt processed.
TCON.0	IT0	Interrupt 0 Type control bit. Set/cleared by software to specify falling edge/low level triggered external interrupts.

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Figure 3. Timer/Counter 0/1 Control (TCON) Register

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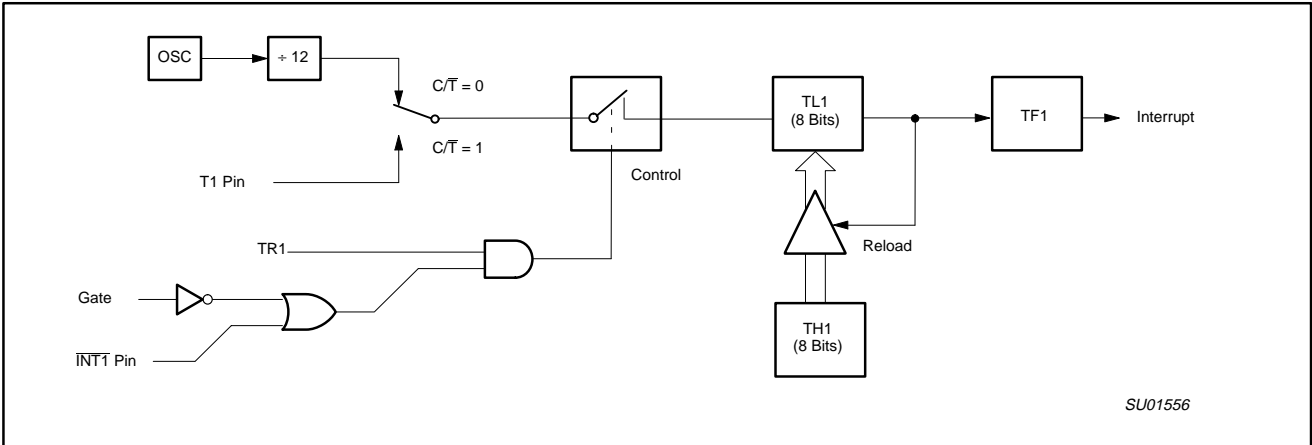


Figure 4. Timer/Counter 0/1 Mode 2: 8-Bit Auto-Load (Timer 1 shown)

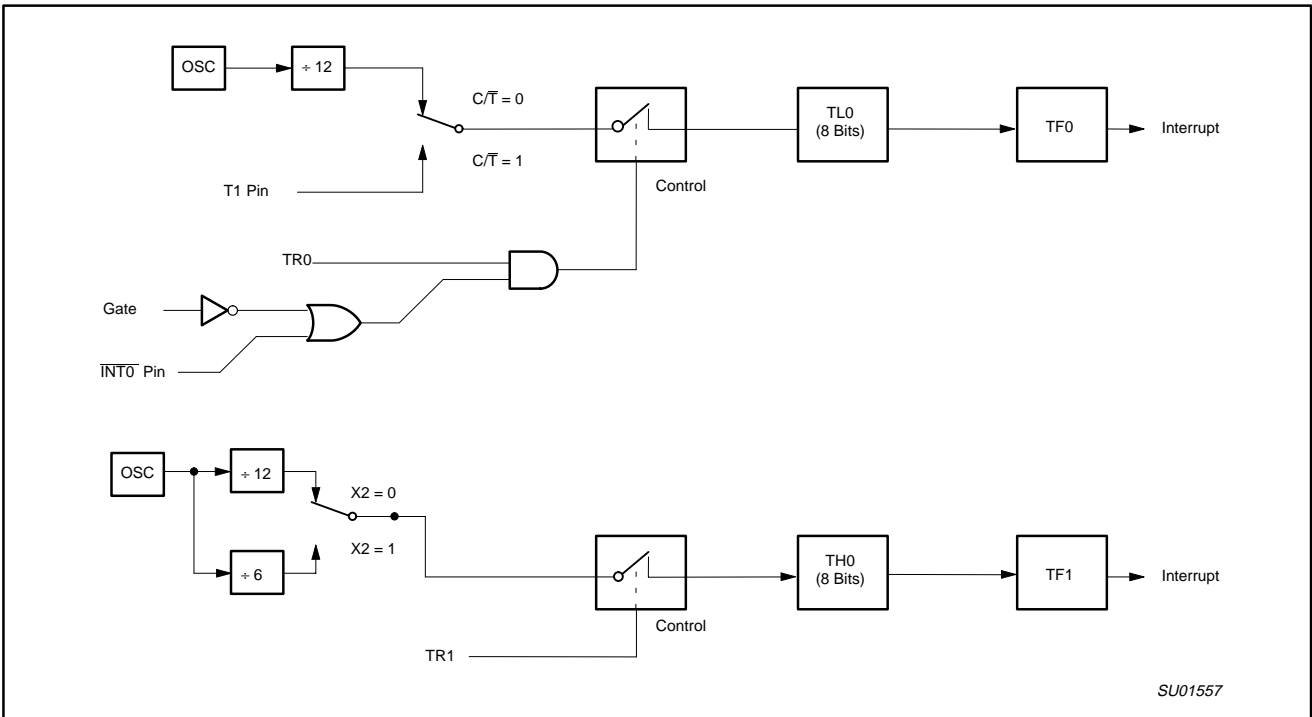


Figure 5. Timer/Counter 0 Mode 3: Two 8-Bit Counters

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TIMER 2 OPERATION

Timer 2

Timer 2 is a 16-bit Timer/Counter which can operate as either an event timer or an event counter, as selected by C/T2 in the special function register T2CON (see Figure 1). Timer 2 has three operating modes: Capture, Auto-reload (up or down counting), and Baud Rate Generator, which are selected by bits in the T2CON as shown in Table 3.

Capture Mode

In the capture mode there are two options which are selected by bit EXEN2 in T2CON. If EXEN2=0, then timer 2 is a 16-bit timer or counter (as selected by C/T2 in T2CON) which, upon overflowing sets bit TF2, the timer 2 overflow bit. This bit can be used to generate an interrupt (by enabling the Timer 2 interrupt bit in the IE register). If EXEN2= 1, Timer 2 operates as described above, but with the added feature that a 1- to -0 transition at external input T2EX causes the current value in the Timer 2 registers, TL2 and TH2, to be captured into registers RCAP2L and RCAP2H, respectively. In addition, the transition at T2EX causes bit EXF2 in T2CON to be set, and EXF2 like TF2 can generate an interrupt (which vectors to the same location as Timer 2 overflow interrupt). The Timer 2 interrupt service routine can interrogate TF2 and EXF2 to determine which event caused the interrupt). The capture mode is illustrated in Figure 2 (There is no reload value for TL2 and TH2 in this mode. Even when a capture event occurs from T2EX, the counter keeps on counting T2EX pin transitions or osc/12 pulses.).

Auto-Reload Mode (Up or Down Counter)

In the 16-bit auto-reload mode, Timer 2 can be configured (as either a timer or counter [C/T2 in T2CON]) then programmed to count up or down. The counting direction is determined by bit DCEN (Down Counter Enable) which is located in the T2MOD register (see

Figure 3). When reset is applied the DCEN=0 which means Timer 2 will default to counting up. If DCEN bit is set, Timer 2 can count up or down depending on the value of the T2EX pin.

Figure 4 shows Timer 2 which will count up automatically since DCEN=0. In this mode there are two options selected by bit EXEN2 in T2CON register. If EXEN2=0, then Timer 2 counts up to 0FFFFH and sets the TF2 (Overflow Flag) bit upon overflow. This causes the Timer 2 registers to be reloaded with the 16-bit value in RCAP2L and RCAP2H. The values in RCAP2L and RCAP2H are preset by software means.

If EXEN2=1, then a 16-bit reload can be triggered either by an overflow or by a 1-to-0 transition at input T2EX. This transition also sets the EXF2 bit. The Timer 2 interrupt, if enabled, can be generated when either TF2 or EXF2 are 1.

In Figure 5 DCEN=1 which enables Timer 2 to count up or down. This mode allows pin T2EX to control the direction of count. When a logic 1 is applied at pin T2EX Timer 2 will count up. Timer 2 will overflow at 0FFFFH and set the TF2 flag, which can then generate an interrupt, if the interrupt is enabled. This timer overflow also causes the 16-bit value in RCAP2L and RCAP2H to be reloaded into the timer registers TL2 and TH2.

When a logic 0 is applied at pin T2EX this causes Timer 2 to count down. The timer will underflow when TL2 and TH2 become equal to the value stored in RCAP2L and RCAP2H. Timer 2 underflow sets the TF2 flag and causes 0FFFFH to be reloaded into the timer registers TL2 and TH2.

The external flag EXF2 toggles when Timer 2 underflows or overflows. This EXF2 bit can be used as a 17th bit of resolution if needed. The EXF2 flag does not generate an interrupt in this mode of operation.

T2CON Address = C8H		Reset Value = 00H								
Bit Addressable										
		(MSB)	7	6	5	4	3	2	1	0 (LSB)
			TF2	EXF2	RCLK	TCLK	EXEN2	TR2	C/T2	CP/RL2
Symbol	Position	Name and Significance								
TF2	T2CON.7	Timer 2 overflow flag set by a Timer 2 overflow and must be cleared by software. TF2 will not be set when either RCLK or TCLK = 1.								
EXF2	T2CON.6	Timer 2 external flag set when either a capture or reload is caused by a negative transition on T2EX and EXEN2 = 1. When Timer 2 interrupt is enabled, EXF2 = 1 will cause the CPU to vector to the Timer 2 interrupt routine. EXF2 must be cleared by software. EXF2 does not cause an interrupt in up/down counter mode (DCEN = 1).								
RCLK	T2CON.5	Receive clock flag. When set, causes the serial port to use Timer 2 overflow pulses for its receive clock in modes 1 and 3. RCLK = 0 causes Timer 1 overflow to be used for the receive clock.								
TCLK	T2CON.4	Transmit clock flag. When set, causes the serial port to use Timer 2 overflow pulses for its transmit clock in modes 1 and 3. TCLK = 0 causes Timer 1 overflows to be used for the transmit clock.								
EXEN2	T2CON.3	Timer 2 external enable flag. When set, allows a capture or reload to occur as a result of a negative transition on T2EX if Timer 2 is not being used to clock the serial port. EXEN2 = 0 causes Timer 2 to ignore events at T2EX.								
TR2	T2CON.2	Start/stop control for Timer 2. A logic 1 starts the timer.								
C/T2	T2CON.1	Timer or counter select. (Timer 2) 0 = Internal timer (OSC/12) 1 = External event counter (falling edge triggered).								
CP/RL2	T2CON.0	Capture/Reload flag. When set, captures will occur on negative transitions at T2EX if EXEN2 = 1. When cleared, auto-reloads will occur either with Timer 2 overflows or negative transitions at T2EX when EXEN2 = 1. When either RCLK = 1 or TCLK = 1, this bit is ignored and the timer is forced to auto-reload on Timer 2 overflow.								

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Figure 1. Timer/Counter 2 (T2CON) Control Register

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Table 3. Timer 2 Operating Modes

RCLK + TCLK	CP/RL2	TR2	MODE
0	0	1	16-bit Auto-reload
0	1	1	16-bit Capture
1	X	1	Baud rate generator
X	X	0	(off)

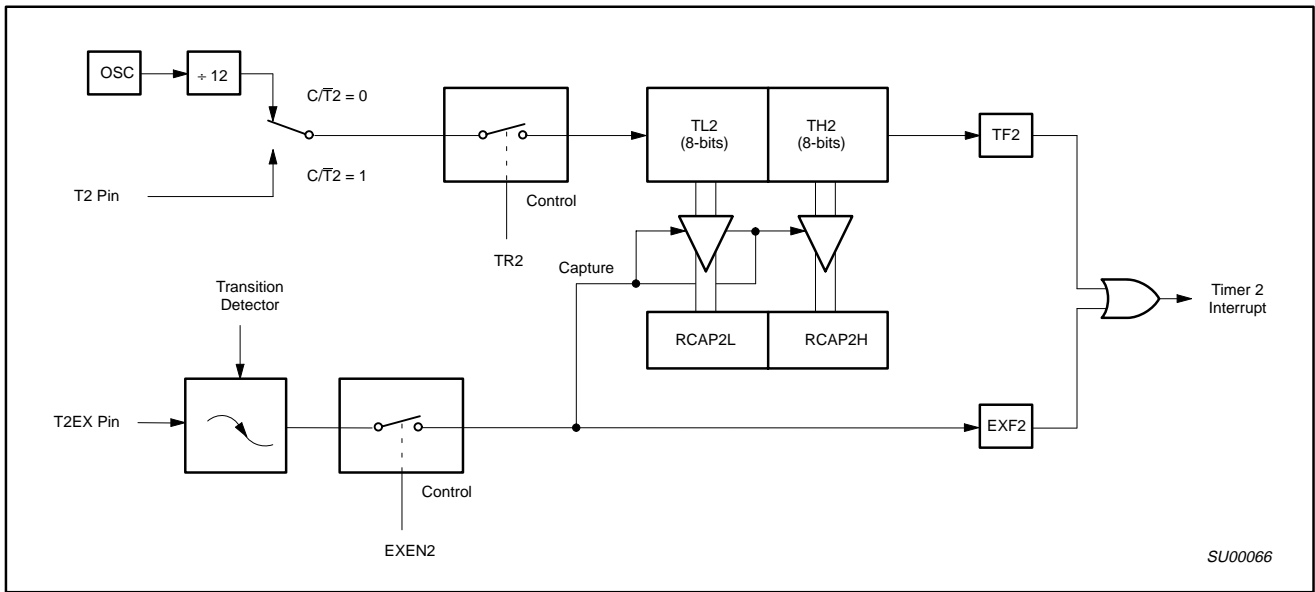


Figure 2. Timer 2 in Capture Mode

T2MOD	Address = 0C9H	Reset Value = XXXX XX00B						
	Not Bit Addressable							
	7	6	5	4	3	2	1	0
	—	—	—	—	—	—	T2OE	DCEN
Symbol	Function							
—	Not implemented, reserved for future use ¹ .							
T2OE	Timer 2 Output Enable bit.							
DCEN	Down Count Enable bit. When set, this allows Timer 2 to be configured as an up/down counter.							

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1. User software should not write 1s to reserved bits. These bits may be used in future 8051 family products to invoke new features. In that case, the reset or inactive value of the new bit will be 0, and its active value will be 1. The value read from a reserved bit is indeterminate.

Figure 3. Timer 2 Mode (T2MOD) Control Register

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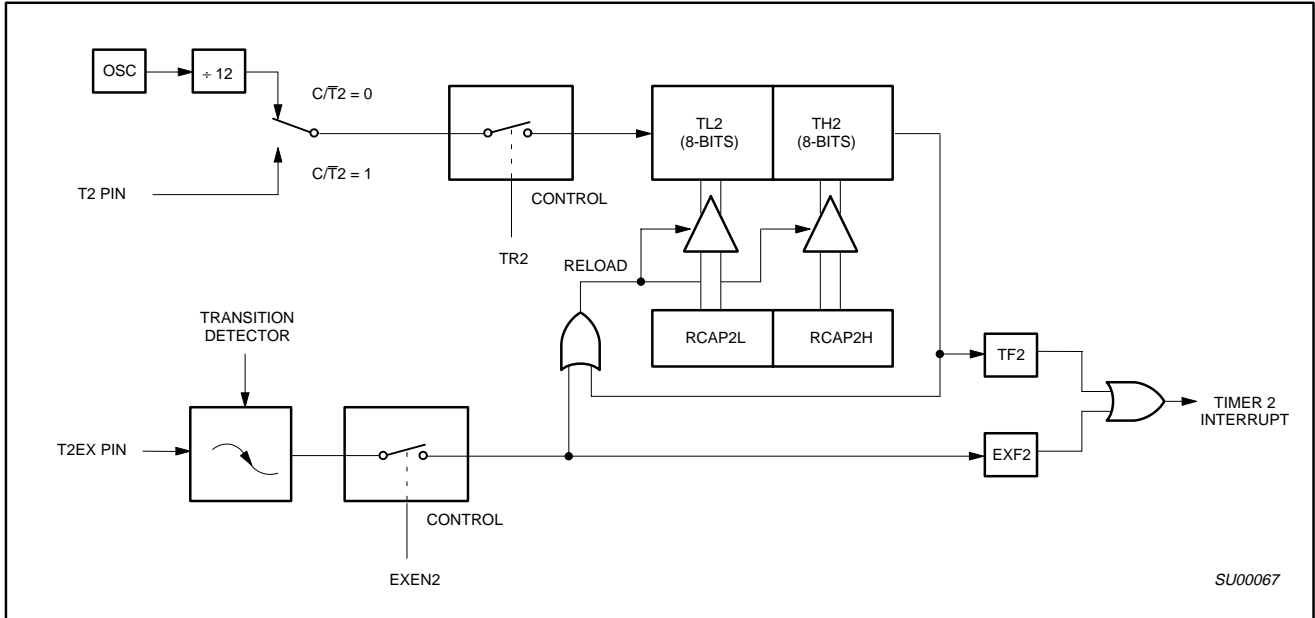


Figure 4. Timer 2 in Auto-Reload Mode (DCEN = 0)

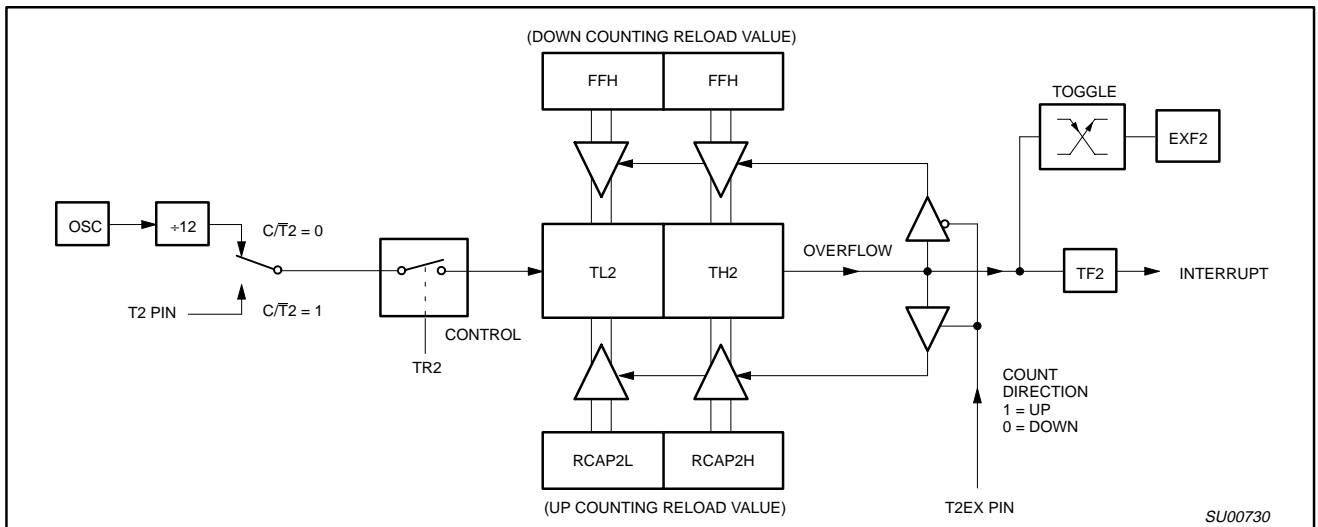


Figure 5. Timer 2 Auto Reload Mode (DCEN = 1)

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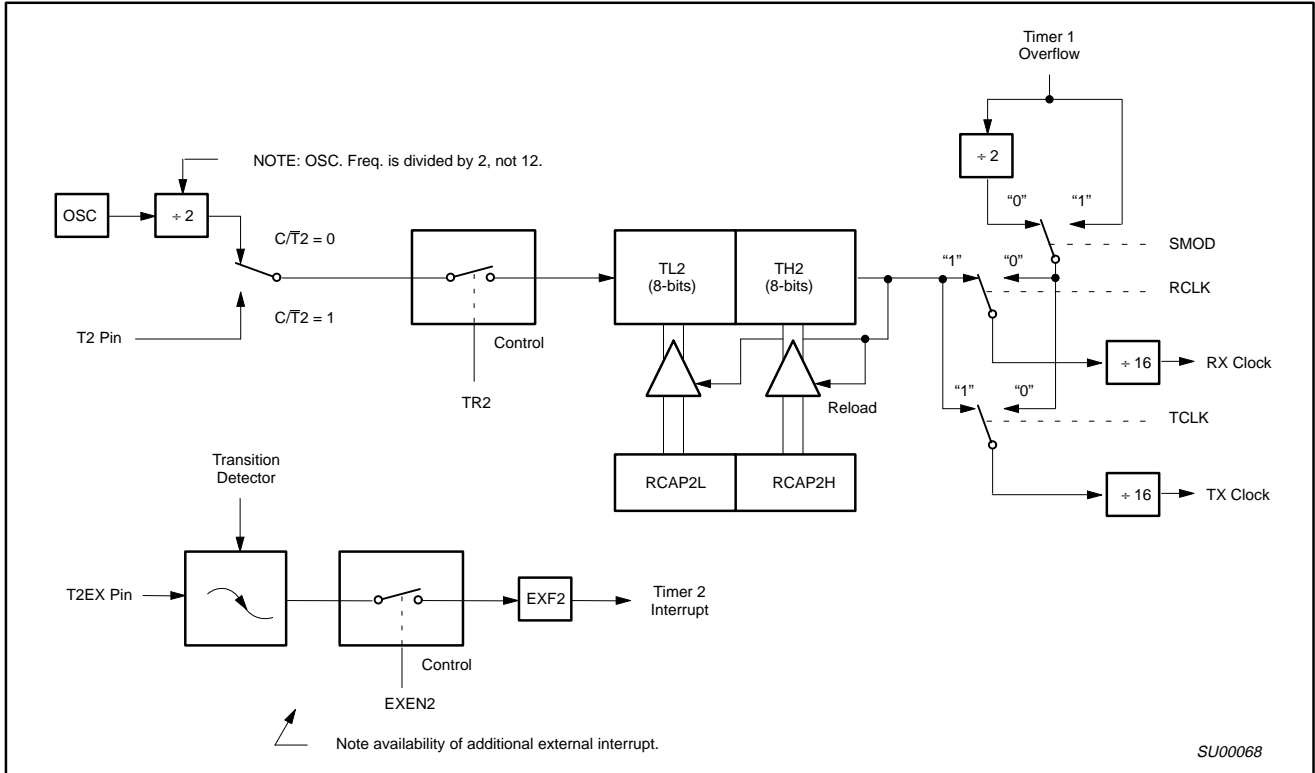


Figure 6. Timer 2 in Baud Rate Generator Mode

Table 4. Timer 2 Generated Commonly Used Baud Rates

Baud Rate	Osc Freq	Timer 2	
		RCAP2H	RCAP2L
375 k	12 MHz	FF	FF
9.6 k	12 MHz	FF	D9
2.8 k	12 MHz	FF	B2
2.4 k	12 MHz	FF	64
1.2 k	12 MHz	FE	C8
300	12 MHz	FB	1E
110	12 MHz	F2	AF
300	6 MHz	FD	8F
110	6 MHz	F9	57

Baud Rate Generator Mode

Bits TCLK and/or RCLK in T2CON (Table 4) allow the serial port transmit and receive baud rates to be derived from either Timer 1 or Timer 2. When TCLK= 0, Timer 1 is used as the serial port transmit baud rate generator. When TCLK= 1, Timer 2 is used as the serial port transmit baud rate generator. RCLK has the same effect for the serial port receive baud rate. With these two bits, the serial port can have different receive and transmit baud rates – one generated by Timer 1, the other by Timer 2.

Figure 6 shows the Timer 2 in baud rate generation mode. The baud rate generation mode is like the auto-reload mode, in that a rollover in TH2 causes the Timer 2 registers to be reloaded with the 16-bit value in registers RCAP2H and RCAP2L, which are preset by software.

The baud rates in modes 1 and 3 are determined by Timer 2's overflow rate given below:

$$\text{Modes 1 and 3 Baud Rates} = \frac{\text{Timer 2 Overflow Rate}}{16}$$

The timer can be configured for either "timer" or "counter" operation. In many applications, it is configured for "timer" operation (C/T2=0). Timer operation is different for Timer 2 when it is being used as a baud rate generator.

Usually, as a timer it would increment every machine cycle (i.e., 1/12 the oscillator frequency). As a baud rate generator, it increments every state time (i.e., 1/2 the oscillator frequency). Thus the baud rate formula is as follows:

$$\text{Modes 1 and 3 Baud Rates} = \frac{\text{Oscillator Frequency}}{[32 \times [65536 - (\text{RCAP2H}, \text{RCAP2L})]]}$$

Where: (RCAP2H, RCAP2L) = The content of RCAP2H and RCAP2L taken as a 16-bit unsigned integer.

The Timer 2 as a baud rate generator mode shown in Figure 6, is valid only if RCLK and/or TCLK = 1 in T2CON register. Note that a rollover in TH2 does not set TF2, and will not generate an interrupt. Thus, the Timer 2 interrupt does not have to be disabled when Timer 2 is in the baud rate generator mode. Also if the EXEN2 (T2 external enable flag) is set, a 1-to-0 transition in T2EX (Timer/counter 2 trigger input) will set EXF2 (T2 external flag) but will not cause a reload from (RCAP2H, RCAP2L) to (TH2, TL2). Therefore when Timer 2 is in use as a baud rate generator, T2EX can be used as an additional external interrupt, if needed.

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When Timer 2 is in the baud rate generator mode, one should not try to read or write TH2 and TL2. As a baud rate generator, Timer 2 is incremented every state time ($f_{osc}/2$) or asynchronously from pin T2; under these conditions, a read or write of TH2 or TL2 may not be accurate. The RCAP2 registers may be read, but should not be written to, because a write might overlap a reload and cause write and/or reload errors. The timer should be turned off (clear TR2) before accessing the Timer 2 or RCAP2 registers.

Table 4 shows commonly used baud rates and how they can be obtained from Timer 2.

Summary Of Baud Rate Equations

Timer 2 is in baud rate generating mode. If Timer 2 is being clocked through pin T2(P1.0) the baud rate is:

$$\text{Baud Rate} = \frac{\text{Timer 2 Overflow Rate}}{16}$$

If Timer 2 is being clocked internally, the baud rate is:

$$\text{Baud Rate} = \frac{f_{osc}}{[32 \times [65536 - (\text{RCAP2H}, \text{RCAP2L})]]}$$

Where f_{OSC} = Oscillator Frequency

To obtain the reload value for RCAP2H and RCAP2L, the above equation can be rewritten as:

$$\text{RCAP2H}, \text{RCAP2L} = 65536 - \left(\frac{f_{osc}}{32 \times \text{Baud Rate}} \right)$$

Timer/Counter 2 Set-up

Except for the baud rate generator mode, the values given for T2CON do not include the setting of the TR2 bit. Therefore, bit TR2 must be set, separately, to turn the timer on. see Table 5 for set-up of Timer 2 as a timer. Also see Table 6 for set-up of Timer 2 as a counter.

Table 5. Timer 2 as a Timer

MODE	T2CON	
	INTERNAL CONTROL (Note 1)	EXTERNAL CONTROL (Note 2)
16-bit Auto-Reload	00H	08H
16-bit Capture	01H	09H
Baud rate generator receive and transmit same baud rate	34H	36H
Receive only	24H	26H
Transmit only	14H	16H

Table 6. Timer 2 as a Counter

MODE	TMOD	
	INTERNAL CONTROL (Note 1)	EXTERNAL CONTROL (Note 2)
16-bit	02H	0AH
Auto-Reload	03H	0BH

NOTES:

1. Capture/reload occurs only on timer/counter overflow.
2. Capture/reload occurs on timer/counter overflow and a 1-to-0 transition on T2EX (P1.1) pin except when Timer 2 is used in the baud rate generator mode.

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Enhanced UART operation

In addition to the standard operation modes, the UART can perform framing error detect by looking for missing stop bits, and automatic address recognition. The UART also fully supports multiprocessor communication.

When used for framing error detect the UART looks for missing stop bits in the communication. A missing bit will set the FE bit in the SCON register. The FE bit shares the SCON.7 bit with SM0 and the function of SCON.7 is determined by PCON.6 (SMOD0) (see Figure 7). If SMOD0 is set then SCON.7 functions as FE. SCON.7 functions as SM0 when SMOD0 is cleared. When used as FE SCON.7 can only be cleared by software. Refer to Figure 8.

Automatic Address Recognition

Automatic Address Recognition is a feature which allows the UART to recognize certain addresses in the serial bit stream by using hardware to make the comparisons. This feature saves a great deal of software overhead by eliminating the need for the software to examine every serial address which passes by the serial port. This feature is enabled by setting the SM2 bit in SCON. In the 9 bit UART modes, mode 2 and mode 3, the Receive Interrupt flag (RI) will be automatically set when the received byte contains either the "Given" address or the "Broadcast" address. The 9 bit mode requires that the 9th information bit is a 1 to indicate that the received information is an address and not data. Automatic address recognition is shown in Figure 9.

The 8 bit mode is called Mode 1. In this mode the RI flag will be set if SM2 is enabled and the information received has a valid stop bit following the 8 address bits and the information is either a Given or Broadcast address.

Mode 0 is the Shift Register mode and SM2 is ignored.

Using the Automatic Address Recognition feature allows a master to selectively communicate with one or more slaves by invoking the Given slave address or addresses. All of the slaves may be contacted by using the Broadcast address. Two special Function Registers are used to define the slave's address, SADDR, and the address mask, SADEN. SADEN is used to define which bits in the SADDR are to be used and which bits are "don't care". The SADEN mask can be logically ANDed with the SADDR to create the "Given" address which the master will use for addressing each of the slaves. Use of the Given address allows multiple slaves to be recognized while excluding others. The following examples will help to show the versatility of this scheme:

Slave 0	SADDR =	1100 0000
	SADEN =	<u>1111 1101</u>
	Given =	1100 00X0

Slave 1	SADDR =	1100 0000
	SADEN =	<u>1111 1110</u>
	Given =	1100 000X

In the above example SADDR is the same and the SADEN data is used to differentiate between the two slaves. Slave 0 requires a 0 in bit 0 and it ignores bit 1. Slave 1 requires a 0 in bit 1 and bit 0 is ignored. A unique address for Slave 0 would be 1100 0010 since slave 1 requires a 0 in bit 1. A unique address for slave 1 would be 1100 0001 since a 1 in bit 0 will exclude slave 0. Both slaves can be selected at the same time by an address which has bit 0 = 0 (for slave 0) and bit 1 = 0 (for slave 1). Thus, both could be addressed with 1100 0000.

In a more complex system the following could be used to select slaves 1 and 2 while excluding slave 0:

Slave 0	SADDR =	1100 0000
	SADEN =	<u>1111 1001</u>
	Given =	1100 0XX0
Slave 1	SADDR =	1110 0000
	SADEN =	<u>1111 1010</u>
	Given =	1110 0X0X
Slave 2	SADDR =	1110 0000
	SADEN =	<u>1111 1100</u>
	Given =	1110 00XX

In the above example the differentiation among the 3 slaves is in the lower 3 address bits. Slave 0 requires that bit 0 = 0 and it can be uniquely addressed by 1110 0110. Slave 1 requires that bit 1 = 0 and it can be uniquely addressed by 1110 and 0101. Slave 2 requires that bit 2 = 0 and its unique address is 1110 0011. To select Slaves 0 and 1 and exclude Slave 2 use address 1110 0100, since it is necessary to make bit 2 = 1 to exclude slave 2.

The Broadcast Address for each slave is created by taking the logical OR of SADDR and SADEN. Zeros in this result are treated as don't-cares. In most cases, interpreting the don't-cares as ones, the broadcast address will be FF hexadecimal.

Upon reset SADDR (SFR address 0A9H) and SADEN (SFR address 0B9H) are loaded with 0s. This produces a given address of all "don't cares" as well as a Broadcast address of all "don't cares". This effectively disables the Automatic Addressing mode and allows the microcontroller to use standard 80C51 type UART drivers which do not make use of this feature.

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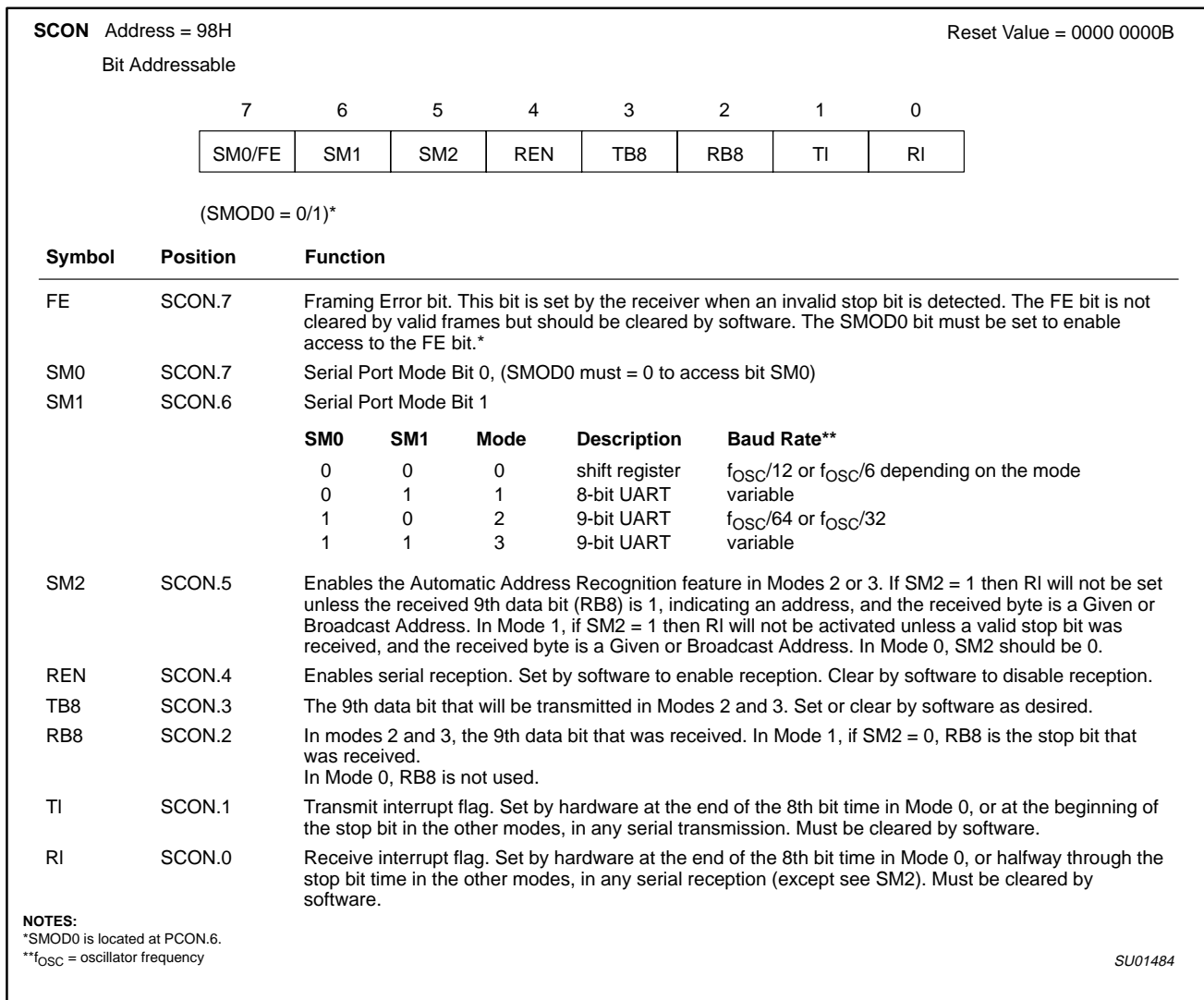


Figure 7. SCON: Serial Port Control Register

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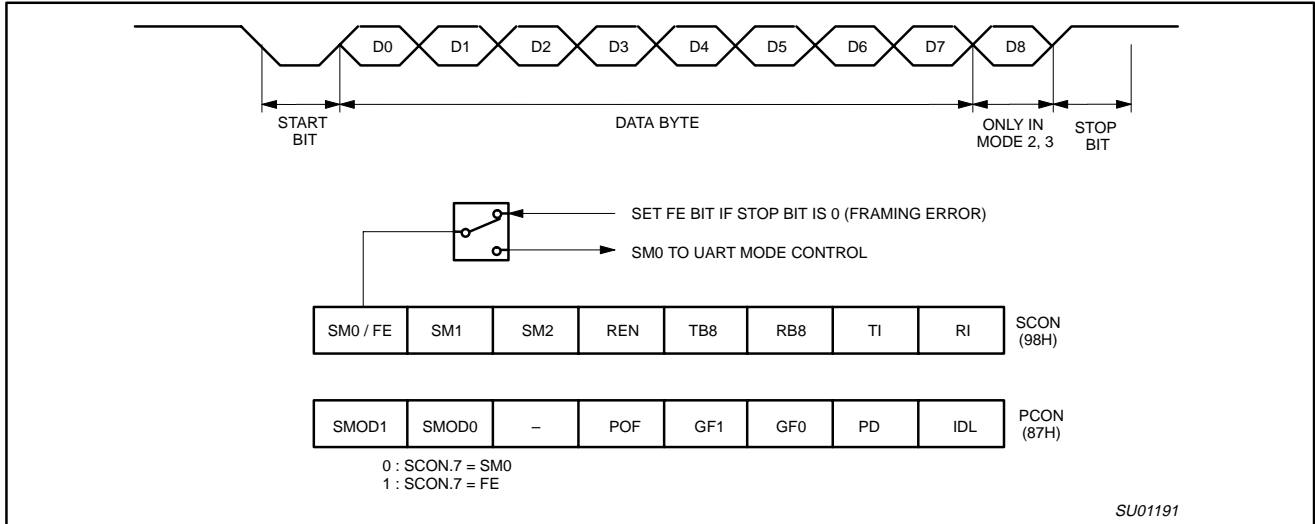


Figure 8. UART Framing Error Detection

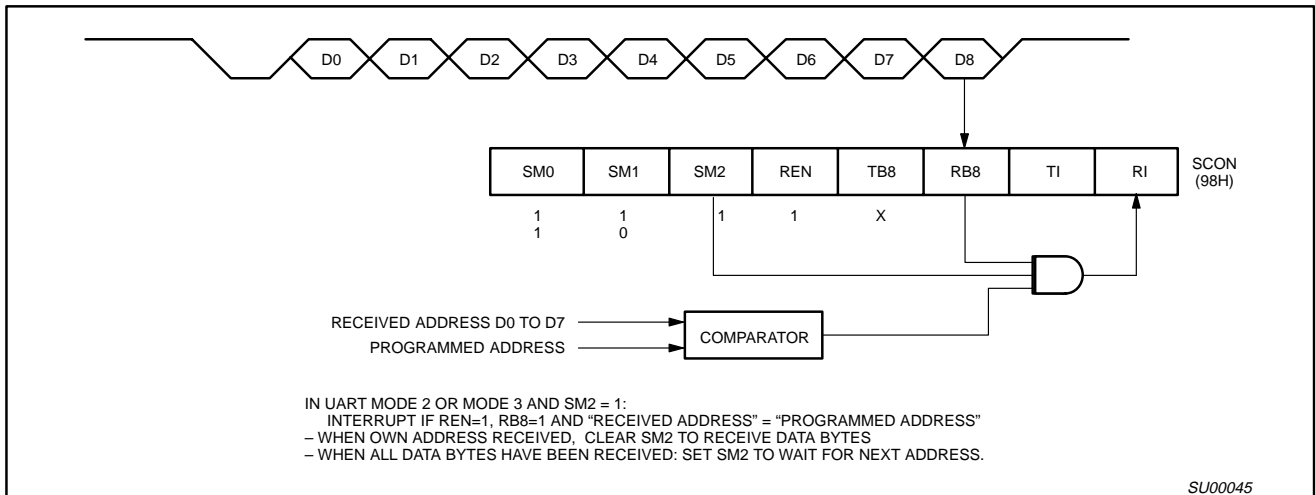


Figure 9. UART Multiprocessor Communication, Automatic Address Recognition

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Interrupt Priority Structure

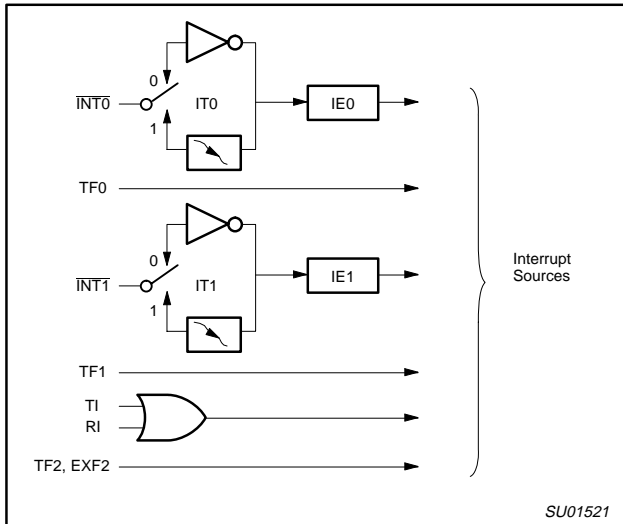


Figure 10. 80C51 Interrupt Sources

Interrupts

The devices described in this data sheet provide six interrupt sources. These are shown in Figure 10. The External Interrupts $\overline{\text{INT0}}$ and $\overline{\text{INT1}}$ can each be either level-activated or transition-activated, depending on bits IT0 and IT1 in Register TCON. The flags that actually generate these interrupts are bits IE0 and IE1 in TCON. When an external interrupt is generated, the flag that generated it is cleared by the hardware when the service routine is vectored to only if the interrupt was transition-activated. If the interrupt was level-activated, then the external requesting source is what controls the request flag, rather than the on-chip hardware.

The Timer 0 and Timer 1 Interrupts are generated by TF0 and TF1, which are set by a rollover in their respective Timer/Counter registers (except see Timer 0 in Mode 3). When a timer interrupt is generated, the flag that generated it is cleared by the on-chip hardware when the service routine is vectored to.

The Serial Port Interrupt is generated by the logical OR of RI and TI. Neither of these flags is cleared by hardware when the service routine is vectored to. In fact, the service routine will normally have to determine whether it was RI or TI that generated the interrupt, and the bit will have to be cleared in software.

All of the bits that generate interrupts can be set or cleared by software, with the same result as though it had been set or cleared by hardware. That is, interrupts can be generated or pending interrupts can be canceled in software.

Each of these interrupt sources can be individually enabled or disabled by setting or clearing a bit in Special Function Register IE (Figure 11). IE also contains a global disable bit, $\overline{\text{EA}}$, which disables all interrupts at once.

Priority Level Structure

Each interrupt source can also be individually programmed to one of four priority levels by setting or clearing bits in Special Function Registers IP (Figure 12) and IPH (Figure 13). A lower-priority interrupt can itself be interrupted by a higher-priority interrupt, but not by another interrupt of the same level. A high-priority level 3 interrupt can't be interrupted by any other interrupt source.

If two request of different priority levels are received simultaneously, the request of higher priority level is serviced. If requests of the same priority level are received simultaneously, an internal polling sequence determines which request is serviced. Thus within each priority level there is a second priority structure determined by the polling sequence as follows:

Source	Priority Within Level
1. IE0 (External Int 0)	(highest)
2. TF0 (Timer 0)	
3. IE1 (External Int 1)	
4. TF1 (Timer 1)	
5. RI+TI (UART)	
6. TF2, EXF2 (Timer 2)	(lowest)

Note that the "priority within level" structure is only used to resolve simultaneous requests of the same priority level.

The IP and IPH registers contain a number of unimplemented bits. User software should not write 1s to these positions, since they may be used in other 80C51 Family products.

How Interrupts Are Handled

The interrupt flags are sampled at S5P2 of every machine cycle. The samples are polled during the following machine cycle. If one of the flags was in a set condition at S5P2 of the preceding cycle, the polling cycle will find it and the interrupt system will generate an LCALL to the appropriate service routine, provided this hardware-generated LCALL is not blocked by any of the following conditions:

1. An interrupt of equal or higher priority level is already in progress.
2. The current (polling) cycle is not the final cycle in the execution of the instruction in progress.
3. The instruction in progress is RETI or any write to the IE or IP registers.

Any of these three conditions will block the generation of the LCALL to the interrupt service routine. Condition 2 ensures that the instruction in progress will be completed before vectoring to any service routine. Condition 3 ensures that if the instruction in progress is RETI or any access to IE or IP, then at least one more instruction will be executed before any interrupt is vectored to.

The polling cycle is repeated with each machine cycle, and the values polled are the values that were present at S5P2 of the previous machine cycle. Note that if an interrupt flag is active but not being responded to for one of the above conditions, if the flag is not still active when the blocking condition is removed, the denied interrupt will not be serviced. In other words, the fact that the interrupt flag was once active but not serviced is not remembered. Every polling cycle is new.

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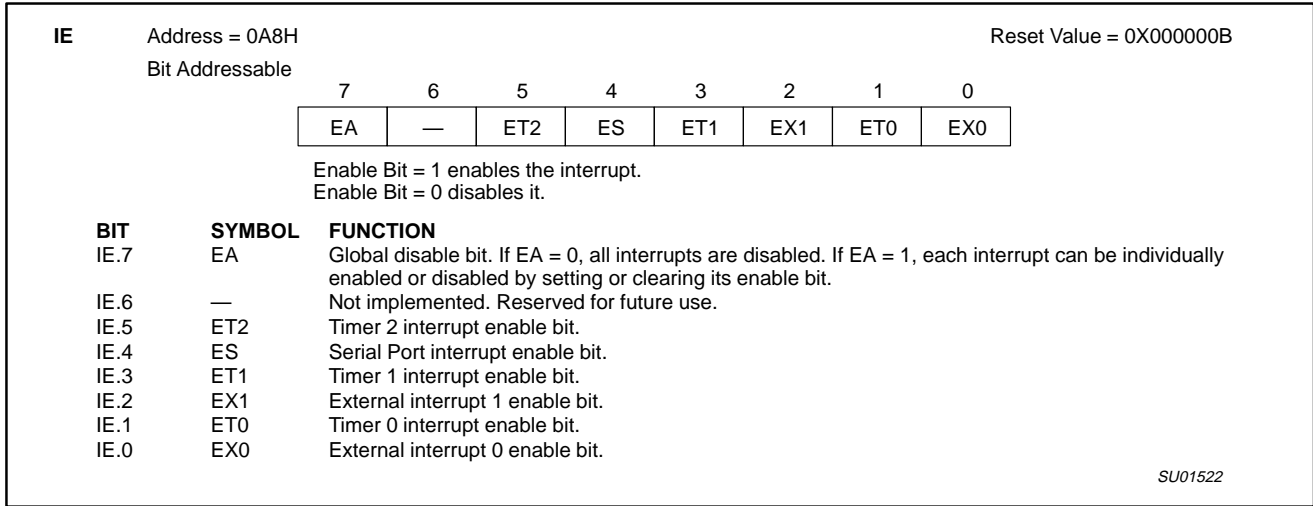


Figure 11. Interrupt Enable (IE) Register

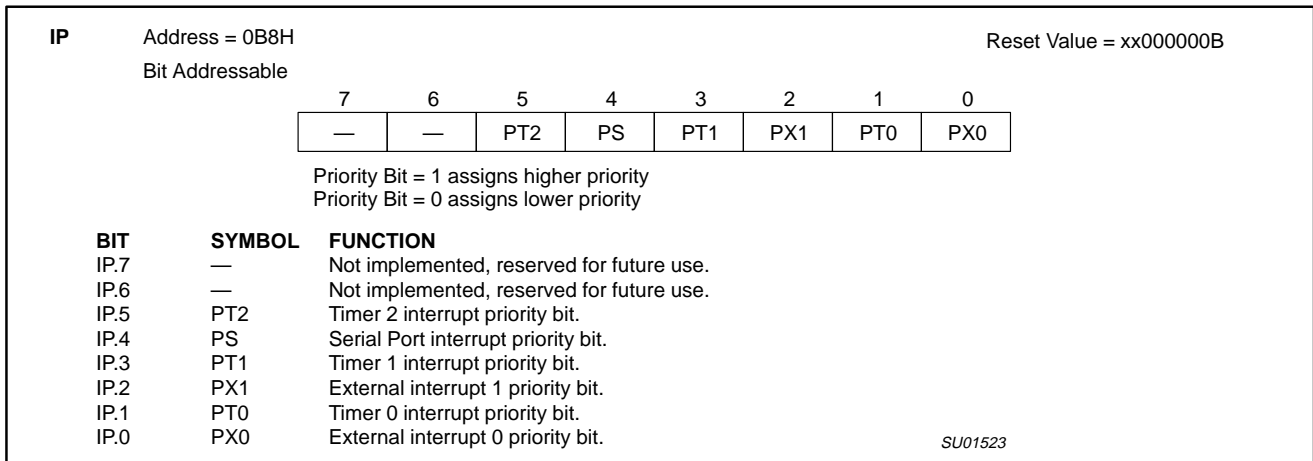


Figure 12. Interrupt Priority (IP) Register

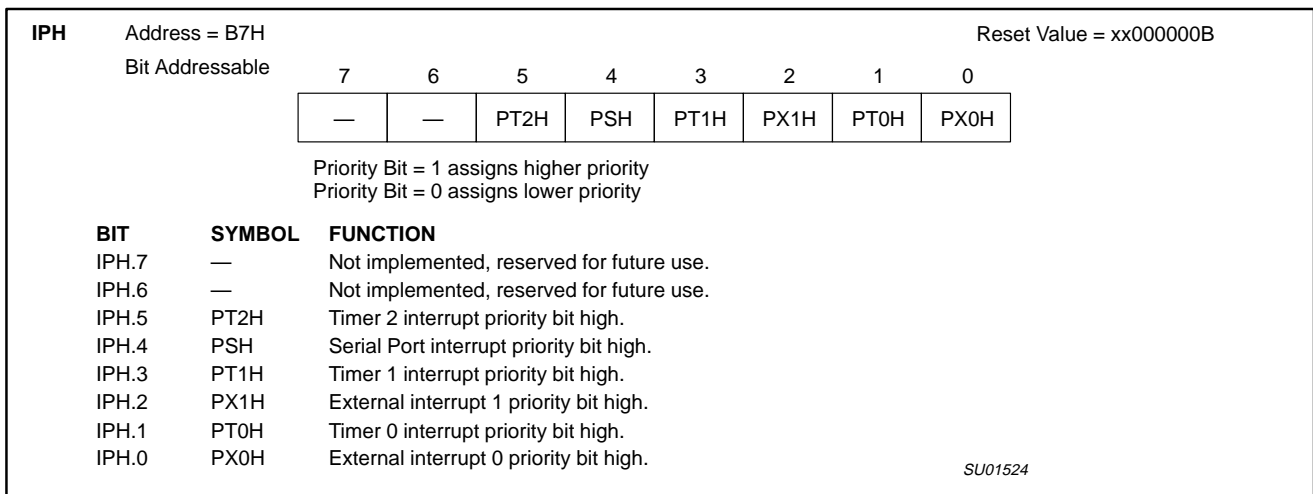


Figure 13. Interrupt Priority HIGH (IPH) Register

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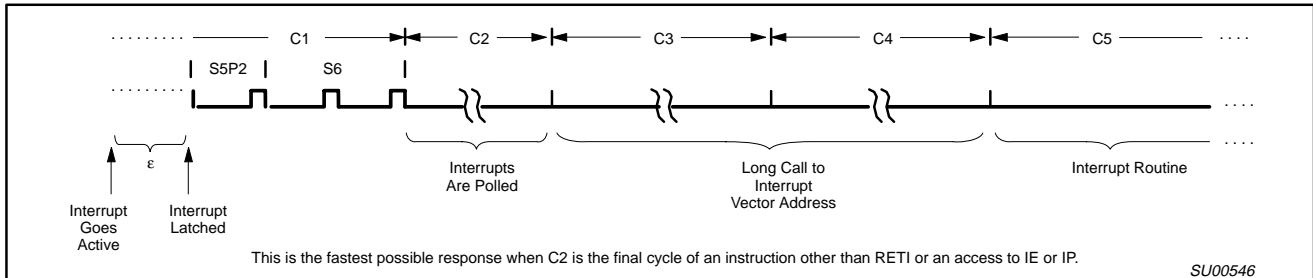


Figure 14. Interrupt Response Timing Diagram

The polling cycle/LCALL sequence is illustrated in Figure 14.

Note that if an interrupt of higher priority level goes active prior to S5P2 of the machine cycle labeled C3 in Figure 14, then in accordance with the above rules it will be vectored to during C5 and C6, without any instruction of the lower priority routine having been executed.

Thus the processor acknowledges an interrupt request by executing a hardware-generated LCALL to the appropriate servicing routine. In some cases it also clears the flag that generated the interrupt, and in other cases it doesn't. It never clears the Serial Port flag. This has to be done in the user's software. It clears an external interrupt flag (IE0 or IE1) only if it was transition-activated. The hardware-generated LCALL pushes the contents of the Program Counter on to the stack (but it does not save the PSW) and reloads the PC with an address that depends on the source of the interrupt being vectored to, as shown in Table 7.

Execution proceeds from that location until the RETI instruction is encountered. The RETI instruction informs the processor that this interrupt routine is no longer in progress, then pops the top two bytes from the stack and reloads the Program Counter. Execution of the interrupted program continues from where it left off.

Note that a simple RET instruction would also have returned execution to the interrupted program, but it would have left the interrupt control system thinking an interrupt was still in progress, making future interrupts impossible.

External Interrupts

The external sources can be programmed to be level-activated or transition-activated by setting or clearing bit IT1 or IT0 in Register TCON. If ITx = 0, external interrupt x is triggered by a detected low at the INTx pin. If ITx = 1, external interrupt x is edge triggered. In this mode if successive samples of the INTx pin show a high in one cycle and a low in the next cycle, interrupt request flag IEx in TCON is set. Flag bit IEx then requests the interrupt.

Since the external interrupt pins are sampled once each machine cycle, an input high or low should hold for at least 12 oscillator periods to ensure sampling. If the external interrupt is transition-activated, the external source has to hold the request pin high for at least one cycle, and then hold it low for at least one cycle. This is done to ensure that the transition is seen so that interrupt request flag IEx will be set. IEx will be automatically cleared by the CPU when the service routine is called.

If the external interrupt is level-activated, the external source has to hold the request active until the requested interrupt is actually generated. Then it has to deactivate the request before the interrupt

service routine is completed, or else another interrupt will be generated.

Response Time

The INT0 and INT1 levels are inverted and latched into IE0 and IE1 at S5P2 of every machine cycle. The values are not actually polled by the circuitry until the next machine cycle. If a request is active and conditions are right for it to be acknowledged, a hardware subroutine call to the requested service routine will be the next instruction to be executed. The call itself takes two cycles. Thus, a minimum of three complete machine cycles elapse between activation of an external interrupt request and the beginning of execution of the first instruction of the service routine. Figure 14 shows interrupt response timings.

A longer response time would result if the request is blocked by one of the 3 previously listed conditions. If an interrupt of equal or higher priority level is already in progress, the additional wait time obviously depends on the nature of the other interrupt's service routine. If the instruction in progress is not in its final cycle, the additional wait time cannot be more than 3 cycles, since the longest instructions (MUL and DIV) are only 4 cycles long, and if the instruction in progress is RETI or an access to IE or IP, the additional wait time cannot be more than 5 cycles (a maximum of one more cycle to complete the instruction in progress, plus 4 cycles to complete the next instruction if the instruction is MUL or DIV).

Thus, in a single-interrupt system, the response time is always more than 3 cycles and less than 9 cycles.

As previously mentioned, the derivatives described in this data sheet have a four-level interrupt structure. The corresponding registers are IE, IP and IPH. (See Figures 11, 12, and 13.) The IPH (Interrupt Priority High) register makes the four-level interrupt structure possible.

The function of the IPH SFR is simple and when combined with the IP SFR determines the priority of each interrupt. The priority of each interrupt is determined as shown in the following table:

PRIORITY BITS		INTERRUPT PRIORITY LEVEL
IPH.x	IP.x	
0	0	Level 0 (lowest priority)
0	1	Level 1
1	0	Level 2
1	1	Level 3 (highest priority)

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An interrupt will be serviced as long as an interrupt of equal or higher priority is not already being serviced. If an interrupt of equal or higher level priority is being serviced, the new interrupt will wait until it is finished before being serviced. If a lower priority level

interrupt is being serviced, it will be stopped and the new interrupt serviced. When the new interrupt is finished, the lower priority level interrupt that was stopped will be completed.

Table 7. Interrupt Table

SOURCE	POLLING PRIORITY	REQUEST BITS	HARDWARE CLEAR?	VECTOR ADDRESS
External interrupt 0	1	IE0	N (L) ¹ Y (T) ²	03H
Timer 0	2	TF0	Y	0BH
External interrupt 1	3	IE1	N (L) Y (T)	13H
Timer 1	4	TF1	Y	1BH
UART	5	RI, TI	N	23H
Timer 2	6	TF2, EXF2	N	2BH

NOTES:

- 1. L = Level activated
- 2. T = Transition activated

Reduced EMI Mode

The AO bit (AUXR.0) in the AUXR register when set disables the ALE output, unless the CPU needs to perform an off-chip memory access.

AUXR	Address = 8EH	Reset Value = xxxx xxx0B																
	Not Bit Addressable																	
	<table border="1" style="margin: auto; border-collapse: collapse;"> <tr> <td style="width: 20px; text-align: center;">7</td> <td style="width: 20px; text-align: center;">6</td> <td style="width: 20px; text-align: center;">5</td> <td style="width: 20px; text-align: center;">4</td> <td style="width: 20px; text-align: center;">3</td> <td style="width: 20px; text-align: center;">2</td> <td style="width: 20px; text-align: center;">1</td> <td style="width: 20px; text-align: center;">0</td> </tr> <tr> <td style="text-align: center;">—</td> <td style="text-align: center;">—</td> <td style="text-align: center;">—</td> <td style="text-align: center;">—</td> <td style="text-align: center;">—</td> <td style="text-align: center;">—</td> <td style="text-align: center;">—</td> <td style="text-align: center;">AO</td> </tr> </table>	7	6	5	4	3	2	1	0	—	—	—	—	—	—	—	AO	
7	6	5	4	3	2	1	0											
—	—	—	—	—	—	—	AO											
Symbol	Function																	
AO	Disable/Enable ALE																	
	AO Operating Mode																	
	0 ALE is emitted at a constant rate of $\frac{1}{3}$ the oscillator frequency (6 clock mode; $\frac{1}{6} f_{OSC}$ in 12 clock mode)																	
	1 ALE is active only during off-chip memory accesses.																	
—	Not implemented, reserved for future use ¹ .																	

SU01560

1. User software should not write 1s to reserved bits. These bits may be used in future 8051 family products to invoke new features. In that case, the reset or inactive value of the new bit will be 0, and its active value will be 1. The value read from a reserved bit is indeterminate.

Figure 15. AUXR: Auxiliary Register

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Dual DPTR

The dual DPTR structure (see Figure 17) is a way by which the chip will specify the address of an external data memory location. There are two 16-bit DPTR registers that address the external memory, and a single bit called DPS = AUXR1/bit0 that allows the program code to switch between them.

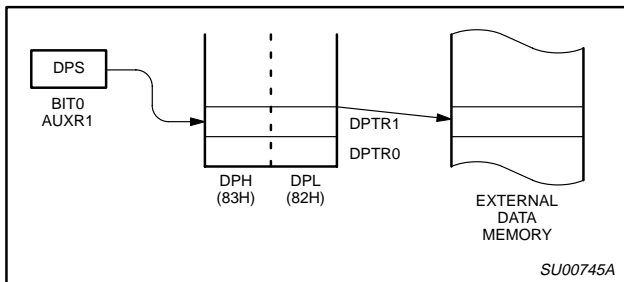
- New Register Name: AUXR1#
- SFR Address: A2H
- Reset Value: xxxx00x0B

AUXR1	Address = A2H							Reset Value = xxxx 00x0B	
	Not Bit Addressable								
		7	6	5	4	3	2	1	0
		—	—	—	—	GF2	0	—	DPS
Symbol	Function								
GF2	The GF2 bit is a general purpose user-defined flag. Note that bit 2 is not writable and is always read as a zero. This allows the DPS bit to be quickly toggled simply by executing an INC AUXR1 instruction without affecting the GF2 bit.								
DPS	DPS = AUXR1/bit0 = Switches between DPTR0 and DPTR1.								
	Select Reg	DPS							
	DPTR0	0							
	DPTR1	1							
—	Not implemented, reserved for future use ¹ .								

SU01561

1. User software should not write 1s to reserved bits. These bits may be used in future 8051 family products to invoke new features. In that case, the reset or inactive value of the new bit will be 0, and its active value will be 1. The value read from a reserved bit is indeterminate.

Figure 16. AUXR1: Auxiliary 1 Register



SU00745A

Figure 17.

DPTR Instructions

The instructions that refer to DPTR refer to the data pointer that is currently selected using the AUXR1/bit 0 register. The six instructions that use the DPTR are as follows:

- | | |
|-------------------|---|
| INC DPTR | Increments the data pointer by 1 |
| MOV DPTR, #data16 | Loads the DPTR with a 16-bit constant |
| MOV A, @ A+DPTR | Move code byte relative to DPTR to ACC |
| MOVX A, @ DPTR | Move external RAM (16-bit address) to ACC |
| MOVX @ DPTR, A | Move ACC to external RAM (16-bit address) |
| JMP @ A + DPTR | Jump indirect relative to DPTR |

The data pointer can be accessed on a byte-by-byte basis by specifying the low or high byte in an instruction which accesses the SFRs. See application note AN458 for more details.

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ABSOLUTE MAXIMUM RATINGS^{1, 2, 3}

PARAMETER	RATING	UNIT
Operating temperature under bias	0 to +70 or -40 to +85	°C
Storage temperature range	-65 to +150	°C
Voltage on \overline{EA}/V_{PP} pin to V_{SS}	0 to +13.0	V
Voltage on any other pin to V_{SS}	-0.5 to +6.5	V
Maximum I_{OL} per I/O pin	15	mA
Power dissipation (based on package heat transfer limitations, not device power consumption)	1.5	W

NOTES:

- Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any conditions other than those described in the AC and DC Electrical Characteristics section of this specification is not implied.
- This product includes circuitry specifically designed for the protection of its internal devices from the damaging effects of excessive static charge. Nonetheless, it is suggested that conventional precautions be taken to avoid applying greater than the rated maximum.
- Parameters are valid over operating temperature range unless otherwise specified. All voltages are with respect to V_{SS} unless otherwise noted.

AC ELECTRICAL CHARACTERISTICS
 $T_{amb} = 0^{\circ}\text{C to } +70^{\circ}\text{C or } -40^{\circ}\text{C to } +85^{\circ}\text{C}$

SYMBOL	PARAMETER	CLOCK FREQUENCY RANGE -f		UNIT
		MIN	MAX	
$1/t_{CLCL}$	Oscillator frequency	0	33	MHz

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DC ELECTRICAL CHARACTERISTICS

 $T_{amb} = 0^{\circ}\text{C to } +70^{\circ}\text{C or } -40^{\circ}\text{C to } +85^{\circ}\text{C}; 5\text{ V } \pm 10\%; V_{SS} = 0\text{ V}$

SYMBOL	PARAMETER	TEST CONDITIONS	LIMITS			UNIT
			MIN	TYP ¹	MAX	
V_{IL}	Input low voltage	$4.5\text{ V} < V_{CC} < 5.5\text{ V}$	-0.5		$0.2 V_{CC} - 0.1$	V
V_{IH}	Input high voltage (ports 0, 1, 2, 3, $\overline{\text{EA}}$)		$0.2 V_{CC} + 0.9$		$V_{CC} + 0.5$	V
V_{IH1}	Input high voltage, XTAL1, RST		$0.7 V_{CC}$		$V_{CC} + 0.5$	V
V_{OL}	Output low voltage, ports 1, 2, 3 ⁸	$V_{CC} = 4.5\text{ V}$ $I_{OL} = 1.6\text{ mA}^2$			0.4	V
V_{OL1}	Output low voltage, port 0, ALE, $\overline{\text{PSEN}}$ ^{7, 8}	$V_{CC} = 4.5\text{ V}$ $I_{OL} = 3.2\text{ mA}^2$			0.4	V
V_{OH}	Output high voltage, ports 1, 2, 3 ³	$V_{CC} = 4.5\text{ V}$ $I_{OH} = -30\text{ }\mu\text{A}$	$V_{CC} - 0.7$			V
V_{OH1}	Output high voltage (port 0 in external bus mode), ALE ⁹ , $\overline{\text{PSEN}}$ ³	$V_{CC} = 4.5\text{ V}$ $I_{OH} = -3.2\text{ mA}$	$V_{CC} - 0.7$			V
I_{IL}	Logical 0 input current, ports 1, 2, 3	$V_{IN} = 0.4\text{ V}$	-1		-75	μA
I_{TL}	Logical 1-to-0 transition current, ports 1, 2, 3 ⁶	$V_{IN} = 2.0\text{ V}$ See Note 4			-650	μA
I_{LI}	Input leakage current, port 0	$0.45 < V_{IN} < V_{CC} - 0.3$			± 10	μA
I_{CC}	Power supply current (see Figure 25): Active mode (see Note 5) Idle mode (see Note 5) Power-down mode or clock stopped (see Figure 29 for conditions)	See Note 5 $T_{amb} = 0^{\circ}\text{C to } 70^{\circ}\text{C}$ $T_{amb} = -40^{\circ}\text{C to } +85^{\circ}\text{C}$		3	100 125	μA μA
R_{RST}	Internal reset pull-down resistor		40		225	$\text{k}\Omega$
C_{IO}	Pin capacitance ¹⁰ (except $\overline{\text{EA}}$)				15	pF

NOTES:

- Typical ratings are not guaranteed. The values listed are at room temperature, 5 V.
- Capacitive loading on ports 0 and 2 may cause spurious noise to be superimposed on the V_{OLS} of ALE and ports 1 and 3. The noise is due to external bus capacitance discharging into the port 0 and port 2 pins when these pins make 1-to-0 transitions during bus operations. In the worst cases (capacitive loading > 100pF), the noise pulse on the ALE pin may exceed 0.8V. In such cases, it may be desirable to qualify ALE with a Schmitt Trigger, or use an address latch with a Schmitt Trigger STROBE input. I_{OL} can exceed these conditions provided that no single output sinks more than 5 mA and no more than two outputs exceed the test conditions.
- Capacitive loading on ports 0 and 2 may cause the V_{OH} on ALE and $\overline{\text{PSEN}}$ to momentarily fall below the $V_{CC} - 0.7$ specification when the address bits are stabilizing.
- Pins of ports 1, 2 and 3 source a transition current when they are being externally driven from 1 to 0. The transition current reaches its maximum value when V_{IN} is approximately 2 V.
- See Figures 26 through 29 for I_{CC} test conditions and Figure 25 for I_{CC} vs Freq.
Active mode: $I_{CC(\text{MAX})} = (0.56 \times \text{FREQ.} + 8.0)\text{mA}$
Idle mode: $I_{CC(\text{MAX})} = (0.30 \times \text{FREQ.} + 2.0)\text{mA}$
- This value applies to $T_{amb} = 0^{\circ}\text{C to } +70^{\circ}\text{C}$.
- Load capacitance for port 0, ALE, and $\overline{\text{PSEN}} = 100\text{pF}$, load capacitance for all other outputs = 80 pF.
- Under steady state (non-transient) conditions, I_{OL} must be externally limited as follows:
Maximum I_{OL} per port pin: 15 mA (*NOTE: This is 85°C specification.)
Maximum I_{OL} per 8-bit port: 26 mA
Maximum total I_{OL} for all outputs: 71 mA
If I_{OL} exceeds the test condition, V_{OL} may exceed the related specification. Pins are not guaranteed to sink current greater than the listed test conditions.
- ALE is tested to V_{OH1} , except when ALE is off then V_{OH} is the voltage specification.
- Pin capacitance is characterized but not tested. Pin capacitance is less than 25 pF. Pin capacitance of ceramic package is less than 15 pF (except $\overline{\text{EA}}$ is 25 pF).

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4K/8K/16K/32K Flash

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AC ELECTRICAL CHARACTERISTICS
 $T_{amb} = 0^{\circ}\text{C to } +70^{\circ}\text{C or } -40^{\circ}\text{C to } +85^{\circ}\text{C}$, $V_{CC} = 5\text{ V} \pm 10\%$, $V_{SS} = 0\text{V}^{1, 2, 3}$

SYMBOL	FIGURE	PARAMETER	VARIABLE CLOCK ⁴		33MHz CLOCK		UNIT
			MIN	MAX	MIN	MAX	
$1/t_{CLCL}$	18	Oscillator frequency Speed versions	3.5	33	3.5	33	MHz
t_{LHLL}	18	ALE pulse width	$2t_{CLCL}-40$		21		ns
t_{AVLL}	18	Address valid to ALE low	$t_{CLCL}-25$		5		ns
t_{LLAX}	18	Address hold after ALE low	$t_{CLCL}-25$		5		ns
t_{LLIV}	18	ALE low to valid instruction in		$4t_{CLCL}-65$		55	ns
t_{LLPL}	18	ALE low to $\overline{\text{PSEN}}$ low	$t_{CLCL}-25$		5		ns
t_{PLPH}	18	$\overline{\text{PSEN}}$ pulse width	$3t_{CLCL}-45$		45		ns
t_{PLIV}	18	$\overline{\text{PSEN}}$ low to valid instruction in		$3t_{CLCL}-60$		30	ns
t_{PXIX}	18	Input instruction hold after $\overline{\text{PSEN}}$	0		0		ns
t_{PXIZ}	18	Input instruction float after $\overline{\text{PSEN}}$		$t_{CLCL}-25$		5	ns
t_{AVIV}	18	Address to valid instruction in		$5t_{CLCL}-80$		70	ns
t_{PLAZ}	18	$\overline{\text{PSEN}}$ low to address float		10		10	ns
Data Memory							
t_{RLRH}	19, 20	$\overline{\text{RD}}$ pulse width	$6t_{CLCL}-100$		82		ns
t_{WLWH}	19, 20	$\overline{\text{WR}}$ pulse width	$6t_{CLCL}-100$		82		ns
t_{RLDV}	19, 20	$\overline{\text{RD}}$ low to valid data in		$5t_{CLCL}-90$		60	ns
t_{RHDX}	19, 20	Data hold after $\overline{\text{RD}}$	0		0		ns
t_{RHDZ}	19, 20	Data float after $\overline{\text{RD}}$		$2t_{CLCL}-28$		32	ns
t_{LLDV}	19, 20	ALE low to valid data in		$8t_{CLCL}-150$		90	ns
t_{AVDV}	19, 20	Address to valid data in		$9t_{CLCL}-165$		105	ns
t_{LLWL}	19, 20	ALE low to $\overline{\text{RD}}$ or $\overline{\text{WR}}$ low	$3t_{CLCL}-50$	$3t_{CLCL}+50$	40	140	ns
t_{AVWL}	19, 20	Address valid to $\overline{\text{WR}}$ low or $\overline{\text{RD}}$ low	$4t_{CLCL}-75$		45		ns
t_{QVWX}	19, 20	Data valid to $\overline{\text{WR}}$ transition	$t_{CLCL}-30$		0		ns
t_{WHQX}	19, 20	Data hold after $\overline{\text{WR}}$	$t_{CLCL}-25$		5		ns
t_{QVWH}	20	Data valid to $\overline{\text{WR}}$ high	$7t_{CLCL}-130$		80		ns
t_{RLAZ}	19, 20	$\overline{\text{RD}}$ low to address float		0		0	ns
t_{WHLH}	19, 20	$\overline{\text{RD}}$ or $\overline{\text{WR}}$ high to ALE high	$t_{CLCL}-25$	$t_{CLCL}+25$	5	55	ns
External Clock							
t_{CHCX}	22	High time	17	$t_{CLCL}-t_{CLCX}$			ns
t_{CLCX}	22	Low time	17	$t_{CLCL}-t_{CHCX}$			ns
t_{CLCH}	22	Rise time		5			ns
t_{CHCL}	22	Fall time		5			ns
Shift Register							
t_{XLXL}	21	Serial port clock cycle time	$12t_{CLCL}$		360		ns
t_{QVXH}	21	Output data setup to clock rising edge	$10t_{CLCL}-133$		167		ns
t_{XHQX}	21	Output data hold after clock rising edge	$2t_{CLCL}-80$		50		ns
t_{XHDX}	21	Input data hold after clock rising edge	0		0		ns
t_{XHDV}	21	Clock rising edge to input data valid		$10t_{CLCL}-133$		167	ns

NOTES:

- Parameters are valid over operating temperature range unless otherwise specified.
- Load capacitance for port 0, ALE, and $\overline{\text{PSEN}}$ = 100 pF, load capacitance for all other outputs = 80 pF.
- Interfacing the microcontroller to devices with float times up to 45 ns is permitted. This limited bus contention will not cause damage to Port 0 drivers.
- Parts are guaranteed to operate down to 0 Hz.

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EXPLANATION OF THE AC SYMBOLS

Each timing symbol has five characters. The first character is always 't' (= time). The other characters, depending on their positions, indicate the name of a signal or the logical status of that signal. The designations are:

- A – Address
- C – Clock
- D – Input data
- H – Logic level high
- I – Instruction (program memory contents)
- L – Logic level low, or ALE

- P – PSEN
- Q – Output data
- R – \overline{RD} signal
- t – Time
- V – Valid
- W – \overline{WR} signal
- X – No longer a valid logic level
- Z – Float

Examples: t_{AVLL} = Time for address valid to ALE low.
 t_{LLPL} = Time for ALE low to PSEN low.

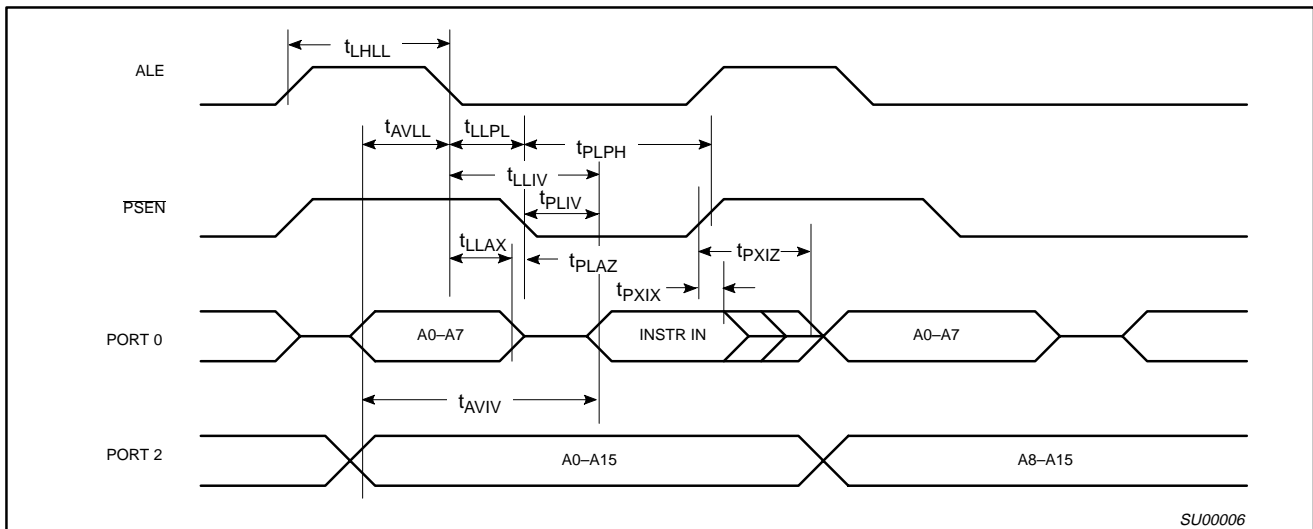


Figure 18. External Program Memory Read Cycle

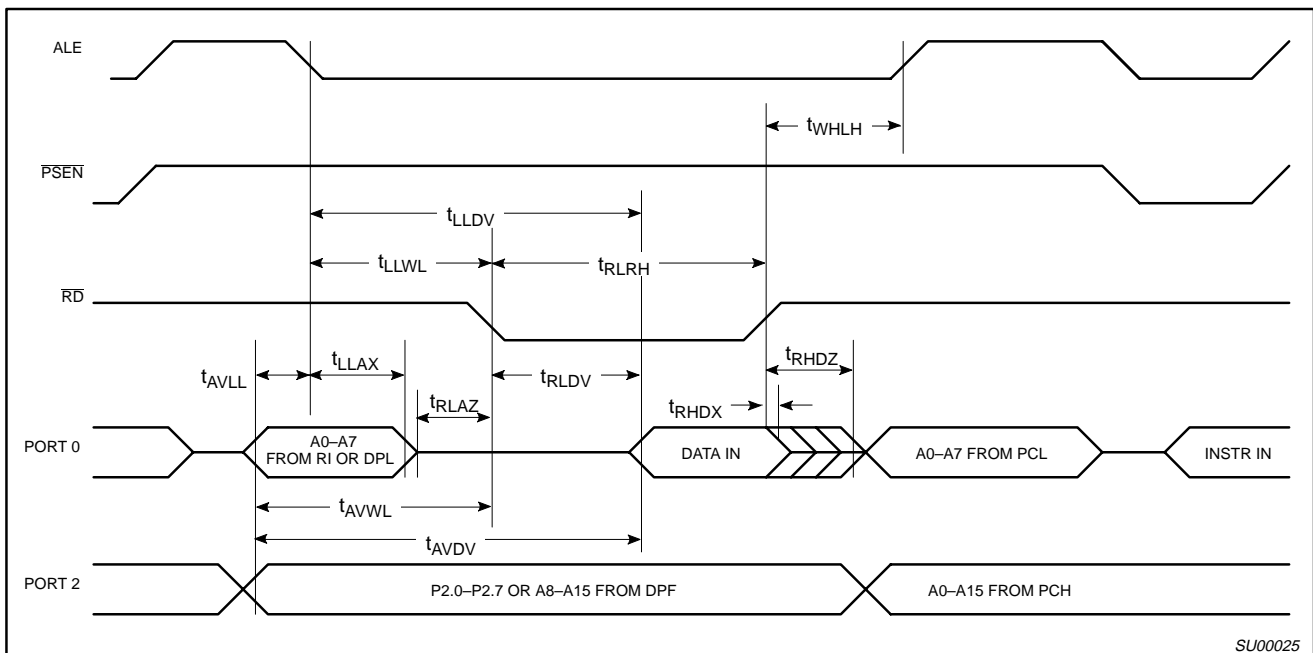


Figure 19. External Data Memory Read Cycle

80C51 8-bit microcontroller family
4K/8K/16K/32K Flash

89C51/89C52/89C54/89C58

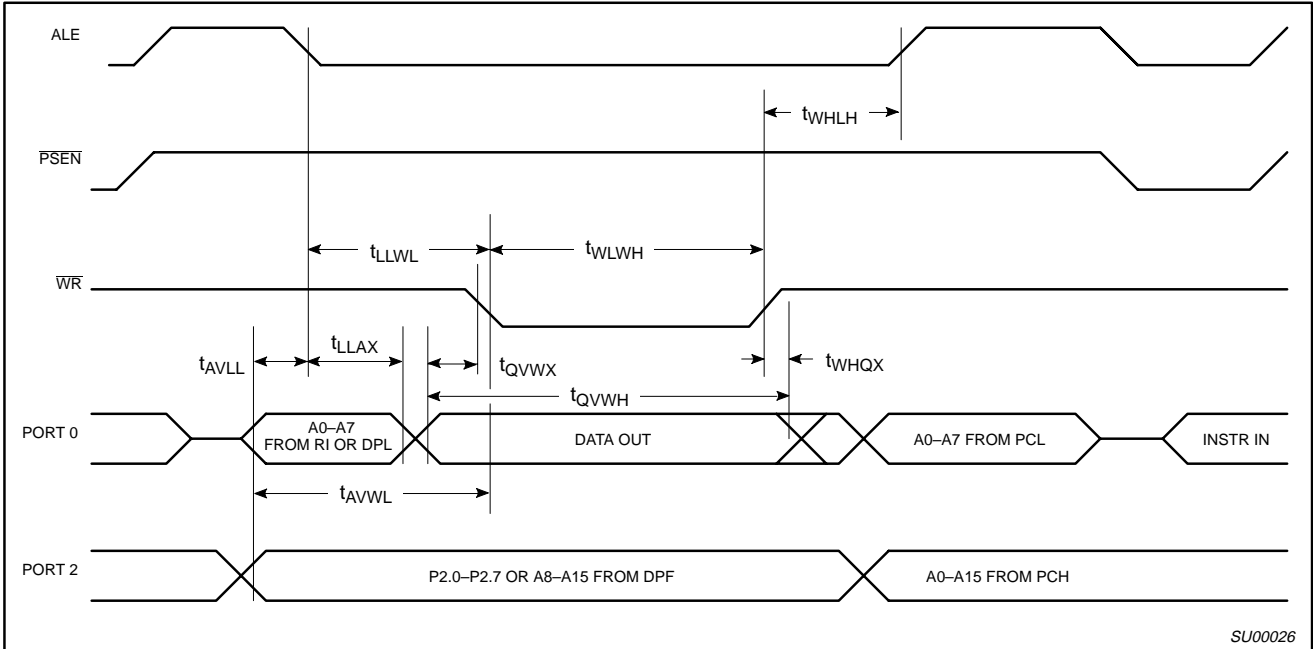


Figure 20. External Data Memory Write Cycle

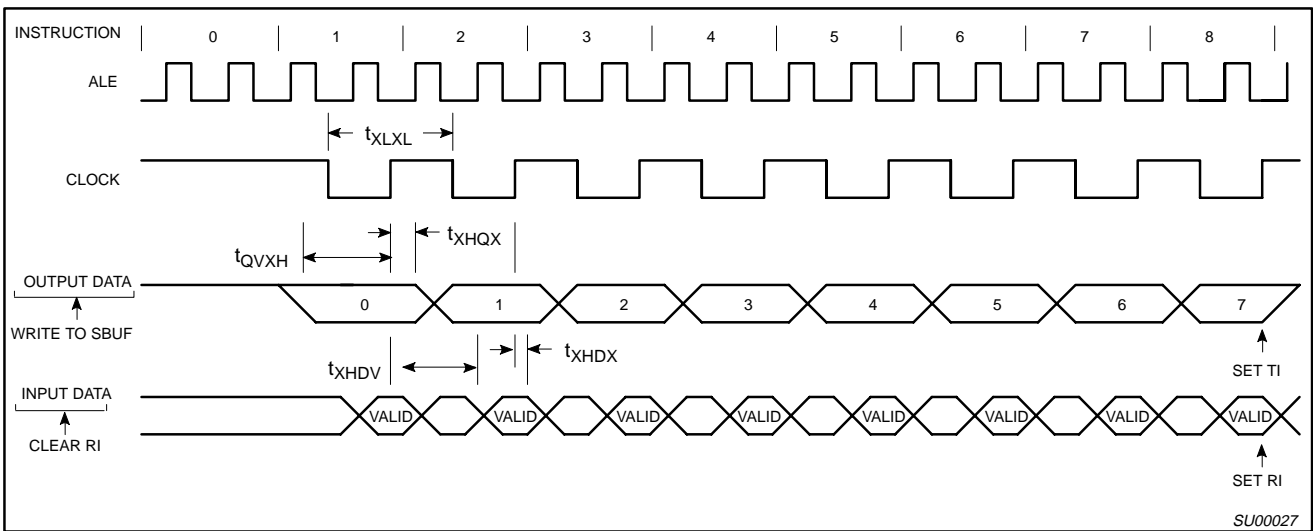


Figure 21. Shift Register Mode Timing

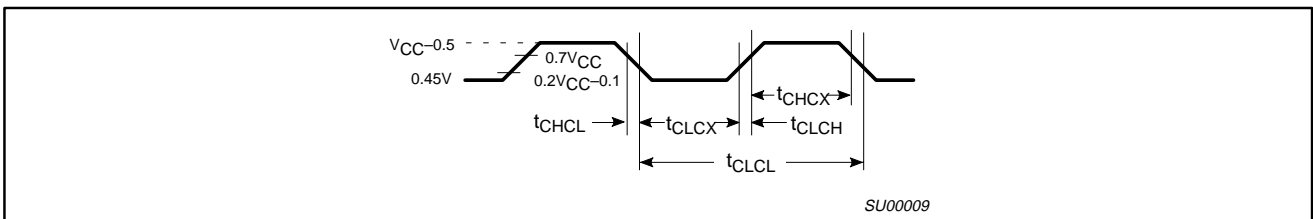


Figure 22. External Clock Drive

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4K/8K/16K/32K Flash

89C51/89C52/89C54/89C58

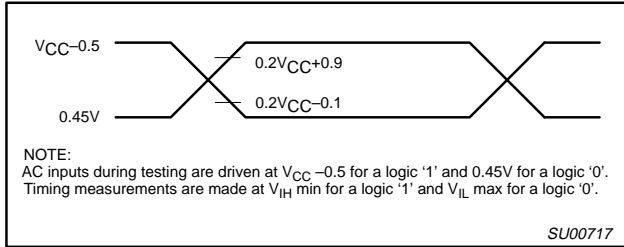


Figure 23. AC Testing Input/Output

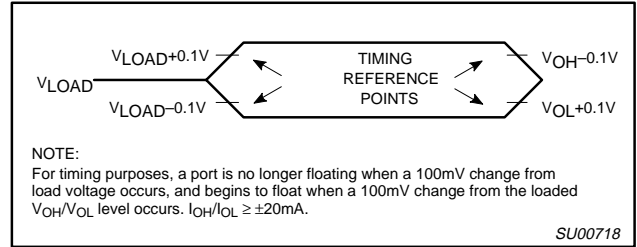


Figure 24. Float Waveform

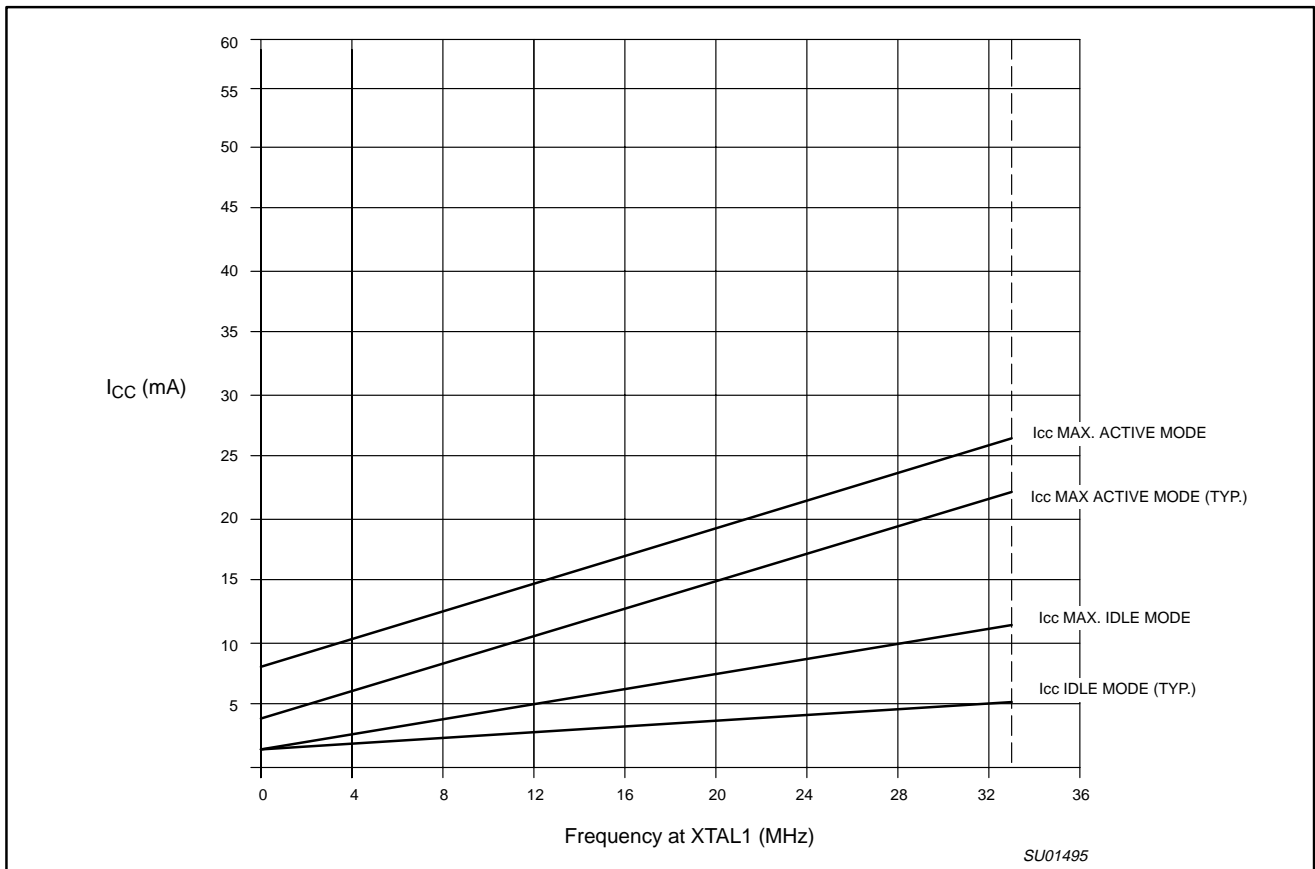


Figure 25. I_{cc} vs. FREQ
Valid only within frequency specifications of the device under test

80C51 8-bit microcontroller family
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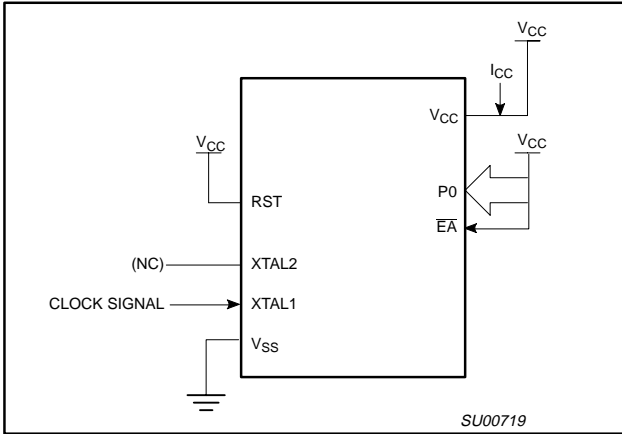


Figure 26. I_{CC} Test Condition, Active Mode
All other pins are disconnected

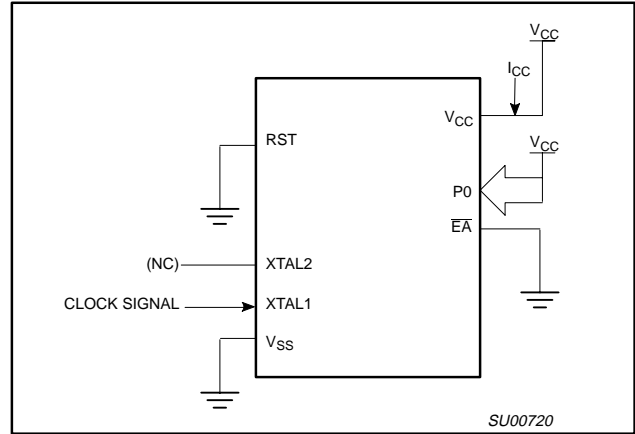


Figure 27. I_{CC} Test Condition, Idle Mode
All other pins are disconnected

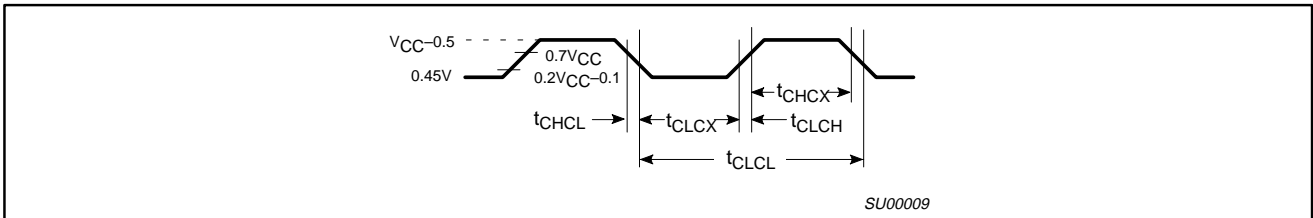


Figure 28. Clock Signal Waveform for I_{CC} Tests in Active and Idle Modes
 $t_{CLCH} = t_{CHCL} = 5\text{ns}$

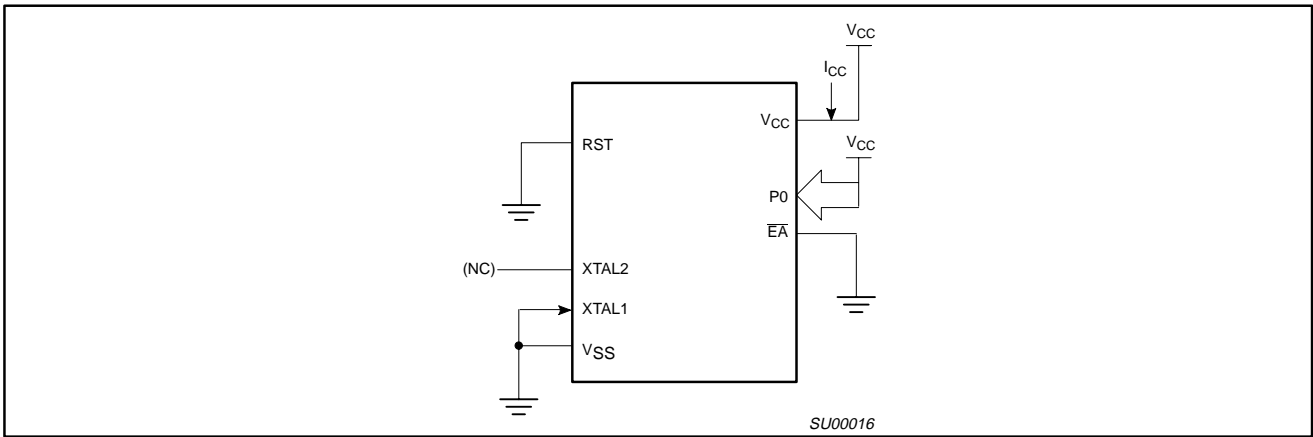


Figure 29. I_{CC} Test Condition, Power Down Mode
All other pins are disconnected. $V_{CC} = 2\text{V to } 5.5\text{V}$

80C51 8-bit microcontroller family
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Security

The security feature protects against software piracy and prevents the contents of the FLASH from being read. The Security Lock bits are located in FLASH. The 89C51/89C52/89C54/89C58 has 3 programmable security lock bits that will provide different levels of protection for the on-chip code and data (see Table 8). Unlike the ROM and OTP versions, the security lock bits are independent. LB3 includes the security protection of LB1.

Table 8.

SECURITY LOCK BITS¹	PROTECTION DESCRIPTION
Level	
LB1	MOVC instructions executed from external program memory are disabled from fetching code bytes from internal memory.
LB2	Program verification is disabled
LB3	External execution is disabled.

NOTE:

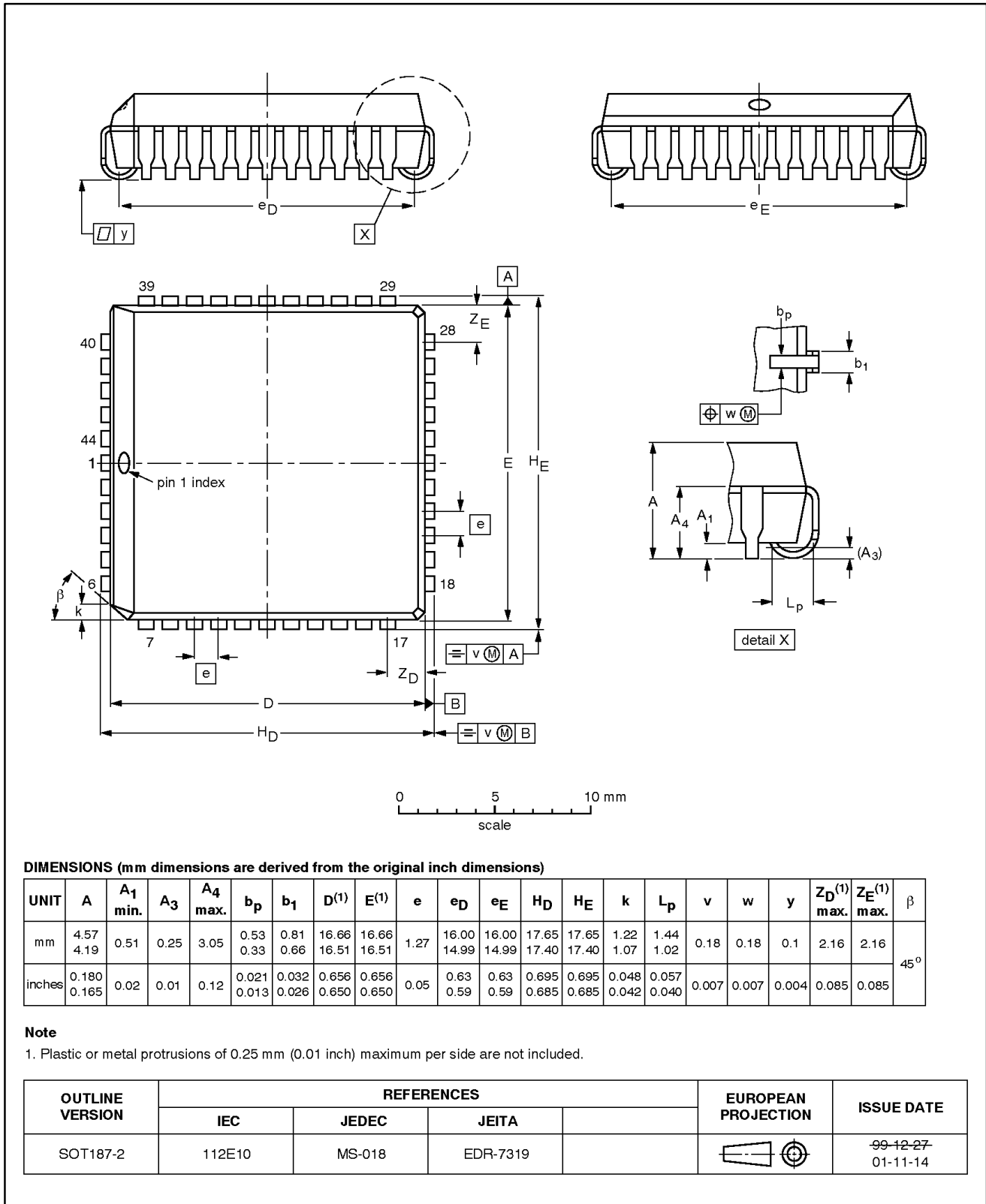
1. The security lock bits are independent.

80C51 8-bit microcontroller family
4K/8K/16K/32K Flash

89C51/89C52/89C54/89C58

PLCC44: plastic leaded chip carrier; 44 leads

SOT187-2

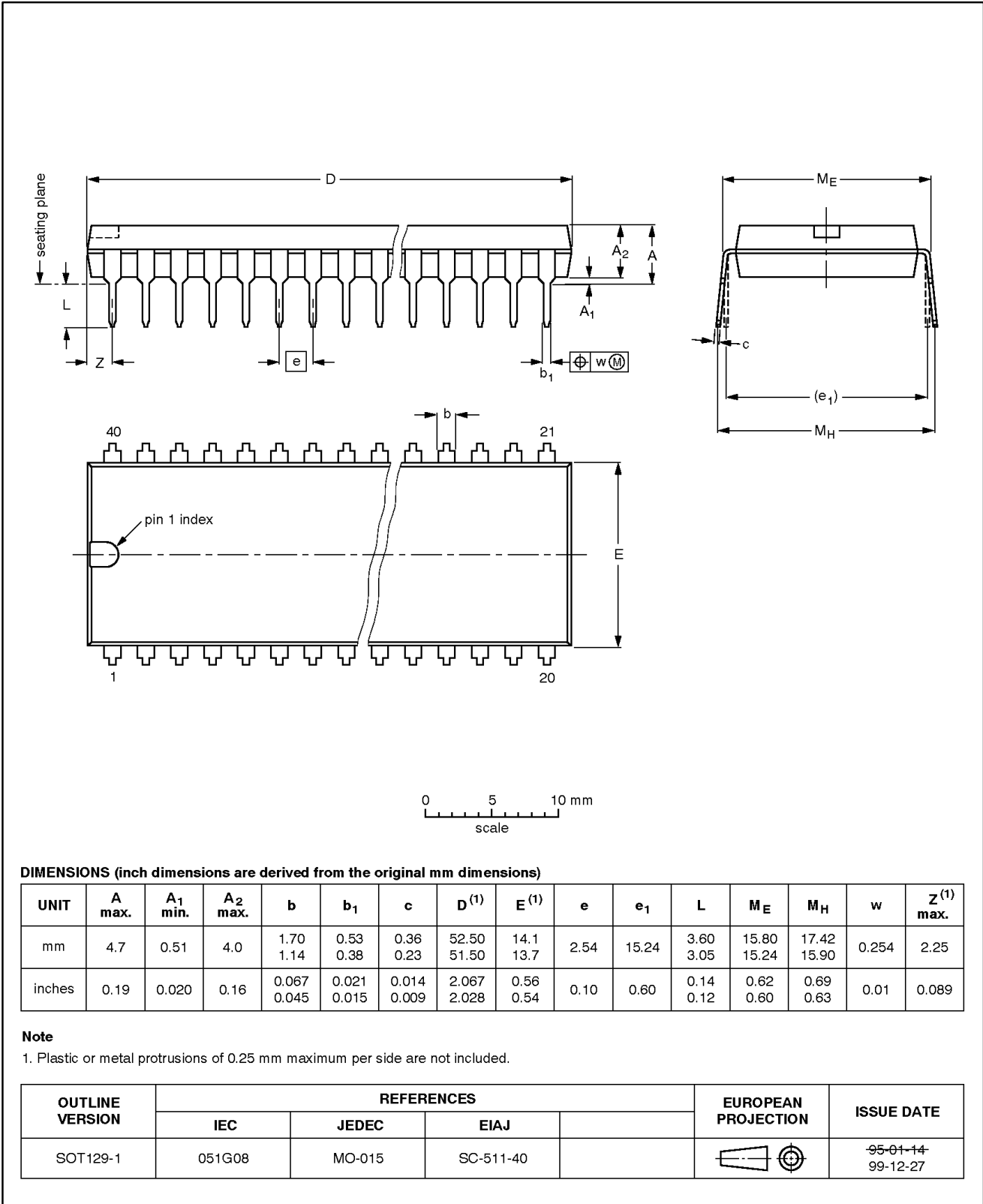


80C51 8-bit microcontroller family
4K/8K/16K/32K Flash

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DIP40: plastic dual in-line package; 40 leads (600 mil)

SOT129-1

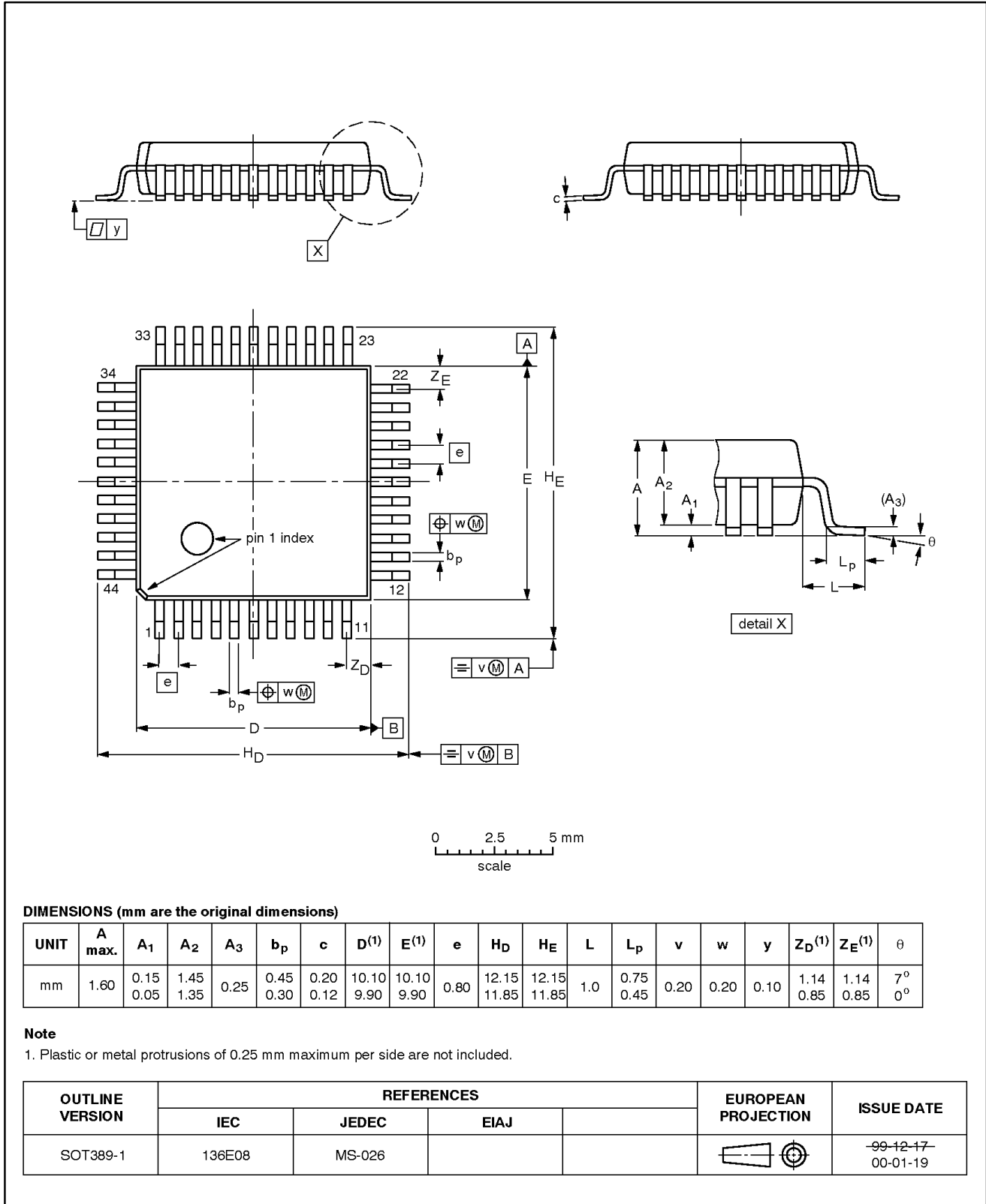


80C51 8-bit microcontroller family
4K/8K/16K/32K Flash

89C51/89C52/89C54/89C58

LQFP44: plastic low profile quad flat package; 44 leads; body 10 x 10 x 1.4 mm

SOT389-1



80C51 8-bit microcontroller family
4K/8K/16K/32K Flash

89C51/89C52/89C54/89C58

REVISION HISTORY

Release date	CPCN	Modifications to previous release
2002 Jan 15	9397 750 09302	PROGRAMMING ALGORITHM MODIFIED due to process change (see device comparison table).
		PQFP package replaced by LQFP package (dimensions see end of data sheet).
		Lower power consumption due to process change.
		DEVICE COMPARISON TABLE inserted (beginning of data sheet).
		Selection Table for Flash devices updated and extended.
		Ordering information table updated.
		Erase and program cycles increased from 100 to 10,000.
1999 Oct 27	9397 750 06613	Combined data sheet for all four parts (89C51/52/54/58).

80C51 8-bit microcontroller family

4K/8K/16K/32K Flash

89C51/89C52/89C54/89C58

Data sheet status

Data sheet status ^[1]	Product status ^[2]	Definitions
Objective data	Development	This data sheet contains data from the objective specification for product development. Philips Semiconductors reserves the right to change the specification in any manner without notice.
Preliminary data	Qualification	This data sheet contains data from the preliminary specification. Supplementary data will be published at a later date. Philips Semiconductors reserves the right to change the specification without notice, in order to improve the design and supply the best possible product.
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[1] Please consult the most recently issued data sheet before initiating or completing a design.

[2] The product status of the device(s) described in this data sheet may have changed since this data sheet was published. The latest information is available on the Internet at URL <http://www.semiconductors.philips.com>.

Definitions

Short-form specification — The data in a short-form specification is extracted from a full data sheet with the same type number and title. For detailed information see the relevant data sheet or data handbook.

Limiting values definition — Limiting values given are in accordance with the Absolute Maximum Rating System (IEC 60134). Stress above one or more of the limiting values may cause permanent damage to the device. These are stress ratings only and operation of the device at these or at any other conditions above those given in the Characteristics sections of the specification is not implied. Exposure to limiting values for extended periods may affect device reliability.

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