THE DATASHEET OF

P87C654X2FA

www.win-source.net 0086-755-83957316

DATA SHEET

P83C654X2/P87C654X2

80C51 8-bit microcontroller family

16 kB OTP/ROM, 256B RAM, low voltage (2.7 to 5.5 V), low power, high speed (30/33 MHz)

Product data

Supersedes data of 2003 Feb 13

2004 Apr 20

Philips
Semiconductors

PHILIPS

80C51 8-bit microcontroller family 16 kB OTP/ROM, 256B RAM, low voltage (2.7 to 5.5 V), low power, high speed (30/33 MHz)

P83C654X2/P87C654X2

DESCRIPTION

The devices are Single-Chip 8-Bit Microcontrollers manufactured in an advanced CMOS process and are derivatives of the 80C51 microcontroller family. The instruction set is 100 % compatible with the 80C51 instruction set.

The devices support 6-clock/12-clock mode selection by programming an OTP bit (OX2) using parallel programming. In addition, an SFR bit (X2) in the clock control register (CKCON) also selects between 6-clock/12-clock mode.

The devices also have four 8-bit I/O ports, three 16-bit timer/event counters, a multi-source, four-priority-level, nested interrupt structure, an enhanced UART and on-chip oscillator and timing circuits.

The added features of the P8xC654X2 make it a powerful microcontroller for applications that require pulse width modulation, high-speed I/O and up/down counting capabilities such as motor control.

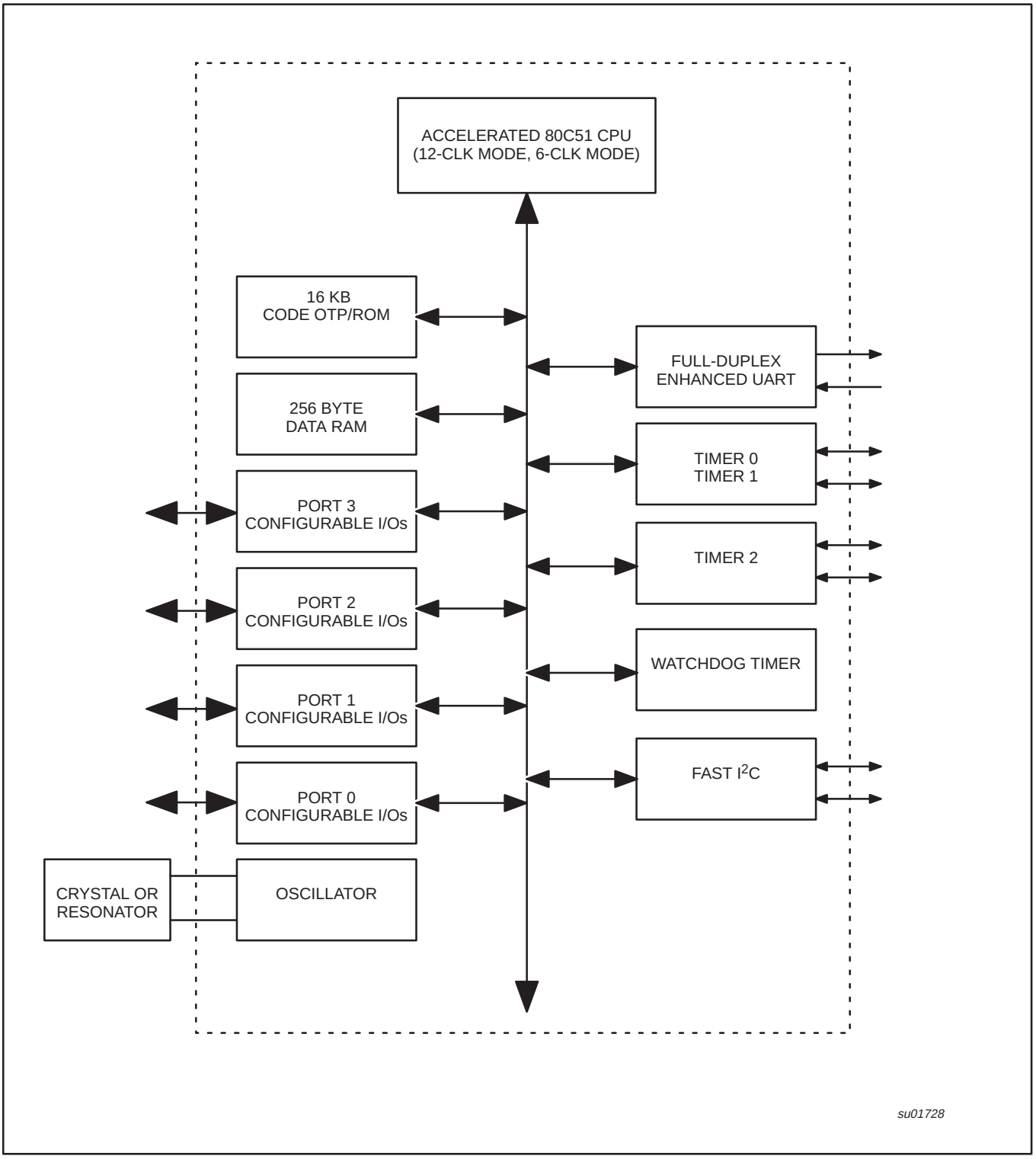
FEATURES

- 80C51 Central Processing Unit
  - 16 kbytes OTP
  - 256 byte RAM
  - Boolean processor
  - Fully static operation
  - Low voltage (2.7 V to 5.5 V at 16 MHz) operation
- 12-clock operation with selectable 6-clock operation (via software or via parallel programmer)
- Memory addressing capability
  - Up to 64 kbytes ROM and 64 kbytes RAM
- Power control modes:
  - Clock can be stopped and resumed
  - Idle mode
  - Power-down mode
- CMOS and TTL compatible
- Two speed ranges at V_{CC} = 5 V
  - 0 to 30 MHz with 6-clock operation
  - 0 to 33 MHz with 12-clock operation
- Parallel programming with 87C51 compatible hardware interface to programmer
- RAM expandable externally to 64 kbytes
- PLCC and LQFP packages
- Extended temperature ranges
- Dual Data Pointers
- Security bits (3 bits)
- Encryption array - 64 bytes
- Seven interrupt sources
- Four interrupt priority levels
- 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)
- Programmable clock-out pin
- Asynchronous port reset
- Low EMI (inhibit ALE, slew rate controlled outputs, and 6-clock mode)
- Wake-up from power-down by an external interrupt
- Watchdog timer

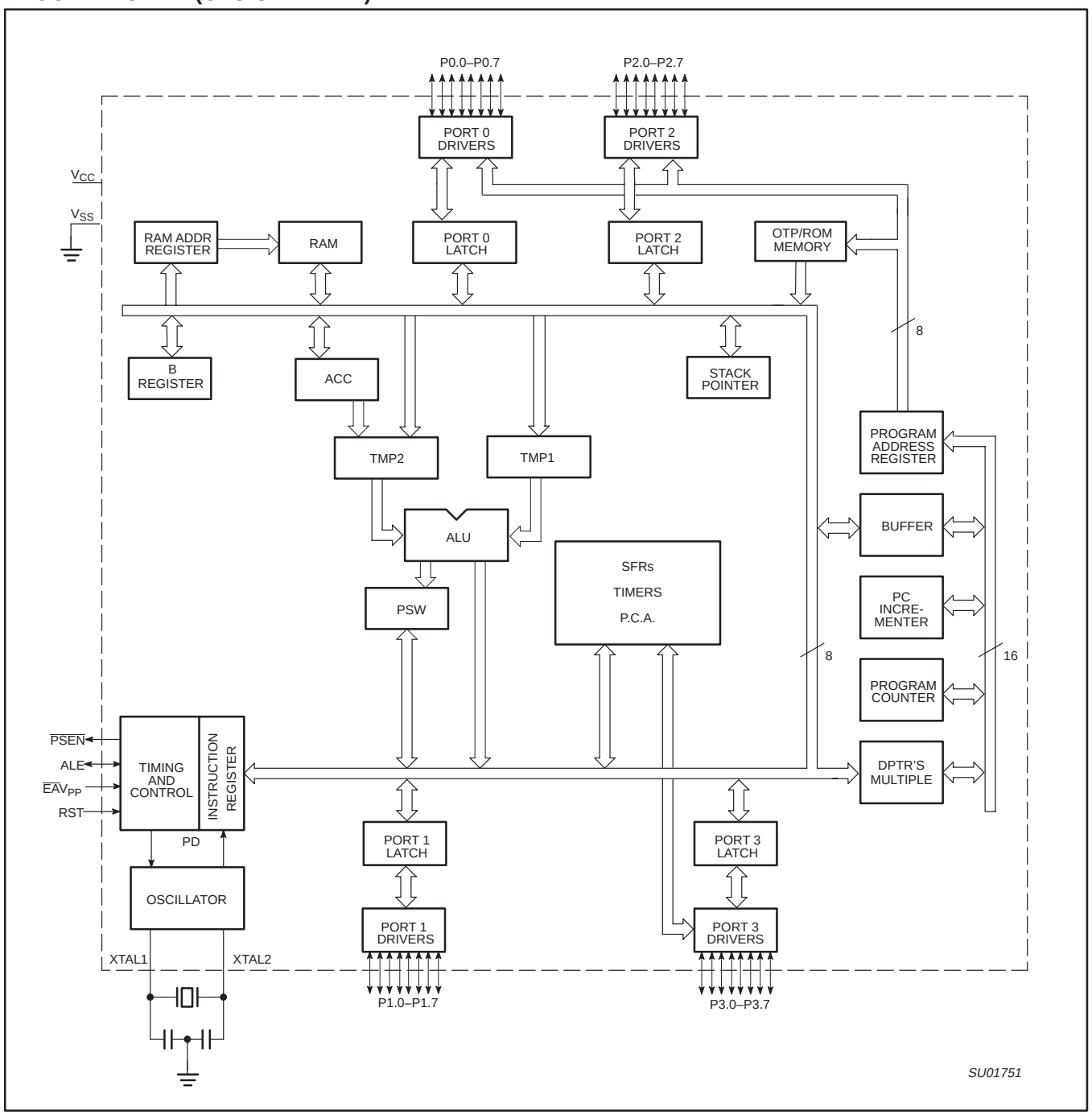
ORDERING INFORMATION

Type number				Package			Temp Range (°C)
	OTP	ROM	RAM	Name	Description	Version	
P83C654X2FA	–	16 KB	256B	PLCC44	plastic leaded chip carrier; 44 leads	SOT187–2	–40 to +85
P83C654X2BBD	–	16 KB	256B	LQFP44	plastic low profile quad flat package; 44 leads; body 10 × 10 × 1.4 mm	SOT389–1	0 to +70
P87C654X2FA	16 KB	–	256B	PLCC44	plastic leaded chip carrier; 44 leads	SOT187–2	–40 to +85
P87C654X2BBD	16 KB	–	256B	LQFP44	plastic low profile quad flat package; 44 leads; body 10 × 10 × 1.4 mm	SOT389–1	0 to +70

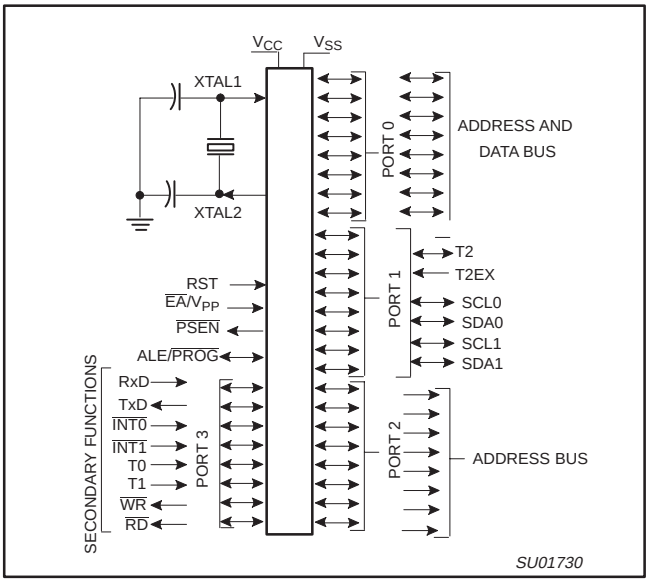
BLOCK DIAGRAM 1



BLOCK DIAGRAM (CPU ORIENTED)

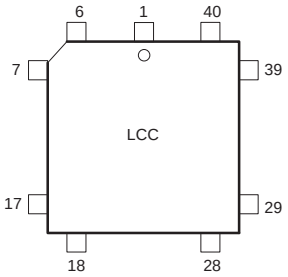


LOGIC SYMBOL



PINNING

Plastic Leaded Chip Carrier

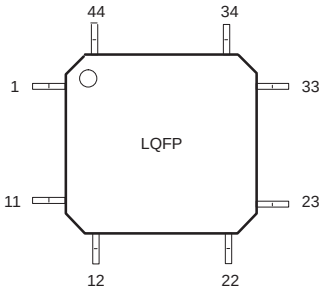


Pin	Function	Pin	Function	Pin	Function
1	NIC[1]	16	P3.4/T0	31	P2.7/A15
2	P1.0/T2	17	P3.5/T1	32	$\overline{PSEN}$
3	P1.1/T2EX	18	P3.6/$\overline{WR}$	33	ALE
4	P1.2/ECI	19	P3.7/$\overline{RD}$	34	V_{SS2}[2]
5	P1.3	20	XTAL2	35	$\overline{EA}/V_{PP}$
6	P1.4	21	XTAL1	36	P0.7/AD7
7	P1.5	22	V_{SS1}	37	P0.6/AD6
8	P1.6/SCL0	23	NIC[1]	38	P0.5/AD5
9	P1.7/SDA0	24	P2.0/A8	39	P0.4/AD4
10	RST	25	P2.1/A9	40	P0.3/AD3
11	P3.0/RxD	26	P2.2/A10	41	P0.2/AD2
12	V_{SS3}[2]	27	P2.3/A11	42	P0.1/AD1
13	P3.1/TxD	28	P2.4/A12	43	P0.0/AD0
14	P3.2/$\overline{INT0}$	29	P2.5/A13	44	V_{CC}
15	P3.3/$\overline{INT1}$	30	P2.6/A14		

SU01729

1. No internal connection
2. May be left open, but it is recommended that V_{SS2} and V_{SS3} be connected to GND to improve EMC performance

Plastic Quad Flat Pack



Pin	Function	Pin	Function	Pin	Function
1	P1.5	16	V_{SS1}	31	P0.6/AD6
2	P1.6/SCL0	17	NIC[1]	32	P0.5/AD5
3	P1.7/SDA0	18	P2.0/A8	33	P0.4/AD4
4	RST	19	P2.1/A9	34	P0.3/AD3
5	P3.0/RxD	20	P2.2/A10	35	P0.2/AD2
6	V_{SS3}[2]	21	P2.3/A11	36	P0.1/AD1
7	P3.1/TxD	22	P2.4/A12	37	P0.0/AD0
8	P3.2/$\overline{INT0}$	23	P2.5/A13	38	V_{CC}
9	P3.3/$\overline{INT1}$	24	P2.6/A14	39	NIC[1]
10	P3.4/T0	25	P2.7/A15	40	P1.0/T2
11	P3.5/T1	26	$\overline{PSEN}$	41	P1.1/T2EX
12	P3.6/$\overline{WR}$	27	ALE	42	P1.2/ECI
13	P3.7/$\overline{RD}$	28	V_{SS2}[2]	43	P1.3
14	XTAL2	29	$\overline{EA}/V_{PP}$	44	P1.4
15	XTAL1	30	P0.7/AD7		

SU01731

1. No internal connection
2. May be left open, but it is recommended that V_{SS2} and V_{SS3} be connected to GND to improve EMC performance

PIN DESCRIPTIONS

MNEMONIC	PIN NUMBER		TYPE	NAME AND FUNCTION
	PLCC	LQFP		
V_{SS}	22	16	I	**Ground:** 0 V reference.
V_{CC}	44	38	I	**Power Supply:** This is the power supply voltage for normal, idle, and power-down operation.
P0.0–0.7[2]	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[2]	2–9	40–44, 1–3	I/O	**Port 1:** Port 1 is an 8-bit bidirectional I/O port with internal pull-ups on all pins. 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 functions for P8xC654X2 Port 1 include:
	2	40	I/O	**T2 (P1.0):** Timer/Counter 2 external count input/Clockout (see Programmable Clock-Out)
	3	41	I	**T2EX (P1.1):** Timer/Counter 2 Reload/Capture/Direction Control
	3	41	I	
	4	42	I	
	5	43	I/O	
	6	44	I/O	
	7	1	I/O	
	8	2	I/O	**SCL (P1.6):** I^2C-bus clock line (open drain)
	9	3	I/O	**SDA (P1.7):** I^2C-bus data line (open drain)
P2.0–P2.7[2]	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[2]	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 P8xC654X2, as listed below:
	11	5	I	**RxD (P3.0):** Serial input port
	13	7	O	**TxD (P3.1):** Serial output port
	14	8	I	**$\overline{\text{INT0}}$ (P3.2):** External interrupt 0
	15	9	I	**$\overline{\text{INT1}}$ (P3.3):** External interrupt 1
	16	10	I	**T0 (P3.4):** Timer 0 external input
	17	11	I	**T1 (P3.5):** Timer 1 external input
	18	12	O	**$\overline{\text{WR}}$ (P3.6):** External data memory write strobe
	19	13	O	**$\overline{\text{RD}}$ (P3.7):** External data memory read strobe
RST[2]	10	4	I	**Reset:** A HIGH on this pin for two machine cycles while the oscillator is running, resets the device. An internal diffused resistor to V_{SS} permits a power-on reset using only an external capacitor to V_{CC}.
ALE[2]	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 constant rate of 1/6 the oscillator frequency in 12x clock mode, 1/3 the oscillator frequency in 6x clock mode, 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.
$\overline{\text{PSEN}}$[2]	32	26	O	**Program Store Enable:** The read strobe to external program memory. When executing code from the external program memory, $\overline{\text{PSEN}}$ is activated twice each machine cycle, except that two $\overline{\text{PSEN}}$ activations are skipped during each access to external data memory. $\overline{\text{PSEN}}$ is not activated during fetches from internal program memory.

MNEMONIC	PIN NUMBER		TYPE	NAME AND FUNCTION
	PLCC	LQFP		
$\overline{EA}$[2]	35	29	I	**External Access Enable/Programming Supply Voltage:** $\overline{EA}$ must be externally held LOW to enable the device to fetch code from external program memory. The value on the $\overline{EA}$ pin is latched when RST is released and any subsequent changes have no effect.
XTAL1	21	15	I	**Crystal 1:** Input to the inverting oscillator amplifier and input to the internal clock generator circuits.
XTAL2	20	14	O	**Crystal 2:** Output from the inverting oscillator amplifier.

NOTES:
1. To avoid "latch-up" effect at power-on, the voltage on any pin (other than $\overline{EA}$) at any time must not be higher than V_{CC} + 0.5 V or less than V_{SS} – 0.5 V, respectively.
2. The pins are designed for test mode also.

SPECIAL FUNCTION REGISTERS

SYMBOL	DESCRIPTION	DIRECT ADDRESS	BIT ADDRESS, SYMBOL, OR ALTERNATIVE PORT FUNCTION MSB							LSB	RESET VALUE
ACC*	Accumulator	E0H	E7	E6	E5	E4	E3	E2	E1	E0	00H
AUXR#	Auxiliary	8EH	–	–	–	–	Fast/STD I^2C	–	–	AO	xxxx1xx0B
AUXR1#	Auxiliary 1	A2H	–	–	–	LPEP	GPS	0	–	DPS	xxxx00x0B
B*	B register	F0H	F7	F6	F5	F4	F3	F2	F1	F0	00H
CKCON	Clock control	8FH	–	–	–	–	–	–	–	X2	xxxxxxx0B
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	
IEN0*	Interrupt Enable 0	A8H	EA	EC	ES1	ES0	ET1	EX1	ET0	EX0	00000000B
IEN1*	Interrupt Enable 1	E8H	–	–	–	–	–	–	ES2	ET2	xxxxxx00B
			BF	BE	BD	BC	BB	BA	B9	B8	
IP*#	Interrupt Priority	B8H	PT2	–	PS1	PS0	PT1	PX1	PT0	PX0	00000000B
			B7	B6	B5	B4	B3	B2	B1	B0	
IPH#	Interrupt Priority High	B7H	PT2H	PPCH	PS1H	PS0H	PT1H	PX1H	PT0H	PX0H	00000000B
			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	SDA	SCL	–	–	–	–	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	$\overline{RD}$	$\overline{WR}$	T1	T0	$\overline{INT1}$	$\overline{INT0}$	TxD	RxD	FFH
PCON#[1]	Power Control	87H	SMOD1	SMOD0	–	POF	GF1	GF0	PD	IDL	00xx0000B
			D7	D6	D5	D4	D3	D2	D1	D0	
PSW*	Program Status Word	D0H	CY	AC	F0	RS1	RS0	OV	F1	P	00000000B
RCAP2H#	Timer 2 Capture High	CBH									00H
RCAP2L#	Timer 2 Capture Low	CAH									00H
SADDR#	Slave Address	A9H									00H
SADEN#	Slave Address Mask	B9H									00H
SBUF	Serial Data Buffer	99H									xxxxxxxxB
			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/$\overline{T}$2	CP/$\overline{RL}$2	00H
T2MOD#	Timer 2 Mode Control	C9H	–	–	–	–	–	–	T2OE	DCEN	xxxxxx00B
TH0	Timer High 0	8CH									00H
TH1	Timer High 1	8DH									00H
TH2#	Timer High 2	CDH									00H

SYMBOL	DESCRIPTION	DIRECT ADDRESS	BIT ADDRESS, SYMBOL, OR ALTERNATIVE PORT FUNCTION MSB							LSB	RESET VALUE
TL0	Timer Low 0	8AH									00H
TL1	Timer Low 1	8BH									00H
TL2#	Timer Low 2	CCH									00H
TMOD	Timer Mode	89H	GATE	C/$\overline{T}$	M1	M0	GATE	C/$\overline{T}$	M1	M0	00H
S1CON	I2C Control	D8H	CR2	ENA1	STA	STO	SI	AA	CR1	CR0	00H
S1STA	I2C STATUS	D9H	SC4	SC3	SC2	SC1	SC0	0	0	0	F8H
S1DAT	I2C DATA	DAH									00H
S1ADR	I2C ADDRESS	DBH								GC	00H
WDTRST	Watchdog Reset Timer	A6H									

* SFRs are bit addressable.
\# SFRs are modified from or added to the 80C51 SFRs.
– Reserved bits.
1. Reset value depends on reset source.

CLOCK CONTROL REGISTER (CKCON)

This device allows control of the 6-clock/12-clock mode by means of both an SFR bit (X2) and an OTP bit. The OTP clock control bit OX2, when programmed (6-clock mode), supersedes the X2 bit (CKCON.0). The CKCON register is shown below in Figure 1.

CKCON Address = 8Fh Reset Value = x0000000B

Not Bit Addressable

7	6	5	4	3	2	1	0
–	–	–	–	–	–	–	X2

BIT	SYMBOL	FUNCTION
CKCON.7	–	Reserved.
CKCON.6		Reserved.
CKCON.5		Reserved.
CKCON.4		Reserved.
CKCON.3		Reserved.
CKCON.2		Reserved.
CKCON.1		Reserved.
CKCON.0	X2	CPU clock; 1 = 6 clocks for each machine cycle, 0 = 12 clocks for each machine cycle

SU01689

Figure 1. Clock control (CKCON) register

Also please note that the clock divider applies to the serial port for modes 0 and 2 (fixed baud rate modes). This is because modes 1 and 3 (variable baud rate modes) use either Timer 1 or Timer 2.

Below is the truth table for the CPU clock mode.

Table 1.

OX2 clock mode bit (can only be set by parallel programmer)	X2 bit (CKCON.0)	CPU clock mode
erased	0	12-clock mode (default)
erased	1	6-clock mode
programmed	X	6-clock mode

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. Minimum and maximum high and low times specified in the data sheet must be observed.

This device is configured at the factory to operate using 12 clock periods per machine cycle, referred to in this datasheet as “12-clock mode”. It may be optionally configured on commercially available EPROM programming equipment to operate at 6 clocks per machine cycle, referred to in this datasheet as “6-clock mode”. (This yields performance equivalent to twice that of standard 80C51 family devices). Also see next page.

RESET

A reset is accomplished by holding the RST pin HIGH for at least two machine cycles (12 oscillator periods in 6-clock mode, or 24 oscillator periods in 12-clock mode), 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 $V_{IH\ (min.)}$ is applied to RESET. The value on the EA pin is latched when RST is deasserted and has no further effect.

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 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 10 ms).

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.

POWER-OFF FLAG

The Power-Off Flag (POF) is set by on-chip circuitry when the V_{CC} level on the P8xC654X2 rises from 0 to 5 V. The POF bit can be set or cleared by software allowing a user to determine if the reset is the result of a power-on or a warm start after power-down. The V_{CC} level must remain above 3 V for the POF to remain unaffected by the V_{CC} level.

Low-Power EPROM operation (LPEP)

The EPROM array contains some analog circuits that are not required when V_{CC} is less than 4 V, but are required for a V_{CC} greater than 4 V. The LPEP bit (AUXR.4), when set, will power-down these analog circuits resulting in a reduced supply current. This bit should be set ONLY for applications that operate at a V_{CC} less than 4 V.

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 122 Hz to 8 MHz at a 16 MHz operating frequency (61 Hz to 4 MHz in 12-clock mode).

To configure the Timer/Counter 2 as a clock generator, bit C/$\overline{T}$2 (in T2CON) must be cleared and bit T20E 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:

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

n = 2 in 6-clock mode
4 in 12-clock mode

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	$\overline{\text{PSEN}}$	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

TIMER 0 AND TIMER 1 OPERATION

Timer 0 and Timer 1

The "Timer" or "Counter" function is selected by control bits C/$\overline{T}$ 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 3 shows the Mode 0 operation.

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 TFn. The counted input is enabled to the Timer when TRn = 1 and either GATE = 0 or $\overline{INTn}$ = 1. (Setting GATE = 1 allows the Timer to be controlled by external input $\overline{INTn}$, to facilitate pulse width measurements). TRn is a control bit in the Special Function Register TCON (Figure 4).

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

Mode 0 operation is the same for Timer 0 as for Timer 1. 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 (TLn) with automatic reload, as shown in Figure 5. Overflow from TLn not only sets TFn, but also reloads TLn with the contents of THn, which is preset by software. The reload leaves THn unchanged.

Mode 2 operation is the same for Timer 0 as for Timer 1.

Mode 3

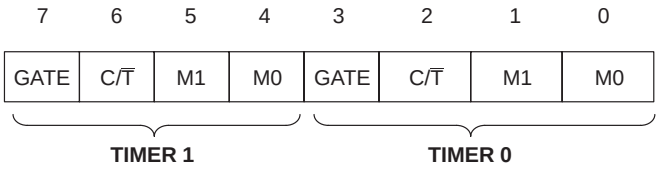
Timer 1 in Mode 3 simply holds its count. The effect is the same as setting TR1 = 0.

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 6. TL0 uses the Timer 0 control bits: C/$\overline{T}$, GATE, TR0, and TF0 as well as pin $\overline{INT0}$. 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.

TMOD Address = 89H Reset Value = 00H

Not Bit Addressable



BIT	SYMBOL	FUNCTION
TMOD.3/ TMOD.7	GATE	Gating control when set. Timer/Counter "n" is enabled only while "$\overline{INTn}$" pin is high and "TRn" control pin is set. when cleared Timer "n" is enabled whenever "TRn" control bit is set.
TMOD.2/ TMOD.6	C/$\overline{T}$	Timer or Counter Selector cleared for Timer operation (input from internal system clock.) Set for Counter operation (input from "Tn" input pin).

M1	M0	OPERATING
0	0	8048 Timer: "TLn" serves as 5-bit prescaler.
0	1	16-bit Timer/Counter: "THn" and "TLn" are cascaded; there is no prescaler.
1	0	8-bit auto-reload Timer/Counter: "THn" holds a value which is to be reloaded into "TLn" each time it overflows.
1	1	(Timer 0) TL0 is an 8-bit Timer/Counter controlled by the standard Timer 0 control bits. TH0 is an 8-bit timer only controlled by Timer 1 control bits.
1	1	(Timer 1) Timer/Counter 1 stopped.

SU01580

Figure 2. Timer/Counter 0/1 Mode Control (TMOD) Register

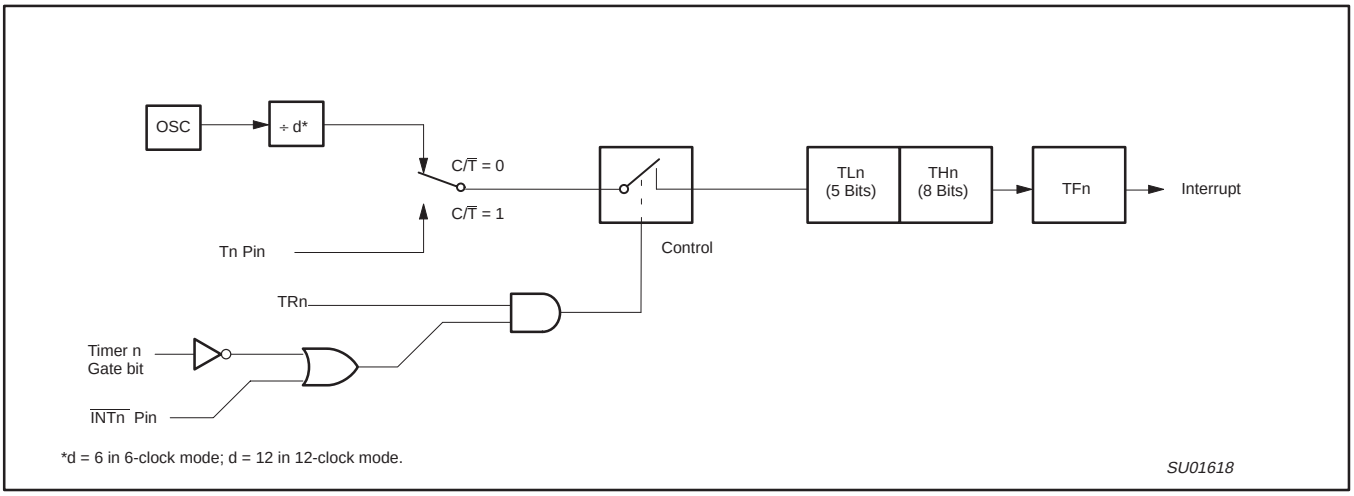


Figure 3. Timer/Counter 0/1 Mode 0: 13-Bit Timer/Counter

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.

SU01516

Figure 4. Timer/Counter 0/1 Control (TCON) Register

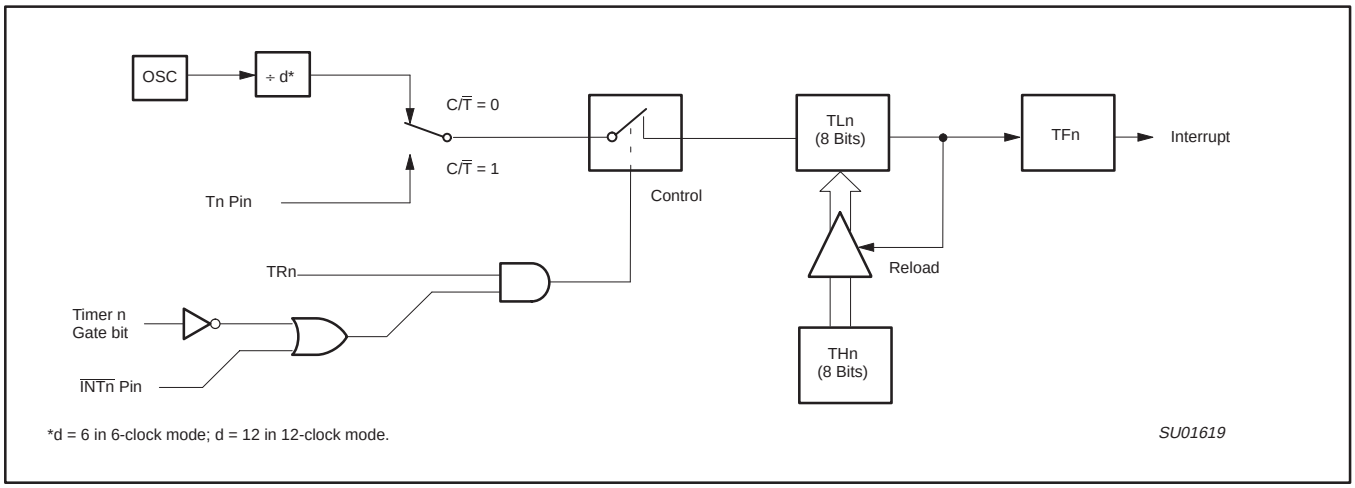


Figure 5. Timer/Counter 0/1 Mode 2: 8-Bit Auto-Reload

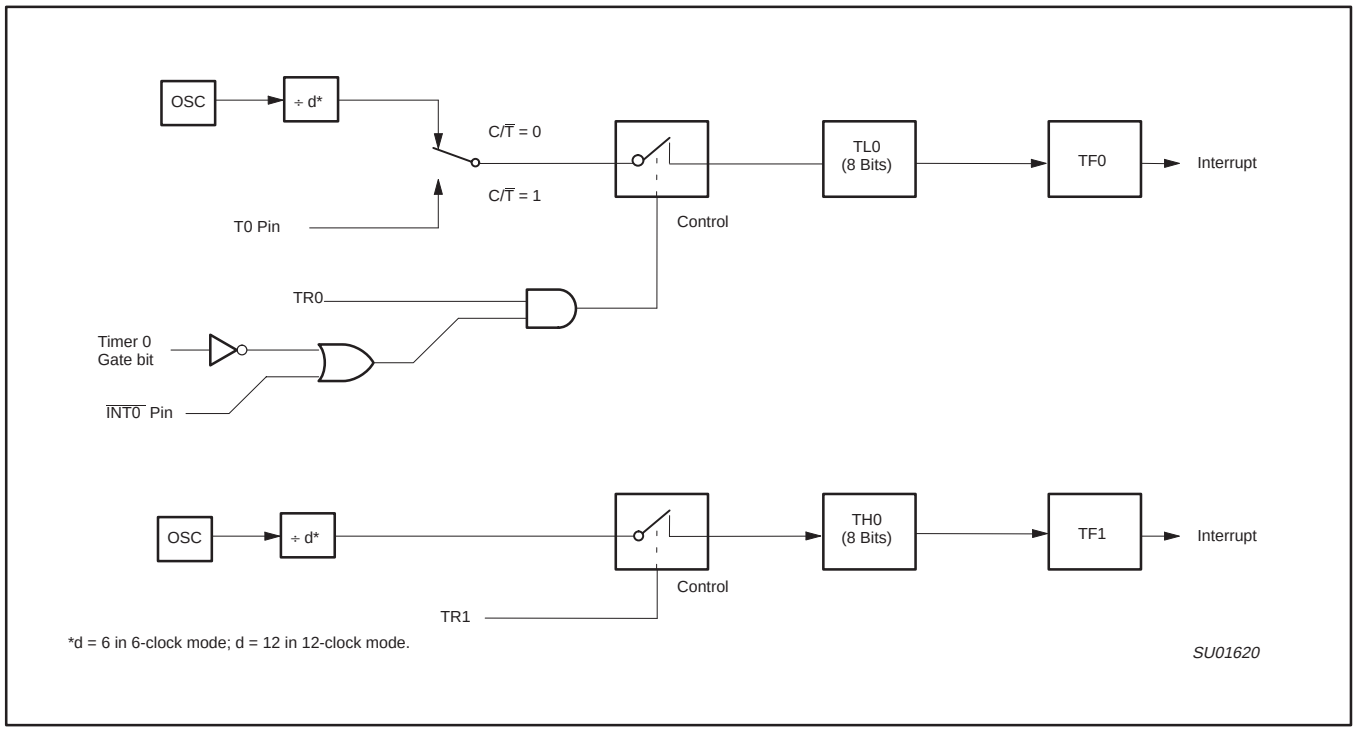


Figure 6. Timer/Counter 0 Mode 3: Two 8-Bit Counters

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/$\overline{T}$2 in the special function register T2CON (see Figure 7). 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/$\overline{T}$2 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 8 (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/6 pulses (osc/12 in 12-clock mode).).

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/$\overline{T}$2 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 9). 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 10 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 11 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.

(MSB) (LSB)

TF2	EXF2	RCLK	TCLK	EXEN2	TR2	C/$\overline{T}$2	CP/$\overline{RL}$2

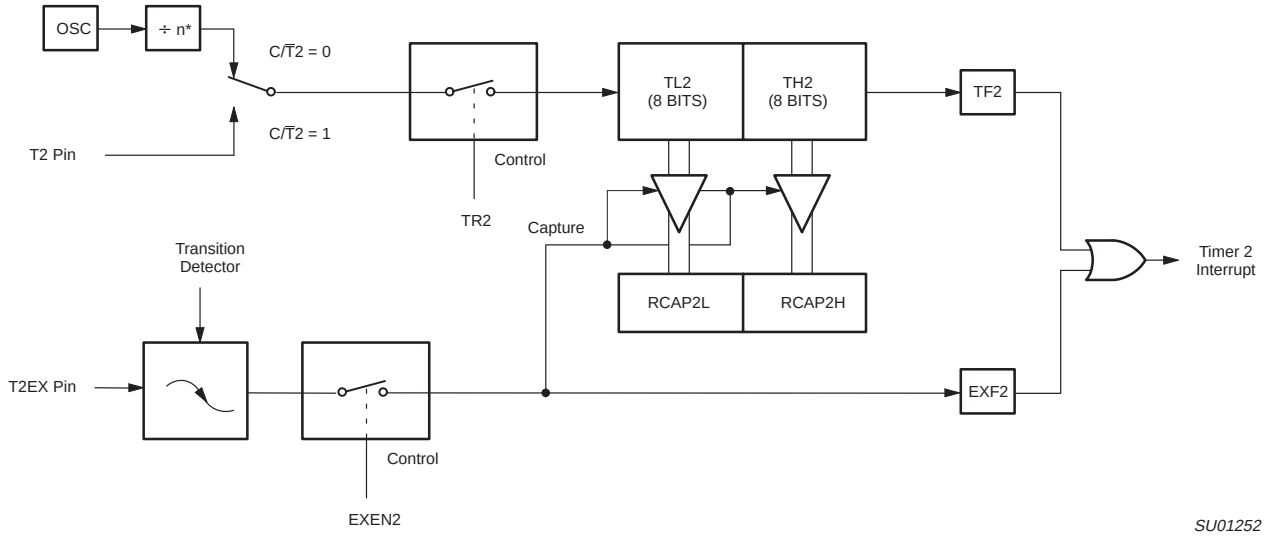
Symbol	Position	Name and Significance
TF2	T2CON.7	Timer 2 overflow flag set by a Timer 2 overflow and must be cleared by software. TF2 will not be set when either RCLK or TCLK = 1.
EXF2	T2CON.6	Timer 2 external flag set when either a capture or reload is caused by a negative transition on T2EX and EXEN2 = 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/$\overline{T}$2	T2CON.1	Timer or counter select. (Timer 2) 0 = Internal timer (OSC/6 in 6-clock mode or OSC/12 in 12-clock mode) 1 = External event counter (falling edge triggered).
CP/$\overline{RL}$2	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.

SU01251

Figure 7. Timer/Counter 2 (T2CON) Control Register

Table 3. Timer 2 Operating Modes

RCLK + TCLK	CP/$\overline{RL2}$	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)



* n = 6 in 6-clock mode, or 12 in 12-clock mode.

Figure 8. Timer 2 in Capture Mode

T2MOD Address = 0C9H Reset Value = XXXX XX00B

Not Bit Addressable

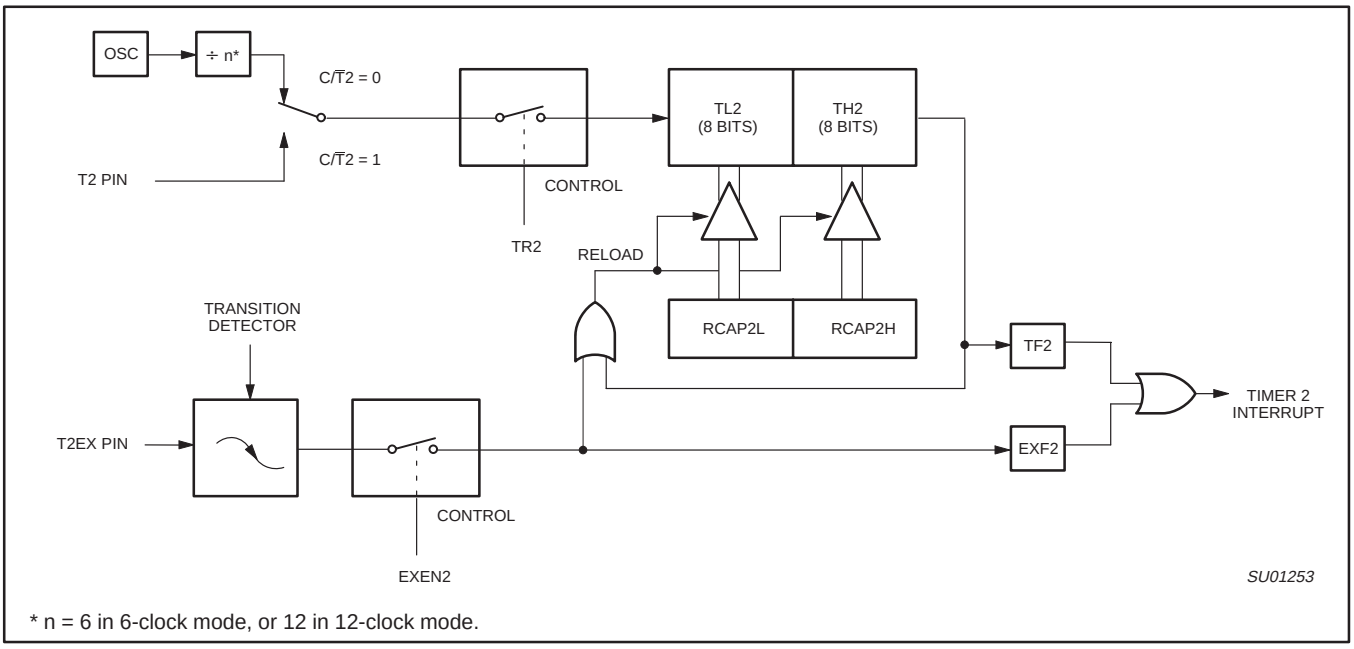
—	—	—	—	—	—	T2OE	DCEN
Bit 7	6	5	4	3	2	1	0

Symbol	Function
—	Not implemented, reserved for future use.*
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.

* 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.

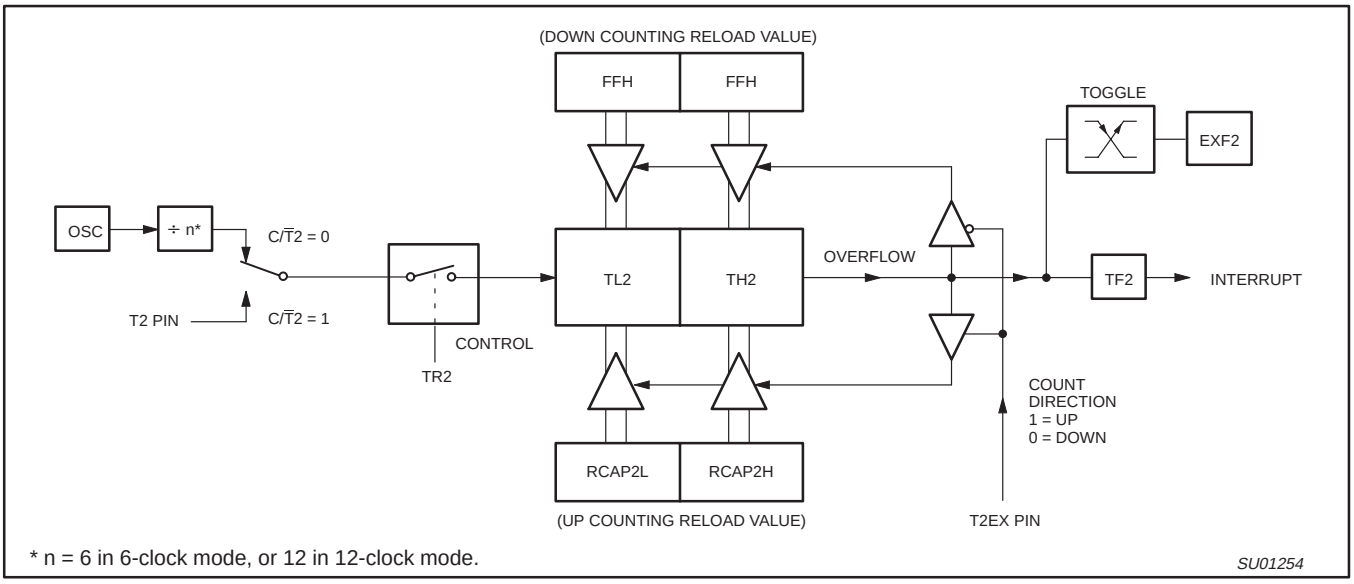
SU00729

Figure 9. Timer 2 Mode (T2MOD) Control Register



* n = 6 in 6-clock mode, or 12 in 12-clock mode.

Figure 10. Timer 2 in Auto-Reload Mode (DCEN = 0)



* n = 6 in 6-clock mode, or 12 in 12-clock mode.

Figure 11. Timer 2 Auto Reload Mode (DCEN = 1)

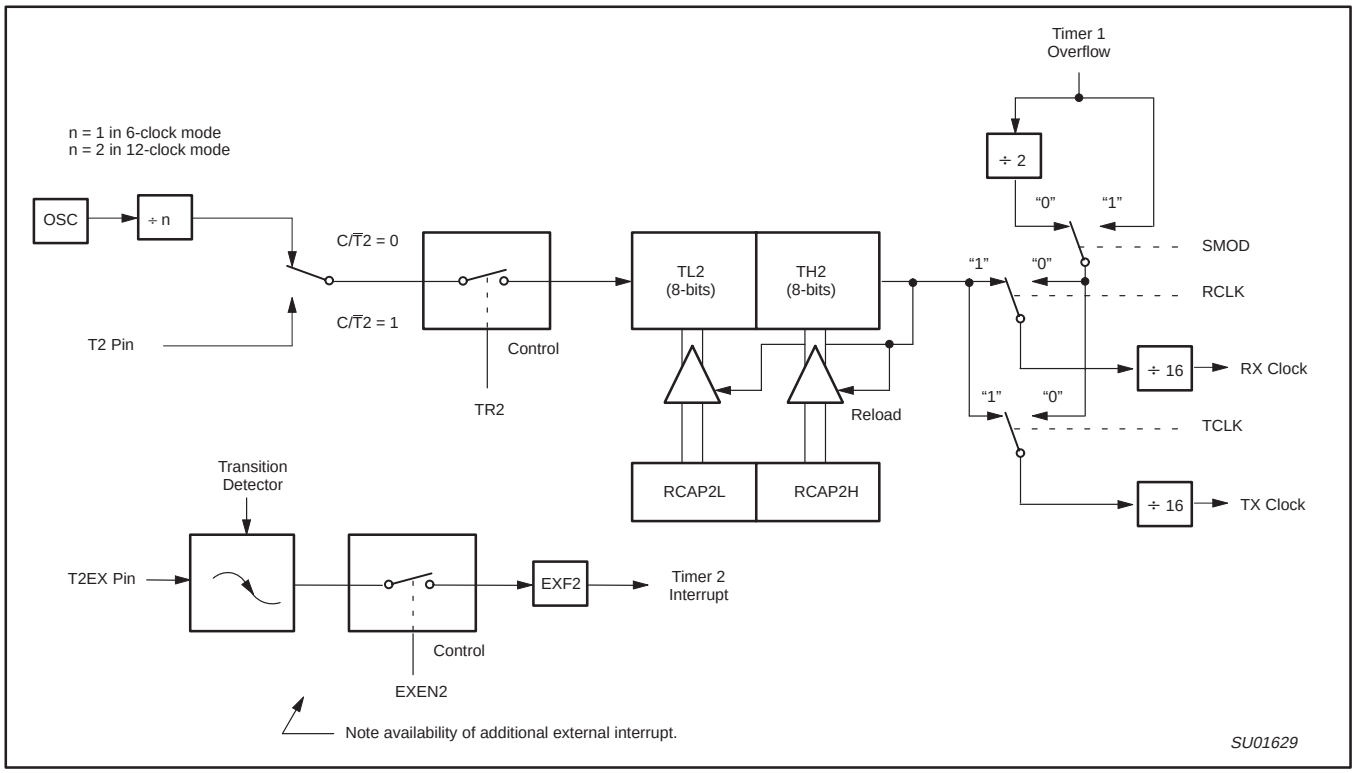


Figure 12. Timer 2 in Baud Rate Generator Mode

Table 4. Timer 2 Generated Commonly Used Baud Rates

Baud Rate		Osc Freq	Timer 2	
12-clock mode	6-clock mode		RCAP2H	RCAP2L
375 k	750 k	12 MHz	FF	FF
9.6 k	19.2 k	12 MHz	FF	D9
4.8 k	9.6 k	12 MHz	FF	B2
2.4 k	4.8 k	12 MHz	FF	64
1.2 k	2.4 k	12 MHz	FE	C8
300	600	12 MHz	FB	1E
110	220	12 MHz	F2	AF
300	600	6 MHz	FD	8F
110	220	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 12 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/$\overline{T}$2 = 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., $^1/_6$ the oscillator frequency in 6-clock mode, $^1/_{12}$ the oscillator frequency in 12-clock mode). As a baud rate generator, it increments at the oscillator frequency in 6-clock mode ($^{OSC}/_2$ in 12-clock mode). Thus the baud rate formula is as follows:

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

* n = 16 in 6-clock mode
32 in 12-clock mode

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 12, 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.

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 (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:

$$\text{Baud Rate} = \frac{f_{OSC}}{[\ n^* \times [65536 - (\text{RCAP2H, RCAP2L})]]}$$

* n = 16 in 6-clock mode
32 in 12-clock mode

Where f_{osc} = Oscillator Frequency

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

$$\text{RCAP2H, RCAP2L} = 65536 - \left(\frac{f_{OSC}}{n^* \times \text{Baud Rate}}\right)$$

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.

FULL-DUPLEX ENHANCED UART

Standard UART operation

The serial port is full duplex, meaning it can transmit and receive simultaneously. It is also receive-buffered, meaning it can commence reception of a second byte before a previously received byte has been read from the register. (However, if the first byte still hasn't been read by the time reception of the second byte is complete, one of the bytes will be lost.) The serial port receive and transmit registers are both accessed at Special Function Register SBUF. Writing to SBUF loads the transmit register, and reading SBUF accesses a physically separate receive register.

The serial port can operate in 4 modes:

Mode 0: Serial data enters and exits through RxD. TxD outputs the shift clock. 8 bits are transmitted/received (LSB first). The baud rate is fixed at 1/12 the oscillator frequency in 12-clock mode or 1/6 the oscillator frequency in 6-clock mode.

Mode 1: 10 bits are transmitted (through TxD) or received (through RxD): a start bit (0), 8 data bits (LSB first), and a stop bit (1). On receive, the stop bit goes into RB8 in Special Function Register SCON. The baud rate is variable.

Mode 2: 11 bits are transmitted (through TxD) or received (through RxD): start bit (0), 8 data bits (LSB first), a programmable 9th data bit, and a stop bit (1). On Transmit, the 9th data bit (TB8 in SCON) can be assigned the value of 0 or 1. Or, for example, the parity bit (P, in the PSW) could be moved into TB8. On receive, the 9th data bit goes into RB8 in Special Function Register SCON, while the stop bit is ignored. The baud rate is programmable to either 1/32 or 1/64 the oscillator frequency in 12-clock mode or 1/16 or 1/32 the oscillator frequency in 6-clock mode.

Mode 3: 11 bits are transmitted (through TxD) or received (through RxD): a start bit (0), 8 data bits (LSB first), a programmable 9th data bit, and a stop bit (1). In fact, Mode 3 is the same as Mode 2 in all respects except baud rate. The baud rate in Mode 3 is variable.

In all four modes, transmission is initiated by any instruction that uses SBUF as a destination register. Reception is initiated in Mode 0 by the condition RI = 0 and REN = 1. Reception is initiated in the other modes by the incoming start bit if REN = 1.

Multiprocessor Communications

Modes 2 and 3 have a special provision for multiprocessor communications. In these modes, 9 data bits are received. The 9th one goes into RB8. Then comes a stop bit. The port can be programmed such that when the stop bit is received, the serial port interrupt will be activated only if RB8 = 1. This feature is enabled by setting bit SM2 in SCON. A way to use this feature in multiprocessor systems is as follows:

When the master processor wants to transmit a block of data to one of several slaves, it first sends out an address byte which identifies the target slave. An address byte differs from a data byte in that the 9th bit is 1 in an address byte and 0 in a data byte. With SM2 = 1, no slave will be interrupted by a data byte. An address byte, however, will interrupt all slaves, so that each slave can examine the received byte and see if it is being addressed. The addressed slave will clear its SM2 bit and prepare to receive the data bytes that will be coming. The slaves that weren't being addressed leave their SM2s set and go on about their business, ignoring the coming data bytes.

SM2 has no effect in Mode 0, and in Mode 1 can be used to check the validity of the stop bit. In a Mode 1 reception, if SM2 = 1, the receive interrupt will not be activated unless a valid stop bit is received.

Serial Port Control Register

The serial port control and status register is the Special Function Register SCON, shown in Figure 13. This register contains not only the mode selection bits, but also the 9th data bit for transmit and receive (TB8 and RB8), and the serial port interrupt bits (TI and RI).

Baud Rates

The baud rate in Mode 0 is fixed: Mode 0 Baud Rate = Oscillator Frequency / 12 (12-clock mode) or / 6 (6-clock mode). The baud rate in Mode 2 depends on the value of bit SMOD in Special Function Register PCON. If SMOD = 0 (which is the value on reset), and the port pins in 12-clock mode, the baud rate is 1/64 the oscillator frequency. If SMOD = 1, the baud rate is 1/32 the oscillator frequency. In 6-clock mode, the baud rate is 1/32 or 1/16 the oscillator frequency, respectively.

Mode 2 Baud Rate =

$$\frac{2^{SMOD}}{n} \times (\text{Oscillator Frequency})$$

Where:

n = 64 in 12-clock mode, 32 in 6-clock mode

The baud rates in Modes 1 and 3 are determined by the Timer 1 or Timer 2 overflow rate.

Using Timer 1 to Generate Baud Rates

When Timer 1 is used as the baud rate generator (T2CON.RCLK = 0, T2CON.TCLK = 0), the baud rates in Modes 1 and 3 are determined by the Timer 1 overflow rate and the value of SMOD as follows:

Mode 1, 3 Baud Rate =

$$\frac{2^{SMOD}}{n} \times (\text{Timer 1 Overflow Rate})$$

Where:

n = 32 in 12-clock mode, 16 in 6-clock mode

The Timer 1 interrupt should be disabled in this application. The Timer itself can be configured for either "timer" or "counter" operation, and in any of its 3 running modes. In the most typical applications, it is configured for "timer" operation, in the auto-reload mode (high nibble of TMOD = 0010B). In that case the baud rate is given by the formula:

Mode 1, 3 Baud Rate =

$$\frac{2^{SMOD}}{n} \times \frac{\text{Oscillator Frequency}}{12 \times [256-(TH1)]}$$

Where:

n = 32 in 12-clock mode, 16 in 6-clock mode

One can achieve very low baud rates with Timer 1 by leaving the Timer 1 interrupt enabled, and configuring the Timer to run as a 16-bit timer (high nibble of TMOD = 0001B), and using the Timer 1 interrupt to do a 16-bit software reload. Figure 14 lists various commonly used baud rates and how they can be obtained from Timer 1.

SCON Address = 98H Reset Value = 00H

Bit Addressable

7	6	5	4	3	2	1	0
SM0	SM1	SM2	REN	TB8	RB8	TI	RI

Where SM0, SM1 specify the serial port mode, as follows:

SM0	SM1	Mode	Description	Baud Rate
0	0	0	shift register	$f_{OSC}/12$ (12-clock mode) or $f_{OSC}/6$ (6-clock mode)
0	1	1	8-bit UART	variable
1	0	2	9-bit UART	$f_{OSC}/64$ or $f_{OSC}/32$ (12-clock mode) or $f_{OSC}/32$ or $f_{OSC}/16$ (6-clock mode)
1	1	3	9-bit UART	variable

SM2 Enables the multiprocessor communication feature in Modes 2 and 3. In Mode 2 or 3, if SM2 is set to 1, then RI will not be activated if the received 9th data bit (RB8) is 0. In Mode 1, if SM2=1 then RI will not be activated if a valid stop bit was not received. In Mode 0, SM2 should be 0.

REN Enables serial reception. Set by software to enable reception. Clear by software to disable reception.

TB8 The 9th data bit that will be transmitted in Modes 2 and 3. Set or clear by software as desired.

RB8 In Modes 2 and 3, is the 9th data bit that was received. In Mode 1, it SM2=0, RB8 is the stop bit that was received. In Mode 0, RB8 is not used.

TI Transmit interrupt flag. Set by hardware at the end of the 8th bit time in Mode 0, or at the beginning of the stop bit in the other modes, in any serial transmission. Must be cleared by software.

RI Receive interrupt flag. Set by hardware at the end of the 8th bit time in Mode 0, or halfway through the stop bit time in the other modes, in any serial reception (except see SM2). Must be cleared by software.

SU01626

Figure 13. Serial Port Control (SCON) Register

Baud Rate			f_{osc}	SMOD	Timer 1		
Mode	12-clock mode	6-clock mode			C/$\overline{T}$	Mode	Reload Value
Mode 0 Max	1.67 MHz	3.34 MHz	20 MHz	X	X	X	X
Mode 2 Max	625 k	1250 k	20 MHz	1	X	X	X
Mode 1, 3 Max	104.2 k	208.4 k	20 MHz	1	0	2	FFH
Mode 1, 3	19.2 k	38.4 k	11.059 MHz	1	0	2	FDH
	9.6 k	19.2 k	11.059 MHz	0	0	2	FDH
	4.8 k	9.6 k	11.059 MHz	0	0	2	FAH
	2.4 k	4.8 k	11.059 MHz	0	0	2	F4H
	1.2 k	2.4 k	11.059 MHz	0	0	2	E8H
	137.5	275	11.986 MHz	0	0	2	1DH
	110	220	6 MHz	0	0	2	72H
	110	220	12 MHz	0	0	1	FEEBH

Figure 14. Timer 1 Generated Commonly Used Baud Rates

More About Mode 0

Serial data enters and exits through RxD. TxD outputs the shift clock. 8 bits are transmitted/received: 8 data bits (LSB first). The baud rate is fixed a 1/12 the oscillator frequency (12-clock mode) or 1/6 the oscillator frequency (6-clock mode).

Figure 15 shows a simplified functional diagram of the serial port in Mode 0, and associated timing.

Transmission is initiated by any instruction that uses SBUF as a destination register. The “write to SBUF” signal at S6P2 also loads a 1 into the 9th position of the transmit shift register and tells the TX Control block to commence a transmission. The internal timing is such that one full machine cycle will elapse between “write to SBUF” and activation of SEND.

SEND enables the output of the shift register to the alternate output function line of P3.0 and also enable SHIFT CLOCK to the alternate output function line of P3.1. SHIFT CLOCK is LOW during S3, S4, and S5 of every machine cycle, and HIGH during S6, S1, and S2. At S6P2 of every machine cycle in which SEND is active, the contents of the transmit shift are shifted to the right one position.

As data bits shift out to the right, zeros come in from the left. When the MSB of the data byte is at the output position of the shift register, then the 1 that was initially loaded into the 9th position, is just to the left of the MSB, and all positions to the left of that contain zeros. This condition flags the TX Control block to do one last shift and then deactivate SEND and set T1. Both of these actions occur at S1P1 of the 10th machine cycle after “write to SBUF.”

Reception is initiated by the condition REN = 1 and R1 = 0. At S6P2 of the next machine cycle, the RX Control unit writes the bits 11111110 to the receive shift register, and in the next clock phase activates RECEIVE.

RECEIVE enable SHIFT CLOCK to the alternate output function line of P3.1. SHIFT CLOCK makes transitions at S3P1 and S6P1 of every machine cycle. At S6P2 of every machine cycle in which RECEIVE is active, the contents of the receive shift register are

shifted to the left one position. The value that comes in from the right is the value that was sampled at the P3.0 pin at S5P2 of the same machine cycle.

As data bits come in from the right, 1s shift out to the left. When the 0 that was initially loaded into the rightmost position arrives at the leftmost position in the shift register, it flags the RX Control block to do one last shift and load SBUF. At S1P1 of the 10th machine cycle after the write to SCON that cleared RI, RECEIVE is cleared as RI is set.

More About Mode 1

Ten bits are transmitted (through TxD), or received (through RxD): a start bit (0), 8 data bits (LSB first), and a stop bit (1). On receive, the stop bit goes into RB8 in SCON. In the 80C51 the baud rate is determined by the Timer 1 or Timer 2 overflow rate.

Figure 16 shows a simplified functional diagram of the serial port in Mode 1, and associated timings for transmit receive.

Transmission is initiated by any instruction that uses SBUF as a destination register. The “write to SBUF” signal also loads a 1 into the 9th bit position of the transmit shift register and flags the TX Control unit that a transmission is requested. Transmission actually commences at S1P1 of the machine cycle following the next rollover in the divide-by-16 counter. (Thus, the bit times are synchronized to the divide-by-16 counter, not to the “write to SBUF” signal.)

The transmission begins with activation of SEND which puts the start bit at TxD. One bit time later, DATA is activated, which enables the output bit of the transmit shift register to TxD. The first shift pulse occurs one bit time after that.

As data bits shift out to the right, zeros are clocked in from the left. When the MSB of the data byte is at the output position of the shift register, then the 1 that was initially loaded into the 9th position is just to the left of the MSB, and all positions to the left of that contain zeros. This condition flags the TX Control unit to do one last shift and then deactivate SEND and set TI. This occurs at the 10th divide-by-16 rollover after “write to SBUF.”

Reception is initiated by a detected 1-to-0 transition at RxD. For this purpose RxD is sampled at a rate of 16 times whatever baud rate has been established. When a transition is detected, the divide-by-16 counter is immediately reset, and 1FFH is written into the input shift register. Resetting the divide-by-16 counter aligns its rollovers with the boundaries of the incoming bit times.

The 16 states of the counter divide each bit time into 16ths. At the 7th, 8th, and 9th counter states of each bit time, the bit detector samples the value of RxD. The value accepted is the value that was seen in at least 2 of the 3 samples. This is done for noise rejection. If the value accepted during the first bit time is not 0, the receive circuits are reset and the unit goes back to looking for another 1-to-0 transition. This is to provide rejection of false start bits. If the start bit proves valid, it is shifted into the input shift register, and reception of the rest of the frame will proceed.

As data bits come in from the right, 1s shift out to the left. When the start bit arrives at the leftmost position in the shift register (which in mode 1 is a 9-bit register), it flags the RX Control block to do one last shift, load SBUF and RB8, and set RI. The signal to load SBUF and RB8, and to set RI, will be generated if, and only if, the following conditions are met at the time the final shift pulse is generated.:

1. RI = 0, and
2. Either SM2 = 0, or the received stop bit = 1.

If either of these two conditions is not met, the received frame is irretrievably lost. If both conditions are met, the stop bit goes into RB8, the 8 data bits go into SBUF, and RI is activated. At this time, whether the above conditions are met or not, the unit goes back to looking for a 1-to-0 transition in RxD.

More About Modes 2 and 3

Eleven bits are transmitted (through TxD), or received (through RxD): a start bit (0), 8 data bits (LSB first), a programmable 9th data bit, and a stop bit (1). On transmit, the 9th data bit (TB8) can be assigned the value of 0 or 1. On receive, the 9the data bit goes into RB8 in SCON. The baud rate is programmable to either 1/32 or 1/64 (12-clock mode) or 1/16 or 1/32 the oscillator frequency (6-clock mode) the oscillator frequency in Mode 2. Mode 3 may have a variable baud rate generated from Timer 1 or Timer 2.

Figures 17 and 18 show a functional diagram of the serial port in Modes 2 and 3. The receive portion is exactly the same as in Mode 1. The transmit portion differs from Mode 1 only in the 9th bit of the transmit shift register.

Transmission is initiated by any instruction that uses SBUF as a destination register. The “write to SBUF” signal also loads TB8 into the 9th bit position of the transmit shift register and flags the TX Control unit that a transmission is requested. Transmission commences at S1P1 of the machine cycle following the next rollover in the divide-by-16 counter. (Thus, the bit times are synchronized to the divide-by-16 counter, not to the “write to SBUF” signal.)

The transmission begins with activation of SEND, which puts the start bit at TxD. One bit time later, DATA is activated, which enables the output bit of the transmit shift register to TxD. The first shift pulse occurs one bit time after that. The first shift clocks a 1 (the stop bit) into the 9th bit position of the shift register. Thereafter, only zeros are clocked in. Thus, as data bits shift out to the right, zeros are clocked in from the left. When TB8 is at the output position of the shift register, then the stop bit is just to the left of TB8, and all positions to the left of that contain zeros. This condition flags the TX Control unit to do one last shift and then deactivate SEND and set TI. This occurs at the 11th divide-by-16 rollover after “write to SUBF.”

Reception is initiated by a detected 1-to-0 transition at RxD. For this purpose RxD is sampled at a rate of 16 times whatever baud rate has been established. When a transition is detected, the divide-by-16 counter is immediately reset, and 1FFH is written to the input shift register.

At the 7th, 8th, and 9th counter states of each bit time, the bit detector samples the value of R-D. The value accepted is the value that was seen in at least 2 of the 3 samples. If the value accepted during the first bit time is not 0, the receive circuits are reset and the unit goes back to looking for another 1-to-0 transition. If the start bit proves valid, it is shifted into the input shift register, and reception of the rest of the frame will proceed.

As data bits come in from the right, 1s shift out to the left. When the start bit arrives at the leftmost position in the shift register (which in Modes 2 and 3 is a 9-bit register), it flags the RX Control block to do one last shift, load SBUF and RB8, and set RI.

The signal to load SBUF and RB8, and to set RI, will be generated if, and only if, the following conditions are met at the time the final shift pulse is generated.

1. RI = 0, and
2. Either SM2 = 0, or the received 9th data bit = 1.

If either of these conditions is not met, the received frame is irretrievably lost, and RI is not set. If both conditions are met, the received 9th data bit goes into RB8, and the first 8 data bits go into SBUF. One bit time later, whether the above conditions were met or not, the unit goes back to looking for a 1-to-0 transition at the RxD input.

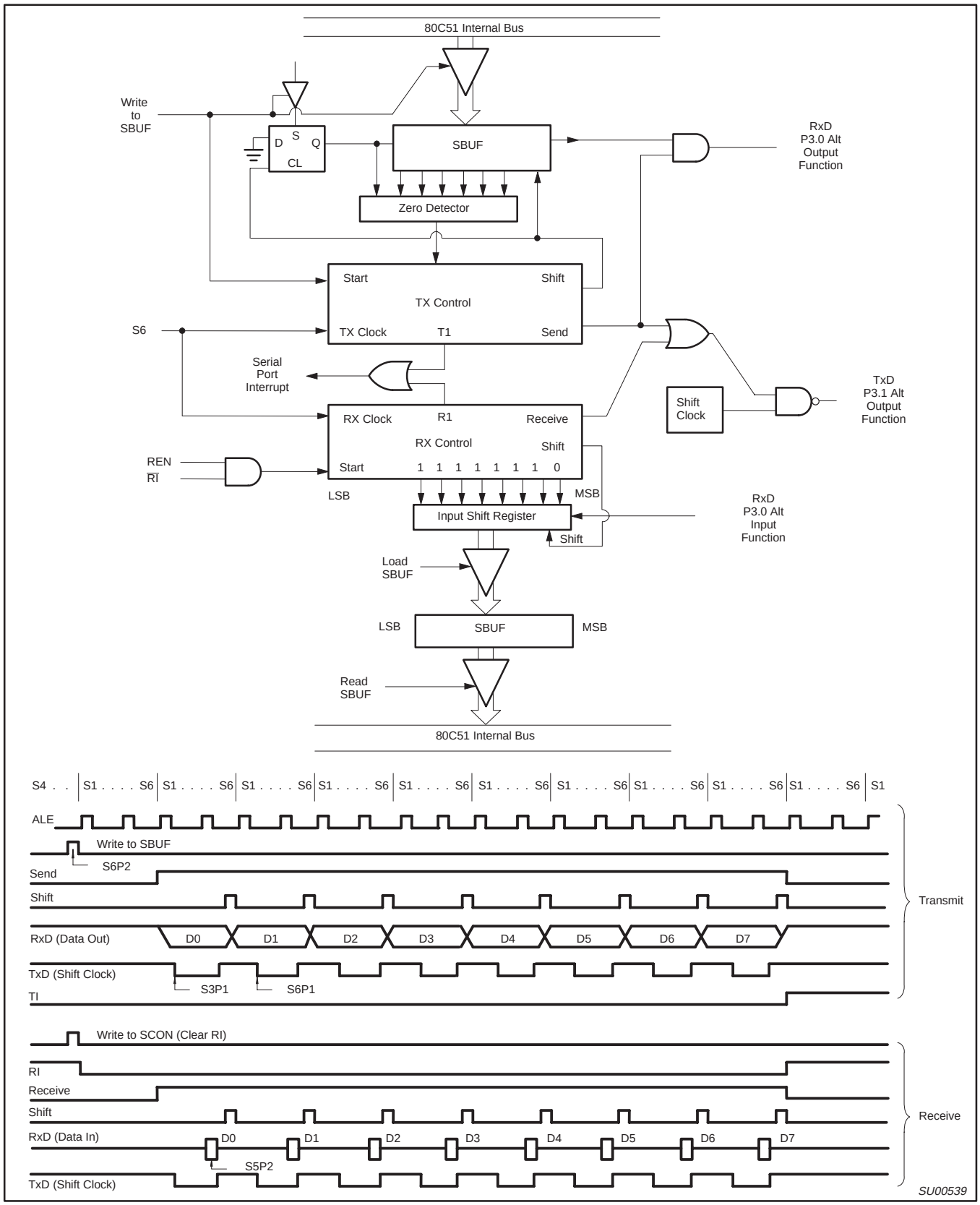


Figure 15. Serial Port Mode 0

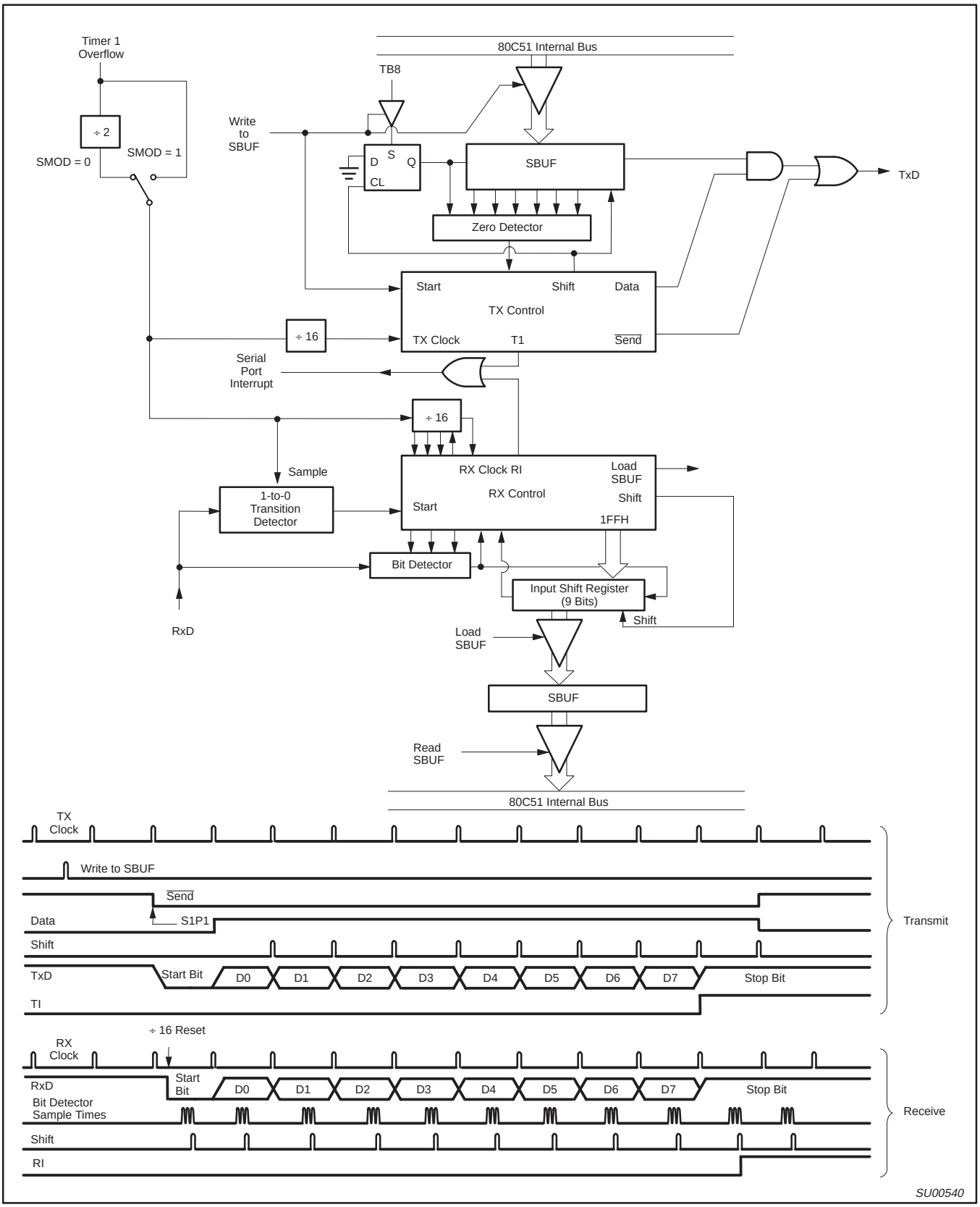


Figure 16. Serial Port Mode 1

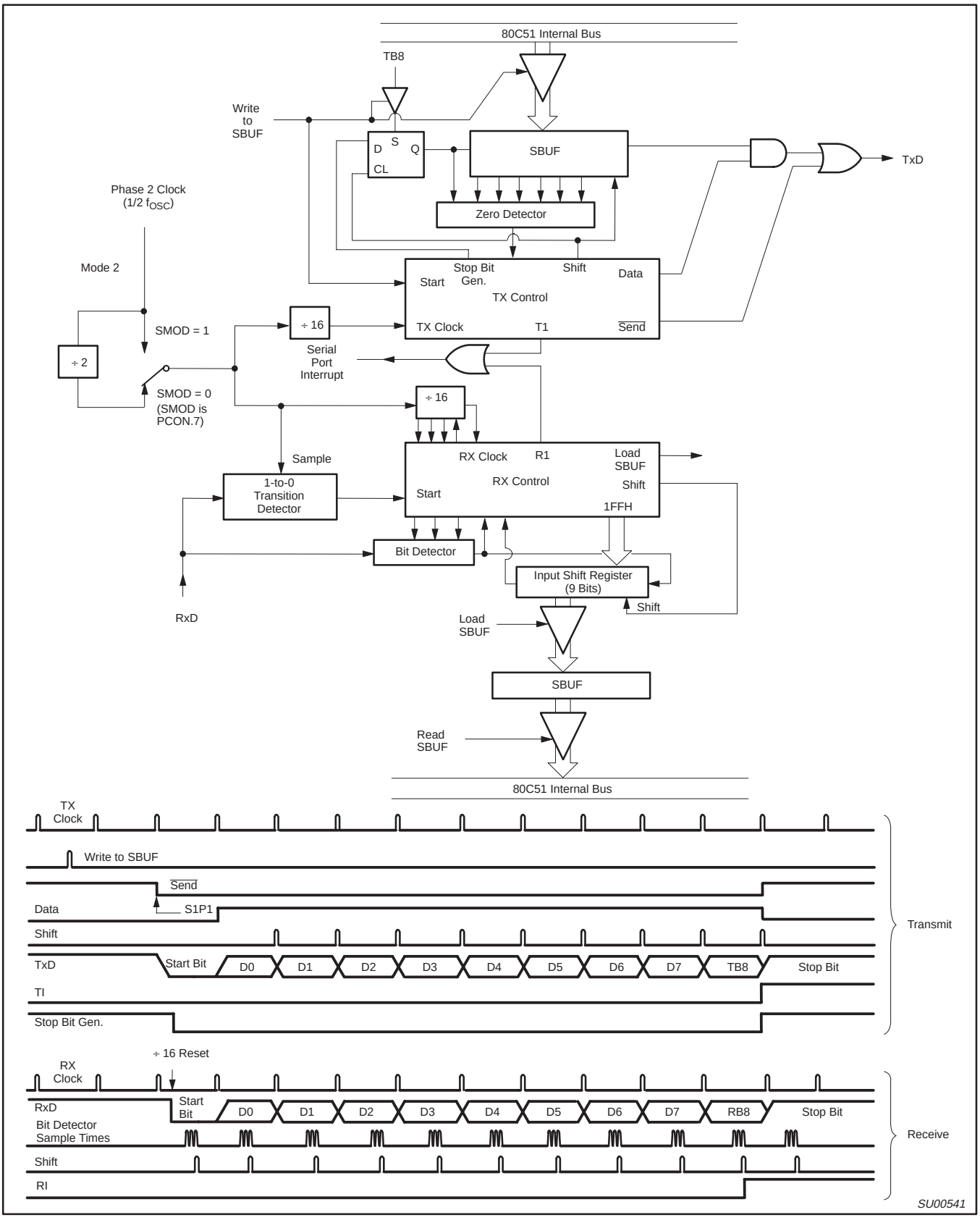


Figure 17. Serial Port Mode 2

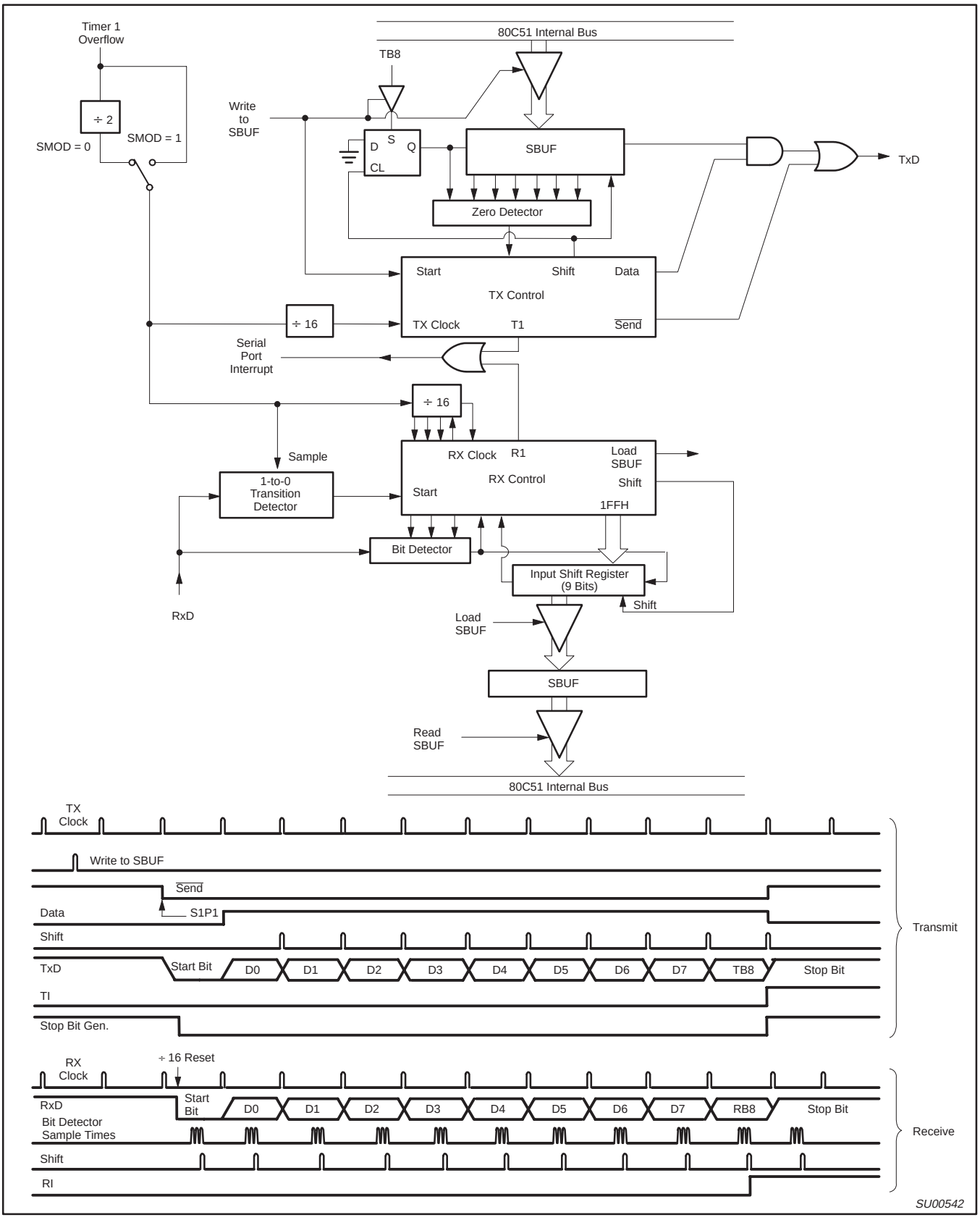


Figure 18. Serial Port Mode 3

Enhanced Features

The UART operates in all of the usual modes that are described in the first section of *Data Handbook IC20, 80C51-Based 8-Bit Microcontrollers*. In addition the UART can perform framing error detect by looking for missing stop bits, and automatic address recognition. The UART also fully supports multiprocessor communication as does the standard 80C51 UART.

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 13). 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 19.

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 20.

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 b 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	=	1111 1101
	Given	=	1100 00X0
Slave 1	SADDR	=	1100 0000
	SADEN	=	1111 1110
	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	=	1111 1001
	Given	=	1100 0XX0
Slave 1	SADDR	=	1110 0000
	SADEN	=	1111 1010
	Given	=	1110 0X0X
Slave 2	SADDR	=	1110 0000
	SADEN	=	1111 1100
	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 trended 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 leaded 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.

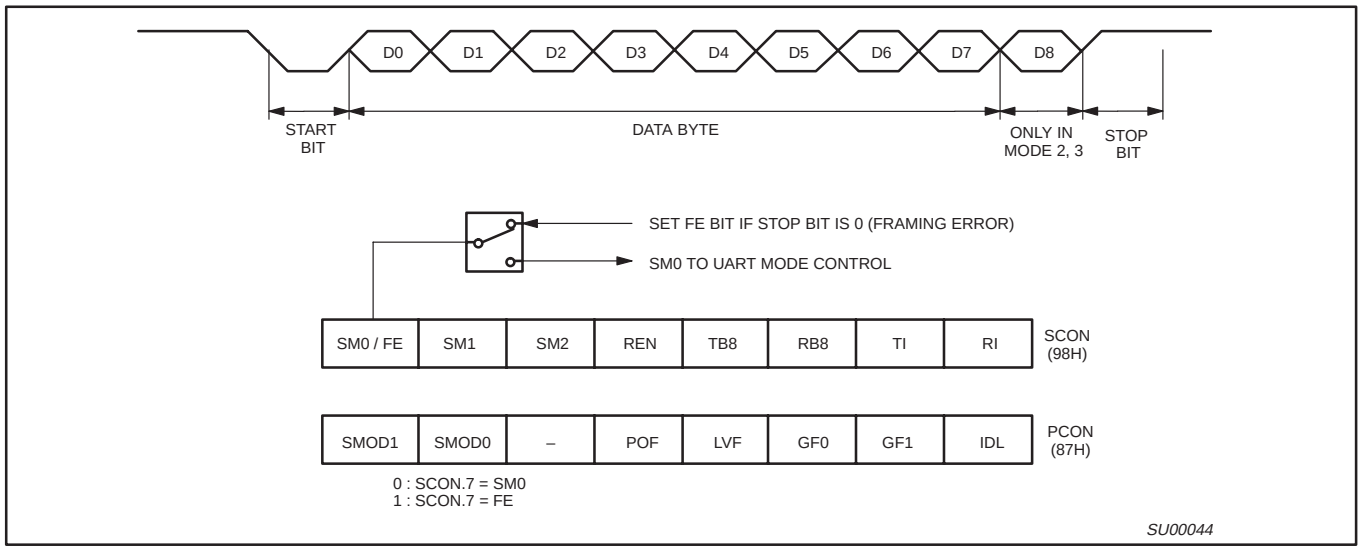


Figure 19. UART Framing Error Detection

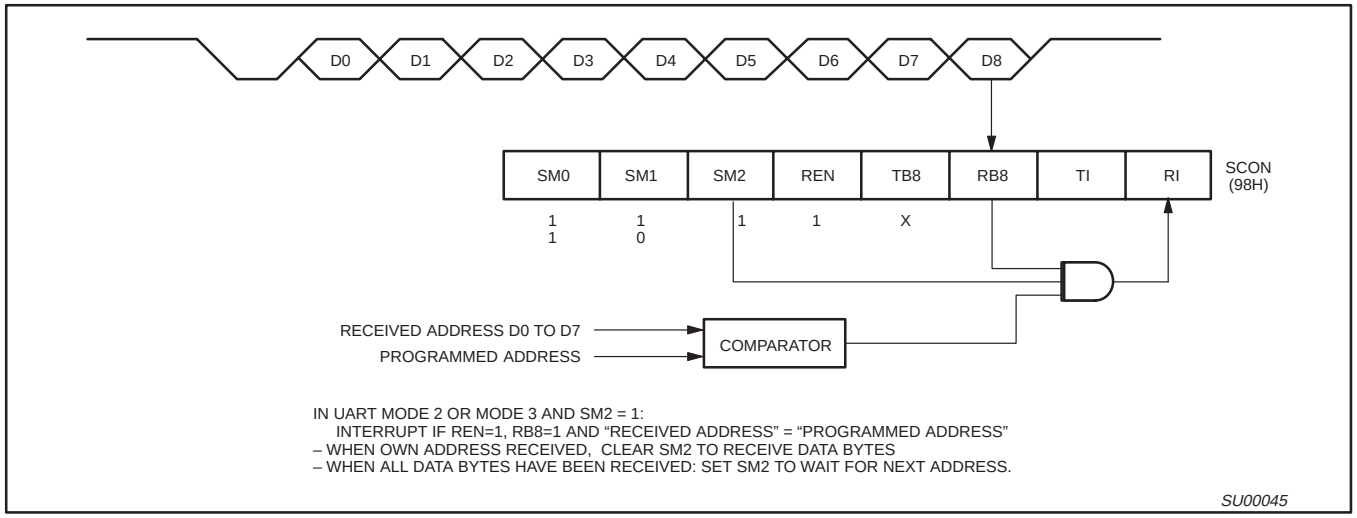


Figure 20. UART Multiprocessor Communication, Automatic Address Recognition

I²C-bus Serial I/O

The I²C-bus serial port is identical to the I²C-bus serial port on the 8xC554 and 8xC652 devices.

Note that in the P8xC654X2, the I²C-bus pins are alternate functions to port pins P1.6 and P1.7. Because of this, P1.6 and P1.7 on these parts do not have a pull-up structure as found on the 80C51; P1.6 and P1.7 have open drain outputs.

The I²C-bus uses two wires (SDA and SCL) to transfer information between devices connected to the bus. The main features of the bus are:

– Bidirectional data transfer between masters and slaves
– Multimaster bus (no central master)
– Arbitration between simultaneously transmitting masters without corruption of serial data on the bus
– Serial clock synchronization allows devices with different bit rates to communicate via one serial bus
– Serial clock synchronization can be used as a handshake mechanism to suspend and resume serial transfer
– The I²C-bus may be used for test and diagnostic purposes

The output latches of P1.6 and P1.7 must be set to logic 1 in order to enable I²C-bus.

The P8xC654X2 on-chip I²C-bus logic provides a serial interface that meets the I²C-bus specification and supports all transfer modes (other than the low-speed mode) from and to the I²C-bus. The I²C-bus logic handles bytes transfer autonomously. It also keeps track of serial transfers, and a status register (S1STA) reflects the status of the I²C-bus.

The CPU interfaces to the I²C-bus logic via the following four special function registers: S1CON (I²C-bus control register), S1STA (I²C-bus status register), S1DAT (I²C-bus data register), and S1ADR (I²C-bus slave address register). The I²C-bus logic interfaces to the external I²C-bus via two port 1 pins: P1.6/SCL (serial clock line) and P1.7/SDA (serial data line).

A typical I²C-bus configuration is shown in Figure 21, and Figure 22 shows how a data transfer is accomplished on the bus. Depending on the state of the direction bit (R/W), two types of data transfers are possible on the I²C-bus:

1. Data transfer from a master transmitter to a slave receiver. The first byte transmitted by the master is the slave address. Next follows a number of data bytes. The slave returns an acknowledge bit after each received byte.
2. Data transfer from a slave transmitter to a master receiver. The first byte (the slave address) is transmitted by the master. The slave then returns an acknowledge bit. Next follows the data bytes transmitted by the slave to the master. The master returns an acknowledge bit after all received bytes other than the last byte. At the end of the last received byte, a “not acknowledge” is returned.

The master device generates all of the serial clock pulses and the START and STOP conditions. A transfer is ended with a STOP condition or with a repeated START condition. Since a repeated START condition is also the beginning of the next serial transfer, the I²C-bus will not be released.

Modes of Operation: The on-chip I²C-bus logic may operate in the following four modes:

1. Master Transmitter Mode:

   Serial data output through P1.7/SDA while P1.6/SCL outputs the serial clock. The first byte transmitted contains the slave address of the receiving device (7 bits) and the data direction bit. In this case the data direction bit (R/$\overline{W}$) will be logic 0, and we say that a “W” is transmitted. Thus the first byte transmitted is SLA+W. Serial data is transmitted 8 bits at a time. After each byte is transmitted, an acknowledge bit is received. START and STOP conditions are output to indicate the beginning and the end of a serial transfer.

2. Master Receiver Mode:

   The first byte transmitted contains the slave address of the transmitting device (7 bits) and the data direction bit. In this case the data direction bit (R/$\overline{W}$) will be logic 1, and we say that an “R” is transmitted. Thus the first byte transmitted is SLA+R. Serial data is received via P1.7/SDA while P1.6/SCL outputs the serial clock. Serial data is received 8 bits at a time. After each byte is received, an acknowledge bit is transmitted. START and STOP conditions are output to indicate the beginning and end of a serial transfer.

3. Slave Receiver Mode:

   Serial data and the serial clock are received through P1.7/SDA and P1.6/SCL. After each byte is received, an acknowledge bit is transmitted. START and STOP conditions are recognized as the beginning and end of a serial transfer. Address recognition is performed by hardware after reception of the slave address and direction bit.

4. Slave Transmitter Mode:

   The first byte is received and handled as in the slave receiver mode. However, in this mode, the direction bit will indicate that the transfer direction is reversed. Serial data is transmitted via P1.7/SDA while the serial clock is input through P1.6/SCL. START and STOP conditions are recognized as the beginning and end of a serial transfer.

In a given application, I²C-bus may operate as a master and as a slave. In the slave mode, the I²C-bus hardware looks for its own slave address and the general call address. If one of these addresses is detected, an interrupt is requested. When the microcontroller wishes to become the bus master, the hardware waits until the bus is free before the master mode is entered so that a possible slave action is not interrupted. If bus arbitration is lost in the master mode, the I²C-bus switches to the slave mode immediately and can detect its own slave address in the same serial transfer.

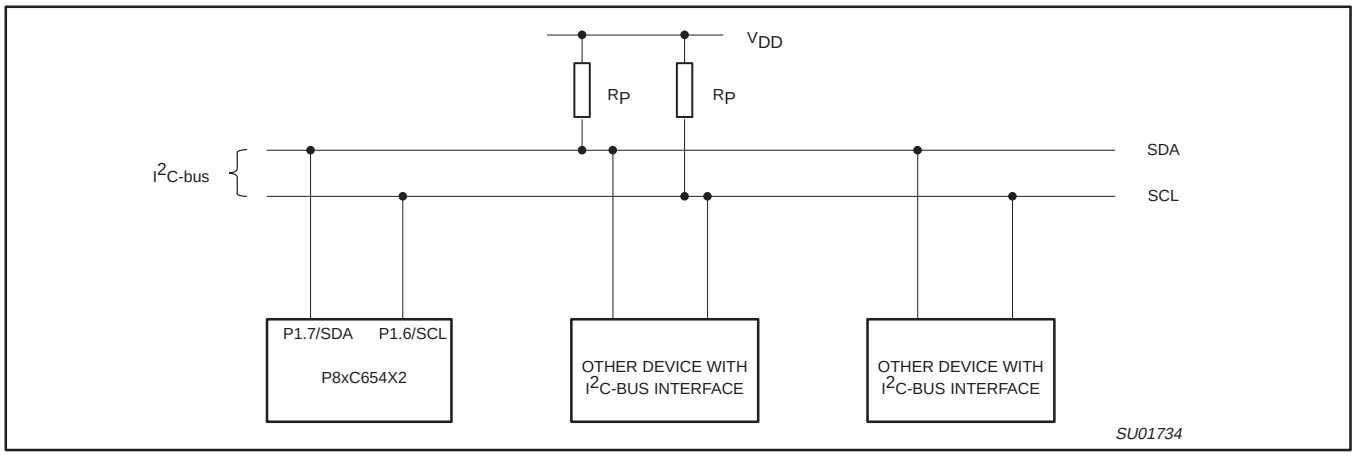


Figure 21. Typical I²C-bus configuration

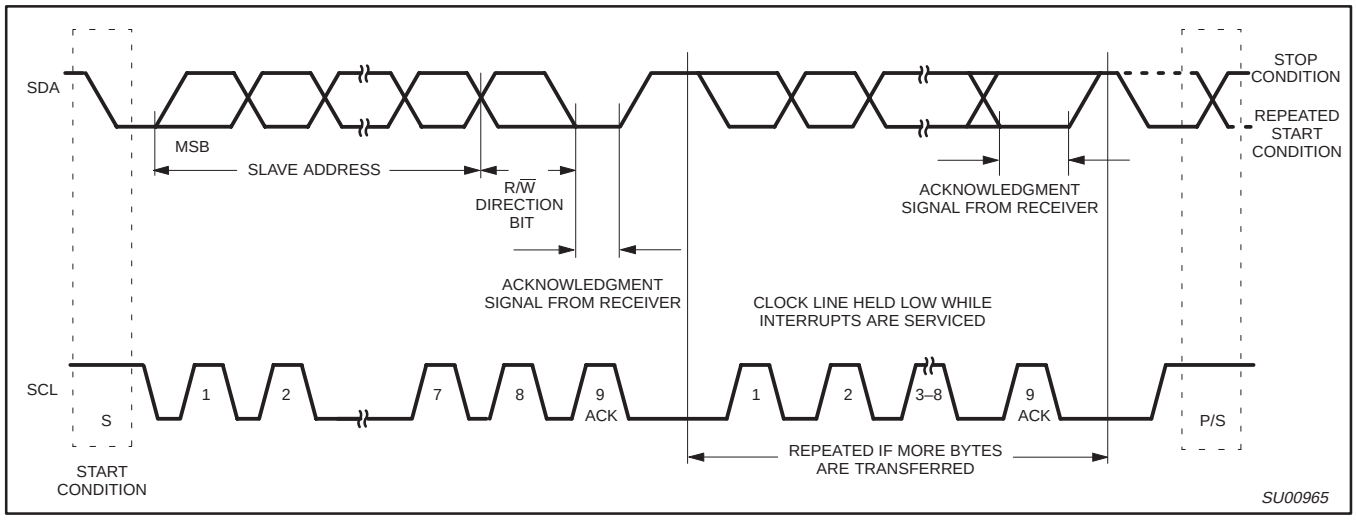


Figure 22. Data Transfer on the I²C-bus

I²C-bus Implementation and Operation: Figure 23 shows how the on-chip I²C-bus interface is implemented, and the following text describes the individual blocks.

INPUT FILTERS AND OUTPUT STAGES

The input filters have I²C-bus compatible input levels. If the input voltage is less than 1.5 V, the input logic level is interpreted as 0; if the input voltage is greater than 3.0 V, the input logic level is interpreted as 1. Input signals are synchronized with the internal clock ($f_{OSC}/4$), and spikes shorter than three oscillator periods are filtered out.

The output stages consist of open drain transistors that can sink 3mA at $V_{OUT} < 0.4$ V. These open drain outputs do not have clamping diodes to V_{DD}. Thus, if the device is connected to the I²C-bus and V_{DD} is switched off, the I²C-bus is not affected.

ADDRESS REGISTER, S1ADR

This 8-bit special function register may be loaded with the 7-bit slave address (7 most significant bits) to which the I²C-bus will respond when programmed as a slave transmitter or receiver. The LSB (GC) is used to enable general call address (00H) recognition.

COMPARATOR

The comparator compares the received 7-bit slave address with its own slave address (7 most significant bits in S1ADR). It also compares the first received 8-bit byte with the general call address (00H). If an equality is found, the appropriate status bits are set and an interrupt is requested.

SHIFT REGISTER, S1DAT

This 8-bit special function register contains a byte of serial data to be transmitted or a byte which has just been received. Data in S1DAT is always shifted from right to left; the first bit to be transmitted is the MSB (bit 7) and, after a byte has been received, the first bit of received data is located at the MSB of S1DAT. While data is being shifted out, data on the bus is simultaneously being shifted in; S1DAT always contains the last byte present on the bus. Thus, in the event of lost arbitration, the transition from master transmitter to slave receiver is made with the correct data in S1DAT.

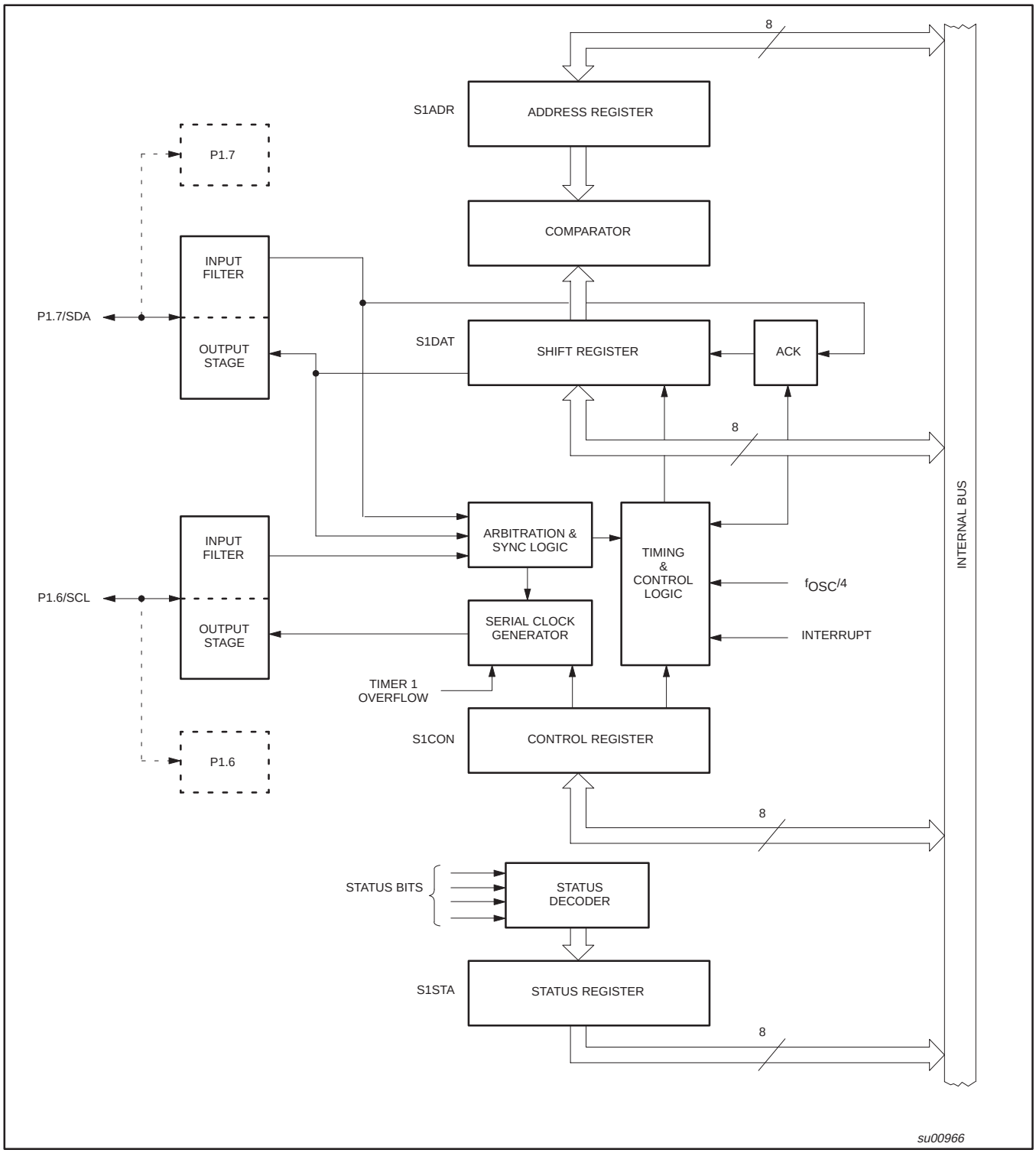


Figure 23. I²C-bus Serial Interface Block Diagram

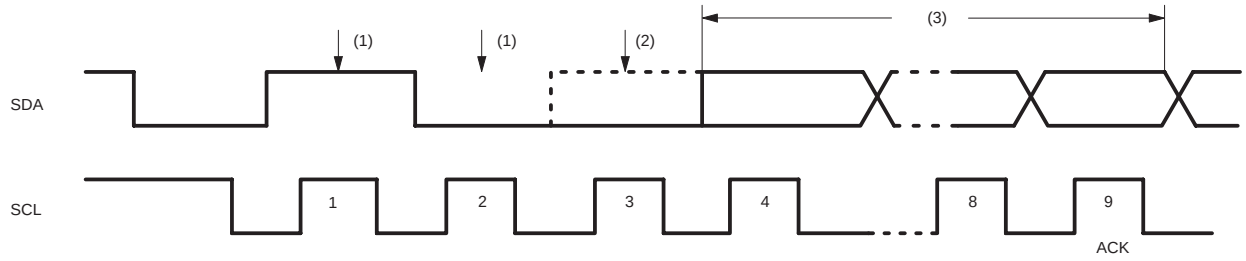
Arbitration and Synchronization Logic

In the master transmitter mode, the arbitration logic checks that every transmitted logic 1 actually appears as a logic 1 on the I^2C-bus. If another device on the bus overrules a logic 1 and pulls the SDA line LOW, arbitration is lost, and the I^2C-bus immediately changes from master transmitter to slave receiver. The I^2C-bus will continue to output clock pulses (on SCL) until transmission of the current serial byte is complete.

Arbitration may also be lost in the master receiver mode. Loss of arbitration in this mode can only occur while the I^2C-bus is returning a "not acknowledge: (logic 1) to the bus. Arbitration is lost when another device on the bus pulls this signal LOW. Since this can occur only at the end of a serial byte, the I^2C-bus generates no further clock pulses. Figure 24 shows the arbitration procedure.

The synchronization logic will synchronize the serial clock generator with the clock pulses on the SCL line from another device. If two or more master devices generate clock pulses, the "mark" duration is determined by the device that generates the shortest "marks," and the "space" duration is determined by the device that generates the longest "spaces." Figure 25 shows the synchronization procedure.

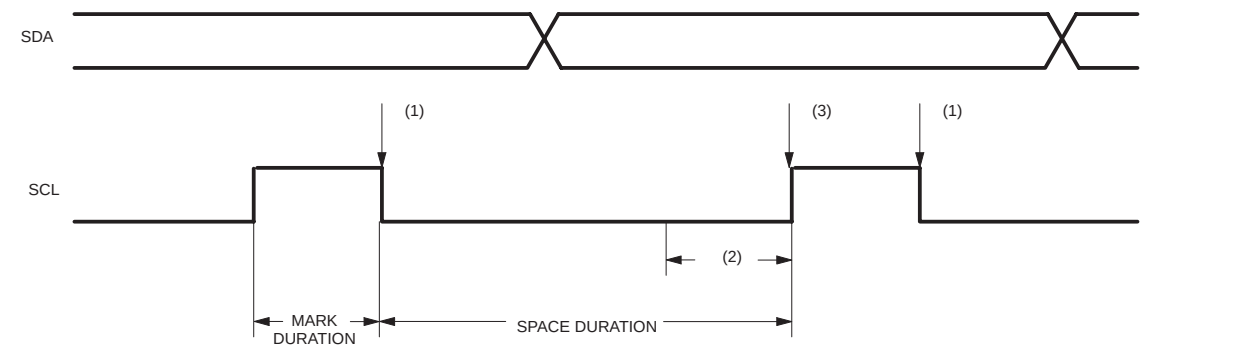
A slave may stretch the space duration to slow down the bus master. The space duration may also be stretched for handshaking purposes. This can be done after each bit or after a complete byte transfer. The I^2C-bus will stretch the SCL space duration after a byte has been transmitted or received and the acknowledge bit has been transferred. The serial interrupt flag (SI) is set, and the stretching continues until the serial interrupt flag is cleared.



1. Another device transmits identical serial data.
2. Another device overrules a logic 1 (dotted line) transmitted by SIO1 (master) by pulling the SDA line low. Arbitration is lost, and SIO1 enters the slave receiver mode.
3. SIO1 is in the slave receiver mode but still generates clock pulses until the current byte has been transmitted. SIO1 will not generate clock pulses for the next byte. Data on SDA originates from the new master once it has won arbitration.

SU00967

Figure 24. Arbitration Procedure



1. Another service pulls the SCL line low before the SIO1 "mark" duration is complete. The serial clock generator is immediately reset and commences with the "space" duration by pulling SCL low.
2. Another device still pulls the SCL line low after SIO1 releases SCL. The serial clock generator is forced into the wait state until the SCL line is released.
3. The SCL line is released, and the serial clock generator commences with the mark duration.

SU00968

Figure 25. Serial Clock Synchronization

Serial Clock Generator

This programmable clock pulse generator provides the SCL clock pulses when the I²C-bus is in the master transmitter or master receiver mode. It is switched off when the I²C-bus is in a slave mode. In standard speed mode, the programmable output clock frequencies are: $f_{OSC}/120$, $f_{OSC}/9600$, and the Timer 1 overflow rate divided by eight. The output clock pulses have a 50 % duty cycle unless the clock generator is synchronized with other SCL clock sources as described above.

Timing and Control

The timing and control logic generates the timing and control signals for serial byte handling. This logic block provides the shift pulses for S1DAT, enables the comparator, generates and detects start and stop conditions, receives and transmits acknowledge bits, controls the master and slave modes, contains interrupt request logic, and monitors the I²C-bus status.

Control Register, S1CON

This 7-bit special function register is used by the microcontroller to control the following I²C-bus functions: start and restart of a serial transfer, termination of a serial transfer, bit rate, address recognition, and acknowledgment.

Status Decoder and Status Register

The status decoder takes all of the internal status bits and compresses them into a 5-bit code. This code is unique for each I²C-bus status. The 5-bit code may be used to generate vector addresses for fast processing of the various service routines. Each service routine processes a particular bus status. There are 26 possible bus states if all four modes of the I²C-bus are used. The 5-bit status code is latched into the five most significant bits of the status register when the serial interrupt flag is set (by hardware) and remains stable until the interrupt flag is cleared by software. The three least significant bits of the status register are always zero. If the status code is used as a vector to service routines, then the routines are displaced by eight address locations. Eight bytes of code is sufficient for most of the service routines (see the software example in this section).

The Four I²C-bus Special Function Registers: The microcontroller interfaces to the I²C-bus via four special function registers. These four SFRs (S1ADR, S1DAT, S1CON, and S1STA) are described individually in the following sections.

The Address Register, S1ADR: The CPU can read from and write to this 8-bit, directly addressable SFR. S1ADR is not affected by the the I²C-bus hardware. The contents of this register are irrelevant when the I²C-bus is in a master mode. In the slave modes, the seven most significant bits must be loaded with the microcontroller's own slave address, and, if the least significant bit is set, the general call address (00H) is recognized; otherwise it is ignored.

	7	6	5	4	3	2	1	0
S1ADR (DBH)	X	X	X	X	X	X	X	GC
	own slave address							

The most significant bit corresponds to the first bit received from the I²C-bus after a start condition. A logic 1 in S1ADR corresponds to a HIGH level on the I²C-bus, and a logic 0 corresponds to a LOW level on the bus.

The Data Register, S1DAT: S1DAT contains a byte of serial data to be transmitted or a byte which has just been received. The CPU can read from and write to this 8-bit, directly addressable SFR while it is not in the process of shifting a byte. This occurs when the I²C-bus is in a defined state and the serial interrupt flag is set. Data in S1DAT remains stable as long as SI is set. Data in S1DAT is always shifted from right to left: the first bit to be transmitted is the MSB (bit 7), and, after a byte has been received, the first bit of received data is located at the MSB of S1DAT. While data is being shifted out, data on the bus is simultaneously being shifted in; S1DAT always contains the last data byte present on the bus. Thus, in the event of lost arbitration, the transition from master transmitter to slave receiver is made with the correct data in S1DAT.

	7	6	5	4	3	2	1	0
S1DAT (DAH)	SD7	SD6	SD5	SD4	SD3	SD2	SD1	SD0
	shift direction							

SD7 - SD0:

Eight bits to be transmitted or just received. A logic 1 in S1DAT corresponds to a HIGH level on the I²C-bus, and a logic 0 corresponds to a LOW level on the bus. Serial data shifts through S1DAT from right to left. Figure 26 shows how data in S1DAT is serially transferred to and from the SDA line.

S1DAT and the ACK flag form a 9-bit shift register which shifts in or shifts out an 8-bit byte, followed by an acknowledge bit. The ACK flag is controlled by the I²C-bus hardware and cannot be accessed by the CPU. Serial data is shifted through the ACK flag into S1DAT on the rising edges of serial clock pulses on the SCL line. When a byte has been shifted into S1DAT, the serial data is available in S1DAT, and the acknowledge bit is returned by the control logic during the ninth clock pulse. Serial data is shifted out from S1DAT via a buffer (BSD7) on the falling edges of clock pulses on the SCL line.

When the CPU writes to S1DAT, BSD7 is loaded with the content of S1DAT.7, which is the first bit to be transmitted to the SDA line (see Figure 27). After nine serial clock pulses, the eight bits in S1DAT will have been transmitted to the SDA line, and the acknowledge bit will be present in ACK. Note that the eight transmitted bits are shifted back into S1DAT.

The Control Register, S1CON: The CPU can read from and write to this 8-bit, directly addressable SFR. Two bits are affected by the I²C hardware: the SI bit is set when a serial interrupt is requested, and the STO bit is cleared when a STOP condition is present on the I²C-bus. The STO bit is also cleared when ENS1 = 0.

	7	6	5	4	3	2	1	0
S1CON (D8H)	CR2	ENS1	STA	STO	SI	AA	CR1	CR0

ENS1, the I²C Enable Bit

ENS1 = 0: When ENS1 is logic 0, the SDA and SCL outputs are in a high impedance state. SDA and SCL input signals are ignored, I²C is in the "not addressed" slave state, and the STO bit in S1CON is forced to 0. No other bits are affected. P1.6 and P1.7 may be used as open drain I/O ports.

ENS1 = 1: When ENS1 is "1", I²C is enabled. The P1.6 and P1.7 port latches must be set to logic 1.

ENS1 should not be used to temporarily release I²C from the I²C-bus since, when ENS1 is reset, the I²C-bus status is lost. The AA flag should be used instead (see description of the AA flag in the following text).

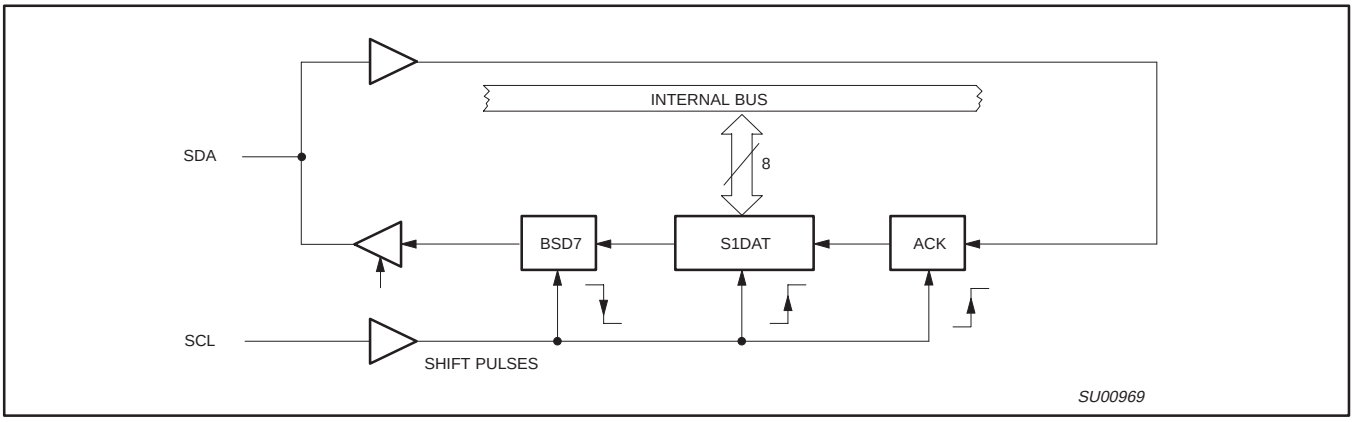


Figure 26. Serial Input/Output Configuration

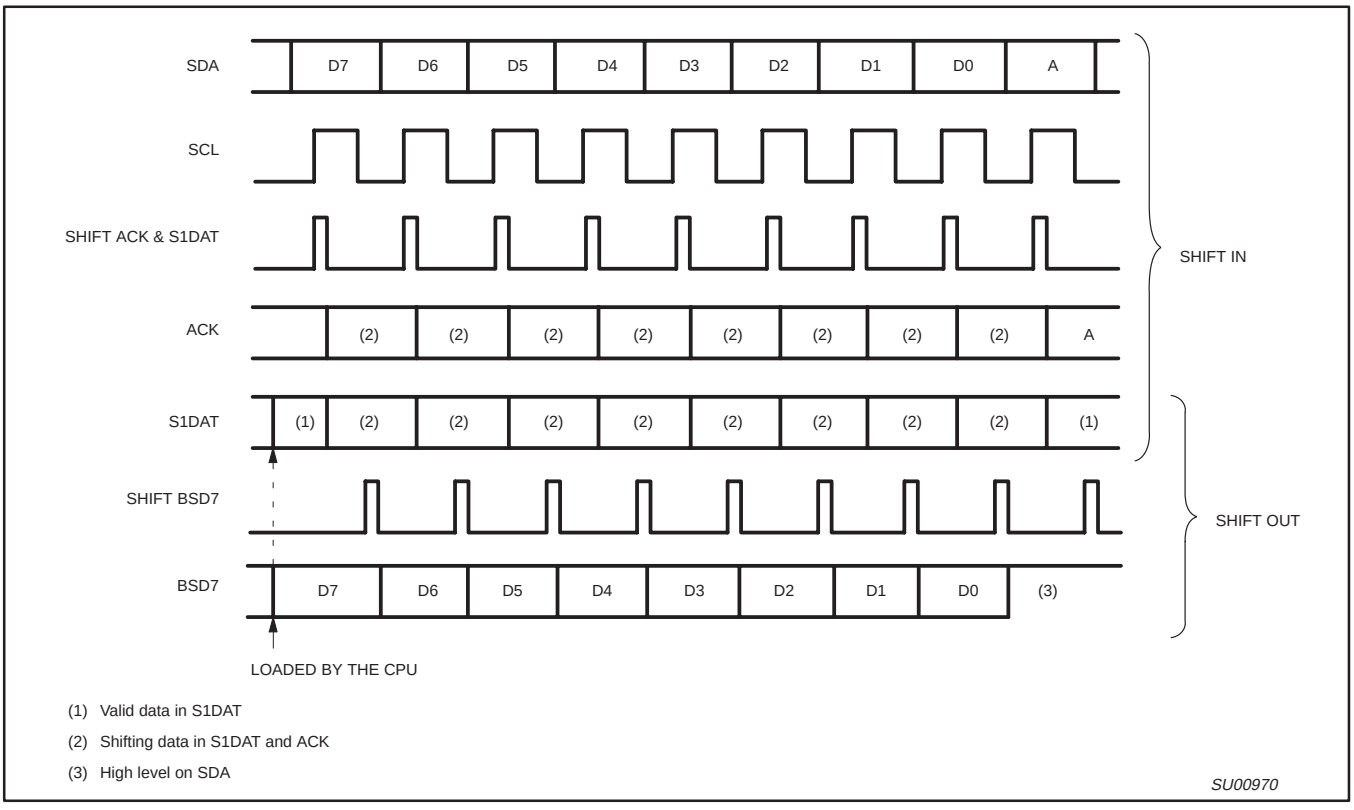


Figure 27. Shift-in and Shift-out Timing

In the following text, it is assumed that ENS1 = 1.

STA, THE START FLAG

STA = 1: When the STA bit is set to enter a master mode, the I^2C hardware checks the status of the I^2C-bus and generates a START condition if the bus is free. If the bus is not free, then I^2C waits for a STOP condition (which will free the bus) and generates a START condition after a delay of a half clock period of the internal serial clock generator.

If STA is set while I^2C is already in a master mode and one or more bytes are transmitted or received, I^2C transmits a repeated START condition. STA may be set at any time. STA may also be set when I^2C is an addressed slave.

STA = 0: When the STA bit is reset, no START condition or repeated START condition will be generated.

STO, THE STOP FLAG

STO = 1: When the STO bit is set while I^2C is in a master mode, a STOP condition is transmitted to the I^2C-bus. When the STOP condition is detected on the bus, the I^2C hardware clears the STO flag. In a slave mode, the STO flag may be set to recover from an error condition. In this case, no STOP condition is transmitted to the I^2C-bus. However, the I^2C hardware behaves as if a STOP condition has been received and switches to the defined “not addressed” slave receiver mode. The STO flag is automatically cleared by hardware.

If the STA and STO bits are both set, the a STOP condition is transmitted to the I²C-bus if I²C is in a master mode (in a slave mode, I²C generates an internal STOP condition which is not transmitted). I²C then transmits a START condition.

STO = 0: When the STO bit is reset, no STOP condition will be generated.

SI, THE SERIAL INTERRUPT FLAG

SI = 1: When the SI flag is set, then, if the EA and ES1 (interrupt enable register) bits are also set, a serial interrupt is requested. SI is set by hardware when one of 25 of the 26 possible I²C states is entered. The only state that does not cause SI to be set is state F8H, which indicates that no relevant state information is available.

While SI is set, the LOW period of the serial clock on the SCL line is stretched, and the serial transfer is suspended. A HIGH level on the SCL line is unaffected by the serial interrupt flag. SI must be reset by software.

SI = 0: When the SI flag is reset, no serial interrupt is requested, and there is no stretching of the serial clock on the SCL line.

AA, THE ASSERT ACKNOWLEDGE FLAG

AA = 1: If the AA flag is set, an acknowledge (low level to SDA) will be returned during the acknowledge clock pulse on the SCL line when:

– The “own slave address” has been received
– The general call address has been received while the general call bit (GC) in S1ADR is set
– A data byte has been received while I²C is in the master receiver mode
– A data byte has been received while I²C is in the addressed slave receiver mode

AA = 0: if the AA flag is reset, a not acknowledge (HIGH level to SDA) will be returned during the acknowledge clock pulse on SCL when:

– A data has been received while I²C is in the master receiver mode
– A data byte has been received while I²C is in the addressed slave receiver mode

When I²C is in the addressed slave transmitter mode, state C8H will be entered after the last serial is transmitted (see Figure 31). When SI is cleared, I²C leaves state C8H, enters the not addressed slave receiver mode, and the SDA line remains at a HIGH level. In state C8H, the AA flag can be set again for future address recognition.

When I²C is in the not addressed slave mode, its own slave address and the general call address are ignored. Consequently, no acknowledge is returned, and a serial interrupt is not requested. Thus, I²C can be temporarily released from the I²C-bus while the bus status is monitored. While I²C is released from the bus, START and STOP conditions are detected, and serial data is shifted in. Address recognition can be resumed at any time by setting the AA flag. If the AA flag is set when the part’s own slave address or the general call address has been partly received, the address will be recognized at the end of the byte transmission.

CR0, CR1, AND CR2, THE CLOCK RATE BITS

These three bits determine the serial clock frequency when I²C is in a master mode. The various serial rates are shown in Table 7.

If the I²C block is to be used in fast mode, bit 3 in AUXR must be set. The user can read but cannot write (write once) to AUXR after setup.

	7	6	5	4	3	2	1	0
AUXR (8EH)	–	–	–	–	FAST/ STD I²C	–	–	A0

A 12.5kHz bit rate may be used by devices that interface to the I²C-bus via standard I/O port lines which are software driven and slow. 100kHz is usually the maximum bit rate and can be derived from a 16 MHz, 12 MHz, or a 6 MHz oscillator. A variable bit rate (0.5kHz to 62.5kHz) may also be used if Timer 1 is not required for any other purpose while I²C is in a master mode.

The frequencies shown in Table 7 are unimportant when I²C is in a slave mode. In the slave modes, I²C will automatically synchronize with any clock frequency up to 100kHz.

The Status Register, S1STA: S1STA is an 8-bit read-only special function register. The three least significant bits are always zero. The five most significant bits contain the status code. There are 26 possible status codes. When S1STA contains F8H, no relevant state information is available and no serial interrupt is requested. All other S1STA values correspond to defined I²C states. When each of these states is entered, a serial interrupt is requested (SI = 1). A valid status code is present in S1STA one machine cycle after SI is set by hardware and is still present one machine cycle after SI has been reset by software.

Table 7. Serial Clock Rates

6 clock mode								
			BIT FREQUENCY (kHz) AT f_{osc}					f_{osc} DIVIDED BY
CR2	CR1	CR0	3MHz	6MHz	8MHz	12MHz	15MHz	
0	0	0	23	47	62.5	94	117	128
0	0	1	27	54	71	107	134	112
0	1	0	31	63	83.3	125	156	96
0	1	1	37	75	100	150	188	80
1	0	0	6.25	12.5	17	25	31	480
1	0	1	50	100	133	200	250	60
1	1	0	100	200	267	400	500	30
1	1	1	0.24<62.5 0 < 255	0.49 < 62.5 0 < 254	0.65 < 55.6 0 < 253	0.98 < 50.0 0 < 251	1.22 < 52.1 0 < 250	48 × (256– (reload value Timer1)) Reload value Timer 1 in Mode 2.
12 clock mode								
			BIT FREQUENCY (kHz) AT f_{osc}					f_{osc} DIVIDED BY
CR2	CR1	CR0	6MHz	12MHz	16MHz	24MHz	30MHz	
0	0	0	23	47	62.5	94	117	256
0	0	1	27	54	71	107	134	224
0	1	0	31	63	83.3	125	156	192
0	1	1	37	75	100	150	188	160
1	0	0	6.25	12.5	17	25	31	960
1	0	1	50	100	133	200	250	120
1	1	0	100	200	267	400	500	60
1	1	1	0.24<62.5 0 < 255	0.49 < 62.5 0 < 254	0.65 < 55.6 0 < 253	0.98 < 50.0 0 < 251	1.22 < 52.1 0 < 250	96 × (256 –(reload value Timer1)) Reload value Timer 1 in Mode 2.

NOTES:
1. These frequencies exceed the upper limit of 100kHz of the I^2C-bus specification and cannot be used in an I^2C-bus application.
2. At f_{osc} = 24 MHz/30 MHz the maximum I^2C-bus rate of 100kHz cannot be realized due to the fixed divider rates.

Table 8. Selection of I^2C-bus bit rate (Fast mode)

			BIT FREQUENCY (kHz) AT f_{osc}	
CR2	CR1	CR0	12 MHz	16 MHz
1	0	0	50	66.7
1	0	1	3.75	5
1	1	0	75	100
1	1	1	100	0
0	0	0	200[1]	266.7[1]
0	0	1	7.5	10
0	1	0	300[1]	400[1]
0	1	1	400[1]	–

NOTES:
1. These bit rates are for “fast-mode” I^2C-bus applications and cannot be used for bit rates up to 100 kbit/sec.
2. Serial status register S1STA is a read only register.

More Information on I²C Operating Modes: The four operating modes are:

– Master Transmitter
– Master Receiver
– Slave Receiver
– Slave Transmitter

Data transfers in each mode of operation are shown in Figures 28–31. These figures contain the following abbreviations:

Abbreviation	Explanation
S	Start condition
SLA	7-bit slave address
R	Read bit (HIGH level at SDA)
W	Write bit (low level at SDA)
A	Acknowledge bit (low level at SDA)
$\overline{A}$	Not acknowledge bit (HIGH level at SDA)
Data	8-bit data byte
P	Stop condition

In Figures 28-31, circles are used to indicate when the serial interrupt flag is set. The numbers in the circles show the status code held in the S1STA register. At these points, a service routine must be executed to continue or complete the serial transfer. These service routines are not critical since the serial transfer is suspended until the serial interrupt flag is cleared by software.

When a serial interrupt routine is entered, the status code in S1STA is used to branch to the appropriate service routine. For each status code, the required software action and details of the following serial transfer are given in Tables 9-13.

Master Transmitter Mode: In the master transmitter mode, a number of data bytes are transmitted to a slave receiver (see Figure 28). Before the master transmitter mode can be entered, S1CON must be initialized as follows:

	7	6	5	4	3	2	1	0
S1CON (D8H)	CR2	ENS1	STA	STO	SI	AA	CR1	CR0
	bit rate	1	0	0	0	X	bit rate	

CR0, CR1, and CR2 define the serial bit rate. ENS1 must be set to logic 1 to enable I²C. If the AA bit is reset, I²C will not acknowledge its own slave address or the general call address in the event of another device becoming master of the bus. In other words, if AA is reset, SIO0 cannot enter a slave mode. STA, STO, and SI must be reset.

The master transmitter mode may now be entered by setting the STA bit using the SETB instruction. The I²C logic will now test the I²C-bus and generate a start condition as soon as the bus becomes free. When a START condition is transmitted, the serial interrupt flag (SI) is set, and the status code in the status register (S1STA) will be 08H. This status code must be used to vector to an interrupt service routine that loads S1DAT with the slave address and the data direction bit (SLA+W). The SI bit in S1CON must then be reset before the serial transfer can continue.

When the slave address and the direction bit have been transmitted and an acknowledgment bit has been received, the serial interrupt flag (SI) is set again, and a number of status codes in S1STA are possible. There are 18H, 20H, or 38H for the master mode and also 68H, 78H, or B0H if the slave mode was enabled (AA = logic 1). The appropriate action to be taken for each of these status codes is detailed in Table 9. After a repeated start condition (state 10H). I²C may switch to the master receiver mode by loading S1DAT with SLA+R).

Master Receiver Mode: In the master receiver mode, a number of data bytes are received from a slave transmitter (see Figure 29). The transfer is initialized as in the master transmitter mode. When the start condition has been transmitted, the interrupt service routine must load S1DAT with the 7-bit slave address and the data direction bit (SLA+R). The SI bit in S1CON must then be cleared before the serial transfer can continue.

When the slave address and the data direction bit have been transmitted and an acknowledgment bit has been received, the serial interrupt flag (SI) is set again, and a number of status codes in S1STA are possible. These are 40H, 48H, or 38H for the master mode and also 68H, 78H, or B0H if the slave mode was enabled (AA = logic 1). The appropriate action to be taken for each of these status codes is detailed in Table 10. ENS1, CR1, and CR0 are not affected by the serial transfer and are not referred to in Table 10. After a repeated start condition (state 10H), I²C may switch to the master transmitter mode by loading S1DAT with SLA+W.

Slave Receiver Mode: In the slave receiver mode, a number of data bytes are received from a master transmitter (see Figure 30). To initiate the slave receiver mode, S1ADR and S1CON must be loaded as follows:

AUXR#	Auxiliary	8EH	–	–	–	–	Fast/ Std I²C	–	–	AO

The upper 7 bits are the address to which I²C will respond when addressed by a master. If the LSB (GC) is set, I²C will respond to the general call address (00H); otherwise it ignores the general call address.

	7	6	5	4	3	2	1	0
S1CON (D8H)	CR2	ENS1	STA	STO	SI	AA	CR1	CR0
	X	1	0	0	0	1	X	X

CR0, CR1, and CR2 do not affect I²C in the slave mode. ENS1 must be set to logic 1 to enable I²C. The AA bit must be set to enable I²C to acknowledge its own slave address or the general call address. STA, STO, and SI must be reset.

When S1ADR and S1CON have been initialized, I²C waits until it is addressed by its own slave address followed by the data direction bit which must be logic 0 (W) for I²C to operate in the slave receiver mode. After its own slave address and the W bit have been received, the serial interrupt flag (I) is set and a valid status code can be read from S1STA. This status code is used to vector to an interrupt service routine, and the appropriate action to be taken for each of these status codes is detailed in Table 11. The slave receiver mode may also be entered if arbitration is lost while I²C is in the master mode (see status 68H and 78H).

If the AA bit is reset during a transfer, I²C will return a not acknowledge (logic 1) to SDA after the next received data byte. While AA is reset, I²C does not respond to its own slave address or a general call address. However, the I²C-bus is still monitored and address recognition may be resumed at any time by setting AA. This means that the AA bit may be used to temporarily isolate I²C from the I²C-bus.

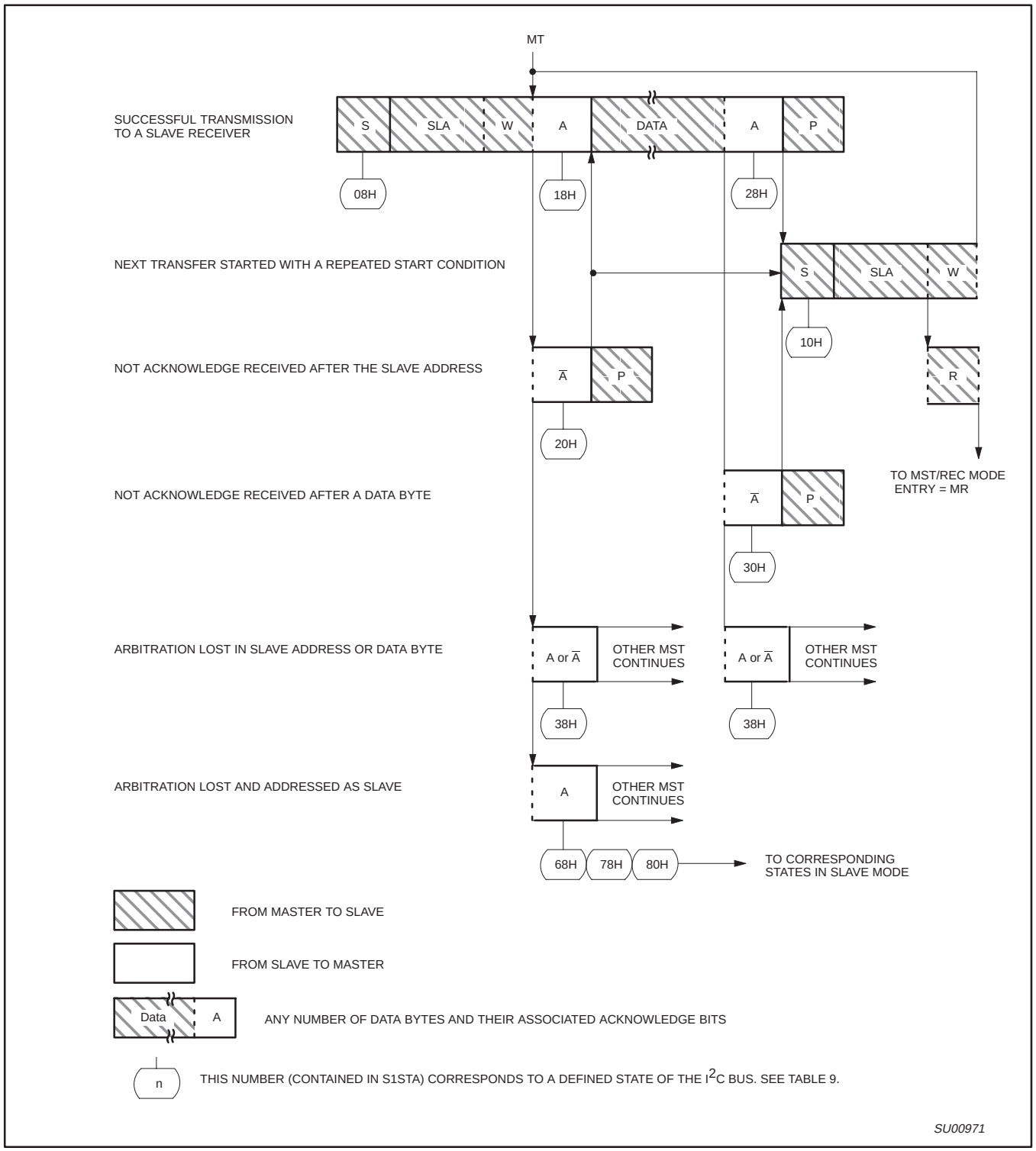


Figure 28. Format and States in the Master Transmitter Mode

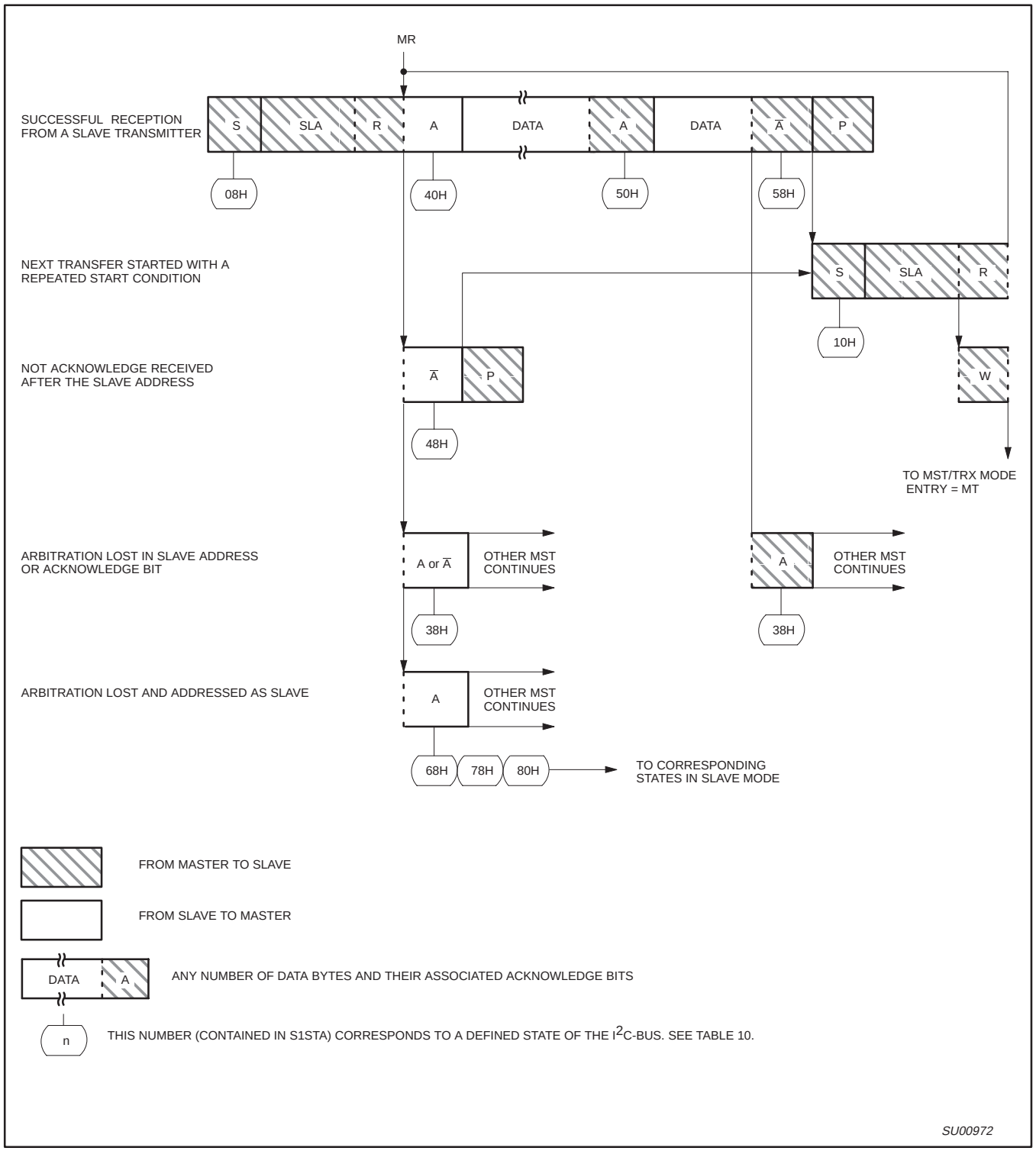


Figure 29. Format and States in the Master Receiver Mode

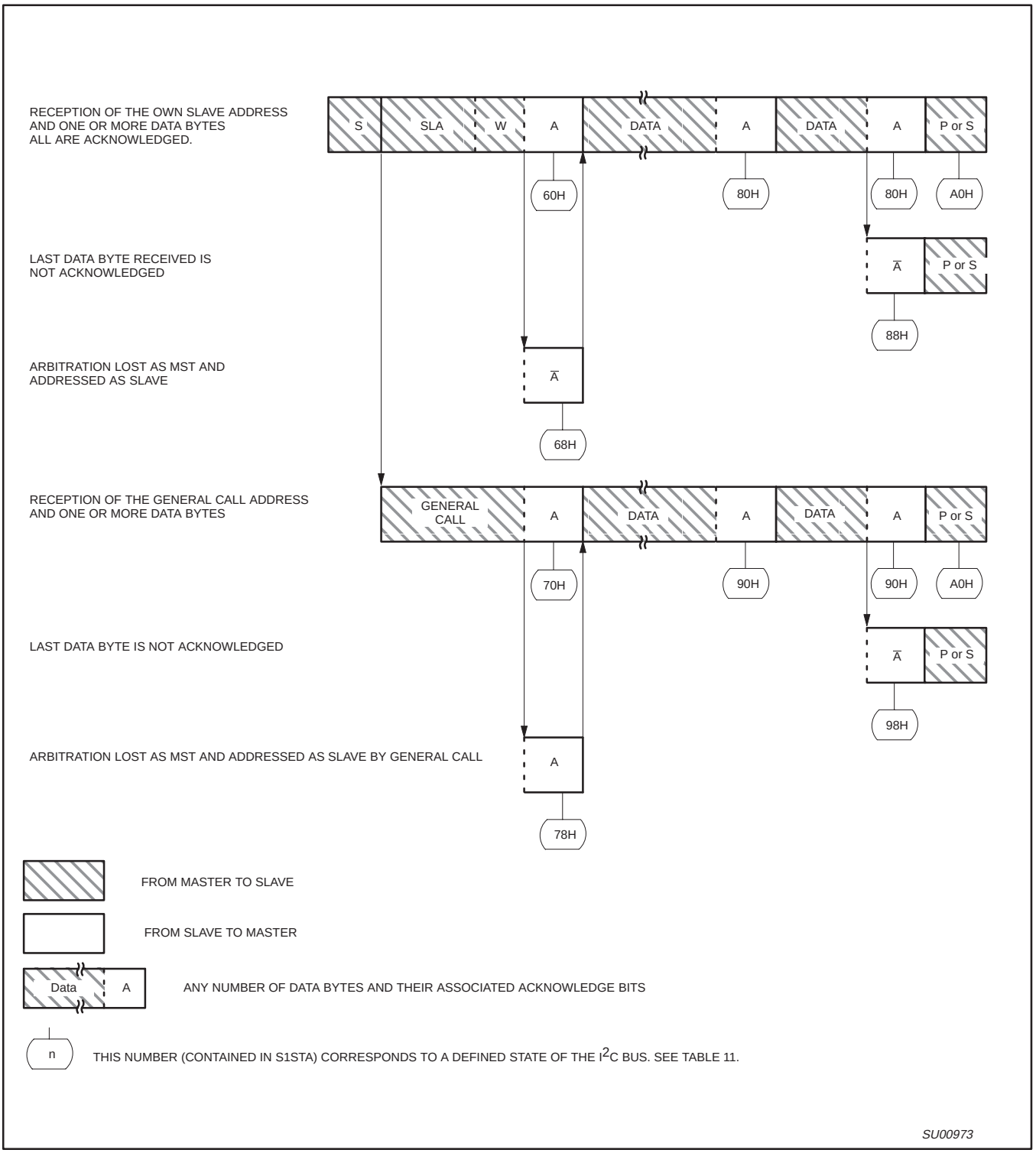


Figure 30. Format and States in the Slave Receiver Mode

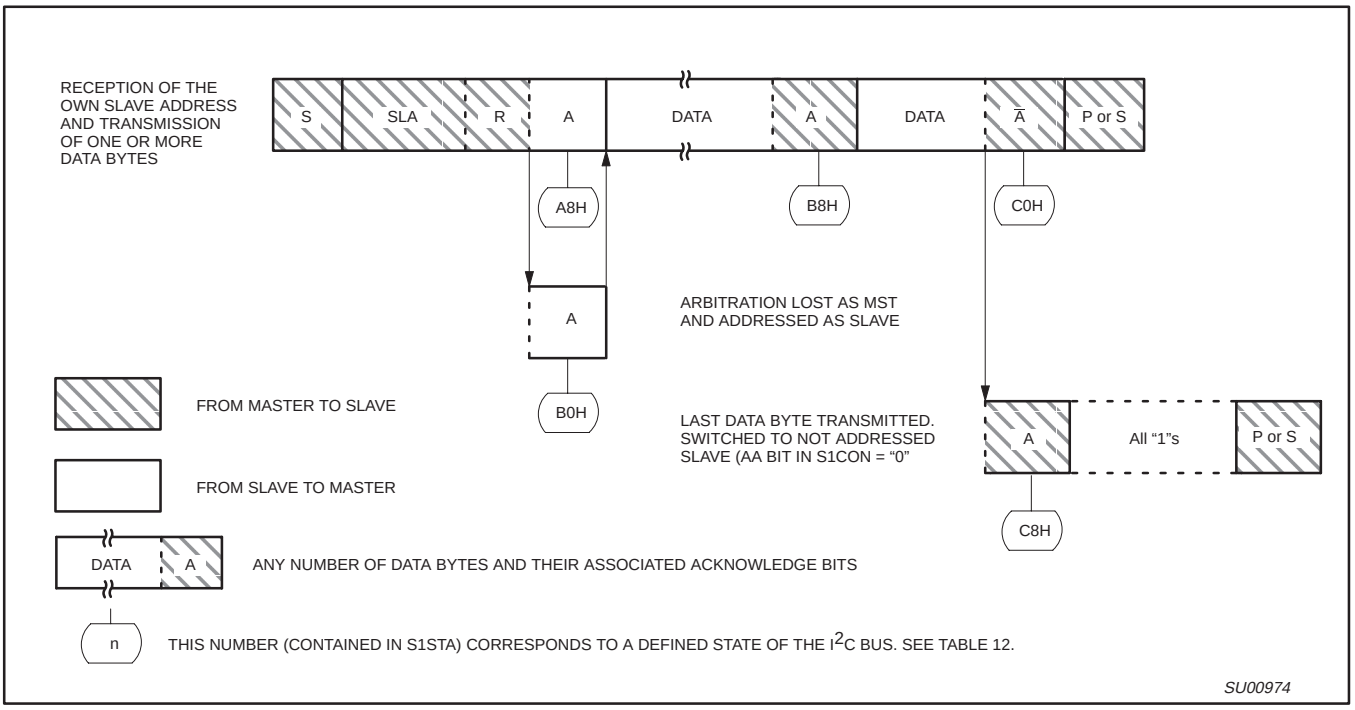


Figure 31. Format and States of the Slave Transmitter Mode

Table 9. Master Transmitter Mode

STATUS CODE (S1STA)	STATUS OF THE I^2C BUS AND HARDWARE	APPLICATION SOFTWARE RESPONSE					NEXT ACTION TAKEN BY AND I^2C HARDWARE
		TO/FROM S1DAT	TO S1CON				
			STA	STO	SI	AA	
08H	A START condition has been transmitted	Load SLA+W	X	0	0	X	SLA+W will be transmitted; ACK bit will be received
10H	A repeated START condition has been transmitted	Load SLA+W or	X	0	0	X	As above
		Load SLA+R	X	0	0	X	SLA+W will be transmitted; I^2C will be switched to MST/REC mode
18H	SLA+W has been transmitted; ACK has been received	Load data byte or	0	0	0	X	Data byte will be transmitted; ACK bit will be received
		no S1DAT action or	1	0	0	X	Repeated START will be transmitted;
		no S1DAT action or	0	1	0	X	STOP condition will be transmitted; STO flag will be reset
		no S1DAT action	1	1	0	X	STOP condition followed by a START condition will be transmitted; STO flag will be reset
20H	SLA+W has been transmitted; NOT ACK has been received	Load data byte or	0	0	0	X	Data byte will be transmitted; ACK bit will be received
		no S1DAT action or	1	0	0	X	Repeated START will be transmitted;
		no S1DAT action or	0	1	0	X	STOP condition will be transmitted; STO flag will be reset
		no S1DAT action	1	1	0	X	STOP condition followed by a START condition will be transmitted; STO flag will be reset
28H	Data byte in S1DAT has been transmitted; ACK has been received	Load data byte or	0	0	0	X	Data byte will be transmitted; ACK bit will be received
		no S1DAT action or	1	0	0	X	Repeated START will be transmitted;
		no S1DAT action or	0	1	0	X	STOP condition will be transmitted; STO flag will be reset
		no S1DAT action	1	1	0	X	STOP condition followed by a START condition will be transmitted; STO flag will be reset
30H	Data byte in S1DAT has been transmitted; NOT ACK has been received	Load data byte or	0	0	0	X	Data byte will be transmitted; ACK bit will be received
		no S1DAT action or	1	0	0	X	Repeated START will be transmitted;
		no S1DAT action or	0	1	0	X	STOP condition will be transmitted; STO flag will be reset
		no S1DAT action	1	1	0	X	STOP condition followed by a START condition will be transmitted; STO flag will be reset
38H	Arbitration lost in SLA+R/$\overline{W}$ or Data bytes	No S1DAT action or	0	0	0	X	I^2C-bus will be released; not addressed slave will be entered
		No S1DAT action	1	0	0	X	A START condition will be transmitted when the bus becomes free

Table 10. Master Receiver Mode

STATUS CODE (S1STA)	STATUS OF THE I^2C-BUS AND HARDWARE	APPLICATION SOFTWARE RESPONSE					NEXT ACTION TAKEN BY I^2C HARDWARE
		TO/FROM S1DAT	TO S1CON				
			STA	STO	SI	AA	
08H	A START condition has been transmitted	Load SLA+R	X	0	0	X	SLA+R will be transmitted; ACK bit will be received
10H	A repeated START condition has been transmitted	Load SLA+R or	X	0	0	X	As above
		Load SLA+W	X	0	0	X	SLA+W will be transmitted; I^2C will be switched to MST/TRX mode
38H	Arbitration lost in NOT ACK bit	No S1DAT action or	0	0	0	X	I^2C-bus will be released; I^2C will enter a slave mode
		No S1DAT action	1	0	0	X	A START condition will be transmitted when the bus becomes free
40H	SLA+R has been transmitted; ACK has been received	No S1DAT action or	0	0	0	0	Data byte will be received; NOT ACK bit will be returned
		no S1DAT action	0	0	0	1	Data byte will be received; ACK bit will be returned
48H	SLA+R has been transmitted; NOT ACK has been received	No S1DAT action or	1	0	0	X	Repeated START condition will be transmitted
		no S1DAT action or	0	1	0	X	STOP condition will be transmitted; STO flag will be reset
		no S1DAT action	1	1	0	X	STOP condition followed by a START condition will be transmitted; STO flag will be reset
50H	Data byte has been received; ACK has been returned	Read data byte or	0	0	0	0	Data byte will be received; NOT ACK bit will be returned
		read data byte	0	0	0	1	Data byte will be received; ACK bit will be returned
58H	Data byte has been received; NOT ACK has been returned	Read data byte or	1	0	0	X	Repeated START condition will be transmitted
		read data byte or	0	1	0	X	STOP condition will be transmitted; STO flag will be reset
		read data byte	1	1	0	X	STOP condition followed by a START condition will be transmitted; STO flag will be reset

Table 11. Slave Receiver Mode

STATUS CODE (S1STA)	STATUS OF THE I^2C BUS AND HARDWARE	APPLICATION SOFTWARE RESPONSE					NEXT ACTION TAKEN BY I^2C HARDWARE
		TO/FROM S1DAT	TO S1CON				
			STA	STO	SI	AA	
60H	Own SLA+W has been received; ACK has been returned	No S1DAT action or	X	0	0	0	Data byte will be received and NOT ACK will be returned
		no S1DAT action	X	0	0	1	Data byte will be received and ACK will be returned
68H	Arbitration lost in SLA+R/$\overline{W}$ as master; Own SLA+W has been received, ACK returned	No S1DAT action or	X	0	0	0	Data byte will be received and NOT ACK will be returned
		no S1DAT action	X	0	0	1	Data byte will be received and ACK will be returned
70H	General call address (00H) has been received; ACK has been returned	No S1DAT action or	X	0	0	0	Data byte will be received and NOT ACK will be returned
		no S1DAT action	X	0	0	1	Data byte will be received and ACK will be returned
78H	Arbitration lost in SLA+R/$\overline{W}$ as master; General call address has been received, ACK has been returned	No S1DAT action or	X	0	0	0	Data byte will be received and NOT ACK will be returned
		no S1DAT action	X	0	0	1	Data byte will be received and ACK will be returned
80H	Previously addressed with own SLV address; DATA has been received; ACK has been returned	Read data byte or	X	0	0	0	Data byte will be received and NOT ACK will be returned
		read data byte	X	0	0	1	Data byte will be received and ACK will be returned
88H	Previously addressed with own SLA; DATA byte has been received; NOT ACK has been returned	Read data byte or	0	0	0	0	Switched to not addressed SLV mode; no recognition of own SLA or General call address
		read data byte or	0	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1
		read data byte or	1	0	0	0	Switched to not addressed SLV mode; no recognition of own SLA or General call address. A START condition will be transmitted when the bus becomes free
		read data byte	1	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1. A START condition will be transmitted when the bus becomes free.
90H	Previously addressed with General Call; DATA byte has been received; ACK has been returned	Read data byte or	X	0	0	0	Data byte will be received and NOT ACK will be returned
		read data byte	X	0	0	1	Data byte will be received and ACK will be returned
98H	Previously addressed with General Call; DATA byte has been received; NOT ACK has been returned	Read data byte or	0	0	0	0	Switched to not addressed SLV mode; no recognition of own SLA or General call address
		read data byte or	0	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1
		read data byte or	1	0	0	0	Switched to not addressed SLV mode; no recognition of own SLA or General call address. A START condition will be transmitted when the bus becomes free
		read data byte	1	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1. A START condition will be transmitted when the bus becomes free.

Table 11. Slave Receiver Mode (Continued)

STATUS CODE (S1STA)	STATUS OF THE I^2C BUS AND HARDWARE	APPLICATION SOFTWARE RESPONSE					NEXT ACTION TAKEN BY I^2C HARDWARE
		TO/FROM S1DAT	TO S1CON				
			STA	STO	SI	AA	
A0H	A STOP condition or repeated START condition has been received while still addressed as SLV/REC or SLV/TRX	No STDAT action or	0	0	0	0	Switched to not addressed SLV mode; no recognition of own SLA or General call address
		No STDAT action or	0	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1
		No STDAT action or	1	0	0	0	Switched to not addressed SLV mode; no recognition of own SLA or General call address. A START condition will be transmitted when the bus becomes free
		No STDAT action	1	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1. A START condition will be transmitted when the bus becomes free.

Table 12. Slave Transmitter Mode

STATUS CODE (S1STA)	STATUS OF THE I^2C BUS AND HARDWARE	APPLICATION SOFTWARE RESPONSE					NEXT ACTION TAKEN BY I^2C HARDWARE
		TO/FROM S1DAT	TO S1CON				
			STA	STO	SI	AA	
A8H	Own SLA+R has been received; ACK has been returned	Load data byte or	X	0	0	0	Last data byte will be transmitted and ACK bit will be received
		load data byte	X	0	0	1	Data byte will be transmitted; ACK will be received
B0H	Arbitration lost in SLA+R/$\overline{W}$ as master; Own SLA+R has been received, ACK has been returned	Load data byte or	X	0	0	0	Last data byte will be transmitted and ACK bit will be received
		load data byte	X	0	0	1	Data byte will be transmitted; ACK bit will be received
B8H	Data byte in S1DAT has been transmitted; ACK has been received	Load data byte or	X	0	0	0	Last data byte will be transmitted and ACK bit will be received
		load data byte	X	0	0	1	Data byte will be transmitted; ACK bit will be received
C0H	Data byte in S1DAT has been transmitted; NOT ACK has been received	No S1DAT action or	0	0	0	01	Switched to not addressed SLV mode; no recognition of own SLA or General call address
		no S1DAT action or	0	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1
		no S1DAT action or	1	0	0	0	Switched to not addressed SLV mode; no recognition of own SLA or General call address. A START condition will be transmitted when the bus becomes free
		no S1DAT action	1	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1. A START condition will be transmitted when the bus becomes free.
C8H	Last data byte in S1DAT has been transmitted (AA = 0); ACK has been received	No S1DAT action or	0	0	0	0	Switched to not addressed SLV mode; no recognition of own SLA or General call address
		no S1DAT action or	0	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1
		no S1DAT action or	1	0	0	0	Switched to not addressed SLV mode; no recognition of own SLA or General call address. A START condition will be transmitted when the bus becomes free
		no S1DAT action	1	0	0	1	Switched to not addressed SLV mode; Own SLA will be recognized; General call address will be recognized if S1ADR.0 = logic 1. A START condition will be transmitted when the bus becomes free.

Table 13. Miscellaneous States

STATUS CODE (S1STA)	STATUS OF THE I²C BUS AND HARDWARE	APPLICATION SOFTWARE RESPONSE					NEXT ACTION TAKEN BY I²C HARDWARE
		TO/FROM S1DAT	TO S1CON				
			STA	STO	SI	AA	
F8H	No relevant state information available; SI = 0	No S1DAT action	No S1CON action				Wait or proceed current transfer
00H	Bus error during MST or selected slave modes, due to an illegal START or STOP condition. State 00H can also occur when interference causes I²C to enter an undefined state.	No S1DAT action	0	1	0	X	Only the internal hardware is affected in the MST or addressed SLV modes. In all cases, the bus is released and I²C is switched to the not addressed SLV mode. STO is reset.

Slave Transmitter Mode: In the slave transmitter mode, a number of data bytes are transmitted to a master receiver (see Figure 31). Data transfer is initialized as in the slave receiver mode. When S1ADR and S1CON have been initialized, I²C waits until it is addressed by its own slave address followed by the data direction bit which must be logic 1 (R) for the I²C to operate in the slave transmitter mode. After its own slave address and the R bit have been received, the serial interrupt flag (SI) is set and a valid status code can be read from S1STA. This status code is used to vector to an interrupt service routine, and the appropriate action to be taken for each of these status codes is detailed in Table 12. The slave transmitter mode may also be entered if arbitration is lost while I²C is in the master mode (see state B0H).

If the AA bit is reset during a transfer, I²C will transmit the last byte of the transfer and enter state C0H or C8H. I²C is switched to the not addressed slave mode and will ignore the master receiver if it continues the transfer. Thus the master receiver receives all 1s as serial data. While AA is reset, I²C does not respond to its own slave address or a general call address. However, the I²C-bus is still monitored, and address recognition may be resumed at any time by setting AA. This means that the AA bit may be used to temporarily isolate I²C from the I²C-bus.

Miscellaneous States: There are two S1STA codes that do not correspond to a defined I²C hardware state (see Table 13). These are discussed below.

S1STA = F8H:
This status code indicates that no relevant information is available because the serial interrupt flag, SI, is not yet set. This occurs between other states and when I²C is not involved in a serial transfer.

S1STA = 00H:
This status code indicates that a bus error has occurred during an I²C serial transfer. A bus error is caused when a START or STOP condition occurs at an illegal position in the format frame. Examples of such illegal positions are during the serial transfer of an address byte, a data byte, or an acknowledge bit. A bus error may also be caused when external interference disturbs the internal I²C signals. When a bus error occurs, SI is set. To recover from a bus error, the STO flag must be set and SI must be cleared. This causes I²C to enter the “not addressed” slave mode (a defined state) and to clear the STO flag (no other bits in S1CON are affected). The SDA and SCL lines are released (a STOP condition is not transmitted).

Some Special Cases: The I²C hardware has facilities to handle the following special cases that may occur during a serial transfer:

Simultaneous Repeated START Conditions from Two Masters

A repeated START condition may be generated in the master transmitter or master receiver modes. A special case occurs if another master simultaneously generates a repeated START condition (see Figure 32). Until this occurs, arbitration is not lost by either master since they were both transmitting the same data.

If the I²C hardware detects a repeated START condition on the I²C-bus before generating a repeated START condition itself, it will release the bus, and no interrupt request is generated. If another master frees the bus by generating a STOP condition, I²C will transmit a normal START condition (state 08H), and a retry of the total serial data transfer can commence.

Data Transfer After Loss of Arbitration
Arbitration may be lost in the master transmitter and master receiver modes (see Figure 24). Loss of arbitration is indicated by the following states in S1STA; 38H, 68H, 78H, and B0H (see Figures 28 and 29).

If the STA flag in S1CON is set by the routines which service these states, then, if the bus is free again, a START condition (state 08H) is transmitted without intervention by the CPU, and a retry of the total serial transfer can commence.

Forced Access to the I²C-bus
In some applications, it may be possible for an uncontrolled source to cause a bus hang-up. In such situations, the problem may be caused by interference, temporary interruption of the bus or a temporary short-circuit between SDA and SCL.

If an uncontrolled source generates a superfluous START or masks a STOP condition, then the I²C-bus stays busy indefinitely. If the STA flag is set and bus access is not obtained within a reasonable amount of time, then a forced access to the I²C-bus is possible. This is achieved by setting the STO flag while the STA flag is still set. No STOP condition is transmitted. The I²C hardware behaves as if a STOP condition was received and is able to transmit a START condition. The STO flag is cleared by hardware (see Figure 33).

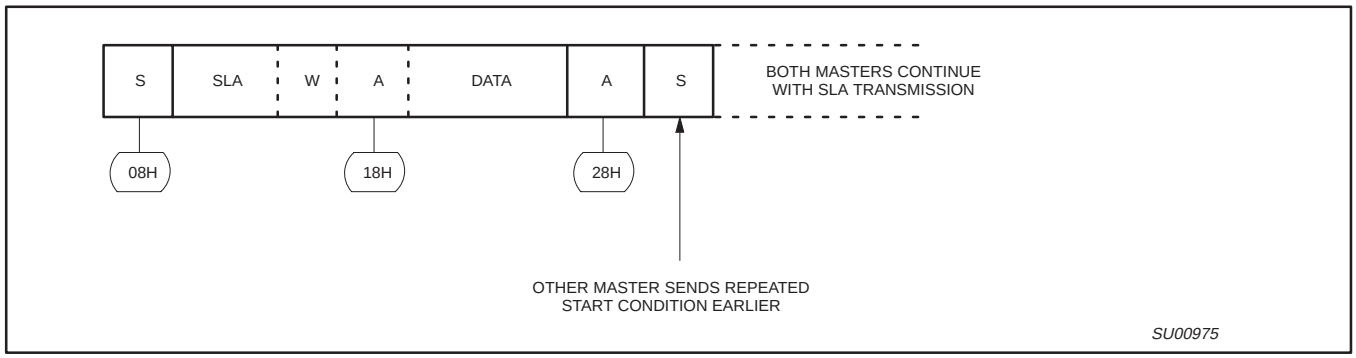


Figure 32. Simultaneous Repeated START Conditions from 2 Masters

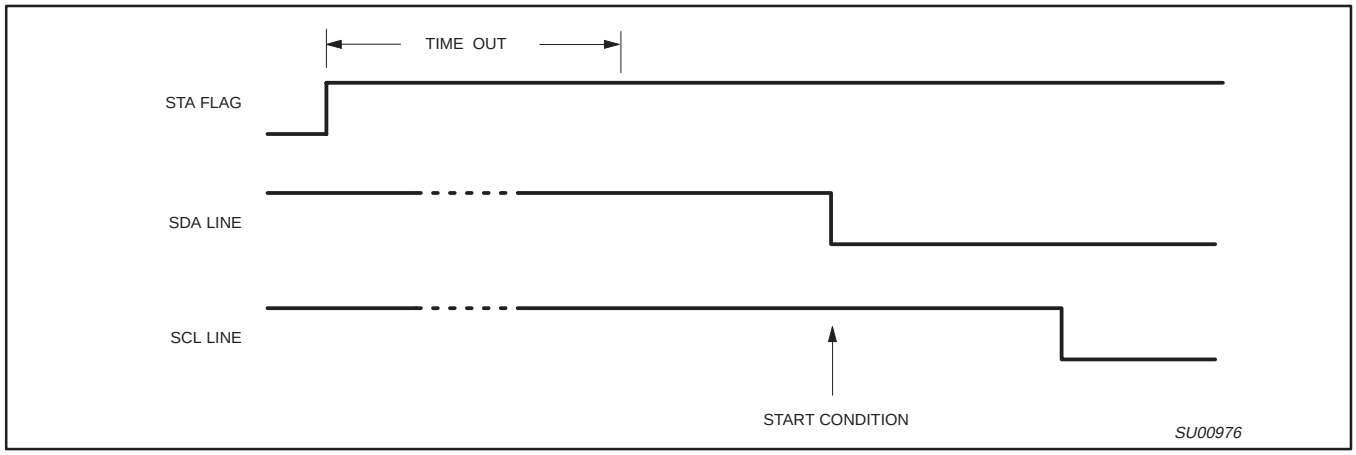


Figure 33. Forced Access to a Busy I²C-bus

I²C-BUS OBSTRUCTED BY A LOW LEVEL ON SCL OR SDA

An I²C-bus hang-up occurs if SDA or SCL is pulled LOW by an uncontrolled source. If the SCL line is obstructed (pulled LOW) by a device on the bus, no further serial transfer is possible, and the I²C hardware cannot resolve this type of problem. When this occurs, the problem must be resolved by the device that is pulling the SCL bus line LOW.

If the SDA line is obstructed by another device on the bus (e.g., a slave device out of bit synchronization), the problem can be solved by transmitting additional clock pulses on the SCL line (see Figure 34). The I²C hardware transmits additional clock pulses when the STA flag is set, but no START condition can be generated because the SDA line is pulled LOW while the I²C-bus is considered free. The I²C hardware attempts to generate a START condition after every two additional clock pulses on the SCL line. When the SDA line is eventually released, a normal START condition is transmitted, state 08H is entered, and the serial transfer continues.

If a forced bus access occurs or a repeated START condition is transmitted while SDA is obstructed (pulled LOW), the I²C hardware performs the same action as described above. In each case, state 08H is entered after a successful START condition is transmitted and normal serial transfer continues. Note that the CPU is not involved in solving these bus hang-up problems.

BUS ERROR

A bus error occurs when a START or STOP condition is present at an illegal position in the format frame. Examples of illegal positions are during the serial transfer of an address byte, a data or an acknowledge bit.

The I²C hardware only reacts to a bus error when it is involved in a serial transfer either as a master or an addressed slave. When a bus error is detected, I²C immediately switches to the not addressed slave mode, releases the SDA and SCL lines, sets the interrupt flag, and loads the status register with 00H. This status code may be used to vector to a service routine which either attempts the aborted serial transfer again or simply recovers from the error condition as shown in Table 13.

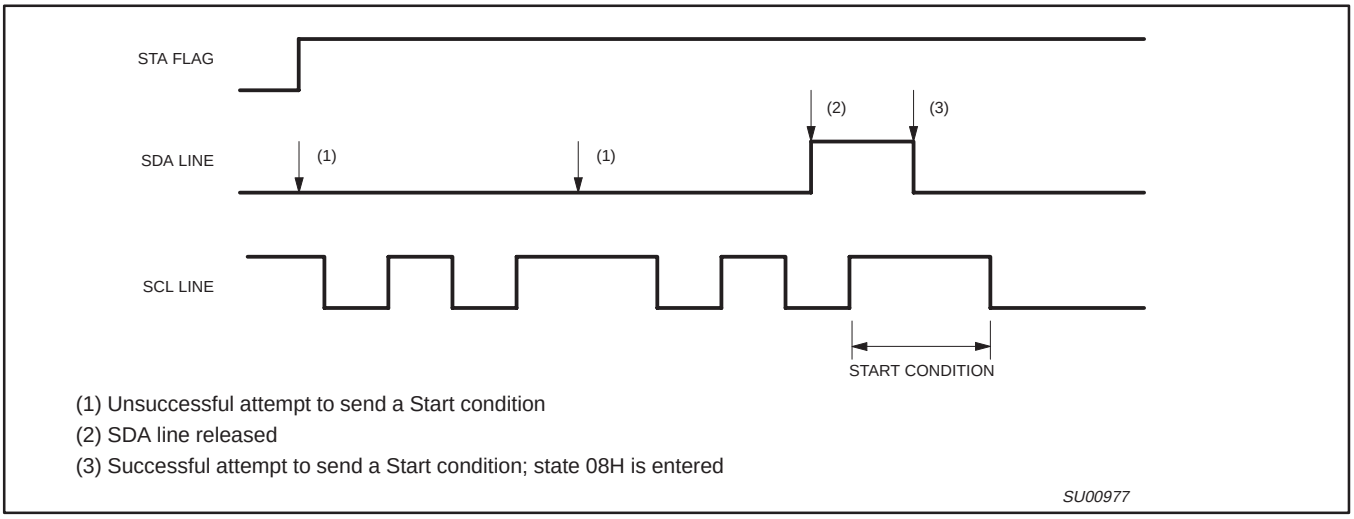


Figure 34. Recovering from a Bus Obstruction Caused by a Low Level on SDA

Software Examples of I²C Service Routines: This section consists of a software example for:

– Initialization of I²C after a RESET
– Entering the I²C interrupt routine
– The 26 state service routines for the
  – Master transmitter mode
  – Master receiver mode
  – Slave receiver mode
  – Slave transmitter mode

INITIALIZATION

In the initialization routine, I²C is enabled for both master and slave modes. For each mode, a number of bytes of internal data RAM are allocated to the SIO to act as either a transmission or reception buffer. In this example, 8 bytes of internal data RAM are reserved for different purposes. The data memory map is shown in Figure 35. The initialization routine performs the following functions:

– S1ADR is loaded with the part's own slave address and the general call bit (GC)
– P1.6 and P1.7 bit latches are loaded with logic 1s
– RAM location HADD is loaded with the high-order address byte of the service routines
– The I²C interrupt enable and interrupt priority bits are set
– The slave mode is enabled by simultaneously setting the ENS1 and AA bits in S1CON and the serial clock frequency (for master modes) is defined by loading CR0 and CR1 in S1CON. The master routines must be started in the main program.

The I²C hardware now begins checking the I²C-bus for its own slave address and general call. If the general call or the own slave address is detected, an interrupt is requested and S1STA is loaded with the appropriate state information. The following text describes a fast method of branching to the appropriate service routine.

I²C INTERRUPT ROUTINE

When the I²C interrupt is entered, the PSW is first pushed on the stack. Then S1STA and HADD (loaded with the high-order address byte of the 26 service routines by the initialization routine) are pushed on to the stack. S1STA contains a status code which is the lower byte of one of the 26 service routines. The next instruction is RET, which is the return from subroutine instruction. When this instruction is executed, the HIGH and LOW order address bytes are popped from stack and loaded into the program counter.

The next instruction to be executed is the first instruction of the state service routine. Seven bytes of program code (which execute in eight machine cycles) are required to branch to one of the 26 state service routines.

```
SI      PUSH   PSW      Save PSW
        PUSH   S1STA    Push status code
                        (low order address byte)
        PUSH   HADD     Push HIGH order address byte
        RET             Jump to state service routine
```

The state service routines are located in a 256-byte page of program memory. The location of this page is defined in the initialization routine. The page can be located anywhere in program memory by loading data RAM register HADD with the page number. Page 01 is chosen in this example, and the service routines are located between addresses 0100H and 01FFH.

THE STATE SERVICE ROUTINES

The state service routines are located 8 bytes from each other. Eight bytes of code are sufficient for most of the service routines. A few of the routines require more than 8 bytes and have to jump to other locations to obtain more bytes of code. Each state routine is part of the I²C interrupt routine and handles one of the 26 states. It ends with a RETI instruction which causes a return to the main program.

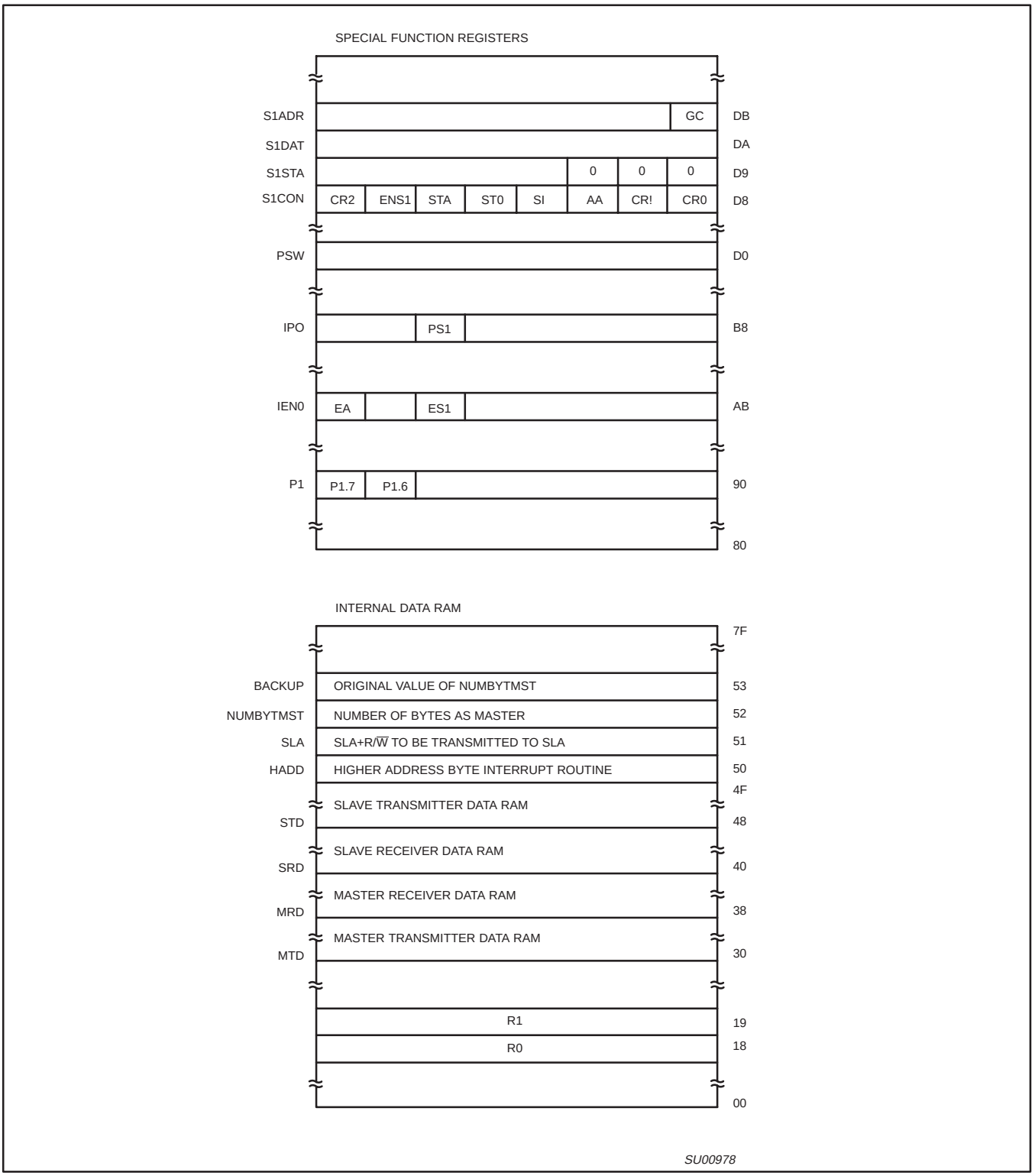


Figure 35. I^2C Data Memory Map

Master Transmitter and Master Receiver Modes

The master mode is entered in the main program. To enter the master transmitter mode, the main program must first load the internal data RAM with the slave address, data bytes, and the number of data bytes to be transmitted. To enter the master receiver mode, the main program must first load the internal data RAM with the slave address and the number of data bytes to be received. The R/$\overline{W}$ bit determines whether I^2C operates in the master transmitter or master receiver mode.

Master mode operation commences when the STA bit in S1CION is set by the SETB instruction and data transfer is controlled by the master state service routines in accordance with Table 9, Table 10, Figure 28, and Figure 29. In the example below, 4 bytes are transferred. There is no repeated START condition. In the event of lost arbitration, the transfer is restarted when the bus becomes free. If a bus error occurs, the I^2C-bus is released and I^2C enters the not selected slave receiver mode. If a slave device returns a not acknowledge, a STOP condition is generated.

A repeated START condition can be included in the serial transfer if the STA flag is set instead of the STO flag in the state service routines vectored to by status codes 28H and 58H. Additional software must be written to determine which data is transferred after a repeated START condition.

Slave Transmitter and Slave Receiver Modes

After initialization, I^2C continually tests the I^2C-bus and branches to one of the slave state service routines if it detects its own slave address or the general call address (see Table 11, Table 12, Figure 30, and Figure 31). If arbitration was lost while in the master mode, the master mode is restarted after the current transfer. If a bus error occurs, the I^2C-bus is released and I^2C enters the not selected slave receiver mode.

In the slave receiver mode, a maximum of 8 received data bytes can be stored in the internal data RAM. A maximum of 8 bytes ensures that other RAM locations are not overwritten if a master sends more bytes. If more than 8 bytes are transmitted, a not acknowledge is returned, and I^2C enters the not addressed slave receiver mode. A maximum of one received data byte can be stored in the internal data RAM after a general call address is detected. If more than one byte is transmitted, a not acknowledge is returned and I^2C enters the not addressed slave receiver mode.

In the slave transmitter mode, data to be transmitted is obtained from the same locations in the internal data RAM that were previously loaded by the main program. After a not acknowledge has been returned by a master receiver device, I^2C enters the not addressed slave mode.

Adapting the Software for Different Applications

The following software example shows the typical structure of the interrupt routine including the 26 state service routines and may be used as a base for user applications. If one or more of the four modes are not used, the associated state service routines may be removed but, care should be taken that a deleted routine can never be invoked.

This example does not include any time-out routines. In the slave modes, time-out routines are not very useful since, in these modes, I^2C behaves essentially as a passive device. In the master modes, an internal timer may be used to cause a time-out if a serial transfer is not complete after a defined period of time. This time period is defined by the system connected to the I^2C-bus.

```
                        !*************************************************************************************************
                        ! SI01 EQUATE LIST
                        !*************************************************************************************************
                        !*************************************************************************************************
                        ! LOCATIONS OF THE SI01 SPECIAL FUNCTION REGISTERS
                        !*************************************************************************************************
00D8                    S1CON     –0xd8
00D9                    S1STA     –0xd9
00DA                    S1DAT     –0xda
00DB                    S1ADR     –0xdb

00A8                    IEN0      –0xa8
00B8                    IP0       –02b8

                        !*************************************************************************************************
                        ! BIT LOCATIONS
                        !*************************************************************************************************

00DD                    STA       –0xdd                    ! STA bit in S1CON
00BD                    SI01HP    –0xbd                    ! IP0, SI01 Priority bit

                        !*************************************************************************************************
                        ! IMMEDIATE DATA TO WRITE INTO REGISTER S1CON
                        !*************************************************************************************************
00D5                    ENS1_NOTSTA_STO_NOTSI_AA_CR0       –0xd5    ! Generates STOP
                                                                    ! (CR0 = 100kHz)
00C5                    ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0    –0xc5    ! Releases BUS and
                                                                    ! ACK
00C1                    ENS1_NOTSTA_NOTSTO_NOTSI_NOTAA_CR0 –0xc1    ! Releases BUS and
                                                                    ! NOT ACK
00E5                    ENS1_STA_NOTSTO_NOTSI_AA_CR0       –0xe5    ! Releases BUS and
                                                                    ! set STA

                        !*************************************************************************************************
                        ! GENERAL IMMEDIATE DATA
                        !*************************************************************************************************
0031                    OWNSLA    –0x31                    ! Own SLA+General Call
                                                           ! must be written into S1ADR
00A0                    ENSI01    –0xa0                    ! EA+ES1, enable I2C interrupt
                                                           ! must be written into IEN0
0001                    PAG1      –0x01                    ! select PAG1 as HADD
00C0                    SLAW      –0xc0                    ! SLA+W to be transmitted
00C1                    SLAR      –0xc1                    ! SLA+R to be transmitted
0018                    SELRB3    –0x18                    ! Select Register Bank 3

                        !*************************************************************************************************
                        ! LOCATIONS IN DATA RAM
                        !*************************************************************************************************
0030                    MTD       –0x30                    ! MST/TRX/DATA base address
0038                    MRD       –0x38                    ! MST/REC/DATA base address
0040                    SRD       –0x40                    ! SLV/REC/DATA base address
0048                    STD       –0x48                    ! SLV/TRX/DATA base address

0053                    BACKUP        –0x53                ! Backup from NUMBYTMST
                                                           ! To restore NUMBYTMST in case
                                                           ! of an Arbitration Loss.
0052                    NUMBYTMST     –0x52                ! Number of bytes to transmit
                                                           ! or receive as MST.
0051                    SLA           –0x51                ! Contains SLA+R/W to be
                                                           ! transmitted.
0050                    HADD          –0x50                ! High Address byte for STATE 0
                                                           ! till STATE 25.
```

```
                        !*************************************************************************************************
                        ! INITIALIZATION ROUTINE
                        ! Example to initialize IIC Interface as slave receiver or slave transmitter and
                        ! start a MASTER TRANSMIT or a MASTER RECEIVE function. 4 bytes will be transmitted or received.
                        !*************************************************************************************************
                        .sect   strt
                        .base   0x00
0000    4100                            ajmp    INIT                    ! RESET

                        .sect   initial
                        .base   0x200
0200    75DB31          INIT:           mov     S1ADR,#OWNSLA           ! Load own SLA + enable
                                                                        ! general call recognition
0203    D296                            setb    P1(6)                   ! P1.6 High level.
0205    D297                            setb    P1(7)                   ! P1.7 High level.
0207    755001                          mov     HADD,#PAG1
020A    43A8A0                          orl     IEN0,#ENSI01            ! Enable SI01 interrupt
020D    C2BD                            clr     SI01HP                  ! SI01 interrupt low priority
020F    75D8C5                          mov     S1CON, #ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                        ! Initialize SLV funct.

                        !*************************************************************************************************

                        !-------------------------------------------------
                        ! START MASTER TRANSMIT FUNCTION
                        !-------------------------------------------------

0212    755204                          mov     NUMBYTMST,#0x4          ! Transmit 4 bytes.
0215    7551C0                          mov     SLA,#SLAW               ! SLA+W, Transmit funct.
0218    D2DD                            setb    STA                     ! set STA in S1CON

                        !-------------------------------------------------
                        ! START MASTER RECEIVE FUNCTION
                        !-------------------------------------------------
021A    755204                          mov     NUMBYTMST,#0x4          ! Receive 4 bytes.
021D    7551C1                          mov     SLA,#SLAR               ! SLA+R, Receive funct.
0220    D2DD                            setb    STA                     ! set STA in S1CON


                        !*************************************************************************************************
                        ! SI01 INTERRUPT ROUTINE
                        !*************************************************************************************************
                        .sect   intvec                                  ! SI01 interrupt vector
                        .base   0x00

                        ! S1STA and HADD are pushed onto the stack.
                        ! They serve as return address for the RET instruction.
                        ! The RET instruction sets the Program Counter to address HADD,
                        ! S1STA and jumps to the right subroutine.

002B    C0D0                            push    psw                     ! save  psw
002D    C0D9                            push    S1STA
002F    C050                            push    HADD
0031    22                              ret                             ! JMP to address HADD,S1STA.

                        !-------------------------------------------------
                        ! STATE    : 00, Bus error.
                        ! ACTION   : Enter not addressed SLV mode and release bus. STO reset.
                        !-------------------------------------------------
                        .sect   st0
                        .base   0x100

0100    75D8D5                          mov     S1CON,#ENS1_NOTSTA_STO_NOTSI_AA_CR0 ! clr SI
                                                                                    ! set  STO,AA
0103    D0D0                            pop     psw
0105    32                              reti
```

```
                        !*************************************************************************************************
                        !*************************************************************************************************
                        ! MASTER STATE SERVICE ROUTINES
                        !*************************************************************************************************
                        ! State 08 and State 10 are both for MST/TRX and MST/REC.
                        ! The R/W bit decides whether the next state is within
                        ! MST/TRX mode or within MST/REC mode.
                        !*************************************************************************************************

                        !-------------------------------------------------------
                        ! STATE     : 08, A, START condition has been transmitted.
                        ! ACTION    : SLA+R/W are transmitted, ACK bit is received.
                        !-------------------------------------------------------
                        .sect       mts8
                        .base       0x108

0108    8551DA                              mov   S1DAT,SLA                   ! Load  SLA+R/W
010B    75D8C5                              mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                              ! clr  SI
010E    01A0                                ajmp  INITBASE1

                        !-------------------------------------------------------
                        ! STATE     : 10, A repeated START condition has been
                        !               transmitted.
                        ! ACTION    : SLA+R/W are transmitted, ACK bit is received.
                        !-------------------------------------------------------
                        .sect       mts10
                        .base       0x110

0110    8551DA                              mov   S1DAT,SLA                   ! Load  SLA+R/W
0113    75D8C5                              mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                              ! clr  SI
010E    01A0                                ajmp  INITBASE1

                        .sect       ibase1
                        .base       0xa0
00A0    75D018  INITBASE1:          mov   psw,#SELRB3
00A3    7930                        mov   r1,#MTD
00A5    7838                        mov   r0,#MRD
00A7    855253                      mov   BACKUP,NUMBYTMST                    ! Save initial value
00AA    D0D0                        pop   psw
00AC    32                          reti



                        !*************************************************************************************************
                        !*************************************************************************************************
                        ! MASTER TRANSMITTER STATE SERVICE ROUTINES
                        !*************************************************************************************************
                        !*************************************************************************************************

                        !-------------------------------------------------------
                        ! STATE     : 18, Previous state was STATE 8 or STATE 10, SLA+W have been transmitted,
                        !               ACK has been received.
                        ! ACTION    : First DATA is transmitted, ACK bit  is received.
                        !-------------------------------------------------------
                        .sect       mts18
                        .base       0x118

0118    75D018                              mov   psw,#SELRB3
011B    87DA                                mov   S1DAT,@r1
011D    01B5                                ajmp  CON
```

```
                        !-------------------------------------------------------
                        ! STATE    : 20, SLA+W have been transmitted, NOT ACK has been received
                        ! ACTION   : Transmit STOP condition.
                        !-------------------------------------------------------
                        .sect      mts20
                        .base      0x120

0120    75D8D5                                mov   S1CON,#ENS1_NOTSTA_STO_NOTSI_AA_CR0
                                                                    ! set  STO, clr  SI
0123    D0D0                                  pop   psw
0125    32                                    reti

                        !-------------------------------------------------------
                        ! STATE    : 28, DATA of S1DAT have been transmitted, ACK received.
                        ! ACTION   : If Transmitted DATA is last DATA then transmit a STOP condition,
                        !            else transmit next DATA.
                        !-------------------------------------------------------
                        .sect      mts28
                        .base      0x128

0128    D55285                                djnz  NUMBYTMST,NOTLDAT1      ! JMP if NOT last DATA
012B    75D8D5                                mov   S1CON,#ENS1_NOTSTA_STO_NOTSI_AA_CR0
                                                                    ! clr  SI, set  AA
012E    01B9                                  ajmp  RETmt

                        .sect      mts28sb
                        .base      0x0b0
00B0    75D018  NOTLDAT1:                     mov   psw,#SELRB3
00B3    87DA                                  mov   S1DAT,@r1
00B5    75D8C5  CON:                          mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                    ! clr  SI, set   AA
00B8    09                                    inc   r1
00B9    D0D0    RETmt     :                   pop   psw
00BB    32                                    reti
                        !-------------------------------------------------------
                        ! STATE    : 30, DATA of S1DAT have been transmitted, NOT ACK received.
                        ! ACTION   : Transmit a STOP condition.
                        !-------------------------------------------------------
                        .sect      mts30
                        .base      0x130

0130    75D8D5                                mov   S1CON,#ENS1_NOTSTA_STO_NOTSI_AA_CR0
                                                                    ! set  STO, clr  SI
0133    D0D0                                  pop   psw
0135    32                                    reti

                        !-------------------------------------------------------
                        ! STATE    : 38, Arbitration lost in SLA+W or DATA.
                        ! ACTION   : Bus is released, not addressed SLV mode is entered.
                        !            A new START condition is transmitted when the IIC-bus is free again.
                        !-------------------------------------------------------
                        .sect      mts38
                        .base      0x138

0138    75D8E5                                mov   S1CON,#ENS1_STA_NOTSTO_NOTSI_AA_CR0
013B    855352                                mov   NUMBYTMST,BACKUP
013E    01B9                                  ajmp  RETmt
```

```
                        !*************************************************************************************************
                        !*************************************************************************************************
                        ! MASTER RECEIVER STATE SERVICE ROUTINES
                        !*************************************************************************************************
                        !*************************************************************************************************

                        !-------------------------------------------------------
                        ! STATE    : 40, Previous state was STATE 08 or STATE 10,
                        !            SLA+R have been transmitted, ACK received.
                        ! ACTION   : DATA will be received, ACK returned.
                        !-------------------------------------------------------
                        .sect      mts40
                        .base      0x140

0140    75D8C5                              mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                    ! clr  STA, STO, SI  set  AA
0143    D0D0                                pop   psw
        32                                  reti

                        !-------------------------------------------------------
                        ! STATE    : 48, SLA+R have been transmitted, NOT ACK received.
                        ! ACTION   : STOP condition will be generated.
                        !-------------------------------------------------------
                        .sect      mts48
                        .base      0x148

0148    75D8D5          STOP:               mov   S1CON,#ENS1_NOTSTA_STO_NOTSI_AA_CR0
                                                                    ! set  STO, clr  SI
014B    D0D0                                pop   psw
014D    32                                  reti

                        !-------------------------------------------------------
                        ! STATE    : 50, DATA have been received, ACK returned.
                        ! ACTION   : Read DATA of S1DAT.
                        !            DATA will be received, if it is last DATA
                                     then NOT ACK will be returned else ACK will be returned.
                        !-------------------------------------------------------
                        .sect      mrs50
                        .base      0x150

0150    75D018                              mov   psw,#SELRB3
0153    A6DA                                mov   @r0,S1DAT                 ! Read received DATA
0155    01C0                                ajmp  REC1

                        .sect      mrs50s
                        .base      0xc0

00C0    D55205          REC1:               djnz  NUMBYTMST,NOTLDAT2
00C3    75D8C1                              mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_NOTAA_CR0
                                                                    ! clr  SI,AA
00C6    8003                                sjmp  RETmr
00C8    75D8C5          NOTLDAT2:           mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                    ! clr  SI, set  AA
00CB    08              RETmr:              inc   r0
00CC    D0D0                                pop   psw
00CE    32                                  reti

                        !-------------------------------------------------------
                        ! STATE    : 58, DATA have been received, NOT ACK returned.
                        ! ACTION   : Read DATA of S1DAT and generate a STOP condition.
                        !-------------------------------------------------------
                        .sect      mrs58
                        .base      0x158

0158    75D018                              mov   psw,#SELRB3
015B    A6DA                                mov   @R0,S1DAT
015D    80E9                                sjmp  STOP
```

```
                        !*************************************************************************************************
                        !*************************************************************************************************
                        ! SLAVE RECEIVER STATE SERVICE ROUTINES
                        !*************************************************************************************************
                        !*************************************************************************************************

                        !-------------------------------------------------------------
                        ! STATE    : 60, Own SLA+W have been received, ACK returned.
                        ! ACTION   : DATA will be received and ACK returned.
                        !-------------------------------------------------------------
                        .sect      srs60
                        .base      0x160
0160    75D8C5                             mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                          ! clr  SI, set  AA
0163    75D018                             mov   psw,#SELRB3
0166    01D0                               ajmp  INITSRD
                        .sect      insrd
                        .base      0xd0

00D0    7840            INITSRD:           mov   r0,#SRD
00D2    7908                               mov   r1,#8
00D4    D0D0                               pop   psw
00D6    32                                 reti

                        !-------------------------------------------------------------
                        ! STATE    : 68, Arbitration lost in SLA and R/W as MST
                        !            Own SLA+W have been received, ACK returned
                        ! ACTION   : DATA will be received and ACK returned.
                        !            STA is set to restart MST mode after the bus is free again.
                        !-------------------------------------------------------------
                        .sect      srs68
                        .base      0x168
0168    75D8E5                             mov   S1CON,#ENS1_STA_NOTSTO_NOTSI_AA_CR0
016B    75D018                             mov   psw,#SELRB3
016E    01D0                               ajmp  INITSRD

                        !-------------------------------------------------------------
                        ! STATE    : 70, General call has been received, ACK returned.
                        ! ACTION   : DATA will be received and ACK returned.
                        !-------------------------------------------------------------
                        .sect      srs70
                        .base      0x170
0170    75D8C5                             mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                          ! clr  SI, set  AA
0173    75D018                             mov   psw,#SELRB3             ! Initialize SRD counter
0176    01D0                               ajmp  initsrd

                        !-------------------------------------------------------------
                        ! STATE    : 78, Arbitration lost in SLA+R/W as MST.
                        !            General call has been received, ACK returned.
                        ! ACTION   : DATA will be received and ACK returned.
                        !            STA is set to restart MST mode after the bus is free again.
                        !-------------------------------------------------------------
                        .sect      srs78
                        .base      0x178
0178    75D8E5                             mov   S1CON,#ENS1_STA_NOTSTO_NOTSI_AA_CR0
017B    75D018                             mov   psw,#SELRB3             ! Initialize SRD counter
017E    01D0                               ajmp  INITSRD
```

```
                        !-------------------------------------------------------
                        ! STATE    : 80, Previously addressed with own SLA. DATA received, ACK returned.
                        ! ACTION   : Read DATA.
                        !             IF received DATA was the last
                        !             THEN superfluous DATA will be received  and NOT ACK returned
                                      ELSE next DATA will be received and ACK returned.
                        !-------------------------------------------------------
                        .sect     srs80
                        .base     0x180

0180    75D018                            mov   psw,#SELRB3
0183    A6DA                              mov   @r0,S1DAT                  ! Read received DATA
0185    01D8                              ajmp  REC2

                        .sect     srs80s
                        .base     0xd8

00D8    D906            REC2:             djnz  r1,NOTLDAT3
00DA    75D8C1          LDAT:             mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_NOTAA_CR0
                                                                             ! clr  SI,AA
00DD    D0D0                              pop   psw
00DF    32                                reti
00E0    75D8C5          NOTLDAT3:         mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                             ! clr  SI, set  AA
00E3    08                                inc   r0
00E4    D0D0            RETsr:            pop   psw
00E6    32                                reti

                        !-------------------------------------------------------
                        ! STATE    : 88, Previously addressed with own SLA. DATA received NOT ACK returned.
                        ! ACTION   : No save of DATA, Enter NOT addressed SLV mode.
                        !             Recognition of own SLA. General call recognized, if S1ADR. 0–1.
                        !-------------------------------------------------------
                        .sect     srs88
                        .base     0x188

0188    75D8C5                            mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                             ! clr  SI, set  AA
018B    01E4                              ajmp  RETsr

                        !-------------------------------------------------------
                        ! STATE    : 90, Previously addressed with general call.
                        !             DATA has been received, ACK has been returned.
                        ! ACTION   : Read DATA.
                                      After General call only one byte will be received with ACK
                        !             the second DATA will be received with NOT ACK.
                        !             DATA will be received and NOT ACK returned.
                        !-------------------------------------------------------
                        .sect     srs90
                        .base     0x190

0190    75D018                            mov   psw,#SELRB3
0193    A6DA                              mov   @r0,S1DAT                  ! Read received DATA
0195    01DA                              ajmp  LDAT
                        !-------------------------------------------------------
                        ! STATE    : 98, Previously addressed with general call.
                        !             DATA has been received, NOT ACK has been returned.
                        ! ACTION   : No save of DATA, Enter NOT addressed SLV mode.
                                      Recognition of own SLA. General call recognized, if S1ADR. 0–1.
                        !-------------------------------------------------------
                        .sect     srs98
                        .base     0x198

0198    75D8C5                            mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                             ! clr  SI, set  AA
019B    D0D0                              pop   psw
019D    32                                reti
```

```
                        !-------------------------------------------------------
                        ! STATE    : A0, A STOP condition or repeated START has been received,
                        !            while still addressed as SLV/REC or SLV/TRX.
                        ! ACTION   : No save of DATA, Enter NOT addressed SLV mode.
                        !            Recognition of own SLA. General call recognized, if S1ADR. 0–1.
                        !-------------------------------------------------------
                        .sect       srsA0
                        .base       0x1a0

01A0    75D8C5                              mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                        ! clr  SI, set  AA
01A3    D0D0                                pop   psw
01A5    32                                  reti



                        !*******************************************************************************************************
                        !*******************************************************************************************************
                        ! SLAVE TRANSMITTER STATE SERVICE ROUTINES
                        !*******************************************************************************************************
                        !*******************************************************************************************************

                        !-------------------------------------------------------
                        ! STATE    : A8, Own SLA+R received, ACK returned.
                        ! ACTION   : DATA will be transmitted, A bit received.
                        !-------------------------------------------------------
                        .sect       stsa8
                        .base       0x1a8

01A8    8548DA                              mov   S1DAT,STD                     ! load DATA in S1DAT
01AB    75D8C5                              mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                        ! clr  SI, set  AA
01AE    01E8                                ajmp  INITBASE2

                        .sect       ibase2
                        .base       0xe8
00E8    75D018  INITBASE2:                  mov   psw,#SELRB3
00EB    7948                                mov   r1, #STD
00ED    09                                  inc   r1
00EE    D0D0                                pop   psw
00F0    32                                  reti

                        !-------------------------------------------------------
                        ! STATE    : B0, Arbitration lost in SLA and R/W as MST.  Own SLA+R received, ACK returned.
                        ! ACTION   : DATA will be transmitted, A bit received.
                        !            STA is set to restart MST mode after the bus is free again.
                        !-------------------------------------------------------
                        .sect       stsb0
                        .base       0x1b0

01B0    8548DA                              mov   S1DAT,STD                     ! load DATA in S1DAT
01B3    75D8E5                              mov   S1CON,#ENS1_STA_NOTSTO_NOTSI_AA_CR0
01B6    01E8                                ajmp  INITBASE2
```

```
                        !-------------------------------------------------------
                        ! STATE    : B8, DATA has been transmitted, ACK received.
                        ! ACTION   : DATA will be transmitted, ACK bit is received.
                        !-------------------------------------------------------
                        .sect      stsb8
                        .base      0x1b8
01B8    75D018                             mov   psw,#SELRB3
01BB    87DA                               mov   S1DAT,@r1
01BD    01F8                               ajmp  SCON

                        .sect      scn
                        .base      0xf8

00F8    75D8C5          SCON:              mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                    ! clr  SI, set  AA
00FB    09                                 inc   r1
00FC    D0D0                               pop   psw
00FE    32                                 reti
                        !-------------------------------------------------------
                        ! STATE    : C0, DATA has been transmitted, NOT ACK received.
                        ! ACTION   : Enter not addressed SLV mode.
                        !-------------------------------------------------------
                        .sect      stsc0
                        .base      0x1c0
01C0    75D8C5                             mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                    ! clr  SI, set  AA
01C3    D0D0                               pop   psw
01C5    32                                 reti

                        !-------------------------------------------------------
                        ! STATE    : C8, Last DATA has been transmitted (AA=0), ACK received.
                        ! ACTION   : Enter not addressed SLV mode.
                        !-------------------------------------------------------
                        .sect      stsc8
                        .base      0x1c8
01C8    75D8C5                             mov   S1CON,#ENS1_NOTSTA_NOTSTO_NOTSI_AA_CR0
                                                                    ! clr  SI, set  AA
01CB    D0D0                               pop   psw
01CD    32                                 reti


                        !*******************************************************************************************************
                        !*******************************************************************************************************
                        ! END OF SI01 INTERRUPT ROUTINE
                        !*******************************************************************************************************
                        !*******************************************************************************************************
```

Interrupt Priority Structure

The P8xC654X2 has an 8 source four-level interrupt structure (see Table 14).

There are four SFRs associated with the four-level interrupt. They are IE, IEN1, IP, and IPH. The IPH (Interrupt Priority High) register makes the four-level interrupt structure possible. The IPH is located at SFR address B7H. The structure of the IPH register and a description of its bits is shown in Figure 38.

The function of the IPH SFR, 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)

Table 14. Interrupt Table

SOURCE	POLLING PRIORITY	REQUEST BITS	HARDWARE CLEAR?	VECTOR ADDRESS
X0	1	IE0	N (L)[1] Y (T)[2]	03H
SI01 (I2C)	2	–	N	2BH
T0	3	TP0	Y	0BH
X1	4	IE1	N (L) Y (T)	13H
T1	5	TF1	Y	1BH
SP	6	RI, TI	N	23H
T2	7	TF2, EXF2	N	3BH

NOTES:
1. L = Level activated
2. T = Transition activated

The priority scheme for servicing the interrupts is the same as that for the 80C51, except there are four interrupt levels rather than two as on the 80C51. 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.

	7	6	5	4	3	2	1	0
IE (0A8H)	EA	–	ET2	ES	ET1	EX1	ET0	EX0

Enable Bit = 1 enables the interrupt.
Enable Bit = 0 disables it.

BIT	SYMBOL	FUNCTION
IE.7	EA	Global disable bit. If EA = 0, all interrupts are disabled. If EA = 1, each interrupt can be individually enabled or disabled by setting or clearing its enable bit.
IE.6	–	–
IE.5	ET2	Timer 2 interrupt enable bit.
IE.4	ES	Serial Port interrupt enable bit.
IE.3	ET1	Timer 1 interrupt enable bit.
IE.2	EX1	External interrupt 1 enable bit.
IE.1	ET0	Timer 0 interrupt enable bit.
IE.0	EX0	External interrupt 0 enable bit.

SU01745

Figure 36. IE Registers

	7	6	5	4	3	2	1	0
IP (0B8H)	–	–	PT2	PS	PT1	PX1	PT0	PX0

Priority Bit = 1 assigns high priority
Priority Bit = 0 assigns low priority

BIT	SYMBOL	FUNCTION
IP.7	–	–
IP.6	–	–
IP.5	PT2	Timer 2 interrupt priority bit.
IP.4	PS	Serial Port interrupt priority bit.
IP.3	PT1	Timer 1 interrupt priority bit.
IP.2	PX1	External interrupt 1 priority bit.
IP.1	PT0	Timer 0 interrupt priority bit.
IP.0	PX0	External interrupt 0 priority bit.

SU01743

Figure 37. IP Registers

	7	6	5	4	3	2	1	0
IPH (B7H)	–	–	PT2H	PSH	PT1H	PX1H	PT0H	PX0H

Priority Bit = 1 assigns higher priority
Priority Bit = 0 assigns lower priority

BIT	SYMBOL	FUNCTION
IPH.7	–	–
IPH.6	–	–
IPH.5	PT2H	Timer 2 interrupt priority bit high.
IPH.4	PSH	Serial Port interrupt priority bit high.
IPH.3	PT1H	Timer 1 interrupt priority bit high.
IPH.2	PX1H	External interrupt 1 priority bit high.
IPH.1	PT0H	Timer 0 interrupt priority bit high.
IPH.0	PX0H	External interrupt 0 priority bit high.

SU01744

Figure 38. IPH Registers

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.

Reduced EMI Mode

AUXR (8EH)

7	6	5	4	3	2	1	0
–	–	–	–	Fast/ STD I^2C	–	–	AO

AUXR.0 AO

Dual DPTR

The dual DPTR structure (see Figure 39) 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: xxxxxxx0B

AUXR1 (A2H)

7	6	5	4	3	2	1	0
–	–	–	LPEP	GFS	0	–	DPS

Where:

DPS = AUXR1/bit0 = Switches between DPTR0 and DPTR1.

Select Reg	DPS
DPTR0	0
DPTR1	1

The DPS bit status should be saved by software when switching between DPTR0 and DPTR1.

The GPS 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 GPS bit.

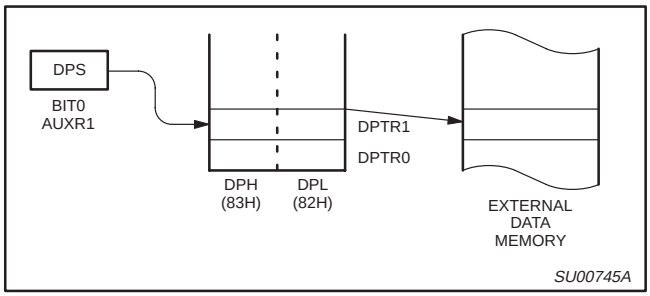


Figure 39.

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.

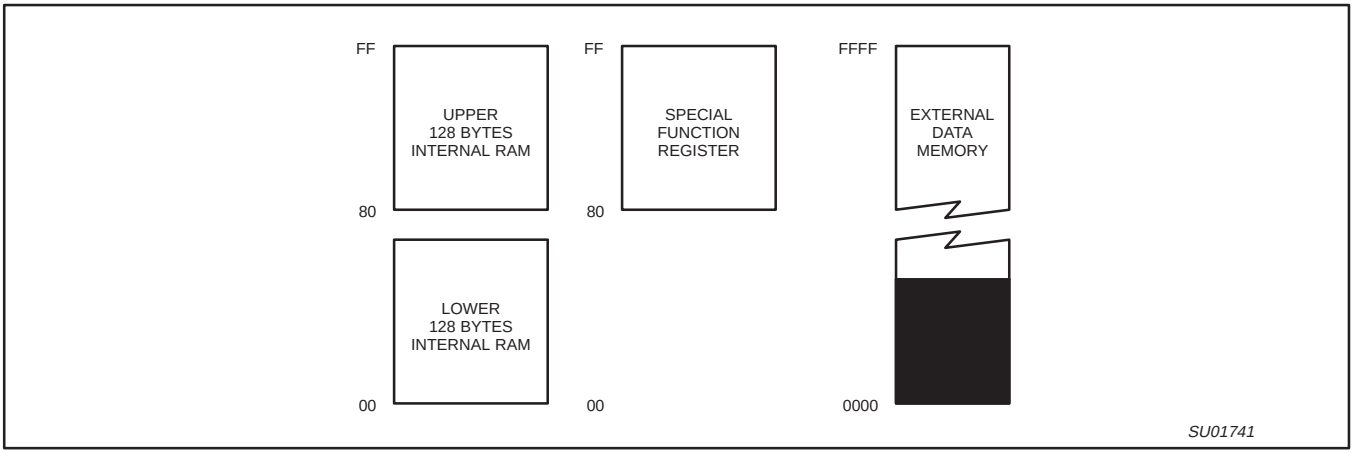


Figure 40. Internal and External Data Memory Address Space with EXTRAM = 0

HARDWARE WATCHDOG TIMER (ONE-TIME ENABLED WITH RESET-OUT FOR P8XC654X2)

The WDT is intended as a recovery method in situations where the CPU may be subjected to software upset. The WDT consists of a 14-bit counter and the WatchDog Timer reset (WDTRST) SFR. The WDT is disabled at reset.

Using the WDT

To enable the WDT, the user must write 01EH and 0E1H in sequence to the WDTRST, SFR location 0A6H. When the WDT is enabled, the user needs to service it by writing 01EH and 0E1H to WDTRST to avoid a WDT overflow. The 14-bit counter overflows when it reaches 16383 (3FFFH) and this will reset the device. When the WDT is enabled, it will increment every machine cycle while the oscillator is running. This means the user must reset the WDT at least every 16383 machine cycles. To reset the WDT, the user must write 01EH and 0E1H to WDTRST. WDTRST is a write only register. The WDT counter cannot be read or written. When the WDT overflows, it will generate an output RESET pulse at the reset pin (see note below). The RESET pulse duration is $98 \times T_{osc}$ (6-clock mode; 196 in 12-clock mode), where $T_{osc} = 1/f_{osc}$. To make the best use of the WDT, it should be serviced in those sections of code that will periodically be executed within the time required to prevent a WDT reset.

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}[4]	–0.5 to +6.0	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:
1. 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.
2. 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.
3. Parameters are valid over operating temperature range unless otherwise specified. All voltages are with respect to V_{SS} unless otherwise noted.
4. Transient voltage only.

AC ELECTRICAL CHARACTERISTICS

T_{amb} = 0°C to +70°C or –40°C to +85°C

SYMBOL	FIGURE	PARAMETER	OPERATING MODE	POWER SUPPLY VOLTAGE	CLOCK FREQUENCY RANGE		UNIT
					MIN	MAX	
$1/t_{CLCL}$	46	Oscillator frequency	6-clock	5 V ±10 %	0	30	MHz
			6-clock	2.7 V to 5.5 V	0	16	MHz
			12-clock	5 V ±10 %	0	33	MHz
			12-clock	2.7 V to 5.5 V	0	16	MHz

DC ELECTRICAL CHARACTERISTICS

T_{amb} = 0 °C to +70 °C or –40 °C to +85 °C; **V_{CC} = 2.7 V to 5.5 V**; V_{SS} = 0 V (16 MHz max. CPU clock)

SYMBOL	PARAMETER	TEST CONDITIONS	LIMITS			UNIT
			MIN	TYP[1]	MAX	
V_{IL}	Input LOW voltage[11], except P1.6 and P1.7	4.0 V < V_{CC} < 5.5 V	–0.5		$0.2V_{CC}$ – 0.1	V
		2.7 V < V_{CC} < 4.0 V	–0.5		$0.7V_{CC}$	V
V_{IL1}	Input LOW voltage to $\overline{EA}$		–0.5		$0.2V_{DD}$ – 0.3	V
V_{IL2}	Input LOW voltage to P1.6/SCL, P1.7/SDA[5]		–0.5		$0.3V_{DD}$	V
V_{IH}	Input HIGH voltage (ports 0, 1, 2, 3, $\overline{EA}$)		$0.2V_{CC}$ + 0.9		V_{CC} + 0.5	V
V_{IH1}	Input HIGH voltage, XTAL1, RST[11]		$0.7V_{CC}$		V_{CC} + 0.5	V
V_{OL}	Output LOW voltage, ports 1, 2[8], except P1.6 and P1.7	V_{CC} = 2.7 V; I_{OL} = 1.6 mA[2]	–		0.4	V
V_{OL1}	Output LOW voltage, port 0, ALE, $\overline{PSEN}$[8, 7]	V_{CC} = 2.7 V; I_{OL} = 3.2 mA[2]	–		0.4	V
V_{OL2}	Output LOW voltage, P1.6/SCL, P1.7/SDA	I_{OL} = 3.0 mA[7]	–		0.4	V
V_{OH}	Output HIGH voltage, ports 1, 2, 3 [3]	V_{CC} = 2.7 V; I_{OH} = –20 µA	V_{CC} – 0.7		–	V
		V_{CC} = 4.5 V; I_{OH} = –30 µA	V_{CC} – 0.7		–	V
V_{OH1}	Output HIGH voltage (port 0 in external bus mode), ALE[9], $\overline{PSEN}$[3]	V_{CC} = 2.7 V; I_{OH} = –3.2 mA	V_{CC} – 0.7		–	V
I_{IL}	Logical 0 input current, ports 1, 2, 3	V_{IN} = 0.4 V	–1		–50	µA
I_{TL}	Logical 1-to-0 transition current, ports 1, 2, 3[6]	V_{IN} = 2.0 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 49 and Source Code):					
	Active mode @ 16 MHz					µA
	Idle mode @ 16 MHz					µA
	Power-down mode or clock stopped (see Figure 45 for conditions) [12]	T_{amb} = 0 °C to 70 °C		2	30	µA
		T_{amb} = –40 °C to +85 °C		3	50	µA
V_{RAM}	RAM keep-alive voltage		1.2			V
R_{RST}	Internal reset pull-down resistor		40		225	kΩ
C_{IO}	Pin capacitance[10] (except $\overline{EA}$)		–		15	pF

NOTES:

1. Typical ratings are not guaranteed. Values listed are based on tests conducted on limited number of samples at room temperature.
2. Capacitive loading on ports 0 and 2 may cause spurious noise to be superimposed on the V_{OL}s 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 > 100 pF), the noise pulse on the ALE pin may exceed 0.8 V. 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.
3. Capacitive loading on ports 0 and 2 may cause the V_{OH} on ALE and $\overline{PSEN}$ to momentarily fall below the V_{CC}–0.7 specification when the address bits are stabilizing.
4. 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.
5. See Figures 51 through 54 for I_{CC} test conditions and Figure 49 for I_{CC} vs. Frequency
   12-clock mode characteristics:
   Active mode (operating): I_{CC} = 1.0 mA + 1.1 mA × FREQ.[MHz]
   Active mode (reset): I_{CC} = 7.0 mA + 0.6 mA × FREQ.[MHz]
   Idle mode: I_{CC} = 1.0 mA + 0.22 mA × FREQ.[MHz]
6. This value applies to T_{amb} = 0 °C to +70 °C. For T_{amb} = –40 °C to +85 °C, I_{TL} = –750 µA.
7. Load capacitance for port 0, ALE, and $\overline{PSEN}$ = 100 pF, load capacitance for all other outputs = 80 pF.
8. 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.
9. ALE is tested to V_{OH1}, except when ALE is off then V_{OH} is the voltage specification.
10. 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 $\overline{EA}$ is 25 pF).

11. To improve noise rejection a nominal 100 ns glitch rejection circuitry has been added to the RST pin, and a nominal 15 ns glitch rejection circuitry has been added to the $\overline{INT0}$ and $\overline{INT1}$ pins. Previous devices provided only an inherent 5 ns of glitch rejection.
12. Power-down mode for 3 V range: Commercial Temperature Range – typ: 0.5 μA, max. 20 μA; Industrial Temperature Range – typ. 1.0 μA, max. 30 μA;

DC ELECTRICAL CHARACTERISTICS

T_{amb} = 0 °C to +70 °C or –40 °C to +85 °C; **V_{CC} = 5 V ±10 %**; V_{SS} = 0 V (30/33 MHz max. CPU clock)

SYMBOL	PARAMETER	TEST CONDITIONS	LIMITS			UNIT
			MIN	TYP[1]	MAX	
V_{IL}	Input LOW voltage[11]	4.5 V < V_{CC} < 5.5 V	–0.5		$0.2V_{CC}$ – 0.1	V
V_{IH}	Input HIGH voltage (ports 0, 1, 2, 3, $\overline{EA}$)		$0.2V_{CC}$ + 0.9		V_{CC} + 0.5	V
V_{IH1}	Input HIGH voltage, XTAL1, RST[11]		$0.7V_{CC}$		V_{CC} + 0.5	V
V_{OL}	Output LOW voltage, ports 1, 2, 3 [8]	V_{CC} = 4.5 V; I_{OL} = 1.6 mA[2]	–		0.4	V
V_{OL1}	Output LOW voltage, port 0, ALE, $\overline{PSEN}$ [7, 8]	V_{CC} = 4.5 V; I_{OL} = 3.2 mA[2]	–		0.4	V
V_{OH}	Output HIGH voltage, ports 1, 2, 3 [3]	V_{CC} = 4.5 V; I_{OH} = –30 µA	V_{CC} – 0.7		–	V
V_{OH1}	Output HIGH voltage (port 0 in external bus mode), ALE[9], $\overline{PSEN}$[3]	V_{CC} = 4.5 V; I_{OH} = –3.2 mA	V_{CC} – 0.7		–	V
I_{IL}	Logical 0 input current, ports 1, 2, 3	V_{IN} = 0.4 V	–1		–50	µA
I_{TL}	Logical 1-to-0 transition current, ports 1, 2, 3[6]	V_{IN} = 2.0 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 Active mode (see Note 5) Idle mode (see Note 5) Power-down mode or clock stopped (see Figure 54 for conditions)	T_{amb} = 0 °C to 70 °C T_{amb} = –40 °C to +85 °C		2 3	30 50	µA µA
V_{RAM}	RAM keep-alive voltage		1.2			V
R_{RST}	Internal reset pull-down resistor		40		225	kΩ
C_{IO}	Pin capacitance[10] (except $\overline{EA}$)		–		15	pF

NOTES:

1. Typical ratings are not guaranteed. The values listed are at room temperature, 5 V.
2. Capacitive loading on ports 0 and 2 may cause spurious noise to be superimposed on the V_{OL}s 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 > 100 pF), the noise pulse on the ALE pin may exceed 0.8 V. 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.
3. Capacitive loading on ports 0 and 2 may cause the V_{OH} on ALE and $\overline{PSEN}$ to momentarily fall below the V_{CC}–0.7 specification when the address bits are stabilizing.
4. 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.
5. See Figures 51 through 54 for I_{CC} test conditions and Figure 49 for I_{CC} vs. Frequency.
   12-clock mode characteristics:
   Active mode (operating): I_{CC} = 1.0 mA + 1.1 mA × FREQ.[MHz]
   Active mode (reset): I_{CC} = 7.0 mA + 0.6 mA × FREQ.[MHz]
   Idle mode: I_{CC} = 1.0 mA + 0.22 mA × FREQ.[MHz]
6. This value applies to T_{amb} = 0°C to +70°C. For T_{amb} = –40°C to +85°C, I_{TL} = –750 µA.
7. Load capacitance for port 0, ALE, and $\overline{PSEN}$ = 100 pF, load capacitance for all other outputs = 80 pF.
8. 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.
9. ALE is tested to V_{OH1}, except when ALE is off then V_{OH} is the voltage specification.
10. 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 $\overline{EA}$ is 25 pF).
11. To improve noise rejection a nominal 100 ns glitch rejection circuitry has been added to the RST pin, and a nominal 15 ns glitch rejection circuitry has been added to the $\overline{INT0}$ and $\overline{INT1}$ pins. Previous devices provided only an inherent 5 ns of glitch rejection.

AC ELECTRICAL CHARACTERISTICS (12-CLOCK MODE, 5 V ±10 % OPERATION)

T_{amb} = 0 °C to +70 °C or –40 °C to +85 °C ; V_{CC} = 5 V ±10 %, V_{SS} = 0 V[1,2,3,4]

Symbol	Figure	Parameter	Limits		16 MHz Clock		Unit
			MIN	MAX	MIN	MAX	
$1/t_{CLCL}$	46	Oscillator frequency	0	33	–	–	MHz
t_{LHLL}	41	ALE pulse width	$2t_{CLCL} – 8$	–	117	–	ns
t_{AVLL}	41	Address valid to ALE LOW	$t_{CLCL} – 13$	–	49.5	–	ns
t_{LLAX}	41	Address hold after ALE LOW	$t_{CLCL} – 20$	–	42.5	–	ns
t_{LLIV}	41	ALE LOW to valid instruction in	–	$4t_{CLCL} – 35$	–	215	ns
t_{LLPL}	41	ALE LOW to $\overline{PSEN}$ LOW	$t_{CLCL} – 10$	–	52.5	–	ns
t_{PLPH}	41	$\overline{PSEN}$ pulse width	$3t_{CLCL} – 10$	–	177.5	–	ns
t_{PLIV}	41	$\overline{PSEN}$ LOW to valid instruction in	–	$3t_{CLCL} – 35$	–	152.5	ns
t_{PXIX}	41	Input instruction hold after $\overline{PSEN}$	0	–	0	–	ns
t_{PXIZ}	41	Input instruction float after $\overline{PSEN}$	–	$t_{CLCL} – 10$	–	52.5	ns
t_{AVIV}	41	Address to valid instruction in	–	$5t_{CLCL} – 35$	–	277.5	ns
t_{PLAZ}	41	$\overline{PSEN}$ LOW to address float	–	10	–	10	ns
Data Memory							
t_{RLRH}	42	$\overline{RD}$ pulse width	$6t_{CLCL} – 20$	–	355	–	ns
t_{WLWH}	43	$\overline{WR}$ pulse width	$6t_{CLCL} – 20$	–	355	–	ns
t_{RLDV}	42	$\overline{RD}$ LOW to valid data in	–	$5t_{CLCL} – 35$	–	277.5	ns
t_{RHDX}	42	Data hold after $\overline{RD}$	0	–	0	–	ns
t_{RHDZ}	42	Data float after $\overline{RD}$	–	$2t_{CLCL} – 10$	–	115	ns
t_{LLDV}	42	ALE LOW to valid data in	–	$8t_{CLCL} – 35$	–	465	ns
t_{AVDV}	42	Address to valid data in	–	$9t_{CLCL} – 35$	–	527.5	ns
t_{LLWL}	42, 43	ALE LOW to $\overline{RD}$ or $\overline{WR}$ LOW	$3t_{CLCL} – 15$	$3t_{CLCL} + 15$	172.5	202.5	ns
t_{AVWL}	42, 43	Address valid to $\overline{WR}$ LOW or $\overline{RD}$ LOW	$4t_{CLCL} –15$	–	235	–	ns
t_{QVWX}	43	Data valid to $\overline{WR}$ transition	$t_{CLCL} – 25$	–	37.5	–	ns
t_{WHQX}	43	Data hold after $\overline{WR}$	$t_{CLCL} – 15$	–	47.5	–	ns
t_{QVWH}	43	Data valid to $\overline{WR}$ HIGH	$7t_{CLCL} – 5$	–	432.5	–	ns
t_{RLAZ}	42	$\overline{RD}$ LOW to address float	–	0	–	0	ns
t_{WHLH}	42, 43	$\overline{RD}$ or $\overline{WR}$ HIGH to ALE HIGH	$t_{CLCL} – 10$	$t_{CLCL} + 10$	52.5	72.5	ns
External Clock							
t_{CHCX}	46	High time	$0.32t_{CLCL}$	$t_{CLCL} – t_{CLCX}$	–	–	ns
t_{CLCX}	46	Low time	$0.32t_{CLCL}$	$t_{CLCL} – t_{CHCX}$	–	–	ns
t_{CLCH}	46	Rise time	–	5	–	–	ns
t_{CHCL}	46	Fall time	–	5	–	–	ns
Shift register							
t_{XLXL}	45	Serial port clock cycle time	$12t_{CLCL}$	–	750	–	ns
t_{QVXH}	45	Output data setup to clock rising edge	$10t_{CLCL} – 25$	–	600	–	ns
t_{XHQX}	45	Output data hold after clock rising edge	$2t_{CLCL} – 15$	–	110	–	ns
t_{XHDX}	45	Input data hold after clock rising edge	0	–	0	–	ns
t_{XHDV}	45	Clock rising edge to input data valid[5]	–	$10t_{CLCL} – 133$	–	492	ns

NOTES:
1. Parameters are valid over operating temperature range unless otherwise specified.
2. Load capacitance for port 0, ALE, and $\overline{PSEN}$ = 100 pF, load capacitance for all outputs = 80 pF
3. Interfacing the microcontroller to devices with float time up to 45 ns is permitted. This limited bus contention will not cause damage to port 0 drivers.
4. Parts are guaranteed by design to operate down to 0 Hz.
5. Below 16 MHz this parameter is $8t_{CLCL} – 133$.

AC ELECTRICAL CHARACTERISTICS (12-CLOCK MODE, 2.7 V TO 5.5 V OPERATION)

T_{amb} = 0 °C to +70 °C or –40 °C to +85 °C ; V_{CC} = 2.7 V to 5.5 V, V_{SS} = 0 V[1,2,3,4]

Symbol	Figure	Parameter	Limits		16 MHz Clock		Unit
			MIN	MAX	MIN	MAX	
$1/t_{CLCL}$	46	Oscillator frequency	0	16	–	–	MHz
t_{LHLL}	41	ALE pulse width	$2t_{CLCL}$ – 10	–	115	–	ns
t_{AVLL}	41	Address valid to ALE LOW	t_{CLCL} – 15	–	47.5	–	ns
t_{LLAX}	41	Address hold after ALE LOW	t_{CLCL} – 25	–	37.5	–	ns
t_{LLIV}	41	ALE LOW to valid instruction in	–	$4t_{CLCL}$ – 55	–	195	ns
t_{LLPL}	41	ALE LOW to $\overline{PSEN}$ LOW	t_{CLCL} – 15	–	47.5	–	ns
t_{PLPH}	41	$\overline{PSEN}$ pulse width	$3t_{CLCL}$ – 15	–	172.5	–	ns
t_{PLIV}	41	$\overline{PSEN}$ LOW to valid instruction in	–	$3t_{CLCL}$ – 55	–	132.5	ns
t_{PXIX}	41	Input instruction hold after $\overline{PSEN}$	0	–	0	–	ns
t_{PXIZ}	41	Input instruction float after $\overline{PSEN}$	–	t_{CLCL} – 10	–	52.5	ns
t_{AVIV}	41	Address to valid instruction in	–	$5t_{CLCL}$ – 50	–	262.5	ns
t_{PLAZ}	41	$\overline{PSEN}$ LOW to address float	–	10	–	10	ns
Data Memory							
t_{RLRH}	42	$\overline{RD}$ pulse width	$6t_{CLCL}$ – 25	–	350	–	ns
t_{WLWH}	43	$\overline{WR}$ pulse width	$6t_{CLCL}$ – 25	–	350	–	ns
t_{RLDV}	42	$\overline{RD}$ LOW to valid data in	–	$5t_{CLCL}$ – 50	–	262.5	ns
t_{RHDX}	42	Data hold after $\overline{RD}$	0	–	0	–	ns
t_{RHDZ}	42	Data float after $\overline{RD}$	–	$2t_{CLCL}$ –20	–	105	ns
t_{LLDV}	42	ALE LOW to valid data in	–	$8t_{CLCL}$ – 55	–	445	ns
t_{AVDV}	42	Address to valid data in	–	$9t_{CLCL}$ – 50	–	512.5	ns
t_{LLWL}	42, 43	ALE LOW to $\overline{RD}$ or $\overline{WR}$ LOW	$3t_{CLCL}$ – 20	$3t_{CLCL}$ +20	167.5	207.5	ns
t_{AVWL}	42, 43	Address valid to $\overline{WR}$ LOW or $\overline{RD}$ LOW	$4t_{CLCL}$ – 20	–	230	–	ns
t_{QVWX}	43	Data valid to $\overline{WR}$ transition	t_{CLCL} – 30	–	32.5	–	ns
t_{WHQX}	43	Data hold after $\overline{WR}$	t_{CLCL} – 20	–	42.5	–	ns
t_{QVWH}	43	Data valid to $\overline{WR}$ HIGH	$7t_{CLCL}$ – 10	–	427.5	–	ns
t_{RLAZ}	42	$\overline{RD}$ LOW to address float	–	0	–	0	ns
t_{WHLH}	42, 43	$\overline{RD}$ or $\overline{WR}$ HIGH to ALE HIGH	t_{CLCL} – 15	t_{CLCL} +15	47.5	77.5	ns
External Clock							
t_{CHCX}	46	High time	$0.32t_{CLCL}$	$t_{CLCL} - t_{CLCX}$	–	–	ns
t_{CLCX}	46	Low time	$0.32t_{CLCL}$	$t_{CLCL} - t_{CHCX}$	–	–	ns
t_{CLCH}	46	Rise time	–	5	–	–	ns
t_{CHCL}	46	Fall time	–	5	–	–	ns
Shift register							
t_{XLXL}	45	Serial port clock cycle time	$12t_{CLCL}$	–	750	–	ns
t_{QVXH}	45	Output data setup to clock rising edge	$10t_{CLCL}$ – 25	–	600	–	ns
t_{XHQX}	45	Output data hold after clock rising edge	$2t_{CLCL}$ – 15	–	110	–	ns
t_{XHDX}	45	Input data hold after clock rising edge	0	–	0	–	ns
t_{XHDV}	45	Clock rising edge to input data valid[5]	–	$10t_{CLCL}$ – 133	–	492	ns

NOTES:
1. Parameters are valid over operating temperature range unless otherwise specified.
2. Load capacitance for port 0, ALE, and $\overline{PSEN}$ = 100 pF, load capacitance for all outputs = 80 pF
3. Interfacing the microcontroller to devices with float time up to 45 ns is permitted. This limited bus contention will not cause damage to port 0 drivers.
4. Parts are guaranteed by design to operate down to 0 Hz.
5. Below 16 MHz this parameter is $8t_{CLCL}$ – 133.

AC ELECTRICAL CHARACTERISTICS (6-CLOCK MODE, 5 V ±10 % OPERATION)

T_{amb} = 0 °C to +70 °C or –40 °C to +85 °C; V_{CC} = 5 V ±10 %, V_{SS} = 0 V[1,2,3,4,5]

Symbol	Figure	Parameter	Limits		16 MHz Clock		Unit
			MIN	MAX	MIN	MAX	
$1/t_{CLCL}$	46	Oscillator frequency	0	30	–	–	MHz
t_{LHLL}	41	ALE pulse width	t_{CLCL} – 8	–	54.5	–	ns
t_{AVLL}	41	Address valid to ALE LOW	$0.5t_{CLCL}$ – 13	–	18.25	–	ns
t_{LLAX}	41	Address hold after ALE LOW	$0.5t_{CLCL}$ – 20	–	11.25	–	ns
t_{LLIV}	41	ALE LOW to valid instruction in	–	$2t_{CLCL}$ –35	–	90	ns
t_{LLPL}	41	ALE LOW to $\overline{PSEN}$ LOW	$0.5t_{CLCL}$ – 10	–	21.25	–	ns
t_{PLPH}	41	$\overline{PSEN}$ pulse width	$1.5t_{CLCL}$ – 10	–	83.75	–	ns
t_{PLIV}	41	$\overline{PSEN}$ LOW to valid instruction in	–	$1.5t_{CLCL}$ – 35	–	58.75	ns
t_{PXIX}	41	Input instruction hold after $\overline{PSEN}$	0	–	0	–	ns
t_{PXIZ}	41	Input instruction float after $\overline{PSEN}$	–	$0.5t_{CLCL}$ – 10	–	21.25	ns
t_{AVIV}	41	Address to valid instruction in	–	$2.5t_{CLCL}$ – 35	–	121.25	ns
t_{PLAZ}	41	$\overline{PSEN}$ LOW to address float	–	10	–	10	ns
Data Memory							
t_{RLRH}	42	$\overline{RD}$ pulse width	$3t_{CLCL}$ – 20	–	167.5	–	ns
t_{WLWH}	43	$\overline{WR}$ pulse width	$3t_{CLCL}$ – 20	–	167.5	–	ns
t_{RLDV}	42	$\overline{RD}$ LOW to valid data in	–	$2.5t_{CLCL}$ – 35	–	121.25	ns
t_{RHDX}	42	Data hold after $\overline{RD}$	0	–	0	–	ns
t_{RHDZ}	42	Data float after $\overline{RD}$	–	t_{CLCL} –10	–	52.5	ns
t_{LLDV}	42	ALE LOW to valid data in	–	$4t_{CLCL}$ – 35	–	215	ns
t_{AVDV}	42	Address to valid data in	–	$4.5t_{CLCL}$ – 35	–	246.25	ns
t_{LLWL}	42, 43	ALE LOW to $\overline{RD}$ or $\overline{WR}$ LOW	$1.5t_{CLCL}$ – 15	$1.5t_{CLCL}$ +15	78.75	108.75	ns
t_{AVWL}	42, 43	Address valid to $\overline{WR}$ LOW or $\overline{RD}$ LOW	$2t_{CLCL}$ –15	–	110	–	ns
t_{QVWX}	43	Data valid to $\overline{WR}$ transition	$0.5t_{CLCL}$ – 25	–	6.25	–	ns
t_{WHQX}	43	Data hold after $\overline{WR}$	$0.5t_{CLCL}$ – 15	–	16.25	–	ns
t_{QVWH}	43	Data valid to $\overline{WR}$ HIGH	$3.5t_{CLCL}$ – 5	–	213.75	–	ns
t_{RLAZ}	42	$\overline{RD}$ LOW to address float	–	0	–	0	ns
t_{WHLH}	42, 43	$\overline{RD}$ or $\overline{WR}$ HIGH to ALE HIGH	$0.5t_{CLCL}$ – 10	$0.5t_{CLCL}$ +10	21.25	41.25	ns
External Clock							
t_{CHCX}	46	High time	$0.4t_{CLCL}$	$t_{CLCL} - t_{CLCX}$	–	–	ns
t_{CLCX}	46	Low time	$0.4t_{CLCL}$	$t_{CLCL} - t_{CHCX}$	–	–	ns
t_{CLCH}	46	Rise time	–	5	–	–	ns
t_{CHCL}	46	Fall time	–	5	–	–	ns
Shift register							
t_{XLXL}	45	Serial port clock cycle time	$6t_{CLCL}$	–	375	–	ns
t_{QVXH}	45	Output data setup to clock rising edge	$5t_{CLCL}$ –25	–	287.5	–	ns
t_{XHQX}	45	Output data hold after clock rising edge	t_{CLCL} – 15	–	47.5	–	ns
t_{XHDX}	45	Input data hold after clock rising edge	0	–	0	–	ns
t_{XHDV}	45	Clock rising edge to input data valid[6]	–	$5t_{CLCL}$ – 133	–	179.5	ns

NOTES:
1. Parameters are valid over operating temperature range unless otherwise specified.
2. Load capacitance for port 0, ALE, and $\overline{PSEN}$=100 pF, load capacitance for all outputs = 80 pF
3. Interfacing the microcontroller to devices with float time up to 45ns is permitted. This limited bus contention will not cause damage to port 0 drivers.
4. Parts are guaranteed by design to operate down to 0 Hz.
5. Data shown in the table are the best mathematical models for the set of measured values obtained in tests. If a particular parameter calculated at a customer specified frequency has a negative value, it should be considered equal to zero.
6. Below 16 MHz this parameter is $4t_{CLCL}$ – 133

AC ELECTRICAL CHARACTERISTICS (6-CLOCK MODE, 2.7 V TO 5.5 V OPERATION)

T_{amb} = 0 °C to +70 °C or –40 °C to +85 °C; V_{CC}=2.7 V to 5.5 V, V_{SS} = 0 V[1,2,3,4,5]

Symbol	Figure	Parameter	Limits		16 MHz Clock		Unit
			MIN	MAX	MIN	MAX	
$1/t_{CLCL}$	46	Oscillator frequency	0	16	–	–	MHz
t_{LHLL}	41	ALE pulse width	t_{CLCL} – 10	–	52.5	–	ns
t_{AVLL}	41	Address valid to ALE LOW	$0.5t_{CLCL}$ – 15	–	16.25	–	ns
t_{LLAX}	41	Address hold after ALE LOW	$0.5t_{CLCL}$ – 25	–	6.25	–	ns
t_{LLIV}	41	ALE LOW to valid instruction in	–	$2t_{CLCL}$ –55	–	70	ns
t_{LLPL}	41	ALE LOW to $\overline{PSEN}$ LOW	$0.5t_{CLCL}$ – 15	–	16.25	–	ns
t_{PLPH}	41	$\overline{PSEN}$ pulse width	$1.5t_{CLCL}$ – 15	–	78.75	–	ns
t_{PLIV}	41	$\overline{PSEN}$ LOW to valid instruction in	–	$1.5t_{CLCL}$ – 55	–	38.75	ns
t_{PXIX}	41	Input instruction hold after $\overline{PSEN}$	0	–	0	–	ns
t_{PXIZ}	41	Input instruction float after $\overline{PSEN}$	–	$0.5t_{CLCL}$ – 10	–	21.25	ns
t_{AVIV}	41	Address to valid instruction in	–	$2.5t_{CLCL}$ – 50	–	101.25	ns
t_{PLAZ}	41	$\overline{PSEN}$ LOW to address float	–	10	–	10	ns
Data Memory							
t_{RLRH}	42	$\overline{RD}$ pulse width	$3t_{CLCL}$ – 25	–	162.5	–	ns
t_{WLWH}	43	$\overline{WR}$ pulse width	$3t_{CLCL}$ – 25	–	162.5	–	ns
t_{RLDV}	42	$\overline{RD}$ LOW to valid data in	–	$2.5t_{CLCL}$ – 50	–	106.25	ns
t_{RHDX}	42	Data hold after $\overline{RD}$	0	–	0	–	ns
t_{RHDZ}	42	Data float after $\overline{RD}$	–	t_{CLCL} – 20	–	42.5	ns
t_{LLDV}	42	ALE LOW to valid data in	–	$4t_{CLCL}$ – 55	–	195	ns
t_{AVDV}	42	Address to valid data in	–	$4.5t_{CLCL}$ – 50	–	231.25	ns
t_{LLWL}	42, 43	ALE LOW to $\overline{RD}$ or $\overline{WR}$ LOW	$1.5t_{CLCL}$ – 20	$1.5t_{CLCL}$ + 20	73.75	113.75	ns
t_{AVWL}	42, 43	Address valid to $\overline{WR}$ LOW or $\overline{RD}$ LOW	$2t_{CLCL}$ – 20	–	105	–	ns
t_{QVWX}	43	Data valid to $\overline{WR}$ transition	$0.5t_{CLCL}$ – 30	–	1.25	–	ns
t_{WHQX}	43	Data hold after $\overline{WR}$	$0.5t_{CLCL}$ – 20	–	11.25	–	ns
t_{QVWH}	43	Data valid to $\overline{WR}$ HIGH	$3.5t_{CLCL}$ – 10	–	208.75	–	ns
t_{RLAZ}	42	$\overline{RD}$ LOW to address float	–	0	–	0	ns
t_{WHLH}	42, 43	$\overline{RD}$ or $\overline{WR}$ HIGH to ALE HIGH	$0.5t_{CLCL}$ – 15	$0.5t_{CLCL}$ + 15	16.25	46.25	ns
External Clock							
t_{CHCX}	46	High time	$0.4t_{CLCL}$	$t_{CLCL} - t_{CLCX}$	–	–	ns
t_{CLCX}	46	Low time	$0.4t_{CLCL}$	$t_{CLCL} - t_{CHCX}$	–	–	ns
t_{CLCH}	46	Rise time	–	5	–	–	ns
t_{CHCL}	46	Fall time	–	5	–	–	ns
Shift register							
t_{XLXL}	45	Serial port clock cycle time	$6t_{CLCL}$	–	375	–	ns
t_{QVXH}	45	Output data setup to clock rising edge	$5t_{CLCL}$ –25	–	287.5	–	ns
t_{XHQX}	45	Output data hold after clock rising edge	t_{CLCL} – 15	–	47.5	–	ns
t_{XHDX}	45	Input data hold after clock rising edge	0	–	0	–	ns
t_{XHDV}	45	Clock rising edge to input data valid[6]	–	$5t_{CLCL}$ – 133	–	179.5	ns
I^2C interface timing							
f_{SCL}		SCL clock frequency	0	100	0	400	kHz
t_{BUF}		Bus free time between a STOP and START condition	4.7	–	1.3	–	µs
$t_{HD;\ STA}$		Hold time (repeated) START condition. After this period, the first clock pulse is generated	4.0	–	0.6	–	µs
t_{LOW}		LOW period of the SCL clock	4.7	–	1.3	–	µs
t_{HIGH}		High period of the SCL clock	4.0	–	0.6	–	µs
$t_{SU;\ STA}$		Set-up time for a repeated START condition	4.7	–	0.6	–	µs

$t_{HD;DAT}$		Data hold time: – for CBUS compatible masters – for I^2C–bus devices	 5.0 0	 – –	 – 0	 – 0.9	µs
$t_{SU;DAT}$		Data set-up time	250	–	100	–	ns
t_{FD}, t_{FC}		Rise time of both SDA and SCL signals	–	1000	20 + 0.1 c_b	300	ns
t_{FD}, t_{FC}		Fall time of both SDA and SCL signals	–	300	20 + 0.1 c_b	300	ns
$t_{SU;\ STO}$		Set-up time for STOP condition	4.0	–	0.6	–	µs
C_b		Capacitive load for each bus line	–	400	–	400	pF
t_{SP}		Pulse width of spikes which must be suppressed by the input filter	–	–	0	50	ns

NOTES:
1. Parameters are valid over operating temperature range unless otherwise specified.
2. Load capacitance for port 0, ALE, and $\overline{PSEN}$=100 pF, load capacitance for all outputs = 80 pF
3. Interfacing the microcontroller to devices with float time up to 45ns is permitted. This limited bus contention will not cause damage to port 0 drivers.
4. Parts are guaranteed by design to operate down to 0 Hz.
5. Data shown in the table are the best mathematical models for the set of measured values obtained in tests. If a particular parameter calculated at a customer specified frequency has a negative value, it should be considered equal to zero.
6. Below 16 MHz this parameter is $4t_{CLCL}$ – 133

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 – $\overline{PSEN}$
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 $\overline{PSEN}$ LOW.

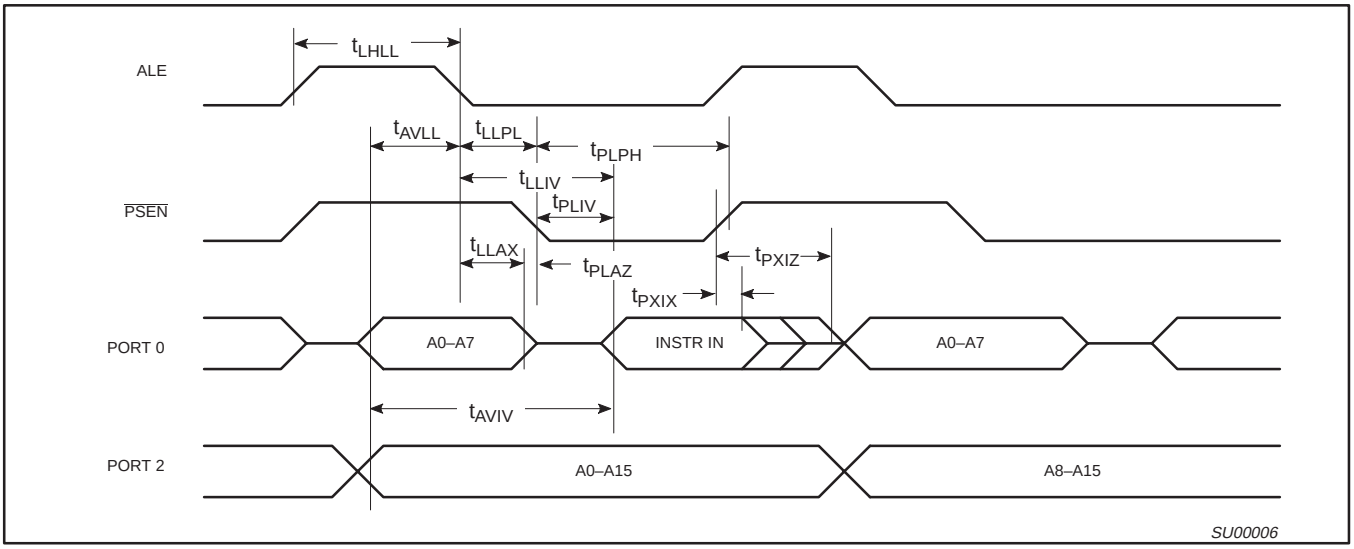


Figure 41. External Program Memory Read Cycle

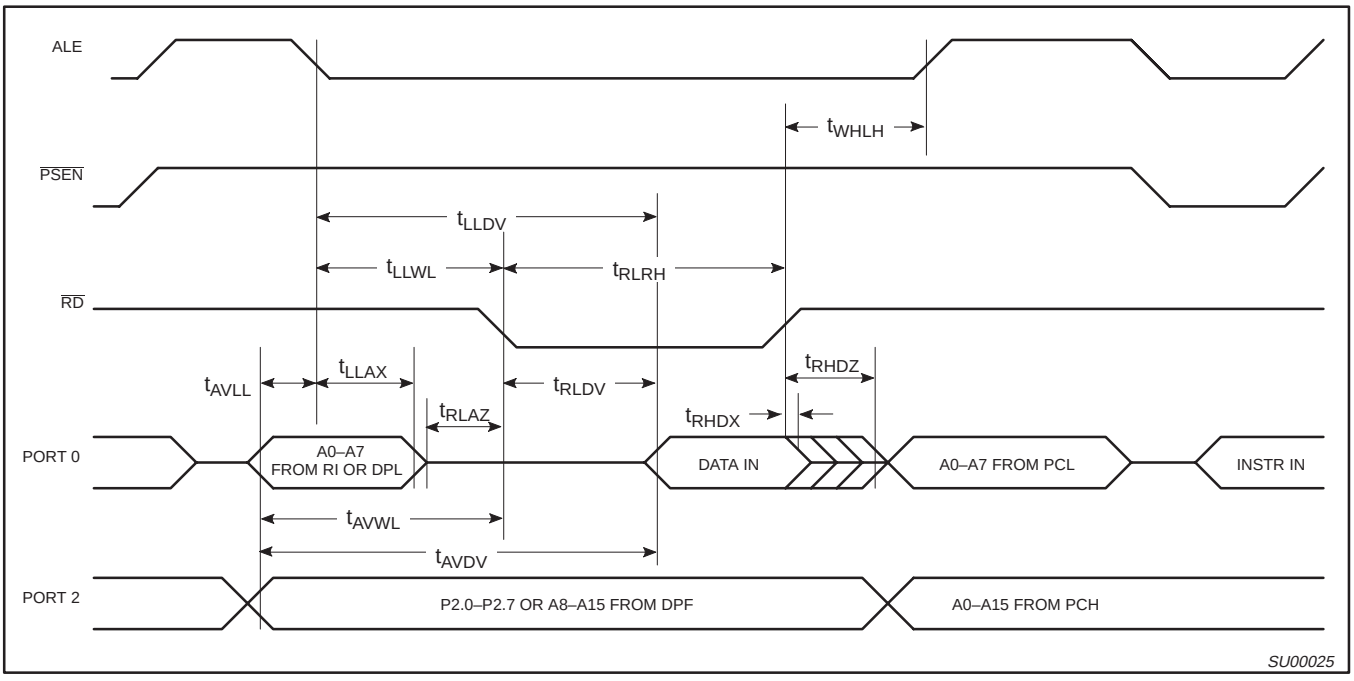


Figure 42. External Data Memory Read Cycle

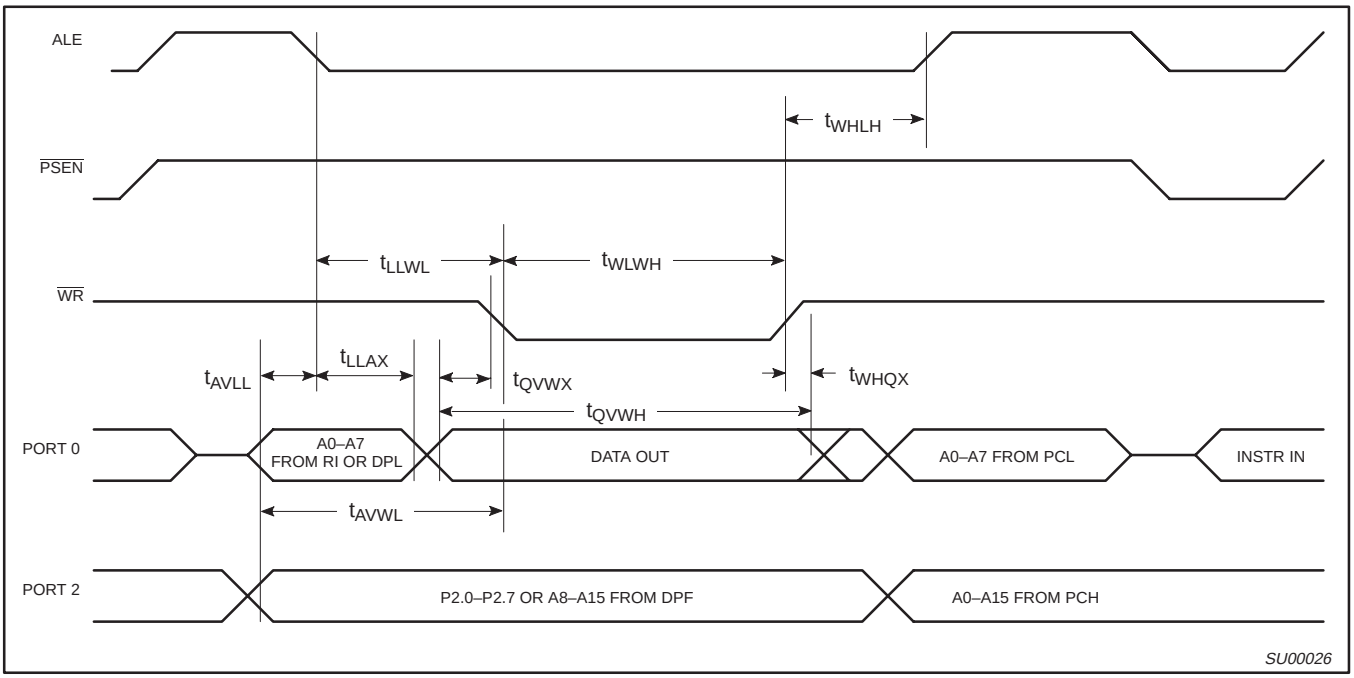


Figure 43. External Data Memory Write Cycle

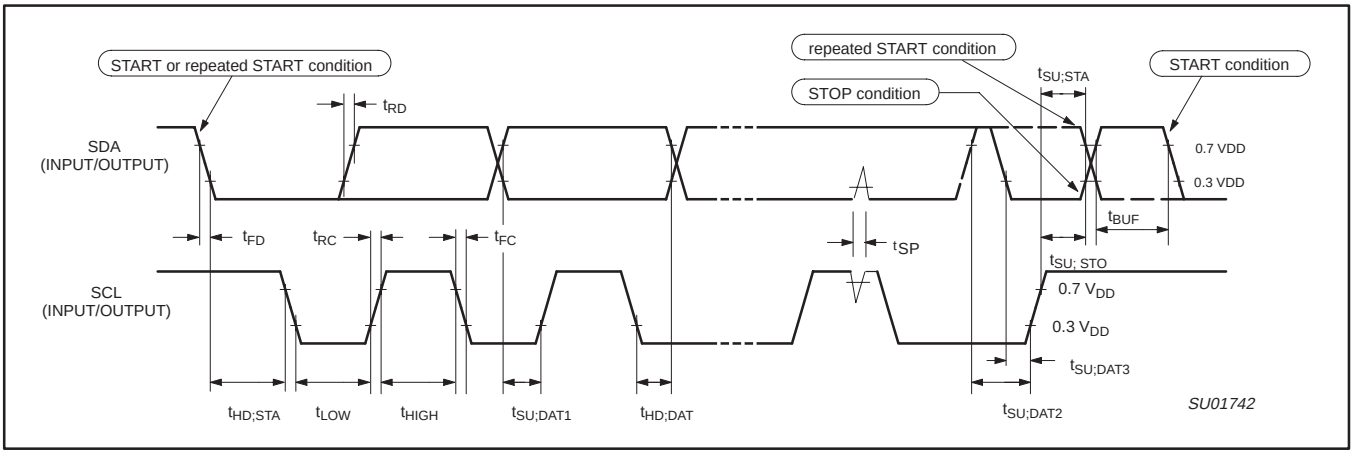


Figure 44. Timing I^2C interface

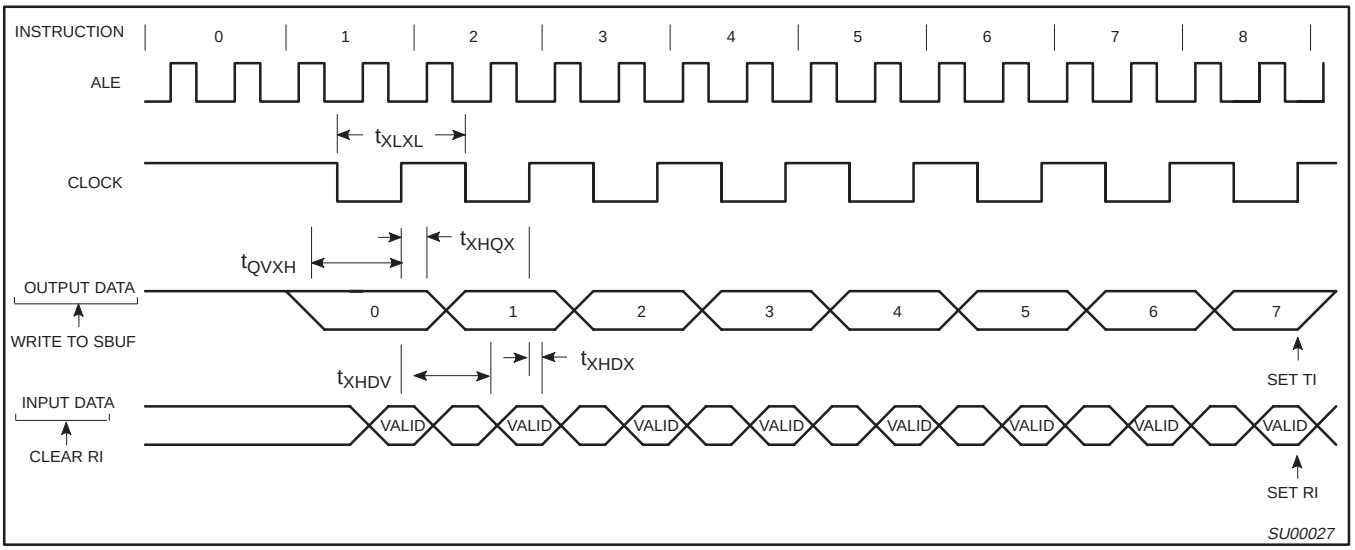


Figure 45. Shift Register Mode Timing

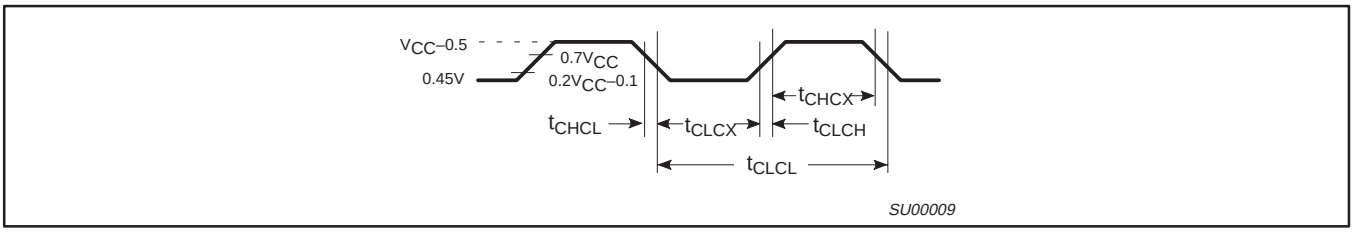


Figure 46. External Clock Drive

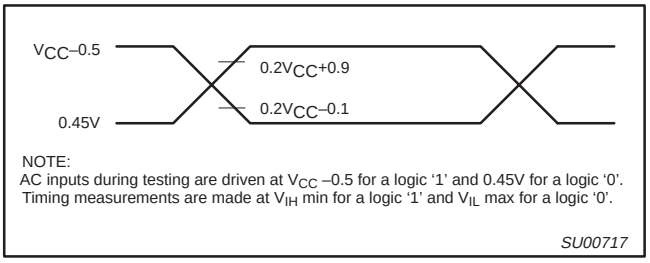


Figure 47. AC Testing Input/Output

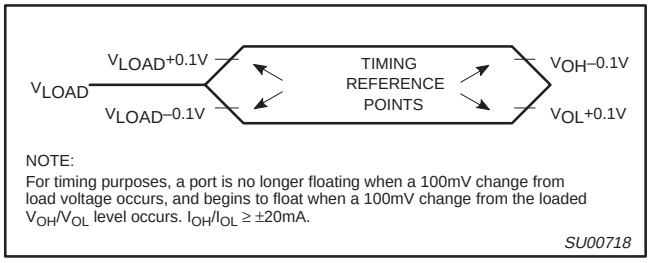


Figure 48. Float Waveform

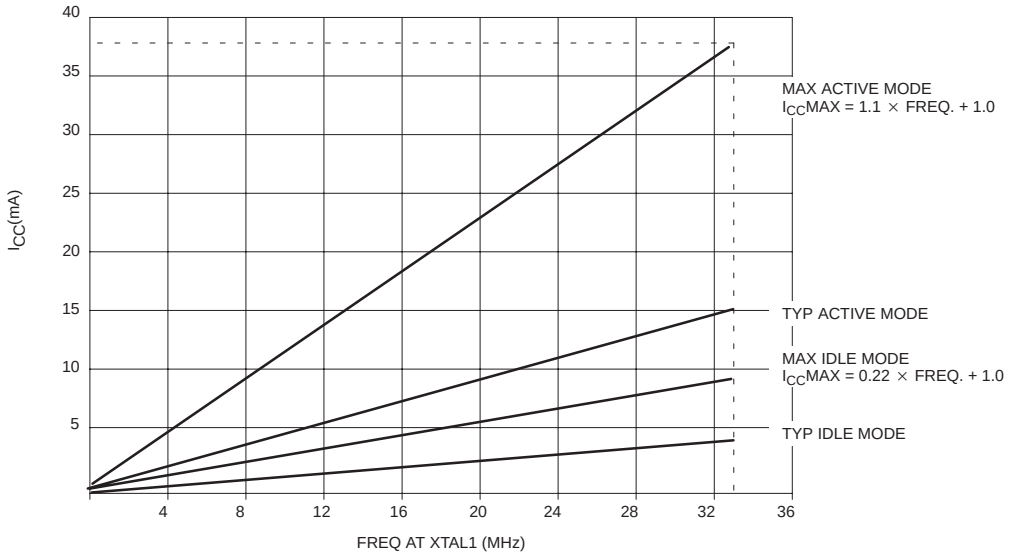


Figure 49. I_{CC} vs. FREQ for 12-clock operation
Valid only within frequency specifications of the specified operating voltage

```
/*
##      as31 version V2.10           / *js* /
##
##
##      source file:  idd_ljmp1.asm
##        list file:  idd_ljmp1.lst   created Fri Apr 20 15:51:40 2001
##
#############################################################
#0000                # AUXR  equ 08Eh
#0000                # CKCON equ 08Fh
                     #
                     #
#0000                # org 0
                     #
                     # LJMP_LABEL:
0000 /75;/8E;/01;    #          MOV     AUXR,#001h   ; turn off ALE
0003 /02;/FF;/FD;    #          LJMP    LJMP_LABEL   ; jump to end of address space
0005 /00;            #          NOP
                     #
#FFFD                # org 0fffdh
                     #
                     # LJMP_LABEL:
                     #
FFFD /02;/FD;FF;     #          LJMP LJMP_LABEL
                     # ;        NOP
                     #
                     #
*/"
```

SU01499

Figure 50. Source code used in measuring I_{DD} operational

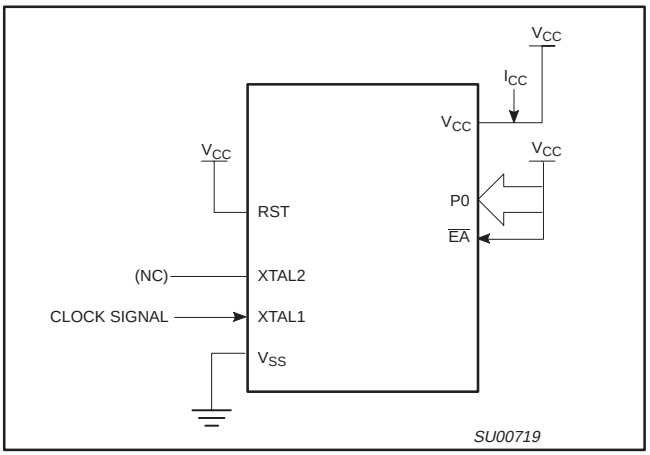


Figure 51. I_{CC} Test Condition, Active Mode
All other pins are disconnected

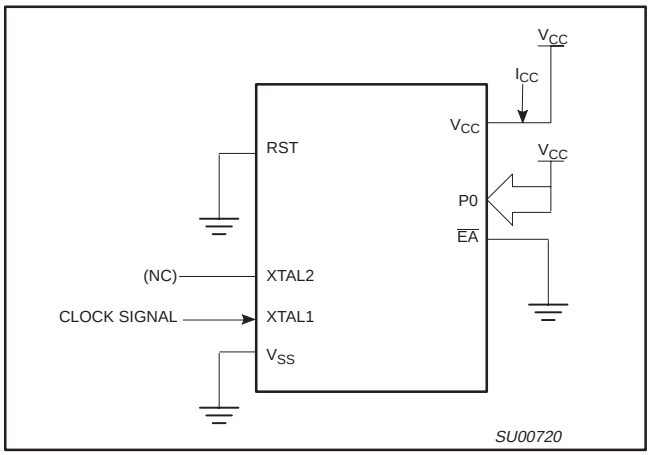


Figure 52. I_{CC} Test Condition, Idle Mode
All other pins are disconnected

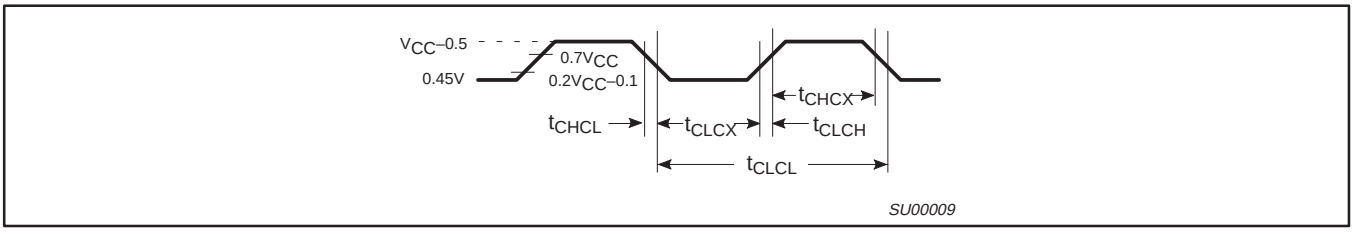


Figure 53. Clock Signal Waveform for I_{CC} Tests in Active and Idle Modes
$t_{CLCH} = t_{CHCL} = 5ns$

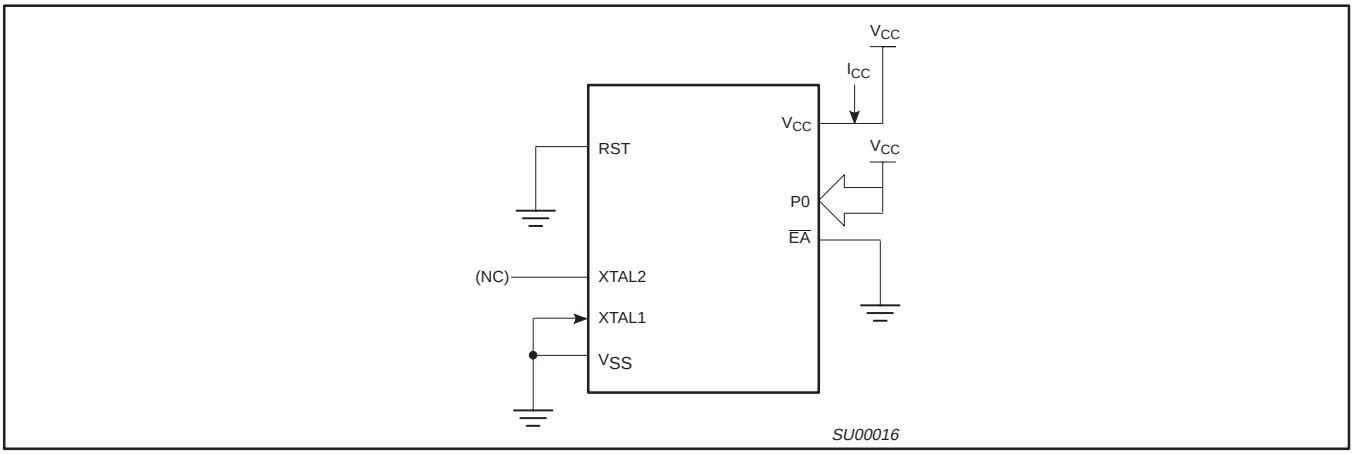


Figure 54. I_{CC} Test Condition, Power-down mode
All other pins are disconnected. V_{CC} = 2 V to 5.5 V

EPROM CHARACTERISTICS

The 87C654X2 can be programmed by using a modified Improved Quick-Pulse Programming™ algorithm. It differs from older methods in the value used for V_{PP} (programming supply voltage) and in the width and number of the ALE/$\overline{PROG}$ pulses.

The family contains two signature bytes that can be read and used by an EPROM programming system to identify the device. The signature bytes identify the device as being manufactured by Philips.

Table 15 shows the logic levels for reading the signature byte, and for programming the program memory, the encryption table, and the security bits. The circuit configuration and waveforms for quick-pulse programming are shown in Figures 55 and 56. Figure 57 shows the circuit configuration for normal program memory verification.

Quick-Pulse Programming

The setup for microcontroller quick-pulse programming is shown in Figure 55. Note that the device is running with a 4 to 6MHz oscillator. The reason the oscillator needs to be running is that the device is executing internal address and program data transfers.

The address of the EPROM location to be programmed is applied to ports 1 and 2, as shown in Figure 55. The code byte to be programmed into that location is applied to port 0. RST, $\overline{PSEN}$ and pins of ports 2 and 3 specified in Table 15 are held at the 'Program Code Data' levels indicated in Table 15. The ALE/$\overline{PROG}$ is pulsed LOW 5 times as shown in Figure 56.

To program the encryption table, repeat the 5 pulse programming sequence for addresses 0 through 1FH, using the 'Pgm Encryption Table' levels. Do not forget that after the encryption table is programmed, verification cycles will produce only encrypted data.

To program the security bits, repeat the 5 pulse programming sequence using the 'Pgm Security Bit' levels. After one security bit is programmed, further programming of the code memory and encryption table is disabled. However, the other security bits can still be programmed.

Note that the $\overline{EA}$/V_{PP} pin must not be allowed to go above the maximum specified V_{PP} level for any amount of time. Even a narrow glitch above that voltage can cause permanent damage to the device. The V_{PP} source should be well regulated and free of glitches and overshoot.

Program Verification

If security bits 2 and 3 have not been programmed, the on-chip program memory can be read out for program verification. The address of the program memory locations to be read is applied to ports 1 and 2 as shown in Figure 57. The other pins are held at the 'Verify Code Data' levels indicated in Table 15. The contents of the address location will be emitted on port 0. External pull-ups are required on port 0 for this operation.

If the 64 byte encryption table has been programmed, the data presented at port 0 will be the exclusive NOR of the program byte with one of the encryption bytes. The user will have to know the encryption table contents in order to correctly decode the verification data. The encryption table itself cannot be read out.

Reading the Signature Bytes

The signature bytes are read by the same procedure as a normal verification of locations 030H and 031H, except that P3.6 and P3.7 need to be pulled to a logic LOW. The values are:
(030H) = 15H indicates manufactured by Philips
(031H) = 99H
(060H) = 02H

Program/Verify Algorithms

Any algorithm in agreement with the conditions listed in Table 15, and which satisfies the timing specifications, is suitable.

Security Bits

With none of the security bits programmed the code in the program memory can be verified. If the encryption table is programmed, the code will be encrypted when verified. When only security bit 1 (see Table 16) is programmed, MOVC instructions executed from external program memory are disabled from fetching code bytes from the internal memory, EA is latched on Reset and all further programming of the EPROM is disabled. When security bits 1 and 2 are programmed, in addition to the above, verify mode is disabled. When all three security bits are programmed, all of the conditions above apply and all external program memory execution is disabled.

Encryption Array

64 bytes of encryption array are initially unprogrammed (all 1s).

™Trademark phrase of Intel Corporation.

Table 15. EPROM Programming Modes

MODE	RST	$\overline{PSEN}$	ALE/$\overline{PROG}$	$\overline{EA}$/V_{PP}	P2.7	P2.6	P3.7	P3.6	P3.3
Read signature	1	0	1	1	0	0	0	0	X
Program code data	1	0	0*	V_{PP}	1	0	1	1	X
Verify code data	1	0	1	1	0	0	1	1	X
Pgm encryption table	1	0	0*	V_{PP}	1	0	1	0	X
Pgm security bit 1	1	0	0*	V_{PP}	1	1	1	1	X
Pgm security bit 2	1	0	0*	V_{PP}	1	1	0	0	X
Pgm security bit 3	1	0	0*	V_{PP}	0	1	0	1	X
Program to 6-clock mode	1	0	0*	V_{PP}	0	0	1	0	0
Verify 6-clock[4]	1	0	1	1	e	0	0	1	1
Verify security bits[5]	1	0	1	1	e	0	1	0	X

NOTES:
1. '0' = Valid LOW for that pin, '1' = valid HIGH for that pin.
2. V_{PP} = 12.75 V ±0.25 V.
3. V_{CC} = 5 V±10 % during programming and verification.
4. Bit is output on P0.4 (1 = 12x, 0 = 6x).
5. Security bit one is output on P0.7.
   Security bit two is output on P0.6.
   Security bit three is output on P0.3.

* ALE/$\overline{PROG}$ receives 5 programming pulses for code data (also for user array; 5 pulses for encryption or security bits) while V_{PP} is held at 12.75 V. Each programming pulse is LOW for 100 µs (±10 µs) and HIGH for a minimum of 10 µs.

Table 16. Program Security Bits for EPROM Devices

PROGRAM LOCK BITS[1, 2]				
	SB1	SB2	SB3	PROTECTION DESCRIPTION
1	U	U	U	No Program Security features enabled. (Code verify will still be encrypted by the Encryption Array if programmed.)
2	P	U	U	MOVC instructions executed from external program memory are disabled from fetching code bytes from internal memory, $\overline{EA}$ is sampled and latched on Reset, and further programming of the EPROM is disabled.
3	P	P	U	Same as 2, also verify is disabled.
4	P	P	P	Same as 3, external execution is disabled. Internal data RAM is not accessible.

NOTES:
1. P – programmed. U – unprogrammed.
2. Any other combination of the security bits is not defined.

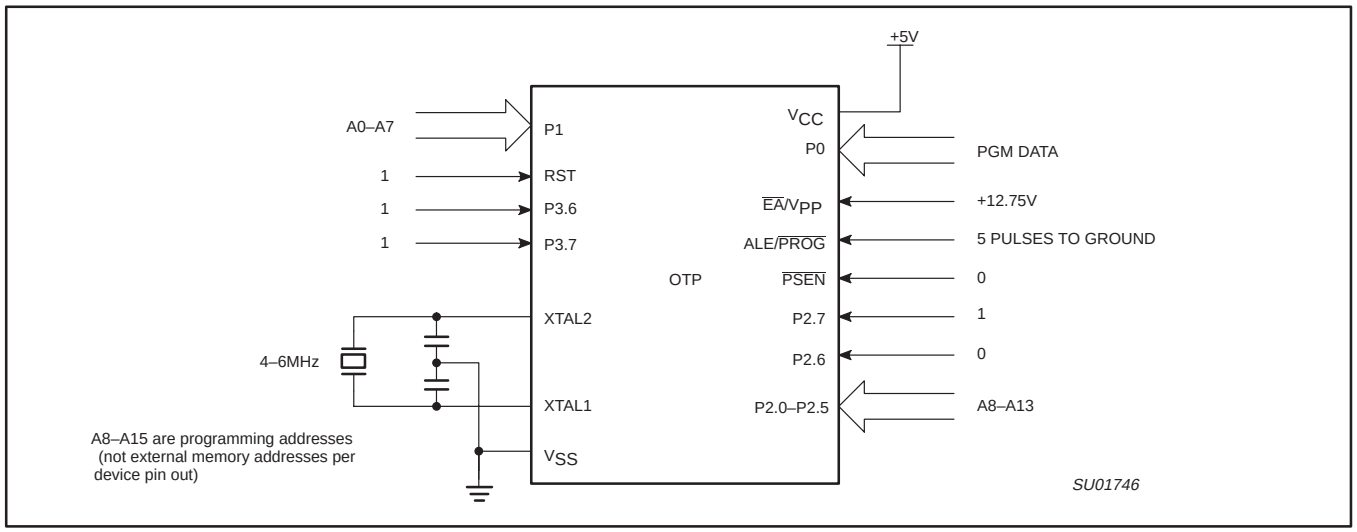


Figure 55. Programming Configuration

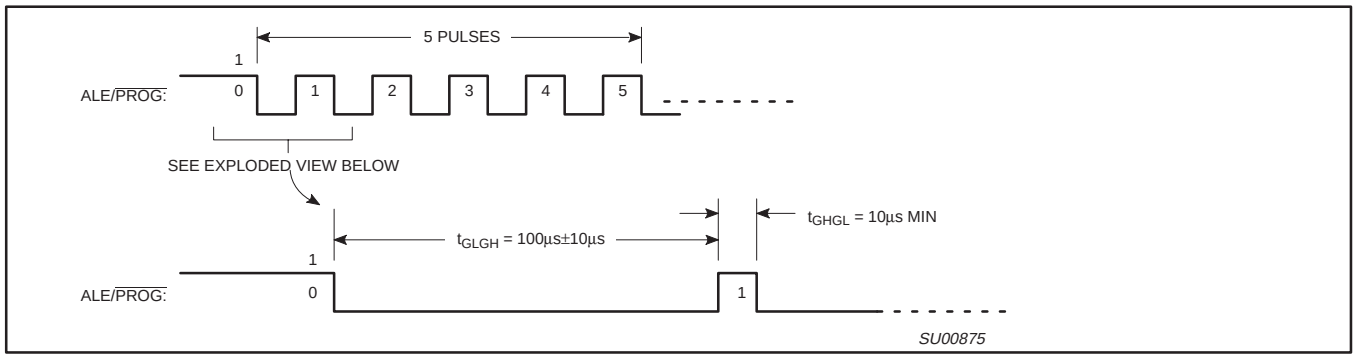


Figure 56. $\overline{\text{PROG}}$ Waveform

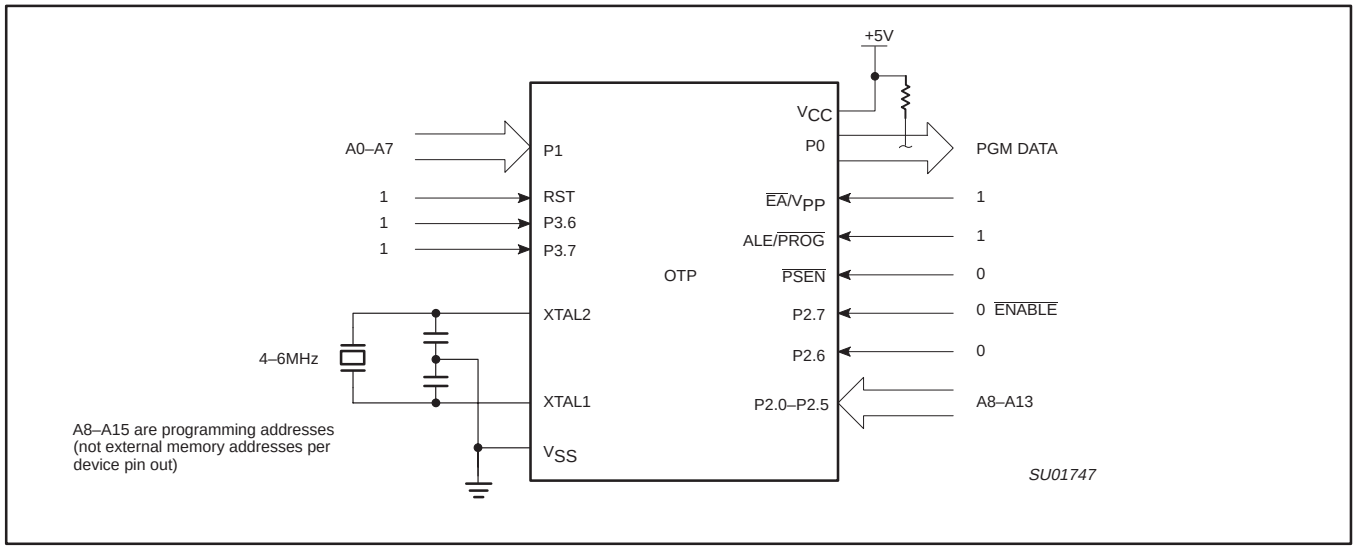


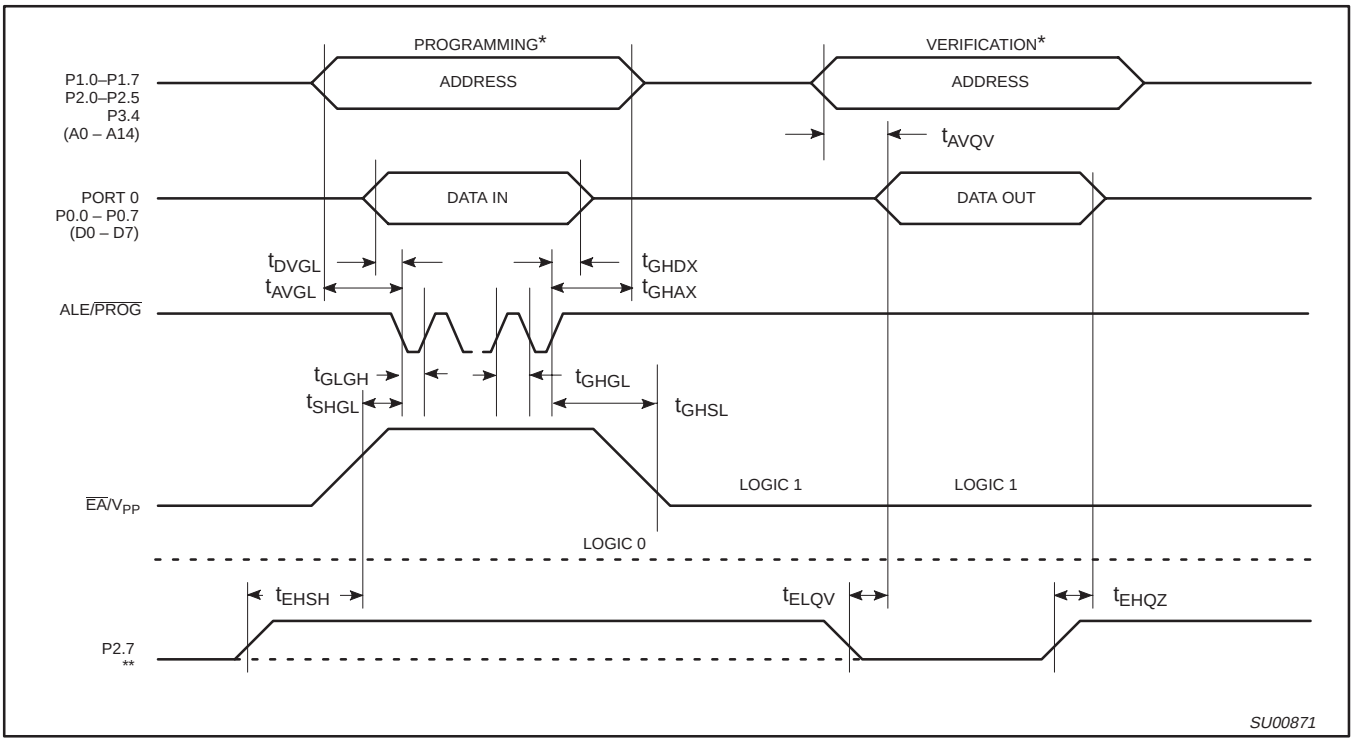
Figure 57. Program Verification

EPROM PROGRAMMING AND VERIFICATION CHARACTERISTICS

T_{amb} = 21°C to +27°C, V_{CC} = 5 V ±10 %, V_{SS} = 0 V (See Figure 58)

SYMBOL	PARAMETER	MIN	MAX	UNIT
V_{PP}	Programming supply voltage	12.5	13.0	V
I_{PP}	Programming supply current		50 [1]	mA
$1/t_{CLCL}$	Oscillator frequency	4	6	MHz
t_{AVGL}	Address setup to $\overline{PROG}$ LOW	$48t_{CLCL}$		
t_{GHAX}	Address hold after $\overline{PROG}$	$48t_{CLCL}$		
t_{DVGL}	Data setup to $\overline{PROG}$ LOW	$48t_{CLCL}$		
t_{GHDX}	Data hold after $\overline{PROG}$	$48t_{CLCL}$		
t_{EHSH}	P2.7 ($\overline{ENABLE}$) HIGH to V_{PP}	$48t_{CLCL}$		
t_{SHGL}	V_{PP} setup to $\overline{PROG}$ LOW	10		µs
t_{GHSL}	V_{PP} hold after $\overline{PROG}$	10		µs
t_{GLGH}	$\overline{PROG}$ width	90	110	µs
t_{AVQV}	Address to data valid		$48t_{CLCL}$	
t_{ELQZ}	$\overline{ENABLE}$ LOW to data valid		$48t_{CLCL}$	
t_{EHQZ}	Data float after $\overline{ENABLE}$	0	$48t_{CLCL}$	
t_{GHGL}	$\overline{PROG}$ HIGH to $\overline{PROG}$ LOW	10		µs

NOTE:
1. Not tested.



NOTES:

* FOR PROGRAMMING CONFIGURATION SEE FIGURE 55.
FOR VERIFICATION CONDITIONS SEE FIGURE 57.

** SEE TABLE 15.

Figure 58. EPROM Programming and Verification

MASK ROM DEVICES

Security Bits

With none of the security bits programmed the code in the program memory can be verified. If the encryption table is programmed, the code will be encrypted when verified. When only security bit 1 (see Table 17) is programmed, MOVC instructions executed from external program memory are disabled from fetching code bytes from the internal memory, $\overline{EA}$ is latched on Reset and all further programming of the EPROM is disabled. When security bits 1 and 2 are programmed, in addition to the above, verify mode is disabled.

Encryption Array

64 bytes of encryption array are initially unprogrammed (all 1s).

Table 17. Program Security Bits

PROGRAM LOCK BITS[1, 2]			
	SB1	SB2	PROTECTION DESCRIPTION
1	U	U	No Program Security features enabled. (Code verify will still be encrypted by the Encryption Array if programmed.)
2	P	U	MOVC instructions executed from external program memory are disabled from fetching code bytes from internal memory, $\overline{EA}$ is sampled and latched on Reset, and further programming of the EPROM is disabled.

NOTES:
1. P – programmed. U – unprogrammed.
2. Any other combination of the security bits is not defined.

ROM CODE SUBMISSION FOR 16K ROM DEVICES

When submitting ROM code for the 16K ROM devices, the following must be specified:

1. 16 kbyte user ROM data
2. 64 byte ROM encryption key
3. ROM security bits.

ADDRESS	CONTENT	BIT(S)	COMMENT
0000H to 3FFFH	DATA	7:0	User ROM Data
4000H to 403FH	KEY	7:0	ROM Encryption Key FFH = no encryption
4040H	SEC	0	ROM Security Bit 1 0 = enable security 1 = disable security
4040H	SEC	1	ROM Security Bit 2 0 = enable security 1 = disable security

Security Bit 1: When programmed, this bit has two effects on masked ROM parts:

1. External MOVC is disabled, and
2. $\overline{EA}$ is latched on Reset.

Security Bit 2: When programmed, this bit inhibits Verify User ROM.

NOTE: Security Bit 2 cannot be enabled unless Security Bit 1 is enabled.

If the ROM Code file does not include the options, the following information must be included with the ROM code.

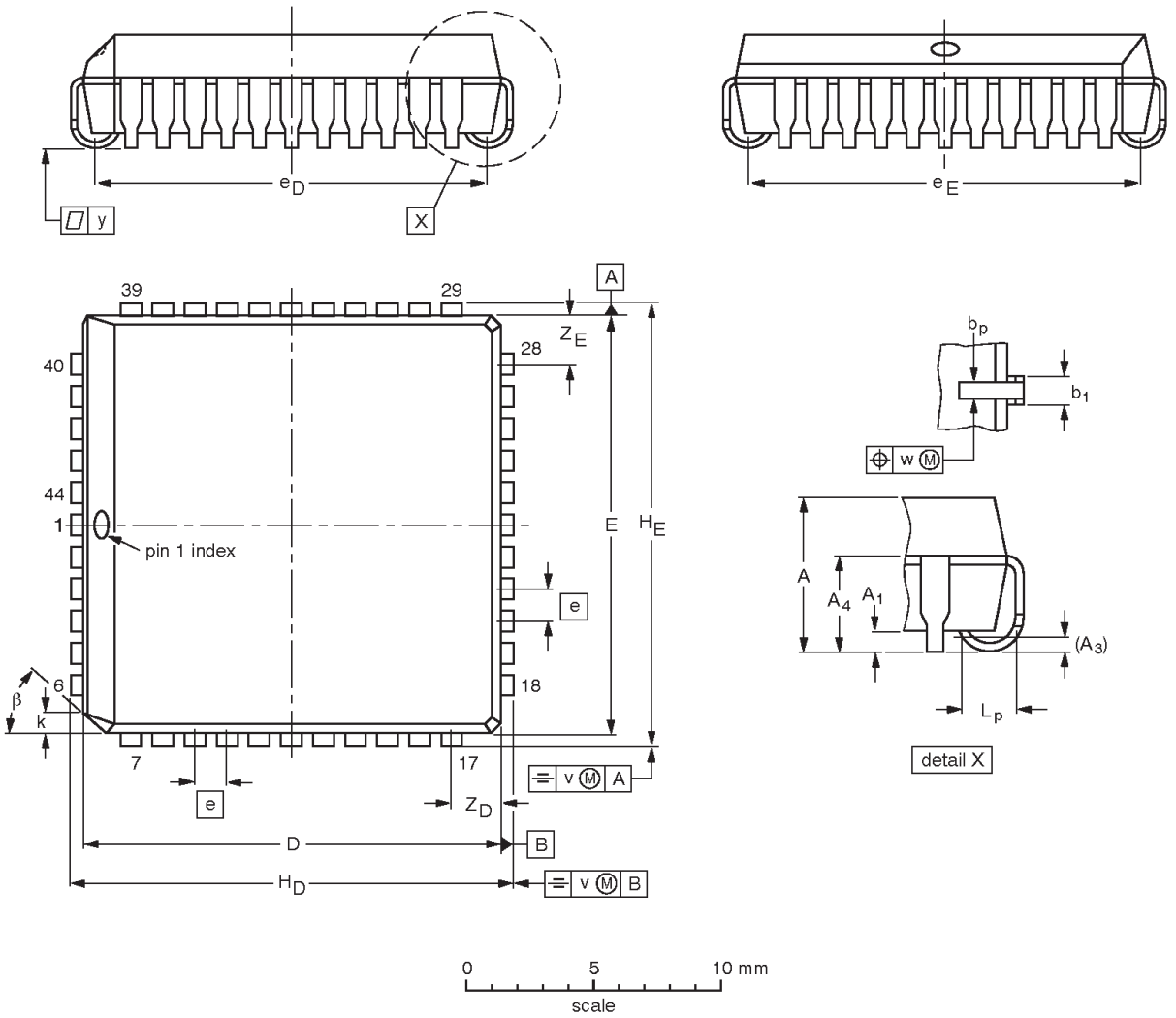
For each of the following, check the appropriate box, and send to Philips along with the code:

Security Bit #1: ☐ Enabled ☐ Disabled

Security Bit #2: ☐ Enabled ☐ Disabled

Encryption: ☐ No ☐ Yes If Yes, must send key file.

PLCC44: plastic leaded chip carrier; 44 leads SOT187-2



DIMENSIONS (mm dimensions are derived from the original inch dimensions)

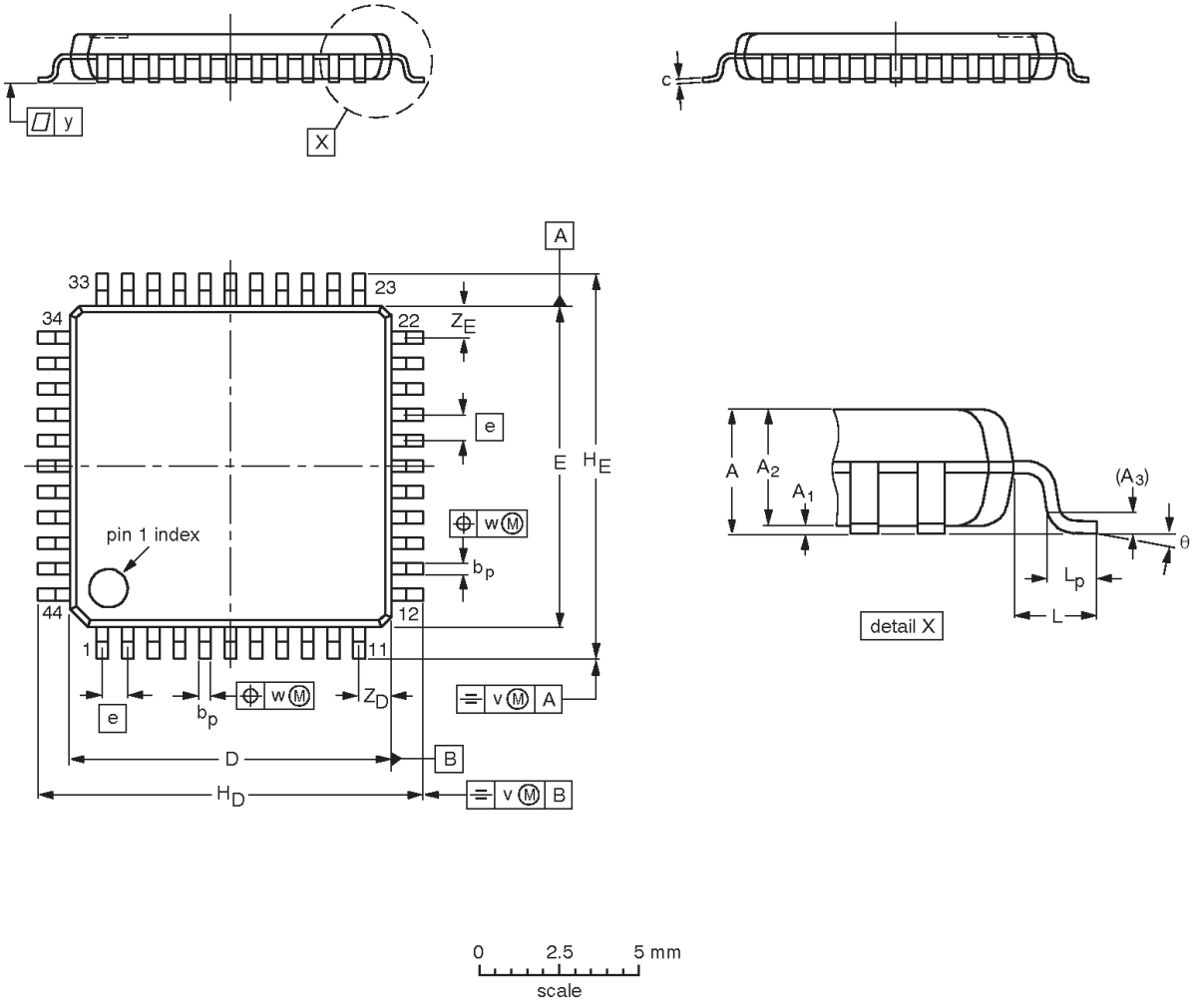
UNIT	A	A_1 min.	A_3	A_4 max.	b_p	b_1	$D^{(1)}$	$E^{(1)}$	e	e_D	e_E	H_D	H_E	k	L_p	v	w	y	$Z_D^{(1)}$ max.	$Z_E^{(1)}$ max.	β
mm	4.57 4.19	0.51	0.25	3.05	0.53 0.33	0.81 0.66	16.66 16.51	16.66 16.51	1.27	16.00 14.99	16.00 14.99	17.65 17.40	17.65 17.40	1.22 1.07	1.44 1.02	0.18	0.18	0.1	2.16	2.16	45°
inches	0.180 0.165	0.02	0.01	0.12	0.021 0.013	0.032 0.026	0.656 0.650	0.656 0.650	0.05	0.63 0.59	0.63 0.59	0.695 0.685	0.695 0.685	0.048 0.042	0.057 0.040	0.007	0.007	0.004	0.085	0.085	

Note

1. Plastic or metal protrusions of 0.25 mm (0.01 inch) maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT187-2	112E10	MS-018	EDR-7319			~~99-12-27~~ 01-11-14

LQFP44: plastic low profile quad flat package; 44 leads; body 10 x 10 x 1.4 mm **SOT389-1**



DIMENSIONS (mm are the original dimensions)

UNIT	A max.	A_1	A_2	A_3	b_p	c	$D^{(1)}$	$E^{(1)}$	e	H_D	H_E	L	L_p	v	w	y	$Z_D^{(1)}$	$Z_E^{(1)}$	θ
mm	1.6	0.15 0.05	1.45 1.35	0.25	0.45 0.30	0.20 0.12	10.1 9.9	10.1 9.9	0.8	12.15 11.85	12.15 11.85	1	0.75 0.45	0.2	0.2	0.1	1.14 0.85	1.14 0.85	7^o 0^o

Note

1. Plastic or metal protrusions of 0.25 mm maximum per side are not included.

OUTLINE VERSION	REFERENCES				EUROPEAN PROJECTION	ISSUE DATE
	IEC	JEDEC	JEITA			
SOT389-1	136E08	MS-026				~~00-01-19~~ 02-06-07

REVISION HISTORY

Rev	Date	Description
_2	20040420	**Product data (9397 750 13173)** Modifications: ● Update Special Function Registers table. ● Remove P3.4 from Figures 55 and 57.
_1	20030213	**Product data (9397 750 10814)**

80C51 8-bit microcontroller family 16 kB OTP/ROM, 256B RAM, low voltage (2.7 to 5.5 V), low power, high speed (30/33 MHz)

P83C654X2/P87C654X2

Purchase of Philips I²C components conveys a license under the Philips' I²C patent to use the components in the I²C system provided the system conforms to the I²C specifications defined by Philips. This specification can be ordered using the code 9398 393 40011.

Data sheet status

Level	Data sheet status [1]	Product status [2] [3]	Definitions
I	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.
II	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.
III	Product data	Production	This data sheet contains data from the product specification. Philips Semiconductors reserves the right to make changes at any time in order to improve the design, manufacturing and supply. Relevant changes will be communicated via a Customer Product/Process Change Notification (CPCN).

[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.

[3] For data sheets describing multiple type numbers, the highest-level product status determines the data sheet status.

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.

Application information — Applications that are described herein for any of these products are for illustrative purposes only. Philips Semiconductors make no representation or warranty that such applications will be suitable for the specified use without further testing or modification.

Disclaimers

Life support — These products are not designed for use in life support appliances, devices, or systems where malfunction of these products can reasonably be expected to result in personal injury. Philips Semiconductors customers using or selling these products for use in such applications do so at their own risk and agree to fully indemnify Philips Semiconductors for any damages resulting from such application.

Right to make changes — Philips Semiconductors reserves the right to make changes in the products—including circuits, standard cells, and/or software—described or contained herein in order to improve design and/or performance. When the product is in full production (status 'Production'), relevant changes will be communicated via a Customer Product/Process Change Notification (CPCN). Philips Semiconductors assumes no responsibility or liability for the use of any of these products, conveys no license or title under any patent, copyright, or mask work right to these products, and makes no representations or warranties that these products are free from patent, copyright, or mask work right infringement, unless otherwise specified.

Contact information

For additional information please visit
http://www.semiconductors.philips.com. Fax: **+31 40 27 24825**

For sales offices addresses send e-mail to:
sales.addresses@www.semiconductors.philips.com.

© Koninklijke Philips Electronics N.V. 2004
All rights reserved. Printed in U.S.A.

Date of release: 04-04

Document order number: 9397 750 13173

Let's make things better.

Philips Semiconductors

PHILIPS

Looking for pricing, stock, or lifecycle information?

Click below to explore more details on WIN SOURCE:

- View P87C654X2FA on WIN SOURCE
- NXP / Nexperia Information

Optimize Your Supply Chain with WIN SOURCE Solutions

- Global Sourcing Solution
- Obsolete Management
- Cost Control Management
- Shortage Management
- Alternative Solution
- Excess Inventory Management