- **PnP Card Autoconfiguration Sequence Compliant**
- **External Terminal-to-Bypass PnP Autoconfiguration Sequence**
- **In UART Bypass Mode, the Stand-Alone PnP Controller is Configured With One Logical Device**
- **Provides 10-Interrupts IRQ3 – IRQ7, IRQ9 – IRQ12, IRQ15**
- **Simple 3-Pin Interface to SGS-Thomson™ EEPROM 2K/4K ST93C56/66**
- **High Output Current Drive. No External Buffer Needed for Data and Interrupt Signals**
- **Programmable Auto-RTS and Auto-CTS**
- **In Auto-CTS Mode, $\overline{\text{CTS}}$ Controls Transmitter**
- **In Auto-RTS Mode, Receiver FIFO Contents and Threshold Control RTS**
- **The Serial and Modem Control Outputs Drive a 1-Meter RJ11 Cable Directly if Equipment Is on the Same Power Drop**
- **Capable of Running With All Existing TL16C450 Software**
- **After Reset, All Registers Are Identical to the TL16C450 Register Set**
- **Clock Prescalar Allows 22-MHz Oscillator Clock to be Divided by 12, 6, 3, or 1**
- **In the TL16C450 Mode, Hold and Shift Registers Eliminate the Need for Precise Synchronization Between the CPU and Serial Data**
- **Programmable Baud Rate Generator Allows Division of Any Input Reference Clock by 1 to (2^{16} – 1) and Generates an Internal 16× Clock**
- **On-Chip I/O Port Address Decoding**
- **In PnP Bypass Mode, 6 External Terminals Configure the I/O Base Address and Interrupt Mapping**
- **Adds or Deletes Standard Asynchronous Communication Bits (Start, Stop, and Parity) to or From the Serial Data Stream**
- **Independent Control of Transmit, Receive, Line Status, and Data Set Interrupts on Each Channel**
- **Programmable Serial Interface Characteristics:**
  - **5-, 6-, 7-, or 8-Bit Characters**
  - **Even-, Odd-, or No-Parity-Bit Generation and Detection**
  - **1-, 1 1/2-, or 2-Stop Bit Generation**
  - **Baud Generation (DC to 1 Mbit Per Second)**
- **False Start Bit Detection**
- **Complete Status Reporting Capabilities**
- **3-State Outputs Provide TTL Drive for Bidirectional Data Bus and Interrupt Lines**
- **Line Break Generation and Detection**
- **Internal Diagnostic Capabilities:**
  - **Loopback Controls for Communications Link Fault Isolation**
  - **Break, Parity, Overrun, and Framing Error Simulation**
- **Fully Prioritized Interrupt System Controls**
- **Modem Control Functions (CTS, RTS, DSR, DTR, RI, and DCD)**
- **Transmitter and Receiver Run at the Same Speed**
- **Up to 16-MHz Clock Rate for Up to 1-Mbaud Operation for the Internal ACE**
- **Available in 68-Pin PLCC**

description

The TL16PNP550A is a functional upgrade of the TL16C550C asynchronous communications element (ACE), which in turn is a functional upgrade of the TL16C450. Functionally equivalent to the TL16C450 on power up (character or TL16C450 mode), the TL16PNP550A, like the TL16C550C, can be placed in an alternate mode (FIFO mode). This relieves the CPU of excessive software overhead by buffering received and transmitted characters. The receiver and transmitter FIFOs store up to 16 bytes including three additional bits of error status



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description (continued)

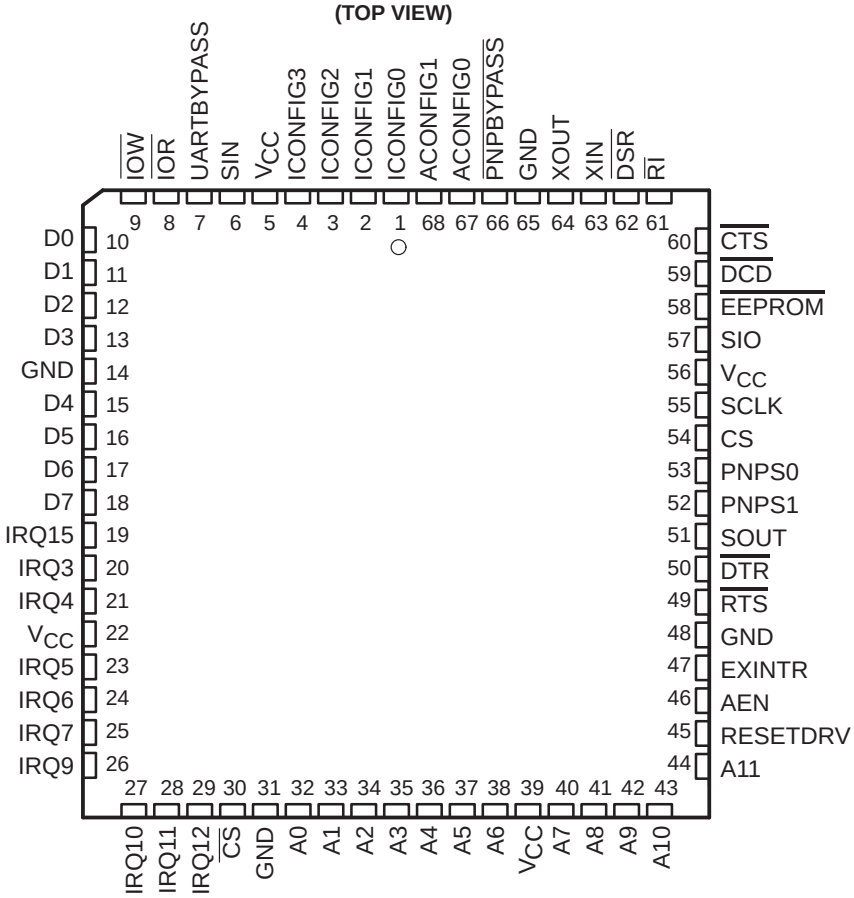
per byte for the receiver FIFO. In the FIFO mode, there is a selectable autoflow control feature that can significantly reduce software overload and increase system efficiency by automatically controlling serial data flow using $\overline{RTS}$ output and $\overline{CTS}$ input signals.

The TL16PNP550A responds to the plug-and-play (PnP) autoconfiguration process. The autoconfiguration process puts all PnP cards in a configuration mode, isolates one PnP card at a time, assigns a card select number (CSN), and reads the card resource data structure from the EEPROM. After the resource requirements and capabilities are determined for all cards, the autoconfiguration process uses the CSN to configure the card by writing to the configuration registers. The TL16PNP550A only implements configuration registers for I/O applications with one logical device and no direct memory access (DMA) support. Finally, the process activates the TL16PNP550A card and removes it from configuration mode. After the configuration process, the ACE starts responding to industry standard architecture (ISA) bus cycles. This device can also be configured to bypass the PnP autoconfiguration sequence. In this mode the TL16PNP500A can be configured to select the COM port address and IRQ level. In the UART bypass mode, the UART is disabled and this device is configured to be a stand-alone PnP controller that supports one logical device and no DMA support.

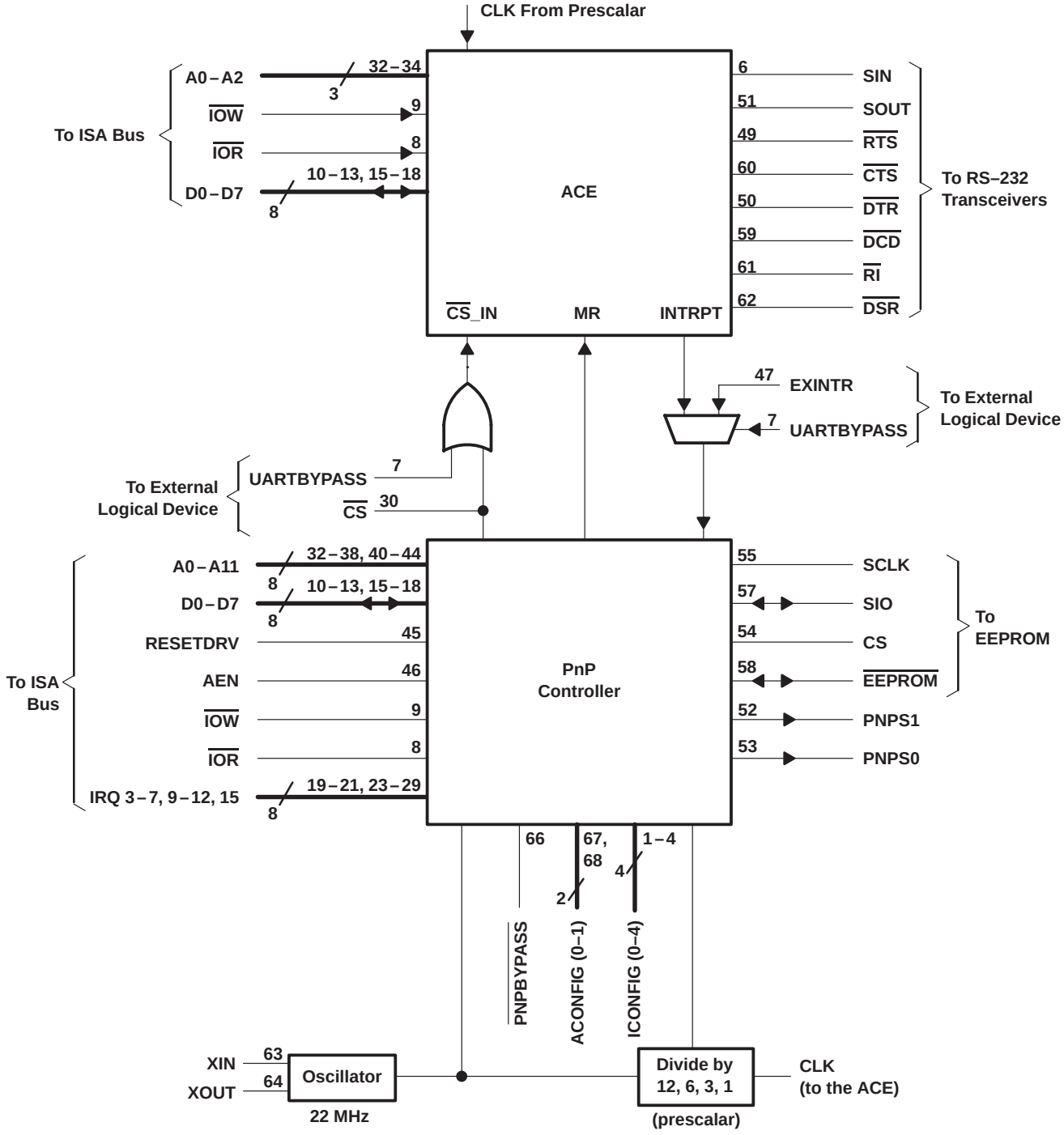
The TL16PNP550A performs serial-to-parallel conversion on data received from a peripheral device or modem and parallel-to-serial conversion on data received from its CPU. The CPU can read and report on the status of the ACE operation. Reported status information includes the type of transfer operation in progress, the status of the operation, and any error conditions encountered.

The TL16PNP550A includes a clock prescalar that divides the 22-MHz input clock by 12, 6, 3, or 1. The prescalar output clock is fed to the programmable baud rate generator, which is capable of dividing this clock by divisors from 1 to $(2^{16} – 1)$.

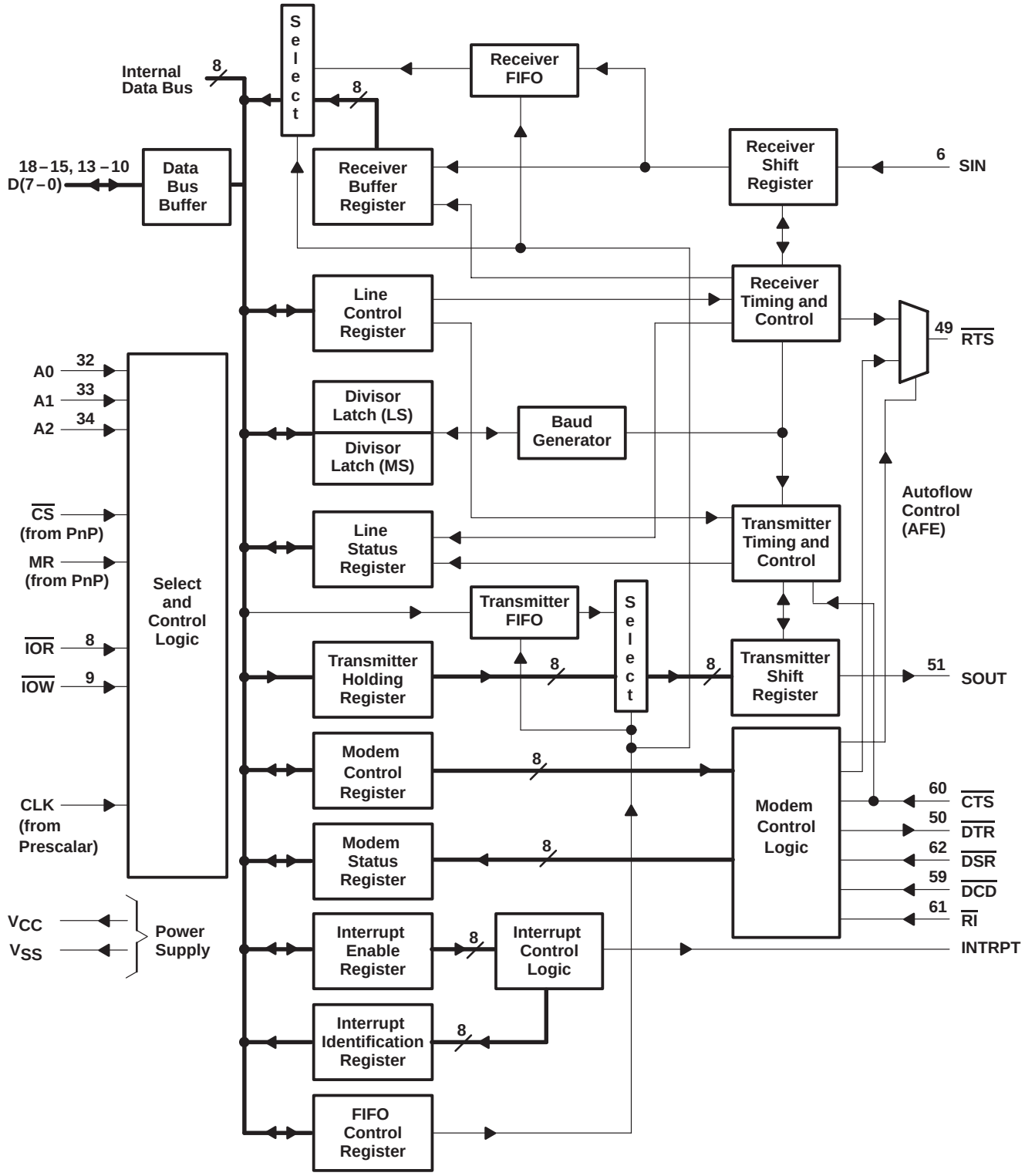
FN PACKAGE
(TOP VIEW)



functional block diagram



ACE functional block diagram



Terminal Functions

TERMINAL NAME	TERMINAL NO. FN	I/O	DESCRIPTION
A0–A6 A7–A11	32–38 40–44	I	12-bit ISA address terminals. All 12 bits are used during PnP autoconfiguration sequence. After autoconfiguration, bits A0–A2 select the ACE registers and bits A3–A9 are used in the address decoding to generate chip select for the device.
ACONFIG0, ACONFIG1	67, 68	I	Address configure. In PnP bypass mode, both ACONFIG0 and ACONFIG1 configure the COM port base address.
AEN	46	I	Address enable. AEN disables the ACE and PnP controller during DMA.
CS	54	O	Chip select. CS is a 3-state output. It controls the activity of the EEPROM. A 100 µA pulldown circuit is connected to this terminal.
$\overline{CS}$	30	O	Chip select. $\overline{CS}$ is the I/O chip select for the logical device.
$\overline{CTS}$	60	I	Clear to send. $\overline{CTS}$ is a modem status signal. Its condition can be checked by reading bit 4 (CTS) of the modem status register (MSR). Bit 0 (ΔCTS) of the modem status register indicates that this signal has changed states since the last read from the MSR. When the modem status interrupt is enabled when $\overline{CTS}$ changes states and the auto-CTS mode is not enabled, an interrupt is generated. $\overline{CTS}$ is also used in the auto-CTS mode to control the transmitter.
D0–D3 D4–D7	10–13 15–18	I/O	Data bus. D0 – D7 are eight data lines with 3-state outputs that provide a bidirectional path for data, control, and status information between the ACE and the CPU. The output drive sinks 24 mA at 0.4 V and sources 12 mA at 2.4 V.
$\overline{DCD}$	59	I	Data carrier detect. $\overline{DCD}$ is a modem status signal. Its condition can be checked by reading bit 7 (DCD) of the MSR. Bit 3 (ΔDCD) of the MSR indicates that this signal has changed levels since the last read from the MSR. When the modem status interrupt is enabled when $\overline{DCD}$ changes states, an interrupt is generated.
$\overline{DSR}$	62	I	Data set ready. $\overline{DSR}$ is a modem status signal. Its condition can be checked by reading bit 5 (DSR) of the MSR. Bit 1 (ΔDSR) of the MSR indicates this signal has changed states since the last read from the MSR. If the modem status interrupt is enabled when the $\overline{DSR}$ changes states, an interrupt is generated.
$\overline{DTR}$	50	O	Data terminal ready. When active (low), $\overline{DTR}$ informs a modem or data set that the ACE is ready to establish communication. $\overline{DTR}$ is placed in its active level by setting the DTR bit of the MCR. $\overline{DTR}$ is placed in its inactive level either as a result of a master reset, during loop mode operation, or clearing the DTR bit.
$\overline{EEPROM}$	58	I/O	EEPROM access. $\overline{EEPROM}$ is a 3-state bidirectional signal. When it is pulled low, either the TL16PNP550A or controller is accessing the EEPROM. A 100 µA pullup circuit is connected to this terminal.
EXINTR	47	I	External interrupt. During UARTBYPASS mode, the external logical device interrupt (EXINTR) is mapped to the configured IRQs.
GND	14, 31, 48, 65		Ground (0 V). These four GND terminals must be tied to ground for proper operation.
ICONFIG0– ICONFIG3	1–4	I	IRQ configure. In PnP bypass mode, ICONFIG0 , ICONFIG2, and ICONFIG3 configure the required IRQ.
$\overline{IOR}$	8	I	Read input. When $\overline{IOR}$ is active while the ACE is selected, the CPU is allowed to read from the ACE.
$\overline{IOW}$	9	I	Write input. When $\overline{IOW}$ is active while the ACE is selected, the CPU is allowed to write to the ACE.
IRQ3–IRQ4 IRQ5–IRQ7 IRQ9–IRQ12 IRQ15	20–21 23–25 26–29 19	O	3-state interrupt requests. When active (high), IRQx informs the CPU that the ACE has an interrupt to be serviced. Four conditions that cause an interrupt to be issued are: a receiver error, received data is available or timed out (FIFO mode only), an empty transmitter holding register, or an enabled modem status interrupt. IRQx is generated when one or all of the above conditions occur and the value of bits 0–3 in the interrupt request level (0×70) is equal to x (of IRQx). The output drive sinks 24 mA at 0.4 V and sources 12 mA at 2.4 V.
$\overline{PNPBYPASS}$	66	I	Bypass PnP configuration sequence. When $\overline{PNPBYPASS}$ is tied to GND, the PnP autoconfiguration sequence is bypassed.
PNPS1– PNPS0	52–53	O	PnP internal states. See the PNPS1 and PNPS0 truth table in the PnP states section of this document.
RESETDRV	45	I	Reset. When active (high), RESETDRV clears most ACE registers and puts the ACE in wait for key state. The CSN is reset to 0×00. All configuration registers are set to their power-up values.

Terminal Functions (Continued)

TERMINAL NAME	TERMINAL NO. FN	I/O	DESCRIPTION
$\overline{RI}$	61	I	Ring indicator. $\overline{RI}$ is modem status signal. Its condition can be checked by reading bit 6 (RI) of the MSR. BIt 2 (TERI) of the MSR indicates that $\overline{RI}$ has transitioned from a low to a high level since the last read from the MSR. If the modem status interrupt is enabled when this transition occurs, an interrupt is generated.
$\overline{RTS}$	49	O	Request to send. When active, $\overline{RTS}$ informs the modem or data set that the ACE is ready to receive data. $\overline{RTS}$ is set to its active level low by setting the RTS modem control register bit and is set to its inactive (high) level either as a result of a master reset or during loop mode operations or by clearing bit 1 (RTS) of the MCR. In auto-RTS mode, $\overline{RTS}$ is set to its inactive level by the receiver threshold control logic.
SCLK	55	O	3-state EEPROM clock. SCLK is a 3-state EEPROM clock output that controls address and data transfer. A 100 μA pulldown circuit is connected to this terminal.
SIN	6	I	Serial data. SIN is input from a connected communications device.
SIO	57	I/O	3-State bidirectional EEPROM serial data bus. During output mode, SIO provides only read opcode and address which are sourced at the falling edge of SCLK. During input mode it provides the data which is captured at the rising edge of SCLK. A 100 μA pulldown circuit is connected to this terminal.
SOUT	51	O	Composite serial data output to a connected communication device. SOUT is set to the marking (high) level as a result of master reset.
UARTBYPASS	7	I	UART bypass. When it is active, UARTBYPASS disables the UART and the TL16PNP550A acts as a PnP stand-alone controller.
V_{CC}	5, 22, 39, 56		5-V supply voltage.
XIN, XOUT	63, 64	I/O	External clock. XIN and XOUT connect the TL16PNP550A to the main timing reference, a 22-MHz clock or crystal.

detailed description

autoflow control

Autoflow control is comprised of auto-CTS and auto-RTS. With auto-CTS, the input must be active before the transmitter FIFO can emit data (see Figure 1). Auto-RTS becomes active when the receiver needs more data and notifies the sending serial device (see Figure 1). When $\overline{RTS}$ is connected to $\overline{CTS}$, data transmission does not occur unless the receiver FIFO has space for the data; thus, overrun errors are eliminated if ACE1 and ACE2 are TL16PNP550As with enabled autoflow control. If autoflow control is not enabled, overrun errors occur when the transmit data rate exceeds the receiver FIFO read latency.

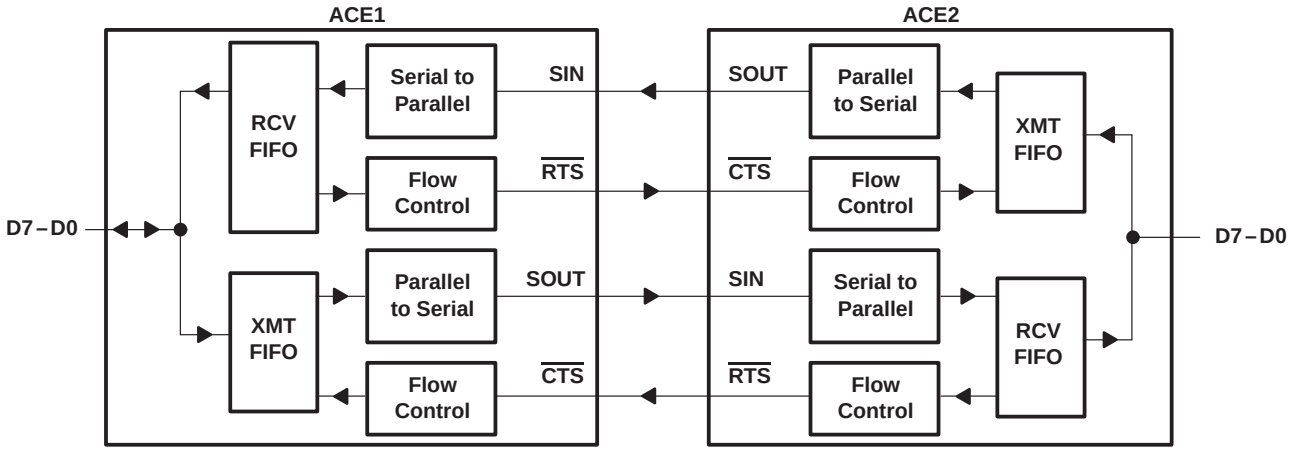


Figure 1. Autoflow Control Example (Auto-RTS and Auto-CTS)

auto-RTS (see Figure 1)

Auto-RTS data flow control originates in the receiver timing and control block (see functional block diagram) and is linked to the programmed receiver FIFO trigger level. When the receiver FIFO level reaches a trigger level of 1, 4, or 8, (see Figure 3), $\overline{RTS}$ is deasserted. With trigger levels of 1, 4, and 8, the sending ACE may send an additional byte after the trigger level is reached (assuming the sending ACE has another byte to send) because it may not recognize the deassertion of $\overline{RTS}$ until after it has begun sending the additional byte. $\overline{RTS}$ is automatically reasserted once the receiver FIFO is emptied by reading the receiver buffer register.

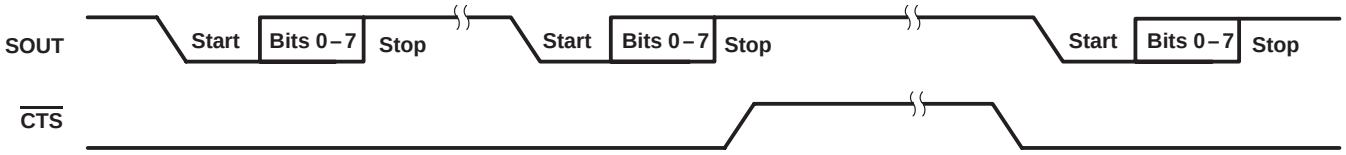
When the trigger level is 14 (see Figure 4), $\overline{RTS}$ is deasserted after the first data bit of the sixteenth character is present on the SIN line. $\overline{RTS}$ is reasserted when the receiver FIFO has at least one available byte space.

auto-CTS (see Figure 1)

The transmitter circuitry checks $\overline{CTS}$ before sending the next data byte. When $\overline{CTS}$ is active, it sends the next byte. To stop the transmitter from sending the following byte, $\overline{CTS}$ must be released before the middle of the last stop bit that is currently being sent (see Figure 2). The auto-CTS function reduces interrupts to the host system. When flow control is enabled, changes of $\overline{CTS}$ level do not trigger host interrupts because the device automatically controls its own transmitter. Without auto-CTS, the transmitter sends any data present in the transmit FIFO and a receiver overrun error may result.

enabling autoflow control and auto-CTS

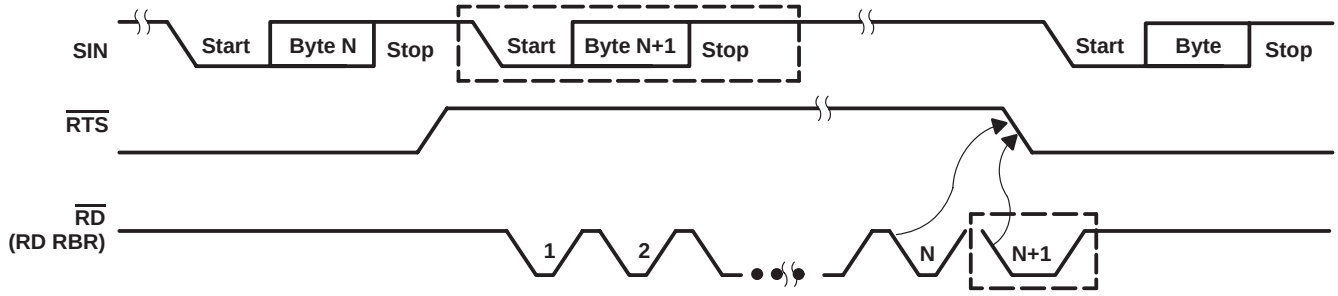
Autoflow control is enabled by setting modem control register bits 5 (autoflow enable or AFE) and 1 (RTS) to 1. Autoflow incorporates both auto-RTS and auto-CTS. If only auto-CTS is desired, bit 1 in the MCR should be cleared (this assumes a control signal is driving $\overline{CTS}$).



NOTE A: When $\overline{CTS}$ is low, the transmitter keeps sending serial data out. If $\overline{CTS}$ goes high before the middle of the last stop bit of the current byte, the transmitter finishes sending the current byte but it does not send the next byte. When $\overline{CTS}$ goes from high to low, the transmitter begins sending data again.

Figure 2. $\overline{CTS}$ Functional Timing Waveforms

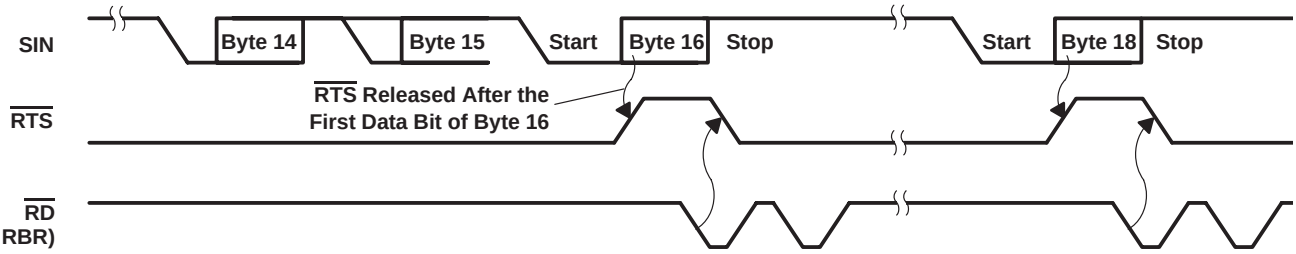
The receiver FIFO trigger level can be set to 1, 4, 8, or 14 bytes. These are described in Figures 3 and 4.



NOTES: A. N = receiver FIFO trigger level (1, 4, or 8 bytes)
B. The two blocks in dashed lines cover the case where an additional byte is sent as described in the preceding auto-RTS section.

Figure 3. $\overline{RTS}$ Functional Timing Waveforms, Receiver FIFO Trigger Level = 1, 4, or 8 Bytes

enabling autoflow control and auto-CTS (continued)



NOTES: A. $\overline{\text{RTS}}$ is deasserted when the receiver receives the first data bit of the sixteenth byte. The receiver FIFO is full after finishing the sixteenth byte.
B. $\overline{\text{RTS}}$ is asserted again when there is at least one byte of space available and no incoming byte is in processing or there is more than one byte of space available.
C. When the receiver FIFO is full, the first receiver buffer register read reasserts $\overline{\text{RTS}}$.

Figure 4. $\overline{\text{RTS}}$ Functional Timing Waveforms, Receiver FIFO Trigger Level = 14 Bytes

flow control and interrupt

When flow control is enabled, bit 0 (ΔCTS) of the modem status register does not cause a modem status interrupt. The ACE accommodates a 1-Mbaud serial rate (16-MHz input clock) so that a bit time is 1 μs, and a typical character time is 10 μs (start bit, 8 data bits, and a stop bit).

The TL16PNP550A ACE includes a programmable, on-board, baud rate generator that divides a reference clock input by 1 to (2^{16} –1) for producing a 16 × clock to drive the internal transmitter logic. Provisions are included to use this 16 × clock to drive the receiver logic. The ACE includes complete modem control capability and a processor interrupt system that may be software tailored to minimize the system overhead for handling the communications link.

absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage range, V_{CC} (see Note 1) . . . . . –0.5 V to 7 V
Input voltage range at any input, V_I . . . . . –0.5 V to 7 V
Output voltage range, V_O . . . . . –0.5 V to 7 V
Operating free-air temperature range, T_A . . . . . 0°C to 70°C
Storage temperature range, T_{stg} . . . . . –65°C to 150°C
Case temperature for 10 seconds, T_C: FN package . . . . . 260°C

† Stresses beyond those listed under “absolute maximum ratings” may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under “recommended operating conditions” is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTE 1: All voltage values are with respect to V_{SS}.

recommended operating conditions

	MIN	NOM	MAX	UNIT
Supply voltage, V_{CC}	4.75	5	5.25	V
High-level input voltage, V_{IH}	2		V_{CC}	V
Low-level input voltage, V_{IL}	–0.5		0.8	V
Operating free-air temperature, T_A	0		70	°C

electrical characteristics over recommended ranges of supply voltage and operating free-air temperature (unless otherwise noted)

PARAMETER		TEST CONDITIONS	MIN	TYP†	MAX	UNIT
V_{OH}‡	High-level output voltage	I_{OH} = –12 mA	V_{CC}–0.8			V
V_{OL}‡	Low-level output voltage	I_{OL} = 24 mA			0.5	V
V_{OH}	High-level output voltage	I_{OH} = –4 mA (see Note 2), V_{CC} = 0.8 V	V_{CC}–0.8			V
V_{OL}	Low-level output voltage	I_{OL} = 4 mA (see Note 2)			0.5	V
I_I	Input current	V_{CC} = 5.25 V, V_{SS} = 0, V_I = 0 to 5.25 V, All other terminals floating			±1	µA
I_{OZ}	High-impedance-state output current	V_{CC} = 5.25 V, V_{SS} = 0, V_O = 0 to 5.25 V, Pullup and pulldown circuits are off			±10	µA
I_{CC}	Supply current	V_{CC} = 5.25 V, T_A = 25°C, SIN, $\overline{DSR}$, $\overline{DCD}$, $\overline{CTS}$, and $\overline{RI}$ at 2 V, All other inputs at 0.8 V, Clock at 4 MHz (no crystal used), No load on outputs, Baud rate = 50 kbit/s			5	mA
$C_{i(CLK)}$	Clock input capacitance	V_{CC} = 0, V_{SS} = 0, f = 1 MHz, T_A = 25°C, All other terminals grounded		15	20	pF
$C_{o(CLK)}$	Clock output capacitance			20	30	pF
C_i	Input capacitance			6	10	pF
C_o	Output capacitance			10	20	pF
$f_{(XIN–XOUT)}$	Oscillator speed (XIN and XOUT)		16		22	MHz

† All typical values are at V_{CC} = 5 V and T_A = 25°C.
‡ These parameters apply only for IRQx and D7–D0.
NOTE 2: These parameters apply for all outputs except XOUT, IRQx, and D7–D0.

clock timing requirements over recommended ranges of supply voltage and operating free-air temperature

PARAMETER		ALTERNATE SYMBOLS	TEST CONDITIONS	MIN	MAX	UNIT
t_{d1}	Delay time, chip select (CS) high to clock (SCLK) high	t_{SHCH}	See Figure 18 and Figure 19	50		ns
t_{d2}	Input valid to clock (SCLK) high	t_{DVCH}		100		ns
t_{pd1}	Propagation delay time, clock (SCLK) high to input transition (SIO)	t_{CHDX}		100		ns
t_{pd2}	Propagation delay time, clock (SCLK) high to output valid (SIO)	t_{CHQV}			500	ns
t_{pd3}	Propagation delay time, clock (SCLK) low to chip select transition (CS)	t_{CLSL}			2	clock periods
t_{d3}	Delay time, chip select (CS) low to output Hi-Z (SIO)	t_{SLQZ}			100	ns
$t_{w(SCLKH)}$	Pulse duration, clock (SCLK) high to clock (SCLK) low (see Note 3)	t_{CHCL}		250		ns
$t_{w(SCLKL)}$	Pulse duration, clock (SCLK) low to clock (SCLK) high (see Note 3)	t_{CLCH}		250		ns
f_{clock}	Clock frequency (SCLK) (see Note 4)	F_{CLK}		0.5	0.68	MHz

NOTES: 3. The ST93C56 chip select, S, must be brought low for a minimum of 250 ns (t_{SLSH}) between consecutive instruction cycles according to the ST93C56 specification.
4. The SCLK signal is attained by internally frequency dividing the XIN signal by 32.

system timing requirements over recommended ranges of supply voltage and operating free-air temperature

PARAMETER		ALTERNATE SYMBOL	FIGURE	TEST CONDITIONS	MIN	MAX	UNIT
t_{cR}	Cycle time, read ($t_{w7} + t_{d8} + t_{d9}$)	RC			87		ns
t_{cW}	Cycle time, write ($t_{w6} + t_{d5} + t_{d6}$)	WC			87		ns
t_{w1}†	Pulse duration, XIN high	t_{XH}	Figure 5	f = 16 MHz maximum	25		ns
t_{w2}†	Pulse duration, XIN low	t_{XL}	Figure 5	f = 16 MHz maximum	25		ns
t_{w6}	Pulse duration, write strobe ($\overline{IOW}$)	t_{WR}	Figure 6		75		ns
t_{w7}	Pulse duration, read strobe ($\overline{IOR}$)	t_{RD}	Figure 7		75		ns
t_{w8}	Pulse duration, master reset	t_{MR}			1		µs
t_{su3}	Setup time, data valid before $\overline{IOW}\uparrow$	t_{DS}	Figure 6		15		ns
t_{h1}	Hold time, chip select (CS) valid after address (A0 – A2) becomes invalid	t_{CH}	Figure 6, Figure 7	From the first rising edge of XIN after address invalid		20	ns
t_{h2}	Hold time, data valid after $\overline{IOW}\uparrow$	t_{DH}	Figure 6		5		ns
t_{d4}	Delay time, chip select ($\overline{CS}$) valid after address valid (A0 – A2)	t_{CSRW}	Figure 6, Figure 7	From the first rising edge of XIN after address valid		30	ns
t_{d5}	Delay time, address valid (A0 – A2) before $\overline{IOW}\downarrow$	t_{AW}	Figure 6		7		ns
t_{d6}	Delay time, address valid (A0 – A2) before $\overline{IOR}\downarrow$	t_{AR}	Figure 7		7		ns
t_{d7}	Delay time, chip select ($\overline{CS}$) valid to data valid (D7 – D0)	t_{CSVD}	Figure 7	C_L = 75 pF		30	ns
t_{d8}	Delay time, $\overline{IOR}\uparrow$ to floating data (D7 – D0)	t_{HZ}	Figure 7	C_L = 75 pF		20	ns
t_{d9}	Delay time, EXINTR$\uparrow$ or EXINTR$\downarrow$ to IRQx$\uparrow$ or IRQx$\downarrow$		Figure 8			15	ns

† This only applies when $\overline{PNPBYPASS}$ is low.

oscillator cell maximum switching characteristics, V_{CC} = 4.75 V, T_J = 115°C

PARAMETER	FROM (INPUT)	TO (OUTPUT)	INTRINSIC DELAY (ns)	DELTA DELAY (ns/pF)	DELAY (ns)			
					C_L = 15 pF	C_L = 50 pF	C_L = 85 pF	C_L = 100 pF
t_{PLH}	XIN	XOUT	–0.25	0.300	4.26	14.76	25.26	29.77
t_{PHL}			–0.24	0.206	2.85	10.06	17.27	20.36
t_r	Output rise time, XOUT				5.83	21.15	36.47	43.04
t_f	Output fall time, XOUT				3.76	13.50	23.24	27.41

baud generator switching characteristics over recommended ranges of supply voltage and operating free-air temperature, C_L = 75 pF (see Figure 5)

PARAMETER		ALTERNATE SYMBOL	TEST CONDITIONS	MIN	MAX	UNIT
t_{w3}†	Pulse duration, PNPS1 low	t_{LW}	f = 16 MHz, CLK ÷ 2	50		ns
t_{w4}†	Pulse duration, PNPS1 high	t_{HW}	f = 16 MHz, CLK ÷ 2	50		ns
t_{d1}†	Delay time, XIN$\uparrow$ to PNPS1$\uparrow$	t_{BLD}			45	ns
t_{d2}†	Delay time, XIN$\uparrow\downarrow$ to PNPS1$\downarrow$	t_{BHD}			45	ns

† This only applies when $\overline{PNPBYPASS}$ is low.

receiver switching characteristics over recommended ranges of supply voltage and operating free-air temperature (see Note 5)

PARAMETER		ALTERNATE SYMBOL	FIGURE	TEST CONDITIONS	MIN	MAX	UNIT
t_{d10}	Delay time, stop (SIN) to set INTRPT or read RBR to LSI interrupt (IRQx)	t_{SINT}	Figure 9, Figure 10, Figure 11			1	RCLK cycle
t_{d11}	Delay time, read RBR/LSR ($\overline{IOR}$) to reset INTRPT (IRQx)	t_{RINT}	Figure 9, Figure 10, Figure 11	C_L = 75 pF		70	ns

NOTE 5: In the FIFO mode, the read cycle (RC) = 425 ns (min) between reads of the receiver FIFO and the status registers (interrupt identification register or line status register).

transmitter switching characteristics over recommended ranges of supply voltage and operating free-air temperature (see Figure 12)

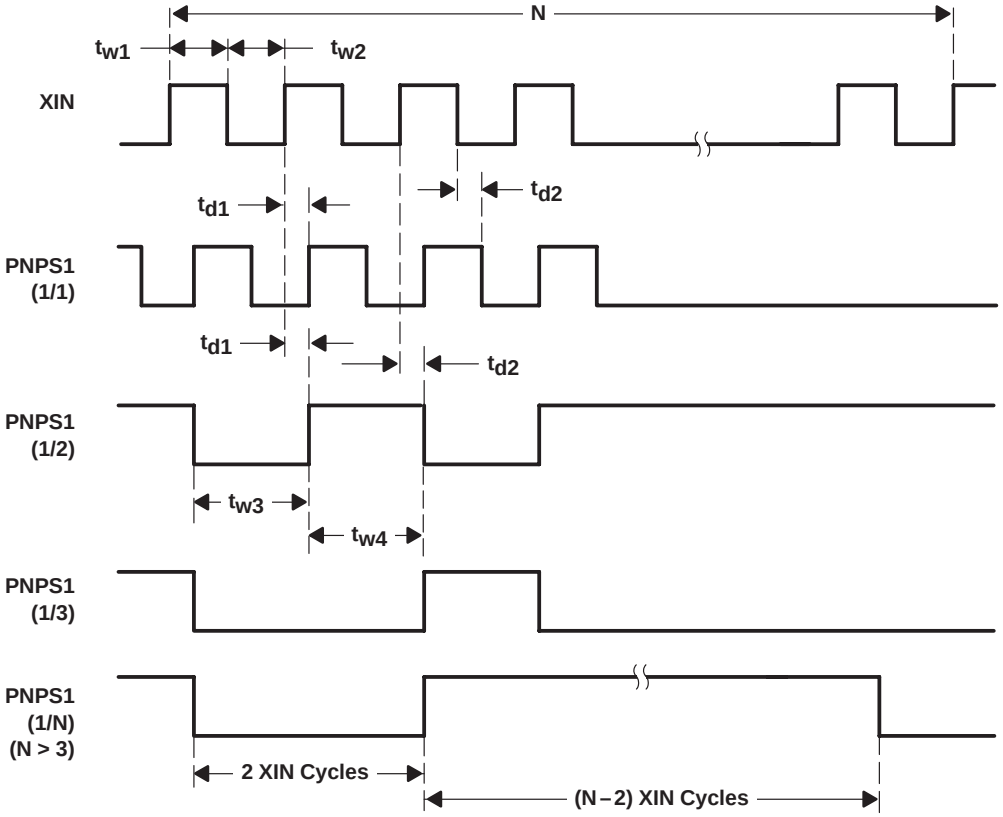
PARAMETER		ALTERNATE SYMBOL	TEST CONDITIONS	MIN	MAX	UNIT
t_{d12}	Delay time, initial write (IRQx) to transmit start (SOUT)	t_{IRS}		8	26	baudout cycles
t_{d13}	Delay time, start (SOUT) to INTRPT (IRQx)	t_{STI}		8	10	baudout cycles
t_{d14}	Delay time, $\overline{IOW}$ (WR THR) to reset INTRPT (IRQx)	t_{HR}	C_L = 75 pF		50	ns
t_{d15}	Delay time, initial write ($\overline{IOW}$) to INTRPT (THRE†) (IRQx)	t_{SI}		16	34	baudout cycles
t_{d16}	Delay time, read IIR† ($\overline{IOR}$) to reset INTRPT (THRE†) (IRQx)	t_{IR}	C_L = 75 pF		35	ns

† THRE = transmitter holding register empty; IIR = interrupt identification register.

modem control switching characteristics over recommended ranges of supply voltage and operating free-air temperature, C_L = 75 pF

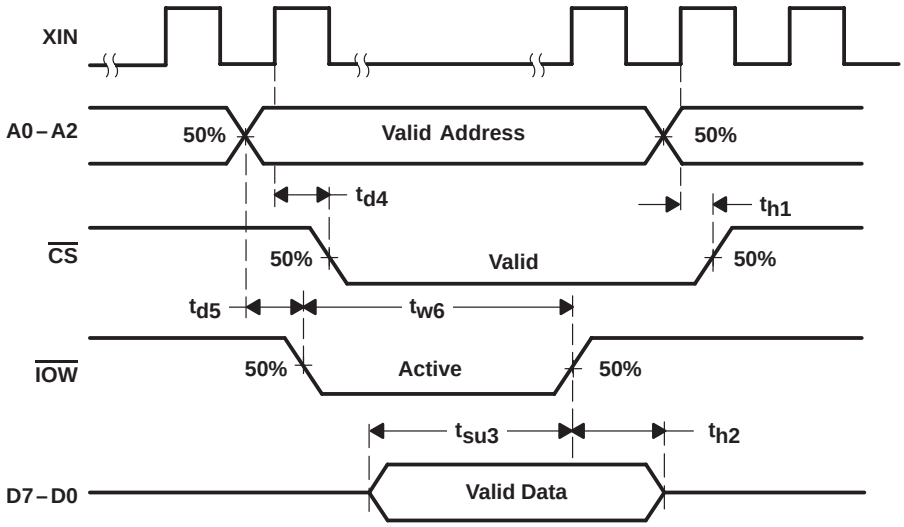
PARAMETER		ALTERNATE SYMBOL	FIGURE	MIN	MAX	UNIT
t_{d17}	Delay time, WR MCR ($\overline{IOW}$) to output ($\overline{RTS}$, $\overline{DTS}$)	t_{MDO}	Figure 13		50	ns
t_{d18}	Delay time, modem interrupt ($\overline{CTS}$, $\overline{DSR}$, $\overline{DCD}$/$\overline{RI}$) to set INTRPT (IRQx)	t_{SIM}	Figure 13		35	ns
t_{d19}	Delay time, RD MSR ($\overline{IOR}$) to reset INTRPT (IRQx)	t_{RIM}	Figure 13		40	ns
t_{d20}	Delay time, $\overline{CTS}$ low to SOUT↓		Figure 14		24	baudout cycles
t_{d21}	Delay time, receiver threshold byte (SIN) to $\overline{RTS}$↑		Figure 15		3	baudout cycles
t_{d22}	Delay time, read of last byte in receiver FIFO ($\overline{IOR}$) to $\overline{RTS}$↓		Figure 15		3	baudout cycles
t_{d23}	Delay time, first data bit of 16th character (SIN) to $\overline{RTS}$↑		Figure 16		3	baudout cycles
t_{d24}	Delay time, RD RBR ($\overline{IOR}$) ↓ to $\overline{RTS}$↓		Figure 16		3	baudout cycles

PARAMETER MEASUREMENT INFORMATION



NOTE A: When $\overline{\text{PNPBYPASS}}$ = 0, the PNPS1 terminal is acting as the $\overline{\text{BAUDOUT}}$. The above timing assumes that the prescalar value is one.

Figure 5. Baud Generator Timing Waveforms



NOTE A: The above timing assumes that AEN = 0.

Figure 6. Write Cycle Timing Waveforms

PARAMETER MEASUREMENT INFORMATION

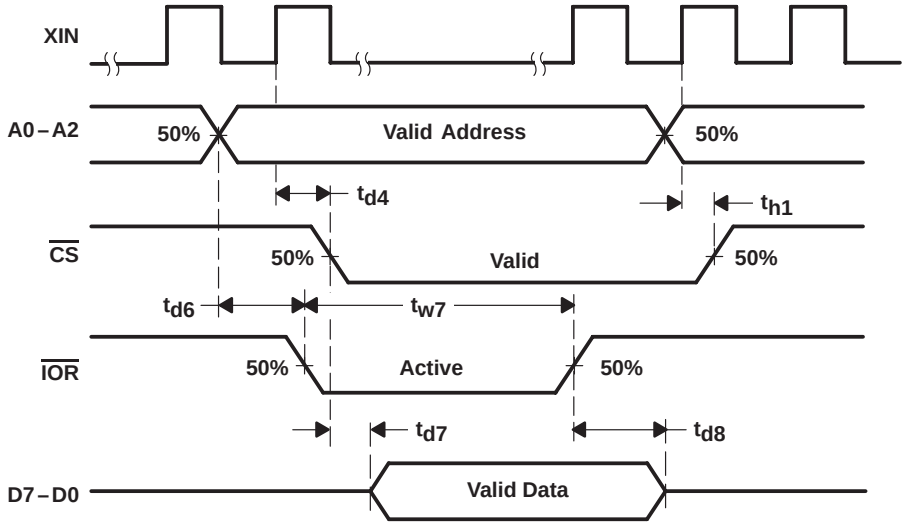


Figure 7. Read Cycle Timing Waveforms

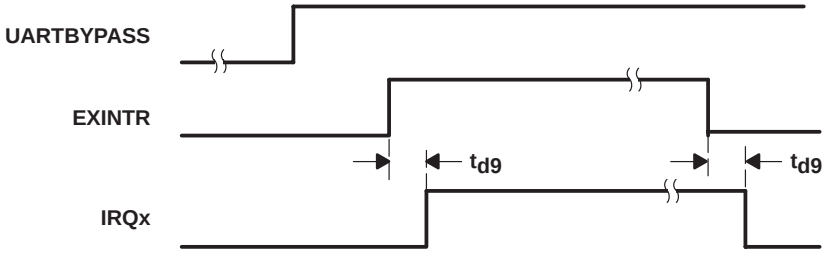
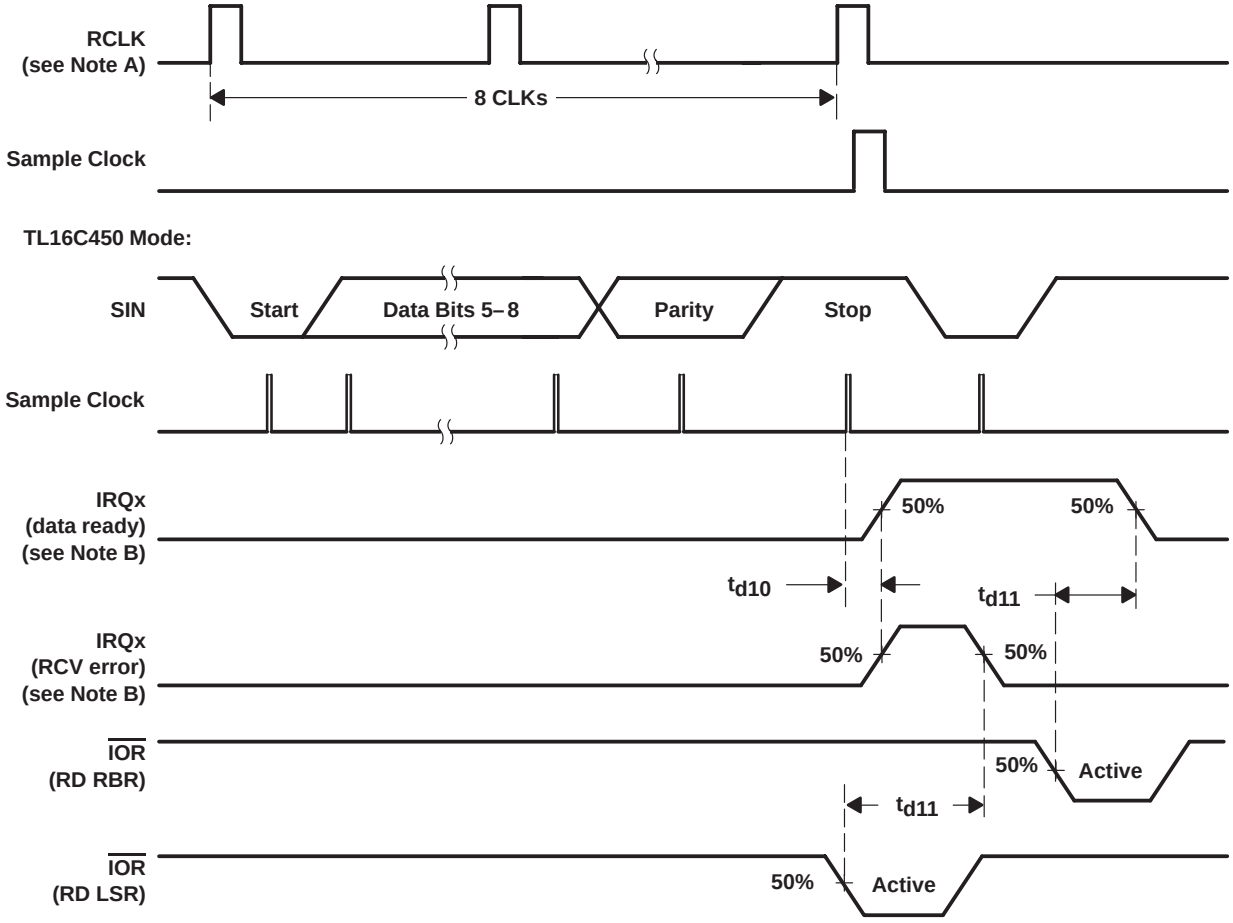


Figure 8. External Interrupt (EXINTR) Timing Waveforms

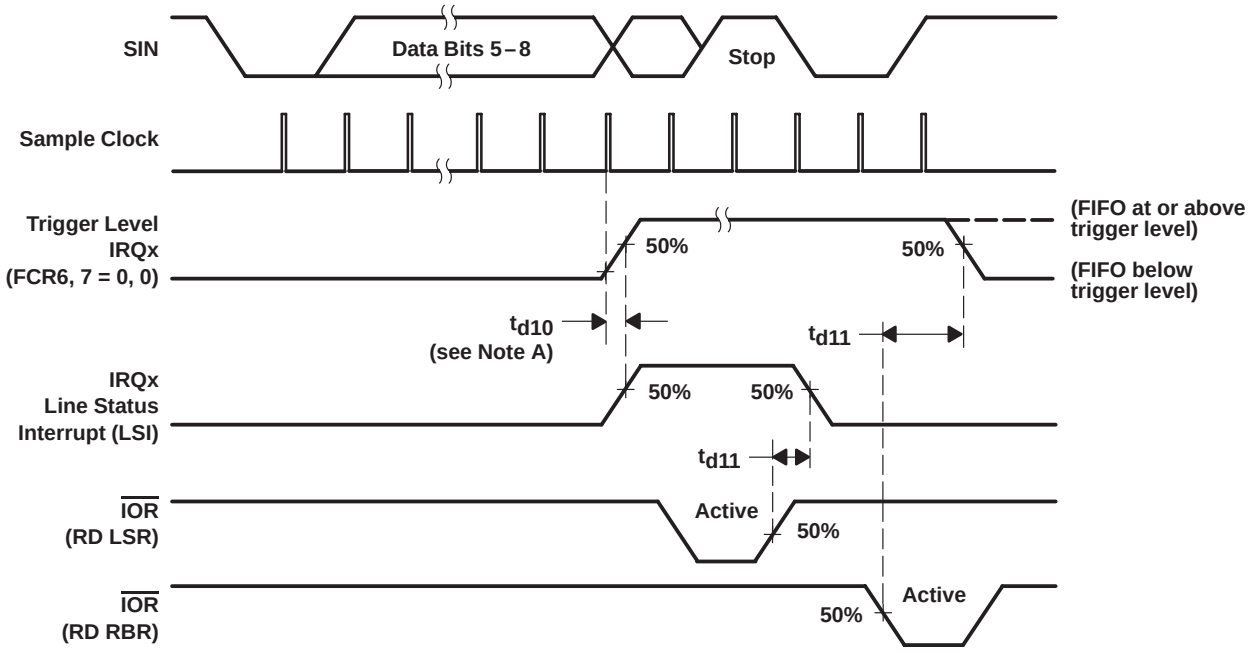
PARAMETER MEASUREMENT INFORMATION



NOTES: A. RCLK is the internal receiver clock.
B. X = 3–5, 7–12, 15

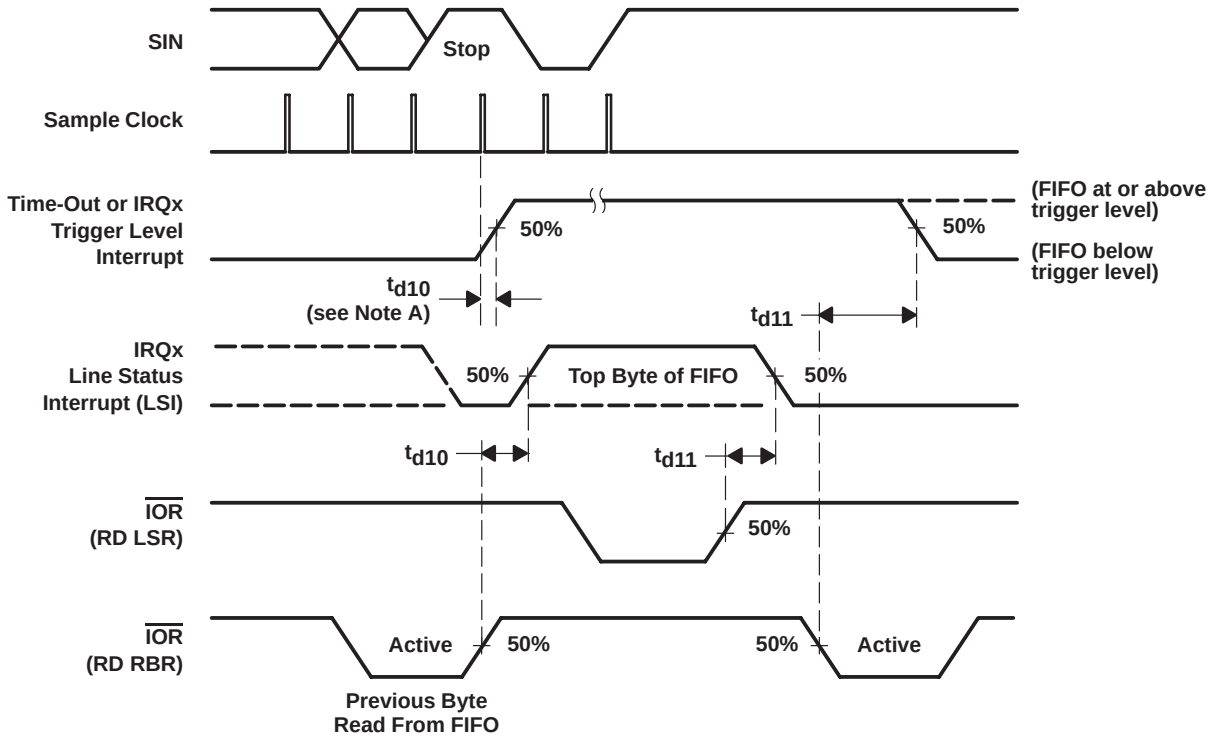
Figure 9. Receiver Timing Waveforms

PARAMETER MEASUREMENT INFORMATION



NOTE A: For a time-out interrupt, t_{d10} = 9 RCLKs.

Figure 10. Receive FIFO First Byte (Sets DR Bit) Waveforms



NOTE A: For a time-out interrupt, t_{d10} = 9 RCLKs.

Figure 11. Receive FIFO Bytes Other Than the First Byte (DR Internal Bit Already Set) Waveforms

PARAMETER MEASUREMENT INFORMATION

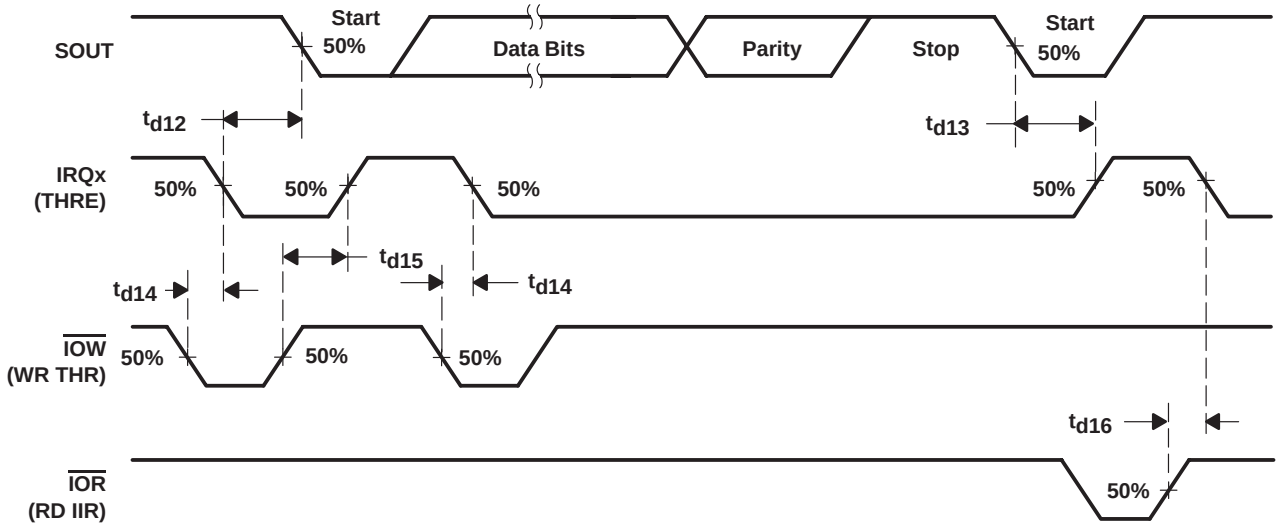


Figure 12. Transmitter Timing Waveforms

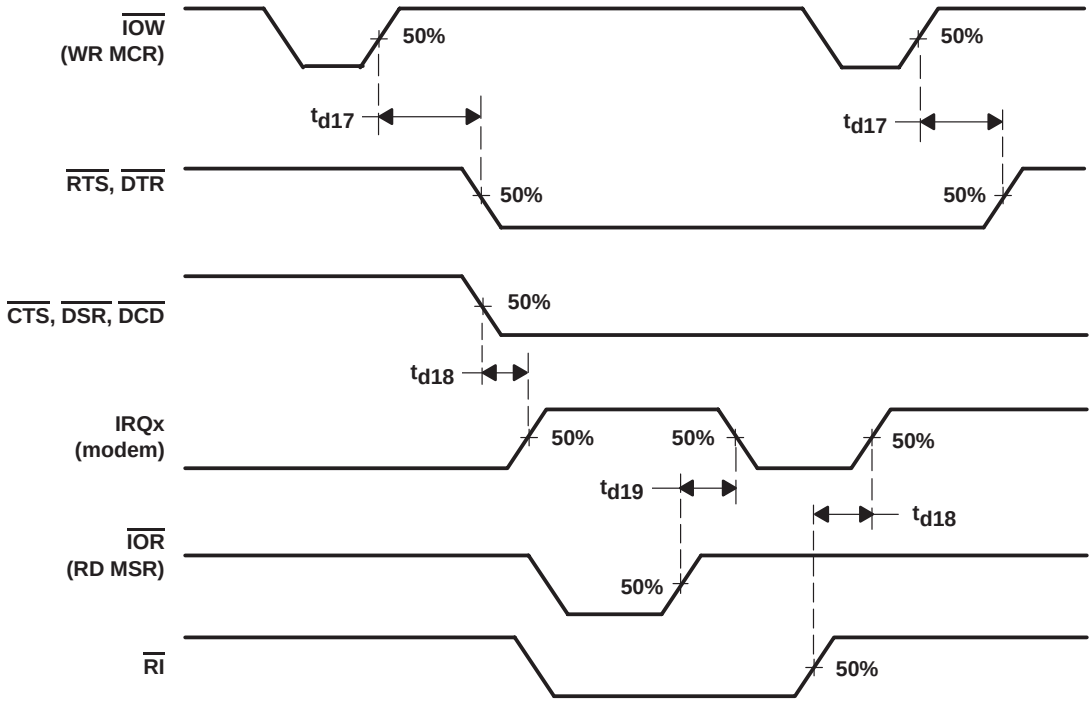


Figure 13. Modem Control Timing Waveforms

PARAMETER MEASUREMENT INFORMATION

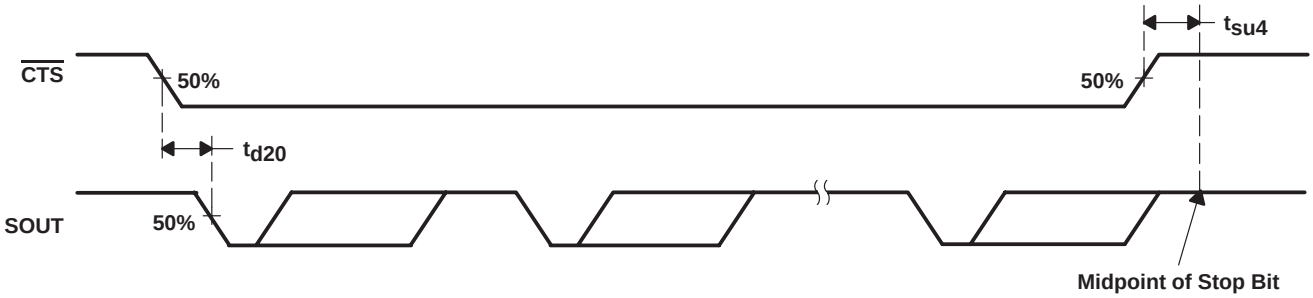


Figure 14. $\overline{CTS}$ and SOUT Autoflow Control Timing (Start and Stop) Waveforms

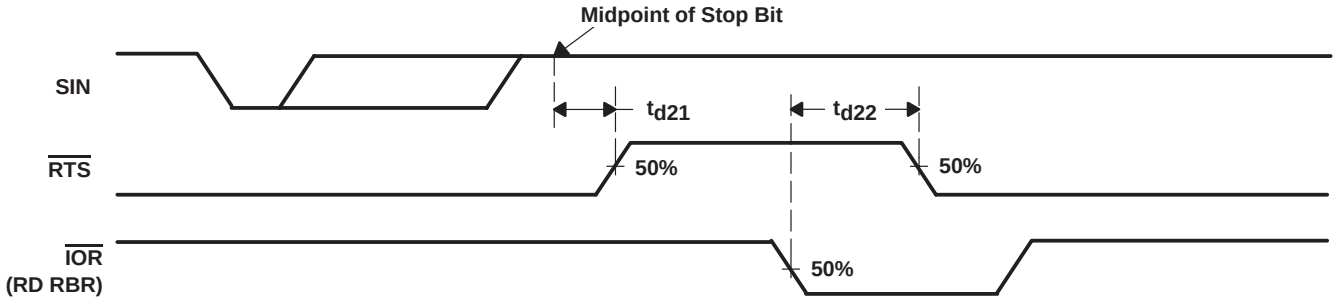


Figure 15. Auto-RTS Timing for Receiver Threshold of 1, 4, or 8 Waveforms

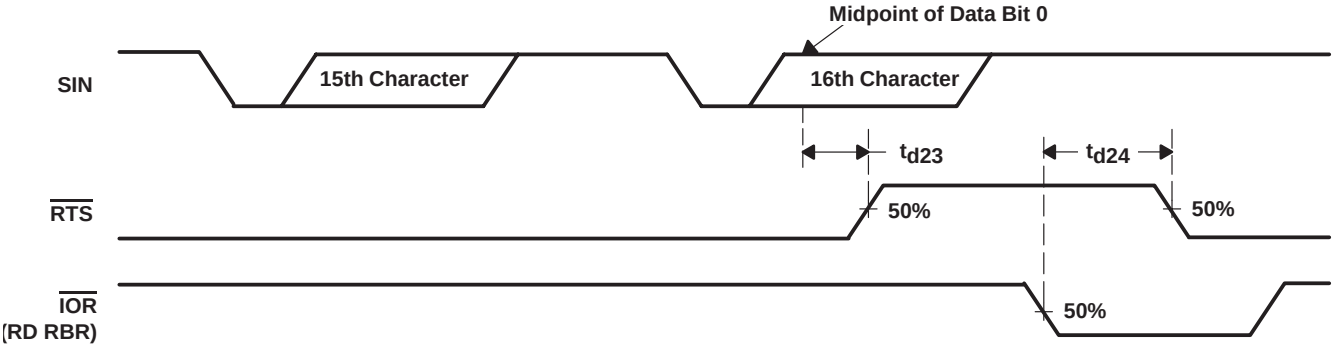


Figure 16. Auto-RTS Timing for Receiver Threshold of 14 Waveforms

PRINCIPLES OF OPERATION

The TL16PNP550A architecture (see functional block diagram) has been designed, so that it can be configured in various operational modes. These modes are described in the Table 1.

Table 1. TL16PNP550A Operational Modes†

MODE DESCRIPTION	UARTBYPASS TERMINAL	$\overline{\text{PNPBYPASS}}$ TERMINAL	ICONFIG<3:0> TERMINAL	ACONFIG <1:0> TERMINAL
PnP controller and logical device (ACE)	0	1	X	X
Stand-alone PnP Controller	1	1	X	X
ACE TL16C550C only	0	0	Active	Active
Manufacturer test mode‡	1	0	X	X

† X = irrelevant, 0 = low level, 1 = high level
‡ During manufacturer test mode, the oscillator clock is disabled. This mode is used by the manufacturer for test only.

Connecting the $\overline{\text{PNPBYPASS}}$ terminal to V_{CC} enables the PnP autoconfiguration sequence. When PnP is enabled, the ACONFIG<1:0> and ICONFIG<3:0> are irrelevant and should be tied to GND or V_{CC}.

In the stand-alone PnP controller mode, the controller responds to the autoconfiguration sequence and supports one logical device, one I/O address, one interrupt, and no DMA. The address decoder only decodes eight contiguous locations. During this mode, the UART is disabled and $\overline{\text{CS}}$ and EXINTR terminals become active. The UART input terminals should be tied to either V_{CC} or GND to avoid floating input terminals.

When PnP is disabled or bypassed, the $\overline{\text{PNPBYPASS}}$ terminal is tied to GND and the configuration in Table 2 applies.

Table 2. PnP Disabled or Bypassed Configuration

ACONFIG<1:0>	COM	I/O BASE ADDRESS
00	COM1	3F8–3FF
01	COM2	2F8–2FF
10	COM3	3E8–3EF
11	COM4	2E8–2EF

The decimal value X of ICONFIG<3:0> content enables the corresponding IRQx. For example, ICONFIG<3:0> = 0011 enables IRQ3 (Table 3).

Table 3. ICONFIG to IRQx

ICONFIG	IRQx	ICONFIG	IRQx
0000	N/A	1000	N/A
0001	N/A	1001	IRQ9
0010	N/A	1010	IRQ10
0011	IRQ3	1011	IRQ11
0100	IRQ4	1100	IRQ12
0101	IRQ5	1101	N/A
0110	IRQ6	1110	N/A
0111	IRQ7	1111	IRQ15

PRINCIPLES OF OPERATION

PnP card configuration sequence

The PnP logic is quiescent on power up and must be enabled by software. The following sequence configures the PnP card:

1. The initiation key places the PnP logic into configuration mode through a series of predefined writes to the ADDRESS port (see autoconfiguration ports section).
2. A serial identifier is accessed bit serially and isolates the Industry Standard Architecture (ISA) cards. Seventy-two READ_DATA port reads are required to isolate each card.
3. Once isolated, a card is assigned a handle [card select number (CSN)] that later selects the card. This assignment is accomplished by programming the CSN.
4. The PnP software then reads the resource data structure on each card. When all resource capabilities and demands are known, a process of resource arbitration is invoked to determine resource allocation for each card.
5. All PnP cards are then activated and removed from the configuration mode. This activation is accomplished by programming the ACTIVE register.

PnP autoconfiguration ports

Three 8-bit ports (see Table 4) are used by the software to access the configuration space on each PnP ISA card. These registers are used by the PnP software to issue commands, check status, access the resource data information, and configure the PnP hardware.

The ports have been chosen so as to avoid conflicts in the installed base of ISA functions, while at the same time minimizing the number of ports needed in the ISA I/O space.

Table 4. Autoconfiguration Ports

PORT NAME	LOCATION	TYPE
ADDRESS	0×0279 (printer status port)	Write only
WRITE_DATA	0×0A79 (printer status port + 0×0800)	Write only
READ_DATA	Relocatable in range 0×0203 to 0×03FF	Read only

The PnP registers are accessed by first writing the address of the desired register to the ADDRESS port, followed by a read of data from the READ_DATA port, or a write of data to the WRITE_DATA port. Once addressed, the desired register may be accessed using the WRITE_DATA or READ_DATA ports.

The ADDRESS port is also the destination of the initiation key writes.

The address of the READ_DATA port is set by programming the SET RD_DATA PORT register. If a card cannot be isolated for a given READ_DATA port address, the READ_DATA port address is in conflict. The READ_DATA port address must then be relocated and the isolation process begun again. The entire range between 0×0203 and 0×3FF is available; however, in practice it is expected that only a few address locations are necessary before the software determines that no PnP cards are present

PRINCIPLES OF OPERATION

PnP registers

PnP card standard registers are divided into three parts: card control, logical device control, and logical device configuration. There is exactly one of each card control register on each ISA card. Card control registers are used for global functions that control the entire card (see Table 5). Logical device control registers and logical device configuration registers are repeated for each logical device. Since the TL16PNP550A has one logical device (ACE) and it is intended only for I/O applications, not all the configuration registers are implemented.

Table 5. PnP Card Control Registers

ADDRESS PORT VALUE	REGISTER NAME VALUE	READ/WRITE CAPABILITY	POWER UP
0×00	SET RD_DATA PORT	Write only	00 00 00 00
	Writing to this location modifies the address port used for reading from the PnP ISA card. Writing to this register is only allowed when the card is in the isolation state. Bit<7:0> Become I/O port address bits [9:2].		
0×01	SERIAL ISOLATION	Read only	00 00 00 00
	A read to this register causes a card in the isolation state to compare one bit of the board ID.		
0×02	CONFIGURATION CONTROL	Write only	0 00
	This 3-bit register consists of three independent commands, which are activated by setting their corresponding register bits. These bits are automatically cleared by the hardware after the commands execute. Bit<2> Setting this bit causes the card to clear its CSN and RD DATA port. Bit<1> Setting this bit causes the card to enter the wait for key state, but the card CSN is preserved and the logical device (ACE) is unaffected. Bit<0> Setting this bit resets the logical device (ACE) configuration registers to their default state and the CSN is preserved.		
0×03	WAKE[CSN]	Write only	00 00 00 00
	A write to this register, if the write data [7:0] matches the card CSN, causes the card to go from the sleep state to either the isolation state, if the write data for this command is zero, or the configuration state if the write data is not zero. The pointer to the SERIAL IDENTIFIER is reset. This register is write only.		
0×04	RESOURCE DATA	Read only	00 00 00 00
	A read from this address reads the next byte of resource information from the EPROM. The STATUS register must be polled until its bit<0> is set, before this register may be read.		
0×05	STATUS	Read only	0
	Bit<0> A 1-bit register that when set, indicates it is okay to read the next data byte from the RESOURCE DATA register.		
0×06	CARD SELECT NUMBER	Read/write	00 00 00 00
	A write to this address sets a card CSN, which is uniquely assigned to this card after the serial identification process, so each card may be individually selected during a WAKE [CSN] command.		
0×07	LOGICAL DEVICE NUMBER	Read	00 00 00 00
	This register has a read-only value of 0×00, since the card has only 1 logical device.		

PRINCIPLES OF OPERATION

PnP logical device control registers

The following registers are repeated for each logical device. These registers control device functions, such as enabling the device onto the ISA bus (see Table 6).

Table 6. PnP Logical Device Control Registers

ADDRESS PORT VALUE	REGISTER NAME VALUE	READ/WRITE CAPABILITY	POWER UP
0×30	ACTIVE	Read/write	00 00 00 00
	This register controls whether the logical device is active on the bus. Bit<7:1> Reserved and must be cleared. Bit<0> When set, activates the logical device. An inactive device does not respond to nor drive any ISA bus signals. Before a logical device is activated, I/O range check must be disabled.		
0×31	I/O RANGE CHECK	Read/write	00 00 00 00
	This register performs a conflict check on the I/O port range programmed for use by the logical device. Bit<7:2> Reserved and must be cleared. Bit<1> When set, I/O range check is enabled. I/O range check is only valid, when the logical device is inactive. Bit<0> When set, the logical device (an ACE in this case) responds to I/O reads of the logical device (ACE) assigned I/O range with a 0×55 when I/O range check is in operation. When clear, the logical device responds with a 0×AA. This register is read/write.		

PnP logical device configuration registers

These registers program the device ISA bus resource use (see Table 7).

Table 7. PnP Logical Device Configuration Registers

ADDRESS PORT VALUE	REGISTER NAME VALUE	READ/WRITE CAPABILITY	POWER UP
0×60	I/O PORT BASE ADDRESS [15:8]	Read/write	00
	This register indicates the selected I/O upper limit address bits [15:8] for I/O descriptor 0. When the device is activated, if there is an address match to register 0×61 and an address match to this register, a chip select is generated. Bit<7:2> Bits 15–10 are not supported, since the logical device uses 10-bit address decoding. Bit<1:0> Indicates address bits 9 and 8.		
0×61	I/O PORT BASE ADDRESS [7:0]	Read/write	00 00 00 00
	This register indicates the selected I/O lower limit address bits [7:0] for I/O descriptor 0. When the device is activated, if there is an address match to register 0×60 and an address match to this register, a chip select is generated. Bit<2:0> Are not supported since the logical device has eight registers. Bit<7:3> Indicates address bits 7–3.		
0×70	INTERRUPT REQUEST LEVEL SELECT	Read/write	00 00
	This register indicates the selected interrupt level. Bit<3:0> Select the interrupt level. This device uses 10 interrupts from IRQ2 to IRQ7 and IRQ9 to IRQ12.		
0×71	INTERRUPT REQUEST TYPE	Read	00 00 00 11
	This register indicates which type of interrupt is used for the selected interrupt level. Bit<7:2> Are reserved. Bit<1> Is set to indicate active high. Bit<0> Is set to indicate level sensitive.		
0×74	DMA CHANNEL SELECT 0	Read only	00 00 01 00
	This register has a value of 4 to indicate that DMA is not supported.		
0×75	DMA CHANNEL SELECT 1	Read only	00 00 01 00
	This register has a value of 4 to indicate that DMA is not supported.		

PRINCIPLES OF OPERATION

PnP terminal states

Terminals PNPS1 and PNPS0 reflect the states of PnP logic when $\overline{\text{PNPBYPASS}}$ is set (see Table 8).

Table 8. PNPx Terminal States

PNPS1	PNPS0	PnP STATE
0	0	WAIT FOR KEY
0	1	SLEEP
1	0	ISOLATION
1	1	CONFIGURATION

If the device leaves the wait-for-key state, it means the device is in configuration mode.

Please note, when $\overline{\text{PNPBYPASS}}$ = 0, $\overline{\text{BAUDOUT}}$ is monitored using PNPS1 and $\overline{\text{RXRDY}}$ is monitored using PNPS0.

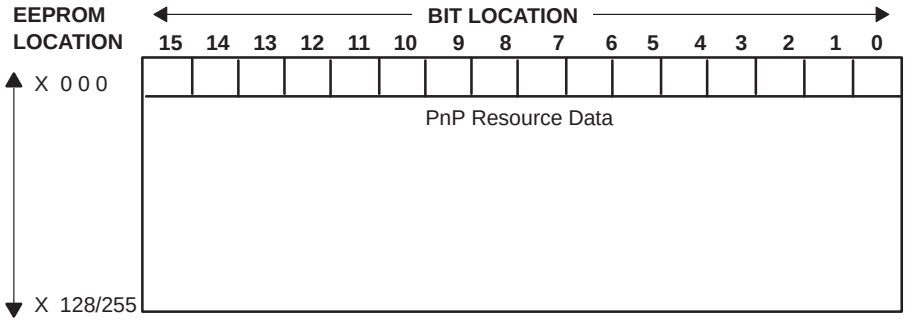
EEPROM

The TL16PNP550A has been designed to interface with the ST93C56/66 EEPROM (SGS-Thomson) or equivalent. The EEPROM provides the clock prescalar divisor and PnP resource data.

memory organization

The EEPROM should be organized as 128/255 words times 16 bits, so its ORG terminal should be connected to V_{CC} or left unconnected. The EEPROM memory organization is shown in Table 9.

Table 9. EEPROM Memory Organization



PRINCIPLES OF OPERATION

clock prescalar

The TL16PNP550A includes a clock prescalar block. The block takes the 22-MHz input clock and divides it by a divisor read from the EEPROM at address zero. After reset, the device reads the EEPROM content at address zero. The 2 most significant data bits of the word (2 bytes) define the divisor value as show in Table 10.

Table 10. Default Deviser Value

EEPROM LOCATION 000 (BITS 15 AND 14)	DIVISOR VALUE
00	12
01	6
10	3
11	1 (default)

The device monitors the EEPROM to check whether the divisor value has been updated or not. Read the EEPROM interface section for more details in this mode. Note the EEPROM address location zero is reserved for the divisor value.

$\overline{\text{EEPROM}}$ signal description (see Figure 17)

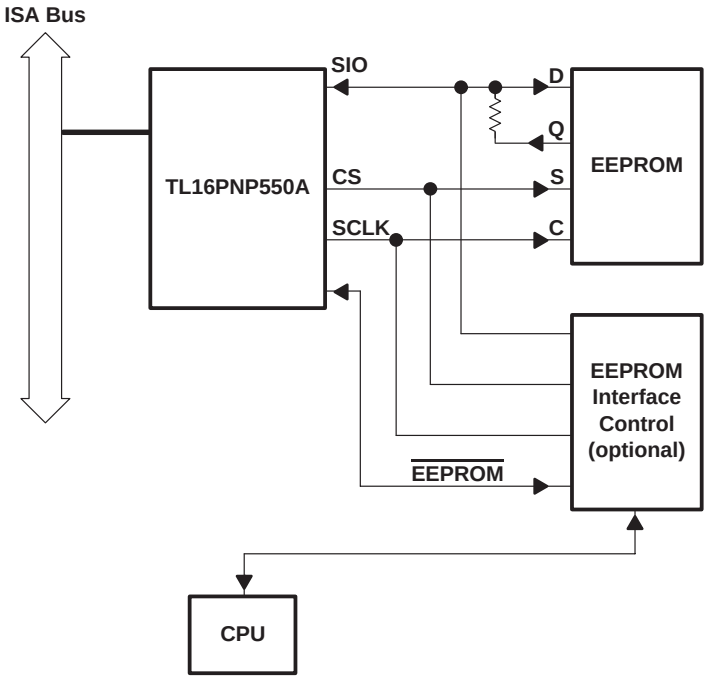


1. During and after reset, the TL16PNP550A gains access to EEPROM interface by asserting $\overline{\text{EEPROM}}$ (low). The device reads the prescalar divisor value from address zero. After it receives the WAKE command, the device starts receiving PnP resource data from address location 00x01H.
2. After the device is configured and leaves the configuration mode (the device is activated and it is in the wait for key state), the TL16PNP550A releases the EEPROM interface by releasing signals $\overline{\text{EEPROM}}$, SCLK, SIO, and CS.
3. The on-board controller is accessing the EEPROM.
4. The TL16PNP550A assumes the prescalar divisor value has been updated.
5. The TL16PNP550A accesses the EEPROM by asserting $\overline{\text{EEPROM}}$ signal. It reads location 00 and updates the prescalar divisor.
6. The TL16PNP550A releases the $\overline{\text{EEPROM}}$ signal and SCLK, CS and SIO signals.

If the device enters the configuration mode again (leaves the wait for key state), it gains access directly to the EEPROM after the $\overline{\text{EEPROM}}$ signal is released.

If the $\overline{\text{EEPROM}}$ is driven by an on-board controller and the TL16PNP550A enters the configuration mode, it is highly recommended that the controller release the $\overline{\text{EEPROM}}$ signal to allow the TL16PNP550A to gain control of $\overline{\text{EEPROM}}$. It is possible to deactivate and reconfigure the TL16PNP550A when it enters the configuration mode. PNPS0 and PNPS1 terminals inform the controller when the TL16PNP550A enters the configuration mode.

PRINCIPLES OF OPERATION



NOTE A: It is recommended that a 2-kΩ resistor be connected between D and Q terminals.

Figure 17. TL16PNP550A and EEPROM Interface

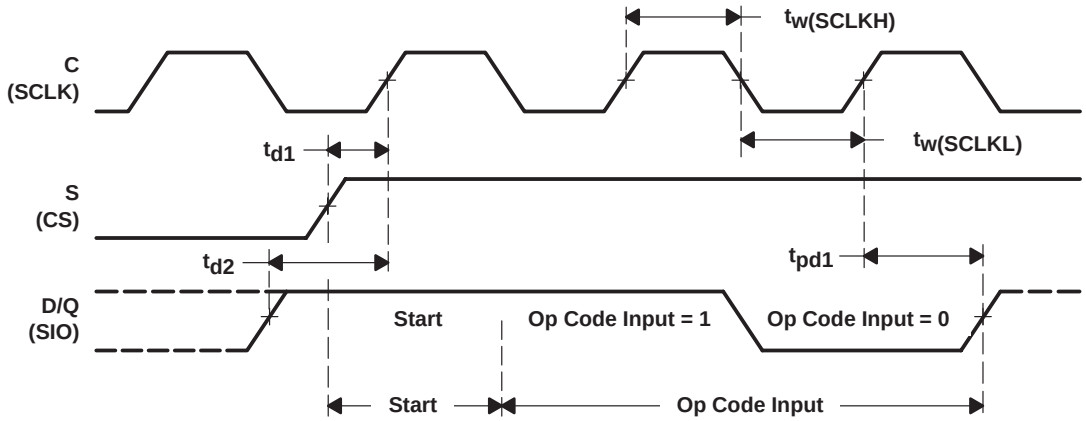
EEPROM READ

The TL16PNP550A only supports read transactions. The READ op code instruction (10) must be sent into the EEPROM. The op code is then followed by an address for the 16-bit word, which is 8-bits long . The READ op code with accompanying address directs the EEPROM to output serial data on the EEPROM data terminal D/Q which is connected to the TL16PNP550A bidirectional serial data bus (SIO). Specifically, when a READ op code and address are received, the instruction and address are decoded and the addressed EEPROM data is transferred into an output shift register in the EEPROM. Each read transaction consists of a start bit, 2-bit op code (10), 8-bit address, and 16-bit data. The TL16PNP550A does not accommodate the EEPROM auto-address next word feature.

PRINCIPLES OF OPERATION

READ op code transfer (see Figure 18)

Initially, the EEPROM chip select signal, S, which is connected to the TL16PNP550A EEPROM chip select (CS), is raised. The EEPROM data, D/Q then samples the TL16PNP550A (SIO) line on the following rising edges of the TL16PNP550A clock (SCLK), until a 1 is sampled and decoded by the EEPROM as a start bit. The TL16PNP550A (SCLK) signal is connected to the EEPROM clock, C. The READ op code (10) is then sampled on the next two rising edges of SCLK. TL16PNP550A sources the op code at the falling edges of SCLK.

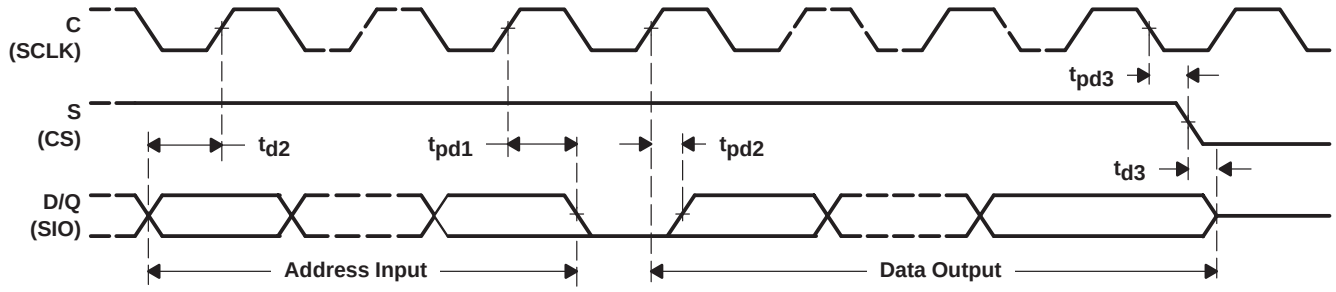


NOTE A: The corresponding TL16PNP550A terminal names are provided in parentheses. D/Q indicates that D and Q terminals in the EEPROMs are tied together with a 2-kΩ resistor.

Figure 18. READ Op Code Transfer Waveforms

READ address and data transfer (see Figure 19)

After receiving the READ op code, the EEPROM samples the READ address on the next eight rising edges of (SCLK). The device sources the address at the falling edge of SCLK. The EEPROM then sends out a dummy 0 bit on the D/Q line, which is followed by the 16-bit data word with the MSB first. Output data changes are triggered by the rising edges of SCLK. The data is also read by the TL16PNP550A on the rising edges of SCLK.



NOTE A: The corresponding terminal names are provided in parentheses. D/Q indicates that D and Q terminals in the EEPROMs are tied together with a 2-kΩ resistor.

Figure 19. READ Address and Data Transfer Waveforms

PRINCIPLES OF OPERATION

Table 11. ACE Register Selection

DLAB†	A2	A1	A0	REGISTER
0	L	L	L	Receiver buffer (read), transmitter holding register (write)
0	L	L	H	Interrupt enable
X	L	H	L	Interrupt identification (read only)
X	L	H	L	FIFO control (write)
X	L	H	H	Line control
X	H	L	L	Modem control
X	H	L	H	Line status
X	H	H	L	Modem status
X	H	H	H	Scratch
1	L	L	L	Divisor latch (LSB)
1	L	L	H	Divisor latch (MSB)

† The divisor latch access bit (DLAB) is the most significant bit of the line control register. The DLAB signal is controlled by writing to this bit location (see Table 13).

Table 12. ACE Reset Functions

REGISTER/SIGNAL	RESET CONTROL	RESET STATE
Interrupt Enable Register	Master Reset	All bits cleared (0–3 forced and 4–7 permanent)
Interrupt Identification Register	Master Reset	Bit 0 is set, bits 1–3, 6, 7 are cleared, and bits 4–5 are permanently cleared
FIFO Control Register	Master Reset	All bits cleared
Line Control Register	Master Reset	All bits cleared
Modem Control Register	Master Reset	All bits cleared (6–7 permanent)
Line Status Register	Master Reset	Bits 5 and 6 are set, all other bits are cleared
Modem Status Register	Master Reset	Bits 0–3 are cleared, bits 4–7 are input signals
SOUT	Master Reset	High
INTRPT (receiver error flag)	Read LSR/MR	Low
INTRPT (received data available)	Read RBR/MR	Low
INTRPT (transmitter holding register empty)	Read IR/Write THR/MR	Low
INTRPT (modem status changes)	Read MSR/MR	Low
$\overline{\text{RTS}}$	Master Reset	High
$\overline{\text{DTR}}$	Master Reset	High
Scratch Register	Master Reset	No effect
Divisor Latch (LSB and MSB) Registers	Master Reset	No effect
Receiver Buffer Registers	Master Reset	No effect
Transmitter Holding Register	Master Reset	No effect
Receiver FIFO	MR/FCR1–FCR0/ ΔFCR0	All bits cleared
XMIT FIFO	MR/FCR2–FCR0/ ΔFCR0	All bits cleared

PRINCIPLES OF OPERATION

accessible registers

The system programmer, using the CPU, has access to and control over any of the ACE registers. These registers control ACE operations, receive data, and transmit data. Descriptions of these registers follow in Table 13.

Table 13. Summary of Accessible Registers

Bit No.	REGISTER ADDRESS											
	0 DLAB = 0	0 DLAB = 0	1 DLAB = 0	2	2	3	4	5	6	7	0 DLAB = 1	1 DLAB = 1
	Receiver Buffer Register (Read Only)	Transmitter Holding Register (Write Only)	Interrupt Enable Register	Interrupt Ident. Register (Read Only)	FIFO Control Register (Write Only)	Line Control Register	Modem Control Register	Line Status Register	Modem Status Register	Scratch Register	Divisor Latch (LSB)	Latch (MSB)
	RBR	THR	IER	IIR	FCR	LCR	MCR	LSR	MSR	SCR	DLL	DLM
0	Data Bit 0†	Data Bit 0	Enable Received Data Available Interrupt (ERBI)	0 If Interrupt Pending	FIFO Enable	Word Length Select Bit 0 (WLS0)	Data Terminal Ready (DTR)	Data Ready (DR)	Delta Clear to Send (ΔCTS)	Bit 0	Bit 0	Bit 8
1	Data Bit 1	Data Bit 1	Enable Transmitter Holding Register Empty Interrupt (ETBEI)	Interrupt ID Bit 1	Receiver FIFO Reset	Word Length Select Bit 1 (WLS1)	Request to Send (RTS)	Overrun Error (OE)	Delta Data Set Ready (ΔDSR)	Bit 1	Bit 1	Bit 9
2	Data Bit 2	Data Bit 2	Enable Receiver Line Status Interrupt (ELSI)	Interrupt ID Bit 2	Transmitter FIFO Reset	Number of Stop Bits (STB)	OUT1	Parity Error (PE)	Trailing Edge of Ring Indicator (TERI)	Bit 2	Bit 2	Bit 10
3	Data Bit 3	Data Bit 3	Enable Modem Status Interrupt (EDSSI)	Interrupt ID Bit 3‡	Reserved	Parity Enable (PEN)	OUT2 UART Interrupt Enable§	Framing Error (FE)	Delta Data Carrier Detect (ΔDCD)	Bit 3	Bit 3	Bit 11
4	Data Bit 4	Data Bit 4	0	0	Reserved	Even Parity Select (EPS)	Loop	Break Interrupt (BI)	Clear to Send (CTS)	Bit 4	Bit 4	Bit 12
5	Data Bit 5	Data Bit 5	0	0	Reserved	Stick Parity	Flow Control Enable (AUTO)	Transmitter Holding Register (THRE)	Data Set Ready (DSR)	Bit 5	Bit 5	Bit 13
6	Data Bit 6	Data Bit 6	0	FIFOs Enabled‡	Receiver Trigger (LSB)	Break Control	0	Transmitter Empty (TEMT)	Ring Indicator (RI)	Bit 6	Bit 6	Bit 14
7	Data Bit 7	Data Bit 7	0	FIFOs Enabled‡	Receiver Trigger (MSB)	Divisor Latch Access Bit (DLAB)	0	Error in Receiver FIFO (see Note 6)	Data Carrier Detect (DCD)	Bit 7	Bit 7	Bit 15

† Bit 0 is the least significant bit. It is the first bit serially transmitted or received.
‡ These bits are always 0 in the TL16C450 mode.
§ By setting this bit high in PNPBYPASS mode, the selected interrupt (IRQx) is enabled, otherwise, IRQx output is in the high-impedance state.

PRINCIPLES OF OPERATION

FIFO control register (FCR)

The FCR is a write-only register at the same location as the IIR, which is a read-only register. The FCR enables the FIFOs, clears the FIFOs, sets the receiver FIFO trigger level, and selects the type of DMA signaling.

- Bit 0: FCR0, when set, enables the transmit and receive FIFOs. This bit must be set when other FCR bits are written to or they are not programmed. Changing this bit clears the FIFOs.
- Bit 1: FCR1, when set, clears all bytes in the receiver FIFO and resets its counter. The shift register is not cleared. The logic 1 that is written to this bit position is self clearing.
- Bit 2: FCR2, when set, clears all bytes in the transmit FIFO and resets its counter. The shift register is not cleared. The logic 1 that is written to this bit position is self clearing.
- Bits 3, 4, and 5: FCR3, FCR4, and FCR5 are reserved for future use.
- Bits 6 and 7: FCR6 and FCR7 set the trigger level for the receiver FIFO interrupt (see Table 14).

Table 14. Receiver FIFO Trigger Level

BIT 7	BIT 6	RECEIVER FIFO TRIGGER LEVEL (BYTES)
0	0	01
0	1	04
1	0	08
1	1	14

FIFO interrupt mode operation

When the receiver FIFO and receiver interrupts are enabled (FCR0 = 1, IER0 = 1, IER2 = 1), receiver interrupt occur as follows:

1. When the receiver FIFO reaches its programmed trigger level, the received data available interrupt is issued to the microprocessor and IIR (3–0) are set to the value 6 (to indicate received data available). The received data available interrupt is cleared and IIR (3–0) are set (no interrupt) when the FIFO drops below its programmed trigger level.
2. The data ready bit (LSR0) is set as soon as a character is transferred from the shift register to the receiver FIFO. It is cleared when the FIFO is empty.
3. The receiver line status interrupt (IIR = 0110h) has higher priority than the received data available (IIR = 0100h) interrupt.

PRINCIPLES OF OPERATION

FIFO interrupt mode operation (continued)

When the receiver FIFO and receiver interrupts are enabled, receiver FIFO time-out interrupt occurs as follows:

1. FIFO time-out interrupt occurs when the following conditions exist:
    a. At least one character is in the FIFO.
    b. The most recent serial character received is longer than the four previous continuous character times (if two stop bits are programmed, the second one is included in this time delay).
    c. The most recent microprocessor read of the FIFO is longer than four previous continuous character times. This causes a maximum character received to interrupt an issued delay of 160 ms at 300 baud with a 12-bit character.
2. Character times are calculated by using the internal receiver clock (RCLK) input for a clock signal (makes the delay proportional to the baud rate). The RCLK frequency equals the clock frequency generated by the prescalar block divided by the user-defined internal UART baud rate generator divisor.
3. When a time-out interrupt has occurred, it is cleared and the timer is reset when the microprocessor reads one character from the receiver FIFO.
4. When a time-out interrupt has not occurred, the time-out timer is reset after a new character is received or after the microprocessor reads the receiver FIFO.

When the transmit FIFO and transmitter interrupts are enabled (FCR0 = 1, IER1 = 1), transmit interrupts occur as follows:

1. The transmitter holding register empty interrupt [IIR (3–0) = 2] occurs when the transmit FIFO is empty. It is cleared [IIR (3–0) = 1] as soon as the THR is written to (1 to 16 characters may be written to the transmit FIFO while servicing this interrupt) or the IIR is read.
2. The transmitter FIFO empty indicator [LSR5 (THRE) = 1] is delayed one character time minus the last stop bit time when there have not been at least two bytes in the transmitter FIFO at the same time since the last time that THRE = 1. The first transmitter interrupt after changing FCR0 is immediate when it is enabled.

Character time-out and receiver FIFO trigger level interrupts have the same priority as the current received data available interrupt; transmit FIFO empty has the same priority as the current transmitter holding register empty interrupt.

FIFO polled mode operation

With FCR0 = 1 (transmitter and receiver FIFOs enabled), clearing IER0, IER1, IER2, IER3, or all four puts the ACE in the FIFO polled mode of operation. Since the receiver and transmitter are controlled separately, either one or both can be in the polled mode of operation.

In this mode, the user program checks receiver and transmitter status using the LSR.

- LSR0 is set as long as there is one byte in the receiver FIFO.
- LSR1 – LSR4 specify which error(s) have occurred. Character error status is handled the same way as when in the interrupt mode; the IIR is not affected since IER2 = 0.
- LSR5 indicates when the transmit FIFO is empty.
- LSR6 indicates that both the transmit FIFO and shift registers are empty.
- LSR7 indicates whether there are any errors in the receiver FIFO.

There is no trigger level reached or time-out condition indicated in the FIFO polled mode. However, the receiver and transmit FIFOs are still fully capable of holding characters.

PRINCIPLES OF OPERATION

interrupt enable register (IER)

The IER enables each of the five types of interrupts (refer to Table 15) and the internal INTRPT output signal in response to an interrupt generation. The IER can also disable the interrupt system by clearing bits 0 through 3. The contents of this register are summarized in Table 13 and are described in the following bulleted list.

- Bit 0: This bit, when set, enables the received data available interrupt.
- Bit 1: This bit, when set, enables the transmitter holding register empty interrupt.
- Bit 2: This bit, when set, enables the receiver line status interrupt.
- Bit 3: This bit, when set, enables the modem status interrupt.
- Bits 4 – 7: These bits in the IER are not used and are always cleared.

interrupt identification register (IIR)

The ACE has an on-chip interrupt generation and prioritization capability that permits a flexible interface with most popular microprocessors.

The ACE provides four prioritized levels of interrupts:

- Priority 1 – Receiver line status (highest priority)
- Priority 2 – Receiver data ready or receiver character time out
- Priority 3 – Transmitter holding register empty
- Priority 4 – Modem status (lowest priority)

When an interrupt is generated, the IIR indicates that an interrupt is pending and the type of that interrupt in its three least significant bits (bits 0, 1, and 2). The contents of this register are summarized in Table 13 and described in Table 15. Details on each bit are as follows:

- Bit 0: This bit can be used either in a hardwire prioritized, or polled interrupt system. When this bit is cleared, an interrupt is pending. When bit 0 is set, no interrupt is pending.
- Bits 1 and 2: These two bits identify the highest priority interrupt pending, as indicated in Table 15.
- Bit 3: This bit is always cleared in the TL16C450 mode. In FIFO mode, this bit is set with bit 2 to indicate that a time-out interrupt is pending.
- Bits 4 and 5: These two bits are not used and are always cleared.
- Bits 6 and 7: These two bits are always cleared in the TL16C450 mode. They are set when bit 0 of the FIFO control register is set.

PRINCIPLES OF OPERATION

interrupt identification register (IIR) (continued)

Table 15. Interrupt Control Functions

INTERRUPT IDENTIFICATION REGISTER				PRIORITY LEVEL	INTERRUPT TYPE	INTERRUPT SOURCE	INTERRUPT RESET METHOD
BIT 3	BIT 2	BIT 1	BIT 0				
0	0	0	1	None	None	None	None
0	1	1	0	1	Receiver line status	Overrun error, parity error, framing error or break interrupt	Reading the line status register
0	1	0	0	2	Received data available	Receiver data available in the TL16C450 mode or trigger level reached in the FIFO mode	Reading the receiver buffer register
1	1	0	0	2	Character time-out indication	No characters have been removed from or input to the receiver FIFO during the last four character times, and there is at least one character in it during this time	Reading the receiver buffer register
0	0	1	0	3	Transmitter holding register empty	Transmitter holding register empty	Reading the interrupt identification register (if source of interrupt) or writing into the transmitter holding register
0	0	0	0	4	Modem status	Clear to send, data set ready, ring indicator, or data carrier detect	Reading the modem status register

line control register (LCR)

The system programmer controls the format of the asynchronous data communication exchange through the LCR. In addition, the programmer is able to retrieve, inspect, and modify the contents of the LCR; this eliminates the need for separate storage of the line characteristics in system memory. The contents of this register are summarized in Table 13 and described in the following bulleted list.

- Bits 0 and 1: These two bits specify the number of bits in each transmitted or received serial character. These bits are encoded as shown in Table 16.

Table 16. Serial Character Word Length

BIT 1	BIT 0	WORD LENGTH
0	0	5 bits
0	1	6 bits
1	0	7 bits
1	1	8 bits

- Bit 2: This bit specifies either one, one and one-half, or two stop bits in each transmitted character. When bit 2 is cleared, one stop bit is generated in the data. When bit 2 is set, the number of stop bits generated is dependent on the word length selected with bits 0 and 1. The receiver clocks only the first stop bit, regardless of the number of stop bits selected. The number of stop bits generated, in relation to word length and bit 2, is shown in Table 17.

PRINCIPLES OF OPERATION

line control register (LCR) (continued)

Table 17. Number of Stop Bits Generated

BIT 2	WORD LENGTH SELECTED BY BITS 1 AND 2	NUMBER OF STOP BITS GENERATED
0	Any word length	1
1	5 bits	1 1/2
1	6 bits	2
1	7 bits	2
1	8 bits	2

- Bit 3: This bit is the parity enable bit. When bit 3 is set, a parity bit is generated in transmitted data between the last data word bit and the first stop bit. In received data, when bit 3 is set, parity is checked. When bit 3 is cleared, no parity is generated or checked.
- Bit 4: Bit 4 is the even parity select bit. When parity is enabled (bit 3 is set) and bit 4 is set, even parity (an even number of logic 1s in the data and parity bits) is selected. When parity is enabled and bit 4 is cleared, odd parity (an odd number of logic 1s) is selected.
- Bit 5: This bit is the stick parity bit. When bits 3, 4, and 5 are set, the parity bit is transmitted and checked as cleared. When bits 3 and 5 are set and bit 4 is cleared, the parity bit is transmitted and checked as set. When bit 5 is cleared, stick parity is disabled.
- Bit 6: This bit is the break control bit. Bit 6 is set to force a break condition; i.e., a condition where the serial output (SOUT) is forced to the spacing (low) state. When bit 6 is cleared, the break condition is disabled and has no affect on the transmitter logic; it only affects the serial output.
- Bit 7: This bit is the divisor latch access bit (DLAB). Bit 7 must be set to access the divisor latches of the baud generator during a read or write. Bit 7 must be cleared during a read or write to access the receiver buffer, the THR, or the IER.

line status register (LSR)†

The LSR provides information to the CPU concerning the status of data transfers. The contents of this register are described in the following bulleted list and summarized in Table 13.

- Bit 0: Bit 0 is the data ready (DR) indicator for the receiver. This bit is set whenever a complete incoming character has been received and transferred into the RBR or the FIFO. Bit 0 is cleared by reading all of the data in the RBR or the FIFO.
- Bit 1‡: Bit 1 is the overrun error (OE) indicator. When this bit is set, it indicates that before the character in the RBR is read, it is overwritten by the next character transferred into the register. The OE indicator is cleared every time the CPU reads the contents of the LSR. If the FIFO mode data continues to fill the FIFO beyond the trigger level, an overrun error occurs only after the FIFO is full and the next character has been completely received in the shift register. An OE is indicated to the CPU as soon as it happens. The character in the shift register is overwritten, but it is not transferred to the FIFO.
- Bit 2‡: Bit 2 is the parity error (PE) indicator. When this bit is set, it indicates that the parity of the received data character does not match the parity selected in the LCR (bit 4). The PE bit is cleared every time the CPU reads the contents of the LSR. In the FIFO mode, this error is associated with the particular character in the FIFO to which it applies. This error is revealed to the CPU when its associated character is at the top of the FIFO.

† The line status register is intended for read operations only; writing to this register is not recommended outside a factory testing environment.
‡ Bits 1 through 4 are the error conditions that produce a receiver line status interrupt.

PRINCIPLES OF OPERATION

line status register (LSR) (continued)†

- Bit 3‡: Bit 3 is the framing error (FE) indicator. When this bit is set, it indicates that the received character did not have a valid (set) stop bit. The FE bit is cleared every time the CPU reads the contents of the LSR. In the FIFO mode, this error is associated with the particular character in the FIFO to which it applies. This error is revealed to the CPU when its associated character is at the top of the FIFO. The ACE tries to resynchronize after a framing error. To accomplish this, it is assumed that the framing error is due to the next start bit. The ACE samples this start bit twice and then accepts the input data.
- Bit 4‡: Bit 4 is the break interrupt (BI) indicator. When this bit is set, it indicates that the received data input was held in the low state for longer than a full-word transmission time. A full-word transmission time is defined as the total time of the start, data, parity, and stop bits. The BI bit is cleared every time the CPU reads

  the contents of the LSR. In the FIFO mode, this error is associated with the particular character in the FIFO to which it applies. This error is revealed to the CPU when its associated character is at the top of the FIFO. When a break occurs, only one 0 character is loaded into the FIFO. The next character transfer is enabled after SIN goes to the marking state and receives the next valid start bit.
- Bit 5: Bit 5 is the transmitter holding register empty (THRE) indicator. This bit is set when the THR is empty, indicating that the ACE is ready to accept a new character. If the THRE interrupt is enabled when the THRE bit is set, an interrupt is generated. THRE is set when the contents of the THR are transferred to the TSR. This bit is cleared concurrent with the loading of the THR by the CPU. In the FIFO mode, this bit is set when the transmit FIFO is empty; it is cleared when at least one byte is written to the transmit FIFO.
- Bit 6: Bit 6 is the transmitter empty (TEMT) indicator. This bit is set when the THR and the TSR are both empty. When either the THR or the TSR contains a data character, the TEMT bit is cleared. In the FIFO mode, this bit is set when the transmitter FIFO and shift register are both empty.
- Bit 7: In the TL16C550C mode, this bit is always cleared. In the TL16C450 mode, this bit is always cleared. In the FIFO mode, LSR7 is set when there is at least one parity error, framing error, or break error in the FIFO. It is cleared when the microprocessor reads the LSR and there are no subsequent errors in the FIFO.

modem control register (MCR)

The MCR is an 8-bit register that controls an interface with a modem, data set, or peripheral device that is emulating a modem. The contents of this register are summarized in Table 13 and are described in the following bulleted list.

- Bit 0: Bit 0 (DTR) controls the data terminal ready ($\overline{\text{DTR}}$) output. Setting this bit forces the $\overline{\text{DTR}}$ output to its low state. When bit 0 is cleared, $\overline{\text{DTR}}$ goes high.
- Bit 1: Bit 1 (RTS) controls the request-to-send ($\overline{\text{RTS}}$) output in a manner identical to bit 0's control over the $\overline{\text{DTR}}$ output.
- Bit 2: Bit 2 (OUT1) controls the internal signal $\overline{\text{OUT1}}$.
- Bit 3: Bit 3 (OUT2) when set in PNPBYPASS mode, the selected interrupt line IRQx is enabled; otherwise, IRQx is 3-state.

† The line status register is intended for read operations only; writing to this register is not recommended outside a factory testing environment.

PRINCIPLES OF OPERATION

modem control register (MCR) (continued)

- Bit 4: Bit 4 provides a local loop back feature for diagnostic testing of the ACE. When this bit is set, the following occurs:
  - The transmitter serial output (SOUT) is asserted high.
  - The receiver serial input (SIN) is disconnected.
  - The output of the TSR is looped back into the receiver shift register input.
  - The four modem control inputs ($\overline{CTS}$, $\overline{DSR}$, $\overline{DCD}$, and $\overline{RI}$) are disconnected.
  - The four modem control outputs ($\overline{DTR}$, $\overline{RTS}$, $\overline{OUT1}$, and $\overline{OUT2}$) are internally connected to the four modem control inputs.
  - The four modem control outputs are forced to their inactive (high) states.

NOTE

$\overline{OUT1}$ is a user-designated output signal for TL16C550. It is an internal signal and not used in the TL16PNP550A.

In the diagnostic mode, data that is transmitted is immediately received. This allows the processor to verify the transmit and receive data paths to the ACE. The receiver and transmitter interrupts are fully operational. The modem control interrupts are also operational, but the modem control interrupt sources are now the lower four bits of the MCR instead of the four modem control inputs. All interrupts are still controlled by the IER.

The ACE flow can be configured by programming bits 1 and 5 of the MCR. Table 18 shows that autoflow control can be enabled by setting MCR bit 5, autoflow enable (AFE) and also setting MCR bit 1, RTS. autoflow incorporates both auto-RTS and auto-CTS. If only auto-CTS is desired, set bit 5 and clear bit 1. If neither auto-RTS nor auto-CTS is desired, clear bit 5.

Table 18. ACE Flow Configuration

MCR BIT 5 (AFE)	MCR BIT 1 (RTS)	ACE FLOW CONFIGURATION
1	1	Auto-RTS and auto-CTS enabled (autoflow control enabled)
1	0	Auto-CTS only enabled
0	X	Auto-RTS and auto-CTS disabled

modem status register (MSR)

The MSR is an 8-bit register that provides information about the current state of the control lines from the modem, data set, or peripheral device to the CPU. Additionally, four bits of this register provide change information; when a control input from the modem changes state, the appropriate bit is set. All four bits are cleared when the CPU reads the MSR. The contents of this register are summarized in Table 13 and are described in the following bulleted list.

- Bit 0: Bit 0 is the change in the clear-to-send (ΔCTS) indicator. This bit indicates that the $\overline{CTS}$ input has changed state since the last time it was read by the CPU . When this bit is set (autoflow control is not enabled and the modem status interrupt is enabled), a modem status interrupt is generated. When autoflow control is enabled, no interrupt is generated.
- Bit 1: Bit 1 is the change in the data set ready (ΔDSR) indicator. This bit indicates that the $\overline{DSR}$ input has changed state since the last time it was read by the CPU. When this bit is set and the modem status interrupt is enabled, a modem status interrupt is generated.

PRINCIPLES OF OPERATION

modem status register (MSR) (continued)

- Bit 2: Bit 2 is the trailing edge of ring indicator (TERI) detector. This bit indicates that the $\overline{RI}$ input to the chip has changed from a low to a high state. When this bit is set and the modem status interrupt is enabled, a modem status interrupt is generated.
- Bit 3: Bit 3 is the change in data carrier detect (ΔDCD) indicator. This bit indicates that the $\overline{DCD}$ input to the chip has changed state since the last time it was read by the CPU. When this bit is set and the modem status interrupt is enabled, a modem status interrupt is generated.
- Bit 4: Bit 4 is the complement of the clear-to-send ($\overline{CTS}$) input. When bit 4 (loop) of the MCR is set, this bit is equivalent to the MCR bit 1 (RTS).
- Bit 5: Bit 5 is the complement of the data set ready ($\overline{DSR}$) input. When bit 4 (loop) of the MCR is set, this bit is equivalent to the MCR bit 1 (DTR).
- Bit 6; Bit 6 is the complement of the ring indicator ($\overline{RI}$) input. When bit 4 (loop) of the MCR is set, this bit is equivalent to the MCR bit 2 (OUT1).
- Bit 7: Bit 7 is the complement of the data carrier detect ($\overline{DCD}$) input. When bit 4 (loop) of the MCR is set, this bit is equivalent to the MCR bit 3 (OUT2).

programmable baud generator

The ACE contains a programmable baud generator that receives a clock input generated by the prescalar block in the range between 1.833 and 22 MHz and divides it by a divisor in the range between 1 and (2^{16}–1). The output frequency of the baud generator is sixteen times (16$\times$) the baud rate. The formula for the divisor is:

divisor # = clock frequency generated by the prescalar block $\div$ (desired baud rate $\times$ 16)

Two 8-bit registers, called divisor latches, store the divisor in a 16-bit binary format. These divisor latches must be loaded during initialization of the ACE in order to ensure correct operation of the baud generator. When either of the divisor latches is loaded, a 16-bit baud counter is also loaded to prevent long counts on initial load.

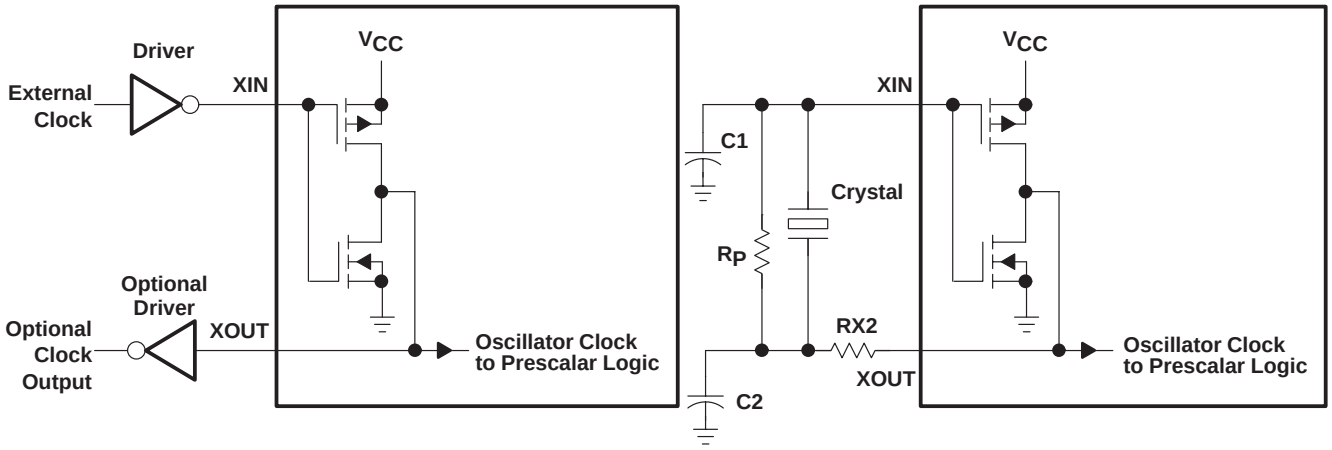
Table 19 illustrates the use of the baud generator with a crystal frequency of 22 MHz and a prescalar divisor of 12. Refer to Figure 20 for an example of a typical clock circuit.

PRINCIPLES OF OPERATION

programmable baud generator (continued)

Table 19. Baud Rates Using a 22-MHz Crystal and a Prescalar Divisor of 12

DESIRED BAUD RATE	DIVISOR USED TO GENERATE 16× CLOCK	PERCENT ERROR DIFFERENCE BETWEEN DESIRED AND ACTUAL
50	2304	
75	1536	
110	1047	0.026
134.5	857	0.058
150	768	
300	384	
600	192	
1200	96	
1800	64	
2000	58	0.69
2400	48	
3600	32	
4800	24	
7200	16	
9600	12	
19200	6	
38400	3	
56000	2	2.86



TYPICAL CRYSTAL OSCILLATOR NETWORK

CRYSTAL	R_P	RX2	C1	C2
22 MHz	1 MΩ	1.5 kΩ	10–30 pF	40–60 pF

Figure 20. Typical Clock Circuits

PRINCIPLES OF OPERATION

receiver buffer register (RBR)

The ACE receiver section consists of a receiver shift register (RSR) and a RBR. The RBR is actually a 16-byte FIFO. Timing is supplied by the 16× receiver clock (RCLK). Receiver section control is a function of the ACE line control register.

The ACE RSR receives serial data from the serial input (SIN) terminal. The RSR then deserializes the data and moves it into the RBR FIFO. In the TL16C450 mode, when a character is placed in the RBR and the received data available interrupt is enabled, an interrupt is generated. This interrupt is cleared when the data is read out of the RBR. In the FIFO mode, the interrupts are generated based on the control setup in the FIFO control register.

scratch register

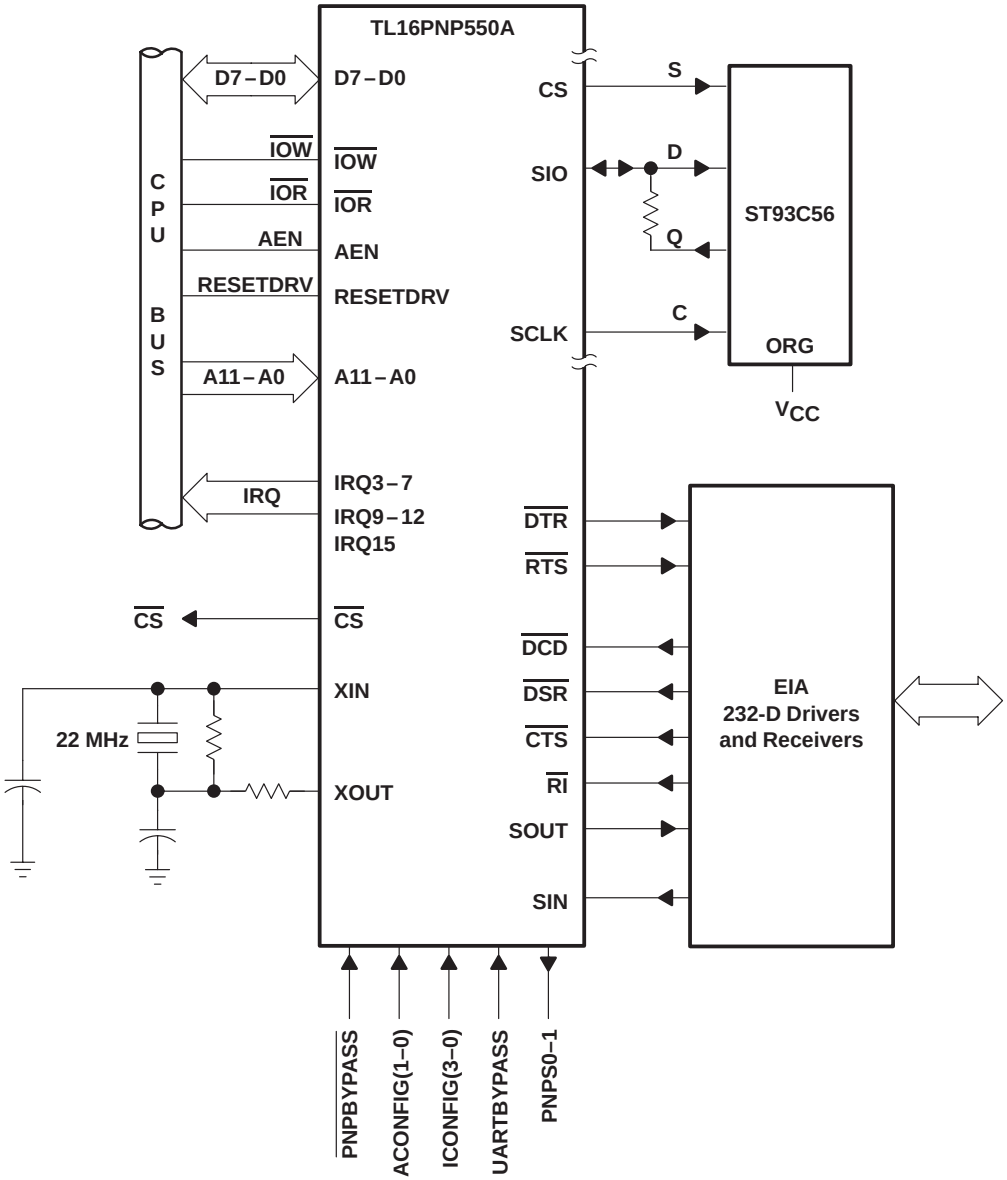
The scratch register is an 8-bit register that is intended for the programmer's use as a scratchpad in the sense that it temporarily holds the programmer's data without affecting any other ACE operation.

transmitter holding register (THR)

The ACE transmitter section consists of a THR and a transmitter shift register (TSR). The THR is actually a 16-byte FIFO. Timing is supplied by the baud out ($\overline{\text{BAUDOUT}}$) clock signal. Transmitter section control is a function of the ACE line control register.

The ACE THR receives data off the internal data bus and when the TSR is idle, moves the data into the TSR. The TSR serializes the data and outputs it at the serial output (SOUT). In the TL16C450 mode, if the THR is empty and the transmitter holding register empty (THRE) interrupt is enabled, an interrupt is generated. This interrupt is cleared when a character is loaded into the register. In the FIFO mode, the interrupts are generated based on the control setup in the FIFO control register.

APPLICATION INFORMATION



NOTES: A. No data or IRQ buffer is needed.
B. Check ST93C56 application note: When D and Q terminals are shorted it is recommended that a 2-kΩ resistor be inserted between terminals D and Q.

Figure 21. Basic TL16PNP550A Configuration

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