

TL16C550C 具有自动流控制的异步通信元件

1 特性

- 可编程自动 $\overline{\text{RTS}}$ 和自动 $\overline{\text{CTS}}$
- 在自动 $\overline{\text{CTS}}$ 模式下, $\overline{\text{CTS}}$ 控制发送器
- 在自动 $\overline{\text{RTS}}$ 模式下, RCV FIFO 内容和阈值控制 $\overline{\text{RTS}}$
- 当设备处于相同的功率降低状态时, 串行和调制解调器控制输出直接驱动 RJ11 线缆
- 能够与所有现有的 TL16C450 软件一起运行
- 复位后, 所有寄存器与 TL16C450 寄存器组相同
- 时钟速率高达 16MHz, 支持高达 1Mbaud 的运行
- 在 TL16C450 模式下, 保持和移位寄存器无需在 CPU 和串行数据之间进行精确同步
- 可编程波特率发生器可对任何输入参考时钟进行 1 至 $(2^{16} - 1)$ 分频并生成一个内部 $16\times$ 时钟
- 向串行数据流添加或从串行数据流中删除的标准异步通信位 (起始位、停止位和奇偶校验位)
- 5V 和 3.3V 运行
- 独立的接收器时钟输入
- 发送、接收、线路状态和数据集中断独立控制
- 完全可编程的串行接口特性：
 - 5 位、6 位、7 位或 8 位字符
 - 偶校验、奇校验或无奇偶校验位生成与检测
 - 可产生 1 个、1 1/2 个或 2 个停止位
 - 波特率生成 (直流到 1Mbit/s)
- 错误启动位检测
- 完成状态报告功能
- 双向数据总线和控制总线的三态输出 TTL 驱动能力
- 线路中断生成和检测
- 内部诊断功能：
 - 通信链路故障隔离的环回控制
 - 中断、奇偶校验、溢出和帧错误仿真
- 完全优先化的中断系统控制
- 调制解调器控制功能 ($\overline{\text{CTS}}$ 、 $\overline{\text{RTS}}$ 、 $\overline{\text{DSR}}$ 、 $\overline{\text{DTR}}$ 、 $\overline{\text{RI}}$ 和 $\overline{\text{DCD}}$)

2 说明

TL16C550C 和 TL16C550CI 是 TL16C550B 异步通信元件 (ACE) 的功能升级型号, 而 TL16C550B 又是 TL16C450 的功能升级型号。TL16C550C 和 TL16C550CI 上电时在功能上与 TL16C450 等效 (字符模式或 TL16C450 模式), 并像 TL16C550B 一样可以置于备用 FIFO 模式。这通过缓冲接收和发送的字符来减轻 CPU 的过多软件开销。接收器和发送器 FIFO 能够存储多达 16 个字节, 包括接收器 FIFO 每字节 3 个额外的错误状态位。在 FIFO 模式下, 器件具有一个可选的自动流控制功能, 此功能可以通过使用 $\overline{\text{RTS}}$ 输出和 $\overline{\text{CTS}}$ 输入信号自动控制串行数据流来大大减少软件过载并提高系统效率。

TL16C550C 和 TL16C550CI 对从外设或调制解调器接收到的数据执行串行至并行转换, 并对从 CPU 接收到的数据执行并行至串行转换。CPU 可以随时读取 ACE 状态。ACE 包括完整的调制解调器控制功能和一个处理器中断系统, 该系统可以进行定制以更大限度地减少通信链路的软件管理。

TL16C550C 和 TL16C550CI ACE 都包含一个可编程波特率发生器, 能够对参考时钟进行 1 至 65535 分频, 并为内部发送器逻辑生成一个 $16\times$ 参考时钟。所含的配置可以将此 $16\times$ 时钟用于接收器逻辑。ACE 支持 1Mbaud 的串行速率 (16MHz 输入时钟), 因此位时间为 $1\mu\text{s}$, 典型字符时间为 $10\mu\text{s}$ (起始位、8 个数据位、停止位)。

TL16C550C 和 TL16C550CI 上的其中两个 TL16C450 端子功能已更改为 $\overline{\text{TXRDY}}$ 和 $\overline{\text{RXRDY}}$, 它们用于为 DMA 控制器提供信号。



Table of Contents

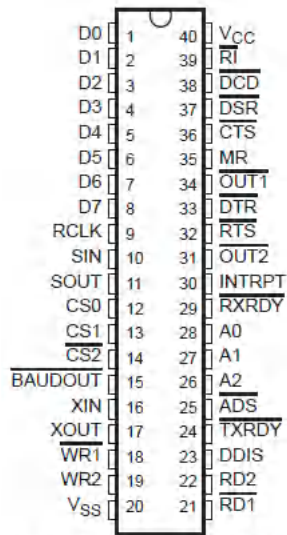
1 特性	1	5.12 Modem Control Switching Characteristics.....	11
2 说明	1	6 Parameter Measurement Information	12
3 Revision History	2	7 Detailed Description	20
4 Pin Configuration and Functions	3	7.1 Autoflow Control (see 图 7-1)	20
5 Specifications	6	7.2 Auto- $\overline{\text{RTS}}$ (see 图 7-1)	20
5.1 Absolute Maximum Ratings.....	6	7.3 Auto- $\overline{\text{CTS}}$ (see 图 7-1)	20
5.2 Recommended Operating Conditions (Low Voltage - 3.3 nominal).....	6	7.4 Enabling Autoflow Control and Auto- $\overline{\text{CTS}}$	20
5.3 Recommended Operating Conditions (Standard Voltage - 5 V nominal).....	7	7.5 Auto- $\overline{\text{CTS}}$ and Auto-RTS Functional Timing.....	21
5.4 Thermal Information.....	7	7.6 Functional Block Diagram.....	22
5.5 Electrical Characteristics (Low Voltage - 3.3 V nominal).....	8	7.7 Principles of Operation.....	22
5.6 Electrical Characteristics (Standard Voltage - 5 V nominal).....	8	8 Application Information	34
5.7 System Timing Requirements.....	9	9 Device and Documentation Support	36
5.8 System Switching Characteristics.....	10	9.1 接收文档更新通知.....	36
5.9 Baud Generator Switching Characteristics.....	10	9.2 支持资源.....	36
5.10 Receiver Switching Characteristics.....	10	9.3 Trademarks.....	36
5.11 Transmitter Switching Characteristics.....	11	9.4 静电放电警告.....	36
		9.5 术语表.....	36
		10 Mechanical, Packaging, and Orderable Information	37

3 Revision History

注：以前版本的页码可能与当前版本的页码不同

Changes from Revision H (January 2006) to Revision I (March 2021)	Page
• 更新了数据表格式.....	1
• Added the <i>Pin Configuration and Functions</i> section.....	3
• Added the <i>Thermal Information</i> table.	7

4 Pin Configuration and Functions



NOTE: 40-pin DIP (N package) will be obsolete as of 7/30/2006. Please contact your local distributor or TI Sales Office for more information.

图 4-1. N Package (Top View)

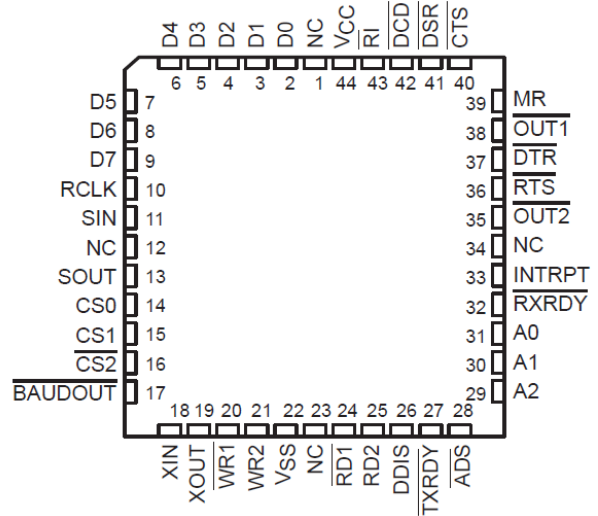


图 4-2. FN Package (Top View)

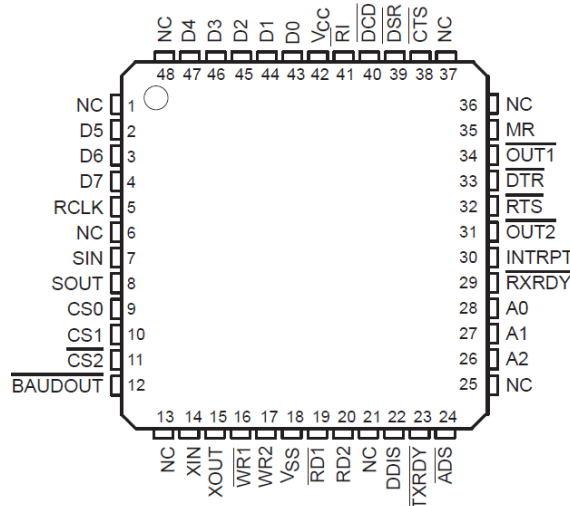


图 4-3. PT/PFB Package (Top View)

NC - No internal connection

表 4-1. Pin Functions

TERMINAL				I/O	DESCRIPTION
NAME	NO.N ⁽¹⁾	NO.FN	NO.PT		
A0	28	31	28	I	Register select. A0 –A2 are used during read and write operations to select the ACE register to read from or write to. Refer to Table 1 for register addresses and refer to ADS description.
A1	27	30	27		
A2	26	29	26		

表 4-1. Pin Functions (continued)

NAME	TERMINAL			I/O	DESCRIPTION
	NO.N ⁽¹⁾	NO.FN	NO.PT		
ADS	25	28	24	I	Address strobe. When \overline{ADS} is active (low), A0, A1, and A2 and CS0, CS1, and CS2 drive the internal select logic directly; when ADS is high, the register select and chip select signals are held at the logic levels they were in when the low-to-high transition of \overline{ADS} occurred
BAUDOUT	15	17	12	O	Baud out. BAUDOUT is a 16 x clock signal for the transmitter section of the ACE. The clock rate is established by the reference oscillator frequency divided by a divisor specified by the baud generator divisor latches. BAUDOUT may also be used for the receiver section by tying this output to RCLK.
CS0 CS1 $\overline{CS2}$	12 13 14	14 15 16	9 10 11	I	Chip select. When CS0 and CS1 are high and $\overline{CS2}$ is low, these three inputs select the ACE. When any of these inputs are inactive, the ACE remains inactive (refer to \overline{ADS} description).
CTS	36	40	38	I	Clear to send. CTS is a modem status signal. Its condition can be checked by reading bit 4 (CTS) of the modem status register. Bit 0 (Δ CTS) of the modem status register indicates that \overline{CTS} has changed states since the last read from the modem status register. If the modem status interrupt is enabled when CTS changes levels and the auto-CTS mode is not enabled, an interrupt is generated. CTS is also used in the auto-CTS mode to control the transmitter
D0 D1 D2 D3 D4 D5 D6 D7	1 2 3 4 5 6 7 8	2 3 4 5 6 7 8 9	43 44 45 46 47 2 3 4	I/O	Data bus. Eight data lines with 3-state outputs provide a bidirectional path for data, control, and status information between the ACE and the CPU.
DCD	38	42	40	I	Data carrier detect. DCD is a modem status signal. Its condition can be checked by reading bit 7 (DCD) of the modem status register. Bit 3 (Δ DCD) of the modem status register indicates that DCD has changed states since the last read from the modem status register. If the modem status interrupt is enabled when DCD changes levels, an interrupt is generated
DDIS	23	26	22	O	Driver disable. DDIS is active (high) when the CPU is not reading data. When active, DDIS can disable an external transceiver.
DSR	37	41	39	I	Data set ready. DSR is a modem status signal. Its condition can be checked by reading bit 5 (DSR) of the modem status register. Bit 1 (Δ DSR) of the modem status register indicates DSR has changed levels since the last read from the modem status register. If the modem status interrupt is enabled when DSR changes levels, an interrupt is generated.
DTR	33	37	33	O	Data terminal ready. When active (low), DTR informs a modem or data set that the ACE is ready to establish communication. DTR is placed in the active level by setting the DTR bit of the modem control register. DTR is placed in the inactive level either as a result of a master reset, during loop mode operation, or clearing the DTR bit.
INTRPT	30	33	30	O	Interrupt. When active (high), INTRPT 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 that is available or timed out (FIFO mode only), an empty transmitter holding register, or an enabled modem status interrupt. INTRPT is reset (deactivated) either when the interrupt is serviced or as a result of a master reset.
MR	35	39	35	I	Master reset. When active (high), MR clears most ACE registers and sets the levels of various output signals (refer to Table 2).
OUT1 OUT2	34 31	38 35	34 31	O	Outputs 1 and 2. These are user-designated output terminals that are set to the active (low) level by setting respective modem control register (MCR) bits (OUT1 and OUT2). OUT1 and OUT2 are set to inactive the (high) level as a result of master reset, during loop mode operations, or by clearing bit 2 (OUT1) or bit 3 (OUT2) of the MCR.

表 4-1. Pin Functions (continued)

TERMINAL				I/O	DESCRIPTION
NAME	NO.N ⁽¹⁾	NO.FN	NO.PT		
RCLK	9	10	5	I	Receiver clock. RCLK is the 16 x baud rate clock for the receiver section of the ACE.
RD1 RD2	21 22	24 25	19 20	I	Read inputs. When either $\overline{RD1}$ or RD2 is active (low or high respectively) while the ACE is selected, the CPU is allowed to read status information or data from a selected ACE register. Only one of these inputs is required for the transfer of data during a read operation; the other input should be tied to its inactive level (i.e., RD2 tied low or $\overline{RD1}$ tied high)
RI	39	43	41	I	Ring indicator. \overline{RI} is a modem status signal. Its condition can be checked by reading bit 6 (RI) of the modem status register. Bit 2 (TERI) of the modem status register indicates that \overline{RI} has transitioned from a low to a high level since the last read from the modem status register. If the modem status interrupt is enabled when this transition occurs, an interrupt is generated
RTS	32	36	32	O	Request to send. When active, \overline{RTS} informs the modem or data set that the ACE is ready to receive data. RTS is set to the active level by setting the RTS modem control register bit and is set to the 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 the auto-RTS mode, RTS is set to the inactive level by the receiver threshold control logic
RXRDY	29	32	29	O	Receiver ready. Receiver direct memory access (DMA) signalling is available with RXRDY. When operating in the FIFO mode, one of two types of DMA signalling can be selected using the FIFO control register bit 3 (FCR3). When operating in the TL16C450 mode, only DMA mode 0 is allowed. Mode 0 supports single-transfer DMA in which a transfer is made between CPU bus cycles. Mode 1 supports multitransfer DMA in which multiple transfers are made continuously until the receiver FIFO has been emptied. In DMA mode 0 (FCR0 = 0 or FCR0 = 1, FCR3 = 0), when there is at least one character in the receiver FIFO or receiver holding register, \overline{RXRDY} is active (low). When \overline{RXRDY} has been active but there are no characters in the FIFO or holding register, \overline{RXRDY} goes inactive (high). In DMA mode 1 (FCR0 = 1, FCR3 = 1), when the trigger level or the time-out has been reached, \overline{RXRDY} goes active (low); when it has been active but there are no more characters in the FIFO or holding register, it goes inactive (high).
SIN	10	11	7	I	Serial data input. SIN is serial data input from a connected communications device.
SOUT	11	13	8	O	Serial data output. SOUT is composite serial data output to a connected communication device. SOUT is set to the marking (high) level as a result of master reset.
TXRDY	24	27	23	O	Transmitter ready. Transmitter DMA signalling is available with TXRDY. When operating in the FIFO mode, one of two types of DMA signalling can be selected using FCR3. When operating in the TL16C450 mode, only DMA mode 0 is allowed. Mode 0 supports single-transfer DMA in which a transfer is made between CPU bus cycles. Mode 1 supports multitransfer DMA in which multiple transfers are made continuously until the transmit FIFO has been filled.
V _{CC}	40	44	42		5-V supply voltage
V _{SS}	20	22	18		Supply common
WR1 WR2	18 19	20 21	16 17	I	Write inputs. When either $\overline{WR1}$ or WR2 is active (low or high respectively) and while the ACE is selected, the CPU is allowed to write control words or data into a selected ACE register. Only one of these inputs is required to transfer data during a write operation; the other input should be tied to its inactive level (i.e., WR2 tied low or $\overline{WR1}$ tied high).
XIN XOUT	16 17	18 19	14 15	I/O	External clock. XIN and XOUT connect the ACE to the main timing reference (clock or crystal).

(1) The N package is **Not Recommended for New Designs**.

5 Specifications

5.1 Absolute Maximum Ratings

over operating free-air temperature range (unless otherwise noted)⁽¹⁾

		MIN	MAX	UNIT	
V _{CC}	Supply voltage range ⁽³⁾	- 0.5	7	V	
V _I	Input voltage range at any input	- 0.5	7	V	
V _O	Output voltage range	- 0.5	7	V	
T _A	Operating free-air temperature range	TL16C550C	0	70	°C
		TL16C550CI	- 40	85	°C
T _{stg}	Storage temperature	- 65	150	°C	
T _C	Case temperature for 10 seconds	FN package		°C	
	Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds	N ⁽¹⁾ ⁽²⁾ or PT package		°C	

- (1) 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.
- (2) The N package is Not Recommended for New Designs.
- (3) All voltage values are with respect to V_{SS}.

5.2 Recommended Operating Conditions (Low Voltage - 3.3 nominal)

	MIN	NOM	MAX	UNIT
Supply voltage, V _{CC}	3	3.3	3.6	V
Input voltage, V _I	0		V _{CC}	V
High-level input voltage, V _{IH} ⁽¹⁾	0.7 V _{CC}			V
Low-level input voltage, V _{IL} ⁽¹⁾			0.3 V _{CC}	V
Output voltage, V _O ⁽²⁾	0		V _{CC}	V
High-level output current, I _{OH} (all outputs)			1.8	mA
Low-level output current, I _{OL} (all outputs)			3.2	mA
Input capacitance			1	pF
Operating free-air temperature, T _A	0	25	70	°C
Junction temperature range, T _J ⁽³⁾	0	25	115	°C
Oscillator/clock speed			14.9	MHz

- (1) Meets TTL levels, V_{IHmin} = 2 V and V_{ILmax} = 0.8 V on nonhysteresis inputs.
- (2) Applies for external output buffers.
- (3) These junction temperatures reflect simulated conditions. Absolute maximum junction temperature is 150°C. The customer is responsible for verifying junction temperature.

5.3 Recommended Operating Conditions (Standard Voltage - 5 V nominal)

		MIN	NOM	MAX	UNIT
Supply voltage, V_{CC}		4.75	5	5.25	V
Input voltage, V_I		0		V_{CC}	V
High-level input voltage, V_{IH}	Except XIN	2			V
	XIN	$0.7 V_{CC}$			
Low-level input voltage, V_{IL}	Except XIN			0.8	V
	XIN			$0.3 V_{CC}$	
Output voltage, V_O ⁽¹⁾		0		V_{CC}	V
High-level output current, I_{OH} (all outputs)				4	mA
Low-level output current, I_{OL} (all outputs)				4	mA
Input capacitance				1	pF
Operating free-air temperature, T_A		0	25	70	°C
Junction temperature range, T_J ⁽²⁾		0	25	115	°C
Oscillator/clock speed				16	MHz

(1) Applies for external output buffers.

(2) These junction temperatures reflect simulated conditions. Absolute maximum junction temperature is 150°C. The customer is responsible for verifying junction temperature.

5.4 Thermal Information

THERMAL METRIC ⁽¹⁾		TL16C550C	TL16C550C	TL16C550C	UNIT
		PT	PFB	FN	
		48 PINS	48 PINS	44 PINS	
$R_{\theta JA}$	Junction-to-ambient thermal resistance	72.5	73.6	62.4	°C/W
$R_{\theta JC(top)}$	Junction-to-case (top) thermal resistance	31.0	26.3	37.2	°C/W
$R_{\theta JB}$	Junction-to-board thermal resistance	36.2	37.2	39.1	°C/W
ψ_{JT}	Junction-to-top characterization parameter	4.4	1.9	19.4	°C/W
ψ_{JB}	Junction-to-board characterization parameter	36.0	37.0	38.7	°C/W

(1) For more information about traditional and new thermal metrics, see the [Semiconductor and IC Package Thermal Metrics](#) application report.

5.5 Electrical Characteristics (Low Voltage - 3.3 V nominal)

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

PARAMETER		TEST CONDITIONS	MIN	TYP ⁽¹⁾	MAX	UNIT
V _{OH} ⁽²⁾	High-level output voltage	I _{OH} = - 1 mA	2.4			V
V _{OL} ⁽²⁾	Low-level output voltage	I _{OL} = 1.6 mA			0.5	V
I _I	Input current	V _{CC} = 3.6 V, V _I = 0 to 3.6 V, V _{SS} = 0, All other terminals floating			10	μ A
I _{OZ}	High-impedance-state output current	V _{CC} = 3.6 V, V _O = 0 to 3.6 V Chip selected in write mode or chip deselect			± 20	μ A
I _{CC}	Supply current	V _{CC} = 3.6 V, SIN, $\overline{\text{DSR}}$, $\overline{\text{DCD}}$, $\overline{\text{CTS}}$, and $\overline{\text{RI}}$ at 2V, All other inputs at 0.8 V, No load on outputs, T _A = 25°C XTAL1 at 4 MHz, Baud rate = 50 kbit/s			8	mA
C _{i(CLK)}	Clock input capacitance	V _{CC} = 0, f = 1 MHz, T _A = 25°C		15	20	pF
C _{o(CLK)}	Clock output capacitance			20	30	pF
C _i	Input capacitance	All other terminals grounded		6	10	pF
C _o	Output capacitance			10	20	pF

(1) All typical values are at V_{CC} = 3.3 V and T_A = 25°C.

(2) These parameters apply for all outputs except XOUT.

5.6 Electrical Characteristics (Standard Voltage - 5 V nominal)

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

PARAMETER		TEST CONDITIONS	MIN	TYP ⁽¹⁾	MAX	UNIT
V _{OH} ⁽²⁾	High-level output voltage	I _{OH} = - 1 mA	2.4			V
V _{OL} ⁽²⁾	Low-level output voltage	I _{OL} = 1.6 mA	0.4			V
I _I	Input current	V _{CC} = 5.25 V, V _I = 0 to 5.25 V, V _{SS} = 0, All other terminals floating			10	μ A
I _{OZ}	High-impedance-state output current	V _{CC} = 5.25 V, V _O = 0 to 5.25 V, Chip selected in write mode or chip deselect			± 20	μ A
I _{CC}	Supply current	V _{CC} = 5.25 V, SIN, $\overline{\text{DSR}}$, $\overline{\text{DCD}}$, $\overline{\text{CTS}}$, and $\overline{\text{RI}}$ at 2V, All other inputs at 0.8 V, No load on outputs, T _A = 25°C XTAL1 at 4 MHz, Baud rate = 50 kbit/s			10	mA
C _{i(CLK)}	Clock input capacitance	V _{CC} = 0, f = 1 MHz, T _A = 25°C		15	20	pF
C _{o(CLK)}	Clock output capacitance			20	30	pF
C _i	Input capacitance	All other terminals grounded		6	10	pF
C _o	Output capacitance			10	20	pF

(1) All typical values are at V_{CC} = 5 V and T_A = 25°C.

(2) These parameters apply for all outputs except XOUT.

5.7 System Timing Requirements

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

	ALT. 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, clock high	t_{XH}	5	f = 16 MHz Max, $V_{CC} = 5\text{ V}$	25	ns
t_{w2}	Pulse duration, clock low	t_{XL}				
t_{w5}	Pulse duration, \overline{ADS} low	t_{ADS}	6.7		9	ns
t_{w6}	Pulse duration, \overline{WR}	t_{WR}	6		40	ns
t_{w7}	Pulse duration, \overline{RD}	t_{RD}	7		40	ns
t_{w8}	Pulse duration, MR	t_{MR}			1	ns
t_{su1}	Setup time, address valid before $\overline{ADS} \uparrow$	t_{AS}	6.7		8	ns
t_{su2}	Setup time, CS valid before $\overline{ADS} \uparrow$	t_{CS}				
t_{su3}	Setup time, data valid before $\overline{WR1} \uparrow$ or $WR2 \downarrow$	t_{DS}	6		15	ns
t_{su4}	Setup time, $\overline{CTS} \uparrow$ before midpoint of stop bit		17		10	ns
t_{h1}	Hold time, address low after $\overline{ADS} \uparrow$	t_{AH}	6.7		0	ns
t_{h2}	Hold time, CS valid after $\overline{ADS} \uparrow$	t_{CH}				
t_{h3}	Hold time, CS valid after $\overline{WR1} \uparrow$ or $WR2 \downarrow$	t_{WCS}	6		10	ns
t_{h4}	Hold time, address valid after $\overline{WR1} \uparrow$ or $WR2 \downarrow$	t_{WA}				
t_{h5}	Hold time, data valid after $\overline{WR1} \uparrow$ or $WR2 \downarrow$	t_{DH}	6		5	ns
t_{h6}	Hold time, chip select valid after $\overline{RD1} \uparrow$ or $RD2 \downarrow$	t_{RCS}	7		10	ns
t_{h7}	Hold time, address valid after $\overline{RD1} \uparrow$ or $RD2 \downarrow$	t_{RA}	7		20	ns
$t_{d4}^{(1)}$	Delay time, CS valid before $\overline{WR1} \downarrow$ or $WR2 \uparrow$	t_{CSW}	6		7	ns
$t_{d5}^{(1)}$	Delay time, address valid before $\overline{WR1} \downarrow$ or $WR2 \uparrow$	t_{AW}				
$t_{d6}^{(1)}$	Delay time, write cycle, $\overline{WR1} \uparrow$ or $WR2 \downarrow$ to $\overline{ADS} \downarrow$	t_{WC}	6		40	ns
$t_{d7}^{(1)}$	Delay time, CS valid to $\overline{RD1} \downarrow$ or $RD2 \uparrow$	t_{CSR}	7		7	ns
$t_{d8}^{(1)}$	Delay time, address valid to $\overline{RD1} \downarrow$ or $RD2 \uparrow$	t_{AR}				
t_{d9}	Delay time, read cycle, $\overline{RD1} \uparrow$ or $RD2 \downarrow$ to $\overline{ADS} \downarrow$	t_{RC}	7		40	ns
t_{d10}	Delay time, $\overline{RD1} \downarrow$ or $RD2 \uparrow$ to data valid	t_{RVD}	7	$C_L = 75\text{ pF}$	45	ns
t_{d11}	Delay time, $\overline{RD1} \uparrow$ or $RD2 \downarrow$ to floating data	t_{HZ}	7	$C_L = 75\text{ pF}$	20	ns

(1) Only applies when \overline{ADS} is low.

5.8 System Switching Characteristics

over recommended ranges of supply voltage and operating free-air temperature⁽¹⁾

PARAMETER	ALT. SYMBOL	FIGURE	TEST CONDITIONS	MIN	MAX	UNIT
$t_{dis(R)}$ Disable time, $\overline{RD1}$ ↓ ↑ or $RD2$ ↑ ↓ to $DDIS$ ↑ ↓	t_{RDD}	7	$C_L = 75$ pF	20		ns

(1) Charge and discharge times are determined by V_{OL} , V_{OH} , and external loading.

5.9 Baud Generator Switching Characteristics

over recommended ranges of supply voltage and operating free-air temperature, $C_L = 75$ pF

PARAMETER	ALT. SYMBOL	FIGURE	TEST CONDITIONS	MIN	MAX	UNIT
t_{w3} Pulse duration, $\overline{BAUDOUT}$ low	t_{LW}	5	$f = 16$ MHz, $CLK \div 2$, $V_{CC} = 5$ V	50		ns
t_{w4} Pulse duration, $\overline{BAUDOUT}$ high	t_{HW}	5				
t_{d1} Delay time, XIN ↑ to $\overline{BAUDOUT}$ ↑	t_{BLD}	5			45	ns
t_{d2} Delay time, XIN ↑ ↓ to $\overline{BAUDOUT}$ ↓	t_{BHD}	5			45	ns

5.10 Receiver Switching Characteristics

over recommended ranges of supply voltage and operating free-air temperature⁽¹⁾

PARAMETER	ALT. SYMBOL	FIGURE	TEST CONDITIONS	MIN	MAX	UNIT
t_{d12} Delay time, RCLK to sample	t_{SCD}	8			10	ns
t_{d13} Delay time, stop to set INTRPT or read RBR to LSI interrupt or stop to RXRDY ↓	t_{SINT}	8, 9, 10, 11, 12			1	RCLK cycle
t_{d14} Delay time, read RBR/LSR to reset INTRPT	t_{RINT}	8, 9, 10, 11, 12	$C_L = 75$ pF		70	ns

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

5.11 Transmitter Switching Characteristics

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

PARAMETER	ALT. SYMBOL	FIGURE	TEST CONDITIONS	MIN	MAX	UNIT
t_{d15} Delay time, initial write to transmit start	t_{IRS}	13		8	24	baudout cycles
t_{d16} Delay time, start to INTRPT	t_{STI}	13		8	10	baudout cycles
t_{d17} Delay time, \overline{WR} (WR THR) to reset INTRPT	t_{HR}	13	$C_L = 75$ pF		50	ns
t_{d18} Delay time, initial write to INTRPT (THRE ⁽¹⁾)	t_{SI}	13		16	34	baudout cycles
t_{d19} Delay time, read IIR ⁽¹⁾ to reset INTRPT (THRE ⁽¹⁾)	t_{IR}	13	$C_L = 75$ pF		35	ns
t_{d20} Delay time, write to \overline{TXRDY} inactive	t_{WXI}	14, 15	$C_L = 75$ pF		35	ns
t_{21} Delay time, start to \overline{TXRDY} active	t_{SXA}	14, 15	$C_L = 75$ pF		9	baudout cycles

(1) THRE = transmitter holding register empty; IIR = interrupt identification register.

5.12 Modem Control Switching Characteristics

over recommended ranges of supply voltage and operating free-air temperature, $C_L = 75$ pF

PARAMETER	ALT. SYMBOL	FIGURE	MIN	MAX	UNIT
t_{d22} Delay time, WR MCR to output	t_{MDO}	16		50	ns
t_{d23} Delay time, modem interrupt to set INTRPT	t_{SIM}	16		35	ns
t_{d24} Delay time, RD MSR to reset INTRPT	t_{RIM}	16		40	ns
t_{d25} Delay time, \overline{CTS} low to SOUT ↓		17		24	baudout cycles
t_{d26} Delay time, RCV threshold byte to \overline{RTS} ↑		18		2	baudout cycles
t_{d27} Delay time, read of last byte in receive FIFO to \overline{RTS} ↓		18		2	baudout cycles
t_{d28} Delay time, first data bit of 16th character to \overline{RTS} ↑		19		2	baudout cycles
t_{d29} Delay time, \overline{RBRD} low to \overline{RTS} ↓		19		2	baudout cycles

6 Parameter Measurement Information

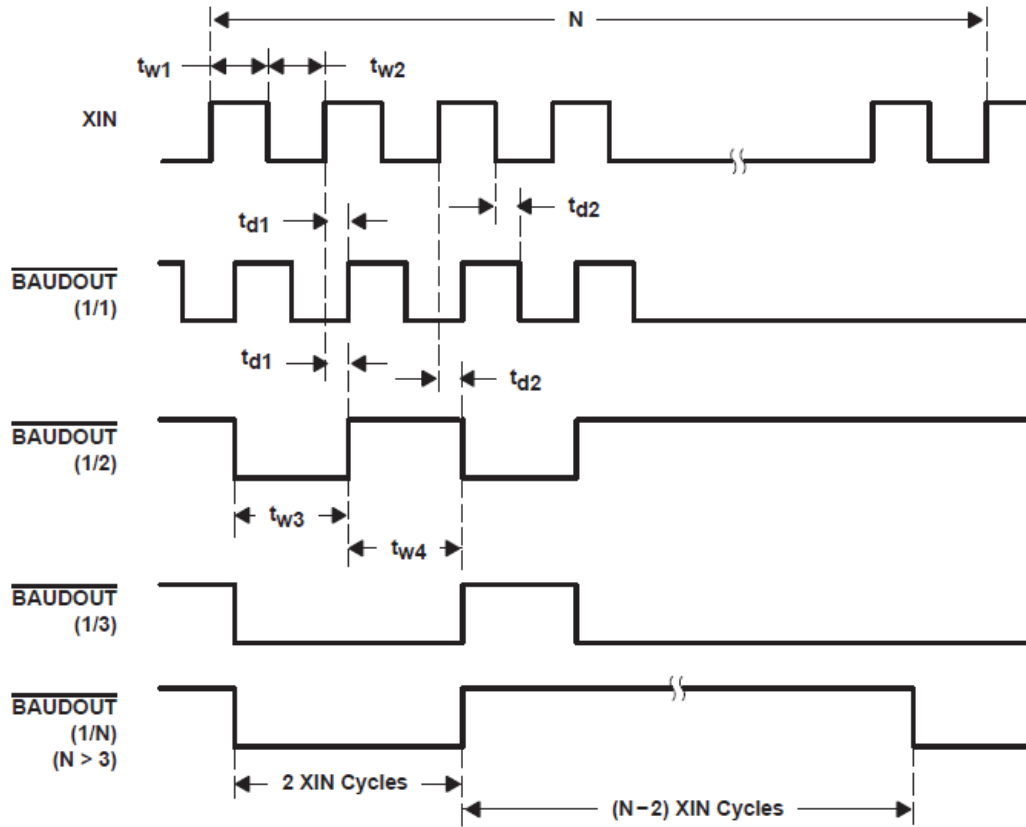


图 6-1. Baud Generator Timing Waveforms

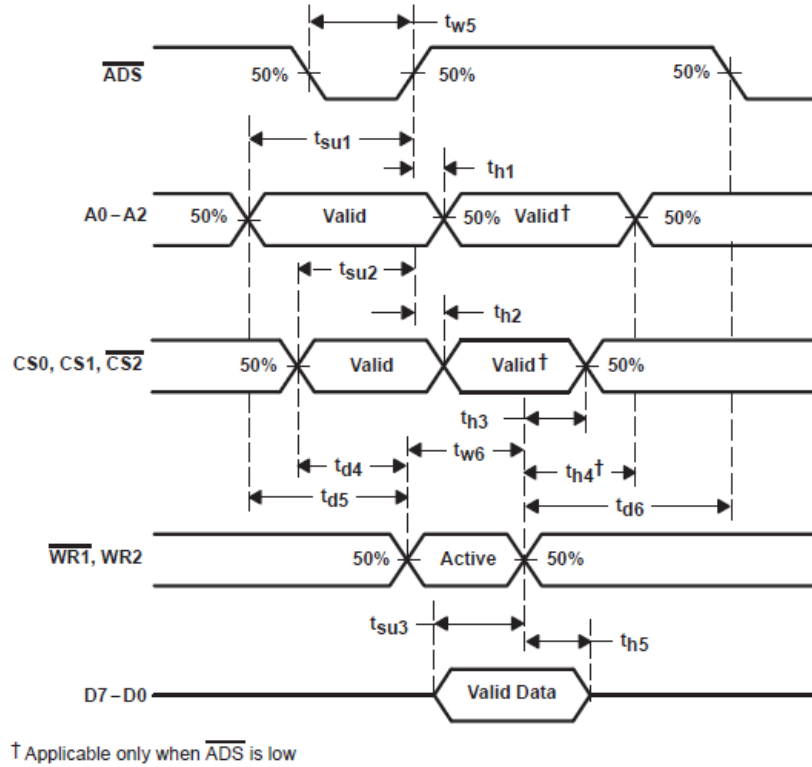
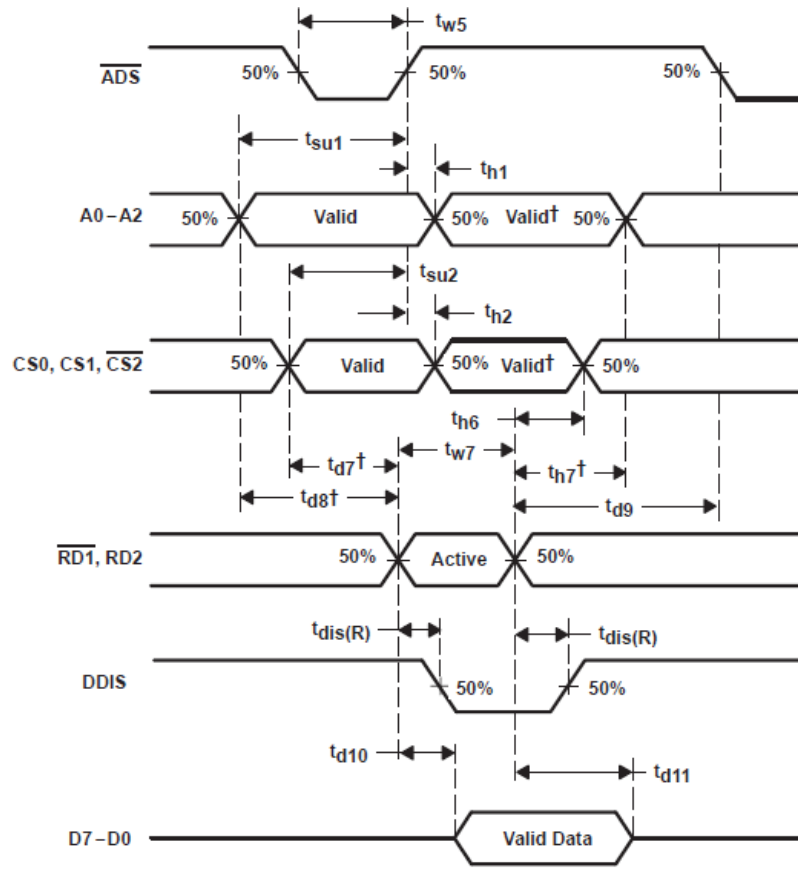


图 6-2. Write Cycle Timing Waveforms



† Applicable only when \overline{ADS} is low

图 6-3. Read Cycle Timing Waveforms

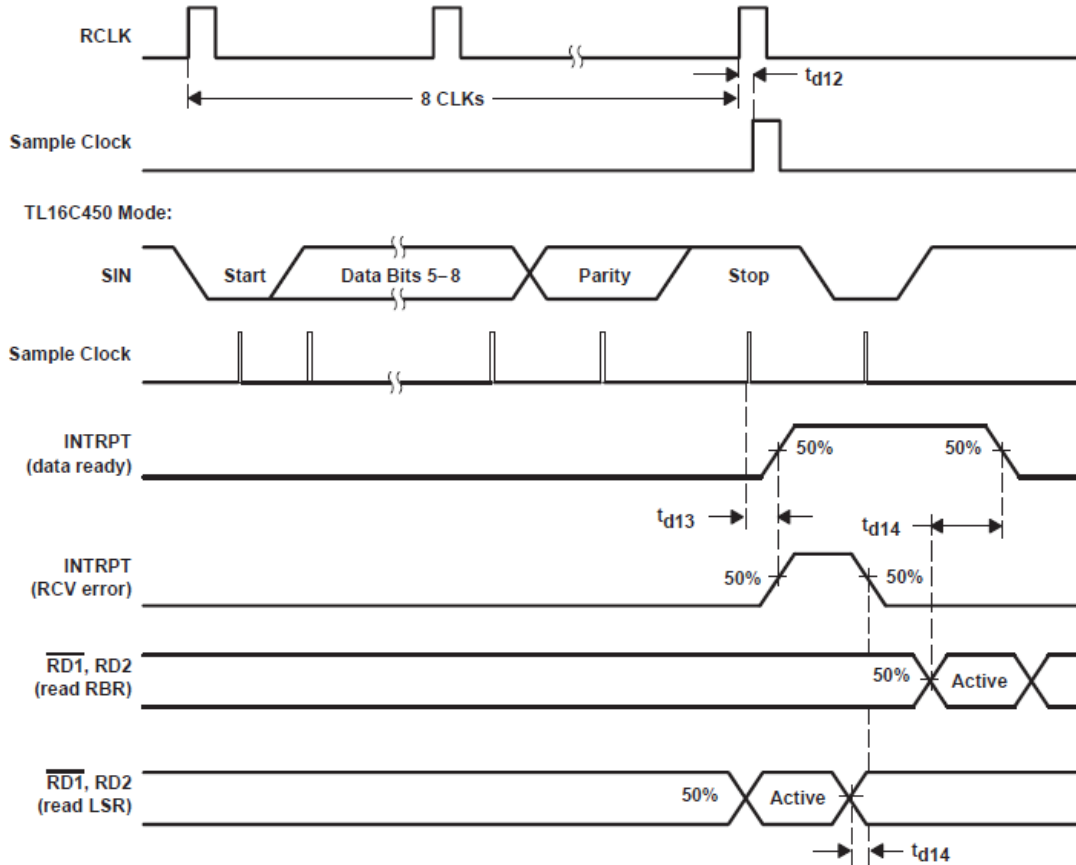


图 6-4. Receiver Timing Waveforms

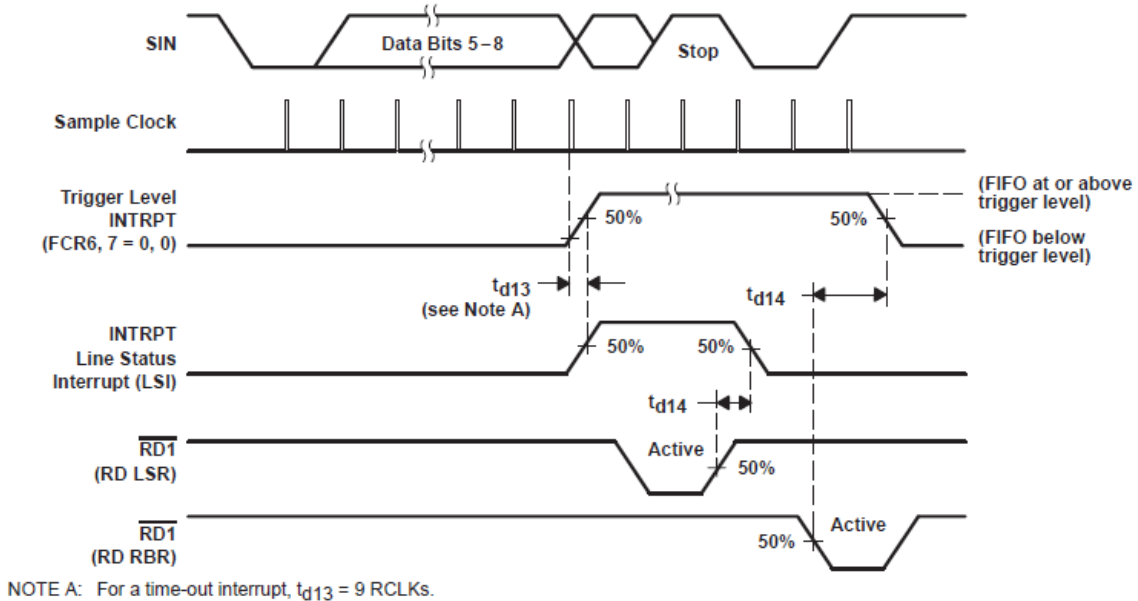
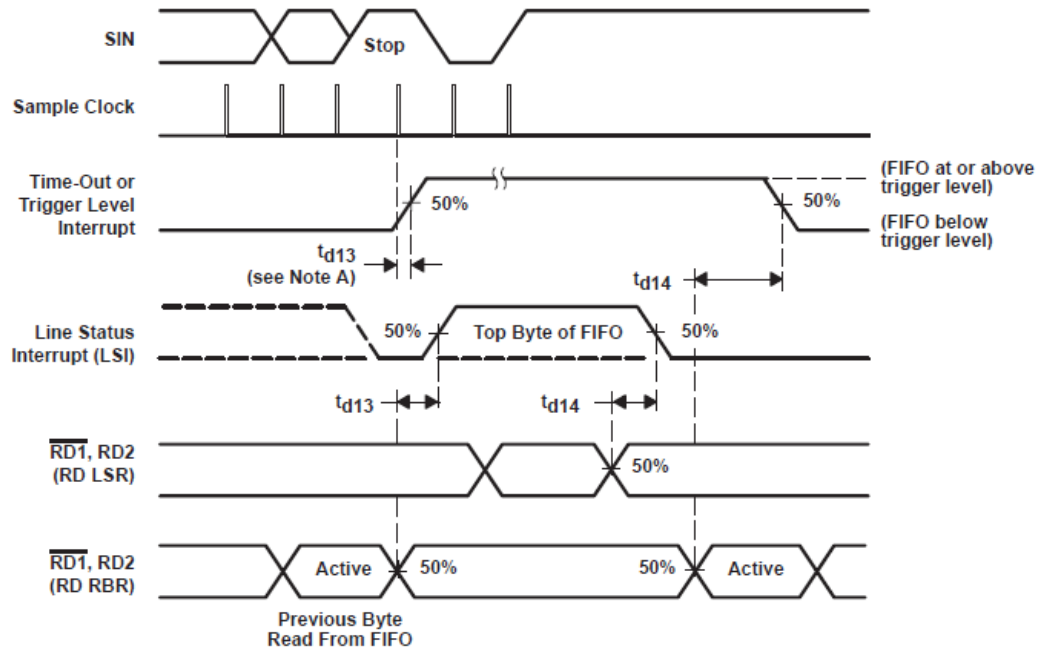
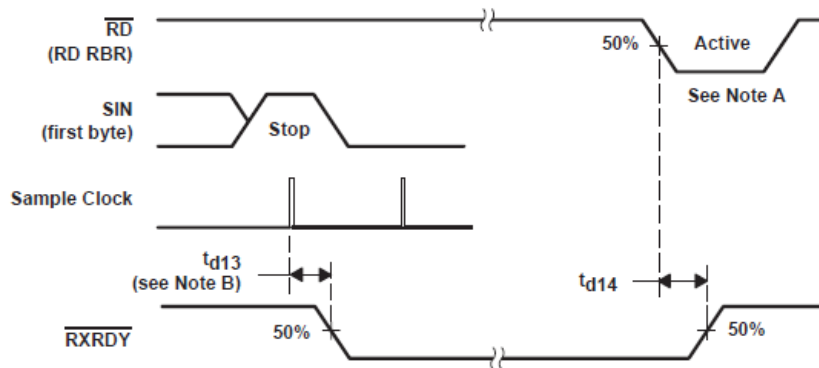


图 6-5. Receive FIFO First Byte (Sets DR Bit) Waveforms



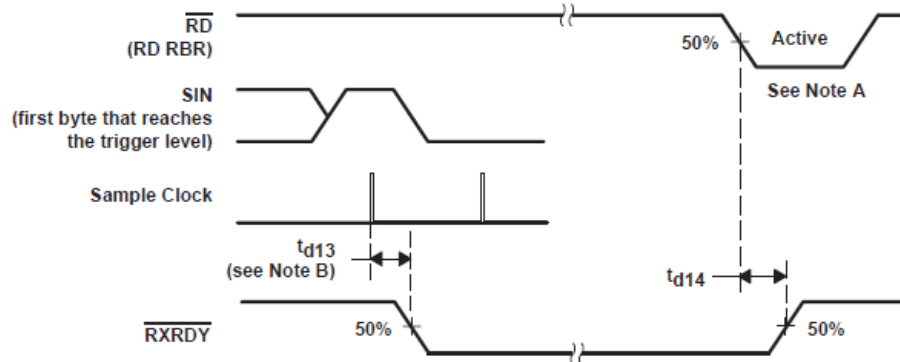
NOTE A: For a time-out interrupt, $t_{d13} = 9$ RCLKs.

图 6-6. Receive FIFO Bytes Other Than the First Byte (DR Internal Bit Already Set) Waveforms



NOTE A: This is the reading of the last byte in the FIFO.

图 6-7. Receiver Ready (\overline{RXRDY}) Waveforms, $FCR0 = 0$ or $FCR0 = 1$ and $FCR3 = 0$ (Mode 0)



NOTES: A. This is the reading of the last byte in the FIFO.
B. For a time-out interrupt, $t_{d13} = 9$ RCLKs.

图 6-8. Receiver Ready (RXRDY) Waveforms, FCR0 = 1 and FCR3 = 1 (Mode 1)

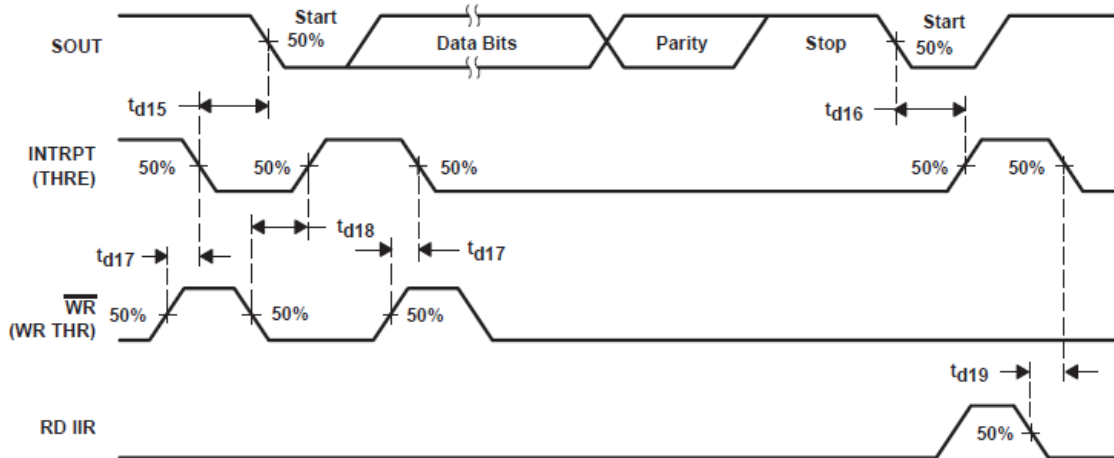


图 6-9. Transmitter Timing Waveforms

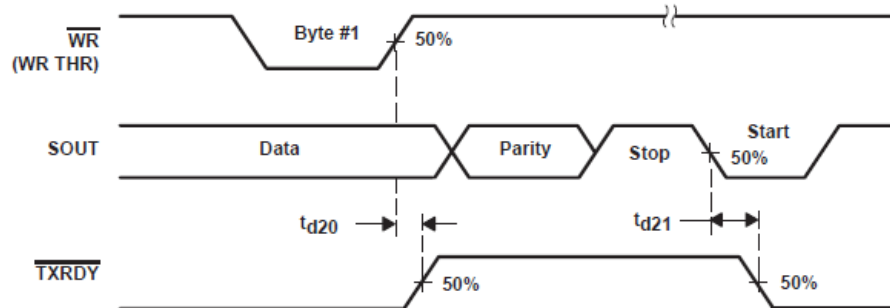


图 6-10. Transmitter Ready (TXRDY) Waveforms, FCR0 = 0 or FCR0 = 1 and FCR3 = 0 (Mode 0)

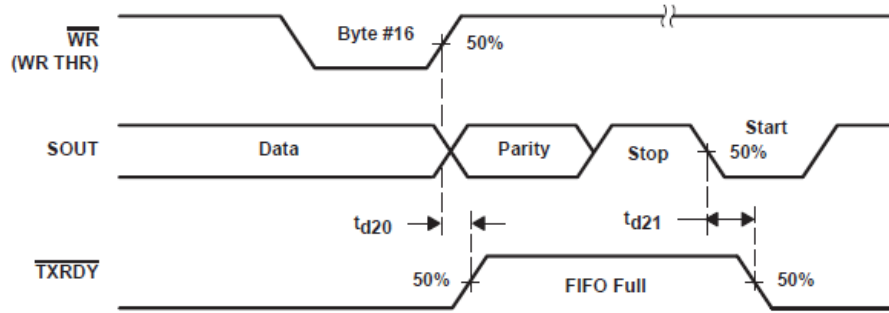


图 6-11. Transmitter Ready ($\overline{\text{TXRDY}}$) Waveforms, FCR0 = 1 and FCR3 = 1 (Mode 1)

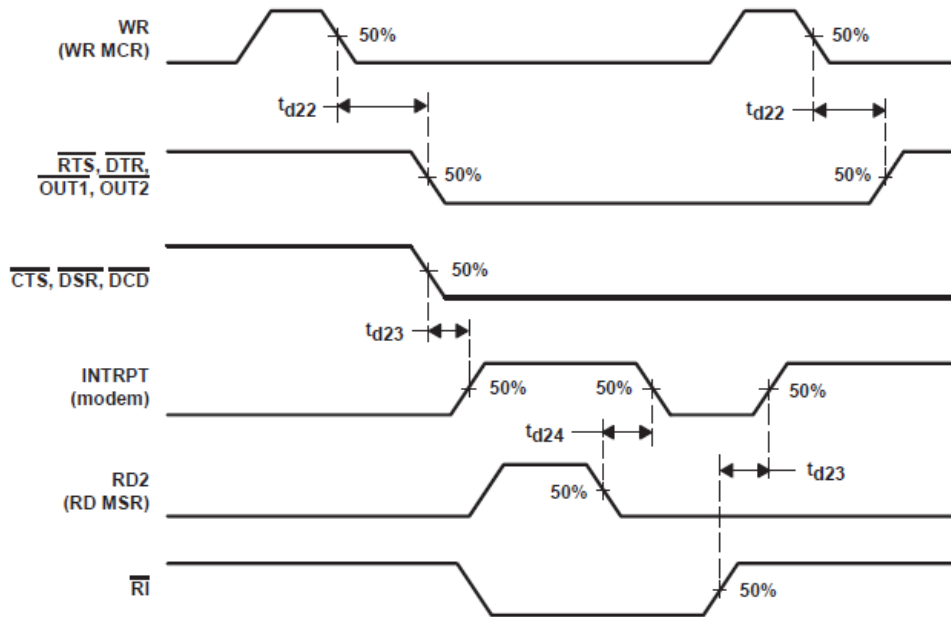


图 6-12. Modem Control Timing Waveforms

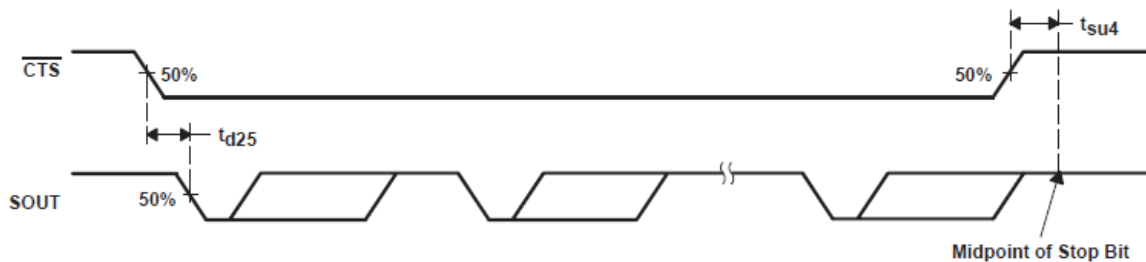


图 6-13. $\overline{\text{CTS}}$ and SOUT Autoflow Control Timing (Start and Stop) Waveforms

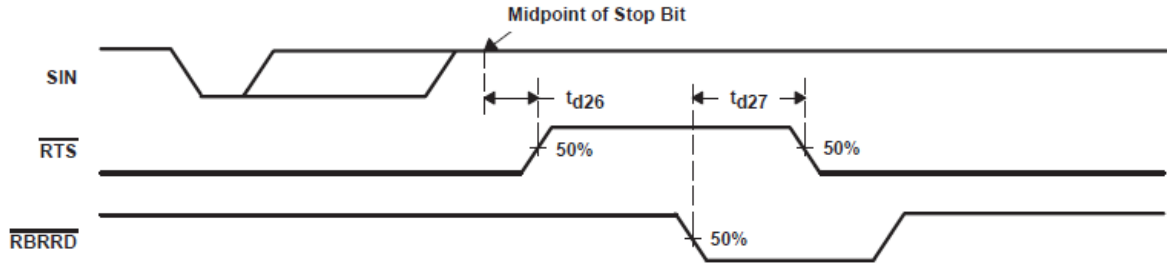


图 6-14. Auto-RTS Timing for RCV Threshold of 1, 4, or 8 Waveforms

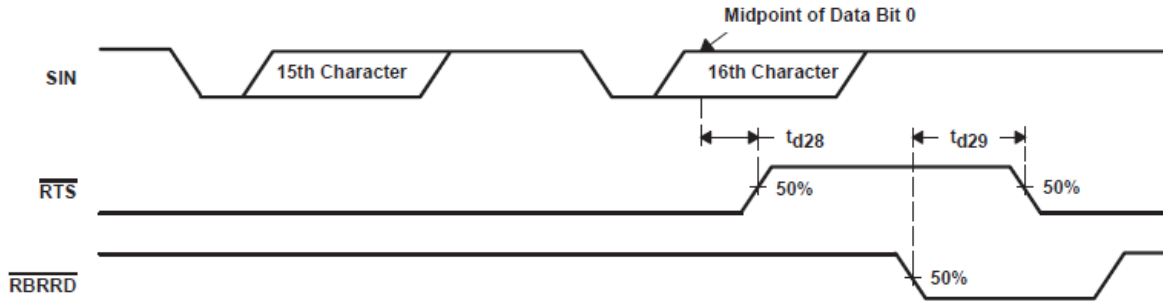


图 6-15. Auto-RTS Timing for RCV Threshold of 14 Waveforms

7 Detailed Description

7.1 Autoflow Control (see 图 7-1)

Autoflow control is comprised of auto- $\overline{\text{CTS}}$ and auto- $\overline{\text{RTS}}$. With auto- $\overline{\text{CTS}}$, the $\overline{\text{CTS}}$ input must be active before the transmitter FIFO can emit data. With auto- $\overline{\text{RTS}}$, $\overline{\text{RTS}}$ becomes active when the receiver needs more data and notifies the sending serial device. When $\overline{\text{RTS}}$ is connected to $\overline{\text{CTS}}$, data transmission does not occur unless the receiver FIFO has space for the data; thus, overrun errors are eliminated using ACE1 and ACE2 from a TLC16C550C with the autoflow control enabled. If not, overrun errors occur when the transmit data rate exceeds the receiver FIFO read latency.

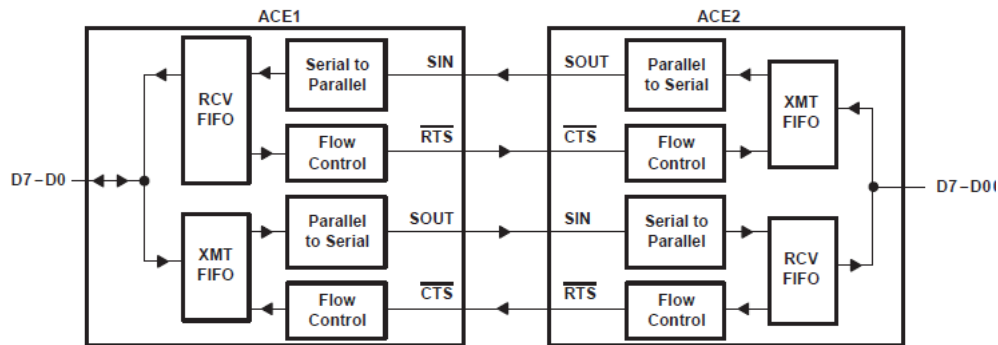


图 7-1. Autoflow Control (Auto- $\overline{\text{RTS}}$ and Auto- $\overline{\text{CTS}}$) Example

7.2 Auto- $\overline{\text{RTS}}$ (see 图 7-1)

Auto- $\overline{\text{RTS}}$ data flow control originates in the receiver timing and control block (see 节 7.6) 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 图 7-3), $\overline{\text{RTS}}$ 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 $\overline{\text{RTS}}$ until after it has begun sending the additional byte. $\overline{\text{RTS}}$ is automatically reasserted once the RCV FIFO is emptied by reading the receiver buffer register.

When the trigger level is 14 (see Figure 4), $\overline{\text{RTS}}$ is deasserted after the first data bit of the 16th character is present on the SIN line. $\overline{\text{RTS}}$ is reasserted when the RCV FIFO has at least one available byte space.

7.3 Auto- $\overline{\text{CTS}}$ (see 图 7-1)

The transmitter circuitry checks $\overline{\text{CTS}}$ before sending the next data byte. When $\overline{\text{CTS}}$ is active, it sends the next byte. To stop the transmitter from sending the following byte, $\overline{\text{CTS}}$ must be released before the middle of the last stop bit that is currently being sent (see 图 7-2). The auto- $\overline{\text{CTS}}$ function reduces interrupts to the host system. When flow control is enabled, $\overline{\text{CTS}}$ level changes do not trigger host interrupts because the device automatically controls its own transmitter. Without auto- $\overline{\text{CTS}}$, the transmitter sends any data present in the transmit FIFO and a receiver overrun error may result.

7.4 Enabling Autoflow Control and Auto- $\overline{\text{CTS}}$

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

7.5 Auto- $\overline{\text{CTS}}$ and Auto- $\overline{\text{RTS}}$ Functional Timing

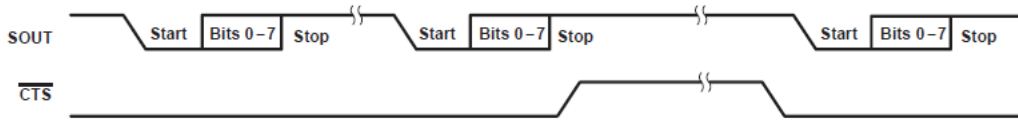


图 7-2. $\overline{\text{CTS}}$ Functional Timing Waveforms

NOTES:

1. When $\overline{\text{CTS}}$ is low, the transmitter keeps sending serial data out.
2. If $\overline{\text{CTS}}$ 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.
3. When $\overline{\text{CTS}}$ goes from high to low, the transmitter begins sending data again.

The receiver FIFO trigger level can be set to 1, 4, 8, or 14 bytes. These are described in 图 7-3 and 图 7-4.

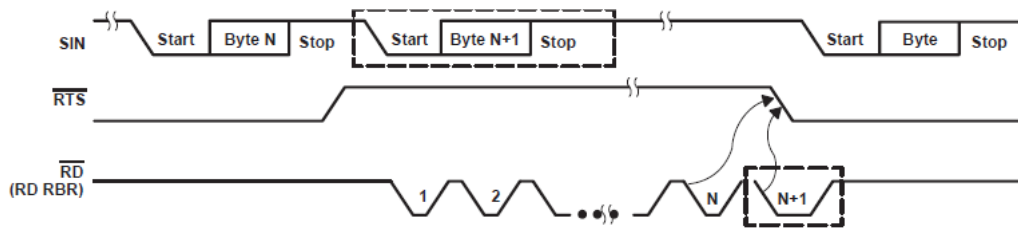


图 7-3. $\overline{\text{RTS}}$ Functional Timing Waveforms, RCV FIFO Trigger Level = 1, 4, or 8 Bytes

NOTES:

1. $N = \text{RCV FIFO trigger level (1, 4, or 8 bytes)}$
2. The two blocks in dashed lines cover the case where an additional byte is sent as described in the preceding auto- $\overline{\text{RTS}}$ section.

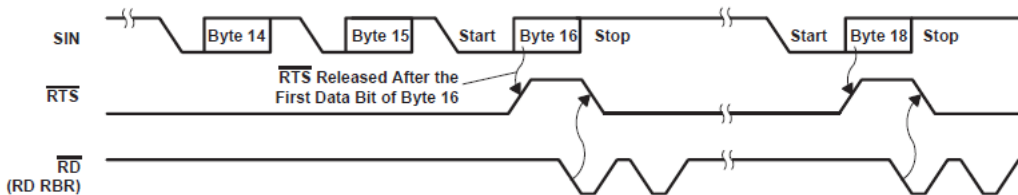
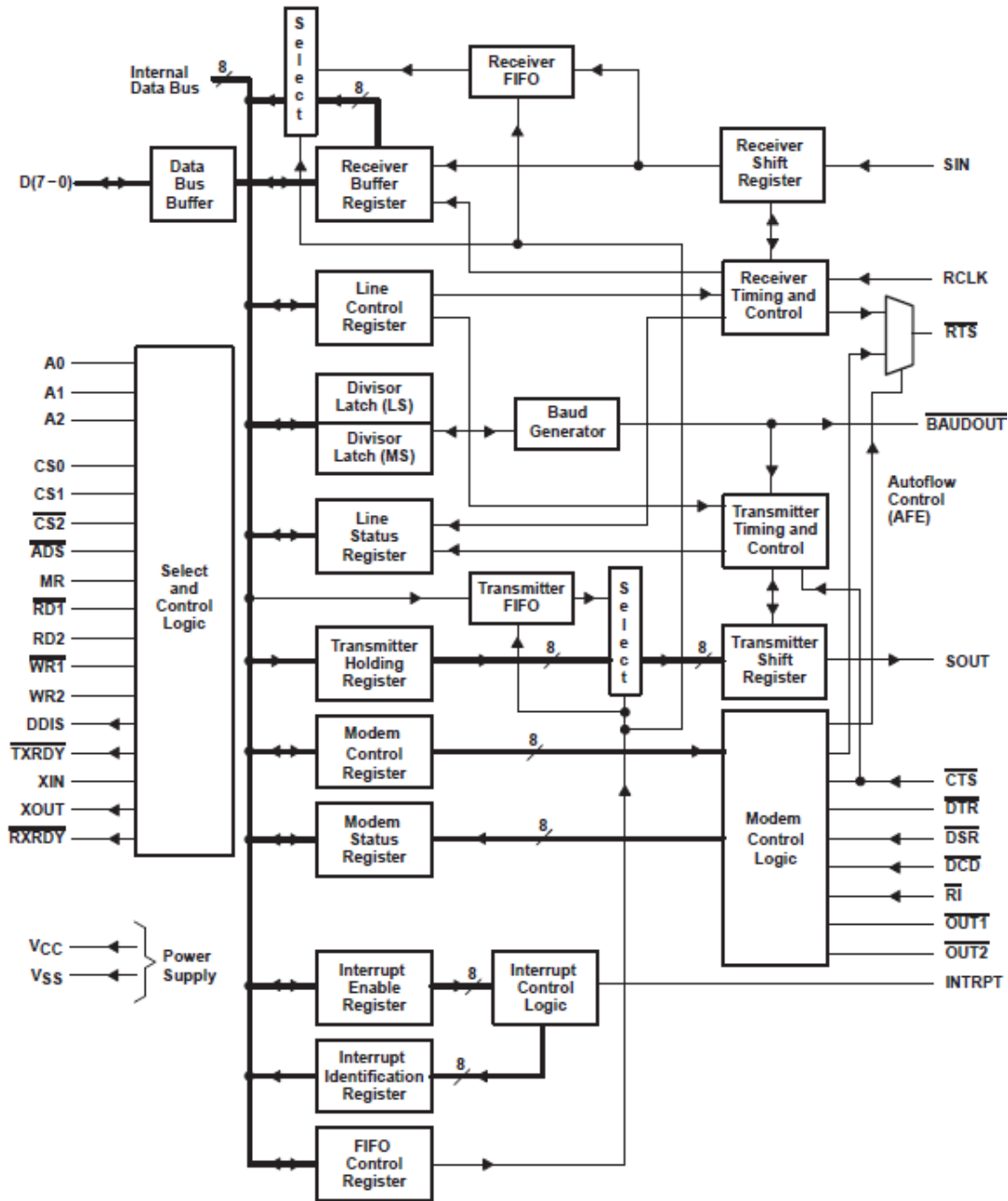


图 7-4. $\overline{\text{RTS}}$ Functional Timing Waveforms, RCV FIFO Trigger Level = 14 Bytes

NOTES:

1. $\overline{\text{RTS}}$ is deasserted when the receiver receives the first data bit of the sixteenth byte. The receive FIFO is full after finishing the sixteenth byte.
2. $\overline{\text{RTS}}$ 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.
3. When the receive FIFO is full, the first receive buffer register read reasserts $\overline{\text{RTS}}$.

7.6 Functional Block Diagram



7.7 Principles of Operation

表 7-1. Register Selection

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

表 7-1. Register Selection (continued)

DLAB ⁽¹⁾	A2	A1	A0	REGISTER
X	H	H	L	Modem status register
X	H	H	H	Scratch register
1	L	L	L	Divisor latch (LSB)
1	L	L	H	Divisor latch (MSB)

(1) 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 4).

表 7-2. 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, 2, 3, 6, and 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
OUT2	Master reset	High
RTS	Master reset	High
DTR	Master reset	High
OUT1	Master reset	High
Scratch register	Master reset	No effect
Divisor latch (LSB and MSB) registers	Master reset	No effect
Receiver buffer register	Master reset	No effect
Transmitter holding register	Master reset	No effect
RCVR FIFO	MR/FCR1 –FCR0/ Δ FCR0	All bits cleared
XMIT FIFO	MR/FCR2 –FCR0/ Δ FCR0	All bits cleared

7.7.1 Accessible Registers

The system programmer, using the CPU, has access to and control over any of the ACE registers that are summarized in [表 7-2](#). These registers control ACE operations, receive data, and transmit data. Descriptions of these registers follow [表 7-3](#).

表 7-3. 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 ⁽¹⁾	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 (Δ CTS)	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 (Δ DSR)	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 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 ⁽²⁾	DMA Mode Select	Parity Enable (PEN)	OUT2	Framing Error (FE)	Delta Data Carrier Detect (Δ DCD)	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	Autoflow Control Enable (AFE)	Transmitter Holding Register (THRE)	Data Set Ready (DSR)	Bit 5	Bit 5	Bit 13
6	Data Bit 6	Data Bit 6	0	FIFOs Enabled ⁽²⁾	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 ⁽²⁾	Receiver Trigger (MSB)	Divisor Latch Access Bit (DLAB)	0	Error in RCVR FIFO ⁽²⁾	Data Carrier Detect (DCD)	Bit 7	Bit 7	Bit 15

(1) Bit 0 is the least significant bit. It is the first bit serially transmitted or received.
 (2) These bits are always 0 in the TL16C450 mode.

7.7.2 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 and clears the FIFOs, sets the receiver FIFO trigger level, and selects the type of DMA signalling.

- Bit 0: This bit, when set, enables the transmitter and receiver FIFOs. Bit 0 must be set when other FCR bits are written to or they are not programmed. Changing this bit clears the FIFOs.
- Bit 1: This bit, when set, clears all bytes in the receiver FIFO and clears its counter. The shift register is not cleared. The 1 that is written to this bit position is self clearing.
- Bit 2: This bit, when set, clears all bytes in the transmit FIFO and clears its counter. The shift register is not cleared. The 1 that is written to this bit position is self clearing.
- Bit 3: When FCR0 is set, setting FCR3 causes $\overline{\text{RXRDY}}$ and $\overline{\text{TXRDY}}$ to change from level 0 to level 1.
- Bits 4 and 5: These two bits are reserved for future use.
- Bits 6 and 7: These two bits set the trigger level for the receiver FIFO interrupt (see [表 7-4](#)).

表 7-4. 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

7.7.3 FIFO Interrupt Mode Operation

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

1. The received data available interrupt is issued to the microprocessor when the FIFO has reached its programmed trigger level. It is cleared when the FIFO drops below its programmed trigger level.
2. The IIR receive data available indication also occurs when the FIFO trigger level is reached, and like the interrupt, it is cleared when the FIFO drops below the trigger level.
3. The receiver line status interrupt (IIR = 06) has higher priority than the received data available (IIR = 04) interrupt.
4. The data ready bit (LSR0) is set when a character is transferred from the shift register to the receiver FIFO. It is cleared when the FIFO is empty.

When the receiver FIFO and receiver interrupts are enabled:

1.
 - At least one character is in the FIFO.
 - The most recent serial character was received more than four continuous character times ago (if two stop bits are programmed, the second one is included in this time delay).
 - The most recent microprocessor read of the FIFO has occurred more than four continuous character times before. This causes a maximum character received command to interrupt an issued delay of 160 ms at a 300 baud rate with a 12-bit character.
2. Character times are calculated by using the RCLK input for a clock signal (makes the delay proportional to the baud rate).
3. When a time-out interrupt has occurred, it is cleared and the timer is cleared when the microprocessor reads one character from the receiver FIFO.
4. When a time-out interrupt has not occurred, the time-out timer is cleared after a new character is received or after the microprocessor reads the receiver FIFO.

When the transmitter FIFO and THRE interrupt 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] when 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 holding register empty interrupt 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 the FIFO was empty. The first transmitter interrupt after changing FCR0 is immediate if it is enabled.

7.7.4 FIFO Polled Mode Operation

With FCR0 = 1 (transmitter and receiver FIFOs enabled), clearing IER0, IER1, IER2, IER3, or all four to 0 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. As stated previously:

- LSR0 is set as long as there is one byte in the receiver FIFO.
- LSR1 – LSR 4 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 THR is empty.
- LSR6 indicates that both the THR and TSR 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 transmitter FIFOs are still fully capable of holding characters.

7.7.5 Interrupt Enable Register (IER)

The IER enables each of the five types of interrupts (refer to [表 7-5](#)) and enables INTRPT 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 [表 7-3](#) and are described in the following bullets.

- Bit 0: When set, this bit enables the received data available interrupt.
- Bit 1: When set, this bit enables the THRE interrupt.
- Bit 2: When set, this bit enables the receiver line status interrupt.
- Bit 3: When set, this bit enables the modem status interrupt.
- Bits 4 through 7: These bits are not used (always cleared).

7.7.6 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 encodes the type of interrupt in its three least significant bits (bits 0, 1, and 2). The contents of this register are summarized in [表 7-3](#) and described in [表 7-5](#). Detail on each bit is as follows:

- Bit 0: This bit is used either in a hardware prioritized or polled interrupt system. When bit 0 is cleared, an interrupt is pending. If 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 3.
- Bit 3: This bit is always cleared in TL16C450 mode. In FIFO mode, bit 3 is set with bit 2 to indicate that a time-out interrupt is pending.
- Bits 4 and 5: These two bits are not used (always cleared).

- Bits 6 and 7: These bits are always cleared in TL16C450 mode. They are set when bit 0 of the FIFO control register is set.

表 7-5. 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	Read 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	Read 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	Read the receiver buffer register
0	0	1	0	3	Transmitter holding register empty	Transmitter holding register empty	Read 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	Read the modem status register

7.7.7 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 [表 7-3](#) 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 [表 7-6](#).

表 7-6. 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 are shown in [表 7-7](#).

表 7-7. 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, if bit 3 is set, parity is checked. When bit 3 is cleared, no parity is generated or checked.
- Bit 4: This bit 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. If 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 SOUT is forced to the spacing (cleared) state. When bit 6 is cleared, the break condition is disabled and has no effect on the transmitter logic; it only effects SOUT.
- 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.

7.7.8 Line Status Register (LSR)

¹The LSR provides information to the CPU concerning the status of data transfers. The contents of this register are summarized in [表 7-3](#) and described in the following bulleted list.

- Bit 0: This bit is the data ready (DR) indicator for the receiver. DR is set whenever a complete incoming character has been received and transferred into the RBR or the FIFO. DR is cleared by reading all of the data in the RBR or the FIFO.
- Bit 1²: This bit is the overrun error (OE) indicator. When OE is set, it indicates that before the character in the RBR was read, it was overwritten by the next character transferred into the register. OE 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 overrun error 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 (**see Footnote 2**): This bit is the parity error (PE) indicator. When PE is set, it indicates that the parity of the received data character does not match the parity selected in the LCR (bit 4). PE 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.
- Bit 3 (**see Footnote 2**): This bit is the framing error (FE) indicator. When FE is set, it indicates that the received character did not have a valid (set) stop bit. FE 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 (**see Footnote 2**): This bit is the break interrupt (BI) indicator. When BI is set, it indicates that the received data input was held low for longer than a full-word transmission time. A full-word transmission time is defined as the total time to transmit the start, data, parity, and stop bits. BI 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 for at least two RCLK samples and then receives the next valid start bit.
- Bit 5: This bit is the THRE indicator. THRE 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 THRE is set, an interrupt is generated. THRE is set when the contents of the THR are transferred to the TSR. THRE is cleared concurrent with the loading of the THR by the CPU. In the FIFO mode, THRE is set when the transmit FIFO is empty; it is cleared when at least one byte is written to the transmit FIFO.
- Bit 6: This bit is the transmitter empty (TEMT) indicator. TEMT bit is set when the THR and the TSR are both empty. When either the THR or the TSR contains a data character, TEMT is cleared. In the FIFO mode, TEMT 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, framing, or break error in the FIFO. It is cleared when the microprocessor reads the LSR and there are no subsequent errors in the FIFO.

¹ The line status register is intended for read operations only; writing to this register is not recommended outside of a factory testing environment.

² Bits 1 through 4 are the error conditions that produce a receiver line status interrupt.

7.7.9 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 [表 7-3](#) and are described in the following bulleted list.

- Bit 0: This bit (DTR) controls the $\overline{\text{DTR}}$ output
- Bit 1: This bit (RTS) controls the RTS output
- Bit 2: This bit (OUT1) controls $\overline{\text{OUT1}}$, a user-designated output signal.
- Bit 3: This bit (OUT2) controls $\overline{\text{OUT2}}$, a user-designated output signal.

When any of bits 0 through 3 are set, the associated output is forced low. When any of these bits are cleared, the associated output is forced high.

- Bit 4: This bit (LOOP) provides a local loop back feature for diagnostic testing of the ACE. When LOOP is set, the following occurs:
 - The transmitter SOUT is set high.
 - The receiver SIN is disconnected.
 - The output of the TSR is looped back into the receiver shift register input.
 - The four modem control inputs ($\overline{\text{CTS}}$, $\overline{\text{DSR}}$, $\overline{\text{DCD}}$, and $\overline{\text{RI}}$) are disconnected.
 - The four modem control outputs ($\overline{\text{DTR}}$, RTS, $\overline{\text{OUT1}}$, and $\overline{\text{OUT2}}$) are internally connected to the four modem control inputs.
 - The four modem control outputs are forced to the inactive (high) levels.
- Bit 5: This bit (AFE) is the autoflow control enable. When set, the autoflow control as described in the detailed description is enabled.

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's 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 as shown in [表 7-8](#).

表 7-8. ACE Flow Configuration

MCR BIT 5 (AFE)	MCR BIT 1 (RTS)	ACE FLOW CONFIGURATION
1	1	Auto- $\overline{\text{RTS}}$ and auto- $\overline{\text{CTS}}$ enabled (autoflow control enabled)
1	0	Auto- $\overline{\text{CTS}}$ only enabled
0	X	Auto- $\overline{\text{RTS}}$ and auto- $\overline{\text{CTS}}$ disabled

7.7.10 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 [表 7-3](#) and are described in the following bulleted list.

- Bit 0: This bit is the change in clear-to-send (Δ CTS) indicator. Δ CTS indicates that the $\overline{\text{CTS}}$ input has changed state since the last time it was read by the CPU. When Δ CTS 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 (Δ CTS is cleared), no interrupt is generated.
- Bit 1: This bit is the change in data set ready (Δ DSR) indicator. Δ DSR indicates that the $\overline{\text{DSR}}$ input has changed state since the last time it was read by the CPU. When Δ DSR is set and the modem status interrupt is enabled, a modem status interrupt is generated.
- Bit 2: This bit is the trailing edge of the ring indicator (TERI) detector. TERI indicates that the $\overline{\text{RI}}$ input to the chip has changed from a low to a high level. When TERI is set and the modem status interrupt is enabled, a modem status interrupt is generated.
- Bit 3: This bit is the change in data carrier detect (Δ DCD) indicator. Δ DCD indicates that the $\overline{\text{DCD}}$ input to the chip has changed state since the last time it was read by the CPU. When Δ DCD is set and the modem status interrupt is enabled, a modem status interrupt is generated.
- Bit 4: This bit is the complement of the clear-to-send ($\overline{\text{CTS}}$) input. When the ACE is in the diagnostic test mode (LOOP [MCR4] = 1), this bit is equal to the MCR bit 1 (RTS).
- Bit 5: This bit is the complement of the data set ready ($\overline{\text{DSR}}$) input. When the ACE is in the diagnostic test mode (LOOP [MCR4] = 1), this bit is equal to the MCR bit 0 (DTR).
- Bit 6: This bit is the complement of the ring indicator ($\overline{\text{RI}}$) input. When the ACE is in the diagnostic test mode (LOOP [MCR4] = 1), this bit is equal to the MCR bit 2 (OUT1).
- Bit 7: This bit is the complement of the data carrier detect ($\overline{\text{DCD}}$) input. When the ACE is in the diagnostic test mode (LOOP [MCR4] = 1), this bit is equal to the MCR bit 3 (OUT2).

7.7.11 Programming Baud Generator

The ACE contains a programmable baud generator that takes a clock input in the range between dc and 16 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 x) the baud rate. The formula for the divisor is:

$$\text{divisor} = \text{XIN frequency input} \div (\text{desired baud rate} \times 16) \quad (1)$$

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 desired 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.

表 7-9 和 表 7-10 illustrate the use of the baud generator with crystal frequencies of 1.8432 MHz and 3.072 MHz respectively. For baud rates of 38.4 kbits/s and below, the error obtained is very small. The accuracy of the selected baud rate is dependent on the selected crystal frequency (refer to 图 7-5 for examples of typical clock circuits).

表 7-9. Baud Rates Using a 1.8432-MHz Crystal

DESIRED BAUD RATE	DIVISOR USED TO GENERATE 16 x 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

表 7-10. Baud Rates Using a 3.072-MHz Crystal

DESIRED BAUD RATE	DIVISOR USED TO GENERATE 16 x CLOCK	PERCENT ERROR DIFFERENCE BETWEEN DESIRED AND ACTUAL
50	3840	
75	2560	
110	1745	0.026
134.5	1428	0.034
150	1280	
300	640	
600	320	
1200	160	
1800	107	0.312
2000	96	
2400	80	
3600	53	0.628

表 7-10. Baud Rates Using a 3.072-MHz Crystal (continued)

DESIRED BAUD RATE	DIVISOR USED TO GENERATE 16 x CLOCK	PERCENT ERROR DIFFERENCE BETWEEN DESIRED AND ACTUAL
4800	40	
7200	27	1.23
9600	20	
19200	10	
38400	5	

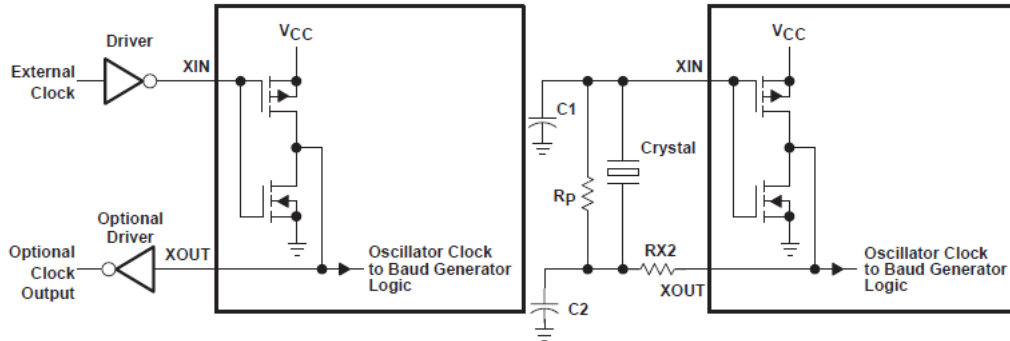


图 7-5. Typical Clock Circuits

表 7-11. TYPICAL CRYSTAL OSCILLATOR NETWORK

CRYSTAL	RP	RX2	C1	C2
3.072 MHz	1 MW	1.5 kW	10 – 30 pF	40 – 60 pF
1.8432 MHz	1 MW	1.5 kW	10 – 30 pF	40 – 60 pF

7.7.12 Receiver Buffet 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 x receiver clock (RCLK). Receiver section control is a function of the ACE line control register.

The ACE RSR receives serial data from SIN. The RSR then concatenates 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 (IER0 = 1), 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.

7.7.13 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.

7.7.14 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 $\overline{\text{BAUDOUT}}$. 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 shift register is idle, moves it into the TSR. The TSR serializes the data and outputs it at SOUT. In the TL16C450 mode, if the THR is empty and the transmitter holding register empty (THRE) interrupt is enabled (IER1 = 1), 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.

8 Application Information

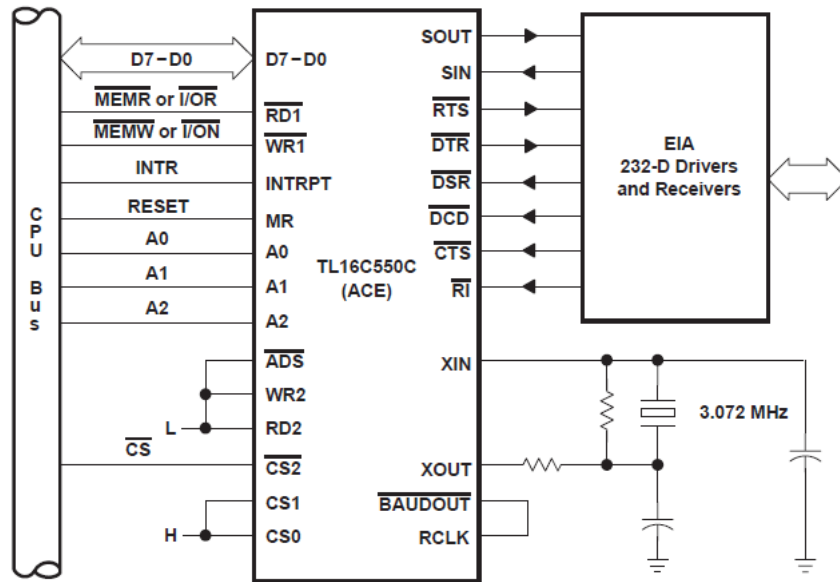


图 8-1. Basic TL16C550C Configuration

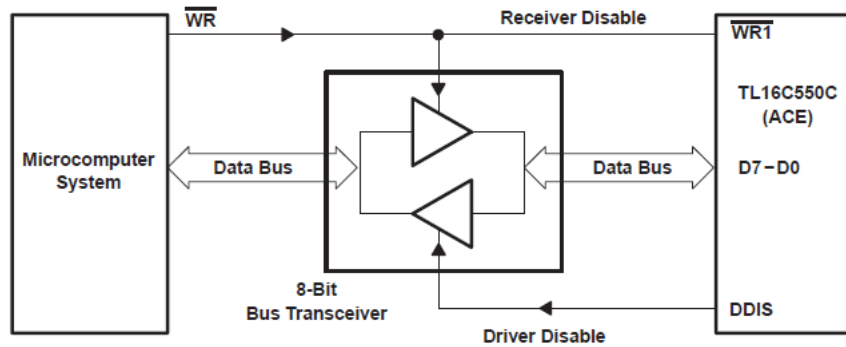


图 8-2. Typical Interface for a High Capacity Data Bus

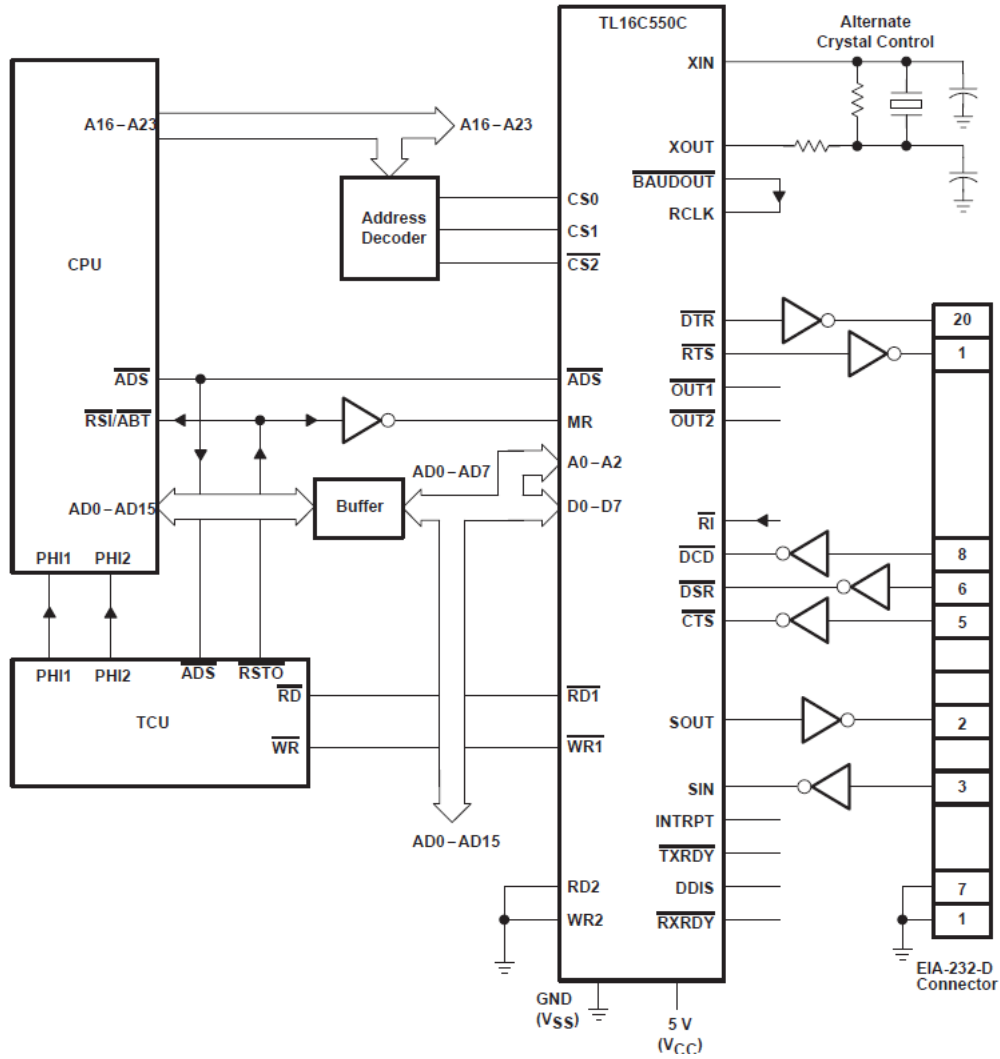


图 8-3. Typical TL16C550C Connection to a CPU

(2)

9 Device and Documentation Support

TI offers an extensive line of development tools. Tools and software to evaluate the performance of the device, generate code, and develop solutions are listed below.

9.1 接收文档更新通知

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9.2 支持资源

TI E2E™ [支持论坛](#) 是工程师的重要参考资料，可直接从专家获得快速、经过验证的解答和设计帮助。搜索现有解答或提出自己的问题可获得所需的快速设计帮助。

链接的内容由各个贡献者“按原样”提供。这些内容并不构成 TI 技术规范，并且不一定反映 TI 的观点；请参阅 TI 的 [《使用条款》](#)。

9.3 Trademarks

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ESD 的损坏小至导致微小的性能降级，大至整个器件故障。精密的集成电路可能更容易受到损坏，这是因为非常细微的参数更改都可能会导致器件与其发布的规格不相符。

9.5 术语表

[TI 术语表](#) 本术语表列出并解释了术语、首字母缩略词和定义。

10 Mechanical, Packaging, and Orderable Information

The following pages include mechanical, packaging, and orderable information. This information is the most current data available for the designated devices. This data is subject to change without notice and revision of this document. For browser-based versions of this data sheet, refer to the left-hand navigation.

PACKAGING INFORMATION

Orderable Device	Status (1)	Package Type	Package Drawing	Pins	Package Qty	Eco Plan (2)	Lead finish/ Ball material (6)	MSL Peak Temp (3)	Op Temp (°C)	Device Marking (4/5)	Samples
TL16C550CFNR	ACTIVE	PLCC	FN	44	500	RoHS & Green	NIPDAU	Level-3-260C-168 HR	0 to 70	TL16C550CFN	Samples
TL16C550CFNRG4	ACTIVE	PLCC	FN	44	500	RoHS & Green	NIPDAU	Level-3-260C-168 HR	0 to 70	TL16C550CFN	Samples
TL16C550CIFNR	ACTIVE	PLCC	FN	44	500	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 85	TL16C550CIFN	Samples
TL16C550CIFNRG4	ACTIVE	PLCC	FN	44	500	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 85	TL16C550CIFN	Samples
TL16C550CIPTR	ACTIVE	LQFP	PT	48	1000	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 85	TA550CI	Samples
TL16C550CIPTRG4	ACTIVE	LQFP	PT	48	1000	RoHS & Green	NIPDAU	Level-3-260C-168 HR	-40 to 85	TA550CI	Samples
TL16C550CPFBR	ACTIVE	TQFP	PFB	48	1000	RoHS & Green	NIPDAU	Level-2-260C-1 YEAR	0 to 70	TA550CPFB	Samples
TL16C550CPTR	ACTIVE	LQFP	PT	48	1000	RoHS & Green	NIPDAU	Level-3-260C-168 HR	0 to 70	TA550C	Samples
TL16C550CPTRG4	ACTIVE	LQFP	PT	48	1000	RoHS & Green	NIPDAU	Level-3-260C-168 HR	0 to 70	TA550C	Samples

(1) The marketing status values are defined as follows:

ACTIVE: Product device recommended for new designs.

LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.

NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.

PREVIEW: Device has been announced but is not in production. Samples may or may not be available.

OBSOLETE: TI has discontinued the production of the device.

(2) **RoHS:** TI defines "RoHS" to mean semiconductor products that are compliant with the current EU RoHS requirements for all 10 RoHS substances, including the requirement that RoHS substance do not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, "RoHS" products are suitable for use in specified lead-free processes. TI may reference these types of products as "Pb-Free".

RoHS Exempt: TI defines "RoHS Exempt" to mean products that contain lead but are compliant with EU RoHS pursuant to a specific EU RoHS exemption.

Green: TI defines "Green" to mean the content of Chlorine (Cl) and Bromine (Br) based flame retardants meet JS709B low halogen requirements of <=1000ppm threshold. Antimony trioxide based flame retardants must also meet the <=1000ppm threshold requirement.

(3) MSL, Peak Temp. - The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

(4) There may be additional marking, which relates to the logo, the lot trace code information, or the environmental category on the device.

⁽⁵⁾ Multiple Device Markings will be inside parentheses. Only one Device Marking contained in parentheses and separated by a "~" will appear on a device. If a line is indented then it is a continuation of the previous line and the two combined represent the entire Device Marking for that device.

⁽⁶⁾ Lead finish/Ball material - Orderable Devices may have multiple material finish options. Finish options are separated by a vertical ruled line. Lead finish/Ball material values may wrap to two lines if the finish value exceeds the maximum column width.

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TAPE AND REEL INFORMATION

QUADRANT ASSIGNMENTS FOR PIN 1 ORIENTATION IN TAPE


*All dimensions are nominal

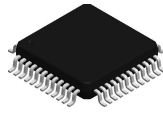
Device	Package Type	Package Drawing	Pins	SPQ	Reel Diameter (mm)	Reel Width W1 (mm)	A0 (mm)	B0 (mm)	K0 (mm)	P1 (mm)	W (mm)	Pin1 Quadrant
TL16C550CIPTR	LQFP	PT	48	1000	330.0	16.4	9.6	9.6	1.9	12.0	16.0	Q2
TL16C550CIPTR	LQFP	PT	48	1000	330.0	16.4	9.6	9.6	1.9	12.0	16.0	Q2
TL16C550CPFBR	TQFP	PFB	48	1000	330.0	16.4	9.6	9.6	1.5	12.0	16.0	Q2
TL16C550CPFBR	TQFP	PFB	48	1000	330.0	16.4	9.6	9.6	1.5	12.0	16.0	Q2
TL16C550CPTR	LQFP	PT	48	1000	330.0	16.4	9.6	9.6	1.9	12.0	16.0	Q2
TL16C550CPTR	LQFP	PT	48	1000	330.0	16.4	9.6	9.6	1.9	12.0	16.0	Q2

TAPE AND REEL BOX DIMENSIONS


*All dimensions are nominal

Device	Package Type	Package Drawing	Pins	SPQ	Length (mm)	Width (mm)	Height (mm)
TL16C550CIPTR	LQFP	PT	48	1000	350.0	350.0	43.0
TL16C550CIPTR	LQFP	PT	48	1000	350.0	350.0	43.0
TL16C550CPFBR	TQFP	PFB	48	1000	350.0	350.0	43.0
TL16C550CPFBR	TQFP	PFB	48	1000	350.0	350.0	43.0
TL16C550CPTR	LQFP	PT	48	1000	350.0	350.0	43.0
TL16C550CPTR	LQFP	PT	48	1000	350.0	350.0	43.0

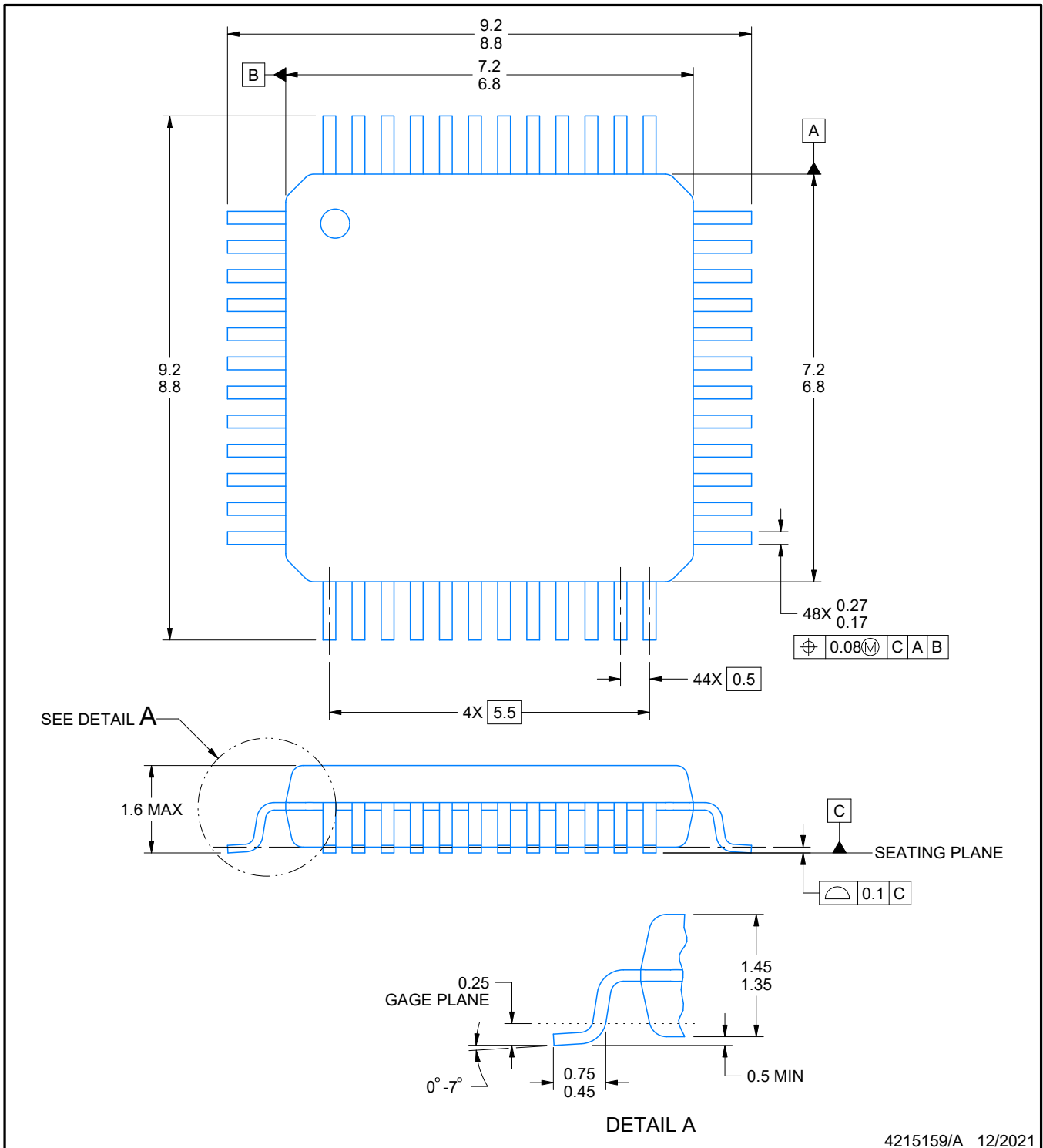
PT0048A



PACKAGE OUTLINE

LQFP - 1.6 mm max height

LOW PROFILE QUAD FLATPACK



NOTES:

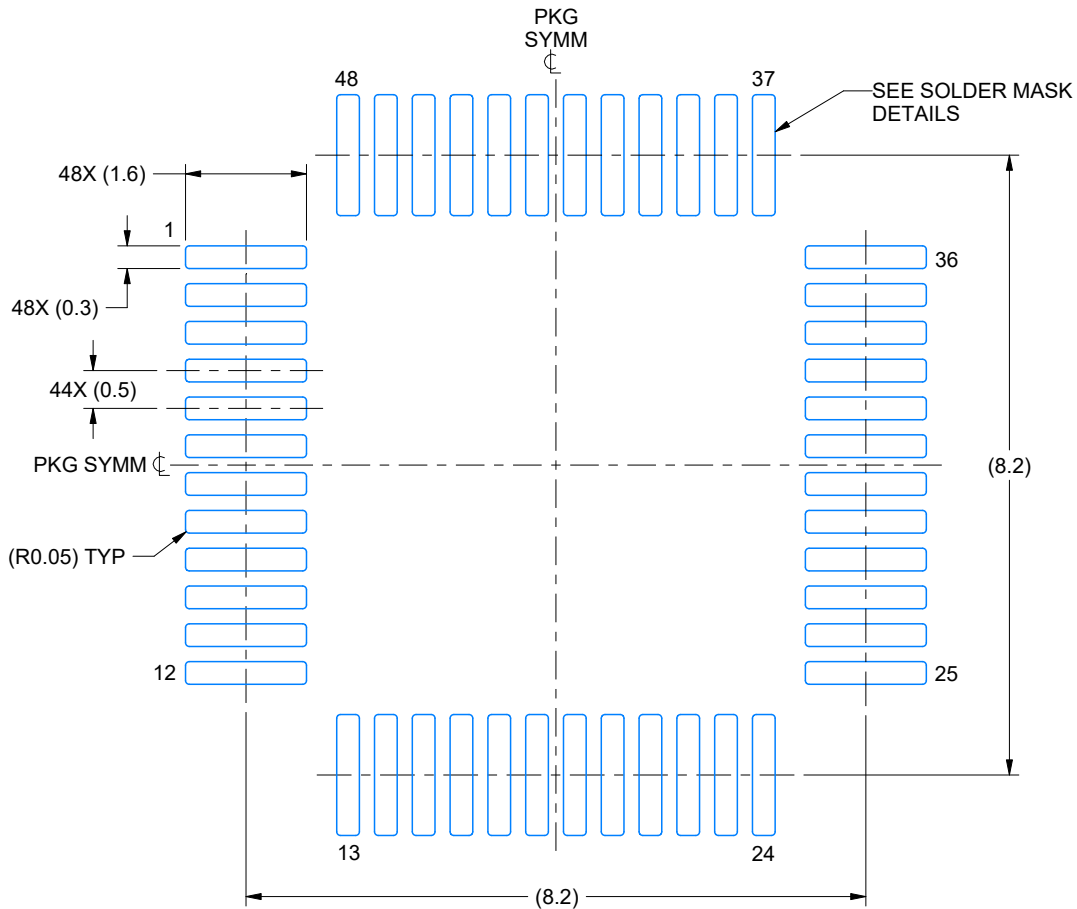
1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Reference JEDEC registration MS-026.
4. This may also be a thermally enhanced plastic package with leads connected to the die pads.

EXAMPLE BOARD LAYOUT

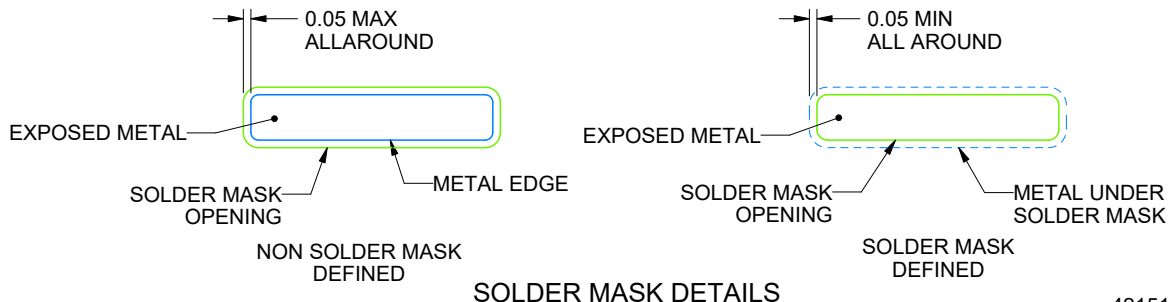
PT0048A

LQFP - 1.6 mm max height

LOW PROFILE QUAD FLATPACK



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE 10.000



SOLDER MASK DETAILS

4215159/A 12/2021

NOTES: (continued)

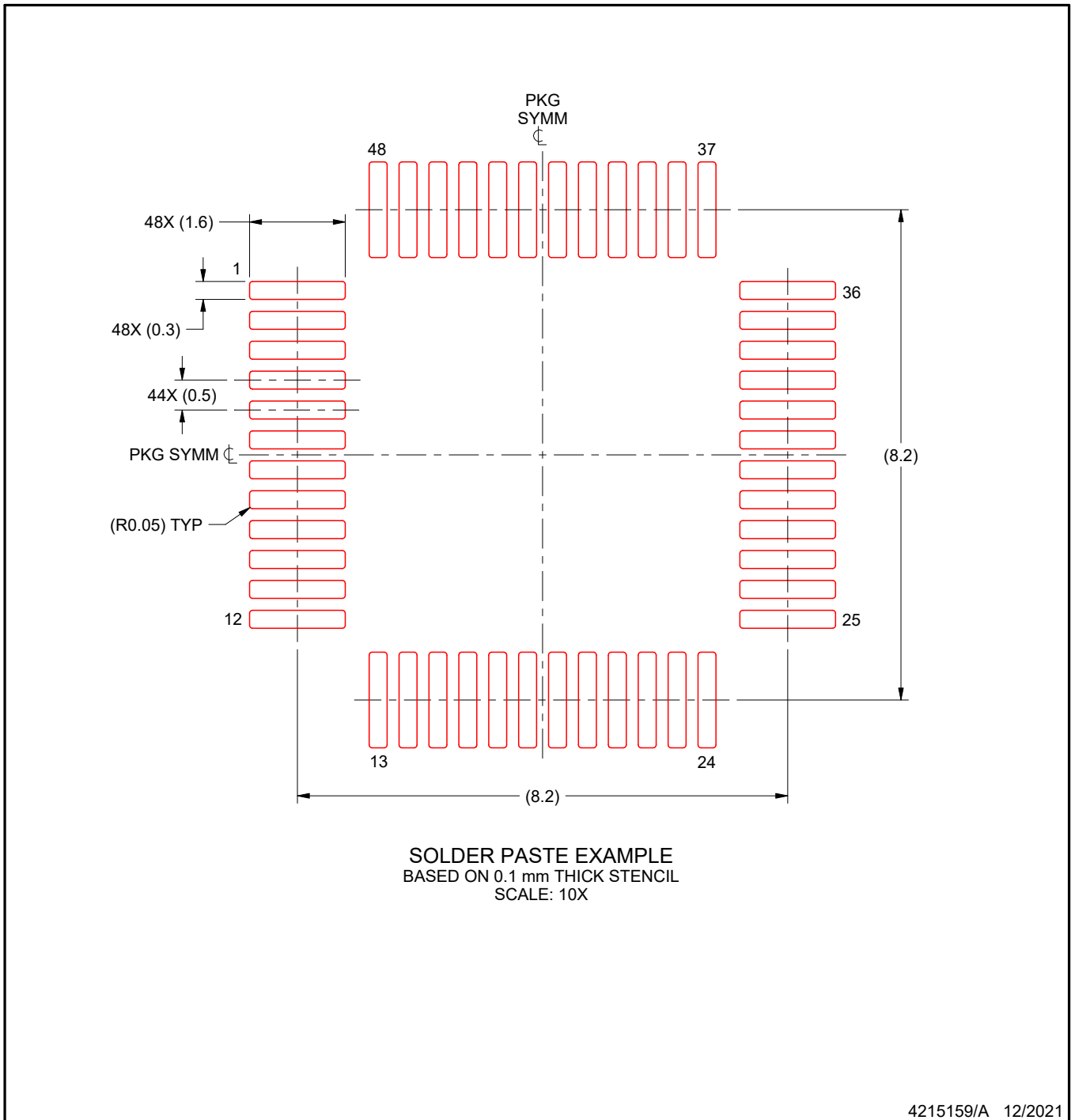
- 5. Publication IPC-7351 may have alternate designs.
- 6. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

PT0048A

LQFP - 1.6 mm max height

LOW PROFILE QUAD FLATPACK



NOTES: (continued)

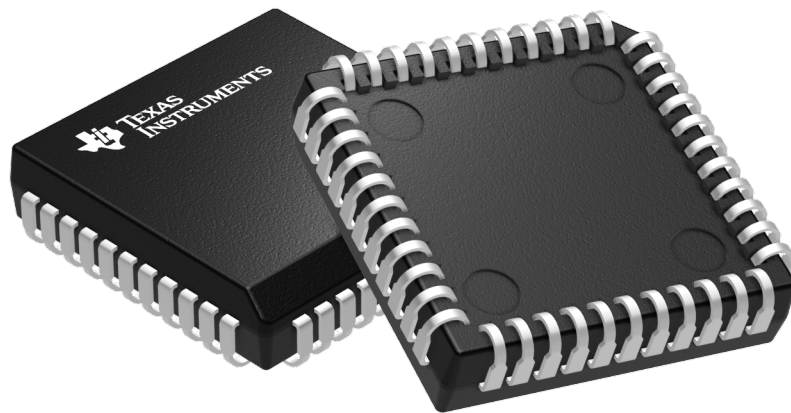
7. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
8. Board assembly site may have different recommendations for stencil design.

GENERIC PACKAGE VIEW

FN 44

PLCC - 4.57 mm max height

PLASTIC CHIP CARRIER



Images above are just a representation of the package family, actual package may vary.
Refer to the product data sheet for package details.

4040005-4/C

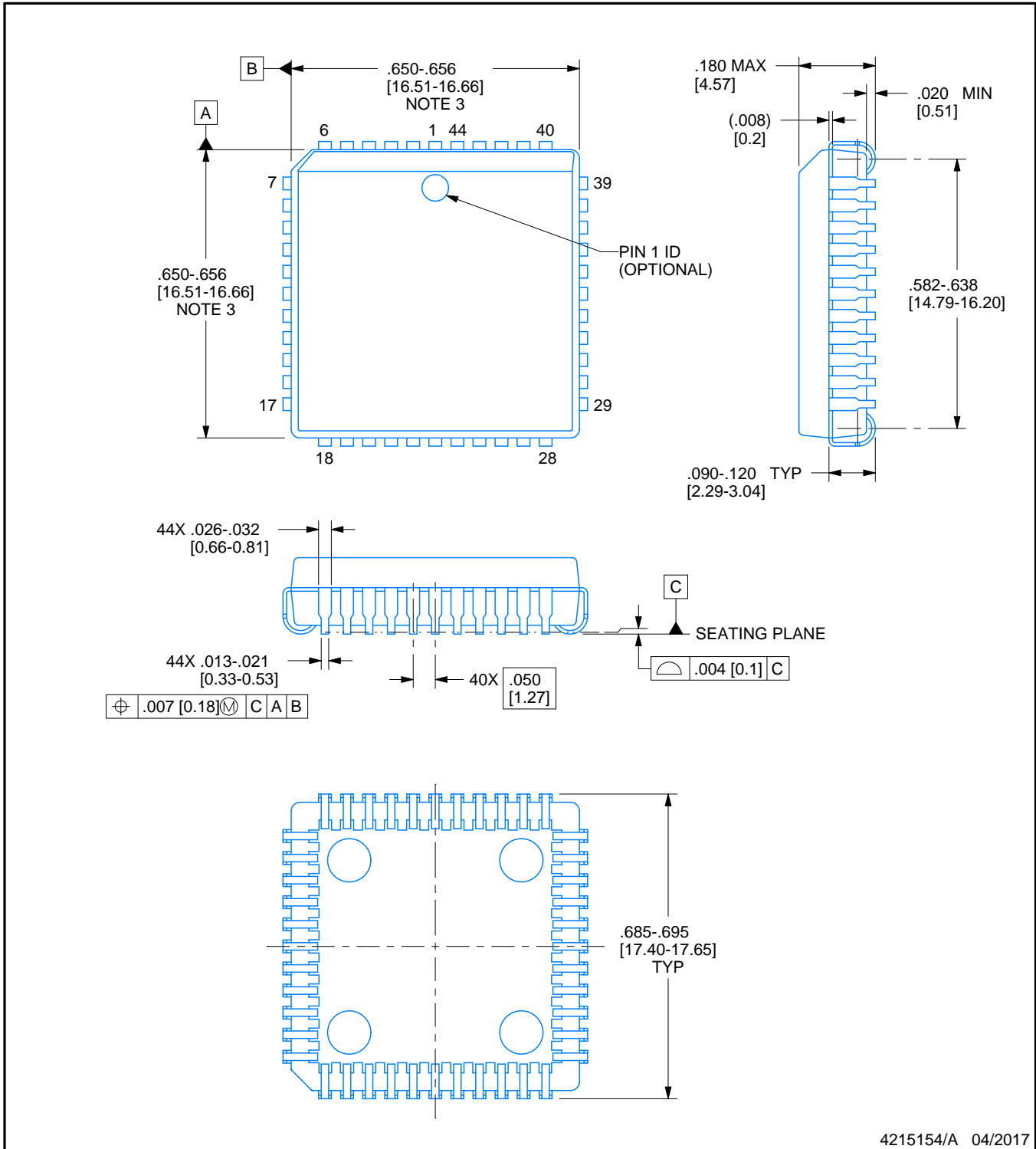


FN0044A

PACKAGE OUTLINE

PLCC - 4.57 mm max height

PLASTIC CHIP CARRIER



4215154/A 04/2017

NOTES:

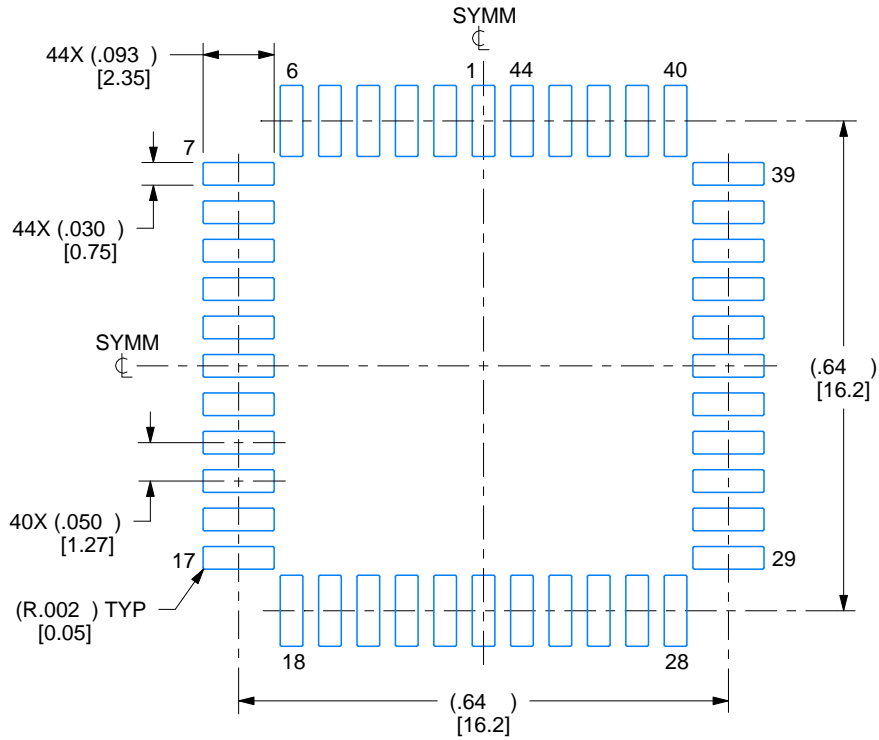
1. All linear dimensions are in inches. Any dimensions in brackets are in millimeters. Any dimensions in parenthesis are for reference only. Controlling dimensions are in inches. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.
3. Dimension does not include mold protrusion. Maximum allowable mold protrusion .01 in [0.25 mm] per side.
4. Reference JEDEC registration MS-018.

EXAMPLE BOARD LAYOUT

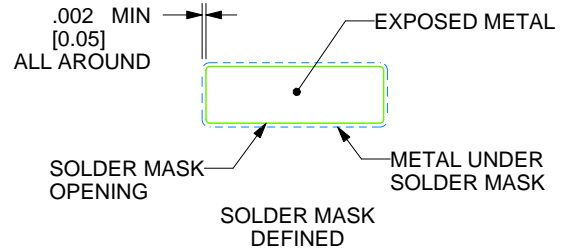
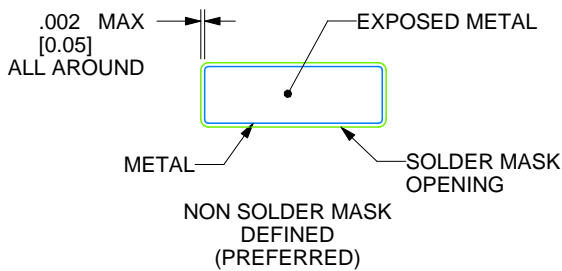
FN0044A

PLCC - 4.57 mm max height

PLASTIC CHIP CARRIER



LAND PATTERN EXAMPLE
EXPOSED METAL SHOWN
SCALE:4X



SOLDER MASK DETAILS

4215154/A 04/2017

NOTES: (continued)

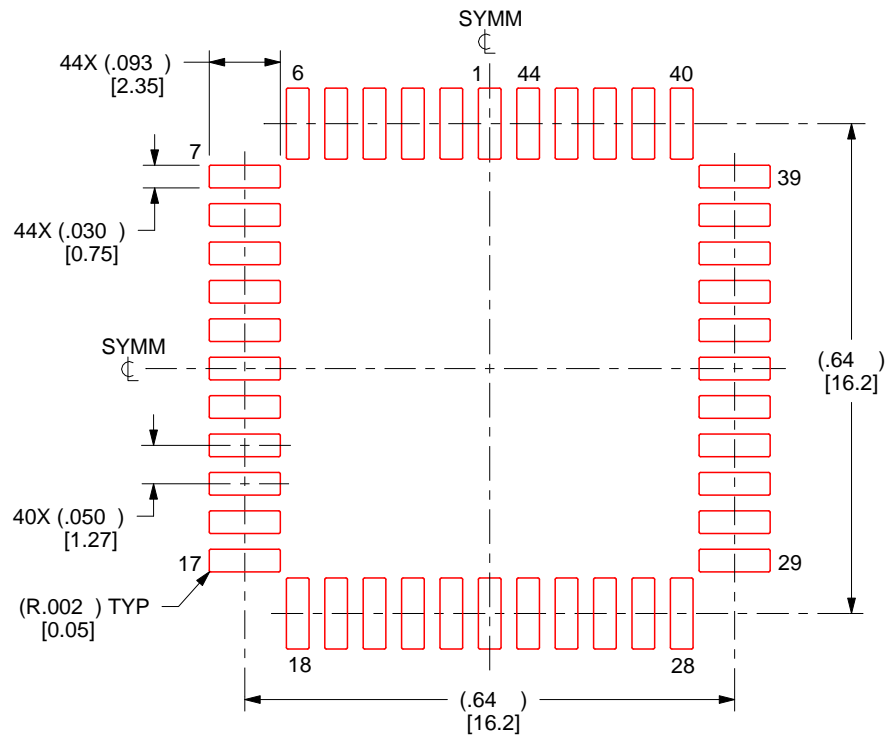
5. Publication IPC-7351 may have alternate designs.
6. Solder mask tolerances between and around signal pads can vary based on board fabrication site.

EXAMPLE STENCIL DESIGN

FN0044A

PLCC - 4.57 mm max height

PLASTIC CHIP CARRIER



SOLDER PASTE EXAMPLE
BASED ON 0.125 mm THICK STENCIL
SCALE:4X

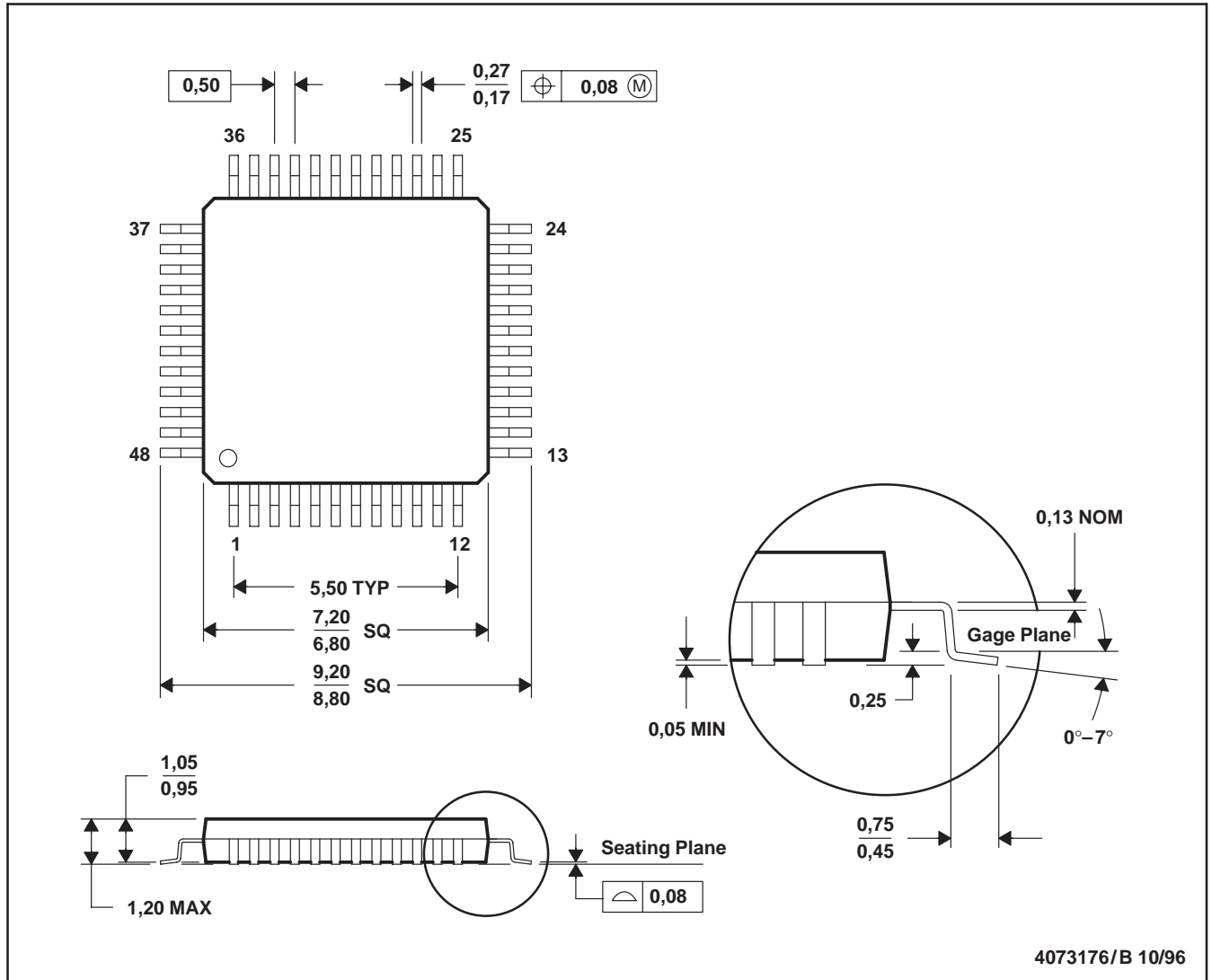
4215154/A 04/2017

NOTES: (continued)

7. Laser cutting apertures with trapezoidal walls and rounded corners may offer better paste release. IPC-7525 may have alternate design recommendations.
8. Board assembly site may have different recommendations for stencil design.

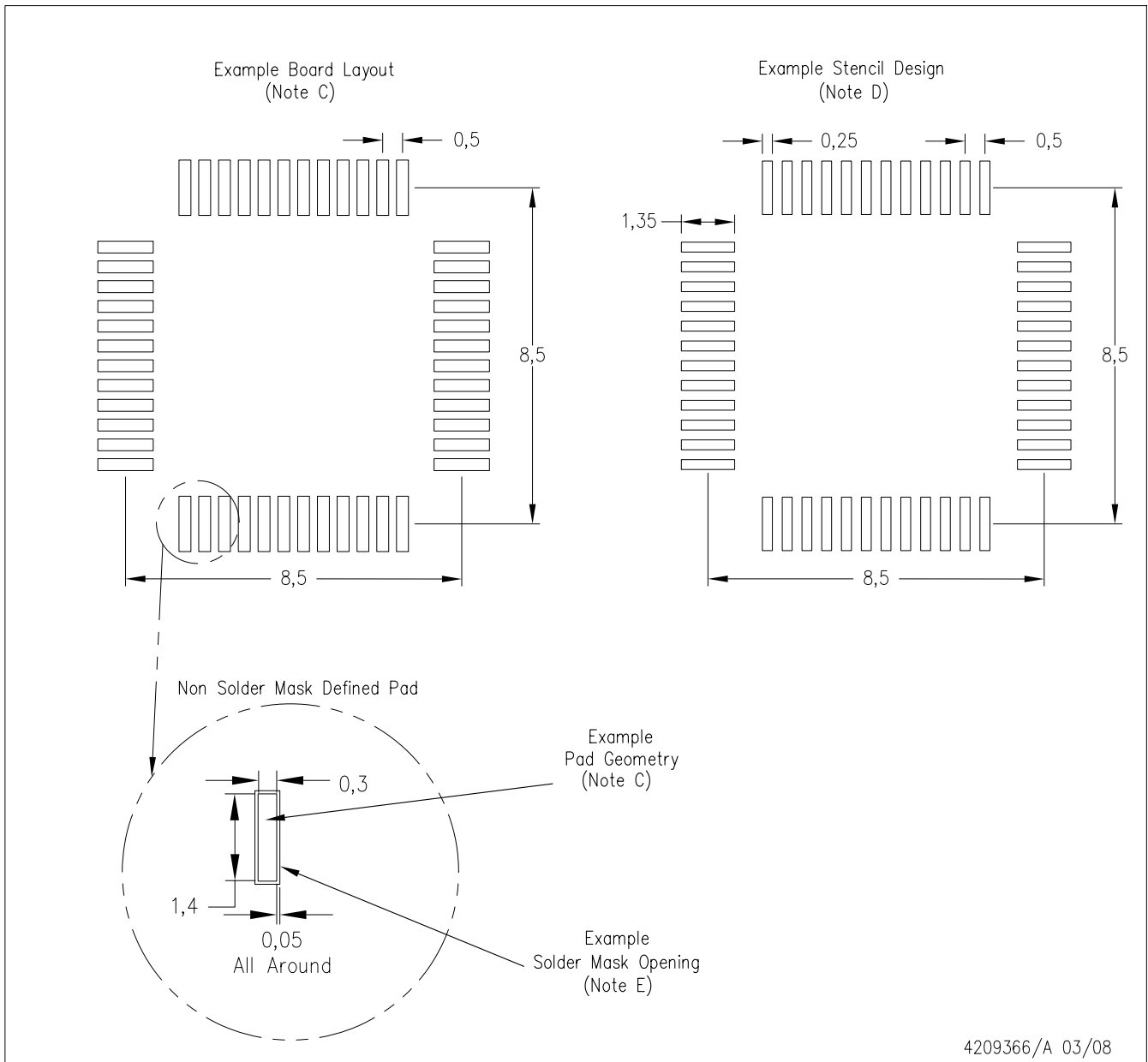
PFB (S-PQFP-G48)

PLASTIC QUAD FLATPACK



- NOTES: A. All linear dimensions are in millimeters.
 B. This drawing is subject to change without notice.
 C. Falls within JEDEC MS-026

PFB (S-PQFP-G48)



- NOTES:
- A. All linear dimensions are in millimeters.
 - B. This drawing is subject to change without notice.
 - C. Publication IPC-7351 is recommended for alternate designs.
 - D. Laser cutting apertures with trapezoidal walls and also rounding corners will offer better paste release. Customers should contact their board assembly site for stencil design recommendations. Refer to IPC-7525.
 - E. Customers should contact their board fabrication site for solder mask tolerances between and around signal pads.

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