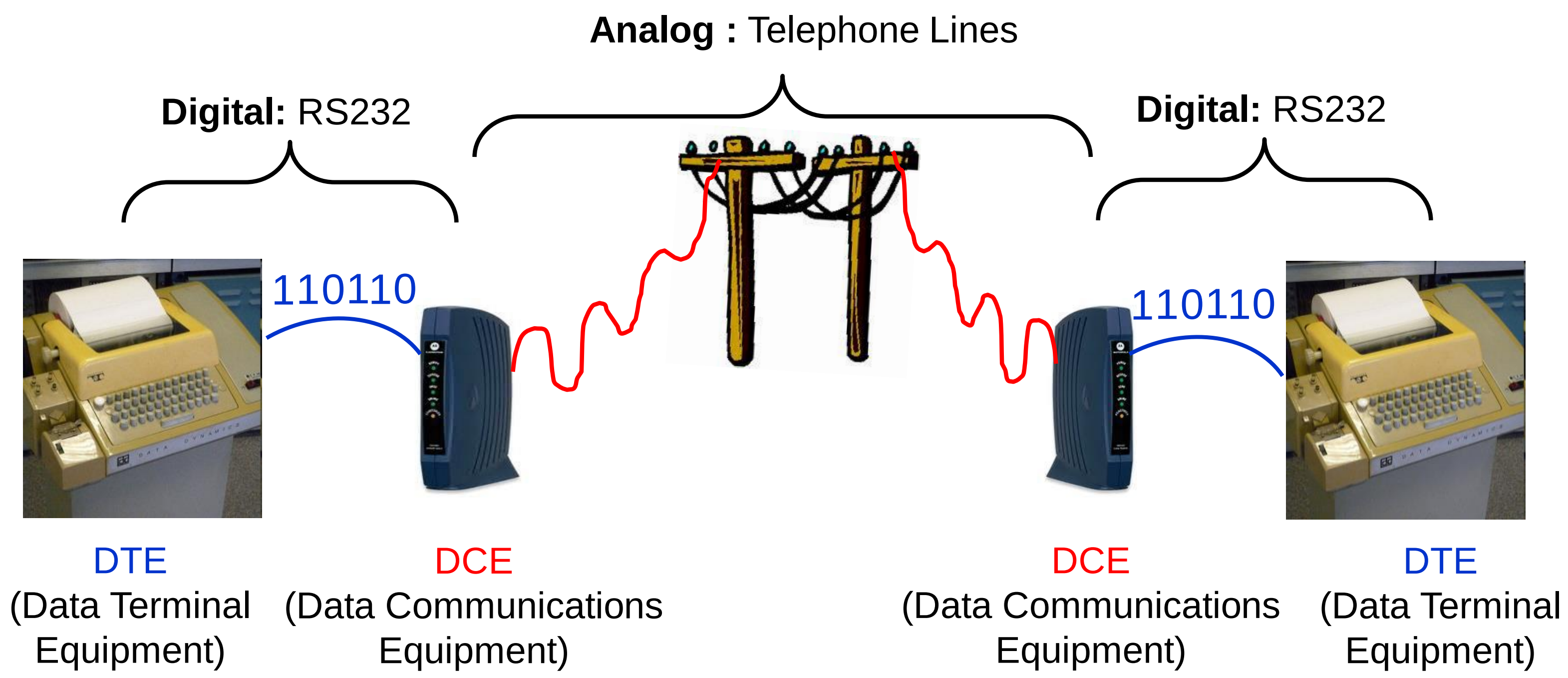
Asynchronous Serial Communications

- **Origins of Serial Communications**
  - Modems and Telephones, DTE/DCE equipment

- **Digital Serial Communications**
  - Simplex, half-duplex and full-duplex
  - Asynchronous serial transmission
  - The Motorola 6850 (ACIA)

- **The RS-232C Standard**
  - Mechanical and electrical specs
  - Control lines
  - Handshaking
  - Null modem

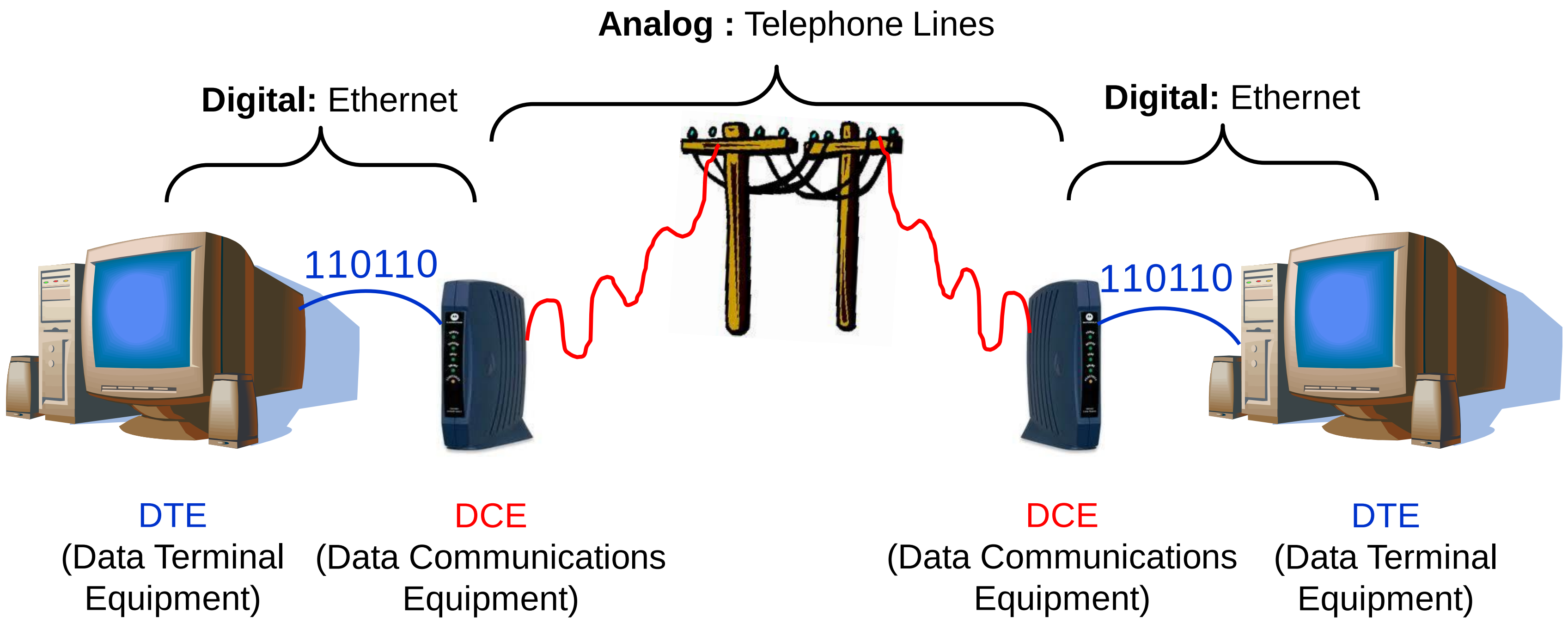
Origins of Serial Communications and RS232


Analog : Telephone Lines
Digital: RS232
Digital: RS232
110110
110110
DTE
(Data Terminal Equipment)
DCE
(Data Communications Equipment)
DCE
(Data Communications Equipment)
DTE
(Data Terminal Equipment)

Communications of the Telephone Line

- DTE equipment lies at each end. It is the origin and destination of data. Typical DTE equipment today includes computers, printers terminals etc.
- DCE equipment sits between DTE equipment and converts digital data into whatever form is required to transmit that data over the communications medium, e.g. telephone lines, fibre optic, wireless comms etc. A typical piece of DCE equipment is a MODEM or Modulator/demodulator
- RS232 is a digital communications standard to link DTE to DCE equipment

Serial Communications and the Internet

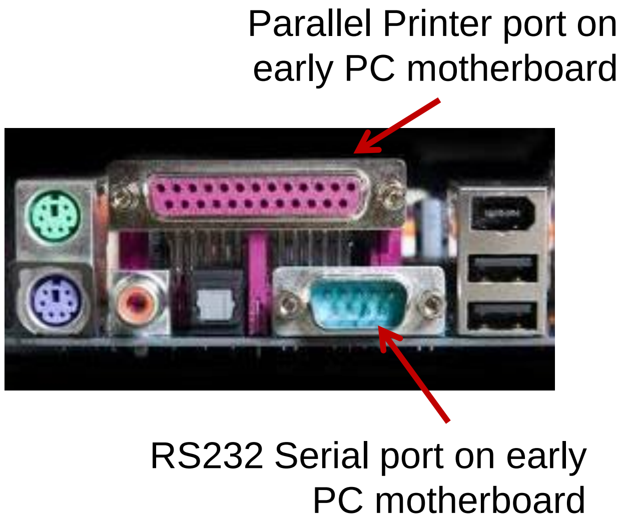

Analog : Telephone Lines
Digital: Ethernet
Digital: Ethernet
110110
110110
DTE
(Data Terminal Equipment)
DCE
(Data Communications Equipment)
DCE
(Data Communications Equipment)
DTE
(Data Terminal Equipment)

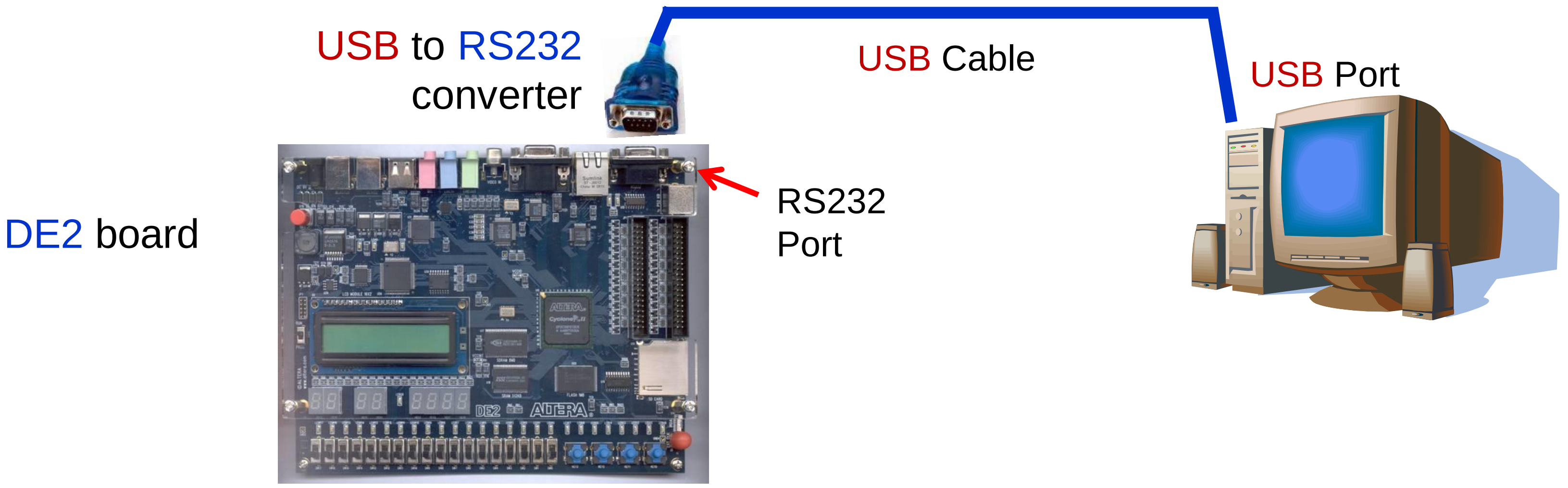
- We use those origins today as the basis of the internet, with high speed modems linking computers around the world, however, the RS232 link has been superseded by Ethernet for massively increased speed.
- RS232 has also been replaced by other forms of serial communications such as USB, Serial ATA (disk drives) and Firewire. Although faster, these are hugely more complex than RS232 from both a S/W and H/W perspective.
- RS232 is still the choice for low speed easy to use communications.

Serial Communications and the Internet

- A few years ago, PCs were equipped with RS232 and Printer ports, but the size of the connectors and the limited applications for them (*in the PC world*) means that they are no longer fitted as standard.

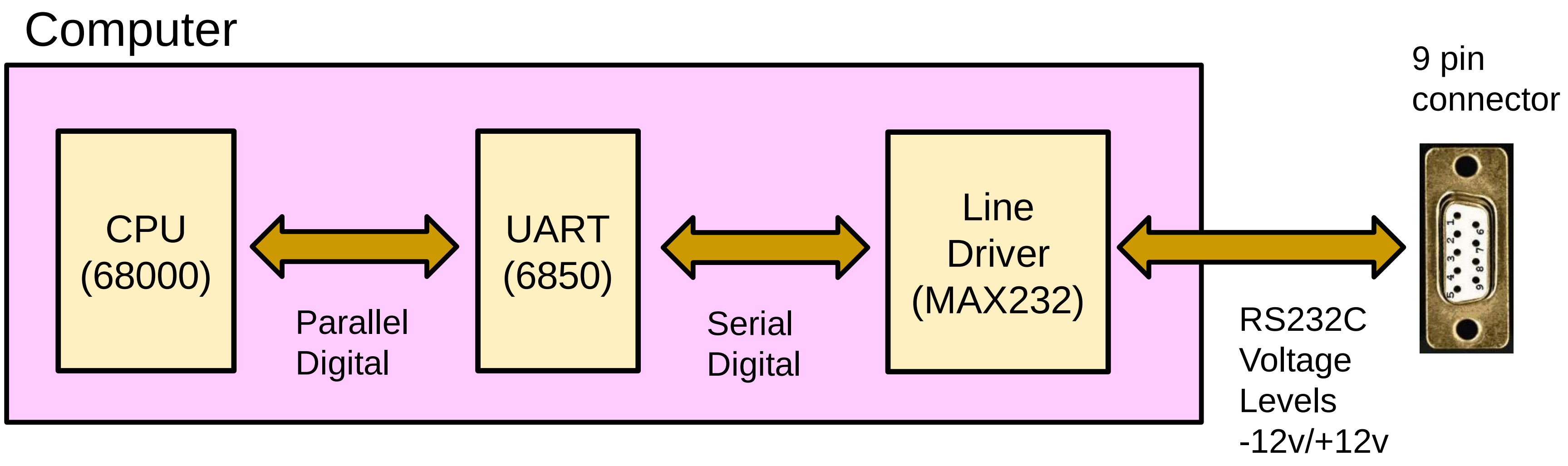
- However many small embedded computers and peripherals still have RS232 ports. You can use a USB/RS232 converter to allow RS232 communications via the PC's USB ports.


Parallel Printer port on early PC motherboard
RS232 Serial port on early PC motherboard



Asynchronous Serial Communications

- RS-232 is a standard defined by the Electronic Industries Association ("EIA").
- There are three flavours of RS-232 (A, B, and C) with each one defining a different voltage range. The most commonly used variety is RS-232C, which uses a voltage range of between -12V to -3V to represent logic 1's and +3v to +12v to represent logic 0's in the digital data stream.
- RS-232C cable lengths are limited to about 25 feet (8m).
- Computers use some kind of UART (Universal Asynchronous Receiver/Transmitter) to convert between parallel (byte wide) data and serial data.
- Line driver chips then convert the stream of digital 0s and 1's coming from the UART into the voltage levels required by the RS232 standard before they emerge from a suitable connector.

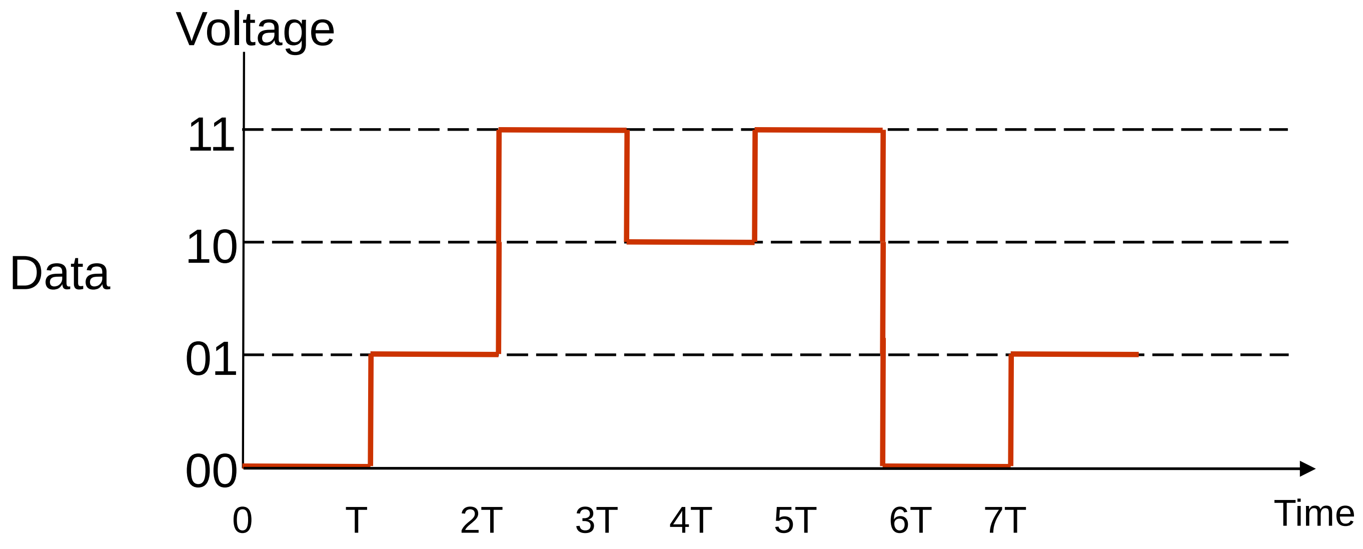


Some Terminology used in Serial Transmission

- **Baud rate -** is a measure of the *switching speed* of a signal, that is, the number of times per second that a signal changes state or transitions.

- **Bits per second (bps)** – is a measure of the rate at which data can be transmitted. For example, a slow dial up modem may quote only 56Kbps

- Baud rate and bps do not always mean the same thing. A signal may transition '10' times per second i.e. it's baud rate is '10', but if the signal's amplitude has 4 distinct levels then each transition can convey 2 bits of information, i.e. its bps is 20.



- For RS232 : BPS = Baud Rate since the signal only transitions between two voltage levels. RS232 always refers to "baud rate" as a measure of BPS.

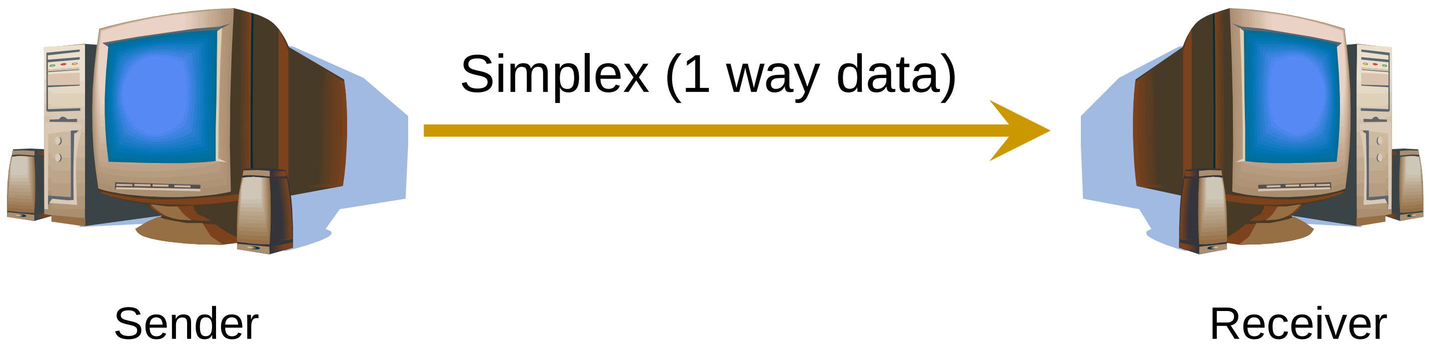
- Industry Standard baud rates are: 110, 300, 600, 1200, 4800, 9600, 14400, 19200, 38400, and so on. The DE2 communicates at 115k Baud (or 115k Bps)

Modes of Communications

- Regardless of how the communication is implemented (e.g. serial, parallel, cable, fibre optic etc.), when two pieces of equipment are connected together, we have a choice about the way in which they are able to communicate.

Simplex Communication (Uni-directional)

- With a simplex connection, data can only flow in one direction, in much the same way that traffic is allowed to travel down a one-way street.
- An example of simplex communication is the television or radio.
- Simplex channels are rarely used in computer based systems because it is not possible for the receiver to send back any error, control or acknowledge signals to the sender.



Modes of Communications

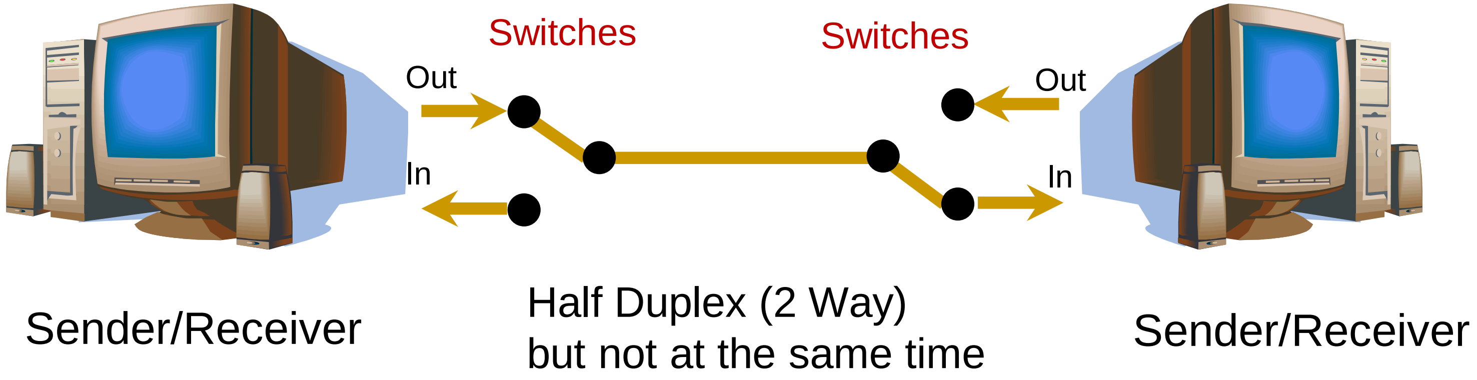
Half Duplex Communications (Bi-directional)

- A half duplex connection can send and receive, but not at the same time. It's like a one-lane bridge where two way traffic must give way in order to cross.

- For bi-directional communications, each end has to reconfigure itself for transmitting or receiving. Computer controlled electronic switches are employed within each piece of equipment to dynamically switch data direction.

- As with the bridge, a problem of synchronisation always exists, i.e. who speaks first. Usually there is a master/slave relationship. The master (e.g. computer) controls all communication and the slave only speaks when spoken to (e.g. disk drive).

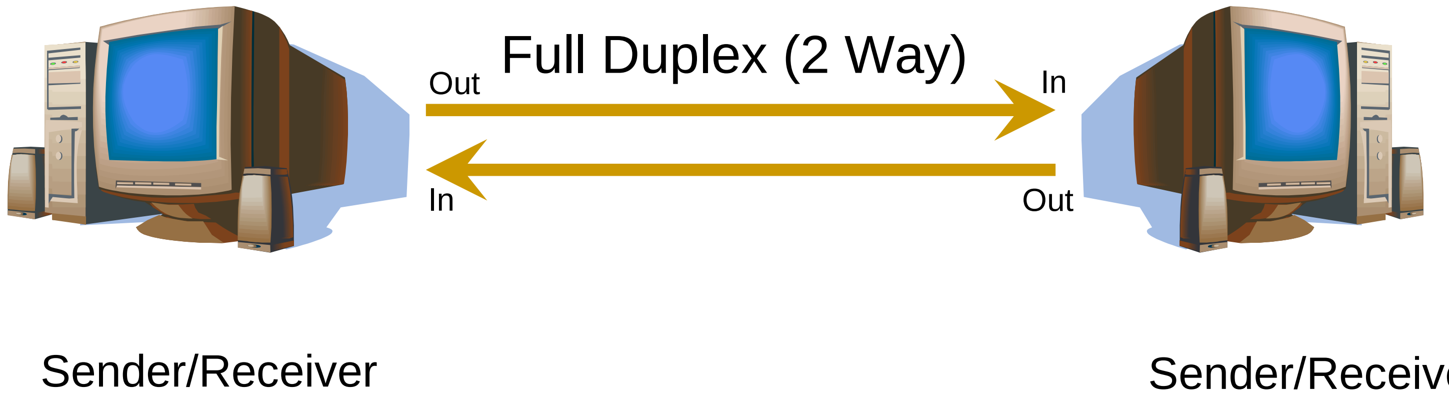
- An example of a Half-duplex communication system might be a walkie-talkie, with a separate speak/listen button. USB and ethernet uses half duplex communications because it results in fewer wires.



Modes of Communications

Full Duplex Communications (Bi-directional)

- Data can travel in both directions simultaneously.
- There is no need to switch between transmit and receive modes.
- Its like a two lane bridge or a two-lane highway.
- This type of communication requires only 3 wires, a ground, a transmit and a receive signal.
- Fire wire and RS-232 use full duplex communications.

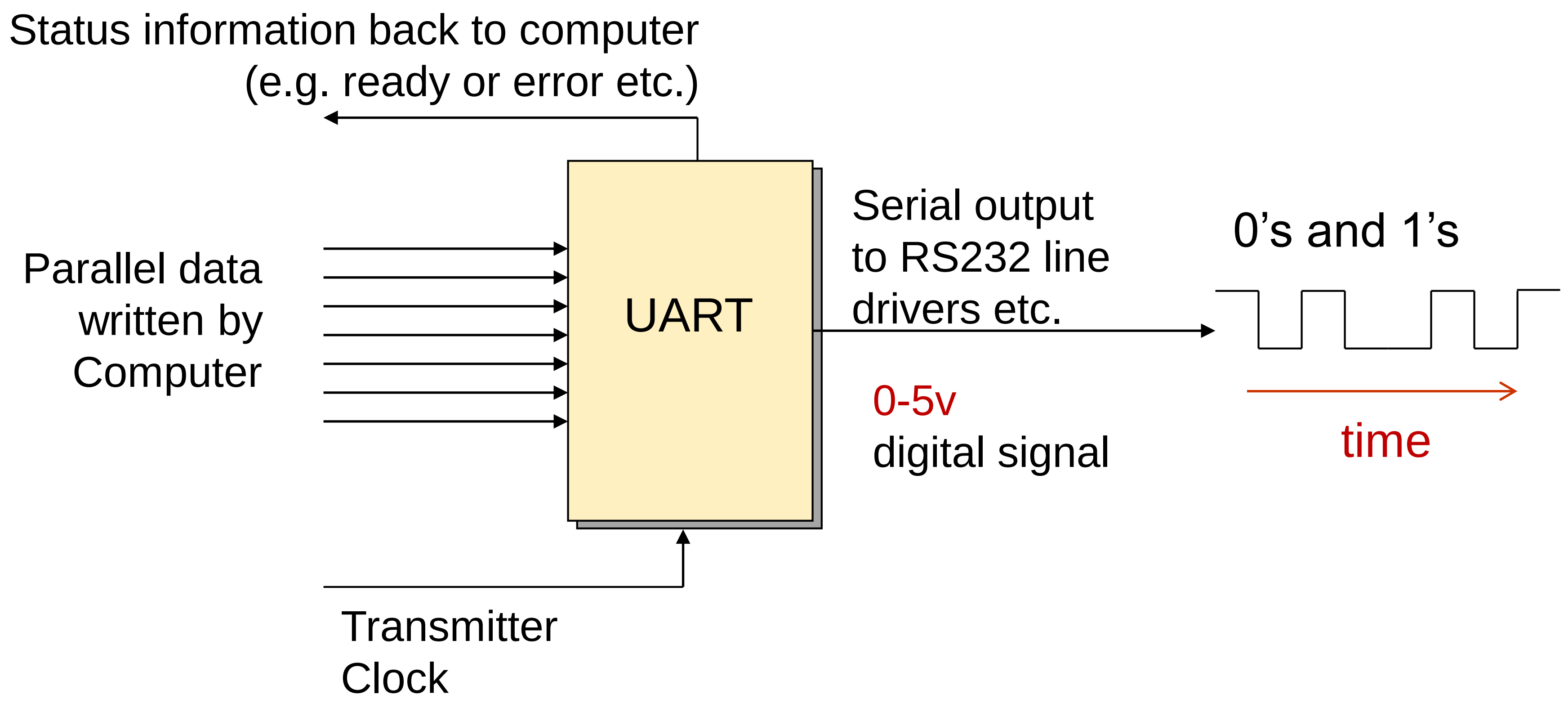


Universal Asynchronous Receiver/Transmitter(UART)

- Most UARTS are full duplex
  - They have separate pins and electronic hardware for the transmitter and receiver sections of the device that allows serial output and serial input to take place at the same time.
- Operation based around shift registers and a clock signal.
- A UART clock (often referred to as the baud rate generator) determine shift register speed and hence data rate (bps)
- Most UARTs can also generate parity bits for transmission and perform parity checking on reception to provide simple error detection.

UART - Transmitter

- Transmitter (Tx) - converts data from parallel to serial format
  - Inserts start and stop bits used to indicate start and end of transmission.
  - Calculates and inserts parity bit if required into transmission.
  - Data rate is determined by the UART transmitter clock.



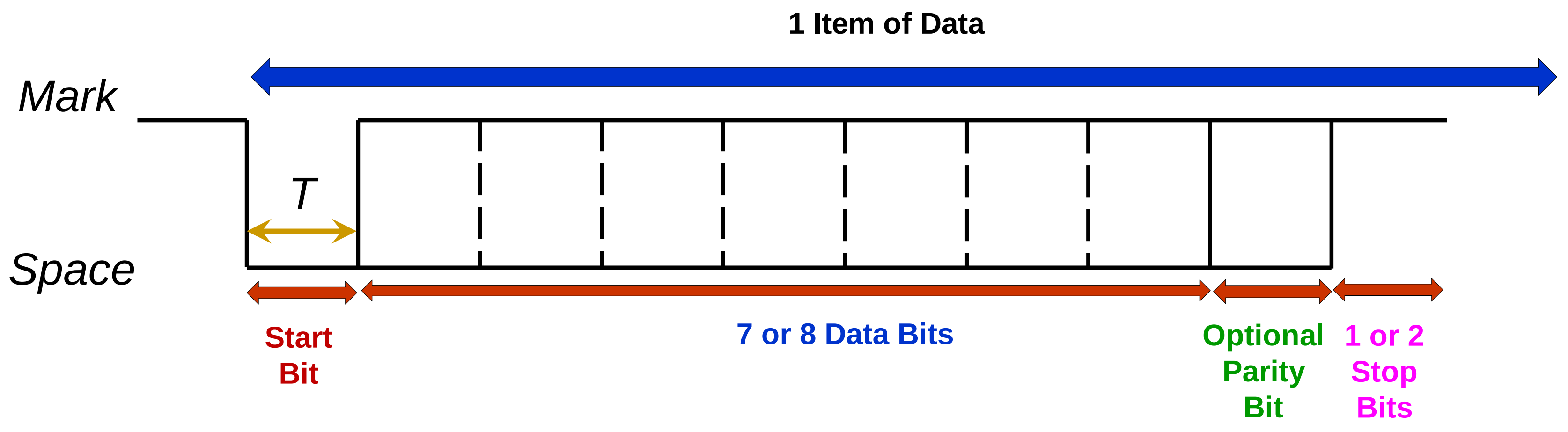
RS232 Data Transmission and Framing

- When no data is being transmitted, the RS232 transmit signal remains at the IDLE (or Mark) level – Logical 1 (but actually -12v).

- Before a character can be transmitted it must first be '**framed**'. The format of a typical character frame is as follows:-

  - **A Start bit:** logical 0 (also called a *space* *+12v*) indicates the start of a character.
  - **7** or **8 Data bits**
  - **An Optional Odd/Even/No Parity bit** used for possible error checking.
  - **1** or **2 Stop bits** at logical 1 (called a *mark*) that is used to indicate the end of the transmission of that item of data.

    (*Two stop bits were used with old teletypes to give the mechanicals the opportunity to recover and prepare for the next characters. These days, 1 stop bit is common*).

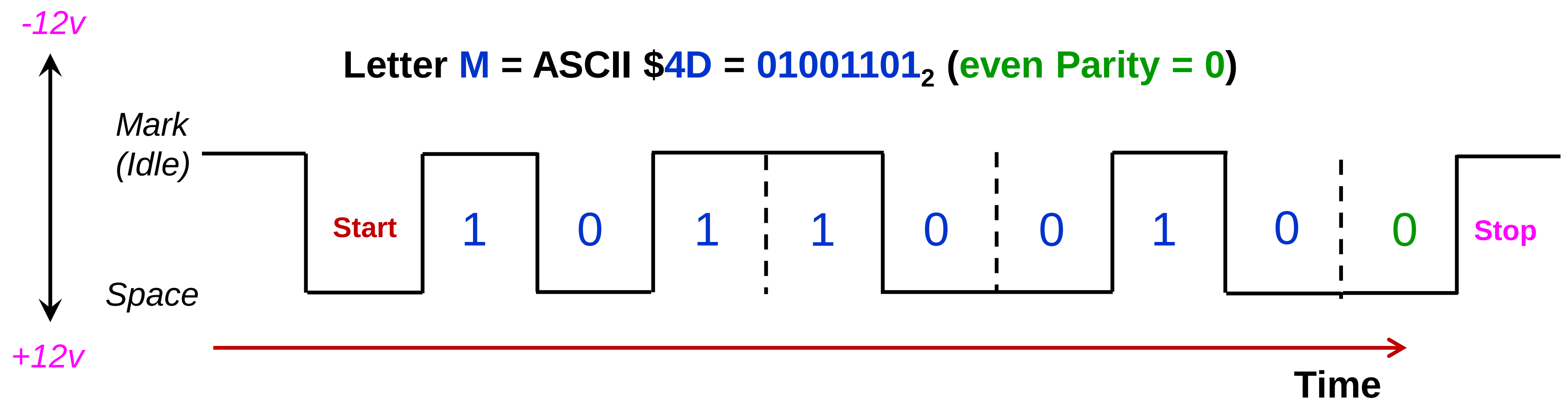


RS232 Data Transmission and Framing

- Given these combinations, there are **12 possible formats** for a character frame. Both transmitter and receiver **have to agree** the format.

- The illustration here shows how the letter 'M' would be framed and transmitted. Notice how the least significant bit is transmitted first, i.e. *little Endian.*

Letter M = ASCII $4D = 01001101$_2$ (even Parity = 0)



- As you can see, Asynchronous transmission is highly inefficient since with 8 data bits, a single start, stop and parity bit, we have only **73% data efficiency**

Problem

Exercise

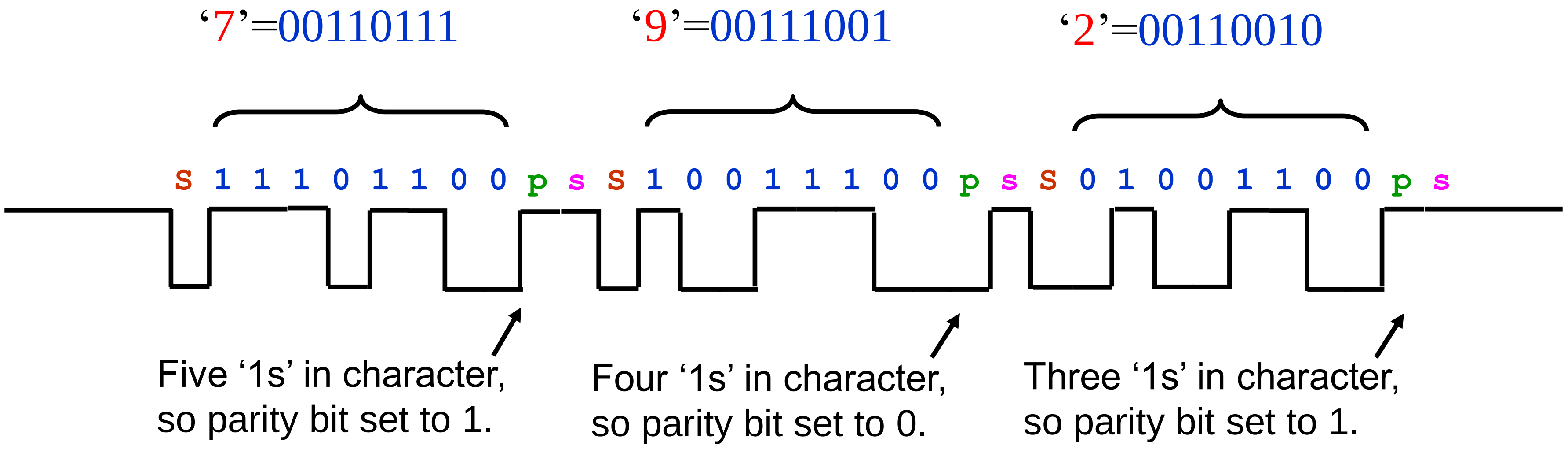
- Draw the RS-232 bit pattern when transmitting the last three digits of your student number in ASCII.

- Assume the serial port is configured as 8-bits, 1 stop bit, even parity.

- How long does it takes to transmit these three digits at a clock speed to 9600 hz?

Character	ASCII
0	$30
1	$31
2	$32
3	$33
4	$34
5	$35
6	$36
7	$37
8	$38
9	$39

Solution

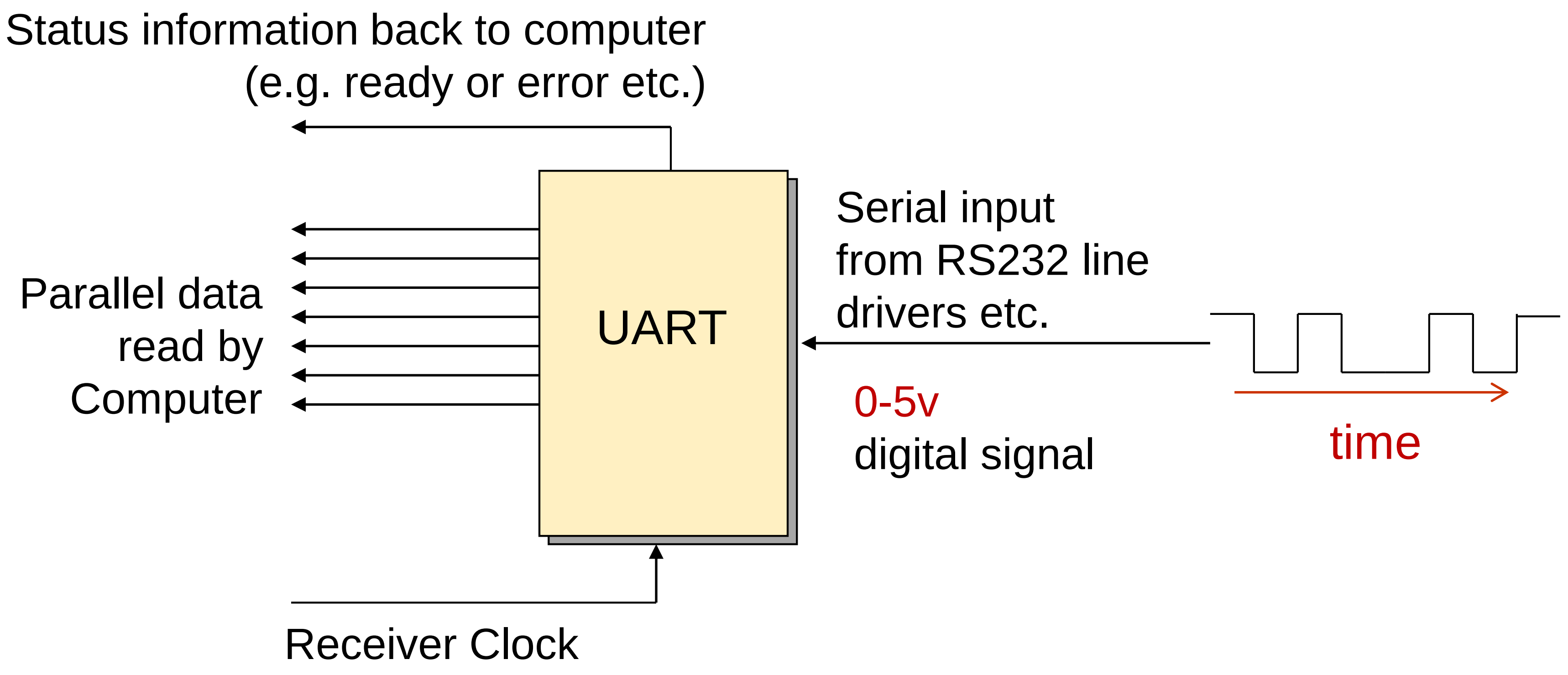

‘7’=00110111
‘9’=00111001
‘2’=00110010
s 1 1 1 0 1 1 0 0 p s s 1 0 0 1 1 1 0 0 p s s 0 1 0 0 1 1 0 0 p s
Five ‘1s’ in character, so parity bit set to 1.
Four ‘1s’ in character, so parity bit set to 0.
Three ‘1s’ in character, so parity bit set to 1.

It takes 3*11*(1/9600)=3.4375ms to transmit the three digits.

UART - Receiver

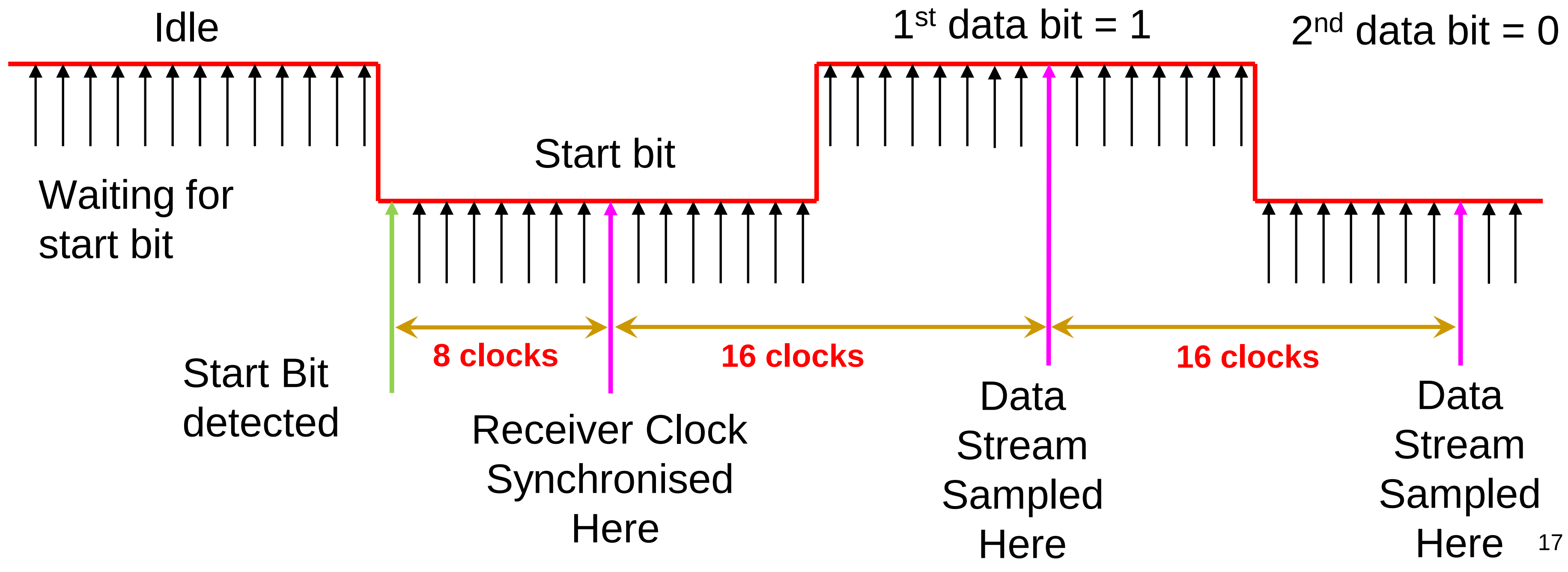
Receiver (Rx) Converts Serial Format Data back to Parallel

- Rx synchronises to transmitter using the start bit.
- Calculates parity and checks against received parity bit.



Synchronising Receiver to Incoming Data

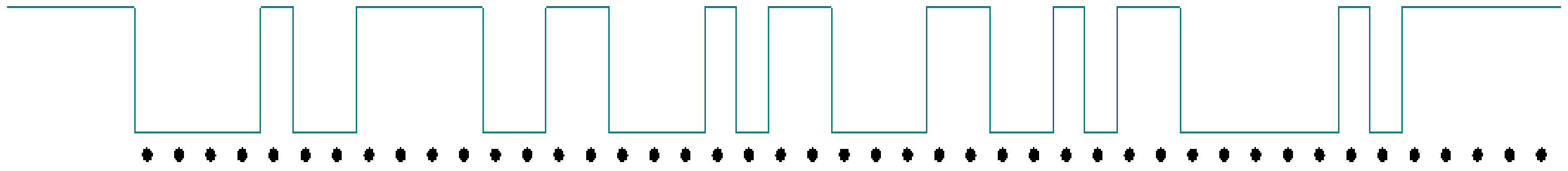
- How is data reception guaranteed given that RS-232 does **not** contain a clock that sender and receiver can synchronise too?
- Receiver samples the incoming data stream 16x's faster than data (bit) rate.
- As soon as the start bit is identified, receiver synchronises it's shift register to middle of 1st data bit time period, (i.e. 8 clock periods after detection of start bit.) and thereafter samples each data bit every 16 clock periods.
- This means sender and receiver clocks can differ by as much as 2% (*easily achieved using crystal oscillators*) and still not drift to the point where the wrong data is sampled.



Exercises

Homework

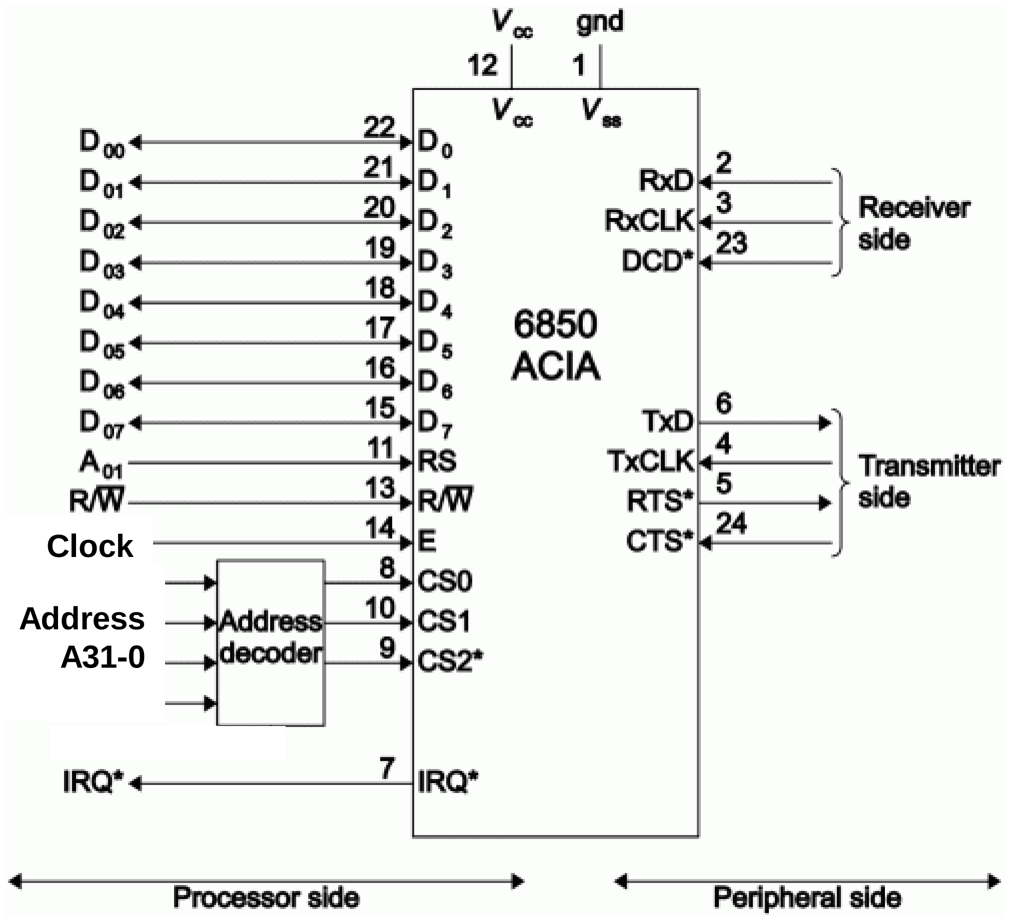
- The bit stream below shows a RS-232 message transmitted with 7 data bits, odd parity, and 2 stop bits.
- Decipher the message assuming the characters transmitted are ASCII.
- **Remember** least significant bits transmitted first.



The Motorola 6850 ACIA (UART)

Introduction, History and External Interface

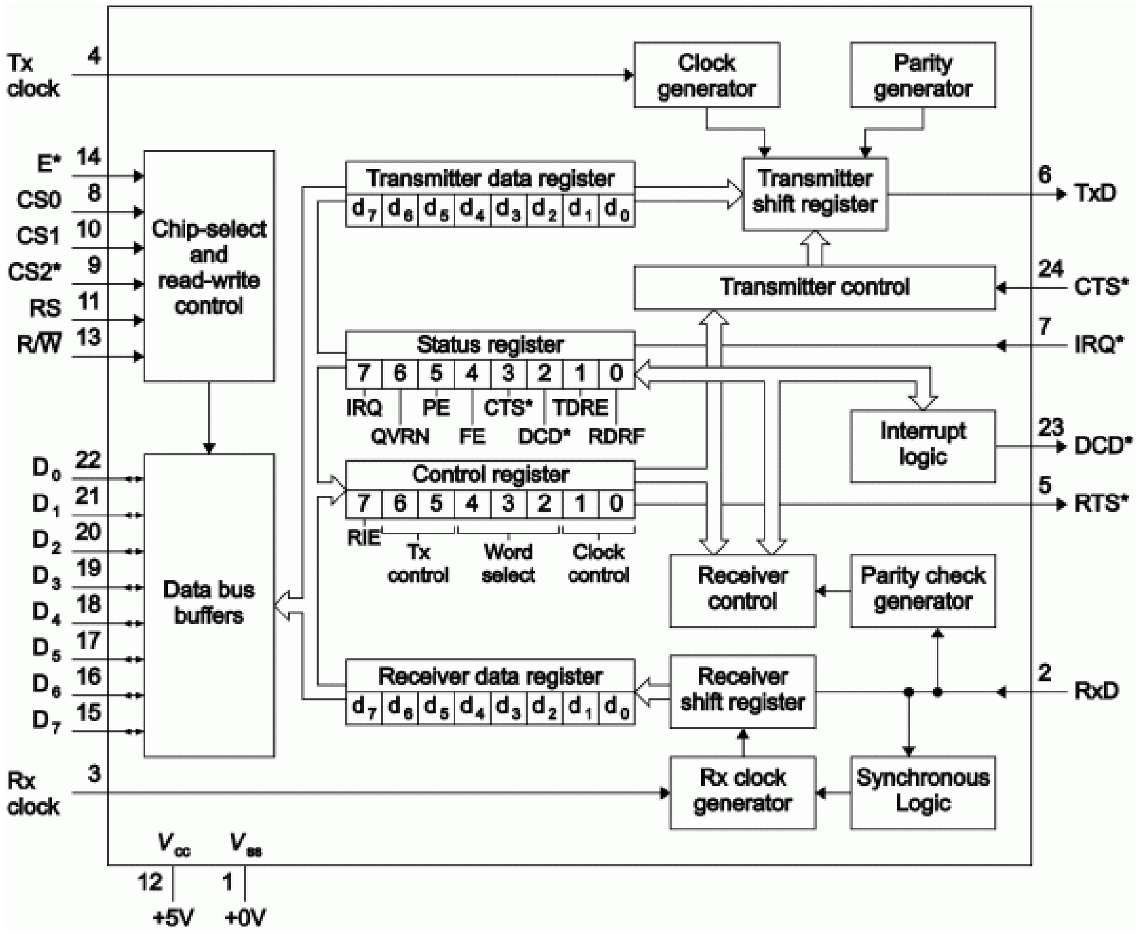
- The Motorola 6850 ACIA (a kind of UART) was one of the first single chip devices to handle the burden of asynchronous serial data.
- It has been rewritten in VHDL for the UBC 68000 processor.



The Motorola 6850 ACIA

6850 Internal Architecture - 4 byte wide Registers:

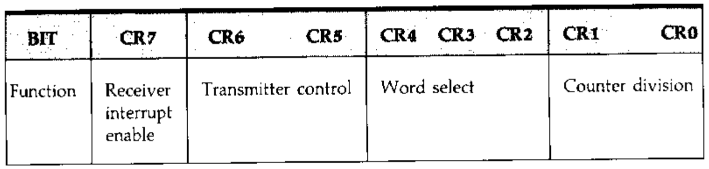
- **Control + Status at Base Address e.g. hex 84000000**
- **Transmit + Receive Data at Base Address + 2 e.g. hex 84000002**



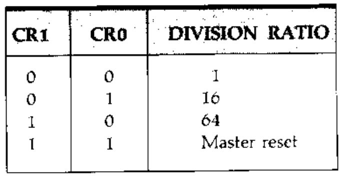
The Motorola 6850 ACIA

The 6850 Control Register (write only)

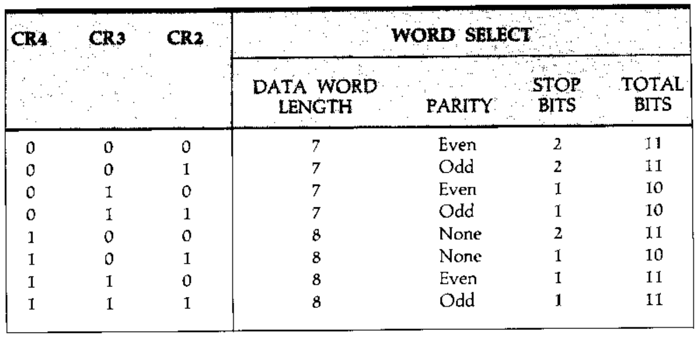
- **Bits 0-1**: ***Reset and Clock divisor***
  - Provide a software master reset for the device.
  - Clock division ratio (1, 16 or 64) for the transmitter and receiver.
- **Bits2-4**: ***Frame Format***
  - Data width (7 or 8 bits),
  - Parity (odd, even, none),
  - Number of stop bits (1 or 2).
- **Bits 5-6**: ***Transmitter Control***
  - The RTS line used with a modem.
  - Whether the transmitter should generate an interrupt when the last character has been sent.
- **Bit 7** : ***Receiver Control***
  - Determines whether the 6850 should generate an interrupt when a character is received.



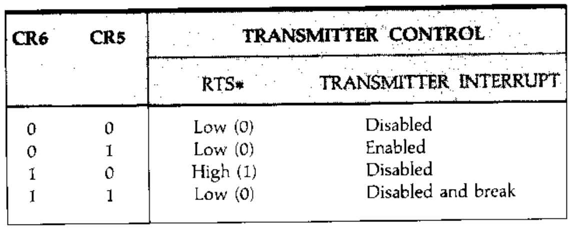
BIT	CR7	CR6 CR5	CR4 CR3 CR2	CR1 CR0
Function	Receiver interrupt enable	Transmitter control	Word select	Counter division



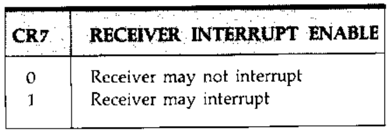
CR1	CR0	DIVISION RATIO
0	0	1
0	1	16
1	0	64
1	1	Master reset



CR4	CR3	CR2	WORD SELECT			
			DATA WORD LENGTH	PARITY	STOP BITS	TOTAL BITS
0	0	0	7	Even	2	11
0	0	1	7	Odd	2	11
0	1	0	7	Even	1	10
0	1	1	7	Odd	1	10
1	0	0	8	None	2	11
1	0	1	8	None	1	10
1	1	0	8	Even	1	11
1	1	1	8	Odd	1	11



CR6	CR5	TRANSMITTER CONTROL	
		RTS*	TRANSMITTER INTERRUPT
0	0	Low (0)	Disabled
0	1	Low (0)	Enabled
1	0	High (1)	Disabled
1	1	Low (0)	Disabled and break



CR7	RECEIVER INTERRUPT ENABLE
0	Receiver may not interrupt
1	Receiver may interrupt

The Motorola 6850 ACIA

The 6850 Status Register (Read only)

- **Bits 0,1 (RDRF, TDRE)**
  - Bit 0 set to logic 1, if the receive data register is holding an unread character.
  - Bit 1 set to logic 1 when the transmit data register is empty.
  - Polling algorithms can check the status of these bits to determine if new characters have been received or previous ones transmitted.
  - Bit 0 is cleared when the receive data register is read from
  - Bit 1 is cleared when the transmit data register is written to.

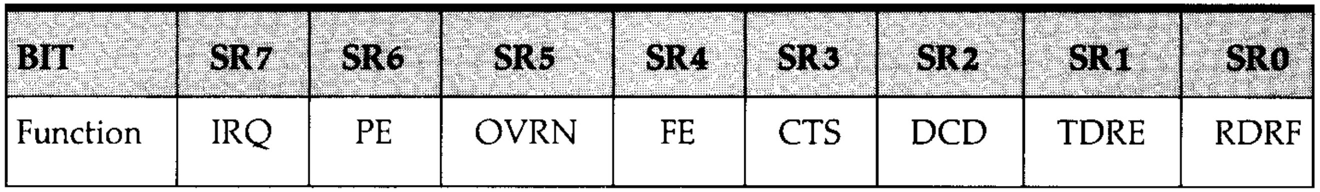
- **Bit 2 (DCD)**
  - This bit reflects the status of the hardware modem control signal 'Data Carrier Detect' (DCD). It is used to inhibit reception of data unless an associated modem has detected a carrier signal.

- **Bit 3 (CTS)**
  - This bit reflects the status of the hardware modem control signal 'Clear to Send'. An active low signal on the 6850 CTS line indicates that some connected device is ready to receive more data from the 6850. This is a handshake signal in effect saying to the 6850 that it is clear to transmit more data.

BIT	SR7	SR6	SR5	SR4	SR3	SR2	SR1	SR0
Function	IRQ	PE	OVRN	FE	CTS	DCD	TDRE	RDRF

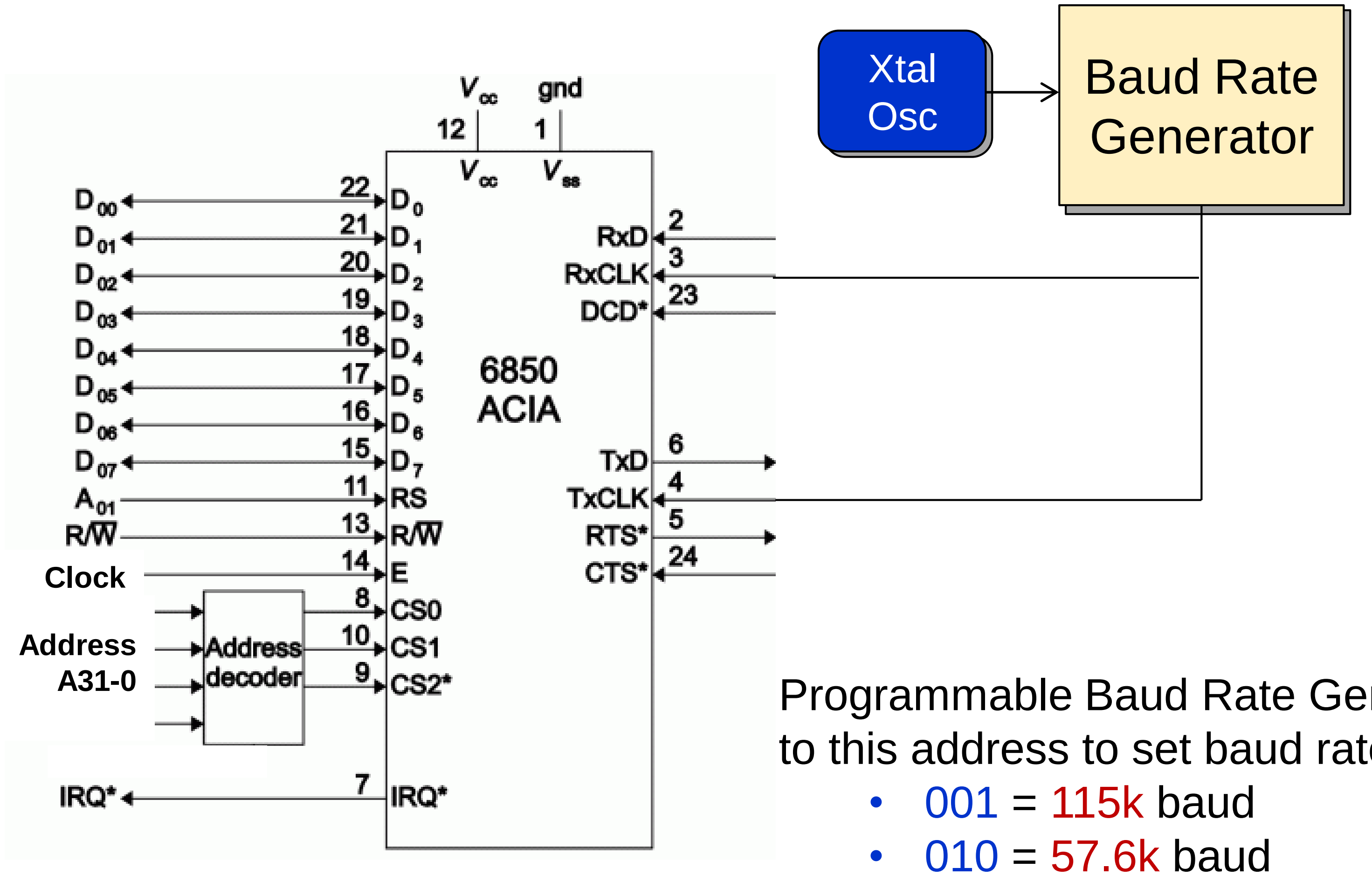
The Motorola 6850 ACIA

- **Bit 4 (FE)**
  - This bit is set whenever the 6850 detects that a received character is *incorrectly framed.* Examples include reception of a character with the incorrect number of stop bits. This bit is set/cleared on a character by character basis.
- **Bit 5 (OVRN)**
  - This bit indicates that the 6850 has been *overrun* by received characters that were not read by the CPU. The implication being that data has been lost. This bit is set/cleared on a character by character basis.
- **Bit 6 (PE)**
  - This bit is set whenever the 6850 detects that a received character has Incorrect Parity. This bit is set/cleared on a character by character basis.
- **Bit 7 (IRQ)**
  - This bit is set whenever the 6850 wishes to interrupt the CPU. Typically this occurs when transmit buffer empty or receive buffer full interrupts have been enabled in the control register and is also set when Bit 2 (DCD) is set



BIT	SR7	SR6	SR5	SR4	SR3	SR2	SR1	SR0
Function	IRQ	PE	OVRN	FE	CTS	DCD	TDRE	RDRF

The Baud Rate Generator



Programmable Baud Rate Generator. Write to this address to set baud rate.

- 001 = 115k baud
- 010 = 57.6k baud
- 011 = 38.4k baud
- 100 = 19.2 baud
- all others = 9600 baud

The Motorola 6850 ACIA

68000 Assembly Language Routines to Initialise 6850

```
ACIAControl     equu       $84000040
ACIAStatus      equ        $84000040
ACIATransmit    equ        $84000042
ACIAReceive     equ        $84000042
BaudRateGen     equ        $84000044

***************************************************************************************
* Initialise 6850 and baud rate generator for 115k Baud
* clock (16x), no RX/TX interrupts, RTS set low, 8 bit data, no parity, 1 stop bit
* All registers preserved
***************************************************************************************
Initialise  move.b   #%00000001, BaudRateGen   ; Program Baud rate for 115k
            move.b   #%00000011, ACIAControl   ; reset ACIA
            move.b   #%00010101, ACIAControl   ; x16 clock, 8 data, no parity, 1 stop, no interrupt
            rts
```

The Motorola 6850 ACIA

68000 Assembly Language routines to Poll for character received

```
ACIAControl     equu      $84000040
ACIAStatus      equ       $84000040
ACIATransmit    equ       $84000042
ACIAReceive     equ       $84000042
BaudRateGen     equ       $84000044

***********************************************************************************************
* Read status register until bit 0 = 1, then read receive data register and
* return character in d0.b. All other registers preserved
***********************************************************************************************
Getchar     move.b     ACIAStatus,d0        ; read status register into d0
            and.b      #%00000001,d0        ; mask off bits 7-1, leaving bit 0
            cmp.b      #%00000001,d0        ; is bit 0 = 1?
            bne        Getchar              ; if not keep polling
            move.b     ACIAReceive,d0       ; read received character into d0
            rts
```

The Motorola 6850 ACIA

68000 Assembly Language routines to Poll status prior to Transmitting

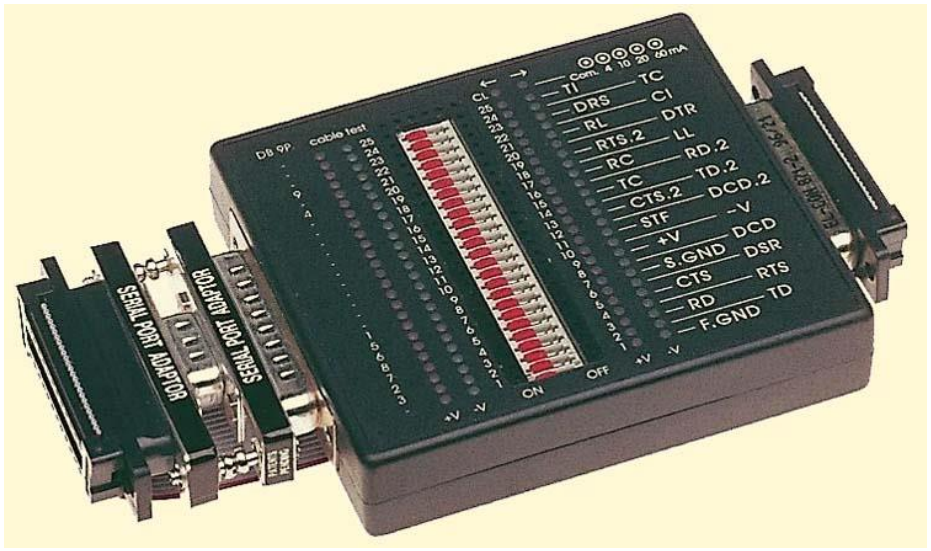
```
ACIAControl     equu    $84000040
ACIAStatus      equ     $84000040
ACIATransmit    equ     $84000042
ACIAReceive     equ     $84000042
BaudRateGen     equ     $84000044

*****************************************************************************************
* Transmit Data
* Character to transmit is in d0.b, all registers preserved
*****************************************************************************************
Putchar   move.b   d0,-(a7)             ; push d0 into stack (save its value somewhere)
TxLoop    move.b   ACIAStatus,d0                 ; read status register into d0
          and.b    #%00000010,d0        ; mask off bits 7-2 and 0, leaving bit 1
          cmp.b    #%00000010,d0        ; is bit 1 = 1?
          bne      TxLoop               ; if not keep polling
          move.b   (a7)+,d0             ; get character to transmit back off stack
          move.b   d0,ACIATransmit      ; write character to transmit register for transmission
          rts
```

The RS232 Standard

- The RS- 232 (Recommended Standard - 232) was initially published in the 60’s.
- Currently the standard has been ‘hacked about’ probably more than any other standard in existence for use way beyond its original applications, such as computer-to-computer or computer-to-printer applications.
- More time has been spent by Engineers attempting to make computer equipment communicate on RS-232 than just about anything else in existence !!!
- It has become so tricky connecting incompatible equipment together that ‘***breakout***’ boxes are now sold so that technicians can play around with connecting one signal to another and observe the state of each signal on LEDs in order to establish communications (see illustration)

RS232 “Break-out” Box

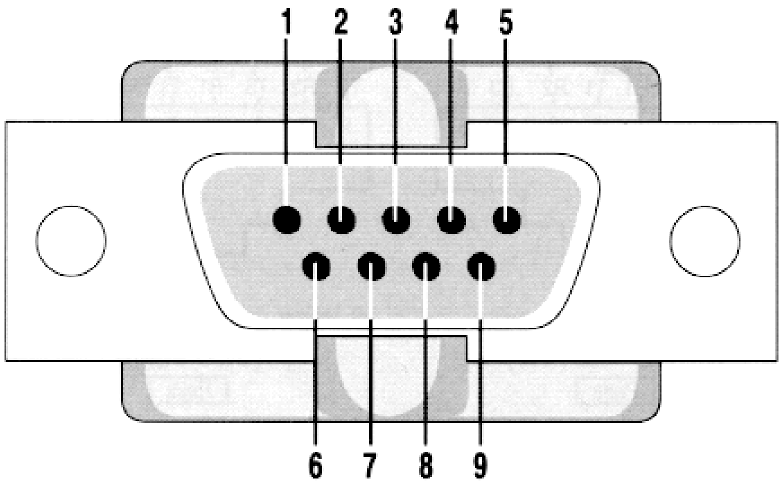


The RS232 Standard

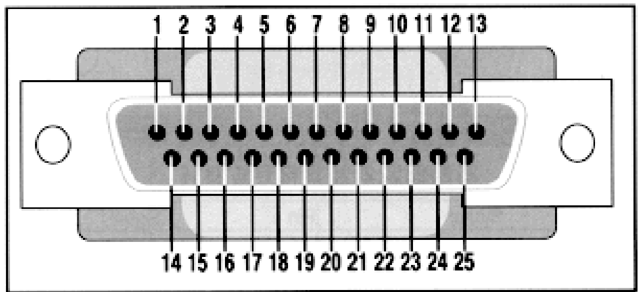
- **The RS232 Standard defines the following**
  - A Mechanical Specification
  - A Protocol to control the transmission of data using handshaking
  - An Electrical Specification

The RS232 Mechanical Standard

- The standard specifies that equipment be connected via a 25 pin D-Type connector (DB-25), although a 9 pin connector (DB-9) is more often employed these days for its associated space and cost savings.
- The Female connector is *generally* (but not always) associated with DCE equipment (e.g. Modems, Printers, Terminals) while the Male connector is *generally* present on DTE equipment (computers etc.)



Pin	Signal	Pin	Signal
1	Data Carrier Detect	6	Data Set Ready
2	Received Data	7	Request to Send
3	Transmitted Data	8	Clear to Send
4	Data Terminal Ready	9	Ring Indicator
5	Signal Ground		

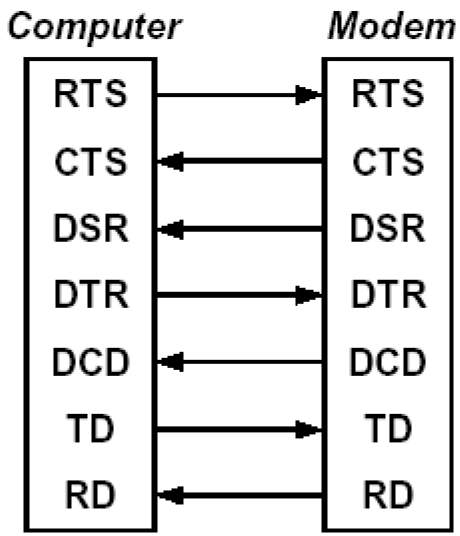


Pin	Description	EIA CKT	From DCE	To DCE
1	Frame Ground	AA		
2	Transmitted Data	BA		D (Data)
3	Received Data	BB	D	
4	Request to Send	CA		C (Control)
5	Clear to Send	CB	C	
6	Data Set Ready	CC	C	
7	Signal Gnd/Common Return	AB		
8	Rcvd. Line Signal Detector	CF	C	
11	Undefined			
12	Secondary Rcvd. Line Sig. Detector	SCF	C	
13	Secondary Clear to Send	SCB	C	
14	Secondary Transmitted Data	SBA		D
15	Transmitter Sig. Element Timing	DB	T (Timing)	
16	Secondary Received Data	SBB	D	
17	Receiver Sig. Element Timing	DD	T	
18	Undefined			
19	Secondary Request to Send	SCA		C
20	Data Terminal Ready	CD		C
21	Sig. Quality Detector	CG		C
22	Ring Indicator	CE	C	
23	Data Sig. Rate Selector (DCE)	CI	C	
23	Data Sig. Rate Selector (DTE)	CH		C
24	Transmitter Sig. Element Timing	DA		T
25	Undefined			

The RS232 Protocol for Information Exchange

- **Request To Send (RTS), Pin 4**
  - Asserted by the computer to inform the modem that it wants to transmit data.
- **Clear To Send (CTS), Pin 5**
  - Asserted by the modem after receiving a RTS signal, indicating that the computer can now transmit.

Control Flow Signals (*Handshaking*)



- **Data Terminal Ready (DTR), Pin 20 (DB25) or Pin 4 (DB9)**
  - This signal is asserted by the computer, to inform the modem that the computer is ready to communicate
- **Data Set Ready (DSR), Pin 6**
  - This signal is asserted by the modem in response to a DTR signal from the computer and indicates the modem is ready to communicate.
- **Data Carrier Detect (DCD), Pin 8**
  - This signal is asserted by the modem, informing the computer that it has established a physical connection with the telephone network.

Status Signals

- **Transmit Data (TD), Pin 2**
  - This signal carries the transmitted data from the computer to the modem.
- **Receive Data (RD), Pin 3**
  - The signal carries the received data from the modem to the computer.

Data Signals

RS-232 Handshaking

Handshaking

- Handshaking is a protocol whereby if the receiver cannot keep up with the data rate of the sender, the receiver can slow down the sender.

- There are two methods of handshaking. Most equipment supports both and is purely down to configuration or choice as to which to support

  - Hardware: Using wires (RTS/CTS).
  - Software: XON, XOFF

RS-232 Handshaking

RTS/CTS Handshaking

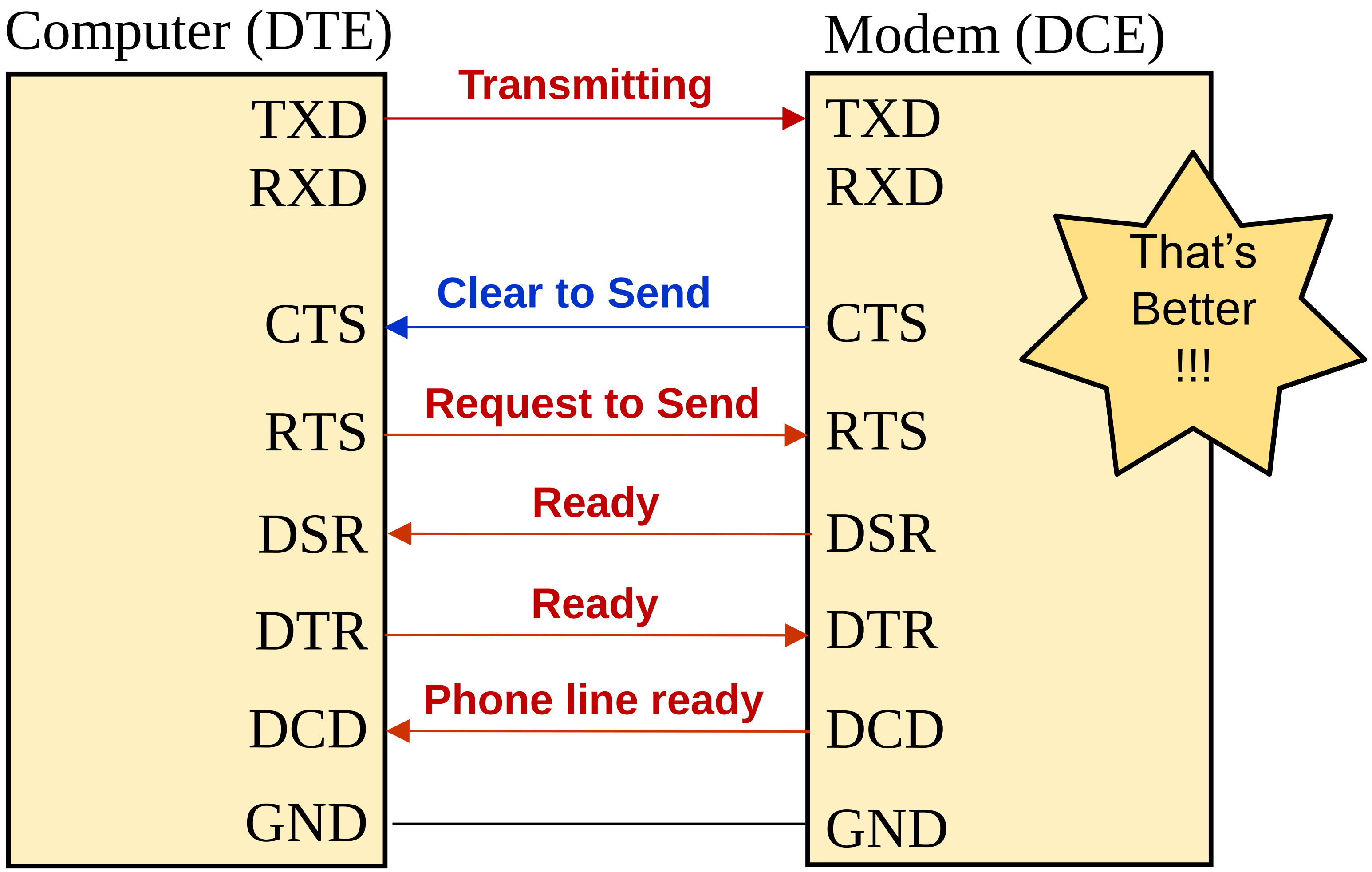
- If the sender is transmitting data too fast for the receiver to keep up, *i.e. the receivers data buffers are getting full and it cannot process that amount of data so quickly*, it will remove the CTS (Clear-to-send) signal, this will disable the sender from transmitting.

- The 6850s transmitter section is hard wired to this signal so it will not transmit unless CTS (Clear-to-send) signal is active.

- Note handshaking works only in one direction, that is, that DCE equipment (e.g. modem, printer, terminal etc.) is slow and thus needs to can control the transmission speed of DTE equipment, e.g. computer.

- It is assumed that a computer (DTE) is fast enough to keep up with any minimal data back from say a printer, terminal or Modem (DCE). Two computers should be fast enough to keep up with each (given that physical communications over the RS232 is quite slow). However, Xon-Xoff can be used if they need to control each other

RS-232 Handshaking

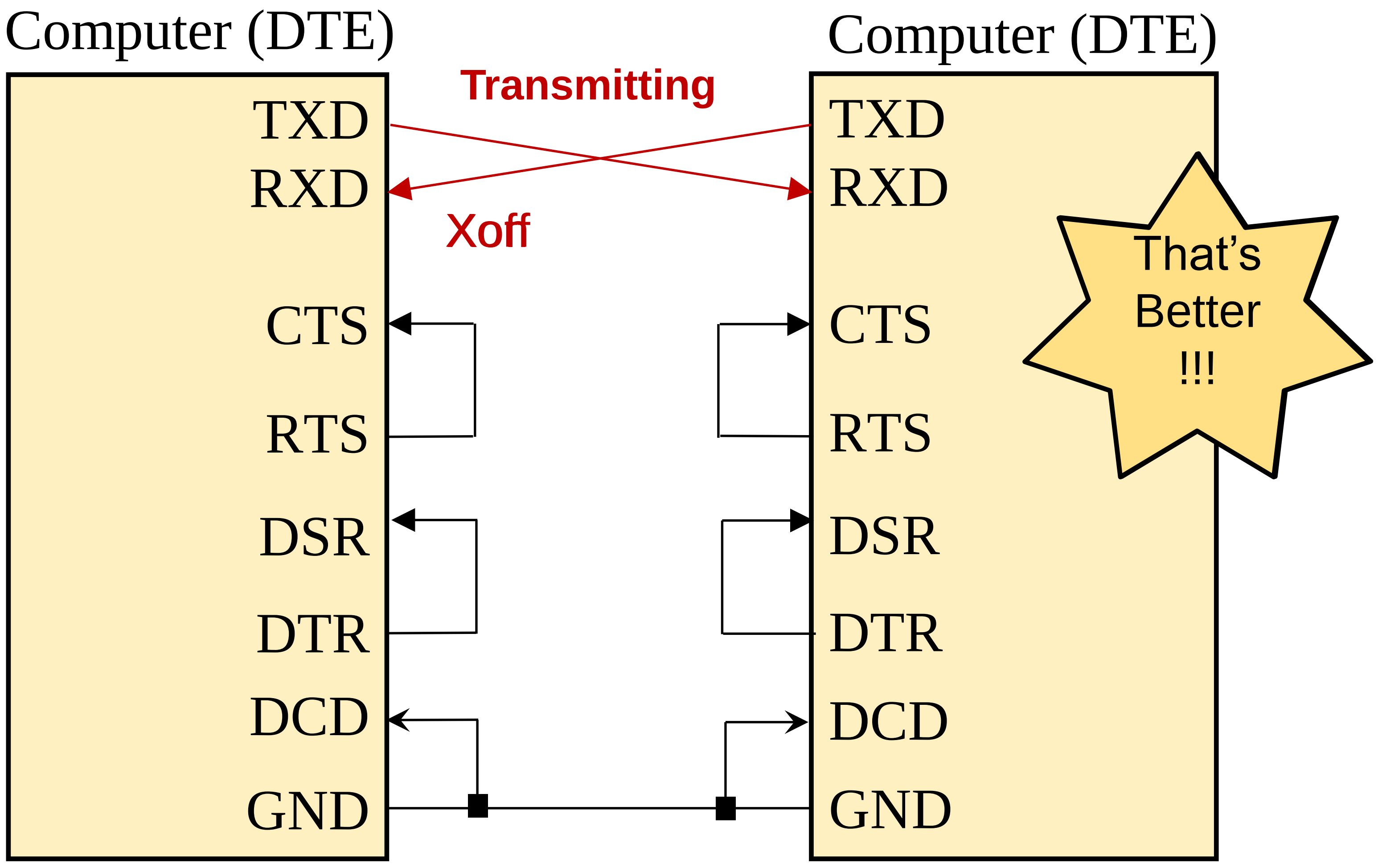


Configuration for Hardware Handshaking, e.g. Computer to Modem

RS-232 Handshaking

- **Soft Handshaking using XON-XOFF**
  - In systems requiring the minimum of cabling complexity and cost, computers and peripherals can be connected without physical/electrical handshaking, that is CTS/RTS handshaking is disabled (or bypassed).
  - Instead, a software protocol (as opposed to an electrical/signalling protocol) is employed whereby two way handshaking is implemented using the transmission of characters XON (free to transmit) and XOFF (stop transmitting).
  - These characters correspond to hex 11 (Ctrl-Q) and hex 13 (Ctrl-S) from the ASCII chart.
  - This protocol is **not** defined by the RS-232 standard but is more commonly used than CTS/RTS signalling, particularly when implementing **Computer-to-Computer** communications.
  - In such situations, the CTS/RTS and DTR/DSR pins have to be wired together to permanently enable the communication devices.
  - The illustration here demonstrates the idea when using a 3 wire cable to connect DTE/DTE equipment.

RS-232 Software Handshaking

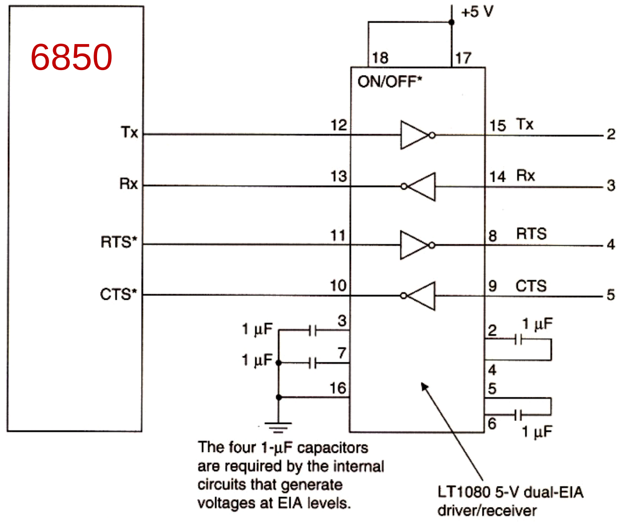


Configuration for Software Handshaking using minimal 3 wire connection Tx, Rx and ground, e.g. Computer to Computer (**Note** crossed over transmit and receive and CTS connected to RTS etc.)

The RS232 Electrical Standard

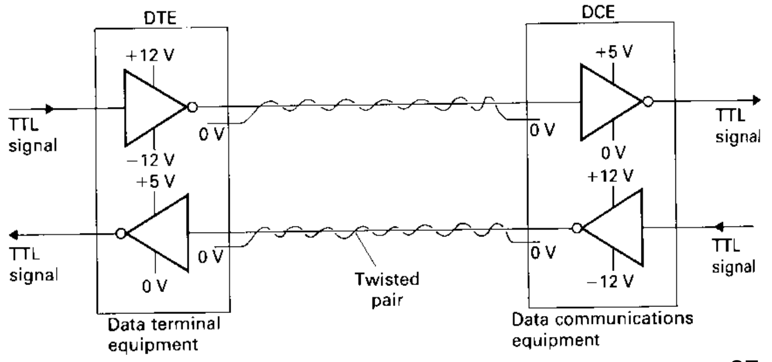
RS232 Electrical Interface

- All Signals are valid in the range ±3 volts to ±25 volts although ±12v is more common. Signals within the range -3 volts to +3 volts are considered invalid.
- MAX do a full range of RS-232 driver chips in various configurations. As do Linear Technologies, these convert digital (TTL voltage levels in he range 0-5 into RS-232 levels in the range ±12v.
- Both sets of chips use on-chip circuitry to generate RS-232 voltage levels from a single 5v supply.
- The example below uses Linear Technologies LT1080 chip.


6850
Tx
Rx
RTS*
CTS*
+5 V
18
17
ON/OFF*
12
15 Tx
2
13
14 Rx
3
11
8 RTS
4
10
9 CTS
5
1 µF
3
1 µF
7
16
2
1 µF
4
5
6
1 µF
The four 1-µF capacitors are required by the internal circuits that generate voltages at EIA levels.
LT1080 5-V dual-EIA driver/receiver

RS232C-to-TTL signal conversion

TTL		RS232C	
Logic	Voltage	Logic	Voltage
High(1)	*2.4 to 5 volts*	*MARK*	*-3 to -25 volts*
Low(0)	*0 to 0.8 volts*	*SPACE*	*+3 to +25 volts*

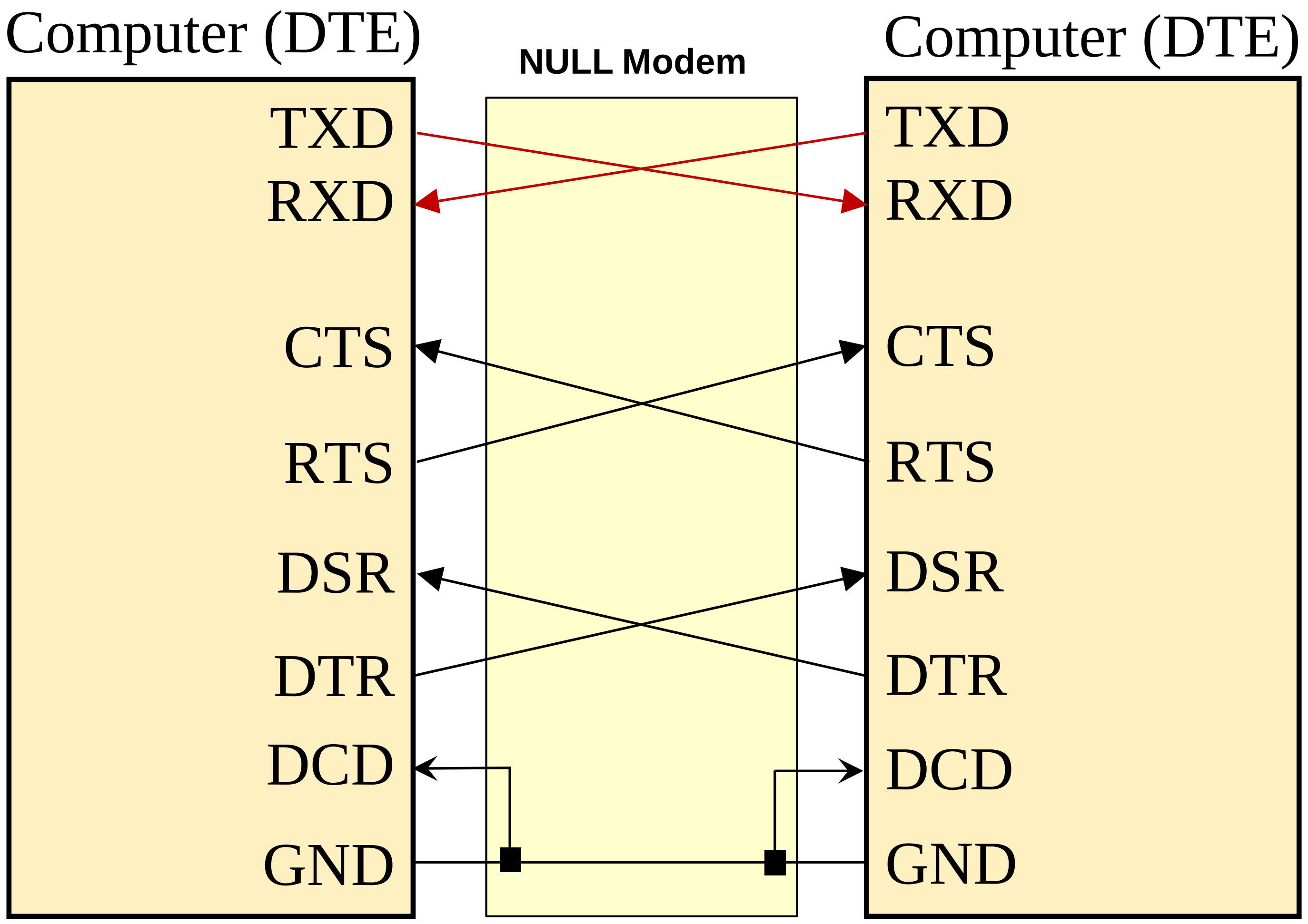


DTE to DTE connections and Null Modems

- RS-232C interface designed originally to connect computers to modems
- However, many of today's RS-232C applications are for connecting a computer (DTE) to either another computer or to a peripheral such as a printer (also considered a DTE), rather than to a modem (DCE)
- In order to connect a computer to a computer (i.e. DTE to a DTE) we must cross over some of the control signals. This is where a break-out box can be useful !!
- This DTE-DTE interface is accomplished with a special connector cable called a *null modem*
  - A NULL modem simulates a DTE-DCE/DCE-DTE circuit
  - A NULL modem has a female connector on both ends.
  - The signals are wired as indicated in the figure overleaf.

DTE to DTE connections and Null Modems

- NULL Modem Connections for Computer to Computer Communication
- Note how everything is crossed over
- Handshaking Can be implemented using RTS/CTS or Xon-Xoff.


Computer (DTE)
NULL Modem
Computer (DTE)
TXD
RXD
CTS
RTS
DSR
DTR
DCD
GND
TXD
RXD
CTS
RTS
DSR
DTR
DCD
GND