CS2204 ANALOG AND DIGITAL COMMUNICATION

UNIT IV DATA COMMUNICATIONS

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- Data communication codes
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Introduction

Data - are defined as information that is stored in digital form. The word data is plural and a single unit of data is a **datum**.

Data communications - is the process of transferring digital information between two or more points.

Information - is defined as knowledge or intelligence. Information that has been processed, organized and stored is called data.

Data communications circuit - which is used to transfer digital information from one place to another.

Network - It is a set of devices sometimes called nodes or stations interconnected by media links.

Data communications networks - are systems of interrelated computers and computer equipments.

Data communications networks applications : ATMs, Internet, workstations,mainframe computers,airline and hotel reservation systems, news networks, Email etc.

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History of Data Communications

1753- Scottish magazine suggested running a communications line between villages comprised of 26 parallel wires.

1833- Carl Friedrich Gauss developed an unusal system based on a five-by-five matrix representing 25 letters.

1832- Samuel F.B.Morse invented telegraph. Morse developed the first practical data communication code which he called the Morse Code. With telegraph, dots and dashes analogous to logic 1s and 0s are transmitted across a wire using electromechanical induction. Various combination of dots and dashes and pauses represented binary codes for letters, numbers and special characters.

1844- The first telegraph line was established between Baltimore and Washington, D.C.

1849- The frist slow-speed telegraph printer was invented.

1850- Western Union Telegraph company was formed in Rochester, NewYork for the purpose of carrying coded messages from one person to another.

1874- Emile Baudot invented a telegraph mulitplexer, which allowed signals from up to six different telegraph machines to be transmitted simulatneously over a single wire.
1875- Alexander Graham Bell invented telephone.

1899- Marconi succeeded in sending radio(wireless) telegraph messages.
1930- German engineer Konrad Zuis developed first electrical computer.

1940- Bell laboratories developed first special purpose computer using electromechanical relays for performing logical operations.

1946- ENIAC computer was developed.

1949- The U.S. National Bureau of Standardds developed the first all-electronic diode-based computer capable of executing stored programs.

1950- Computers used punch cards for inputting information, printers for outputting information and magnetic tape reels for permanently storing information.

1960- Batch-processing systems were replaced by on-line processing systems with terminals connected directly to the computer through serial or parallel communication lines.

1970- Microprocessors based Microcomputers were introduced.

1980s- Personal computers and Main frame computers were introduced.

1980s to 1995- Internet connection was developed slowly.

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Standards Organizations for Data Communications

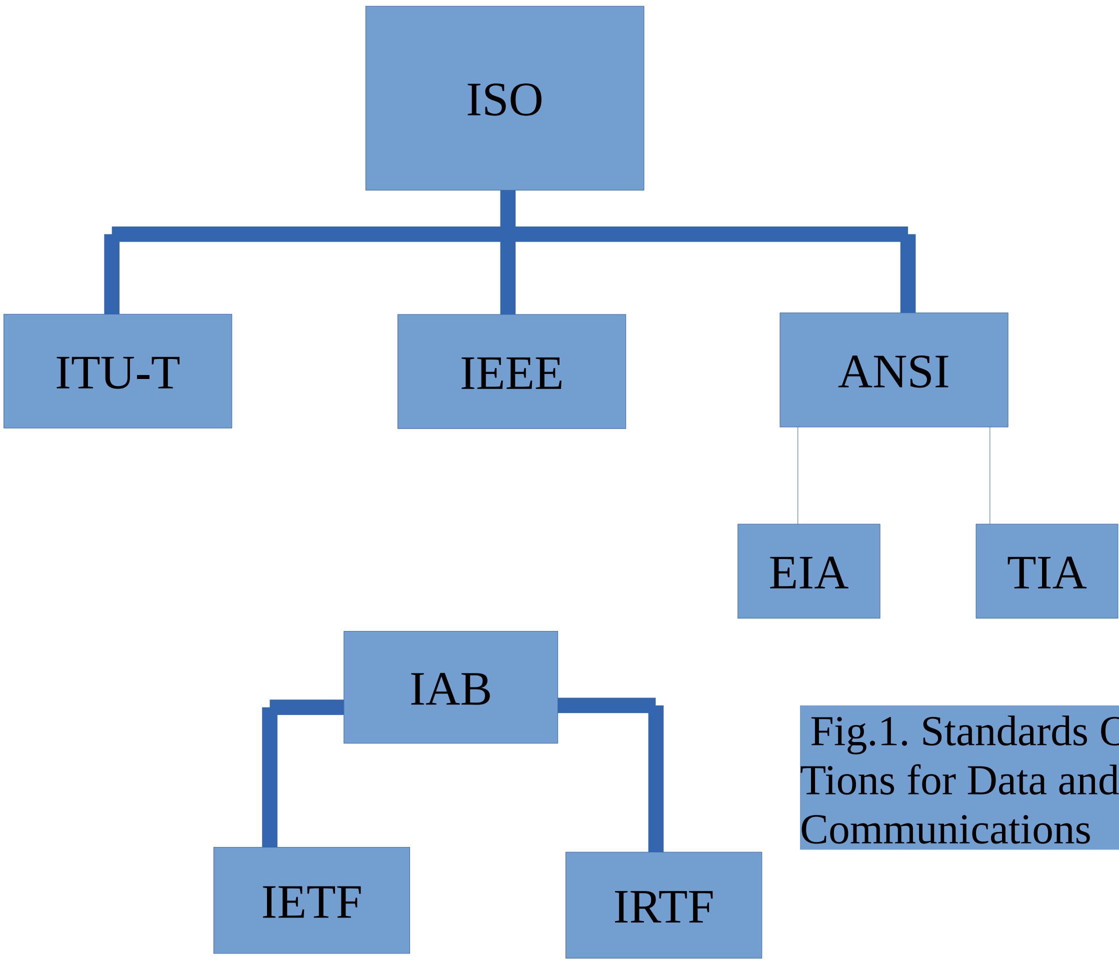

Fig.1. Standards Organiza-Tions for Data and Network Communications

[1]. International Standards Organization (ISO)

ISO was started in 1946. The members of ISO are selected from various governments throughout the world. The ISO creates the sets of rules and standards for graphics and document exchange and provides models for equipment and system compatibility, quality and reduced costs. The ISO is responsible for coordinating the work of the other standards organizations.

The member body of the ISO from the United States is the American National Standards Institute (ANSI).

[2]. International Telecommunications Union-Telecommunications Sector(ITU-T)

It was formerly called as CCITT (Committe Consultant for International Telephony and Telegraphy). It is situated in Geneva, Switzerland. Membership in the ITU-T consists of government authorities and representatives from many countires.

It develops the recommended sets of rules and standards for telephone and data communications. It has developed three sets of specifications:(1). The **V series for modem** interfacing and data transmission over telephone lines (2). The **X series for data transmission over public digital networks,Email** and directory serivces (3). The **I and Q series for Integrated Services Digital Network (ISDN)** and its extension is Broadband ISDN.

The ITU-T is separated into **14 study groups**.

[3]. Institute of Electrical and Electronics Engineering(IEEE)

The IEEE is an international professional organization founded in united states and is comprised of electronics, computer and communications engineers.

The IEEE works along with ANSI **to develop communications and information processing standards with the aim of advancing theory, creativity and product quality in any field associated with electrical engineering.**

[4]. American National Standards Institute(ANSI)

It is an official standards agency for the united states and is the U.S voting representative for the ISO.

ANSI is a completely private, nonprofit organization comprised of euipment manufacturers and users of data processing equipment and services.

A**NSI membership is comprised of people from professional societies, industry associations, governmental and regulatory bodies and consumer groups**.

[5]. Electronics Industry Association(ESA)

EIA activities include standards development and inncreasing public awareness. The EIA is responsible for **RS(Recommended Standard) series of standards** for data and telecommunications.

[6]. Telecommunications Industry Association (TIA)

Its a trade assocaition in the communications and information technology industry. It represents manufacturers of communications and information technology products and services providers for the global marketplace.

[7]. Internet Architecture Board(IAB)

The responsibilities of IAB are:
(1). Internet Architecture protocol.
(2). Create Internet standards.
(3). Administration of the various Internet assigned numbers.
(4). Acts as representative for Internet Society.
(5). Acts as a source of advice and guidance.

[8]. Internet Engineering Task Force (IETF)

Its a large international community of network designers, operators, venders, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet.

[9]. Internet Research Task Force(IRTF)

It promotes the research on evolution of future internet in the topics related to Internet protocols, applications, architecture and technology.

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Data Communications Circuits

Fig.2. Simplified Block Diagram of a two-station data communications circuit.

Data Communication Circuit – Its purpose is to provide a transmission path between locations and to transfer digital information from one station to another using electronic circuits.
Station- is simply an endpoint where subscribers gain access to the circuit.
Node- A station is sometimes called as node, which is the location of computers, computer terminals, workstation and other digital computing equipment.

The communication facilities are provided to data communication users through p**ublic telephone networks (PTN), public data networks(PDN)** and a multitude of private data communications systems.

The fundamental components of the circuit are:
(1).Source of digital information (2). Transmitter (3). Transmission medium (4). Receiver and (5). Destination for the digital information.

Bidirectional transmission is possible by providing a duplicate set of circuit components in the opposite direction.

(1). **Source-** The source may be a mainframe computer, personal computer, workstation, or any other digital equipment.
(2). **Transmitter-** The transmitter encodes the source information and converts it to a different form and the transmitter acts as an interface between the source equipment and the transmission medium.

(3). **Transmission Medium-** The transmission medium carries the encoded signals from the transmitter to the receiver. Types of transmission medium:
(i).Free-space radio transmission such as terristrial microwave, satellite radio and cellular telephone.
(ii).Metallic cables.
(iii).Optical fiber cables.

(4). **Receiver-** The receiver converts the encoded signals received from the transmission medium back to their original form. The receiver acts as an interface between the transmission medium and the destination equipment.

(5). **Destination-** Destination may be mainframe computer, personal computer, workstation or any other digital equipment.

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Data Communications Codes

- Data communications codes are used to represent characters and symbols such as letters, digits and punctuation marks.
- Data communications codes are called character codes, character sets, symbol codes or character languages.
- The relationship of bytes to characters is determined by a *character code.*
- Each time a user presses a key on a terminal/PC, a binary code is generated for the corresponding character.
- Various character codes have been used in data communication including:

  Morse, Baudot

  EBCDIC, ASCII

  Unicode

[1]. Baudot Code

The Baudot code (sometimes called the Telex code) was the first fixed-length character code.One of first codes developed for machine to machine communication.

It uses 1's and 0's instead of dots and dashes. It was used for transmitting telex messages (punch tape).

- Fixed character length (5-bits)
- 32 different codes
- increased capacity by using two codes for shifting
- 11111 (32) Shift to Lower (letters)
- 11011 (27) Shift to Upper (digits, punctuation)
- 4 special codes for SP, CR, LF & blank
- Total = 26 + 26 + 4 = 56 different characters

Problems with Baudot:

- required shift code to switch between character sets
- no lower case, few special characters
- no error detection mechanism
- characters not ordered by binary value
- designed for transmitting data, not for data processing

International Baudot

- Added a 6th bit for parity
- Used to detect errors within a single character

Character		Data bits				
Lower case	Upper case	5	4	3	2	1
A	_	0	0	0	1	1
B	?	1	1	0	0	1
C	:	0	1	1	1	0
D	$	0	1	0	0	1
E	3	0	0	0	0	1
F	!	0	1	1	0	1
G	&	1	1	0	1	0
H	#	1	0	1	0	0
I	8	0	0	1	1	0
J	'	0	1	0	1	1
K	(	0	1	1	1	1
L	)	1	0	0	1	0
M	.	1	1	1	0	0
N	,	0	1	1	0	0
O	9	1	1	0	0	0
P	0	1	0	1	1	0
Q	1	1	0	1	1	1
R	4	0	1	0	1	0
S	BELL	0	0	1	0	1
T	5	1	0	0	0	0
U	7	0	0	1	1	1
V	;	1	1	1	1	0
W	2	1	0	0	1	1
X	/	1	1	1	0	1
Y	6	1	0	1	0	1
Z	"	1	0	0	0	1
Letters (shift to Lower case column)		1	1	1	1	1
Figures (shift to Upper case column)		1	1	0	1	1
Space		0	0	1	0	0
Carriage return		0	1	0	0	0
Line feed		0	0	0	1	0
Blank		0	0	0	0	0

Table.1.Baudot code

[2]. ASCII Code

- American Standard Code for Information Interchange.
- 7-bit code developed by the American National Standards Institute (ANSI).
- most popular data communication character code today.
- Allows for 128 different character representations (2^7).
- includes upper and lower case.
- lots of special characters (non-printable).
- generally used with an added parity bit.
- better binary ordering of characters than EBCDIC.
- Extended ASCII uses 8 data bits and no parity
- Used for processing and storage of data.
- Allows for international characters.
- 8th bit stripped of for transmission of standard character set.

Bits 7654321	Character	Bits 7654321	Character	Bits 7654321	Character	Bits 7654321	Character
0000000	NUL	0100000	SP	1000000	@	1100000	`
0000001	SOH	0100001	!	1000001	A	1100001	a
0000010	STX	0100010	“	1000010	B	1100010	b
0000011	ETX	0100011	#	1000011	C	1100011	c
0000100	EOT	0100100	$	1000100	D	1100100	d
0000101	ENQ	0100101	%	1000101	E	1100101	e
0000110	ACK	0100110	&	1000110	F	1100110	f
0000111	BEL	0100111	'	1000111	G	1100111	g
0001000	BS	0101000	(	1001000	H	1101000	h
0001001	HT	0101001	)	1001001	I	1101001	i
0001010	LF	0101010	*	1001010	J	1101010	j
0001011	VT	0101011	+	1001011	K	1101011	k
0001100	FF	0101100	,	1001100	L	1101100	1
0001101	CR	0101101	-	1001101	M	1101101	m
0001110	SO	0101110	.	1001110	N	1101110	n
0001111	SI	0101111	/	1001111	O	1101111	o
0010000	DLE	0110000	0	1010000	P	1110000	p
0010001	DC1	0110001	1	1010001	Q	1110001	q
0010010	DC2	0110010	2	1010010	R	1110010	r
0010011	DC3	0110011	3	1010011	S	1110011	s
0010100	DC4	0110100	4	1010100	T	1110100	t
0010101	NAK	0110101	5	1010101	U	1110101	u
0010110	SYN	0110110	6	1010110	V	1110110	v
0010111	ETB	0110111	7	1010111	W	1110111	w
0011000	CAN	0111000	8	1011000	X	1111000	x
0011001	EM	0111001	9	1011001	Y	1111001	y
0011010	SUB	0111010	:	1011010	Z	1111010	z
0011011	ESC	0111011	;	1011011	[	1111011	{
0011100	FS	0111100	<	1011100	\	1111100	|
0011101	GS	0111101	=	1011101	]	1111101	}
0011110	RS	0111110	>	1011110	^	1111110	~
0011111	US	0111111	?	1011111	—	1111111	DEL

Table.2.7-bit ASCII code

ASCII control characters			
BEL	Bell	EM	End of Medium
CAN	Cancel	ESC	Escape
DC1	Device Control 1	NUL	Null
DC2	Device Control 2	SI	Shift In
DC3	Device Control 3	SO	Shift Out
DC4	Device Control 4	SUB	Substitute
DEL	Delete		
Control codes			
ACK	Acknowledge	ETX	End of Text
DLE	Data Link Escape	NAK	Negative Acknowledge
ENQ	Enquiry	SOH	Start of Heading
EOT	End of Transmission	STX	Start of Text
ETB	End of Transmission Block	SYN	Synchronous Idle
Format effectors			
BS	Backspace	HT	Horizontal Tabulation
CR	Carriage Return	LF	Line Feed
FF	Form Feed	VT	Vertical Tabulation
Information separators			
FS	File Separator	RS	Record Separator
GS	Group Separator	US	Unit Separator

Table.3. ASCII Non-Printable Codes

[3]. EBCDIC Code

- Extended Binary Coded Decimal Interchange Code.
- 8-bit character code developed by IBM.
- used for data communication, processing and storage.
- extended earlier proprietary 6-bit BCD code.
- designed for backward compatibility or marketing?
- still in use today on some mainframes and legacy systems.
- Allows for 256 different character representations (2^8).
- includes upper and lower case.
- lots of special characters (non-printable).
- lots of blank (non-used codes).
- assigned to international characters in various versions.

- used with/without parity (block transmissions).

Bit 4 5 6 7 / 0 1 2 3	0 0 0 0	0 0 0 1	0 0 1 0	0 0 1 1	0 1 0 0	0 1 0 1	0 1 1 0	0 1 1 1	1 0 0 0	1 0 0 1	1 0 1 0	1 0 1 1	1 1 0 0	1 1 0 1	1 1 1 0	1 1 1 1
0 0 0 0	NUL	SOH	STX	ETX	PF	HT	LC	DEL				VT	FF	CR	SO	SI
0 0 0 1	DLE	DC1	DC2	DC3	RES	NL	BS	IL	CAN	EM			IFS	IGS	IRS	IUS
0 0 1 0			FS		BYP	LF	EOB	PRE			SM			ENQ	ACK	BEL
0 0 1 1			SYN		PN	RS	UC	EOT					DC4	NAK		SUB
0 1 0 0	SP										¢	.	<	(	+	|
0 1 0 1	&										!	$	*	)	;	¬
0 1 1 0	-	/									¦	,	%	-	>	?
0 1 1 1										\	:	#	@	'	=	"
1 0 0 0		a	b	c	d	e	f	g	h	i						
1 0 0 1		j	k	l	m	n	o	p	q	r						
1 0 1 0		~	s	t	u	v	w	x	y	z						
1 0 1 1																
1 1 0 0	{	A	B	C	D	E	F	G	H	I						
1 1 0 1	}	J	K	L	M	N	O	P	Q	R						
1 1 1 0			S	T	U	V	W	X	Y	Z						
1 1 1 1	0	1	2	3	4	5	6	7	8	9						□

Note: To read this chart, simply find the character on the chart, then look to the left side of the row for bits 0, 1, 2, and 3, and to the top of the column for bits 4, 5, 6, and 7. This is only one of many possible implementations of EBCDIC.

EBCDIC special characters					
ACK	Acknowledgement	EOT	End of Transmission	PF	Punch Off
BEL	Bell	ETX	End of Text	PN	Punch On
BS	Backspace	FF	Form Feed	PRE	Prefix
BYP	Bypass	FS	File Separator	RES	Restore
CAN	Cancel	HT	Horizontal Tab	RS	Reader Stop
CR	Carriage Return	IFS	Information File Separator	SI	Shift In
DC1	Device Control 1	IGS	Information Group Separator	SM	Start Message
DC2	Device Control 2	IL	Idle	SO	Shift Out
DC3	Device Control 3	IRS	Information Record Separator	SOH	Start of Heading
DC4	Device Control 4	IUS	Information Unit Separator	SP	Space
DEL	Delete	LC	Lower Case	STX	Start of Text
DLE	Data Link Escape	LF	Line Feed	SUB	Substitute
EM	End of Medium	NAK	Negative Acknowledgement	SYN	Synchronous Idle
ENQ	Enquiry	NL	New Line	UC	Upper Case
EOB	End of Block	NUL	Null	VT	Vertical Tab

Table.4. EBCDIC Code

SUMMARY OF CHARACTER CODES

Morse	=	• —
Baudot	=	5 bit (no parity)
Int. Baudot	=	6 bit (5 data + 1 parity)
ASCII	=	8 bit (7 data + 1 parity)
EBCDIC	=	9 bit (8 data + 1 parity)
UNICODE	=	16 bits (no parity)

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DATA MODEMS

- The primary purpose of a data modem is to interface computers, computer networks and other digital terminal equipment to analog communication lines and radio channels.
- The word modem is a contraction derived from the words modulator and demodulator.
- In a modem transmitter, digital signals modulate an analog carrier and in a receiving modem, analog signals are demodulated and converted into digital signals.
- A modem is sometimes called as DCE(Data communication equipment), a data set, a dataphone.
- Modems are generally classified as either asynchronous or synchronous.
- Modems use one of the following modulation techniques:

  (1). Amplitude Shift Keying (ASK)

  (2). Frequency Shift Keying (FSK)

  (3). Phase Shift Keying (PSK)

  (4). Quadrature Amplitude Modulation (QAM)

Difference between Synchronous and Asynchronous Modems

Synchronous Modems	Asynchronous Modems
In these type of Modems, clocking information is recovered in the receiver.	In these type of Modems, clocking information is not recovered at receiver and may not require.
These Modems uses the modulation techniques like PSK and QAM.	These Modems uses the modulation techniques like ASK and FSK.
It can be used for Medium and High Speed applications up to 57.6 Kbps.	It can be used for Low Speed applications below 2.4 Kbps.

Low-Speed Modems

- Low speed modems are generally asynchronous.
- It uses Non-coherenr FSK.
- The transmit carrier and clock frequencies need not be recovered by the receive modem.
- Therefore, they don't need scrambler and descrambler circuits.
- Speed 1200 to 1800 baud.

Medium and High-Speed Modems

- Medium and High speed Modems are used where transmission rates of 2400 bps or baud are required.
- PSK or QAM modulation techniques are used.
- These Modems are synchronous.
- Because these Modems are synchronous, clock timing recovery and carrier recovery must be

required.

- These Modems contain scrambler and descrambler circuits and adaptive equalizers.
- Example: the 208 Modem is a synchronous, 4800 baud rate, 8-DPSK modulation technique.

Each symbol represents three bits and is 0.625 milliseconds duration.

Modem Control

The smart Modems are controlled by other larger computers through a system of commands. The most common system of modem commands is the AT command set which is also known as the Hayes command set. Hayes Microcomputer Products originally developed the AT command set for its own line of modems.

Characters	Command
AT	**Attention**
A	**Answer an incoming call**
DT	**Dial using DTMF tones**
DP	**Dial using Pulse dialing**
E0	**Do not echo transmitted data to terminal screen**
E1	**Echo transmitted data to terminal screen**
F0	**Half-duplex communications**
F1	**Full-duplex communications**
H	**Go on-hook (Hang up)**
O	**Switch from command to on-line mode**
Z	**Reset Modem**
+++	**Escape code; switch from on-line mode to command mode**

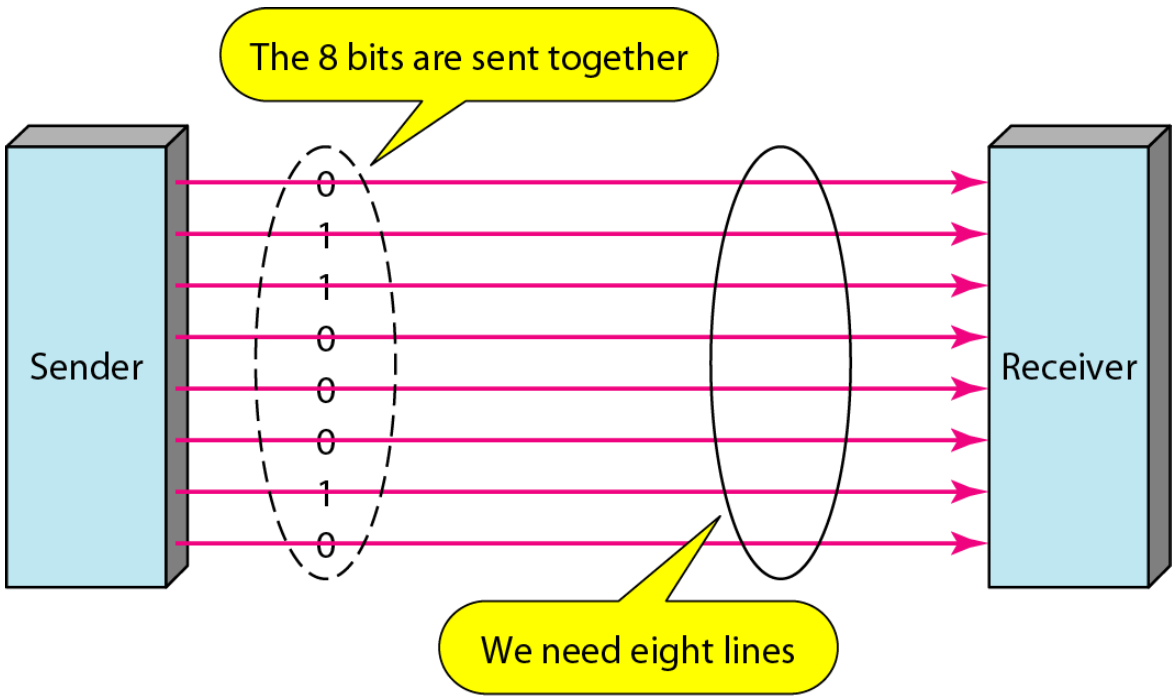
AT command mode

- All modem commands in the AT command set begin with the ASCII characters AT (Attention).
- In the command mode, the modem monitors the information sent to it through the DTE(Data Terminal Equipment-Computer system)[Modem called as DCE-Data Communication Equipment] by the local terminal looking for the ASCII characters AT.
- ASCII character 'T' is the command to use tones rather than pulses and the character 'D' is the command to dial.
- For example to dial the telephone number 91-424-2533279, the character sequence would be ATDT914242533279.

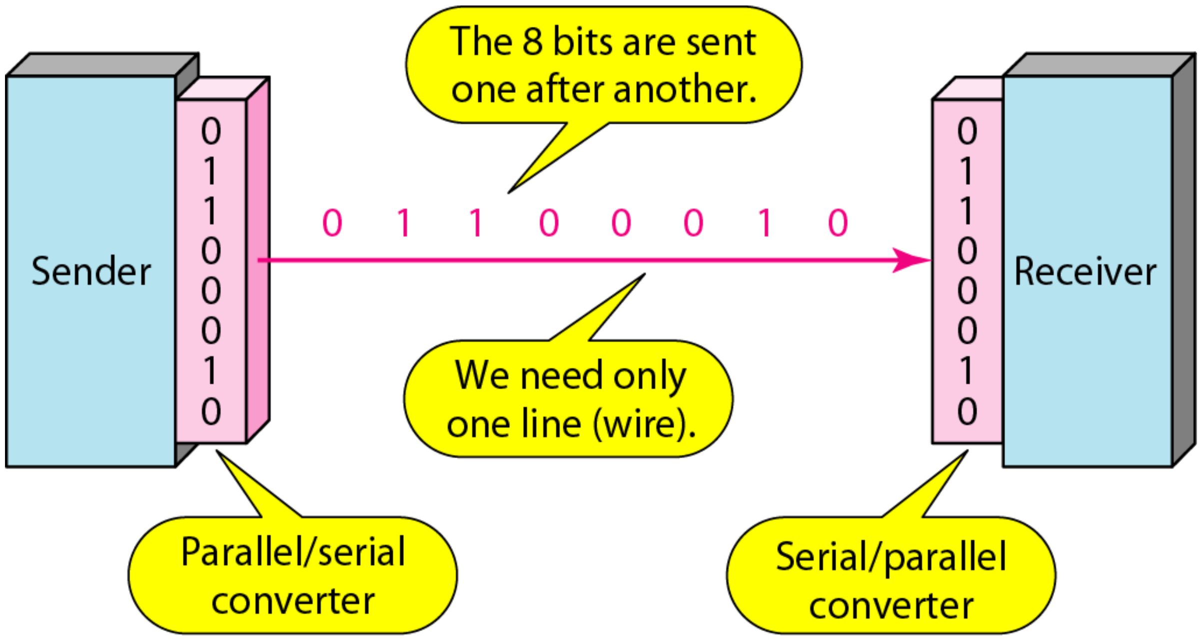
AT on-line mode

- Once communications have been established with a remote modem, the local modem switches to the on-line mode.
- The local modem simply accepts the characters and allows them to modulate its carrier before sending them to a remote location.
- The local terminal (computer system) can switch the modem from the on-line mode to the command mode by sending three consecutive plus signs (+ + +). This sequence is called as escape code.
- In response to the escape code, the modem switches to the command mode and begins monitoring data for the ASCII AT command code.

Parallel Transmission

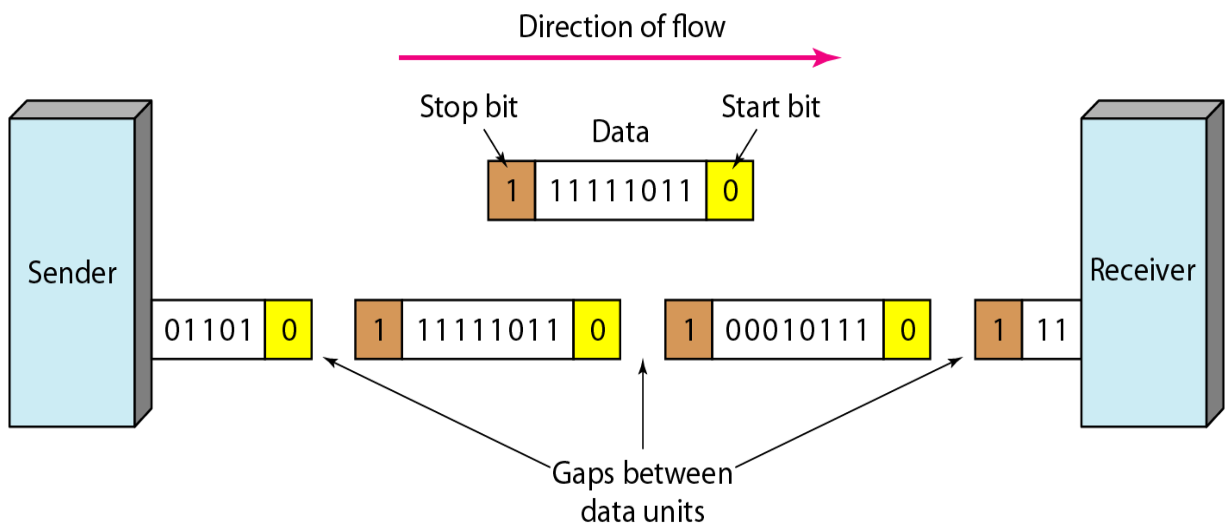


Serial Transmission



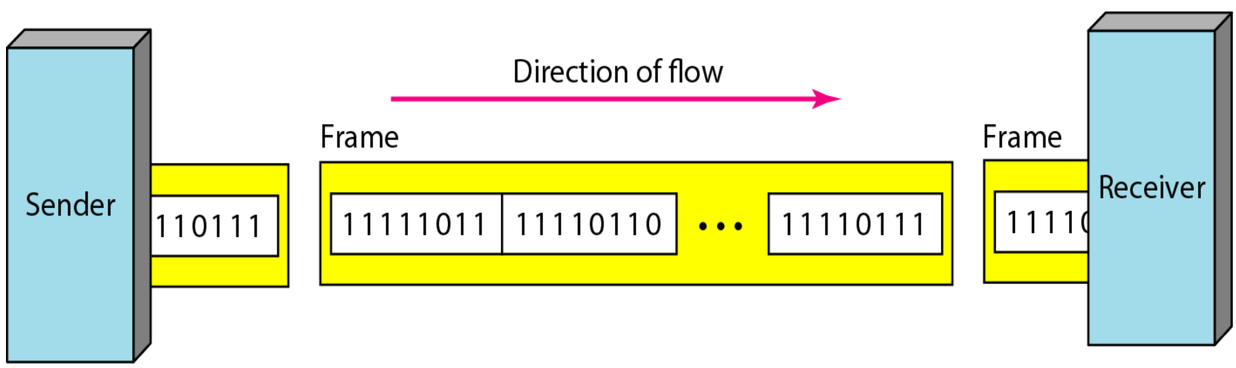
ASynchronous Transmission

- **In asynchronous transmission, send 1 start bit (0) at the beginning and 1 or more stop bits (1s) at the end of each byte. There may be a gap between each byte.**
- **Asynchronous here means "asynchronous at the byte level," but the bits are still synchronized; their durations are the same.**

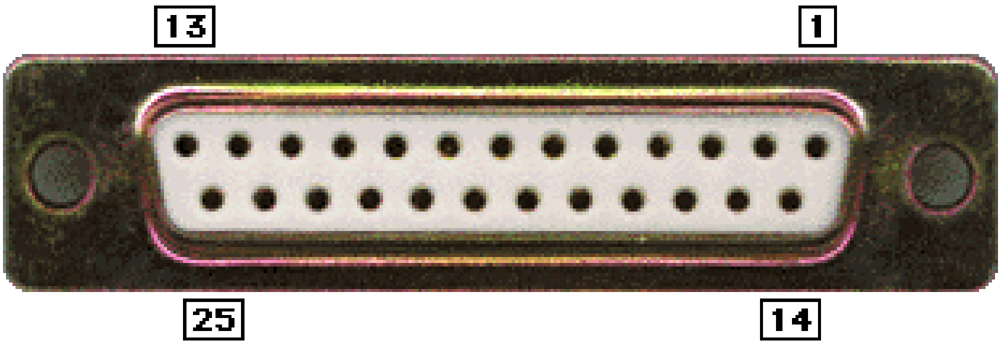


Synchronous Transmission

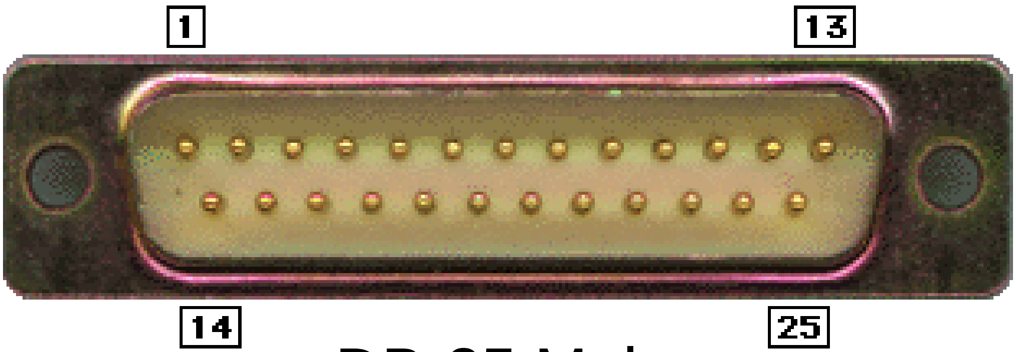
- **In synchronous transmission, we send bits one after another without start or stop bits or gaps. It is the responsibility of the receiver to group the bits. The bits are usually sent as bytes and many bytes are grouped in a frame. A frame is identified with a start and an end byte.**



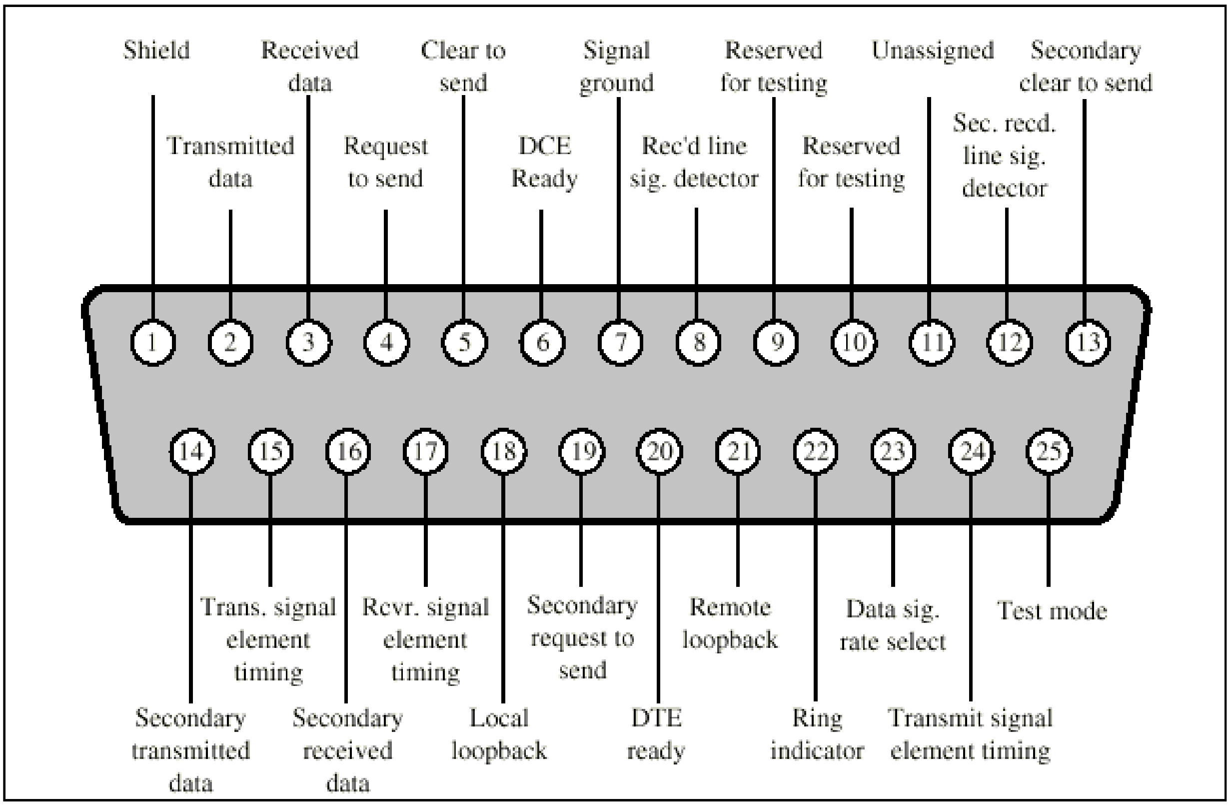
Serial Interfaces- RS 232



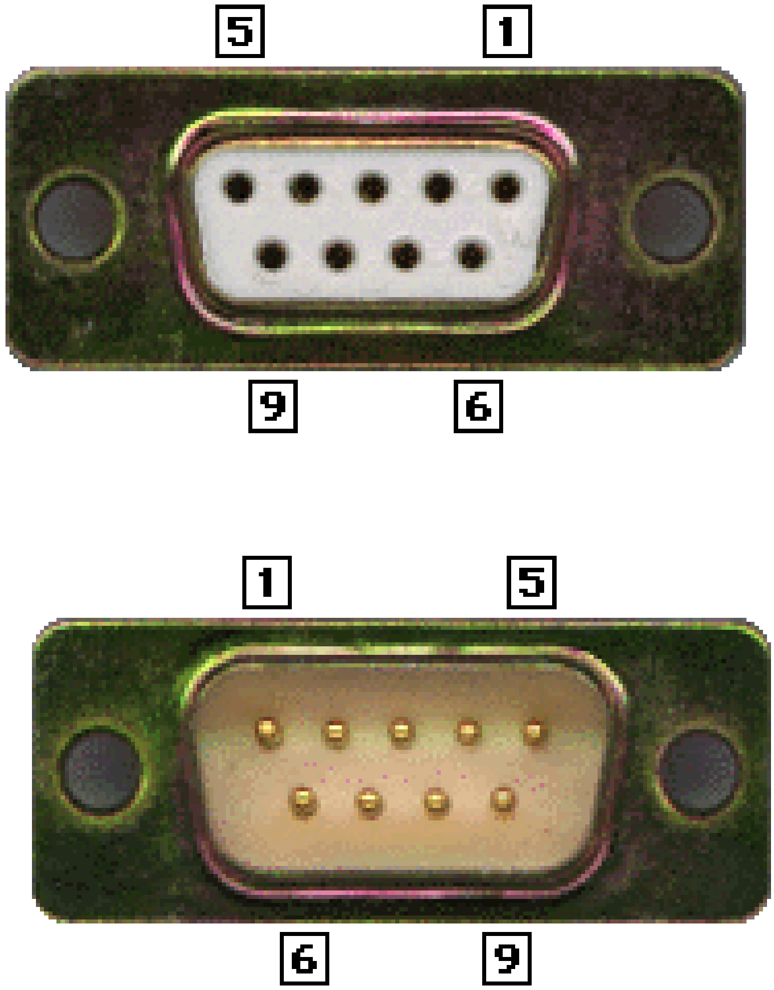
DB-25 Female



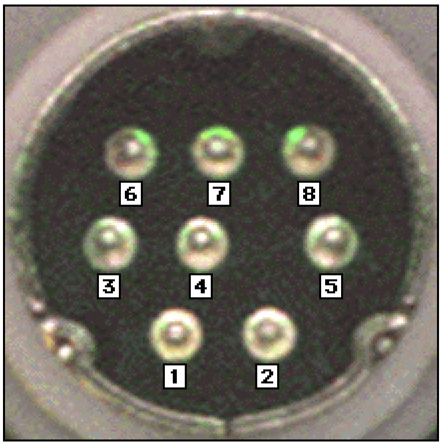
DB-25 Male



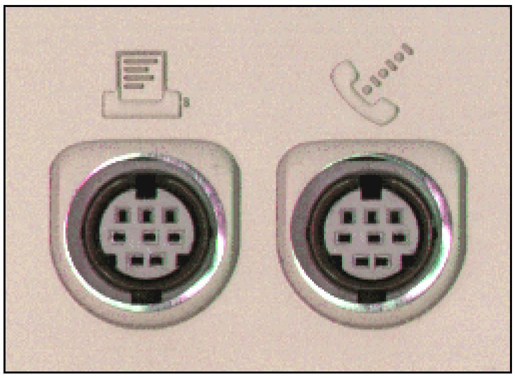
RS-232 DB-25 Pinouts



RS-232 DB-9 Connectors



DIN-8 Male



DIN-8 Female

Error Control

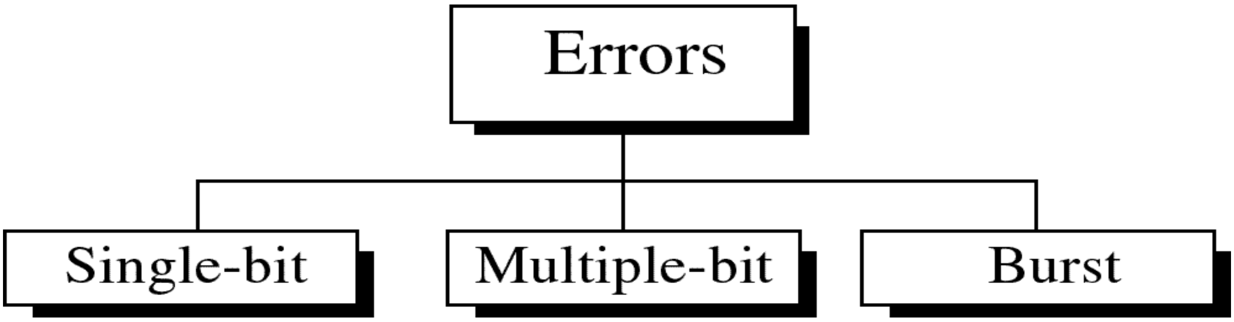
Networks must be able to transfer data from one device to another with complete accuracy. Data can be corrupted during transmission. For reliable communication, errors must be detected and corrected. Error control can be divided into two general categories:

[1]. Error Detection

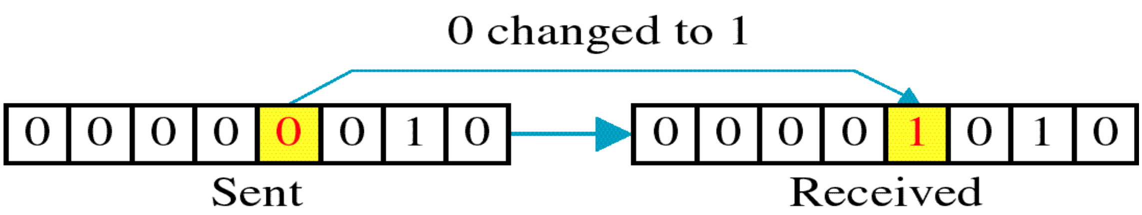
[2]. Error Correction

Error detection and Error correction are implemented either at the **data link layer** or the **transport layer** of the OSI model.

Types of Errors

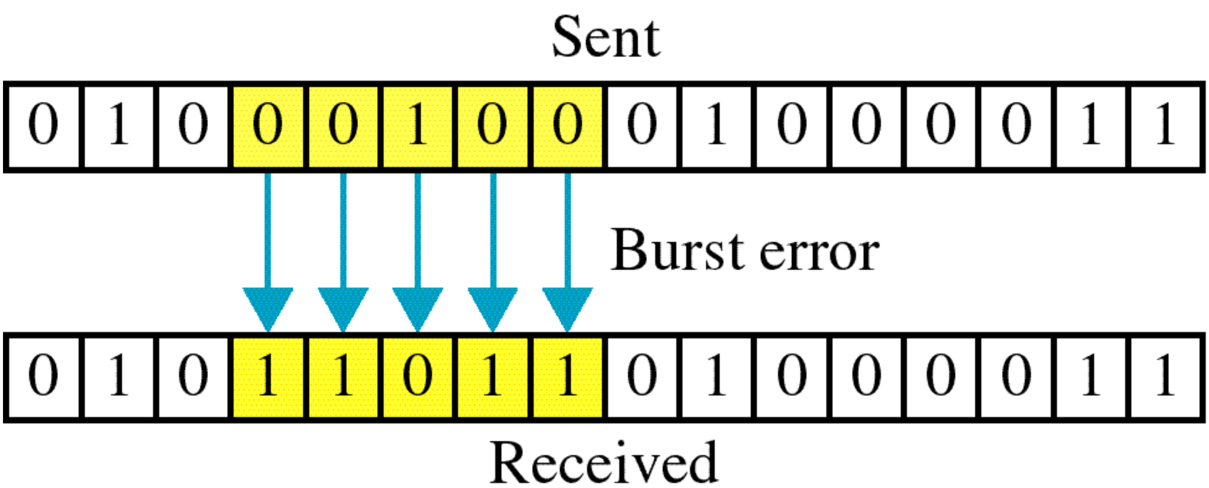


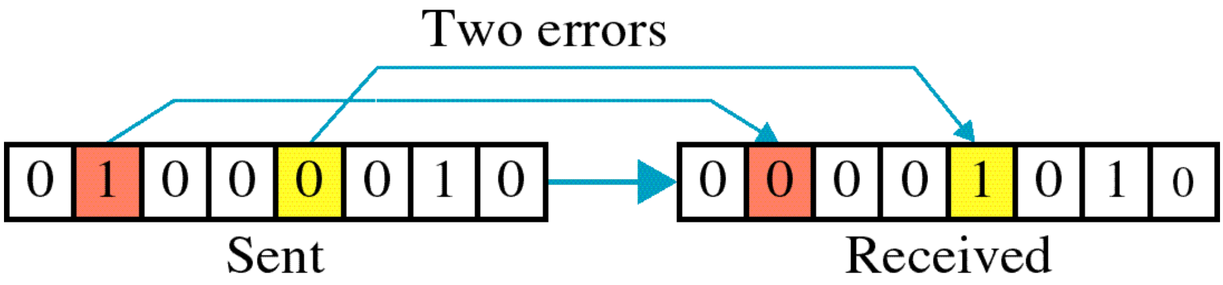
[1]. Single-bit error



Single bit errors are the **least likely** type of errors in serial data transmission because the noise must have a very short duration which is very rare. However this kind of errors can happen in parallel transmission.

[2]. Burst error





The term **burst error** means that two or more bits in the data unit have changed from 1 to 0 or from 0 to 1.

Burst errors does not necessarily **mean that the errors occur in consecutive bits**, the length of the burst is measured from the first corrupted bit to the last corrupted bit. Some bits in between may not have been corrupted.

Burst error is most likely to happen in serial transmission since the duration of noise is normally longer than the duration of a bit. The number of bits affected depends on the data rate and duration of noise.

[1]. Error detection

Error detection means to decide whether the received data is correct or not without having a copy of the original message. Error detection **uses the concept of redundancy**, **which means** adding extra bits for detecting errors at the destination.

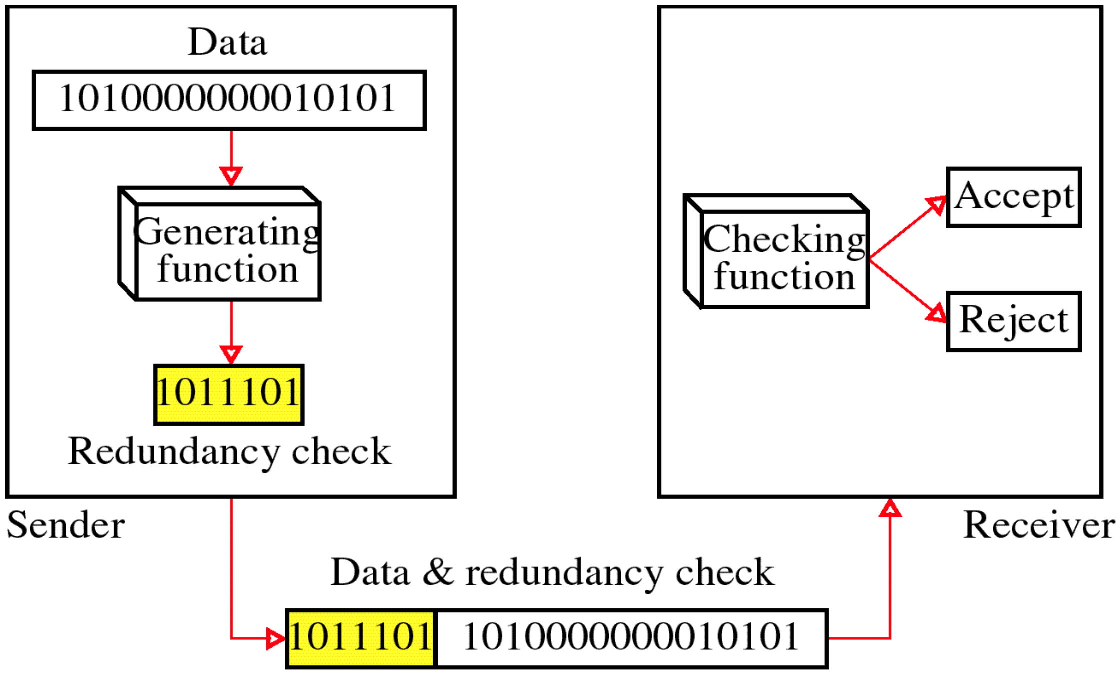
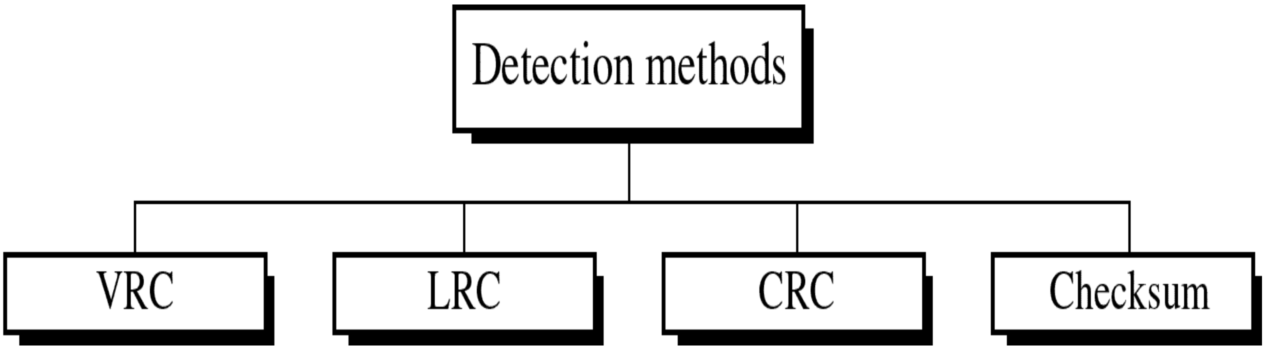


Fig. Redundancy

Redundancy Checks Types:



(1). VRC - **Vertical Redundancy Check**

(2). LRC - **Longitudinal Redundancy Check**

(3). CRC - **Cyclic Redundancy Check**

(4). Checksum

(1). VRC - Vertical Redundancy Check

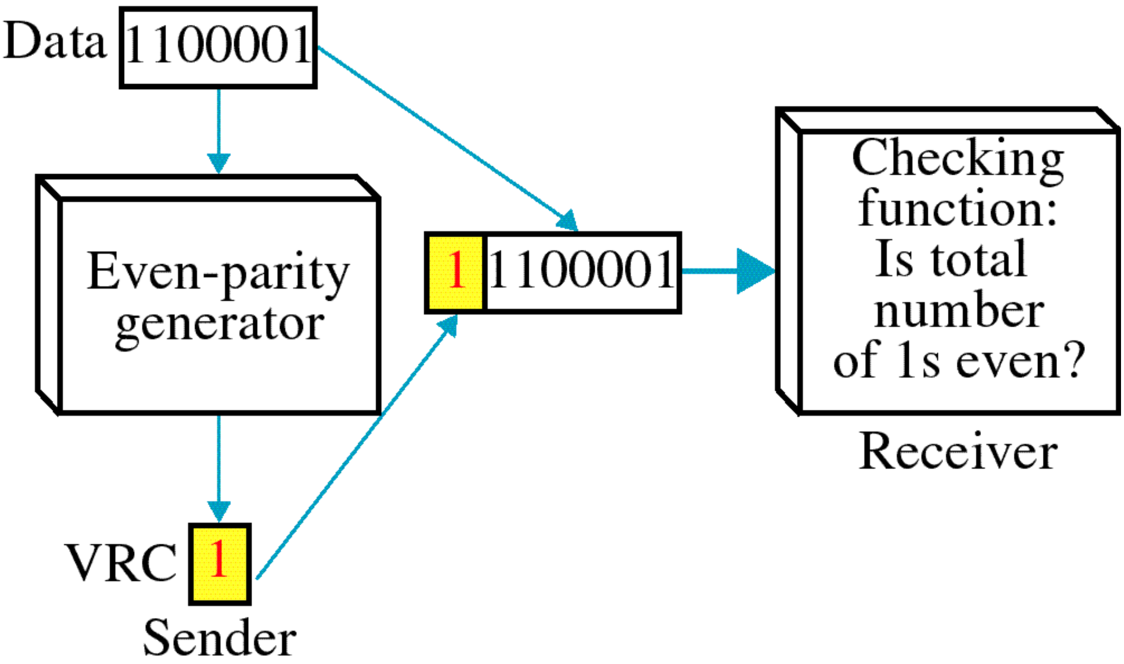


Fig. VRC-Vertical Redundancy Check

VRC is also referred to as character parity. With character parity, each character has its own error-detection bit called the parity bit. The parity bit is considered as a redundant bit. An n-character message would have 'n' redundant parity bits.

- It can detect single bit error.
- It can detect burst errors only if the total number of errors is odd.

(2). <u>LRC - Longitudinal Redundancy Check</u>

LRC is also referred to as message parity since it is used to check error occurred within a message. With LRC each bit position has a parity bit. <u>LRC is the result of XORing the bits present in all the characters present in a message</u> whereas V<u>RC is the result of XORing the bits within a single character.</u>

- In LRC even parity is generally used, whereas with VRC odd parity is generally used.
- LCR increases the likelihood of detecting burst errors.
- If two bits in one data units are damaged and two bits in exactly the same positions in another data unit are also damaged, the LRC checker will not detect an error.

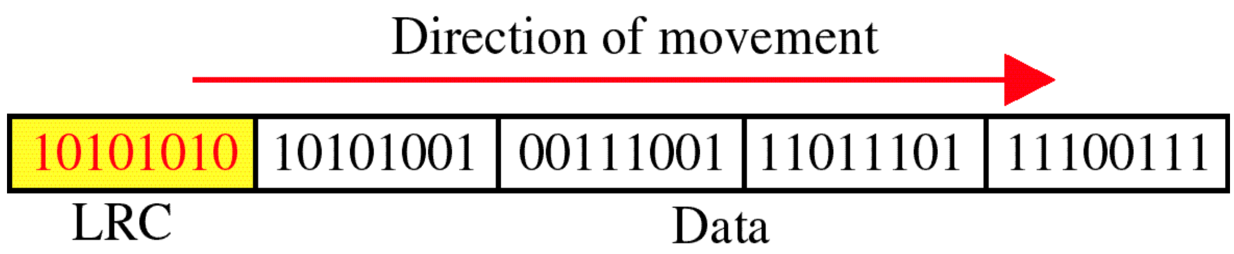


Fig.**LRC - Longitudinal Redundancy Check**

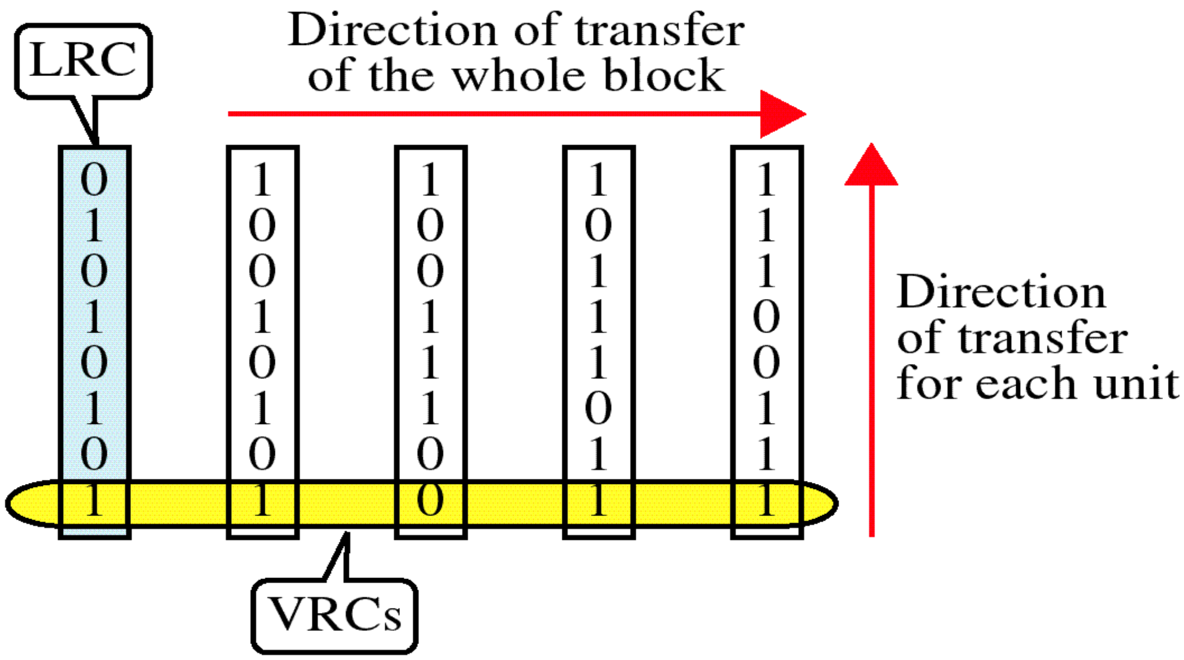


Fig. VRC and LRC

(3). <u>Checksum</u>

The characters within a message are combined together to produce an error-checking character called as checksum, which can be as simlple as the arithmetic sum of the numerical values of all the characters in the message. The checksum is appended to the end of the message.

The receiver replicates the combining operation and determines its own checksum. The receivers checksum is compared with transmitter checksum appended with the message, and if they are the same, it is assumed that no transmission errrors have occurred.

(4). <u>CRC - Cyclic Redundancy Check</u>

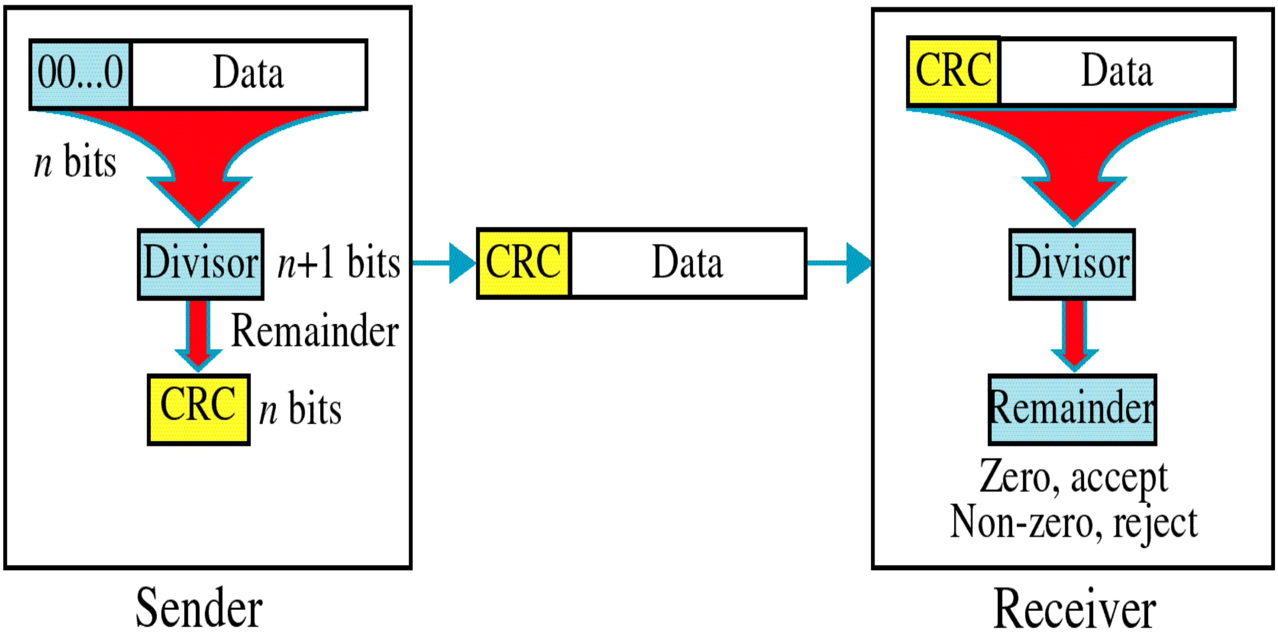
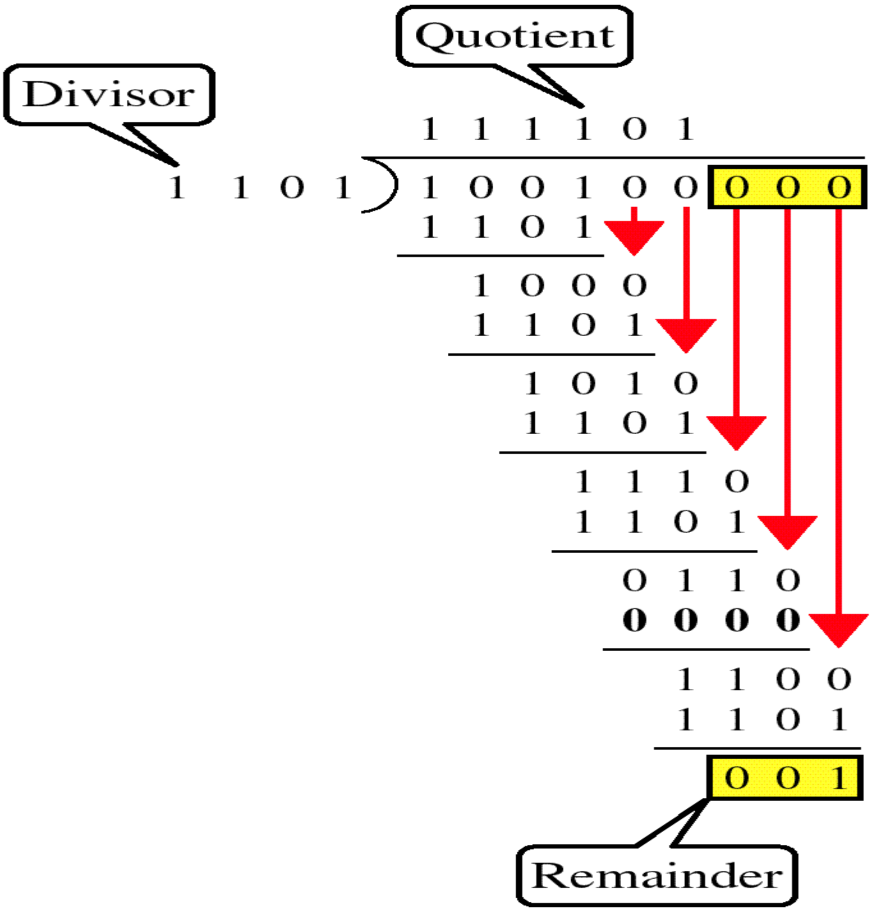


Fig. Cyclic Redundancy Check

It's a most reliable redundancy checking technique for errror detection is a convolutional coding scheme called **Cyclic Redundancy Check(CRC).** Given a k-bit frame or message, the transmitter generates an (n-k) bit sequence, known as a ***frame check sequence (FCS)(or) Block Check Code(BCS)***, so that the resulting frame, consisting of 'n' bits, is exactly divisible by some predetermined number. The receiver then divides the incoming frame by the same number and, if there is no remainder, assumes that there was no error.



$$\frac{G(x)}{P(x)}=Q(x)+R(x)$$

G(x) = Message Polynomial (message or Data)

P(x) = Generator Polynomial

Q(x) = Quotient

R(x) = Remainder (CRC bits)

For this example

$$G(x)=x^5+x^2$$
$$P(x)=x^3+x^2+x^0$$

$$G(x)=\{1,0,0,1,0,0\}$$
$$P(x)=\{1,1,0,1\}$$

Here in this example CRC bits are {0,0,1}

__________________________________ X __________________________________

[2]. Error Correction

Error correction is the detection of errors and reconstruction of the original, error-free data. Error correction may generally be realized in two different ways:

- ***Automatic repeat request*** *(ARQ)* [Retransmission method] (sometimes also referred to as *backward error correction*): This is an error control technique whereby an error detection scheme is combined with requests for retransmission of erroneous data. Every block of data received is checked using the error detection code used, and if the check fails, retransmission of the data is requested – this may be done repeatedly, until the data can be verified.
- ***Forward error correction*** *(FEC)*: The sender encodes the data using an *error-correcting code (ECC)* prior to transmission. The additional information **(redundancy)** added by the code is used by the receiver to recover the original data. In general, the reconstructed data is what is deemed the "most likely" original data.

ARQ and FEC may be combined, such that minor errors are corrected without retransmission, and major errors are corrected via a request for retransmission: this is called ***hybrid automatic repeat-request*** *(HARQ)*.

Forward Error Correction- Example Hamming Code.

Hamming Code.

Hamming code is an error-correcting code used for correcting transmission errors in synchronous data streams. The Hamming code will correct only single-bit errors. It cannot correct mulitple-bit errors. Hamming bits also sometimes called as error bits are inserted in to a character at random manner.

The combination of data bits (m bits) and Hamming bits(n bits) called as Hamming code (m+n bits).

To correct an error, the receiver reverses the value of the altered bit. To do so, it must know which bit is in error.

Number of redundancy bits (Hamming bits) 'n' needed:
Let data bits = *m*
Redundancy bits = *n*
Total message sent = *m+n*
The value of 'n' must satisfy the following relation:

$$2^n \geq m+n+1$$

X