

## L01 - Transmission Principles

### Transmission Principles

Serialization, Bit synchronization, Framing, Error Checking  
Physical Aspects of Transmission, Modem

### Agenda

- Introduction
- **Bit synchronization**
  - asynchronous
  - synchronous
- **Frame synchronization**
  - framing
  - byte stuffing
  - bit stuffing
- **Frame protection**
- **Physical aspects**

## L01 - Transmission Principles

### Representation of Information

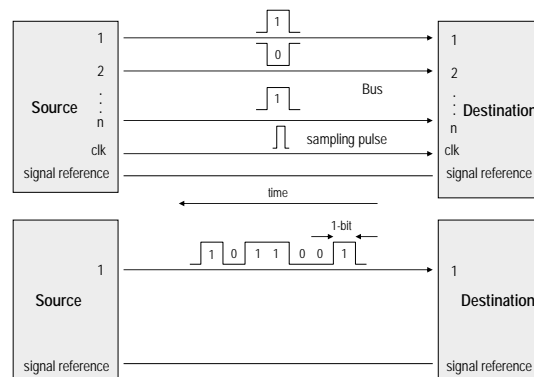
- **information is stored, processed and exchanged by computer systems in binary form**
  - bit (binary digit)
  - values 0 or 1
- **these values are physically represented**
  - electrical transmission systems (using copper e.g. coax-, twisted-pair cables)
    - voltage level
    - current level
  - optical transmission systems (using fiber e.g. multi-mode, single-mode fiber)
    - light on / off

### Transmission of Information

- **within a computer system**
  - parallel transfer mode
  - a data word (8-bit, 16-bit, ...) is transferred at the same time using several parallel lines called "Bus"
    - data-bus for transferring data words
    - address-bus for addressing memory location
    - control-bus for signaling direction of transfer (read/write), clock (clk.), interrupt, ...
- **between computer systems**
  - bit-serial transmission
  - bits are transferred bit by bit using a single line
  - basic transmission technique used in data communication networks

## L01 - Transmission Principles

## Parallel versus Serial



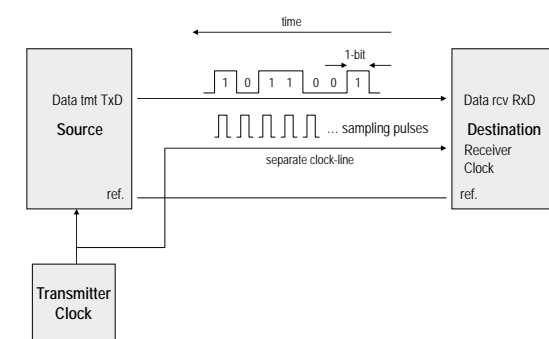
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## Separate Clock-Line ?



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## Serial Transmission

- what does serial transmission mean?

- bits are transmitted on one physical line a single bit at a time using a constant time interval (bit-cell) for each bit
- the receiver of a serial transmission line must sample bits at the right time in order to interpret the bit pattern correctly
- receiver clock must be synchronized to transmitter clock
- one way is to use a separate clock line as it is done by parallel transmission technique
- in case of WAN a separate clock line is not acceptable for reasons of cost
- therefore so called bit (clock) synchronization techniques are used

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## Bit Synchronization

- clock synchronization of receiver clock for serial transmission is called

- bit synchronization

- bit synchronization principle

- signal changes are used by the receiver for clock recovery
- recovered clock generate pulses which are used to sample the bit stream to decide if 0 or 1
- sampling should occur in the center of bit-cell
  - because signal attenuation, bandwidth limitation, delay distortion will modify signal form

- depending on duration of bit synchronization we can differentiate between

- asynchronous and synchronous transmission method

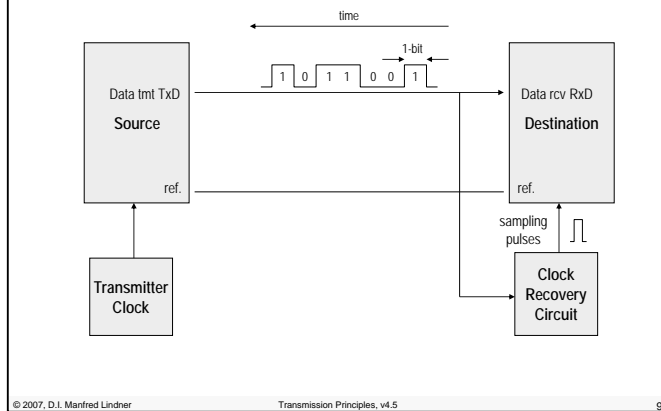
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## Clock (Bit) Synchronization



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## Agenda

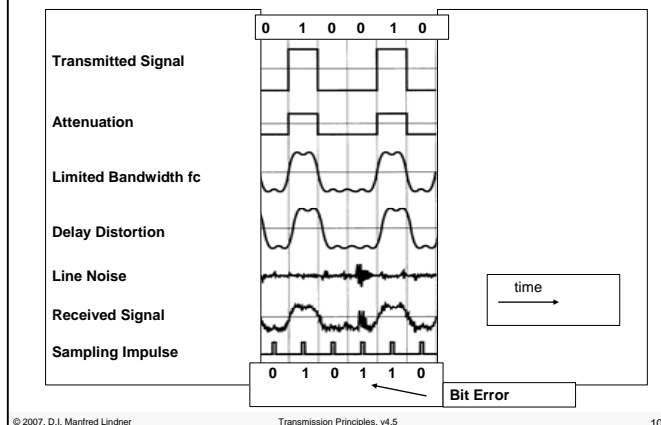
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## What Happens to a Signal?



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## Asynchronous Transmission

- bit synchronization lasts only for the time needed to transmit one data word
- data words could be sent independently and are synchronized independently from each other
- **technique of start/stop bit is used**
  - start bit
    - indicated by a binary change from 1 to 0
    - synchronizes the following 8-bit data word by over sampling
  - stop bit(s)
    - one or two bits being binary 1
    - makes sure that every following start bit is recognized correctly regardless of the transmitted data

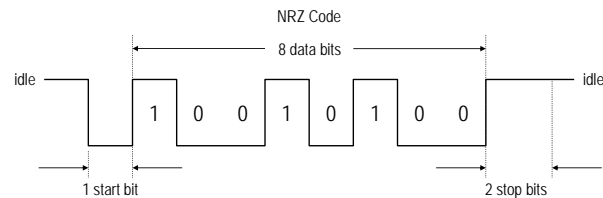
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## Data Word Framing by Start / Stop Bits



- NRZ (non return to zero) describes the encoding of bits where level 1 refers to logical 1 and level 0 refers to logical 0
- Idle .... no data is transmitted, no change of signal level

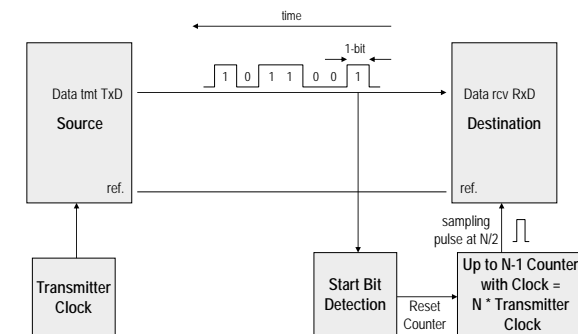
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## Bit Synchronization Circuit Asynchronous



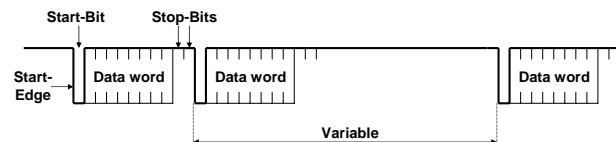
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## Asynchronous Transmission

- **Independent clocks at transmitter and receiver**
  - Nearly same frequency
- **Only phase is synchronized**
  - Using Start-bits and Stop-bits
  - Variable intervals between data words
  - Synchronism only during transmission of a data word
- **Inefficient**
  - 8 bits data need additional 3 bits for bit synchronization!



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## Synchronous Transmission

- **bit synchronization lasts at least for the time to transport a block of data**
- **requirement**
  - sufficient changes of signal levels to enable clock recovery at the receiver
    - Phased Locked Loop (PLL) technique is used to freeze the receiver clock in times where no signal changes are present
- **in contrast to asynchronous transmission bit overhead is reduced**
  - only at the beginning of a data block additional synchronization bits are necessary, later bit stream itself will keep bit synchronization going on

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## Synchronous Transmission

- **Synchronized clocks**
  - Most important today!
- **Phase and Frequency synchronized**
- **Phased-Locked-Loop (PLL) control circuit**
  - Requires frequent signal-edges
    - Achieved by line coding or scrambling of data
      - Encoding at the sender side
      - Decoding at the receiver side
- **Allows continuous data stream**
  - Receiver remains synchronized for a long while

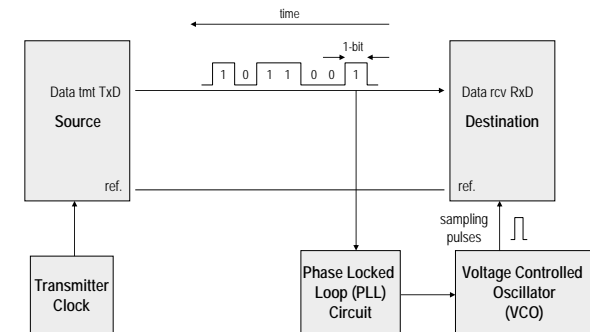
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## Bit Synchronization Circuit Synchronous



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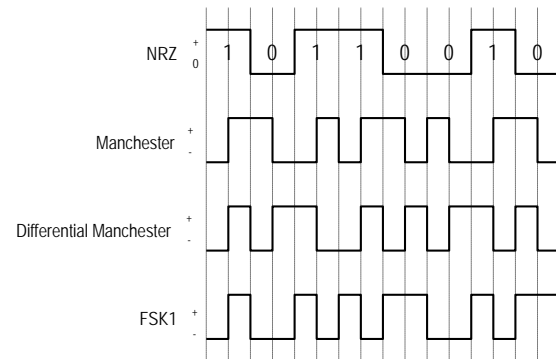
## Synchronous Transmission

- **bit synchronization depends on sufficient signal changes within the bit stream**
  - for long series of 0s or 1s simple NRZ encoding is not able to provide this changes
- **two methods are used to guarantee signal changes**
  - encoding of bits that every bit contains a signal change
    - Manchester-code (Biphase code), Differential-Manchester-code, Frequency Shift Keying (FSK)-code, commonly used in a LANs
  - encoding of bits in such a way that there are enough signal changes in the bit stream
    - NRZI (with bitstuffing), RZ and AMI (with scrambler)
    - HDB3 (with code violations), commonly used in a WANs

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**L01 - Transmission Principles****Manchester-Codes, FSK-Codes**

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**Encoding Rules For Manchester**

- **Manchester**

- bit is divided into two half-bits
- first half-bit is the complement of the data bit, second half-bit is identical to data bit
- change of signal level occurs in the center of each bit
  - change from 1 to 0 describes a logical 0
  - change from 0 to 1 describes a logical 1

- **differential Manchester**

- logical 0 is defined by a signal change at the beginning and at the center of the bit
- change of signal only at the center identifies a logical 1
- no signal change at the center of a bit can be used for code violation (J and K symbols)

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**L01 - Transmission Principles****Encoding Rules for FSK**

- **FSK1**

- logical 1 is defined by a signal change at the beginning and at the center of bit
- change of signal level only at the beginning of a bit identifies a logical 0

- **FSK0**

- vice versa to FSK1

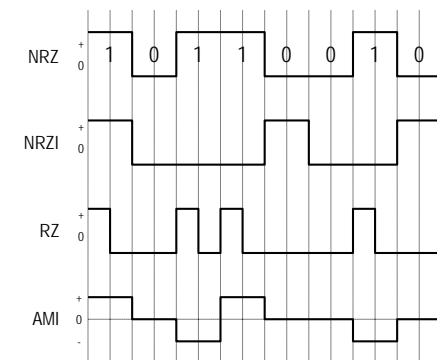
- **principle characteristics of Manchester and FSK codes**

- bandwidth requirement is twice of NRZ
- they have no or constant dc (direct current) component

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**NRZI, RZ, AMI Code**

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## Encoding Rules for NRZI, RZ

- **NRZI (Non Return to Zero Inverted)**

- logical 0 is defined by change of signal level at beginning of bit, logical 1 does not produce any change of signal
- bit stuffing prevents large numbers of 1's in bit stream
- bandwidth requirements are identical to NRZ
- has a dc component

- **RZ (Return to Zero)**

- positive impulse (half bit length) describes a logical 1, logical 0 does not trigger any signal change
- scrambler prevents large numbers of 0's in bit stream
- bandwidth requirements are twice of NRZ
- has a dc component

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## Encoding Rules for AMI

- **AMI (Alternate Mark Inversion)**

- three level encoding (+, 0, -)
- pulses (length = 1 bit) with changing polarity describe logical 1's, no pulse characterizes a logical 0
- scrambler prevents large numbers of 0's in bit stream
- bandwidth requirements are identical to NRZ
- has no or constant dc component

- **NRZI, AMI used in WAN's**

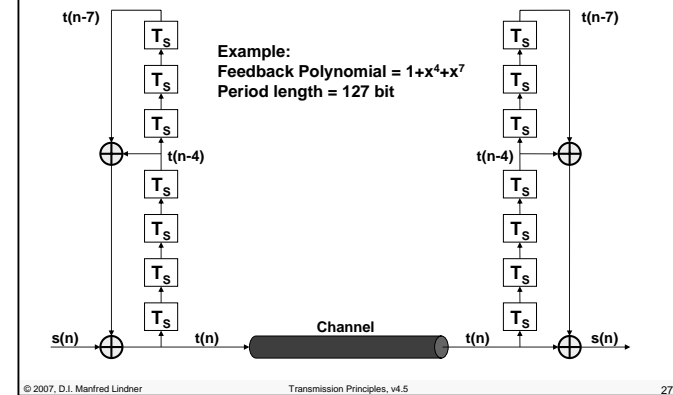
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## How Does a Scrambler Circuit Look Like?

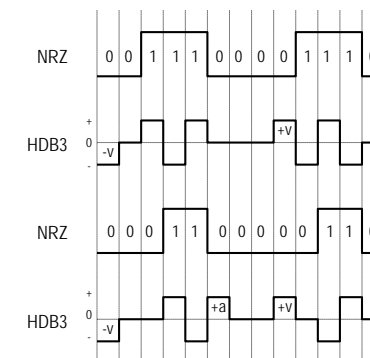


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## HDB3 (High Density Bipolar 3) Code



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## Encoding Rules for HDB3

- **logical 1's** are encoded using pulses with alternate polarity, a logical 0 never generates a pulse
- **exception for sequence of 0's:**
  - four 0's are encoded by a special pattern consisting of one or two impulses (A and V-bits)
  - V-bits are code violations, breaking the rule of alternating pulses
  - the following rule avoids DC portion using A- and V-bits
  - bandwidth requirements are identical to NRZ
  - has no or constant dc component

	polarity of last pulse	amount of pulses since last violation	
		odd	even
bit pattern	plus	0 0 0 +V	-A 0 0 -V
	minus	0 0 0 -V	+A 0 0 +V

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## Basic Requirements

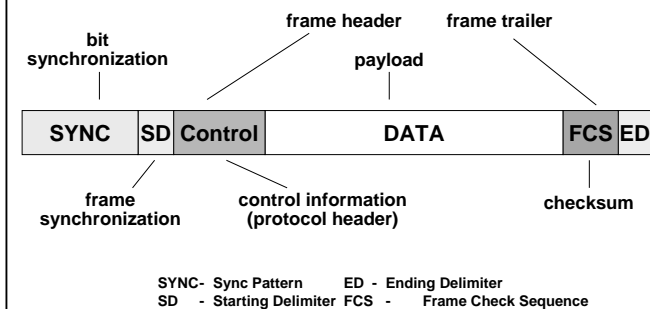
- **information between systems is exchanged in blocks of data or information frames**
- **the recognition of the beginning and the end of a block is necessary**
  - frame synchronization
- **errors on physical lines may lead to damage of digital information**
  - 0 becomes 1 and vice versa
  - the longer the block the higher the probability for an error
- **methods necessary for error checking**
  - frame protection
  - error detection

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## Generic Frame Format



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## SYNC

- **SYNC is a special bit pattern**

- used for bit synchronization after an idle period
- can be used as fill pattern during idle times to keep the receiver clock synchronized
- typically a 0101010...-pattern
- e.g. 8 Byte preamble in Ethernet frames



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## Control Field

- **is used for implementing protocol procedures**

- **contains information such as**

- frame type, protocol type
  - Data, Ack, Nack, Connect, Disconnect, Reset, etc.
  - IP, IPX, AppleTalk, etc.
- sequence numbers for identification of frame sequence
  - necessary for error recovery and flow control with connection oriented services
- address information of source and destination in case of a multipoint line
- frame length, etc.



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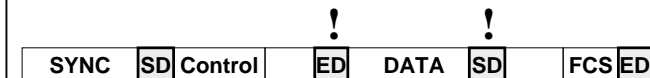
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## SYNC, SD and ED

- **SD, ED are special bit patterns to mark the beginning and the end of a block**

- not allowed inside the frame

- **What, if delimiter symbols occur within frame ?**



- **If application of sender must care of avoiding this bit patterns in the data stream**

- transmission is not data-transparent
- goal is data transparency

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## Data Transparency

- **techniques to avoid this bit pattern inside the frame**

- byte stuffing with character based method
  - e.g. IBM BSC (Binary Synchronous Control) protocol
  - e.g. PPP over asynchronous line
- bit stuffing with bit oriented method
  - e.g. HDLC (High level Data Link Control)
  - e.g. PPP over synchronous line
- code violations
  - e.g. Token Ring J,K Symbols of Differential-Manchester-code
- byte count technique
  - e.g. DDCMP (Digital Data Communications Message Protocol)
- idle line/sync bits before special SD and idle line as ED
  - e.g. Ethernet

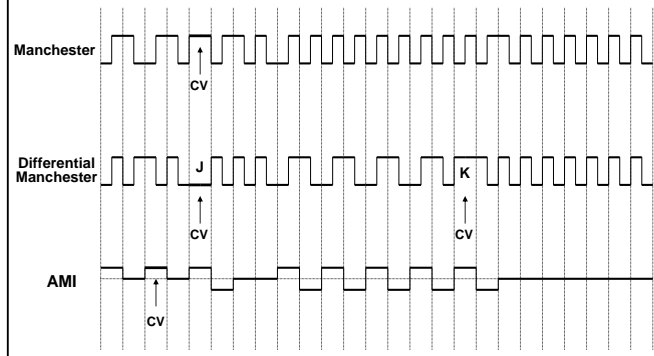
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## Code Violations



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## Character Based Transmission - ASCII-Code

American Standard Code for Information Interchange

Bit Positions	7	6	5	4	3	2	1	0
	0	0	0	0	1	1	1	1
	0	0	0	1	0	0	1	1
0 0 0 0	Nul	DLE	SP	0	@	P	\	p
0 0 0 1	SOH	DC1	!	1	A	Q	a	q
0 0 1 0	STX	DC2	"	2	B	R	b	r
0 0 1 1	ETX	DC3	#	3	C	S	c	s
0 1 0 0	EOT	DC4	\$	4	D	T	d	t
0 1 0 1	ENQ	NAK	%	5	E	U	e	u
0 1 1 0	ACK	SYN	&	6	F	V	f	v
0 1 1 1	BEL	ETB	'	7	G	W	g	w
1 0 0 0	BS	CAN	(	8	H	X	h	x
1 0 0 1	HT	EM	)	9	I	Y	i	y
1 0 1 0	LF	SUB	*	:	J	Z	j	z
1 0 1 1	VT	ESC	+	;	K	[	k	{
1 1 0 0	FF	FS	,	<	L	\	l	
1 1 0 1	CR	GS	-	=	M	]	m	}
1 1 1 0	SO	RS	.	>	N	^	n	~
1 1 1 1	SI	US	/	?	O	_	o	DEL
4 3 2 1								

Transmission Control

Format Control

Printable Character

Information Separator

Others

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## Character Based Transmission without and with Byte Stuffing

SYNC	SD					ED
Idle/Sync	SOH	Control	STX	Data Block + FCS	ETX	Idle/Sync

transmission in non-data transparent mode; control character not allowed in data block

DLE	SOH	Control	DLE	STX	" A B C "	SOH	" U V "	DLE	DLE	" W "	DLE	ETX
	SOH control character			STX control character		no control character		DLE			ETX control character	

transmission in data transparent mode with byte stuffing;  
control character allowed in data blockbyte stuffing: DLE inside data portion will be doubled by sender;  
receiver deletes this doubled DLE

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### Character Based Transmission Byte Stuffing

- the following control characters are used (ASCII, EBCDIC)
  - SOH (Start of Header; ASCII 0x01)
  - STX (Start of Text; ASCII 0x02)
  - ETX (End of Text; ASCII 0x03)
- not allowed inside the data portion
  - printable characters don't contain control characters
- no such restriction with byte stuffing
  - control characters are only recognized as control characters with "DLE" (Data Link Escape; ASCII 0x10) in front of them
  - if "DLE" is to be transmitted as data, it will be doubled

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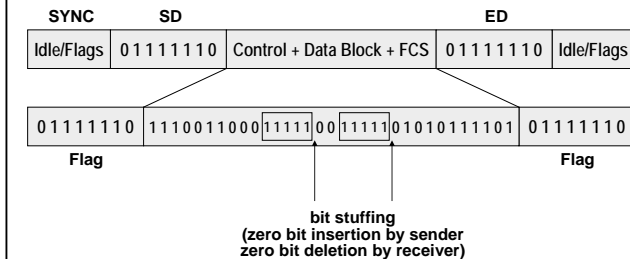
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### Bit Oriented Transmission Bit Stuffing



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### Bit Oriented Transmission Bit Stuffing

- SD and ED equals 01111110, called flag
  - also used for SYNC
  - any bit pattern different to flag will be interpreted as beginning of the frame
- flag should not occur inside the frame
  - would indicate the end of the frame
- bit stuffing avoids the occurrence of the flag within a frame
  - sender automatically inserts a zero after a sequence of 5 ones
  - receiver automatically deletes inserted zero bits
  - a sequence of 6 ones only occurs at the end of the frame

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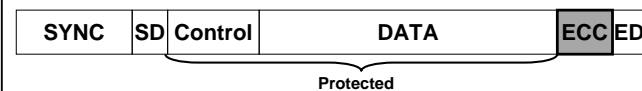
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## Error Correction versus Error Detection

- Two basic strategies developed by network designers
- 1. Forward Error Control
  - Include enough redundant information with each block of data to enable receiver to correct errors occurred -> error correcting codes (important -> "Hamming Distance")
  - Required for "extreme" conditions
    - High BER (Bit Error Rate), EMR
    - Long delays, space links
  - Example: Reed-Solomon codes, Hamming-codes



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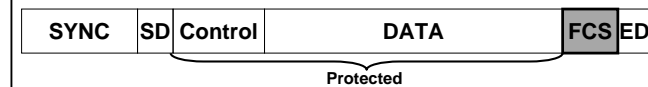
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## L01 - Transmission Principles

## Error Correction versus Error Detection

- 2. Feedback Error Control
  - Include enough redundant information with each block of data to enable receiver to detect only errors occurred -> error detecting codes -> Frame Check Sequence
  - After error detection a retransmission of frame is initiated through feedback to the sender



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## Frame Check Sequence (FCS)

- sender generates checksum (FCS) using an agreed rule in order to protect the data block
  - FCS is added at the end of the frame (FCS\_tmt)
  - frame protection
- receiver calculates its own FCS\_rcv and compares it with FCS\_tmt
  - error detection
  - FCS\_rcv = FCS\_tmt ... no error
  - FCS\_rcv not equal FCS\_tmt ... ERROR
- detection of an error
  - error recovery done by retransmission of frame

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**L01 - Transmission Principles****FCS Methods**

- **many possibilities for creating checksums (FCS)**
  - parity bit (even, odd)
  - summarization of all data words modulo 2
  - Cyclic Redundancy Check (CRC) which is based on theory of polynomial code (most complex method)
- **complexity of checksum method determines**
  - types of errors that can be detected for 100%
  - error probability for undetectable errors for a given frame size
- **different FCS methods were standardized**
  - depending on physical network type and expected line error patterns

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**L01 - Transmission Principles****Theoretical Basis for Data Transmission**

- **How can a digital signal be represented?**
  - Fourier analysis proves that any periodic function  $g(t)$  with period  $T$  can be constructed by summing a (infinite in case of rectangle pulses) number of sinus and cosines functions

$$g(t) = (1/2)c + \sum_{n=1}^{\infty} a_n \sin(2\pi n f t) + \sum_{n=1}^{\infty} b_n \cos(2\pi n f t)$$

- with  $f = 1/T$  and  $a_n$  and  $b_n$  as amplitudes of the  $n^{\text{th}}$  harmonics and  $c$  as the dc component
- such a decomposition is called Fourier series

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**Fourier Coefficients**

- **How can the values of  $c$ ,  $a_n$  and  $b_n$  be computed?**

$$c = (2/T) \int_0^T g(t) dt$$

$$a_n = (2/T) \int_0^T g(t) \sin(2\pi n f t) dt$$

$$b_n = (2/T) \int_0^T g(t) \cos(2\pi n f t) dt$$

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## L01 - Transmission Principles

## Imperfect Real Data Transmission

1

- **no transmission systems can transmit signals without losing some power (attenuation)**
  - if all harmonics would be equally diminished the signal would be reduced in amplitude but not distorted
  - unfortunately all transmission systems diminish different harmonics by different amounts
  - usually amplitudes from 0 up to certain frequency  $f_c$  are transmitted undiminished with all frequencies above  $f_c$  are strongly attenuated
    - $f_c$  may be caused by a physical property of the transmission medium
    - $f_c$  may be caused by filter function introduced intentionally in the transmission system (Pupin)
    - $f_c$  is synonymous for useable bandwidth  $B$  of a given transmission system

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## Imperfect Real Data Transmission

2

- **no transmission systems can transmit different Fourier components with the same speed (delay distortion)**
  - for digital data it may happen that fast components from one bit may catch up and overtake slow components from the bit ahead and hence bits are mixed
  - inter-symbol interference
    - eye-diagram for visualization of delay distortion
- **no transmission systems is free from noise**
  - noise is unwanted energy from sources other than from the transmitter

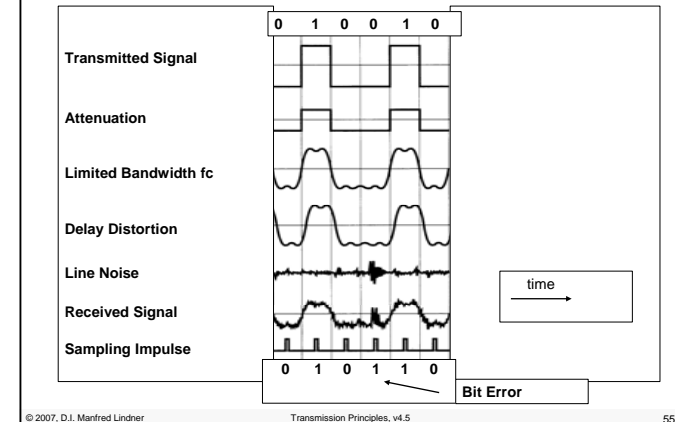
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## L01 - Transmission Principles

## What Happens to a Signal?



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## Real Data Transmission

- **in real transmission systems**
  - the original signal will be attenuated, distorted and influenced by noise when traversing the transmission line
- **by increasing the bit rate**
  - bit synchronization even in middle of a bit becomes more and more difficult because of these impairments
  - above a certain rate bit synchronization will be impossible
- **relationship**
  - between bandwidth  $f_c$ , line length and maximum achievable bit rate on a certain transmission line (system)

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**L01 - Transmission Principles****Nyquist's Law**

- **How many bits can be transported over a ideal (noiseless) transmission channel ?**

- Nyquist's law:  $R = 2 * B * \log_2 V$ 
  - valid for a noiseless channel
  - R ... maximum bit rate (bits/sec)
  - B ... bandwidth range of a bandwidth limited transmission
  - V ... number of signal levels (e.g. 2 for binary transmission)
- example analogue telephone line
  - B = 3000 Hz (range 400 – 3400 Hz)
  - R = 6000 bits/sec for V = 2
  - R = 18000 bits/sec for V = 8

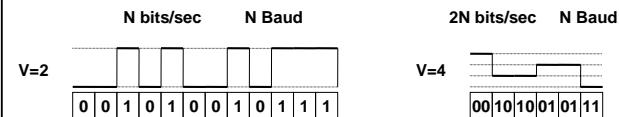
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**Bit and Baud**

- **the rate of changes of a signal**
  - is called signaling rate  $R_s$  and is measured in Baud
- **the rate of bits transported**
  - is called bit rate R and is measured in bits/sec (bps)
  - $R = R_s * \log_2 V$ 
    - V ... number of signal levels
- **$R = R_s$** 
  - for binary transmission where V = 2



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**L01 - Transmission Principles****Shannon's Law**

- **How many bits can be transported over a noisy transmission channel ?**

- disturbance caused by crosstalk, impulse noise, thermal or white noise
- Shannon's law:  $\max R = B * \log_2 (1+S/N)$ 
  - S ... signal power, N ... noise power
  - SNR ... Signal to Noise Ratio measured in decibel (db)
  - $SNR = 10 * \log_{10} S/N$
- example analogue telephone line
  - B = 3000 Hz
  - SNR = 30 db means  $30 = 10 * \log_{10} (S/N) \rightarrow S/N = 1000$
  - max R = approximately 30000 bits/sec

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**Baseband Mode**

- **all the available bandwidth of the serial line is used to derive a single transmission path**
- **signals travel as rectangle pulses**
- **physical property of transmission medium, power of sender, sensitivity of receiver and S/N ratio are the limiting factors for the achievable bit rate**
- **appropriate encoding**
  - to ensure bit synchronization
  - to avoid dc component
  - to keep electromagnetic radiation low

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## L01 - Transmission Principles

## Narrowband Mode

- **bandwidth is intentionally limited and hence binary signals (rectangle pulses) must be adapted before using the line**
- **adaptation is done by modulation**
  - e.g. Modem for transport of data over telephone network
- **several techniques were developed**
  - amplitude modulation (amplitude-shift-keying ASK)
  - frequency modulation (frequency-shift-keying FSK)
  - phase modulation (phase-shift-keying PSK)
  - combination of above like QAM (Quadrature Amplitude Modulation) used in modern high speed modems today
    - 12 phase shifts and two amplitudes are used to represent 16 valid combinations -> 4 bits are transported in a single step
    - used e.g. by V.32 with 9600 bit/sec over 2400 baud line

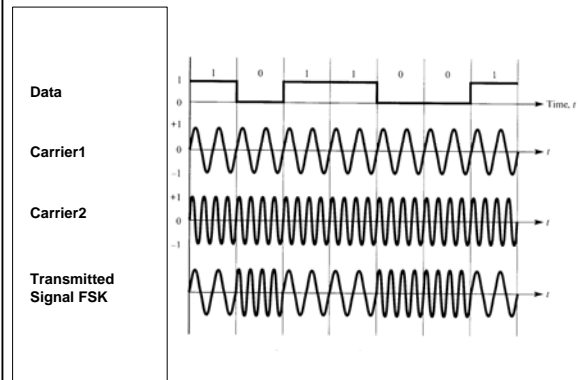
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## L01 - Transmission Principles

## Frequency Modulation (FM, FSK)

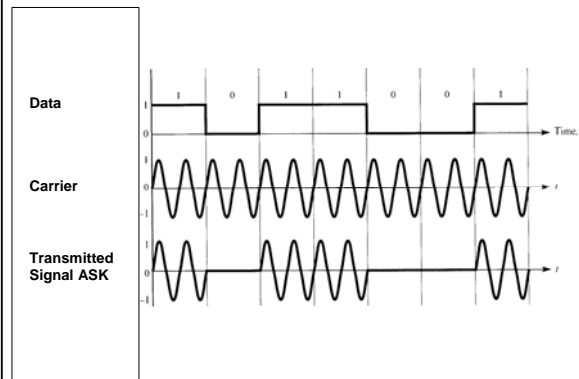


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## Amplitude Modulation (AM, ASK)

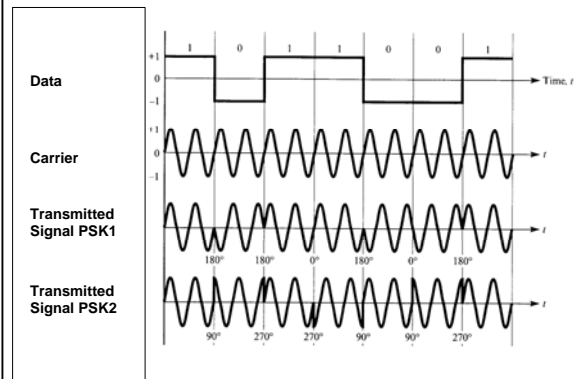


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## Phase Modulation (PSK)

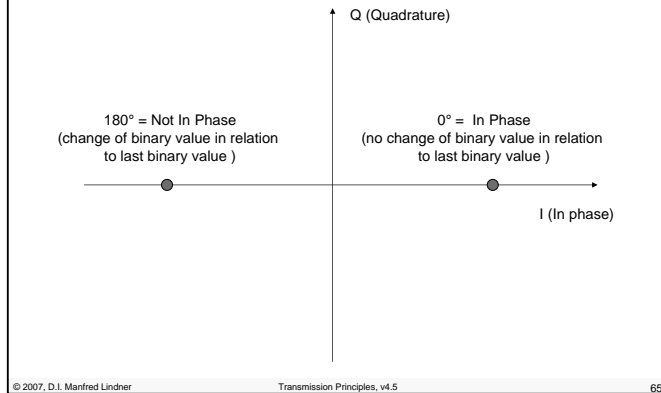
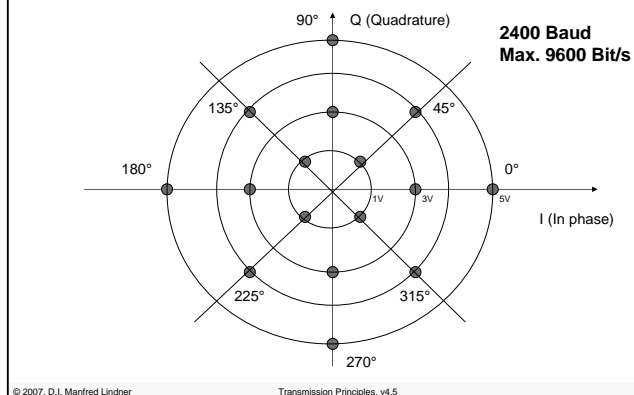


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**L01 - Transmission Principles****Phase Diagram for PSK1****Modem: V.29 (QAM)****L01 - Transmission Principles****Modem****• Modulator / Demodulator**

- modem adapts digital (rectangle) signals in order to be transported over analogous telephone network
  - limited bandwidth (200 - 3500 Hz)
- done by different modulation techniques
  - AM, FM, Phase-Modulation, QAM, Trellis-Code, etc.
- 1st Wave
  - Frequency Division Protocols, all rates to 2400 bits/s
    - Modems: advanced analog filters
    - Telco: pass audio frequencies of 200 Hz to 2.4 KHz
- 2nd Wave
  - 1st generation Echo Canceling Protocols, 9600 & 14400 bits/s
    - Modems: low cost DSPs
    - Telco: pass audio frequencies of 200 Hz to 2.4 KHz

**Modem (cont.)**

- 3rd Wave
  - 2nd gen. Echo Canceling Protocols, rates to 28.8 Kbits/s
    - Modems: higher performing, low cost DSPs
    - Telco: pass audio frequencies of 200 Hz to 2.8 KHz
- 4th Wave
  - extending Echo Canceling Protocols, rates to 33.6 Kbits/s
    - Modems: higher performing, low cost DSPs
    - Telco: pass audio frequencies of 200 Hz to 3.1 KHz
- 5th Wave
  - Digital stepping protocols, 34 Kbits/s to 56 Kbits/s
    - Modems: higher performing, low cost DSPs
    - Telco: pass audio frequencies of 200 Hz to 3.1 KHz, all digital path to subscriber line, 64K PCM digital to analog conversion, limited loop length, no line conditioners

**L01 - Transmission Principles****Modem Control by EIA-232 / V.24**

- **EIA-232 / V.24 standard**

- serial interface definition between a DCE and DTE
  - DTE (Data Terminal Equipment e.g. end system)
  - DCE (Data Circuit Terminating Equipment e.g. modem)
- for short distance and low speed connectivity
- specifies a set of physical lines and necessary electrical / mechanical aspects
  - data signals for serial transmission, control signals for modem (DCE) control, unbalanced transmission, connector
- also known as RS232-C/D/E, V.24/V.28



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**EIA-232 Data and Control Signals**

- data signals:
  - transport of serial data bit-stream
  - TxD (Transmit Data) DTE -> DCE
  - RxD (Receive Data) DCE -> DTE
- control signals:
  - control function between modem and end system
  - RTS (Request To Send) DTE -> DCE
    - DTE requests permission to send data to modem
  - CTS (Clear To Send) DCE -> DTE
    - DCE grants permission to send
  - DCD (Data Carrier Detect) DCE -> DTE
    - DCE indicates that it is receiving carrier from remote modem
  - DSR (Data Set Ready) DCE -> DTE
    - DCE indicates that it is operational (the modem is powered on)

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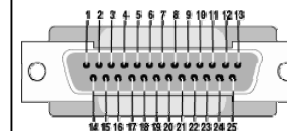
**L01 - Transmission Principles****EIA-232 Control Signals (cont.)**

- control signals (cont.)
  - DTR (Data Terminal Ready) DTE -> DCE
    - DTE indicates that it is operational (the end system is powered on)
  - RI (Ring Indicator) DCE -> DTE
    - DCE indicates that the phone is ringing
  - Transmitter Signal Element Timing DCE -> DTE
    - used in synchronous mode to provide clock to the DTE for TxD
  - Receiver Signal Element Timing DCE -> DTE
    - used in synchronous mode to provide clock to the DTE for RxD
  - Transmitter Signal Element Timing Return DTE -> DCE
- EIA-232 specified limits:
  - Length: 15m, 30m
  - Speed: 20kbit/sec, 64kbit/sec / Practice: up to 200kbit/sec

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**EIA-232 Pinout DB-25**

- 2 Transmit Data (TxD)
- 3 Receive Data (RxD)
- 4 Request to Send (RTS)
- 5 Clear to Send (CTS)
- 6 Dataset Ready (DSR)
- 7 Signal Ground
- 8 Data Carrier Detect (DCD)
- 15 Transmit Clock
- 17 Receive Clock
- 20 Data Terminal Ready (DTR)
- 24 Auxiliary Clock

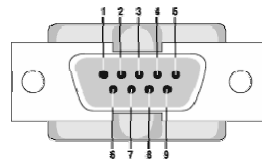
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## L01 - Transmission Principles

## EIA-232 Pinout DE-9



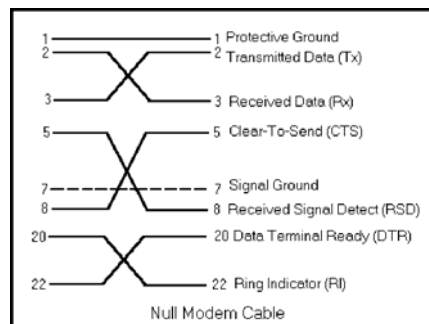
- 1 Data Carrier Detect (DCD)
- 2 Transmit Data (TxD)
- 3 Receive Data (RxD)
- 4 Data Terminal Ready (DTR)
- 5 Signal Ground
- 6 Dataset Ready (DSR)
- 7 Request to Send (RTS)
- 8 Clear to Send (CTS)
- 9 Ring Indicator (RI)

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## EIA-232 Null Modem Cable



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## L01 - Transmission Principles

## Broadband Mode

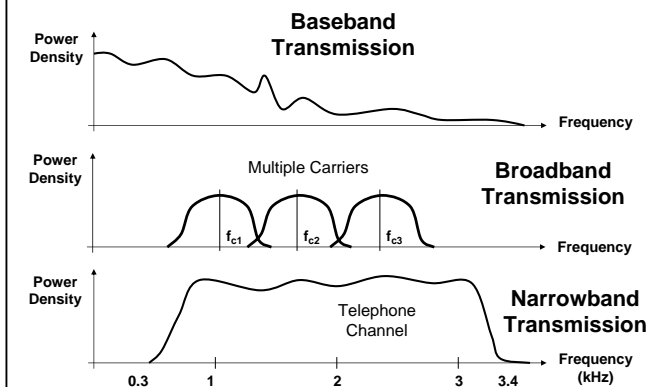
- the available bandwidth of the serial line is divided to derive a number of lower bandwidth transmission paths on one serial line
- in analogue systems every path is modulated by a unique carrier
  - a certain base-frequency which together with the necessary bandwidth range for that channel occupies a certain frequency band of the given transmission system
  - cable television as example
- in digital systems broadband means sometimes high speed only
  - e.g. B-ISDN = ATM
  - but no modulation is used to achieve these

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## Frequency Usage for the Communication Channel



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