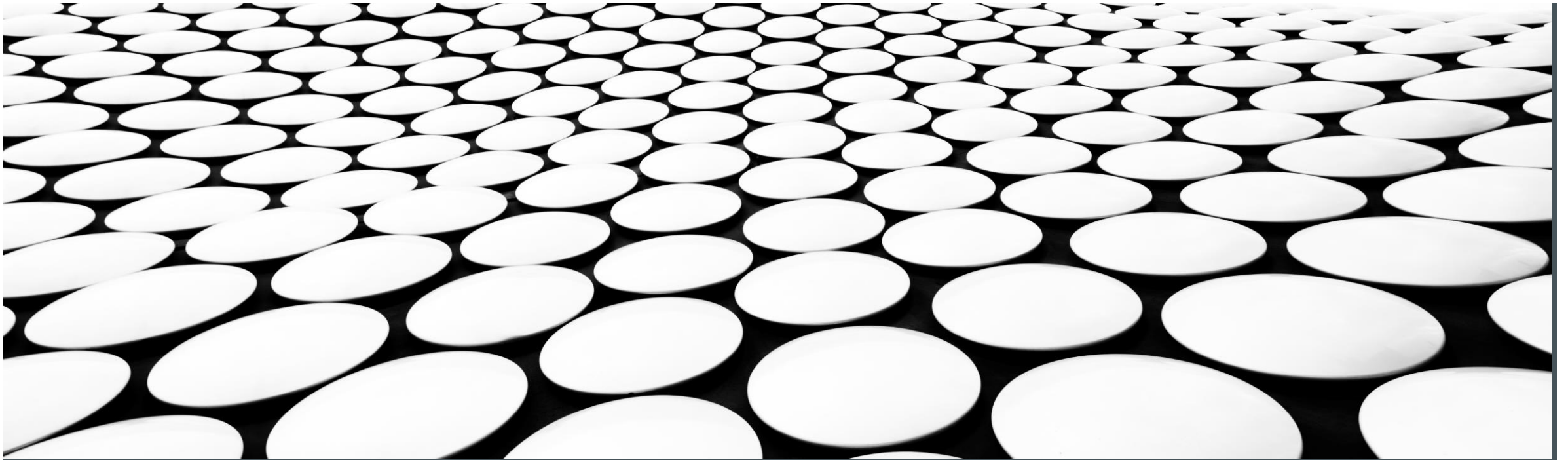

COMPUTER NETWORKS

DATA LINK LAYER AND PHYSICAL LAYER (CH.24-25)

HEMANT GHAYVAT, (hemant.ghayvat@lnu.se)



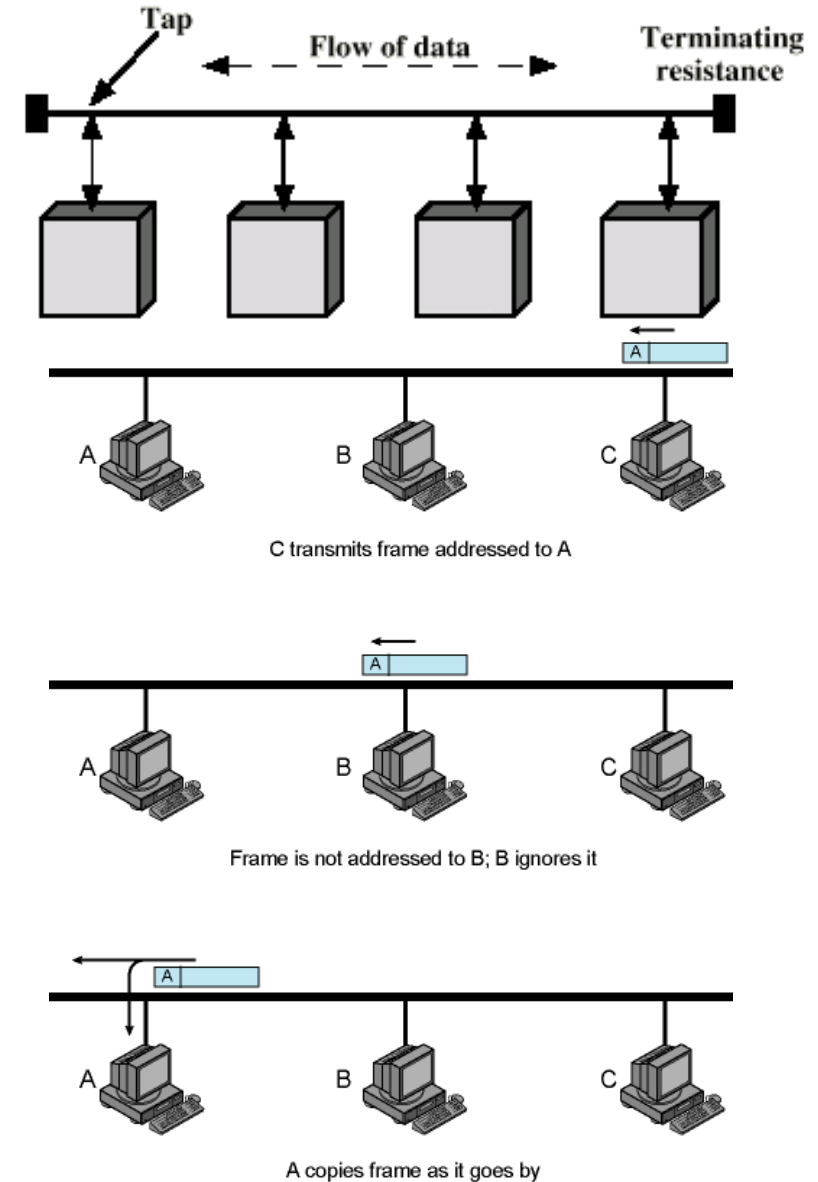


LAN TOPOLOGIES

- Bus
- Ring
- Star

BUS TOPOLOGY - 1

- Stations attach to linear medium (bus)
 - Via a tap - allows for transmission and reception
- Transmission propagates in medium in both directions
- Received by all other stations
 - Not addressed stations ignore
- Need to identify target station
 - Each station has unique address
 - Destination address included in frame header
- Terminator absorbs frames at the end of medium

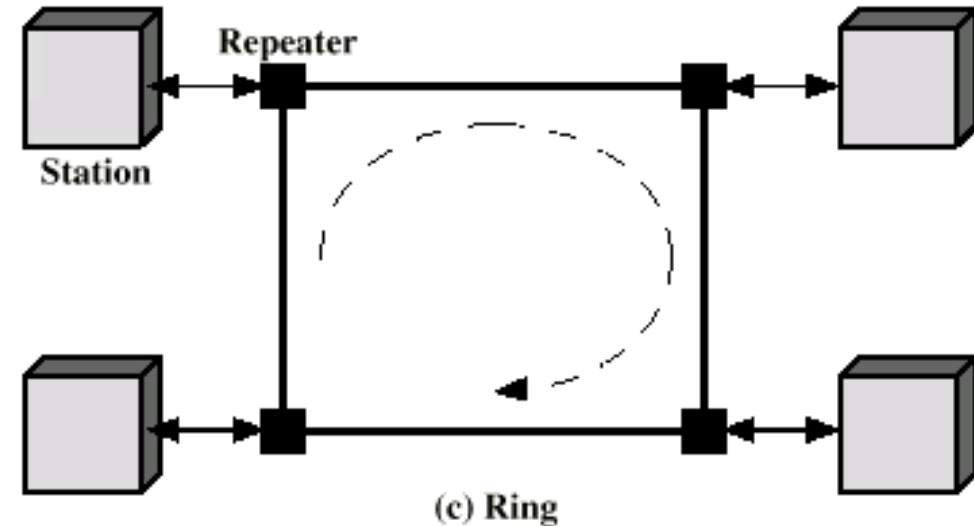


BUS TOPOLOGY - 2

- Need to regulate transmission; mainly due to two reasons:
 - To avoid collisions
 - If two stations attempt to transmit at same time, signals will overlap and become garbage
 - To avoid continuous transmission from a single station. If one station transmits continuously, access is blocked for others
 - Solution: Transmit Data in small blocks – frames

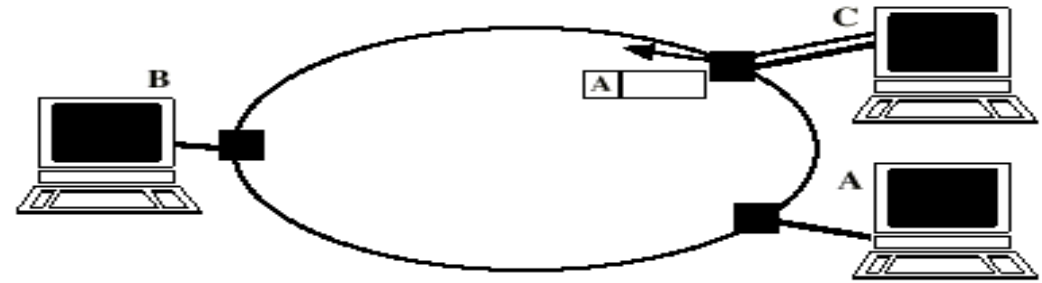
RING TOPOLOGY

- Repeaters joined by point-to-point links in closed loop
 - Links are unidirectional
 - Receive data on one link and retransmit on another
 - Stations attach to repeaters
- Data transmitted in frames
 - Frame passes all stations in a circular manner
 - Destination recognizes address and copies frame
 - Frame circulates back to source where it is removed
- Medium access control is needed to determine when station can insert frame

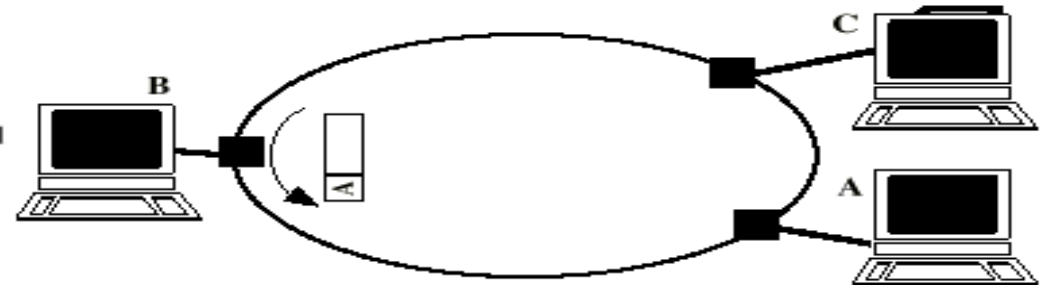


FRAME TRANSMISSION RING LAN

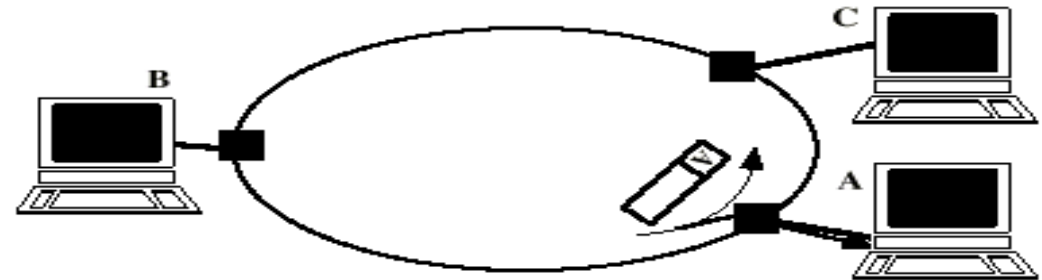
(a) C transmits frame addressed to A



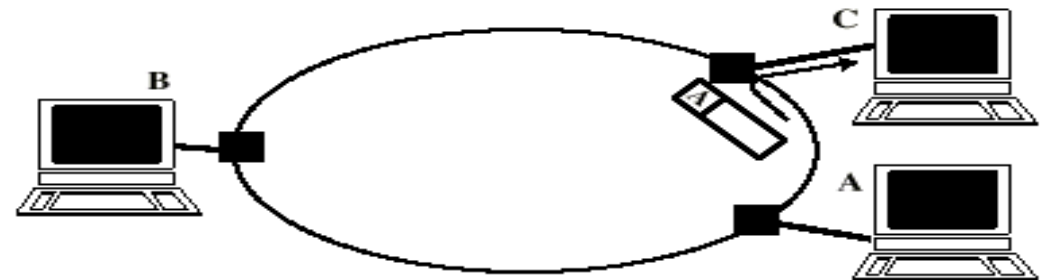
(b) Frame is not addressed to B; B ignores it



(c) A copies frame as it goes by

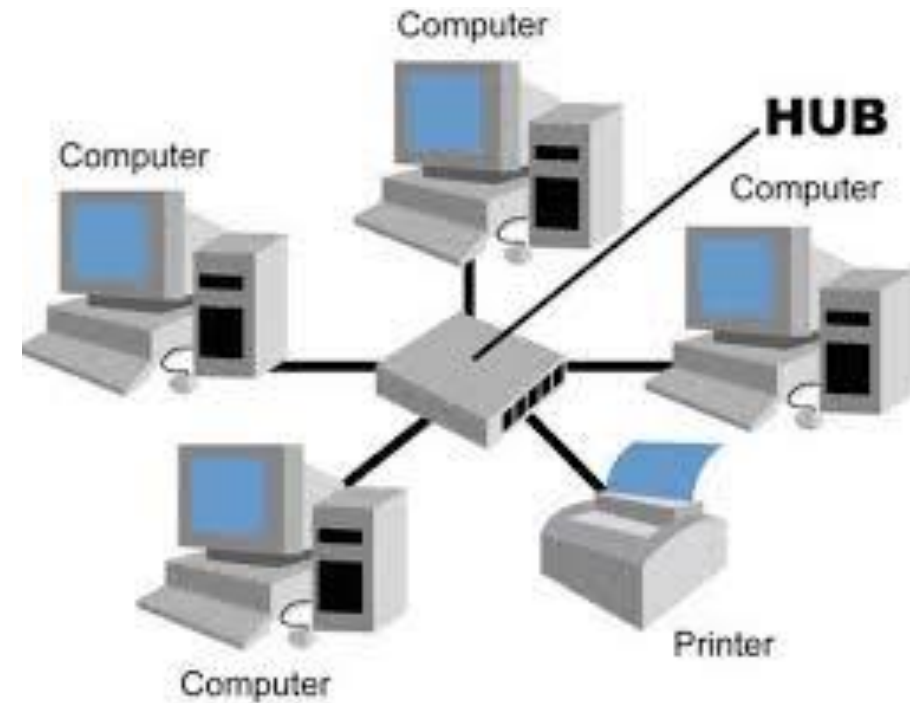


(d) C absorbs returning frame



STAR TOPOLOGY

- Each station connected directly to central node
 - using a full-duplex (bi-directional) link
- Central node can broadcast (hub)
 - Physical *star*, but logically like *bus* due to broadcast medium
 - Only one station can transmit at a time; otherwise, collision occurs
- Central node can act as frame switch
 - retransmits only to destination
 - today's technology



CONTROLLED ACCESS

In **controlled access**, the stations consult one another to find which station has the right to send. A station cannot send unless it has been authorized by other stations. We discuss three popular controlled-access methods.

Topics discussed in this section:

Reservation

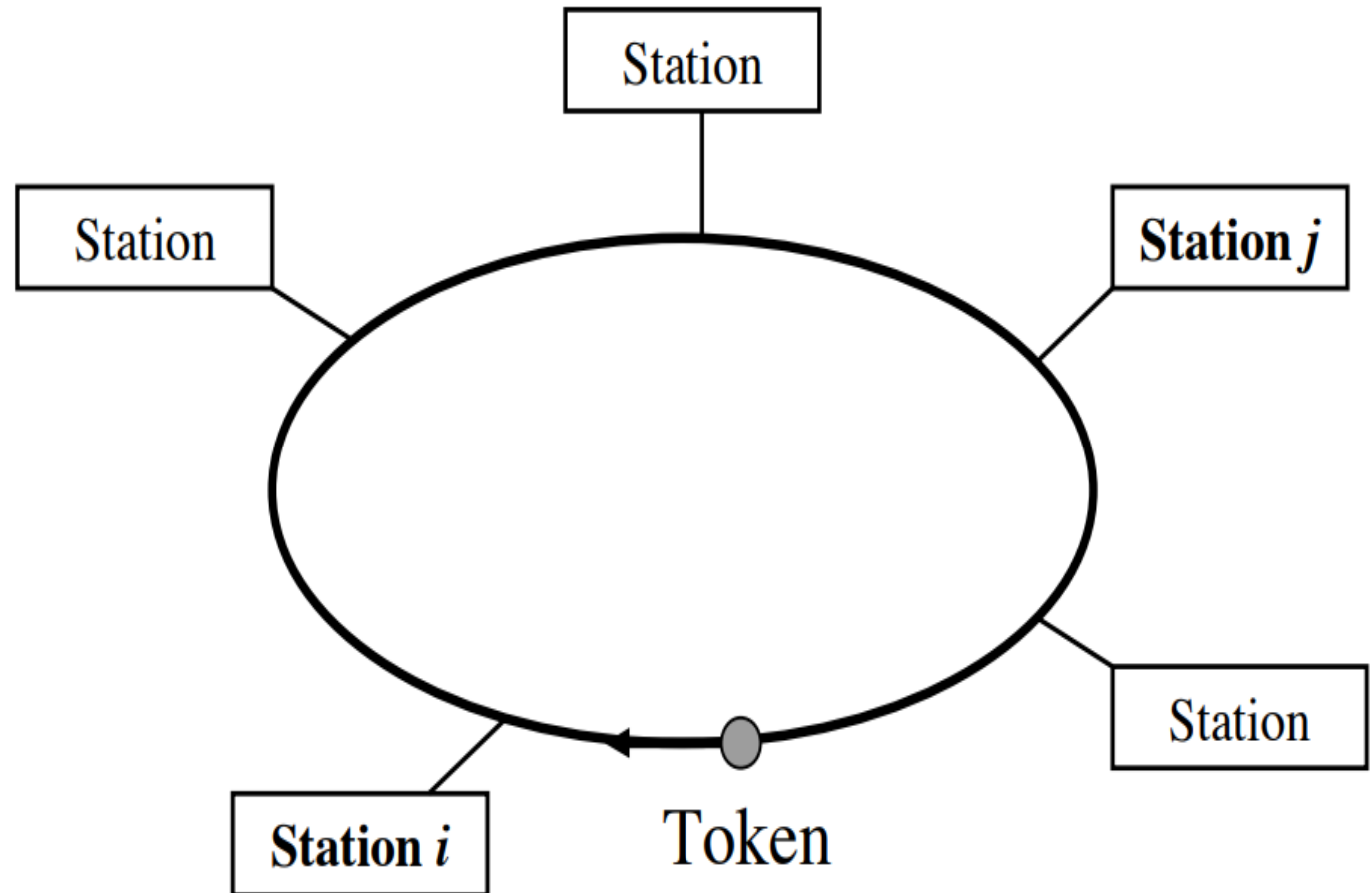
Polling

Token Passing

WAIT FOR YOUR TURN

Token-passing is a broadcast-based technology because all stations see every frame. The forwarding of both the token and data frames is performed by NICs in hardware.

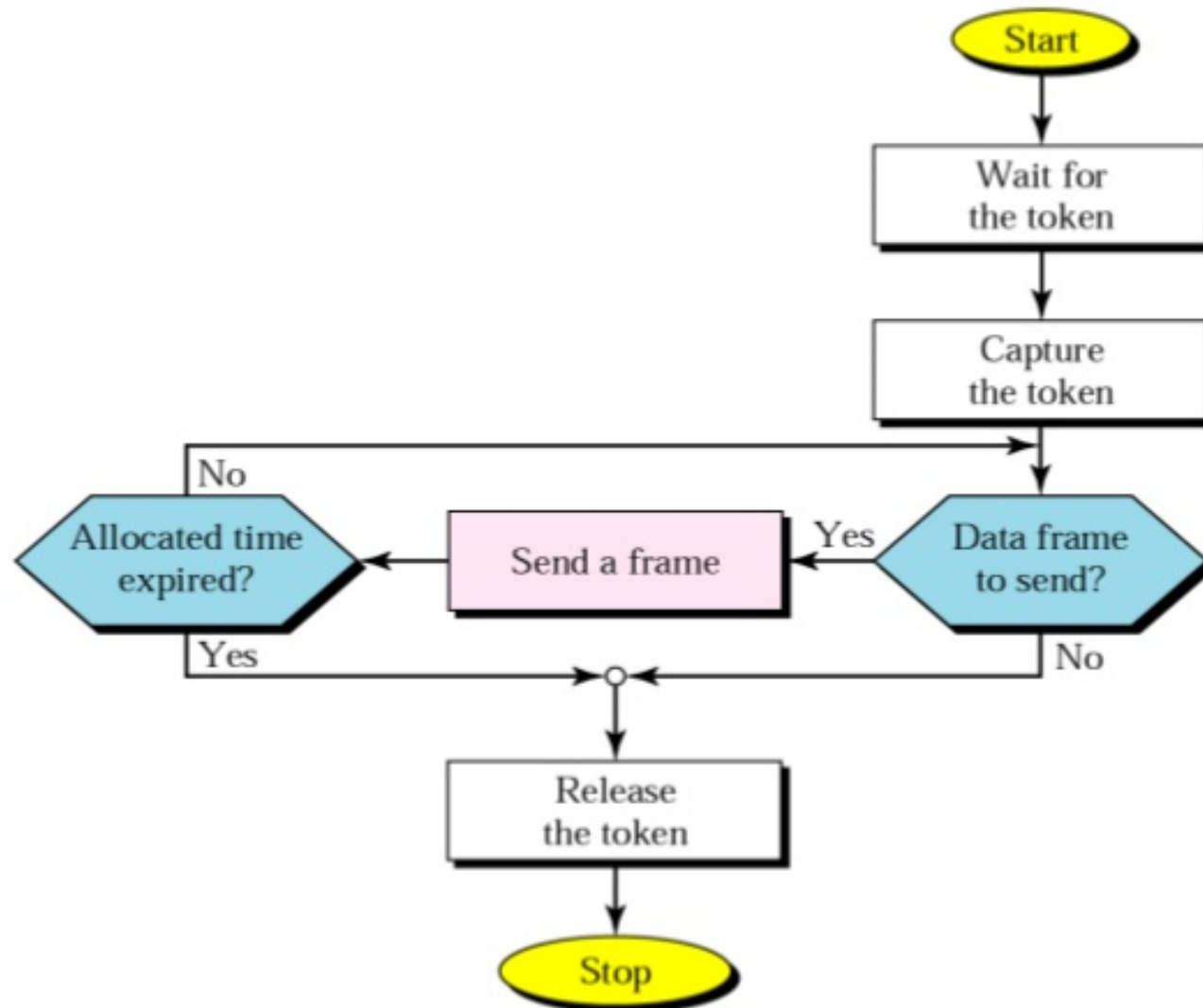
A token circulates among all stations. The token is a miniature, 3-byte frame (including start and end flags)



TOKEN-PASSING

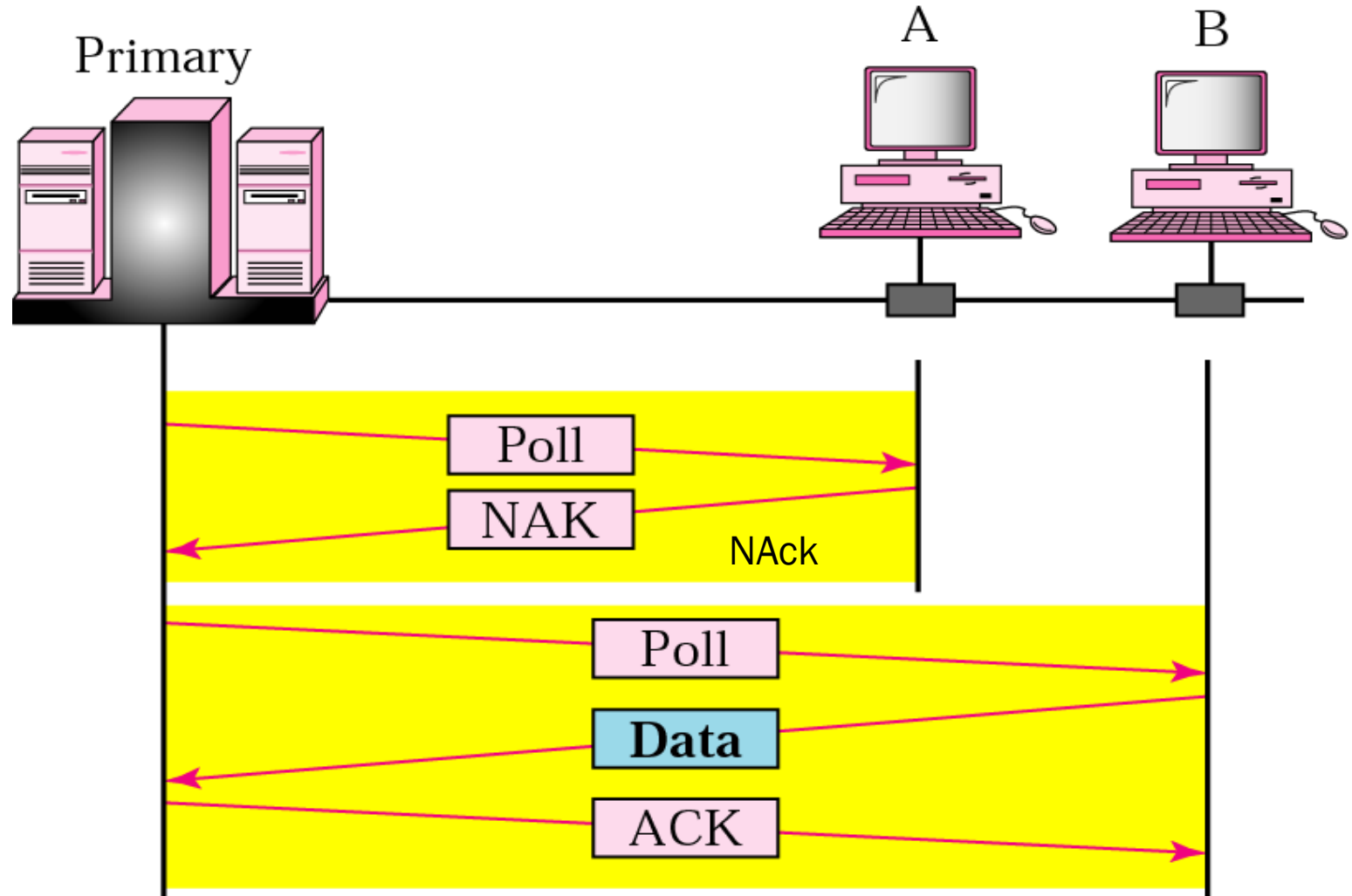
- When the token arrives, a station either seizes the token and sends a frame or passes the token to the next station. Assuming that station i has a frame f to send to station j .
- 1. Station i waits for the arrival of the token and seizes the token
- 2. Station i sends f to station $i+1$, which in turn passes f to station $i+2$
- 3. When frame f arrives at station j , station j picks up f and simultaneously forwards f to station $j+1$
- 4. Eventually, f returns to station i , which passes the token, rather than f , to station $i+1$

TOKEN PASSING FLOW CHART :



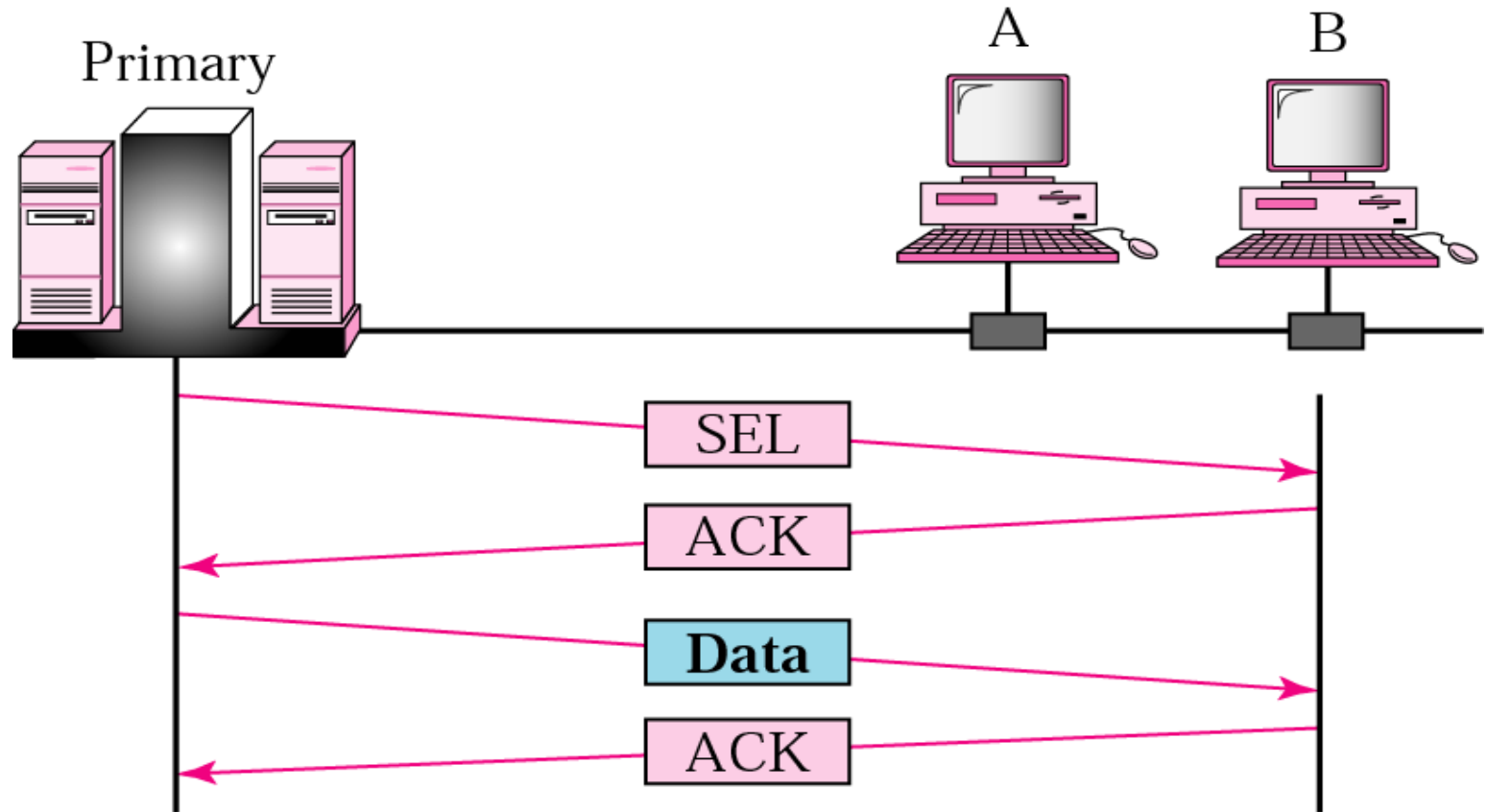
Polling

Whenever the primary station wants to receive the data, it asks the secondary stations present in its channel, this method is polling. In the first diagram, we see that primary station asks station A if it has any data ready for transmission, since A does not have any data queued for transmission it sends NAK (negative acknowledgement), and then it asks station B, since B has data ready for transmission, so it transmits the data and in return receives acknowledgement from primary station.



Polling

In the next case, if primary station wants to send data to the secondary stations, it sends a select message, and if the secondary station accepts the request from the primary station, then it sends back an acknowledgement and then primary station transmits the data and in return receives an acknowledgement.



TOKEN-BASED MAC VS CSMA/CD

- » When the medium is quiet, a sending station:
 - » Wastes no time in waiting with CSMA/CD.
 - » Must wait for the arrival of the token with token-based approaches.
 - » Thus, CSMA/CD outperforms token-based approaches in light traffic.

Token-based MAC handles heavy loads better than CSMA/CD, no waste of bandwidth due to collisions..

TOKEN-BASED MAC VS CSMA/CD

- Moreover, token-based MAC has advantages in handling real-time traffic:
 - » Fairness: stations access the medium in a round-robin manner.
 - » Bounded delays: a station can predict the next time the token returns to it (in CSMA/CD, a station waits for a "random period of time" before retransmission).

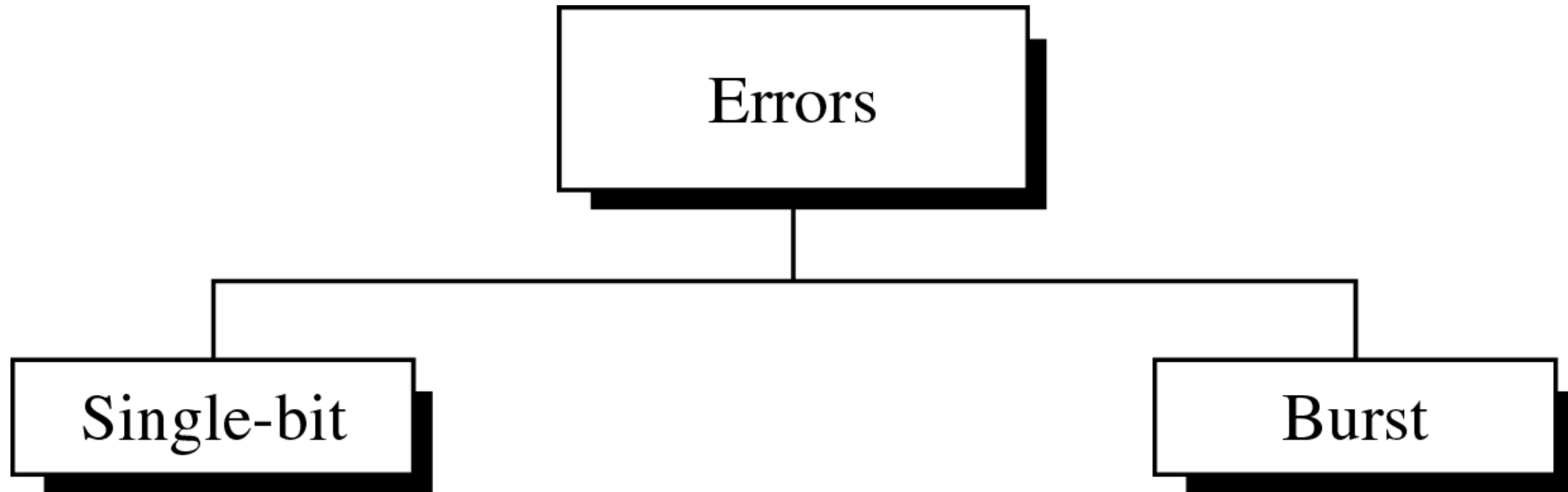
RESERVATION

- Whenever we travel from a train or an airplane, the first thing we do is to reserve our seats, similarly here a station must make a reservation first before transmitting any data-frames.
- This reservation timeline consists of two kinds of periods:
 1. Reservation interval of a fixed time duration
 2. Data transmission period of variable frames



ERRORS

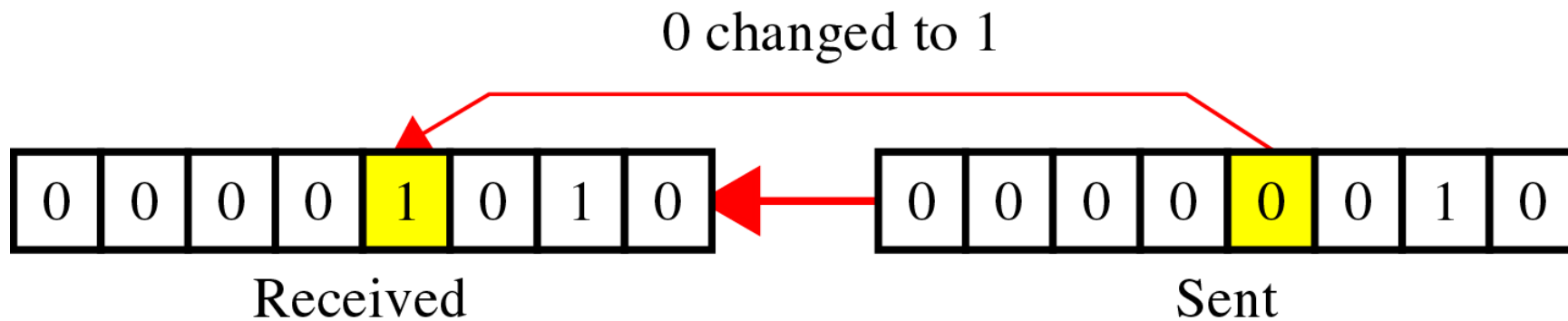
TYPE OF ERRORS



TYPE OF ERRORS(CONT'D)

- **Single-Bit Error**

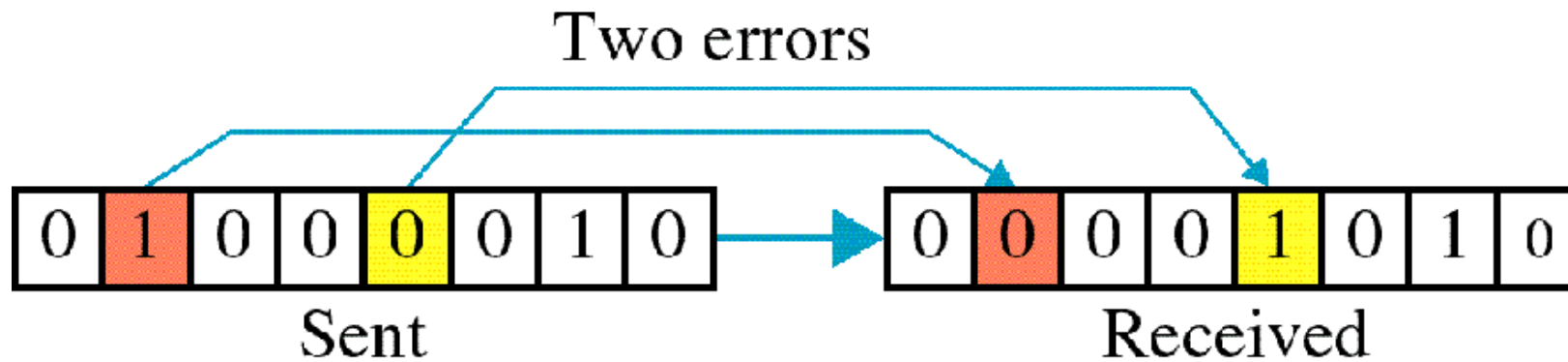
~ is when only one bit in the data unit has changed (ex : ASCII STX - ASCII LF)



TYPE OF ERRORS(CONT'D)

- Multiple-Bit Error

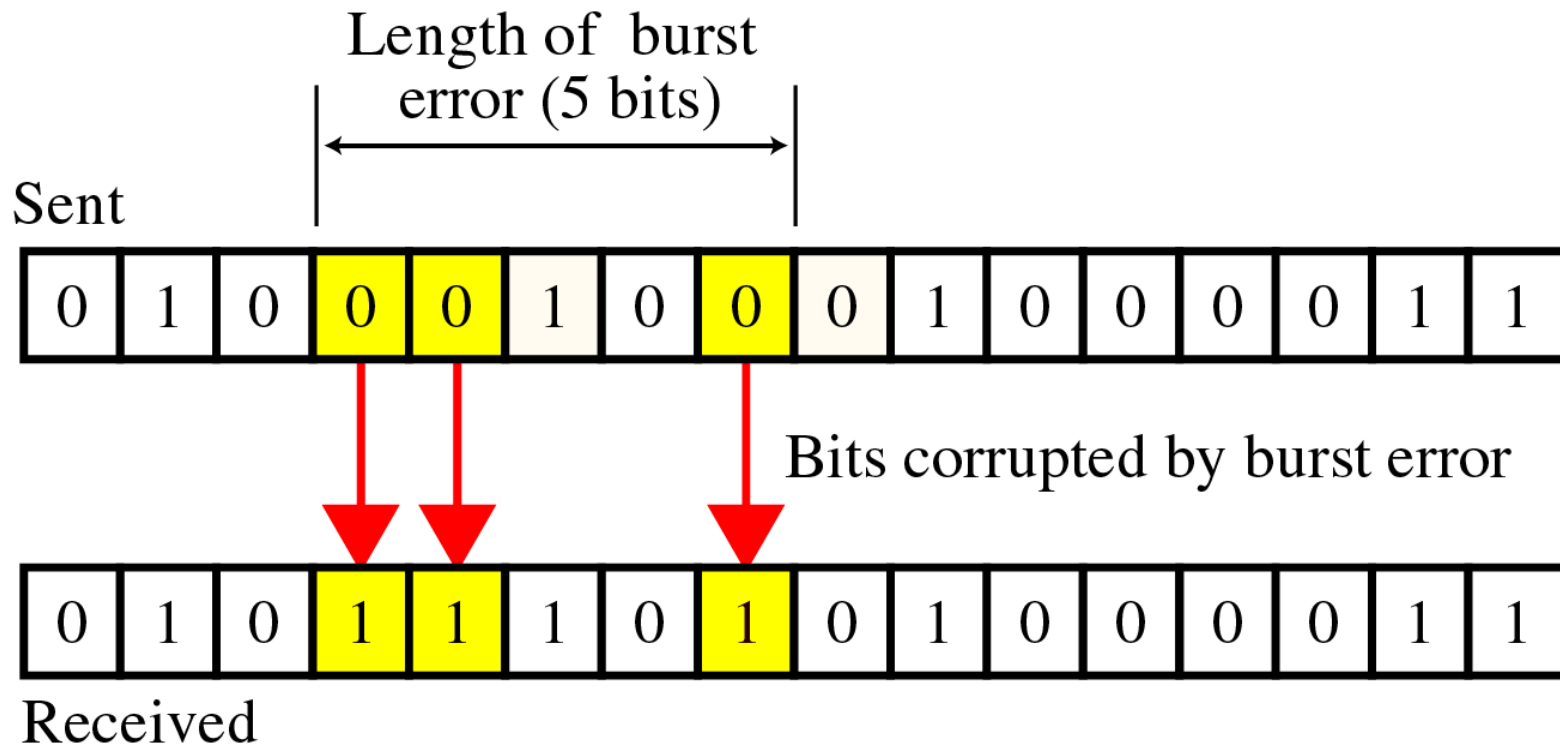
~ is when two or more nonconsecutive bits in the data unit have changed(ex : ASCII B - ASCII LF)



TYPE OF ERRORS(CONT'D)

- Burst Error

~ means that 2 or more consecutive bits in the data unit have changed



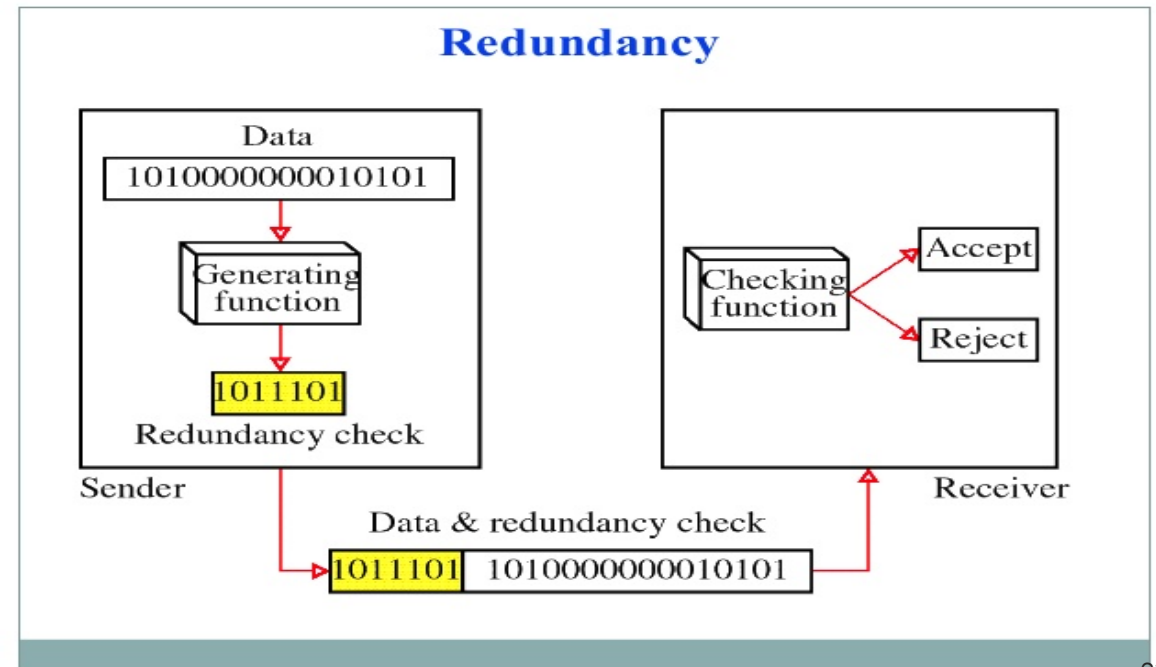
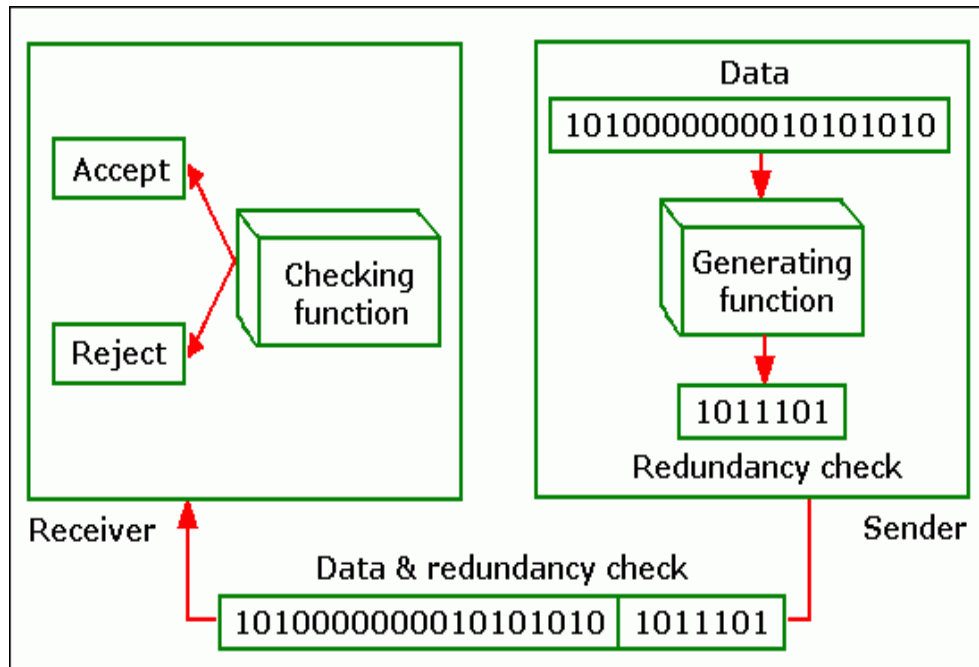


DETECTION

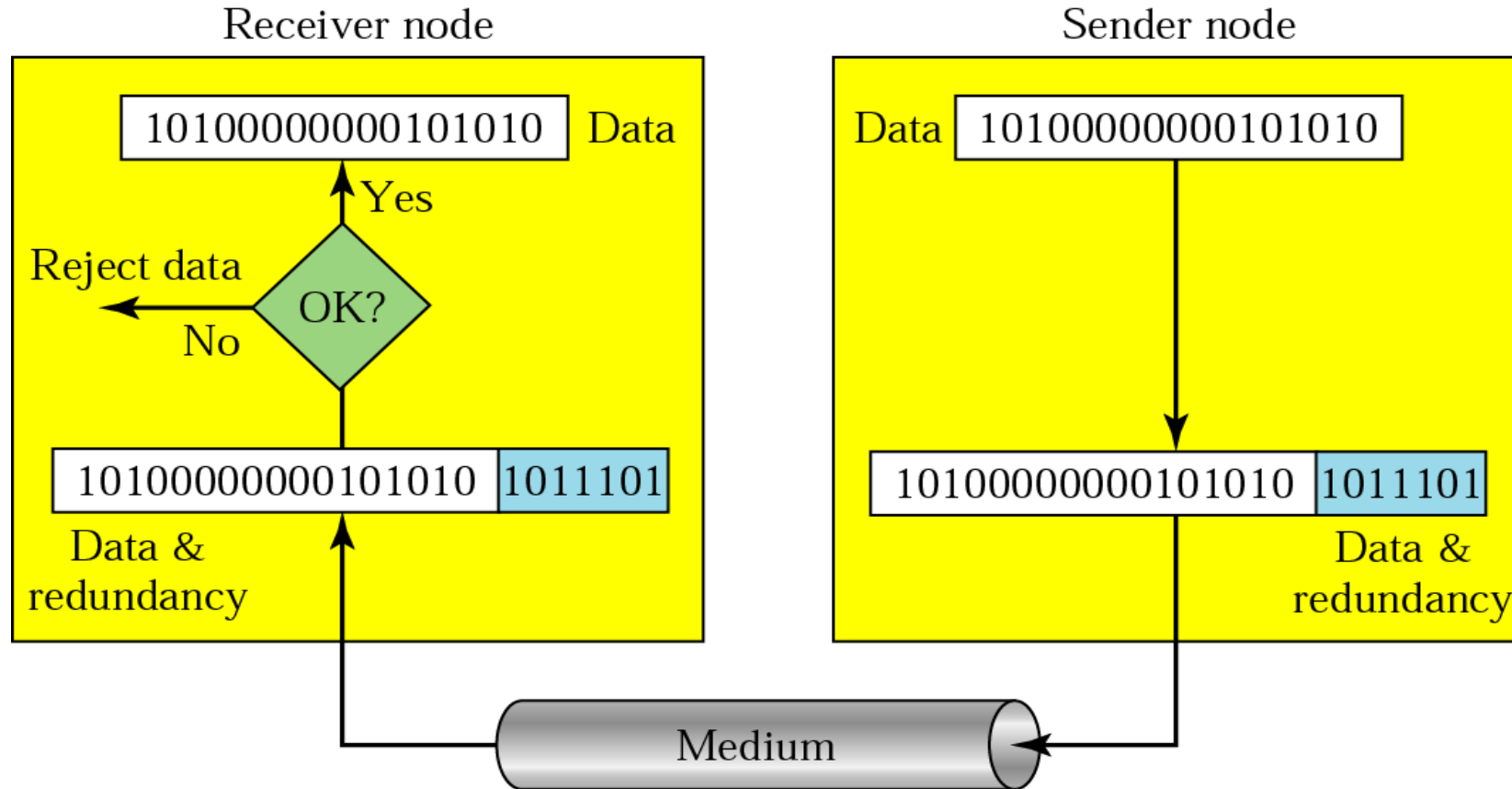
- Error detection uses the concept of redundancy, which means adding extra bits for detecting errors at the destination

REDUNDANCY

To be able to detect or correct errors, we need to send some extra bits with our data. These redundant bits are added by the sender and removed by the receiver. Their presence allows the receiver to detect or correct corrupted bits. The concept of including extra information in the transmission for error detection is a good one. But instead of repeating the entire data stream, a shorter group of bits may be appended to the end of each unit. This technique is called redundancy because the extra bits are redundant to the information: they are discarded as soon as the accuracy of the transmission has been determined.

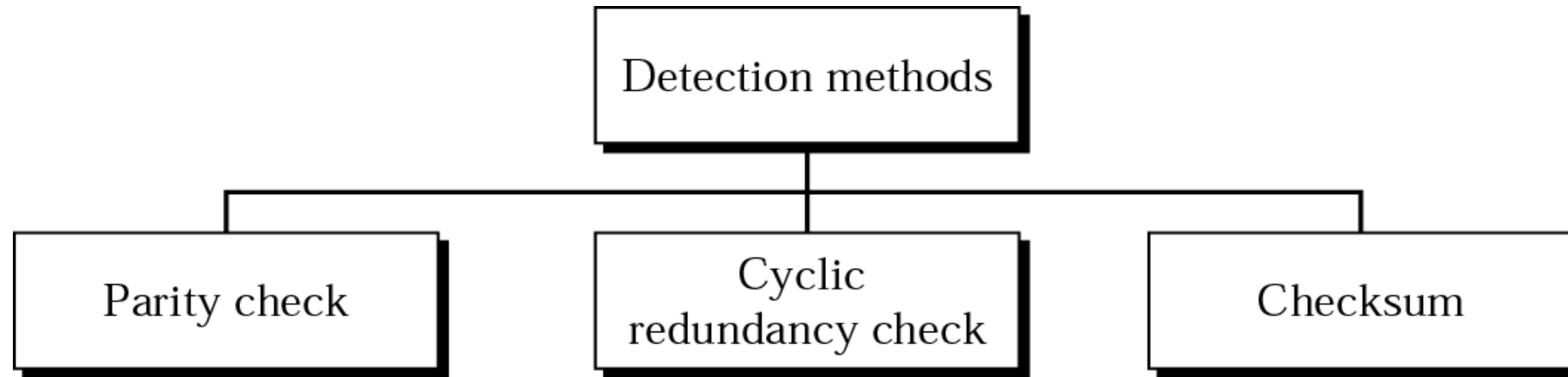


DETECTION(CONT'D)



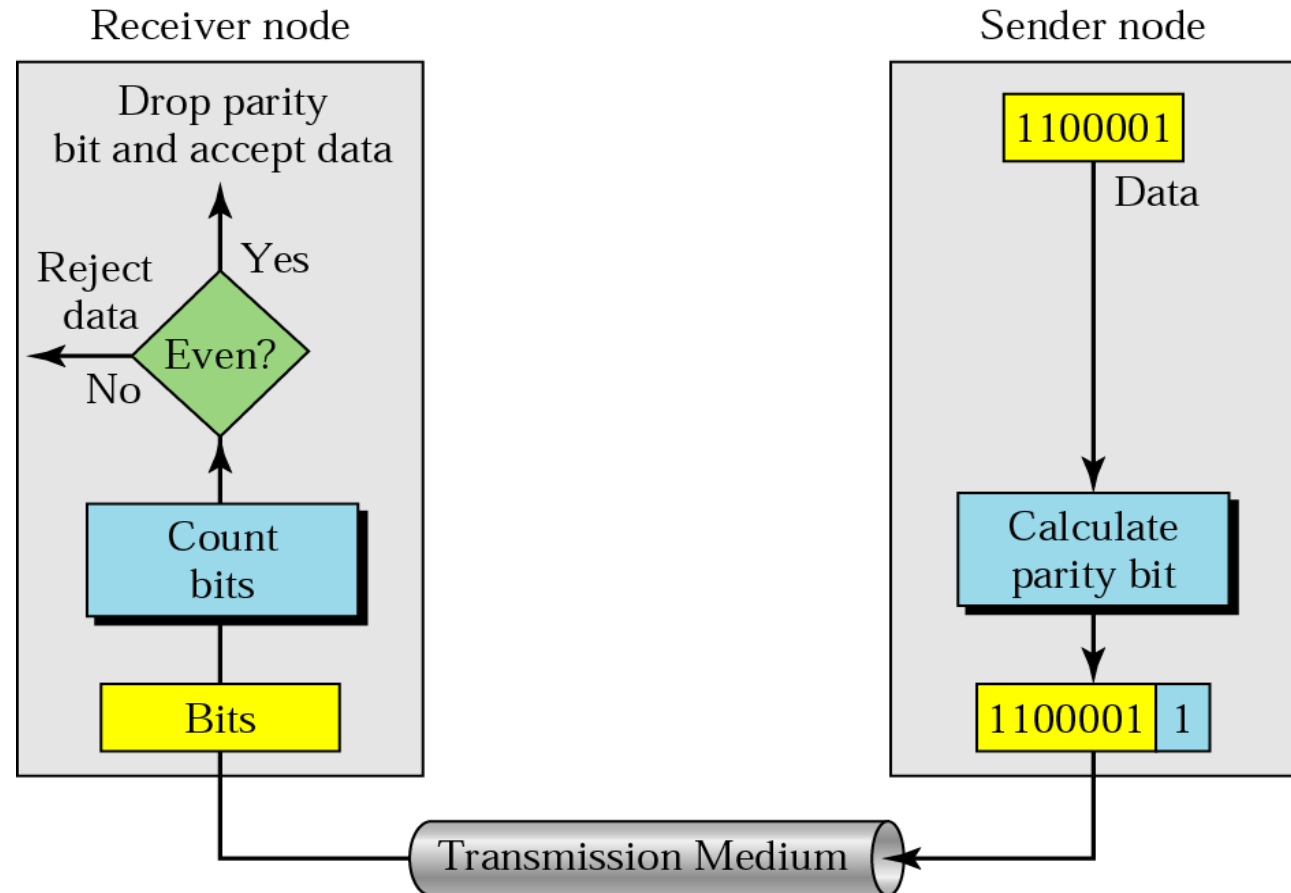
DETECTION(CONT'D)

- Detection methods



DETECTION(CONT'D)

- Parity Check
 - A parity bit is added to every data unit so that the total number of 1s(including the parity bit) becomes even for even-parity check or odd for odd-parity check
 - Simple parity check



DETECTION -EXAMPLES

Suppose the sender wants to send the word *world*. In ASCII the five characters are coded as

1110111 1101111 1110010 1101100 1100100

The following shows the actual bits sent

11101110 11011110 11100100 11011000 11001001

DETECTION – EXAMPLES

Now suppose the word world in Example 1 is received by the receiver without being corrupted in transmission.

11101110 11011110 11100100 11011000 11001001

The receiver counts the 1s in each character and comes up with even numbers (6, 6, 4, 4, 4). The data are accepted.

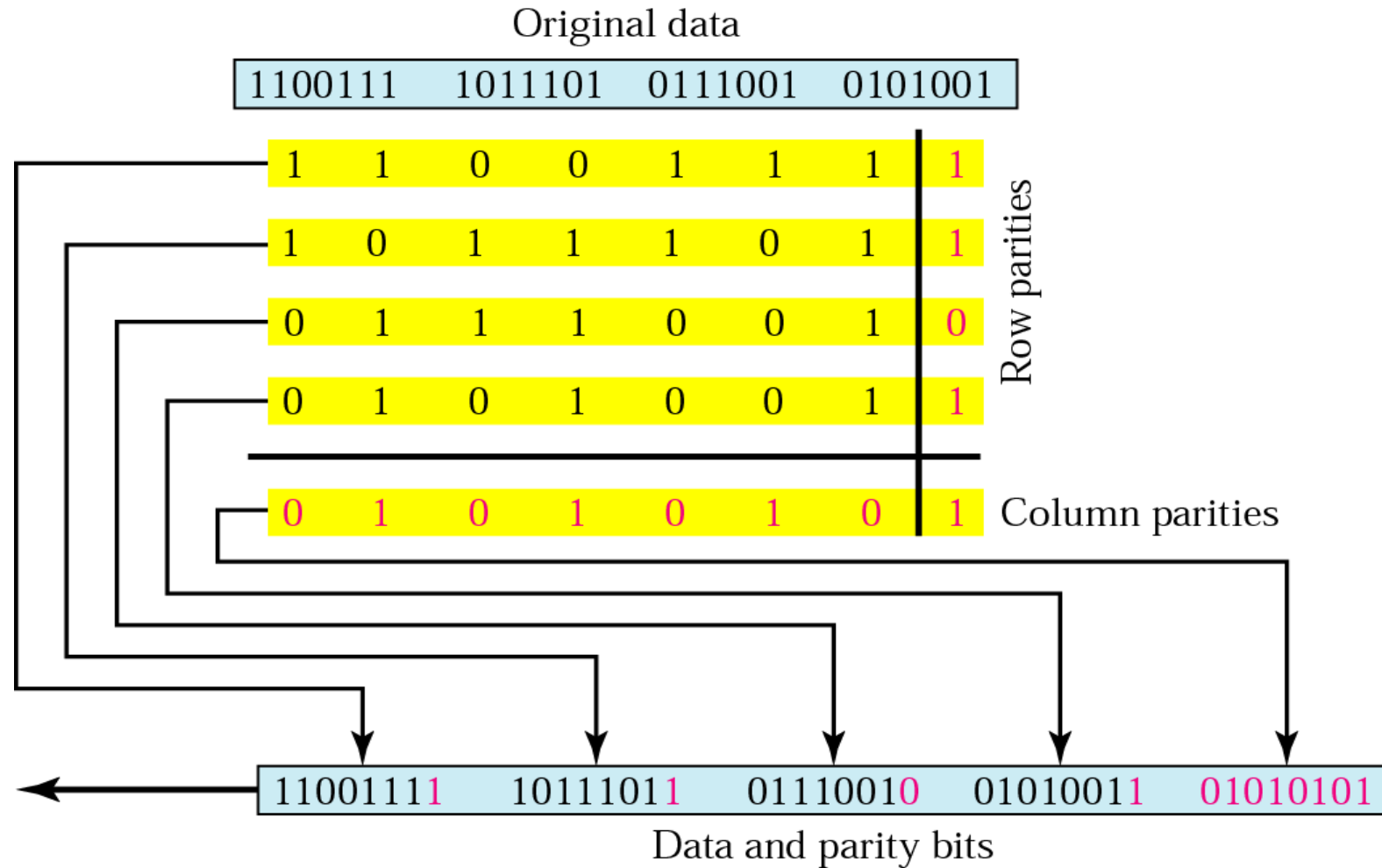
DETECTION – EXAMPLES

Now suppose the word world in Example 1 is corrupted during transmission.

11111110 11011110 11101100 11011000 11001001

The receiver counts the 1s in each character and comes up with even and odd numbers (7, 6, 5, 4, 4). The receiver knows that the data are corrupted, discards them, and asks for retransmission.

TWO - DIMENSIONAL PARITY CHECK



DETECTION - EXAMPLE

Suppose the following block is sent:

10101001 00111001 11011101 11100111 10101010

However, it is hit by a burst noise of length 8, and some bits are corrupted.

10100011 10001001 11011101 11100111 10101010

When the receiver checks the parity bits, some of the bits do not follow the even-parity rule and the whole block is discarded.

10100011 10001001 11011101 11100111 10101010



CHECKSUM

- ~ used by the higher layer protocols
- ~ is based on the concept of redundancy(VRC, LRC, CRC)

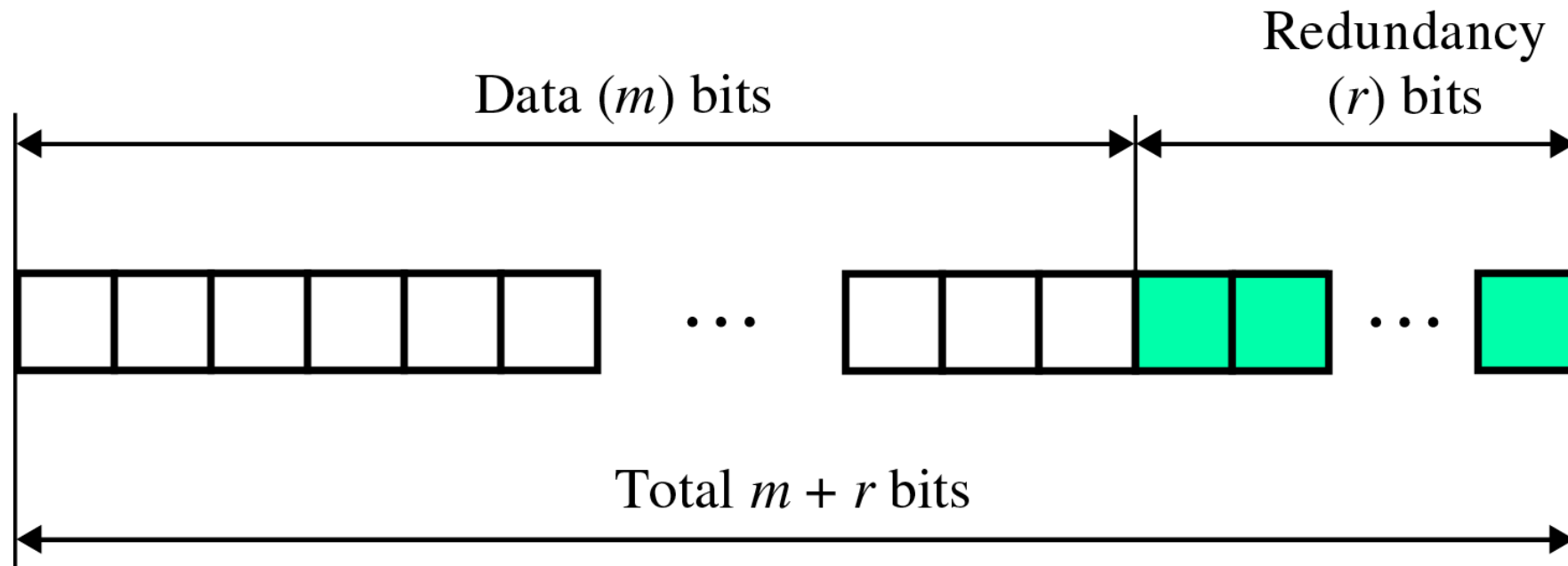
ERROR CORRECTION(CONT'D)

- Single-Bit Error Correction
 - parity bit
 - The secret of error correction is to locate the invalid bit or bits
 - For ASCII code, it needs a three-bit redundancy code(000-111)

ERROR CORRECTION(CONT'D)

- Redundancy Bits

~ to calculate the number of redundancy bits (R) required to correct a given number of data bit (M)



ERROR CORRECTION(CONT'D)

- If the total number of bits in a transmittable unit is $m+r$, then r must be able to indicate at least $m+r+1$ different states

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

ex) For value of m is 7(ASCII), the smallest r value that can satisfy this equation is 4

$$2^4 \geq 7 + 4 + 1$$



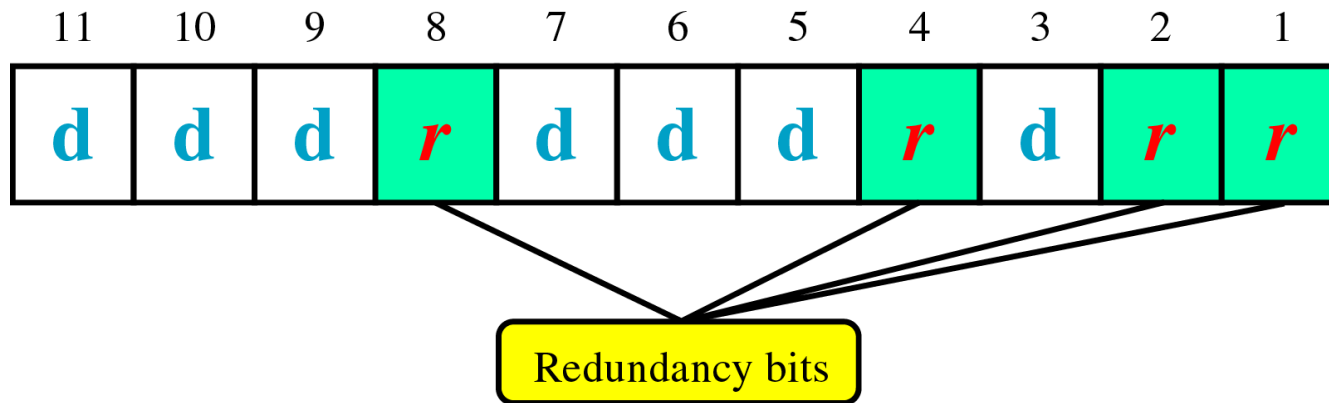
ERROR CORRECTION(CONT'D)

- Relationship between data and redundancy bits

HAMMING CODE

~ developed by R.W.Hamming

- positions of redundancy bits in Hamming code



HAMMING CODE

- each r bit is the VRC bit for one combination of data bits

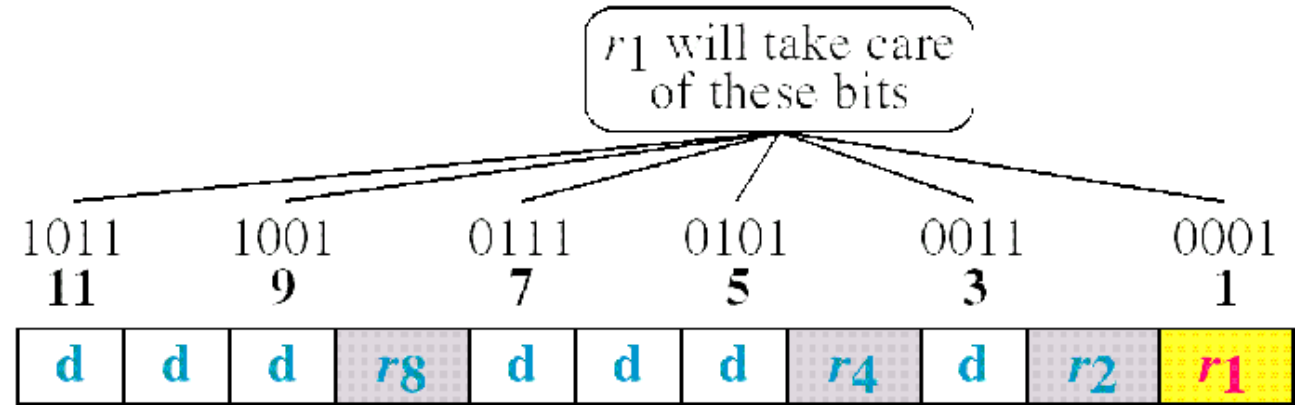
r_1 = bits 1, 3, 5, 7, 9, 11

r_2 = bits 2, 3, 6, 7, 10, 11

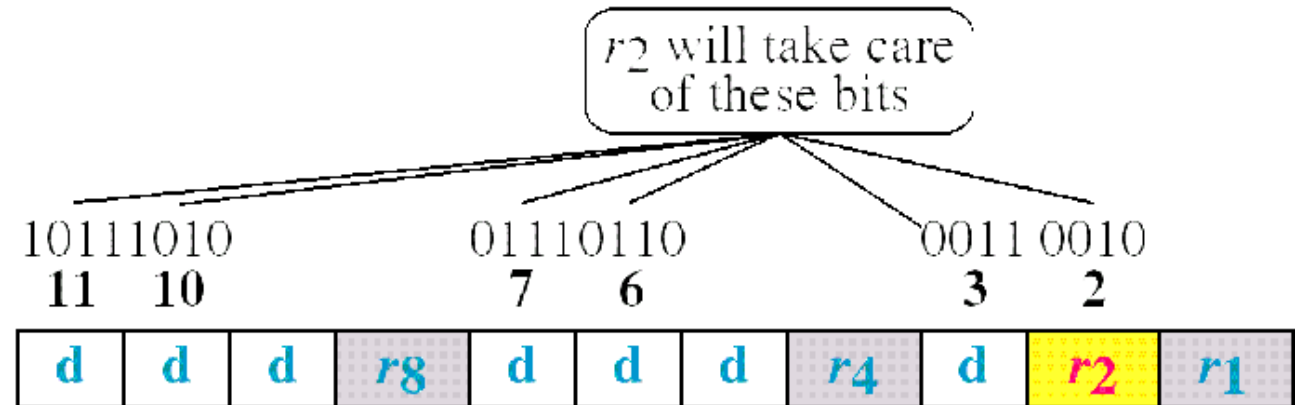
r_4 = bits 4, 5, 6, 7

r_8 = bits 8, 9, 10, 11

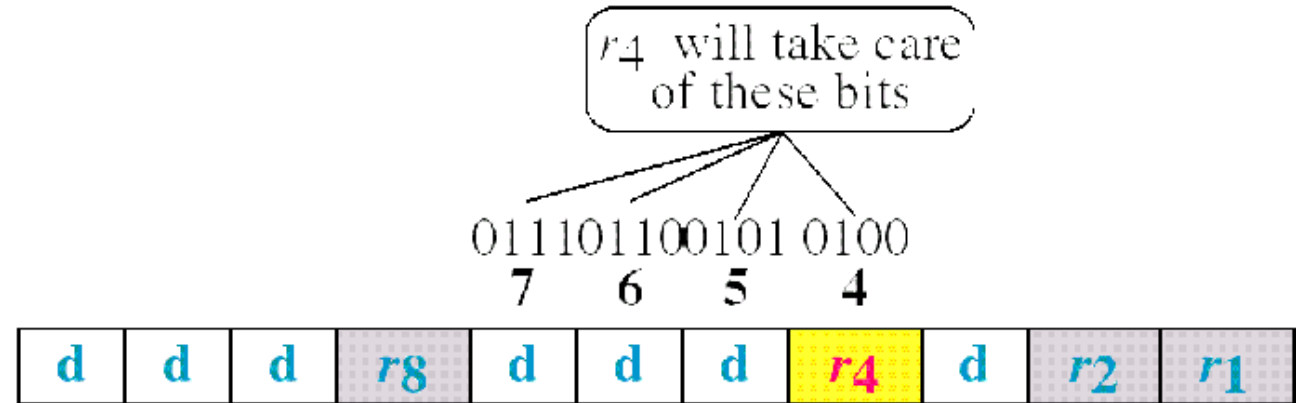
HAMMING CODE (CONT'D)



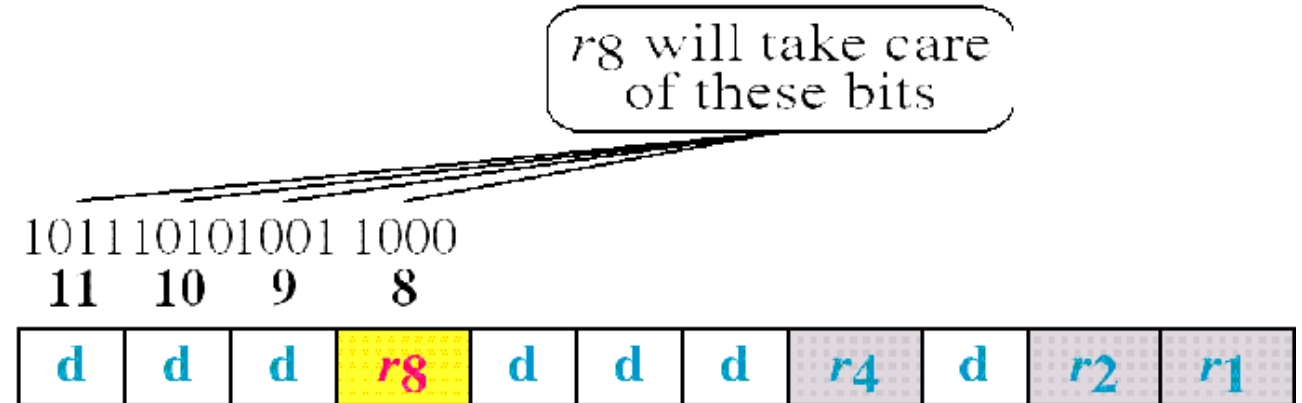
- Redundancy bits calculation(cont'd)



ERROR CORRECTION(CONT'D)

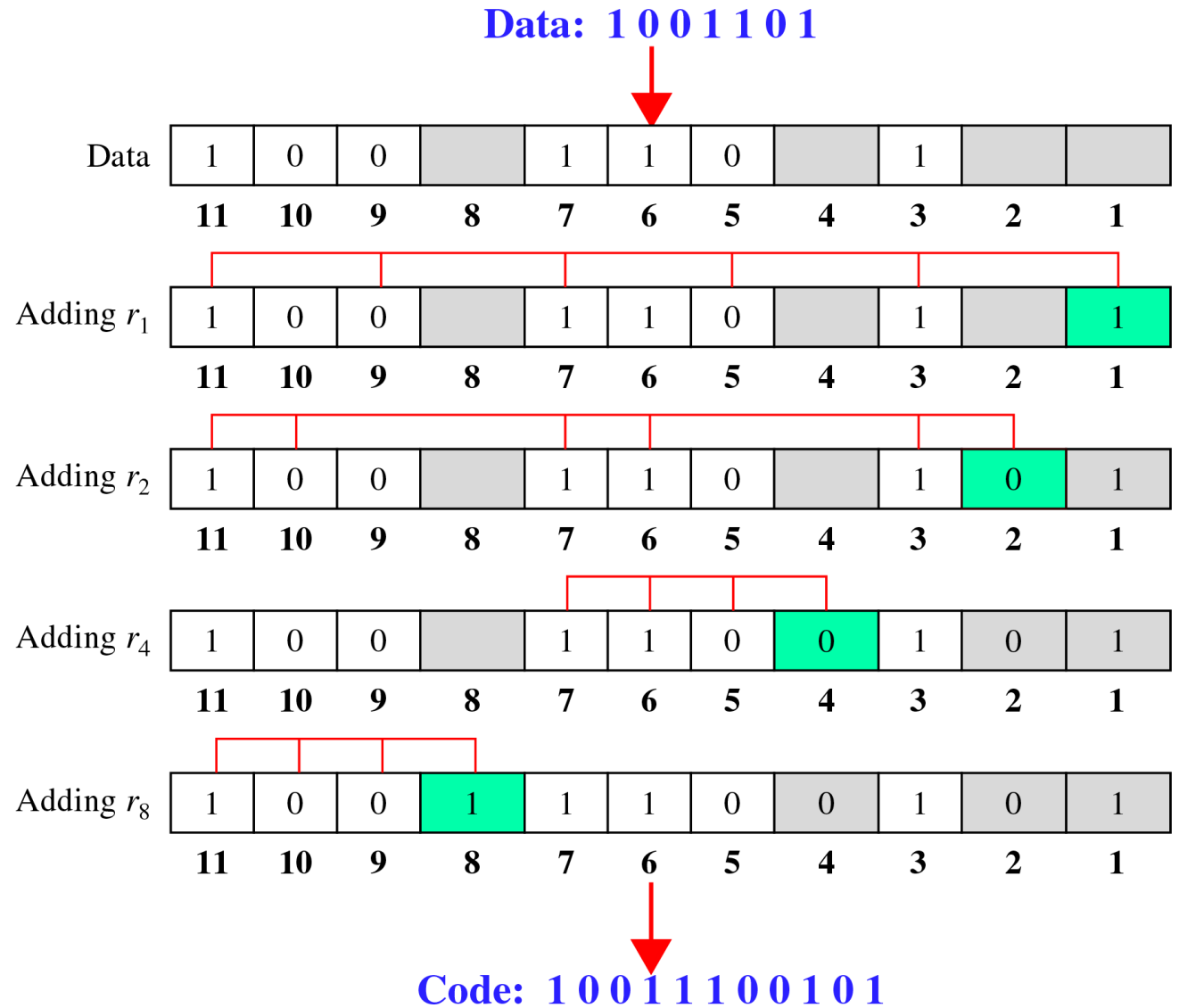


- Redundancy bits calculation



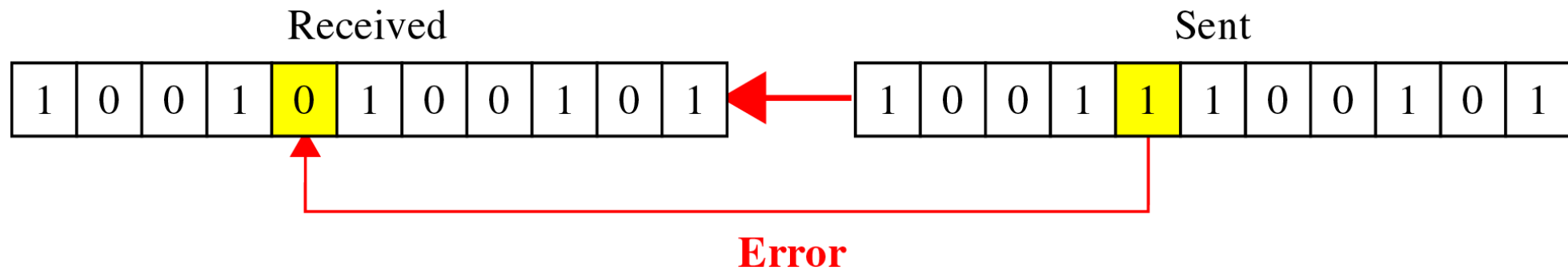
HAMMING CODE (CONT'D)

- Calculating the r values



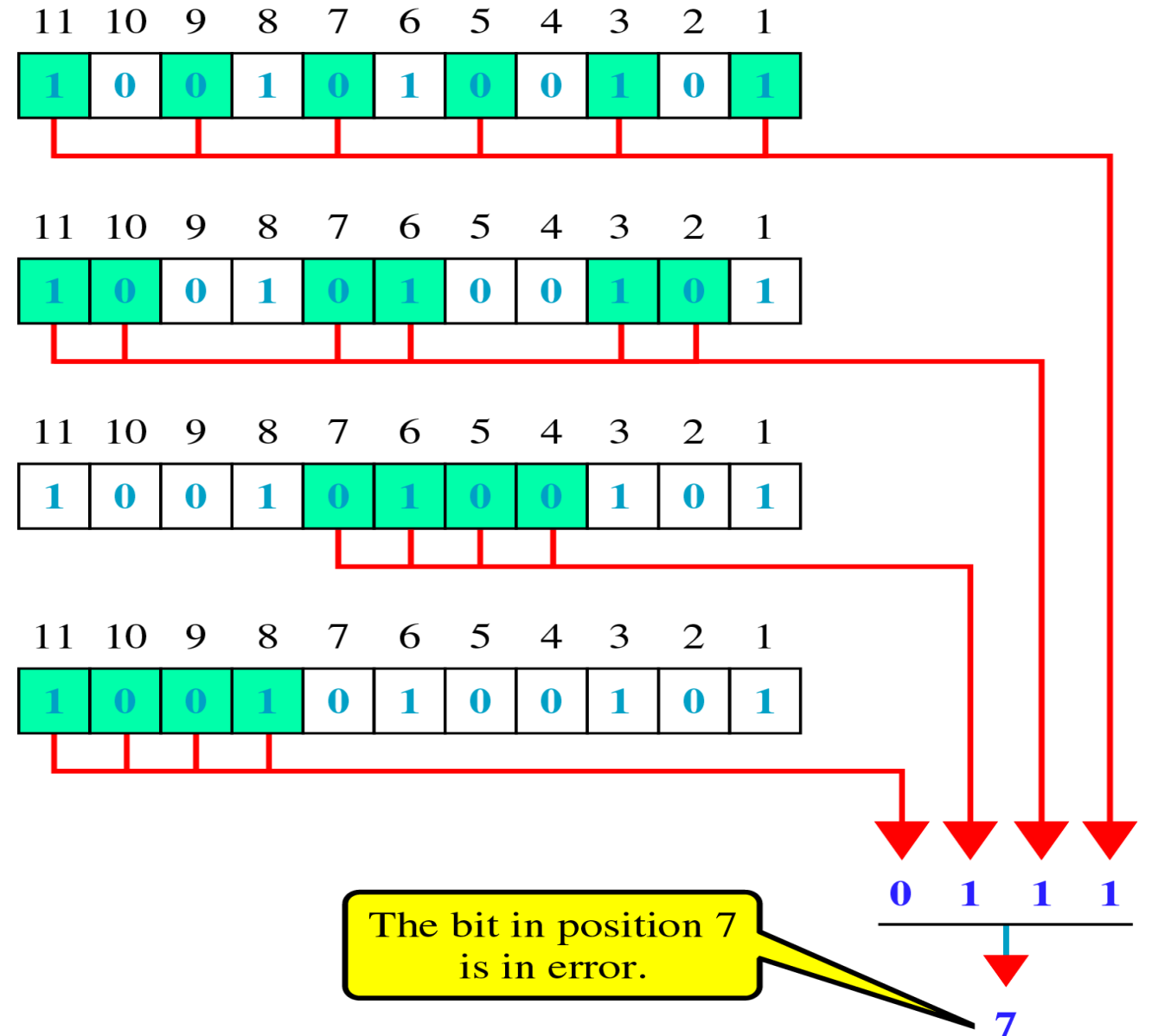
HAMMING CODE (CONT'D)

- Error Detection and Correction




HAMMING CODE (CONT'D)

- Error detection using Hamming Code



PHYSICAL LAYER SERVICES



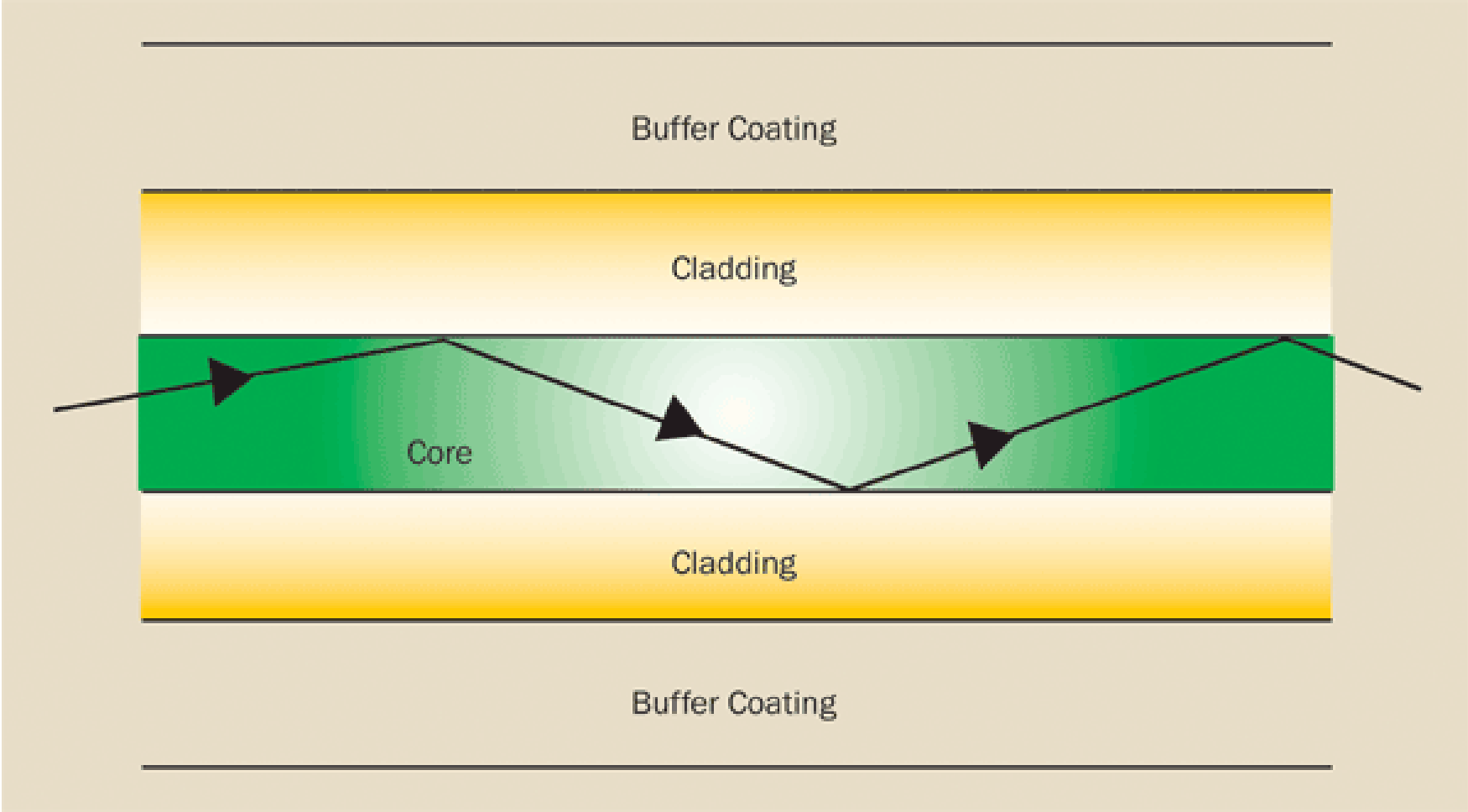
GUIDED TRANSMISSION MEDIA

- » Waves are guided along solid medium:
- » Twisted pair
- » Coaxial cable
- » Optical fiber



OPTICAL FIBER

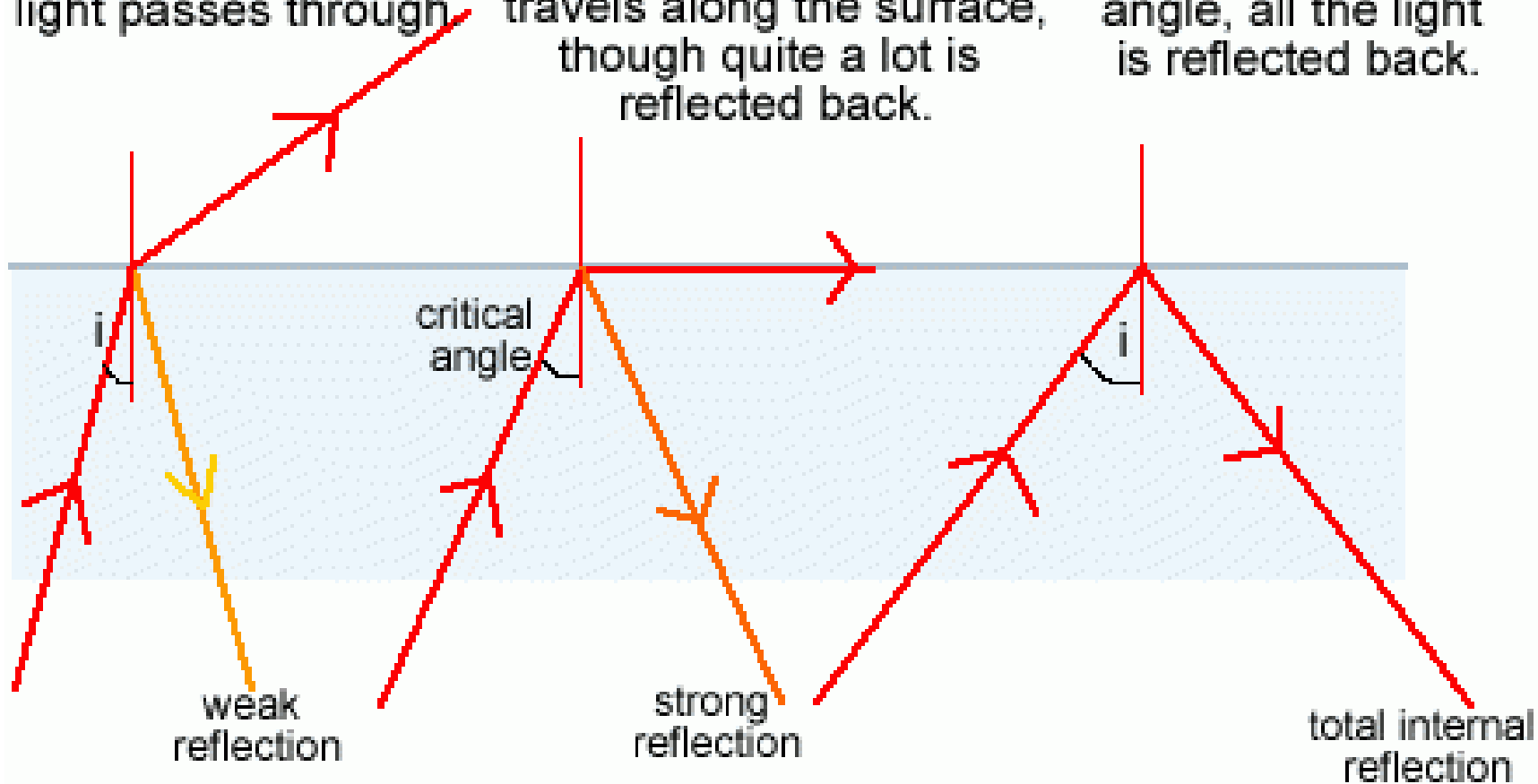
- » Three components: light source, transmission system, and a detector:
 - » Optical rays travel in glass or plastic core.
 - » The detector generates an electric pulse when hit by light.
- » Used in long distance communication.
- » Not affected by external electromagnetic fields, and do not radiate energy.



If angle of incidence is **less** than critical angle, most of the light passes through

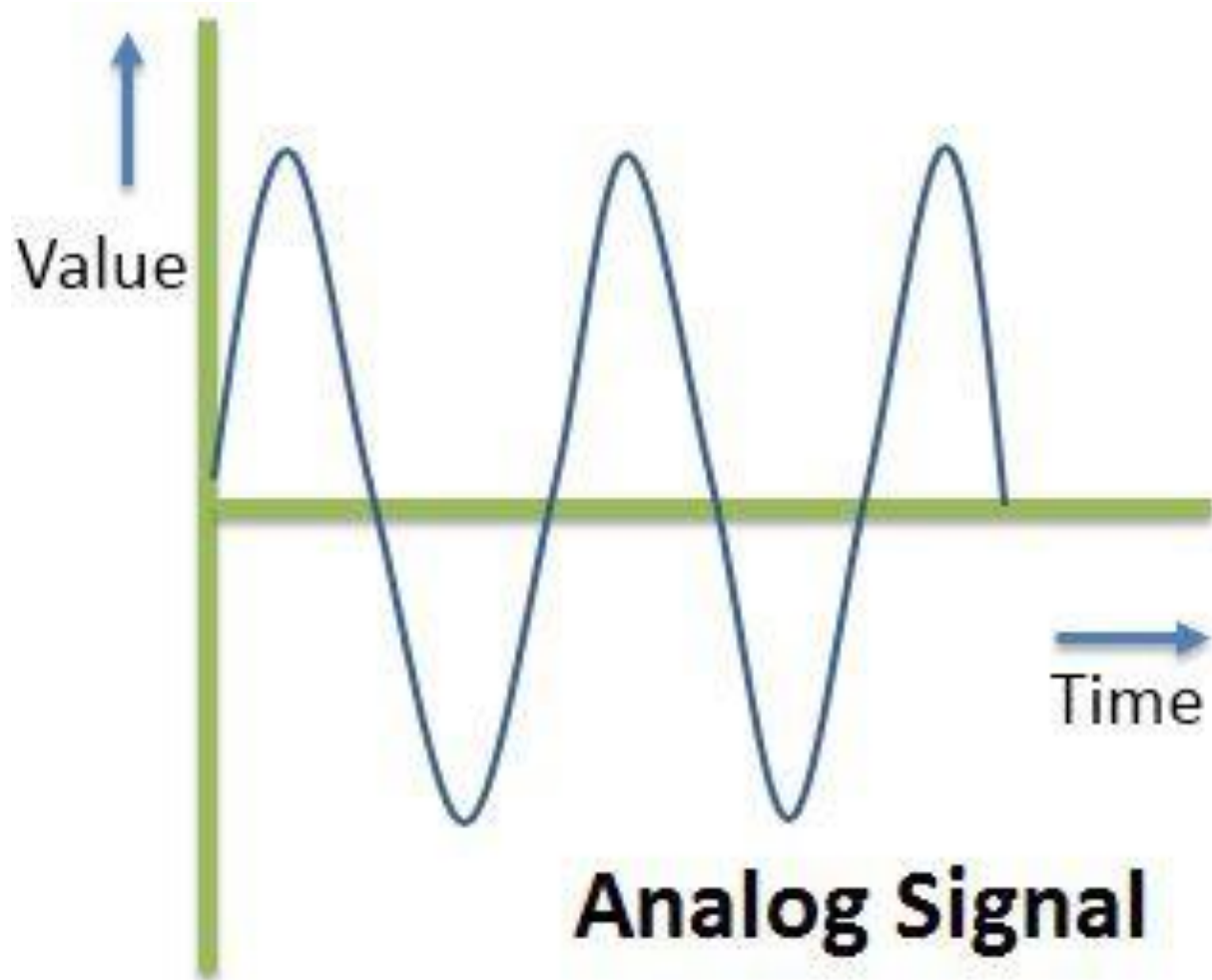
If the angle of incidence is **equal** to the critical angle, most of the light travels along the surface, though quite a lot is reflected back.

If the angle of incidence is **greater** than the critical angle, all the light is reflected back.

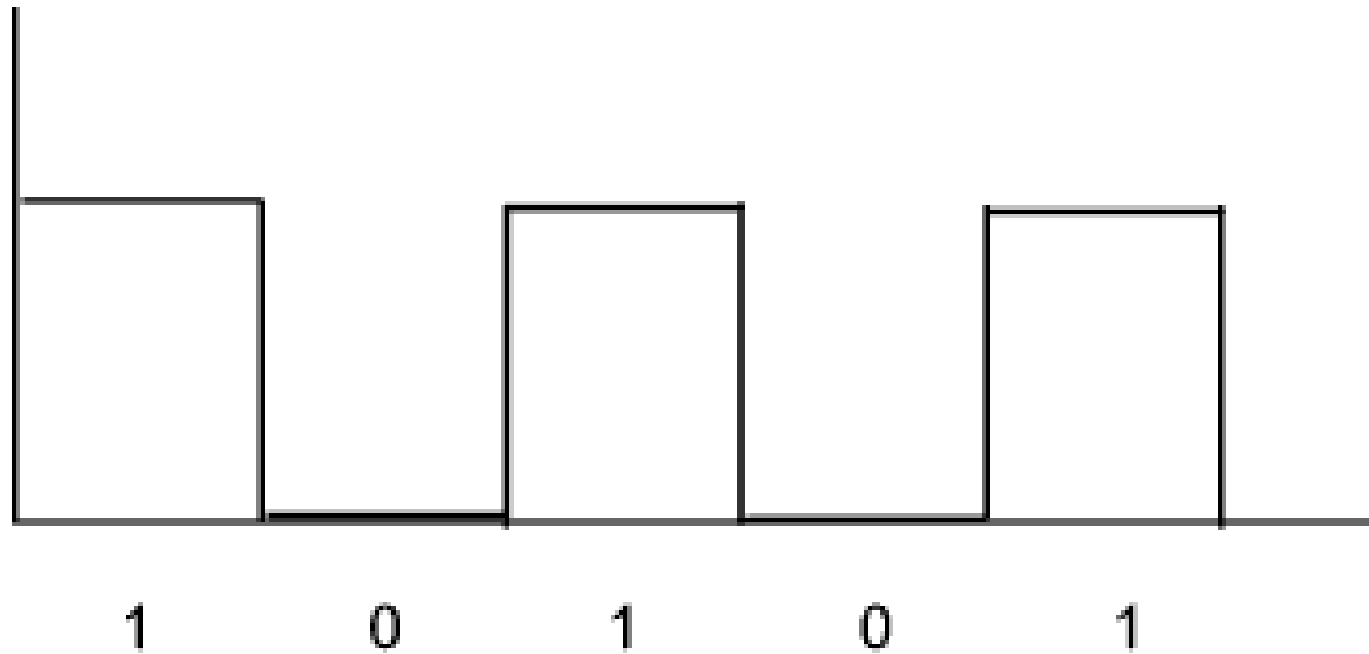




MODULATION



**MEDIA
CARRIES
ANALOG
SIGNALS**



**WE WANT
(MACHINE)
THIS SIGNAL**



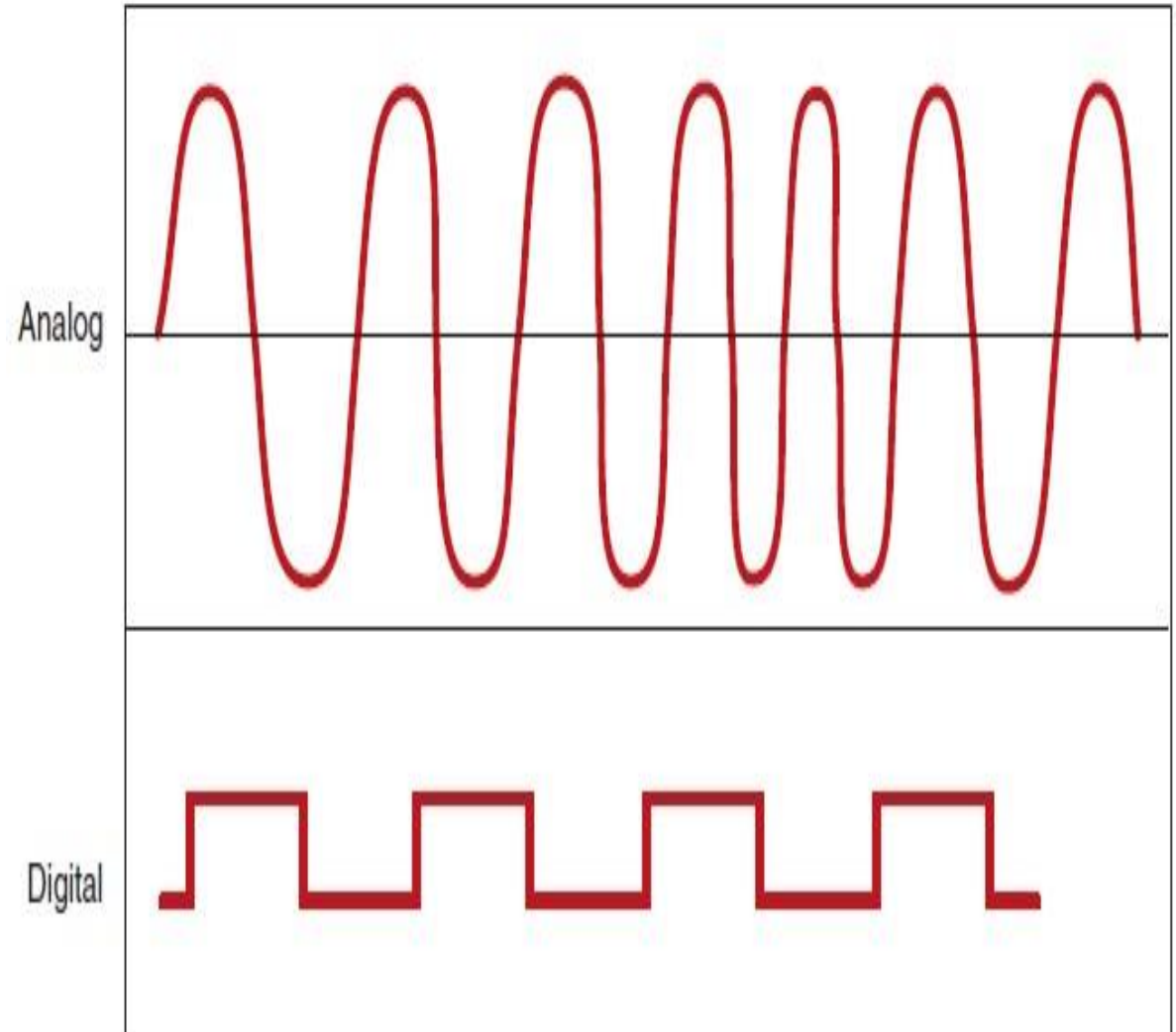
**SO HOW TO DELIVER
THE BITS OVER THE
ANALOG SIGNAL ?**



SIGNALS

- » To be transmitted, data must be transformed to electromagnetic signals.
- » Signals can be analog or digital. Analog signals can have an infinite number of values in a range; digital signals can have only a limited number of values.
- » In data communication, we commonly use periodic analog signals and aperiodic digital signals.

- A continuous signal is one in which the signal intensity varies in a smooth fashion over time.
- A discrete signal is one in which the signal intensity maintains a constant level for some period of time and then changes to another constant



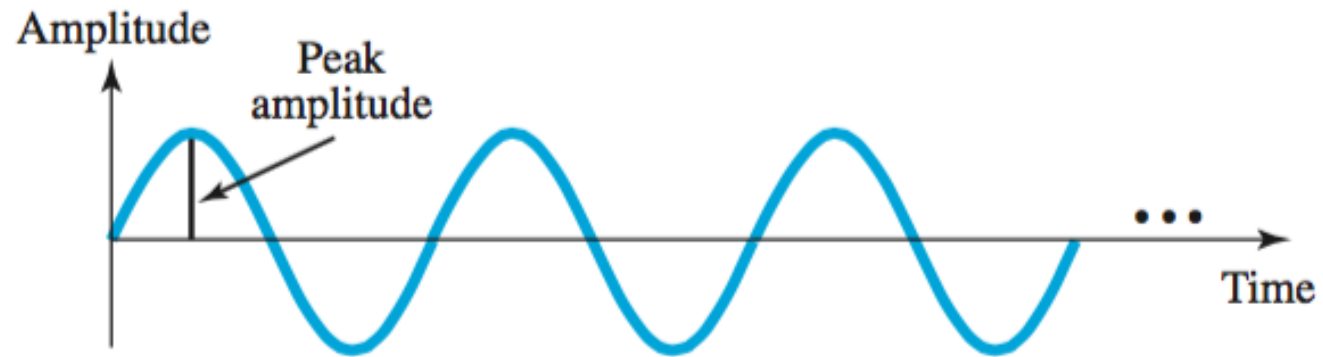
PERIODIC SIGNALS

- A signal is defined to be periodic if and only if:
 $x(t) = x(t+T)$ true for all positive and negative values of t .

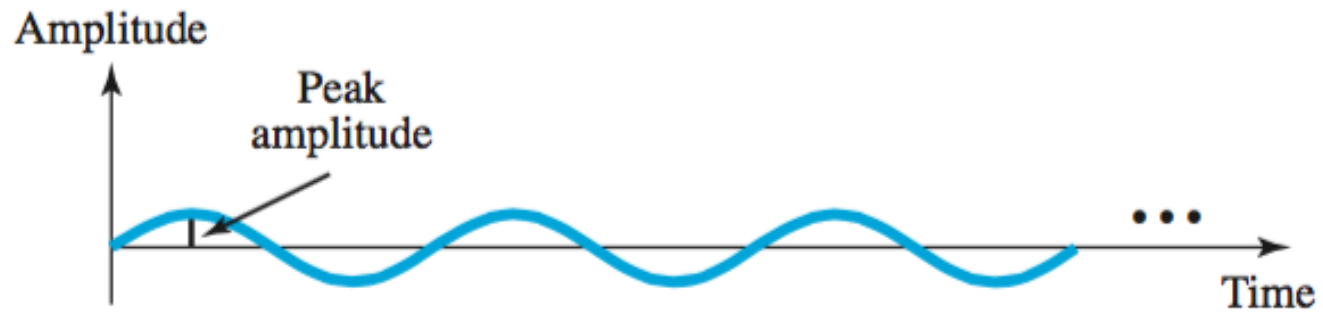
T is the period

SINE WAVE

- The sine wave is the fundamental continuous signal. A general sine wave can be represented by three parameters:
- » amplitude, frequency ,phase
- The amplitude is the peak value or strength of the signal over time; typically, this value is measured in volts or watts.



a. A signal with high peak amplitude



b. A signal with low peak amplitude

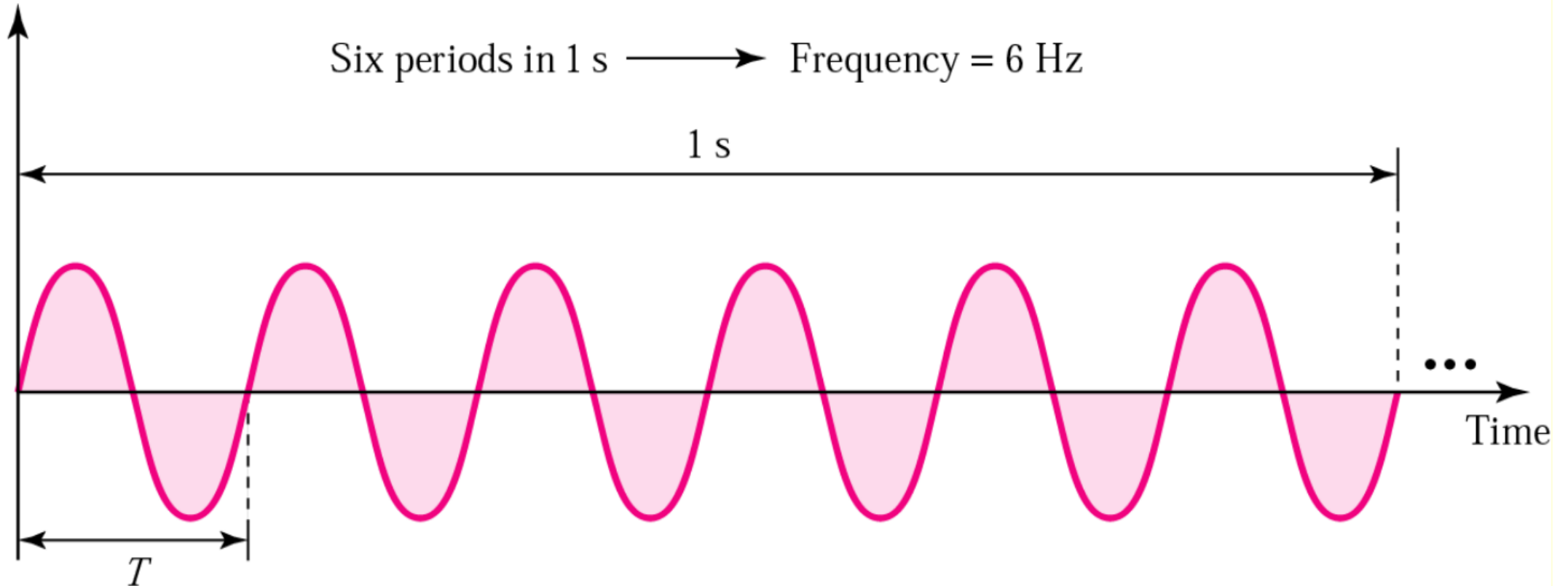
AMPLITUDE

SINE WAVE

- The frequency is the rate (in cycles per second, or Hertz (Hz)) at which the signal repeats. An equivalent parameter is the period (T) of a signal, which is the amount of time it takes for one repetition; therefore,
- Frequency = $1/\text{period} = \text{number of cycles}/\text{time}$
- $f = 1/T = N/t$
 - T = period, the time which is required for one cycle
 - N = a particular number of cycles
 - t = a particular amount of time
- If a signal does not change at all, its frequency is zero. If a signal changes instantaneously, its frequency is infinite.

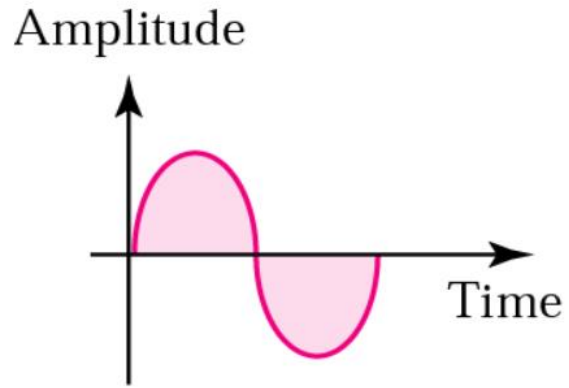
PERIODS AND FREQUENCY

Amplitude

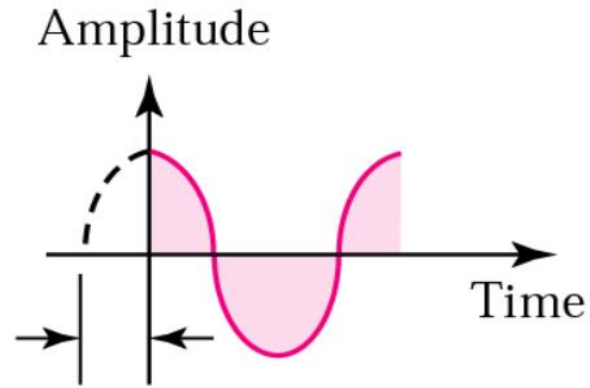


Period = $1/6$ s

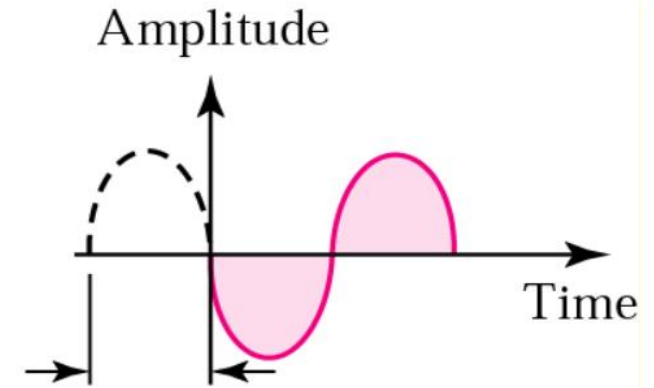
PHASE



a. 0°



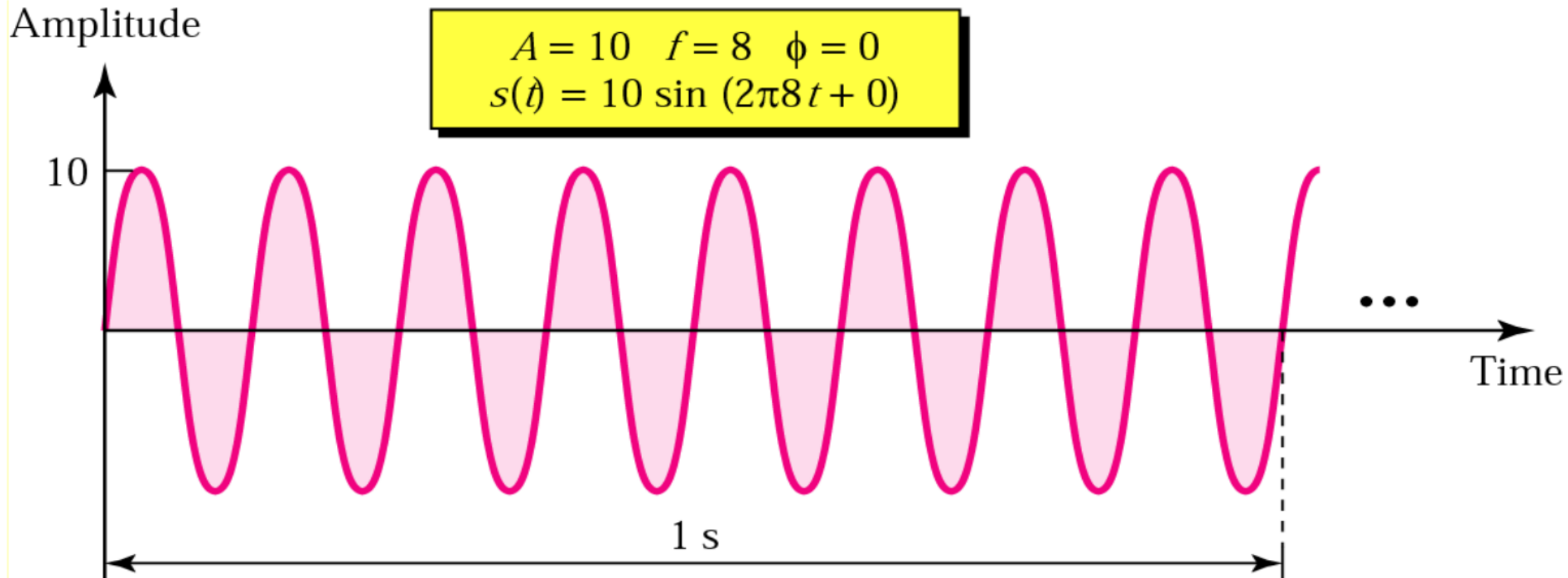
b. 90°



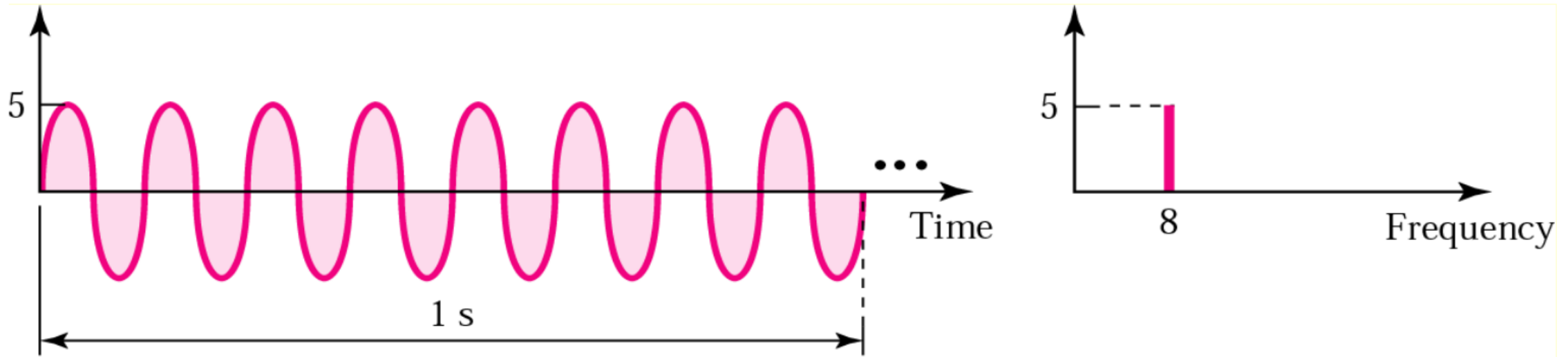
c. 180°

Phase describes the position of the waveform relative to time zero.

AMPLITUDE PHASE FREQ



TIME AND FREQUENCY DOMAINS

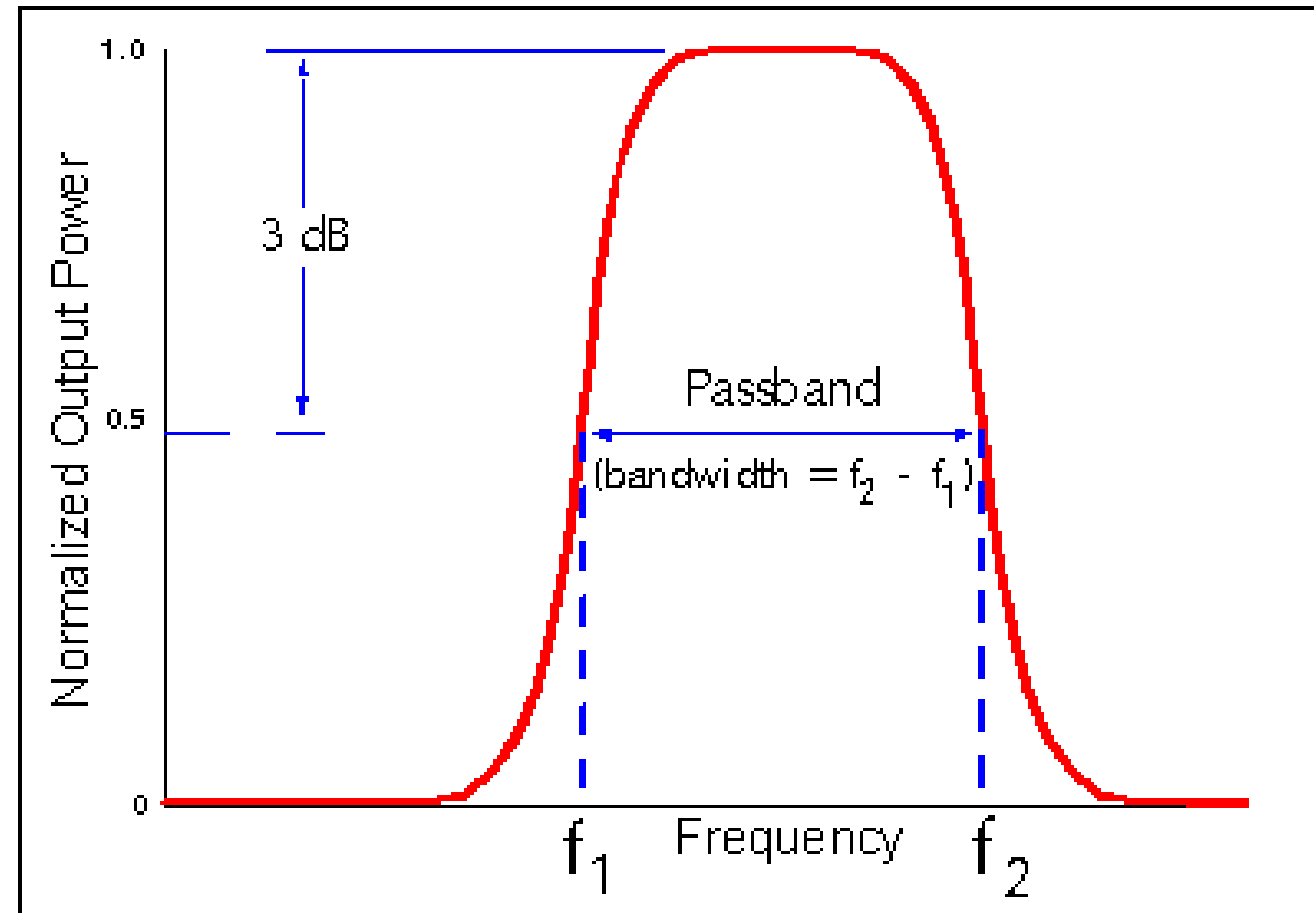


An analog signal is best represented in the frequency domain.

a **time-domain** graph shows how a signal changes over time, whereas a **frequency-domain** graph shows how much of the signal lies within each given **frequency** band over a range of **frequencies**.

BANDWIDTH

- » The bandwidth is a property of a medium:
 - » The difference between the highest and the lowest frequencies that the medium can satisfactorily pass.

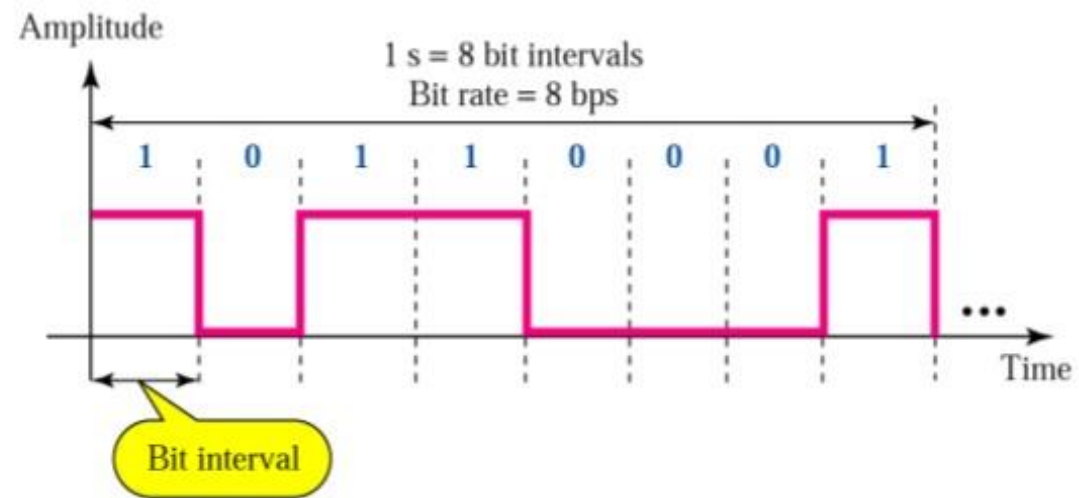


bandpass filter

BASEBAND AND PASSBAND

- **Difference between Meaning** Baseband signal, as the name suggests, refers to the original transmission signal generated from the message source with no modulation of high frequency carrier whatsoever.
- Passband signal, on the other hand, is yet another form of digital transmission that uses modulation meaning the frequency or phase of the carrier signal is modulated to transmit the bits. It is based on the concept of digital data transmission post modulation of high frequency sinusoidal carrier.

Bit rate and bit interval



BIT RATE AND BAUD RATE

- Bit rate, N , is the number of bits per second (bps).
- Baud rate (S) is the number of signal elements per second (bauds).
- In the analog transmission of digital data, the signal or baud rate is less than or equal to the bit rate.
- $S = N \times 1/r$ bauds
- Where r is the number of data bits per signal element.

MODULATION

- Modulation - process (or result of the process) of translation the baseband message signal to bandpass (modulated carrier) signal at frequencies that are very high compared to the baseband frequencies.
- Demodulation is the process of extracting the baseband message back the modulated carrier.
- An information-bearing signal (carrier) is non-deterministic, i.e. it changes in an unpredictable manner.



WHY MODULATION

- The baseband signals are incompatible for direct transmission. For such a signal, to travel longer distances, its strength has to be increased by modulating with a high frequency carrier wave, which doesn't affect the parameters of the modulating signal.

DIGITAL TO ANALOG CONVERSION

- Digital data needs to be carried on an analog signal.
- A **carrier** signal (frequency f_c) performs the function of transporting the digital data in an analog waveform.
- The analog carrier signal is manipulated to uniquely identify the digital data being carried.

ANALOG MODULATION

- Amplitude Modulation
 - AM radio
- Frequency Modulation
 - FM radio, TV audio signal
- Phase Modulation
 - TV color image signal (including Amplitude Modulation)

AM RADIO OR FM RADIO ?

- **FM** uses a higher frequency range and a bigger bandwidth **than AM**. ... Each **FM station** is allocated 150 kHz of bandwidth, which is approx 15 times that of an **AM station**. This means that an **FM station** can transmit 15 times as much information as an **AM station** and explains why music sounds so much **better** on **FM**.

MODULATION PROCESS

$$f = f(a_1, a_2, a_3, \dots, a_n, t) \dots \dots \dots \text{carrier}$$

$a_1, a_2, a_3, \dots, a_n \dots \dots \dots \text{modulation parameters}$

$t \dots \dots \dots \text{time}$

- Modulation implies varying one or more characteristics (modulation parameters a_1, a_2, \dots, a_n) of a carrier f in accordance with the information-bearing (modulating) baseband signal.
- Sinusoidal waves, pulse train, square wave, etc. can be used as carriers

CONTINUOUS CARRIER

Carrier: $A \sin[\omega t + \varphi]$

- $A = \text{const}$
- $\omega = \text{const}$
- $\varphi = \text{const}$
- Amplitude modulation (AM)
 - $A = A(t)$ - carries information
 - $\omega = \text{const}$
 - $\varphi = \text{const}$

- Frequency modulation (FM)
 - $A = \text{const}$
 - $\omega = \omega(t)$ - carries information
 - $\varphi = \text{const}$
- Phase modulation (PM)
 - $A = \text{const}$
 - $\omega = \text{const}$
 - $\varphi = \varphi(t)$ - carries information

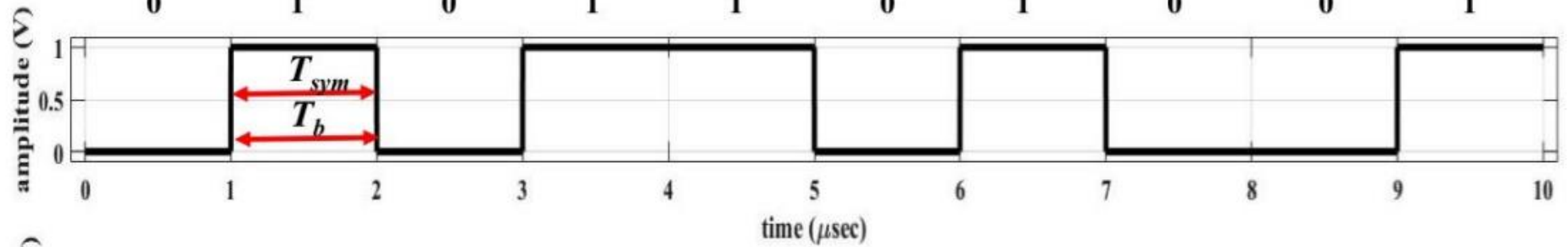
SHIFT KEYING

- Binary digital modulation refers to types of modulation where there are two symbols, and so each symbol carries 1 bit of information.
- Recall the equation for a high frequency carrier: Carrier: $A \sin[\omega t + \phi]$
- We can use an information signal (message) to modulate a carrier by varying its amplitude, frequency, or phase. So, how do we go about representing digital information (1s and 0s) with modulation?
- Just as we can vary amplitude, frequency, and phase of a high frequency carrier in accordance with an analog information (message) waveform, we can do the same with a digital waveform. Since bit values “shift” between 0s and 1s, digital modulation techniques that vary the carrier’s amplitude, frequency, and phase are referred to as “shift keying.”

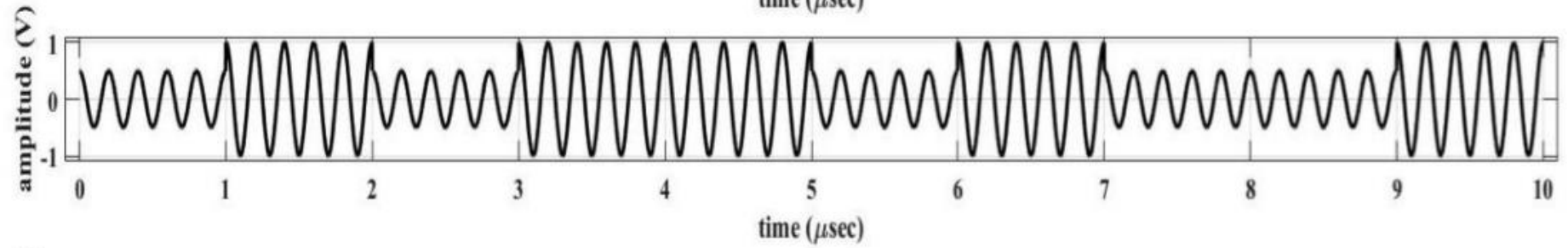
Information (bits):

0 1 0 1 1 0 1 0 0 1

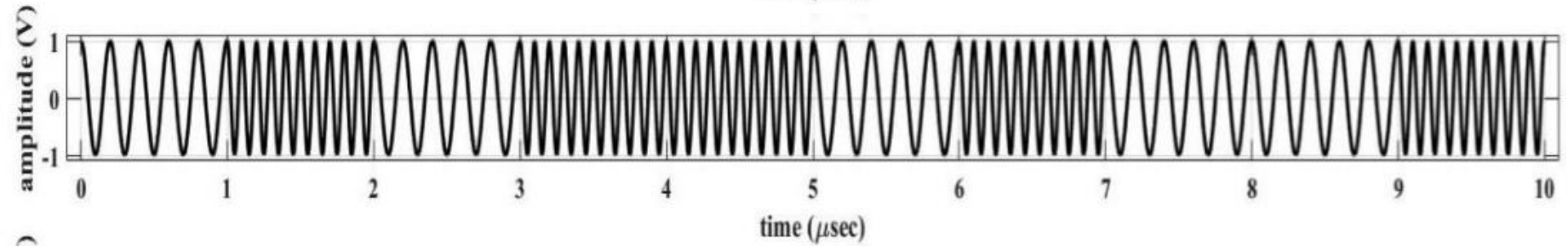
**Baseband signal
(voltage pulses):**



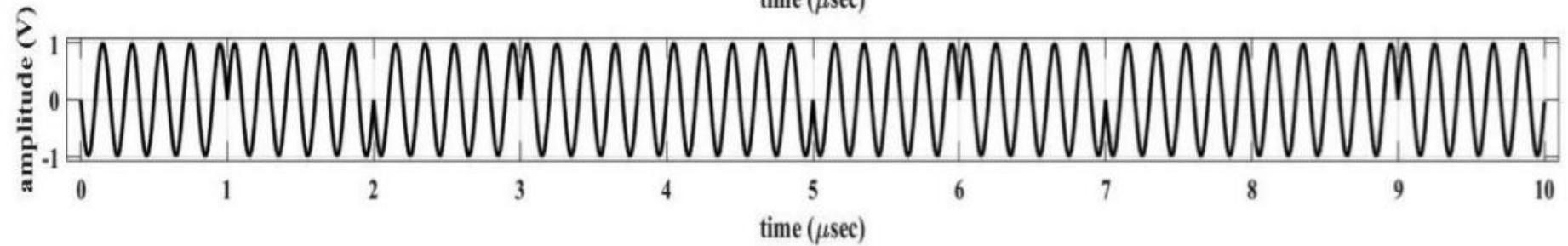
**Modulated signal
if using ASK:**



**Modulated signal
if using FSK:**



**Modulated signal
if using BPSK:**

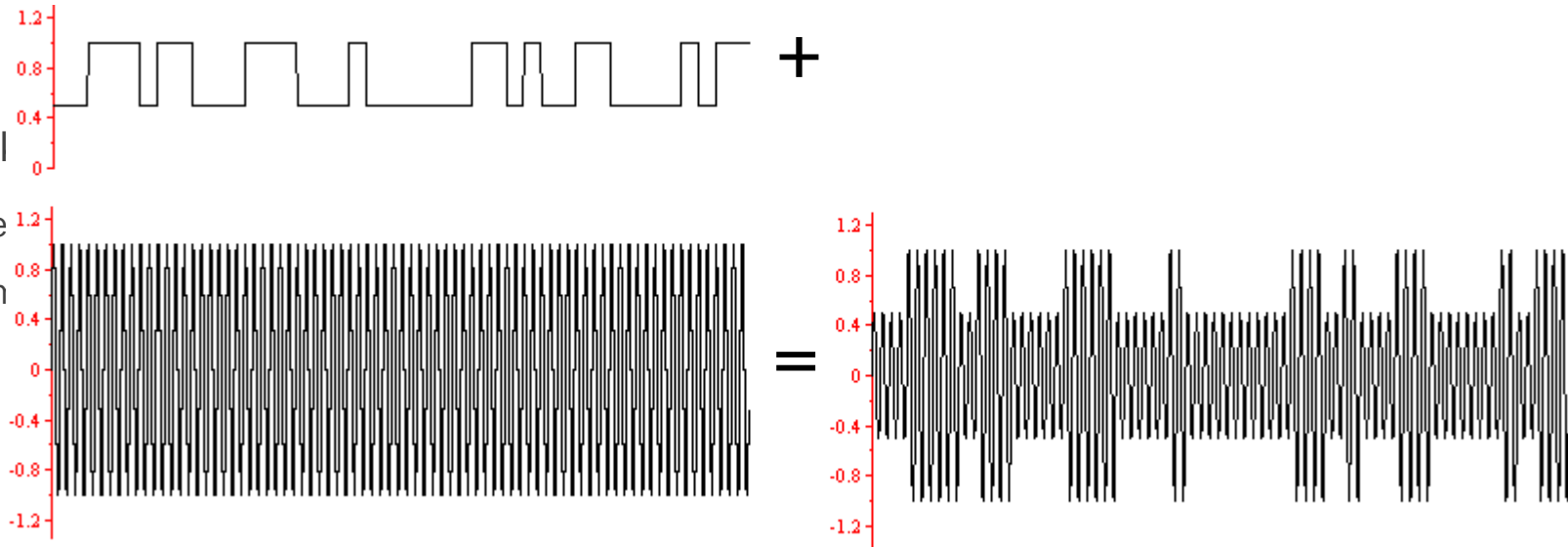


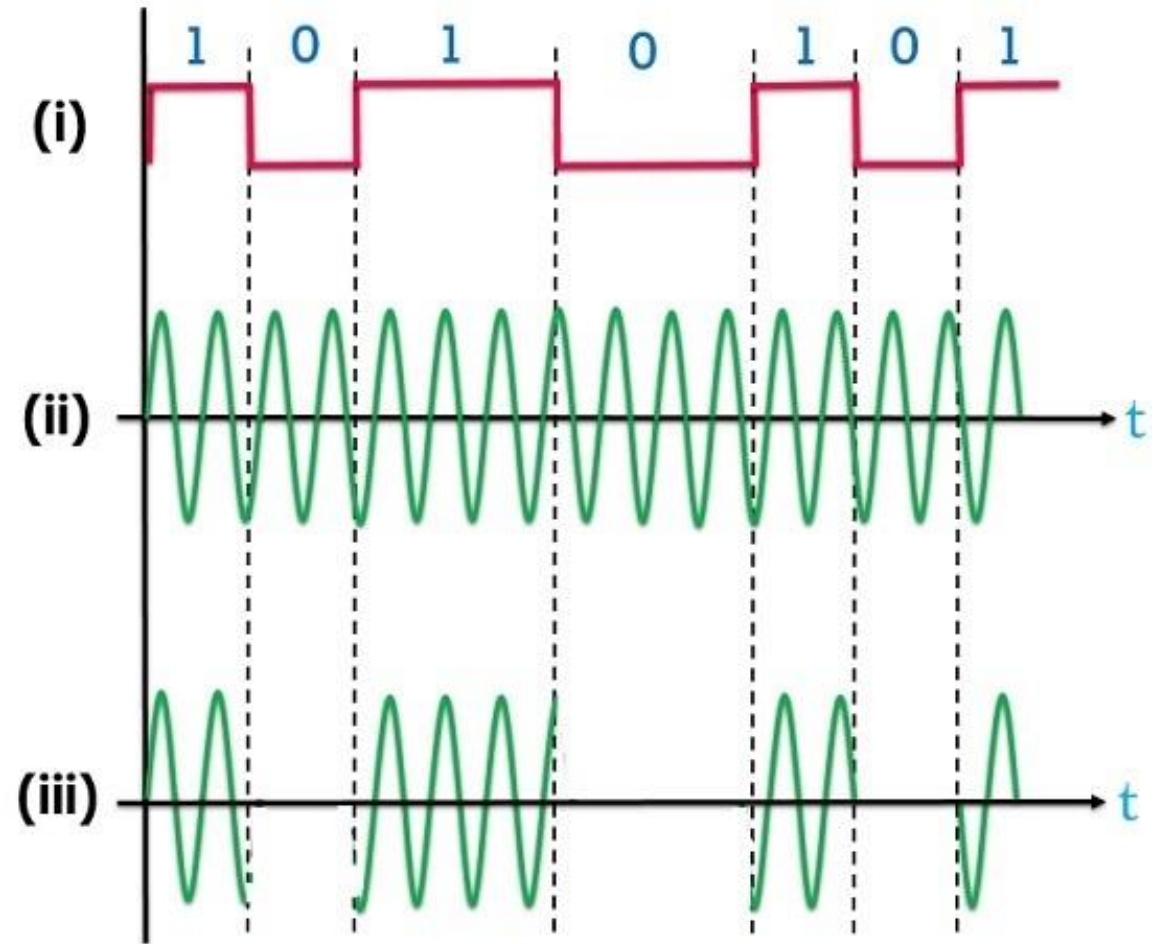
AMPLITUDE SHIFT KEYING (ASK)

- ASK is implemented by changing the amplitude of a carrier signal to reflect amplitude levels in the digital signal.
- For example: a digital “1” could not affect the signal, whereas a digital “0” would, by making it zero.
- The line encoding will determine the values of the analog waveform to reflect the digital data being carried.

ASK

- Amplitude shift keying
 - 1's or 0's represented by presence or absence of carrier
 - Could be accomplished by multiplying



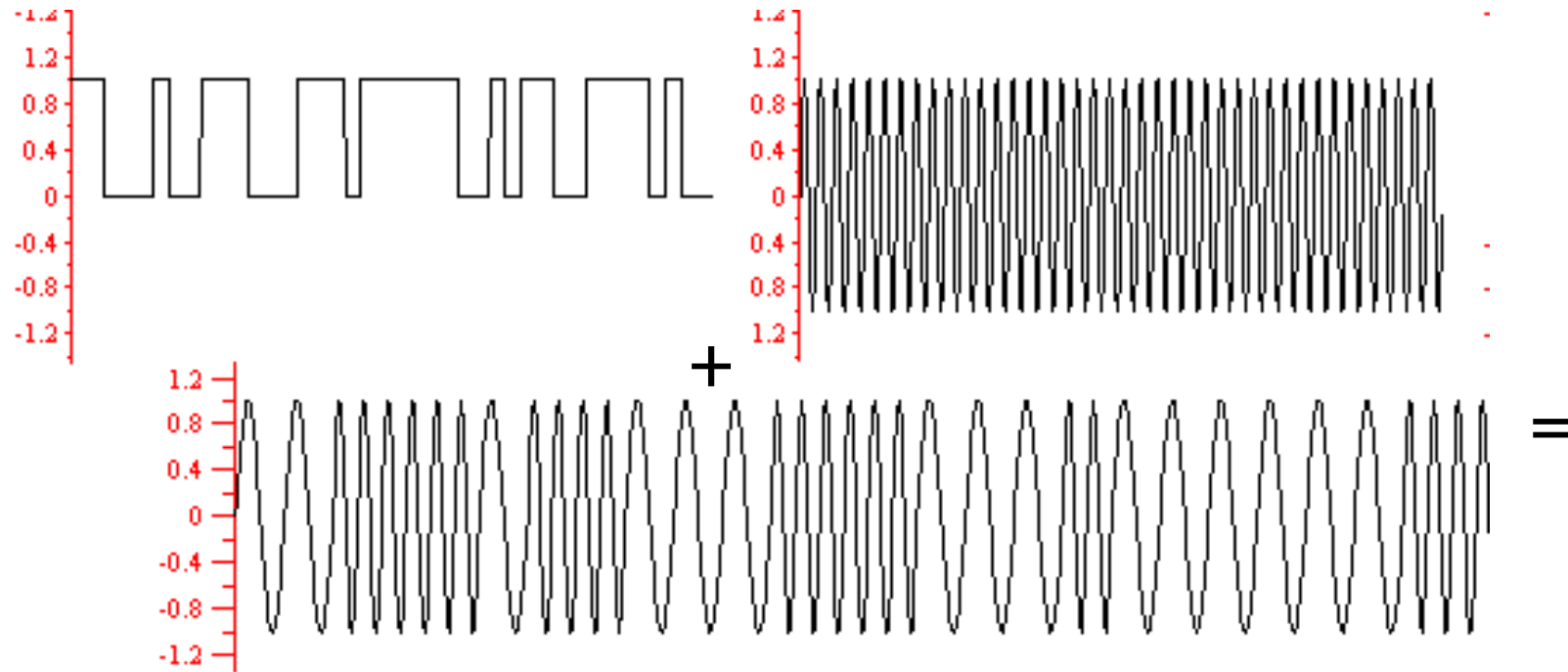


- (i) = Digital bit sequence
- (ii) = Carrier wave
- (iii) = ASK modulated wave

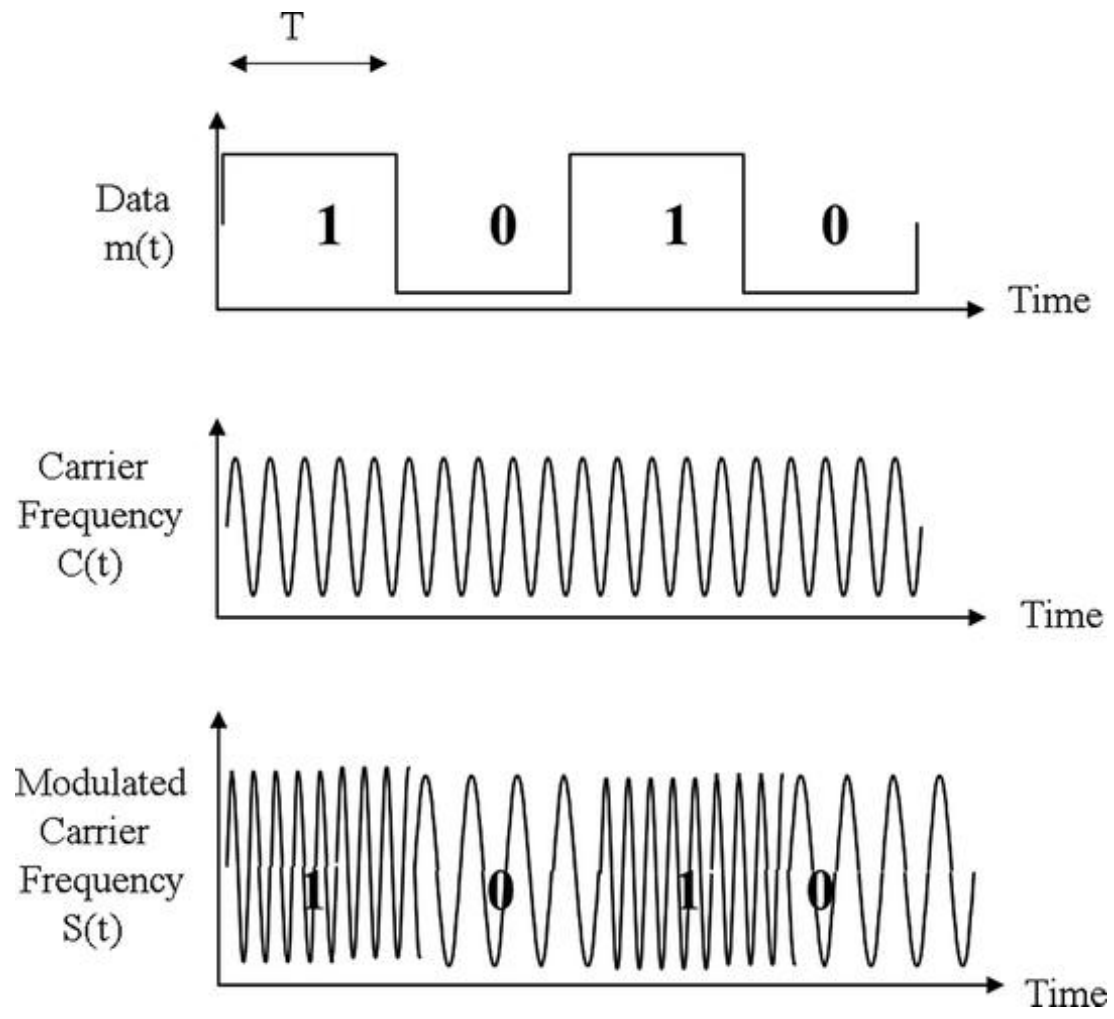
FREQUENCY SHIFT KEYING

- Frequency-shift keying (FSK) is a frequency modulation scheme in which digital information is transmitted through discrete frequency changes (shifts) of a carrier wave. The simplest form of FSK is Binary FSK (BFSK), in which a carrier's frequency is shifted to a low frequency or a high frequency to transmit 0s and 1s. The plot below shows a sample FSK signal along with the associated bits.
- The digital data stream changes the frequency of the carrier signal, f_c .
- For example, a "1" could be represented by $f_1=f_c +\Delta f$, and a "0" could be represented by $f_2=f_c-\Delta f$.

FSK



- Frequency shift keying
 - Select frequency based on each bit, 0 or 1
 - Could be done with simple FM system



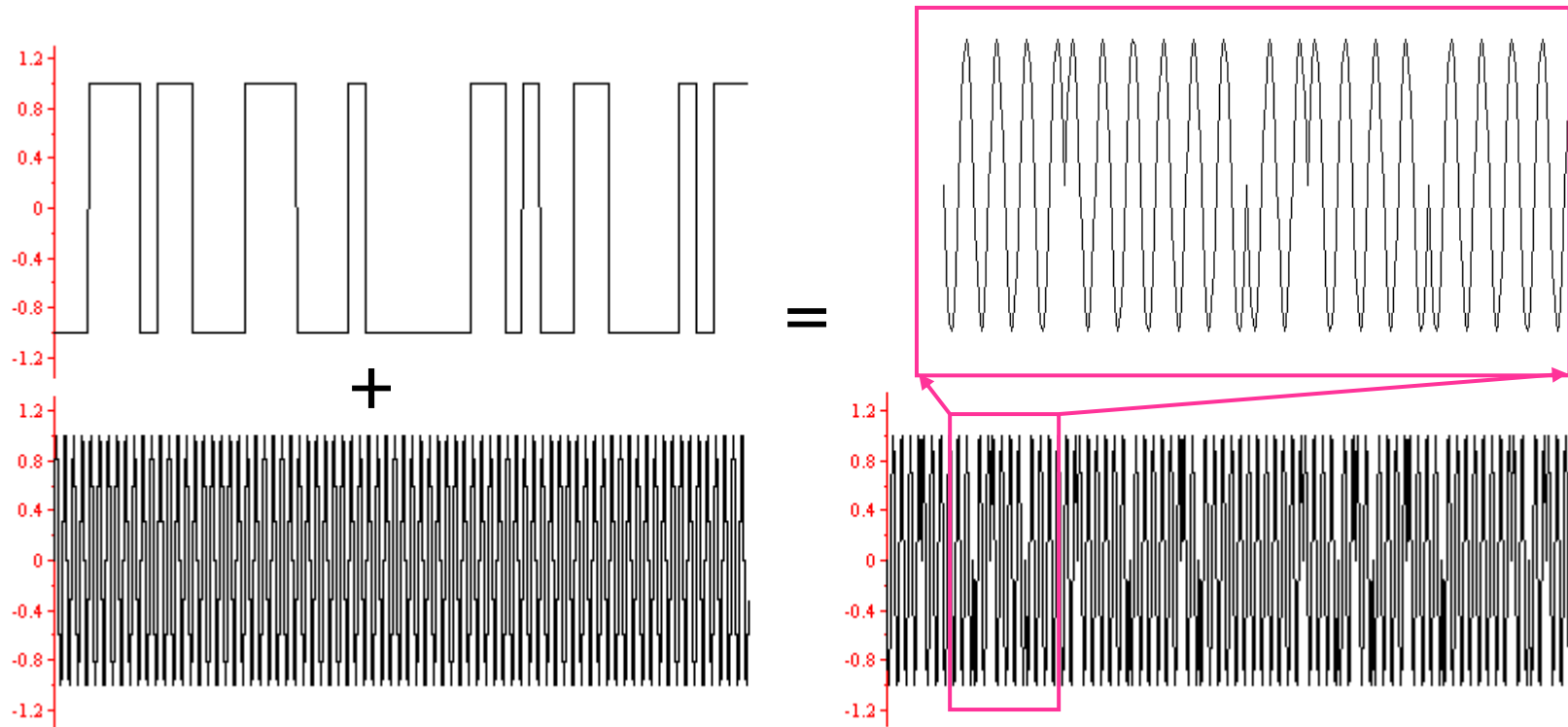
FSK

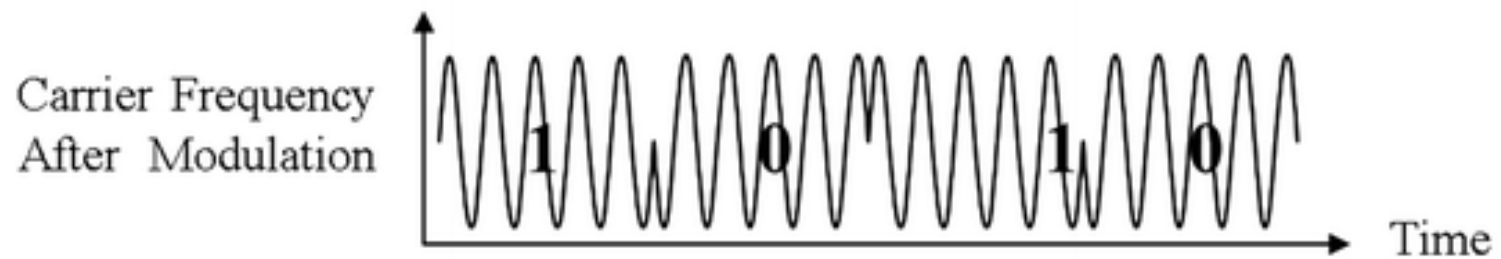
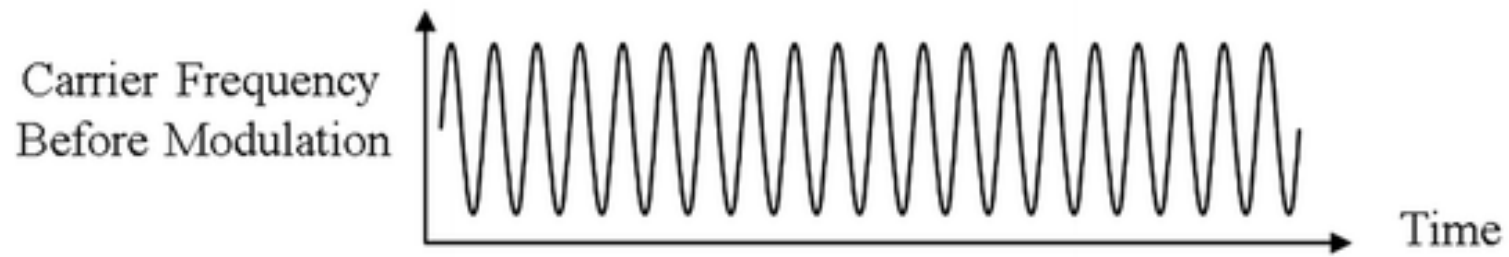
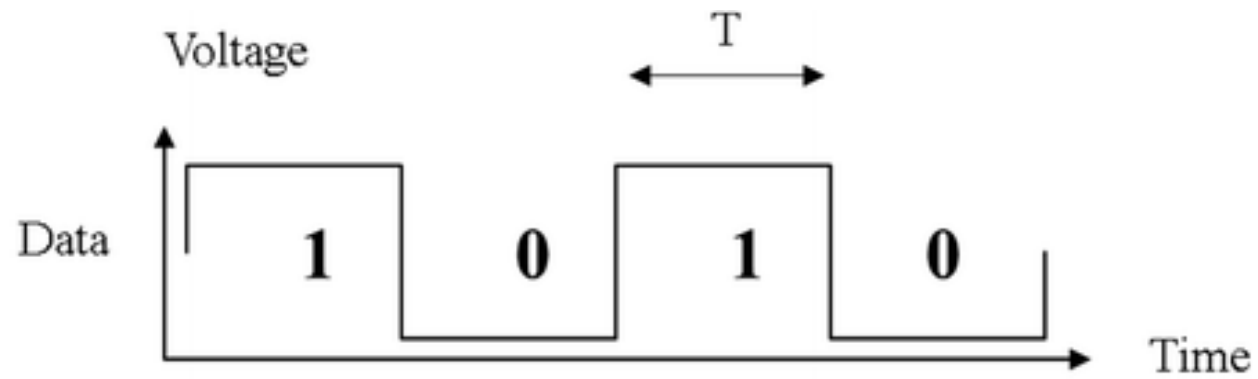
PHASE SHIFT KEYING (PSK)

- Binary Phase Shift Keying (BPSK) is a form of phase modulation where the carrier's phase shifts to one of a finite set of possible phases based on the bits that are input.
- For binary phase shift keying (BPSK), the carrier phase is shifted between one of only two phases
- (typically 0 and 180) depending on whether a 0-bit or a 1-bit is being transmitted. For example: 0-bit: the symbol transmitted in Carrier: $A \sin[\omega t + \varphi]$, where $\varphi=0$
- 1-bit: the symbol transmitted is $A \sin[\omega t + \varphi]$, where $\varphi=\pi$
- ω usually $2\pi f$

PSK

- Phase shift keying
 - At the bit transitions invert the phase by 180°





CONSTELLATION DIAGRAM ?

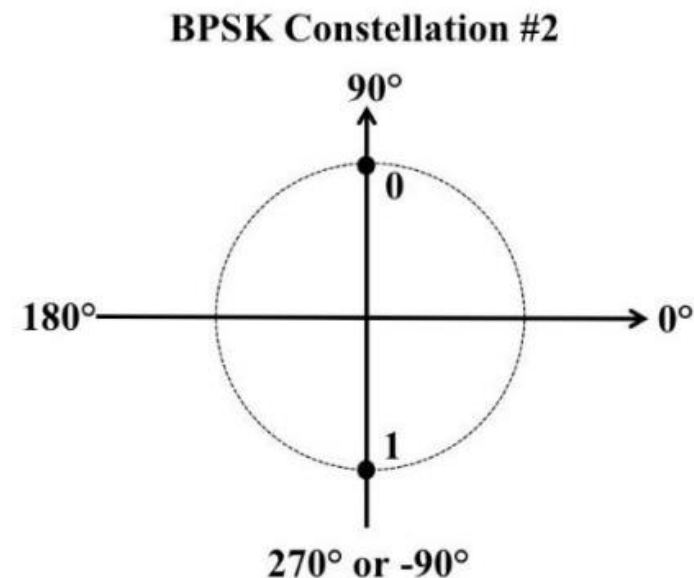
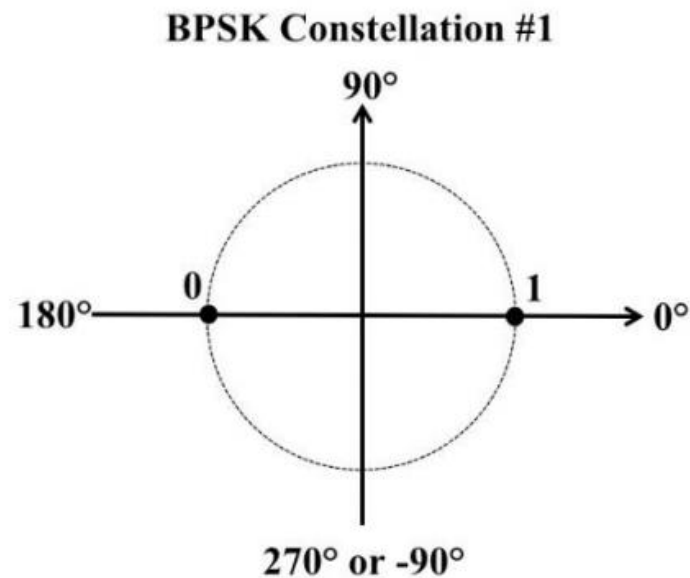


CONSTELLATION DIAGRAM

- Before launching into more complicated digital modulation, we'll introduce a graphical way to relate what the output symbols are, and the bits that each symbol represents. This is called a constellation diagram.
- A constellation diagram is a plot of the phase and relative amplitude of the output symbols for a digital modulation system, in polar coordinates. In terms of the symbol's phase, 0° is along the positive x-axis, and phase increases as you move counterclockwise around the x-y plane.
- The symbol's relative amplitude is measured as distance from the origin of the plot. The possible output symbols are represented with large dots, and adjacent to them are the bits they represent. Symbols that have the same amplitude are the same distance from the origin (you can think of them as laying on the same circle around the origin). All symbols with the same phase would fall on the same line segment that originates at the origin and goes out at a certain angle.

EXAMPLE

Here are two possible BPSK systems' constellation diagrams. In BPSK, the output symbols both have the same amplitude (both of the symbols are equidistant from the origin), but their phases are 180° apart. There are other possible combinations of two carrier phases that might be used (such as $+90^\circ$ and -90°), but the actual constellation used is not important, as long as the transmitter and receiver use the same constellation.



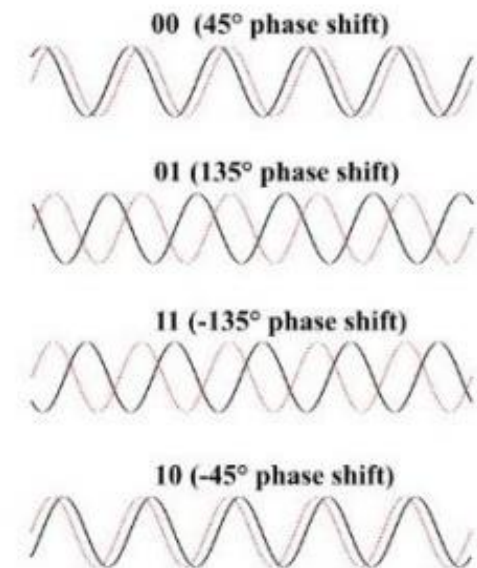
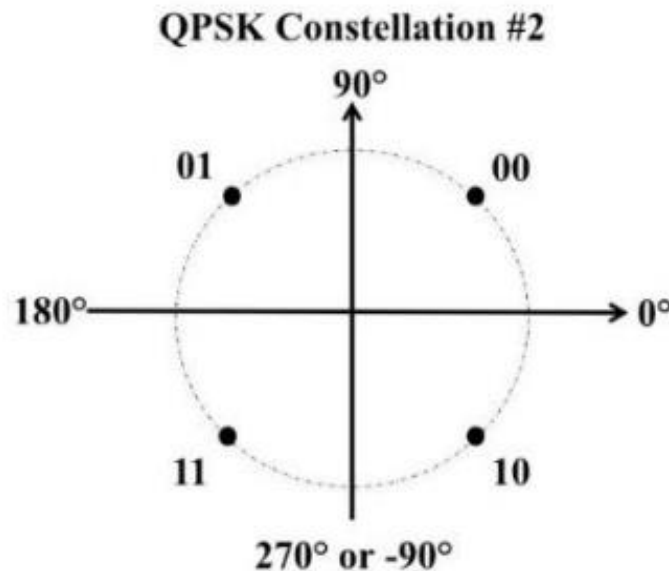
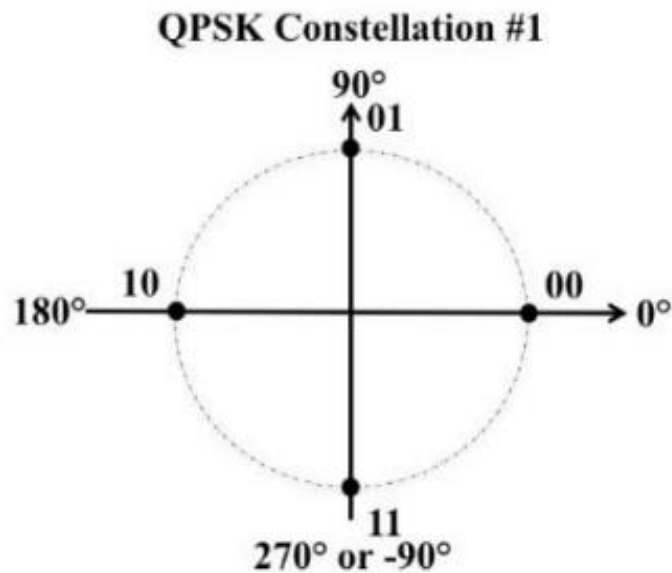
FASTER TRANSMISSION ! , YES PLEASE USE QPSK

- Note that BPSK transmits 1 bit per symbol, so only one bit value is placed next to each symbol. If it is desired to get the information from the transmitter to the receiver faster, we could increase the number of bits per second (bps) that are transmitted. The cost of increasing the bitrate (besides requiring more complex components) is that it increases the transmission bandwidth, as **$BW = 2R_{syb}$ or twice the symbol rate**
- Is there a way to transmit a higher bitrate but using a smaller transmission bandwidth? The answer is yes, using M-ary digital modulation.
- In M-ary modulation, we can preserve bandwidth if we keep the symbol rate the same and increase the number of bits per symbol. For example, instead of transmitting just 2 possible phase shifts (0° and 180°), we could transmit one of 4 possible phase shifts per symbol. This is called quadrature phase shift keying (QPSK).

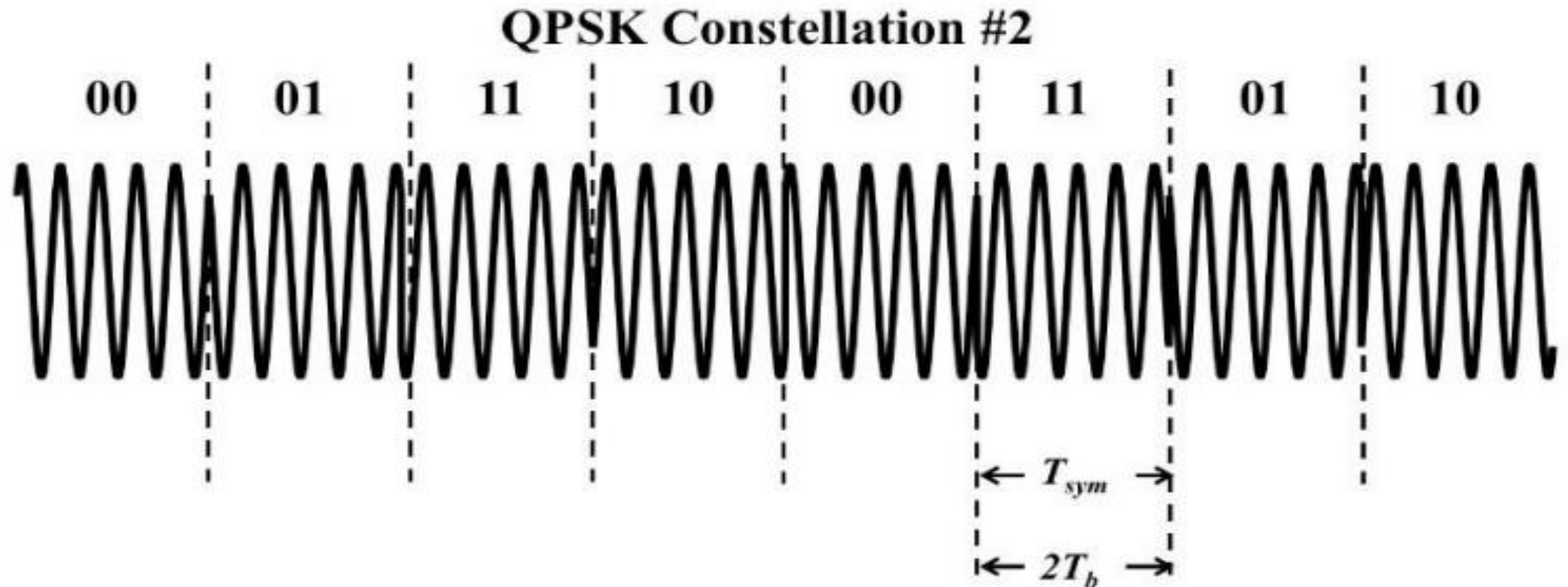
QPSK

- In QPSK, there are 4 symbols ($M = 4$) and there are 2 bits per symbol ($N = 2 = \log_2 M$). Two of the possible constellation diagrams for QPSK are shown in the following figures, and the four symbols from QPSK Constellation #2 are shown to the right of this constellation. The carrier with a phase of 0° is plotted in a dashed line with each symbol for reference.

- The four symbols in the right-hand constellation are: $A \cos(2\pi f_c t + 45^\circ)$, $A \cos(2\pi f_c t + 135^\circ)$, $A \cos(2\pi f_c t - 135^\circ)$ and $A \cos(2\pi f_c t - 45^\circ)$.

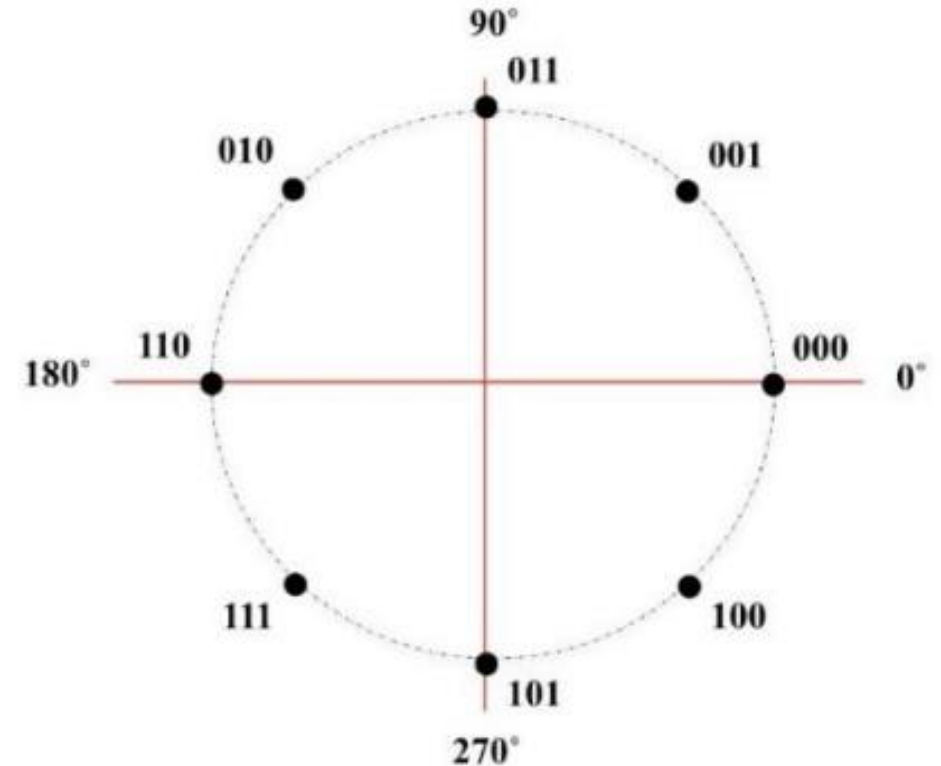


The following figure is a plot of the use of QPSK constellation #2 in the previous figure to transmit the bit stream 0001111000110110. Also shown is the bit duration, and the symbol duration for QPSK.



M-ARY PSK

- We can further increase the number of bits per symbol by increasing the number of possible phase shifts. The M in M-ary refers to the number of symbols.
- Consider the 8-PSK constellation to the right (one of many possible 8-PSK constellations).
- How many bits per symbol are transmitted? There are 8 symbols ($M = 8$), so $N = \log_2 M = \log_2 8 = 3$ bits/symbol. This is also evident from the diagram because the three bits associated with each symbol appear next to the symbol.



16, 32 OR 64 OR 128 PSK WHAT ABOUT NOISE?

- We could further increase to 4 bits/symbol using 16-PSK. Here, $M = 16$ and $N = 4$ bits/symbol. A 16-PSK constellation is shown to the right, where each phase is separated by $360^\circ / 16 = 22.5^\circ$. More complex M-ary PSK modulation is possible: 32-PSK, 64-PSK, etc., but it becomes more susceptible to noise as the symbols get closer together.
- As a reminder, for PSK, all of the symbols have the same carrier frequency and amplitude; it is their phase that is different. For that reason, on a PSK constellation diagram, all of the symbols appear on a circle about the origin.

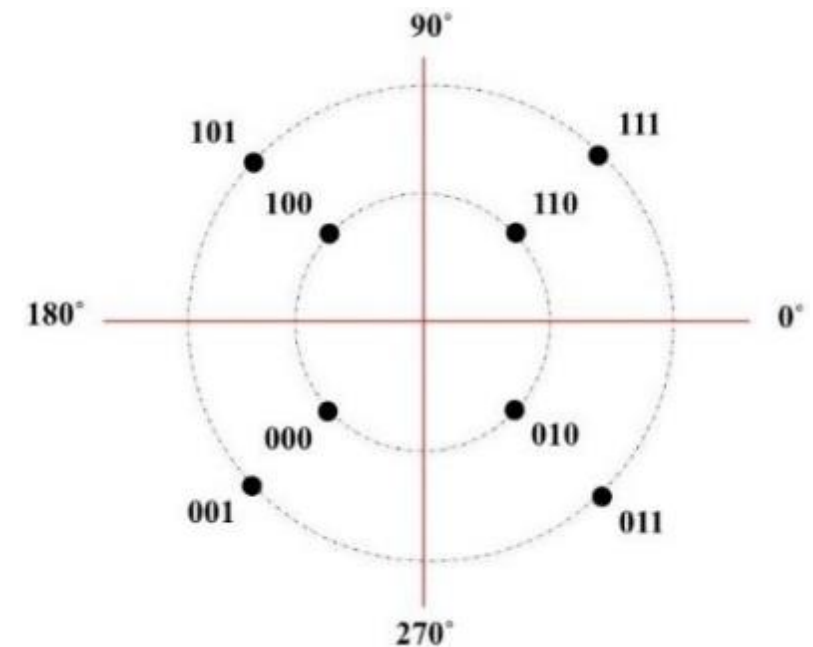


QUADRATURE AMPLITUDE MODULATION (QAM)

- In order to increase the distance between symbols in a constellation, another option is to modulate both the amplitude and the phase of the carrier. This is called Quadrature Amplitude Modulation (QAM).

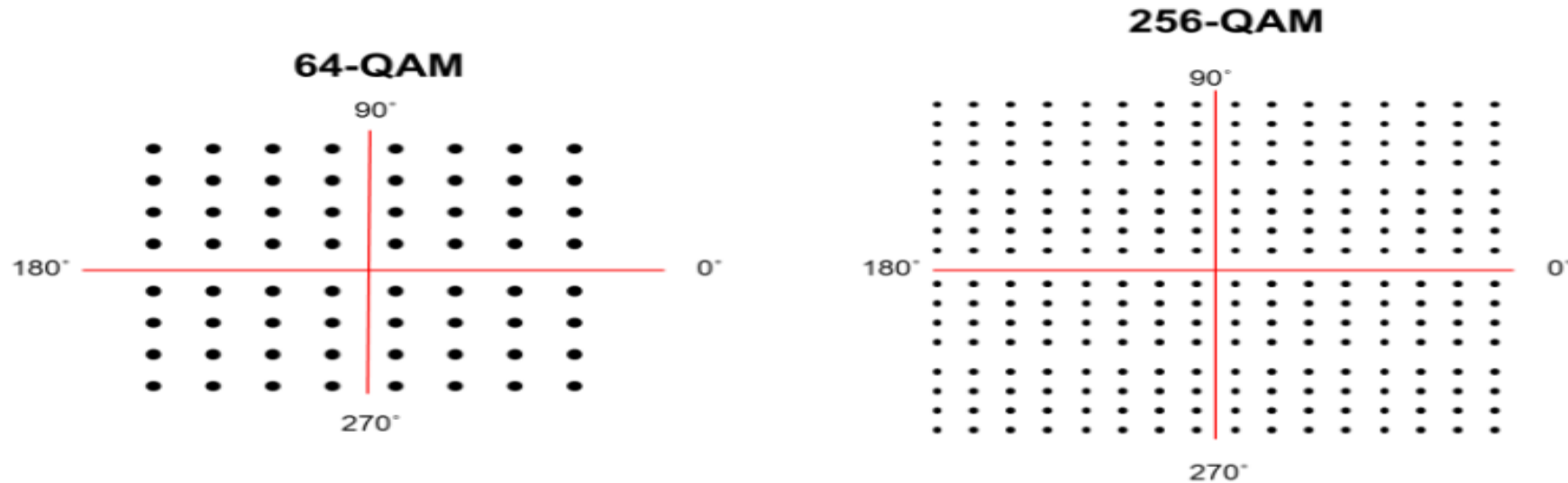
8-QAM

- An 8-QAM constellation is shown below (one of many possible 8-QAM constellations). The eight symbols along with the 3-bit digital words corresponding to each are shown to the right of the constellation.
- This system uses 2 possible amplitudes and 4 possible phases. In 8-QAM, the duration of a symbol is three times the duration of a bit (since each symbol carries 3 bits).
- Note that there are both phase and/or amplitude changes for each symbol. For the system with the constellation shown below, the eight output symbols might be $2 \cos(2\pi f_c t \pm 45^\circ)$, $2 \cos(2\pi f_c t \pm 135^\circ)$, $4 \cos(2\pi f_c t \pm 45^\circ)$, and $4 \cos(2\pi f_c t \pm 135^\circ)$.
- What is the bandwidth for 8-QAM? The same as for 8-PSK, since the bandwidth for all digital modulation types (except for FSK) is given by $BW = 2R_{\text{sym}} = 2R_b / N = 2R_b / 3$



64-QAM OR 256-QAM

- QAM signaling can be extended to have a larger number of symbols, which then allows a much higher bit rate in the same bandwidth (because there are more bits per symbol). 64-QAM and 256-QAM are common in cable modems, satellites, and high-speed fixed broadband wireless. Some possible constellations are in the following figure.



In 256-QAM, you find that for each symbol you are transmitting (there are 256 symbols), there are 8 bits of information. Assuming the symbol rate remains constant, then for the same bandwidth you are sending 8 times more information when you use 256-QAM than when you use OOK, ASK or BPSK. For 256-QAM, if the bitrate is 600 kbps, the bandwidth is $2(600,000)/8 = 150$ kHz.

Now that's powerful!

REFERENCES

- https://www.net.t-labs.tu-berlin.de/teaching/computer_networking
- <https://techterms.in/>
- <https://www.youtube.com/channel/UCJQJ4GjTiq5Imn8czf8oo0Q>
- <https://github.com/HanochShi/Supplements-ComputerNetworking-ATopDownApproach-7th-ed>

READING INSTRUCTIONS

- » Ch. 6: Make sure you understand the terms, e.g., Bit rate, Baud, Bandwidth, Lossy and lossless compression. Also, learn how a digital signal is converted to analog on a high level (steps and challenges, no need for deep understanding of these).
- » Ch. 7: Make sure you understand the difference between guided and unguided media, and have a high level understanding of the common technologies (e.g., twisted pair, coaxial, fiber, radio). Make sure you understand the main points of 19-22.
- » Ch. 8: All » Ch. 9: 1-5, 10, 12. Also, make sure you understand the difference between synchronous and asynchronous transmission.
- » Ch. 10: 3-6, 9. The important part in this chapter is to understand how you can encode many bits per baud, i.e., a high level understanding of different ways to modulate.



READING INSTRUCTIONS

- » # Reading instructions
- » Ch. 11: 1-4, 6, 8-14
- » Ch. 13: All
- » Ch. 14: 1-2, 5, 6
- » Ch. 15: All

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OF THIS LECTURE
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MORGAN
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