College of Engineering &Technology

University of Sargodha

Department of Electrical Engineering Technology

ET-314

Telecommunication Technology

Lecture 11

Digital Modulation

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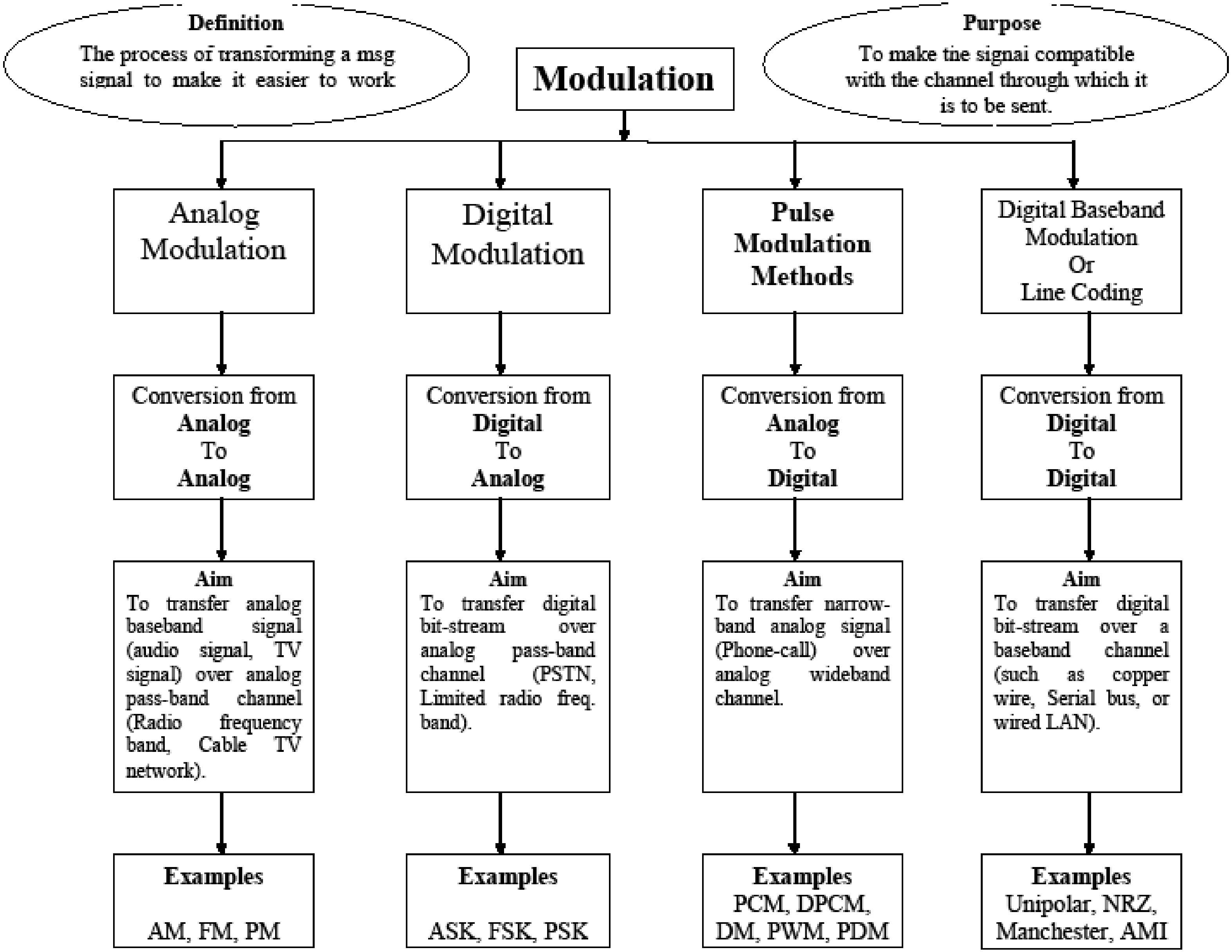
Digital Modulation


Definition
The process of transforming a msg signal to make it easier to work
Modulation
Purpose
To make the signal compatible with the channel through which it is to be sent.
Analog Modulation
Digital Modulation
Pulse Modulation Methods
Digital Baseband Modulation Or Line Coding
Conversion from Analog To Analog
Conversion from Digital To Analog
Conversion from Analog To Digital
Conversion from Digital To Digital
Aim
To transfer analog baseband signal (audio signal, TV signal) over analog pass-band channel (Radio frequency band, Cable TV network).
Aim
To transfer digital bit-stream over analog pass-band channel (PSTN, Limited radio freq. band).
Aim
To transfer narrow-band analog signal (Phone-call) over analog wideband channel.
Aim
To transfer digital bit-stream over a baseband channel (such as copper wire, Serial bus, or wired LAN).
Examples
AM, FM, PM
Examples
ASK, FSK, PSK
Examples
PCM, DPCM, DM, PWM, PDM
Examples
Unipolar, NRZ, Manchester, AMI

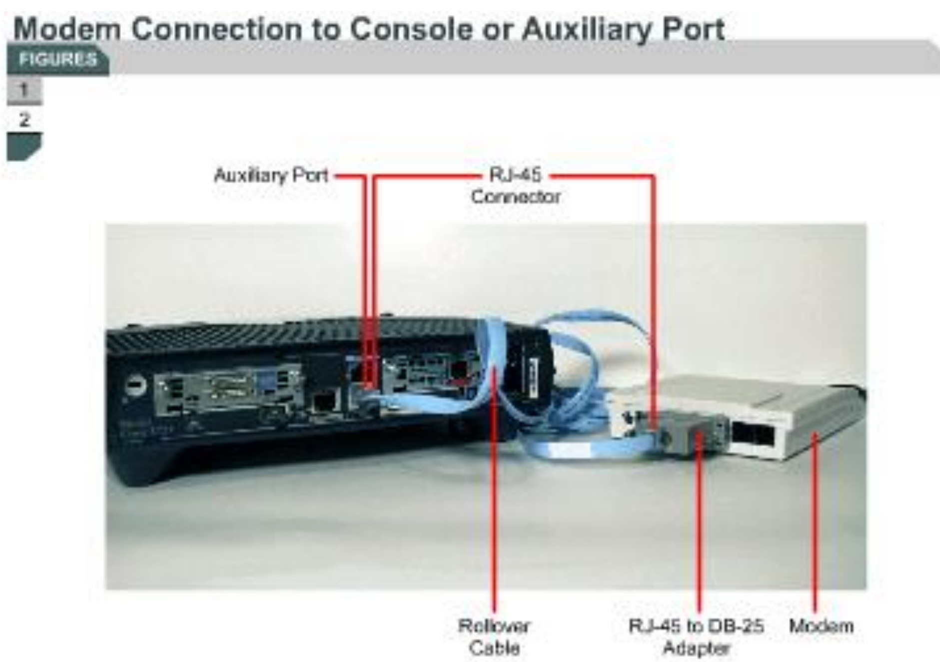
Digital Modulation

- Digital Data (0 and 1) is translated into an analog signal (baseband signal)

- It is required if the digital data has to be transmitted over a medium that only allows for analog transmission

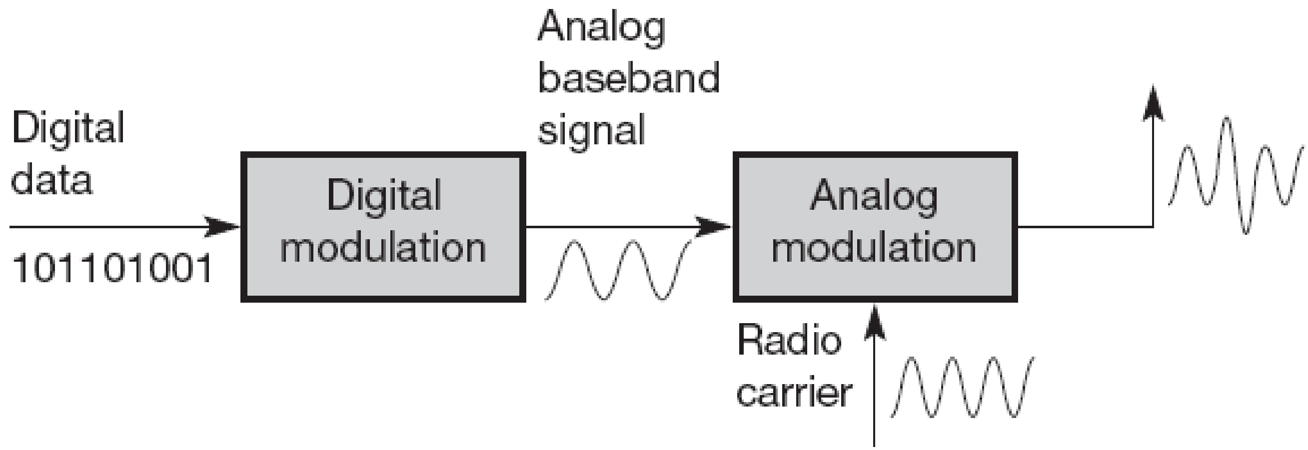
Digital Modulation

- Example
  - An old analog telephone system (wired network)
  - To connect a computer to this system a modem is needed
  - The modem then translate the digital data into analog signals and vice versa

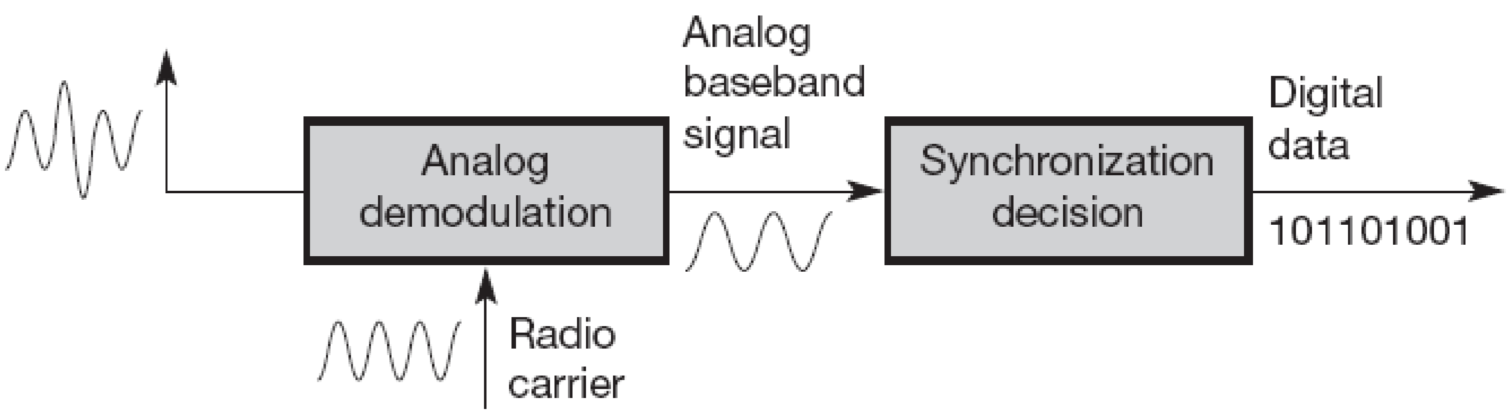


Limitations of Digital Transmission

- In wireless networks, digital transmission cannot be used
- Here, the binary bit stream has to be translated into analog signal first
- Wireless transmission requires an additional modulation, an analog modulation that shifts the centre frequency of the baseband signal generated by the digital modulation up to the radio carrier



Modulation In A Transmitter



Demodulation And Data Reconstruction In the Receiver

Types Of Digital Modulation

- Three basic methods for translating the binary bit-stream into an analog signal are:
    - Amplitude Shift Keying (ASK)
    - Frequency Shift Keying (FSK)
    - Phase Shift Keying (PSK)

Types Of Digital Modulation

These digital modulation schemes differ in many issues e.g.

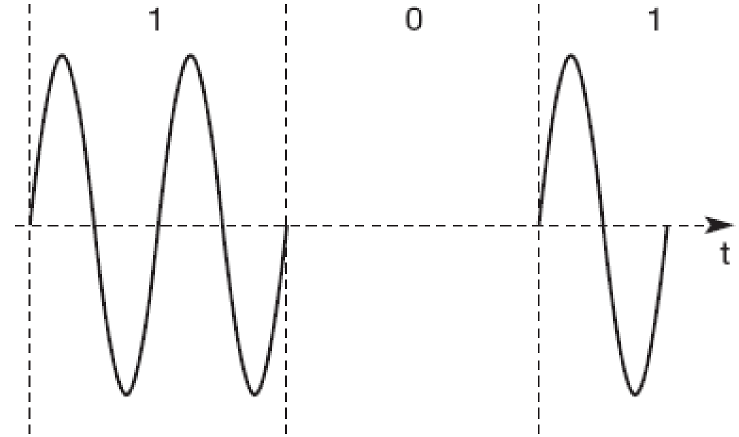
- Spectral Efficiency
  - How efficiently the modulation scheme utilizes the available frequency spectrum
- Power Efficiency
  - How much power is needed to transfer the bits – which is very important for portable devices that are battery dependent
- Robustness
  - How much robust it is to multipath propagation, noise, interference

Amplitude Shift Keying
(ASK)

Amplitude Shift Keying (ASK)

- The most simple digital modulation scheme is shown.
- The two binary values, 1 and 0, are represented by two different amplitudes

$$x_c(t) = \begin{cases} A\cos\omega_c t & symbol\ 1 \\ 0 & symbol\ 0 \end{cases}$$



Disadvantages

- This simple scheme only requires low bandwidth, but is very susceptible to interference.
- Effects like multipath propagation, noise, or path loss heavily influence the amplitude.
- In a wireless environment, a constant amplitude cannot be guaranteed, so ASK is typically not used for wireless radio transmission

Uses:

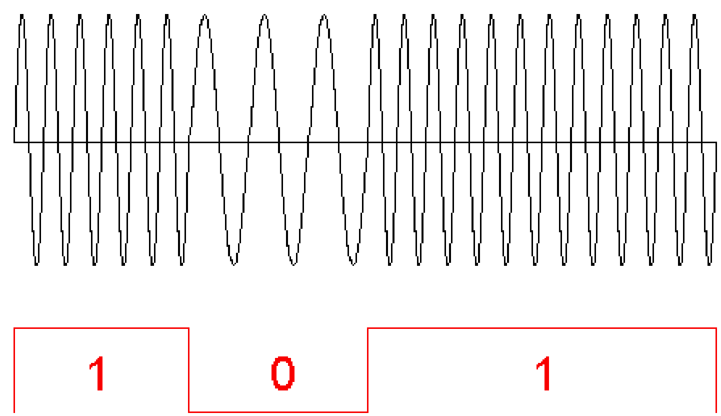
- The wired transmission scheme with the highest performance, namely **Optical Transmission**, uses ASK
- Here, a light pulse may represent a 1, while the absence of light represents a 0
- The carrier frequency in optical systems is some hundred THz.
- ASK can also be applied to **Wireless Infra-red Transmission**, using directed beam or diffuse light.

Frequency Shift Keying (FSK)

Frequency Shift Keying (FSK)

- A modulation scheme often used for wireless transmission
- Simplest form known as Binary FSK (BFSK)
- Assigns one frequency f_1 to binary 1 and frequency f_2 to binary 0

$$x_c(t) = \begin{cases} A\cos\omega_1 t & symbol\ 1 \\ A\cos\omega_1 t & symbol\ 0 \end{cases}$$



Modulator Implementation

- A very simple way to implement FSK is to switch between two oscillators, one with frequency f_1 and other with f_2, depending on the input

Demodulator Implementation

- A simple way to implement demodulator is by using two bandpass filters
  - One for f_1
  - Other for f_2
- A comparator can then compare the signal levels of the filter outputs to decide which of them is stronger

Some Other Properties

- Compared to ASK, it needs a larger bandwidth
- Compared to ASK, it is much less susceptible to errors
- To avoid sudden changes in phase, special frequency modulators with continuous phase modulation (**CPM**) can be used

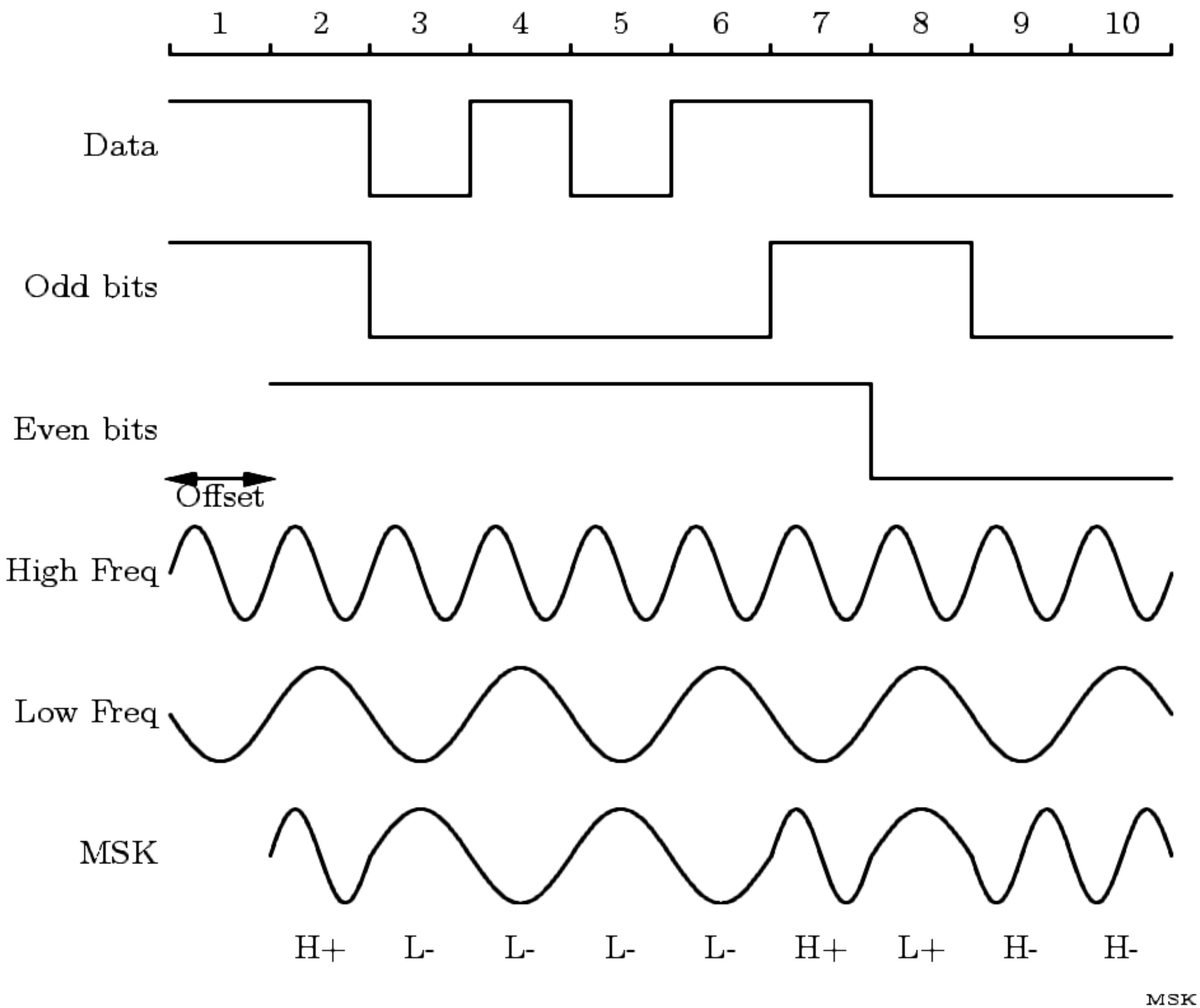
Advanced Frequency Shift Keying

- A famous FSK scheme used in many wireless systems is Minimum Shift Keying (**MSK**)

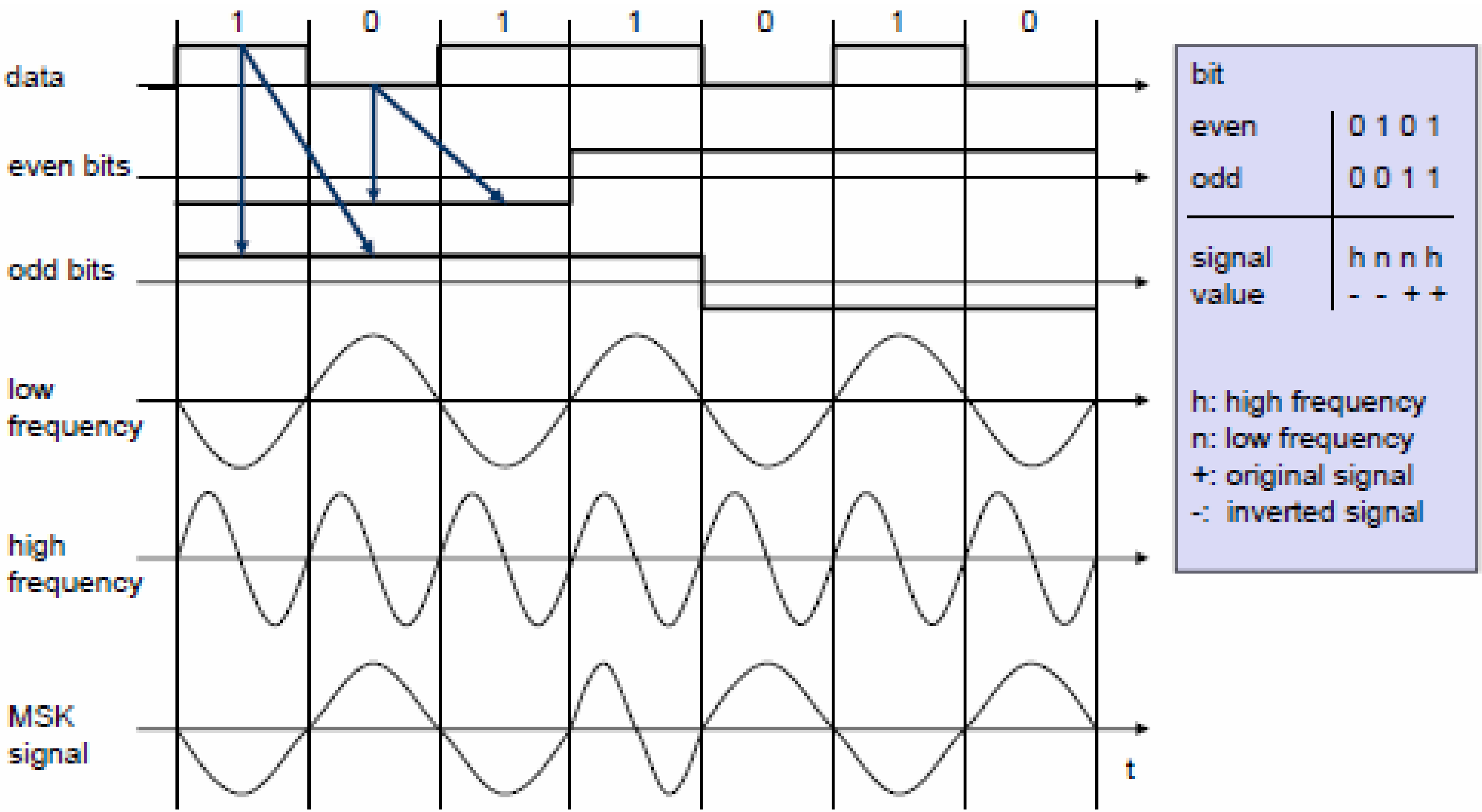
- It is basically BFSK without abrupt phase changes i.e. belongs to CPM scheme

- The figure next, shows the implementation of MSK

Minimum Shift Keying (MSK)



Minimum Shift Keying (MSK)



No phase shifts!

Minimum Shift Keying (MSK)

- In the first step, data bits are separated into even and odd bits.
- Duration of each bit being doubled
- This scheme also uses two frequencies:
  - f_1, the lower frequency
  - f_2, the higher frequency, with $f_2 = 2f_1$
- The lower or higher frequency is chosen (either inverted or non-inverted) to generate the MSK signal

Rules:

- If even bit = 0 & odd bit = 0
  - Higher frequency f_2 is Inverted (Phase Shift of 180^o)
- If even bit = 1 & odd bit = 0
  - Lower frequency f_1 is Inverted.
- If even bit = 0 & odd bit = 1
  - Lower frequency f_1 is taken without changing.
- If even bit = 0 & odd bit = 0
  - Higher frequency f_2 is taken without changing.

Summary of Rules

- A high frequency is always chosen if
    - Even Bit = Odd Bits
- The signal is inverted if
    - Odd Bit = 0
- This scheme avoids all phase shifts in the resulting MSK signal

Gaussian-Minimum Shift Keying

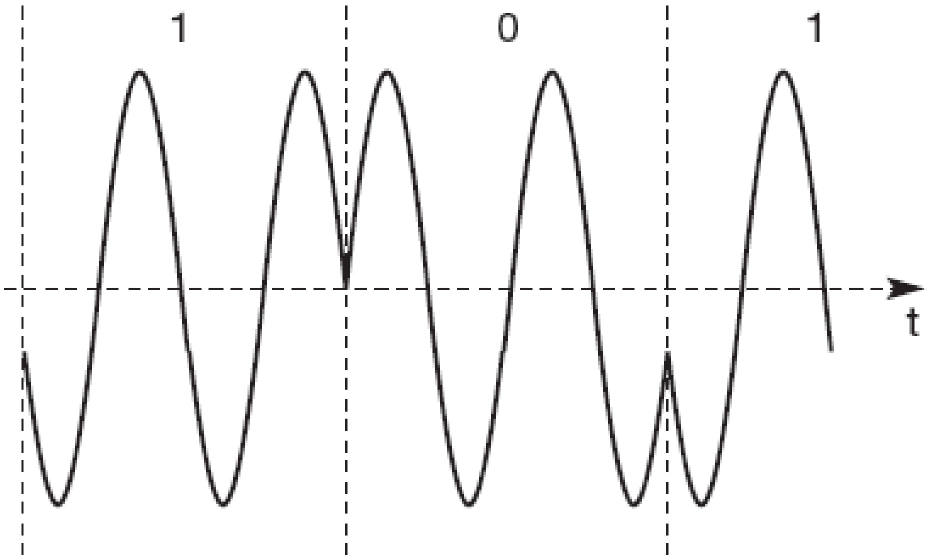
- Adding a so called Gaussian Low Pass Filter to the MSK scheme results in Gaussian-MSK (GMSK)
- The filter reduces the large spectrum needed by MSK
- This is a Digital modulation scheme for many European Wireless Standards e.g. GSM

Phase Shift Keying (PSK)

Phase Shift Keying (PSK)

- Uses Shifts in the Phase of a Signal to Represent Data
- Figure shows a phase shift of 180° or π as the 0 follows the 1 (the same happens as the 1 follows the 0).
- **Binary PSK (BPSK)** shifts the phase by 180° each time the value of data changes.

$$x_c(t) = \begin{cases} A\cos\omega_c t & symbol\ 1 \\ A\cos(\omega_c t + \pi) & symbol\ 0 \end{cases}$$



Modulator Implementation

- The Simple Implementation of a BPSK modulator could multiply a frequency f with +1 if the binary data is 1 and with –1 if the binary data is 0.

Demodulator Implementation

- To receive the signal correctly, the receiver must synchronize in frequency and phase with the transmitter.

- This can be done using a **Phase Lock Loop (PLL)**.

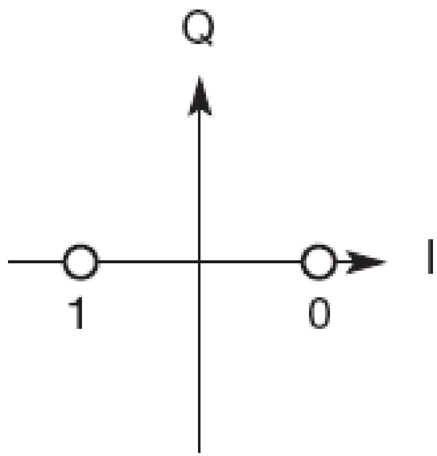
Comparison

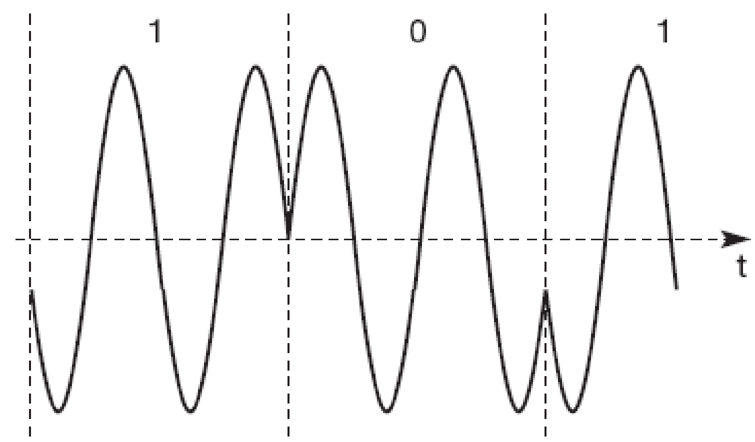
- Compared to FSK, PSK is more resistant to interference

- Receiver and Transmitter are also more complex

Advanced Phase Shift Keying

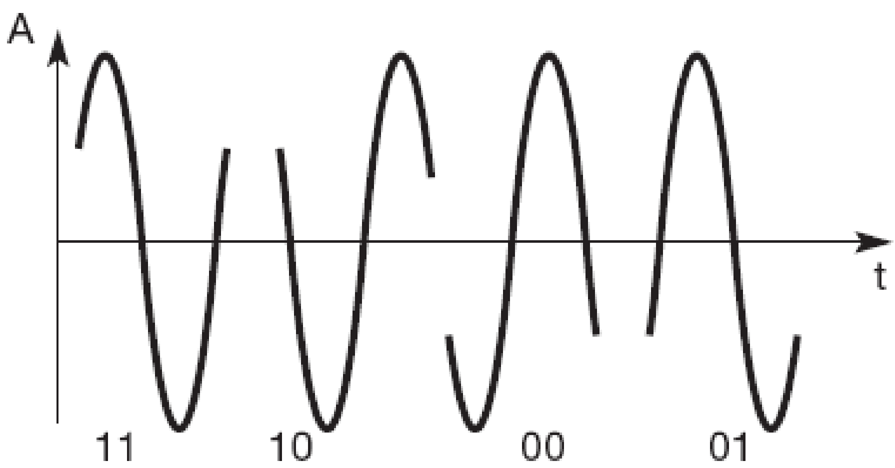
- The simple PSK scheme can be improved in many ways.
- The basic **BPSK** scheme only uses one possible phase shift of 180°.
- The Figure below shows BPSK in the phase domain (which is typically the better representation compared to the time domain representation)



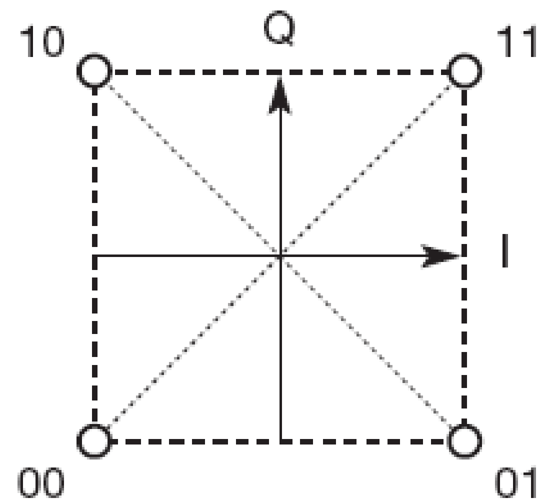


Advanced Phase Shift Keying

- One of the Most Common PSK Schemes is **Quadrature PSK (QPSK)** (Sometimes also called **Quaternary PSK**).
- Higher bit rates can be achieved for the same bandwidth by coding two bits into one phase shift.
- Alternatively, one can reduce the bandwidth and still achieve the same bit rates as for BPSK.



QPSK in the time domain



BPSK and QPSK in the phase domain

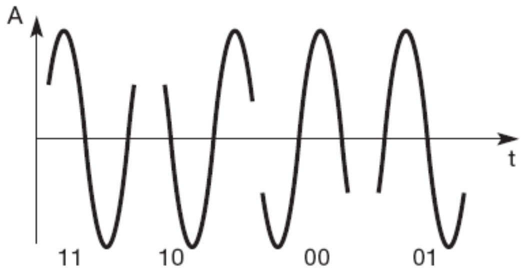
Advanced Phase Shift Keying

- The phase shift can always be relative to a **Reference Signal** (with the same frequency).

- If this scheme is used, a phase shift of 0 means that the signal is in phase with the reference signal.

- A QPSK signal will then exhibit a phase shift of:

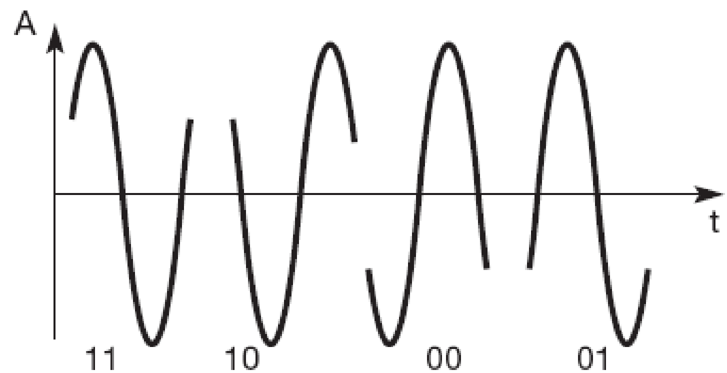
  45° for the data 11,
  135° for the data 10,
  225° for the data 00, and
  315° for the data 01



  – With all phase shifts being relative to the reference signal.

Advanced Phase Shift Keying

- The transmitter 'selects' parts of the signal as shown in Figure and concatenates them.



- To reconstruct data, the receiver has to compare the incoming signal with the reference signal.

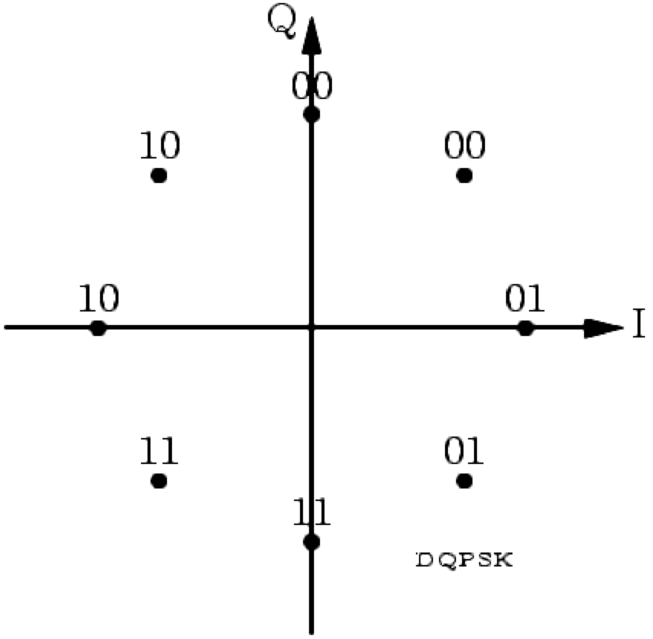
Disadvantage

- One Problem of this Scheme Involves Producing a **Reference Signal** at the Receiver.

- Transmitter and Receiver have to be Synchronized Very Often, e.g., By Using Special Synchronization Patterns Before User Data Arrives or Via a Pilot Frequency as Reference.

Solution

- One way to avoid this problem is to use **Differential QPSK (DQPSK)**.
- Here the phase shift is not relative to a reference signal but to the phase of the previous two bits.
- In this case, the receiver does not need the reference signal but only compares two signals to reconstruct data.
- **DQPSK** is used in US wireless technologies IS-136 and PACS and in Japanese PHS.

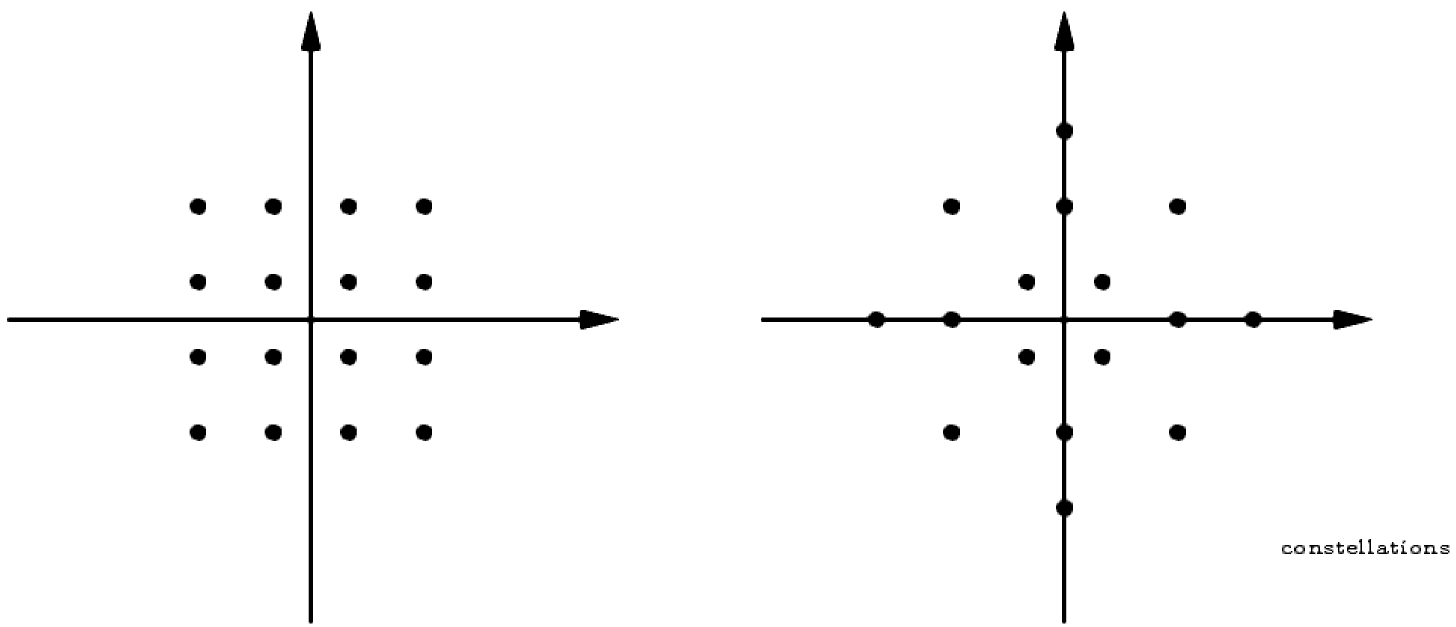


Can This Scheme Be Enhanced Any Further???

Further Advancements

- One could think of extending the scheme to more and more angles for shifting the phase.

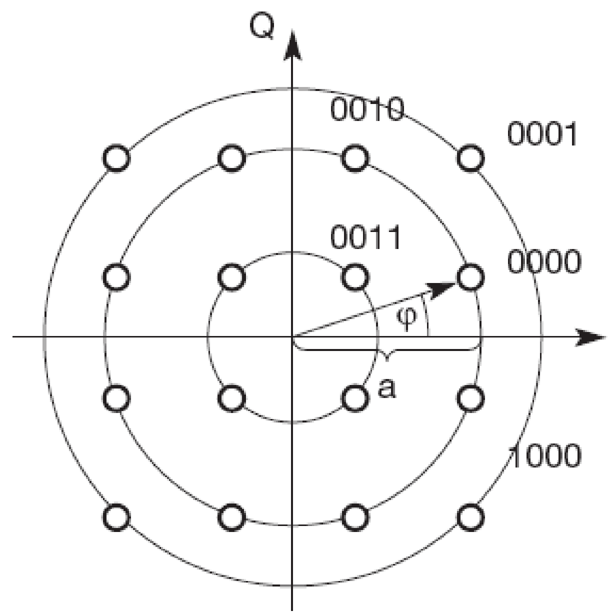
- For example, one can think of coding 3 bits per phase shift using 8 angles.



Quadrature Amplitude Modulation (QAM)

- The **PSK** scheme could be combined with **ASK** as is done in **Quadrature Amplitude Modulation (QAM)** for Standard 9,600 bit/s modems

- Here, three different amplitudes and 12 angles are combined coding 4 bits per phase/amplitude change.



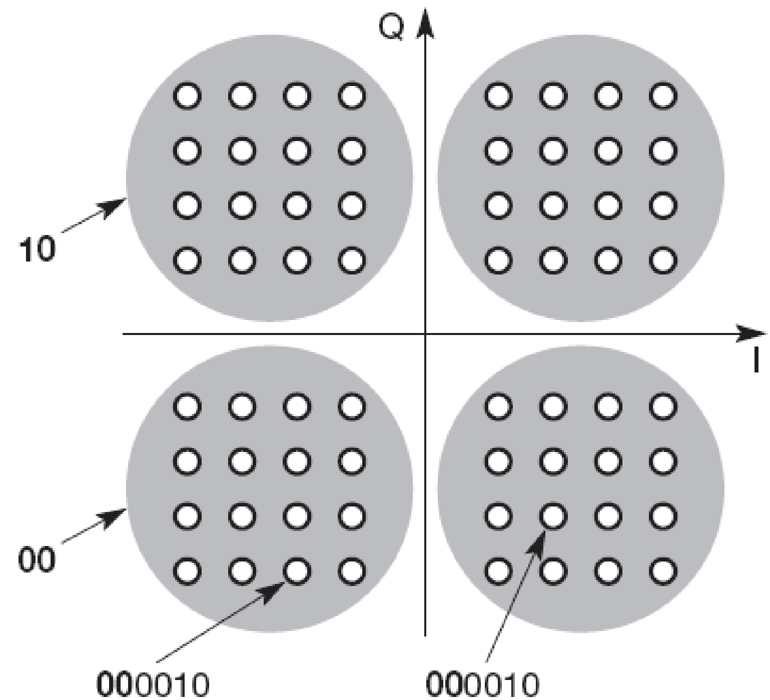
16 Quadrature Amplitude Modulation

Quadrature Amplitude Modulation (QAM)

- Problems occur for Wireless Communication in case of Noise or ISI.
- The more ‘points’ used in the phase domain, the harder it is to separate them.
- DQPSK has been proven as one of the most efficient schemes under these considerations (Wesel, 1998).

Further Advancements

- A more advanced scheme is a hierarchical modulation as used in the digital TV standard DVB-T.
- A 64 QAM can code 6 bit per symbol.
- Here the two most significant bits are used for the QPSK signal embedded in the QAM signal.
- If the reception of the signal is good the entire QAM constellation can be resolved.
- Under poor reception conditions, e.g., with moving receivers, only the QPSK portion can be resolved.



Hierarchical 64 QAM

64 QAM

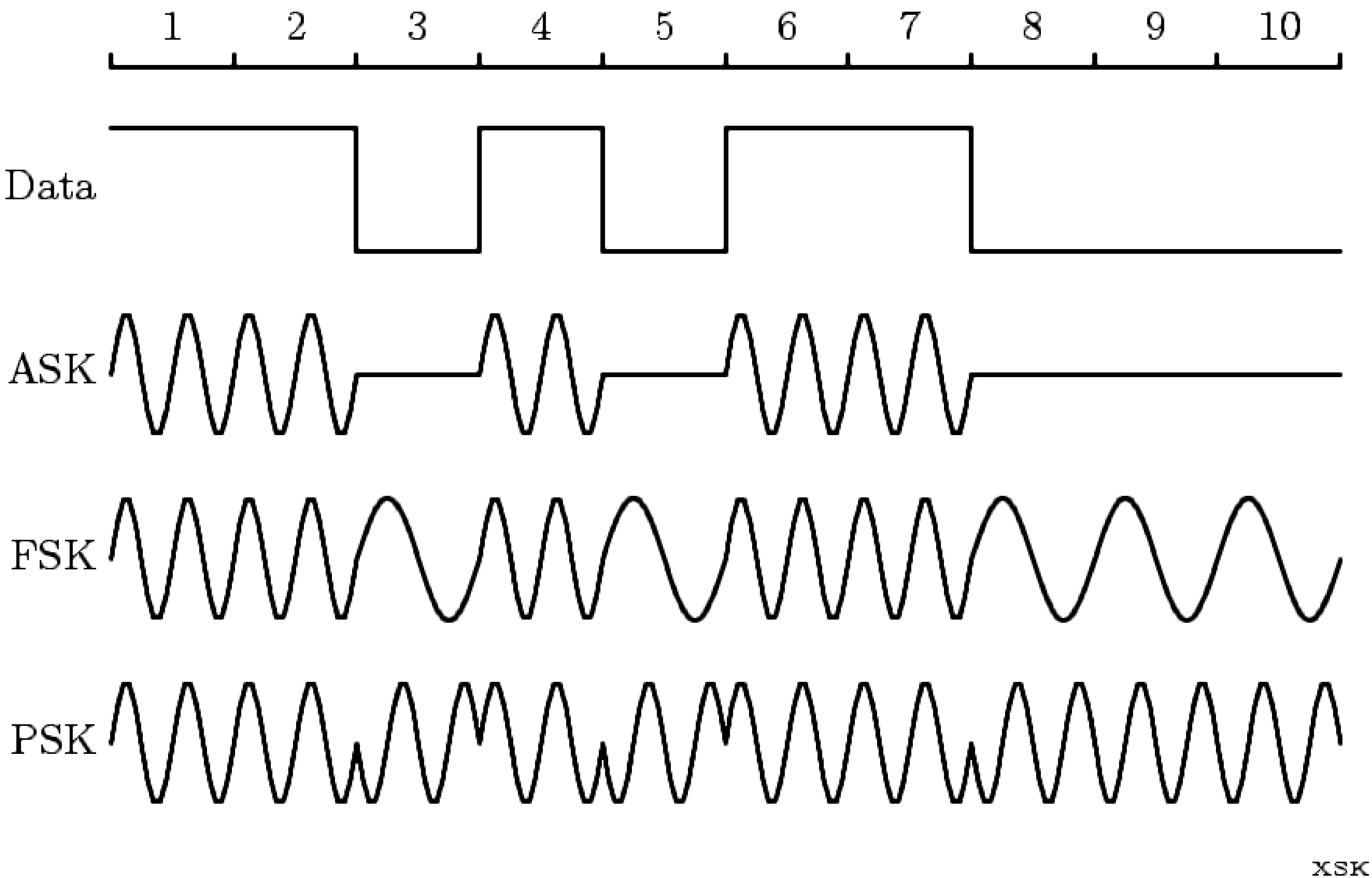
- A **High Priority Data** stream in DVB-T is coded with QPSK using the **two** most significant bits.

- The remaining 4 bits represent **Low Priority Data**.

- For TV this could mean that
    - the **Standard Resolution** data stream is coded with **High Priority**,
    - the **High Resolution** information with **Low Priority**.

- If the signal is distorted, at least the standard TV resolution can be received.

Digital Modulation Schemes



Chapter# 4

(Bernard Sklar)

Bandpass Modulation & Demodulation

Digital Bandpass Modulation

- A process (either Analog or Digital) by which an information is converted to a sinusoidal waveform

Or

- The process whereby the Amplitude, Frequency, or Phase of an RF carrier, or a combination of them, is varied in accordance with the information to be transmitted

- For Digital Modulation, such a sinusoid of duration **T** is referred to as a **Digital Symbol**

Digital Bandpass Signaling

Types

- Coherent
  - Phase Shift Keying (PSK),
  - Frequency Shift Keying (FSK),
  - Amplitude Shift Keying (ASK),
  - Continuous Phase Modulation (CPM),
  - Hybrids
- Non-Coherent
  - Differential Phase Shift Keying (DPSK),
  - Frequency Shift Keying (FSK),
  - Amplitude Shift Keying (ASK),
  - Continuous Phase Modulation (CPM),
  - Hybrids

Digital Bandpass Modulation

- Coherent Modulation
  - Receiver exploits the knowledge of carrier's phase to detect the signal
  - Ideally, a prototype of each possible arriving signal is available at the receiver
  - These prototype waveforms attempt to duplicate the transmitted signal set in every respect, even RF phase
  - The receiver is then phase locked to the incoming signal

Digital Bandpass Modulation

- Coherent Detection/Demodulation
    - The receiver multiplies and integrates (Correlates) the incoming signal with each of its prototype replicas

Digital Bandpass Modulation

- Non-Coherent Demodulation
  - The receiver does not utilize Phase Reference Information
  - Refers to the systems employing demodulators that are designed to operate without knowledge of the absolute value of the incoming signal’s phase
  - Thus, Phase estimation is not required

Any Advantage

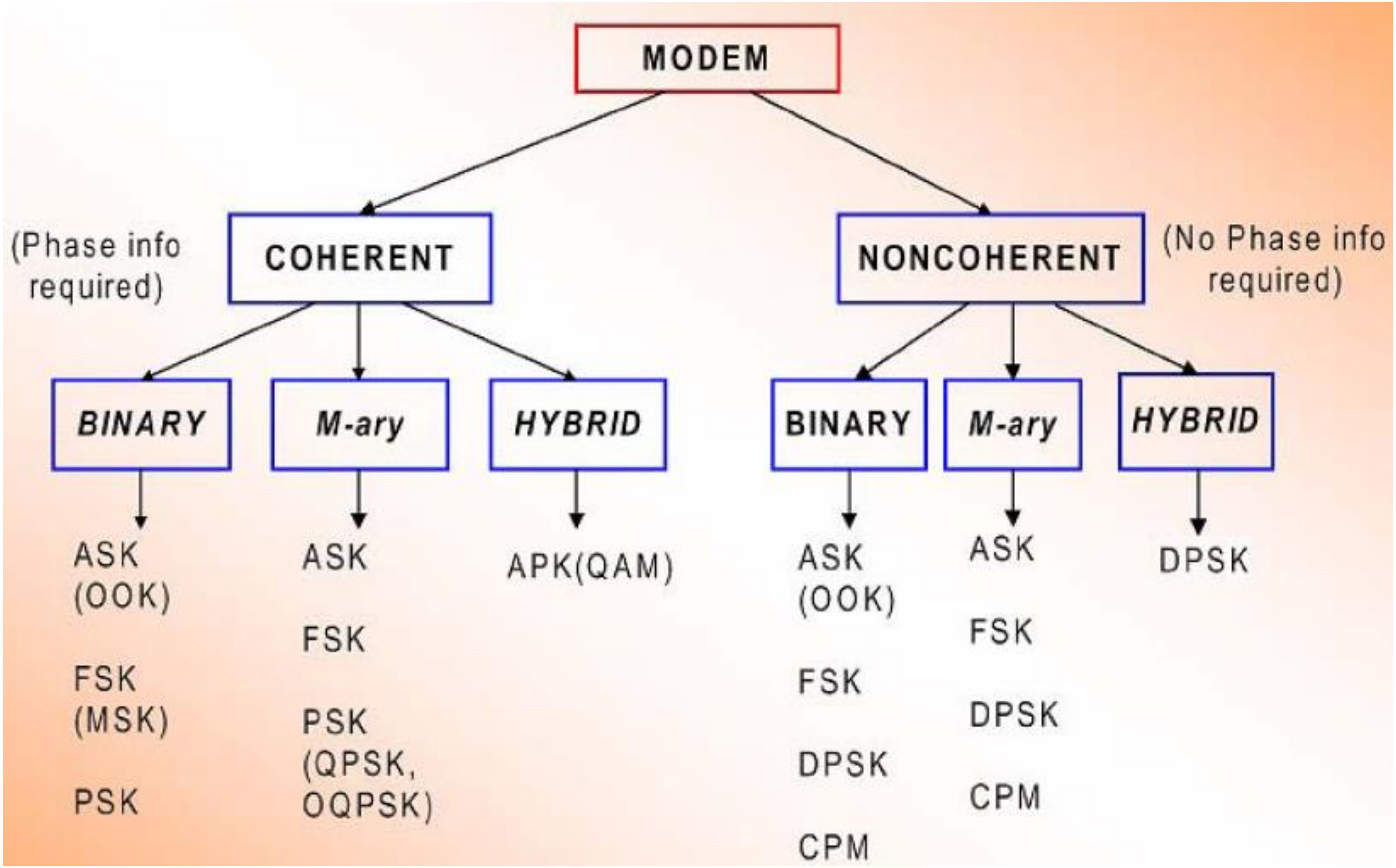
Coherent
Vs.
Non-Coherent

- The advantage of Non-Coherent over Coherent system is **Reduced Complexity**

Trade-off

Increased probability of Error (P_E)

Bandpass Modulation & Demodulation



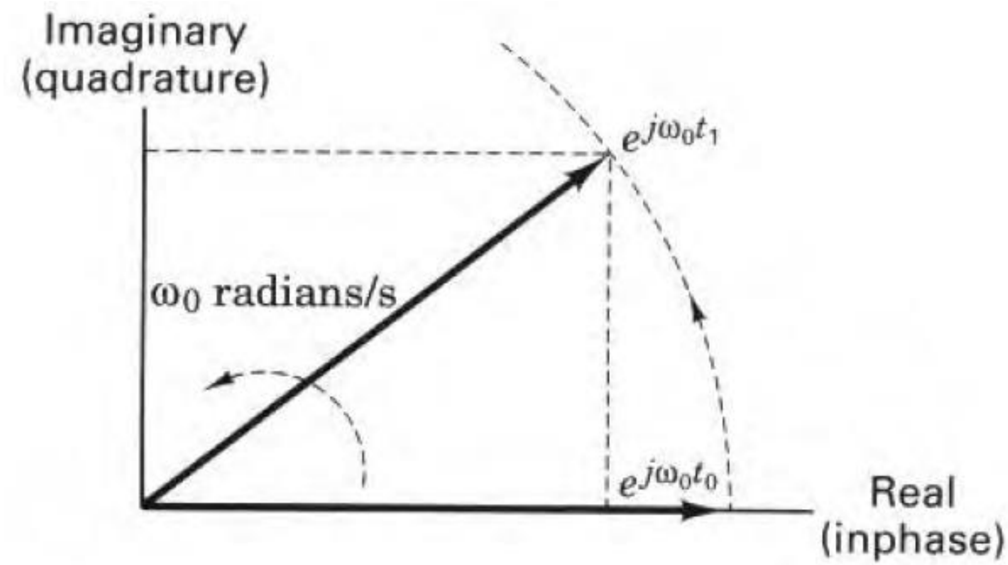
Phasor Representation of a Sinusoid

Phasor Representation of a Sinusoid

- Consider the trigonometric identity called the Euler's Theorem:

$$e^{j\omega_0 t} = \cos(\omega_0 t) + j\sin(\omega_0 t)$$

- Using this identity, we can have the phasor representation of the sinusoids:



Phasor Representation of a Sinusoid

- $e^{jw_o t}$ contains the inphase (real) and the quadrature (imaginary) components that are orthogonal to each other
- The unmodulated carrier wave is conveniently represented in a polar coordinate system as a unit vector or phasor rotating counter-clockwise at a constant rate of w_o radians/s
- As time is increasing, we can visualize the time varying projections of the rotating phasor on the Inphase (I) axis and the Quadrature (Q) axis
- To modulate the carrier wave with information, this modulation can be viewed as a perturbation of the rotating phasor (and its projections)

Phasor Representation of a Sinusoid

- Consider the AM signal in phasor form

$$s(t) = \mathrm{Re}\left\{ e^{j\omega_0 t}\left(1 + \frac{e^{j\omega_m t}}{2} + \frac{e^{-j\omega_m t}}{2}\right)\right\}$$