UNIT 9
Digital Modulation Schemes
(Digital modulation schemes for transmission of discrete signals)

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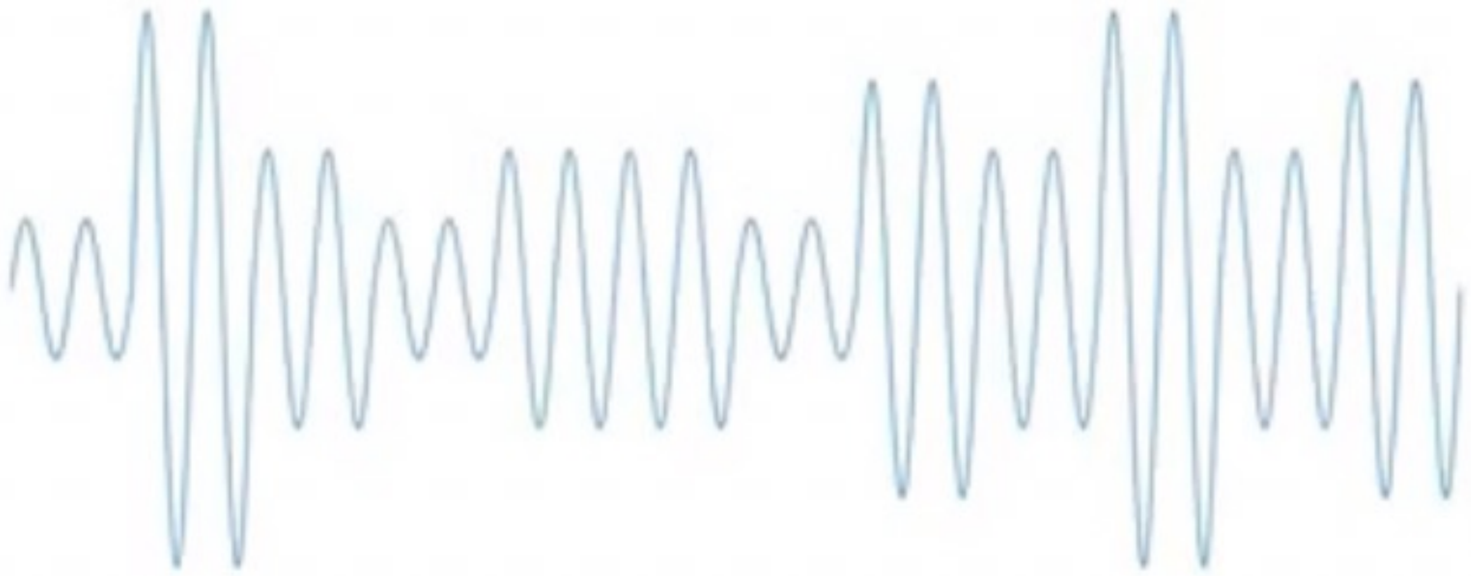
Outcomes

- Define ASK, FSK and PSK Schemes
- Applications of digital modulation schemes
- Analyze ASK, FSK and PSK systems
- Compare APSK schemes and QAM Schemes
- Discuss multiple access schemes and their usages

Digital Modulation – (Shift Keying)

- Digital data is sent using different **States** or **Symbols** which correspond to different bits
  - **Amplitude Shift Keying:** different amplitudes

Amplitude Shift Keying
(different amplitudes)



Digital Modulation – (Shift Keying)

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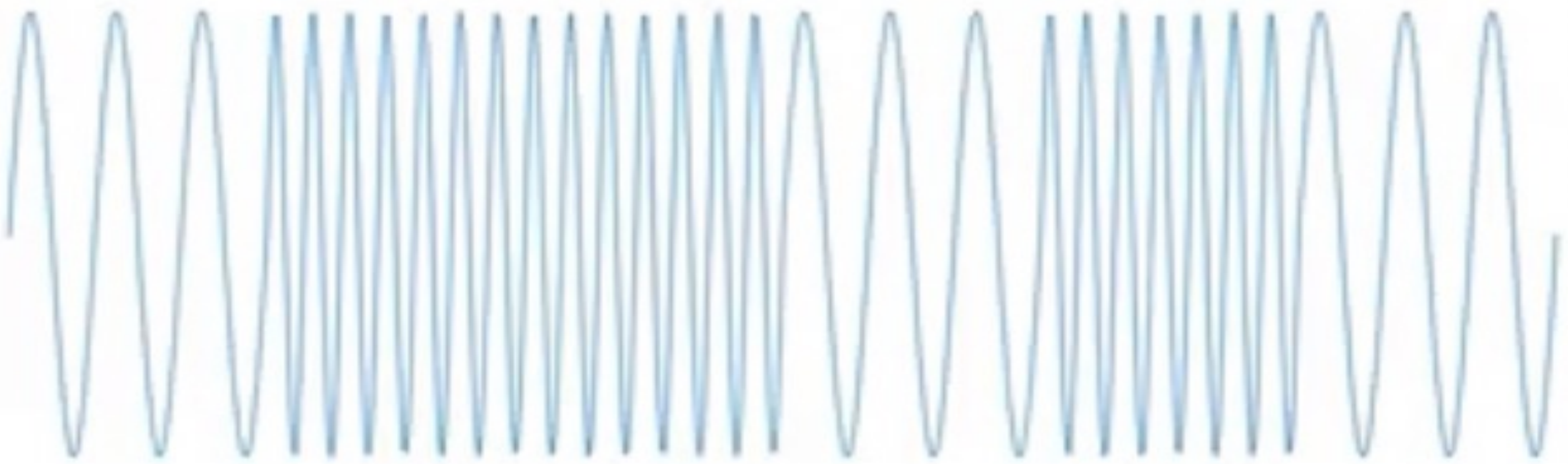
  - **Frequency Shift Keying:** different frequencies

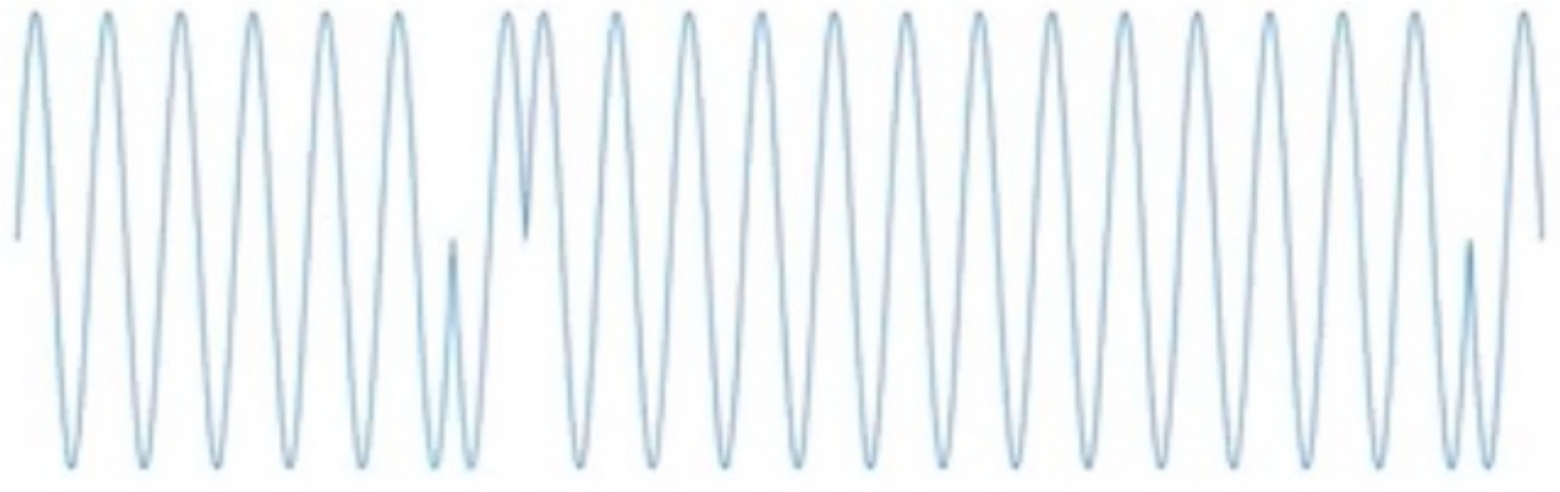
Frequency Shift Keying
(different frequencies)



Digital Modulation – (Shift Keying)

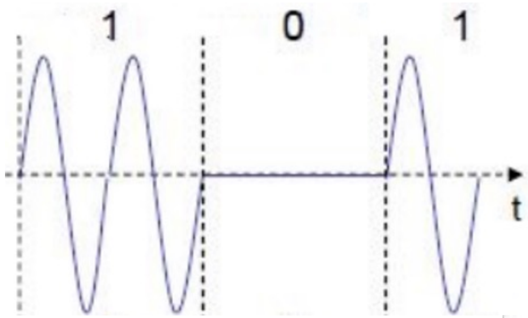
- Digital data is sent using different **States** or **Symbols** which correspond to different bits
  - **Amplitude Shift Keying:** different amplitudes
  - **Frequency Shift Keying:** different frequencies
  - **Phase Shift Keying:** different Phase Transitions

Phase Shift Keying
(different Phase transitions)

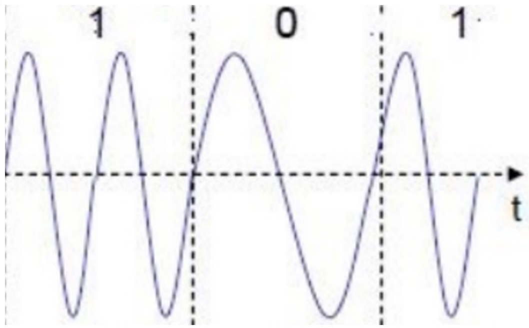


Digital Modulation Key Features

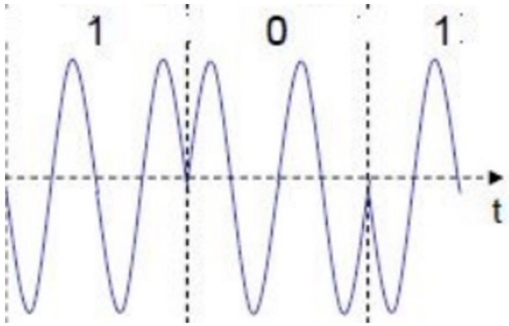
- Amplitude Shift Keying (ASK):
  - very simple
  - low bandwidth requirements
  - very susceptible to interference



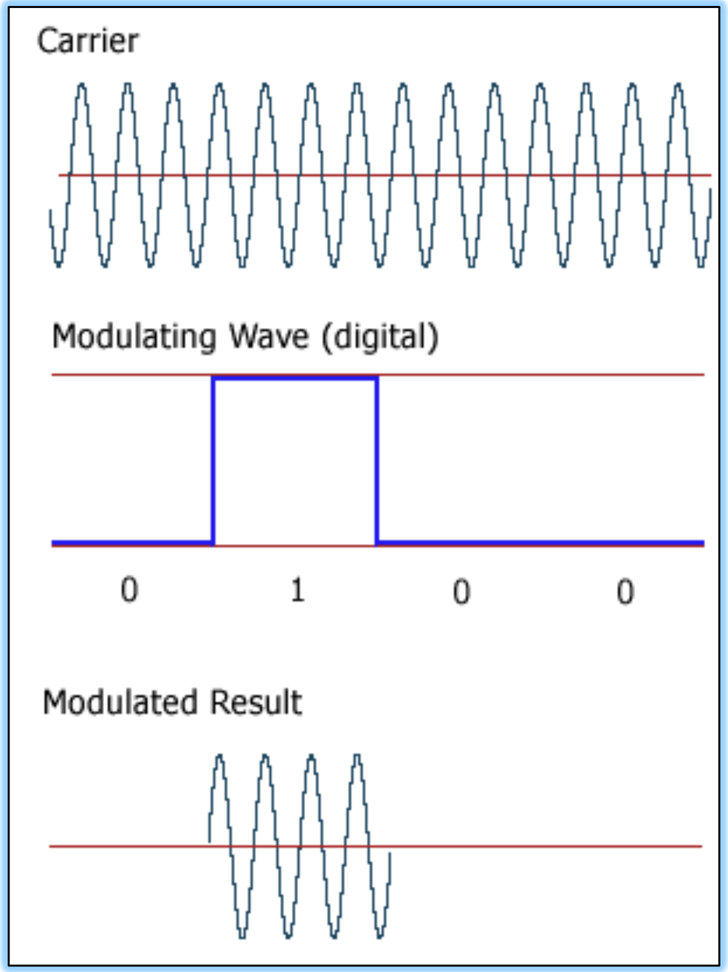
- Frequency Shift Keying (FSK):
  - needs larger bandwidth



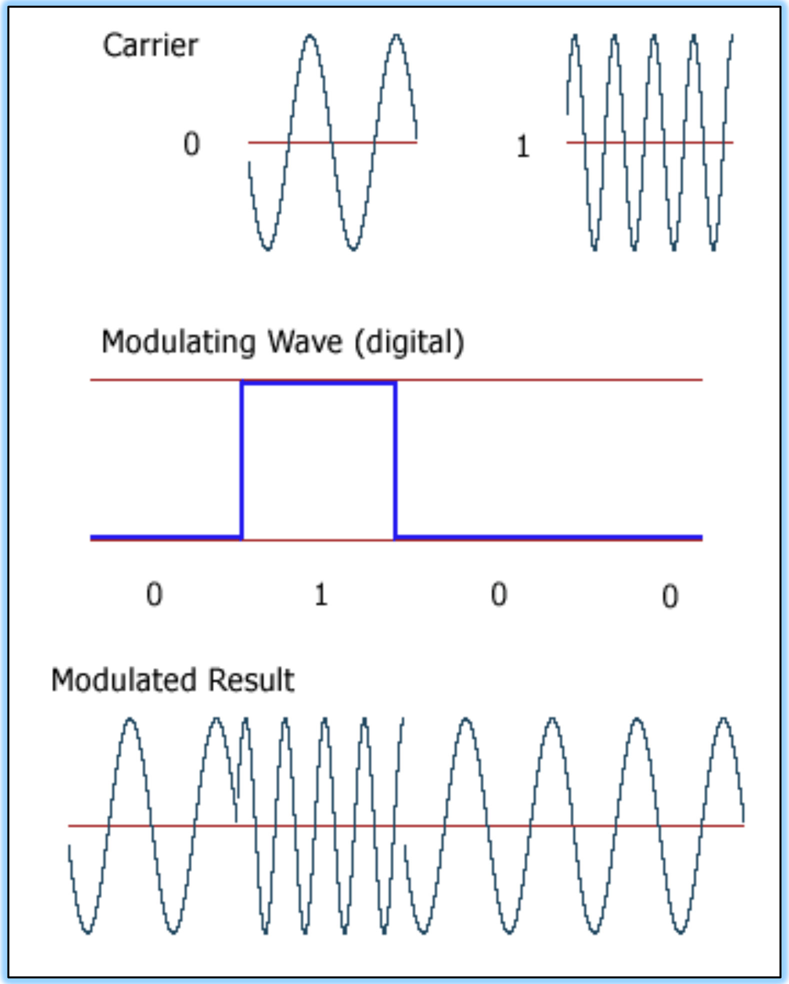
- Phase Shift Keying (PSK):
  - more complex
  - robust against interference



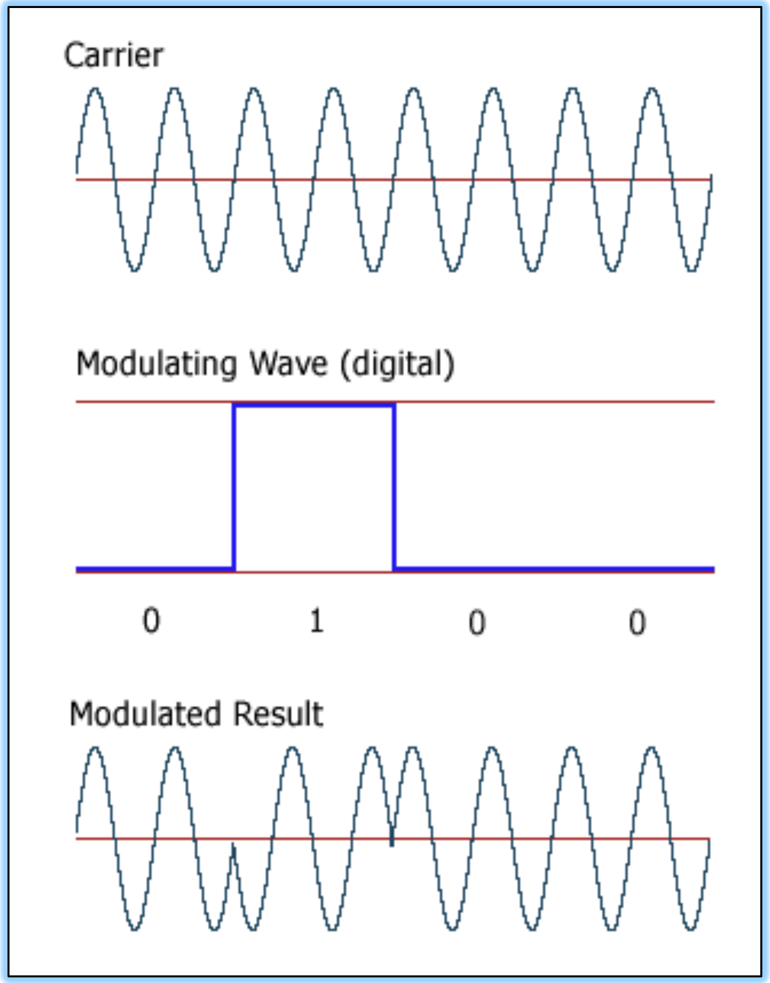
Example of ASK, FSK and PSK



ASK



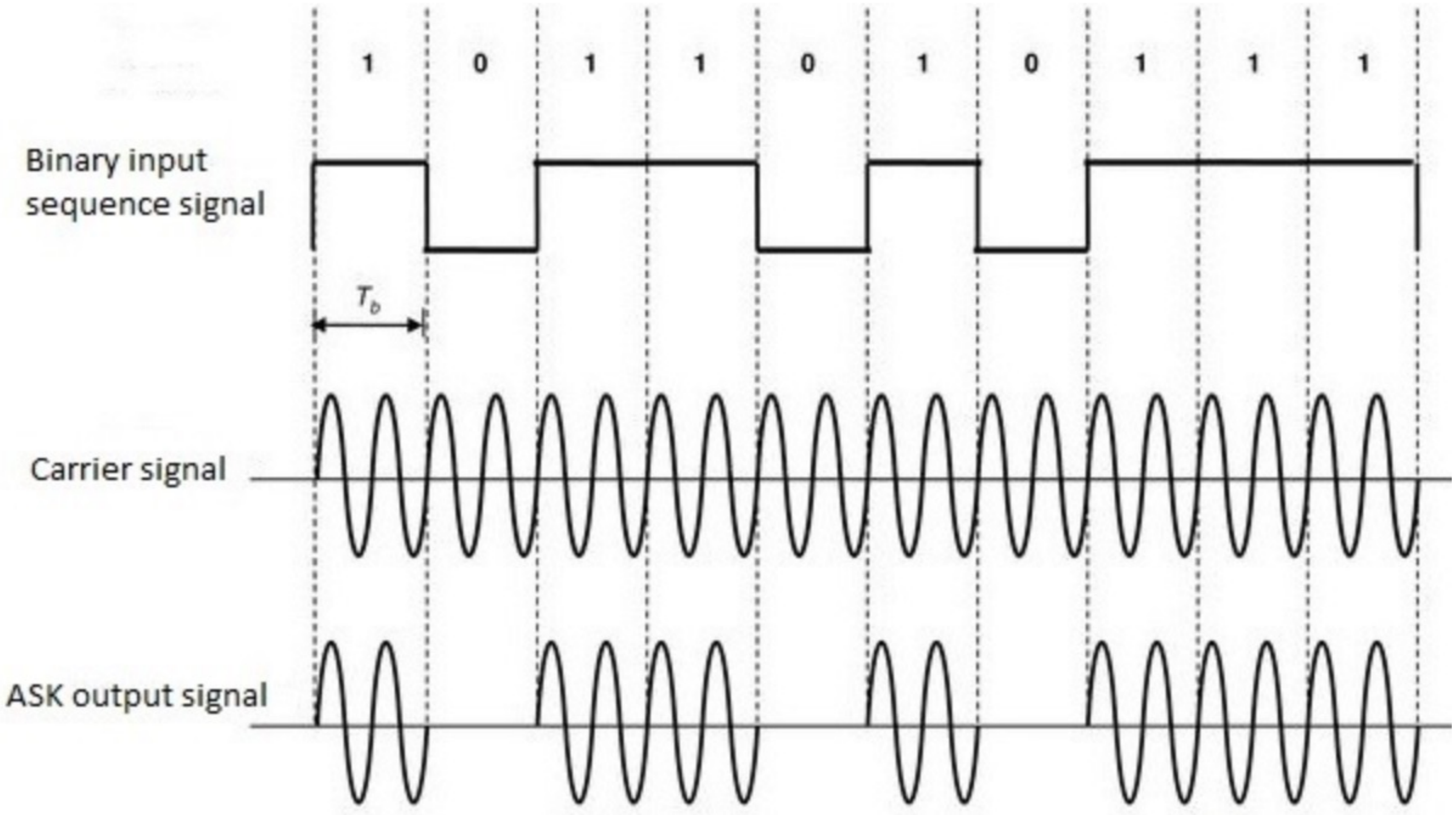
FSK



PSK

AMPLITUDE SHIFT KEYING (ASK)

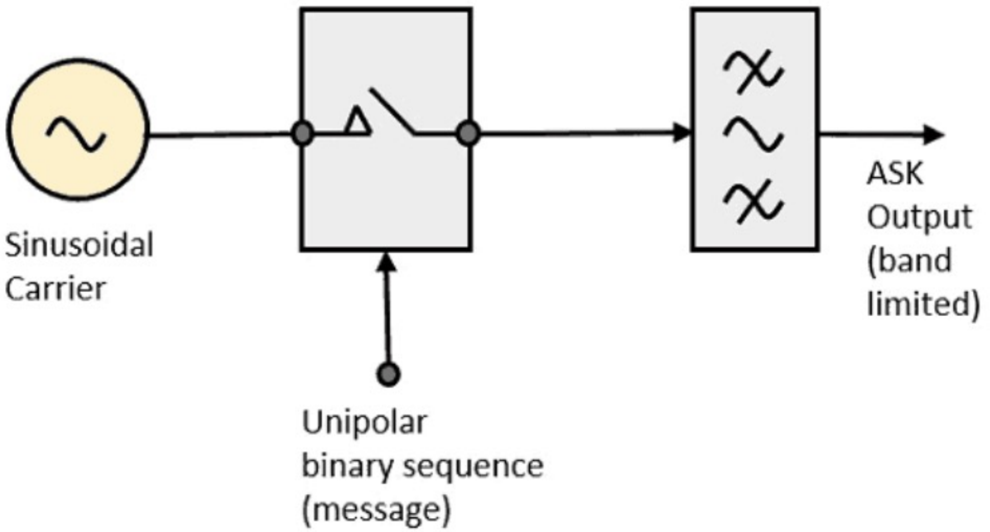
Amplitude Shift Keying



Keying is indicating the transmission of digital signal over the channel.

In ASK, it requires two input signals,
First input is binary sequence signal and the second input is carrier signal.

ASK Modulator



It consists of the carrier signal generator, the binary sequence from the message signal and the band-limited filter.

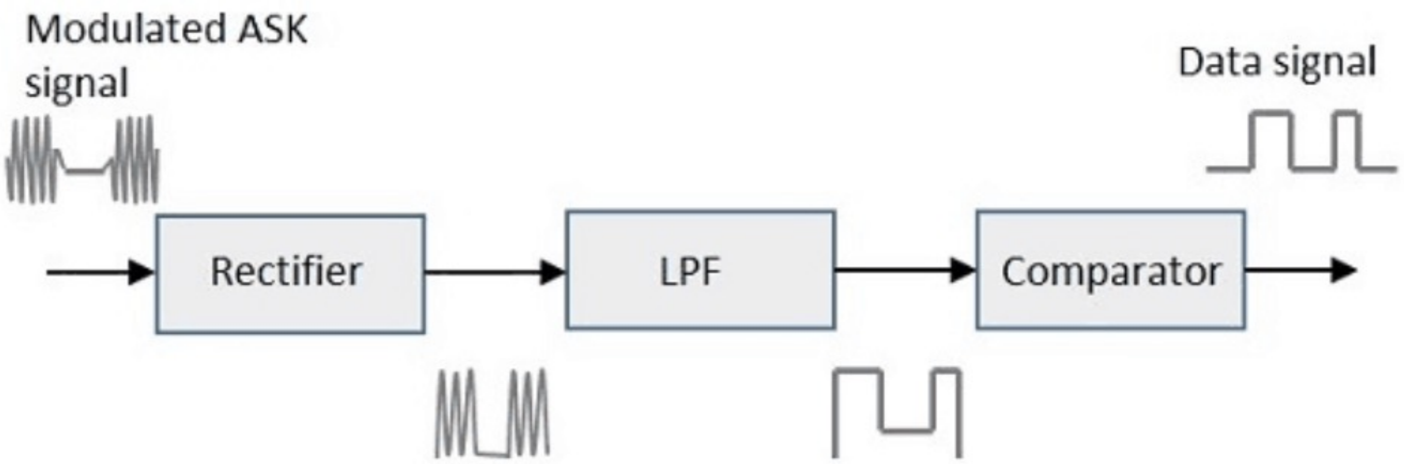
- The carrier generator, sends a continuous high-frequency carrier.
- The binary sequence from the message signal makes the unipolar input to be either High or Low.
- The high signal closes the switch, allowing a carrier wave. Hence, the output will be the carrier signal at high input.
- When there is low input, the switch opens, allowing no voltage to appear. Hence, the output will be low.
- The band-limiting filter, shapes the pulse depending upon the amplitude and phase characteristics of the band-limiting filter or the pulse-shaping filter.

ASK Demodulator

- Asynchronous ASK Demodulation
- Synchronous ASK Demodulation

- The clock frequency at the transmitter when matches with the clock frequency at the receiver, it is known as a Synchronous method, as the frequency gets **synchronized**.
- Otherwise, it is known as **Asynchronous**.

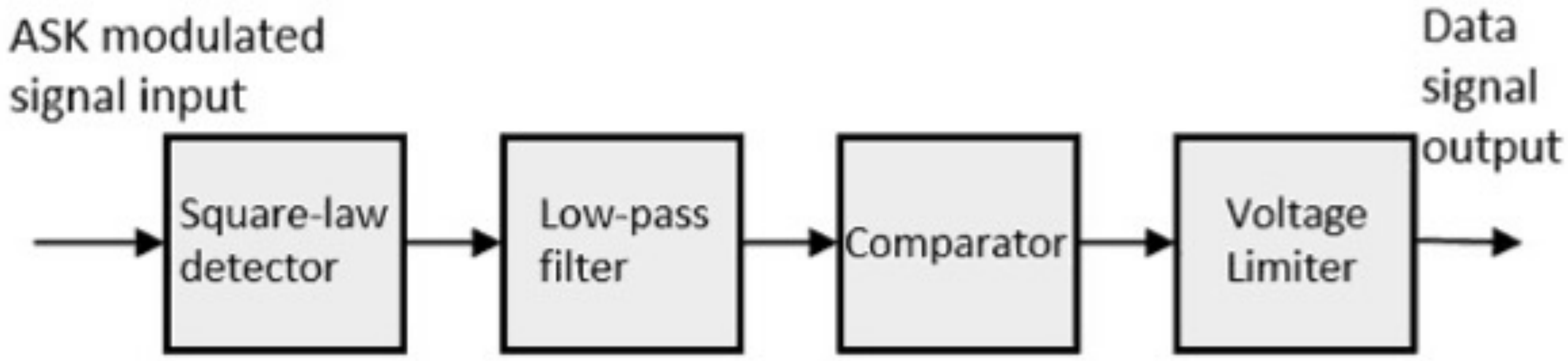
Asynchronous ASK Demodulator



- It consists of a half-wave rectifier, a low pass filter, and a comparator.
- When the ASK signal pass through the rectifier, we can obtain the positive half wave signal.
- After that the signal will pass through a low-pass filter and obtain an envelop detection.
- Then get rid of the DC signal, the digital signal will be recurred.

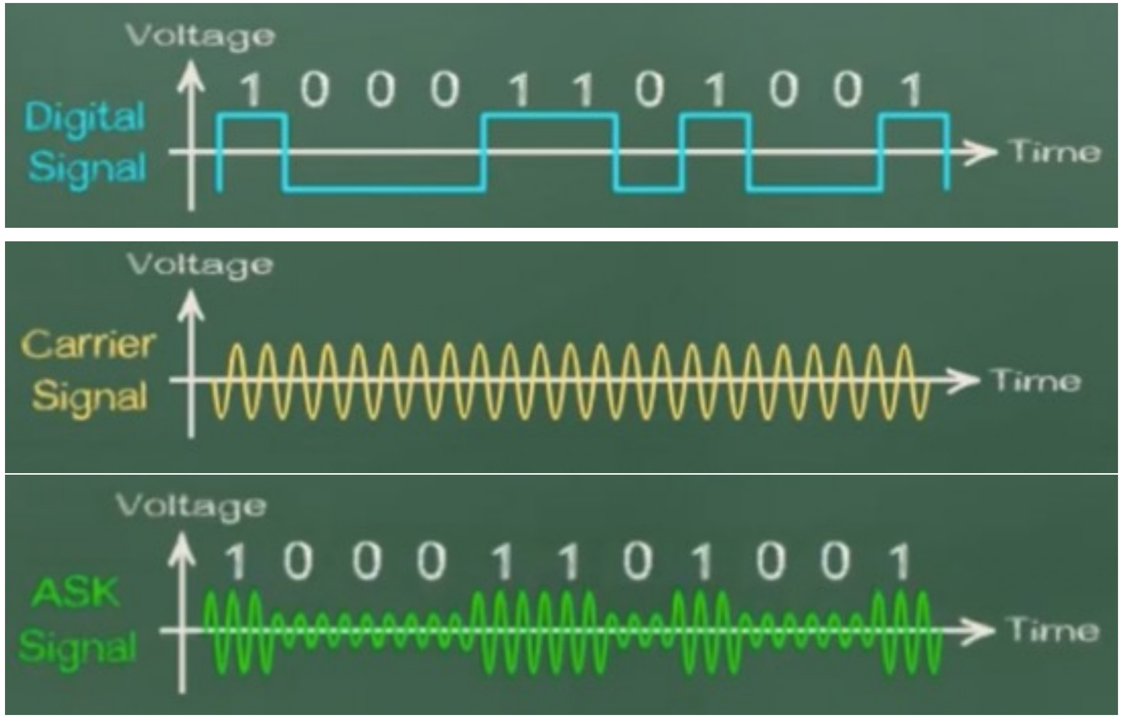
Synchronous ASK Demodulator

- It consists of a Square law detector, low pass filter, a comparator, and a voltage limiter.
- The ASK modulated input signal is given to the Square law detector. A square law detector is one whose output voltage is proportional to the square of the amplitude modulated input voltage.
- The low pass filter minimizes the higher frequencies.
- The comparator and the voltage limiter help to get a clean digital output.



ASK Applications

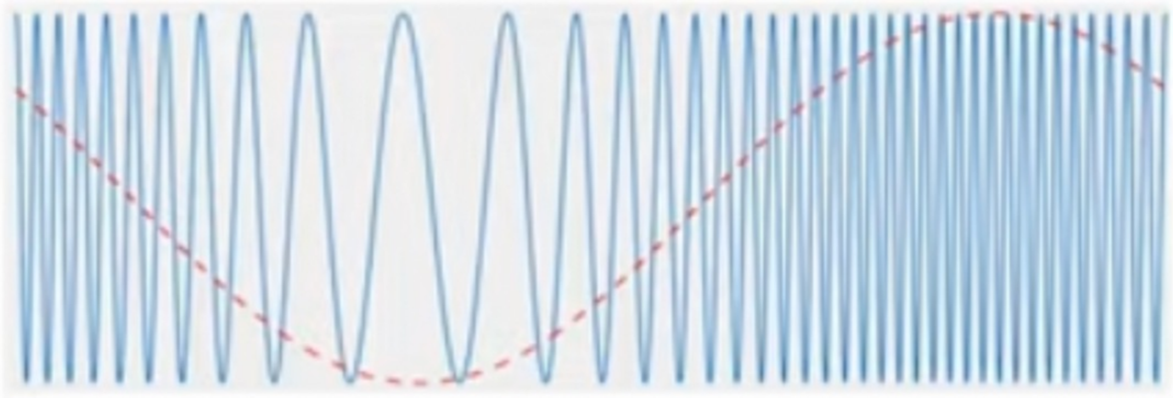
- Low-frequency RF applications
- Home automation devices
- Industrial networks devices
- Wireless base stations
- Tire pressuring monitoring systems

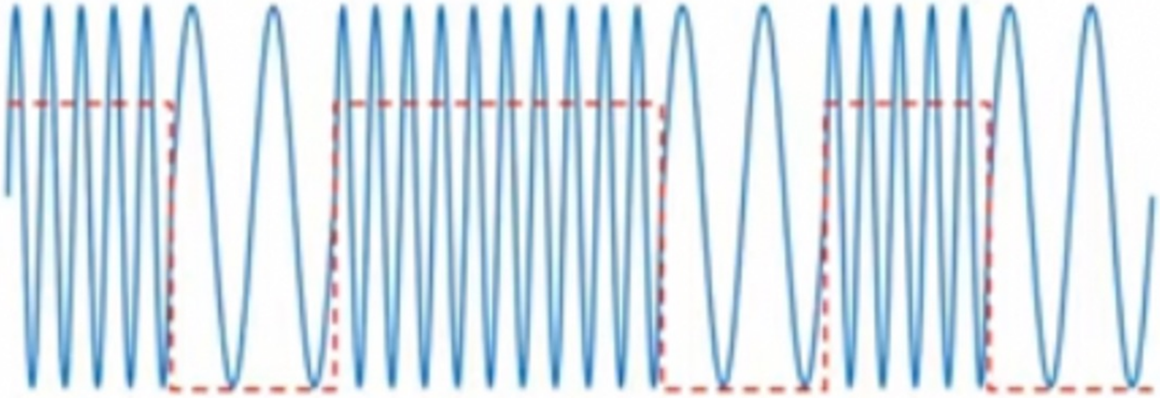


FREQUENCY SHIFT KEYING (FSK)

Frequency shift keying (FSK)

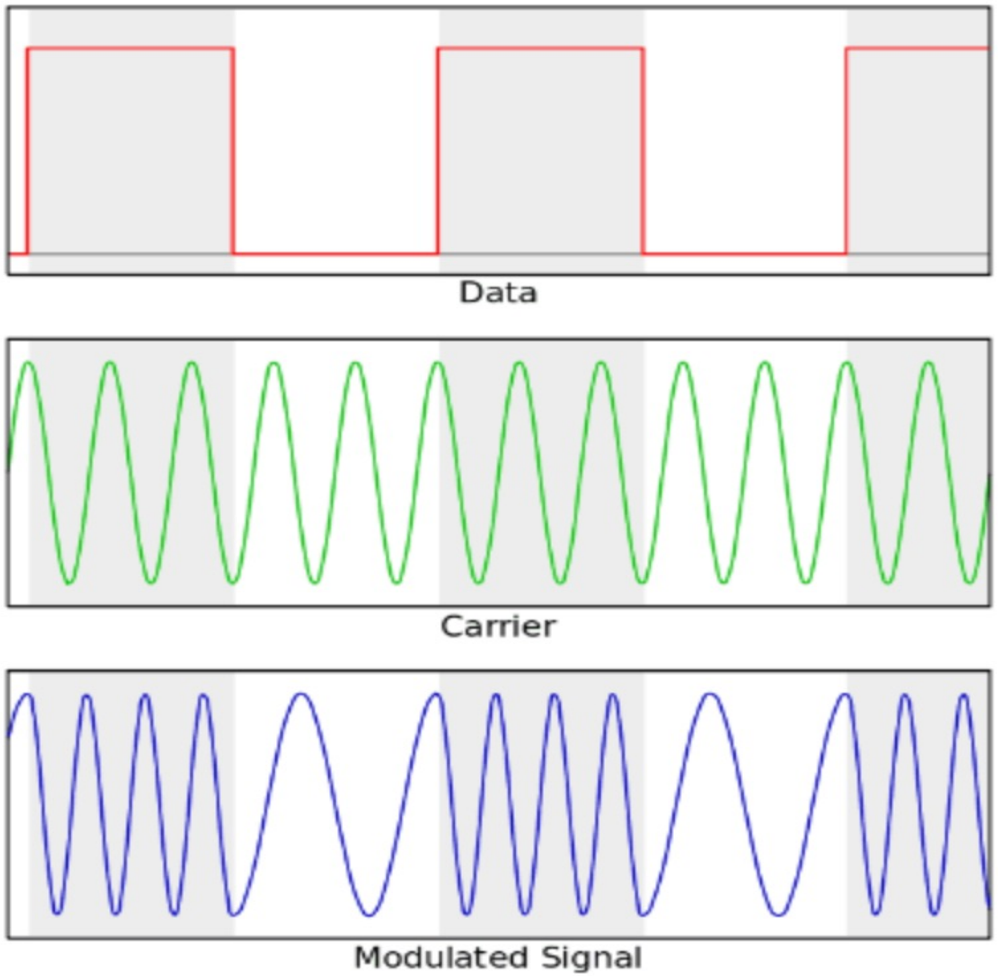
- In contrast with analog FM modulation where the carrier is continuously varied based on analog input Signal
- Frequency shift keying (FSK) transmits DIGITAL information by switching a carrier between discreate frequencies
- This is used in communication systems such as amateur radio, caller ID, and urgent situation broadcasts.





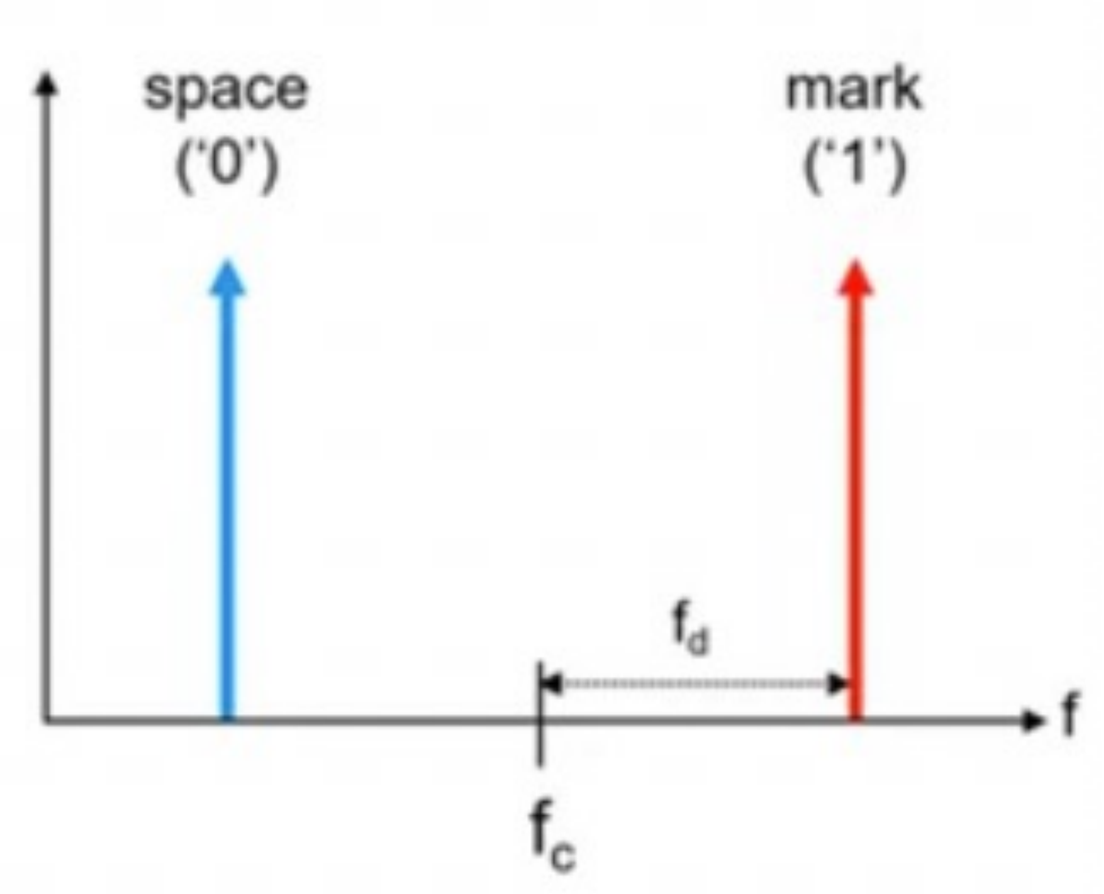
Frequency Shift Keying cont.

- FSK is a digital modulation technique in which the frequency of the carrier signal changes according to the input binary data.
- In FSK, carrier Amplitude or Phase will NOT be changed, but only frequency
- The output of a FSK modulated wave is high in frequency for a binary High ('1') input and is low in frequency for a binary Low ('0') input.
- Number of discrete frequencies can be
  - Two: Binary FSK
  - More than two: M (-ary) FSK



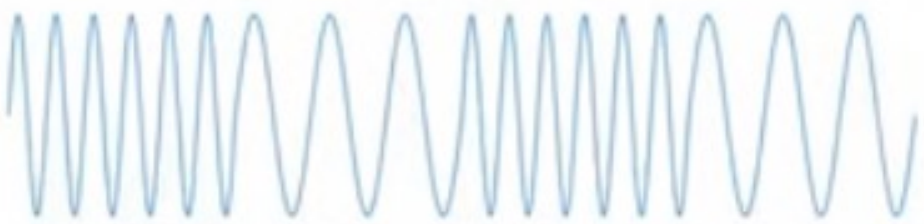
Binary Frequency Shift Keying (BPSK)

- Binary FSK (or 2FSK) uses two frequencies
  - Mark – corresponds to logical 1
  - Space – corresponds to logical 0
- The distance between carrier and the nominal center frequencies (f_c) is called the **deviation** (f_d or Δf_c) or **Shift**
- In BPSK, the Bit rate equal to Baud rates
  - Each symbol (marl or space) is a one bit

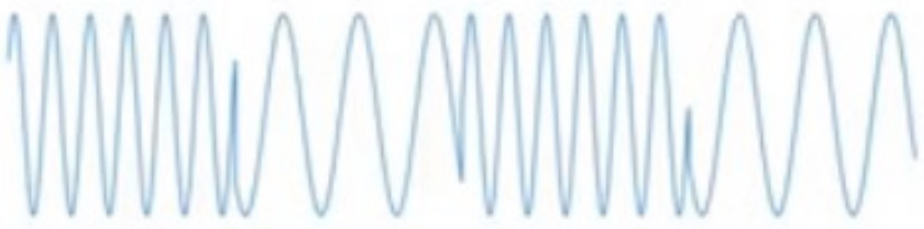


Coherent vs Non-coherent FSK

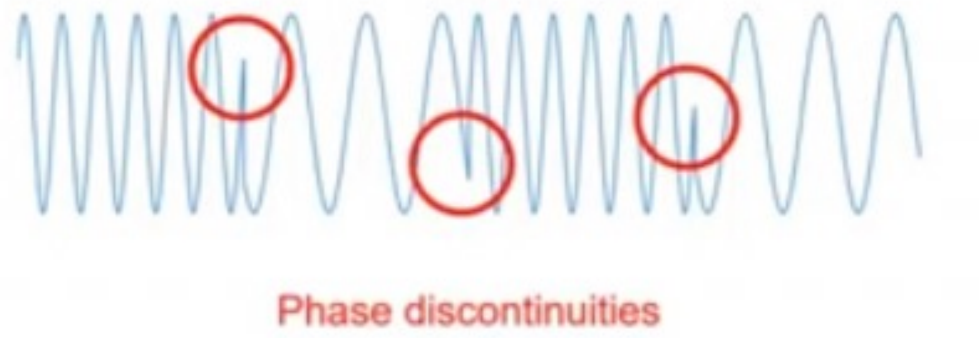
- If the two tones are generated by the same Oscillator, the results is **coherent** FSK
- If the two tones are generated by separated oscillators the results is **Non-Coherent** FSK
  - Can produce phase discontinuities at the switching points
  - Can create issues such as spectral regrowth & higher BER, but is cheaper and easier to implement
- Coherent FSK include
  - Minimum Shift Keying (MSK) and
  - Gaussian Minimum Shift Keying (GMSK)



Coherent FSK



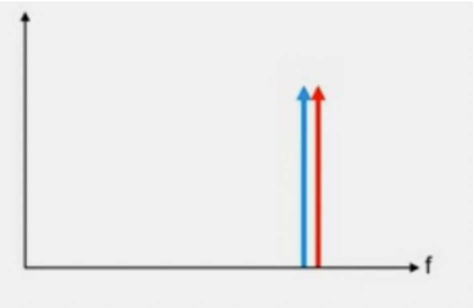
Non-coherent FSK

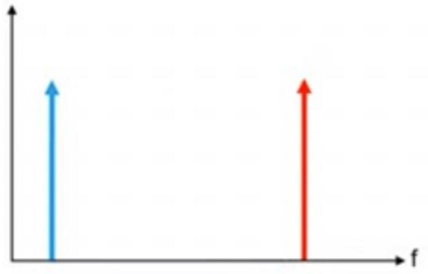


Cause Higher BER

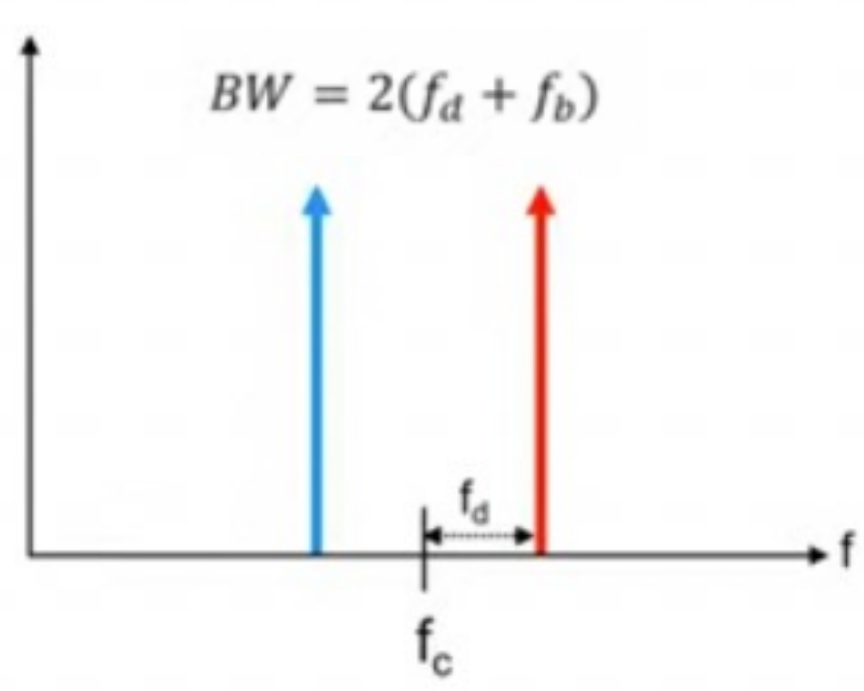
Frequency Spacing (Tone Spacing)

- How far apart the Mark and Space be
  - What value of Deviation, f_d ?
  - Too close will causes ISI (inter symbol interference)
  - Too far apart is spectrally inefficient (excessive BW)



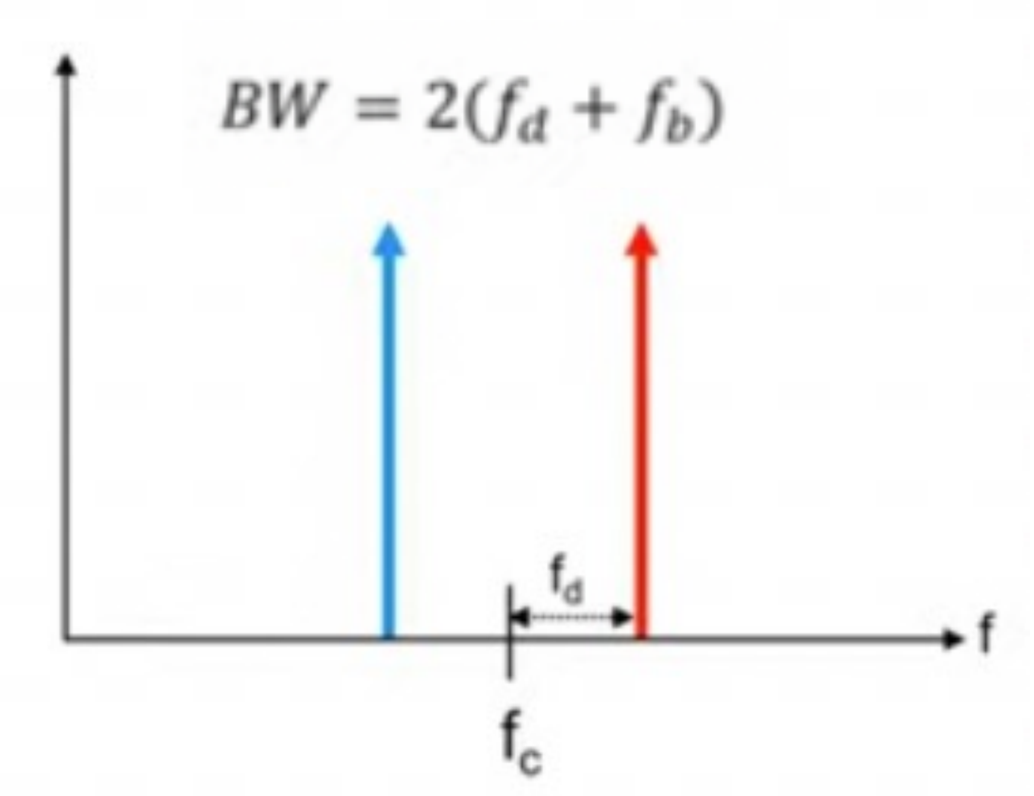


Minimum FSK bandwidth is a function of
- Frequency deviation (f_d)
- Bit rate (f_b)



Frequency Spacing (Tone Spacing)

- Minimum FSK BW is a function of <u>frequency deviation (f_c) and Bit rate (f_d)</u>
- Paging example
  - f_b= 512, 1200 or 2400 bps
  - f_d= 4.5 kHz (typically



- BW_{512} = 2 (512+4500) = 10 kHz
- BW_{512} = 2 (1200+4500) = 11.4 kHz
- BW_{512} = 2 (2400+4500) = 13.8 kHz

Modulation Index

- Tone should be as close as possible without creating ISI
- Modulation Index ($\boldsymbol{\mu}$) is the ration

$$\mu = \frac{2.f_d}{f_b}$$

Optimal detection Occurs when $\boldsymbol{\mu} \geq 1$

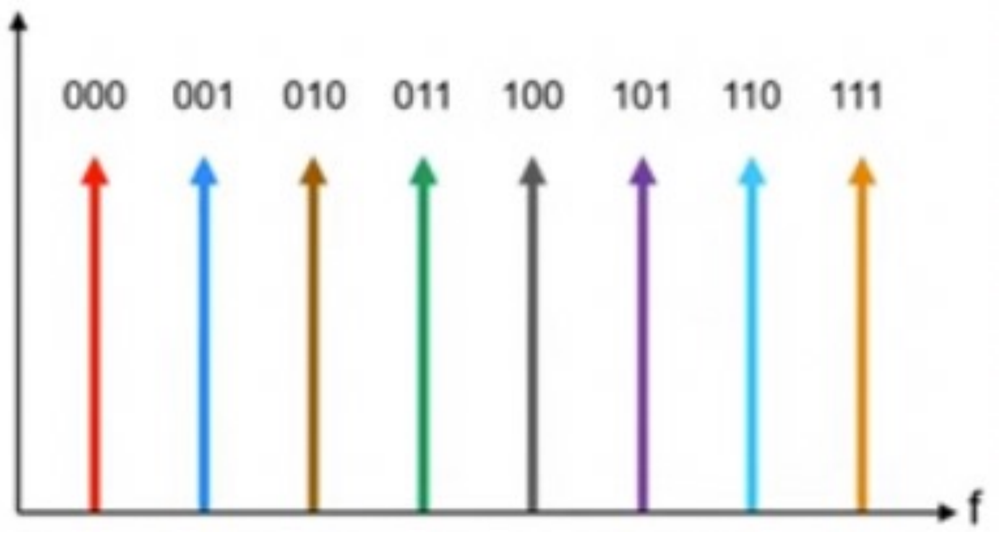
Example: f_d= 20kHz and
f_b= 40kbps

$$\boldsymbol{\mu} = 1.0$$

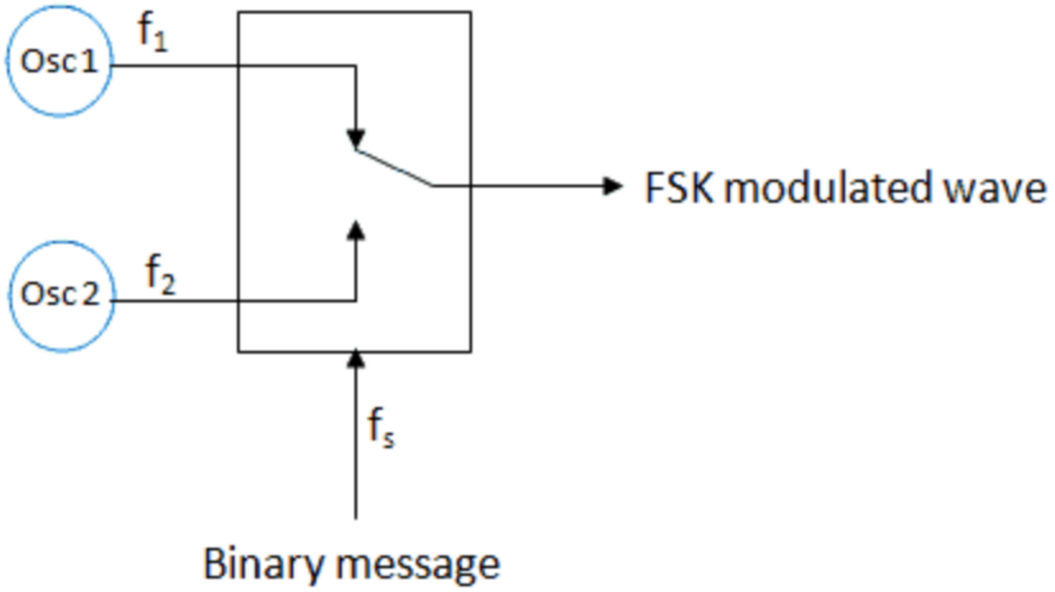
- Some coherent FSK variants can properly detect signal when $\boldsymbol{\mu}$ is below 1.0

M(-ary) FSK

- FSK that uses more than 2 frequencies is called "M-ary" FSK or "MFSK".
- Number of Tones (M) is always even: 4FSK, 8FSK, 16FSK etc.
- Each tone represent $log_2(M)$ bits. Example $log_2(8)$ = 3 bits, each tone of 8PSK represent 3 bits



FSK Modulator

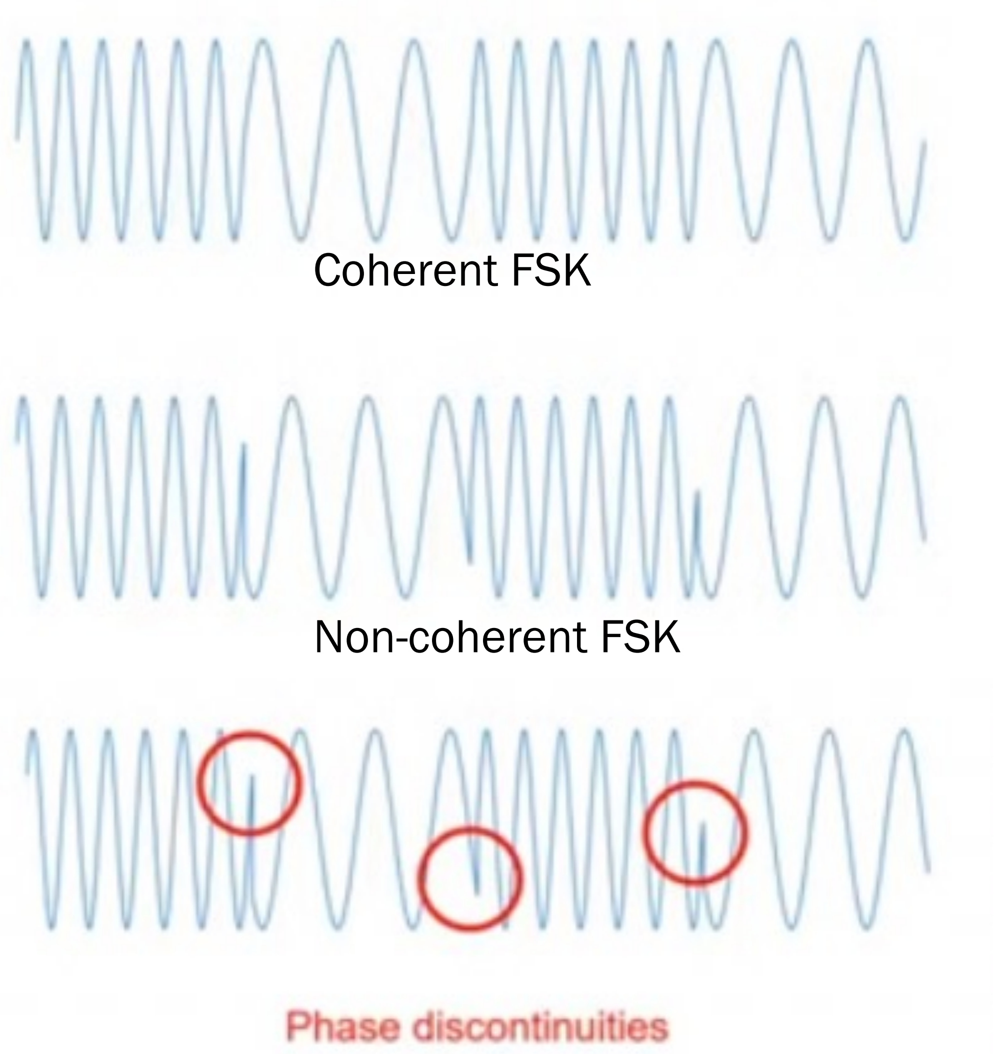


it consists of two oscillators with a clock and the input binary sequence.

- The oscillators Osc 1 produces a higher frequency (f_1) signal whereas the oscillator Osc 2 produces a lower frequency (f_2) signal.
- These two oscillators are connected to a switch along with an internal clock.
- To avoid the abrupt phase discontinuities of the output waveform during the transmission of the message, a clock is applied to both the oscillators, internally.

FSK Demodulator

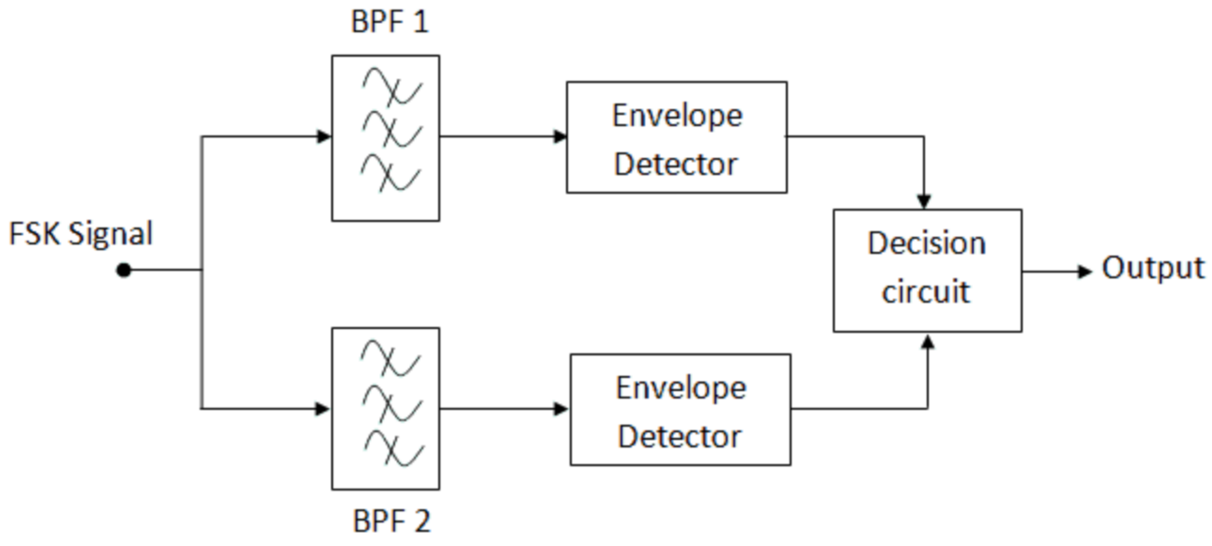
- These methods are classified into
  - Asynchronous detection (Non-coherent) and
  - synchronous detection (coherent)



Cause Higher BER

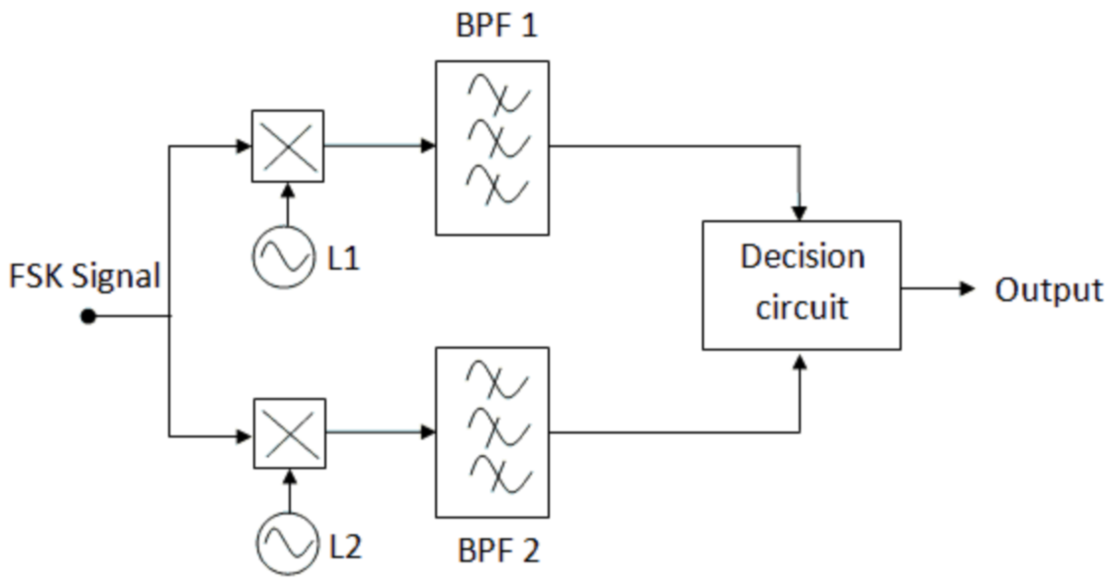
Asynchronous FSK Detector

- It consists of two band pass filters, two envelope detectors, and a decision circuit.
- The FSK input signal is passed through the two Band Pass Filters (BPF 1 and BPF 2) and tuned to Space and Mark frequencies.
- The output from these two BPFs look like ASK signal, which is given to the envelope detector.
- The signal in each envelope detector is modulated asynchronously.



- The decision circuit chooses which output is more likely and selects it from any one of the envelope detectors.
- It also re-shapes the waveform to a rectangular one.

Synchronous FSK Detector



It consists of two mixers with local oscillator circuits, two band pass filters and a decision circuit.

- The FSK signal input is given to the two mixers with local oscillator circuits.
- These two are connected to two band pass filters.
- These combinations act as demodulators.
- Then the decision circuit chooses which output is more likely and selects it from any one of the detectors.
- The two signals have a minimum frequency separation.
- For both of the demodulators, the bandwidth of each of them depends on their bit rate.
- This synchronous demodulator is more complex than asynchronous type demodulators.

Limitations and Solutions

- FSK used mostly for **lower rate digital data**
  - cannot meet modern high-rate data transmission requirements
- We can increase throughput by increasing the number of symbols (modulation order)
  - **2FSK**

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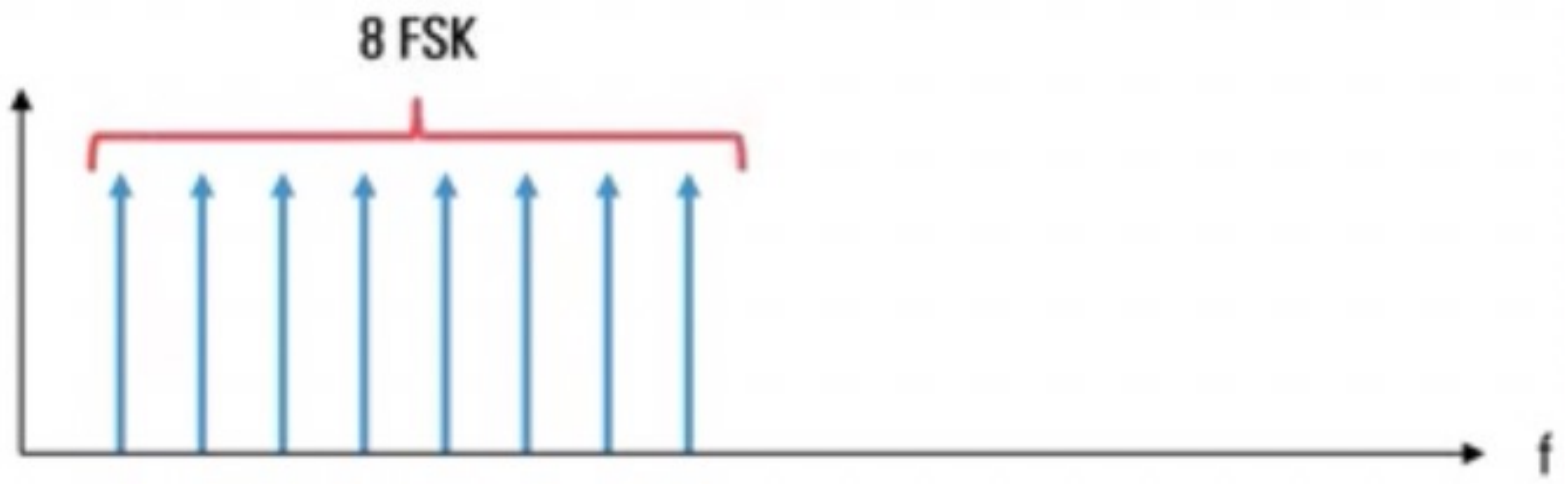
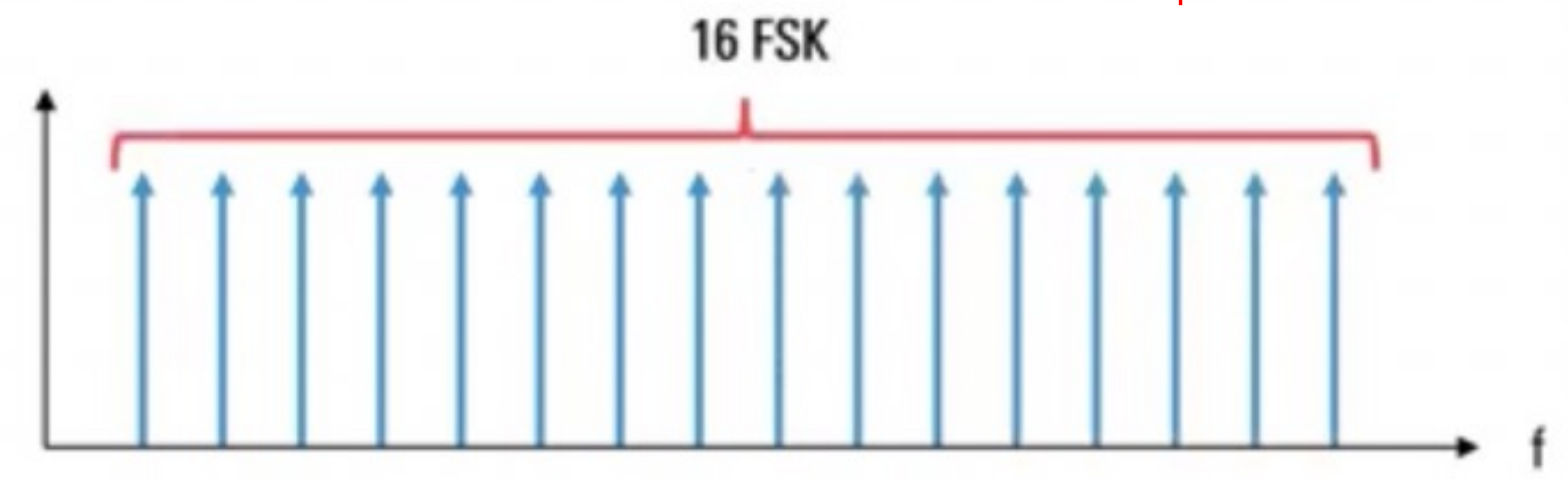
- We can <u>increase throughput</u> by <u>increasing the number of symbols</u> (modulation order)
  - **2FSK < 4FSK < 8FSK**



Limitations and Solutions

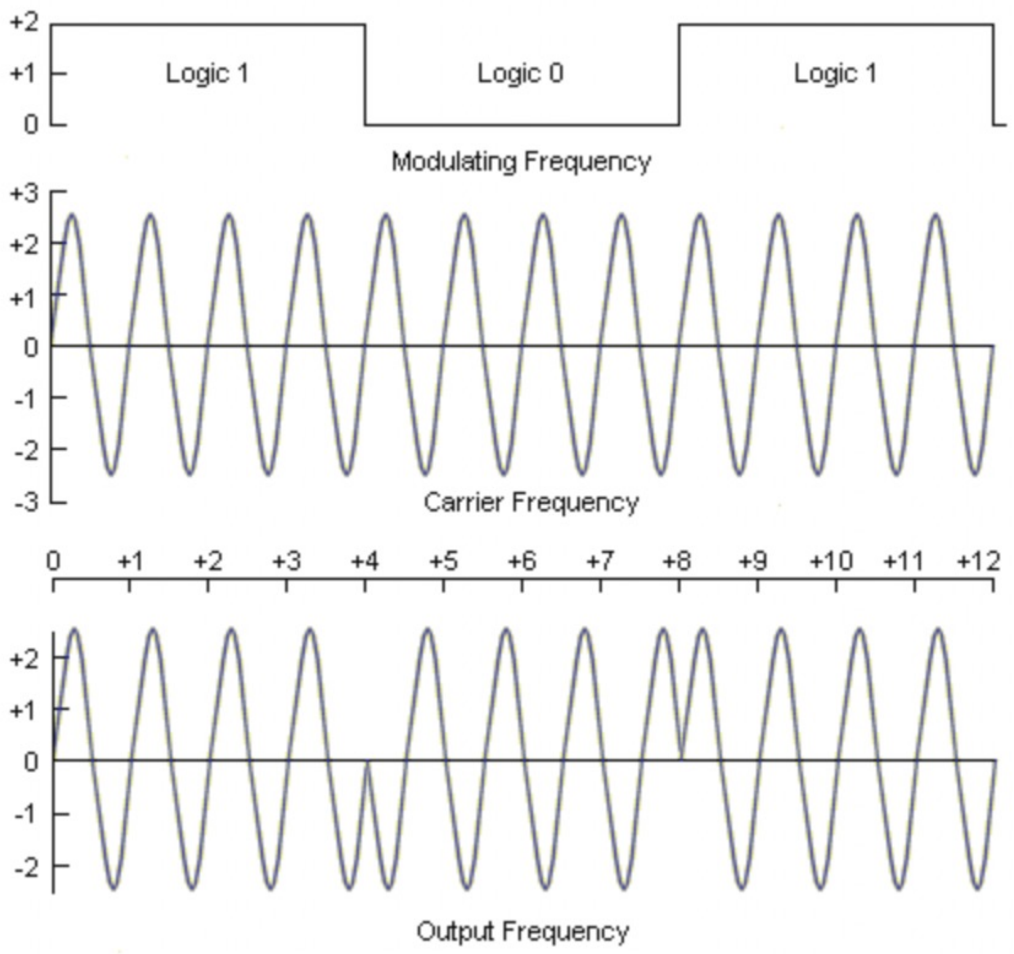
- FSK used mostly for **lower rate digital data**
  - cannot meet modern high-rate data transmission requirements
- We can increase throughput by increasing the number of symbols (modulation order)
  - **2FSK < 4FSK < 8FSK < 16FSK**

There is LIMIT to the maximum practical order: **Bandwidth**



PHASE SHIFT KEYING (PSK)

Phase Shift Keying

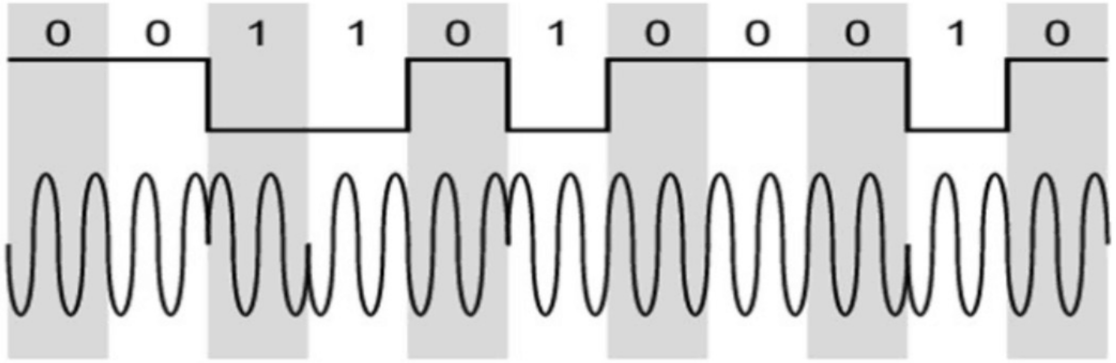


- Phase-shift keying (PSK) is a method of modulating digital signals onto an analogue carrier wave in which the phase of the carrier wave is shifted between two or more values, depending upon the logic state of the input bit stream.

- The simplest method uses two phases - 0 degrees and 180 degrees

Differential PSK

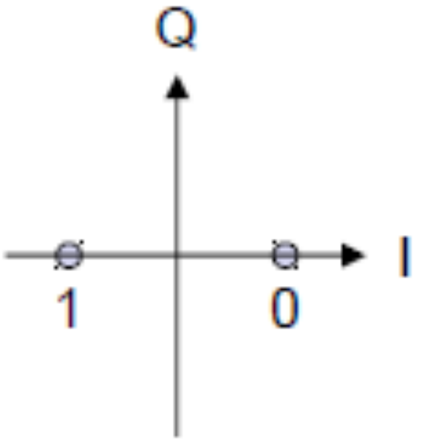
- Differential phase shift keying (DPSK) is a common type of phase modulation that conveys data by changing the phase of the carrier wave.
- In DPSK the phase of the modulated signal is shifted relative to the previous signal element.
- The signal phase follows the high or low state of the previous element.
- DPSK does not need a synchronous (coherent) carrier at the demodulator.

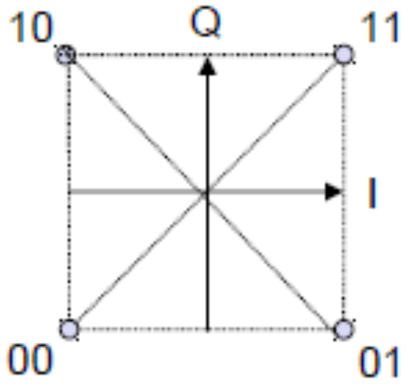


It cab seen from the above figure that, when the data bit is Low i.e., ‘0’, the phase of the signal is not reversed, and continued as it was.
When the data is a High i.e., ‘1’, the phase of the signal is reversed.

Advanced Phase Shift Keying

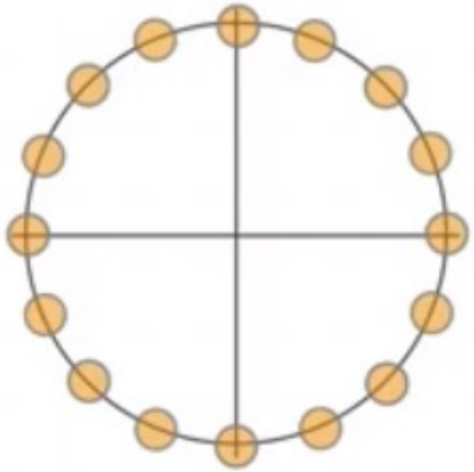
- BPSK (Binary Phase Shift Keying):
  - bit value 0: sine wave
  - bit value 1: inverted sine wave
  - very simple PSK
  - low spectral efficiency
  - robust, used e.g. in satellite systems
- QPSK (Quadrature Phase Shift Keying):
  - 2 bits coded as one symbol
  - symbol determines shift of sine wave
  - needs less bandwidth compared to BPSK
  - more complex



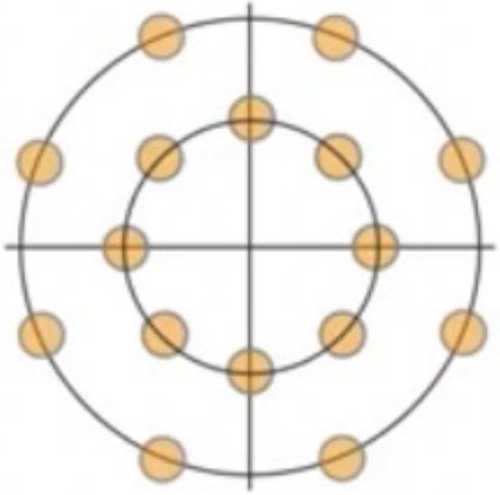


PSK Upper Bound and Possible Solutions

- The practical upper bound to PSK modulation order
  - Distance between symbols decreases and hence increases risk of errors
- Solution: Add Amplitude States
  - Concentric circles with different, but constant amplitude
  - Same number of points, but split across different circles
  - Points are now further apart, allowing higher throughputs (higher orders)



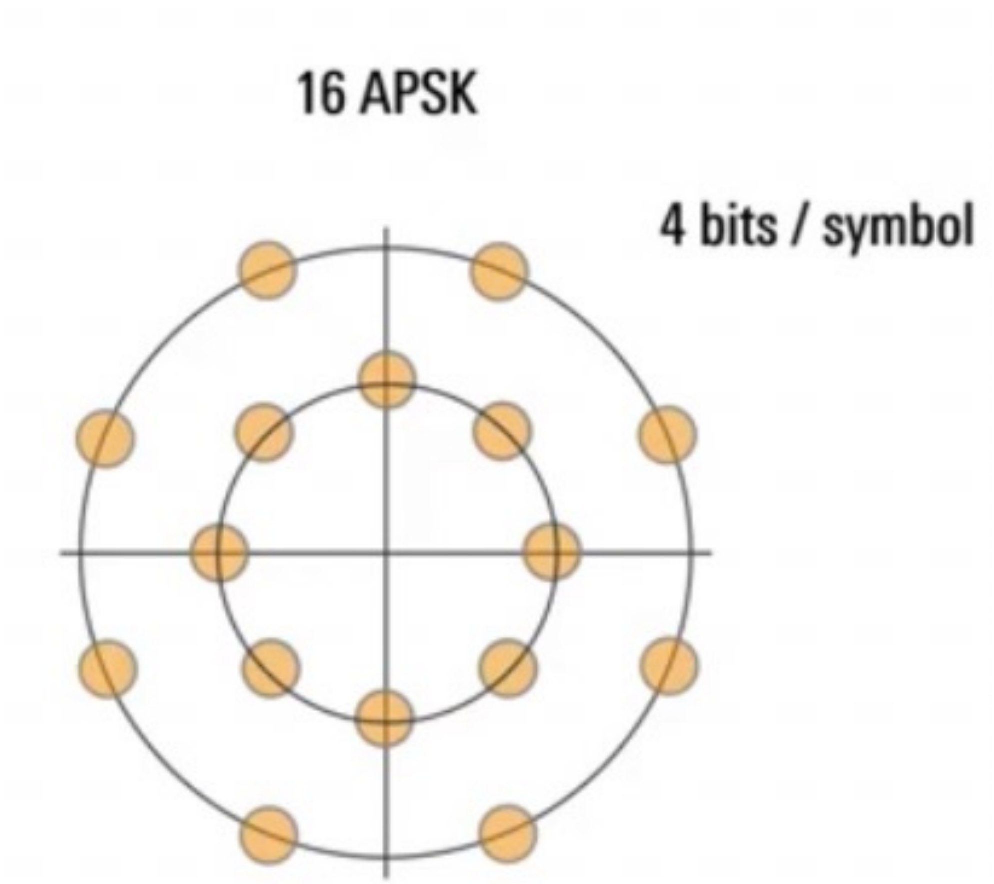
16 PSK

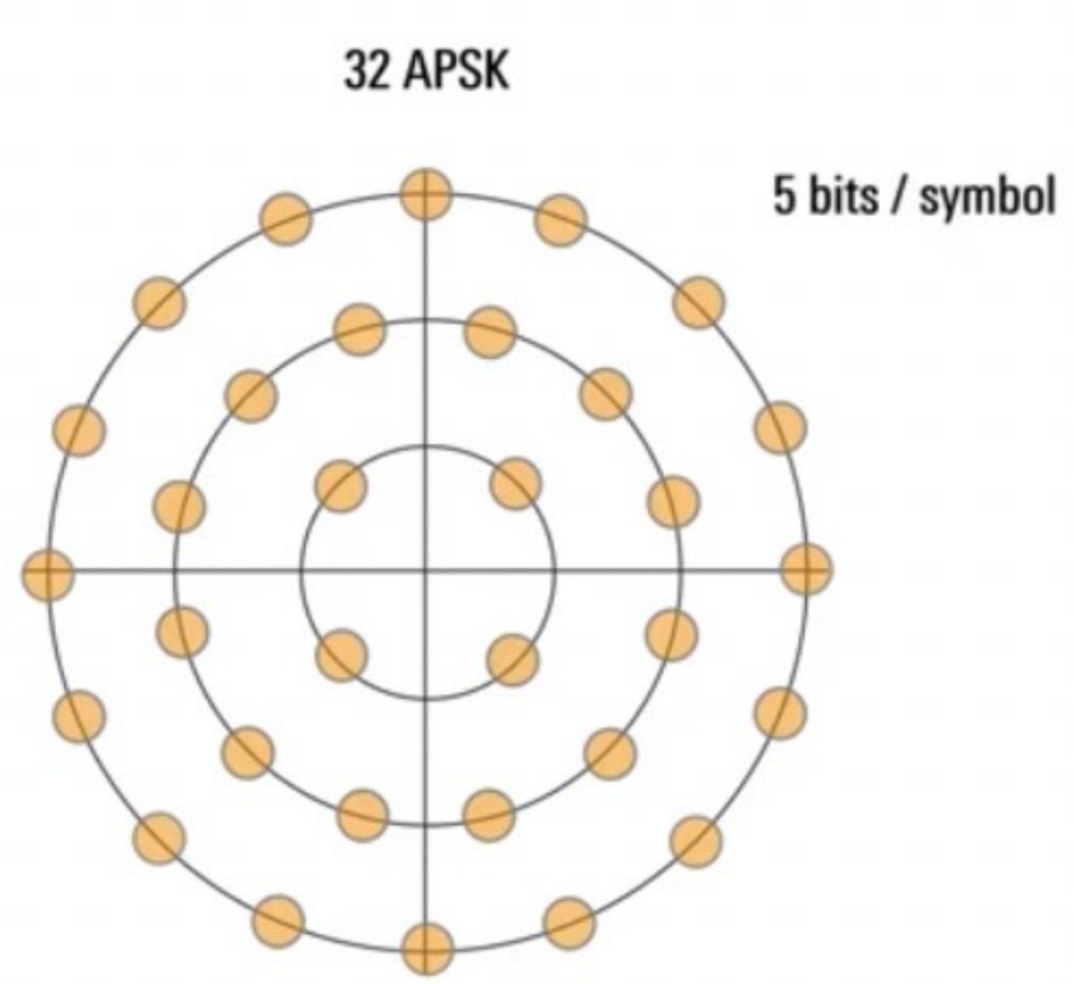


16 APSK

Combine PSK and multiple Amplitudes called **APSK (Amplitude Phase Shift Keying)**

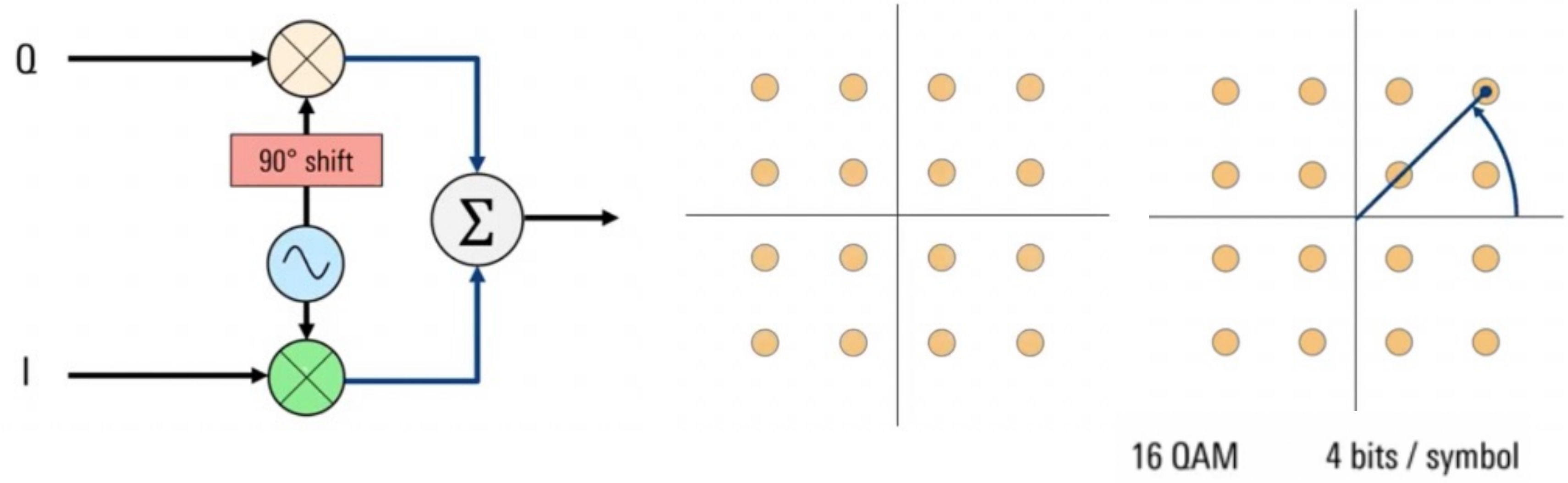
APSK constellations: 16PSK and 32 PSK





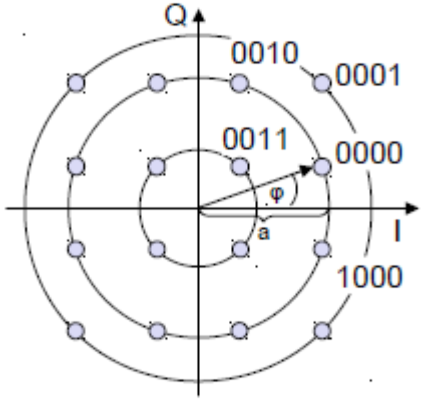
Quadrature Amplitude Modulation (QAM)

- Combines amplitude and phase shifts
- Many digital signal creates using “IQ” modulations
  - Quadrature → Shift by 90^0
- Resulting constellations are usually square

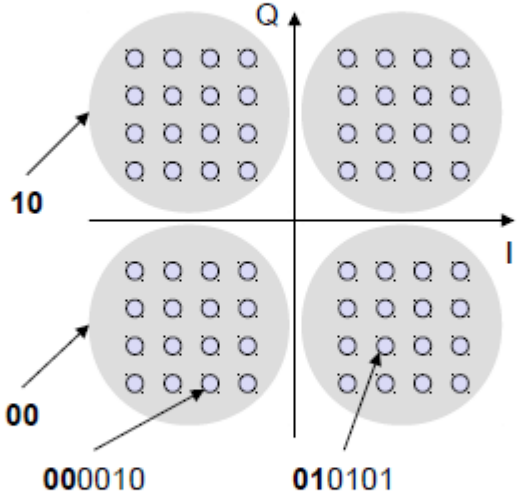


QAM Cont.

- QAM: combines amplitude and phase modulation
- it is possible to code n bits using one symbol
- 2^n discrete levels, n=2 identical to QPSK
- bit error rate increases with n, but less errors compared to comparable PSK scheme
  - Example: 16-QAM (4 bits = 1 symbol)
- Symbols 0011 and 0001 have the same phase φ, but different amplitude a.
- 0000 and 1000 have different phase, but same amplitude



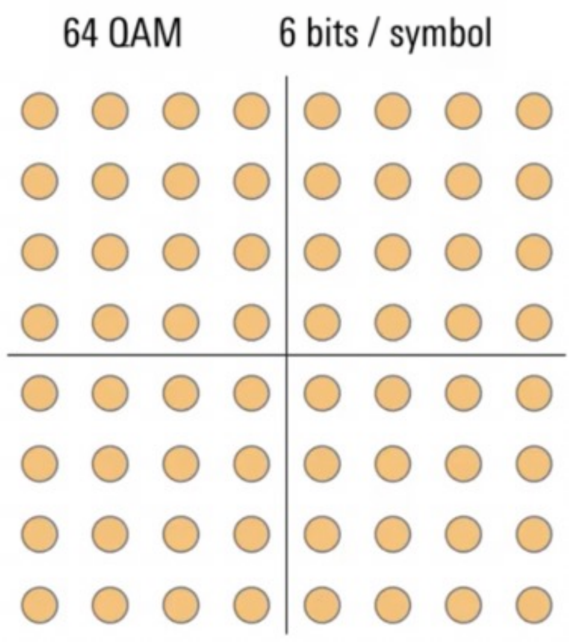
16QAM

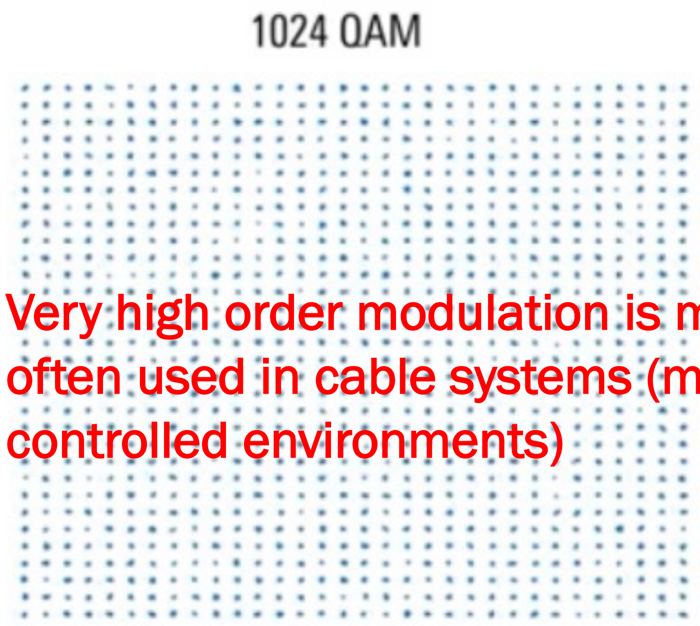


64QAM

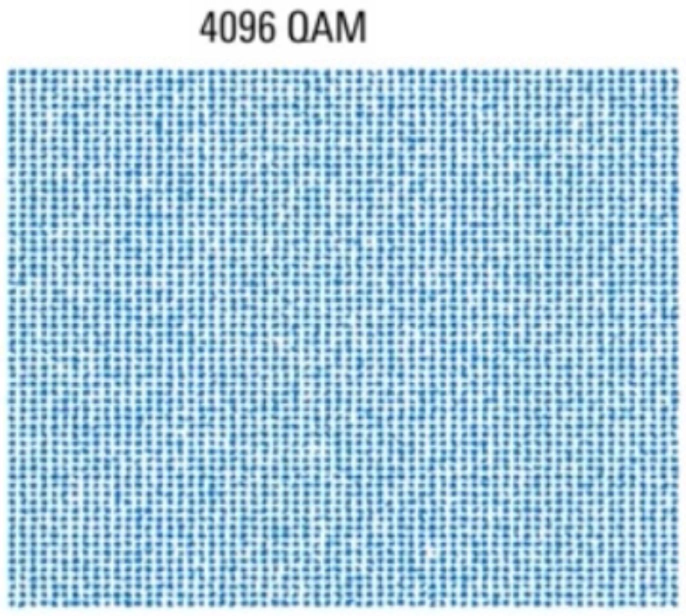
QAM Modulation Orders

- Increase the modulation order (number of states): Increases throughputs while reducing resistance to errors
- More common QAM variants are 16QAM, 64QAM, 256QAM, 1024QAM and 4096QAM
- Many over the air systems (cellular & Wifi) dynamically adapt modulation order based on channel conditions
  - Higher order when condition is good, Fall back to lower order when condition are poor



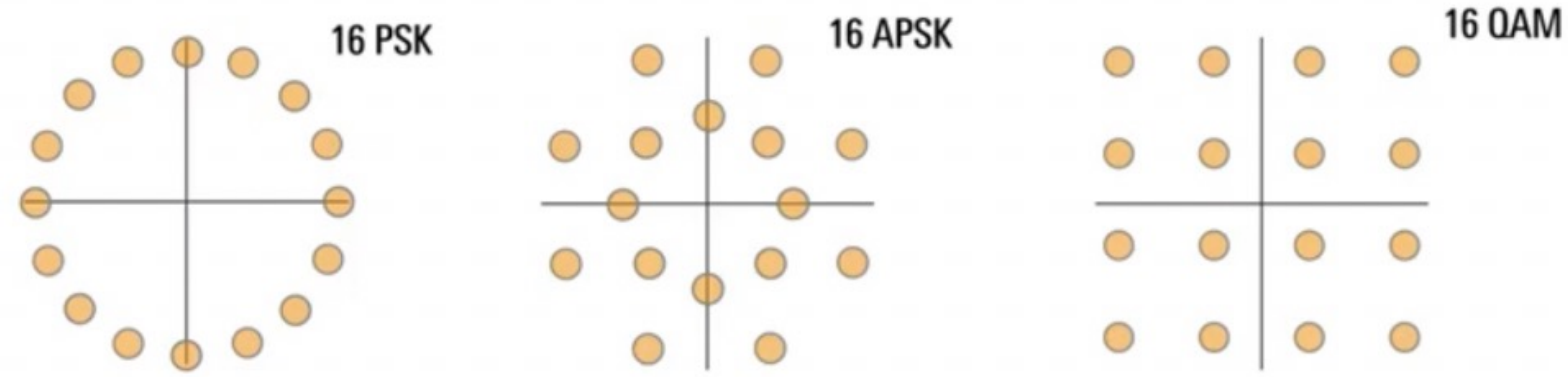


Very high order modulation is most often used in cable systems (more controlled environments)



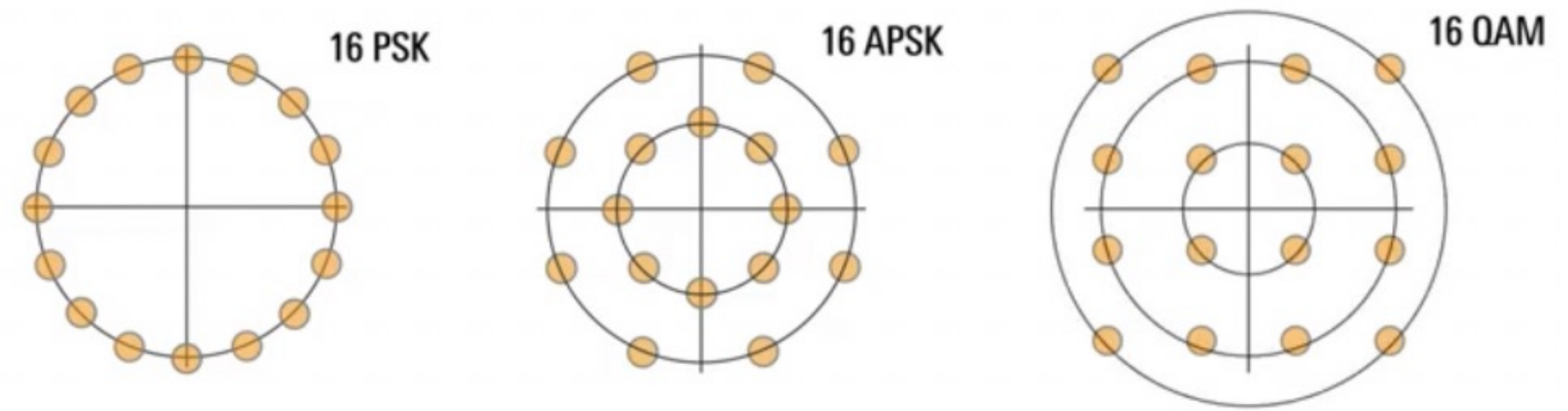
APSK and QAM Comparison

- For a given order, QAM points are further apart / more evenly distributed than APSK: More Error Resistance



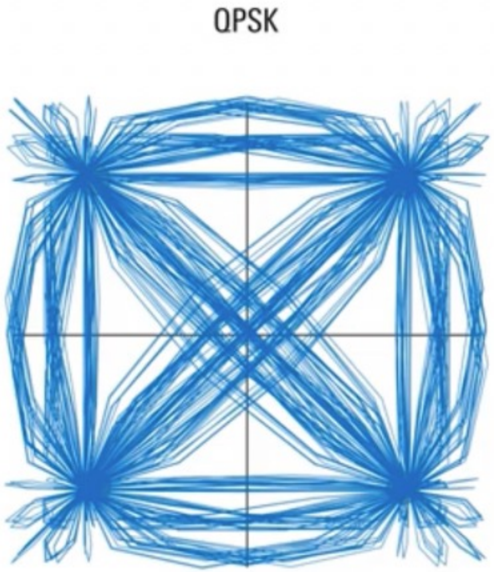
APSK and QAM Comparison

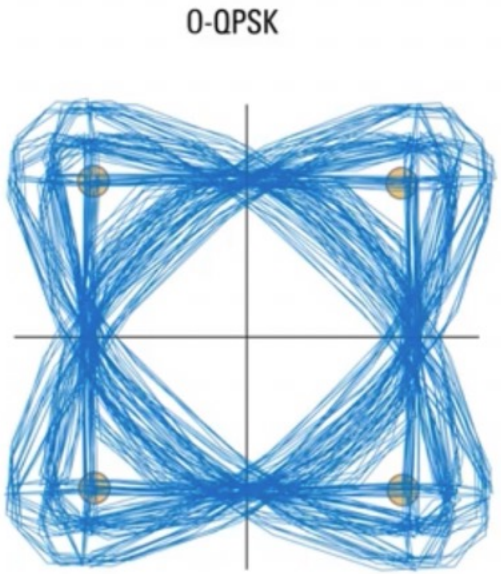
- For a given order, QAM points are further apart / more evenly distributed than APSK: More Error Resistance
- Increasing Amplitude states means higher PAPR → Higher linearity requirement



Constellation Diagram vs Vector Diagrams

- Constellation diagram show decision points
- Vector diagram shows the path the signal takes between decision points
  - Useful for differentiating between different modulation variants: PSK and OPSK/DPSK

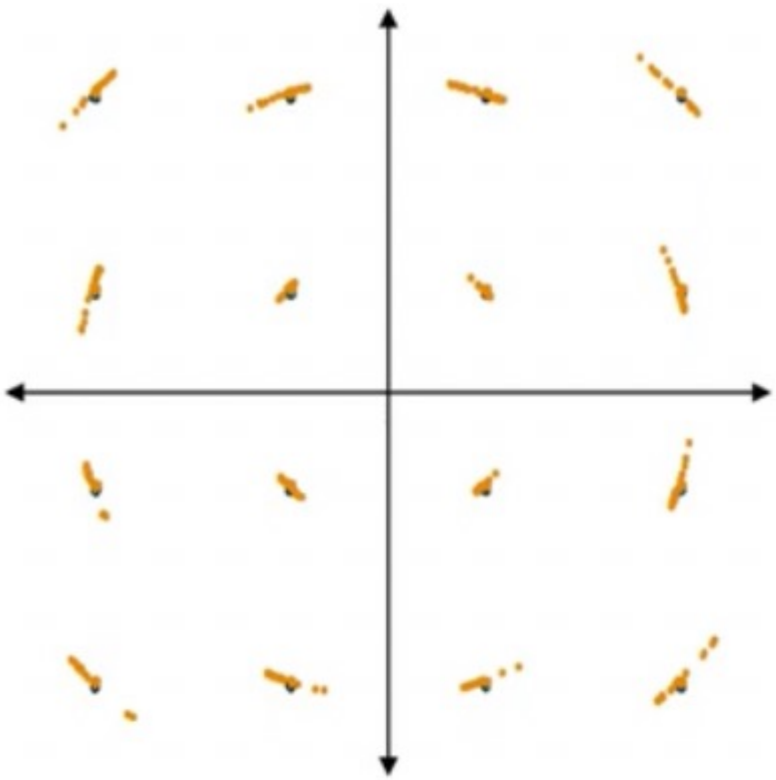




Modulation Issues

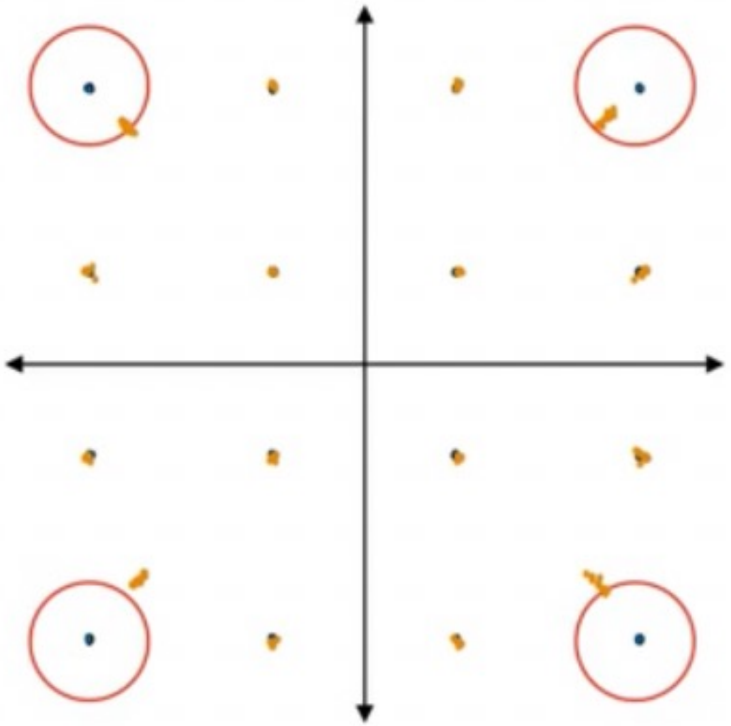
- Phase Effects (Phase Noise)
- Amplitude Effects (Compression)
- Noise Effects (AWGN, Low Noise, Spurs)
- IQ Imperfections (Gain and Quadrature Imbalances)

Modulation Issues: Phase error and Compression



Phase error / Phase Noise

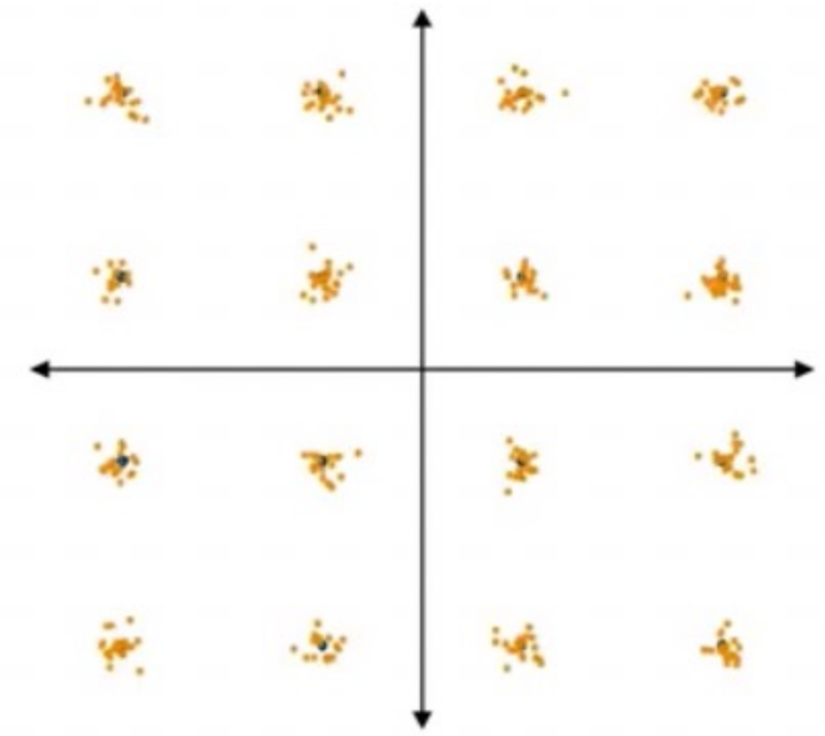
undesired variation in the phase due to by transmitter or receiver



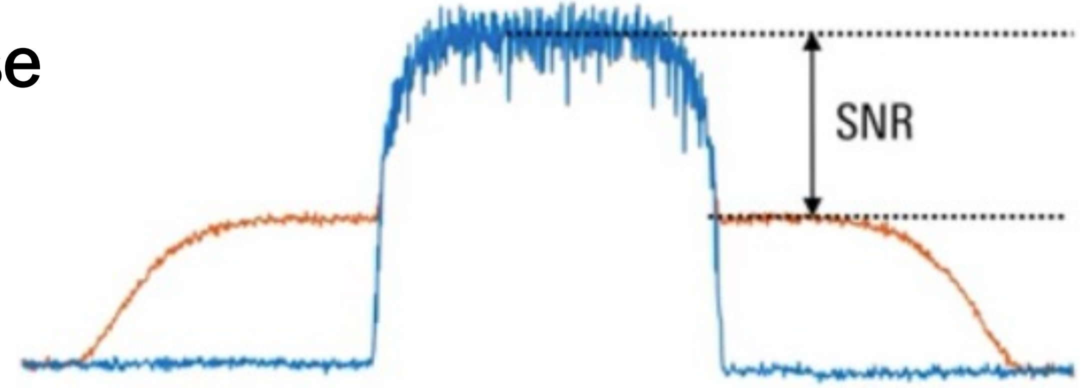
Compression

Characteristics of power amplifiers, amplification is not uniform for all levels. low gain for high input powers – referred to as Compression

Modulation Issues - Noise

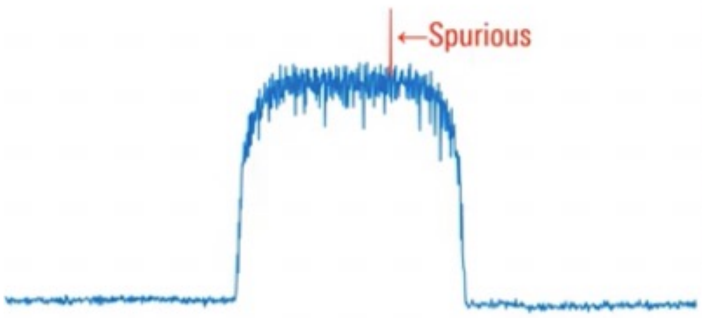


Noise

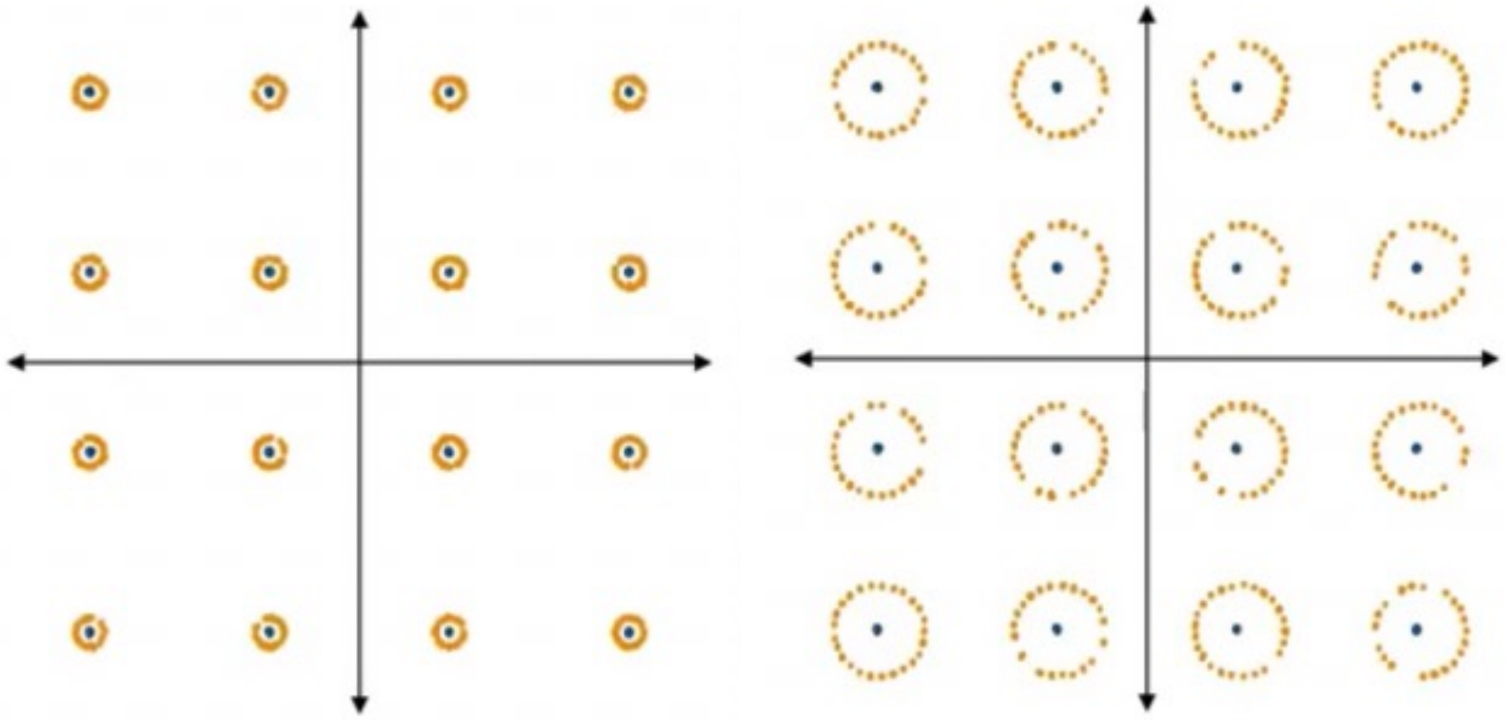


Amplitude issue: Lower SNR cause the point to spread out; lower SNR more spread out
- Noise is wideband / uncorrelated

Modulation Issues: In-band spurious

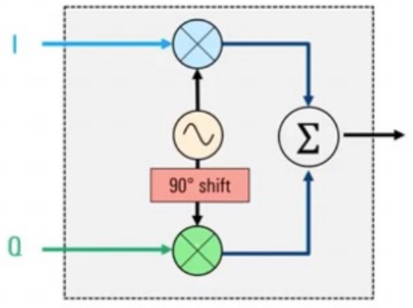


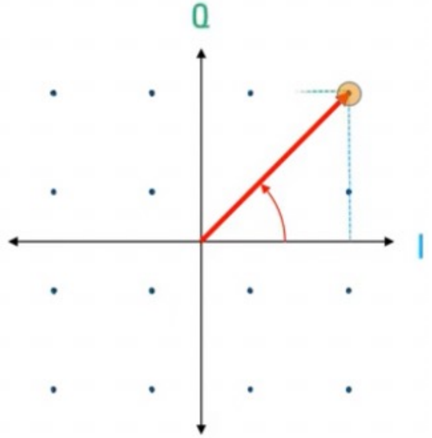
Narrow interference with the signal BW

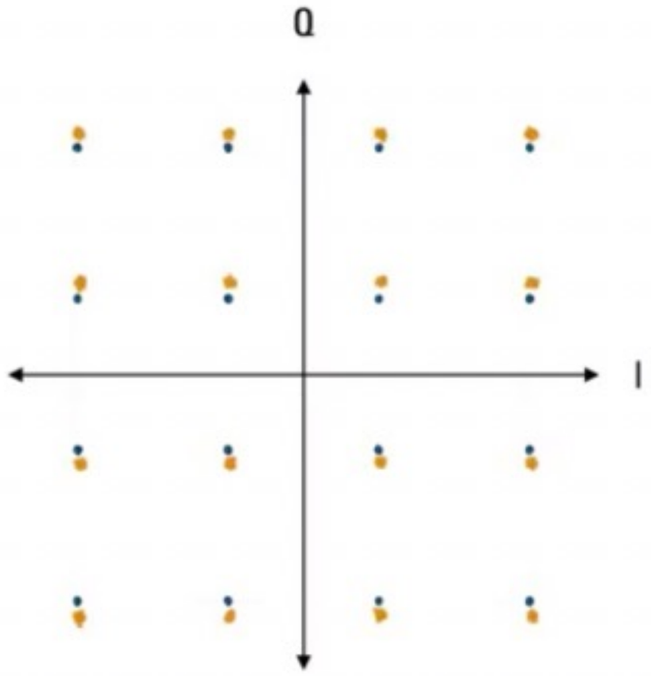


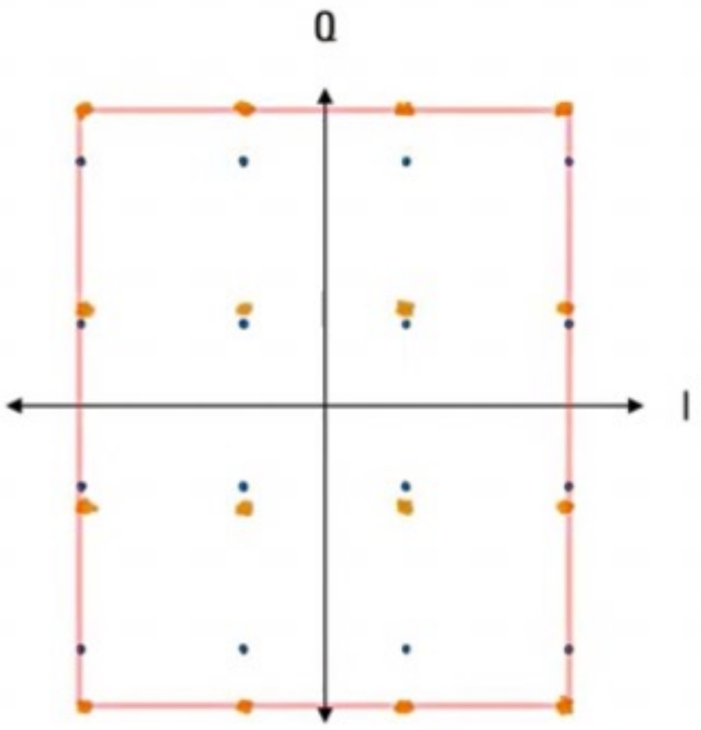
Creates circles around the reference points. Radius depends on the spurious signal level (higher level of spurs produce larger circles

Modulation Issues: IQ gain imbalance





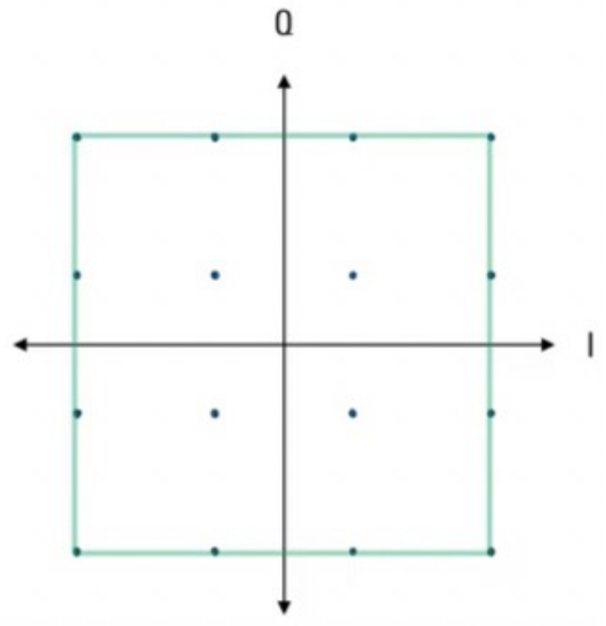


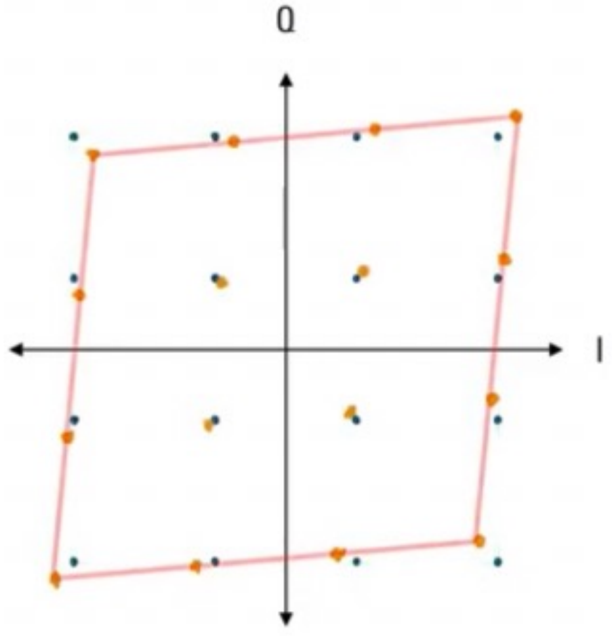


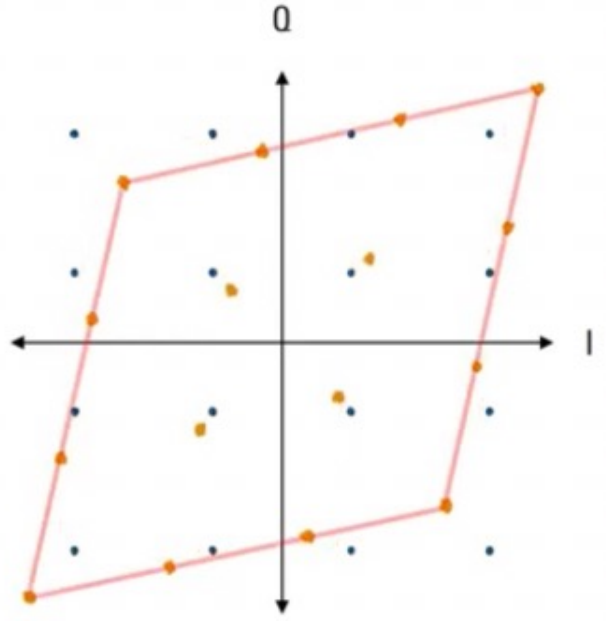
IQ Constellation – Normal
In-Phase (I) & Quadrature (Q)

QAM usually Square, IQ gain imbalance is a difference in gain between I & Q channels
Causes the constellation to be stretched in one direction (Rectangular Vs Square)
Amount of distortion is proportional to the level of imbalance

Modulation Issues: Quadrature Error







Edges of most QAM constellations should be perpendicular (90^0 to each other)

Quadrature error (offset/skew) occurs when I and Q signals are not separated by exactly 90^0

Quadrature error causes the constellation to become tilted or trapezoidal

Amount of distortion is proportional to the deviation from 90^0 separation

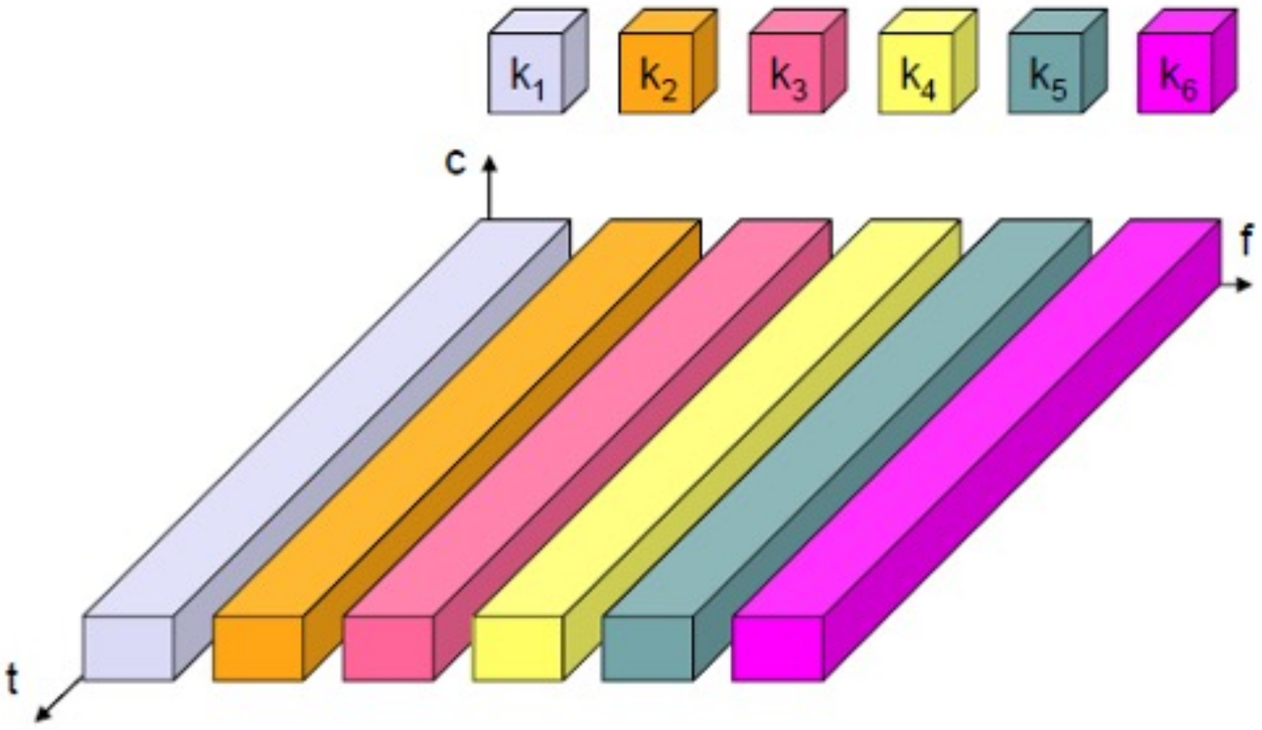
MULTIPLEXING SCHEMES

Basic multiplex schemes

- Divide spectrum into portions in order to implement different channels
- Incase Assigning these channels to different users, also called multiple access schemes
  - Frequency Division Multiple Access Scheme (FDMA)
  - Time Division Multiple Access Scheme (TDMA)
  - Code Division Multiple Access Scheme (CDMA)
  - Space Division Multiple Access Scheme (SDMA)

Frequency Division Multiple Access (FDMA)

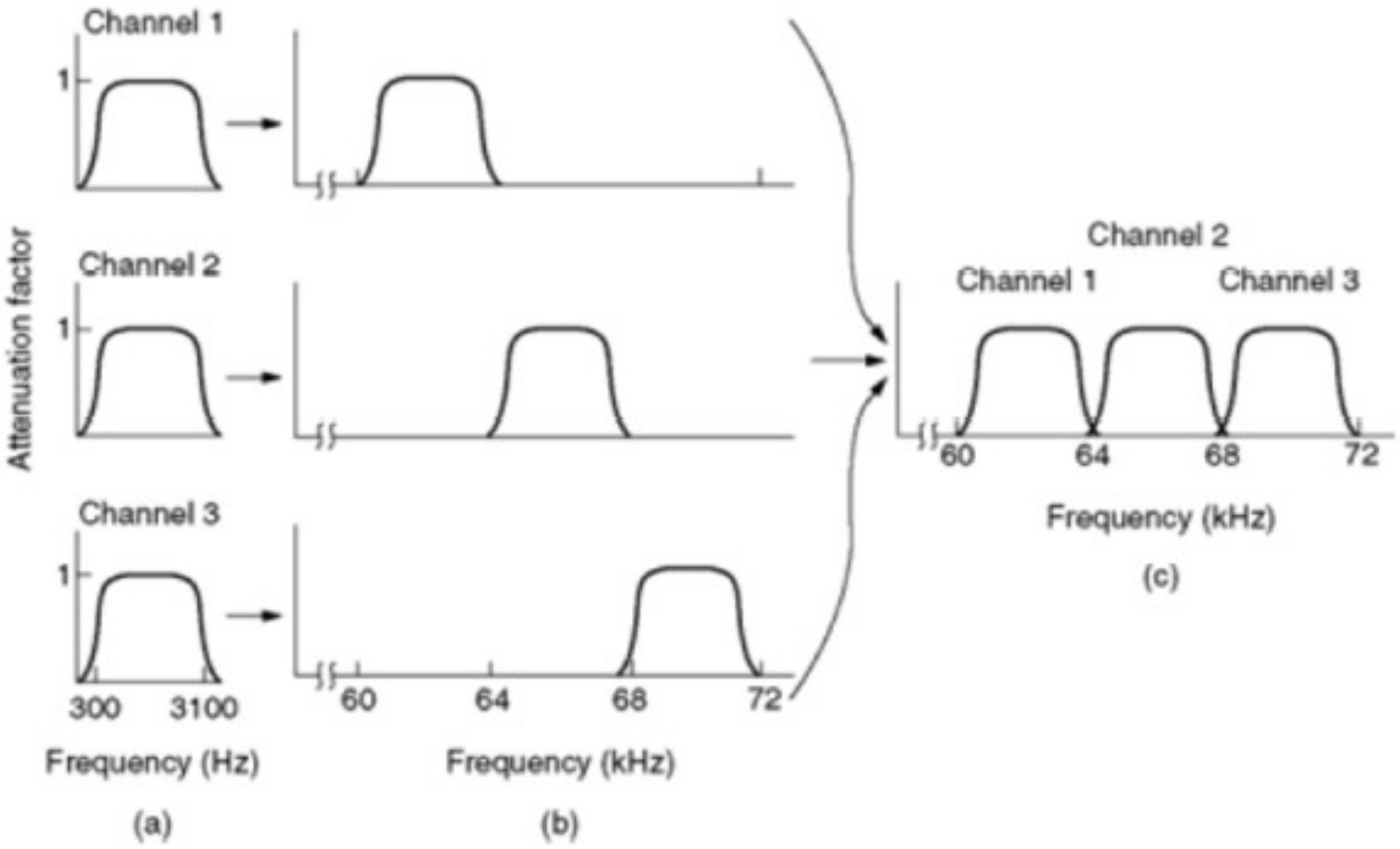
- Separation of whole spectrum into smaller frequency bands
- A channel gets a certain frequency band of the spectrum for the whole time
- Advantages
  - No dynamic coordination is needed
  - Applicable to analog signals
- Disadvantages
  - Inflexible
  - Need additional guard band
  - Waste of BW if the traffic is distributed unevenly



FDMA Cont.

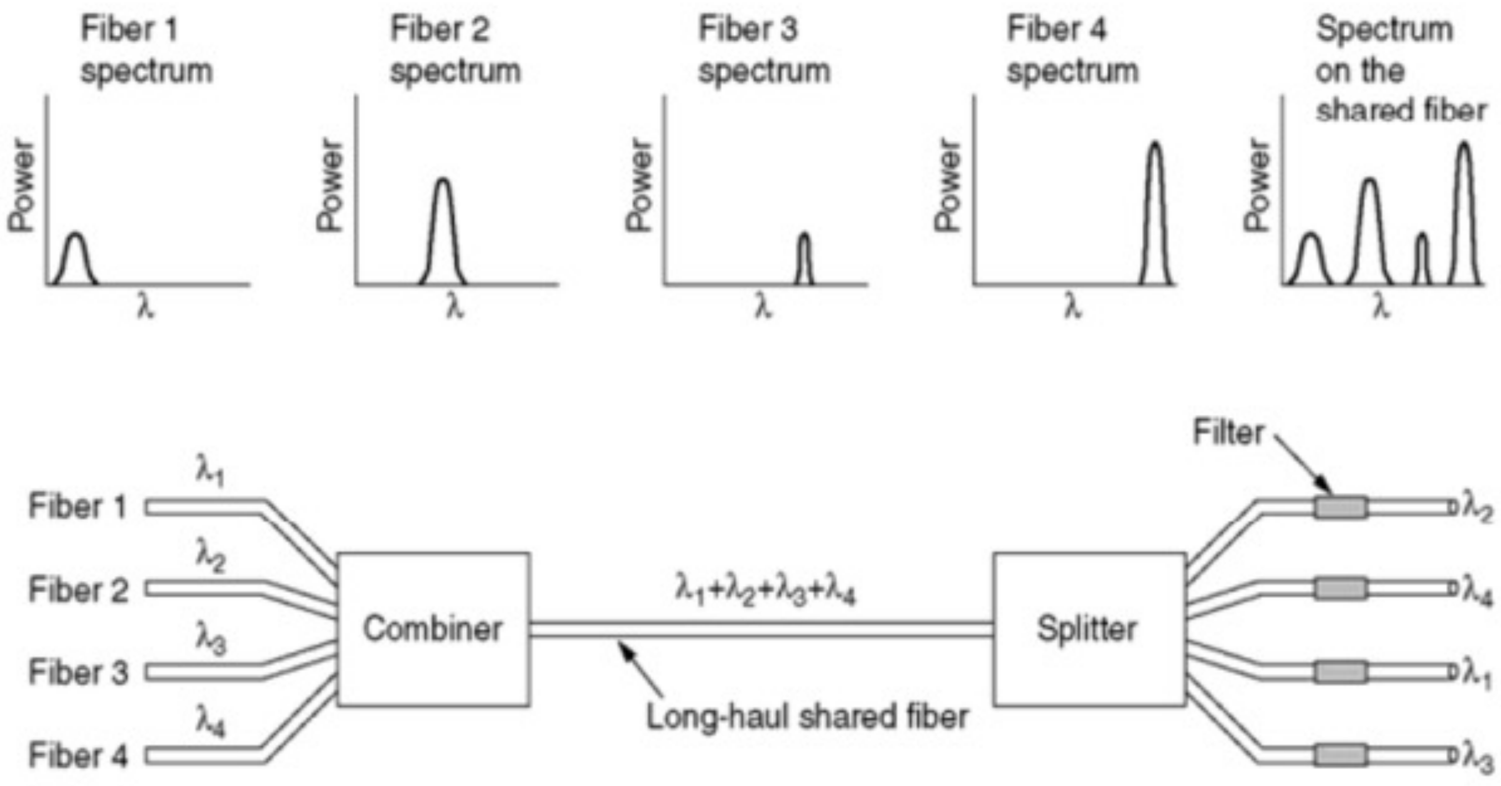
- In FDM, the frequency spectrum is divided into several frequency bands, each of which is assigned exclusively to a user. Figure shows how telephone channels are multiplexed using FDM

- *Even though there is a gap between two adjacent channel to keep them separated, there is still some overlap between them, because the band pass filter doesn't have a sharp edge.*



Wavelength Division Multiplexing (WDM)

- WDM is a variation of FDM, which is used in optical fibers. WDM can be seen as frequency division multiplexing at very high frequencies.

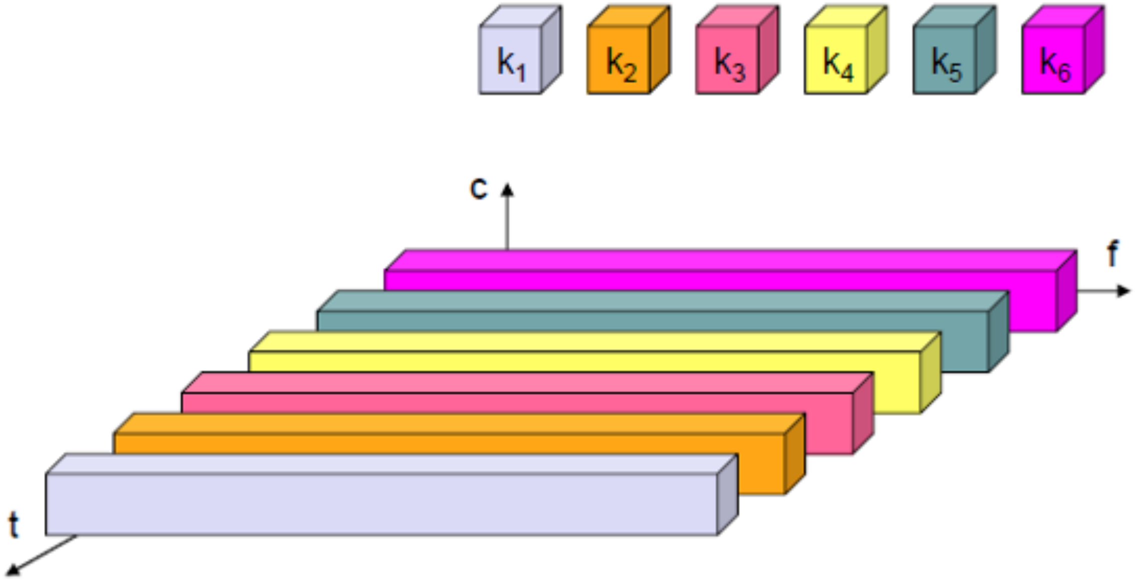


Time Division Multiple Access (TDMA)

- A channel gets whole spectrum for a certain amount of time

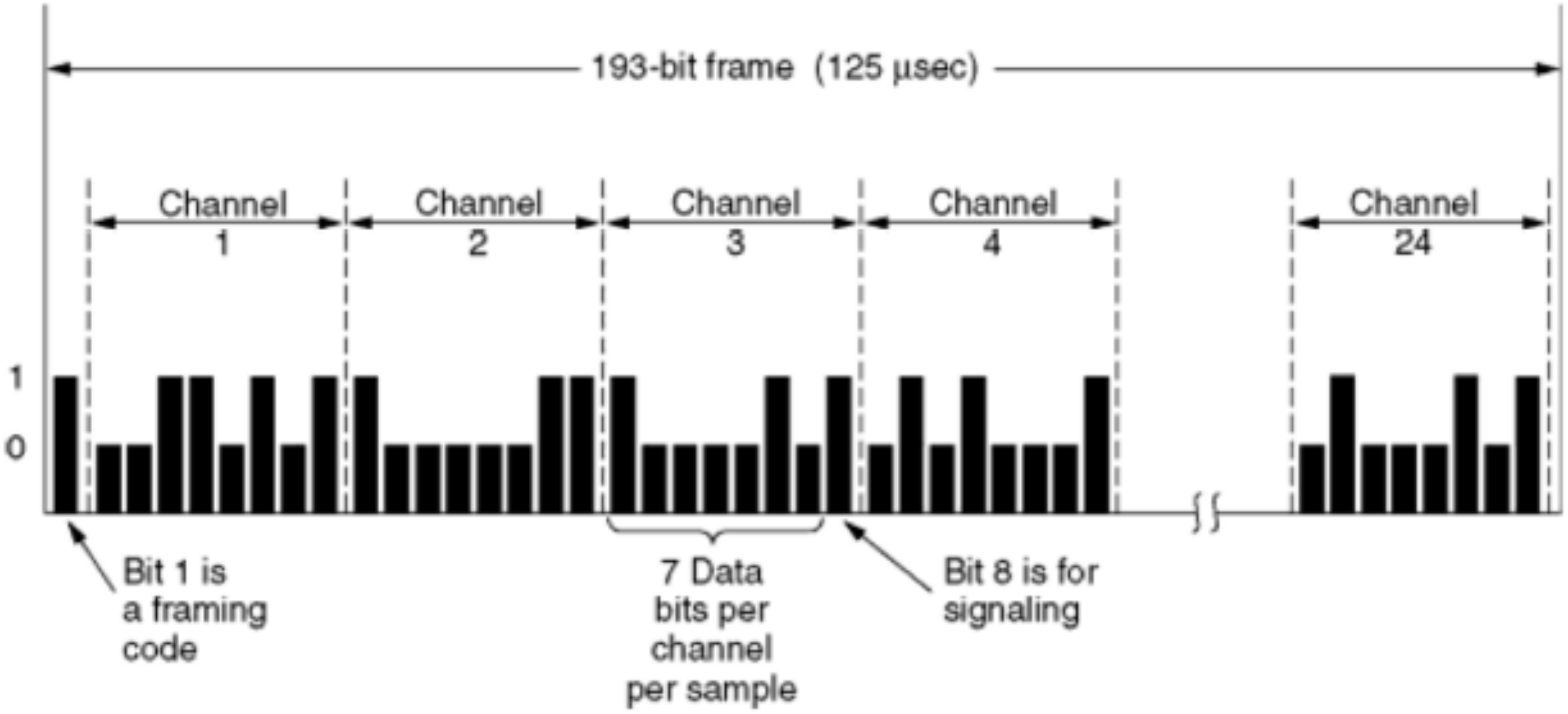
- Advantages
  - Only one carrier in the medium at any time
  - Throughput high for many uses (good for uneven traffic)

- Disadvantages
  - Precise synchronization is needed



TDMA cont.

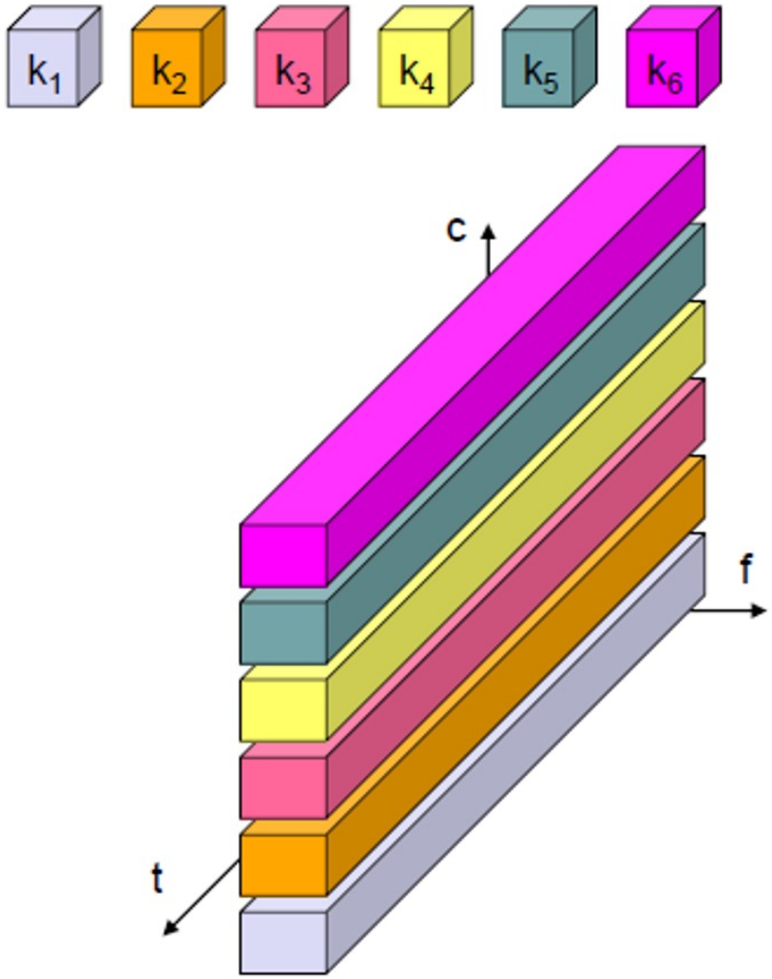
- In TDM, the channels are divided into time slots, each of which is assigned to a specific user. Users get the entire bandwidth during their time slot. Different from FDM, which requires analog data, TDM can be used only for digital data.



Code Division Multiple Access (CDMA)

- Each channel has unique code
  - UMTS and HSPA
- All channels uses the same spectrum at the same time

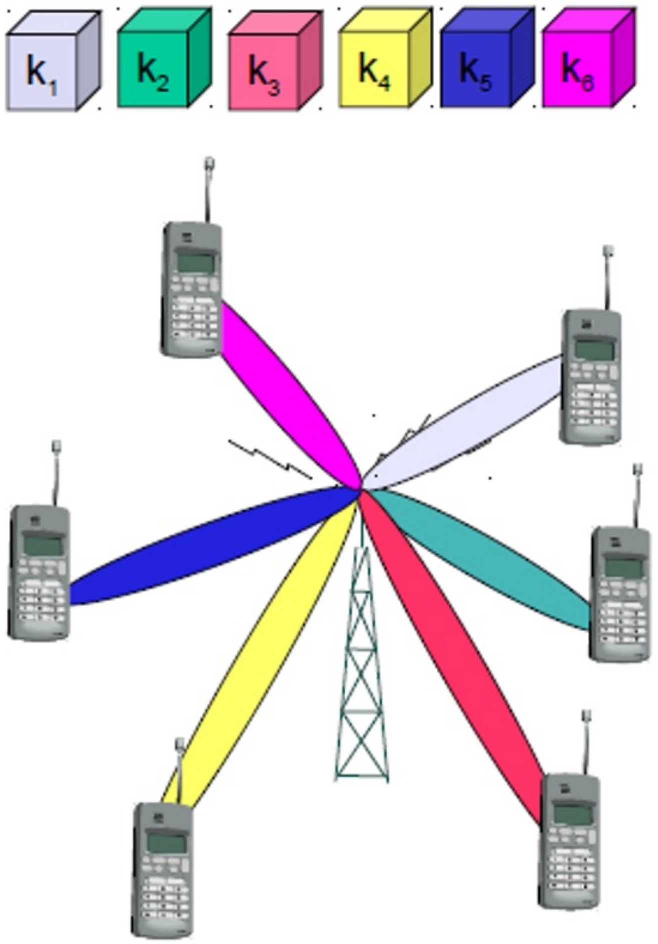
- **Advantages**
  - Bandwidth efficient
  - No coordination or synchronization is necessary
  - Good protection against interference and trapping
- **Disadvantages**
  - More complex receivers
  - Intra-cell interference



Space Division Multiple Access (SDMA)

- Every user can be separated from other users by means of directional antenna (beamforming)
- All users use the same spectrum at the same time

- Advantages
  - Bandwidth efficient
  - No coordination or synchronization is necessary
- Disadvantages
  - Mutual interference can not be fully avoided
  - Lower user data rates
  - More complex signal regeneration

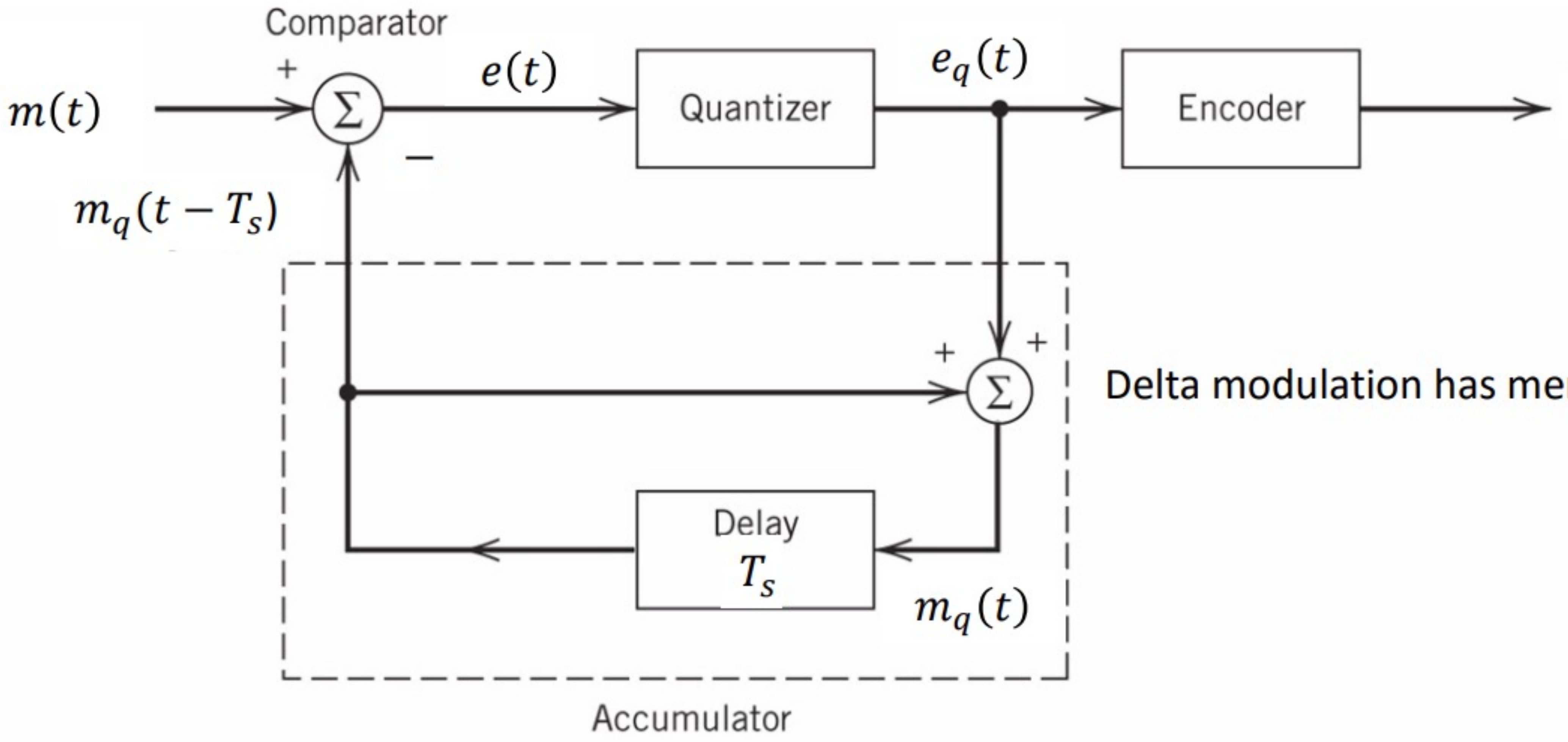


ANY QUESTION??

THANK YOU!!

Delta Modulation

- A delta modulation (DM or Δ-modulation) is an analog-to-digital and digital-to-analog signal conversion technique used for transmission of voice information where quality is not of primary importance.
- The difference between the input signal $x(t)$ and staircase approximated signal is confined to two levels, i.e., $+\Delta$ and $-\Delta$.
- A single bit PCM code to achieve digital transmission of analog signal. Use only 1 bit either logic "1" or "0"
- Logic "0" is transmitted if current sample is smaller than the previous sample
- Logic "1" is transmitted if current sample is larger than the previous sample



Delta modulation has memory

Applications of Delta Modulations

- Delta modulation is employed to realize high signal to noise ratio.
- This modulation is applied to ECG waveform for database reduction and real-time signal processing.