Lesson 4
Modulation and encoding
Topic objectives
By the end of the topic the learner should be able to:

i. Distinguish between baud and data rate
ii. Describe the need for modulation
iii. Describe different types of modulation

Data encoding-Terminologies

- ***Signaling***: is a method of using electrical, light energy or radio waves to communicate.
- **Encoding:** is the process of changing a signal to represent data – digital signaling
- **Modulation:** is the process of changing a signal to represent data – analog signaling
- ***Signaling element***: it's the part of a signal that occupies the shortest time interval of a signal code. It's the smallest element recognizable by a receiver and can be a part of bit, bit or multiple bits.
- Unipolar
  - All signal elements have same sign (+ve or –ve voltages)
- Polar
  - One logic state represented by positive voltage the other by negative voltage
- Data rate
  - Rate of data transmission in bits per second
- Duration or length of a bit
  - Time taken for transmitter to emit the bit
- Modulation rate
  - Rate at which the signal level changes
  - Measured in baud = signal elements per second
- Mark and Space
  - Binary 1 and Binary 0 respectively

Interpreting Signals

- Need to know
  - Timing of bits - when they start and end
  - Signal levels
- Factors affecting successful interpreting of signals
  - Signal to noise ratio SNR
  - Data rate
  - Bandwidth

The encoding technique depends on the media, communication facilities available and the requirements that have to be met such as:

- Data integrity-repeaters (digital) are less noisy than amplifiers(analog)
- Signal integration –convenience/economics of carrying voice, video , data (multimedia) etc together
- Bandwidth / capacity utilization- Time Division Multiplexing TDM(digital) better than Frequency Division Multiplexing FDM (analog)

- Security and privacy: encryption techniques are digital

Comparison of Encoding Schemes

- Signal Spectrum
  - Lack of high frequencies reduces required bandwidth
  - Lack of DC component allows AC coupling via transformer or capacitors, providing noise isolation
  - Concentrate power in the middle of the bandwidth
- Clocking
  - Synchronizing transmitter and receiver
  - External clock
  - Sync mechanism based on signal
- Error detection
  - Can be built in to signal encoding
- Signal interference and noise immunity
  - Some codes are better than others
- Cost and complexity
  - Higher signal rate (& thus data rate) lead to higher costs
  - Some codes require signal rate greater than data rate

Example of Data Communication System:

Here is a picture of the overall wireless transmission and receiving system:

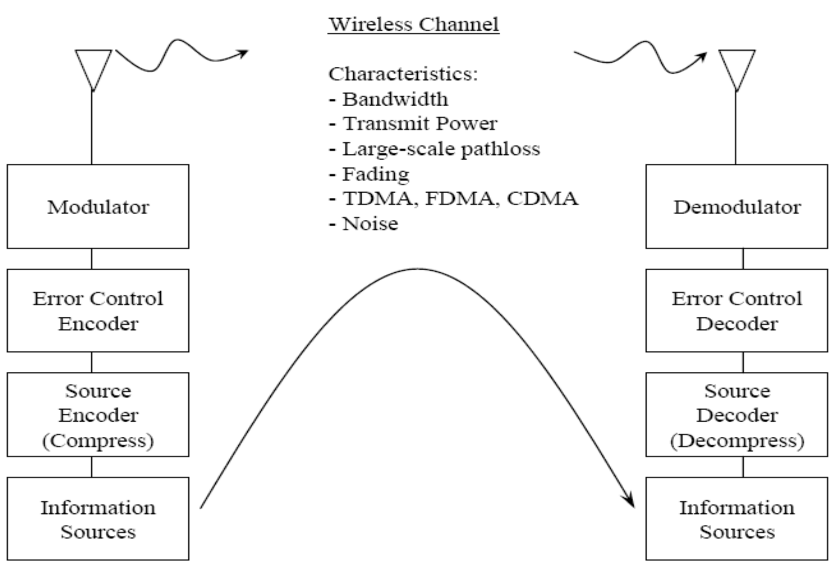


Fig 4.1 Wireless communication system

Most communications systems fall into one of three categories:

- Bandwidth efficient
- Power efficient
- Cost efficient (best quality- low BER).

Bandwidth efficiency describes the ability of a modulation scheme to accommodate data within a limited bandwidth. This require that we differentiate between Data rate and Baud Rate

- Bit Rate / Baud Rate
    - *Bit rate is the number of bits per second. Baud rate is the number of signal units per second. Baud rate is less than or equal to the bit rate.*
    - *Bit rate is important in computer efficiency*
    - *Baud rate is important in data transmission.*
        - *Baud rate determines the bandwidth required to send signal*
    - *Baud rate = bit rate / Number of bits per signal unit*
    - An analog signal carries 4 bits in each signal unit. If 1000 signal units are sent per second, find the baud rate and the bit rate
        - Baud rate = 1000 (baud/s), Bit rate = 1000 x 4 = 4000 bps
- The bit rate of a signal is 3000. If each signal unit carries 6 bits, what is the baud rate?
    - Baud rate = 3000/6 =500 bauds/sec
- Bandwidth similar to ASK, but data rate can 2 or more times greater.
- Given a bandwidth of 5000 Hz for an 8-PSK signal, what are the baud rate and bit rate?

For PSK the baud rate is the same as the bandwidth, which means the baud rate is 5000. But in 8-PSK the bit rate is 3 times the baud rate, so the bit rate is 15,000 bps

- A constellation diagram consists of eight equally spaced points on a circle. If the bit rate is 4800 bps, what is the baud rate?
- The constellation indicates 8-PSK with the points 45 degrees apart. Since $2^3 = 8$, 3 bits are transmitted with each signal unit. Therefore, the baud rate is 4800 / 3 = 1600 baud
    - What is the bit rate for a 1000-baud 16-QAM signal.
- A 16-QAM signal has 4 bits per signal unit since $\log_2 16 = 4$. Thus, (1000)(4) = 4000 bps
    - Compute the baud rate for a 72,000-bps 64-QAM signal.
    - A 64-QAM signal has 6 bits per signal unit since $\log_2 64 = 6$.

Therefore, 72000 / 6 = 12,000 baud

Power efficiency describes the ability of the system to reliably send information at the lowest practical power level. In most systems, there is a high priority on bandwidth efficiency

The parameter to be optimized depends on the demands of the particular system, as can be seen in the following two examples:

For designers of digital terrestrial microwave radios, their highest priority is good bandwidth efficiency with low bit-error-rate. They have plenty of power available and are not concerned with power efficiency. They are not especially concerned with receiver cost or complexity because they do not have to build large numbers of them.

On the other hand, designers of hand-held cellular phones put a high priority on power efficiency because these phones need to run on a battery.

Cost is also a high priority because cellular phones must be low-cost to encourage more users. Accordingly, these systems sacrifice some bandwidth efficiency to get power and cost efficiency.

Every time one of these efficiency parameters (bandwidth, power or cost) is increased, another parameter is decreases, or becomes more complex or does not perform well in a poor environment. Cost is a dominant system priority.

Low-cost radios will always be in demand. In the past, it was possible to make a radio low-cost by sacrificing power and bandwidth efficiency. This is no longer possible. The radio spectrum is very valuable and operators who do not use the spectrum efficiently could lose their existing licenses or lose out in the competition for new ones. These are the tradeoffs that must be considered in digital RF communications design.

Why we do modulation and encoding

For data to be **reliably** transmitted over a long noisy channel, the data must be encoded ie (conditioned for transmission) – channel coding.

Channel coding refers to:

- Error control;
    - Error detection - Error detection is the ability to detect the presence of errors caused by noise or other impairments during transmission from the transmitter to the receiver.
    - Error correction- Error correction is the additional ability to reconstruct the original, error-free data.
- Line encoding

Error control

An error in digital data communication is the inversion of a "1" to "0" or vice versa.

Causes of errors

- Human errors and Network errors
- Corrupted data
- Extra data/Lost data
- Signal distortion eg Electro Magnetic Interference EMI, Adjacent Channels
- Synchronization problems
- Malfunctioning devices

A signal loss can be caused by errors on link such as:
Propagation delay - delay from the time a signal was transmitted to the time it's received. It's a major problem if it's not the same across all frequencies.
Jitter (vibrations) –caused by minute vibrations in amplitude, phase and frequency.
Attenuation- reduction in signal strength, high frequencies attenuate faster than low frequencies, thin cables have more attenuation than thick cables.
White noise- it's caused by thermal agitation of electrons in a conductor, thus it's not easy to eliminate in electrical channels.

Types of errors control:

The two ways to design the channel code and protocol for an error correcting system are:

- Back ward error control (BEC): The transmitter sends the data and also an error detection code, which the receiver uses to check for errors, and initiates an Automatic repeat-request (ARQ) retransmission of erroneous data. In many cases, the request is implicit; the receiver sends an acknowledgement (ACK) of correctly received data, and the transmitter re-sends anything not acknowledged within a reasonable period of time.
- ARQs are of several types such as:
  - Stop - and – wait; slow and inefficient.
  - Go – back – N times; its continuous
  - Selective- continuous requires buffer memory, track and full duplex communication
  - Hybrid ARQ – combines the advantages of the other ARQs
- Forward error correction (FEC): The transmitter encodes the data with an **error-correcting code** (ECC) and sends the coded message. The receiver decodes what it receives into the "most likely" data. The codes are designed so that it would take an "unreasonable" amount of noise to trick the receiver into misinterpreting the data.

It is possible to combine the two, so that minor errors are corrected without retransmission, and major errors are detected and a retransmission requested.

Error detection schemes

Repetition schemes

For example, if we want to send "1011", we may repeat this block three times each. Suppose we send "1011 1011 1011", and this is received as "1010 1011 1011". As one group is not the same as the other two, the receiver can determine that an error has occurred.

Parity schemes

A *parity bit* is an *error detection* mechanism that detect only an odd number of errors. The stream of data is broken up into blocks of bits, and the number of 1 bits is counted. Then, a "parity bit" is set (or cleared) if the number of one bits is odd (or even). (This scheme is called even parity; odd parity can also be used.) If the tested blocks overlap, then the parity bits can detect, and even correct it if the error affects a single bit:

Checksum

A checksum of a message is an arithmetic sum of message code words of a certain word length, for example byte values, and their carry value. The sum is negated by means of ones-complement, and stored or transferred as an extra code word extending the message.

On the receiver side, a new checksum may be calculated, from the extended message. If the new checksum is not 0, error is detected.

Checksum schemes include parity bits, check digits, and longitudinal redundancy check

Cyclic redundancy checks

More complex error detection (and correction) methods make use of the properties of finite fields and polynomials over such fields.

The cyclic redundancy check considers a block of data as the coefficients to a polynomial and then divides by a fixed, predetermined polynomial. The coefficients of the result of the division is taken as the redundant data bits, the CRC. On reception, one can re-compute the CRC from the payload bits and compare this with the CRC that was received. A mismatch indicates that an error occurred.

MODULATION

Definition

1. Modulation is the process of encoding information onto a carrier wave ie shifting the signal frequency from low frequency(Audio Frequency) to high frequency(Radio Frequency) or
2. Changing the signal from analogue to digital or vice versa.

- Modulation is used because:
    - The channel does not include the 0 Hz frequency and baseband signaling is impossible
    - The bandwidth of the channel is split between several channels for frequency multiplexing

For wireless radio-communications, the size of the antenna decreases when the transmitted frequency increases

In the definition, we have seen that message signal can be varied according to the angular or amplitude of the carrier signal. What happens if message signal is varied in accordance to angular of carrier signal and what happens if message signal is varied according to the amplitude of carrier signal?

Carrier signal equations

Looking at the theory, it is possible to describe the carrier in terms of a sine wave as follows:

$$C(t) = C \sin(\omega c + \varphi)$$

Where:

carrier frequency in Hertz is equal to $\omega c / 2\pi$
C is the carrier amplitude
φ is the phase of the signal at the start of the reference time

Both C and φ can be omitted to simplify the equation by changing C to "1" and φ to "0".

Modulating signal equations

The modulating waveform can either be a single tone. This can be represented by a cosine waveform, or the modulating waveform could be a wide variety of frequencies - these can be represented by a series of cosine waveforms added together in a linear fashion.

For the initial look at how the signal is formed, it is easiest to look at the equation for a simple single tone waveform and then expand the concept to cover the more normal case. Take a single tone waveform:

$$m(t) = M \sin(\omega m + \varphi)$$

Where:

modulating signal frequency in Hertz is equal to $\omega m / 2\pi$
M is the carrier amplitude
φ is the phase of the signal at the start of the reference time

Both C and φ can be omitted to simplify the equation by changing C to "1" and φ to "0".

It is worth noting that normally the modulating signal frequency is well below that of the carrier frequency.

Overall modulated signal for a single tone

The equation for the overall modulated signal is obtained by multiplying the carrier and the modulating signal together.

$$y(t) = [A + m(t)] . c(t)$$

The constant A is required as it represents the amplitude of the waveform.

Substituting in the individual relationships for the carrier and modulating signal, the overall signal becomes:

$$y(t) = [A + M \cos(\omega m\, t + \varphi] . \sin(\omega c\, t)$$

The trigonometry can then be expanded out to give an equation that includes the components of the signal:

$$y(t) = [A + M\cos(\omega m\, t + \varphi)] \cdot \sin(\omega c\, t)$$

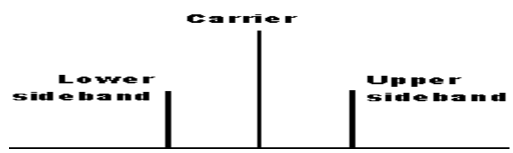
This can be expanded out using the standard trigonometric rules:

$$y(t) = A \cdot \sin(\omega c\, t) + M/2\, [\sin((\omega c + \omega m)\, t + \varphi) + M/2\, [\sin((\omega c - \omega m)\, t - \varphi)$$

In this theory, three terms can be seen which represent the carrier, and upper and lower sidebands:

Carrier: $A \cdot \sin(\omega c\, t)$
Upper sideband: $M/2\, [\sin((\omega c + \omega m)\, t + \varphi)$
Lower sideband: $M/2\, [\sin((\omega c - \omega m)\, t - \varphi)$

Note also that the sidebands are separated from the carrier by a frequency equal to that of the tone.



Sidebands on an amplitude modulated carrier when modulated with a single tone

It can be seen that for a case where there is 100% modulation, i.e. M = 1, and where the carrier is not suppressed, i.e. A = 1, then the sidebands have half the value of the carrier, i.e. a quarter of the power each.

Advantages of Modulation:

- With the help of modulation, we can increase the quality of reception.
- We can also decrease the height and size of the antenna.
- Avoid mixing of different frequency signals
- Increase the range of communication
- Allow the flexibility for adjusting the bandwidth.

1. **Analogue data – analogue signal**

Device used is Analogue Transceiver (Transmitter – Receiver)

Amplitude Modulation:

In the amplitude modulation, amplitude of carrier signal wave is varied in accordance with the modulating or message signal by keeping the phase and frequency of the signals constant. The carrier signal frequency would be greater than the modulating signal frequency. Amplitude modulation is first type of modulation used for transmitting messages for long distances by the mankind. The AM radio ranges in between 535 to 1705 kHz which is great. But when compared to frequency modulation, the Amplitude modulation is weak, but still it is used for transmitting messages. Bandwidth of amplitude modulation should be twice the frequency of modulating signal or message signal. If the modulating signal frequency is 10 kHz then the Amplitude modulation frequency should be around 20 kHz. In AM radio broadcasting, the modulating signal or message signal is 15 kHz. Hence the AM modulated signal which is used for broadcasting should be 30 kHz.

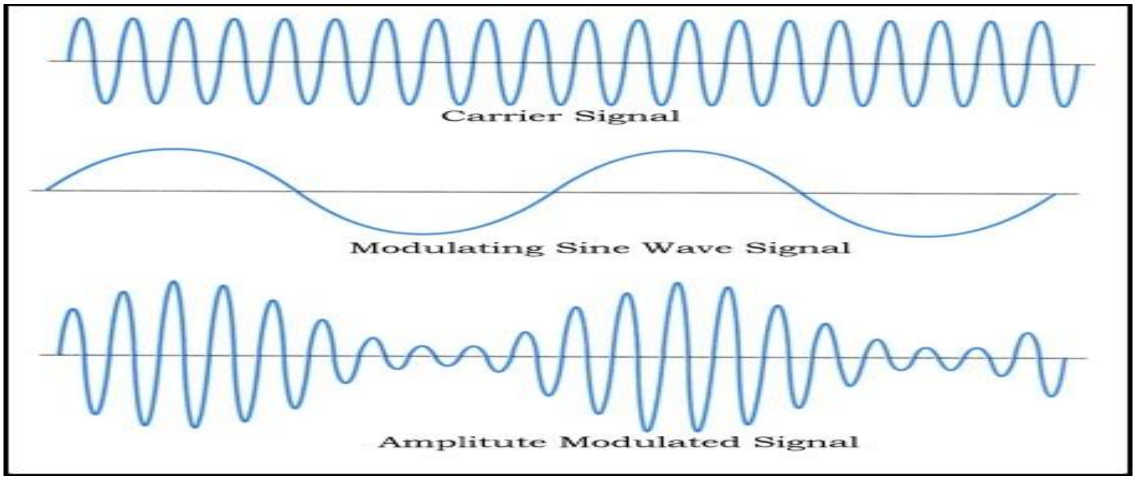


Fig 4.2 Amplitude Modulation

Advantages of Amplitude Modulation:

- Because of amplitude modulation wavelength, AM signals can propagate longer distances.
- For amplitude modulation, we use simple and low cost circuit; we don't need any special equipment and complex circuits that are used in frequency modulation.
- The Amplitude modulation receiver will be wider when compared to the FM receiver. Because, atmospheric propagation is good for amplitude modulated signals.
- Bandwidths limit is also big advantage for Amplitude modulation, which doesn't have in frequency modulation.
- Transmitter and receiver are simple in Amplitude modulation. When we take a demodulation unit of AM receiver, it consists of RC filter and a diode which will demodulate the message signal or modulating signal from modulated AM signal, which is unlike in Frequency modulation.
- Zero crossing in Amplitude modulation is equidistant.

Disadvantages of Amplitude Modulation:

- Adding of noise for amplitude modulated signal will be more when compared to frequency modulated signals. Data loss is also more in amplitude modulation due to noise addition. Demodulators cannot reproduce the exact message signal or modulating signal due to noise.
- More power is required during modulation because Amplitude modulated signal frequency should be double than modulating signal or message signal frequency. Due to this reason more power is required for amplitude modulation.

- Sidebands are also transmitted during the transmission of carrier signal. More chances of getting different signal interfaces and adding of noise is more when compared to frequency modulation. Noise addition and signal interferences are less for frequency modulation. That is why Amplitude modulation is not used for broadcasting songs or music.

Applications of Amplitude Modulation:

- Used to carry message signals in early telephone lines.
- Used to transmit Morse code using radio and other communication systems.
- Used in Navy and Aviation for communications as AM signals can travel longer distances.
- Widely used in amateur radio.

Angle Modulation:

In the angle modulation, again there are two different types of modulations.

A. Frequency modulation
B. Phase modulation.

A. Frequency Modulation:

The process where the carrier signal frequency is varied according to the message signal or modulation signal frequency by keeping the amplitude constant is called frequency modulation.

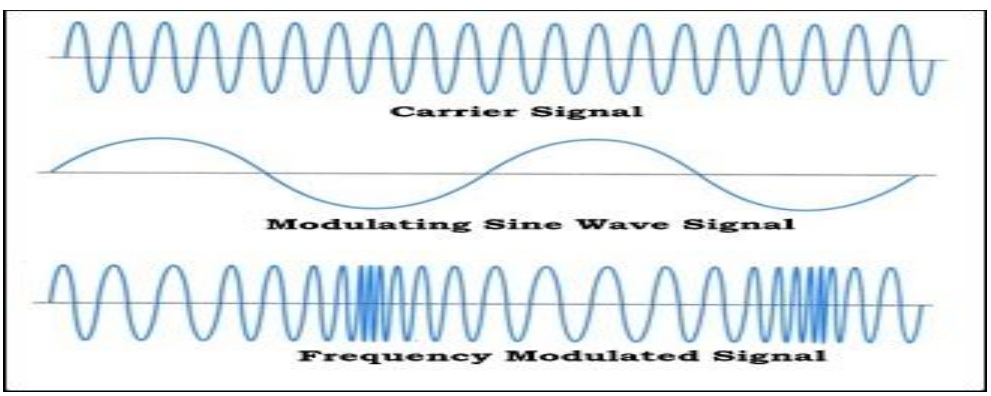


Fig 4.3 Frequency Modulation

Advantages of Frequency Modulation:

- Frequency modulation has more noise resistivity when compared to other modulation techniques. That's why they are mainly used in broadcasting and radio communications as we can easily find out the noise in the amplitude by using a limiter.

- The frequency modulation is having greater resistance to rapid signal strength variation, which we will use in FM radios even while we are travelling and frequency modulation is also mainly used in mobile communication purposes.
- For transmitting messages in frequency modulation, it does not require special equipment like linear amplifiers or repeaters and transmission levels are higher when compared to other modulation techniques. It does not require any class C or B amplifiers for increasing the efficiency.
- Transmission rate is good for frequency modulation when compared to other modulation that is frequency modulation can transmit around 1200 to 2400 bits per second.
- Frequency modulation has a special effect called capture effect in which high frequency signal will capture the channel and discard the low frequency or weak signals from interference.

Disadvantages of Frequency Modulation:

- In the transmission section, we don't need any special equipment but in the reception, we need more complicated demodulators for demodulating the carrier signal from message or modulating signal.
- Frequency modulation cannot be used to find out the speed and velocity of a moving object. Static interferences are more when compared to phase modulation. Outside interference is one of the biggest disadvantages in the frequency modulation. There may be mixing because of nearby radio stations, pagers, construction walkie-talkies etc.
- To limit the bandwidth in the frequency modulation, we use some filter which will again introduce some distortions in the signal.
- Transmitters and receiver should be in same channel and one free channel must be there between the systems.
- Spectrum space is limit for the frequency modulation and careful controlling the deviation ration.

Applications of Frequency Modulation (FM):

- Frequency modulation is used in radio's which is very common in our daily life.
- Frequency modulation is used in audio frequencies to synthesize sound.
- For recording the video signals by VCR systems, frequency modulation is used for intermediate frequencies.
- Used in applications of magnetic tape storage.

B. Phase Modulation:

In the phase modulation, we vary the carrier signal in accordance with the phase of the modulating signal or message signal by keeping the frequency constant. If the amplitude of message or modulating signal is huge then the phase shift will also be greater.

Advantages and Disadvantages of Phase Modulation:

- The main advantage of phase modulation is that it has less interference from static, which is why we use this type of modulation in finding out the speed or velocity of a moving object. In frequency modulation, we cannot find out the velocity of moving object.
- The main disadvantage is phase ambiguity comes if we increase the phase modulation index, and data loss is more and we need special equipment like frequency multiplier for increasing the phase modulation index.

Applications of Phase Modulation:

- Phase modulation application is not different from frequency modulation. Phase modulation is also used in communication systems.
- It may be used in binary phase shift keying.

1. **Digital Data - Analog Channel –**

Device used is MOdulator – DEModulator (MODEM)

DIGITAL MODULATION

Why digital modulation?

The move to digital modulation provides more information capacity, compatibility with digital data services, higher data security, better quality communications, and quicker system availability. Developers of communications systems face these constraints:

- Available bandwidth
- Permissible power
- Inherent noise level of the system

The RF spectrum must be shared, yet every day there are more users for that spectrum as demand for communications services increases. Digital modulation schemes have greater capacity to convey large amounts of information than analog modulation schemes.

A. Performance advantages:

- Resistant to noise, fading, & interference
- Can combine multiple information types (voice, data, & video) in a **single** channel
- Improved security (e.g., encryption) → deters phone cloning + eavesdropping
- Error coding is used to detect/correct transmission errors
- Signal conditioning can be used to combat hostile multi ratio combining MRC environment
- Can implement mod/dem functions using digital signal processing DSP software (instead of hardware circuits).

B. Choice of digital modulation scheme

a. Many types of digital modulation methods → subtle differences
b. Performance factors to consider

i. Low Bit Error Rate (BER) at low S/N signal to noise ratio
ii. Resistance to interference (adjacent/co-channel interference ACI & CCI), multipath fading

iii. Occupying a minimum amount of BW
iv. Easy and cheap to implement in mobile unit
v. Efficient use of battery power in mobile unit

Classification of digital modulation

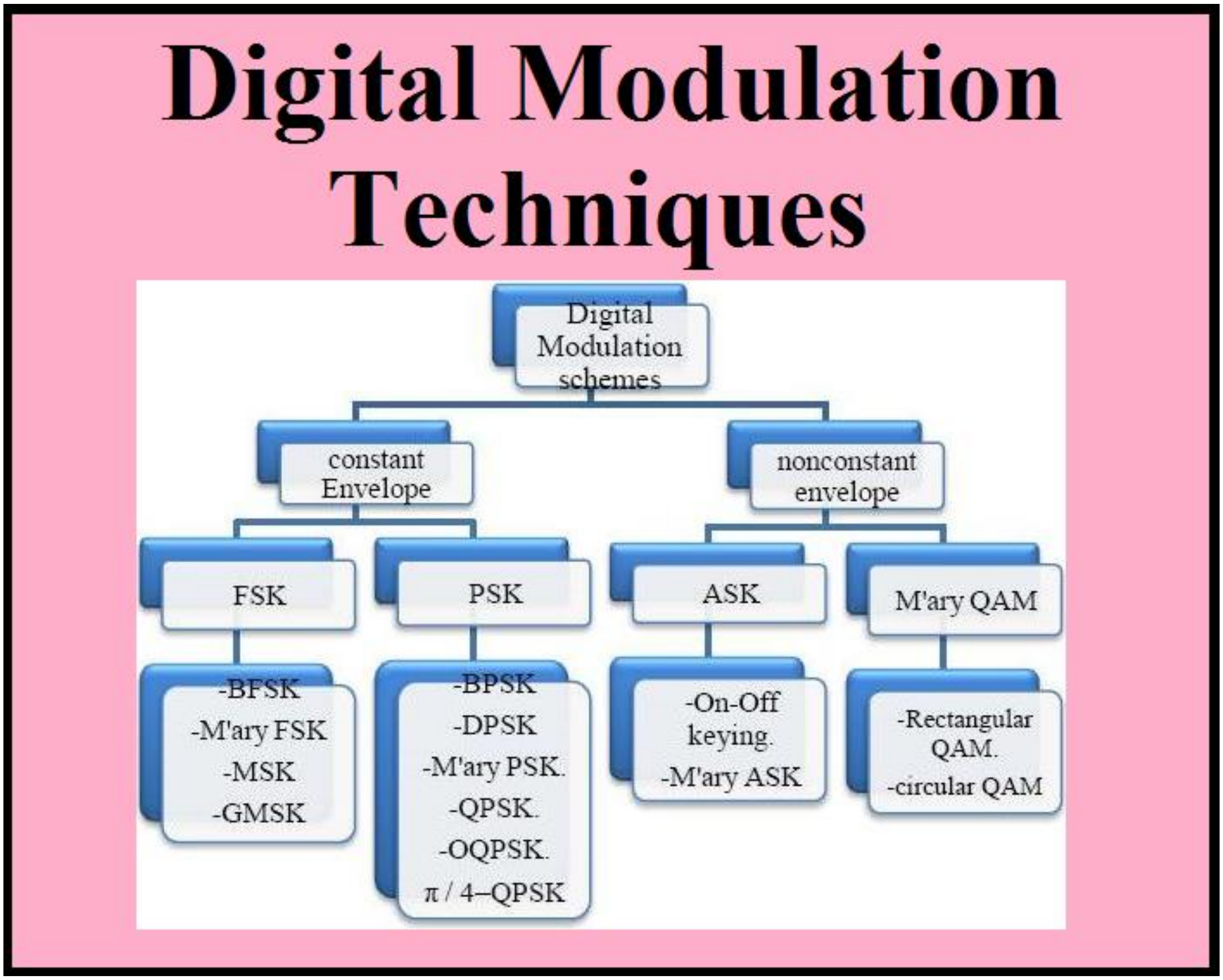


Fig 4.4 digital modulatio techniques.

- CPM: Continuous Phase Modulation
    - Frequency or phase modulation
    - Example: MSK, GMSK
    - Characteristic: constant envelope modulation
- QAM: Quadrature Amplitude Modulation
    - Example: QPSK, OQPSK, 16QAM
    - Characteristic: High spectral efficiency

- Multicarrier Modulation
    - Example: OFDM, DMT
    - Characteristic: Muti-path delay spread tolerance, effectivness against channel distortion

- Public telephone system
    — 300Hz to 3400Hz
    — Use modem (modulator-demodulator)

Common modulation schemes

- Amplitude shift keying (ASK)
- Frequency shift keying (FSK)
- Phase shift keying (PSK)

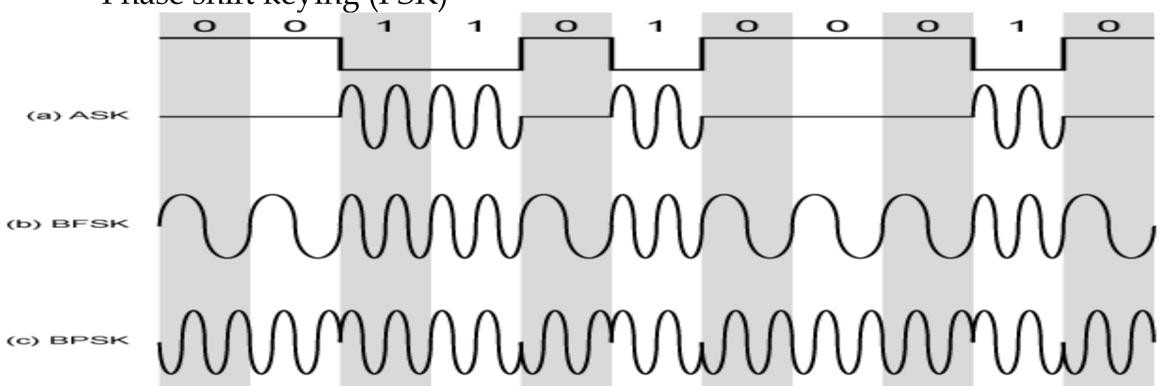


Fig 4.5 ASK, FSK and PSK schemes

Amplitude Shift Keying

- Values represented by different amplitudes of carrier
- Usually, one amplitude, zero no amplitude
    — i.e. presence and absence of carrier is used
- Susceptible to sudden gain changes
- Inefficient
- Up to 1200bps on voice grade lines
- Used over optical fiber

Binary Frequency Shift Keying

- Most common form is binary FSK (BFSK)
- Two binary values represented by two different frequencies (near carrier)
- Less susceptible to error than ASK
- Up to 1200bps on voice grade lines
- High frequency radio
- Even higher frequency on LANs using co-axial cables

Multiple FSK

- More than two frequencies used
- More bandwidth efficient
- More prone to error
- Each signalling element represents more than one bit

Phase Shift Keying

- Phase of carrier signal is shifted to represent data
- Binary PSK
  - — Two phases represent two binary digits
- Differential PSK
  - — Phase shifted relative to previous transmission rather than some reference signal

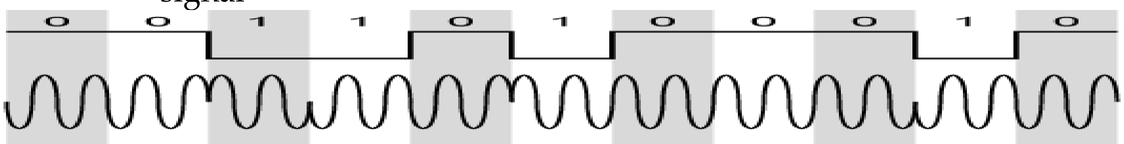


Fig 4.6 Differential PSK

PSK constellation diagrams

Using this scheme, the phase of the signal is represented by the angle around the circle, and the amplitude by the distance from the origin or centre of the circle. In this way the signal can be resolved into quadrature components representing the sine or I for In-phase component and the cosine for the quadrature component. Most phase shift keyed systems use a constant amplitude and therefore points appear on one circle with a constant amplitude and the changes in state being represented by movement around the circle. For binary shift keying using phase reversals the two points appear at opposite points on the circle. Other forms of phase shift keying may use different points on the circle and there will be more points on the circle.

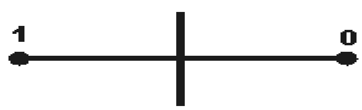


Fig 4.7 Constellation diagram for BPSK

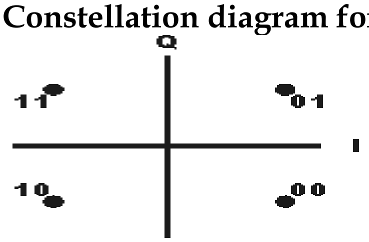


Fig 4.8 Constellation diagram for QPSK

Using a constellation view of the signal enables quick fault finding in a system. If the problem is related to phase, the constellation will spread around the circle. If the problem is related to magnitude, the constellation will spread off the circle, either towards or away from the origin. These graphical techniques assist in isolating problems much faster than when using other techniques.

Forms of phase shift keying

The list below gives some of the more commonly used forms of phase shift keying, PSK, and related forms of modulation that are used:

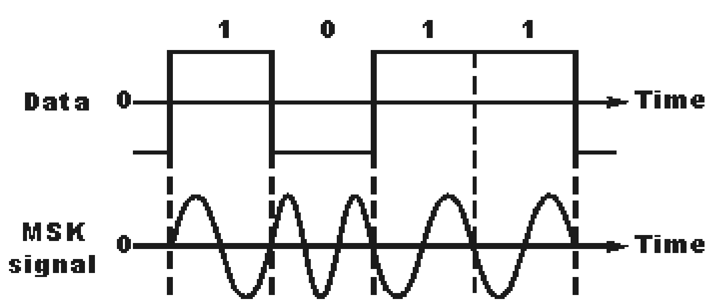
- PSK - Phase Shift Keying
- BPSK - Binary Phase Shift Keying
- QPSK - Quadrature Phase Shift Keying
- O-QPSK - Offset Quadrature Phase Shift Keying
- 8 PSK - 8 Point Phase Shift Keying
- 16 PSK - 16 Point Phase Shift Keying
- QAM - Quadrature Amplitude Modulation
- 16 QAM - 16 Point Quadrature Amplitude Modulation
- 64 QAM - 64 Point Quadrature Amplitude Modulation
- MSK - Minimum Shift Keying
- GMSK - Gaussian filtered Minimum Shift Keying

MSK, Minimum Shift Keying Modulation

Minimum shift keying, MSK, is a form of phase shift keying, PSK, that is used in a number of applications. A variant of MSK modulation, known as Gaussian filtered Minimum Shift Keying, GMSK, is used for a number of radio communications applications including being used in the GSM cellular telecommunications system. In addition to this MSK has advantages over other forms of PSK and as a result it is used in a number of radio communications systems.

Reason for Minimum Shift Keying, MSK

It is found that binary data consisting of sharp transitions between "one" and "zero" states and vice versa potentially creates signals that have sidebands extending out a long way from the carrier, and this creates problems for many radio communications systems, as any sidebands outside the allowed bandwidth cause interference to adjacent channels and any radio communications links that may be using them.



Signal using MSK modulation

Fig 4.9 MSK

Quadrature Amplitude Modulation

Quadrature Amplitude Modulation or QAM is a form of modulation which is widely used for modulating data signals onto a carrier used for radio communications. It is widely used because it offers advantages over other forms of data modulation such as PSK, although many forms of data modulation operate alongside each other.

Quadrature Amplitude Modulation, QAM is a signal in which two carriers shifted in phase by 90 degrees are modulated and the resultant output consists of both amplitude and phase variations. In view of the fact that both amplitude and phase variations are present it may also be considered as a mixture of amplitude and phase modulation.

Analogue and digital QAM

Quadrature amplitude modulation, QAM may exist in what may be termed either analogue or digital formats. The analogue versions of QAM are typically used to allow multiple analogue signals to be carried on a single carrier. For example it is used in PAL and NTSC television systems, where the different channels provided by QAM enable it to carry the components of chroma or colour information. In radio applications a system known as C-QUAM is used for AM stereo radio. Here the different channels enable the two channels required for stereo to be carried on the single carrier.

Digital formats of QAM are often referred to as "Quantised QAM" and they are being increasingly used for data communications often within radio communications systems. Radio communications systems ranging from cellular technology through wireless systems including WiMAX, and Wi-Fi 802.11 use a variety of forms of QAM, and the use of QAM will only increase within the field of radio communications.

QAM advantages and disadvantages

Although QAM appears to increase the efficiency of transmission for radio communications systems by utilising both amplitude and phase variations, it has a number of drawbacks. The first is that it is more susceptible to noise because the states are closer together so that a lower level of noise is needed to move the signal to a different decision point. Receivers for use with phase or frequency modulation are both able to use limiting amplifiers that are able to remove any amplitude noise and thereby improve the noise reliance. This is not the case with QAM.

The second limitation is also associated with the amplitude component of the signal. When a phase or frequency modulated signal is amplified in a radio transmitter, there is no need to use linear amplifiers, whereas when using QAM that contains an amplitude component, linearity must be maintained. Unfortunately linear amplifiers are less efficient and consume more power, and this makes them less attractive for mobile applications.

QAM applications

QAM is in many radio communications and data delivery applications. However some specific variants of QAM are used in some specific applications and standards.

Variants of QAM are also used for many wireless and cellular technology applications.

Constellation diagrams for QAM

The constellation diagrams show the different positions for the states within different forms of QAM, quadrature amplitude modulation. As the order of the modulation increases, so does the number of points on the QAM constellation diagram.

The diagrams below show constellation diagrams for a variety of formats of modulation:

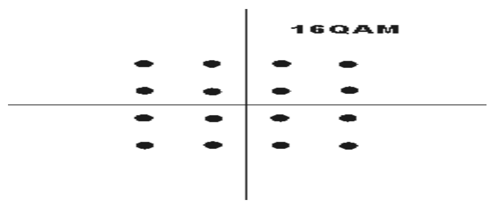


Fig 4.10 constellation diagrams 16 QAM

QAM bits per symbol

The advantage of using QAM is that it is a higher order form of modulation and as a result it is able to carry more bits of information per symbol. By selecting a higher order format of QAM, the data rate of a link can be increased.

The table below gives a summary of the bit rates of different forms of QAM and PSK.

Modulation	Bits per symbol	Symbol Rate
BPSK	1	1 x bit rate
QPSK	2	1/2 bit rate
8PSK	3	1/3 bit rate
16QAM	4	1/4 bit rate
32QAM	5	1/5 bit rate
64QAM	6	1/6 bit rate

QAM noise margin

While higher order modulation rates are able to offer much faster data rates and higher levels of spectral efficiency for the radio communications system, this comes at a price. The higher order modulation schemes are considerably less resilient to noise and interference.

As a result of this, many radio communications systems now use dynamic adaptive modulation techniques. They sense the channel conditions and adapt the modulation scheme to obtain the highest data rate for the given conditions. As signal to noise ratios decrease errors will increase along with re-sends of the data, thereby slowing throughput. By reverting to a lower order modulation scheme the link can be made more reliable with fewer data errors and re-sends

William Stallings Data and Computer Communications 7th Edition Chapter 5

Signal Encoding Techniques

https://www.google.co.ke/?gws_rd=ssl#q=data+encoding+in+computer+networks

http://www.electronicshub.org/modulation-and-different-types-of-modulation/