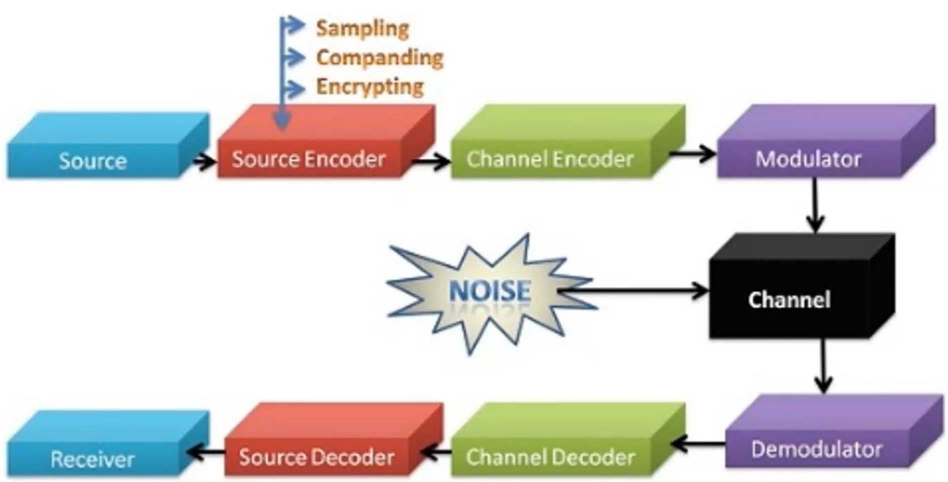
Definition of Digital Communication

Digital Communication is the one which uses digital signals for transmitting information between source and destination. Digital signals are represented by a square wave. This signal consists of discrete values rather than continuous values.

The digital signal is formed by the sampling of the analog signal. The samples of Analog signal are taken, and they are quantized. Digital signals usually consist of signals with two states **ON or OFF,** i.e. **1 & 0.** After the sampling and quantization, the digital signal so obtained is modulated by digital modulation techniques.

The significant advantage of using **Digital Communication** is that it is not deteriorated by channel noise. This is because the digital signal is not a continuously varying signal.

Thus, if noise affects mix with the digital signal, the original signal can be retrieved from the distorted signal. This is because if noise effects one of the points of the signal amplitude, we know the range in which that point lies because digital signal consists of discrete values.



Block Diagram of Digital Communication

Digital communication supports **higher noise immunity** than analog communication. But at the same time, digital data requires **more bandwidth** as compared to an analog signal.

In Digital communication, error detection and correction can be implemented easily. Digital modulation provides much more **efficient** results when compared to analog communication.

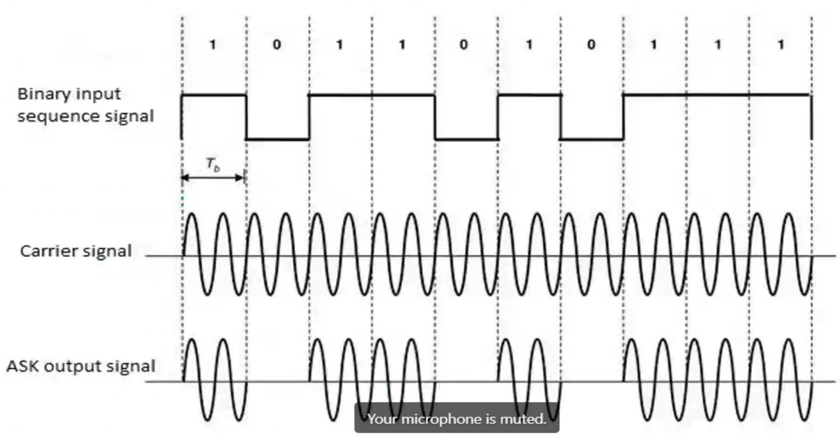
Digital Communication Types :

- ASK – Amplitude Shift Keying
- FSK – Frequency Shift Keying
- PSK – Phase Shift Keying

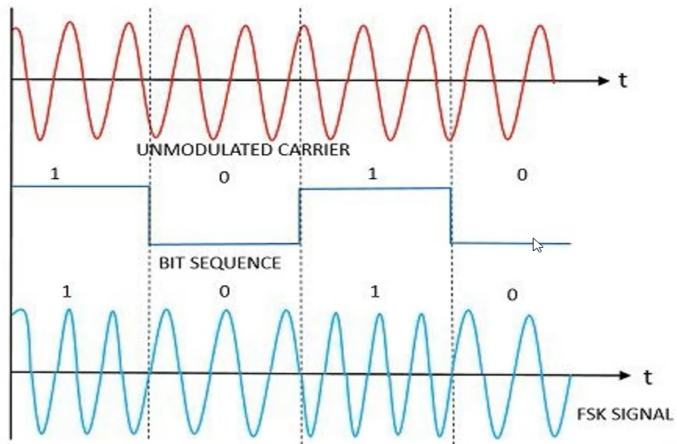
  BPSK, QPSK, 8PSK, 16PSK
- QAM – Quadrature Amplitude Modulation

  Formats : *8QAM, 16QAM, 64QAM, 128QAM, 256QAM*

Amplitude shift keying or ASK: The signal carrying digital bit stream is modulated with the amplitude of carrier signal.

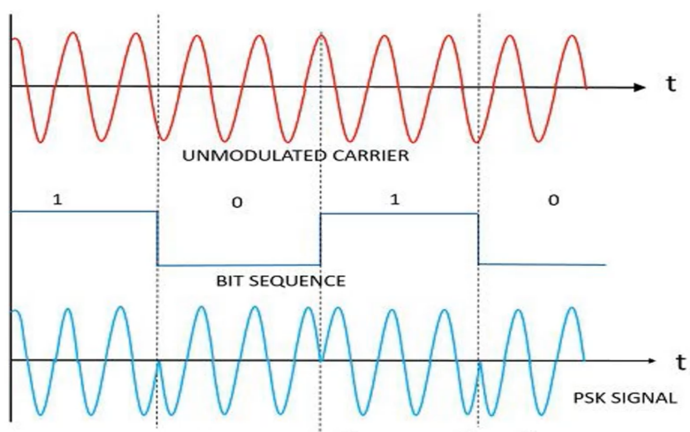


Frequency shift keying or FSK: In this, the frequency of carrier signal is varied according to the digital bit stream of information bearing signal.



FREQUENCY SHIFT KEYING WAVEFORM

Phase shift keying or PSK: This technique ensures the data to be transmitted in a more efficient manner as compared to FSK. In this, the phase of the carrier is varied with respect to the digital bit stream of the information signal.



PHASE SHIFT KEYING WAVEFORM

Mobile Phones / Cellular Telecommunications

- Cellular / mobile communication basics
- 3GPP
- 2G GSM
  - 2G GPRS
  - 2G GSM EDGE
- IS95 / cdmaOne
- 3G UMTS
  - 3G HSPA
- 4G LTE
  - LTE Advanced
- 5G technology
- 6G - next generation concepts

Your microphone is muted.

Wireless Connectivity

- WiFi - IEEE 802.11
- Bluetooth
- RFID: radio frequency identification
- NFC: near field communication
- IEEE 802.15.4
- WiMAX
- DECT
- SIGFOX
- LoRa
- Zigbee
- Z-Wave
- Wireless M bus
- WHDI

Wired Connectivity

- Erlang
- E carrier
- Optical fibre communications
- VoIP
- Networking fundamentals
- Cloud
- Network, functions virtualization, NFV
- Software defined networking, SDN
- SD-WAN
- ISDN
- Ethernet IEEE 802.3
- USB, Universal Serial Bus
- Serial data standards
    - RS232
    - RS422
    - RS449
    - RS485

Radio systems

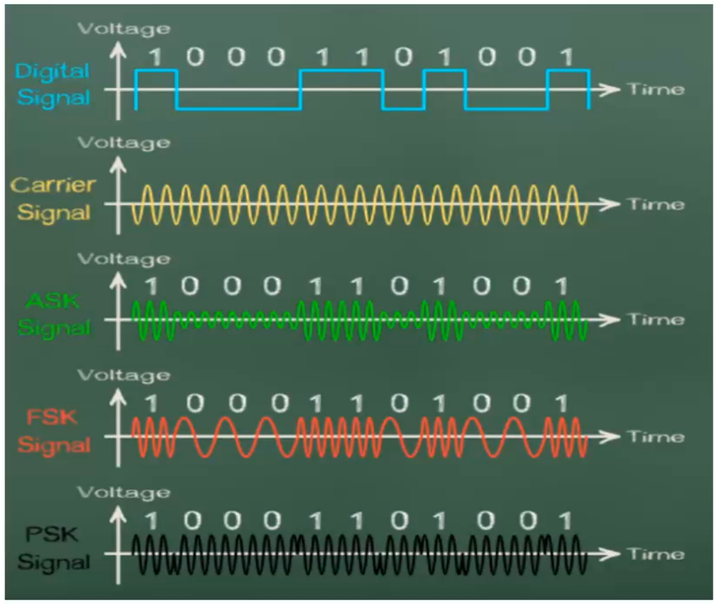
- Licence-free radio systems
- Land / private mobile radio summary
- TETRA
- DMR
- dPMR
- APCO P25
- NXDN

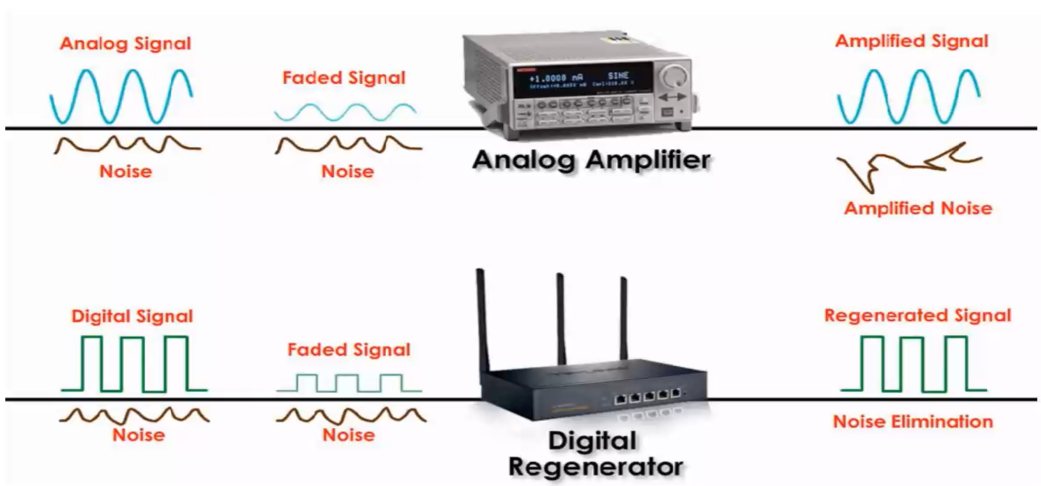
- Key Differences between Analog & Digital Communication

1. **Bandwidth:** This factor creates the key difference between Analog and Digital communication. Analog signal requires less bandwidth for the transmission while Digital signal requires more bandwidth for the transmission.
2. **Power Requirement:** Power requirement in case of Digital communication is less a compared to Analog communication. Since the bandwidth requirement in digital systems is more thus, they consume less power. And Analog communication system requires less bandwidth thus more power.
3. **Fidelity:** Fidelity is a factor which creates a crucial difference between Analog and digital communication. Fidelity is the ability of the receiver which receives the output exactly in coherence with that of transmitted input. Digital communication offers more fidelity as compared to Analog Communication.
4. **Hardware Flexibility:** The hardware of Analog communication system is not as flexible as Digital communication. The equipment used in digital technology are compact in size and consumes less power.
5. **Error Rate:** Error rate is another significant difference which separates Analog and Digital Communication. In Analog instruments, there is an error due to parallax or other kinds of observational method.
6. **Synchronization:** Digital communication system offers to synchronize which is not effective in Analog communication. Thus, synchronization also creates a key difference between Analog and Digital Communication.
7. **Cost:** Digital communication equipments are costly and Digital signal require more bandwidth for transmission.

- Comparison Chart

PARAMETERS	ANALOG COMMUNICATION	DIGITAL COMMUNICATION
Definition	Analog Communication is the technology which uses Analog signal for the transmission of information.	Digital Communication is the technology which uses digital signal for the transmission of information.
Noise and Distortion	Get affected by Noise	Immune from Noise and Distortion
Error Probability	Error Probability is high due to parallax.	Error Probability is low
Hardware	Hardware is complicated and less flexible than digital system.	Hardware is flexible and less complicated than Analog system.
Cost	Low Cost	High Cost
Bandwidth Requirement	Low bandwidth requirement	High bandwidth Requirement
Power Requirement	High power is required	Low Power Requirement
Portability	Less Portable as the components are heavy	More portable due to compact equipment.
Modulation Used	Amplitude and Angle Modulation	Pulse coded Modulation or PCM, DPCM etc.
Representation of Signal	Analog signal can be represented by sine wave.	Digital signal is represented by square wave.
Signal Values	Consists of continuous values	Consists of discrete values
Example of Signal	Analog signal comprises of voice, sound etc.	Digital signals are used in computers

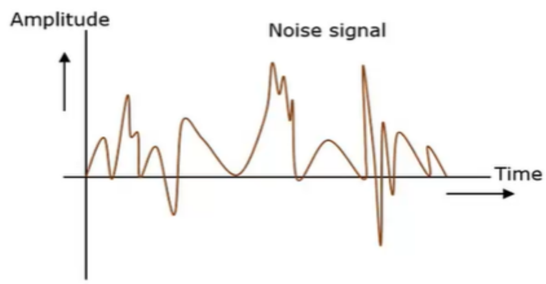

Voltage
Digital Signal
1 0 0 0 1 1 0 1 0 0 1
Time
Voltage
Carrier Signal
Time
Voltage
ASK Signal
1 0 0 0 1 1 0 1 0 0 1
Time
Voltage
FSK Signal
1 0 0 0 1 1 0 1 0 0 1
Time
Voltage
PSK Signal
1 0 0 0 1 1 0 1 0 0 1
Time


Analog Signal
Noise
Faded Signal
Noise
Analog Amplifier
Amplified Signal
Amplified Noise
Digital Signal
Noise
Faded Signal
Noise
Digital Regenerator
Regenerated Signal
Noise Elimination

In any communication system, during the transmission of the signal, or while receiving the signal, some unwanted signal gets introduced into the communication, making it unpleasant for the receiver, questioning the quality of the communication. Such a disturbance is called as **Noise**.

What is Noise?

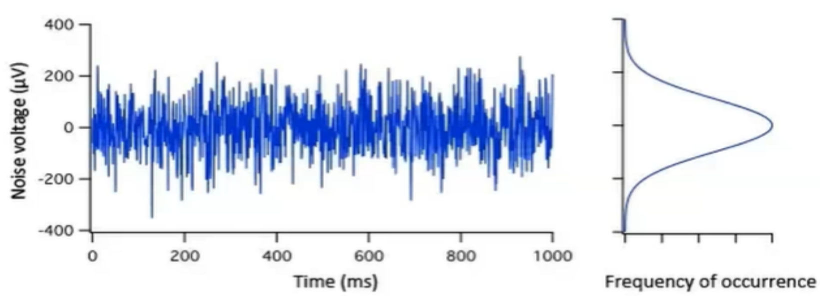
Noise is an **unwanted signal** which interferes with the original message signal and corrupts the parameters of the message signal. This alteration in the communication process, leads to the message getting altered. It is most likely to be entered at the channel or the receiver.
The noise signal can be understood by taking a look at the following example.



Hence, it is understood that noise is some signal which has no pattern and no constant frequency or amplitude. It is quite random and unpredictable. Measures are usually taken to reduce it, though it can't be completely eliminated.

Most common examples of noise are :

- "Hiss" sound in radio receivers
- "Buzz" sound amidst telephonic conversations
- "Flicker" in television receivers etc.



Types of Noise

The classification of noise is done depending upon the type of source, the effect it shows or the relation it has with the receiver etc.

There are two main ways of which noise gets produced. One is through some external source while the other is created by the internal source, within the receiver section.

External Source

This noise is produced by the external sources which may occur in the medium or channel of communication, usually. This noise can't be completely eliminated. The best way is to avoid the noise from affecting the signal.

Examples :

Most common examples of this type of noise are:

- Atmospheric Noise (due to irregularities in the atmosphere).
- Extra-terrestrial noise such as solar noise and cosmic noise.
- Industrial noise.
- AWGN

Internal Source

This noise is produced by the receiver components while functioning. The components in the circuits, due to continuous functioning, may produce a few types of noise. This noise is quantifiable. A proper receiver design may lower the effect of this internal noise.

Examples :

Most common examples of this type of noise are:

- Thermal agitation noise (Johnson noise or Electrical noise)
- Shot noise (due to the random movement of electrons and holes)
- Transit-time noise (during the transition)
- Miscellaneous noise is another type of noise which includes flicker, resistance effect, and mixer generated noise, etc.

Atmospheric noise

It is radio noise caused by natural atmospheric processes, primarily lightning discharges in thunderstorms. It is mainly caused by cloud-to-ground flashes as the current is much stronger than that of cloud-to-cloud flashes. On a worldwide scale, 3.5 million lightning flashes occur daily. This are about 40 lightning flashes per second.

The sum of all these lightning flashes results in atmospheric noise. It can be observed, with a radio receiver, in the form of a combination of white noise (coming from distant thunderstorms) and impulse noise (coming from a near thunderstorm). The power-sum varies with seasons and nearness of thunderstorm centers.

Although lightning has a broad-spectrum emission, its noise power increases with decreasing frequency. Therefore, it is seen at very low frequency and low frequency, atmospheric noise often dominates, while at high frequency, man-made noise dominates in urban areas.

Consequently, it mainly affects long-range navigation systems (maritime radio), terrestrial radio broadcasting stations (LW, MW, and SW) and to a considerably lesser extent, FM and TV reception.

Extraterrestrial Noise

It is safe to say that there are almost as many types of space noise as there are sources.

For convenience, a division into two subgroups will suffice.

1) Solar noise : The sun radiates so many things our way that we should not be too surprised to find that noise is noticeable among them, again there are two types. Under normal "quiet" conditions, there is a constant noise radiation from the sun, simply because it is a large body at a very high temperature (over 6000°C on the surface).

It therefore radiates over a very broad frequency spectrum which includes the frequencies we use for communications. However, the sun is a constantly changing star which undergoes cycles of peak activity from which electrical disturbances erupt, such as corona flares and sunspots. Even though the additional noise produced comes from a limited portion of the sun's surface, it may still be Orders of magnitude greater than that received during periods of quiet sun.

2) Cosmic noise : Since distant stars are also suns and have high temperatures, they radiate RF noise. in the same manner as our sun, and what they lack in nearness they nearly make up in numbers which in combination can become significant. The noise received is called *thermal* (or *black-body)* noise and is distributed fairly uniformly over the entire sky.

We also receive noise from the center of our own galaxy (the Milky ~ Way), from other galaxies, and from other virtual point sources such as "quasars" and "pulsars." This *galactic* noise is very intense, but it comes from sources which are only points in the sky. Two of the strongest sources, which were also two of the earliest discovered, are Cassiopeia A and Cygnus A. Note that it is inadvisable to refer to the previous statements as "noise" sources when talking with radio astronomers!

Industrial Noise

Between the frequencies of 1 to 600 MHz (in urban, suburban and other industrial areas) the intensity of noise made by humans easily outstrips that created by any other source, internal or external to the receiver, Under this heading, sources such as auto mobile and aircraft ignition, electric motors and switching equipment, leakage from high-voltage lines and a multitude of other heavy electric machines are all included.

Fluorescent lights are another powerful source of such noise and therefore should not be used where sensitive receiver reception or testing is being conducted. The noise is produced by the arc discharge present in all these operations, and under these circumstances it is not surprising that this noise should be most intense in industrial and densely populated areas.

AWGN

In signal processing, **White Noise** is a random signal having equal intensity at different frequencies, giving it a constant power spectral density. The term is used, with this or similar meanings, in many scientific and technical disciplines, including physics, acoustical engineering, telecommunications, and statistical forecasting. White noise refers to a statistical model for signals and signal sources, rather than to any specific signal. White noise draws its name from white light, although light that appears white generally does not have a flat power spectral density over the visible band.

In discrete time, white noise is a discrete signal whose samples are regarded as a sequence of serially uncorrelated random variables with zero mean and finite variance; a single realization of white noise is a random shock. Depending on the context, one may also require that the samples be independent and have identical probability distribution (in other words independent and identically distributed random variables are the simplest representation of white noise). ***In particular, if each sample has a normal distribution with zero mean, the signal is said to be* Additive White Gaussian Noise (AWGN).**

Thermal-Agitation Noise

The noise generated in a resistance or the resistive component is random and is referred to as *thermal, agitation, white* or *Johnson* noise. It is due to the rapid and random motion of the molecules (atoms and electrons) inside the component itself.

In thermodynamics, kinetic theory shows that the temperature of a particle is away of expressing its internal kinetic energy. Thus the "temperature" of a body is the statistical root mean square (rms) value of the velocity of motion of the particles in the body. As the theory states, the kinetic energy of these particles becomes approximately zero (Le., their motion ceases) at the temperature of absolute zero, which is 0 K (kelvins, formerly called degrees Kelvin) and very nearly equals -273°C. It becomes apparent that the noise generated by a resistor is proportional to its absolute temperature, in addition to being proportional to the bandwidth over which the noise is to be measured.

Shot Noise

Thenmal agitation is by no means the only source of noise in receivers.

The mm important of all the other sources is the *shot* effect, which leads to shot noise in all amplifying devices and virtually all active devices. *It is caused by random variations* is *the arrival of electrons* (or holes) *at the output electrode* of an amplifying device an appears as a randomly varying noise current superimposed on the output. When amplified, it is supposed to sound as though a shower of lead shot were falling on a met~ sheet. Hence the name *shot* noise.

Transit-Time Noise

If the time taken by an electron to travel from the emitter to the collector of a transistor becomes significant to the period of the signal being amplified, i.e., at frequencies in the upper VHF range and beyond, the so-called *transit-time effect* takes place, and the noise input admittance of the transistor increases. The minute currents induced in the input of the device by random fluctuations in the output current become of great importance at such frequencies and create random noise (frequency distortion).

Miscellaneous Noise

Flicker - At low audio frequencies, a poorly understood form of noise called *flicker* or *modulation noise* is found in transistors. It is proportional to emitter current and junction temperature, but since it is *inversely proportional to frequency,* it may be completely ignored above about 500 Hz. It is no longer very serious.

Resistance Thermal noise - Sometimes called *resistance* noise, it also present in transistors. It is due to the base, emitter, and collector internal resistances, and in most circumstances the base resistance makes the largest contribution. From above 500 Hz up to about fab/5, transistor noise remains relatively constant, so that an equivalent input resistance for shot and thermal noise may be freely used.

Noise in mixers - Mixers (nonlinear amplifying circuits) are much noisier than amplifiers using identical devices, except at microwave frequencies, where the situation is rather complex. This high value of noise in mixers is caused by two separate effects First, *conversion transconductance* of mixers is much lower than the transconductance of amplifiers. Second, if *image frequency rejection* is inadequate, as often happens a shortwave frequencies, noise associated with the image frequency will also be accepted.

Signal-to-Noise Ratio (SNR) is the **ratio of the signal power to the noise power**. The higher the value of SNR, the greater will be the quality of the received output.

Signal to Noise Ratio.

Noise is usually expressed as a power because the received signal is also expressed in terms of power. By Knowing the signal to noise powers the signal to noise ratio can be computed. Rather than express the signal to noise ratio as simply a number, you will usually see it expressed in terms of decibels.

$$Signal\ TO\ Noise\ Ratio = 10 \log \frac{Signal\ power}{Noise\ Power} = 10 \log \frac{P_s}{P_n}$$

A receiver has an input signal power of l.2μW. The noise power is 0.80μW. The signal to noise ratio is

Signal to Noise Ratio = 10 Log (1.2/0.8)

= 10 log 1.5

= 10 (0.176)

= 1.76 dB

Noise Figure

Noise Figure **F** is designed as the ratio of the signal-to-noise power at the input to the signal to noise power at the output.

The device under consideration can be the entire receiver or a single amplifier stage. The noise figure **F** also called the **noise factor** can be computed with the expression

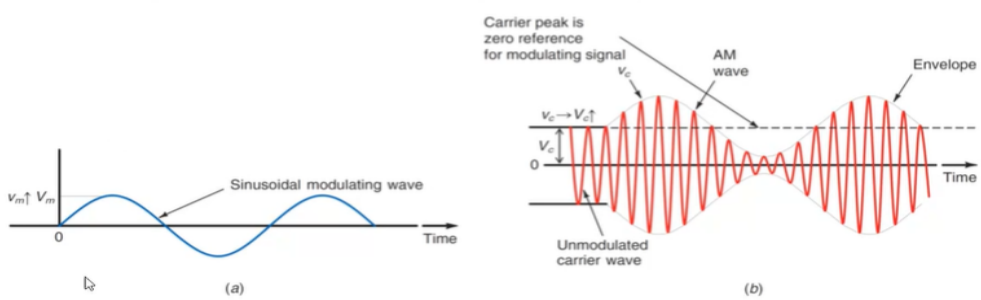
F = Signal to Noise power Input/Signal to noise power output

You can express the noise figure as a number, more often you will see it expressed in decibels.

It describes the performance of a device.

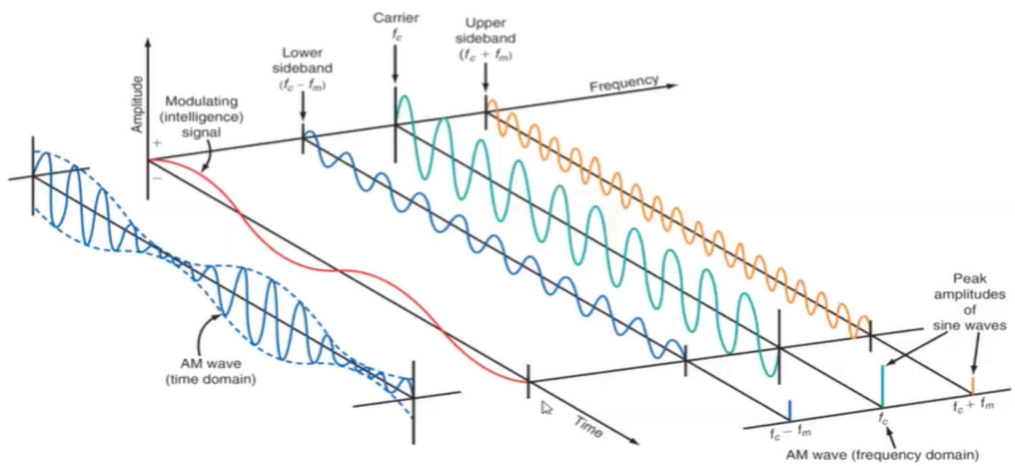
Amplitude Modulation

Amplitude modulation. (*a*) The modulating or information signal. (*b*) The modulated carrier.



Amplitude Modulation Fundamentals

The relationship between the time and frequency domains.



$$A_{\max} + A_{\min} = A_c + A_m + A_c - A_m = 2A_c$$

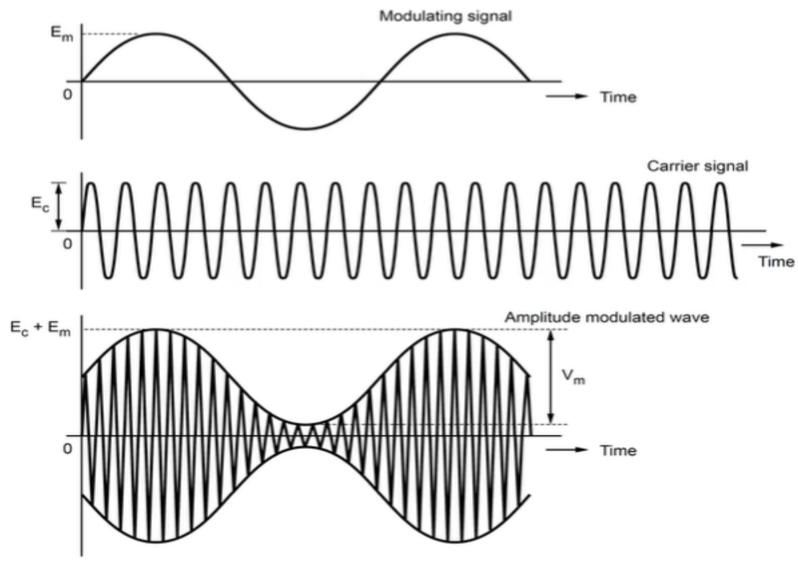
$$\Rightarrow A_c = \frac{A_{\max} + A_{\min}}{2}$$

$$A_{\max} - A_{\min} = A_c + A_m - (A_c - A_m) = 2A_m$$

$$\Rightarrow A_m = \frac{A_{\max} - A_{\min}}{2}$$

$$\frac{A_m}{A_c} = \frac{(A_{max} - A_{min})/2}{(A_{max} + A_{min})/2}$$

$$\Rightarrow \mu = \frac{A_{\max} - A_{\min}}{A_{\max} + A_{\min}}$$



Using the above mathematical expressions for modulating and carrier signals, we can create a new mathematical expression for the complete modulated wave. It is given as,

$$E_{AM} = E_c + e_m$$
$$= E_c + E_m \sin \omega_m t$$

$\therefore$ The instantaneous value of the amplitude modulated wave can be given as,

$$e_{AM} = E_{AM} \sin \theta$$
$$= E_{AM} \sin \omega_c t$$

$$\therefore \quad \boxed{e_{AM} = (E_c + E_m \sin \omega_m t) \sin \omega_c t}$$

This is an equation of AM wave.

Modulation Index and Percent Modulation

The ratio of maximum amplitude of modulating signal to maximum amplitude of carrier signal is called modulation index. i.e.,

$$\boxed{\text{Modulation index, } m = \frac{E_m}{E_c}}$$

Value of E_m must be less than value of E_c to avoid any distortion in the modulated signal. Hence maximum value of modulation index will be equal to 1 when $E_m = E_c$. Minimum value will be zero. If modulation index is higher than 1, then it is called *over modulation*. Data is lost in such case. When modulation index is expressed in percentage, it is also called percentage modulation.

Taking the ratio of equation

$$m = \frac{E_m}{E_c} = \frac{\dfrac{E_{max} - E_{min}}{2}}{\dfrac{E_{max} + E_{min}}{2}}$$

$$\therefore \qquad \boxed{m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}}}$$

This equation gives the technique of calculating modulation index from AM wave.

Frequency Spectrum and Bandwidth

The modulated carrier has new signals at different frequencies, called side frequencies or sidebands. They occur above and below the carrier frequency.

i.e.
$$f_{USB} = f_c + f_m$$
$$f_{LSB} = f_c - f_m$$

Here f_c is carrier frequency.

f_m is modulating signal frequency.

Modulation Index

Modulation Index for Sinusoidal AM

For sinusoidal AM, the modulating waveform is of the form

$$e_m(t) = E_{m\,\max}\cos(2\pi f_m t + \phi_m)$$

In general the fixed phase angle ϕ_m is unrelated to the fixed phase angle ϕ_c for the carrier, showing that these two signals are independent of each other in time. However, the amplitude modulation results are independent of these phase angles, which may therefore be set equal to zero to simplify the algebra and trigonometry used in the analysis. The equation for the sinusoidally modulated wave is therefore

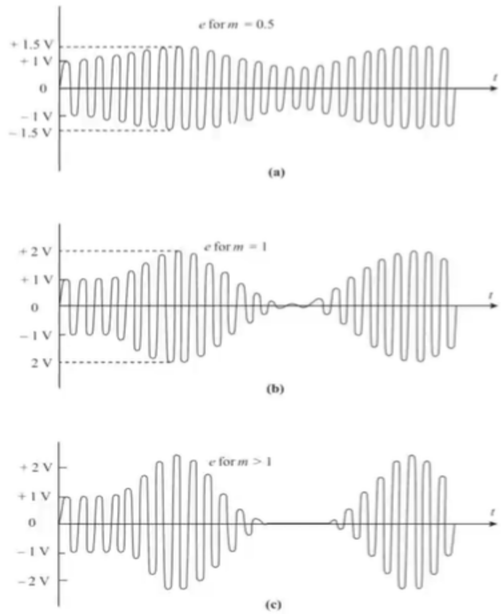
$$e(t) = (E_{c\,\max} + E_{m\,\max}\cos 2\pi f_m t)\cos 2\pi f_c t$$

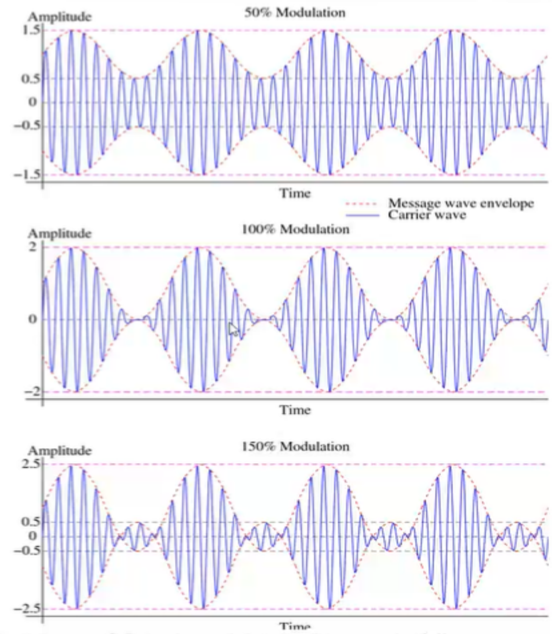
Since in this particular case $E_{\max} = E_{c\,\max} + E_{m\,\max}$ and $E_{\min} = E_{c\,\max} - E_{m\,\max}$ the modulation index is given by

$$m = \frac{E_{\max} - E_{\min}}{E_{\max} + E_{\min}}$$
$$= \frac{E_{m\,\max}}{E_{c\,\max}}$$

The equation for the sinusoidally amplitude modulated wave may therefore be written as

$$e(t) = E_{c\,\max}(1 + m\cos 2\pi f_m t)\cos 2\pi f_c t$$





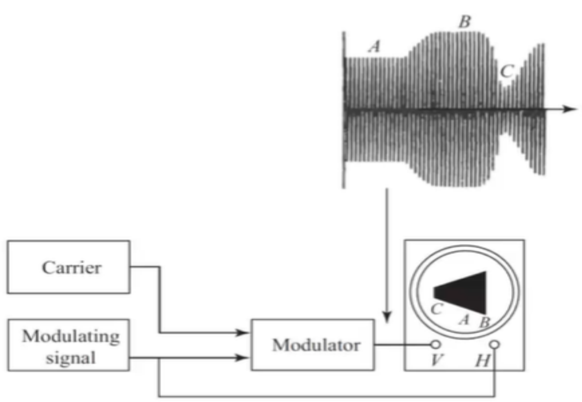
Sinusoidally amplitude modulated waveforms for (a) $m = 0.5$ (undermodulated), (b) $m = 1$ (fully modulated), and (c) $m > 1$ (overmodulated).

Amplitude Modulation Index

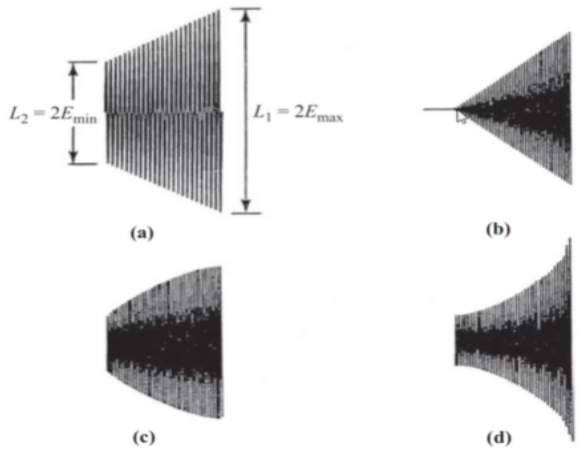
Amplitude Modulation Index

the *modulation index* is defined as

$$m = \frac{E_{\max} - E_{\min}}{E_{\max} + E_{\min}}$$



$$m = \frac{E_{max} - E_{min}}{E_{max} + E_{min}} = \frac{L_1 - L_2}{L_1 + L_2}$$



(a) Normal trapezoidal pattern. (b) Trapezoidal pattern for $m > 1$. (c) Envelope distortion resulting from insufficient RF drive to the modulator. (d) Envelope distortion resulting from non-linearities in the modulator.

It will be seen that the modulation index is zero when $E_{max} = E_{min}$ $E_{c\,max}$, and it is unity when $E_{min} = 0$. Thus, in practice, the modulation index should be in the range

$$0 \leq m \leq 1$$

A modulating signal consists of a symmetrical triangular wave having zero dc component and peak-to-peak voltage of 11 V. It is used to amplitude modulate a carrier of peak voltage 10 V. Calculate the modulation index and the ratio of the side lengths L_1/L_2 of the corresponding trapezoidal pattern.

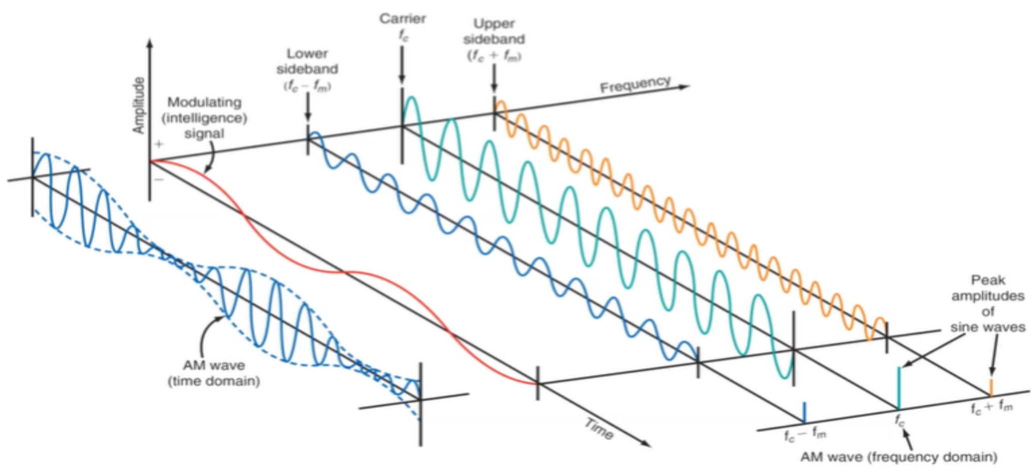
$$E_{max} = 10 + \frac{11}{2} = 15.5\,\text{V}$$

$$E_{min} = 10 - \frac{11}{2} = 4.5\,\text{V}$$

$$\therefore\ m = \frac{15.5 - 4.5}{15.5 + 4.5} = \mathbf{0.55}$$

L_1 is proportional to 15.5 V, L_2 to 4.5 V, and therefore $L_1/L_2 = 15.5/4.5 = \mathbf{3.44}$.

The relationship between the time and frequency domains.

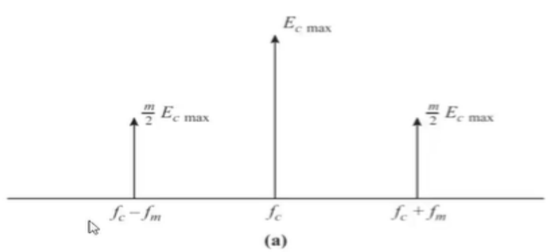


Frequency Spectrum for Sinusoidal AM

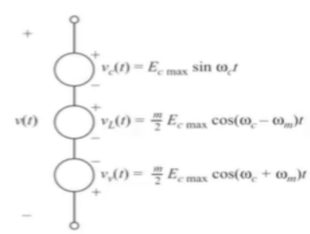
Although the modulated waveform contains two frequencies f_c and f_m, the modulation process generates new frequencies that are the sum and difference of these. The spectrum is found by expanding the equation for the sinusoidally modulated AM as follows:

$$\begin{aligned} e(t) &= E_{c\,\max}(1 + m\cos 2\pi f_m t)\cos 2\pi f_c t \\ &= E_{c\,\max}\cos 2\pi f_c t + mE_{c\,\max}\cos 2\pi f_m t \times \cos 2\pi f_c t \\ &= E_{c\,\max}\cos 2\pi f_c t + \frac{m}{2}E_{c\,\max}\cos 2\pi(f_c - f_m)t + \frac{m}{2}E_{c\,\max}\cos 2\pi(f_c + f_m)t \end{aligned}$$

Equation shows that the sinusoidally modulated wave consists of three components: a carrier wave of amplitude $E_{c\,\max}$ and frequency f_c, a *lower side frequency* of amplitude $mE_{c\,\max}/2$ and frequency $f_c - f_m$, and an *upper side frequency* of amplitude $mE_{c\,\max}/2$ and frequency $f_c + f_m$. The amplitude spectrum is shown in Fig.



(a) Amplitude spectrum for a sinusoidally amplitude modulated wave.



The upper sideband f_{USB} and lower sideband f_{LSB} are computed as

$f_{USB} = f_c + f_m$ and $f_{LSB} = f_c - f_m$

EXAMPLE

A carrier wave of frequency 10 MHz and peak value 10 V is amplitude modulated by a 5-kHz sine wave of amplitude 6 V. Determine the modulation index and draw the amplitude spectrum.

SOLUTION $m = \frac{6}{10} = 0.6$

The side frequencies are $10 \pm 0.005 = 10.005$ and 9.995 MHz. The amplitude of each side frequency is $0.6 \times 10/2 = 3$ V. The spectrum is shown in Fig.

A standard AM broadcast station is allowed to transmit modulating frequencies up to 5 kHz. If the AM station is transmitting on a frequency of 980 kHz, compute the maximum and minimum upper and lower sidebands and the total bandwidth occupied by the AM station.

$$f_{USB} = 980 + 5 = 985 \text{ kHz}$$

$$f_{LSB} = 980 - 5 = 975 \text{ kHz}$$

$$BW = f_{USB} - f_{LSB} = 985 - 975 = 10 \text{ kHz} \qquad \text{or}$$

$$BW = 2(5 \text{ kHz}) = 10 \text{ kHz}$$