COMMUNICATION ENGINEERING

By Prof. Hitesh Dholakiya

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ABSTRACT

I am preparing this material to help my students studying in Engineering. I wish all my students will progress in their life and live happily. Your Suggestions are most welcome to me, so please give your valuable suggestions. For Video learning you can see my YouTube Channel Engineering Funda. God Bless You

Prof. Hitesh L. Dholakiya

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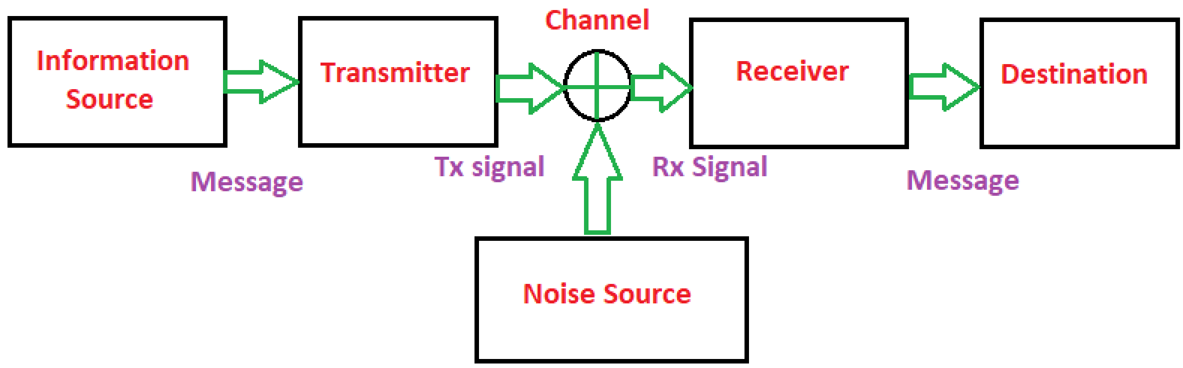
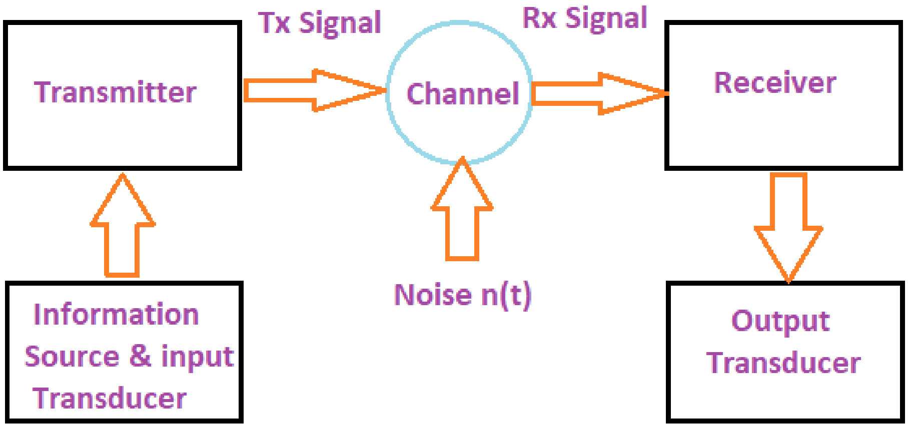
Analog Communication

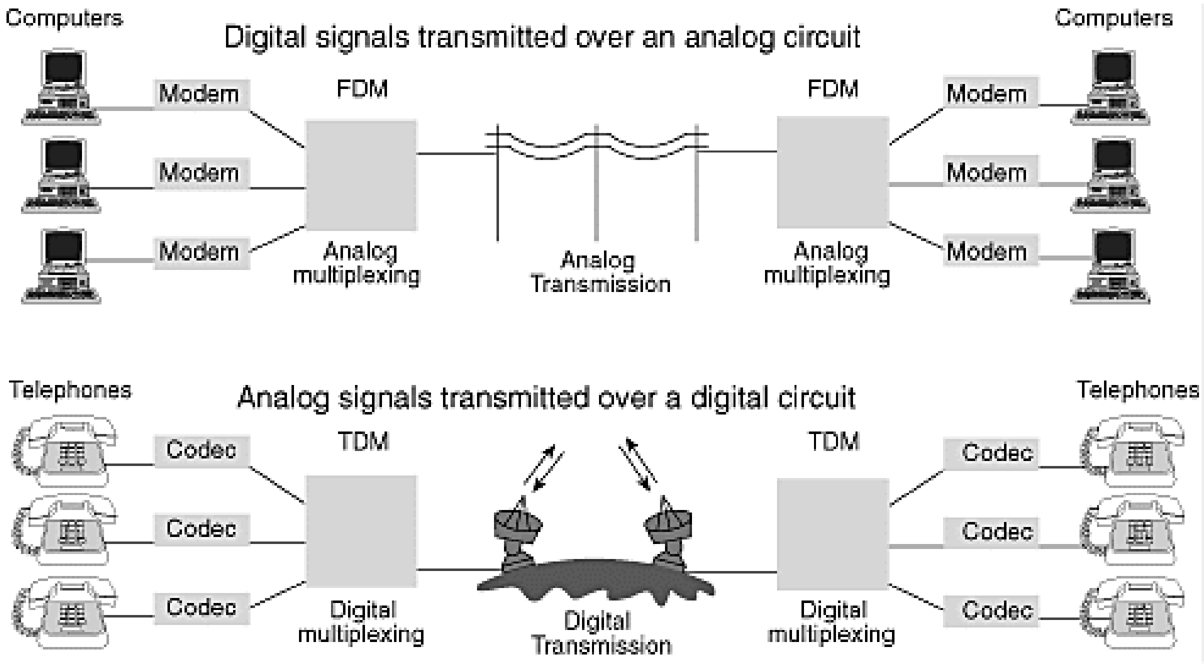
Block Diagram of a generalised Communication System



Basic elements of a communication system



Basic Analog and Digital data transmission



Frequency Bands

Frequency	Name	Medium	Applications
3-30 kHz	Very Low frequency (VLF)	Wire pairs	Long range navigation, sonar
30-300kHz	Low Frequency (LF)	Wire pairs	Navigational aids, radio beacons.
300-3000kHz	Medium Frequency (MF)	Coaxial Cable	Maritime radio, direction finding.
2-30MHz	High Frequency (HF)	Coaxial Cable	Search and rescue, aircraft comm.
30-300MHz	Very High Frequency (VHF)	Coaxial Cable	VHF TV channels, FM radio.
0.3-3 GHz	Ultra High Frequency (UHF)	Coaxial Cable/ Waveguide	UHF TV channels, Satellite comm.
3-30 GHz	Super High Frequency (SHF)	Waveguide	Satellite comm., weather RADAR.
30-300 GHz	Extremely High Frequency	Waveguide	Railroad service, RADAR landing.
>300 GHz	Optical Frequency	Optical Fiber	Wideband data, experimental.

Classification of Communication systems

Based on the type of communication system

I. Analog Communication systems
II. Digital Communication systems

Based on the type of transmission wave

I. Light wave
II. RF transmission

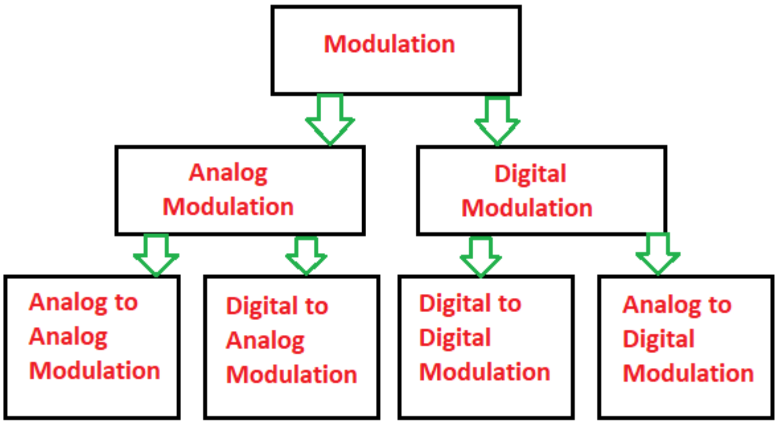
Based on the type of transmission system

I. Carrier
II. Direct baseband

Communication channels

I. Twisted wire pair
II. Coaxial cable
III. Waveguides
IV. Optical fiber

Communication modulation

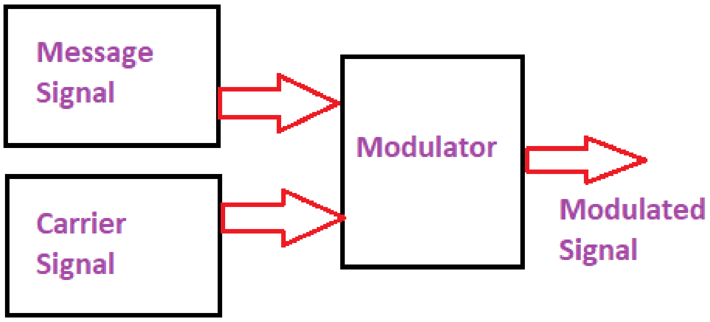


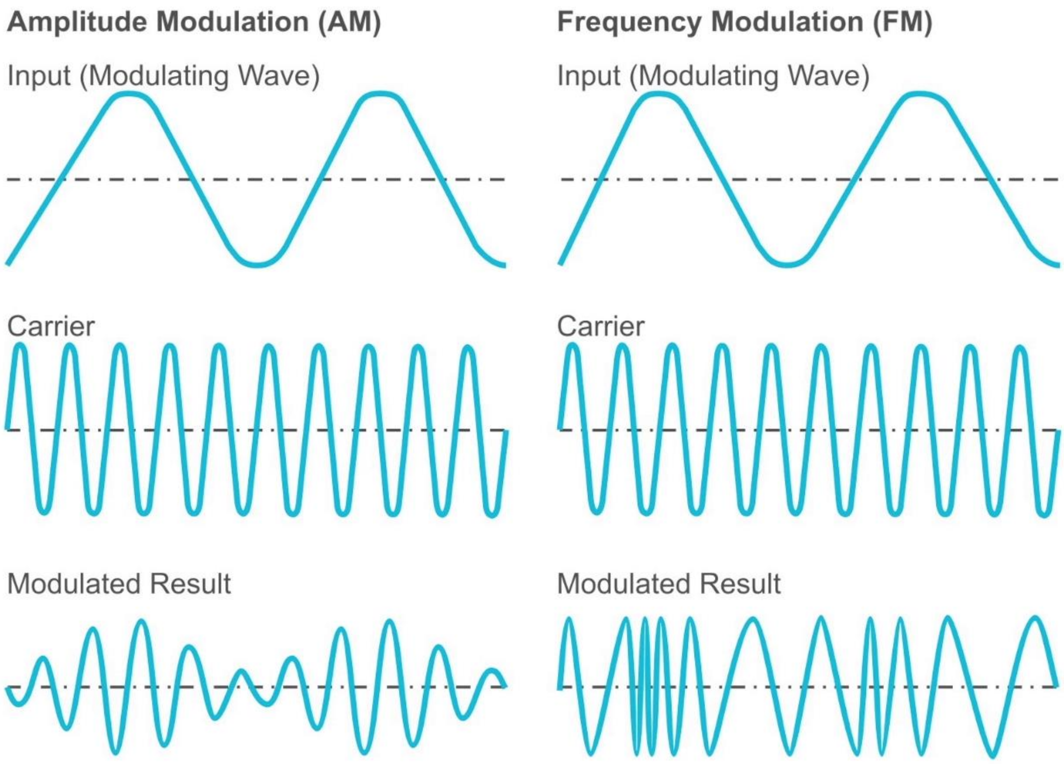
Spectral Analysis

Periodic signals: Fourier series

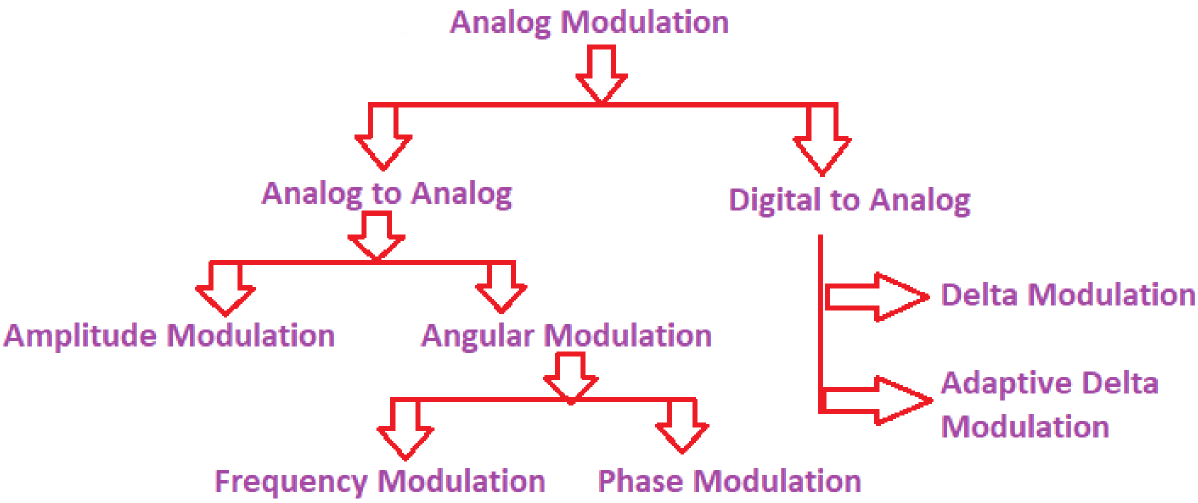
Sine cosine (quadrature) representation $x(t) = a_0 + \sum_{n=1}^{\infty} a_n \cos\left(\frac{2\pi n}{T} t\right) + \sum_{n=1}^{\infty} b_n \sin\left(\frac{2\pi n}{T} t\right)$ **Magnitude and phase representation** $x(t) = c_0 + \sum_{n=1}^{\infty} c_n \sin\left(\frac{2\pi n}{T} t + \theta_n\right)$ $\quad$ $\boldsymbol{Or}$ $x(t) = c_0 + \sum_{n=1}^{\infty} c_n \sin\left(\frac{2\pi n}{T} t - \theta_n\right)$ **Complex representation** $x(t) = \sum_{n=-\infty}^{\infty} \gamma_n e^{jn\frac{2\pi}{T}t}$	**Where,** $w_0 = 2\pi f_0 = \frac{2\pi}{T}\ Rad/sec$ $a_n = c_n \sin\theta_n$ $b_n = c_n \cos\theta_n$

Analog Modulation





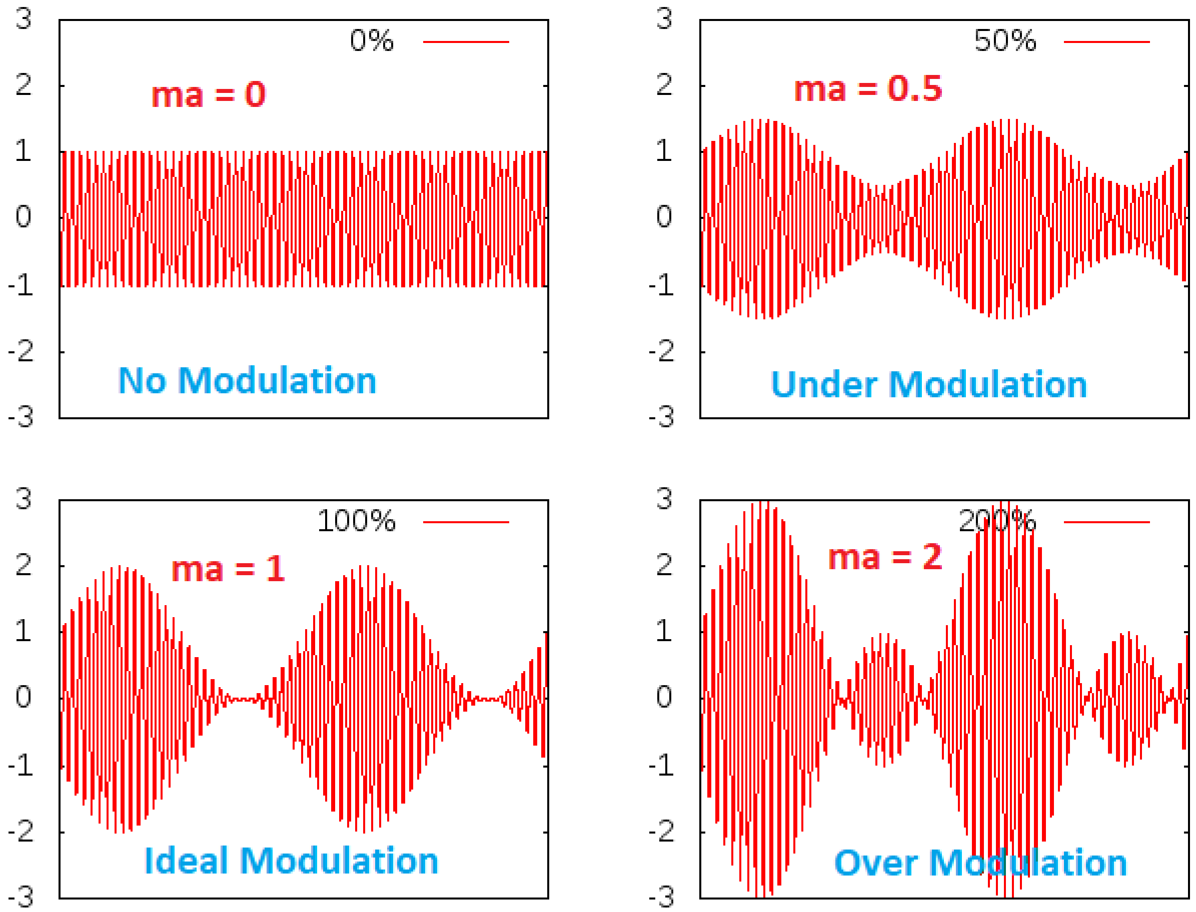
Amplitude Modulation



Single Tone Modulation

Modulating wave $V_m(t) = V_m \cos \omega_m t$ **Carrier wave** $V_c(t) = V_c \cos \omega_c t$ **AM modulated wave** $V_{AM}(t) = [V_C + k_a V_m \cos \omega_m t] \cos \omega_c t$ **Modulation Index** $m_a = k_a \frac{V_m}{V_C} = \frac{A_{max} - A_{min}}{A_{max} + A_{min}}$	**Where,** $V_m(t)$ = Modulating signal or Message Signal $V_c(t)$ = Carrier signal V_m = Peak message volt V_C = Peak carrier volt ω_C = Carrier frequency in rad/sec ω_m = message frequency in rad/sec A_{max} = Max. amplitude of message A_{min} = Min. amplitude of message

Modulation index behaviour



Amplitude modulation types

I. Double SideBand with Carrier DSB+S / Amplitude Modulation with Full Carrier
II. Double SideBand Suppressed Carrier DSC-SC
III. Single Side Band SSB
IV. Single Side Band Full Carrier SSBFC
V. Vestigial Side Band VSB

Representation of various AM signal

AM / DSB-FC

Standard AM Signal

$$V_{AM}(t) = V_C \cos \omega_c t + 0.5 m_a V_C [\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)\, t]$$

Total Power required for AM or DSB-FC

$$P_t = P_{carrier} + P_{USB} + P_{LSB}$$

$$P_t = P_c(1 + 0.5{m_a}^2)$$

DSB-SC

Standard AM Signal

$$V_{AM}(t) = 0.5 m_a V_C [\cos(\omega_c + \omega_m)t + \cos(\omega_c - \omega_m)\, t]$$

Total Power required for AM or DSB-FC

$$P_t = P_{USB} + P_{LSB}$$

$$P_t = P_c(0.5{m_a}^2)$$

SSB-FC

Standard AM Signal

$$V_{AM}(t) = V_C \cos \omega_c t + 0.5 m_a V_C [\cos(\omega_c - \omega_m)\, t]$$

Total Power required for AM or DSB-FC

$$P_t = P_{carrier} + P_{USB}\ or\ P_{LSB}$$

$$P_t = P_c(1 + 0.25{m_a}^2)$$

SSB-SC

Standard AM Signal

$$V_{AM}(t) = 0.5 m_a V_C [\cos(\omega_c - \omega_m)\, t]$$

Total Power required for AM or DSB-FC

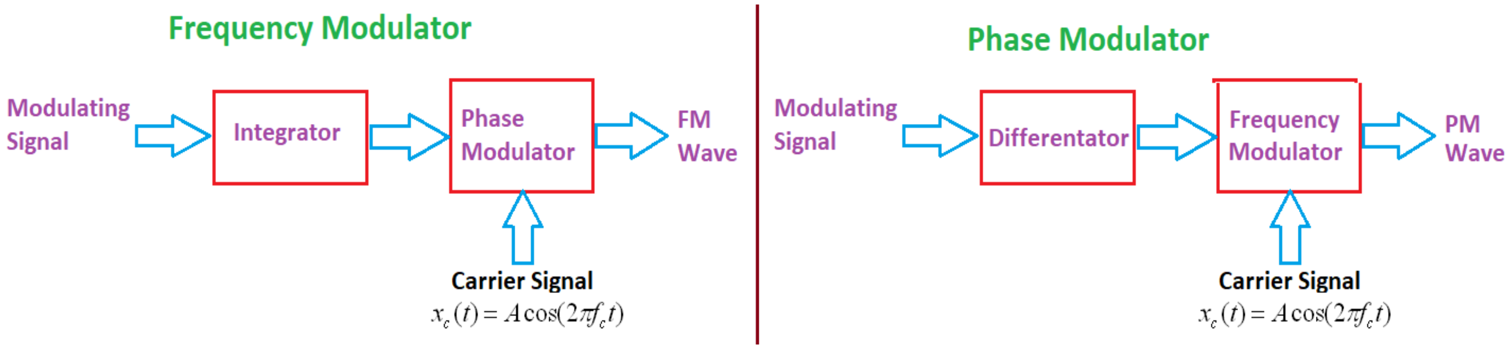
$$P_t = P_{USB}\ or\ P_{LSB}$$

$$P_t = P_c(0.25{m_a}^2)$$

Multi Tone Modulation (Non - Sinusoidal)

AM / DSB-FC	AM / DSB-SC
Standard AM signal (Time domain) $V(t) = (A + f(t))[0.5(e^{j\omega_c t} + e^{-j\omega_c t})]$	Standard AM signal (Time domain) $V(t) = f(t)[0.5(e^{j\omega_c t} + e^{-j\omega_c t})]$
Standard AM signal (Frequency domain) $V(\omega) = (\pi A + 0.5)[F(\omega - \omega_C) + F(\omega + \omega_C)]$	Standard AM signal (Frequency domain) $V(\omega) = 0.5[F(\omega - \omega_C) + F(\omega + \omega_C)]$

Angle Modulation



Frequency Modulation

If **carrier wave** is

$$x_c(t) = A_c \cos(2\pi f_c t)$$

Modulating signal is

$$m(t) = A_m \cos(2\pi f_m t)$$

Then general expression of **FM** is given by,

$$y_{fm}(t) = A_c \cos(2\pi f_c t + \beta \sin 2\pi f_m t) = A_c \cos\left(2\pi f_c t + k_f \int m(t)dt\right)$$

Frequency deviation

$$\Delta f = \frac{k_f A_m}{2\pi}$$

Modulation Index

$$\beta = \frac{\Delta f}{f_m}$$

When $\beta \ll 1$, FM is NarrowBand FM (NBFM)

When $\beta = 1$, FM is WideBand FM (WBFM)

Bandwidth of FM is $BW = 2(\Delta f + B)$

Phase Lock Loop FM Demodulation

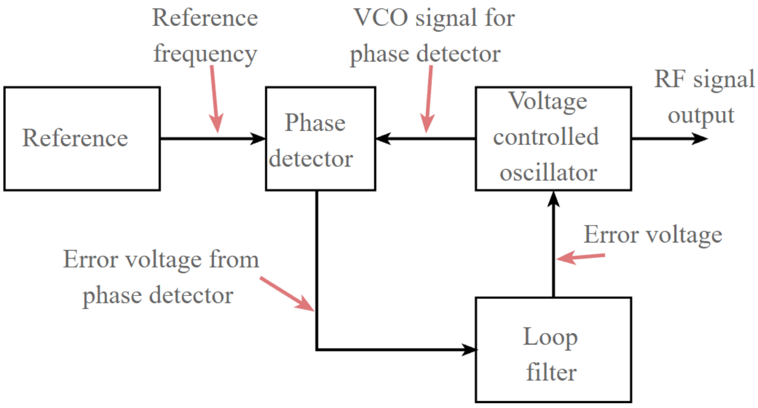


Image signal frequency $f_{si} = f_s + 2f_i$

Where, f_s = Source frequency and f_i = image frequency

Phase Modulation

If **carrier wave** is

$x_c(t) = A_c \cos(2\pi f_c t)$

Modulating signal is

$m(t) = A_m \cos(2\pi f_m t)$

Then general expression of **PM** is given by,

$y_{pm}(t) = A_c \cos\left(2\pi f_c t + k_p m_p(t)\right)$

The **phase modulation index** β_p is given by,

$\beta_p = \Delta\emptyset = k_p max\left|m_p(t)\right|$

Bandwidth of PM is given by,

$BW = 2(\Delta f + B)$

Frequency deviation

$\Delta f = \dfrac{\Delta\emptyset}{2\pi}$

Where,

k_p is phase sensitivity

Noise in Analog Communications

Signal to Noise ratio (SNR)

$$(SNR)_0 = \frac{Average\ power\ of\ message\ signal\ at\ the\ receiver\ output}{Average\ power\ of\ the\ noise\ at\ the\ receiver\ output}$$

$$(SNR)_c = \frac{Average\ power\ of\ modulated\ signal}{Average\ power\ of\ the\ noise\ measured\ in\ message\ bandwidth}$$

Figure of merit

$$Figure\ of\ merit = \frac{(SNR)_0}{(SNR)_c}$$

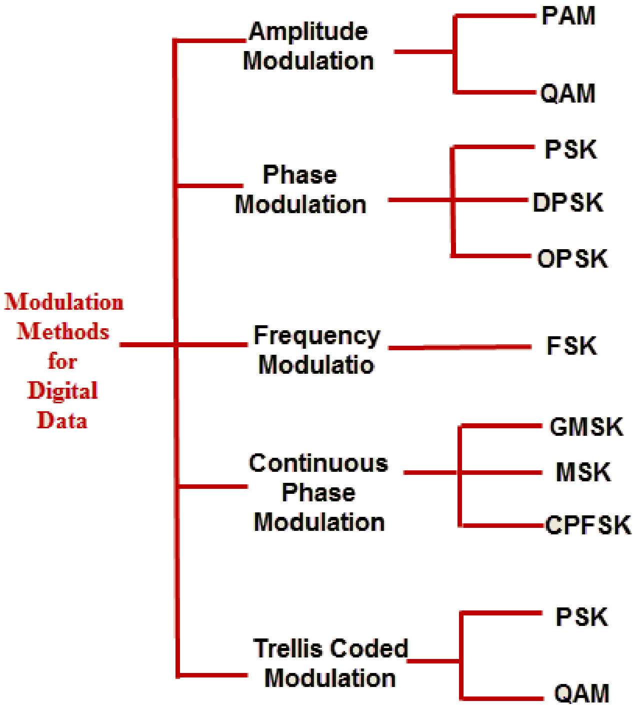
Comparison of AM and FM

AM Signal	FM Signal
SNR ratio for DSBFC modulation is given by $$(SNR)_0 = (SNR)_c = \frac{{A_c}^2 P}{2WN_0}$$ The figure of merit is $$Figure\ of\ merit = \frac{(SNR)_0}{(SNR)_c} = 1$$ SNR ratio for SSBSC modulation is given by $$(SNR)_0 = (SNR)_c = \frac{{A_c}^2 P}{4WN_0}$$ The figure of merit is $$Figure\ of\ merit = \frac{(SNR)_0}{(SNR)_c} = 1$$	The output SNR ratio is given by $$(SNR)_0 = \frac{{A_c}^2 {k_f}^2 P}{2W^3 N_0}$$ The channel SNR ratio is given by $$(SNR)_c = \frac{{A_c}^2}{2WN_0}$$ The figure of merit is given by $$Figure\ of\ merit = \frac{(SNR)_0}{(SNR)_c} = \frac{{k_f}^2}{W^2}$$

Digital Communication

Digital Modulation

General Types of Digital Modulation



Pulse Modulation

Sampling Theorem

Sampling frequency,

$$f_s = \frac{1}{T_s} \geq 2f_m$$

Nyquist rate of Sampling,

$$f_s = \frac{1}{T_s} = 2f_m$$

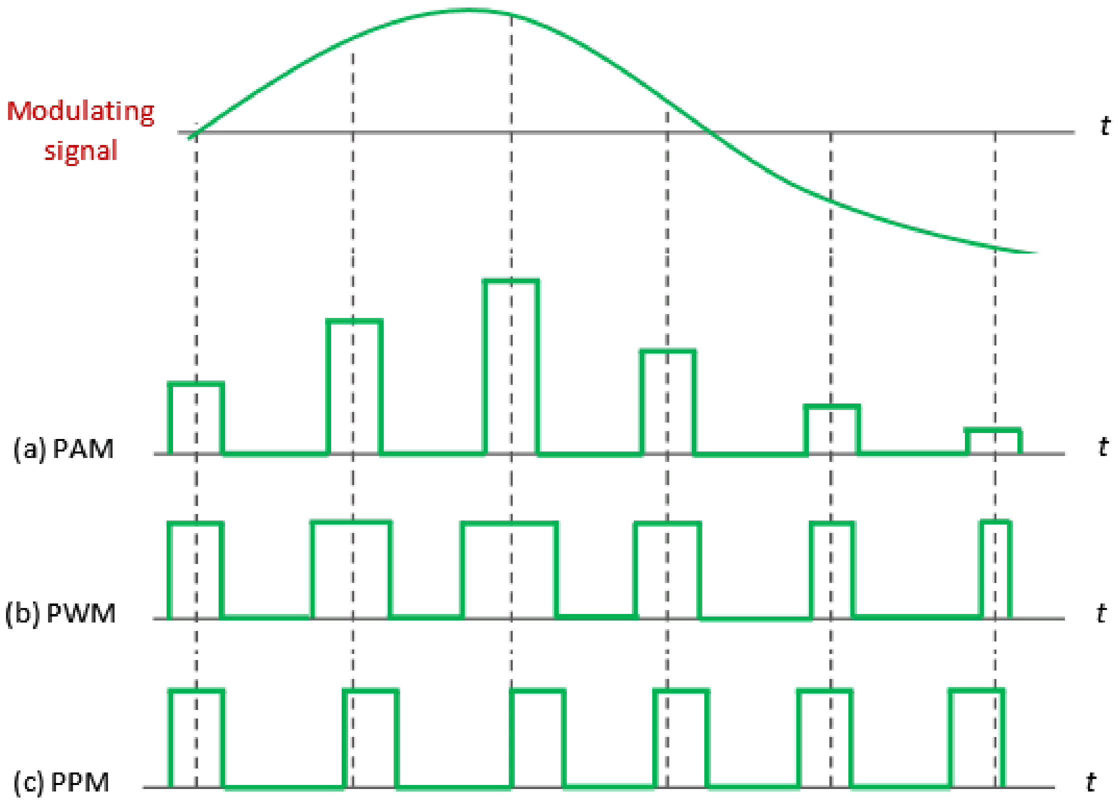
Where,

f_s = Sampling frequency

T_s = Sampling period

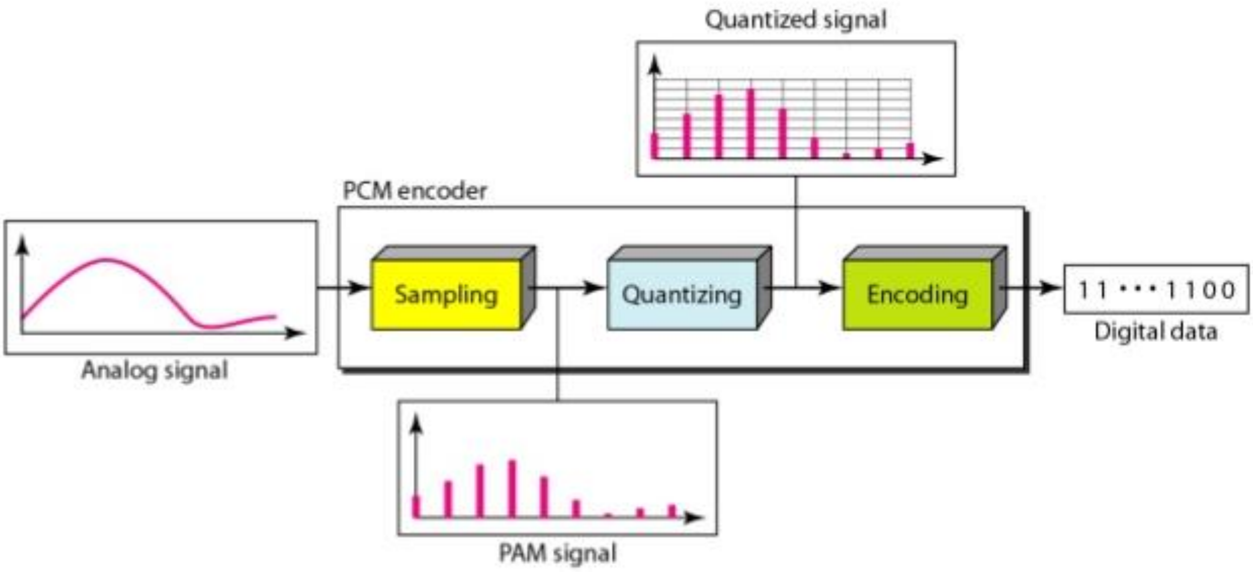
f_m = Maximum frequency of the modulating signal

Comparison between PAM, PWM, PPM



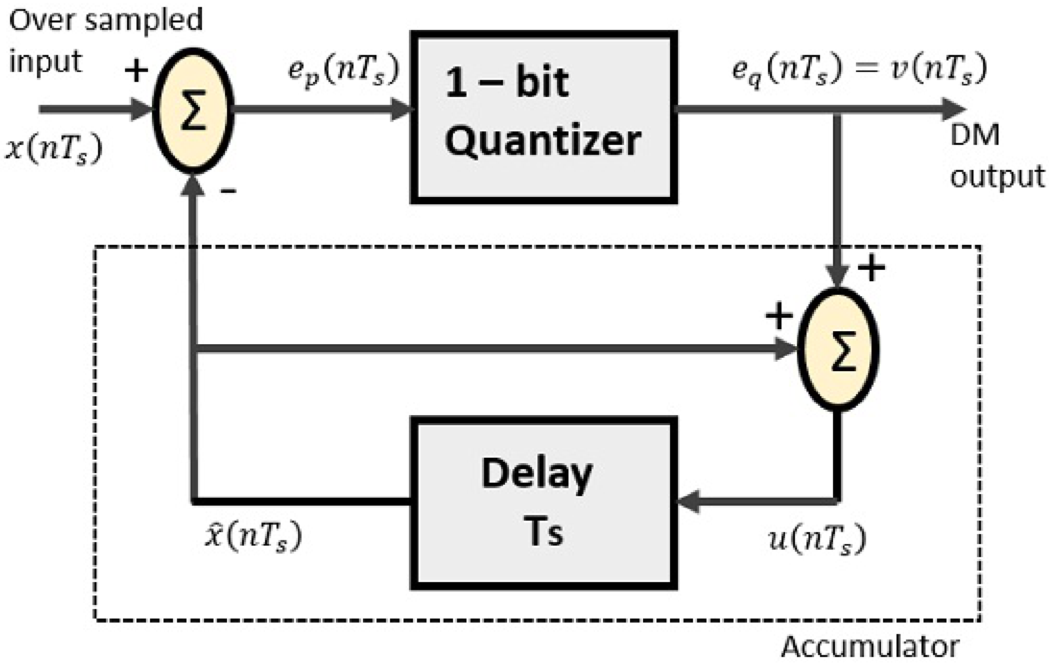
S.No	Pulse Amplitude Modulation (PAM)	Pulse Duration/Width Modulation (PDM/PWM)	Pulse Position Modulation (PPM)
1	Amplitude of the pulse proportional to amplitude of modulating signal	Width of the pulse is proportional to amplitude of modulating signal	The relative position of the pulse is proportional to amplitude of modulating signal
2	Bandwidth of the transmission channel depends on the pulse width	Bandwidth of the transmission channel depends on the rise time of the pulse	Bandwidth of the transmission channel depends on the rising time of the pulse
3	Instantaneous power of the transmitter varies	Instantaneous power of the transmitter varies	Instantaneous power of the transmitter remains constant
4	Noise interference is high	Noise interference is minimum	Noise interference is minimum
5	System is complex to implement	System is simple to implement	System is simple to implement
6	Similar to amplitude modulation	Similar to frequency modulation	Similar to phase modulation

Pulse Code Modulation PCM



Quantization levels $$M = 2^N$$ Step size $$\delta = \frac{2V_m}{M}$$ Signal Power $$s_i = \frac{(M\delta)^2}{12}$$ Signal to Noise ratio $$\frac{S_i}{N_Q} = M^2, \quad \frac{S_o}{N_Q} = \frac{3}{2}M^2$$ Bit rate $$r_b = Nf_s$$ Minimum Bandwidth $$BW_{Min} = \frac{r_{b(min)}}{2}$$	Where, N = Number of bits to represent levels V_m = Max amplitude of signal f_s = Number of samples per sec.

Delta Modulation



Condition for slope overload

$$\frac{\delta}{T_s} \geq 2\pi a_m f \quad \boldsymbol{Or} \quad a_m \leq \frac{\delta}{2\pi f T_s}$$

The maximum allowable power

$$P_{max} = \frac{{a_m}^2}{2} = \frac{\delta^2}{8\pi^2 f^2 {T_s}^2}$$

Quantization noise power

$$N_Q = \frac{\delta^2}{3}$$

The in band quantization noise power

$$= \frac{f}{f_s} N_Q$$

Signal to Noise Ratio SNR

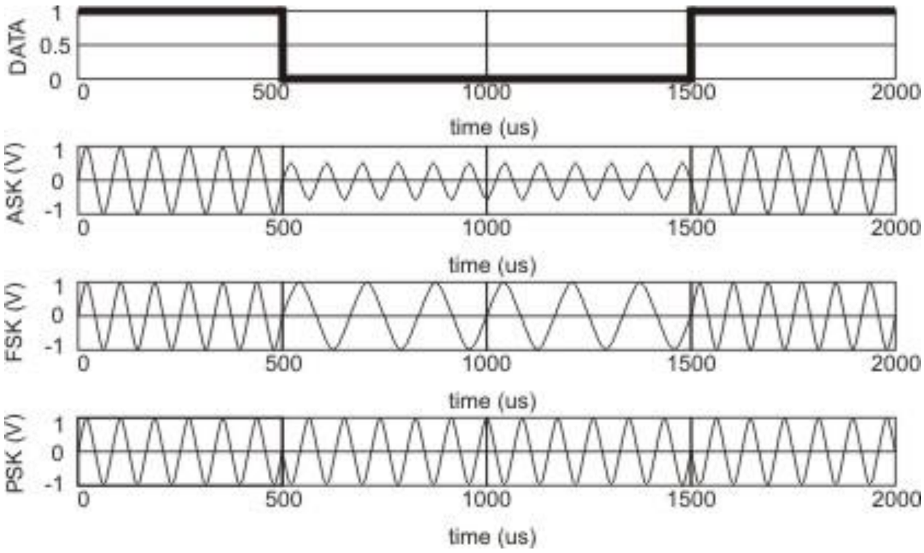
$$SNR = \frac{3}{8\pi^2}\left(\frac{f_s}{f}\right)^3$$

Where,

δ = step size

a_m = peak amplitude

ASK, FSK, PSK



$$V(t) = V_a \sin(2\pi f + \theta)$$

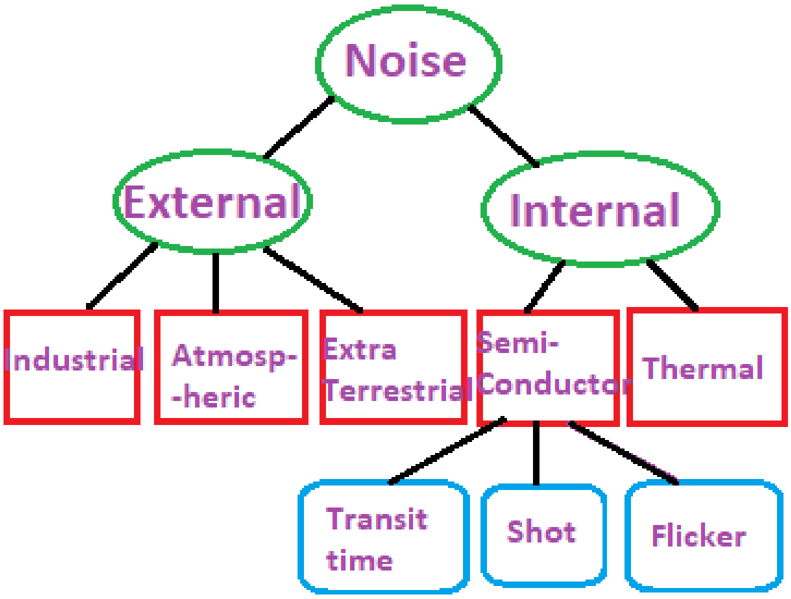
ASK FSK PSK

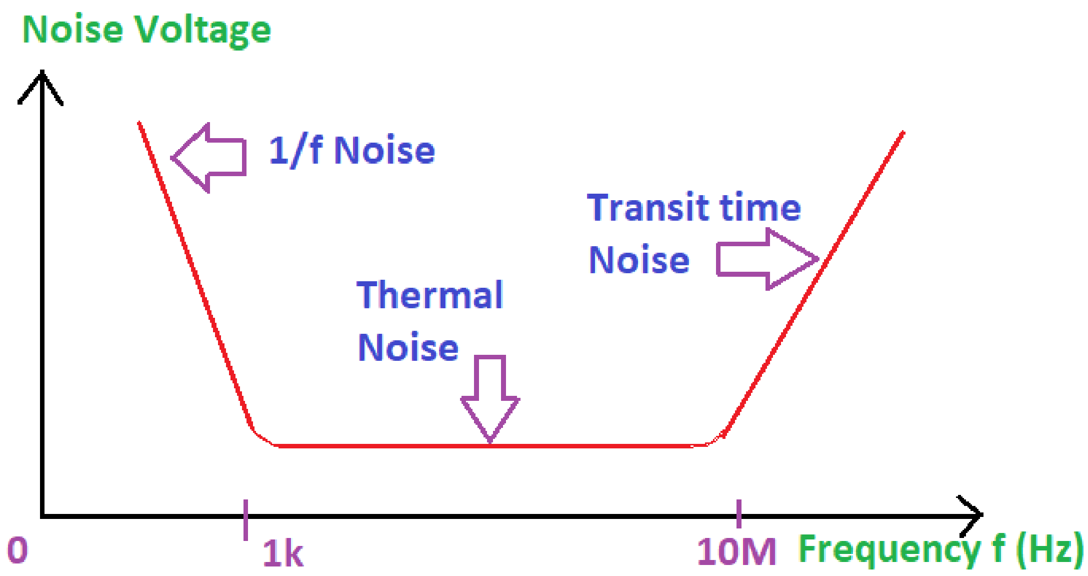
+

QAM

Noise in Digital Communications

Noise categories





Thermal Noise

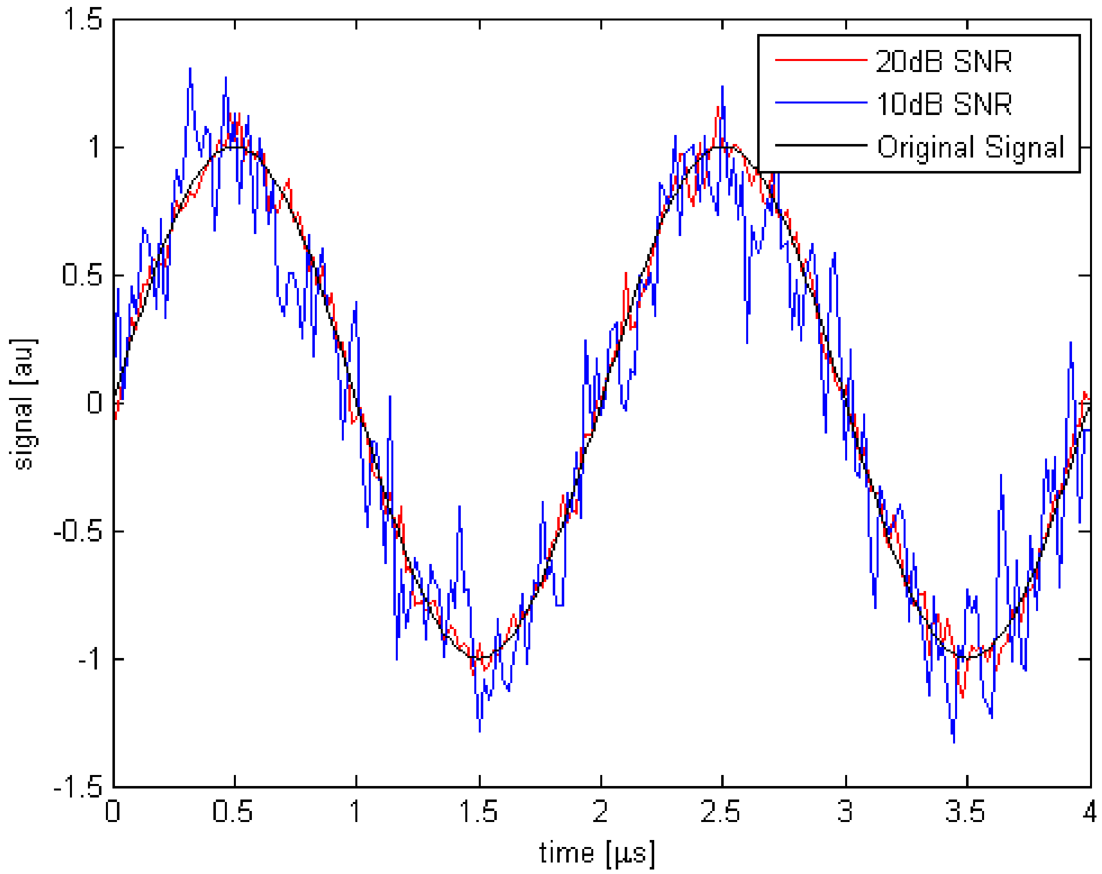
Thermal noise voltage is given by

$$V_n = \sqrt{4kTBR}$$

Where,

V_n = rms Noise voltage
k = Boltzman's constant ($1.38 \times 10^{-23} J/K$)
T = Temperature in Kelvin
B = Bandwidth
R = Thermal Resistance

Measuring noise SNR



Signal to Noise Ratio (SNR)

$$\frac{S}{N} = \frac{V_s}{V_n} \quad or \quad \frac{S}{N} = \frac{P_s}{P_n}$$

Signal to Noise Ratio (Decibels)

SNR in dB using Voltage

$$dB = 20 \log \frac{V_s}{V_n}$$

SNR in dB using Power

$$dB = 10 \log \frac{P_s}{P_n}$$

Noise ratio (NR)

$$NR = \frac{SNR\ input}{SNR\ output}$$

Noise Figure (NF)

$$NF = 10\ log\ NR \quad (dB)$$

Noise in cascaded stages

$$NR = NR_1 + \frac{NR_2 - 1}{A_1} + \frac{NR_3 - 1}{A_1 A_2} + \frac{NR_4 - 1}{A_1 A_2 A_3} + \cdots$$

Random Signals and Processes

Probability distribution function

$$F_x(x) = P(X \leq x) = \int_{-\infty}^{x} f_x(u)du$$

Probability density function

$$f_x(x) = \frac{dF_x(x)}{dx}$$

Gaussian Probability function

$$f_x(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{(x-\overline{X})^2}{2\sigma^2}\right]$$

Independence

$$f_{X,Y}(x,y) = f_X(x)\, f_Y(y)$$

Expectation

$$E[X] = \int_{-\infty}^{\infty} x f_x(x)dx$$

$$E[X^2] = \int_{-\infty}^{\infty} x^2 f_x(x)dx$$

Variance

$${\sigma_x}^2 \triangleq E[X - E[X]^2] = E[X^2] - E^2[X]$$

Addition of random variables

$$E[X+Y] = E[X] + E[Y]$$

Independent random variables

$$E[XY] = E[X]E[Y]$$

Correlation

$$R_{XY} = E[XY] = \iint_{-\infty}^{\infty} xy\, f_{X,Y}(x,y)dxdy$$