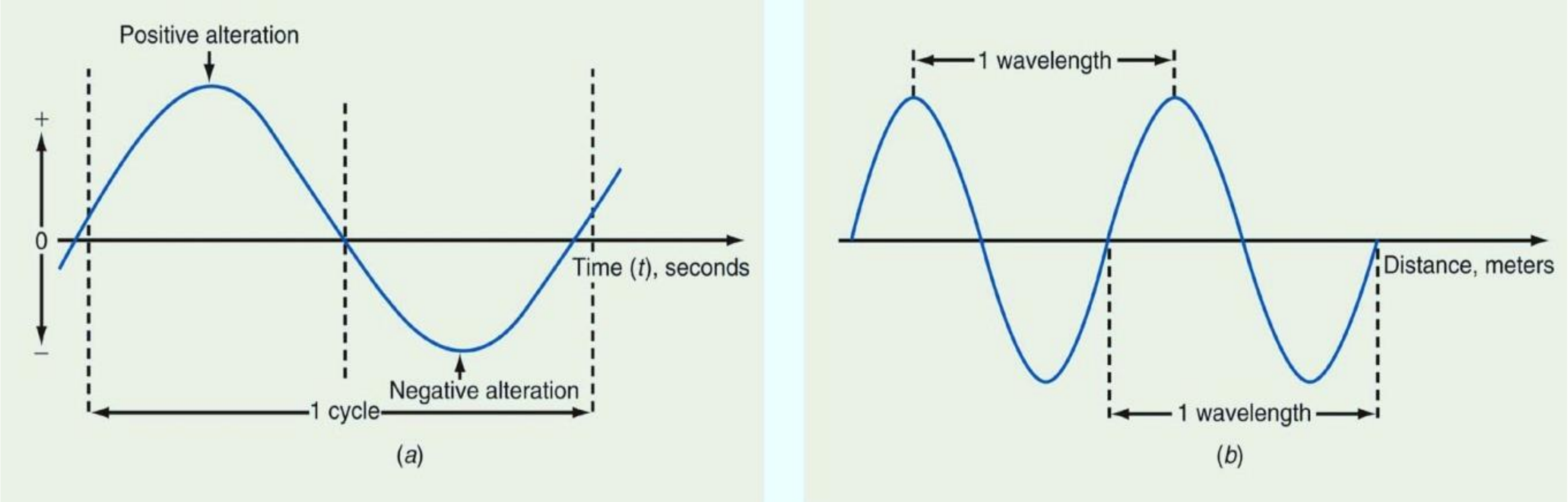
- **Frequency (*f*)**
  - A signal is located on the frequency spectrum according to its frequency and wavelength.
  - Frequency is the number of cycles of a repetitive wave that occur in a given period of time.
  - Frequency is measured in cycles per second (cps). The unit of frequency is the hertz (Hz).

- **Wavelength (λ)**
  - Wavelength is the distance occupied by one cycle of a wave and is usually expressed in meters.
  - Wavelength is also the distance travelled by an electromagnetic wave during the time of one cycle



Fundamental Concepts : Frequency and Wavelength

Wavelength (λ) = speed of light ÷ frequency

$$\lambda = c / f$$

Speed of light **c** = 3 × 10^8 meters/second

Example: What is the wavelength if the frequency is 4MHz?

Solution : λ = 3 × 10^8 / 4 MHz =300,000,000/4,000,000 = 75 meters (m)

In wireless communication, the signals are transmitted via electromagnetic (E/W) waves. For efficient transmission and reception, the antenna length should be comparable to wavelength. so that the antenna properly senses the time variation of the signal. We can obtain transmission with a reasonable antenna length if the transmission frequency is high (for example, if ν is 1 MHz, then λ is 300 m). Commonly **length of antenna or (antenna height) is equal to λ /4** for better radiation.

Example Telephone-quality speech contains frequencies between 200 Hz and 3000 Hz. How long should the antenna be?

Solution : for 200 Hz, the wavelength is λ = c/f =3 × 10^8 /200 = 1.5 × 10^6 m = 1500 km!
Antenna length is 1500km/4= 375 km!
For 3000 Hz, is λ = c/f =3 × 10^8 /3000 = 10^5 m = 100 km! 
Antenna length is 100km/4= 25 km !!!

Example: What frequency E/M wave is well matched to an antenna with a length of 4 cm?

Solution:

Antenna length = λ/ 4= 4 cm ; thus λ=16 cm =0.16m

So the frequency is $f = c / \lambda = 3 \times 10^8$ m per s /0.16 m ≈ 1.8×10^9 ≈ 2 GHz

Hints: Modern cell phones use frequencies near 2 GHz.

- **kHz** (kilohertz, 10^3 **Hz**),
- **MHz** (**megahertz**, 10^6 **Hz**),
- **GHz** (gigahertz, 10^9 **Hz**)
- **THz** (**terahertz**, 10^{12} **Hz**).

So the lowest frequencies produce the longest wavelengths and the highest frequencies produce the shortest wavelengths . So the smaller the signal wavelength, easier the antenna construction. This is why low frequency signals are **modulated** before transmission, instead of directly sending them out.

Exercise : What frequency E/M wave is well matched to an antenna with a length of 10 cm?

- **Signal to Noise Ratio (SNR):**
- SNR is defined as the ratio of signal power to noise power. Noise distorts the signal and accumulated along the path.
- The dB value is calculated by taking the log of the ratio of the measured or calculated power (P_S) w.r.t a reference power (P_N) level.
- Commonly referred to as the *power ratio form* for dB

$$SNR = \frac{signal\ power(W)}{noise\ power(W)} = \frac{P_S}{P_N} \qquad SNR_{dB} = 10\log_{10}\frac{P_S}{P_N} = 10\log_{10}\left(\frac{V_s^2 / R_{in}}{V_n^2 / R_{out}}\right)$$

- Decibel (dB) is a relative unit of measurement used frequently in electronic communications to describe power gain or loss
- e.g.: SNR of 10, 100 and 1000 correspond to 10, 20, and 30dBs, respectively.

- dBm is a dB level using a 1mW reference.

Note : dB is a relative unit that describes gain and dBm is an absolute unit referenced to 1 milliwatt (mW).

Example – A receiver produces a noise power of 200mW with no signal. The output level increases to 5 W when a signal is applied. a) Calculate (S + N)/N as a power ratio and b) in decibels.

Solution: $$\frac{S+N}{N}=\left(\frac{P_{out}}{P_{input}}\right)$$

a) $$\text{Power Ratio} = \frac{S+N}{N}=\left(\frac{5000}{200}\right)=25$$

What about SNR?

b) In decibels

$$=10\log_{10}\left(\frac{P_{out}}{P_{input}}\right)dB=14\,dB$$

Example - Convert 1mW to dBm

Sol $P_{(dBm)} = 10 \cdot \log_{10}(P_{(mW)} / 1mW) = 0$ dBm.

Example - Convert 13dBm to milliwatts:

Sol P(mW) = 1mW · 10^(13dBm/ 10) = 19.95mW

Exercise 1– A measured value of 10mW will result in what dBm power level?

2 - A laser diode outputs 10dBm. Convert this value to watts.

Bandwidth

- Bandwidth is the difference between the upper and lower frequency limits of the signal or the equipment operation range.

- Signal bandwidth is a measure of the extent of significant spectral components of the signal for positive frequencies. It is the difference between the highest and lowest frequencies contained in the information. To determine the frequency content of the signal ***x(t)*** use its Fourier transform:

$$X(f) = \mathcal{F}\left[x(t)\right]$$

- System bandwidth is a measure of the range of frequencies that the system can handle.
- Let h(t) be the impulse response function of a LTI system. To determine the range of frequencies the LTI system can handle, use the frequency response function:

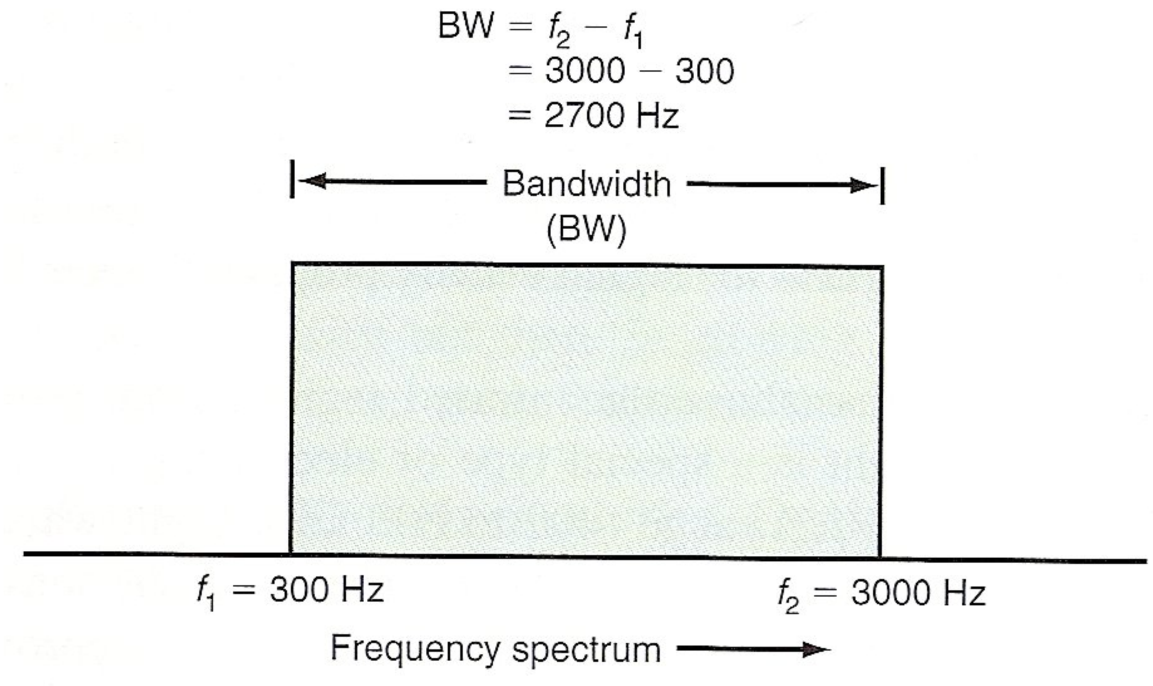
$$H(f) = \mathcal{F}\left[h(t)\right]$$

- Bandwidth of a communication channel is the difference bet[illegible]d lowest frequencies that the channel will allow to pass through it (i.e: its pass band).

Note that the bandwidth of a communication signal ⊘ bandwidth of the information signal.

Example: Figure below shows the bandwidth of the voice frequency range from 300 to 3000Hz. The upper frequency is f_2 and the lower frequency is f_1. The bandwidth, then is

$$BW = f_2 - f_1$$



Example : AM radio broadcast signals cover the frequency band [fc–5, fc+5] kHz, where fc is the carrier frequency assigned to the radio station.

Then the AM radio broadcast signal bandwidth is 10 kHz

Exercise what is the bandwidth of a station assigns AM carrier frequencies from 540 – 1,600 kHz?

Rate of Communication

- Rate of information transmission is directly proportional with its bandwidth
- Shannon's channel capacity theorem which relates B and SNR:
- Shannon limit for information capacity, C is given by

$$C = B \log_2 (1 + SNR) \text{ bits/s}$$
$$C = 3.32\, B \log_{10} (1 + SNR)$$

Where C = information capacity (bits per second- bps)
B = bandwidth (Hz)
SNR = signal to noise ratio (no unit)

Note that : $\log_2(x) = \log_{10}(x)/\log_{10}(2)$.

Example -The telephone channel has a bandwidth of about 3KHz. Calculate the capacity of a telephone channel that has an SNR of 1023.

Solution :

$C = B\ log_2(1 + SNR) = 3000 \ \frac{\log\ (1+1023)}{\log 2} = 3000 \text{ x } 10 = 30,000$ bps

Example – For a standard telephone circuit with a SNR of 30dB and a bandwidth of 3.3 KHz, determine the Shannon limit for information capacity.

Solution:

We have SNR in dB thus it should be changed to power ratio ,

$SNR_{ratio} = 10^{SNR_{dB}/10} = 10^{30/10} = 1000.$

Hence,

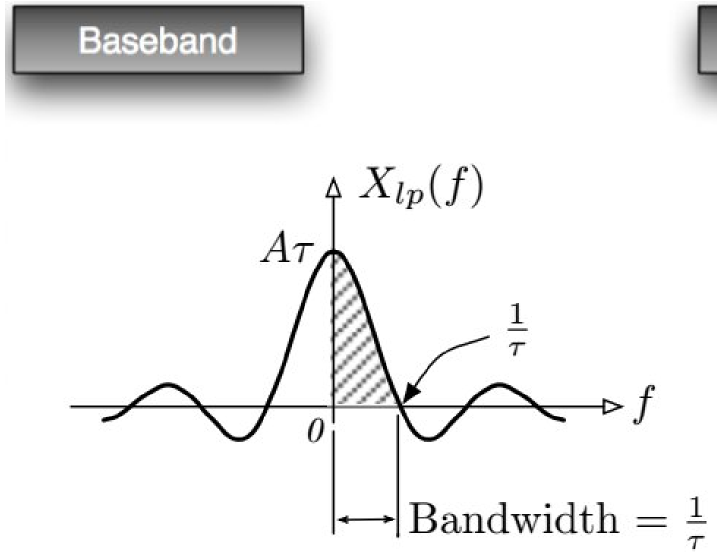
$C = B\ log_2(1 + SNR) = 3.3 \text{ KHz} \ \frac{\log\ (1+1000)}{\log 2} = 3300 \text{ x } 9.96 = 3289\text{bps} = 32.89\text{kbps}$

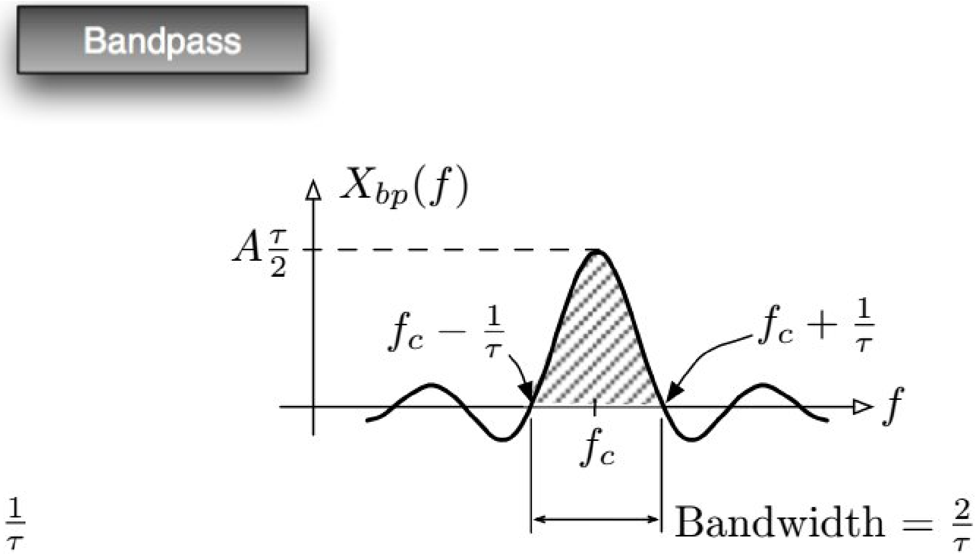
Exercise : A radio channel has a bandwidth of 10 KHz and a SNR of 15 dB. What is the maximum data rate that can be transmitted?

Communication systems can be classified into two groups depending on the range of frequencies they use to transmit information. These communication systems are classified into **BASEBAND** or **PASSBAND** system.

The term **baseband** is used to describe the band of frequencies of the signal delivered by the source or the input transducer. **Baseband transmission** sends the information signal as it is without frequency shifting. Baseband signals are those that have frequencies relatively close to zero such as the **human voice.** The telephone system used for homes and offices, for example, may transmit the baseband audio signal as it is when the call is local (from your home to your neighbour's home). However, when the telephone call is a long–distance call that is transmitted via microwave or satellite links, the baseband audio signal becomes unsuitable for transmission and the communication system becomes a passband system.

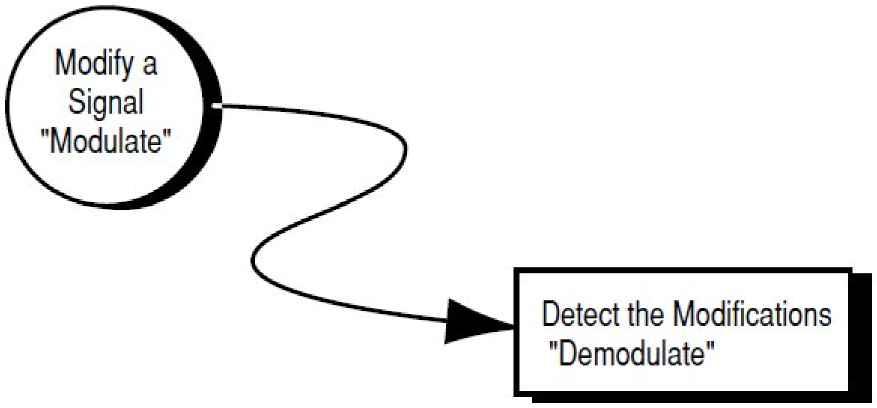
Passband transmission shifts the signal to be transmitted in frequency to a higher frequency and then transmits it, where at the receiver the signal is shifted back to its original frequency. Communication that uses ***modulation*** to shift the frequency spectrum of a signal is also known as **carrier communication.**





WHAT IS MODULATION ?

Modulation is the process of changing some property of the information sources/signal into suitable form for transmission through the physical medium/channel. It is performed in the Transmitter by a device called **Modulator**. It is the process of putting information onto a high frequency carrier in a transmitter.



Any reliably detectable change in signal characteristics can carry information

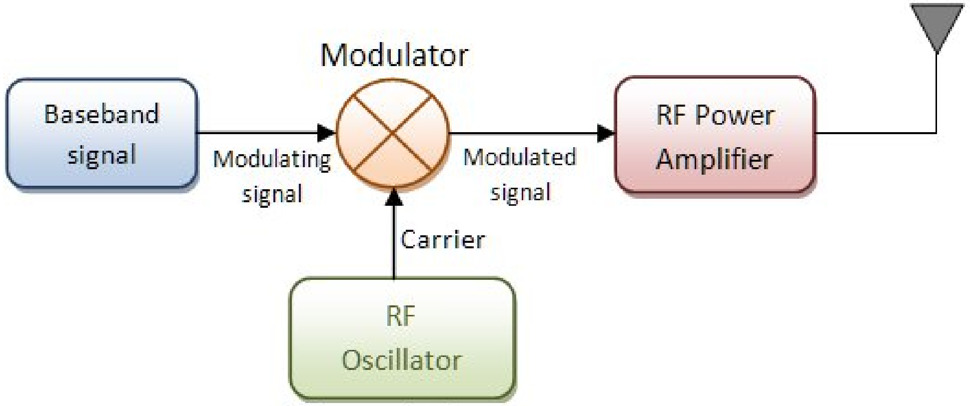
Modulation is important because:

- Ease of radiation - related to antenna design & smaller size.
- Low loss and dispersion.
- Channel assignment (various information sources are not always suitable for direct transmission over a given channel)
- Reduce noise & interference and overcome equipment limitation.
- Simultaneous transmission of several signals – enables the multiplexing i.e. combining multiple signals for Tx at the same time over the same carrier.

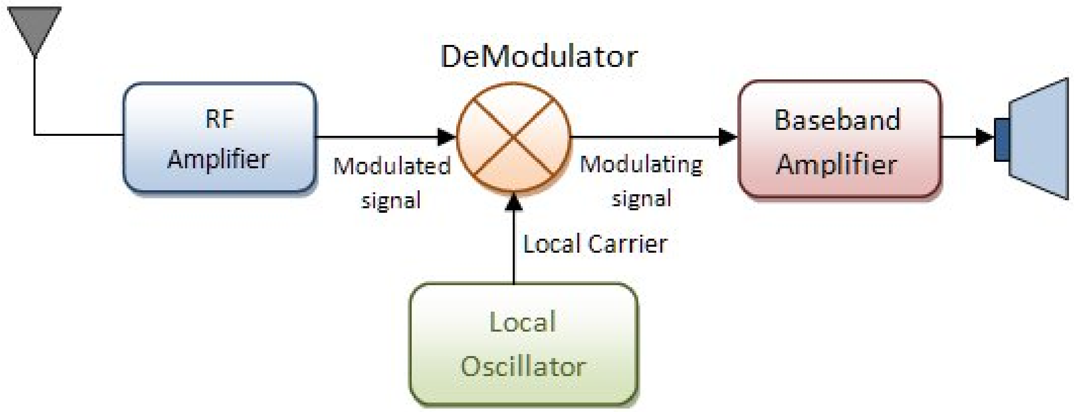
Here baseband signals comes from a audio/video or computer. Baseband signals are also called modulating signal as it modulates carrier signal. carrier signals are high frequency radio waves it generally comes from a radio frequency (RF) oscillators. These two signals are combined in modulator. Modulator takes the instantaneous amplitude of baseband signal and varies amplitude/frequency/phase of carrier signal. Resultant signal is a modulated signal. It goes to an RF-amplifier for signal power boosting and then feed to antenna or a transmission medium.

DEMODULATION ?

Demodulation is the opposite process of modulation. It is extracting the original information signal from a modulated carrier signal. It is the process of shifting the passband signal to baseband frequency range at the receiver A radio antenna receives low power signal. An RF amplifier boosts the signal amplitude. Then the signal goes to a demodulator. demodulator does the reverse of modulation and extracts the back band signal from carrier. Then the baseband signal is amplified to feed a audio speaker or video monitor.



Modulation Block Diagram



Demodulation Block Diagram

A modem receives signals and also transmits signals thus it does modulation and demodulation at the same time. Thus, the name ***modem*** has been given (***mo***dulation and ***dem***odulation).

By modulation, characteristics in the carrier signal are changed according to the message signal. Two most common used forms of carriers – **Periodic pulse wave and Sinusoidal wave.** Correspondingly, we identify two main classes of modulation

– Pulse modulation which includes

- **Pulse Analog Modulation : such as** pulse amplitude (PAM) and pulse time modulations (PTM) respectively.
- **Pulse Digital Modulation :** Examples are pulse code modulation (PCM) and delta modulation (DM).

– Continuous wave (CW) which includes

- **Amplitude Modulation (AM)**
- **Angle Modulation which includes**

\- **Frequency Modulation-(FM)**

\- **Phase Modulation-(PM)**

Continuous Wave (CW) Modulation

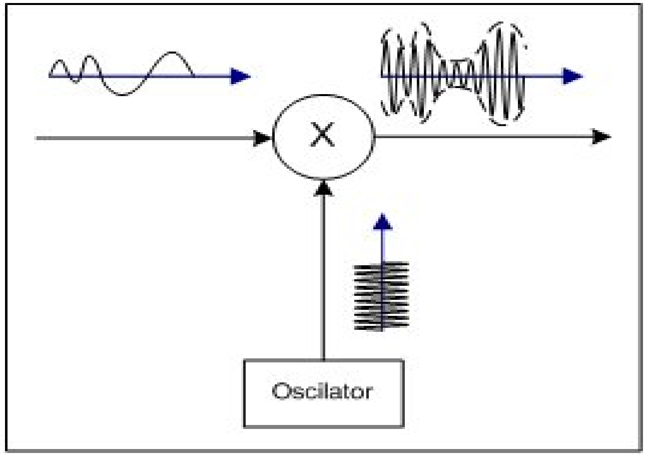
- CW modulation means that some characteristic of a **sinusoidal carrier** is varied in accordance with the message (modulating) signal.
- In CW modulation, the modulated carrier is normally sinusoidal signal of the form

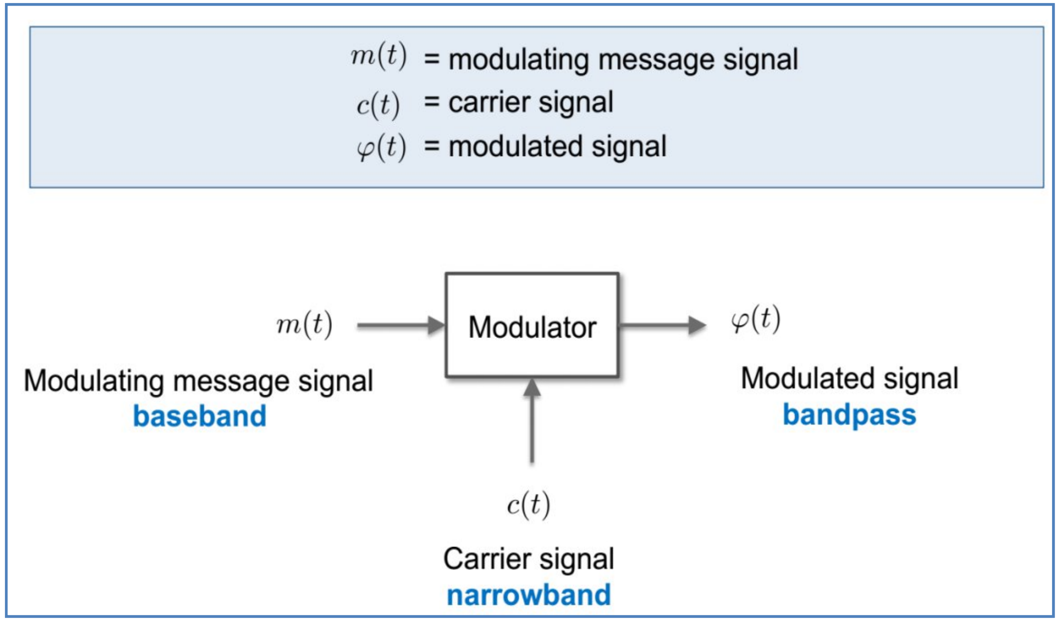
$$c(t) = A_c \cos(2\pi f_c t + \theta)$$

Where $\boldsymbol{A_c}$, $\boldsymbol{f_c}$ and $\boldsymbol{\theta}$ are the amplitude, frequency and angle respectively, of the carrier.

Varied characteristics:

Amplitude – Amplitude Modulation (AM)
Frequency – Frequency Modulation (FM)
Phase – Phase Modulation (PM)





CW Modulation Types

$$c(t) = A_c \; Cos\,(2\pi f_c t + \theta)$$

Vary this with the message, you get Amplitude Modulation (AM)

Vary this with the message signal, you get Phase Modulation (PM)

Vary this with the message signal, you get Frequency Modulation (FM)