Modulation

Modulation often refers to a process that moves the message signal into a specific frequency band that is dictated by the physical channel. The term baseband is used to designate the frequency band of the message signal from the source or input transducer. In telephony the baseband signal is the audio band i.e. 0 to 3.5 KHz.

Analog communication system can be classified into two major categories: base band communication and carrier communication. In baseband communication, message signals/base band signal are directly transmitted without any modification. In this type of communication, dedicated communication channels like twisted pairs of copper cable, co-axial cables are assigned to each user for communication. Since no modulation is present, more than one baseband signal in communication channel will have overlapping bands. Thus, those baseband signals will interfere; and also baseband communication will leave maximum channel spectrum unused. Therefore, we can say that baseband communication for multiple signals through same channel will not be an efficient way of communication.

On the other hand, carrier communication utilizes modulation to shift the frequency spectrum of the base band/message signal. Thus, it is easier to multiplex more than one base band signal and transmitt the same through a common channel. In the case of carrier communication, one of the basic parameters of a high frequency carrier (like amplitude, frequency and phase) is varied linearly with the accordance of message signal $m(t)$. Thus, in modern communication system we always try to incorporate carrier modulation.

Need of modulation

The need of modulation in communication system can be broadly discussed as,

(i) Ease of transmission

For efficient radiation of electromagnetic signal, the radiating antenna should be on the order of a fraction or more of the wavelength (λ) of the driving signal. Typically, the antenna height is given by ($\lambda/4$). For an audio signal with frequency 20 KHz will require an antenna height of $\sim$15 km. Now, antenna with this dimension will be impossible to make. Reduction of antenna dimension is possible, if we can increase the driving signal frequency. For example, if the frequency can be increased upto 10 MHz, then the required antenna dimension is ~ 3 m. In this respect, we can assume that modulation is allowing the baseband signal ~~on the~~ hitch a ride on a high-frequency (HF) sinusoidal carrier.

(ii) Simultaneous transmission of multiple signals

Modulation allows multiple signals to be transmitted at the same time in the same geographical locations without any direct mutual interference. Multiplexing is the method to combine different signals into a single signal which should be transmitted through the channel. Multiplexing of analog signals can be done by frequency division multiplexing (FDM) and or time division multiplexing (TDM). Thus, efficient use of communication channel can be obtained if we employ modulation technique.

(iii) Increment in coverage area

Mathematically, it can be proven that the coverage area of an EM signal directly relates to its power. Higher the signal power, higher will be the coverage area. Since, modulation translates the information of the message signal into much higher frequency signal which has higher power, thus the coverage area of the modulated signal also improves.

(iv) Improvement in radiated power

The power radiated by an antenna in the form of EM signal can be given by,

$$P \propto \left(\frac{I}{\lambda}\right)^2$$

or, $$P = k\frac{I^2}{\lambda^2}$$

Now from the above expression it is clear that, if 'λ' reduces the amount of power also increases and hence the coverage area. Since, modulation helps to reduce the operating 'λ' during transmission, it helps to improve both radiated power and coverage area.

Classification of modulation :-

- Modulation
  - Analog Modulation
    - Amplitude Modulation (AM)
      - DSB-SC
      - DSB-FC
      - SSB
      - VSB
    - Frequency Modulation (FM)
      - NBFM
      - WBFM
    - Phase Modulation (PM)
  - Digital Modulation
    - Baseband Modulation
      - Pulse Modulation
        - PAM
        - PWM / PPM
        - PCM
          - DPCM
          - ADPCM
      - OOK
    - Band-pass Modulation.
      - Bandpass PAM
      - PSK
      - BPSK
      - QPSK (MSK)
      - OQPSK (MSK)
      - GMSK (MSK)
      - FSK
      - (Others)

Introduction to Analog Modulation :-

Let us denote the carrier signal to be c(t). Mathematically,

$$c(t) = A(t)\cos[\omega_c t + \phi(t)] = A(t)\cos[2\pi f_c t + \phi(t)]$$

From the above expression we can say that, there are 3 parameters of the signal available:

$A(t)$: Amplitude
f_c : Frequency
$\phi(t)$: Phase

Now any one these three parameters of c(t) can be varied according to the message signal m(t) to carry the information. Based on the parameter varied of the carrier signal, we name the modulation technique.

$A(t) \propto m(t)$: Amplitude Modulation (f_c; $\phi(t)$ = constant)
$f_c \propto m(t)$: Frequency Modulation ($A(t)$; $\phi(t)$ = Constant)
$\phi_c(t) \propto m(t)$: Phase Modulation ($A(t)$; f_c = constant)

Concept of Frequency Translation

Frequency translation is a very important concept in case of communication system. Any signal may be translated to a new spectral range by simply multiplying the signal with an auxilliary signal.

Let us assume that, the two signal can be represented by

$$\left.\begin{aligned} v_m(t) &= A_m \cos \omega_m t \\ v_c(t) &= A_c \cos \omega_c t \end{aligned}\right\} \text{ where } \omega_c \gg \omega_m.$$

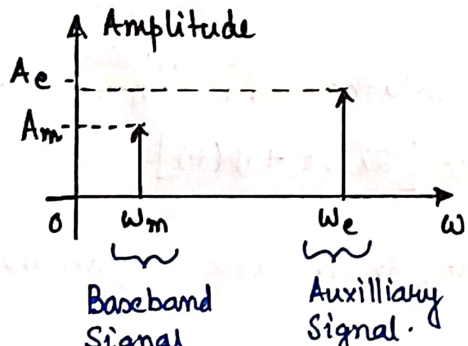
We also designate that, the signal is $v_m(t)$ and the auxilliary signal is $v_c(t)$. Therefore the frequency translation can be easily achieved by multiplying $v_m(t)$ with $v_c(t)$. Mathematically,

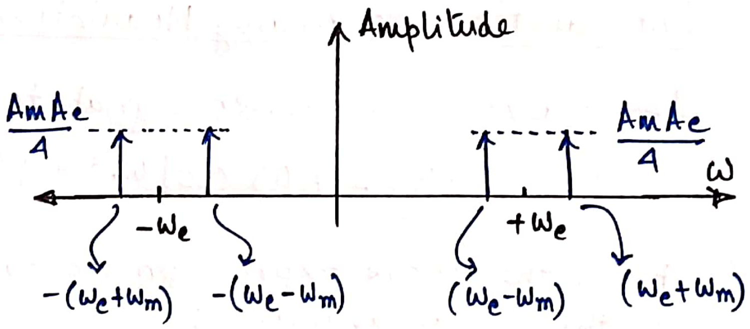
$$v_T(t) = v_m(t)\, v_c(t)$$

$$= \frac{A_m A_c}{2}\left(2 \cos \omega_m t \cos \omega_c t\right) = \frac{A_m A_c}{2}\left(\cos(\omega_c+\omega_m)t + \cos(\omega_c-\omega_m)t\right)$$

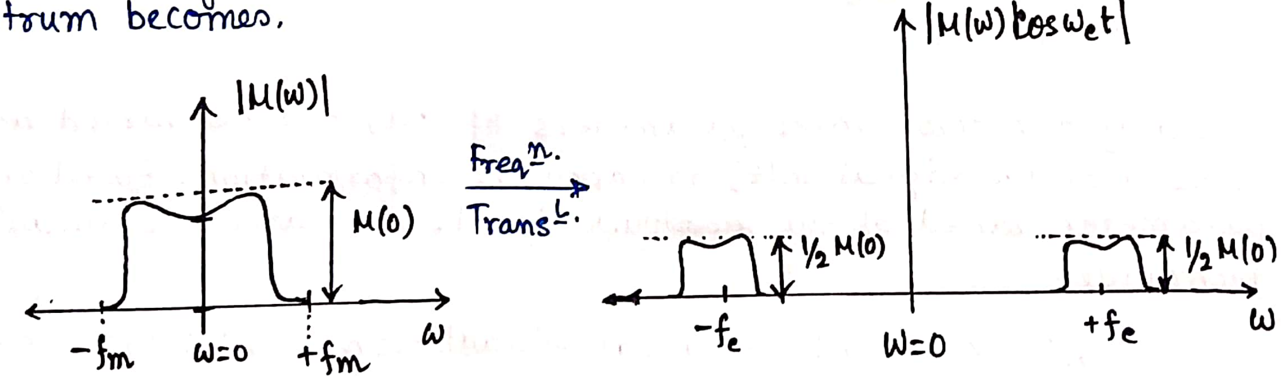
$$= \frac{A_m A_c}{4}\left[e^{j(\omega_c+\omega_m)t} + e^{-j(\omega_c+\omega_m)t} + e^{j(\omega_c-\omega_m)t} + e^{-j(\omega_c-\omega_m)t}\right]$$

The frequency domain spectra of $v_T(t)$ can be given by,





For an arbitary shaped signal m(t) the frequency translated signal spectrum becomes,



Recovery of Baseband Signal from Frequency Translated Signal

Recovery of the original signal from the frequency translated signal is another major concept. Generally this step is also called as reverse translation. Conceptually, reverse translation can be achieved by multiplying the same auxilliary signal with the frequency translated signal. Mathematically we can write,

$$
\begin{aligned}
v_{RT}(t) &= v_T(t)\, v_c(t) \\
&= (m(t)\cos w_c t)(\cos w_c t) \qquad (\because A_c = 1\ ;\ \text{assume for simpler analysis}) \\
&= \frac{m(t)}{2}(2\cos^2 w_c t) \\
&= \underbrace{\frac{m(t)}{2}}_{\text{Baseband Signal}} + \underbrace{\frac{m(t)}{2}\cos(2w_c t)}_{\text{HF term.}}
\end{aligned}
$$

Recall that, $w_c \gg w_m$, Thus the HF or high frequency term can easily be removed by applying a filter (LPF or low-pass filter). The schematic block diagram can be represented as,