Al-Mustaqbal University
Department of Medical Instrumentation Techniques Engineering
Class: Third
Subject: Medical Communication Syatems
Lecturer: Dr. Bayan Mahdi Sabbar & Dr. Mayasah Razzaq Abd-Ali
Lecture:4

Lecture 4

AM & FM systems .

5.1 Baseband vs. Passband Communication Systems

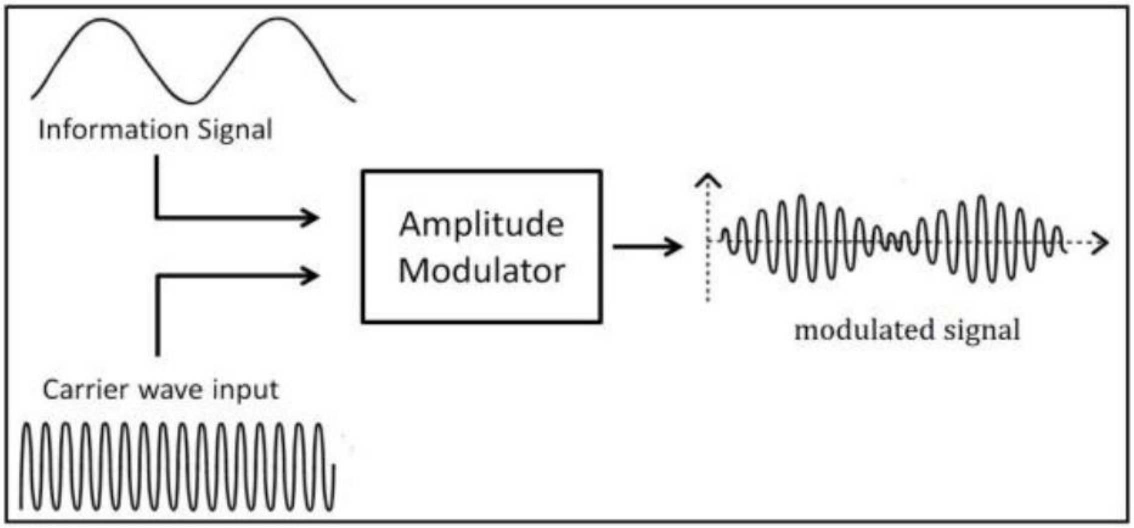
Communication systems can be classified into two groups depending on the range of frequencies they use to transmit information. These communication systems are classified into BASEBAND or PASSBAND system. Baseband transmission sends the information signal as it is without modulation (without frequency shifting). 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. Almost all sources of information generate baseband signals. Baseband signals are those that have frequencies relatively close to zero such as the human voice (20 Hz – 5 kHz) and the video signal from a TV camera (0 Hz – 5.5 MHz).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 neighbor'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. Similarly, transmitting the video signal from your camera to your TV using a wire represents a baseband communication while transmitting that video signal via satellites passband transmission. Therefore, baseband transmission, which is easier than passband transmission, is usually used when communicating over wires, while over the air transmission requires passband transmission. Notice that even over wires, the transmission may be passband transmission in specific applications.

5.2 Modulation and Demodulation

The process of shifting the baseband signal to passband range for transmission is known as **MODULATION** and the process of shifting the passband signal to baseband frequency range at the receiver is known as **DEMODULATION**. In modulation, one characteristic or more of a signal (generally a sinusoidal wave) known as the carrier is changed based on the information signal that we wish to transmit. The characteristics of the carrier signal that can be changed are the amplitude, frequency, or phase, which result in Amplitude modulation, Frequency modulation, or Phase modulation.

5.3 Amplitude Modulation

Amplitude modulation is the process of changing the amplitude of a relatively high frequency carrier signal in proportion with the instantaneous value of the information signal. Here frequency and phase are kept constant. In other word, AM is defined as a process in which the amplitude of the carrier wave $\boldsymbol{c}(\boldsymbol{t})$ is varied about a mean value, linearly with baseband signal $\boldsymbol{m}(\boldsymbol{t})$.AM modulators are two input devices. One input is a single, relatively high frequency carrier signal of constant amplitude, and the second input is comprised of relatively low frequency information signals that may be a single frequency or a complex waveform made up of many frequencies.



AM is itself divided into different types:

1. Double Sideband Large Carrier (DSB-LC): This is the most widely used type of AM modulation. In fact, all radio channels in the AM band use this type of modulation.

2. Double Sideband Suppressed Carrier (DSB-SC): This is the same as the AM modulation above but without the carrier.

3. Single Sideband (SSB): In this modulation, only half of the signal of the DSBSC is used.

4. Vestigial Sideband (VSB): This is a modification of the SSB to ease the generation and reception of the signal.

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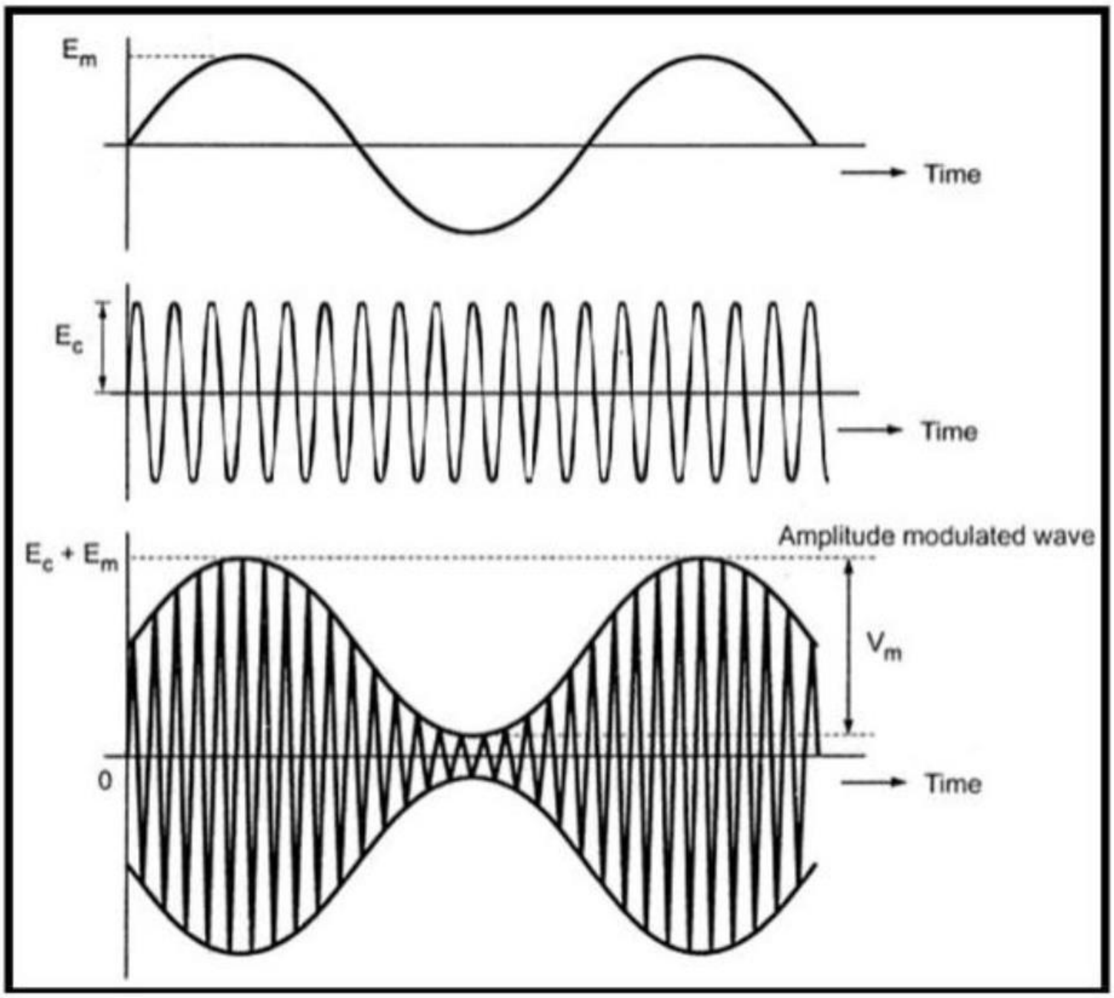
5.4 Double Sideband Large Carrier (DSB-LC)

There are several types of amplitude modulation and the most commonly used is AM double sideband large carrier (DSB-LC) scheme. It is also called conventional AM. The following figure illustrates the relationship among the carrier, the modulating signal and the modulated signal for conventional AM.



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The expression of AM wave is given by:

$$e_{AM}(t) = [\, E_c + m(t)\,] \cos(w_c t)$$

$$\text{If} \quad m(t) = E_m \cos(w_m t)$$

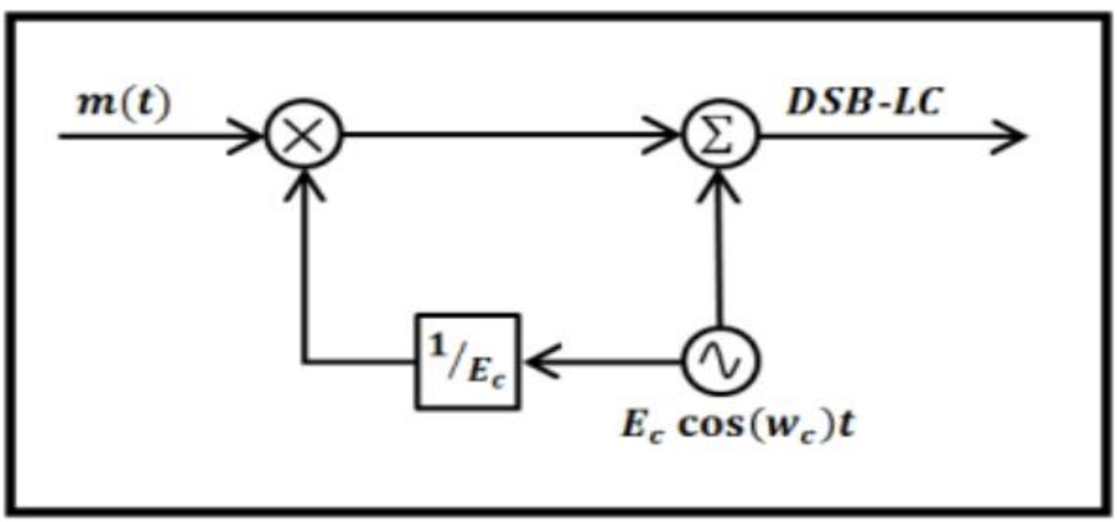
$$e_{AM}(t) = E_c \cos(w_c t) + E_m \cos(w_m t) \cos(w_c t)$$

$$\boldsymbol{e_{AM}(t) = \underbrace{E_c \cos(w_c t)}_{\textbf{Carrier}} + \underbrace{\frac{E_m}{2} \cos(w_c - w_m)t}_{\textbf{LSB}} + \underbrace{\frac{E_m}{2} \cos(w_c + w_m)t}_{\textbf{USB}}}$$

Where: Ec: Carrier voltage Em : Modulating voltage $m(t)$: Modulating signal

5.4.1 Generation of Double Sideband Large Carrier (DSB-LC)

A process of generating a DSB-LC is shown in figure 1. DSB-LC modulation can be achieved by using a non-linear device, such as a diode. This is shown in figure 2



Figure(1) Generation of DSB-LC

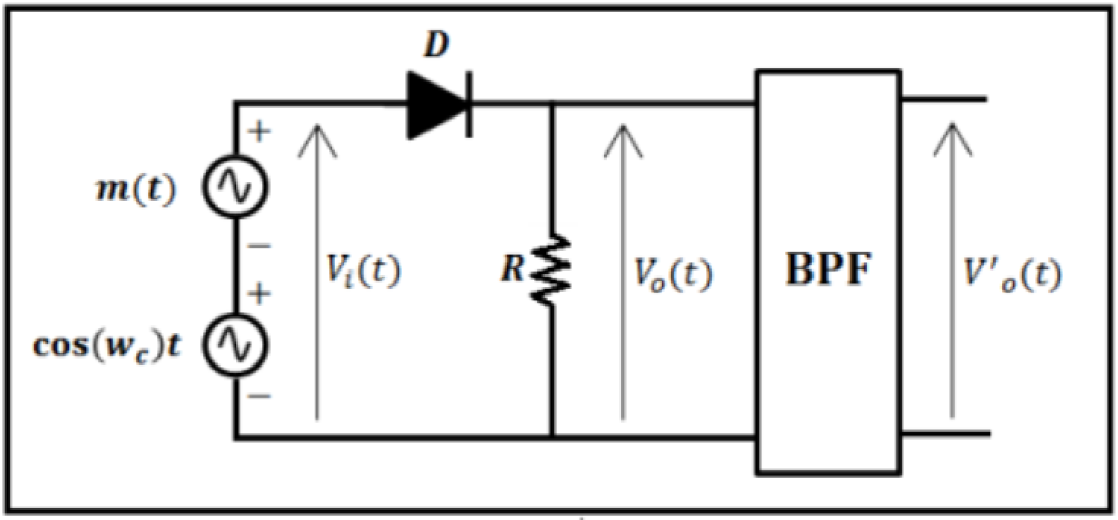


Figure (2) Amplitude modulator using a diode.

5.4.2 Spectrum of DSB-LC

Amplitude modulation DSB-LC simply shifts the spectrum of $\boldsymbol{m(t)}$ to the carrier frequency $\boldsymbol{fc}$. The resultant modulated signal consists of three frequencies: 1. The carrier frequency $\boldsymbol{fc}$. 2. Upper sideband frequency ($\boldsymbol{fc}$ + $\boldsymbol{fm}$). 3. Lower sideband frequency ($\boldsymbol{fc}$- $\boldsymbol{fm}$). These three components of the modulated wave constitute the spectrum of the AM modulated wave when the modulating wave is a single frequency. The bandwidth of the modulated waveform is twice the information bandwidth.

$$\mathbf{BW = maximum\ freq. - minimum\ freq}$$

$$\mathbf{BW} = (\boldsymbol{fc} + \boldsymbol{fm}) - (\boldsymbol{fc} - \boldsymbol{fm})$$

$$\mathbf{BW} = 2\,\boldsymbol{fm}$$

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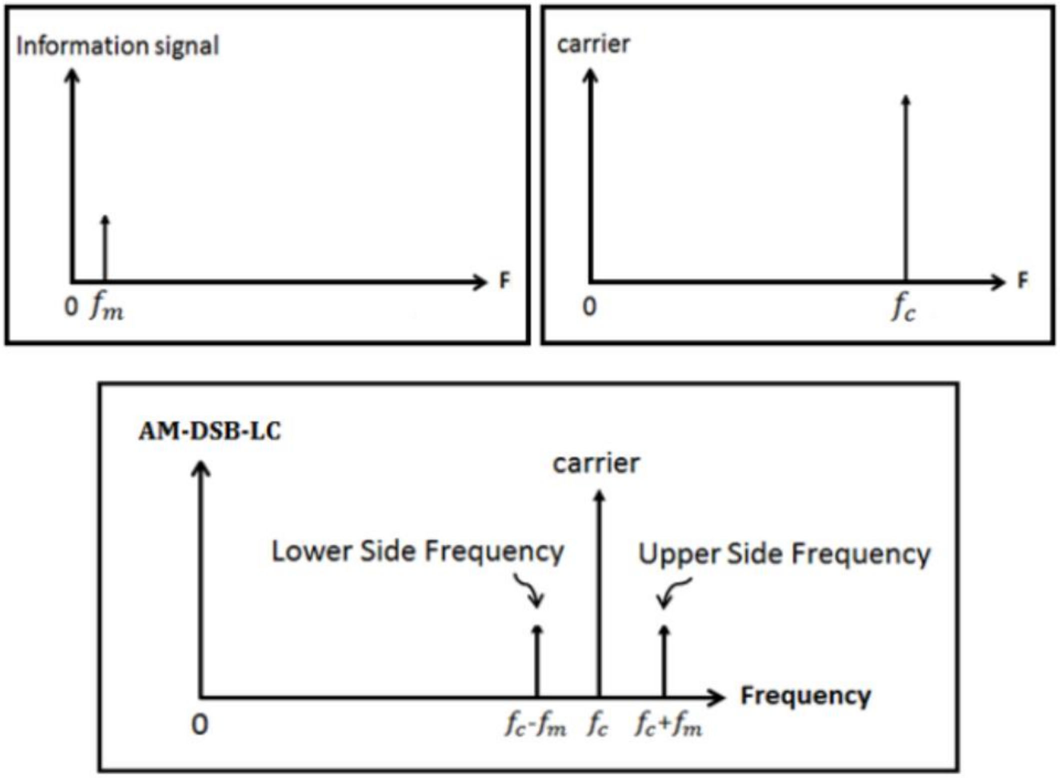
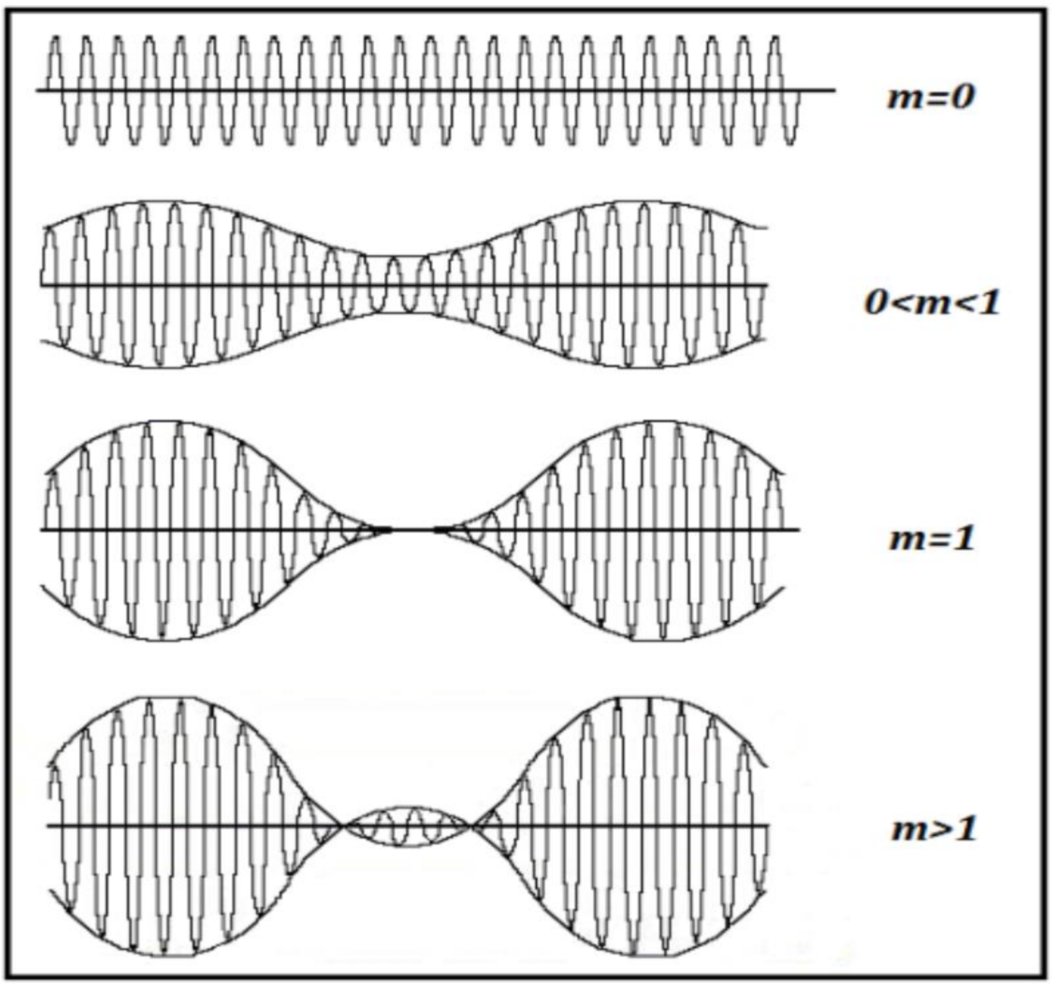


5.4.3 Modulation index

The modulation index is defined as the ratio of the amplitude of the modulating signal to that of the unmodulated carrier. It is a value between 0 and 1 which describes the "degree of modulation" of the carrier. The modulation index should always greater than zero and less than one. If (m=0), the resultant modulated waveform is just a constant envelope of amplitude Ec (there is no modulation of the carrier wave). If (m > 1), the resultant waveform is over modulated and is distorted (the maximum modulation that can occur without distortion, when modulation index equal one)

$$m = \frac{E_m}{E_c}$$

The modulation index should always greater than zero and less than one. If (m=0), the resultant modulated waveform is just a constant envelope of amplitude Ec (there is no modulation of the carrier wave). If (m > 1), the resultant waveform is over modulated and is distorted (the maximum modulation that can occur without distortion, when modulation index equal one).



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$Vmax$ and $Vmin$ are the peak voltage of the modulated signal envelope. It is much easier to measure $Vmax$ and $Vmin$ on an oscilloscope than it is to measure Em or Ec.

$$E_m = \frac{1}{2}(V_{max} - V_{min})$$

$$E_c = \frac{1}{2}(V_{max} + V_{min})$$

Thus

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

5.4.4 Power of DSB-LC

There are three components for any DSB-LC waveform, the upper sideband, the lower sideband and the carrier frequency. If the powers in the three of these are added up, the total power in the modulated signal will be

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

$$P_c = \frac{(E_c)^2}{2R}$$

$$P_{USB} = \frac{m^2 P_c}{4}$$

$$P_{LSB} = \frac{m^2 P_c}{4}$$

$$P_t = P_c + \frac{m^2 P_c}{4} + \frac{m^2 P_c}{4}$$

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$$P_s = \frac{m^2 P_c}{2}$$, The power of the upper and lower sidebands.

The efficiency of DSB-LC signal is defined as

$$\eta = \frac{P_s}{P_t} \times 100\%$$

5.4.5 Demodulation of DSB-LC

In DSB-LC signals, the desired signal waveform is available in the envelope of the modulated signal. The use of synchronous detection will, of course, yield the desired waveform but it is possible to demodulate AM signals by much simpler techniques. The simplest and most popular method is that one which detects the envelope of the modulated waveform directly and is called the envelope detector.

The Envelope Detector:

Any circuit whose output follows the envelope of the input signal waveform will serve as an envelope detector. The simplest form of an envelope detector is a nonlinear charging circuit with a fast charge time and a slow discharge time. It can easily be constructed using a diode in series with a capacitor, as shown in figure 3. A resistor placed across the capacitor controls the discharge time.

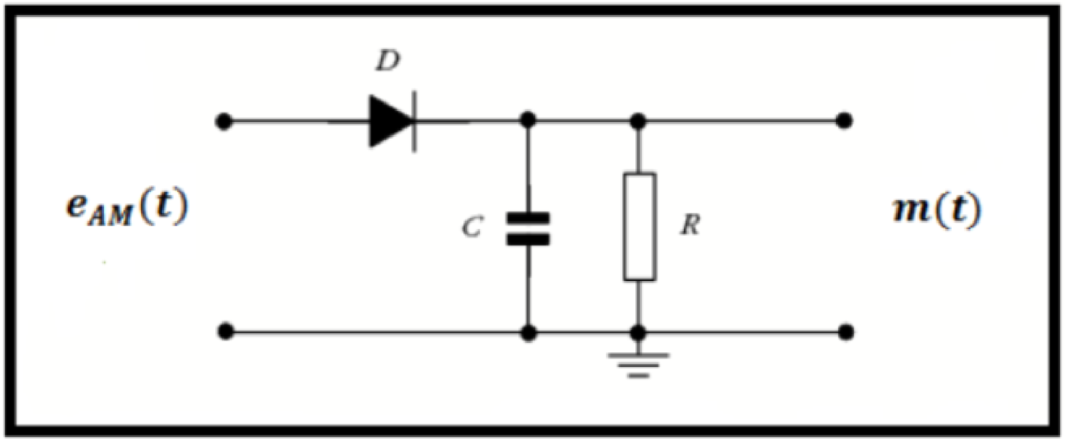


Figure (3) Envelope Detector

5.5 Double Sideband Suppressed Carrier (DSB-SC)

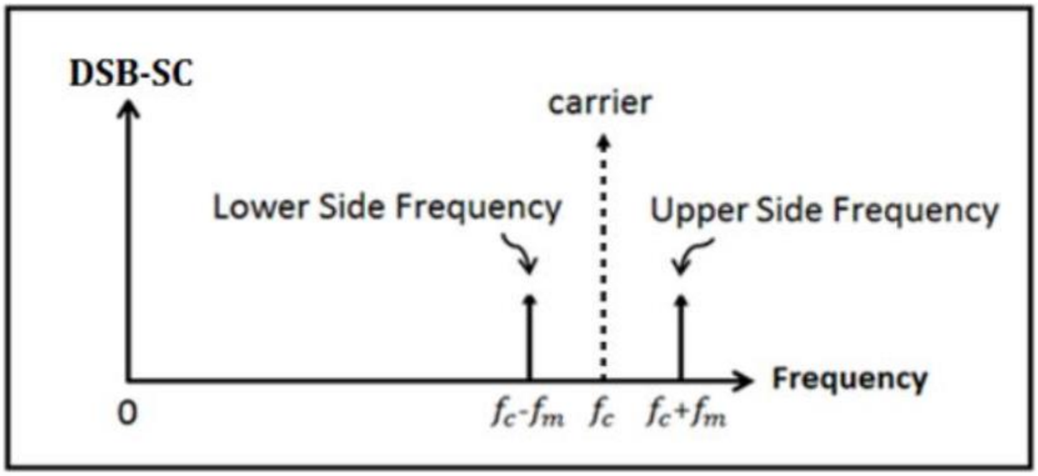
Double-sideband suppressed-carrier transmission (DSB-SC) is transmission in which frequencies produced by amplitude modulation (AM) are symmetrically spaced above and below the carrier frequency and the carrier level is reduced to the lowest practical level, ideally being completely suppressed. The expression of DSBSC modulation is given by:

$$e_{DSB-SC}(t) = m(t)\cos(w_c t)$$

$$\text{But} \quad m(t) = E_m \cos(w_m t)$$

$$e_{DSB-SC}(t) = E_m \cos(w_m t)\cos(w_c t)$$

$$\boldsymbol{e_{DSB-SC}(t) = \frac{E_m}{2}\cos(w_c - w_m)t + \frac{E_m}{2}\cos(w_c + w_m)t}$$



The bandwidth of the modulated waveform is twice the information bandwidth

$$\mathbf{BW = maximum\ freq. - minimum\ freq}$$

$$\mathrm{BW} = (fc + fm) - (fc - fm)$$

$$\mathrm{BW} = 2\,fm$$

5.5.1 Generation of Double Sideband Suppressed Carrier (DSB-SC)

A process of generating a DSB-SC is shown in figure (4)

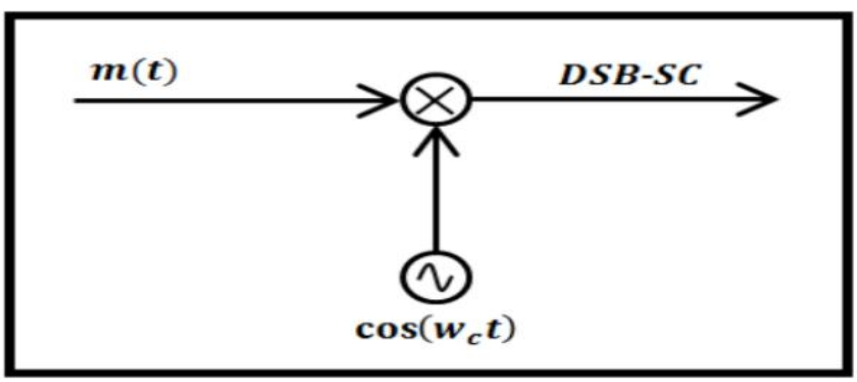
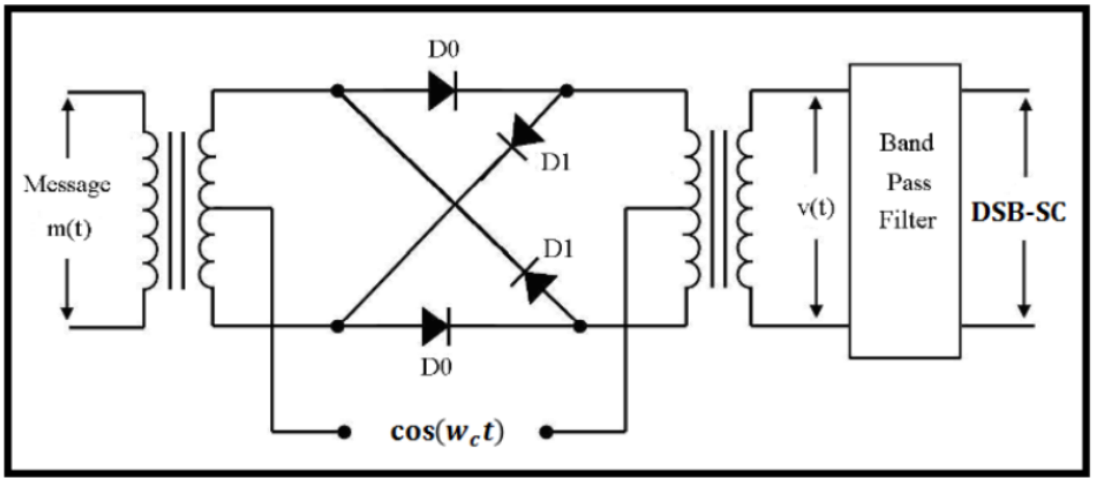


Figure (4) Generation of DSB-SC

The double-side band suppressed carrier (DSB-SC) form of amplitude modulation is usually generated using the ring modulator, which uses two Centre tapped transformers, four diodes followed by a band pass filter. This is shown in figure (5)



Figure(5) The ring modulator used for the generation of (DSB-SC)

5.5.2 Power of DSB-SC

There are two components for any DSB-SC waveform, the upper sideband and the lower sideband frequency. If the powers in the two of these are added up, the total power in the modulated signal will be

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

$$P_{USB} = \frac{(E_m)^2}{8R}$$

$$P_{LSB} = \frac{(E_m)^2}{8R}$$

$$P_t = \frac{(E_m)^2}{4R}$$

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5.5.3 Demodulation of DSB-SC

The DSB-SC wave is applied to a product modulator in which it is multiplied with the locally generated carrier $\cos(wct)$, which is exactly coherent or synchronized in both frequency and phase with the original carrier wave used to generate the DSBSC wave. This method of detection is therefore called as coherent detection or synchronous detection. The output of the product modulator is applied to the low pass filter (LPF) which eliminates all the unwanted frequency components and produces the message signal.

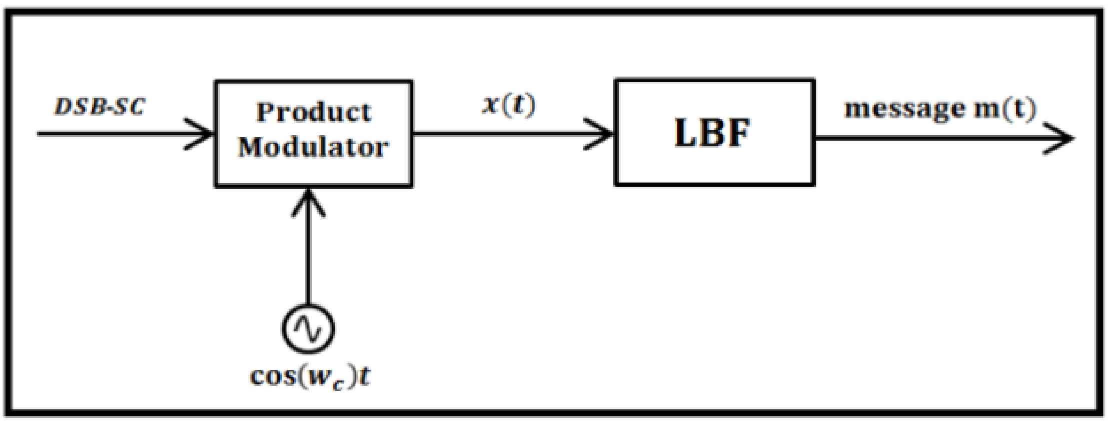

Figure (6) Coherent Detection of DSB-SC modulated wave.

5.6 Single Sideband (SSB)

We have seen that both DSB-LC and DSB-SC signals required a transmission band width equal to twice the bandwidth of the message signal $m(t)$. Since either the upper sideband (USB) or the lower sideband (LSB) contains the complete information of the message signal, we can conserve bandwidth by transmitting only one sideband. The modulation is called Single Sideband (SSB) modulation.

5.6.1 Generation of Single Sideband (SSB)

There are two common methods to generate a Single Sideband (SSB) signal.

1. Filtering Method

One method of producing an SSB signal is to remove one of the sidebands via Band Pass Filter (BPF), leaving only either the upper sideband (USB), the sideband with the higher frequency, or less commonly the lower sideband (LSB), the sideband with the lower frequency. Most often, the carrier is reduced or removed entirely (suppressed), being referred to in full as single sideband suppressed carrier (SSBSC). Figure (7) shows the generation of a single sideband (SSB) signal using the filter method.

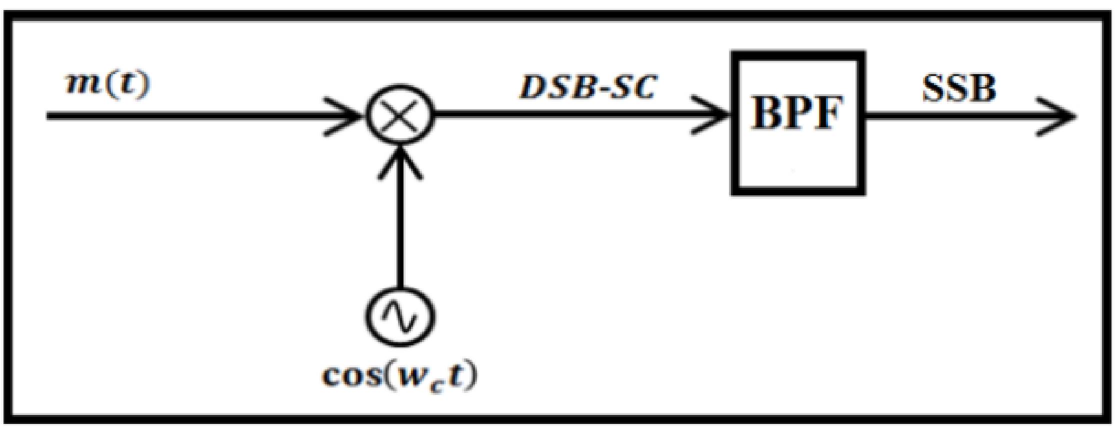

Figure (7) Generation of SSB signal using filter method

2. Phasing Method

An alternate method of generation known as a Hartley modulator, uses phasing to suppress the unwanted sideband. To generate an SSB signal with this method, two versions of the original signal are generated, mutually 90° out of phase for any single frequency within the operating bandwidth. Each one of these signals then

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modulates carrier waves (of one frequency) that are also 90° out of phase with each other. By either adding or subtracting the resulting signals, a lower or upper sideband signal results. Figure (8) shows the generation of a single sideband (SSB) signal using the phasing method.

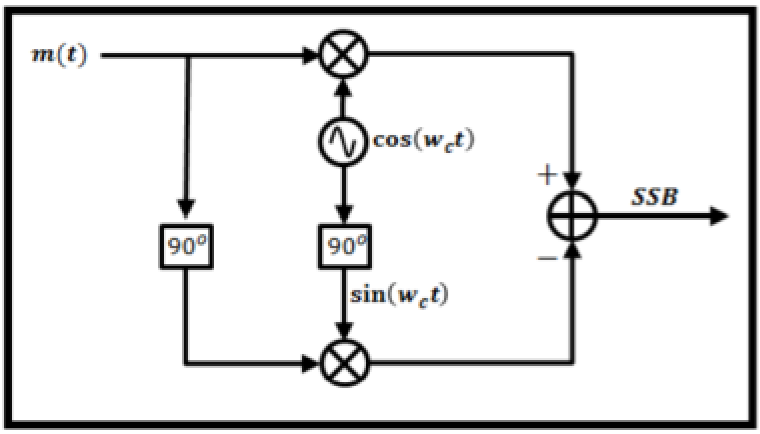

Figure (8) Generation of SSB signal using phasing method.

5.6.2 Power of SSB

The power of the SSB modulated signal is less than what would be obtained using DSB modulation

$$P_{SSB-SC} = P_{USB}$$

$$P_{SSB-LC} = P_c + P_{USB}$$

5.6.3 Demodulation of SSB

Demodulation of SSB signals can be accomplished by using a synchronous detector as used in the demodulation of DSB-SC.

5.7 Vestigial Sideband (VSB)

The vestigial sideband (VSB) modulation works by combining some small part of one of the sidebands together with the entire other one. DSB transmits the both entire sidebands, SSB transmits only one entire sideband, and VSB transmits one entire sideband and some vestige of the other. The bandwidth used by VSB will lie between that calculated for DSB and SSB.The situations where VSB is desirable are where the input signal is very wide and there is a need to conserve frequency or spectrum space. The bandwidth of a VSB signal is between 1 and 2 times the original modulating signal bandwidth, depending on how much of the vestige sideband is transmitted.

5.8 Frequency Division Multiplexing (FDM)

One of the basic problems in communication engineering is the design of a system which allows many individual signals from users to be transmitted simultaneously over a single communication channel. The most common method is to translate individual signals from

one frequency region to another frequency region. Frequency translation can be accomplished by multiplying a low frequency modulating signal with a high frequency carrier signal. Frequency-division multiplexing (FDM) is a scheme in which numerous signals are combined for transmission on a single communications line or channel. Each signal is assigned a different frequency (sub-channel) within the main channel. Figure (9) and figure (10) show the transmitter and receiver of a 3-FDM system.

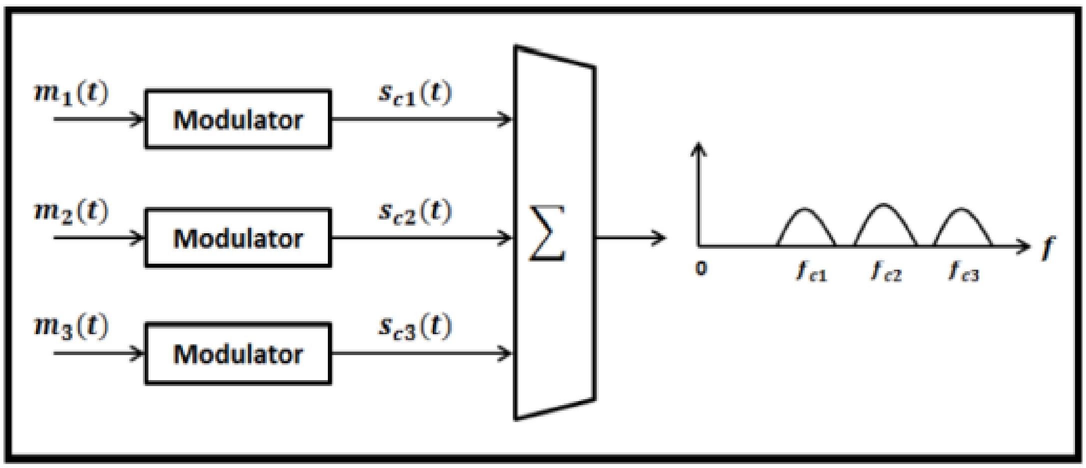

Figure (9) FDM transmitter

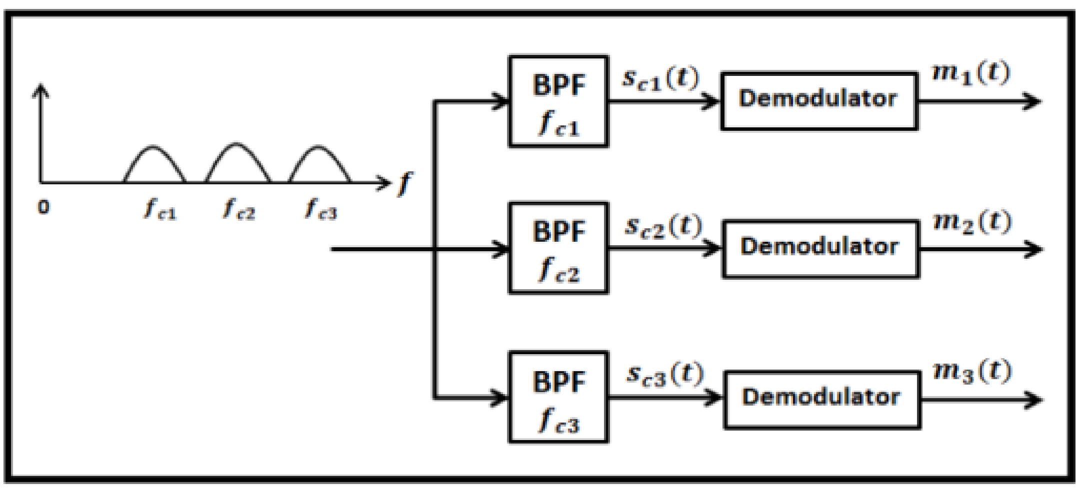

Figure (10) FDM receiver

Example 1: For a particular DSB-SC modulator with a carrier frequency of 1000 rad/sec, a load resistance of 50 Ω, and a modulating signal $m(t)$ = 10 cos(20t). Find the following: 1. The peak voltage ($\boldsymbol{Em}$). 2. The modulating frequency. 3.

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The DSB-SC bandwidth. 4. The USB bandwidth and frequencies 5. The LSB bandwidth and frequencies 6. The total power.

Solution:

1. $E_m = 10$ V.
2. $f_m = \frac{w_m}{2\pi} = \frac{20}{2\pi} = 3$ Hz.
3. The DSB-SC bandwidth is $2f_m = 6$ Hz.
4. The USB bandwidth = 3 Hz.
   The USB start at $f_c = 159$ Hz and extends to $(f_c + f_m) = 162$ Hz.
5. The LSB bandwidth = 3 Hz.
   The LSB start at $(f_c - f_m) = 156$ Hz and extends to $f_c = 159$ Hz.
6. $P_t = \frac{(E_m)^2}{4R} = \frac{100}{200} = 0.5$ W.

Example 2: An AM/DSB modulated signal is given by:

$\boldsymbol{eAM(t)} = \mathbf{3}[\ \mathbf{1} + \mathbf{0.5}\ \mathbf{sin}(\mathbf{12.566} * \mathbf{103}\boldsymbol{t})\ ]\ \mathbf{sin}(\mathbf{6.28} * \mathbf{106}\boldsymbol{t})$ Calculate the following

a) Amplitude and frequency of each sideband.

b) Carrier power, sideband power, total power and the efficiency.

c) Sketch the wave form of above AM/DSB signal in time domain and in frequency domain.

Solution:

$e_{AM}(t) = [\, E_c + m(t) \,] \sin(w_c t)$

$e_{AM}(t) = [\, 3 + 1.5 \sin(12.566 * 10^3\, t) \,] \sin(6.28 * 10^6 t)$

From the equation, we have

$E_c = 3\ V$

$E_m = 1.5\ V$

$$f_m = \frac{12.566 * 10^3}{2\pi} = 2 \text{ KHz}$$

$$f_c = \frac{6.28 * 10^6}{2\pi} = 1000 \text{ KHz}$$

a) The amplitude of each sideband $= \frac{E_m}{2} = \frac{1.5}{2} = 0.75$ V

$F_{LSB} = f_c - f_m = 1000 - 2 = 998$ KHz

$F_{USB} = f_c + f_m = 1000 + 2 = 1002$ KHz

b) $P_c = \frac{(E_c)^2}{2R} = \frac{(3)^2}{2} = 4.5\text{ W}$

$P_{USB} = \frac{(E_m)^2}{8R} = \frac{(1.5)^2}{8} = 0.28125\text{ W}$

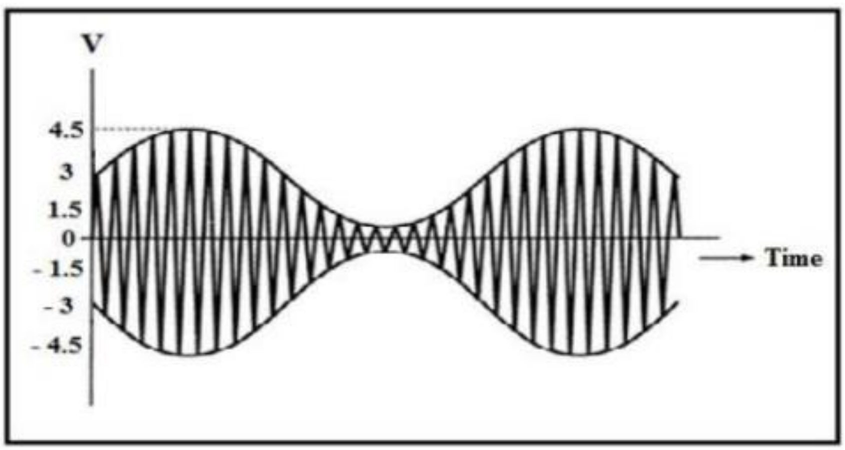
$P_{LSB} = \frac{(E_m)^2}{8R} = \frac{(1.5)^2}{8} = 0.28125\text{ W}$

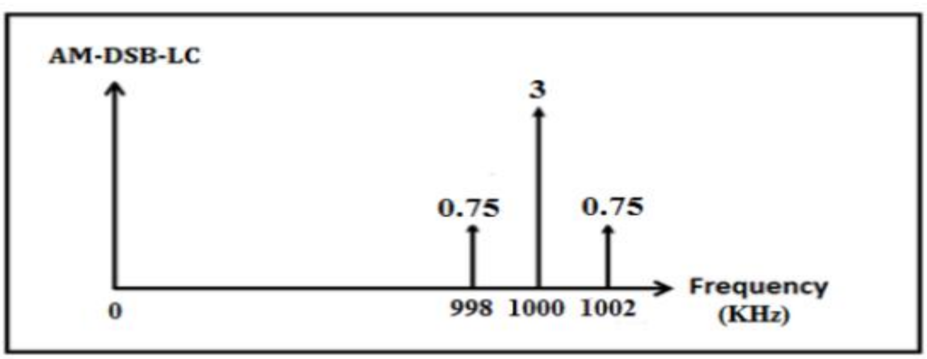
$P_t = 4.5 + 0.28125 + 0.28125 = 5.0625\text{ W}$

$\eta = \frac{P_s}{P_t} \times 100\%$

$\eta = \frac{0.5625}{5.0625} \times 100\% = 11.11\%$

c)





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Example 3: A signal $\boldsymbol{m(t)}$ is band-limited to a frequency range of 0-10 KHz. This frequency is translated by multiplying it by the signal $\boldsymbol{c(t)} = \boldsymbol{\cos(2\pi fct)}$. Find fc so that the bandwidth of the translated signal is 1% of the frequency fc .

Solution:

The bandwidth of the translated signal $= 2f_m$

$$BW = 2 * 10 = 20 \text{ KHz}$$

Thus,

$$20 \text{ KHz} = 0.01\, f_c$$

$$f_c = \frac{20 \text{ KHz}}{0.01} = 2 \text{ MHz}$$

Example 4: An AM broadcast station transmits an average carrier power of 40 KW. If this station uses a modulation index of 0.707 for DSB-LC modulation, calculate: a) Total average power. b) Transmission efficiency. c) Peak amplitude of the output if the antenna is represented by a 50Ω resistive load.

Solution:

a)

$$P_t = P_c + \frac{m^2\,P_c}{4} + \frac{m^2\,P_c}{4}$$

$$P_t = P_c\left(1 + \frac{m^2}{2}\right)$$

$$P_t = 40\left(1 + \frac{(0.707)^2}{2}\right)$$

$$P_t = 50\ \text{KW}$$

b)

$$\eta = \frac{P_s}{P_t} \times 100\% \qquad , \quad P_s = \frac{m^2\,P_c}{2} = \frac{(0.707)^2 * 40}{2} = 10\ KW$$

$$\eta = \frac{10}{50} \times 100\%$$

$$\eta = 20\%$$

c)

$$P_c = \frac{(E_c)^2}{2R}$$

$E_c = \sqrt{P_c * 2R}$

$E_c = \sqrt{(40 * 10^3) * (2 * 50)}$

$E_c = 2000\ V$

Peak amplitude of the output $= E_m + E_c$

Peak amplitude of the output $= mE_c + E_c$

Peak amplitude of the output $= (0.707 * 2000) + 2000 = 3414$ V

h.w/

1. For a particular broadcast AM radio station with a carrier frequencyof 40 cos(1000t), a load resistance of 50 Ω, and a modulating signal

$m(t)$ = 10 cos(20t). Find the following:

a) The modulated signal, $eAM(t)$.

b) The peak carrier voltage, Ec

c) The carrier frequency, wc

d) The peak modulating voltage, Em.

e) The modulation frequency, wm.

f) The LSB bandwidth and frequencies.

g) The USB bandwidth and frequencies.

h) The DSB-LC bandwidth.

i) The modulation index.

j) The total average power.

2. A sinusoidal carrier signal of frequency 1000 KHz and amplitude of 80 V, is amplitude modulated by an audio signal with a frequency of 4KHz producing 50%modulation. Calculate the frequency and amplitude of the upper sideband and lower sideband.

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