The tuned circuit of the oscillator in a simple AM transmitter employs a 40 μH coil and 12 nF capacitor. If the oscillator output is modulated by audio frequency of 5 kHz, what are the lower and upper sideband frequencies and the bandwidth required to transmit this AM wave ?

Sol. : The frequency of the LC oscillator is given as,

$$f_c = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{40\times10^{-6}\times12\times10^{-9}}} = 230 \text{ kHz}$$

The modulating frequency is $f_m = 5$ kHz

$$\therefore \qquad f_{USB} = f_c + f_m = 230 + 5 = 235 \text{ kHz}$$

and $$f_{LSB} = f_c - f_m = 230 - 5 = 225 \text{ kHz}$$

We know that bandwidth of AM wave is,

$$BW = 2 f_m = 2 \times 5\,kHz = 10 \text{ kHz}$$

An audio frequency signal $10 \sin 2\pi\times 500\, t$ is used to amplitude modulate a carrier of $50 \sin 2\pi\times 10^5\, t$. Calculate

i) Modulation index

ii) Sideband frequencies

iii) Amplitude of each sideband frequencies

iv) Bandwidth required

Sol. : i) The given modulating signal is $e_m = 10 \sin 2\pi \times 500\, t$. Hence, $E_m = 10$. The given carrier signal is $e_c = 50 \sin 2\pi \times 10^5\, t$, hence, $E_c = 50$. Therefore modulation index will be,

$$m = \frac{E_m}{E_c} = \frac{10}{50} = 0.2 \quad \text{or} \quad 20\ \%$$

ii) From the given equations,

$\omega_m = 2\pi \times 500,$ Hence $f_m = 500$ Hz

And $\omega_c = 2\pi \times 10^5$ Hence $f_c = 10^5$ Hz or 100 kHz

We know that $f_{USB} = f_c + f_m = 100 \text{ kHz} + 500 \text{ Hz} = 100.5 \text{ kHz}$

and $P_{LSB} = f_c - f_m = 100 \text{ kHz} - 500 \text{ Hz} = 99.5 \text{ kHz}.$

iii) From equation we know that the amplitudes of upper and lower sidebands is given as,

$$\text{Amplitude of upper and lower sidebands} = \frac{m\,E_c}{2} = \frac{0.2 \times 50}{2} = 5\text{ V}$$

iv) Bandwidth of AM wave is given by equation

$$BW \text{ of } AM = 2 f_m = 2 \times 500 \text{ Hz} = 1 \text{ kHz}$$

In an AM modulator, 500 kHz carrier of amplitude 20 V is modulated by 10 kHz modulating signal which causes a change in the output wave of ± 7.5 V. Determine :

1) Upper and lower side band frequencies

2) Modulation index

3) Peak amplitude of upper and lower side frequency

4) Maximum and minimum amplitudes of envelope.

Find the carrier, modulating frequency, modulation index and maximum deviation of the FM wave represented by the equation $e_{FM}(t) = 12\sin\left(6\times10^{8}\ t + 5\ \sin 1250\,t\right)$. *What power will FM wave dissipate in a 10 Ω resistance ?*

Solution : The given FM equation can be compared with standard equation, i.e.

$$e_{FM}(t) = E_c \sin(\omega_c\, t + m \sin \omega_m\, t)$$

We get,

$$E_c = 12\ \text{V}$$

$$\omega_c = 6\times10^{8}\ \ \text{rad/sec}$$

$$m = 5$$

$$\omega_m = 1250\ \ \text{rad/sec}$$

$$R = 10\ \Omega$$

i) Carrier frequency (ω_c) :

The carrier frequency is

$$\omega_c = 6\times10^{8}\ \ \text{rad/sec}$$

or $$f_c = \frac{6\times10^{8}}{2\pi} = 95.5\ \text{MHz}$$

ii) Modulating frequency (ω_m or f_m) :

The modulating frequency is,

$$\omega_m = 1250\ \ \text{rad/sec}$$

or $$f_m = \frac{1250}{2\pi} = 198.5\ \ \text{Hz}$$

iii) Modulation index (m) :

The modulation index is, $m = 5$.

iv) Maximum frequency deviation (δ) :

Modulation index, $m = \dfrac{\delta}{f_m}$

$\therefore \quad \delta = m\, f_m = 5 \times 198.5 = 992.50 \text{ Hz}$

Amplitude Modulation with USB & LSB

In radio transmission, the AM signal is amplified by a power amplifier and fed to the antenna with a characteristic impedance that is ideally, but not necessarily, almost pure resistance. The AM signal is really a composite of several signal voltages, namely, the carrier and the two sidebands, and each of these signals produces power in the antenna. The total transmitted power P_T is simply the sum of the carrier power P_c and the power in the two sidebands P_{USB} and P_{LSB}:

$$P_T = P_c + P_{\text{LSB}} + P_{\text{USB}}$$

You can see how the power in an AM signal is distributed and calculated by going back to the original AM equation:

$$v_{\text{AM}} = V_c \sin 2\pi f_c t + \frac{V_m}{2} \cos 2\pi t (f_c - f_m) - \frac{V_m}{2} \cos 2\pi t (f_c + f_m)$$

where the first term is the carrier, the second term is the lower sideband, and the third term is the upper sideband.

Now, remember that V_c and V_m are peak values of the carrier and modulating sine waves, respectively. For power calculations, rms values must be used for the voltages. We can convert from peak to rms by dividing the peak value by $\sqrt{2}$ or multiplying by 0.707. The rms carrier and sideband voltages are then

$$v_{AM} = \frac{V_c}{\sqrt{2}} \sin 2\pi f_c t + \frac{V_m}{2\sqrt{2}} \cos 2\pi t (f_c - f_m) - \frac{V_m}{2\sqrt{2}} \cos 2\pi t (f_c + f_m)$$

The power in the carrier and sidebands can be calculated by using the power formula $P = V^2/R$, where P is the output power, V is the rms output voltage, and R is the resistive part of the load impedance, which is usually an antenna. We just need to use the coefficients on the sine and cosine terms above in the power formula:

$$P_T = \frac{(V_c/\sqrt{2})^2}{R} + \frac{(V_m/2\sqrt{2})^2}{R} + \frac{(V_m/2\sqrt{2})^2}{R} = \frac{V_c^{\ 2}}{2R} + \frac{V_m^{\ 2}}{8R} + \frac{V_m^{\ 2}}{8R}$$

Remembering that we can express the modulating signal V_m in terms of the carrier V_c by using the expression given earlier for the modulation index $m = V_m/V_c$; we can write

$$V_m = mV_c$$

If we express the sideband powers in terms of the carrier power, the total power becomes

$$P_T = \frac{(V_c)^2}{2R} + \frac{(mV_c)^2}{8R} + \frac{(mV_c)^2}{8R} = \frac{V_c^{\ 2}}{2R} + \frac{m^2 V_c^{\ 2}}{8R} + \frac{m^2 V_c^{\ 2}}{8R}$$

Since the term $V_c^{\ 2}/2R$ is equal to the rms carrier power P_c, it can be factored out, giving

$$P_T = \frac{V_c^{\ 2}}{2R}\left(1 + \frac{m^2}{4} + \frac{m^2}{4}\right)$$

Finally, we get a handy formula for computing the total power in an AM signal when the carrier power and the percentage of modulation are known:

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

For example, if the carrier of an AM transmitter is 1000 W and it is modulated 100 percent ($m = 1$), the total AM power is

$$P_T = 1000\left(1 + \frac{1^2}{2}\right) = 1500 \text{ W}$$

Effective Voltage and Current for Sinusoidal AM

Effective Voltage and Current for Sinusoidal AM

The effective or rms voltage E of the modulated wave is defined by the equation

$$\frac{E^2}{R} = P_T$$

Likewise, the effective or rms voltage E_c of the carrier component is defined by

$$\frac{E_C^2}{R} = P_C$$

$$\frac{E^2}{R} = P_C\left(1 + \frac{m^2}{2}\right)$$

$$= \frac{E_C^2}{R}\left(1 + \frac{m^2}{2}\right)$$

$$E = E_C\sqrt{1 + \frac{m^2}{2}}$$

A similar argument applied to currents yields

$$I = I_C\sqrt{1 + \frac{m^2}{2}}$$

where I is the rms current of the modulated wave and I_c the rms current of the unmodulated carrier. The current equation provides one method of monitoring modulation index, by measuring the antenna current with and without modulation applied.

$$m = \sqrt{2\left[\left(\frac{I}{I_c}\right)^2 - 1\right]}$$

The rms antenna current of an AM radio transmitter is 10 A when unmodulated and 12 A when sinusoidally modulated. Calculate the modulation index.

SOLUTION $m = \sqrt{2\left[\left(\frac{12}{10}\right)^2 - 1\right]} = \mathbf{0.94}$

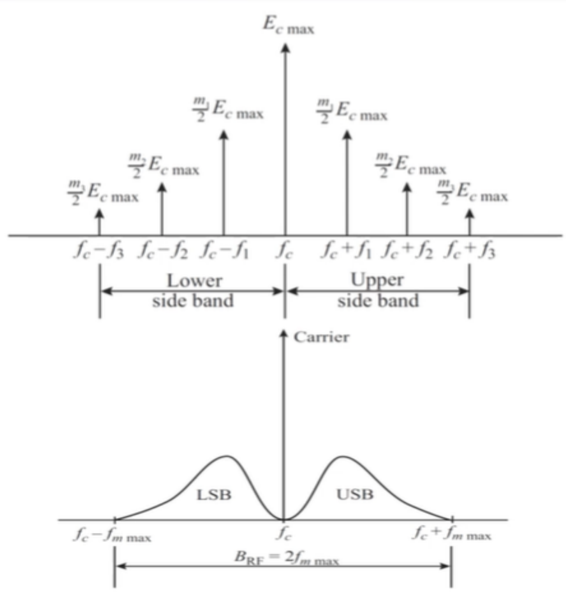
Multiple Sine Waves Modulation

Nonsinusoidal modulation produces upper and lower *sidebands,* corresponding to the upper and lower side frequencies produced with sinusoidal modulation. Suppose, for example, that the modulating signal has a line spectrum as shown

$$e_m(t) = E_{1\max} \cos 2\pi f_1 t + E_{2\max} \cos 2\pi f_2 t + E_{3\max} \cos 2\pi f_3 t + \cdots$$

As before, the AM wave is

$$e(t) = [E_{c\ \max} + e_m(t)] \cos 2\pi f_c t$$



(b)

(a) Amplitude spectrum resulting from line spectra modulation. (b) Amplitude spectrum for a power density modulating spectra.

The total power in the AM wave having two modulating sine waves will be written as,

$$P_{total} = P_c + P_{USB1} + P_{USB2} + P_{LSB1} + P_{LSB2}$$

We can write the above equation on the basis of equation

$$P_{total} = \frac{(E_c/\sqrt{2})^2}{R} + \frac{m_1^2 E_c^2}{8R} + \frac{m_2^2 E_c^2}{8R} + \frac{m_1^2 E_c^2}{8R} + \frac{m_2^2 E_c^2}{8R}$$

$$= \frac{E_c^2}{2R}\left(1 + \frac{m_1^2}{4} + \frac{m_2^2}{4} + \frac{m_1^2}{4} + \frac{m_2^2}{4}\right) = \frac{E_c^2}{2R}\left(1 + \frac{m_1^2}{2} + \frac{m_2^2}{2}\right)$$

Since $P_c = \frac{E_c^2}{2R}$ above equation will be,

$$P_{total} = P_c\left(1 + \frac{m_1^2}{2} + \frac{m_2^2}{2}\right)$$

Compare this equation with similar relation given by equation for one sine wave. i.e.,

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

Thus we can generalize equation for many sine waves as,

$$P_{total} = P_c\left(1 + \frac{m_1^2}{2} + \frac{m_2^2}{2} + \frac{m_3^2}{2} + \ldots\right)$$

The total average power can be obtained by adding the average power for each component (just as was done for single-tone modulation), which results in

$$P_T = P_c\left(1 + \frac{m_1^2}{2} + \frac{m_2^2}{2} + \frac{m_3^2}{2} + \cdots\right)$$

Hence an effective modulation index can be defined in this case as

$$m_{\text{eff}} = \sqrt{m_1^2 + m_2^2 + m_3^2 + \cdots}$$

It follows that the effective voltage and current in this case are

$$E = E_c\sqrt{1 + \frac{m_{\text{eff}}^2}{2}}$$

$$I = I_c\sqrt{1 + \frac{m_{\text{eff}}^2}{2}}$$

It will be seen therefore that standard AM produces upper and lower sidebands about the carrier, and hence the RF bandwidth required is double that for the modulating waveform.

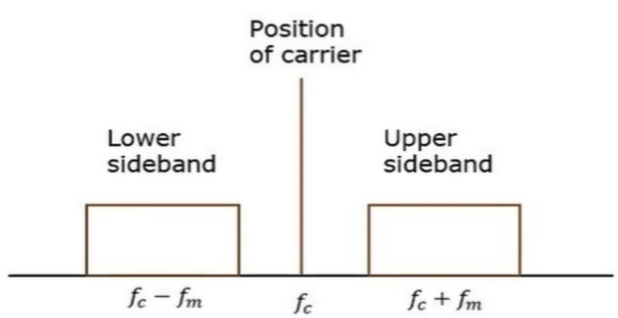
$$B_{RF} = (f_c + f_{m\,\max}) - (f_c - f_{m\,\max})$$
$$= 2 f_{m\,\max}$$

where $f_{m\,\max}$ is the highest frequency in the modulating spectrum. As with the sinusoidal modulation, either sideband contains all the modulating signal information, and therefore considerable savings in power and bandwidth can be achieved by transmitting only one sideband. Single sideband (SSB) transmission

DSB – Double Side Band Modulation : DSBFC & DSBSC

In the process of Amplitude Modulation, the modulated wave consists of the carrier wave and two sidebands. The modulated wave has the information only in the sidebands. **Sideband** is nothing but a band of frequencies, containing power, which are the lower and higher frequencies of the carrier frequency.

The transmission of a signal, which contains a carrier along with two sidebands can be termed as **Double Sideband Full Carrier** system or simply **DSBFC**. It is plotted as shown in the following figure.



Solution : The given FM equation can be compared with standard equation, i.e.

$$e_{FM}(t) = E_c \sin(\omega_c t + m \sin \omega_m t)$$

We get,

$$E_c = 12 \text{ V}$$
$$\omega_c = 6\times10^8 \text{ rad/sec}$$
$$m = 5$$
$$\omega_m = 1250 \text{ rad/sec}$$
$$R = 10\ \Omega$$

i) Carrier frequency (ω_c) :

The carrier frequency is

$$\omega_c = 6\times10^8 \text{ rad/sec}$$

or $$f_c = \frac{6\times10^8}{2\pi} = 95.5 \text{ MHz}$$

ii) Modulating frequency (ω_m or f_m) :

The modulating frequency is,

$$\omega_m = 1250 \text{ rad/sec}$$

or $$f_m = \frac{1250}{2\pi} = 198.5 \text{ Hz}$$

iii) Modulation index (m) :

The modulation index is, $m = 5$.

iv) Maximum frequency deviation (δ) :

Modulation index, $m = \frac{\delta}{f_m}$

$\therefore$ $$\delta = m f_m = 5\times 198.5 = 992.50 \text{ Hz}$$

A broadcast transmitter radiates 20 kW when the modulation percentage is 75. Calculate carrier power and power of each sideband.

Sol. : Here total power $P_{total} = 20{,}000\ \text{W}$ and $m = 0.75$

From equation we have $P_{total} = P_c\left(1+\frac{m^2}{2}\right)$

$$\therefore \quad 20{,}000 = P_c\left(1+\frac{(0.75)^2}{2}\right)$$

$$\therefore \quad P_c = 15.6\ \text{kW}$$

We know that $P_{total} = P_c\left(1+\frac{m^2}{2}\right) = P_c + P_c\,\frac{m^2}{2}$

The second term in above equation represents total sideband power. Hence power of one sideband will be,

$$P_{SB} = \left(P_c\,\frac{m^2}{2}\right)\times\frac{1}{2} = 15.6\times\frac{(0.75)^2}{2}\times\frac{1}{2} = 2.2\ \text{kW}$$

Thus $P_{USB} = P_{LSB} = 2.2\ \text{kW}$

The total antenna current of an AM transmitter is 5 A. If modulation index is 0.6, calculate the carrier current in antenna.

Sol. : Here $I_{total} = 5$ A and $m = 0.6$

From equation we have,

$$I_{total} = I_c \sqrt{1 + \frac{m^2}{2}}$$

$$5 = I_c \sqrt{1 + \frac{(0.6)^2}{2}}$$

$$\therefore \quad I_c = 4.6 \text{ A}$$

A certain AM transmitter radiates 10 kW with the carrier modulated and 11.8 kW when the carrier is sinusoidally modulated. Calculate the modulation index. If another sine wave, corresponding to 30 % modulation, is transmitted simultaneously, determine the total radiated power.

Your microphone is muted.

Sol. : Here $P_c = 10$ kW, $P_{total} = 11.8$ kW

Modulation index, $$m = \sqrt{2\left(\frac{P_{total}}{P_c} - 1\right)} = \sqrt{2\left(\frac{11.8}{10} - 1\right)} = 0.6$$

This is first signal. Hence $m_1 = 0.6$. The another signal modulates 30 %. Hence $m_2 = 0.3$. Hence combined total modulation index due to two signals is,

$$m_t = \sqrt{m_1^2 + m_2^2} = \sqrt{0.6^2 + 0.3^2} = 0.67$$

Total power is, $$P_{total} = P_c\left(1 + \frac{m_t^2}{2}\right) \quad \text{... By equation}$$

$$= 10\left(1 + \frac{(0.67)^2}{2}\right) = 12.24 \text{ kW}$$

For an AM DSBFC wave with a peak unmodulated carrier voltage $V_c = 12\,V$, and modulation coefficient $m = 1$ with load resistance $R_L = 12\ \Omega$, determine the

i) Carrier power and the upper and lower sideband power (P_c, P_{USB}, P_{LSB})

ii) Total power of the modulated wave

iii) Draw the power spectrum.

Sol. : Given : $E_c = V_c = 12$ V, $m = 1$, $R = R_L = 12\ \Omega$

i) Carrier and sidebands power :

Carrier power, $$P_c = \frac{E_c^2}{2R} = \frac{12^2}{2 \times 12} = 6 \text{ W}$$

Sidebands power, $$P_{LSB} = P_{USB} = \frac{m^2 E_c^2}{8R} = \frac{1^2 \times 12^2}{8 \times 12} = 1.5 \text{ W}$$

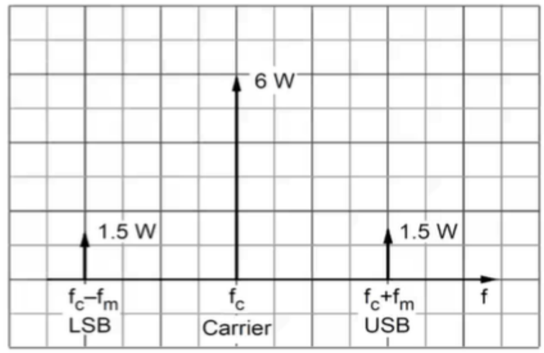
ii) Total power of the modulated wave :

$$P_{total} = P_c\left(1 + \frac{m^2}{2}\right) = 6\left(1 + \frac{1^2}{2}\right) = 9 \text{ W}$$

$$P_{SB} = P_{LSB} + P_{USB} = 2 \times \frac{m^2 E_c^2}{8R} = \frac{m^2 E_c^2}{4R}$$

iii) Power spectrum

Fig. shows the power spectrum based on sideband and carrier powers obtained above.

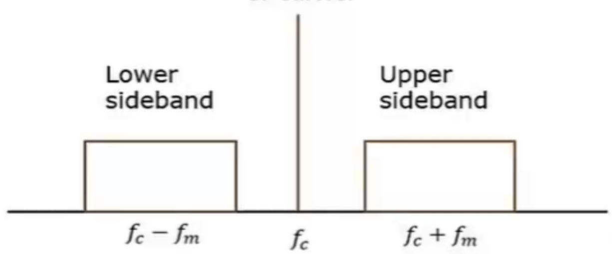


Power spectrum

DSB – Double Side Band Modulation : DSBFC & DSBSC

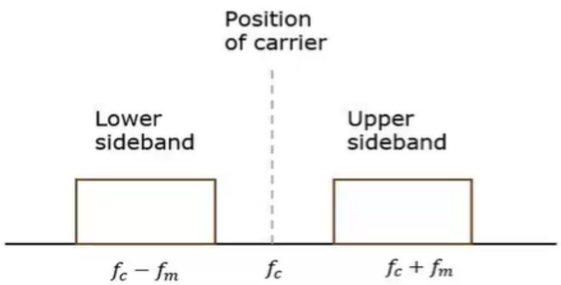
In the process of Amplitude Modulation, the modulated wave consists of the carrier wave and two sidebands. The modulated wave has the information only in the sidebands. **Sideband** is nothing but a band of frequencies, containing power, which are the lower and higher frequencies of the carrier frequency.

The transmission of a signal, which contains a carrier along with two sidebands can be termed as **Double Sideband Full Carrier** system or simply **DSBFC**. It is plotted as shown in the following figure.

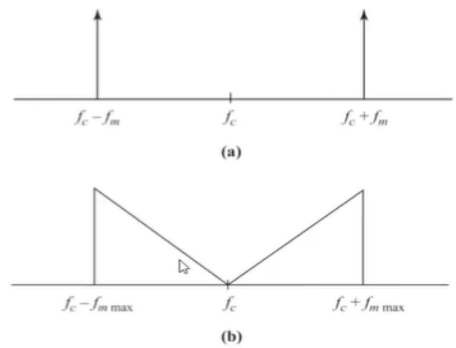


However, such a transmission is inefficient. Because, two-thirds of the power is being wasted in the carrier, which carries no information.

If this carrier is suppressed and the saved power is distributed to the two sidebands, then such a process is called as **Double Sideband Suppressed Carrier** system or simply **DSBSC**. It is plotted as shown in the following figure.



Carrier is suppressed and sidebands are allowed for transmission



DSBSC spectrum for
(a) sinusoidal modulation and (b) the general case.

i.e., Modulating signal

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

Carrier signal

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

Mathematically, we can represent the **equation of DSBSC wave** as the product of modulating and carrier signals.

$$s(t) = m(t)\, c(t)$$

$$\Rightarrow s(t) = A_m A_c \cos(2\pi f_m t) \cos(2\pi f_c t)$$

Power Calculations of DSBSC Wave

Consider the following equation of DSBSC modulated wave.

$$s(t) = \frac{A_m A_c}{2} \cos[2\pi (f_c + f_m) t] + \frac{A_m A_c}{2} \cos[2\pi (f_c - f_m) t]$$

Power of DSBSC wave is equal to the sum of powers of upper sideband and lower sideband frequency components.

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

We know the standard formula for power of cos signal is

$$P = \frac{{v_{rms}}^2}{R} = \frac{(v_m \sqrt{2})^2}{R}$$

First, let us find the powers of upper sideband and lower sideband one by one.

Upper sideband power

$$P_{USB} = \frac{(A_m A_c / 2\sqrt{2})^2}{R} = \frac{{A_m}^2 {A_c}^2}{8R}$$

Similarly, we will get the lower sideband power same as that of upper sideband power.

$$P_{USB} = \frac{{A_m}^2 {A_c}^2}{8R}$$

Now, let us add these two sideband powers in order to get the power of DSBSC wave.

$$P_t = \frac{{A_m}^2 {A_c}^2}{8R} + \frac{{A_m}^2 {A_c}^2}{8R}$$

$$\Rightarrow P_t = \frac{{A_m}^2 {A_c}^2}{4R}$$

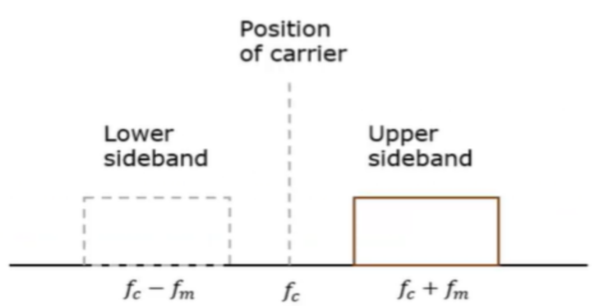
Therefore, the power required for transmitting DSBSC wave is equal to the power of both the sidebands.

Communications in the HF bands have become increasingly crowded in recent years, requiring closer spacing of signals in the spectrum. Single-sideband systems requiring only half the bandwidth of normal AM and considerably less power are used extensively in this portion of the spectrum as a result.

It was noted in earlier discussion that each sideband of a normal AM signal contains all the information necessary for signal transmission and recovery. It was also pointed out that for 100% sinusoidal modulation each sideband contains one-sixth of the total signal power, while the carrier contains two-thirds of the total power. Furthermore, the carrier itself carries no information contributed by the modulating signal.

The process of suppressing one of the sidebands, along with the carrier and transmitting a single sideband is called as **Single Sideband Suppressed Carrier** system, or simply **SSB-SC** or **SSB**. It is plotted as shown in the following figure.

SSBSC system



Carrier and a sideband are suppressed and a single sideband is allowed for transmission

This SSB-SC or SSB system, which transmits a single sideband has high power, as the power allotted for both the carrier and the other sideband is utilized in transmitting this **Single Sideband (SSB)**.

Hence, the modulation done using this SSB technique is called as **SSB Modulation**.

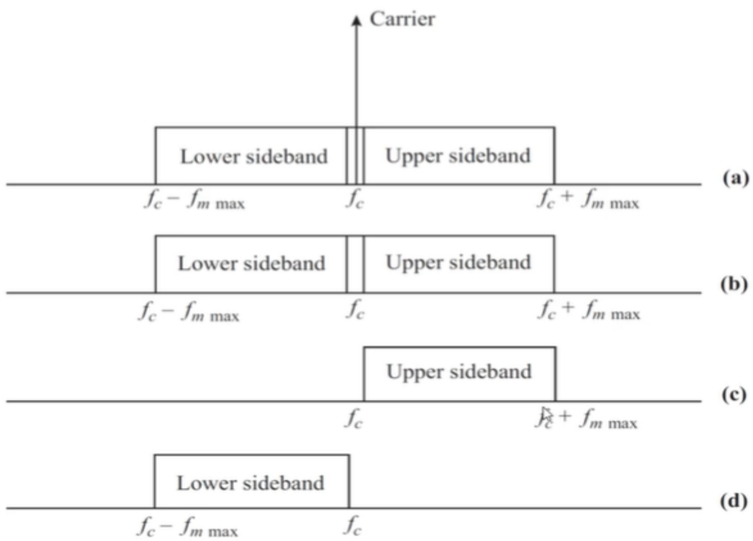


Figure Amplitude-modulated signal spectra: (a) normal amplitude modulation, or double-sideband full carrier; (b) double-sideband suppressed carrier (DSBSC); (c) single-sideband suppressed carrier (SSBSC) using the upper side-band (USB); (d) single-sideband suppressed carrier (SSBSC) using the lower sideband (LSB).

Mathematical Expressions

Let us consider the same mathematical expressions for the modulating and the carrier signals as we have considered in the earlier chapters.

Modulating signal

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

Carrier signal

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

Mathematically, we can represent the equation of SSBSC wave as

$$s(t) = \frac{A_m A_c}{2} \cos[2\pi (f_c + f_m) t]$$ for the upper sideband

$$s(t) = \frac{A_m A_c}{2} \cos[2\pi (f_c - f_m) t]$$ for the lower sideband

Bandwidth of SSBSC Wave

We know that the DSBSC modulated wave contains two sidebands and its bandwidth is $2f_m$.

Since the SSBSC modulated wave contains only one sideband, its bandwidth is half of the bandwidth of DSBSC modulated wave.

i.e., ***Bandwidth of SSBSC modulated wave*** = $\frac{2f_m}{2} = f_m$

Therefore, the bandwidth of SSBSC modulated wave is f_m and it is equal to the frequency of the modulating signal.

Power Calculations of SSBSC Wave

Power of SSBSC wave is equal to the power of any one sideband frequency components.

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

We know that the standard formula for power of cos signal is

$$P = \frac{{v_{rms}}^2}{R} = \frac{(v_m/\sqrt{2})^2}{R}$$

In this case, the power of the upper sideband is

$$P_{USB} = \frac{(A_m A_c/2\sqrt{2})^2}{R} = \frac{{A_m}^2 {A_c}^2}{8R}$$

Similarly, we will get the lower sideband power same as that of the upper side band power.

$$P_{LSB} = \frac{{A_m}^2 {A_c}^2}{8R}$$

Therefore, the power of SSBSC wave is

$$P_t = P_{USB} = P_{LSB} = \frac{{A_m}^2 {A_c}^2}{8R}$$

Advantages

- Bandwidth or spectrum space occupied is lesser than AM and DSBSC waves.
- Transmission of more number of signals is allowed.
- Power is saved.
- High power signal can be transmitted.
- Less amount of noise is present.
- Signal fading is less likely to occur.

Disadvantages

- The generation and detection of SSBSC wave is a complex process.
- The quality of the signal gets affected unless the SSB transmitter and receiver have an excellent frequency stability.

Applications

- For power saving requirements and low bandwidth requirements.
- In land, air, and maritime mobile communications.
- In point-to-point communications.
- In radio communications.
- In television, telemetry, and radar communications.
- In military communications, such as amateur radio, etc.

For an AM DSBFC transmitter with an unmodulated carrier power P_c = 100 W that is modulated simultaneously by three modulating signals with coefficients of modulation m_1 = 0.2, m_2 = 0.4 and m_3 = 0.5, determine :
1) Total coefficient of modulation 2) Upper and lower sideband power 3) Total transmitted power.

Sol. :

$$P_c = 100 \text{ W}, m_1 = 0.2, m_2 = 0.4, m_3 = 0.5$$

$$m_t = \sqrt{m_1^2 + m_2^2 + m_3^2} = \sqrt{0.2^2 + 0.4^2 + 0.5^2} = 0.671$$

$$P_{total} = P_c\left(1 + \frac{m_t^2}{2}\right) = 100\left(1 + \frac{0.671^2}{2}\right) = 122.5 \ W$$

$$P_{total} = P_c + P_{SB}$$

$$\therefore \quad P_{SB} = P_{total} - P_c = 122.5 - 100 = 22.5 \ W$$

$$\therefore \quad P_{LSB} = P_{USB} = \frac{P_{SB}}{2} = \frac{22.5 W}{2} = 11.25 \ W$$