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# DIGITAL COMMUNICATION

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- Amplitude Modulation : USB & LSB
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# 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 $P_{\text{USB}}$ and $P_{\text{LSB}}$:

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

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

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

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

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

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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**

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

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# 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

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

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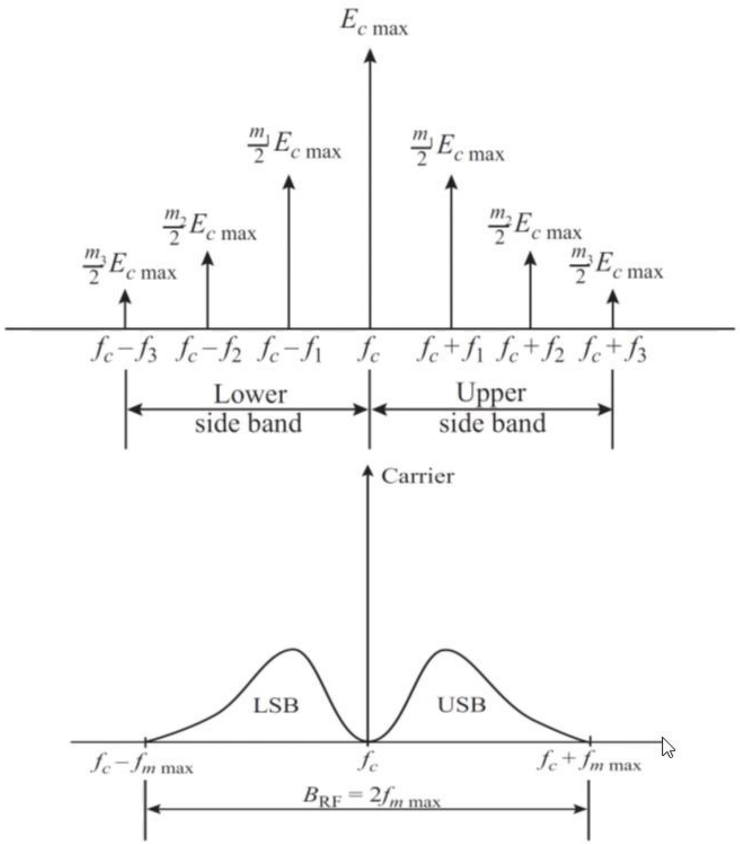


(b)

(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,

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

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.

$$\begin{aligned} B_{\mathrm{RF}} &= (f_c + f_{m\,\max}) - (f_c - f_{m\,\max}) \\ &= 2 f_{m\,\max} \end{aligned}$$

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.