Communication Systems

Lecture 3

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Principles of Electronic Communication Systems
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Chapter 3

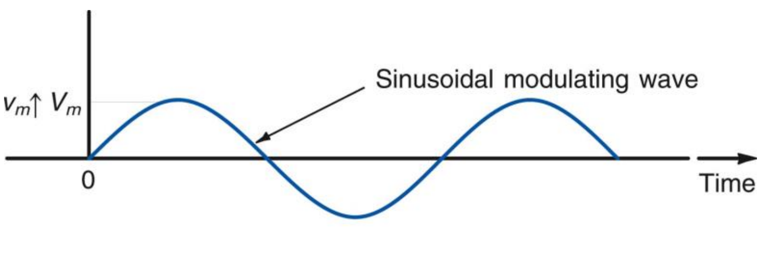
Amplitude Modulation Fundamentals

Topics Covered in Chapter 3

- 3-1: AM Concepts
- 3-2: Modulation Index and Percentage of Modulation
- 3-3: Sidebands and the Frequency Domain
- 3-4: AM Power
- 3-5: Single-Sideband Modulation

3-1: AM Concepts

- In the modulation process, the voice, video, or digital signal modifies another signal called the carrier.
- In **amplitude modulation (AM)** the information signal varies the amplitude of the carrier sine wave.
- The instantaneous value of the carrier amplitude changes in accordance with the amplitude and frequency variations of the modulating signal.



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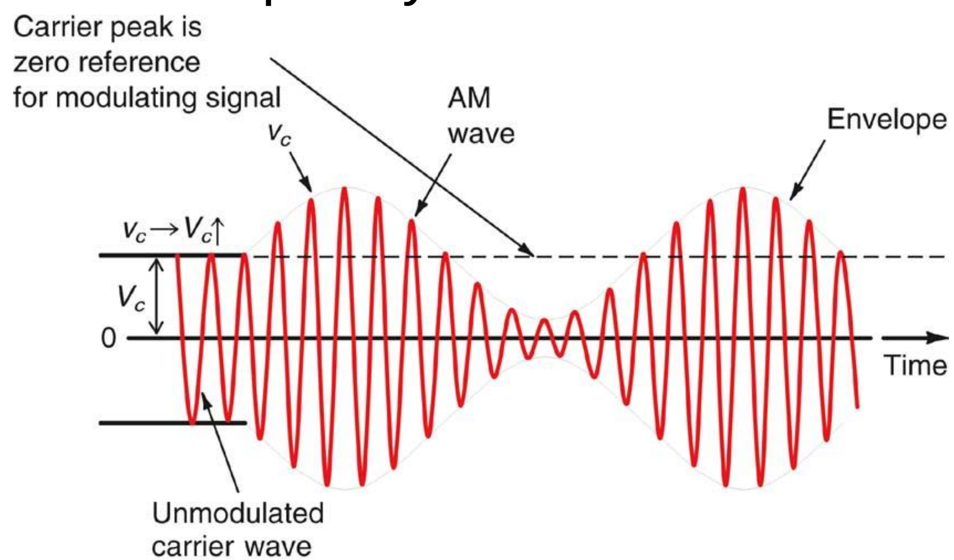

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3-1: AM Concepts

- An imaginary line called the **envelope** connects the positive and negative peaks of the carrier waveform.
- The modulating signal uses the peak value of the carrier rather than zero as its reference point.
- The envelope of the modulating signal varies above and below the peak carrier amplitude.
- The instantaneous value of either the top or the bottom voltage envelope u_1 can be computed by

$$v_1 = V_c + v_m = V_c + V_m \sin 2\pi f_m t$$

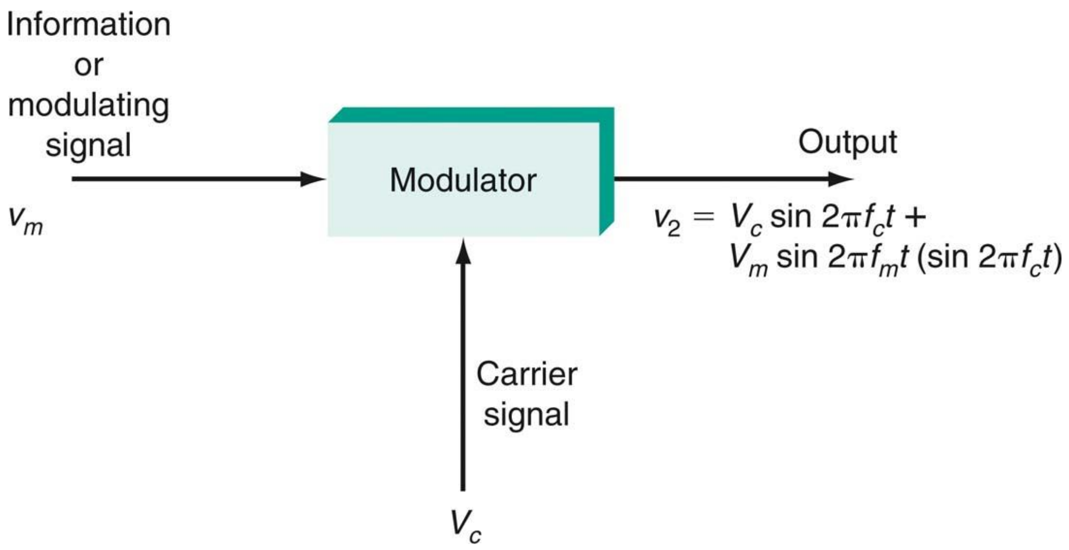
- The instantaneous value of the AM modulated wave u_2 by substituting u_1 for the peak value of carrier

$$v_2 = (V_c + V_m \sin 2\pi f_m t) \sin 2\pi f_c t = V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$$

3-1: AM Concepts

AM Modulator:

- AM modulator is a circuit that produce multiplication of the carrier and modulating signals.
- Circuits that compute the product of two analog signals are also known as analog multipliers, mixers, converters, product detectors, and phase detectors.



3-2: Modulation Index and Percentage of Modulation

- The **modulation index (*m*)** is a value that describes the relationship between the amplitude of the modulating signal and the amplitude of the carrier signal.

$$m = V_m / V_c$$

- This index is also known as the **modulating factor** or **coefficient**, or the **degree of modulation**.
- Multiplying the modulation index by 100 gives the percentage of modulation.
- The ideal condition for AM is when Vm = Vc, or m = 1, which gives 100 percent modulation. This results in the greatest output power at the transmitter and the greatest output voltage at the receiver, with no distortion

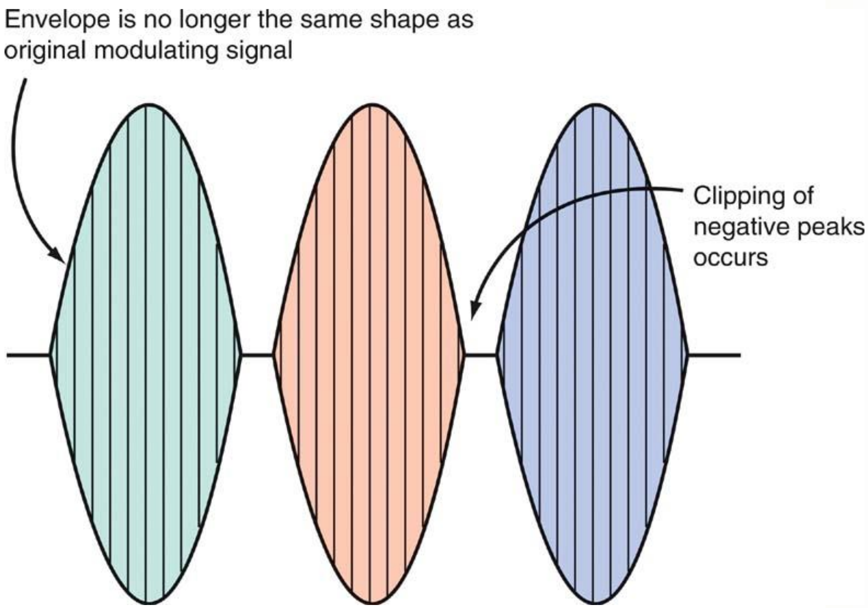
3-2: Modulation Index and Percentage of Modulation

Overmodulation and Distortion

- The modulation index should be a number between 0 and 1.
- If the amplitude of the modulating voltage is higher than the carrier voltage, *m* will be greater than 1, causing distortion.
- If the distortion is great enough, the intelligence signal becomes unintelligible:

✓ Distortion of voice transmissions produces garbled, harsh, or unnatural sounds in the speaker.

✓ Distortion of video signals produces a scrambled and inaccurate picture on a TV screen.

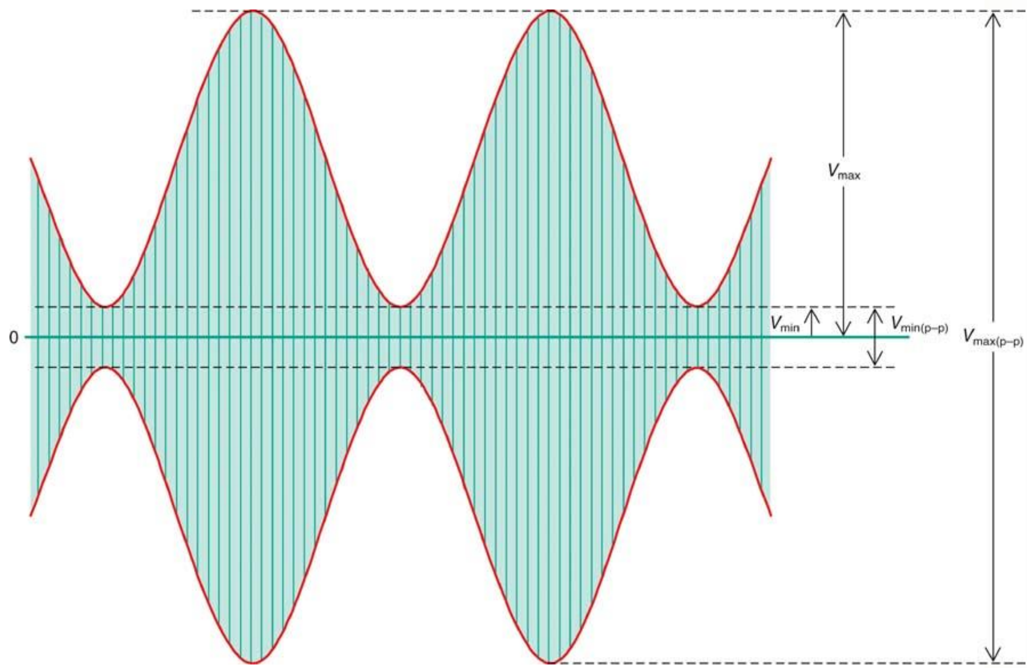


3-2: Modulation Index and Percentage of Modulation

Percentage of Modulation

- The modulation index is commonly computed from measurements taken on the composite modulated waveform.
- Using oscilloscope voltage values:

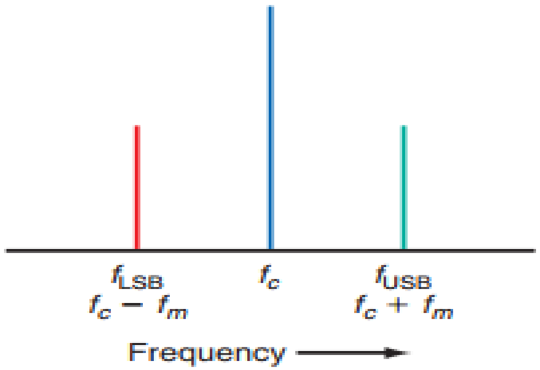
$$Vm = \frac{V_{max} - V_{min}}{2}$$



3-3: Sidebands and the Frequency Domain

- **Side frequencies**, or **sidebands** are generated as part of the modulation process and occur in the frequency spectrum directly above and below the carrier frequency.
- Single-frequency sine-wave modulation generates two sidebands.
- Complex wave (e.g. voice or video) modulation generates a range of sidebands.
- The upper sideband (f_{USB}) and the lower sideband (f_{LSB}) are calculated:

$$f_{USB} = f_c + f_m$$
$$f_{LSB} = f_c - f_m$$



3-3: Sidebands and the Frequency Domain

- The existence of sidebands can be demonstrated mathematically, starting with the equation for an AM signal described previously

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

- By using the trigonometric identity

$$\sin A \sin B = \frac{\cos(A - B)}{2} - \frac{\cos(A + B)}{2}$$

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

3-3: Sidebands and the Frequency Domain

Frequency-Domain Representation of AM

- Observing an AM signal on an oscilloscope, you see only amplitude variations of the carrier with respect to time.
- A spectrum analyzer is used to display the frequency domain
- Bandwidth is the difference between the upper and lower sideband frequencies.

$$BW = f_{USB} - f_{LSB}$$

Example:

A standard AM broadcast station is allowed to transmit modulating frequencies up to 5 kHz. If the AM station is transmitting on a frequency of 980 kHz, what are sideband frequencies and total bandwidth?

f_{USB} = 980 + 5 = 985 kHz
f_{LSB} = 980 – 5 = 975 kHz
BW = f_{USB} – f_{LSB} = 985 – 975 = 10 kHz
BW = 2 (5 kHz) = 10 kHz

3-3: Sidebands and the Frequency Domain

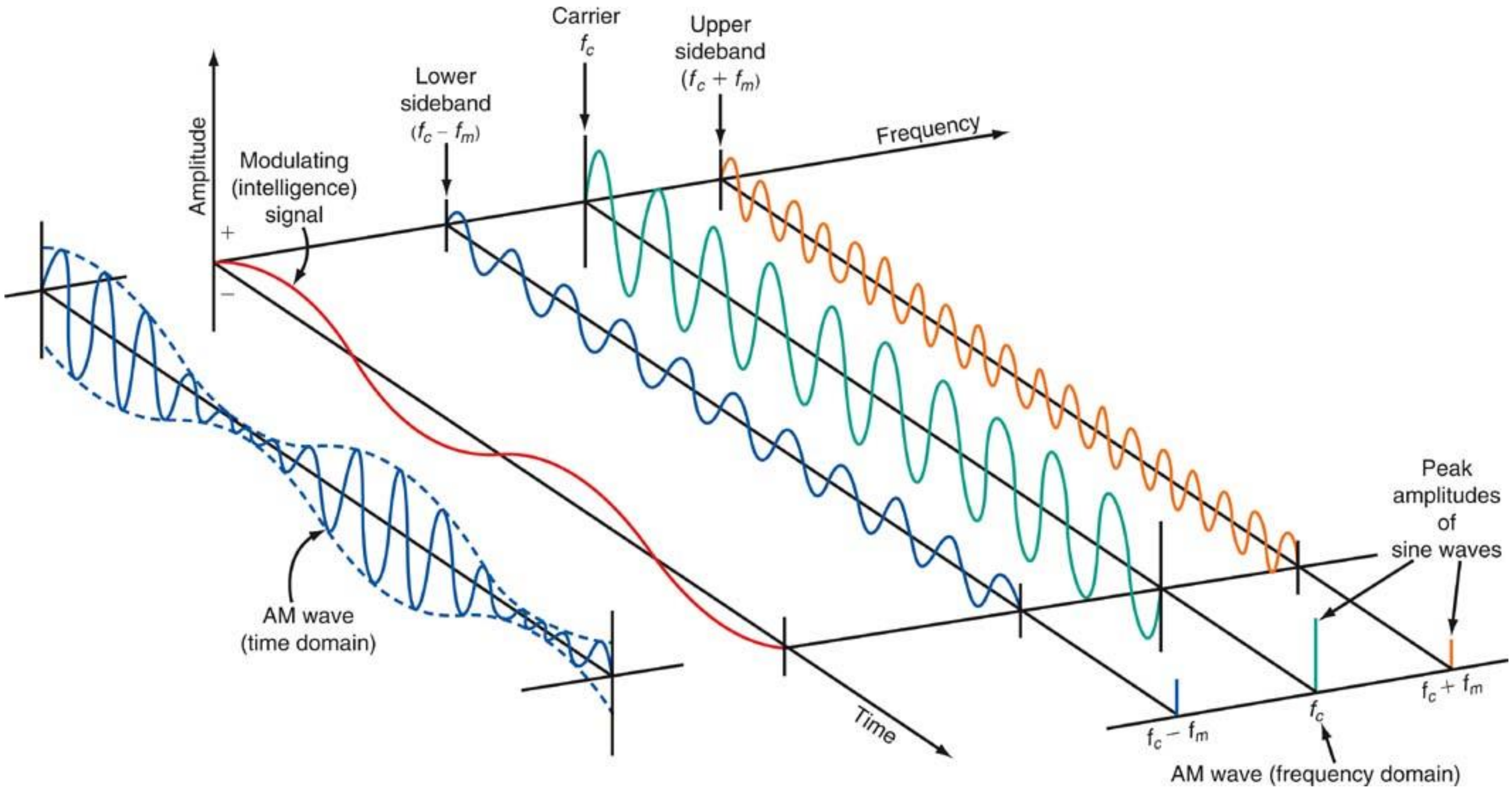
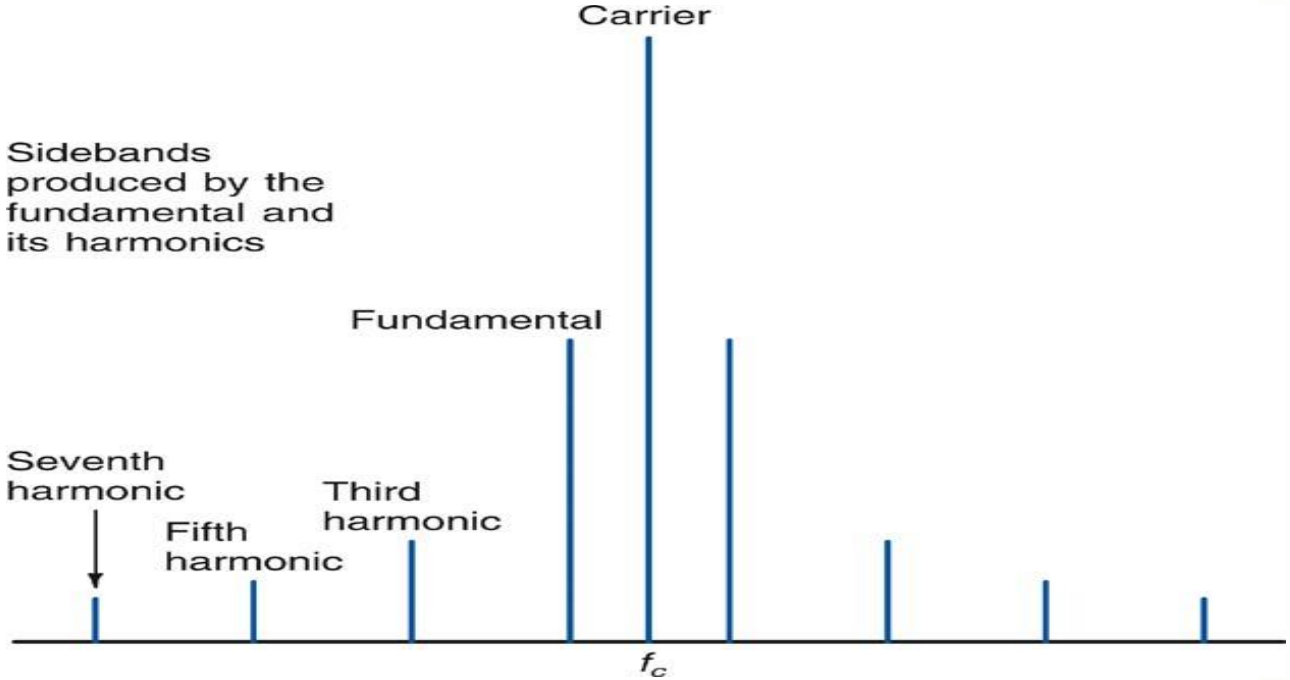


Figure 3-8: The relationship between the time and frequency domains.

3-3: Sidebands and the Frequency Domain

Pulse Modulation

- When complex signals such as pulses or rectangular waves modulate a carrier, a broad spectrum of sidebands is produced.
- A modulating square wave will produce sidebands based on the fundamental sine wave as well as the third, fifth, seventh, etc. harmonics.



3-3: Sidebands and the Frequency Domain

- Such harmonic sideband interference is sometimes called *splatter* because of the way it sounds at the receiver.

- Overmodulation and splatter are easily eliminated simply by:
  - ✓ Reducing the level of the modulating signal by using gain control or
  - ✓ Using amplitude-limiting or compression circuits.

3-4: AM Power

- In radio transmission, AM signal is amplified by a power amplifier.
- A radio antenna has a characteristic impedance that is ideally almost pure resistance.
- The AM signal is a composite of the carrier and sideband signal voltages.
- Each signal produces power in the antenna.
- Total transmitted power (P_T) is the sum of carrier power (P_c) and power of the two sidebands (P_{USB} and P_{LSB}).

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

- For power calculations, rms values must be used for the voltages

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

3-4: AM Power

- Remembering that we can express the modulating signal V_m in terms of the carrier V_c

$$V_m = mV_c$$

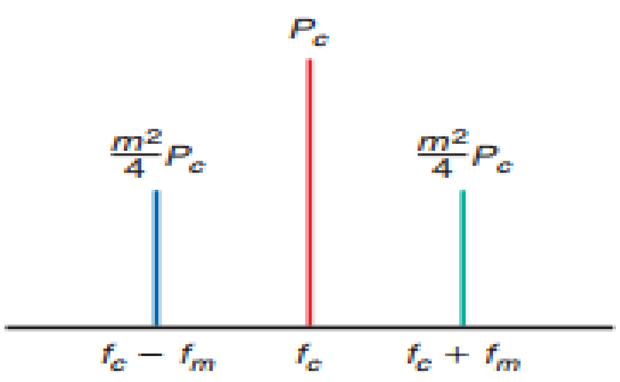
$$P_T = \frac{(V_c)^2}{2R} + \frac{(mV_c)^2}{8R} + \frac{(mV_c)^2}{8R} = \frac{V_c^{\,2}}{2R} + \frac{m^2V_c^{\,2}}{8R} + \frac{m^2V_c^{\,2}}{8R}$$

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

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

- The greater the percentage of modulation, the higher the sideband power and the higher the total power transmitted.
- Power in each sideband is calculated

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



3-5: Single-Sideband Modulation

- Maximum power appears in the sidebands when the carrier is 100% modulated.
- In amplitude modulation, two-thirds (for m=1) of the transmitted power is in the carrier, which conveys no information.
- **However, the information signal is contained within the sidebands**.

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

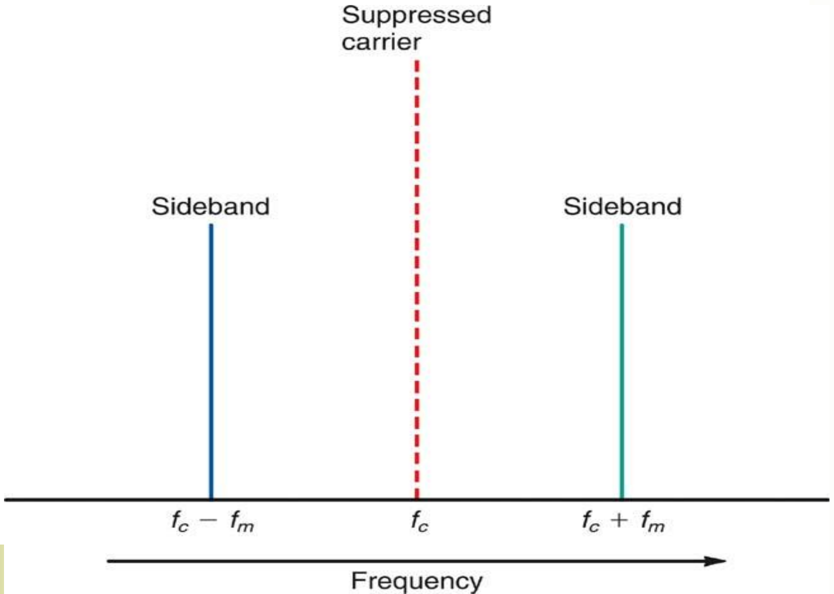
- **<u>Why to waste power on the carrier?</u>**

3-5: Single-Sideband Modulation

DSB Signals

- The first is to suppress the carrier, leaving the upper and lower sidebands.
- This type of signal is called a **double-sideband suppressed carrier (DSSC)** signal. No power is wasted on the carrier.
- A balanced modulator is a circuit used to produce the sum and difference frequencies of a DSSC signal but to cancel or balance out the carrier.

DSB is not widely used because the signal is difficult to demodulate (recover) at the receiver.

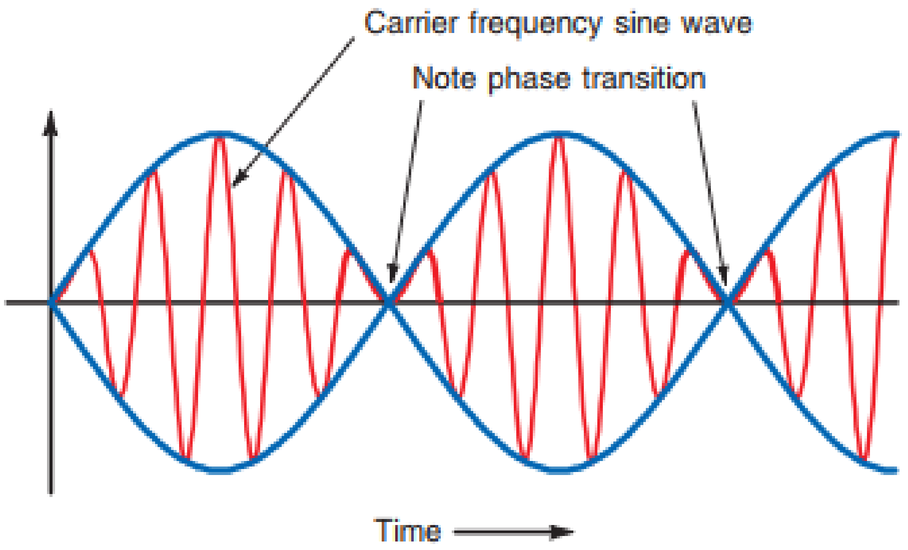


3-5: Single-Sideband Modulation

DSB Signals

- A typical DSB signal is shown in Figure, which is the algebraic sum of the two sinusoidal sidebands
- The envelope of this waveform is not the same as that of the modulating signal, as it is in a typical AM signal

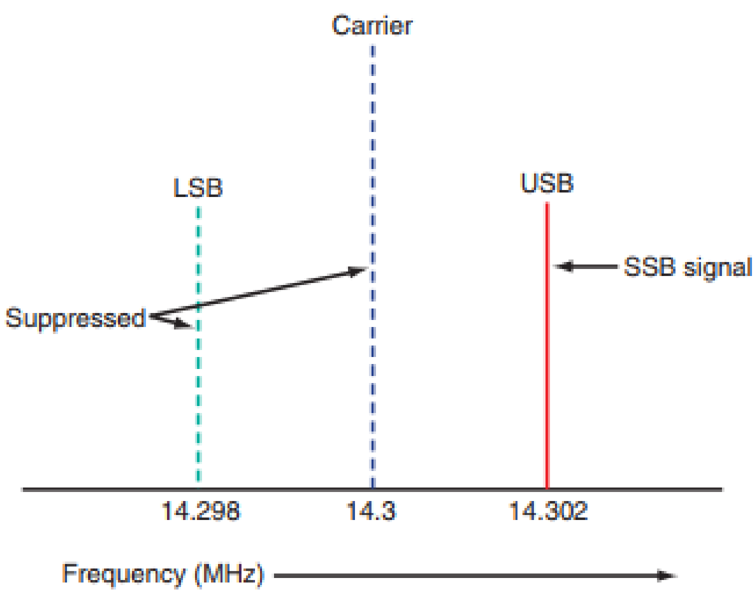
- A unique characteristic of the DSB signal is the phase transitions (two adjacent positive-going half-cycles at the null points in the wave)

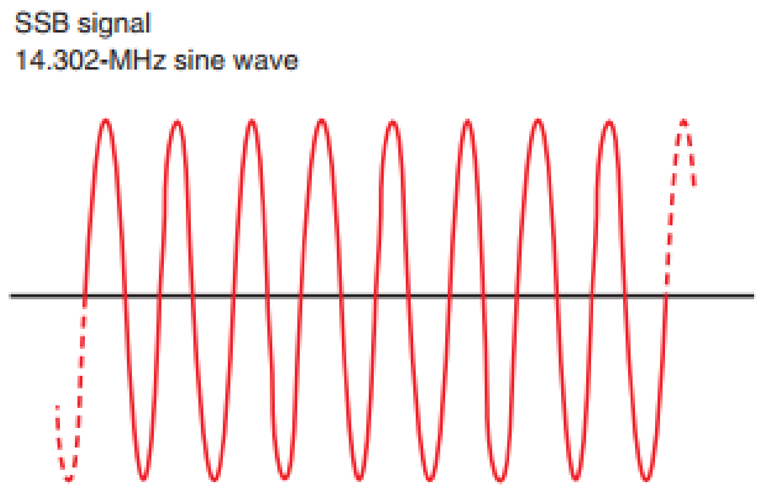


3-5: Single-Sideband Modulation

SSB Signals

- One sideband is all that is necessary to convey information
- **A single-sideband suppressed carrier (SSSC)** signal is generated by suppressing the carrier and one sideband.





An SSB signal produced by a 2-kHz sine wave modulating a 14.3-MHz sine wave carrier

3-5: Single-Sideband Modulation

- In SSB, when no information or modulating signal is present, no RF signal is transmitted.
- In a standard AM transmitter, the carrier is still transmitted even though it may not be modulated

- SSB signals offer four major benefits:
  1. Spectrum space is conserved and allows more signals to be transmitted in the same frequency range.
  2. All power is channeled into a single sideband. This produces a stronger signal that will carry farther and will be more reliably received at greater distances.
  3. Occupied bandwidth space is narrower and noise in the signal is reduced.
  4. There is less selective fading over long distances.

3-5: Single-Sideband Modulation

Disadvantages of DSB and SSB

- Single and double-sideband are not widely used because the signals are difficult to recover (i.e. demodulate) at the receiver.
- A low power, **pilot carrier** is sometimes transmitted along with sidebands in order to more easily recover the signal at the receiver.