电子科技大学格拉斯哥学院

Glasgow College, UESTC

Communication Circuits Design

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Lecture 3.1: Amplitude Modulation (AM)

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What is Modulation?

- Modulation is the process of converting data into radio waves by adding information to an electronic or optical carrier signal.

  OR

  The process of impressing a *low-frequency* intelligence signal onto a higher-*frequency* "carrier" signal may be defined as modudation.

- A carrier signal is one with a steady waveform - constant height, or amplitude, and frequency.

Why do we use modulation?

- The reasons that modulation is used in electronic communications is explained as:
  - Direct transmission of intelligible signals would result in catastrophic interference problems because the resulting radio waves would be at approximately the same frequency.
  - Modulation allows to send a signal over a bandpass frequency range
  - Most intelligible signals occur at relatively low frequencies. Efficient transmission and reception of radio waves at low frequencies is not practical due to the large antennas required. Therefore, modulating a signal allows the use of a smaller antenna

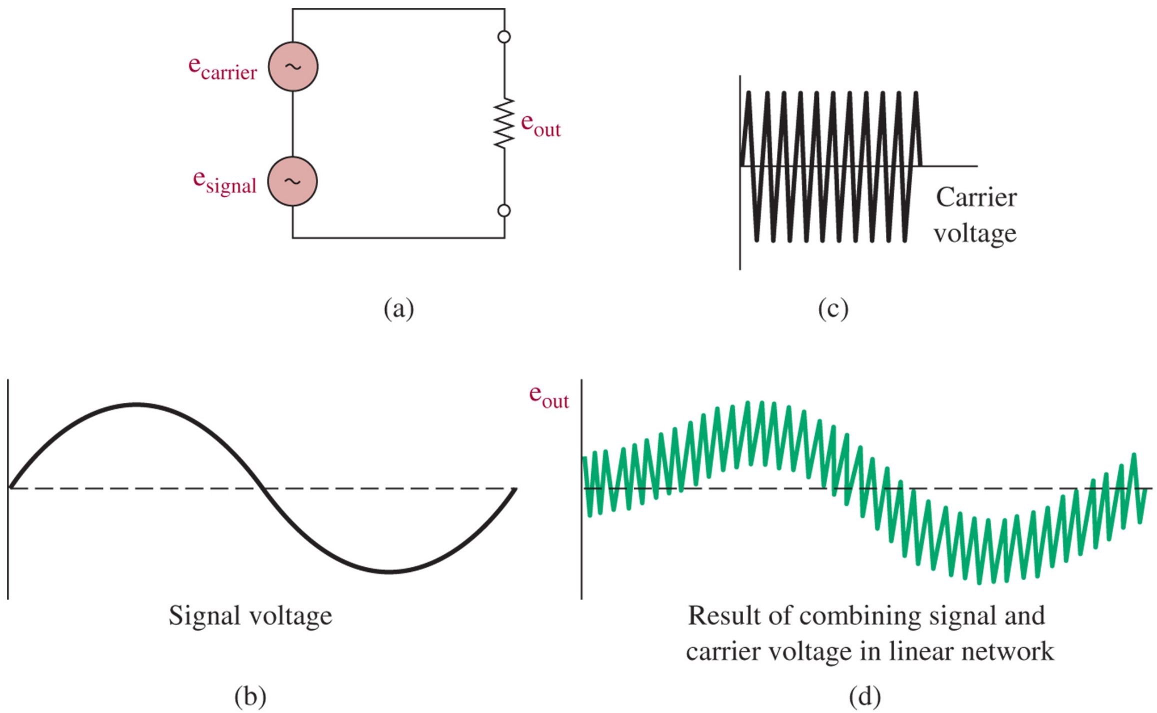
Amplitude Modulation (AM)

- AM Modulation in which the amplitude of a carrier wave is varied in accordance with some characteristic of the modulating signal (intelligence).

AM Modulation - Linear

- Combining two widely different sine-wave frequencies such as a carrier and intelligence in a linear fashion results in their simple algebraic addition
- A circuit that would perform this function is shown in Figure below.

The result e_{out} is not suitable for transmission as an AM waveform.



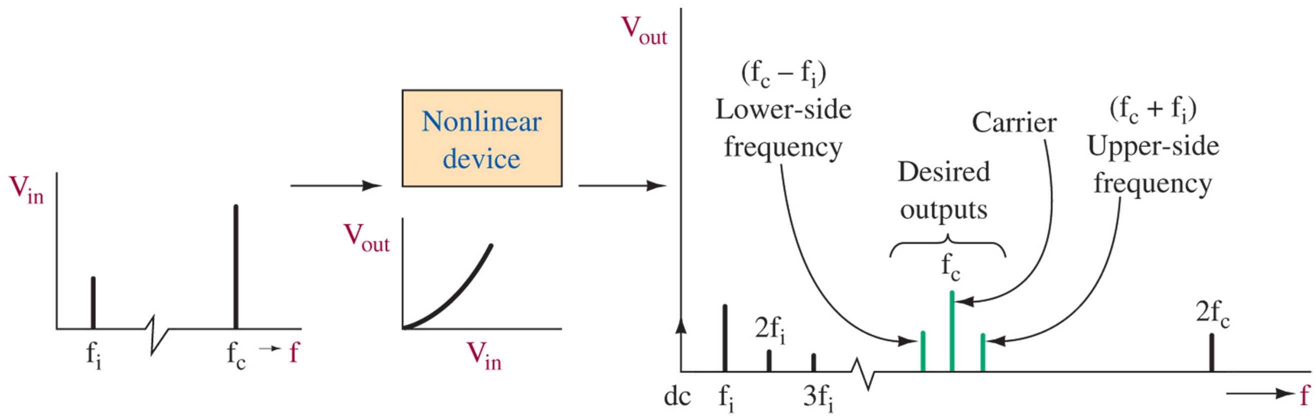
AM Modulation – Nonlinear (1)

- The method utilized to produce a usable AM signal is to combine the carrier and intelligence through a nonlinear device.
- It can be mathematically proven that the combination of any two sine waves through a nonlinear device produces the following frequency components:

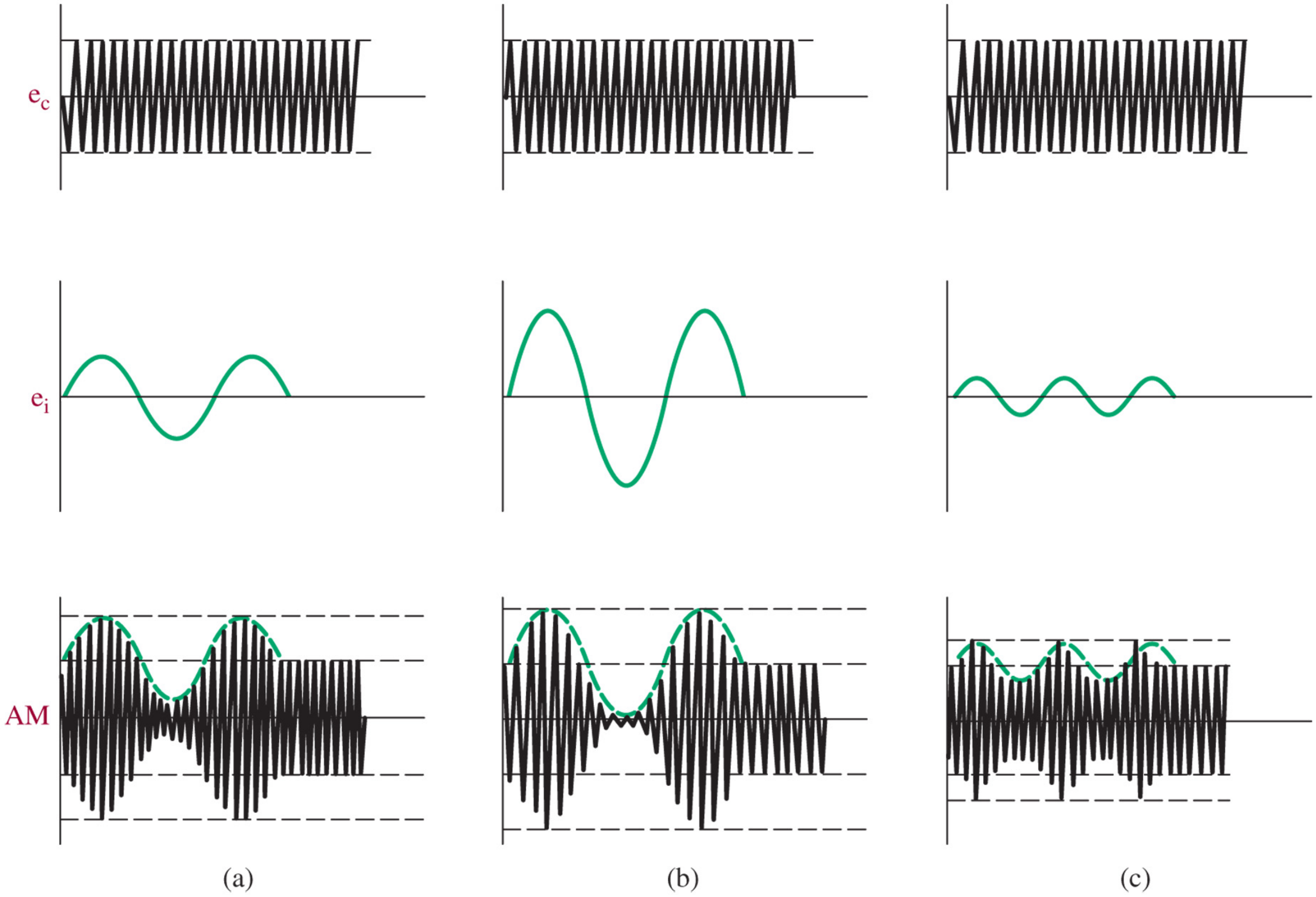
1. A dc level
2. Components at each of the two original frequencies
3. Components at the sum and difference frequencies of the two original frequencies
4. Harmonics of the two original frequencies

AM Modulation – Nonlinear (2)

- Figure shows this process pictorially with the two sine waves, labeled f_c and f_i, to represent the carrier and intelligence.
- If all but the $f_c - f_i$, and $f_c + f_i$ components are removed (perhaps with a bandpass filter), the three components left form an AM waveform.
- *They are referred to as:*
  1. *The lower-side frequency ($f_c - f_i$)*
  2. *The carrier frequency (f_c)*
  3. *The upper-side frequency ($f_c + f_i$)*



AM Waveforms (1)



AM waveform under varying intelligence signal (e_i) conditions

AM Waveforms (2)

- Note in Figure (a) that the resultant AM waveform is basically a signal at the carrier frequency whose amplitude is changing at the same rate as the intelligence frequency.
- As the intelligence amplitude reaches a maximum positive value, the AM waveform has a maximum amplitude.
- The AM waveform reaches a minimum value when the intelligence amplitude is *at a* maximum negative value.

AM Waveforms (3)

- In Figure (b), the intelligence frequency remains the same, but its amplitude has been increased. The resulting AM waveform reacts by reaching *a* larger maximum value and smaller minimum value.
- In Figure (c), the intelligence amplitude is reduced and its frequency has gone up. The resulting AM waveform, therefor, has reduced maximums and minimums, and the rate at which it swings between these extremes has increased to the same frequency as the intelligence.

Equation for the Envelope (1)

- the top and bottom envelopes of an AM waveform are replicas of the frequency and amplitude of the intelligence (notice the 180^o phase shift).
- However, the AM waveform does *not* include any component at the intelligence frequency. The equation for the AM waveform (envelope) is:

$$e = (E_c + E_i \sin \omega_i t) \sin \omega_c t$$

where E_c = the peak amplitude of the carrier signal

E_i = the peak amplitude of the intelligence signal

$\omega_i t$ = the radian frequency of the intelligence signal

$\omega_c t$ = the radian frequency of the carrier signal

$\omega = 2\pi f$

Equation for the Envelope (2)

- This equation indicates that an AM waveform will contain the carrier frequency plus the products of the sine waves defining the carrier and intelligence signals.
- Based on the trigonometric identity:

$$(\sin x)(\sin y) = 0.5 \cos(x - y) - 0.5 \cos(x + y)$$

where *x* is the carrier frequency and *y* is the intelligence frequency.

- The product of the carrier and intelligence sine waves will produce the sum and differences of the two frequencies.

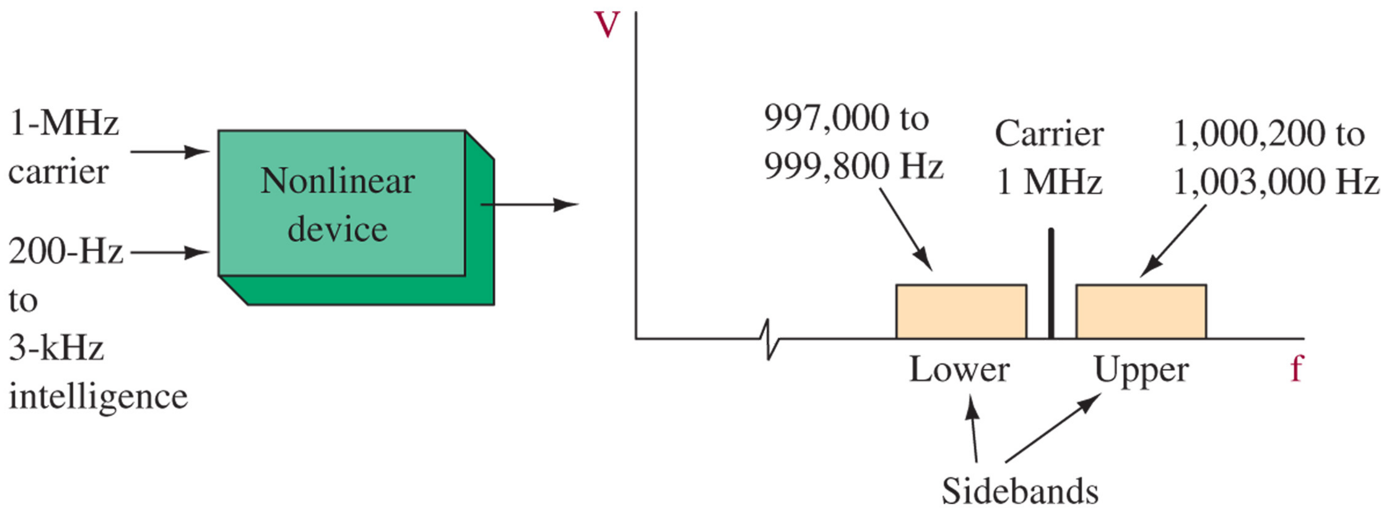
Example 1

- If a 1-MHz carrier were modulated by a 5-kHz intelligence signal, the AM waveform would Include the following components:

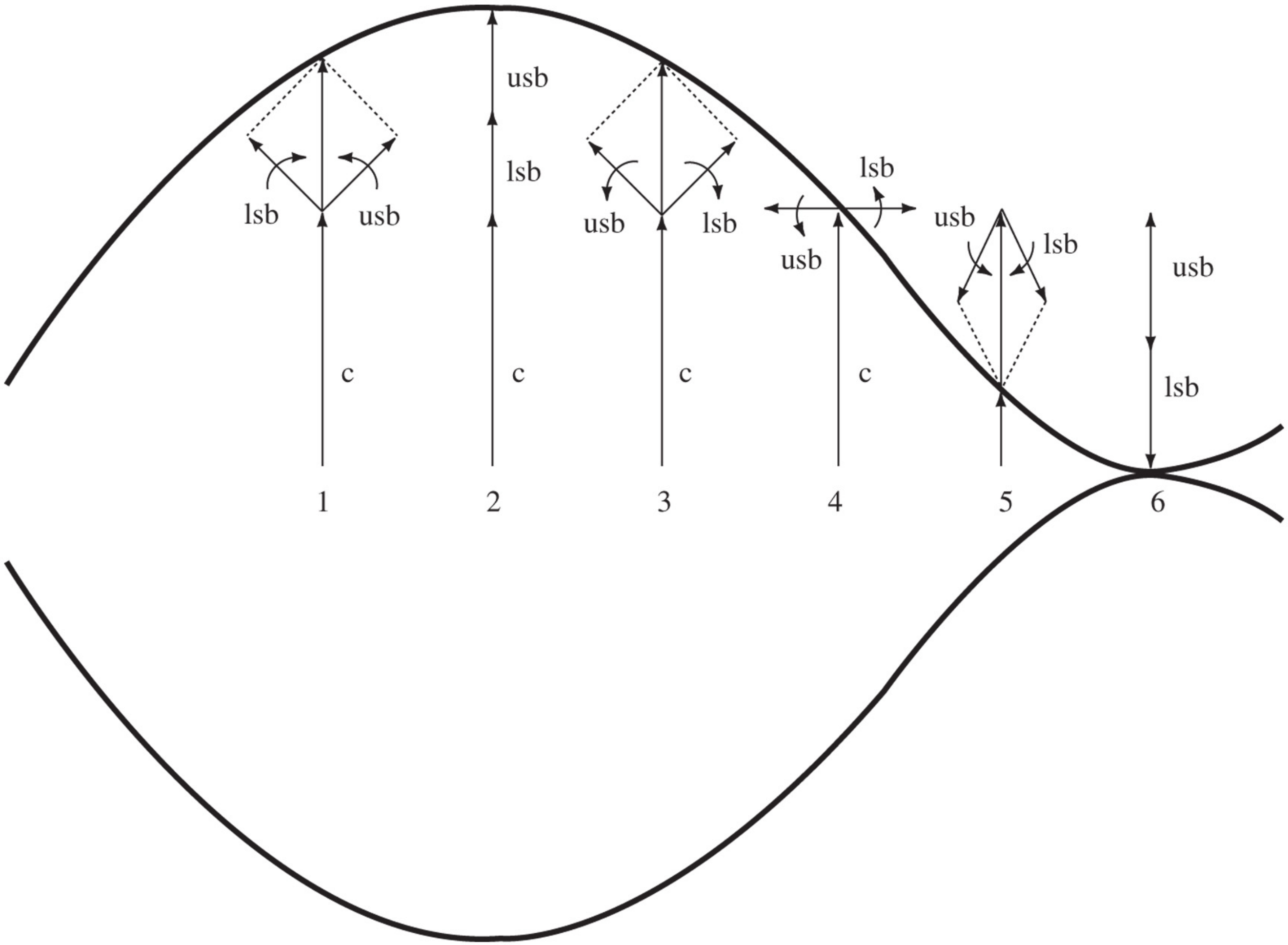
1-MHz + 5-kHz = 1,005,000 Hz (upper-side frequency)

1-MHz = 1,005,000 Hz (carrier frequency)

1-MHz - 5-kHz = 995,000 Hz (lower-sidle frequency)



Phase Representation of AM



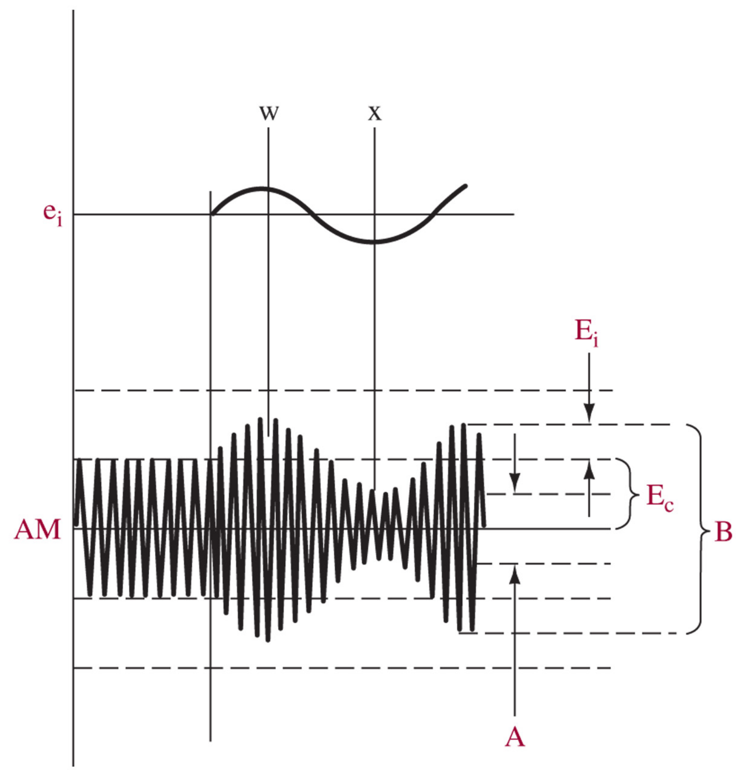
AM representation using vector addition of phasors.

Percentage Modulation

- It was determined earlier that an increase in intelligence amplitude resulted in an AM signal with larger maximums and smaller minimums.
- It is helpful to have a mathematical relationship between the relative amplitude of the carrier and intelligence signals.
- The percentage modulation provides this, and it is a measure of the extent to which a carrier voltage is varied by the intelligence.
- The percentage modulation is also referred to as modulation index or modulation factor, and they are symbolized by *m*.

Percentage Modulation

- The two most common used methods for determining the percentage modulation when modulating with sine waves is illustrates in Figure below.
- Notice that when the intelligence signal is zero, the carrier is unmodulated and has a peak amplitude labeled as E_c.
- When the intelligence reaches its first peak value (point w), the AM signal reaches a peak value labeled E_i (the increase from E_c.).



Percentage modulation is given as:

$$\% \ m = \frac{E_i}{E_c} \times 100\%$$

or

$$\% \ m = \frac{B - A}{B + A} \times 100\%$$

Overmodulation (1)

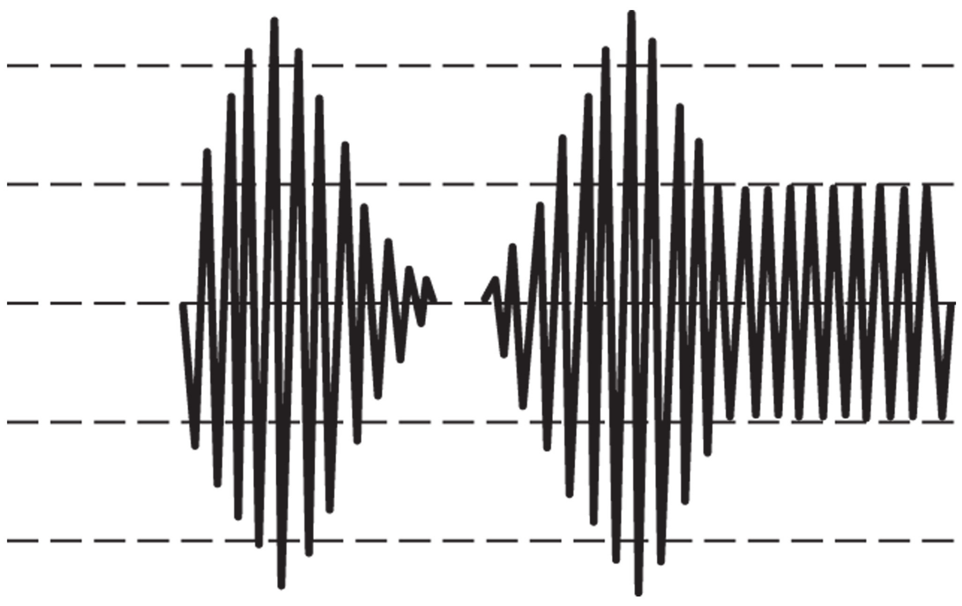
- If the AM waveforne's minimum value A falls to zero as a result of an increase in the intelligence amplitude, the percentage modulation becomes

$$\%m = \frac{B - A}{B + A} \times 100\% = \frac{B - O}{B + O} \times 100\% = 100\%$$

- This is the maximum possible degree of modulation. In this situation the carrier is being varied between zero and double its unmodulated value.
- Any further increase in the intelligence amplitude will cause a condition known as overmodulation to occur.
- If this does occur, the modulated carrier will go to more than double its unmodulated value but will fall I to zero for an interval of time, as shown in Figure.

Overmodulation (2)

- This "gap" produces distortion lemma sideband splatter, which results in the transmission of frequencies outside a station's normal allocated range.
- This is an unacceptable condition because it causes severe interference to other stations and causes a loud splattering sound to be heard at the receiver.



AM Analysis (1)

- The instantaneous value of the AM waveform can be developed as follows. The equation for the amplitude of an AM waveform can be written as the carrier peak amplitude, E_c, plus the intelligence signal, e_i. Thus, the amplitude E is

$$E = E_c + e_i$$

- but $e_i = E_r \sin w_i t$, so

$$E = E_c + E_i \sin \omega_i t$$

- From Equation, $Ei = mE_c$, so that

$$\begin{aligned} E &= E_c + mE_c \sin \omega_i t \\ &= E_c(1 + m \sin \omega_i t) \end{aligned}$$

AM Analysis (2)

- The instantaneous value of the AM wave is the amplitude term *E* just developed times sin $w_c t$. Thus,

$$
\begin{aligned}
e &= E \sin \omega_c t \\
&= E_c(1 + m \sin \omega_i t) \sin \omega_c t
\end{aligned}
$$

Notice that the AM wave *(e)* is the result of the product of two sine waves.

- This product can be expanded with the help of the trigonometric relation sin x sin y = 1/2[cos (x - y) - cos (x + y)]. Therefore,

$$
e = \overbrace{E_c \sin \omega_c t}^{①} + \overbrace{\frac{mE_c}{2} \cos (\omega_c - \omega_i)t}^{②} - \overbrace{\frac{mE_c}{2} \cos (\omega_c + \omega_i)t}^{③}
$$

Side-frequency Amplitude

- In the case where a carrier is modulated by a pure sine wave, it can be shown that at 100 percent modulation, the upper- and lower-side frequencies are one-half the amplitude of the carrier. In general, as just developed,

$$E_{SF} = \frac{mE_c}{2}$$

where E_{SF} = side-frequency amplitude
m = modulation index
E_c = carrier amplitude

- In an AM transmission, the carrier amplitude and frequency always remain constant, while the sidebands are usually changing in amplitude and frequency.
- The carrier contains no information since it never changes. However, it does contain the most power since its amplitude is always at least double (when *m* = 100%) the sidehand's amplitude. It is the sidebands that contain the information.

Transmitted Power

- A valuable relationship for many AM calculations is the transmitted power:

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

where P_t = total transmitted power (sidebands and carrier)

P_c = carrier power

m = modulation index

Transmitted Current

- Equation for Power calculation can be manipulated to utilize current instead of power.
- This is a useful relationship since current is often the most easily measured parameter of a transmitter's output to the antenna.

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

where I_t = total transmitted current

I_c = carrier current

m = modulation index

- Equation for current can also be used *with E* substituted for *I*

$\left(E_t = E_c\sqrt{1 + m^2/2}\right)$.

Example 2

- A 500-W carrier is to be modulated to a 90 percent level. Determine the total transmitted power

Example 3

- An AM broadcast station operates at its maximum allowed total output of 50 kW and at 95 percent modulation. How much of its transmitted power is intelligence (sidebands)?