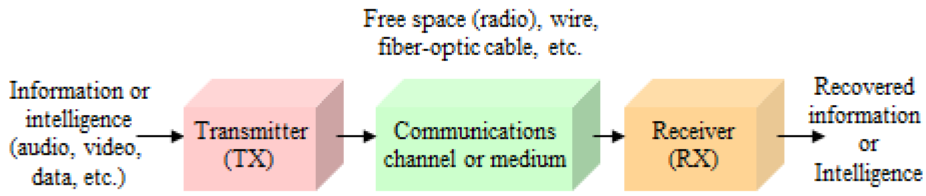
EE302 Lesson 7

Sources: (1) Course materials developed by CDR Hewitt Hymas, USN
(2) Frenzel, Principles of Electronic Communication Systems, 3rd ed., McGraw Hill, 2008

Amplitude Modulation So far we have discussed information signals (voice, music, data) and their frequency content. Now we will introduce a means of transmitting an information signal across a channel to a receiver.



Before it can be transmitted, information must be converted to an electrical signal.

- Microphones convert acoustic pressure waves (sound) into voltages.
- Video cameras convert light into analog or digital voltage signals.
- Computer inputs (keyboard or mouse) are converted to binary electrical signals.

All of these are referred to as **baseband** signals.

Transmitting Baseband Signals

In some communications systems, baseband information signals can be sent directly and unmodified over the medium. This process is called **baseband transmission**. Examples:

- Simple telephone and intercom systems
- Computer networks using coaxial or twisted-pair cabling.

But in most systems, transmission of intelligence signals at their original frequencies is impractical.

- Baseband signals are often incompatible with the transmission medium (free space, fiber optic)
  - ☐ Electromagnetic waves would not propagate well.
  - ☐ Antenna sizes for audio frequencies would be impractically large.
- In a shared medium (public airwaves) use of baseband transmission would result in interference.

Modulation

To overcome limitations of the communications channel and permit multiple access, information signals are *impressed* upon a higher-frequency carrier signal for transmission. This process is called **modulation**.

Mathematically, the sine wave representing the higher-frequency carrier is given by:

$$v_c = V_c \sin(2\pi f_c t + \theta)$$

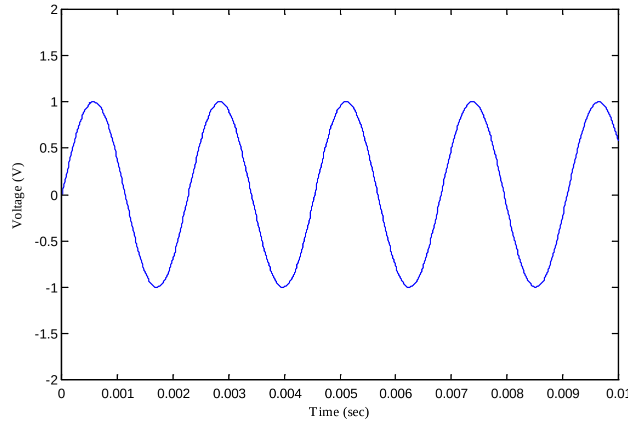
We can vary any of these three variables in accordance with the low-frequency information signal to achieve modulation.

- varying V_c (amplitude) $\Rightarrow$ amplitude modulation (AM)
- varying f_c (frequency) $\Rightarrow$ frequency modulation (FM)
- varying θ (phase angle) $\Rightarrow$ phase modulation (PM)

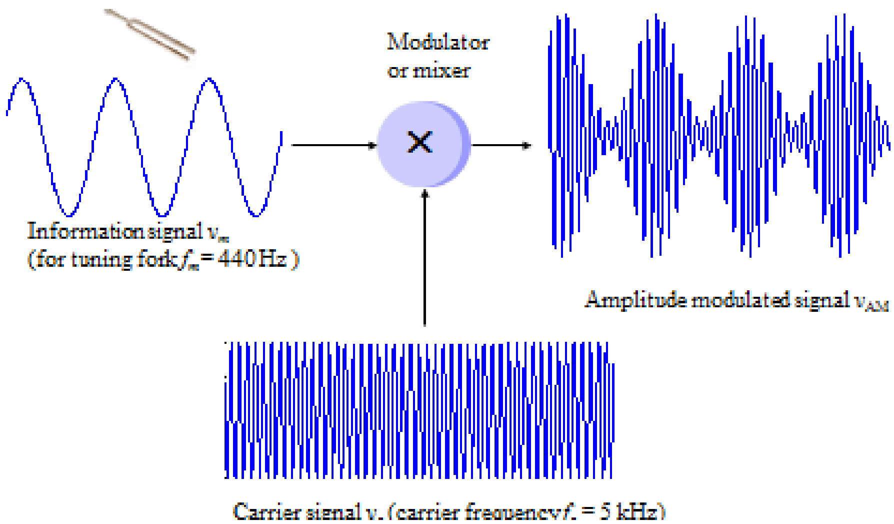
A modulator is a component within the transmitter that mixes the baseband intelligence signal with a higher-frequency carrier.

Amplitude Modulation In amplitude modulation, the information signal varies the amplitude of the carrier sine wave. For simplicity, consider a sine wave information signal, v_m (a 440 Hz tuning fork).

$$v_m = V_m \sin 2\pi f_m t$$

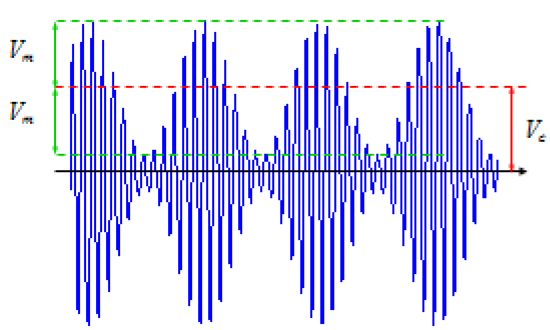


Information signal v_m (for tuning fork f_m = 440 Hz)



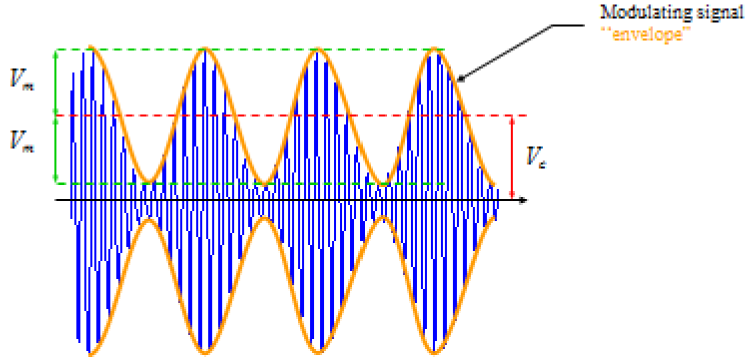
The AM wave (v_{AM}) is the product of the carrier and the intelligence signal (with an added offset, Vc) and is given by:

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



The "envelope" of the modulating signal varies above and below the peak carrier amplitude, V_c

In order to prevent distortion, note that $V_c > V_m$

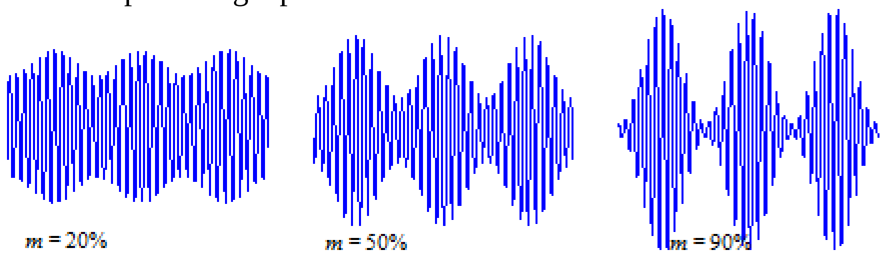


Modulation Index

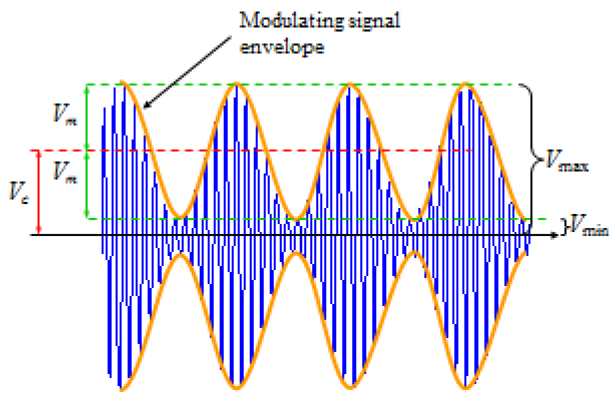
The relationship between the modulating signal amplitude, V_m , and the carrier amplitude, V_c , is expressed as a ratio called the *modulation index*, *m*, defined as:

$$m = \frac{V_m}{V_C}$$

Sometimes *m* is expressed as a percentage: percent modulation = *m* x 100%



We can also determine the modulation index *m* from the maximum and minimum values of the envelope of v_{AM}

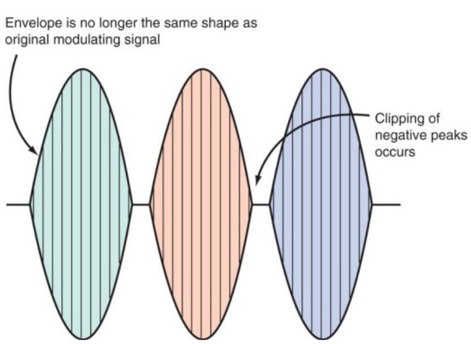


$$V_m = \frac{V_{\max} - V_{\min}}{2}$$

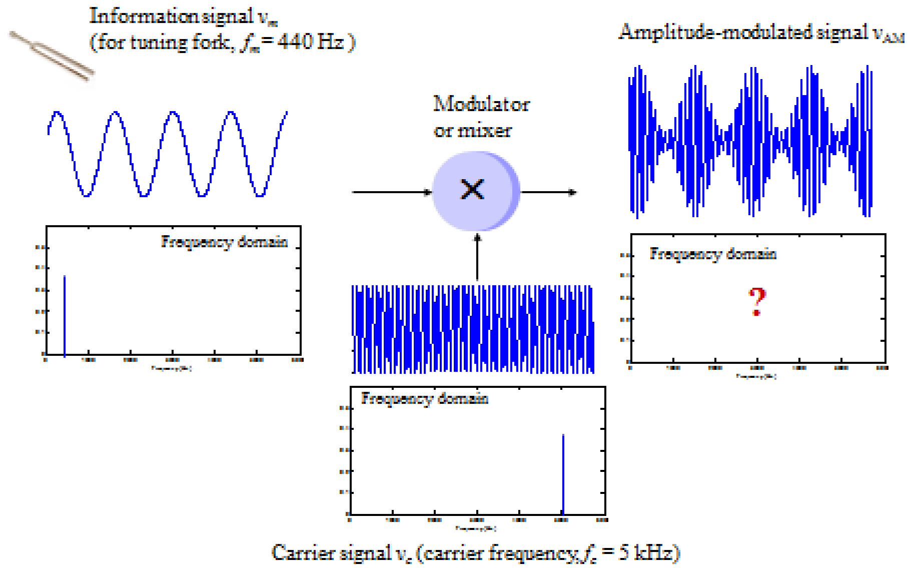
$$V_c = \frac{V_{\max} + V_{\min}}{2}$$

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

Overmodulation *m* should range between 0 and 1. The condition in which *m* > 1 is called overmodulation and will result in distortion.



AM in the Frequency Domain



- v_{AM} is given by: $v_{AM} = (V_c + V_m \sin 2\pi f_m t) \sin 2\pi f_c t$
  $= V_c \sin 2\pi f_c t + (V_m \sin 2\pi f_m t)(\sin 2\pi f_c t)$
- Applying the trigonometric identity for the product of two sine functions:

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

we can write:

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

- This form shows that v_{AM} consists of just three frequency components.

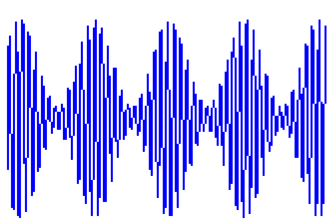
$$v_{AM} = \frac{V_m}{2} \cos 2\pi (f_c - f_m)t + V_c \sin 2\pi f_c t - \frac{V_m}{2} \cos 2\pi (f_c + f_m)t$$

Sideband amplitude is one half of the original message amplitude

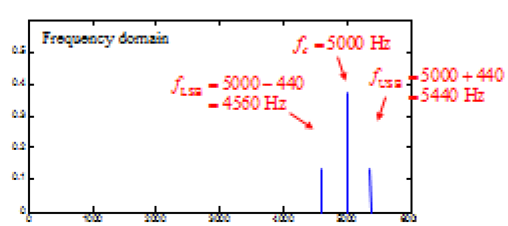
Lower sideband ($f_{LSB} = f_c - f_m$)

Carrier frequency f_c

Upper sideband ($f_{USB} = f_c + f_m$)

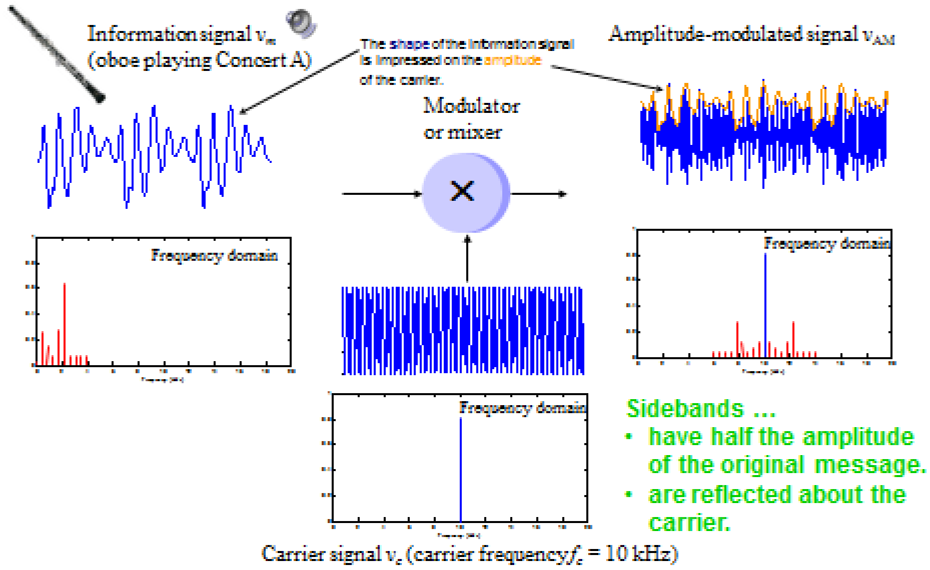


Amplitude modulated signal v_{AM}

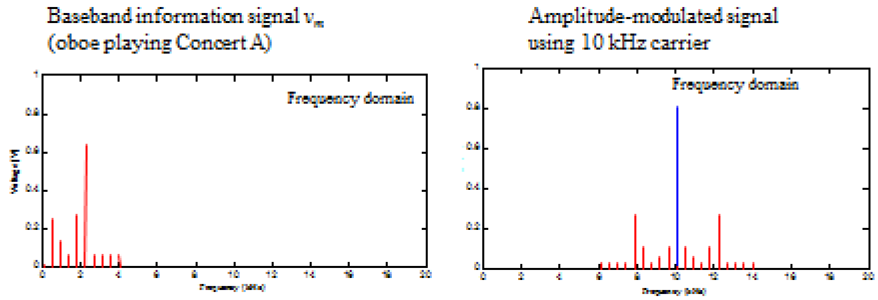


In a f-domain plot, you can't distinguish between sin and cos.

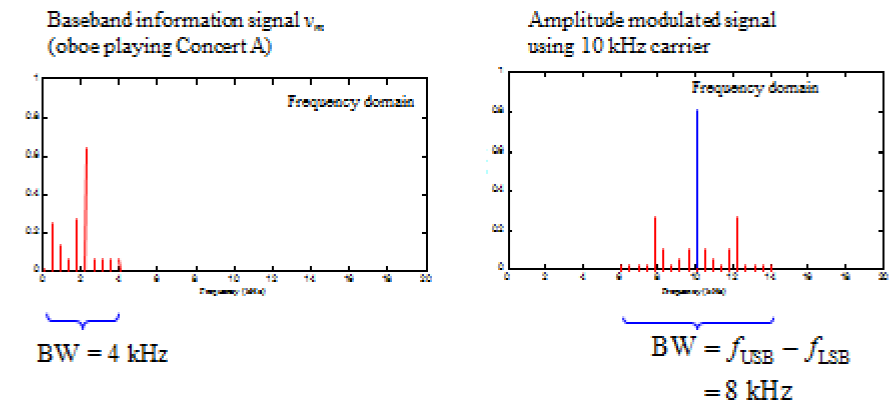
Specific example: an oboe:



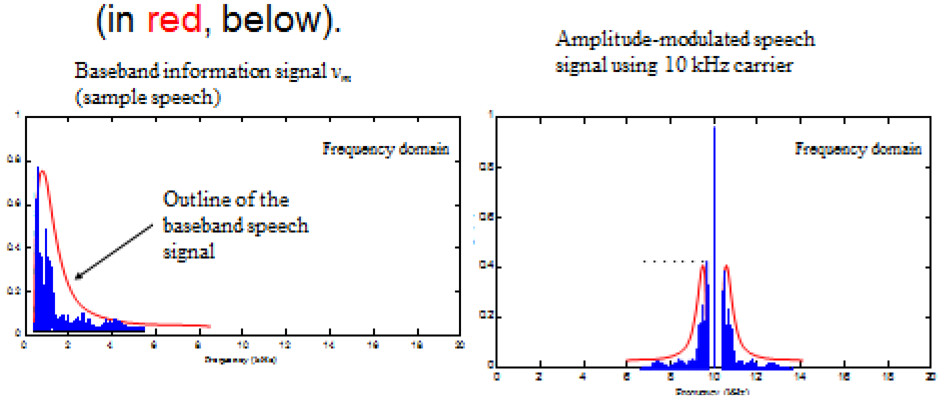
- In the frequency domain, we can see that amplitude modulation <u>translates</u> the baseband signal in frequency and produces a reflected version about the carrier.



- Notice that amplitude modulation doubles the bandwidth of the signal.



- For complex signals (speech, music) we often represent the frequency content with an “outline” (in red, below).



<u>Example Problem 1</u>

If a carrier signal with an amplitude of 9 V is modulated by a sine wave signal with an amplitude of 7.5 V, what is the percentage modulation of the resulting signal?

<u>Example Problem 2</u> You are looking at an AM signal on an oscilloscope. The maximum value of the modulating wave is 11.8 V and the minimum value is 2.4 V. What is the modulation index?

<u>Example Problem 3</u> 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, compute the maximum and minimum frequencies of the upper and lower sidebands and the total bandwidth occupied by the AM station.