Analog Modulation Techniques for Mobile Radio

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Outline

- Summary
- Modulation types
- Amplitude modulation
- demodulation

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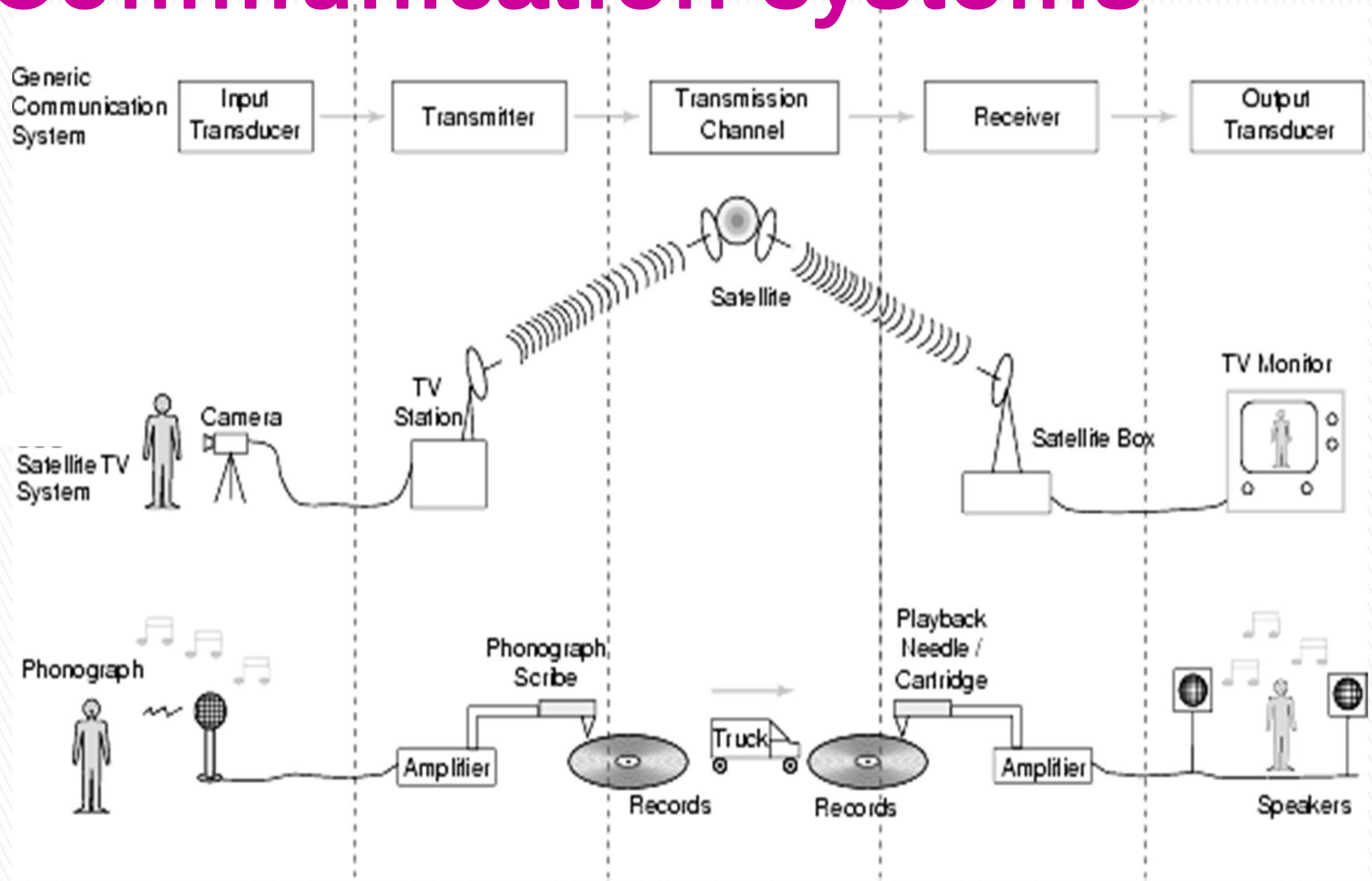
Recaptulation

- Modern Wireless Communications
  - 2G, 2.5G, 3G networks
- Cellular concept
  - Frequency reuse
  - Cochannel interference
  - Cell coverage and capacity
- Mobile radio propagation
  - Propagation models
  - Large scale fading
  - Small scale fading

Communication Systems



The block diagram shows the blocks common to all communication systems

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Components of a Communication System

Remember the components of a communications system:

- ***Input transducer:***

  The device that converts a physical signal from source to an electrical, mechanical or electromagnetic signal more suitable for communicating

- ***Transmitter:***

  The device that sends the transduced signal

- ***Transmission channel:***

  The physical medium on which the signal is carried

- ***Receiver:***

  The device that recovers the transmitted signal from the channel

- ***Output transducer:***

  The device that converts the received signal back into a useful quantity

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Modulation

- Modulation is the process of encoding the information from message source in a manner suitable for transmission.

Modulation Techniques

Modulation

Analog modulation
(first generation Radio)
- **Amplitude modulation**
- **Frequency modulation**
- **Phase modulation**

Digital modulation
(present and future Radio systems)
- **QPSK, QAM,QFSK**
- **MSK, GMSK**
- **CDMA, FH-SS, DS-SS**

modulation/demodulation

- Baseband signal (original signal) must be transmitted through a communication channel such as air using electromagnetic waves
- An appropriate procedure is needed to shift the range of baseband frequencies to other frequency ranges suitable for transmission,
- A corresponding shift back to the original frequency range after reception.
- This is called the process of *modulation* and *demodulation*

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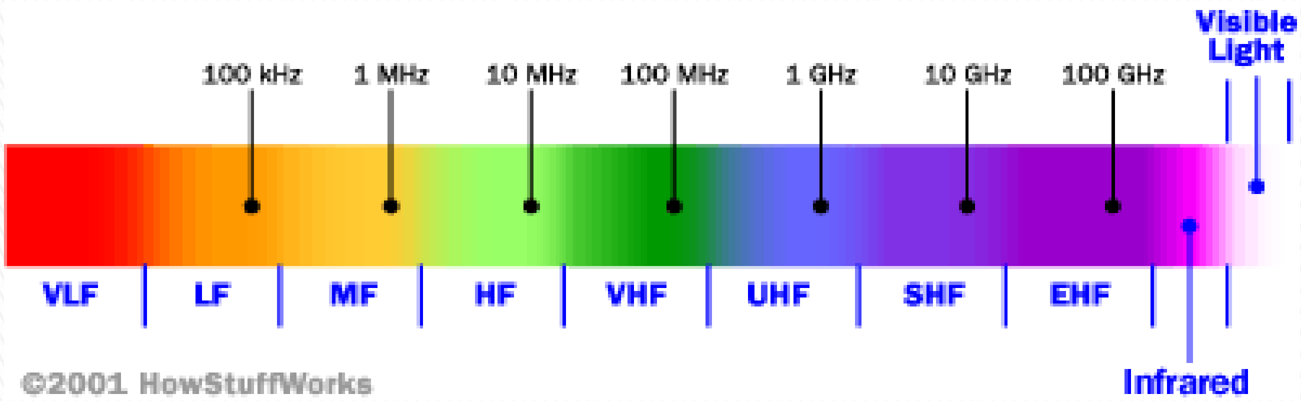
- Remember the radio spectrum:



- An AM radio system transmits electromagnetic waves with frequencies of around a few hundred kHz (MF band)

- The FM radio system must operate with frequencies in the range of 88-108 MHz (VHF band)

Modulation…

- The **transmitter** block in any communications system contains the modulator device which does the frequency-band shifting
- The **receiver** block in any communications system contains the demodulator device

- The modulator **modulates a** *carrier wave* (the electromagnetic wave) which has a frequency that is selected from an appropriate band in the radio spectrum
  - the frequency of a carrier wave for FM can be chosen from the VHF band of the radio spectrum
  - For AM, the frequency of the carrier wave may be chosen (to be around a few hundred kHz) from the MF band of the radio spectrum

- The demodulator extracts the original baseband signal from the received modulated signal

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❑In Nutshell;

- Modulation is the process of impressing a low-frequency information signal (baseband signal) onto a higher frequency carrier signal

- Modulation is done to bring information signals up to the Radio Frequency (or higher) signal

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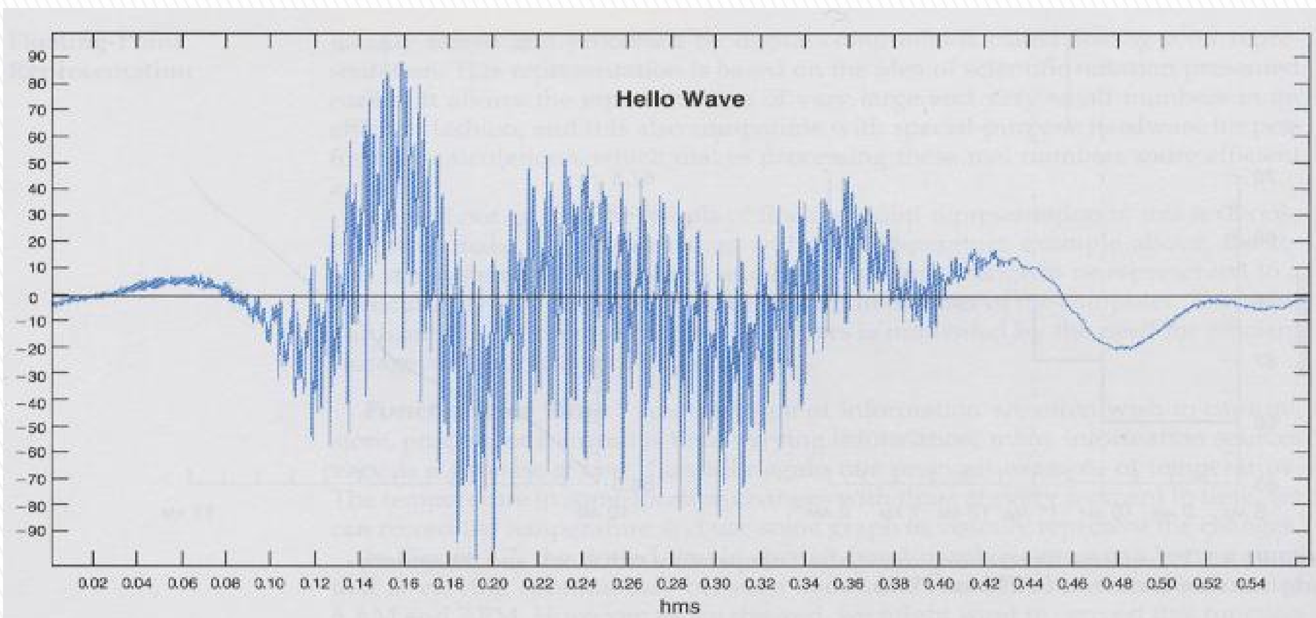
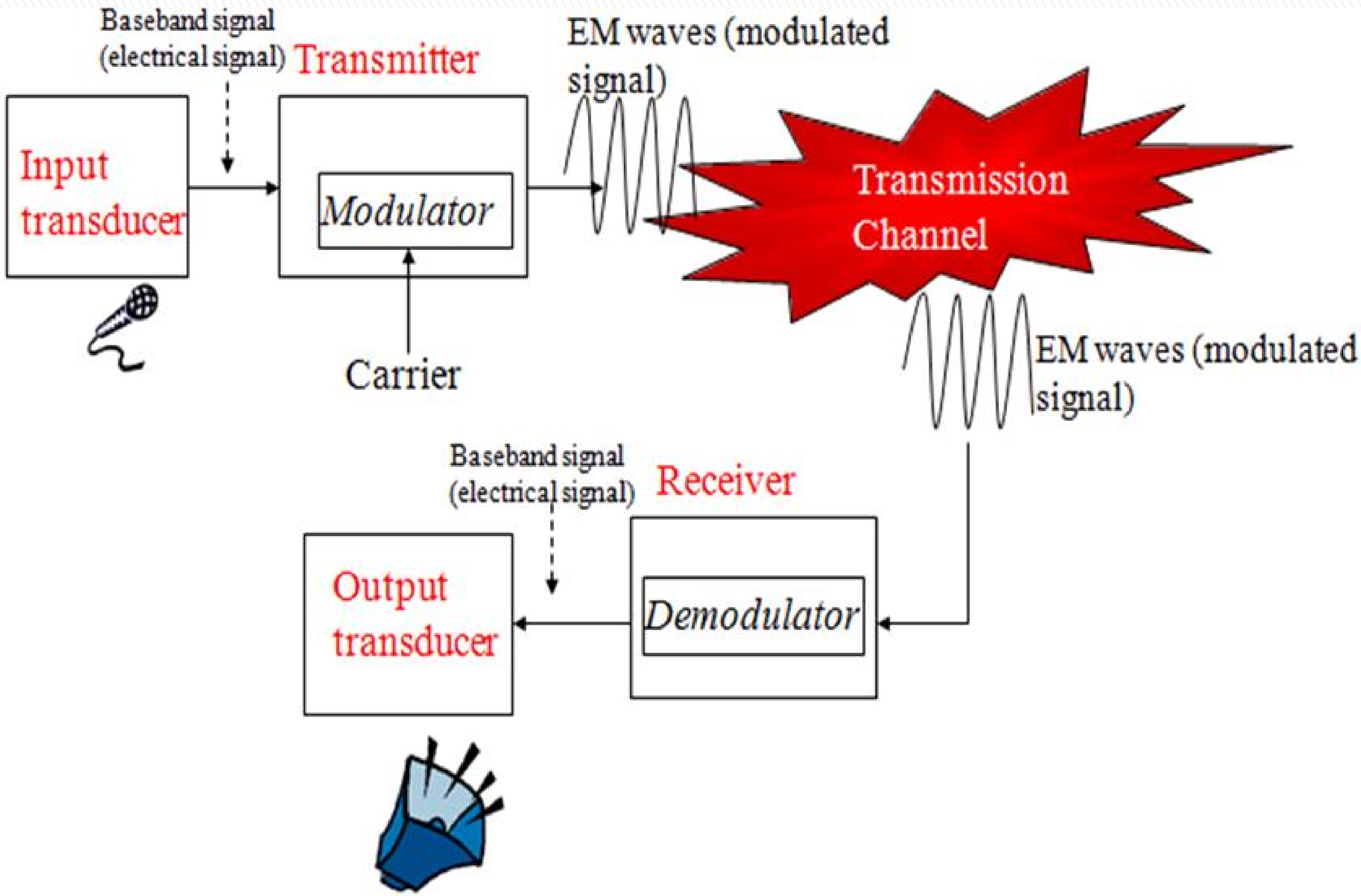
Analog modulation

- The purpose of a communication system is to transmit information signals (baseband signals) through a communication channel
- The term *baseband* is used to designate the band of frequencies representing the original signal as delivered by the input transducer
  - For example, the voice signal from a microphone is a baseband signal, and contains frequencies in the range of 0-3000 Hz
  - The “hello” wave is a baseband signal:



Basic analog communications system



Types of Analog modulation

- Amplitude Modulation (AM)
  - Amplitude modulation is the process of ***varying the amplitude of a carrier wave in proportion to the amplitude of a baseband signal.*** The frequency of the carrier remains constant
- Frequency Modulation (FM)
  - Frequency modulation is the process of ***varying the frequency of a carrier wave in proportion to the amplitude of a baseband signal.*** The amplitude of the carrier remains constant
- Phase Modulation (PM)
  - Another form of analog modulation technique which in general is similar to FM.

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Parameters in Analog modulation

- Sine wave (carrier) described by 3 parameters:
  amplitude,
  frequency and
  phase.

$$v(t) = A \sin(\omega t + \phi)$$

So we can have

- Amplitude modulation (AM)
- Frequency modulation (FM)
- Phase modulation (PM)
  - FM and PM closely related
  - "AM" radio band ~500 to 1600 kHz
  - "FM" radio band 88 to 108 MHz

Amplitude Modulation-mathematical consideration

- In amplitude modulation,
  - the amplitude of a high frequency carrier signal is varied in accordance to the instantaneous amplitude of the modulating message signal.
  - If $A_c \cos(2\pi f_c t)$ is the carrier signal and m(t) is the modulating message signal AM signal can be represented as:

$$s_{AM}(t) = A_c[1 + m(t)]\cos(2\pi f_c t)$$

- The *modulation index*
  - *m* of an AM signal is defined as the ratio of the peak message signal amplitude to the peak carrier amplitude.
  - For a sinusoidal modulating signal

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

The modulation index is given by:

$$m = \frac{A_m}{A_c}$$

- The modulation index is often expressed as a percentage , and is called *percentage modulation*
- A percentage of modulation greater than 100% will distort the message signal if detected by an envelope detector

Amplitude Modulation – physical considerations

Figure below shows a sinusoidal modulating signal and the corresponding AM signal

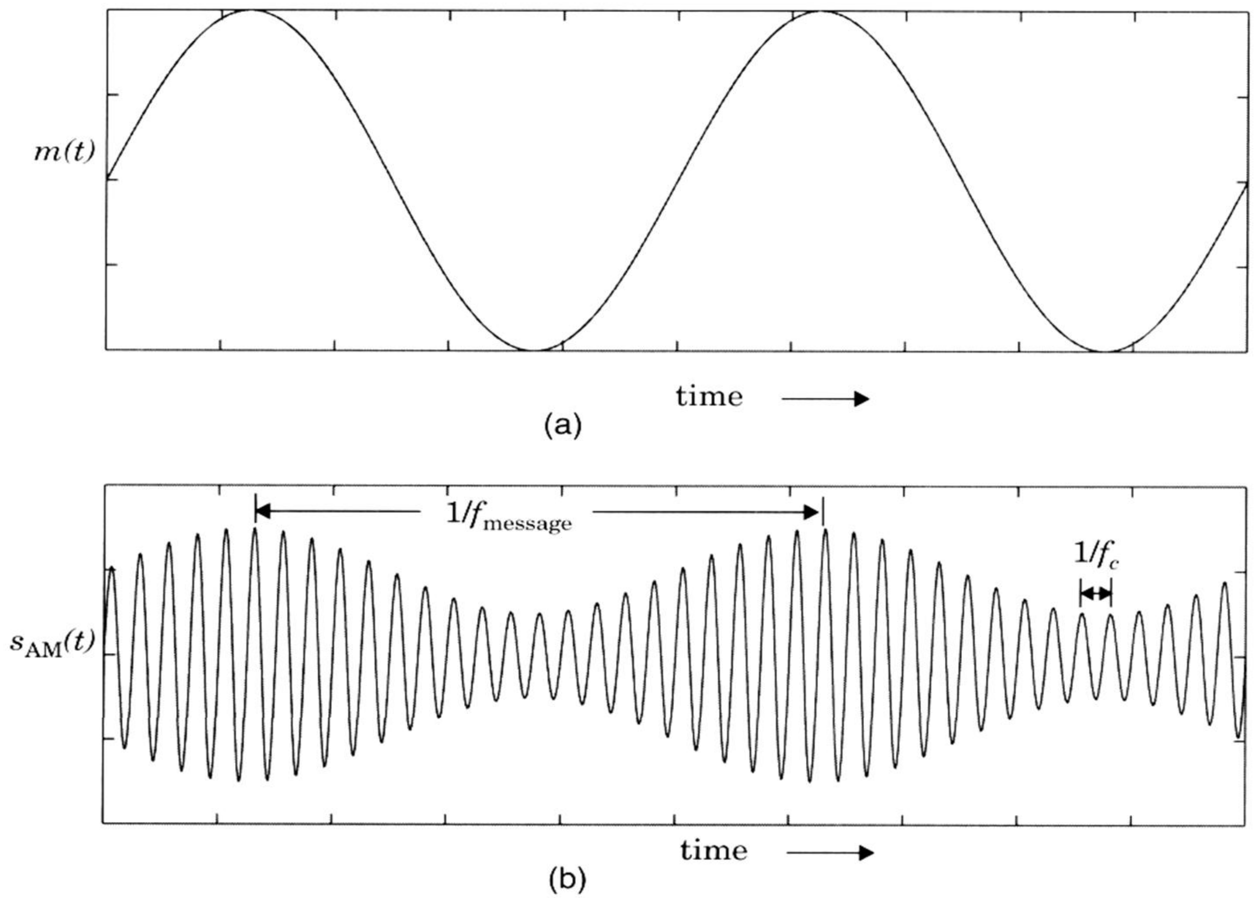
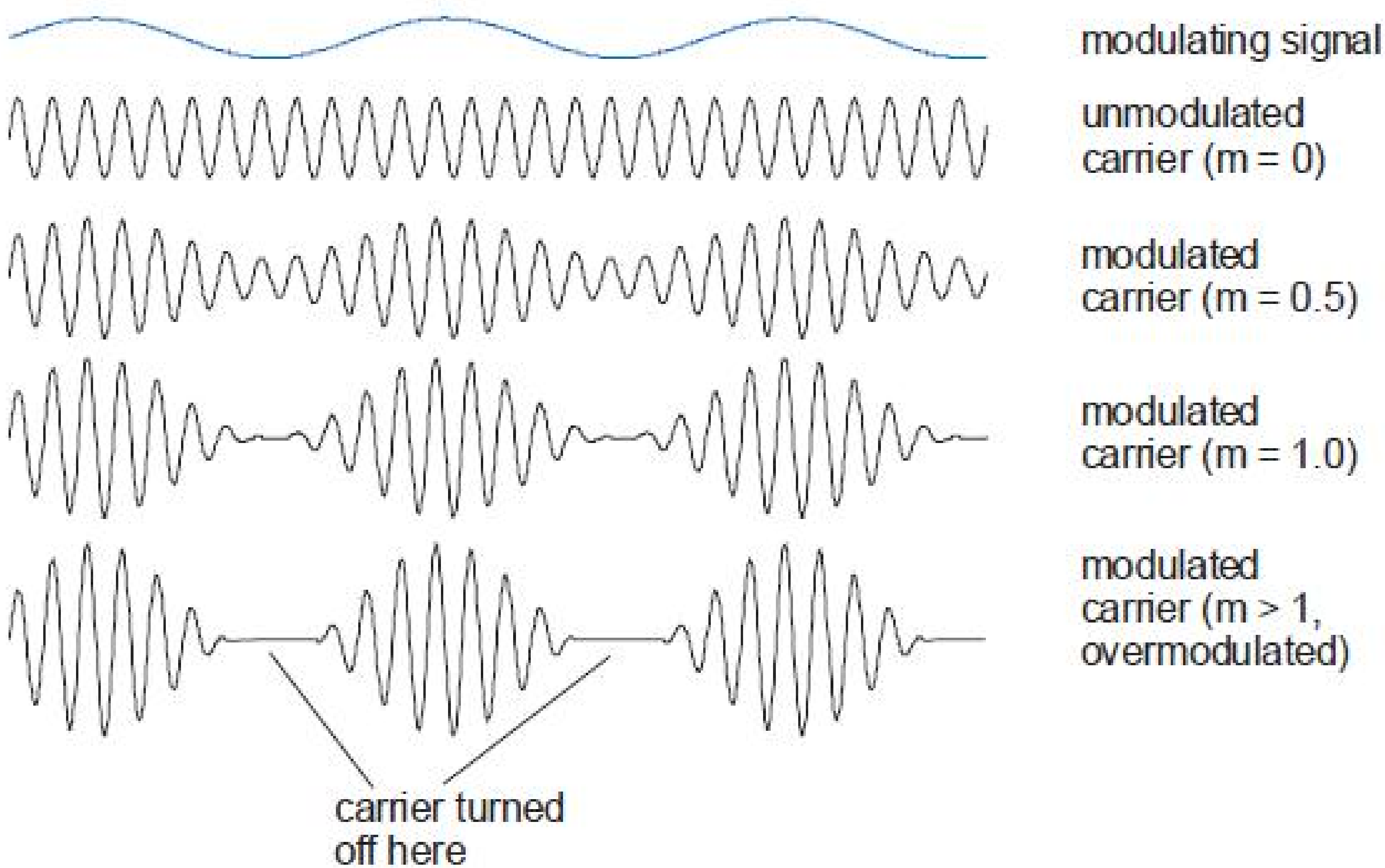


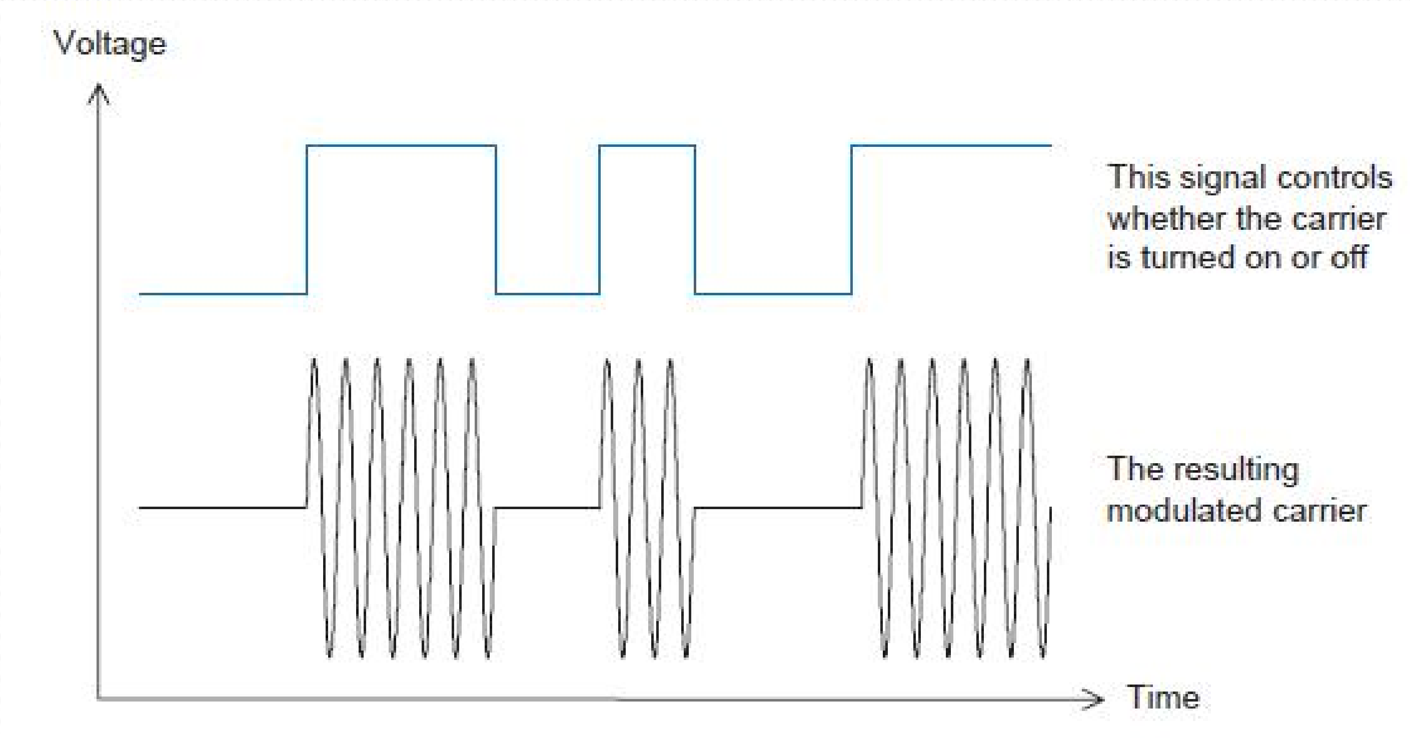
Figure . (a) A sinusoidal modulating signal and (b) the corresponding AM signal with modulation index 0.5.

Varying modulation index



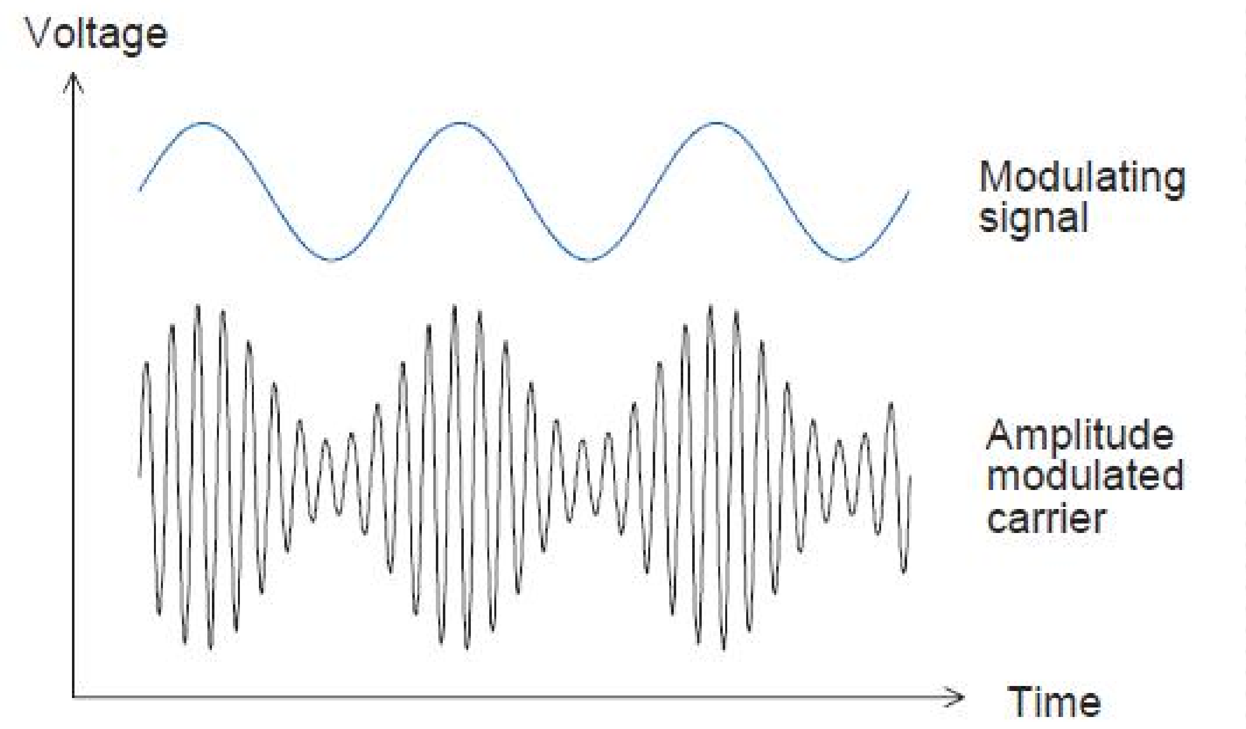
Amplitude Modulation is - carrier turned on or off

- Simplest case of AM is where carrier is just turned on or off



Envelope shape

- Continous amplitude modulation (eg AM radio)
- Information contained in the envelope shape



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Amplitude Modulation

- The spectrum of an AM signal can be shown to be:

$$S_{AM}(f) = \frac{1}{2}A_c[\delta(f-f_c) + M(f-f_c) + \delta(f+f_c) + M(f+f_c)]$$

where $\delta(\cdot)$ is the unit impulse function, and $M(f)$ is the message signal spectrum

- fig on next slide shows an AM spectrum for a message signal whose magnitude spectrum is a triangular function

- also it can be seen that the AM spectrum consists of an impulse at the carrier frequency and two sidebands which replicate the message spectrum

- the sidebands above and below the carrier frequency are called the upper and the lower sidebands, respectively

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Double sideband Spectrum

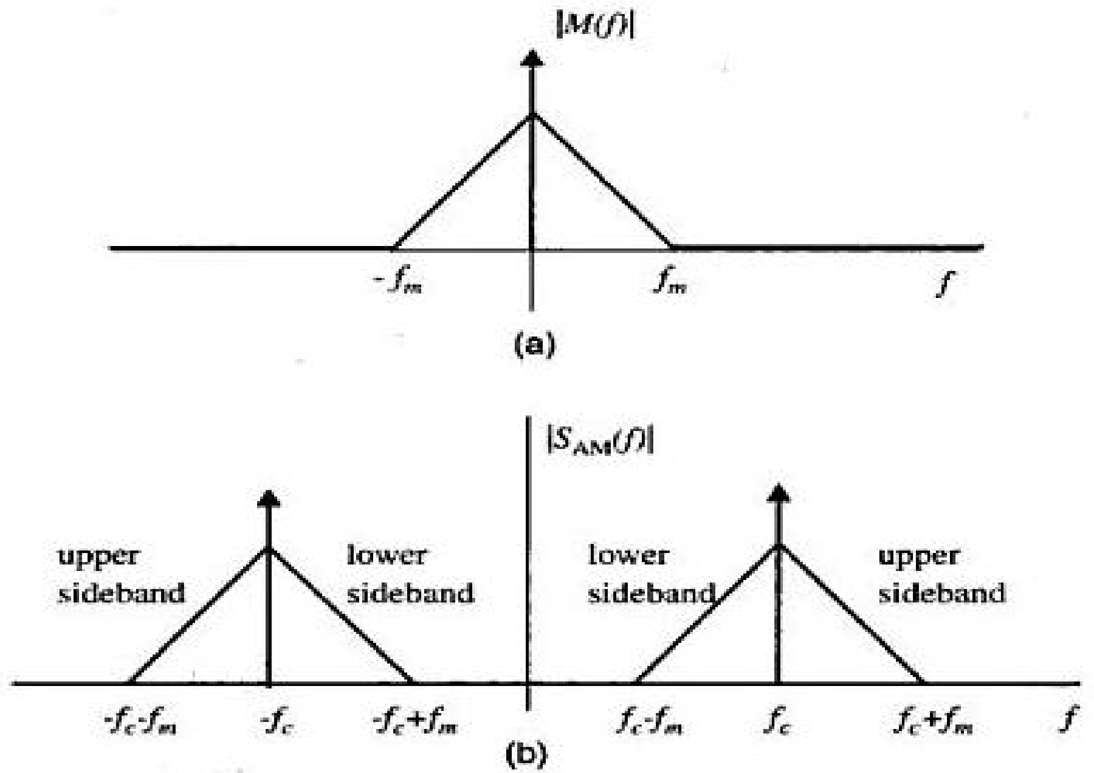
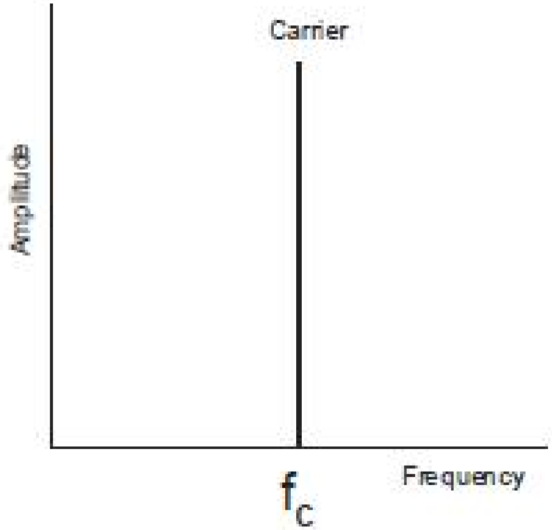
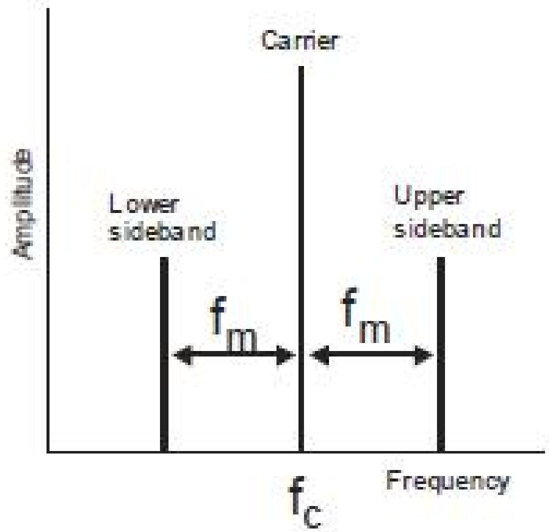


Figure 6.2 (a) Spectrum of a message signal; (b) spectrum of the corresponding AM signal.

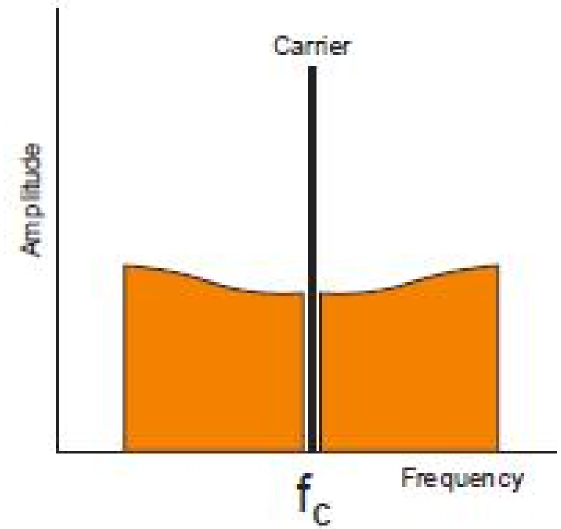
AM spectrum



unmodulated carrier



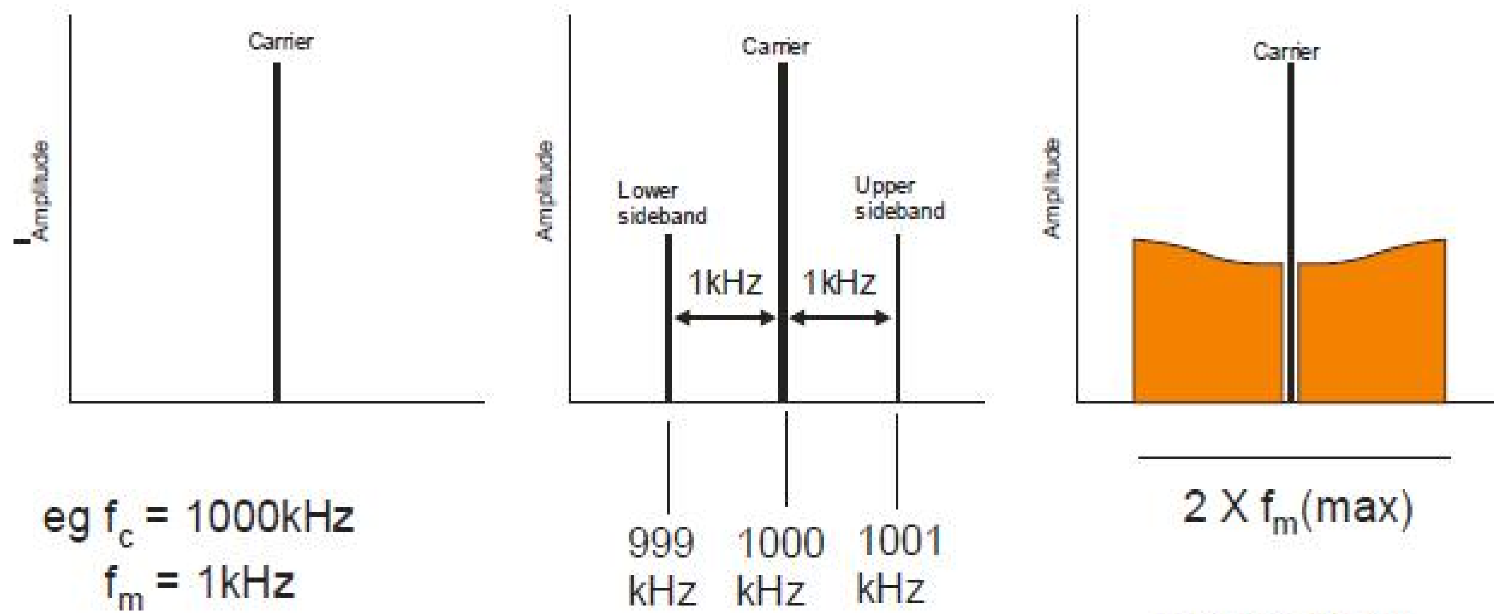
carrier modulated with a sine wave



carrier modulated with a range of frequencies

AM spectrum

- Example: f_c = 1000 kHz, f_m = 1 kHz



unmodulated carrier

carrier modulated with a sine wave

carrier modulated with a range of frequencies

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From where do we get the sidebands?

- Expand $v(t) = A_C \cos(2\pi f_C t)\{1 + m\cos(2\pi f_m t)\}$
- Using trig identities to get:

  $$v(t) = A_C \cos(2\pi f_C t) + 0.5mA_C \cos(2\pi [f_C - f_m]t) + 0.5mA_C \cos(2\pi [f_C + f_m]t)$$

- This expression consists of 3 sine waves at frequencies of carrier (f_c), lower sideband (f_c-f_m) and upper sideband (f_c+f_m).

Double Sideband Spectrum

- The RF bandwidth of an AM signal can be shown to be:

$$B_{AM} = 2f_m$$

where f_m is the maximum frequency contained in the modulating message signal

- The total power in an AM signal can be shown to be:

$$P_{AM} = \frac{1}{2}A_c^2[1 + P_m] = P_c\left[1 + \frac{k^2}{2}\right]$$

- where $P_c = A_c^2/2$ is the power in the carrier signal, $P_m = \langle m^2(t) \rangle$ is the power in the modulating signal m(t) and k is the modulation index

Numerical example

Example 6.1
A zero mean sinusoidal message is applied to a transmitter that radiates an AM signal with 10 kW power. Compute the carrier power if the modulation index is 0.6. What percentage of the total power is in the carrier? Calculate the power in each sideband.

Solution
Using Equation

$$P_c = \frac{P_{AM}}{1 + k^2/2} = \frac{10}{1 + 0.6^2/2} = 8.47 \text{ kW}$$

Percentage power in the carrier is

$$\frac{P_c}{P_{AM}} \times 100 = \frac{8.47}{10} \times 100 = 84.7\,\%$$

Power in each sideband is given by

$$\frac{1}{2}(P_{AM} - P_c) = 0.5 \times (10 - 8.47) = 0.765 \text{ kW}$$

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Single side band (SSB) AM

- Since both the sidebands of an AM signal carry the same information, it's possible to remove one of them without losing any information
- SSB AM systems transmit only one of the sidebands (either upper or lower) about the carrier and hence occupy half the bandwidth of conventional AM systems
- An SSB signal can be mathematically expressed as:

$$s_{SSB}(t) = A_c[m(t)\cos(2\pi f_c t) \mp \hat{m}(t)\sin(2\pi f_c t)]$$

where the negative sign in eqn above is used for upper sideband SSB and positive sign is used for lower sideband SSB

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Generation of SSB

- The two common techniques for generation of an SSB signal are the

  1. filter method

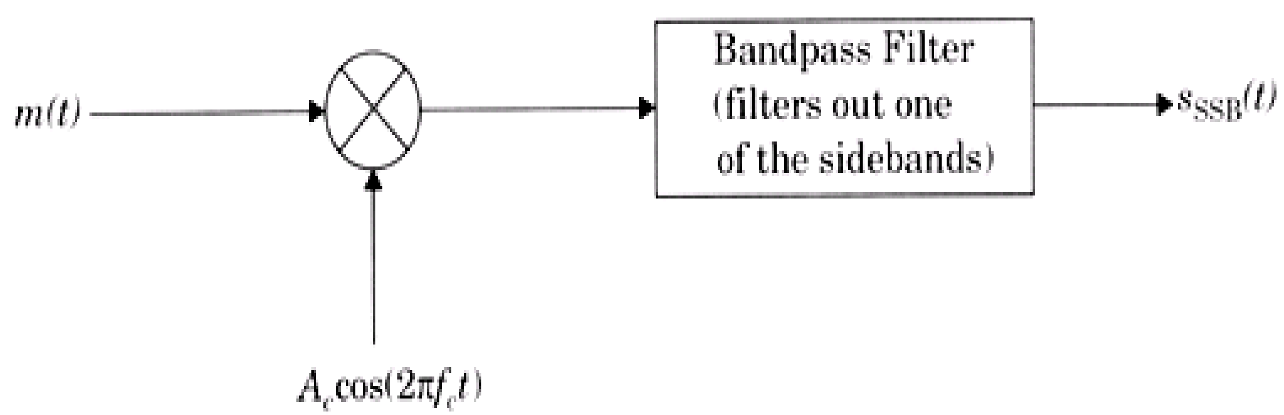
  2. balanced modulator method

-

Filter method

- In the *filter method*, SSB signals are generated by passing a double sideband AM signal through a bandpass filter which removes one of the sideband

- Excellent sideband suppression can be obtained using crystal filters at an intermediate frequency



Balanced modulator

- Balanced modulator is a direct implementation of the equation of SSB signal
- Diagram shown in next slide shows that the signal is split into two identical signals
- One of them would modulate the in-phase carrier
- Other is passed through a -90 degree phase shifter before modulating a quadrature carrier
- The sign used for the quadrature component determines whether USSB or LSSB is transmitted

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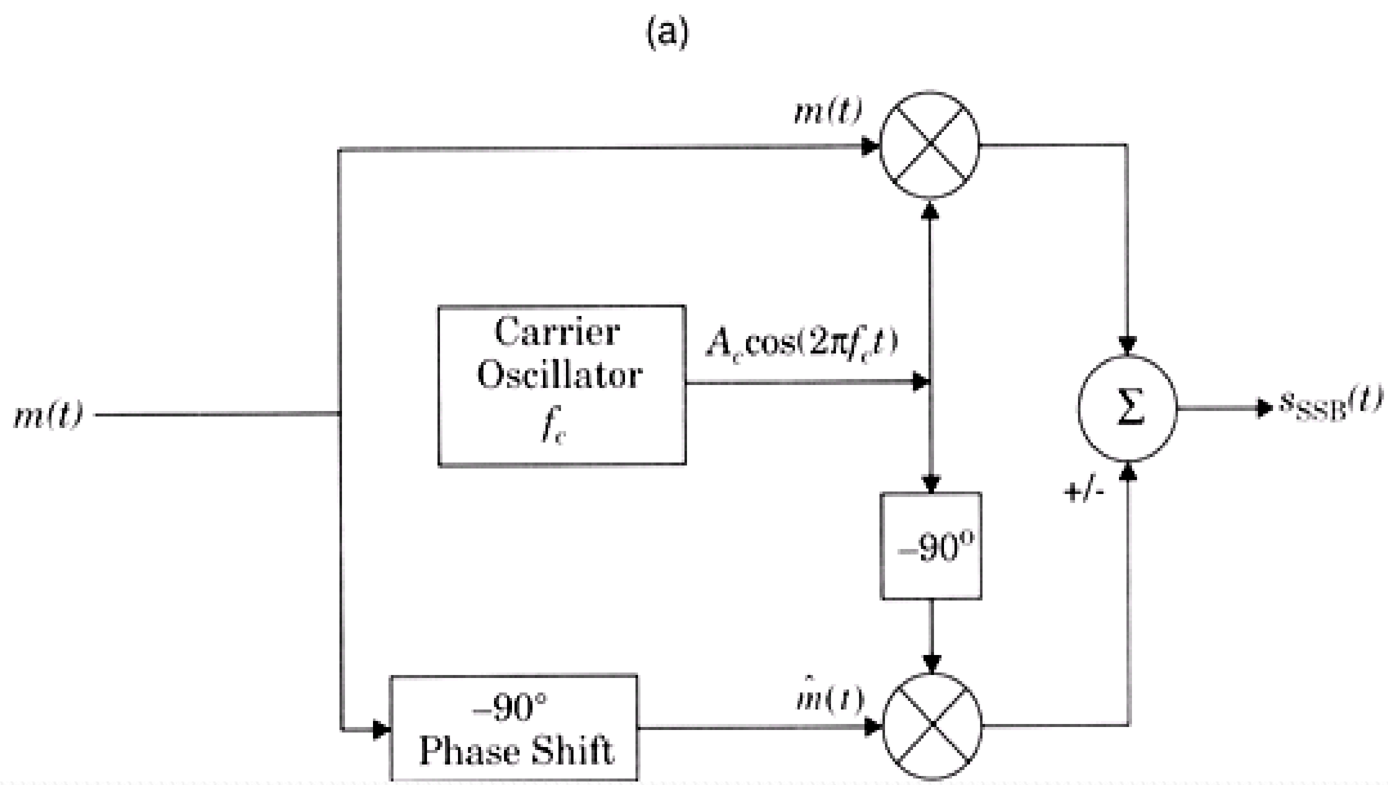
A balanced modulator



Demodulation of AM signals

- Demodualtion techniques:
  - *coherent and*
  - *non-coherent*
- *Cohrent demodulation* requires knowledge of the transmitted carrier frequency and phase at the receiver
- *Non –coherent demodulation* requires no phase information
- Practically, in AM receivers the received signal is filtered and amplified at the carrier frequency and then converted to an intermediate frequency (IF) using a superheterodyne receiver
- The IF signal retains exact information of spectral shape as the RF signal

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Product detector (*coherent)*

- A product detector is a converter circuit which converts the input bandpass signal to a baseband signal
- If the input is of the form $R(t)\cos(2\pi f_c t + \theta_r)$ (AM signal) the output of the signal can be expressed as

$$v_1(t) = R(t)\cos(2\pi f_c t + \theta_r) A_0 \cos(2\pi f_c t + \theta_0)$$

f_c –oscillator carrier frequency

θ_r and θ_0 - received signal phase and oscillator phases

- using trigonometric identities $v_1(t)$ may be written as:

$$v_1(t) = \tfrac{1}{2} A_0 R(t)\cos(\theta_r - \theta_0) + \tfrac{1}{2} A_0 R(t)\cos(2\pi f_c t + \theta_r + \theta_0)$$

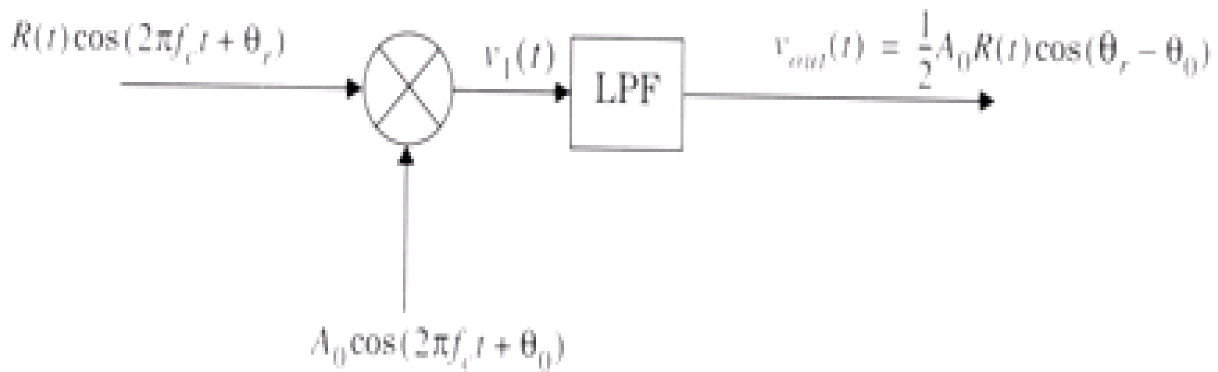
- Since the low pass filter following the product detector removes the double carrier frequency term ,the output is

$$v_{out}(t) = \tfrac{1}{2} A_0 R(t)\cos(\theta_r - \theta_0) = K\,|R(t)|$$

- where k is the gain constant

Block diagram of a Product detector

- Fig shows the block diagram of a product detector



Non-Coherent Technique

- Non coherent envelope detectors are often used in order to demodulate AM signals which are easy and cheap to build
- An ideal envelope detector is a circuit that has an output proportional to the real envelope of input signal
- If the input to envelope detector is represented as $R(t)\cos(2\pi f_c t+\theta_r)$ then the output is given by

$$v_{out}(t) = K\,|R(t)|$$

- K is gain constant

References

- Wireless communications : by Theodore S. Rappaport
- Internet

Home work 2

Write brief notes on:

- Digital cellular standard
- IS-95 system
- Standard for cordless telephone

- Date of submission: