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Communication Circuits Design

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Lecture 3.4: Frequency Modulation (FM)

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Angle Modulation (1)

- There are three parameters of a sine-wave carrier that can be varied to allow it to carry a low-frequency intelligence signal.
- They are its amplitude, frequency, and phase.
- The latter two, frequency and phase, are actually interrelated, as one cannot be changed without changing the other.
- They both fall under the general category of *angle modulation.*
- Angle modulation is defined as modulation where the angle of a sine-wave carrier is varied from its reference value.

Angle Modulation (2)

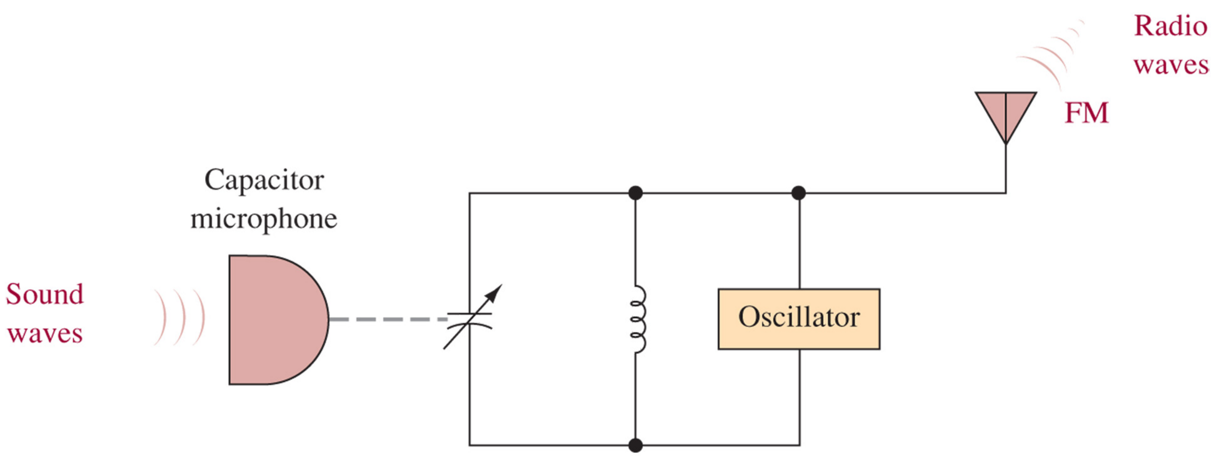
- Angle modulation has two subcategories, phase modulation and frequency modulation, with the following definitions:
  - Phase modulation (PM): angle modulation where the phase angle of a carrier is caused to depart from its reference value by an amount proportional to the modulating signal amplitude.
  - Frequency modulation (FM): angle modulation where the instantaneous frequency of a carrier is caused to vary by an amount proportional to the modulating signal amplitude.

Angle Modulation (3)

- The key difference between these two similar forms of modulation is that in PM the amount of phase change is proportional to intelligence amplitude,
- In FM it is the frequency change that is proportional to intelligence amplitude.
- As it turns out, PM is *not* directly used as the transmitted signal in communications systems but does have importance because it is often used to help generate FM, *and* a knowledge of PM helps us to understand the superior noise characteristics of FM as compared to AM systems.
- In recent years, it has become fairly common practice to denote angle modulation simply as FM instead of specifically referring to FM and PM.

FM Generator (1)

- A very simple, yet highly instructive, FM transmitting system is illustrated in Figure below.
- It consists of an *LC* tank circuit, which, in conjunction with an oscillator circuit, generates a sine-wave output.
- The capacitance section of the *LC* tank is not a standard capacitor but is a capacitor microphone.
- This popular type of microphone is often referred to as a condenser mike and is, in fact, a variable capacitor.



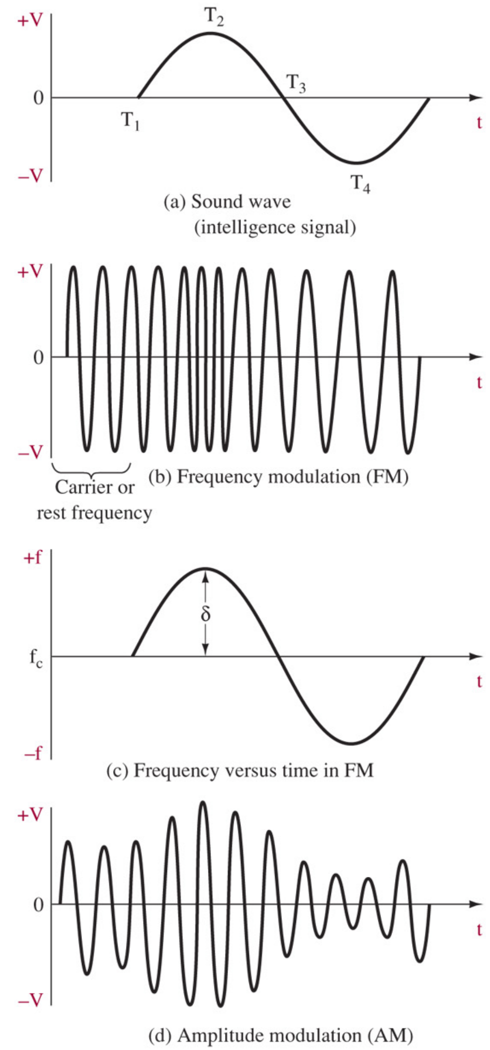
FM Generator (2)

- The *rate* of this capacitance change is equal to the frequency of the sound waves striking the mike, *and* the *amount* of capacitance change is proportional to the amplitude of the sound waves.

- Because this capacitance value has a direct effect on the oscillator's frequency, the following two *important* conclusions can be made concerning the system's output frequency:
  - The frequency of impinging sound waves determines the *rate* of frequency change.
  - The amplitude of impinging sound waves determines the *amount* of frequency change.

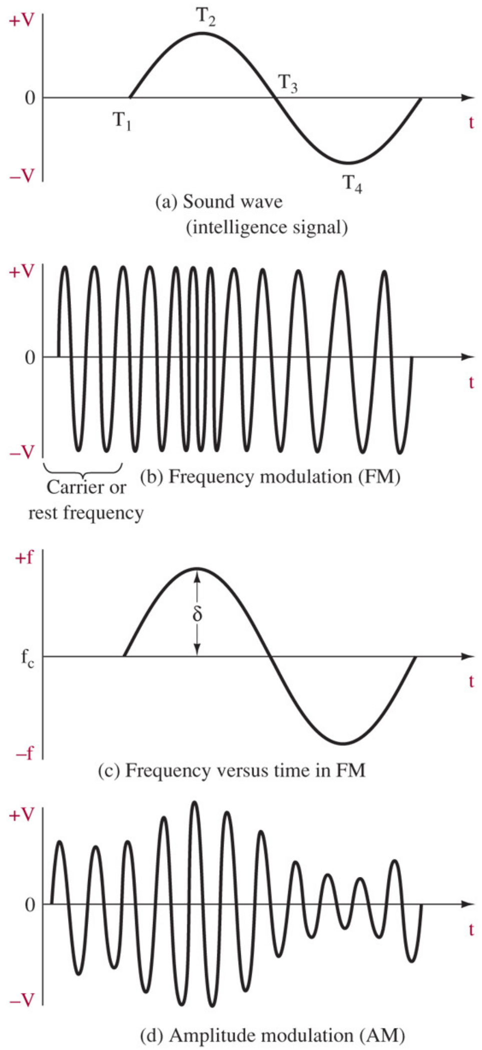
FM Representation (1)

- Consider the case of the sinusoidal sound wave (the intelligence signal) shown in Figure (a).
- Up until time T_1 the oscillator's waveform in Figure (b) is a constant frequency with constant amplitude.
- This corresponds to the carrier frequency *(f_c)* or *rest* frequency in FM systems.
- At T_1 the sound wave in Figure (a) starts increasing sinusoidally and reaches a maximum positive value at T_2.



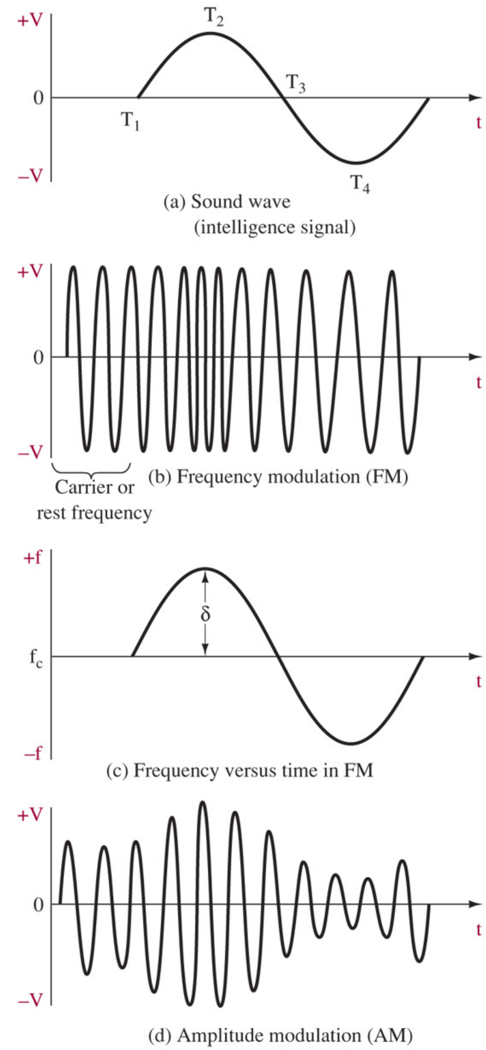
FM Representation (2)

- During this period, the oscillator frequency is gradually increasing and reaches its highest frequency when the sound wave has maximum amplitude at time T_2.
- From time T_2 to T_4 the sound wave goes from maximum positive to maximum negative and the resulting oscillator frequency goes from a maximum frequency *above* the rest value to a maximum value *below* the rest frequency.
- At time T3 the sound wave is passing through zero, and therefore the oscillator output is instantaneously equal to the carrier frequency.



Frequency Deviation

- The amount of oscillator frequency increase and decrease around f_c is called the frequency deviation, δ (delat). This deviation is shown in Figure (c) as a function of time.
- It is ideally shown as a sine-wave replica of the original intelligence signal. It shows that the oscillator output is indeed an FM waveform.
- Figure (d) shows the AM wave resulting from the intelligence signal shown in Figure(a). This should help you to see the difference between an AM and FM signal.



FM signal generator

- The relationship for the FM signal generated by the capacitor microphone can be written as:

$$f_{out} = f_c + ke_i$$

where f_{out} = instantaneous output frequency

f_c = output carrier frequency

k = deviation constant [kHz/V]

e_i = modulating (intelligence) input

- Equation above shows that the output carrier frequency *(f_c)* depends on the amplitude and the frequency of the modulating signal *(e_i)* and also on the frequency deviation generated by the microphone *(k)* for a given input level.
- The unit *k* is called a deviation constant. This defines how much the carrier frequency will deviate (change) for a given input voltage level. The deviation constant *(k)* is defined in units of kHz/V.

Point to Remember

- In FM generator:
  - The intelligence amplitude determines the *amount* of carrier frequency deviation.
  - The intelligence frequency *(f_i)* determines the *rate* of carrier frequency deviation.

Phase Modulation

- For phase modulation (PM), the equation for the instantaneous voltage is

$$e = A \sin(\omega_c t + m_p \sin \omega_i t)$$

where e = instantaneous voltage

A = peak value of original carrier wave

ω_c = carrier angular velocity $(2 \pi f_c)$

m_p = maximum phase shift caused by the intelligence signal (radians)

ω_i = modulating (intelligence) signal angular velocity $(2 \pi f_i)$

- The maximum phase shift caused by the intelligence signal, m_p, is defined as the modulation index for PM.

Modulation Index

- The following equation provides the equivalent formula for FM:

$$e = A \sin(\omega_c t + m_f \sin \omega_i t)$$

- All the terms in the PM Equation and this one are same, with the exception of the new term, m_f. In fact, the two equations are identical except for that term. It is defined as the modulation index for FM, m_f. It is equal to

$$m_f = \text{FM modulation index} = \frac{\delta}{f_i}$$

where δ = maximum frequency shift caused by the intelligence signal (deviation)

f_i = frequency of the intelligence (modulating) signal

Carson’s Rule

- Deviation and bandwidth are related but different.
- They are related because deviation determines modulation index, which in turn determines significant sideband pairs.
- The bandwidth, however, is computed by sideband pairs and not deviation frequency.
- Therefore, the deviation is *not* the bandwidth but *does* have an effect on the bandwidth.
- An approximation known as Carson's rule is often used to predict the bandwidth necessary for an FM signal:

$$\mathrm{BW} \simeq 2(\delta_{\max} + f_{i_{\max}})$$

- This approximation includes about 98 percent of the total power; that is, about 2 percent of the power is in the sidebands outside its predicted BW.

Deviation Ratio

- Another way to describe the modulation index is by deviation ratio (DR).
- Deviation ratio equals the result of dividing the maximum possible frequency deviation by the maximum input frequency, as shown in Equation:

$$\mathrm{DR} = \frac{\text{maximum possible frequency deviation}}{\text{maximum input frequency}} = \frac{f_{\mathrm{dev(max)}}}{f_{i(\mathrm{max})}}$$

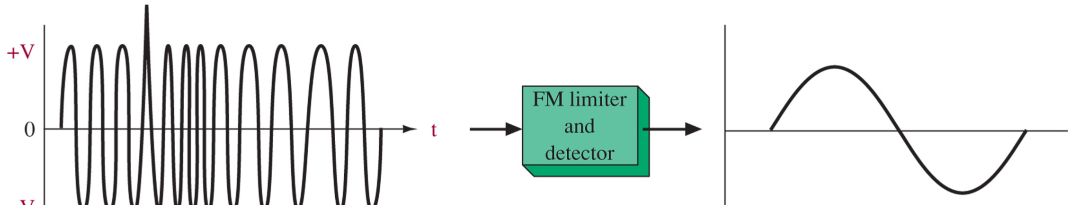
- *Deviation ratio is* a commonly used term in both television and FM broadcasting.
- FM systems that have a deviation ratio greater than or equal to 1 (DR >= 1) are considered to be wideband systems, whereas FM systems that have a deviation ratio less than 1 (DR =< 1) are considered to be narrowband FM systems.

Noise Suppression (1)

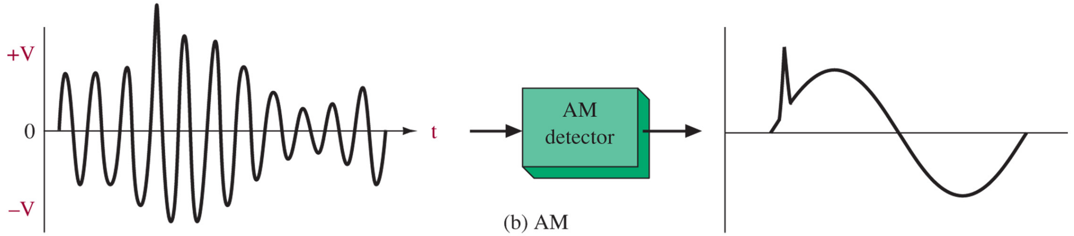
- The most important advantage of FM over AM is the superior noise characteristics.
- You are probably aware that static noise is rarely heard on FM, although it is quite common in AM reception. You may be able to guess a reason for this improvement.
- The addition of noise to a received signal causes a change in its amplitude.
- Since the amplitude changes in AM contain the intelligence, any attempt to get rid of the noise adversely affects the received signal.
- However, in FM, the intelligence is *not* carried by amplitude changes but instead by frequency changes. The spikes of external noise picked up during transmission are clipped off by a limiter circuit and/or through the use of detector circuits that are insensitive to amplitude changes

Noise Suppression (2)

- Figure (a) shows the noise removal action of an FM limiter circuit, while in Figure (b) the noise spike feeds right through to the speaker in an AM system.
- The advantage for FM is clearly evident; in fact, you may think that the limiter removes all the effects of this noise spike.
- While it is possible to clip the noise spike off, it still causes an undesired phase shift and thus frequency shift of the FM signal, and this frequency shift *cannot* be removed.



(a) FM



(b) AM

Noise Suppression (3)

- The noise signal frequency will be close to the frequency of the desired FM signal due to the selective effect of the tuned circuits in a receiver.
- In other words, if you are tuned to an FM station at 96 MHz, the receiver's selectivity provides gain only for frequencies near 96 MHz.
- The noise that will affect this reception must, therefore, also be around 96 MHz because all other frequencies will be greatly attenuated.
- The effect of adding the desired and noise signals will give a resultant signal with a different phase angle than the desired FM signal alone.
- Therefore, the noise signal, even though it is clipped off in amplitude, will cause phase modulation (PM), which indirectly causes undesired FM.

Noise Suppression (4)

- The amount of frequency deviation (FM) caused by PM is

$$\delta = \phi \times f_i$$

where δ = frequency deviation

Φ = phase shift (radians)

f_i = frequency of intelligence signal

References

- Chapter 5 & 6, Beasley and Miller, Modern Electronic Communication, 9th Edition.