Chapter 8 Objectives

At the conclusion of this chapter, the reader will be able to:

- Explain how an oscillator is modulated to produce FM.
- Calculate the parameters of an FM signal, such as spectral content and bandwidth.
- Identify the topology of an FM transmitter.
- Predict the signals at each major point in an FM transmitter.
- Describe the technical characteristics of FM stereo multiplex and SCA signals.
- Explain how to use a station monitor to verify the operation of an FM transmitter.

Chapter 8: Frequency Modulation: Transmission

In AM the voltage of the carrier signal is varied to represent the information. Because many noise sources produce amplitude disturbances, AM reception is very susceptible to them. Atmospheric noise (from lightning and other discharges) is a constant source of crackling and popping sounds in AM receivers.

Frequency modulation, or FM, was first theorized and experimented with in the 1930s. FM broadcasting on a large scale began in the late 1940s. In FM, the *frequency* of the carrier signal is changed to convey the information. The amplitude of the carrier remains constant.

There are two primary advantages to FM. First, since FM only changes the frequency, and not the amplitude of the carrier wave, FM receivers can be built to ignore amplitude (voltage) changes. Therefore, FM receivers ignore most external noise sources. Second, it is much easier to design systems to reproduce *high-fidelity* sound using FM. High-fidelity means accurate signal reproduction with a minimum of distortion. The reproduced information signal is a very close replica of the original in an FM system.

These advantages do come at a price. First, a typical FM broadcast station uses up to 200 kHz of bandwidth (compare this with the 10 kHz allotted for AM broadcast). Because of the high bandwidth requirements, FM broadcasting is done in the VHF band between 88 and 108 MHz and requires higher transmitter power. FM receivers and detectors are slightly more complex than those for AM, and the higher frequencies used for FM (VHF) complicate overall transmitter and receiver design.

For most serious music listeners, FM broadcast has become the medium of choice. AM broadcast has largely been relegated to talk radio, where high fidelity is not a serious concern.

Frequency and phase modulation (PM) are cousins. They are both considered *angle modulation.* PM directly changes the phase angle of the carrier wave to impart the information. FM indirectly changes the phase angle because it changes the frequency (which is the rate of phase change). PM is rarely broadcast directly for voice communications, but instead is used to gain an analytical understanding of FM. PM does find heavy application in digital (data) communications, the subject of a later chapter.

8-1 A Simple FM Transmitter

To create frequency modulation, the frequency of the carrier signal must be changed in step with the information signal. This suggests that the modulation process should take place at the *oscillator*. An RF oscillator's frequency can be controlled by using an LC resonant circuit, so if we can make either the L or C change in step with the information, frequency modulation will be created. Figure 8-1 shows one way of doing this. It's not an entirely practical way of building an FM transmitter, but it works!

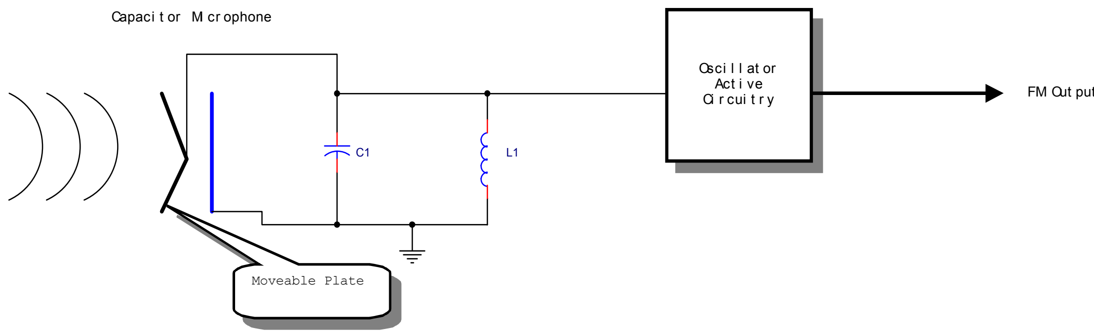

Figure 8-1: A crude FM transmitter

The circuit in Figure 8-1 has a unique type of microphone connected in parallel with the LC resonant tank circuit of the oscillator. This is a *condensor* or *capacitance* microphone. The condensor mike has two metal plates separated by an insulating air space. One of the plates is very thin (like a piece of aluminum foil) and is free to vibrate back and forth when sound strikes it. When sound strikes the moveable plate of the condensor microphone, it causes the capacitance of the microphone to change in step with the sound. Recall that the capacitance of a capacitor is given by

$$C = \frac{\varepsilon A}{d} \qquad (8\text{-}1)$$

Where ε is the *dielectric constant* of the insulating material (air in this case), *A* is the area of one of the capacitor plates, and *d* is the distance between the plates.

The vibration of the capacitance microphone's plate causes the distance between the plates to vary in step with the information. Thus, the total tank capacitance varies. Varying the tank capacitance changes the resonant frequency, which in turn changes the oscillator frequency.

In other words, the condensor microphone *frequency modulates* the oscillator circuit. When the microphone plates are closer together, the total tank capacitance increases, causing the resonant frequency to *decrease*. The opposite happens when the plates move farther apart; the total tank capacitance decreases, causing the oscillator to *increase* in frequency. Since it is the information (sound) that is causing the condensor microphone's moveable plate to vibrate, the frequency changes on the carrier will follow the information signal. Figure 8-2 shows this relationship.

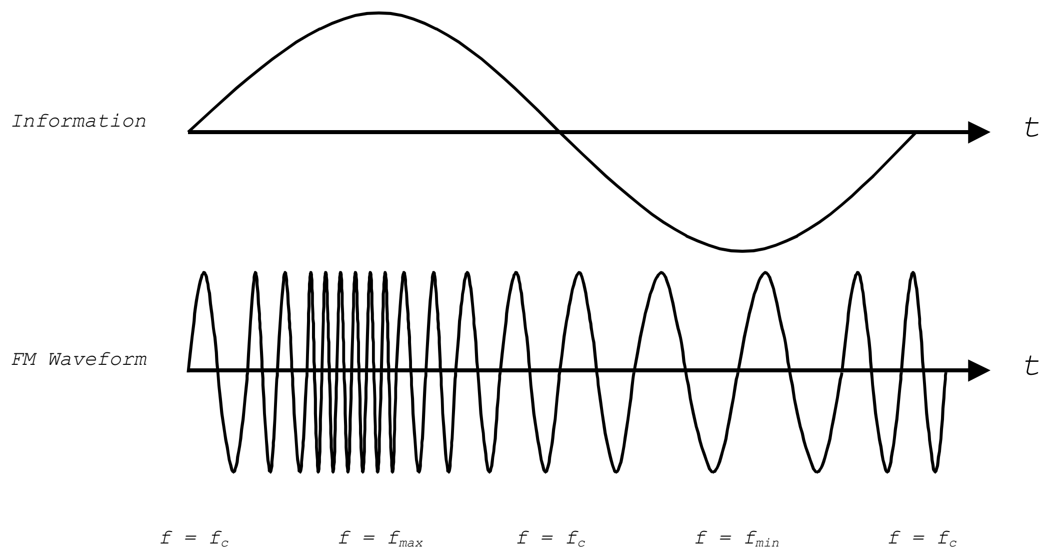

Figure 8-2: The information signal, and the resulting FM waveform

The FM waveform in Figure 8-2 has a *constant* amplitude. The only thing that is being changed is the *frequency*. When the information signal is positive, the FM signal's frequency increases. The cycles of the FM waveform are squeezed closer together here. On the negative half-cycle, the opposite happens -- we can see the FM waveform spreading out. Its period has become larger, indicating a lower frequency.

The capacitor microphone isn't a very practical method of generating FM. Because its wire leads are part of the tank circuit, moving the microphone would cause the capacitance of the tank circuit to shift, forcing the transmitter off frequency! In an actual FM transmitter, we use an electronic circuit called a *reactance modulator* to replace the condensor microphone. A reactance modulator converts a changing voltage into a changing capacitance (or inductance). This eliminates the need for the condensor microphone, and allows an intelligence voltage to modulate the transmitter. Reactance modulators will be presented in a later section.

Center Frequency and Deviation

In Figure 8-2, the FM waveform is changing frequency in step with the information signal. Whenever the information signal is passing through zero, the frequency of the waveform is equal to the *carrier frequency* of the transmitter.

The frequency produced by an FM transmitter when no information voltage is present is known by many names. Among these are the *carrier* frequency, the *center* frequency, and the *resting* frequency.

When the information signal goes to its maximum positive value, the carrier instantaneous frequency also becomes maximum. This is indicated by f_{max} in Figure 8-2. Likewise, the minimum frequency produced, f_{min}, occurs at the negative peak of the information signal.

The *deviation* of an FM transmitter is equal to the *peak* frequency change produced by the information signal. The symbol δ (the lowercase Greek letter *delta*) is often used to represent the deviation. We can calculate the deviation in one of two ways:

(8-2) $\delta = f_{\max} - f_c$

(8-3) $\delta = f_c - f_{\min}$

Both equations will give the same result. The carrier frequency normally swings equally above and below the center frequency. The deviation plays a major role in determining the *bandwidth* of an FM transmitter, so it is very useful to calculate it.

What controls the amount of deviation? Since deviation is just frequency change, we can see that the *voltage* or *amplitude* of the information must be responsible. Again, look at Figure 8-2. As the information voltage increases, the frequency increases. If the information voltage were made larger, the amount of frequency change (deviation) would increase in direct proportion. The deviation will decrease if the information voltage is made smaller. Since the voltage of the information is related to its loudness, we can say that increasing the volume of the sound at the transmitter will increase the amount of deviation produced.

The quantity of deviation is *directly proportional* to the amplitude of the information. Doubling the information voltage will double the deviation; halving the information voltage cuts the deviation in half.

Example 8-1

Suppose that the center frequency f_c in Figure 8-2 is 100 kHz, and that f_{min} = 95 kHz, and f_{max} = 105 kHz. The information signal Vm is 5 V peak.

a) Calculate the deviation, δ

b) Recalculate the deviation if the information signal is increased to 7.5 V peak.

Solution

a) Since we know both f_{max} and f_{min}, we can use eithe r equation 8-2 or 8-3. Substituting, we get:

$$\delta = f_{\max} - f_c = 105kHz - 100kHz = \underline{\underline{5kHz}}$$

b) The deviation is *directly proportional* to the information voltage. We can set up a proportion as follows:

$$\frac{Vm'}{Vm} = \frac{\delta'}{\delta}$$

Don't let this scare you! We're just saying that the *new* information voltage, Vm' (the ' mark is pronounced "prime" and means "new value") compared to the *old* information voltage, Vm, will be the same as the *new* deviation compared to the *old*.

We know Vm and Vm', and the original deviation. A little rearranging will give us:

$$\delta' = \delta\left(\frac{Vm'}{Vm}\right) = 5kHz\left(\frac{7.5V}{5V}\right) = \underline{\underline{7.5kHz}}$$

The new deviation will increase to 7.5 kHz. This will also increase the amount of frequency space, or *bandwidth* required by the FM signal. This will be one of the topics of the next section.

Section Checkpoint

8-1 Why are FM receivers largely unbothered by static?
8-2 List two advantages of FM when compared to AM.
8-3 Why does an FM broadcast transmitter require more power to provide the same coverage as an AM broadcast transmitter?
8-4 What frequency range is used for FM broadcast, and why?
8-5 List the two forms of *angle modulation*.
8-6 Where is the modulation performed in an FM transmitter?
8-7 How can a capacitor microphone help in generating FM?
8-8 How could the amplitude of an FM signal be described?
8-9 What does a *reactance modulator* do?
8-10 What are two other names for the *center frequency* of an FM transmitter?
8-11 Explain how to calculate *deviation* for an FM transmitter.
8-12 What controls the amount of deviation in an FM transmitter?

8-2 FM Signal Analysis

During the analysis of AM in Chapter 3, we looked at AM signals in both the time and frequency domains. An FM signal can be examined in the same ways. One thing we quickly discover is that an FM signal doesn't look very impressive on an oscilloscope! The frequency changes (deviation) shown in Figure 8-2 are greatly exaggerated. *You will rarely be able to directly observe the frequency deviation of an FM signal on an oscilloscope*. The amount of frequency change is fairly small when compared to the carrier center frequency. A "real life" FM signal is shown in Figure 8-3:

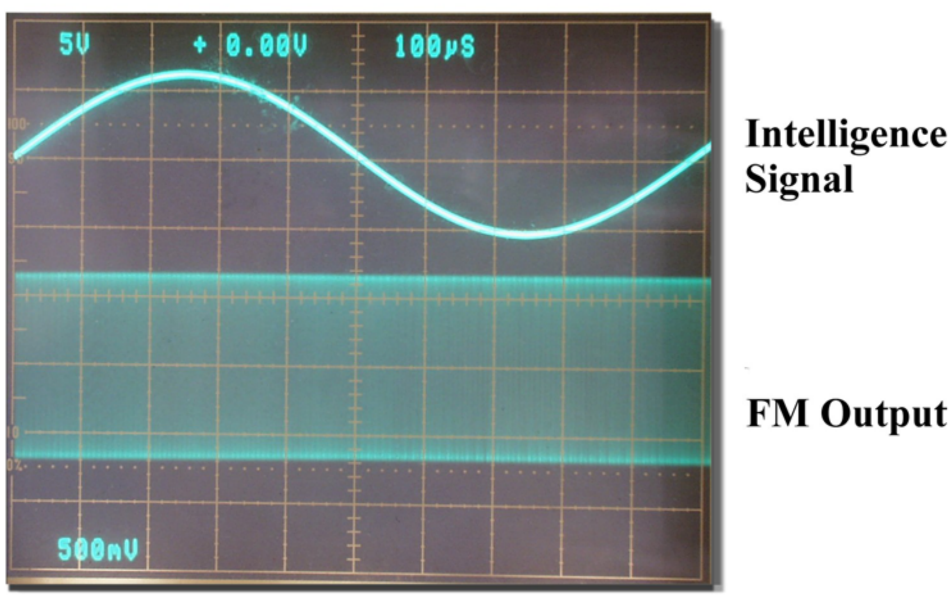

Figure 8-3: An FM signal seen on an oscilloscope (f_c = 100 kHz, δ=5 kHz)

As you might have guessed, we'll receive a lot more information by looking at an FM signal in the frequency domain with a spectrum analyzer. There are four specific quantities that a technician normally can be expected to measure or estimate in an FM signal. These are the *percentage of modulation,* the *deviation rate*, the *modulation index*, and the *bandwidth*.

Percentage of Modulation

In AM, the percentage of modulation is a practical measure of how much information voltage is being placed on top of the carrier. The more information voltage, the louder the sound in the receiver. The definition holds the same practical meaning for FM, but the formula for calculating it is different. For FM, percentage of modulation is defined by

(8-4) $$\%MOD = \left(\frac{\delta}{\delta_{\max}}\right) \times 100\%$$

In Equation 8-4, δ is the deviation of the transmitter, and δ_{max} is the maximum allowed deviation for the particular type of FM transmission being used. For broadcast FM, δ_{max} is 75 kHz. For the sound portion of an analog TV signal, an FM carrier is used, with a δ_{max} of 25 kHz. Communications FM (such as emergency services and amateur radio) commonly uses a δ_{max} of 5 kHz. *To calculate FM percentage of modulation, you must know the maximum allowed deviation!*

You might wonder why "communications" applications use such a small amount of deviation when compared to FM broadcast. High-fidelity isn't a strong design goal for voice communications. Instead, a large number of users must share a fixed amount of RF spectrum (frequency space). By lowering deviation, the bandwidth required for each transmitter is reduced -- and therefore, more transmitters can share the airwaves.

Example 8-2

An FM broadcaster is operating on 98.1 MHz, and the maximum frequency from the transmitter is 98.15 MHz. The information voltage is 5 Vp, and the information frequency is 1 kHz.

a) What is the percentage of modulation?

b) If the information voltage is changed to 4 Vp, what happens to the percentage of modulation?

c) What information voltage will 100% modulate the transmitter?

Solution

a) To calculate percentage of modulation, we must first know deviation:

$$\delta = f_{\max} - f_c = 98.15MHz - 98.1MHz = \underline{50KHz}$$

Since this is an FM broadcast (88 - 108 MHz), we know that the maximum deviation is 75 kHz. Therefore:

$$\%MOD = \left(\frac{\delta}{\delta_{\max}}\right) \times 100\% = \left(\frac{50KHz}{75KHz}\right) \times 100\% = \underline{\underline{66.7\%}}$$

b) The information voltage controls the deviation. Since the voltage has *decreased* to 4 Vp, we can expect the amount of deviation to decrease in a like manner:

$$\delta' = \delta\left(\frac{Vm'}{Vm}\right) = 50KHz\left(\frac{4Vpk}{5Vpk}\right) = \underline{40KHz}$$

This isn't exactly the answer that was needed; we need to express it as a percentage of modulation:

$$\%MOD = \left(\frac{\delta}{\delta_{\max}}\right) \times 100\% = \left(\frac{40KHz}{75KHz}\right) \times 100\% = \underline{\underline{53.3\%}}$$

c) This is a rather "backwards" request, but it is quite solvable. Remember that 100% modulation is 75 kHz (the deviation we desire), and substitute that into the proportion for deviation:

$$\frac{Vm'}{Vm} = \frac{\delta'}{\delta}$$

Here Vm' is the new (unknown) information voltage, δ' is the new (desired) deviation, and *Vm* and δ are the original values. By manipulating the equation, we get:

$$Vm' = \left(\frac{\delta'}{\delta}\right)Vm = \left(\frac{75KHz}{50KHz}\right)5Vp = \underline{\underline{7.5Vp}}$$

Therefore, an information voltage of 7.5 Vp will be required to 100% modulate the transmitter.

Deviation Rate

The *deviation rate* (DR) of an FM transmitter is the number of up and down frequency changes (swings) of the RF carrier that take place per second. It is always the same number as the *information frequency*.

Suppose that we send a very low information frequency, 1 Hz into an FM modulator. The carrier will swing up to its maximum frequency, down to its minimum frequency, then back to center again exactly *once* every second.

If the information is increased to 2 Hz, then the carrier frequency changes will take place *twice* per second. It doesn't matter what the information voltage is. Only the *frequency* of the information is important.