Chapter 9 Objectives

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

- Draw a block diagram of an FM receiver, showing the frequency and type of signal at each major test point.
- Explain the operation and alignment of Foster-Seeley/Ratio, PLL, and quadrature FM detector circuits.
- Describe the features of noise-suppressing circuits in an FM receiver.
- Draw a block diagram of a frequency-synthesized FM receiver.
- Trace the signal flow through FM stereo and SCA decoder circuits.
- Describe the alignment procedures unique to FM receivers.
- Apply basic troubleshooting methods to FM receivers.

Chapter 9: FM Receivers

FM is popular as a communications mode because of its superior noise performance and fidelity, when compared to AM. The operation of AM and FM receivers is very similar; the same familiar circuit techniques are used in both. The primary differences in an FM receiver stem from the relatively high frequencies used for FM transmission (the VHF and UHF bands), and the differences in detector circuitry. FM receivers tend to be more "feature-laden." The addition of circuitry to support FM stereo, SCA, and other features adds complexity to the set.

FM is a fundamental technology, like AM. Its techniques are used in satellite and data communications, telemetry (remote measurement), and a score of other non-broadcast applications. A technician with a strong knowledge of FM can go far in communications!

9-1 FM Superheterodyne Receivers

FM receivers use the superheterodyne principle, as shown in Figure 9-1. Recall that a superhet receiver operates by converting the desired incoming RF carrier frequency down to the *IF* or *intermediate frequency*, where most of the amplification is provided and receiver bandwidth is defined. The sections of the receiver that are new or different compared to an AM receiver are in blue.

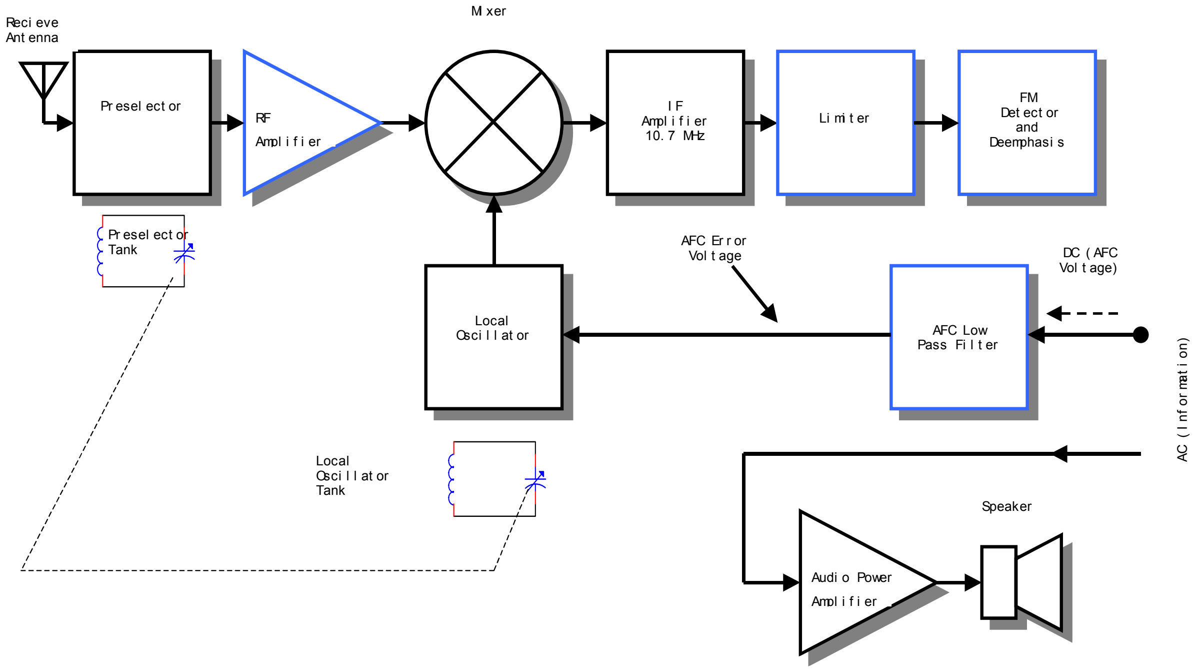

Figure 9-1: An FM superheterodyne receiver

An FM receiver contains several stages that are new or different from those in an AM set. These include the *detector*, *limiter*, *RF amplifier,* and *AFC stages.*

FM Detector

Naturally, detecting an FM signal requires different circuitry than that for demodulating AM. There are several popular types of FM detectors. All them can be thought of as *frequency to voltage converters.* That is, they take a varying input frequency (a frequency-modulated carrier wave) and convert that into a varying output voltage. This is exactly the opposite of the action of the modulator in an FM transmitter, so the output of an FM detector is a replica of the original information signal.

Limiter

In FM the information is encoded by changing the frequency of the carrier wave. Ideally, the carrier wave amplitude remains constant; in other words, the transmitter does not amplitude-modulate the carrier, and the envelope carries no information.

However, between the transmitter and receiver are various sources of external noise, such as atmospheric noise and man-made noise sources. These noise sources add at random to the voltage of the FM signal envelope, as shown below in Figure 9-2(a). An AM receiver is affected quite strongly by noise because an AM receiver recovers the envelope of the modulated wave. Not so with FM!

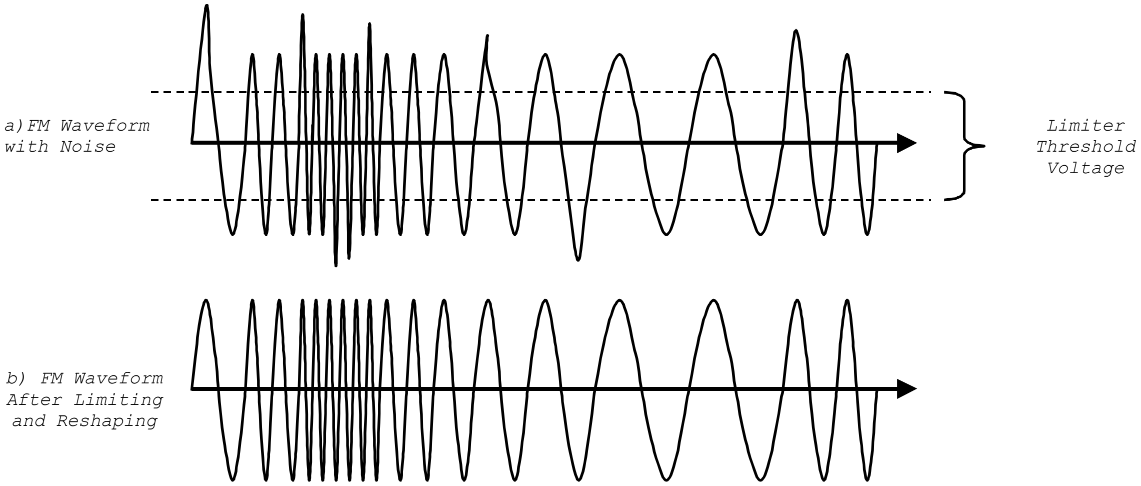

Figure 9-2: An FM signal before and after limiting

Because an FM signal contains information only in the wave's frequency, an FM receiver can safely ignore all amplitude changes without losing any information. The *limiter* in an FM receiver is a stage that essentially flattens the top and bottom of the modulated waveform prior to detection, as shown in Figure 9-2(b).

Flattening or clipping the waveform eliminates most of the noise, but preserves the information. This is why FM reception is virtually free of all sorts of static interference, even in the immediate presence of very strong noise signals (thunderstorms, nearby electric motors, and so on). Because the limiter removes most of the amplitude changes, the detector sees only frequency changes in the modulated waveform, and therefore, the output of the detector is only the original information signal.

RF Amplifier

In an AM broadcast receiver, there is seldom an RF amplifier in the front end. In an FM broadcast receiver, an RF amplifier provides two important actions, *amplification* and *local oscillator energy suppression.* The signal from the antenna in a VHF receiver (such as an FM broadcast receiver) can be very tiny. A "strong" signal may be only 50 µV, and often signals are only a few microvolts in strength. This is due to the high frequencies (VHF and UHF) that are being used, combined with the small antennas employed for reception at these frequencies (recall that wavelength and antenna size decrease as frequency increases). When such a small signal is mixed with the local oscillator (for conversion down to the IF frequency), it can be easily lost in the noise from the mixer. The mixer adds a considerable level of *internal noise* to signals that pass through it. In an AM broadcast receiver, this is not a problem; signal levels at the antenna are in the hundreds of microvolts. An RF amplifier is not needed. *The RF amplifier provides sufficient gain for the incoming RF signal to overcome the noise floor of the mixer*. The noise floor of the mixer is the noise power level, in dBm (decibels with respect to 1 mW) , that the mixer produces by itself with no RF input from the antenna.

The RF amplifier serves a second purpose: *local oscillator energy suppression.* The local oscillator in a receiver operates at a typical power level of 0 dBm (1 mW) to 10 dBm (10 mW). This doesn't sound like much energy, but think about what could happen if the local oscillator's output were coupled to an antenna. The receiver would become a *transmitter*! The wavelength at VHF is short compared to the MF frequencies used for AM broadcast. This means that even the telescoping rod antenna of a portable receiver can be a fairly effective transmitting antenna. If the local oscillator energy is allowed to couple to the antenna, the receiver can become quite a potent interference source. *The RF amplifier prevents local oscillator reradiation by allowing signals to flow in only one direction, from the antenna to the mixer circuit.* This prevents most of the energy from leaving the receiver.

Example 9-1

What is the wavelength of a 100 MHz FM broadcast signal? Compare this to the length of a typical rod antenna (20").

Solution

From Chapter 1, we know that:

$$\lambda = \frac{v}{f} = \frac{3 \times 10^8 M/S}{100MHz} = \underline{\underline{3meters}}$$

To compare these lengths, let's convert the wavelength into inches:

$$\lambda_{inches} = \lambda_{meters} \times \frac{39.37"}{1M} = 3M \frac{39.37"}{1M} = \underline{\underline{118.11"}}$$

Only about one-quarter of a wavelength is needed for an antenna to be an efficient radiator. One quarter of 118.11" is $\underline{\underline{29.5"}}$. You can see that the rod antenna isn't nearly this long, but it is in the ballpark (20"), and therefore could radiate significantly! (We will discuss the theory of antennas in much more detail in a later chapter.)

AFC Stages

The local oscillator in an FM receiver operates at very high frequencies. Before the advent of frequency synthesizers, the frequency of the local oscillators in FM receivers was controlled by discrete LC resonant “tank” circuits, just like in an AM receiver. Using an LC tank allows the oscillator to drift off frequency, and as luck would have it, drift becomes much more difficult to control in a VHF oscillator. In addition, receiver frequency drift rapidly degrades the quality of FM reception. The signal becomes distorted quickly as tuning degrades. *The automatic frequency control or AFC system is built into analog FM receivers to correct local oscillator drift.* The receiver local oscillator is essentially frequency-locked onto the carrier frequency from the transmitter, which is crystal controlled.

The AFC control voltage is developed at the FM detector, which is a frequency-to-voltage converter. As the receiver drifts off frequency, a positive or negative DC voltage is produced at the FM detector. This DC voltage is fed back to the local oscillator, which pushes the local oscillator back in the correct direction. A low-pass filter is included so that only steady DC is sent back to the local oscillator circuit. The local oscillator contains a *reactance modulator*, not shown in Figure 9-1, which converts the DC AFC voltage into a varying capacitance or inductance, which corrects the oscillator frequency. The AFC system operates almost exactly like the control method in a Crosby FM transmitter.

Many modern receivers are *digitally synthesized*. They lack the mechanical tuning capacitors of older sets; instead, they sport keypads, buttons, and digital frequency displays. In synthesized receivers, there is no need for AFC, since the local oscillator is actually a PLL or DDS frequency synthesizer, and is locked to a stable quartz frequency reference.

Choice of IF Frequency

There's one other difference between AM and FM receivers that you may have already noticed. The standard IF frequency for AM is 455 kHz, and FM it is 10.7 MHz. Why is a higher IF frequency used?

Recall from Chapter 8 that the bandwidth allocated for each FM broadcast station is 200 kHz, including guard bands. An AM broadcast uses only 10 kHz. FM uses a *lot* more bandwidth than AM! By raising the IF frequency, the IF bandwidth increases accordingly. Accomodating a 200 kHz-wide signal in a 455 kHz IF would be tough!

In general, the wider the bandwidth of the receiver, the higher the chosen IF frequency will be.

Example 9-2

Calculate the range of local oscillator frequencies required for an FM broadcast receiver (88.1 to 107.9 MHz) with an IF of 10.7 MHz, assuming high-side injection.

Solution

From Chapter 5, we know that when high-side injection is being used:

$$f_{LO} = f_c + f_{IF}$$

So this same relationship will be applied at bottom and top of the FM broadcast band. At the bottom of the band, we get:

$$f_{LO(MIN)} = f_c + f_{IF} = 88.1MHz + 10.7MHz = \underline{\underline{98.8MHz}}$$

And at the top of the band:

$$f_{LO} = f_c + f_{IF} = 107.9MHz + 10.7MHz = \underline{\underline{118.6MHz}}$$

118.6 MHz falls within the *aviation* band. This is one reason why you can't play a portable FM radio onboard a commercial aircraft. The local oscillator energy may leak out and interfere with the sensitive communication receivers onboard the plane!

Annoy your Friends!

Even though an FM receiver uses an RF amplifier to prevent local oscillator energy leakage, a tiny amount of RF *does* leak out of an FM receiver. You can easily demonstrate this by "listening" to the local oscillator of a receiver with a second receiver. Analog sets in plastic cases work best:

1) Place the two receivers close together (a few inches is best).
2) Tune one receiver to a blank spot *high* on the FM dial (such as 107.3 MHz).
3) Tune the second receiver *10.7 MHz below* the frequency of the first (96.6 MHz, for example). This is the "transmitter."

If your second receiver is a good "leaker," you'll hear the sound of *dead air* in the first receiver. The local oscillator is an unmodulated carrier, after all!

Feeling adventuresome? If you've picked up the carrier, *carefully* turn up the volume on the first receiver (107.3 MHz) and at the same time, tap on the case of the second unit. What do you hear, and why?

No Need for AGC

FM receivers don't respond to amplitude variations, thanks to the operation of the limiter circuitry. Because the relative amplitude of the signal going into the limiter and detector is unimportant, most FM receivers don't have any automatic gain control (AGC) circuitry. The exceptions to this rule are certain communications-grade FM receivers that must operate over a very wide range of antenna signal voltages. In these receivers, a modified AGC called *delayed AGC* or *DAVC* is often used.

Section Checkpoint

9-1 What type of receivers are used for both AM and FM?
9-2 An FM detector converts ________ into ________.
9-3 What is the purpose of the *limiter* in an FM receiver?
9-4 Give two reasons for the use of an RF amplifier.
9-5 Why is AFC needed in analog FM receivers?
9-6 What type of receivers don't require AFC?
9-7 What governs the choice of IF frequency in a receiver?
9-8 Why isn't AGC used in FM receivers?