Intro to Superhets

Part 2: From oscillators to detectors.

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This is the second part in the series on the introduction to superheterodyne receivers. The first part covered the history of the receiver's development and began a discussion of the stages within the receiver. The next stages to be discussed now begin with the oscillator and end with detectors. Part 3 will discuss some of the more popular accessory circuits used with superhet receivers.

Oscillator

The purpose of an oscillator is to provide a local signal to beat against (mix with) the incoming signal at the mixer to provide superheterodyning action. There are many different types of oscillators and they fall into basically two categories: fixed and tunable. Fixed oscillators may be crystal-controlled, synthesized PLL, or direct digital synthesized. The objective is to provide a very stable oscillator signal. And, if synthesized, it will usually be adjustable to a multiple number of discrete frequencies.

A tunable oscillator is of the type used in low-end broadcast and FM radios. The oscillator is free-running and varied in frequency by changing either the tuning capacitance or inductance. The objective of using a tunable oscillator in a modern receiver is to accommodate low cost and compactness, and perhaps to be less complicated than utilizing a synthesizer.

One of the specific requirements of the oscillator is to provide a stable signal free of distortion. This means that the oscillator waveform must be as close to a sine wave as possible. Should distortion be present in the oscillator output, the signal would create multiple mixes generating many spurious signals. The IF would be flooded with a series of spurious signals resulting in mixes which would confuse the listener, should they propagate through the receiver. In any case, the spurious signals would increase the receiver-generated noise which could mask a desired incoming signal.

IF amplifier

More and more signals are being transmitted each day as the need for communication increases. With only a given amount of frequency spectrum available, it is necessary to crowd these signals close together to make room for others. The receiver must select the desired signal and reject all others.

To do this, the IF amplifier in the receiver must have a narrow passband to allow only a narrow range of frequencies to pass. Multiple-tuned resonant circuits, ceramic and crystal filters, and mechanical filters are the methods used for narrowing the passband.

The property of a receiver to pass a narrow range of frequencies is called selectivity. The selectivity of an IF amplifier is a measure of the total response of all of the tuned circuits in the amplifier. A typical IF response curve is shown in **Fig. 1**. The broadness of the peak portion of the curve for each tuned circuit depends upon its

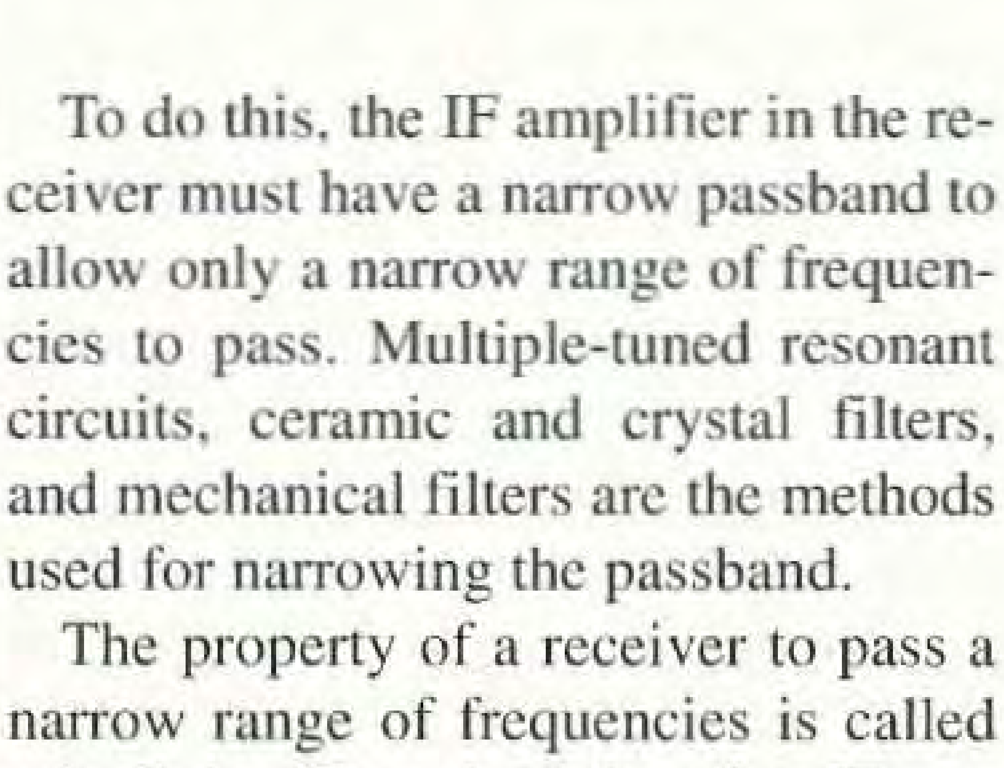

Fig. 1. *IF response curve showing where bandwidth is measured at 6 dB points as a function of voltage levels.*

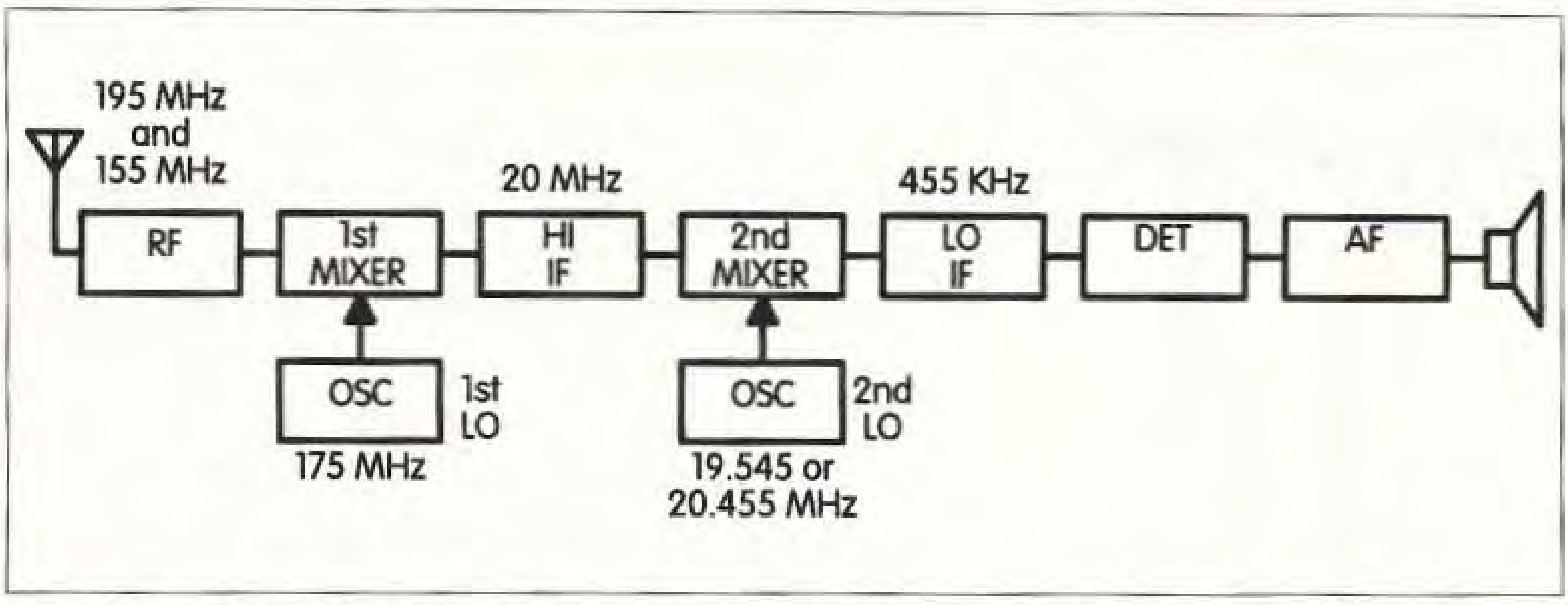

Fig. 2. Dual-conversion superheterodyne receiver showing desired and image signal inputs. Alternate second local oscillator frequencies are shown.

Q factor. In general, the response of a tuned circuit is given approximately by the relation:

$$\text{Bandwidth (kHz)} = \frac{\text{Tuned frequency (kHz)}}{\text{Q of tuned circuit}}$$

The sensitivity of an IF amplifier is determined by measuring the signal-to-noise ratio. In the past, the sensitivity was determined by comparing the signal level to noise quieting with the result indicated in decibels, but signal-to-noise ratio is more definitive as a measure of sensitivity.

For the IF amplifier to perform properly, it should have sufficient gain to amplify the weak signal output from the mixer to a level sufficiently high to drive a detector. Consider the fact that an IF theoretically could function with a gain of perhaps one, and doing so might not generate any noise that would contribute to the masking of an incoming signal.

The question arises then as to how the signal amplitude could be raised to be usable by the receiver operator. If the signal is sufficiently strong to be detectable, the increase in desired amplitude could be accomplished all in the audio amplifier, where noise generation is reasonably easy to control. Although this concept holds some promise, it is typical to have considerable signal gain in the IF amplifier because some detector circuits are very dependent upon the incoming signal level being above a threshold value for that detector to function.

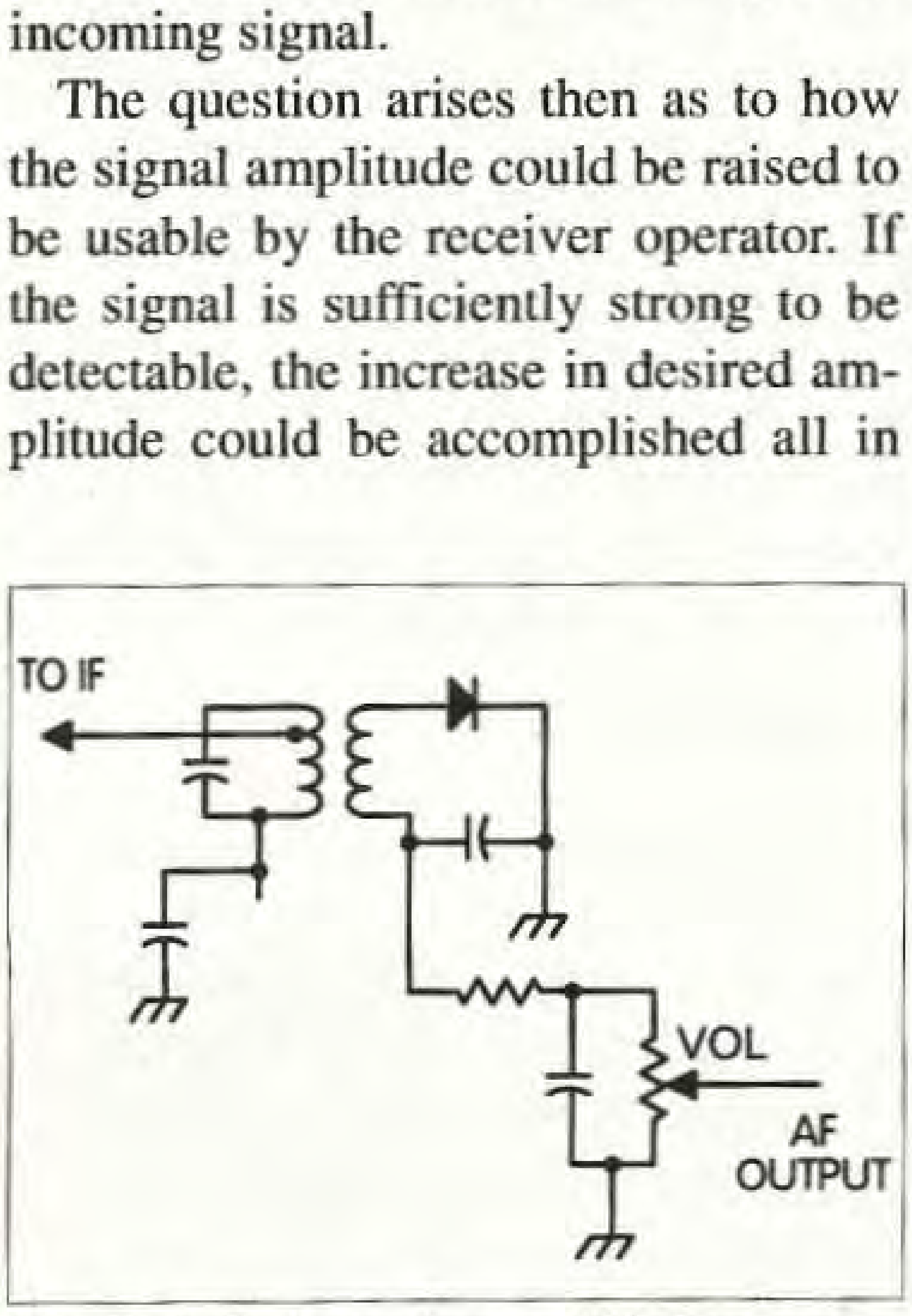

Fig. 3. A diode used as an AM detector.

Selection of the proper IF amplifier frequency is important and is the decision of the receiver designer. If the IF passband is too narrow, a tunable receiver will be difficult to tune; if too wide, the receiver may not be selective enough. There are many standard frequencies that have been used over the years for the IF, with 455 kHz and 10.7 MHz being very common. Should a low-frequency IF be selected for, say, a VHF/UHF receiver, the potential for images is very high, causing severe interference problems. By raising the IF amplifier frequency, the interference can be reduced and possibly eliminated. However, the bandwidth of the receiver will be increased and may allow adjacent channel signals to enter the receiver.

The receiver should have multiple conversions, to obtain image rejection and to achieve a narrow passband. If two conversions are utilized, the receiver is called a double conversion receiver. This is shown in **Fig. 2**. The receiver has a desired input frequency of 155 MHz and a first IF of 20 MHz. The oscillator frequency is placed above the input signal to eliminate images from aircraft at 115 MHz. With the oscillator at 175 MHz, the image would be at 195 MHz. The high frequency first IF stage places the image

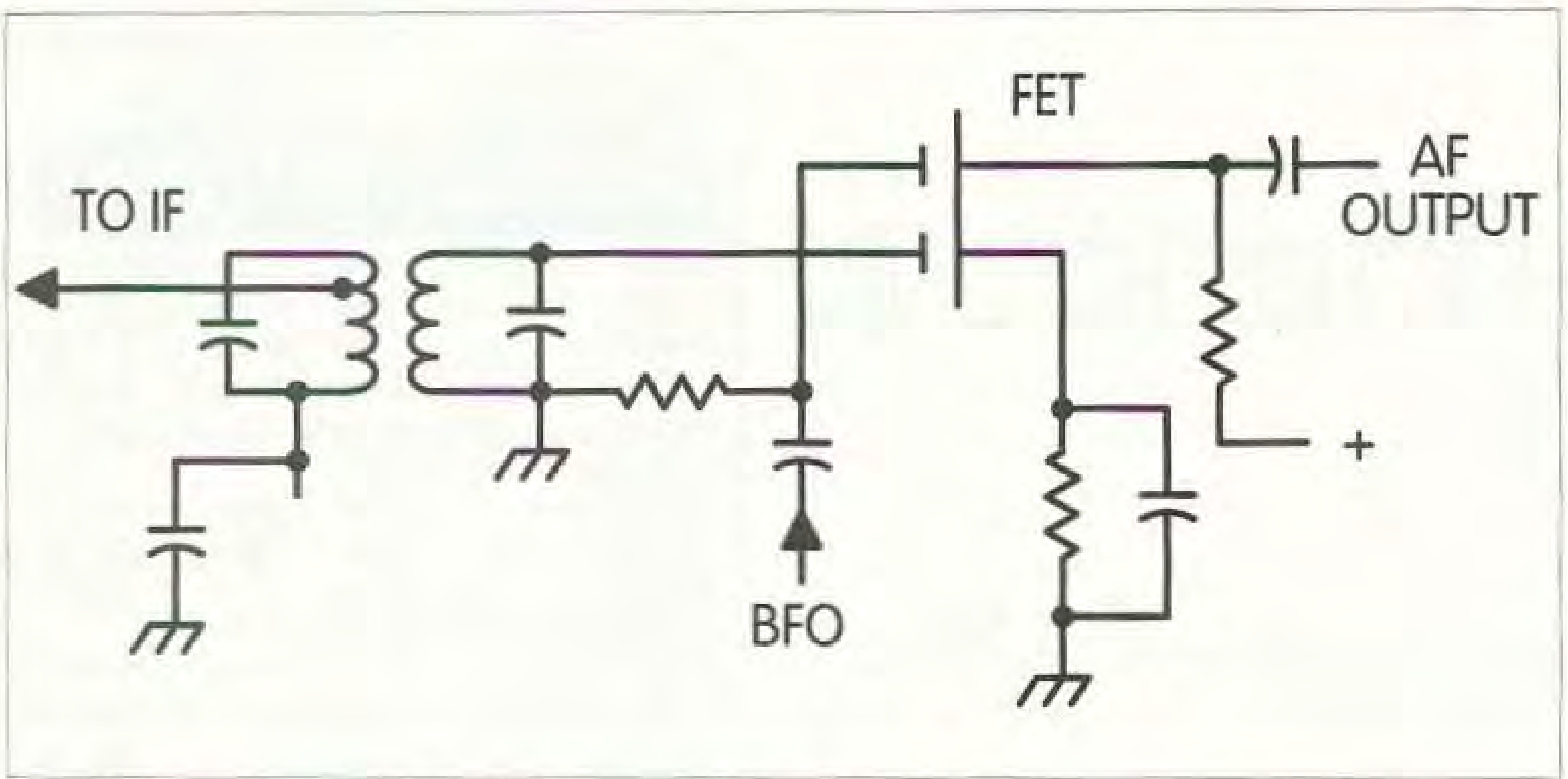

Fig. 4. A product detector implemented with a dual-gate FET.

40 MHz away from the desired incoming signal and essentially eliminates the image completely. Then, to obtain selectivity in the receiver, a low-frequency second IF at 455 kHz is used. The second conversion converts the 20 MHz signal to 455 kHz by beating the 20 MHz signal against a low-frequency oscillator of either 19.545 or 20.455 MHz.

The low-frequency oscillator may be placed above or below the high IF amplifier frequency. The only concern here is whether the harmonic of the low-frequency oscillator signal creates an interference problem at the receiver's input of 155 MHz. The eighth harmonic of the 19.545 MHz frequency is 156.36 MHz, which is 1.36 MHz away from the desired input at 155 MHz and little, if any, interference would occur. But if interference *should* occur, the 20.455 MHz frequency would be considered as an alternate following the same analysis.

After the high-frequency IF moves the image outside of the receiver's front end passband, the low-frequency IF is then used to narrow the passband to provide the desired selectivity.

Converting RF from one frequency to another has become the norm in receiver design, but there is a simpler design that is currently being used with success in the ham bands. The receiver is a direct conversion superhet that converts the RF directly to audio. Direct conversion eliminates the IF amplifier, but does generate a new set of problems requiring resolution. One of the major issues is having the oscillator (LO) operating essentially at the same frequency as the incoming signal. As a result, the LO output must be isolated from the incoming signal path. When used as a CW receiver, the LO doubles as the BFO.

Some nonsynthesized ham band receivers use a crystal-controlled first oscillator that is switched to achieve various bands and/or band sections. Each band/section is tuned by tuning the frequency of the second conversion oscillator. The objective of crystal-controlling the first conversion and tuning the second is to provide stability in the first converter and bandspread capability with the second.

In the past, when the receiver was to be used to receive FM signals, the last stage or two of the IF operated as an amplitude limiter to effectively remove any amplitude variations in the received signal, providing FM with a relatively noise-free performance. Limiter action was created by operating the stage at a high gain and having a low signal saturation threshold. When a signal was received, the limiter would create a DC bias relative to the strength of the incoming FM signal. The DC bias on the input would reduce the dynamic range of the stage, causing it to limit its amplitude response. In other words, the output amplitude remained fairly constant over a fairly wide range of input signal amplitude variations. Since most noise creates a voltage amplitude change, the limiter was effective in stripping the noise off the incoming signal. The limiter was required specifically when the FM detector was a Foster-Seeley discriminator, which was sensitive to both amplitude and frequency signal changes. Other types of FM detectors tend to be self-amplitude-limiting, which eliminates the requirement for having IF amplifier limiters.

However, one of the effective features of using an IF amplifier limiter is that all signals reaching an FM detector will be of equal amplitude. When the signal amplitude to the detector is a constant, the recovered audio level is then a function of the frequency deviation. For the user, this is important because all received signals from a specific service would tend to sound equally loud. Unlike FM, signals received by an AM receiver will have an audio recovery that is dependent both upon the strength of the received signal and the percentage of modulation used. Automatic gain control (AGC), originally called automatic volume control (AVC), was utilized to assist in keeping the recovered audio level at a near-constant value by attempting to control the sensitivity of the overall receiver through individual stage gain control.

Detectors

In the discussion of receivers up until now, little concern had been expressed regarding the type of modulation that exists on the received signal (carrier). Each transmitted signal has a carrier (present or suppressed) that has been modulated in order to transfer intelligence from the transmitter to the receiver. The purpose of the detector is to demodulate the received signal and recover the modulation. To gain an understanding of how the detector functions, let's discuss typical detectors for each modulation type.

AM detector

An AM detector is perhaps the simplest of all detectors, consisting simply of a diode (see **Fig. 3**). The diode operates as a half-wave rectifier, rectifying all signals that appear at the output of the IF amplifier. The detected output follows the modulation envelope of the received signal. Once the signal arrives at the detector, the carrier is no longer required and is separated from the modulation to leave just the audio. To perform this operation, an RC filter is used, usually consisting of two capacitors and a resistor. The filter is typically also used as the de-emphasis network that reshapes the recovered audio to make it sound normal. Without the de-emphasis network, the audio would sound "brilliant" with an overabundance of highs. During the transmission of AM signals, the higher audio frequencies tend to be less emphasized than the lower frequencies. As a result, it is necessary to increase the amplitude of the higher audio frequencies through pre-emphasis to make up for the loss during transmission. After filtering out the carrier, the recovered modulation is an audio voltage that has been reshaped to match the audio entering the transmitter's microphone.

Although the diode detector was most suitable for AM, it could also be used for slope detecting FM. One of the difficulties of slope detection is the loss of audio amplitude as the signal deviation approaches the bandwidth of the IF, creating distortion in the recovered audio.

Product detector

In the case of single sideband (SSB), the carrier and one set of modulation sidebands are intentionally suppressed at the transmitter, leaving only one set of sidebands to be transmitted. When the signal arrives at the receiver, the carrier must then be restored in order to demodulate the sideband properly. Restoration of the carrier is accomplished by using a local oscillator for "carrier reinsertion." All of the transmitted intelligence is carried in one set of sidebands, which permits the suppression of one set at the transmitter. In addition, no intelligence is transmitted in the carrier; therefore, suppressing the carrier and one sideband allows all of the available transmitter power to be applied to the one transmitted sideband.

Another form of amplitude detector, as shown in **Fig. 4**, is the product detector used for demodulating an SSB signal. There are many different circuit designs available for use. The name "product" comes from the fact that two incoming signals are multiplied together to form the resulting output. One of the incoming signals is the local oscillator used for carrier reinsertion, and the other is the received signal exiting the IF. The carrier reinsertion level is fixed in amplitude and, essentially, added to the incoming modulation envelope of the SSB signal. The resulting output is an audio voltage that follows the modulation envelope pattern of the transmitted signal.

There are many differing designs for a product detector, but each does essentially the same job in the demodulation process. Of concern is that the local-carrier amplitude be as high as possible in order to minimize intermodulation distortion products, yet isolation is essential in preventing the oscillator signal from feeding back into the IF.

As in the AM detector, all RF signal energy must be removed before the audio is presented to the audio amplifier. An RC filter is used for this purpose.

FM detectors

An AM detector may be used to detect FM, but the performance of the receiver would be poorer than if an FM detector were used. An FM detector is somewhat more complex than an AM detector, and there are many available. Each operates on the principle of converting a changing frequency (deviated signal) to an amplitude-changing voltage, where the method of detection may relate to an amplitude change as a function of frequency, a phase shift, or a detection of the actual frequency shift. To see how each type functions, let's examine a few of the typical detectors used over the years of receiver development.

Foster-Seeley discriminator

A Foster-Seeley discriminator as shown in **Fig. 5** was the staple of FM detectors for a long period of time. It was really a takeoff on the AM detector from the standpoint that it is sensitive to both amplitude and frequency

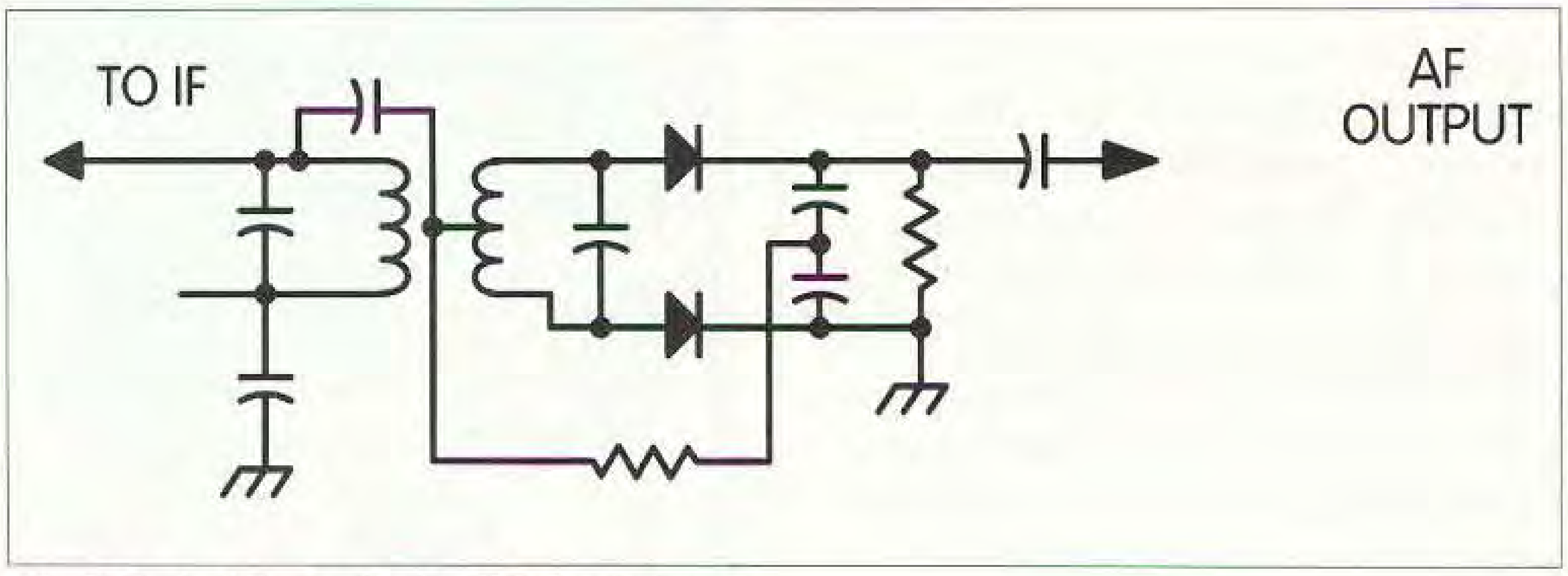

Fig. 5. Typical Foster-Seeley FM discriminator.

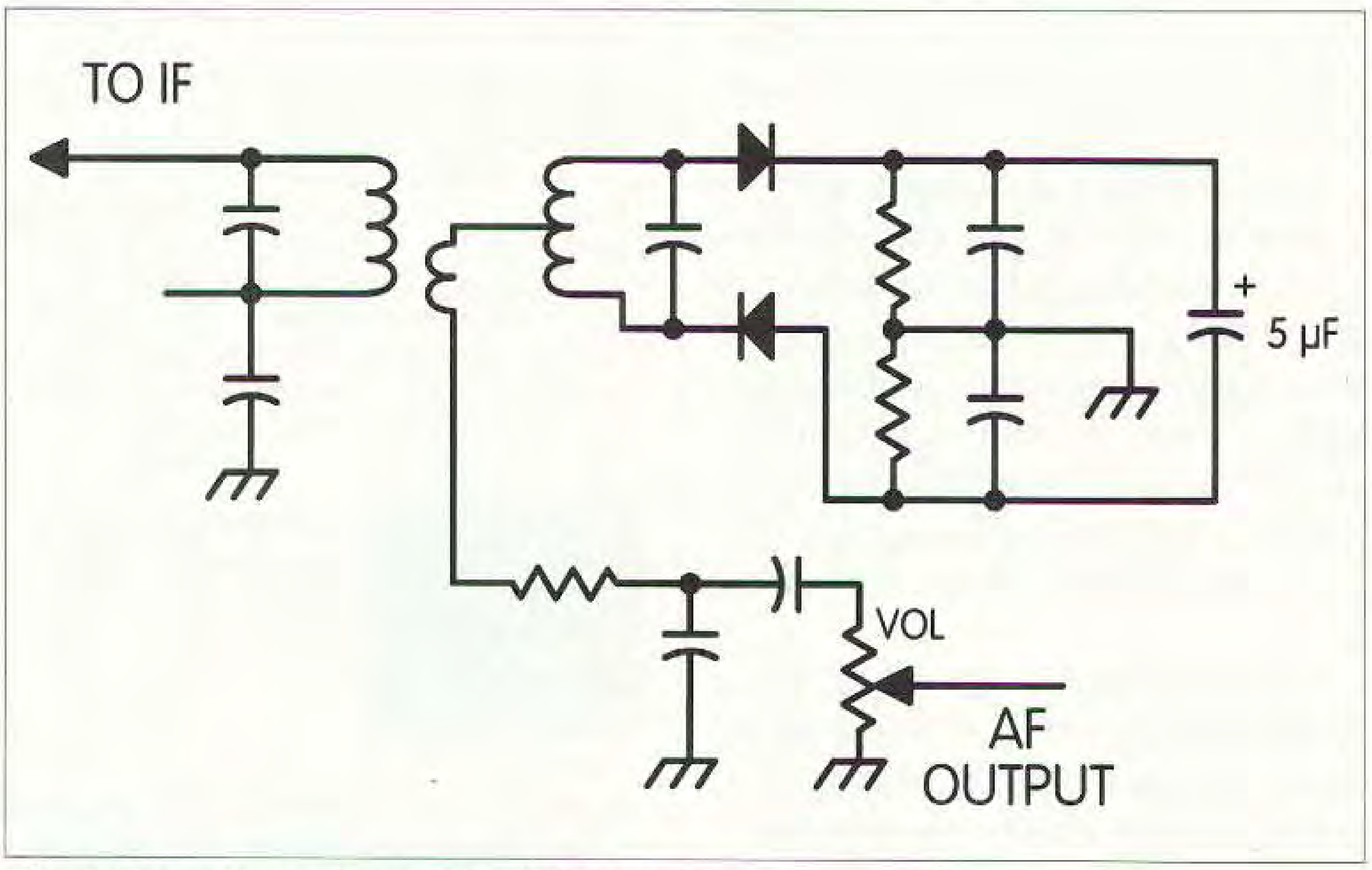

Fig. 6. Typical ratio detector for FM demodulation.

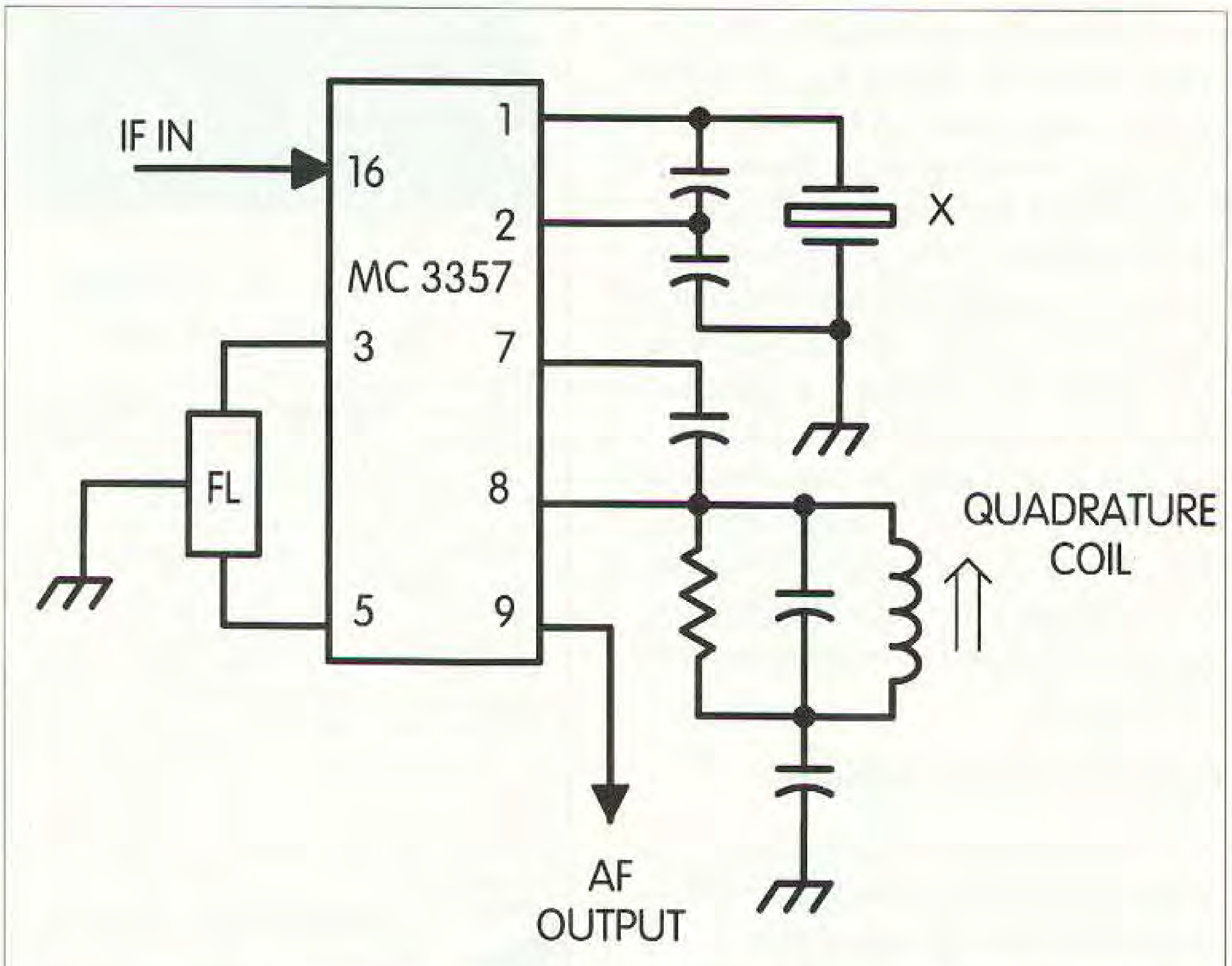

Fig. 7. Quadrature detector for FM demodulation utilizing an MC3357. The quadrature coil operates at 90 degrees from the signal through FL.

changes. The amplitude sensitivity aspect was "cured" by preceding the detector with an IF limiter. Then the recovered audio amplitude was in direct proportion to the frequency deviation. In looking at **Fig. 5**, you can see that a coupling capacitor ties the top of the primary winding to the center tap of the secondary winding, and both windings are tuned to resonance at the intermediate frequency. As a result, the secondary winding is provided both inductive and capacitive coupling to the primary, developing an IF voltage across the secondary, which is 90 degrees out of phase with the primary. Each diode receives an equal voltage to be rectified, and the diode output differential will be zero when the carrier is centered within the receiver's passband. When the incoming signal moves (deviates) to one side or the other from the zero point, then each diode will conduct a current which is proportional to the frequency shift from zero. This results in a differential voltage produced at the detector output which is relative in magnitude to the amount of deviation. The recovered audio is usually filtered and shaped with an RC filter before the audio voltage is presented to an audio amplifier.

Ratio detector

Ratio detectors, as shown in **Fig. 6**, operate on the same principle of a 90-degree phase shift between primary and secondary windings as a Foster-Seeley discriminator. However, the voltage developed across the output circuit remains fairly constant because the diodes conduct in series, aiding, not opposing as in a discriminator. The output voltage produced across the 5 µF capacitor is proportional to the strength of the received signal, rendering the detector insensitive to noise and AM signals. The large capacitor is used to provide a long RC time constant for limiting amplitude variations. Although an IF limiter was not required ahead of the ratio detector for noise elimination, the detector was still responsive to the amplitude strength differences between received signals, meaning that one station might sound louder than another. The

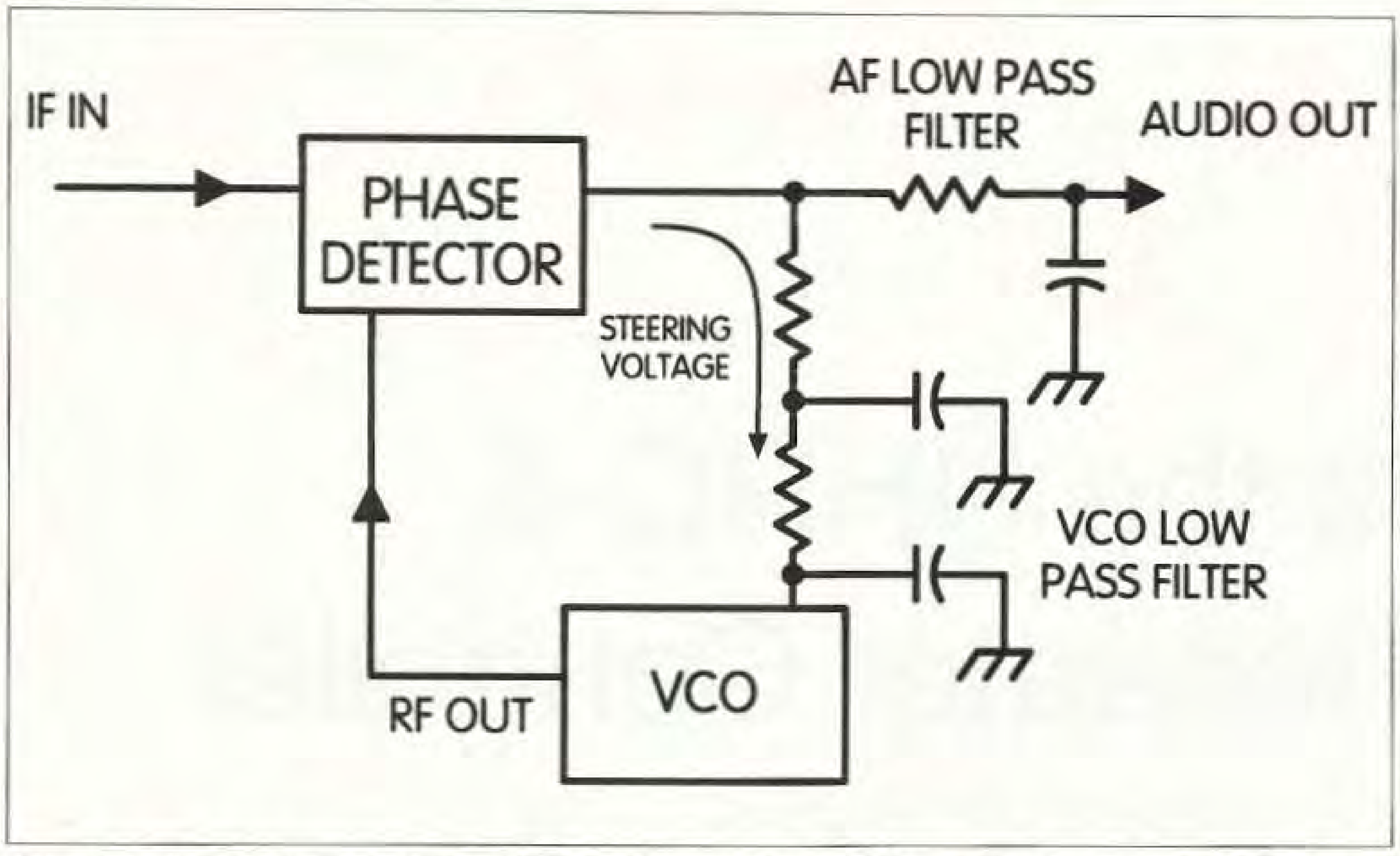

Fig. 8. PLL FM demodulator. VCO steering voltage follows the frequency deviation of the incoming signal.

use of an IF limiter "cured" that problem when the need was critical.

Audio output from the detector was taken from the center tap of the secondary winding, where the recovered audio voltage amplitude was proportional to the shift in the deviated carrier.

Quadrature detector

Quadrature detectors were originally developed for TV receivers because they were inexpensive and easy to implement. However, a special tube type was required for the circuit. Then, with the advent of solid state radios, a solid state version of the detector was developed, which is now pretty much a standard for communications radios. The most popular IC used for receiver IF and detector circuits is the MC3357, a portion of which is shown in **Fig. 7**, which incorporates the electronics portion of the quadrature detector circuit. A quadrature coil is used external to the IC as a reference signal for detecting the deviation of a received signal. In essence, when a signal is received, a portion of the signal is split off and used to excite the quadrature coil, causing it to resonate at the intermediate frequency. In a quadrature detector, a 90-degree phase shift exists between the voltage produced by the coil and the incoming signal. The two resulting voltages are compared and produce an audio voltage proportional to the signal deviation. An RC filter is used at the audio output to shape the audio being presented to the audio amplifier.

Phase locked loop detector

Phase locked loops (PLL) are used for many purposes. One of the prime ones is generating a multitude of available frequencies, each having the stability of a crystal. Using the PLL as a detector, as shown in **Fig. 8**, follows the principle of tuning the VCO to the intermediate frequency and allowing the VCO to lock to the incoming signal. A phase detector exists between the VCO and the incoming reference signal and is used to compare the phase of the two signals. The phase difference between the two input terminals is 90 degrees, and a DC output voltage will be produced which is proportional to the difference in the phase between the two signals. A long time constant is utilized at the steering voltage input to the VCO, to prevent the VCO from following the deviation of the incoming signal. What this means is that the steering voltage, while attempting to drive the VCO, will be proportional in magnitude to the amount of deviation of the incoming signal. Audio is then recovered from the steering voltage line between the phase detector and the VCO. Three of the more popular PLL detector ICs have been the NE560, NE565, and the 4046. A resistor and capacitor are used for adjusting the frequency lock range of the internal VCO.

Next time: Accessory circuits can make superhet receivers more user-friendly, as well as adaptable to many applications. 73