

Chapter 5: AM Receivers

Chapter 5 Objectives

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

- Explain the steps necessary in the reception of a radio signal.
- Explain how a diode AM detector works.
- Draw a block diagram of a TRF radio receiver.
- List at least two limitations of TRF radio receivers.
- Draw a block diagram of a superheterodyne AM receiver, explaining the signals at each point.
- Given a carrier and local oscillator frequency, calculate the frequency of the various tuned circuits in a superheterodyne receiver.
- Calculate the image frequency of a signal.
- Given the schematic diagram, recognize the functional blocks and signal flow in a superheterodyne receiver.
- Describe the alignment procedures for AM receivers.
- Given a receiver with a problem, isolate the fault to a particular AF or RF stage.

A radio receiver completes a communications system. Without a receiver, a transmitter is useless! Receivers come in many different forms. They can be designed to receive voice, digital data, and many other kinds of signals. Receivers of all types share many common features. The understanding of AM receivers will be an important foundation for the study of more advanced systems.

The Secrets Inside Everyday Objects

Technology and its products surround us, and we're accustomed to being dazzled by the magic inside the latest gadgets. There's nothing flashy about a transistor radio, a digital wristwatch, or a pocket calculator. These products are inexpensive, readily available, and have been around for a long time. But look inside them -- what does it take to *build* a radio, watch, calculator, or computing tablet? Perhaps this question is what led you to the study of electronics.

When we look at the *details* inside such mundane everyday devices, we're overwhelmed. How did anyone ever figure all of this out? There has to be some *magic* in there somewhere. But there isn't; all electronic devices must obey the laws of physics.

There are many years of electronics knowledge built into the humblest widget. Historically men and women have contributed to this store of knowledge for more than a century. No one can learn it all in one night. Don't be intimidated if you don't understand a principle immediately. Most of us need to review and study technical material repeatedly in order for it to "stick." Be persistent. Be patient. You can learn any area of electronics if you apply yourself!

5-1 Receiver Operation

The process of receiving a radio signal can be broken down into a series of five steps. Not every receiver will perform every step, but most do. Figure 5-1 shows this in block diagram form.

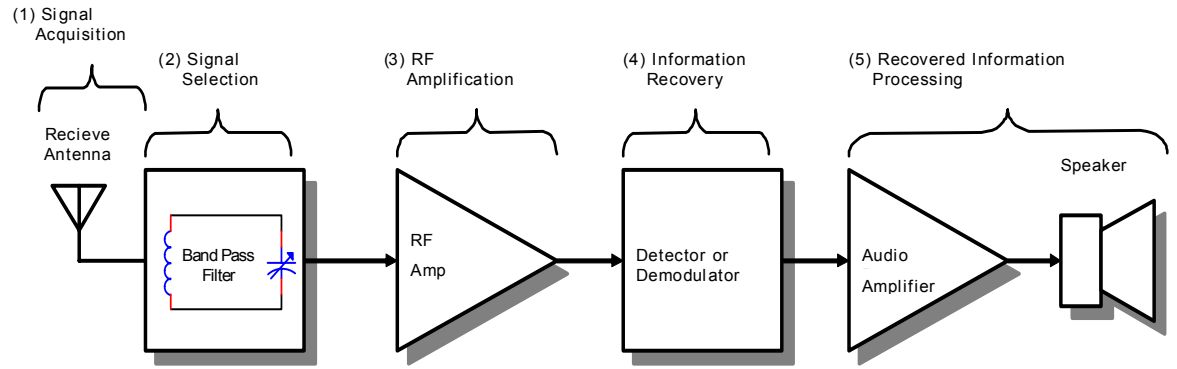


Figure 5-1: The Steps in Receiving a Radio Signal

Steps in Reception

1. *Signal Acquisition:* To *acquire* a signal means to get it. Radio signals are in the form of electromagnetic energy traveling through space at the speed of light. In order for a radio signal to be useful in an electronic circuit, it must first be converted back into an electrical signal. This is the job of the *antenna*.
2. *Signal Selection:* There are thousands of radio signals in the air at any instant in time. An antenna combines many of them in its electrical output to a receiver. Reception of more than one signal at a time would be annoying to the listener. It would be like listening in a crowded room. How can one signal be extracted from the pile? Right -- every radio transmitter uses a different *carrier frequency*. The receiver's *bandpass filter* is tuned to the frequency of the radio station we wish to receive. Ideally, *only* the desired carrier will get through this filter. In reality, there are problems with this approach; filters are not perfect, and interfering signals can get through.
3. *RF Amplification:* The distance between a radio transmitter and receiver can be very small, or many miles. The transmitted power can be a fraction of a watt, or millions of watts. In general, the signal received at a receiver's antenna is very small. At a receiving antenna, the amplitude of a "strong" received signal is usually 100 μV or less. Many receivers must deal with signals less than 1 μV in size. Before such small signals can be processed, they must be amplified. The RF amplifiers developed in chapter 4 can be adapted and used in receivers as well.
4. *Information Recovery:* The actions in the first three steps resulted in reproduction of the *modulated carrier wave* that was sent from the transmitter. The modulated carrier wave holds the information; in order to recover the information, we use a *detector* or *demodulator* circuit. Both words have the same meaning. When we detect a signal, we are extracting the information from the modulated carrier wave. The information is saved and used, and the carrier portion of the wave is discarded.
5. *Recovered Information Processing:* This is a general way of saying that we'll be doing something useful with the information the detector extracted. The type of receiver will determine what needs to be done with the information. In a radio receiver, the detected information is an *audio* signal with insufficient voltage and current to drive a loudspeaker. Therefore, the last stage in a radio receiver is an audio power amplifier which provides the voltage and current needed to operate the loudspeaker. For example, a *television* receiver differs from a radio receiver only in how the detected information (a *video signal* in analog TV, or a *data signal* in digital TV) is processed.

These are the basic steps a receiver needs to perform. In simple radio receivers, some of the tasks can be omitted. For example, you may have built a *crystal radio receiver*. A crystal receiver uses only the energy from the incoming radio wave to produce the sound. A long wire antenna is usually required in order to receive sufficient signal. Figure 5-2 shows the schematic of one type of crystal receiver. There are thousands of different possible crystal receiver designs. Many active enthusiast groups build and study these simple receivers.

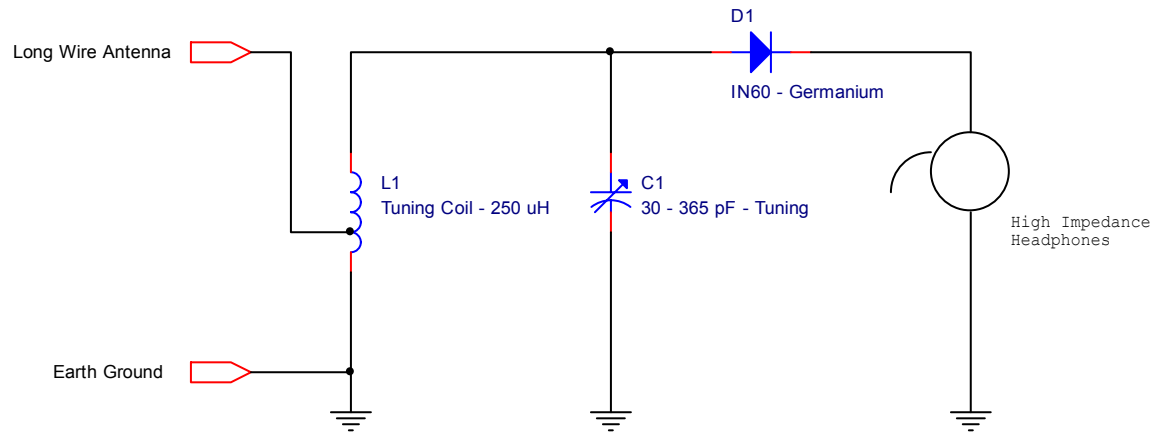


Figure 5-2 A Crystal Radio Receiver

There isn't much to the circuit of Figure 5-2! A *long wire* antenna is connected to the upper input terminal. (A length of wire 50' or longer will work well.) The *earth ground* terminal must be connected to a good earth ground in order to provide an AC return path for the antenna signal. (A ground rod, or metallic cold water pipe could be used.)

The process of *selection* is accomplished with L1 and C1, which form a parallel-resonant bandpass filter. The output of the filter is sent to the detector diode, D1. Two types of variable capacitors for receivers are shown in Figure 5-3. The miniature type is very commonly used in portable receivers.

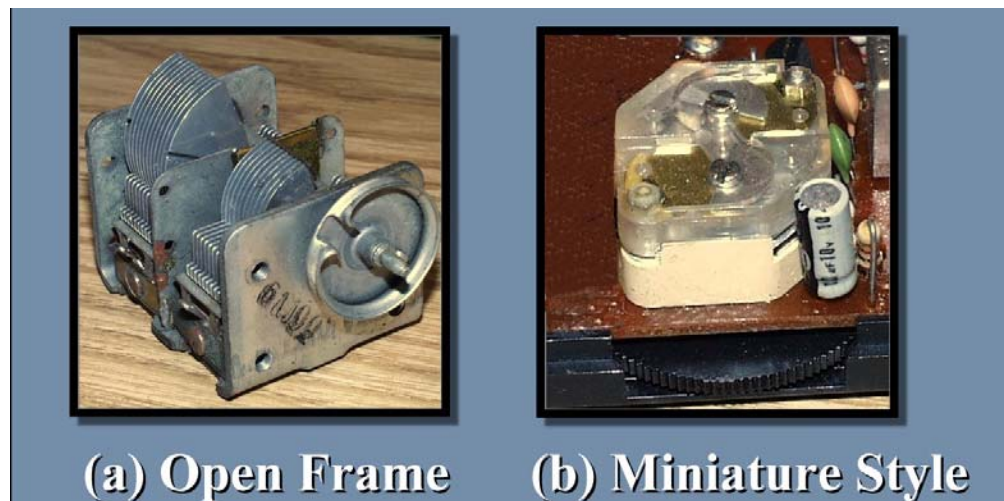


Figure 5-3: Typical receiver variable capacitors

D1 is a *germanium* diode. The use of this type of diode is common in AM detectors. A silicon diode requires a forward bias of 0.7 volt in order to conduct. In contrast, a germanium diode will begin conduction at only 0.2 to 0.3 volts. This greatly increases the sensitivity of the receiver. *The sensitivity of a receiver is its ability to process small input signals.*

The detected signal is a copy of the original information, and leaves the cathode of D1. It consists of a DC component, and two AC components, the AF information, and the RF carrier. The headphones receive this signal, but can only respond to the audio information -- the RF energy changes polarity too quickly for the headphones to respond. Thus, the headphones produce sound that is a copy of the original sound from the transmitter.

Example 5-1

What is the approximate tuning range of the receiver of Figure 5-2?

Solution

L1 and C1 form a bandpass filter. The resonant frequency of this filter controls what carrier frequency the receiver will receive. C1 is a variable capacitor that is adjustable from 30 to 365 pF. This is the tuning control. By setting C1 to its maximum and minimum values, we can find the range of resonant frequencies:

$$f_{\min} = \frac{1}{2\pi\sqrt{LC_{\max}}} = \frac{1}{2\pi\sqrt{(250\mu H)(365\text{ pF})}} = \underline{\underline{527\text{ kHz}}}$$

$$f_{\max} = \frac{1}{2\pi\sqrt{LC_{\min}}} = \frac{1}{2\pi\sqrt{(250\mu H)(30\text{ pF})}} = \underline{\underline{1838\text{ kHz}}}$$

The receiver can tune from 527 kHz to 1838 kHz. This more than covers the AM broadcast band, which runs from 535 kHz to 1620 kHz.

Section Checkpoint

- 5-1 What are the five steps in the reception of a radio signal?
- 5-2 What type of circuit is used for *selection* of a signal?
- 5-3 Why are RF amplifiers necessary in receivers?
- 5-4 What steps of reception are performed in the circuit of Figure 5-2?
- 5-5 Why are germanium diodes used in AM detectors?
- 5-6 How does the end user control the frequency of the bandpass filter in the receiver of Figure 5-2?

5-2 AM Detection

There are several types of AM detectors in use. The most common of these is the *diode detector* of Figure 5-4. The diode detector generates some distortion of the information, but is the simplest and least expensive approach. A diode detector works because a diode is a nonlinear device. In general, a nonlinear device is required to both *modulate* and *demodulate* (detect) AM signals.

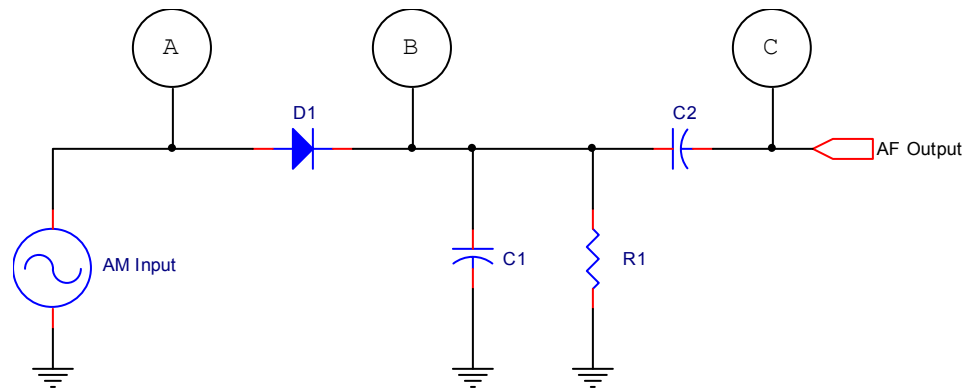


Figure 5-4: The Diode Detector

The waveforms for the diode detector are shown in Figure 5-5. The primary action that takes place in a diode detector is *rectification*. The AM detector is very similar to a half wave power supply in this regard. When the AM signal is applied to the input, the diode cuts off the negative half cycles, since it can only conduct when it is forward biased.

The third waveform of Figure 5-5 illustrates this action. This waveform would be obtained at test point *B* if capacitor *C1* were removed from the circuit. Although it doesn't look like it, there are actually *three* primary frequency components in the half-wave rectified signal at test point *B*. They are the *modulated AM carrier signal and sidebands*, the *information frequency*, and a *DC level*.

Detector Time Domain Analysis

The rectified waveform from *D1* is passed to capacitor *C1*, which charges up to the voltage of each positive peak of the rectified RF wave. Resistor *R1* is a bleeder resistor. Without *R1* to continually discharge *C1*, *C1* would just charge up and hold the highest positive DC level! The time constant of *R1* and *C1* is designed to be as short as possible so that the voltage on *C1* will follow the AM envelope as closely as possible.

The jagged shape of the recovered information is due to the charging and discharging of *C1*. A capacitor cannot change its voltage instantaneously. When the envelope is *falling* (getting smaller), the voltage on *C1* can fall only as fast as the RC time constant of *R1* and *C1* permits.

The bottom waveform in Figure 5-5 contains the information and a DC component. The DC component is useful as a *signal strength* indicator, and can be used to operate the automatic gain control (AGC) circuit in a receiver. The DC component is *not* useful for audio amplification, so it is removed by capacitor *C2*.

Detector Frequency Domain Analysis

The detector's operation can also be explained in the frequency domain. The signal at test point *B* contains the AM carrier (an RF signal), the information frequency (an AF signal), and a DC level. We desire to recover the information frequency and discard the AM carrier signal. This job is performed by a *low-pass filter* built with *C1* and *R1*. The low pass filter works because the carrier frequency is much higher than the information frequency.

For example, the receiver might be tuned to 810 kHz with an information frequency of 4 kHz. The low-pass filter can easily reject the 810 kHz (carrier) component and pass the 4 kHz (information) component. The bottom waveform results. The jagged shape of the recovered information is a result of imperfect filter action. A small amount of the 810 kHz carrier signal gets through the filter and shows up as a high-frequency ripple in the detected output.

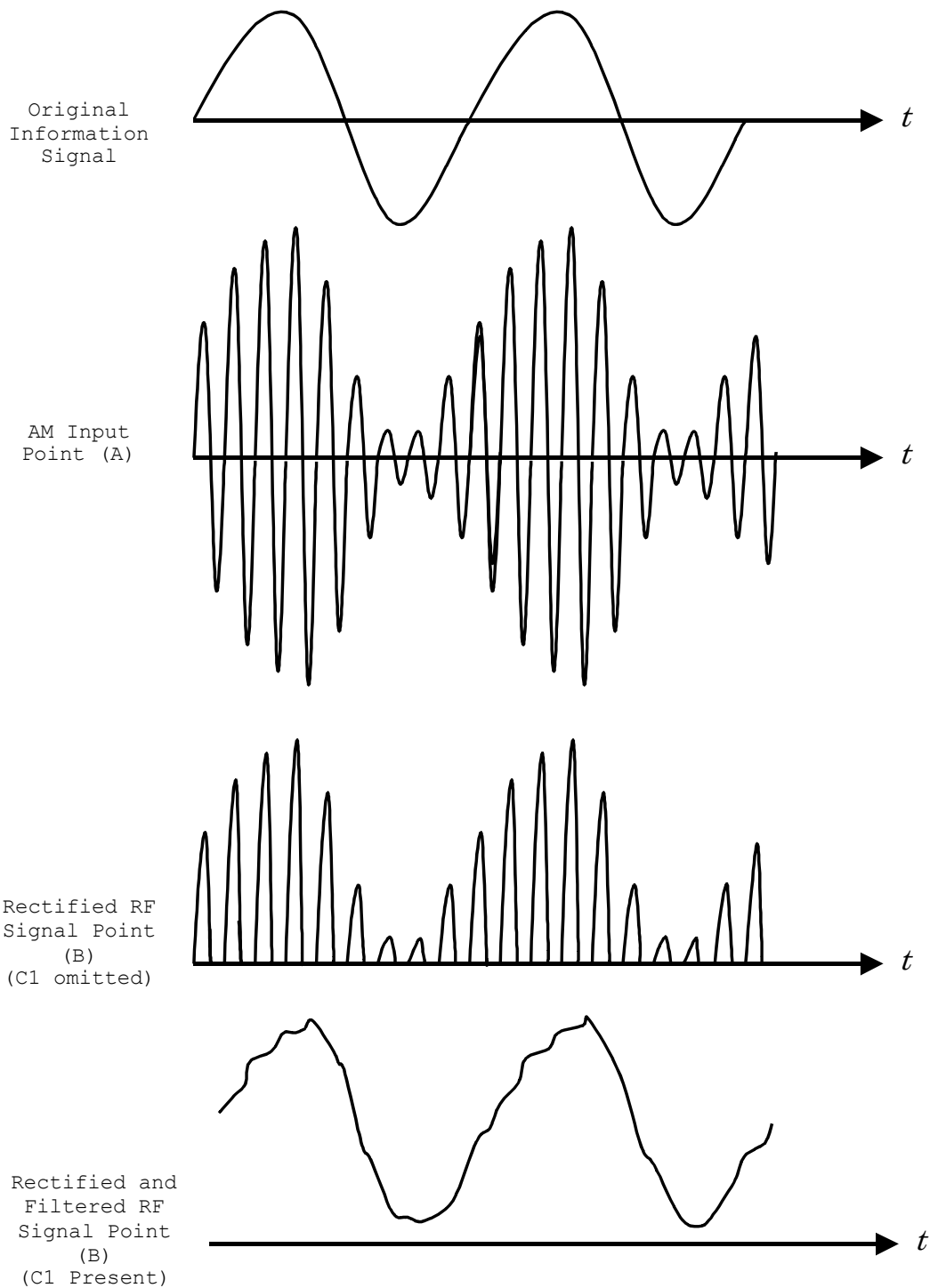


Figure 5-5: Waveforms for the Diode Detector

Distortion in the AM Detector

A diode AM detector doesn't produce a perfect copy of the information. C1 can't discharge (through R1) rapidly enough to keep up when the envelope falls rapidly. The recovered information is distorted as a result.

The dotted trace in Figure 5-6 represents the voltage on C1. C1 rapidly charges when the peaks get larger, but can't follow closely enough on the downward slopes. The

result is called *diagonal clipping distortion*, and is shown in Figure 5-6. This type of distortion is most likely to show up when a high percentage of modulation is present. The use of a more sophisticated detector called a *synchronous detector* can nearly eliminate this distortion, but it is much more complicated and costly to construct.

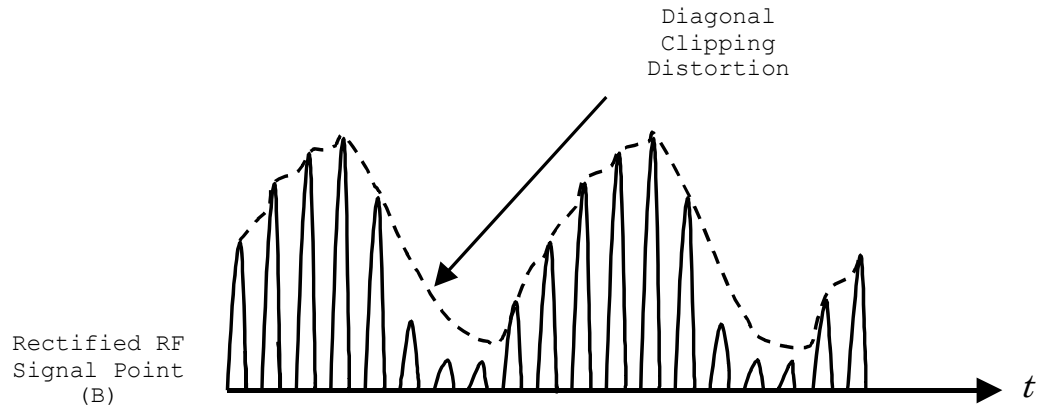


Figure 5-6: Diagonal clipping distortion

The Case of the Bandit (Unintended AM Signal Detection)

Jim was getting more than a little frustrated. For the third night in a row, he sat down to eat dinner and listen to music when an anonymous voice suddenly blared over the speakers: "Breaker 14, this is the Bandit, this is the Bandit..."

Jim got up and snapped off the stereo's power switch. What happened next stunned him. The voice wouldn't go away! Jim looked in the stereo in disbelief. Even pulling the power plug from the outlet had no effect. This was really spooky. "Neil has got to see this," Jim thought to himself as he dialed the phone. "Hey, Neil. You've got to come over here. This 'Bandit' character comes over my stereo even when I unplug it. I think I might know who he is!"

In his 15 years as a ham radio operator, Neil hadn't seen any case of interference quite like this. "Jim, did you notice that your neighbor across the street has a huge *beam* antenna -- and it seems to be pointed right at your place? If that's him, he'll be literally pounding RF signal right into your equipment -- no wonder that you can pick him up even when your set is unplugged. They'll never believe this at work!"

Neil continued: "Since you've disconnected your stereo from the power line, we can eliminate the AC power line as the path for the Bandit's signal. The only thing left is your speaker wiring. Those speaker cables are about 8 feet long apiece; hmm...that's close to a quarter-wavelength on the CB band. Let's try putting an RF bypass capacitor at each speaker output jack on your receiver."

Neil had brought an assortment of capacitors, and in no time had connected a 0.1 μF capacitor in parallel with each speaker connector. "These 0.1 μF caps will look like an open circuit to the audio, but a short to the RF from Bandit's transmitter."

The voice disappeared mid-sentence as Neil connected the last capacitor. Jim was amazed.

"Neil, how did you know to use capacitors?" "Well, since we figured that the signal was coming in on the speaker wires, that in itself wouldn't be enough to make any sound. Radio frequencies are too high for us to hear directly, even if they get into the loudspeakers. There has to be some sort of *rectification* somewhere to get audio from an RF signal. The *output transistors* in your stereo were still connected to the speaker leads, even when the power was turned off. The P-N junctions in the output transistors were acting as diodes, detecting the Bandit's AM signal. The speaker wires were acting as the antenna, and the output transistors in the stereo were the AM detector. The speakers were just responding to the rectified RF signal. The 0.1 μF capacitors prevented the RF signal from getting back into the stereo where it would be rectified by the output transistors."

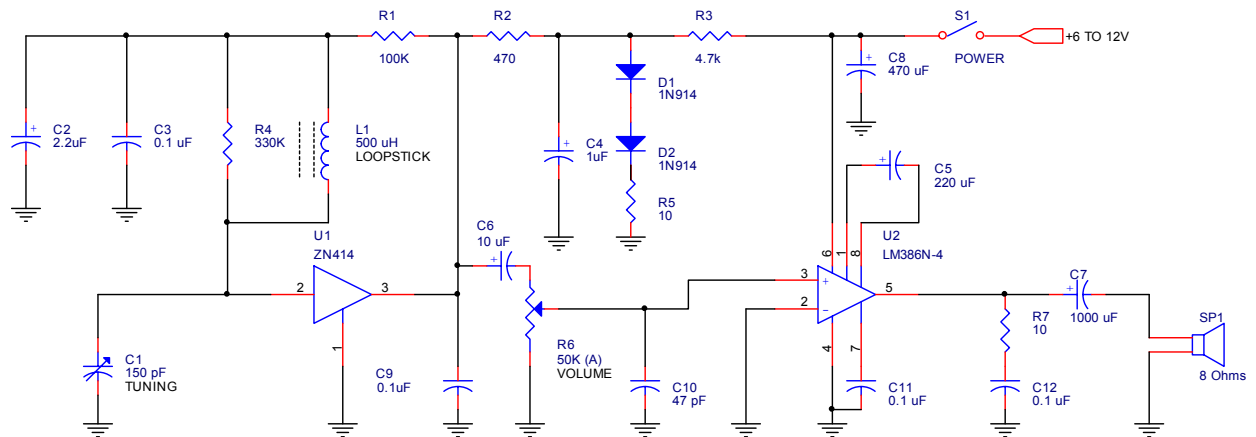
The Bandit was no longer the dinner speaker at Jim's house!

Section Checkpoint

- 5-7 How is an AM detector similar to a half-wave DC power supply?
- 5-8 Why is the diode detector popular for AM?
- 5-9 What component in Figure 5-4 "stores" the envelope voltage between RF peaks?
- 5-10 Why is bleeder resistor R1 needed?
- 5-11 What type of filter does R1 and C1 form?
- 5-12 What is the primary type of distortion caused by a diode AM detector?
- 5-13 What causes diagonal clipping distortion?

5-3 The TRF Receiver

The signal processing approach of Figure 5-1 is the first electronic approach that was used to build radio receivers. It is known as the *tuned radio frequency* or *TRF* receiver. The TRF receiver isn't used much in modern practice, but it is still constructed by hobbyists. Figure 5-7 shows a modern version of the TRF that provides fairly good performance.



CONSTRUCTION NOTES:

1. ZN414 available from ALL ELECTRONICS CORP. 1-800-826-5432
2. All capacitors 16 WV or better.
3. LOOPSTICK L1 can be constructed as 100 turns #30 wire on a 5/16" dia ferrite rod. Rod length not critical.
4. C10 should be located close to U2.
5. C9 should be close to U1.
6. Keep leads on pin 2 of U1 as short as possible, and away from the speaker leads.
7. R4 used to prevent U1 from oscillating. May not be needed in all units, depending on choice of L1 and U1 Lot number.

Figure 5-7: A TRF Receiver Built with Two IC Chips. Note: If ZN414 is unavailable, MK484 or TA7642 may be substituted.

TRF Receiver Circuit Analysis

The integrated circuit U1 does most of the work. U1 is designed as a TRF radio receiver on a chip; it contains the following stages:

- Nine stages of RF amplification, with over 70 dB of available gain.
- An active AM detector using a transistor as a "diode."
- An automatic gain control (AGC) circuit to compensate for signal fading.

All that is needed to utilize U1 is a 1.5 volt DC power supply, an RF input signal, and a detector filter capacitor. The output of U1 is a detected audio signal, which needs only power amplification in order to drive a speaker.

Diodes D1 and D2 are forward biased by R3 and R5 to provide a 1.5 volt operating supply for U1. These components act as a simple voltage regulator. C4 filters the DC power supply for U1.

There seems to be no antenna on this schematic! How does U1 get an RF signal? The answer is that a special antenna called a *loopstick antenna* is used. The loopstick antenna is coil L1 on the schematic. A loopstick antenna is a coil of wire wound on a ferrite rod. Ferrite is a magnetic material like iron, but is essentially an insulator. Iron cores are very lossy at radio frequencies because they are good conductors of electricity. Eddy currents induced in iron cores cause RF energy to be lost. Ferrite is essentially *rust!* It contains iron in *oxide* form, which is essentially an insulator. The iron retains much of its magnetic properties in ferrite. Because ferrite isn't a good conductor, it works well at radio frequencies.

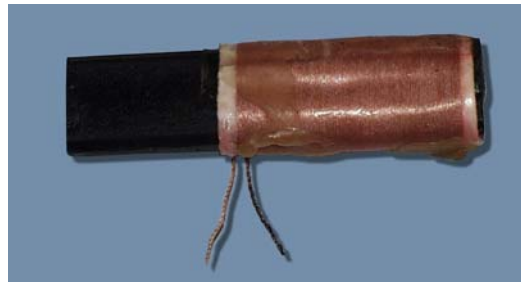


Figure 5-8: A Loopstick Antenna

A radio wave contains both an electric and a magnetic field. The ends of the ferrite rod in Figure 5-8 are open, which allows the magnetic field of the radio wave to enter the rod. The ferrite rod intensifies the magnetic field, increasing the receiver's sensitivity. Since the magnetic field fluctuates back and forth at the carrier frequency, it induces an AC voltage in the coil. The AC voltage in the coil is the carrier voltage, and can be sent to an RF amplifier for amplification and eventual detection.

The loopstick antenna L1 serves a dual purpose in this circuit. It acts as the antenna, but is also parallel-resonated by variable capacitor C1, the tuning capacitor. L1 therefore also acts as part of the *selector* circuit; L1 and C1 form a *bandpass filter*. The user adjusts C1 to select the station frequency. The filtered output from L1 and C1 is the carrier frequency. It is a very tiny signal -- perhaps 100 μV at best!

The carrier signal from L1 and C1 enters pin 1 of U1. (U1 has only three pins and is in a plastic transistor package!) U1 amplifies the RF signal and detects it. The recovered information leaves U1 on pin 3. Pin 3 of U1 is used to provide the DC power for the IC (through R2), and extract the information (through DC block C6). C9 completes the detector low-pass filter (the "resistor" for the filter is inside U1).

The recovered information signal is passed through the *volume control* R6, which is really just a variable voltage divider. Rotating the volume control moves the wiper of R6 up or down on the resistor. The higher the wiper position of R6, the more AF voltage that will be passed into pin 3 of U2, the audio power amplifier, and the louder the sound in the speaker will become.

U2, an LM386, is a complete audio voltage and power amplifier on one chip. C5 sets the gain of the LM386 to maximum, and C7 AC couples the amplified audio signal into the speaker. C11 and C8 are power supply filters, which are very important in a receiver. Radio receivers have tremendous gain, which can lead to oscillation problems if the power supplies are not adequately filtered.

Problems with the TRF Receiver

The TRF receiver is not used in many applications, although it is certainly the most logical approach. There are two problems with TRF receivers. The *selectivity* of TRF receivers is not constant, and it is nearly impossible to design a TRF receiver for operation at HF or above (3 MHz or above).

Selectivity

Selectivity can be defined as the ability of a receiver to *select* or choose a desired signal, while rejecting all others. (Compare this with *sensitivity*, the ability to work with weak signals). As you might guess, the *bandwidth* of the receiver's circuits control its selectivity. The bandwidth of a receiver should be just wide enough to accept the desired signal -- and no more! Excessive receiver bandwidth reduces selectivity, and increases the noise level (recall that noise power is proportional to bandwidth). A closer examination of the tuning circuit of the TRF receiver reveals this problem, as the following example shows.

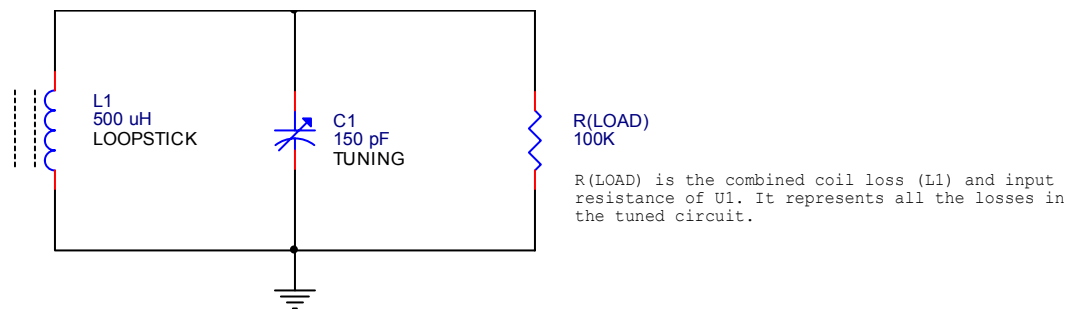


Figure 5-9: Model of TRF Receiver Tuning Circuit

Example 5-2

Calculate the bandwidth for the modeled tuning circuit of Figure 5-9 at the following frequencies: 540 kHz (bottom of AM dial); 980 kHz (middle of dial); 1620 kHz (top of dial).

Solution

To calculate bandwidth, we must calculate the quality factor (Q) of the resonant circuit at each frequency. From electronic fundamentals, we know that a reactive circuit with the resistance in *shunt* with the circuit, the Q is calculated by:

$$Q_p = \frac{R_p}{X_p}$$

(Where R_p is the parallel/shunt resistance, and X_p is the capacitive or inductive reactance, whichever is easiest to calculate.)

We also know that the bandwidth of a circuit can be calculated if we know frequency and Q:

$$BW = \frac{f}{Q}$$

At 540 kHz, we get:

$$X_p = X_C = X_L = 2\pi fL = 2\pi(540\text{KHz})(500\mu\text{H}) = 1696 \Omega$$

$$Q_p = \frac{R_p}{X_p} = \frac{100\text{K}\Omega}{1696\Omega} = 59$$

Therefore, we can find the bandwidth at 540 kHz:

$$BW = \frac{f}{Q} = \frac{540 \text{ KHz}}{59} = \underline{\underline{9.152 \text{ kHz}}}$$

This is a reasonable bandwidth (perhaps a little wide), since an AM broadcast uses 8 kHz of bandwidth. By repeating the procedure at 980 kHz, we get:

$$X_p = X_C = X_L = 2\pi fL = 2\pi(980 \text{ kHz})(500\mu\text{H}) = 3079 \Omega$$

$$Q_p = \frac{R_p}{X_p} = \frac{100 \text{ K}\Omega}{3079 \Omega} = 32.5$$

$$BW = \frac{f}{Q} = \frac{980 \text{ KHz}}{32.5} = \underline{\underline{30.2 \text{ KHz}}}$$

The bandwidth seems to be getting larger. Let's try it at 1620 kHz:

$$X_p = X_C = X_L = 2\pi fL = 2\pi(1620\text{kHz})(500\mu\text{H}) = 5089 \Omega$$

$$Q_p = \frac{R_p}{X_p} = \frac{100 \text{ K}\Omega}{5089 \Omega} = 19.7$$

$$BW = \frac{f}{Q} = \frac{1620 \text{ KHz}}{19.7} = \underline{\underline{82.2 \text{ kHz}}}$$

Wow! The receiver's bandwidth has increased from 9 kHz to more than 80 kHz over its tuning range! *This is unacceptable performance.* More than 8 stations might be received at the same time! (Stations are spaced every 10 kHz on the AM broadcast band.)

An ideal receiver should have constant bandwidth, and therefore constant selectivity. The TRF approach fails miserably here!

Why doesn't the TRF receiver have a constant bandwidth? The reason is within the tuning circuit. When we change the tuning dial position, we are changing the resonant frequency of the tuned circuit. The bandwidth of the tuned circuit depends upon its *frequency* and *Q*. The *Q* is furthermore determined by *circuit losses*, which depend on frequency as well. Even if the *Q* were held constant in Example 5-2, the bandwidth would still increase as we moved up the dial because the frequency would be changed! The fact that *Q* is also decreasing makes the bandwidth degrade even faster.

The bandwidth of any tuned circuit depends on the frequency it is tuned to. In general, for a parallel-loaded capacitively-tuned circuit, the higher the tuning frequency, the greater the bandwidth, and the poorer the selectivity.

For any tuned circuit to have a constant selectivity, the tuned frequency of the circuit must not be changed.

High
Frequency
Operation not
Practical for
TRF Receivers

Operation at frequencies above a few MHz also pose problems for TRF receivers. It becomes impossible to find discrete L and C components that will satisfy the tank requirements.

Example 5-3

What *Q* is needed for the tuned circuit of a TRF receiver designed to operate on CB channel 19 (27.185 MHz)? The required bandwidth is 10 kHz.

Solution

To calculate *Q*, we simply manipulate the formula for bandwidth and *Q*:

$$Q = \frac{f}{BW} = \frac{27.185 \text{ MHz}}{10 \text{ kHz}} = \underline{\underline{2,718.5}}$$

Wow! I don't think we'll be finding any L or C components with this high a *Q*. The maximum *Q* for discrete inductors and capacitors is around 200 to 300. This is far below what the circuit requires. Can you think of any other circuit components that have a really high *Q* and might work as a filter? Crystals? Yes, a crystal *might* be used here. But a crystal can't be tuned. You put it into the circuit, and essentially operate on one frequency. However, crystals are sometimes used in high performance receiver filters when the frequency is fixed (as in the intermediate frequency or *IF* amplifier of a *superheterodyne* receiver, as we'll soon see.)

A practical TRF receiver is nearly impossible to build at high frequencies; the required *Q* for the selector tank components is much higher than can be obtained with real-world components.

The Superhet
is King - For
Now

The problem of receiving different carrier frequencies while maintaining a constant bandwidth perplexed early radio designers. After all, moving the selector dial of a radio receiver changed the frequency of the internal tuned circuits, which upset the bandwidth. Many different and elaborate circuits were devised in attempts to cure the problem. These receiver circuits were difficult to align and operate, and weren't very reliable.

The true solution to the selectivity problem is to operate the tuned circuits at one constant frequency. This is the approach developed by Armstrong, and it is called the *superheterodyne* receiver. The superhet is the king of modern receivers; nearly all modern radio receivers are built using Armstrong's circuitry.

Software Defined Radio (SDR) - The New Superhet

Newer approaches are now being introduced that are essentially software implementations of Armstrong's superheterodyne principle. The latest radio receivers and transmitters use specialized digital signal processing (DSP) chipsets that implement in software the principles of the superhet receiver. This new approach is called Software Defined Radio (SDR) and has been made possible by the falling price of computing hardware. An SDR receiver still uses the same principles invented by Armstrong; the only difference is that the action happens in software (computer programs) rather than hardware (transistors, capacitors, inductors, and so forth).

Section Checkpoint

- 5-14 How is the selection process achieved in a TRF receiver?
- 5-15 What is a *loopstick* antenna?
- 5-16 Why is a ferrite, rather than iron, core used in a loopstick antenna?
- 5-17 What are the two functions of L1 in Figure 5-7?
- 5-18 What are the two limitations of TRF receiver designs?
- 5-19 What causes the bandwidth and selectivity of a tuned circuit to change as its frequency is adjusted?

5-4 The Superheterodyne Receiver

The superheterodyne receiver was a breathtaking advance in the radio art. Prior to its development, engineers spent a great deal of time and effort getting reasonable performance from the tuning (selection) circuits in a receiver. The engineers were in effect "moving the receiver to the signals" by changing the operating frequency of the receiver's tuned circuits to match the incoming signals.

The superhet receiver does exactly the opposite. Instead of trying to tune all of its tuned circuits to the incoming carrier frequency, it instead moves the carrier frequency to the frequency of its own tuned circuits! This process is called *frequency conversion*, and is shown in block diagram form in Figure 5-10.

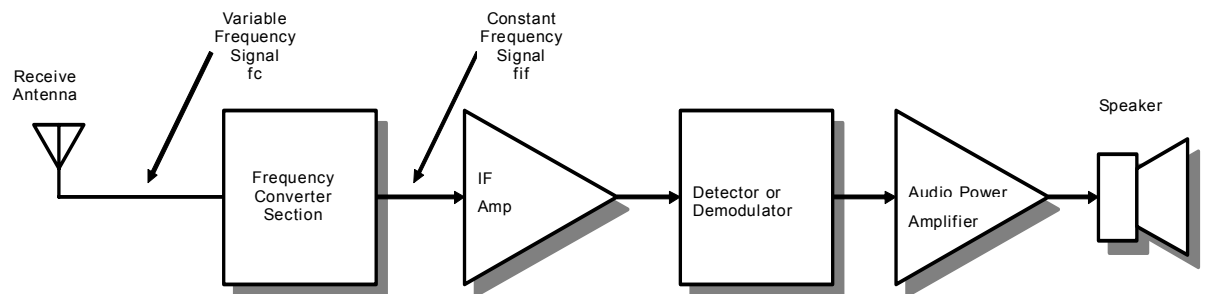


Figure 5-10: The Superheterodyne Concept

In a superheterodyne receiver the incoming signal is applied at the left side of the *frequency converter* section. The frequency of this signal is f_c , the original carrier frequency. The output of the frequency converter is always a *constant* frequency, regardless of the value of f_c . The constant frequency produced by the frequency converter is called the *intermediate frequency*, or f_{if} . For AM broadcast receivers, the value of f_{if} is fairly well standardized at 455 kHz, though other values are occasionally used.

Advantages of Using a Fixed IF Frequency

A fixed IF frequency provides several important advantages. First, since the IF frequency is constant, the tuned circuits in the IF amplifier will have a constant bandwidth and selectivity, regardless of what carrier frequency the receiver is tuned to. The TRF receiver's variable-tuned circuits could not achieve this.

Second, the IF amplifier usually operates at a lower frequency than the carrier frequency. It is easier to build low-noise RF amplifiers at lower frequencies. Providing most of the RF signal gain at the IF frequency improves the receiver's noise figure.

Finally, since the IF amplifiers operate at only one frequency, receiver alignment is simplified. The IF amplifiers need be adjusted only once, at the factory.

The IF amplifier in a superhet receiver provides most of the receiver's gain, and sets the receiver's bandwidth.

The Frequency Converter Section

The details of the frequency converter section are shown in Figure 5-11. The frequency converter consists of the *preselector*, the *mixer*, and the *local oscillator*. Note that there are *two* tuned circuits that are mechanically connected. These are the *preselector* filter tank, and the *local oscillator* tank. The dotted line between the two variable capacitors is used to show this on a schematic. The tuning knob turns both of these capacitors at the same time; they share a common shaft. The variable capacitor of Figure 5-3(a) is actually a dual-section unit.

The purpose of the frequency converter is to produce a constant output frequency, f_{if} , regardless of what the input carrier frequency f_c is. Before we can completely understand what is happening in the converter, we need to examine the mixer's operation in more detail.

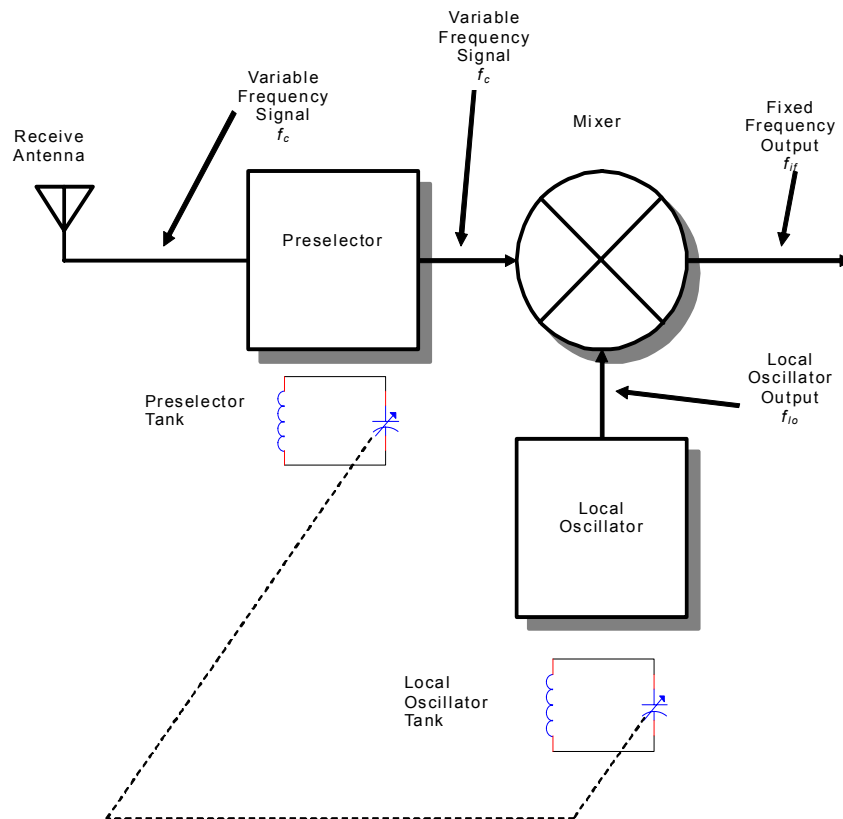


Figure 5-11: The Frequency Converter Section

Mixer Operation

The converter contains a nonlinear device called a *mixer*. A mixer is usually constructed with diodes or transistors. A mixer causes nonlinear distortion of the two signals being applied to it. When signals are distorted in this way, new frequencies are created (just as in the process of modulation).

Suppose that we applied two frequencies to an ideal mixer, $f_1 = 700 \text{ kHz}$ and $f_2 = 100 \text{ kHz}$, as shown below in Figure 5-12. What output frequencies could be expected?

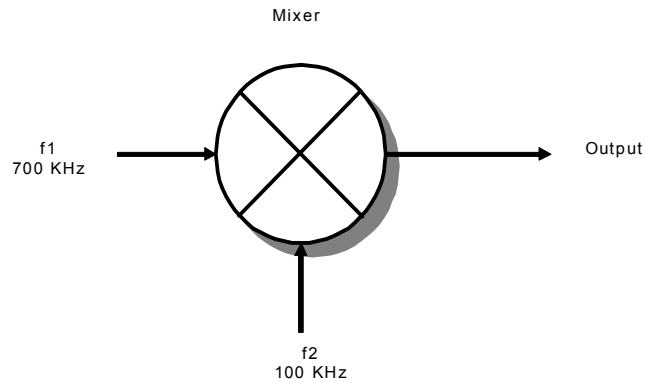


Figure 5-12: Ideal Mixer Operation

Given two input frequencies f_1 and f_2 , an ideal mixer will produce the following outputs:

- The **original** two frequencies, f_1 and f_2
- The **sum** of the two frequencies, $(f_1 + f_2)$
- The **difference** of the two frequencies, $(f_1 - f_2)$

With 700 kHz and 100 kHz applied, the output frequencies of an ideal mixer would therefore be:

- 700 kHz and 100 kHz (The *original* frequencies)
- 800 kHz (The *sum* of the two frequencies)
- 600 kHz (The *difference* of the two frequencies)

Example 5-4

A certain mixer is producing the following output frequencies: 900 kHz, 700 kHz, 500 kHz, and 200 kHz. What are the two most likely input frequencies?

Solution

All we need to do is carefully examine the output frequencies. Two of the output frequencies are the same as the two input frequencies, and if these frequencies are added and subtracted, the *other* two output frequencies will result.

By examining the frequencies in pairs, we will find that the two input frequencies must be 700 kHz and 200 kHz, because the sum of these is 900 kHz (one of the output frequencies), and the difference is 500 kHz (the remaining output frequency).

Frequency Converter Operation

The job of the frequency converter is to move the incoming carrier frequency f_c down to the intermediate frequency f_{if} . By carefully choosing a local oscillator frequency f_{lo} , this can be made to happen. Suppose that we wish to receive a signal on a carrier frequency of 710 kHz. We will tune the *preselector* to 710 kHz, so that 710 kHz becomes one of the input frequencies to the mixer (see Figure 5-11).

The preselector is always tuned to the carrier frequency. The preselector is not a narrow filter; it may even allow adjacent carrier frequencies to pass into the mixer.

We need to get a frequency of 455 kHz out of the mixer, because that is the frequency the IF amplifier is tuned to. How can 710 kHz be converted to 455 kHz? Right, the *local oscillator* plays an important part. If the local oscillator is tuned to the correct frequency, we'll get a 455 kHz output. All we need to do is make the local oscillator operate at a frequency that is *different* from the desired carrier (710 kHz) by the IF frequency (455 kHz).

In other words, the local oscillator must operate 455 kHz *above* the carrier, or 455 kHz *below* the carrier. There are *two* local oscillator frequencies that will work, but only one of them is used in an actual circuit.

The preselector and local oscillator circuits are mechanically connected so that they will "track" each other. When the two circuits properly track, they maintain a 455 kHz (f_{if}) difference.

The two possible frequencies for the local oscillator are given below:

$$(5-1) \quad f_{lo} = f_c + f_{if} \text{ (High-Side Injection)}$$

One of the possible local oscillator frequencies is therefore (710 kHz + 455 kHz), or 1165 kHz. This is the frequency that will be used in a broadcast receiver.

$$(5-2) \quad f_{lo} = f_c - f_{if} \text{ (Low-Side Injection)}$$

The other possible local oscillator frequency is (710 kHz - 455 kHz), or 255 kHz.

You may hear the terms "high side injection" and "low side injection" used in practice. These are just a fancy way of saying that the local oscillator operates either *above* (high-side) or *below* (low-side) the carrier frequency. Low-side injection causes some problems for AM broadcast receivers, so high-side injection is generally used. Other receivers may use either method.