Unit III

Receiver in Communication System

AM/FM Radio System

- The source signal is audio
- Different sources have different spectrum
  - Voice (speech)
  - Music
  - Hybrid signals (music, voice, singing)

AM/FM Radio System

- Different audio sources have different bandwidth “W”
  - Speech- 4kHz
  - High quality music- 15kHz
  - AM radio limits “baseband” bandwidth W to 5kHz
  - FM radio uses “baseband” bandwidth W to 15kHz

AM/FM Radio System

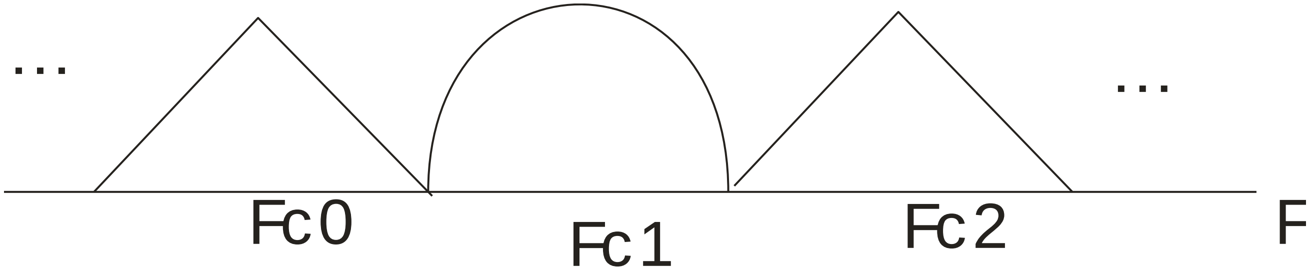
- Radio system should be able to receive any type of audio source simultaneously.
- Different stations with different sources transmit signals simultaneously.
- Different listeners tune to different stations simultaneously.

AM/FM Radio System

- The different radio stations share the frequency spectrum over the air through AM and FM modulation.
- Each radio station, within a certain geographical region, is designated a carrier frequency around which it has to transmit
- Sharing the AM/FM radio spectrum is achieved through Frequency Division Multiplexing (FDM)

Example of AM Radio Spectrum

- Different radio stations, different source signals



- Carrier spacing- 10kHz (AM)
- Bandwidth (3-5kHz)

AM/FM Radio System

- For AM radio, each station occupies a maximum bandwidth of 10 kHz
- Carrier spacing is 10 kHz
- For FM radio, each station occupies a bandwidth of 200 kHz, and therefore the carrier spacing is 200 kHz

AM/FM Radio System

- Transmission Bandwidth:
- B_T is the bandwidth occupied by a message signal in the radio frequency spectrum
- B_T is also the carrier spacing
- AM: $B_T = 2W$
- FM: $B_T = 2(D+1)W$ (Carson's Rule)

AM/FM Radio Receiver

- Design of AM/FM radio receiver
- The radio receiver has to be cost effective
- Requirements:
  - Has to work with both AM and FM signals
  - Tune to and amplify desired radio station
  - Filter out all other stations
  - Demodulator has to work with all radio stations regardless of carrier frequency

AM/FM Radio Receiver

- For the demodulator to work with any radio signal, we "convert" the carrier frequency of any radio signal to

  <u>Intermediate Frequency (IF)</u>

- Radio receiver design can be optimized for that frequency

- IF filter and a demodulator for IF frequency

AM/FM Radio Spectrum

- Recall that AM and FM have different radio frequency (RF) spectrum ranges:
  - AM: 540 kHz – 1600 kHz
  - FM: 88 MHz – 108 MHz
- Therefore, two IF frequencies
  - AM: 455 kHz
  - FM: 10.7 MHz

Basic Principles of Signal Reproduction

- In radio communication systems, the transmitted signal is very weak when it reaches the receiver, particularly when it has traveled over a long distance.
- The signal has also picked up noise of various kinds.
- Receivers must provide the sensitivity and selectivity that permit full recovery of the original signal.
- The radio receiver best suited to this task is known as the **superheterodyne receiver**.

Basic Principles of Signal Reproduction

- A communication receiver must be able to identify and select a desired signal from the thousands of others present in the frequency spectrum (**selectivity**) and to provide sufficient amplification to recover the modulating signal (**sensitivity**).

- A receiver with good selectivity will isolate the desired signal and greatly attenuate other signals.

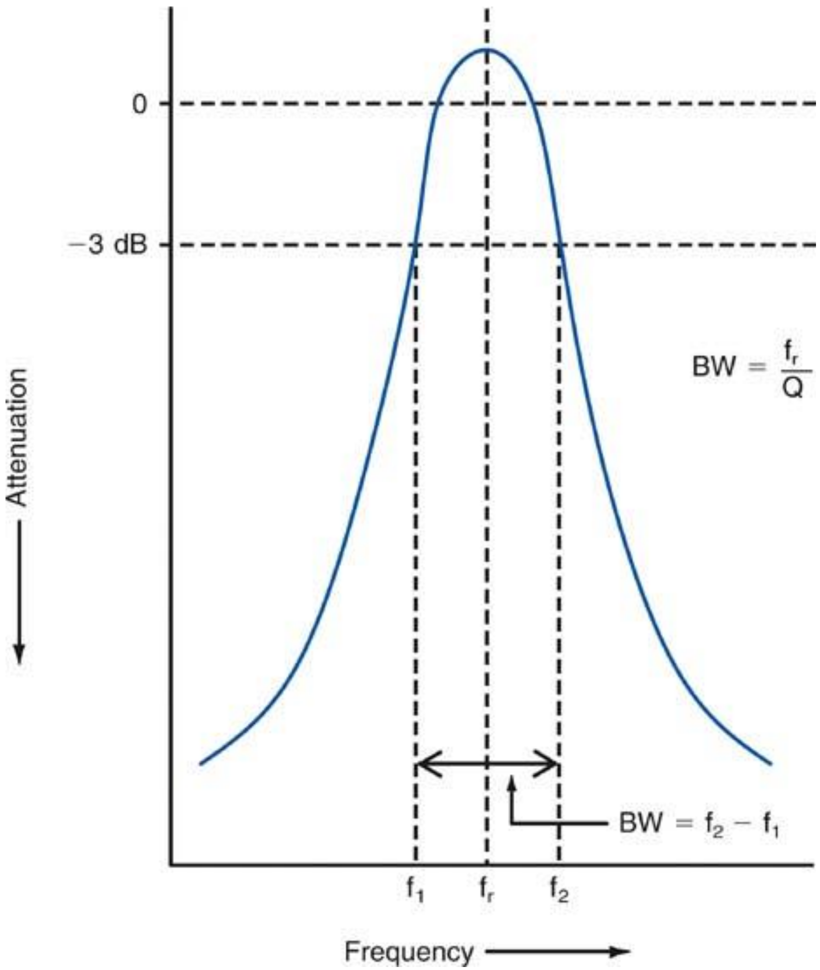
- A receiver with good sensitivity involves high circuit gain.

Basic Principles of Signal Reproduction

Selectivity: *Q* and Bandwidth

- Selectivity in a receiver is obtained by using tuned circuits and/or filters.
- *LC* tuned circuits provide initial selectivity.
- Filters provide additional selectivity.
- By controlling the *Q* of a resonant circuit, you can set the desired selectivity.
- The optimum bandwidth is one that is wide enough to pass the signal and its sidebands but narrow enough to eliminate signals on adjacent frequencies.

Basic Principles of Signal Reproduction



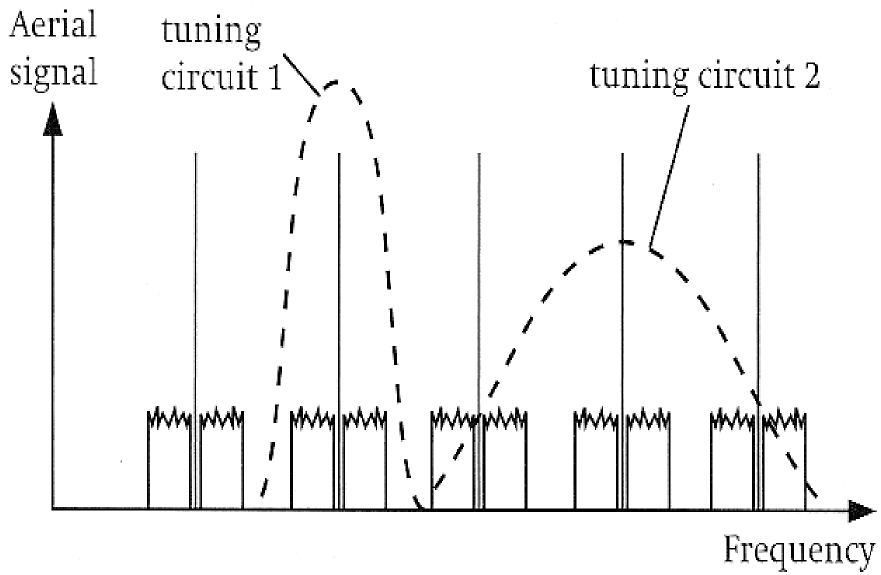


Figure 1: Selectivity curve of a tuned circuit.

Basic Principles of Signal Reproduction

Sensitivity

- A communication receiver's sensitivity, or ability to pick up weak signals, is a function of overall gain, the factor by which an input signal is multiplied to produce the output signal.
- The higher the gain of a receiver, the better its sensitivity.
- The more gain that a receiver has, the smaller the input signal necessary to produce a desired level of output.
- High gain in receivers is obtained by using multiple amplification stages.

Basic Principles of Signal Reproduction

Sensitivity

- Another factor that affects the sensitivity of a receiver is the signal-to-noise (*S/N*) ratio (SNR).
- One method of expressing the sensitivity of a receiver is to establish the **minimum discernible signal (MDS).**
- The MDS is the input signal level that is approximately equal to the average internally generated noise value.
- This noise value is called the **noise floor** of the receiver.
- MDS is the amount of signal that would produce the same audio power output as the noise floor signal.

Basic Principles of Signal Reproduction

Basic Receiver Configuration

- The simplest radio receiver is a crystal set consisting of a tuned circuit, a diode (crystal) detector, and earphones.
- The tuned circuit provides the selectivity.
- The diode and a capacitor serve as an AM demodulator.
- The earphones reproduce the recovered audio signal.

Basic Principles of Signal Reproduction

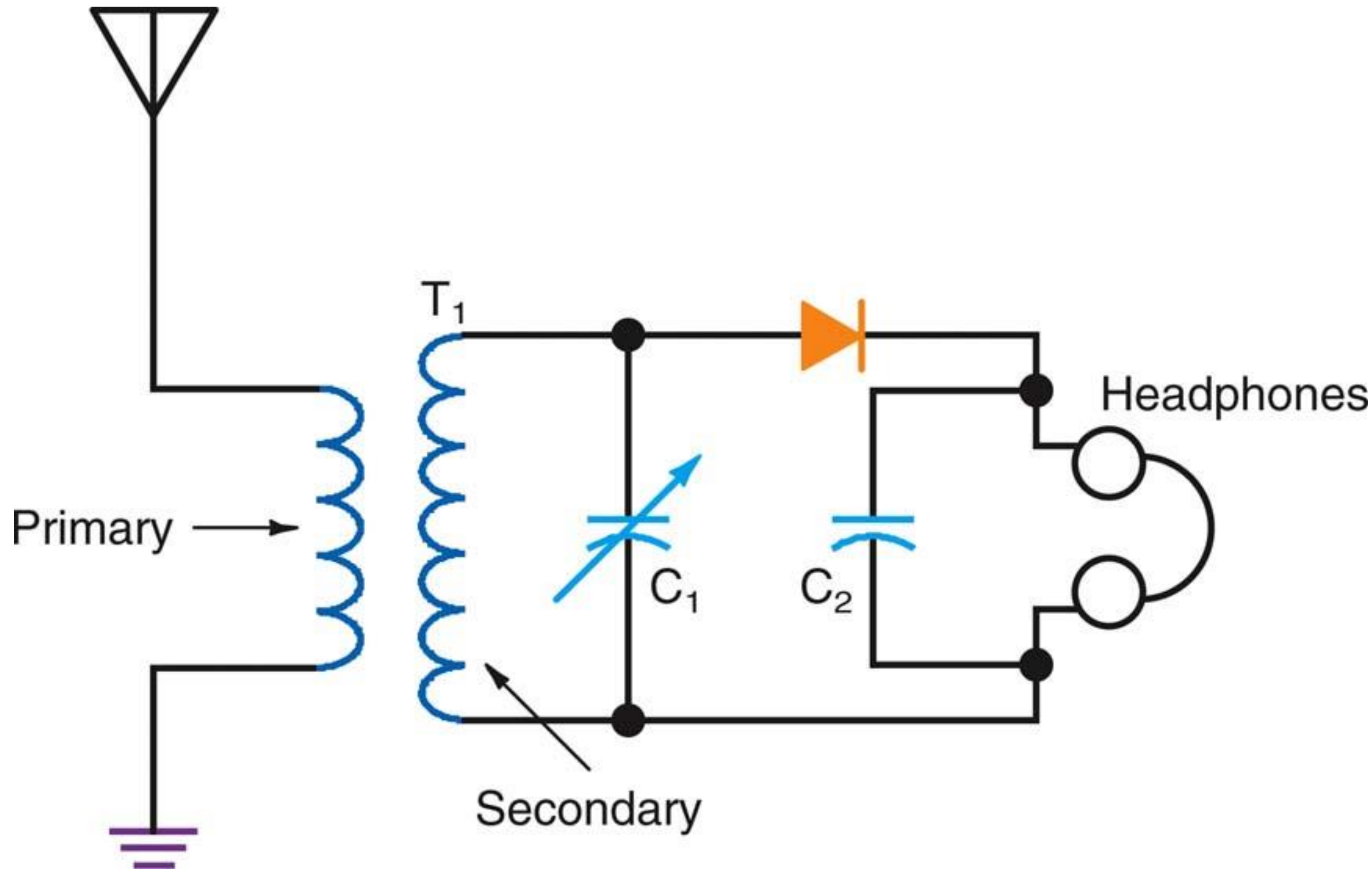


Figure: The simplest receiver—a crystal set.

Basic Principles of Signal Reproduction

Tuned Radio Frequency (TRF) Receiver

- In the tuned radio frequency (TRF) receiver sensitivity is improved by adding a number of stages of RF amplification between the antenna and detector, followed by stages of audio amplification.

- The RF amplifier stages increase the gain before it is applied to the detector.

- The recovered signal is amplified further by audio amplifiers, which provide sufficient gain to operate a loudspeaker.

Basic Principles of Signal Reproduction

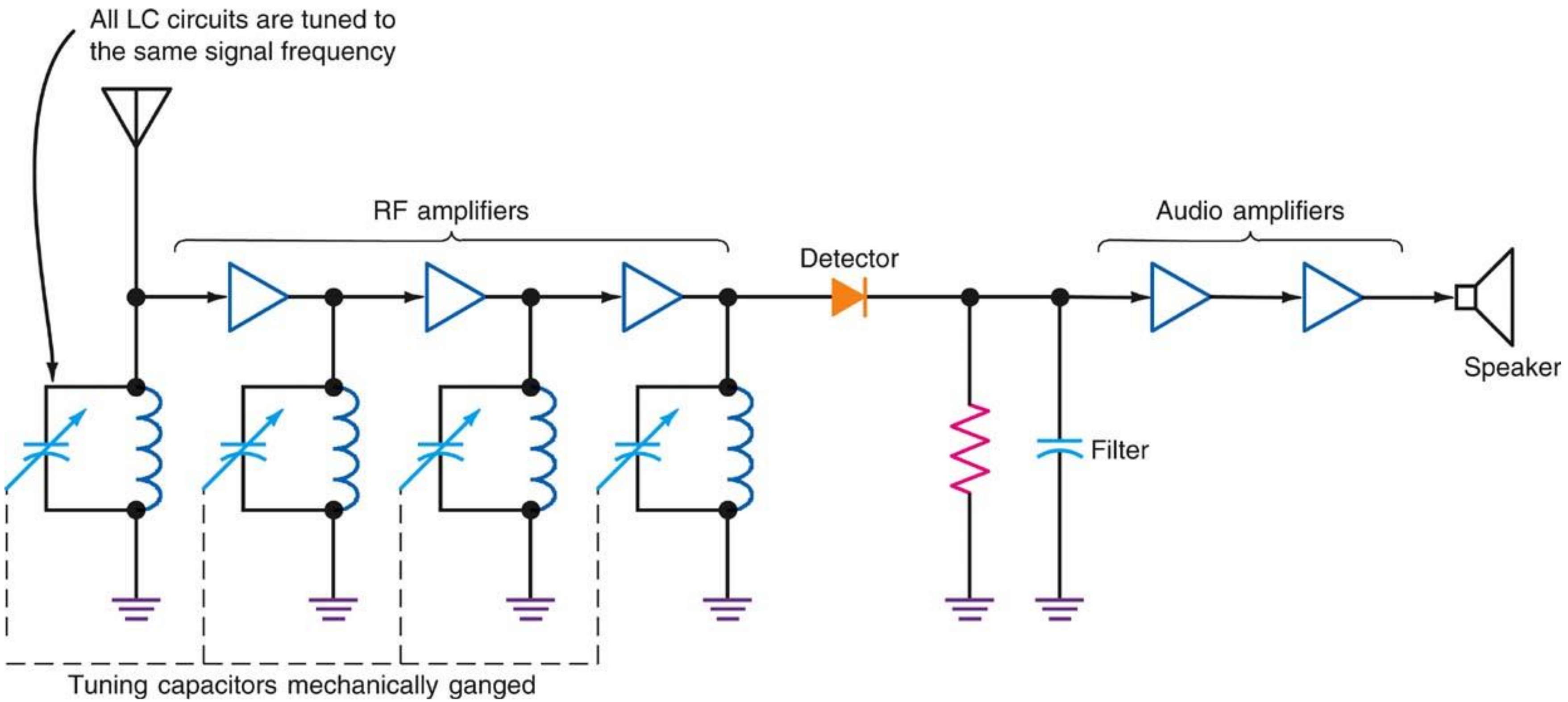


Figure Tuned radio-frequency (TRF) receiver.

Basic Principles of Signal Reproduction

Tuned Radio Frequency (TRF) Receiver

- Many RF amplifiers use multiple tuned circuits.
- Whenever resonant *LC* circuits tuned to the same frequency are cascaded, overall selectivity is improved.
- The greater the number of tuned stages cascaded, the narrower the bandwidth and the steeper the skirts.
- The main problem with TRF receivers is tracking the tuned circuits.
- In a receiver, the tuned circuits must be made variable so that they can be set to the frequency of the desired signal.
- Another problem with TRF receivers is that selectivity varies with frequency.

TRF(cont'd)-Example

Given a tuned radio frequency (TRF) tuning circuit consists of a 500µH loopstick, with a 50 to 500ρF variable capacitor for tuning. The equivalent tank parallel resistance is 200K Ohms.

- Determine

  i) the tuning range of the receiver

  ii) the circuit bandwidth when tuned to 540KHz

TRF(cont'd)-Solution

- Tuning range:
  - $F_{min}=1/(2\pi\sqrt{LC_{max}})$;
  - $F_{max}=1/(2\pi\sqrt{LC_{min}})$;
- Circuit bandwidth:
  - $X_L=2\pi fL$
  - $Q=R/X_L$
  - $B=f/Q$

Superheterodyne Receivers

- **Superheterodyne receivers** convert all incoming signals to a lower frequency, known as the **intermediate frequency (IF),** at which a single set of amplifiers is used to provide a fixed level of sensitivity and selectivity.
- Gain and selectivity are obtained in the IF amplifiers.
- The key circuit is the mixer, which acts like a simple amplitude modulator to produce sum and difference frequencies.
- The incoming signal is mixed with a local oscillator signal.

Superheterodyne Receivers

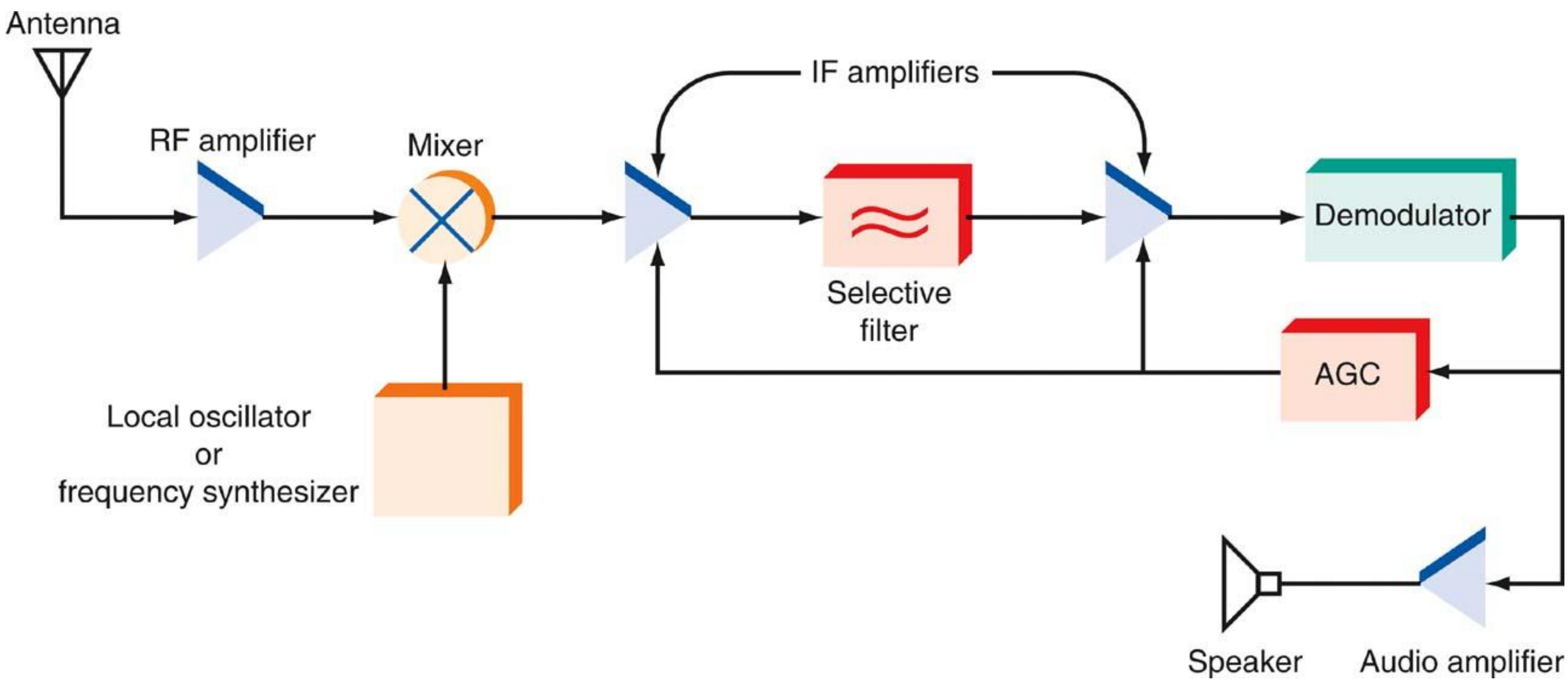


Figure : Block diagram of a superheterodyne receiver.

Superheterodyne Receivers

RF Amplifier

- The antenna picks up the weak radio signal and feeds it to the **RF amplifier**, also called a **low-noise amplifier (LNA).**
- RF amplifiers provide some initial gain and selectivity and are sometimes called **preselectors**.
- Tuned circuits help select the frequency range in which the signal resides.
- RF amplifiers minimize oscillator radiation.
- Bipolar and FETs can be used as RF amplifiers.

Superheterodyne Receivers

Mixers and Local Oscillators

- The output of the RF amplifier is applied to the input of the mixer.
- The mixer also receives an input from a local oscillator or frequency synthesizer.
- The mixer output is the input signal, the local oscillator signal, and the sum and difference frequencies of these signals.
- A tuned circuit at the output of the mixer selects the difference frequency, or intermediate frequency (IF).
- The local oscillator is made tunable so that its frequency can be adjusted over a relatively wide range.

Superheterodyne Receivers

IF Amplifiers

- The output of the mixer is an IF signal containing the same modulation that appeared on the input RF signal.
- The signal is amplified by one or more IF amplifier stages, and most of the gain is obtained in these stages.
- Selective tuned circuits provide fixed selectivity.
- Since the intermediate frequency is usually lower than the input frequency, IF amplifiers are easier to design and good selectivity is easier to obtain.

Superheterodyne Receivers

Demodulators

- The highly amplified IF signal is finally applied to the demodulator, which recovers the original modulating information.
- The demodulator may be a diode detector (for AM), a quadrature detector (for FM), or a product detector (for SSB).
- The output of the demodulator is then usually fed to an audio amplifier.

Superheterodyne Receivers

Automatic Gain Control

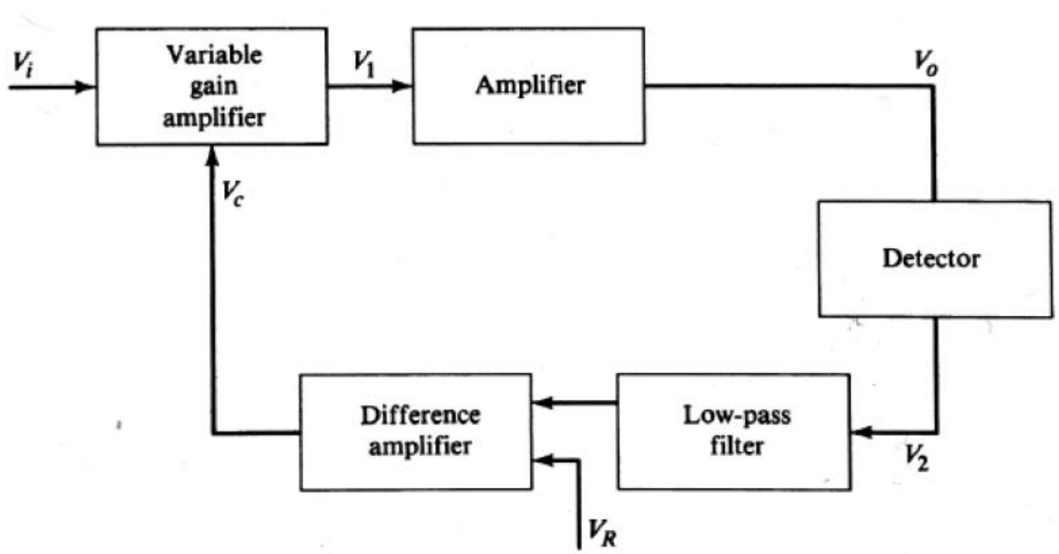
- The output of a demodulator is usually the original modulating signal, the amplitude of which is directly proportional to the amplitude of the received signal.

- The recovered signal, which is usually ac, is rectified and filtered into a dc voltage by a circuit known as the **automatic gain control (AGC)** circuit.

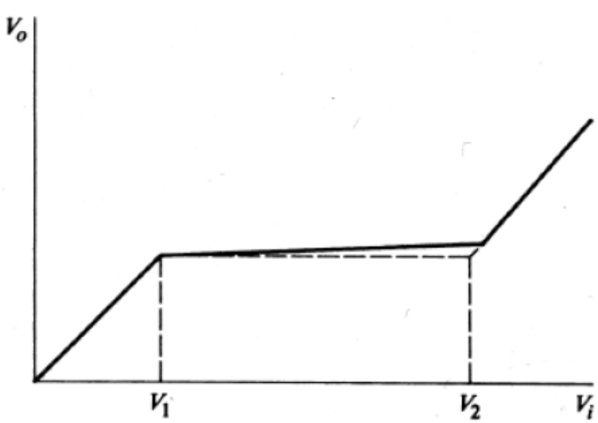
- This dc voltage is fed back to the IF amplifiers, and sometimes the RF amplifier, to control receiver gain.

- AGC circuits help maintain a constant output level over a wide range of RF input signal levels.

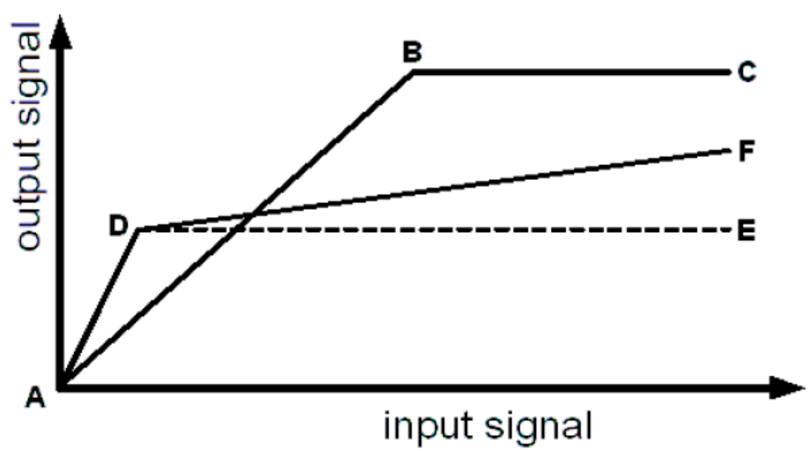
Automatic Gain Control



AGC Block Diagram



AGC Ideal Transfer Function



AGC Real Transfer Function

Automatic Gain Control

- The input signal is amplified by a Variable Gain Amplifier (VGA), whose gain is controlled by an external signal control voltage (Vc) .
- The output from the VGA can be further amplified by a second stage to generate and adequate level of Vo.
- Some the output signal's parameters, such as amplitude, carrier frequency, index of modulation or frequency, are sensed by the detector;
- Any undesired component is filtered out and the remaining signal is compared with a reference signal.
- The result of the comparison is used to generate the control voltage (Vc) and adjust the gain of the VGA.
- If the control time constants are determined primarily by the detector circuit and the additional amplifier has a wider bandwidth than the detector, then the attack and decay times will be shortened by the amount of the post-amplification
- An AGC circuit in the receiver provides a substantially constant signal level to the demodulator independent of the input signal level.

Superheterodyne Receivers

Automatic Gain Control

- The amplitude of the RF signal at the antenna of a receiver can range from a fraction of a microvolt to thousands of microvolts; this wide signal range is known as the *dynamic range.*

- Typically, receivers are designed with very high gain so that weak signals can be reliably received.

- However, applying a very high-amplitude signal to a receiver causes the circuits to be overdriven, producing distortion and reducing intelligibility.

- With AGC, the overall gain of the receiver is automatically adjusted depending on the input signal level.

Frequency Conversion

- **Frequency conversion** is the process of translating a modulated signal to a higher or lower frequency while retaining all the originally transmitted information.

- In radio receivers, high-frequency signals are converted to a lower, intermediate frequency. This is called **down conversion**.

- In satellite communications, the original signal is generated at a lower frequency and then converted to a higher frequency. This is called **up conversion**.

Frequency Conversion

Mixing Principles

- Frequency conversion is a form of amplitude modulation carried out by a mixer circuit or converter.

- The function performed by the mixer is called **heterodyning**.

Frequency Conversion

Mixing Principles

- Mixers accept two inputs: The signal to be translated to another frequency is applied to one input, and the sine wave from a local oscillator is applied to the other input.
- Like an amplitude modulator, a mixer essentially performs a mathematical multiplication of its two input signals.
- The oscillator is the carrier, and the signal to be translated is the modulating signal.
- The output contains not only the carrier signal but also sidebands formed when the local oscillator and input signal are mixed.

Frequency Conversion

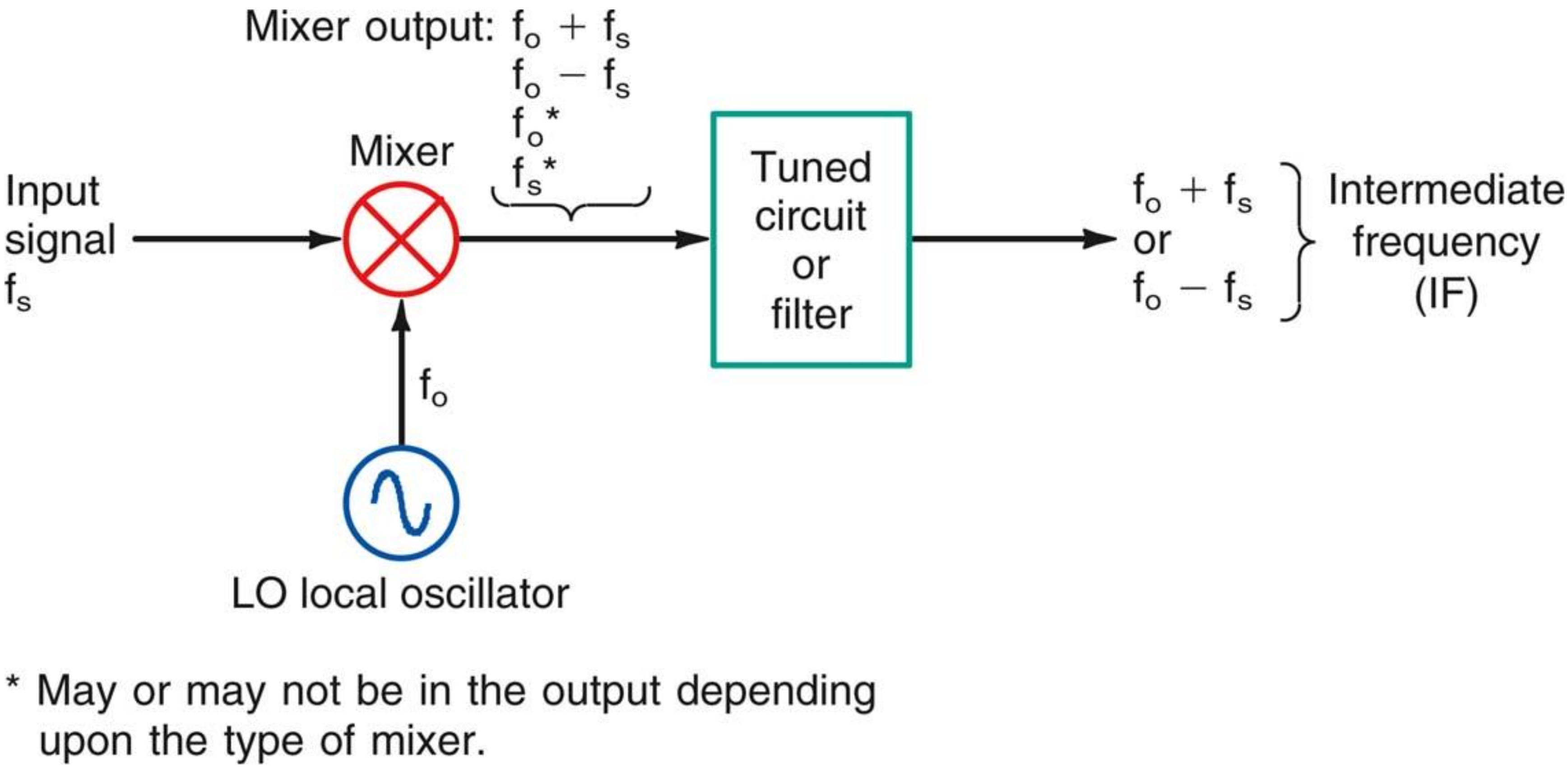


Figure : Concept of a mixer.

e.g.

a) If the carrier frequency f_c = 1.4MHz and local oscillator frequency f_o = 1.85MHz then the frequencies produced at the output of the mixer will be

f_c = **1.4 MHz**.

f_o-f_c = 1.85 MHz – 1.4 MHz = 0.450 MHz = **450 kHz**.

f_o+f_c = 1.85 MHz + 1.4 MHz = **2.25 MHz**.

f_o = **1.85 MHz**

b. If the carrier frequency changes to f_c = 1.1MHz determine the new frequencies produced at the output of the mixer.

We know that local oscillator frequency tracks the carrier frequency.

From part a) we see that f_o is 450kHz *above* f_c

so f_o = 1.1MHz + 450kHz = 1.55MHz

and the new frequencies are

f_c = **1.1 MHz**.

$f_o - f_c$ = 1.55 MHz – 1.1 MHz = 0.450 MHz = **450 kHz**.

$f_o + f_c$ = 1.55 MHz + 1.1 MHz = **2.65 MHz**.

f_o = **1.55 MHz**

Even though f_c and f_o have changed in these two examples $f_o - f_c$ gives an output of 450 kHz.

Frequency Conversion

Mixer and Converter Circuits: Diode Mixer

- The primary characteristic of mixer circuits is nonlinearity.
- Any device or circuit whose output does not vary linearly with the input can be used as a mixer.
- One of the most widely used types of mixer is the simple diode modulator.

Frequency Conversion

Mixer and Converter Circuits: Diode Mixer

- The input signal is applied to the primary winding of the transformer.

- The signal is coupled to the secondary winding and applied to the diode mixer, and the local oscillator signal is coupled to the diode by way of a capacitor.

- The input and local oscillator signals are linearly added and applied to the diode, which produces the sum and difference frequencies.

- The output signals are developed across the tuned circuit which selects the difference frequency.

Frequency Conversion

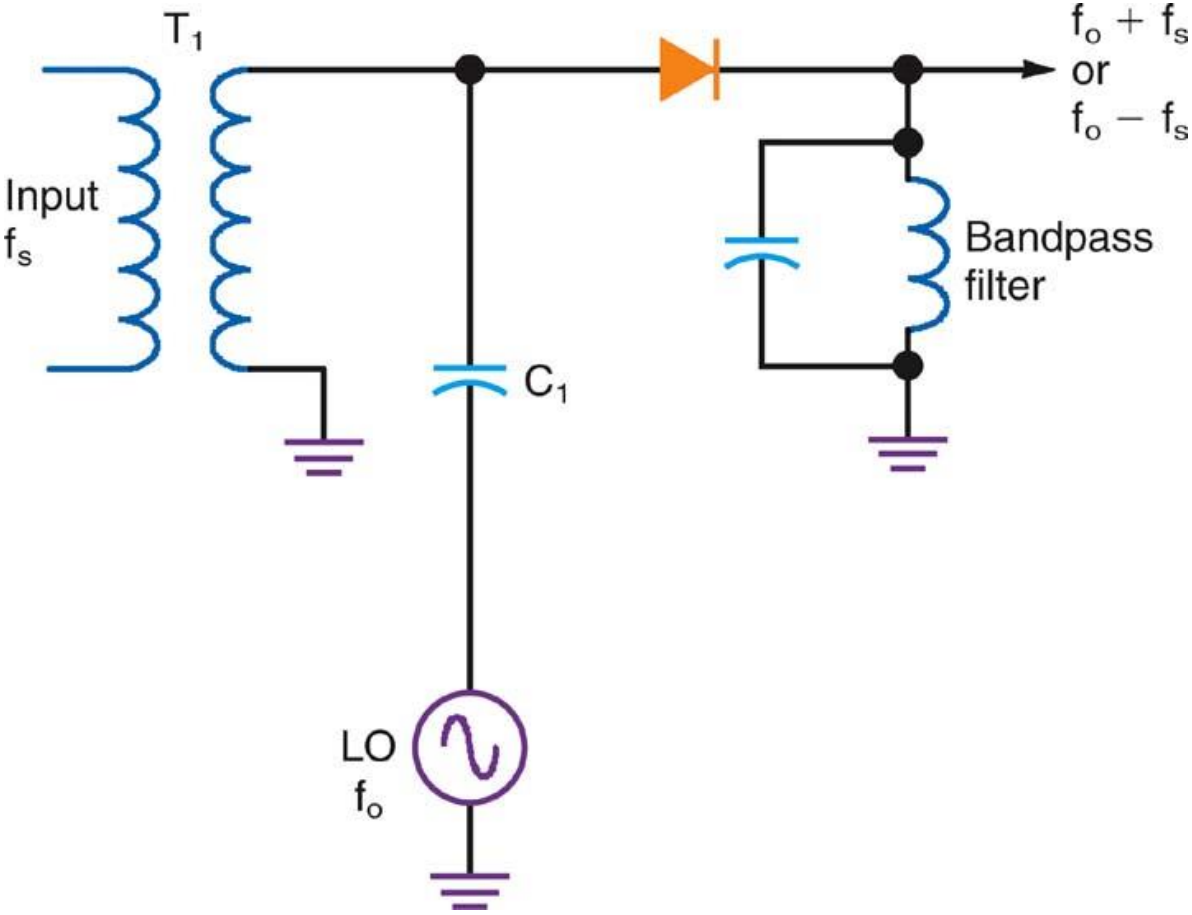
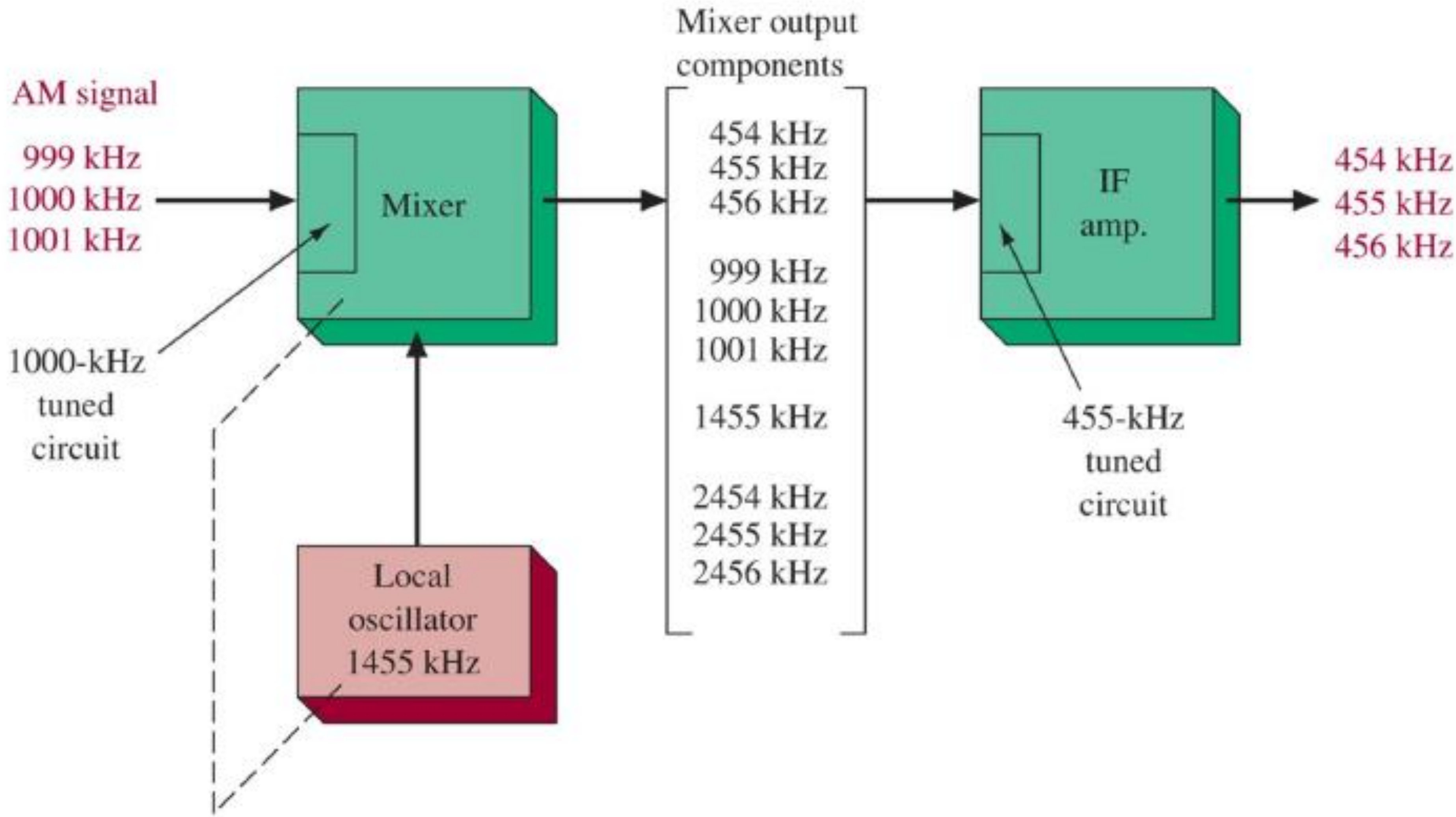


Figure : A simple diode mixer.

Frequency Conversion Process



Intermediate Frequency and Images

- The primary objective in the design of an IF stage is to obtain good selectivity.
- Narrow-band selectivity is best obtained at lower frequencies.
- At low frequencies, circuits are more stable with high gain.

Intermediate Frequency and Images

- At low frequencies, **image** interference is possible. An image is an RF signal two times the IF above or below the incoming frequency.
- At higher frequencies, circuit layouts must take into account stray inductances and capacitances.
- At higher frequencies, there is a need for shielding.

Intermediate Frequency and Images

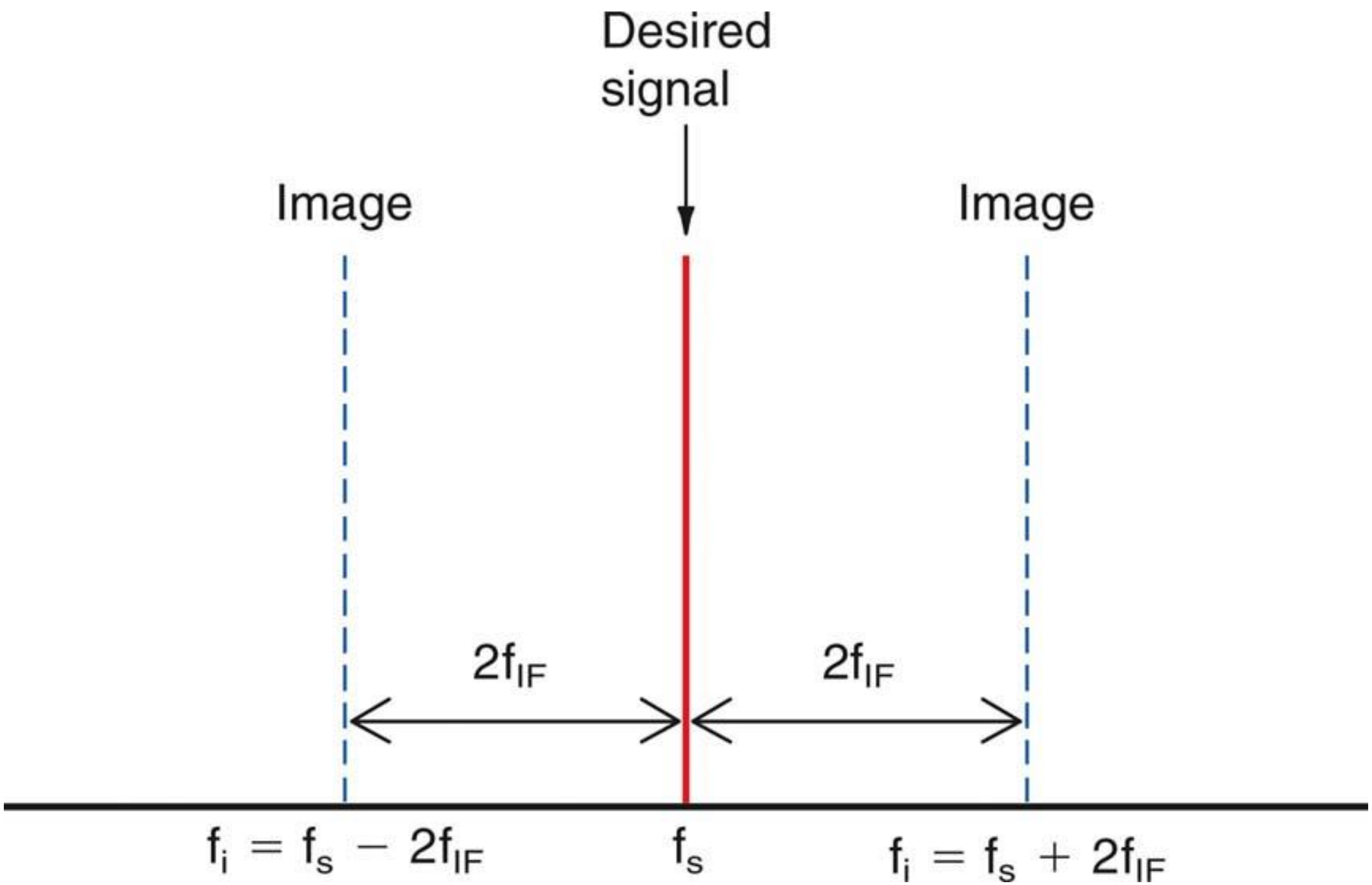


Figure : Relationship of the signal and image frequencies.

Intermediate Frequency and Images

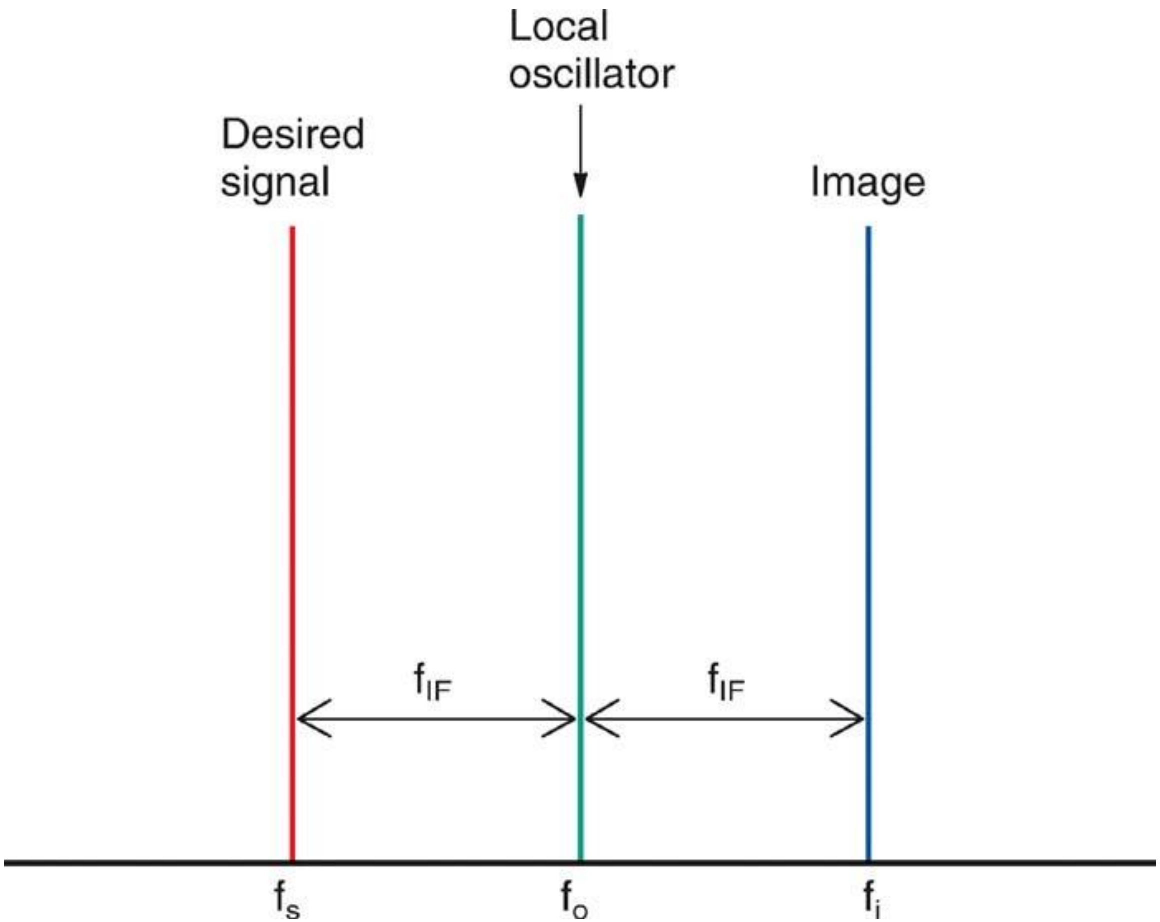


Figure : Signal, local oscillator, and image frequencies in a superheterodyne.

Intermediate Frequency and Images

Solving the Image Problem

- To reduce image interference, high-*Q* tuned circuits should be used ahead of the mixer or RF amplifier.

- The IF is made as high as possible for effective elimination of the image problem, yet low enough to prevent design problems.

- In most receivers the IF varies in proportion to the frequencies that must be covered.

Intermediate Frequency and Images

- Image frequency

  $$f_{im} = f_{RF} + 2f_{IF}$$

- Image Frequency rejection ratio

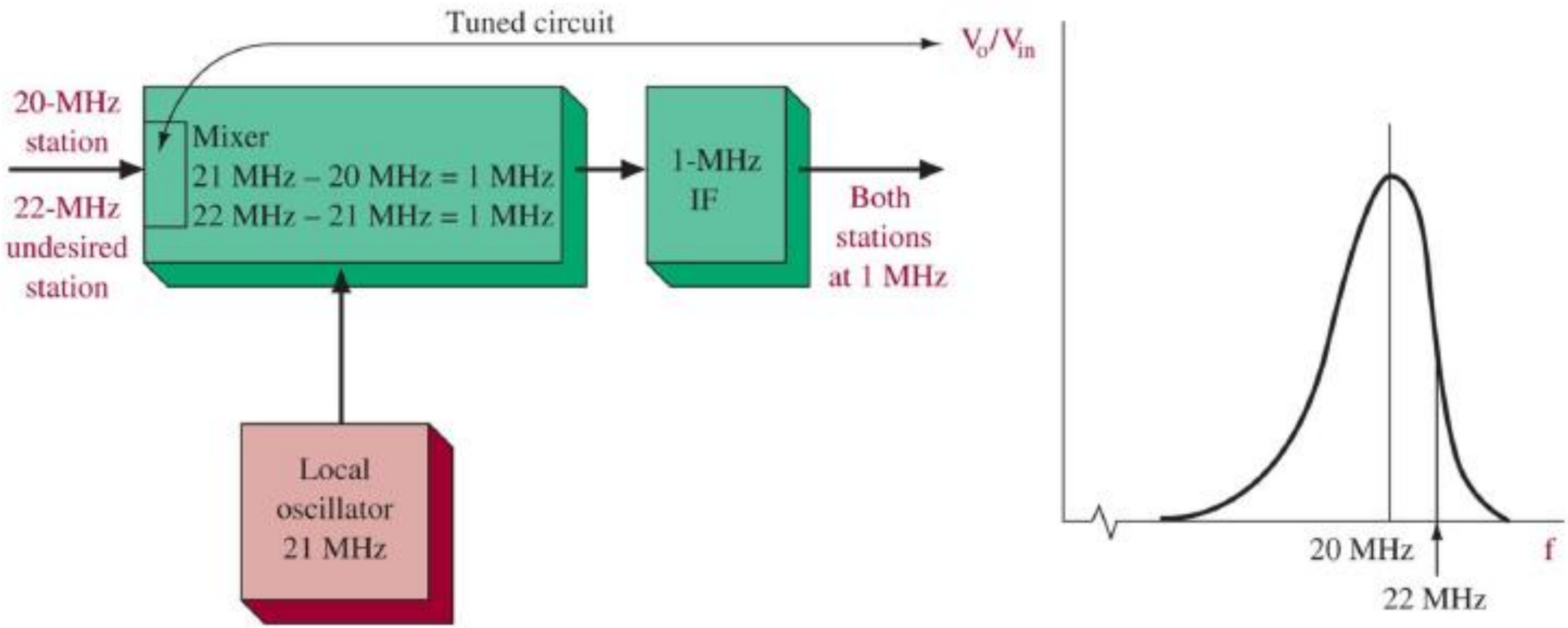
  $$IFRR = \sqrt{(1 + Q^2 \rho^2)}$$

where $\rho = (f_{im}/f_{RF}) - (f_{RF}/f_{im})$

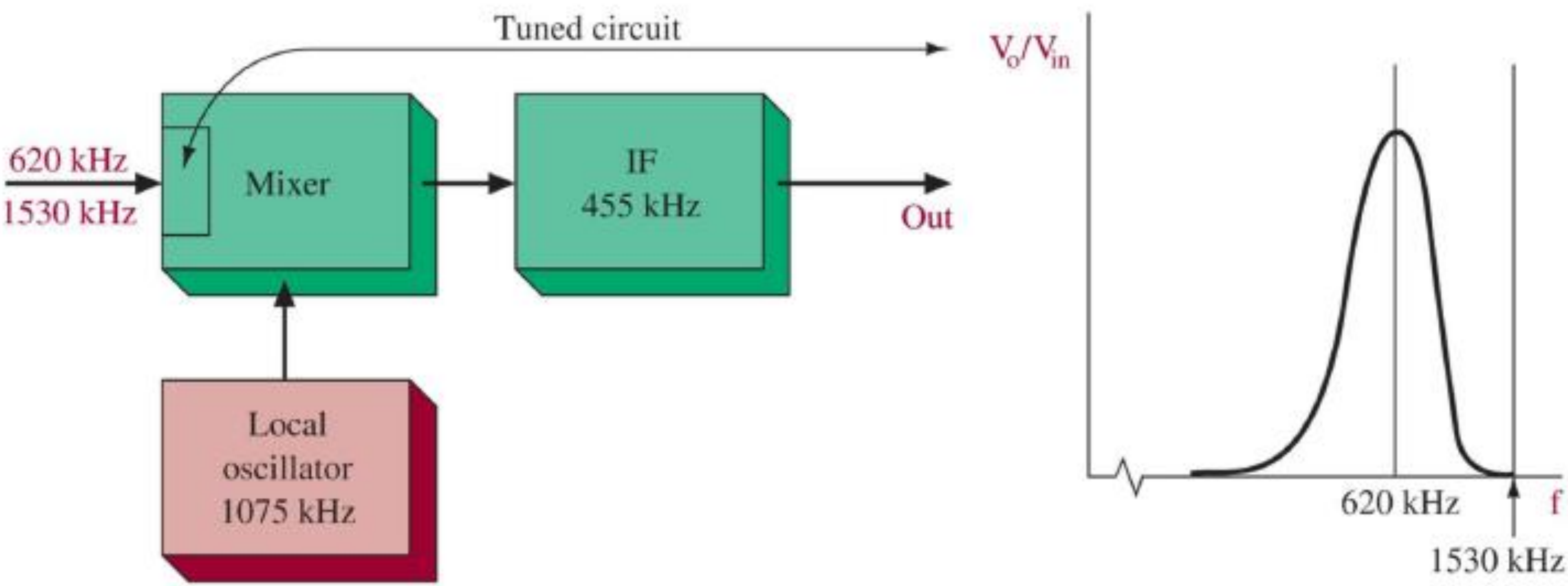
Superhereodyne Image Frequency Problem

- Frequency conversion performed by mixer-oscillator sometimes allows undesired station to be fed into IF Amplifier
  - See Fig for problem illustration
- Designing receivers with high image frequency rejection is an important design consideration
- Not a major problem on standard broadcast since stations properly spaced to allow good selectivity
  - See Fig for illustration
- If needed, *double conversion* technique can be used to solve problem

Intermediate Frequency and Images



Intermediate Frequency and Images



Intermediate Frequency and Images

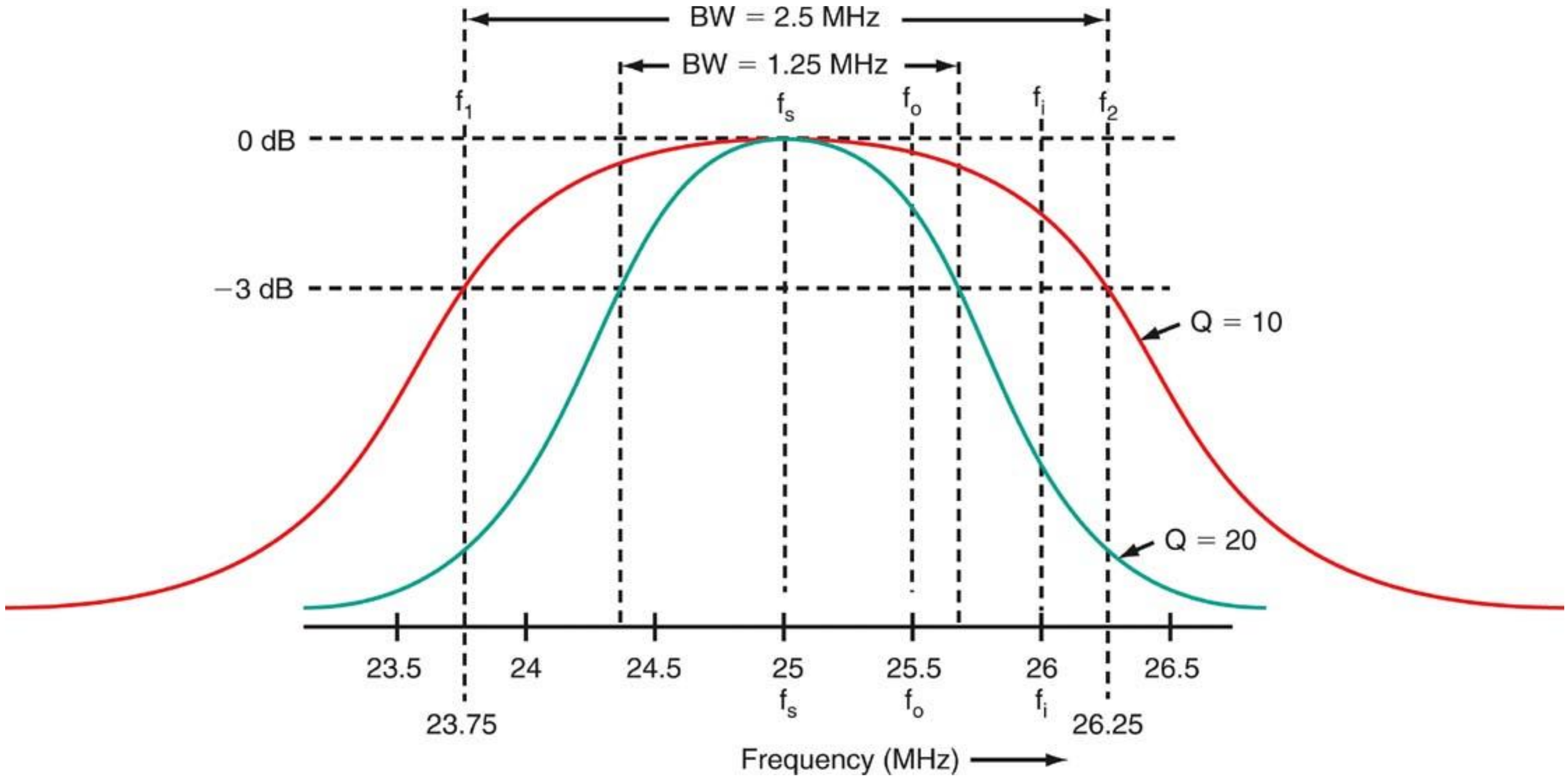


Figure : A low IF compared to the signal frequency with low-Q tuned circuits causes images to pass and interfere.

Intermediate Frequency and Images

Dual-Conversion Receivers

- Another way to obtain selectivity while eliminating the image problem is to use a **dual-conversion superheterodyne receiver.**

- A typical receiver uses two mixers and local oscillators, so it has two IFs.

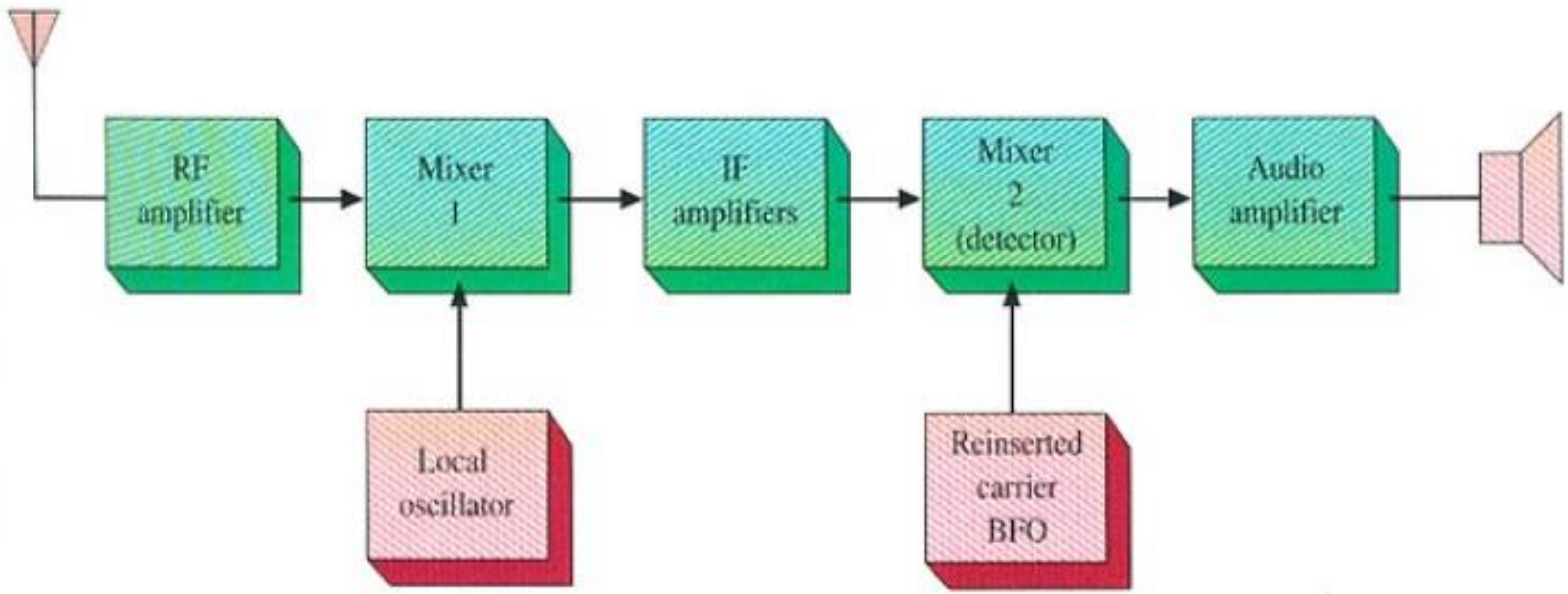
- The first mixer converts the incoming signal to a high intermediate frequency to eliminate the images.

- The second mixer converts that IF down to a much lower frequency, where good selectivity is easier to obtain.

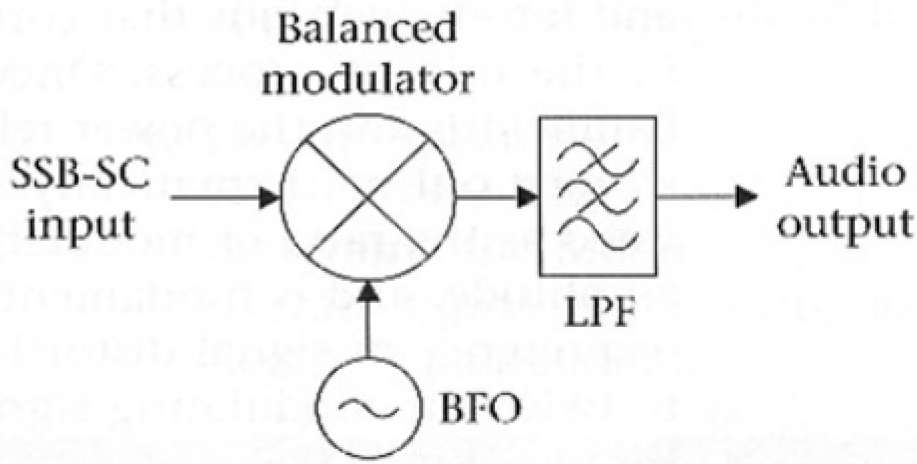
SSB Receiver

SSB Receivers (Coherent receiver)

As in the SSBSC transmission, where the carrier was suppressed at the transmitter, a carrier must be reinserted again at the receiver side for proper intelligence detection.



SSB Receiver



The detector of SSB receiver is a balanced modulator which is driven by a beat-frequency oscillator (BFO). If the BFO is at the correct frequency and phase coordination between transmitter and receiver, these two signals mix together and produce the original modulating signal.

Intermediate Frequency and Images

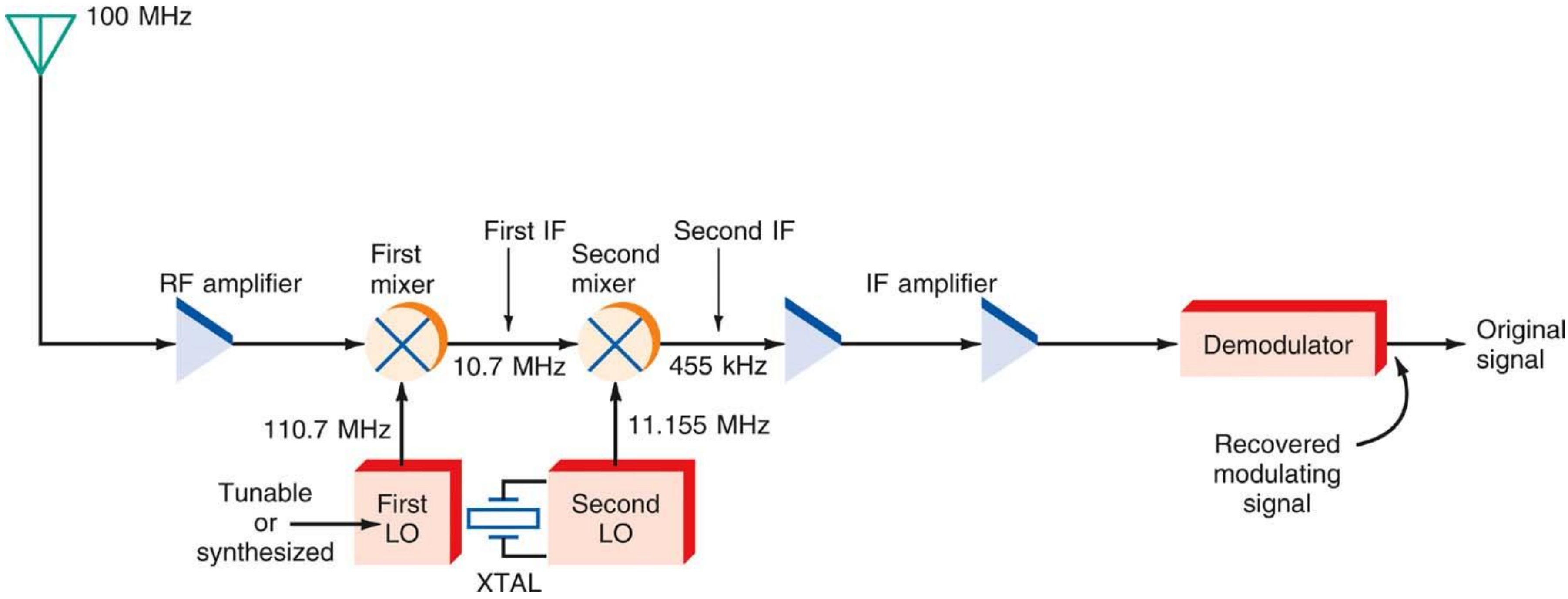


Figure : A dual-conversion superheterodyne SSB Receiver.

Choice of IF Frequency

- Practical filter bandwidths depend on Q of circuits

For an IF of 470kHz, and BW 6kHz,

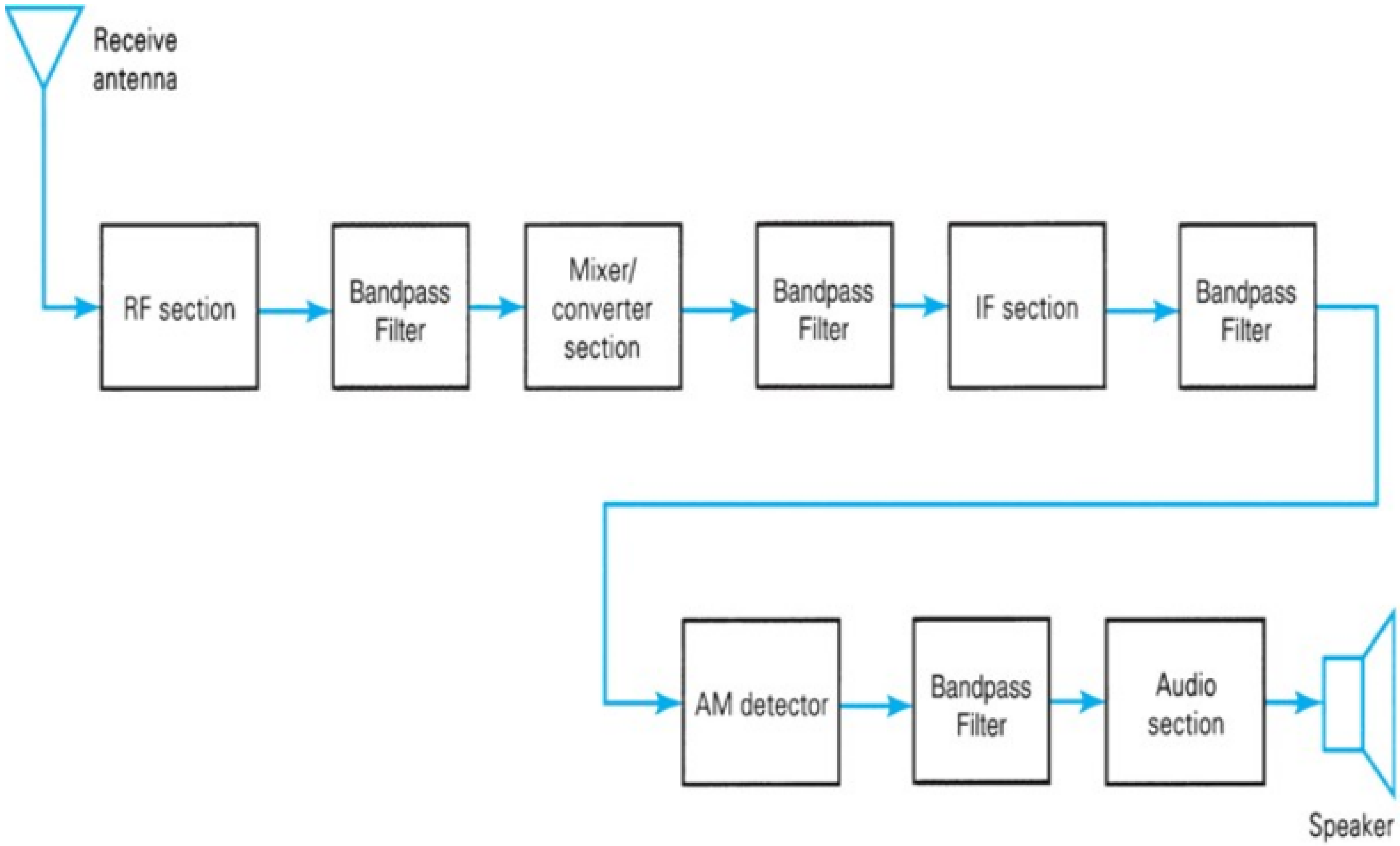
Q=470/6 = 78. Realistic with LC circuits

- Practical bandwidths for crystal filters
  - Depends on temperature drift, and initial accuracy
  - Hand-tuned crystal filters narrower but larger and cost more
- Ceramic filters also often used
- Standard frequencies are preferred 455kHz, 1.4MHz, 10.7MHz, 21.4MHz, 45MHz, 70MHz
  - Standard crystal and ceramic filters are low cost
  - Oddball frequencies & bandwidths much more expensive

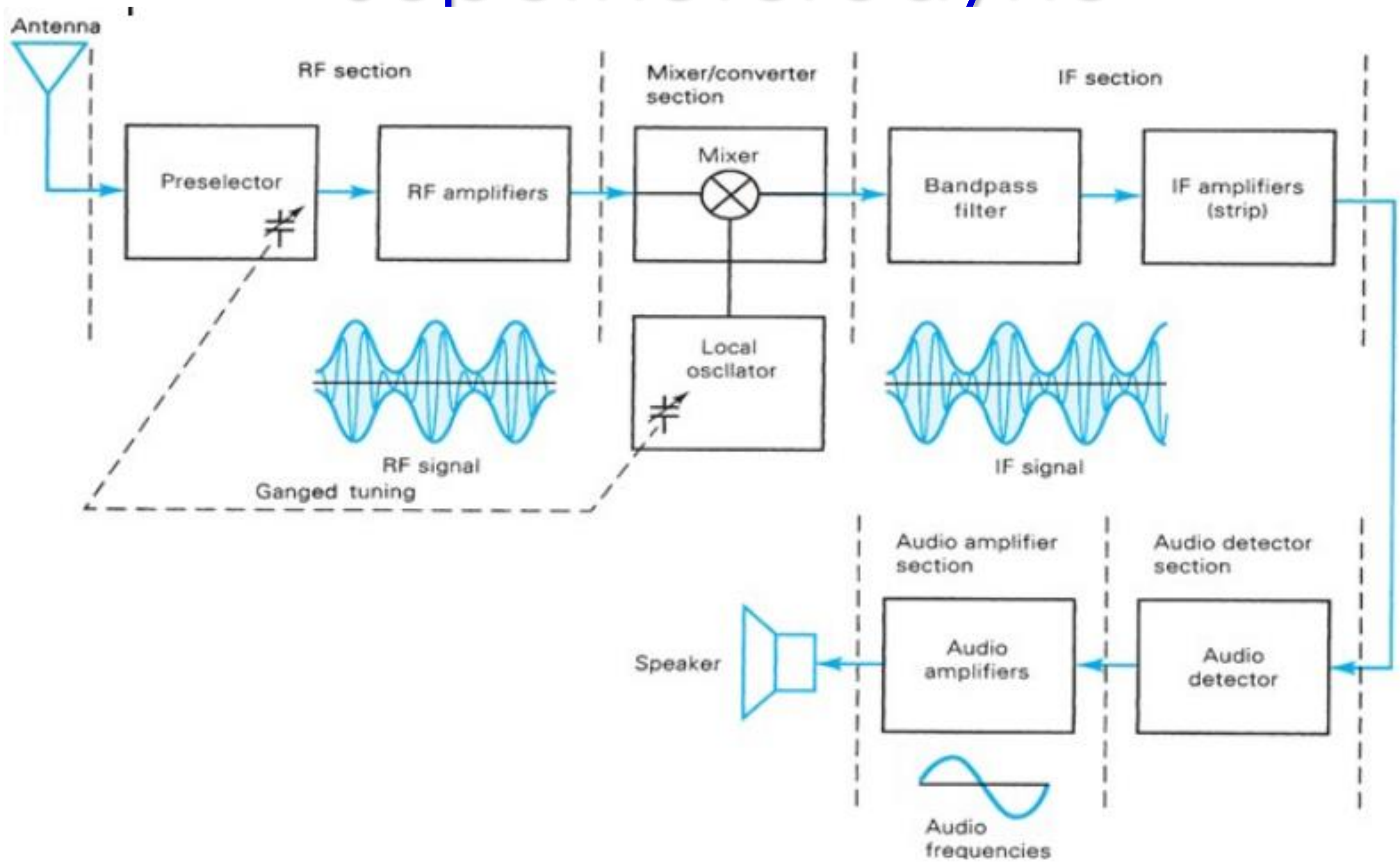
Choice of IF Frequency

- Image is 2x IF away from the wanted frequency
  - Larger IF frequency makes suppression of image easier
  - Too low an IF and the RF input filters are too difficult
  - LO radiation is also a problem if it leaks up the antenna
- Tuning range of receiver cannot cross the IF
  - Hence HF receivers often have a very high 1st IF, > 60MHz
- Realistic RF filtering usually forces the choice of 1st IF.
  - This may not be good for selectivity!
- Hence a second lower IF is often used – DUAL CONVERSION
  - High 1st IF gives good image rejection
  - Low 2nd IF gives good selectivity
- NBFM (2.5 kHz dev) demodulation also requires a low IF, 455kHz
  - For WBFM (75 kHz dev) it can be greater, 10.7 MHz

Communication Receiver – Superheterodyne (Non-coherent)

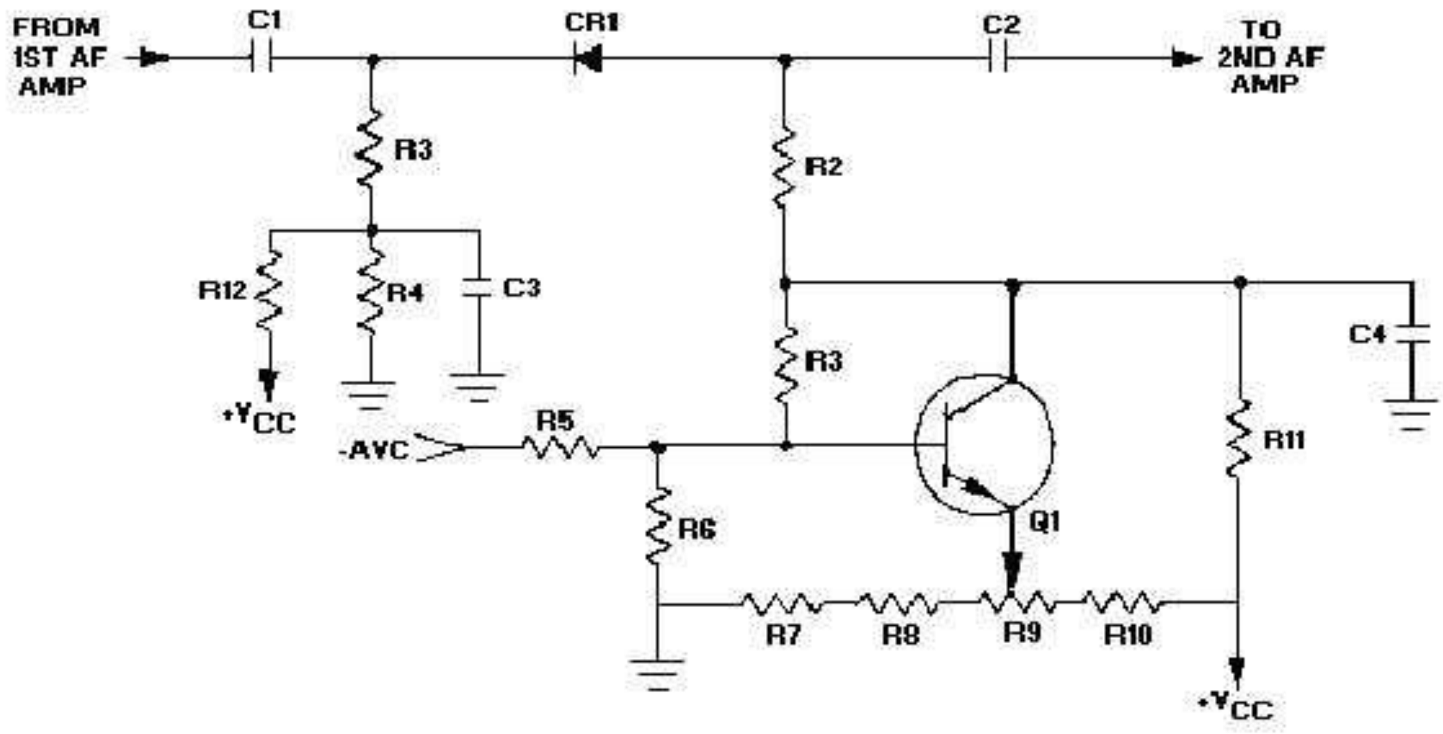


Communication Receiver - Superheterodyne



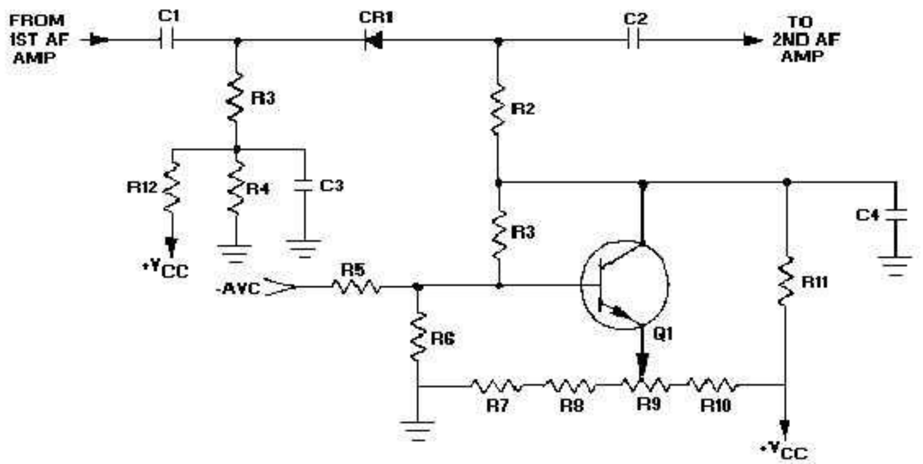
Squelch or Mute circuit

- The purpose of the squelch circuit is to quite a receiver in the absence of a received signal
- The squelch circuit amplify and rectify received noise and use the resulting DC voltage to block an amplifier circuit until a signal is received
- Tone activated mute circuits provide security and privacy



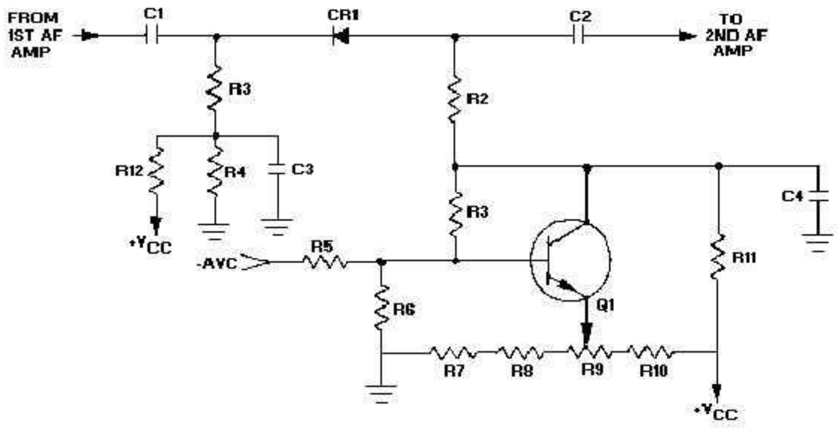
Squelch or Mute circuit

- The circuit cuts off receiver output when no input signal is being received. It accomplishes this by blocking either the detector or audio amplifier when no signal is present.
- The squelch diode CR1 connects the output of the first AF stage to the input of the second. Amplifier Q1 serves as the control transistor for the circuit.
- The anode and cathode voltages of CR1 are normally biased positive with respect to ground. With no input signal, R9 is adjusted until Q1 draws enough collector current to reduce its collector voltage and the anode voltage of CR1 to a value below the voltage on the cathode of CR1.



Squelch or Mute circuit

- At this point the anode voltage of the squelch diode is negative with respect to its cathode, and conduction ceases. Audio output is now reduced to zero and the receiver is silent.
- The base of Q1 is connected to the automatic volume control (avc) line. Anytime a signal enters the receiver, a negative avc voltage is applied to the base of Q1.
- This reduces the collector current and increases the collector voltage, which in turn increases the anode voltage of CR1 until the anode becomes positive with respect to the cathode.
- Once again diode CR1 will conduct, and the signal will be passed to the second af amplifier. Diode CR1 is effectively a switch controlled by the avc voltage.



Receiver Analysis