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DECLARATION

This project we did through the whole semester is done by us and we maintained regular communication with our supervisor and showed him our work and progress regularly.

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ACKNOWLEDGEMENT

We are dedicatedly grateful and thankful to our supervisor Dr. Ahmed Kamal. Without whom we would not have been able to learn and do such a significant task. And thanks for his belief that we can make this project successful.

First we were worried because we did not have a co-adviser.

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THESIS TITLE:

**Development of a Prototype Voice Communication
System**

ABSTRACT

A cellular voice communication system is developed using two transceiver (handsets).The RF components of the handsets were collected and integrated with proper care. Our focus was on integrating RF transceivers operating at FM bands. The transceiver is consisting of cutting-edge multi-band antennas, amplifiers, mixers etc. which was individually and collectively searched and combined by us.

Radio frequency Front End:

The RF front end is generally defined as everything between the antenna and the digital baseband system.

For a receiver, this "between" area includes all the filters, low-noise amplifiers (LNAs), and down-conversion mixer(s) needed to process the modulated signals received at the antenna into signals suitable for input into the baseband analog-to-digital converter (ADC). For this reason, the RF front end is often called the analog-to-digital or RF-to-baseband portion of a receiver. Radios receive RF waves which contains previously modulated information sent by a RF transmitter. Receiver is basically a low noise amplifier that down converts the incoming signal. Hence, Sensitivity and selectivity are the tow primary concerns to design a receiver.

Transmitter up converts the outgoing signal prior to passage through a high power amplifier. Non-linearity is the primary concern for a transmitter. With these differences, the design of the receiver front end and the design of the transmitter back end share many common elements like local oscillators.

After the advanced design and manufacture of integrated circuits (ICs), some of the traditional analog IF signal processing tasks can be handled digitally. These analog tasks like filtering and up-down conversion are handled by digital filters and digital signal processors (DSPs). Texas Instruments have coined the term digital radio processors for this type of circuits.

Why Front End is so important?

This is possibly the most critical part of the whole receiver. Trade-offs in overall system performance, power consumption, and size are determined between the receiver front end and the ADCs in the baseband (middle end). The analog front end sets the stage for what digital bit-

error-rate (BER) performance is possible at final bit detection. It is here that the receiver can, within limits, be designed for the best potential signal to noise ratio (SNR).

RF Applications:

1. Radio
2. Cellular phone
3. Wired telephony system



Oscillator:

Basically we will describe LC oscillator because we have made a type of LC oscillator in this semester from many experimental circuits.

LC Oscillator:

This oscillator consists of a capacitor and a coil connected in parallel. To understand how the LC oscillator basically works, let's start off with the basics. Suppose a capacitor is charged by a battery. Once the capacitor is charged, one plate of the capacitor has more electrons than the other plate, thus it is charged. Now, when it is discharged through a wire, the electrons return to the positive plate, thus making the capacitor's plates neutral, or discharged. However, this action works differently when you discharge a capacitor through a coil. When current is applied through a coil, a magnetic field is generated around the coil. This magnetic field generates a voltage across the coil that opposes the direction of electron flow. Because of this, the capacitor does not discharge right away. The smaller the coil, the faster the capacitor discharges. Now the

interesting part happens. Once the capacitor is fully discharged through the coil, the magnetic field starts to collapse around the coil. The voltage induced from the collapsing magnetic field recharges the capacitor oppositely. Then the capacitor begins to discharge through the coil again, generating a magnetic field. This process continues until the capacitor is completely discharged due to resistance.

Example:

1. Hartley Oscillator
2. Colpitts Oscillator
3. Chaotic Colpitts Oscillator

Colpitts Oscillator

A **Colpitts oscillator**, named after its inventor *Edwin H. Colpitts*, is one of a number of designs for electronic oscillator circuits using the combination of an inductance (L) with a capacitor (C) for frequency determination, thus also called LC oscillator. The distinguishing feature of the Colpitts circuit is that the feedback signal is taken from a voltage divider made by two capacitors in series. One of the key features of this type of oscillator is its simplicity (needs only a single inductor) and robustness.

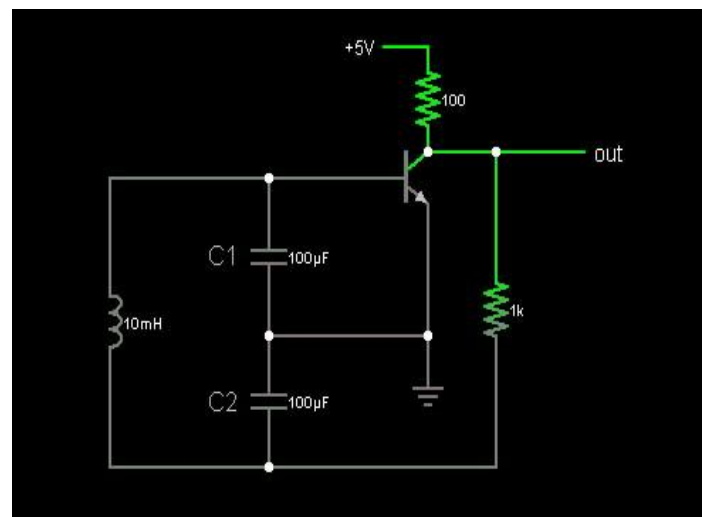


Fig: Colpitts oscillator

The fundamental frequency,

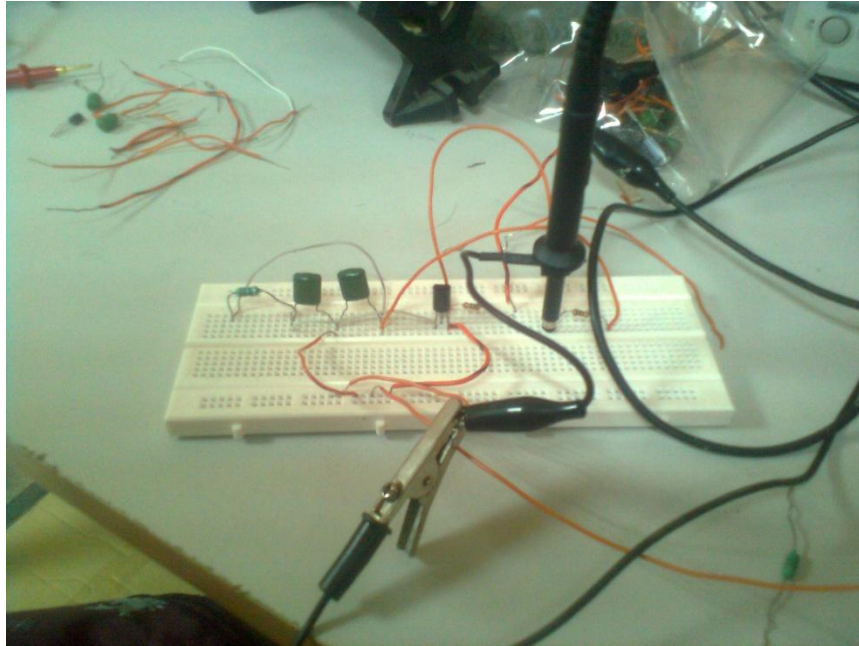
$$f_0 = \frac{1}{2\pi \sqrt{L \cdot \left(\frac{C_1 \cdot C_2}{C_1 + C_2}\right)}}$$

A Colpitts oscillator is the electrical dual of a Hartley oscillator. Above figure shows the basic Colpitts circuit, where two capacitors and one inductor determine the frequency of oscillation. The feedback needed for oscillation is taken from a voltage divider made of two capacitors, whereas in the Hartley oscillator the feedback is taken from a voltage divider made of two inductors.

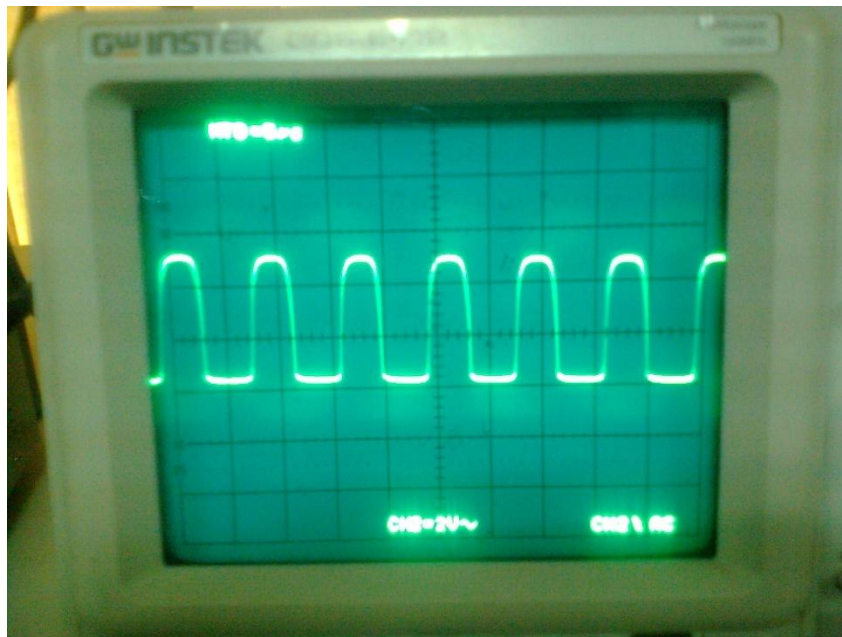
As with any oscillator, the amplification of the active component should be marginally larger than the attenuation of the capacitive voltage divider, to obtain stable operation. Thus, a Colpitts oscillator used as a variable frequency oscillator (VFO) performs best when a variable inductance is used for tuning, as opposed to tuning one of the two capacitors. If tuning by variable capacitor is needed, it should be done via a third capacitor connected in parallel to the inductor.

Working principle of Colpitts Oscillator

When the collector supply voltage V_{cc} is switched on, the capacitors C_1 and C_2 are charged. These capacitors C_1 and C_2 discharge through the coil L , setting up oscillations of frequency $f = 1 / 2\pi \sqrt{L \left[\frac{1}{C_1} + \frac{1}{C_2} \right]}$. The oscillations across capacitor C_2 are applied to the base-emitter junction and appear in the amplified form in the collector circuit. Of course, the amplified output in the collector circuit is of the same frequency as that of the oscillatory circuit. This amplified output in the collector circuit is supplied to the tank circuit in order to meet the losses. Thus the tank circuit is getting continuously energy from the circuit to make up for the losses occurring in it and, therefore, ensures undamped oscillations. The energy supplied to the tank circuit is of correct phase, as already explained and if $A\beta$ exceeds unity, oscillations are sustained in the circuit.



Colpitts oscillator made by us



Output of above figure

Transmitter Tunability

We have found mono, microphone-type transmitters, and/or are not adjustable as in like how our fm transmitter has a tuning knob. Yes, it is tunable with some inductor/tune and set pot, but once set they are set almost permanently. Then there are those that are (tunable), but require large amounts of power and are not portable.

The simple FM transmitters connect their antenna directly to the LC tuned circuit so the frequency changes when something moves toward or moves away.

It does not have a voltage regulator so the frequency also changes as the battery runs down.

It does not have pre-emphasis (treble boost) like all FM radio stations have so their sound heard on an FM radio (they all have de-emphasis) is muffled like your stereo with its treble tone control turned all the way down.

The audio signal, after coming through the DC filtering capacitor pulses at the base electrode of the transistor with any additional power from the power rail. Note: In FM transmitter, we have the biasing of the transistor's base electrode affected by the 47k resistor and 1nf capacitor.

A capacitor with an inductor is known as a LC Circuit, or a tank circuit. A tank circuit creates the carrier wave frequency that the audio signal is then "imprinted on". Since the red trimmer cap is tunable (variable capacitor), we are guessing that this is the LC circuit that does just this. As you tune to specific frequencies by changing the capacitance, your FM radio is able to pick up whatever is resonant.

In our transmitter the additional 10pf capacitor allows us to tune the transmitter in the 98MHz to 105MHz.

So this signal amplifies/modulates the carrier wave frequency set by the carrier wave, and in FM transmitter - that mixed signal heads off to the antenna.

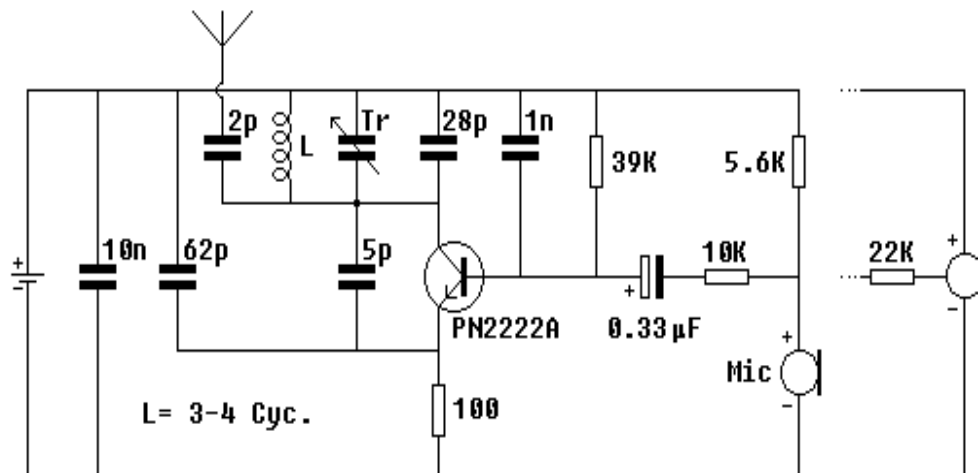
We calculate the frequency by using this formula,

$$f = \frac{1}{2\pi\sqrt{LC}}$$

Simple FM Transmitter with a Single Transistor:

Mini FM transmitters take place as one of the standard circuit types in an amateur electronics fan's beginning steps. When done right, they provide very clear wireless sound transmission through an ordinary FM radio over a remarkable distance. We've seen lots of designs through the whole semester, some of them were so simple, some of them were powerful, some of them were hard to build etc.

Here is the last step of this evolution, the most stable, smallest, problem less, and energy saving champion of this race. Circuit given below will serve as a durable and versatile FM transmitter till you break or crush it's PCB. Frequency is determined by a parallel L-C resonance circuit and shifts very slow as battery drains out.



Simple FM Transmitter, 30/50 meters range, operates with 1.5V

Simple FM Transmitter involves on a single transistor oscillator

Technical Data:

Supply voltage : 1.1 - 3 Volts
Power consumption : 1.8 mA at 1.5 Volts
Range : 30 meters max. at 1.5 Volts

Main advantage of this circuit is that power supply is a 1.5Volts cell (any size) which makes it possible to fix PCB and the battery into very tight places. Transmitter even runs with standard NiCd rechargeable cells, for example a 750mAh AA size battery runs it about 500 hours (while it drags 1.4mA at 1.24V) which equals to 20 days. This way circuit especially valuable in amature spy operations.

Transistor is not a critical part of the circuit, but selecting a high frequency / low noise one contributes the sound quality and range of the transmitter. PN2222A, 2N2222A, BFxxx series, BC109B, C, and even well known BC238 runs perfect. Key to a well functioning, low consumption circuit is to use a high hFE / low C_{eb} (internal junction capacity) transistor.

Not all of the condenser microphones are the same in electrical characteristics, so after operating the circuit, use a 10K variable resistance instead of the 5.6K, which supplies current to the internal amplifier of microphone, and adjust it to an optimum point where sound is best in amplitude and quality. Then note the value of the variable resistor and replace it with a fixed one.

The critical part is the inductance L which should be handmade. Get an enameled copper wire of 0.5mm (AWG24) and round two loose loops having a diameter of 4-5mm. Wire size may vary as well. Rest of the work is much dependent on your level of knowledge and experience on inductances: Have an FM radio near the circuit and set frequency where no reception is. Apply power to the circuit and put a iron rod into the inductance loops to chance its value. When you find the right point, adjust inductance's looseness and, if required, number of turns. Once it works, trimmer capacitor can be used to make further frequency adjustments. Do not forget to fix inductance by pouring some glue onto it against external forces. If the reception on the radio lost in a few meters range, than it's probably caused by a wrong coil adjustment and you are in fact listening to a harmonic of the transmitter instead of the center frequency. Place radio far away from the circuit and re-adjust. An oscilloscope would make it easier, if you know how to use it in this case.

Components List:

| | |
|----------------|------------|
| 10n Ω | |
| 62p Ω | |
| 5p Ω | |
| 2p Ω | |
| L | 3-4 cycles |
| Trimmer | 10-50Pf |
| 28p Ω | |
| 1n Ω | |
| 39k Ω | |
| 0.33uF | |
| 10k Ω | |
| 5.6k Ω | |
| 22k Ω | |
| PN2222A | |
| 100 Ω | |
| microphone | |
| Voltage source | 1.5 volts |

Working Principle of Transmitter

The transistor does the oscillation as well as the amplification

Amplification:

FM amplification describes a technology that uses wireless radio frequencies to transmit audio signals directly into hearing aids. Typically, the signal of interest is speech, although other audio sources such as television, music, theater, church, etc., might also be transmitted by the frequency modulated(FM) system. Although the hearing aid itself is, of course, the most common means of providing personal amplification for the hearing impaired person, a major drawback is the need for the person speaking to be close by for clarity of amplification. A second drawback to hearing aid use is that the hearing aid amplifies background noise which is an extremely irritating factor because it masks the clarity of the desired signal. FM amplification represents the best solution to these hearing aid problems. A wireless microphone is worn near the speaker's mouth, or placed near the desired audio source, and the desired acoustic signal is transmitted directly into the hearing aid(s) by radio frequency. Through the Microphone the input voice signals is collected and send through the filter capacitance of 0.33uF which is a positive feedback of the transistor and send to the base where it amplifies the signal. And the signal is later send to oscillation. Other components of the amplification part help the signal to filter and also aid the amplification process.

An audio amplifier is design to amplify audio frequency signals. These frequencies are generally considered to range from about 20 to 20000cps. Since these frequencies are in the range of hearing of the human ear, audio amplifiers are associated with voice or other sound signals. There are two basic types of amplifiers -

1. Audio Voltage
2. Voltage Amplifier

The difference between the two is the amount of power contained in the output signal. Voltage amplifiers deliver high-voltage, low power output while power amplifiers deliver large amounts of power. Frequently, the two are used together with the voltage amplifier increasing the signal-voltage amplitude to the required level, and the power amplifier then receiving this signal as an input and delivering as an output a signal that contains sufficient current to drive an audio output device such as a loudspeaker.

Oscillation:

The parallel L-C resonance circuit with the timer does the actual oscillation. The amplified signal is collected from the collector of the PN2222a and it goes through oscillation. The L here is of 3-4 turns/cycles and the 2p, together make our Resonance circuit where the oscillation happens. The timer parallel to it helps decipher the desired frequency and which makes the circuit tunable. Through the _ antenna, we finally transmit our voice input, which can be received by tuning on the transmitted channel which in our case is 98.0-98.3Mhz channel on a FM radio receiver. Other entity on the collector and emitter helps the transistor to work properly and enhances the oscillation process.

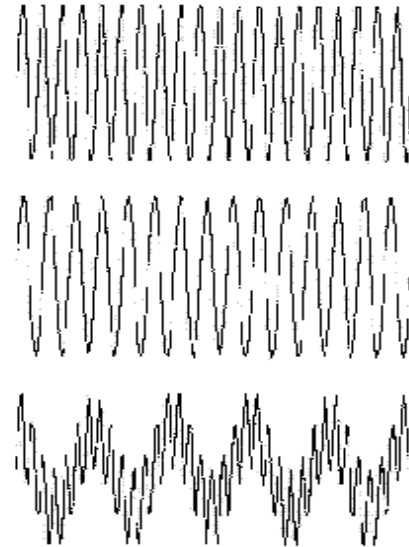
RF Mixing:

RF mixing is one of the key processes within RF technology and RF design. RF mixing enables signals to be converted to different frequencies and thereby allowing the signals to be processed more effectively.

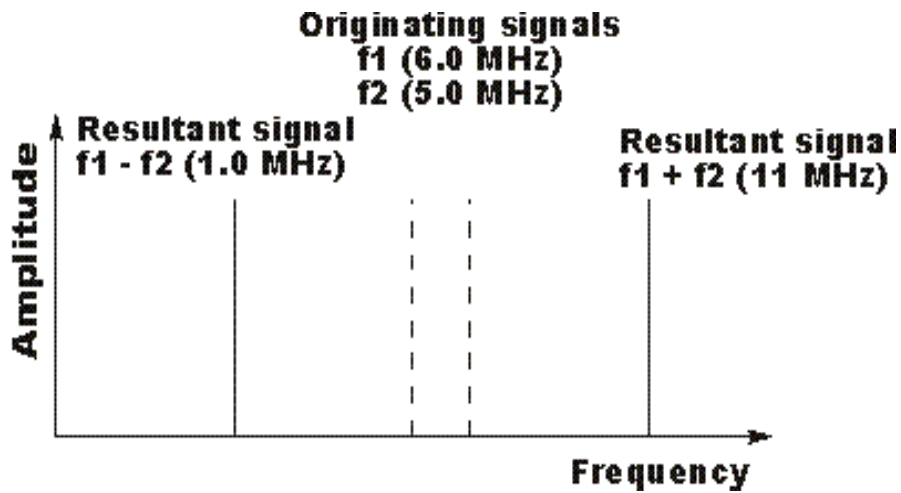
In view of the importance of RF mixing, there are many basic RF mixer circuits available, but in addition to this there are many high performance RF mixers that are available on the market. These RF mixers have very high levels of specification and perform to very high standards.

Radio frequency or RF mixing is a non-linear process that involves the instantaneous level of one signal affecting the level of the other at the output. This process involves the two signal levels are multiplying together at any given instant in time and the output is a complex waveform consisting of the product of the two input signals.

In the diagram, the top two traces show the input signals to the RF mixer, and the bottom trace shows the output from the RF mixer. Looking at a plot or oscilloscope trace of the output it can be imagined that signals on different frequencies are produced, and this is in fact the case.

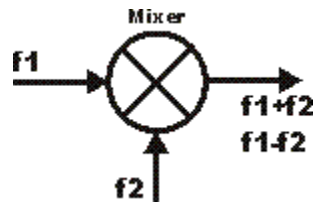


When two signals enter an RF mixer and are mixed together, new signals are seen at frequencies that are the sum and difference of the two input signals, i.e. if the two input frequencies are f_1 and f_2 , then new signals are seen at frequencies of (f_1+f_2) and (f_1-f_2) . To take an example, if two signals, one at a frequency of 5 MHz and another at a frequency of 6 MHz are mixed together then new signals at frequencies of 11 MHz and 1 MHz are generated.



The RF mixing process

When added to a circuit diagram, an RF mixer is often denoted by a circle with a cross in it as shown below. As can be seen, there are the two inputs and one output as shown.



Circuit symbol for an RF mixer

RF Mixer Mathematics

It is possible to easily represent the action of an RF mixer mathematically. The two input waveforms are represented by simple sine waves, and these are multiplied together. By expanding the resulting waveform using standard trigonometric processes, it is possible to deduce what the output is.

If the input waveforms are taken as:

$$\begin{aligned} V1 &= A \sin (2 \pi f1 t) \\ V2 &= B \sin (2 \pi f2 t) \end{aligned}$$

Then it is necessary to use the trigonometrically expression:

$$\sin (a) \times \sin (b) = 1/2 [\cos (A - B) - \cos (A + B)]$$

Applying this to the input waveforms, i.e. multiplying them together in the RF mixer, the output is then:

$$V1 \times V2 = (A \times B) / 2 [\cos (2 \pi \{f1 - f2\} t) - \cos (2 \pi \{f1 + f2\} t)]$$

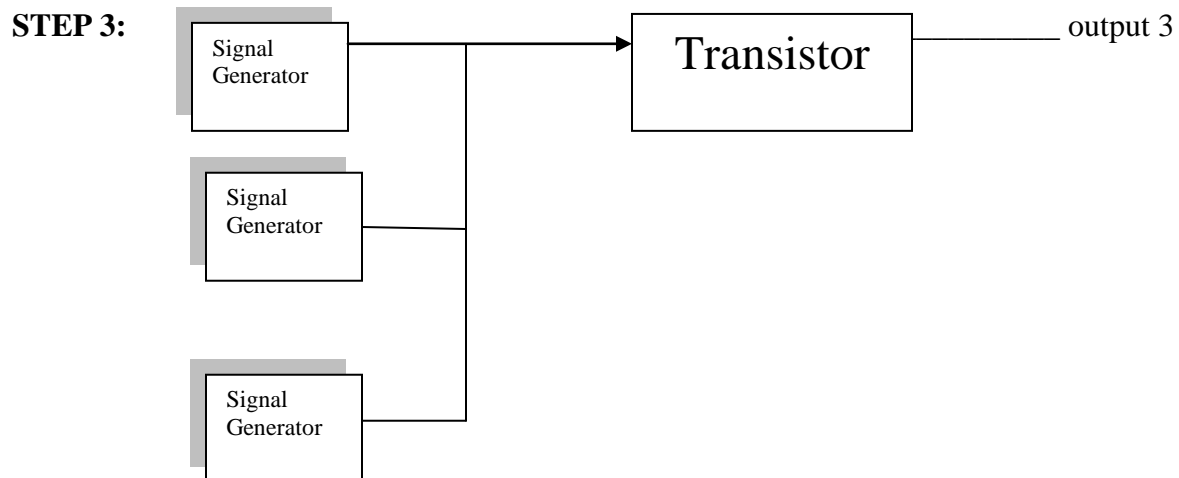
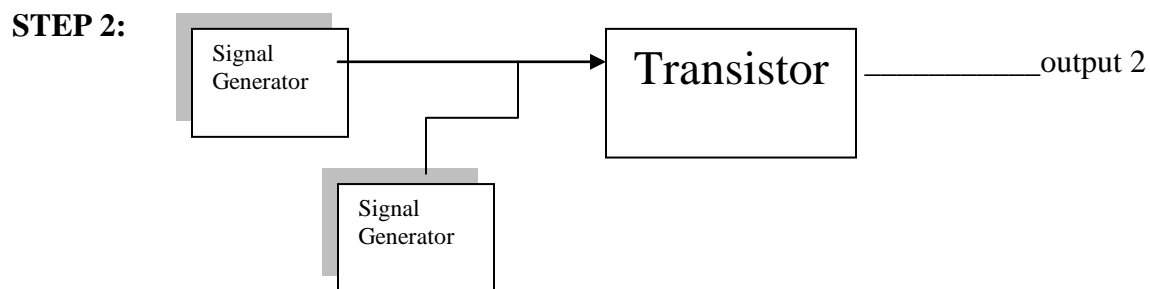
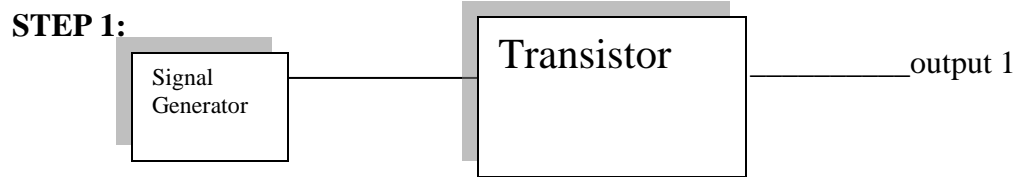
From this it can be seen that the two terms: (f1 - f2) and (f1 + f2) can be seen, and these represent the sum and difference frequencies that are seen on the traces above.

RF Mixer Summary

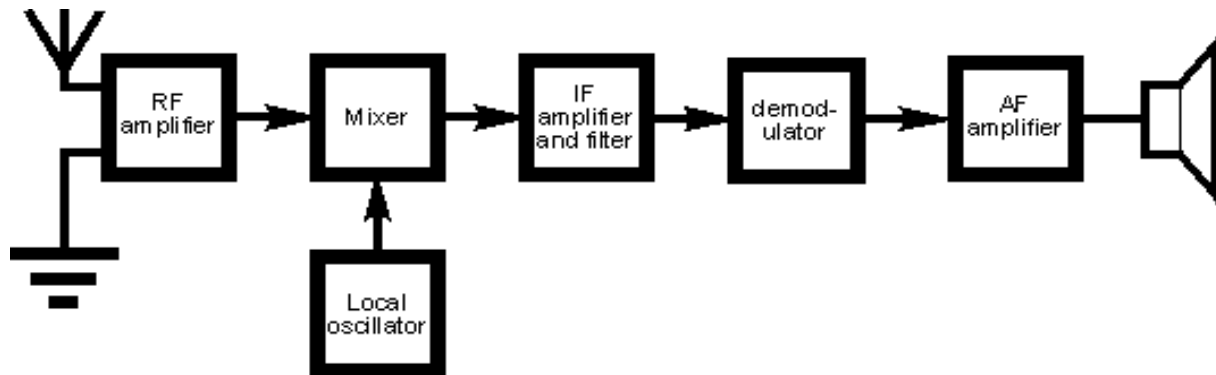
RF mixers are particularly useful components for any RF design or item of RF equipment. RF mixers are widely used as either circuit built using discrete components, or they may be bought as circuit items ready for inclusion in an RF circuit or RF design. These RF mixer block are normally high performance items and may save considerable amounts of time designing and constructing an RF mixer to an equivalent level of performance.

RF mixers are important components for RF design. The correct operation of an RF mixer is essential to any RF design, and part of this process is to ensure that the correct RF mixer specification is generated to choose the correct component for the particular RF design or circuit. In view of the high levels of performance required in some RF circuits and RF designs, it is often appropriate to buy RF mixers as components from specialist suppliers. These RF mixers are able to provide very high levels of performance and normally better than those that could be obtained by using discrete components on a circuit board.

When determining the correct RF mixer for a particular RF design or circuit, there are a few key RF mixer specifications that need to be known. Some are easy to define, but others may need a little more knowledge of the particular circuit of RF design being undertaken.



Superheterodyne Receiver Radio Block Diagram



Functionality

Signals enter the front end circuitry from the antenna. This contains the front end tuning for the superhet to remove the image signal and often includes an RF amplifier to amplify the signals before they enter the mixer. The level of this amplification is carefully calculated so that it does not overload the mixer when strong signals are present, but enables the signals to be amplified sufficiently to ensure a good signal to noise ratio is achieved.

The tuned and amplified signal then enters one port of the mixer. The local oscillator signal enters the other port. The local oscillator may consist of a variable frequency oscillator that can be tuned by altering the setting on a variable capacitor. Alternatively it may be a frequency synthesizer that will enable greater levels of stability and setting accuracy.

Once the signals leave the mixer they enter the IF stages. These stages contain most of the amplification in the receiver as well as the filtering that enables signals on one frequency to be separated from those on the next. Filters may consist simply of LC tuned transformers providing inter-stage coupling, or they may be much higher performance ceramic or even crystal filters, dependent upon what is required.

Once the signals have passed through the IF stages of the superheterodyne receiver, they need to be demodulated. Different demodulators are required for different types of transmission, and as a result some receivers may have a variety of demodulators that can be switched in to accommodate the different types of transmission that are to be encountered. The output from the

demodulator is the recovered audio. This is passed into the audio stages where they are amplified and presented to the headphones or loudspeaker

Frequency modulation is used in radio broadcast in the bandwidth range from 88 MHz till 108 MHz. This range is being marked as “FM” on the band scales of the radio receivers, and the devices that are able to receive such signals are called the FM receivers.

FM receivers are used for the reception and reproduction of frequency modulated signals. On a block diagram level, they are somewhat similar to AM superheterodyne receivers. This can be seen from the basic FM receiver shown. The FM signal to be received is selected and amplified by an RF amplifier. It is then converted, with no loss of intelligence, to receiver’s intermediate frequency by a mixer and local oscillator. The IF signal has constant amplitude and varies above and below the intermediate frequency in accordance with the modulation. In other words, the center frequency of the FM signal is converted to the receiver’s intermediate frequency.

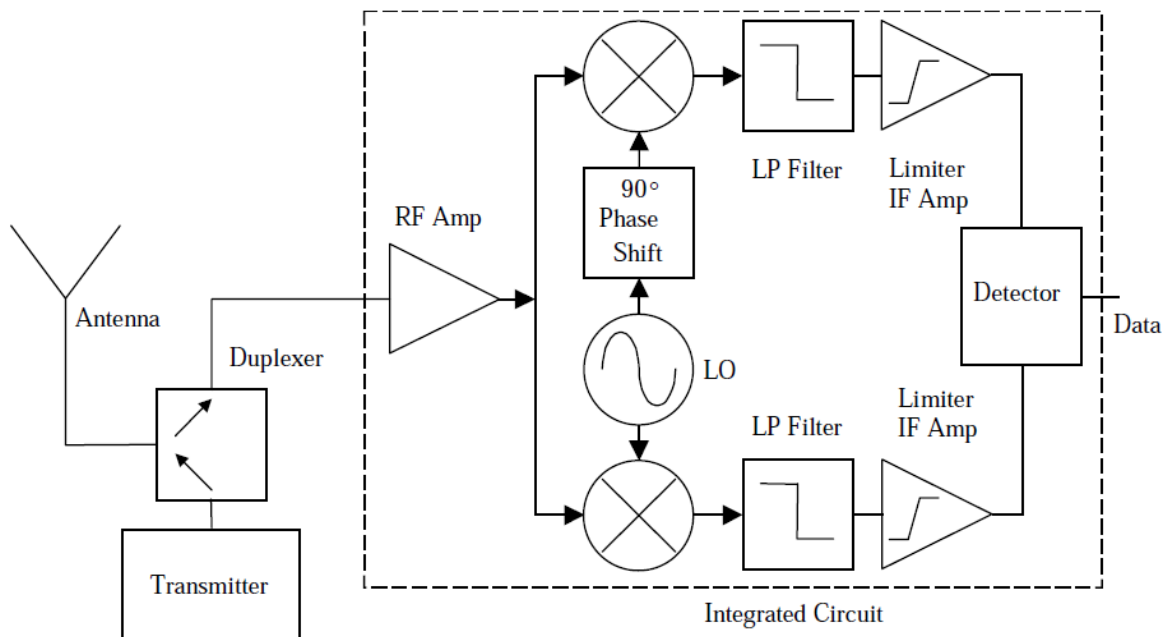
The IF signal is amplified by a series of IF amplifiers, then applied to an FM detector. The detector converts the frequency variations of the IF signal into a corresponding audio signal, then feeds this signal to a de-emphasis network. The de-emphasis process is essentially the reverse of the preemphasis process accomplished at the FM transmitter. The de-emphasis network restores the relative amplitudes of the signal’s frequency components to what they were before preemphasis was carried out. It does this by delivering a greater output at the lower frequencies than it does at higher ones. After deemphasis, the audio signal is amplified and applied to a speaker.

Homodyne (Zero IF) Receiver

A homodyne, direct conversion, or zero-IF (no intermediate frequency) receiver translates the desired RF frequency directly to baseband for information recovery. Baseband is the range of frequencies occupied by the signal before modulation or after demodulation.

Baseband signals are typically at frequencies substantially below the carrier frequencies.

On the low end of baseband, signals may approach or include DC. The upper frequency limit of baseband depends on the data rate, or speed, at which information is sent, and whether or not special signals called subcarriers are utilized. Figure 1 shows an example block diagram of a zero-IF receiver architecture. A nonlinear circuit known as a mixer translates the RF frequency directly to baseband. A local oscillator (LO) signal, tuned to the same frequency as the desired RF signal, is injected into the mixer. The RF and LO signals mix to produce the baseband frequency. Some digital radios also employ an I/Q mixer to recover baseband information. When translating directly from RF to baseband, a DC component (along with the bandlimited information signal) is realized at the output of the mixer. The DC component (or DC-offset) must be removed to prevent large DC pulses from de-sensitizing the baseband demodulator. The system can either be AC-coupled or incorporate some form of DC notch filtering after the mixer. The system can either be AC-coupled or incorporate some form of DC notch filtering after the mixer.



The zero-IF receiver can provide narrow baseband filtering with integrated low-pass (LP) filters. Often, the filters are active op-amp-based filters known as gyrators. The gyrators provide protection from most undesired signals. The gyrator filters eliminate the need for expensive crystal and ceramic IF filters, which take more space on a printed circuit board.

The zero-IF topology offers the only fully integrated receiver currently possible. This fully integrated receiver solution minimizes required board real estate, the number of required parts, receiver complexity, and cost. Most zero-IF receiver architectures also do not require image reject filters, thus reducing cost, size, and weight.

Zero-IF receiver limitations require tighter frequency centering of the LO and RF frequencies. Significant offsets in the RF or LO frequencies degrade bit error rate. When the desired signal is above the VHF range, the zero-IF design becomes more complex, partially due to these frequency offset problems. One solution for higher frequency zero-IF designs is to add automatic frequency control (AFC). AFC prevents the centering problem by adjusting the frequency of the LO automatically.

Performance is typically limited in a zero-IF architecture in several ways. Sensitivity and rejection to some undesired signals, such as intermodulation distortion, can be difficult to achieve. The active gyrator filters compress with some large undesired signals. Once the gyrator is compressed, filter rejection is reduced, thus limiting protection. Zero-IF receivers typically require an automatic gain control (AGC) circuit to protect against large signal interference that compresses the gyrator filters.

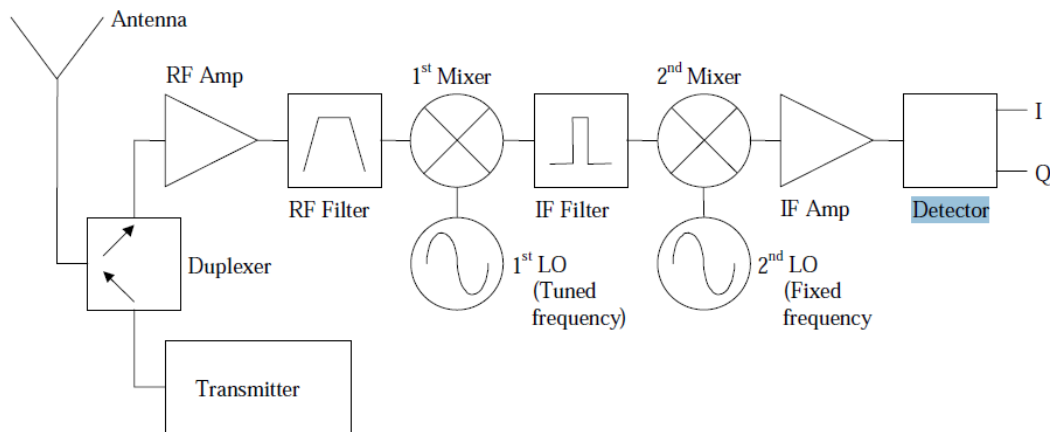
Because the local oscillator is tuned to the RF frequency, self-reception may also be an issue. Self-reception can be reduced by running the LO at twice the RF frequency and then dividing-by-two before injecting into the mixer. Because the Zero-IF local oscillator is tuned to RF frequencies, the receiver LO may also interfere with other nearby receivers tuned to the same frequency. The RF amplifier reverse isolation, however, prevents most LO leakage to the receiver antenna.

Heterodyne Receiver

A heterodyne receiver translates the desired RF frequency to one or more intermediate frequencies before demodulation. Modulation information is recovered from the last IF frequency. Figure 2 shows a dual-conversion superheterodyne receiver. Mixers translate the RF signal to IF frequencies. LO signals tuned at a particular spacing above or below the RF signal are injected into the mixer circuits. The RF and LO signals mix to produce a difference frequency known as the IF frequency. The result is a dual-conversion receiver, described as such because of the two down-conversion mixers.

The advantages that a heterodyne receiver has over a zero-IF receiver include better immunity from interfering signals and better selectivity

Figure. Dual-Conversion Superheterodyne Receiver



Narrow-bandwidth passive IF filtering is typically accomplished using crystal, ceramic, or SAW filters. These filters offer better protection than the zero-IF receiver gyrator filters against signals close to the desired signal because passive filters are not degraded by the compression resulting from large signals. The active gyrator circuit does not provide such protection. However, the price for improved protection is larger physical size and required printed circuit board real estate.

Undesired signals that cause a response at the IF frequency in addition to the desired signal are known as spurious responses. Spurious responses must be filtered out before reaching mixer stages in the heterodyne receiver. One spurious response is known as an image frequency. An RF filter (known as a preselector filter) is required for protection against the image unless an image-reject mixer is used. An advantage of the zero-IF receiver is that no image exists and an image-reject filter (or image-reject mixer) is not required.

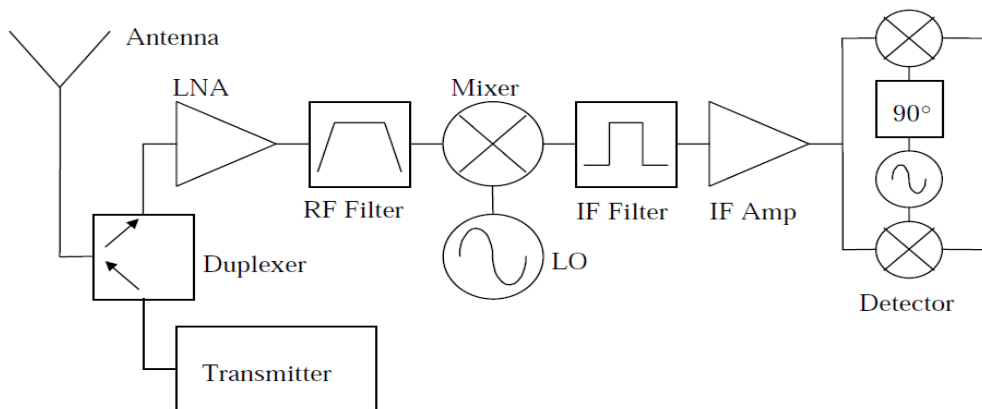
Additional crystal-stabilized oscillators are required for the heterodyne receiver.

Superheterodyne receivers typically cost more than zero-IF receivers due to the additional oscillators and passive filters. These items also require extra receiver housing space. However, a super heterodyne receiver's superior selectivity may justify the greater cost and size in many applications.

Receiver Building Blocks

Optimal receiver sensitivity begins by properly choosing receiver components. A receiver system consists of numerous active and passive function blocks or components, each of which contributes to the system's overall signal gain/loss and noise figure. These components include antennas, amplifiers, filters, mixers, and signal sources, as shown in

Figure



Receiver Components

Antenna

The antenna provides an interface between free space and the receiver input. An antenna is sometimes considered a matching circuit that matches the free-space impedance to the receiver input. Antennas are characterized by a number of performance parameters, such as bandwidth, gain, radiation efficiency, beamwidth, beam efficiency, radiation loss, and resistive loss.

Antenna gain is often defined relative to a theoretical ideal isotropic antenna that radiates energy equally in all directions. With this convention, an antenna rated for 3-dBi gain in one direction has 3 dB more gain than an isotropic antenna in that same direction. An antenna is characterized relative to a half-wave dipole antenna having a gain of 2 dBi. A gain value of 3 dBd indicates a signal level 3 dB above that achieved by a dipole antenna (5 dBi).

An antenna's gain is defined as either the power gain or directive gain. The directive gain is the ratio of the radiation intensity in a given direction to the radiation intensity of an isotropic radiator. Directivity is the value of the directive gain in the direction of maximum radiation. Radiation efficiency is given by equation

$$E = \frac{P_r}{P_t}$$

Where:

P_r is antenna-radiated power.

P_t is the total power supplied to the antenna.

Antenna beamwidth is the angle formed by the radiating field where the electric field strength or radiation pattern is 3 dB less than its maximum value. The antenna main lobe is the energy traveling in the primary direction of propagation. Energy traveling to the sides of the primary

propagation direction is called side lobe energy. Energy flowing to the rear of the antenna is called the back lobe radiation.

Effective radiated power (ERP) is equal to the input power to an antenna P_i multiplied by the transmitter antenna gain (G_t) with respect to a half-wave dipole.

$$ERP = P_i \times G_t$$

The effective isotropic radiated power (EIRP) is the actual power delivered to the antenna multiplied by its numeric gain with respect to an isotropic radiator. Because the gain for an isotropic antenna differs from the gain for a dipole antenna (2 dB), EIRP is about 2 dB higher than the ERP for a given transmission system.

When an antenna is used with a receiver, its noise temperature provides a useful measure of its noise contributions to the system, notably in satellite systems. The noise power available at the output feed port in watts is given by equation

$$P_n = K T_a B$$

Where

K ° = Boltzmann's constant = 1.38×10^{-23} J/°K.

T_a ° = antenna noise temperature in degrees °K.

B ° = noise equivalent bandwidth in Hertz (Hz).

The antenna matching circuit matches the antenna output impedance to the receiver input. A gain versus noise figure trade-off is selected for optimum receiver sensitivity when the antenna is connected directly to an amplifier input. When connecting to a filter or diplexer circuit, optimum sensitivity is obtained with a power match. The antenna matching components should have the lowest loss possible because loss increases noise figure as detailed in the section, Noise Figure. Proximity effects such as metal structures, human bodies, and other nearby objects alter antenna performance. Antenna gain, impedance, radiation pattern, and resistive loss are all affected by proximity effects.

Duplexers

A duplexer allows simultaneous transmitter and receiver operation with a single antenna.

The ideal duplexer perfectly isolates the receiver and transmitter from each other while providing lossless connection to the antenna for both.

Duplexers are constructed in a variety of ways. One method uses an RF switch to toggle the antenna back and forth between the receiver and transmitter. The toggling occurs with a “push-to-talk” (PTT) button or is time-shared automatically by a microprocessor.

For this method, a separate preselect filter is often needed on the receive path prior to the LNA to limit the incoming frequencies to the band of interest.

Another method uses two singly terminated designed filters known as a duplexer. Singly terminated filters allow either a low impedance or high impedance termination on one port. The two filters are connected at this port, thus forming a three-terminal network.

Duplexers are employed where the transmitter and receiver frequencies are in different bands. The pass band of one filter is the stop band for the other. For example, one filter may be a low pass whereas the other may be a high pass. The receiver-band filter rejects transmitter-band signals and the transmit-band filter rejects receiver-band signals. For this method, the duplexer can also act as the preselect filter.

Circulators are also used as duplexers.

Circulators are also used as duplexers. A circulator is a three-port device that allows RF signals to travel in only one direction. Thus, a signal connected to port 1 transfer to port 2 unimpeded and is isolated from port 3. A signal incident on port 2 transmits to port 3 and is isolated from port 1. A signal input at port 3 travels to port 1 while being isolated from port 2. The ideal circulator provides 0-dB insertion loss from port 1 to port 2; port 2 to port 3; and port 3 to port 1. The ideal circulator also provides infinite isolation between ports 1 to port3; port 3 to port 2; and port 2 to port 1. High isolation between the receiver and transmitter minimizes

leakage of transmitter power into the receiver and prevents receiver signals from entering the transmitter.

In addition, a duplexer is characterized by insertion loss. Excessive insertion loss degrades the noise figure of the system, which in turn inhibits signal-to-noise ratio performance.

Low-Noise Amplifier (LNA)

An RF amplifier is a network that increases the amplitude of weak signals, thereby allowing further processing by the receiver. Receiver amplification is distributed between RF and IF stages throughout the system. The ideal amplifier increases the amplitude of the desired signal without adding distortion or noise. Numeric gain factor is defined as the output signal power S_{out} divided by the input signal power S_{in} . Numeric gain factor G is defined mathematically by equation

$$G = \frac{S_{out}}{S_{in}}$$

An increase in signal amplitude indicates a numeric gain factor greater than unity.

Conversely, a decrease in signal amplitude indicates a numeric gain factor less than unity. A gain factor of unity indicates no change in signal amplitude processed by the two port network. The RF amplifier provides a gain factor greater than unity. (Gain factor is also used to describe losses in the system.) Numeric gain factor is converted to gain in dB (GdB) using equation (6).

$$G_{dB} = 10\log(G) = 10\log\left(\frac{S_{out}}{S_{in}}\right)$$

Amplifiers unfortunately add noise and distortion to the desired signal. The first amplifier after the antenna in a receiver chain contributes most significantly to system noise figure, assuming

low losses in front of the amplifier. Adding gain in front of noisy networks reduces noise contribution to the system from those networks. Subsequent stages have less and less influence on the overall noise figure of the system. Increasing gain from the low-noise amplifier improves system noise figure.

On the other hand, too much gain compresses circuits further back in the receiver chain.

The receiver design must make a trade-off between system noise figure and gain.

A low-noise amplifier is typically constructed from active devices operated in the “linear range”.

The active device is operated in its “linear range,” but the output signal isn’t perfectly linear.

Thus, distortion is added to the amplified signal by nonlinearities of the transistor. Gain compression, harmonic distortion, cross-modulation, and intermodulation distortion directly result from amplifier nonlinearity.

RF Filters

An RF filter is a network that allows a range of RF frequencies to pass. The wanted frequency range is known as the pass band. The filter blocks RF signals outside of the pass band. The blocked area is known as the stop band. The perfect RF filter passes desired RF signals unimpeded and infinitely attenuates signals in the stopband. Many receivers use two RF filters in the receive path: a preselect filter (before the LNA) and an image-reject filter (after the LNA). The preselect filter prevents signals far outside of the pass band from saturating the front end and producing intermodulation distortion products related to those signals at far away frequencies only. The image-reject filter rejects signals such as the first image, half-IF, and local oscillator spurious responses.

However, the RF filters typically provide little protection against third-order intermodulation distortion produced by “close-in” signals. The nonideal RF filter degrades receiver noise figure by adding loss to the desired signal.

Filters are designed with one of several responses, such as Butterworth, Chebyshev, elliptic, and Bessel responses. A Butterworth response has flat gain across the passband

(maximally flat filter) with a gradual roll-off in the transition region from the passband to the stopband. Its phase response is nonlinear about the cutoff region with a group delay that increases slightly toward the band edges.

Chebyshev filters have equal-ripple response in their passbands with better selectivity than a Butterworth for the same order filter but worse phase response because of groupdelay variations at the band edges.

An elliptic filter achieves the maximum amount of roll-off possible for a given order but with an extremely nonlinear phase. This type of filter exhibits equal-ripple amplitude response in both passband and stopbands. Its group delay is lower than that of a Chebyshev filter but varies rapidly at the band edges.

A Bessel response is maximally flat in phase within the passband, with a relative equalripple response but less than ideal sharpness in the roll-off region.

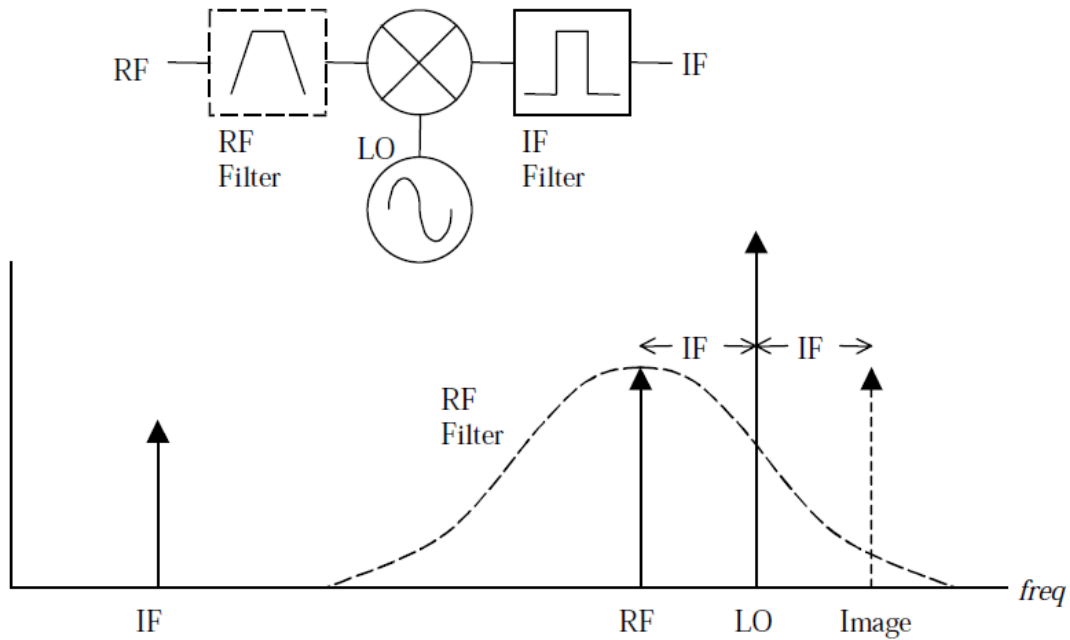
Preselect filters are often ceramic, lumped-element LC or SAW. Ceramic filters typically offer lower loss and are less expensive, but their larger size is a drawback. Image-reject filters are usually either ceramic or SAW devices in cellular receiver front ends. SAW filters are similar to digital FIR filters and have sharp roll-off and linear phase.

Mixers

Mixer circuits translate an RF frequency to both a higher and lower intermediate frequency (IF) value. Figure 11 shows a mixer driven by an LO signal. An IF filter selects either the higher or lower (sum or difference) output frequency. One frequency is passed while the other is rejected. Selecting the higher frequency is up-conversion; selecting the lower frequency is down-conversion. The translation uses a local oscillator (LO) signal that mixes with the RF frequency. The RF and LO frequencies are spaced apart by an amount equal to the IF frequency. High-side injection has the LO frequency above the RF frequency. Low-side injection puts the LO below the RF frequency. High-side injection is shown in Figure 11.

The down-conversion signal is the frequency difference between the RF and LO frequencies. An additional signal called the image frequency has the opportunity to mix with the LO for an IF response. Image-reject RF filters (by filtering the image prior to the mixer) and image-reject

mixers (by reducing the image component during the mixing process) provide protection against the image. The image and LO frequencies are spaced apart by an amount equal to the IF frequency. The difference between the LO and image frequencies produces an IF response coincident with the IF response due to the RF signal. An RF (preselector or image) filter in front of the mixer rejects an image frequency that interferes with the desired RF signal.



The mixer design uses nonlinear devices, such as diodes or transistors. Using diodes, the mixer is passive and has a conversion loss. Using active devices, such as transistors, a conversion gain is possible. A variety of circuit topologies exist for mixers. A single-ended mixer is usually based on a single Schottky diode or transistor. A balanced mixer typically incorporates two or more Schottky diodes or a Schottky quad (four diodes in a ring configuration). A balanced mixer offers advantages in third-order intermodulation configuration.

While the mixer operates within its linear range, increases in IF output power closely correspond to increases in RF input power. Conversion compression occurs outside the linear range. The 1-dB compression point is where the conversion-gain is 1 dB lower than the conversion gain in the linear region of the mixer.

Mixer intermodulation-distortion (IMD) performance contributes to the limits on spur-free dynamic range. The highest possible values of second-order and third-order intercept points provide the greatest spur-free dynamic range.

The LO power coupled into the mixer controls performance. Inadequate LO power for a given mixer degrades conversion-gain and noise figure and, therefore, system sensitivity.

Conversion gain factor is specified at a particular LO drive level and is defined as the ratio of the numeric single-sideband (SSB) IF output-power to the numeric RF input power.

The ratio is converted to dB using equation

$$CG_{dB} = 10\log\left(\frac{P_{IF}}{P_{RF}}\right) = 10\log(P_{IF}) - 10\log(P_{RF})$$

Equation yields a positive value for an IF output power greater than the RF input power indicating conversion gain. A negative result occurs for conversion loss.

Image-reject mixers are formed from a pair of balanced mixers. Input signals are offset by 90° through a hybrid splitter and translated to the IF outputs (with the same 90° offset).

The IF outputs are passed through an IF hybrid to separate the desired and image sidebands.

Because of tight phase requirements for the IF hybrid, such mixers are usually limited in bandwidth.

Local Oscillator

The local oscillator is a reference signal required for mixer injection to facilitate frequency translation in the receiver system. The LO is a large signal that drives the mixer diodes or transistors into a nonlinear region, thereby allowing the mixer to generate fundamental frequencies along with harmonics and mixing terms. The local oscillator signal mixes with the desired RF signal to produce an IF. The sum (LO+RF) and difference (LO–RF or RF–

LO) terms are output to the IF mixer port. The oscillator frequency is tuned to select a desired frequency to be down-converted to an intermediate frequency. Proper planning for spurious signals ultimately determines the frequency offset (IF) between the oscillator and desired RF frequency. Once the oscillator is tuned, a signal that has the same spacing as the IF frequency away from the LO frequency is down-converted and passed through the IF filter.

In most wireless receivers, LO signals are generated by synthesized sources consisting of voltage-controlled oscillators (VCOs) stabilized by a phase-lock loop (PLL). A PLL consists of a phase detector, amplifier, loop filter, and VCO. In a PLL synthesizer, the VCO is locked in phase to a high-stability reference oscillator (usually a crystal oscillator).

A phase detector compares the phase of a divided VCO frequency output to that of the precise reference oscillator and creates a correction voltage for the VCO based on phase differences between the reference and the VCO. A loop filter limits noise but also limits -time (frequency switching speed). Wider loops provide faster lock-times at the expense of higher reference spurs and phase noise. The loop filter must be narrow enough to limit oscillator reference spurs but wide enough to allow signal phase locking within the loop bandwidth with a tuning speed required by the receiver. The loop acquisition time is directly dependent on the time constant of the loop filter.

Key specifications for an LO (a receiver may have more than one, depending upon the number of IFs and the system architecture) include tuning range, frequency stability, spurious output levels, lock-time, and phase noise. Most of these specifications determine an LO's suitability for a particular wireless receiver application; the spurious and phase-noise performance also impact sensitivity and dynamic-range performance.

A noise analysis of a PLL oscillator must include several noise sources, including the VCO, the phase detector, and any prescalers or dividers used in the loop. In addition, noise sources on the VCO voltage control line, such as power-supply deviations and harmonics, can lead to spurious signals at the output of the PLL source.

IF Filter

An IF filter is a network that allows only an IF frequency to pass to the detection circuitry, System noise bandwidth is defined by the IF filter. If several IF filters are cascaded bandwidth. System noise bandwidth is key in determining a receiver's sensitivity level. In addition, IF filters reject signals very close to the desired signal. Adjacent channel selectivity is performed entirely by IF filtering in a superheterodyne receiver. (However, phase noise from the local oscillator can degrade adjacent channel selectivity.) Ripple is the amount of amplitude variation induced by a filter on signals through the passband. Group delay describes the relative changes in phase of signals at different frequencies. One definition of group delay distortion is the difference between the maximum and minimum group delay value over the occupied signal bandwidth. High group-delay distortion results in phase distortion of pulsed or multi-frequency signals as well as information losses when processing digitally modulated signals.

Group delay is defined as the change in phase with respect to frequency, defined mathematically by equation

$$G_{\text{delay}} = -\frac{d\phi}{d\omega}$$

In cellular receiver front ends, SAW devices are usually used for IF filtering.

IF Amplifier

RF signals are translated down in frequency because amplifying a low frequency signal is easier (less expensive and a more efficient use of current) than amplifying a high frequency signal. Filtering close-in undesired adjacent channel signals with high-Q ceramic and crystal filters is also easier. Information recovery is easier at the lower IF frequency than the original RF

frequency. The IF amplifier provides the necessary gain to boost the IF signal to a level required by the detector or to an additional down-conversion stage.

IF amplifier stages have less effect on the overall receiver noise figure, although dynamic-range characteristics are important to receiver performance. As with RF amplifier stages, IF amplifier linearity is important to the overall receiver dynamic range since intermodulation products can limit system performance.

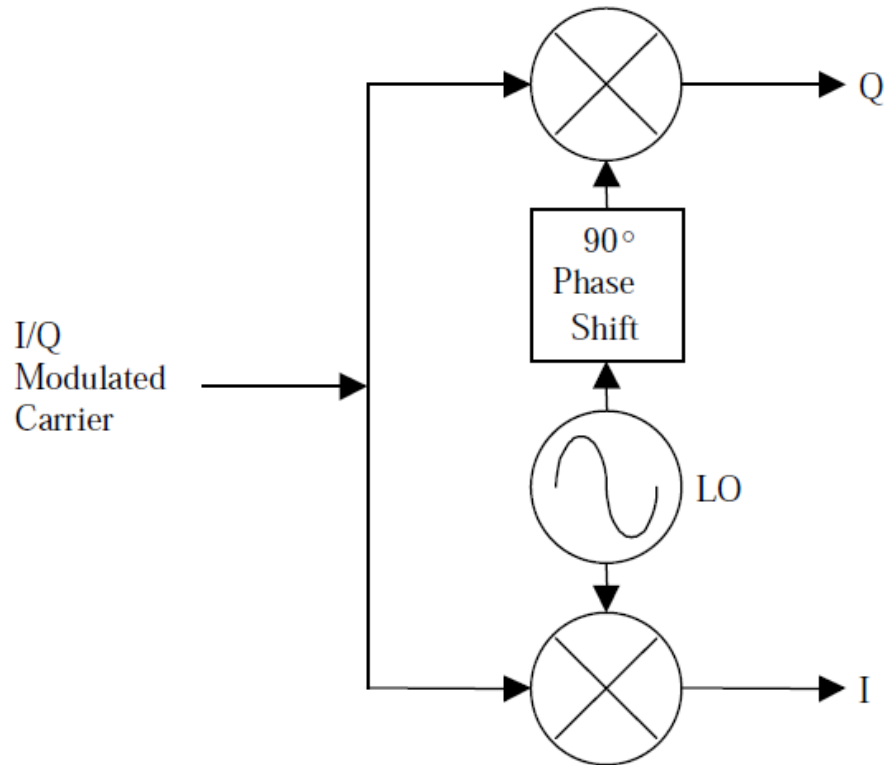
For optimum performance, IF amplifiers should be specified with the highest possible second- and third-order intercept points and adequate gain to drive the detector or additional down-conversion stages. However, interfering signals are usually greatly reduced by the IF filter, making the second- and third-order intercept point requirements of the IF amplifier minimal. Although noise figure is not as crucial in the IF amplifier stage, it can have an impact if gain in front of the stage is relatively low.

Detectors

A receiver detector is based on the type of modulation format. For simple FM, a quadrature detector offers a straightforward means of decoding modulation information.

In this approach, deviations from resonant frequency cause deviations from phase quadrature, which is detected by a phase detector. To demodulate PSK signals, the amplitude of incoming signals must be limited and the phase detected.

An I/Q detector can detect and demodulate GMSK and other quadrature digital modulation formats. The I/Q demodulator is essentially a pair of double-balanced mixers offset by 90° and fed by a common, in-phase LO. Signals with $\pi/4$ DQPSK can be detected via coherent demodulation, differential detection, or frequency discrimination.



Receiver Sensitivity

Receiver systems are normally required to process very small signals. The weak signals cannot be processed if the noise magnitude added by the receiver system is larger than that of the received signal. Increasing the desired signal's amplitude is one method of raising the signal above the noise of the receiver system. Signal amplitude can be increased by raising the transmitter's output power. Alternately, increasing the antenna aperture of the receiver, the transmitter, or both allows a stronger signal at the receiver input terminals. Increasing the physical size of an antenna is one method to increase its aperture.

Higher heat dissipation is typically required to increase transmitter output power. Cost, government regulations, and interference with other channels also limit the transmitter power

available for a given application. Physically increasing transmitter antenna size may cause weight and wind load problems on the tower to which the antenna is mounted.

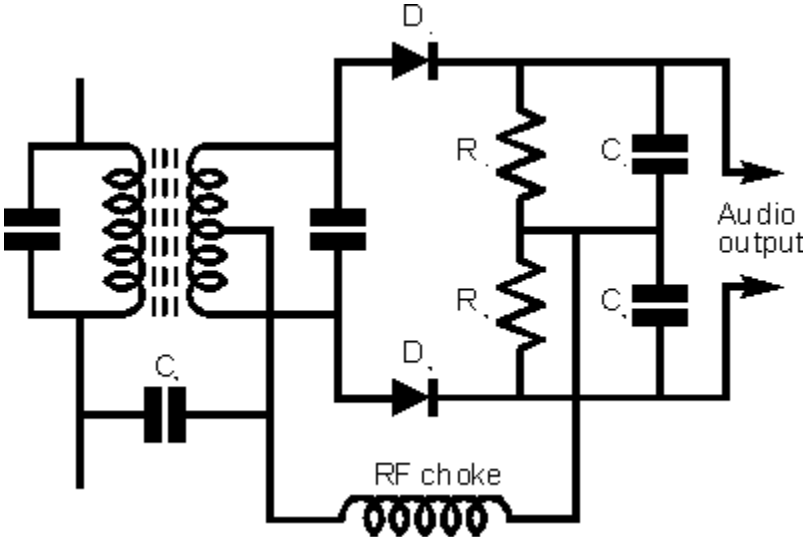
Increasing receiver antenna size obviously increases the housing size for a portable product enclosing the antenna structure, such as a cellular telephone or pager.

Because raising the desired signal amplitude above the noise added by the receiver may not always be practical, a weak signal might be processed by lowering the added noise.

In this case, the noise must be decreased such that the noise amplitude is somewhat below the weak signal amplitude.

Foster Seeley Discriminator or FM Detector

The Foster Seeley detector or as it is sometimes described the Foster Seeley discriminator has many similarities to the ratio detector. The circuit topology looks very similar, having a transformer and a pair of diodes, but there is no third winding and instead a choke is used.



The Foster-Seeley discriminator / detector

Like the ratio detector, the Foster-Seeley circuit operates using a phase difference between signals. To obtain the different phased signals a connection is made to the primary side of the transformer using a capacitor, and this is taken to the centre tap of the transformer. This gives a signal that is 90 degrees out of phase.

When an un-modulated carrier is applied at the centre frequency, both diodes conduct, to produce equal and opposite voltages across their respective load resistors. These voltages cancel each one another out at the output so that no voltage is present. As the carrier moves off to one side of the centre frequency the balance condition is destroyed, and one diode conducts more than the other. This results in the voltage across one of the resistors being larger than the other, and a resulting voltage at the output corresponding to the modulation on the incoming signal.

The choke is required in the circuit to ensure that no RF signals appear at the output. The capacitors C1 and C2 provide a similar filtering function.

Both the ratio and Foster-Seeley detectors are expensive to manufacture. Wound components like coils are not easy to produce to the required specification and therefore they are comparatively costly. Accordingly these circuits are rarely used in modern equipment.

Summary

Several parameters limit the reception of signals by the receiver. Design trade-offs are not trivial and the RF environment dictates the optimal solution. A thorough understanding of noise sources and methods of minimizing degradation allows an optimal design for signals with small amplitudes (far away). Undesired signals hinder the reception of desired signals because of circuit nonlinearity. A full understanding of nonlinearity and undesired response mechanisms is critical when providing protection against these undesired responses. A low-noise system design typically does not produce the best linearity, and high linearity typically produces more noise. Oscillator phase noise generated by the receiver oscillators also hinders reception of a desired signal, if an undesired signal with large amplitude is nearby in frequency. A thorough understanding of the receiver RF environment allows proper design specifications for optimal noise and linearity considerations.

FUTURE WORK

Varactors

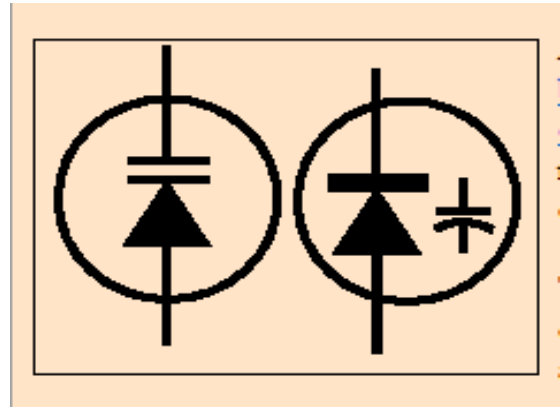
A Varactor is also known as a *variable capacitance diode* or a *varicap*. It provides an electrically controllable capacitance, which can be used in tuned circuits. It is small and inexpensive, which makes its use advantageous in many applications. Its disadvantages compared to a manually controlled variable capacitor are a lower Q, nonlinearity, lower voltage rating and a more limited range

A Varactor diode uses a p-n junction in reverse bias and has a structure such that the capacitance of the diode varies with the reverse voltage. A voltage controlled capacitance is useful for tuning applications.

Any PN junction has a junction capacitance that is a function of the voltage across the junction, as discussed in any account of PN junctions. The

electric field in the depletion layer that is set up by the ionized donors and acceptors is responsible for the voltage difference that balances the applied voltage. A higher reverse bias widens the depletion layer, uncovering more fixed charge and raising the junction potential. The capacitance of the junction is $C = Q(V)/V$, and the *incremental capacitance* is $c = dQ(V)/dV$. The capacitance to be used in the formula for the resonant frequency is the incremental capacitance, where it is assumed that the voltage excursions dV are small compared to V . Finite voltages give rise to nonlinearities. Efforts may be made to reduce these nonlinearities in some cases.

The capacitance decreases as the reverse bias increases, according to the relation $C = C_o/(1 + V/V_o)^n$, where C_o and V_o are constants. V_o is approximately the forward voltage of the diode. The exponent n depends on how the doping density of the semiconductors depend on distance



away from the junction. For a graded junction (linear variation), $n = 0.33$. For an abrupt junction (constant doping density), $n = 0.5$. If the density jumps abruptly at the junction, then decreases (called hyperabrupt), n can be made as high as $n = 2$. I expect that the doping on one side of the junction is heavy, and the depletion layer is predominately on one side, but this is a constructional detail.

Tuning of Varactor Diodes

Sprague-Goodman silicon based varactor diodes offer a broad selection of models for operation from VHF through Microwave frequencies.

Control of the epitaxial junction growth process in the construction of our varactor diodes, produces several desirable characteristics, such as highly linear tuning, high Capacitance tuning ratios (C_t/V_r), and superior Q values.

Sprague-Goodman varactor diodes are available with a variety of responses of Capacitance versus Voltage (C-V curves), described as abruptness of the junction. Package styles include the plastic surface mount SOT-23 package, and higher performance ceramic substrate packages for more demanding surface mount applications.

RF Varactor Diodes at a Glance:

- Best-in-class RF performance and deep RF expertise
- Proven high volume production guarantees highest part-to-part uniformity
- Long-term commitment for product offerings
- Advanced package miniaturization technology supporting highly integrated modules
- Automotive quality (AEC Q101 qualified)
- RoHS compliant

Application examples:

- Voltage-controlled oscillator (VCO) for mobile phones, cordless phones
- Local Oscillator for LNB
- Pre-filters in Satellite, UHF, VHF and FM tuner pre-stages

References

1. http://en.wikipedia.org/wiki/RF_front_end
2. <http://www.mipi.org/specifications/rf-front-end>
3. http://en.wikipedia.org/wiki/Colpitts_oscillator
4. <http://www.electronics-tutorials.ws/oscillator/colpitts.html>
5. <http://www.jdsu.com/News-and-Events/news-releases/Pages/jdsu-creates-worlds-smallest-tunable-optical-transmitter.aspx>
6. <http://transmitters.tripod.com>
7. <http://www.radio-electronics.com/info/rf-technology-design/mixers/rf-mixers-mixing-basics-tutorial.php>
8. <http://www.radio-electronics.com/info/rf-technology-design/superheterodyne-radio-receiver/basics-tutorial.php>
9. <http://www.radio-electronics.com/info/rf-technology-design/fm-reception/ratio-foster-seeley-fm-detector-discriminator.php>
10. <http://www.radio-electronics.com/info/data/semicond/varactor-varicap-diodes/basics-tutorial.php>
11. Understanding and Enhancing Sensitivity in Receivers for Wireless Applications Edited by Matt Loy Wireless Communication Business Unit