

Chapter 6. Oscillator

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6.1 Introduction

6.1.1 Types of Oscillator

Most electronic communication systems operate with sources of sinusoidal electrical waves. Many classes of oscillator circuits are used to produce these sinusoids.

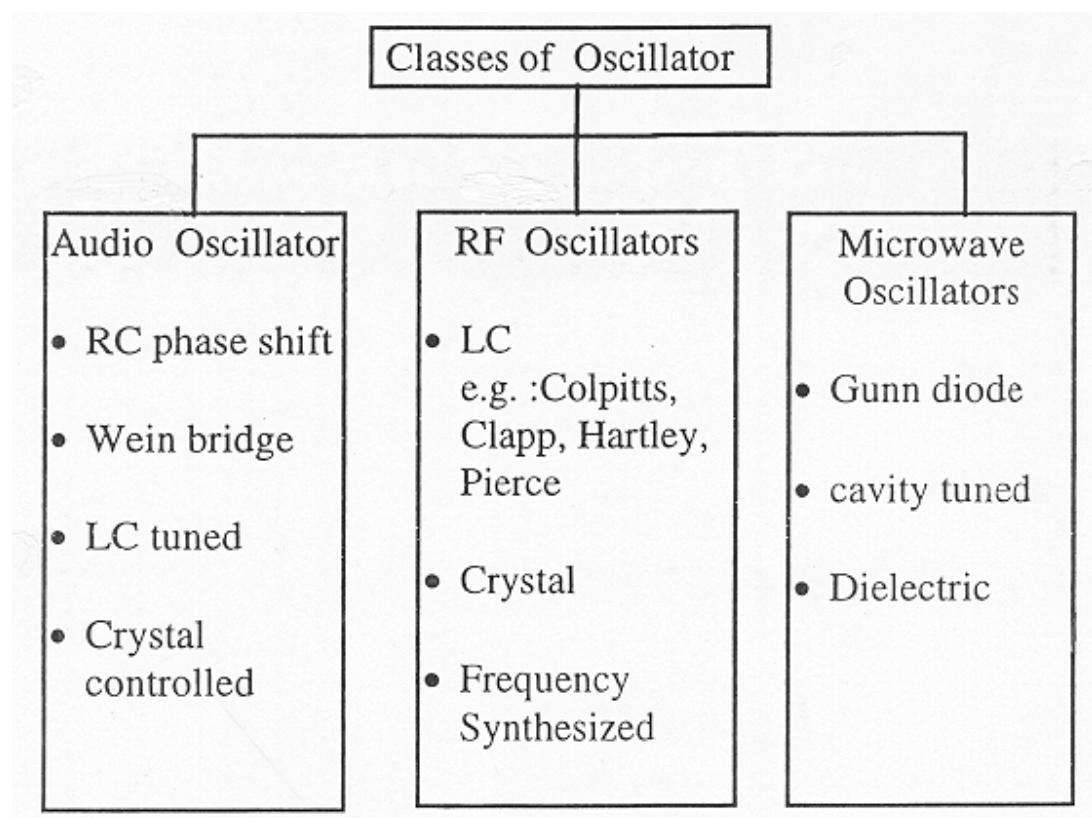


Fig.6-1: Classes of Oscillator

The choice of oscillator type will usually depend on the following performance:

- operating frequency
- output amplitude
- frequency stability
- amplitude stability
- purity of waveform

6.1.2 Review of Oscillator Basics

The basic structure of a sinusoidal oscillator usually consists of an amplifier and a frequency selective network connected in a positive feedback loop. The selective network could be a tuned circuit or piezoelectric crystal in the feedback path.

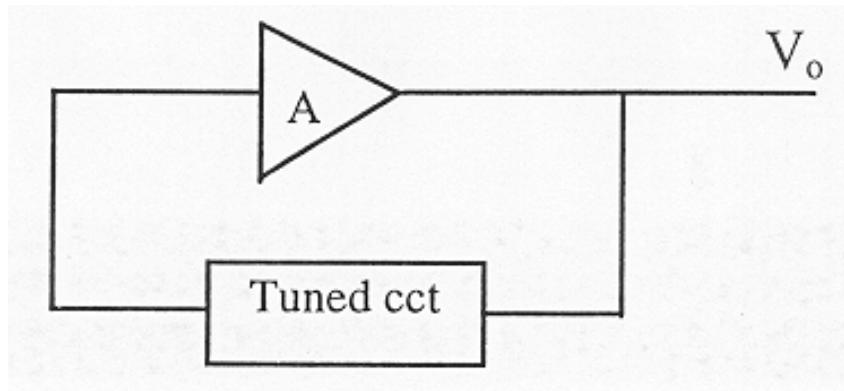


Fig.6-2: The oscillator as a positive feedback amplifier

6.1.3 General LC Oscillator Analysis

The general form of a tuned oscillator circuit is shown below. The amplifier provides the necessary gain and the impedances (Z_1 , Z_2 and Z_3) is the feedback network that perform the necessary phase shifting between the input and output of the amplifier.

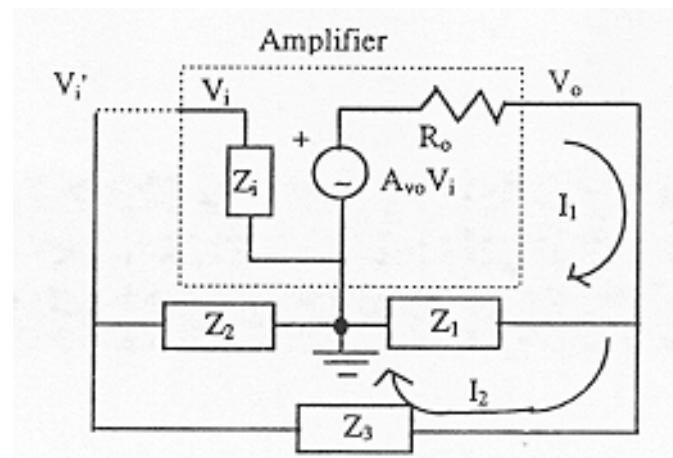


Fig.6-3: General Oscillator Circuit

Some of the common feedback oscillator topologies are shown as following:

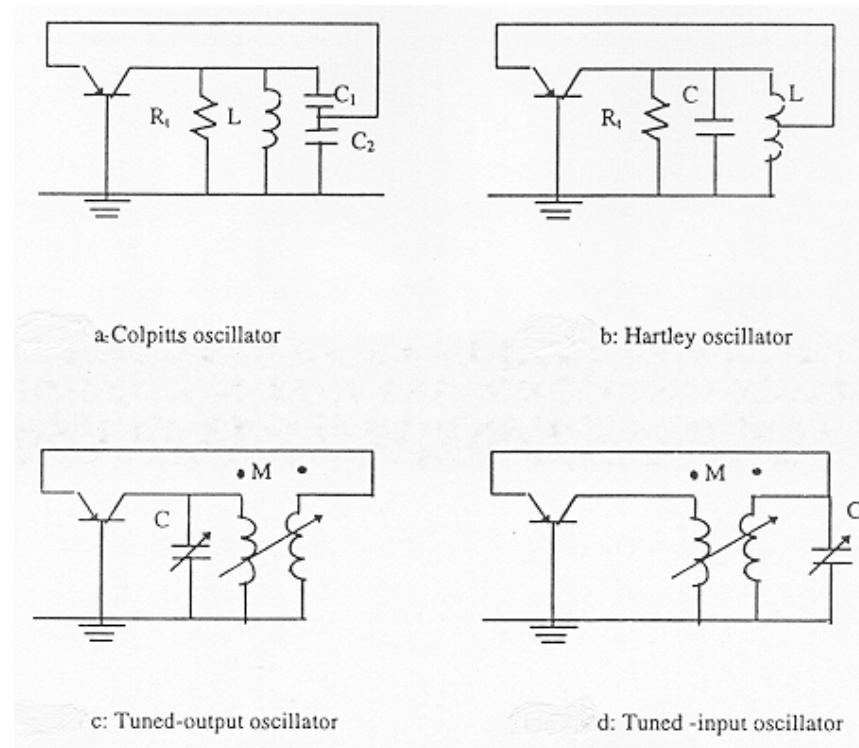


Fig.6-4: Typical RF Oscillators

6.2 Colpitts Oscillator

6.2.1 Common Emitter or Common Source Colpitts Oscillator

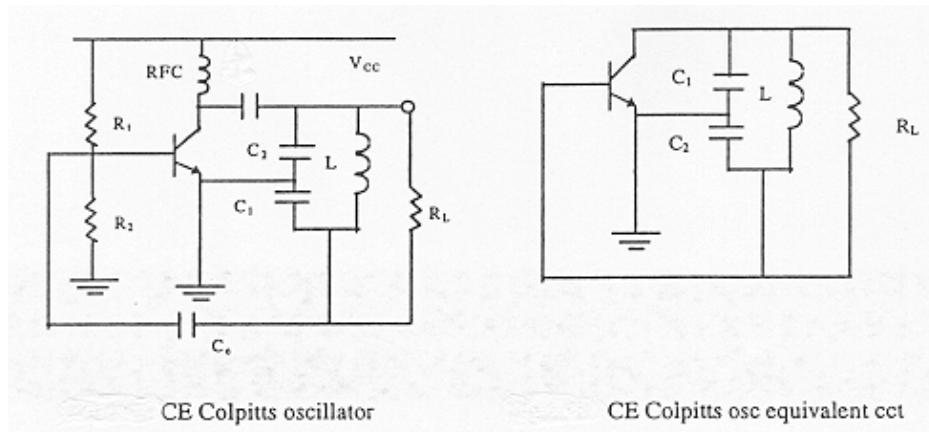


Fig.6-5: Common Emitter Colpitts Oscillator

1. Choose a given inductor, L and calculate the equivalent capacitance required for tuned circuit based on the following equation

$$f_o = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

Where $C_{eq} = C_1 C_2 / (C_1 + C_2)$

2. Calculate the open loop gain of the circuit A_{vo} , from the given transistor data.

$$A_{vo} = g_m R_t$$

Where R_t is the total resistive loading of the tuned circuit and g_m is the transconductance of the transistor.

3. Select an appropriate loop gain, $A_{vo}\beta \geq 1$. Rule of thumb for loop gain is $2 \sim 4$ to ensure oscillator will self start.
4. Determine the open loop feedback ratio, β

Calculate the open loop feedback ratio β from step 3.

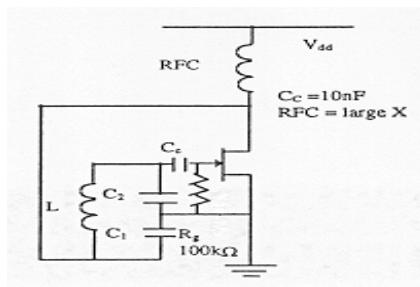
Based on this ratio, calculate the C_1 / C_2 ratio, where

$$\beta = X_2 / X_1 = C_1 / C_2$$

5. Based on step 4 and the C_{eq} calculated, C_1 and C_2 can be computed.

Example 6-1:

Design a common source Colpitts oscillator which is given below such that it oscillates at 2.72 MHz. Assume that the JFET is biased to give an initial g_m of 2 mS and an r_d of 10 K Ω .



Solution:

1. Choose a suitable inductor, L and calculate the equivalent capacitance required for tuned circuit based on the following equation

$$f_o = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

If an inductor of 75 μ H is selected,

$$C_{eq} = \frac{1}{(2\pi \times 2.72 \times 10^6)^2 (75 \times 10^{-6})} = 45.65 \text{ pF}$$

2. Calculate the open loop gain of the circuit, A_{vo} from the given transistor data.

$$A_{vo} = g_m R_t = g_m r_d = 2 \text{ mS} \times 10 \text{ K}\Omega = 20$$

3. Select an appropriate loop gain, $A_{vo}\beta$

Select a loop gain of 2, i.e. $A_{vo}\beta = 2$

4. Calculate the feedback ratio, β

$$\beta = 2 / A_{vo} = 2 / 20 = 1 / 10$$

5. Based on this ratio

$$\beta = X_2 / X_1 = C_1 / C_2 = 1 / 10$$

$$C_1 C_2 / (C_1 + C_2) = 45.65$$

$$C_1 \approx 50 \text{ pF} \text{ and } C_2 \approx 500 \text{ pF}$$

6.2.2 Common Base Colpitts Oscillator

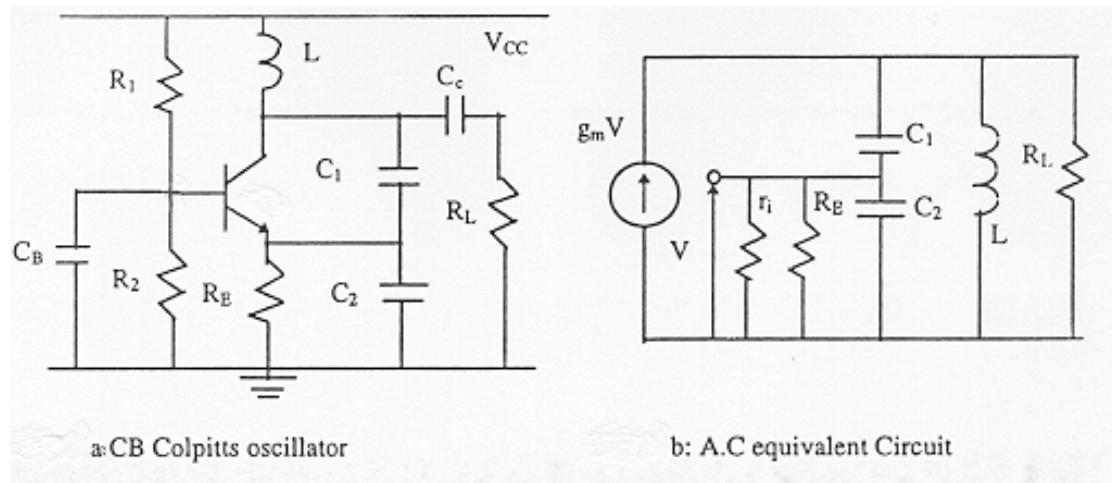


Fig.6-6: Common Base Colpitts Oscillator

1. Calculate the equivalent capacitance C_{eq}

Select an appropriate inductor, L and calculate C_{eq} from the following equation

$$C_{eq} = 1 / (\omega_0^2 L)$$

2. Calculate the input impedance

Select an appropriate bias current, I_c . This will allow the g_m of the transistor and the input impedance of the oscillator circuit to be calculated

$$r_i = 25 / I_c = 1 / g_m$$

3. Select an appropriate loop gain, $A_{vo}\beta \geq 1$. Rule of thumb for loop gain is $2 \sim 4$ to ensure oscillator will self start.

Calculate the open loop gain, A_{vo}

$$A_{vo} = g_m R_L' = g_m (R_t / R_L) \approx R_t$$

Where R_t is the transformed loading of the input impedance, r_i of the transistor. i.e. $R_t = N^2 r_i$

$$N \approx (C_1 + C_2) / C_1$$

Assuming R_L is large and $R_E > r_i$, so that $A_{vo} = N_2$

Calculate the open loop feedback ration

$$\beta = C_1 / (C_1 + C_2) = 1 / N$$

Therefore $A_{vo}\beta \approx N$

4. Compute value for C_1 and C_2 based on the step 1 and step 3

6.3 Clapp Oscillator

- The Clapp oscillator is a variation of the Colpitts oscillator. The difference between the two is that X_3 is comprised of an inductor and capacitor in series such that the net reactance is inductive.
- The capacitors used for X_1 and X_2 are much larger than the one used in X_3 , so the series resonant frequency is controlled mainly by C_3 . As a result, the transistor output capacitance C_o which appears in parallel with C_1 , don't have as much effect on the resonant frequency as they do in the Colpitts circuit. This results in a more stable oscillator circuit as compared to the Colpitts circuit.

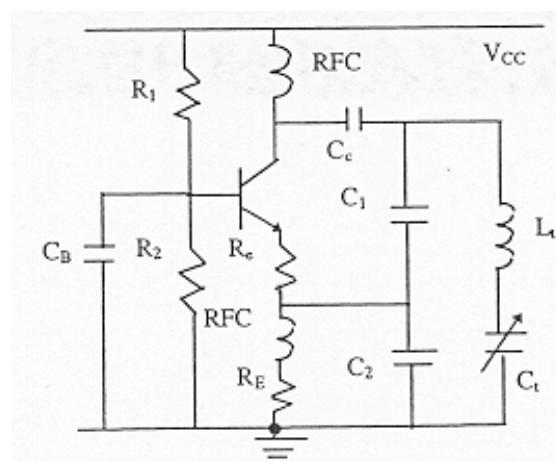


Fig.6-7: Clapp Oscillator

The resonance frequency is given by

$$f = \frac{1}{2\pi\sqrt{LC_{eq}}}$$

Where

$$C_{eq} = \frac{1}{\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}}$$

Note:

1. At high frequencies, the presence of small C_3 results in the use of an inductor which is larger than that of a Colpitts oscillator. The larger inductor helps to reduce the influence of stray inductance caused by connecting leads and PCB tracks. It is also easier to realize a practical coil with larger inductance.
2. A large frequency change is possible as compared with the Colpitts oscillator, for the same variation in capacitance value. This is important when a small physical capacitor is desired in a compact equipment.

6.4 Voltage Controlled Oscillator

- Diodes known as varactor or varicaps exist which function as a voltage variable capacitor. If a varactor is included in the oscillator circuit, the frequency of oscillation can be varied by changing the DC bias voltage across the varactor. The oscillator is then known as voltage controlled oscillator (VCO).
- One main difficulty in VCO design is to achieve a linear voltage frequency transfer characteristic. The capacitance voltage characteristic of the varactor is given by the graph shown below.

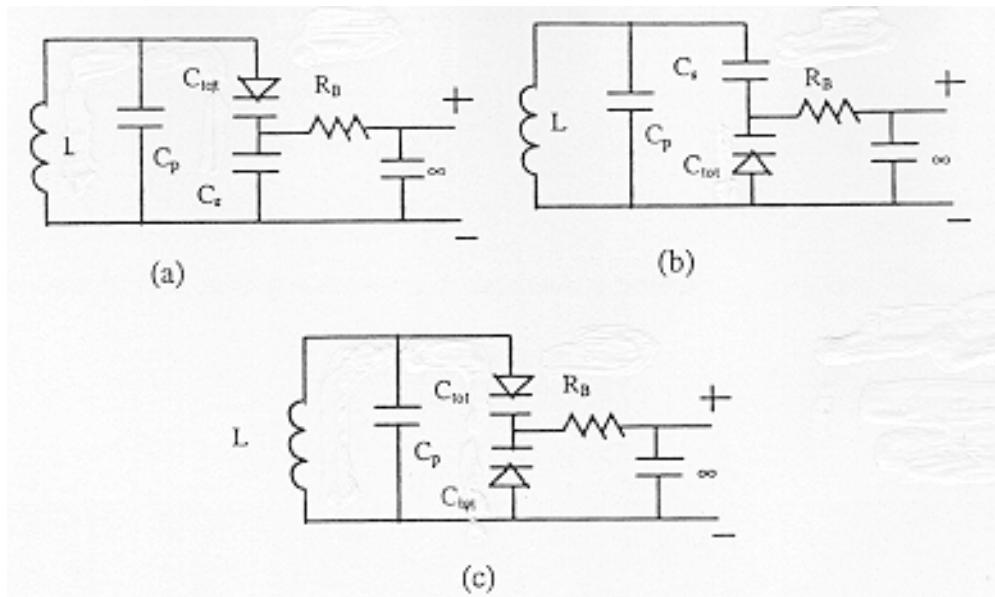


Fig.6-8: Typical VCO Circuits, (a) single diode in circuit low side; (b) single diode in circuit high side; (c) two diodes in series back to back arrangement

- V_{tune} is applied through a large resistance R_B . R_B can also be replaced by a RFC.
- R_B is shunted across lower capacitance and can be converted to a shunt resistance across the tank circuit which will affect cct. Q.

6.5 Factors Affecting Oscillator Performance

Oscillator performance is always important in communication systems such as transmitters and receivers. There are several performance characteristics that must be considered in selecting the best oscillator circuit for a particular application.

These characteristics are:

- operating frequency
- output amplitude
- frequency stability

- amplitude stability
- purity of waveform

6.5.1 Frequency of operation

- At frequencies below 100 KHz, RC oscillators have good frequency stability, constant output power over a wide tuning range and no bulky inductors.
- Oscillators of the LC type are used extensively at frequencies from 100 KHz to 500 MHz. Above this frequency, lumped inductors and capacitors are generally replaced with resonant transmission lines.

6.5.2 Frequency stability

- An oscillator stability can be classified under both long term and short term stability and is dependent on:
 - the components used (LC and active devices)
 - the Q of the resonant circuit
 - the load impedance
 - power supply variation

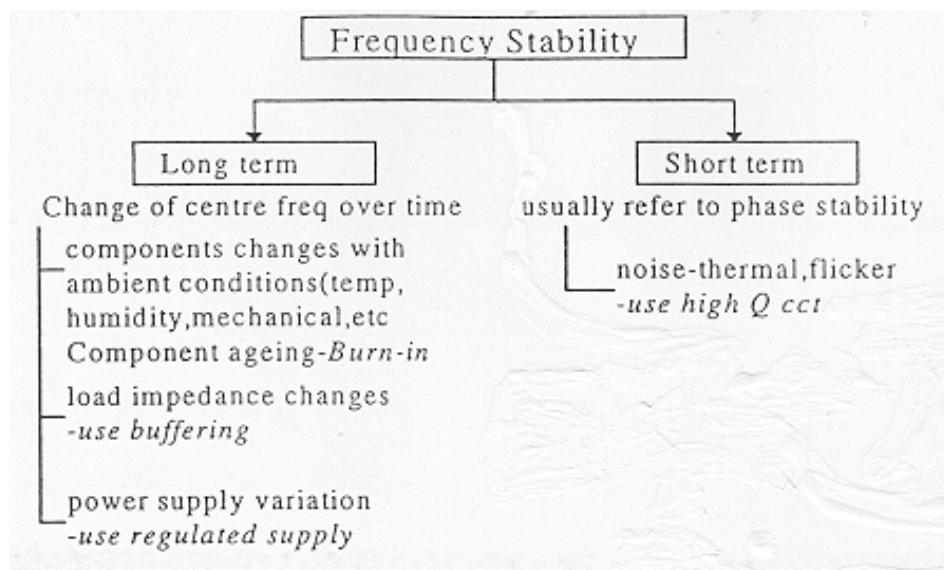


Fig.6-9: Frequency Stability Reason

Long Term Stability

- Long term stability describes the slow drift of the output frequency over a period of time (minutes, hours, days, weeks or years). Aging of components, change in component values due to temperature change and variation in supply voltages are factors that affect long term stability.
- Frequency stability is a function of the stability of the components used in the oscillator circuit. Variation of the component values can be due to the following reasons.

1. Aging

The aging of components will affect the frequency of oscillation over time due to a change in component values. Re-alignment of the frequency controlling part of the oscillator circuit might be necessary if no automatic frequency control circuit is present to correct for such drift.

2. Temperature change

Any change in temperature will change the values of the frequency controlling components. This will result in a drift of the oscillator frequency. These frequency changes are characterized by the temperature coefficient of the components.

3. Components affecting the frequency of oscillation

Capacitor:

- Negative TC capacitors are normally used to compensate for typically positive TC inductors.

Inductor

- The best inductor in terms of temperature stability is air wound. However it is difficult to obtain small air coil for large inductance value, this would constrict equipment size.

The practical approach is to use slug-tuned coil that is properly secured with a good doping compound.

- Magnetic core coils such as toroids and potcores are not recommended when there is a large variation in ambient temperature because of the large changes in frequency brought about by changes in core permeability due to temperature variations.
- Oscillator coils should be placed at least one coil diameter away from nearby conducting objects such as shield enclosure to prevent degradation of the circuit Q.

They should also be shielded to prevent stray coupling to adjacent circuits. A properly shielded coil would also be relatively immune to ambient temperature changes such as air drafts.

PCB and layout

- Double sided PCB is not recommended in oscillator circuit because the ground plane forms numerous capacitors in combination with the etched elements on the opposite side of the PCB. This unwanted capacitance which is created is temperature sensitive.
- PCB tracks which are used to connect different nodes become parasitic inductance at RF frequency. They should therefore be kept as short as possible since the track is temperature sensitive. In addition, the track should not be too thin, otherwise they become over dependent on the etching processing accuracy.
- Heavy duty PCB of the glass epoxy kind is one of the best for oscillator board. This kind of PCB exhibit little flexing under stress. Flexing will changes the properties of the stray capacitance and inductance of the PCB, thus causing frequency shift.
- Oscillator PCB should be anchored at several points to improves rigidity of the board. Heavy duty metal shield used as enclosure will further aid the mechanical stability.

4. Variation in the load

Any change in the load of an oscillator will cause a phase shift. This will result in a change in the oscillating frequency to regain the zero phase shift requirement for oscillation. Light coupling between the oscillator and the load or an addition buffer stage are some of the common preventive measures to reduce this effect.

5. Variation of power supply

The transistor capacitance (C_{cb} , C_{ce} and C_{be}) are affected by the biasing conditions. Any variations in the power supply will result in some change in the capacitance of the transistor. This will cause some shift in the oscillator frequency. Use of power supply regulation will help to reduce effect of this problem.

Short Term Stability

This is measured in seconds or even much shorter periods of time. They can be seen in terms of AM, FM and phase noise.

AM

The oscillator is amplitude modulated when its output level changes up and down. Besides the oscillator fundamental and harmonic frequencies, sidebands will also appear.

FM

The oscillator is frequency modulated when the oscillator frequency shifts back and forth. Again, sidebands will also appear.

Phase Noise

- Any random noise generated within the device will cause both AM and FM, thus creating noise sidebands. The sidebands generated are usually quite close to the oscillator frequency and once generated, are extremely hard to filter away.

Phase noise is a useful measure of short term frequency stability. The most common method for specifying it is with a plot of the single

sideband (SSB) phase noise in a 1 Hz bandwidth versus the offset from the carrier. It is expressed in dB relative to the carrier (dBc).

- One way to reduce the noise level is to raise the Q of the tuned circuit. This will however lower the tuning range of the oscillator if it is a VCO. Another way is to use active devices with low NF and flicker noise.
- Power supply filtering and shielding of the oscillator section can help to reduce the modulation of the oscillator by external noise.

6.5.3 *Signal Purity*

Harmonics of the oscillator frequency will always be present. Their amplitude can be reduced with properly designed low pass or band pass filters. Whether the harmonics were too high or not would depend on the actual power level and the use the oscillator was intended for.

6.6 Crystal Controlled Oscillators

- A crystal controlled oscillator is an oscillator with a crystal and is able to provide an output waveform at a specified frequency accurately. The crystal may be used to replace part of the frequency determining network in the oscillator.
- Crystals are used in some oscillator design because it can (a) provide the necessary accuracy (b) improve significantly the frequency stability.
- The design for crystal oscillator is the same as that for the non-crystal oscillator (LC type) except that the biasing network may be different since crystal block DC voltage. It can be approached in two ways, depending upon whether the oscillators are operating in series mode or parallel mode.

6.6.1 *Parallel Mode Crystal Oscillator*

The load impedance across the crystal terminal is of high impedance. In parallel mode oscillator, the crystal serves as an inductor. A parallel mode crystal is cut to be anti-resonant at the desired oscillating frequency when the external capacitance across the crystal is a specific amount.

1. Common base crystal oscillator

- For common base oscillator, the crystal Q is degraded by the transformed loading of the low input impedance of the transistor.
- RFC must be large to avoid reducing the crystal Q
- Crystal sees load capacitance C_1 series C_2 i.e. $C_1C_2 / (C_1 + C_2)$

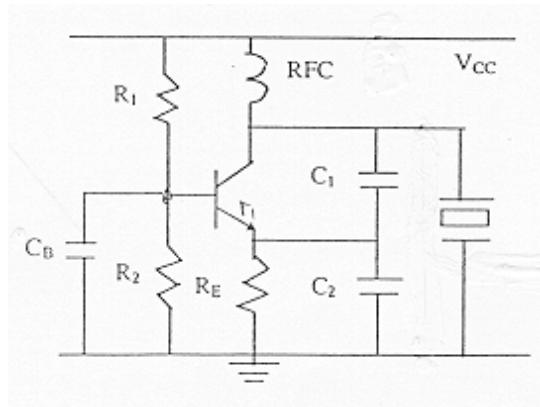


Fig.6-10: Common Base Crystal Oscillator

2. Common collector crystal oscillator

- For common collector oscillator, the shunt biasing resistors will significantly reduce the Q of the crystal if they are not sufficiently large enough.
- Crystal sees load capacitance C_1 series C_2 i.e. $C_1C_2 / (C_1 + C_2)$

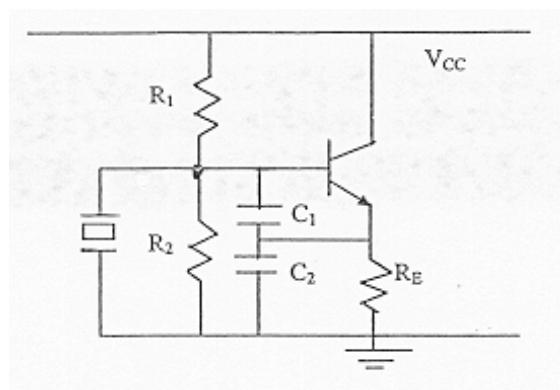


Fig.6-11: Common Collector Crystal Oscillator

3. Common emitter crystal oscillator

- The common emitter oscillator (Pierce oscillator), normally has the highest Q and hence best frequency stability. It is therefore the best choice provided one terminal of the crystal need not be ground.
- Crystal sees load capacitance C_1 series C_2 i.e. $C_1C_2 / (C_1 + C_2)$

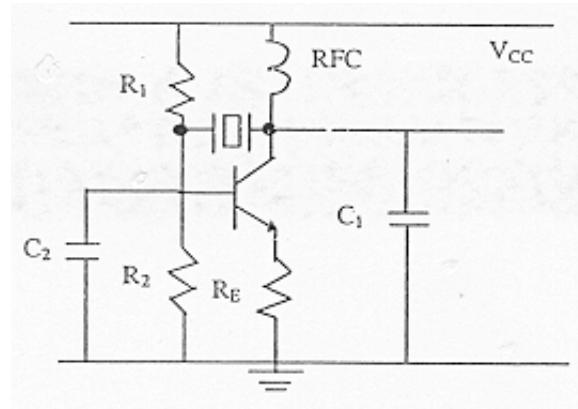


Fig.6-12: Common Emitter Crystal Oscillator

6.6.2 Series Mode Crystal Oscillator

One characteristic of the crystal is that its fundamental frequency is inversely proportional to the crystal thickness. High frequency crystals require thin plates and they are very fragile. For this reason, high frequency crystals usually operate on an overtone of the fundamental frequency which allows for thicker, less fragile crystal. Overtone crystals are usually used in the series mode.

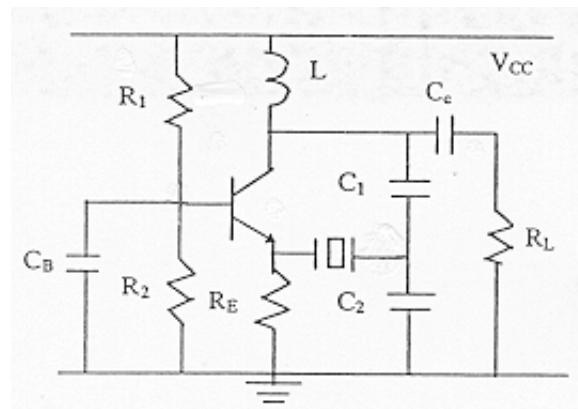


Fig.6-13: Colpitts oscillator with crystal in series mode

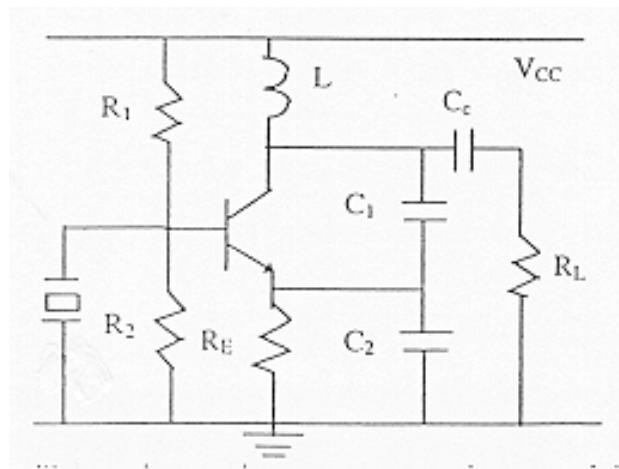


Fig.6-14: Colpitts oscillator using a series resonant crystal to ground the base

Chapter 7: Mixer

7.1 Introduction

7.2 Mixer Performance Parameters

7.3 Passive Mixers

7.4 Active Mixers

7.4.1 FET Mixer

7.4.2 BJT Mixers

7.5 Summary of Mixer Characteristics

7.1 Introduction

Mixer performs frequency translation:

- Up conversion in transmitter, for efficient transmission at RF frequency.
- Down conversion in receiver, for ease of signal processing and demodulation at lower IF frequency

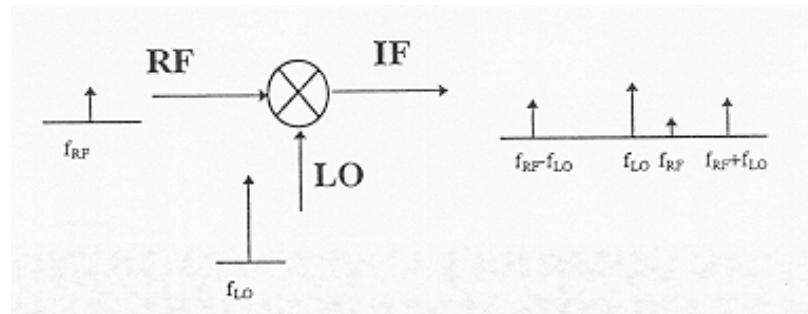


Fig.7-1: Mixer

RF : Radio Frequency

LO: Local Oscillator

IF: Intermediate Frequency

Upconversion: $F_{IF} = F_{RF} + F_{LO}$

Downconversion: $F_{IF} = F_{RF} - F_{LO}$ if $F_{RF} > F_{LO}$

$F_{IF} = F_{LO} - F_{RF}$ if $F_{RF} < F_{LO}$

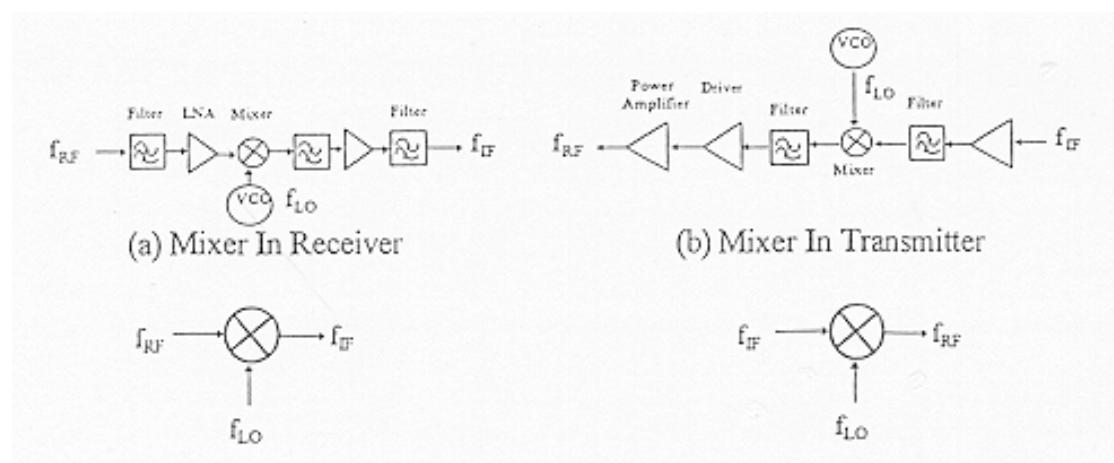


Fig.7-2: Mixer application

7.2 Mixer Performance Parameters

- **Conversion Loss**

A measurement of how efficiently a mixer converts energy from one frequency to another. It is the ratio of the output power (IF) to the input power (RF) for a given local oscillator power (LO) applied (typically, 7 dBm, 17 dBm, 23 dBm). Conversion loss is a function of LO power.

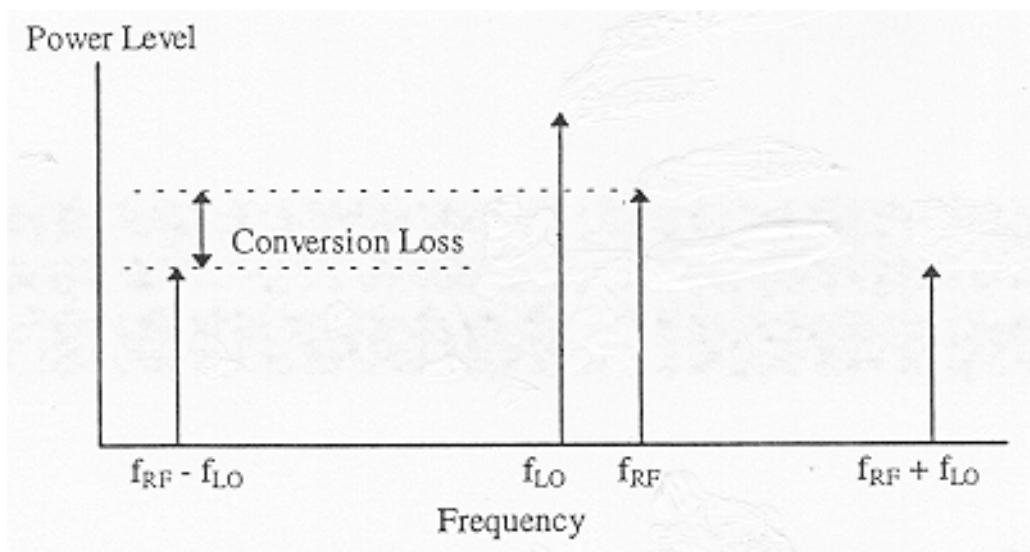


Fig.7-3: Conversion Loss Diagram

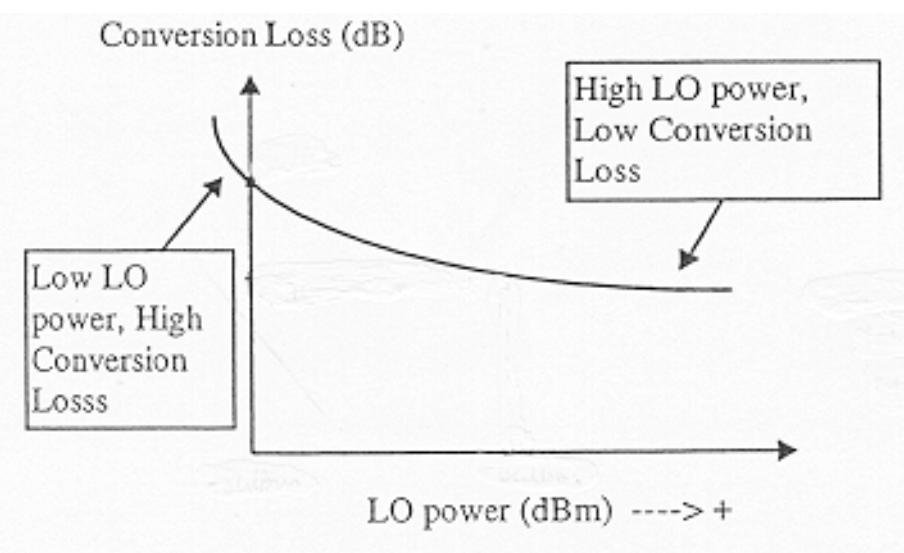


Fig.7-4: Conversion Loss Ver LO Power

- **Isolation**

The amount of attenuation provided when a signal is applied to one port of a mixer and measured at another port.

Three types of isolation are defined:

- LO to RF isolation
- LO to IF isolation, or LO feedthru
- RF to IF isolation, or RF feedthru

Remarks: RF feedthru is usually less of a problem than the LO isolation terms because the LO power level is significantly higher than the RF power drive.

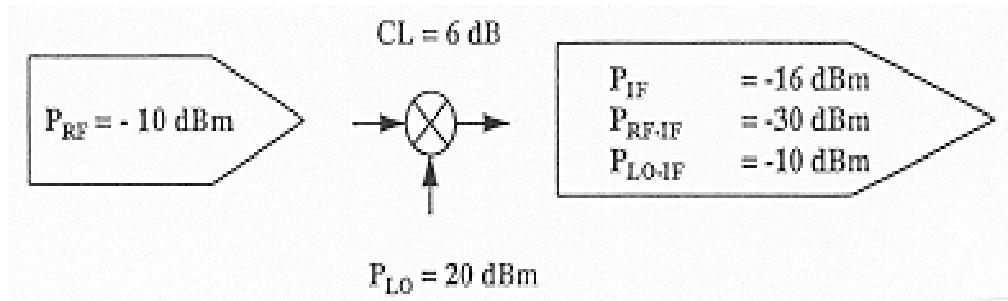


Fig.7-5: Isolation Diagram

- **Noise Figure**

The noise characteristic of the mixer, usually very close to conversion loss. It is defined as the SNR at the input (RF) port divided by the SNR at output (IF) port.

- **1 dB Compression Point**

The RF input level for which the IF output level deviates from linearity by 1 dB. Typically it is 6 dB below the LO power.

- **Dynamic Range**

The power range over which a mixer provides useful operation.

Upper limit – 1 dB compression point

Lower limit – Noise floor

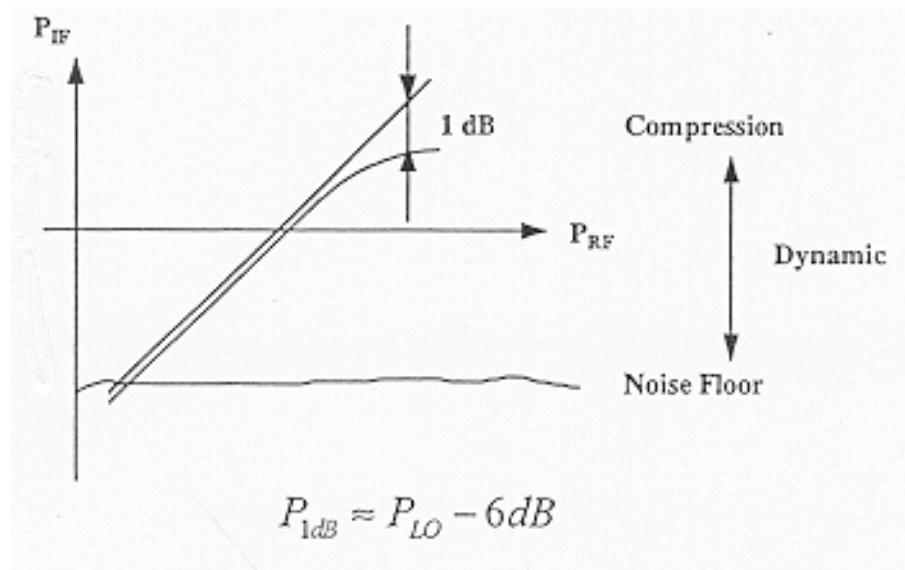


Fig.7-6: Dynamic Range Diagram

7.3 Passive Mixers

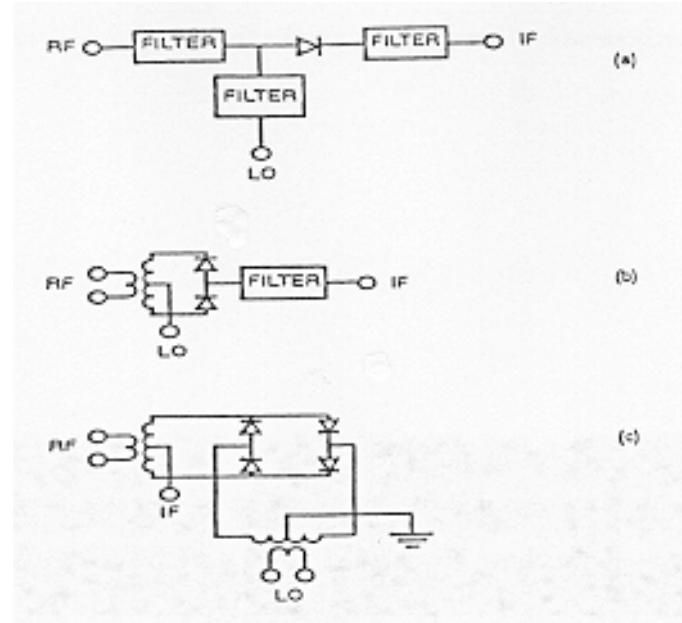


Fig.7-7: Passive Mixer diagram

- **Single Ended Mixer (SEM)**

- Simplest class of mixer, use single diode.

- It needs low LO power (-3 dBm to + 3 dBm).
 - Low dynamic range.
 - No port to port isolation.
 - No IMD suppression.
 - Low cost, easy to design.
 - Narrow band applications.
- **Single Balanced Mixer (SBM)**
 - Use two (or more) diodes.
 - More LO power required, typically 3 dB higher than SEM.
 - Better dynamic range.
 - Good LO isolation.
 - Usually no isolation for RF – IF.
 - More costly.
 - Broadband applications.
 - **Double Balanced Mixer (DBM)**
 - Use four diodes.
 - Greater LO power, typically 3 dB higher than SBM.
 - Good LO, RF isolation.
 - Suppression of even order RF and LO terms, thus, better IMD performance.
 - More costly.
 - Broadband, high isolation applications.

7.4 Active Mixers

The mixer is typically the noisiest stage in the receiver front end. If, as with diode mixers, this stage also introduces a conversion loss, the noise generated in the first IF stage may also be a contributor to the overall noise figure. Consequently, FET and BJT mixers that have a conversion gain on the order of 20 dB for BJTs or 10 dB for FETs are attractive.

7.4.1 FET Mixer

- Low conversion gain
- Good noise figure
- Good IMD

FET Mixers Topologies

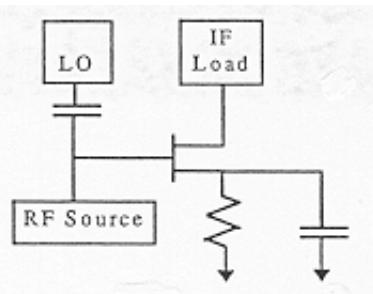


Fig.7-8: JFET mixer with LO and RF injection at the gate:
good gain, poor LO – RF isolation

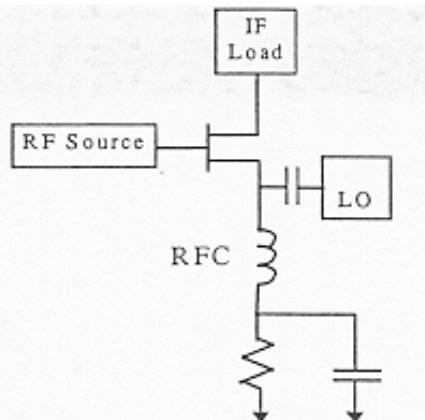


Fig.7-9: JFET mixer with LO injection at the source terminal:
poor gain, good LO – RF isolation

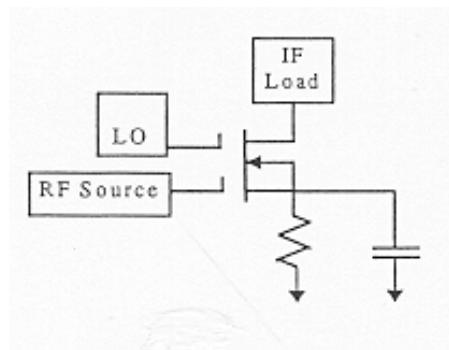


Fig.7-10: MOSFET dual – gate mixer with RF and LO injected on separate gate: good gain, best LO – RF isolation.

7.4.2 BJT Mixers

- High conversion gain
- Low noise figure
- High IMD
- Small dynamic range

BJT Mixer Topologies:

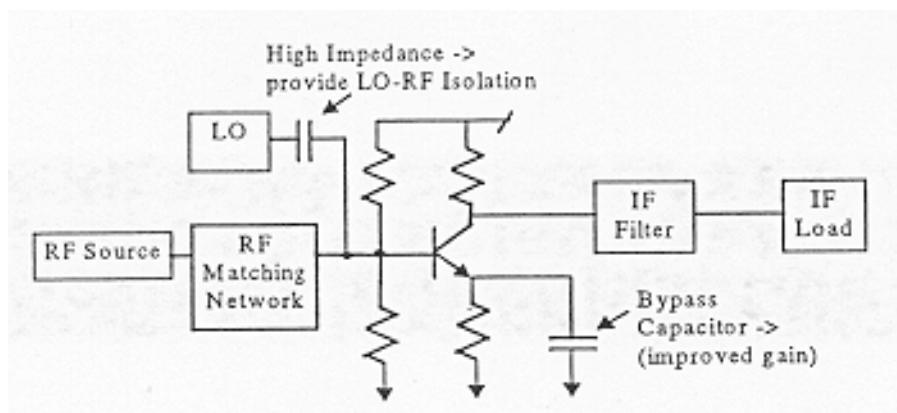


Fig.7-11: Both RF and LO injected at base: high conversion gain, poor LO – RF isolation

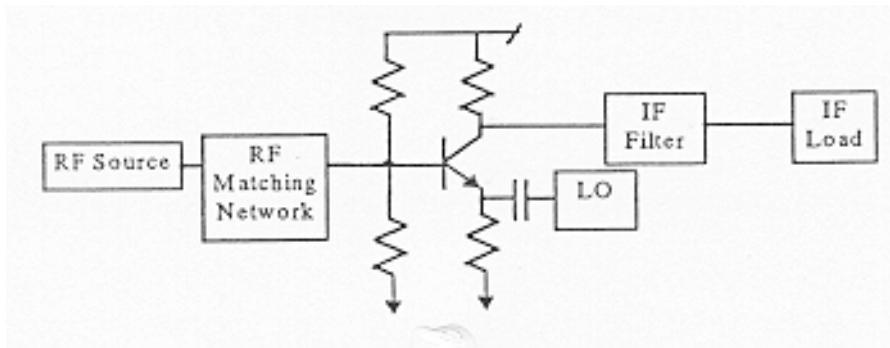


Fig.7-12: RF injection at base, LO at emitter: low conversion gain, good LO – RF isolation

7.5 Summary of Mixer Characteristics

	Single-Ended	Single-Balanced	Double-Balanced
Conversion Gain	High	Moderate	Low
Spurious Performance	None	Moderate	High
Dynamic Range	Low	Moderate	High
Isolation	None	Moderate	High
LO Pump Power	Low	Moderate	High
Complexity	Low	Moderate	High
Bandwidth	Narrow	Wide	Wide

- Single- ended mixers: low cost, narrow band applications.
- Double-balance mixers: wideband, good IMD performance, good isolation.
- BJT, FET mixers: low noise figure, good conversion gain.

Generally, the double balance mixer is very widely used and is a safe selection in most cases. BJT, FET mixers are used when low noise figure and conversion gain are required.