Understanding VCO Concepts

OSCILLATOR FUNDAMENTALS

An oscillator circuit can be modeled as shown in Figure 1 as the combination of an amplifier with gain $A(j\omega)$ and a frequency dependent feedback loop $H(j\omega) = \beta A$. The general expression is

$$\frac{V_o}{Vi} = \frac{A}{(1-\beta A)}$$

which states that the system will oscillate, provided $\beta A = 1$. At the frequency of oscillation, the total phase shift around the loop must be 360 degrees, and the magnitude of the open loop gain must be unity. The common emitter circuit provides 180 degree phase shift. If the circuit is used with feedback from collector to base, the feedback circuit must provide additional 180 degree phase shift. If a common base circuit is used, there is no phase shift between the emitter and collector signals, the feedback circuit must provide either 0 degree or full 360 degree phase shift.

Although the model shown in Figure 1 can be used to analyze and determine the necessary and sufficient conditions for oscillation, it is easier to use the model shown in Figure 2 where the analysis is performed in terms of a negative resistance concept. This is based on the concept that a tuned circuit, once excited, will oscillate continuously if there is no resistive element present to dissipate the energy. It is the function of the amplifier to generate the negative resistance or maintain oscillation by supplying an amount of energy equal to that dissipated. The selection of the circuit topology is dictated by several factors:
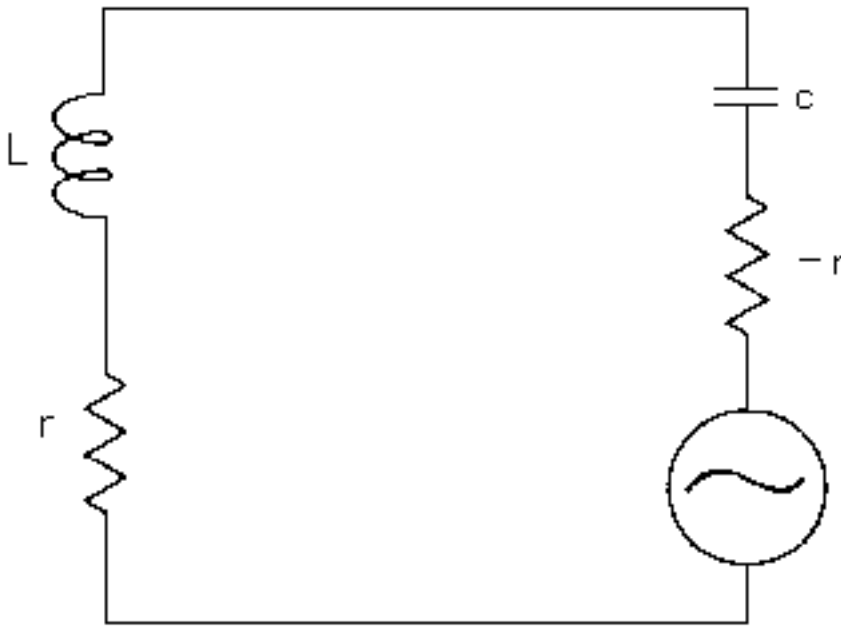
(a) Frequency of oscillation
(b) Tuning range
(c) Choice of transistor, and
(d) Type of resonator.

Figure 1

$$\frac{Vo}{Vi} = \frac{A}{1-\beta A}$$
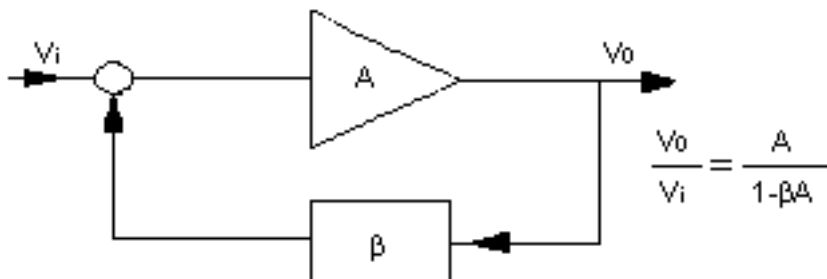
An oscillator may be modeled as the combination of an amplifier and a feedback loop

Figure 2
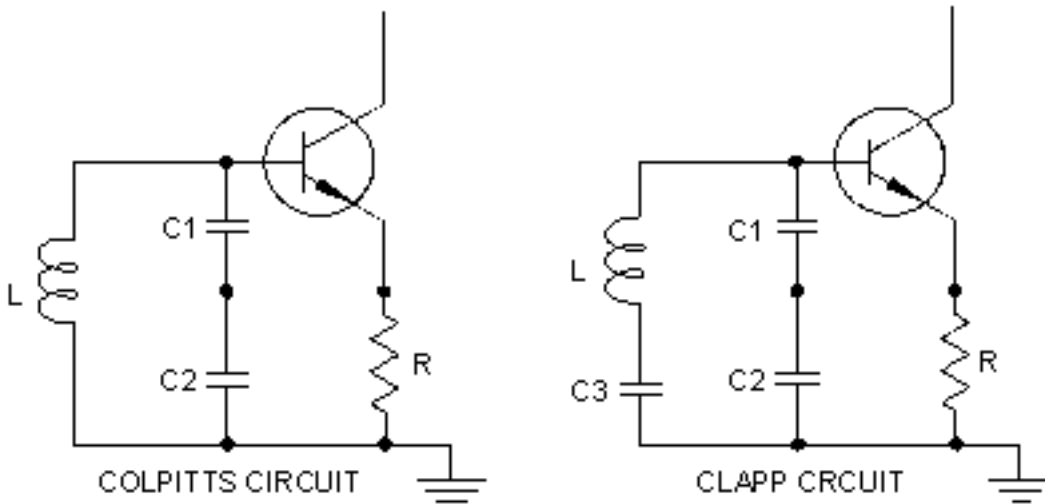

An oscillator may be modeled using a negative resistance concept

EXAMPLES OF OSCILLATOR DESIGN

A bipolar transistor with capacitances between the base and emitter, and the emitter and ground, can be used to generate a negative resistance. Examples of these circuits are shown in Figure 3.

Figure 3

COLPITTS CIRCUIT   CLAPP CRCUIT

Form of oscillator circuit discussed (RF equivalent)

An inductive resonator may be used in any parallel resonant oscillator circuit such as Colpitts or Clapp. The resonator operates at a point where it resonates with the load capacitance. The circuit of Figure 3 is preferred for high stability oscillator circuits because of the ease with which the resonator may be isolated from the load.

Consider the circuit shown in Figure 4(a). The design equations are derived below by replacing the circuit by its equivalent circuit. This is illustrated in Figure 4(b).

The input impedance seen to the right of the dotted line in Figure 4(b) is given by

$$V = \frac{i}{j\omega C_1} + \frac{i + g_m V_{be}}{j\omega C_2}$$

where $V_{be} = \dfrac{i}{j\omega C_1}$

$$\frac{V}{i} = \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} - \frac{g_m}{\omega^2 C_1 C_2}$$

The quantity $(g_m/^2 C1.C2)$ is negative indicating a negative resistance component and therefore in order to maintain oscillations we must have

$$r < \frac{g_m}{\omega^2 C_1 C_2}$$

where r is the series resistance of the resonator.

The frequency of oscillation is given by

$$(\omega^2)L = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

The ratio C_1/C_2 is selected to be greater than 1 so that the circuit has sufficient loop gain for start up condition at the lowest operating temperature. A VCO is obtained by replacing a fixed capacitor such as C3 with a varactor. The bipolar transistor with an inductive reactance between the base and the ground can also generate a negative resistance (See Figure 5). This topology is preferred at higher frequencies. The oscillator is obtained by adding a tank circuit as shown in Figure 6.
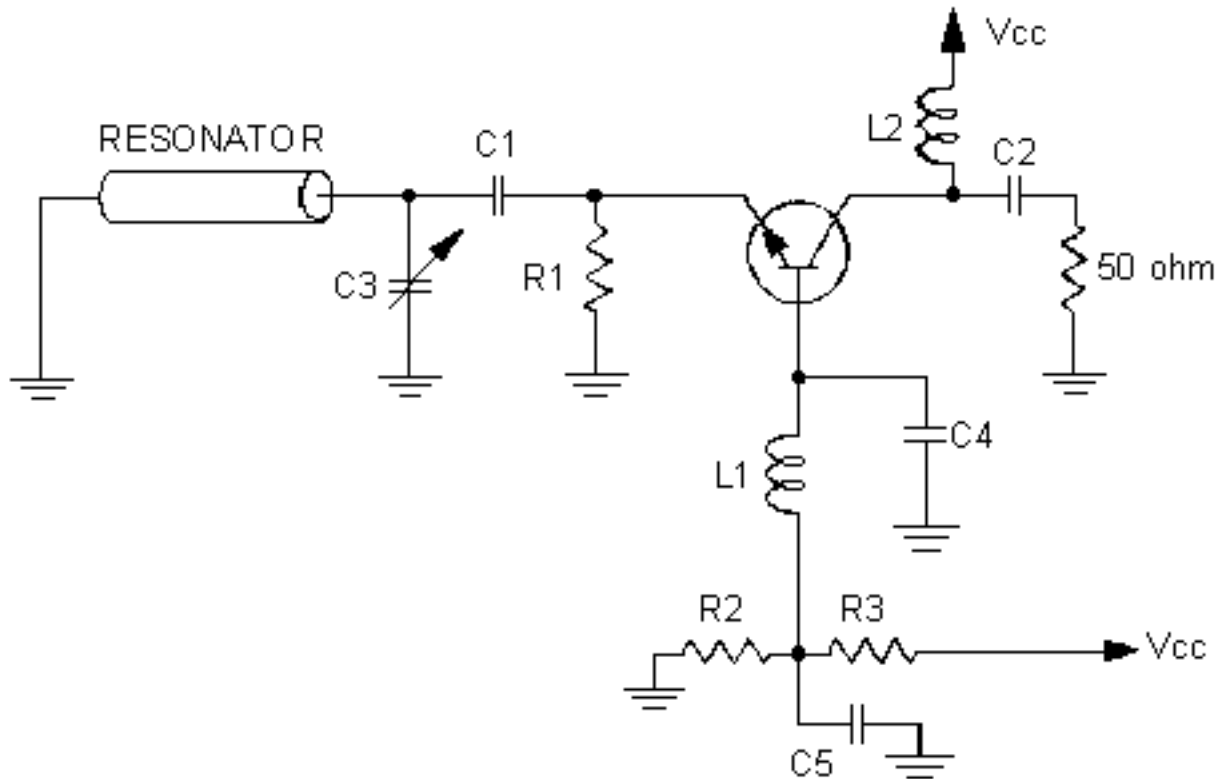
Figure 4(a) and 4(b)
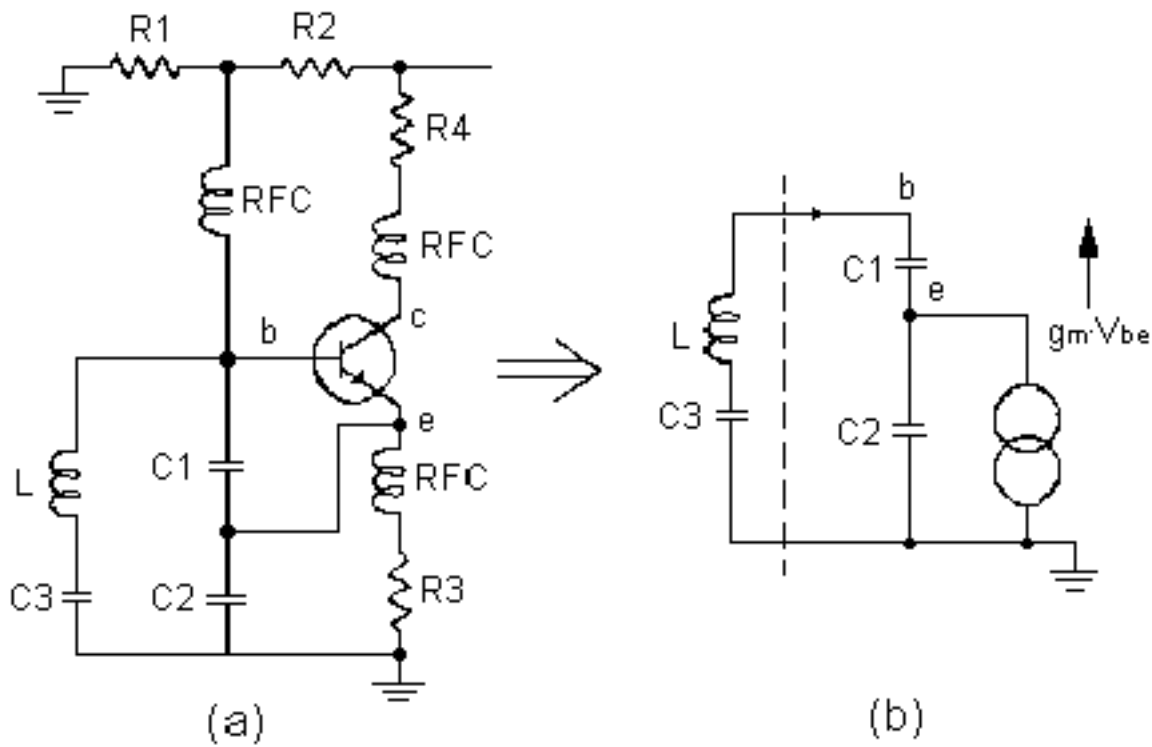
Oscillator design evaluation for CLAPP circuit

Figure 5
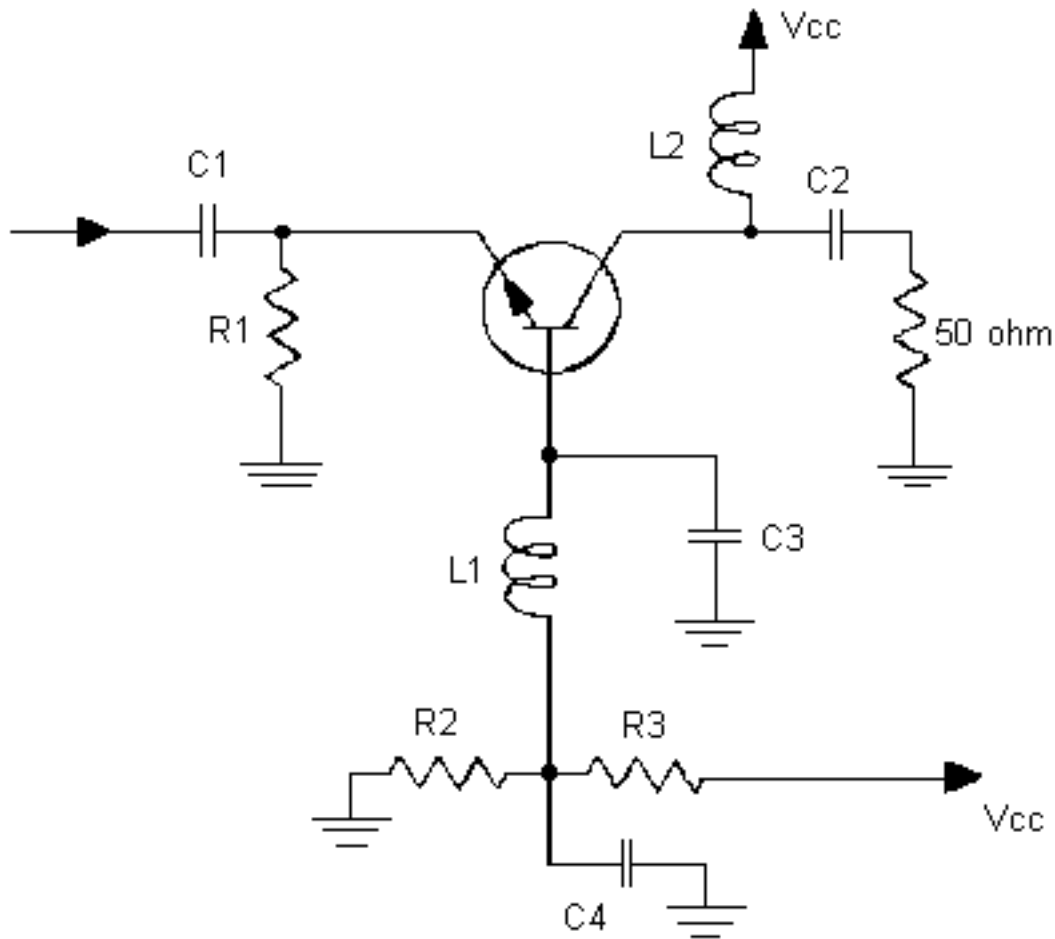
Common base circuit configured for generating negative resistance

Figure 6

Common base circuit configured as an oscillator

TUNING SENSITIVITY CHARACTERISTICS

There are two basic types of varactors: Abrupt and Hyperabrupt. The abrupt tuning diodes will provide a very high Q and will also operate over a very wide tuning voltage range (0 to 60 V). The abrupt tuning diode provides the best phase noise performance because of its high quality factor.

The hyperabrupt tuning diodes, because of their linear voltage vs. capacitance characteristic, will provide a much more linear tuning characteristic than the abrupt diodes. These are the best choice for wide band tuning VCO's. An octave tuning range can be covered in less than 20 V tuning range. Their disadvantage is that they have a much lower Q and therefore provide a phase noise characteristic higher than that provided by the abrupt diodes.

For a varactor diode, the capacitance is related to the bias voltage by the following equation:

$$C = \frac{A}{(V_R + \Phi)^n} \qquad \ldots\ldots\ldots\ldots(1)$$

where A is a constant, V_R is the applied reverse bias voltage, and Φ is the built-in potential which is 0.7 for silicon diodes, and 1.2 V for Gallium Arsenide diodes. For the analysis that follows, we may write

$$C = \frac{A}{V^n} \qquad \ldots\ldots\ldots\ldots(2)$$

where A is the capacitance of the diode when V is one volt and n is a number between 0.3 and 0.6, but can be as high as two for an abrupt junction. The tank circuit of a typical VCO has a parallel tuned circuit consisting of an inductance L, a fixed capacitance Cf, and a varactor diode C. The frequency of oscillation can be written as

$$\frac{1}{\omega^2} = L(C_f + AV^{-n}) \qquad \ldots\ldots\ldots\ldots(3)$$

Let ω_o be the angular frequency of the unmodulated carrier and V_o and C_o be the corresponding values of V and C. Then from Equation (3) we have

$$L = \frac{1}{\omega_0^2(C_f + C_0)} \qquad \ldots\ldots\ldots\ldots(4)$$

If V_o is modulated by a small voltage V, the carrier will be deviated by a small frequency $\delta\omega$.

$$(\omega_0 + \delta\omega)^2 = L[C_f + A(V_0 + \delta V)^{-n}]$$

Substituting for L and rearranging, we have

$$\left(1 + \frac{\delta\omega}{\omega_0}\right)^{-2} = \frac{C_f + C_0\left(1 + \frac{\delta V}{V_0}\right)^{-n}}{C_f + C_0}$$

The oscillator tuning sensitivity K can therefore be written as

$$K_1 = \frac{d\omega}{dv} = \frac{n\omega_0}{2V_0}\left(\frac{C_0}{C_f + C_0}\right)$$

The units of K_1 is rad/sec/volt.