

Module 4: Feedback and Oscillator Circuits



Mr. Nataraj Vijapur
Assoc. Professor
Dept of Electronics & Communication Engg
KLE Dr M S Sheshgiri College of Engg & Tech,
Udyambag, Belagavi 590008
Mob: 9845734228
Email id: nvijapur@gmail.com

SYLLABUS

Feedback concepts, Feedback connection types, Practical feedback circuits, Oscillator operation, FET Phase shift oscillator, Wein bridge oscillator, Tuned Oscillator circuits, Crystal oscillator, UJT construction, UJT Oscillator.

Courtesy:

Robert L. Boylestad and Louis Nashelsky, “Electronics Devices and Circuit Theory”, Pearson, 10th Edition, 2012, ISBN: 978-81-317-6459-6.

Adel S. Sedra and Kenneth C. Smith, “Micro Electronic Circuits Theory and Applications,” Oxford University Press, 5th Edition, ISBN:0198062257.

J.Millman & C.C.Halkias, “Integrated Electronics”, 2nd edition, 2010, TMH. ISBN 0-07-462245-5.

U A Bakshi & A P Godse, “Analog Electronics”, 1st Edition-2009, Technical Publications, Pune

Feedback Concepts:

Feedback plays an important role in every system. Majority of practical electronics systems and circuits employ feedback. Feedback in electronic circuits can be of two types

1. Positive Feedback
2. Negative Feedback

1. Positive Feedback

Here feedback voltage adds to the incoming input OR feedback voltage has same phase as that of incoming signal. Positive Feedback is used for generation of oscillations. All oscillators employ positive Feedback. Figure 4.1 illustrates Positive feedback. Any feedback system comprises of Amplifier and a feedback network. Amplifier amplifies the incoming signal. Feedback network attenuates the output signal and generates feedback signal. A- Gain of open-loop Amplifier and β - Gain of Feedback network.

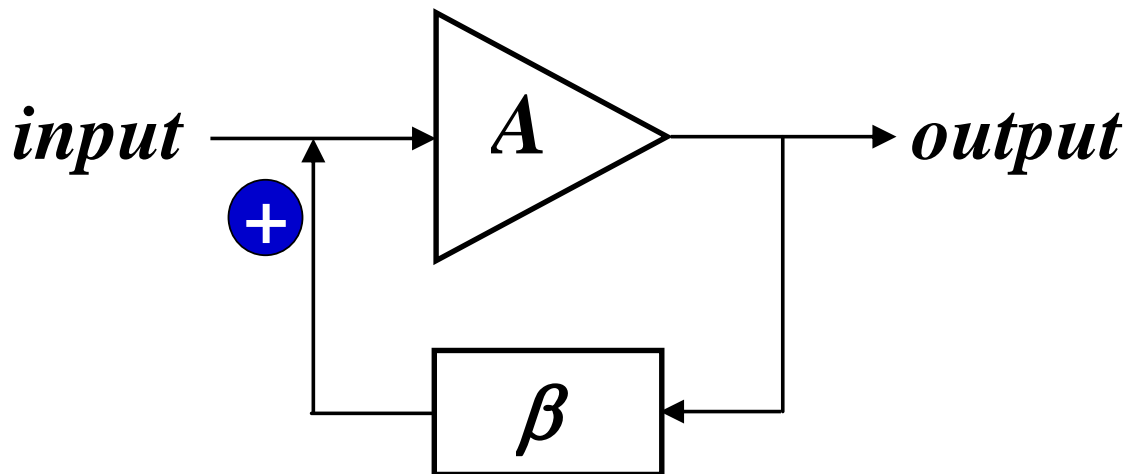


Figure 4.1 Positive Feed back

2. Negative Feedback

Here feedback voltage subtracts from the incoming input signal OR feedback voltage has opposite phase as that of incoming signal. Negative Feedback is used for amplification of input signal. Amplifiers employ negative Feedback. Figure 4.2 illustrates Negative feedback. Any Negative feedback system comprises of open loop Amplifier and a feedback network. Amplifier amplifies the incoming signal. Feedback network attenuates the output signal and generates feedback signal. A- Gain of open-loop Amplifier and β - Gain of Feedback network.

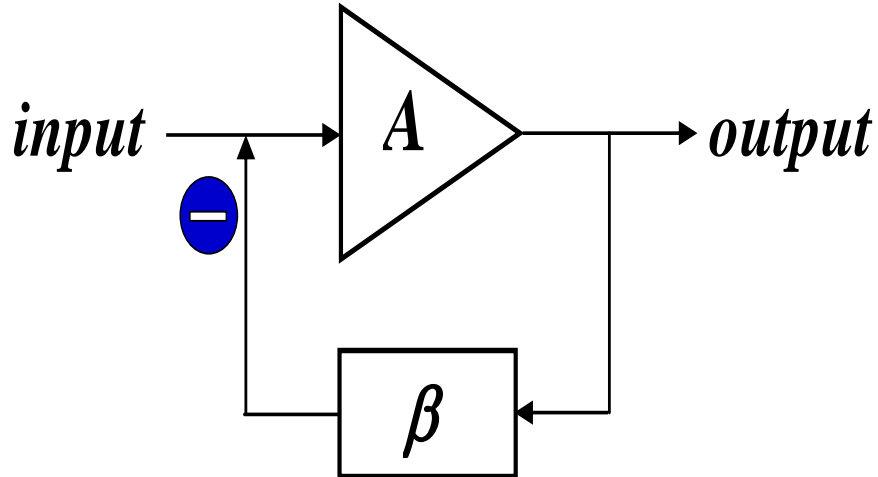


Figure 4.2 Negative feedback

Concepts of Negative feedback

A typical feedback connection is shown in Figure 4.3. The input signal V_s is subtracted with a feedback signal V_f . The difference of these signals V_i is the input voltage to the amplifier. A portion of the amplifier output V_o is connected to the feedback network (β), which provides a reduced portion of the output as feedback signal at the input.

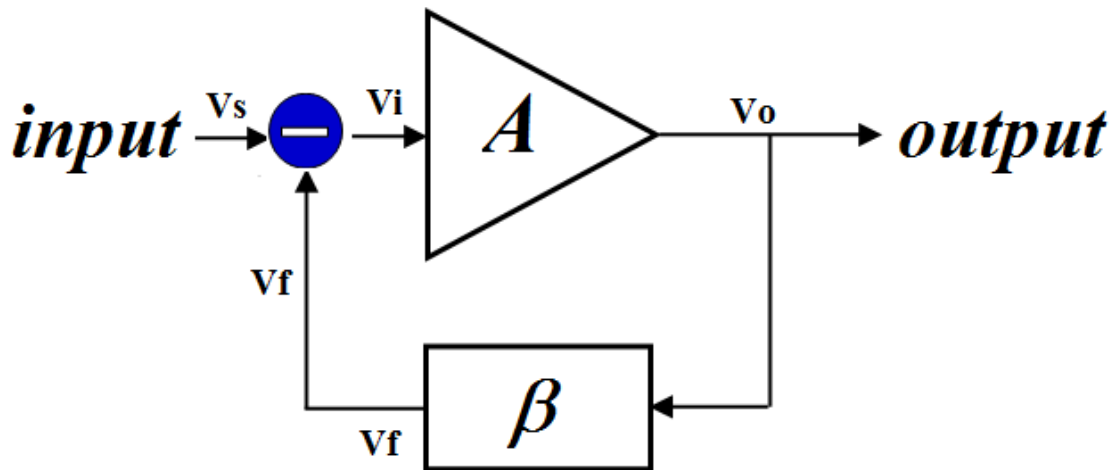


Figure 4.3 Feedback Amplifier

Overall Gain of the closed loop system shown in the above Figure 4.3 is given by,

$$A_f = \frac{V_O}{V_S} = \frac{A}{1+A\beta} \dots\dots\dots(1)$$

A_f denotes the closed loop gain OR gain with feedback

Negative feedback results in reduced gain but results in lot of improvements:

Advantages :

4. Higher input impedance
2. More stable gain
3. Improved frequency response
4. Lower output impedance
5. Reduced noise
6. More linear operation

Feedback Connection Types

Depending on whether voltage OR current is subjected to feedback and feedbacks mixing at the input, feedback circuits are classified into four types:

- Voltage-series feedback
- Voltage-shunt feedback
- Current-series feedback
- Current- Shunt feedback

1) Voltage-series feedback

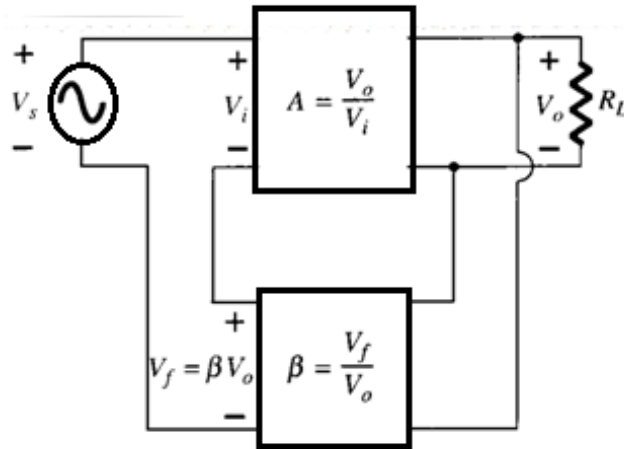


Figure 4.4 Voltage series feedback

Here part of output voltage is fed as input to the feedback network; Output of feedback network mixes in series with the input signal voltage. Series feedback connection increases the input impedance. Voltage feedback at output reduces the output impedance. Voltage amplifiers employ this feedback connection.

Gain with feedback is given by,

$$Af = \frac{V_o}{V_s} \dots \dots \dots (2)$$

Analysis of Voltage Series Feedback To Find Closed Loop Gain

In the above Figure 4.4,

$$V_i = V_s - V_f \dots \dots \dots (3)$$

Since,

$$V_o = AV_i = A(V_s - V_f) = AV_s - AV_f$$

$$V_o = AV_s - A(\beta V_o)$$

then

$$(1 + \beta A)V_o = AV_s$$

Therefore, the Overall voltage gain with feedback is

$$Af = \frac{V_o}{V_s} = \frac{A}{1 + A\beta} \dots \dots \dots (4)$$

Input impedance of Voltage series feedback

Detailed block diagram of voltage series feedback connection is shown in Figure 4.5

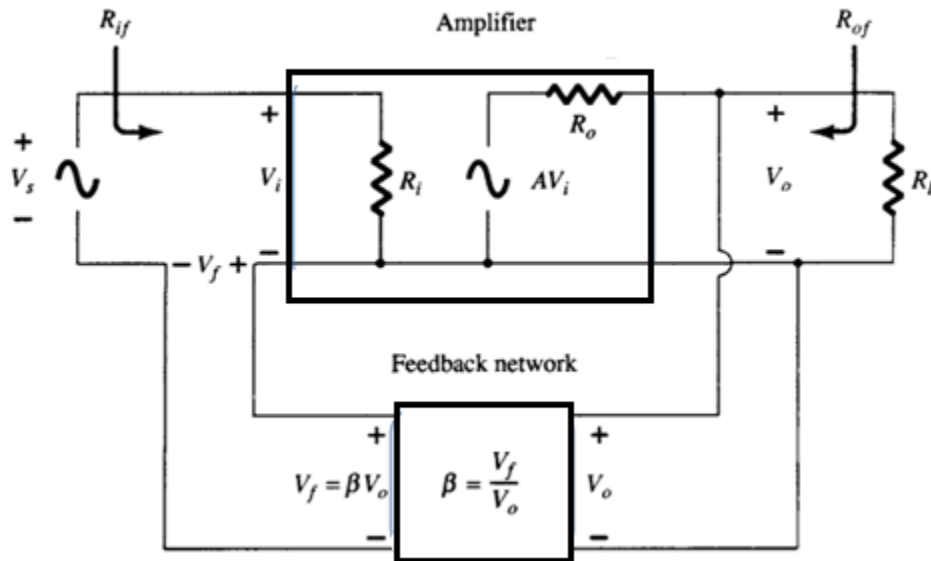


Figure 4.5 Voltage series feedback with more details

Input impedance can be derived as,

$$\begin{aligned}
 I_i &= V_i / Z_i = V_s - V_f / Z_i \\
 &= V_s - \beta V_o / Z_i \\
 &= V_s - \beta A V_i / Z_i \\
 I_i Z_i &= V_s - \beta A V_i \\
 V_s &= I_i Z_i + \beta A V_i = I_i Z_i + \beta A I_i Z_i \\
 Z_{if} &= V_s / I_i \\
 &= Z_i + (\beta A) Z_i \dots \dots \dots (5)
 \end{aligned}$$

Output impedance of Voltage series feedback

The output impedance is determined by applying a voltage V , at the o/p resulting in a current I , with V_s shorted out ($V_s = 0$). Figure 4.6 shows the section of output of amplifier.

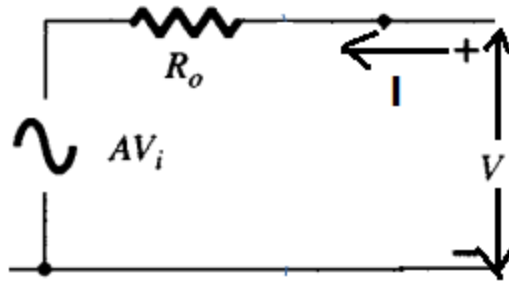


Figure 4.6 Network at the output of amplifier with test input V.

The voltage V is then given by

$$V = IZ_o + AV_i$$

For $V_s = 0$, $V_i = -V_f$

Which implies, $V = IZ_o - AV_f = IZ_o - A(\beta V)$

Rewriting the equation as

$$V + \beta AV = IZ_o$$

$$Z_{of} = V/I = Z_o / (1 + A\beta) \dots \dots \dots (6)$$

2) Voltage-shunt feedback Configuration

Here output voltage is fed back to feedback network and feedback signal is connected in parallel with the input current source. Shunt feedback connection decreases the input impedance. Voltage feedback at output also reduces the output impedance. Transresistance amplifiers employ this type feedback connection.

$$A_f = V_o / I_s \dots \dots \dots (7)$$

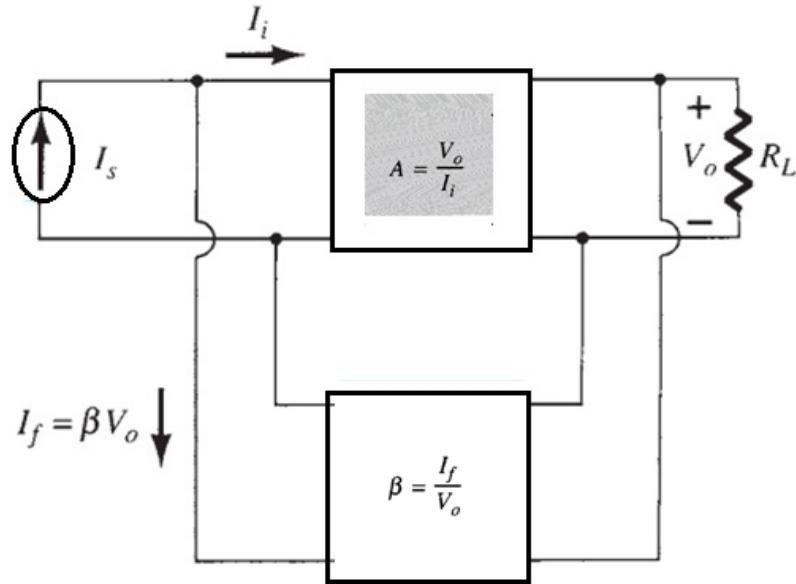


Figure 4.7 Voltage shunt feedback configuration

Gain with Voltage-shunt feedback Configuration

Overall Gain OR Gain with feedback can be expressed as,

$$\begin{aligned}
 A_f &= V_o/I_s \\
 &= A I_i / (I_i + I_f) \\
 &= A I_i / (I_i + \beta V_o) \\
 &= A I_i / (I_i + \beta A I) \\
 A_f &= \frac{A}{1 + A\beta} \dots\dots\dots(8)
 \end{aligned}$$

Input impedance with Voltage-shunt feedback Configuration

To determine input impedance, the Figure 4.7 can be redrawn as,

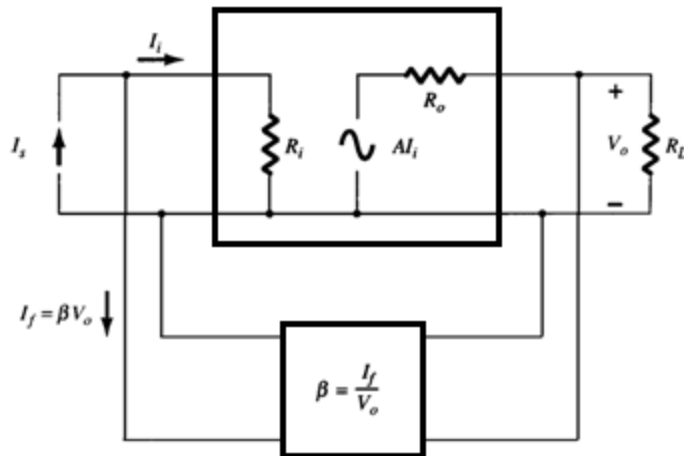


Figure 4.8 Voltage shunt feedback configuration with details

From, the Figure 4.8,

$$Z_{if} = V_i / I_s$$

$$= V_i / (I_i + I_f)$$

$$= V_i / (I_i + \beta V_o)$$

$$= (V_i / I_i) / ((I_i / I_i) + \beta (V_o / I_i))$$

$$Z_{if} = Z_i / (1 + \beta A) \dots\dots\dots(9)$$

3) Current-series feedback Configuration

Here current from output is feedback to input. The fed back signal is mixed in series with the input current. Series feedback connection increases the input impedance. Current feedback at output also increases the output impedance. Transconductance amplifiers employ this type feedback connection.

Overall Gain or Gain with feedback can be expressed as,

$$A_f = I_o / V_s \dots\dots\dots (40)$$

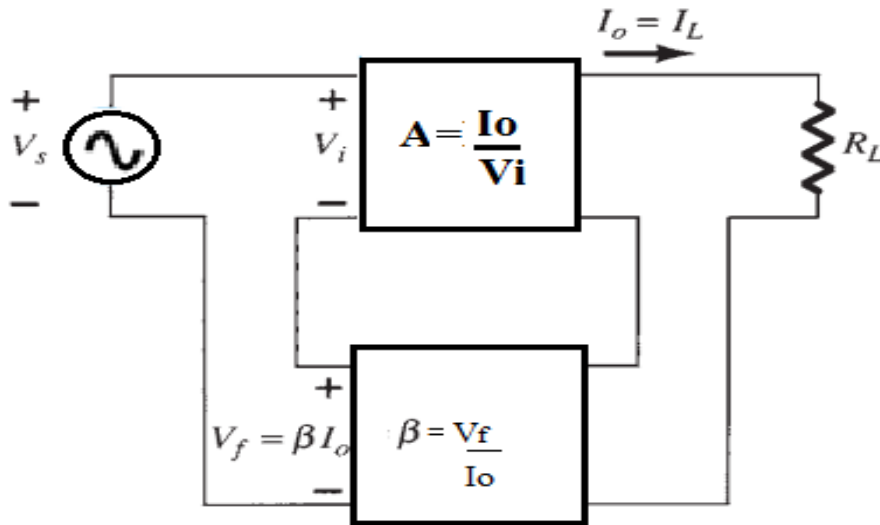


Figure 4.9 Current series feedback

Output impedance of current series feedback configuration

To determine output impedance the current series feedback configuration can be drawn as shown in Figure 4.10

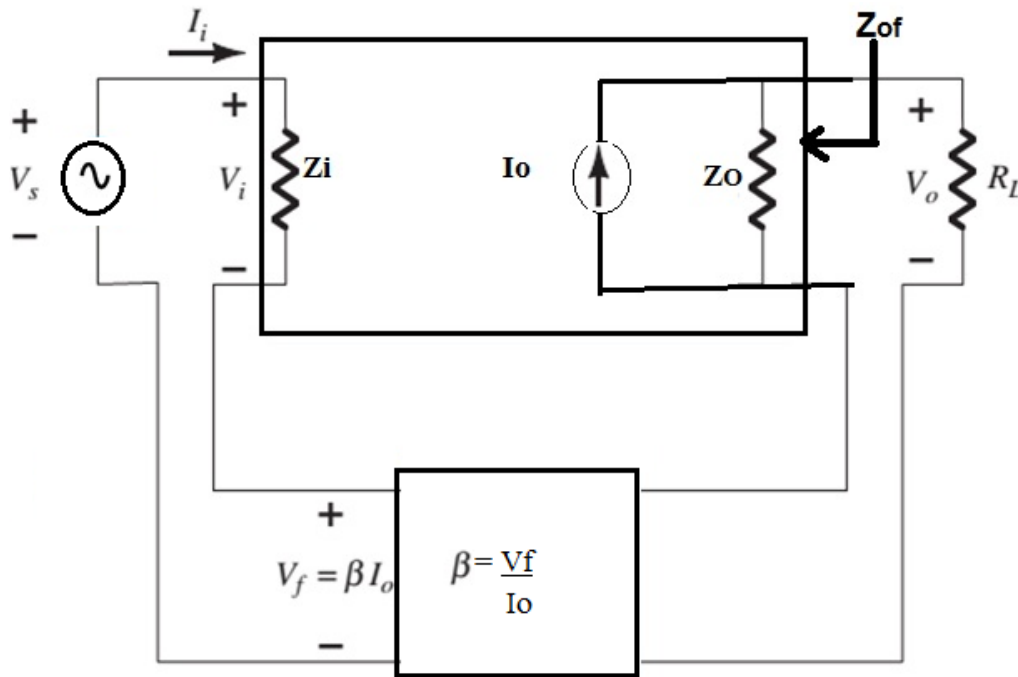


Figure 4.10 current series feedback configuration in detail

Output impedance is determined by applying a test signal V to the output with V_s shorted out ($V_s=0$), resulting in a current I , the ratio of V to I being the output impedance. The circuitry at the output is redrawn as shown in the Figure 4.11

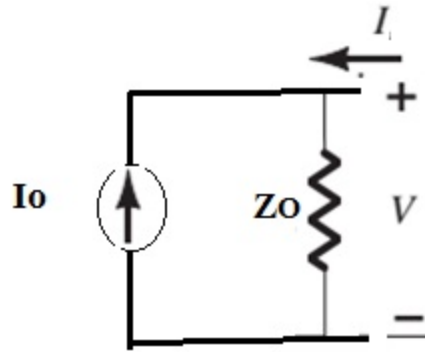


Figure 4.11 Output section of current series feedback configuration

With $V_s=0$,

$$V_i = V_f$$

$$I = (V/Z_o) - AV_i$$

$$= (V/Z_o) - AV_f$$

$$= (V/Z_o) - A\beta I$$

$$Z_o(1 + \beta A)I = V$$

$$Z_{of} = V/I = Z_o(1 + A\beta) \dots \dots \dots (11)$$

4) Current-shunt feedback Configuration

Here current is fed to feedback network. Fed back signal is mixed in parallel with the input current source. Shunt feedback connection decreases the input impedance. Current feedback at output increases the output impedance. This topology is applied in current amplifiers.

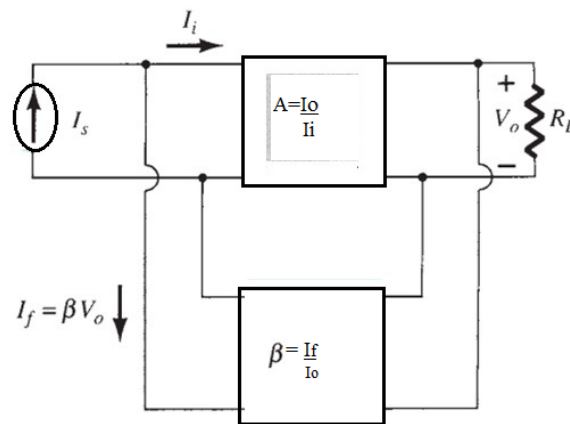


Figure 4.12 Current shunt feedback configurations

Here Overall Gain OR Gain with feedback can be expressed as,

$$A_f = I_o / I_s$$

Frequency Distortion with Feedback (Reduction in Frequency Distortion)

- If loop gain $A\beta \gg 1$, then closed loop gain becomes, $A_f \equiv 1/\beta$

Thus if the feedback network is purely resistive then closed loop gain becomes independent of reactive components although amplifier has a reactive response.

Noise and Nonlinear Distortion (Reduction in Noise and Nonlinear Distortion)

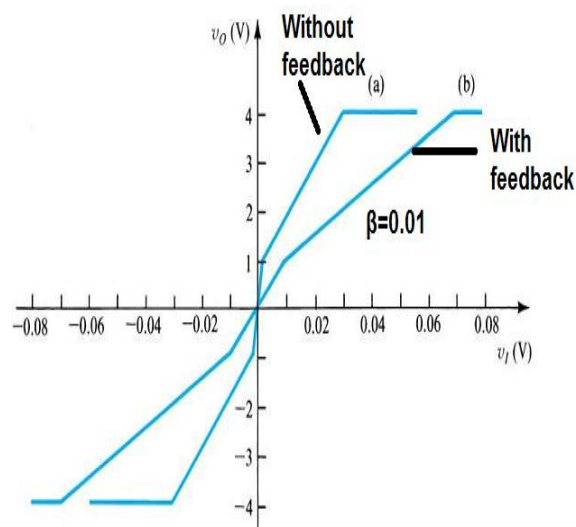


Figure 4.13 Reductions in Non-Linear Distortion

Application of negative feedback makes the system more linear. In Figure 4.13, Curve (a) shows transfer characteristic without negative feedback. Curve (b) shows the curve with negative feedback of $\beta=0.01$. We can see that The amplifier transfer characteristic can be considerably linearized (through the application of negative feedback). Thus large changes in open-loop gain (1000 to 100 in this case) give rise to much smaller corresponding changes in the closed-loop gain We can say that Feedback reduces noise and non-linear distortion

Effect of Negative Feedback on Gain and Bandwidth

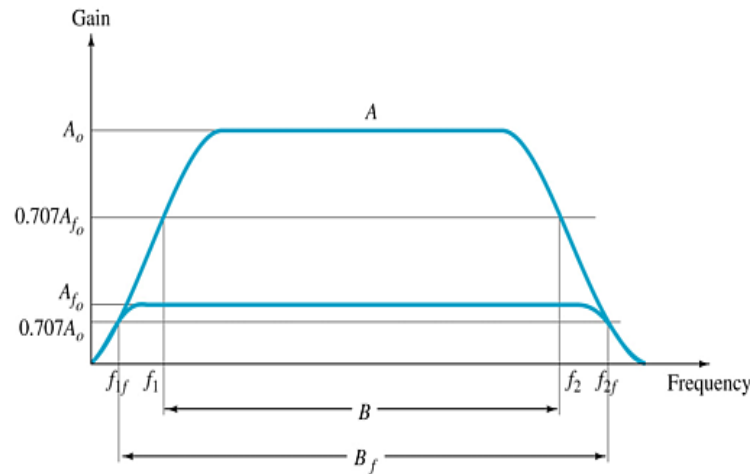


Figure 4.14 Effect of negative feedback on Bandwidth

Negative feedback results in improved Bandwidth. If f_1 is the lower cutoff frequency without feedback then we can see that it is pre-poned. New lower cutoff frequency is given by

$$f_{1f} = f_1 / (1 + A\beta) \dots (12)$$

. If f_2 is the upper cutoff frequency without feedback then we can see that it is postponed. New upper cutoff frequency is given by

$$f_{2f} = (1 + A\beta) f_2 \dots (13)$$

Thus overall Bandwidth is improved by Negative feedback. B_f is more than B .

Gain Stability with Feedback

Gain becomes more stable with feedback. From equation (4), we can deduce that,

$$\left| \frac{dAf}{Af} \right| = \frac{1}{|1 + \beta A|} \left| \frac{dA}{A} \right|$$

$$\left| \frac{dAf}{Af} \right| \cong \left| \frac{1}{\beta A} \right| \left| \frac{dA}{A} \right| \text{ for } \beta A \gg \dots (14)$$

This shows that the Magnitude of the relative change in gain $\left| \frac{dAf}{Af} \right|$ is reduced more by the factor $|\beta A|$ compared to that of without feedback $\left(\left| \frac{dA}{A} \right| \right)$. This can be illustrated by the problem.

Thus effect of negative feedback can be summarized as,

Table 1: Effect of Negative feedback

Parameter	Voltage series	Current Series	Voltage Shunt	Current shunt
Gain with feedback	Decreases	Decreases	Decreases	Decreases
Stabilty	Improves	Improves	Improves	Improves
Frequency Response	Improves	Improves	Improves	Improves
Frequency Distortion	Decreases	Decreases	Decreases	Decreases
Noise and non linear distortion	Decreases	Decreases	Decreases	Decreases

Practical feedback circuits

Voltage-Series Feedback:

Let us study the voltage series feedback by the following circuits shown in Figures 4.15, 4.16 and 4.17:

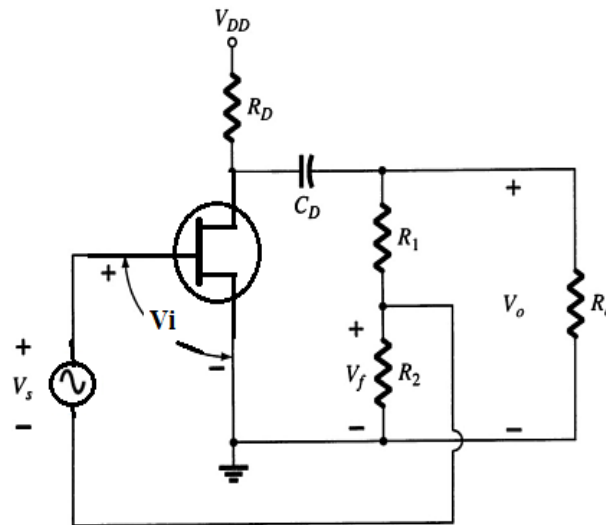


Figure 4.15 Practical Voltage Series Feedback

Figure 4.15 shows an FET amplifier stage with voltage-series feedback. A part of the output signal (V_o) is obtained using a feedback network of resistors R_1 and R_2 . The feedback voltage V_f is connected in series with the source signal V_s ,

Without feedback the amplifier gain is

$$A = \frac{V_o}{V_i} = -g_m R_L \dots \dots \dots (15)$$

where R_L is the parallel combination of resistors:

$$R_L = R_D \parallel R_o \parallel (R_1 + R_2) \dots \dots \dots (16)$$

The feedback network provides a feedback factor of

$$\beta = \frac{V_f}{V_o} = \frac{-R_2}{R_1 + R_2} \dots \dots \dots (17)$$

Using the values of A and β above in Eq. For series feedback gain, we find the gain with negative feedback to be

$$A_f = \frac{1}{1 + \beta A} = \frac{-g_m R_L}{1 + \left[\frac{R_2 R_L}{R_1 + R_2} \right] g_m} \dots \dots \dots (18)$$

If $\beta A \gg 1$, we have,

$$A_f \cong \frac{1}{\beta} = -\frac{R_1 + R_2}{R_2} \dots \dots \dots (19)$$

Problem.

1. Calculate the gain without and with feedback for the FET amplifier circuit with the following circuit values: $R_1 = 80 \text{ k}\Omega$, $R_2 = 20 \text{ k}\Omega$, $R_o = 10 \text{ k}\Omega$, $R_D = 10 \text{ k}\Omega$, and $g_m = 4000 \text{ }\mu\text{S}$.

Solution:

$$R_L \cong \frac{R_o R_D}{R_o + R_D} = \frac{10 \text{ k}\Omega (10 \text{ k}\Omega)}{10 \text{ k}\Omega + 10 \text{ k}\Omega} = 5 \text{ k}\Omega$$

Neglecting the $100\text{-k}\Omega$ resistance of R_1 and R_2 in series gives

$$A = -g_m R_L = -(4000 \times 10^{-6} \text{ }\mu\text{S})(5 \text{ k}\Omega) = -20$$

The feedback factor is

$$\beta = \frac{-R_2}{R_1 + R_2} = \frac{-20 \text{ k}\Omega}{80 \text{ k}\Omega + 20 \text{ k}\Omega} = -0.2$$

The gain with feedback is

$$A_f = \frac{A}{1 + \beta A} = \frac{-20}{1 + (-0.2)(-20)} = \frac{-20}{5} = -4$$

Voltage series Feedback using OPAMP

Here op-amp is connected in a Non-inverting amplifier mode. Input signal is applied to Non-inverting terminal. Output voltage is feedback via potential divider network to inverting terminal. Op-amp amplifies difference between its Non-Inverting and Inverting terminals.

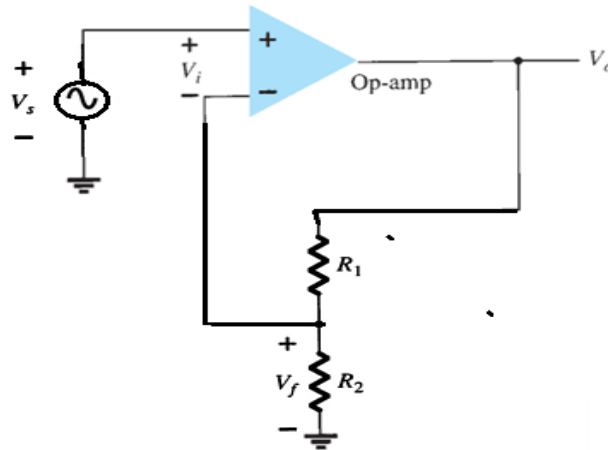


Figure 4.16 Voltage series feedback using OPAMP

Here,

Gain of feedback network is given by, $\beta = \frac{R_2}{R_1+R_2} \dots \dots \dots (20)$

Voltage Series Feedback Emitter Follower:

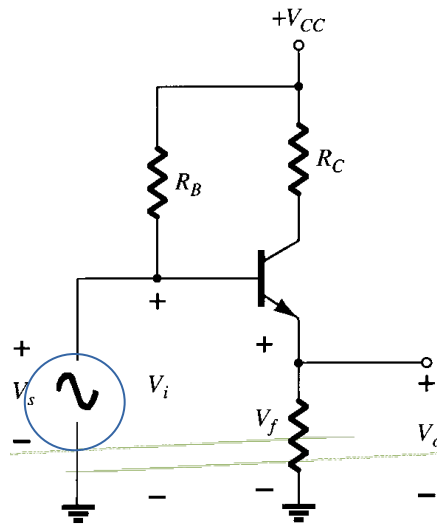


Figure 4.17 Voltage Series Feedback Emitter Follower

The emitter-follower circuit of Fig. 4.17 provides voltage-series feedback. The signal voltage V_s is the input voltage V_i . Resistor R_E acts as feedback resistor and also as a output resistance. The output voltage V_o subtracts in series with the input voltage. The amplifier, as shown in Fig. 4.18, provides the operation with feedback.

The operation of the circuit without feedback provides $V_f = 0$, so that

$$A = \frac{V_o}{V_s} = \frac{h_{fe} I_b R_E}{V_s} = \frac{h_{fe} R_E (\frac{V_s}{h_{ie}})}{V_s} = \frac{h_{fe} R_E}{h_{ie}} \dots\dots\dots(21)$$

and

$$\beta = \frac{V_f}{V_o} = 1 \dots\dots\dots(22)$$

The operation with feedback then provides that,

$$A_f = \frac{V_o}{V_s} = \frac{A}{1+BA} = \frac{h_{fe} R_E/h_{ie}}{1+(1)(h_{fe} R_E/h_{ie})} = \frac{h_{fe} R_E}{h_{ie} + h_{fe} R_E} \dots\dots\dots(19)$$

for $h_{fe} R_E \gg h_{ie}$

$$A_f \cong 1$$

Current-series feedback:

Let us study the current series feedback by the following circuit shown in Figure 4.18.

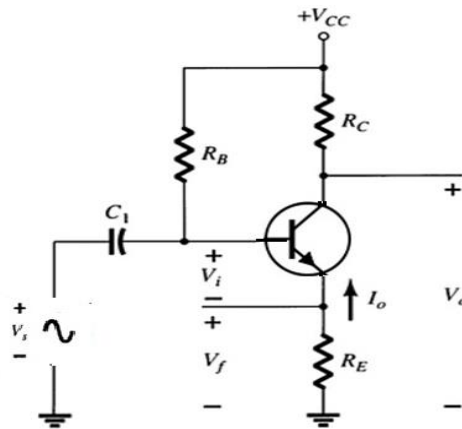


Figure 4.18 Practical Current series feedback

Transistor amplifier is an example of Current series feedback. Resistor R_E acts as a feedback resistor as it is common to input and output sections of amplifier. Here Effective voltage at input increases/decreases depending on feedback voltage. This effective voltage at input further alters the input current in proportion which brings changes in output voltage in proportion.

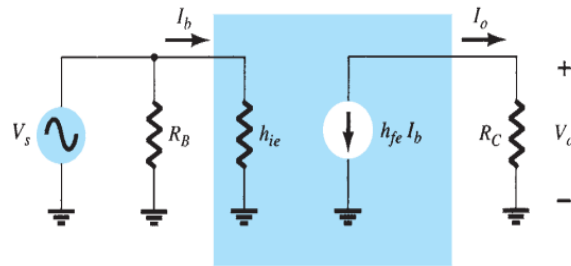


Figure 4.19 AC equivalent of amplifier without feedback

$$A = \frac{I_o}{V_i} = \frac{h_{fe} I_b}{h_{ie} R_e} \dots \dots \dots (23)$$

$$\beta = \frac{V_f}{I_o} = \frac{-I_o R_e}{I_o} = -R_e \dots \dots \dots (24)$$

$$Z_i = R_B || (h_{ie} + R_e) \cong h_{ie} + R_e$$

$$Z_o = R_c$$

The input and output impedances are calculated as specified in summary table :

$$Z_{if} = Z_i(1 + \beta A) \cong h_{ie} \left(1 + \frac{h_{fe} R_e}{h_{ie}}\right) = h_{ie} + h_{fe} R_e \dots \dots \dots (25)$$

$$Z_{of} = Z_o(1 + \beta A) = R_c \left(1 + \frac{h_{fe} R_e}{h_{ie}}\right) \dots \dots (26)$$

The voltage gain A with feedback is

$$A_{vf} = \frac{V_o}{V_s} = \frac{I_o R_c}{V_s} = \left(\frac{I_o}{V_s}\right) R_c = A_f R_c \cong \frac{-h_{fe} R_c}{h_{ie} + h_{fe} R_e} \dots \dots (27)$$

Voltage-shunt Feedback:

Let us study the Voltage-shunt feedback by the circuit shown in Figures 4.20 and 4.21. In Figure 4.20 Voltage-Shunt Feedback is demonstrated using op-amp. Here op-amp is connected in a Inverting amplifier mode. Input signal is applied to Inverting terminal. Output voltage is feedback via potential divider network to the Non-inverting terminal. Op-amp amplifies difference between its Non-Inverting and Inverting terminals. Output voltage is fed back in parallel with the input.

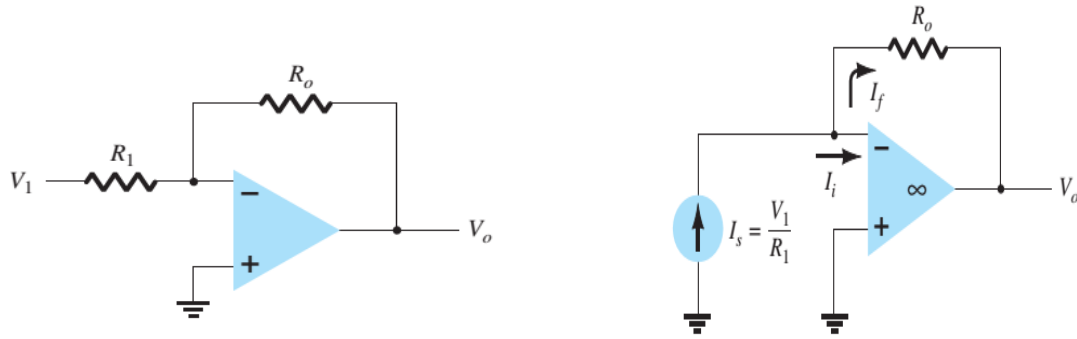


Figure 4.20 Voltage Shunt Feedback using OPAMP

The constant-gain op-amp circuit of Figure 4.21 provides voltage-shunt feedback. Referring to Figure 4.21 and the op-amp ideal characteristics $I_i = 0$, $V_i = 0$, and voltage gain of infinity, we have

$$A = \frac{V_o}{I_i} = \infty$$

$$\beta = \frac{I_f}{V_o} = \frac{-1}{R_o}$$

The gain with feedback is then

$$A_f = \frac{V_o}{I_s} = \frac{V_o}{I_i} = \frac{A}{1 + \beta A} = \frac{1}{\beta} = -R_o$$

This is a transfer resistance gain. The more usual gain is the voltage gain with feedback,

$$A_{vf} = \frac{V_o I_s}{I_s V_1} = (-R_o) \frac{1}{R_1} = \frac{-R_o}{R_1}$$

Voltage-Shunt Feedback using FET

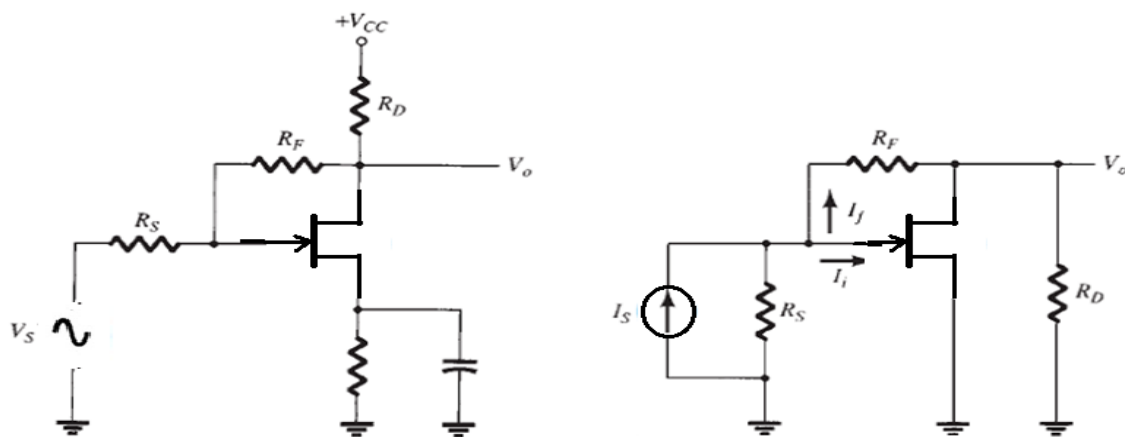


Figure 4.21 Voltage Shunt Feedback using FET

The circuit of Fig. 4.21 is a voltage-shunt feedback amplifier using an FET. Resistor R_F acts as a feedback resistor and is present between Drain and Gate of FET. Output voltage is fed back in parallel with the input.

with no feedback, $V_f = 0$.

$$A = \frac{V_o}{I_i} \cong -g_m R_D R_S$$

The feedback is

$$\beta = \frac{I_f}{V_o} = \frac{-1}{R_f}$$

With feedback, the gain of the circuit is

$$A_f = \frac{V_o}{I_s} = \frac{A}{1 + BA} = \frac{-g_m R_D R_S}{1 + \left(-\frac{1}{R_F}\right)(-g_m R_D R_S)} = \frac{-g_m R_D R_S R_F}{R_f + g_m R_D R_S} \dots \dots \dots (28)$$

The voltage gain of the circuit with feedback is then

$$A_{vf} = \frac{V_o}{I_s} \frac{I_s}{V_s} = \frac{-g_m R_D R_S R_F}{R_f + g_m R_D R_S} \left(\frac{1}{R_S}\right) \dots \dots \dots (29)$$

$$= \frac{-g_m R_D R_F}{R_f + g_m R_D R_S} = (-g_m R_D) \frac{R_F}{R_f + g_m R_D R_S} \dots \dots (30)$$

Current shunt feedback

Let us study the Current-shunt feedback by the circuit shown in Figures 4.22. In the circuit of Figure 4.22 two transistor amplifiers are cascaded to have more current gain. Feedback from 2nd transistors Emitter to 1st transistors Base.

At input side $I_i = I_s - I_f \dots \dots \dots (31)$

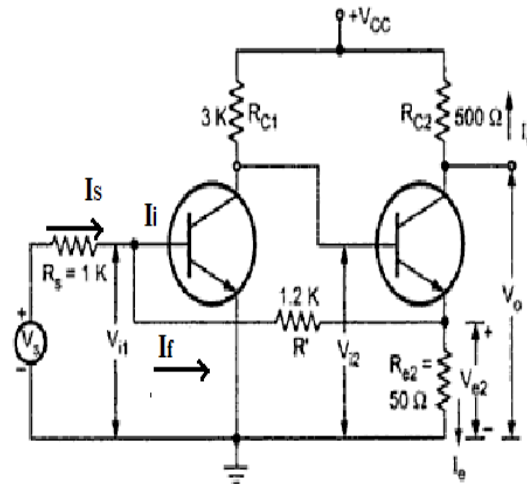


Figure 4.22 Current Shunt Feedback using transistors

Stability problem in feedback amplifiers

Usually both Amplifier and feedback network are reactive in nature, Then, Closed loop transfer function is given by

$$Af(s) = \frac{A(s)}{1 + A(s)\beta(s)} \quad \text{Where, } s = j\omega,$$

In Negative feedback, Feedback network produces signal which is 180° out of phase with input.

At a Certain frequency, the total loop phase shift becomes 180° , Therefore net phase shift will be 360° . Therefore Loop Gain becomes,

$$L(j\omega) = A(j\omega)\beta(j\omega) = -1.$$

The feedback is thus positive and the amplifier, itself, becomes unstable and begins to break into oscillations due to positive feedback. If the amplifier oscillates at some low or high frequency, it is no longer useful as an amplifier. Proper feedback-amplifier design requires that the circuit will be stable at all frequencies, not merely those in the range of interest. Otherwise, a transient disturbance could cause a seemingly stable amplifier to suddenly start oscillating. The conditions of instability can be studied using Bode plots shown in Figure 4.22.

Stability study using Bode Plots

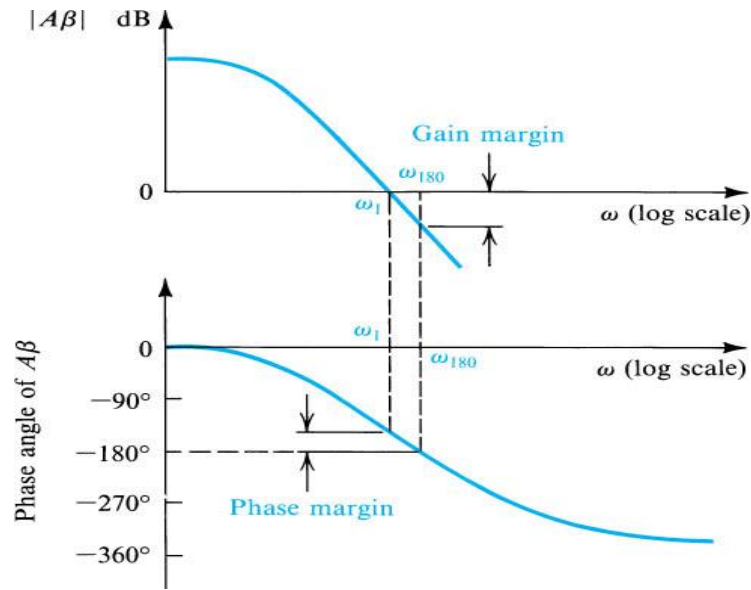


Figure 4.22 Stability study using Bode plots

Here loop gain $A\beta$ is plotted as a function of frequency for one example of closed loop transfer function. If loop gain of unity and phase shift of 180° occurs at same time then there is threat of instability at corresponding frequency. Gain margin represents the amount by which the loop gain can be increased while stability is maintained. Phase margin represents the amount by which the loop phase shift can be changed while stability is maintained.

Oscillators

Oscillators are the electronics circuits which generate voltages of desired frequency amplitude and shape. Oscillators can be classified based

- Based on output waveform
Example: Sinusoidal, Square wave or saw-tooth etc
- Based on circuit components
Example: RC Oscillator, LC Oscillator and Crystal Oscillator etc
- Based on range of frequency
Example: Audio frequency Oscillator, Radio Frequency Oscillator etc
- Based on presence of feedback
Oscillators with feedback circuit and without feedback.

Barkhausen criterion

Any oscillator comprises of two stages:

- The Amplifier stage
- A feedback network

For any oscillator to generate and sustain oscillations Barkhausen criteria needs to be satisfied. Barkhausen criterion states that to sustain oscillations,

- The total phase shift around the loop should be 360° or 0° .
- The product of open loop gain of the amplifier and the feedback network should be unity.

Oscillations start with a noise voltage and are sustained at a frequency at which Barkhausen criteria is satisfied.

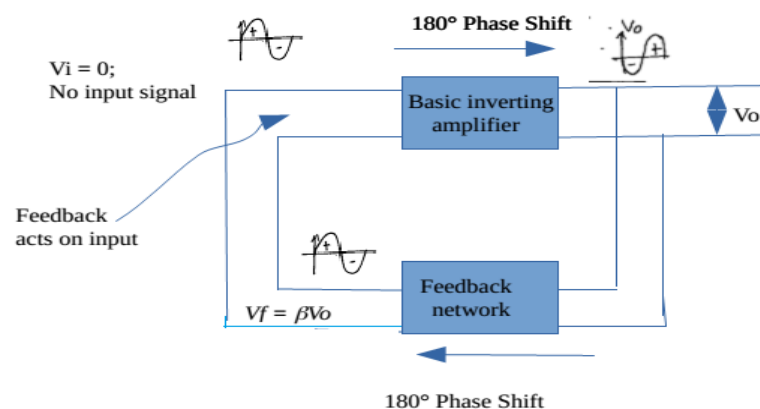


Figure 4.23 Barkhausen Criteria

As shown in the figure 4.23, The output of inverting amplifier is given by

$$V_o = AV_i \dots\dots\dots(32)$$

The feedback network decides the amount of feedback to be given to the input i.e.,

$$V_f = \beta V_o \dots\dots\dots(33)$$

From equation (32) we can write equation (33) as,

$$V_f = \beta AV_i \dots\dots\dots (34)$$

LOOP GAIN $A\beta$

Depending on the value of loop gain $A\beta$, the circuit generates oscillations as shown below.

If $|A\beta| > 1$ circuit generates oscillations of growing type as shown in Figure 4.27

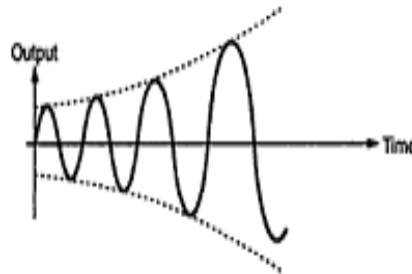


Figure 4.27 $|A\beta| > 1$

If $|A\beta| = 1$ the circuit generates oscillations of fixed amplitude as shown in Figure 4.28

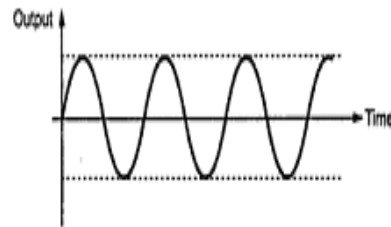


Figure 4.28 $|A\beta| = 1$

If $|A\beta| < 1$ the circuit generates oscillations of decaying nature as shown in Figure 4.29

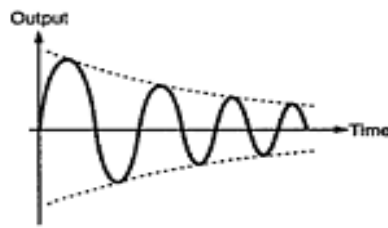


Figure 4.29 $|A\beta| > 1$

Types of Oscillator Circuits

- FET Phase shift oscillator
- Wein bridge oscillator
- Tuned Oscillator circuit
- Crystal oscillator
- UJT Oscillator.

Phase-Shift Oscillator

Phase shift oscillator consists of an amplifier and Phase shift network constituted by RC elements as shown in Figure 4.30.

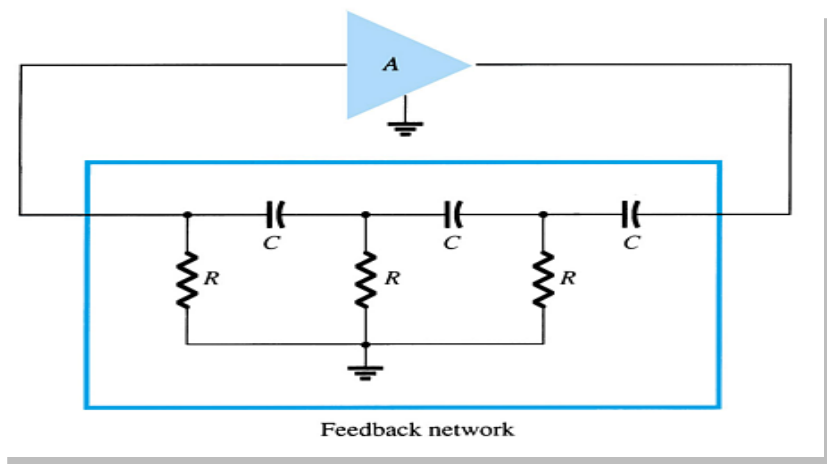


Figure 4.30 Phase shift oscillator feedback network

In phase shift oscillator,

- The amplifier and a feedback network consisting of RC Sections are present
- The RC networks provide the necessary phase shift for a positive feedback.
- The values of the RC components determine the frequency of oscillation:

Frequency of generated oscillations is given by,

$$f = \frac{1}{2\pi RC\sqrt{6}}$$

FET Phase Shift Oscillator

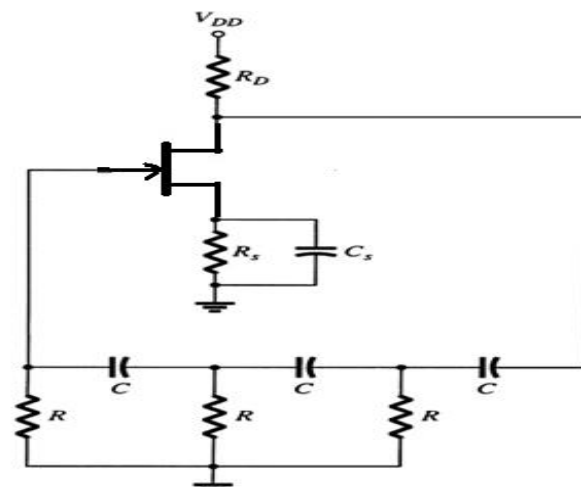


Figure 4.31 FET phase shift oscillator

A practical version of a phase-shift oscillator circuit is shown in Figure 4.31. The circuit is drawn to show clearly the amplifier and feedback network. Here FET amplifier introduces 180° phase shift. The 3 RC sections further introduce 180° phase shift. Total phase shift around the loop is 360° ensuring Positive feedback. The amplifier stage is self biased with a capacitor bypassed source resistor R_S and a drain bias resistor R_D . The FET device parameters of interest are g_m and r_d . From FET amplifier theory, the amplifier gain magnitude is calculated from

$$|A| = g_m R_L \text{ ----- (35)}$$

where R_L in this case is the parallel resistance of R_D and r_d ,

$$R_L = \frac{R_D r_d}{R_D + r_d} \text{ ----- (36)}$$

Let us assume that the input impedance of the FET to be infinity. This assumption is valid as long as the oscillator operating frequency is low enough so that FET capacitive

impedances can be neglected. The output impedance of the amplifier stage given by R_L should also be small compared to the impedance seen looking into the feedback network so that no attenuation due to loading occurs.

$$f = \frac{1}{2\pi\sqrt{6}RC} \quad \text{.....(37)}$$

Wien-Bridge Oscillator

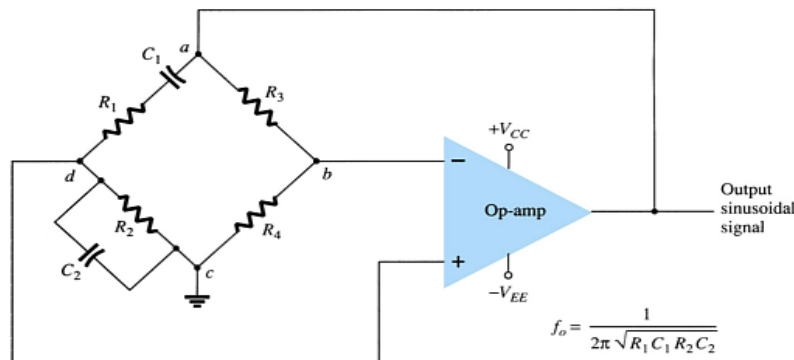


Figure 4.32 Wein Bridge oscillator

Wien-Bridge Oscillator circuit uses an op-amp and RC bridge circuit, with the oscillator frequency set by the R and C components of bridge. Note that in basic bridge connection. Resistors R_4 and R_2 and capacitors C_4 and C_2 form the frequency-adjustment elements, and resistors R_3 and R_4 form part of the feedback path. The op-amp output is connected as the bridge input at points a and c. The bridge circuit output at points b and d is the input to the op-amp.

Neglecting loading effects of the op-amp input and output impedances, the analysis of the bridge circuit results in

$$\frac{R_3}{R_4} = \frac{R_1}{R_2} + \frac{C_2}{C_1} \quad \text{-----(38)}$$

and,

$$f_o = \frac{1}{2\pi\sqrt{R_1C_1R_2C_2}} \quad \text{----- (39)}$$

If, in particular, the values are $R_4 = R_2 = R$ and $C_4 = C_2 = C$, the resulting oscillator frequency is

$$f_o = \frac{1}{2\pi RC} \quad \text{-----(40)}$$

and also,

$$R_3/R_4=2 \quad \text{----- (41)}$$

Thus a ratio of R3 to R4 greater than 2 will provide sufficient loop gain for the circuit to Oscillate at the frequency calculated using eqn. (40)

RC Phase shift Oscillator

1. Circuit is simple to design.
2. Can produce output over audio frequency range.
3. Produces sinusoidal waveform.
4. It is a fixed frequency oscillator. Cannot achieve a variable frequency.
5. Frequency stability is poor due to temperature, aging etc...

Tuned Oscillator Circuits

- Tuned oscillators use a parallel LC resonant circuit (LC tank) to provide the oscillations. Frequency range from KHZ to several GHz.
- Frequency of generated oscillations is given by,

$$f = \frac{1}{2\pi\sqrt{LC}} \quad \text{.....(41)}$$

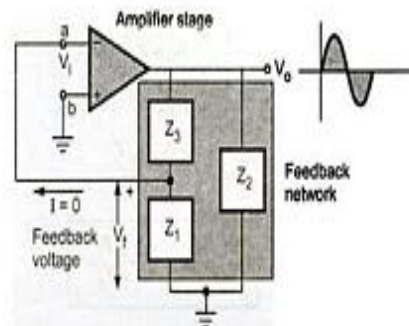


Figure 4.33 Basic form of LC oscillations

Basic form of LC oscillator circuit consists of an Amplifier and a feedback network consisting of LC resonant circuit. In the feedback network, either L or C is broken down into two impedances Z1 and Z3. Depending on the arrangement we have two types of tuned oscillator circuits.

Colpitts Oscillator— The feedback network consists of two inductive and one capacitive impedances.

Hartley Oscillator— The feedback network consists of two inductive and one capacitive impedances.

Colpitts Oscillator Circuit

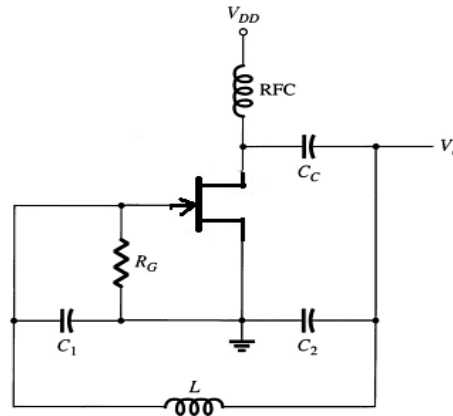


Figure 4.34 Colpitts oscillator

A practical version of an FET Colpitts oscillator is shown in Figure 4.34. The circuit is basically the same form as shown in resonant oscillator circuit with the addition of the components needed for dc bias of the FET amplifier. Here FET amplifier introduces 180° phase shift. The LC feedback network further introduces 180° phase shift. Thus, Total phase shift around the loop is 360° ensuring Positive feedback.

The oscillator frequency can be found to be

$$f_o = \frac{1}{2\pi\sqrt{LC_{eq}}} \dots(42)$$

$$\text{where, } C_{eq} = \frac{C_1 C_2}{C_1 + C_2}$$

Hartley Oscillator:

A practical version of an Hartley oscillator is shown in Figure 4.35. The circuit is basically the same form as shown in resonant oscillator circuit with the addition of the components needed for dc bias of the BJT amplifier. Here BJT amplifier introduces 180° phase shift. The LC feedback network further introduces 180° phase shift. Thus, Total phase shift around the loop is 360° ensuring Positive feedback.

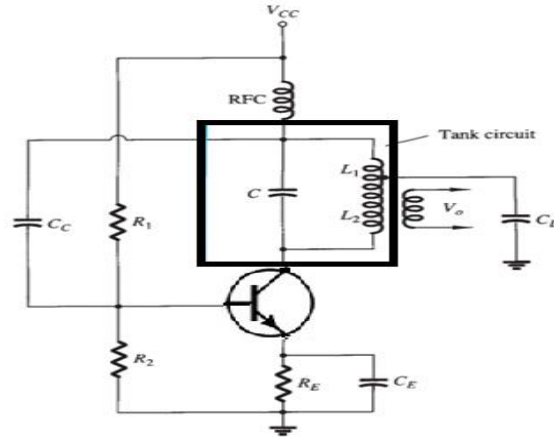


Figure 4.35 Transistorized Hartley Oscillator

The oscillator frequency can be found to be

$$f_o = \frac{1}{2\pi\sqrt{L_{eq}C}} \text{ -----(43)}$$

where,

$$L_{eq} = L_1 + L_2 + 2M \text{ -----(44)}$$

To sustain oscillations the desired value of hfe is given by,

$$hfe = \frac{L_1 + M}{L_2 + M} \text{ -----(45)}$$

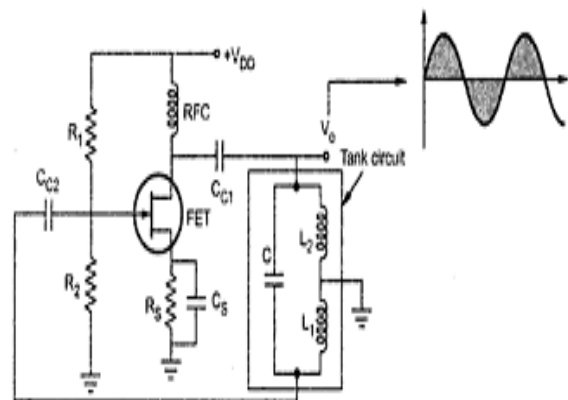


Figure 4.36 FET Hartley Oscillator Circuit

An FET Hartley oscillator circuit is shown in Fig.4.36. The circuit is drawn so that the feedback network conforms to the form shown in the basic resonant circuit. Note, however, that inductors L4 and L2 have a mutual coupling M, which must be taken into account in determining the equivalent inductance for the resonant tank circuit. Here FET

amplifier introduces 180° phase shift. The LC feedback network further introduces 180° phase shift. Thus, Total phase shift around the loop is 360° ensuring Positive feedback. The frequency of oscillations is then given by equation (43) and (44).

Frequency stability of LC oscillator

1. Due to change in temperature values of L and C in tank circuit changes. This affects frequency of oscillator.
2. Due to change in temperature transistor parameters are also affected.
3. Variation in power supply affect the frequency of oscillator.
4. Aging of circuitry also affects the frequency of oscillation.
5. Change in Q_L affects the internal resistance of tank circuit. This affects frequency of oscillations.
6. The internal capacitance of transistor also affects the frequency of oscillations.

Crystal Oscillators

The Quartz, Tourmaline and Rochelle salt exhibit piezo-electric effect. This means under the influence of mechanical stress, The voltage gets generated across opposite faces of crystal. Conversely, if electric potential is applied across the crystal, it vibrates causing mechanical distortion in the crystal sheet. This mechanical vibration generates electrical signal at constant frequency. Crystal has greater stability in holding its frequency. Out of Quartz, Tourmaline and Rochelle salt, Rochelle salt exhibits high piezo-electric activity and Rochelle salt are mechanically weakest. They break easily. Tourmaline is the strongest of three but is very expensive. Quartz crystal is the compromise between the two, it is naturally available in abundant quantity and exhibits reasonably good piezo-electric activity. Quartz crystals are used in all ratio frequency oscillators and filters.

AC Equivalent Circuit:

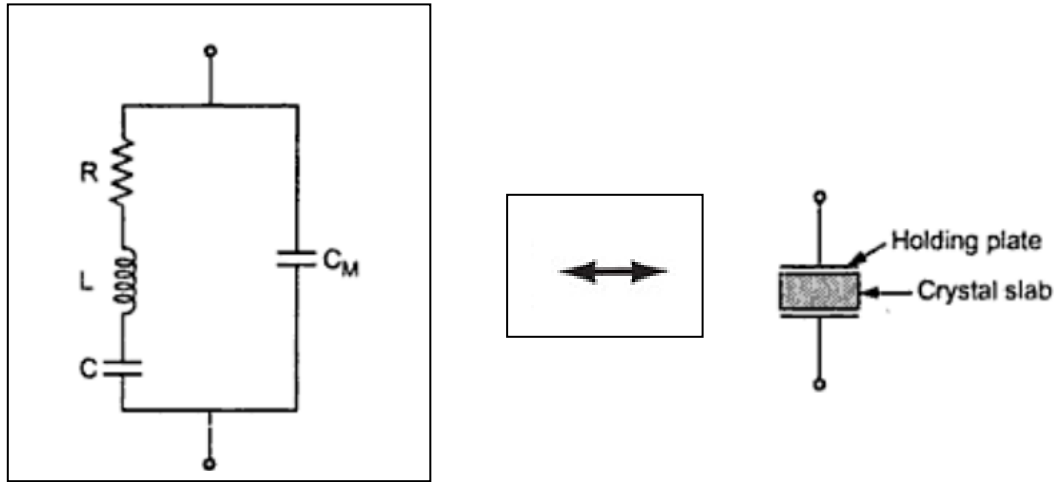


Fig. 4.37 AC equivalent circuit of Crystal Oscillator

For the practical views, Crystal is cut as a rectangular slab and is held between two mechanical plates. When the crystal is not vibrating it is equivalent to parallel plate capacitor, i.e., a dielectric medium (Crystal slab) present between two metallic plates of the capacitor. This is represented as capacitance C_M .

When the crystal is vibrating there are internal frictional loss which is denoted by resistance “R”. The mass of crystal corresponds to its inertia represented by “L”. The stiffness of crystal is denoted by “C”. This forms a series RLC circuit and corresponding series resonant frequency is

$$f_r = \frac{1}{2\pi\sqrt{LC}} \dots\dots(46)$$

Actually frequency of generated oscillations is inversely proportional to thickness. There exists a parallel resonant circuit also. This is formed due to the presence of inductor L and capacitance C_{eq} . At parallel resonant frequency, impedance is maximum. It is given by,

$$f_p = \frac{1}{2\pi\sqrt{LC_{eq}}} \dots\dots(47)$$

where,

$$C_{eq} = \frac{C_M C}{C_M + C}$$

Actually f_r and f_p are very close to each other. The graph of impedance vs Frequency is as shown in Figure 4.38.

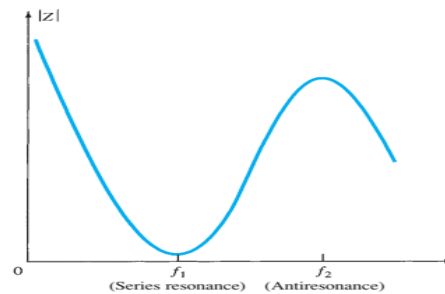


Figure. 4.38 Impedance of a crystal oscillator

Crystals can be used in both series and parallel resonant mode to generate oscillations.

Series Resonant Crystal Oscillator using BJT

Here Crystal is connected in feedback path of the amplifier. The voltage feedback from collector to base is a maximum when the crystal impedance is minimum (in series-resonant mode). The resulting circuit frequency of oscillation is set by the series-resonant frequency of the crystal. The resistance R_1 , R_2 and R_E provide DC bias while Capacitor C_E is emitter bypass capacitor. RFC coil provides for dc bias while decoupling any ac signal on the power lines from affecting the output signal. The resonant frequency is given equation (46). The crystal oscillator provides good frequency stability i.e., the oscillating frequency is not affected by supply variations, temperature and transistor parameters.

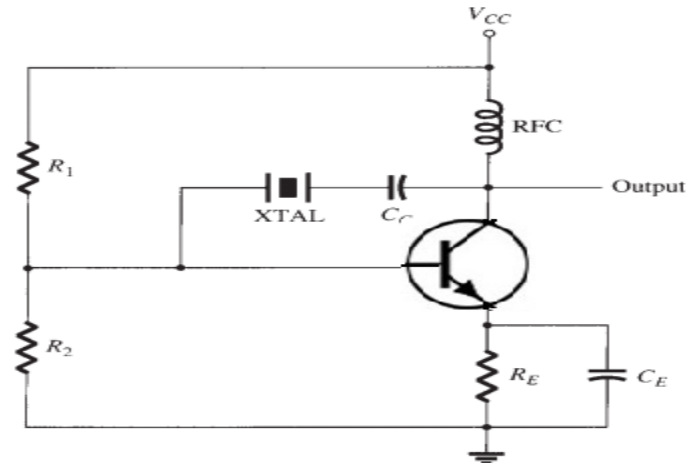


Figure 4.39 Series Resonant Crystal Oscillator using BJT

Series Resonant Crystal Oscillator using FET

Here Crystal is connected in feedback path of the FET amplifier. The voltage feedback from Drain to Gate is a maximum when the crystal impedance is minimum (in series-resonant mode). The resulting circuit frequency of oscillation is set by the series-resonant frequency of the crystal. RFC coil provides for dc bias while decoupling any ac signal on the power lines from affecting the output signal. Changes in supply voltage, transistor device parameters, and so on, have no effect on the circuit operating frequency. The resulting circuit frequency of oscillations is set by the series-resonant frequency of the crystal. The resonant frequency is given equation (46).

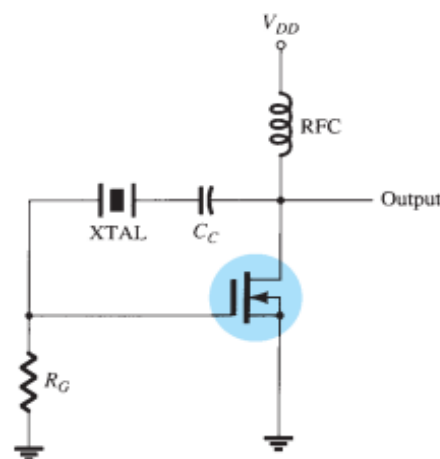


Fig 4.40 Series Resonant Crystal Oscillator using FET

Parallel Resonant Crystal Oscillators

Crystal is connected as an inductor in the modified Colpitts oscillator circuit. At the parallel-resonant operating frequency, a crystal appears as an inductive reactance of large value. The resulting circuit frequency of oscillation is set by the parallel-resonant frequency of the crystal. The resistance R_1 , R_2 and R_E provide DC bias while Capacitor C_E is emitter bypass capacitor. RFC coil provides for dc bias while decoupling any ac signal on the power lines from affecting the output signal. The resonant frequency is given equation (47).

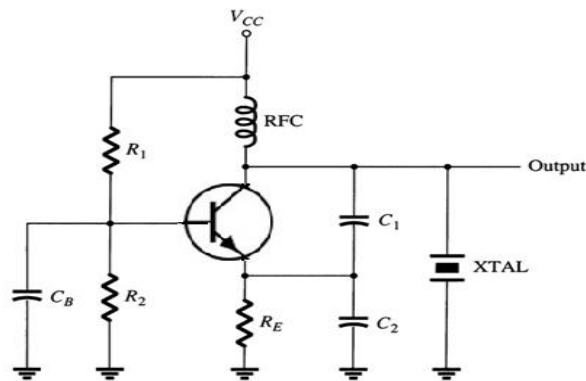


Figure. 4.44 Parallel Resonant Crystal Oscillator

Miller's Crystal Oscillator

The Hartley oscillator can be modified using crystal at one of the inductors of the tank circuit. The crystal behaves as inductor "L" connected to base and ground. The internal capacitance of transistor acts as capacitors C_1 and C_2 of the tank circuit. The crystal decides operating frequency of oscillator. A tuned LC circuit in the drain section is adjusted to the crystal parallel-resonant frequency. The resonant frequency is given equation (47).

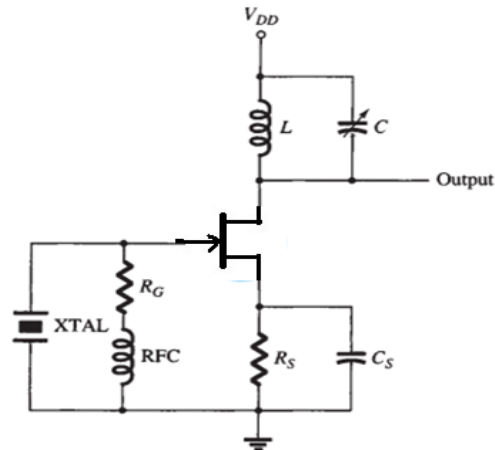


Fig. 4.45 Millers Crystal Oscillator

Unijunction Transistor

The Unijunction Transistor (UJT) has three terminals: an emitter (E) and two bases (B_1 and B_2). The base is formed by lightly doped n-type bar of silicon. Two ohmic contacts B_1 and B_2 are attached at its ends. The emitter is of p-type and it is heavily doped; this single PN junction gives the device its name. The resistance between B_1 and B_2 when the emitter is open-circuit is called inter-base resistance. The emitter junction is usually located closer to base-2(B_2) than base-1(B_1) so that the device is not symmetrical, because symmetrical unit does not provide optimum electrical characteristics for most of the applications (Refer Figure 4.46).

The schematic diagram symbol for a unijunction transistor represents the emitter lead with an arrow, showing the direction of conventional current flow when the emitter-base junction is conducting a current. A complementary UJT would use a p-type base and an n-type emitter, and operates the same as the n-type base device but with all voltage polarities reversed.

The structure of a UJT is similar to that of an N-channel JFET, but p-type (gate) material surrounds the N-type (channel) material in a JFET, and the gate surface is larger than the emitter junction of UJT. A UJT is operated with emitter junction forward-biased while the JFET is normally operated with the gate junction reverse-biased. It is a current controlled negative resistance device.

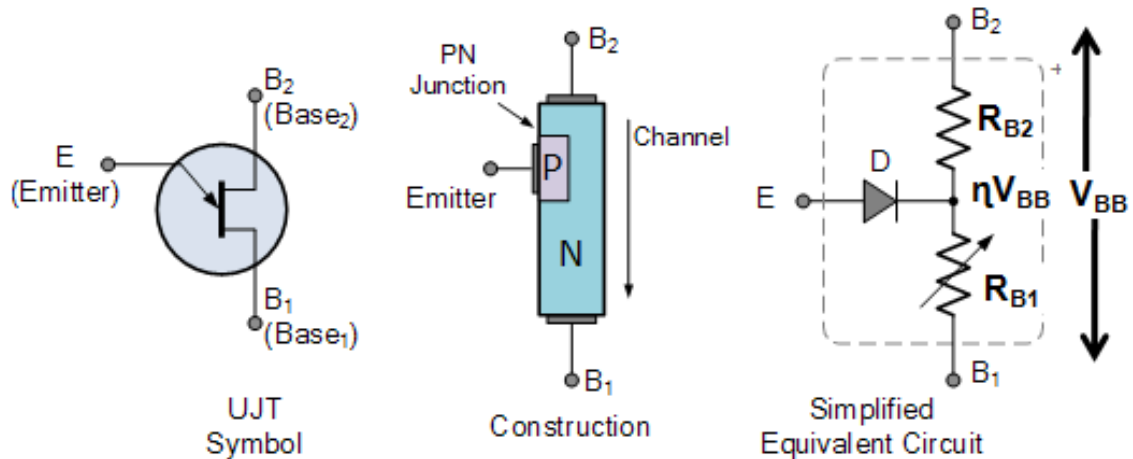


Figure 4.46 UJT Transistor

The device has a unique characteristic that when it is triggered, its emitter current increases regeneratively until it is restricted by emitter power supply. It exhibits a negative resistance characteristic and so it can be employed as an oscillator. UJT has an intrinsic stand-off ratio denoted by,

$$\eta = \frac{R_{B1}}{(R_{B1} + R_{B2})} \dots\dots\dots(48)$$

Where, η is termed as intrinsic standoff ratio with values between 0.4 to 0.6

The UJT is biased with a positive voltage between the two bases. This causes a potential drop along the length of the device. When the emitter voltage is driven approximately one diode voltage above the voltage at the point where the P diffusion (emitter) is, current will begin to flow from the emitter into the base region. Because the base region is very lightly doped, the additional current (actually charges in the base region) causes conductivity modulation which reduces the resistance of the portion of the base between the emitter junction and the B2 terminal. This reduction in resistance means that the emitter junction is more forward biased, and so even more current is injected. Overall, the effect is a negative resistance at the emitter terminal. This is what makes the UJT useful, especially in simple oscillator circuits.

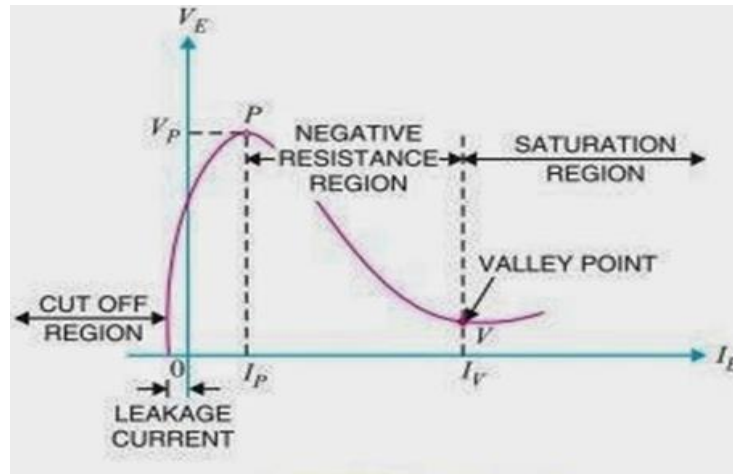


Figure 4.47 UJT Characteristics

Unijunction as a Relaxation Oscillator

The unijunction transistor can be as a relaxation oscillator as shown by the basic circuit in Figure 4.48. Resistor R_T and capacitor C_T are the timing components that set the circuit oscillating rate. The oscillating frequency may be calculated using Equation (44) shown below. Which includes the unijunction transistor intrinsic stand-off ratio η as a factor (in addition to R_T and C_T) in the oscillator operating frequency.

$$f_o = \frac{1}{T} = \frac{1}{R_3 C_1 \ln[1/(1-\eta)]} \dots\dots\dots(49)$$

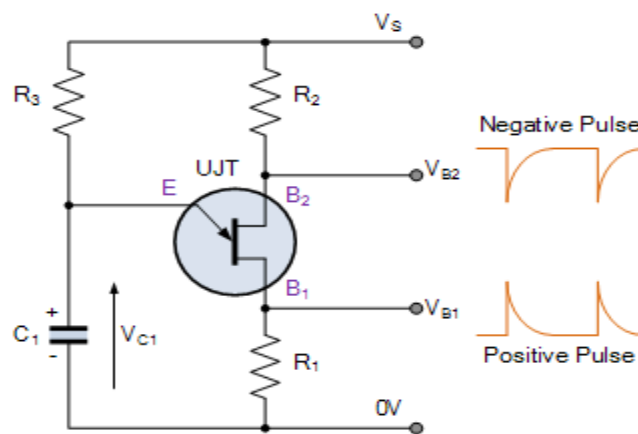


Figure 4.48 UJT as a Relaxation Oscillator

Capacitor C_1 is charged through resistor R_3 toward supply voltage V_s . As long as the capacitor voltage V_E is below a stand-off voltage (V_P) the unijunction emitter lead appears as an open circuit. When the emitter voltage across capacitor C_1 exceeds this value V_P , the unijunction transistor conducts discharging into the capacitor. The signal at

the emitter is a sawtooth voltage waveform which represents capacitor charging and discharging action. Base 2 is a signal representing sudden discharge of capacitor voltage.

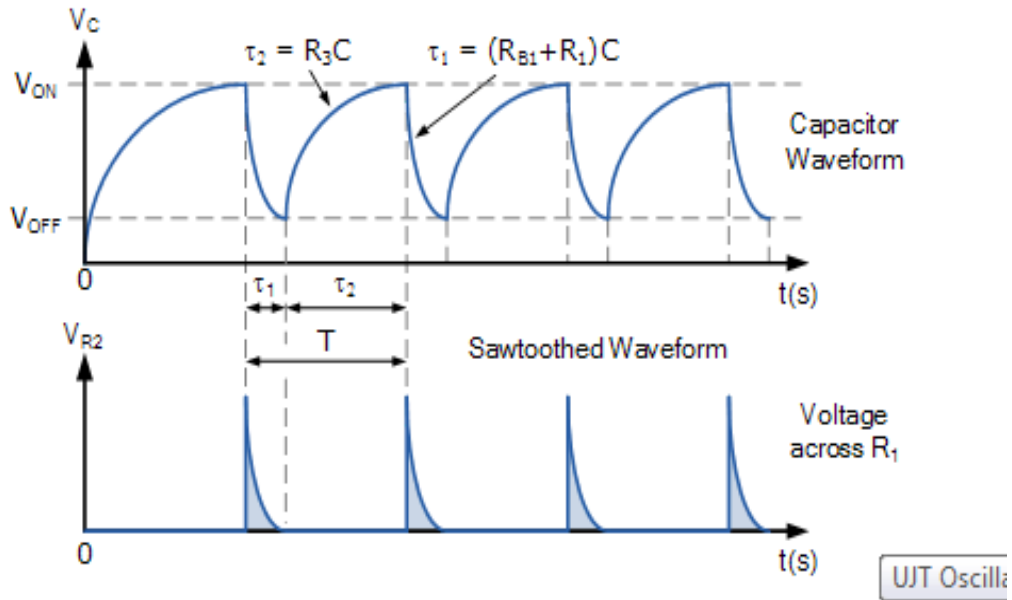


Figure 4.50 Waveforms of UJT as a Relaxation Oscillator