Module -4

BJT Applications, Feedback Amplifiers and Oscillators

BJT as an amplifier, BJT as a switch
Transistor switch circuit to switch ON|OFF an
LED and a lamp in a power circuit using
a relay [refer 4.4 and 4.5 of Text 2).

Feedback Amplifiers

Principle, properties & Advantages of Negative
Feedback, Types of feedback,
Voltages series feedback, gain stability with
feedback (7.1 - 7.3 of Text 1)

Oscillators -

Barkhaunsen's criteria for oscillation,
RC phase shift oscillator, Wien Bridge oscillator
(7.7 - 7.9 of Text 1)

IC 555 Timer and Astable oscillator using
IC 555 (17.2 and 17.3 of Text 1)

[RBT Levels: L1, L2 & L3)

BJT as an amplifier

Amplification is the process of linearly increasing the amplitude of an electrical signal and is one of the major properties of a transistor.

BJT exhibits high current gain called β.

When a BJT is biased in the active (or linear) region. the Base-Emitter (BE) junction has a low resistance due to forward bias & the Base-Collector (BC) junction has a high resistance due to reverse bias.

Representation of DC and AC Quantities.

- Here italic capital letters are used for both dc and ac currents (I) and voltage (V).
- Ac current & voltages are always rms values unless stated otherwise.
- lower case i & v used for instantaneous values of current and voltage respectively.
- DC quantities always carry an upper case roman (nonitalic) subscript.

  Example. I_B, I_C, and I_E are DC Transistor currents

  V_{BE}, V_{CB}, and V_{CE} are DC voltages from one terminal to other.

  V_B, V_C, V_E represents dc voltages from the transistor terminal to ground.

*- AC & all time varying quantities carry a lower case italic subscript.

Example:- I_b, I_c, and I_e are ac transistor currents.

V_{be}, V_{cb} and V_{ce} are ac voltages from one terminal to other.

V_b, V_c & V_e are ac voltages from transistor terminal to ground.

*- Transistors have internal ac resistance that are designated by lowercase r' with an appropriate subscript.

Eg. r'_e → internal ac emitter resistance.

*- Circuit resistance external to transistor itself use the standard italic capital R with a subscript to identifies the resistance as dc or ac.

Eg. R_E ⇒ external dc emitter resistance

R_e ⇒ external ac emitter resistance.

Voltage amplification

In Bipolar junction Transistor, In common emitter configuration, The output current and Input current relationship is given by

$$I_C = \beta I_B$$

i,e transistor amplifies current because of the collector current is equal to the base current multiplied by current gain.

Here I_B is very small compared to collector current (I_C) and emitter current (I_E). hence here

$$\boxed{I_C \simeq I_E}$$

Basic transistor amplifier circuit with ac source voltage V_s and dc bias voltage V_{BB} superimposed is shown in figure ①.

V_s is superimposed on the V_{BB} by capacitive coupling. The dc bias voltage V_{CC} is connected to the collector through the collector resistor R_C.

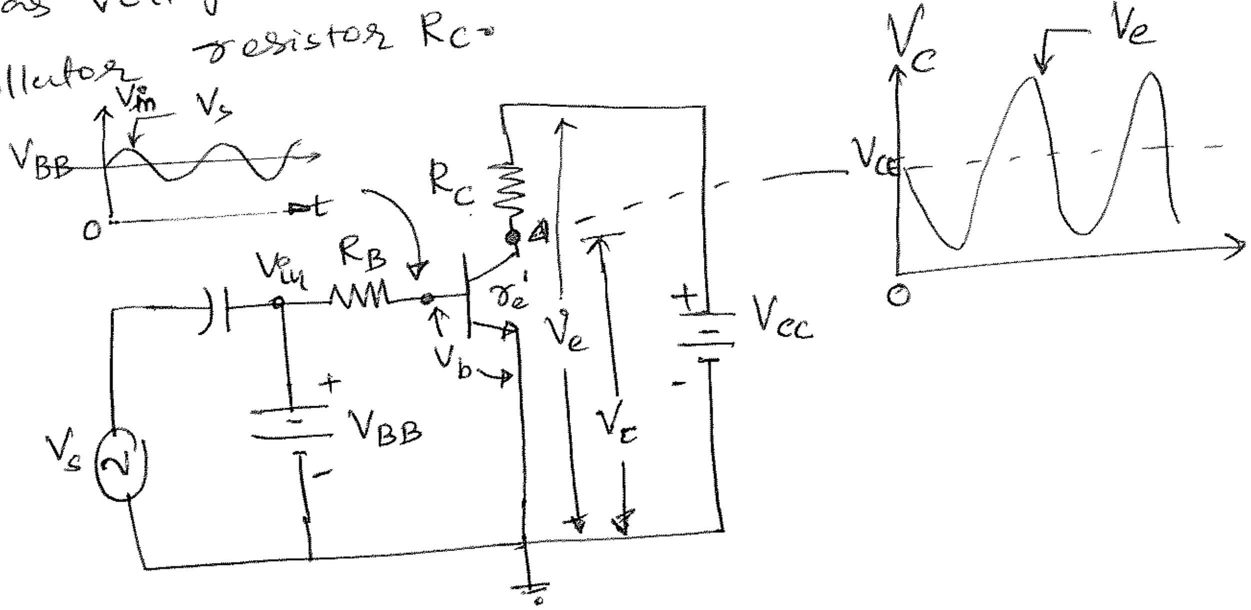


Fig ① Transistor amplifier circuit
Common emitter configuration.

The ac input voltage produces an ac base current, which results in a much larger ac collector current.

The ac collector current produces an ac voltage across R_C, thus producing an amplified but inverted, reproduction of ac input voltage in the active region of operation.

The forward biased - base emitter junction presents a very low resistance to the ac signal. This internal ac emitter resistance is designated r_e' in fig ① & appears in series with R_B. The ac base voltage is

$$V_b = I_e r_e'$$

The ac collector voltage V_c, equals to voltage drop across the R_C.

$$V_c = I_c R_C$$

Here $I_c \simeq I_e$, ac collector voltage is

$$V_c \cong I_e R_C$$

V_b is given by apply KVL to input side.

$$V_S - V_b - I_b R_B$$

$$V_b = V_S - I_b R_B.$$

Here V_c is transistor ac voltage. For a transistor voltage gain is defined as the radio of the output voltage to the input voltage.

The ratio of V_c to V_b is ac voltage gain A_v of transistor.

$$A_v = \frac{V_c}{V_b}.$$

Subsitute $V_c = I_e R_C$ & $V_b = I_e r_e'$

$$A_v = \frac{I_e R_C}{I_e r_e'}$$

$$\boxed{A_v \cong \frac{R_c}{r_e'}} \longrightarrow (*).$$

equation (*) shows that the transistor provides amplification in the form of voltage gain, which is dependent on the values of R_C and r_e'.

R_c is greater than r_e' hence the output voltage is greater than input voltage. hence Transistor in CE mode is also a very Good Voltage amplifier.

Determine the voltage gain and the ac input voltage in figure. if $r_e' = 50\Omega$.

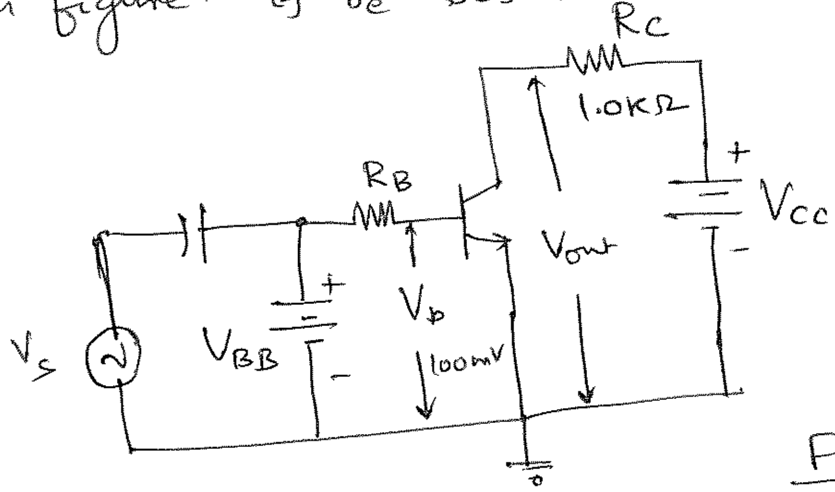


Fig (2).

The voltage gain is

$$A_V \cong \frac{R_C}{r_e'} = \frac{1.0K\Omega}{50\Omega} = 20.$$

Therefore, the ac output voltage is

$$V_{out} = A_V V_b$$

$$= 20 * 100\,mV = 2\,V_{rms}$$

(2) Determine the value of Rc in fig (2) when it will take to have a voltage gain of 50.

$R_C = ?$ $\quad A_V = 50, \quad r_e' = 50$

$A_V = \frac{R_C}{r_e'}$ $\quad R_C = A_V * r_e' = 50 * 50$

$= 2500$

$$\boxed{R_C = 2.5\,K\Omega}$$

The BJT as a Switch

The first appliction of BJT as a linear amplifier. The second major appliction area is BJT as a Switch. For first appliction BJT will be in Active region of operation. For second appliction BJT normally operated alternatively in cutoff and Saturation.

When transistor is applied with external voltage i,e Biased, The transistor works in one of the following three regions. They are

1 active region
2. Cut off region
3. Saturation region.

Region.	Emitter – Base Juntion	Collector - Base Juntion
1. Active	Forward biased	Reverse Biased
2. Cut-off	Reverse biased	Reverse biased
3. Saturation	Forward biased	Forward biased.

For Normal operation of transistor, Base-emitter juntion is forward biased and Collector - Base is reverse biased.

Switching operation.

Figure 3 shows the Basic operation of a BJT as a switching device.

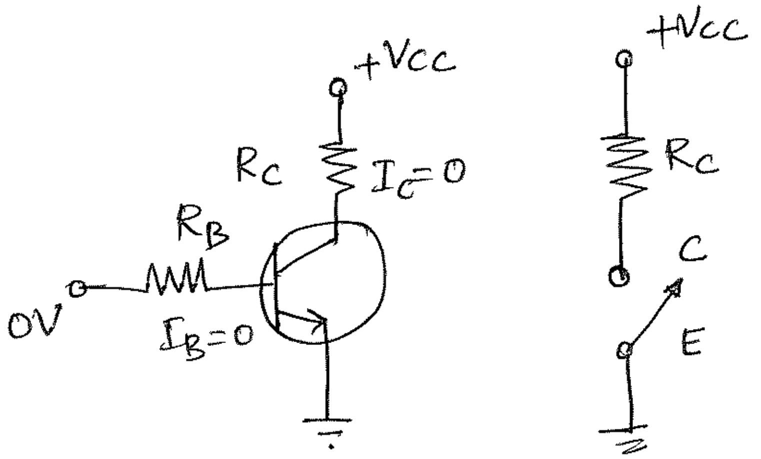
In fig 3(a), the transistor is operated in the Cut off region because Base - emitter juntion is not forward Biased.

In this case, transistor is idealy, an open between collector and emitter, as indicated in equivalent circuit.

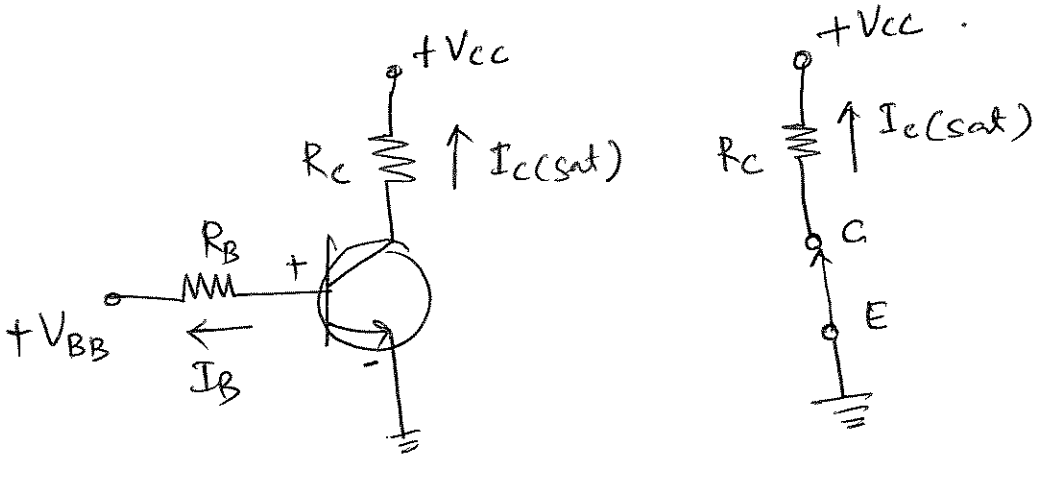
In figure 3 (b). transistor is in the saturation region because the base emitter junction and base-collector junction are forward biased and the base current is made large enough to cause the collector current to reach its saturation value.

The transistor acts as a closed switch, hence there is a short between collector & emitter, as shown in equivalent circuit.

Here a small voltage drop appears across the transistor which is saturation voltage. $V_{CE(sat)}$.



(a) Transistor is in cut off region - open switch.



(b). Transistor in saturation - closed switch.

Figure (3). Switching action of an ideal Transistor.

In Cut-off regions of operation, neglecting leakage current, all of the currents are zero, and V_{CE} is equal to V_{CC}

$$V_{CE(cutoff)} = V_{CC}$$

During saturation, the base-emitter junction is forward biased and there is enough base current to produce a maximum collector current, the transistor is saturated.

Apply KVL to equivalent circuit.

$$V_{CC} - I_{C(sat)}R_C - V_{CE(sat)} = 0.$$

Then. Collector saturation current is given by

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C}$$

$V_{CE(sat)} << V_{CC}$. hence can be neglected.

$$I_{C(sat)} \cong \frac{V_{CC}}{R_C}.$$

The minimum value of base current needed to produce saturation is.

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}}$$

Normally I_B. value choosen will be greater than $I_{B(min)}$ to ensure that the transistor is saturated.

<u>Note</u>:- The ratio of output current I_C with respect to input current I_B is called as common-emitter current gain β.

$$\boxed{\beta = \frac{I_C}{I_B}}$$

problem:

For the transistor circuit shown figure (4).

(a) what is V_{CE} when $V_{in} = 0V$?

(b) what minimum value of I_B is required to saturate this transistor if β_{dc} is 200? neglect $V_{CE(sat)}$

(c) Calculate the maximum value of R_B when $V_{in} = 5V$.

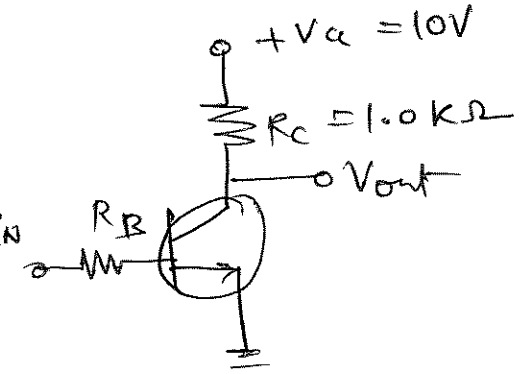


Figure (4)

Solution:-

(a) when $V_{IN} = 0V$,
the transistor is in cutoff mode (acts as open switch).

$$V_{CE} = V_{CC} = 10V.$$

(b) Since $V_{CE(sat)}$ is neglated $= 0V$

$$I_{C(sat)} = \frac{V_{CC}}{R_C} = \frac{10V}{1.0K\Omega} = 10mA.$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{10mA}{200} = 50\mu A.$$

(c) when the Transistor is on, $V_{BE} = 0.7V$. The voltage across R_B is

$$V_{RB} = V_{IN} - V_{BE} = 5V - 0.7V = 4.3V$$

using ohm's law.

$$R_{B(max)} = \frac{V_{RB}}{I_{Bmin}} = \frac{4.3V}{50\mu A} = 86K\Omega$$

Problem (2)

Determine the minimum value of I_B required to saturate the transistor in Figure (4) if β_{DC} is 125 & $V_{CE(sat)}$ is 0.2V.

$$I_{C(sat)} = \frac{V_{CC} - V_{CE(sat)}}{R_C} = \frac{10 - 0.2}{1.0} = 9.8mA.$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{dc}} = \frac{9.8mA}{125} =$$

A simple application of a transistor switch

The transistor in Figure 5 is used as a switch to turn the LED on and off. For Example, a square wave input voltage with a period of 2 is applied to the input as shown. when the square wave is at 0V, the transistor is in cutoff; and since there is no collector current, the LED does not emit light.

when the square wave goes to its high level, the transistor saturates. This forward biases the LED, the resulting collector current through the LED causes it to emit light. Thus, the LED is on for 1 second and off for 1 second.

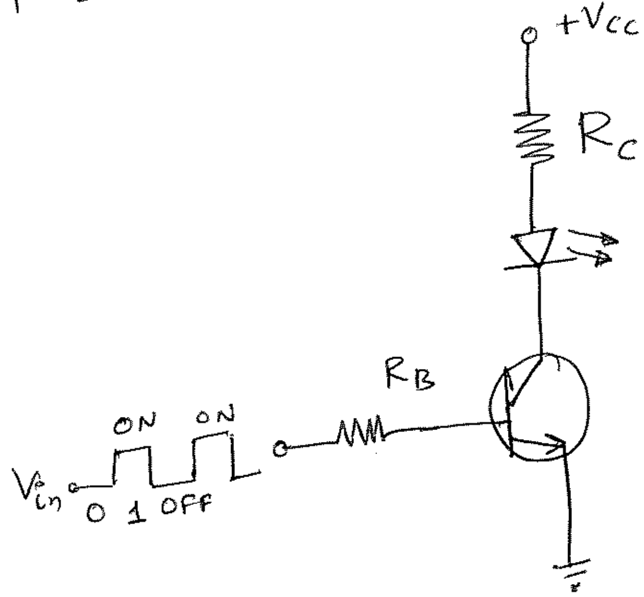


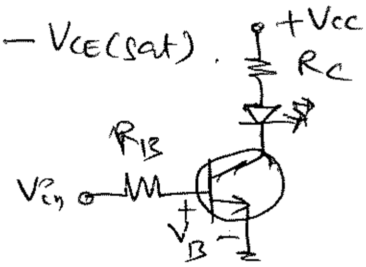
Fig 5. A Transistor used to switch an LED On and Off.

problem.

The LED in figure 5 requires 30 mA to emit a sufficient level of light. Therefore, the collector current should be approximately 30 mA. For the following circuit values, determine the amplitude of the square wave input voltage necessary to make sure that the transistor saturates. Use double the minimum value of base current as a safety margin to ensure saturation.

$V_{CC} = 9V$, $V_{CE(sat)} = 0.3V$, $R_C = 220\,\Omega$, $R_B = 3.3\,K\Omega$, $\beta_{DC} = 50$, and $V_{LED} = 1.6V$

Apply KVL $\Rightarrow I_{C(sat)} R_C = V_{CC} - V_{LED} - V_{CE(sat)}$.



Solution:-

$$I_{C(sat)} = \frac{V_{CC} - V_{LED} - V_{CE(sat)}}{R_C}$$

$$= \frac{9 - 1.6 - 0.3}{220} = 32.3\,mA.$$

$$I_{B(min)} = \frac{I_{C(sat)}}{\beta_{DC}} = \frac{32.3\,mA}{50} = 646\,\mu A.$$

To ensure saturation, use twice the value of $I_{B(min)}$, which is 1.29 mA.

Apply KVL to input side.

$$V_{in} - I_B R_B - V_{BE} = 0.$$

$$I_B = \frac{V_{in} - V_{BE}}{R_B} = \frac{V_{R_B}}{R_B}$$

To calculate V_{in}.

$$V_{in} = V_{BE} + I_B R_B$$
$$= 0.7 + (1.29\,mA)(3.3\,K\Omega).$$

$$\boxed{V_{in} \simeq 4.96V.}$$

Feedback Amplifiers

- In a feedback amplifier, voltage or current output is feedback to the input through a modifying network, which determines the magnitude & phase.
- Here a fraction of the amplifier output is fed back to the input circuit.
- This partial dependence of amplifier output on its input helps to control the output.
- A feedback amplifier has two parts namely
    - An Amplifier
    - Feedback circuit

The feedback centre opposes the input (negative feedback) or aids the input (positive feedback).

characteristics of the amplifier can be altered in a desirable manner using feedback. The main purpose of amplifier is to amplify the signal without changing its characteristics except its amplitude.

The amplifier which works on the principal of feedback is known as feedback amplifier.

Feedback is a process where in a fraction of output (voltage | current) is fed back to the input. Then there will be two signals at the input i.e the original input signal & fed back signal.

There are two types of Feedback, namely

- positive feedback
- Negative feed back

This classification is based upon how and in what phase the input signal and fraction of output are mixed.

positive feedback amplifier

positive feed back amplifier is shown in figure ①. The two inputs to the amplifiers are input signal and returned signal (fed back signal) are in same phase, & these signals are then added up and the resultant output increases, These circuits performing above operation are called positive feedback amplifier.

The positive feedback is also called as regenerative or direct feed back. positive feedback causes distortion and instability in amplifiers and hence it is not suitable | used as amplifier.

But positive feedback amplifier increases the gain & overall power of input signal hence used as oscillator circuits.

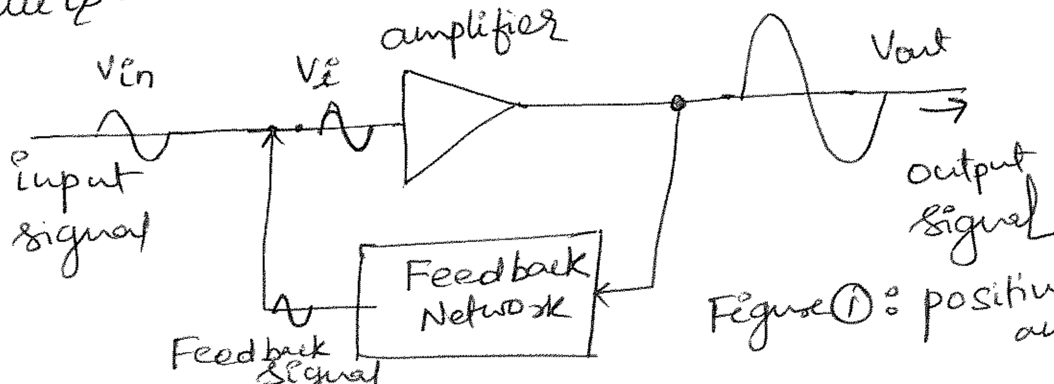


Figure ①: positive feed back amplifier

Voltage gain with positive feedback is given by

$$A_f = \frac{A}{(1-\beta A)}, \text{ where } \beta \rightarrow \text{Feedback factor.}$$

From Figure 1.

$$V_i = V_{in} + \beta V_{out}$$

we know that

$$V_{out} = A \cdot V_i = A V_{in} + A\beta V_{out}$$

$$V_{out} = A V_{in} + A\beta V_{out}$$

$$A V_{in} = V_{out} - A\beta V_{out}$$

$$V_{out}(1 - A\beta) = A \cdot V_{in}$$

$$\boxed{A_f = \frac{V_{out}}{V_{in}} = \frac{A}{1-\beta A}}$$

Negative Feedback amplifier :-

In negative feedback amplifier, the fed back signal (returned signal) has phase opposite to the input signal, the net input signal is a difference of input and feedback signals. Here the negative feedback is also called as inverse or degenerative feedback.

Negative feedback reduces the overall gain of the amplifier but it has numerous advantages such as gain stability, less distortion hence widely used as amplifier circuit applications.

The figure ② shows the negative feedback amplifier. The voltage gain with negative feedback is given by

$$A_f = \frac{A}{1+\beta A} \qquad \beta \rightarrow \text{feedback factor.}$$

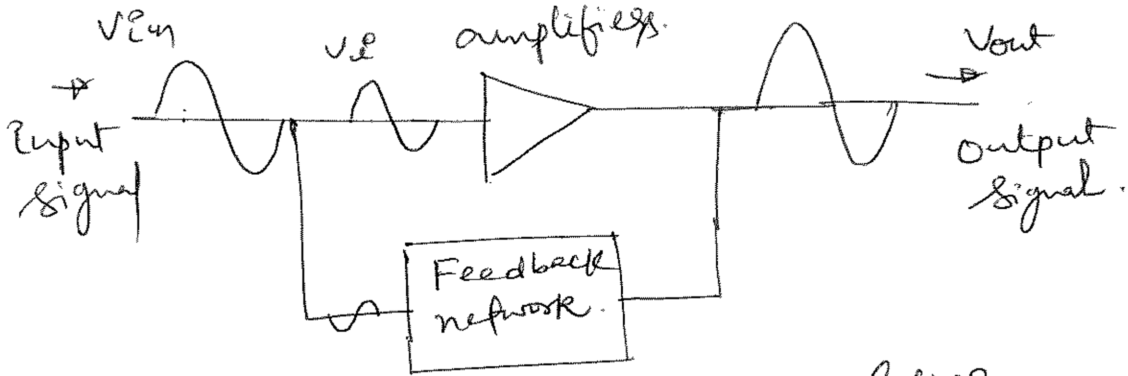


Figure ②. Negative feed back amplifier.

$$A_F = \frac{V_{out}}{V_{in}}$$

$$V_i = V_{in} - \beta V_{out}$$

$$V_{out} = V_i \cdot A_F.$$

$$V_{out} = A \ast \{V_{in} - \beta V_{out}\}$$

$$V_{out} + A\ \beta \cdot V_{out} = A\ V_{in}.$$

$$\boxed{A_f = \frac{V_{out}}{V_{in}} = \frac{A}{1+\beta A}}$$

Properties of Negative Feedback Amplifier

- Desensitize the gain : It brings stability to amplifier by making gain less sensitive to all kind of variations.

- Reduce nonlinear distortion
  In negative feedback amplifier, the negative feedback makes the output proportional to the inputs i.e. reduces non-linear distortion.

- Reduce the effect of Noise.
  The another property of Negative feedback amplifier are minimizes the contribution by unwanted electrical signals. These unwanted signals are called noise, these may be generated by circuit components or by extraneous interference.

- Control the input & output impedances
  Negative feedback amplifiers are capable of modifying or controlling [i.e increase or decrease] the input and output impedances. This is done by choosing appropriate feedback topology.

- Extend the bandwidth of the amplifier
  By incorporating negative feedback, the bandwidth can be increased.

Advantages of Negative feedback

In negative feedback amplifier, the gain of the amplifier reduces, however it is still used in almost every amplifier due to its various advantages.

- Gain stability
- Significant extension of Bandwidth
- very less distortions
- Decreased output resistance
- Stable operating point
- Reduces noise and other Interference in amplifier

Types of feedback

There are Four types of feedback

1) Voltage series
2) Voltage shunt
3) Current series
4) Current shunt

The voltage series feedback circuit is shown in figure ③. It is also known as series - parallel feedback circuit. Here also the feedback is negative.

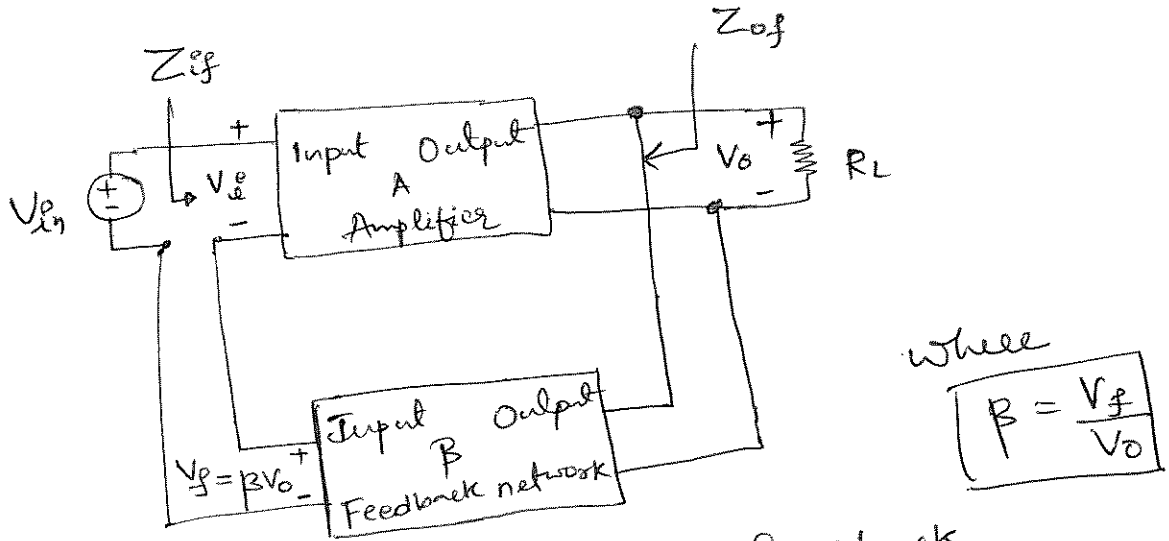


Figure ③. Voltage-series feedback

From Figure ③. The $V_i = V_{in} - V_f$

$$V_i = V_{in} - \beta V_o$$

The gain of the amplifier is given by $A = \frac{V_o}{V_i}$

$$V_o = A V_i = A V_{in} - A\beta V_o \longrightarrow (1)$$

The gain with feed back is given by

$$A_F = \frac{V_o}{V_{in}} \Rightarrow$$

From (1)

$$V_o + A\beta V_o = A V_{in}$$

$$V_o(1 + A\beta) = A V_{in}$$

$$A_F = \boxed{\frac{V_o}{V_{in}} = \frac{A}{1+\beta A}}$$

This general gain with feedback applies to all types of feedback circuits.

The amplifier gain reduces by a factor of $(1+\beta A)$.

Note:- gain stability is important feature of series v/g negative feedback amplifiers.

A negative feedback amplifier has an open loop gain of 400 and a feedback factor of 0.1. If the open loop gain changes by 20% due to temperature, find the percentage change in closed loop gain.

given Data:- $A = 400$ & $\beta = 0.1$

closed loop gain.

$$A_F = \frac{A}{1+\beta A} = \frac{400}{1+(400\times 0.1)}$$

$$= 9.75.$$

when $A = 320$, i.e. open loop gain varied by $400\times\left(\frac{20}{100}\right) = 80$.

$20\% = (400-80) = 320$

$$A_F = \frac{320}{1+(0.1\times 320)} = 9.7.$$

if 20% variation in open loop gain then.

$$A = (400+80) = 480.$$

$$A_F = \frac{480}{1+(0.1\times 480)} = 9.8.$$

It is seen that while the open loop amplifier gain varies by $\pm 20\%$, the amplifier gain with feedback varied by only $\pm 0.5\%$.

An improvement of $\frac{20}{0.5} = 40$ times observed.

(2) The overall gain of a multistage amplifier is 140. when negative voltage feedback is applied, the gain is reduced to 17.5. Find the fraction of the output that is fedback to the input.

given Data:

$$A = 140, \quad A_F = 17.5$$

let β be the feedback fraction.

voltage gain with negative feedback is given by

$$A_F = \frac{A}{1+\beta A}$$

$$17.5 = \frac{140}{1+\beta(140)}$$

$$17.5(1+\beta \times 140) = 140$$

$$\beta = \frac{140-17.5}{17.5 \times 140} = 0.05 = \frac{1}{20}$$

(3). With a negative voltage feedback, an amplifier gives an output of 10V with an input of 0.5V. when feedback is removed, it requires 0.25 V input for the same output. Calculate (i). gain without feedback (ii) feedback fraction β.

(i) gain without feedback $= A = \frac{V_o}{V_i} = \frac{10}{0.25}$

$$= 40$$

(ii) gain with feedback $= A_F = \frac{V_o}{V_{in}} = \frac{10}{0.5}$

$$= 20$$

(4) when negative voltage feedback is applied to an amplifier of gain 100, the overall gain falls to 50.

(i) Calculate the fraction of the output voltage fedback

(ii) If this fraction is maintained, Calculate the value of the amplifier gain required if the overall stage gain is to be 75.

Given data :-

(i) gain without feedback = 100

gain with feedback = 50.

let β be the fraction of the output voltage fed back.

$$A_F = \frac{A}{1+\beta A}$$

$$50 = \frac{100}{1+\beta \times 100} \Rightarrow 50 + 5000\beta = 100$$

$$\beta = \frac{100-50}{5000} = \underline{\underline{0.01}}$$

(ii). $A_F = 75$, $\beta = 0.01$, $A = ?$

$$A_F = \frac{A}{1+\beta A}$$

$$75 = \frac{A}{1+0.01A}$$

$$75 + 0.75A = A.$$

$$A = \frac{75}{1-0.75} = \underline{\underline{300.}}$$

(5). The voltage gain of an amplifier without feedback is 3000. Calculate the voltage gain of the amplifier if negative voltage feedback is introduced in the circuit. given that feedback fraction $\beta = 0.01$.

given date:-

$$A = 3000, \quad \beta = 0.01$$

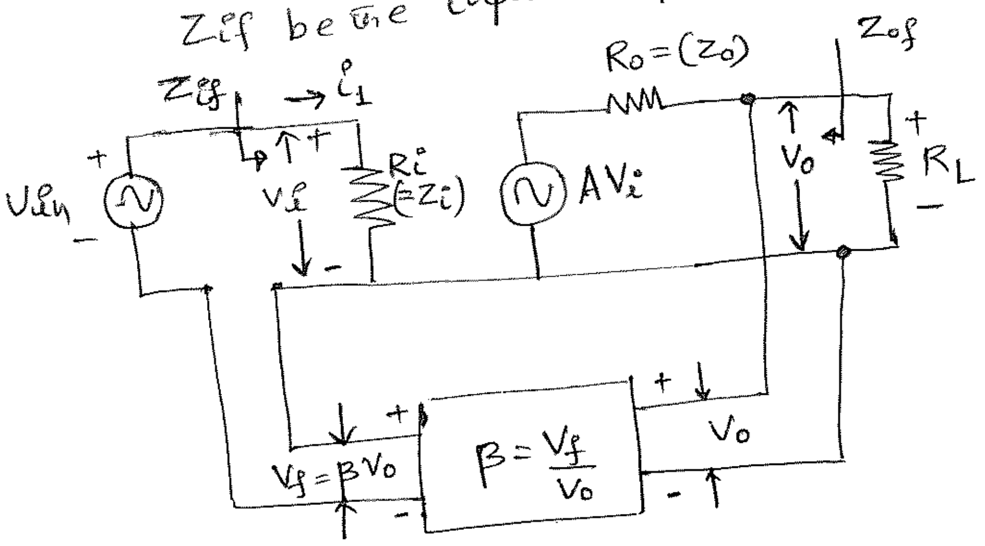
∴ Voltage gain with negative feedback is

$$A_F = \frac{A}{1+\beta A} = \frac{3000}{1+3000 \times 0.01} = \frac{3000}{31} = 97.$$

Input Impedance of Negative feedback amplifier

Let Z_i be the input impedance without feedback.

Z_{if} be the input impedance with feedback.



Voltage series feedback.

Voltage gain without feedback $A = \frac{V_o}{V_i}$

feedback fraction (factor) $= \beta = \frac{V_f}{V_o}$.

Voltage gain with feedback

$$A_F = \frac{V_o}{V_{in}} = \frac{A}{1+\beta A}$$

In Voltage series feedback circuit, The input current $i_i = \frac{V_i}{Z_i}$, where V_i = input voltage.

But $= V_i = V_{in} - V_f$ where V_f = feedback voltage

$$i_i = \frac{V_{in} - V_f}{Z_i} = \frac{V_{in} - \beta V_o}{Z_i}.$$

But $V_o = AV_i$ where A — open loop voltage gain.

$$i_i = \frac{V_{in} - \beta A V_i}{Z_i}$$

$$i_i Z_i = V_{in} - \beta A V_i$$

$$V_{in} = i_i Z_i + A\beta V_i$$

substitute $i_i Z_i = V_i$.

$$V_{in} = V_i + A\beta V_i$$

$$V_{in} = V_i(1 + A\beta).$$

$$V_{in} = i_i Z_i(1 + A\beta).$$

$$\frac{V_{in}}{i_i} = Z_i(1 + A\beta).$$

But $\frac{V_{in}}{i_i} = Z_{if} = Z_i(1 + A\beta).$

The input impedance with feedback.

$$\therefore \boxed{Z_{if} = Z_i(1 + A\beta).}$$

Hence the input impedance with feedback is $(1 + A\beta)$ times the input impedance without feedback. Thus the effect of negative feedback is to increase the input impedance of a series-voltage negative feedback amplifier by a factor $(1 + A\beta)$.

Output impedance of Negative feedback amplifier.

Let Z_o output impedance without feedback.
& Z_{of} → be the output impedance with feedback

Let the source signal voltage V_{in} be set equal to zero, & let a voltage V be applied to the output port. Let the resulting current in the output circuit be i.

we have $$AV_i + iZ_o = V \quad \rightarrow (*)$$ putting $Z_o = R_o$.

In general.

$$V_i = V_{in} - V_f \quad \text{where } V_f = \text{feedback voltage}$$

when $V_{in} = 0$.

$$V_i = -V_f. \quad \rightarrow (1)$$

sub eq^n (1) in (*)

$$\therefore V = -V_f A + iZ_o.$$

or.

$$V = iZ_o - A(\beta V).$$

i.e.

$$V + A\beta V = iZ_o$$

$$V(1 + A\beta) = iZ_o.$$

or

$$\frac{V}{i} = \frac{Z_o}{(1 + A\beta)}$$

But $\frac{V}{i} = Z_{of}$ = the output impedance with feedback

$$Z_{of} = \frac{Z_o}{(1 + A\beta)}$$

Hence Due to negative feedback, the output impedance gets reduced by the factor $(1 + A\beta)$.

Voltage series feedback amplifier has input impedance with feedback,

$$Z_{if} = Z_i(1+\beta A), \text{ increases}.$$

Output impedance with feedback,

$$Z_{of} = \frac{Z_o}{(1+\beta A)} \text{ . decreases.}$$

We know that closed loop gain. [gain with feedback]

$$A_f = \frac{A}{1+\beta A}$$

If $\beta A >> 1$ then closed loop gain.

$$A_f = \frac{A}{\beta A} = \frac{1}{\beta}.$$

This means that feedback gain independent of amplifier gain. Thus all the distortions do not appear in A_f.
This also happens to a noise signal, which gets attenuated by feedback.

Any variations in magnitude of A does not appear in A_f, which means A_F has high gain stability.

Gain and Bandwidth of feedback amplifier

The negative feedback reduces the amplifier gain. Therefore, as per the principle the amplifier increases its bandwidth. In RC-Coupled amplifier, the gain reduces at low frequency and high frequency ends. So βA_o is no longer much more than unity.

As a result, the percent reduction in gain is less at the two feedback ends compared to the mid-band.

The reduction in gain & increase in bandwidth of amplifiers are shown in figure (4).

As $f_1 << f_2$ and $f_{1f} << f_{2f}$.

$$BW = (f_2 - f_1) \simeq f_2$$

$$BW = (f_{2f} - f_{1f}) \simeq f_{2f}.$$

The constant product of gain bandwidth is

$$A_0 (f_2 - f_1) = A_{0f} (f_{2f} - f_{1f})$$

$$A_0 f_2 = A_{0f} f_{2f}$$ for $f_1 << f_2$ & $f_{1f} << f_{2f}$.

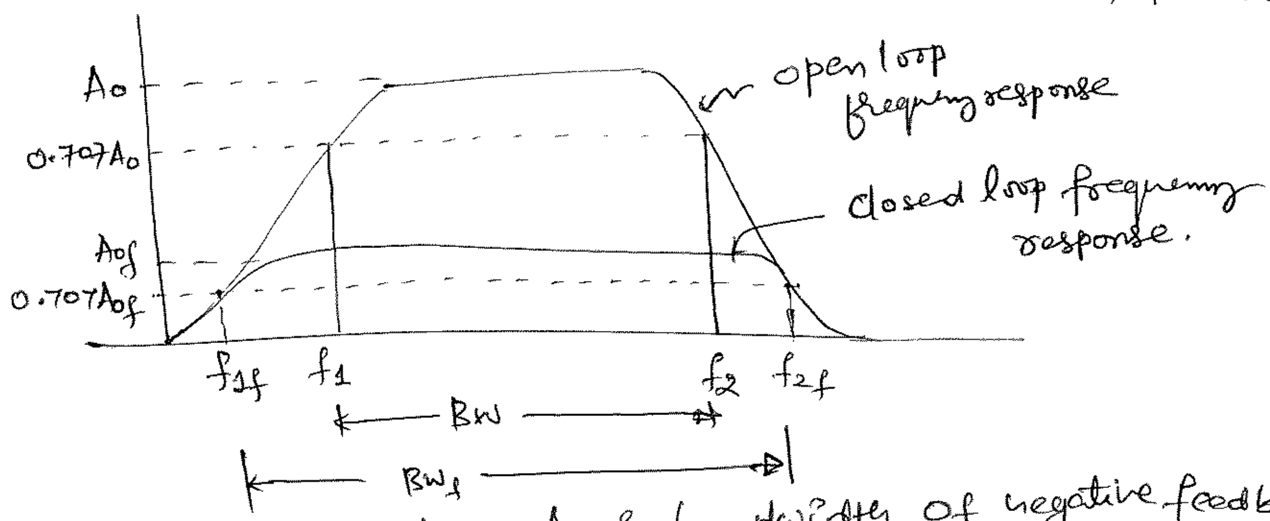


Fig (4):- effect on A_0 & bandwidth of negative feedback

Bandwidth of an amplifier without feedback is equal to seperation between the 3dB frequency f_1 and f_2.

f_1, f_2 are lower & upper 3dB frequency.

The gain Bandwidth product is.

$$= A * BW.$$

$$= A * (f_2 - f_1)$$

When the negative feedback is applied, the amplifier gain is reduced. Since the gain Bandwidth product has to remain the same in both the cases, it is obvious that the Bandwidth must increase to compensate for the decrease in the gain.

In negative amplifier, the lower & upper 3dB frequencies of an amplifier become.

$$f_{1f} = \frac{f_1}{(1+\beta A)} \quad \& \quad f_{2f} = f_2(1+\beta A).$$

$f_{1f} \rightarrow$ has decreased and $f_{2f} \rightarrow$ has increased, these by giving a wider seperation or bandwidth.

$$A\,BW = A_f\,BW_f.$$

In negative feedback amplifier, gain is reduced & Band width is increased.

Gain Stability with feedback

The overall gain with negative feedback is

$$A_f = \frac{A}{1+\beta A}.$$

Differentiation of the above equation leads to

$$\frac{dA_f}{A_f} = \frac{1}{(1+\beta A)} \cdot \frac{dA}{A}$$

$$\frac{dA_f}{A_f} = \frac{1}{\beta A}\frac{\partial A}{A} \cdot \text{ for } \beta A \gg 1$$

The above relation shows that the relative change (dA/A) in the basic amplifier gain is reduced by the factor βA in the relative change (dA_f/A_f) in the overall gain of the feedback amplifier.

An amplifier has a high frequency response described as

$$A = \frac{A_0}{1 + (j\omega/\omega_2)} \quad \text{where } A_0 = 1000, \ \omega_2 = 10^4 \text{ rad/s}$$

Find the feedback (negative) factor β, which will raise the upper corner frequency (ω_2) to 10^5 rad/s. What is the corresponding overall gain of the amplifier? Find the gain-bandwidth product in each case.

<u>Soln:</u> For amplifier, we divide A_0 by $(1+\beta A_0)$ & we multiply frequency ω_2 by $(1+\beta A_0)$. hence gain with feedback is given by

$$A_f = \frac{A_0/(1+\beta A_0)}{1+\{j\omega/[\omega_2(1+\beta A_0)]\}} = \frac{A_0(\text{new})}{1+[j\omega/\omega_2(\text{new})]}$$

where $A(\text{new}) = \dfrac{A_0}{1+\beta A_0}$

$$\omega_2(\text{new}) = \omega_2(1+\beta A_0)$$

Substituting values, $10^5 = 10^4(1+\beta \times 1000)$

$$\beta = 0.009$$

$$A_{new} = \frac{A_0}{1+\beta A_0} = 100$$

Gain bandwidth products, without & with feedback are

$$\omega_2 A_0 = 10^4 \times 10^3 = 10^7$$

$$\omega_2(\text{new})\, A(\text{new}) = 10^5 \times 100 = 10^7$$

Here Gain-bandwidth product is maintained constant.

Oscillators.

Introduction :- The process of raising the strength of a weak signal without any change in its shape is known as faithful amplification.

The dc signal applied to the amplifier is amplified in accordance with the instantaneous value of input ac signal.

But an oscillator is an energy converter. It receives dc energy and changes it into ac energy of desired frequency.

The frequency of oscillations depends upon the constants of the device. The composite electric circuit associated with an active device when used to produce an alternating current is called an oscillator circuit.

Oscillators can be both sinusoidal and non-sinusoidal. Non-sinusoidal oscillators are also called Relaxation oscillators which are rich in harmonics.

Classification of oscillator.

Based on the nature of output waveform.

(a). Sinusoidal

(b) Non-sinusoidal | Relaxation oscillators.

Based on the wether feed back is used or not

(a) Feedback type

(b) Non-feedback type Eg. UJT Relaxation type oscillator.

Based on the range of operating frequency.

(a) Low frequency or Audio frequency (20Hz to 200KHz)

(b) High frequency or Radio frequency (200KHz to few GigaHz)

(c). UHF oscillators.

(d). Microwave oscillators.

According to the circuit employed.

(a) LC oscillators.

(b) RC oscillators.

Barkhausen criterion.

Let us take a basic amplifier having an open-loop gain. A. The feedback network has feedback factor β is less than unity.

Here the amplifier is inverting, it produces a phase shift of 180° between input and output as shown in figure (1)

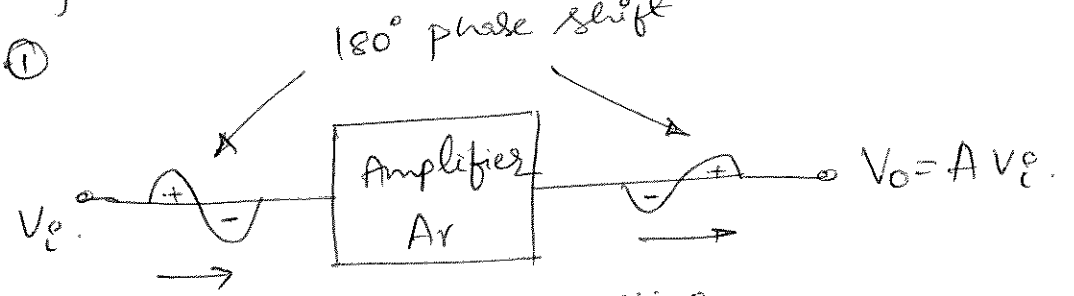


Fig (1). Inverting amplifier.

But the feedback must be positive, i.e., the voltage derived from the output using feedback network must be in phase with Vi. Thus the feedback network must introduce a phase shift of 180° while feeding back the voltage from output to input as shown in figure (2).

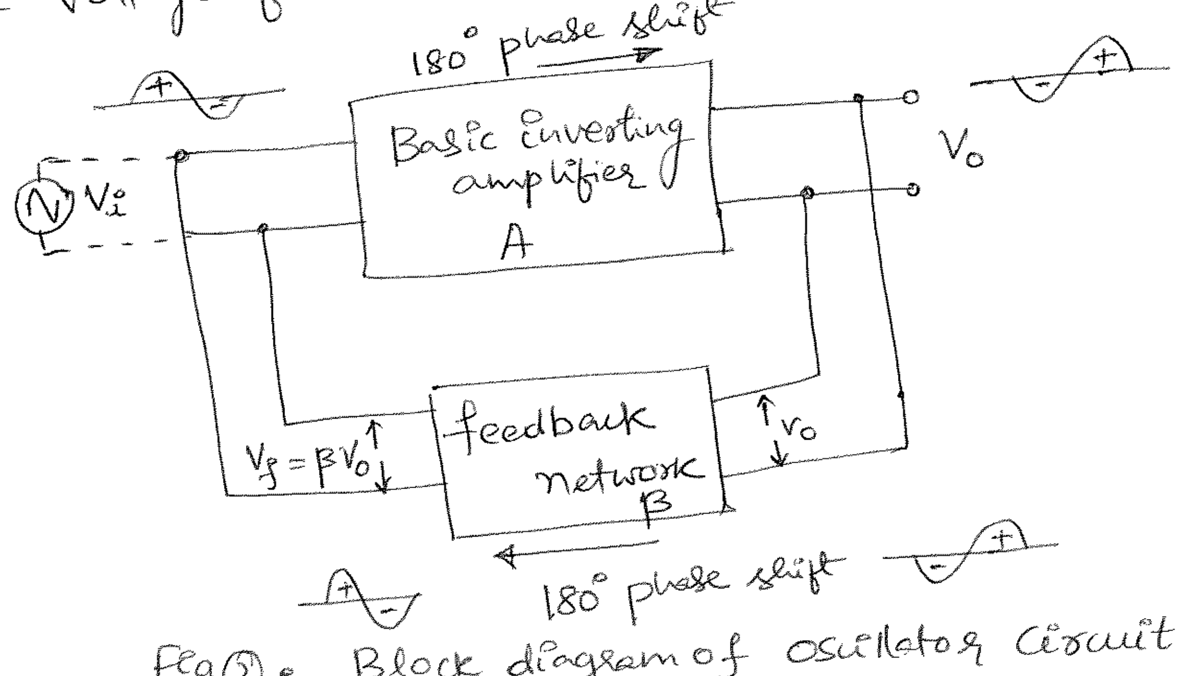


Fig (2). Block diagram of oscillator circuit.

Consider a voltage V_i applied at the input of the amplifier.

$$V_o = A\ V_i \quad \rightarrow (1)$$

The feedback factor β determines the feedback given to the input.

$$V_f = \beta V_o \quad \rightarrow (2)$$

substitute (1) in (2) we get

$$V_f = A\beta V_i \quad \rightarrow (3)$$

For the oscillator, it is necessary that the feedback should drive the amplifier and hence V_f must act as V_i.

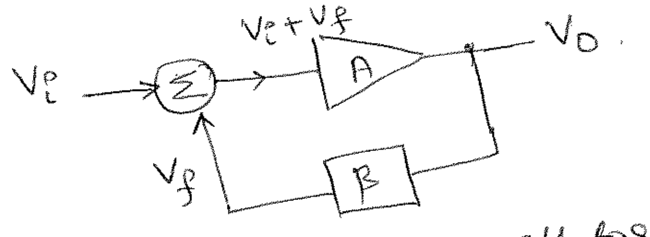


Fig (3): oscillator.

Form Fig (3)
Here we can write

$$V_o = A.(V_i - V_f)$$

$$V_o = A.V_i - A\beta V_o$$

$$V_o + A\beta V_o = AV_i$$

$$\frac{V_o}{V_i} = \frac{A}{(1+A\beta)}$$

Here For gain to be 'A' the

we can say that V_f is sufficient to act as V_i when

$$|A\beta| = 1$$

Also, the phase of V_f is the same as the phase of V_i, i.e., the feedback network should introduce 180° phase shift in addition to the 180° phase shift introduced by the inverting amplifier. This ensures positive feedback. Hence the total phase shift around the loop is 360°.

under such circumstances, V_f drives the circuit and without any external input, this circuit works as an oscillator.

The two Conditions discussed above, necessary for the circuit to function as an oscillator are Called the Barkhausen Criterion for oscillation.

The Barkhausen criterion states that:

1. The total phase shift around a loop, as the signal proceeds from the input through the amplifier, feedback network, back to the input again, Completing a loop is precisely 0° or 360°.

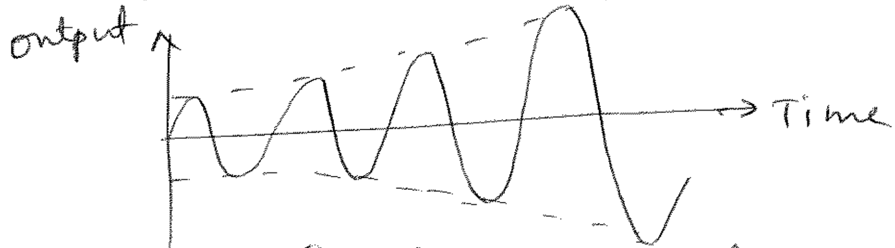
2. The magnitude of the product of the open-loop gain of the amplifier (A) and the magnitude of the feedback factor β is unity i.e $|A\beta| = 1$.

In reality, no input signal is needed to start the oscillations. In practice, $A\beta$ is made greater than 1 to start the oscillations and then the circuit adjusts itself to get $A\beta = 1$, finally leading to self-sustained oscillations.

Effect of the magnitude of the product $A\beta$ on the nature of the oscillations.

① $|A\beta| > 1$.

When the total phase shift around a loop is 0° or 360° and $|A\beta| > 1$, then the output oscillates but the oscillations are of the growing type. The amplitude of the oscillations keeps on increasing as shown in figure.



Growing type osillations.

So that to start the oscillations without input $|A\beta|$ is kept higher than unity and the circuit adjusts itself to get $|A\beta| = 1$. to result in sustained oscillations.

problems..

② $|A \cdot \beta| = 1$

As stated by Barkhausen criterion, when the total phase around a loop is 0° or 360° ensuring positive feedback and $|A\beta| = 1$, then the oscillations are with constant frequency and amplitude called sustained oscillations. Such oscillations are shown in figure below.

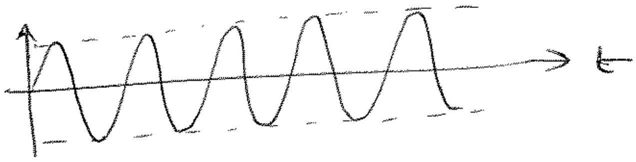


Figure. Sustained oscillations.

③ $|A\beta| < 1$.

When the total phase shift around a loop is 0° or 360° but $|A\beta| < 1$, then the oscillations are of the decaying type, i.e., the amplitude of such oscillations decreases exponentially till they finally die out. In such cases the circuit works as an amplifier without oscillations. The decaying oscillations are shown in figure.

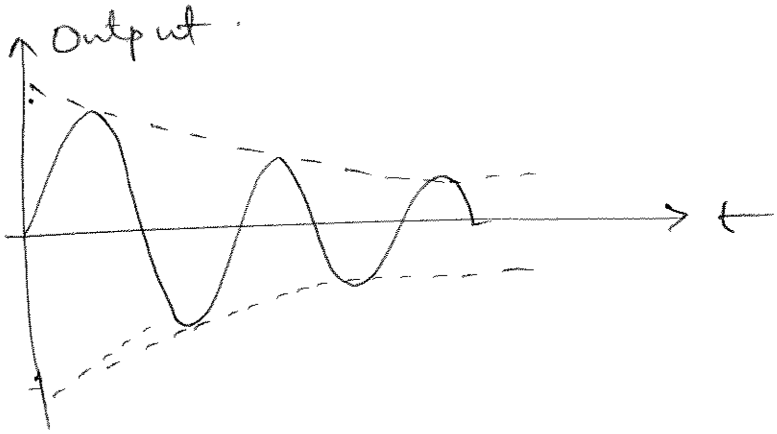


Figure. Exponentially decaying oscillations.

Oscillators.

Rc phase shift oscillator

Figure (9) shows the Rc phase shift oscillator, Here are phase shift is achieved by Rc-network. Because of loading effect, three RC-stages are needed.
It is used to produce sustained well shaped sine wave oscillations.

Appl^n:- Local oscillator for synchronous receivers.
Musical instruments.

The main part of an RC phase shift oscillator is an op-amp inverting amplifier with its output fed back into its input using a regenerative feed back RC filter network. The RC phase shifting filter network is shown in figure (1).

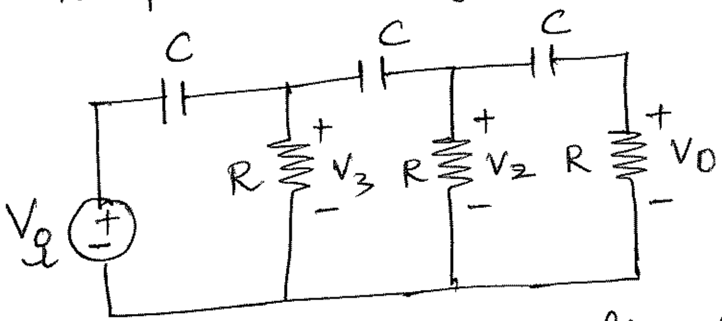


Fig (1). Rc phase shifting network.

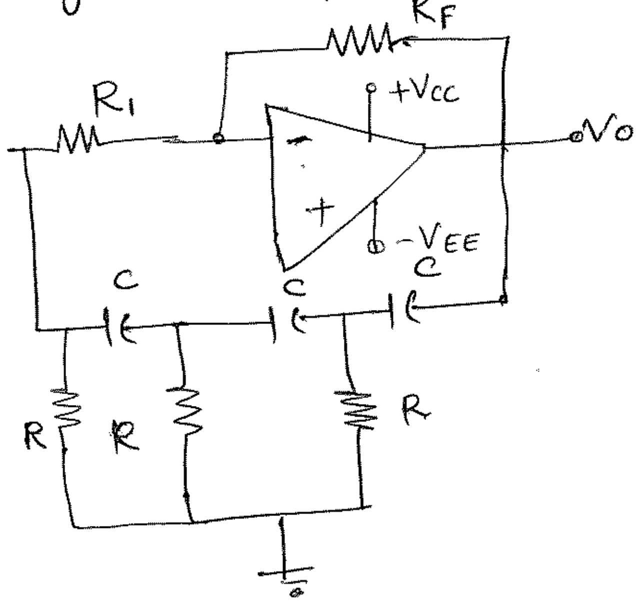
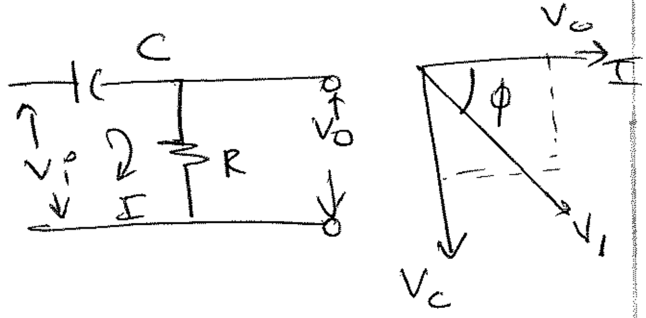


Fig.(2). phase shift Oscillator.

For the RC phase shifting network. we can write feedback factor

$$\beta = \frac{\vec{V_o}(j\omega)}{\vec{V_i}(j\omega)}.$$

For Example by Considering on RC network we derive the frequency of operation. Let a current I flow through both R and C. V_o is in phase I, whereas the voltage across the capacitor; C lags behind by 90°.
The vector sum of V_c and V_o is V_1.



$V_o = IR \quad V_c = IX_c$

$$\& \tan\phi = \frac{V_c}{V_o}$$

$$\tan\phi = \frac{IX_c}{IR} = \frac{X_c}{R}$$

$$X_c = \left(\frac{1}{2\pi f C}\right), \quad \tan\phi = \frac{1}{2\pi f C R}$$

$$f = \frac{1}{2\pi RC \tan\phi}.$$

as there are three RC sections in the phase shift network, each one Contributes a phase shift $\phi = 60^\circ$.

$$\therefore \tan\phi = \tan 60^\circ = \sqrt{3}$$

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

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

$\boxed{\omega = 2\pi f}$

$\boxed{\omega = \frac{1}{RC\sqrt{6}}}$ $\quad \& \ \beta\omega = \frac{-1}{29}$; 180° phase shift

For oscillation to occur. $|\beta| > \frac{1}{29}$.

The feedback resistor required to ~~maintain~~ sustained oscillation is

$$R_f = 29 \cdot R \qquad \text{when } R_1 = R_2 = R_3 = R$$

$$C_1 = C_2 = C_3 = R.$$

we know that gain of opamp is given by. [inverting op-amp is used]

$$A = -\frac{R_f}{R}$$

$$A = -\frac{29R}{R}$$

$$\boxed{A = -29} \qquad |A| = 29.$$

$$A\beta = \left(-\frac{1}{29}\right)\left(-\frac{R_F}{R}\right)$$

$$A\beta = \frac{R_F}{29R} > 1.$$

hence $\boxed{R_f = 29R}$

problem:- For a RC phase shift oscillator, the phase-shift network uses resistance $R = 2.2\,K\Omega$ & a capacitor $C = 0.47\,\mu F$. Find the ~~capacitor~~ frequency of oscillations.

The frequency of oscillation is given by

$$f = \frac{1}{2\pi RC\sqrt{6}} \qquad R = 2.2\,K\Omega$$

$$C = 0.47\,\mu F$$

$$\therefore f = \frac{1}{2\pi \times \sqrt{6} \times 2.2 \times 10^{3} \times 0.47 \times 10^{-6}}$$

$$= 63\,Hz.$$

working of RC phase shift oscillator

A RC phase-shift oscillator circuit produces a sine wave output. It consists of op-amp as amplifier element. This inverting amplifier output is fed back to its input through a phase-shift network consisting of capacitor and resistor in a ladder network.

The feedback network shifts the phase of the amplifier output by 180° at the oscillation frequency to give positive feedback.

appl^n: audio oscillator.

(27). A three section ladder type phase shift oscillator has 3 similar phase-advancing sections, each containing a $100 K\Omega$ resistor and $0.0005 \mu F$ capacitor. Calculate the frequency of oscillations.

Solution:- $R = 100 K\Omega$, $C = 0.0005 \mu F$.

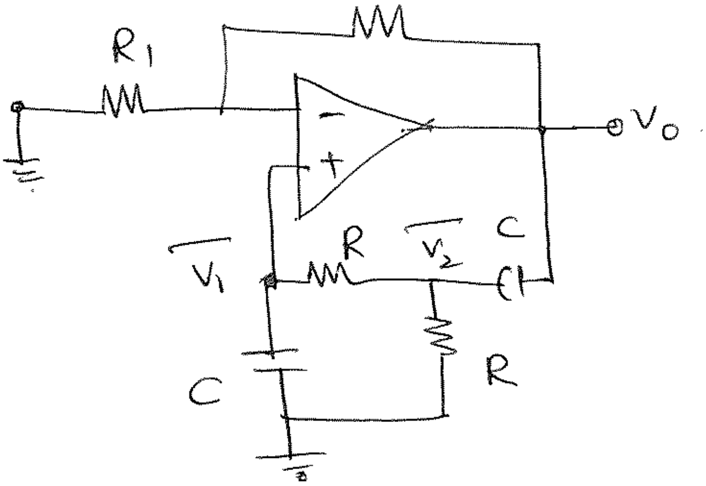
$$f = \frac{1}{2\pi RC\sqrt{6}}$$

$$= \frac{1}{2\pi \times 100 \times 10^3 \times 0.0005 \times 10^{-6}\sqrt{6}}$$

$$= 1300 Hz$$

$$\boxed{f = 1.3 KHz}$$

(3) For the feedback op-amp circuit of figure determine the condition for oscillation and the oscillation frequency



At node 2,

$$j\omega C(\bar{V}_2 - \bar{V}_0) + \frac{\bar{V}_2}{R} + \frac{\bar{V}_2 - \bar{V}_1}{R} = 0 \longrightarrow (1)$$

At node 1,

$$\frac{\bar{V}_1 - \bar{V}_2}{R} + j\omega C\bar{V}_1 = 0$$

$$(V_1 - V_2) + j\omega RCV_1 = 0$$

$$V_1 + j\omega RCV_1 = V_2$$

$$V_2 = (1 + j\omega RC)V_1 \longrightarrow (2)$$

Substitute eq^n (2) in (1)

$$\Rightarrow j\omega C\left[\left((1 + j\omega RC)V_1 - \bar{V}_0\right)\right] + \frac{(1 + j\omega RC)V_1}{R} + \left[\frac{(1 + j\omega RC) * V_1 - V_1}{R}\right] = 0$$

$$\Rightarrow j\omega CV_1 + \omega^2 RC^2 V_1 - j\omega CV_0 + \frac{1}{R} \cdot V_1 + \frac{j\omega RCV_1}{R} + \frac{j\omega RCV_1}{R} = 0$$

$$j\omega CV_1 + \omega^2 RC^2 V_1 + \frac{1}{R}V_1 + \frac{2j\omega RCV_1}{R} = j\omega CV_0$$

$$\beta = \frac{V_1}{V_0} = \frac{1}{3 + j\left(\omega RC - \frac{1}{\omega RC}\right)}$$

For β to be real, the j-term should be zero.
This happen when.

$$\omega = \frac{1}{RC} = f = \frac{1}{2\pi RC}$$

Then $\beta = \frac{1}{3}$ possitive feed back

Forward gain. $A = \frac{V_0}{V_i} = 1 + \frac{R_2}{R_1}$

For osillations to occur.

$$A\beta = \frac{1}{3}\left(1 + \frac{R_2}{R_1}\right) > 1$$

$$\boxed{\frac{R_2}{R_1} > 2}$$

(4) Estimate the values of R and C for an output frequency of 1 KHz in a RC phase shift osillator.

frequency of osillation $f = \frac{1}{2\pi RC\sqrt{6}}$.

let $R = 100 K\Omega$, & given $f = 1 KHz$.

$$C = \frac{1}{2\pi * 100\times10^3 * 1\times10^3 * \sqrt{6}}.$$

$$\boxed{C = 0.00065 \mu F}$$

Here $\underline{R = 100 K\Omega}$, $\underline{C = 0.00065 \mu F}$.

Wien Bridge Oscillator

It is an audio frequency sine wave oscillator of high stability and simplicity.

It is a two stage RC amplifier circuit connected in wheat stone's bridge with an amplifier stage.

Wein Bridge oscillator uses non-inverting amplifier & hence does not provide any phase shift and no need of phase shift through the feedback network.

Wein Bridge oscillator is shown in figure. It consists of op-amp and RC bridge circuit, with the oscillator frequency set by the R and C components. Two RC combination using R_1, R_2, C_1 and C_2 and R_3 and R_4 form the Bridge. The op-amp output is connected as the bridge input at points a and c.

The bridge circuit output at points b and d provide negative and positive inputs to the op-amp.

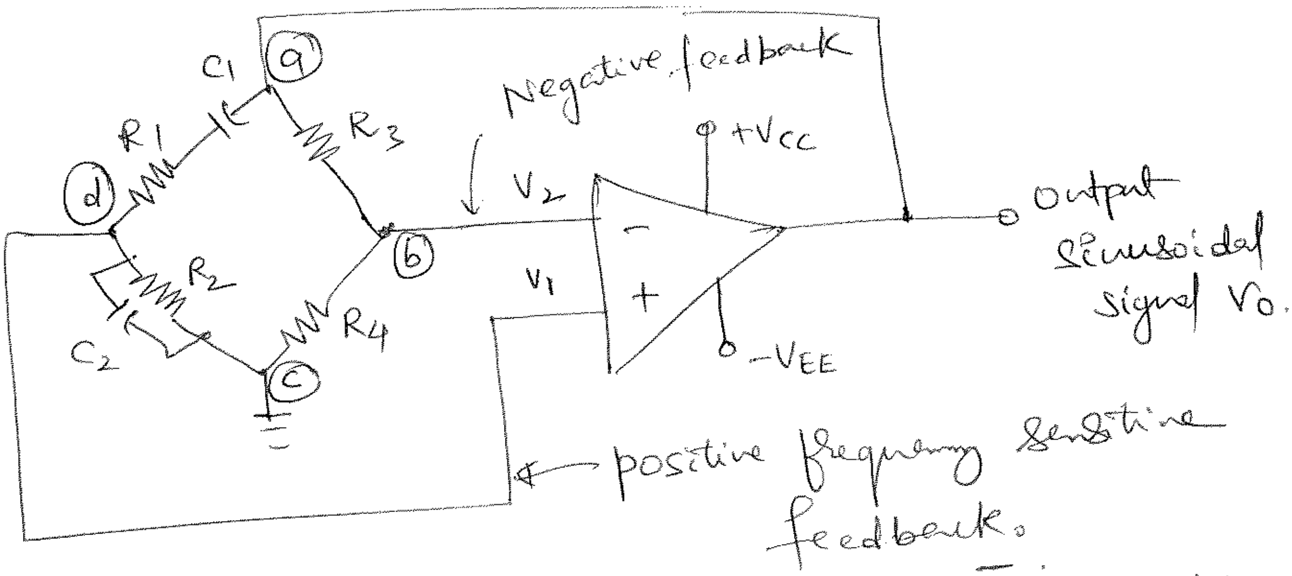


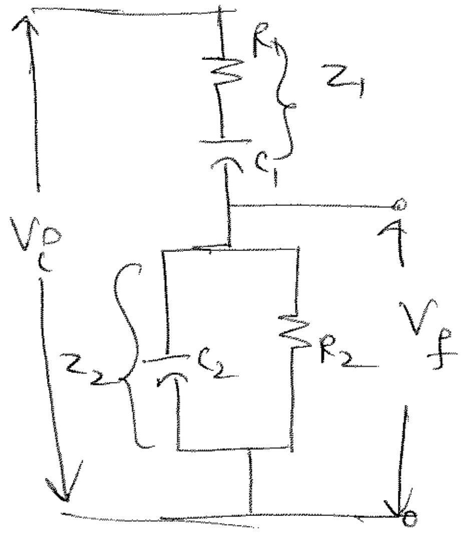
Figure:- Wein Bridge oscillator using an op-amp amplifier

The Two RC network is responsible for determining the frequency of oscillation.

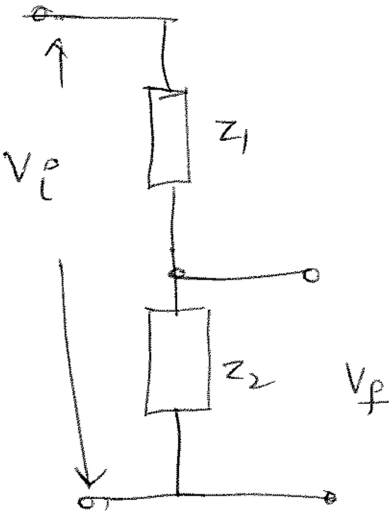
The two RC network arms i,e Series R_1C_1 and parallel R_2C_2 are called the frequency sensitive arms.

To understand the gain of the feedback network let's rearrange the circuit.

This configuration is also called lead-lag network because it acts like a lead at very low frequency and lag network at very high frequencies.



To calculate the gain of the network Consider a series RC as Z_1 and parallel RC as Z_2.



where

$$Z_1 = R_1 + \frac{1}{j\omega C_1} \qquad Z_2 = R_2 \parallel \frac{1}{j\omega C_2}$$

$$= \frac{j\omega R_1C_1 + 1}{j\omega C_1} \qquad = \frac{R_2}{1 + j\omega R_2C_2}.$$

The simplified circuit is shown aside which is a voltage divider fig. Equivalent circuit.

Circuit hence

$$\beta = \frac{V_f}{V_i} = \frac{Z_2}{Z_1 + Z_2}$$ This is feedback gain at non-inverting terminal.

$$= \frac{R_2 / (1 + j\omega R_2C_2)}{\frac{R_2}{(1 + j\omega R_2C_2)} + \frac{(1 + j\omega R_1C_1)}{j\omega C_1}}$$

$$= \frac{\dfrac{R_2}{(j\omega C_2 R_2 \cancel{+1})}}{\dfrac{R_2 j\omega C_1 + (1+j\omega C_1 R_1)(1+j\omega R_2 C_2)}{j\omega C_1 (1+j\omega \cancel{R_2 C_2})}}$$

$$= \frac{j\omega C_1 R_2}{j\omega C_1 R_2 + 1 + j\omega C_1 R_1 + j\omega R_2 C_2 + j^2\omega^2 C_1 R_1 C_2 R_2}$$

$$= \frac{j\omega C_1 R_2}{(1-\omega^2 C_1 R_1 C_2 R_2) + j\omega(R_1 C_1 + R_2 C_2 + R_2 C_1)} \qquad j^2 = -1$$

Rationalising the expression we get

$$\beta = \frac{V_o}{V_i} = \frac{j\omega C_1 R_2 \left[(1-\omega^2 C_1 R_1 C_2 R_2) - j\omega(R_1 C_1 + R_2 C_2 + R_2 C_1)\right]}{(1-\omega^2 C_1 R_1 C_2 R_2)^2 + \omega^2 (R_1 C_1 + R_2 C_2 + R_2 C_1)^2}$$

$$= \frac{\omega^2 C_1 R_2 (R_1 C_1 + R_2 C_2 + R_2 C_1) + j\omega R_2 C_1 (1-\omega^2 C_1 C_2 R_1 R_2)}{(1-\omega^2 C_1 R_1 C_2 R_2)^2 + \omega^2 (R_1 C_1 + R_2 C_2 + R_2 C_1)^2}$$

To have a zero phase shift of the feed back network its imaginary part must be zero.

$$\therefore \omega R_2 C_1 (1-\omega^2 C_1 C_2 R_1 R_2) = 0$$

$$1-\omega^2 R_1 R_2 C_1 C_2 = 0$$

$$\omega^2 R_1 R_2 C_1 C_2 = 1$$

$$\omega^2 = \frac{1}{R_1 R_2 C_1 C_2} \Rightarrow \omega = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}$$

$$\omega = 2\pi f \Rightarrow \qquad f = \frac{1}{2\pi\sqrt{R_1 R_2 C_1 C_2}}$$

Hence the frequency of the oscillator shows that the components i.e. R_1, R_2, C_1, C_2 of the frequency sensitive arms are the deciding factors for the frequency

let $R_1 = R_2 = C$, $C_1 = C_2 = C$.

$$f = \frac{1}{2\pi\sqrt{R^2C^2}} = \frac{1}{2\pi RC}$$

The gain of the feedback network becomes.

$$\beta = \frac{V_o}{V_i} = \frac{\omega^2 CR(3RC) + j\omega RC(1-\omega^2R^2C^2)}{(1-\omega^2R^2C^2)^2 + \omega^2(3RC)^2}$$

substitute $\omega = \frac{1}{RC}$

$$= \frac{\frac{3}{\cancel{R^2C^2}}\cancel{(RC)^2} + j\frac{1}{RC} \times RC\left[1 - \frac{1}{\cancel{R^2C^2}} \times \cancel{R^2C^2}\right]}{\left[1 - \frac{1}{\cancel{R^2C^2}}\cancel{R^2C^2}\right]^2 + \frac{1}{\cancel{R^2C^2}} \times \cancel{9}R^2C^2}$$

$$\beta = \frac{3}{9} = \frac{1}{3}.$$

The positive sign of β indicates that the phase shift by the feedback network is zero.

For sustained oscillations.

$$|A\beta| \geq 1$$

$$|A| \geq \frac{1}{|\beta|} = \frac{1}{\frac{1}{3}} = 3$$

$$|A| \geq 3.$$

Forward gain inverting terminal

$$A = -\frac{V_0}{V_2} = -\left[1 + \frac{R_3}{R_4}\right]$$

For oscillations, Barkhausen criterion.

$$A\beta \geq 1. \qquad \beta = \frac{1}{3}$$

$$\left(1 + \frac{R_3}{R_4}\right)\left(\frac{1}{3}\right) \geq 1.$$

$$\frac{R_3}{R_4} \geq 3 - 1 . \Rightarrow \geq 2$$

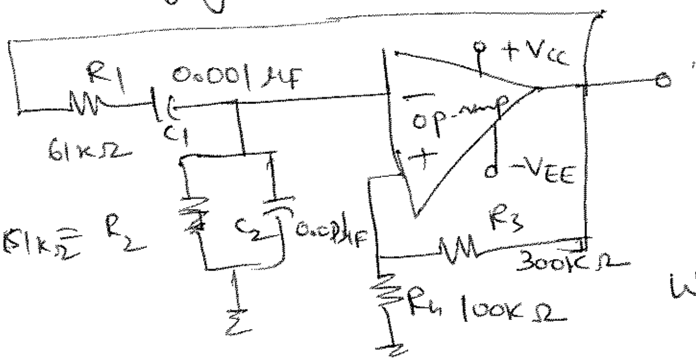
$$\boxed{R_3 = 2R_4}$$

Thus the ratio of R_3 & R_4 should be greater than or equal to 2 to provide sufficient loop gain for the circuit to oscillate at the frequency calculated as

$$f = \frac{1}{2\pi RC}.$$

Problems.

Calculate the resonant frequency of the wein bridge oscillator of figure.



Wein bridge oscillator Circuit.

Soln: $f = \frac{1}{2\pi RC} = \frac{1}{2 \times \pi \times 61 \times 10^3 \times 0.01 \times 10^{-6}}$

$= 260.9 \text{ Hz}$

(2) Design the RC elements of a Wien bridge oscillator as in figure for operation at $f = 10\,KHz$.

$$RC = \frac{1}{2\pi f} = \frac{1}{2 * \pi * 10 \times 10^3}$$

choose

$R = 150\,K\Omega$

$$C = \frac{1}{6.28 * (10 \times 10^3 * 150 \times 10^3}$$

$$C = 238.5\ F$$

we can use $R_3 = 300\,K\Omega$ & $R_4 = 100\,K\Omega$ to provide a ratio R_3/R_4 ; greater than 2 for oscillation to take place.

Clock and Timing Circuits.

Introduction :-

Heart of a computer is the clock which produces clock pulses with the precise cycle time. The clock pulses advance the various circuits of the computer one step at a time. The clock pulses are normally Rectangular; positive pulses followed by negative pulses as shown in fig ①.

The Duty cycle could be other than 50% but the cycle time must be precise. All logic elements must complete their transition in one cycle.

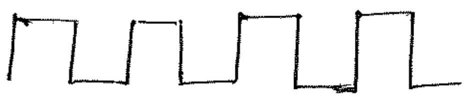


fig ①. Ideal clock pulses.

The clock pulses can be generated by IC-555 timer or by a crystal oscillator.

IC-555 Timer :-

It is an integrated circuit used in a variety of timer, pulse generation and oscillator applications. It is a highly stable device for generation of accurate time delays and oscillations.

The entire circuit is available in an 8-pin package as shown in fig ②. details are shown in fig ③.

(i) It consists of two op-amp comparator set at 2/3 Vcc and 1/3 Vcc respectively.

(ii) A three resistor circuit, to obtain voltage 2/3 Vcc and 1/3 Vcc to set the comparator.

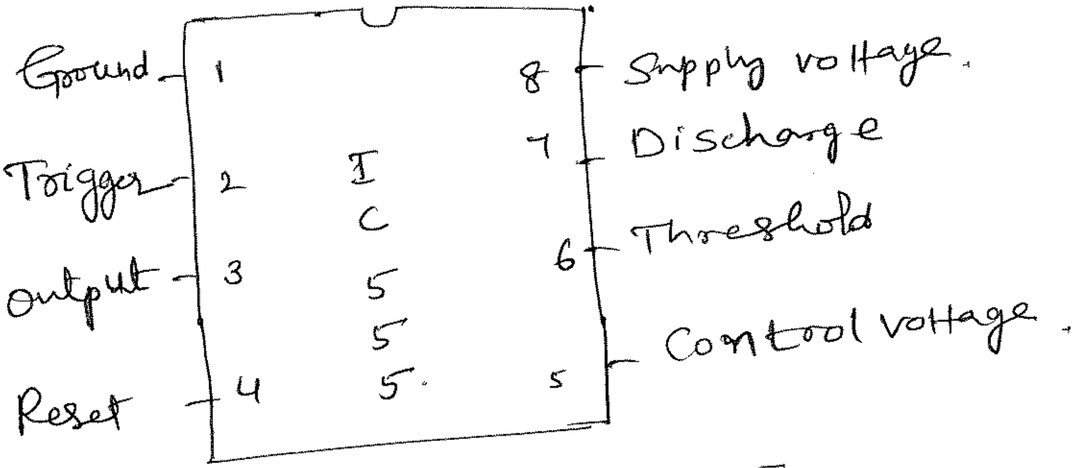
- The Comparator's output sets or resets the FlipFlop (F/F) which feeds the output stage.

The FlipFlop operates as

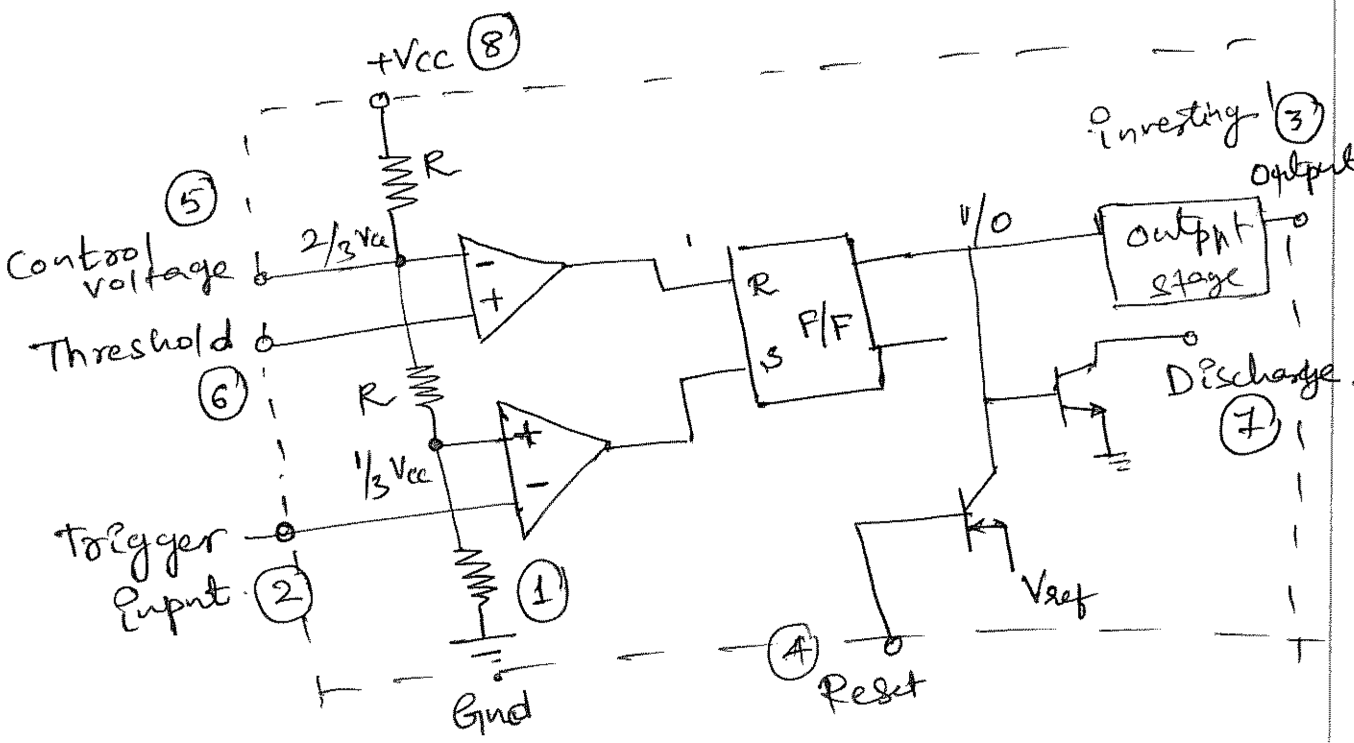
R = 1, S = 0, Output = 0

R = 0, S = 1 Output = 1.

The FlipFlop also operates a transistor which when driven low, discharges a timing capacitor (external).



Fig②. Pin details of IC 555.



Internal Details of IC 555 timer.

pin 1: Ground

It Connects the IC 555 timer to the negative (0V) Supply.

pin 2:- Trigger.

The negative input to Comparator 2. A negative pulse on this pin "sets" the internal Flip-Flop when the Voltage drops below $1/3\ V_{CC}$ Causing the output to Switch from a LOW to a HIGH state.

pin 3:- Output.

It Can drive any Transistor Transistor logic [TTL] Circuit and is Capable of sourcing or sinking up to 200mA of current at an output voltage equal to approximately $V_{CC} = 1.5V$ so Small speakers, LED's or motor Can be directly Connected to the output.

pin 4:- reset.

It is used to reset the internal FlipFlop Controlling the state of the output pin 3.

pin 5:- Control Voltage.

It Controls the timing of the 555 by overriding $2/3\ V_{CC}$ Level of the voltage divider network.
We Can vary RC Timing by applying voltage to this pin when not used Connected to ground through 10nF Capacitor to eliminate the noise.

pin 6:- Threshold.

The positive input to Comparator 1. This pin is used to reset the FlipFlop when the Voltage applied to it exceeds $2/3\ V_{CC}$ Causing the output to switch from 'High' to 'Low' State. It Connects directly to RC Timing Circuits.

Pin 7 :- Discharge :-

It is directly connected to the Collector of an internal NPN transistor which is used to 'discharge' the timing Capacitor to ground when the output at pin 3 switches Low.

pin 8 : Supply + Vcc

This is the power supply pin & for general purpose TTL 555 timer's is between 4.5V & 15V.

The three 5KΩ resistors Connected together internally producing a voltage divider network between the supply voltage at pin 8 and ground at pin 1.

———— o ————

Astable operation :—

A common application of the 555 Timer is as astable multivibrator or clock circuit.

Fig 4. shows a stable circuit built using two external Resistors and a capacitor, which sets the timing integral of the output.

Astable multivibrator is also called free running or self triggering mode. It does not have any stable state, it ~~consists~~ of two quasi stable state (High & Low)

No external triggering is used here, it automatically interchange its two states on a particular interval, hence generates a rectangular waveform.

Astable mode works as a oscillator circuit, in which output oscillate at a particular frequency & generate pulses or rectangular waveform.

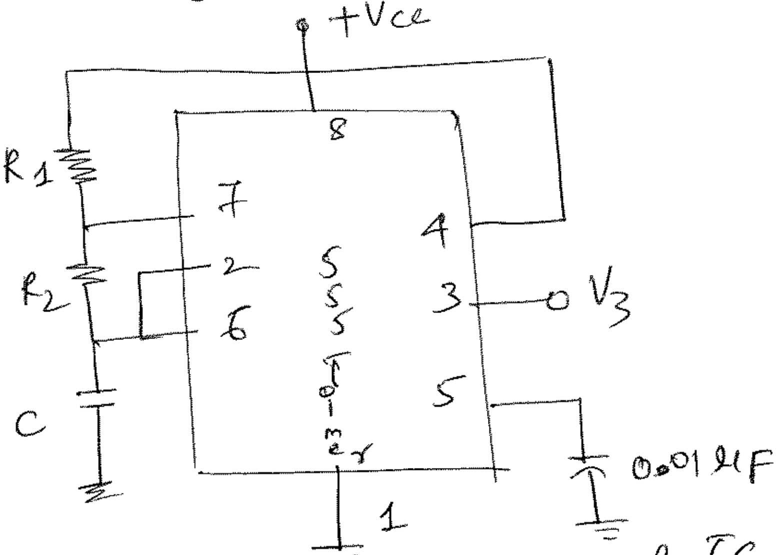


Fig (4). Astable operation of IC 555 timer.

The capacitor begins to charge from the dc source Vcc. When the voltage of the threshold pin 6 tends to increase beyond $2/3 V_{cc}$, the comparator 1 saturates & its output triggers the flipflop and so the output at pin 3 goes low.

At the same time, the transistor becomes ON causing the output at pin 7 to discharge the capacitor through R_2 at time constant $\tau_2 = R_2 C$.

As the capacitor voltage which is the trigger input at pin 2 falls below $(1/3) V_{cc}$, the comparator 2 output causes the flip-flop to reset, the output at pin 3 becomes high & the transistor goes OFF.

The capacitor now begins to charge through R_1 & R_2 at time constant $\tau_1 = (R_1 + R_2) C$. The process then repeats continuously.

The output waveform & Capacitor charging & discharging are shown in fig. 5.

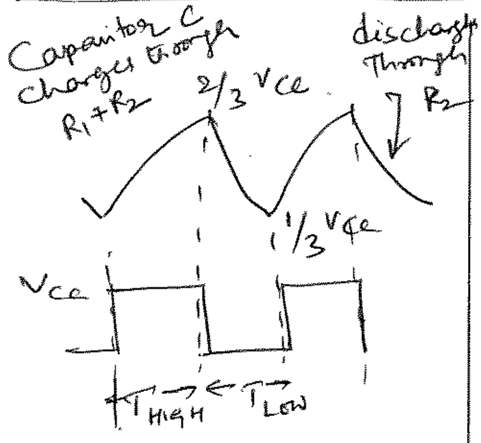


Fig 5 Output waveform & Capacitor charging & discharging cycle.

The exponential expression for R_2C discharging and (R_1+R_2) charging from Vcc we can find T_{High} & T_{Low} periods.

Duty cycle of square wave is given by

$$D = T_{ON}/T.$$

T is sum of charging time (T_{High}) & T_{OFF} discharging time.

The value of T_{High} or the charge time is given by

$$T_{High} = 0.693 * (R_1+R_2)\,C$$

The value of T_{Low} or the discharge time is given by

$$T_{Low} = 0.693 * R_2 C$$

Therefore the time period for the cycle T is given by

The oscillation period

$$T = T_{high} + T_{low} = T_{ON} + T_{OFF}.$$

$$= 0.693 * (R_1+R_2)C + 0.693 R_2 C.$$

The Oscillation frequency

$$T = 0.693\,(R_1+2R_2)\,C.$$

$$f = \frac{1}{T} = \frac{1}{0.693 * (R_1+2R_2)\,C}.$$

$$= \frac{1.44}{(R_1+2R_2)\cdot C}.$$

Duty cycle is given by

$$D = \frac{T_{high}}{T} = \frac{T_{high}}{T_{high} + T_{low}}$$

$$= \frac{0.693\,(R_1+R_2)\cancel{C}}{\cancel{0.693}\,(R_1+2R_2)\cancel{C}}$$

$$= \frac{R_1+R_2}{R_1+2R_2}$$; less than 50%

Derivation of charging and discharging Time

Discharging:- $V_c(t_1) = \frac{2}{3} V_{cc}\, e^{-t_1/\tau_1} = \frac{1}{3} V_{cc}$

$$2e^{-t_1/\tau_1} = 1, \quad \log_e 2 - \log_e e^{-t_1/\tau_1} = \log_e 1$$

$$= \ln 2 - \frac{t_1}{\tau_1} = 0$$

OR $\boxed{t_1 = \tau_1 \ln 2}$

Charging:- $V_c(t) = V_{cc} + A \cdot e^{-t/\tau_2}$

At t_2, $V_c(t_2) = V_{cc} + A \cdot e^{-t/\tau_2} = \frac{1}{3} V_{cc}$

Substitute $A = -\frac{2}{3} V_{cc}$

$$V_c(t_2) = V_{cc} - \frac{2}{3} V_{cc}\, e^{-t/\tau_2} = \frac{2}{3} V_{cc}$$

$$1 - \frac{2}{3} e^{-t_2/\tau_2} = \frac{2}{3} \Rightarrow 1 - \frac{2}{3} = \frac{2}{3} e^{-t_2/\tau_2}$$

$$\frac{1}{3} = \frac{2}{3} e^{-t_2/\tau_2} \Rightarrow 2e^{-t_2/\tau_2} = 1$$

$$= \ln 2 + \ln e^{-t_2/\tau_2} = \ln 1$$

$$\ln 2 - t_2/\tau_2 \ln e = 0$$

$$\ln 2 - t_2/\tau_2 \ln e = 0 \qquad \ln e = 1.$$

$$\log_e e = 1.$$

$$t_2/\tau_2 = \ln 2$$

$$\boxed{t_2 = \tau_2 \ln 2}$$