MODULE 4

Module – 4 BJT Applications, Feedback Amplifiers & Oscillators

Notes includes links to videos

SYLLABUS:

1. ***BIT as an amplifier, BIT as a switch, Transistor switch circuit to switch ON/OFF an LED and a lamp in a power circuit using a relay (4.4 and 4.5 of Text 2).***
2. ***Feedback Amplifiers -Principle, Properties and advantages of Negative Feedback, Types of feedback, Voltage series feedback, Gain stability with feedback (7.1-7.3 of Text 1).***
3. ***Oscillators -Barkhaunsen's criteria for oscillation, RC Phase Shift oscillator, Wien Bridge oscillator (7.7-7.9of Text 1)***
4. ***IC 555 Timer and Astable Oscillator using IC 555 (17 .2 and 17.3 of Text 1)***

TEXTBOOKS:

1. ***"Basic Electronics", D.P. Kothari, I. J. Nagrath, MHE (India) Private Limited, 2014.***
2. ***"Electronic Devices", Thomas L Floyd, Pearson Education, 9th edition 2012***

NOTES

4.0 Bipolar Junction Transistor

[please read this sub section for understanding the operation of BJT only – light reading till 4.1]

Structure of pnp and npn transistor

A bipolar transistor is simply a sandwich of one type of semiconductor material (p-type or n-type) between two layers of the opposite type. An npn transistor has a p-type material between two layers of n-type as in Fig.4.2(a) and a pnp transistor has a n-type material between two layers of p-type as in Fig.4.2 (b). Circuit symbols of pnp and npn transistor are shown in Fig.4.1. The arrowhead identifies the emitter terminal and **indicates the direction of conventional current**.

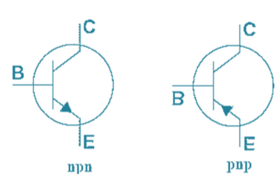


Fig.4.1: BJT Symbol

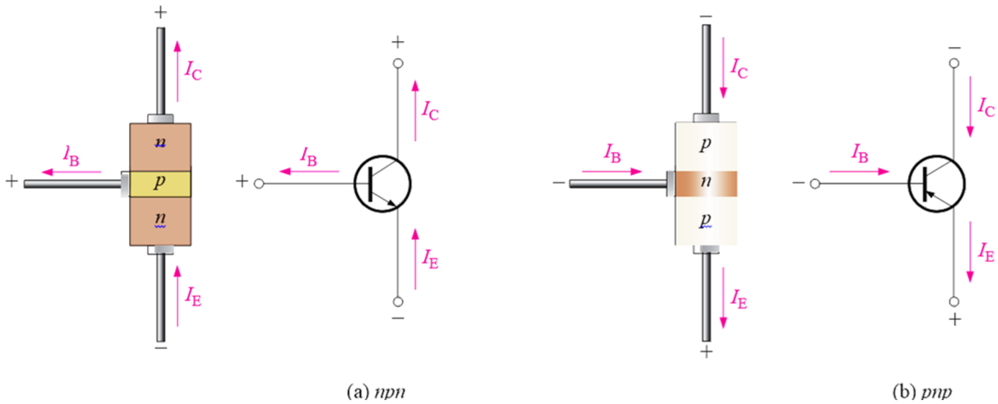


Fig.4.2: npn and pnp transistor representation

The BJT has three layers base (B), emitter (E), collector (C) and two pn-junctions: collector-base junction and emitter-base junction.

Emitter

- **moderate size** + **heavily doped**
- main function - to **supply majority carriers for conduction**
- emits majority carriers, hence called **Emitter.**

Base

- The middle layer **thin** and **lightly doped**.
- Main function - to **pass** the majority carriers from **E to C.**

Collector

- **Larger** in size than emitter and base **+ moderately doped**
- **collecting the carriers**.

Transistor Biasing

BJT has two pn junctions a Base Emitter junction and a Collector-Base junction. Biasing is controlling the operation of the transistor by providing power supply as in Fig.4.3 .

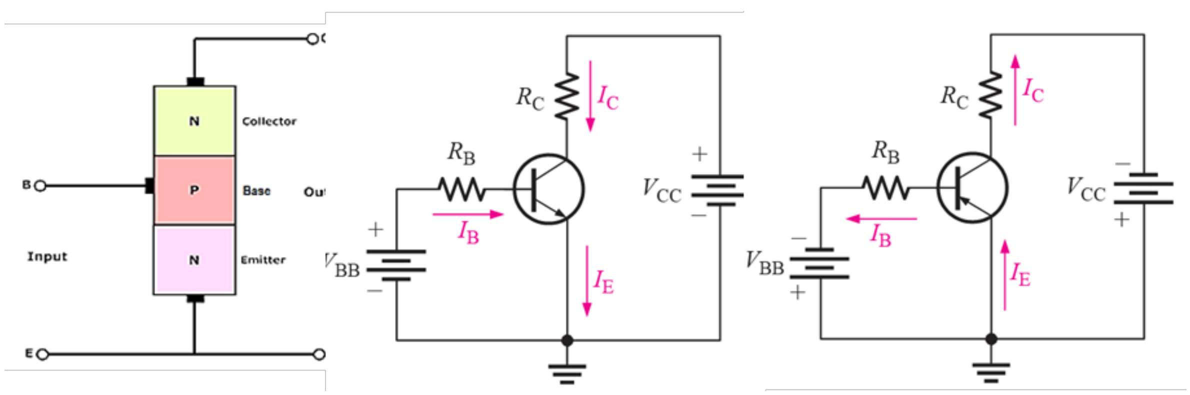


Fig.4.3 Biasing NPN and PNP transistors in common emitter configuration

Operation of NPN / PNP Transistor

i. The conduction in a transistor takes place through MAJORITY CHARGE CARRIERS.

ii. The base emitter junction forward biased and collector-base junction reverse biased.

iii. The increase or decrease in the emitter current affects the collector current.

4.0.1 Common Emitter Characteristics

Common emitter circuit

The input is applied between base-emitter and output is measured between collector-emitter terminal. Since emitter terminal is COMMON for both input and output, the configuration is called as **common emitter configuration**.

Common emitter input characteristics

In input characteristics the **output voltage V_{CE} is kept constant and input voltage V_{BE} is varied**.

1. At each input voltage V_{BE}, input current I_B is measured and plotted to get the input characteristics.

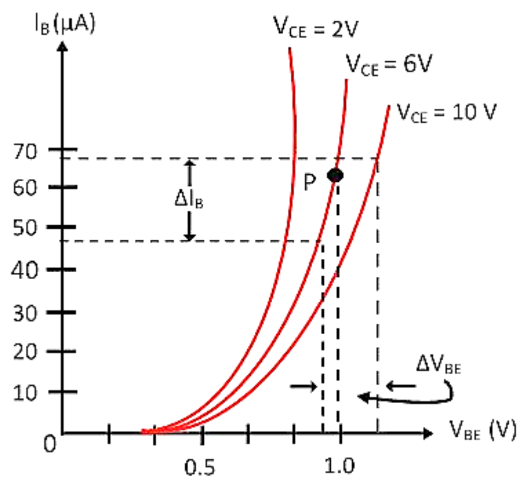


Fig.4.4: Input characteristics

2. Since emitter-base junction is forward biased the input characteristics is similar to diode forward characteristics.
3. For constant V_{BE}, the input current I_B is reduced when output voltage V_{CE} is increased.

Common emitter output characteristics

1. For output characteristics the input current I_B is kept constant and output voltage V_{CE} is varied. At each output voltage V_{CE}, the output current I_C is measured and plotted to get the output characteristics. It shows that the output current I_C is almost equal to I_E and it remains constant when output voltage V_{CB} is increased
2. The region in which collector-base junction is forward biased is known as SATURATION REGION.
3. The region in which collector-base junction is reverse biased is known as **ACTIVE REGION**.

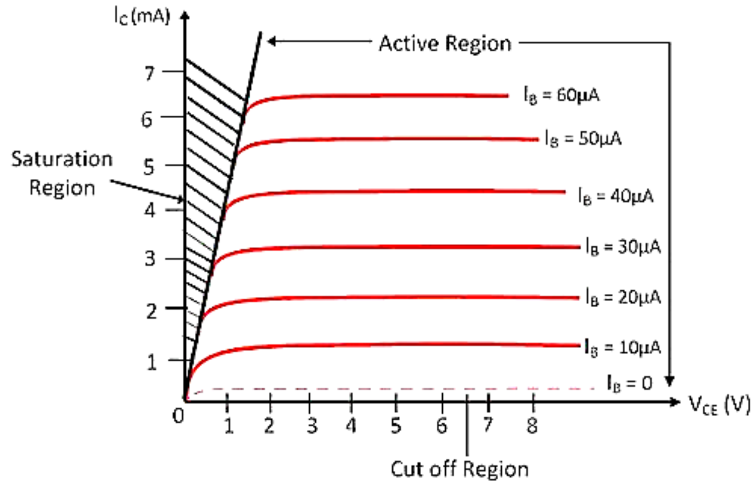


Fig.4.5: Output characteristics

4.1 Transistor currents (IMPORTANT READ CAREFULLY)

1. For a pnp transistor, emitter current I_E flows into the transistor. The base current I_B and collector current I_C, flows out of the transistor as shown.

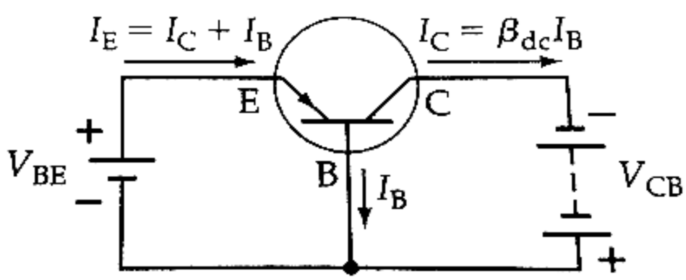


Fig.4.6: Terminal currents of a pnp transistor

$$\mathbf{I_E = I_C + I_B}$$

2. Almost all of emitter current I_E crosses to collector and only a small portion flow out of the base terminal.

$$I_C = \alpha_{dc} I_E$$

$$\alpha_{dc} = \frac{I_C}{I_E}$$

α_{dc} defined as –

ratio of collector current to emitter current or emitter to collector current gain.

3. Collector current I_C can also be expressed by using equations as

$$I_C = \alpha_{dc}(I_C + I_B)$$

$$I_C - \alpha_{dc} I_C = \alpha_{dc} I_B \qquad I_C(1 - \alpha_{dc}) = \alpha_{dc} I_B$$

$$I_C = \frac{\alpha_{dc}}{1 - \alpha_{dc}} I_B$$

$$I_C = \beta_{dc} I_B$$

$$\beta_{dc} = \frac{I_C}{I_B} = \frac{\alpha_{dc}}{1 - \alpha_{dc}}$$

β_{dc} defined as -

ratio of collector current to base current or base to collector current gain. It is also defined as h_{FE} based on the h-parameter analysis of a transistor.

4. Terminal currents derived for a pnp device will apply for npn transistor, only difference is I_B and I_C flows into transistor and I_E flows out of the transistor as shown in the Fig.4.7

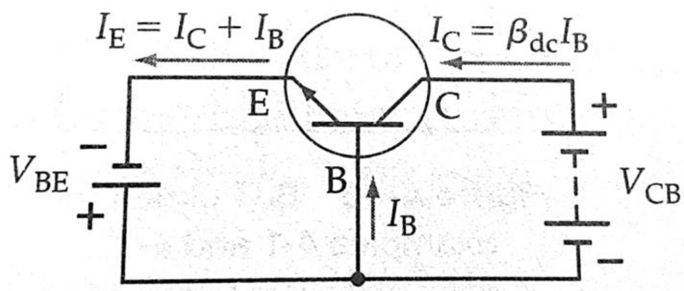


Fig.4.7: Terminal currents of a npn transistor

Links to videos: *Introduction To BJT https://Youtu.Be/-Vwpsdqmdjm*

Problems

1. Calculate I_C & I_E for a transistor $\alpha_{dc} = 0.98$ $I_B = 100\mu A$, β_{dc} =?

Collector current is given by $I_C = \beta_{dc} I_B$ substituting for β_{dc} $\mathbf{I_C = \frac{\alpha_{dc}}{1-\alpha_{dc}} I_B}$

$$I_C = \frac{0.98}{1-0.98} * 100\mu \quad \mathbf{I_C = 4.9mA}$$

Emitter current is got from $I_C = \alpha_{dc} I_E$ hence $I_E = \frac{I_C}{\alpha_{dc}} = \frac{4.98m}{0.98}$ $\mathbf{I_E = 5mA}$

ratio of the collector current to base current is $\beta_{dc} = \frac{I_C}{I_B} = \frac{\alpha_{dc}}{1-\alpha_{dc}}$

$$\beta_{dc} = \frac{0.98}{1 - 0.98}$$

$$\boldsymbol{\beta_{dc} = 49}$$

2. A transistor has measured a currents of I_C = 3mA and I_E = 3.03mA. Calculate the new current levels when the transistor is replaced with a device that has β_{dc} = 75. Assume that I_B remains constant.

Emitter current is given by $I_E = I_C + I_B$ | $I_B = 3.03m - 3m$

$$\mathbf{I_B = 30\mu A}$$

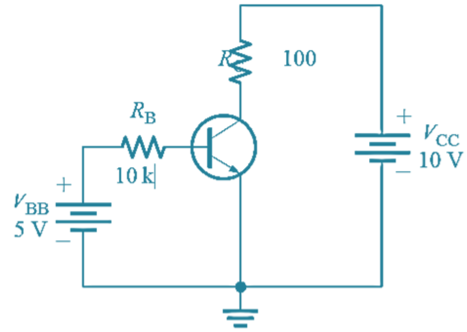
New current levels for β_{dc} = 75 are $I_C = \beta_{dc} I_B$ | $I_C = 75 * 30\mu$

$$\mathbf{I_C = 2.25mA}$$

Emitter current is given by $I_E = I_C + I_B$ | $I_E = 2.25m + 30\mu$

$$\mathbf{I_E = 2.28mA}$$

3. **Determine I_B, I_C, I_E, V_{BE}, V_{CE}, and V_{CB} in the circuit of Figure** The transistor has $\beta_{DC} = 150$



$$I_B = \frac{V_{BB}-V_{BE}}{R_B} = \frac{5-9.7}{10k} = \mathbf{430\ \mu A}$$

$$\boldsymbol{I_c = \beta_{dc} I_B} = 150 \text{ X } 430\ \mu\text{A} = \mathbf{64.5mA}$$

$$\boldsymbol{I_E = I_C + I_B} = 64.5\text{mA} + 430\ \mu\text{A} = \mathbf{64.93\ mA}$$

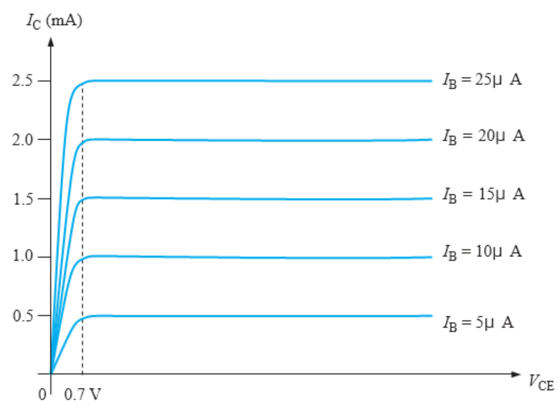
$$\boldsymbol{V_{CE}} = V_{CC} - I_C R_C = 10 - 64.5\,\text{m} * 100 = 10 - 6.45 = \mathbf{3.55\ V}$$

$$\boldsymbol{V_{CB}} = V_{CE} - V_{BE} = 3.55\text{ V} - 0.7\text{ V} = \mathbf{2.85\ V}$$

Sketch an ideal family of collector curves for the circuit in Figure above for I_B = 5 mA to 25 mA in 5 mA increments. Assume β_{DC}=100 and that V_{CE} does not exceed breakdown

Using the relationship $I_C = \beta_{DC} I_B$, values of I_C are calculated and tabulated in Table 4–1. The resulting curves are plotted

I_B	I_C
5 uA	0.5 mA
10 uA	1.0 mA
15 uA	1.5 mA
20 uA	2.0 mA
25 uA	2.5 mA



4.2 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.

Voltage Amplification

BJT transistor amplifies current because the collector current at the output is equal to the base current an input factor multiplied by the gain, β.

1. The base current in a transistor is very small compared to the collector and emitter currents, hence the collector current is approximately equal to the emitter current.
2. An AC voltage Vs, is superimposed on DC voltage V_{BB} by capacitive coupling as shown.
3. The DC bias voltage V_{CC} is connected to the collector through the collector resistor, R_C.
4. The AC input voltage produces an AC base current, Resulting in a much larger AC collector current.
5. The AC collector current produces an AC voltage across R_C, thus producing an

AMPLIFIED, but inverted OUTPUT.

6. The forward-biased base-emitter junction presents a very low resistance to the ac signal. This internal AC emitter resistance r'_e is in series with R_B.

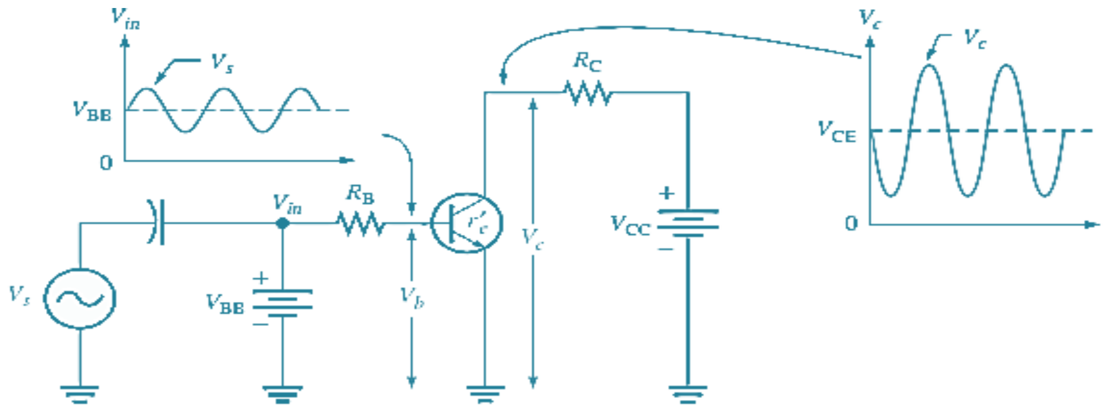


Fig.4.8: BJT as an amplifier

7. **Expression for Voltage gain** The AC base voltage is given by

$$\mathbf{V_b = I_e r'_e}$$

- The AC collector voltage, $\mathbf{V_C}$ is equal to the AC voltage drop across $\mathbf{R_C}$ and is given by

$$\mathbf{V_c = I_c R_C}$$

- Since $\mathbf{I_e \approx I_c}$, therefore the AC collector voltage is given by

$$\mathbf{V_c = I_e R_C}$$

- Since voltage gain is defined as the ratio of the output voltage to the input voltage, the ratio of $\mathbf{V_c}$ to $\mathbf{V_b}$ is the ac voltage gain A_v of the transistor.

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

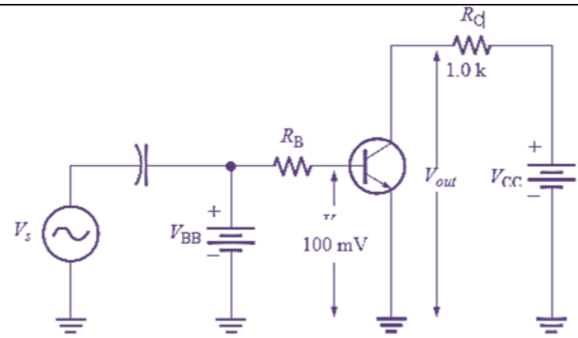
- On substituting V_c and V_b

$$A_v = \frac{I_e R_C}{I_e r'_e}$$

$$\boxed{\mathbf{A_v = \frac{R_C}{r'_e}}}$$

Links to video : BJT Amplifier : Https://Youtu.Be/Qwwj3bqnudk

Problem: Determine the voltage gain and the ac output voltage in Figure if $r_e' = 50\Omega$



Solution The voltage gain is

$$A_v = \frac{R_C}{r'_e} = \frac{1.0k}{50} = 20$$

Voltage $V_{out} = A_v * V_b = 20 * 100\ m = \mathbf{2V}$

4.3 BJT as a switch

The working of a transistor as a switching device is shown in Fig.4.9.

1. When the **transistor is in the cutoff region,** the base-emitter junction is not forward-biased - the transistor is essentially **SWITCHED OFF** as indicated by the switch equivalent.
2. When the transistor is in the **saturation region** the base emitter and the base-collector junction are forward-biased and the base current drives the collector current to reach saturation value, it is as if the transistor is **SWITCHED ON** as indicated by the switch equivalent.

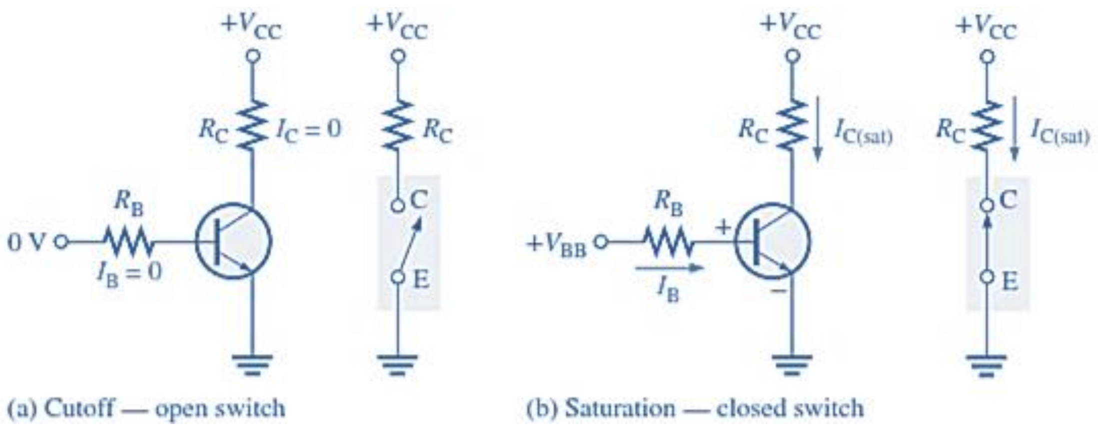


Fig.4.9: BJT as a switch

Conditions in Cutoff

- When $V_B = 0$, the base-emitter junction is not forward-biased hence transistor is in the cutoff region. As no currents flow, V_{CE} is equal to V_{CC}

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

Conditions in Saturation

- When $V_B = +V_{BB}$, the base-emitter junction is forward-biased and there is enough base current to produce a maximum collector current, the transistor is saturated and $V_{CE} = 0$

$$\mathbf{V_{CE}}|_{saturation} \approx \mathbf{0}$$

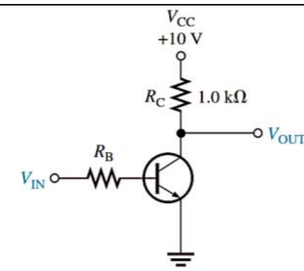
- It may also be noted that $I_C = \frac{V_{CC} - V_{CE\ sat}}{R_C} \approx \frac{V_{CC}}{R_C} =$
- The minimum value of base current needed Produce saturation is $I_B|_{min} = \frac{I_{C\,sat}}{\beta_{DC}}$

When BJT is used as an electronic switch, it is normally **operated alternately in cutoff and saturation.** Many digital circuits use the BJT as a switch.

Problem: (a) For the transistor circuit in Figure what is V_{CE} when V_{IN} = 0 V?

(b)What min value of I_B is required to saturate the transistor if β_{DC}=200, neglect $V_{CE}|_{sat}$

(c) calculate max value of R_B when V_{in} =5V



Solution (a) When V_{IN} = 0 V, the transistor is in cutoff (acts like an open switch) ∴ $V_{CE} = V_{CC} = \mathbf{10\,V}$

(b) I_B is got from I_C , - got by applying KVL to collector loop

Since $V_{CE(sat)}$ is neglected (assumed to be 0 V),

$$I_{C\,sat} = \frac{V_{CC}}{R_C} = \frac{10}{1.0k} = 10mA$$

$$I_{B\,min} = \frac{I_{Csat}}{\beta_{DC}} = \frac{10m}{200} = 50\mu A$$ This is the I_B necessary to drive the transistor to saturation.

(c) Maximum value of R_B to allow a minimum I_B of 50 µA, calculated using Ohm's law we have:

$$\boldsymbol{R_{B\,max}} = \frac{\boldsymbol{V_{RB}}}{\boldsymbol{I_{Bmin}}} = \frac{?}{\boldsymbol{50\mu A}}$$ V_{R_B}voltage across R_B is given as

$V_{R_B} = V_{in} - V_{BE}$ |When transistor is on V_{BE} 0.7V. V_{R_B} = 5 – 0.7 = 4.3 V

Substituting now to calculate R_B $\boldsymbol{R_{B\,max}} = \frac{V_{RB}}{I_{Bmin}} = \frac{4.3}{50\mu A}$=**86kΩ**

What minimum value of I_B is required to saturate this transistor if β_{DC} is 125? $V_{CE(sat)}$=0.2V for the circuit in previous problem.

Solution I_B is got from I_C , - got by applying KVL to collector loop

Since $V_{CE(sat)}$ is 0.2V,

$$I_{C\,sat} = \frac{V_{CC} - V_{CE\,sat}}{R_C} = \frac{10 - 0.2}{1.0k} = 9.8mA$$

$$I_{B\,min} = \frac{I_{Csat}}{\beta_{DC}} = \frac{9.8m}{125} = 7.84\mu A$$ This is the I_B necessary to drive the transistor to saturation.

A Simple Application of a Transistor Switch

1. The transistor shown in the Fig.4.14 is used to switch the LED ON and OFF. Consider a square wave input voltage with a period of 2s is applied to the input as indicated

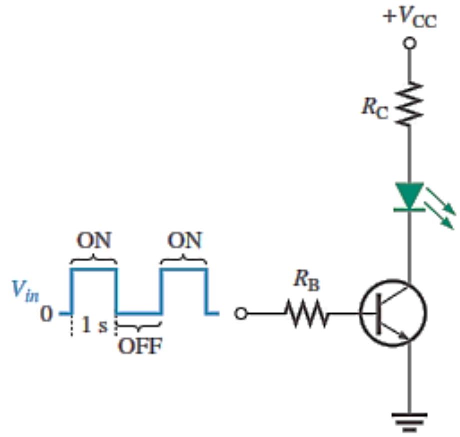


Fig.4.10: A transistor used to switch an LED on and off

2. When the square wave is at 0V, the transistor is in cut OFF; and with no collector current, the LED does NOT emit light.
3. When the **square wave goes HIGH**, the transistor saturates or is **switched ON in turn** forward-biasing the **LED** causing it to **turn ON** and emit light. Thus, the LED is **ON** for 1 second and off for 1 second.

Problems: The LED in Figure 4.10 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=220Ω, R_B = 3.3 k Ω,, β_{DC} = 50, and V_{LED} = 1.6 V

$$I_{C(sat)} = \frac{V_{CC} - V_{LED} - V_{CE(sat}}{R_C} = \frac{9-1.6-0.3}{220} = 32.3\ \text{mA}$$

$$I_{B\,min} = \frac{I_{C\,sat}}{\beta_{DC}} = \frac{32.3\ \text{m}}{50} = 0.646\ mA$$

To ensure saturation, use twice the value of $I_{B(min)}$, which is 1.29 mA. Using Ohm's law to solve for V_{in}, WKT,

$$\boldsymbol{I_B} = \frac{V_{RB}}{R_B} = \frac{V_{in}-V_{BE}}{R_B} = \frac{V_{in}-0.7}{3.3K} \implies V_{in} - 0.7\ \text{V} = 2I_{B(min)}R_B = (1.29\ \text{mA})(3.3\ \text{k}\Omega)$$

$$V_{in} = (1.29\ \text{mA})(3.3\ \text{k}\Omega) + 0.7\ \text{V} = \mathbf{4.96\ V}$$

If you change the LED in the previous problem to one that requires 50 mA for a specified light emission and you can't increase the input amplitude above 5 V or V_{CC} above 9 V, how would you modify the circuit? Specify the component(s) to be changed and the value(s).

Links to Videos: .BJT As A Switch : Https://Youtu.Be/Ilcnr83gs_U

4.4 Feedback Amplifier

A **feedback-amplifier** is defined as an amplifier which has feedback path from output to input through a modifying network, which determines the magnitude and phase.

1. A feedback amplifier generally consists of two parts. The **amplifier** and **the feedback circuit** as shown in the Fig.4.10.

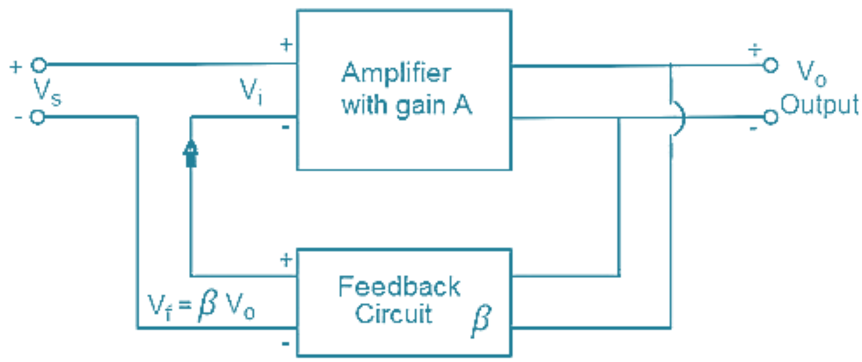


Fig.4.10: Basic block diagram of feedback amplifier (Voltage series)

2. The gain of the amplifier is usually represented as **A** – it is **the ratio of output voltage V_o to the input voltage V_i.**
3. The feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.
4. The quantity $\beta = V_f/V_o$ is called as feedback ratio or feedback fraction.
5. This voltage is added for positive feedback and subtracted for negative feedback, from the signal voltage V_s.

   $V_i = V_s + V_f = V_s + \beta V_o$ *for positive feedback* | $V_i = V_s - V_f = V_s - \beta V_o$ *Negative feedback*

Gain for Negative Feedback

6. Let us consider the case of negative feedback. The output V_o must be equal to the input voltage (V_s - βV_o) multiplied by the gain A of the amplifier. Hence,

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

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

$$AV_s = V_o(1 + A\beta), \text{ Therefore,}$$

$$\frac{V_o}{V_s} = \frac{A}{1 + A\beta}$$

7. Let $\mathbf{A_f}$ be the overall gain (gain with the feedback) of the amplifier. This is defined as the ratio of output voltage V_o to the applied signal voltage V_s, i.e.,

$$A_f = \frac{\text{Output voltage}}{\text{Input signal voltage}}$$

$$A_f = \frac{V_o}{V_s}$$

8. The gain of the feedback amplifier, with negative feedback is given by

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

9. The gain of the feedback amplifier, with positive feedback boils down to:

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

Problems

Links to Videos:

Types of Feedback Amplifier

Feedback is mainly used to reduce the noise as well as to make the amplifier more stable in operation. Based on the feedback: positive & negative feedback amplifier.

i. ***Positive Feedback Amplifier*** - feedback current or voltage is applied for increasing the input voltage, then it is called as positive feedback.

ii. ***Negative Feedback Amplifier*** - the feedback current or voltage is applied for reducing the amplifier input, then it is called as negative feedback.

Feedback Topologies

- There are four basic ways of connecting the feedback signal. Both voltage and current can be fed back to the input either in series or parallel.
- There are four different feedback topologies
  - i. Voltage-Series Feedback
  - ii. Voltage-Shunt Feedback
  - iii. Current-Series Feedback
  - iv. Current- Shunt Feedback

Voltage-Series Feedback

1. In the voltage series feedback circuit, a fraction of the output voltage is applied in series with the input voltage through the feedback circuit as shown in Fig.4.10.

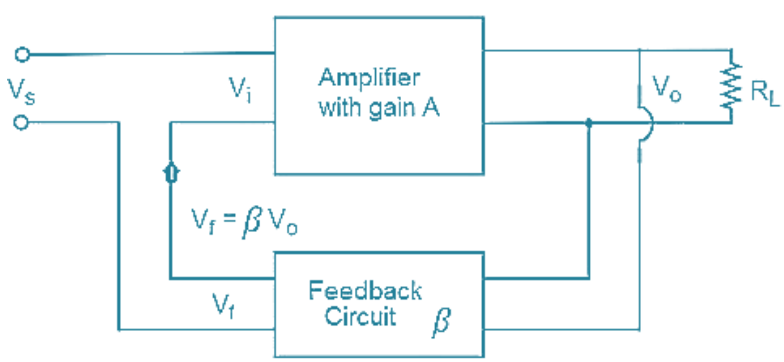


Fig.4.10: Voltage series feedback amplifier

2. As the feedback circuit is connected in shunt with the output, the output impedance is decreased and because the input is in series connection, input impedance is increased.

Properties of negative feedback Amplifiers

1. *Desensitize the gain:* brings stability to amplifier by making gain less sensitive to all kinds of variations.

2. *Reduce nonlinear distortion:* the negative feedback makes the output proportional to the input.

3. *Reduce the effect of noise:* It minimizes the contribution by unwanted electric signals.

4. *Control the input and output impedance:* It increases or decreases the input and output impedances.

5. *Extend the bandwidth of the amplifier:* By incorporating negative feedback, the bandwidth can be increased.

Advantages of negative feedback Amplifiers in detail:

Although negative feedback results in reduced gain, it has many advantages. They are,

1. **Reduction in Frequency Distortion:** In a negative feedback amplifier with feedback gain β, the overall loop gain of the amplifier is reduced by a factor (1 + βA). If we assume βA >> 1, the gain with feedback is $A_f \cong \frac{1}{\beta}$ It follows that the gain with feedback does not dependent on frequency even though the main amplifier gain is frequency dependent. Therefore, the frequency distortion arising because of varying amplifier gain with frequency is considerably reduced in a negative voltage feedback amplifier circuit.

2. **Reduction in Noise and Nonlinear Distortion:** In the whole scheme it is observed that in feedback amplifiers along with overall gain , noise signal suffers a significant reduction by the amount **(1 + βA)**
3. **Increased Bandwidth:** Seen that the negative feedback reduces the amplifier gain, as per the law that gain and bandwidth product of an amplifier should remain constant, naturally the bandwidth should increase. The reduction in gain and increase in bandwidth of feedback amplifier illustrated in Fig. If $BW= f_2- f_1$ is the bandwidth with out feedback then BW_f is the Bandwidth with feedback

$$\mathbf{BW_{f}= (f_{2f} - f_{1f})}$$

$f_{2f} = f_2(1+ \beta A)$ and $f_{1f}=f_1/(1+ \beta A)$ are upper and lower cutoff frequencies with feedback

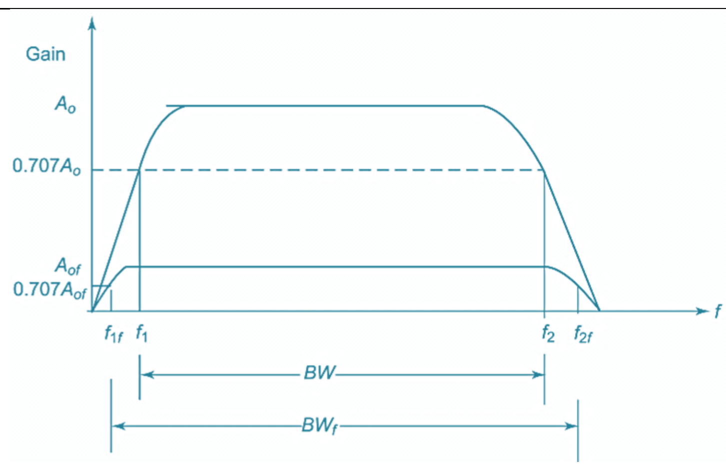


Fig 4.11 Gain Bandwidth Plot

As $f_1 << f_2$ and $f_{1f} << f_{2f}$, BW ª f_2 BW_f ª f_{2f}

Also as $A_2 * BW = A_{of} BW_f$ = constant product of gain bandwidth   the above illustration can be appreciated.

4. **Gain Stability and Sensitivity with Feedback:** gain is made more stable and sensitive by feedback with sensitivity $S = \frac{1}{1+A\beta}$ a factor much much less than 1 (very sensitive)– which is very good . Hence negative feedback brings stability to amplifier by making gain less sensitive to all kinds of variations.
5. **Higher Input Impedance:** Input impedance with feedback. $Z_{if} = Z_i(1+A\beta)$ increases,
6. **Lower Output Impedance:** Output impedance with feedback. $Z_{of} = Z_o/(1+A\beta)$ decreases.
7. **Reduction in phase distortion:** It can be mathematically proven that phase distortion reduces by feedback.
8. **Stable Operation in the linear operation** :the negative feedback makes the output proportional to the input.

Problems

1. An operational amplifier has an open-loop gain of 10^6 and open-loop upper cut-off frequency of 10Hz. If this operational amplifier is connected as an amplifier with a closed-loop gain of 100, what will be the new upper cut-off frequency?

Solution: The closed-loop gain is Here, $A = 10^6$ and $A_f = \frac{A}{1+A\beta} = 100$ implies $1 + A\beta = 10^4$

Given open-loop upper cut-off frequency f_2=10Hz.

With feedback the new upper cut-off frequency $f_{2f} = f_2(1 + A\beta)$ ➔ $f_{2f} = f_2(10^4)$=100kHz

2. Calculate the gain of a negative feedback amplifier having A=2000, if the feedback factor is 20%.

Given $A = 2000$ and $\beta = 0.2$ | We Know That : Gain with feedback $A_f = \frac{A}{1+A\beta} = \frac{2000}{1+2000(0.2)}$

hence $\mathbf{A_f} = \frac{2000}{401} = \mathbf{4.98}$

3. A two-stage amplifier uses two identical stages with a gain of 10^2. If the circuit uses a negative feedback of 0.5%. What is the gain with feedback?

Solution Given $\beta = 0.5\% = 0.005$ | stage gain = $A_1 = A_2$ =100

cascaded gain $A = A_1 \times A_2 = 100(100) = 10^4$

Gain with feedback $A_f = \frac{A}{1+A\beta} = \frac{10^4}{1+10^4\,(0.005)} = \frac{10^4}{51}$ A_f=**196.08**

4. **An amplifier without feedback has voltage gain of 2000. If the voltage gain changes by 20% due to variation in temperature, find the change in gain of the feedback amplifier. Given that β = 0.1.**

Given $A = 2000$ and $\beta = 0.1$ | Change in gain without feedback $\% \frac{dA}{A} = 20\%$

differentiating both sides of $\mathbf{A_f} = \frac{\mathbf{A}}{\mathbf{1+A\beta}}$ we get $dA_f = dA \left[\frac{1}{1+A\beta}\right]^2$

multiplying numerator and denominator by A we get $dA_f = dA \; A_f \frac{1}{1+A\beta} * \frac{1}{A}$

$$\frac{dA_f}{A_f} = \frac{1}{1+A\beta} * \frac{dA}{A} \approx \frac{dA_f}{A_f} = \frac{1}{A\beta} * \frac{dA}{A} \quad \text{as} \quad A\beta \gg 1$$

Substituting here, $\frac{dA_f}{A_f} = \frac{1}{A\beta} * \frac{dA}{A} = \frac{1}{A\beta}\left(\frac{dA}{A}\right) = \frac{1}{2000(0.1)}(0.2) = 0.000995$

$\frac{dA_f}{A_f}$ =**0.0995%**

---

5. A voltage–series feedback amplifier has A = –100, R_i = 25 kΩ, R_o=100 kΩ and feedback factor β = –0.1. (a) Determine overall gain, input impedance, and output impedance of the feedback amplifier. (b) If the gain has been reduced to –2.5, what will be the feedback factor?

Solution given A = –100, R_i = 25 kΩ, R_o=100 kΩ and β = –0.1.

$A_f = \frac{A}{1+A\beta} = \frac{400}{1+400(0.1)}$=9.756

Input impedance with feedback $Z_{if} = Z_i(1+A\beta)$ =25X $10^3(1 + (400)0.1)$ **Z_{if}=275 kΩ**

Output impedance with feedback. $Z_{of} = \frac{Z_O}{1+A\beta} = \frac{100 \; x \; 10^3}{1+(400)0.1}$ Z_{of} =909.09 **KΩ**

(b) If the gain reduced to –2.5 with feedback implies, new $A_f = A_f{}' = 2.5$

WKT $A_f{}' = \frac{A}{1+A\beta} = 2.5 = \frac{100}{1+100\beta}$ $\beta = \frac{40-1}{100}$ $A_f{}' = 0.39$

---

6. A feedback amplifier comprises two amplifying blocks in tandem; each block having a gain of 100. What should be the gain of the feedback block in order for overall gain to be 100? If the gain of each amplifier block reduces to 50% due to parameter variations, what is the percentage change in the gain of the complete feedback unit?

Solution**:** To get the percentage change in Gain with feedback after drop in gain – we need to consider **2 cases**

Case 1 consider A = 100 (given); forward gain =A∗A =A^2 = 10^4

Given A_f **=**100 ; $\mathbf{A_f|_{case\,1}} = \frac{\mathbf{A}}{\mathbf{1+A\beta}}$ implies β = 0.0099

Case 2 Now A = 50 ; forward gain =A∗A =A^2 = 2500

$\mathbf{A_f|_{case\,2}} = \frac{\mathbf{2500}}{\mathbf{1+2500(0.0099)}}$ $\mathbf{A_f|_{case\,2}}$**=97.09**

Hence **Reduction in overall gain = 100 – 97.09 = 2.91%**

---

7. An amplifier has a high frequency response described by A =A_o /(1+j(ω/ω_2)=) wherein A= 1000, ω_2 = 10^4 rad/s. Find the feedback factor which will raise the upper corner frequency ω_2 to 10^5 rad/s. What is the corresponding gain of the amplifier? Find also the gain bandwidth product in this case.

Solution: Find A_f for the new gain, Gain bandwidth product

WKT $\mathbf{A_f} = \frac{\mathbf{A}}{\mathbf{1+A\beta}}$, but given $A = \frac{A_0}{1+j\left(\frac{\omega}{\omega_2}\right)}$ so, substituting that in A_f, we get

$$A_f = \frac{\frac{A_0}{1+j\left(\frac{\omega}{\omega_2}\right)}}{1+\frac{A_0}{1+j\left(\frac{\omega}{\omega_2}\right)}\beta} = \frac{\frac{A_0}{\cancel{1+j}\left(\frac{\omega}{\omega_2}\right)}}{\frac{1+j\left(\frac{\omega}{\omega_2}\right)+A_0\beta}{\cancel{1+j}\left(\frac{\omega}{\omega_2}\right)}} = \frac{A_0}{j\left(\frac{\omega}{\omega_2}\right)+(1+A_0\beta)} = \frac{A_0}{j\left(\frac{\omega}{\omega_2}\right)+\frac{\omega_2(1+A_0\beta)}{\omega_2}}$$

Dividing numerator and denominator with $1+A_0\beta$

$$A_f = \frac{\frac{A_0}{(1+A_0\beta)}}{\frac{j\left(\frac{\omega}{\omega_2}\right)+\omega_2(1+A_0\beta)}{1+A_0\beta}}$$ {by taking $A_{new} = \frac{A_0}{1+A_0\beta}$ and $\omega_{new} = \omega_2(1+A_0\beta)$ we get

$$A_f = \frac{A_{new}}{j\left(\frac{\omega}{\omega_2}\right)\frac{1}{1+A_0\beta}+\omega_{new}} = \frac{A_{new}}{\omega_{new}+j\frac{\omega}{\omega_{new}}}$$

$$\boxed{A_f = \frac{A_{new}}{\omega_{new}+j\frac{\omega}{\omega_{new}}}}$$

Substituting Values In $\omega_{new} = \omega_2(1+A_0\beta)$ we have $10^5 = 10^4(1+1000(\beta))$

Hence $\beta = \frac{9}{1000} = 0.009$ substituting in $A_{new} = \frac{A_0}{1+A_0\beta} = \frac{1000}{1+1000\left(\frac{9}{1000}\right)}$ hence $A_{new} = 100$

Now to get the gain bandwidth product

$$A_{new}\omega_{new} = 100 * \omega_2(1+A_0\beta) = 100\left(10^4(1+1000(0.009))\right) = 10^7$$

As a cross check this value should remain constant for an amplifier hence $A_0\omega_2$=1000(10^4)= 10^7

Gain bandwith product for the given amplifier =10^7 $A_{new}\omega_{new} = A_0\omega_2$

Links to Videos:

Feedback Amplifiers: Properties, Advantages of Negative Feedback: https://youtu.be/d8DMggA81o8

Types of feedback, Voltage series feedback, Gain stability with feedback: https://youtu.be/TVdyG9M2bDs

4.5 IC 555 Timer

- An IC 555 timer is a monolithic timing circuit, capable of generating a precise and extremely stable time delays. It is available as an 8-pin DIP (dual-in-package) as shown in the Fig.4.12.
- It can be operated under three operating modes:

i. **Monostable mode:** the timer generates only single pulse when the timer gets an indication from i/p of the trigger button.

ii. **Astable mode:** the timer produces the continuous pulses with exact frequency based on the value of the two resistors and capacitors.

iii. **Bistable mode:** the timer produces 2-stable state signals which are low and states. The o/p signals of low and high state signals are controlled by reset & activate the i/p pins, not by the charging & discharging of capacitors.

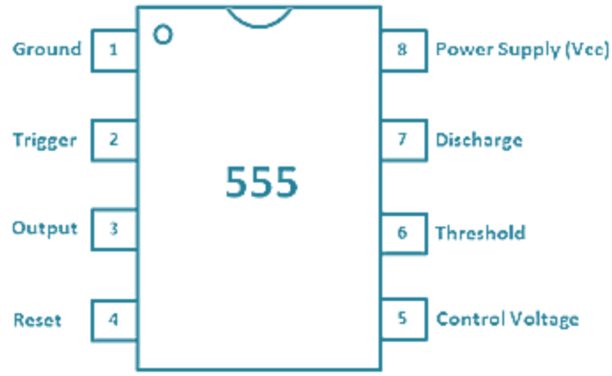


Fig.4.12: Pin diagram of IC 555 Timer

1. Fig.4.13 shows the block diagram of IC 555 timer. It consists of 2 comparators, a flip-flop, a voltage divider, a discharge transistor and an output stage.
2. The **voltage divider** consists of three identical 5k resistors which create two reference voltages at 1/3 and 2/3 of the supplied voltage, which can range from 4.5 to 15V.
3. A **comparator** compares the input voltages at its positive (non-inverting) and negative (inverting) input terminal and outputs a zero or a one.
4. If the comparator input at positive terminal is higher than that at the negative terminal the output will be 1.
5. If the comparator input at negative terminal is higher than that at the positive terminal, the output will be 0.

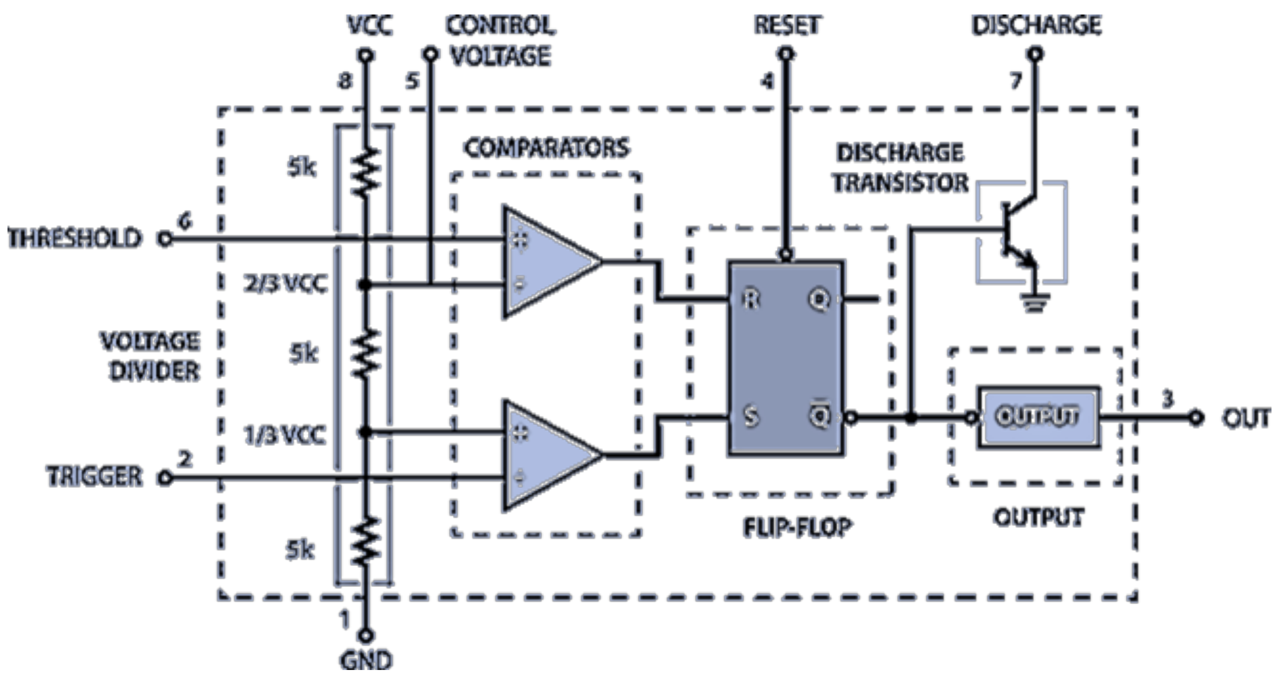


Fig.4.13: Block diagram of IC 555 timer

6. Using the three pins, Trigger, Threshold and Control, the output of the two comparators can be controlled and they are fed to the R and S inputs of the flip-flop.
    - Additionally the flip-flop can be reset via the external pin called "RESET" which can override the two inputs, thus reset the entire timer at any time.

- The Q-bar output of the flip-flip goes to the output stage.
- The output of the flip-flip is also connected to a transistor that connects the "Discharge" pin to ground.

4.5.1 555 Timer – Astable Mode

In astable mode the 555 Timer IC becomes an oscillator or also called Free Running Multivibrator. It doesn't have a stable state and continuously switches between High and Low without application of any external trigger.

1. Astable mode requires two resistors and a capacitor. Initially, the voltage source will start charging the capacitor through the Resistors R1 and R2.
2. While charging the trigger comparator output will be 1 - the input voltage at the trigger pin is still lower than 1/3 of the supplied voltage. Output of the 555 Timer is High.

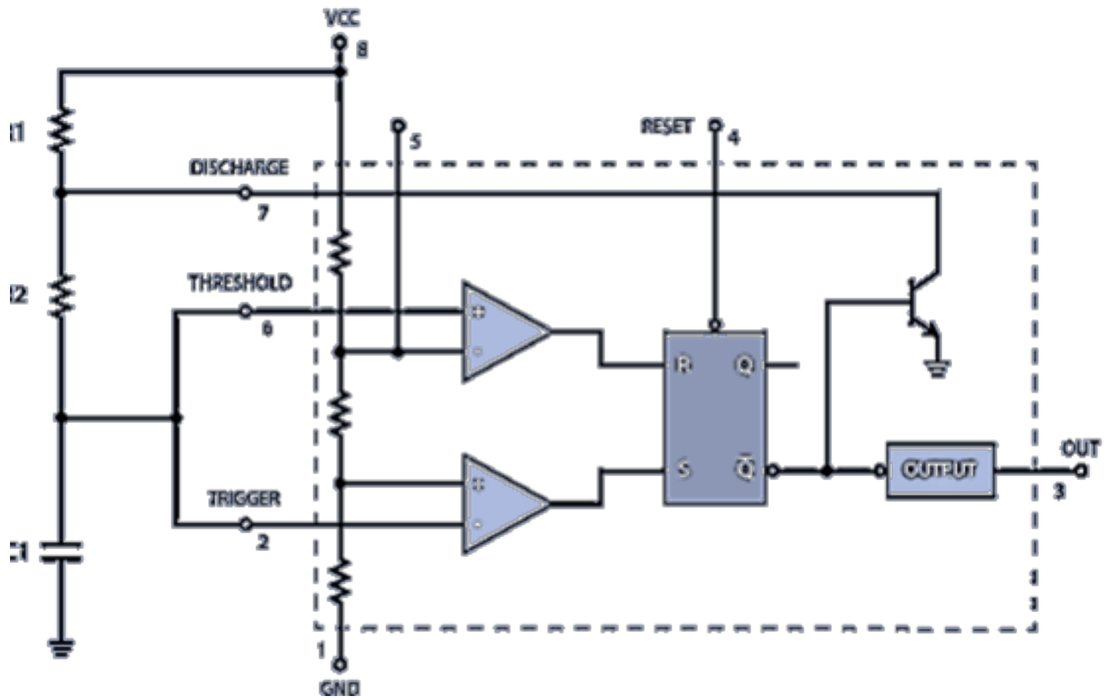


Fig.4.14: IC 555 Astable Mode

3. Once the voltage across the capacitor reaches 1/3 of the supplied voltage, the Trigger comparator will output 0 but it won't do any change as both R and S inputs of the flip-flop are 0.
4. The capacitor voltage rises, and once it reaches 2/3 V_{CC}, the threshold comparator will output 1 to the R input of the flip-flop. This will activate the discharging transistor and now the capacitor will start discharging through the resistor R2 and the discharging transistor. At this moment the output of the 555 Timer is Low.
5. While discharging, capacitor voltage starts to decrease, and drops to 1/3 V_{CC}, the Trigger comparator will output 1. This will turn off the discharge transistor and the capacitor will start to charge again. So this processes of charging and discharging between 2/3 and 1/3 of

the supplied voltage will keep running on its own, thus producing a square wave on the 555 Timer output.

6. The HIGH and LOW times are added to get the Period of one cycle. The frequency is how many times this happens in one second, so one over the Period will give the frequency of the square wave output.
   - HIGH time $T_H = 0.693 * (R_1 + R_2)C_1$
   - LOW time $T_L = 0.693 * R_2C_1$

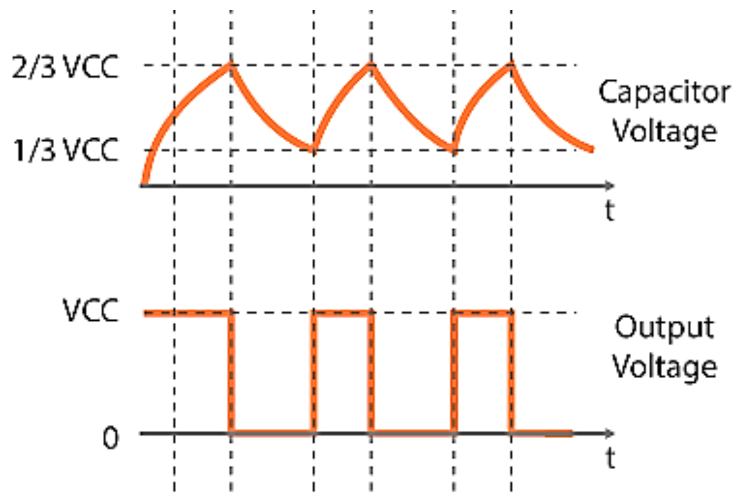


Fig.4.15: Output voltage of IC 555 timer in Astable Mode

Links to Videos: *https://youtu.be/i0SNb__dkYI* *https://youtu.be/iJYm_BGqa1A*

4.6 Oscillator

An **oscillator** is a circuit that produces a periodic waveform with only DC supply voltage as an input. The output voltage can be either sinusoidal or not, depending on the type of oscillator. Given in Fig.4.16a. is an amplifier with a voltage gain 'A' and a **positive feedback** network with feedback gain of β. A sinusoidal input signal V_S is applied as an input while the output signal is V_O. The feedback network feeds part of V_O to the input by an amount β. i.e. $V_f = \beta V_O$ | ($V_O = AV_{in}$) | Vin = Vf Feedback network may be called as a tank circuit that generates a regenerative feedback and may consist of elements that are not purely resistive as discussed below. There are mainly 3 types of feedback that give rise to oscillations.

Barkhausen Criterion or Conditions for Oscillation

1. **The loop gain must be unity or greater in absolute magnitude**

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

2. **The phase shift around the loop is zero or an integer multiple of 2π.**

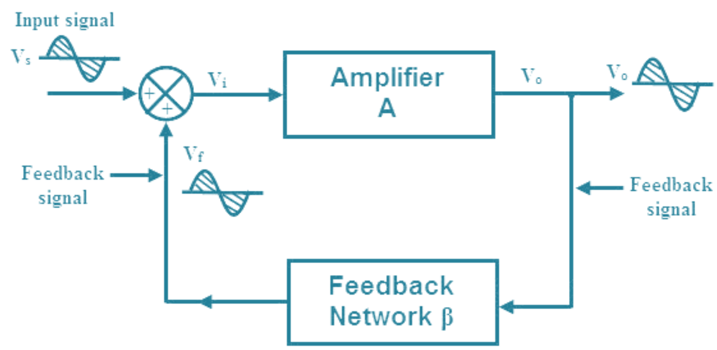


Fig.4.16a: General block diagram of oscillator

1. **| βA| > 1:** **Feedback is greater than the input** voltage . Addition of input and feedback results in larger amplitude and as oscillation goes on the amplitude will **increase cumulatively – leading to an astable behavior** that can be harmful for device.

2. **| βA| < 1:** **Feedback is less than the input** voltage Addition of input and feedback here results in smaller amplitude wave and as oscillation goes on the **amplitude will gradually die out, called damped oscillations.**

3. **| βA|=1,** **Feedback equal to the input** voltage Addition of input wave and feedback wave results in the wave amplitude being equal to that of input and as oscillation goes on the **amplitude continues to remain constant and achieving sustained oscillation**.

4. The phase shift around the loop is zero or an integer multiple of

$$2\pi \ \angle\beta A = 2\pi n \quad n \in 0,1,2,\ldots$$

Complex value of βA is given by βA=1+j0 In above expression imaginary part is zero as it is assumed that the phase shift zero or 360º, if phase shift isn't zero then |βA|≠1 , which is not suitable condition for oscillation. For phase shift equal to 180º | βA|=1 but input and feedback signal will be out of phase and they will cancel each other hence **phase shift must be an integer multiple of 2π**

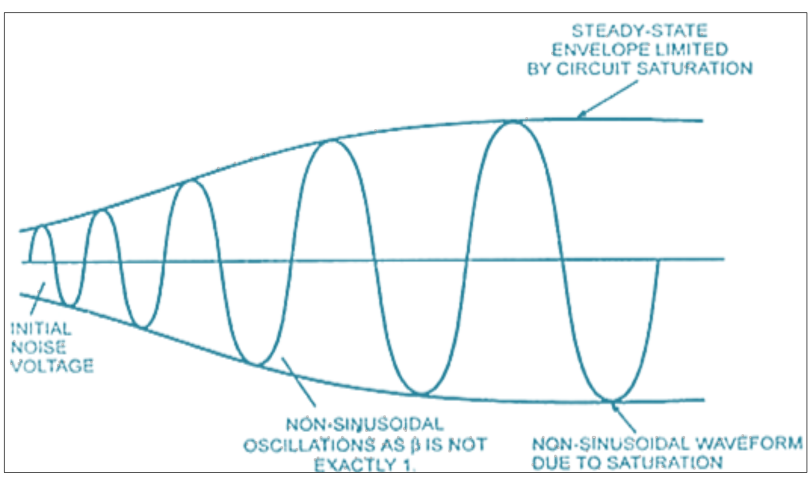


Fig.4.16b: Build up of sustained oscillations in steady state

Links to Videos: How Oscillator Works : https://www.youtube.com/watch?v=XVS8Puf4tiw

RC phase shift Oscillator Circuit

1. RC phase shift oscillator shown consists of an inverting amplifier followed by a feedback network with phase shift of 180 degree.

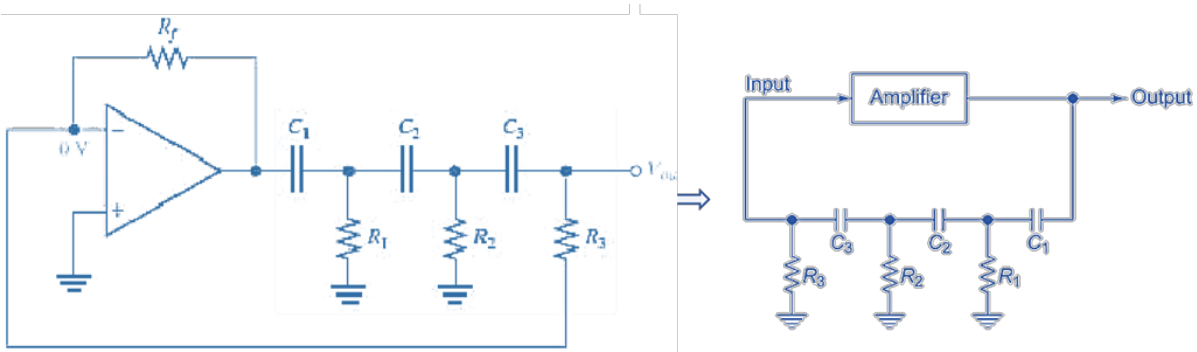


Fig.4.17: RC phase shift oscillator

2. The 180 degree phase shift at the feedback can be obtained by
   - **combination of resistors and capacitors using regenerative feedback** by the ability of the capacitor to store an electric charge The R and C of the phase shift network are designed to produce a phase shift of 180 degree at the desired frequency of oscillation. &
   - the **inverting amplifier** itself produces a phase shift of 180 degree.
3. The RC phase shift oscillator produces a sine wave output signal the generalized equation for the frequency of oscillation produced by a RC phase shift oscillator is given by

$$f_o = \frac{1}{2\pi RC\sqrt{6}}; \ \omega_o = \frac{1}{RC\sqrt{6}}$$

where:

Ƒo, ω_o Output Frequency in Hertz and rad/s	C - Capacitance in Farads
R - Resistance in Ohms	6=2N is the number of RC stages. Here N=3

Point to note: As per the circuit of RC phase shift oscillator we get the feedback factor at ω_0 as

$$\beta_{\omega_0} = \frac{1}{29}$$

For sustained oscillations WKT $\mathbf{A\beta \geq 1}$ substituting for A if we have an inverting amplifier

$$A = -\frac{R_F}{R} \ \text{we get,}$$

$$\text{Hence } A\beta = \left(\frac{\boldsymbol{R_F}}{\boldsymbol{R}}\right)\frac{1}{29} > 1$$

$$\boxed{\boldsymbol{R_F} > 29R}$$

links to Videos:
How Oscillators Work - Working Principle: https://www.youtube.com/watch?v=XVS8Puf4tiw
RC Phase Shift Oscillator (using Op-Amp) :https://youtu.be/Gvb4GIV5ig8

Wien Bridge Oscillator

A Wien bridge oscillator produces sine waves using RC network as the frequency determining portion of the circuit.

1. The output of the amplifier is applied between the terminals 1 and 3 while the input to the amplifier stage is supplied from terminals 2 and 4, hence the amplifier output becomes input voltage of the bridge while the output of the bridge becomes the input voltage of the amplifier.
2. The Wien-Bridge network comprises of four arms connected in a bridge fashion. Two arms are purely resistive while the other two arms are a combination of resistors and capacitors. In one arm it has **resistor and capacitor connected in series (R_1 and C_1)** while the other has **resistor and capacitor connected in parallel (R_2 and C_2).**
3. The operational amplifier is used in an **inverting** configuration and feedback form a voltage divider network. The resistances R_1 and R_3 forms the part of the feedback path.

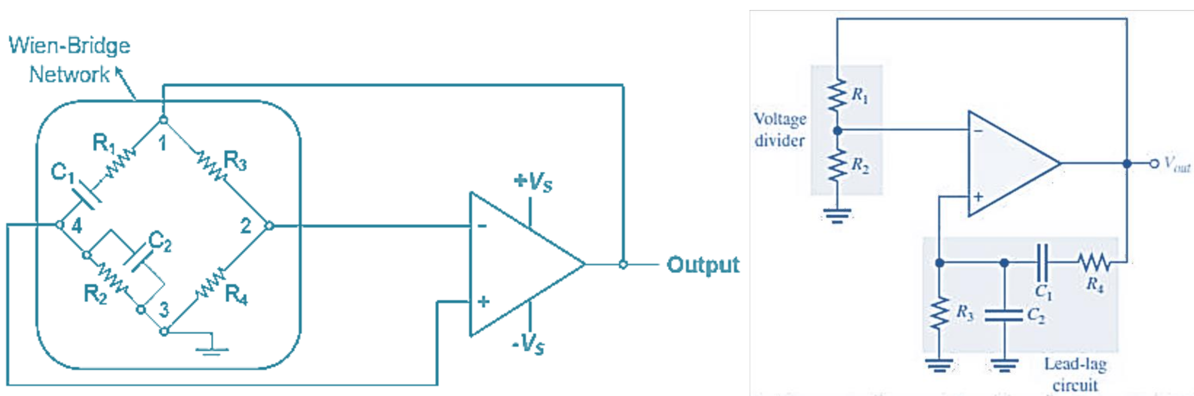


Fig.4.18: Wien-Bridge oscillator (both are the same circuit)

4. The feedback network elements are chosen such that the phase shift of the signal input to the amplifier is zero at a given frequency. Since the amplifier is non-inverting which introduce zero phase shift plus the feedback network zero phase shift, the total phase shift becomes zero around the loop hence the required condition of oscillations.

The Wien bridge oscillator works as a sine wave generator whose frequency of oscillations is determined by R and C components and given by

$$f_r = \frac{1}{2\pi RC}$$

where: f_r - Output Frequency in Hertz | R - Resistance in Ohms | C - Capacitance in Farads

Links to Videos: Wien Bridge Oscillator Explained : https://www.youtube.com/watch?v=gbUXbaxvX94

QUESTION BANK

BJT Applications

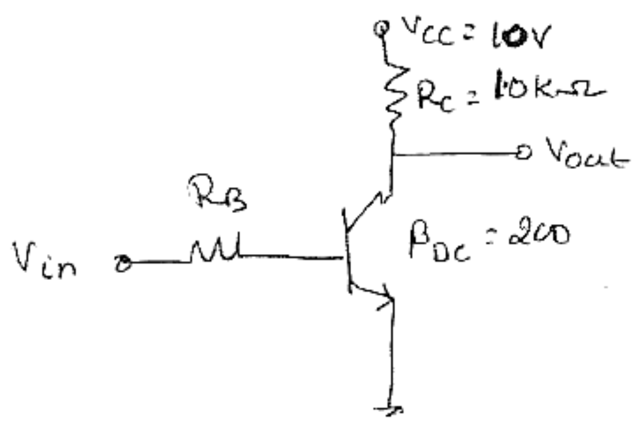
1. Derive an expression for α and β of BJT.
2. Explain the operation of BJT as an amplifier and as a switch.
3. What is a feedback amplifier? Briefly explain different feedback topologie of feedback amplifiers.
4. Calculate I_C and I_E for a transistor that has $\alpha = 0.98$ and $I_B = 100\mu A$. determine the value of β for the transistor.
5. What is an amplifier? Explain the operation of transistor amplifier circuit. **(MQP'18 – 8M)**
6. With neat circuit diagram, explain how transistor is used as a voltage amplifier. Derive an equation for A_v. **(Jun '19 – 6M, Dec '18 – 8M)**

7. Briefly explain how a transistor is used as an electronic switch. **(MQP'18 – 6M)**

8. Explain the operation of BJT (transistor) as an amplifier and as a switch. **(MQP'18 – 10M)**

9. With a neat circuit diagram, explain how transistor can be used to switch an LED ON/OFF and give the necessary equations. **(Dec'18 – 8M)**

10. Determine the value of the collector resistor in an npn transistor amplifier with $\beta_{dc} = 250$, $V_{BB} = 25$ V, $V_{CC} = 9$ V, $V_{CE} = 4$ V and $R_B = 100$ kΩ.
11. In a transistor amplifier circuit, determine the voltage gain and the ac output voltage if $V_b = 100$ mV, $R_C = 1$ kΩ and $r'_e = 50$ Ω.
12. The transistor in common emitter configuration is shown in figure, with $R_C = 10$ kΩ and $\beta_{dc} = 200$. Determine V_{CE} at $V_{in} = 0$ (ii) $I_{B(min)}$ to saturate the collector current (iii) $R_{B(max)}$ when $V_{in} = 5$ V. $V_{CE(sat)}$ can be neglected. **(Dec'18 – 4M)**



Feedback Amplifiers

8. Define feedback amplifier? With necessary diagram and equation explain the different types of feedback?

9. What is feedback amplifier? What are the properties of negative feedback amplifier? *(Jun'19 – 6M)*

10. What is a feedback amplifier? Briefly explain different types of feedback amplifiers. *(MQP'18 – 6M)*

11. Define feedback amplifier. With necessary diagram and equation explain the different types of feedback. ***(MQP'18 – 12M)***

12. List the advantages of negative feedback in an amplifier. Explain the voltage series feedback amplifier. Show that the gain bandwidth product for a feedback amplifier is constant. *(MQP '18 – 10M)*

13. Draw and explain the operation of a voltage series feedback amplifier circuit and derive an expression for its voltage gain A_v with feedback. *(Jun '19 – 6M, Dec '18 – 4M, MQP '18 – 6M)*
14. With necessary equations, explain how gain is stabilized by using feedback. An amplifier has a high frequency response described by $A = A_o / (1+j\omega/\omega^2)=)$ wherein A= 1000, 0

ω2 = 104 rad/s. Find the feedback factor which will raise the upper corner frequency ω2 to 105 rad/s. What is the corresponding gain of the amplifier? Find also the gain bandwidth product in this case.(MQP '18 – 4M)

555 TIMER

1. Explain the internal structure of 555 timer
2. Explain the working of an Astable oscillator constructed using IC- 555 timer.
3. Write a note on IC 555 timer.
4. Explain the operation of IC-555 timer as an astable oscillator with neat circuit diagram and necessary equations. (Jun '19 – 8M, Dec '18 – 8M, MQP '18 – 8M)

Oscillators

1. Explain the Barkhausens' criteria for oscillations.
2. Explain the operation of an RC phase shift oscillator.
3. Define an oscillator? Derive the equation for Wien bridge oscillator.
4. Explain the Barkhausens' criteria for oscillations. (MQP '18 – 6M)
5. What is an oscillator? Write a note on classification of oscillators.
6. Explain RC phase shift oscillator with circuit diagram and necessary equations. (Dec '18 – 8M)
7. With a neat circuit diagram, explain the operation of an RC phase shift oscillator.(MQP '18 – 6M)
8. With a neat circuit diagram, explain the working of Wien bridge oscillator. (Jun '19 – 8M)
9. Define an oscillator. Derive the equation for Wien bridge oscillator. (MQP '18 – 8M)
10. Design a RC phase shift oscillator for a frequency of 1 kHz. Draw the circuit diagram with designed values. (Jun '19 – 6M)
11. The frequency sensitivity arms of the Wein bridge oscillator uses C1 = C2 = 0.01 μF and R1 = 10 kΩ while R2 is kept variable. The frequency is to be varied from 10 kHz to 50 kHz by varying R2. Find the minimum and maximum values of R2. (MQP '18 – 4M)