Sri Chandrasekharendra Saraswathi Viswa Maha Vidyalaya

Department of Electronics and Communication Engineering

Course Material Preparation – Dr.R. Jayalakshmi

Proposed Subject Name: **Analog Electronics**

YEAR: II Department: ECE SEMESTER: IV

Pre-requisite: Basic Knowledge of Electronic Devices

Course Objectives:

- To develop fundamental knowledge about need for biasing & it's various methods.
- To analyze small signal equivalents circuits & high frequency analysis of BJT & FET.
- To analyze methods of constructing feedback amplifiers, oscillators & tuned amplifiers.
- To understand basic concepts of operational amplifier and its various applications.
- To know about various analog switches and different A/D and D/A convertors.

Unit I: Amplifier Models: Diode Circuits, Voltage amplifier, current amplifier, trans-conductance amplifier and trans-resistance amplifier. Biasing schemes for BJT and FET amplifiers, bias stability, various configurations (such as CE/CS, CB/CG, CC/CD) and their features, small signal analysis, low frequency transistor models, estimation of voltage gain, input resistance, output resistance etc., Design procedure for particular specifications, Low frequency analysis of multistage amplifiers.

Unit II: Power & Feedback Amplifiers: High frequency transistor models, frequency response of single stage and multistage amplifiers, Cascode amplifier. Various classes of operation (Class A, B, AB, C etc.), their power efficiency and linearity issues - Feedback topologies: Voltage series, current series, voltage shunt, current shunt, effect of feedback on gain, bandwidth etc. calculation with practical circuits, concept of stability, gain margin and phase margin.

Unit III: Oscillators & Differential Amplifiers: Review of the Basic Concept, Barkhausen criterion, RC oscillators (Phase shift, Wien Bridge etc), LC oscillators (Hartley, Colpitts, Clapp etc), Non sinusoidal oscillators. Current mirror: Basic topology and its variants, V-I characteristics, output resistance and minimum sustainable voltage (VON), maximum usable load. Differential amplifier: Basic structure and principle of operation, calculation of differential gain, common mode gain, CMRR and ICMR. OP-AMP design: Design of differential amplifier for a given specification, design of gain stages and output stages, compensation.

Unit IV: OP-AMP Applications: Review of Inverting and non-inverting amplifiers, integrator and differentiator, summing amplifier, precision rectifier, Schmitt trigger and its applications-Active filters: Low pass, high pass, band pass and band stop, design guidelines.

Unit V: DAC & ADC: Digital-to-analog converters (DAC): Weighted resistor, R-2R ladder, Resistor string etc. Analog to- digital converters (ADC): Single slope, Dual slope, Successive approximation, Flash etc - Switched capacitor circuits: Basic concept, practical configurations, application in amplifier, integrator, ADC etc.

Text Books & Reference Books:

1. J.V. Wait, L.P. Huelsman & GA Korn, “Introduction to Operational Amplifier theory and applications”, McGraw Hill, 1992

2. J. Millman and A. Grabel, “Microelectronics”, 2nd edition, McGraw Hill, 1988.

3. P. Horowitz and W. Hill, “The Art of Electronics”, 2nd edition, Cambridge University Press, 1989.

4. A.S. Sedra and K.C. Smith, “Microelectronic Circuits”, Oxford University Press, V Edition, 2004.

5. Paul R. Gray and Robert G. Meyer, “Analysis and Design of Analog Integrated Circuits”, John Wiley, 3rd Edition, 1992.

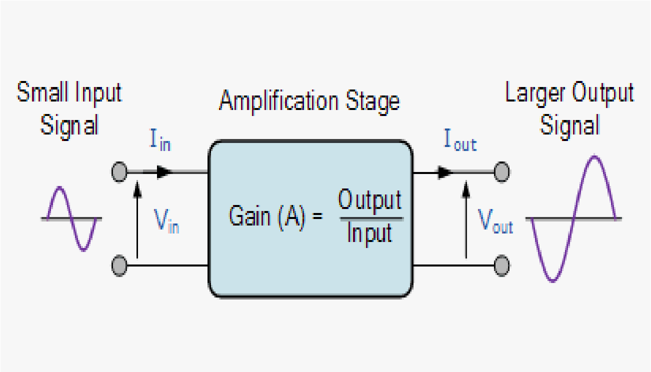
Course Outcomes:

At the end of this course students will be able to -

- Determine the configuration and apply the characteristics of diodes and transistors.
- Design and analyze various Rectifier and Amplifier circuits.
- Design sinusoidal and non-sinusoidal oscillators
- Characterize the functioning of OP-AMP and design OP-AMP based circuits
- Design ADC and DAC circuits.

Unit I: Amplifier Models

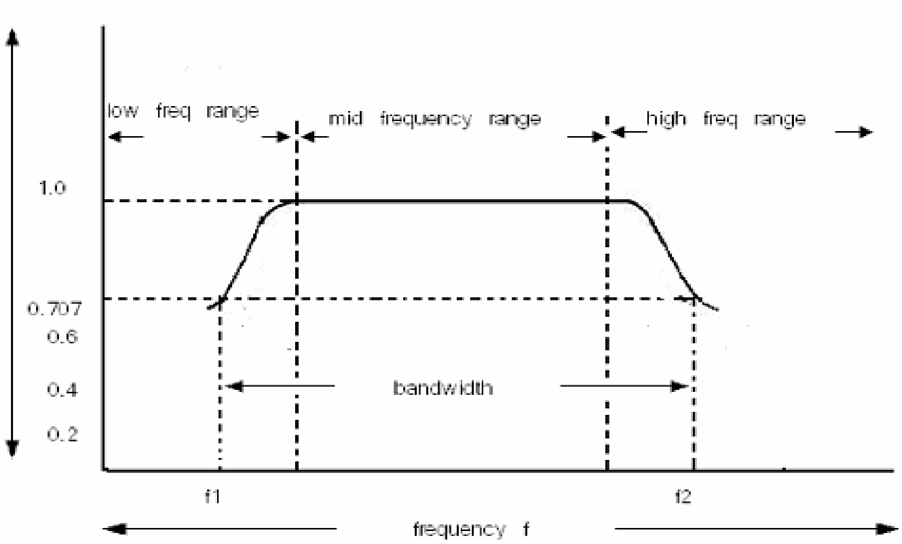
- Small signal and Large Signal
- Small signal means that you're operating the device at a limited range of voltage or current where the characteristic curve is linear.
- The idea behind small signal analysis is to model the behaviour of the device using linear equations.
- The small signal model accounts for the behavior which is linear around an operating point.
- When the signal is large in amplitude, the behavior becomes non-linear and we have to use the model which accounts for non-linearity, and thus called large signal model.
- Amplifier: An **amplifier**, **electronic amplifier** or (informally) **amp** is an electronic device that can increase the power of a signal (a time-varying voltage or current).
- It is a two-port electronic circuit that uses electric power from a power supply to increase the amplitude of a signal applied to its input terminals, producing a proportionally greater amplitude signal at its output.
- The amount of amplification provided by an amplifier is measured by its gain: the ratio of output voltage, current, or power to input.
- Small signal Amplifier
- The **Small Signal Amplifier** is generally referred to as a “Voltage” **amplifier** because they usually convert a **small** input voltage into a much larger output voltage.
- Small signal response is analyzed using the h-parameter model.
- Response of an amplifier depends on frequency considerations.



Small Signal Analysis of Amplifiers

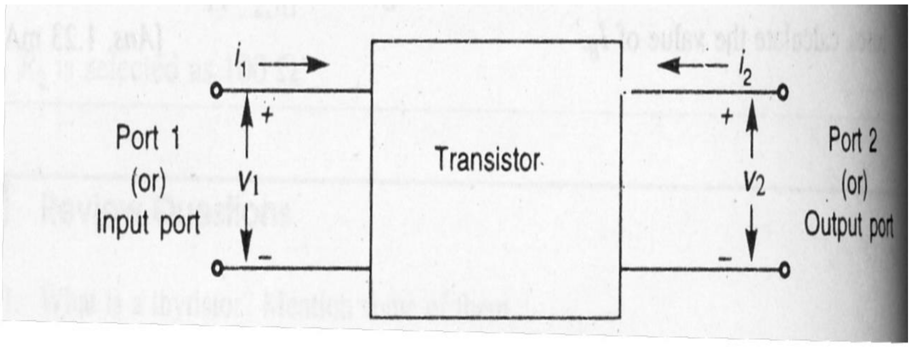
- Frequency response curves of RC Coupled amplifier is shown.
- There are 3 regions of frequency: low, mid and high
- The difference between high and low frequency is the bandwidth.

RC Coupled Amplifier



- **Hybrid h-Parameter model for an amplifier**
- The equivalent circuit of a transistor can be drawn using simple approximation by retaining its essential features.

- These equivalent circuits will aid in analyzing transistor circuits easily and rapidly.
- A transistor can be treated as a two-port network.
- The terminal behavior of any two-port network can be specified by the terminal voltages V_1 & V_2 at ports 1 & 2 respectively and current i_1 and i_2, entering ports 1 & 2, respectively, as shown in figure.



Hybrid Parameters or h-parameters

If the input current i_1 and output Voltage V_2 are takes as independent variables,

Then input voltage V_1 and output current i_2 can be written as:

$$V_1 = h_{11}\, i_1 + h_{12}\, V_2$$

$$i_2 = h_{21}\, i_1 + h_{22}\, V_2$$

The four hybrid parameters : h_{11}, h_{12}, h_{21} and h_{22} are defined as follows.

- $h_{11} = [V_1 / i_1]$ with $V_2 = 0$, : Input Resistance with output port short circuited.

- $h_{12} = [V_1 / V_2]$ with $i_1 = 0$, : reverse voltage transfer ratio with i/p port open circuited.

- $h_{21} = [i_2 / i_1]$ with $V_2 = 0$, : Forward current gain with output part short circuited.
- $h_{22} = [i_2 / V_2]$ with $i_1 = 0$, : Output admittance with input part open circuited.
- <u>The dimensions of h – parameters are as follows</u>:

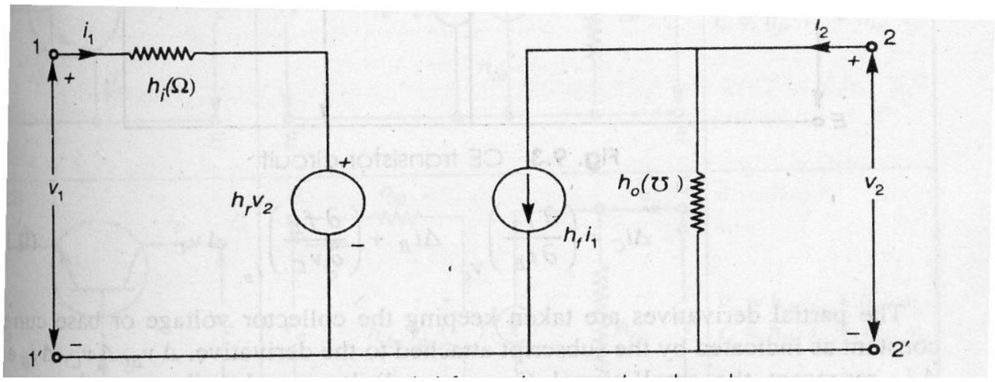
  h_{11} - Ω

  h_{12} – dimension less.

  h_{21} – dimension less.

  h_{22} – mhos

- as the dimensions are not alike, (i.e) they are hybrid in nature, and these parameters are called as hybrid parameters.



$$\begin{bmatrix} V_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} h_i & h_r \\ h_f & h_o \end{bmatrix} \begin{bmatrix} I_1 \\ V_2 \end{bmatrix}$$

Advantages of Transistor Hybrid Model

Use of h – parameters to describe a transistor have the following advantages:

- h – parameters are real numbers up to radio frequencies.

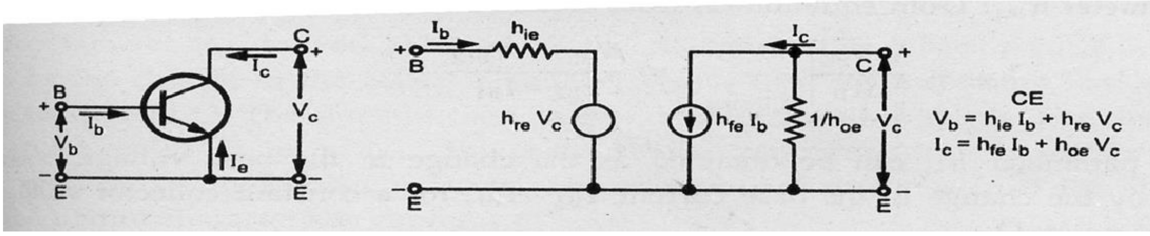
- They are easy to measure
- They can be determined from the transistor static characteristics curves.
- They are convenient to use in circuit analysis and design.
- Easily convert able from one configuration to other.
- Readily supplied by manufactories.

Transistor Hybrid Model CE Configuration

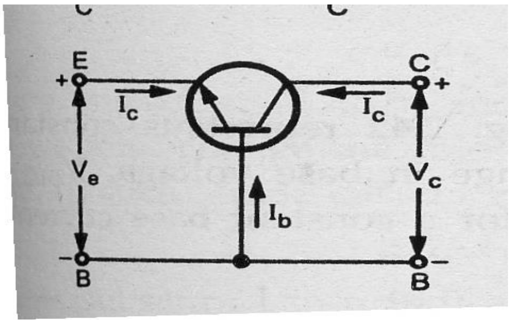
- In common emitter transistor configuration, the input signal is applied between the base and emitter terminals of the transistor and output appears between the collector and emitter terminals.
- The input voltage (V_{be}) and the output current (i_c) are given by the following equations:

$$V_{be} = h_{ie}.i_b + h_{re}.V_c$$

$$i_c = h_{fe}.i_b + h_{oe}.V_c$$



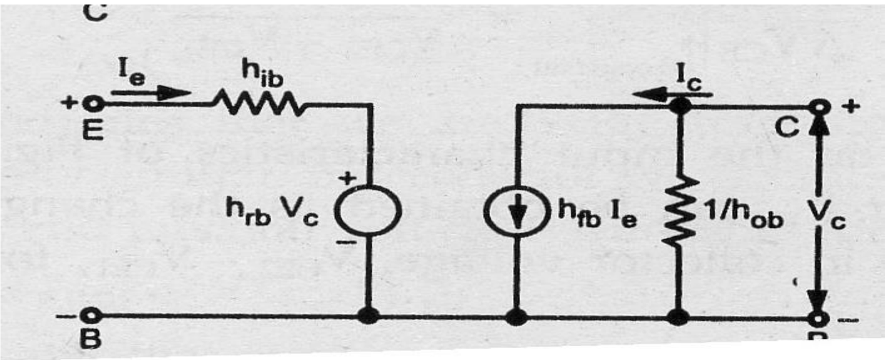
Transistor Hybrid Model CB Configuration



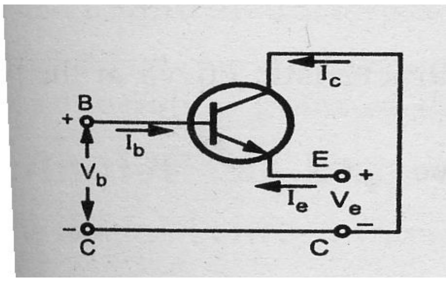
CB

$V_e = h_{ib} I_e + h_{rb} V_c$

$I_c = h_{fb} I_e + h_{ob} V_c$



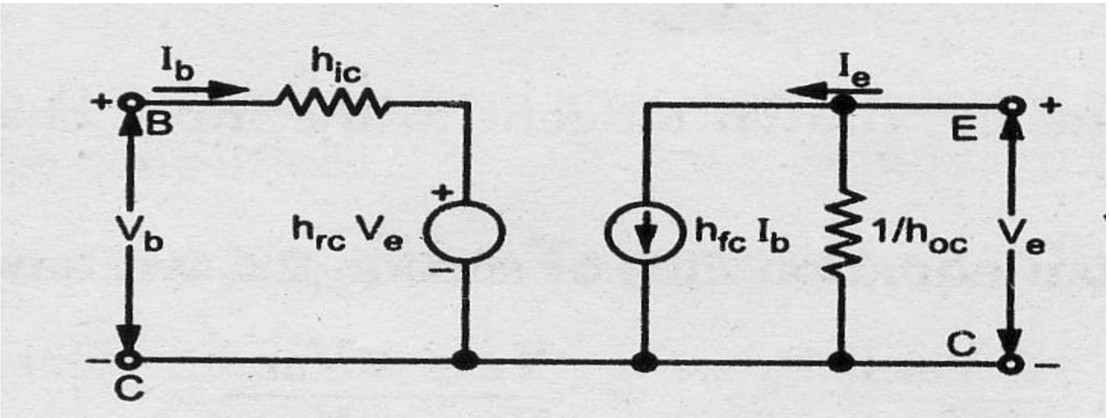
Transistor Hybrid Model CC Configuration



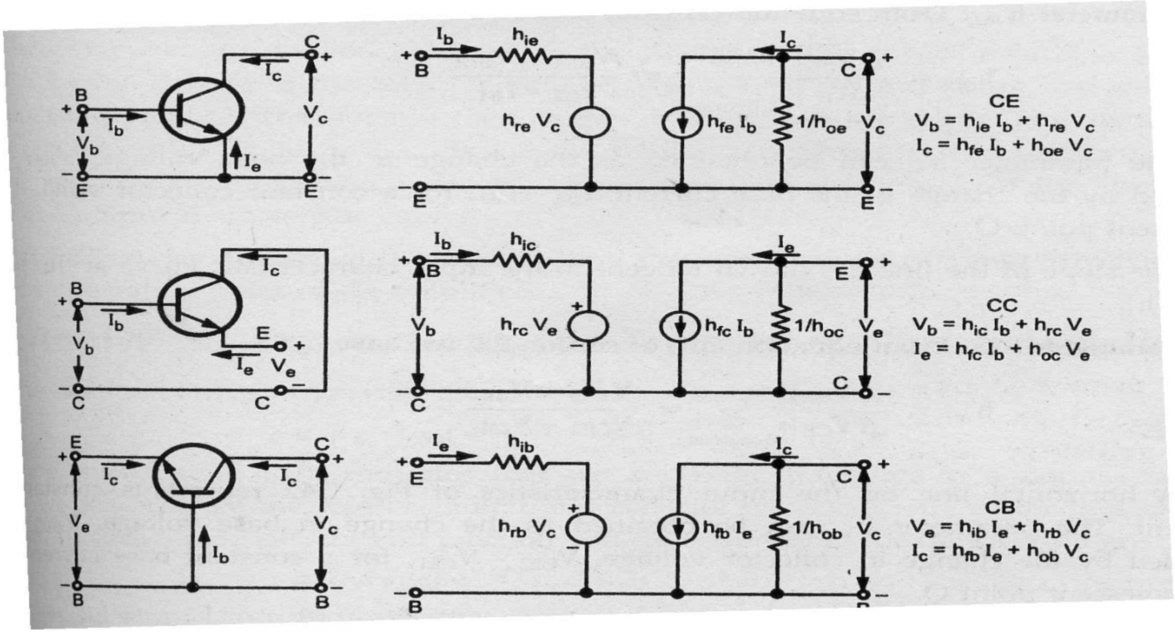
CC

$V_b = h_{ic} I_b + h_{rc} V_e$

$I_e = h_{fc} I_b + h_{oc} V_e$



Hybrid Model and Equations for the transistor in three different configurations are are given below.



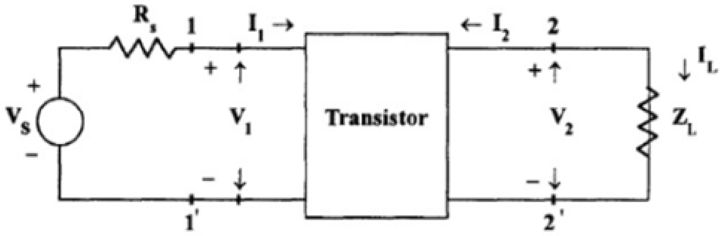
Analysis using h – Parameter Model

- Analysis of Transistor Amplifier using Complete h-Parameter Model
- Analysis of Transistor Amplifier using simplified h-Parameter Model

Parameter	Meaning	Condition	Transistor Configuration		
			CE	CB	CC
$h_{11}(h_i)$	Input Resistance	Output short	h_{ie}	h_{ib}	h_{ic}
$h_{12}(h_r)$	Reverse voltage gain	Input open	h_{re}	h_{rb}	h_{rc}
$h_{21}(h_f)$	Forward Current gain	Output short	h_{fe}	h_{fb}	h_{fc}
$h_{22}(h_o)$	Output Conductance	Input open	h_{oe}	h_{ob}	h_{oc}

Analysis of a Transistor amplifier circuit using h-parameters

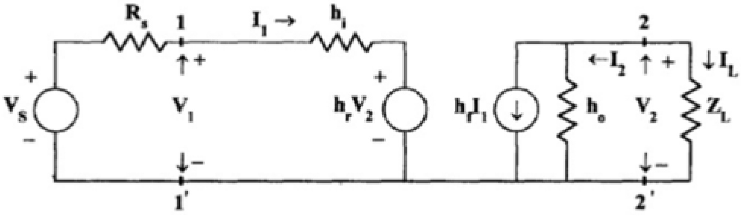
A transistor amplifier can be constructed by connecting an external load and signal source and biasing the transistor properly.



Basic Amplifier Circuit

The two port network represents a transistor in any one of its configuration. It is assumed that h-parameters remain constant over the operating range.The input is sinusoidal and I_1,V_1,I_2 and V_2 are phase quantities.

Analysis of Transistor Amplifier using Complete h-Parameter Model



Transistor replaced by its Hybrid Model

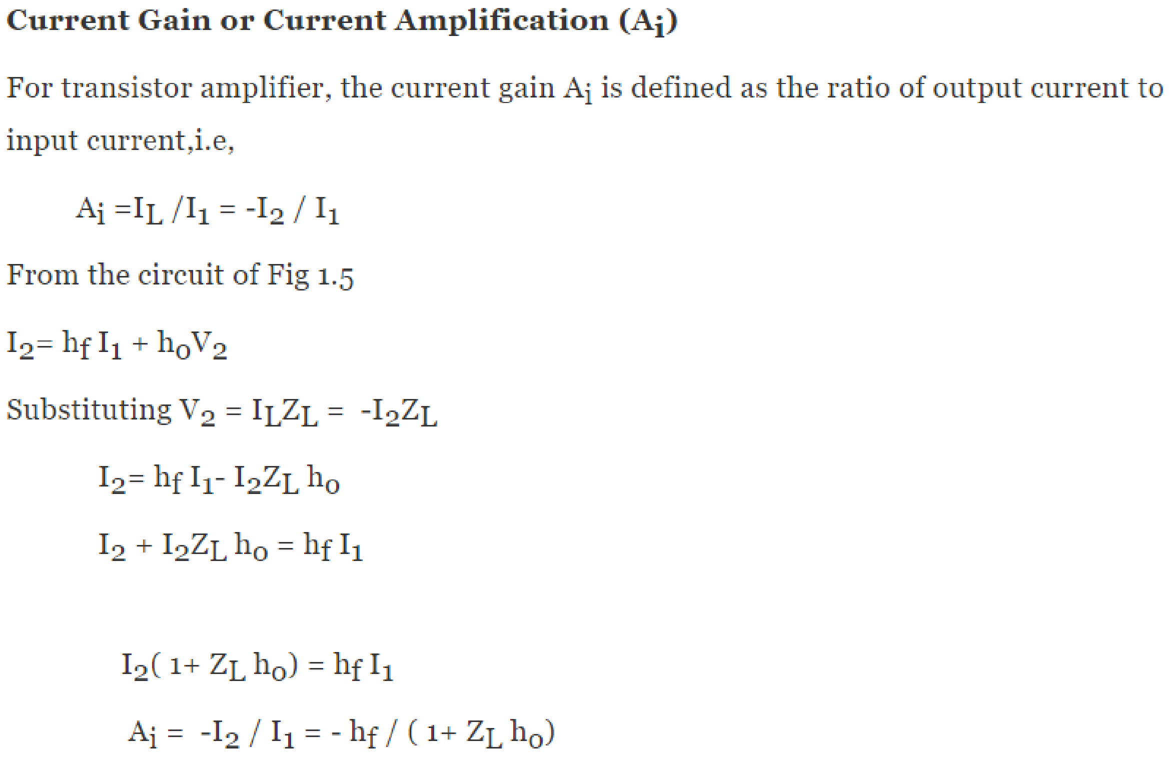
In the h-parameter model consider the following., load Resistance Z_L

Z_i input impedance

R_s source resistance

input signal V_s.

The expressions for Current gain, Voltage gain, input and output impedance are analysed.



Current Gain or Current Amplification (A_i)

For transistor amplifier, the current gain A_i is defined as the ratio of output current to input current,i.e,

$$A_i = I_L / I_1 = -I_2 / I_1$$

From the circuit of Fig 1.5

$$I_2 = h_f I_1 + h_o V_2$$

Substituting $V_2 = I_L Z_L = -I_2 Z_L$

$$I_2 = h_f I_1 - I_2 Z_L h_o$$

$$I_2 + I_2 Z_L h_o = h_f I_1$$

$$I_2 (1 + Z_L h_o) = h_f I_1$$

$$A_i = -I_2 / I_1 = -h_f / (1 + Z_L h_o)$$

Current Gain:

$$A_i = -h_f / (1 + h_o Z_L)$$

Where A_i is the current amplification or current gain.

Input Impedance (Z_i)

In the circuit , R_S is the signal source resistance .The impedance seen when looking into the amplifier terminals $(1,1')$ is the amplifier input impedance Z_i,

$Z_i = V_1/I_1$

From the input circuit of Fig $V_1 = h_i I_1 + h_r V_2$

$Z_i = (h_i I_1 + h_r V_2) / I_1$

$= h_i + h_r V_2 / I_1$

Substituting

$V_2 = -I_2 Z_L = A_1 I_1 Z_L$

$Z_i = h_i + h_r A_1 I_1 Z_L / I_1$

$= h_i + h_r A_1 Z_L$

Substituting for A_i

$Z_i = h_i - h_f h_r Z_L / (1+ h_o Z_L)$

$= h_i - h_f h_r Z_L / Z_L(1/Z_L + h_o)$

Taking the Load admittance as $Y_L = 1/ Z_L$

$Z_i = h_i - h_f h_r / (Y_L + h_o)$

Input Impedance (Zi)

$Z_i = h_i + h_r A_i Z_L$

Voltage Gain or Voltage Gain Amplification Factor(A_V)

The ratio of output voltage V_2 to input voltage V_1 give the voltage gain of the transistor i.e,

$A_V = V_2 / V_1$

Substituting

$V_2 = -I_2 Z_L = A_1 I_1 Z_L$

$A_V = A_1 I_1 Z_L / V_1 = A_i Z_L / Z_i$

Voltage Gain (A_v):

$A_v = (A_i * Z_L) / Z_i$

Output Admittance (Y_O)

Y_O is obtained by setting V_S to zero, Z_L to infinity and by driving the output terminals from a generator V_2. If the current is I_2 then $Y_O = I_2/V_2$ with $V_S=0$ and $R_L=\infty$.

Output Admittance(Y_o)

$Y_o=h_o-h_f * h_r/(h_i+R_s)$.

Let us derive.,

From the circuit of fig

$I_2 = h_f I_1 + h_o V_2$

Dividing by V_2,

$I_2 / V_2 = h_f I_1/V_2 + h_o$

With $V_2 = 0$, by KVL in input circuit,

$R_S I_1 + h_i I_1 + h_r V_2 = 0$

$(R_S + h_i) I_1 + h_r V_2 = 0$

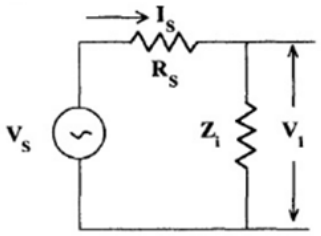
Hence, $I_2 / V_2 = -h_r / (R_S + h_i)$

$= h_f (-h_r/(R_S + h_i)+h_o$

$Y_O = h_O - h_f h_r/(R_S + h_i)$

The output admittance is a function of source resistance. If the source impedance is resistive then Y_O is real.

Voltage Amplification Factor(A_{VS}) is taking into account the resistance (R_S) of the source.



Thevenin's Equivalent Input Circuit

This overall voltage gain A_{VS} is given by

$$A_{VS} = V_2 / V_S = V_2 V_1 / V_1 V_S = A_V V_1 / V_S$$

From the equivalent input circuit using Thevenin's equivalent for the source

$V_1 = V_S Z_i / (Z_i + R_S)$

$V_1 / V_S = Z_i / (Z_i + R_S)$

Then, $A_{VS} = A_V Z_i / (Z_i + R_S)$

Substituting $A_V = A_i Z_L / Z_i$

$A_{VS} = A_i Z_L / (Z_i + R_S)$

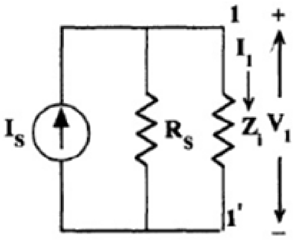
$A_{VS} = A_i Z_L R_S / (Z_i + R_S) R_S$

$A_{VS} = A_{iS} Z_L / R_S$

Voltage gain taking source resistance is given by

$$A_{vs}=(A_v * Z_i)/(Z_i+R_s)$$

Current Amplification (A_{iS}) taking into account the source Resistance(R_S)



Norton's Equivalent Input Circuit

The modified input circuit using Norton's equivalent circuit for the calculation of A_{iS} is

Overall Current Gain, $A_{is} = -I_2 / I_S = - I_2 I_1 / I_1 I_S = A_i\ I_1 / I_S$

$$I_1 = I_S R_S / (R_S + Z_i)$$

$$I_1 / I_S = R_S / (R_S + Z_i)$$

and hence, $A_{is} = A_i R_S / (R_S + Z_i)$

The overall current gain taking source resistance is given by:

$A_{is} = A_i * R_s / (Z_i + R_s)$

Operating Power Gain (Ap)

The operating power gain Ap of the transistor is defined as

$Ap = P_2 / P_1 = -V_2 I_2 / V_1 I_1 = A_v A_i = A_i A_i Z_L / Z_i$

$Ap = A_i^2 (Z_L / Z_i)$

Transistor	Current Gain	Input Impedance	Voltage Gain	Output Admittance
General hybrid	$-h_f/(1+h_o Z_L)$	$h_i + h_r A_i Z_L$	$(A_i * Z_L)/ Z_i$	$h_o -(h_f * h_r/(h_i + R_s))$
CE	$-h_{fe}/(1+h_{oe} Z_L)$	$h_{ie} + h_{re} A_i Z_L$	$(A_i * Z_L)/ Z_i$	$h_{oe} -(h_{fe} * h_{re}/(h_{ie} + R_s))$
CB	$-h_{fb}/(1+h_{ob} Z_L)$	$h_{ib} + h_{rb} A_i Z_L$	$(A_i * Z_L)/ Z_i$	$h_{ob} -(h_{fb} * h_{rb}/(h_{ib} + R_s))$
CC	$-h_{fc}/(1+h_{oc} Z_L)$	$h_{ic} + h_{rc} A_i Z_L$	$(A_i * Z_L)/ Z_i$	$h_{oc} -(h_{fc} * h_{rc}/(h_{ic} + R_s))$

Multistage Amplifiers

Two or more amplifiers can be connected to increase the gain of an ac signal. The overall gain can be calculated by simply multiplying each gain together.

$$A'v = Av1Av2Av3 \ldots\ldots$$

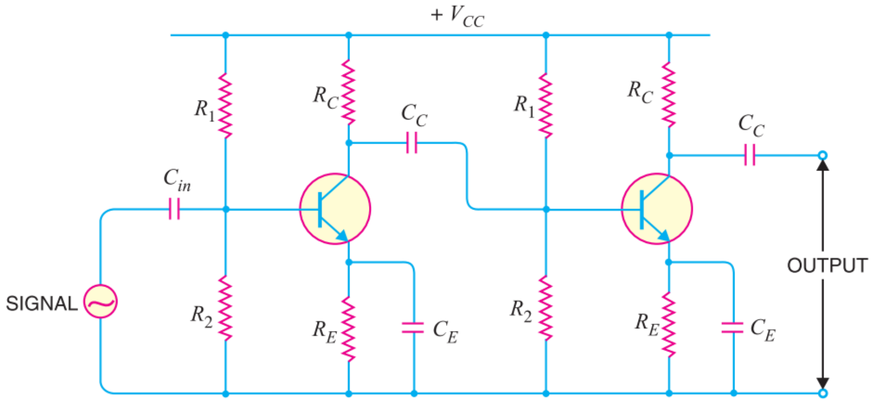
Types of Coupling

(i)In RC coupling, a capacitor is used as the coupling device. The capacitor connects the output of one stage to the input of the next stage in order to pass the a.c. signal on while blocking the d.c. bias voltages.

(ii)In transformer coupling, transformer is used as the coupling device. The transformer coupling provides the same two functions (viz.to pass the signal on and blocking d.c.) but permits in addition impedance matching.

(iii)In direct coupling or d.c. coupling, the individual amplifier stage bias conditions are so designed that the two stages may be directly connected without the necessity for d.c. isolation.

RC Coupled Transistor Amplifier



The Figure shows two stages of an RC coupled amplifier.

- A coupling capacitor CC is used to connect the output of first stage to the base (i.e., Input) of the second stage and soon.

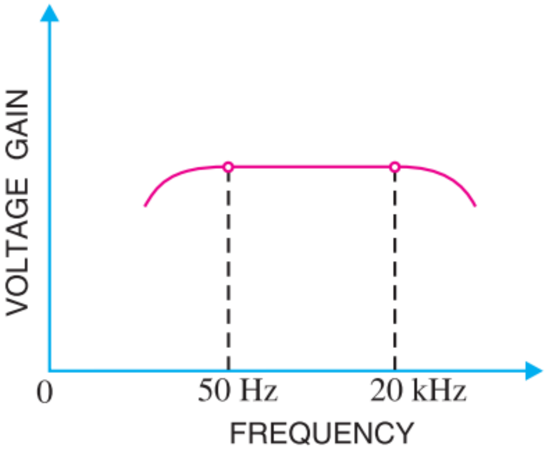
- As the coupling from one stage to next is achieved by a coupling capacitor followed by a connection to a shunt resistor, therefore, such amplifiers are called resistance-capacitance coupled amplifiers.

- The resistances R1, R2 and RE form the biasing and stabilization network.

- The emitter bypass capacitor offers low reactance path to the signal. Without it, the voltage gain of each stage would be lost.

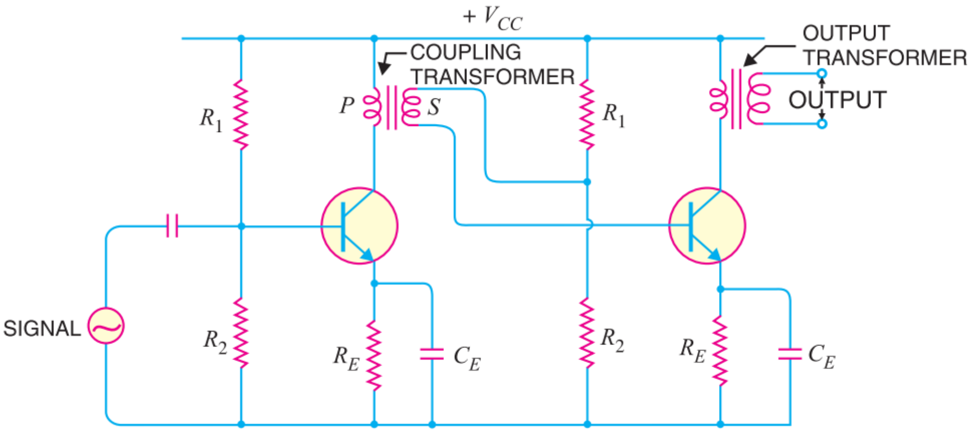
- The coupling capacitor CC transmits a.c. signal but blocks d.c. This prevents d.c. interference between various stages and the shifting of operating point.

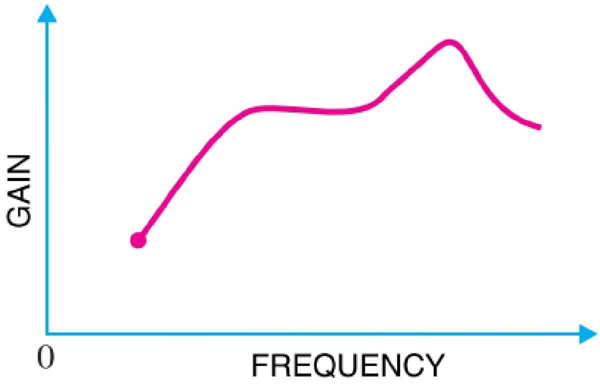
Frequency response



Transformer-Coupled Amplifier

Operation When an a c signal is applied to the base of first transistor, it appears in the amplified form across primary P of the coupling transformer. The voltage developed across primary is transferred to the input of the next stage by the transformer secondary as shown in Fig. The second stage renders amplification in an exactly similar manner.





Frequency response

- The frequency response of a transformer coupled amplifier is shown in Fig.
- The frequency response is rather poor i e gain is constant only over a small range of frequency.
- The output voltage is equal to the collector current multiplied by reactance of primary At low frequencies, the reactance of primary begins to fall, resulting in decreased gain.

- At high frequencies, the capacitance between turns of windings acts as a bypass condenser to reduce the output voltage and hence gain.

- Therefore, that there will be disproportionate amplification of frequencies in a complete signal such as music, speech etc.

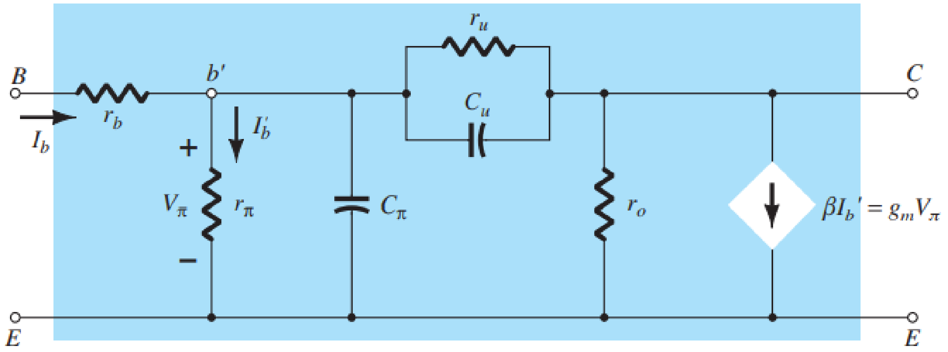
- Hence, transformer coupled amplifier introduces frequency distortion.

- In a properly designed transformer, it is possible to achieve a fairly constant gain over the audio frequency range.

- But a transformer that achieves a frequency response comparable to RC coupling may cost 10 to 20 times as much as the inexpensive RC coupled amplifier.

Hybrid p model

The hybrid p model is shown in Fig which includes parameters that do not appear in the other two models primarily to provide a more accurate model for high frequency effects.



Giacoletto (or hybrid π) high-frequency transistor small-signal ac equivalent circuit.

r_π, r_o, r_b, and r_u

The resistors r_π, r_o, r_b, and r_u are the resistances between the indicated terminals of the device when the device is in the active region. The resistance r_π (using the symbol π to agree with the hybrid π terminology) is simply βr_e as introduced for the common-emitter r_e model.

That is,

$$\boxed{r_\pi = \beta r_e}$$

The output resistance r_o is the output resistance normally appearing across an applied load. Its value, which typically lies between 5 kΩ and 40 kΩ, is determined from the hybrid parameter h_{oe}, the Early voltage, or the output characteristics.

The resistance r_b includes the base contact, base bulk, and base spreading resistance levels. The first is due to the actual connection to the base. The second includes the resistance from the external terminal to the active region of the transistor, and the last is the actual resistance within the active base region. It is typically a few ohms to tens of ohms.

The resistance r_u (the subscript *u* refers to the *union* it provides between collector and base terminals) is a very large resistance and provides a feedback path from output to input circuits in the equivalent model. It is typically larger than βr_o, which places it in the megohm range.

$\beta I'_b$ or $g_m V_\pi$

It is important to note in Fig. 5.123 that the controlled source can be a voltage-controlled current source (VCCS) or a current-controlled current source (CCCS), depending on the parameters employed.

Note the following parameter equivalence in Fig. 5.1

$$\boxed{g_m = \frac{1}{r_e}}$$

C_π and C_u

All the capacitors that appear in Fig. 5.123 are stray parasitic capacitors between the various junctions of the device. They are all capacitive effects that really only come into play at high frequencies. For low to mid-frequencies their reactance is very large, and they can be considered open circuits. The capacitor C_π across the input terminals can range from a few *pF* to tens of *pF*. The capacitor C_u from base to collector is usually limited to a few *pF* but is magnified at the input and output by an effect called the Miller effect.

UNIT II Power Amplifiers

- The basic function of transistor is amplification.
- The process of raising the strength of weak signal without any change in its general shape is referred as faithful amplification.
- For faithful amplification it is essential that:
- Emitter-Base junction is forward biased
- Collector- Base junction is reversed biased
- Proper zero signal collector current
- The proper flow of zero signal collector current and the maintenance of proper collector emitter voltage during the passage of signal is called transistor biasing or To operate the transistor in the desired region, we have to apply external dc voltages of correct polarity and magnitude to the two junctions of the transistor.
- This is known as biasing of the transistor.
- Since DC voltages are used to bias the transistor, it is called as DC biasing.
- Application of DC voltages (bias) establishes a fixed level of current and voltage.
- For transistor amplifiers the resulting DC current and voltage establishes an operating point on the characteristics that define the region that will be employed for amplification of the applied signal.
- Since the operating point is a fixed point on the characteristics, it is called as Quiescent point (Q - Point).

- Need for Biasing : To operate the transistor in the desired region.
- • The DC sources supplies the power to the transistor circuit, to get the output signal power greater than the input signal power.
- • If the transistor is not biased properly, it would work inefficiently and produce distortion in output signal.
- Load Line and its Types:
- LOAD LINE:
- It is a straight line drawn on the characteristic curve with two end points A and B.
- It is used to fixed the operating point of a transistor.
- TYPES OF LOAD LINE:
- DC load line
- AC load line

Power Amplifiers

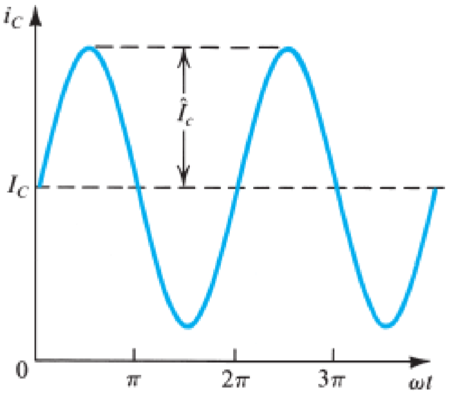
A power amplifier is an amplifier with a high-power output stage.

Classification of Output Stages

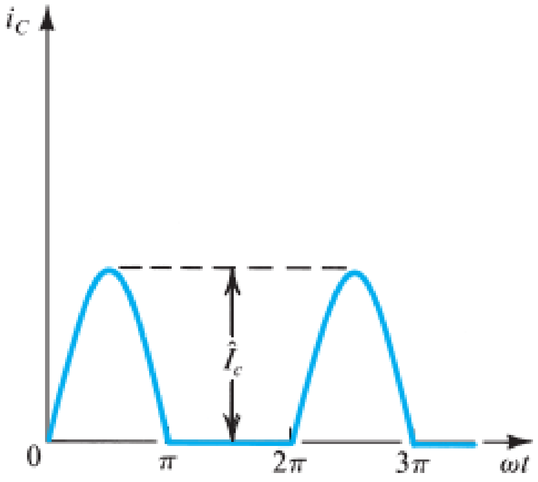
Output stages are classified according to the collector-current waveform that results when an input signal is applied.

The class A stage, whose associated waveform is shown in Fig, is biased at a current IC that is greater than the amplitude of the signal current, *ic*.

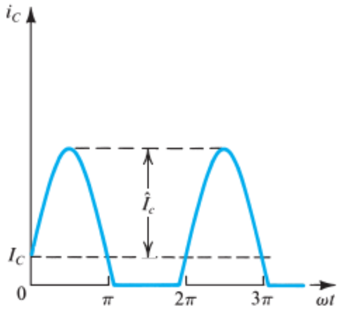
Thus, the transistor in a class A stage conducts for the entire cycle of the input signal; that is, the conduction angle is 360°.



- The class B stage, whose associated waveform is shown in Fig., is biased at zero dc current.
- Thus, a transistor in a class B stage conducts for only half the cycle of the input sine wave, resulting in a conduction angle of 180°.
- In applications, the negative halves of the sinusoid will be supplied by another transistor that also operates in the class B mode and conducts during the alternate half-cycles.

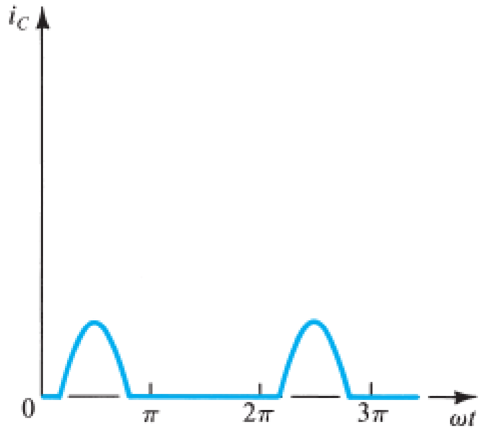


- An intermediate class between A and B, appropriately named class AB, involves biasing the transistor at a nonzero dc current much smaller than the peak current of the sine-wave signal.
- As a result, the transistor conducts for an interval slightly greater than half a cycle, as illustrated in Fig.
- The resulting conduction angle is greater than 180° but much less than 360°.
- The class AB stage has another transistor that conducts for an interval slightly greater than that of the negative half-cycle, and the currents from the two transistors are combined in the load. It follows that, during the intervals near the zero crossings of the input sinusoid, both transistors conduct.



- Figure shows the collector-current waveform for a transistor operated as a class C amplifier.
- Observe that the transistor conducts for an interval shorter than that of a half-cycle; that is, the conduction angle is less than 180°.

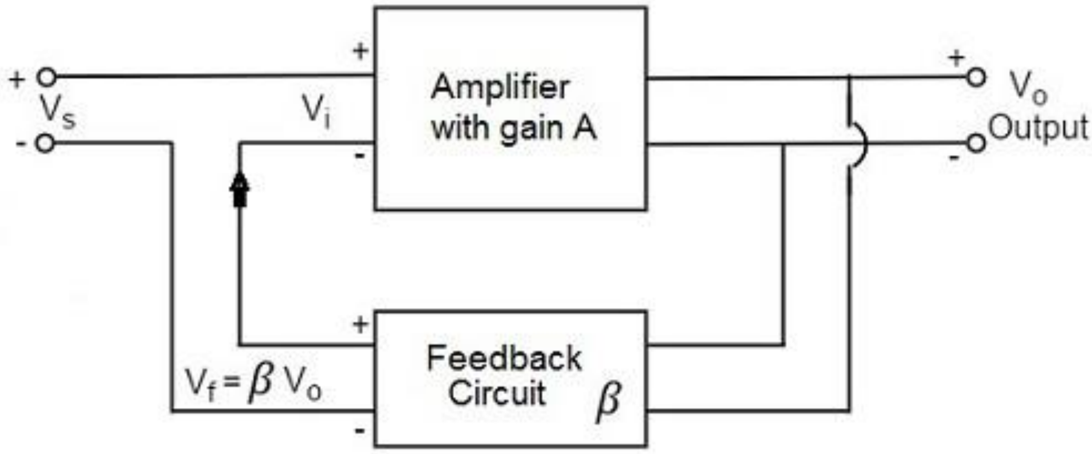
- The result is the periodically pulsating current waveform shown. To obtain a sinusoidal output voltage, this current is passed through a parallel *LC* circuit, tuned to the frequency of the input sinusoid. The tuned circuit acts as a bandpass filter and provides an output voltage proportional to the amplitude of the fundamental component in the Fourier-series representation of the current waveform.



Feedback Amplifiers

- An amplifier circuit simply increases the signal strength.
- But while amplifying, it just increases the strength of its input signal whether it contains information or some noise along with information.
- This noise or some disturbance is introduced in the amplifiers because of their strong tendency to introduce **hum** due to sudden temperature changes or stray electric and magnetic fields.
- Therefore, every high gain amplifier tends to give noise along with signal in its output, which is very undesirable.
- The noise level in the amplifier circuits can be considerably reduced by using **negative feedback** done by injecting a fraction of output in phase opposition to the input signal.

- A feedback amplifier generally consists of two parts.
- They are the **amplifier** and the **feedback circuit**. The feedback circuit usually consists of resistors.
- The concept of feedback amplifier can be understood from the following figure.



From the above figure, the gain of the amplifier is represented as A. the gain of the amplifier is the ratio of output voltage V_o to the input voltage V_i.

the feedback network extracts a voltage $V_f = \beta V_o$ from the output V_o of the amplifier.

This voltage is added for positive feedback and subtracted for negative feedback, from the signal voltage V_s.

The quantity $\beta = V_f/V_o$ is called as feedback ratio or feedback fraction.

Let us consider the case of negative feedback.

The output V_o must be equal to the input voltage $(V_s - \beta V_o)$ multiplied by the gain A of the amplifier.

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

Let 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.,

So, from the above two equations, we can understand that,

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

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

The equation of gain of the feedback amplifier, with positive feedback is given by

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

The process of injecting a fraction of output energy of some device back to the input is known as **Feedback**.

It has been found that feedback is very useful in reducing noise and making the amplifier operation stable.

Depending upon whether the feedback signal **aids** or **opposes** the input signal, there are two types of feedbacks used.

Positive Feedback

- The feedback in which the feedback energy i.e., either voltage or current is in phase with the input signal and thus aids it is called as **Positive feedback**.
- Both the input signal and feedback signal introduces a phase shift of 180^o thus making a 360^o resultant phase shift around the loop, to be finally in phase with the input signal.
- Though the positive feedback **increases the gain** of the amplifier, it has the disadvantages such as
- Increasing distortion
- Instability
- It is because of these disadvantages the positive feedback is not recommended for the amplifiers.
- If the positive feedback is sufficiently large, it leads to oscillations, by which oscillator circuits are formed.
- Amplifiers Negative Feedback
- Negative feedback in an amplifier is the method of feeding a portion of the amplified output to the input but in opposite phase.
- The phase opposition occurs as the amplifier provides 180^o phase shift whereas the feedback network doesn’t.
- While the output energy is being applied to the input, for the voltage energy to be taken as feedback, the output is taken in shunt connection and for the current energy to be taken as feedback, the output is taken in series connection.
- There are two main types of negative feedback circuits. They are −
- Negative Voltage Feedback

- Negative Current Feedback
- Negative Voltage Feedback
- In this method, the voltage feedback to the input of amplifier is proportional to the output voltage. This is further classified into two types −
- Voltage-series feedback
- Voltage-shunt feedback
- Negative Current Feedback
- In this method, the voltage feedback to the input of amplifier is proportional to the output current. This is further classified into two types.
- Current-series feedback
- Current-shunt feedback

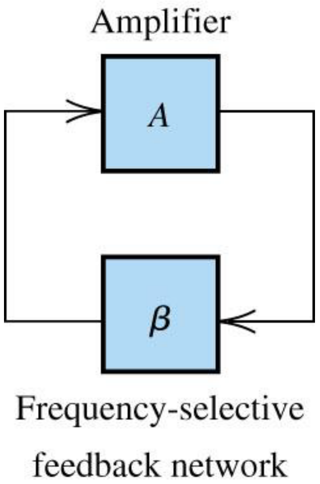
UNIT III Oscillators

Oscillators are circuits that generate periodic signals.

•An oscillator converts DC power from power supply to AC signals power spontaneously – without the need for an AC input source (Note: Amplifiers convert DC power into AC output power only if an external AC input signal is present.)

•There are several approaches to design of oscillator circuits. The approach to be discussed is related to the feedback using amplifiers. A frequency-selective feedback path around an amplifier is placed to return part of the output signal to the amplifier input, which results in a circuit called a linear oscillator that produces an approximately sinusoidal output.

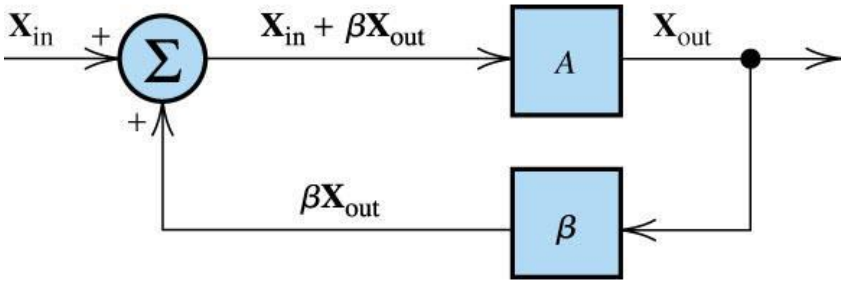
•Under proper conditions, the signal returned by the feedback network has exactly the correct amplitude and phase needed to sustain the output signal.



The Barkhuizen Criterion

• Typically, the feedback network is composed of passive lumped components that determine the frequency of oscillation. So, the feedback is complex transfer function, hence denoted as beta.

- We can derive the requirements for oscillation as follows: initially, assume a sinusoidal driving source with phasor Xin is present. But we are interested to derive the conditions for which the output phasor Xout can be non-zero even the input Xin is zero.



- The Product of β.Av = 1 and the angle of β.Av = 360 °. These are the two conditions of Barkhausen criteria.

Different types of oscillators:

An oscillator has a positive feedback with the loop gain infinite. Feedback-type sinusoidal oscillators can be classified as LC (inductor-capacitor) and RC (resistor-capacitor) oscillators.

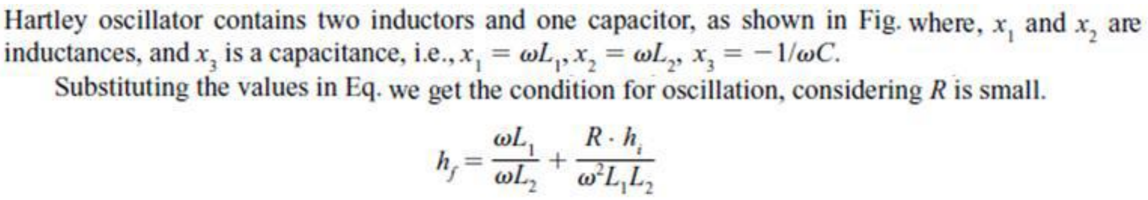
- Tuned oscillator
- Hartley oscillator
- Colpitts oscillator
- Clapp oscillator
- Phase-shift oscillator
- Wien-bridge and
- Crystal oscillator

An oscillator is an electronic system.

- It comprises active and passive circuit elements and sinusoidal produces repetitive waveforms at the output without the application of a direct external input signal to the circuit.

- It converts the dc power from the source to ac power in the load. A rectifier circuit converts ac to dc power, but an oscillator converts dc noise signal/power to its ac equivalent.
- The general form of a harmonic oscillator is an electronic amplifier with the output attached to a narrow-band electronic filter, and the output of the filter attached to the input of the amplifier.
- The oscillator analysis is done in two methods—first by a general analysis, considering all other circuits are the special form of a common generalized circuit and second, using the individual circuit KVL analysis.

Hartley Oscillator



Hartley oscillator contains two inductors and one capacitor, as shown in Fig. where, x_1 and x_2 are inductances, and x_3 is a capacitance, i.e., $x_1 = \omega L_1, x_2 = \omega L_2, x_3 = -1/\omega C$.

Substituting the values in Eq. we get the condition for oscillation, considering R is small.

$$h_f = \frac{\omega L_1}{\omega L_2} + \frac{R \cdot h_i}{\omega^2 L_1 L_2}$$

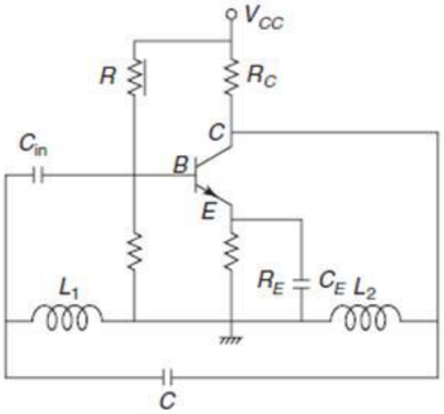


Figure Hartley Oscillator

Wien-Bridge Oscillator

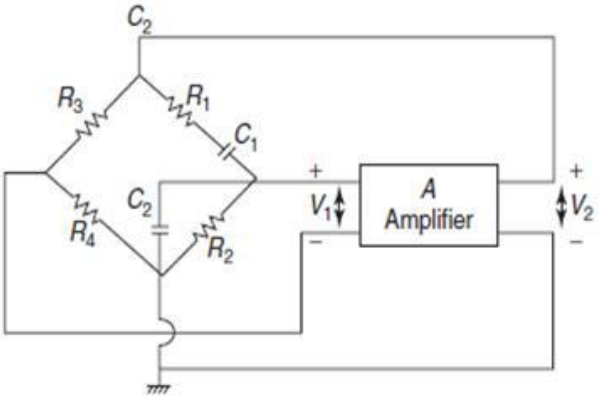


Figure Wien-bridge oscillator with an amplifier

Advantages of Wien-Bridge Oscillator:

1. The frequency of oscillation can be easily varied just by changing *RC network*

2. High gain due to two-stage amplifier

3. Stability is high

Disadvantages of Wien-Bridge Oscillator

The main disadvantage of the Wien-bridge oscillator is that a high frequency of oscillation cannot be generated.

Crystal Oscillator

Crystal oscillator is most commonly used oscillator with high-frequency stability. They are used for laboratory experiments, communication circuits and biomedical instruments. They are usually, fixed frequency oscillators where stability and accuracy are the primary considerations.

- In order to design a stable and accurate LC oscillator for the upper HF and higher frequencies it is absolutely necessary to have a crystal control; hence, the reason for crystal oscillators.

- Crystal oscillators are oscillators where the primary frequency determining element is a quartz crystal. Because of the inherent characteristics of the quartz crystal the crystal oscillator may be held to extreme accuracy of frequency stability.

- Temperature compensation may be applied to crystal oscillators to improve thermal stability of the crystal oscillator.

- The crystal size and cut determine the values of L, C, R and C'. The resistance R is the friction of the vibrating crystal, capacitance C is the compliance, and inductance L is the equivalent mass. The capacitance C' is the electrostatic capacitance between the mounted pair of electrodes with the crystal as the dielectric.

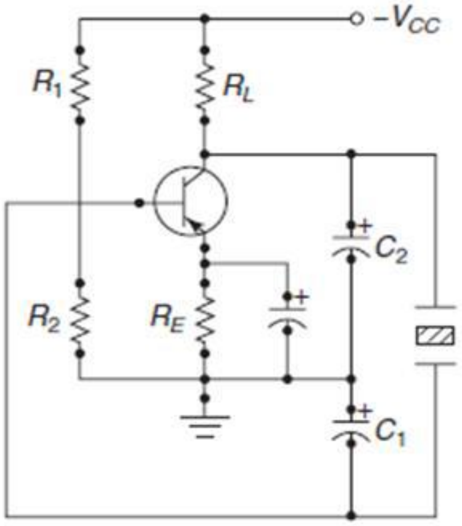


Figure Circuit of a crystal oscillator

Oscillators are a common element of almost all electronic circuits. They are used in various applications, and their use makes it possible for circuits and subsystems to perform numerous useful functions.

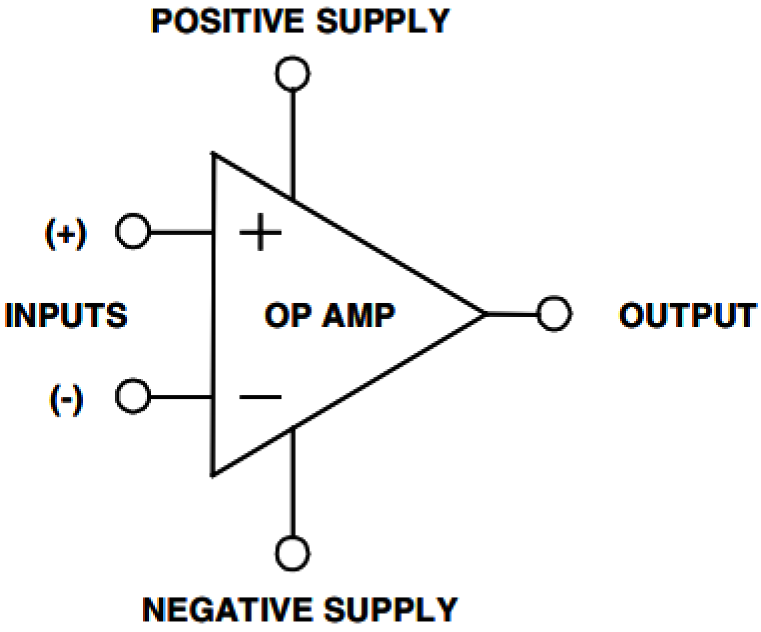
- In oscillator circuits, oscillation usually builds up from zero when power is first applied under linear circuit operation.
- The oscillator’s amplitude is kept from building up by limiting the amplifier saturation and various non-linear effects.
- Oscillator design and simulation is a complicated process. It is also extremely important and crucial to design a good and stable oscillator.
- Oscillators are commonly used in communication circuits. All the communication circuits for different modulation techniques—AM, FM, PM—the use of an oscillator is must.
- Oscillators are used as stable frequency sources in a variety of electronic applications.
- Oscillator circuits are used in computer peripherals, counters, timers, calculators, phase-locked loops, digital multi-meters, oscilloscopes, and numerous other applications.

Operational Amplifiers

An op amp (operational amplifier) is a circuit with two inputs and one output. The gain, A, is usually very large: e.g. $A = 10^5$ at low frequencies.

Basic Operation The basic operation of the op amp can be easily summarized. First, we assume that there is a portion of the output that is fed back to the inverting terminal to establish the fixed gain for the amplifier. This is negative feedback. Any differential voltage across the input terminals of the op amp is multiplied by the amplifier’s open-loop gain.

The open-loop gain of the amplifier will attempt to force the differential voltage to zero. As long as the input and output stay in the operational range of the amplifier, it will keep the differential voltage at zero, and the output will be the input voltage multiplied by the gain set by the feedback. Note from this that the inputs respond to differential mode not common-mode input voltage.

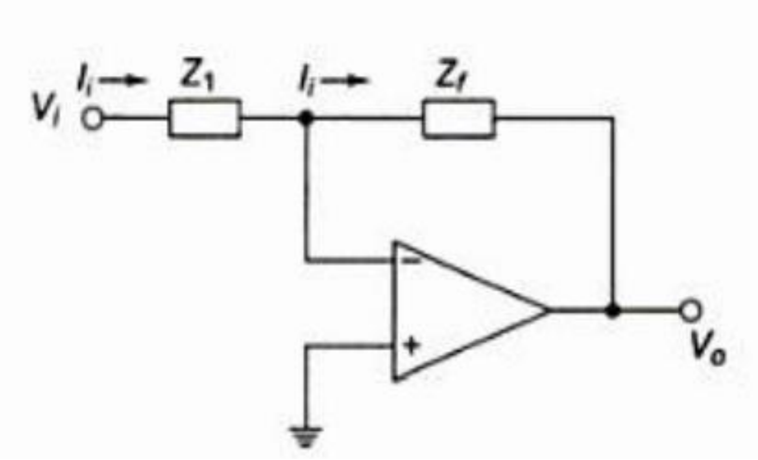


If the magnitude of this differential voltage is more positive on the inverting (-) terminal than on the noninverting (+) terminal, the output will go more negative. If the magnitude of the differential voltage is more positive on the noninverting (+) terminal than on the inverting (-) terminal, the output voltage will become more positive.

UNIT **IV. APPLICATIONS OF OPERATIONAL AMPLIFIERS**

Sign Changer (Phase Inverter)

The basic inverting amplifier configuration using an op-amp with input impedance Z1 and feedback impedance Z_f . If the impedance Z1 and Z f are equal in magnitude and phase, then the closed loop voltage gain is -1, and the input signal will undergo a 180° phase shift at the output. Hence, such circuit is also called phase inverter. If two such amplifiers are connected in cascade, then the output from the second stage is the same as the input signal without any change of sign. Hence, the outputs from the two stages are equal in magnitude but opposite in phase and such a system is an excellent paraphase amplifier.



Scale Changer:

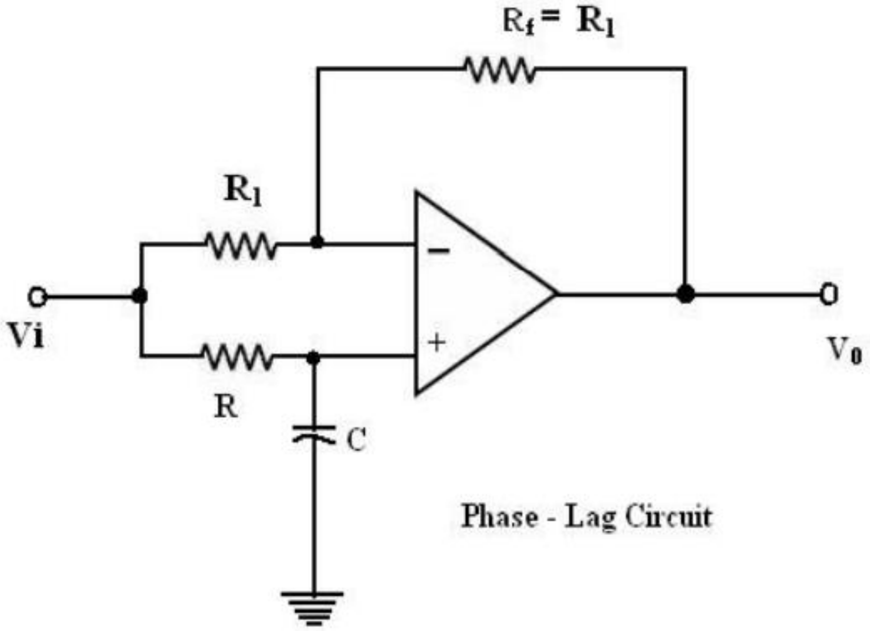
Referring the above diagram, if the ratio Zf / Z1 = k, a real constant, then the closed loop gain is – k, and the input voltage is multiplied by a factor –k and the scaled output is available at the output. Usually, in such applications, Zf and Z1 are selected as precision resistors for obtaining precise and scaled value of input voltage.

Phase Shift Circuits

The phase shift circuits produce phase shifts that depend on the frequency and maintain a constant gain. These circuits are also called constant-delay filters or all-pass filters. That constant delay refers to the fact the time difference between input and output remains constant when frequency is changed over a range of operating frequencies. This is called all-pass because normally a constant gain is maintained for all the frequencies within the operating range. The two types of circuits, for lagging phase angles and leading phase angles.

Phase-lag circuit:

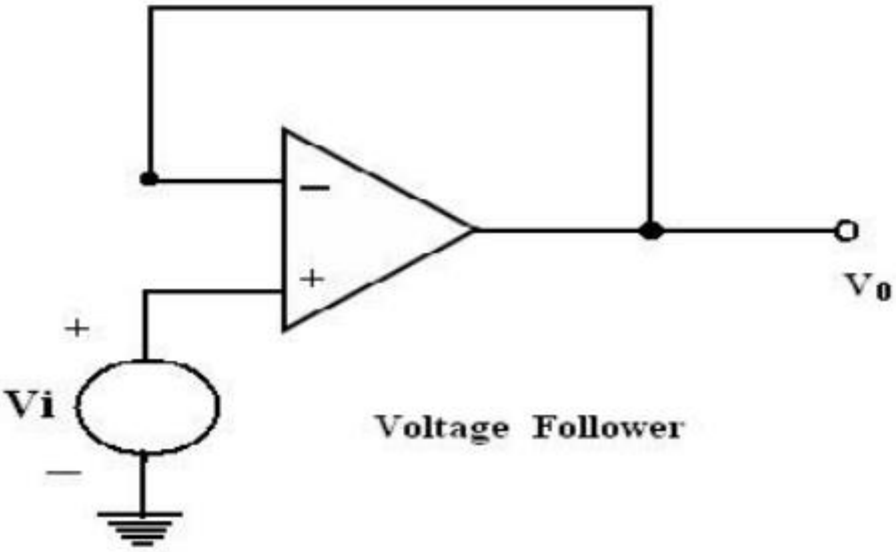
Phase log circuit is constructed using an op-amp, connected in both inverting and non-inverting modes. To analyze the circuit operation, it is assumed that the input voltage v1 drives a simple inverting amplifier with inverting input applied at (-) terminal of op-amp and a non-inverting amplifier with a low-pass filter. It is also assumed that inverting gain is -1 and non-inverting gain after the low-pass circuit is $1 + R_f/R_1 = 1 + 1 = 2$ Since R f =R1.



Phase - Lag Circuit

Voltage follower:

If R1=∞ and Rf =0 in the non-inverting amplifier configuration. The amplifier act as a unity-gain amplifier or voltage follower. The circuit consists of an op-amp and a wire connecting the output voltage to the input, i.e. the output voltage is equal to the input voltage, both in magnitude and phase. V0=Vi. Since the output voltage of the circuit follows the input voltage, the circuit is called voltage follower. It offers very high input impedance of the order of MΩ and very low output impedance. Therefore, this circuit draws negligible current from the source. Thus, the voltage follower can be used as a buffer between a high impedance source and a low impedance load for impedance matching applications.



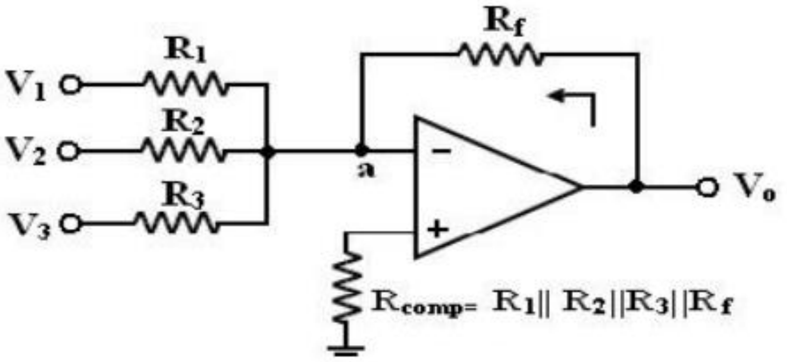
Adder:

Op-amp may be used to design a circuit whose output is the sum of several input signals.

Such a circuit is called a summing amplifier or a summer or adder.

Inverting Summing Amplifier:

A typical summing amplifier with three input voltages V1, V2 and V3 three input resistors R1, R2, R3 and a feedback resistor Rf is shown in figure 2. The following analysis is carried out assuming that the op-amp is an ideal one, AOL= ∞.



Non-Inverting Summing Amplifier:

Since the input bias current is assumed to be zero, there is no voltage drop across the resistor R_{comp} and hence the non-inverting input terminal is at ground potential.

I= V1/R1+V2/R2…..+Vn/Rn;

Vo= - Rf I=Rf/R(V1+V2+….Vn).

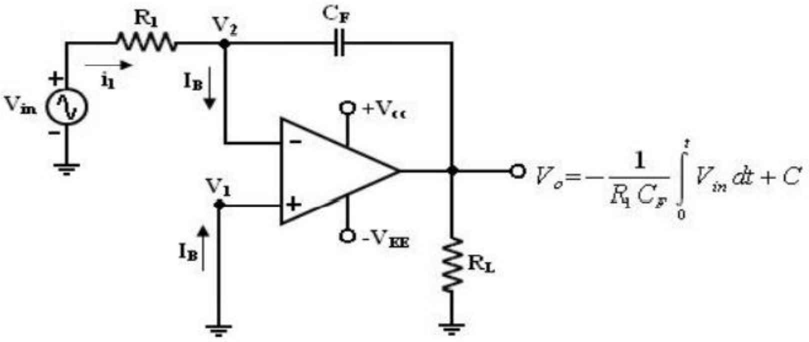
To find Rcomp, make all inputs V1 = V2 = V3 = 0.

So, the effective input resistance Ri = R1 || R2 || R3.

Therefore, Rcomp = Ri || Rf = R1 || R2 || R3 || Rf.

Integrator:

A circuit in which the output voltage waveform is the integral of the input voltage waveform is the integrator or Integration Amplifier. Such a circuit is obtained by using a basic inverting amplifier configuration if the feedback resistor RF is replaced by a capacitor CF. The expression for the output voltage V0 can be obtained by KVL eqn. at node V2.

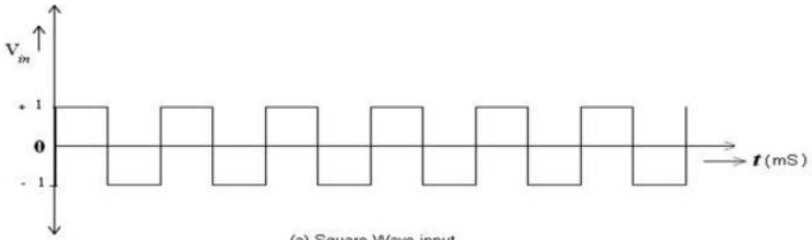


Integrator Circuit

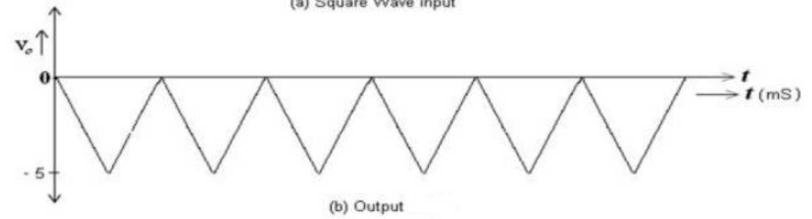
i1 = IB + if

Since IB is negligible small, i1 =iF

Relation between current through and voltage across the capacitor is i_C (t) = Cdvc(t)/dt



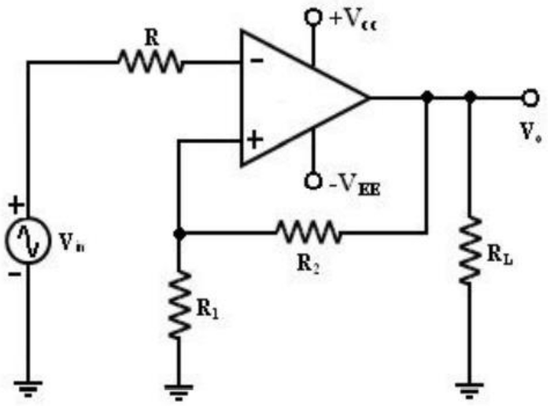
(a) Square Wave input

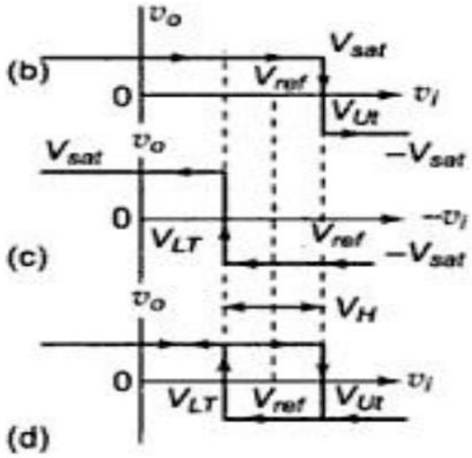


(b) Output

4 Schmitt Trigger: [Square Circuit]

This circuit converts an irregular shaped waveform to a square wave or pulse. The circuit is known as Schmitt Trigger or squaring circuit. The input voltage Vin triggers (changes the state of) the o/p V0 every time it exceeds certain voltage levels called the upper threshold Vut and lower threshold voltage.





These threshold voltages are obtained by using the voltage divider R1– R2, where the voltage across R1 is feedback to the (+) input.

The voltage across R1 is variable reference threshold voltage that depends on the value of the output voltage.

When V0 = +Vsat, the voltage across R1 is called upper threshold voltage Vut. The input voltage Vin must be more positive than Vut in order to cause the output V0 to switch from +Vsat to -Vsat using voltage divider rule, Voltage at (+) input terminal is VUT=Vref+ R2 (Vsat-Vref)/(R1+R2) when V0= +vsat.

When v0= -vsat. Hysteris width VH= VUT - VLT = 2 R2 (Vsat)/ (R1+R2) When V0 = -Vsat, the voltage across R1 is called lower threshold voltage Vlt .the Vin must be more negative than Vlt in order to cause V0 to switch from –Vsat to +Vsat. for Vin > Vlt , V0 is at –Vsat. Voltage at (+) terminal is VLT=Vref - R2 (Vsat+Vref)/(R1+R2).

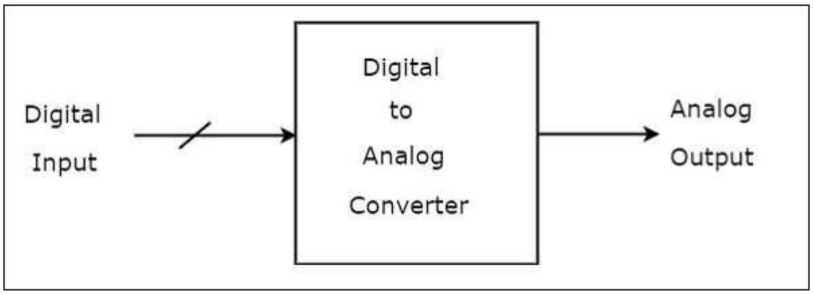
If the threshold voltages Vut and Vlt are made larger than the input noise voltages, the positive feedback will eliminate the false o/p transitions.

Also the positive feedback, because of its regenerative action, will make V0 switch faster between +Vsat and –Vsat. Resistance Rcomp=R1 || R2 is used to minimize the offset problems.

The comparator with positive feedback is said to exhibit hysteresis, a dead band condition. (i.e) when the input of the comparator exceeds Vut its output switches from +Vsat to –Vsat and reverts to its original state, +Vsat when the input goes below VLT. The hysteresis voltage is equal to the difference between Vut and Vlt. Therefore VH= Vut – Vlt. • If Vref=0, Vut= -VLT =2 R2(Vsat)/(R1+R2)

Unit V: DAC & ADC

A **Digital to Analog Converter (DAC)** converts a digital input signal into an analog output signal. The digital signal is represented with a binary code, which is a combination of bits 0 and 1.



A Digital to Analog Converter (DAC) consists of a number of binary inputs and a single output. In general, the **number of binary inputs** of a DAC will be a power of two.

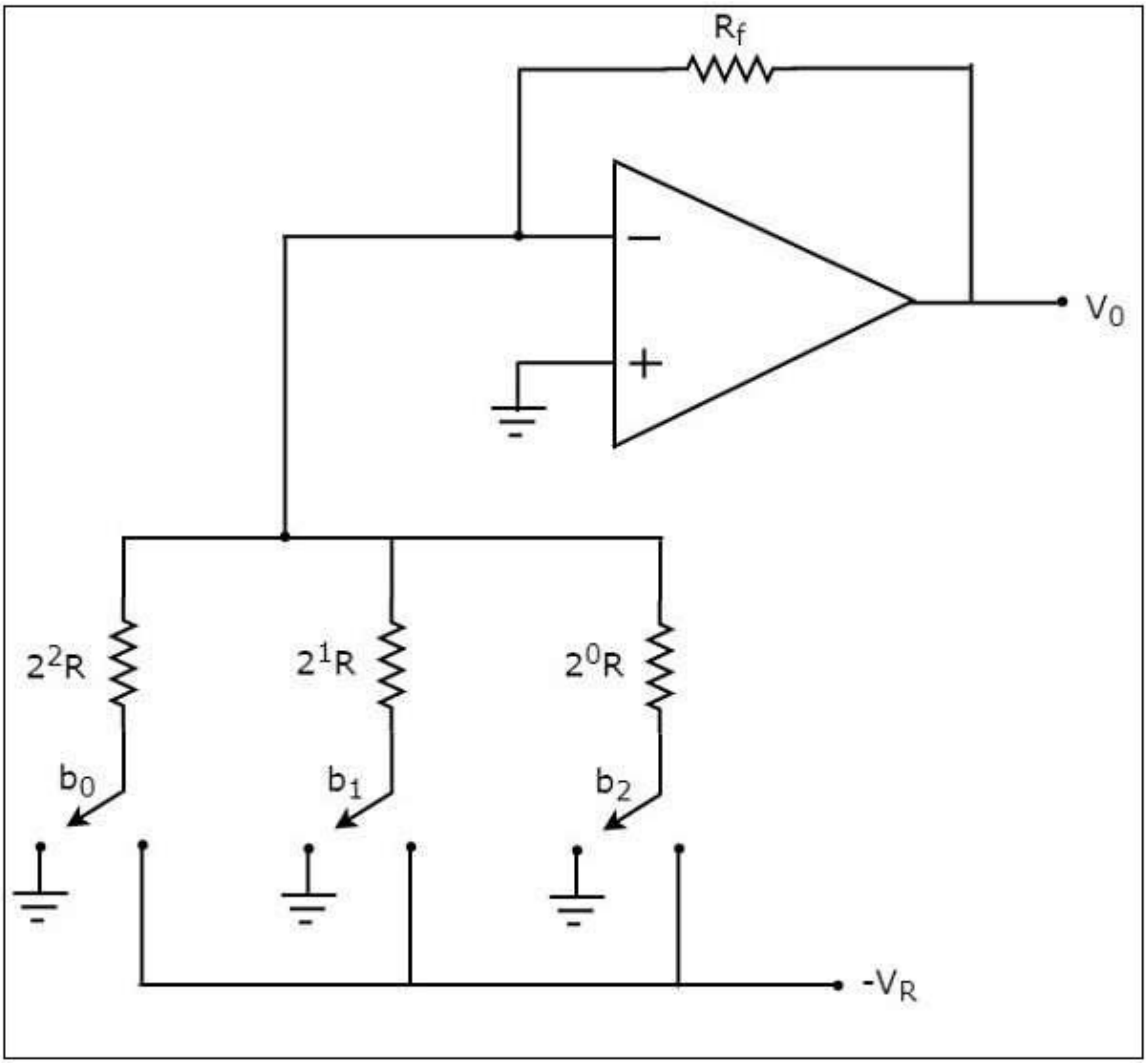
Types of DACs: There are **two types** of DACs

- Weighted Resistor DAC
- R-2R Ladder DAC

Weighted Resistor DAC

A weighted resistor DAC produces an analog output, which is almost equal to the digital (binary) input by using **binary weighted resistors** in the inverting adder circuit. In short, a binary weighted resistor DAC is called as weighted resistor DAC.

The **circuit diagram** of a 3-bit binary weighted resistor DAC is shown in the following figure



The bits of a binary number can have only one of the two values. i.e., either 0 or 1. Let the **3-bit binary input** is b2b1b0. Here, the bits b2b2 and b0b0 denote the **Most Significant Bit (MSB) and Least Significant Bit (LSB)** respectively.

The **digital switches** shown in the above figure will be connected to ground, when the corresponding input bits are equal to '0'. Similarly, the digital switches shown in the above figure will be connected to the negative reference voltage, −VR when the corresponding input bits are equal to '1'.

In the above circuit, the non-inverting input terminal of an op-amp is connected to ground. That means zero volts is applied at the non-inverting input terminal of op-amp.

According to the **virtual short concept**, the voltage at the inverting input terminal of op-amp is same as that of the voltage present at its non-inverting input terminal. So, the voltage at the inverting input terminal's node will be zero volts.

The **nodal equation** at the inverting input terminal's node is:

$$\frac{0+V_R b_2}{2^0 R}+\frac{0+V_R b_1}{2^1 R}+\frac{0+V_R b_0}{2^2 R}+\frac{0-V_0}{R_f}=0$$

$$=> \frac{V_0}{R_f}=\frac{V_R b_2}{2^0 R}+\frac{V_R b_1}{2^1 R}+\frac{V_R b_0}{2^2 R}$$

$$=> V_0=\frac{V_R R_f}{R}\left\{\frac{b_2}{2^0}+\frac{b_1}{2^1}+\frac{b_0}{2^2}\right\}$$

Substituting, R=2Rf in above equation.

$$=> V_0=\frac{V_R R_f}{2R_f}\left\{\frac{b_2}{2^0}+\frac{b_1}{2^1}+\frac{b_0}{2^2}\right\}$$

$$=> V_0=\frac{V_R}{2}\left\{\frac{b_2}{2^0}+\frac{b_1}{2^1}+\frac{b_0}{2^2}\right\}$$

The above equation represents the **output voltage equation** of a 3-bit binary weighted resistor DAC. Since the number of bits are three in the binary (digital) input, we will get seven possible values of output voltage by varying the binary input from 000 to 111 for a fixed reference voltage, VR. We can write the **generalized output voltage equation** of an N-bit binary weighted resistor DAC as shown below based on the output voltage equation of a 3-bit binary weighted resistor DAC.

$$=> V_0 = \frac{V_R}{2}\left\{\frac{b_{N-1}}{2^0} + \frac{b_{N-2}}{2^1} + \ldots + \frac{b_0}{2^{N-1}}\right\}$$

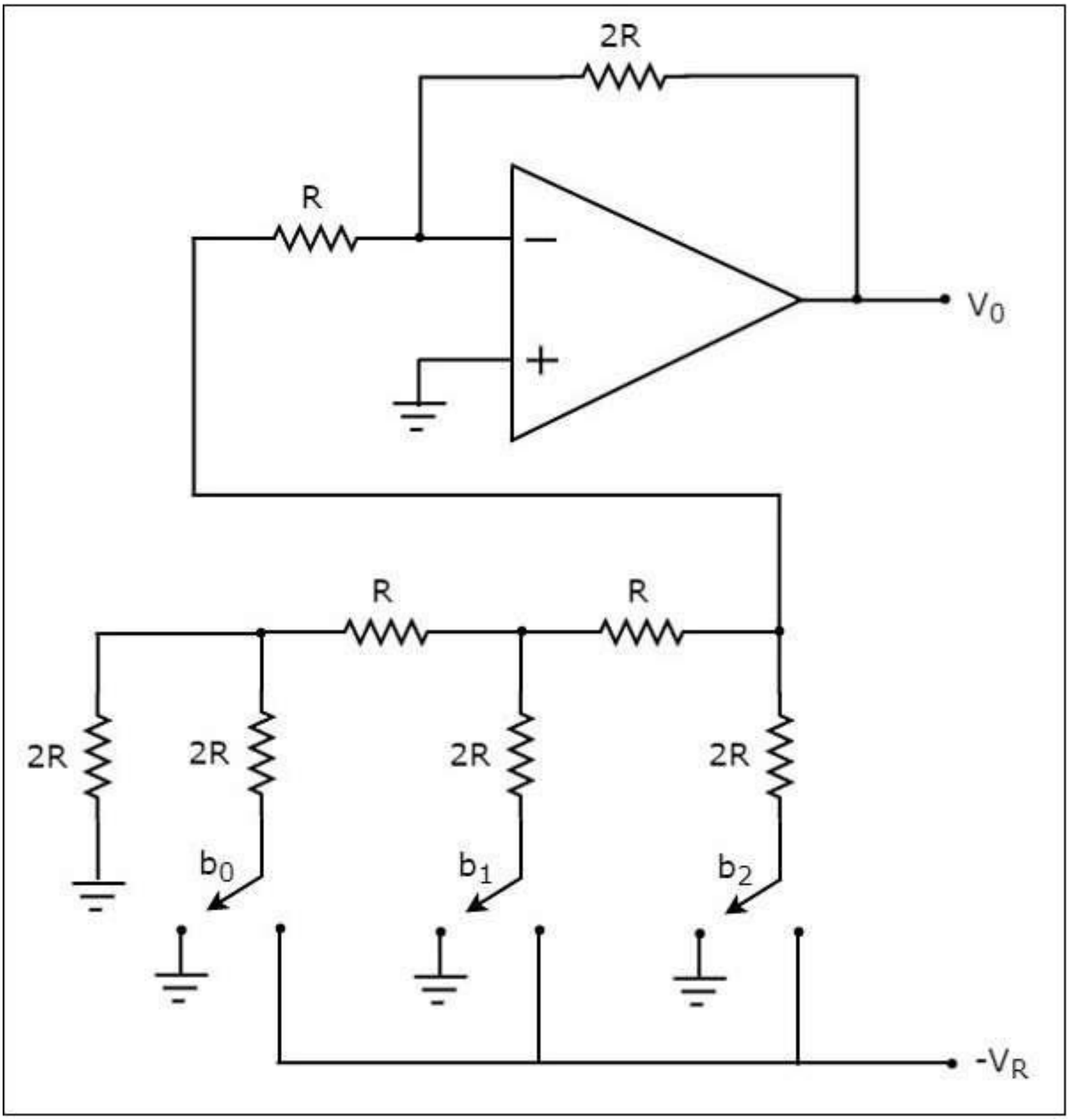
The **disadvantages** of a binary weighted resistor DAC are as follows −

- The difference between the resistance values corresponding to LSB & MSB will increase as the number of bits present in the digital input increases.
- It is difficult to design more accurate resistors as the number of bits present in the digital input increases.

R-2R Ladder DAC

The R-2R Ladder DAC overcomes the disadvantages of a binary weighted resistor DAC. As the name suggests, R-2R Ladder DAC produces an analog output, which is almost equal to the digital (binary) input by using a **R-2R ladder network** in the inverting adder circuit.

The **circuit diagram** of a 3-bit R-2R Ladder DAC is shown in the following figure.,



The bits of a binary number can have only one of the two values. i.e., either 0 or 1. Let the **3-bit binary input** is b2b1b0. Here, the bits b2b2 and b0b0 denote the Most Significant Bit (MSB) and Least Significant Bit (LSB) respectively.

The digital switches shown in the above figure will be connected to ground, when the corresponding input bits are equal to ‘0’. Similarly, the digital switches shown in above figure will be connected to the negative reference voltage, −VR when the corresponding input bits are equal to ‘1’.

It is difficult to get the generalized output voltage equation of a R-2R Ladder DAC. But we can find the analog output voltage values of R-2R Ladder DAC for individual binary input combinations easily.

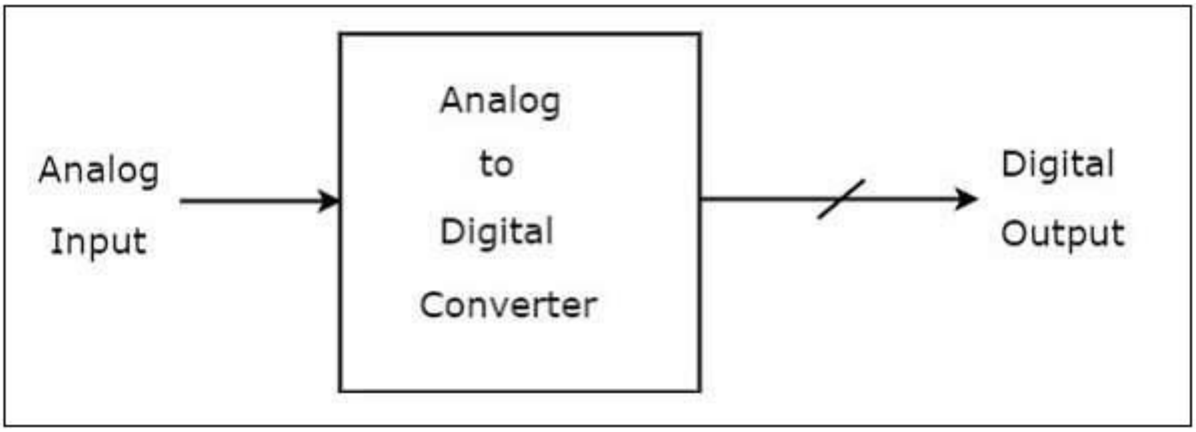
The **advantages** of a R-2R Ladder DAC are as follows −

- R-2R Ladder DAC contains only two values of resistor: R and 2R. So, it is easy to select and design more accurate resistors.
- If a greater number of bits are present in the digital input, then we have to include required number of R-2R sections additionally.

Due to the above advantages, R-2R Ladder DAC is preferable over binary weighted resistor DAC.

An Analog to Digital Converter **(ADC)** converts an analog signal into a digital signal. The digital signal is represented with a binary code, which is a combination of bits 0 and 1.

The **block diagram** of an ADC is shown in the following figure.,



There are **two types** of ADCs: Direct type ADCs and Indirect type ADC.

If the ADC performs the analog to digital conversion directly by utilizing the internally generated equivalent digital (binary) code for comparing with the analog input, then it is called as **Direct type ADC**.

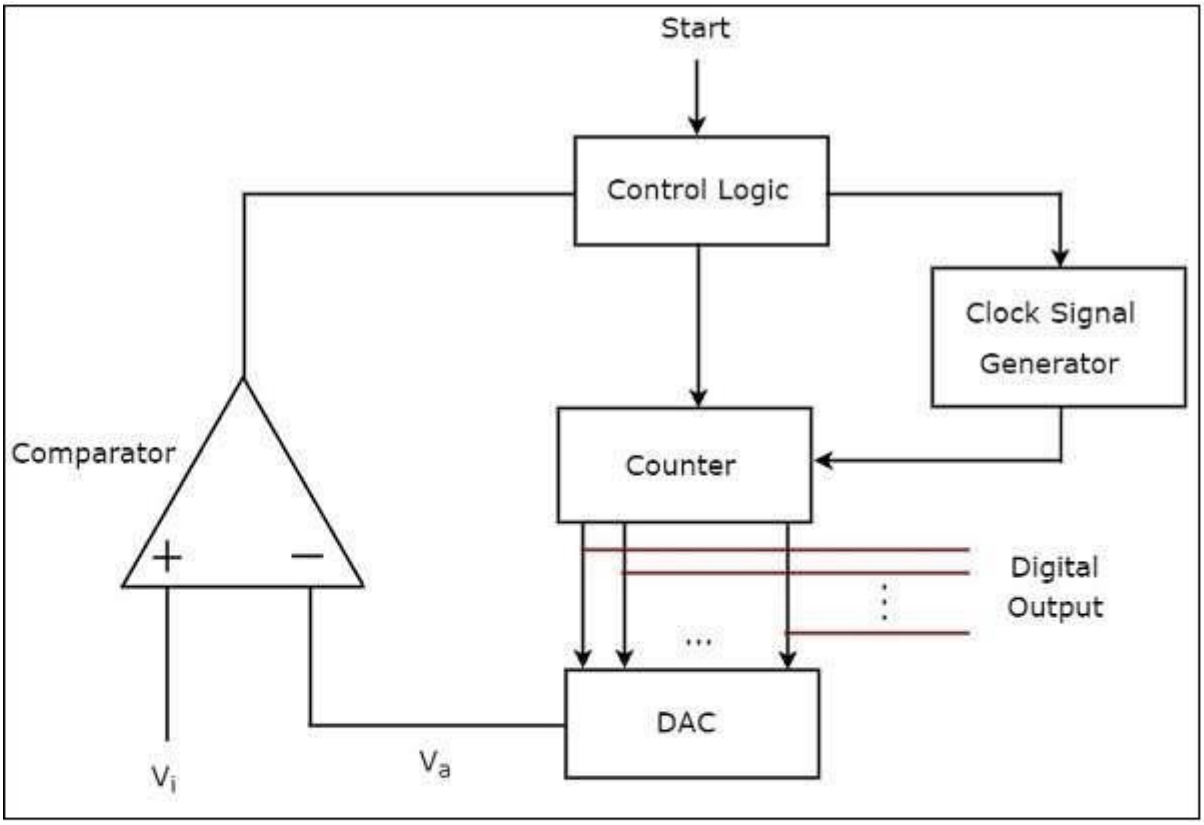
The following are the **examples** of Direct type ADCs −

- Counter type ADC
- Successive Approximation ADC
- Flash type ADC

Counter type ADC

A **counter type ADC** produces a digital output, which is approximately equal to the analog input by using counter operation internally.

The **block diagram** of a counter type ADC is shown in the following figure



The counter type ADC mainly consists of 5 blocks: Clock signal generator, Counter, DAC, Comparator and Control logic.

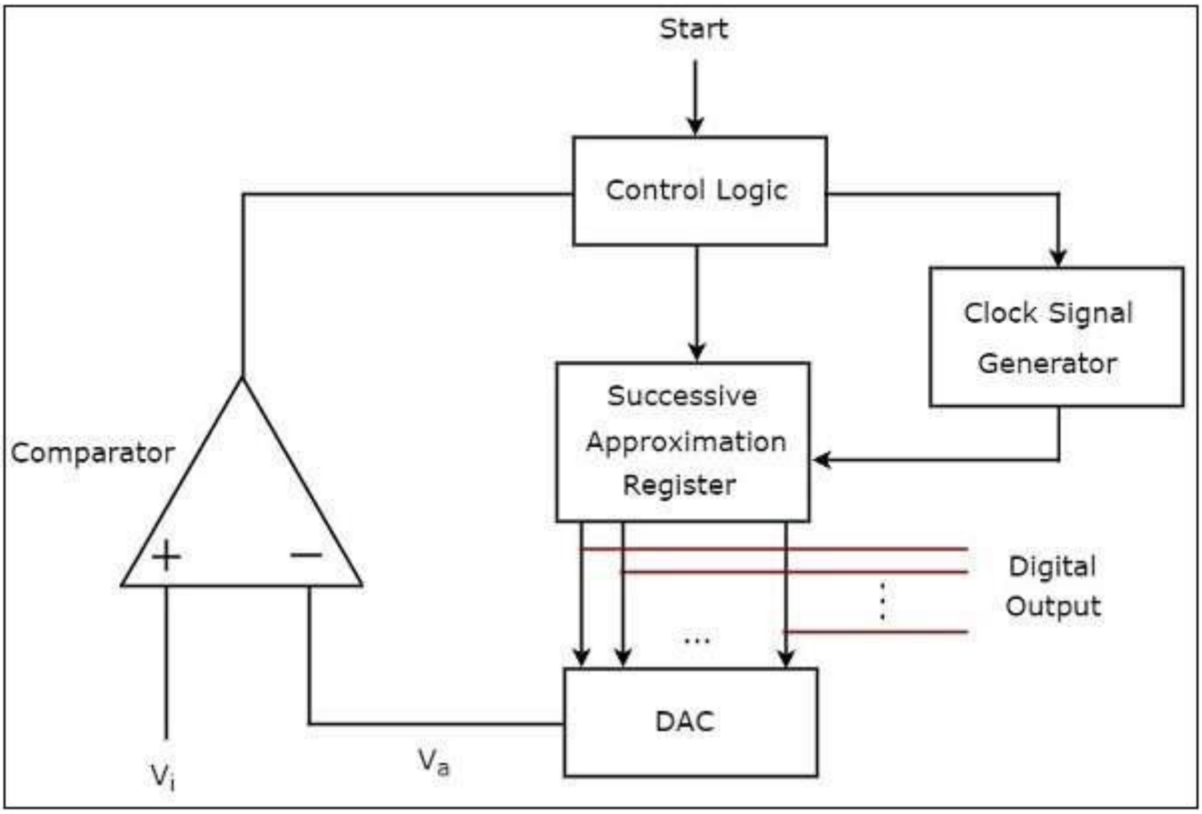
The **working** of a counter type ADC is as follows −

- The **control logic** resets the counter and enables the clock signal generator in order to send the clock pulses to the counter, when it received the start commanding signal.
- The **counter** gets incremented by one for every clock pulse and its value will be in binary (digital) format. This output of the counter is applied as an input of DAC.
- **DAC** converts the received binary (digital) input, which is the output of counter, into an analog output. Comparator compares this analog value, Va with the external analog input value Vi.
- The **output of comparator** will be **'1'** as long as Vi is greater than. The operations mentioned in above two steps will be continued as long as the control logic receives '1' from the output of comparator.
- The **output of comparator** will be **'0'** when Vi is less than or equal to Va. So, the control logic receives '0' from the output of comparator. Then, the control logic disables the clock signal generator so that it doesn't send any clock pulse to the counter.
- At this instant, the output of the counter will be displayed as the **digital output**. It is almost equivalent to the corresponding external analog input value Vi.

Successive Approximation ADC

A **successive approximation type ADC** produces a digital output, which is approximately equal to the analog input by using successive approximation technique internally.

The **block diagram** of a successive approximation ADC is shown in the following figure



The successive approximation ADC mainly consists of 5 blocks− Clock signal generator, Successive Approximation Register (SAR), DAC, comparator and Control logic.

The **working** of a successive approximation ADC is as follows −

- The **control logic** resets all the bits of SAR and enables the clock signal generator in order to send the clock pulses to SAR, when it received the start commanding signal.
- The binary (digital) data present in **SAR** will be updated for every clock pulse based on the output of comparator. The output of SAR is applied as an input of DAC.
- **DAC** converts the received digital input, which is the output of SAR, into an analog output. The comparator compares this analog value Va with the external analog input value Vi.
- The **output of a comparator** will be ‘1’ as long as Vi is greater than Va. Similarly, the output of comparator will be ‘0’, when Vi is less than or equal to Va.

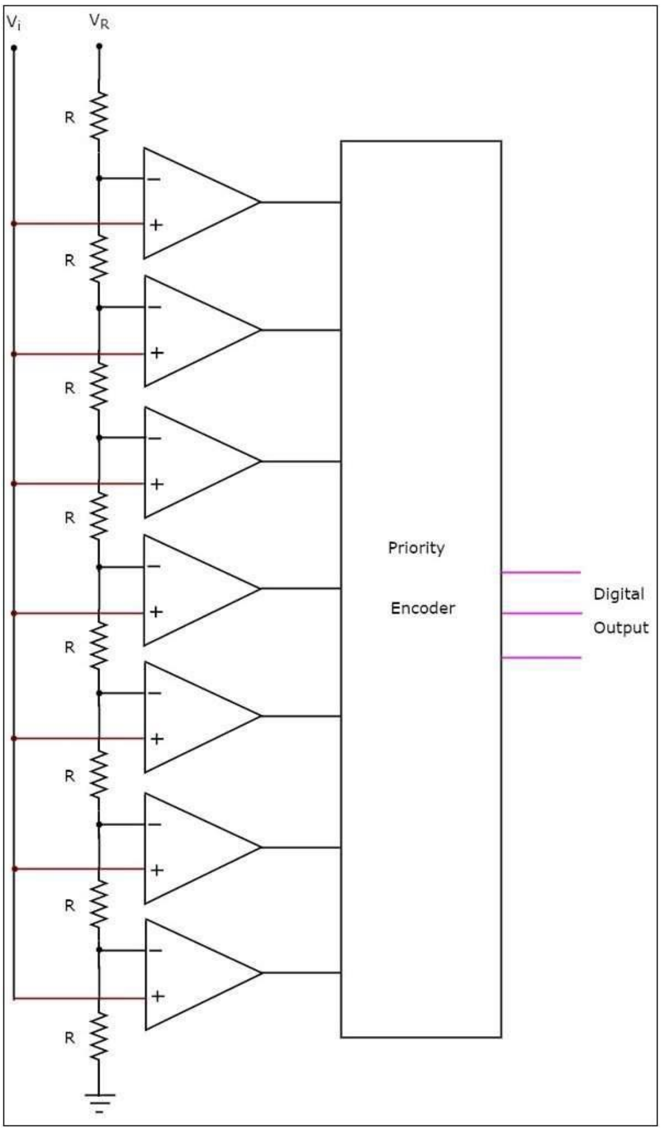
- The operations mentioned in above steps will be continued until the digital output is a valid one.

The digital output will be a valid one, when it is almost equivalent to the corresponding external analog input value Vi.

Flash type ADC

A **flash type ADC** produces an equivalent digital output for a corresponding analog input in no time. Hence, flash type ADC is the fastest ADC.

The **circuit diagram** of a 3-bit flash type ADC is shown in the following figure –



The 3-bit flash type ADC consists of a voltage divider network, 7 comparators and a priority encoder.

The **working** of a 3-bit flash type ADC is as follows.

- The **voltage divider network** contains 8 equal resistors. A reference voltage VR is applied across that entire network with respect to the ground. The voltage drop across each resistor from bottom to top with respect to ground will be the integer multiples (from 1 to 8) of VR/8.
- The external **input voltage** Vi is applied to the non-inverting terminal of all comparators. The voltage drop across each resistor from bottom to top with respect to ground is applied to the inverting terminal of comparators from bottom to top.
- At a time, all the comparators compare the external input voltage with the voltage drops present at the respective other input terminal. That means, the comparison operations take place by each comparator **parallelly**.
- The **output of the comparator** will be ‘1’ as long as Vi is greater than the voltage drop present at the respective other input terminal. Similarly, the output of comparator will be ‘0’, when, Vi is less than or equal to the voltage drop present at the respective other input terminal.
- All the outputs of comparators are connected as the inputs of **priority encoder**. This priority encoder produces a binary code (digital output), which is corresponding to the high priority input that has ‘1’.
- Therefore, the output of priority encoder is nothing but the binary equivalent **(digital output)** of external analog input voltage, Vi.

The flash type ADC is used in the applications where the conversion speed of analog input into digital data should be very high.

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