ANALOG AND PULSE CIRCUITS

Course code: AECB11

II B.Tech IV semester

Regulation: IARE R-18

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CO's	Course outcomes
CO1	Discuss the frequency response and analysis of multistage amplifiers and transistor at high frequency.
CO2	Analyze the effect of feedback on Amplifier characteristics in feedback amplifiers.
CO3	Discuss the frequency response of various oscillators and analyze the large signal and tuned amplifiers.
CO4	Understand the linear wave shaping and different types of sampling gates with operating principles using diodes, transistors.
CO5	Analysis and Design of Bistable, Monostable, Astable Multivibrators and Schmitt trigger using Transistors.

MODULE– I
MULTISTAGE AMPLIFIERS

CLOs	Course Learning Outcome
CLO1	Understand the classification of amplifiers, distortions in amplifiers and different coupling schemes used in amplifiers.
CLO2	Analyze various multistage amplifiers such as Darlington, Cascode etc.
CLO3	Understand and remember the concept of Hybrid - model of Common Emitter transistor.

MODULE - I

❖ Multistage Amplifiers

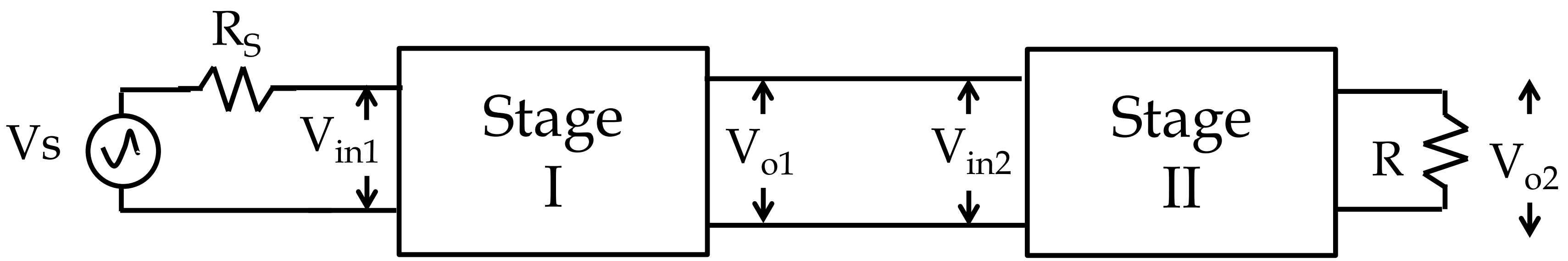
I. Classification of amplifiers
II. Distortion in amplifiers
III. Different coupling schemes used in amplifiers
IV. Frequency response and analysis of multistage amplifiers
V. Cascode amplifier
VI. Darlington pair
VII. **Transistor at high frequency**:
   i. Hybrid - model of common emitter transistor model
   ii. f_{α}, β and unity gain bandwidth, gain band width product

Multistage Amplifiers

- **Need for cascading**
  - Amplifier should have desired voltage, current gain and its input impedance should match with source & output impedance with load.
  - Most of the times these requirements can't be achieved by using the single stage amplifier.
  - Hence more than one amplifier circuits are cascaded such that input and output provides impedance matching and the other stages provide most of the amplification.

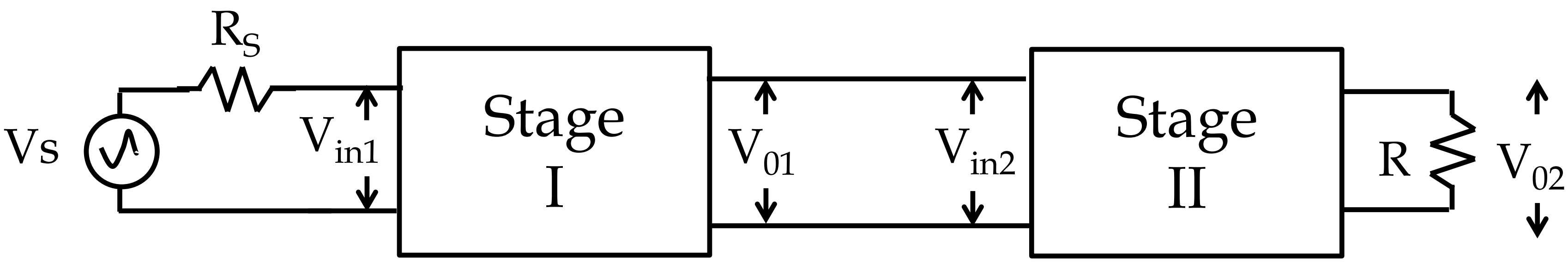
Multistage Amplifiers

- **Need for cascading**
  - Example for 2-stage cascaded amplifier is



  - These stages are connected such that output of first stage is connected to input of second stage.

Multistage Amplifiers



- Overall gain = Output/ Input = Vo2 / Vin1

$$A_V = (Vo2 / Vin2).(Vin2 / Vin1)$$

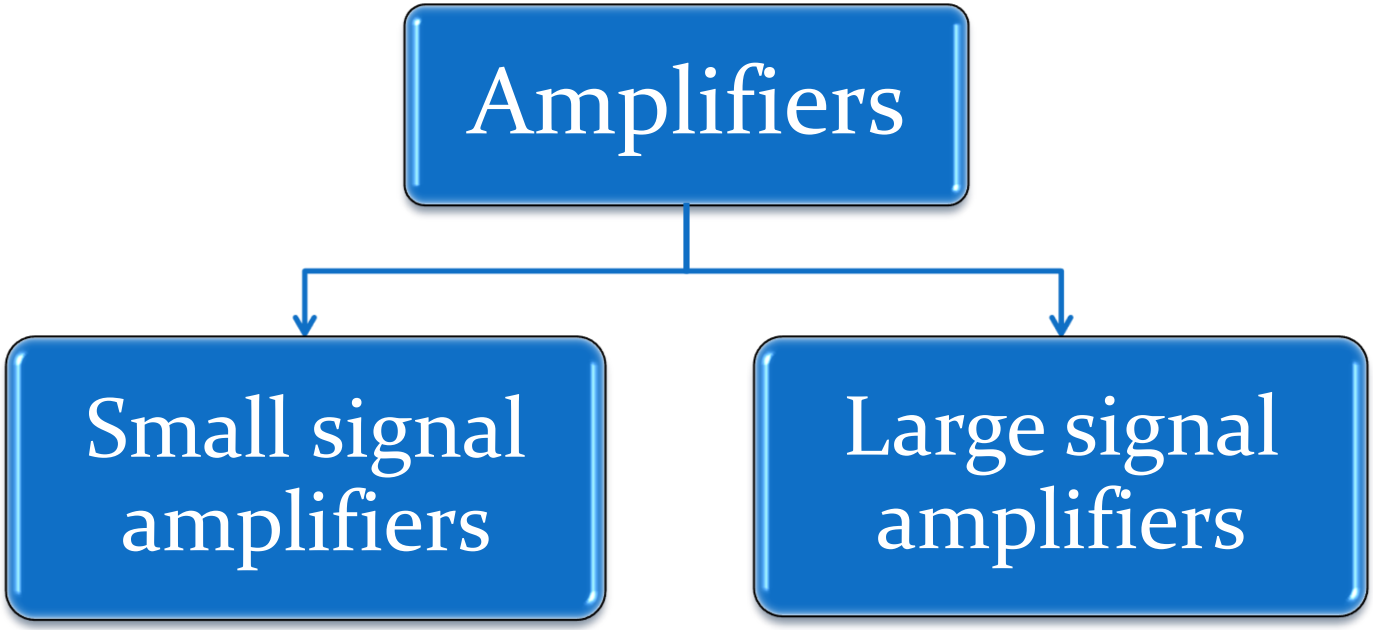
$$A_V = (Vo2 / Vin2).(Vo1 / Vin1)$$

$$A_V = A_{V2}.A_{V1}$$

- Hence voltage gain of a multi stage amplifier is the product of voltage gains of individual stages.

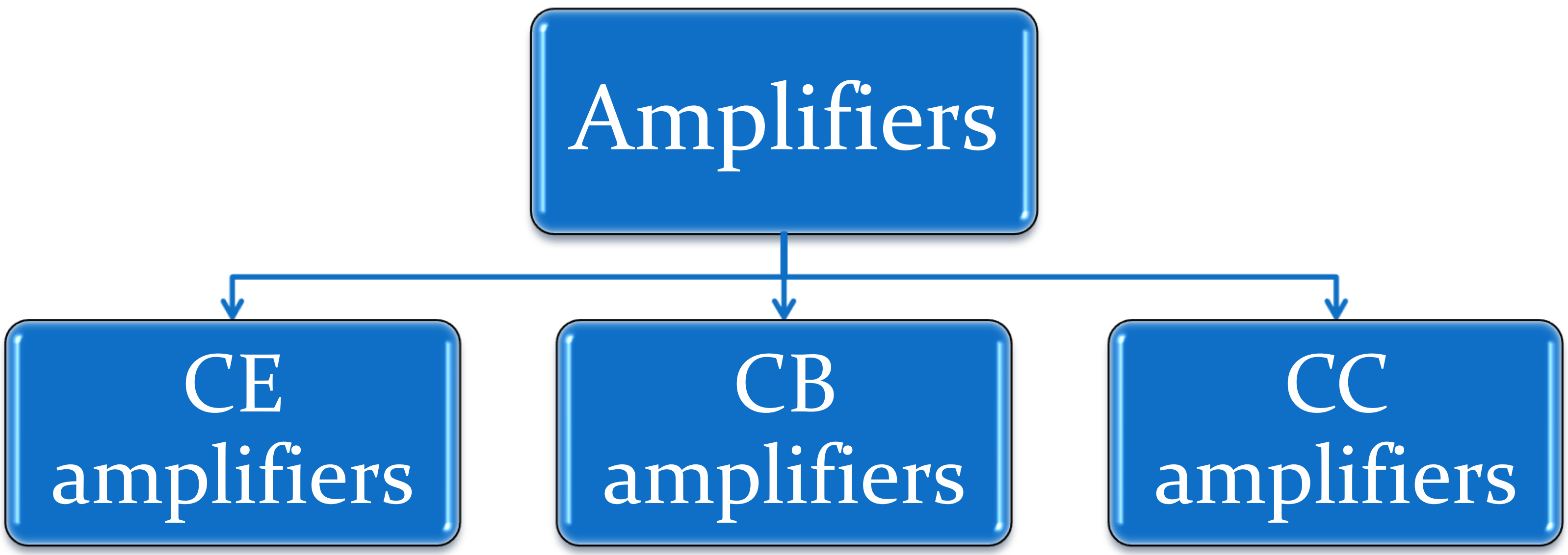
Classification of Amplifiers

I. Based on type of signal



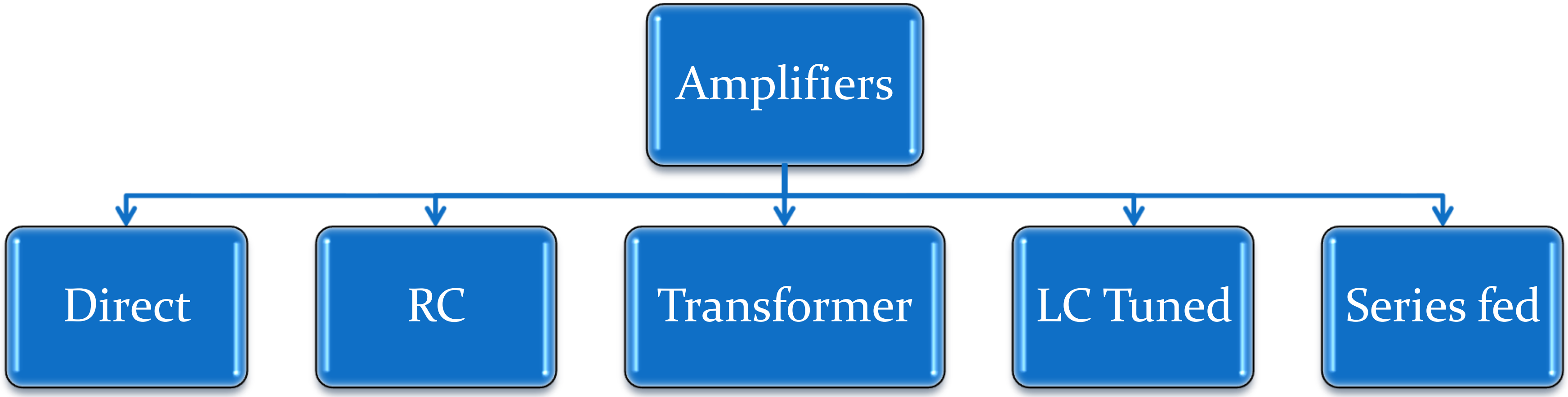
Classification of Amplifiers

II. Based on configuration



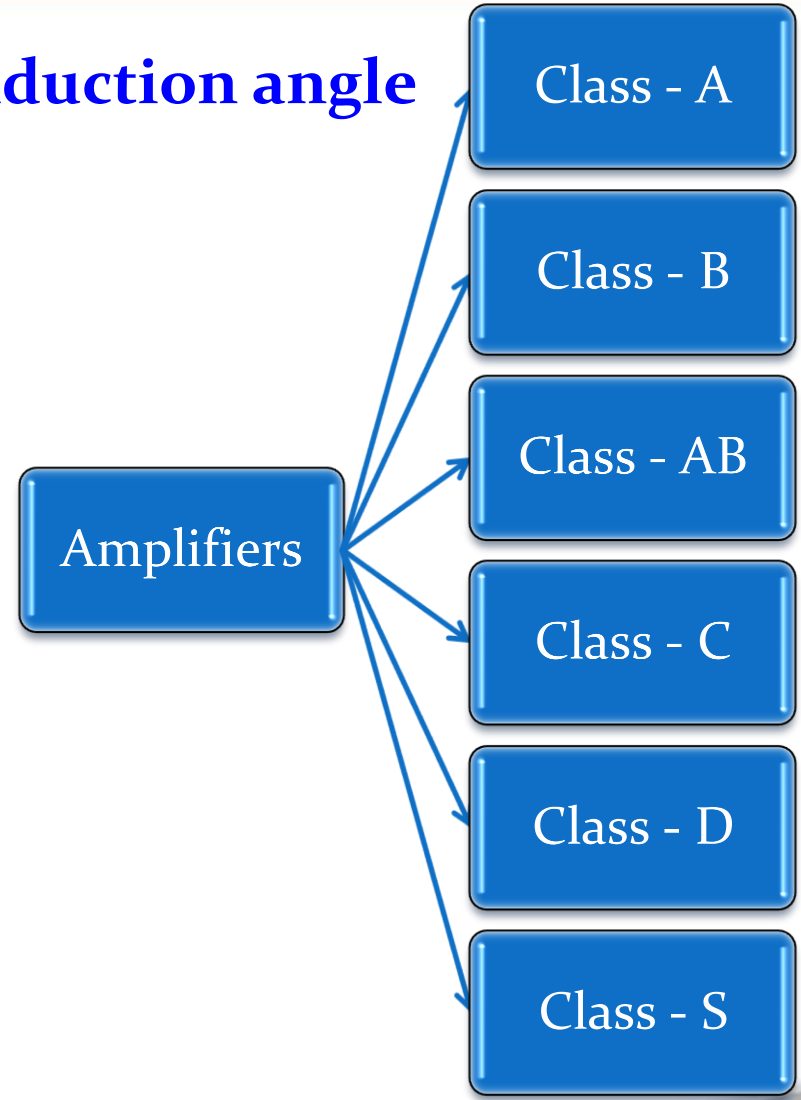
Classification of Amplifiers

III. Based on coupling



Classification of Amplifiers

IV. Based on conduction angle



Classification of Amplifiers

V. Based on frequency range

Amplifiers

AF	20 Hz – 20 KHz
RF	> 20 KHz
Video Frequency	5 KHz – 8 KHz
VLF	10 KHz – 30 KHz
LF	30 KHz – 300 KHz
MF	300 KHz – 3 MHz
HF	3 MHz – 30 MHz
VHF	30 MHz – 300 MHz
UHF	300 MHz – 3 GHz
SHF	3 GHz – 30 GHz

Distortion in amplifiers

- The input signal applied to amplifiers is alternating in nature.
- The basic features of any alternating circuit are amplitude, frequency and phase.
- The amplifier output should be reproduced faithfully. (i.e. no change in amplitude, frequency and phase of signal).
- The possible distortions in any amplifier are amplitude (or non linear) distortion, frequency distortion and phase (or delay) distortion.

Distortion in amplifiers

I. **Amplitude (non linear or harmonic) distortion**

- In practical circuits, the dynamic characteristics of a transistor are not perfectly linear in the active region.
- Due to such non-linearities in the dynamic characteristics, the waveform of the o/p voltage differs from that of the i/p signal.
- Such distortion is called "non-linear" or "amplitude" distortion.

Distortion in amplifiers

II. Frequency distortion

- This type of distortion exists when the signal components of different frequencies are amplified differently.
- This distortion may be caused by the internal device capacitances.
- If the frequency response is not a horizontally straight line over the range of frequencies under consideration, the circuit is said to exhibit frequency distortion.

Distortion in amplifiers

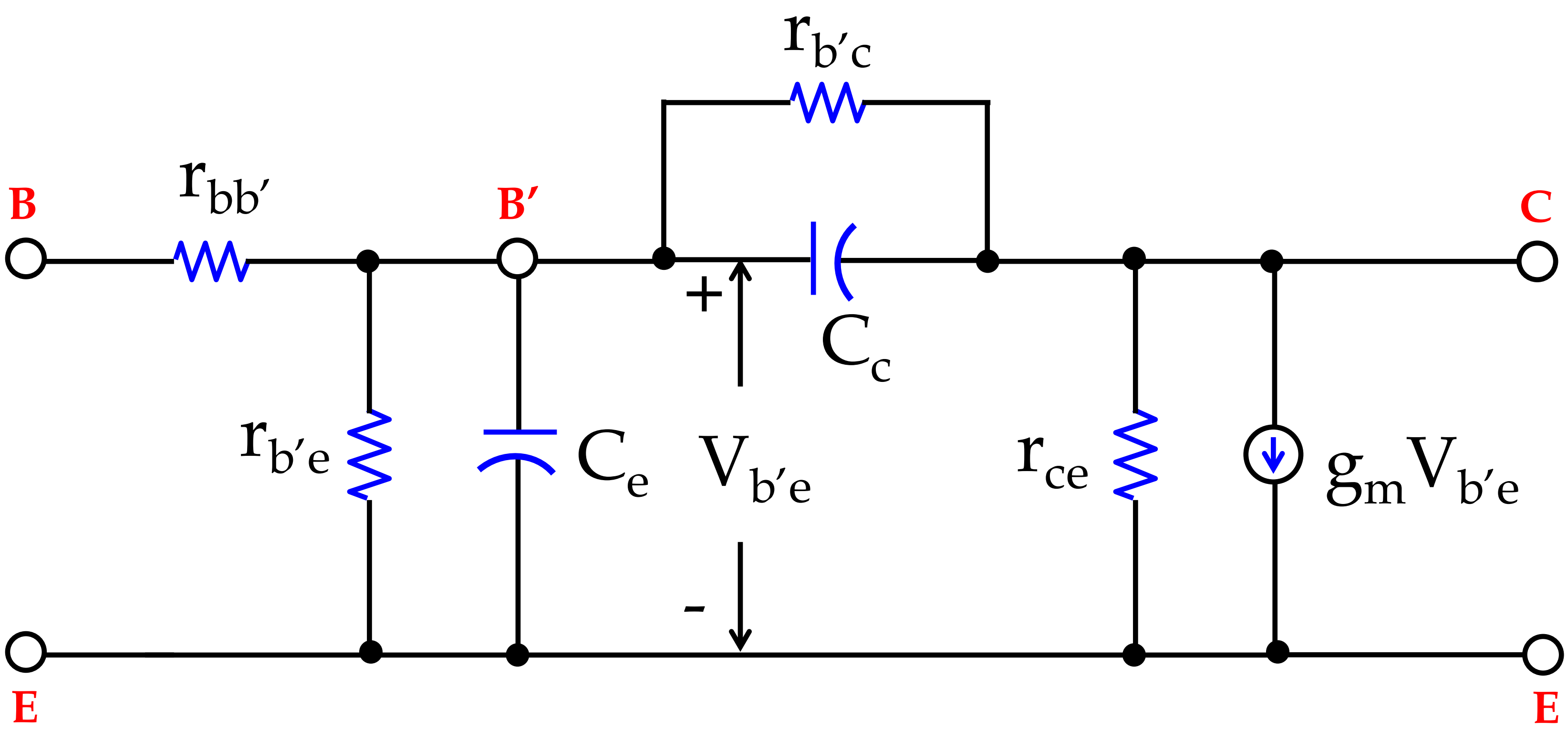
III. Delay or phase distortion

- It results due to unequal phase shifts of signals of different frequencies.
- When this distortion exists, the phase angle of the gain (A) depends on the frequency.

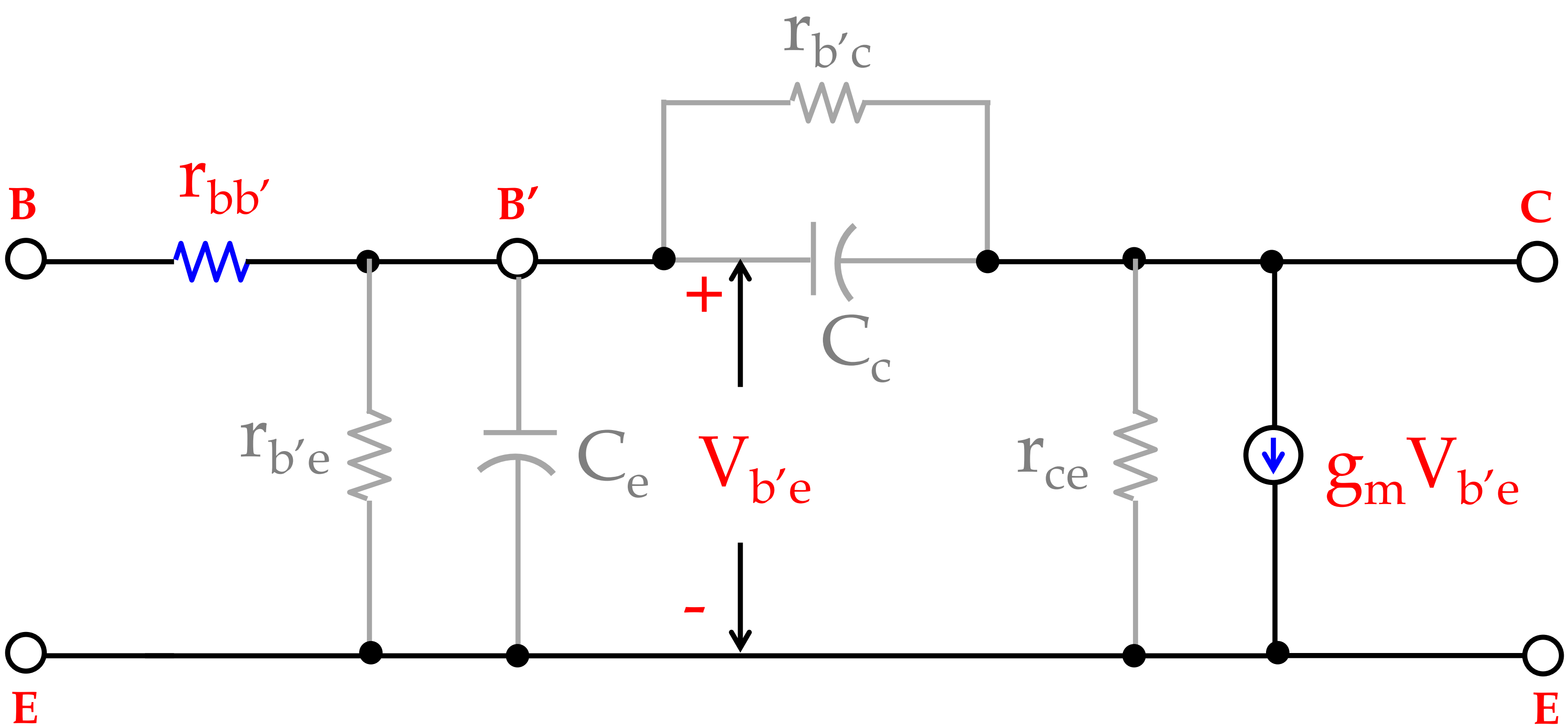
Transistor at high frequencies

- The values of h-parameters are not constant at high frequencies.
- Therefore, it is necessary to analyze transistor at each and every frequency, which is impracticable.
- At high frequency h-parameters become complex in nature.
- Due to the above reasons hybrid π model is used for high frequency analysis of the transistor.
- This model gives a reasonable compromise between **accuracy and simplicity** to do high frequency analysis of the transistor.

Hybrid-Pi (π) Common-Emitter Transistor Model



Hybrid-Pi (π) Common-Emitter Transistor Model



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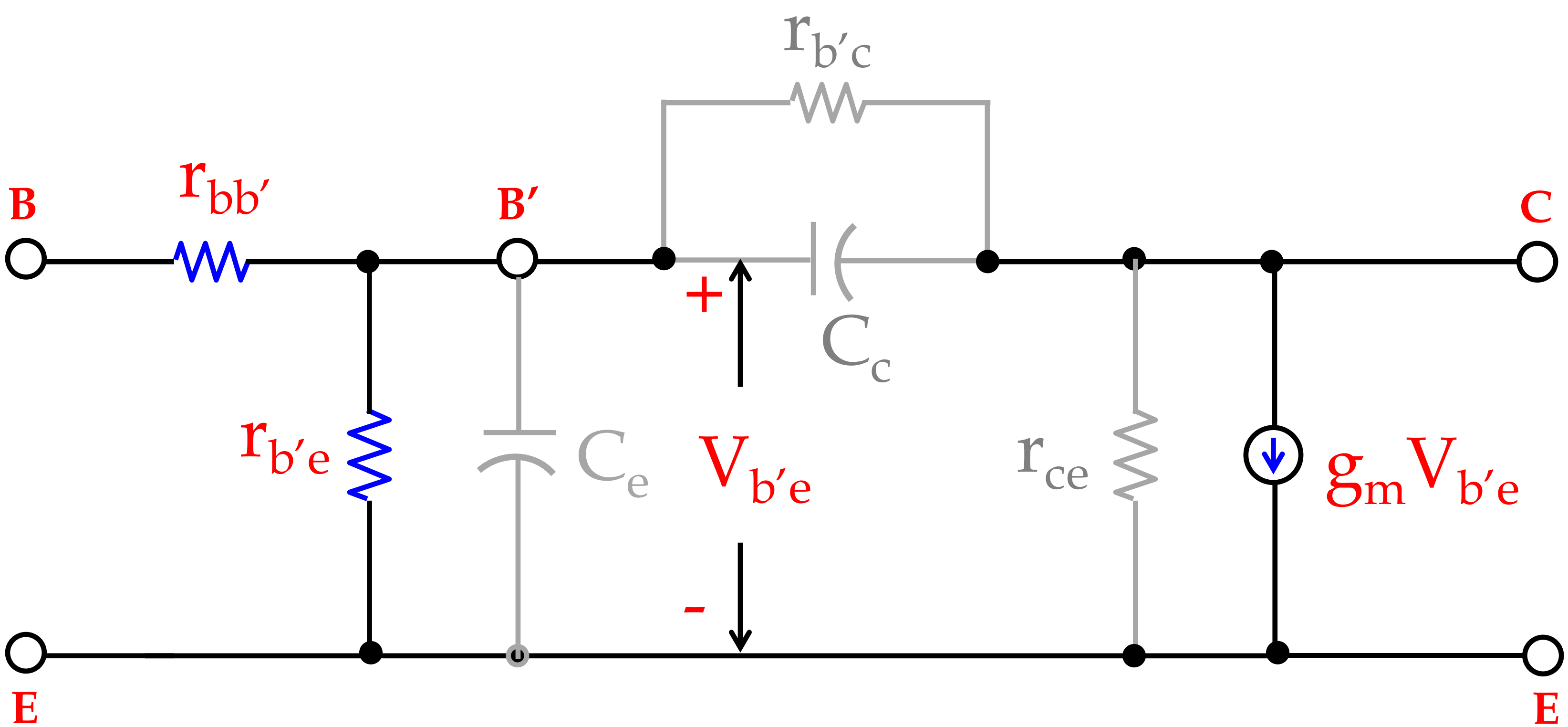

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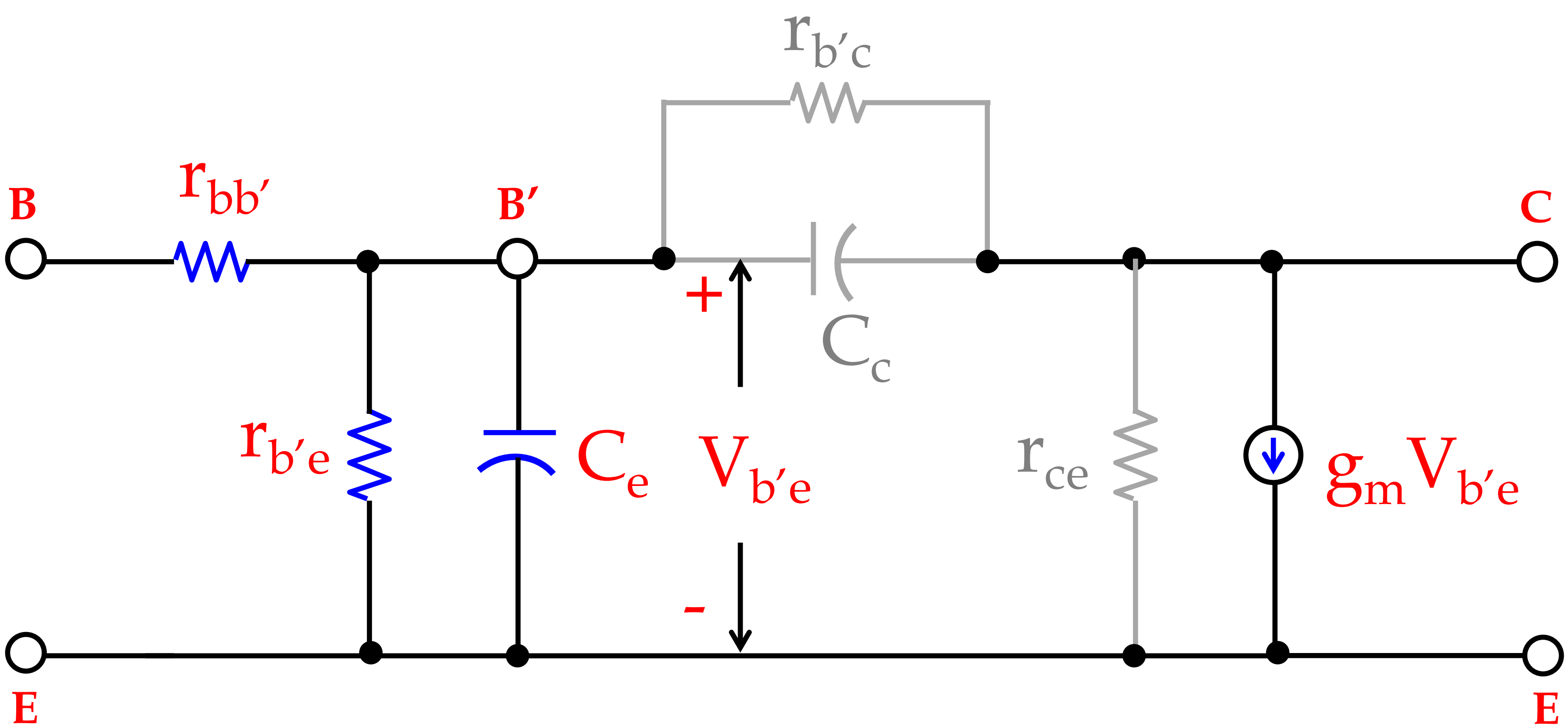

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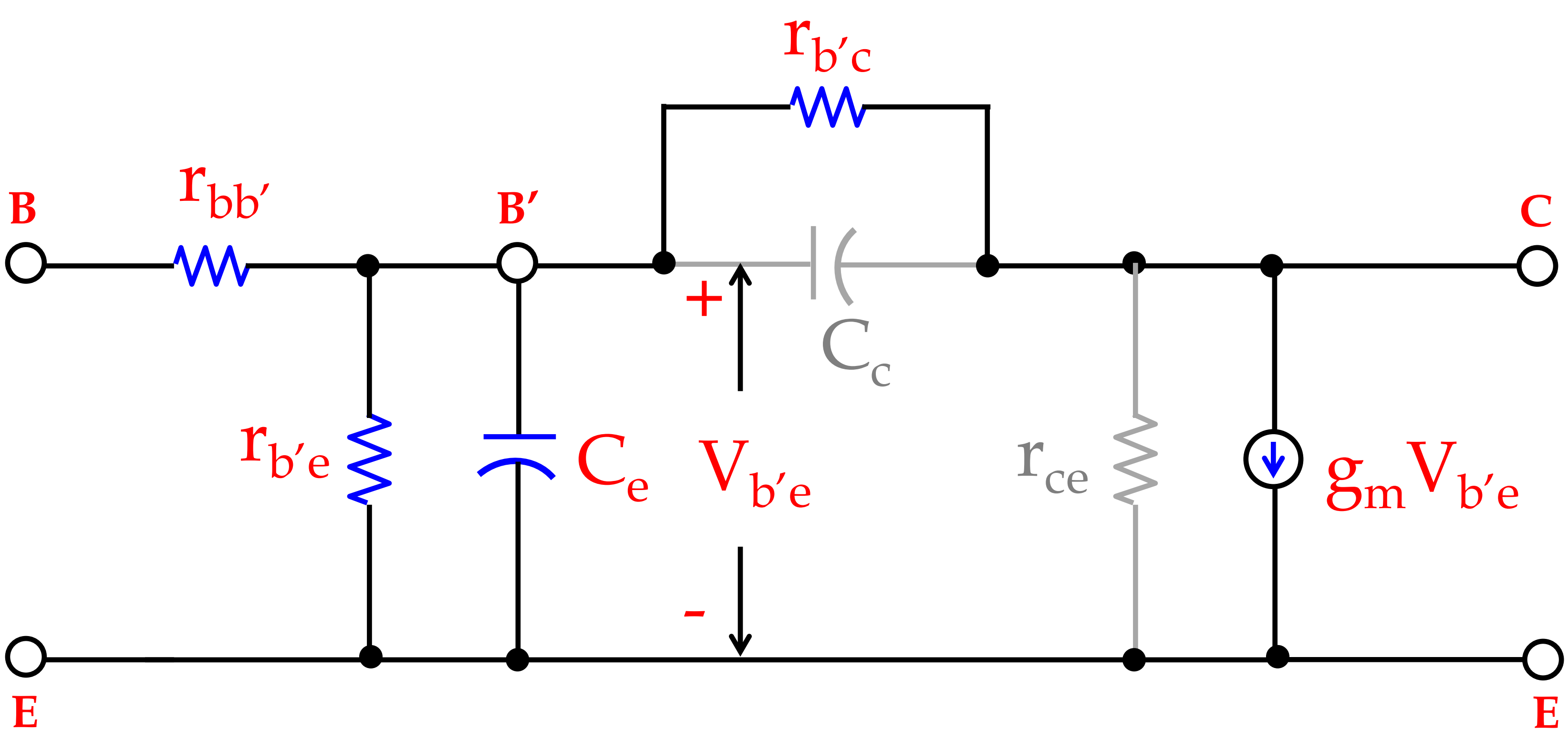
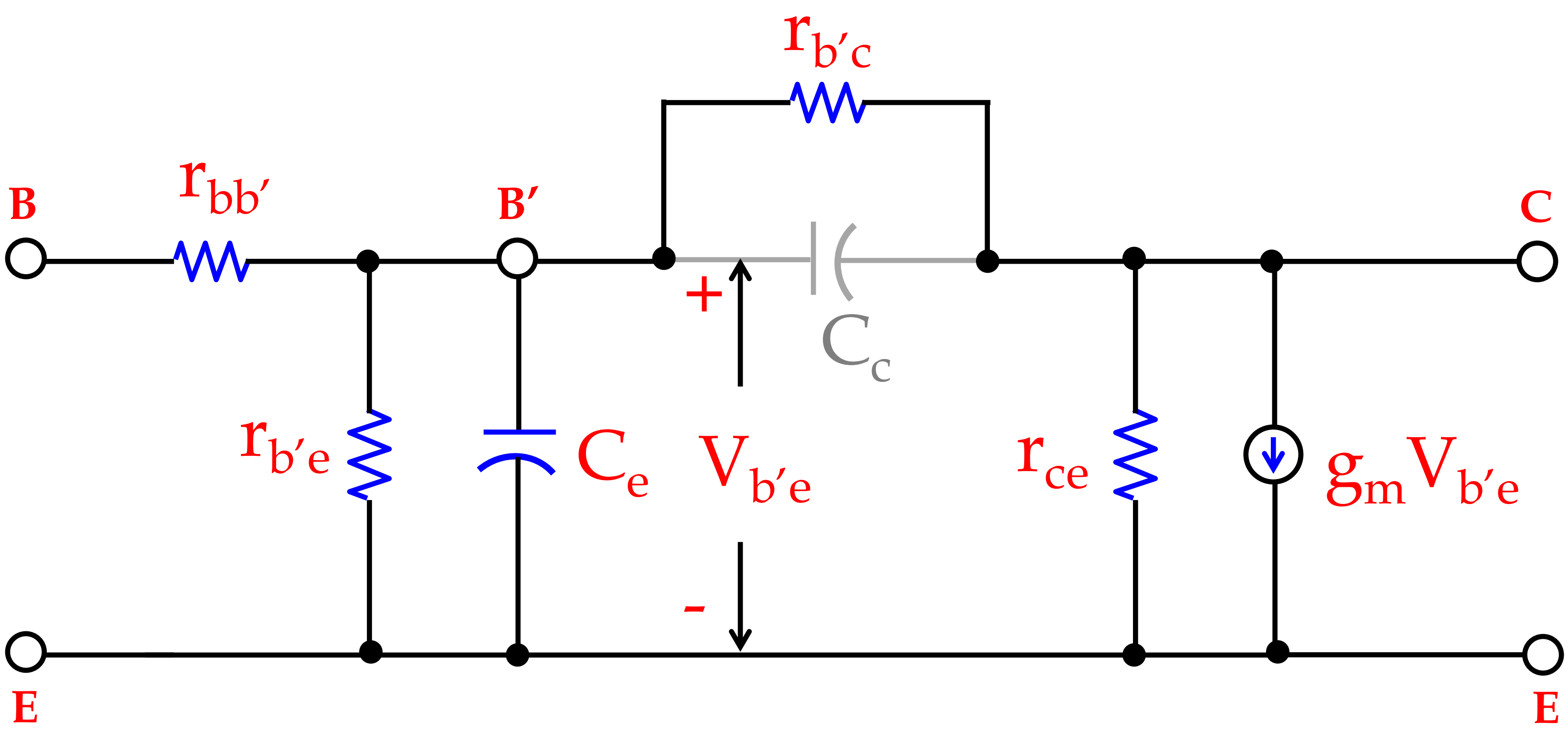
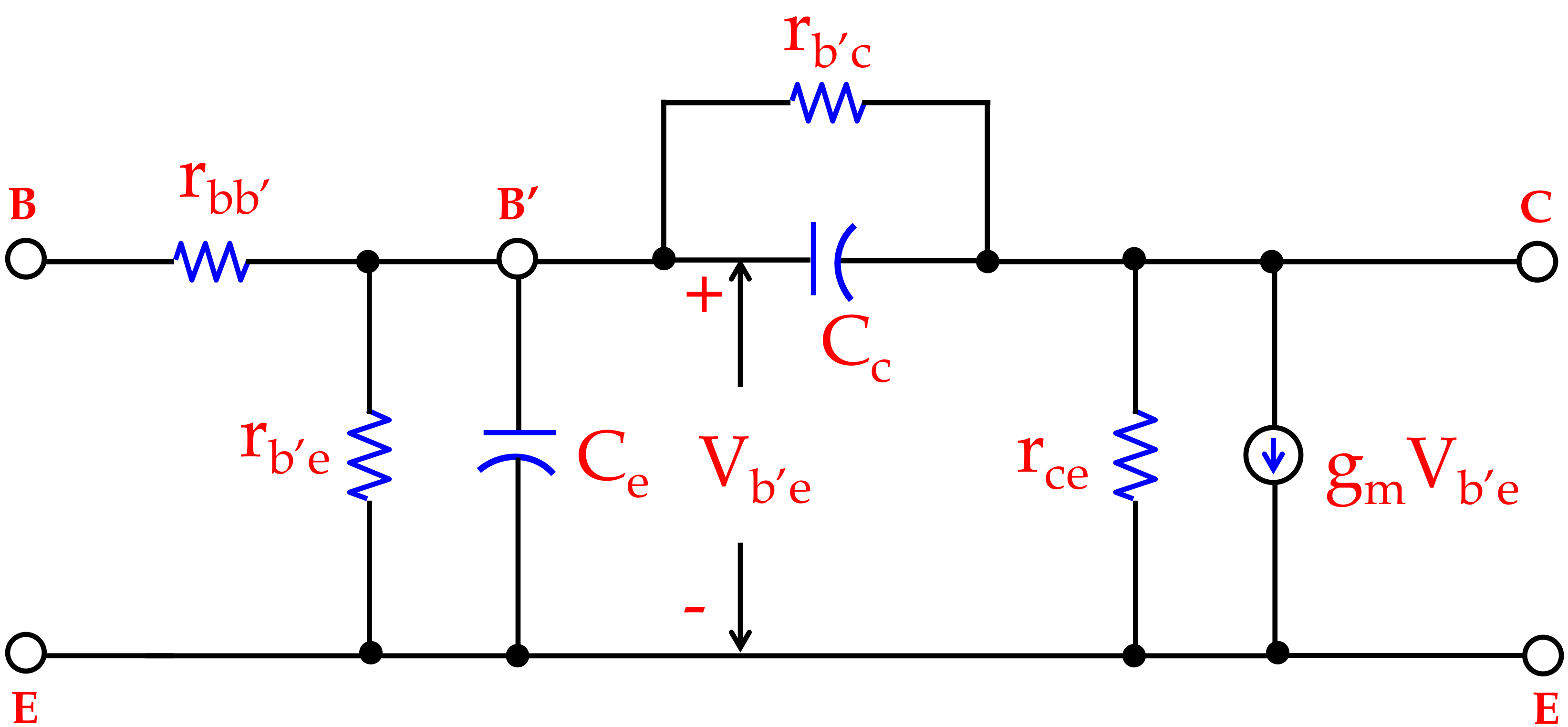


Hybrid-Pi (π) Common-Emitter Transistor Model



Hybrid-Pi (π) Common-Emitter Transistor Model



Discussion of circuit components

- C_e or $C_{b'e}$: Diffusion capacitance between B' and E
- C_c or $C_{b'c}$: Collector junction barrier capacitance between B' and C
- $r_{bb'}$: Ohmic base-spreading resistance
- $r_{b'e}$: Resistance between B' and E
- $r_{b'c}$: Resistance between reverse biased B' and C
- g_m : Transistor conductance
- r_{ce} : Output resistance between C and E

Hybrid-π Parameter Values

- At room temperature and I_C=1.3mA

Parameter	Value
g_m	50 mA/V
$r_{bb'}$	100 Ω
$r_{b'e}$	1 KΩ
$r_{b'c}$	4 MΩ
r_{ce}	80 KΩ
C_c or $C_{b'c}$	3 pF
C_e or $C_{b'e}$	100 pF

Analysis of Hybrid-Pi (π) C-E Transistor Model

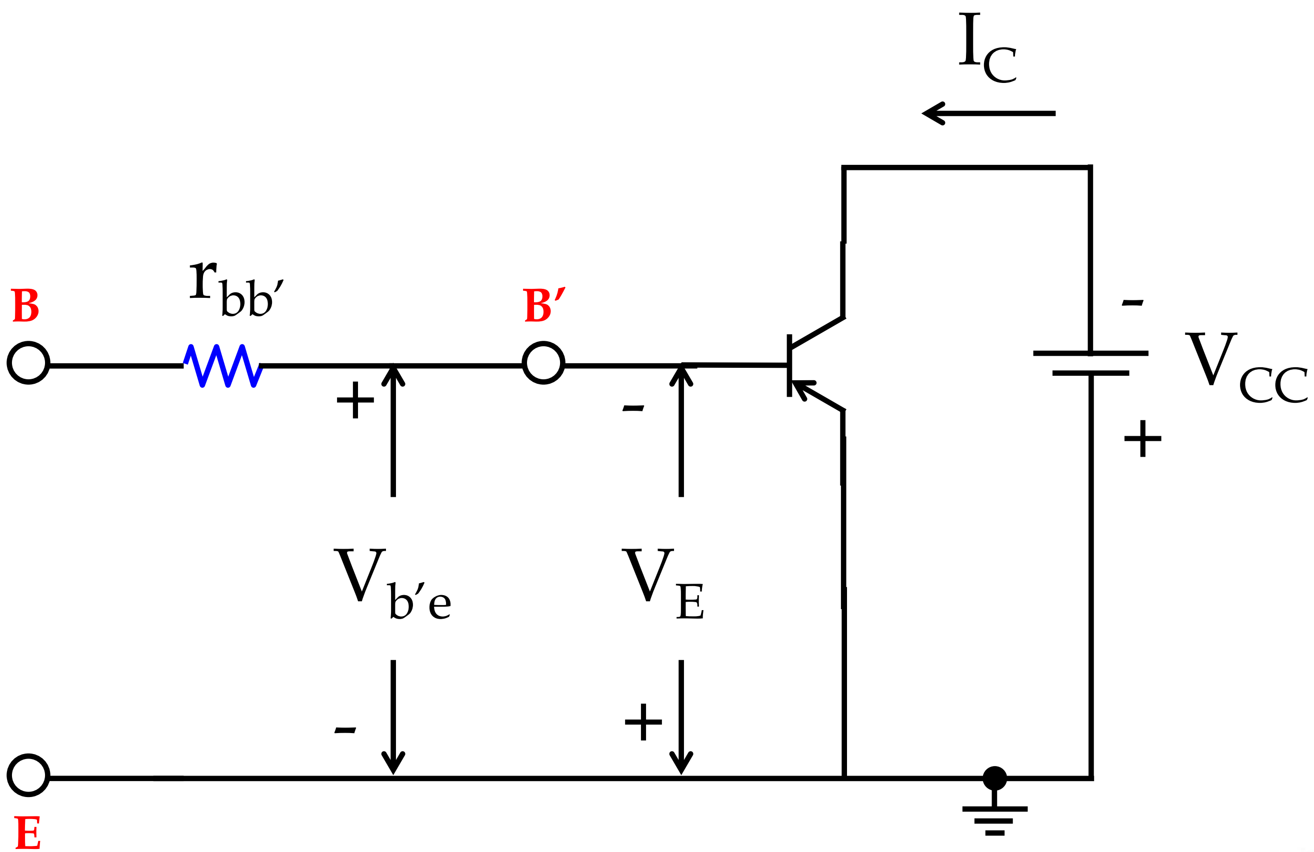
1. Hybrid-Pi (π) Conductances

2. Hybrid-Pi (π) Capacitances

Hybrid-Pi (π) Conductances

1. Transistor conductance g_m
2. The input Conductance $g_{b'e}$
3. Feedback Conductance $g_{b'c}$
4. The base-spreading resistance $r_{bb'}$
5. The output Conductance g_{ce}

1. Transistor Transconductance g_m



1. Transistor Transconductance g_m

- It is the ration of rate of change of collector current to the rate of change of $V_{b'e}$

$$g_m = \frac{\partial I_C}{\partial V_{b'e}} \qquad (1)$$

- The fundamental collector current equation is

$$I_C = I_{CO} - \alpha_O I_E \qquad (2)$$

Where α_O is current amplification factor

$$\partial I_C = -\alpha_O \partial I_E \qquad (3)$$

1. Transistor Transconductance g_m

- From (1) and (2)

$$g_m = -\alpha_O \frac{\partial I_E}{\partial V_{b'e}} \qquad (4)$$

- For p-n-p transistor, $V_E = -V_{b'e}$

$$g_m = \alpha_O \frac{\partial I_E}{\partial V_{b'e}} \qquad (5)$$

- If the emitter resistance is r_e,

$$r_e = \frac{\partial V_E}{\partial I_E} \qquad (6)$$

- Then

$$g_m = \frac{\alpha_o}{r_e} \qquad (7)$$

1. Transistor Transconductance g_m

- The dynamic resistance of a forward-biased diode is as

$$r_e = \frac{V_T}{I_E} \qquad (8)$$

$$Where \quad V_T = \frac{kT}{q}$$

- Hence

$$g_m = \frac{\alpha_o I_E}{V_T} \qquad (9)$$

$$g_m = \frac{|I_{CO} - I_C|}{V_T} \qquad (10)$$

1. Transistor Transconductance g_m

- For a p-n-p transistor Ic is negative.
- For n-p-n transistor Ic is positive, with $V_E = V_{b'e}$ leads to

$$g_m = \frac{(I_C - I_{CO})}{V_T}$$

- Hence, for either type of transistor, g_m is postive.
- Since, $|I_C| >> |I_{CO}|$

$$g_m = \frac{|I_C|}{V_T} \qquad (11)$$

1. Transistor Transconductance g_m

- By substituting, V_T

$$g_m = \frac{|I_C| q}{kT} \quad (12)$$

- At room temperature, 300°K

$$g_m = \frac{|I_C| \times 1.6 \times 10^{-19}}{1.38 \times 10^{-23} \times 300}$$

$$g_m = \frac{|I_C|(mA)}{26} \quad (13)$$

- For Ic=1.3mA, g_m=0.05℧ =50mA/V
- For Ic=10mA, g_m=400mA/V
- These values are much larger than the transconductance obtained with FET

2. The input Conductance $g_{b'e}$

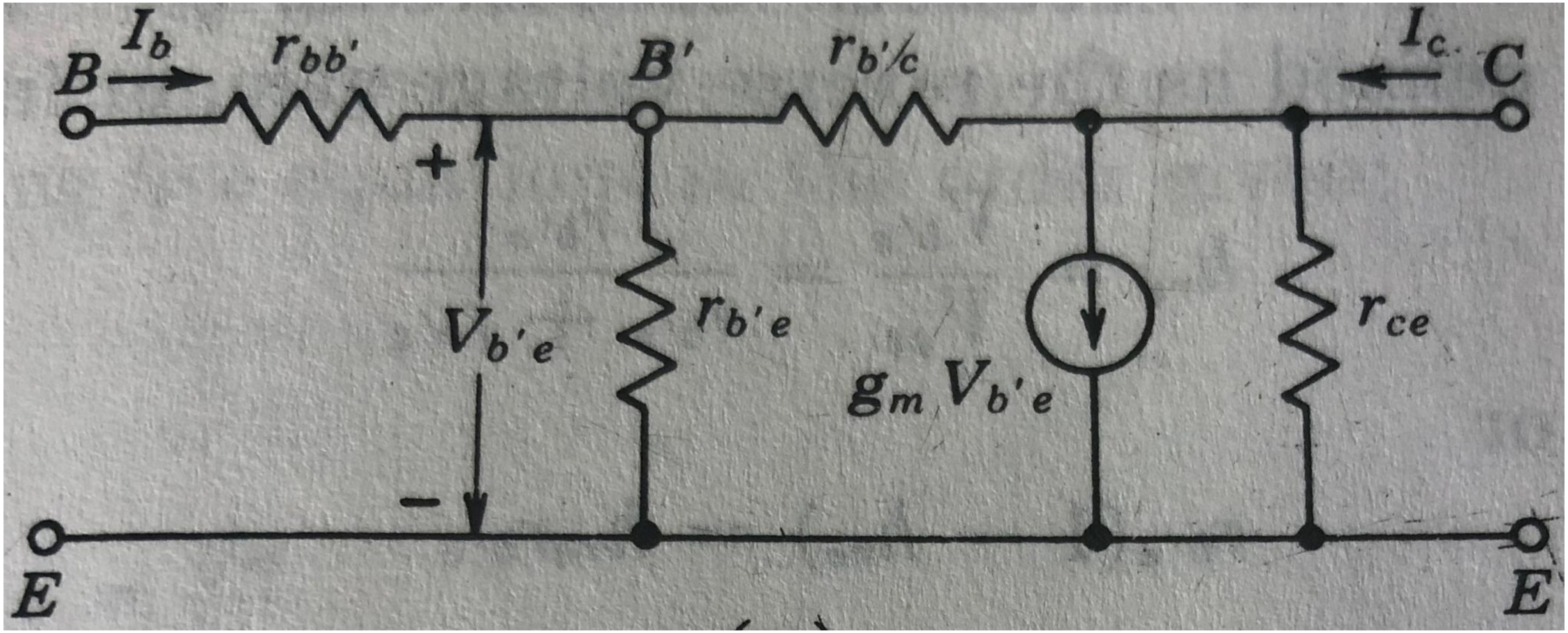


Fig. The hybrid-π model at low frequencies

2. The input Conductance $g_{b'e}$

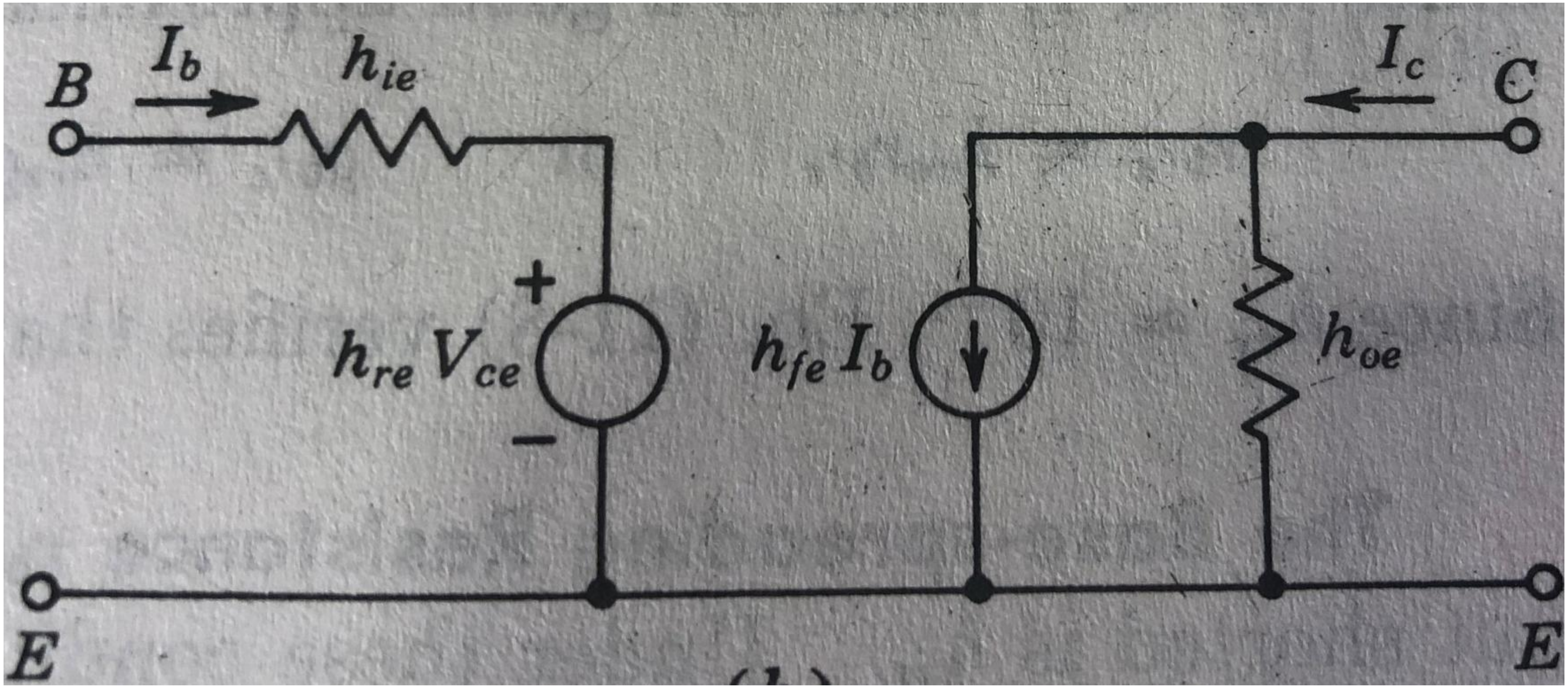


Fig. The h-parameter model at low frequencies

2. The input Conductance $g_{b'e}$

- While determining the input circuit parameters, output is short circuited i.e $V_{CE}=0$
- While determining the output circuit parameters, input is open circuited i.e $I_b=0$
- Let us assume the output is short circuited i.e $V_{CE}=0$

$$I_C=h_{fe}I_b+h_{oe}V_{ce}$$

- as $V_{CE}=0$

$$I_C=h_{fe}I_b$$

$$\Rightarrow h_{fe}=\frac{I_C}{I_b}\ldots\ldots(1)$$

2. The input Conductance $g_{b'e}$

- From hybrid π model $$V_{b'e} = r_{b'e} \cdot I_b \qquad \ldots\ldots(2)$$
- As Vce=0,

$$I_C = g_m V_{b'e}$$

$$\Rightarrow I_C = g_m r_{b'e} \cdot I_b$$

$$\Rightarrow \frac{I_C}{I_b} = g_m r_{b'e}$$

$$\Rightarrow h_{fe} = g_m r_{b'e}$$

$$\Rightarrow r_{b'e} = \frac{h_{fe}}{g_m}$$

$$\Rightarrow g_{b'e} = \frac{g_m}{h_{fe}}$$

$$\Rightarrow g_{b'e} = \frac{|I_C|}{h_{fe} V_T}$$

3. Feedback Conductance $g_{b'c}$

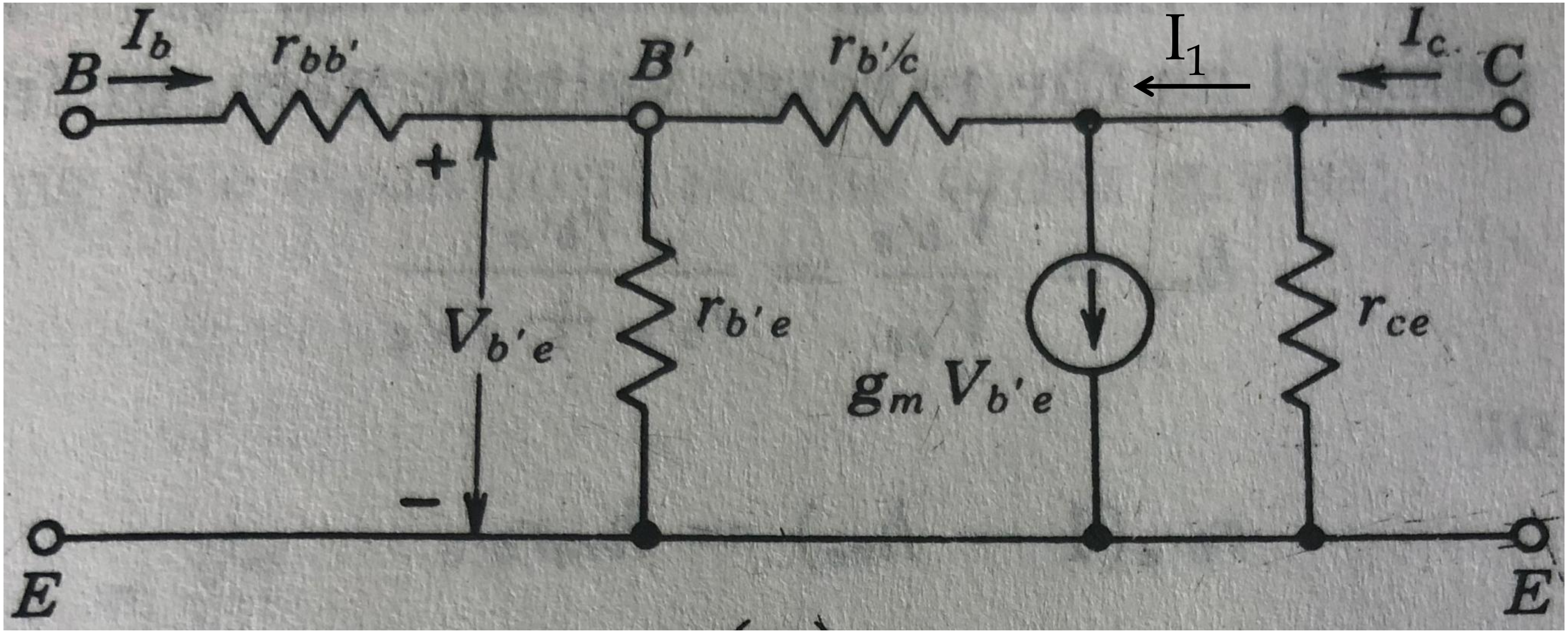


Fig. The hybrid-π model at low frequencies

3. Feedback Conductance $g_{b'c}$

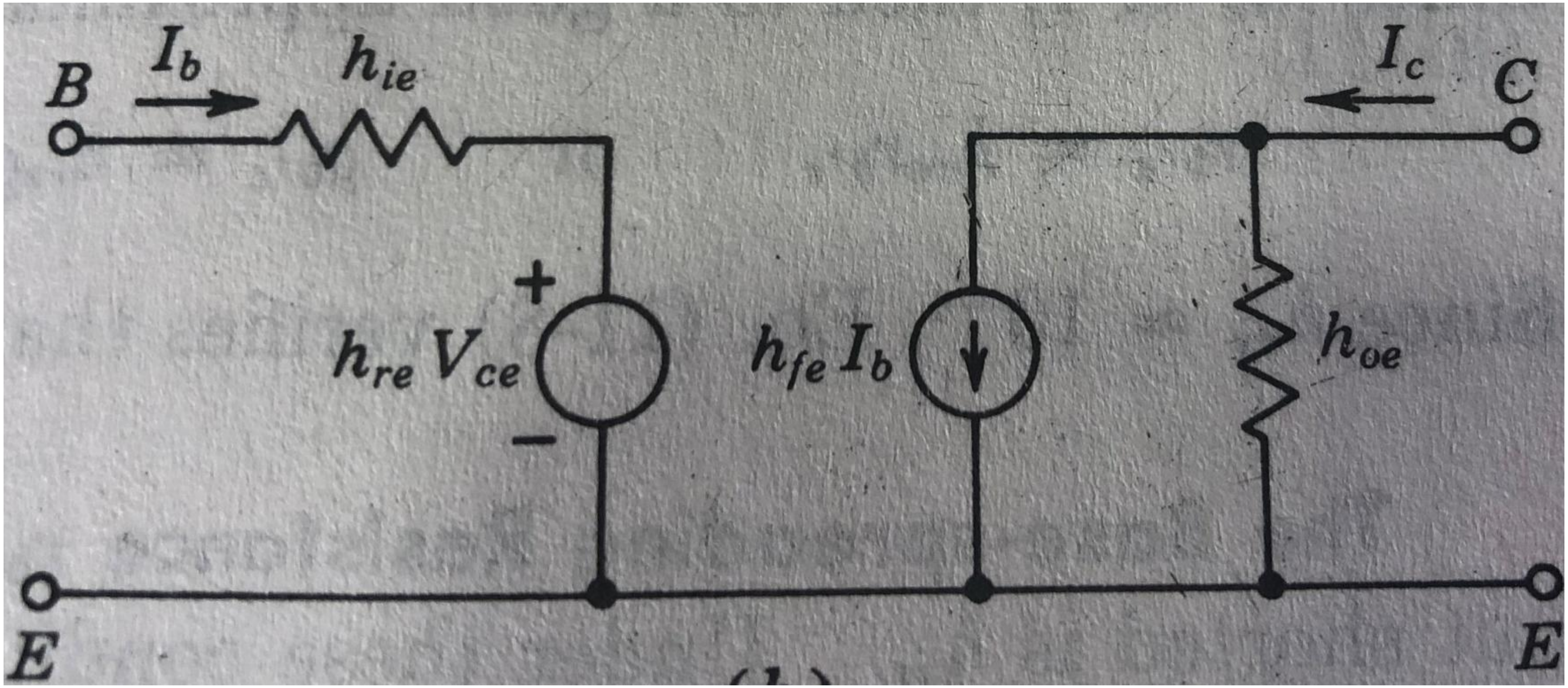


Fig. The h-parameter model at low frequencies

3. Feedback Conductance $g_{b'c}$

- As $g_{b'c}$ is feedback conductance, we need to assume the input in open circuit condition, i.e $\boldsymbol{I_b=0}$
- As $\boldsymbol{I_b=0}$,

$$V_{b'e} = h_{re} \cdot V_{ce} \quad \ldots\ldots(1)$$

- From the output part of hybrid π model

$$I_1 = \frac{V_{ce}}{r_{b'e} + r_{b'c}}$$

$$V_{b'e} = I_1 \cdot r_{b'e} = \frac{V_{ce} \cdot r_{b'e}}{r_{b'e} + r_{b'c}} \qquad (2)$$

3. Feedback Conductance $g_{b'c}$

- From (1) and (2)

$$h_{re} \cdot V_{ce} = \frac{V_{ce} \cdot r_{b'e}}{r_{b'e} + r_{b'c}}$$

$$\Rightarrow h_{re}\left(r_{b'e} + r_{b'c}\right) = r_{b'e}$$

$$\Rightarrow r_{b'c} = \frac{r_{b'e} - h_{re} r_{b'e}}{h_{re}}$$

$$\Rightarrow r_{b'c} = \frac{\left(1 - h_{re}\right) r_{b'e}}{h_{re}}$$

Since $h_{re} << 1$

$$\therefore r_{b'c} = \frac{r_{b'e}}{h_{re}}$$

$$\Rightarrow g_{b'c} = \frac{h_{re}}{r_{b'e}}$$

$$\Rightarrow g_{b'c} = h_{re} \cdot g_{b'e}$$

$$\Rightarrow g_{b'c} = \frac{h_{re}\left|I_C\right|}{h_{fe} V_T}$$

4. The base-spreading resistance $r_{bb'}$

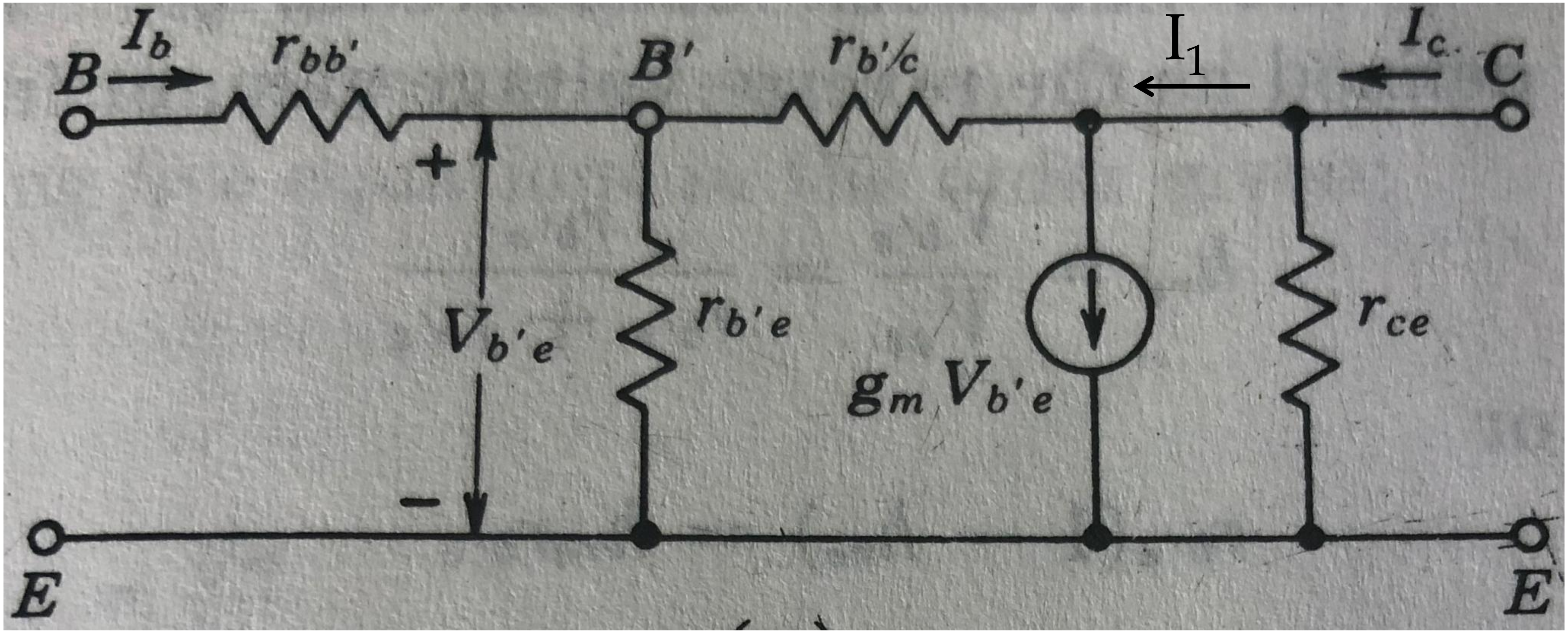


Fig. The hybrid-π model at low frequencies

4. The base-spreading resistance $r_{bb'}$

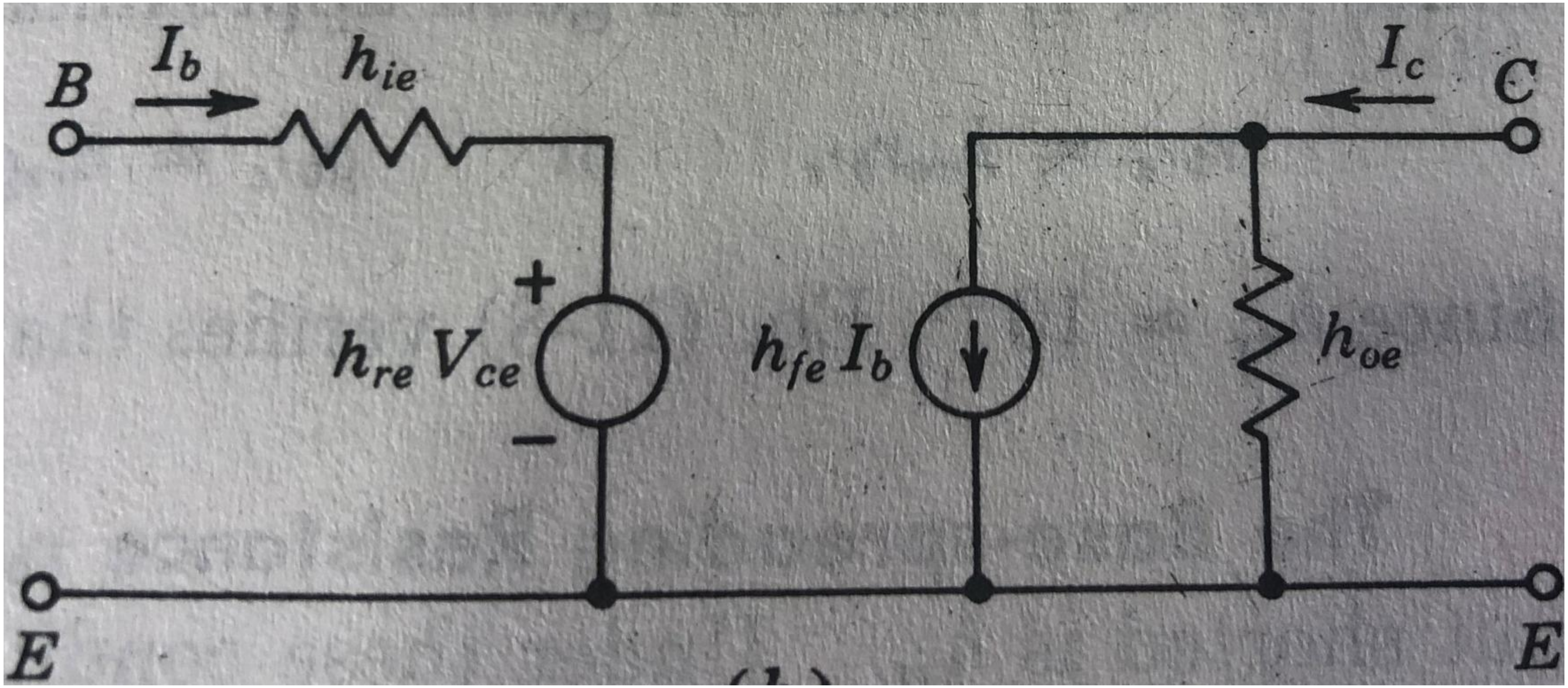


Fig. The h-parameter model at low frequencies

4. The base-spreading resistance $r_{bb'}$

- Assume output is short circuited, i.e $V_{ce}=0$
- From the h-parameter model, the input resistance

$$R_i = h_{ie} \qquad (1)\left[\because V_{ce} = 0\right]$$

- From the hybrid π model

$$R_i = r_{bb'} + \left(r_{b'e} \| r_{b'c}\right)$$

$$R_i = r_{bb'} + r_{b'e} \qquad (2) \qquad \left(\because r_{b'c} >> r_{b'e}\right)$$

4. The base-spreading resistance $r_{bb'}$

- From (1) & (2)

$$h_{ie} = r_{bb'} + r_{b'e}$$

$$r_{bb'} = h_{ie} - r_{b'e}$$

$$r_{bb'} = h_{ie} - \frac{h_{fe} V_T}{|I_C|}$$

5. The output Conductance g_{ce}

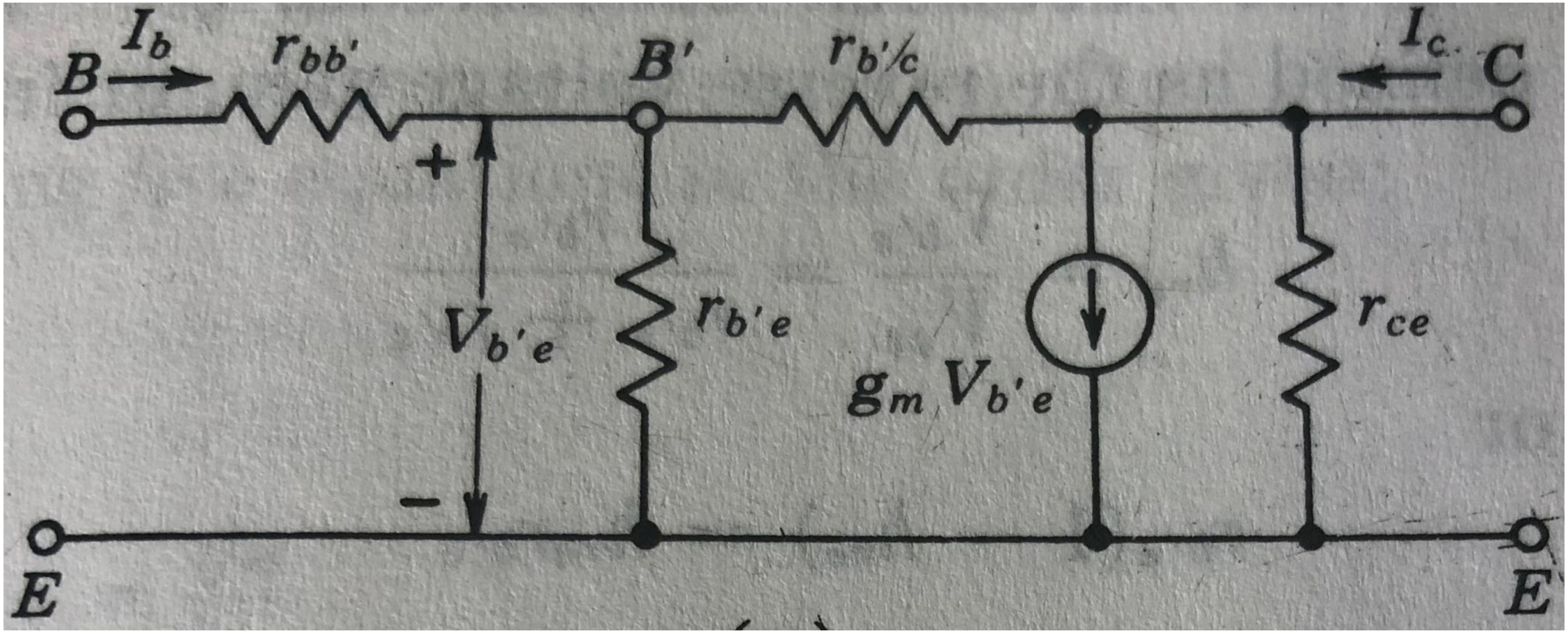


Fig. The hybrid-π model at low frequencies

5. The output Conductance g_{ce}

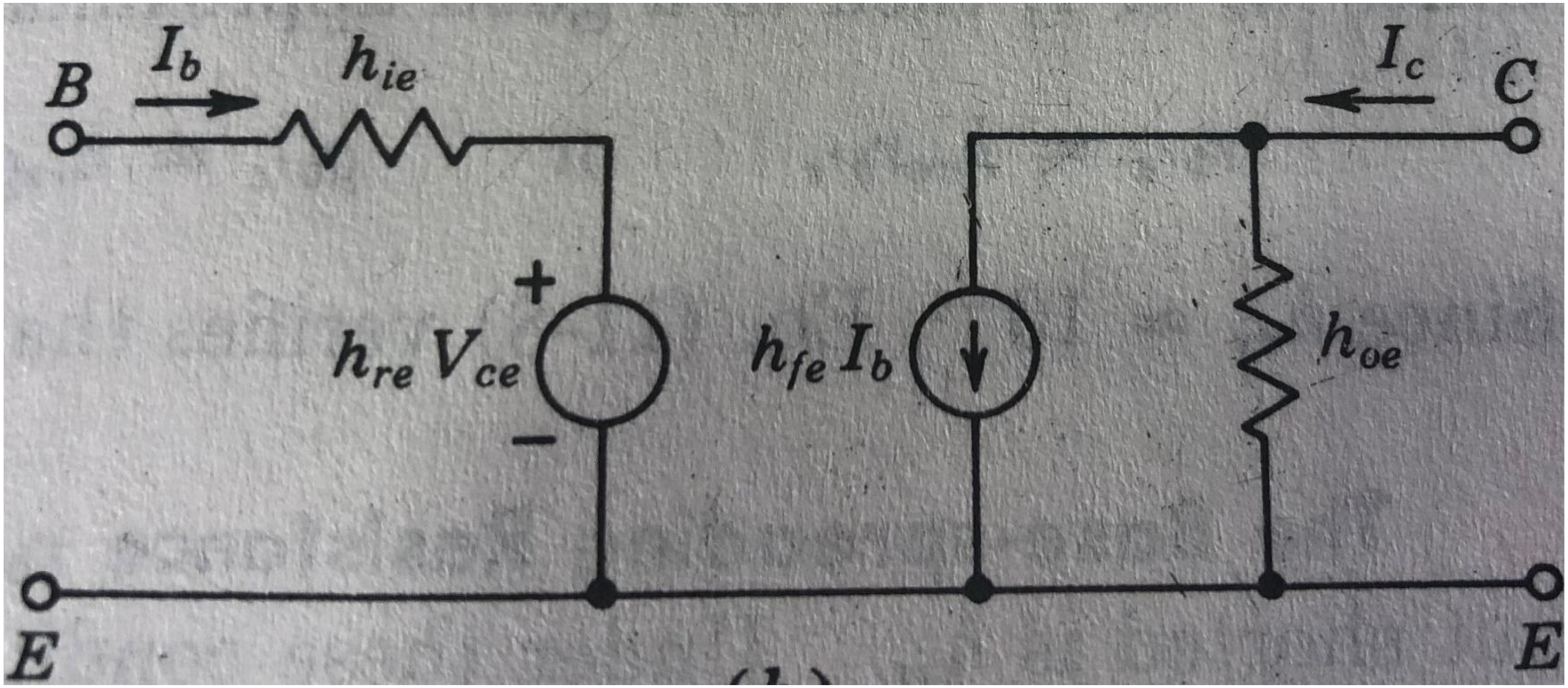


Fig. The h-parameter model at low frequencies

5. The output Conductance g_{ce}

- Make input as open circuit, i.e $I_b=0$
- From h-parameter model

$$\frac{1}{h_{oe}} = \frac{V_{ce}}{I_C}$$

$$\Rightarrow h_{oe} = \left.\frac{I_C}{V_{ce}}\right|_{I_B=0} \quad \ldots\ldots(1)$$

- From the hybrid π model, by applying KCL to the output circuit

$$I_C = \frac{V_{ce}}{r_{ce}} + g_m V_{b'e} + I_1$$

5. The output Conductance g_{ce}

$$I_C = \frac{V_{ce}}{r_{ce}} + g_m V_{b'e} + I_1$$

- By substituting the values of Vb’e and I_1

$$\Rightarrow I_C = \frac{V_{ce}}{r_{ce}} + g_m I_1 r_{b'e} + \frac{V_{ce}}{r_{b'e} + r_{b'c}}$$

$$\Rightarrow I_C = \frac{V_{ce}}{r_{ce}} + g_m \frac{V_{ce} r_{b'e}}{r_{b'e} + r_{b'c}} + \frac{V_{ce}}{r_{b'e} + r_{b'c}}$$

$$\Rightarrow \frac{I_C}{V_{ce}} = \frac{1}{r_{ce}} + g_m \frac{r_{b'e}}{r_{b'e} + r_{b'c}} + \frac{1}{r_{b'e} + r_{b'c}} \quad (2)$$

5. The output Conductance g_{ce}

- From (1) & (2)

$$\Rightarrow h_{oe} = \frac{1}{r_{ce}} + \frac{g_m r_{b'e}}{r_{b'e} + r_{b'c}} + \frac{1}{r_{b'e} + r_{b'c}}$$

$$\Rightarrow h_{oe} = \frac{1}{r_{ce}} + \frac{h_{fe}}{r_{b'e} + r_{b'c}} + \frac{1}{r_{b'e} + r_{b'c}}$$

$$\Rightarrow h_{oe} = \frac{1}{r_{ce}} + \frac{1 + h_{fe}}{r_{b'e} + r_{b'c}}$$

5. The output Conductance g_{ce}

$$\Rightarrow h_{oe} = \frac{1}{r_{ce}} + \frac{1+h_{fe}}{r_{b'e} + r_{b'c}}$$

$$\Rightarrow h_{oe} = g_{ce} + \frac{h_{fe}}{r_{b'c}} \qquad (\therefore h_{fe} >> 1 and\, r_{b'c} >> r_{b'e})$$

$$\Rightarrow \boxed{g_{ce} = h_{oe} - h_{fe} g_{b'c}}$$

Representation of Hybrid-Pi (π) parameters in terms of h-parameters

1. Transistor conductance $g_m = \frac{|I_C|}{V_T}$
2. The input Conductance $g_{b'e} = \frac{|I_C|}{h_{fe} V_T}$
3. Feedback Conductance $g_{b'c} = \frac{h_{re}|I_C|}{h_{fe} V_T}$
4. The base-spreading resistance $r_{bb'} = h_{ie} - \frac{h_{fe} V_T}{|I_C|}$
5. The output Conductance $g_{ce} = h_{oe} - h_{fe} g_{b'c}$

Typical values of h-parameters

Parameter	CE	CB	CC
h_i	1100 Ω	21.6Ω	1100Ω
h_r	2.5×10^{-4}	2.9×10^{-4}	=1
h_f	50	-0.98	-51
h_o	25 µA/V	0.49 µA/V	25 µA/V

Typical values of h-parameters

- At room temperature and I_C=1.3mA

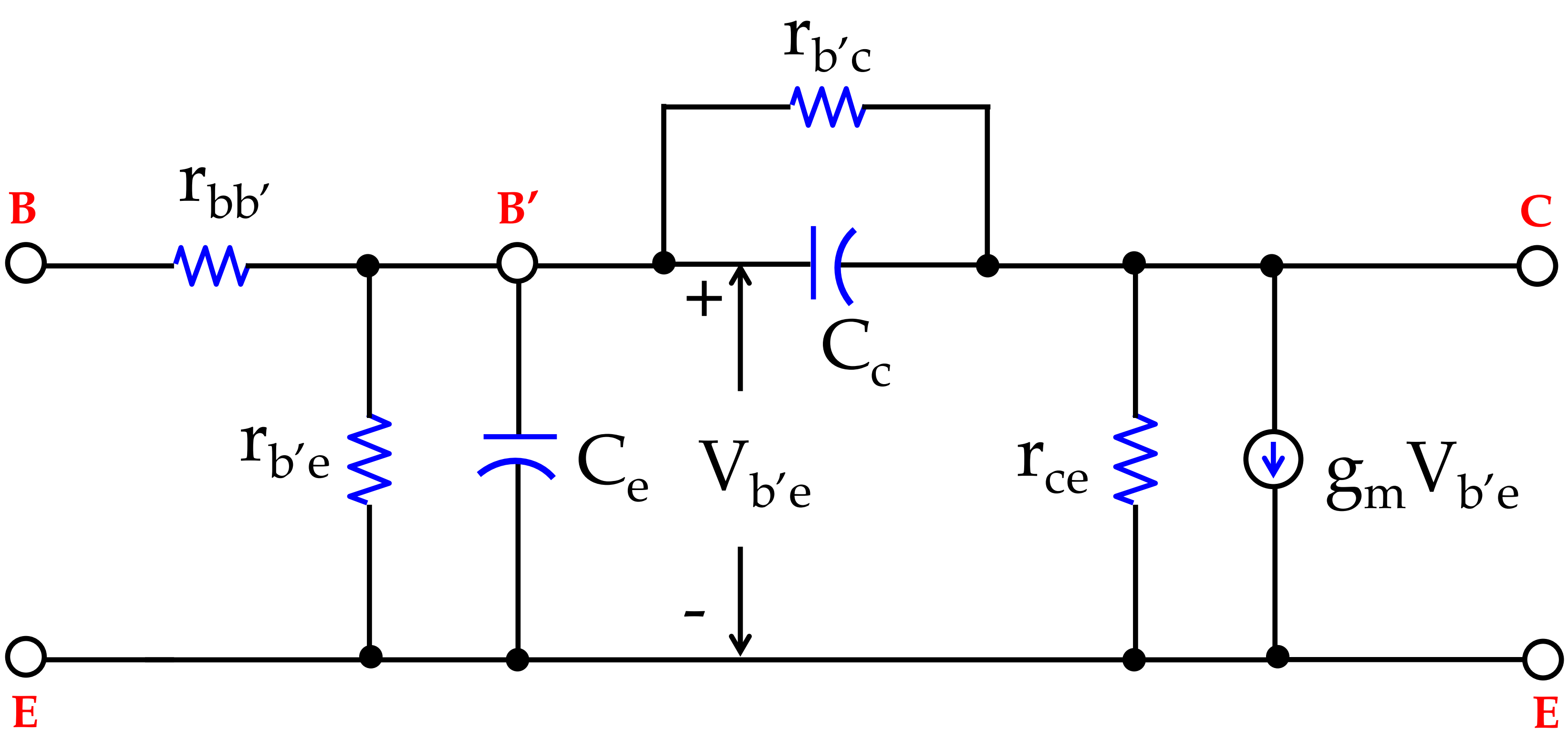
Parameter	Value
g_m	50 mA/V
$r_{bb'}$	100 Ω
$r_{b'e}$	1 KΩ
$r_{b'c}$	4 MΩ
r_{ce}	80 KΩ
C_c or $C_{b'c}$	3 pF
C_e or $C_{b'e}$	100 pF

Analysis of Hybrid-Pi (π) C-E Transistor Model

1. Hybrid-Pi (π) Conductances

2. Hybrid-Pi (π) Capacitances

Hybrid-Pi (π) Common-Emitter Transistor Model



Discussion of circuit components

- C_e or $C_{b'e}$: Diffusion capacitance between B' and E
- C_c or $C_{b'c}$: Collector junction barrier capacitance between B' and C
- $r_{bb'}$: Ohmic base-spreading resistance
- $r_{b'e}$: Resistance between B' and E
- $r_{b'c}$: Resistance between reverse biased B' and C
- g_m : Transistor conductance
- r_{ce} : Output resistance between C and E

Hybrid-Pi (π) Capacitances

1. Diffusion capacitance C_{De} or C_e

2. Transition capacitance C_{Te} or C_C

Hybrid-Pi (π) Capacitances

1. Diffusion capacitance C_{De} or C_e

- The capacitance Ce represents the sum of the emitter diffusion capacitance C_{De} and the emitter junction capacitance C_{Te}.

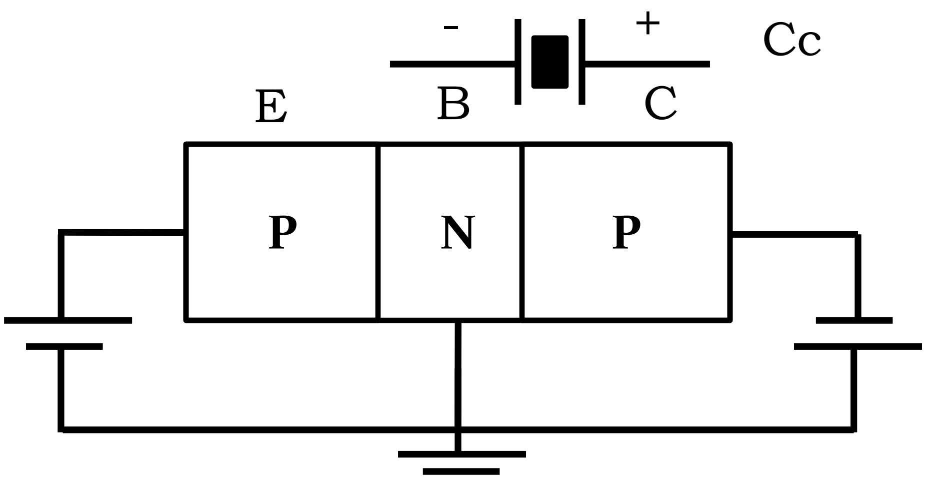
$$C_e = C_{De} + C_{Te}$$

- For a forward-biased emitter junction, C_{De} is usually much larger than C_{Te}

$$C_e = C_{De}$$

- C_{De} is proportional to the emitter bias current I_E and is independent of temperature.

Transition Capacitance



- When P-N junction is reverse biased, depletion region acts as insulator and p-region, n-region acts as parallel plates.
- Thus, this P-N junction can be considered as parallel plate capacitor called transition capacitance.

Transition Capacitance

- For transistor as an amplifier, output should be reverse biased. Hence C_T is formed at output junction. Hence named as $C_{b'c}$ or C_C.
- Since reverse bias causes the majority carriers to move away from the junction, so the thickness of depletion region denoted as 'W' increases with the increase in reverse bias voltage.

Transition Capacitance

- Hence the value of transition capacitance varies as V_{CB}^{-n} i.e

$$C_C \propto \frac{1}{(V_{CB})^{-n}}$$

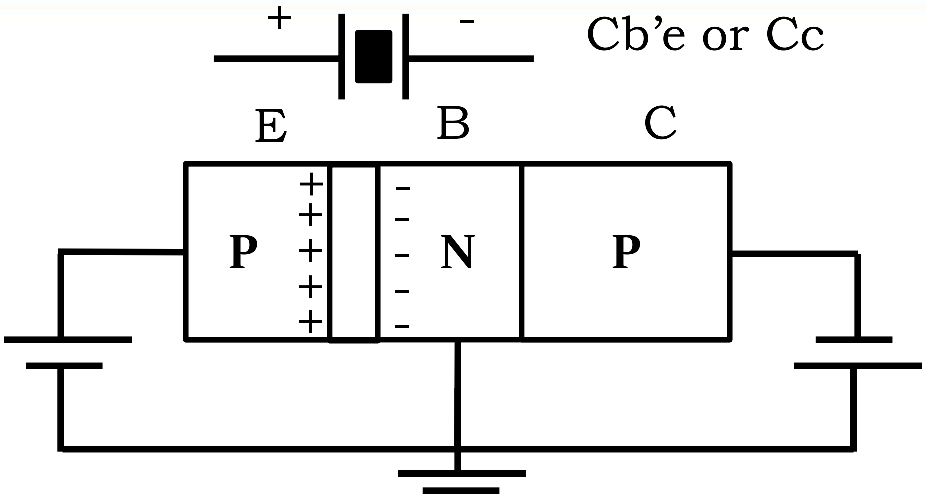
Where n=1/2 for abrupt junction

Where n=1/3 for abrupt junction

- Transition capacitance is represented as

$$C_C = \frac{\varepsilon A}{W}$$

Diffusion Capacitance



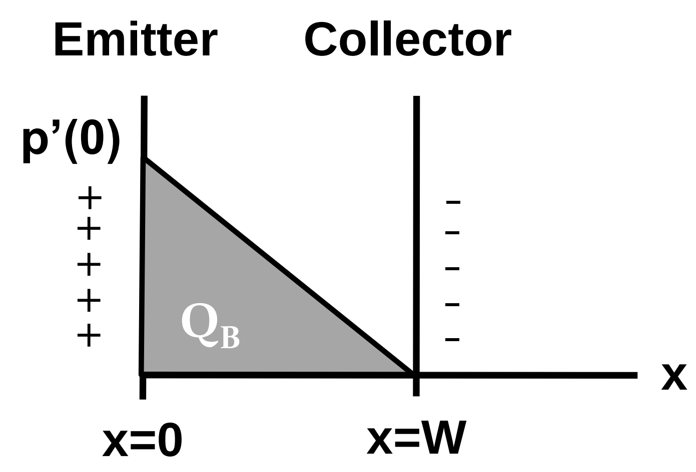
- When P-N junction is forward biased, the capacitance exists which is known as diffusion capacitance C_D.
- As shown in the above figure diffusion capacitance is formed in the forward bias where emitter base junction of a transistor is forward biased for an amplifier

$$C_D = C_{b'e} = C_e$$

Diffusion Capacitance

- During forward bias the potential barrier is reduced and charge carriers move near to the barrier.
- The density of charge is higher near to junction and reduces as distance increases.
- Thus, charge stored on both sides of the junction and varies with applied voltage.

Derivation for Diffusion Capacitance



1. Figure represents the injected hole concentration Vs base distance in base region of PNP
2. The base width W is assumed to be small with diffusion length of minority carriers.

Derivation for Diffusion Capacitance

3. Since collector junction is reverse biased, the injected charge concentration P'(0) at collector junction is zero.
4. If $W \ll L_B$, P' varies almost linearly from the value P'(0) at emitter to zero at collector.
5. The stored base charge

$$Q_B = \frac{P^{'}(0)}{2} \times q \times A \times W$$

Derivation for Diffusion Capacitance

5. The stored base charge

$$Q_B = \frac{P'(0)}{2} \times q \times A \times W$$

$$Where, \frac{P'(0)}{2} \quad = Average concentration$$

$$A \quad = Cross sectional base areas$$

$$A \times W \quad = Volume of base$$

$$q \quad = Electron Charge$$

$$\Rightarrow P'(0) = \frac{2Q_B}{AWq}$$

Derivation for Diffusion Capacitance

- Diffusion capacitance is directly proportional to diode current

$$I = A \times q \times D_B \times \frac{dp}{dx}$$

$$Where,\ D_B = Diffucion\ cons\tan t$$

$$dp = Difference\ of\ concentration$$

$$= p'(0) - 0$$

$$dp = p'(0)$$

$$dx = W$$

Derivation for Diffusion Capacitance

$$\therefore I = A \times q \times D_B \times \frac{p'(0)}{W}$$

$$P'(0) = \frac{2Q_B}{AWq}$$

$$\Rightarrow I = \frac{2D_B Q_B}{W^2}$$

$$\Rightarrow Q_B = \frac{W^2}{2D_B} \cdot I$$

Derivation for Diffusion Capacitance

- The static emitter diffusion capacitance C_{De} is given by the rate of change of Q_B with respect to emitter voltage V, or

$$\Rightarrow C_{De} = \frac{dQ_B}{dV} = \frac{W^2}{2D_B} \cdot \frac{dI}{dV}$$

$$\Rightarrow C_{De} = \frac{W^2}{2D_B} \cdot \frac{1}{r_e}$$

- Where $\Rightarrow r_e \equiv \frac{dV}{dI} = \frac{V_T}{I_E}$ is the emitter-junction incremental resistance.

Derivation for Diffusion Capacitance

$$\Rightarrow C_{De} = \frac{W^2}{2D_B} \cdot \frac{I_E}{V_T} \quad \Rightarrow C_{De} = \frac{W^2}{2D_B} \cdot g_m$$

- Which indicates that the diffusion capacitance is proportional to emitter bias current I_E
- Experimentally, Ce is determined from a measurement of f_T, the frequency at which the CE short-circuit current gain drops to unity.

$$\Rightarrow C_e \approx \frac{g_m}{2\pi f_T}$$

Validity of hybrid - π model

- The network elements of Hybrid-π equivalent circuit, are frequency-independent provided that

$$2\pi f \frac{W^2}{6D_B} << 1 \qquad (1)$$

- Where W is base width

  D_B is diffusion constant

  f is input signal frequency

- We know

$$C_{De} = g_m \cdot \frac{W^2}{2D_B} \qquad C_e \approx \frac{g_m}{2\pi f_T}$$

Validity of hybrid - π model

$$C_{De} = g_m \cdot \frac{W^2}{2D_B} \qquad C_e \approx \frac{g_m}{2\pi f_T}$$

$$\Rightarrow \frac{W^2}{6D_B} = \frac{C_e}{3g_m} = \frac{1}{6\pi f_T}$$

- Eq. (1) becomes

$$2\pi f \frac{W^2}{6D_B} << 1$$

$$\Rightarrow 2\pi f \cdot \frac{1}{6\pi f_T} << 1$$

$$\Rightarrow f << 3 f_T$$

- The hybrid-π model is valid for frequencies up to approximately $f_T/3$

Summary

1. $g_m = \dfrac{|I_C|}{V_T}$

2. $r_{b'e} = \dfrac{h_{fe}}{g_m}$

3. $r_{b'c} = \dfrac{r_{b'e}}{h_{re}}$

4. $r_{bb'} = h_{ie} - r_{b'e}$

5. $r_{ce} = \dfrac{1}{h_{oe} - h_{fe} g_{b'c}}$

6. $C_C = \dfrac{\varepsilon A}{W}$ or $C_C \propto \dfrac{1}{(V_{CB})^{-n}}$

7. $C_e = \dfrac{W^2}{2D_B} \cdot g_m$ or $C_e = \dfrac{g_m}{2\pi f_T}$

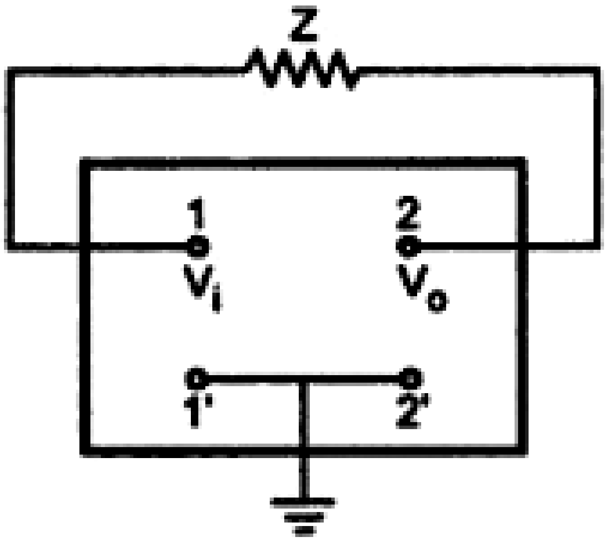
Variation of hybrid-π Parameters

- Dependence of parameters upon current, voltage, and temperature

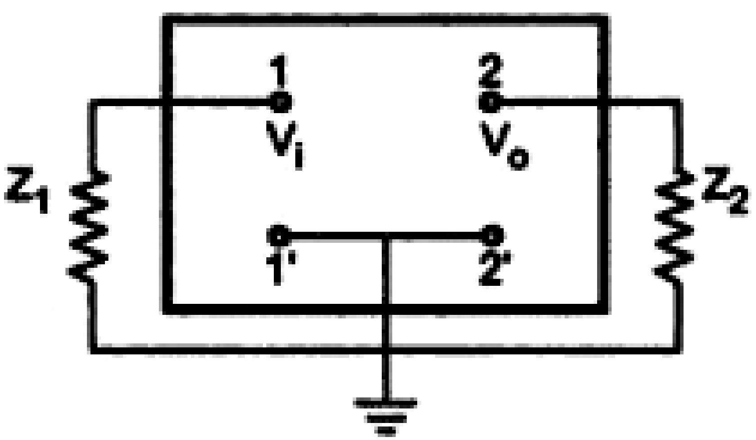
Parameter	Variation with increasing:		
	|Ic|	|Vce|	|T|
Gm	Increases	Independent	Decreases
$r_{b'e}$	Decreases	Increases	Increases
$r_{b'c}$	Decreases	Increases	Increases
$r_{bb'}$	Decreases	Independent	Increases
Ce	Increases	Decreases	Decreases
Cc	Independent	Decreases	Independent
h_{ie}	Decreases	Increases	Increases
h_{fe}	Increases for small values of Ic and decreases with large values of Ic	Increases	Increases

Miller's theorem

- In general, Miller's theorem is used for converting any circuit having configuration in the form of Fig. (a) to another configuration shown in Fig. (b).



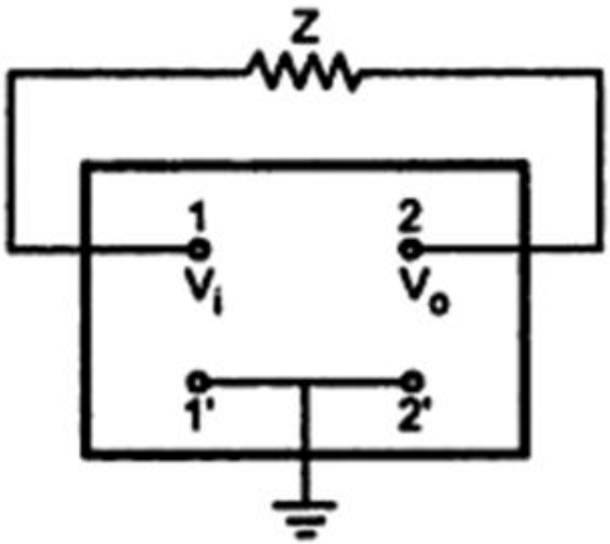
(a)

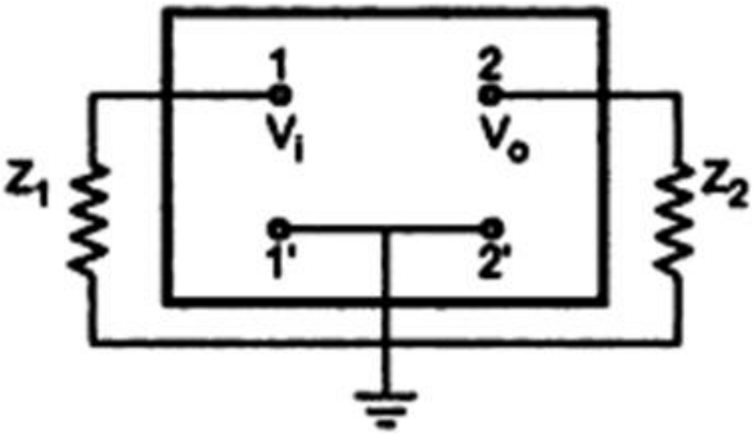


(b)

Miller's theorem

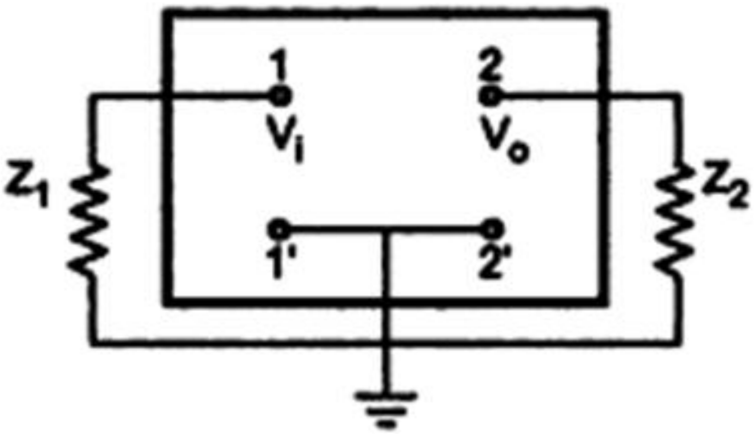
- Z is the impedance connected in between two nodes 1 and 2.





- It is replaced by two separate impedances Z_1 and Z_2; where Z_1 is connected between 1 and ground and Z_2 is connected between 2 and ground.

Miller's theorem



- Vin and Vo are voltages at node 1 and node 2, respectively.
- The values of Z_1 and Z_2 can be derived from the ratio

$$K = \frac{V_0}{V_{in}}$$

$$Z_1 = \frac{Z}{1-K} \; and \; Z_2 = \frac{Z \cdot K}{K-1}$$

Miller's theorem

- **Statement:** Miller's theorem states that the effect of resistance Z on the input circuit is a ratio of Vin to current I which flows from input to output.

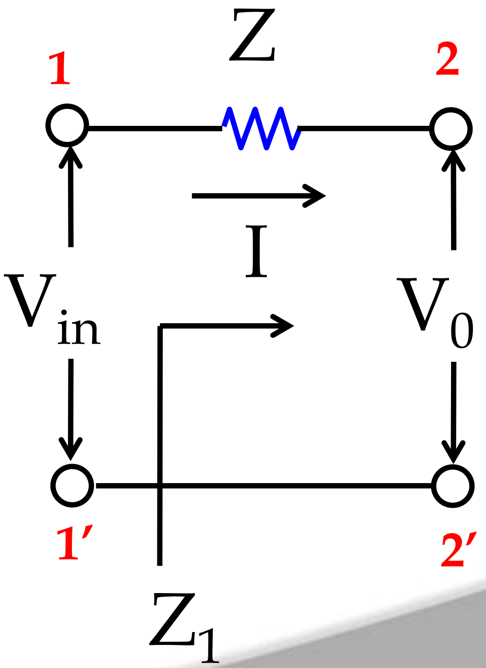
- **Proof:**

$$Z_1 = \frac{V_{in}}{I}$$

$$I = \frac{V_{in} - V_0}{Z}$$

$$Z_1 = \frac{V_{in}}{V_{in} - V_0} \cdot Z \Rightarrow Z_1 = \frac{Z}{1 - \frac{V_0}{V_{in}}}$$

$$let \;\; K = \frac{V_0}{V_{in}} \Rightarrow Z_1 = \frac{Z}{1 - K}$$



Miller's theorem

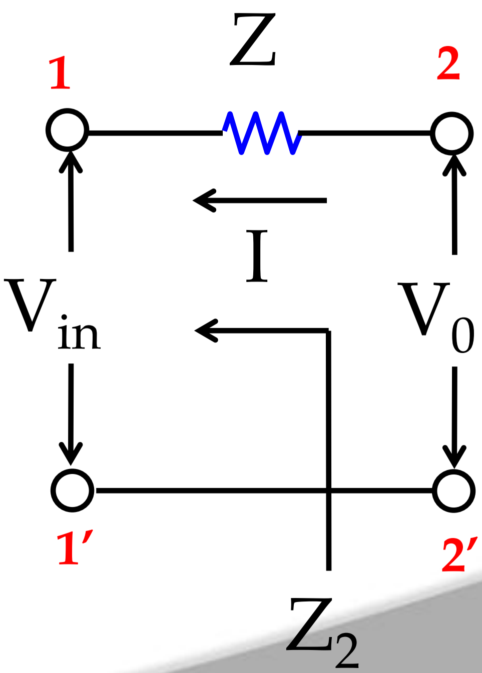
- **Output side:** Miller's theorem states that the effect of resistance Z on the output circuit is the ratio of output voltage Vo to the current I which flows from output to input.

$$Z_2 = \frac{V_0}{I}$$

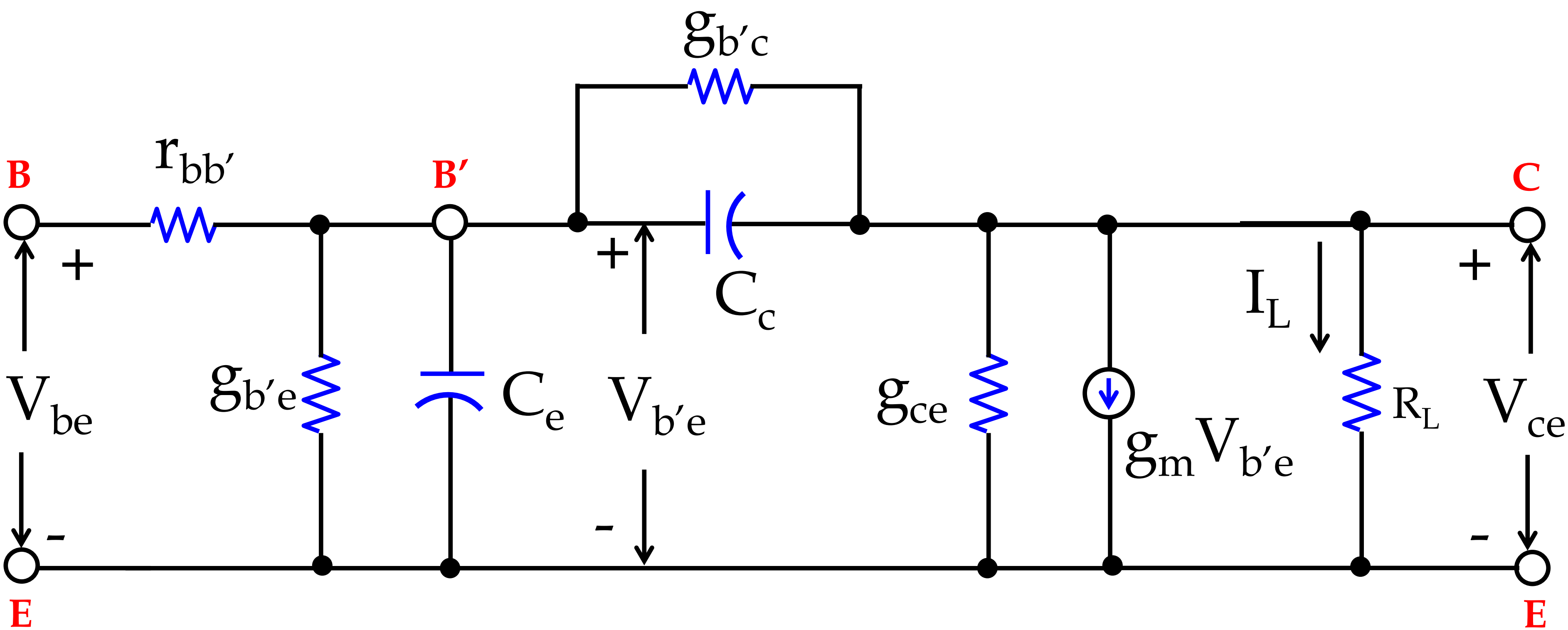
$$Where \;\; I = \frac{V_0 - V_{in}}{Z}$$

$$\therefore Z_2 = \frac{V_0}{V_0 - V_{in}} \cdot Z \Rightarrow Z_2 = \frac{Z}{1 - \dfrac{V_{in}}{V_0}}$$

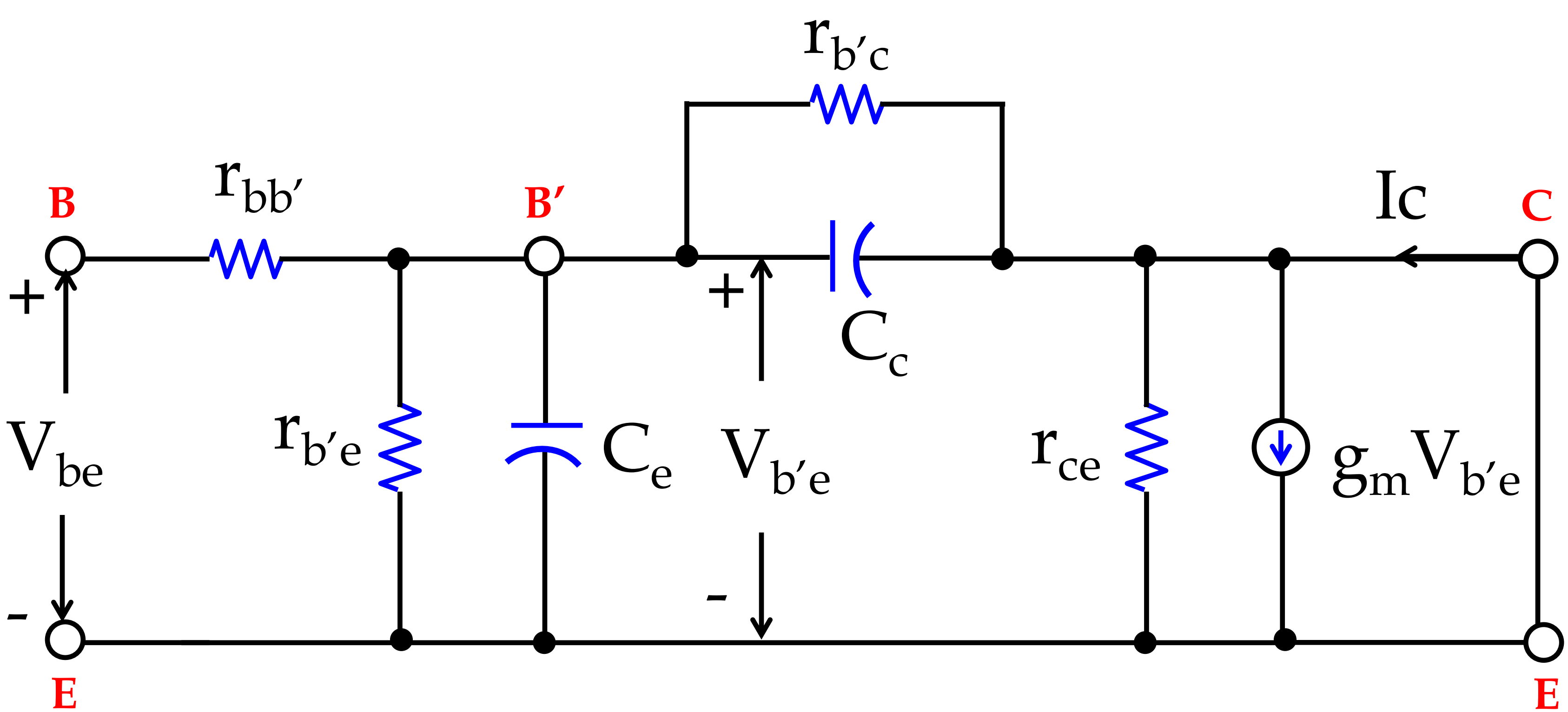
$$\Rightarrow Z_2 = \frac{Z}{1 - \dfrac{1}{K}} = Z \cdot \frac{K}{K-1}$$



The CE short-circuit current gain

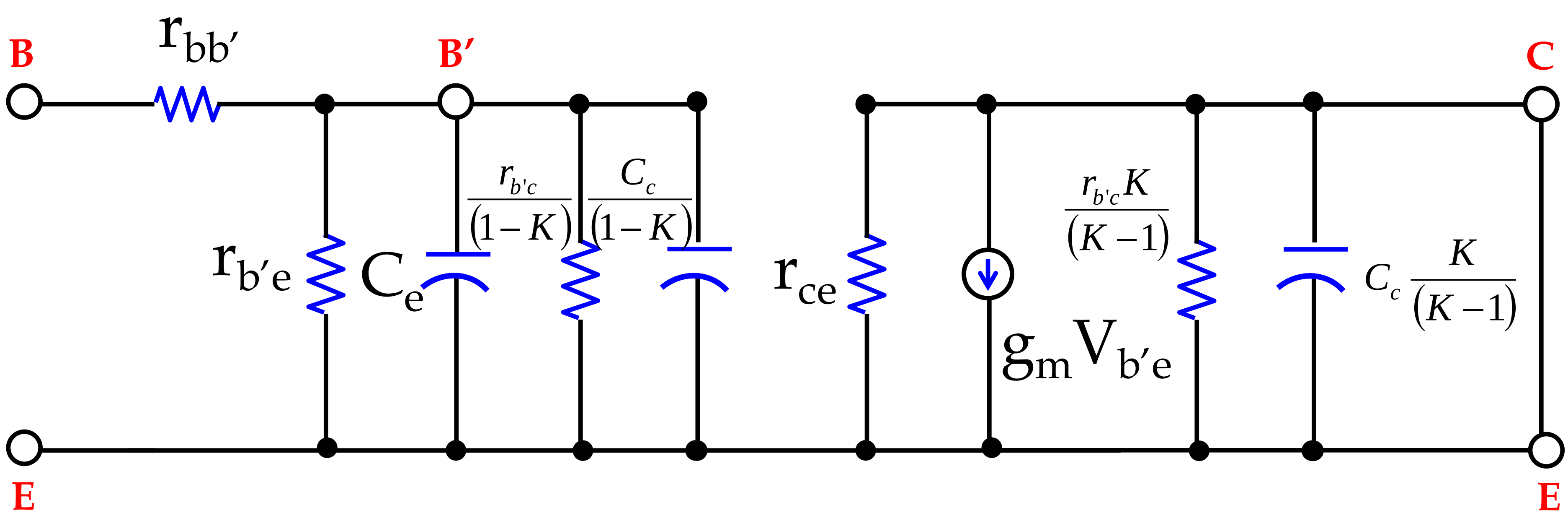


The CE short-circuit current gain



The CE short-circuit current gain

- By applying the Miller's theorem



The CE short-circuit current gain

$$Where\,K = \frac{V_0}{V_{in}} = \frac{0}{V_{in}} = 0$$

❖Input Side

$$\frac{r_{b'c}}{1-K} = r_{b'c}$$

$$r_{b'e} \| r_{b'c}$$

$$but \qquad r_{b'c} >> r_{b'e}$$

$$r_{b'e} \| r_{b'c} = r_{b'e}$$

$$C_e \| C_c /(1-K)$$

$$\Rightarrow C_e \| C_c = C_e + C_C$$

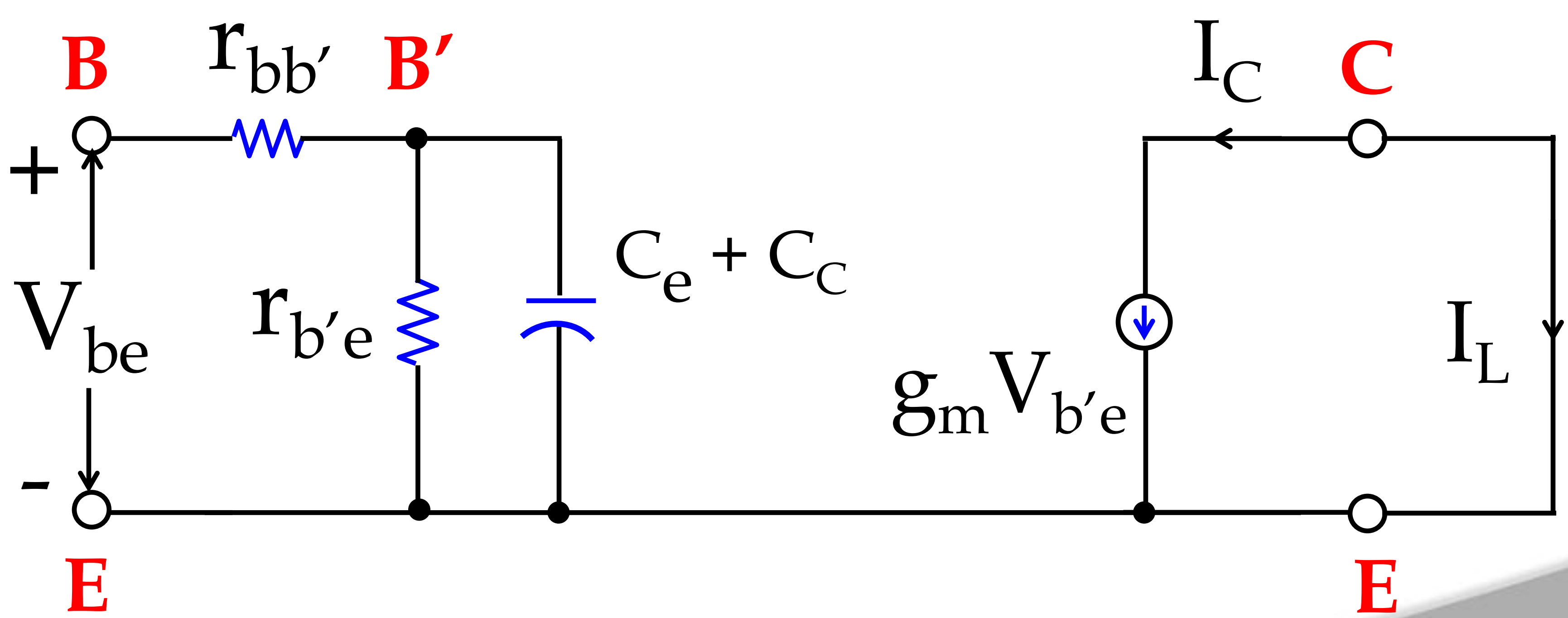
❖Output Side

$$r_{b'c} \cdot \frac{K}{K-1} = 0 \quad \& \; r_{ce} = 0$$

$$C_c \frac{K-1}{K} = Negligible$$

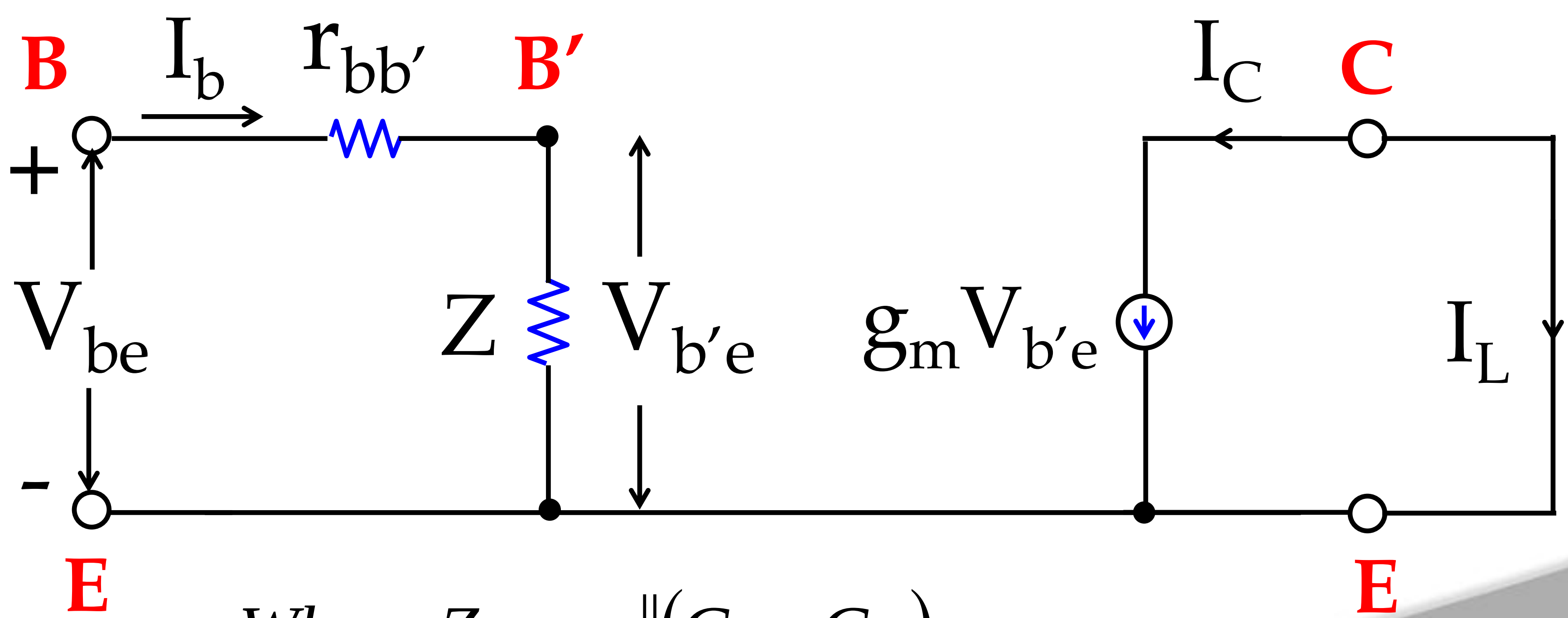
The CE short-circuit current gain

- Approximate equivalent circuit for the calculation of the short-circuit CE current gain



The CE short-circuit current gain

- Approximate equivalent circuit for the calculation of the short-circuit CE current gain



$$Where\,Z = r_{b'e} \| (C_e + C_C)$$

The CE short-circuit current gain

$$\therefore Current\, gain\, A_I = \frac{I_L}{I_B}$$

$$Where \quad I_L = -g_m V_{b'e}$$

$$V_{b'e} = I_B Z$$

$$\therefore \Rightarrow A_I = \frac{-g_m I_B Z}{I_B}$$

$$\Rightarrow A_I = -g_m Z$$

$$Where\, Z = r_{b'e} \| (C_e + C_C)$$

$$\Rightarrow Z = \frac{r_{b'e} \cdot X_{C_e + C_C}}{r_{b'e} + X_{C_e + C_C}}$$

$$= \frac{r_{b'e} \cdot \frac{1}{j\omega(C_e + C_C)}}{r_{b'e} + \frac{1}{j\omega(C_e + C_C)}}$$

$$\Rightarrow Z = \frac{r_{b'e}}{1 + j\omega r_{b'e}(C_e + C_C)}$$

The CE short-circuit current gain

$$\Rightarrow A_I = -g_m Z \qquad \Rightarrow Z = \frac{r_{b'e}}{1 + j\omega r_{b'e}(C_e + C_C)}$$

$$\Rightarrow A_I = -g_m \cdot \frac{r_{b'e}}{1 + j\omega r_{b'e}(C_e + C_C)}$$

$$but \qquad r_{b'e} = \frac{h_{fe}}{g_m} \Rightarrow r_{b'e} \cdot g_m = h_{fe}$$

$$\Rightarrow A_I = \frac{-h_{fe}}{1 + j\omega r_{b'e}(C_e + C_C)}$$

$$\Rightarrow A_I = \frac{-h_{fe}}{1 + j2\pi f r_{b'e}(C_e + C_C)}$$

The CE short-circuit current gain

$$\Rightarrow A_I = \frac{-h_{fe}}{1 + j2\pi f r_{b'e}\left(C_e + C_C\right)}$$

$$Let \qquad f_H = \frac{1}{2\pi r_{b'e}\left(C_e + C_C\right)}$$

$$\Rightarrow A_I = \frac{-h_{fe}}{1 + j\dfrac{f}{f_H}}$$

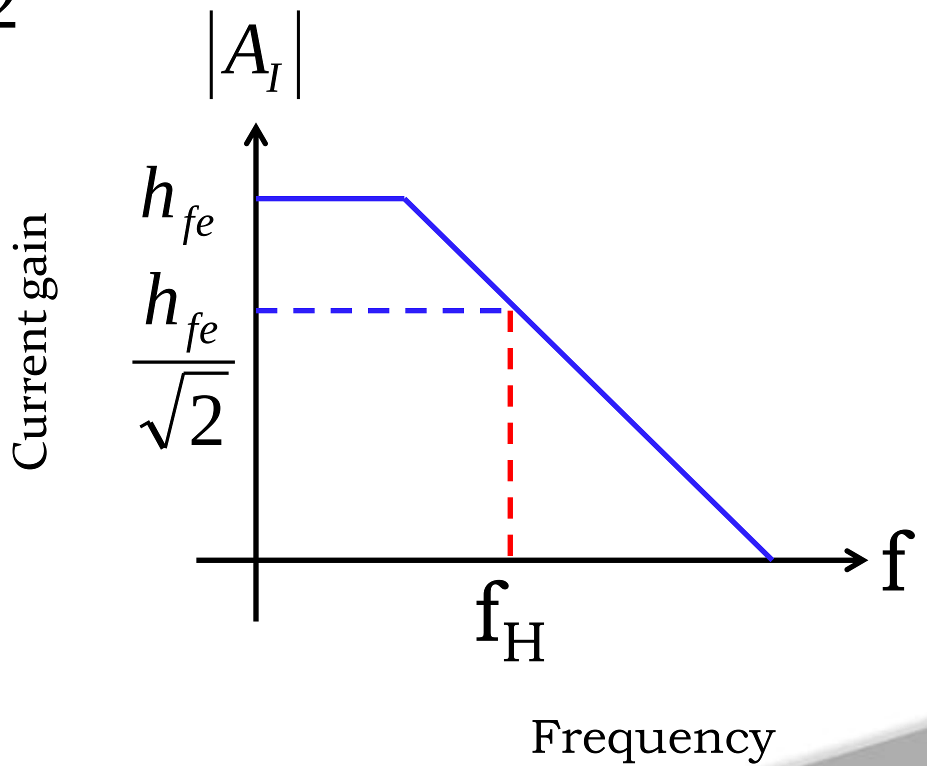
$$\therefore \left|A_I\right| = \frac{h_{fe}}{\sqrt{1 + \left(\dfrac{f}{f_H}\right)^2}}$$

The CE short-circuit current gain

1. $f \ll f_H$ $\quad |A_I| = h_{fe}$

2. $f = f_H$ $\quad |A_I| = h_{fe}/\sqrt{2}$

3. $f \gg f_H$ $\quad |A_I| = \downarrow\downarrow$



Cut-off frequencies: 1) The parameter f_β

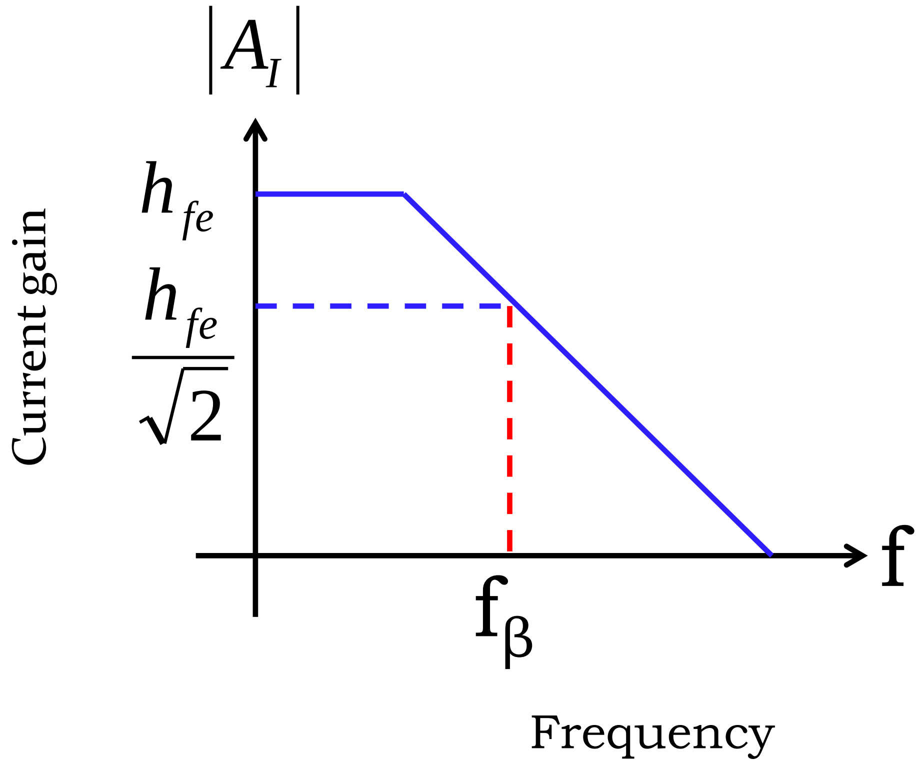
- It is defined as the frequency at which the transistor short circuit current gain drops by 3dB or $1/\sqrt{2}$ times the highest magnitude in CE configuration.

$$|A_I| = \frac{h_{fe}}{\sqrt{1+\left(\frac{f}{f_\beta}\right)^2}}$$

$$Where \quad f_\beta = \frac{1}{2\pi r_{b'e}(C_e + C_C)}$$

1) The parameter f_β

- Frequency response



2) The parameter f_α

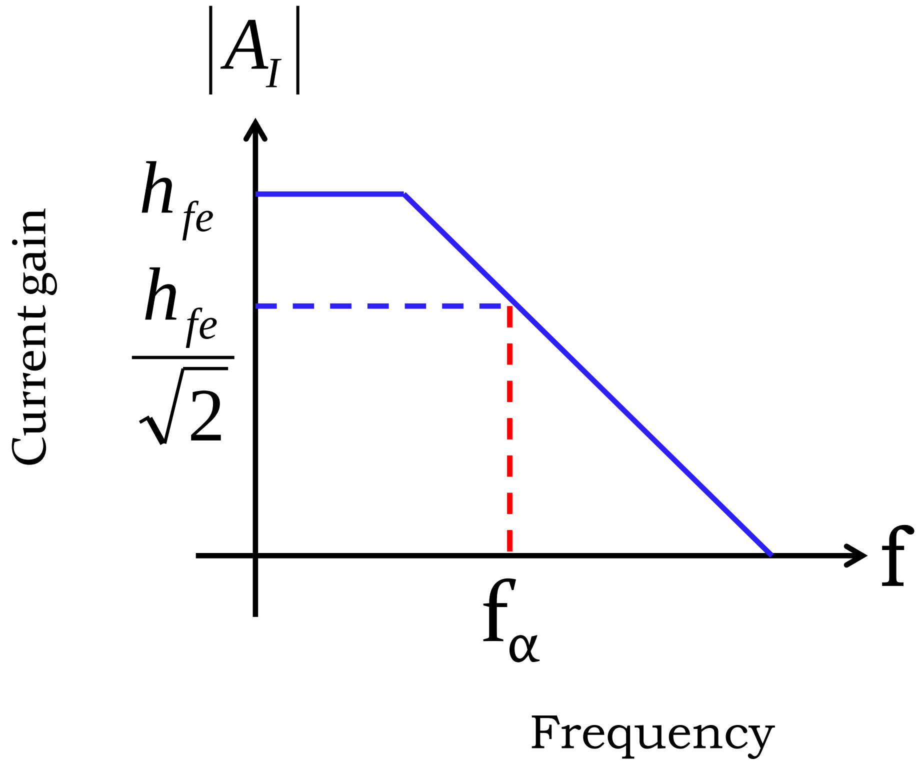
- It is defined as the frequency at which the transistor short circuit current gain drops by 3dB or 1/√2 times the highest magnitude in CB configuration.

$$|A_I| = \frac{h_{fe}}{\sqrt{1+\left(\frac{f}{f_\alpha}\right)^2}}$$

$$\text{Where} \quad f_\alpha = \frac{1}{2\pi r_{b'e}\left(1+h_{fb}\right)C_e}$$

2) The parameter f_α

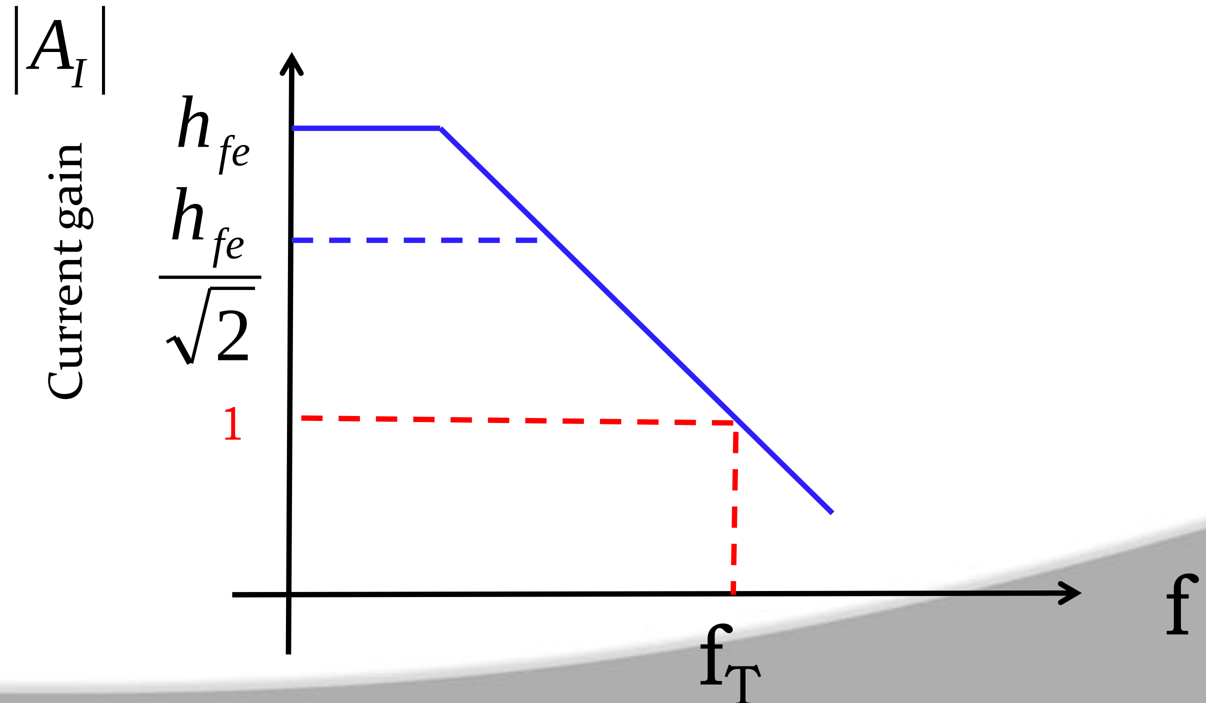
- Frequency response



3) The parameter f_T

- It is defined as the frequency at which the short-circuit common-emitter current gain attains unit magnitude.

$$i.e \qquad at\ f = f_T \qquad |A_I| = 1$$



3) The parameter f_T

$$|A_I| = \frac{h_{fe}}{\sqrt{1+\left(\frac{f}{f_\beta}\right)^2}}$$

$$\Rightarrow 1 = \frac{h_{fe}}{\sqrt{1+\left(\frac{f_T}{f_\beta}\right)^2}}$$

- The relation of f_T/f_β is quite large compared to 1

$$\Rightarrow 1 = \frac{h_{fe}}{\left(\frac{f_T}{f_\beta}\right)} \quad \Rightarrow \boxed{f_T = h_{fe} f_\beta}$$

3) The parameter f_T

$$f_T = h_{fe} \cdot \frac{1}{2\pi r_{b'e}(C_e + C_C)}$$

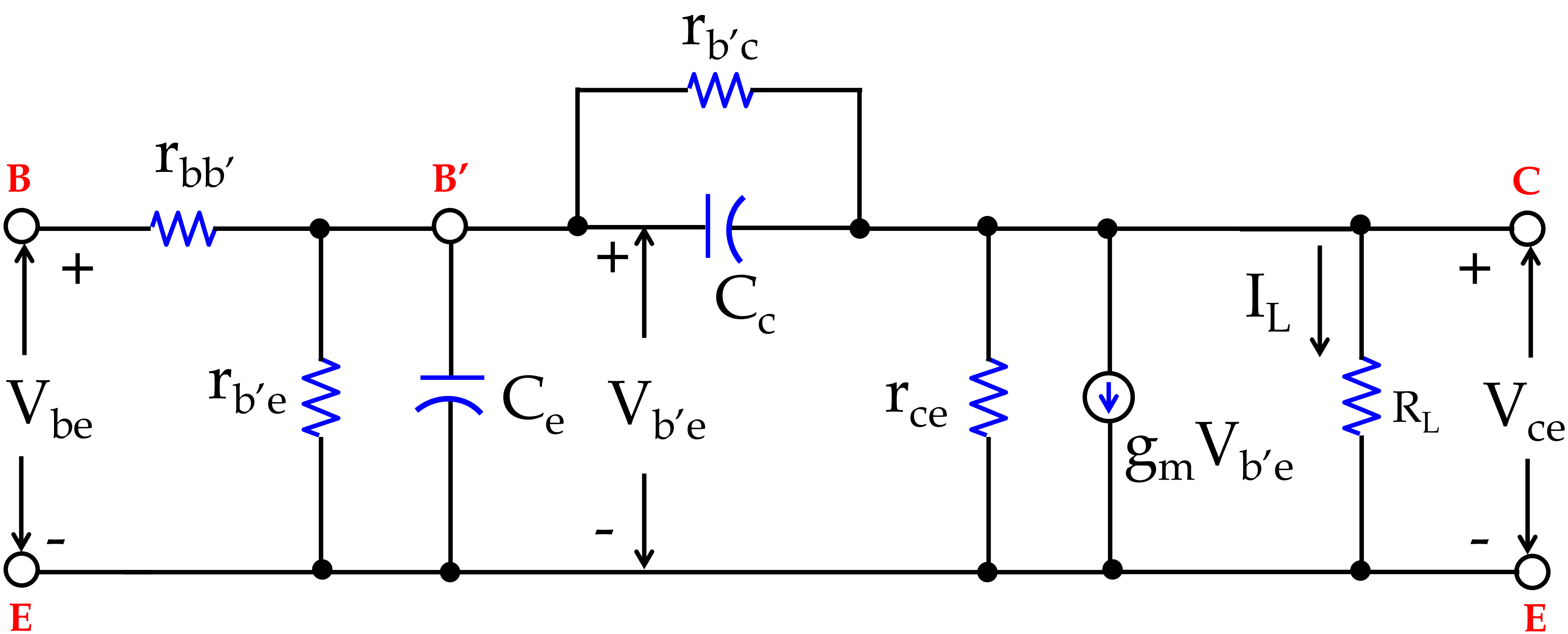
$$r_{b'e} = \frac{h_{fe}}{g_m}$$

$$\Rightarrow f_T = h_{fe} \cdot \frac{1}{2\pi \frac{h_{fe}}{g_m}(C_e + C_C)}$$

$$\Rightarrow f_T = \frac{g_m}{2\pi(C_e + C_C)}$$

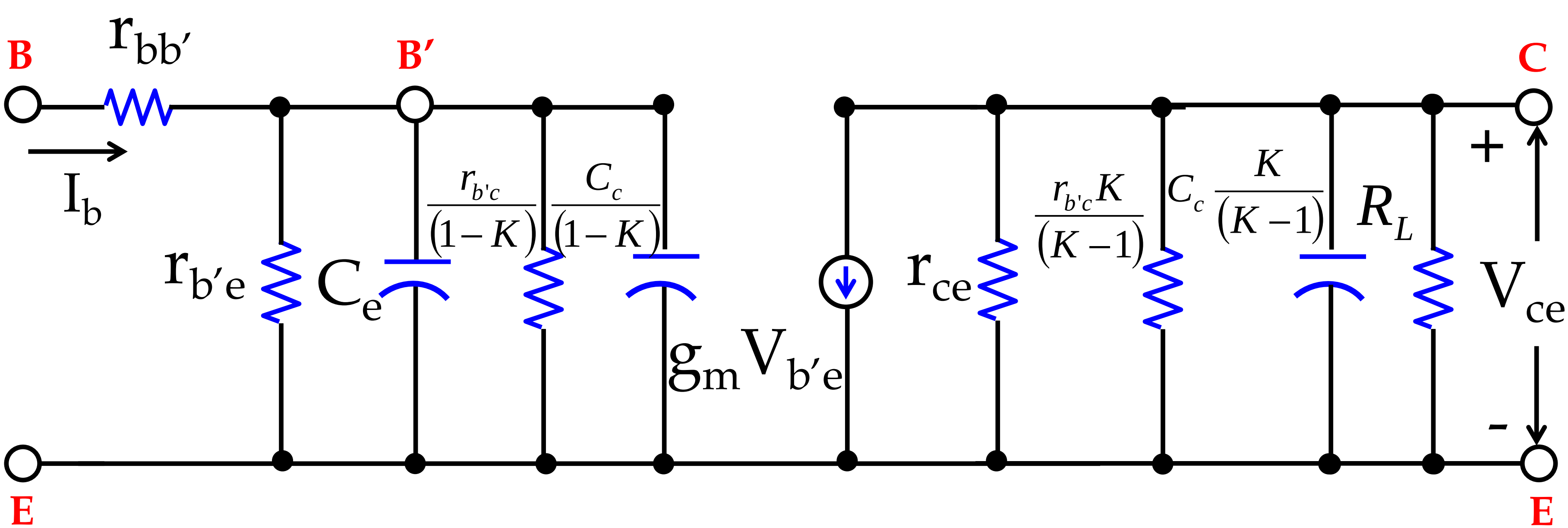
$$\Rightarrow \boxed{f_T = \frac{g_m}{2\pi C_e}} \quad \because C_e >> C_C$$

The CE short-circuit current gain with resistive load



The CE short-circuit current gain with resistive load

- By applying the Miller's theorem



The CE short-circuit current gain with resistive load

- Input Side

$$r_{b'e} \left\| \frac{r_{b'c}}{(1-K)} \right. = r_{b'e} \qquad \because r_{b'c} >> r_{b'e}$$

$$C_e \left\| \frac{C_C}{(1-K)} \right. = C_e + \frac{C_C}{(1-K)}$$

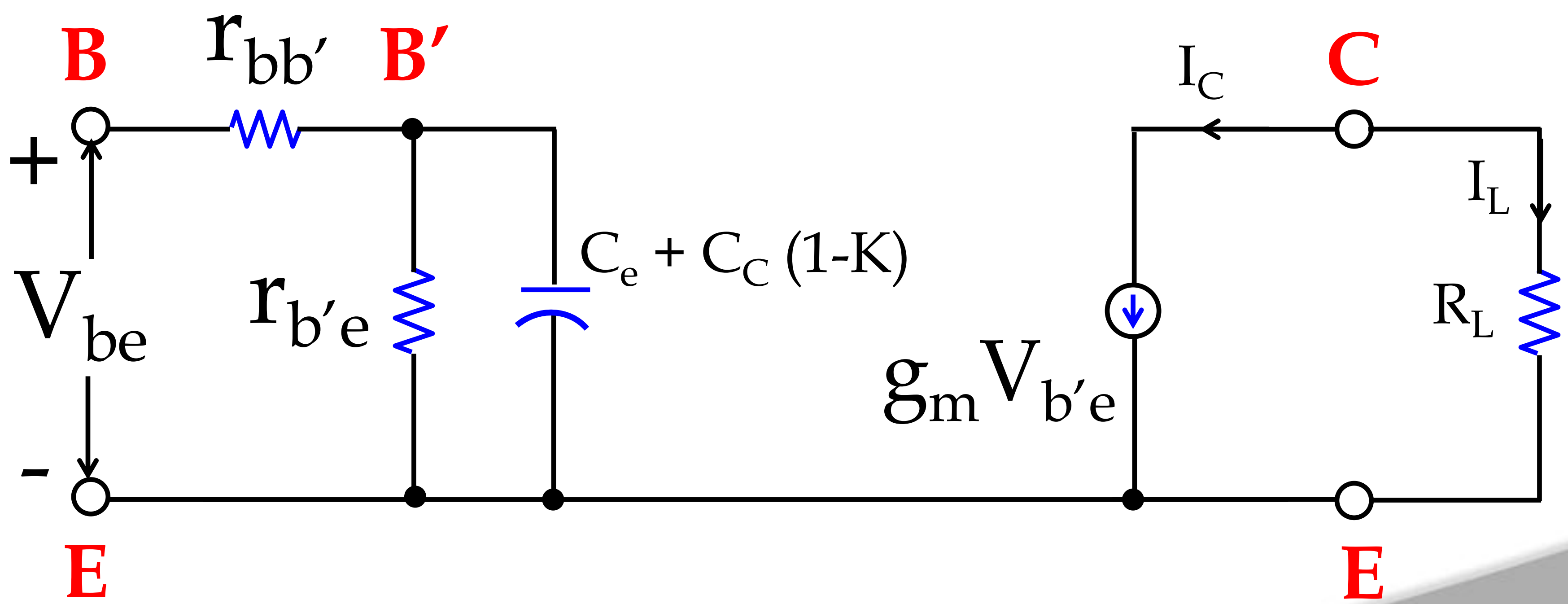
- Output Side

$$r_{ce} \left\| r_{b'c} \frac{K}{K-1} \right\| R_L \approx R_L$$

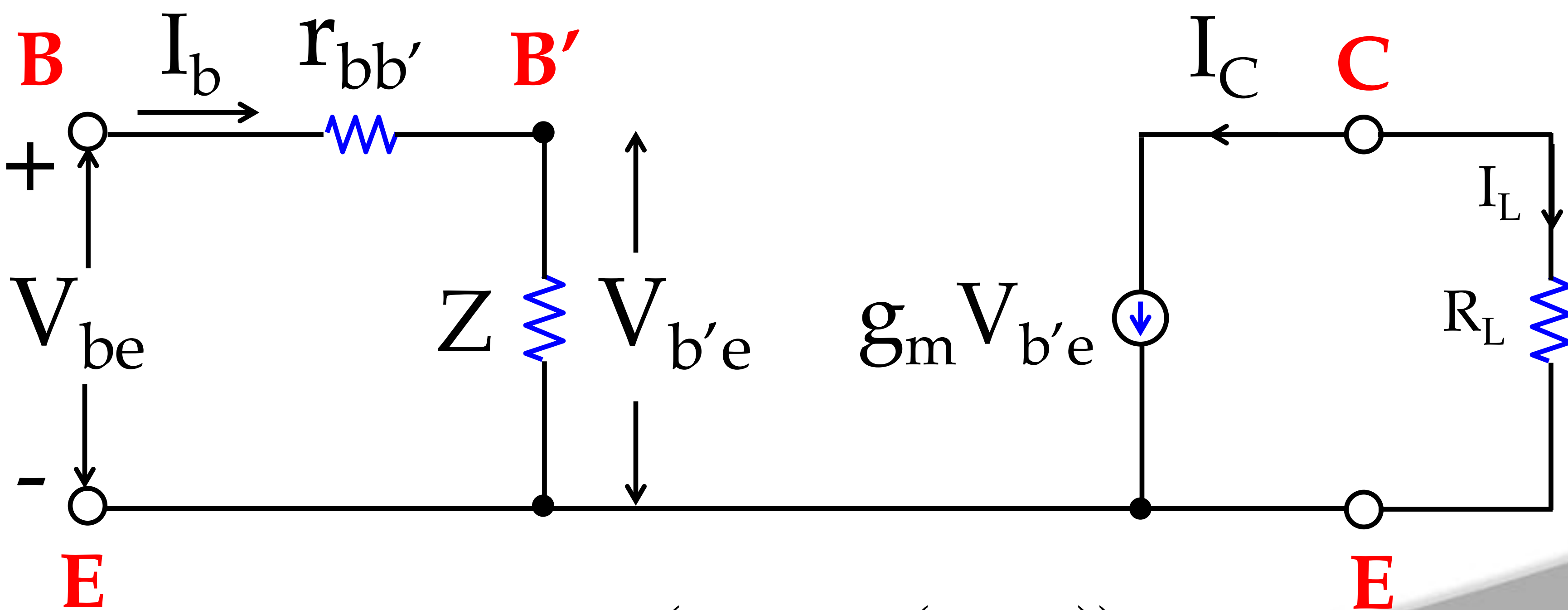
$$\because r_{ce} = 80K\Omega \quad r_{b'c} = 4M\Omega$$

$$R_L = 1K\Omega$$

The CE short-circuit current gain with resistive load



- Approximate equivalent circuit for the calculation of the short-circuit CE current gain



$$Where\, Z = r_{b'e} \| \left(C_e + C_C \left(1 - K\right)\right)$$

The CE short-circuit current gain with resistive load

$$\therefore Voltage\,gain\,A_V = \frac{V_0}{V_{in}}$$

$$= \frac{I_L R_L}{V_{b'e}}$$

$$Where \quad I_L = -g_m V_{b'e}$$

$$\therefore \Rightarrow A_V = \frac{-g_m V_{b'e} R_L}{V_{b'e}}$$

$$\Rightarrow \boxed{A_V = -g_m R_L = K}$$

$$\therefore Current\,gain\,A_I = \frac{I_L}{I_B}$$

$$Where \quad I_L = -g_m V_{b'e}$$

$$I_B = \frac{V_{b'e}}{Z}$$

$$\therefore \Rightarrow A_I = \frac{-g_m V_{b'e}}{\left(\frac{V_{b'e}}{Z}\right)}$$

$$\Rightarrow \boxed{A_I = -g_m Z}$$

The CE short-circuit current gain with resistive load

$$Where\,Z = r_{b'e} \| \left(C_e + C_C (1 - K) \right)$$

$$Z = r_{b'e} \| \left(C_e + C_C (1 + g_m R_L) \right)$$

$$\Rightarrow Z = \frac{r_{b'e} \cdot X_C}{r_{b'e} + X_C}$$

$$= \frac{r_{b'e} \cdot \dfrac{1}{j\omega \left(C_e + C_C (1 + g_m R_L) \right)}}{r_{b'e} + \dfrac{1}{j\omega \left(C_e + C_C (1 + g_m R_L) \right)}}$$

$$\Rightarrow Z = \frac{r_{b'e}}{1 + j\omega r_{b'e} \left(C_e + C_C (1 + g_m R_L) \right)}$$

The CE short-circuit current gain with resistive load

$$A_I = -g_m Z \qquad Z = \frac{r_{b'e}}{1 + j\omega r_{b'e}\left(C_e + C_C\left(1 + g_m R_L\right)\right)}$$

$$\Rightarrow A_I = -g_m \frac{r_{b'e}}{1 + j\omega r_{b'e}\left(C_e + C_C\left(1 + g_m R_L\right)\right)}$$

$$but \qquad r_{b'e} = \frac{h_{fe}}{g_m} \Rightarrow r_{b'e} \cdot g_m = h_{fe}$$

$$\Rightarrow A_I = \frac{-h_{fe}}{1 + j\omega r_{b'e}\left(C_e + C_C\left(1 + g_m R_L\right)\right)}$$

The CE short-circuit current gain with resistive load

$$\Rightarrow A_I = \frac{-h_{fe}}{1 + j\omega r_{b'e}\left(C_e + C_C\left(1 + g_m R_L\right)\right)}$$

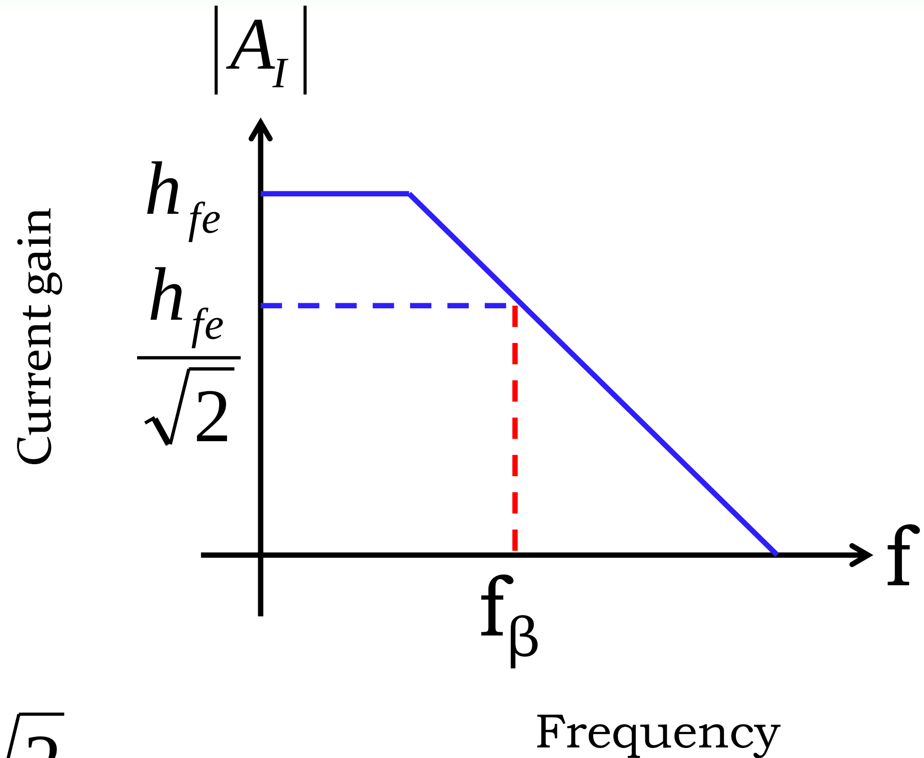
$$Let \qquad f_\beta = \frac{1}{2\pi r_{b'e}\left(C_e + C_C\left(1 + g_m R_L\right)\right)}$$

$$\Rightarrow A_I = \frac{-h_{fe}}{1 + j\dfrac{f}{f_\beta}}$$

$$\therefore \left|A_I\right| = \frac{h_{fe}}{\sqrt{1 + \left(\dfrac{f}{f_\beta}\right)^2}}$$

The CE short-circuit current gain

- Frequency response



1. $f \ll f_\beta \qquad |A_I| = h_{fe}$
2. $f = f_\beta \qquad |A_I| = h_{fe}/\sqrt{2}$
3. $f \gg f_\beta \qquad |A_I| = \downarrow\downarrow$

Summary

1. $g_m = \frac{|I_C|}{V_T}$

2. $r_{b'e} = \frac{h_{fe}}{g_m}$

3. $r_{b'c} = \frac{r_{b'e}}{h_{re}}$

4. $r_{bb'} = h_{ie} - r_{b'e}$

5. $r_{ce} = \frac{1}{h_{oe} - h_{fe} g_{b'c}}$

6. $C_C = \frac{\varepsilon A}{W}$ or $C_C \propto \frac{1}{(V_{CB})^{-n}}$

7. $C_e = \frac{W^2}{2D_B} \cdot g_m$ or $C_e = \frac{g_m}{2\pi f_T}$

Summary

8. $$|A_I| = \frac{h_{fe}}{\sqrt{1+\left(\frac{f}{f_\beta}\right)^2}}$$

9. $$f_T = h_{fe} f_\beta$$

$$f_T = \frac{g_m}{2\pi C_e}$$

$$f_T = |A_I| f$$

10. $$f_\alpha = \frac{f_T (C_e + C_C)}{C_e}$$

Problems

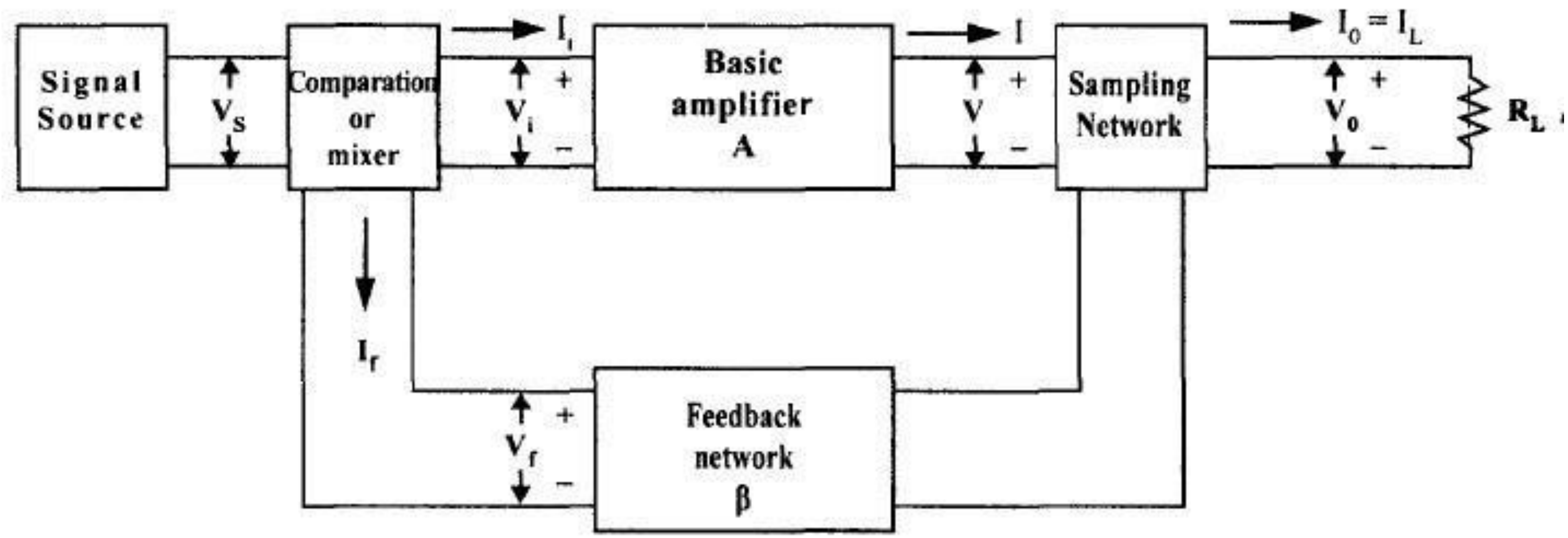
- H-parameters of a transistor are Ic=8mA, Vce=10V at room temperature, hie=1KΩ, hoe , hoe=$2x10^{-5}$ A/V, hfe=50, hre=$2.5x10^{-4}$. At the same operating point f_T=60MHz. Compute hybrid-pi parameters if Cob=2pF.

- An NPN transistor has β cutoff frequency of 1Mhz and CE short low frequency current gain is 200. Find unity gain frequency and fα. Assume Ce=9pF and Cc=1pF.

MODULE– II
FEEDBACK AMPLIFIERS

CLOs	Course Learning Outcome
CLO4	Analyze the importance of positive feedback and negative feedback in connection in electronic circuits..
CLO5	Analyze various types of feedback amplifiers like voltage series, voltage shunt, current series and current shunt.

GENERALIZED BLOCK SCHEMATIC



Introduction To Feedback

- The process of injecting a fraction of output energy of some device back to the input is known as **feedback.**
- some of the short comings(drawbacks) of the amplifier circuit are:

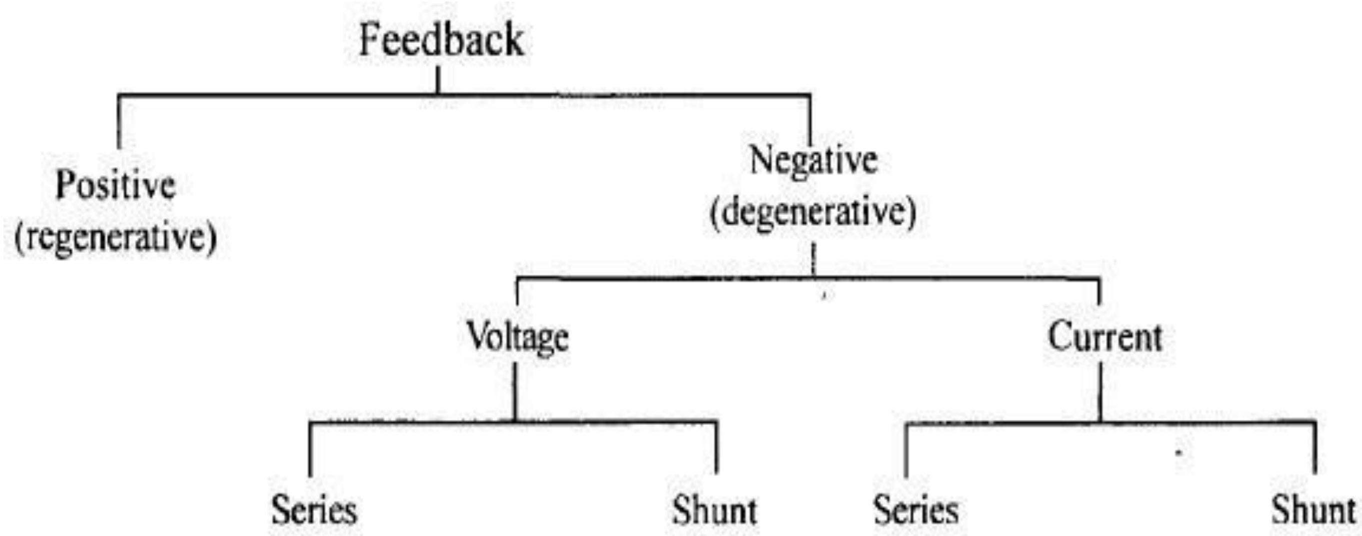
1.Change in the value of the gain due to variation in supplying voltage, temperature or due to components.

2.Distortion in wave-form due to non linearities in the operating characters of the amplifying device.

3. The amplifier may introduce noise (undesired signals)

- The above drawbacks can be minimizing if we introduce feedback

basic types of feedback in amplifiers



Positive feedback

•When the feedback energy (voltage or current) is in phase with the input signal and thus aids it, it is called *positive feedback.*

•*Both amplifier* and feedback network introduce a phase shift of 180 . The result is a 360 phase shift around the loop, causing the *feedback voltage Vf to be in phase with the input signal Vin.*

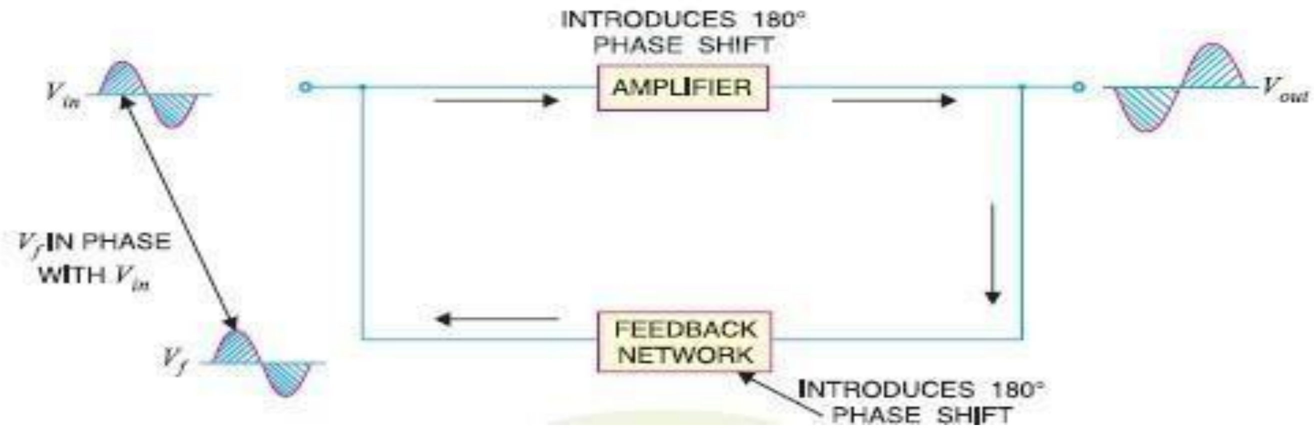


Fig. Block diagram for positive feedback

Negative feedback.

•When the feedback energy (voltage or current) is out of phase with the input signal and thus opposes it, it is called *negative feedback.*

•The amplifier introduces a phase shift of 180° into the circuit while the feedback network is so designed that it introduces no phase shift (*i.e., 0° phase shift).*

•Negative feedback is also called as *degenerative feedback.*

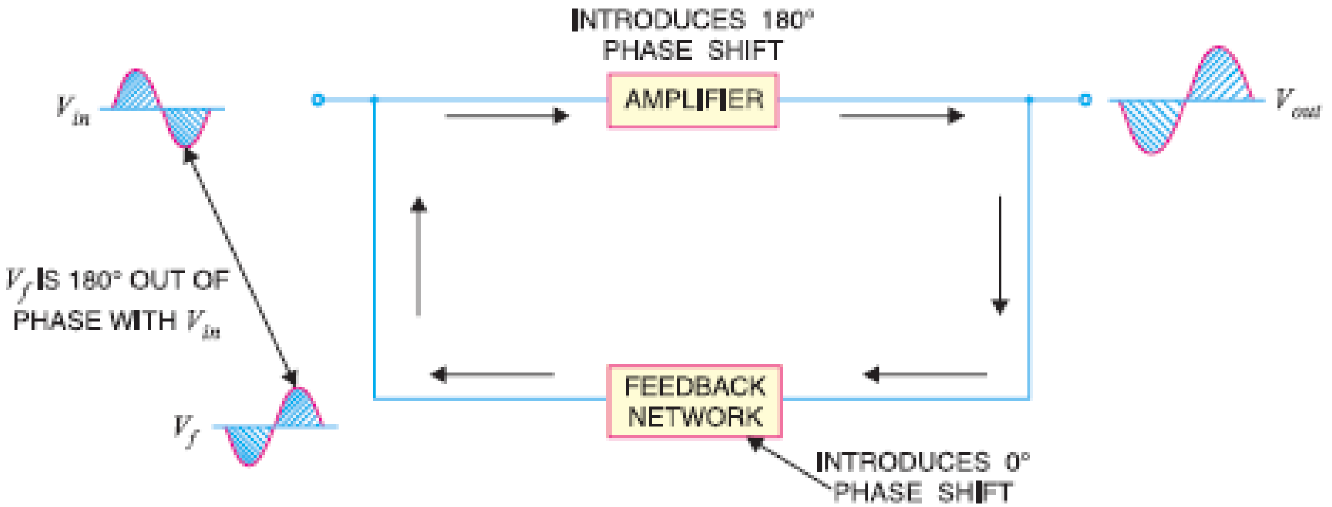


Fig.negative feedback amplifier

CLASSIFACTION OF FEEDBACK AMPLIFIERS

voltage series feedback.

Voltage shunt Feedback

Current Shunt Feedback

Current Series Feedback

$$A_{Vf} = \frac{V_o}{V_s}$$

$$A_{If} = \frac{I_o}{I_s}$$

$$G_{Mf} = \frac{I_o}{V_s}$$

$$R_{Mf} = \frac{V_o}{I_s}$$

EFFECT OF NEGATIVE FEEDBACK ON TRANSFER GAIN

- REDUCTION IN GAIN

$$A'_V = \frac{A_v}{1+\beta A_v}$$ Denominator is > 1. $\therefore$ $A'_V < A_V$

❖ INCREASE IN BANDWIDTH

$$f_H' = f_H\,(1 + \beta_v A_{v\,(mid)})$$

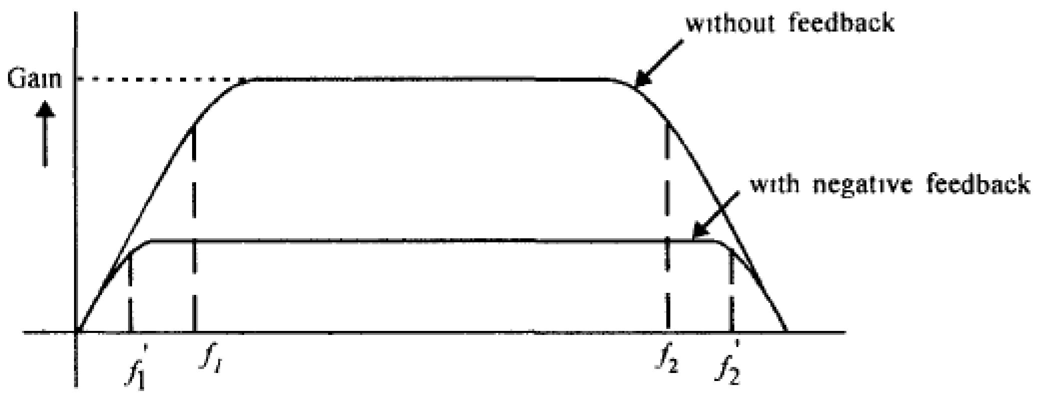
$$f_L' = \frac{f_L}{1 + \beta_v A_{v(mid)}}$$

❖ REDUCTION IN DISTORTION

$$\frac{D}{1 + \beta_v A_v} \text{ is } < D$$

- FEEDBACK TO IMPROVE SENSITIVITY
- FREQUENCY DISTORTION
- BAND WIDTH

$$(BW)_f = (1 + \beta A_m)\, BW$$



SENSITIVITY OF TRANSISTOR GAIN

$$\textit{Sensitivity} = \frac{\left|\frac{dA_f}{A_f}\right|}{\left|\frac{dA}{A}\right|}$$

$$\textit{Densitivity}\ \boxed{D = (1 + \beta A).}$$

REDUCTION OF NONLINEAR DISTORTION

$$B_{2f} = \frac{B_2}{1 + \beta A} \quad B_{2f} < B_2$$

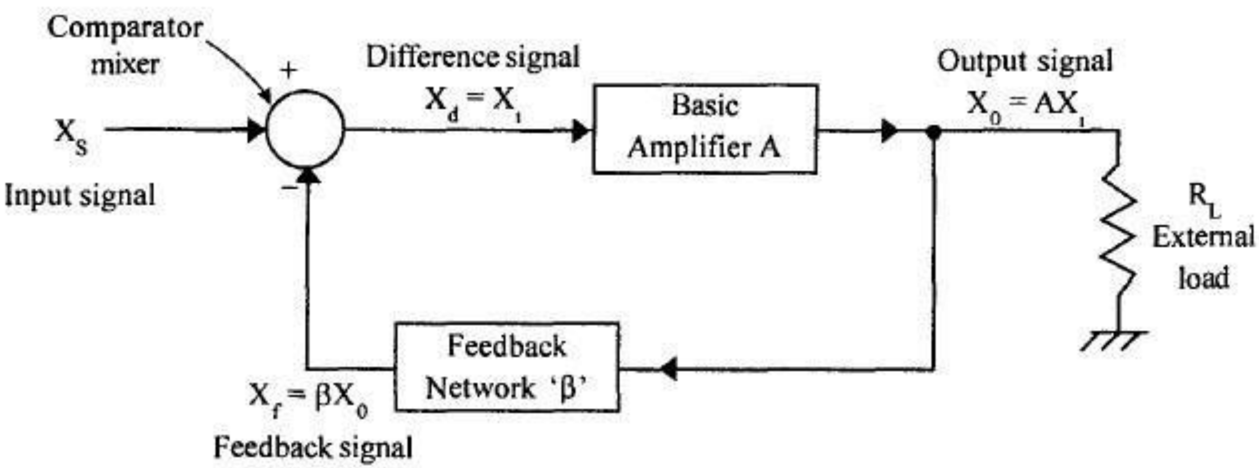
❖ REDUCTION OF NOISE

$$N_F = \frac{N}{1+\beta A}$$

$N_F < N$. Noise is reduced with negative feedback.

TRANSFER GAIN WITH FEEDBACK

Consider the generalized feedback amplifier



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

A_f = gain with feedback.

A = transfer gain without feedback.

If $|A_f| < |A|$ the feedback is called as negative or degenerative, feedback

If $|A_f| > |A|$ the feedback is called as positive or regenerative, feedback

LOOP GAIN

Return Ratio

βA = Product of feedback factor β and amplification factor A is called as *Return Ratio.*

Return Difference (D)

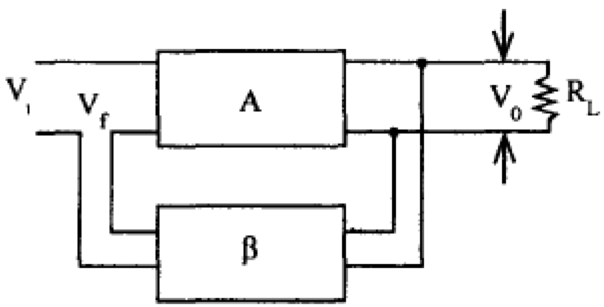
The difference between unity (1) and return ratio is called as *Return difference.*

$$D = 1-(-\beta A) = 1+\beta A.$$

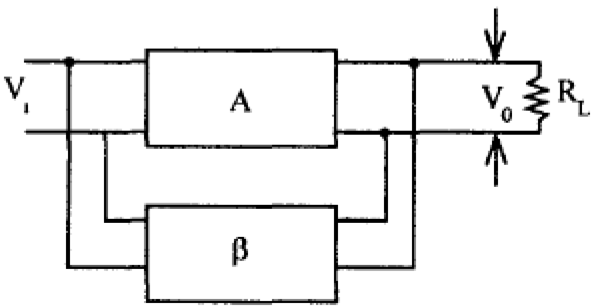
CLASSIFACTION OF FEEDBACK AMPLIFIERS

There are four types of feedback,

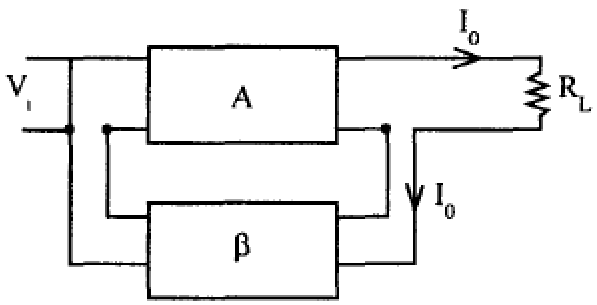
1. Voltage series feedback.
2. Voltage shunt feedback.
3. Current shunt feedback.
4. Current series feedback



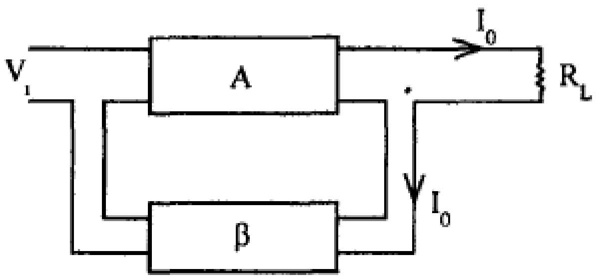
voltage series feedback.



Voltage shunt Feedback



Current Shunt Feedback



Current Series Feedback

EFFECT OF FEEDBACK ON INPUT RESISTANCE

Voltage shunt Feedback

$$R_i' = \frac{R_i}{(1 + \beta_i\ A_i)}$$

Current Shunt Feedback

$$R_{if} = \frac{V_i}{(1 + \beta A_I)I_i} = \frac{R_i}{1 + \beta . A_I}$$

voltage series feedback.

Current Series Feedback

$$R_{if} = R_i\,(1+\beta A)$$

$$R_{if} = R_i\left(1+\beta.\frac{V_o}{V_i}\right) = R_i(1+\beta.A_V)$$

EFFECT OF NEGATIVE FEEDBACK ON Ro

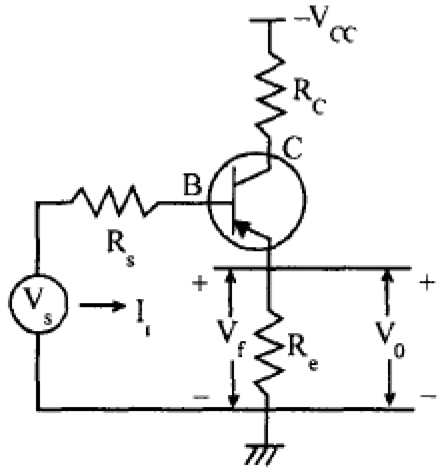
voltage series feedback.

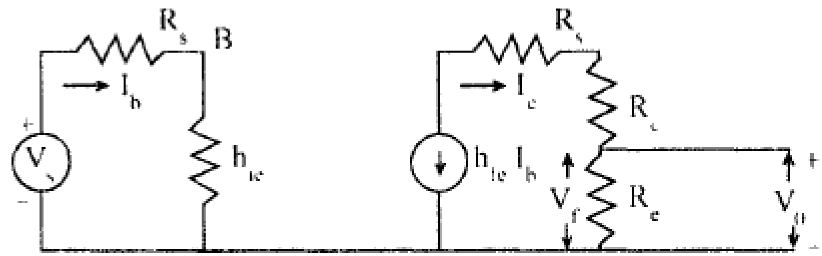
Current Shunt Feedback

$$R_{of}' = \frac{\frac{R_o}{1+\beta A_V} \times R_L}{\frac{R_0}{1+\beta A_V} + R_L} = \frac{R_o R_L}{R_o + R_L + \beta.A_v R_L}$$

$$\boxed{R_{of}' = R_0\,(1+\beta A_i)}$$

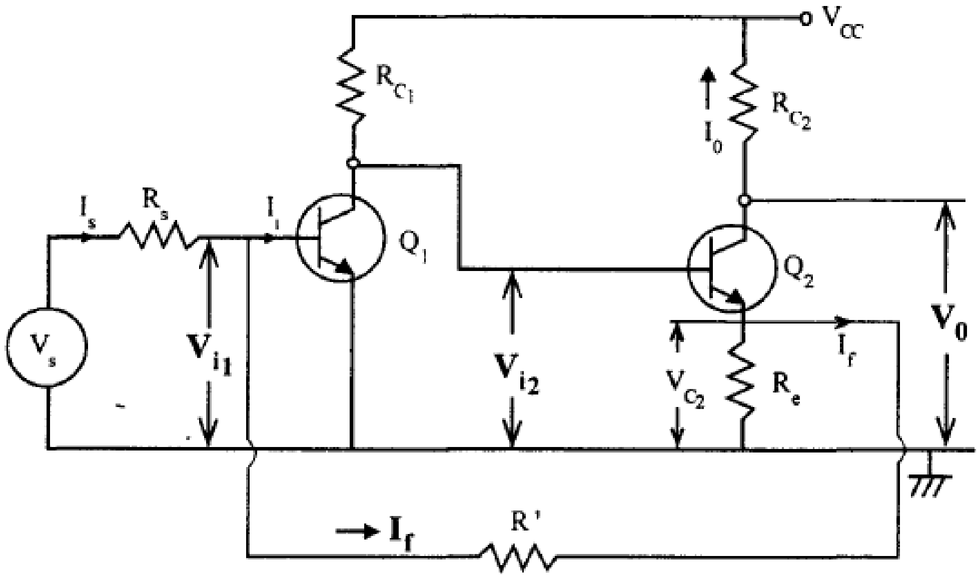
ANALYSIS OF FEEDBACK AMPLIFIERS

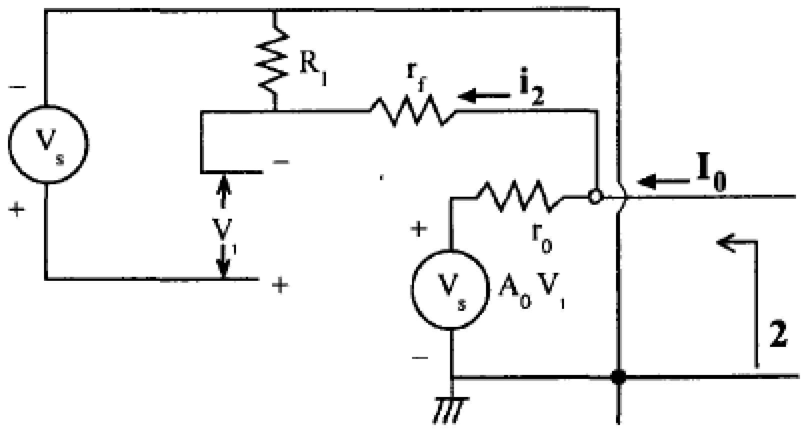




Block Schematic

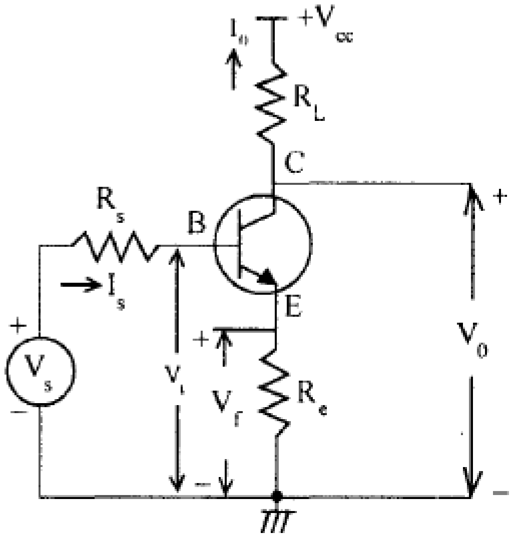
Current shunt feedback.



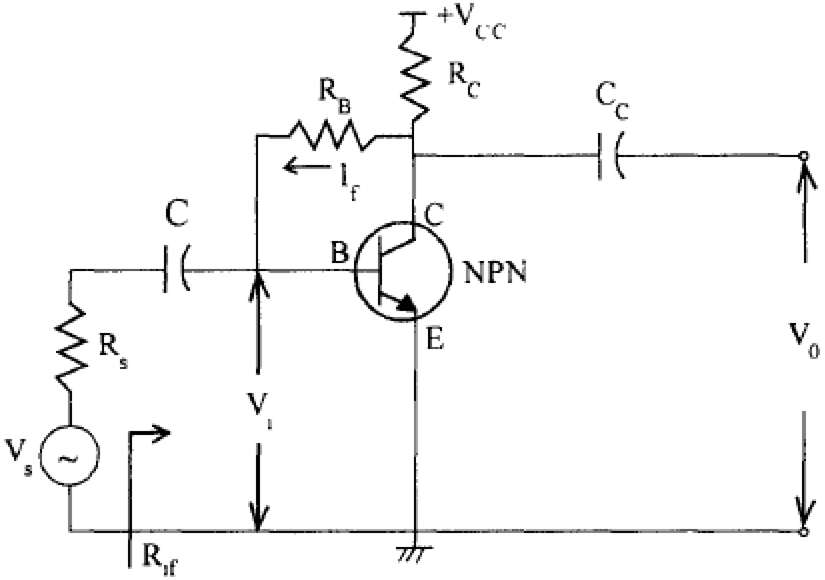


Equivalent circuit.

CURRENT SERIES FEEDBACK



VOLTAGE SHUNT FEEDBACK



OSCILLATORS

Oscillator Circuit

- Oscillator is an electronic circuit which converts dc signal into ac signal.
- Oscillator is basically a positive feedback amplifier with unity loop gain.
- For an inverting amplifier- feedback network provides a phase shift of 180° while for non-inverting amplifier- feedback network provides a phase shift of 0° to get positive feedback .

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

If $\beta A=1$ then $V_o = \infty$; Very high output with zero input.

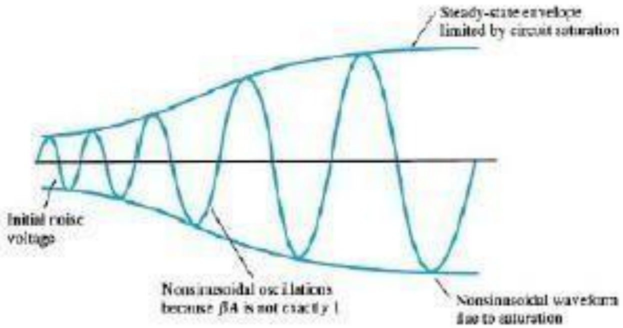
Use positive feedback through frequency-selective feedback network to ensure sustained oscillation at ω_0

Use of Oscillator Circuits

- Clock input for CPU, DSP chips …
- Local oscillator for radio receivers, mobile receivers, etc
- As a signal generators in the lab
- Clock input for analog-digital and digital-analog converters

Oscillators

- If the feedback signal is not positive and gain is less than unity, oscillations dampen out.
- If the gain is higher than unity then oscillation saturates.



Type of Oscillators

Oscillators can be categorized according to the types of feedback network used:

- RC Oscillators: Phase shift and Wien Bridge Oscillators
- LC Oscillators: Colpitt and Hartley Oscillators
- Crystal Oscillators

4

There are two types of oscillators circuits:

I. Harmonic Oscillators

2. Relaxation Oscillators

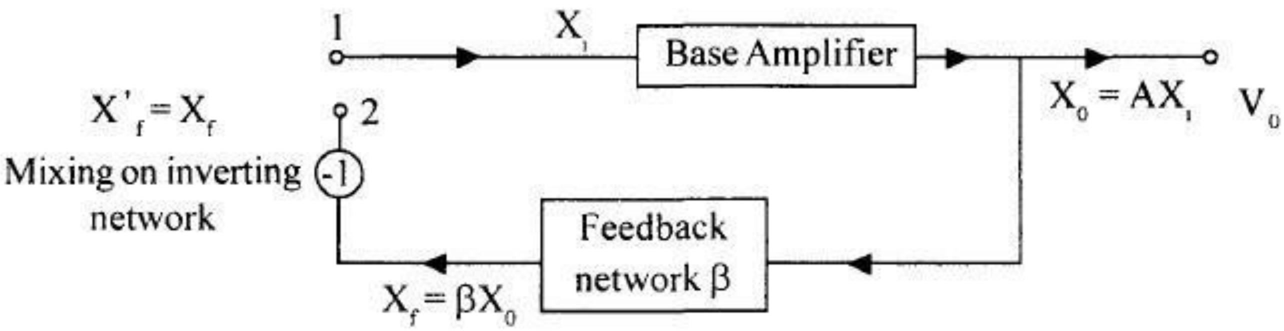
PERFORMANCE MEASURES OF OSCILLATOR CIRCUITS:

- ***Stability:***
- ***Amplitude stability:***
- ***Output Power:***
- ***Harmonics:***

Total phase shift = 360^0 (180 + 180). Therefore, to get sustained oscillations,

1. The loop gain must be unit 1.
2. Total Loop phase shift must be 0^0 or 360^0. (Amplifier circuit produces 180^0 phase shift and feedback network another 180^0.

SINUSOIDAL OSCILLATORS

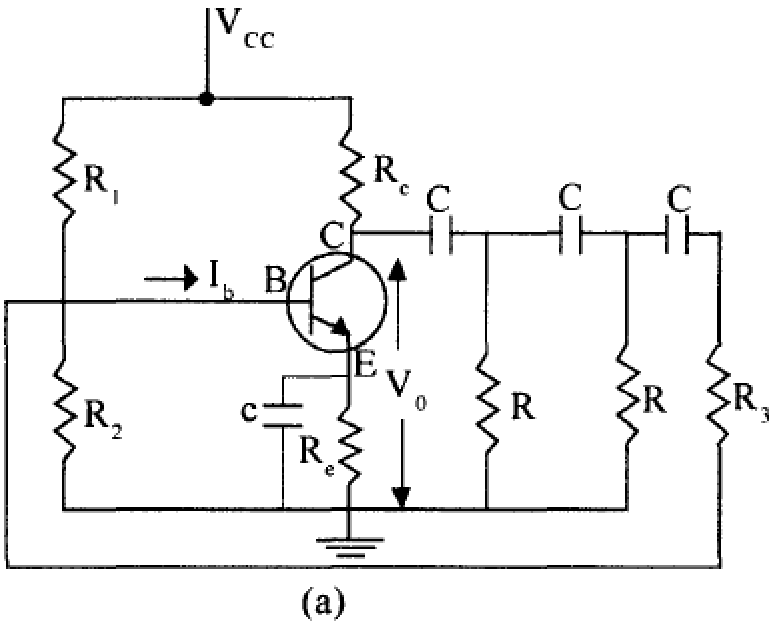


Block schematic

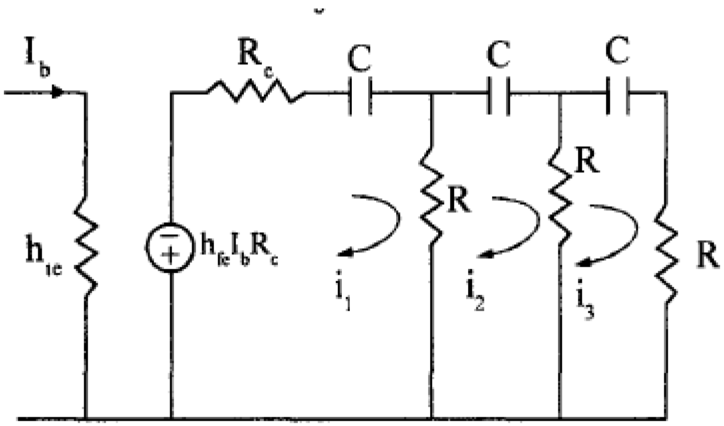
BARKHAUSEN CRITERION

$|\beta A| = 1$ and phase of $-A\beta = 0$.

R - C PHASE-SHIFT OSCILLATOR



Transistor phase shift oscillator.



R - C Equivalent circuit.

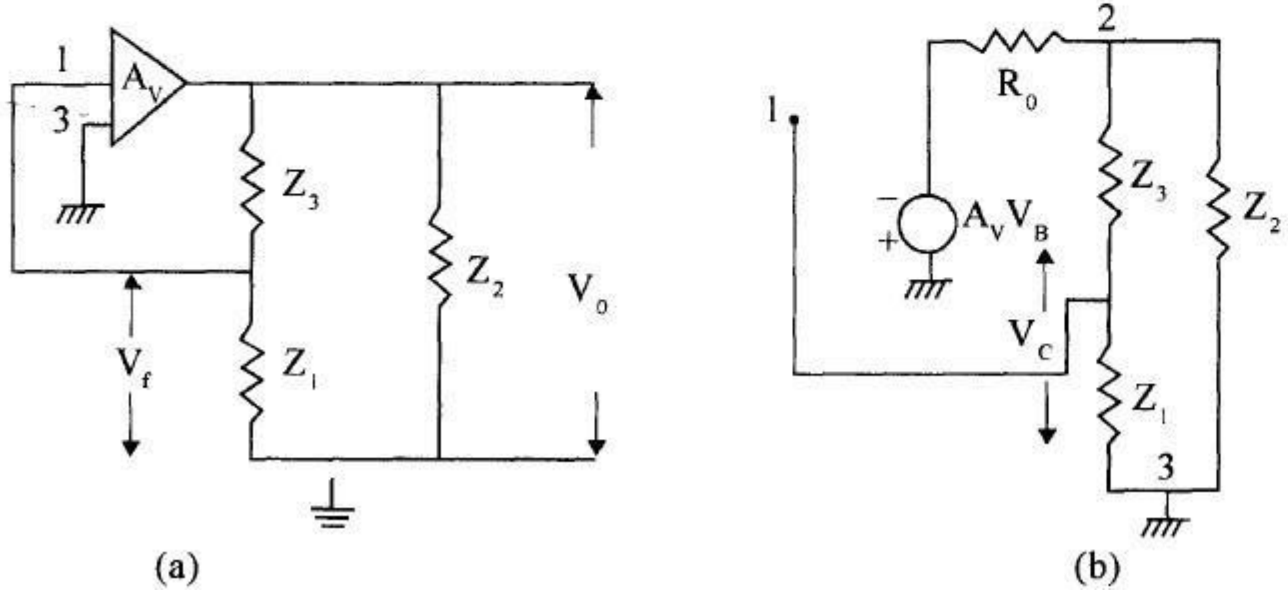
$$h_{fe} K > 4K^2 + 23K + 29$$

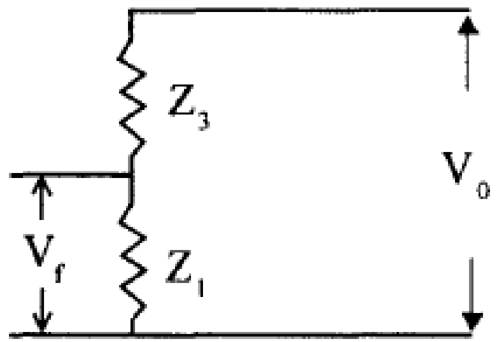
$$h_{fe} > 4K + 23 + \frac{29}{K}$$

$$K < 2.7$$

$$h_{fe} > 44.5$$

A GENERAL FORM OF LC OSCILLATOR CIRCUIT



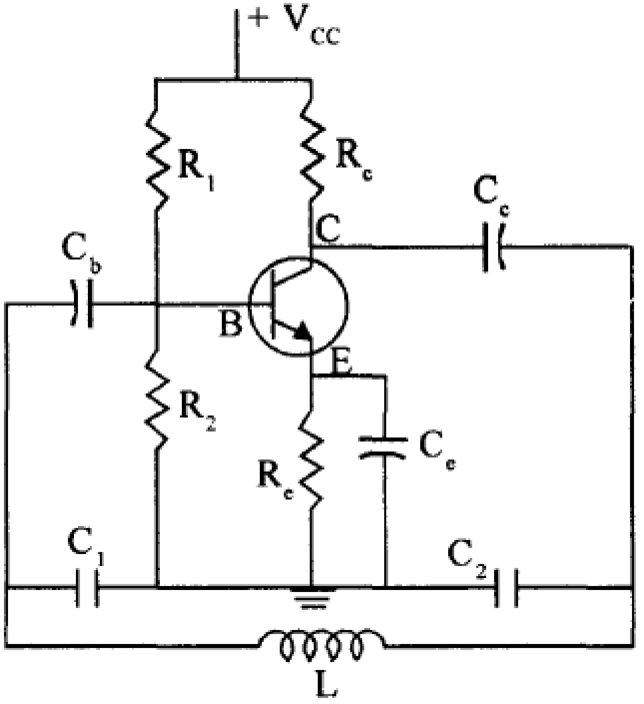


$$-A\beta = \frac{A_V X_1}{X_2}.$$

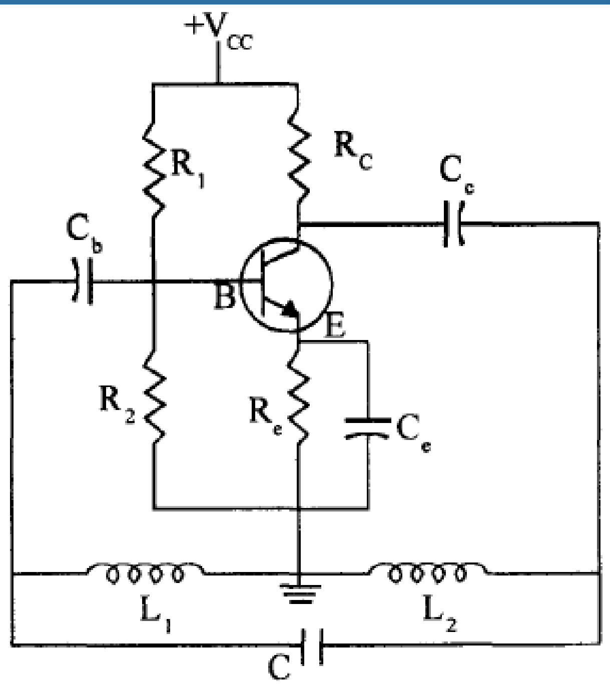
- Aβ must be positive, and at least unity in magnitude. Than XI and X2 must have the same sign.

So if X_1 and X_2 are capacitive, X_3 should be inductive and vice versa.

If X_1 and X_2 are capacitors, the circuit is called ***Colpitts Oscillator***
If X_1 and X_2 are inductors, the circuit is called ***Hartely Oscillators***



(a) Colpitts oscillator



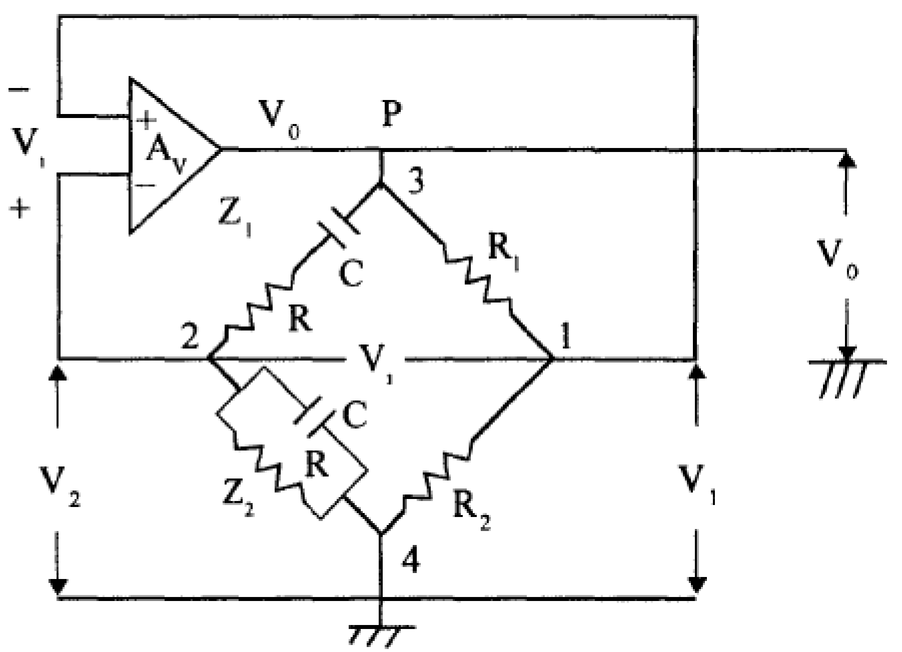
(b) Hartely oscillator circuit

$$f = \frac{1}{2\pi\sqrt{L\,C_T}}$$

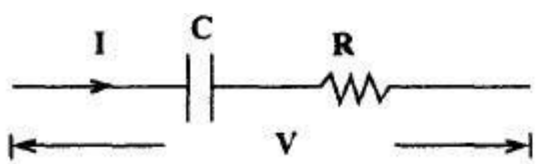
where $C_T = \dfrac{C_1 C_2}{C_1 + C_2}$

$$f = \frac{1}{2\pi\sqrt{(L_1 + L_2)\,C_3}}$$

Wien bridge oscillator circuit.

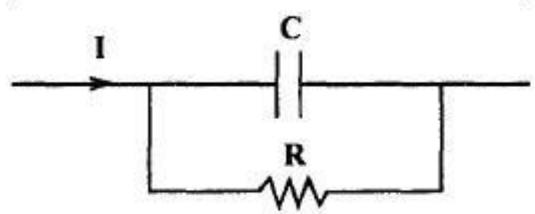


Lead Network :

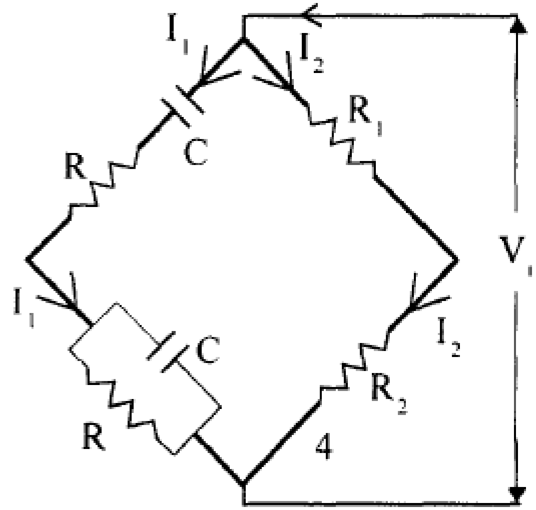


Same I is passing through C and R.
So I leads V.

Lag Network :



I lags with respect to V.

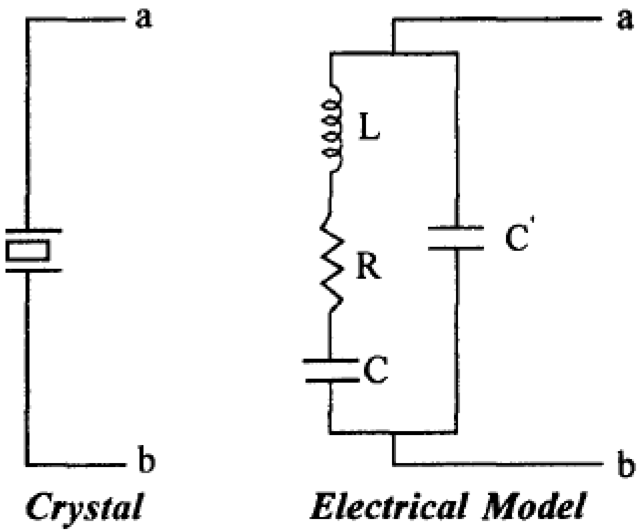


Wien Bridge oscillator circuit.

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

$$h_{fe} = 4k + 23 + \frac{29}{K}.$$

CRYSTAL OSCILLATORS



$$f = \frac{1}{2\pi}\sqrt{\frac{1}{LC} - \frac{R^2}{L^2}}$$

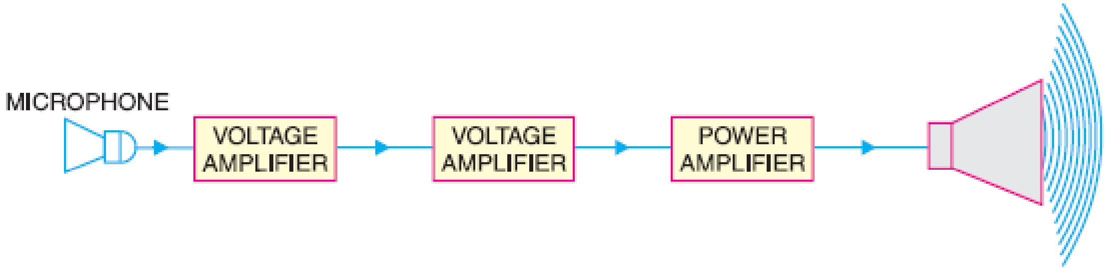
Amplifier

- A transistor amplifier which raises the power level of the signals that have audio frequency range is known as **transistor audio power amplifier.**
- A transistor that is suitable for power amplification is generally called a *power transistor*.
- The typical power output rating of a power amplifier is 1W or more.

large signal amplifiers:

- Output power
- Distortion Operating
- region Thermal
- considerations
- Efficiency (η)

block diagram of an audio amplifier



Difference Between Voltage and Power Amplifiers

S. No.	Particular	Voltage amplifier	Power amplifier
1.	β	High (> 100)	low (5 to 20)
2.	R_C	High (4 – 10 kΩ)	low (5 to 20 Ω)
3.	*Coupling*	usually *R* – *C* coupling	Invariably transformer coupling
4.	*Input voltage*	low (a few mV)	High (2 – 4 V)
5.	*Collector current*	low (≃ 1 mA)	High (> 100 mA)
6.	*Power output*	low	high
7.	*Output impedance*	High (≃ 12 kΩ)	low (200 Ω)

Performance Quantities of Power Amplifiers

(i) Collector efficiency

The ratio of a.c. output power to the zero signal power (i.e. d.c. power) supplied bythe battery of a power amplifier is known as **collector efficiency**.

(ii) Distortion

The change of output wave shape from the input wave shape of an amplifier is known as **distortion.**

(iii) Power dissipation capability

The ability of a power transistor to dissipate heat is known as **powerdissipation capability.**

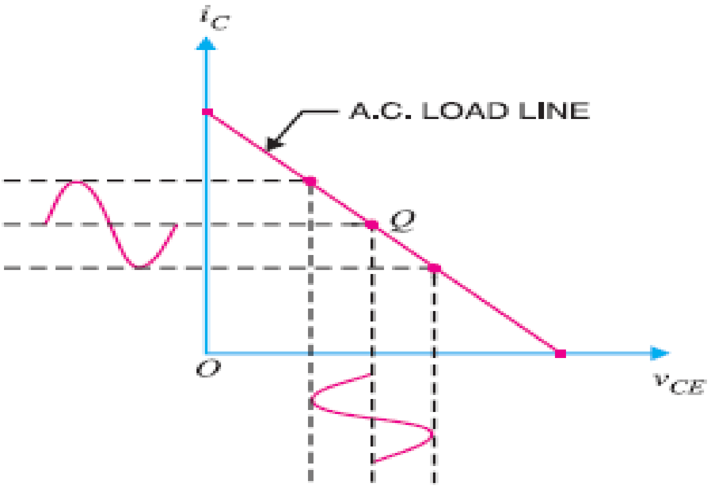
Classification of Power Amplifiers

- Class A: It is one, in which the active device conducts for the full 360°.
- Class B: Conduction for 180 °.
- Class C: Conduction for < 180°.
- Class AB :Conduction angle is between 180°. and 360°.
- Class D: These are used in *transmitters because their efficiency is high: 100%.*
- Class S:Switching regulators are based on class'S' operation.

Class A power amplifier

- If the collector current flows at all times during the full cycle of the signal, the power amplifier is known as **classApower amplifier.**

- If the Q point is placed near the centre a/the linear region a/the dynamic curve, class A operation results. Because the transistor will conduct for the complete 360 , distortion is low for small signals and conversion efficiency is low.



Types of class-A power Amplifiers

1. Series fed

There is no transformer in the circuit. RL is in series with V cc. There is DC power drop across RL. Therefore efficiency = 25% (maximum).

2. Transformer coupled

- The load is coupled through a transformer. DC drop across the primary of the transformer is negligible. There is no DC drop across RL. Therefore efficiency = 50% maximum.

Series Fed class-A power Amplifier

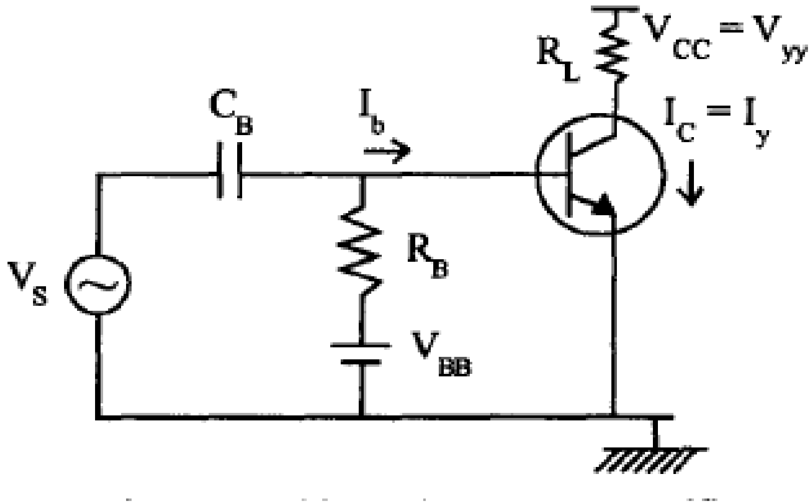


Fig.(a)Series fedClass A power amplifier circuit

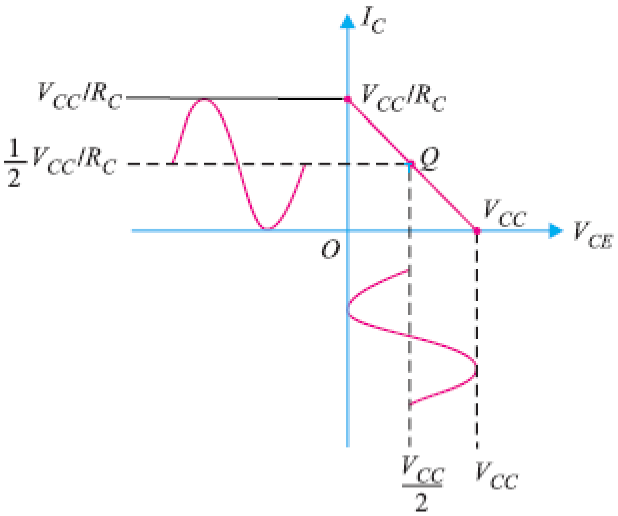
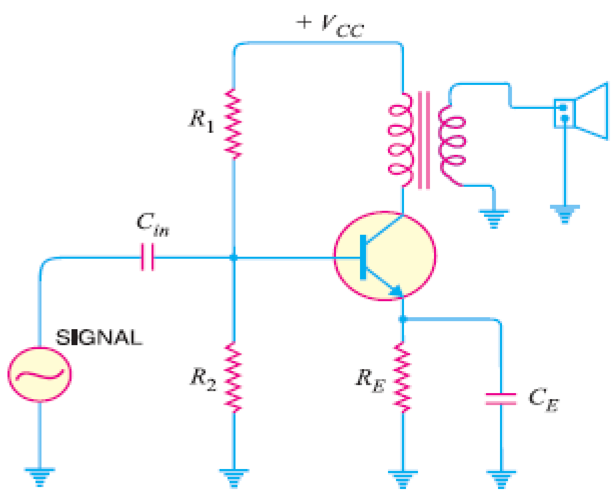


Fig.(b)Transter curve

Transformer Coupled class-Apower Amplifier



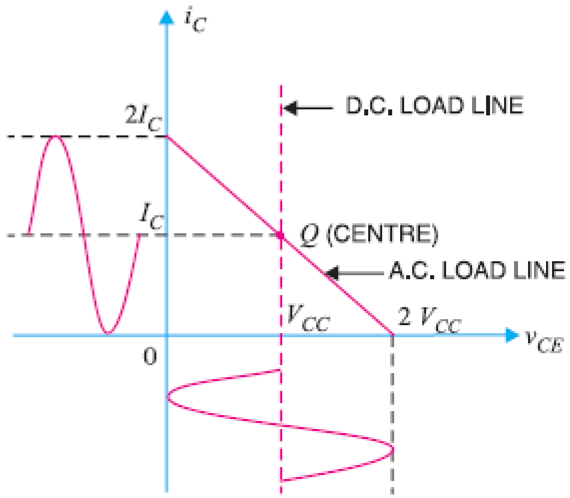


Fig.(a)Transformer Coupled Class A power amplifier circuit

Fig.(b)Transfer curve

Important Points About Class A Power Amplifier

- A transformer coupled class A power amplifier has a maximum collector efficiency of ***50%***
- The power dissipated by a transistor is given by :

$$P_{dis} = P_{dc} - P_{ac}$$

- When no signal is applied to a class *A power amplifier, Pac = 0.*

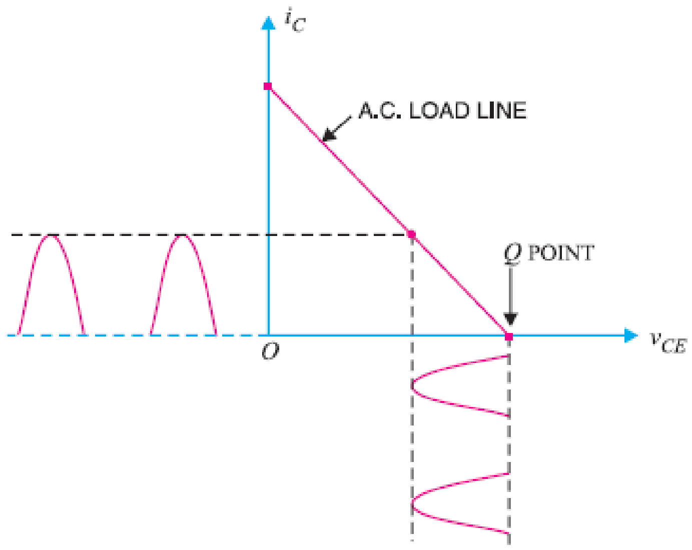
$$\therefore P_{dis} = P_{dc}$$

- When a class *A power amplifier is used in the final stage, it is called* ***single ended class A power amplifier.***

Class B power amplifier

- If the collector current flows only during the positive half-cycle of the input signal, it is called a **class B power amplifier**.

- For class B operation the Q point is set near cutoff. So output power will be more and conversion efficiency is more. Conduction is only for 180



Transfer curve

Types of class-B power Amplifiers

- **Push-PullAmplifier**

  The standard class B push-pull amplifier requires a centre tapped transformer

- **Complimentary Symmetry Circuits (Transformer Less Class B PowerAmplifier)**

  Complementary symmetry circuits need only one phase

  They don't require a centre tapped transformer.

# of Class B power Amplifier

Advantages

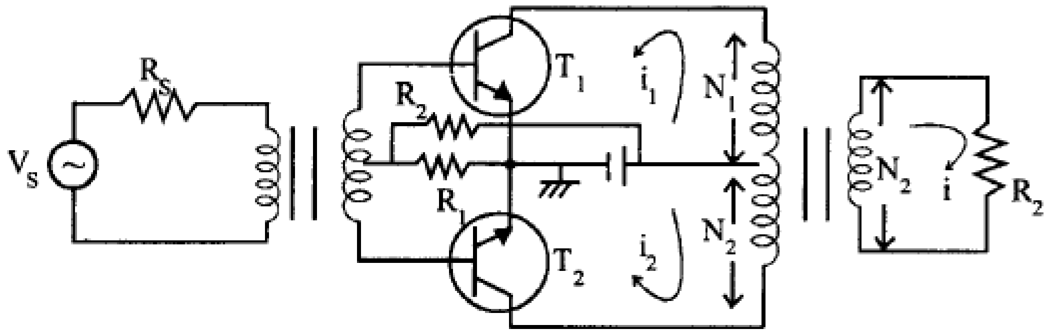
1. More output power; efficiency = 78.5%. Max.
2. Efficiency is higher. Since the transistor conducts only for 180°, when it is not conducting, it will not draw DC current.

3.Negligible power loss at no signal.

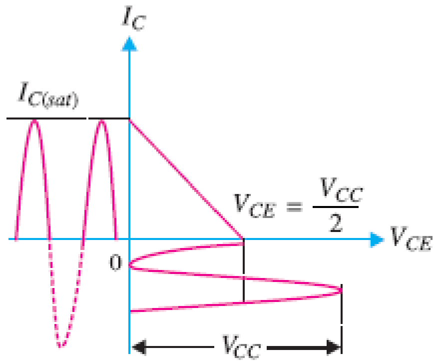
Disadvantages:

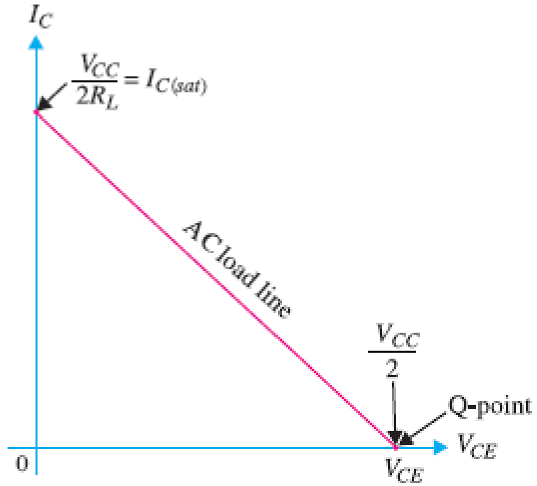
4. Supply voltage V cc should have good regulation. Since if V cc changes, the operating point changes (Since Ic changes). Therefore transistor may not be at cut off.
5. Harmonic distortion is higher. (This can be minimized by pushpull connection).

Class B Push-Pull Amplifier



Push Pull amplifier circuit





Complimentary Symmetry Circuits (Transformer Less Class B Power Amplifier)

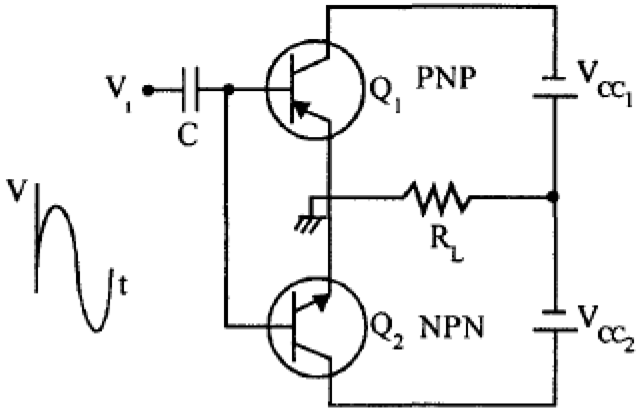


Fig. Complimentary Symmetry circuit

of Class B complementary power Amplifier

- **Advantages**

(i)This circuit does not require transformer. This saves on weight and cost.

(ii) Equal and opposite input signal voltages are not required.

- **Disadvantages**

(i)It is difficult to get a pair of transistors (npn and pnp) that have similar characteristics.

(ii)Werequire both positive and negative supply voltages.

Differences between class-A & B power Amplifiers

Class A	Class B
Less power	More power
Lesser η	More η upto 78.5%
Less Harmonic distortion	Harmonic distortion is more

Heat Sinks

- The metal sheet that serves to dissipate the additional heat from the power transistor is known as **heat sink.**
- The purpose of heat sinks is to keep the operating temperature of the transistor low, to prevent thermal breakdown.
- Almost the entire heat in a transistor is produced at the collector-base junction. If the temperature exceeds the permissible limit, this junction is destroyed and the transistor is rendered useless.
- Most of power is dissipated at the collector-base junction. This is because collector-base voltage is much greater than the base-emitter voltage, although currents through the two junctions are almost the same.

Mathematical Analysis Of Heat Sinks

$$\theta_{ja} = \theta_{jc} + \theta_{cn} + \theta_{na}$$
$$\theta_{jc} = (T_j - T_c) / P$$
$$\theta_{cs} = (T_c - T_s) / P$$
$$\theta_{sa} = (T_s - T_a) / P$$

θ_{ja} = Junction to ambient thermal resistance
θ_{jc} = Junction to casing thermal resistance
θ_{cs} = Casing to heat sink thermal resistance
θ_{sa} = Heat sink to ambient thermal resistance
T_j = Average junction temperature
T_c = Average case temperature
T_{sa} = Average heat sink temperature
T_a = Ambient temperature
P = Power dissipated in Watts.

Classification of heat Sinks

1. Low Power TransistorType.

2. High Power TransistorType.

MODULE– III
OSCILLATORS

CLOs	Course Learning Outcome
CLO6	Understand the condition for Oscillations and various types of Oscillators.
CLO7	Design various sinusoidal Oscillators like RC Phase shift, Wien bridge, Hartley and Colpitts oscillator for various frequency ranges.
CLO8	Design different types of power amplifiers for practical applications of desired specifications like efficiency, output power, distortion, etc.
CLO9	Design the tuned circuits used in single tuned amplifiers and understand its frequency response.

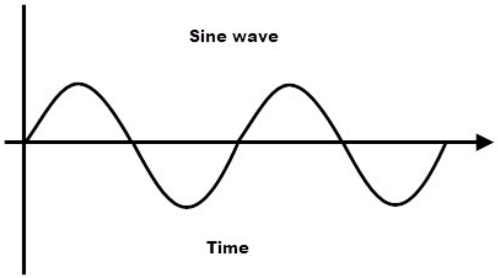
Oscillator

- Any circuit which is used to generate a periodic voltage without an input AC signal is called an oscillator.
- To generate the periodic voltage, the circuit is supplied with energy from DC source.
- It converts DC signal to AC signal.

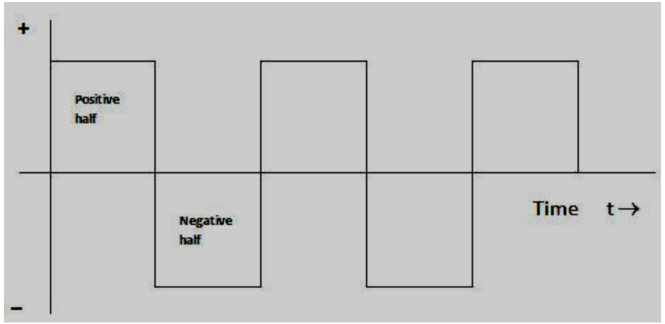
Classification of Oscillators

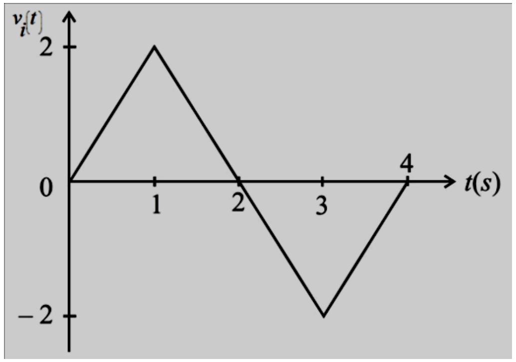
1. According to waveform generated

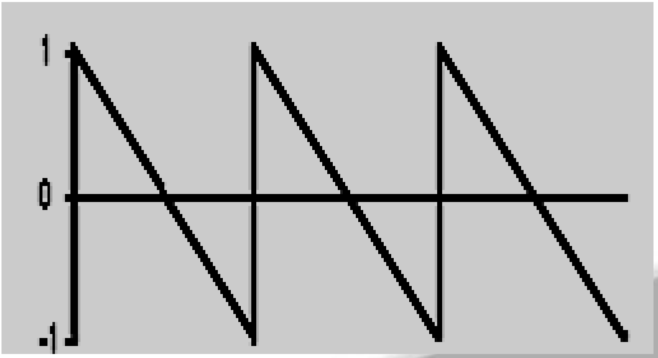
- Sinusoidal oscillators



- Non-sinusoidal oscillators







Classification of Oscillators

2. According to fundamental mechanism involved

- Negative resistance oscillators:
  - Consists primarily 2-terminal devices that have negative resistance in a portion of its operating characteristics and a frequency selective network.
  - Eg: UJT, Tunnel diode
- Feedback oscillators:
  - Uses the positive feedback in the feedback amplifier to satisfy the Barkhausen criteria.

Classification of Oscillators

3. According to frequency generated

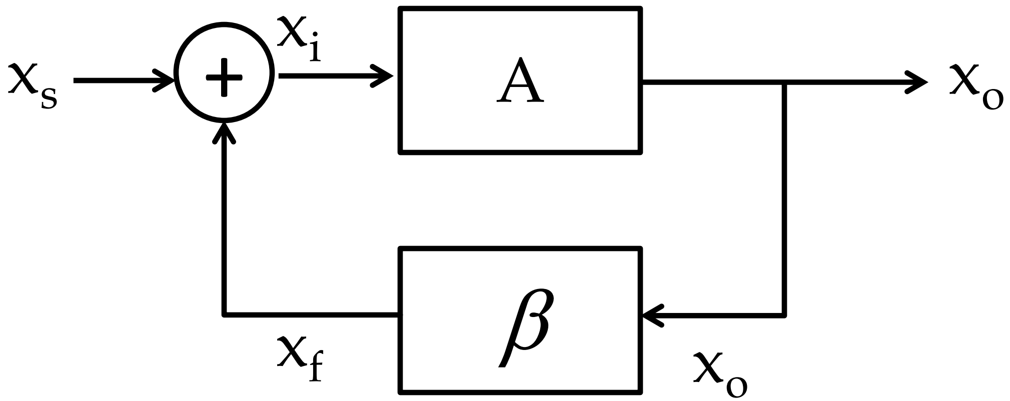
- Audio frequency oscillator - up to 20 KHz
- Radio frequency oscillator - 20 KHz – upto GHz
  - High frequency oscillator - 3 MHz – 30 MHz
  - Very high frequency oscillator -30 MHz – 300 MHz
  - Ultra high frequency oscillator -300 MHz - 3 GHz
  - Microwave frequency oscillator -Above 3 GHz

Classification of Oscillators

4. According to type of components used

- LC tuned oscillator
- RC phase shift oscillator

Condition for Oscillation

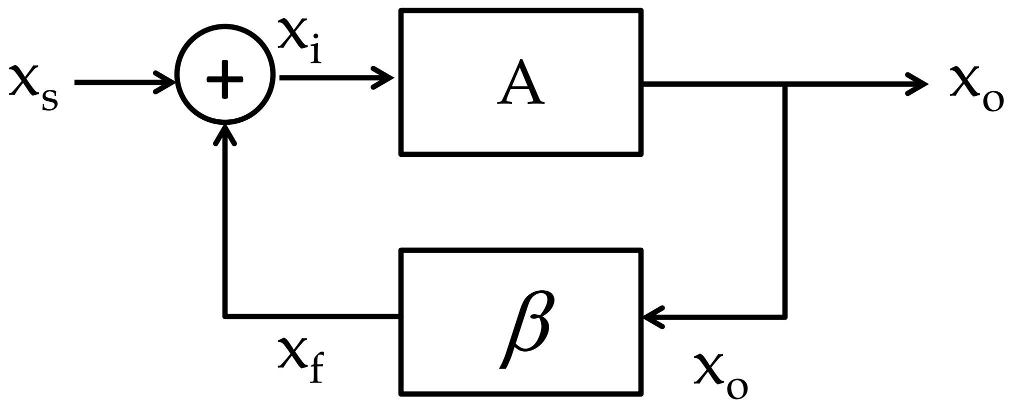


$$A = \frac{x_o}{x_i} = \text{Gain without feedback}$$

$$A_f = \frac{x_o}{x_s} = \text{Gain with feedback}$$

$$A_f = \frac{x_o}{x_s} = \frac{x_o}{x_i - x_f} = \frac{Ax_i}{x_i - \beta x_o} = \frac{Ax_i}{x_i(1 - \beta \frac{x_o}{x_i})} = \frac{A}{1 - \beta A}$$

Condition for Oscillation



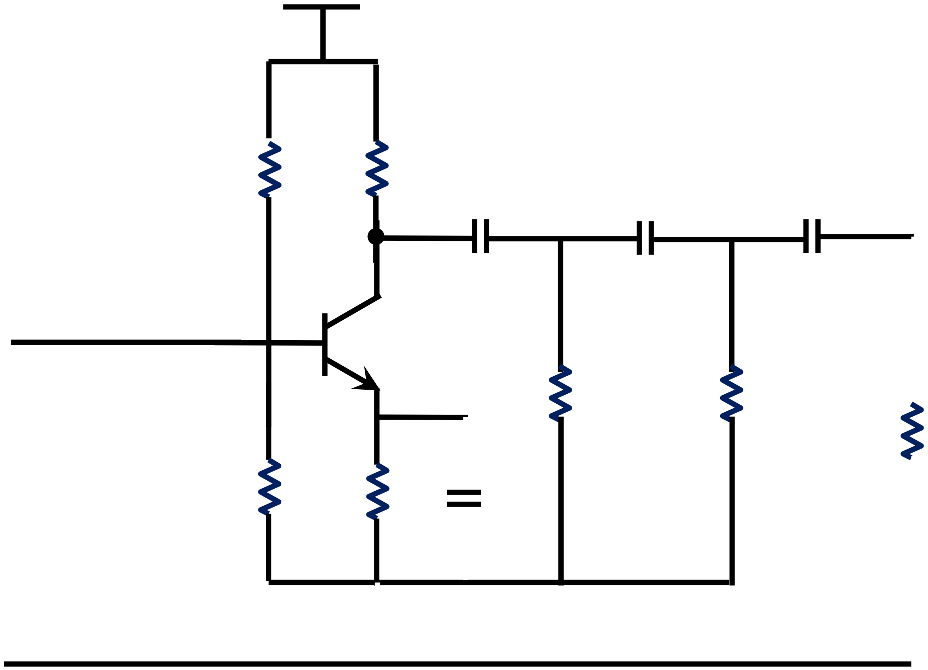
$$A_f = \frac{A}{1 - A\beta}$$

$$If\ A\beta = 1 \Rightarrow A_f = \infty$$

The condition for oscillations (Barkhausen criterion)

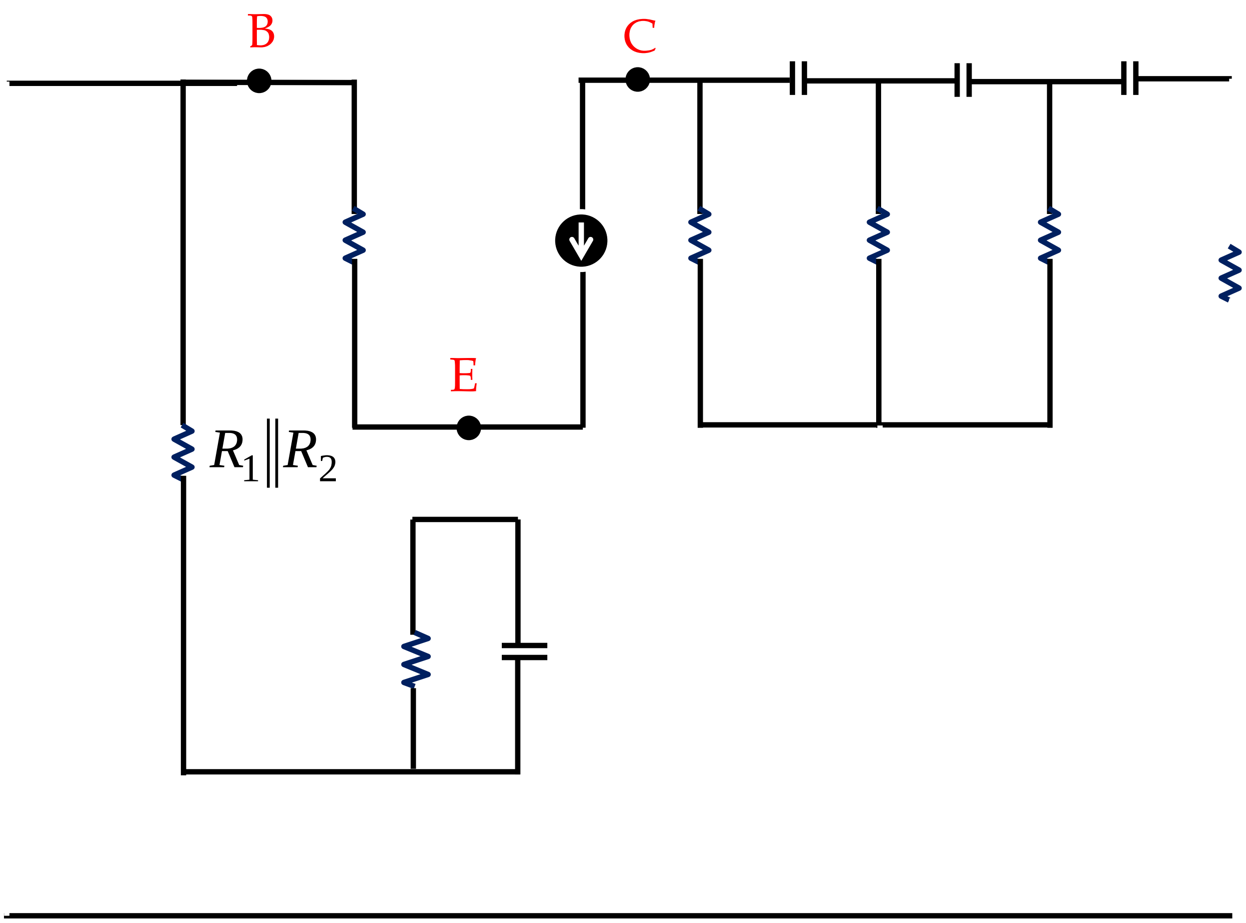
1. Magnitude of loop gain must be unity
2. The total phase shift around the closed loop should be 0^0 or 360^0

RC Phase shift oscillator: Design

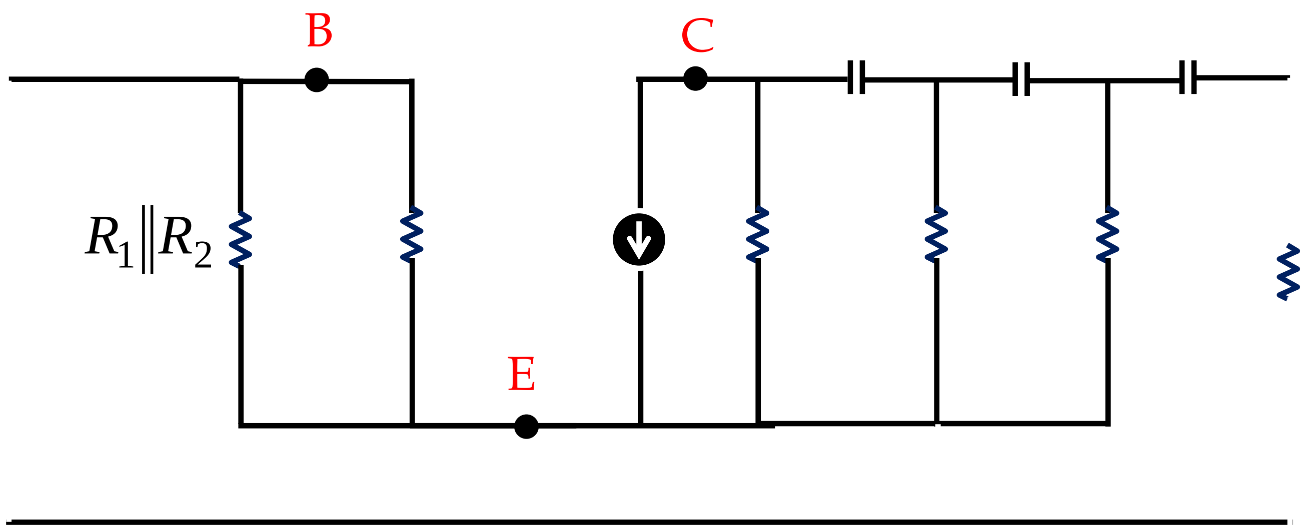


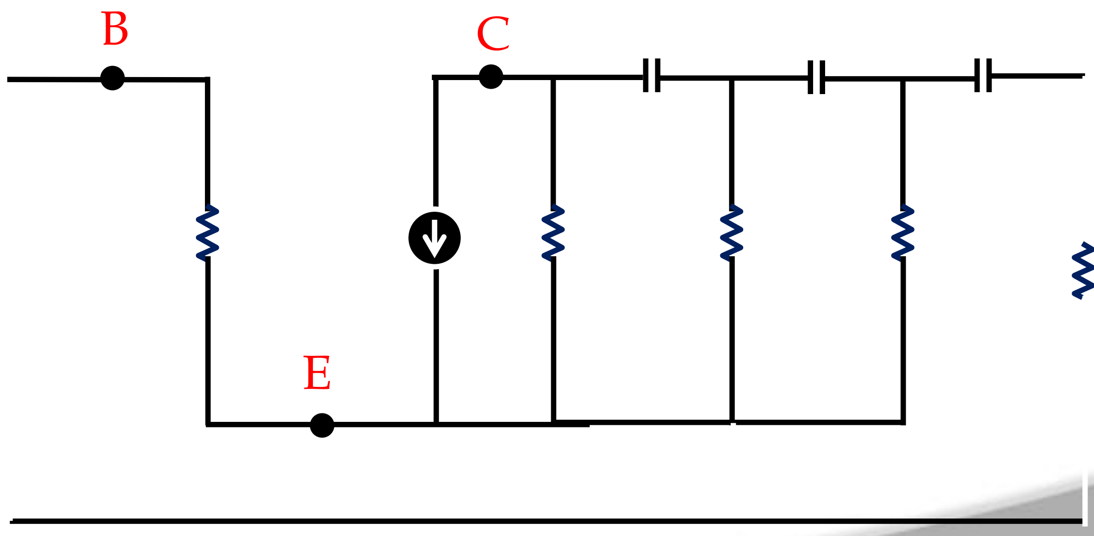
- CE amplifier followed by RC phase shift network which provides phase shift of 180°
- Feedback network is positive and provides a total phase shift of 360°.

Frequency of Oscillation

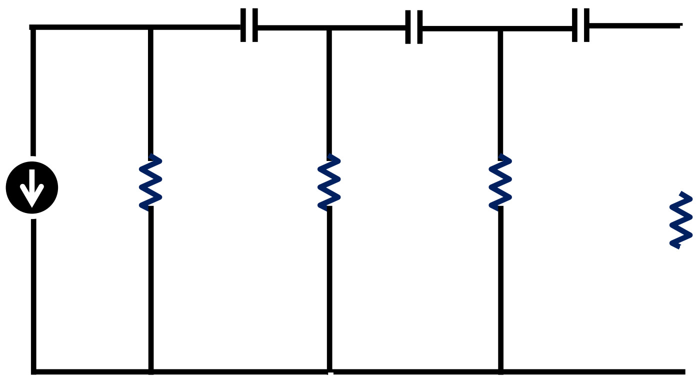


Frequency of Oscillation

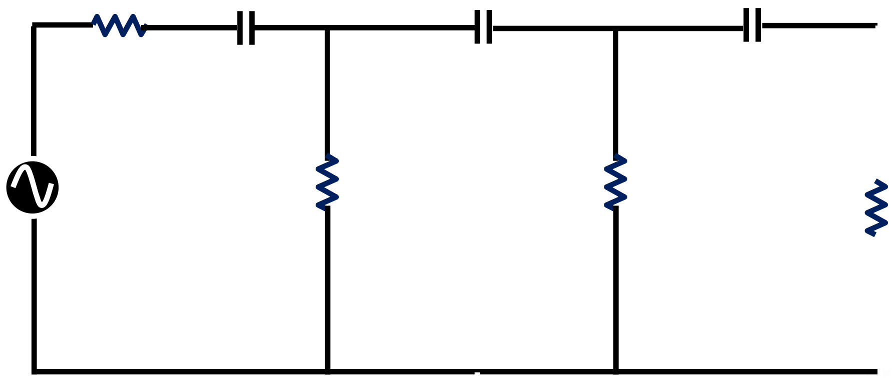




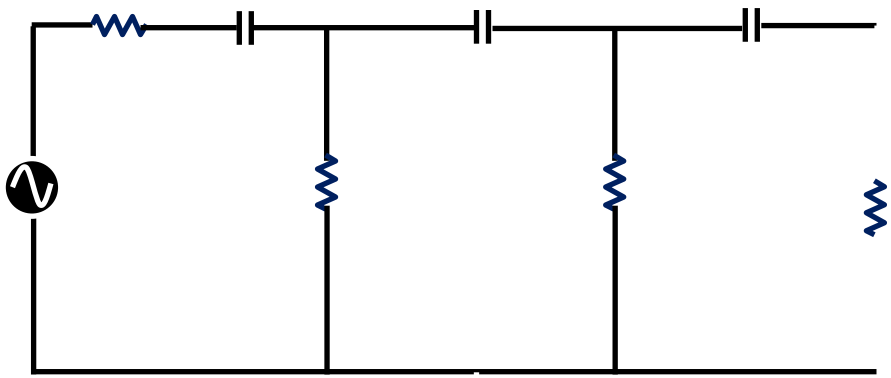
Frequency of Oscillation



- After applying source transformation



Frequency of Oscillation

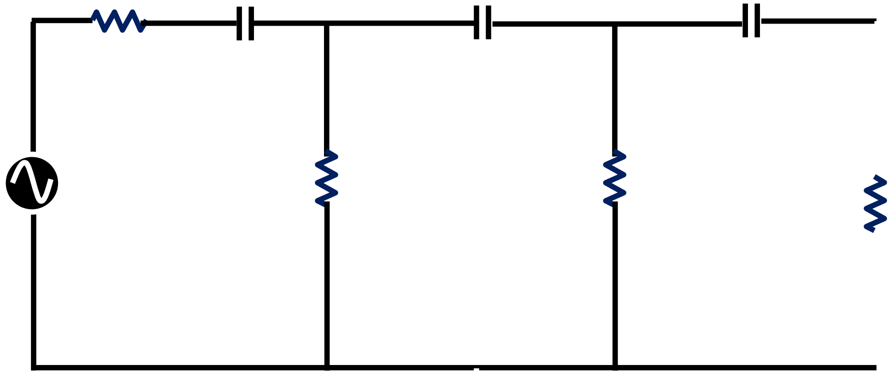


- KVL at loop 1

$$-h_{fe}I_bR_c = I_1R_c + \frac{1}{j\omega c}I_1 + R(I_1 - I_2)$$

$$-h_{fe}I_bR_c = I_1\left(R_c + \frac{1}{j\omega c} + R\right) + I_2(-R)$$

Frequency of Oscillation

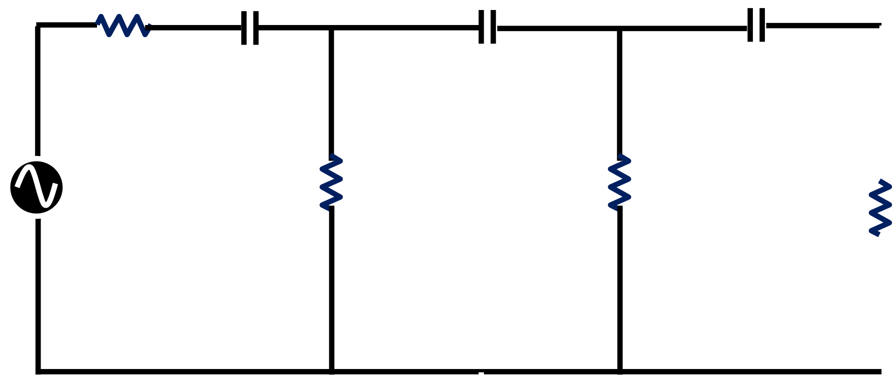


- KVL at loop 2

$$\frac{1}{j\omega c} I_2 + R(I_2 - I_3) + R(I_3 - I_2) = 0$$

$$-RI_1 + (2R + \frac{1}{j\omega c})I_2 - RI_3 = 0$$

Frequency of Oscillation



- KVL at loop 3

$$\frac{1}{j\omega c} I_3 + RI_3 + R(I_3 - I_2) = 0$$

$$-RI_2 + (2R + \frac{1}{j\omega c}) I_3 = 0$$

Frequency of Oscillation

- From equations (1), (2), and (3)

$$\begin{bmatrix} -h_{fe}I_bR_c \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} R_c + \dfrac{1}{j\omega c} + R & -R & 0 \\ -R & 2R + \dfrac{1}{j\omega c} & -R \\ 0 & -R & 2R + \dfrac{1}{j\omega c} \end{bmatrix} \begin{bmatrix} I_1 \\ I_2 \\ I_3 \end{bmatrix}$$

- Determinant of coefficient matrix

$$\begin{vmatrix} R_c + \dfrac{1}{j\omega c} + R & -R & 0 \\ -R & 2R + \dfrac{1}{j\omega c} & -R \\ 0 & -R & 2R + \dfrac{1}{j\omega c} \end{vmatrix}$$

Frequency of Oscillation

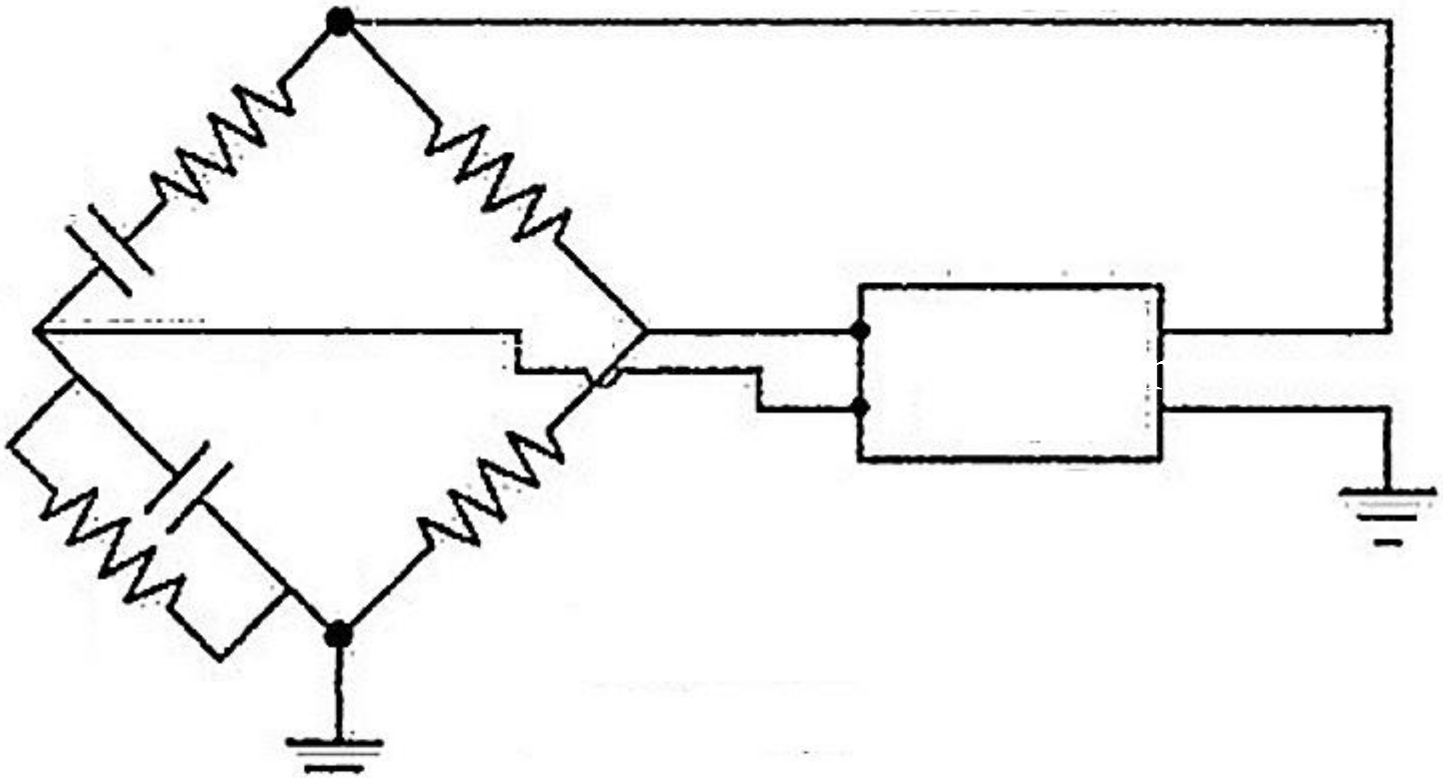
- Determinant of coefficient matrix

$$\Delta = \begin{vmatrix} R_c + \frac{1}{j\omega c} + R & -R & 0 \\ -R & 2R + \frac{1}{j\omega c} & -R \\ 0 & -R & 2R + \frac{1}{j\omega c} \end{vmatrix}$$

- Consider, R_c=kR and jω=s for simplification

$$\Delta = \begin{vmatrix} (k+1)R + \frac{1}{sc} & -R & 0 \\ -R & 2R + \frac{1}{sc} & -R \\ 0 & -R & 2R + \frac{1}{sc} \end{vmatrix}$$

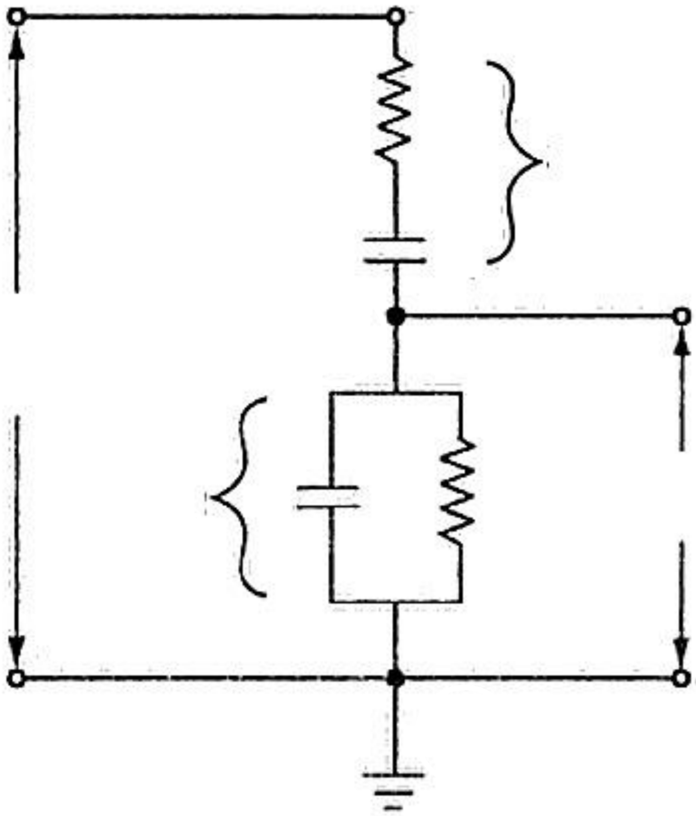
Wien Bridge oscillators



Wien Bridge oscillators

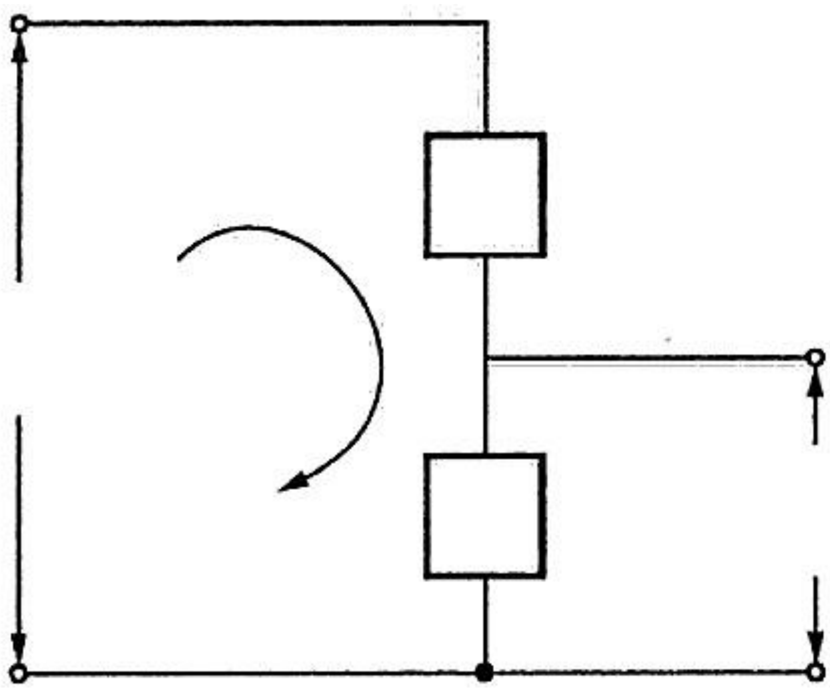
1. Output of amplifier is applied between 1 and 3 terminals which is input to the feedback network.
2. Output of feedback network between 2 and 4 terminals is applied as input to the amplifier.
3. Wien bridge oscillator uses a non-inverting amplifier and provides 0^o phase shift during amplifier stage.
4. The two arms of the bridge R_1, C_1 in series and R_2, C_2 in parallel are frequency sensitive arms as they provide frequency of oscillation.

Wien Bridge oscillators



- Output of amplifier V0 is applied as input to feedback network between 1 and 3.
- Output of feedback network, V_f is obtained at 4 w.r.t ground.

Wien Bridge oscillators



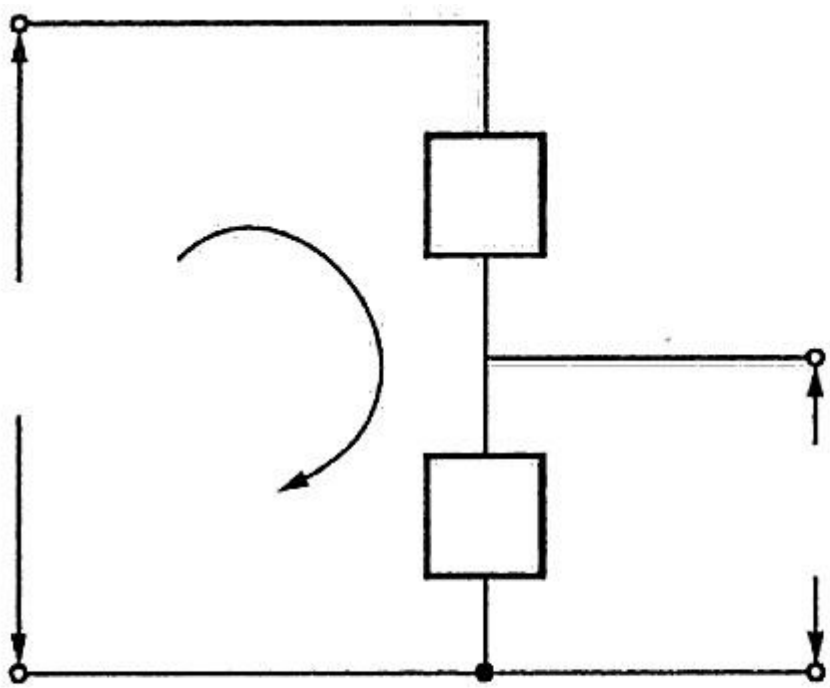
$$Z_1 = R_1 + X_{C1} \quad = R_1 + \frac{1}{j\omega C_1}$$

$$\Rightarrow Z_1 = \frac{1 + j\omega R_1 C_1}{j\omega C_1}$$

$$Z_2 = R_2 \| X_{C2} \quad = \frac{R_2 X_{C2}}{R_2 + X_{C2}}$$

$$\Rightarrow Z_2 = \frac{R_2 \cdot \frac{1}{j\omega C_2}}{R_2 + \frac{1}{j\omega C_2}} \quad = \frac{R_2}{1 + j\omega R_2 C_2}$$

Wien Bridge oscillators



$$I = \frac{V_0}{Z_1 + Z_2}$$

$$V_f = I \cdot Z_2 = \frac{V_0}{Z_1 + Z_2} \cdot Z_2$$

$$\Rightarrow \beta = \frac{V_f}{V_0} = \frac{Z_2}{Z_1 + Z_2}$$

Wien Bridge oscillators

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

$$\Rightarrow \beta = \frac{R_2}{1 + j\omega R_2 C_2} \cdot \frac{1}{\dfrac{1 + j\omega R_1 C_1}{j\omega C_1} + \dfrac{R_2}{1 + j\omega R_2 C_2}}$$

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

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

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

Wien Bridge oscillators

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

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

$$\Rightarrow \beta = \frac{j\omega C_1 R_2 - j\omega^3 R_1 R_2^2 C_1^2 C_2 + \omega^2 R_1 R_2 C_1^2 + \omega^2 R_2^2 C_1 C_2^2 + \omega^2 R_2^2 C_1^2}{(1-\omega^2 R_1 R_2 C_1 C_2)^2 + \omega^2 (R_1 C_1 + R_2 C_2 + R_2 C_1)^2}$$

Frequency of Oscillation

At frequency of oscillation imaginary terms should be zero.

$$\Rightarrow \frac{\omega C_1 R_2 (1-\omega^2 R_1 R_2 C_1 C_2)}{(1-\omega^2 R_1 R_2 C_1 C_2)^2 + \omega^2 (R_1 C_1 + R_2 C_2 + R_2 C_1)^2} = 0$$

$$\Rightarrow \frac{\omega C_1 R_2 (1-\omega^2 R_1 R_2 C_1 C_2)}{(1-\omega^2 R_1 R_2 C_1 C_2)^2 + \omega^2 (R_1 C_1 + R_2 C_2 + R_2 C_1)^2} = 0$$

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

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

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

$$If\ R_1 = R_2 = R\ and\ C_1 = C_2 = C$$

$$\Rightarrow \boxed{f = \frac{1}{2\pi RC}} \quad or \quad \boxed{\omega = \frac{1}{RC}}$$

Condition of Oscillation

$$\Rightarrow \beta = \frac{j\omega C_1 R_2 - j\omega^3 R_1 R_2^2 C_1^2 C_2 + \omega^2 R_1 R_2 C_1^2 + \omega^2 R_2^2 C_1 C_2^2 + \omega^2 R_2^2 C_1^2}{(1-\omega^2 R_1 R_2 C_1 C_2)^2 + \omega^2 (R_1 C_1 + R_2 C_2 + R_2 C_1)^2}$$

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

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

$$R_1 = R_2 = R \; and \; C_1 = C_2 = C$$

$$\Rightarrow \beta = \frac{\omega^2 RC(3RC)}{(1-\omega^2 R^2 C^2)^2 + \omega^2 (3RC)^2}$$

$$\Rightarrow \boxed{\beta = \frac{1}{3}}$$

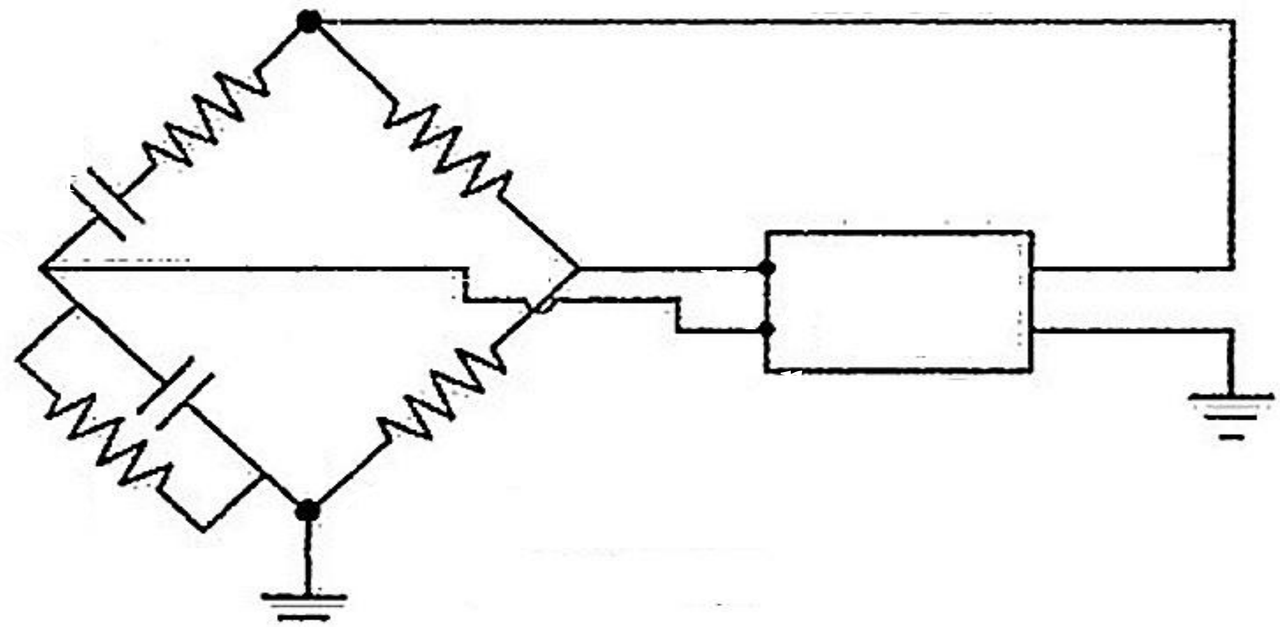
According to barkhausen criterion

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

$$\Rightarrow |A| \geq \frac{1}{|\beta|} \geq \frac{1}{1/3}$$

$$\Rightarrow \boxed{|A| \geq 3}$$

Wien Bridge oscillator



Frequency of oscillation

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

Amplifier gain condition

$$\Rightarrow |A| \geq 3$$

Wien Bridge oscillator

- Advantages
  - Uses both positive and negative feedback. Hence it provides better stability.
  - Overall gain is high, because of cascaded amplifier stage.
  - Frequency can be easily adjusted by varying R or C.
- Disadvantages
  - Frequency is not more stabile.
  - Cannot be used to generate high frequency of oscillations.

LC Oscillators

LC Oscillators

1. The oscillators which use elements L and C to produce oscillations are called LC oscillators.
2. Any active device like BJT, FET, Op-amp or vacuum tubes can be used for amplification.
3. Z_1, Z_2, and Z_3 are reactive elements used for feedback tank circuit which determine the frequency of oscillation.
4. Voltage across Z_1 is the feedback voltage and voltage across Z_2 is the output voltage.

LC Oscillators

❖ The overall impedance of the above circuit is

$$Z_L = \left[\left(Z_1 \| h_{ie}\right) + Z_3\right] \| Z_2$$

$$Z_L = \left[\left(Z_1 \| h_{ie}\right) + Z_3\right] \| Z_2$$

$$\Rightarrow Z_L = \left[\frac{Z_1 h_{ie}}{Z_1 + h_{ie}} + Z_3\right] \Bigg\| Z_2$$

$$\Rightarrow Z_L = \left[\frac{Z_1 h_{ie} + Z_3(Z_1 + h_{ie})}{Z_1 + h_{ie}}\right] \Bigg\| Z_2$$

$$\Rightarrow Z_L = \frac{\left[\frac{Z_1 h_{ie} + Z_3(Z_1 + h_{ie})}{Z_1 + h_{ie}}\right] Z_2}{\left[\frac{Z_1 h_{ie} + Z_3(Z_1 + h_{ie})}{Z_1 + h_{ie}}\right] + Z_2}$$

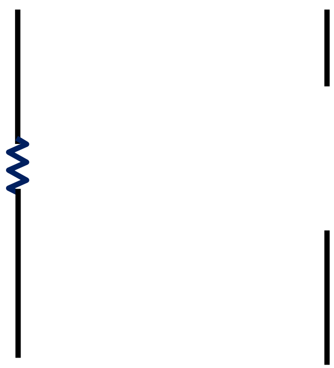
$$\Rightarrow Z_L = \frac{\left[Z_1 h_{ie} + Z_3(Z_1 + h_{ie})\right] Z_2}{Z_1 h_{ie} + Z_3(Z_1 + h_{ie}) + Z_2\left(Z_1 + h_{ie}\right)}$$

LC Oscillators

- Gain of the CE amplifier can be calculated as

$$A_V = \frac{-h_{fe}}{h_{ie}} \times Z_L$$

By applying voltage division rule V_f can be calculated as



$$V_f = V_o \frac{Z_1 \| h_{ie}}{Z_1 \| h_{ie} + Z_3}$$

$$\beta = \frac{V_f}{V_o} = \frac{\frac{Z_1 h_{ie}}{Z_1 + h_{ie}}}{\frac{Z_1 h_{ie}}{Z_1 + h_{ie}} + Z_3}$$

$$\Rightarrow \beta = \frac{Z_1 h_{ie}}{Z_1 h_{ie} + Z_3 (Z_1 h_{ie})}$$

LC Oscillators

- According to barkhausen criterion, to generate oscillations

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

$$A_V = \frac{-h_{fe}}{h_{ie}} \times \frac{[Z_1 h_{ie} + Z_3(Z_1 + h_{ie})]Z_2}{Z_1 h_{ie} + Z_3(Z_1 + h_{ie}) + Z_2(Z_1 + h_{ie})} \qquad \beta = \frac{Z_1 h_{ie}}{Z_1 h_{ie} + Z_3(Z_1 h_{ie})}$$

$$\Rightarrow \frac{-h_{fe}}{h_{ie}} \times \frac{[Z_1 h_{ie} + Z_3(Z_1 + h_{ie})]Z_2}{Z_1 h_{ie} + Z_3(Z_1 + h_{ie}) + Z_2(Z_1 + h_{ie})} \cdot \frac{Z_1 h_{ie}}{Z_1 h_{ie} + Z_3(Z_1 h_{ie})} = 1$$

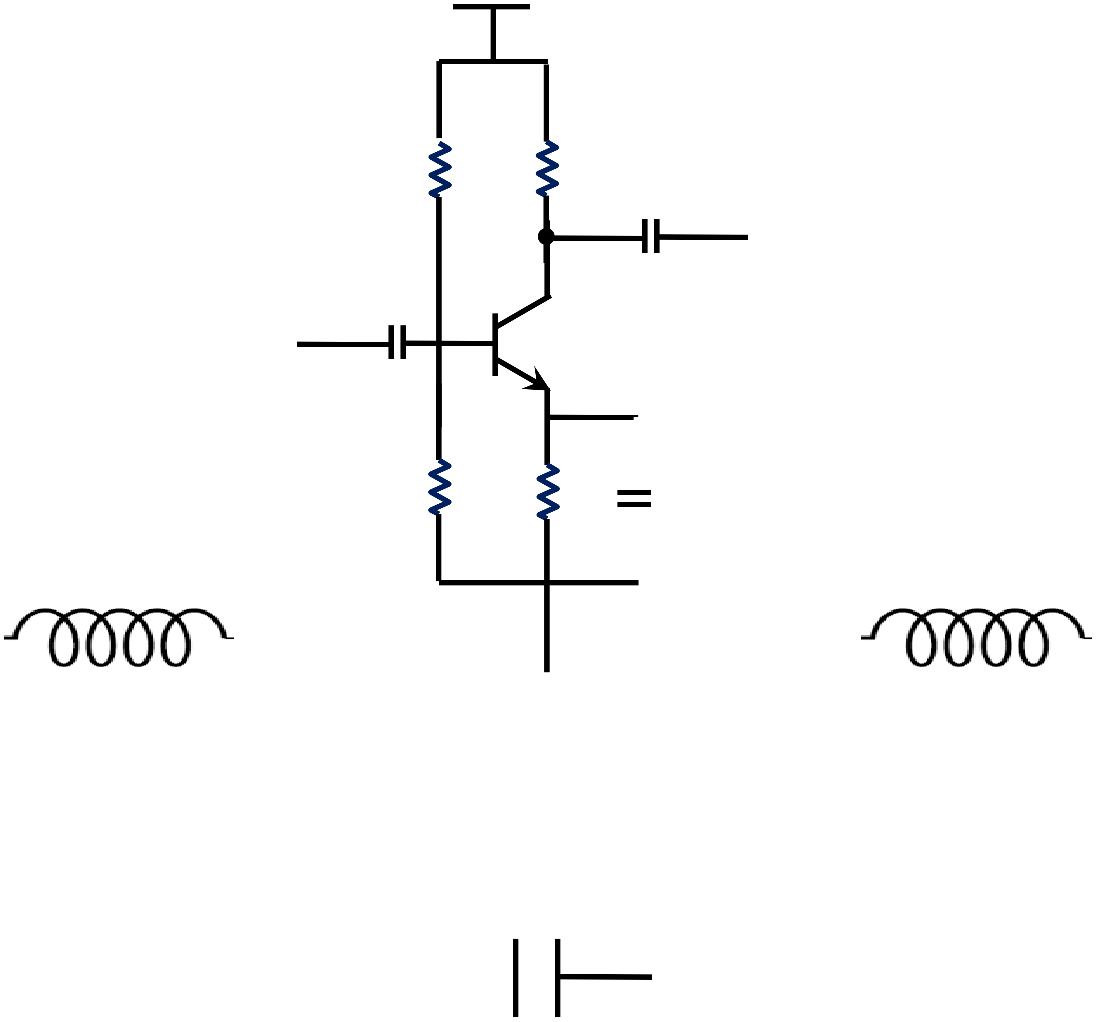
$$\Rightarrow \frac{-h_{fe} Z_1 Z_2}{Z_1 h_{ie} + Z_3(Z_1 + h_{ie}) + Z_2(Z_1 + h_{ie})} = 1$$

$$\Rightarrow Z_1 h_{ie} + Z_1 Z_3 + Z_3 h_{ie} + Z_1 Z_2 + Z_2 h_{ie} + h_{fe} Z_1 Z_2 = 0$$

$$\Rightarrow h_{ie}(Z_1 + Z_2 + Z_3) + Z_1 Z_2 + Z_1 Z_3 + h_{fe} Z_1 Z_2 = 0$$

$$\Rightarrow (1 + h_{fe}) Z_1 Z_2 + Z_1 Z_3 + h_{ie}(Z_1 + Z_2 + Z_3) = 0$$

Hartley Oscillator using BJT



Analysis

- The general equation of LC oscillators is given by

$$(1+h_{fe})Z_1Z_2 + Z_1Z_3 + h_{ie}(Z_1+Z_2+Z_3) = 0$$

$$\Rightarrow (1+h_{fe})Z_1Z_2 + Z_1Z_3 + h_{ie}(Z_1+Z_2+Z_3) = 0$$

$$Z_1 = j\omega L_1 \qquad Z_2 = j\omega L_2 \qquad Z_3 = \frac{1}{j\omega C}$$

$$\Rightarrow -(1+h_{fe})(\omega^2 L_1L_2) + \frac{L_1}{C} + h_{ie}[j\omega(L_1+L_2) + \frac{1}{j\omega C}] = 0$$

$$\Rightarrow -(1+h_{fe})(\omega^2 L_1L_2) + \frac{L_1}{C} + h_{ie}[j\omega(L_1+L_2) - \frac{j}{\omega C}] = 0$$

Frequency of oscillations

At resonant frequency imaginary terms should be zero

$$\Rightarrow h_{ie}[\omega(L_1 + L_2) - \frac{1}{\omega C}] = 0$$

$$\Rightarrow L_1 + L_2 = \frac{1}{\omega^2 C}$$

$$\Rightarrow \omega = \frac{1}{\sqrt{(L_1 + L_2)C}}$$

$$\Rightarrow \boxed{f = \frac{1}{2\pi\sqrt{(L_1 + L_2)C}}}$$

By including mutual inductance

$$\Rightarrow \boxed{f = \frac{1}{2\pi\sqrt{(L_1 + L_2 + 2M)C}}}$$

Condition for oscillations

From the general equation,

$$\Rightarrow -(1+h_{fe})(\omega^2 L_1 L_2) + \frac{L_1}{C} = 0$$

$$\Rightarrow (1+h_{fe})(\omega^2 L_1 L_2) = \frac{L_1}{C}$$

$$\omega = \frac{1}{\sqrt{(L_1 + L_2)C}}$$

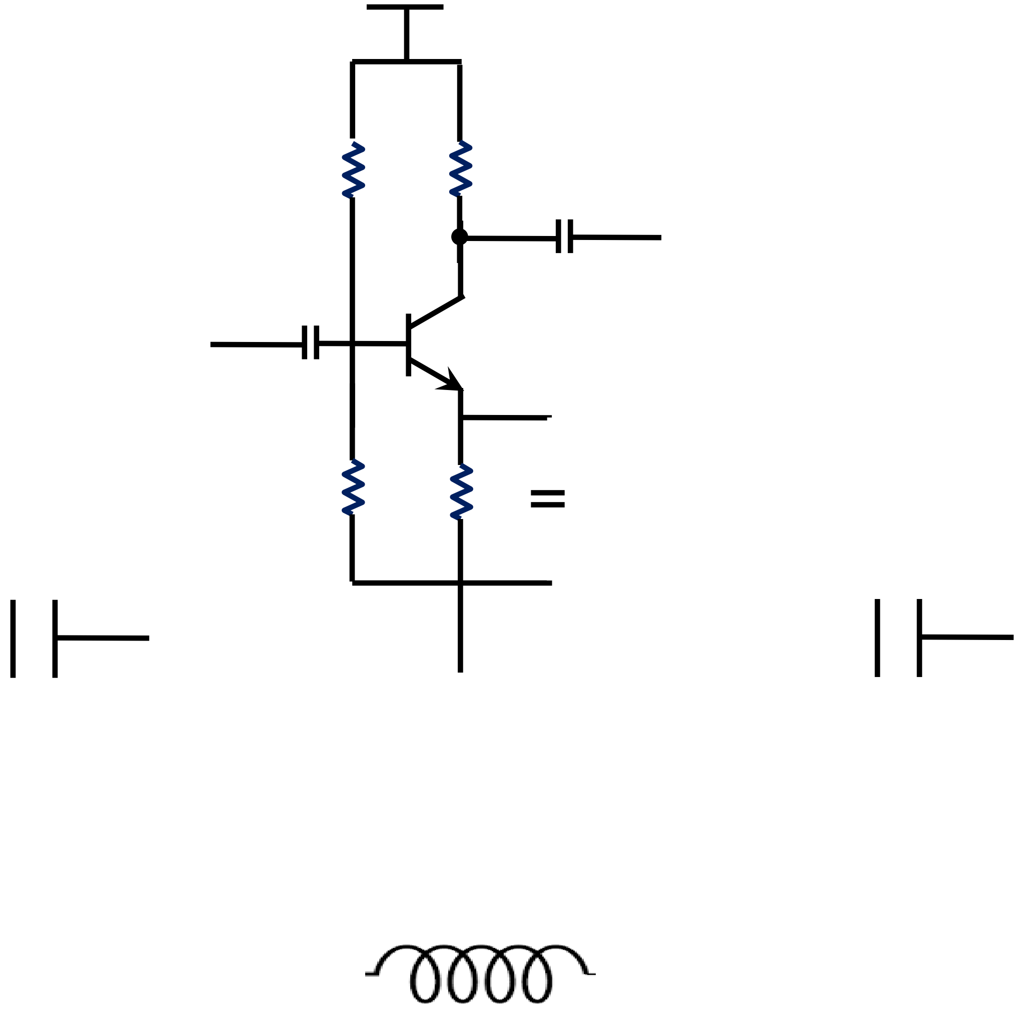
$$\Rightarrow 1 + h_{fe} = \frac{L_1}{L_2} + 1$$

$$\Rightarrow \boxed{h_{fe} = \frac{L_1}{L_2}}$$

By including mutual inductance

$$\Rightarrow \boxed{h_{fe} = \frac{L_1 + M}{L_2 + M}}$$

Colpitts Oscillator using FET



Analysis

- The general equation of LC oscillators is given by

$$(1+h_{fe})Z_1Z_2 + Z_1Z_3 + h_{ie}(Z_1+Z_2+Z_3) = 0$$

$$Z_1 = \frac{1}{j\omega C_1} \qquad Z_2 = \frac{1}{j\omega C_2} \qquad Z_3 = j\omega L$$

$$\Rightarrow -(1+h_{fe})\frac{1}{\omega^2 C_1 C_2} + \frac{L}{C_1} + h_{ie}[j\omega(L - \frac{1}{\omega^2 C_2} - \frac{1}{\omega^2 C_1}) = 0$$

Frequency of oscillations

At resonant frequency imaginary terms should be zero

$$h_{ie}[j\omega(L - \frac{1}{\omega^2 C_2} - \frac{1}{\omega^2 C_1})] = 0$$

$$\Rightarrow L = \frac{1}{\omega^2 C_1} + \frac{1}{\omega^2 C_2}$$

$$\Rightarrow \omega^2 L = \frac{1}{C_1} + \frac{1}{C_2}$$

$$Let \qquad \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{C_{eq}}$$

$$\Rightarrow \omega^2 L = \frac{1}{C_{eq}} \Rightarrow \omega^2 = \frac{1}{LC_{eq}} \Rightarrow \omega = \frac{1}{\sqrt{LC_{eq}}}$$

$$\Rightarrow \boxed{f = \frac{1}{2\pi\sqrt{LC_{eq}}}}$$

Condition for oscillations

From the general equation,

$$\Rightarrow -(1+h_{fe})\frac{1}{\omega^2 C_1 C_2}+\frac{L}{C_1}=0$$

$$\Rightarrow L=(1+h_{fe})\frac{1}{\omega^2 C_2}$$

$$\omega=\sqrt{\frac{1}{L}\left(\frac{1}{C_1}+\frac{1}{C_1}\right)}$$

$$\Rightarrow (1+h_{fe})=L\omega^2 C_2$$

$$\Rightarrow (1+h_{fe})=L\left(\frac{1}{L}\left(\frac{1}{C_1}+\frac{1}{C_1}\right)\right)C_2$$

$$\Rightarrow (1+h_{fe})=1+\frac{C_2}{C_1}\Rightarrow \boxed{h_{fe}=\frac{C_2}{C_1}}$$

MODULE– IV
LINEAR WAVE SHAPING AND SAMPLING GATES

CLOs	Course Learning Outcome
CLO10	Analyze the response of high pass RC to different non sinusoidal inputs with different time constants and identify RC circuit’s applications.
CLO11	Understand the basic operating principle of sampling gates.
CLO12	Analyze the response of low pass RC circuits to different non sinusoidal inputs with different time constants and identify RC circuit’s applications.

Transistor Audio Power Amplifier:

- A transistor amplifier which raises the power level of the signals that have audio frequency range is known as **transistor audio power amplifier.**
- A transistor that is suitable for power amplification is generally called a *power transistor*.
- The typical power output rating of a power amplifier is 1W or more.

Factors to be considered in large signal amplifiers:

1. Output power
2. Distortion Operating
3. Region Thermal
4. Considerations
5. Efficiency

Difference Between Voltage and Power Amplifiers

S. No.	Particular	Voltage amplifier	Power amplifier
1.	β	High (> 100)	low (5 to 20)
2.	R_C	High (4 – 10 kΩ)	low (5 to 20 Ω)
3.	*Coupling*	usually *R* – *C* coupling	Invariably transformer coupling
4.	*Input voltage*	low (a few mV)	High (2 – 4 V)
5.	*Collector current*	low (≃ 1 mA)	High (> 100 mA)
6.	*Power output*	low	high
7.	*Output impedance*	High (≃ 12 kΩ)	low (200 Ω)

Performance Quantities of Power Amplifiers

(i) Collector efficiency

The ratio of a.c. output power to the zero signal power (i.e. d.c. power) supplied by the battery of a power amplifier is known as collector efficiency.

(ii) Distortion

The change of output wave shape from the input wave shape of an amplifier is known as distortion.

(iii) Power dissipation capability

The ability of a power transistor to dissipate heat is known as power dissipation

capability.

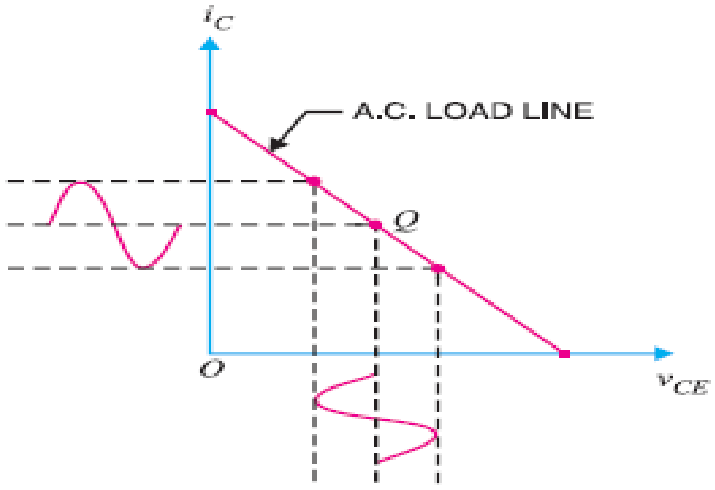
Classification of Power Amplifiers

- **Class A:** It is one, in which the active device conducts for the full 360°.
- **Class B:** Conduction for 180 °.
- **Class C:** Conduction for < 180°.
- **Class AB:** Conduction angle is between 180°. and 360°.
- **Class D:** These are used in *transmitters because their efficiency is high: 100%.*
- **Class S:** Switching regulators are based on class'S' operation.

Class A power amplifier:

- If the collector current flows at all times during the full cycle of the signal, the power amplifier is known as **class A power amplifier.**

- If the Q point is placed near the centre a/the linear region a/the dynamic curve, class A operation results. Because the transistor will conduct for the complete 360 , distortion is low for small signals and conversion efficiency is low.



Types of class-A power Amplifiers:

1. **Series fed:**

- There is no transformer in the circuit. RL is in series with V cc. There is DC power drop across RL. Therefore efficiency = 25% (maximum).

2. **Transformer coupled:**

- The load is coupled through a transformer. DC drop across the primary of the transformer is negligible. There is no DC drop across RL. Therefore efficiency = 50% maximum.

Series Fed class-A power Amplifier:

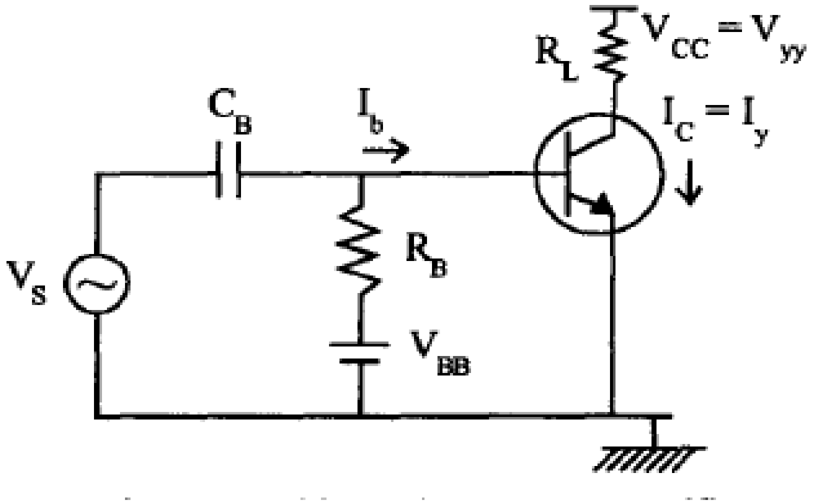


Fig.(a)Series fedClass A power amplifier circuit

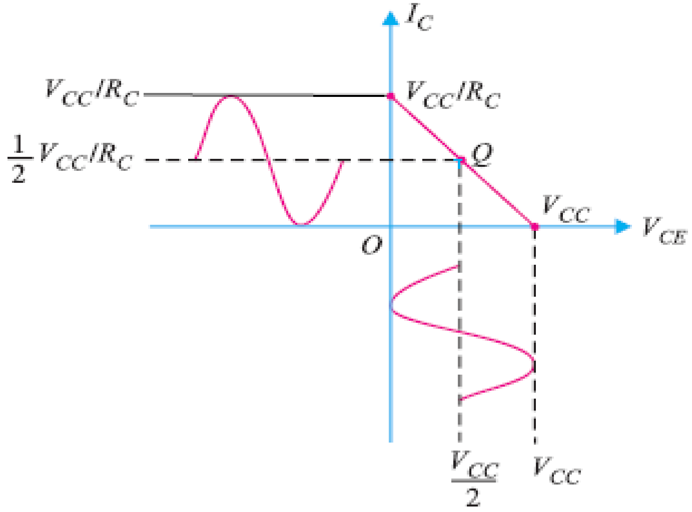
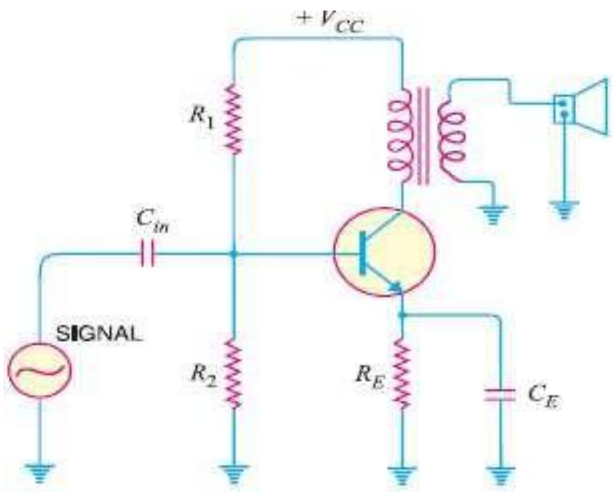


Fig.(b)Transter curve

Transformer Coupled class-A power Amplifier



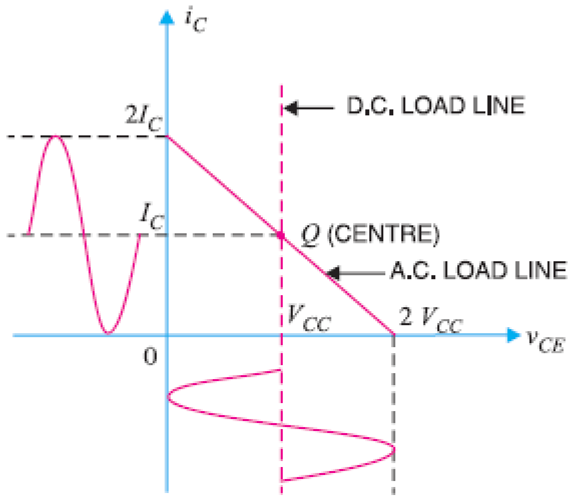


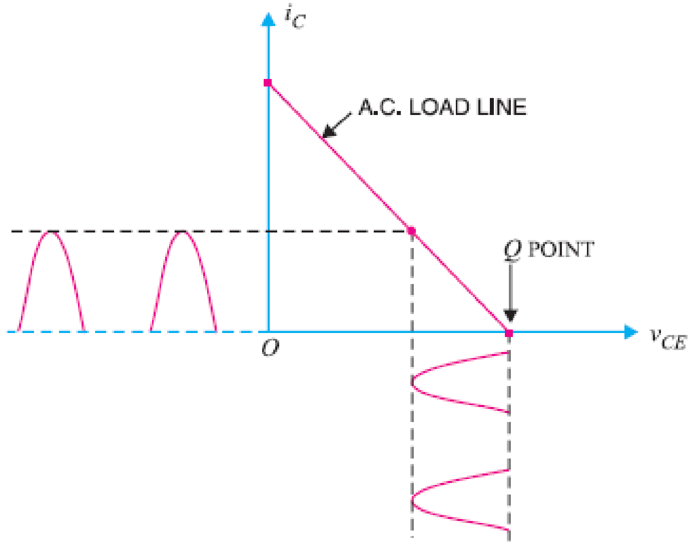
Fig.(a)Transformer Coupled Class A power amplifier circuit

Fig.(b)Transfer curve

Class B power amplifier

- If the collector current flows only during the positive half-cycle of the input signal, it is called a **class B power amplifier.**

- For class B operation the Q point is set near cutoff. So output power will be more and conversion efficiency is more. Conduction is only for 180.



Transfer curve

Types of class-B power Amplifiers

- **Push-Pull Amplifier:**

  The standard class B push-pull amplifier requires a centre tapped transformer

- **Complimentary Symmetry Circuits (Transformer Less Class B Power Amplifier)**

  Complementary symmetry circuits need only one phase They don't require a centre tapped transformer.

Advantages & Disadvantages of Class B power Amplifier

Advantages:

1.More output power; efficiency = 78.5%. Max.

2.Efficiency is higher. Since the transistor conducts only for 180°, when it is not conducting, it will not draw DC current.

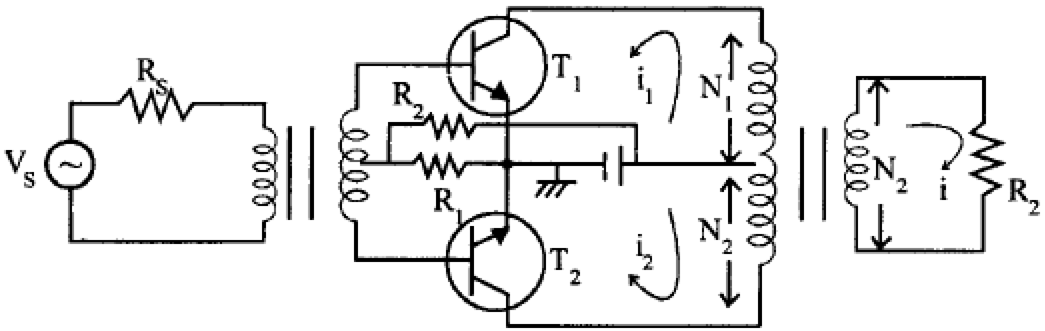
3.Negligible power loss at no signal.

Disadvantages:

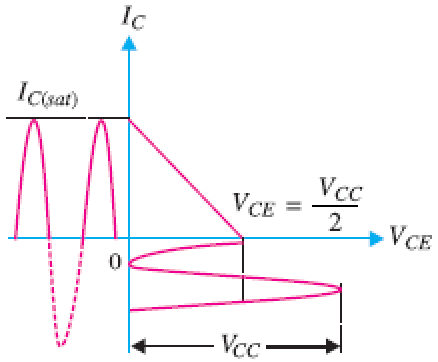
1.Supply voltage V_{cc} should have good regulation. Since if V_{cc} changes, the operating point changes (Since I_c changes). Therefore transistor may not be at cut off.

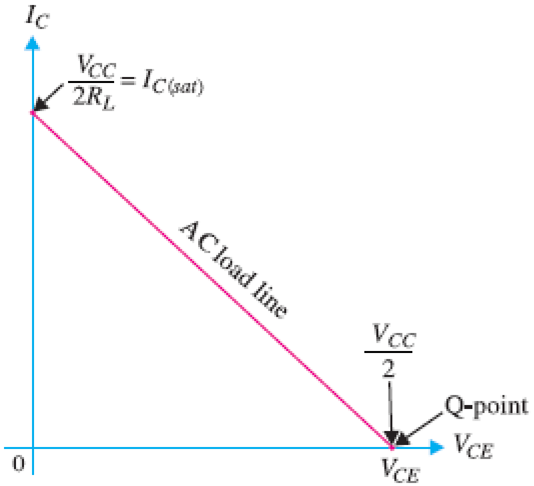
2.Harmonic distortion is higher. (This can be minimized by push pull connection).

Class B Push-Pull Amplifier:

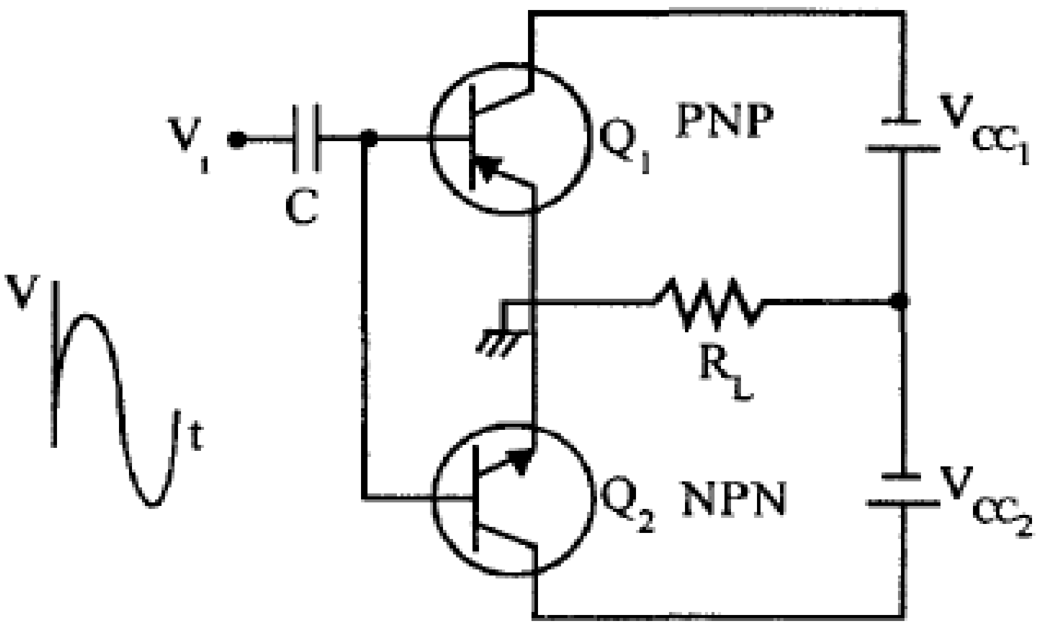


Push Pull amplifier circuit





Complimentary Symmetry Circuits (Transformer Less Class B Power Amplifier):



Differences between class-A & B power Amplifiers

Class A	Class B
Less power	More power
Lesser η	More η upto 78.5%
Less Harmonic distortion	Harmonic distortion is more

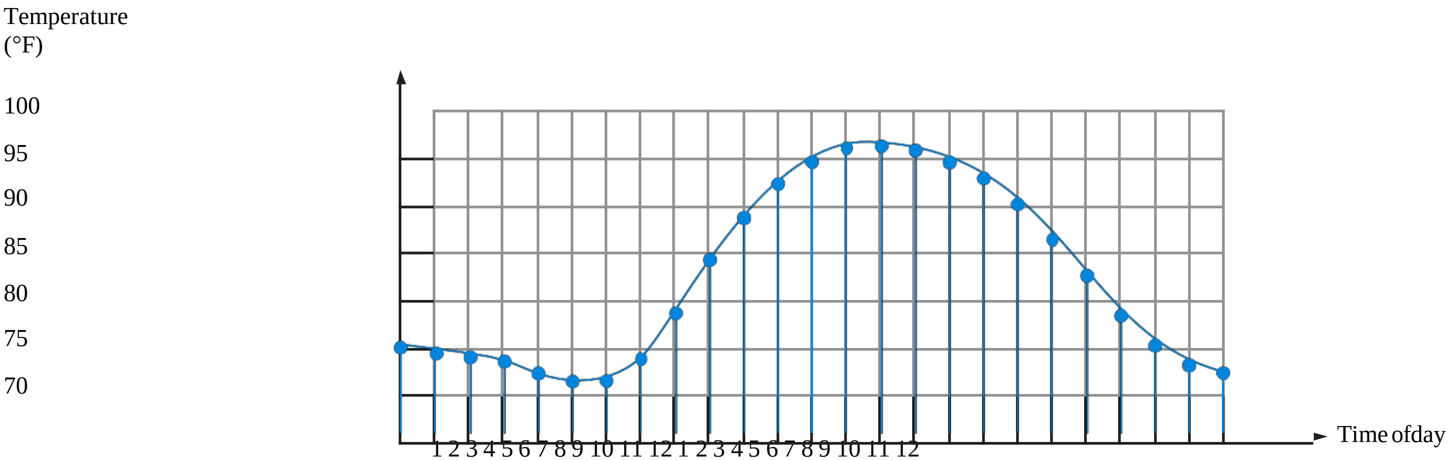
UNIT – V
MULTIVIBRATORS

MODULE– V
MULTIVIBRATORS

CLOs	Course Learning Outcome
CLO13	Illustrate the Bistable multivibrator with various triggering methods and apply design procedures to different bistable multivibrator circuits.
CLO14	Analyze the Monostable, Astable multivibrator circuits with applications and evaluate time, frequency parameters.
CLO15	Evaluate triggering points, hysteresis width of Schmitt trigger circuit and also design practical Schmitt trigger circuit.

Analog Quantities

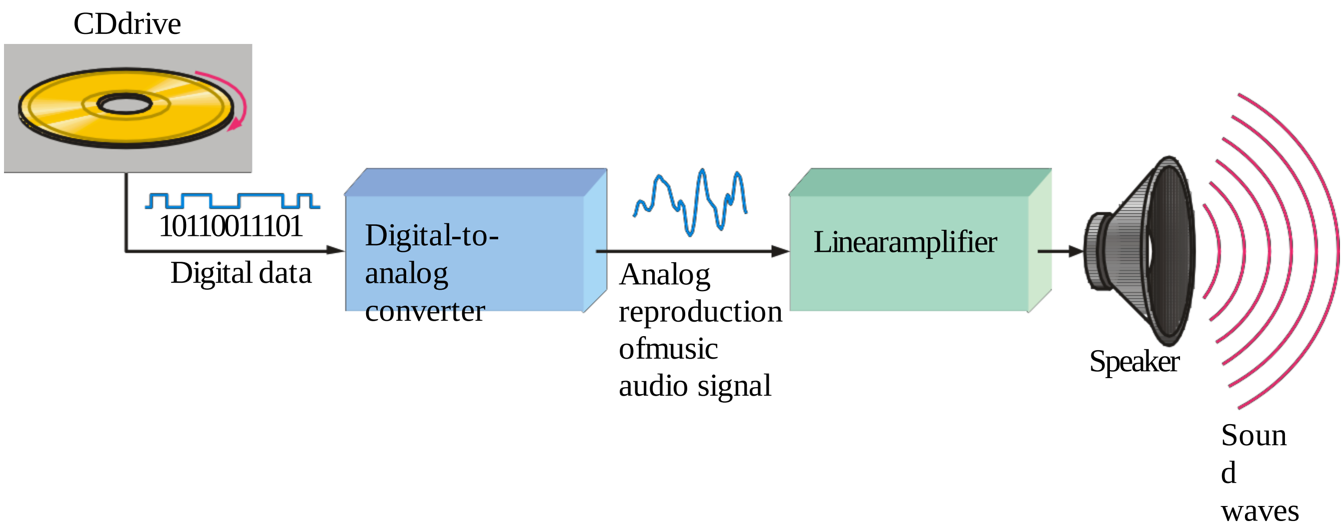
- Most natural quantities that we see are **analog** and vary continuously. Analog systems can generally handle higher power than digital systems



- Digital systems can process, store, and transmit data more efficiently but can only assign discrete values to each point

Systems

- Digital systems can process, store, and transmit data more efficiently but can only assign discrete values to eachpoint

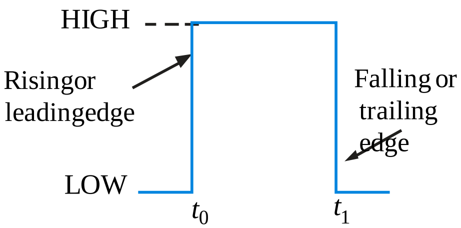


.

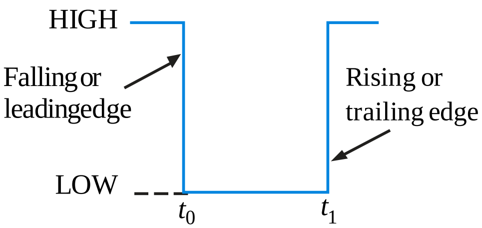
- Digital electronics uses circuits that have two states, which are represented by two different voltage levels called HIGH and LOW. The voltages represent numbers in the binary system
- In binary, a single number is called a *bit* (for *b*inary dig*it*). A bit can have the value of either a 0 or a 1, depending on if the

Signals

- Digital waveforms change between the LOW and HIGH levels. A positive going pulse is one that goes from anormally LOW logic level to a HIGH level and then back again. Digital waveforms are made up of a series of pulses



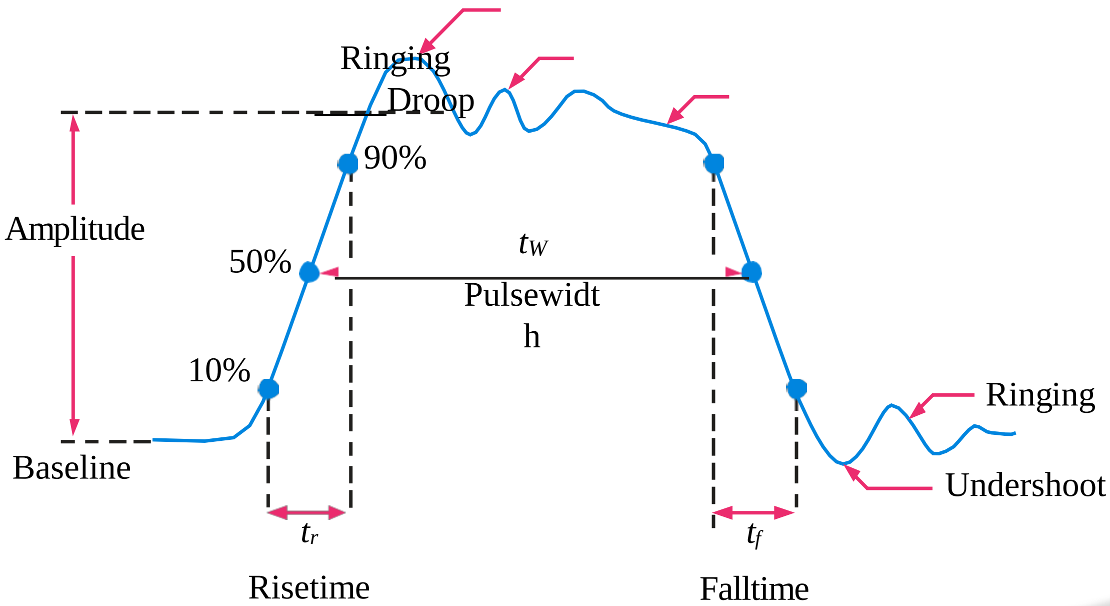
(a) Positive–goingpulse



(b)Negative–going pulse

Definitions

- Actual pulses are not ideal but are described by the rise time, fall time, amplitude, and other characteristics.



Waveforms

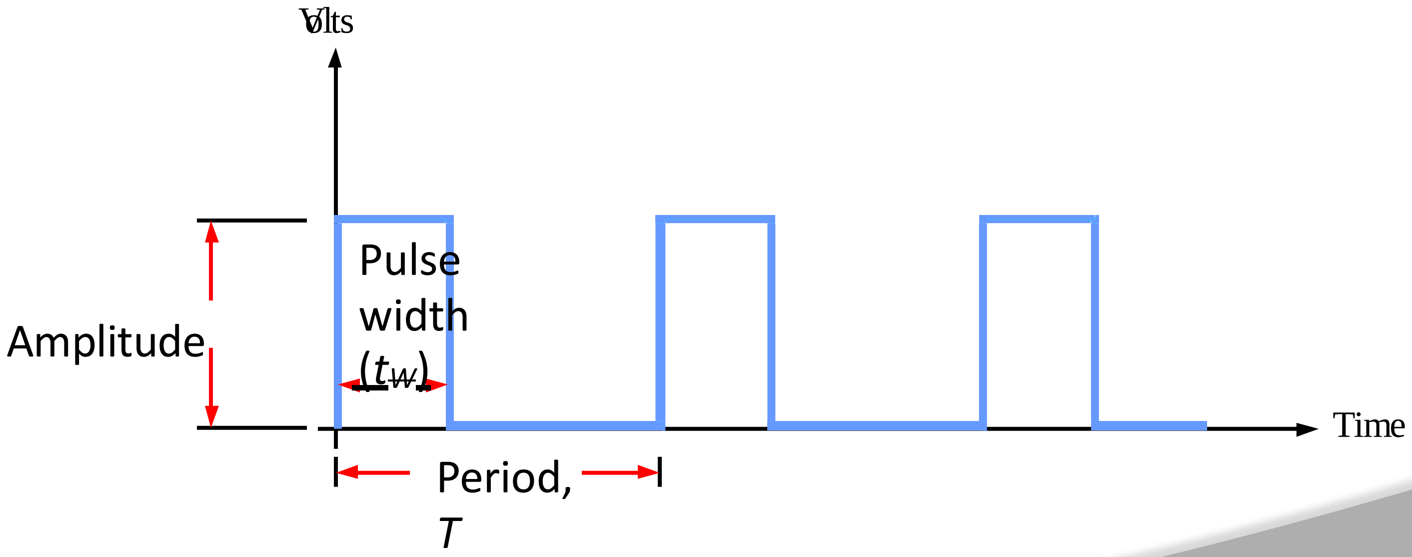
- Periodic pulse waveforms are composed of pulses that repeats in a fixed interval called the **period**.
- The **frequency** is the rate it repeats and is measured in hertz. The **clock** is a basic timing signal that is an example of a periodic wave.
-

$T = \frac{1}{f}$ z

What is the period of a repetitive wave if f = 3.2 GHz?

Definitions

- In addition to frequency and period, repetitive pulse waveforms are described by the amplitude (A), pulse width (t_W) and duty cycle. Duty cycle is the ratio of t_W to T.

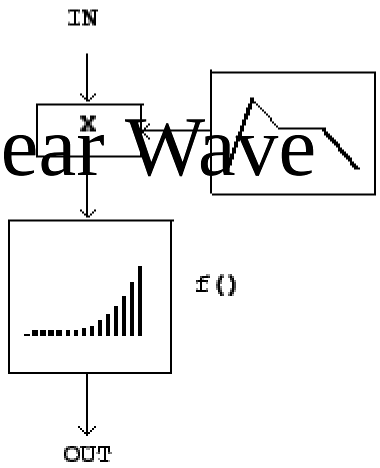


Shaping

Definition: It is the process of changing the shape of input signal with linear / non-linear circuits.

Types:

i.Linear Wave Shaping ii.Non-linear Wave Shaping



Shaping

Definition: The process where by the form of a non-sinusoidal signal is changed by transmission through a linear network is called Linear Wave Shaping.

Types:

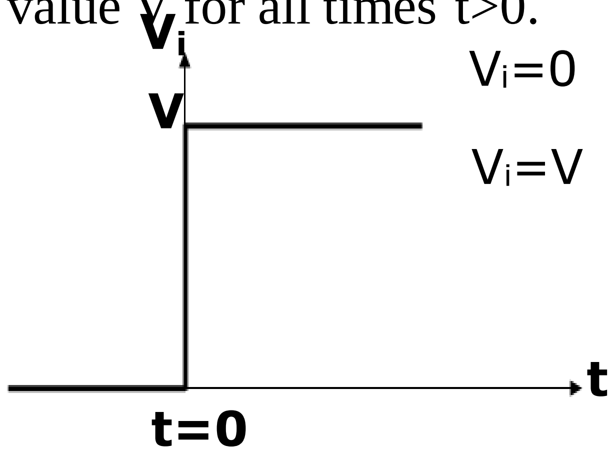
i.High Pass RC Circuit. ii.Low Pass RC Circuit.

Non-sinusoidal wave forms

1) Step
2) Pulse
3) Square wave
4) Ramp
5) Exponential wave forms.

Waveform

A step voltage is one which maintains the value zero for all times t<0 and maintains the value V for all times t>0.

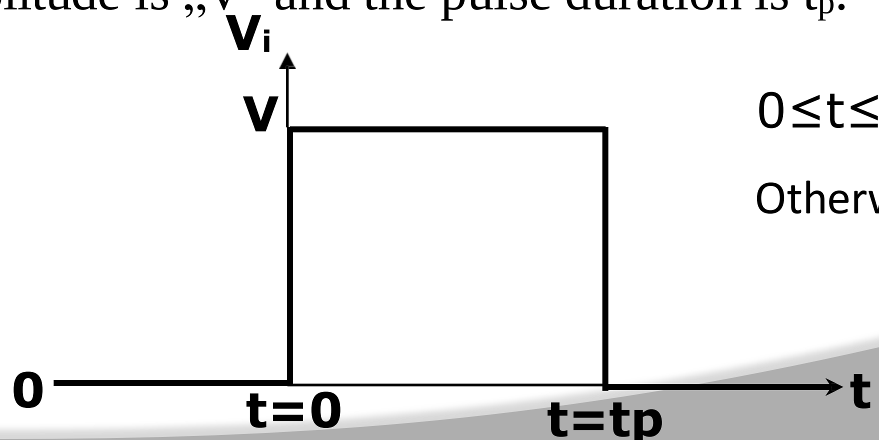


$V_i = 0 \quad t < 0$

$V_i = V \quad t > 0$

Pulse

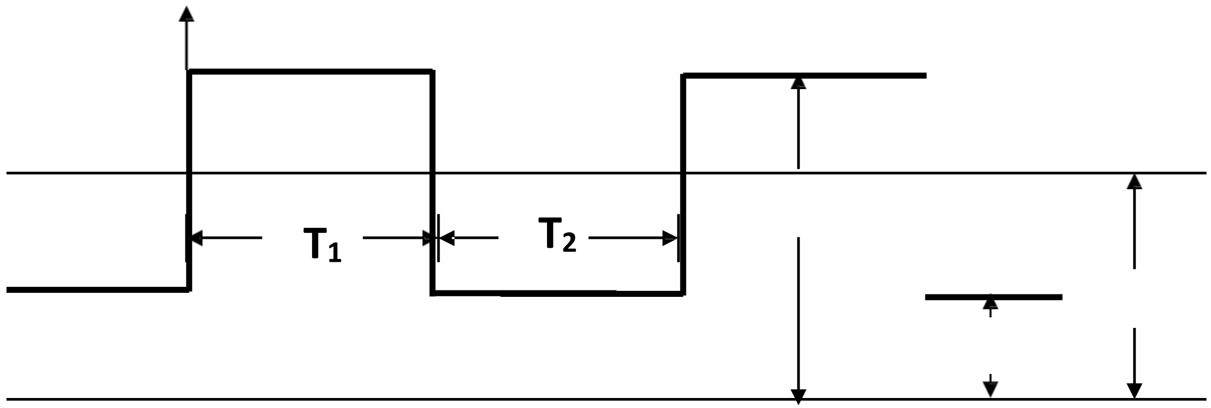
The pulse amplitude is „V" and the pulse duration is t_p.



$0 \leq t \leq tp \quad V_i = V$

Otherwise $\quad V_i = 0$

- A wave form which maintains itself at one constant level V^1 for a time T_1 and at other constant Level V^{11} for a time T_2 and which is repetitive with a period $T = T_1 + T_2$ is called a square-wave.

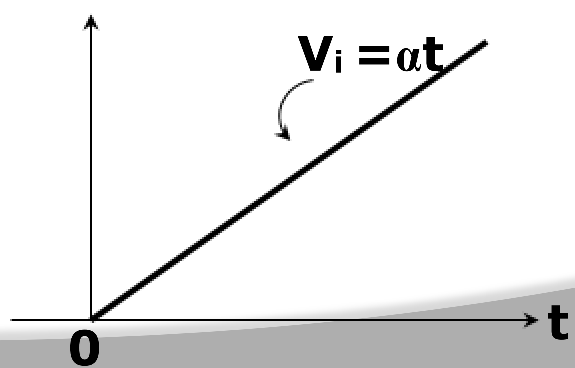


Ramp

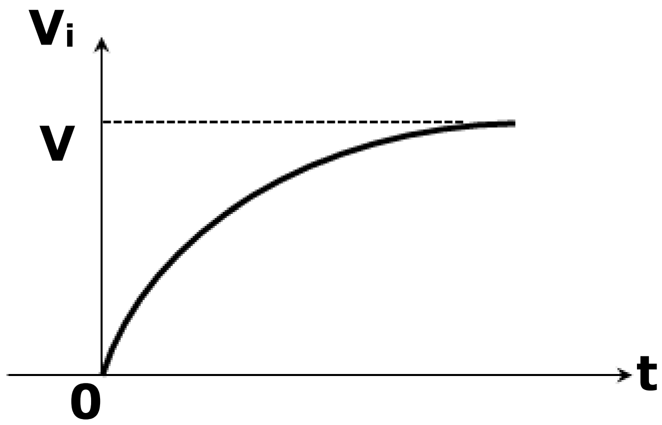
A waveform which is zero for t<0 and which increases linearly with time for t>0.

V_i

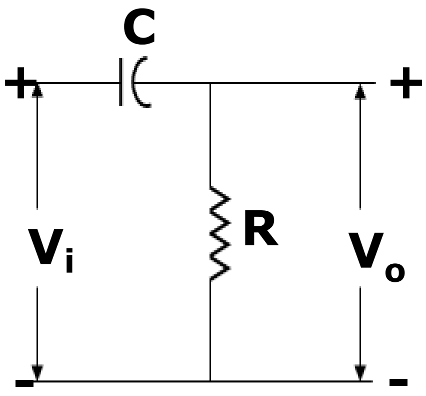
$V_i = \alpha t$, $t > 0$



- The exponential waveform input is givenby
  where T is the time constant of the exponential input



Circuit



$$X_C = \frac{1}{2\Pi fC}$$

If f=low, X_c becomeshigh
C act as open circuit, so theV_o=0.

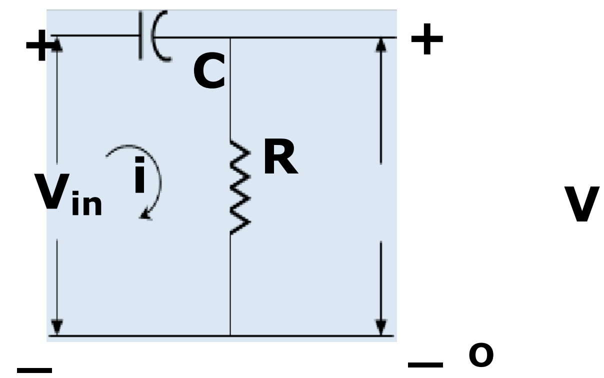
If f=high, X_c becomes low
C acts as short circuit, so we get the output.

Thehigher frequency components in the input signal appear at the output with less attenuation due to this behavior the circuit is called “High Pass Filter”.

input

- For Sinusoidal input, the output increases in
amplitude with increasing frequency.

$$V_o = iR$$



$$i = \frac{V_{in}}{R - jX_C} = \frac{V_{in}}{R - \frac{j}{2\pi fC}}$$

$$i = \frac{V_{in}}{R\left[1 - \frac{j}{2\pi fRC}\right]}$$

$$V_O = iR = \frac{V_{in} \times R}{R\left[1 - \frac{j}{2\pi fRC}\right]} = \frac{V_{in}}{1 - \frac{j}{2\pi fRC}}$$

$$1 - j\frac{f_1}{f} \qquad 2\pi RC$$

$$\frac{V_O}{V_{in}} = \frac{1}{1 + j\left(-\frac{f1}{f}\right)}$$

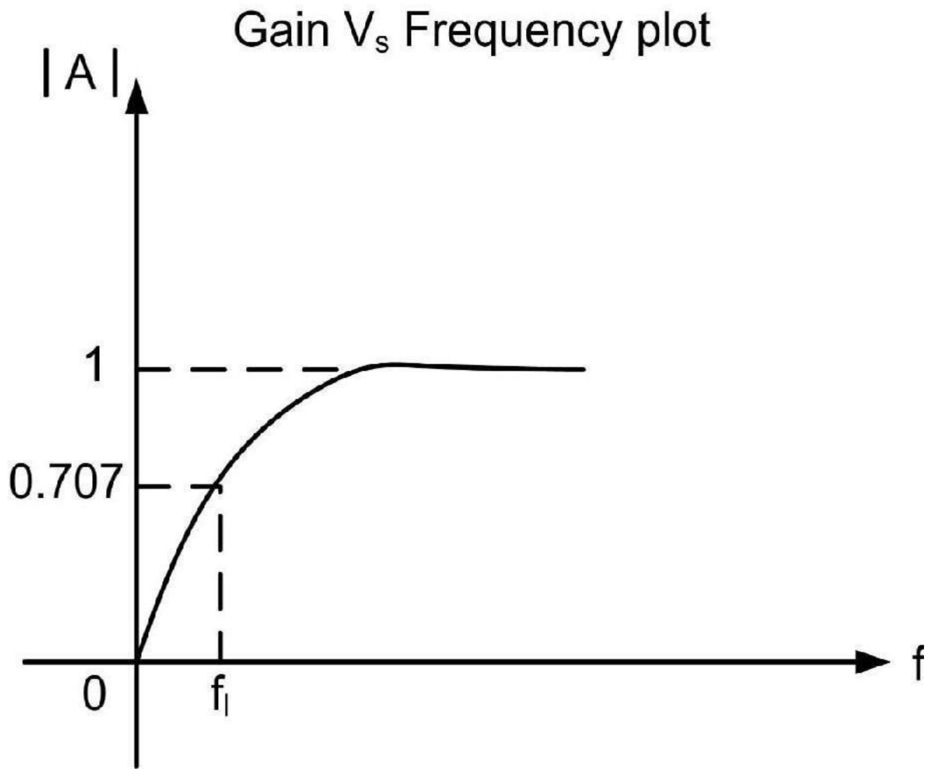
$$\left|\frac{V_O}{V_{in}}\right| = \frac{1}{\sqrt{1 + \left(\frac{f_1}{f}\right)^2}}$$

$$|A| = 0.707$$

$$\theta = -\tan^{-1}\left(\frac{-f_1}{f}\right) = \tan^{-1}\left(\frac{f_1}{f}\right)$$

At the frequency $f = f_1$

$$\left|\frac{V_O}{V_{in}}\right| = \frac{1}{\sqrt{1+1}} = \frac{1}{\sqrt{2}} = 0.707$$



At $f = f_1$ the gain is 0.707 or this level corresponds to a signal reduction of 3 decibels(dB).

∴ f_1 is referred to as Lower 3-dB frequency.

- Percentage Tilt (%Tilt)

Tilt is defined as the decay in the amplitude of the output voltage wave due to the input voltage maintaining constant level

$$P = \frac{V_1 - V_1^1}{V/2} X100$$

$$V_1' = V_1 . e^{-T_1/RC} \longrightarrow (1)$$

$$V_2' = V_2 . e^{-T_2/RC} \longrightarrow (2)$$

$$V_1' - V_2 = V \longrightarrow (3)$$

$$V_1 - V_2' = V \longrightarrow (4)$$

By substituting these in above equation (3)

- $$V_1' = -V_2'$$

$$V = V_1' - V_2$$

-T2RC -

V=V1.e V2

-T2RC+ V=V1.e V1

-T2RC

V=V1(1+e)

$$V_1 = \frac{V}{1 + e^{-T/2RC}} \longrightarrow \text{I}$$

Equation (1)

$$V_1' = V_1 \,.\, e^{-\frac{T}{2RC}}$$

$$V_1' = \frac{V}{1 + e^{-T/2RC}} \times e^{-T/2RC} = \frac{V}{1 + e^{T/2RC}}$$

$$V_1' = \frac{V}{1 + e^{T/2RC}} \longrightarrow \text{II}$$

$$V_1 \cong \frac{V}{2}\left(1+\frac{T}{4RC}\right) \;\&\; V_1' \cong \frac{V}{2}\left(1-\frac{T}{4RC}\right)$$

The percentage tilt 'P' is defined by $P = \frac{V_1 - V_1'}{V/2} \times 100$

$$P = \frac{\frac{V}{1+e^{-T/2RC}} - \frac{V}{1+e^{T/2RC}}}{V/2} \times 100$$

$$P = \left[\frac{1}{1+e^{-T/2RC}} - \frac{1}{1+e^{T/2RC}}\right] \times 200$$

$$P = \left[\frac{1}{1+e^{-T/2RC}} - \frac{e^{-T/2RC}}{1+e^{T/2RC}}\right] \times 200$$

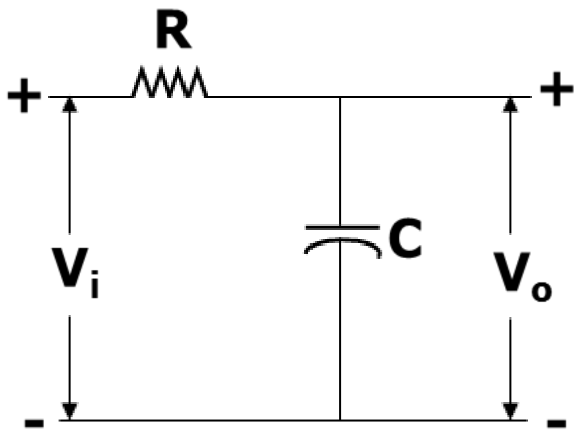
$$P = \frac{1-e^{-T/2RC}}{1+e^{-T/2RC}} \times 200\%$$

as differentiator:-

- The time constant of high pass RC circuit in very small in comparison within the time required for the input signal to make an appreciable change, the circuit is called a *"differentiator"*.
- Under this circumstances the voltage drop across R will be very small in comparison with the drop across C. Hence we may consider that the total input V_i appears across C, so that the current is determined entirely by the capacitance.
- Then the current is $i = C\frac{dV_i}{dt}$ and the output signal across R is $V_0 = iR$

$V_0 = RC\frac{dV_i}{dt}$

- hence the output is proportional to the derivative of the input.



$$X_C = \frac{1}{2\Pi f C}$$

If f=low, X_c becomes high

C act as open circuit, so we get the output.

If f=high, X_c becomes low

C acts as short circuit, so V_o=0.

As the lower frequency signals appear at the output, it is called as "Low pass RC circuit".

input

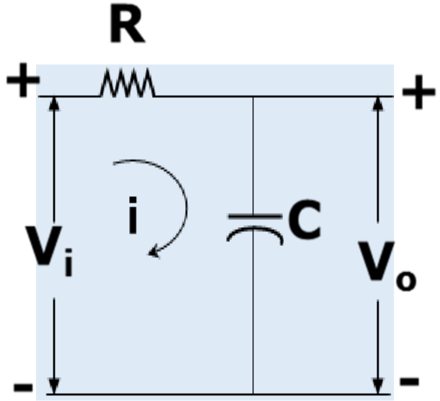
$$V_o = \frac{1}{CS} i$$

$$V_O = \frac{V_{in} \times \frac{X_C}{j}}{R + \frac{X_C}{j}}$$

where $X_C = \frac{1}{2\pi f C}$

$$V_O = \frac{V_{in} \times \frac{1}{j\omega C}}{R + \frac{1}{j\omega C}}$$

$$V_O = \frac{V_{in}}{j\omega RC + 1} = \frac{V_{in}}{1 + j2\pi fRC}$$



$$1 + j\frac{f}{f_2} \qquad f_2 = \frac{1}{2\pi RC}$$

$$A = \frac{V_O}{V_{in}} = \frac{1}{1 + j\frac{f}{f_2}}$$

$$|A| = \frac{1}{\sqrt{1+\left(\frac{f}{f_2}\right)^2}}$$

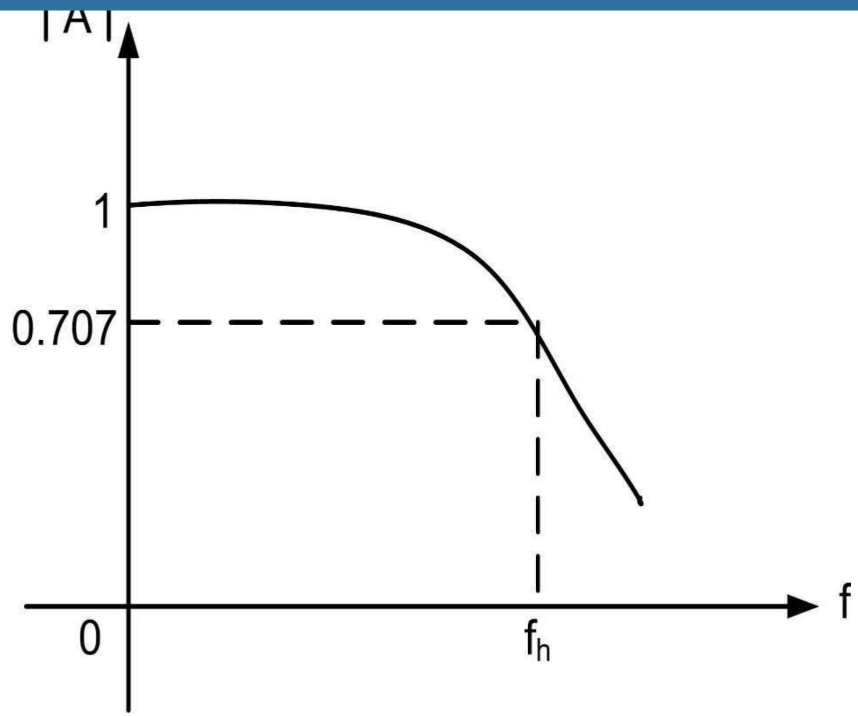
and

$$\theta = -\tan^{-1}\left(\frac{f}{f_2}\right)$$

At the frequency $f = f_2$

$$\left|\frac{V_O}{V_{in}}\right| = \frac{1}{\sqrt{1+1}} = \frac{1}{\sqrt{2}} = 0.707$$

$$|A| = 0.707$$



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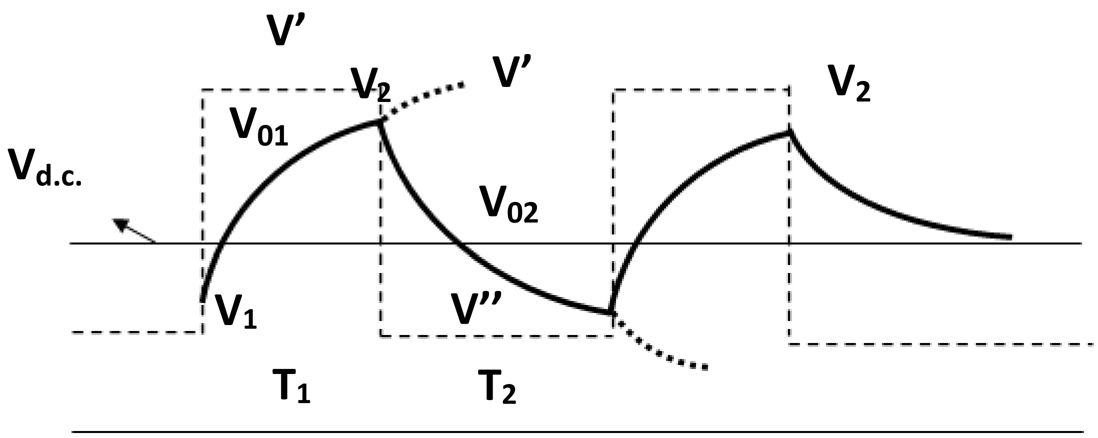
• Rise Time(t_r):

The time required for the voltage to rise from 0% to 10% 90% of the final steady value is called "Rise Time".

$$t_r = 2.2RC$$



$$\Rightarrow V_O = V_f + (V_i - V_f)\, e^{RC}$$

The output voltage V_{01} & V_{02} is givenby

$$V_{01} = V^{1} + (V1 - V^{1}) \cdot e^{-T_1/RC} \quad ....(1)$$

$$V_{02} = V^{11} + (V2 - V^{11}) \cdot e^{-T_2/RC} \quad ....(2)$$

if weset and

$V_{01} = V_2$ at $t = T_1$

$V_{02} = V_1$ at $t = T_1 + T_2$

$$V_2 = V^{1} + (V1 - V^{1})\, e^{-T_1/RC}$$

$$V_1 = V^{11} + (V2 - V^{11})\, e^{-T_2/RC}$$

Since the average across R is zero then the d.c voltage at the output is same as that of the input. This average value is indicated as Vd.c.

Consider a symmetrical square wave with zero average value, so that

$$V^1 = -V^{11} = V/2 \quad \& \quad V_1 = -V_2$$

$$V_2 = \frac{V}{2} + \left(-V_2 - \frac{V}{2}\right) e^{-\frac{T}{2RC}}$$

$$V_2 \left[1 + e^{-\frac{T}{2RC}}\right] = \frac{V}{2}\left[1 - e^{-\frac{T}{2RC}}\right]$$

$$V = \frac{V}{2}\left[\frac{1 - e^{-T/2RC}}{1 + e^{-T/2RC}}\right]$$

$$V_2 = \frac{V}{2}\left[\frac{e^{T/2RC} - 1}{e^{T/2RC} + 1}\right]$$

$$V_2 = \frac{V}{2} \cdot \frac{e^{2x} - 1}{e^{2x} + 1} \quad \text{where } x = \frac{T}{4RC}$$

$$\boxed{V_2 = \frac{V}{2} \tan hx}$$

Integrator

- The time constant is very large in comparison with the time required for the input signal to make an appreciable change, the circuit is called an "Integrator".
- As RC>>T the voltage drop across C will be very small in comparison to the voltage drop across R and we may consider that the total input V_i appear and across R, then

$V_i = iR$

$$i = \frac{V_i}{R}$$

For low pass RC circuit the output voltage V_o is given by

$$V_O = \frac{1}{C}\int i\,dt$$

$$V_O = \frac{1}{C}\int \frac{V_i}{R}\,dt$$

$$V_O = \frac{1}{RC}\int V_i\,dt$$

differentiator

- Integrators are almost invariably preferred over differentiators in analog computer applications for the following reasons.

- The gain of the integrator decreases with frequency where as the gain of the differentiator increases linearly with frequency. It is easier to stabilize the former than the latter with respect to spurious oscillations.

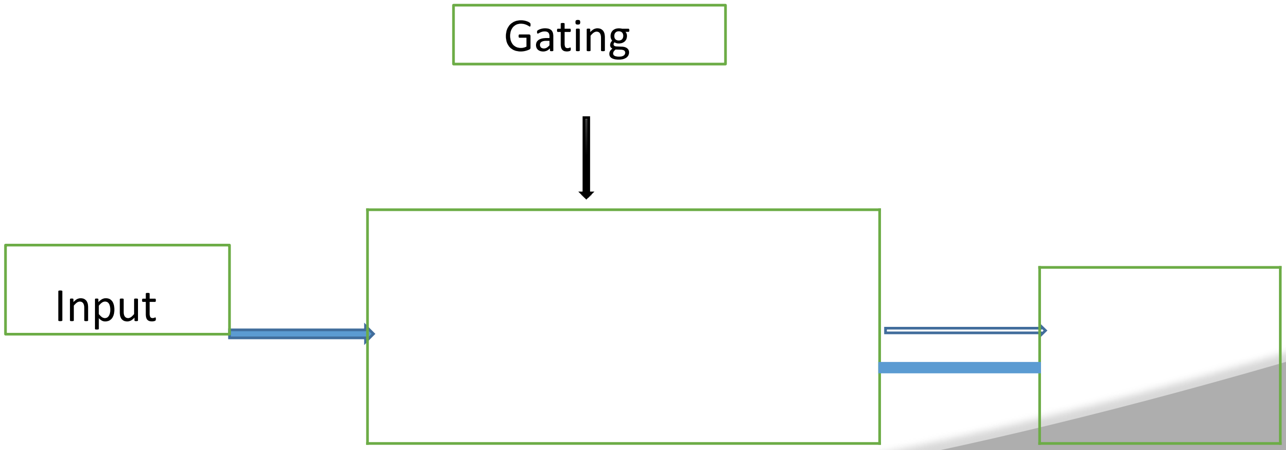
- As a result of its limited band width an integrator is less sensitive to noise voltages than a differentiator.

- If the input wave form changes very rapidly, the amplifier of a differentiator may over load.

- It is more convenient to introduce initial conditions in an integrator.

Gates

- Sampling Gates are also called as Transmission gates ,linear
gates and selection circuits,in which the output is exact reproduction of the input during a selected time interval and zero otherwise.
- It has two inputs – gating signal, rectangular wave



Principle of operation of a linear gate:

- Principle of operation of a linear gate: Linear gates can use (a) a series switch or (b) a shunt switch fig

Fig. Linear gates

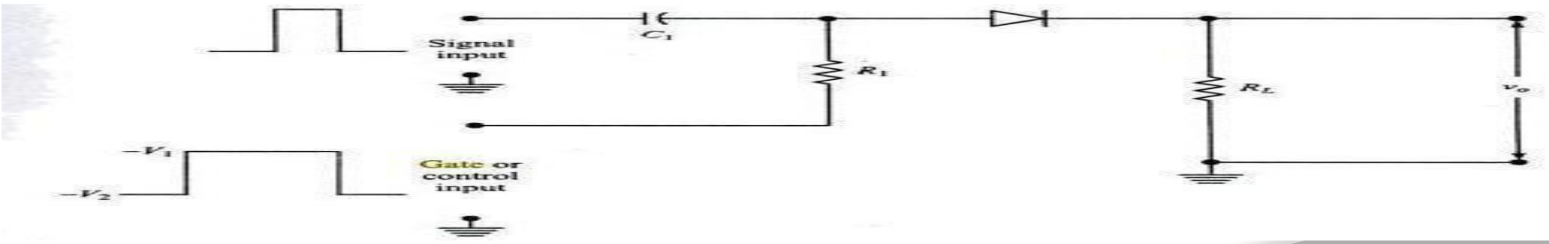
In (a) the switch closes for transmitting the signal whereas in (b) the switch is open for transmission to take place.

Gate

- unidirectional sampling gates are those which transmit signals of only one

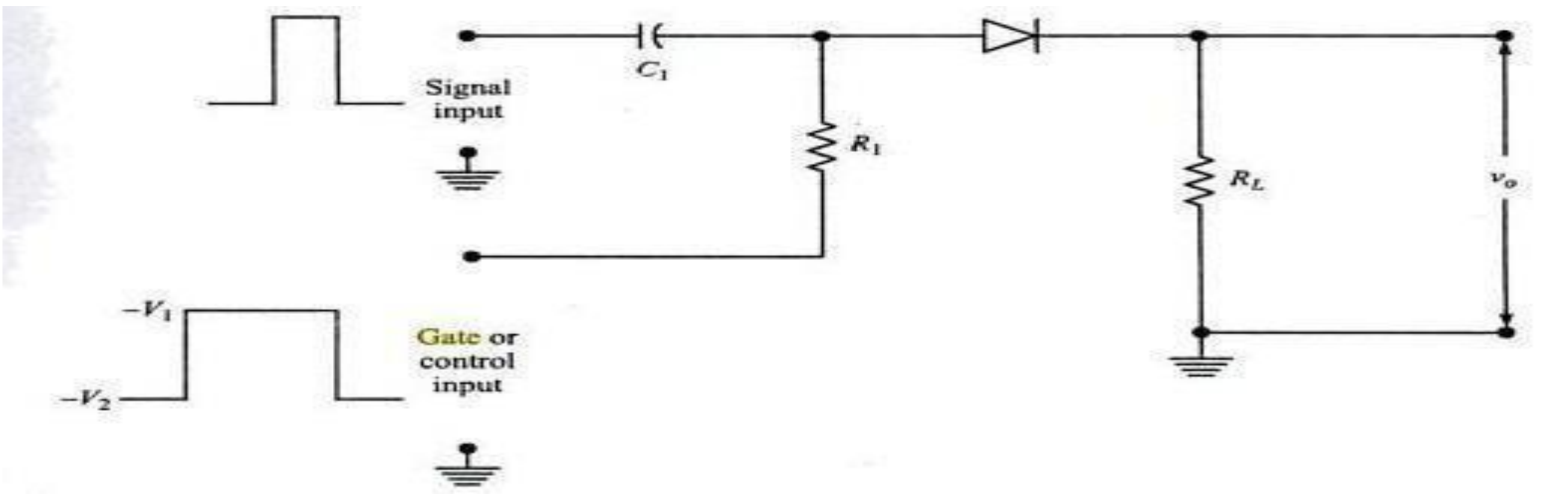
polarity(i.e,. either positive or negative)

- The gating signal is also known as control pulse, selector pulse or an enabling pulse. It is a negative signal, the magnitude of which changes abruptly between –V2 and –V1.

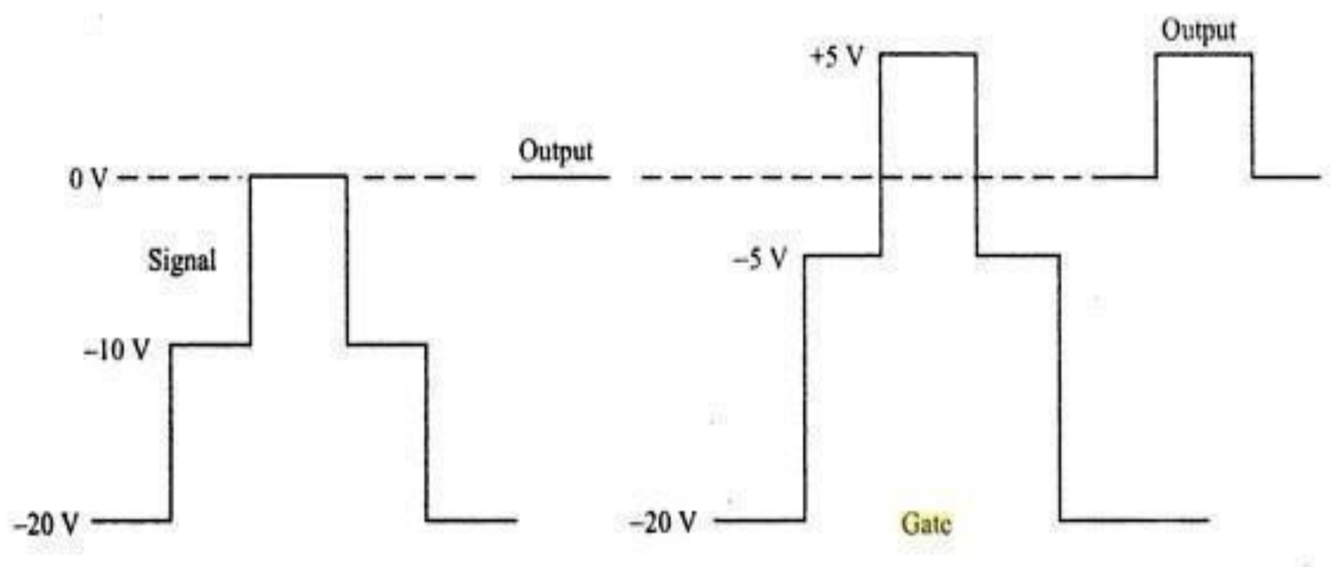


gate

•Consider the instant at which the gate signal is –V1 which is a reasonably large negative voltage. Even if an input pulse is present at this time instant, the diode remains OFF as the input pulse amplitude may not be sufficiently large so as to forward bias it. Hence there is no output. Now consider the duration when the gate signal has a value –V2 and when the input is also present (coincidence occurs).

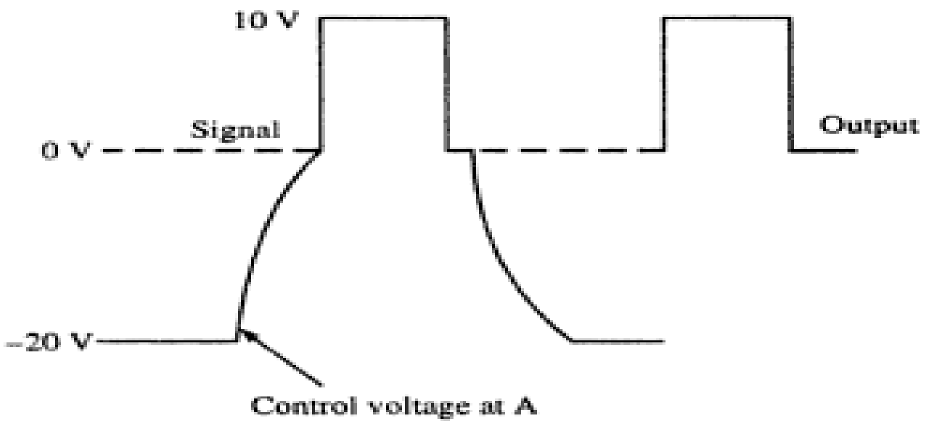


- When the control signal shifted to upward



pedestal

- When the control signal is shifted to positive value ,so it will be superimposed on input and control signals .so the pedestal occurs



Unidirectional diode coincidence gate

- When any of the control voltages is at –V1, point X is at a large negative voltage, even if the input pulse Vs is present., D0 is reverse biased. Hence there is no signal at the output.
- When all the control voltages, on the other hand, are at –V2 , if an input signal Vs is present, D0 is forward biased and the output is a pulse of 5V. Hence this circuit is a coincidence circuit or AND circuit.

A unidirectional diode coincidence gate is shown below.

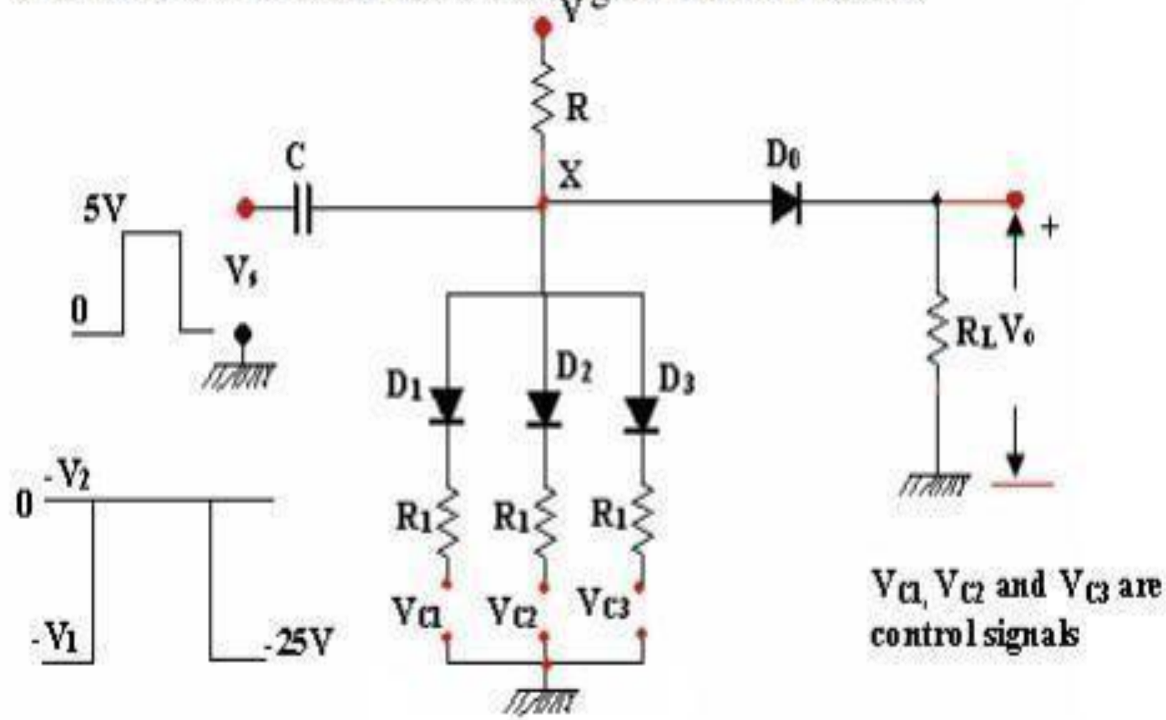
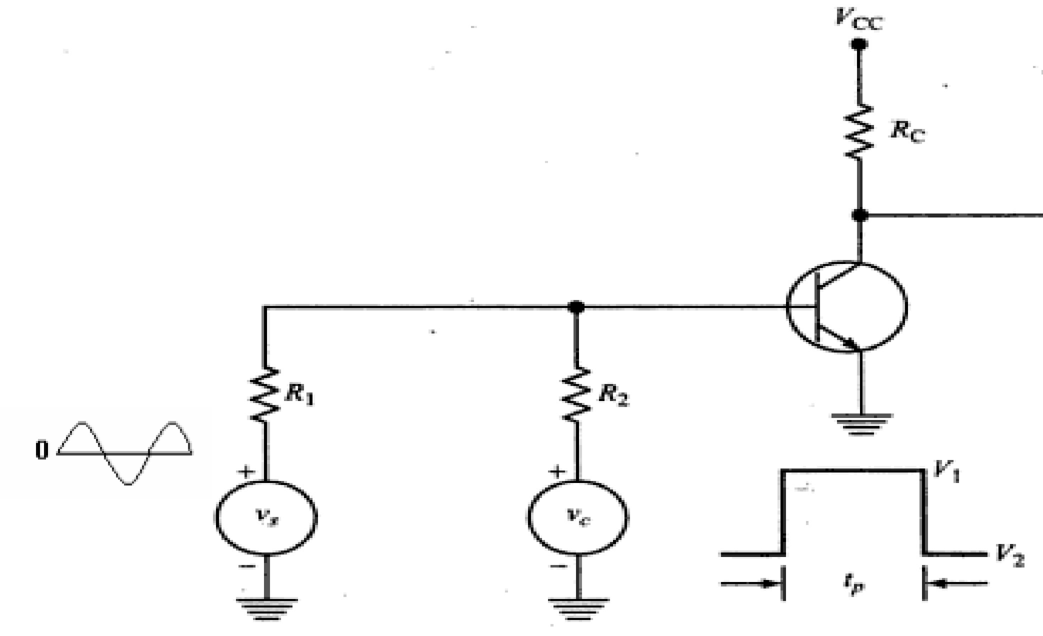
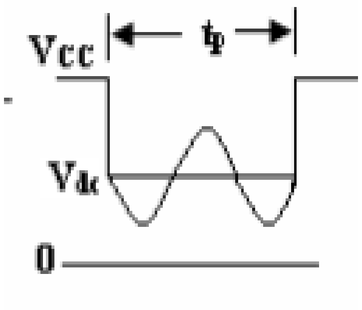


Fig. A unidirectional diode AND gate

Bidirectional Sampling gate

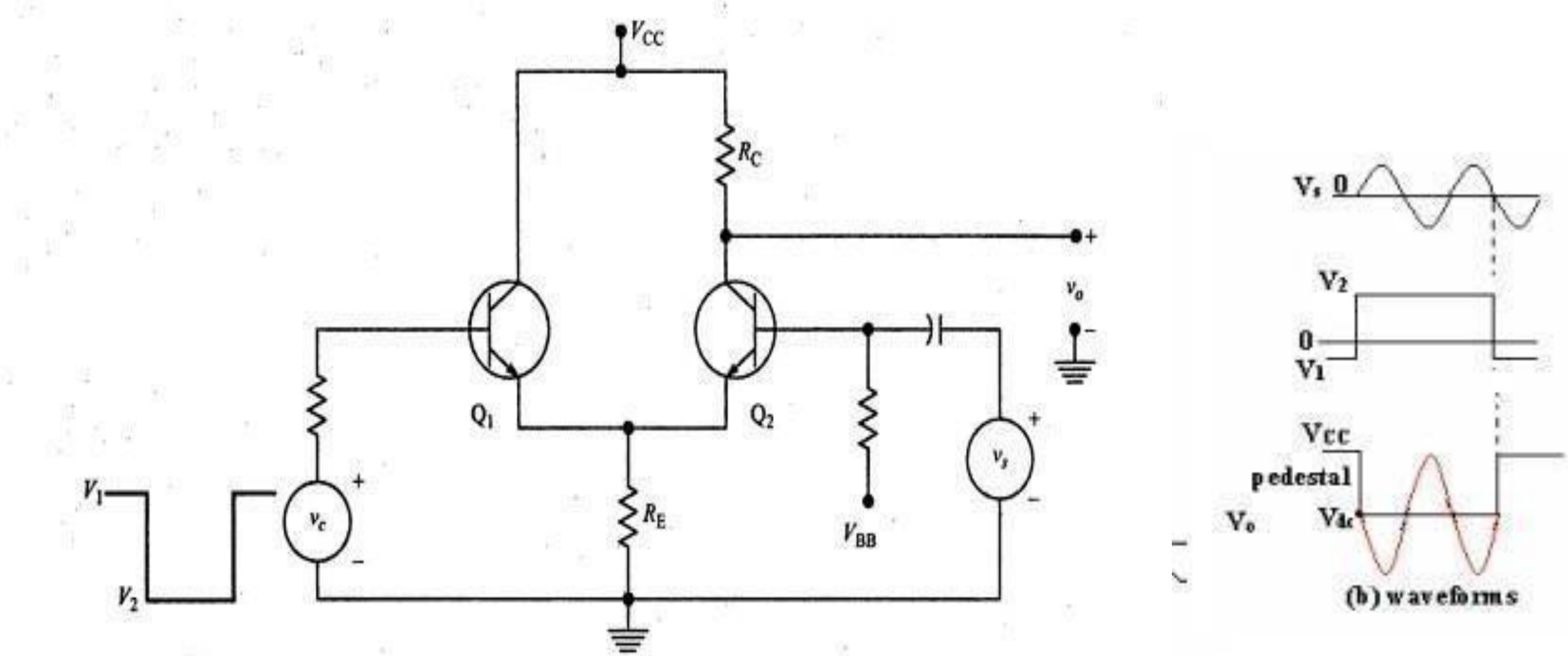
- Bidirectional sampling gates are those whichtransmit signals of both the polarities.





gate using Transistor

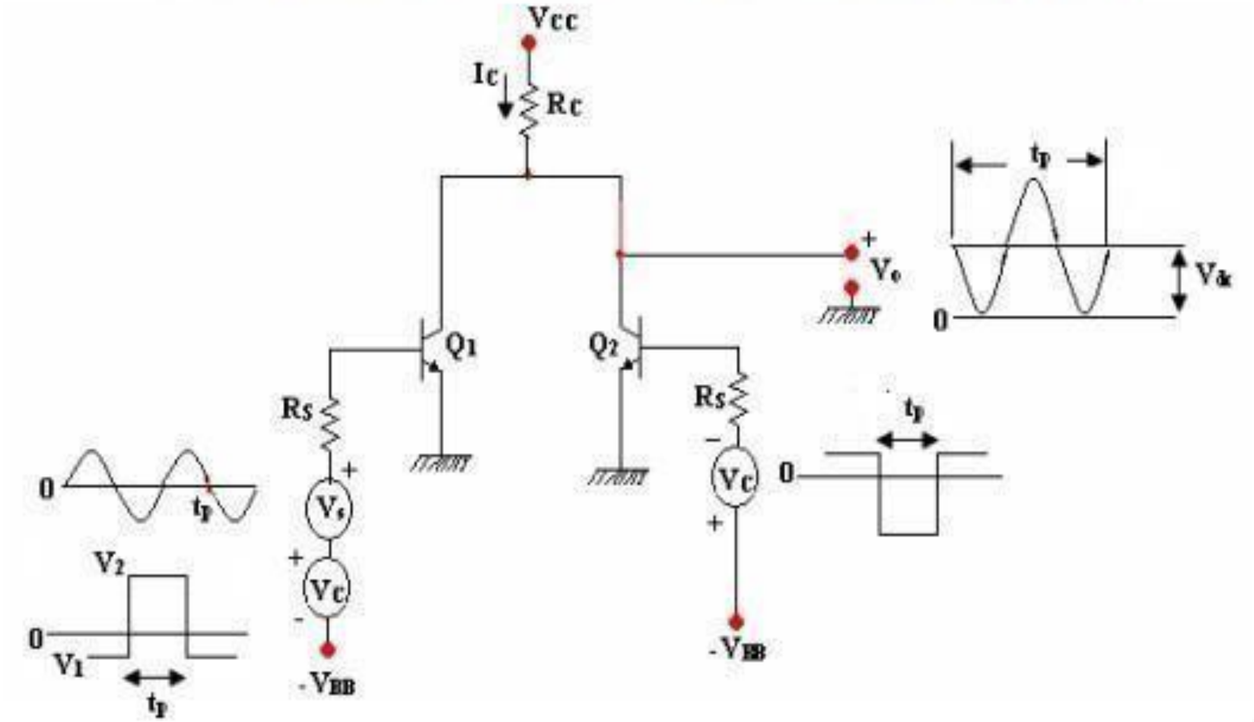
- Bidirectional sampling gates are those which transmit signals of both the polarities.



pedestal

- Circuit that minimizes the pedestal

A circuit arrangement that reduces this pedestal is shown in fig.



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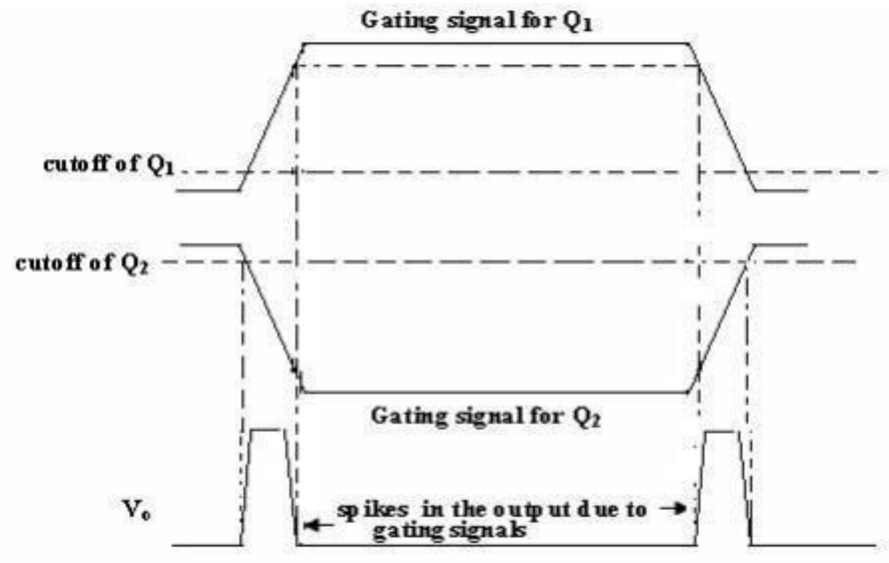
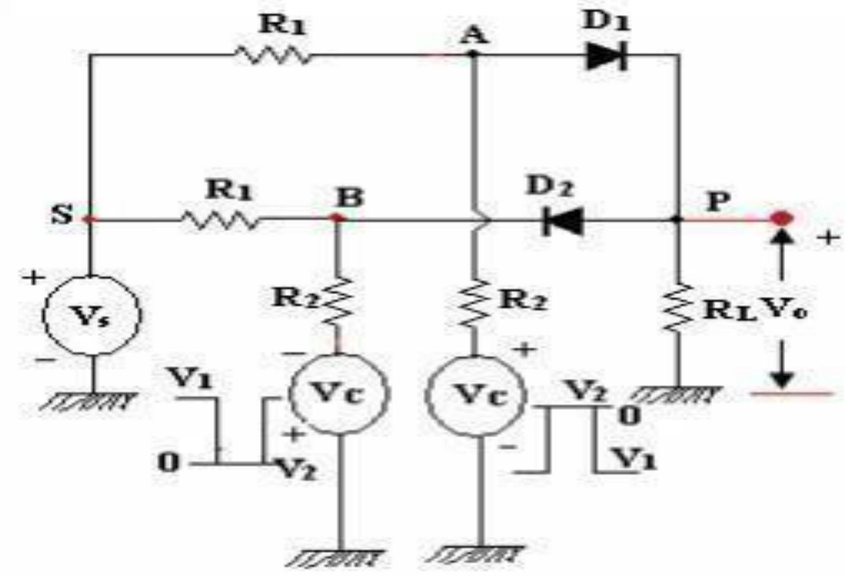
• The control signal applied to the base of Q2 is of opposite polarity to that applied to the base of Q1. When the gating signal connected to Q1 is negative, Q1 is OFF and at the same time the gating signal connected to Q2 drives Q2 ON and draws current IC. As a result there is a dc voltage Vdc at the collector. But when the gate voltage at the base of Q1 drives Q1 ON, Q2 goes OFF. But during this gate period if the input signal is present, it is amplified and is available at the output, with phase inversion. But the dc reference level practically is Vdc. As such the pedestal is either eliminated or minimized.



(a) when the rise time of the gating signal is large

gate

•When the control signals are at V1, D1 and D2 are OFF, no input signal is transmitted to the output. But when control signals are at V2, diode D1 conducts if the input is positive pulses and diode D2 conducts if the input is negative pulses. Hence these bidirectional inputs are transmitted to the output. This arrangement eliminates pedestal, because of the circuit symmetry.



gate

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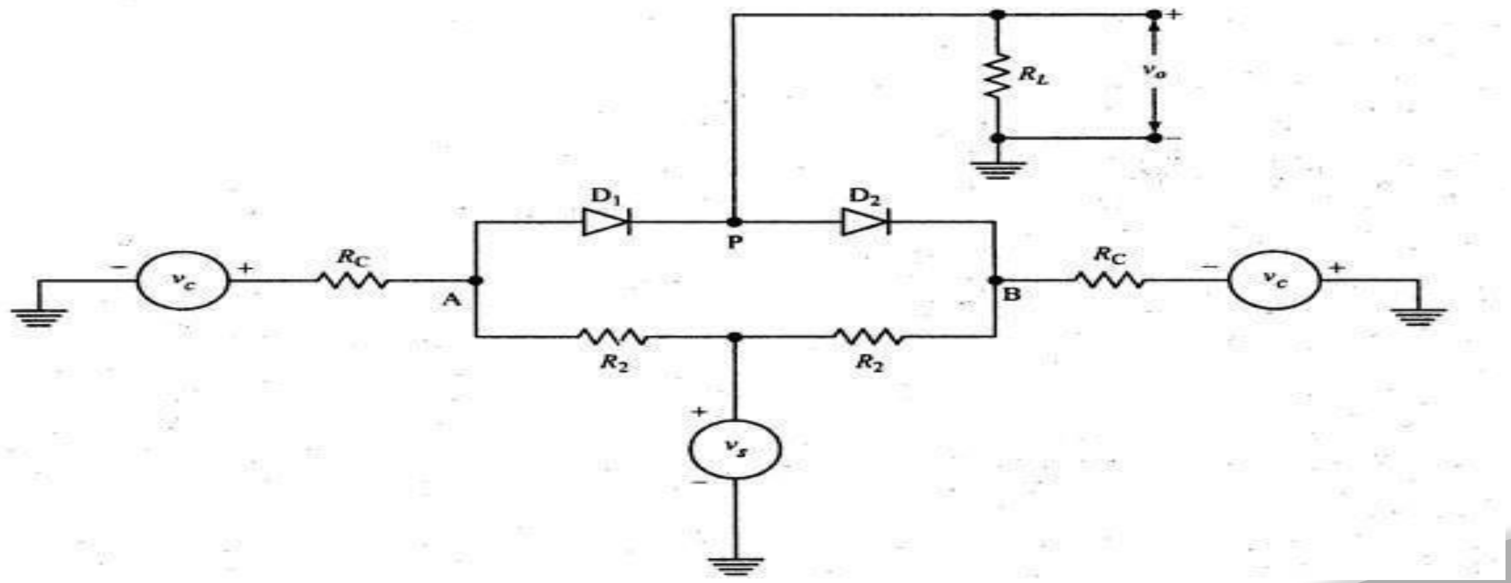

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- ChopperAmplifier
- Multiplexers
- ADC
- Sampling Scope
- Sample and hold circuits


Thank you