Ch1 : BJT Biasing and basic amplifier configuration

Classification of Amplifiers

Type of Signal	Based on No.of Stages	Type of Configuration	Classification based on conduction angle	Frequency of Operation
Small Signal	Single Stage	Common Emitter	Class A Amplifier	Direct Current (DC)
Large Signal	Multistage	Common Base	Class B Amplifier	Audio Frequencies (AF)
		Common Collector	Class AB Amplifier	Radio Frequencies (RF)
			Class C Amplifier	VHF, UHF and SHF Frequencies

Different Regions Of Operation

Region of Operation	Emitter Base Junction	Collector Base Junction
Cut off	Reverse biased	Reverse biased
Active	Forward biased	Reverse biased
Saturation	Forward biased	Forward biased

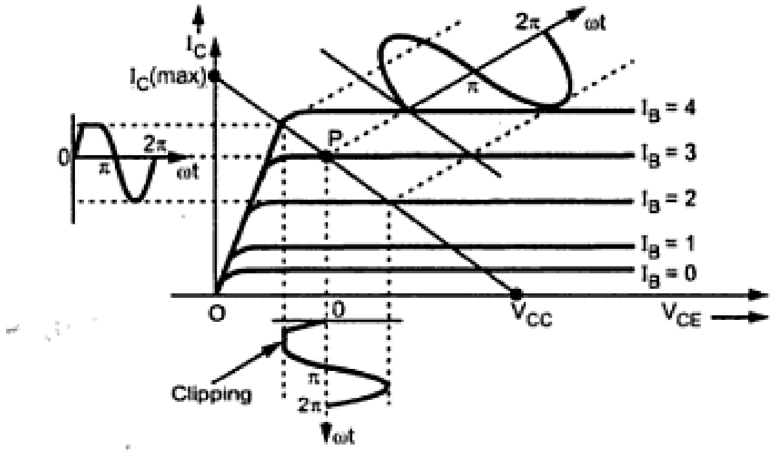
Transistor Voltage specifications For Various Operating Regions

Transistor	$V_{CE\,(sat)}$	$V_{BE\,(sat)}$	$V_{BE\,(active)}$	$V_{BE\,(cut\text{-}in)}$	$V_{BE\,(cut\text{-}off)}$
Si	0.2 V	0.8 V	0.7 V	0.5 V	0 V
Ge	0.1 V	0.3 V	0.2 V	0.1 V	– 0.1 V

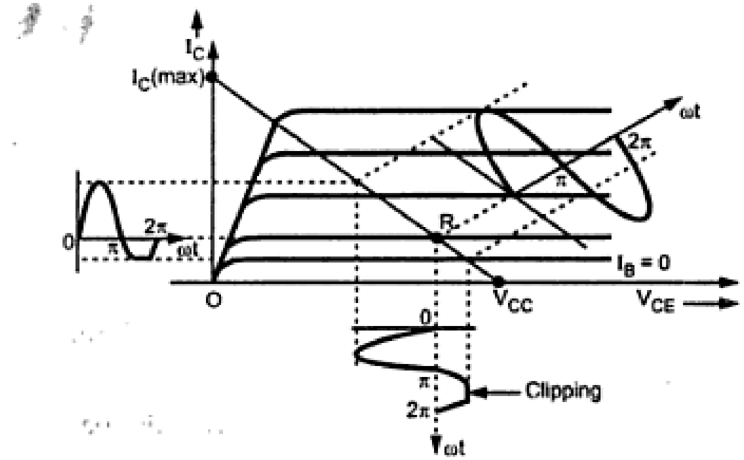
Condition for Active & Saturation Regions

For saturation : $\boxed{I_B > \frac{I_C}{\beta_{dc}}}$

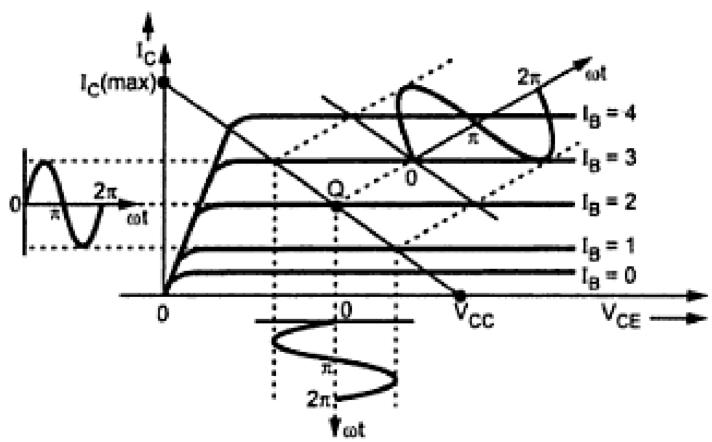
For active region : $\boxed{V_{CE} > V_{CE\,(sat)}}$



Operating point near saturation region gives clipping at the positive peaks

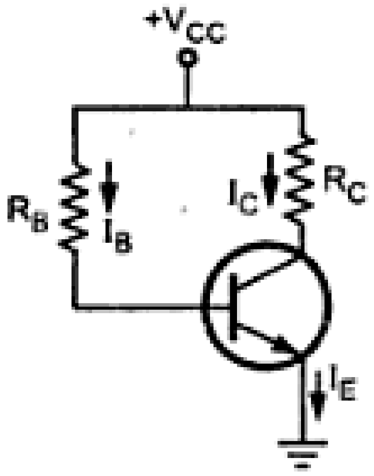


Operating point near cut-off region gives clipping at the negative peaks

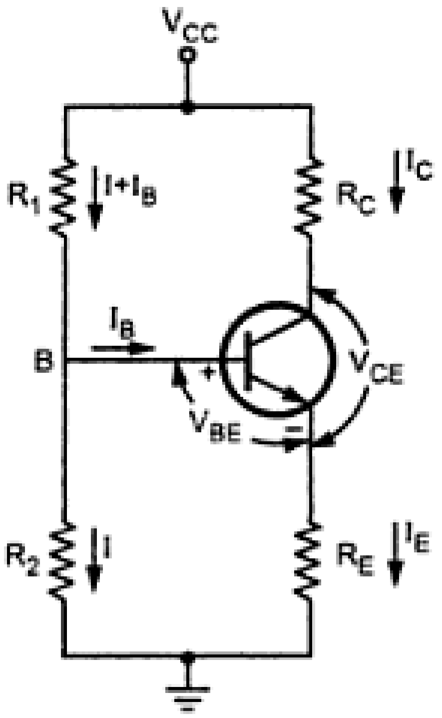


Operating point at the centre of active region is most suitable

Transistor Biasing

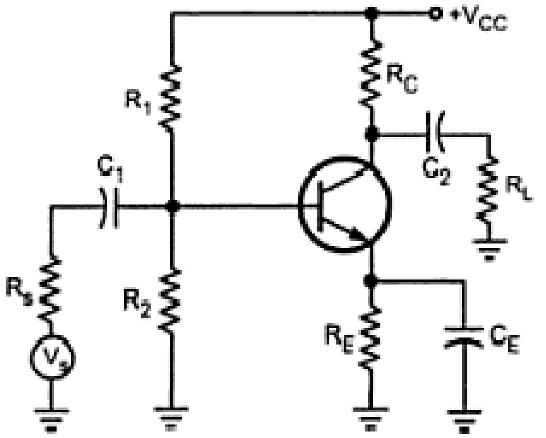


Fixed bias circuit

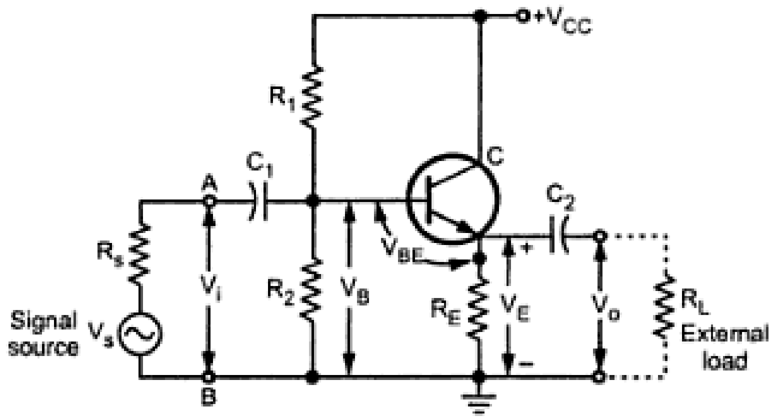


Voltage divider bias circuit

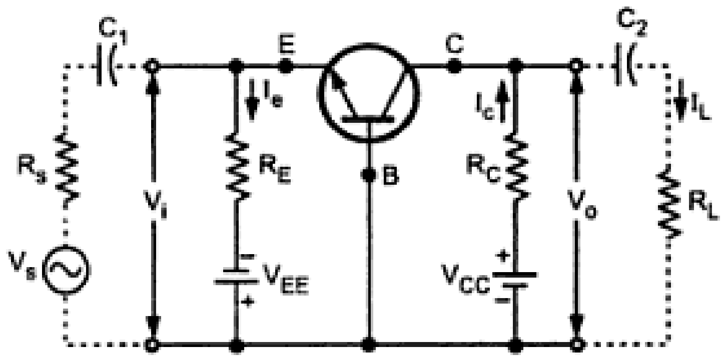
CE, CC, & CB Amplifiers



Practical common emitter amplifier circuit



Common collector circuit



Common base circuit

H-Parameters Representation Of An Amplifier

$$V_i = h_{11} I_i + h_{12} V_o$$

$$I_o = h_{21} I_i + h_{22} V_o$$

Definitions of h-parameter

The parameters in the above equation are defined as follows :

$h_{11} = \left.\frac{V_i}{I_i}\right|_{V_o=0}$ = Input resistance with output short-circuited, in ohms.

$h_{12} = \left.\frac{V_i}{V_o}\right|_{I_i=0}$ = Fraction of output voltage at input with input open circuited.

This parameter is ratio of similar quantities, hence unitless

$h_{21} = \left.\frac{I_o}{I_i}\right|_{V_o=0}$ = Forward current transfer ratio or current gain with output short circuited.

This parameter is a ratio of similar quantities, hence unitless.

$h_{22} = \left.\frac{I_o}{V_o}\right|_{I_i=0}$ = Output admittance with input open-circuited, in mhos.

a) With output short circuited :

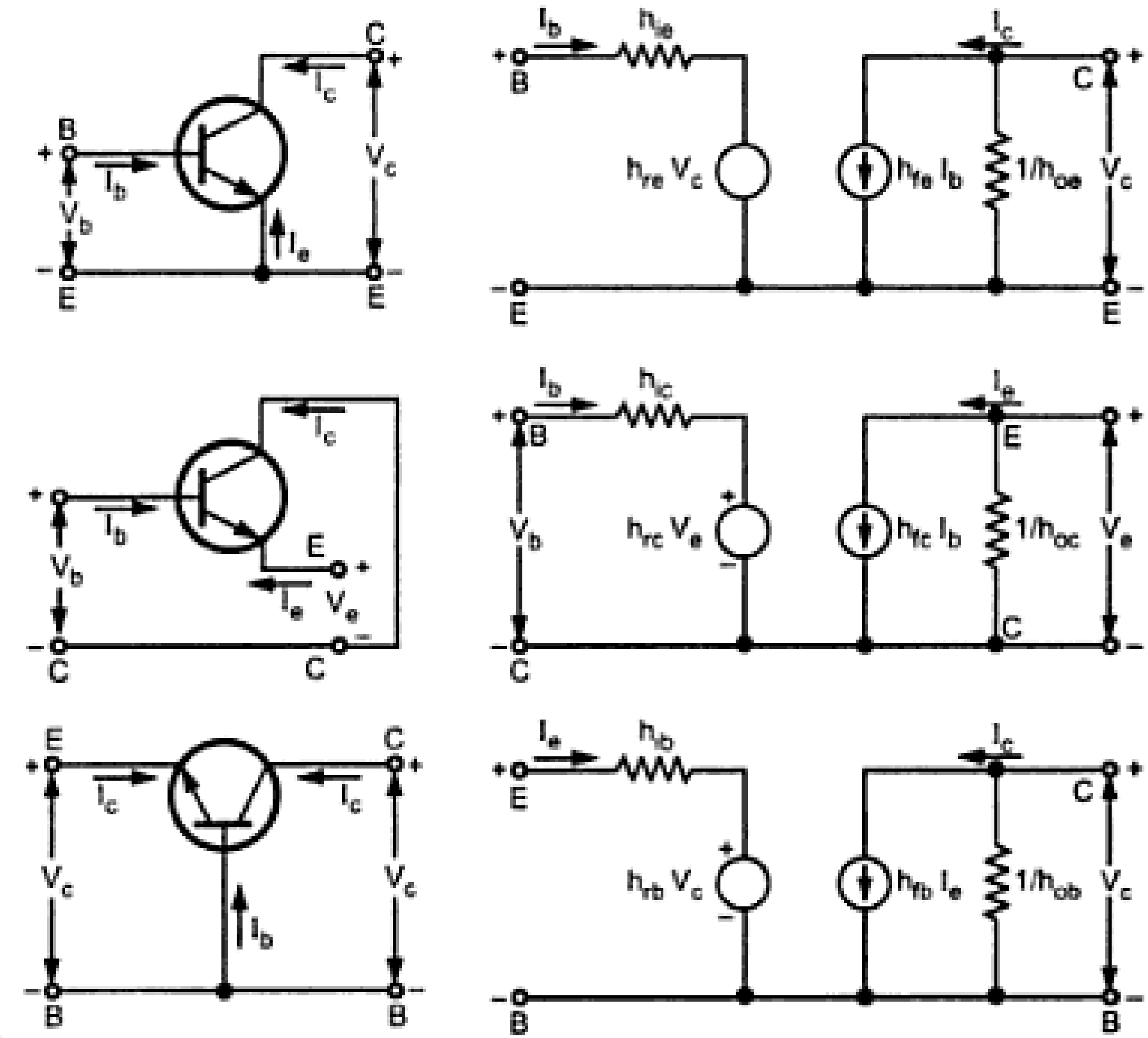
$h_{11} = h_i$: Input resistance

$h_{21} = h_f$: Short circuit current gain

b) With input open circuited :

$h_{12} = h_r$: Reverse voltage transfer ratio

$h_{22} = h_o$: Output admittance



CE

$$V_b = h_{ie} I_b + h_{re} V_c$$
$$I_c = h_{fe} I_b + h_{oe} V_c$$

CC

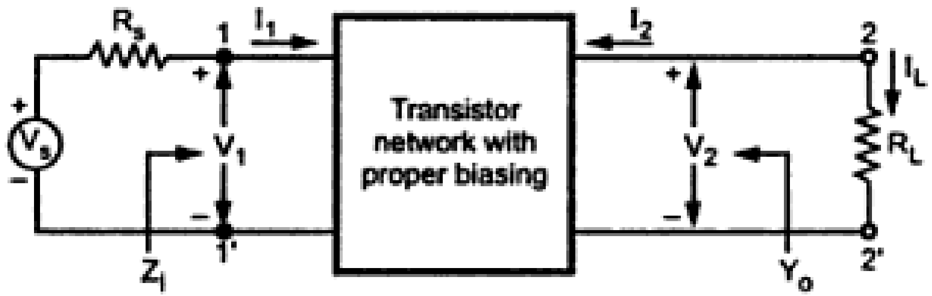
$$V_b = h_{ic} I_b + h_{rc} V_e$$
$$I_e = h_{fc} I_b + h_{oc} V_e$$

CB

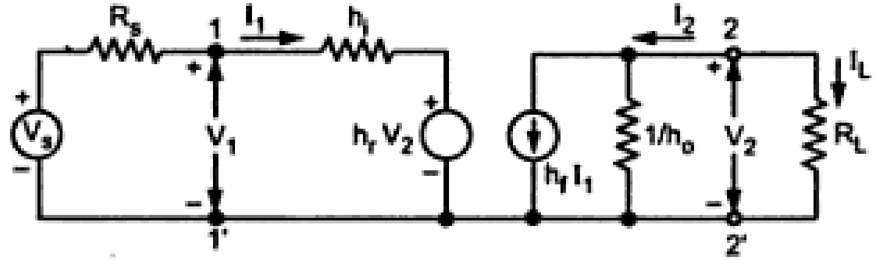
$$V_e = h_{ib} I_e + h_{rb} V_c$$
$$I_c = h_{fb} I_e + h_{ob} V_c$$

Transistor configurations and their hybrid models

Small Signal Analysis Of A Junction Transistor



Basic transistor amplifier



Transistor amplifier in its h-parameter model

small-signal analysis of a transistor amplifier

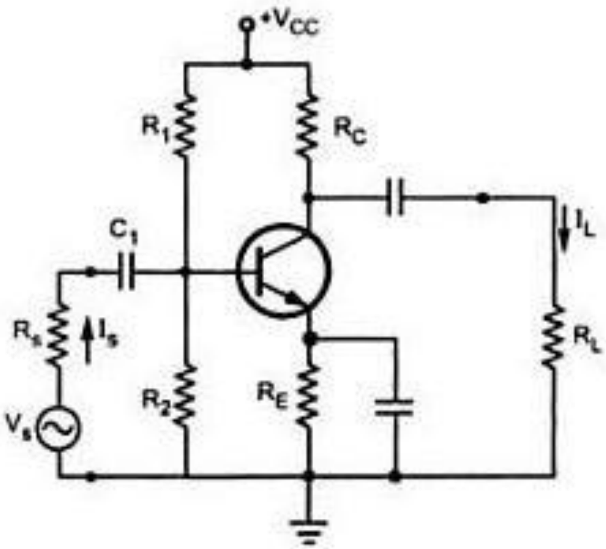
$A_i = -\dfrac{h_f}{1 + h_o R_L}$
$A_{is} = \dfrac{A_i R_s}{Z_i + R_s}$
$Z_i = h_i + h_r A_i R_L = h_i - \dfrac{h_f h_r}{h_o + Y_L}$
$A_v = \dfrac{A_i R_L}{Z_i}$
$A_{VS} = \dfrac{A_v R_i}{Z_i + R_s} = \dfrac{A_i R_L}{Z_i + R_s} = \dfrac{A_{is} R_L}{R_s}$
$Y_o = h_o - \dfrac{h_f h_r}{h_i + R_s} = \dfrac{1}{Z_o}$
$A_P = A_V A_i = A_i^2 \dfrac{R_L}{Z_i}$

Guidelines for Analysis of a Transistor Circuit

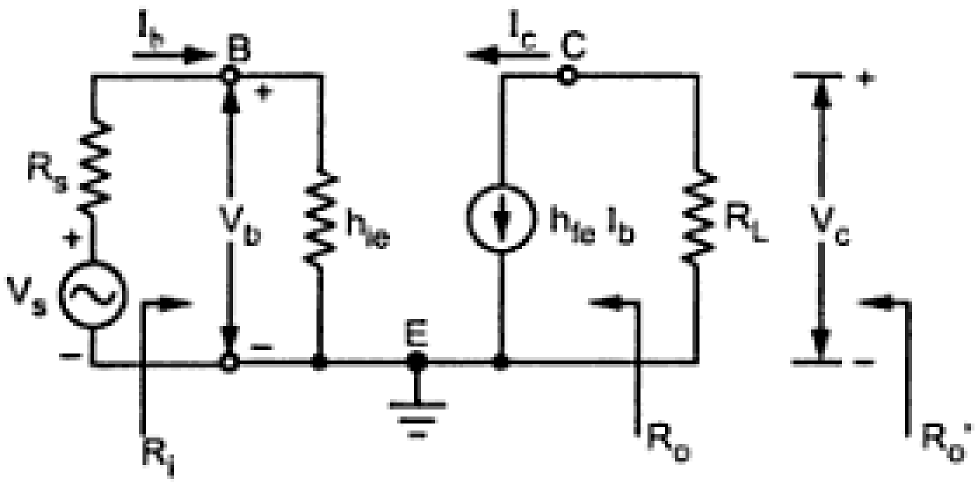
1. Draw the actual circuit diagram.
2. Replace coupling capacitors and emitter bypass capacitor by short circuit.
3. Replace dc source by a short circuit. In other words, short V_{CC} and ground lines.
4. Mark the points B(base), C(collector), E(emitter) on the circuit diagram and locate these points as the start of the equivalent circuit.
5. Replace the transistor by its h-parameter model.

Design Problem

➡ *Consider a single stage CE amplifier with* $R_s = 1\ k\Omega$, $R_1 = 50\ K$, $R_2 = 2K$, $R_C = 1K$, $R_L = 1.2\ K$, $h_{fe} = 50$, $h_{ie} = 1.1\ K$, $h_{oe} = 25\ \mu A/V$ *and* $h_{re} = 2.5 \times 10^{-4}$, *as shown in Fig.*



Approximate H-Model For CE Amplifier



Approximate CE model

Current Gain $A_i \approx -h_{fe}$

Input Impedance $R_i \approx h_{ie}$

Voltage Gain : $A_v = \frac{A_i R_L}{R_i} = \frac{A_i R_L}{h_{ie}}$

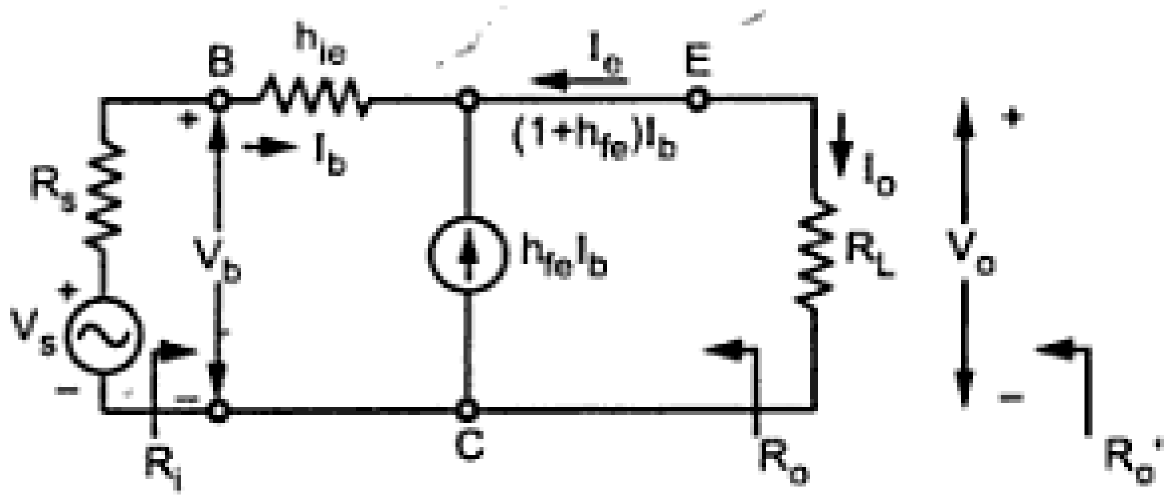
Output Impedance

$$Y_o = 0$$

$$R_o = \frac{1}{Y_o} = \infty$$

$$R'_o = R_o \parallel R_L = \infty \parallel R_L = R_L$$

Approximate H-Model For CC Amplifier



Simplified CC model

Current gain $A_i = \frac{I_o}{I_b} = \frac{-I_e}{I_b} = 1 + h_{fe}$

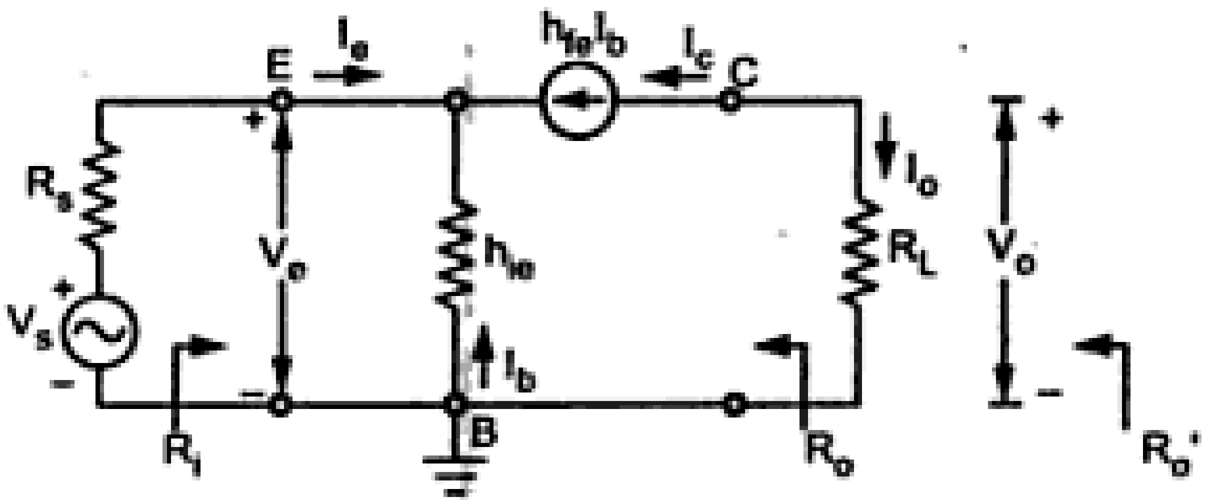
Input resistance : $R_i = \frac{V_b}{I_b} = h_{ie} + (1 + h_{fe})\, R_L$

Voltage gain (A_v) $A_v = \frac{(1 + h_{fe})\, R_L}{h_{ie} + (1 + h_{fe})\, R_L} \cong 1$

Output resistance R_o $R_o = \frac{V_o}{I_e} = \frac{R_s + h_{ie}}{1 + h_{fe}}$

$$\underline{R'_o = R_o \parallel R_L = \infty \parallel R_L = R_L}$$

Approximate H-Model For CB Amplifier



Simplified CB model

Current gain $A_i = \dfrac{h_{fe}}{1+h_{fe}}$

Input resistance (R_i) $R_i = \dfrac{h_{ie}}{1+h_{fe}}$

Voltage gain (A_v)

$$A_v = \dfrac{\dfrac{h_{fe}}{1+h_{fe}} \times R_L}{\dfrac{h_{ie}}{1+h_{fe}}} \doteq \dfrac{h_{fe}R_L}{h_{ie}}$$

Output resistance (R_o) $R_o = \left.\dfrac{V_o}{I_c}\right|_{V_s=0}$

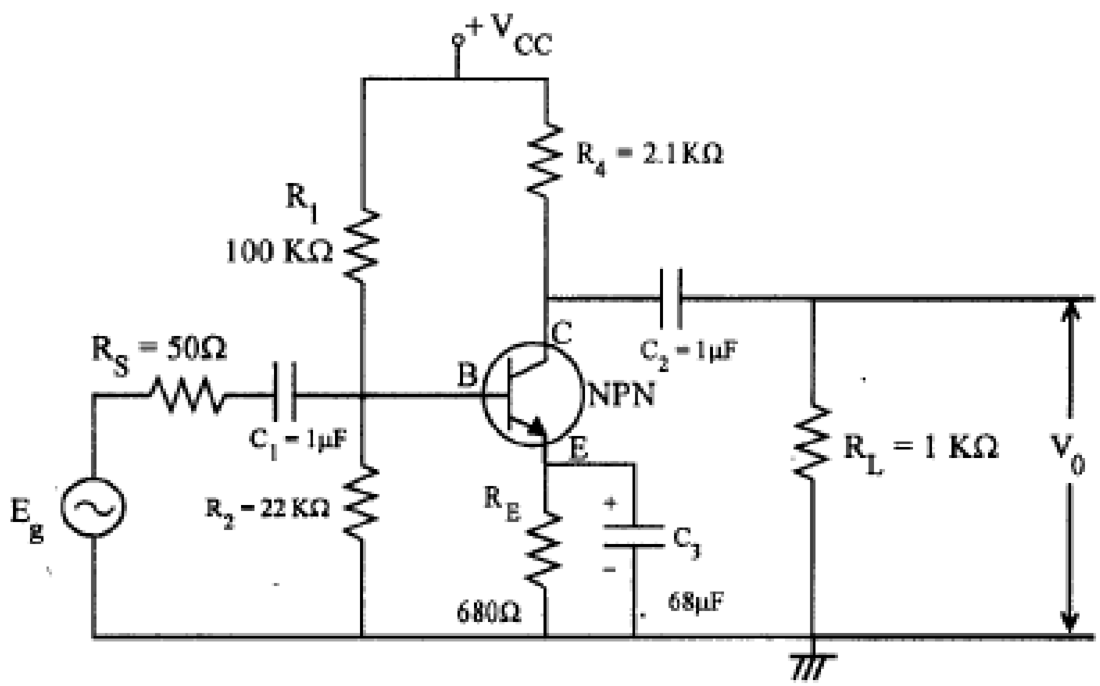
$$R'_o = R_o \parallel R_L = \infty \parallel R_L = R_L$$

Design Problem

For the circuit shown in Fig. estimate A_I, A_v, R_i and R_o using reasonable approximations. The ***h-parameters*** for the transistor are given as

$h_{fe} = 100$ $h_{ie} = 2000\ \Omega$ h_{re} is negligible and $h_{oe} = 10^{-5}$ mhos(℧).

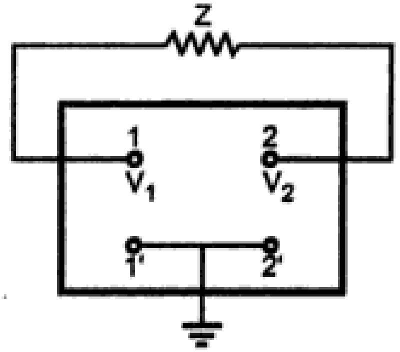
$I_b = 100\ \mu A$.



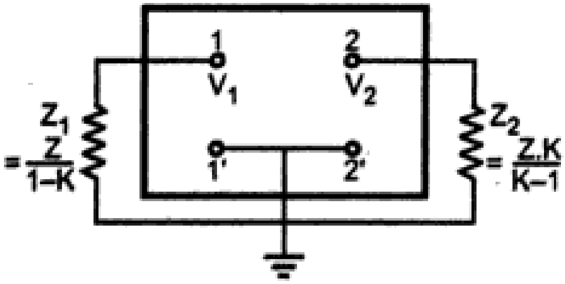
CE Amplifier Circuit

Miller's Theorem

Millers theorem is used to simplify the analysis of a circuit whenever there is a feedback connection in the circuit



(a)

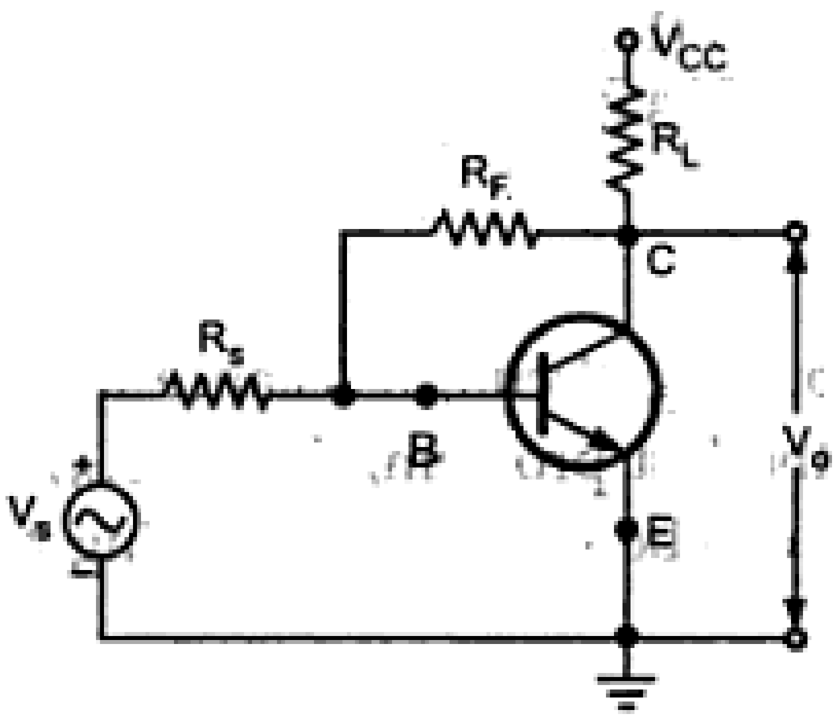


(b)

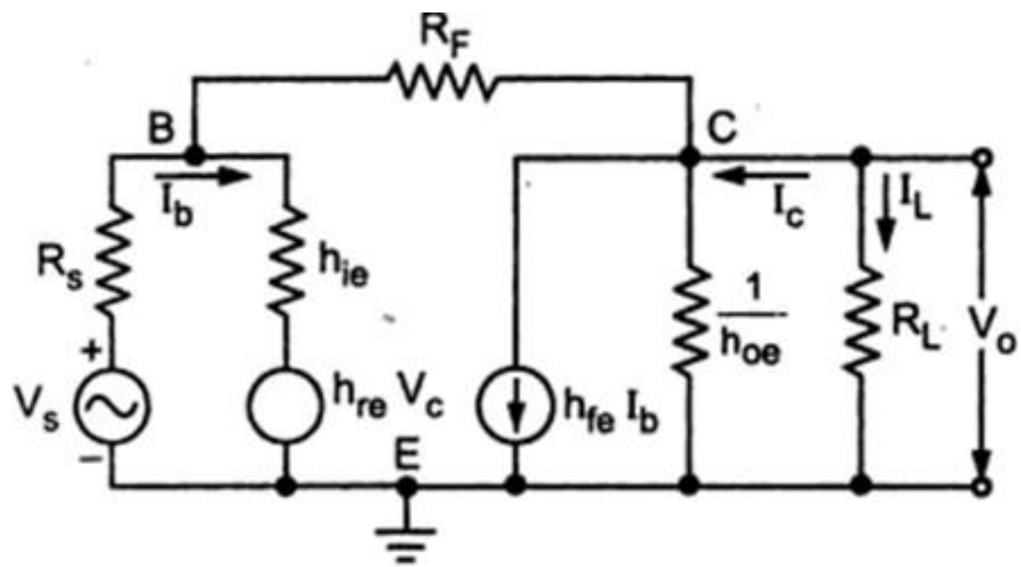
$$Z_1 = \frac{Z}{1-K}$$

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

Analysis of Common Emitter Amplifier with Collector to Base Bias

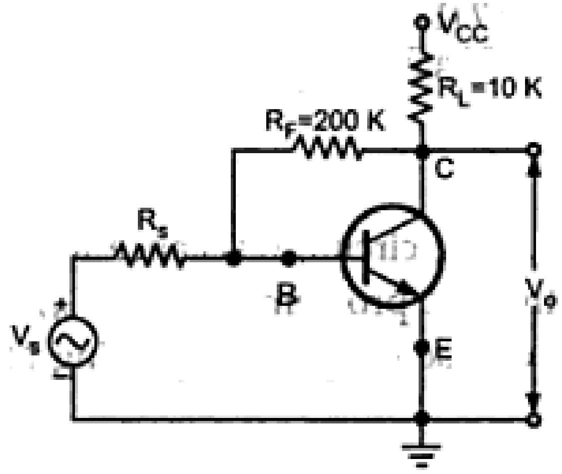


AC equivalent circuit



Design Problems

➡ The Fig. shows common emitter amplifier with collector to base bias. Calculate R_i, R_i', A_v, A_{vs}, A_i. The transistor parameters are h_{ie} = 1.1 K, $h_{fe} = 50$, $h_{oe} = 25 \times 10^{-6}$ A/V, $h_{re} = 2.5 \times 10^{-4}$.



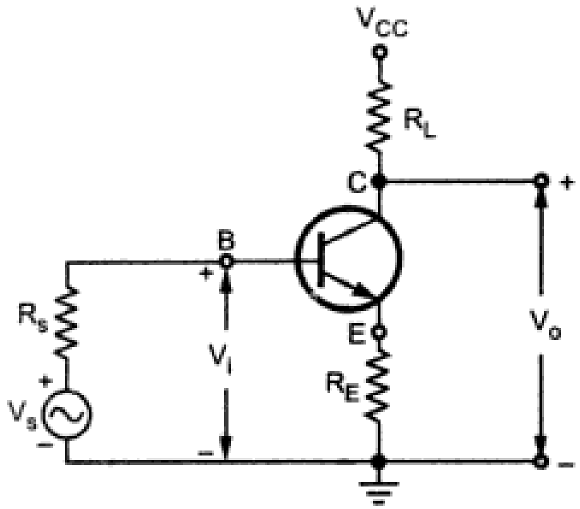
Design Problems

➠ For a Common Emitter Configuration, what is the maximum value of R_L for which R_1 differs by not more than 10% of its value at $R_2 = 0$?

$$h_{ie} = 1100\Omega \; ; \qquad h_{fe} = 50$$

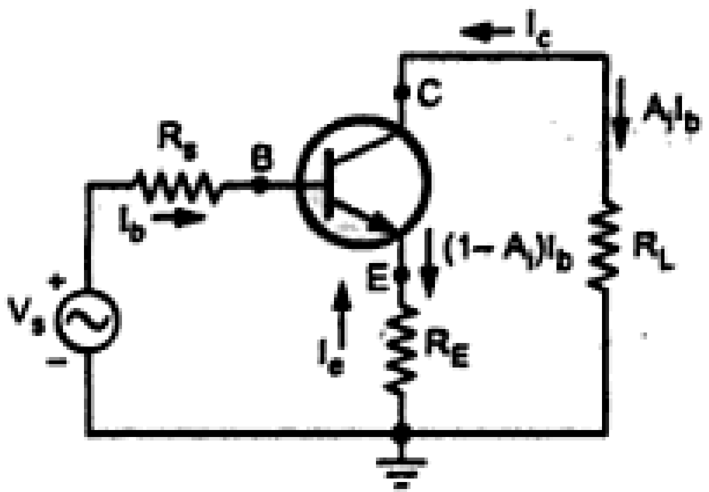
$$h_{re} = 2.50 \times 10^{-4} \; ; \qquad h_{oe} = 25\mu \text{ A/v}$$

Analysis Of CE Amplifier With Unbypassed R_E

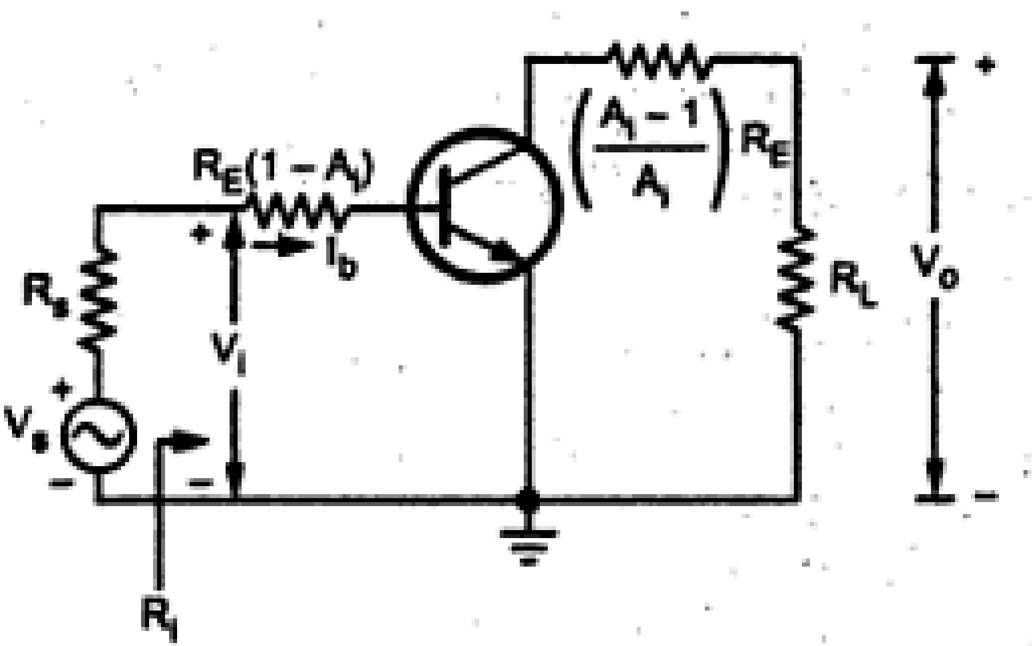


- R_E is added to stabilize the gain of the amplifier
- R_E acts as a feedback resistor
- The overall gain will reduce with unbypassed R_E

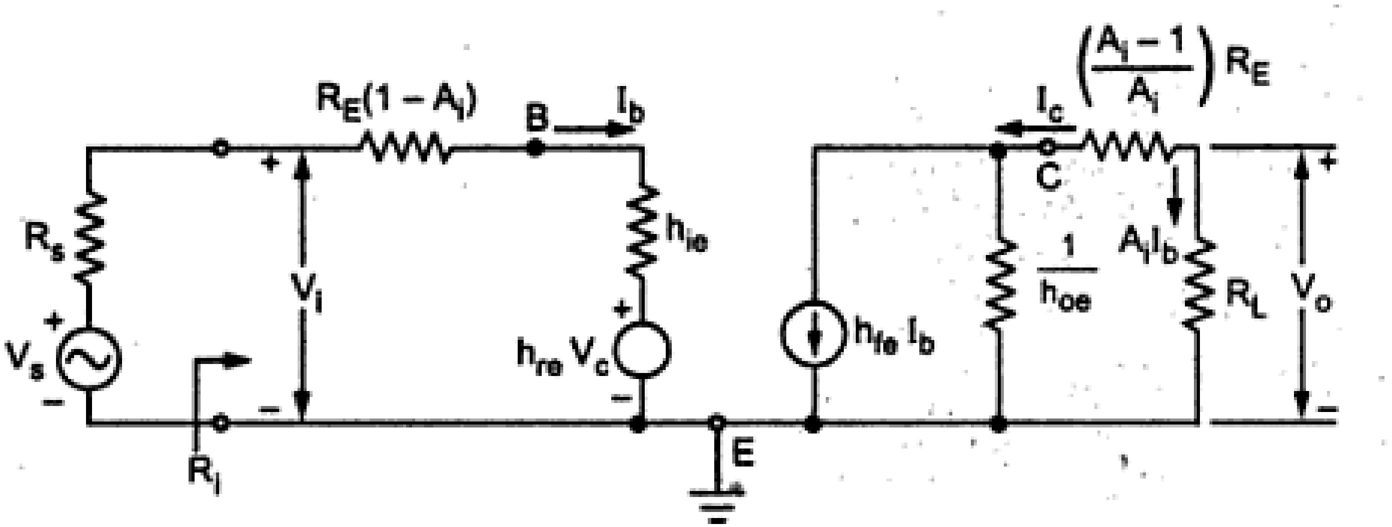
AC Equivalent Circuit For CE Amplifier with Unbypassed R_E



AC Equivalent Circuit For CE Amplifier with R_E Splitted using dual of Miller's Theorem

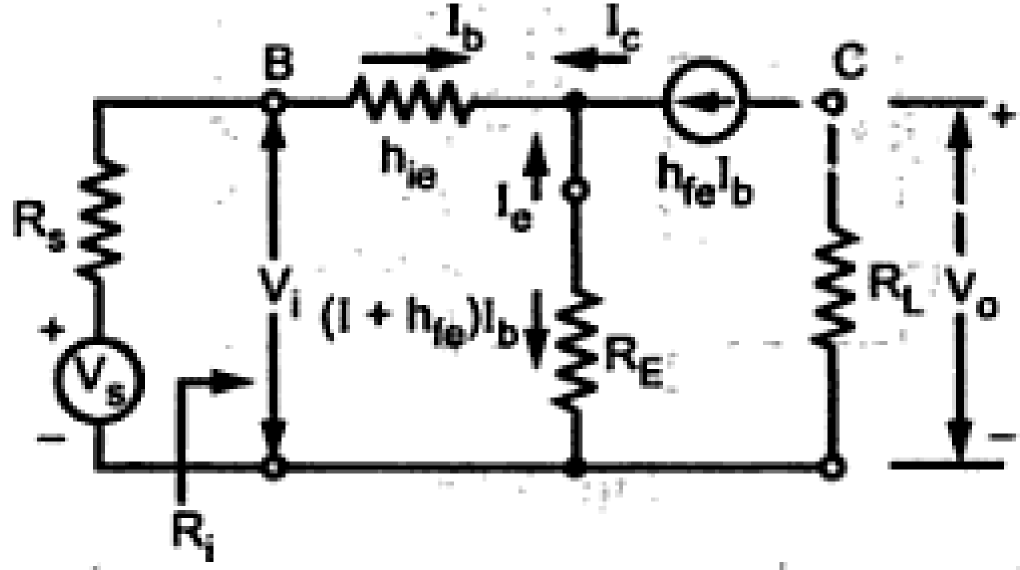


h-Parameter Equivalent Circuit (Exact Analysis)



$$A_i = \frac{-h_{fe}}{1+h_{oe}R_L'} = \frac{-h_{fe}}{1+h_{oe}\left(R_L + \frac{A_i-1}{A_i}R_E\right)}$$

h-Parameter Equivalent Circuit (Approximate Analysis)



Approximate model for CE amplifier with R_E

Current gain $A_i = \dfrac{-I_c}{I_b} = \dfrac{-h_{fe}I_b}{I_b} = -h_{fe}$

Input resistance $R_i = \dfrac{V_i}{I_b} = h_{ie} + (1 + h_{fe})\, R_E$

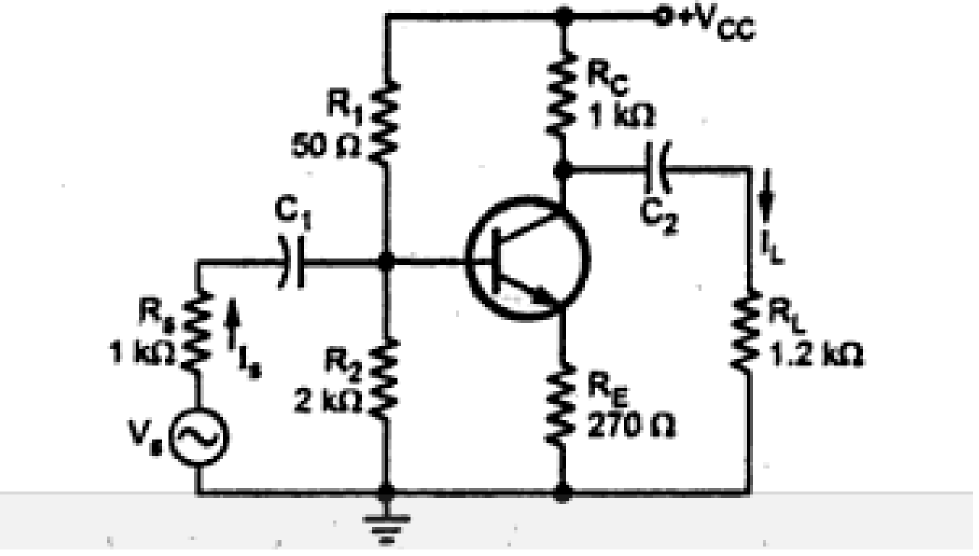
Voltage gain $A_v = \dfrac{A_i R_L}{R_i} = \dfrac{-h_{fe}R_L}{h_{ie} + (1 + h_{fe})R_E}$

Output resistance $R_o = \left.\dfrac{V_o}{I_o}\right|_{V_s=0}$

$R'_o = R_o \parallel R_L = \infty \parallel R_L = R_L$

Design Problems

Example *Fig. shows a single stage CE amplifier with unbypassed emitter resistance find current gain, input resistance, voltage gain and output resistance. Use typical values of h-parameter*

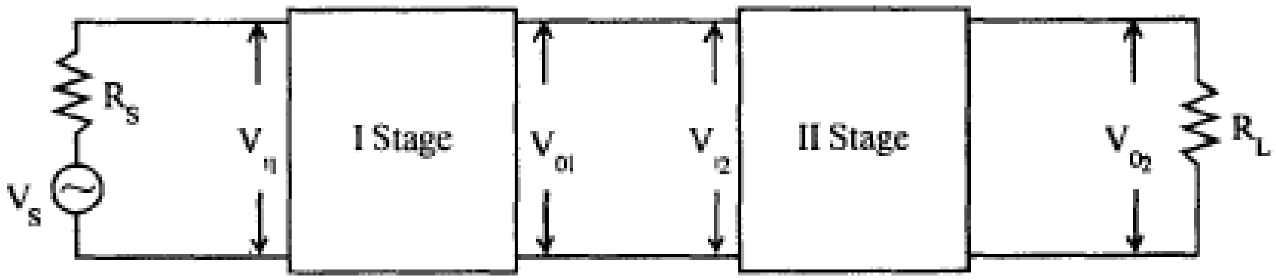


MULTISTAGE AMPLIFIERS

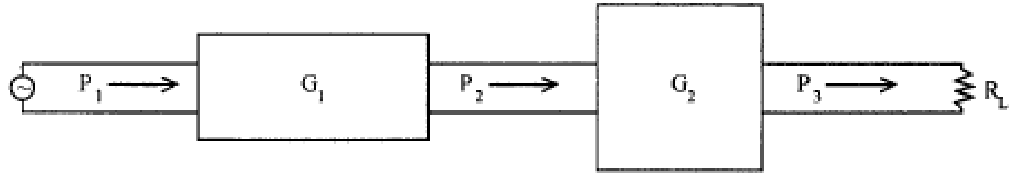
Need For Cascading

- When the amplification of a single stage amplifier is not sufficient, or,
- When the input or output impedance is not of the correct magnitude, for a particular application two or more amplifier stages are connected, in cascade. Such amplifier, with two or more stages is also known as multistage amplifier.

Block diagram of 2-Stage Cascade Amplifier



Gain of 2-Stage Cascade Amplifier



$$G_1 = \frac{P_2}{P_1}; \; G_2 = \frac{P_3}{P_2}$$

Overall gain $$G = \frac{P_3}{P_1}$$

$$= \frac{P_2}{P_1} \cdot \frac{P_3}{P_2}$$

$$\mathbf{G = G_1 G_2}$$

Decibel Voltage Gain

Cascaded Stages

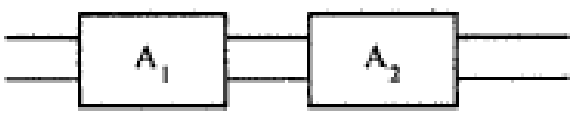


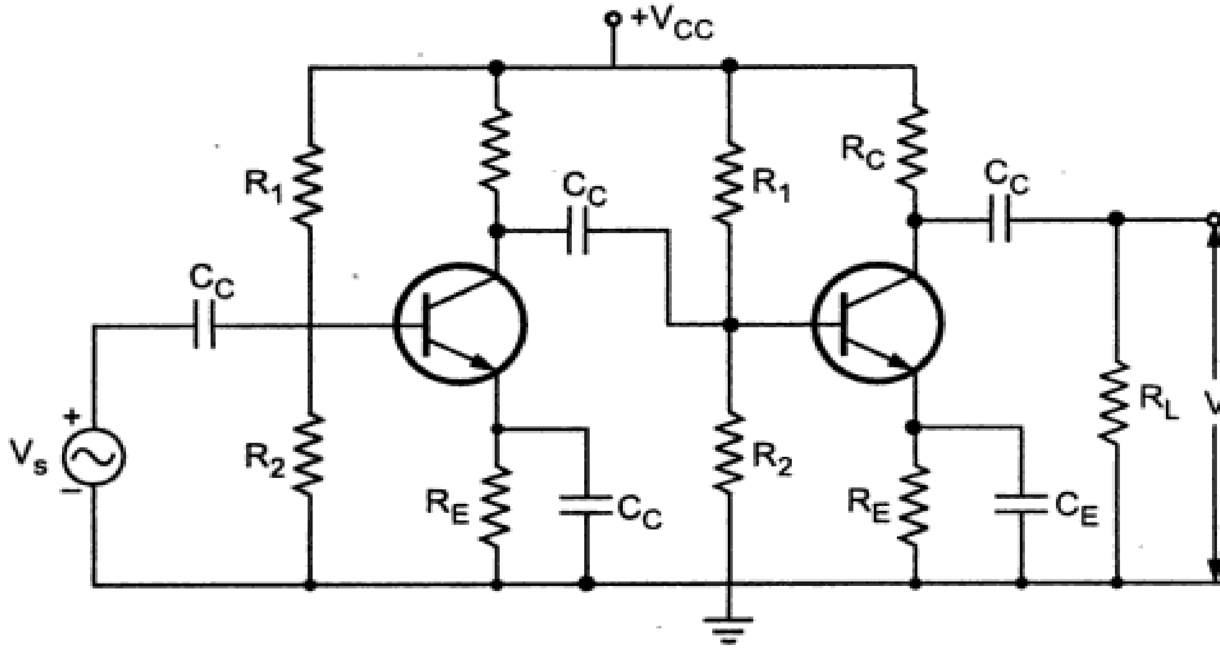
Fig. 2.23 Cascaded stages

$$A = A_1 \times A_2$$
$$A_1 = A_1{}' + A_2{}' \text{ (in decibels)}$$

Methods of Inter Stage Coupling

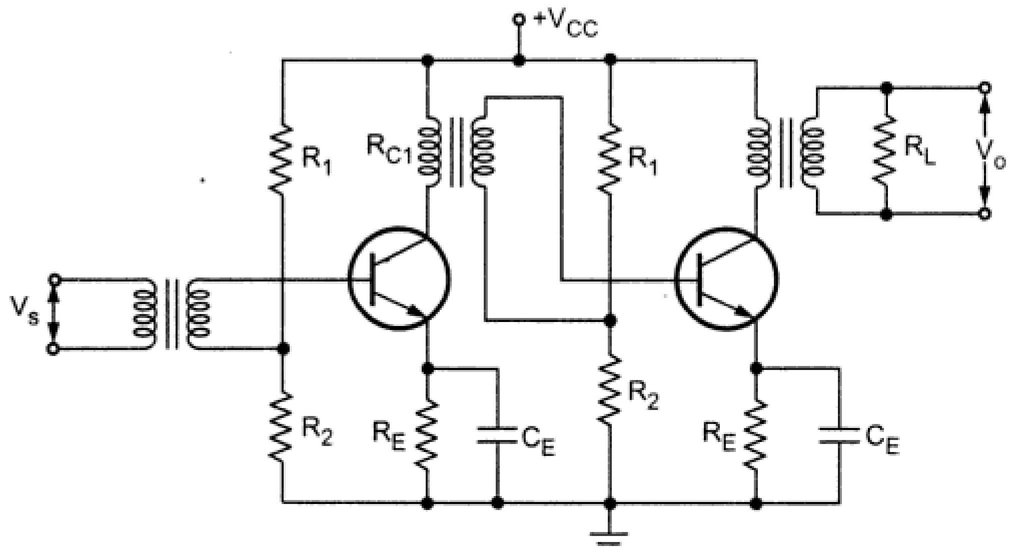
In multistage amplifier, the output signal of preceding stage is to be coupled to the input circuit of succeeding stage. For this interstage coupling, different types of coupling elements can be employed. These are :

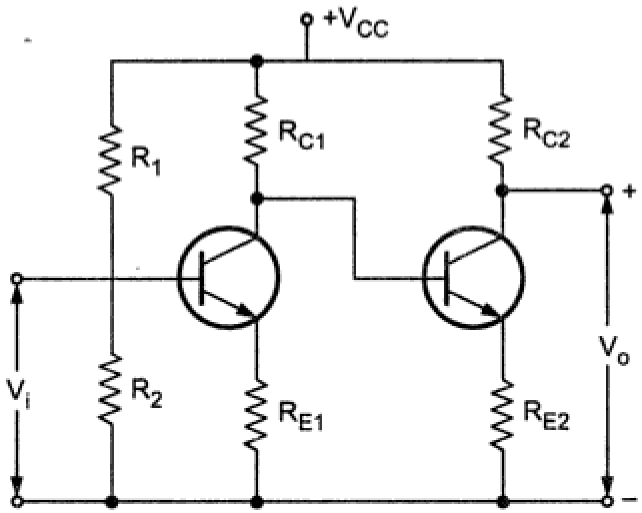
1. RC coupling
2. Transformer coupling
3. Direct coupling



Two stage RC coupled amplifier using transistors

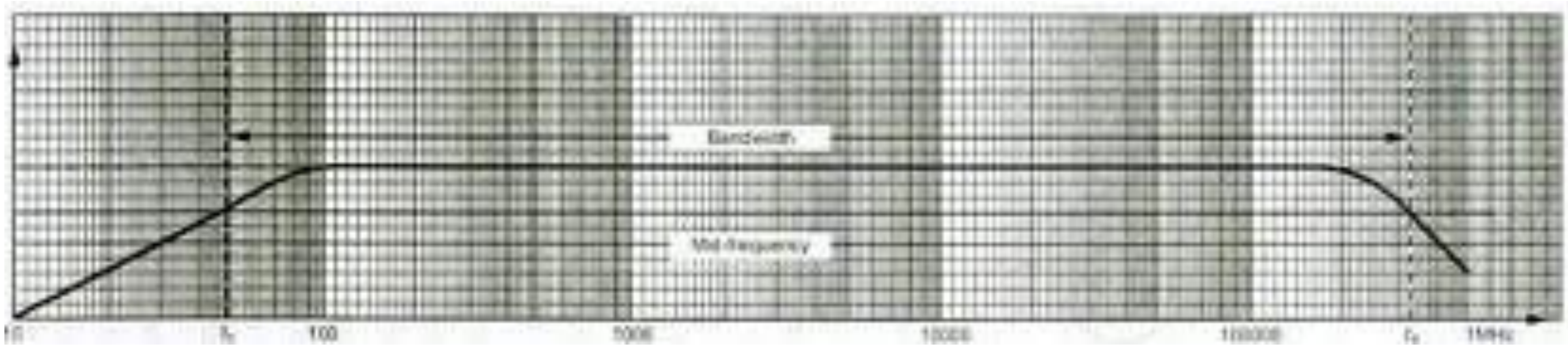
Two stage transformer coupled amplifier using transistors





Two stage directly coupled amplifier using transistors

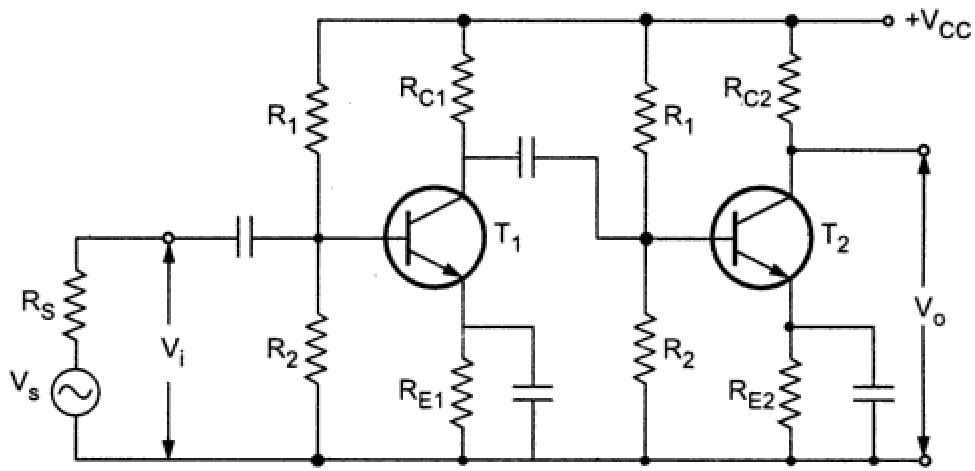
Frequency Response of 2-Stage RC Coupled Amplifier



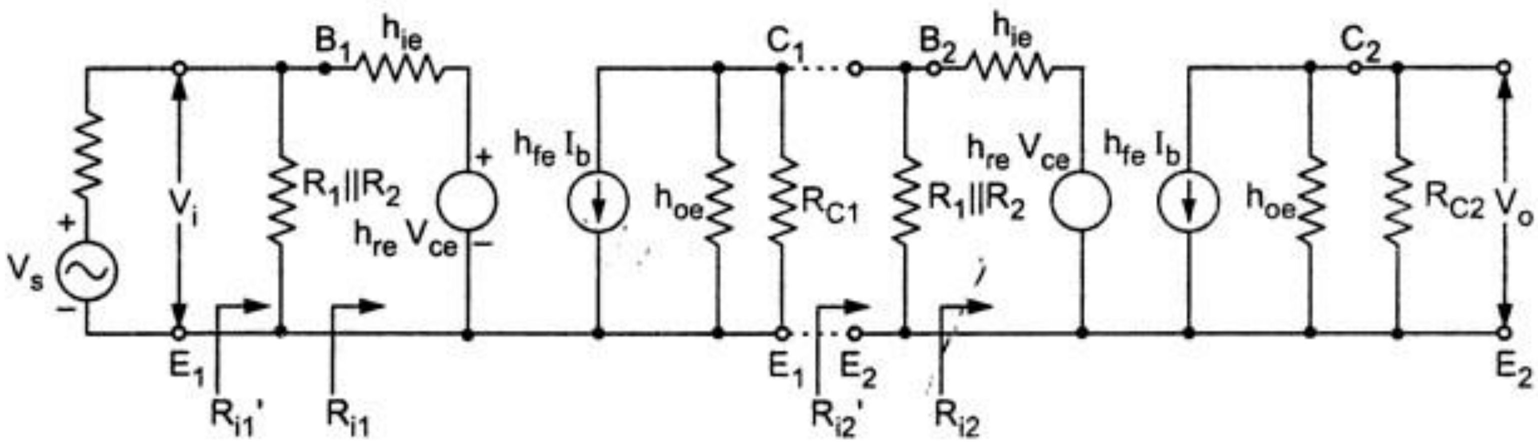
Comparison Between Coupling Method

Parameter	RC Coupled	Transformer Coupled	Direct Coupled
Coupling Components	Resistor and Capacitor	Impedance matching transformer	–
Block DC	Yes	Yes	No
Frequency response	Flat at middle frequencies	Not uniform, high at resonant frequency and low at other frequencies	Flat at middle frequencies and improvement in the low frequency response
Impedance matching	Not achieved	Achieved	Not achieved
DC amplification	No	No	Yes
Weight	Light	Bulky and heavy	
Drift	Not present	Not present	Present
Hum	Not present	Present	Not present
Application	Used in all audio small signal amplifiers. Used in record players, tape recorders, public address systems, radio receivers and television receivers.	Used in amplifier where impedance matching is an important criteria. Used in the output stage of the pubic address system to match the impedance of loudspeaker. Used in the RF amplifier stage of the receiver as a tuned voltage amplifier.	Used in amplification of slow varying parameters and where DC amplification is required.

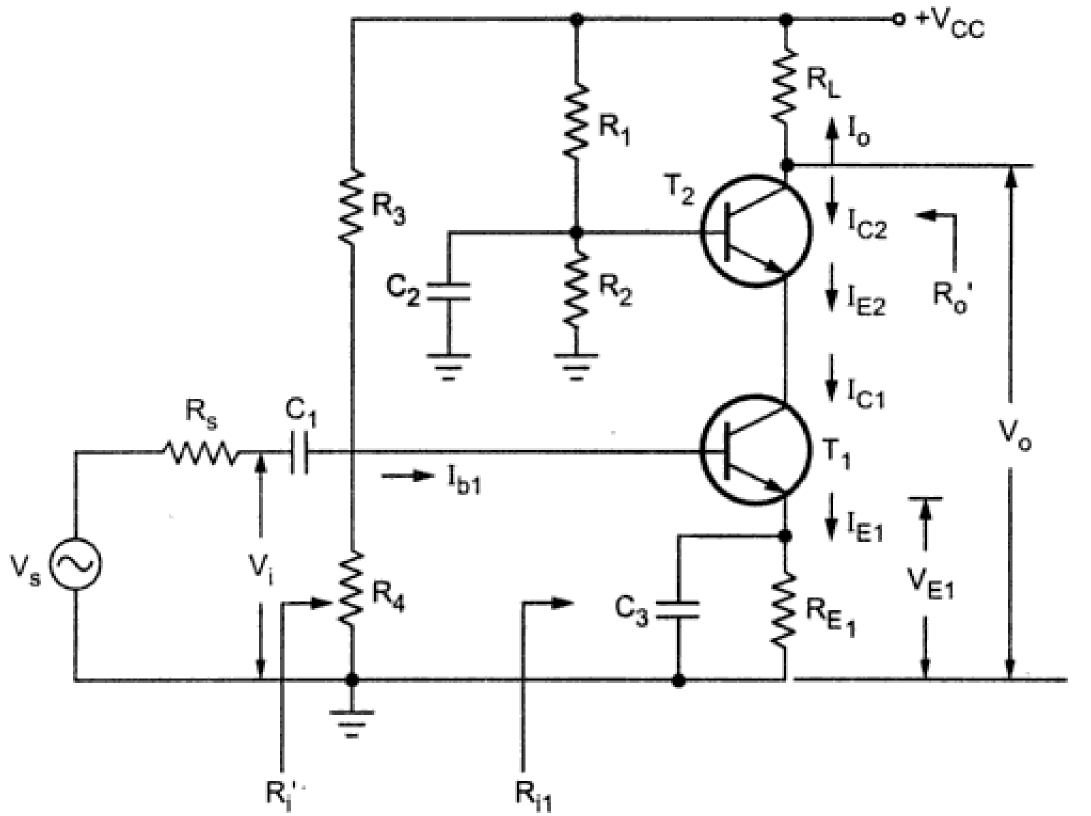
CE-CE Cascade Amplifier



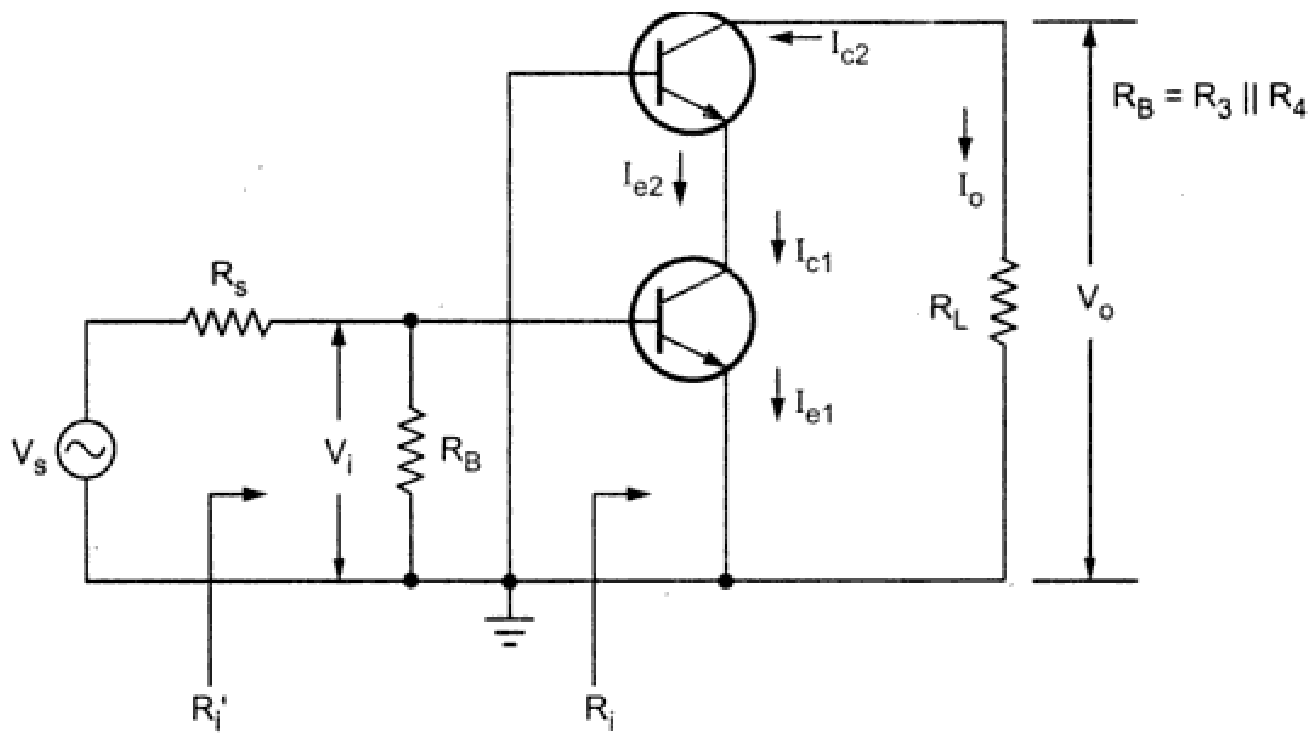
h-parameter equivalent circuit for CE-CE cascade amplifier



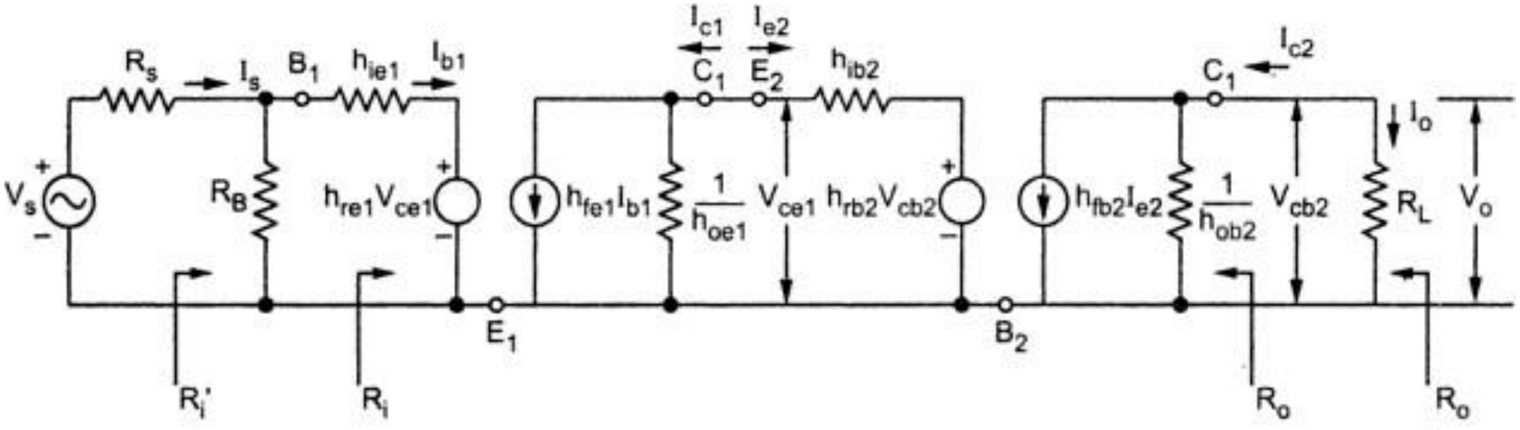
Cascode Amplifier



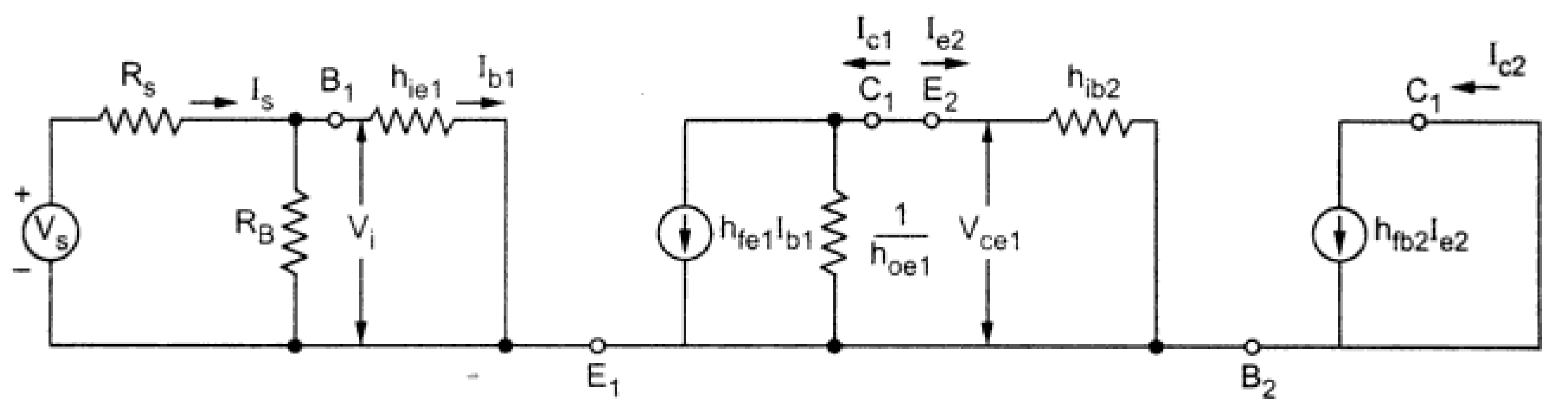
AC equivalent circuit



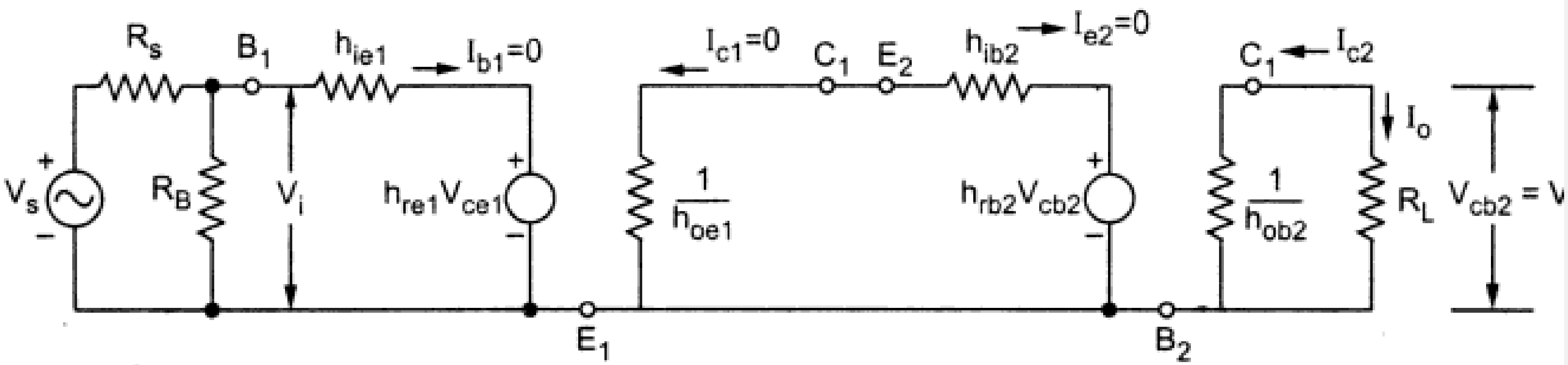
h-parameter equivalent circuit for cascode amplifier



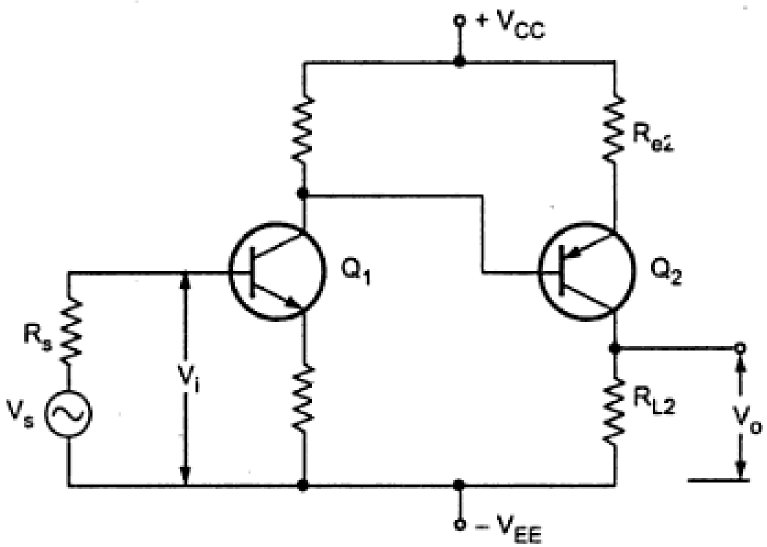
h-parameter equivalent circuit when output shorted



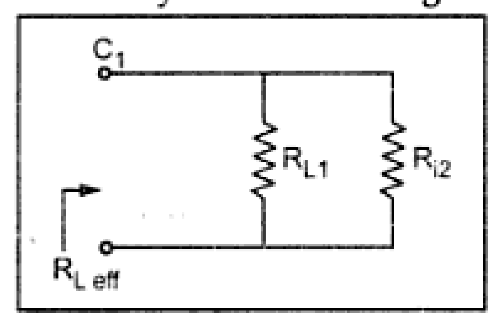
h-parameter equivalent circuit when $I_b = 0$



CE-CC Amplifier

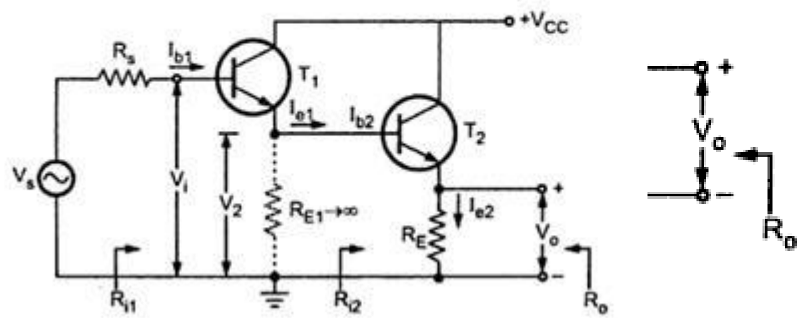


Analysis for first stage

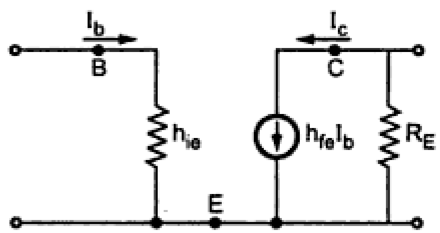


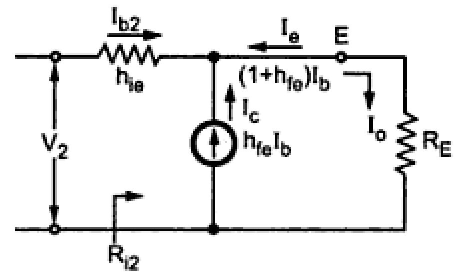
Darlington Transistors

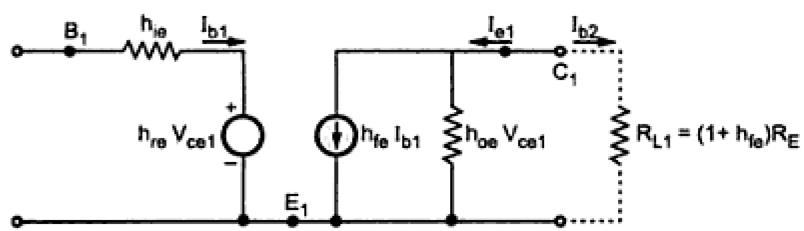
Darlington Transistors $+V_{CC}$

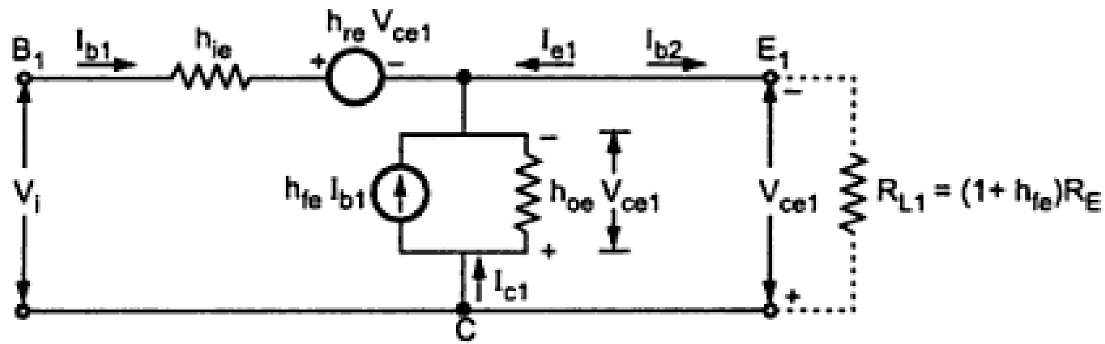


AC Equivalent Circuit :



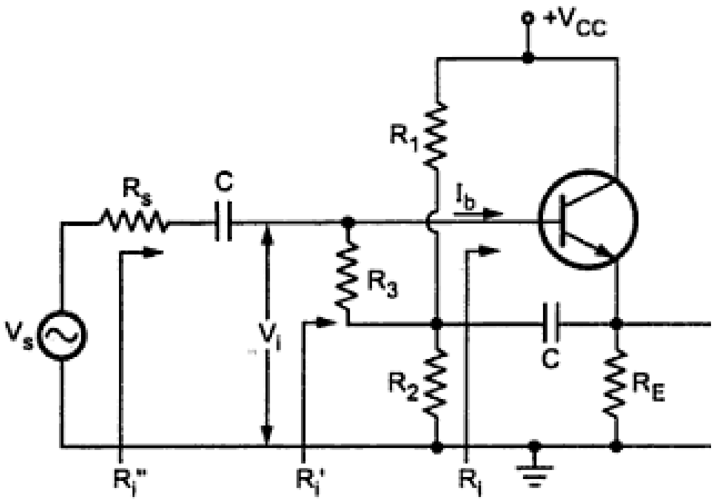


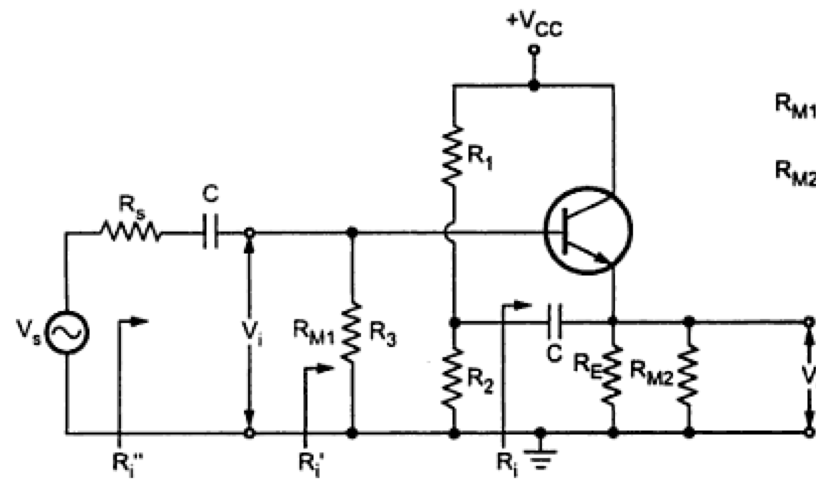




Parameter	Single stage	Darlington
Input Resistance	$R_i = (1 + h_{fe})\, R_E = 168.3\ \text{k}\,\Omega$	$R_i = \dfrac{(1+h_{fe})^2 R_E}{1+h_{oe}\,(1+h_{fe})\,R_E} \approx 1.65\ \text{M}\,\Omega$
Current Gain	$A_i = 1 + h_{fe} = 51$	$A_i = \dfrac{(1+h_{fe})^2}{1+h_{oe}\,(1+h_{fe})\,R_E} \approx 500$

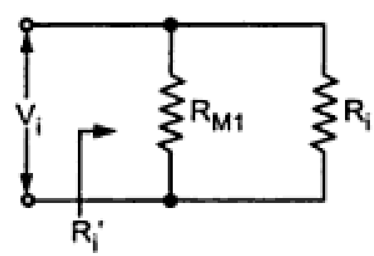
Bootstrap Emitter Follower

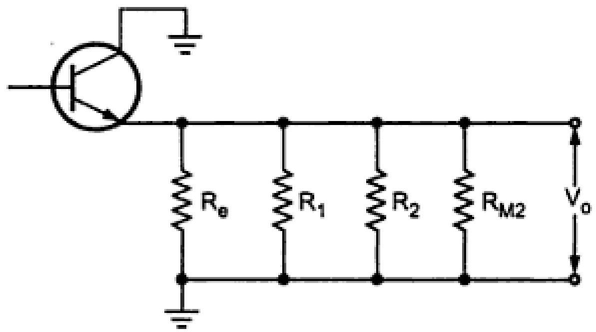




$$R_{M1} = \frac{R_3}{1 - A_v}$$

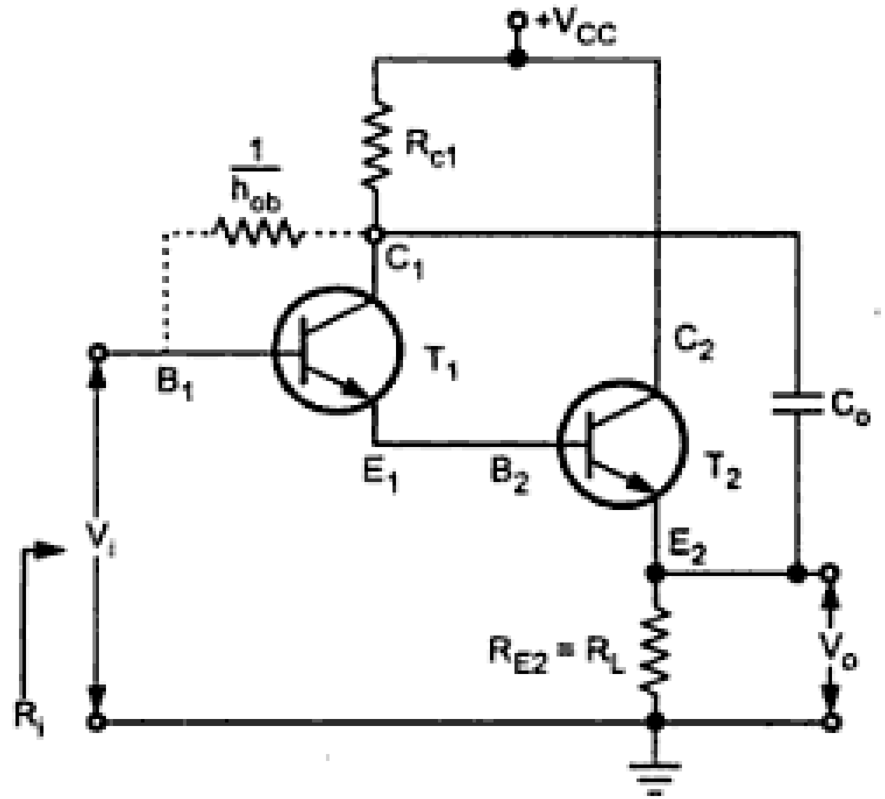
$$R_{M2} = \frac{R_3 A_v}{A_v - 1}$$



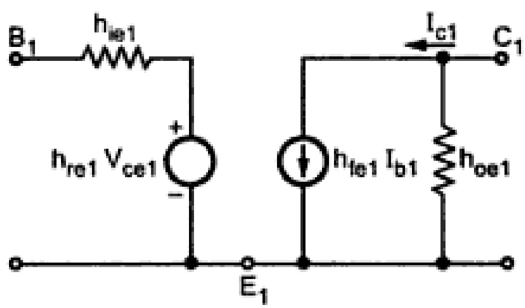


Re
R1
R2
RM2
Vo

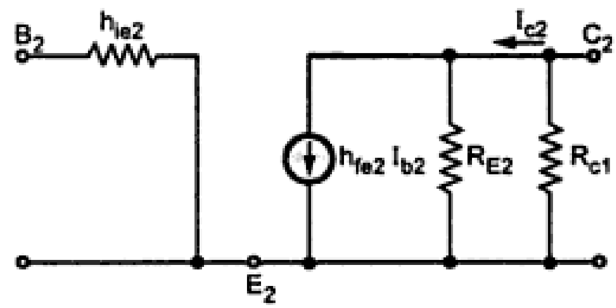
Bootstrapped Darlington circuit



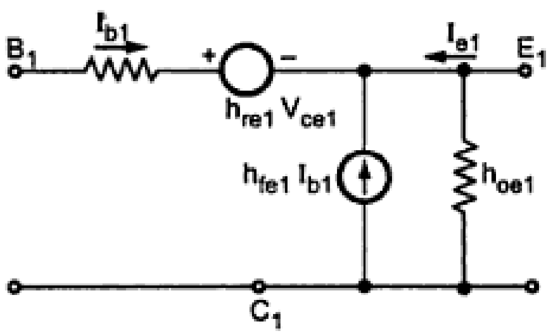
AC Equivalent circuit for bootstrapped Darlington circuit



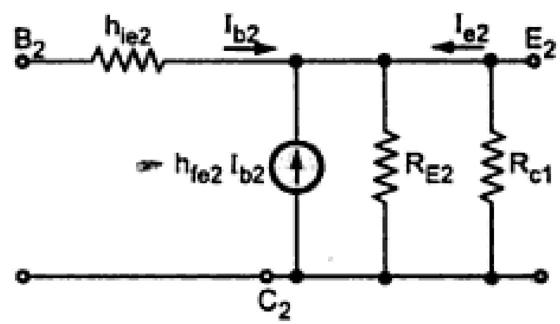
(a)



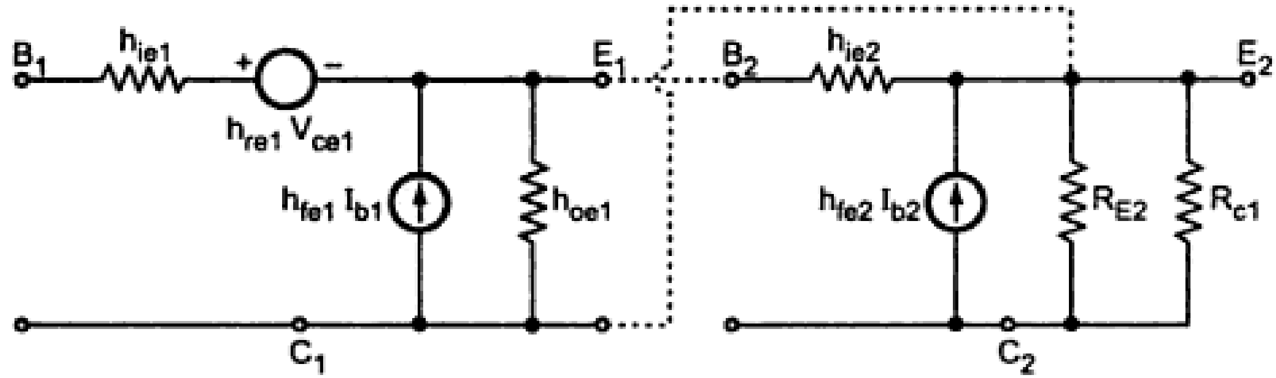
(b)

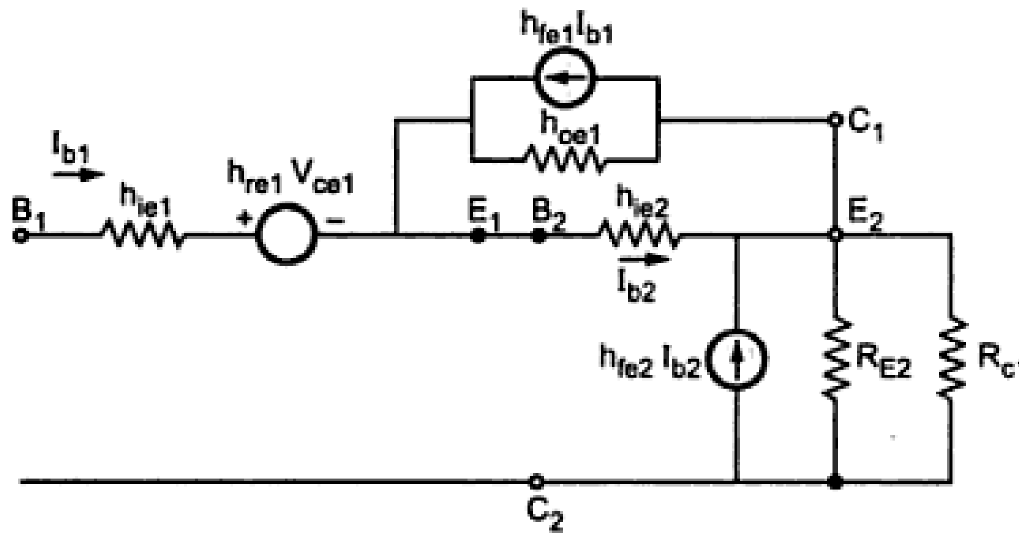


(c)

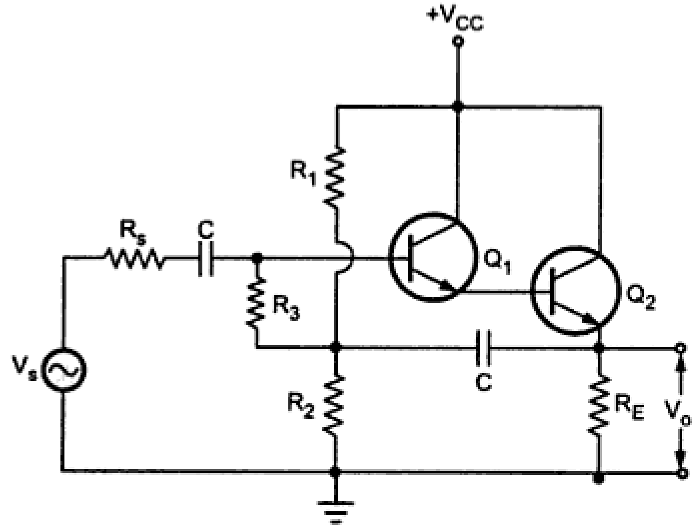


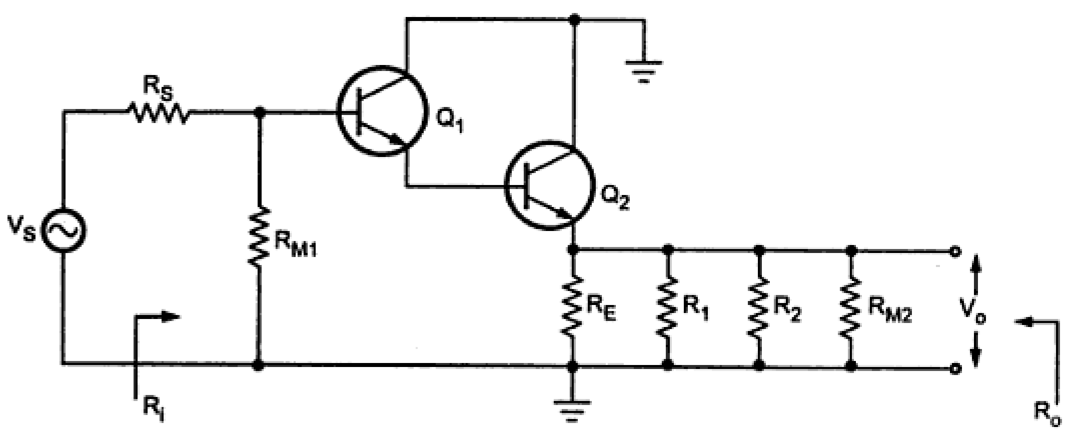
(d)


B1
hie1
+
−
hre1 Vce1
hfe1 Ib1
hoe1
E1
C1
B2
hie2
hfe2 Ib2
RE2
Rc1
E2
C2


hfe1Ib1
hoe1
C1
Ib1
B1
hie1
hre1 Vce1
+
−
E1
B2
hie2
Ib2
E2
hfe2 Ib2
RE2
Rc1
C2

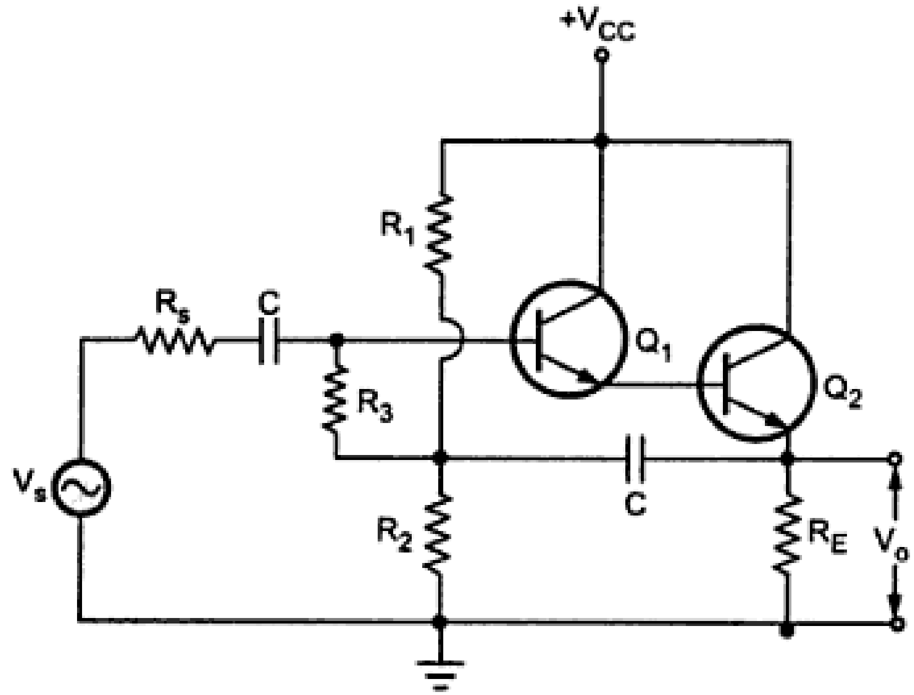
Bootstrapped Darlington Circuit Alternative Approach

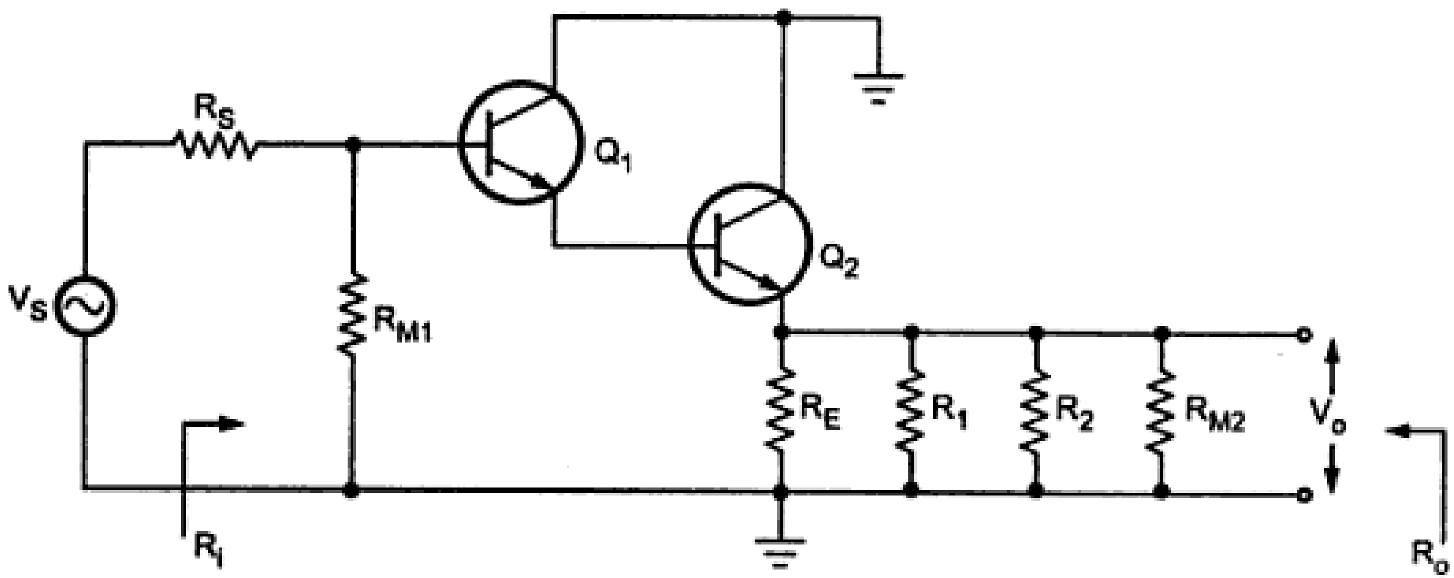




AC equivalent circuit

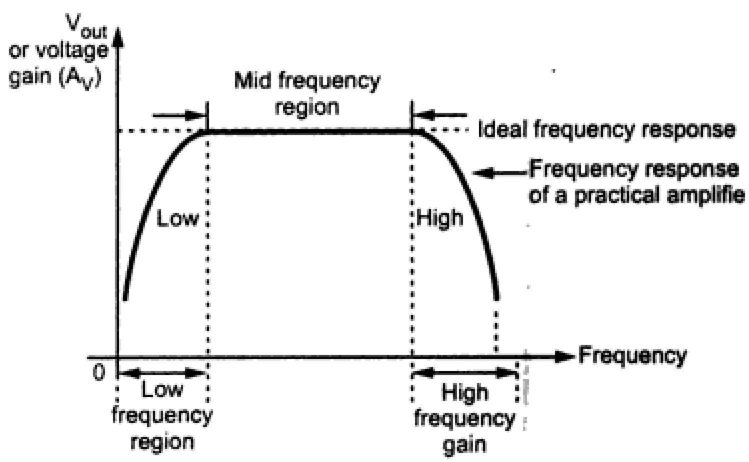
Bootstrapped Darlington Circuit Alternative Approach



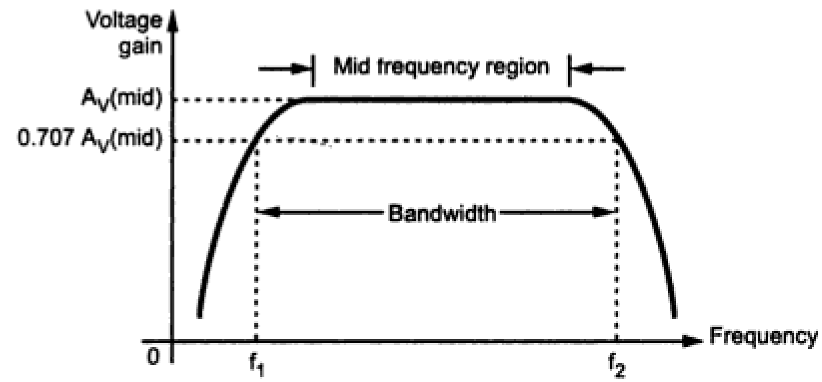


AC equivalent circuit

Frequency Response of an RC Coupled Amplifier

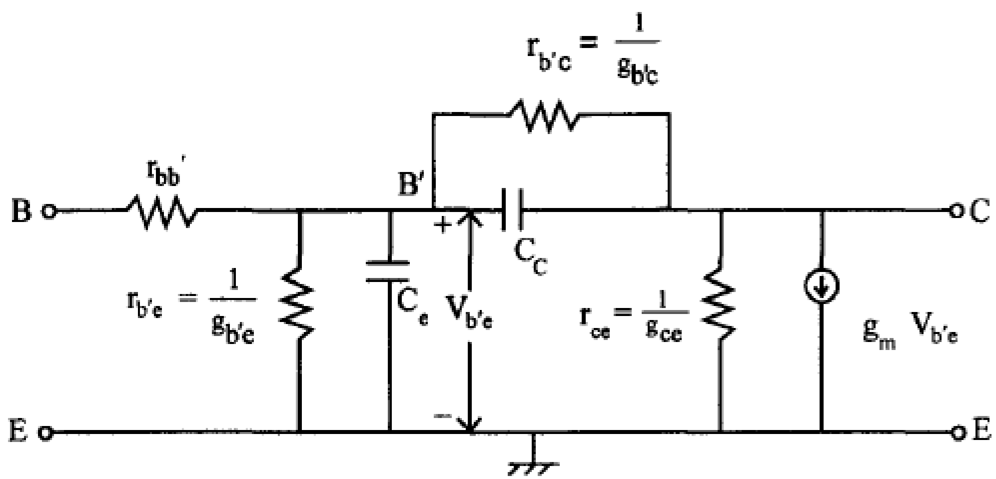


Bandwidth of an Amplifier



Frequency response, half power frequencies and bandwidth of an RC coupled amplifier

Hybrid – π Common Emitter Transc onductance Model



Hybrid - π C.E BJT Model