Chapter 5

Amplifiers

LEARNING OBJECTIVES

After reading this chapter, you will be able to understand:

- The re transistor model
- BJT AC analysis
- Emitter follower configuration
- Common base configuration
- 3 π – model
- The hybrid equivalent model
- Hybrid h – parameter model for common emitter
- Two port systems approach
- Frequency response analysis of amplifiers
- Miller's theorem
- Multi stage amplifiers
- RC coupled BJT amplifier
- Cascode connection
- Darlington connection
- Frequency response
- FET amplifier stages
- AC equivalent model of MOS FET
- AC equivalent Circuit
- Amplifier AC equivalent model

Introduction

The transistors can be employed as an amplifying device, i.e., the output AC power is greater than the input power. There is an exchange of DC power to AC domain, that power permits establishing a higher output AC power.

The superposition theorem is applicable for the analysis and design of the DC and AC components of a BJT network, permitting the separation of the analysis of the DC and AC responses of the system.

There are three models commonly used in the small signal AC analysis of transistor network

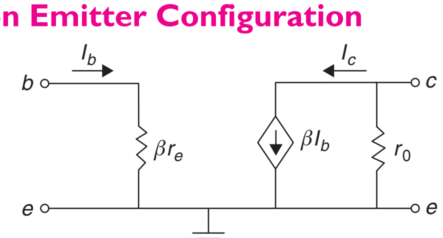
1. r_e model,
2. Hybrid π model
3. Hybrid equivalent model.

The AC equivalent of a network is obtained by

1. Setting all DC sources to zero, and replacing them by a short circuit equivalent.
2. Replacing all capacitors by a short circuit equivalent.
3. Removing all elements by passed by short circuit equivalents, introduced by steps 1 and 2.
4. Redrawing the network in more convenient and logical form.

The r_e Transistor Model

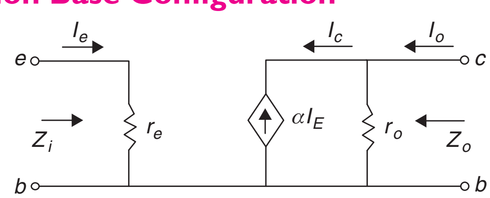
Common Emitter Configuration



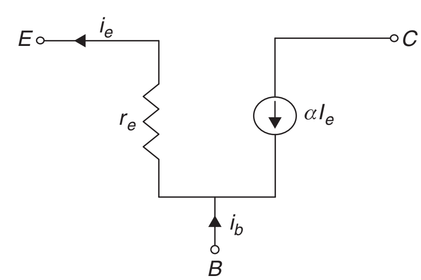
$$r_e = \frac{26\text{ mV}}{I_E},\ Z_{e=}(\beta+1)\ r_e \simeq \beta r_e$$

$$r_o = \frac{\Delta V_{CE}}{\Delta I_C}$$

Common Base Configuration



$$r_e = \frac{26\text{ mV}}{I_E}$$



For common collector configuration, the equivalent is same as common Emitter configuration.

For p-n-p transistor, the direction of currents are reversed

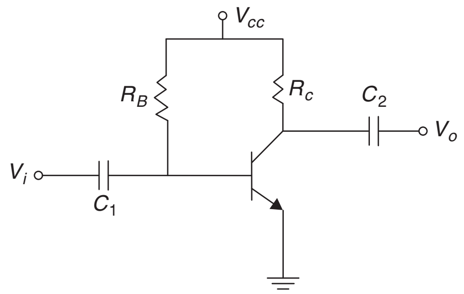
r_e = dynamic emitter resistance $= \dfrac{26\text{ mV}}{I_E}$

α = current gain of CB

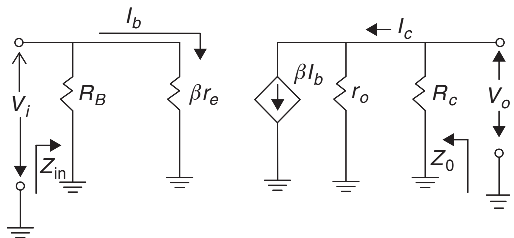
β = current gain of CE

BJT AC ANALYSIS

Common Emitter Fixed Bias Configuration



(1) Common Emitter fixed bias configuration.



$Z_i = R_B \parallel \beta r_e$ Ω input resistance

$Z_i \simeq \beta r_e$ if $R_B \geq 10\ \beta r_e$

Output impedance $Z_o = R_C \parallel r_o$

If $r_o \geq 10 R_c$ $Z_o \cong R_c$

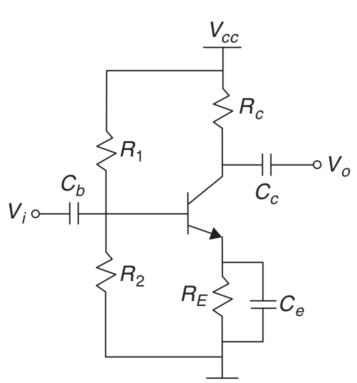
$$V_o = -\beta I_b (R_1 \parallel r_o),\ I_b = \frac{V_i}{\beta r_e}$$

$$\text{So}\quad V_o = -\beta\left(\frac{V_i}{\beta r_e}\right)(R_c \parallel r_o)$$

$$A_v = \frac{V_o}{V_i} = \frac{-(R_c \parallel r_o)}{r_e} = \frac{-R_c}{r_e};\ r_o \geq 10 R_c,\ A_i = \beta$$

The negative sign in the equation A_v, reveals that a 180° phase shift occurs between the input and output signals.

Voltage Divider Bias



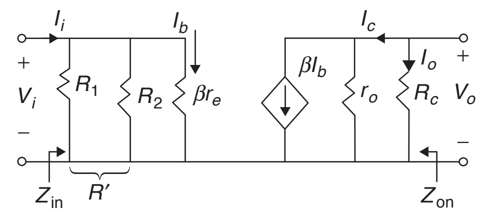


Figure 1 AC equivalent circuit

$$\text{Say}\ R' = \frac{R_1 R_2}{R_1 + R_2} = R_1 \parallel R_2$$

Z_i Input impedance $= R' \parallel \beta r_e$

Z_o Output impedance $= R_c \parallel r_o$

$$A_v = \frac{V_o}{V_1} = \frac{-R_c \parallel r_o}{r_e}$$

$$\text{if } r_o \geq 10\ R_c \text{ then } A_v = \frac{-R_c}{r_e}$$

Negative sign reveals a 180° phase shift between V_o and V_i.

Common Emitter, Emitter-bias Configuration

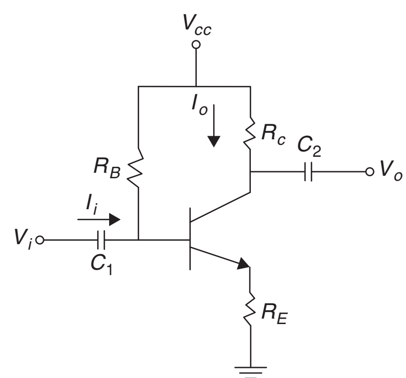


Figure 2 CE, emitter bias configuration

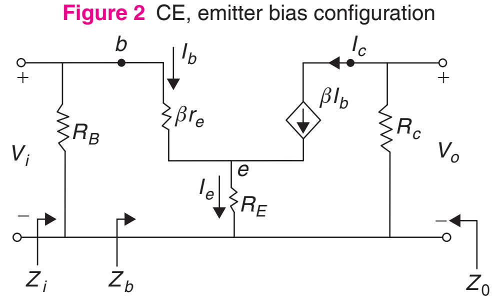


Figure 3 AC equivalent circuit

Applying Kirchhoff's voltage law to the input,

$V_i = I_B\ \beta r_e + I_e R_E = I_B \beta r_e + (\beta + 1)\ I_B R_E$

$$Z_b = \frac{V_i}{I_B} = \beta r_e + (\beta + 1) R_E$$

$\simeq \beta r_e + \beta R_E = \beta(r_e + R_E)$

$\simeq \beta R_E$ as $R_E >> r_e$

Z_i Input impedance $(Z_i) = Z_b \parallel R_B = Z_b \parallel R_B$
With V_i set to zero, $I_b = 0$, and βI_b can be replaced by an open circuit equivalent,
Out put impedance $Z_o = R_c$
Gain A_v,

$$I_b = \frac{V_i}{Z_b}$$

$$V_o = -I_o R_c = -\beta I_b R_c$$

$$= -\beta\left(\frac{V_i}{Z_b}\right)R_c$$

$$A_v = \frac{V_o}{V_i} = \frac{-\beta R_c}{Z_b}$$

$$Z_b = b(r_e + R_E) \text{ gives}$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_c}{r_e + R_E} \simeq \frac{-R_c}{R_E}$$

Effect of r_o

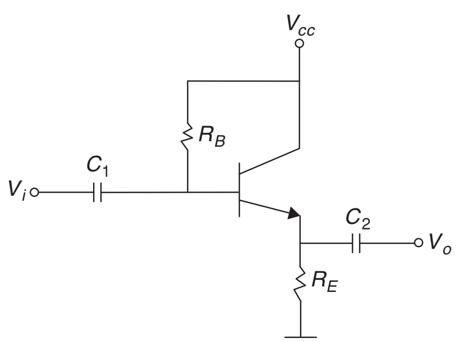
$Z_b = \beta r_e + (\beta + 1)R_E \simeq \beta(r_e + R_E)$

$r_o \geq 10(R_c + R_E)$

$Z_i = Z_b \parallel R_B$, $Z_o = R_c$, $A_v = \frac{\beta R_c}{Z_b}$ $\quad r_o \geq 10R_c$

If R_E is by passed by a capacitor, the AC circuit will be same as of fixed bias configuration.

Emitter Follower Configuration



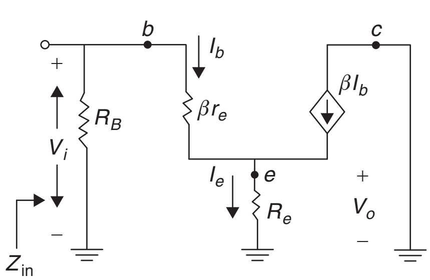


Figure 4 AC equivalent circuit

$Z_i = R_B \parallel Z_b$

$Z_b = \beta r_e + (\beta + 1)\, R_E$

$Z_b = \beta R_E \qquad (R_E >> r_e)$

$Z_o = R_E \parallel r_e$

$Z_o = r_e \quad (R_E >> r_e)$

$$A_v = \frac{V_o}{V_i} = \frac{R_E}{R_E + r_e} \simeq \frac{R_E}{R_E} = 1$$

V_o and V_i are in phase for Emitter-follower configuration.

Common Base Configuration

The common base configuration is characterized as having relatively low input and a high output impedance and a current gain less than 1. The voltage gain can be quite large.

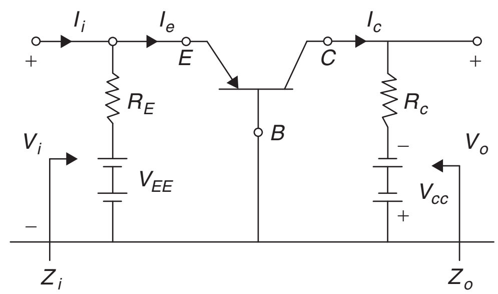
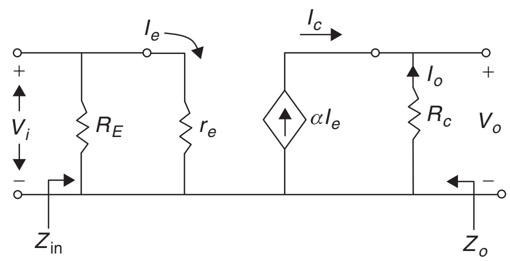


Figure 5 Common base configuration (p-n-p)



$$Z_i = R_E \parallel r_e$$

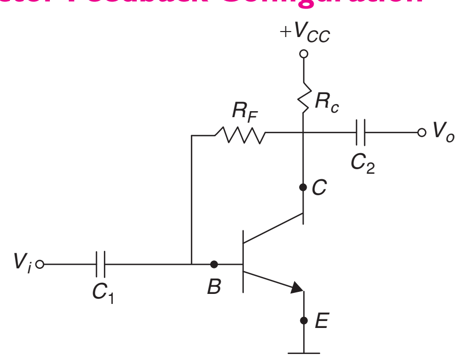
$$Z_o = R_c$$

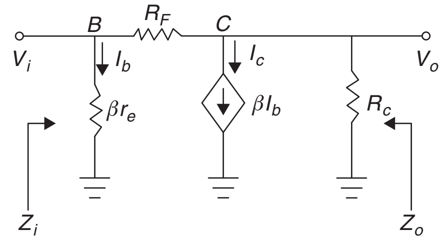
$$A_v = \frac{V_o}{V_i} = \frac{\alpha R_c}{r_e} \simeq \frac{R_c}{r_e}$$

$$A_i = \frac{I_o}{I_i} = -\alpha \simeq -1$$

The fact that A_v is a positive number shows that V_o and V_i are in phase for the common base configuration.

Collector Feedback Configuration





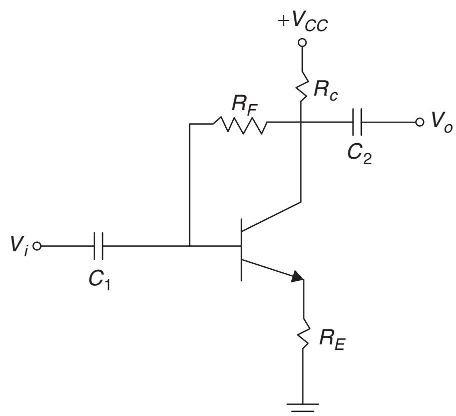
Substituting r_e equivalent circuit into the AC network,

$$Z_i = \frac{r_e}{\frac{1}{\beta} + \frac{R_c}{R_F}}$$

$$Z_o = R_c \parallel R_F$$

$$A_v = \frac{V_o}{V_i} = \frac{-R_c}{r_e}, \; A_i = \frac{R_F}{R_c}$$

The negative sign in A_v equation shows 180° phase shift between input V_i and out put V_o.



Collector feedback with R_E

$$Z_i = \frac{R_E}{\left[\frac{1}{\beta} + \frac{R_E + R_c}{R_F}\right]}$$

$$Z_o = R_c \parallel R_F$$

$$A_v = \frac{-R_c}{R_E}$$

Determining the Current Gain

$$A_{iL} = -A_{vL}\frac{Z_i}{R_L}$$

Effect of R_L and R_S

The loaded voltage gain of an amplifier is always less than the no-load gain.

The gain obtained with a source resistance in place will always be less than that obtained under loaded or unloaded conditions.

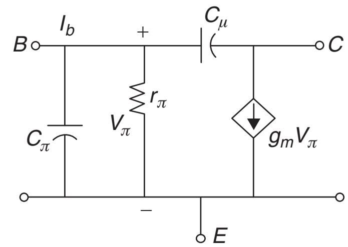
For the same configuration

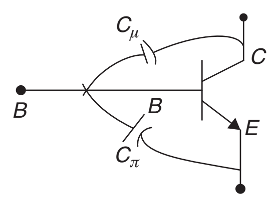
$$A_{v\,\text{no load}} > A_{v\,\text{load}} > A_{v\,\text{load and source}}$$

for a particular design, the larger the level of R_L the greater is the level of AC gain.

For a particular amplifier, the smaller the internal resistance of the signal source, the greater is the overall gain.

π–Model





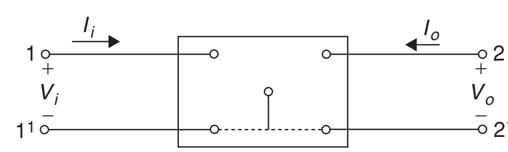
C_π = Forward biased diffusion capacitance

C_μ = Reverse biased diffusion capacitance

$r_\pi = \beta r_e$

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

The Hybrid Equivalent Model



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

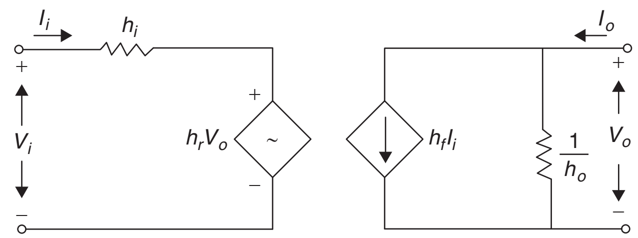
$I_o = h_{21}I_i + h_{22}V_o$

h_{11} – input resistance – $h_i = \left.\frac{V_i}{I_i}\right|_{V_o = 0}$ ohm

h_{12} – reverse transfer voltage ratio – $h_r = \left.\frac{V_i}{I_i}\right|_{V_0 = 0}$

h_{21} – forward transfer current ratio – $h_f = \left.\frac{I_o}{I_i}\right|_{V_0 = 0}$

h_{22} – output conductance – $h_o = \left.\frac{I_o}{V_o}\right|_{I_i = 0}$ Siemens



For common emitter circuit $h_{ie} = \beta r_e$, $h_{fe} = \beta_{ac}$

For common base circuit $h_{ib} = r_e$, $h_{fb} = -\alpha \sim -1$

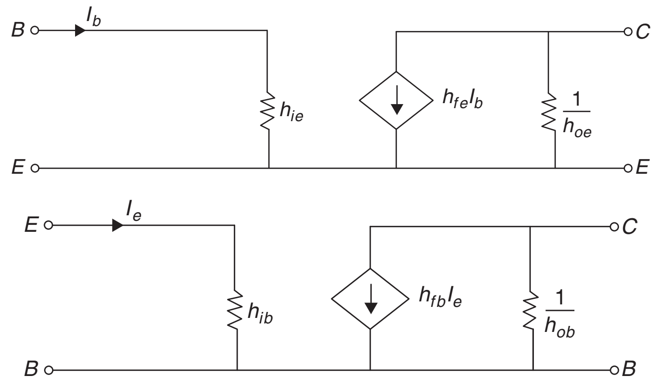
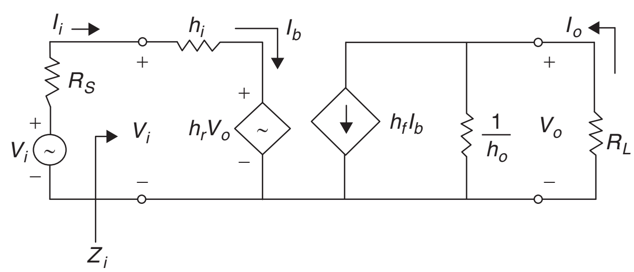


Figure 6 Approximate common base hybrid equivalent circuit

H–parameter Model with R_S and R_L

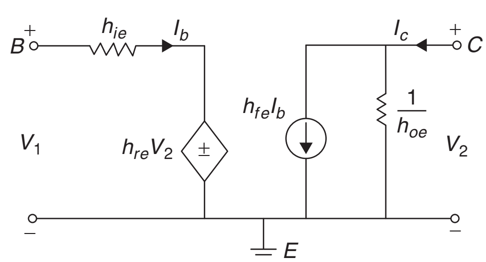


Current gain $A_i = \dfrac{I_o}{I_i} = \dfrac{h_f}{1+h_oR_L}$

Voltage gain $A_v = \dfrac{V_o}{V_i} = \dfrac{-h_fR_L}{h_i+(h_ih_o-h_fh_r)R_L}$

$$Z_i = h_i - \frac{h_fh_rR_L}{1+h_oR_L},\ Z_o = \frac{1}{h_o-[h_fh_r/(h_i+R_S)]}$$

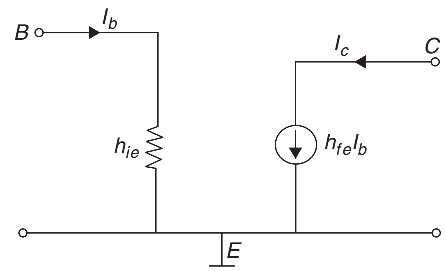
Hybrid H–parameter Model for Common Emitter



Typical values of h-parameters for CE configuration:

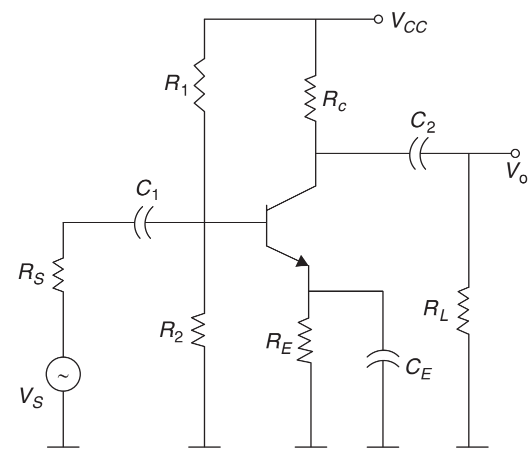
$$h_{ie} = 3.5\text{ k}\Omega$$
$$h_{re} = 1.3 \times 10^{-4}$$
$$h_{fe} = 120$$
$$h_{oe} = 8.5\ \mu\text{S}$$
$$\Rightarrow \frac{1}{h_{0e}} = 0.12\text{ m}\Omega$$

Simplified 'h' parameters model: (CE n-p-n configuration)



For p-n-p transistor, the direction of current is reversed in the equivalent circuit.

RC Coupled CE Amplifier



Small signal analysis using simplified h-parameter model

1. Make all the DC sources to zero.
2. Replace the coupling capacitors with short.

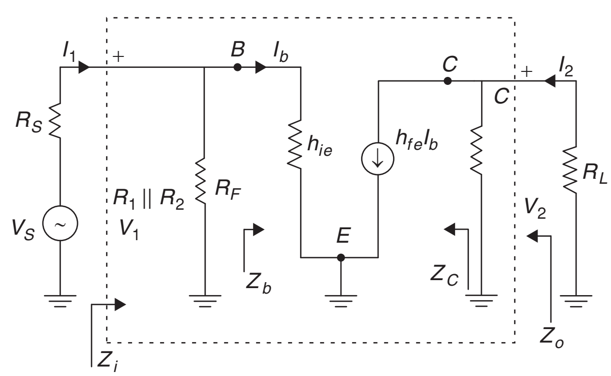
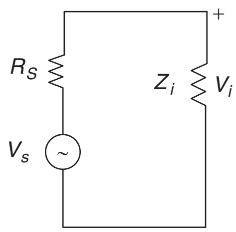
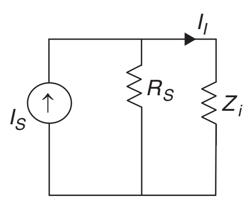


Table 1 *Equivalent circuit without considering R_E*

Without R_E	Considering R_E
$Z_b = h_{ie}$	$Z_b = h_{ie} + (1 + h_{fe}) R_E$
$Z_i = h_{ie} \| R_1 \| R_2$	$Z_i = Z_b \| R_1 \| R_2$
$Z_C = \dfrac{1}{h_{oe}}$	$Z_C = \dfrac{1}{h_{oe}}$
$Z_0 = \left(\dfrac{1}{h_{oe}}\right)$	$Z_0 = \left(\dfrac{1}{h_{oe}}\right) \| R_c \| R_L$
$A_v = \dfrac{-h_{fe}R_C}{h_{ie}}$	$A_v = \dfrac{(R_C \| R_2)}{r_e}$

Voltage and current gain by taking source into consideration:



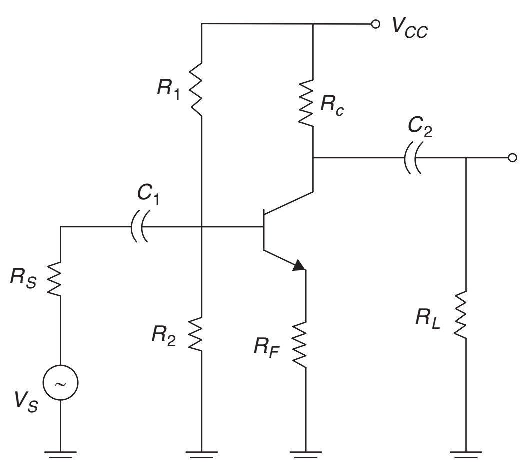


$$A_{VS} = \frac{V_0}{V_S} = \frac{V_0}{V_1} \times \frac{V_1}{V_S} \qquad A_{IS} = \frac{I_0}{I_S} = \frac{I_0}{I_1} \times \frac{I_1}{I_S}$$

$$A_{VS} = \frac{A_V Z_i}{R_S + Z_i} \qquad A_{IS} = \frac{A_I R_S}{R_S + Z_i}$$

Example 1: Determine A_V, A_I, A_{VS}, A_{IS}, Z_i, Z_o for the following amplifier circuit

$C_1 = 10\ \mu F$	$R_1 = 40\ k\Omega$	$R_L = 2.2\ k\Omega$
$C_E = 20\ \mu F$	$R_2 = 10 k\Omega$	$\beta = 100$
$C_C = 1\ \mu F$	$R_E = 2\ k\Omega$	$C_{CC} = 20$ V
$R_2 = 1\ k\Omega$	$R_C = 4\ k\Omega$	



Solution:

(i) $A_V = \dfrac{-(R_C \| R_L)}{r_e}$

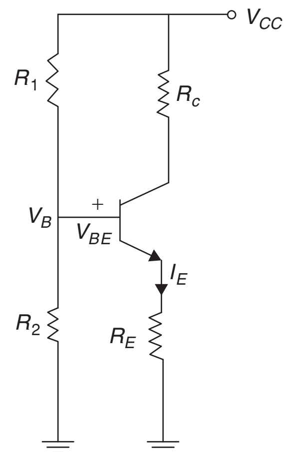
Determining 'r_e':

$$r_e = \frac{26\ \text{mV}}{I_E}$$

So DC equivalent circuit is needed to calculate I_E.

DC Equivalent Circuit

1. Make AC sources short.
2. Replace coupling capacitors with open.



Apply KVL at input side gives

$$V_B - V_{BE} - I_E R_E = 0$$

$$I_E = \frac{V_B - V_{BE}}{R_E}$$

$$V_B = \frac{4 - 0.7}{2\ k\Omega} = 1.65\ \text{mA}$$

$$\therefore \quad r_e = \frac{26\ \text{mv}}{I_E} = 15.76\ \text{ohms}$$

$$\therefore \quad A_V = -\frac{(R_C \| R_L)}{r_e} = -90$$

3. $A_I = \beta = 100$
4. $A_{VS} = \dfrac{A_V \cdot Z_i}{R_S + Z_i}$

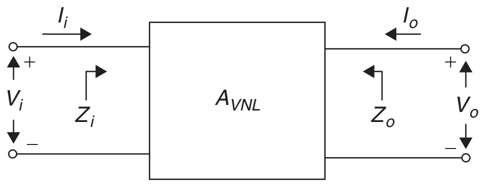
   $Z_i = Z_b \| R_1 \| R_2$
   $Z_b = h_{ie} = \beta r_e = 15.76\ k\Omega$
   $Z_i = 1.32\ k\Omega$

   $$A_{VS} = \frac{-90(1.32\ k\Omega)}{(2.32\ k\Omega)} = -51.21$$

5. $A_{IS} = \dfrac{A_I \cdot R_S}{R_S + Z_i} = \dfrac{100 \times 1\ k\Omega}{2.32\ k\Omega}$

   $A_{IS} = 43.103$
6. $Z_0 \times R_C = 4\ k\Omega$

Two Port Systems Approach

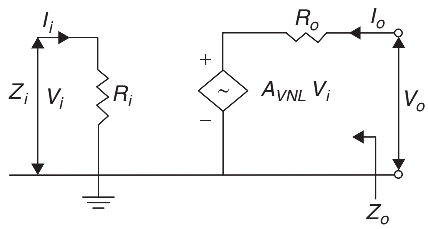


If we take a Thevenin look at the output terminals we find V_i, set to zero.

$$Z_{\text{th}} = Z_o = R_o$$

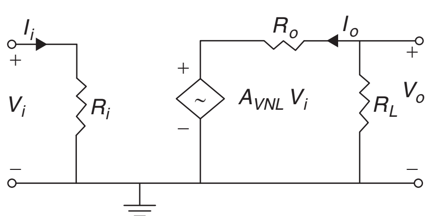
E_{th} is the open circuit voltage between the output terminals identified as V_o.

$$A_{VNL} = \frac{V_o}{V_i}, V_o = A_{VNL}V_i = E_{\text{th}}$$



Substituting the internal elements for 2 port network.

Applying a Load to the Two Port Network System

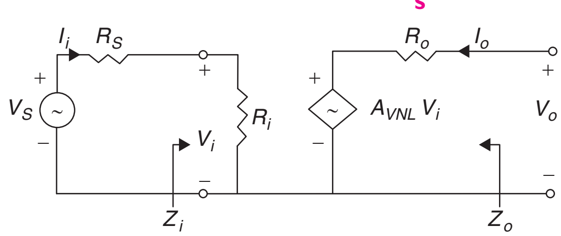


$$V_o = \frac{R_L}{R_L + R_o} \cdot A_{VNL} \cdot V_i$$

$$A_{VL} = \frac{V_o}{V_i} = \frac{R_L}{R_L + R_o} \cdot A_{VNL}$$

$$A_{iL} = -A_{VL} \cdot \frac{Z_i}{R_L}$$

Effects of Source Resistance R_S



The parameters Z_i and A_{VNL} of a two port system are unaffected by the internal resistance of the applied source, the output impedance may be affected by the magnitude of R_S.

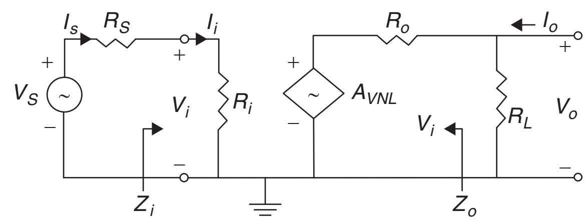
$$V_i = \frac{R_i}{R_i + R_S} \cdot V_S$$

$$V_o = A_{VNL} \cdot V_i$$

$$= A_{VNL} \frac{R_i}{R_i + R_s} \cdot V_S$$

$$A_{VS} = \frac{V_o}{V_S} = \frac{R_i}{R_i + R_S} \cdot A_{VNL}$$

The Effects of R_s and R_L



$$V_i = \frac{R_i}{R_i + R_S} \cdot V_S, \; V_o = \frac{R_L}{R_L + R_o} \cdot A_{VNL} \cdot V_i$$

$$A_{VL} = \frac{V_o}{V_i} = \frac{R_L \cdot A_{VNL}}{R_L + R_o}$$

$$A_{VS} = \frac{V_o}{V_S} = \frac{V_o}{V_i} \cdot \frac{V_i}{V_S} = \frac{R_i}{R_i + R_S} \cdot \frac{R_L}{R_L + R_o} \cdot A_{VNL}$$

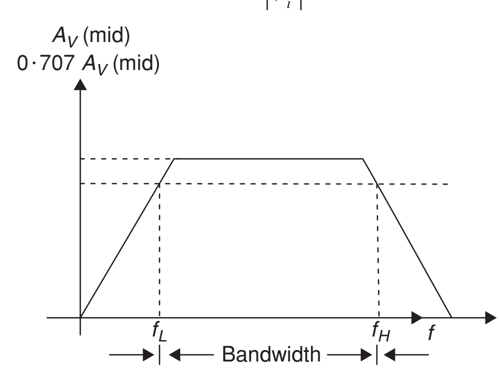
$$A_{iL} = -A_{VL} \cdot \frac{R_i}{R_L} \text{ as } I_i = \frac{V_i}{R_i}$$

$$I_S = \frac{V_S}{R_S + R_i}$$

$$A_{iS} = -A_{VS} \frac{R_S + R_i}{R_L}$$

Frequency Response Analysis of Amplifiers

$$|A_v| = \left|\frac{V_0}{V_i}\right|$$

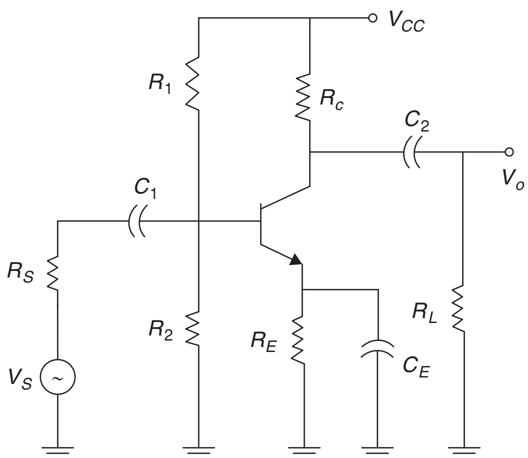


Frequency Rrange	Coupling and by Pass Capacitor	Parasitic Capacitance
low	Consider	Open
mid	Short	Open
high	Short	Consider

$A_{V(\text{mid})}$ = mid band gain of the amplifier

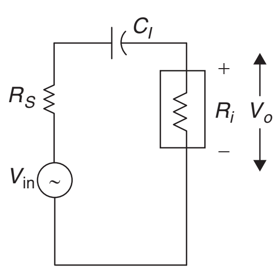
Bandwidth $= f_H - f_L$

Low Frequency Response of an RC Coupled CE Amplifier

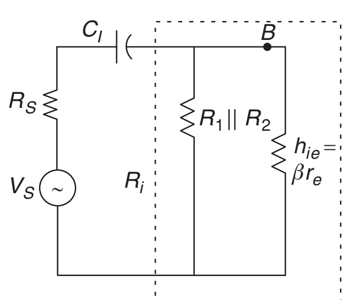


Low frequency Response depends on C_1, C_2, and C_E

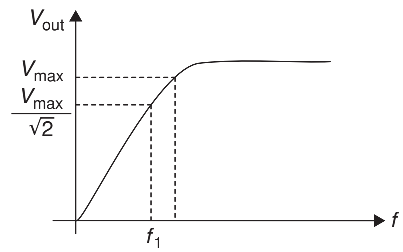
Due to C_I



AC equivalent network



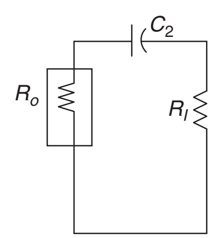
Frequency response due to C_I

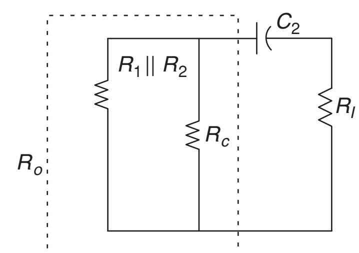


$$f_1 = \frac{1}{2\pi(R_S + R_i)C_1}$$

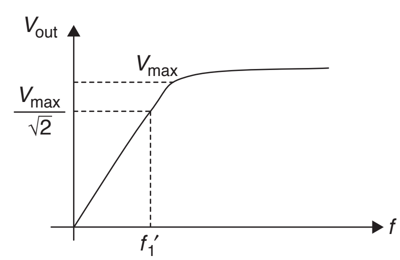
Where $R_i = R_1 || R_2 || \beta r_e$

Due to C_2





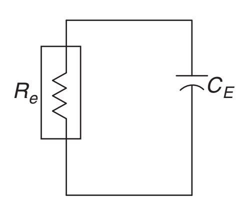
Frequency response due to C_2



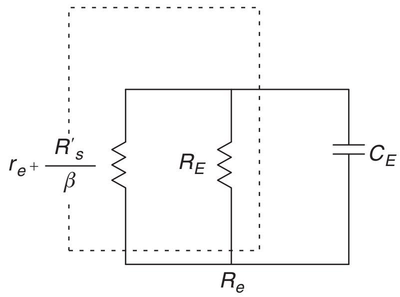
$$f_1' = \frac{1}{2\pi(R_S + R_i)C_2}$$

Where $R_0 = r_0 \alpha R_C$

Due to C_E



AC equivalent network

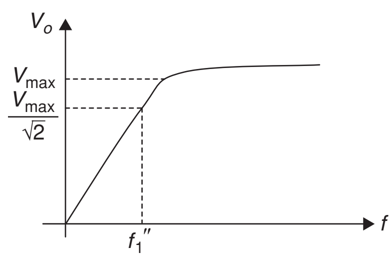


$$f_1'' = \frac{1}{2\pi R_e C_E}$$

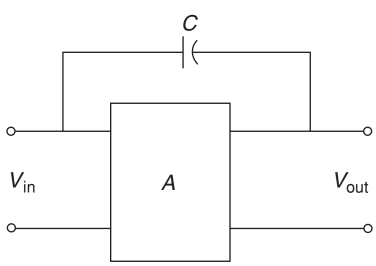
Where $R_e = R_E \,||\left(r_e + \frac{R'S}{\beta}\right)$,

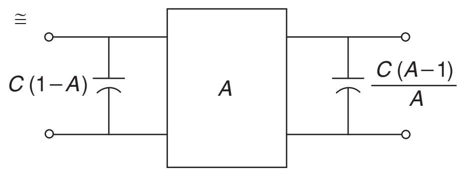
$R_S' = R_S \,||\, R_1 \,||R_2$

Frequency response



Miller's theorem





C_{iw}, C_{ow} = Wiring (stray) capacitance

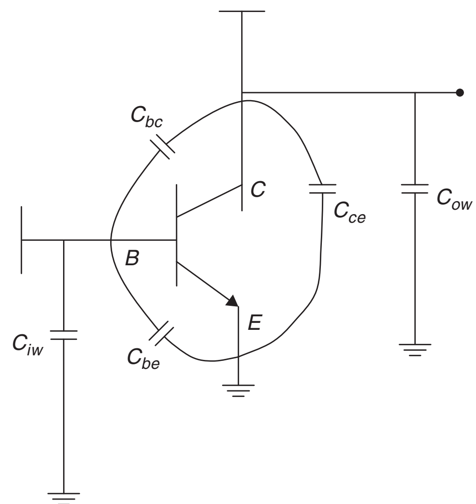
C_{bc} = miller capacitance

C_{be}, C_{ce} = junction capacitance/parasitic capacitance

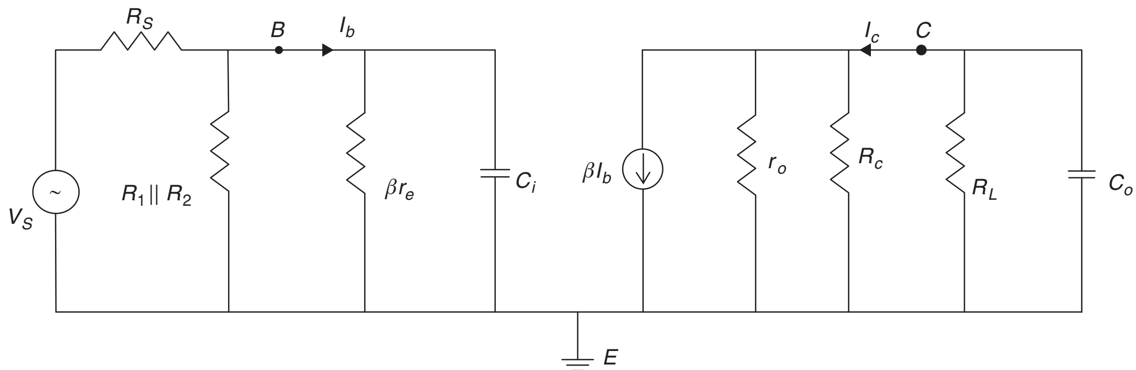
C_{in} (miller) = $C(1 - A)$

$$C_{out}\,(\text{miller}) = \frac{C(A-1)}{A}$$

High Frequency Response of an RC Coupled CE Amplifier

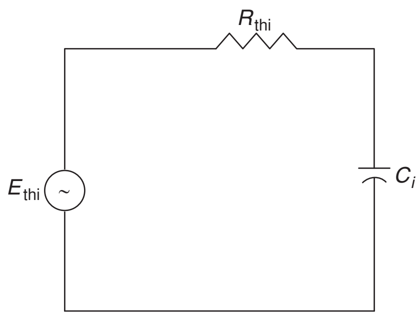


AC equivalent network



Thevenin's circuit

Input side

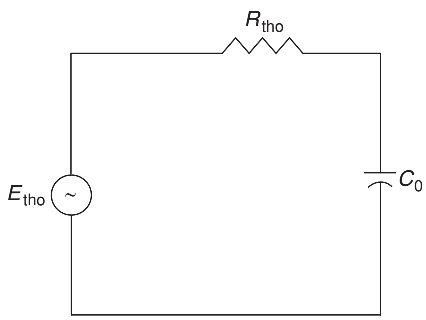


$$f_i = \frac{1}{2\pi R_{thi} C_i}$$

$R_{thi} = R_S \parallel R_1 \parallel R_2 \parallel \beta r_e$

$C_i = C_{wirei} + C_{be} + (1 - A)\ C_{bc}$

Output side

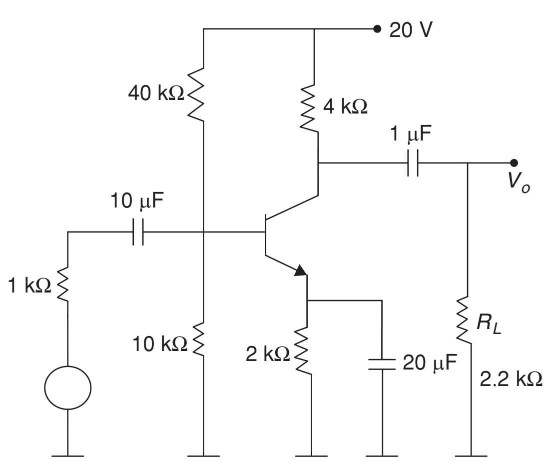


$$F_0 = \frac{1}{2\pi R_{tho} C_0}$$

$$R_{tho} = r_0 \parallel R_C \parallel R_L$$

$$C_0 = C_{wireo} + C_{ce} + C_{bc} \frac{(A-1)}{A}$$

Example 2: Determine the lower cut off frequency for the circuit given $\beta = 100$, $r_0 = \infty$ ohms



(A) 6.86 Hz (B) 25.68 Hz
(C) 327 Hz (D) 350 Hz

Solution: (C)

Determining 'r_e'

$$r_e = \frac{26 \text{ mv}}{I_E}$$

$R_e = 15.76$ ohms (refer GE04557)

$\beta r_e = 1.576$ kΩ

$$\text{Mid band gain } A_V = \frac{-(R_C \parallel R_L)}{r_e}$$

$$A_V = -90$$

$$R_i = R_1 \parallel R_2 \parallel \beta r_e = 1.32 \text{ k}\Omega$$

$$R_s' = R_s \parallel R_1 \parallel R_2 = 0.889 \text{ k}\Omega$$

$$R_e = R_E \parallel \left(\frac{Rs'}{\beta} + r_e\right) = 24.35\ \Omega$$

$$f_1 = \frac{1}{2\pi(R_S + R_i)C_1} = 6.86 \text{ Hz}$$

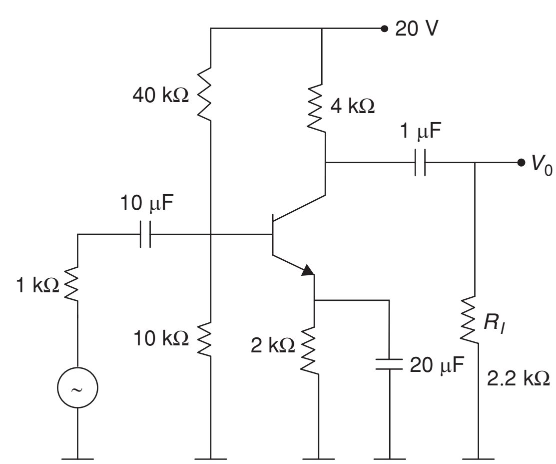
$$f_1' = \frac{1}{2\pi(R_C + R_L)C_2} = 25.86 \text{ Hz}$$

$$f_1^{\alpha} = \frac{1}{2\pi R_E C_E} = 327 \text{ Hz}$$

∴ Dominant lower cut-off frequency
= 327 Hz (highest).

Example 3: Determine the higher cut off frequency for the given circuit given $\beta = 100$, $r_0 = \infty$ ohms, $V_{cc} = 20$ V, $C_{be} = 36$ pF, $C_{bc} = 4$ pF

$$C_{ce} = 1 \text{ pF}, C_{wi} = 6 \text{ pF}, C_{wo} = 8 \text{ pF}$$



(A) 738.24 kHz (B) 8.6 MHZ
(C) 10 MHZ (D) 800 kHz

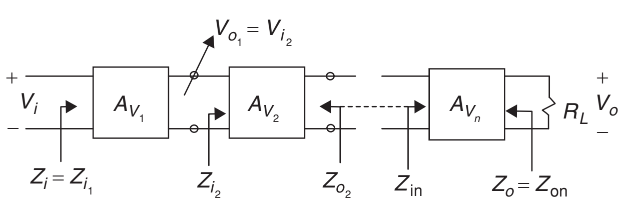
Solution: (A)

$$R_{\text{thi}} = R_s \,||\, R_1 \,||R_2 \,||\, \beta r_e$$
$$r_e = 1.32 \text{ k}\Omega$$
$$R_{\text{thi}} = 0.531 \text{ k}\Omega$$
$$C_i = C_{\text{wirei}} + C_{be} + (1 - A)\, C_{bc}$$
$$A = -90 \text{ (refer GE04557)}$$
$$C_i = 406 \text{ pF}$$
$$R_{\text{tho}} = R_c \,||\, R_L = 1.419 \text{ k}\Omega$$
$$C_0 = C_{wo} + C_{ce} + C_{bc}\frac{(A-1)}{A} = 13.04 \text{ pF}$$
$$f_i = \frac{1}{2\pi R_{\text{thi}} RC_i} = 738.24 \text{ kHz}$$
$$f_0 = \frac{1}{2\pi R_{\text{tho}} RC_0} = 8.6 \text{ MHZ}$$

∴ Higher cut-off frequency is 738.24 kHz (lowest).

Multi Stage Amplifiers

Cascaded Systems



The two port systems approach is partially useful for cascaded systems such as that appearing in fig. where Av_1, Av_2, …, Av_n are voltage gains of each stage, under loaded conditions, that is Av_1 is determined with the input impedance to Av_2 acting as load on Av_1.

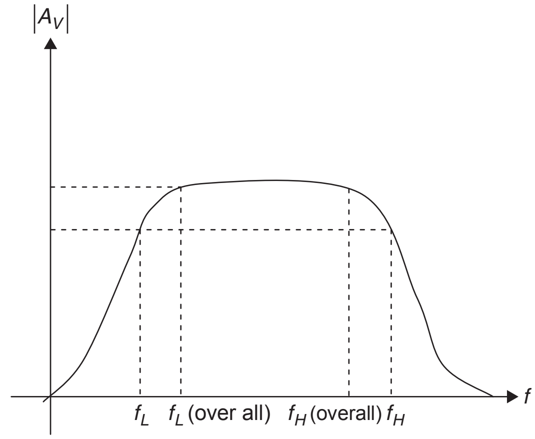
The total gain of the system is product of individual gains.

$Av = Av_1 \,.\, Av_2 \,.\, Av_3, \ldots, Av_n$ and total current gain is $A_i = -Av\dfrac{Z_i}{R_L}$

Effect of cascading on frequency response:

1. Gain is multiplied.
2. Bandwidth is reduced.

If n' amplifiers having lower cutoff frequency of f_L and highest cut-off frequency of f_H, then the frequency response is given below



$$f_l\text{(overall)} = \frac{f_L}{\sqrt{2^{\frac{1}{n}} - 1}}$$

$$f_h\text{(overall)} = f_H\sqrt{2^{\frac{1}{n}} - 1}$$

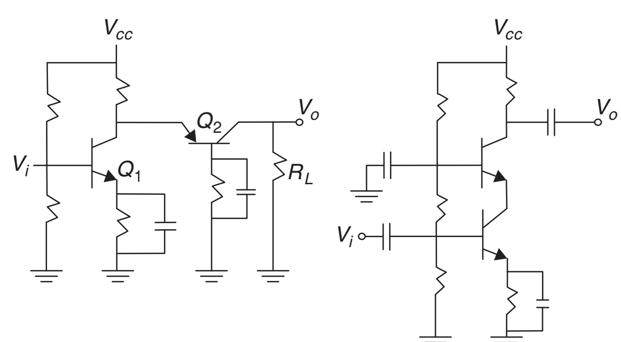
Where f_L and f_H are the lower and higher cut off frequencies of the individual amplifier stages.

RC coupled BJT amplifier

The name is derived from the Capacitive coupling (Capacitor (C_C)) and the fact that the load on first stage is on RC combination. The Coupling capacitor isolates the two stages from a DC point of view, but acts as short circuit equivalent for the AC response. The input impedance of second stage acts as load for the first stage.

Cascode connection (CE–CB)

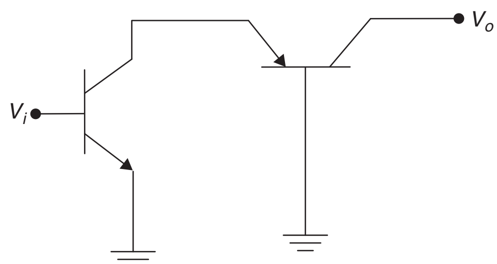
If the collector of the loading transistor is connected to the emitter of the following transistor, it is called as cascode connection. The possible configurations are



Advantages:

1. Larger output impedance
2. Wider band width

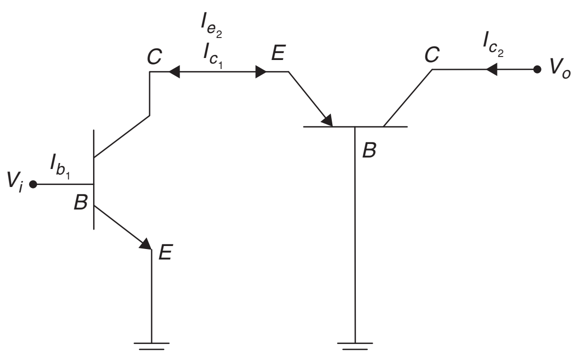
Example 4: For the connection shown below, find the overall transconductance of the circuit. Given g_{m_1}, is the transconductance of CE amplifier and g_{m_2} is the transconductance of CB-amplifier



(A) g_{m_2} (2) $g_{m_1} \parallel g_{m_2}$

(C) g_{m_1} (D) $g_{m_1} + g_{m_2}$

Solution: (C)

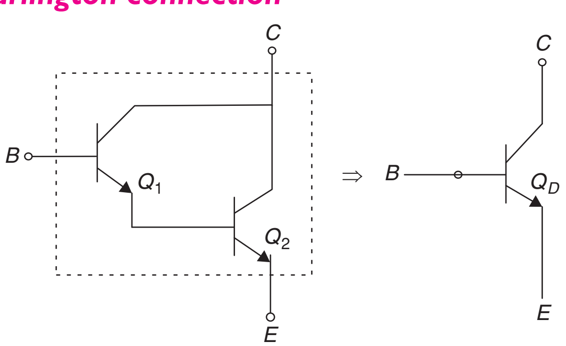


$$\text{Overall transconductance} = \frac{I_{c_2}}{V_i}$$

$$I_{C_2} = I_{e_2} = I_{C_1}$$

$$\therefore \quad g_m(\text{overall}) = \frac{I_{c_1}}{V_i} = g_{m_1}.$$

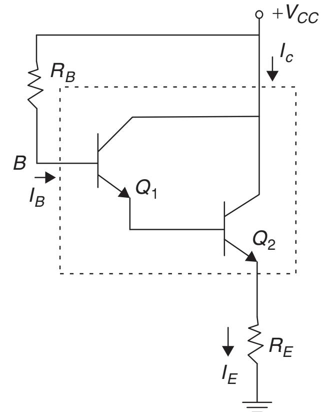
Darlington connection



The main feature of the Darlington connection is that the composite transistor acts as a single unit with a current gain that is product of the current gains of the individual transistors.

$$\beta_D = \beta_1 \cdot \beta_2$$

A darling ton transistor connection provides a transistor having a very large current gain typically a few thousand, and high input resistance



DC bias

$$I_B = \frac{V_{CC} - V_{BE}}{R_B + \beta_D R_E}$$

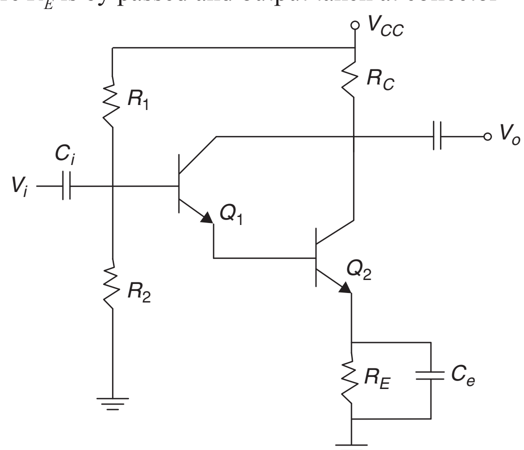
$$I_E = (\beta_D + 1)\, I_B$$

AC Analysis

$$Z_i = R_B \parallel \beta_1 \beta_2 R_E, \quad A_i = \frac{\beta_D R_E}{R_B + \beta_D R_E}$$

$$A_v \cong 1,\ Z_o = \frac{r_{e_1}}{\beta_2} + r_{e_2}$$

Where R_E is by passed and output taken at collector



$$Z_i = R_1 \parallel R_2 \parallel \beta_1 (r_{e_1} + \beta_D r_{e_2})$$

$$A_i = \frac{\beta_D (R_1 \parallel R_2)}{R_1 \parallel R_2 + Z_i'}$$

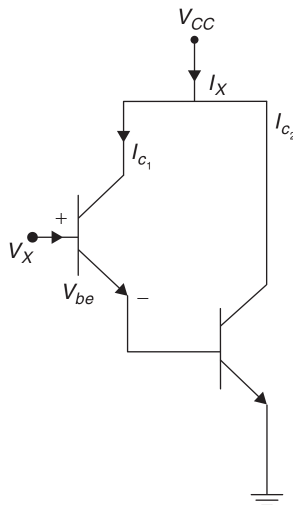
Where $Z_i' = \beta(r_{e_1} + \beta_2 r_{e_2})$

$$Z_o = RC \parallel r_{o_2}$$

$$A_v = \frac{V_o}{V_i} = \frac{\beta_D R_C}{Z_i^1}$$

Example 5: Given the transconductance of Q_1 is g_{m_1} and Q_2 is g_{m_2}.

Find the overall transconductance $\frac{I_X}{V_X}$ (β is large)



(A) g_{m_1}
(B) 0.5 g_{m2}
(C) 0.5 g_{m_1}
(D) g_{m_2}

Solution: (B)

$$I_X = I_{C_1} + I_{C_2}$$

$$I_{C_2} \simeq I_{E_2} = (\beta + 1) I_{E_1}$$

$$I_{C_2} \simeq (\beta + 1) I_{C_1}$$

$$I_{C_2} \simeq (\beta + 1)^2 I_{b_1}$$

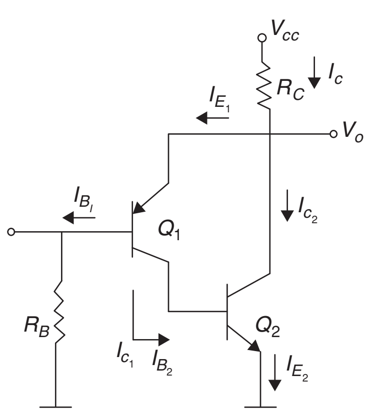
as 'β' is large $I_{C_2} >> I_{C_1}$

$$\therefore \quad I_X \simeq I_{C_2}$$

$V_x = 2V_{be}$ (KVL at input)

$$\frac{I_X}{V_X} = \frac{I_{C_2}}{2V_{be}} = 0.5 g_{m_2}.$$

Feedback pair



DC Analysis

$$I_{B_1} = \frac{V_{cc} - V_{BE_1}}{R_B + \beta_D R_C}$$

$$I_c \simeq I_{c_2}$$

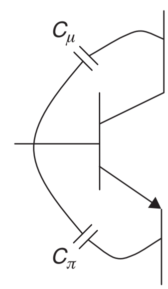
AC Analysis

$$Z_i' = \beta_1 \beta_2 R_c, \; Z_i = R_B \parallel Z_i'$$

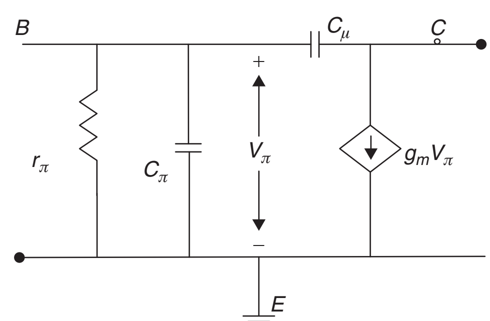
$$A_i = \frac{I_o}{I_i} = \frac{-\beta_1 \beta_2 R_B}{R_B + \beta_1 \beta_2 R_c}$$

$$A_v = \frac{\beta_2 R_c}{r_{e_1} + \beta_2 R_c} \simeq 1, \; Z_o = \frac{r_{e_1}}{\beta_2}$$

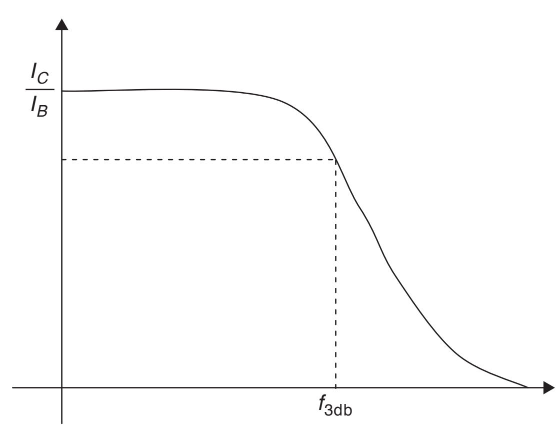
High Frequency Response of an Amplifier (π model)



AC Equivalent Circuit



Frequency Response



f_T = unity gain frequency

f_{3dB} = 3 – dB frequency

$$f_{3dB} = \frac{1}{2\pi r_\pi (C_\pi + C\mu)}$$

$$f_T = \frac{g_m}{2\pi (C_\pi + C\mu)}$$

$$\frac{f_T}{f_{3dB}} = g_m r_\pi = h_{fe}$$

Example 6: An amplifier has a gain of 60 dB with a band width of 10 MHz. Find the unity gain frequency?

(A) 10 GHz (B) 100 GHz
(C) 10 MHz (D) 100 MHz

Solution: (A)

Gain = A_{in} dB = 60

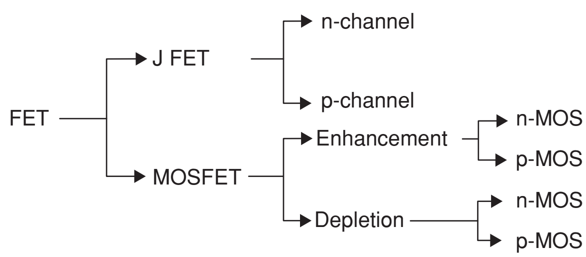
20 log A = 60

$\Rightarrow$ A = 10^3 = 1000

f_T = (1000) (10×10^6)

f_T = 10 GHz.

FET Amplifier Stages



For JFET and depletion mode MOSFET analysis, Shockley's equation holds good.

$$\text{i.e., } I_D = I_{DSS}\left[1 - \frac{V_{GS}}{V_P}\right]^2 = \text{Source Current}$$

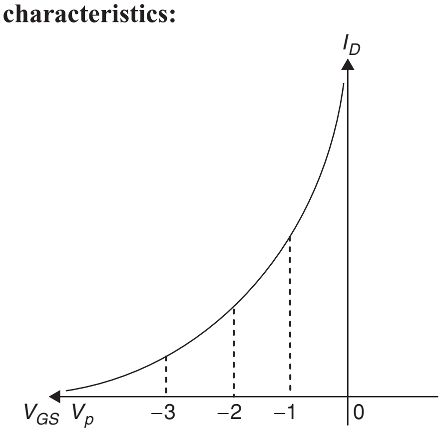
I_D =Drain current = I_S

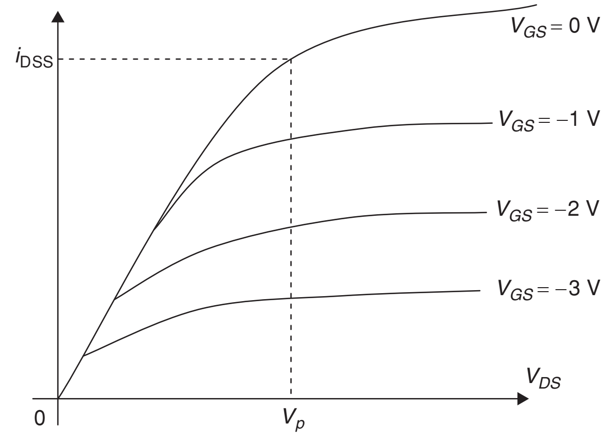
I_{DSS} = Drain saturation current

V_P = Pinch off voltage where I_D = 0 A

JFET Transfer Characteristics

Output characteristics:





Enhancement Mode MOSFET Analysis

$i_D = K(V_{GS} - V_T)^2$

i_D = Instantaneous drain current

V_{GS} = Instantaneous gate-source voltage

V_T = Threshold voltage

Symbols used to represent DC, AC and instantaneous values:

I_d = AC drain current

I_D = DC drain current

i_D = Instantaneous drain current = $I_D + i_d$

Region of Operation:

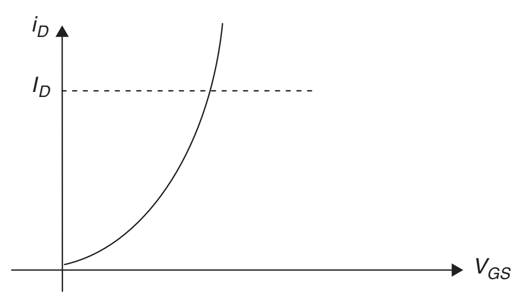
Case (i): $V_{GS} < V_T$: cut-off region

Case (ii): $V_{GS} > V_T$ and $V_{DS} < (V_{GS} - V_T)$: linear/triode region

Case (iii): $V_{GS} > V_T$ and $V_{DS} \geq (V_{GS} - V_T)$: saturation region

Case (iv): $V_{GS} > V_T$ and $V_{DS} \geq 2(V_{GS} - V_T)$: break down region

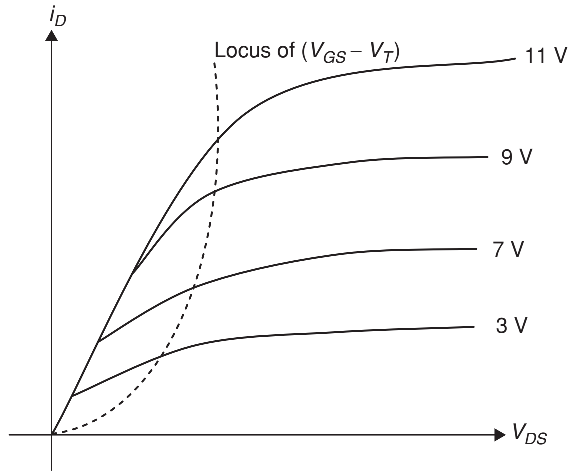
Transfer Characteristics:



$$\text{Slope} = g_m = \frac{\Delta i_d}{\Delta V_{gs}}\bigg|_{V_{GSQ}}$$

g_m : Transconductance

Output characteristics:



$$\text{Slope } = r_D = \left(\frac{di_D}{dv_{DS}}\right)^{-1} \Big| V_{GS} = V_{GSQ}$$

r_D = Drain resistance

Transconductance (g_m)

1. $i_D = k\,(V_{GS} - V_T)^2$
   $i_D = I_D + i_d$
   $v_{GS} = V_{GS} + V_{gs}$
   $i_d = 2k_n\,(V_{GS} - V_T)$ at V_{GSQ}

   Where $k_n = \mu_n C_{ox}\left(\frac{W}{L}\right)$ represents MOSFET

Fabrication constant

$$g_m = 2k_n\sqrt{\frac{i_D}{k_n}}$$

$$g_m = 2\sqrt{k_n I_{DQ}}$$

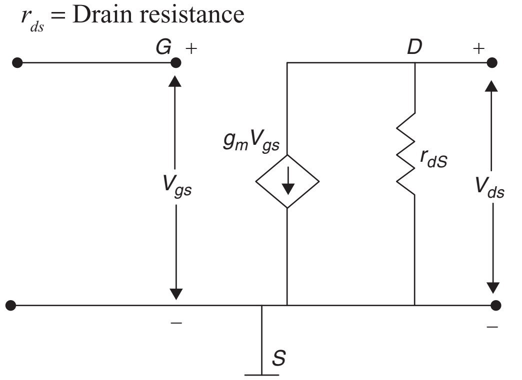
AC Equivalent Model of MOSFET

$$i_d = f(V_{gs}, V_{ds})$$

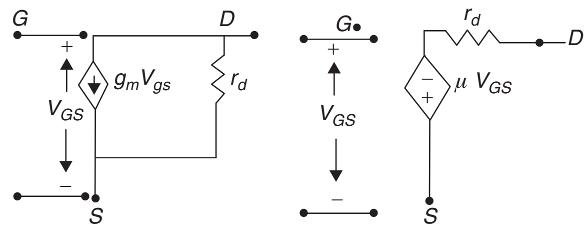
By super position theorem

$$i_d = g_m V_{gs} + \frac{V_{ds}}{r_{ds}}$$

Where g_m = Trans conductance
r_{ds} = Drain resistance



Small signal equivalent circuits



$$\mu = g_m r_d$$

$$g_m = \frac{2}{|V_P|}\sqrt{I_{DQ} I_{DSS}} \quad \text{for JFET}_S$$

$$g_m = 2\sqrt{k\frac{W}{L} I_{DQ}} \quad \text{for MOSFET}_S$$

$$r_d = \frac{1}{\lambda I_{DQ}} = \frac{V_A}{I_{DQ}}$$

The values of both g_m and r_d are bias-dependent. The output resistance r_d is usually not sufficiently large, so it may not be neglected (as r_o is often neglected in the BJT model).

The quantity μ is called amplification factor $\mu = g_m r_d$. The open circuit between gate and source in the model makes $I_g = 0$, so we consider $A_V\, R_o$ only (A_I and R_i are very High).

Equations for FET stages

Common source stage

$$A_v = -\frac{\mu R_D}{r_d + R_D} = \frac{-g_m R_D}{1 + R_D/r_d}$$

$$R_o = r_d, R_o' = R_D \| r_d$$

Common source stage with source resistance

$$A_v = \frac{\mu R_D}{r_d + R_o + (1+\mu)R_S} = \frac{-g_m\,(r_o \| R_D)}{1 + g_m R_S R_L / R_D}$$

$$R_o = r_d + R_S\,(1+\mu) = r_d\,(1 + g_m R_S)$$

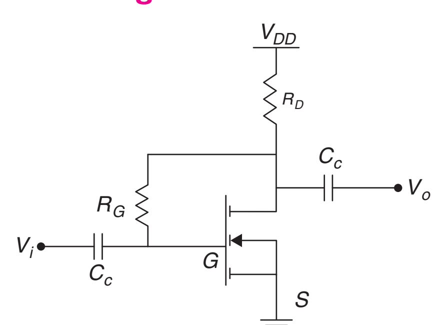
$$R_o' = R_o \| R_D$$

Common drain configuration

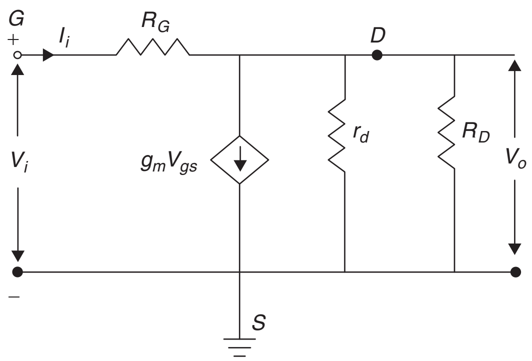
$$A_v = \frac{\mu R_S}{r_d + R_S(1+\mu)} = \frac{g_m R_S}{1 + g_m R_S},\; R_o = \frac{r_d}{1+\mu} = \frac{1}{g_m}$$

$$R_o' = R_s \| R_o$$

Enhancement Mode MOSFET Drain Feedback Configuration



AC equivalent model



$r_d = r_{ds}$ = Drain resistance

Input-impedance:

$$z_i = \frac{R_F + (r_d \parallel R_D)}{[1 + (r_d \parallel R_D g_m)]}$$

$$\text{if } R_F \gg (r_d \parallel R_D) \Rightarrow z_i = \frac{R_F}{1 + g_m(r_d 11 R_D)}$$

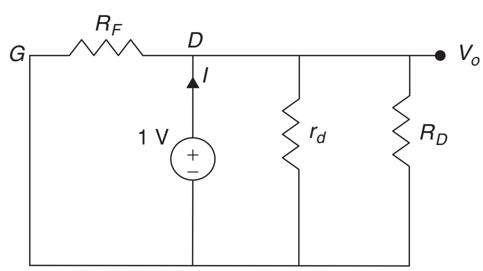
$$\text{if } R_F \gg (r_d \parallel R_D) \text{ and } \Rightarrow z_i = \frac{R_F}{1 + g_m R_D}$$

$$r_d \geq 10R_D$$

Output-impedance:

1. Make input voltage = 0
2. Connect a voltage source at the output and find $\frac{V}{I}$

AC equivalent circuit



$z_0 = R_F \parallel r_d \parallel R_D$

if $R_F >> (r_d \parallel R_D)$ and $r_d \geq 10R_D$

$z_0 \simeq R_D$

Voltage gain:

$$A_v = \frac{\left(\frac{1}{R_F}\right) - g_m}{\left(\frac{1}{R_F}\right) + \frac{1}{(r_d \parallel R_D)}}$$

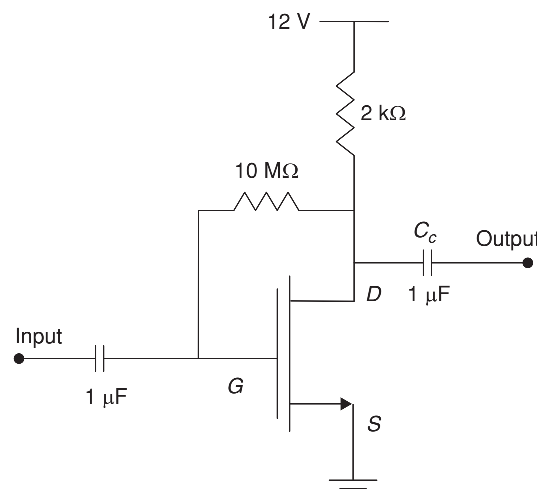
Approximations:

1. If $R_F \gg (r_d \parallel R_D)$
   $A_V \simeq -g_m (r_d \parallel R_D)$
2. if $R_F \gg (r_d \parallel R_D)$ and $r_d \geq 10R_D$
   $A_V \simeq -g_m R_D$
3. $g_m \gg \frac{1}{R_F}$ then $A_V = -g_m(r_d \parallel R_D \parallel R_F)$

Summary

Without Approximation	With Approximation
$A_V = -g_m(r_d \| R_D)$	$A_V = -g_m R_D$
$z_i = \frac{R_F}{1+g_m(r_d \parallel R_D)}$	$z_i = \frac{R_F}{1+g_m R_D}$
$z_o = r_d \| R_D$	$z_0 = R_D$

Example 6:



Find g_m, r_d, z_i, z_0, A_v?

K = 0.2×10^{-3} A/V^2

V_T = 3 V

Y_d = 20 μs

V_{GSQ} = 6.4 V

I_{DQ} = 2.75 mA

Solution:

(i) $g_m = 2\,k(V_{GSQ} - V_T)$
= 1.632 mA/V
g_m = 1.632 ms

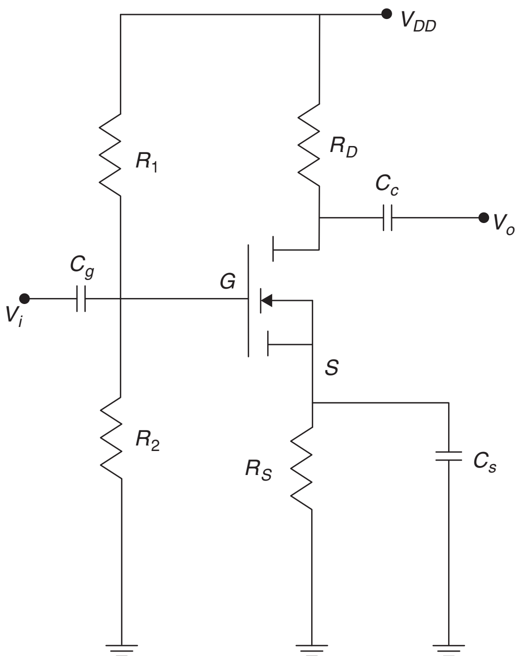
(ii) $r_d = \frac{1}{y_d} = 50\ \text{k}\Omega$

(iii) $z_i = \frac{R_F}{1 + g_m(r_d \parallel R_D)} = 2.42\ \text{m}\Omega$

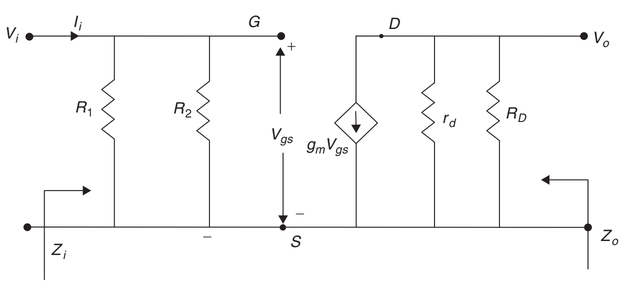
(iv) $z_0 = R_F \parallel r_d \parallel R_D = 1.923\ \text{k}\Omega$

(v) $A_v = -g_m(r_d \parallel R_D \parallel R_F) = -3.14$

Common Source Amplifier (Voltage Divider-bias)



Amplifier AC equivalent model

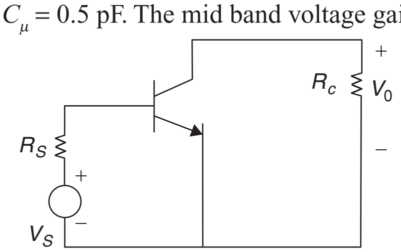


1. $z_i = R_1 \| R_2$
2. $z_0 = r_d \| R_D$
3. $A_v = -g_m(r_d \| R_D)$
   If $r_d \gg 10\, R_D$ then $A_v \simeq -g_m R_D$

Solved Examples

Directions for questions 1 to 7: Select the correct alternative from the given choices.

Example 1: The amplifier circuit with $R_S = 500\ \Omega$, $R_C = 1.5$ kΩ operates at $I_C = 1$ mA, the parameters are $\beta_0 = 125$, $f_T = 300$ MHz, $C_\mu = 0.5$ pF. The mid band voltage gain is



(A) −51.72 (B) −32.42
(C) −28.34 (D) −13.50

Solution: (A)

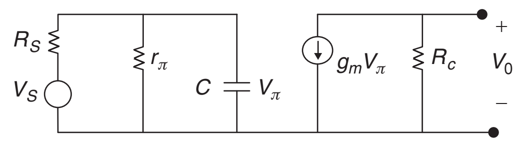
$$g_m = \frac{I_{C(\text{mA})}}{25} = \frac{1}{25}$$

$$\beta_o = g_m \cdot r_\pi \quad \Rightarrow \quad r_\pi = \frac{\beta_0}{g_m} = \frac{125}{1/25} = 3125\ \Omega$$

$$\omega_T = \frac{g_m}{C_\pi + C_\mu} = 2\pi \times 300 \times 10^6$$

$$C_\pi + C_\mu = \frac{g_m}{\omega_T} = \frac{1}{25 \times 2\pi \times 300 \times 10^6} = 21 \text{ pF}$$

The AC equivalent circuit using unilateral hybrid π.



$$\frac{V_o}{V_1} = g_m R_C$$

$$C = C_x + C_\mu(1 + g_m R_C)$$

$$= C_\pi + C_\mu + C_\mu g_m R_C$$

$$V_\pi = \frac{V_S r_\pi}{R_S + r_\pi} \cdot \frac{1}{1 + \dfrac{S}{\omega_H}} \text{ where } \omega_H = \frac{1}{RC}$$

$R = R_S \| r_\pi$

$$\frac{V_o}{V_S} = \frac{-\beta_o R_C}{R_S + r_\pi} \cdot \frac{1}{1 + \dfrac{s}{\omega_H}}$$

$$\text{Mid band gain } A_0 = \frac{-\beta_o R_C}{R_S + r_\pi} = \frac{125 \times 1.5}{0.5 + 3.125} = -51.72$$

Example 2: The value of $\omega_H = 2\pi f_H$ which is the upper cut off frequency in the above question?

(A) 75.7 M radians/second (B) 54.6 M radians/second
(C) 39.2 M radians/second (D) 32.9 M radians/second

Solution: (C)

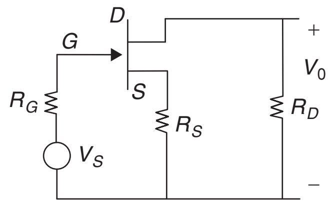
$C = (C_\pi + C_\mu) + C_\mu g_m R_C$

$$= 21 + 0.5 \times \frac{1}{25} \times 1500 = 21 + 30 = 51 \text{ pF}$$

$$\omega_H = \frac{1}{RC} = \frac{1}{500 \times 51 \text{ pF}}$$

$= 39.2$ M radians/second

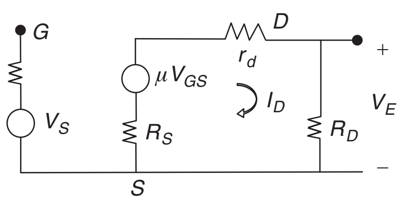
Example 3: For the common source amplifier with R_S, find the values of $\frac{V_O}{V_S}$ and R_O (output impedance), given R_D = 16 kΩ, R_S = 1 kΩ, FET parameters are r_d = 32 kΩ, μ = 60.



(A) 8.8, 93 kΩ (B) –8.8, 93 kΩ
(C) –4.2, 56 kΩ (D) +4.2, 56 kΩ

Solution: (B)
The equivalent current in the loop equation from KVL

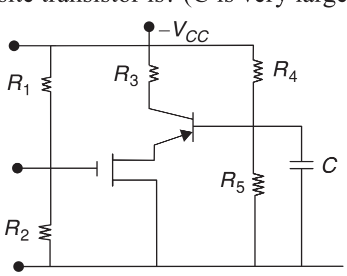
$I_d\,(R_S + R_D\,, r_d) = \mu V_{gs}$
$V_{gs} = V_s - R_s I_d$
$V_0 = -I_d R_D$



By solving $A_V = \frac{V_O}{V_S} = \frac{-\mu R_D}{r_d + R_S(1+\mu) + R_D}$

$R_0 = r_d + R_S\,(1 + \mu)$
$R_S = 1$ kΩ, $R_D = 16$ kΩ, $r_d = 32$ kΩ, $\mu = 60$
$A_V = -8.8$
$R_O = 32 + 1 \times 61 = 93$ kΩ

Example 4: The given figure shows a composite transistor consisting of a MOSFET and a bipolar transistor in cascade. The MOSFET has trans conductance g_m of $\frac{3 \text{ mA}}{\text{V}}$ and bipolar transistor has β of 99. The overall transconductance of the composite transistor is? (C is very large)



(A) 1.98 mA/V (B) 19.8 mA/V
(C) 29.7 mA/V (D) 2.97 mA/V

Solution: (C)

$$g_m \cdot V_{\text{in}} = I_E(BJT),\ \alpha = \frac{I_C}{I_E} = (BJT)$$

$$I_c = \alpha I_E = \alpha \cdot g_m \cdot V_{\text{in}},$$

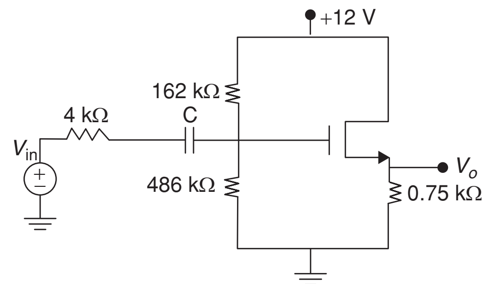
$$\alpha = \frac{\beta}{\beta+1} = 0.99$$

$$g_m(\text{over all}) = \frac{I_c}{V_{\text{in}}} = g_m \cdot a$$

$$= 3 \times 10^{-3} \times 0.99 = 2.97 \times 10^{-3} \text{ Mho}$$

Common Data for Questions 5 to 7:

Example 5: The source follower amplifier circuit shown in following figure transistor parameters are V_{th} = 1.2 V, k_n = 4 mA/V², λ = 0.01 V⁻¹ small signal trans conductance and I_D are

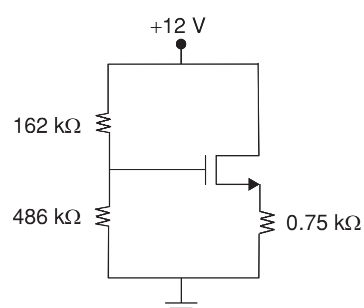


(A) 8.47 mA and 14.8 mA/V
(B) 6.47 mA and 14.8 mA/V
(C) 6.47 mA and 11.6 mA/V
(D) 8.47 mA and 11.6 mA/V

Solution: (D)
DC analysis of the circuit

$$\frac{V_G - 12}{162} + \frac{V_G - 0}{486} = 0 \ \Rightarrow\ V_G = 9 \text{ V}$$

$$I_D = \frac{V_G - V_{GS}}{(0.75 \text{ k}\Omega)} = k_n(V_{GS} - V_{\text{th}})^2$$



$$(9 - V_{GS}) = (0.75)(4)(V_{GS} - 1.2)^2$$

$$(9 - V_{GS}) = 3(V_{GS} - 1.2)^2$$

$$9 - V_{GS} = 3V_{GS}^{\ 2} - 7.2V_{GS} + 4.32$$

$$3V_{GS}^{\ 2} - 6.2V_{GS} - 4.68 = 0$$

$V_{GS} = 2.65$ or -0.58 (by solving)

V_{GS} should be positive $V_{GS} = 2.65$ V

$$I_D = \frac{V_G - V_{GS}}{0.75\text{ k}\Omega} = \frac{6.35}{0.75} = 8.47\text{ mA}$$

Small signal trans conductance is

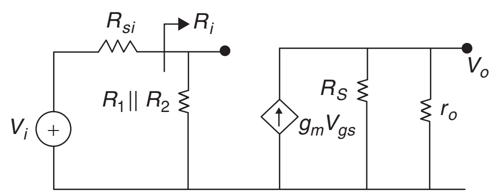
$$g_m = \frac{dI_D}{dV_{GS}} = 2\,k_n(V_{GS} - V_{\text{th}})$$

$$= 2 \times 4 \times (2.65 - 1.2) = 11.6\text{ mA/V}$$

Example 6: Small signal voltage gain $A_v = \frac{V_o}{V_i}$ is is

(A) 1.2 (B) 1.13
(C) 0.98 (D) 0.86

Solution: (D)
The small signal equivalent circuit of the given amplifier is



$R_{si} = 4$ kΩ, $R_1 = 162$ kΩ, $R_2 = 486$ kΩ, $R_s = 0.75$ kΩ

$$r_o \approx [\lambda I_D]^{-1} = 1/0.01 \times 8.47 = 11.8\text{ k}\Omega$$

$$R_i = R_1 \| R_2 = 121.5\text{ k}\Omega$$

Voltage gain $A_9 = \frac{g_m(R_S \| r_o)}{1 + g_m(R_S \| r_o)} \cdot \frac{R_i}{R_i + R_{si}}$

$$= \frac{11.6(0.75 \| 11.8)}{1 + 11.6(0.75 \| 11.8)} \times \frac{121.5}{121.5 + 4} = 0.86$$

Example 7. The output resistance of the amplifier circuit is
(A) 87.8 Ω (B) 82.3 Ω (C) 79.3 Ω (D) 76.6 Ω

Solution: (D)
By small signal equivalent circuit, output independence is

$$R_0 = \frac{1}{gm} \| R_s \| r_0$$

$$= 0.086 \| 0.75 \| 11.8\text{ k}\Omega$$

$$0.076\text{ k}\Omega \Rightarrow 76.6\ \Omega$$

Exercises

Practice Problems I

Directions for questions 1 to 30: Select the correct alternative from the given choices.

Common Data for Questions 1 and 2: A BJT has h_{fe} = 220, $g_m = 40 \times 10^{-3}\Omega$, $C_{cb} = 10$ pF and $C_{be} = 50$ pF.

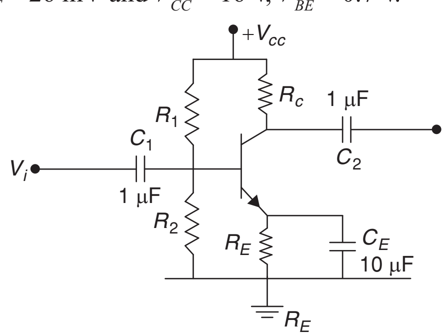
1. What is unity gain frequency f_T?
   (A) 80.6 MHz (B) 106.6 MHz
   (C) 20 MHz (D) 100 kHz
2. What is β cutoff frequency f_β?
   (A) 4.84 kHz (B) 0.359 MHz
   (C) 3.59 kHz (D) 0.484 MHz

Common Data for Questions 3 and 4: A CE amplifier is shown below with the following specifications.

$R_1 = 40$ kΩ, $R_2 = 4.7$ kΩ

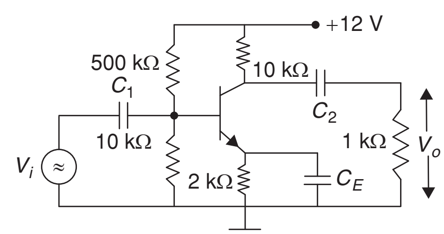
$R_C = 4$ kΩ, $R_E = 1.2$ kΩ, $\beta = 100$

And $V_T = 26$ mV and $V_{CC} = 16$ V, $V_{BE} = 0.7$ V.



3. What is the voltage gain A_V of the amplifier?
   (A) −132.3 (B) −10
   (C) −121.5 (D) −30.6
4. If the bypass capacitor C_E is removed, the voltage gain is ______
   (A) −100 (B) −3.33
   (C) −2.73 (D) −121.5
5. The transistor shown below has $r_e = \frac{V_T}{I_E} = 2.6\ \Omega.$

   The mid band voltage gain of the amplifier is ______



   (A) −350 (B) −177
   (C) −212 (D) −182
6. A multi stage amplifier is to be constructed using 4 identical stages, each of which has a lower cut-off frequency 60 Hz and upper cut-off frequency 1MHz. The band width of multi stage amplifier is __________
   (A) 0.39 MHz (B) 4 MHz
   (C) 0.435 MHz (D) 0.51 MHz

7. A multistage amplifier has 3 stages. The voltage gain of 3 stages are 30, 50 and 60 respectively. The overall gain in db is ________

(A) 60 dB (B) 105.2 dB
(C) 140 dB (D) 99.06 dB

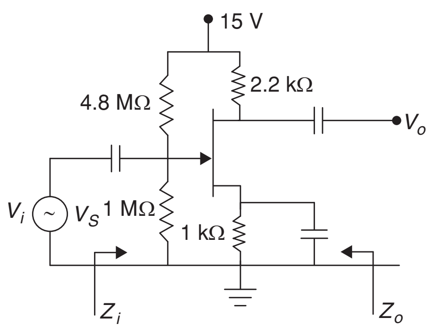
8. A multistage amplifier has 2 identical stages. If each stage has $R_{in} = 2$ kΩ, $\beta = 80$ and $R_C = 3.5$ kΩ. The overall voltage gain is _____

(A) 2090 (B) 19600
(C) 280 (D) 70

9. The following parameters were measures on transistor biased at $I_C = 2$ mA
$h_{fe} = 80$ $h_{re} = 0.5 \times 10^{-4}$
$h_{oe} = 1.4 \times 10^{-6}$A/V
Calculate g_m and r_π?

(A) $g_m = 0.769$ ℧, $r_\pi = 10.4$ kΩ
(B) $g_m = 76.9$ ℧, $r_\pi = 1.04$ kΩ
(C) $g_m = 76.9 \times 10^{-3}$ ℧, $r_\pi = 1.04$ kΩ
(D) $g_m = 76.9 \times 10^{-3}$ ℧, $r_\pi = 10$ kΩ

Common Data for Question 10 to 12: A JFET common source amplifier is given below. The specifications are $r_d = 100$ kΩ, $g_m = 3 \times 10^{-3}$S



10. The input impedance Z_i is

(A) 827 kΩ (B) 82.7 MΩ
(C) 1 MΩ (D) 5 MΩ

11. The output impedance Z_o is

(A) 220 Ω (B) 3.2 kΩ
(C) 2.2 kΩ (D) 2.152 kΩ

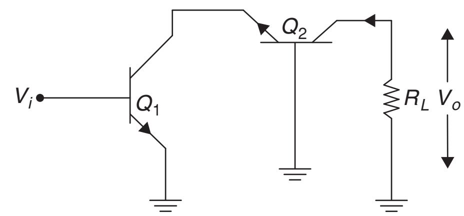
12. The voltage gain A_V is

(A) −6.6 (B) −3
(C) −300 (D) −6.456

13. In a single stage amplifier,
$R_C = 10$ kΩ, $R_{in} = 2$ kΩ, $\beta = 50$ and $R_L = 10$ kΩ. A small signal voltage $V_i(t) = 0.5 \sin \omega t$ mV is applied, the output voltage V_o is _______

(A) $-62.5 \sin\omega t$ mV (B) $-125 \sin\omega t$, mV
(C) $-31.5 \sin\omega t$, mV (D) $62.5 \sin\omega t$, volt

14. In the cascode amplifier shown in figure, if the common emitter stage Q_1 has $r_{e_1} = 26\ \Omega$ and common base Q_2 has $r_{e_2} = 12\ \Omega$, then the output current i_o for $V_i = 0.2$ V is ________



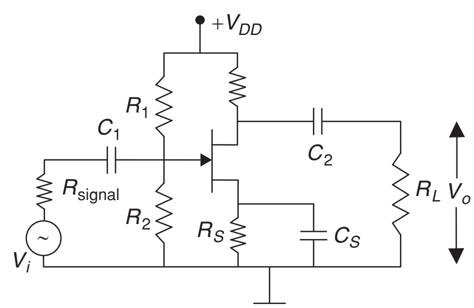
(A) 16 mA (B) 7.7 mA
(C) 6.2 mA (D) None

15. A CE amplifier has a unity gain frequency of 305 MHz with a gain of 92 dB. The 3 dB bandwidth is _______

(A) 16.2 MHz
(B) 305 MHz
(C) 4 MHz
(D) 7.66 kHz

Common Data for Questions 16 and 17: A FET amplifier is shown with the following specifications.

$R_1 = 1$ MΩ, $R_2 = 200$ kΩ, $R_S = 1$ kΩ, $R_D = 2$ kΩ, $R_L = 1.8$ kΩ, $R_{signal} = 5$ kΩ, $C_1 = C_2 = 0.1$ μF and $V_{DD} = 20$ V. The other parameters of FET are $r_d = 100$ kΩ, $C_{gs} = 4$ PF, $C_{ds} = 0.5$ PF, $C_{gd} = 1.2$ PF and $g_m = 4 \times 10^{-3}$ ℧



16. The approximate lower cutoff frequency is _______

(A) 9.35 Hz
(B) 60.5 Hz
(C) 21.5 Hz
(D) 425.5 Hz

17. The approximate upper cutoff frequency is _____

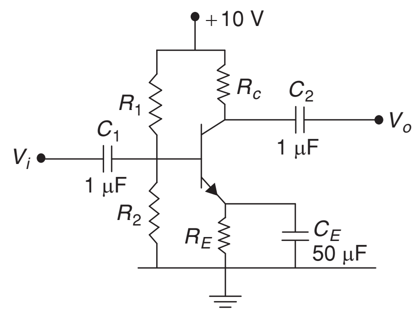
(A) 84.6 MHz
(B) 10 MHz
(C) 5.7 MHz
(D) 210 MHz

18. An amplifier circuit with $R_C = 2$ kΩ operating at $I_C = 1.2$ mA. If the gain bandwidth product of the amplifier is 125 kHz then the bandwidth of the same amplifier, assuming $V_T = 26$ mv, is ______

(A) 2.7 kHz (B) 62.5 kHz
(C) 1.35 kHz (D) None of these

19. A RC coupled CE amplifier is shown below with following specifications.

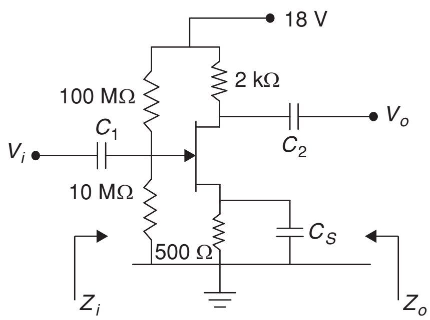
$R_1 \| R_2 = 4$ kΩ, $\beta = 50$, $h_{ie} = 1$ kΩ, $R_C = 2$ kΩ and $R_E = 0.5$ kΩ. What is the loss in gain if the bypass capacitor C_E is removed?



(A) 4% (B) 0%
(C) 0.4% (D) 96%

Common Data for Questions 20 to 22: A AFET amplifier is given below with following specifications.

$I_{DSS} = 5$ mA, $V_P = -2.5$ V and $r_d = 80$ kΩ



20. The input impedance Z_i is
(A) 100 MΩ
(B) 9.09 MΩ
(C) 110 MΩ
(D) 10 MΩ

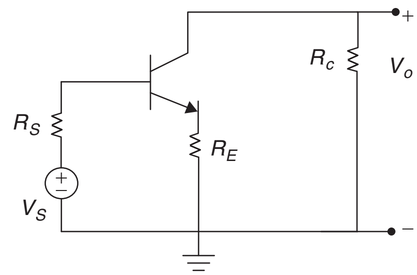
21. The output impedance Z_o is
(A) 1.95 kΩ (B) 80 kΩ
(C) 10 kΩ (D) 2.5 kΩ

22. The output V_o for $V_i = 30$ mV is
(A) −0.95 V
(B) −150 mV
(C) −40.5 mV
(D) −81.432 mV

23. The emitter follower using a p-n-p transistor with $\beta_0 = 150$ is biased at $I_C = 0.25$ mA, the voltage signal source has $R_S = 3$ kΩ. In order to make the overall $R_0 = 110$ Ω, the value of R_E is
(A) 1.42 Ω (B) 2.04 Ω
(C) 0.71 kΩ (D) 1.42 kΩ

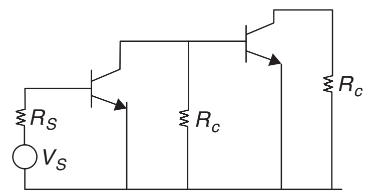
24. For the above value of R_E, the values of A_V, R_i (input resistance) are
(A) 1, 230 kΩ (B) 2.8, 330 kΩ
(C) 0.92, 230 kΩ (D) 0.92, 330 kΩ

25. In the circuit shown, the transistor has $\beta_0 = 125$, and operated $I_C = 0.3$ mA, the element values are $R_S = 2$ kΩ, $R_G = 5$ kΩ, $R_E = 100$ Ω, the value of V_O/V_S is?



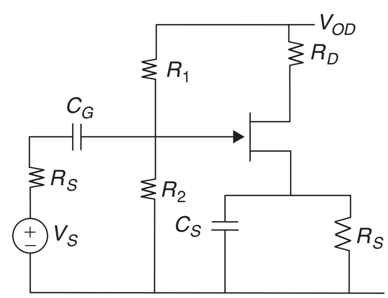
(A) −18.35 (B) 20.46
(C) −24.98 (D) 32.46

26. Both the transistors have $\beta_0 = 120$, and operated at $I_C = 1$ mA, $R_S = 0.5$ kΩ, $R_C = 1.5$ kΩ, overall gain is?



(A) 91.4 (B) 1028
(C) 2056 (D) 3084

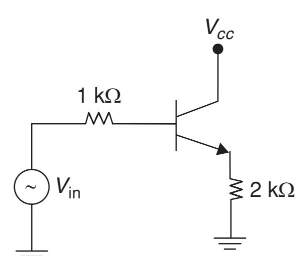
27.



A FET amplifier shown in the above figure has parameters $g_m = 2$ m Mho, $r_d = 20$ kΩ, what is the value of load R_D for mid band gain of −20? Assume that R_S, C_S bias is short $R_S = 300$ Ω, $R_1 = 160$ kΩ, $R_2 = 40$ kΩ
(A) 20 kΩ (B) 30 kΩ
(C) 40 kΩ (D) 0 Ω

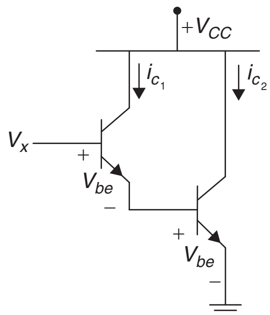
28. The value of input coupling capacitor C_G for lower cut-off frequency $f_L = 300$ Hz in the above circuit is.
(A) 0.025 μF (B) 0.052 μF
(C) 0.016 μF (D) 0.043 μF

29. An amplifier circuit is shown in the figure given below; assume that the transistor works in active region. The low frequency small signal parameters for the BJT are $g_m = 20$ mS, $\beta = 50$, $r_o = \infty$, $r_b = 0$, $\frac{V_0}{V_{in}}$ of the amplifier is



(A) 0.967 (B) 0.976
(C) 0.983 (D) 0.998

30. The Darlington pair stage is shown in the following figure. If the transconductance of Q_1 is 8×10^{-3} ℧ and Q_2 is 6×10^{-3} ℧, the overall transconductance g_m is ______.

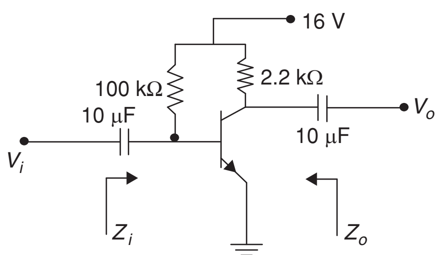


(A) 14×10^{-3} ℧
(B) 2×10^{-3} ℧
(C) 3×10^{-3} ℧
(D) 6×10^{-3} ℧

Practice Problems 2

Directions for questions 1 to 22: Select the correct alternative from the given choices.

Common Data for Questions 1 to 3: The h-parameters of the transistor are h_{ie} = 400 Ω, h_{fe} = 80 and the transistor amplifier is given below



1. What is the input impedance Z_i as seen from source?
(A) 400 Ω (B) 100 kΩ
(C) 500 kΩ (D) 398 Ω

2. What is the output impedance Z_o?
(A) 2.2 kΩ (B) 10 kΩ
(C) 6.2 kΩ (D) 6 kΩ

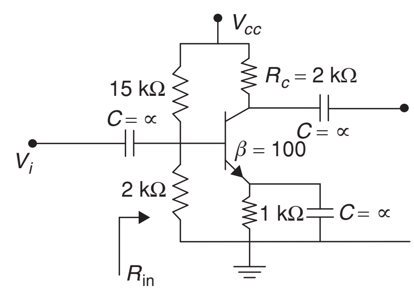
3. What is the voltage gain of the amplifier?
(A) −80 (B) −440
(C) −612 (D) 1

Common Data for Questions 4 and 5: The typical parameters of the hybrid-π model of transistor at room temperature and for I_C = 1.8 mA are
C_π = 100 pF and f_T = 80 MHz

4. The value of g_m in mA/V is ________
(A) 6.9 (B) 0.69
(C) 0.069 (D) 69

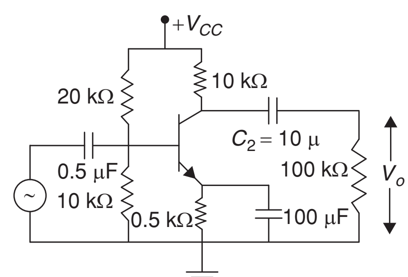
5. The capacitance C_μ is ________
(A) 38 pF (B) 2 pF
(C) 3.8 pF (D) 0.38 pF

6. The Transconductance g_m of the transistor shown is 8 mS. The value of input resistance R_{in} seen from source is ________.



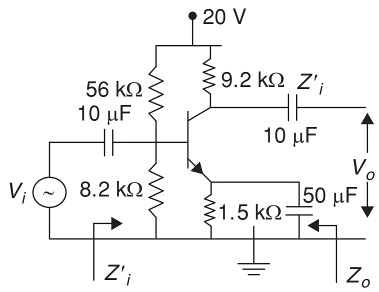
(A) 1.54 kΩ
(B) 12.5 kΩ
(C) 1.764 kΩ
(D) 2.5 kΩ

7. A RC coupled CE amplifier is shown in the figure. The lower cut-off frequency f_1 due to coupling capacitor C_2 is ________



(A) 29 Hz
(B) 145 Hz
(C) 50 HZ
(D) 32 Hz

Common Data for Questions 8 and 9: A CE transistor amplifier is shown below with

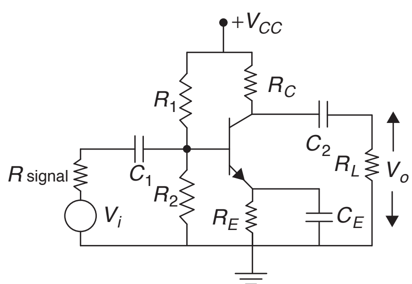


$h_{ie} = 2.12$ kΩ, $h_{re} = 0$, $h_{fe} = 50$ and $h_{oe} = 0.2 \times 10^{-3}$ ℧

8. The input impedance Z_i' is ____________
   (A) 7.15 kΩ (B) 8.78 kΩ
   (C) 2.12 kΩ (D) 1.63 kΩ

9. The output impedance Z_o is ________
   (A) 7.77 kΩ (B) 9.2 kΩ
   (C) 43.2 kΩ (D) 50 kΩ

Common Data for Questions 10 to 12: A RC coupled CE amplifier is shown below.



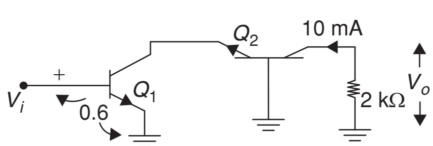
The specifications are
$R_{\text{signal}} = 1$ kΩ, $R_1 = 20$ kΩ, $R_2 = 5$ kΩ, $R_C = 1$ kΩ, $R_E = 1$ kΩ, $R_L = 1$ kΩ, $C_1 = 0.5$ μF, $C_2 = 1$ μF and $C_E = 100$ μF.

10. The lower cut-off frequency due to C_1 is
    (A) 23.4 Hz (B) 64 Hz
    (C) 32 Hz (D) 128 Hz

11. The lower cut-off frequency due to C_2 is
    (A) 0 Hz (B) 100 Hz
    (C) 64 Hz (D) 80 Hz

12. What is the value of C_2 required to have a lower cut-off frequency of 100 Hz.
    (A) 80 μF (B) 8 pF
    (C) 0.8 μF (D) 8 μF

13. A cascode amplifier is given below. The voltage gain $A_v = \frac{V_o}{V_i}$ is ________



    (A) −67 (B) −33.3
    (C) −16.6 (D) −1

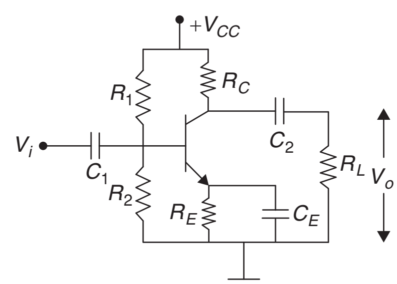
14. The 3 amplifier stages are cascoded to provide overall gain of 12000. The first two stages have a gain of 45 db and 25.12 respectively, the gain of 3rd stage in dB is ________
    (A) 3 dB
    (B) 28 dB
    (C) 80 dB
    (D) 8.58 dB

15. The rise time of the amplifier to the input is 70 n sec. The bandwidth of the amplifier is ________
    (A) 1 MHz
    (B) 5 MHz
    (C) 10 MHz
    (D) 0.5 MHz

16. The mid frequency gain of RC coupled CE amplifier is 200. The lower and upper cut-off frequencies are 50 Hz and 80 kHz.

    The frequencies at which gain falls to 150 are _____ and _______
    (A) 50 Hz and 80 kHz
    (B) 56.69 Hz and 70.55 kHz
    (C) 25 Hz and 40 kHz
    (D) 10 Hz and 90 kHz

17. A CE transistor amplifier shown below specified with $h_{fe} = 50$, $h_{ie} = 2$ kΩ and $R_L = 10$ kΩ. The value of R_C required to maintain a mid band gain $A_V = -120$ is __________ kΩ.



    (A) 10
    (B) 5
    (C) 2.75
    (D) 9.23

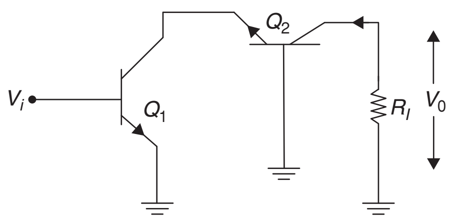
18. The mid band gain of the amplifier is 62 dB. The gain at lower (or) upper 3 dB is ________
    (A) 59 dB
    (B) 31 dB
    (C) $\frac{62}{\sqrt{2}}$ dB
    (D) 65 dB

19. A cascode amplifier is shown below. The transistor

    Q_1 has $g_{m_1} = 5$ mA/V and

    Q_2 has $g_{m_2} = 1.25$ mA/V.

    The overall transconductance g_m of the cascode amplifier is ________



(A) 5 mA/V
(B) 1.25 mA/V
(C) 6.25 mA/V
(D) 4 mA/V

Common Data for Questions 20 to 22: A multi stage amplifier has 4 identical stages. Each stage is specified with gain A = 60, lower cutoff f_1 = 30 Hz and upper cutoff f_2 = 90 kHz.

20. The overall gain A' in dB is
(A) 47.6 dB
(B) 32.55 dB
(C) 142.25 dB
(D) 60 dB

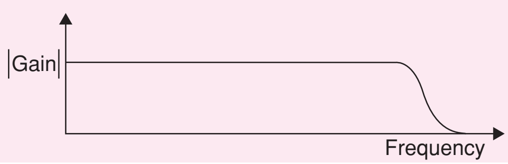
21. The overall lower cutoff frequency f_1' is ______
(A) 120 Hz (B) 69 Hz
(C) 7.5 Hz (D) 21.2 Hz

22. The overall upper cutoff frequency f_2' is ______
(A) 22.5 kHz
(B) 45 kHz
(C) 39.13 kHz
(D) 360 kHz

Previous Years' Questions

1. The typical frequency response of a two-stage direct coupled voltage amplifier, as shown in the below figures, is. **[2005]**

(A)


(B)


(C)


(D)


Answers Keys

Exercises

Practice Problems 1

1. B	**2.** D	**3.** C	**4.** B	**5.** A	**6.** C	**7.** D	**8.** B	**9.** C	**10.** A
11. D	**12.** D	**13.** A	**14.** B	**15.** D	**16.** D	**17.** C	**18.** C	**19.** D	**20.** B
21. A	**22.** D	**23.** D	**24.** C	**25.** C	**26.** C	**27.** A	**28.** C	**29.** A	**30.** C

Practice Problems 2

1. D	**2.** A	**3.** B	**4.** C	**5.** A	**6.** A	**7.** B	**8.** D	**9.** A	**10.** B
11. D	**12.** C	**13.** B	**14.** D	**15.** B	**16.** B	**17.** D	**18.** A	**19.** A	**20.** C
21. B	**22.** C								

Previous Years' Questions

1. B