JEPPIAAR INSTITUTE OF TECHNOLOGY

“Self-Belief | Self Discipline | Self Respect”

DEPARTMENT

OF

ELECTRONICS AND COMMUNICATION ENGINEERING

LECTURE NOTES

EC8351 – ELECTRONIC CIRCUITS 1

(Regulation 2017)

Year/Semester: II/03

2021 – 2022

Prepared by

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SYLLABUS

EC8351 **ELECTRONIC CIRCUITS 1** **L T P C 3 0 0 3**

OBJECTIVES:

- To understand the methods of biasing transistors
- To design and analyze single stage and multistage amplifier circuits
- To analyze the frequency response of small signal amplifiers
- To design and analyze the regulated DC power supplies.
- To troubleshoot and fault analysis of power supplies

UNIT I BIASING OF DISCRETE BJT, JFET AND MOSFET

BJT– Need for biasing — DC Load Line and Bias Point — DC analysis of Transistor circuits — Various biasing methods of BJT — Bias Circuit Design — Thermal stability — Stability factors — Bias compensation techniques using Diode, thermistor and sensistor — Biasing BJT Switching Circuits- JFET — DC Load Line and Bias Point — Various biasing methods of JFET — JFET Bias Circuit Design — MOSFET Biasing — Biasing FET Switching Circuits.

UNIT II BJT AMPLIFIERS

Small Signal Hybrid p equivalent circuit of BJT — Early effect — Analysis of CE, CC and CB amplifiers using Hybrid p equivalent circuits — AC Load Line Analysis- Darlington Amplifier — Bootstrap technique — Cascade, Cascode configurations — Differential amplifier, Basic BJT differential pair — Small signal analysis and CMRR.

UNIT III SINGLE STAGE FET, MOSFET AMPLIFIERS

Small Signal Hybrid p equivalent circuit of FET and MOSFET — Analysis of CS, CD and CG amplifiers using Hybrid p equivalent circuits — Basic FET differential pair- BiCMOS circuits.

UNIT IV FREQUENCY RESPONSE OF AMPLIFIERS

Amplifier frequency response — Frequency response of transistor amplifiers with circuit capacitors — BJT frequency response — short circuit current gain — cut off frequency — fa, fß and unity gain bandwidth — Miller effect — frequency response of FET — High frequency analysis of CE and MOSFET CS amplifier — Transistor Switching Times.

UNIT V POWER SUPPLIES AND ELECTRONIC DEVICE TESTING

Linear mode power supply — Rectifiers — Filters — Half-Wave Rectifier Power Supply — Full- Wave Rectifier Power Supply — Voltage regulators: Voltage regulation — Linear series, shunt and switching Voltage Regulators — Over voltage protection — BJT and MOSFET — Switched mode power supply (SMPS) — Power Supply Performance and Testing — Troubleshooting and Fault Analysis, Design of Regulated DC Power Supply.

TOTAL: 45 PERIODS

OUTCOMES:

After studying this course, the student should be able to:

•Acquire knowledge of ♣Working principles, characteristics and applications of BJT and FET♣Frequency response characteristics of BJT and FET amplifiers

•Analyze the performance of small signal BJT and FET amplifiers - single stage and multi stage amplifiers

•Apply the knowledge gained in the design of Electronic circuits

TEXT BOOKS:

1. Donald. A. Neamen, Electronic Circuits Analysis and Design, 3rd Edition, Mc Graw Hill Education (India) Private Ltd., 2010. (Unit I-IV)

2. Robert L. Boylestad and Louis Nasheresky, ―Electronic Devices and Circuit Theory‖, 11thEdition, Pearson Education, 2013. (Unit V)

REFERENCES

1. Millman J, Halkias.C.and Sathyabrada Jit, Electronic Devices and Circuits, 4th Edition, Mc Graw Hill Education (India) Private Ltd., 2015.
2. Salivahanan and N. Suresh Kumar, Electronic Devices and Circuits, 4th Edition, , Mc Graw Hill Education (India) Private Ltd., 2017.
3. Floyd, Electronic Devices, Ninth Edition, Pearson Education, 2012.
4. David A. Bell, Electronic Devices & Circuits, 5th Edition, Oxford University Press, 2008.
5. Anwar A. Khan and Kanchan K. Dey, A First Course on Electronics, PHI, 2006.
6. Rashid M, Microelectronics Circuits, Thomson Learning, 2007

UNIT IV

4.1 General shape of frequency response of amplifiers

An audio frequency amplifier which operates over audio frequency range extending from 20 Hz to 20 kHz. Audio frequency amplifiers are used in radio receivers, large public meeting and various announcements to be made for the passengers on railway platforms. Over the range of frequencies at which it is to be used an amplifier should ideally provide the same amplification for all frequencies. The degree to which this is done is usually indicated by the curve known as frequency response curve of the amplifier.

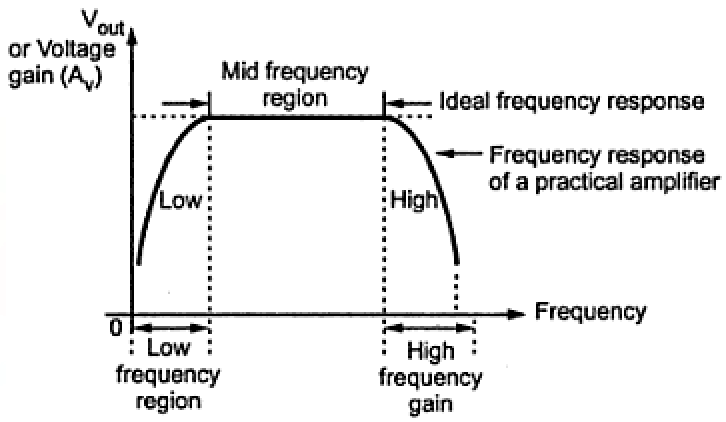


Fig. A typical frequency response of an amplifier

To plot this curve, input voltage to the amplifier is kept constant and frequency of input signal is continuously varied. The output voltage at each frequency of input signal is noted and the gain of the amplifier is calculated. For an audio frequency amplifier, the frequency range is quite large from 20 Hz to 20 kHz. In this frequency response, the gain of the amplifier remains constant in mid-frequency while the gain varies with frequency in low and high frequency regions of the curve. Only at low and high frequency ends, gain deviates from ideal characteristics. The decrease in voltage gain with frequency is called roll-off.

4.2 Definition of cut-off frequencies and bandwidth:

The range of frequencies can be specified over which the gain does not deviate more than 70.7% of the maximum gain at some reference mid-frequency.

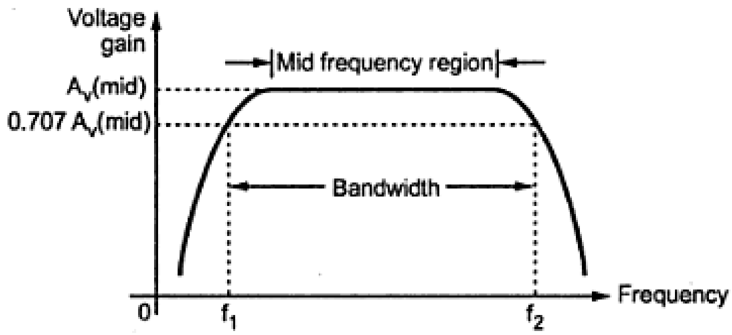


Fig. Frequency response, half power frequencies and bandwidth of an RC coupled amplifier

From above figure, the frequencies f_1 & f_2 are called lower cut-off and upper cut-off frequencies.
Bandwidth of the amplifier is defined as the difference between f_2 & f_1.
Bandwidth of the amplifier = $f_2 - f_1$

The frequency f_2 lies in high frequency region while frequency f_1 lies in low frequency region. These two frequencies are also called as half-power frequencies since gain or output voltage drops to 70.7% of maximum value and this represents a power level of one half the power at the reference frequency in mid-frequency region.

4.3 Low frequency analysis of amplifier to obtain lower cut-off frequency:

4.3.1 Decibel Unit:

The decibel is a logarithmic measurement of the ratio of one power to another or one voltage to another. Voltage gain of the amplifier is represented in decibels (dBs). It is given by,

$$\text{Voltage gain in dB} = 20 \log A_v$$

Power gain in decibels is given by,

$$\text{Power gain in dB} = 10 \log A_p$$

Where A_v is greater than one, gain is positive and when A_v is less than one, gain is negative. The positive and negative gain indicates that the amplification and attenuation respectively. Usually the maximum gain is called mid frequency range gain is assigned a 0 db value. Any value of gain below mid frequency range can be referred as 0 db and expressed as a negative db value.

Example:

Assume that mid frequency gain of a certain amplifier is 100. Then,

Voltage gain = 20 log 100 = 40 db

At f_1 and f_2 $A_v = 100/\sqrt{2} = 70.7$

Voltage gain at f_1 = Voltage gain at f_2 = 20 log 70.7 = 37 db

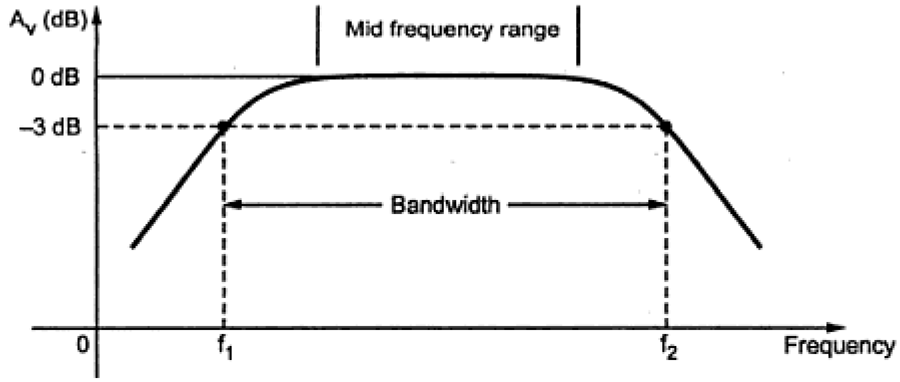


Fig. Normalized voltage gain vs frequency

From above figure, it shows that the voltage gain at f_1 and f_2 is less than 3db of the maximum voltage gain. Due to this the frequencies f_1 and f_2 are also called as 3 db frequencies. At f_1 & f_2 power gain drops by 3 db. For all frequencies within the bandwidth, amplifier power gain is at least half of the maximum power gain. This bandwidth is also referred to as 3 db bandwidth.

4.3.2 Significance of octaves and decades:

The octaves and decades are the measures of change in frequency. A ten times change in frequency is called a decade. Otherwise, an octave corresponds to a doubling or halving of the frequency.

Example:

An increase in frequency from 100 Hz to 200 Hz is an octave.

A decrease in frequency from 100 kHz to 50 kHz is also an octave.

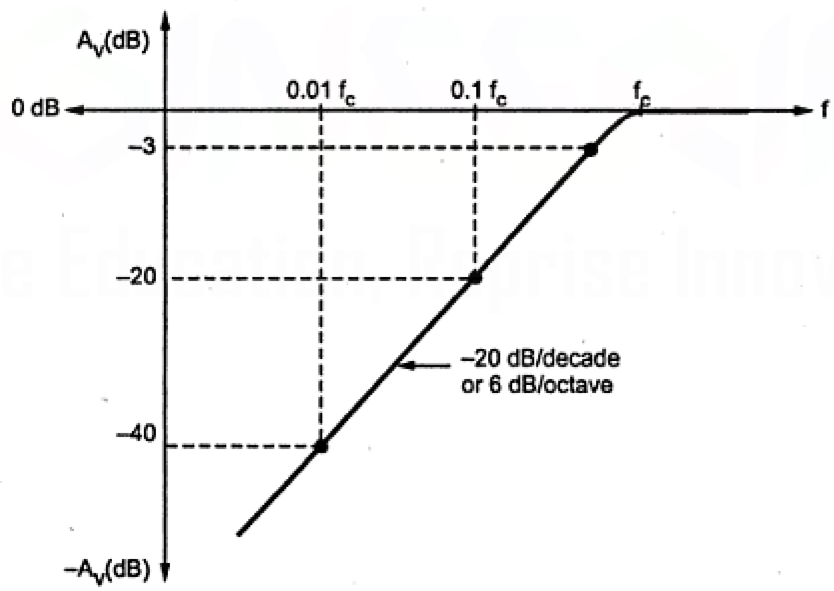


Fig. Frequency response showing significance of decade and octave

At lower and higher frequencies the decrease in the gain of amplifiers is often indicated in terms of db/decades or db/octaves. If the attenuation in gain is 20 db for each decade, then it is indicated by line having slope of 20 db/decade. A rate of -20 db/decade is approximately equivalent to -6db/octave. A rate of -40 db/decade is approximately equivalent to -12db/octave.

4.3.3 Midband gain:

It is defined as the band of frequencies between 10 f_1 and 0.1 f_2. It is denoted as midband gain or A_{mid}.

The voltage gain of the amplifier outside the midband is approximately given as,

$$A = \frac{A_{mid}}{\sqrt{1+(f_1/f)^2}\sqrt{1+(f/f_2)^2}}$$

In midband,

$$f_1/f \approx 0 \text{ and } f/f_2 \approx 0.$$

Midband:

$$A = A_{mid}$$

Below the midband,

$$f/f_2 \approx 0$$

As a result, the equation becomes,

Below midband:

$$A = \frac{A_{mid}}{\sqrt{1+(f_1/f)^2}}$$

Above midband,

$$f_1/f \approx 0.$$

As a result, the equation becomes,

Above midband:

$$A = \frac{A_{mid}}{\sqrt{1+(f/f_2)^2}}$$

Problem:

For an amplifier, midband gain = 100 and lower cutoff frequency is 1 kHz. Find the gain of an amplifier at frequency 20 Hz.

Solution:

Below midband:

$$A = \frac{A_{mid}}{\sqrt{1+(f_1/f)^2}}$$

$$A = \frac{100}{\sqrt{1+\left(\frac{1000}{20}\right)^2}} = 2$$

4.4 Effect of various capacitors on frequency response:

4.4.1 Effect of coupling capacitors:

The reactance of the capacitor is $X_c = 1/2\prod f_c$

At medium and high frequencies, the factor f makes X_c very small, so that all coupling capacitors behave as short circuits. At low frequencies, X_c increases. This increase in X_c drops the signal voltage across the capacitor and reduces the circuit gain. As signal frequencies decrease, capacitor reactance increase and gain continues to fall, reducing the output voltage.

4.4.2 Effect of Bypass capacitors:

At lower frequencies, bypass capacitor C_E is not a short. So emitter is not at ac ground. X_c in parallel with R_E creates an impedance. The signal voltage drops across this impedance reducing the circuit gain.

4.4.3 Effect of internal transistor capacitances:

At high frequencies, coupling and bypass capacitors act as short circuit and do not affect the amplifier frequency response. At high frequencies, internal capacitances, commonly known as junction capacitances. The following figure shows the junction capacitances for both BJT and FET. Incase of BJT, C_{be} is the base emitter junction capacitance and C_{bc} is the base collector junction capacitance. Incase of FET, C_{gs} is the internal capacitance between gate and source and C_{gd} is the internal capacitance between gate and drain.

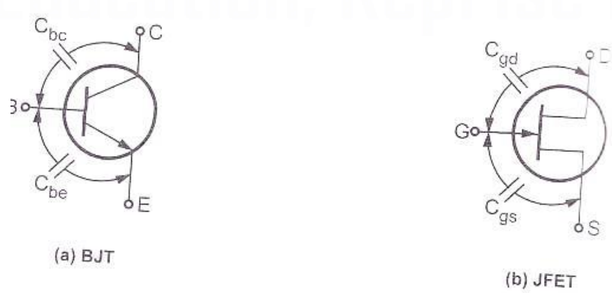


Fig. Internal transistor capacitances

4.5 Miller Theorem:

In transistor amplifiers, it is necessary to split the capacitance between input and output. It can be achieved by using miller's theorem. In the following figure, A_v

represents absolute voltage gain of the amplifier at midrange frequencies and C represents either C_{bc} (incase of BJT) or C_{gd} (incase of FET).

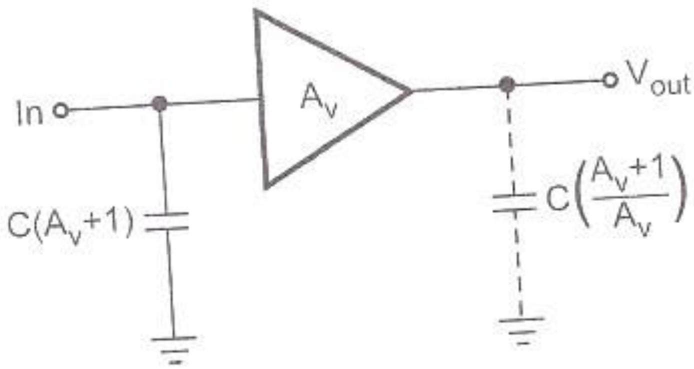


Fig. Splitting of capacitor using Miller's theorem

4.6 Low frequency analysis of BJT:

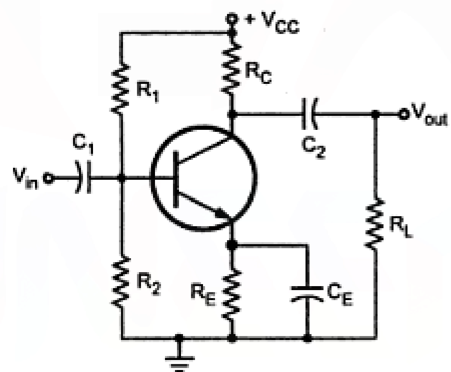


Fig. Typical RC coupled common emitter amplifier

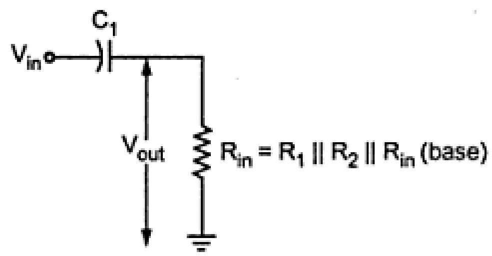
From above figure, it has three RC networks that affect its gain as the frequency is reduces below midrange. These are,

1. RC network formed by the input coupling capacitor C_1 and input impedance of the amplifier.
2. RC network formed by the output coupling capacitor C_2, resistance looking in at the collector and load resistance.
3. RC network formed by the emitter bypass capacitor C_E and resistance looking in at the emitter.

Input RC network:

The following figure shows the input RC network formed by C_1 and the input impedance of the amplifier.

The resistance value is $R_{in} = R_1 \parallel R_2 \parallel R_{in}(base)$



Applying voltage divider rule,

$$V_{out} = \left(\frac{R_{in}}{\sqrt{R_{in}^2 + X_{C1}^2}} \right) V_{in}$$

A critical point in the amplifier response is generally accepted to occur when the output voltage is 70.7 % of the input. At critical point,

$$\frac{R_{in}}{\sqrt{R_{in}^2 + X_{C1}^2}} = 0.707 = \frac{1}{\sqrt{2}}$$

At this condition, $R_{in} = X_{c1}$

Overall gain is reduced due to attenuation provided by the input RC network. The reduction in overall gain is given by,

$$A_v = 20 \log \left(\frac{V_{out}}{V_{in}} \right) = 20 \log (0.707) = -3 \text{ dB}$$

The frequency f_c at this condition is called lower critical frequency and it is given by,

$$f_c = \frac{1}{2 \pi R_{in} C_1}$$

where $R_{in} = R_1 || R_2 || h_{ie}$

$$\therefore \quad f_c = \frac{1}{2 \pi (R_1 || R_2 || h_{ie}) C_1}$$

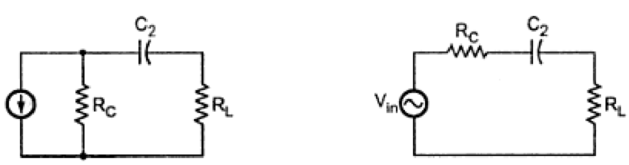
If the resistance of input source is taken into account the above equation becomes,

$$f_c = \frac{1}{2 \pi (R_s + R_{in}) C_1}$$

The phase angle in an input RC circuit is expressed as

$$\theta = \tan^{-1} \left(\frac{X_{C1}}{R_{in}} \right)$$

Output RC network:



(a) Current source (b) Current source replaced by voltage source

The above figure shows the output RC network formed by C_2, resistance looking in at the collector and load resistance.

The critical frequency for this RC network is given by,

$$f_c = \frac{1}{2\pi(R_C + R_L)C_2}$$

The phase angle in output RC network is given as,

$$\theta = \tan^{-1}\left(\frac{X_{C2}}{R_C + R_L}\right)$$

Bypass network:

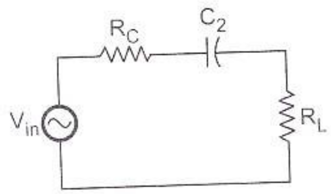


Fig. Current source replaced by voltage source

From above figure,

$$\left(\frac{h_{ie} + R_{TH}}{\beta}\right)$$

is the resistance looking in at the emitter. It is derived as follows,

R= $(V_b / \beta I_b) + h_{ie} / \beta$

$$= \frac{I_b R_{TH}}{\beta I_b} + \frac{h_{ie}}{\beta} = \frac{R_{TH} + h_{ie}}{\beta}$$

Where $R_{TH} = R_1 \parallel R_2 \parallel R_s$. It is the thevenin's equivalent resistance looking from the base of the transistor towards the input.

The critical frequency for the bypass network is

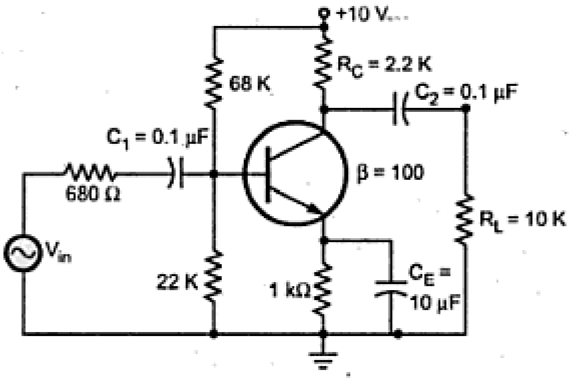
$$f_c = \frac{1}{2\pi R C_E}$$

or

$$f_c = \frac{1}{2\pi\left[\left(\frac{h_{ie} + R_{TH}}{\beta}\right) \parallel R_E\right] C_E}$$

Problem:

Determine the low frequency response of the amplifier circuit shown in the figure.



Solution:

It is necessary to analyze each network to determine the critical frequency of the amplifier.

a) Input RC network

$$f_c \text{ (input)} = \frac{1}{2\pi[R_s + (R_1 \parallel R_2 \parallel h_{ie})]C_1}$$

$$= \frac{1}{2\pi[680 + (68\text{ K} \parallel 22\text{ K} \parallel 1.1\text{ K})] \times 0.1 \times 10^{-6}}$$

$$= \frac{1}{2\pi[680 + 1031.7] \times 0.1 \times 10^{-6}} = 929.8\text{ Hz}$$

b) Output RC network

$$f_{c\,(output)} = \frac{1}{2\pi(R_C + R_L)C_2} = \frac{1}{2\pi(2.2\text{K}+10\text{K}) \times 0.1 \times 10^{-6}} = 130.45\text{ Hz}$$

c) Bypass RC network

$$f_{c\,(bypass)} = \frac{1}{2\pi\left[\left(\frac{R_{TH} + h_{ie}}{\beta}\right) \parallel R_E\right]C_E}$$

$$R_{TH} = R_1 \parallel R_2 \parallel R_s = 68\text{ K} \parallel 22\text{ K} \parallel 680 = 653.28\ \Omega$$

$$f_{c\,(bypass)} = \frac{1}{2\pi\left[\left(\frac{653.28 + 1100}{100}\right) \parallel 1\text{K}\right] \times 10 \times 10^{-6}} = \frac{1}{2\pi(17.23) \times 10 \times 10^{-6}} = 923.7$$

The above analysis shows that the input network produces the dominant lower critical frequency. Then the low frequency response of the given amplifier is shown in the following figure.

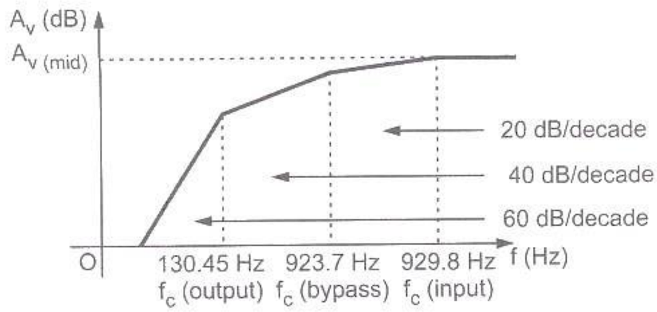


Fig. Low frequency response of the amplifier

4.7 Low frequency analysis of FET amplifier:

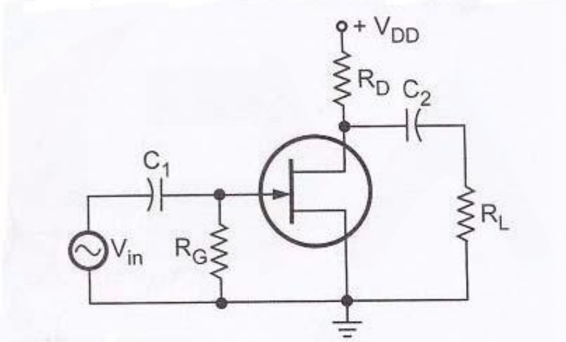


Fig. Typical RC coupled common source amplifier

From above figure, it has two RC networks that affect its gain as the frequency is reduced below midrange. These are,

1. RC network formed by the input coupling capacitor C_1 and input impedance of the amplifier.
2. RC network formed by the output coupling capacitor and the output impedance looking in at the drain.

`Input RC network:

Lower critical frequency of this network is given as,

$$f_c = \frac{1}{2\pi R_{in} C_1}$$

where $R_{in} = R_G \,||\, R_{in\,(gate)}$

The value of R_{in}(gate) can be determined from the data sheet as follows:

$$R_{in\,(gate)} = \left| \frac{V_{GS}}{I_{GSS}} \right|$$

where I_{GSS} is the gate reverse current.

The phase shift in low frequency input RC circuit is $\theta = \tan^{-1} (X_{C1} / R_{in})$

Output RC network:

Lower critical frequency of this network is given as,

$$f_c = \frac{1}{2\pi(R_D + R_L)C_2}$$

The phase shift in low frequency output RC circuit is $\theta = \tan^{-1} (X_{C2} / R_D + R_L)$

4.8 Hybrid - π equivalent circuits of BJTs:

At low frequencies, we can analyze the transistor using h-parameters. But for high frequency, analysis of h-parameter model is not suitable for following reasons.

1. The values of h-parameters are not constant at high frequencies. So it is necessary to analyze transistor at each and every frequency which is impractical.
2. At high frequency h-parameters become complex in nature.

Due to the above reasons, modified T model and hybrid ∏ models are used for high frequency analysis of the transistor. These models give a reasonable compromise between accuracy and simplicity to do high frequency analysis of the transistor.

4.4.1 Hybrid - π common emitter transistor model:

Common emitter circuit is most important practical configuration and this is useful for the analysis of transistor using hybrid - ∏ model. The following figure shows the hybrid - ∏ model for a transistor in CE configuration. For this model, all parameters are assumed to be independent of frequency. But they may vary with the quiescent operating point.

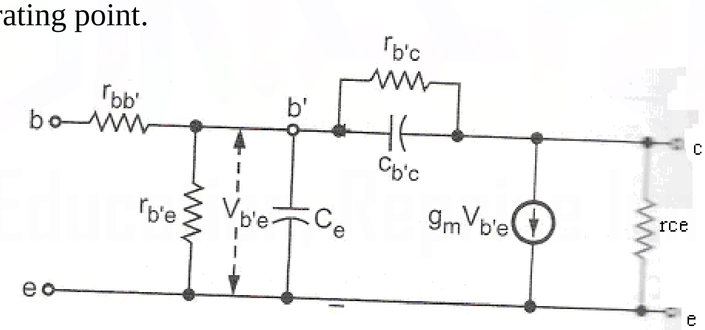


Fig. Hybrid - ∏ model for a transistor in CE configuration

4.8.1 Elements in hybrid – π model:

$C_{b'e}$ and $C_{b'c}$: Forward biased PN junction exhibits a capacitive effect called diffusion capacitance. This capacitive effect of normally forward biased base-emitter junction of the transistor is represented by $C_{b'e}$ or C_e. The diffusion capacitance is connected between b' and e represents the excess minority carrier storage in the base.

The reverse bias PN junction exhibits a capacitive effect called transition capacitance. This capacitive effect of normally reverse biased collector base junction of the transistor is represented by $C_{b'c}$ or C_c.

$r_{bb'}$: The internal node b' is physically not accessible bulk node b represents external base terminal.
$r_{b'e}$: It is the portion of the base emitter which may be thought of as being in series with the collector junction. This establishes a virtual base b' for junction capacitances to be connected instead of b.
$r_{b'c}$: Due to early effect, varying voltages across collector to emitter junction results in base-width modulation. A change in the effective base-width causes the emitter current to change. This feedback effect between output and input is taken into account by connecting $g_{b'c}$ or $r_{b'c}$ between b' and c.
g_m: Due to small changes in voltage $V_{b'e}$ across emitter junction, there is excess minority carrier concentration injected into the base which is proportional to $V_{b'e.}$ So resulting small signal collector current with collector shorted to the emitter is also proportional to $V_{b'e.}$
g_m is also called as transconductance and it is given as,

$$g_m = \frac{\Delta I_C}{\Delta V_{b'e}} \text{ at a constant } V_{CE}$$

r_{ce}: It is the output resistance. It is also the result of early effect.

4.4.1.2 Hybrid – π parameter values:

The following table shows the typical values for hybrid - π parameters at room temperature and for I_c = 1.3mA.

Parameter	**Meaning**	**Value**
g_m	Mutual conductance	50mA/V
$r_{bb'}$	Base spreading resistance	100Ω
$r_{b'e}$ or $g_{b'e}$	Resistance between b' and e Conductance between b' and e	1kΩ 1m mho
$r_{b'c}$ or $g_{b'c}$	Resistance of reverse biased PN junction between base and collector Conductance of reverse biased PN junction between base and collector	4MΩ $0.25*10^{-6}$ mho
r_{ce} or g_{ce}	Output resistance between c and e Conductance between c and e	80kΩ $12.5*10^{-6}$ mho
C_e	Junction capacitance between b and e	100pF
C_c	Junction capacitance between base and collector	3pF

4.8.2 Hybrid – π conductances:

4.8.2.1 Transistor Transconductance g_m:

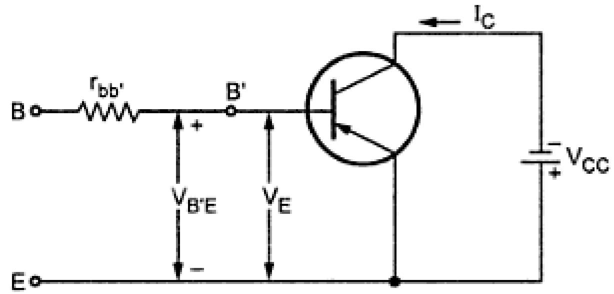


Fig. Pertaining to the derivation of g_m

Let us consider a p-n-p transistor in CE configuration with V_{cc} bias in the collector circuit as shown in the above figure.

Transconductance g_m is given as,

$$g_m = \left.\frac{\partial I_C}{\partial V_{B'E}}\right|_{V_{CE}}$$

The collector current in active region is given as,

$$I_C = I_{CO} - \alpha I_E$$

$$\partial I_C = \alpha\, \partial I_E \quad \because I_{CO} = \text{constant.}$$

Substituting value of ∂I_C

$$g_m = \alpha \frac{\partial I_E}{\partial V_{B'E}} \equiv \alpha \frac{\partial I_E}{\partial V_E} \quad \because V_E = V_{B'E}$$

The emitter diode resistance, r_e is given as,

$$r_e = \frac{\partial V_E}{\partial I_E}$$

$$\frac{1}{r_e} = \frac{\partial V_E}{\partial I_E}$$

Substituting r_e in place of $\partial I_E / \partial V_E$ we get,

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

The emitter diode is a forward biased diode and its dynamic resistance is given as,

$$r_e = \frac{V_T}{I_E}$$

The emitter diode is a forward biased diode and its dynamic resistance is given as,

$$r_e = \frac{V_T}{I_E}$$

where V_T is the "volt equivalent of temperature", defined by

$$V_T = \frac{KT}{q}$$

where K is the Boltzmann constant in joules per degree kelvin (1.38×10^{-23}J/°K) is the electronic charge (1.6×10^{-19} C).

Substituting value of r_e in equation (3) we get,

$$g_m = \frac{\alpha I_E}{V_T} = \frac{I_{CO} - I_C}{V_T} \quad \because\ I_C = I_{CO} - \alpha I_E$$

For p-n-p transistor I_C is negative. For an n-p-n transistor I_C is positive, but the foregoing analysis (with $V_E = +V_{BE}$) leads to $g_m = (I_C - I_{CO})/V_T$.

Hence, for either type of transistor, g_m is positive.

$$g_m = \frac{I_C - I_{CO}}{V_T} \qquad \because\ I_C >> I_{CO}$$

For I_c = 1.3mA, g_m = 0.05mho or 50 mA/V. For I_c = 7.8mA, g_m = 0.3mho or 300mA/V. These values are much larger than the transconductances obtained with FETs.

4.8.2.2 Input Conductance $g_{b'e}$:

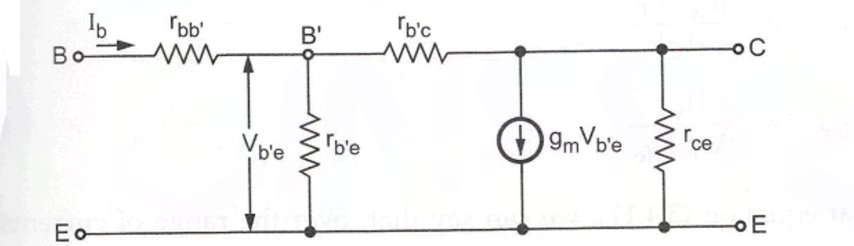


Fig. Hybrid - π model for CE configuration at low frequency

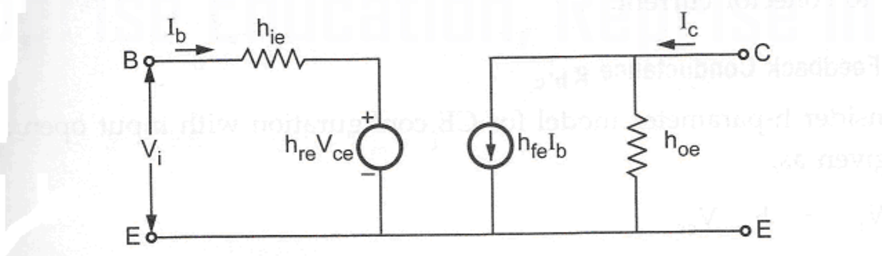


Fig. h-parameter model for CE configuration at low frequency

First consider h-parameter model for CE configuration. Applying KCL to output circuit,

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

Making V_{ce} = 0, the short circuit current gain h_{fe} is defined as,

$$h_{fe} = \frac{I_C}{I_b}$$

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

$$= g_m I_b r_{b'e} \qquad \because V_{b'e} = I_b r_{b'e}.$$

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

Substituting the value of I_C / I_b,

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

or

$$r_{b'e} = \frac{h_{fe}}{g_m} \quad \text{or} \quad g_{b'e} = \frac{g_m}{h_{fe}}$$

$$g_m = I_C / V_T$$

$$\therefore \qquad r_{b'e} = \frac{h_{fe} V_T}{|I_C|}$$

$$\text{or} \qquad g_{b'e} = \frac{|I_C|}{V_T h_{fe}}$$

4.8.2.3 Feedback Conductance $g_{b'c}$:

Let us consider h-parameter model for CE configuration with input open circuit ($I_b = 0$), V_i is given as,

$$V_i = h_{re} V_{ce}$$

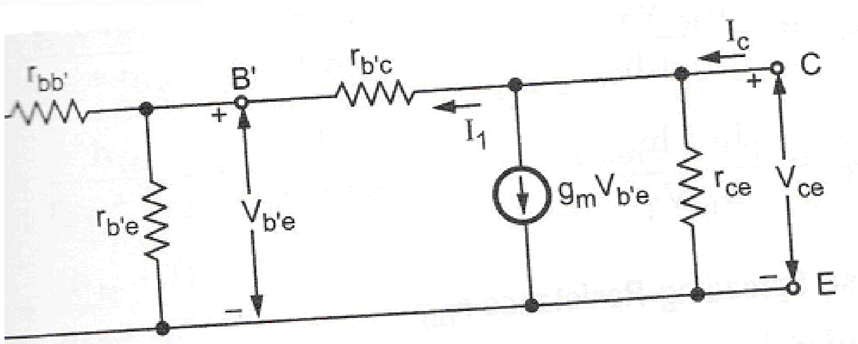


Fig. Hybrid –π model for CE configuration

With $I_b = 0$, V_{ce} is given as,

$$V_{ce} = I_1 \left(r_{b'c} + r_{b'e}\right)$$

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

Voltage between b' and e, $V_{b'e}$ can be given as,

$$V_{b'e} = I_1 \, r_{b'e}$$

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

With $I_b = 0$,
$V_i = V_{b'e}$

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

Substituting the value of V_i,

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

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

$$= h_{re} \, r_{b'c} + h_{re} \, r_{b'e}$$

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

$$= \frac{r_{b'e}}{h_{re}} \qquad \because 1 - h_{re} \approx 1$$

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

Substituting the value of $r_{b'e}$,

$$r_{b'c} = \frac{h_{fe} V_T}{|I_C| h_{re}}$$

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

4.8.2.4.Base Spreading Resistance $r_{bb'}$:

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

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

Substituting the value of $r_{b'e}$,

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

4.8.2.5 Output Resistance g_{ce}:

Using h-parameters output conductance is given as,

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

Applying KCL to the output circuit,

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

$$1/r_{ce} = g_{ce} = h_{oe} - g_{b'c} h_{fe}$$

Relation between hybrid-π and h-parameters:

Sr. No.	Parameter relation
1.	$g_m = \frac{I_C}{V_T}$
2.	$r_{b'e} = \frac{h_{fe}}{g_m}$
3.	$r_{bb'} = h_{ie} - r_{b'e}$
4.	$r_{b'c} = \frac{r_{b'e}}{h_{re}}$
5.	$g_{ce} = \frac{1}{r_{ce}} = h_{oe} - g_{b'c}\, h_{fe}$

4.4.3 Hybrid – π capacitances:

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

$$C_e = \frac{gm}{2\pi f_t}$$

4.4.4 CE short circuit current gain using hybrid- π model:

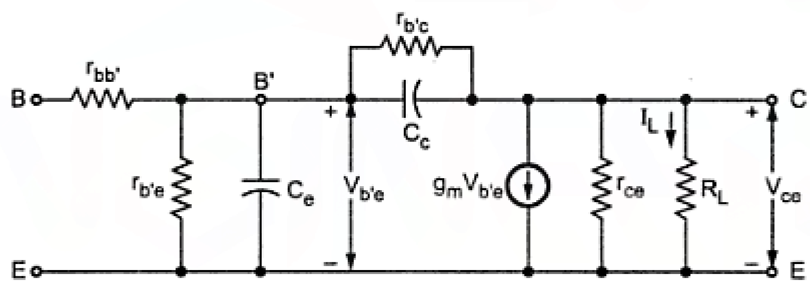


Fig. Hybrid- π model for a single transistor with a resistive load R_L

Miller capacitance is $C_M = C_{b'c}\,(1 + g_m R_L)$

Here, $R_L = 0$

$\therefore \quad C_M = C_{b'c}\,(C_c)$

Parallel combination of $r_{b'e}$, and $(C_e + C_c)$ is given as

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

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

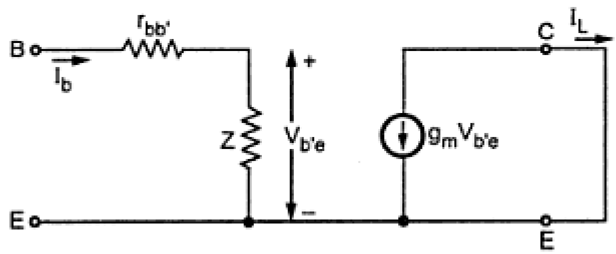


Fig. Further simplified hybrid - π model

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

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

The current gain for the circuit is,

$$A_i = \frac{I_L}{I_b} = \frac{-g_m V_{b'e}}{I_b} \quad \because I_L = -g_m V_{b'e}$$

$$A_i = -g_m Z$$

$$= \frac{-g_m r_{b'e}}{1 + j\omega r_{b'e}(C_e + C_c)}$$

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

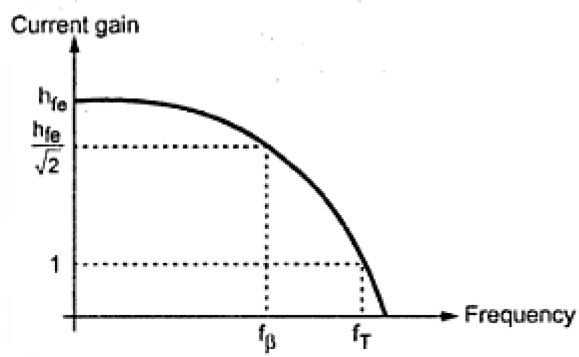


Fig. Frequency vs current gain

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

$$A_i = \frac{-h_{fe}}{1 + j\frac{f}{f_\beta}}$$

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

f_β (Cutoff frequency):

It is the frequency at which the transistor short circuit CE current gain drops by 3dB or 1/√√2 times from its value at low frequency. It is given as,

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

or

$$= \frac{g_{b'e}}{2\pi (C_e + C_c)}$$

or

$$= \frac{1}{h_{fe}} \frac{g_m}{2\pi (C_e + C_c)} \quad \because \; g_{b'e} = \frac{1}{r_{b'e}} = \frac{g_m}{h_{fe}}$$

f_α (Cut-off frequency):

It is the frequency at which the transistor short circuit CB current gain drops by 3dB or 1/√√2 times from its value at low frequency.
The current gain for CB configuration is given as,

$$A_i = \frac{-h_{fb}}{1 + j\frac{f}{f_\alpha}}$$

where

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

$$= \frac{1 + h_{fe}}{2\pi r_{b'e} C_e} \approx \frac{h_{fe}}{2\pi r_{b'e} C_e}$$

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

At

$$f = f_\alpha$$

$$|A_i| = \frac{h_{fb}}{\sqrt{2}}$$

Parameter f_T:

It is the frequency at which short circuit CE current gain becomes unity.
At $f = f_T$,

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

The ratio of f_T / f_β is quite large compared to 1.

$f_T = g_m / 2\pi C_e$

Problem:

Short circuit CE current gain of transistor is 25 at a frequency of 2MHz if f_β = 200 kHz. Calculate (i) f_T (ii) h_{fe} (iii) Find $|A_i|$ at a frequency of 10 MHz and 100 MHz.

Solution:

i) $f_T = |A_i| \times f = 25 \times 2 \times 10^6$

$= 50$ MHz

ii) $h_{fe} = \frac{f_T}{f_\beta} = \frac{50\text{ MHz}}{200\text{ kHz}} = 250$ kHz

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

At $f = 10$ MHz

$$|A_i| = \frac{250}{\sqrt{1+\left(\frac{10\times 10^6}{200\times 10^3}\right)^2}} = 5$$

At $f = 100$ MHz

$$|A_i| = \frac{250}{\sqrt{1+\left(\frac{100\times 10^6}{200\times 10^3}\right)^2}} = 0.5$$

4.4.5 Current gain with resistive load:

$$C_{eq} = C_e + C_c\,(1 + g_m\,R_L)$$

For further simplification,

At output circuit value of C_c can be calculated as,

$$\frac{\dfrac{1}{j\omega C_c}}{\dfrac{k-1}{k}} \approx \frac{1}{j\omega C_c} \qquad \because\ k = -100$$

$$\therefore \quad C_c\left(\frac{k}{k-1}\right) \approx C_c$$

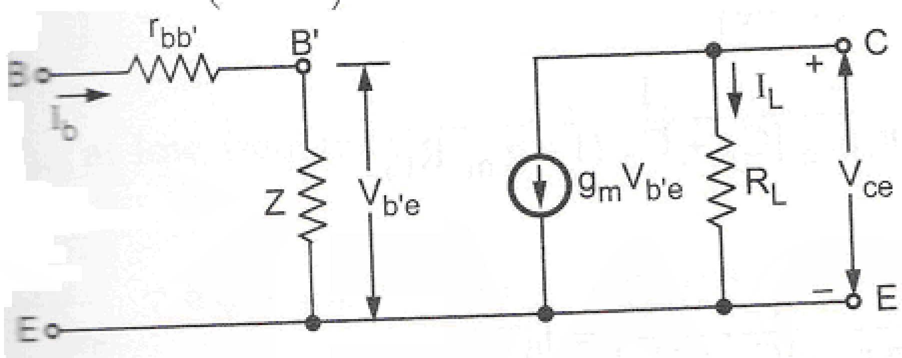


Fig. Simplified hybrid – π model for CE with R_L

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

$$A_i = \frac{-h_{fe}}{1 + j\left(\dfrac{f}{f_H}\right)}$$

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

At

$$f = f_H$$

$$A_i = \frac{h_{fe}}{\sqrt{2}}$$

f_H is the frequency at which the transistor gain drops by 3dB or $1/\sqrt{2}$ times from its value at low frequency. It is given as,

$$f_H = \frac{1}{2\pi r_{b'e} C_{eq}}$$

$$= \frac{1}{2\pi r_{b'e} [C_e + C_c (1 + g_m R_{L)}]}$$

At

$$R_L = 0$$

$$f_H = \frac{1}{2\pi r_{b'e} [C_e + C_c]} = f_\beta$$

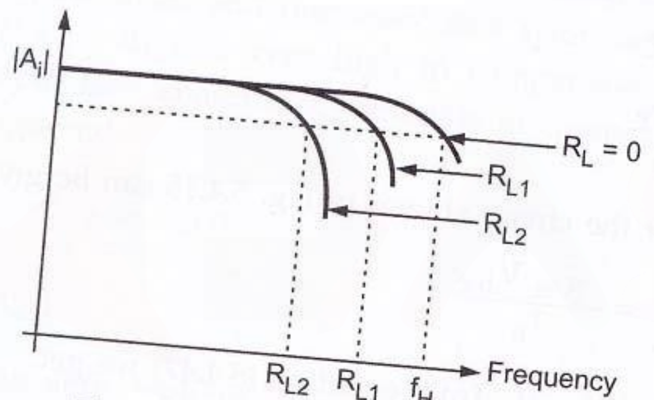


Fig. Variation f_H with R_L

4.8.6 Current gain including source resistance:

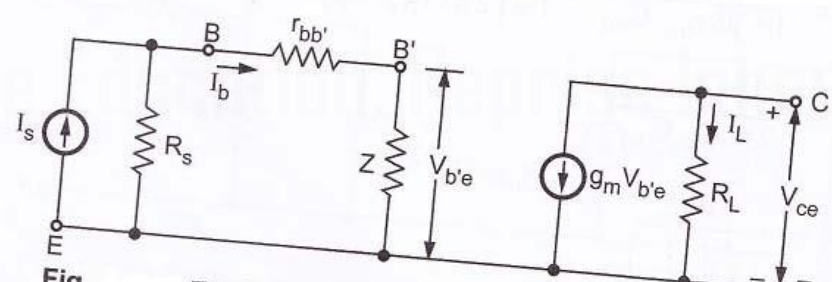


Fig. Equivalent circuit assuming current source

$$\frac{I_L}{I_s} = \frac{-g_m r_{b'e} R_s}{R_s + r_{bb'} + r_{b'e}}$$

A_{is} at low frequency =

$$= \frac{- h_{fe} R_S}{R_s + h_{ie}}$$

4.8.7 Voltage gain including source resistance:

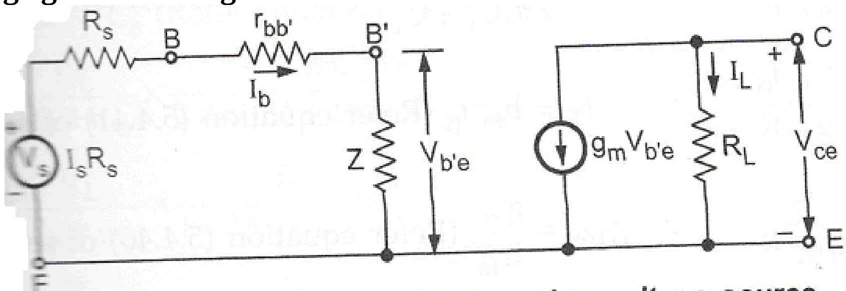


Fig. Equivalent circuit assuming voltage source

$$A_{vs} = \frac{V_o}{V_s} = \frac{I_L}{I_s}\frac{R_L}{R_s} = \frac{-g_m Z R_s}{R_s + r_{bb'} + Z} \times \frac{R_L}{R_s}$$

$$= \frac{-g_m Z R_L}{R_s + r_{bb'} + Z}$$

$$A_{vs\ low} = \frac{I_L}{I_s}\frac{R_L}{R_s} = \frac{-h_{fe} R_s}{R_s + h_{ie}} \times \frac{R_L}{R_s}$$

$$= \frac{-h_{fe} R_L}{R_s + h_{ie}}$$

4.8.8 Cutoff frequency including source resistance:

$$A_{is\ high} = \frac{A_{is}}{1 + j\left(\frac{f}{f_H}\right)}$$

$$A_{vs\ high} = \frac{A_{vs}}{1 + j\left(\frac{f}{f_H}\right)}$$

where, $f_H = \frac{1}{2\pi R_{eq} C_{eq}}$

where, $R_{eq} = r_{b'e} \parallel (r_{bb'} + R_s)$

and $C_{eq} = C_e + C_c\,[1 + g_m R_L]$

For $R_L = 0$,

$$f_H = \frac{1}{2\pi R(C_e + C_c)}$$

$$= \frac{f_T}{g_m R} \qquad \because \; f_T = \frac{g_m}{2\pi(C_e + C_c)}$$

$$= \frac{h_{fe} f_\beta}{g_m R} \qquad \because \quad f_T = h_{fe} f_\beta$$

$$= \frac{f_\beta}{g_{b'e} R} \qquad \because \; g_{b'e} = \frac{g_m}{h_{fe}}$$

4.8.9 Gain Bandwidth Product:

4.8.9.1 Gain Bandwidth Product for Voltage:

$$|A_{vs\ low}\ f_H| = |A_{vso}\ f_H| = \frac{-h_{fe} R_L}{R_s + h_{ie}} \times \frac{1}{2\pi R_{eq} C_{eq}}$$

$$= \frac{R_L}{R_s + r_{bb'}} * \frac{f_T}{1 + 2\pi f_T C_c R_L}$$

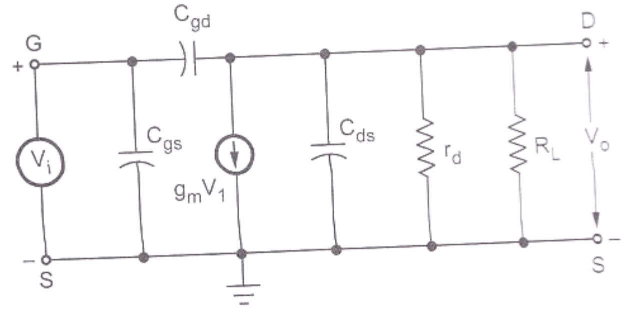
4.8.9.2 Gain Bandwidth Product for current:

$$|A_{iso} \times f_H| = \frac{g_m R_s}{2\pi C(R_s + r_{bb'})}$$

$$= \frac{f_T}{1 + 2\pi f_T C_c R_L} \cdot \frac{R_s}{R_s + r_{bb'}}$$

4.9 High frequency analysis of FET

4.9.1 Common source amplifier at high frequencies:



Small signal equivalent circuit at high frequencies

$$Y = \frac{1}{Z} = Y_L + Y_{ds} + g_d + Y_{gd}$$

where $Y_L = \frac{1}{R_L}$: admittance corresponding to R_L

$Y_{ds} = j\omega C_{ds}$: admittance corresponding to C_{ds}

$g_d = \frac{1}{r_d}$: conductance corresponding to r_d

$Y_{gd} = j\omega C_{gd}$: admittance corresponding to C_{gd}

$$I = -g_m V_i + V_i Y_{gd} = V_i(-g_m + Y_{gd})$$

Voltage gain:

The voltage gain for common source amplifier circuit with the load R_L is given by,

$$A_v = \frac{V_o}{V_i} = \frac{IZ}{V_i} = \frac{I}{V_i Y}$$

Substituting the values of I and Y from equations (2) and (3) we have,

$$A_v = \frac{-g_m + Y_{gd}}{Y_L + Y_{ds} + g_d + Y_{gd}}$$

At low frequencies, Y_{ds} and $Y_{gd} = 0$ and hence equation (4) reduces to

$$A_v = \frac{-g_m}{Y_L + g_d} = \frac{-g_m r_d Z_L}{(Y_L + g_d) r_d Z_L} = \frac{-g_m r_d Z_L}{r_d + Z_L}$$

$$= -g_m Z'_L \qquad \text{where} \quad Z'_L = r_d \parallel Z_L$$

Input Admittance:

$$Y_i = Y_{gs} + (1 - A_v) Y_{gd}$$

Input capacitance (Miller Effect):

$A_v = -g_m R'_d$ where $R'_d = r_d R_d$

Substituting the value of A_v

$$\frac{Y_i}{j\omega} \equiv C_i = C_{gs} + (1 + g_m R'_d) C_{gd}$$

This increase in input capacitance C_i over the capacitance from gate to source is called Miller effect.

This input capacitance affects the gain at high frequencies in the operation of cascaded amplifiers. In cascaded amplifiers, the output from one stage is used as the input to a second amplifier. The input impedance of a second stage acts as a shunt across output of the first stage and R_d is shunted by the capacitance C_i.

Output Admittance:

From above figure, the output impedance is obtained by looking into the drain with the input voltage set equal to zero. If $V_i = 0$ in figure, r_d , C_{ds} and C_{gd} in parallel. Hence the output admittance with R_L considered external to the amplifier is given by,

$$Y_o = g_d + Y_{ds} + Y_{gd}$$

4.9.2 Common Drain Amplifier at High Frequencies:

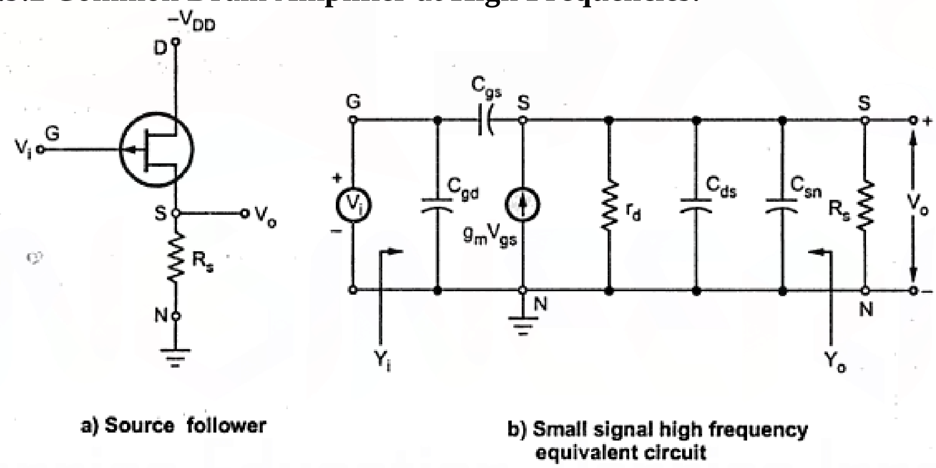


Fig. Common Drain Amplifier Circuit & Small signal equivalent circuit at high frequencies

Voltage gain:

The output voltage V_o can be found from the product of the short circuit and the impedance between terminals S and N. Voltage gain is given by,

$$\frac{V_o}{V_i} = \frac{g_m + j\omega C_{gs}}{R_s + (g_m + g_d + j\omega C_T)}$$

where $C_T \equiv C_{gs} + C_{ds} + C_{sn}$

$$A_v = \frac{(g_m + j\omega C_{gs})R_s}{1 + (g_m + g_d + j\omega C_T)R_s}$$

At low frequencies the gain reduces to

$$A_v = \frac{g_m R_s}{1 + (g_m + g_d)R_s}$$

Input Admittance:

Input Admittance Y_i can be obtained by applying Miller's theorem to C_{gs}. It is given by,

$$Y_i = j\omega C_{gd} + j\omega C_{gs}(1 - A_v) \approx j\omega C_{gd}$$

because $A_v \approx 1.$

Output Admittance:

Output Admittance Y_o with R_s considered external to the amplifier, it is given by,

$$Y_o = g_m + g_d + j\omega C_T$$

At low frequencies, output resistance R_o is given by,

$$R_o = \frac{1}{g_m + g_d} \approx \frac{1}{g_m} \qquad \text{since } g_m >> g_d$$

4.9.3 Frequency Response of Common Source Amplifier:

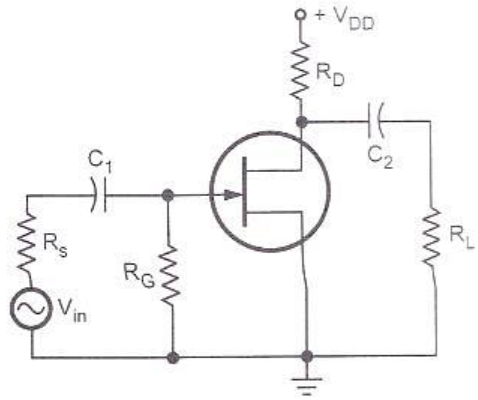


Fig. Typical RC coupled common source amplifier

Let us consider a typical common source amplifier as shown in the above figure.

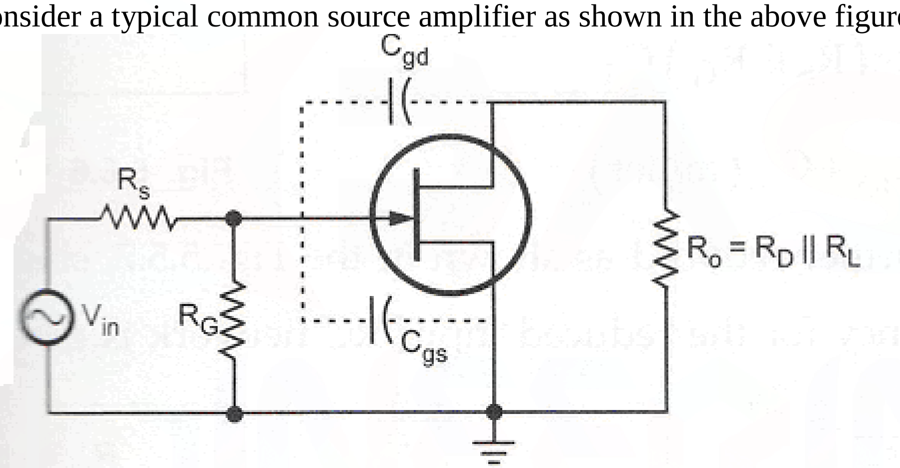


Fig. High frequency equivalent circuit

From above figure, it shows the high frequency equivalent circuit for the given amplifier circuit. It shows that at high frequencies coupling and bypass capacitors act as short circuits and do not affect the amplifier high frequency response. The equivalent circuit shows internal capacitances which affect the high frequency response.

Using Miller theorem, this high frequency equivalent circuit can be further simplified as follows:

The internal capacitance C_{gd} can be splitted into $C_{in(miller)}$ and $C_{out(miller)}$ as shown in the following figure.

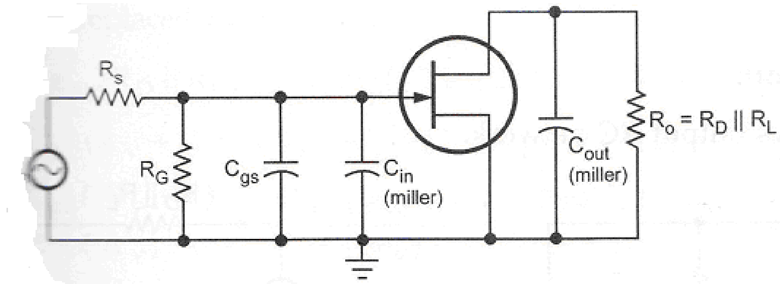


Fig. Simplified high frequency equivalent circuit

$$C_{in\,(miller)} = C_{gd}\,(A_v + 1)$$
$$C_{out\,(miller)} = C_{gd}\,\frac{(A_v + 1)}{(A_v)}$$

Where

$$C_{gd} = C_{rss}$$
$$C_{gs} = C_{iss} - C_{rss}$$

From simplified high frequency equivalent circuit, it has two RC networks which affect the high frequency response of the amplifier. These are,

1. Input RC network
2. Output RC network

Input RC network:

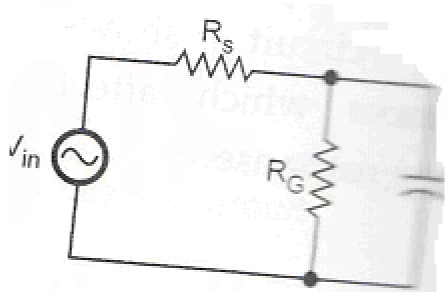


Fig. Input RC network

From above figure,

$$f_{c(input)} = \frac{1}{2\pi(R_S \parallel R_G)C_T}$$

where $C_T = C_{gs} + C_{in}(miller)$

This network is further reduced as follows since $R_s \ll R_G$

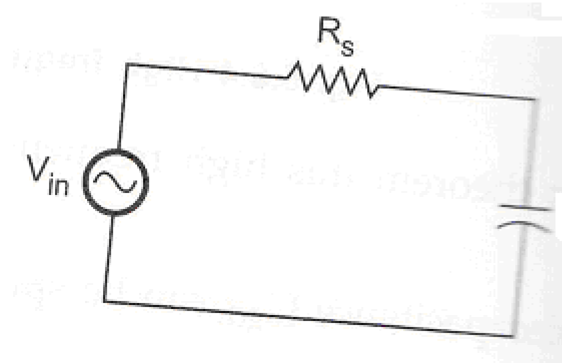


Fig. Reduced input RC network

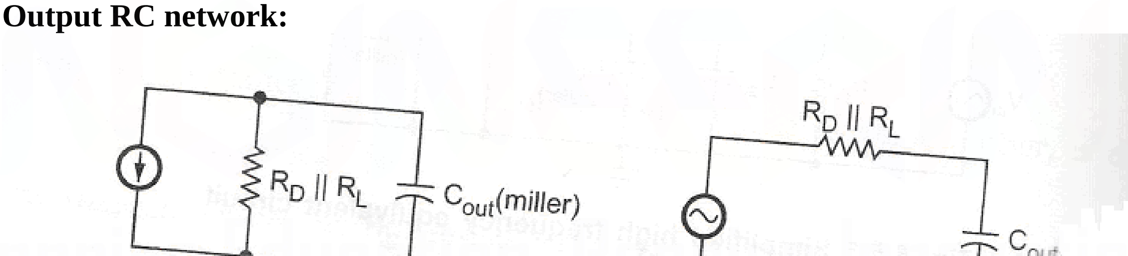
The critical frequency for the reduced input RC network is,

$$f_{c\,(input)} = \frac{1}{2\pi R_s\, C_T}$$

$$\text{or} \quad f_c = \frac{1}{2\pi R_s\, [C_{gs} + C_{in\,(miller)}]}$$

The phase shift in high frequency RC network is $\theta = \tan^{-1}\left(\frac{R_s}{X_{C_T}}\right)$

Output RC network:



(a) Output network with current source (b) Output network with voltage source

Fig. Output RC network

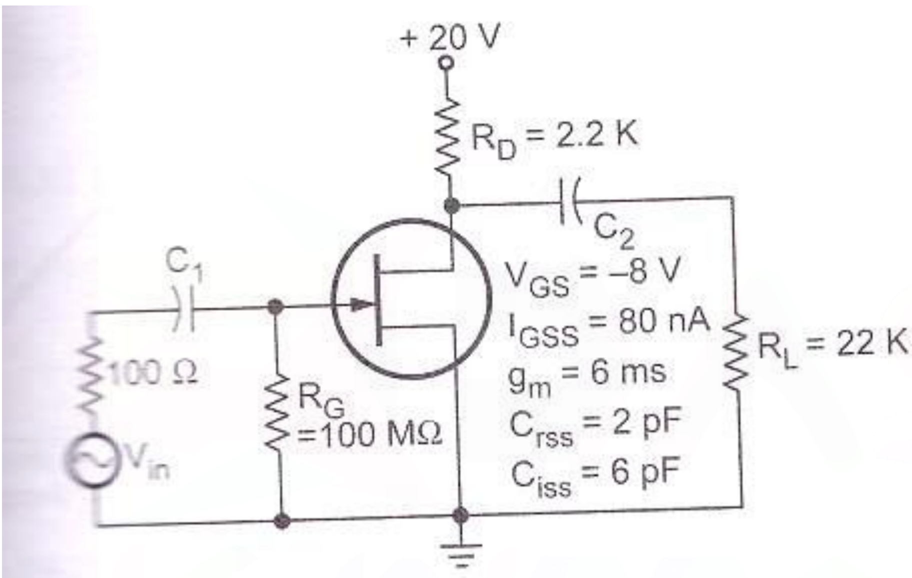
The critical frequency for the above circuit is,

$$f_c = \frac{1}{2\pi R_o\, C_{out\,(miller)}} = \frac{1}{2\pi (R_D \,||\, R_L)\, C_{out\,(miller)}}$$

It is not necessary that these frequencies should be equal. The network which has lower critical frequency than other network is called dominant network.

The phase shift in high frequency is $$\theta = \tan^{-1}\left(\frac{R_o}{X_{C_{out(Miller)}}}\right)$$

Problem:
Determine the high frequency response of the amplifier circuit shown in the following figure.



Solution:
Before calculating critical frequencies it is necessary to calculate mid frequency gain of the given amplifier circuit. This is required to calculate $C_{in(miller)}$ and $C_{out(miller)}$.
$A_v = -g_m R_D$
Here R_D should be replaced by $R_D \parallel R_L$
$A_v=$

$$-g_m\, R_D \parallel R_L) = -6\ \text{mS}(2.2\,\text{K} \parallel 22\,\text{K}) = -6\ \text{mS}\ (2\ \text{K}) = -12$$

$C_{in(miller)}=$
$$C_{gd}\,(A_v + 1) = C_{rss}\,(A_v + 1) = 2\ \text{pF}\ (12 + 1) = 26\ \text{pF}$$

$C_{out(miller)}=$
$$\frac{C_{gd}(A_v + 1)}{(A_v)} = \frac{C_{rss}\,(A_v + 1)}{(A_v)} = \frac{2\ \text{pF}\,(12 + 1)}{12} = 2.166\ \text{pF}$$

$C_{gs} = C_{iss} - C_{rss} = 4\text{pF}$
Now analyze the input and output network for critical frequency,

$$f_{c(input)} = \frac{1}{2\pi R_s C_T}$$

$$= \frac{1}{2\pi R_s \times [C_{gs} + C_{in\,(miller)}]}$$

$$= \frac{1}{2\pi \times 100 \times [4\text{ pF} + 26\text{ pF}]}$$

$$= \frac{1}{2\pi \times 100 \times [30\text{ pF}]} = 53\text{ MHz}$$

$$f_c\,(\text{output}) = \frac{1}{2\pi (R_D \,||\, R_L) \times C_{out\,(miller)}}$$

$$= \frac{1}{2\pi (2.2\text{ K} \,||\, 22\text{ K}) \times 2.166\text{ pF}}$$

$$= 36.74\text{ MHz}$$

The above analysis shows that the output network produces the dominant higher critical frequency. High frequency response of the given amplifier is shown in the following figure.

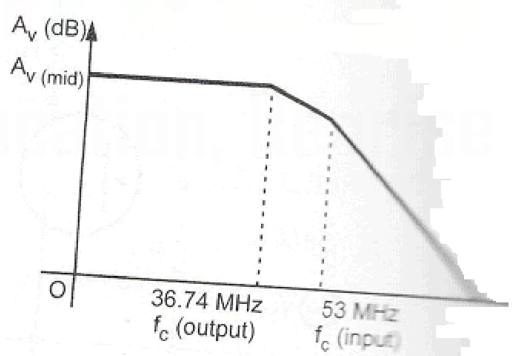


Fig. High frequency response of the amplifier

4.10 Frequency Response of Multistage Amplifiers:

The bandwidth of multistage amplifier is always less than that of the bandwidth of single stage amplifier.

4.10.1 Overall Lower Cut-off Frequency of Multistage Amplifier:

Let us consider the lower 3dB frequency of n identical cascaded stages as f_L (n). It is the frequency for which the overall gain falls to $1/\sqrt{2}$ (3dB) of its midband value.

$$\left[\frac{1}{\sqrt{1+\left(\frac{f_L}{f_L(n)}\right)^2}}\right]^n = \frac{1}{\sqrt{2}}$$

$$\sqrt{2} = \left[\sqrt{1+\left(\frac{f_L}{f_L(n)}\right)^2}\right]^n$$

Squaring on both the sides &

Taking n[th] root on both sides we get,

$$2^{\frac{1}{n}} = 1+\left(\frac{f_L}{f_L(n)}\right)^2$$

$$2^{\frac{1}{n}} - 1 = \left(\frac{f_L}{f_L(n)}\right)^2$$

Taking square root on both the sides,

$$\sqrt{2^{1/n} - 1} = \frac{f_L}{f_L(n)}$$

$$f_L(n) = \frac{f_L}{\sqrt{2^{1/n} - 1}}$$

where $f_L(n)$ = Lower 3 dB frequency of identical cascaded stages

f_L = Lower 3 dB frequency of single stage

n = Number of stages

4.10.2 Overall Higher Cut-off Frequency of Multistage Amplifier:

Let us consider the upper 3dB frequency of n identical cascaded stages as $f_H(n)$. It is the frequency for which the overall gain falls to $1/\sqrt{2}$ (3dB) of its midband value.

$$\left[\frac{1}{\sqrt{1+\left(\frac{f_H(n)}{f_H}\right)^2}}\right]^n = \frac{1}{\sqrt{2}}$$

$$\sqrt{2} = \left[\sqrt{1+\left(\frac{f_H(n)}{f_H}\right)^2}\right]^n$$

Squaring both the sides,

$$2 = \left[1+\left(\frac{f_H(n)}{f_H}\right)^2\right]^n$$

Taking n^{th} root on both the sides,

$2^{1/n} = 1 + [\ f_H(n)/f_H\ ]^2$

$2^{1/n} - 1 = [\ f_H(n)/f_H\ ]^2$

Taking square root on both the sides,

$\sqrt{2^{1/n} - 1} = f_H(n)/f_H$

$f_H(n) = f_H \sqrt{2^{1/n} - 1}$

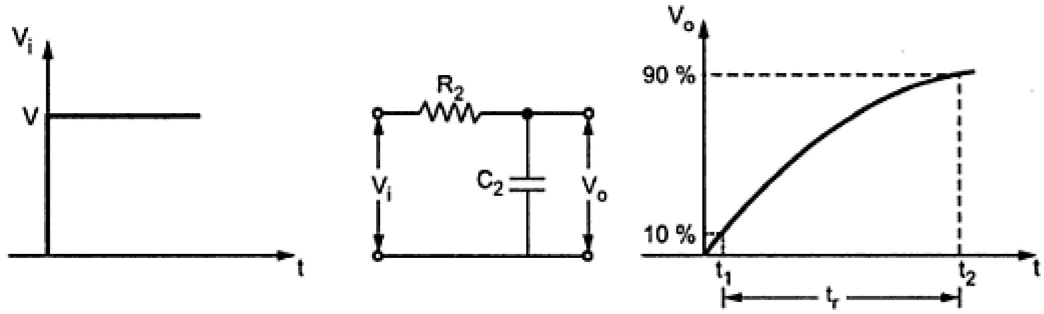
In multistage amplifier $f_L(n)$ is always greater than f_L and $f_H(n)$ is always less than f_H. So the bandwidth of multistage amplifier is always less than single stage amplifier.

If stages are not identical f_H can be given as,

$$\frac{1}{f_H} = 1.1\sqrt{\frac{1}{f_1^2}+\frac{1}{f_2^2}+\cdots+\frac{1}{f_n^2}}$$

4.11 Rise time and its Relation to Upper Cut-off Frequency:

4.11.1 Upper 3 dB Frequency:



When a step input is applied, amplifier high frequency RC network prevent the output from responding immediately to the step input. The output voltage starts from zero and rises towards the steady state value V, with a time constant R_2C_2 as shown in the above figure.
The output voltage is given by,

$$V_o = V(1 - e^{-t_1/R_2C_2})$$

The time required for V_o to reach one-tenth of its final value is calculated as,

The time required for V_o to reach one-tenth of its final value is calculated as,

$$0.1\ V = V\ (1 - e^{-t_1/R_2C_2})$$

$$\therefore \quad 0.1 = 1 - e^{-t_1/R_2C_2}$$

$$\therefore \quad 0.9 = e^{-t_1/R_2C_2}$$

$$\therefore \quad \frac{t_1}{R_2\ C_2} = 0.1$$

$$\therefore \quad t_1 = 0.1\ R_2\ C_2$$

Similarly, the time required for V_o to reach nine-tenths of its final value is calculated as,

$$0.9\ V = V\ (1 - e^{-t_2/R_2C_2})$$

$$\therefore \quad 0.9 = 1 - e^{-t_2/R_2C_2}$$

$$\therefore \quad 0.1 = e^{-t_2/R_2C_2}$$

$$\therefore \quad \frac{t_2}{R_2\ C_2} = 2.3$$

The difference between these two values is called as rise time t_r of the circuit. The rise time is given as,

$$t_r = t_2 - t_1 = 2.3\ R_2\ C_2 - 0.1\ R_2\ C_2$$

$$= 2.2\ R_2\ C_2$$

The Upper 3dB frequency is given as,

$$f_H = \frac{1}{2\pi R_2\ C_2}$$

Upper 3dB frequency in terms of rise time is given as,

$$f_H = \frac{2.2}{2\pi t_r} = \frac{0.35}{t_r}$$

From above equation, it shows that upper 3dB frequency is inversely proportional to the rise time t_r.

4.12 Relation between Bandwidth and Rise time:

The frequency range from f_L to f_H is called bandwidth of the amplifier. Usually $f_L << f_H$. So we can approximate the equation for bandwidth as follows,

$$BW = f_H - f_L$$
$$\approx f_H$$

The relation between rise time with upper frequency as,

$$f_H = \frac{2.2}{2\pi t_r} = \frac{0.35}{t_r}$$

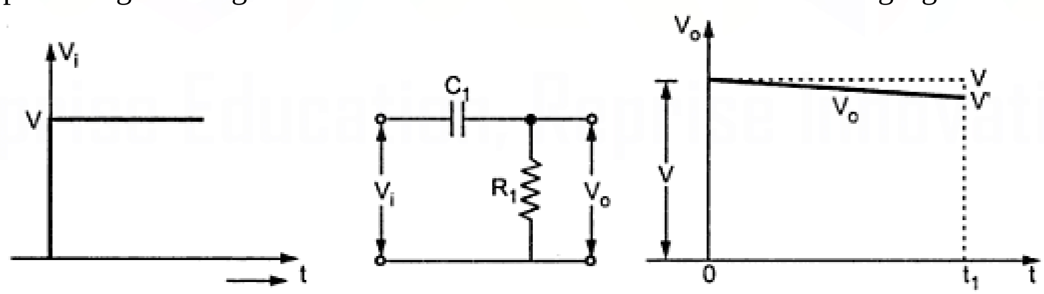
So we can relate bandwidth with rise time as follows,

$$BW \approx f_H = \frac{0.35}{t_r}$$

Problem:
If the rise time of BJT is 35ns, what is the bandwidth that can be obtained using this BJT.
Solution:
$t_r = 0.35 / f_2 = 0.35 / BW$
$BW = 0.35 / t_r = 0.35 / (35 * 10^{-9}) = 10MHz$

4.9 Sag and its Relation to Lower Cut-off Frequency:

The amplifier low frequency RC network consists of coupling and bypass capacitors make amplifier output to decrease with large time constant. As a result, the output voltage has sag or tilt associated with it as shown in the following figure.



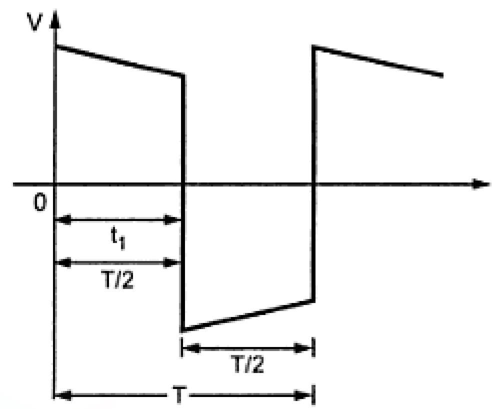
The tilt or sag in time t_1 is given by,

$$\% \text{ tilt} = P = \frac{V - V'}{V} \times 100$$
$$= \frac{t_1}{R_1 C_1} \times 100 \%$$

The lower 3 dB frequency can be determined from the output response by carefully measuring the tilt.
The lower 3 dB frequency is given as,

$$f_L = \frac{1}{2\pi R_1 C_1}$$

So, the lower 3 dB frequency can be represented in terms of tilt is measured from the following figure.



$$P = \frac{T}{2R_1C_1} \times 100$$

$$= \frac{1}{2f\,R_1C_1} \times 100 \qquad \because T = \frac{1}{F}$$

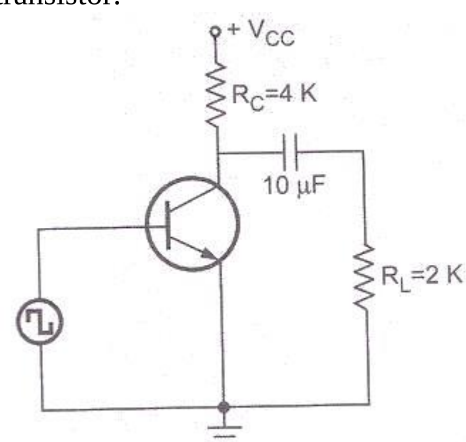
$$= \frac{\pi}{2\pi f\,R_1C_1} \times 100$$

$$= \pi f_L / f * 100$$

$$f_L = \frac{Pf}{100\pi}$$

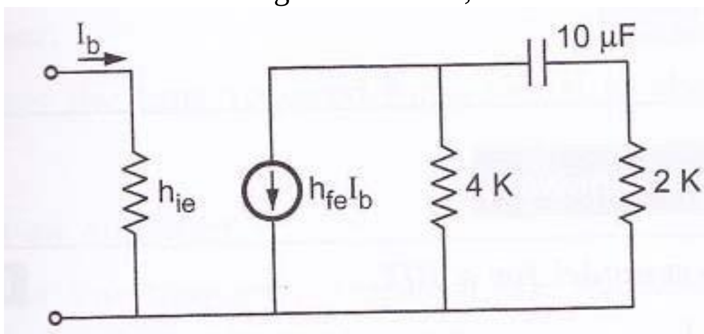
Problem 1:

For a circuit shown in the following figure, calculate percentage tilt. Assume approximate h-parameter circuit for the transistor.



Solution:

Equivalent h-parameter circuit for the given circuit is,



$$f_L = \frac{1}{2\pi R_1 C_1}$$

Here $R_1 = R_C + R_L$ = 4K + 2K
= 6KΩ

$$f_L = \frac{1}{2\pi \times 6 \times 10^3 \times 10 \times 10^{-6}} = 2.65 \text{ Hz}$$

We know that, P = (∏f_L / f) * 100
Assuming f = 200 Hz
P = (∏ * 2.65 / 200) * 100
P = 4.1%

QUESTIONS

2 MARKS

1. Draw the frequency response curve of an amplifier.
2. What is the bandwidth of an amplifier?
3. Define rise time.
4. What kind of techniques required increasing the input impedance?
5. Give relation between rise time and bandwidth.
6. Give the main reason for the drop in gain at the low frequency region & high frequency region.
7. If the rise time of BJT is 35nS, what is the bandwidth that can be obtained using this BJT?
8. For an amplifier, mid band gain is 100 & lower cutoff frequency is 20KHz. Find the gain of an amplifier at frequency 20Hz.
9. For an amplifier, 3dB gain is 200 & higher cutoff frequency is 20KHz. Find the gain of an amplifier at frequency 100KHz.
10. Why common base amplifier is preferred for high frequency signal when compared to CE amplifier?
11. Draw the hybrid π equivalent circuit of BJTs.
12. What is the difference between small signal equivalent & hybrid π equivalent circuit.

13. What is high frequency effect?
14. What are the causes for occurrence of upper cutoff frequency in BJT?
15. What is Miller’s effect? What is gain bandwidth product?
16. Give equation of overall lower and upper cutoff frequency of multistage amplifier.
17. What is significance of octaves and decades in frequency response?
18. What are the causes for occurrence of upper cutoff frequency in BJT?
19. What is the major contribution to the Miller capacitance in a MOSFET?
20. Define cut off frequency for a MOSFET.

16 MARKS

1. With neat sketch explain hybrid π CE transistor model. Derive the expression for various components in terms of ‘h’ parameters.
2. Discuss the frequency response of multistage amplifiers. Calculate the overall upper & lower cutoff frequencies.
3. Discuss the low frequency response & the high frequency response of an amplifier. Derive its cutoff frequencies.
4. Discuss the terms rise time and sag.
5. Write short notes on high frequency amplifier.
6. Derive the gain bandwidth for high frequency FET amplifiers.
7. Derive the expression for the CE short circuit current gain of transistor at high frequency
8. What is the effect of Cb’e on the input circuit of a BJT amplifier at High frequencies? Derive the equation for gm which gives the relation between gm, Ic and temperature.
9. Explain the high frequency analysis of JFET with necessary circuit diagram & gain bandwidth product.
10. Discuss the frequency response of MOSFET CS amplifier.
11. Determine the bandwidth of CE amplifier with the following specifications. R1=100kΩ, R2=10kΩ, RC=9kΩ, RE=2kΩ, C1= C2=25μF, CE=50μF, rbb’=100Ω, rb’e=1.1KΩ, hfe=225, Cb’e=3pF and Cb’c=100pF.
12. At Ic=1mA & VCE=10v, a certain transistor data shows Cc=Cb’c=3pF, hfe=200, & ωT=-500M rad/sec. Calculate gm, rb’e, Ce=Cb’e & ωβ.