LAKIREDDY BALI REDDY COLLEGE OF ENGINEERING
(AUTONOMOUS)
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Approved by AICTE, New Delhi and Affiliated to JNTUK, Kakinada
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Department of Electronics and Communication Engineering

Course Name & Code: Analog Circuit Design

Dr. Poornaiah Billa

COURSE EDUCATIONAL OBJECTIVES :In this course student will learn about

COURSE EDUCATIONAL OBJECTIVES (CEOs): This course gives the ability to analyze and design analog electronic circuits using discrete components. To empower the students to understand the design, working and analysis of BJT / FET amplifiers using appropriate equivalent models. And it gives the importance and effect of feedback in amplifiers to improve stability and to design oscillators.

COURSE OUTCOMES (CO):The student can able to do

CO1: Design different single stage and multistage amplifiers.

CO2: Understand the effect of capacitances on frequency response.

CO3: Understand the applications of power and tuned amplifiers.

CO4: Know the importance of negative feedback in amplifiers.

CO5: Design Sinusoidal oscillators for different frequencies.

BOS APPROVED REFERENCE BOOKS:

BOS APPROVED TEXT BOOKS:

T1. Jacob Millman, Christos C Halkias, “Electronic Devices and Circuits”, Tata McGraw Hill, Publishers, New Delhi, Fourth reprint 2011.

T2. Donald A.Neamen, “Electronic Circuit Analysis and Design”,Tata McGraw Hill Publishers, 2nd Edition.

R1 P.John Paul, “Electronic Devices and Circuits”, New Age International Publishers.

R2 R.L. Boylestad and Louis Nashelsky, Electronic Devices and Circuits, Pearson education Publishers, 10th Edition.

UNIT-I : Small Signal Low Frequency Transistor Amplifiers

UNIT-II : Multistage Amplifiers , Transistor at High Frequencies, Frequency Response of Amplifiers

UNIT-III : Power Amplifiers, Tuned amplifiers

UNIT-IV : Feedback Amplifiers

UNIT-V : Sinusoidal Oscillators

UNIT – I

Small Signal Low Frequency Transistor Amplifiers: Hybrid parameter model of a Two Port Network, h parameter model for Transistor in CE, CB and CC Configurations, typical h parameter values, h parameter conversion from one configuration to another configuration, Analysis of CE, CB and CC Amplifiers using h parameter model, CE Amplifier with emitter resistance.

FET Amplifiers: Analysis of CG, CS and CD FET amplifiers.

UNIT-I :

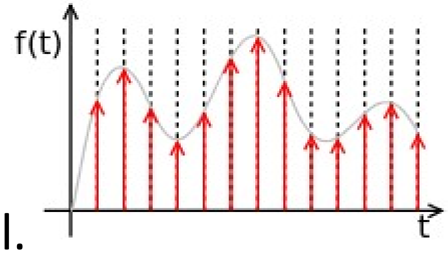
SMALL SIGNAL LOW FREQUENCY TRANSISTOR AMPLIFIERS

Signal : *Signal* is a function, that represents the variation of a physical quantity with respect to any parameter. In Electronics and Electrical , usually signal is variation of electrical quantity (current or voltage) with time.

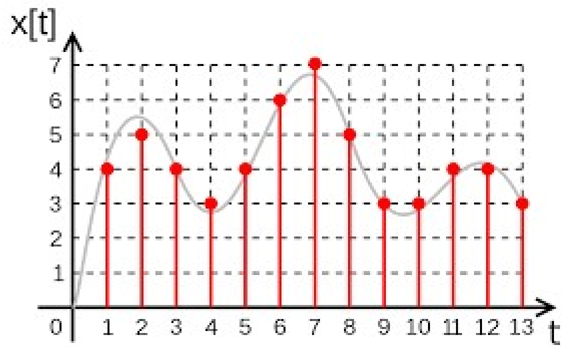
Analog signal : Amplitude of Signal continuously varies with time.

Discrete signal : The signal which is defined for the discrete intervals of time.

Figure shows Continuous (blue) and discrete (red) line



Digital signal : Discretise in both time and magnitude of signal.



- *Analog circuits : The circuits that process the analog signals are called analog circuits. Analog circuits are linear circuits.*
- *Linear circuits : A circuit constitute by linear elements is called linear circuits. Linear elements follows the linear property.*

  Ex: R, L, C, amplifiers.
- *Linear property : A circuit / element which gives for every input there should be corresponding output. No two inputs having same output. Graph between Input and output should be straight line i.e y=mx where m is slope. gain should be constant.*
- *Non linear property : Number of inputs has same output.*

  Ex: Electronic devices, logic gates, digital circuits.

Amplifier : It is a electronic circuit , which amplifies or increases the strength or magnitude (amplitude) of the input signal.

Linear amplifier : It amplifies an input signal and produce output signal which is larger and directly proportional to the input signal.

Amplifiers are designed by basic component, i.e transistor(BJT or FET).

BJT : Current controlled device (output current (Ic) is controlled by input base current)

FET : Voltage controlled device (output is controlled by input voltage).

BJTs are traditionally used in linear amplifiers because of their high gain.

A **Transistor** is a three terminal semiconductor device that regulates current or voltage flow and acts as a switch or gate for signals. It is a Non linear device.

Transistor is operating in three regions

1. Cut-off region (both the junction are reverse biased)
2. Saturation region (both the junction are forward biased)
3. Active region (Emitter - base junction is forward bias and base – collector junction is reverse biased)

Applications of a transistor: Based on region of operations

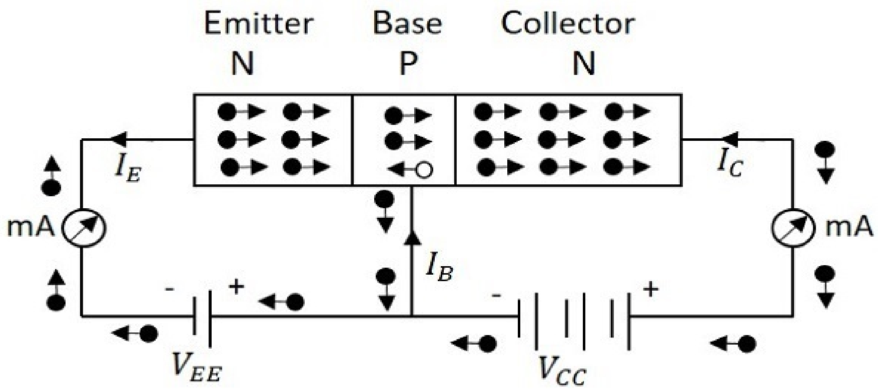
A transistor acts as **an Amplifier**, where the signal strength has to be increased.

A transistor also acts as a **switch** to choose between available options.

It also **regulates** the incoming **current and voltage** of the signals.

- Transistor exhibits linear property ,when it is operates in active region.

How transistor act as a Amplifier: Transistor is operated in active mode, It act as a amplifier



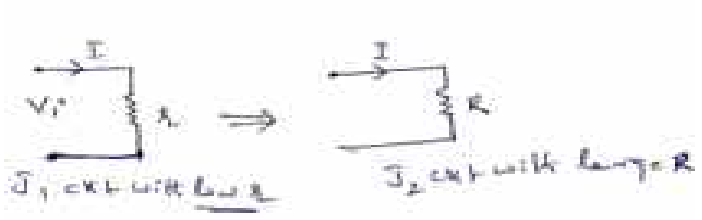
The operation of an NPN transistor can be explained by having a look at the following figure, in which emitter-base junction is forward biased and collector-base junction is reverse biased.

The voltage $\mathbf{V_{EE}}$ provides a negative potential at the emitter which repels the electrons in the N-type material and these electrons cross the emitter-base junction, to reach the base region. There, a very low percent of electrons re-combine with free holes of P-region. This provides very low current which constitutes the base current $\mathbf{I_B}$. The remaining most electrons cross the collector-base junction, to constitute the collector current $\mathbf{I_C}$. 2 to 5% electrons combined in base and 95% electrons move to collector create collector current.

Junction one(E-B) forward bias resistance at J1 is zero.

Junction two(B-C) reverse bias resistance at J2 is very large or infinity.

Above circuit current transfer from low resistance to high resistance.



Voltage in input Vi = I r

Voltage at output V_o = I R

R is large compared with r.

Therefore Vi < Vo

So weak signal applied at input side but we have received amplified signal at output.

Transistor used as a amplifier but it is a non linear device and amplifier is linear circuit. To analyse non linear device is very difficult or complex.

So to simplify the analysis of the transistor, its operation is restricted to linear characteristics region i.e. Active region. This approximation possible only with small input signals.

Small signal means signal amplitude is small i.e. Amplitude is in milli volts

Amplifier is a linear device. So amplifier is designed by transistor, it can be operated in linear region (active region).

For small signals the operating point (Q-point) is not vary so the output is not effected.

For large input signal operating point varies that cause to distortion in output.

So to analyse the amplifier, the transistor is replaced by equivalent linear approximation circuit or model i.e. h-parameter model

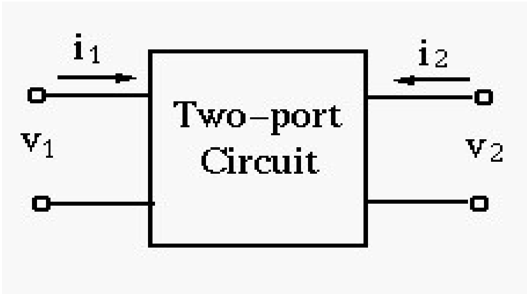
Amplifier analysis : 1. DC analysis   2. AC analysis

DC analysis: Biasing –it is used to set operating point and know the stability
AC analysis : To measure gain (Av,Ai,Ap), input and output impedances

Small signal : Small signal means signal amplitude is small i.e. Amplitude is in milli volts

Low frequency : The frequency is in terms of hertz , At low frequencies (50 hz), large capacitances offer medium reactance (cannot short circuited), which cannot treated as short circuit . At mid frequencies (4 khz) large capacitances offer low reactance (short circuited).

Transistor is a two port device or network i.e transistor having input port and output port (input and output characteristics) but diode is a single port because it is having V –I characteristics only.



Two port networks are analysed by Y, Z, h- parameters. But transistor used as a amplifier , analysis of amplifier transistor is replaced by h-parameter equivalent model.

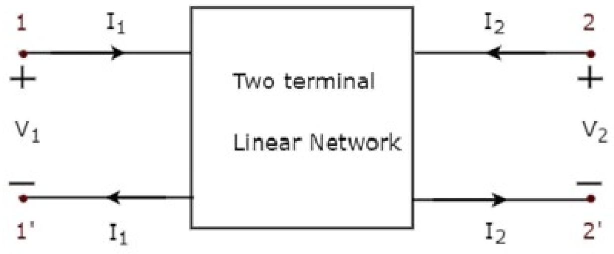
In order to analyse transistorised amplifier circuits , h-parameter model is used to describe its input impedance, output impedance, voltage gain and current gain based on those parameters, amplifier is used different applications such as voltage amplifiers, current amplifiers, Impedance matching etc.

h – parameters mans hybrid (mixed) parameters such as impedance, admittance, gain etc. So transistor is replaced by its equivalent h-parameter approximation model to know exact analysis of amplifiers.

*Advantages of h-parameters: 1. h- parameters are **real numbers** up to radio frequency.*
2. Easy to measure
3. It can be obtained from the transistor static characteristic curves.
4. Convenient to use circuit analysis and design
5. Most of the transistor manufacturers specify the h-parameter of transistor.

h – parameter model

Equivalent circuit(model): it is a combination of circuit elements properly chosen to best represent the actual behaviour of the device under specific operating point.



Here, one pair of terminals, 1 & 1’ represents one port, which is called as **port1** and the other pair of terminals, 2 & 2’ represents another port, which is called as **port2**. There are **four variables** V_1, V_2, I_1 and I_2 in a two port network as shown in the figure. Out of which, we can choose two variables as independent and another two variables as dependent.

h-parameters

We will get the following set of two equations by considering the variables V_1 & I_2 as dependent and I_1 & V_2 as independent. The coefficients of independent variables, I_1 and V_2, are called as **h-parameters**.

$$V_1 = h_{11}I_1 + h_{12}V_2$$
$$I_2 = h_{21}I_1 + h_{22}V_2$$

The h-parameters are

$$V_1 = h_{11}I_1 + h_{12}V_2$$
$$I_2 = h_{21}I_1 + h_{22}V_2$$

$h_{11} = V_1 / I_1$ when $V_2=0$, input impedance when output is short circuited

$h_{12} = V_1 / V_2$ when $I_1=0$, Reverse voltage gain when input is open circuited

$h_{21} = I_2 / I_1$ when $V_2=0$, forward current gain when output is short circuited

$h_{22} = I_2 / V_2$ when $I_1=0$, output admittance when input is open circuited

h-parameters are called as **hybrid parameters**. The parameters, h_{12} and h_{21}, do not have any units, since those are dimension-less. The units of parameters, h_{11} and h_{22}, are Ohm and Mho respectively.

We can calculate two parameters, h_{11} and h_{21} by doing short circuit of port2. Similarly, we can calculate the other two parameters, h_{12} and h_{22} by doing open circuit of port1.

The h-parameters or hybrid parameters are useful in transistor modelling circuits

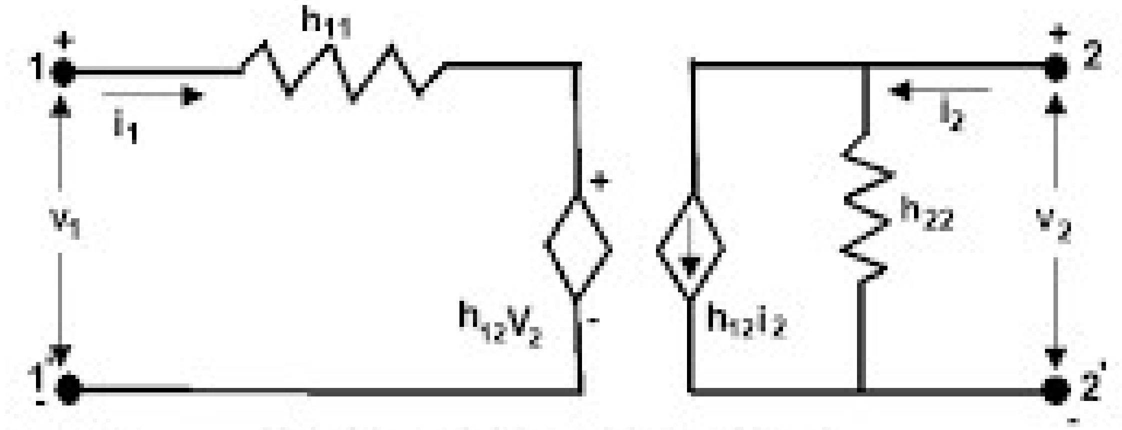
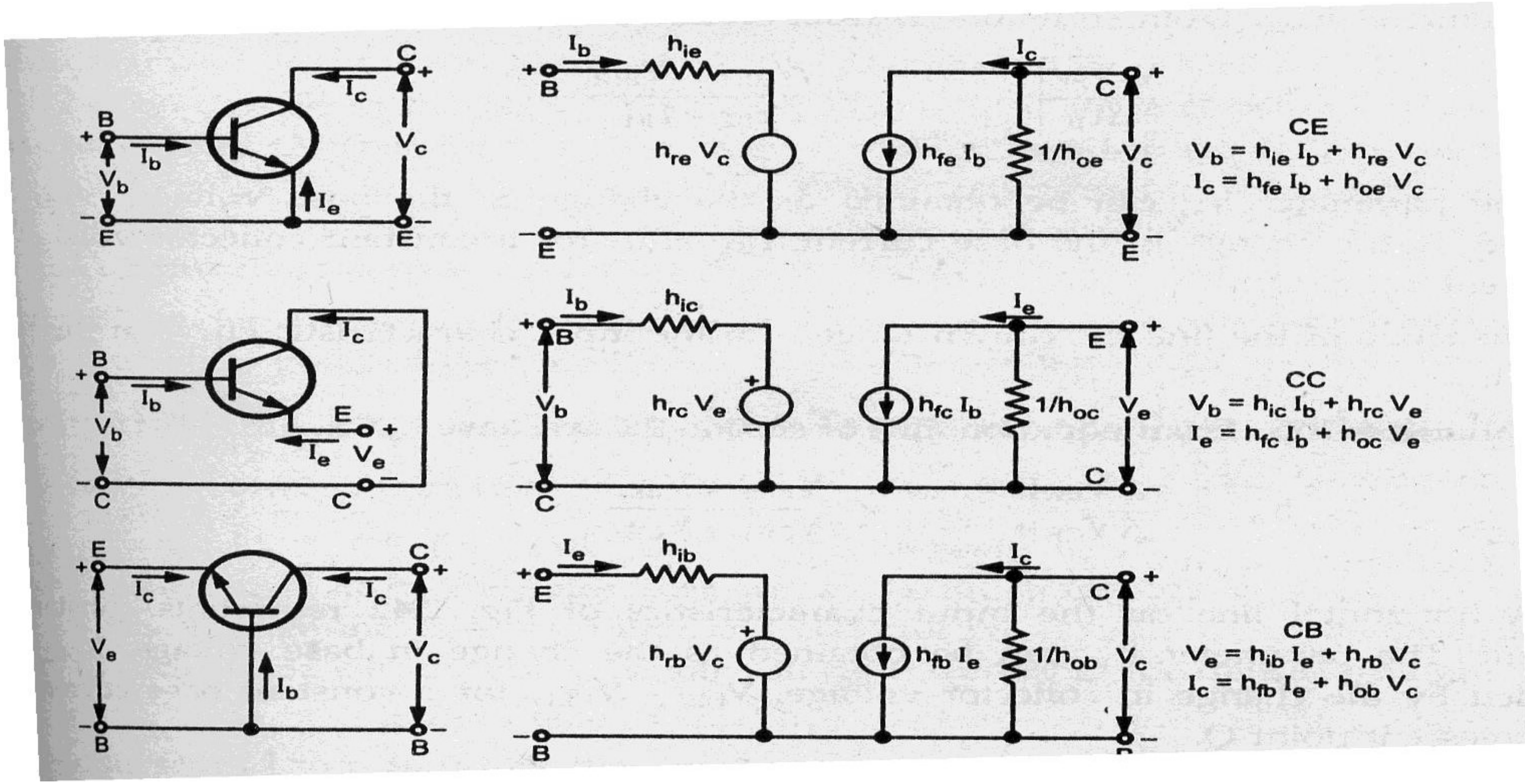


Figure (a) Hybrid model for a Linear Circuit

h-parameter representation of transistor:

At low frequencies, we analyze transistor using h-parameter. But for high frequency analysis the h-parameter model is not suitable, because :-
(1) The value of h-parameters are not constant at high frequencies.
(2)At high frequency h-parameters becomes very complex in nature.



CE configuration

$V_{be} = h_{ie} I_b + h_{re} V_{ce}$

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

CC configuration

$V_{bc} = h_{ic} I_b + h_{rc} V_{ec}$

$I_e = h_{fc} I_b + h_{oc} V_{ec}$

CB configuration

$V_{eb} = h_{ib} I_e + h_{rb} V_{cb}$

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

Common Emitter	Common Collector	Common Base	Definitions
$h_{ie} = \frac{v_{be}}{i_b}$	$h_{ic} = \frac{v_{bc}}{i_b}$	$h_{ib} = \frac{v_{eb}}{i_e}$	Input Impedance with Output Short Circuit
$h_{re} = \frac{v_{be}}{v_{ce}}$	$h_{rc} = \frac{v_{bc}}{v_{ec}}$	$h_{rb} = \frac{v_{eb}}{v_{cb}}$	Reverse Voltage Ratio Input Open Circuit
$h_{fe} = \frac{i_c}{i_b}$	$h_{fc} = \frac{i_e}{i_b}$	$h_{fb} = \frac{i_c}{i_e}$	Forward Current Gain Output Short Circuit
$h_{oe} = \frac{i_c}{v_{ce}}$	$h_{oc} = \frac{i_e}{v_{ec}}$	$h_{ob} = \frac{i_c}{v_{cb}}$	Output Admittance Input Open Circuit

Typical values of h-parameters at quiescent operating point

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

Typical values of h-parameters at quiescent operating point

Characteristic	**CE**	**CB**	**CC**
Input resistance	Low (1K to 2K)	Very low (30-150 Ω)	High (20-500 KΩ)
Output resistance	Large (≈ 50 K)	High (≈ 500 K)	Low (50-1000 KΩ)
Current gain	B high	α < 1	High (1 + β)
Voltage gain	High (≈ 1500)	High (≈ 1500)	Less than one
Power gain	High (≈ 10,000)	High (≈ 7500)	Low (250-500)
Phase between input and output	reversed	same	same

Conversion formulas : in terms of CE

CB configuration

$$h_{ib} = \frac{h_{ie}}{1 + h_{fe}}$$

$$h_{rb} = \frac{h_{ie}\, h_{oe}}{1 + h_{fe}} - h_{re}$$

$$h_{fb} = -\frac{h_{fe}}{1 + h_{fe}}$$

$$h_{ob} = \frac{h_{oe}}{1 + h_{fe}}$$

CC configuration

$h_{ic} = h_{ie}$

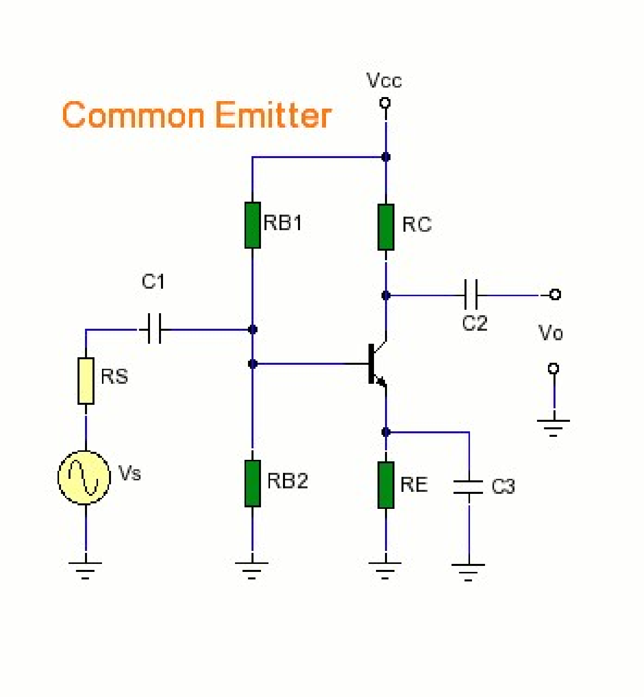
$h_{rc} = 1$

$h_{fc} = -(1 + hfe)$

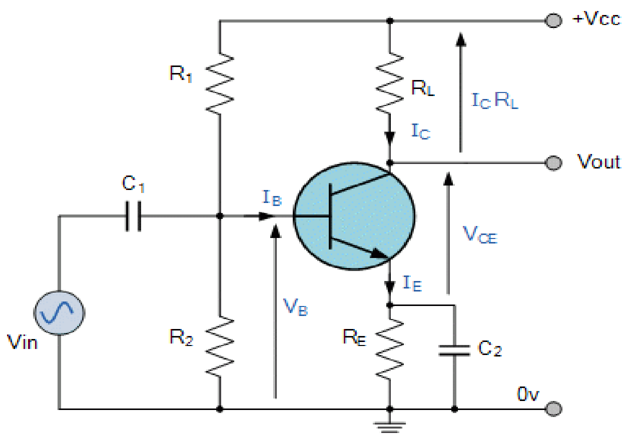
$h_{oc} = h_{oe}$

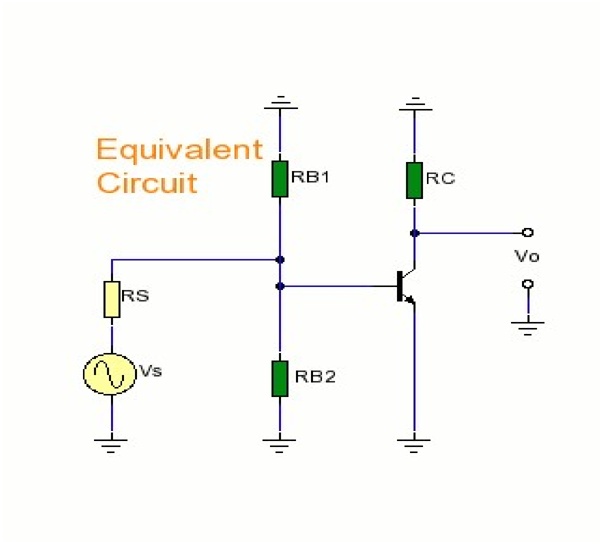
Analysis of transistor Amplifiers: AC equivalent circuit of amplifier

CE Amplifier: The amplifier circuit that is formed using a CE configured transistor combination is called as CE amplifier.
In CE amplifiers, emitter is common to both input and output.
CE Amplifier *It amplifies an input signal and produce output signal which is larger and directly proportional to the input signal.*

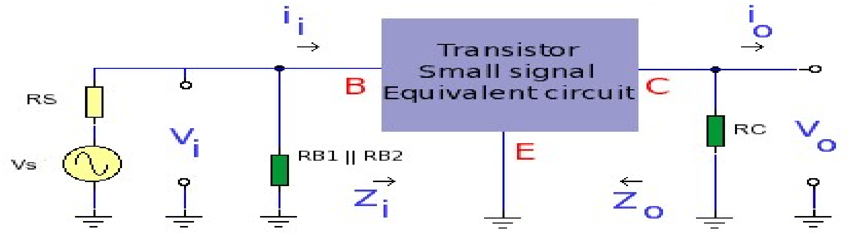


To get the AC equivalent circuit of the amplifier the following sequence of steps has to be applied.
Step 1: All external capacitors (C1,C2-coupling capacitors and C3-bypass) are short circuited.
Step 2: DC power connected to ground.
Step 3: Draw the modified circuit.
Step 4: Transistor is replaced by h-parameter model and draw final modified circuit.





As RB1 and RB2 are now in parallel the input impedance will be RB1 || RB2. The collector resistor RC also appears from collector to emitter (as emitter is bypassed). See below :



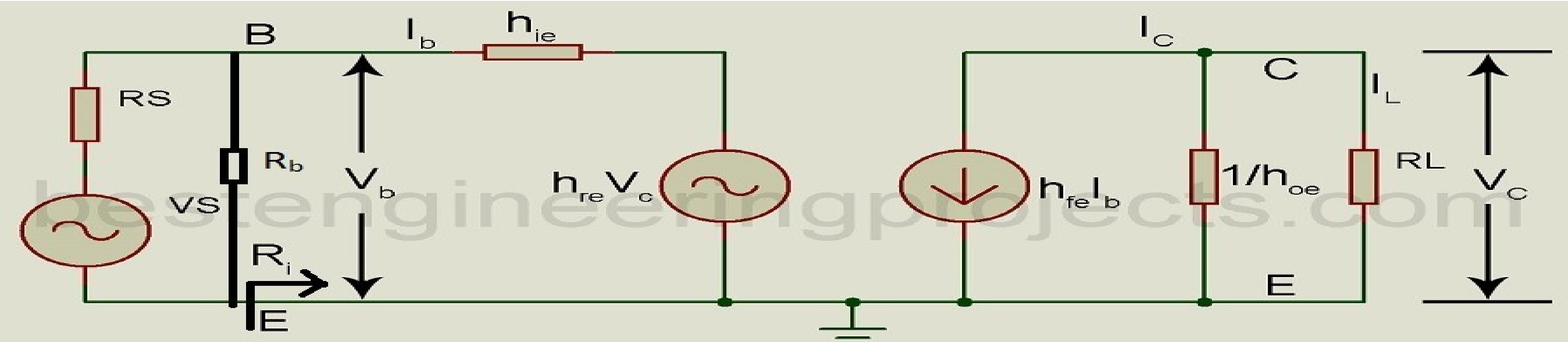


Figure 2: Equivalent Circuit of CE amplifier using h-model

The hybrid model is suitable for small signals at mid band and describes the action of the transistor. Two equations can be derived from the diagram, one for input voltage v_{be} and one for the output i_c:

$$v_{be} = h_{ie}\, i_b + h_{re}\, v_{ce}$$

$$i_c = h_{fe}\, i_b + h_{oe}\, v_{ce}$$

Current Gain or Current Amplification (A_I):

Current gain is defined as the ratio of the load current I_1 to the input current I_b.

Thus Current Gain $A_I = \frac{I_L}{I_b} = -\frac{I_c}{I_b}$ --------------(1)

But from figure $I_c = h_{fe} \times I_b + h_{oe} \times V_c$ --------------(2)

Also $V_c = I_L \times R_L = -I_c \times R_L$ --------------(3)

Combining Equation (2) and (3) we get,

$$I_c = h_{fe} I_b - h_{oe} \times I_c \times R_L or (1 + h_{oe} \times R_L) I_c = h_{fe} \times I_b$$

Hence current gain $A_I = -\frac{I_c}{I_b} = -\frac{h_{fe}}{1 + h_{oe} \times R_L}$

Input Impedance R_i: Ratio of input voltage to the input current

$$R_i = V_{be} / I_b$$

$$V_{be} = h_{ie} I_b + h_{re} V_c$$

$$V_c = -I_c \times R_L = A_I I_b R_L$$

$$V_{be} = h_{ie} I_b + h_{re} (-I_c R_L)$$

$$R_i = \frac{V_{be}}{I_b} = h_{ie} + h_{re} \left(-\frac{I_c}{I_b}\right) R_L$$

$$A_I = -\frac{I_c}{I_b} = -\frac{h_{fe}}{1 + h_{oe} \times R_L}$$

$$R_i = \frac{V_b}{I_b} = h_{ie} + h_{re} A_I R_L$$

$$= h_{ie} - \frac{h_{fe} h_{re}}{h_{oe} + Y_L}$$

Where $Y_L = \frac{1}{R_L}$

Voltage Gain or Voltage Amplification:

It is the ratio of the output voltage V_c to the input voltage V_b. Thus,

Voltage Gain

$$A_v = \frac{V_c}{V_b} = -\frac{I_c R_L}{I_b R_i} = \frac{A_I R_L}{R_i}$$

Output Admittance Y_0:

It is the ratio of the output current I_c to the output voltage V_c with V_s = 0. Hence

$$Y_0 = \frac{I_c}{V_c} \quad \text{with } V_S = 0 \qquad \text{------- 1}$$

$$I_c = h_{fe} \times I_b + h_{oe} \times V_c$$

$$Y_0 = h_{fe} \times \frac{I_b}{V_c} + h_{oe} \qquad \text{----------2}$$

But with V_s = 0, Figure gives $(R_s + h_{ie})\, I_b + h_{re}\, V_c = 0$

or

$$\frac{I_b}{V_c} = -\frac{h_{re}}{h_{ie} + R_s} \qquad \text{--------------3}$$

(3) In (2) we get

$$Y_0 = h_{oe} - \frac{h_{fe} \times hre}{h_{ie} + R_s}$$

Output impedance

$$R_0 = \frac{1}{Y_0}$$

Overall Voltage Gain Considering R_s:

Source voltage V_s applied at the input of an amplifier results in voltage V_b between bae and emitter terminals (input terminals) of the transistor and voltage V_c at the output. Then the overall voltage gain considering the source resistance is given by

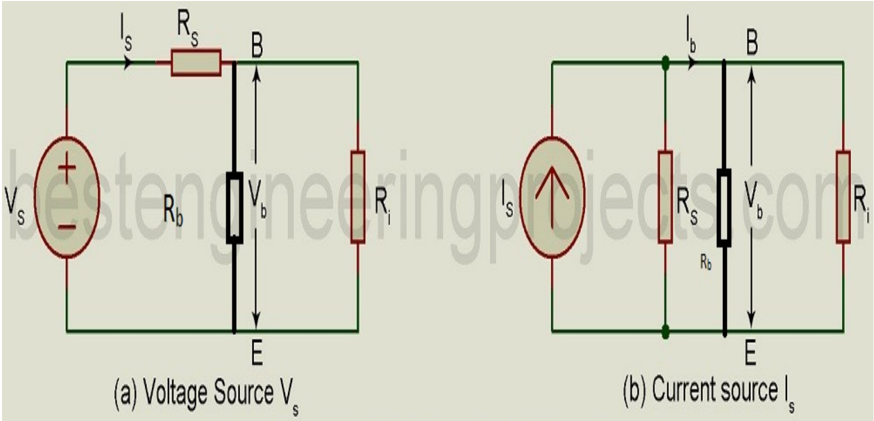


Figure 3: Voltage source Vs or Current source Is driving the amplifier

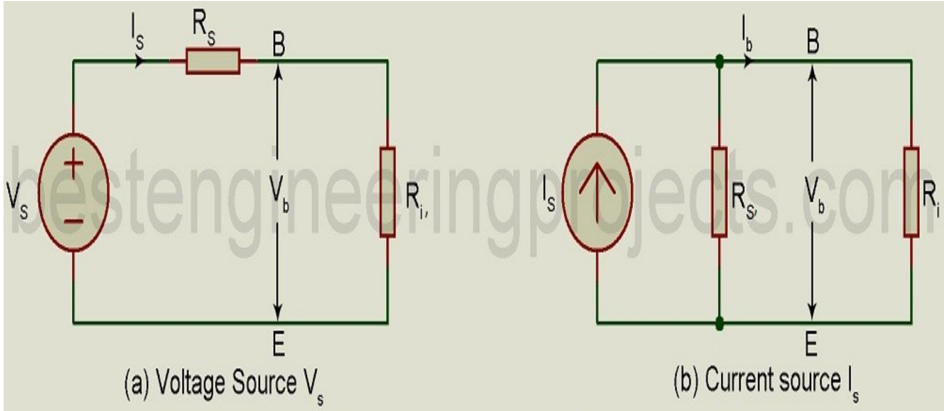


Figure 3: Voltage source Vs or Current source Is driving the amplifier

$$A_{vs} = \frac{V_c}{V_s} = \frac{V_c}{V_b} x \frac{V_b}{V_s} = A_v x \frac{V_b}{V_s}$$

$$V_b = V_s \; X \; \frac{R_i'}{R_s + R_{i'}} \qquad R_{i'} = R_b \; // \; Ri$$

$$\frac{V_b}{V_s} = \frac{R_i'}{R_s + R_i'}$$

$$A_{vs} = \frac{V_c}{V_s} = \frac{V_c}{V_b} x \frac{V_b}{V_s} = A_v x \frac{V_b}{V_s} = A_v x \frac{R_i'}{R_s + R_i'}$$

Overall Current Gain Considering R_s:

We may replace the voltage source V_s with series source resistance R_s by what is known as the Norton's equivalent source shown in Figure 3(b), consisting of current source I_s with source resistance R_s in shunt. This current source drives the amplifier resulting in I_b at the input terminals of the amplifier and current I_L through the load impedance. Then the overall current gain A_{Is} is given by:

$$A_{Is} = \frac{-I_c}{I_s} = \frac{-I_c}{I_b} x \frac{I_b}{I_s} = A_I x \frac{I_b}{I_s} = A_I x \frac{R_s'}{R_i + R_s'}$$

From figure

$$I_b = \frac{R_s'}{R_i + R_{s'}} I_s$$

$$R_{s'} = R_s \; // \; Rb$$

$$\frac{I_b}{I_s} = \frac{R_s'}{R_i + R_{s'}} = A_{IS}$$

Formulas

$$A_I = -\frac{h_{fe}}{1 + h_{oe} \times R_L}$$

$$R_i = h_{ie} + h_{re} \times A_I \times R_L$$

$$A_V = \frac{A_I \times R_L}{R_i}$$

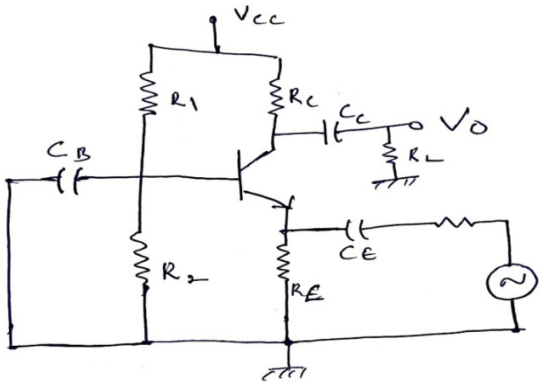
$$Y_0 = h_{oe} - \frac{h_{re} h_{fe}}{h_{ie} + R_s} = \frac{1}{Z_0}$$

$$A_{VS} \frac{A_V R_i}{R_i + R_s}$$

$$A_{IS} = \frac{A_I R_s}{R_i + R_s}$$

CB Amplifier: The amplifier circuit that is formed using a CB configured transistor combination is called as CB amplifier.

In CB amplifiers, Base is common to both input and output.



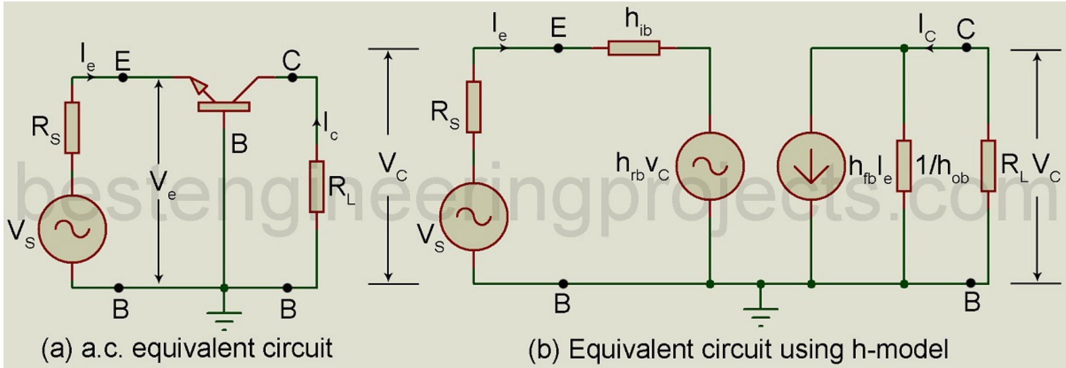


Figure 2: Small signal equivalent circuits of CB amplifier

$$A_I = -\frac{I_c}{I_e} = -\frac{h_{fb}}{1 + h_{ob} \times R_L}$$

$$A_V = \frac{V_c}{V_e} = \frac{A_I \times R_L}{R_i}$$

$$A_{IS} = \frac{I_L}{I_s} = A_I \frac{R_s}{R_i + R_s}$$

$$R_i = \frac{V_e}{I_e} = h_{ib} - \frac{h_{fb} \times h_{rb}}{h_{ob} + Y_L}$$

$$Y_0 = \frac{I_c}{V_c} = h_{ob} - \frac{h_{fb} \times h_{rb}}{h_{ib} + R_s}$$

$$A_P = \frac{P_L}{P_i} = A_V \times A_I = A_{I2} \times \frac{R_L}{R_i}$$

$$Y_L = \frac{1}{R_L}$$

$$A_{VS} = \frac{V_c}{V_s} = A_V \times \frac{R_i}{R_i + R_s}$$

Ex: A transistor in CB configuration is driven by a voltage source V_s of internal resistance R_s = 1000. The load impedance is a resistor R_L = 4k. the h-parameters are : h_{ib} = 220, h_{rb} 3×10^{-4} , h_{fb} = – 0.98 and h_{0b} = $0.5 \mu S$. For this amplifier, calculate the current gain A_I, input resistance R_i, voltage gain A_V, overall voltage gain A_{VS}, overall current gain A_{IS} output resistance R_0 and power gain A_p.

$$A_I = -\frac{h_{fb}}{1 + h_{ob} \times R_L} = \frac{-(-0.98)}{1 + (0.5 \times 10^{-6} \times 4000)} = 0.98$$

$$R_i = h_{ib} + h_{rb} \times A_I \times R_L = 22 + (3 \times 10^{-4})(0.98)(4000) = 23.18$$

$$A_V = \frac{A_I R_L}{R_I} = \frac{0.98\ X\ 4000}{23.18} = 169$$

$$A_{VS} = \frac{A_V R_i}{R_i + R_s} = \frac{169 \times 23.18}{23.18 + 1000} = 3.8$$

$$A_{IS} = \frac{A_I R_s}{R_i + R_s} = \frac{0.98 \times 1000}{23.18 + 1000} = 0.958$$

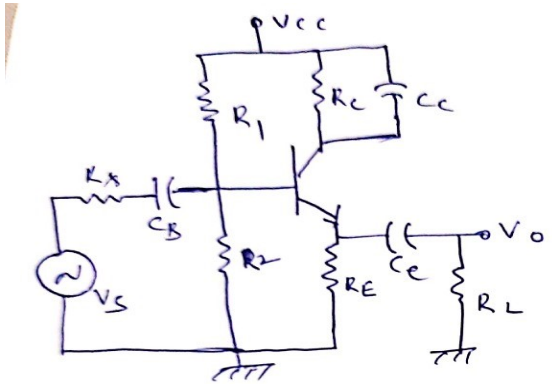
$$Y_0 = h_{ob} - \frac{h_{fb} \times h_{rb}}{h_{ib} + R_s} = (0.5 \times 10^{-6}) - \frac{(0.98)(3 \times 10^{-4})}{22 + 1000} = 0.78 \times 10^{-6} S$$

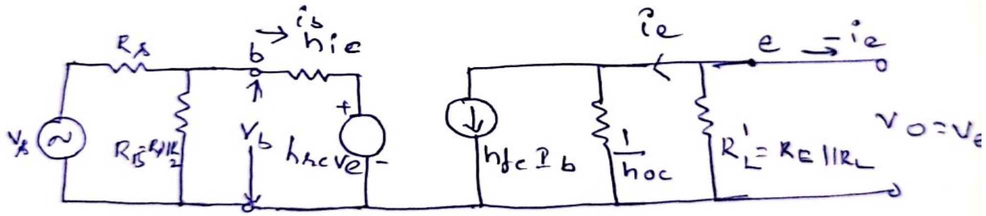
$$Z_0 = \frac{1}{Y_0} = \frac{106}{0.78} = 1.282$$

$$A_P = A_V \times A_I = 169 \times 0.98 = 166$$

CC Amplifier: The amplifier circuit that is formed using a CC configured transistor combination is called as CC amplifier.
In CC amplifiers, Collector is common to both input and output.

$$A_I = -\frac{h_{fc}}{1 + h_{oc}R_{L'}} \qquad R_{L'} = R_E \; // \; R_L$$





$$R_I = h_{ic} + h_{rc}A_iR_{L'}$$

$$A_V = \frac{A_iR_{L'}}{R_i}$$

$$Y_o = h_{oc} - \frac{h_{fc}h_{rc}}{R_{s'} + h_{ic}}$$

$$A_{VS} = A_V X \frac{R_{i'}}{R_{i'} + R_S}$$

$$A_{is} = A_i X \frac{R_{s'}}{R_{s'} + R_i}$$

$$R_{i'} = R_i \; // \; R_B$$

$$R_{s'} = R_s \; // \; R_B$$

Characteristics of CE, CB, CC amplifiers

Characteristic	**CE**	**CB**	**CC**
Input resistance	Low (1K to 2K)	Very low (30-150 Ω)	High (20-500 KΩ)
Output resistance	Large (≈ 50 K)	High (≈ 500 K)	Low (50-1000 KΩ)
Current gain	B high	$\alpha < 1$	High $(1 + \beta)$
Voltage gain	High (≈ 1500)	High (≈ 1500)	Less than one
Power gain	High (≈ 10,000)	High (≈ 7500)	Low (250-500)
Phase between input and output	reversed	same	same

Application of CE,CB, CC amplifier

CE amplifier has a high input impedance and lower output impedance than CB amplifier. The voltage gain and power gain are also high in CE amplifier and hence this is mostly used for amplification purpose in AF amplifiers ,RF amplifiers Signal generators..

If CC configuration is considered for amplification, though CC amplifier has better input impedance and lower output impedance than CE amplifier, the voltage gain of CC is very less which limits its applications to impedance matching only.

CB amplifier: It is used to match low input impedance source circuit with the high impedance load. It useful in audio and radio frequency applications as a current buffer. It is suitable for AF, RF amplifiers as voltage amplifiers.

Analysis of transistor amplifiers using simplified (approximation) h-parameter model

In the analysis of transistor amplifier, we have as far used the exact h-model for the transistor. In practice, we may conveniently use an approximately h-model for the transistor which introduces error < 10% in most cases.
This much error may be conveniently tolerated since the h-parameters themselves are not steady but vary considerably for the same type of transistor.

In most practical cases approximate model is used to describe the transistor amplifiers and this provide same response.

It is applicable only if $h_{oe}R_L \ll 0.1$

In approximation or Simplified model h_{oe} *and* h_{re} are neglected . Because

$$h_{oe} = 25\ \mu A/V = 25 \times 10^{-6} \approx 0$$

$$h_{re} = 25 \times 10^{-4} \approx 0$$

Simplified Analysis of CE amplifier using h-parameter model

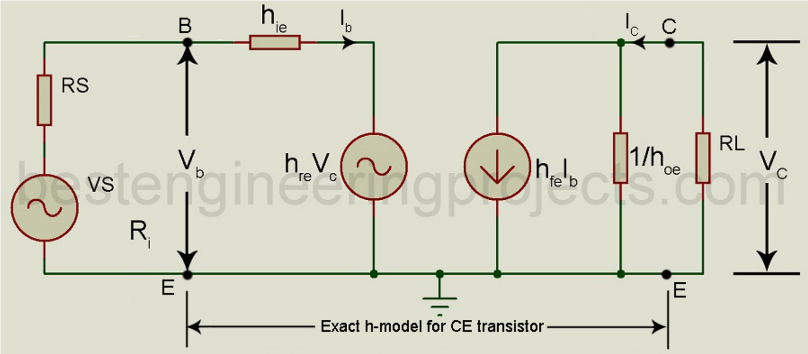


Figure 1: Equivalent circuit using exact h-model

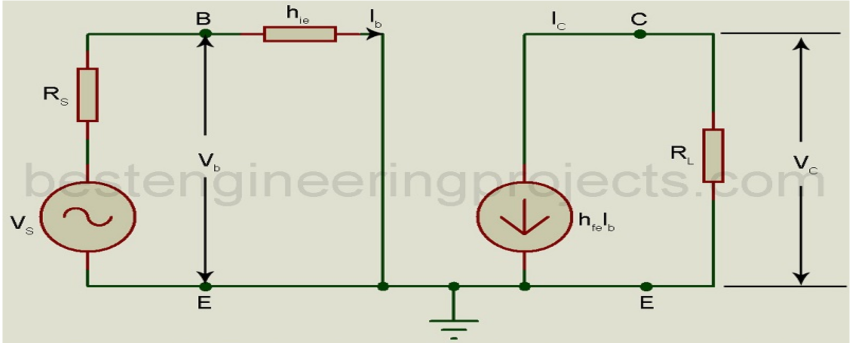


Figure 2: Equivalent circuit using approximate h-model of CE amplifier

Figure 2 is simplified model in which h_{oe} and h_{re} are neglected because their values are almost nearly zero.

From the figure 1/ h_{oe} is parallel with R_L , two unequal resistances are parallel, the resultant resistance is approximately equal to low resistance.

i.e $1/h_{oe} \gg R_L$ so $1/h_{oe} // R_L \approx R_L$

Approximate h-model Valid for all the three Configuration

The approximate CE h-model of Figure 2 is redrawn in figure 3. This model may be used for any of the three configurations by grounding the appropriate node and analysis done accordingly. It may be proved that the error in values of A_I, R_i, A_V or output terminal resistance R_{ot} (= $R_0 \parallel R_L$) caused by use of approximate model does not exceed 10% if $h_{oe} \times R_L < 0.1$

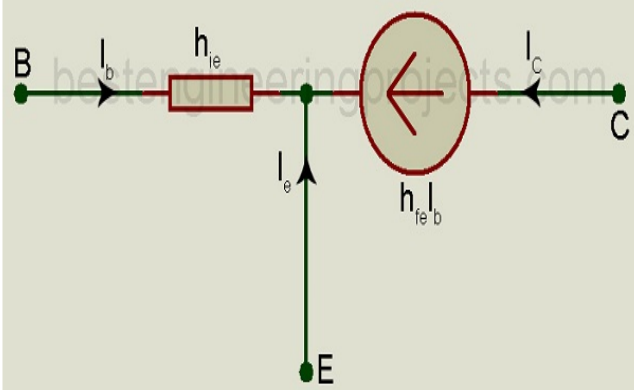


Figure 3: Approximate h-model valid for all the three configurations of a transistor

Analysis of CE Amplifier using Approximate h-model

Figure 2 gives the equivalent circuit of CE amplifier using approximate h-model for the transistor. For this equivalent circuit we get

Current gain $A_I = \frac{I_L}{I_b} = -\frac{I_C}{I_b}$ = output current / input current

From the figure $I_C = h_{fe} I_b$

$$A_I = \frac{-h_{fe} \times I_b}{I_b} = -h_{fe}$$

Input resistance : $R_i = h_{ie}$ $R_i = \frac{V_b}{I_b} = h_{ie} + h_{re} A_I R_L$ Neglect h_{re}

Voltage gain $$A_V = A_I \times \frac{R_L}{R_i} = \frac{-h_{fe} \times R_L}{h_{ie}}$$

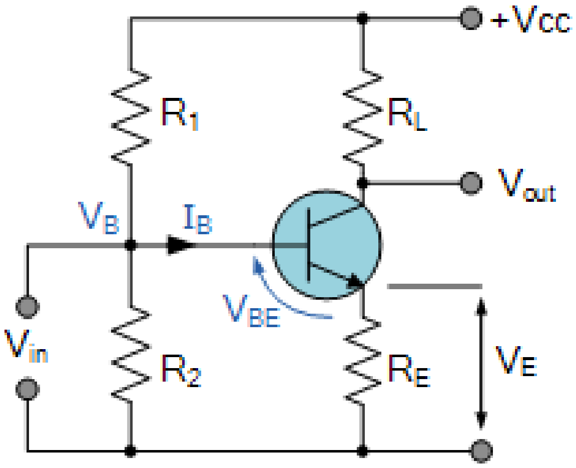
Output resistance R_0 : From this approximate equivalent circuit of figure 1(b) with $V_s = 0$ and with external voltage source connected across the output, we get $I_b = 0$ and therefore $I_C = 0$. Hence output resistance $R_0 = \infty$ However, in actual practice, R_0 lies between $40K\Omega$ to $80K\Omega$ depending on the value of R_S.

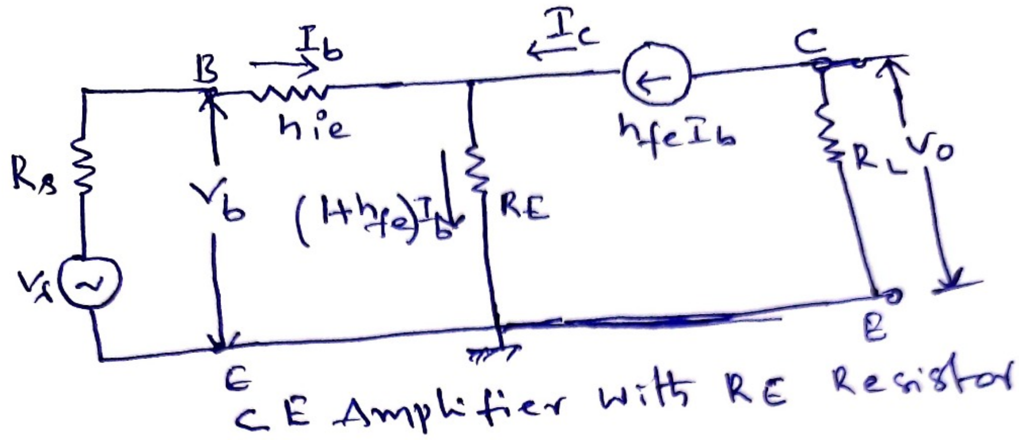
Simplified Analysis of CE amplifier with emitter resistance using h-parameter model

In CE amplifiers emitter resistance is neglected it is bypassed with emitter capacitance (Ce) to improve the output voltage or gain due no voltage drop across emitter resistance.

But to get stabilized voltage amplification, it is necessary to consider emitter resistance R_E .

The gain is provided by an amplifier is not sufficient, it is necessary to cascade the number of stages of the amplifier. In such cases it become important to stabilize the voltage at the output of the each amplifier stage. Instability of the voltage amplification is not desired. Simple and effective way to obtain stability of voltage amplification by adding emitter resistor.





Current gain $(A_I) = \frac{I_L}{I_b} = -\frac{I_c}{I_b}$ = output current / input current

from figure $I_C = h_{fe} I_b$

$$A_I = \frac{-h_{fe} \times I_b}{I_b} = -h_{fe}$$

Input Resistance($R_i) = \frac{V_b}{I_b} = \frac{h_{ie} I_b + (1+h_{fe}) I_b R_E}{I_b}$

$$R_i = \frac{V_b}{I_b} = h_{ie} + (1 + h_{fe}) R_E$$

The input resistance due to the factor $(1 + h_{fe})R_E$ is very much larger than h_{ie} . Hence emitter resistance greatly increases input resistance.

Voltage gain $(A_V) = \frac{A_i R_L}{R_i}$

$$A_V = -\frac{h_{fe} R_L}{h_{ie} + \left(1 + h_{fe}\right) R_E}$$

Output Resistance(R_0): $It\ is\ resistance\ of\ amplifier\ without\ source\ voltage\ and\ load.$ R_0= output voltage/output current with Vs =0, $R_0 = \infty$

Analysis of CB Amplifier using the Approximate Model

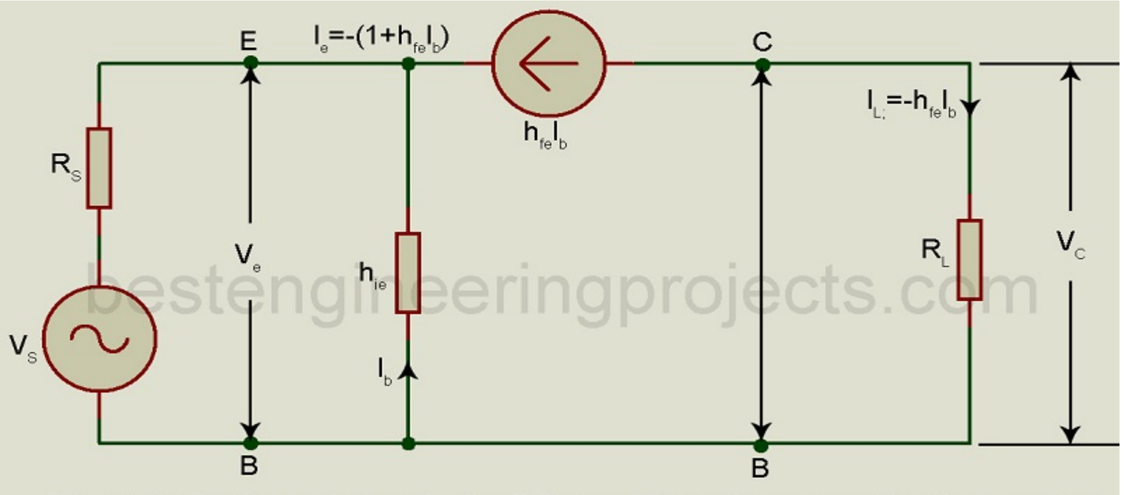
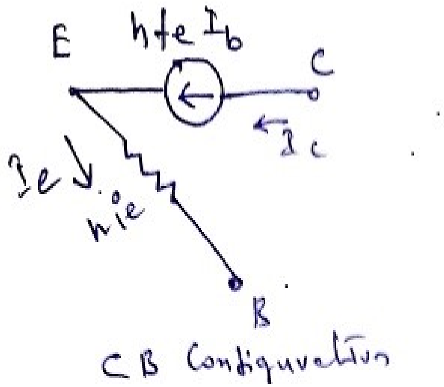


Figure 4: Equivalent circuit of a CB amplifier using approximate h-model



Current gain (A_i) = output current / input current : $A_I = -\frac{I_c}{I_b} = \frac{I_L}{I_b}$

$$A_I = \frac{I_L}{I_e} = \frac{-h_{fe} \times I_b}{-(1+h_{fe}) \times I_b} = \frac{h_{fe}}{1+h_{fe}}$$

Current gain always less than 1

Input Resistance= input voltage / input current $:R_I = \frac{V_E}{I_E}$

$$V_e = -I_b \times h_{ie} \qquad I_e = -(1 + h_{fe}) \times I_b$$

$$R_i = \frac{V_e}{I_e} = \frac{-I_b \times h_{ie}}{-I_b(1 + h_{fe})} = \frac{h_{ie}}{1 + h_{fe}}$$

Voltage Gain A_V = output voltage / input voltage

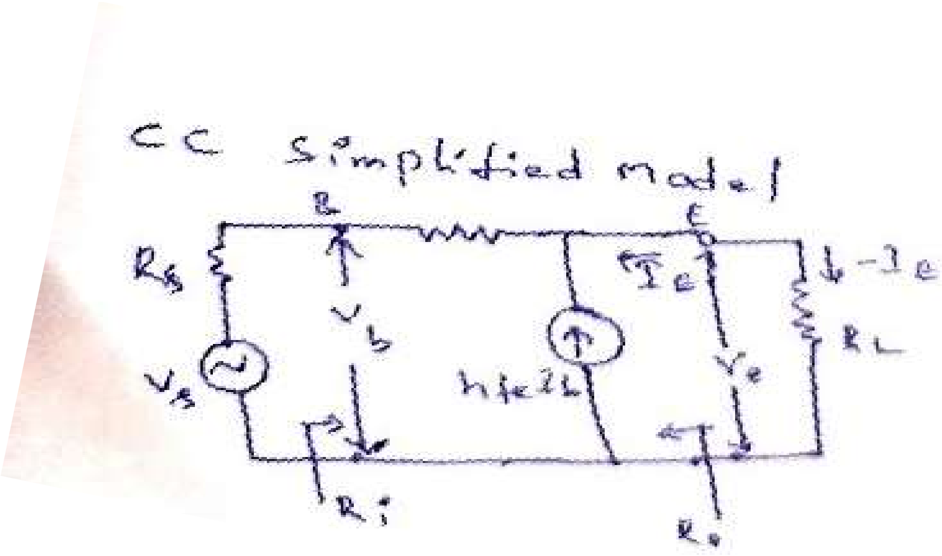
$$A_V = \frac{V_C}{V_e} = \frac{-h_{fe} \times I_b \times R_L}{-I_b \times h_{ie}} = \frac{h_{fe} \times R_L}{h_{ie}} \qquad V_C = -h_{fe} \times I_b \times R_L$$

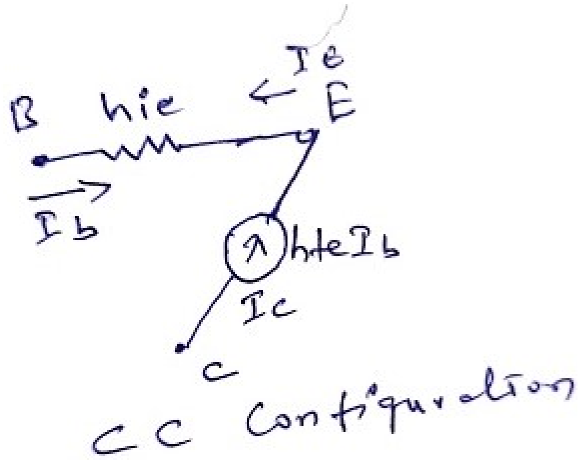
Output Resistance:

Output resistance In the equivalent circuit of figure 3, with $V_s = 0$, we get I_{-e} = 0. Hence, $I_b = 0$. Hence the output resistance $R_0 = \infty$

Output Terminal Resistance $R_{ot} = R_0 || R_L = \infty || R_L = R_L$

Analysis of CC Amplifier using the Approximate Model





Current gain (A_i) = output current / input current : $A_I = -\frac{I_e}{I_b} = \frac{I_L}{I_b}$

From the circuits $I_b + I_e + h_{fe} I_b = 0$ $\quad I_e = -(1 + h_{fe}) I_b$

$$A_I = \frac{I_L}{I_b} = (1 + h_{fe}) \qquad I_L = (1 + h_{fe}) I_b$$

Input resistance R_i

$$V_b = I_b \times h_{ie} + (1 + h_{fe}) I_b \times R_L$$

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

Voltage Gain A_V

$$V_e = (1 + h_{fe}) I_b \times R_L$$

$$A_V = \frac{V_e}{V_b} = \frac{(1 + h_{fe}) I_b \times R_L}{I_b \times h_{ie} + (1 + h_{fe}) I_b \times R_L}$$

$$A_V = \frac{(1+h_{fe})R_L}{h_{ie}+(1+h_{fe})R_L} = 1 - \frac{h_{ie}}{h_{ie}+(1+h_{fe})R_L} = 1 - \frac{h_{ie}}{R_i}$$

Output Resistance :

$$R_0 = \frac{Open\ circuit\ output\ voltage}{Short\ circuit\ output\ current} = \frac{h_{ie} + R_s}{1 + h_{fe}}$$

Open circuit output voltage = V_S

Short circuit output current $I = (1 + h_{fe}) I_b = \frac{(1 + h_{fe}) V_s}{h_{ie} + R_s}$

FET Amplifiers

A Field Effect Transistor (FET) is a three-terminal semiconductor device. Its is a voltage controlled device (output current controlled by input small voltage). By appearance .However, BJT is a current controlled device (output current is controlled by input small current). Most commonly two types of FETs are available.

•Junction Field Effect Transistor (JFET)

•Metal Oxide Semiconductor FET (IGFET)

JFET amplifiers provides an excellent voltage gain with high input impedance. Because its high input impedance other characteristics JFET preferred over BJTs for certain applications. No feed back from output to input in FET but In BJT, feedback from output to input with the parameter h_{re}.

There are three configurations in FET

1. Common Source   2. Common drain   3. Common gate

Advantages of JFET:

- Very high input impedance (up to 10kΩ)
- Operation of JFET depends on the bulk material current carriers that do not cross junctions.
- Very high power gain.
- Smaller in size and having high efficiency.

Difference between BJT and FET

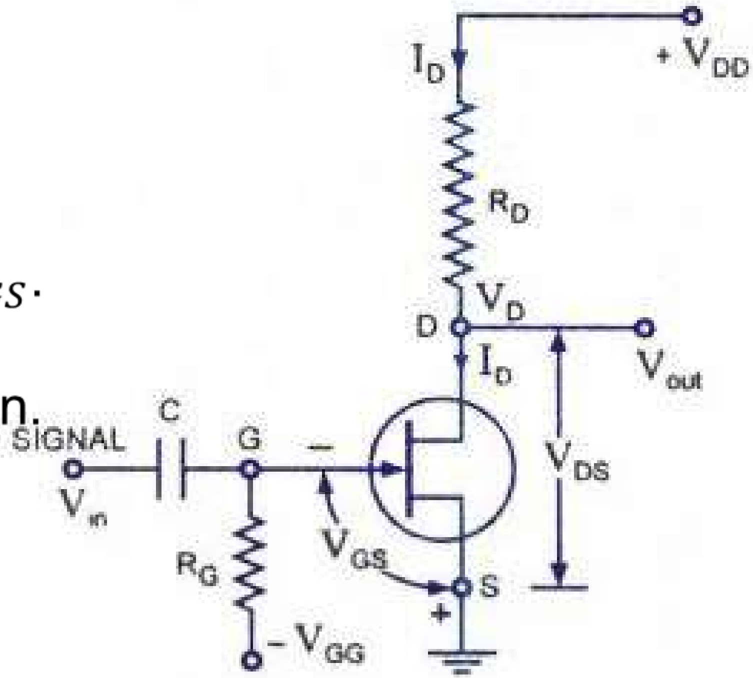
- Bipolar junction transistors are bipolar devices, in this transistor there is a flow of both majority & minority charge carriers.
- Field effect transistors are unipolar devices, in this transistor there are only the majority charge carriers flows.
- Bipolar junction transistors are current controlled.
- Field effect transistors are voltage controlled.
- In many applications FETs are used than bipolar junction transistors.
- The input impedance of field effect transistors has high compared with bipolar junction transistors.
- A BJT needs a small amount of current to switch on the transistor. The heat dissipated on bipolar stops the total number of transistors that can be fabricated on the chip.
- Whenever the ‘G’ terminal of the FET transistor has been charged, no more current is required to keep the transistor ON.
- The BJT is responsible for overheating due to a negative temperature co-efficient.
- FET has a +Ve temperature coefficient for stopping over heating.
- BJTs are applicable for low current applications.
- FETS are applicable for low voltage applications.
- FETs have low to medium gain.
- BJTs have a higher max frequency and a higher cutoff frequency.

JFET low frequency small signal model

V_{GG} provides necessary reverse bias between gate and source of JFET, The signal to be amplified is Vin.

In pinch of region I_D depends only on V_{GS}. Pinch of voltage is drain to source voltage at which JFET enter to saturation.

han



The drain to source current I_D is controlled by gate to source voltage V_{GS}.

The change in the drain current due to change in gate to source voltage can be obtain using transconductance factor (g_m).

$$\Delta I_d = g_m \Delta V_{gs}$$

Another important parameter of JFET is drain resistance r_d.

$$r_d = \frac{\Delta V_{DS}}{\Delta I_d}$$

AC equivalent circuit of JFET

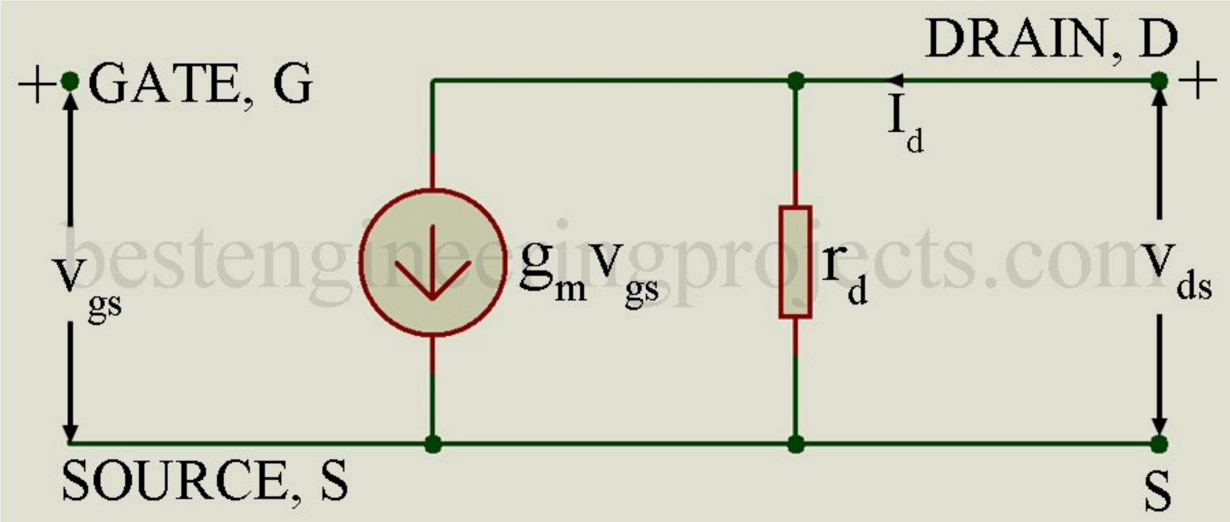


Figure 1: Low frequency small signal model of FET

Analysis of Common source(CS) amplifier with fixed bias

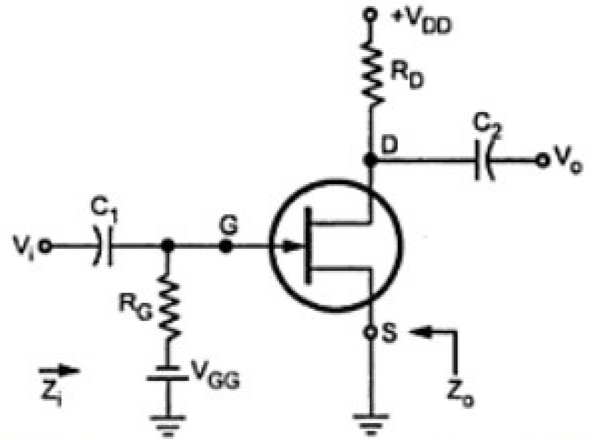


Fig3.2 Common source circuit of JFET

Figure shows Common Source Amplifier With Fixed Bias. The coupling capacitor C1 and C2 which are used to isolate the d.c biasing from the applied ac signal act as short circuits for ac analysis.

All capacitors and d.c supply voltages with short circuit.

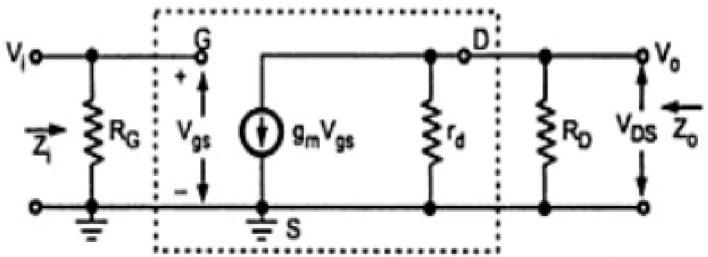


Fig3.3 small signal model of CS JFET amplifier

The following figure shows the low frequency equivalent model for Common Source Amplifier With Fixed Bias.

Input impedance (Z_i): from the circuit

$$Z_i = R_G$$

Output Impedance (Zo) :

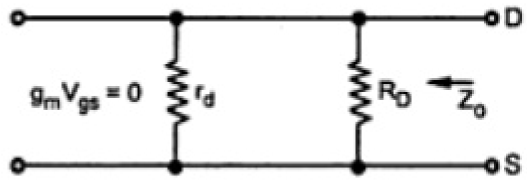


Fig3.4 Equivalent circuit model of JFET for output

It is the impedance measured looking from the output side with input voltage Vi equal to Zero. As Vi=0,Vgs =0 and hence g_mVgs =0 . And it allows current source to be replaced by an open circuit.

So $$Z_o = R_D \| r_d$$

If the resistance rd is sufficiently large compared to R_D, then

$$Z_i = R_D$$

Voltage Gain A_v :

The voltage gain $A_v = \frac{V_{ds}}{V_{gs}} = \frac{V_o}{V_i}$

Looking at Fig. we can write

$$V_o = -g_m V_{gs} \ (r_d \| R_D)$$

As we know $V_i = V_{gs}$ we can write

$$V_o = -g_m V_i \ (r_d \| R_D)$$

$$\therefore \quad A_v = \frac{V_o}{V_i} = -g_m \ (r_d \| R_D)$$

and if $r_d >> R_D$,

$$A_v \approx -g_m R_D$$

Table summarizes performance of common source amplifier with fixed bias.

Parameter	Exact	With $r_d >> R_D$
Z_i	R_G	R_G
Z_o	$R_D \| r_d$	R_D
A_v	$-g_m \ (R_D \| r_d)$	$-g_m \ R_D$

Common source amplifier with self bias (Bypassed Rs)

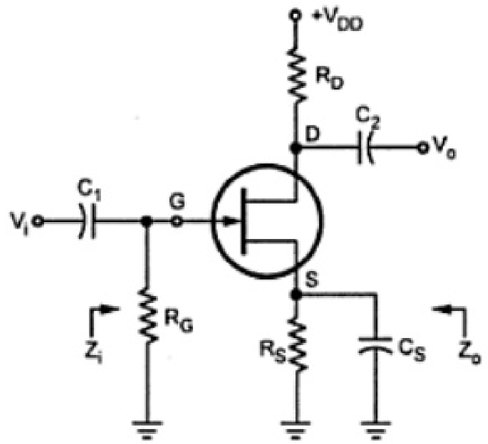


Fig3.5 **Common source amplifier** model of JFET

Figure shows Common Source Amplifier With self Bias. The coupling capacitor C1 and C2 which are used to isolate the d.c biasing from the applied ac signal act as short circuits for ac analysis. Bypass capacitor Cs also acts as a short circuits for low frequency analysis.

The following figure shows the low frequency equivalent model for Common Source Amplifier With self Bias.

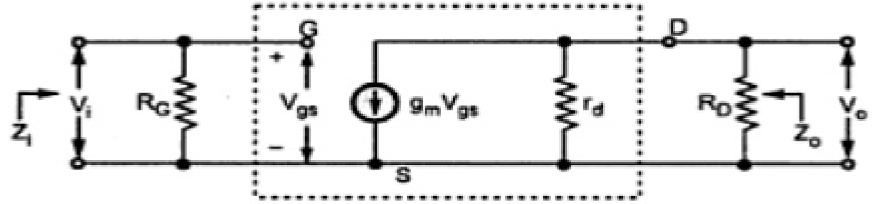


Fig3.6 **Small signal model for Common source amplifier** model of JFET

i) Input impedance Z_i : $Z_i = R_G$

ii) Output impedance Z_o : $Z_o = r_d \,||\, R_D$

if $r_d >> R_D$ $Z_o \approx R_D$

iii) Voltage gain A_v : $A_v = -g_m (r_d \,||\, R_D)$

If $r_d >> R_D$ $A_v = -g_m R_D$

Common source amplifier with self bias (unbypassed R_s)

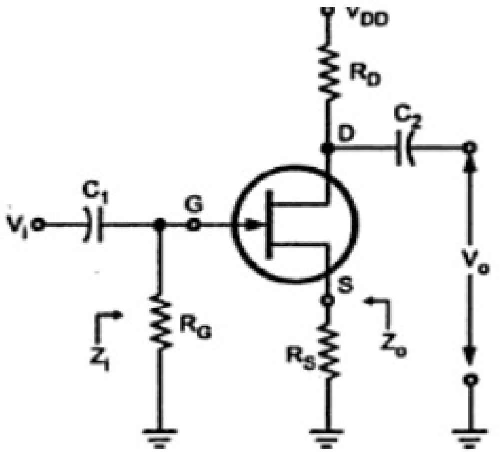


Fig3.7 **Common source amplifier** model of JFET

Now Rs will be the part of low frequency equivalent model as shown in figure.

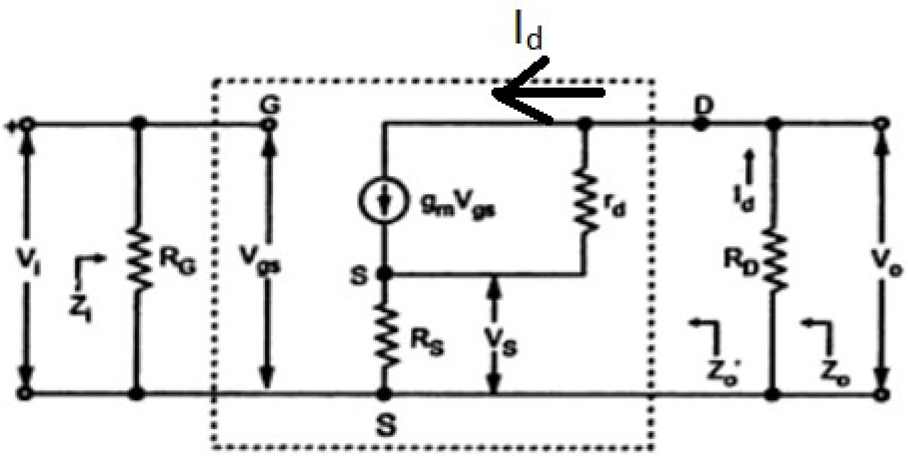


Fig3.8 **Small signal model for Common source amplifier** model of JFET

Input Impedance (Z_i)

$$Z_i = R_G$$

Output Impedance (Z_o)

$$Z_o = Z_o' \| R_D$$

where $$Z_o' = \left.\frac{V_o}{I_d}\right|_{V_i=0}$$

Apply KVL to output circuit

$$V_0 = (I_d - g_m V_{gs})r_d + I_d R_s$$

Apply KVL to input outer loop $V_{gs} = V_{in} - I_d R_s$

$$V_{in} = 0$$

$$V_{gs} = -I_d R_s$$

Substitute V_{gs} in V_0

$$V_0 = (I_d - g_m(-I_d R_s)\ \ )r_d + I_d R_s$$

$$V_0 = I_d(r_d + g_m R_s r_d + R_s)$$

$$Z_{0'} = \frac{V_o}{I_d} = \frac{I_d(r_d + g_m R_s r_d + R_s)}{I_d}$$

$$Z_{0'} = \frac{V_o}{I_d} = r_d + g_m R_s r_d + R_s$$

$$\mu = g_m r_d$$

$$Z_{0'} = \frac{V_o}{I_d} = r_d + \mu R_s + R_s$$

$$Z_{0'} = \frac{V_o}{I_d} = r_d + (\mu + 1)R_s$$

$$Z_0 \quad = Z_{0'} // R_D$$

$$Z_0 = (r_d + (\mu + 1)R_s) // R_D$$

Voltage gain (A_v)

$$V_0 = (I_d - g_m V_{gs}) r_d + I_d R_s$$

Apply KVL to input outer loop $V_{gs} = V_{in} - I_d R_s$

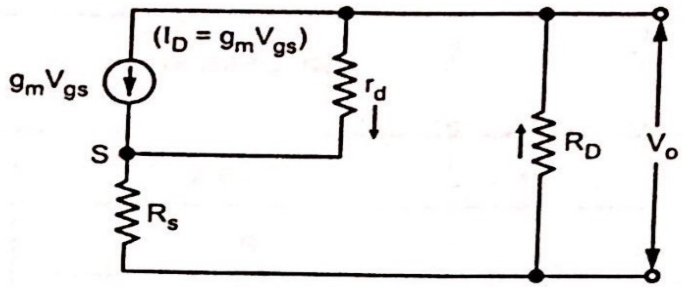


Fig. 1.78

Substituting value of V_{gs} in equation (25) we get,

$$[I_d - g_m (V_i - I_d R_s)] r_d + I_d R_s + I_d R_D = 0 \quad \ldots ($$

$$I_d r_d - g_m V_i r_d + g_m I_d R_s r_d + I_d R_s + I_d R_D = 0 \quad \ldots ($$

$$\therefore \quad I_d (r_d + R_s + R_D + g_m R_s r_d) = g_m V_i r_d \quad \ldots ($$

$$\therefore \quad I_d = \frac{g_m V_i r_d}{r_d + R_s + R_D + g_m R_s r_d} \quad \ldots ($$

Voltage gain (A_v)

$$A_v = \frac{V_o}{V_i}$$

We know that,

$$V_o = -I_d R_D$$

$$A_v = \frac{V_o}{V_i} = \frac{-g_m r_d R_D}{r_d + R_s + R_D + g_m R_s r_d}$$

Dividing numerator and denominator by r_d we get,

$$\therefore \quad A_v = \frac{V_o}{V_i} = \frac{-g_m R_D}{1 + g_m R_s + \dfrac{R_s + R_D}{r_d}}$$

If $r_d >> R_s + R_D$

$$A_v = \frac{V_o}{V_i} = \frac{-g_m R_D}{1 + g_m R_s}$$

Table summarizes performance of common source amplifier with self bias.

Parameter	Bypassed R_S		Unbypassed R_S	
	Exact	$r_d >> R_D$	Exact	$r_d >> R_D$
Z_i	R_G	R_G	R_G	R_G
Z_o	$R_D \parallel r_d$	R_D	$[r_d + R_S(g_m r_d + 1)] \parallel R_D$ or $[r_d + R_S(\mu + 1)] \parallel R_D$	$[r_d + R_S(g_m r_d + 1)] \parallel R_D$ or $[r_d + R_S(\mu + 1)] \parallel R_D$
A_v	$-g_m(R_D \parallel r_d)$	$-g_m R_D$	$\dfrac{-g_m R_D}{1 + g_m R_S + \dfrac{R_S + R_D}{r_d}}$	$\dfrac{-g_m R_D}{1 + g_m R_S}$

Analysis of Common drain (CD) FET amplifier

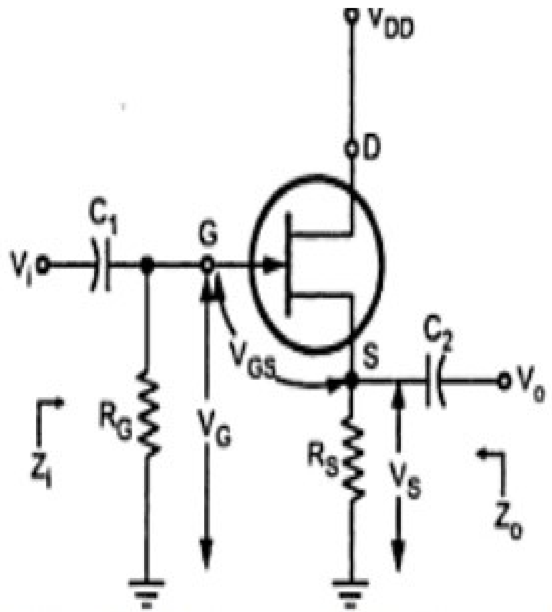


Fig3.12 **Circuit of Common Drain amplifier**

In this circuit, input is applied between gate and source and output is taken between source and drain.

In this circuit, the source voltage is $V_s = V_G + V_{GS}$

When a signal is applied to the JFET gate via C_1, VG varies with the signal. As VGS is fairly constant and $V_s = V_G + V_{GS}$, Vs varies with Vi.

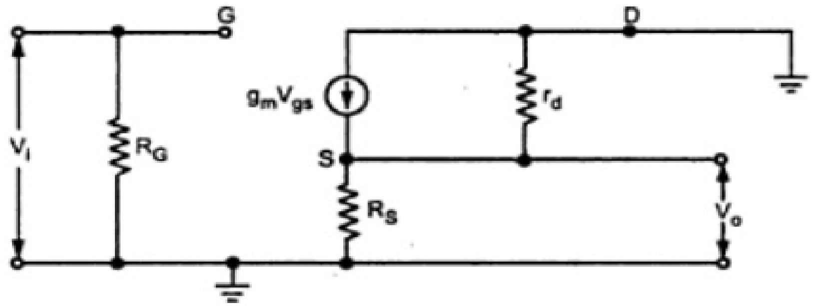


Fig3.13 **small model of Common Drain amplifier**

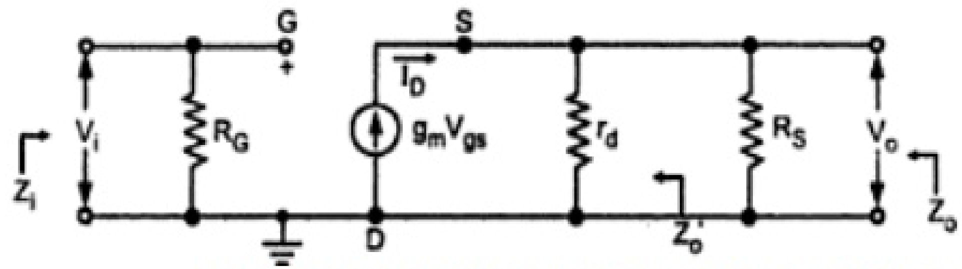


Fig3.13 Simplified small model of Common Drain amplifier

Input Impedance Z_i $Z_i = R_G$

Output Impedance Z_o

It is given by

$$Z_o = Z'_o \,||\, R_s$$

where $$Z'_o = \left.\frac{V_o}{I_d}\right|_{V_i=0}$$

Applying KVL to the outer loop we can have,

$$V_i + V_{gs} - V_o = 0$$

As $$V_i = 0,$$

$$V_{gs} = V_o$$

Looking at Fig. we can write that,

$$g_m V_{gs} = I_d$$

But Vgs = Vo, so

$$g_m V_o = I_d$$

$$Z_o' = \frac{V_o}{I_d} = \frac{1}{g_m}$$

$$\therefore \quad Z_o = \frac{1}{g_m} \,||\, R_s$$

Voltage gain (A_v)

$$A_v = \frac{V_o}{V_i}$$

Looking at Fig. we can write that,

$$V_o = -I_d (r_d || R_s)$$

and

$$I_d = g_m V_{gs}$$

$\therefore$

$$V_o = -g_m V_{gs} (r_d || R_s)$$

But

$$V_i = -V_{gs} + V_o$$

$$= -V_{gs} + [-g_m V_{gs} (r_d || R_s)]$$

$$A_v = \frac{-g_m V_{gs} (r_d || R_s)}{-V_{gs} (1 + g_m (r_d || R_s))}$$

$$= \frac{g_m (r_d || R_s)}{1 + g_m (r_d || R_s)}$$

if $r_d >> R_s$

$$A_v = \frac{g_m R_s}{1 + g_m R_s}$$

if $g_m R_s >> 1$

$A_v \approx 1$, but it is always less than one.

Analysis of Common gate (CG) FET amplifier

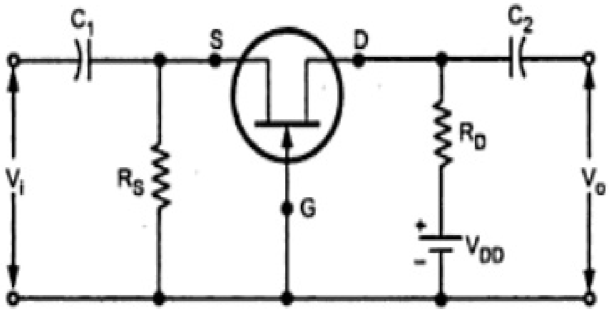


Fig3.14 **Circuit diagram of Common gate amplifier**

In this circuit, input is applied between source and gate and output is taken between drain and gate.

In CG Configuration, gate potential is at constant potential. so, increase in input voltage Vi in positive direction increase the negative gate source voltage. Due to I_D reduces, reduces, reducing the drop I_DR_D. Since $V_D = V_{DD} - I_DR_D$, the reduction in I_D results in an increase in output voltage.

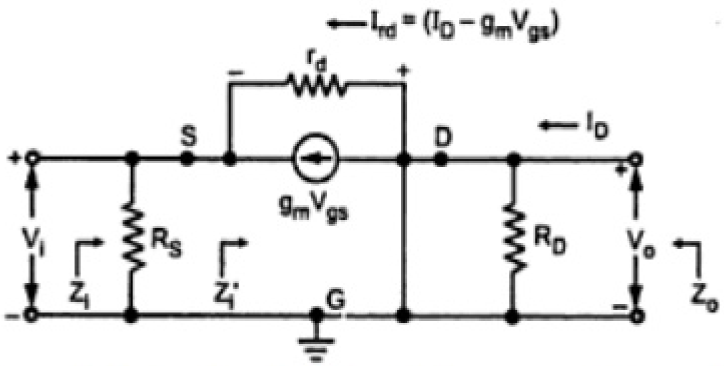


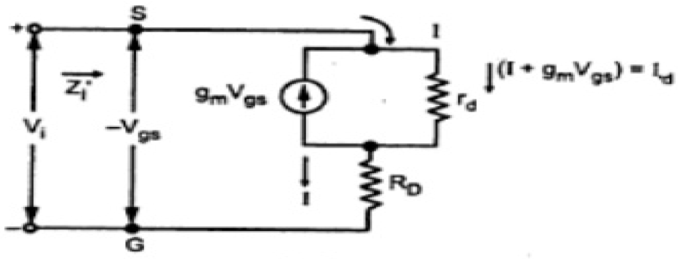
Fig3.15 **small signal model for Common gate amplifier**

Input Impedance (Zi)

$$Z_i = R_s \parallel Z_i'$$

And

$$Z_i' = \frac{V_i}{I}$$



$$I_{rd} = I + g_m V_{gs}$$

$$\therefore \quad I = I_{rd} \quad g_m V_{gs}$$

where $$I_{rd} = \frac{V_i - IR_D}{r_d}$$

$$\frac{V_i}{I} = \frac{1 + \frac{R_D}{r_d}}{\frac{1}{r_d} + g_m} = \frac{r_d + R_D}{1 + g_m r_d}$$

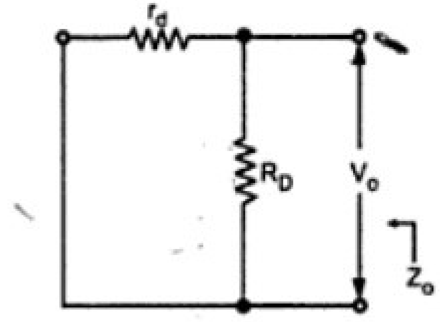
And

$$Z_i = R_s \parallel Z_i' = R_s \parallel \frac{r_d + R_D}{1 + g_m r_d}$$

If $r_d >> R_D$ and $g_m r_d >> 1$ then we can write,

$$Z_i = R_s \parallel \frac{r_d}{g_m r_d} = R_s \parallel \frac{1}{g_m}$$

Output Impedance (Z_0)



It is given by

$$Z_o = r_d \parallel R_D$$

If $r_d >> R_D$

$$Z_o \approx R_D$$

Voltage gain (A_v)

$$A_v = \frac{V_o}{V_i}$$

$$V_o = -I_D R_D$$

$$V_i = -V_{gs}$$

Using KVL to the outer loop, after simplification

$$A_v = \frac{V_o}{V_i} = \frac{-I_d + R_D}{\frac{-I_d(r_d + R_D)}{1 + g_m r_d}}$$

$$= \frac{R_D(1 + g_m r_d)}{r_d + R_D}$$

If $r_d >> R_D$ and $g_m r_d >> 1$

$$A_v = \frac{R_D(g_m r_d)}{r_d} = R_D g_m$$