3.1 BJT SMALL SIGNAL MODEL

CE, CB and CC Amplifiers:

An amplifier is used to increase the signal level. It is used to get a largersignal output from a small signal input. Assume a sinusoidal signal at the input of the amplifier. At the output, signal must remain sinusoidal in waveform with frequency same as that of input. To make the transistor work as an amplifier, it is to be biased tooperate in active region. It means base-emitter junction is forward biased and base- collector junction is reverse biased.

Let us consider the common emitter amplifier circuit using voltage divider bias.

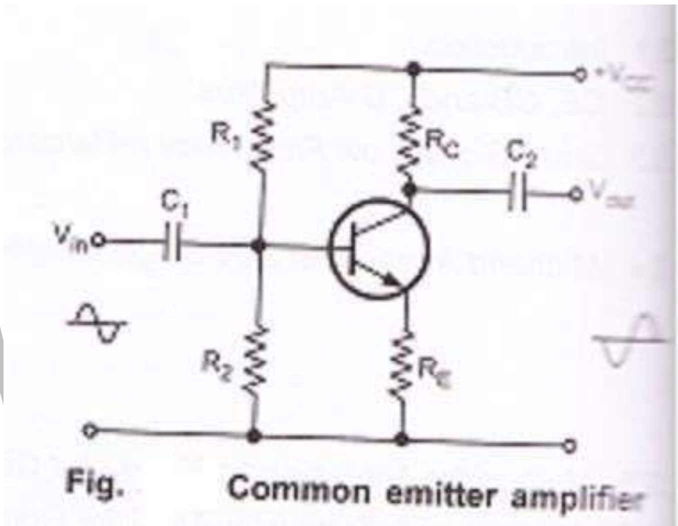

Figure: 3.1.1 I_{BQ} is quiescent DC base current

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 128]

In the absence of input signal, only D.C. voltage is present in the circuit. It is known as zero signal or no signal condition or quiescent condition. D.C. collector- emitter voltage V_{CE}, D.C. collector current I_C and base current I_B is the quiescent operating point for the amplifier. Due to this base current varies sinusoidaly as shown in the below figure.

If the transistor is biased to operate in active region, output is linearly proportional to the input. The collector current is β times larger than the input base current in CE configuration. The collector current will also vary sinusoidally about its quiescent value I_{CQ}. The output voltage will also vary sinusoidally as shown in the below figure.

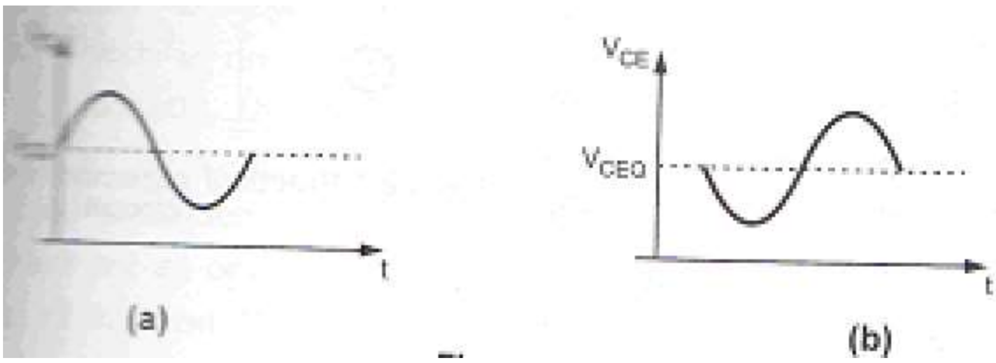

Figure: 3.1.2 Output Voltage

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 128]

Variations in the collector current and voltage between collector and emitter dueto change in base current are shown graphically with the help of load line in the above figure.

Common Emitter Amplifier Circuit:

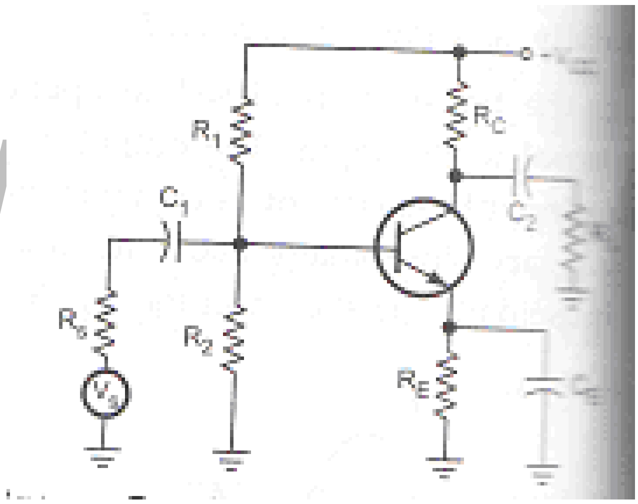

Fig. 3.1.3 Practical common-emitter amplifier circuit

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 128]

From above circuit, it consists of different circuit components. The functions of these components are as follows:

- Biasing Circuit:

Resistors R1, R2 and RE forms the voltage divider biasing circuit for CE amplifier and it sets the proper operating point for CE amplifier.

- Input Capacitor C1:

C1 couples the signal to base of the transistor. It blocks any D.C. component present in the signal and passes only A.C. signal for amplification.

- Emitter Bypass Capacitor CE:

CE is connected in parallel with emitter resistance RE to provide a low reactancepath to the amplified A.C. This will reduce the output voltage and reducing the gain value.

- Output Coupling Capacitor C2:

C2 couples the output of the amplifier to the load or to the next stage of the amplifier. It blocks D.C. and passes only A.C. part of the amplified signal.

Need for C1, C2, and CE:

The impedance of the capacitor is given by,

$$X_C = 1/ (2\prod fc)$$

Phase reversal:

The phase relationship between the input and output voltages can be determined by considering the effect of positive and negative half cycle separately. The collector current is β times the base current, so the collector current will also increases. This increases the voltage drop across RC.

$$V_C = V_{CC} - I_C R_C$$

Increase in IC results in a drop in collector voltage VC, as VCC is constant. Vi increases in a positive direction, Vo goes in negative direction and negative half cycleof output voltage can be obtained for positive half cycle at the input. In negative half cycle of input, A.C. and D.C. voltage will oppose each other. This will reduce the base current. Accordingly collector current and drop across RC both will reduce and it increases the output voltage. So positive half cycle at the output for negative half cycle at the input can be obtained. So there is a phase shift of 180° between input and output voltages for a common emitter amplifier.

Common Collector Amplifier Circuit:

Let us consider the transistor amplifier as a block box.

From above circuit, D.C. biasing is provided by R1, R2 and RE. The load resistance is capacitor coupled to the emitter terminal of the transistor. When a signal is applied to base of the transistor, VB is increased and decreased as the signal goes positive and negative respectively.

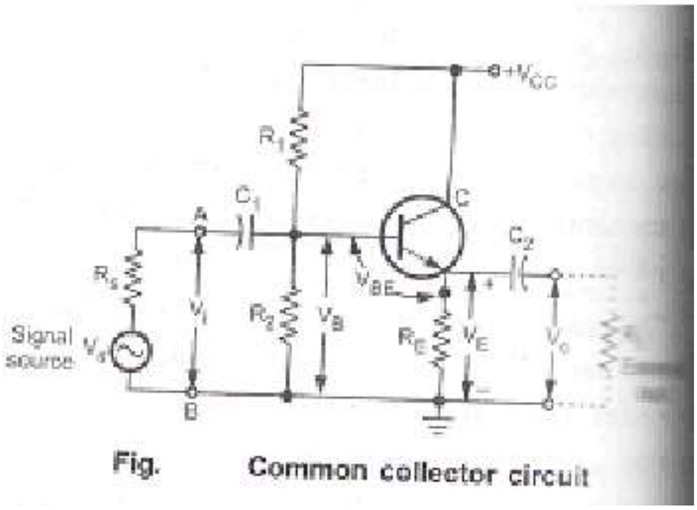

Figure: 3.1.4 Common collector circuit

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 129]

From figure,

$$VE = VB - VBE$$

Consider VBE is constant, so the variation in VB appears at emitter and emitter voltage VE will vary same as base voltage VB. In common collector circuit, emitter terminal follows the signal voltage applied to the base. It is also known as emitter follower.

Common Base Amplifier Circuit:

From above circuit, the signal source is coupled to the emitter of the transistor through C1. The load resistance RL is coupled to the collector of the transistor through C2. The positive going pulse of input source increases the emitter voltage. As base voltage is constant, forward bias of emitter- base junction reduces. This reduces Ib, Ic and drop across Rc.

$$Vo = VCC - ICRC$$

Reduction in IC results in an increase in Vo. Positive going input produces positive going output and vice versa. So there is no phase shift between input and output in common base amplifier.

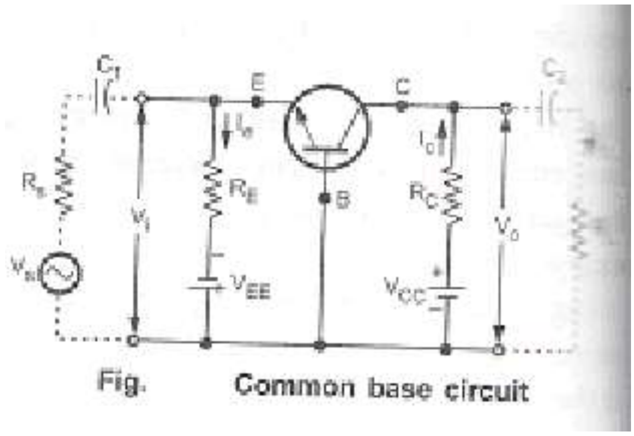

Figure: 3.1.5 Common base circuit

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 129]

3.4 Common source amplifier with self-bias (Bypassed Rs)

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.

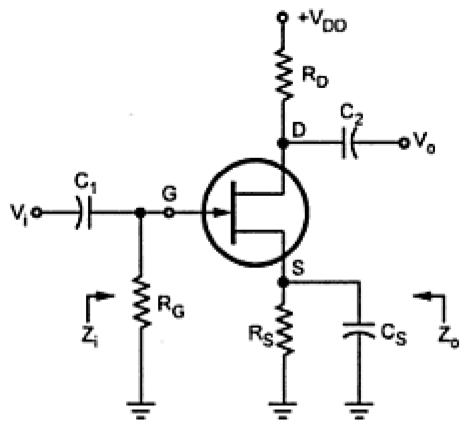

Fig 3.4.1 Common source amplifier model of MOSFET

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 136]

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

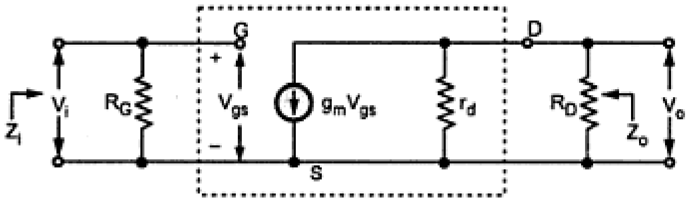

Fig 3.4.2 Small signal model for Common source amplifier model of MOSFET

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 136]

The negative sign in the voltage gain indicates there is a 180o phase shift between input and output voltages.

Common source amplifier with self-bias (UN bypassed Rs)

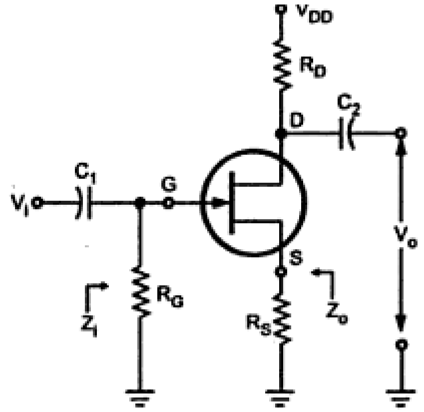

Fig 3.4.3 Common source amplifier model of MOSFET

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 136]

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

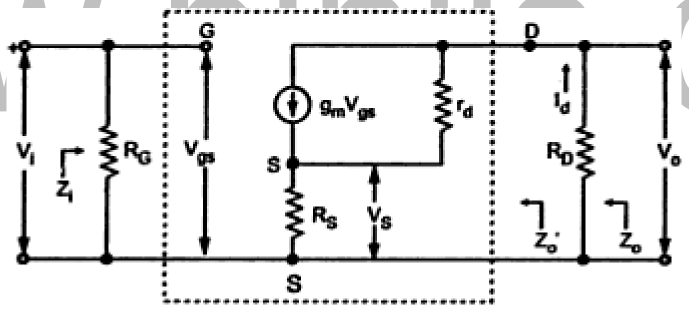

Fig 3.4.4 Small signal model for Common source amplifier model of MOSFET

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 136]

Input Impedance Zi o Zi = RG

Output Impedance Zo

3.5 Frequency Response of Common Source Amplifier:

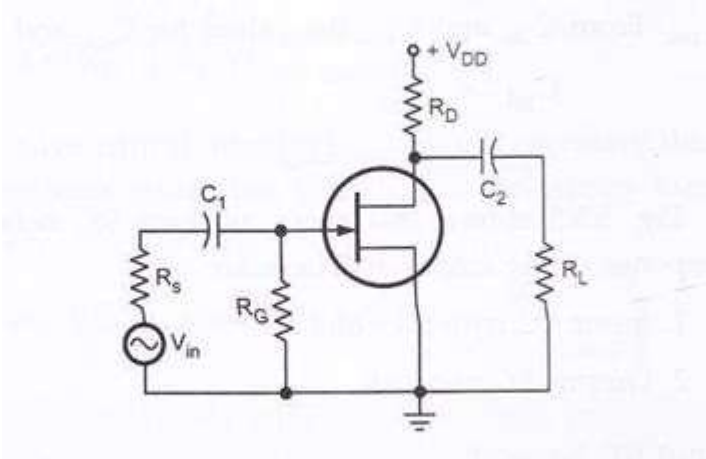

Figure: 3.5.1 RC coupled common source amplifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 138]

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

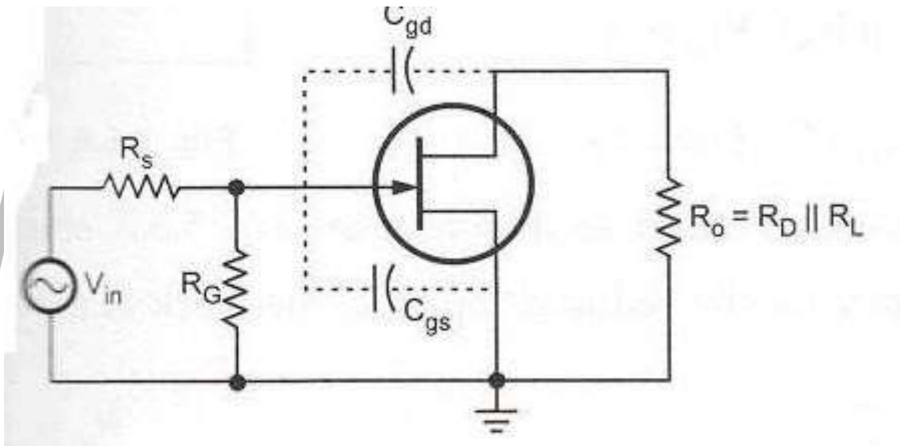

Figure: 3.5.2 High frequency equivalent circuit

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 138]

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 Cgd can be splitted into Cin (miller) and Cout (miller) as shown in the following figure.

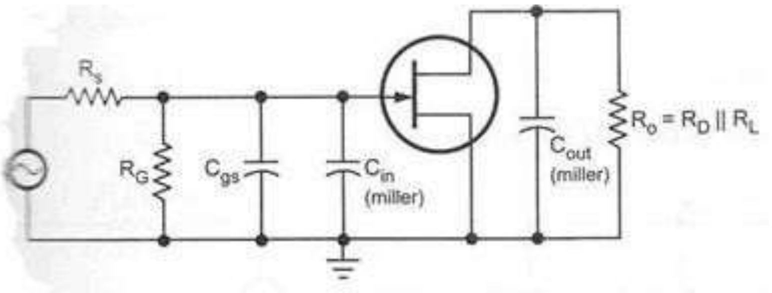

Figure: 3.5.3 Simplified High frequency equivalent circuit

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 138]

3.2 General shape of frequency response of amplifiers:

An audio frequency amplifier which operates over audio frequency rangeextending from 20 Hz to 20 kHz. Audio frequency amplifiers are used in radioreceivers, large public meeting and various announcements to be made for thepassengers on railway platforms. Over the range of frequencies at which it isto 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 curveknown as frequency response curve of the amplifier.

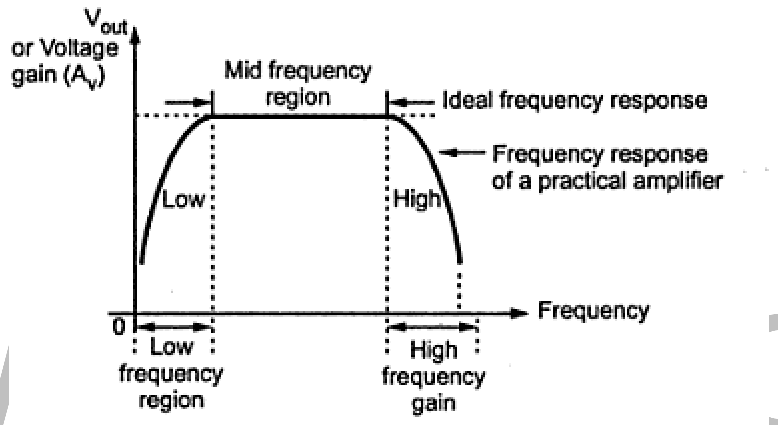

Fig. A typical frequency response of an amplifier

Figure: 3.2.1 typical frequency response of an amplifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 131]

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.

Definition of cut-off frequencies and bandwidth:

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

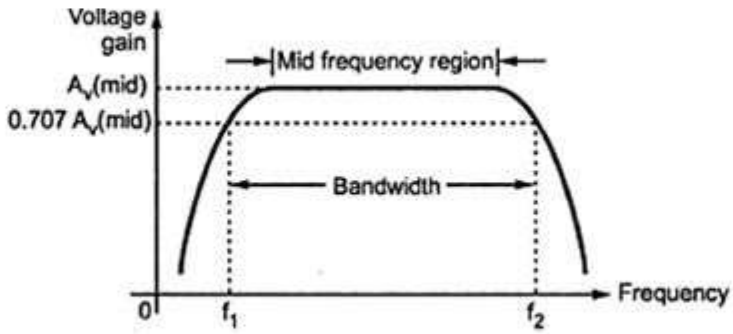

Figure: 3.2.2 Frequency response RC coupled amplifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 131]

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-powerfrequencies 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.

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

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,

Voltage gain in dB = 20 logA_v Power gain in

decibels is given by,

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 rangecan 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 = 40db 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

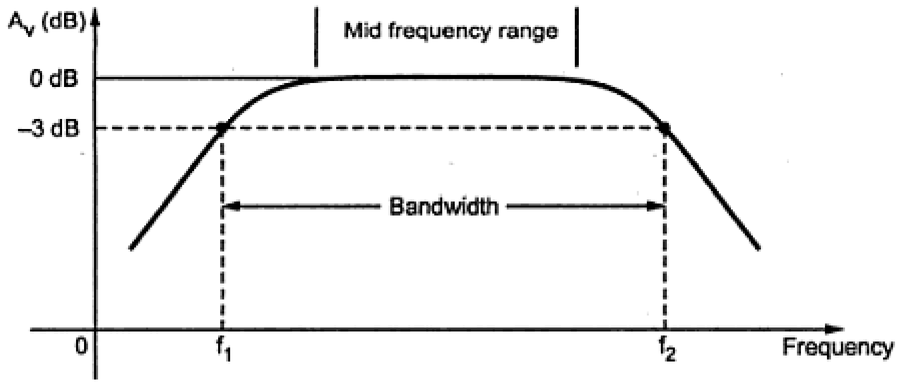

Figure: 3.2.3 Normalized voltage gain vs frequency

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 132]

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

This bandwidth is also referred to as 3 db bandwidth.

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.

3.3 MOSFET small signal model Amplifiers

It provides an excellent voltage gain with high input impedance. Due to these characteristics, it is often preferred over BJT.

Three basic FET configurations

Common source, common drain and common gate

MOSFET low frequency a.c Equivalent circuit

Figure shows the small signal low frequency a.c Equivalent circuit for n-channel JFET.

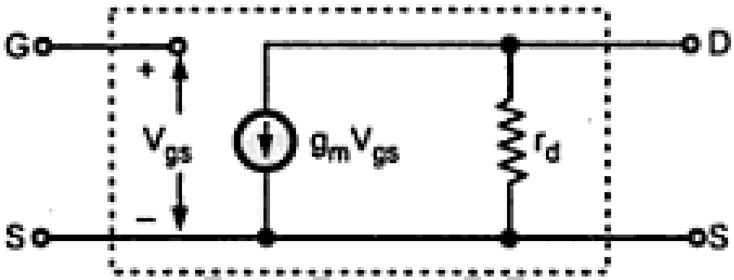

Fig 3.3.1 small signal model of JFET

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 135]

Common Source Amplifier with Fixed Bias

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.

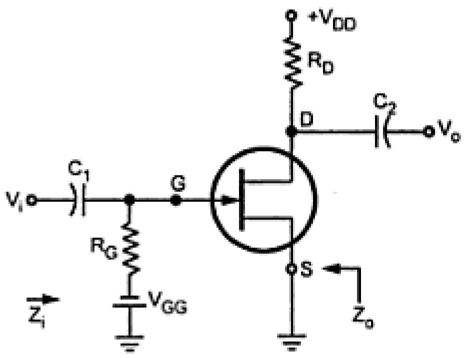

Fig 3.3.2 Common source circuit of JFET

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 135]

The following figure shows the low frequency equivalent model for Common Source Amplifier with Fixed Bias. It is drawn by replacing

- All capacitors and d.c supply voltages with short circuit
- JFET with its low frequency a.c Equivalent circuit

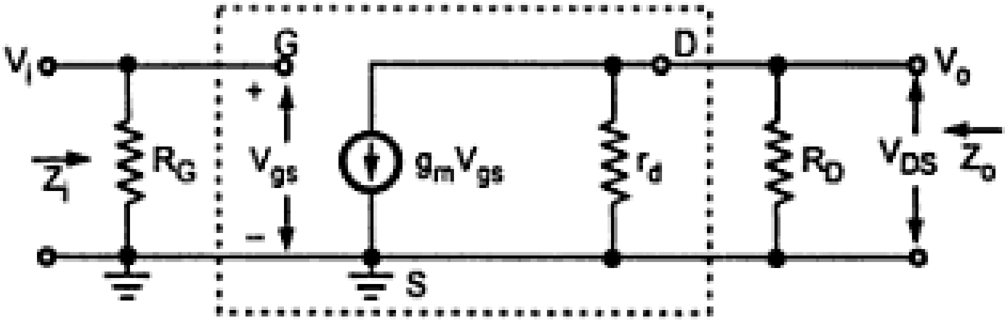

Fig 3.3.3 small signal model of CS MOSFET amplifier

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 135]

- Input Impedance Zi o Zi = RG
- Output Impedance Zo

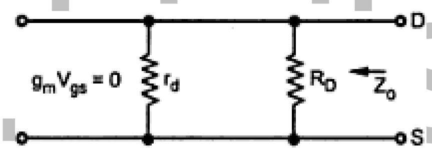

Fig 3.3.4 Equivalent circuit model of MOSFET for output

[Source: "Electronic devices and circuits" by "Balbir Kumar, Shail.B.Jain, and Page: 136]

It is the impedance measured looking from the output side with input voltage Vi equal toZero.

As Vi=0, Vgs =0 and hence gm Vgs =0 . And it allows current source to be replaced by anopen circuit.