Chapter 5

Frequency Response of BJT and FET

5.1. Introduction

The analysis thus far has been limited to a particular frequency. For the amplifier, it was a frequency that normally permitted ignoring the effects of the capacitive elements, reducing the analysis to one that included only resistive elements and sources of the independent and controlled variety. We will now investigate the frequency effects introduced by the larger capacitive elements of the network at low frequencies and the smaller capacitive elements of the active device at the high frequencies. Since the analysis will extend through a wide frequency range, the logarithmic scale will be defined and used throughout the analysis and concept of the decibel is introduced in some detail.

Logarithms

Relationship between the variables of a logarithmic function

$\mathbf{a = b^x, \quad x = \log_b a}$

$\text{Common logarithm}: x = \log_{10} a$

$\text{Natural logarithm}: y = \log_e a$

The two are related by: $\log_e a = 2.3 \log_{10} a$

$$\log_{10} 1 = 0$$

$$\log_{10} \frac{a}{b} = \log_{10} a - \log_{10} b$$

$$\log_{10} \frac{1}{b} = -\log_{10} b$$

$$\log_{10} ab = \log_{10} a + \log_{10} b$$

Semi log

Most graph paper available is of the semi log or double-log (log-log) variety. The term semi (meaning one-half) indicates that only one of the two scales is a log scale, whereas double-log indicates that both scales are log scales. A semi log scale appears in Fig.1 below.

Decibels

Decibel is a measure of the difference in magnitude between two power levels, P1 and P2. The term decibel is from the fact that power and audio levels are related on a logarithmic basis. The terminal rating of electronic communication equipment is commonly in $\mathbf{G = \log_{10} \frac{P_2}{P_1} \text{ (bel)}}$ decibels.

Bel-is too large unit of measurement for practical purposes, so decibel (dB) was defined such that

$$\mathbf{G_{dB} = 10 \log_{10} \frac{P_2}{P_1} \text{ (dB)}}$$

$$\mathbf{10\,dB = 1\,bel}$$

The reference power P1 is generally accepted to be 1mW. The resistance to be associated with the 1-mW power level is 600 Ω chosen because it is the characteristic impedance of audio transmission lines. When the 1-mW level is employed as the reference level, the decibel symbol frequently appears as dBm.

$$G_{dBm} = 10\log_{10}\frac{P_2}{1mW}\bigg|_{600\Omega}$$

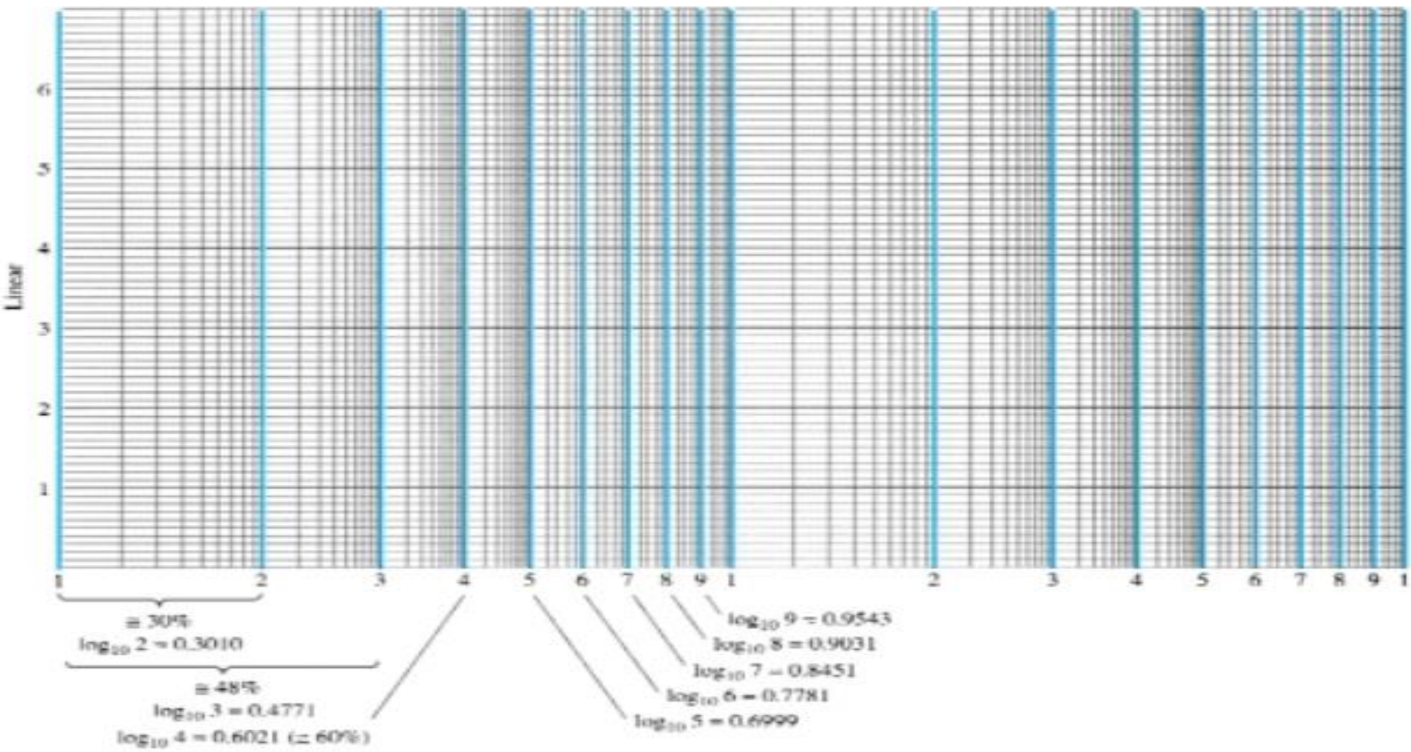


Fig.1 Semi log graph paper

There exists a second equation for decibels that is applied frequently. It can be best described through the system of Fig.2 below. For V_i equal to some value V_1, $P_1=V^2_1/R_i$, where R_i, is the input resistance of the system. If V_i should be increased (or decreased) to some other level, V_2, then $P_2 = V^2_2/R_i$. If we substitute into the decibel equation to determine the resulting difference in decibels between the power levels,

$$G_{dB} = 20\log_{10}\frac{V_2}{V_1} \quad (dB)$$

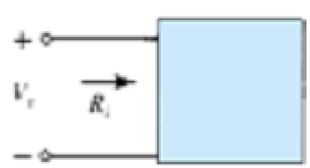


Fig.2:

Advantages of the logarithmic relationship, it can be applied to cascade stages.

$$G_{dB_T} = G_{dB_1} + G_{dB_2} + G_{dB_3} + \cdots\cdots + G_{dBn}$$

Gain versus Frequency

In Fig.3, the gain at each frequency is divided by the mid-band value. Obviously, the mid-band value is then 1 as indicated. At the half-power frequencies, the resulting level is $0.707 = 1/\sqrt{2}$. There is a band of frequencies in which the magnitude of the gain is either equal or relatively close to the midband value. To fix the frequency boundaries of relatively high gain, 0.707A was chosen to be the gain at the cutoff levels. The corresponding frequencies f_1 and f_2 are generally called the corner, cutoff, band, break, or half-power frequencies. The multiplier 0.707 was chosen because at this level the output power is half the midband power output, that is, at mid frequencies,

$$P_{o_{mid}} = \frac{|V_o^2|}{R_o} = \frac{|A_{v_{mid}} V_i|^2}{R_o}$$

and at the half-power frequencies,

$$P_{o_{HPF}} = \frac{|0.707 A_{v_{mid}} V_i|^2}{R_o} = 0.5 \frac{|A_{v_{mid}} V_i|^2}{R_o}$$

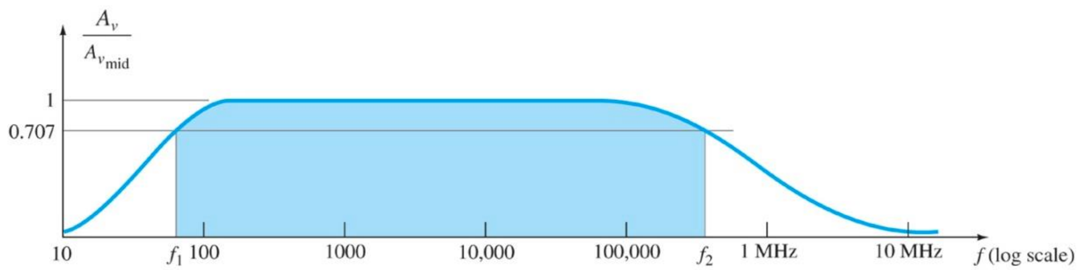


Fig.3: Normalized gain versus frequency plot

A decibel plot can now be obtained by applying decibel equation in the following manner:

$$\frac{A_v}{A_{Vmid}}|dB = 20log_{10}(\frac{A_v}{A_{vmid}})$$

At mid-band frequencies, $20 \log_{10} 1 = 0$, and at the cutoff frequencies, $20 \log_{10} 1/\sqrt{2} = -3$ dB. Both values are clearly indicated in the resulting decibel plot below. The smaller the fraction ratio, the more negative the decibel level.

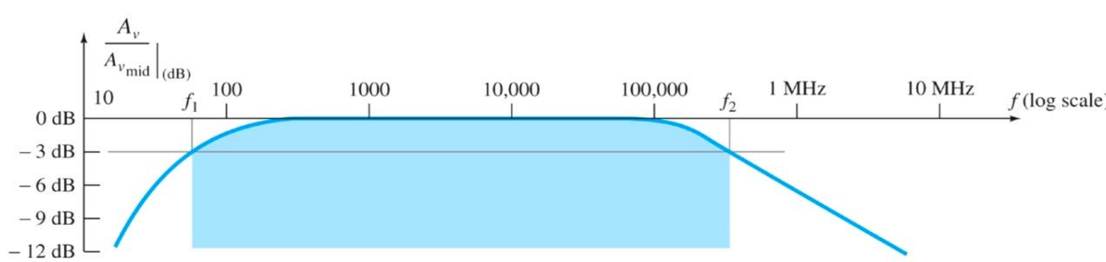


Fig.4. Decibel plot of the normalized gain versus frequency plot

It should be understood that most amplifiers introduce a 180° phase shift between input and output signals. This fact must now be expanded to indicate that this is the case only in the mid-band region. At low frequencies, there is a phase shift such that Vo lags Vi by an increased angle. At high frequencies, the phase shift will drop below 180°. Fig. 5 is a standard phase plot for an RC-coupled amplifier.

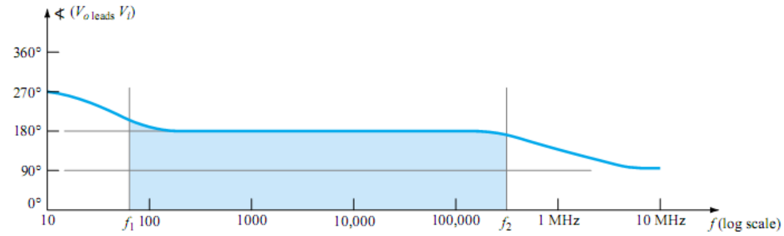


Fig.5: Phase plot of RC- coupled amplifier system

5.2. Low-Frequency Analysis—Bode Plot

In the low-frequency region of the single-stage BJT or FET amplifier, it is the R-C combinations formed by the network capacitors C_C, C_E, and C_s and the network resistive parameters that determine the cutoff frequencies. In fact, an R-C network similar to Fig. 6 can be established for each capacitive element and the frequency at which the output voltage drops to 0.707 of its maximum value determined. Once the cutoff frequencies due to each capacitor are determined, they can be compared to establish which will determine the low-cutoff frequency for the system.

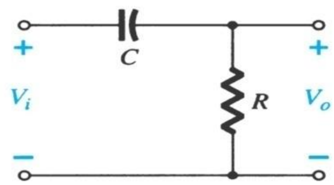


Fig.6. R-C combination that will define a low cutoff frequency

RC circuit at very high frequencies: $X_C = \dfrac{1}{2\pi fC} \cong 0\Omega$

The result is that Vo = Vi at high frequencies.

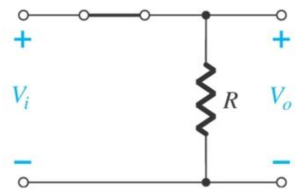


Fig.7. R-C circuit at very high frequencies

RC circuit at f = 0 Hz. $X_C = \dfrac{1}{2\pi fC} = \dfrac{1}{2\pi(0)C} = \infty\Omega$

Vo = 0 V.

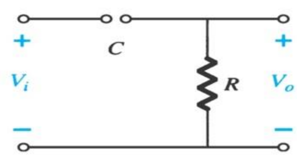


Fig.8. R-C circuit at f = 0Hz

At low frequency, the reactance of the capacitive becomes very large, so a significant portion of a signal dropped across them. Then as the frequency approaches zero or at dc, the capacitive reactance approach infinity or become an open circuit. As the frequency increases, the capacitive reactance decreases and more of the input voltage appears across the output terminals. Between the two extremes, the ratio Av = Vo/Vi will vary as shown in Fig.9 below

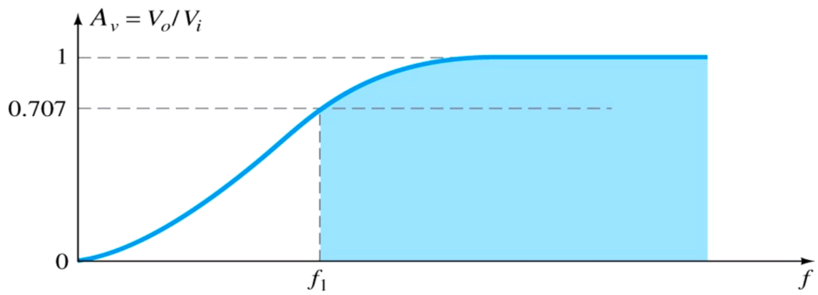


Fig.9. Low-frequency response for the RC circuit

The output and input voltages are related by the voltage-divider rule in the following manner:

$$\mathbf{V}_o = \frac{\mathbf{R}\mathbf{V}_i}{\mathbf{R} + \mathbf{X}_C}$$

With the magnitude of V_o determined by

$$V_o = \frac{RV_i}{\sqrt{R^2 + X_C^2}}$$

For the special case where $X_C = R$,

$$V_o = \frac{RV_i}{\sqrt{2R^2}} = \frac{RV_i}{\sqrt{2}R} = \frac{1}{\sqrt{2}} V_i$$

$$|A_v| = \frac{V_o}{V_i} = \frac{1}{\sqrt{2}} = 0.707|_{X_C=R}$$

At the frequency of which $X_C = R$, the output will be 70.7% of the input. The frequency at which this occurs is determined from:

$$X_C = \frac{1}{2\pi f_1 C} = R$$

$$f_1 = \frac{1}{2\pi RC}$$

In terms of logs,

$$G_v = 20 \log_{10} A_v = 20 \log_{10} \frac{1}{\sqrt{2}} = -3 \text{ dB}$$

While at Av = Vo/Vi = 1 or Vo = Vi (the maximum value),

$$Gv = 20 \log_{10} 1 = 20(0) = 0 \text{ dB}$$

If the gain equation is written as:

$$A_v = \frac{V_o}{V_i} = \frac{R}{R - jX_C} = \frac{1}{1 - j(X_C/R)} = \frac{1}{1 - j(1/\omega CR)} = \frac{1}{1 - j(1/2\pi fCR)}$$

And using the frequency defined above,

$$A_v = \frac{1}{1 - j(f_1/f)}$$

In the magnitude and phase form,

$$A_v = \frac{V_o}{V_i} = \underbrace{\frac{1}{\sqrt{1 + (f_1/f)^2}}}_{\text{magnitude of } A_v} \underbrace{\angle \tan^{-1}(f_1/f)}_{\text{phase} \measuredangle \text{ by which } V_o \text{ leads } V_i}$$

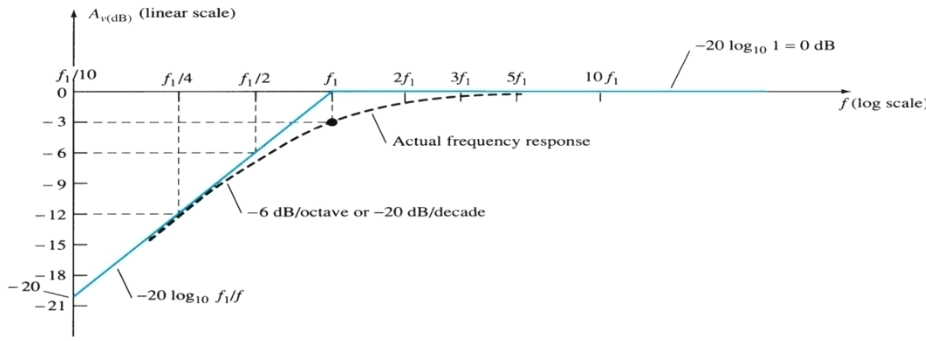


Fig.10. Bode plot for the low-frequency region

The phase angle of Θ is determined from

$$\theta = \tan^{-1} \frac{f_1}{f}$$

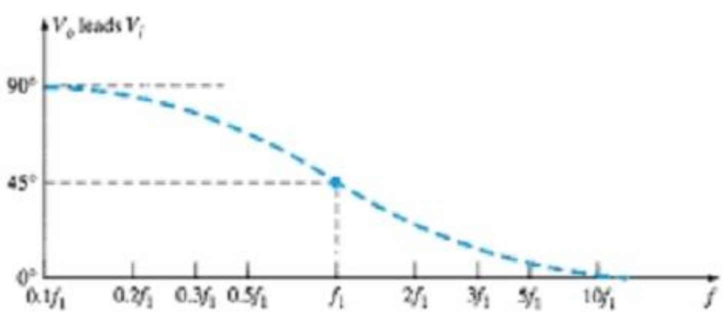


Fig.11. phase response for the R-C circuit

5.3. Low-Frequency Response —BJT Amplifier

At low frequencies Coupling capacitors (C_s, C_C) and Bypass capacitors (C_E) will have capacitive reactance (X_C) that affect the circuit impedances.

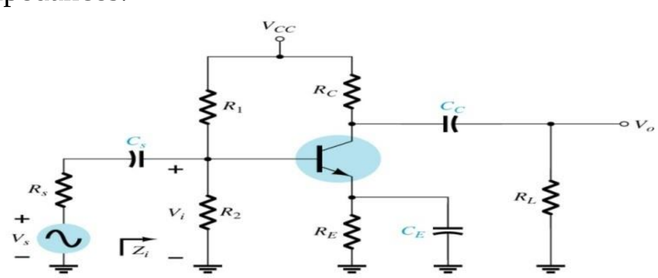


Fig.12. loaded BJT amplifier with capacitors that affect the low frequency response

Coupling Capacitor - C_S

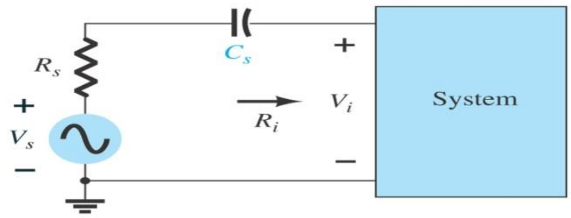


Fig.13. determining the effect of C_S on the low frequency response

Cutoff frequency $$f_{Ls} = \frac{1}{2\pi(R_s + R_i)C_s}$$

Voltage V_i $$V_i = \frac{R_i V_s}{R_i + R_s}$$

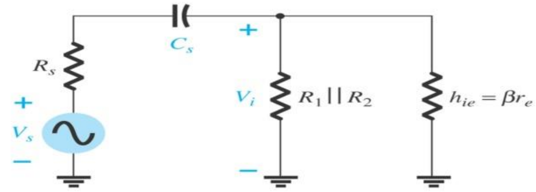


Fig.14. localized ac equivalent for C

$$R_i = R_1 \| R_2 \| \beta re$$

Coupling Capacitor - C_C

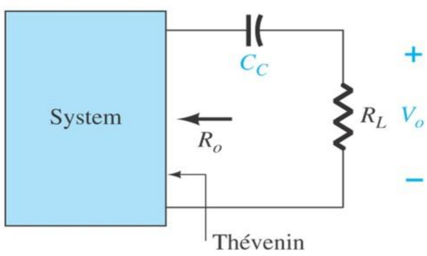


Fig.15. determining the effect of CC on the low-frequency response

Cutoff frequency: $$f_{LC} = \frac{1}{2\pi(R_o + R_L)C_C}$$

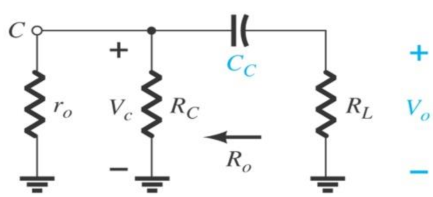


Fig.16. localized ac equivalent for C_C with Vi = 0V

$$R_o = R_C \| r_o$$

Bypass Capacitor - C_E

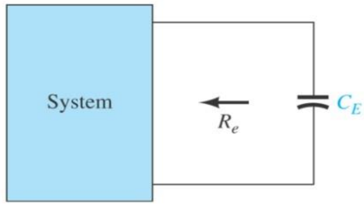


Fig.17. determining the effect of CE on the low-frequency response

Cutoff frequency: $$f_{L_E} = \frac{1}{2\pi R_e C_E}$$

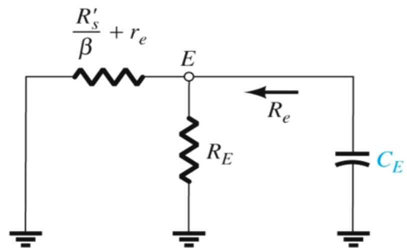


Fig.18. localized ac equivalent for C_E

$$R_e = R_E \parallel \left(\frac{R'_s}{\beta} + r_e\right)$$

$$R'_s = R_s \parallel R_1 \parallel R_2$$

Example.1

a. Determine the lower cutoff freq. for the network of Fig. 13 using the following parameters:
   $C_s = 10\mu F$, $C_E = 20\mu F$, $C_c = 1\mu F$
   $R_s = 1K\Omega$, $R_1 = 40K\Omega$, $R_2 = 10K\Omega$,
   $R_E = 2k\Omega$, $R_c = 4k\Omega$, $R_L = 2.2K\Omega$,
   $\beta = 100$, $r_0 = \infty\Omega$, $V_{cc} = 20V$
b. Sketch the frequency response using a Bode plot

Solution

(a) Determining re for dc conditions:

$$\beta R_E = (100)(2\ k\Omega) = 200\ k\Omega \gg 10R_2 = 100\ k\Omega$$

The result is:

$$V_B \cong \frac{R_2 V_{CC}}{R_2 + R_1} = \frac{10\ k\Omega(20\ V)}{10\ k\Omega + 40\ k\Omega} = \frac{200\ V}{50} = 4\ V$$

$$I_E = \frac{V_E}{R_E} = \frac{4\ V - 0.7\ V}{2\ k\Omega} = \frac{3.3\ V}{2\ k\Omega} = 1.65\ mA$$

$$r_e = \frac{26\ mV}{1.65\ mA} \cong \mathbf{15.76\ \Omega}$$

Cs

$$R_i = R_1 \| R_2 \| \beta r_e = 40\ k\Omega \| 10\ k\Omega \| 1.576\ k\Omega \cong 1.32\ k\Omega$$

$$f_{L_s} = \frac{1}{2\pi(R_s + R_i)C_s} = \frac{1}{(6.28)(1\ k\Omega + 1.32\ k\Omega)(10\ \mu F)}$$

$$f_{L_s} \cong \mathbf{6.86\ Hz}$$

Cc

$$f_{L_C} = \frac{1}{2\pi(R_C + R_L)C_C}$$

$$= \frac{1}{(6.28)(4\ \text{k}\Omega + 2.2\ \text{k}\Omega)(1\ \mu\text{F})}$$

$$\cong \mathbf{25.68\ Hz}$$

C_E

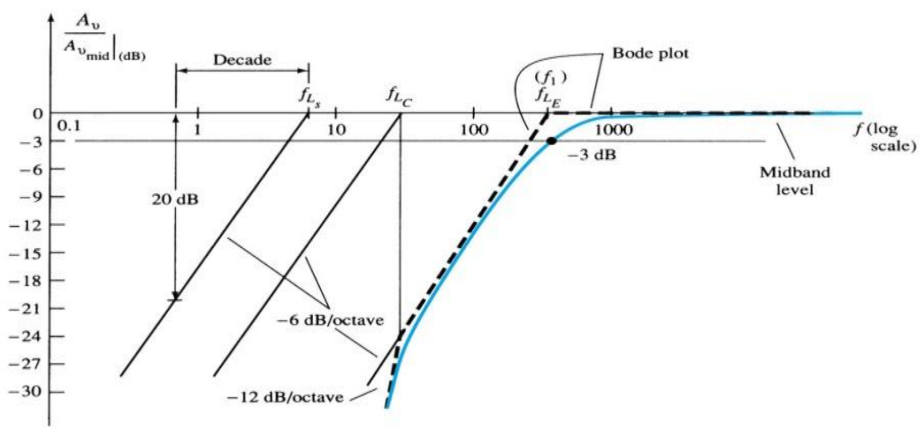
$$R'_s = R_s \| R_1 \| R_2 = 1\ \text{k}\Omega \| 40\ \text{k}\Omega \| 10\ \text{k}\Omega \cong 0.889\ \text{k}\Omega$$

$$R_e = R_E \left\| \left(\frac{R'_s}{\beta} + r_e \right) = 2\ \text{k}\Omega \right\| \left(\frac{0.889\ \text{k}\Omega}{100} + 15.76\ \Omega \right)$$

$$= 2\ \text{k}\Omega \| (8.89\ \Omega + 15.76\ \Omega) = 2\ \text{k}\Omega \| 24.65\ \Omega \cong 24.35\ \Omega$$

$$f_{L_E} = \frac{1}{2\pi R_e C_E} = \frac{1}{(6.28)(24.35\ \Omega)(20\ \mu\text{F})} = \frac{10^6}{3058.36} \cong \mathbf{327\ Hz}$$

Bode plot of low frequency response



The Bode plot indicates that each capacitor may have a different cutoff frequency. It is the device that has the ***highest*** of the low cutoff frequency (f_L) that dominates the overall frequency response of the amplifier (f_{LE}). For the above case the lower cutoff frequency of the network is equal to f_{LE} =327Hz.

5.4. Low-Frequency Response — FET Amplifier

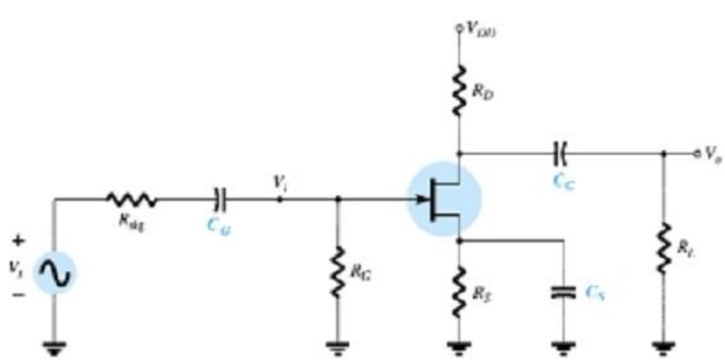


Fig.19. capacitive elements that affect the low-frequency response of a JFET amplifier

C_G

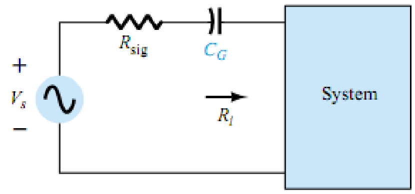


Fig.20. determining the effect of C_G on the low frequency response

$$f_{L_G} = \frac{1}{2\pi(R_{sig} + R_i)C_G}$$

$$R_i = R_G$$

C_C

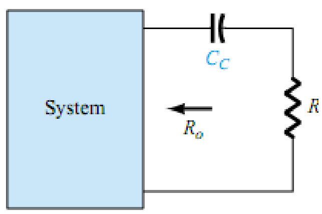


Fig.21. determining the effect of C_C on the low frequency response

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C}$$

$$R_o = R_D \| r_d$$

C_S

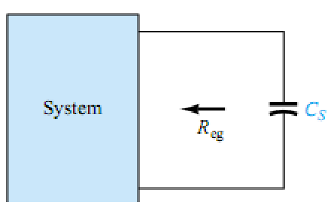


Fig.22. determining the effect CS on the low frequency response

$$f_{L_S} = \frac{1}{2\pi R_{eq} C_S}$$

$$R_{eq} = \frac{R_S}{1 + R_S(1 + g_m r_d)/(r_d + R_D \| R_L)}$$

$$R_{eq} = R_S \| \frac{1}{g_m}$$

5.5. Miller Effect Capacitance

In the high-frequency region, the capacitive elements of importance are the interelectrode (between terminals) capacitances internal to the active device and the wiring capacitance between leads of the network. The large capacitors of the network have all been replaced by their short-circuit equivalent due to their very low reactance levels.

For ***inverting*** amplifiers (phase shift of 180° between input and output resulting in a negative value for *Av*), the input and output capacitance is increased by a capacitance level sensitive to the interelectrode capacitance between the input and output terminals of the device and the gain of the amplifier.

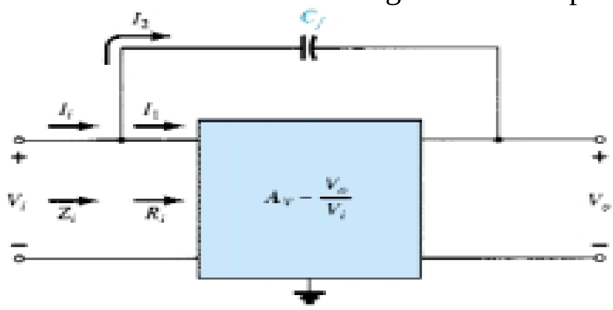


Fig.23: Interelectrode capacitance

Applying Kirchhoff's current law and Using Ohm's law yields

$$I_i = I_1 + I_2$$

$$I_i = \frac{V_i}{Z_i}, \qquad I_1 = \frac{V_i}{R_i}$$

$$I_2 = \frac{V_i - V_o}{X_{C_f}} = \frac{V_i - A_v V_i}{X_{C_f}} = \frac{(1 - A_v)V_i}{X_{C_f}}$$

$$\frac{V_i}{Z_i} = \frac{V_i}{R_i} + \frac{(1 - A_v)V_i}{X_{C_f}}$$

$$\frac{1}{Z_i} = \frac{1}{R_i} + \frac{1}{X_{C_f}/(1 - A_v)}$$

$$\frac{X_{C_f}}{1 - A_v} = \frac{1}{\omega \underbrace{(1 - A_v)C_f}_{C_M}} = X_{C_M}$$

$$\frac{1}{Z_i} = \frac{1}{R_i} + \frac{1}{X_{C_M}}$$

The above relation establishes the equivalent network of Fig. 24.

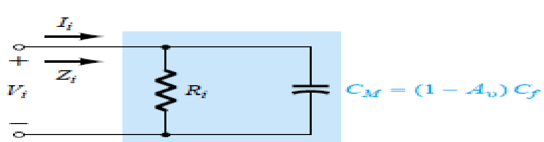


Fig.24. Input circuit

The Miller effect input capacitance is defined by

$$C_{Mi} = (1 - A_v)C_f$$

The Miller effect will also increase the level of output capacitance.
Applying Kirchhoff's law

$$I_o = I_1 + I_2$$

$$I_1 = \frac{V_o}{R_o} \qquad \text{and} \qquad I_2 = \frac{V_o - V_i}{X_{C_f}}$$

The resistance *Ro* is usually sufficiently large to permit ignoring the first term of the equation compared to the second term and assuming that

$$I_o \cong \frac{V_o - V_i}{X_{C_f}}$$

Substituting *Vi* = *Vo*/*Av* from *Av* = *Vo*/*Vi* will result in

$$I_o = \frac{V_o - V_o/A_v}{X_{C_f}} = \frac{V_o(1 - 1/A_v)}{X_{C_f}}$$

$$\frac{I_o}{V_o} = \frac{1 - 1/A_v}{X_{C_f}}$$

$$\frac{V_o}{I_o} = \frac{X_{C_f}}{1 - 1/A_v} = \frac{1}{\omega C_f(1 - 1/A_v)} = \frac{1}{\omega C_{M_o}}$$

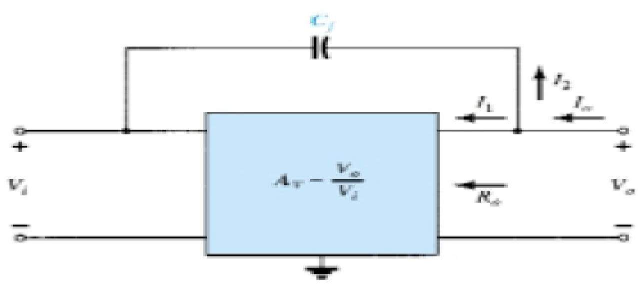


Fig. 25

Then the output miller capacitance will be

$$C_{M_o} = (1 - \frac{1}{A_v})C_f$$

For the usual situation where *Av* >>1

$$C_{M_o} \cong C_f$$

5.6. High-Frequency Response — BJT Amplifier

At the high-frequency end, there are two factors that will define the cut off frequencies: the network capacitance (parasitic and introduced) and the frequency dependence of h_{fe}.

At increasing frequencies, the reactance *XC* will decrease in magnitude, resulting in a shorting effect across the output and a decrease in gain. The derivation leading to the corner frequency for this *RC* configuration follows along similar lines to that encountered for the low-frequency region. The most significant difference is in the general form of *Av* appearing below:

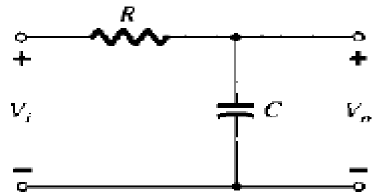


Fig.27. an RC circuit similar to low frequency ckt

$$A_v = \frac{1}{1 + j(^f/_{f_2})}$$

The various parasitic capacitances (*Cbe*, *Cbc*, *Cce*) of the transistor have been included with the wiring capacitances (*CWi*, *CWo*) introduced during construction. The high-frequency equivalent model for the network of Fig. 11.44 appears in Fig. 11.45.

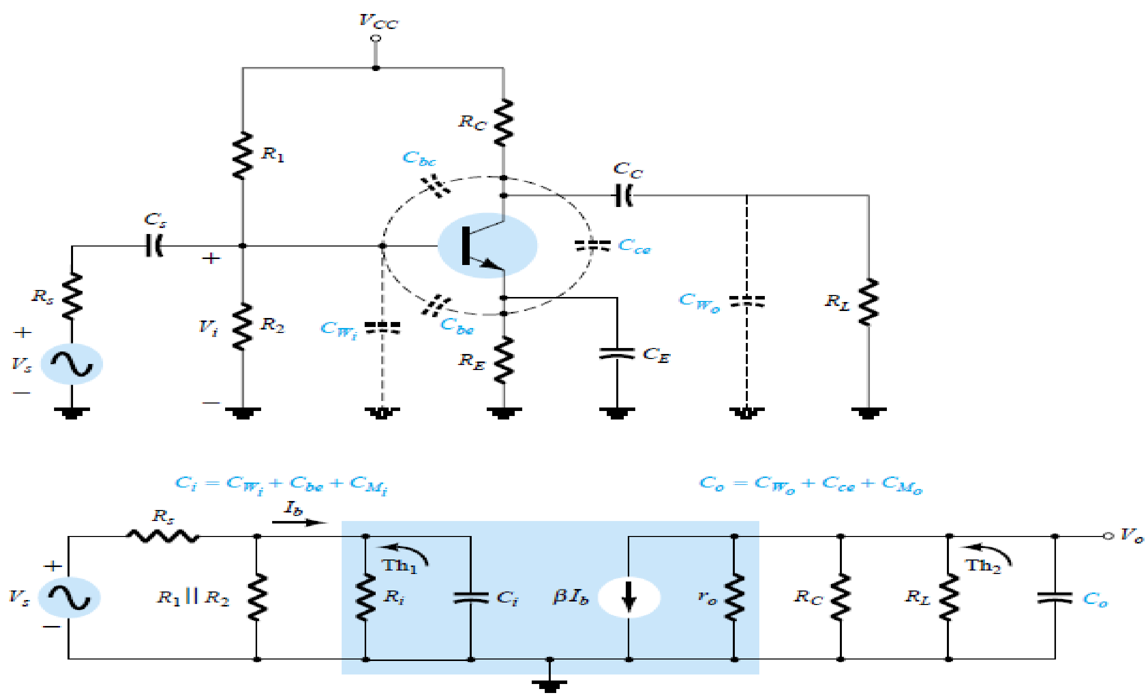
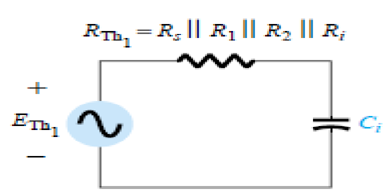


Fig.28. (a)upper- amplifier ckt with capacitance values in high frequency analysis (b)lower-small signal model

Determining the Thévenin equivalent circuit for the input and output networks of Fig. 28(a) will result in the configurations of Fig. 28(b) For the input network, the -3-dB frequency is defined by



$$f_{H_i} = \frac{1}{2\pi C_i R_{Th_1}}$$

Fig. 29 simplified input circuit

At very high frequencies, the effect of *Ci* is to reduce the total impedance of the parallel combination of *R*1, *R*2, *Ri*, and *Ci* in Fig. 28(b). The result is a reduced level of voltage across *Ci*, a reduction in *Ib*, and a gain for the system.

$$R_{Th_1} = R_s//R_1//R_2//R_i$$

$$C_i = C_{w_i} + C_{be} + C_{M_i} = C_{W_i} + C_{be} + (1 - A_v)C_{be}$$

For the output network

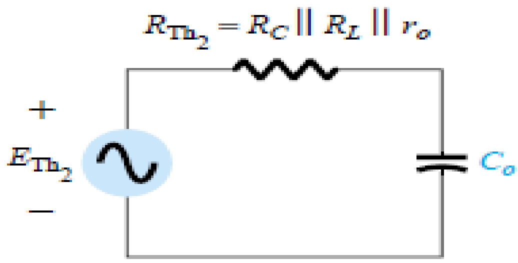


Fig. 30 simplified output circuit

$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o}$$

$$R_{Th_2} = R_c//R_L//r_o$$

$$C_o = C_{W_o} + C_{ce} + C_{M_o}$$

At very high frequencies, the capacitive reactance of *Co* will decrease and consequently reduce the total impedance of the output parallel branches of Fig. 11.45. If the parasitic capacitors were the only elements to determine the high cutoff frequency, the lowest frequency would be the determining factor. However, the decrease in *hfe* with frequency must also be considered as to whether its break frequency is lower than *fHi* or *fHo*.

Example

For the network of Fig. 11.44 with the same parameters as in Example 11.9, that is,

$R_s = 1\ \text{k}\Omega$, $R_1 = 40\ \text{k}\Omega$, $R_2 = 10\ \text{k}\Omega$, $R_E = 2\ \text{k}\Omega$, $R_C = 4\ \text{k}\Omega$, $R_L = 2.2\ \text{k}\Omega$

$C_s = 10\ \mu\text{F}$, $C_C = 1\ \mu\text{F}$, $C_E = 20\ \mu\text{F}$

$\beta = 100$, $r_o = \infty\ \Omega$, $V_{CC} = 20\ \text{V}$

with the addition of

$$C_{be} = 36\ \text{pF},\ C_{bc} = 4\ \text{pF},\ C_{ce} = 1\ \text{pF},\ C_{W_i} = 6\ \text{pF},\ C_{W_o} = 8\ \text{pF}$$

(a) Determine f_{H_i} and f_{H_o}.

Solution

From Example 11.9:

$$R_i = 1.32\ \text{k}\Omega, \qquad A_{v_{mid}}(\text{amplifier}) = -90$$

and

$$R_{Th_1} = R_s||R_1||R_2||R_i = 1\ \text{k}\Omega||40\ \text{k}\Omega||10\ \text{k}\Omega||1.32\ \text{k}\Omega \cong 0.531\ \text{k}\Omega$$

with

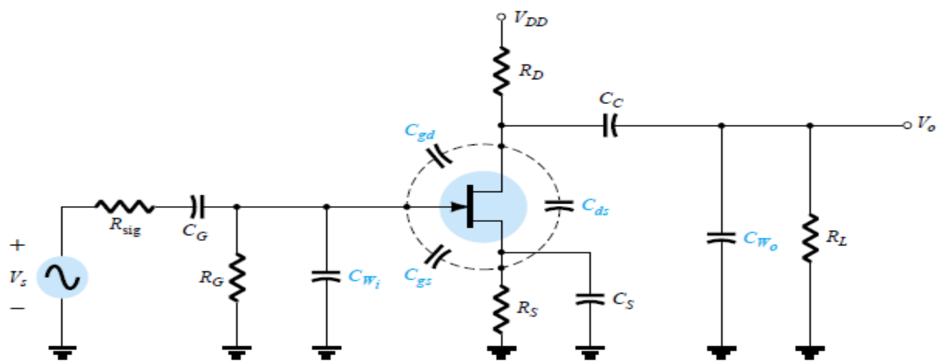
$$C_i = C_{W_i} + C_{be} + (1 - A_v)C_{be} = 6\ \text{pF} + 36\ \text{pF} + [1 - (-90)]4\ \text{pF} = 406\ \text{pF}$$

$$f_{H_i} = \frac{1}{2\pi R_{Th_1} C_i} = \frac{1}{2\pi(0.531\ k\Omega)(406\ pF)}$$
$$= 738.24\ kHz$$
$$R_{Th_2} = R_C \| R_L = 4\ k\Omega \| 2.2\ k\Omega = 1.419\ k\Omega$$
$$C_o = C_{W_o} + C_{ce} + C_{M_o} = 8\ pF + 1\ pF + \left(1 - \frac{1}{-90}\right) 4\ pF$$
$$= 13.04\ pF$$
$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o} = \frac{1}{2\pi(1.419\ k\Omega)(13.04\ pF)}$$
$$= 8.6\ MHz$$

h_{fe} also has frequency dependence, with f_B as the cutoff frequency. f_B is determined by a set of parameters employed in a modified hybrid model frequently applied to best represent the transistor in the high-frequency region.

5.7. High-Frequency Response — FET Amplifier

There are interelectrode and wiring capacitances that will determine the high-frequency characteristics of the amplifier.



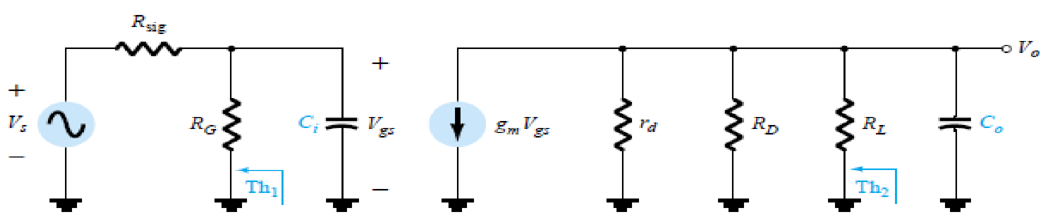
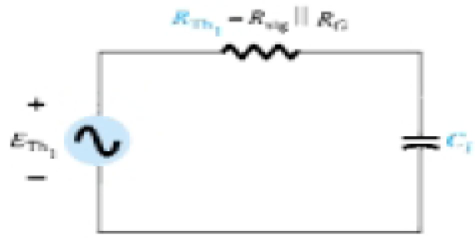


Fig. 31(a)upper- FET amplifier ckt with high frequency capacitance (b)lower- small signal model

The cutoff frequencies defined by the input and output circuits can be obtained by first finding the Thévenin equivalent circuits for each section as shown in Fig. 32 and 33.The actual high frequency cutoff value is approximately the lowest of the two values.
For the input circuit



$$f_{H_i} = \frac{1}{2\pi R_{Th_1} C_i}$$

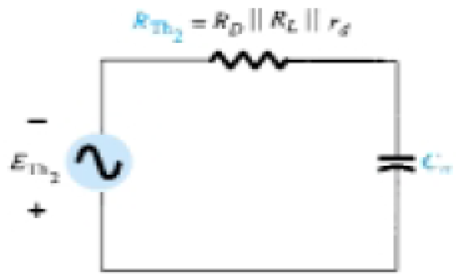
$$R_{Th_1} = R_{sig} // R_G$$

$$C_i = C_{W_i} + C_{gs} + C_{M_i}$$

$$C_{M_i} = (1 - A_v) C_{gd}$$

Fig. 32. input ckt

For the output circuit,



$$f_{H_o} = \frac{1}{2\pi R_{Th_2} C_o}$$

$$R_{Th_2} = R_D // R_L // r_d$$

$$C_o = C_{W_o} + C_{ds} + C_{M_o}$$

$$C_{M_o} = (1 - \frac{1}{A_v}) C_{gd}$$

Fig. 33. output ckt

Example

(a) Determine the high cutoff frequencies for the network of Fig. 11.52 using the same parameters as Example 11.10:

$$C_G = 0.01\ \mu\text{F}, \quad C_C = 0.5\ \mu\text{F}, \quad C_S = 2\ \mu\text{F}$$

$$R_{sig} = 10\ \text{k}\Omega, \quad R_G = 1\ \text{M}\Omega, \quad R_D = 4.7\ \text{k}\Omega, \quad R_S = 1\ \text{k}\Omega, \quad R_L = 2.2\ \text{k}\Omega$$

$$I_{DSS} = 8\ \text{mA}, \quad V_P = -4\ \text{V}, \quad r_d = \infty\ \Omega, \quad V_{DD} = 20\ \text{V}$$

with the addition of

$$C_{gd} = 2\ \text{pF}, \quad C_{gs} = 4\ \text{pF}, \quad C_{ds} = 0.5\ \text{pF}, \quad C_{W_i} = 5\ \text{pF}, \quad C_{W_o} = 6\ \text{pF}$$

Solution

$$R_{Th_1} = R_{sig} || R_G = 10\ \text{k}\Omega || 1\ \text{M}\Omega = 9.9\ \text{k}\Omega$$

From Example 11.10, $A_v = -3$.

$$\begin{aligned} C_i &= C_{W_i} + C_{gs} + (1 - A_v) C_{gd} \\ &= 5\ \text{pF} + 4\ \text{pF} + (1 + 3)2\ \text{pF} \\ &= 9\ \text{pF} + 8\ \text{pF} \\ &= 17\ \text{pF} \end{aligned}$$

$$\begin{aligned} f_{H_i} &= \frac{1}{2\pi R_{Th_1} C_i} \\ &= \frac{1}{2\pi (9.9\ \text{k}\Omega)(17\ \text{pF})} = \mathbf{945.67\ kHz} \end{aligned}$$

$$R_{Th_2} = R_D \| R_L$$
$$= 4.7\ k\Omega \| 2.2\ k\Omega$$
$$\cong 1.5\ k\Omega$$

$$C_o = C_{W_o} + C_{ds} + C_{M_o} = 6\ pF + 0.5\ pF + \left(1 - \frac{1}{-3}\right)2\ pF = 9.17\ pF$$
$$f_{H_o} = \frac{1}{2\pi(1.5\ k\Omega)(9.17\ pF)} = \mathbf{11.57\ MHz}$$

From the above result we can see that the input capacitance with its Miller effect capacitance will determine the upper cutoff frequency.