FREQUENCY RESPONSE

Frequency response ⇨ divided into three frequency ranges

High frequency ⁂ Mid frequency ⁂ Low frequency

☞ **H.F.R ⇨ *parallel capacitances* ⇨ must be considered**

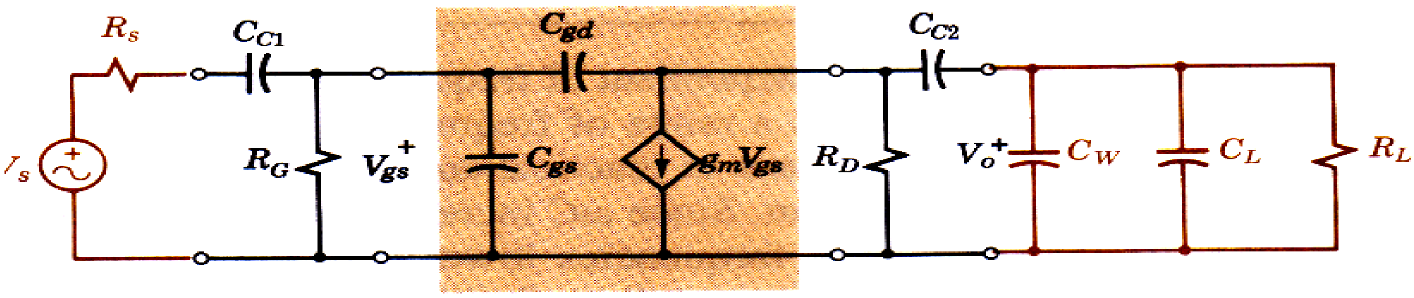
☞ **M.F.R ⇨ *capacitances* ⇨ can be neglected**

☞ **L.F.R ⇨ *series capacitances C_C* ⇨ must be considered**

Midfrequency Gain

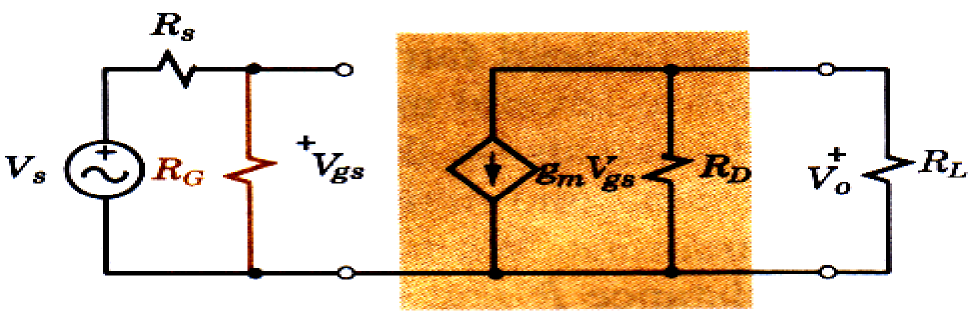
FET

➨ **The general model ⇩**



(a) FET

➨ **replaced by the purely resistive circuits ⇩**



(a) FET

FET. Since $R_G \gg R_s$, $V_{gs} = V_s$ and R_G can be omitted in most cases. If, for convenience, we represent the parallel combination of R_D and R_L by R_o, the output voltage is

$$V_o = -g_m V_{gs}(R_D \| R_L) = -g_m V_s R_o \tag{14-3}$$

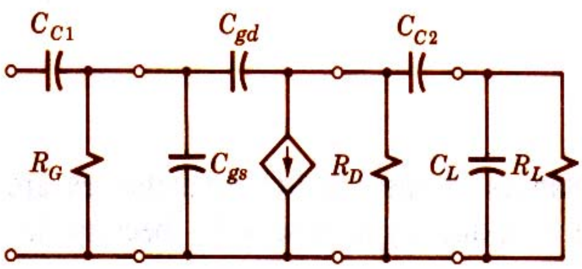
and the midfrequency voltage gain is

$$A_{VO} = \frac{V_o}{V_s} = -g_m R_o \tag{14-4}$$

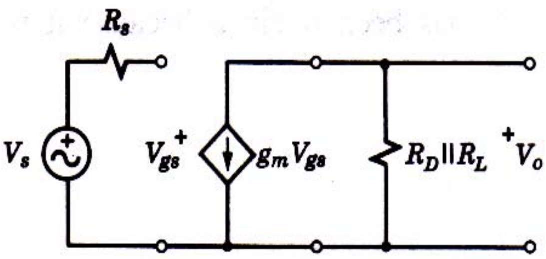
where subscripts V and O are for "voltage" and "midfrequency." The negative sign indicates a 180° phase reversal of the output signal with respect to the input.

EXAMPLE 1

A JFET with $g_m = 2000\ \mu\text{S}$, $C_{gs} = 20$ pF, and $C_{gd} = 2$ pF is used in an RC-coupled amplifier with $R_G = 1\ \text{M}\Omega$, $R_S = 2\ \text{k}\Omega$, and $R_D = 5\ \text{k}\Omega$. Signal source resistance $R_s = 1\ \text{k}\Omega$ and load resistance $R_L = 5\ \text{k}\Omega$. Coupling capacitance $C_{C1} = C_{C2} = 1\ \mu\text{F}$ and $C_S = 20\ \mu\text{F}$; the load capacitance (including wiring) $C_L = 20$ pF. Predict the voltage gain V_o/V_s at $\omega = 10^4$ rad/s ($f = 1590$ Hz).



(a) General model



(b) Midfrequency model

Figure 14.7 Midfrequency simplification.

At the given frequency,

$$1/\omega C_S = 1/10^4 \times 20 \times 10^{-6} = 5\ \Omega$$

Therefore, $R_S = 2000\ \Omega$ is effectively shorted and the model is as shown in Fig. 14.7a.

Since C_{C1} and C_{C2} are effectively in series with R_G and R_L, 1 MΩ and 5 kΩ respectively, the reactances

$$1/\omega C_C = 1/10^4 \times 10^{-6} = 100\ \Omega$$

are negligibly small (Eq. 14-1).

With C_{C1} and C_{C2} omitted, C_L is in parallel with $R_o = R_D \| R_L = 2500\ \Omega$ and C_{gs} is in series with R_s. The reactances

$$1/\omega C_L = 1/\omega C_{gs} = 1/10^4 \times 20 \times 10^{-12} = 5\ \text{M}\Omega$$

are so large that C_L and C_{gs} can be omitted.

The reactance

$$1/\omega C_{gd} = 1/10^4 \times 2 \times 10^{-12} = 50\ \text{M}\Omega$$

is so large that a negligible current will flow in C_{gd}.

In other words, 1590 Hz is in the "midfrequency" range of this amplifier and the model of Fig. 14.7b is appropriate. The midfrequency gain (Eq. 14-4) is

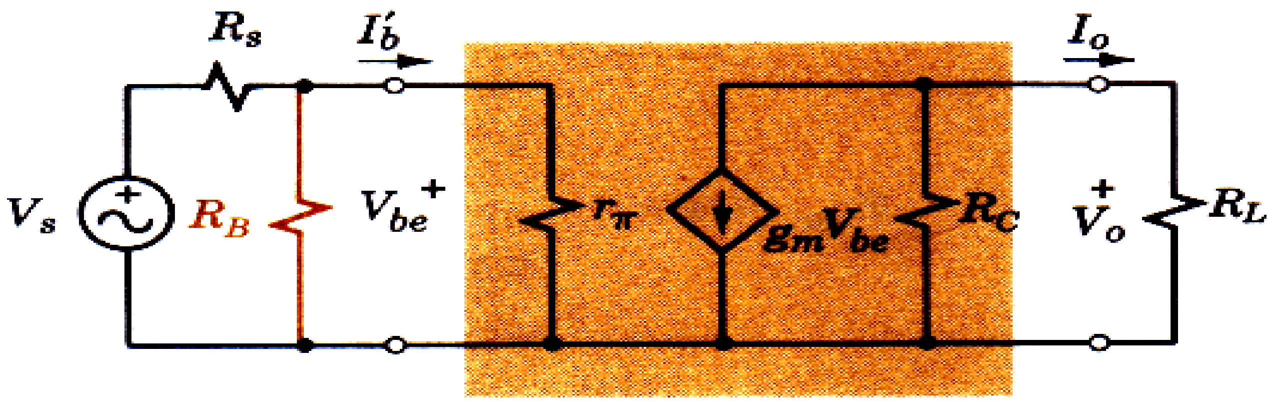
$$A_{VO} = -g_m R_o = -2000 \times 10^{-6} \times 2500 = -5$$

Conclusion: Working from the simplified model, calculation of the midfrequency gain is straightforward.

BJT

$$\frac{R_B + R_E}{\beta} \cong \frac{R_B}{\beta} \ll R_E \qquad (12\text{-}12)$$

- *For stability* ⇨ $R_B << \beta R_E$
- $R_B >> r_\pi$



(b) BJT

- *The ideal condition* ⇩

$$r_\pi \ll R_B \ll \beta R_E$$

- *The circuit stable and simple to analyze*

If R_B is neglected in Fig. 14.6b, r_π and R_s constitute a voltage divider.the output voltage is

$$V_o = -g_m V_{be}(R_C \| R_L) = -g_m \frac{r_\pi}{r_\pi + R_s} V_s R_o = -\beta \frac{V_s}{r_\pi + R_s} R_o \qquad (14\text{-}5)$$

and the midfrequency voltage gain is

$$A_{VO} = \frac{V_o}{V_s} = -\frac{r_\pi}{r_\pi + R_s} g_m R_o = -\beta \frac{R_o}{r_\pi + R_s} \qquad (14\text{-}6)$$

Performance of these one-stage amplifiers is influenced by the characteristics of the source (R_s) and the load (R_L). In the multistage amplifiers discussed later, the source and the load for each stage are other similar stages.

Practice Problem 14-2

Low-Frequency Response

Below the midfrequencies

- ***The susceptances of the parallel capacitors neglibly small ⇩***

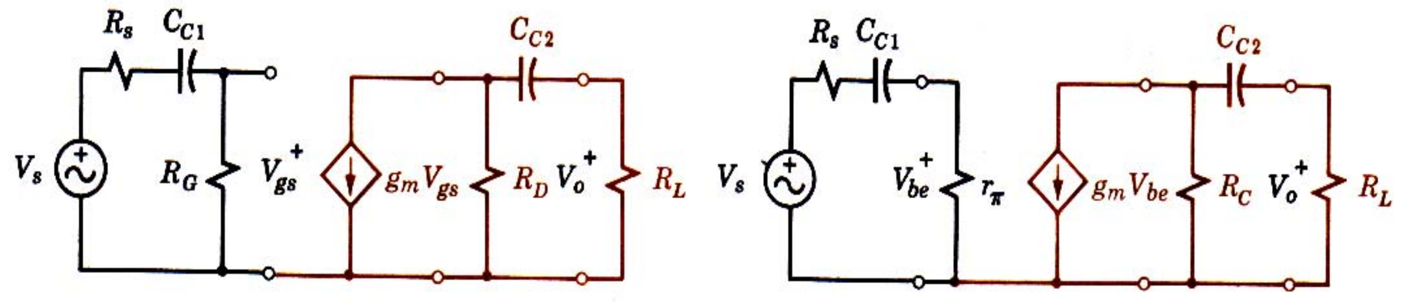
$$Z_{par} = \frac{1}{\sqrt{(1/R)^2 + (\omega C)^2}} = \frac{R}{\sqrt{1 + (\omega CR)^2}}$$

- ***The reactance of the coupling capacitance increasliy important ⇩***

$$Z_{ser} = \sqrt{R^2 + (1/\omega C)^2} = R\sqrt{1 + (1/\omega CR)^2}$$

Coupling Capacitors

The general model ⇨ reduced to ⇨ simpler low frequency model

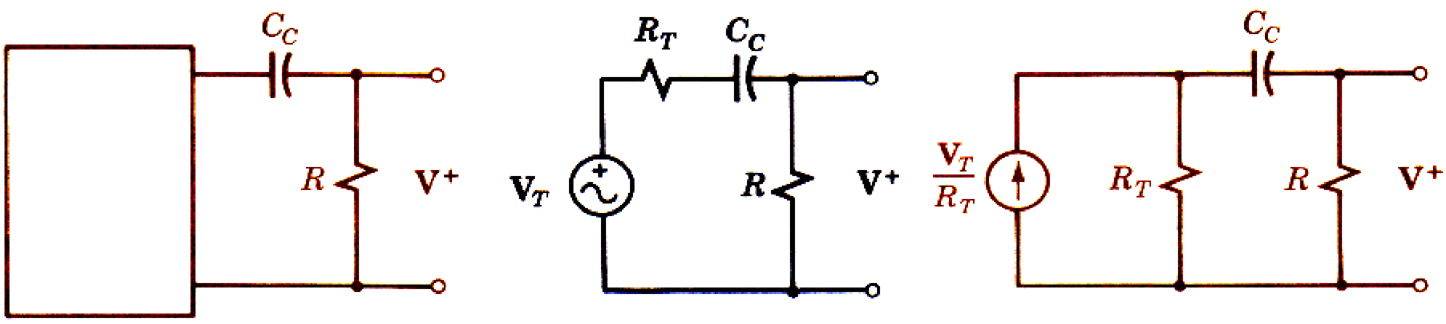


(a) FET (b) BJT

Figure 14.8 Low-frequency models of amplifiers.

- ***R_G ⇨ retained ⇨ significant***
- ***R_B ⇨ omitted ⇨ large compared to r_π***

FET ⁂ BJT ⇨ models are analogous ⇨ one analysis ⇨ serve for both



(a) General circuit (b) Thévenin form (c) Norton form

- ***The general circuit ⇨ (a) ⇨ replaced by ⇩***

Thevenin form ⇨ input circuit

OR

Norton form ⇨ output circuit

- *The two forms ⇨ are equivalents ⇨ C_C ⇨ effectively shorted*

The output of ⇨ Thevenin circuit ⇩

$$\mathbf{V} = \mathbf{V}_O = \frac{R}{R + R_T}\mathbf{V}_T$$

At low frequencies where C_C is significant, the output of the Thévenin circuit is

$$\mathbf{V}_L = \frac{R}{R + R_T - j\dfrac{1}{\omega C_C}}\mathbf{V}_T = \frac{\dfrac{R}{R + R_T}\mathbf{V}_T}{1 - j\dfrac{1}{\omega C_C(R + R_T)}} = \frac{\mathbf{V}_O}{1 - j\dfrac{1}{\omega C_C(R + R_T)}} \qquad (14\text{-}8)$$

- *The low-frequency output V_L related to the midfrequency output by ⇨ complex factor dependent on ⇩*

frequency ⁂ RC product

- *As frequency ⇨ decreased ⇨ large fraction of ⇨ V_T ⇨ appears ⇨ across C_C ⇨ V at the output ⇨ reduced*
- *The cutoff ⇨ half - power frequency ⇩*

$$V_L/V_O = |1/(1 - j1)| = 1/\sqrt{2}$$

Defined by

$$\omega_{co} = \frac{1}{C_C(R + R_T)}$$

- ***The behavior of ⇨ FET ⁂ BJT ⇨ predicted at low-frequency⇩***

- $$\omega_{11} = \frac{1}{C_{C1}(R_s + R_G)} \quad \text{or} \quad \omega_{11} = \frac{1}{C_{C1}(R_s + r_\pi)}$$

- ***The input voltage ⇨ V_{gs} ⁂ V_{be} ⇨ down to 70% of V_o at ⇩***

$$\omega_{12} = \frac{1}{C_{C2}(R_D + R_L)} \quad \text{or} \quad \omega_{12} = \frac{1}{C_{C2}(R_C + R_L)}$$

- ***The output voltage ⇨ V_o ⇨ down to 70% of $g_m V_{gs} R_o$ ⁂ $g_m V_{be} R_o$ ⇨ the corresponding amplifier gain ⇨ reduced***
- ***The overall ⇨ low-frequency voltage gain ⇨ for ⇩***

FET

$$\mathbf{A}_L = \mathbf{A}_O \cdot \frac{1}{1 - j\dfrac{1}{\omega C_{C1}(R_s + R_G)}} \cdot \frac{1}{1 - j\dfrac{1}{\omega C_{C2}(R_D + R_L)}}$$

- ***The relative gain for ⇨ BJT OR FET***

$$\frac{\mathbf{A}_L}{\mathbf{A}_O} = \frac{1}{1 - j\omega_{11}/\omega} \cdot \frac{1}{1 - j\omega_{12}/\omega}$$

- ***To predict the behavior of a given circuit determine*** ⇩

  ☞ ω_{11} ⁂ ω_{12} ⇨ ***the higher is***

- ***To design a circuit calculate*** ⇩

  ☞ C_{C1} ⁂ C_{C2}

EXAMPLE 2

In the circuit of Fig. 14.8b, $R_s = 1\ \text{k}\Omega$, $r_\pi = 2\ \text{k}\Omega$, $R_C = 4.5\ \text{k}\Omega$, $R_L = 9\ \text{k}\Omega$, $g_m = 60$ mS, and $C_{C1} = C_{C2} = 1\ \mu\text{F}$. Predict the midfrequency voltage gain and the lower cutoff frequency.

At midfrequencies the capacitors are effectively shorted and

$$A_{VO} = -\frac{r_\pi}{r_\pi + R_s} g_m (R_C \| R_L)$$

$$= -\frac{2}{2+1}(0.06)(4500 \| 9000) = -120$$

The lower cutoff frequencies are

$$\omega_{11} = \frac{1}{C_{C1}(R_S + r_\pi)} = \frac{1}{10^{-6} \times 3000} = 333.3\ \text{rad/s}$$

$$\omega_{12} = \frac{1}{C_{C2}(R_C + R_L)} = \frac{1}{10^{-6} \times 13{,}500} = 74.1\ \text{rad/s}$$

Therefore, the lower cutoff frequency of the amplifier is

$$\omega_{l2} = 333.3\ \text{rad/s} \quad \text{or} \quad f_{l2} = 333.3/2\pi = 53\ \text{Hz}$$

<u>H-W P.P 14-3</u>