ECE 312
Electronic Circuits (A)

Lec. 13: BJT Low Frequency Response

Instructor

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Agenda

- Low Frequency Analysis- Bode Plot
- Low Frequency Response – BJT Amplifier with R_L
- Impact of R_S on the BJT Low Frequency Response

Low Frequency Analysis- Bode Plot

Defining the Low Cutoff Frequency

- In the low-frequency region of the single-stage BJT amplifier, it is the RC combinations formed by the network capacitors C_C, C_E, and C_s and the network resistive parameters that determine the cutoff frequencies

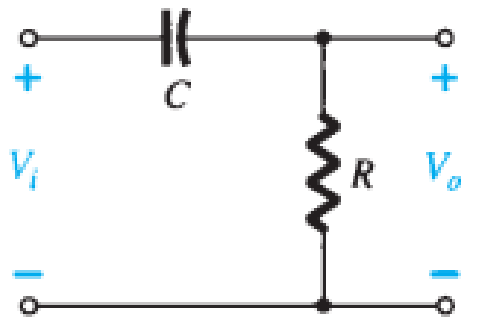


FIG. 9.14
RC combination that will define a low-cutoff frequency.

- Voltage-Divider Bias Config.

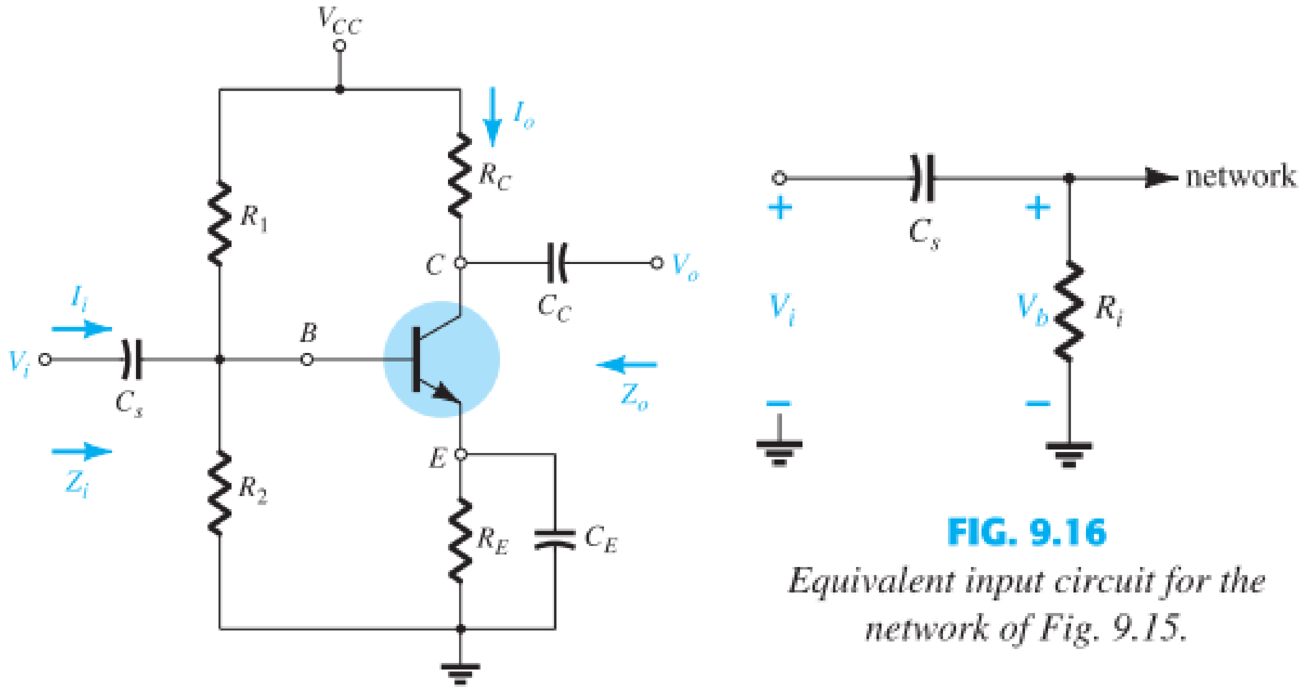


FIG. 9.15
Voltage-divider bias configuration.

FIG. 9.16
Equivalent input circuit for the network of Fig. 9.15.

$$Z_i = R_i = R_1 \| R_2 \| \beta r_e$$

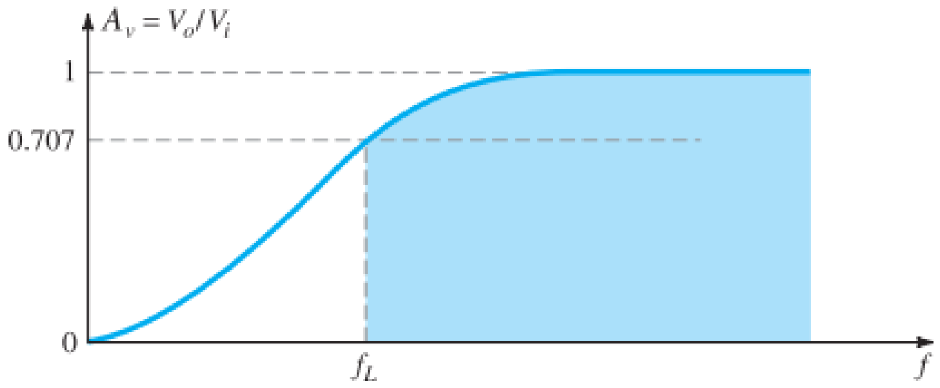
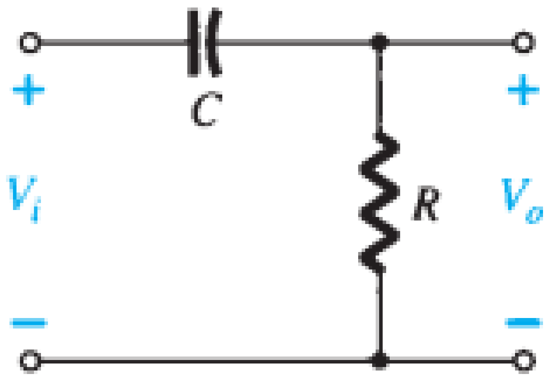


FIG. 9.19
Low-frequency response for the RC circuit of Fig. 9.14.

Defining The Low Cutoff Frequency ..



$$\mathbf{V_o = \frac{RV_i}{R + X_C}}$$

The magnitude of V_o is

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

For the special case where $X_C = R$,

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

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

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

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

Defining The Low Cutoff Frequency ..

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

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

In the magnitude and phase form,

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

$$A_{v(\text{dB})} = 20 \log_{10} \frac{1}{\sqrt{1 + (f_L/f)^2}}$$

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

when $f = f_L$,

$$|A_v| = \frac{1}{\sqrt{1 + (1)^2}} = \frac{1}{\sqrt{2}} = 0.707 \Rightarrow -3 \text{ dB}$$

Bode Plot

$$A_{v(\mathrm{dB})} = 20\log_{10}\frac{1}{\sqrt{1+(f_L/f)^2}}$$

$$A_{v(\mathrm{dB})} = -20\log_{10}\left[1+\left(\frac{f_L}{f}\right)^2\right]^{1/2}$$

$$= -\left(\tfrac{1}{2}\right)(20)\log_{10}\left[1+\left(\frac{f_L}{f}\right)^2\right]$$

$$= -10\log_{10}\left[1+\left(\frac{f_L}{f}\right)^2\right]$$

For frequencies where $f \ll f_L$ or $(f_L/f)^2 \gg 1$,

$$A_{v(\mathrm{dB})} = -10\log_{10}\left(\frac{f_L}{f}\right)^2$$

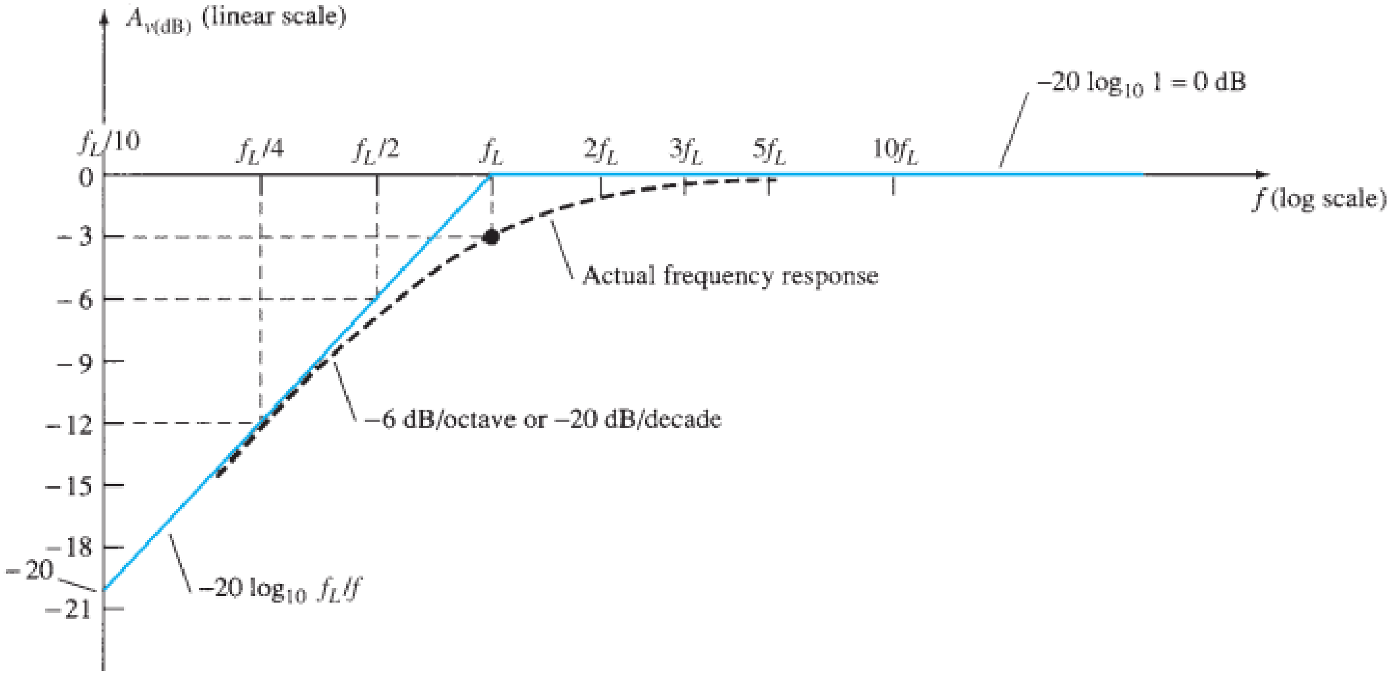
$$A_{v(\mathrm{dB})} = -20\log_{10}\frac{f_L}{f}$$

$f \ll f_L$

Bode Plot

$$A_{v(\text{dB})} = -20 \log_{10} \frac{f_L}{f}$$ $f \ll f_L$

- The piecewise linear plot of the asymptotes and associated breakpoints is called a Bode plot of the magnitude versus frequency.



- A change in frequency by a factor of two, equivalent to one octave, results in a 6-dB change in the ratio, as shown by the change in gain from $f_L/2$ to f_L.
- For a 10:1 change in frequency, equivalent to one decade, there is a 20-dB change in the ratio, as demonstrated between the frequencies of $f_L/10$ and f_L.

Bode Plot..

- Phase Angle:

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

For frequencies $f \ll f_L$,

$$\theta = \tan^{-1}\frac{f_L}{f} \rightarrow 90^\circ$$

For instance, if $f_L = 100f$,

$$\theta = \tan^{-1}\frac{f_L}{f} = \tan^{-1}(100) = 89.4^\circ$$

For $f = f_L$,

$$\theta = \tan^{-1}\frac{f_L}{f} = \tan^{-1}1 = 45^\circ$$

For $f \gg f_L$,

$$\theta = \tan^{-1}\frac{f_L}{f} \rightarrow 0^\circ$$

For instance, if $f = 100f_L$,

$$\theta = \tan^{-1}\frac{f_L}{f} = \tan^{-1}0.01 = 0.573^\circ$$

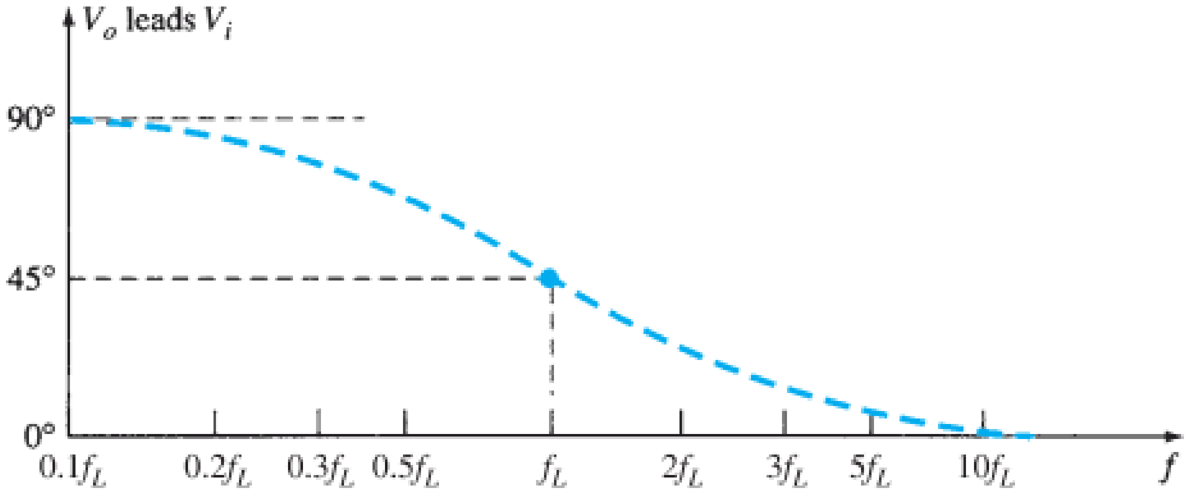


FIG. 9.22
Phase response for the RC circuit of Fig. 9.14.

Example

EXAMPLE 9.10 For the network of Fig. 9.23:

a. Determine the break frequency.
b. Sketch the asymptotes and locate the −3-dB point.
c. Sketch the frequency response curve.
d. Find the gain at $A_{v(\text{dB})} = -6$ dB.

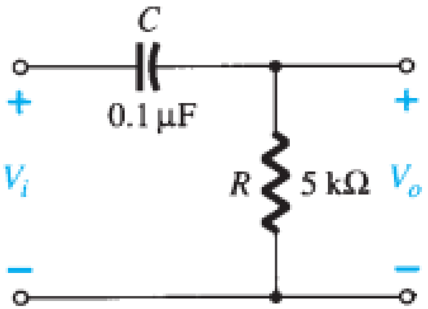


FIG. 9.23

Solution:

a. $f_L = \dfrac{1}{2\pi RC} = \dfrac{1}{(6.28)(5 \times 10^3\ \Omega)(0.1 \times 10^{-6}\ \text{F})}$

$\cong$ **318.5 Hz**

b. and c. See Fig. 9.24.

d. Eq. (9.27): $A_v = \dfrac{V_o}{V_i} = 10^{A_{v(\text{dB})}/20}$

$= 10^{(-6/20)} = 10^{-0.3} = 0.501$

and $V_o = 0.501\ V_i$ or approximately 50% of V_i.

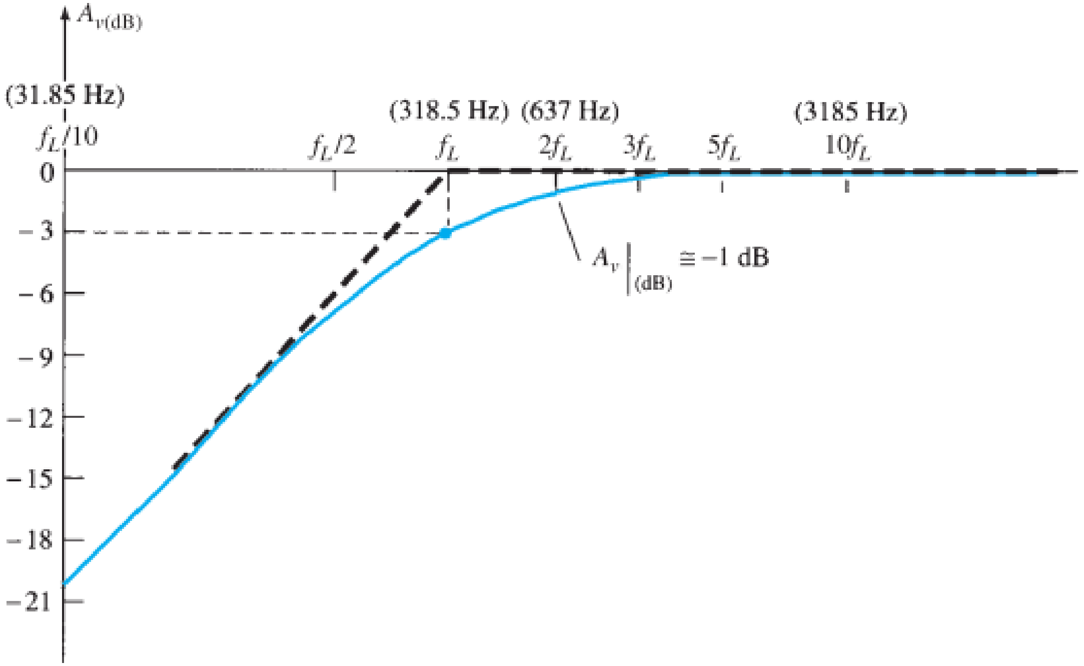


FIG. 9.24
Frequency response for the RC circuit of Fig. 9.23.

Low Frequency Response – BJT Amplifier with R_L

Loaded BJT Amplifier

In the voltage-divider ct.
→ the capacitors Cs, C_C , and C_E will determine the low-frequency response.

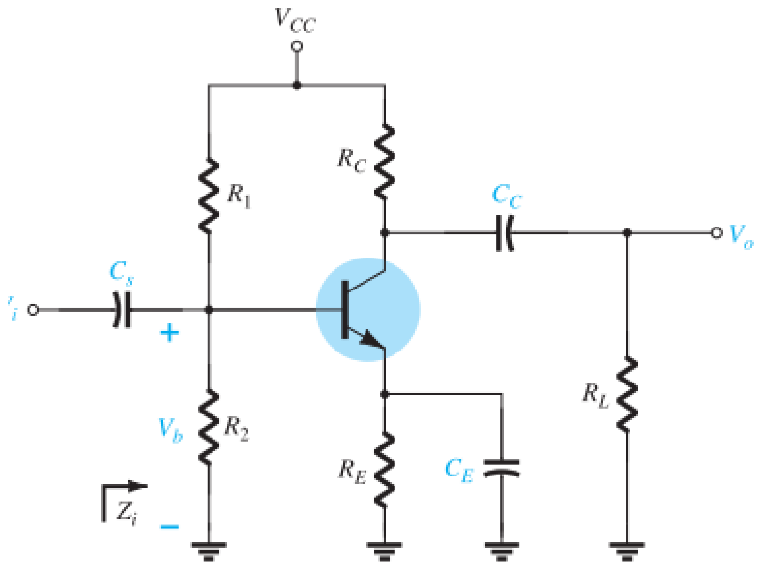


FIG. 9.25
Loaded BJT amplifier with capacitors that affect the low-frequency response.

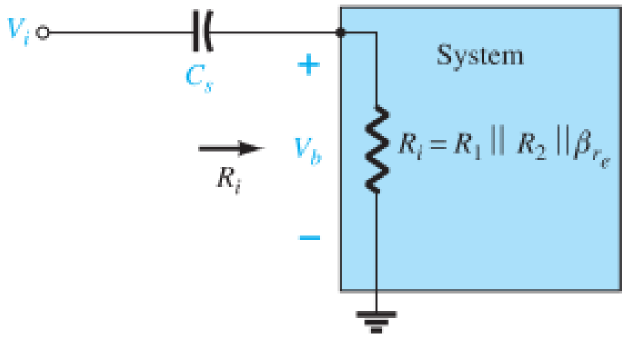


FIG. 9.26
Determining the effect of C_s on the low-frequency response.

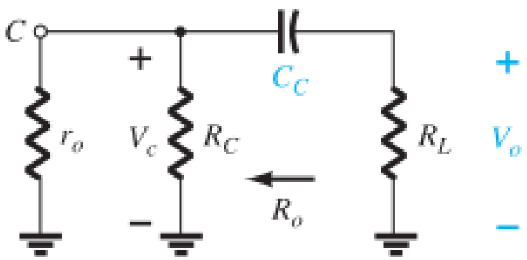


FIG. 9.28
Localized ac equivalent for C_C with $V_i = 0$ V.

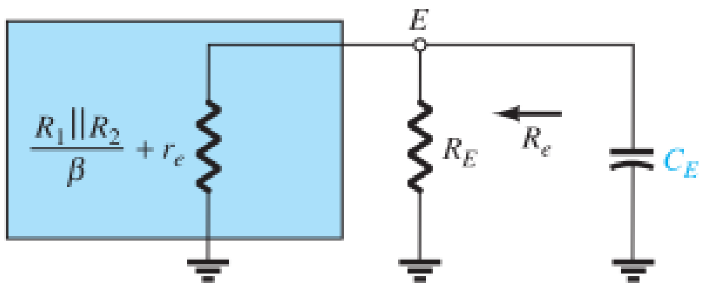


FIG. 9.30
Localized ac equivalent of C_E.

$f_L = \max(f_{Ls}, f_{Lc}, f_{LE})$

Loaded BJT Amplifier

→Cs:

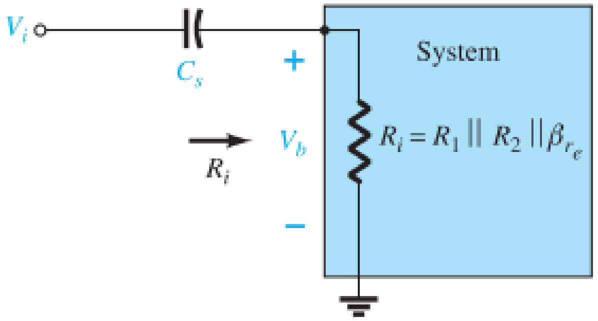


FIG. 9.26
Determining the effect of C_s on the low-frequency response.

$$R_i = R_1 \| R_2 \| \beta r_e.$$

$$f_{L_s} = \frac{1}{2\pi R_i C_s}$$

→ Cc:

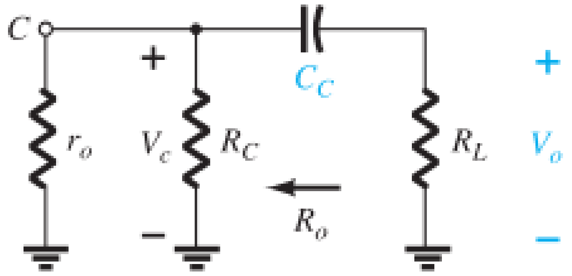


FIG. 9.28
Localized ac equivalent for C_C with $V_i = 0$ V.

$$R_o = R_C \| r_o$$

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

→ C_E:

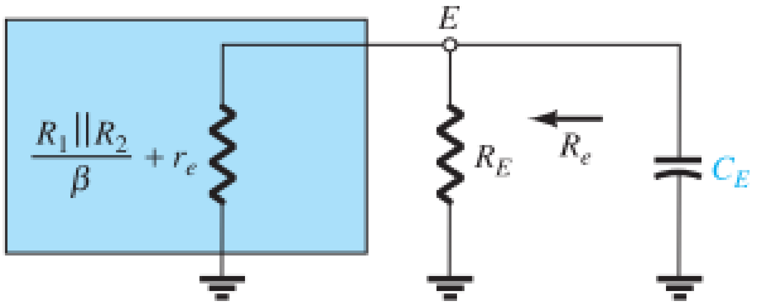


FIG. 9.30
Localized ac equivalent of C_E.

$$R_e = R_E \| \left(\frac{R_1 \| R_2}{\beta} + r_e\right)$$

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

$f_L = \max(f_{Ls}, f_{Lc}, f_{LE})$

Impact of R_S on the BJT Low Frequency Response

Impact of R_S

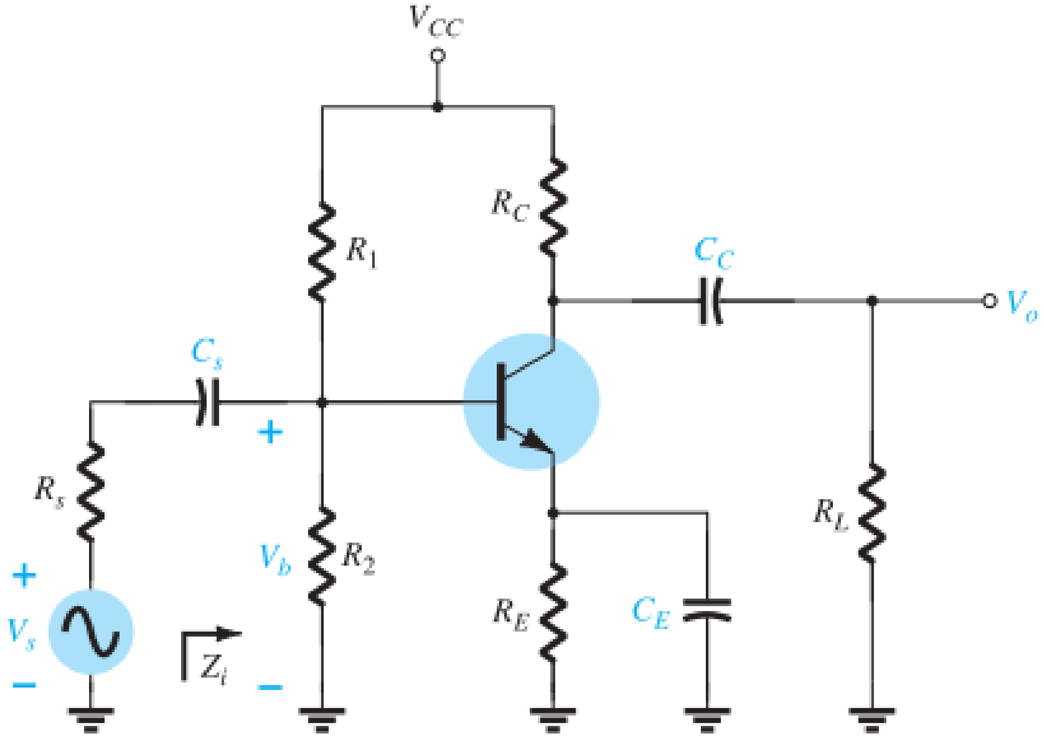


FIG. 9.32
Determining the effect of R_s on the low-frequency response of a BJT amplifier.

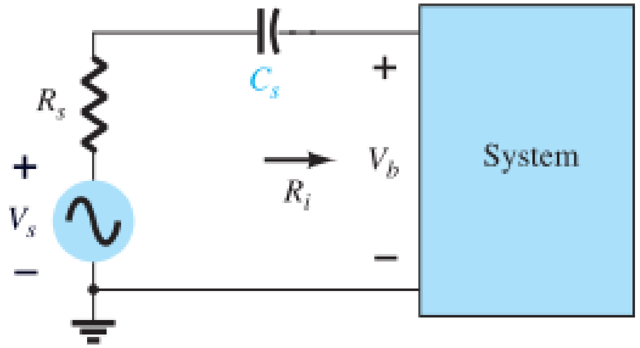


FIG. 9.33
Determining the effect of C_s on the low-frequency response.

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

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

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

$$R_e = R_E \| \left(\frac{R_s'}{\beta} + r_e\right) \text{ and } R_s' = R_s \| R_1 \| R_2$$


Thank You!