

Analog Electronics Application

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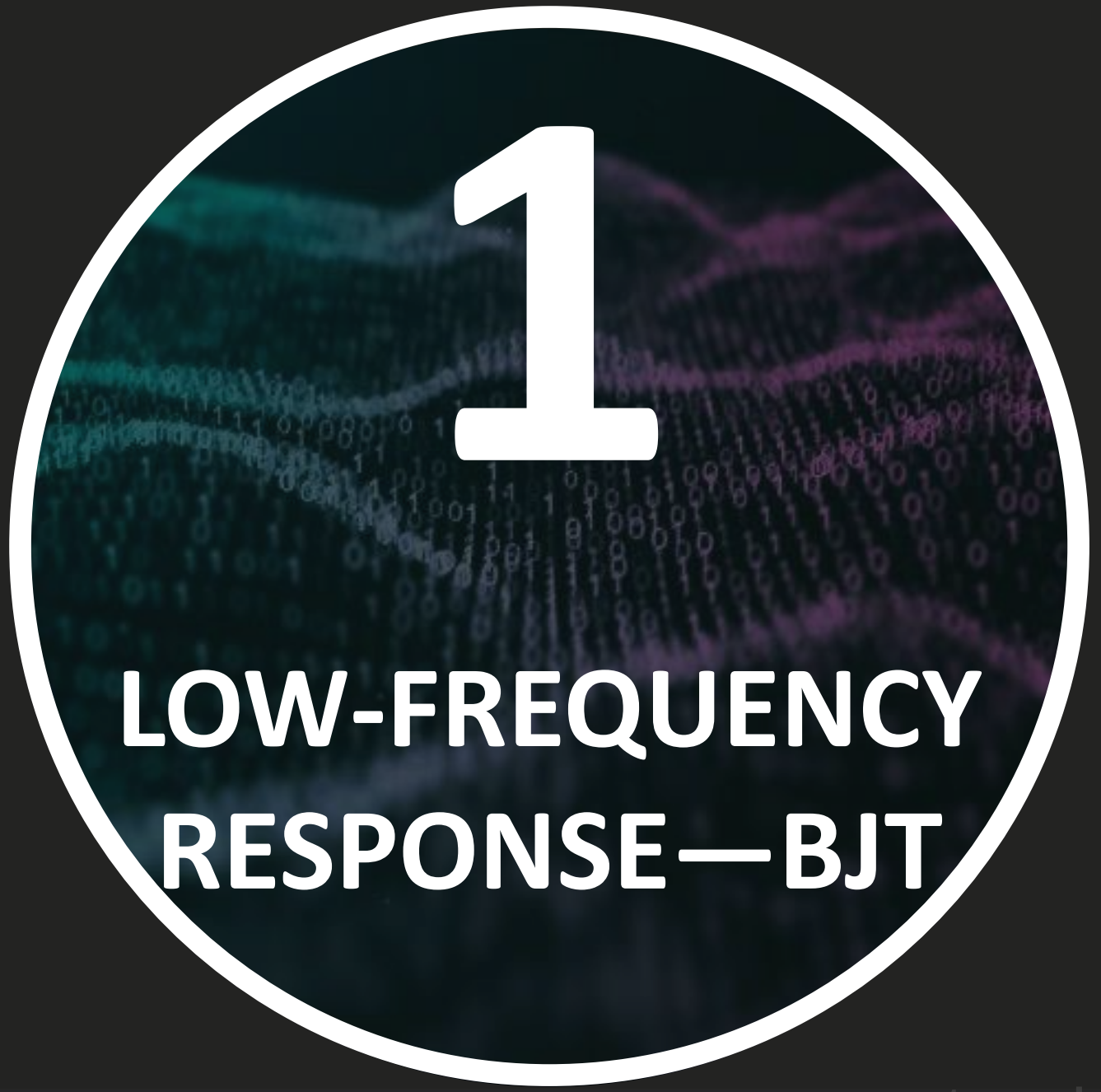
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LOW-FREQUENCY RESPONSE—BJT

$$f_{L_s} = \frac{1}{2\pi(R_s + R_i)C_s}, \qquad R_i = R_1 \| R_2 \| \beta r_e$$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C}, \qquad R_o = R_C \| r_o$$

$$f_{L_E} = \frac{1}{2\pi R_e C_E}, \qquad R_e = R_E \| \left(\frac{R'_s}{\beta} + r_e \right), \qquad R'_s = R_s \| R_1 \| R_2$$

$$r_e = \frac{26\ \text{mV}}{I_E}$$

Important Formulas



TABLE 4.1
TABLE 5.1
TABLE 5.2

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LOW-FREQUENCY RESPONSE—BJT

EXAMPLE 9.11 Determine the cutoff frequencies for the network of Fig. 9.25 using the following parameters:

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

$R_1 = 40\,\text{k}\Omega, \quad R_2 = 10\,\text{k}\Omega, \quad R_E = 2\,\text{k}\Omega, \quad R_C = 4\,\text{k}\Omega,$

$R_L = 2.2\,\text{k}\Omega$

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

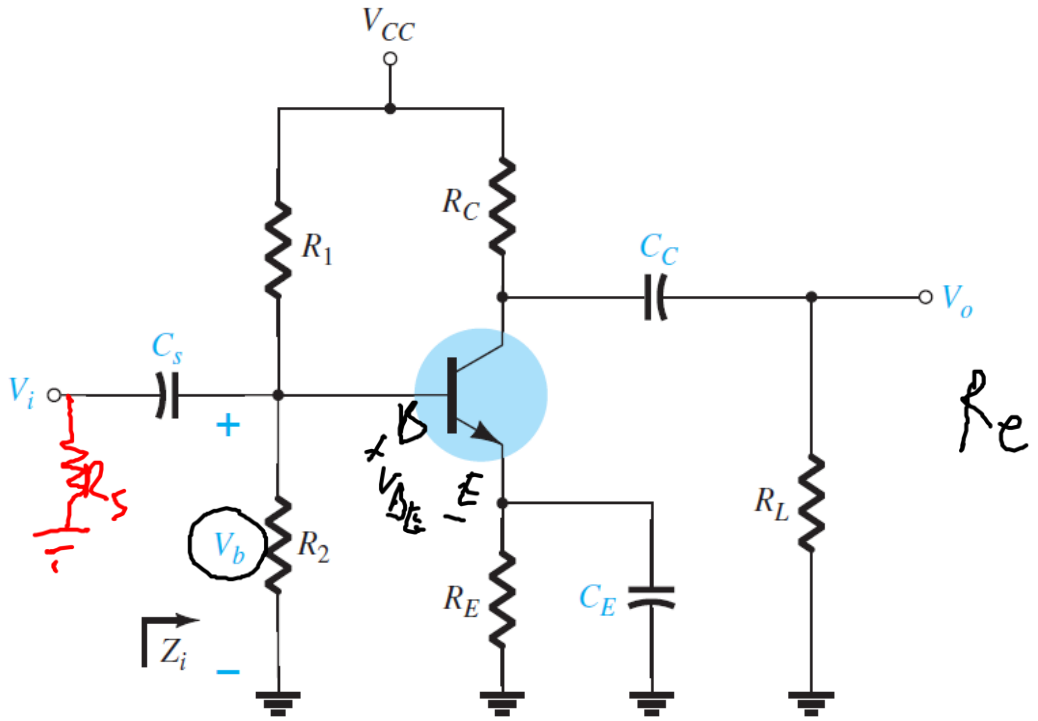


FIG. 9.25

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LOW-FREQUENCY RESPONSE—BJT

DC Analysis

$$R_{TH} = R_1 \| R_2 = \frac{40k\Omega \cdot 10k\Omega}{50k\Omega} = 8k\Omega$$

$$V_B = E_{TH} = \frac{R_2 \cdot V_{CC}}{R_1 + R_2} = \frac{10k\Omega \cdot (20V)}{40k\Omega + 10k\Omega} = 4V$$

[in table 5.2]

$$A_V = \frac{-(R_L \| R_C)}{r_e} = \frac{2.2k\Omega \| 4k\Omega}{16,45\Omega} \simeq 86,2$$

$$I_B = \frac{V_B - V_{BE}}{R_{TH} + (\beta+1) \cdot R_E} = \frac{4V - 0.7V}{8k\Omega + (101) \cdot 2k\Omega}$$

$$I_B = 1,57 \times 10^{-2} mA$$

$$I_E = (\beta+1) \cdot I_B = 101 \cdot (1,57 \times 10^{-2}) = 1,58 mA$$

$$\rightarrow r_e = \frac{26mV}{I_E} = \frac{26mV}{1.58mA} = 16,45\Omega$$

$$\beta r_e = \beta \cdot r_e = 100 \cdot 16,45\Omega = 1,645 k\Omega$$

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LOW-FREQUENCY RESPONSE—BJT

$$F_{L_S} = \frac{1}{2\pi R_i \cdot C_S} = \frac{1}{2\pi \cdot (1{,}36\,k\Omega) \cdot (10\,\mu F)} = 12{,}05\,Hz$$

$R_i = R_1 \parallel R_2 \parallel \beta r_e = 40\Omega \parallel 10k\Omega \parallel 1{,}65k\Omega$

$R_i = 1{,}36\,k\Omega$

$$F_{L_C} = \frac{1}{2\pi \cdot (R_s + R_i) \cdot C_C} = \frac{1}{2\pi (4\,k\Omega + 2{,}2k\Omega) \cdot (1\,\mu F)} = 25{,}68\,Hz$$

$R_C \parallel r_o \cong R_L$

$$F_{L_E} = \frac{1}{2\pi \cdot R_e \cdot C_E} = \frac{1}{2\pi (92{,}01\,\Omega) \cdot 20\mu F} = 87{,}13\,Hz$$

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

$$R_e = 2k\Omega \parallel \left(\frac{40 \parallel 10}{100} + 16{,}45\Omega \right)$$

$R_e = 92{,}01\,\Omega$

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IMPACT OF R_S ON THE BJT

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IMPACT OF R_S ON THE BJT

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

$R_s = 1k\Omega$

From Example 9.12

$$F_{L_S} = \frac{1}{2\pi \cdot (R_i + R_s) \cdot C_s} = \frac{1}{2\pi (1{,}36k\Omega + 1k\Omega) \cdot (10\,\mu F}$$

$$F_{L_S} = 6{,}34\ Hz$$

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

$$R_e = 2k\Omega \,||\left(\frac{1\,||40||10}{100} + 26{,}5\right)$$

$$R_e \cong 24{,}35\,\Omega$$

$$F_{L_E} = \frac{1}{2\pi R_e C_E} = \frac{1}{2\pi (24{,}35\,\Omega) \cdot (20\,\mu F)}$$

$$F_{L_E} = 327\ Hz$$

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LOW-FREQUENCY RESPONSE—FET AMPLIFIER

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

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C}, \qquad R_o = R_D \| r_d$$

$$f_{L_S} = \frac{1}{2\pi R_{eq} C_S}, \qquad R_{eq} = \frac{R_S}{1 + R_S(1 + g_m r_d)/(r_d + R_D \| R_L)} \cong R_S \left\| \frac{1}{g_m} \right|_{r_d \cong \infty\,\Omega}$$

Important Formulas



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LOW-FREQUENCY RESPONSE—FET AMPLIFIER

EXAMPLE 9.13

a. Determine the lower cutoff frequency for the network of Fig. 9.37 using the following parameters:

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

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

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

$\frac{2I_{DSS}}{|V_P|} = \frac{2(8\text{mA})}{|-4\text{V}|} = 4\text{mS}$

$g_m = g_{m0}\left(1 - \frac{V_{GS}}{|V_P|}\right)$

$g_m = 4\text{mS}\left(1 - \frac{(-2\text{V})}{(-4\text{V})}\right)$

$g_{m0} = \frac{2\text{mS}}{\Gamma}$

$F_{L_G}, F_{L_C}, F_{L_S}, A_V = ?$

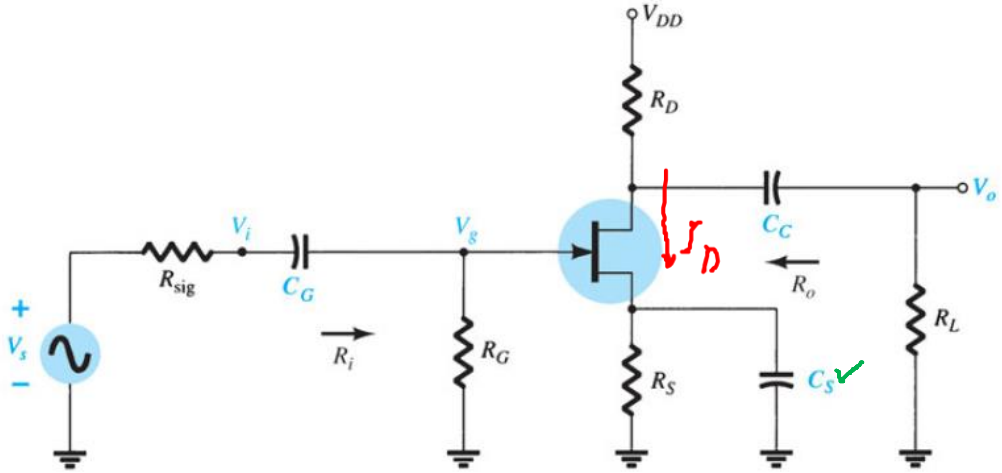


FIG. 9.37

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LOW-FREQUENCY RESPONSE—FET AMPLIFIER

$V_{GS} = V_G - V_S \Rightarrow V_{GS} = -I_D \cdot R_S$

$V_G \downarrow 0 \quad V_S \downarrow -I_D \cdot R_S$

$V_{GS} = -(2mA) \cdot 1k\Omega$

$\boxed{V_{GS} = -2V}$

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

$$= \frac{1}{2\pi (10k\Omega + 1M\Omega) \cdot (0{,}01\,\mu F)}$$

$f_{L_G} = 15{,}8\ Hz$

$$I_D = I_{DSS} \cdot \left(1 - \frac{V_{GS}}{V_P}\right)^2$$

$$I_D = 8mA \cdot \left(1 - \frac{(-I_D \cdot 1k\Omega)}{(-4V)}\right)^2$$

$$I_D = \frac{-b \mp \sqrt{b^2 - 4ac}}{2a}$$

$I_D = 8 \cdot 10^{-3} - 4 I_D \cdot 10^{-3} + \frac{1}{2} I_D^2 \cdot 10^{-3}$

$I_D^2 - 12 I_D + 16 = 0$

$I_D \quad -8$

$I_D \quad -2$

$\Rightarrow I_D = 8mA$

$\boxed{I_D = 2mA}$

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LOW-FREQUENCY RESPONSE—FET AMPLIFIER

$$F_{L_C} = \frac{1}{2\pi \cdot (R_D + R_L) \cdot C_C} = \frac{1}{2\pi \cdot (4.7k\Omega + 2.2k\Omega) \cdot (0,5\mu F)} = 46,13\,Hz$$

$R_D \| r_d \cong R_D$

$$F_{L_S} = \frac{1}{2\pi \cdot R_{eq} \cdot C_S} = \frac{1}{2\pi \cdot (333.33k\Omega) \cdot (2\mu F)} = 238,73\,Hz$$

$R_S \| \frac{1}{g_m} = 1k\Omega \| \frac{1}{2mS} = 333.33k\Omega$

From Table 8.2

$A_V = -g_m (R_D \| R_L)$

$A_V = 2mS \cdot (4.7k\Omega \| 2.2k\Omega)$

$A_V = -3$

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HIGH-FREQUENCY RESPONSE—BJT

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HIGH-FREQUENCY RESPONSE—BJT

$$A_v = \frac{1}{1 + j(f/f_H)}, \qquad f_{H_i} = \frac{1}{2\pi R_{\text{Th}_i} C_i}, \qquad R_{\text{Th}_i} = R_s \| R_1 \| R_2 \| R_i,$$

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

$$f_{H_o} = \frac{1}{2\pi R_{\text{Th}_o} C_o}, \qquad R_{\text{Th}_o} = R_C \| R_L \| r_o, \qquad C_o = C_{W_o} + C_{ce} + C_{M_o},$$

$$h_{fe} = \frac{h_{fe_{\text{mid}}}}{1 + j(f/f_\beta)}$$

$$f_\beta \cong \frac{1}{2\pi \beta_{\text{mid}} r_e (C_{be} + C_{bc})}$$

$$f_T \cong h_{fe_{\text{mid}}} f_\beta$$

$$C_{M_i} = (1 - A_v)C_f, \qquad C_{M_o} = \left(1 - \frac{1}{A_v}\right)C_f$$

$C_f \rightarrow C_{bc}$, $C_f \rightarrow C_{bc}$

or

For A_v large (typical):

and

$$C_o = C_{W_o} + C_{ce} + (1 - 1/A_v)C_{bc}$$

$$1 \gg 1/A_v$$

$$\rightarrow \boxed{C_o \cong C_{W_o} + C_{ce} + C_{bc}}$$

No Approx C_{M_o}

Important Formulas



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HIGH-FREQUENCY RESPONSE—BJT

EXAMPLE 9.14 Use the network of Fig. 9.47 with the same parameters as in Example 9.12, that is,

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

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

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

with the addition of

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

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

b. Find f_β and f_T.

r_e ← R_{TH}, I_B, I_E

R_e

A_v

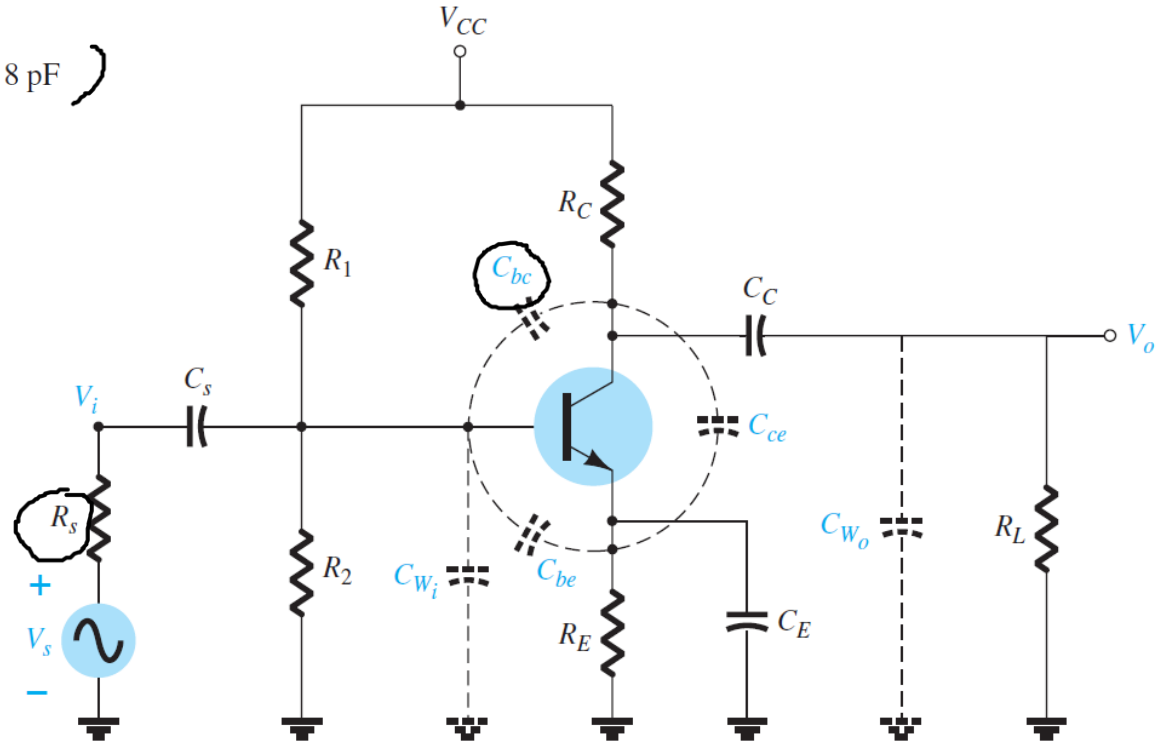


FIG. 9.47

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HIGH-FREQUENCY RESPONSE—BJT

From Example 9.12 $\beta_{re} = 1645\,k\Omega$, $A_v = -86,2$

$$R_{THi} = R_s \parallel R_1 \parallel R_2 \parallel \beta_{re} = 1 \parallel 40 \parallel 10 \parallel 1,645 \cong 0,57\,k\Omega$$

$$F_{Hi} = \frac{1}{2\pi \cdot R_{THi} \cdot C_i}$$

$$F_{Hi} = \frac{1}{2\pi \cdot (0,57k\Omega) \cdot (390,8pF)} = 8,6\,MHz$$

$$C_{Mi} = \frac{1}{A_v} \cdot C_{bc} = \frac{1}{-86,2} \cdot 4pF$$

$$C_i = 390,8\,pF$$

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HIGH-FREQUENCY RESPONSE—BJT

$$F_{H_o} = \frac{1}{2\pi \cdot R_{TH_o} \cdot C_o} = \frac{1}{2\pi \cdot (1{,}49\,k\Omega) \cdot (13{,}04\,pF)}$$

$R_{TH_o} \rightarrow R_C \| R_L = 1{,}49\,k\Omega$

$$F_{H_o} = 8{,}6\,MHz$$

$$F_\beta = \frac{1}{2\pi \cdot h_{fe} \cdot r_e (C_{be} + C_{bc})} = \frac{1}{2\pi \cdot (100) \cdot (16{,}45\,\Omega) \cdot (60\,pF)}$$

$$= 2{,}52\,MHz$$

$$F_T = h_{fe} \cdot F_\beta = 252\,MHz$$

$$C_o = C_{wo} + C_{ce} + C_{Mo}$$

$C_{Mo} \rightarrow 1 - \frac{1}{A_V} \cdot C_f$, $C_f = C_{bc}$

$$C_o = 8\,pF + 1\,pF + 1 - \left(-\frac{1}{8}\right) \cdot 4\,pF$$

$$C_o = 13{,}04\,pF$$

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HIGH-FREQUENCY RESPONSE—FET

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HIGH-FREQUENCY RESPONSE—FET

$$f_{H_i} = \frac{1}{2\pi R_{\text{Th}_i} C_i}, \quad R_{\text{Th}_i} = R_{\text{sig}} \| R_G, \quad C_i = C_{W_i} + C_{gs} + C_{M_i},$$

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

$$f_{H_o} = \frac{1}{2\pi R_{\text{Th}_o} C_o}, \quad R_{\text{Th}_o} = R_D \| R_L \| r_d, \quad C_o = C_{W_o} + C_{ds} + C_{M_o},$$

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

Exact / Approx

No approx with C_{M_o} → C_{gd}

Important Formulas



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HIGH-FREQUENCY RESPONSE—FET

EXAMPLE 9.15

a. Determine the high-cutoff frequencies for the network of Fig. 9.55 using the same parameters as Example 9.13:

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

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

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

with the addition of

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

$F_{Hi} > F_{Ho}$!

DC Ana → V_{GS} , I_D

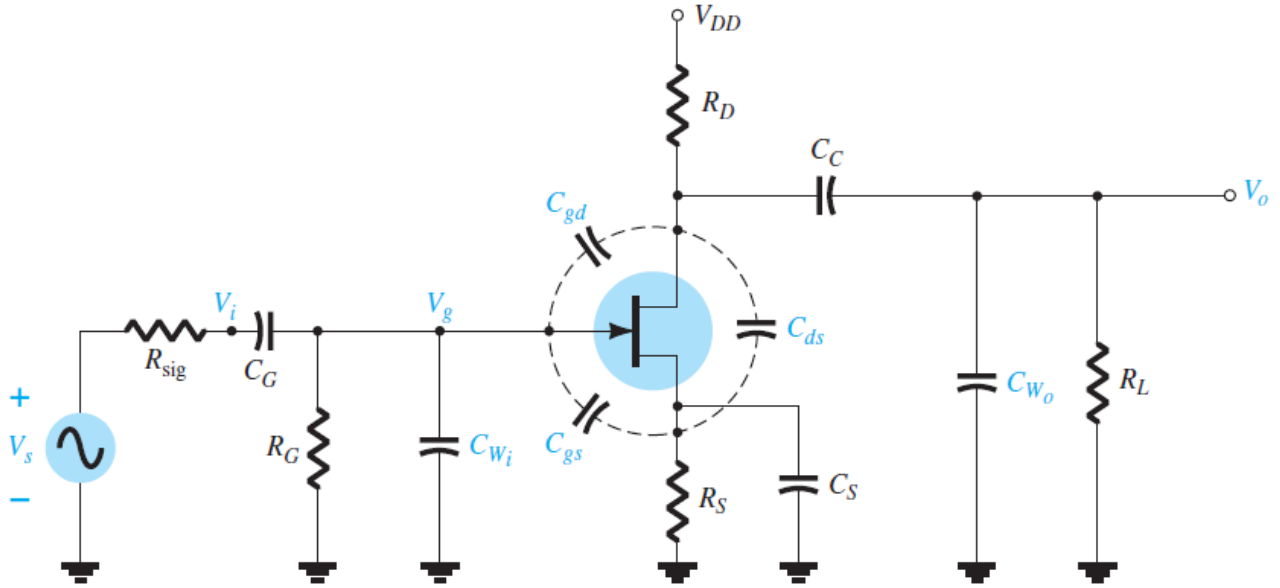


FIG. 9.55

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HIGH-FREQUENCY RESPONSE—FET

From Example 9.13 → $A_V = -3$

$$f_{Hi} = \frac{1}{2\pi \cdot R_{THi} \cdot C_i}$$

(1) (1)

$$= \frac{1}{2\pi \cdot (9.9\,k\Omega) \cdot (17\,pF)}$$

$$f_{Hi} = 945{,}67\ kHz$$

1-) $R_{THi} = R_{sig} \parallel R_G = 10\,k\Omega \parallel 1\,M\Omega$

$= 9.9\,k\Omega$

2-) $C_i = C_w + C_{gs} + C_{M_1}$

$= 5\,pF + 4\,pF + \left(1 - \frac{1}{(-3)}\right) \cdot 2\,pF$

$= 17\,pF$

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HIGH-FREQUENCY RESPONSE—FET

$$F_{H_0} = \frac{1}{2\pi \cdot R_{TH_0} \cdot C_0}$$

$$F_{H_0} = \frac{1}{2\pi \cdot (1{,}5\,k\Omega) \cdot (9{,}17\,pF)} = 11{,}52\,MHz$$

$$R_{TH_0} = R_D \parallel R_L$$

$$= 5{,}7\,k\Omega \parallel 2{,}2\,k\Omega$$

$$= 1{,}5\,k\Omega$$

$$C_0 = C_{wo} + C_{ds} + C_{M_0}$$

$$= 6\,pF + 0{,}5\,pF + \left(1 - \frac{1}{(-3)}\right) 2\,pF$$

$$C_0 = 9{,}17\,pF$$

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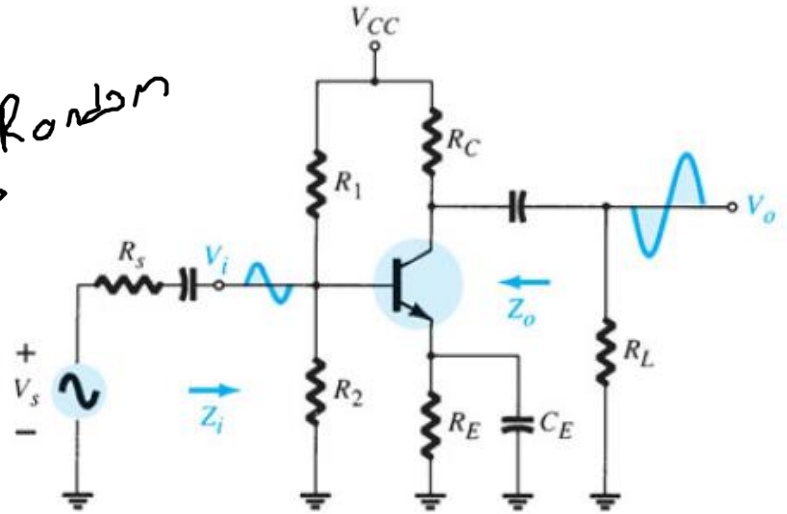


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Advance and Advice (BJT)

Parameter	Value
VCC	29V
hfe	290
R1	29kΩ
R2	8.3kΩ
RC	2.9kΩ
RE	1.1kΩ
RL	9.8kΩ
RS	1.1kΩ
CS	11µF
CE	29µF
CC	3.2µF
Cbe	32pF
Cbc	4.8pF
Cce	1.1pF
Cwi	6.2pF
Cwo	8.3pF

Random



Please determine F_{LE} without the effect of R_S

Please determine F_{LE} with the effect of R_S

Please determine F_{THi}

Please determine F_{THo} (No approximations with CMo)

Please determine F_T → F_β

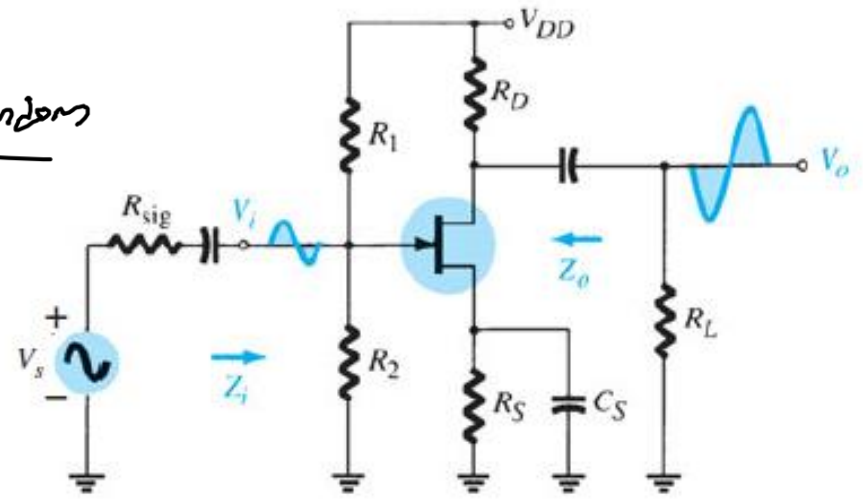
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Advance and Advice (FET)

Parameter	Value
V_{DD}	29V
V_p	−11V
I_{DSS}	11mA
R_D	4.8kΩ
R_S	1.1kΩ
R_1	2.9MΩ
R_2	32.0kΩ
r_d	∞
R_{sig}	11.0kΩ
R_L	2.9kΩ
C_G	11.0nF
C_C	10.0μF
C_S	2.9μF
C_{gd}	2.9pF
C_{gs}	4.8pF
C_{ds}	10.0pF
C_{wi}	5.5pF
C_{wo}	6.2pF

Random

Please find the V_{GS} , F_{LG} , F_{LS} , F_{THi} and F_{THo} (No approximations with C_{Mo})



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Thanks

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