unity. For the MOSFET, \( f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})} \), and for the BJT, \( f_T = \frac{g_m}{2\pi(C_e + C_{ce})} \).

- The internal capacitances of the MOSFET and the BJT cause the amplifier gain to fall off at high frequencies. An estimate of the amplifier bandwidth is provided by the frequency \( f_H \) at which the gain drops 3 dB below its value at midband, \( A_m \). A figure-of-merit for the amplifier is the gain–bandwidth product \( GB = A_m f_H \). Usually, it is possible to trade off gain for increased bandwidth, with \( GB \) remaining nearly constant. For amplifiers with a dominant pole with frequency \( f_H \), the gain falls off at a uniform 6-dB/octave (20-dB/decade) rate, reaching 0 dB at \( f_i = GB \).

- The high-frequency response of the CS and CE amplifiers is severely limited by the Miller effect: The small capacitance \( C_{gd} \) (\( C_{ce} \)) is multiplied by a factor approximately equal to the gain from gate to drain (base to collector) \( g_m R_i \) and thus gives rise to a large capacitance at the amplifier input. The increased \( C_{in} \) interacts with the effective signal-source resistance \( R_{sig} \) and causes the amplifier gain to have a 3-dB frequency \( f_H = 1/2\pi R_{sig} C_{in} \).

- The method of open-circuit time constants provides a simple and powerful way to obtain a reasonably good estimate of the upper 3-dB frequency \( f_H \). The capacitors that limit the high-frequency response are considered one at a time with \( V_{sig} = 0 \) and all the other capacitances set to zero (open circuited). The resistance seen by each capacitance is determined, and the overall time constant \( \tau_H \) is obtained by summing the individual time constants. Then \( f_H \) is found as \( 1/2\pi \tau_H \).

- The high-frequency response of the differential amplifier can be obtained by considering the differential and common-mode half-circuits. The CMRR falls off at a relatively low frequency determined by the output impedance of the bias current source.

- Combining two transistors in a way that eliminates or minimizes the Miller effect can result in a much wider bandwidth. Some such configurations are presented in Section 9.9.

- The key to the analysis of the high-frequency response of a multistage amplifier is to use simple macro models to estimate the frequencies of the poles formed at the interface between each two stages, in addition to the input and output poles. The pole with the lowest frequency dominates and determines \( f_H \).

### Computer Simulation Problems

#### Problems identified by this icon are intended to demonstrate the value of using SPICE simulation to verify hand analysis and design, and to investigate important issues such as gain–bandwidth tradeoff. Instructions to assist in setting up PSpice and Multisim simulations for all the indicated problems can be found in the corresponding files on the disc. Note that if a particular parameter value is not specified in the problem statement, you are to make a reasonable assumption.

*difficult problem; ** more difficult; *** very challenging and/or time-consuming; D: design problem.

#### Section 9.1: Low-Frequency Response of the CS and CE Amplifiers

**D 9.1** The amplifier in Fig. P9.1 is biased to operate at \( g_m = 1 \text{ mA/V} \). Neglecting \( r_o \), find the midband gain. Find the value of \( C_t \) that places \( f_i \) at 20 Hz.

**9.2** Consider the amplifier of Fig. 9.2(a). Let \( R_o = 10 \text{ k}\Omega \), \( r_o = 100 \text{ k}\Omega \), and \( R_i = 10 \text{ k}\Omega \). Find the value of \( C_{Cg} \) specified to one significant digit, to ensure that the associated break frequency is at, or below, 10 Hz. If a higher-power design results in doubling \( I_{ds} \) with both \( R_o \) and \( r_o \) reduced by a factor of 2, what does the corner frequency (due to \( C_{Cg} \)) become? For
9.3 The NMOS transistor in the discrete CS amplifier circuit of Fig. P9.3 is biased to have \( g_m = 5 \text{ mA/V} \). Find \( A_{mP}, f_P, f_P2, f_P3 \), and \( f_L \).

**Figure P9.1**

increasingly higher-power designs, what is the highest corner frequency that can be associated with \( C_C \)?

9.4 Consider the low-frequency response of the CS amplifier of Fig. 9.2(a). Let \( R_{sig} = 0.5 \text{ M}\Omega, R_o = 2 \text{ M}\Omega, g_m = 3 \text{ mA/V}, R_D = 20 \text{ k}\Omega, \) and \( R_L = 10 \text{ k}\Omega \). Find \( A_m \). Also, design the coupling and bypass capacitors to locate the three low-frequency poles at 50 Hz, 10 Hz, and 3 Hz. Use a minimum total capacitance, with capacitors specified only to a single significant digit. What value of \( f_L \) results?

**Figure P9.3**

9.5 A particular version of the CS amplifier in Fig. 9.2 uses a transistor biased to operate with \( g_m = 5 \text{ mA/V} \). Resistances \( R_{sig} = 200 \text{ k}\Omega, R_G = 10 \text{ M}\Omega, R_D = 3 \text{ k}\Omega, \) and \( R_L = 5 \text{ k}\Omega \). As an initial design, the circuit designer selects \( C_{C1} = C_{C2} = C_S = 1 \mu\text{F} \). Find the frequencies \( f_P1, f_P2, \) and \( f_P3 \) and rank them in order of frequency, highest first. Calculate the ratios of the first to second, and second to third. The final design requires that the first pole dominate at 10 Hz with the second a factor of 4 lower, and the third another a factor of 4 lower. Find the values of all the capacitances and the total capacitance needed. If the separation factor were 10, what capacitor values and total capacitance would be needed? (Note: You can see that the total capacitance need not be much larger to spread the poles, as is desired in certain applications.)

**D 9.6** Repeat Example 9.1 to find \( C_S, C_{C1}, \) and \( C_{C2} \) that provide \( f_L = 20 \text{ Hz} \) and the other pole frequencies at 4 Hz and 1 Hz. Design to keep the total capacitance to a minimum.

**D 9.7** Reconsider Exercise 9.1 with the aim of finding a better-performing design using the same total capacitance, that is, 3 \( \mu\text{F} \). Prepare a design in which the break frequencies are separated by a factor of 5 (i.e., \( f_L / 5 \), and \( f_L / 25 \)). What are the three capacitor values, the three break frequencies, and \( f_L \) that you achieve?

9.8 Repeat Exercise 9.2 for the situation in which \( C_E = 50 \mu\text{F} \) and \( C_{C1} = C_{C2} = 2 \mu\text{F} \). Find the three break frequencies and estimate \( f_L \).

**D 9.9** Repeat Example 9.2 for a related CE amplifier whose supply voltages and bias current are each reduced to half their original value but \( R_{E}, R_C, R_{sig}, \) and \( R_L \) are left unchanged. Find \( C_{C1}, C_E, \) and \( C_{C2} \) for \( f_L = 100 \text{ Hz} \). Minimize the total capacitance used, under the following conditions. Arrange that the contributions of \( C_E, C_{C1}, \) and \( C_{C2} \) are 80%, 10%, and 10%, respectively. Specify capacitors to two significant digits, choosing the next highest value, in general, for a conservative design, but realizing that for \( C_E \), this may represent a larger capacitance increment. Check the value of \( f_L \) that results. (Note: An attractive approach can be to select \( C_E \) on the small side, allowing it to contribute more than 80% to \( f_L \), while making \( C_{C1} \) and \( C_{C2} \) larger, since they must contribute less to \( f_L \).)

**D 9.10** A particular current-biased CE amplifier operating at 100 \( \mu\text{A} \) from \( \pm3\text{-V} \) power supplies employs \( R_C = 20 \text{ k}\Omega, \) \( R_E = 200 \text{ k}\Omega \); it operates between a 20-k\( \Omega \) source and a 10-k\( \Omega \) load. The transistor \( \beta = 100 \). Select \( C_E \) first for a minimum value specified to one significant digit and providing up to 90% of \( f_L \). Then choose \( C_{C1} \) and \( C_{C2} \), each specified to one significant digit, with the goal of minimizing the total capacitance used. What \( f_L \) results? What total capacitance is needed?

9.11 Consider the common-emitter amplifier of Fig. P9.11 under the following conditions: \( R_{sig} = 5 \text{ k}\Omega, R_1 = 33 \text{ k}\Omega, R_T = 22 \text{ k}\Omega, R_E = 3.9 \text{ k}\Omega, R_C = 4.7 \text{ k}\Omega, R_L = 5.6 \text{ k}\Omega, V_{CC} = 5 \text{ V} \). The dc emitter current can be shown to be \( I_E = 0.3 \text{ mA} \), at which \( \beta = 120 \). Find the input resistance \( R_E \) and the midband gain \( A_m \). If \( C_{C1} = C_{C2} = 1 \mu\text{F} \) and \( C_E = 20 \mu\text{F} \), find the three break frequencies \( f_P1, f_P2, \) and \( f_P3 \) and an estimate for \( f_L \). Note that \( R_E \) has to be taken into account in evaluating \( f_P2 \).
Section 9.3: High-Frequency Response of the CS and CE Amplifiers

9.29 In a particular common-source amplifier for which the midband voltage gain between gate and drain (i.e., \(-g_mR'_L\)) is \(-29\) V/V, the MOSFET has \(C_{gs} = 0.5\) pF and \(C_{gd} = 0.1\) pF. What input capacitance would you expect? For what range of signal-source resistances can you expect the 3-dB frequency to exceed 10 MHz? Neglect the effect of \(R_G\).

D 9.30 A design is required for a CS amplifier for which the MOSFET is operated at \(g_m = 5\) mA/V and has \(C_{gs} = 5\) pF and \(C_{gd} = 1\) pF. The amplifier is fed with a signal source having \(R_{sig} = 1\) kΩ, and \(R_G\) is very large. What is the largest value of \(R'_L\) for which the 3-dB frequency is at least 10 MHz? What is the corresponding value of midband gain and gain–bandwidth product? If the specification on the upper 3-dB frequency can be relaxed by a factor of 3, that is, to \((10/3)\) MHz, what can \(A_M\) and \(GB\) become?

9.31 Reconsider Example 9.3 for the situation in which the transistor is replaced by one whose width \(W\) is half that of the original transistor while the bias current remains unchanged. Find modified values for all the device parameters along with \(A_M\), \(f_{th}\), and the gain–bandwidth product, \(GB\). Contrast this with the original design by calculating the ratios of new value to old for \(W, V_{OFF}, g_m, C_{gs}, C_{gd}, C_{in}, A_M, f_{th}\), and \(GB\).

D 9.32 In a CS amplifier, such as that in Fig. 9.2(a), the resistance of the source \(R_{sig} = 100\) kΩ, amplifier input resistance (which is due to the biasing network) \(R_a = 100\) kΩ, \(C_{gs} = 1\) pF, \(C_{gd} = 0.2\) pF, \(g_m = 3\) mA/V, \(r_s = 50\) kΩ, \(R_o = 8\) kΩ, and \(R_L = 10\) kΩ. Determine the expected 3-dB cutoff frequency \(f_{th}\) and the midband gain. In evaluating ways to double \(f_{th}\), a designer considers the alternatives of changing either \(R_s\) or \(R_{sa}\). To raise \(f_{th}\) as described, what separate change in each would be required? What midband voltage gain results in each case?

9.33 A discrete MOSFET common-source amplifier has \(R_o = 1\) MΩ, \(g_m = 5\) mA/V, \(r_s = 100\) kΩ, \(R_o = 10\) kΩ, \(C_{gs} = 2\) pF, and \(C_{gd} = 0.4\) pF. The amplifier is fed from a voltage source with an internal resistance of 500 kΩ and is connected to a 10-kΩ load. Find:

(a) the overall midband gain \(A_M\)
(b) the upper 3-dB frequency \(f_{th}\)

9.34 The analysis of the high-frequency response of the common-source amplifier, presented in the text, is based on the assumption that the resistance of the signal source, \(R_{sig}\) is large and, thus, that its interaction with the input capacitance \(C_{in}\) produces the "dominant pole" that determines the upper 3-dB frequency \(f_{th}\). In some situations, however, the CS amplifier is fed with a very low \(R_{sig}\). To investigate the high-frequency response of the amplifier in such a case, Fig. P9.34 shows the equivalent circuit when the CS amplifier is fed with an ideal voltage source \(V_{sig}\) having \(R_{sig} = 0\). Note that \(C_s\) denotes the total capacitance at the output node. By writing a node equation at the output, show that the transfer function \(V_o/V_{sig}\) is given by

\[
V_o/V_{sig} = \frac{-g_mR'_L}{1 - s(C_{gd}/g_m) + s(C_L + C_{gd})R_L/R_L}.
\]

At frequencies \(\omega \ll (g_m/C_{gd})\), the \(s\) term in the numerator can be neglected. In such case, what is the upper 3-dB frequency resulting? Compute the values of \(A_M, f_{th}\) for the case: \(C_{gd} = 0.4\) pF, \(C_s = 2\) pF, \(g_m = 5\) mA/V, and \(R'_L = 5\) kΩ.

![Figure P9.34](image)

9.35 The NMOS transistor in the discrete CS amplifier circuit of Fig. P9.3 is biased to have \(g_m = 1\) mA/V and \(r_o = 100\) kΩ. Find \(A_M\). If \(C_{gs} = 1\) pF and \(C_{gd} = 0.2\) pF, find \(f_{th}\).

D 9.36 A designer wishes to investigate the effect of changing the bias current \(I\) on the midband gain and high-frequency response of the CE amplifier considered in Example 9.4. Let \(I\) be doubled to 2 mA, and assume that \(\beta_c\) and \(f_r\) remain unchanged at 100 and 800 MHz, respectively. To keep the node voltages nearly unchanged, the designer reduces \(R_a\) and \(R_c\) by a factor of 2, to 50 kΩ and 4 kΩ, respectively. Assume \(r_o = 50\) Ω, and recall that \(V_f = 100\) V and that \(C_{mu}\) remains constant at 1 pF. As before, the amplifier is fed with a source having \(R_{sig} = 5\) kΩ and feeds a load \(R_L = 5\) kΩ. Find the new values of \(A_M, f_{th}\), and the gain–bandwidth product, \(A_M f_{th}\). Comment on the results. Note that the price paid for whatever improvement in performance is achieved is an increase in power. By what factor does the power dissipation increase?

9.37 The purpose of this problem is to investigate the high-frequency response of the CE amplifier when it is fed with a relatively large source resistance \(R_{sig}\). Refer to the amplifier in Fig. 9.4 (a) and to its high-frequency, equivalent-circuit model and the analysis shown in Fig. 9.14. Let \(R_B \gg R_{sig}\), \(r_s \ll R_{sig}\), \(R_{sig} \gg r_{sv}, g_mR'_L\), and \(g_mR'_L/C_{mu} \gg C_s\). Under these conditions, show that:

(a) the midband gain \(A_M = -\beta R'_L/R_{sig}\)
(b) the upper 3-dB frequency \(f_{th} = 1/2\pi C_{mu}R'_L\)
(c) the gain–bandwidth product \(A_M f_{th} = 1/2\pi C_{mu}R_{sig}\)

Evaluate this approximate value of the gain–bandwidth product for the case \(R_{sig} = 25\) kΩ and \(C_{mu} = 1\) pF. Now, if the transistor is biased at \(I_c = 1\) mA and has \(\beta = 100\), find the midband gain and \(f_{th}\) for the two cases \(R'_L = 25\) kΩ and \(R'_L = 2.5\) kΩ. On
9.73 Consider a CS amplifier loaded in a current source with an output resistance equal to $r_o$ of the amplifying transistor. The amplifier is fed from a signal source with $R_{sig} = r_o/2$. The transistor is biased to operate with $g_m = 2$ mA/V and $r_o = 20$ kΩ; $C_{gs} = C_{gd} = 0.1$ pF. Use the Miller approximation to determine an estimate of $f_H$. Repeat for the following two cases: (i) the bias current $I$ in the entire system is reduced by a factor of 4, and (ii) the bias current $I$ in the entire system is increased by a factor of 4. Remember that both $R_{sig}$ and $R_L$ will change as $r_o$ changes.

9.74 Use the method of open-circuit time constants to find $f_H$ for a CS amplifier for which $g_m = 1.5$ mA/V, $C_{gs} = C_{gd} = 0.2$ pF, $r_o = 20$ kΩ, $R_L = 12$ kΩ, and $R_{sig} = 100$ kΩ for the following cases: (a) $C_L = 0$, (b) $C_L = 10$ pF, and (c) $C_L = 50$ pF. Compare with the value of $f_H$ obtained using the Miller approximation.

Section 9.6: High-Frequency Response of the Common-Gate and Cascode Amplifiers

9.75 A CG amplifier is specified to have $C_{gs} = 2$ pF, $C_{gd} = 0.1$ pF, $C_L = 2$ pF, $g_m = 4$ mA/V, $R_{sig} = 1$ kΩ, and $R'_L = 20$ kΩ. Neglecting the effects of $r_o$, find the low-frequency gain $v_o/v_{sig}$, the frequencies of the poles $f_{p1}$ and $f_{p2}$, and hence an estimate of the 3-dB frequency $f_H$.

*9.76 Sketch the high-frequency equivalent circuit of a CB amplifier fed from a signal generator characterized by $V_{sig}$ and $R_{sig}$ and feeding a load resistance $R_L$ in parallel with a capacitance $C_L$.

(a) Show that for $r_o = \infty$ the circuit can be separated into two parts: an input part that produces a pole at

$$f_{p1} = \frac{1}{2\pi C_{gd}(R_{sig} \parallel r_o)}$$

and an output part that forms a pole at

$$f_{p2} = \frac{1}{2\pi (C_{gd} + C_L)R_L}$$

Note that these are the bipolar counterparts of the MOS expressions in Eqs. (9.109) and (9.110).

(b) Evaluate $f_{p1}$ and $f_{p2}$ and hence obtain an estimate for $f_H$ for the case $C_{gs} = 14$ pF, $C_{gd} = 2$ pF, $L_C = 1$ pF, $g_m = 1$ mA, $R_{sig} = 1$ kΩ, and $R_L = 10$ kΩ. Also, find $f_T$ of the transistor.

*9.77 Consider a CG amplifier loaded in a resistance $R_L = r_o$ and fed with a signal source having a resistance $R_{sig} = r_o/2$. Also let $C_L = C_{gs}$. Use the method of opencircuit time constants to show that for $g_m r_o \gg 1$, the upper 3-dB frequency is related to the MOSFET $f_T$ by the approximate expression
\[ f_H = f_r' / \left( g_m r_o \right) \]

**9.78** For the CG amplifier in Example 9.12, how much additional capacitance should be connected between the output node and ground to reduce \( f_H \) to 300 MHz?

**9.79** Find the dc gain and the 3-dB frequency of a MOS cascode amplifier operated at \( g_m = 1 \) mA/V and \( r_o = 50 \) kΩ. The MOSFETs have \( C_{gs} = 30 \) fF, \( C_{gd} = 10 \) fF, and \( C_{db} = 40 \) fF. The amplifier is fed from a signal source with \( R_{sig} = 100 \) kΩ and is connected to a load resistance of 2 MΩ. There is also a load capacitance \( C_L \) of 40 fF.

**9.80** (a) Consider a CS amplifier having \( C_{gd} = 0.2 \) pF, \( R_{sig} = R_L = 20 \) kΩ, \( g_m = 4 \) mA/V, \( C_{gs} = 2 \) pF, \( C_L \) (including \( C_{gs} \)) = 1 pF, \( C_{qd} = 0.2 \) pF, and \( r_o = 20 \) kΩ. Find the low-frequency gain \( A_m \) and estimate \( f_{d1} \) using open-circuit time constants. Hence determine the gain–bandwidth product.

(b) If a CG stage is cascaded with the CS transistor in (a) to create a cascode amplifier, determine the new values of \( A_m, f_{d1} \), and gain–bandwidth product. Assume \( R_t \) remains unchanged.

**D 9.81** It is required to design a cascode amplifier to provide a dc gain of 74 dB when driven with a low-resistance generator and utilizing NMOS transistors for which \( V_T = 10 \) V, \( \mu C_{ox} = 200 \) μA/V², \( W/L = 50 \), \( C_{gs} = 0.1 \) pF, and \( C_{L} = 1 \) pF. Assuming that \( R_L = R_s \), determine the overdrive voltage and the drain current at which the MOSFETs should be operated. Find the unity-gain frequency and the 3-dB frequency. If the cascode transistor is removed and \( R_t \) remains unchanged, what will the dc gain become?

**9.82** Consider a bipolar cascode amplifier biased at a current of 1 mA. The transistors used have \( \beta = 100 \), \( r_o = 100 \) kΩ, \( C_s = 14 \) pF, \( C_{gd} = 2 \) pF, \( C_{gs} = 0 \), and \( C_{db} = 10 \) pF. The amplifier is fed with a signal source having \( R_{sig} = 4 \) kΩ. The load resistance \( R_L = 2.4 \) kΩ. Find the low-frequency gain \( A_m \), and estimate the value of the 3-dB frequency \( f_{d1} \).

**9.83** In this problem we consider the frequency response of the bipolar cascode amplifier in the case that \( r_o \) can be neglected.

(a) Refer to the circuit in Fig. 9.31, and note that the total resistance between the collector of \( Q \), and ground will be equal to \( r_{c2} \), which is usually very small. It follows that the pole introduced at this node will typically be at a very high frequency and thus will have negligible effect on \( f_{d1} \). It also follows that at the frequencies of interest the gain from the base to the collector of \( Q \) will be \( -g_m r_{s2} = -1 \). Use this to find the capacitance at the input of \( Q \), and hence show that the pole introduced at the input node will have a frequency

\[ f_{p1} = \frac{1}{2 \pi R_{sig} \left( C_{x1} + 2 C_{mu} \right)} \]

Then show that the pole introduced at the output node will have a frequency

\[ f_{p2} = \frac{1}{2 \pi R_{sig} \left( C_{gs} + C_{gs} \right)} \]

(b) Evaluate \( f_{p1} \) and \( f_{p2} \), and use the sum-of-the-squares formula to estimate \( f_H \) for the amplifier with \( I = 1 \) mA, \( C_x = 5 \) pF, \( C_{gs} = 5 \) pF, \( C_{s} = C_L = 0 \), \( \beta = 100 \), and \( r_o = 0 \) in the following two cases:

(i) \( R_{sig} = 1 \) kΩ

(ii) \( R_{sig} = 10 \) kΩ

**9.84** A BJT cascode amplifier uses transistors for which \( \beta = 100 \), \( V_A = 100 \) V, \( f_T = 1 \) GHz, and \( C_{gs} = 0.1 \) pF. It operates at a bias current of 0.1 mA between a source with \( R_{sig} = r_x \) and a load \( R_L = \beta r_o \). Let \( C_L = C_{gs} = 0 \) and find the overall voltage gain at dc, \( f_H \), and \( f_1 \).

**Section 9.7: High-Frequency Response of the Source and Emitter Followers**

**9.85** A source follower has \( g_m = 5 \) mA/V, \( r_o = 20 \) kΩ, \( R_{sig} = 20 \) kΩ, \( R_L = 2 \) kΩ, \( C_{gs} = 2 \) pF, \( C_{gd} = 0.1 \) pF, and \( C_{L} = 1 \) pF. Find \( A_m, f_{d1}, \) and \( f_{d2} \). Also, find the percentage contribution of each of the three capacitances to the time-constant \( r_{in} \).

**9.86** Using the expression for the source follower \( f_H \) in Eq. (9.129) show that for situations in which \( R_{sig} \) is large and \( R_L \) is small,

\[ f_H = \frac{1}{2 \pi R_{sig} \left[ C_{gs} \left( 1 + g_m R_L' \right) \right]} \]

Find \( f_H \) for the case \( R_{sig} = 100 \) kΩ, \( R_L = 1 \) kΩ, \( r_o = 20 \) kΩ, \( g_m = 5 \) mA/V, \( C_{gd} = 10 \) fF, and \( C_{gs} = 30 \) fF.

**9.87** Refer to Fig. 9.32(b). In situations in which \( R_{sig} \) is large, the high-frequency response of the source follower is determined by the low-pass circuit formed by \( R_{sig} \) and the input capacitance. An estimate of \( C_{in} \) can be obtained by using the Miller approximation to replace \( C_{gs} \) with an input capacitance \( C_{eq} = C_{gs} (1 - K) \) where \( K \) is the gain from gate to source. Using the low-frequency value of \( K = g_m R'_L/(1 + g_m R'_L) \) find \( C_{eq} \) and hence \( C_{in} \) and an estimate of \( f_H \). Is this estimate higher or lower than that obtained by the method of open-circuit time constants?

**9.88** For an emitter follower biased at \( I_e = 1 \) mA and having \( R_{sig} = R_L = 1 \) kΩ, and using a transistor specified to have \( f_T = 2 \) GHz, \( C_{gs} = 0.1 \) pF, \( r_o = 100 \) Ω, \( \beta = 100 \), and \( V_T = 20 \) V, evaluate the low-frequency gain \( A_m \) and the 3-dB frequency \( f_{d1} \).