can be as large as 1 mV of unknown polarity, what range of offset current is possible?

2.106 A Miller integrator with $R = 10\ \text{k}\Omega$ and $C = 10\ \text{nF}$ is implemented by using an op amp with $V_{OS} = 2\ \text{mV}$, $I_B = 0.1\ \mu\text{A}$, and $I_{OS} = 20\ \text{nA}$. To provide a finite dc gain, a 1-MΩ resistor is connected across the capacitor.

(a) To compensate for the effect of I_B, a resistor is connected in series with the positive-input terminal of the op amp. What should its value be?
(b) With the resistor of (a) in place, find the worst-case dc output voltage of the integrator when the input is grounded.

Section 2.7: Effect of Finite Open-Loop Gain and Bandwidth on Circuit Performance

2.107 The data in the following table apply to internally compensated op amps. Fill in the blank entries.

A_0	f_b (Hz)	f_t (Hz)
10^5	10^2	
10^6		10^6
	10^3	10^8
	10^{-1}	10^6
2×10^5	10	

2.108 A measurement of the open-loop gain of an internally compensated op amp at very low frequencies shows it to be 98 dB; at 100 kHz, this shows it is 40 dB. Estimate values for A_0, f_b, and f_t.

2.109 Measurements of the open-loop gain of a compensated op amp intended for high-frequency operation indicate that the gain is 4×10^3 at 100 kHz and 20×10^3 at 10 kHz. Estimate its 3-dB frequency, its unity-gain frequency, and its dc gain.

2.110 Measurements made on the internally compensated amplifiers listed below provide the dc gain and the frequency at which the gain has dropped by 20 dB. For each, what are the 3 dB and unity-gain frequencies?

(a) 2×10^5 V/V and 5×10^2 Hz
(b) 20×10^5 V/V and 10 Hz
(c) 1800 V/V and 0.1 MHz
(d) 100 V/V and 0.1 GHz
(e) 25 V/mV and 250 kHz

2.111 An inverting amplifier with nominal gain of −50 V/V employs an op amp having a dc gain of 10^4 and a unity-gain frequency of 10^6 Hz. What is the 3-dB frequency f_{3dB} of the closed-loop amplifier? What is its gain at $0.1 f_{3dB}$ and at $10 f_{3dB}$?

2.112 A particular op amp, characterized by a gain–bandwidth product of 20 MHz, is operated with a closed-loop gain of +100 V/V. What 3-dB bandwidth results? At what frequency does the closed-loop amplifier exhibit a −6° phase shift? A −84° phase shift?

2.113 Find the f_t required for internally compensated op amps to be used in the implementation of closed-loop amplifiers with the following nominal dc gains and 3-dB bandwidths:

(a) −50 V/V; 100 kHz
(b) +50 V/V; 100 kHz
(c) +2 V/V; 5 MHz
(d) −2 V/V; 5 MHz
(e) −1000 V/V; 10 kHz
(f) +1 V/V; 1 MHz
(g) −1 V/V; 1 MHz

2.114 A noninverting op-amp circuit with a gain of 96 V/V is found to have a 3-dB frequency of 8 kHz. For a particular system application, a bandwidth of 32 kHz is required. What is the highest gain available under these conditions?

2.115 Consider a unity-gain follower utilizing an internally compensated op amp with $f_t = 2$ MHz. What is the 3-dB frequency of the follower? At what frequency is the gain of the follower 1% below its low-frequency magnitude? If the input to the follower is a 1-V step, find the 10% to 90% rise time of the output voltage. (*Note:* The step response of STC low-pass networks is discussed in Appendix E. Specifically, note that the 10%–90% rise time of a low-pass STC circuit with a time constant τ is 2.2τ.)

D *2.116 It is required to design a noninverting amplifier with a dc gain of 10. When a step voltage of 100 mV is applied at the input, it is required that the output be within 1% of its final value of 1 V in at most 200 ns. What must the f_t of the op amp be? (*Note:* The step response of STC low-pass networks is discussed in Appendix E.)

D *2.117 This problem illustrates the use of cascaded closed-loop amplifiers to obtain an overall bandwidth greater than can be achieved using a single-stage amplifier with the same overall gain.

SIM = Multisim/PSpice; * = difficult problem; ** = more difficult; *** = very challenging; D = design problem

(a) Show that cascading two identical amplifier stages, each having a low-pass STC frequency response with a 3-dB frequency f_1, results in an overall amplifier with a 3-dB frequency given by

$$f_{3dB} = \sqrt{\sqrt{2}-1}\, f_1$$

(b) It is required to design a noninverting amplifier with a dc gain of 40 dB utilizing a single internally compensated op amp with $f_t = 2$ MHz. What is the 3-dB frequency obtained?

(c) Redesign the amplifier of (b) by cascading two identical noninverting amplifiers each with a dc gain of 20 dB. What is the 3-dB frequency of the overall amplifier? Compare this to the value obtained in (b) above.

D **2.118 A designer, wanting to achieve a stable gain of 100 V/V at 5 MHz, considers her choice of amplifier topologies. What unity-gain frequency would a single operational amplifier require to satisfy her need? Unfortunately, the best available amplifier has an f_t of 40 MHz. How many such amplifiers connected in a cascade of identical noninverting stages would she need to achieve her goal? What is the 3-dB frequency of each stage she can use? What is the overall 3-dB frequency?

2.119 Consider the use of an op amp with a unity-gain frequency f_t in the realization of:

(a) An inverting amplifier with dc gain of magnitude K.
(b) A noninverting amplifier with a dc gain of K.

In each case find the 3-dB frequency and the gain–bandwidth product (GBP $\equiv$ |Gain| $\times f_{3dB}$). Comment on the results.

***2.120** Consider an inverting summer with two inputs V_1 and V_2 and with $V_o = -(V_1 + 3V_2)$. Find the 3-dB frequency of each of the gain functions V_o/V_1 and V_o/V_2 in terms of the op amp f_t. (*Hint:* In each case, the other input to the summer can be set to zero—an application of superposition.)

Section 2.8: Large-Signal Operation of Op Amps

2.121 A particular op amp using ±15-V supplies operates linearly for outputs in the range −14 V to +14 V. If used in an inverting amplifier configuration of gain −100, what is the rms value of the largest possible sine wave that can be applied at the input without output clipping?

2.122 Consider an op amp connected in the inverting configuration to realize a closed-loop gain of −100 V/V utilizing resistors of 1 kΩ and 100 kΩ. A load resistance R_L is connected from the output to ground, and a low-frequency sine-wave signal of peak amplitude V_p is applied to the input. Let the op amp be ideal except that its output voltage saturates at ±10 V and its output current is limited to the range ±20 mA.

(a) For $R_L = 1$ kΩ, what is the maximum possible value of V_p while an undistorted output sinusoid is obtained?
(b) Repeat (a) for $R_L = 200$ Ω.
(c) If it is desired to obtain an output sinusoid of 10-V peak amplitude, what minimum value of R_L is allowed?

2.123 An op amp having a slew rate of 10 V/μs is to be used in the unity-gain follower configuration, with input pulses that rise from 0 to 2 V. What is the shortest pulse that can be used while ensuring full-amplitude output? For such a pulse, describe the output resulting.

2.124 For operation with 10-V output pulses with the requirement that the sum of the rise and fall times represent only 20% of the pulse width (at half-amplitude), what is the slew-rate requirement for an op amp to handle pulses 2 μs wide? (*Note:* The rise and fall times of a pulse signal are usually measured between the 10%- and 90%-height points.)

2.125 What is the highest frequency of a triangle wave of 10-V peak-to-peak amplitude that can be reproduced by an op amp whose slew rate is 20 V/μs? For a sine wave of the same frequency, what is the maximum amplitude of output signal that remains undistorted?

2.126 For an amplifier having a slew rate of 40 V/μs, what is the highest frequency at which a 20-V peak-to-peak sine wave can be produced at the output?

D *2.127 In designing with op amps one has to check the limitations on the voltage and frequency ranges of operation of the closed-loop amplifier, imposed by the op-amp finite bandwidth (f_t), slew rate (SR), and output saturation (V_{omax}). This problem illustrates the point by considering the use of an op amp with $f_t = 20$ MHz, SR = 10 V/μs, and $V_{omax} = 10$ V in the design of a noninverting amplifier with a nominal gain of 10. Assume a sine-wave input with peak amplitude V_i.

(a) If $V_i = 0.5$ V, what is the maximum frequency before the output distorts?
(b) If $f = 200$ kHz, what is the maximum value of V_i before the output distorts?
(c) If $V_i = 50$ mV, what is the useful frequency range of operation?
(d) If $f = 50$ kHz, what is the useful input voltage range?