Some general suggestions: layout circuit before coming to Lab.
☆ use colored wire
use Radio Shack alligator clips

EEAP 243 — Lab Work:
Lab 6 — Questions Due:

INTRODUCTION TO REAL-OPERATIONAL AMPLIFIERS

READING: Horowitz, pgs. 92-98 (skip Section 3.08), 103-116, 127-130, 132, 136-143.

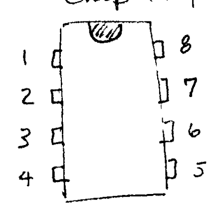
Abstract:
In this laboratory, you will investigate practical operational amplifiers. Your Circuits I course presented ideal operational amplifiers. In this lab, we will examine the limitations of real operational amplifiers such as slew rate and clipping and examine the basic inverting amplifier topology.

Part I: Basic Operational Amplifiers

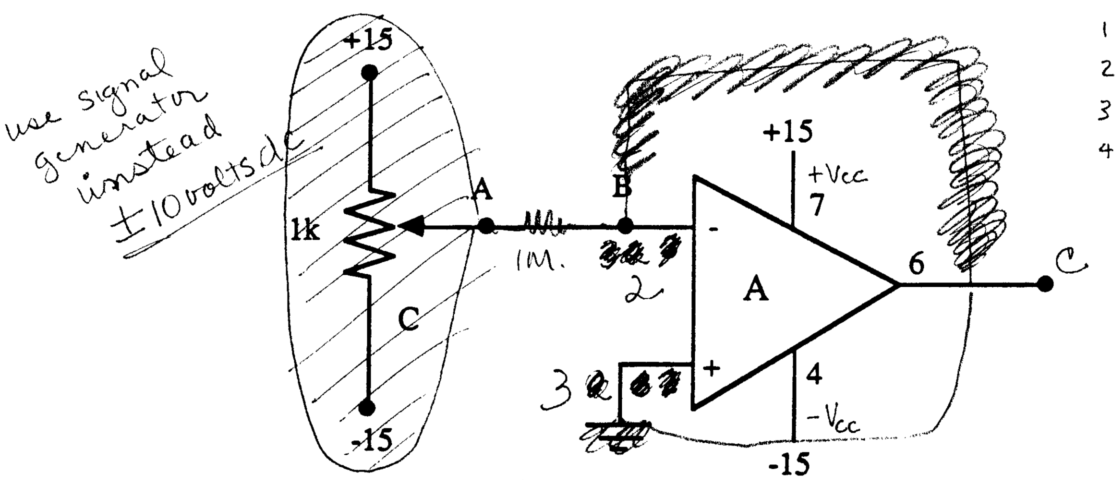
The operational amplifiers used in this experiment are integrated circuits (ICs) housed in 8-pin dual in-line packages (DIPs). Please be careful when inserting and removing your op-amps from your protoboard. You may need to straighten the two rows of pins before plugging the op-amp into your breadboard. To remove the op-amp from your breadboard, pry it out with your screwdriver. Please try not to bend the pins of your op-amps. Bent pins often break, leaving an otherwise good IC useless.

You will make five connections to the op-amp: the positive power supply ($+V_{CC}$), the negative power supply ($-V_{CC}$), the non-inverting input (+), the inverting input (-), and the output. Please refer to the data sheets for the IC's pin assignments. The power supply connections for your op-amps are $+V_{CC}$ = +15 V and $-V_{CC}$ = -15 V. Connections can be made using your breadboard, test leads, alligator clips, and short pieces of solid wire. Pin #1 of the integrated circuit is usually marked with a dot.

chip (top view)



Section 3.02



Remove pin 2 from ground or connect pin 2 to pin 6

Figure 1 - Basic open loop high-gain op amp

(1) Build the simple circuit shown in Figure 1 using an LM741. Attempt to measure the dc input voltage at point A and the dc output voltage at point C with your DMM. Record any results you get in Table 6.1.

(2) Replace the short between A and B with a 1M resistor. Measure the dc voltage drop across this resistor with your DMM. Record your results in Table 6.2.

Adjust your dc input to result in a dc output at C of 5 volts.

dependent upon voltage drop?

(3) Replace your 741 op-amp with a LF357. The pin outs are identical. Repeat step 2.

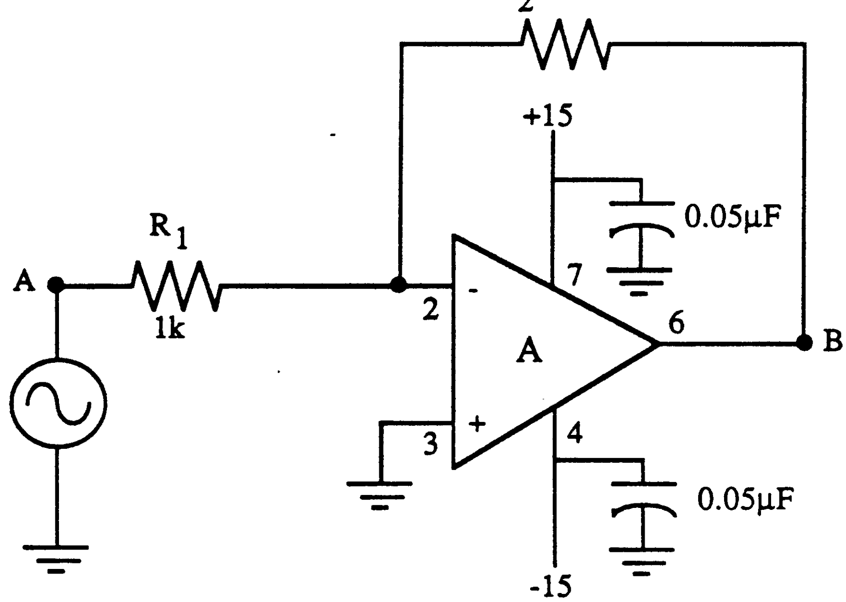


Figure 2 - Basic Inverting Amplifier Configuration

An inverting amplifier is probably the most common operational amplifier circuit and will be used to illustrate some basic concepts.

(1) Set the signal generator to deliver a 2 $V_{p\text{-}p}$ sine wave with zero DC offset at 1 KHz before connecting it to the circuit. (The displayed waveform will not jump when the coupling is switched from AC to DC if the DC offset is zero.)
(2) Build the circuit of Fig. 2 using an LM741. Do NOT put the 0.05 μF capacitors in your circuit yet.
(3) Display point A on channel 1 (CH1) with 1 V/cm, display point B on channel B (CH2) with 5 V/cm, and DC couple both channels.
(4) Record the waveforms at points A and B in Table 6.3. Make special note of the phase difference between the two signals.

Instability is often a problem when using high frequency op-amps. One common source of instability in op-amp circuits is coupling between the amplifier's output and its power supply connections. The inductance and capacitance of the power supply wires can provide a path for positive feedback to the op-amp input which can make it oscillate at a very high frequency. A "decoupling" capacitor is usually connected from each power supply connection to ground. These capacitors provide an effective short circuit for any high frequency signals which may appear at the power supply connections, thus eliminating the feedback and consequent oscillation.

(5) Replace the LM741 with an LF357 op-amp. The scope display should become unintelligible.
(6) NOW connect a 0.05 μF decoupling capacitor from $+V_{cc}$ to ground and from $-V_{cc}$ to ground as shown in Figure 2. The circuit should now operate as it did in step 4.

(7) Record the signal (peak-peak) amplitudes at points A and B in Table 6.4 and make special note of the phase difference between them.

"Clipping" occurs when an amplifier tries to amplify a signal to voltages beyond the range of its power supplies. For example, consider an amplifier with +15 V and -15 V power supplies, a gain of ⊕5, and an input signal of +10 V DC. The output voltage of the amplifier ought to be ⊕50 V but it will "saturate" somewhere around ⊕15 V since the amplifier cannot produce voltages beyond its power supply. When an AC input signal causes the output to lie partially inside and partially outside the range of voltages which the op amp can produce, the output will be faithfully reproduced for the in range portion and will remain fixed at the saturation voltage for the out of range portion. Thus the output, when viewed on an oscilloscope, will appear as though a portion has been clipped off.

really should be negative

(1) Put the LM741 back into the circuit and set ground at the center of the screen for both scope channels.
(2) Starting with the generator's DC offset knob fully counterclockwise, slowly turn it fully clockwise and make note of what happens.
(3) Record the highest positive and lowest negative voltages produced at the op-amp's output in Table 6.5.
(4) Set the generator's DC offset to zero and slowly increase the amplitude of the generator, making note of what happens at point B.
(5) Record the waveform at B in Table 6.6 for 5 V_{p-p} at point A, making special note of the DC voltages at which the signal flattens.
(6) Repeat steps 2 to 5 using the LF357 in the circuit.

Slew rate is one parameter which determines the quality of an amplifier. The slew rate of an op-amp is the maximum rate at which the output voltage can change and is usually expressed in volts per microsecond. A high quality op-amp usually has a very high slew rate.

(1) With the generator still on 5 V_{p-p}, change the signal to a square wave and put the LM741 back in the circuit.
(2) Increase the frequency until the waveform at point B looks like a slightly flattened triangle wave. Record this waveform in Table 6.7. Be sure to measure the time it takes for point B to ramp from the positive saturation voltage to the negative saturation voltage.
(3) Repeat steps 2 and 3 using the LF357 in the circuit.

PLEASE CALL A TEACHING ASSISTANT TO CHECK YOUR DATA BEFORE CONTINUING

Fig. 2 in the LM741 data sheet shows the open loop frequency response (gain versus frequency) of the device. An op-amp has its greatest gain when there is no feedback (open loop). However, this maximum possible gain decreases as the frequency to be amplified increases. As a matter of fact, the product of the frequency times the maximum gain at that frequency (the gain bandwidth product) is a constant from 100 Hz to 1 MHz.

It is a simple matter to predict the frequency response of an amplifier circuit with feedback. Simply draw a horizontal line across the open loop graph at the appropriate gain up to the point where it intersects the open loop line and follow the open loop line from that point on. For example, the frequency response for an amplifier with a gain of 1000 would be a horizontal line along the +60 db line up to 1 KHz, at which point it would start to decrease at a rate of 20 db per decade.

(1) Build the circuit shown in Fig.3, making R_3=10Ω.
(2) Set the signal generator to a 1 $V_{p\text{-}p}$ sine wave at 100 Hz.
(3) Measure the signal amplitudes (peak-peak) at points A and B.
(4) Increase the signal generator frequency and record in Table 6.8 the frequency for which the signal amplitude at B falls to 0.7 $V_{p\text{-}p}$. i.e −3db compared to the voltage at B at 1kHz.
(5) Repeat steps 2 to 4 for R_3 equal to 100Ω, 1K, and an open circuit.

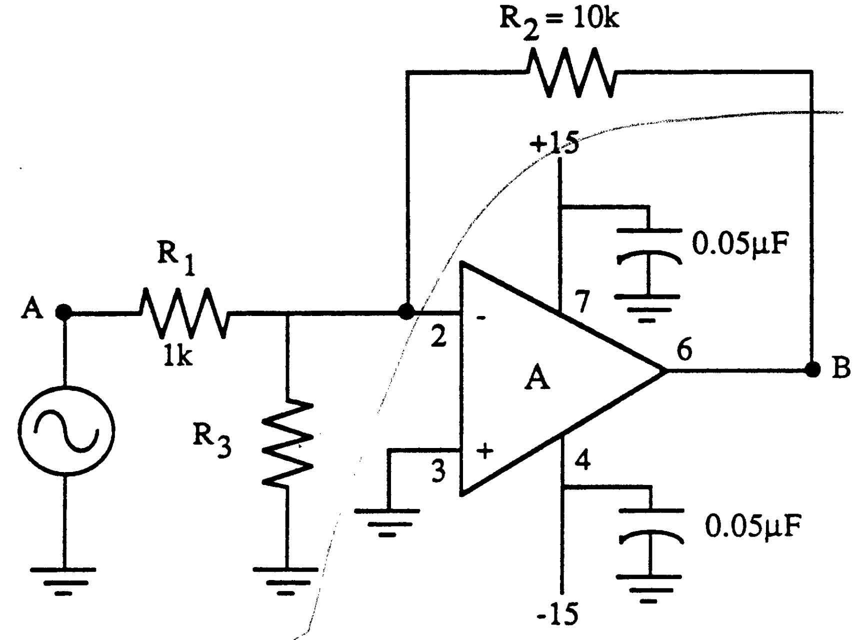


Figure 3 - Inverting Amplifier

The LF357 has a much higher bandwidth than the LM741 and can effectively amplify much higher frequencies.

(6) Repeat steps 2 to 4 above using the LF357 op-amp with R_3 resistances of 10Ω, 100Ω, and 1K. Record your results in Table 6.8.

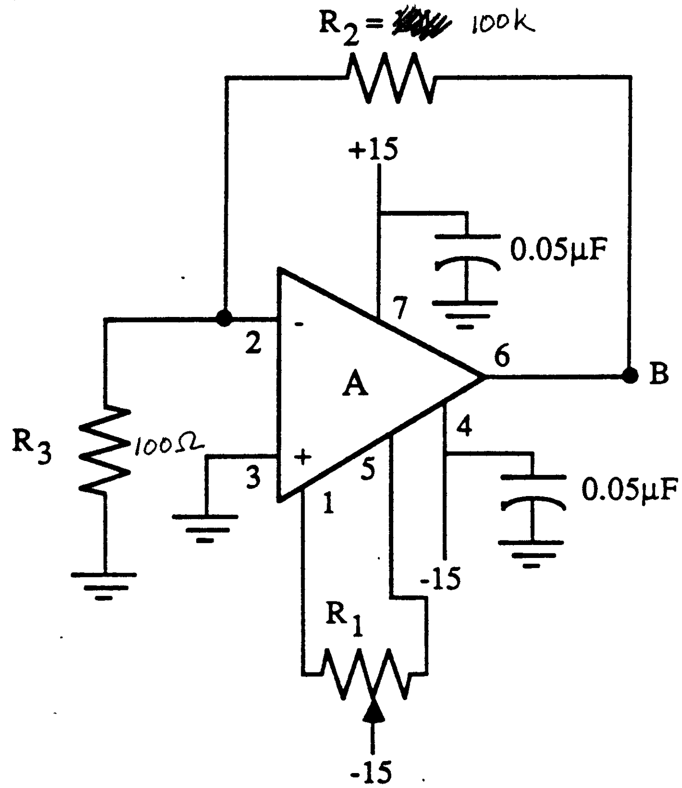
Real op-amps do not have a zero output voltage for zero input voltage. As you will learn later this is due to mismatches between transistors in the input stage of the op-amp. This non-zero output voltage is modeled as a dc voltage source called the input offset voltage connected between the op-amp inputs. This offset voltage is not a real problem in most applications but can be significant when you are attempting to amplify very weak signals or are using several dc coupled amplifiers.

(1) Replace the LM741 in your circuit of Figure 3. To measure the input offset voltage V_{OS} disconnect the signal generator from your previous circuit. You may also remove R1. Change R_2 to 100k and R_3 to 100Ω. This results in a very high gain (×1000) amplifier which will allow us to see the input offset voltage.
(2) Measure the dc output voltage (at point B) with your DMM and record your results in Table 6.9. Even though the input voltage to the op-amp is zero your

output is non-zero. The input offset voltage is simply the voltage you measured at B divided by the gain of the amplifier.

(3) Replace the LM741 with the LF357. Repeat step 2.

(4) Op-amps can be "trimmed" so that their output voltage IS zero for zero input signal and chip manufacturers provide special "trimming" circuits to adjust the amplifier output to zero by applying a variable potential between two pins of the chip. The 741 can be trimmed by connecting a 10k (R_1) potentiometer between pins 1 and 5. Build the circuit of Figure 4. Be sure that the wiper of your potentiometer is connected to the -15 volt power supply. While measuring the voltage at point B with the DMM, adjust the potentiometer to make the DC voltage at point B zero.



Stop here! too long!

Figure 4 - Input offset voltage trimming circuit

The penalty for using op-amps with high slew rate and bandwidth is instability. You already corrected one instability problem by using decoupling capacitors. However, certain configurations such as the unity gain configuration are particularly prone to instability.

(1) Set the generator to 1 KHz. Build the circuit of Figure 5 without R_3 and C_3. Connect point A to your generator output.

(2) Examine point B with the CH1 input of your scope. Your circuit should be oscillating at a very high frequency.

(3) Connect R_3 and C_3 as shown in Fig.5. Use values of C_3=100pF and R_3=1k. These components increase the effective gain at high frequencies and eliminate the oscillation you saw in step (2).

(4) Measure the amplitudes at point B for frequencies of 1 KHz, 10 KHz, 100 KHz, and 1 MHz. Record your results in Table 6.10

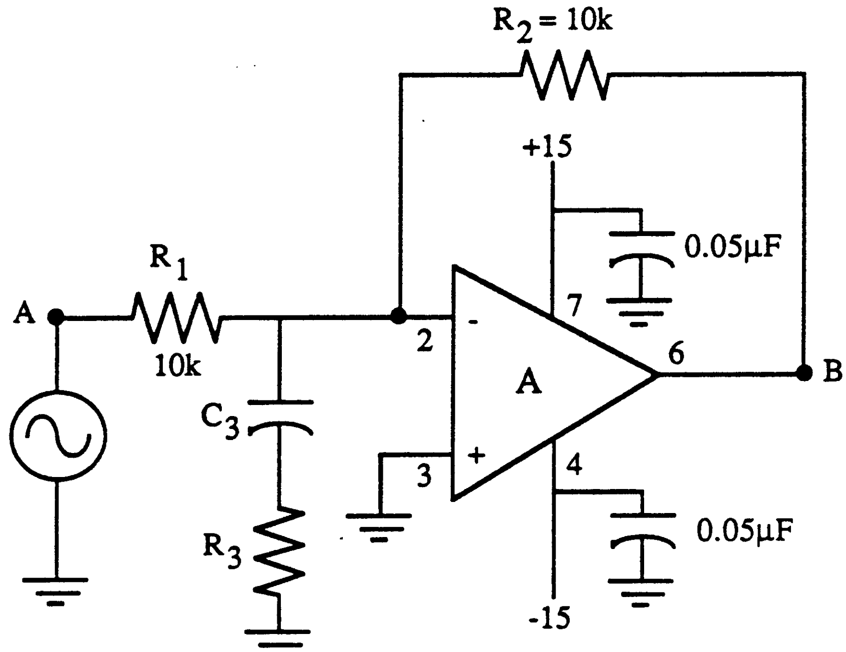


Figure 5 - Unity Gain Amplifier

Built with LF357
Try it with a 741 - no oscillations

Questions:

1. (a) Can you estimate the gain from your data of Table 6.1? If so, what was it?
   (b) The 741 is supposed to have a gain of approximately 200,000? Does this agree with your data?
   (c) What is the input resistance of the amplifier circuit (the resistance looking to the right of point A)?
2. (a) Using your data of Table 6.3 what is the input current of the LM741 and LF357?
   (b) This current is specified on the manufacturer's data sheet as I_{bias}. The manufacturer's values are 80 nA (typical) for the 741 and 0.03 nA (typical) for the 357. Is this data consistent with your results?
3. (a) What is the overall gain (B/A) of the circuit of Figure 2? Use your data of Table 6.3.
   (b) Did the signal generator output voltage (point A) change when you connected it to the circuit?
   (c) What is the input resistance of the amplifier circuit (the resistance looking to the right of point A)?
4. (a) At what voltages does the LM741 saturate?
   (b) At what voltages does the LF357 saturate?
   (c) What would you have expected from an ideal amplifier?
   (d) Which is the better op-amp when it comes to saturation voltage?
5. (a) Calculate the slew rate of the LM741 using your data of Table 6.7.
   (b) Calculate the slew rate of the LF357.
   (c) How do your measured values of slew rate compare with the data sheet values?
   (d) Which is the better op-amp when it comes to slew rate?
6. (a) Prove that for any value of R_3, the THEORETICAL overall gain (B/A) of the circuit shown in Figure 3 is [redacted] −10
   (b) For each value of R_3, transform the signal generator, R_1, and R_3 into a single Thevenin voltage source (V_{thev}) and resistance (R_{thev}).
   (c) Calculate the THEORETICAL Thevenized gain of the circuit (B/V_{thev}) for each value of R_3.
   (d) Reproduce Fig.2 from the LM741 data sheet on a sheet of graph paper, add lines for each of the gains calculated in part (c), and find the frequency at which each line intersects the open loop curve.
   (e) How do these frequencies compare with the 3-db frequencies recorded in Table 6.9?
7. (a) Reproduce the open loop frequency response curve from the LF357 data sheet on a sheet of graph paper, add lines for each of the theoretical thevenized gains, and find the frequency at which each line intersects the open loop curve.
   (b) How do these frequencies compare with the 3-db frequencies recorded in table 6.9?
   (c) Just how much better than the LM741 is the LF357.
8. Did the resistor and capacitor adversely affect the gain up to 1 MHz in your amplifier of Figure 4?
9. (a) What is the overall gain (B/A) of the circuit of Figure 5?
   (b) Did the signal generator output voltage (point A) change when you connected it to the circuit?
   (c) What is the input resistance of the amplifier circuit (the resistance looking to the right of point A)?
   (d) What is the purpose of the 47 μF capacitor?
   (e) Why is R_3 needed?

EEAP 243 LAB 6 EVALUATION

NAME (print)__________________________ CHECKPOINT #1 ___ DATE _____
GRADE _____/_____ CHECKPOINT #2 ___ DATE _____

With respect to the course material, this lab was: (pick one)
___ highly relevant ___ relevant ___ not relevant ___ completely irrelevant

This lab was: (pick one)
___ too long ___ long ___ just right ___ short ___ too short

This lab was: (pick one)
___ too hard ___ hard ___ just right ___ easy ___ too easy

The background material in the lab assignment was: (pick one)
___ too detailed ___ just right ___ sufficient ___ insufficient ___ totally inadequate

The step by step procedures in the lab assignment were: (pick one)
___ too detailed ___ just right ___ sufficient ___ insufficient ___ totally inadequate

Describe any mistakes made in the lab assignment.

Describe anything that just didn't work right.

Describe how this lab could be made better.

QUIZ

NOTE: THE TEACHING ASSISTANT IS TO SELECT BOTH QUESTIONS FROM THE UNDERLINED OPTIONS AT THE SECOND CHECKPOINT

Question #1

Assume that A is disconnected from B and that H is connected to I in Fig. 6.2. What will happen to the DC voltage at point D if we increase/decrease the resistance of the R_S/R_{B1}/R_{B2}/R_C/R_{E1}/R_{E2}/R_L ?

It will increase / decrease / stay the same.

Question #2

Assume that A is disconnected from B and that H is connected to I in Fig. 6.2. What will happen to the AC voltage at point H if we increase/decrease the resistance of the R_S/R_{B1}/R_{B2}/R_C/R_{E1}/R_{E2}/R_L ?

It will increase / decrease / stay the same.

EEAP 243

NAMES: ____

Lab 6 Data

input voltage (DC)	output voltage (DC)
________	________
________	________
________	________
________	________
________	________

Table 6.1

	LM741	LF357
voltage drop	________	________

Table 6.2

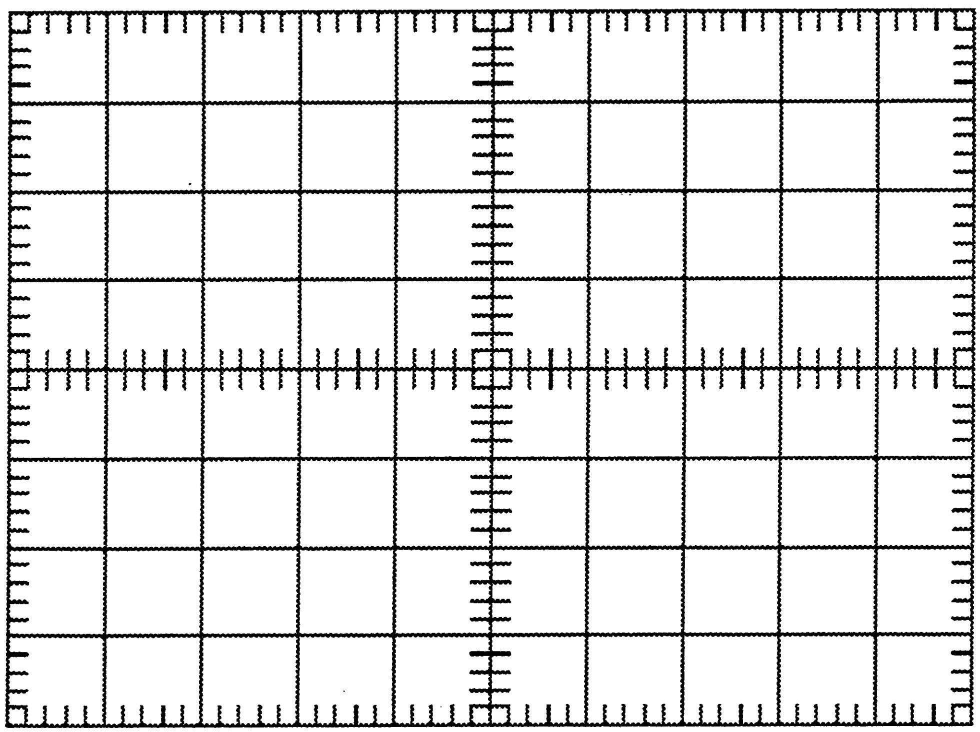


Table 6.3

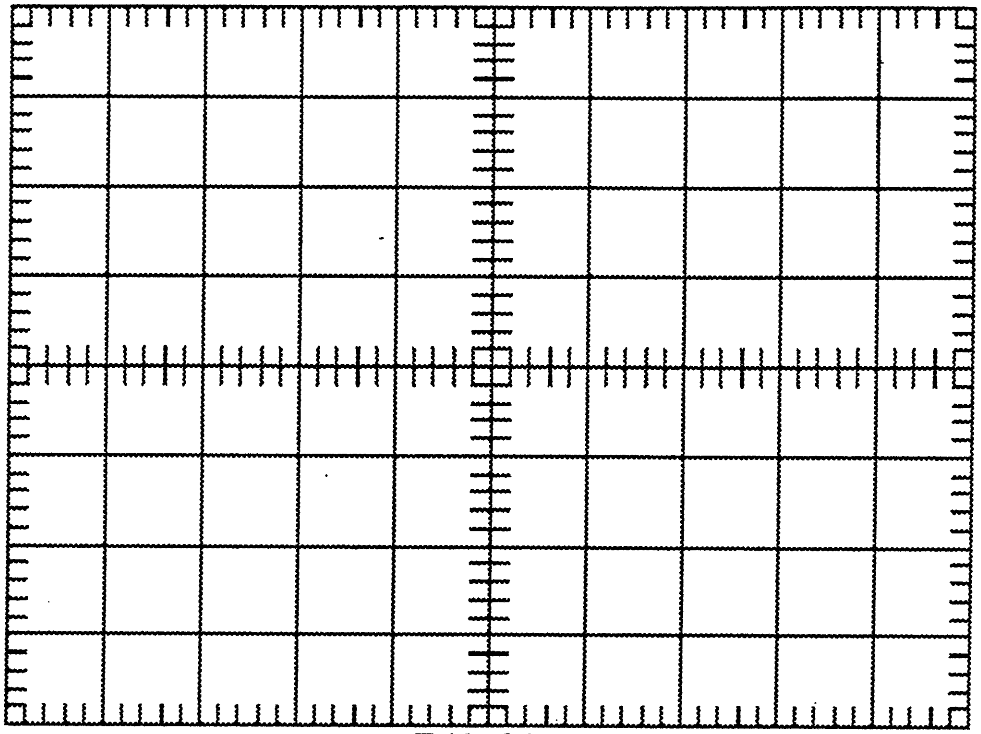


Table 6.4

	maximum + voltage	maximum - voltage
LM741	____________	____________
LF357	____________	____________

Table 6.5

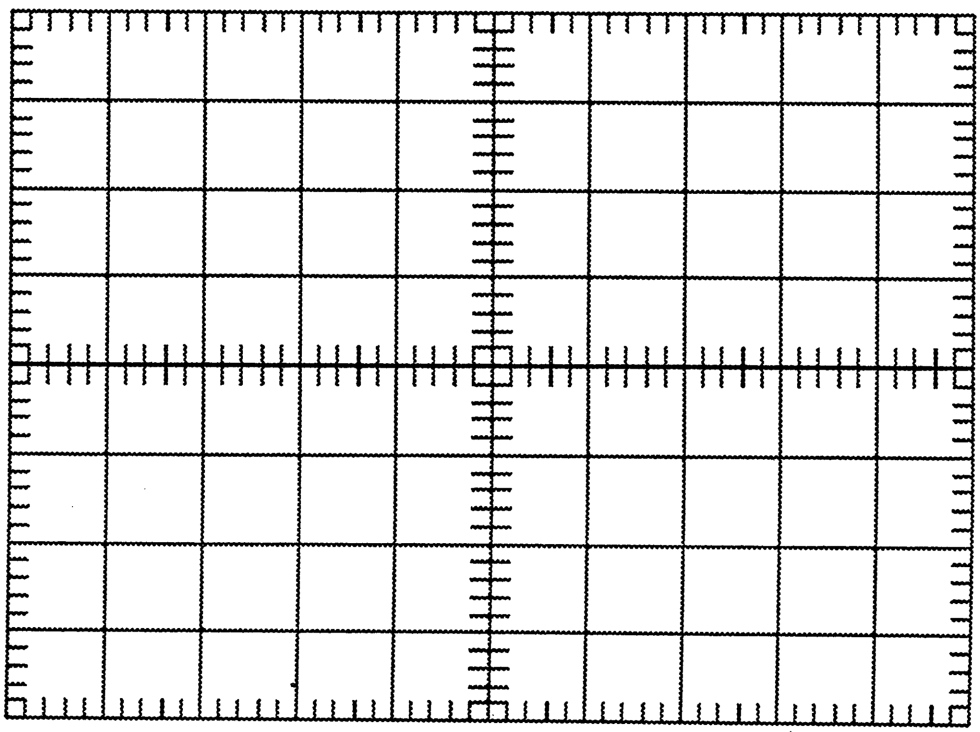


Table 6.6

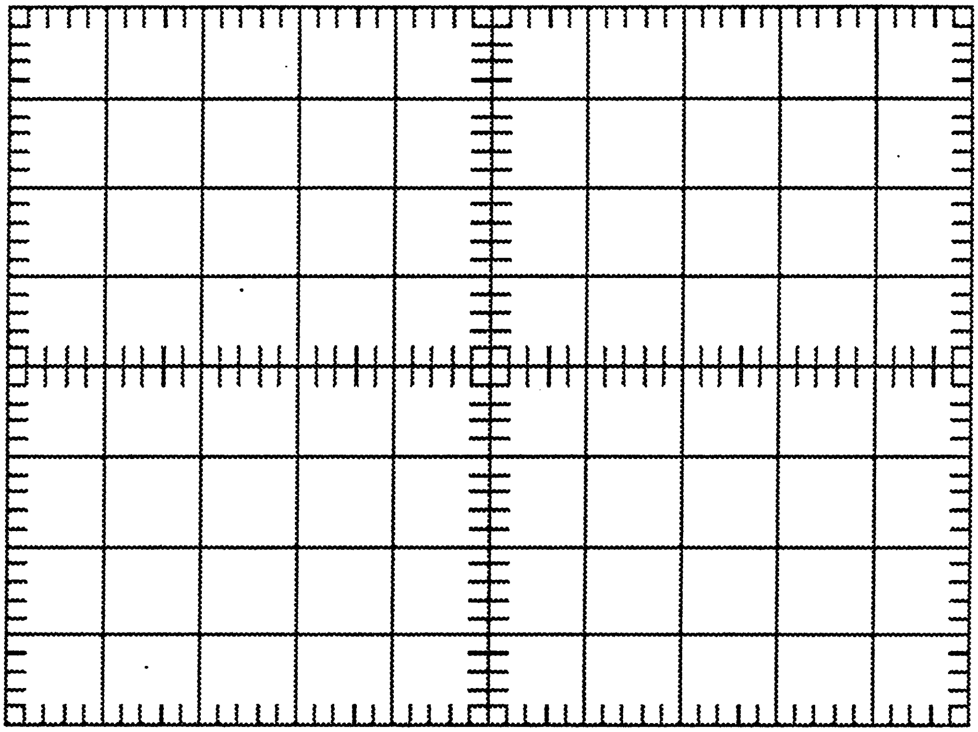


Table 6.7

	LM741	LF357
10	____________	____________
100	____________	____________
1000	____________	____________
open-circuit	____________	____________

Table 6.8 High frequency roll-off frequencies.

	LM741	LF357
V_{OS}	____________	____________

Table 6.9 Input Offset Voltage

frequency	$V_{p\text{-}p}$
1 kHz	____________
10 kHz	____________
100 kHz	____________
1 MHz	____________

Table 6.10 High frequency cutoff characteristics.