Infrared Communications Lab

This lab assignment assumes that the student knows about:
Ohm's Law
Voltage, Current and Resistance
Operational Amplifiers (See Appendix I)

The first part of the lab is to develop a model for electrical signals which pass through an optical communications channel. For the purposes of this lab we will use an extremely simple optical channel as shown in Figure 1.

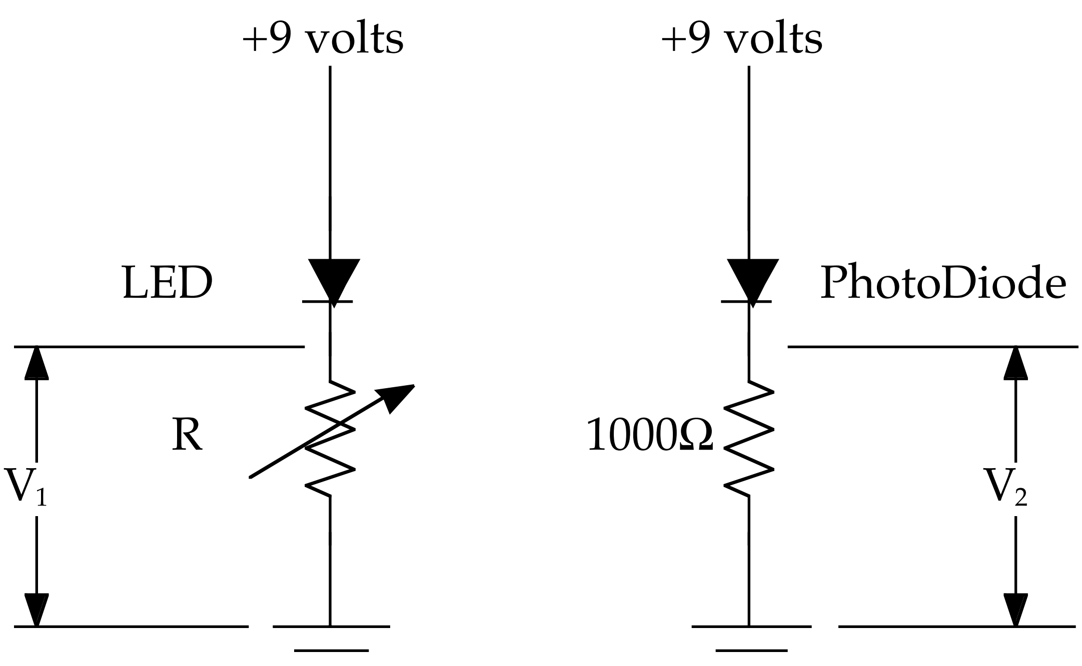


Figure 1. Experimental Setup for Optical Channel Characteristics

In Figure 1 we are using a light-emitting diode (LED) to produce visible or infrared radiation. The amount of output light is controlled by the current passing through the LED. In this experimental setup you can adjust the current by varying R (suggested values are 50Ω to 5000Ω) and measuring the voltage drop across this resistor. The LED diode current I_{LED} is then given by $I_{LED}=V_{MEAS}/R$. Note that the best way to do this experiment is to use several different FIXED values of R rather than using a mechanically variable resistor called a potentiometer. The LED converts current into light through a complicated mechanism and has a non-linear characteristic as a function of current. [References]

In an optical communications system you want to convert an electrical signal to light, transmit it, and then convert it back to an electrical signal. We have done only the first part of the conversion. Couple your LED to the photodiode. Short drinking straws are ideal for this purpose. This is your optical channel. The photodiode will convert the light striking it into variations in current I_{PD} through the diode. Since we are interested in current we can use a fixed resistance such as 1000Ω in series with the photodiode. Note that the precise value of this resistor is not critical to this experiment. You can measure the value of the photodiode current by measuring the voltage across the 1000Ω resistor.

Construct the circuit shown in Figure 1. Nine volts is a suggested value since 9 volt batteries are useful for our later experiments. Vary R and complete the following table. Note that several of the columns are measured values and others must be computed.

Your goal is to complete the following table

R	V_1	$I_{LED}=V_1/R$	V_2	$I_{PD}=V_2/1000$

Now plot IPD versus ILED. What you have is a special curve called a trasnfer function which describes the input/output characteristics of your optical source/channel/optical detector combination. As long as you don't change them this curve will remain an accurate model of your system. This curve will vary but will roughly look like that shown in Figure 2.

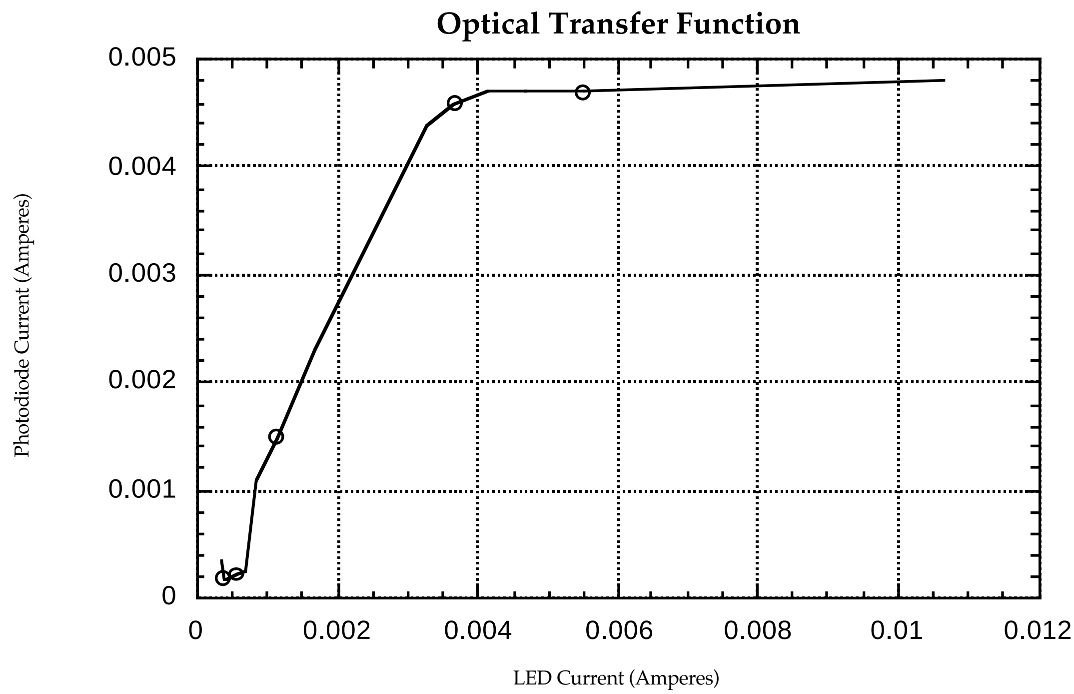


Figure 2. Optical Channel Transfer Function

Note this this curve has a region between 0.001 and 0.0035 amperes where the curve is linear. This is very important for an electronic system. In this region, the output is an exact multiple of the input and no distortion of the input signal takes place.

What we will do a apply a constant DC voltage which will "bias" us in the middle of the linear curve. This way, any small signals (which can go either positive or negative) will vary about this "bias" point. As long as the signals remain small they will see a linear curve and will be amplified without distortion (Figure 3).

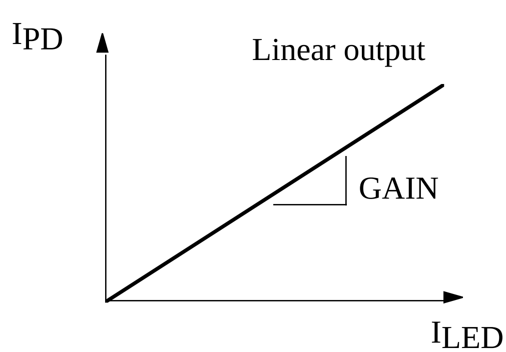


Figure 3. Signal being amplifier by linear transfer function.

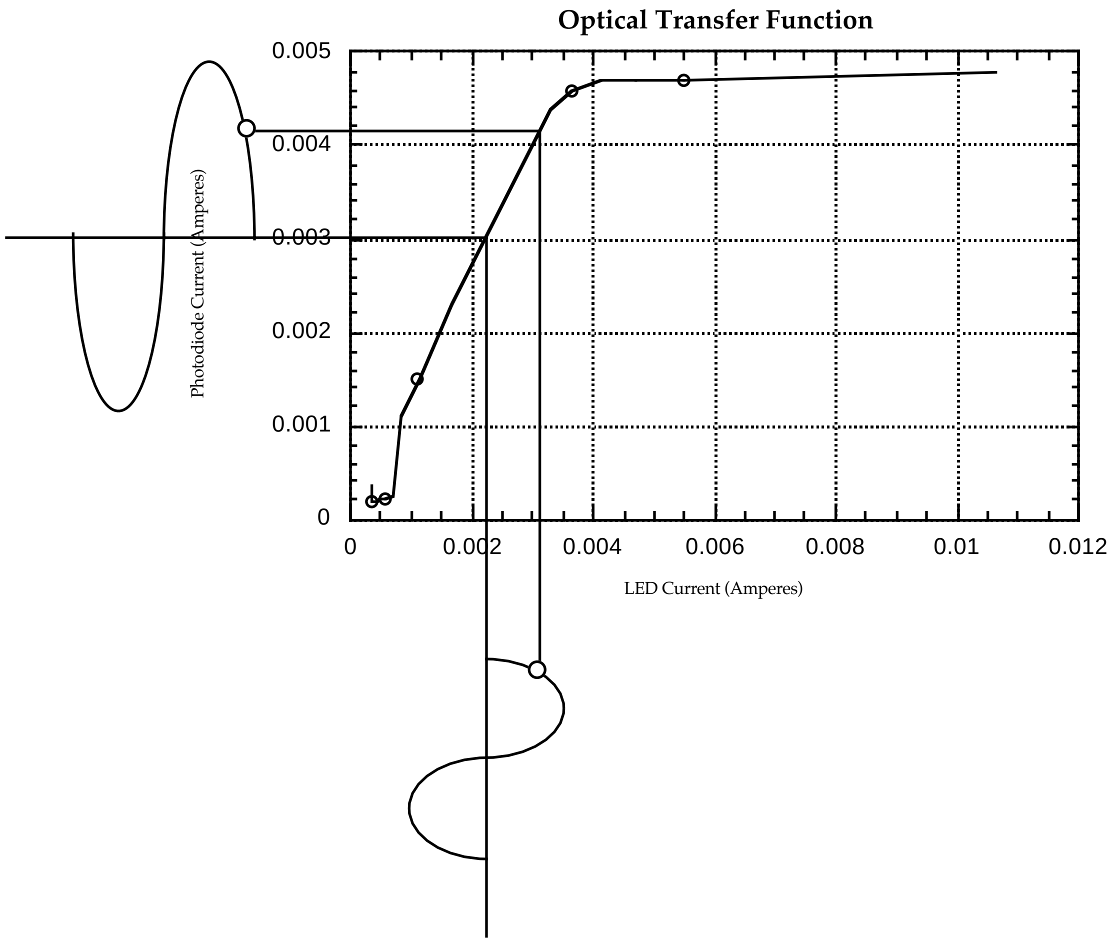


Figure 4. Electrical signal being transmitted through optical channel.

This is shown in detail in Figure 4. The input signal is a sinusoidal signal. Note that as this signal current increases the output signal current also increases linearly. This is because the bias current positions this signal in the linear region. If this bias were not present the signal would be distorted. Try positioning the input signal about zero current and predict the output current resulting from the input current.

The goal of this lab will be to develop the appropriate system which can convert an input voltage signal from a microphone or other source into a current to drive the LED. This LED current will be converted into a current at the photodiode according to your transfer function.   Appropriate circuits can be selected from those described in Appendix II. Specifically, we need a circuit to convert an electrical voltage signal into an electrical current signal to drive the LED. We also need an electrical circuit to convert the electrical output current from the photodiode into a voltage suitable for driving an amplifier. This is shown schematically in Figure 5.

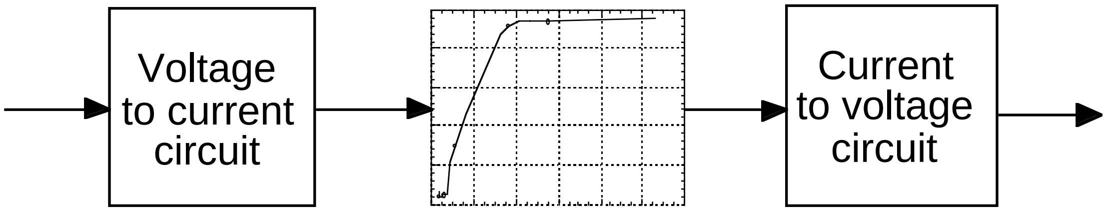


Figure 5. Optical Communications System (Block Diagram)

To build such a system we can use some common op-amp circuits given in Appendix II. Specifically, a circuit that converts an electrical voltage signal into a current signal is called a tranconductance amplifier. It gets this name because the units of ourput over input are amps/volts, which is the reciprocal of resistance, and is called conductance. Similarly, the current to voltage circuit is called a tranimpedance amplifier because its units of output over input are volts/amps which is resistance, or impedance. We can combine these circuits as shown in Figure 6 to get an optical communications system.

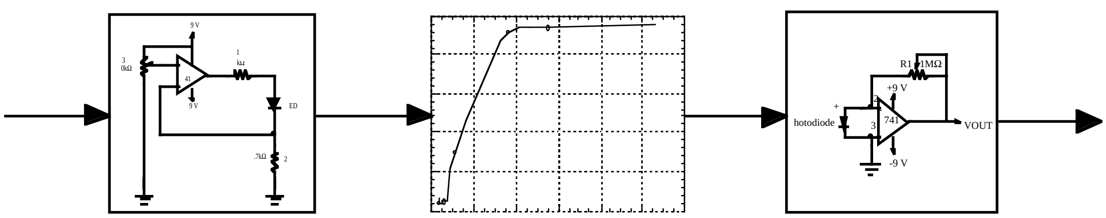


Figure 6. Optical Communications System (Circuit Diagram)

You goal is to design and develop this system. Don't forget that you need to bias the LED to get a linear transfer function. This can be done by adding a small DC voltage at the input of the transconductance amplifier. A complete system which may have some values different from yours is shown in Figure 7.

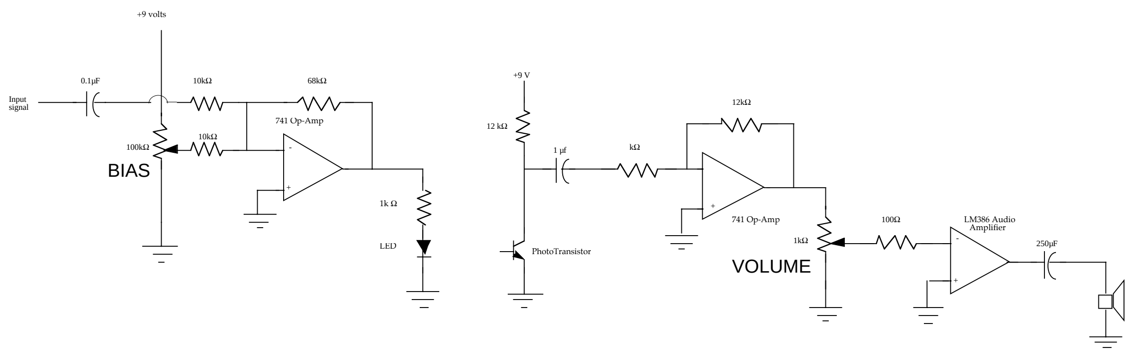


Figure 7. Complete optical communications system.

The volume control and LM386 are optional and simply provide a clearly audible output to adjust your system. An audio signal from a boom box or CD player is perfect for testing this system. Note that the adjustment of the BIAS control is very critical. Only in a very narrow range of settings will there be a clear output of the system. Measure the corresponding current through the LED for no signal at the input. This is your DC bias voltage and should be compared to your original transfer function that you measured.

Appendix I: Operational Amplifiers

An amplifier produces an output signal from the input signal. The input and output signals can be either voltage or current. The output can be either smaller or larger (usually larger) than the input in magnitude. In a linear amplifier, the input and output signals usually have the same waveform but may have a phase difference that could be as much as 180 degrees. For instance, an inverting amplifier is one for which $v_{out} = -A_v v_{in}$. For a sinusoidal input, this is equivalent to a phase shift of 180 degrees.

The ratio of the amplitude of the output signal to the amplitude of the input is known as the gain or amplification factor, A: A_V if the input and output are voltages, and A_I if they are currents.

An operational amplifier (op amp) is a high-gain DC amplifier that multiplies the difference in input voltages. The equivalent circuit of an op amp is shown in Fig. 1.

$$v_o = A_v\left(v_{in+} - v_{in-}\right) \qquad [1]$$

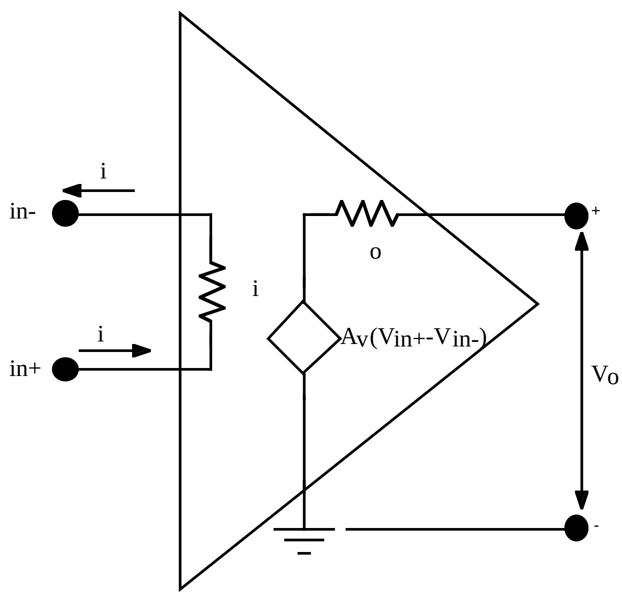


Figure 1. Equivalent Circuit for an Ideal Operational Amplifier

The characteristics of an ideal op amp are infinite positive gain, A_V, infinite input impedance, R_i, zero output impedance, R_o, and infinite bandwidth. (Infinite bandwidth means that the gain is constant for all frequencies down to 0 Hz.) Since the input impedance is infinite, ideal op amps draw no current. An op amp has two input terminals- an inverting terminal marked "-" and a non-inverting terminal marked "+". From Eq. [1],

$$\frac{v_o}{A_v} = \left(v_{in+} - v_{in-}\right) \qquad [2]$$

As the gain is considered infinite in an op amp,,

$$\frac{v_o}{A_v} = 0 \qquad [3]$$

Combining Eqs. [2] and [3],

$$v_{in+} - v_{in-} = 0 \qquad [4]$$

$$v_{in+} = v_{in-} \qquad [5]$$

This is called a virtual short circuit, which means that, in an ideal op amp, the inverting and non-inverting terminals are at the same voltage. The virtual short circuit, and the fact that with infinite input impedance the input current i_i is zero, simplify the analysis of op amp circuits.

With real op amps, the gain is not infinite but is nevertheless very large (i.e., $A_V = 10^5$ to 10^8). If V_{in+} and V_{in-} are forced to be different, then by Eq. [1] the output will tend to be very large, saturating the op amp at around ±10-15 V.

The input impedance of an op amp circuit is the ratio of the applied voltage to current drawn (v_{in}/i_{in}). In practical circuits, the input impedance is determined by assuming that the op amp itself draws no current; any current drawn is assumed to be drawn by the remainder of the biasing and feedback circuits. Kirchhoff's voltage law is written for the signal-to-ground circuit.

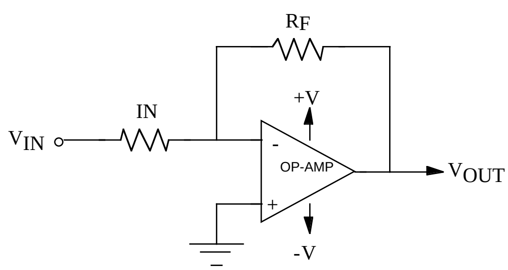
Depending on the method of feedback, the op amp can be made to perform a number of different operations, some of which are illustrated in Table 1. The gain of an op amp by itself is positive. An op amp with a negative gain is assumed to be connected in such a manner as to achieve negative feedback.

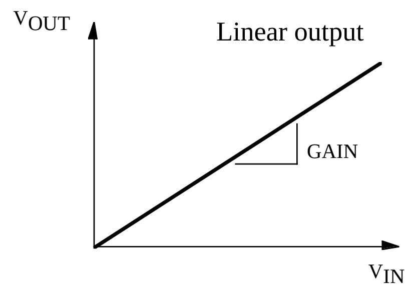
Appendix II Useful OpAmp Circuits

The operational amplifier or op-amp is a high-performance linear amplifier which has a huge variety of uses. The op-amp has two inputs, one inverting (-) and the other non-inverting (+), and one output. The polarity of a signal applied to the inverting input is reversed at the output; a signal applied to the non-inverting input retains its polarity at the output.

The gain (amplification) of an op-amp is determined by a feedback resistor that feeds some of the amplified signal from the output to the inverting input. This reduces the amplitude of the output signal and, hence, the gain. The smaller the feedback resistor, the lower the gain.

Here is a basic inverting amplifier made with an op-amp. Note that the op-amp can be used to linearly amplify an input signal. This linearity is critical for many analog op-amp amplifications such as audio amplifiers.





The basic equations for the op-amp amplifier are:

Gain = R_F/R_{IN}

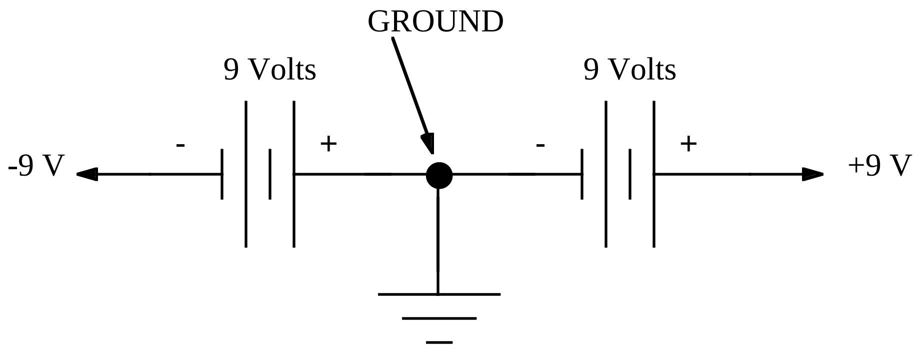
$V_{OUT} = -V_{IN}(R_F/R_{IN})$

The gain is independent of the supply voltage. Note that the unused input is grounded. Therefore the op-amp amplifies the difference between the input (Vin) and ground (0 volts). The op-amp is then a <u>differential</u> amplifier.

The feedback resistor (R_F) and an op-amp form a closed feedback loop. When R_F is omitted, the op-amp is said to be in its open loop mode. The op-amp then exhibits maximum gain, but its output then swings from full on to full off or vice versa for very small changes in input voltage. Therefore the open loop mode is not practical for linear amplification. Instead this mode is used to indicate when the voltage at one input differs from that at the other. In this mode the op-amp is called a comparator since it compares one input voltage with the other.

POWERING OP-AMPS

Most op-amps and op-amp circuits require a dual polarity power supply. Here is a simple dual polarity supply made from two 9-volt batteries:



IMPORTANT: The leads from the supply to the op-amp should be short and direct. If they exceed about 6 inches, the op-amp's supply pins must be bypassed by connecting a 0.1µf capacitor between each power supply pin and ground. Otherwise the op-amp may oscillate or fail to operate properly. Always use fresh batteries. Both must supply the same voltage. Be sure the battery clips are clean and tight. Don't apply an input signal when the power supply is switched off or disconnected.

OP-AMP SPECIFICATIONS

Op-amps are characterized by dozens of specifications, some of which are given on the following pages. Those whose meaning is not obvious are:

input offset voltage - Even with no input voltage an op-amp gives a very small output voltage. The offset voltage is that which, when applied to one input, causes the output to be at 0 volts.

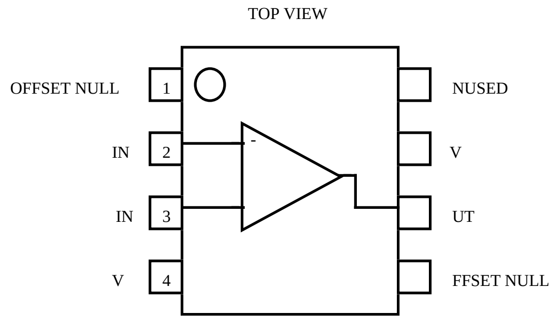
common mode rejection ratio - This is a measure of the ability of an op-amp to reject a signal simultaneously applied to both inputs.

bandwidth - The frequency range over which an op-amp will function. The frequency at which the gain falls to 1 is the unity gain frequency.

slew rate - The rate of change in the output of an op-amp in volts per microsecond when the gain is 1.

741 OP-AMP

The 741 is a very popular general purpose op-amp. It is simple to use, reliable, and inexpensive. It will be used in most of the circuits you will encounter in your undergraduate classes.



MAXIMUM RATINGS

Supply voltage	±18 volts
Power dissipation	500 milliwatts
Differential input voltage	±30 volts
Input voltage (Note 1)	±15 volts
Output short circuit time	indefinite
Operating temperature	0°C to 70°C

Note 1: input voltage should not exceed the supply voltage when supply voltage is less than ±15 volts.

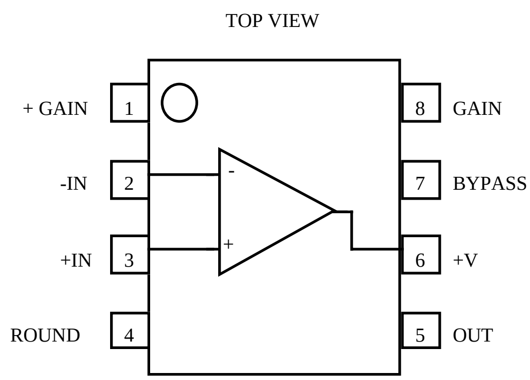
CHARACTERISTICS (Note 2)

Input offset voltage	2 to 6 millivolts
Input resistance	0.3 to 2 Megohms
Voltage gain	20,000 to 200,000
Common-mode rejection ratio	70 to 90 decibels
Bandwidth	0.5 Hz to 1.5 MHz
Slew rate	0.5 volts/microsecond
Supply current	1.7 to 2.8 milliamperes
Power consumption	50 to 85 milliwatts

Note 2: Values shown are typical or minimum to typical.

386 AUDIO AMPLIFIER

Simple to use audio amplifier with gain of 20. Operates from single polarity supply. Connect 10 µf capacitor between pins 1 and 8 for gain of 200.



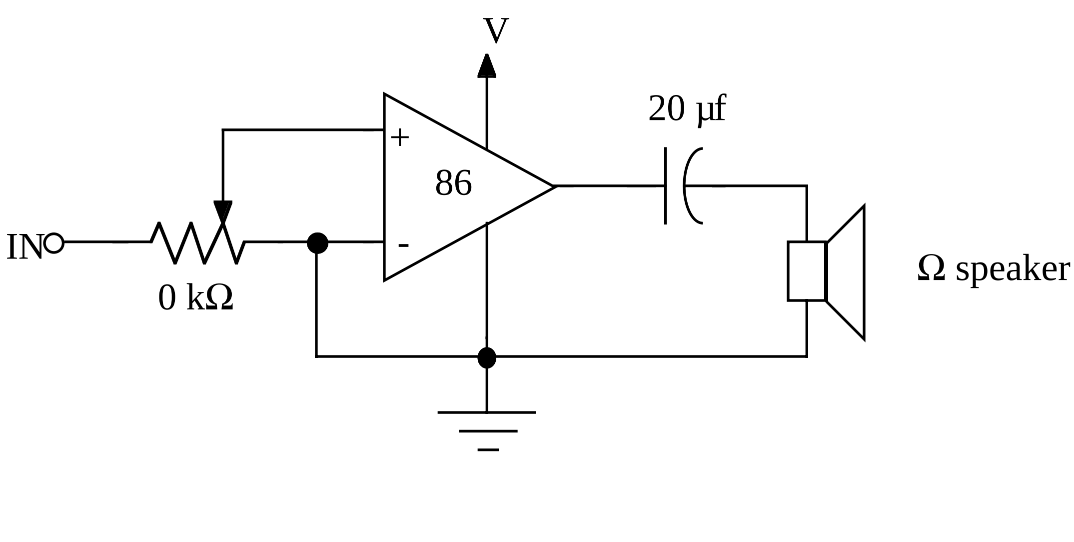
MAXIMUM RATINGS

Supply voltage	±15 volts
Power dissipation	660 milliwatts
Input voltage	±0.4 volts
Operating temperature	0°C to 70°C

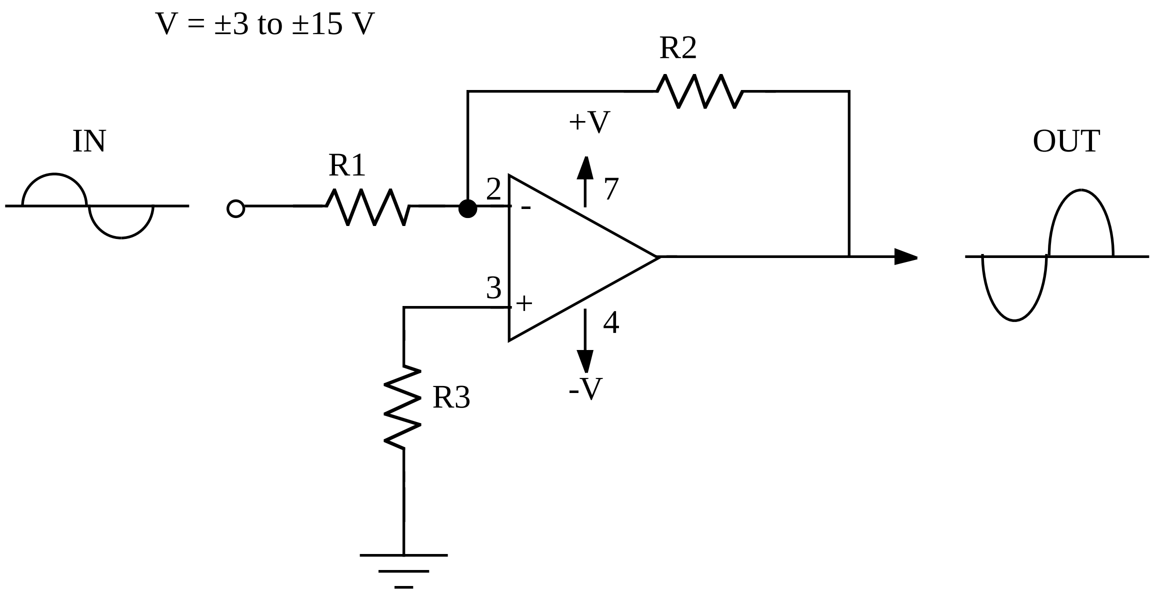
CHARACTERISTICS

Supply voltage range	+4 to +12 volts
Standby current	4 to 8 mA
Output power	250 to 325 milliwatts
Voltage gain	20 to 200
Bandwidth	300 kHz
Total harmonic distortion	0.2%
Input resistance	50 kΩ

TYPICAL APPLICATION



BASIC INVERTING AMPLIFIER

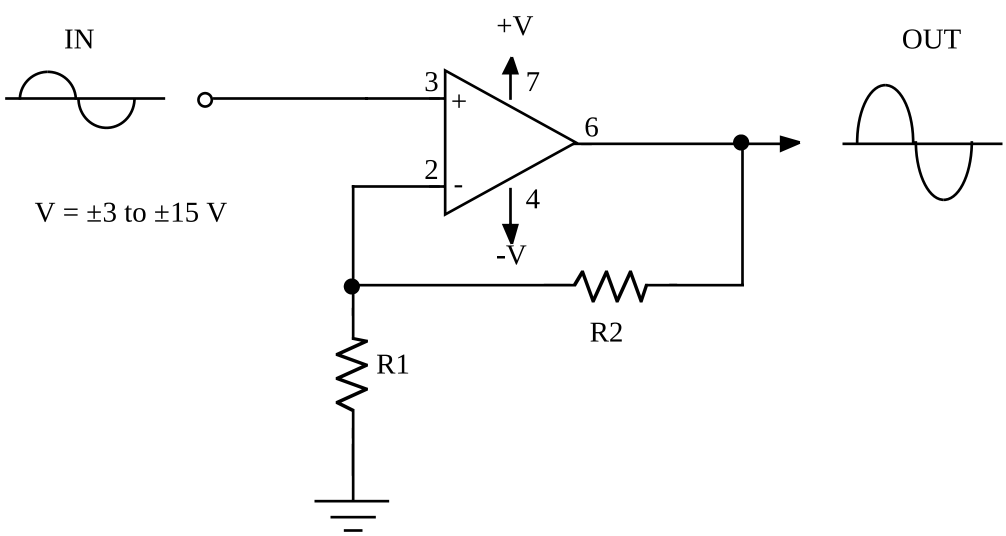


GAIN = - (R2/R1)

Typically R3=0.

Example: If R_1 = 1000Ω and R_2=10,000Ω, then gain = $-R_2/R_1$ = -(10,000)/(1,000) = -10.

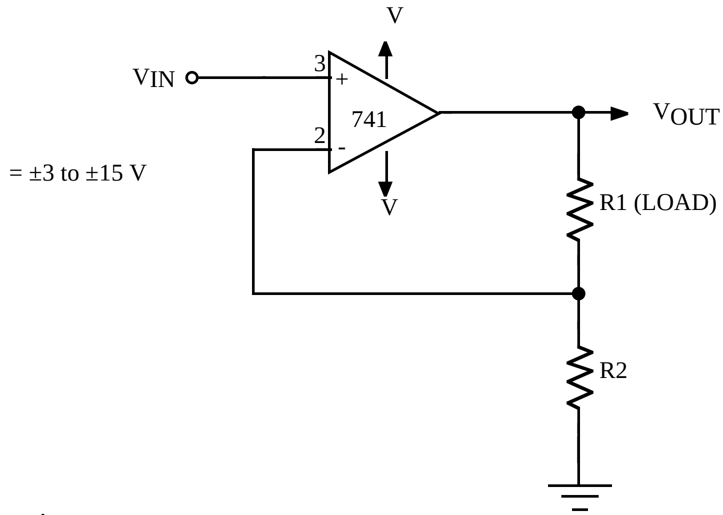
NON-INVERTING AMPLIFIER



Example: If R_1 = 1000Ω and R_2=10,000Ω, then gain = 1 + R_2/R_1 = 1 + (10,000)/(1,000) = 1 + 10.

Note that V_{OUT} is an amplified, but non-inverted version of V_{in}.

TRANSCONDUCTANCE AMPLIFIER



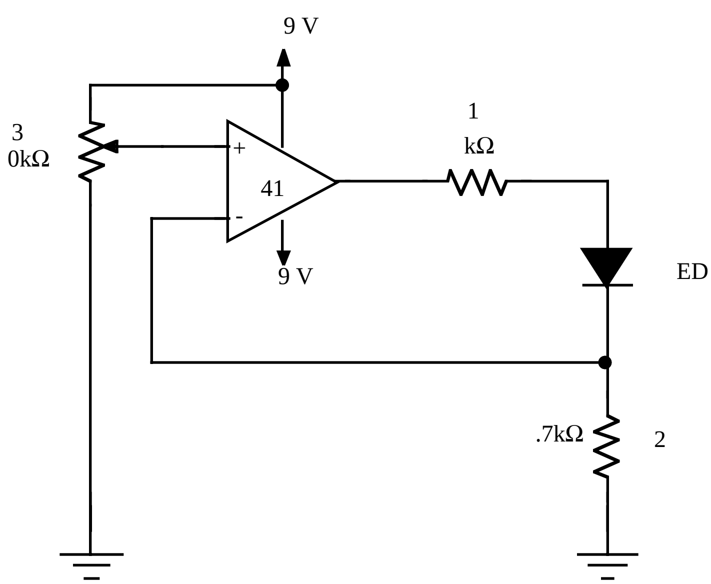
The governing equations are:

$V_{OUT}=[V_{IN}(R_1+R_2)]R_2$

$I_{OUT}=V_{OUT}/(R_1+R_2)$

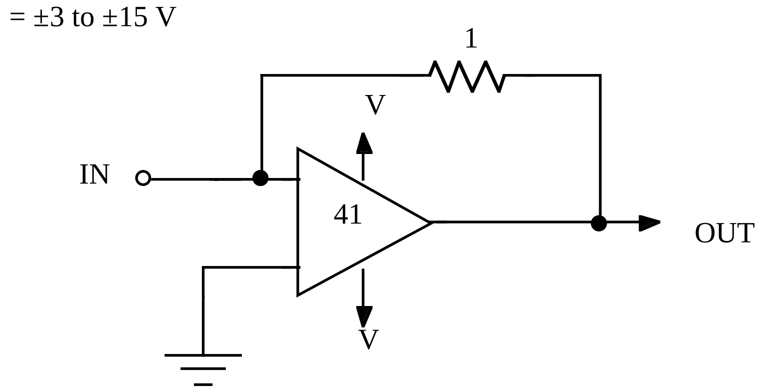
$I_{OUT}=V_{IN}/R_2$

This circuit is a voltage-to-current converter. The circuit shown below permits an input voltage to control the brightness of a current controlled device such as an LED in the circuit shown below.



R_3 controls V_{in}. Vary R_3 to alter I_{OUT}, hence the brightness of the LED.

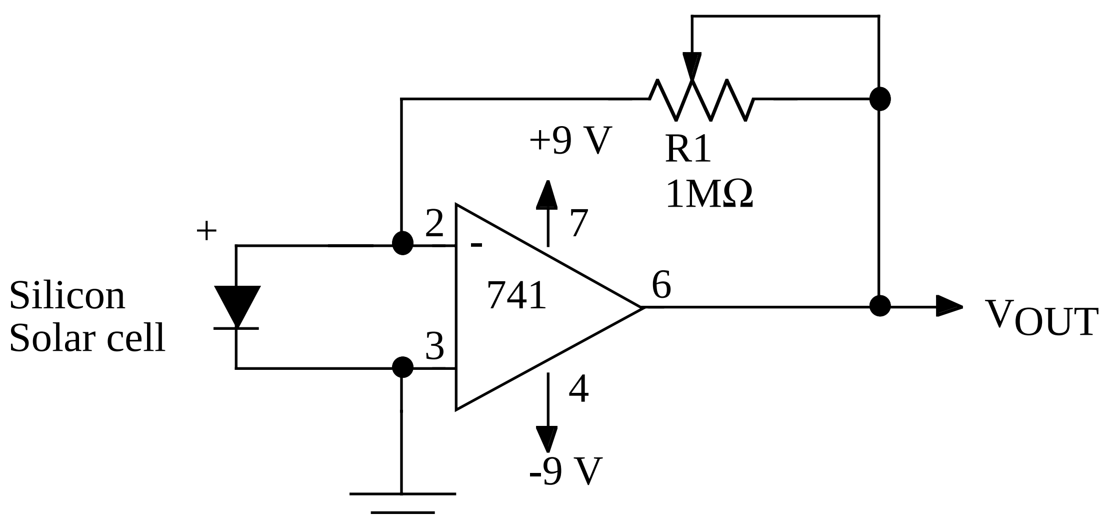
TRANSIMPEDANCE AMPLIFIER



In this amplifier the gain is specified by:
Gain = V_{OUT}/I_{IN} = -R1.

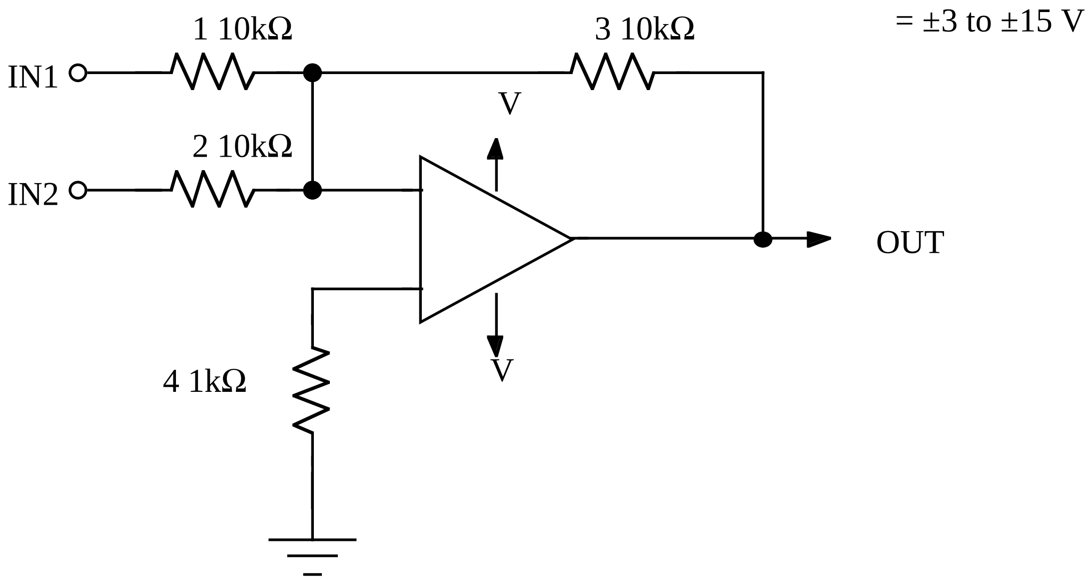
In the above example: If R_1 = 1000Ω, then gain = -1,000.

The circuit shown below is a current-to-voltage converter. It transforms an input current from a solar cell or other sensor into an output voltage. Resistor R1 adjusts the gain of the circuit.



This circuit can amplify the signal from non-current sensors such as thermistors and photoresistors. Simply remove the solar cell and connect one side of the sensor to +9 volts and the other to pin 2 in the above circuit.

SUMMING AMPLIFIER



This amplifier's output is given by:
$V_{OUT} = -(V_{IN1} + V_{IN2})$

The output of the summing amplifier is the sum of the input voltages. The sum of the inputs should not exceed ±V less a volt or two. You can add more inputs by connecting a 10kΩ resistor between each input and pin 2 of the op-amp.