Breadboarding guide

The Board:

This guide is intended to provide some general guidance in the use of a solderless breadboard to develop circuits. For this document we will be using the 3M Solderless breadboard Model 309. A diagram can be seen below in figure 1.

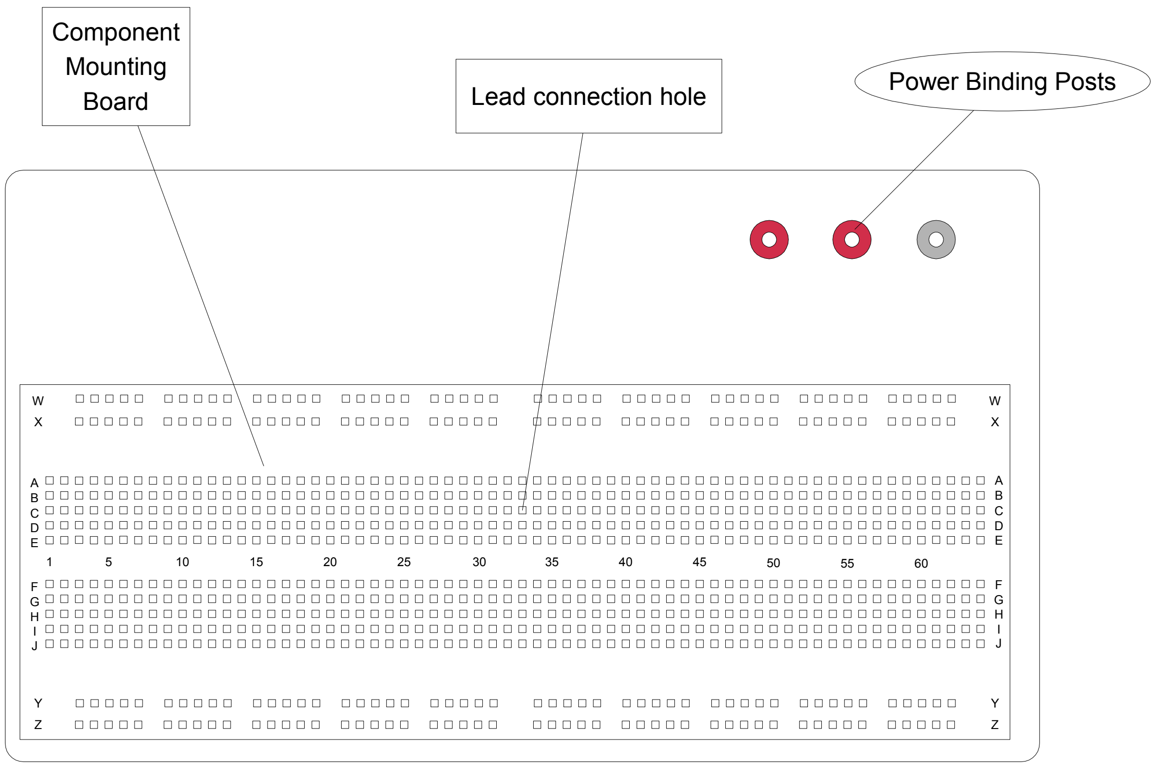


Figure 1 - Solderless Breadboard

This type of board consistes of several parts.

- The first of these parts is a metal baseplate. This plate is connected to the black (ground) binding post. This allows for some noise dampening if the circuit is built fairly close to the board.
- The second portion of the board is the binding pose area. This part of the board is typically used to bring power supply leads onto the board. The black is typically ground and the two red posts can be used for other power (i.e. +/- 15VDC). Unscrewing the top of the post reveals a hole used for connecting a discrete wire. Pushing the stripped end of the wire in this hole and tightening down the cap will make a good electrical connection. The top of the post is hollow to accept a banana connector from a power supply.
- The third and most important part is the breadboard itself. This white plastic board contains a series of holes with metal connector strips underneath. This

allows component leads to be pushed into the holes to make contact with other leads and wires. This breadboard area is broken up into two areas

- Power buss strips: rows W,X,Y and X. These are used to supply power to circuit at various points. These strips are usually jumpered to the binding posts by the user. These are joined together internally to form busses. For example Row W columns 3 thru 31 are joined together and Row W column 34 thru 62 are joined to form another buss.
- Component area: rows A-J. These holes are grouped in sets of 5 (column 1 rows A-E, column 1 rows F-J, etc) for placing components and making connections. The layout of the connections can be seen in figure 2. The lines connecting the holes represent the connections made by the metal strips under the plastic.

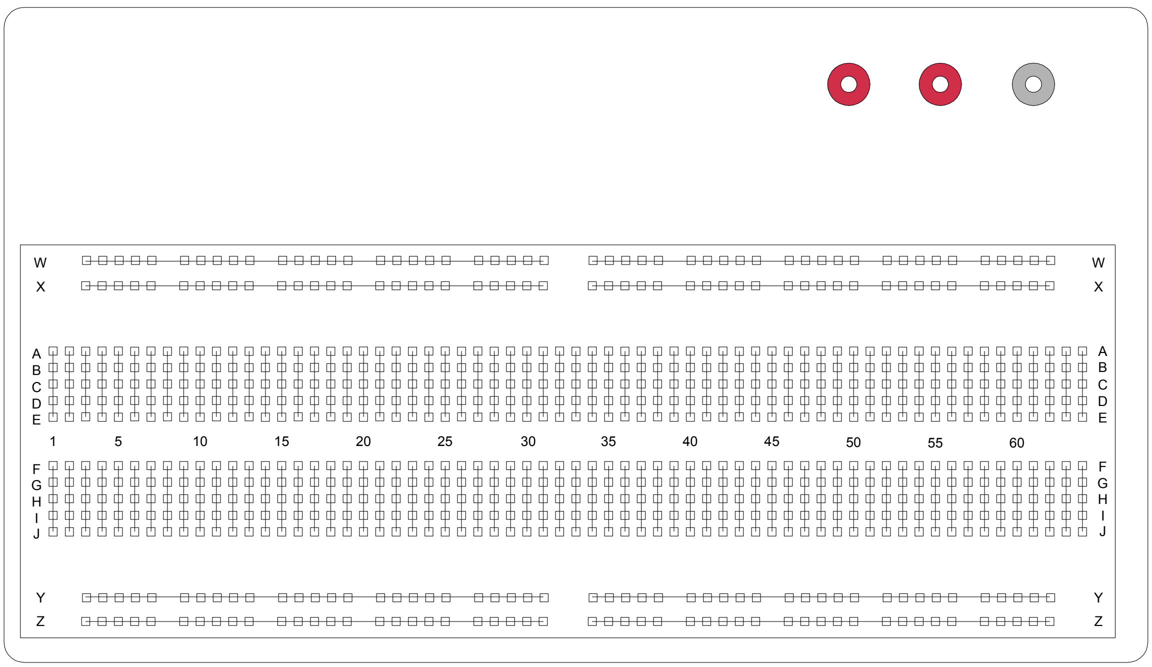


Figure 2 - Interconnections inside board

Planning a Circuit:

The breadboard can be used to develop and test a circuit with a minimum amount of time and effort. There are several basic steps involved in the process successfully building a circuit. These are:

1. Draw a complete schematic before starting, including pin numbers of all devices being used and pin outs of devices such as transistors.
2. Lay out the devices that will be on the board. Be sure to leave plenty of room around the devices for connections and other components, such as capacitors and resistors
3. Connect the needed power busses to the binding posts. Remember to jumper column 31 to 34 if you want the whole buss length available.

4. Keep all components and lead wires as close to the board as possible.
5. Only put one lead in each hole. Multiple wires in a hole will ruin the spring connection inside and give you an intermittent connection. This will be very hard to find when your circuit doesn't work.

The circuit for a simple non-inverting operational amplifier (op-amp) circuit can be seen in figure 3. The amplifier selected for this circuit is the National Semiconductor LM741CN plastic dip op-amp. A complete specification sheet can be found in the appendix. This amplifier has the normal inverting (-) input, non-inverting (+) input, output, +V and –V supply lines and also two offset null lines. For this first circuit we will build just a simple un-compensated non-inverting amplifier circuit.

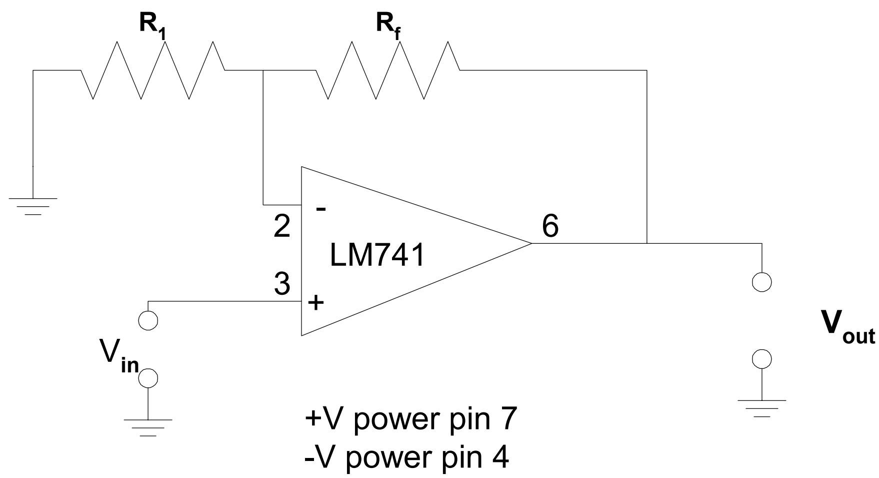


Figure 3 non-inverting amplifier

The LM741 amplifier shown here resides in a plastic dual inline plastic package as seen in figure 4. Note how the pins on the physical package relate to the functional connections in the schematic. In particular note that the power supply pins do not actually appear in the schematic, but are just a note. If you look in a typical textbook or application note, these pins are assumed and not included in the schematic. Don't forget to account for them in your design, or your circuit wont work at all. Also note that the plastic dip package will have a notch on one end or a small dimple on the upper left hand corner of the package. This is there to denote the location of pin 1.

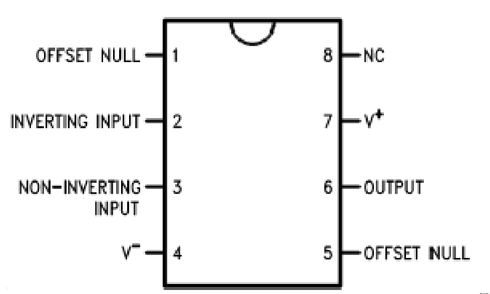


Figure 4 Pin layout for LM741CN

The circuit in figure 3 describes a standard non-inverting amplifier circuit. The gain of this amplifier is set by the two resistor values based on the equation

$$\frac{V_{out}}{V_{in}} = \frac{A_{ol}}{1 + \frac{A_{ol} R_1}{R_1 + R_f}}$$

where A_{ol} is the open loop gain of the amplifier. For the LM741C the data sheet shows this value to be typically 200. Working this equation out for a nominal value of 10K for R_1 and a voltage gain of 20 results in a value of 190K for R_f.

Building the Circuit:

The first step in building the circuit is to prepare the power supply busses and position the main components. In this case it we will be placing the op-amp in the board and setting up power supplys for +15V, -15V and ground (GND). In this case we will set up row W as +15 volts, Row Y as –15 volts and Rows X and Z as ground. Don't forget to place the jumpers in at row 30. We have also placed the op-amp in its location at column 40.

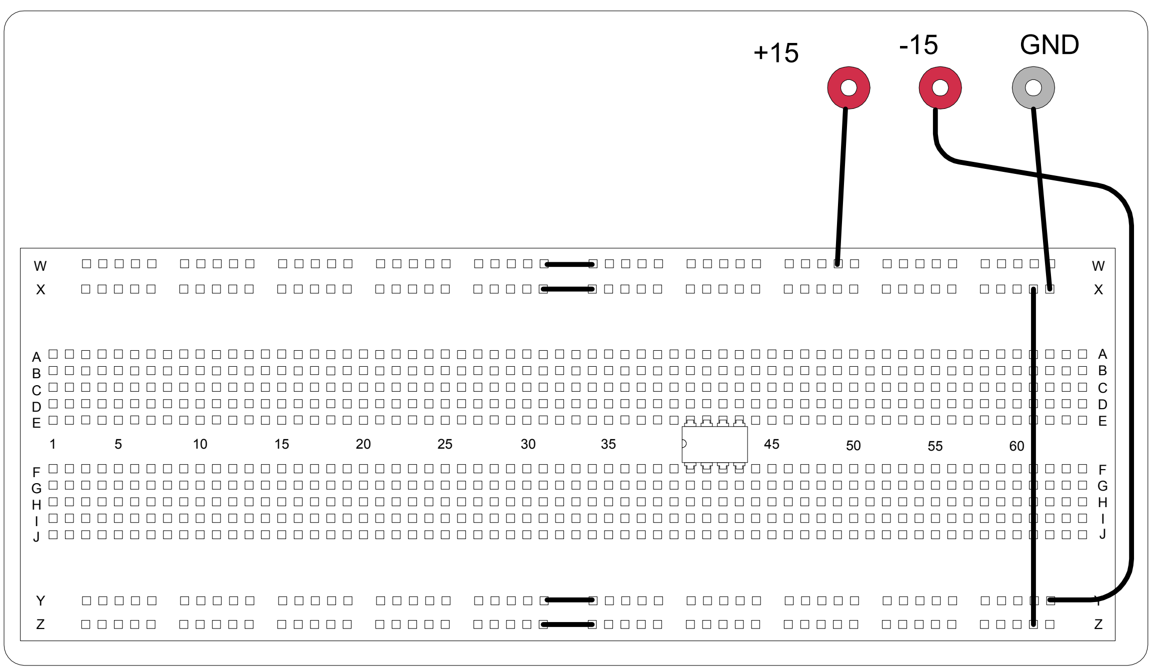
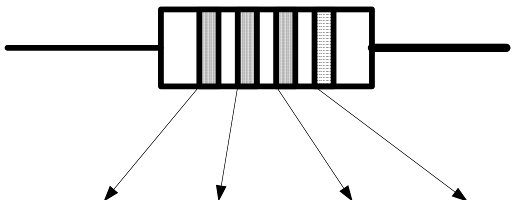


Figure 5 Power supply busses and op amp placed on board

Once the main components are in place you can start setting up the connections to the power buss and putting down the smaller components. In this case we need to connect pin 7 to the +15 volt buss and pin 4 to the –15 volt buss. We can also place the resistors R_1 (10K ohm) and R_f (190K) in place on the board. Once these two are done then the only remaining step is to bring the input and output points to an easy place to connect to.

You will need to select the resistors from the component drawers with the values as close as you can get to your selected theoretical values. You may decide to set them down on the table and loose track of which resistor is which. If you do you can determine the value by either measuring it with a meter, or looking at the color coded stripes on the package. The following table shows how to read this color code.



Color	1st dig(X)	2nd dig(Y)	Mult	Tolerance
Black	0	0	XY.0 ohm	
Brown	1	1	XY0 ohm	
Red	2	2	X.Y K ohm	
Orange	3	3	XY K ohm	
Yellow	4	4	XY0 Kohm	
Green	5	5	X.Y M ohm	
Blue	6	6	XY M ohm	
Violet	7	7	XY0 M ohm	
Gray	8	8	X.Y G ohm	
White	9	9	XY G ohm	
Gold			X.Y ohm	5%
Silver			0.XY ohm	10%
None				20%

Given a resistor with red, orange, red and silver stripes you can see that the nominal resistance value should be 2.3K (2300) ohms. However the silver stripe indicates that it is a 10% tolerance resistor and can have an actual value of 2070 to 2530 ohms.

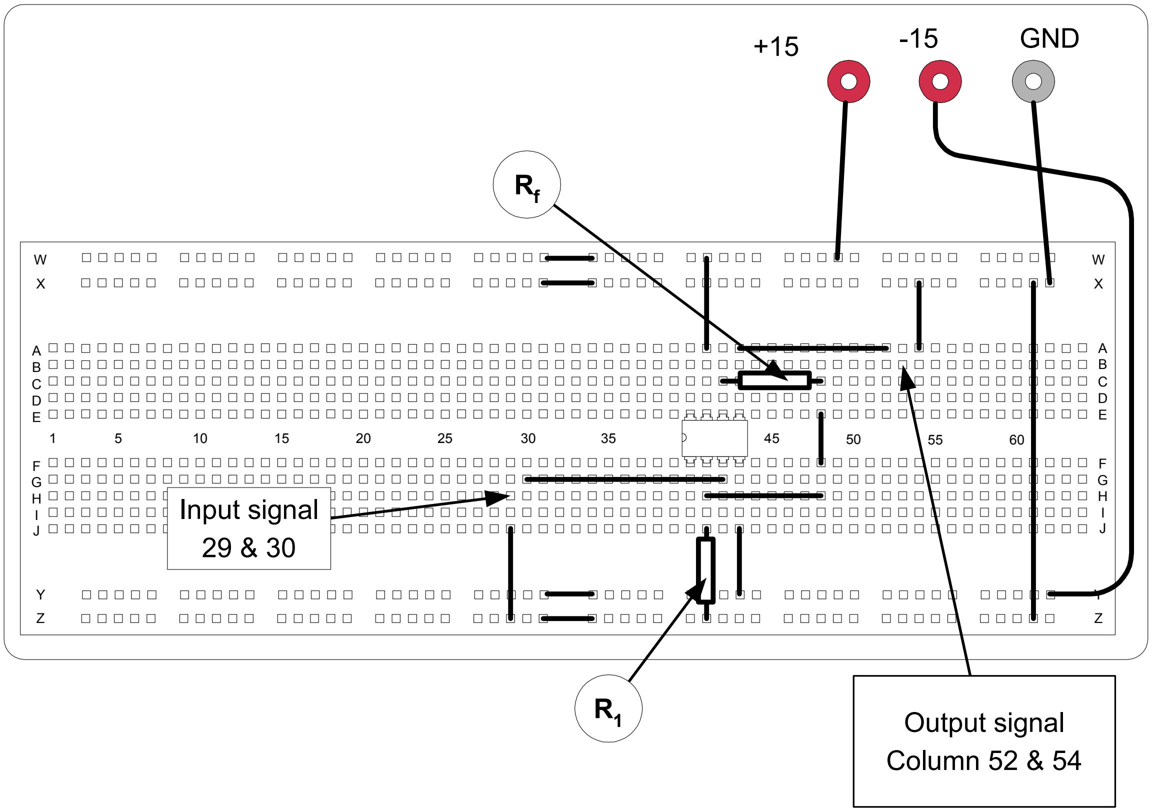


Figure 6 Minor components and wires in place

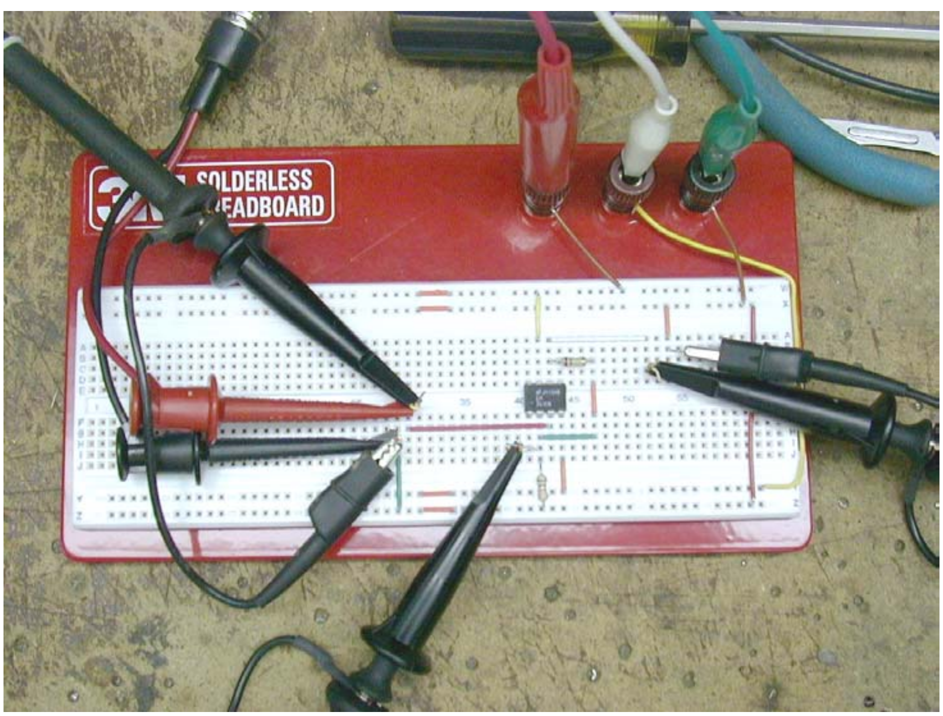
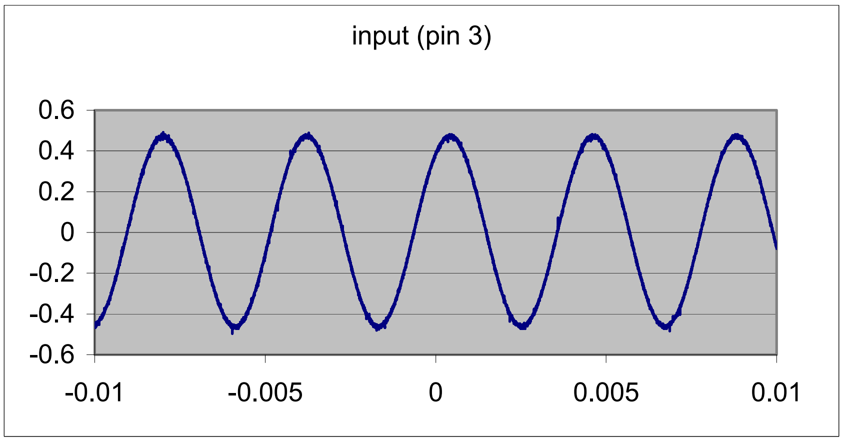
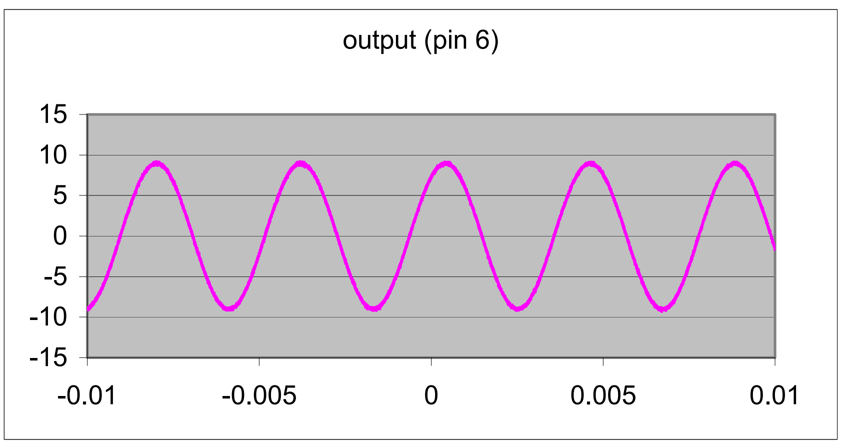


Figure 7 Actual circuit laid out for testing

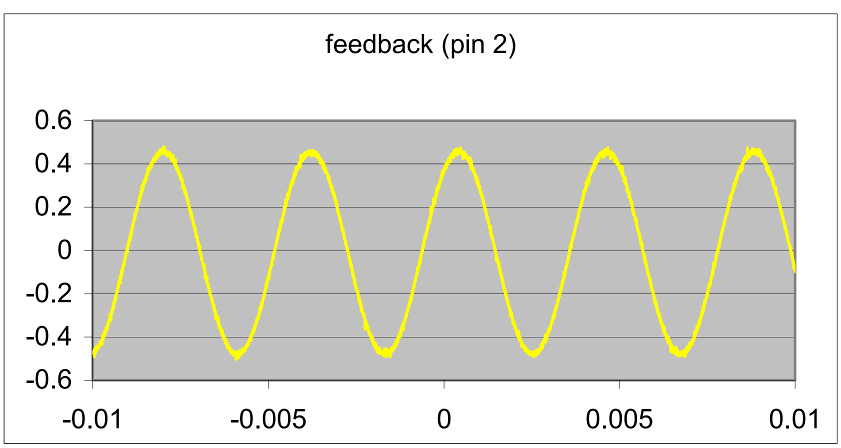
The above photograph shows the completed circuit ready for testing. A 1 volt sign wave was fed into the circuit at the Vin point, and the input (pin3), output (pin 6) and feedback (pin 2) were monitored on an oscilloscope. The traces seen below show the signals at these three points.



V p-p	0.98
DC Offset	-0.012



V p-p	18.4
DC Offset	-0.2



V p-p	0.972
DC Offset	-0.036

We can experimentally determine the gain of the circuit by dividing the output peak to peak voltage by the input peak to peak voltage. In this case 18.4 / .98 = 18.8 gain. This varies from the theoretical primarily due to the resistor tolerance. The actual value of the resistors used were 9.9K and 172.6K ohms, resulting in a theoretical gain of 18.43 based on the actual resistances. We can also se that there is some offset in the output that is undesirable. The LM741 allows for correcting this by adding a potentiometer to pins 1 and 5 as seen in the updated schematic.

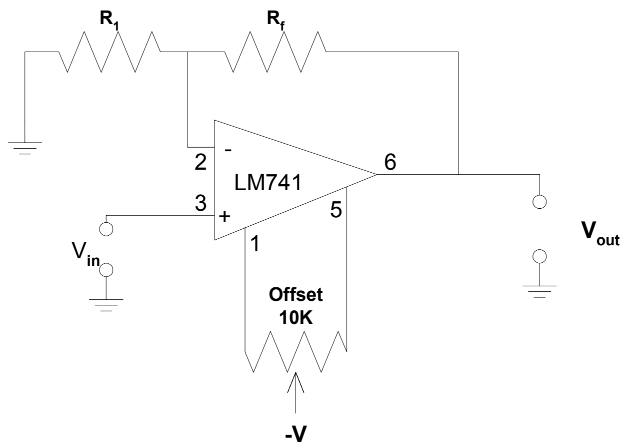


Figure 8 Offset adjustment

The 10K variable resistor will allow you to trim the output offset out of your circuit. To add this potentiometer we will have to make some minor changes to the circuit. The potentiometer that will be inserted into the circuit has pin relationships as shown in figure 9 and is a 10 turn type trim pot. This device requires 10 turns of the screw to move the wiper from one end of the resistor to the other. Unlike the resistors there is no color code for the resistance value of the potentiometer. The resistance value can be determined by the number on the top of the case. For this device the number is 103, indicating that it's resistance value is 10, with 3 zeros following, ohms. A 5k would be a 502 and a 100K would read as 104.

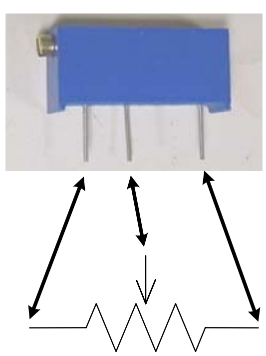


Figure 9 Pin relationship for potentiometer

Placing the potentiometer into the board with the first pin in column 33, we have the wiper in column 35 and the second end of the resistance element in column 38. We can wire the wiper (column 35) to –V (row Y) and the two ends of the resistance element to pins 1 and 5 of the chip. Figure 10 illustrates the placement and wiring of the pot and associated wiring in the final circuit.

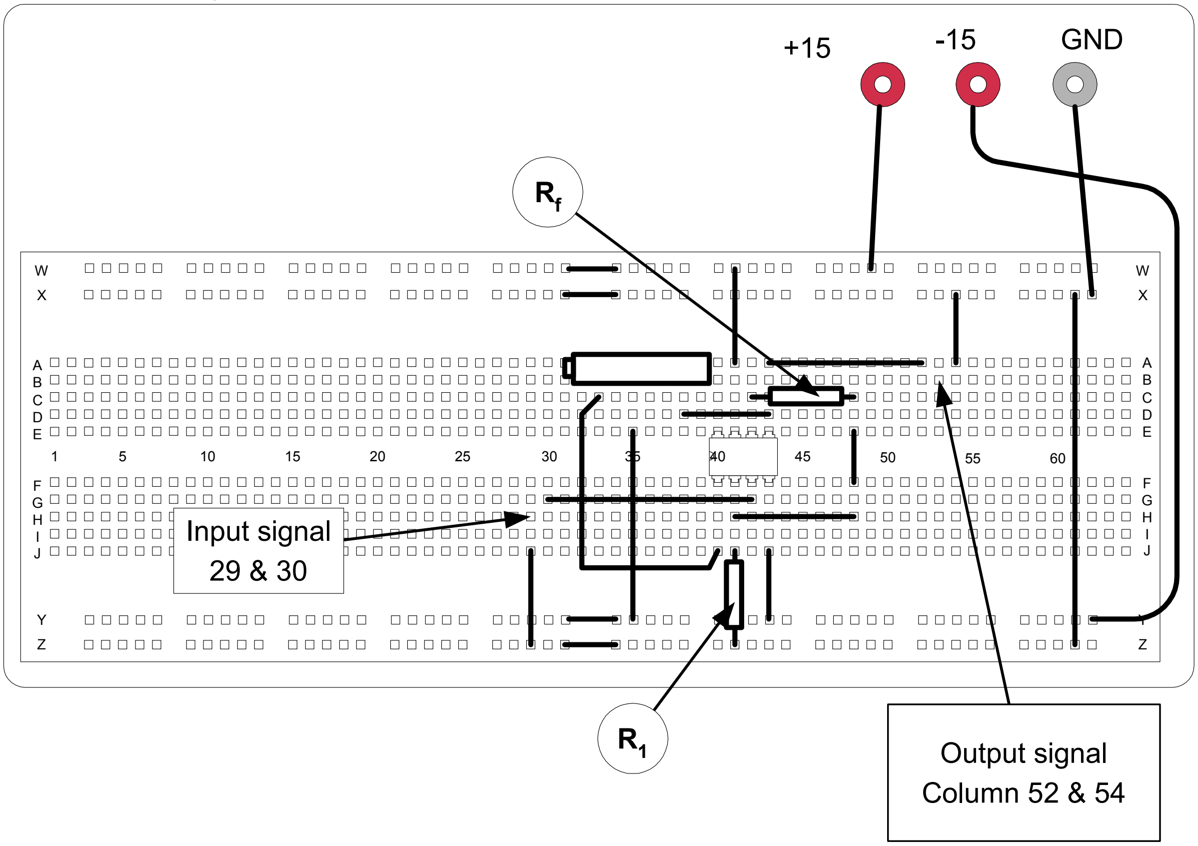


Figure 10 Circuit layout with offset pot added

Additional Components:

There are a number of additional components you may decide to place into your circuit. These include, but are not limited to capacitors, diodes, transistors and inductors. The most common are diodes and capacitors.

Capacitors come in a variety of types, sizes and styles. Different types have different applications that they are best suited for. The most common are the “orange drop”, ceramic, electrolytic, and tantilum. Figure 11 shows exaples of these types of capacitors.

Unlike resistors, there is no single marking system for size or polarity of capacitors. Some capacitors use code systems (104M) to indicate the size while others use spelled out sizes (1000µF), In addition some manufacturers mark the positive leg while others mark the negative leg of the device. Also some types of capacitors are polarized while others are not. All of these things combine to make capacitors an interesting problem.

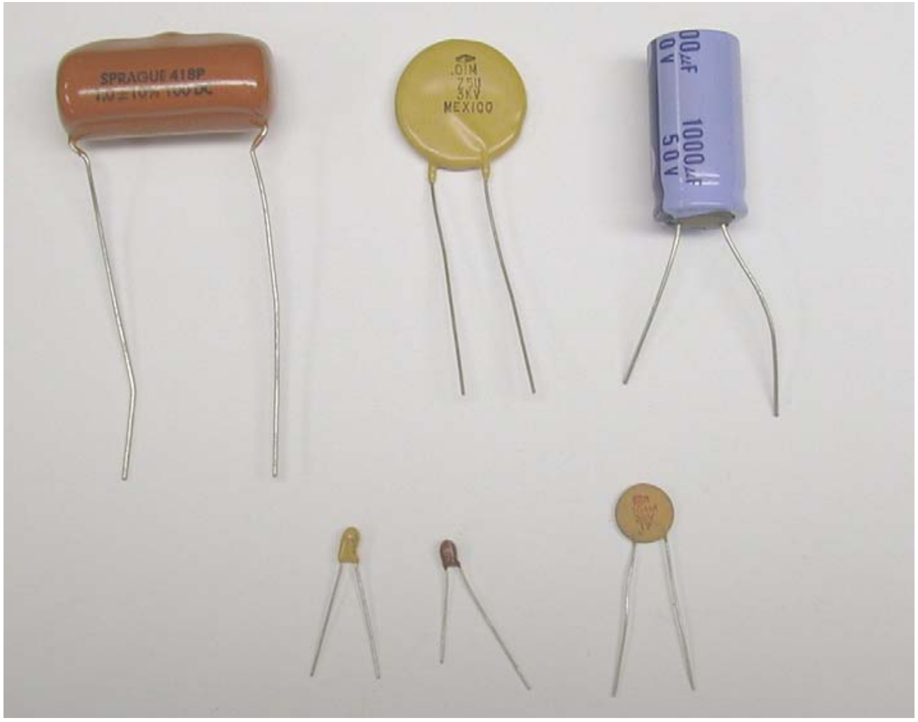
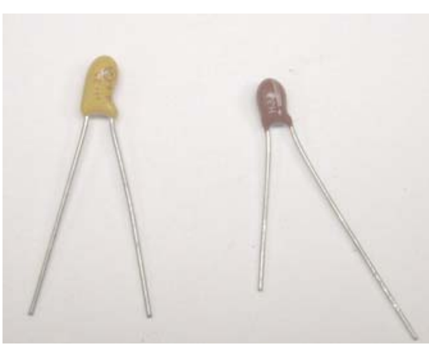


Figure 11 - various types of capacitors

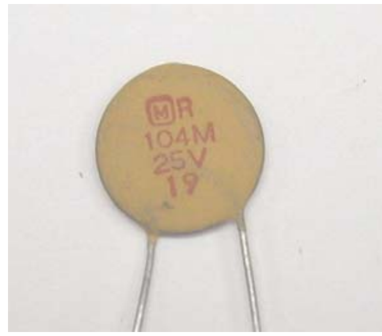
The electrolytic capacitor is a polarized capacitor. These are usually in a can type package with two leads out one end, or an axial package with one lead on each end. The package shown here is a can type 1000µF 50 Volt dc unit. The negative lead is marked with a dark band and a – sign. The negative lead should always be connected to the more negative signal lead. This could be the negative power supply lead or ground, depending how it is inserted. Never put the negative lead to the more positive terminal. This can cause the capacitor to explode with a rather vile odor.

Another polarized capacitor that you may use frequently is the tantalum capacitor. Like the electrolytic it requires that one leg be placed on a more positive lead. Looking at a closeup of two of these devices you can see that the markings are quite different from the electrolytic. The small size of the package does not allow for the value to be printed all the way out. For this reason the value is coded in various ways. These two capacitors come from different manufacturers. The tan colored unit is marked with a .1-35 indicating a 35Volt 0.1uf capacitor. The darker component is labeled with a H33. The manufacturer of this component uses this code to denote a 0.33uf 25Volt component. Both pieces also show the markings on the posative leg. The



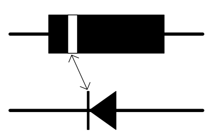
first part shows this with two plus signs. The manufacturer of the second unit marked it with a single plus sign and a heavy band. They also made the legs different lengths so these could be used with automated machinery.

Ceramic and orange drop capacitors are non-polarized. In other words they don't care which leg is more positive. The different manufacturers have also used different types of markings to show the values.



Both of these devices are 0.01uf capacitors from different manufacturers. One is a higher working voltage (3000V) than the other (25V), and are different physical sizes because of that. Note that each manufacturer has used a different type of marking to denote value.

Diodes come in a multitude of package types sizes and styles. Most are labeled with the industry standard labeling system, that being the part number (such as 1n2002) and a band. The band indicates the cathode end and relates to the schematic symbol banded end as shown in the following figure. Note that the current flow is in the direction of the arrow, and blocked in the reverse direction. The voltage drop is specified in the data sheets for the device. Light Emitting Diodes (LED's) are a special case. These usually have a long leg and a flat side to indicate the positive leg.



It is my hope that the information contained in this document will allow you to better create a circuit for you class work. I can not stress enough how a few extra minutes of preparation and careful construction practices can save hours of troubleshooting time.

Mitchell Cottrell
11/15/01

National Semiconductor

August 2000

LM741
Operational Amplifier

General Description

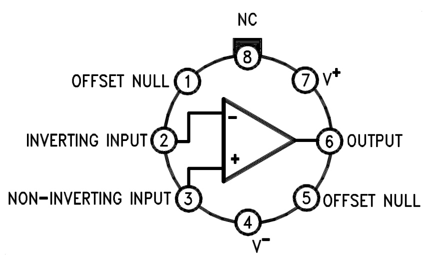
The LM741 series are general purpose operational amplifiers which feature improved performance over industry standards like the LM709. They are direct, plug-in replacements for the 709C, LM201, MC1439 and 748 in most applications.

The amplifiers offer many features which make their application nearly foolproof: overload protection on the input and output, no latch-up when the common mode range is exceeded, as well as freedom from oscillations.

The LM741C is identical to the LM741/LM741A except that the LM741C has their performance guaranteed over a 0˚C to +70˚C temperature range, instead of −55˚C to +125˚C.

Connection Diagrams

Metal Can Package

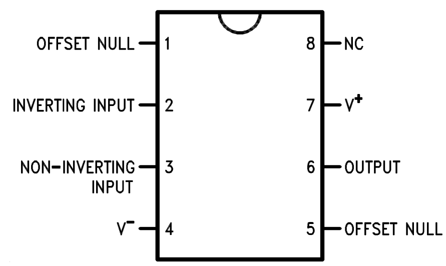


DS009341-2

Note 1: LM741H is available per JM38510/10101

Order Number LM741H, LM741H/883 (Note 1), **LM741AH/883 or LM741CH**
See NS Package Number H08C

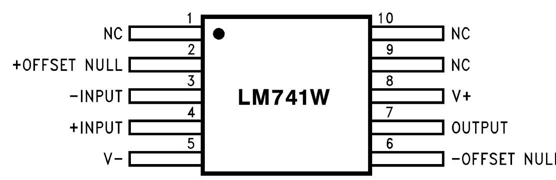
Dual-In-Line or S.O. Package



DS009341-3

Order Number LM741J, LM741J/883, LM741CN
See NS Package Number J08A, M08A or N08E

Ceramic Flatpak

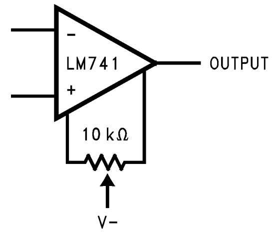


DS009341-6

Order Number LM741W/883
See NS Package Number W10A

Typical Application

Offset Nulling Circuit



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 DS009341

Absolute Maximum Ratings (Note 2)

If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/ Distributors for availability and specifications.

(Note 7)

	LM741A	LM741	LM741C
Supply Voltage	±22V	±22V	±18V
Power Dissipation (Note 3)	500 mW	500 mW	500 mW
Differential Input Voltage	±30V	±30V	±30V
Input Voltage (Note 4)	±15V	±15V	±15V
Output Short Circuit Duration	Continuous	Continuous	Continuous
Operating Temperature Range	−55˚C to +125˚C	−55˚C to +125˚C	0˚C to +70˚C
Storage Temperature Range	−65˚C to +150˚C	−65˚C to +150˚C	−65˚C to +150˚C
Junction Temperature	150˚C	150˚C	100˚C
Soldering Information			
N-Package (10 seconds)	260˚C	260˚C	260˚C
J- or H-Package (10 seconds)	300˚C	300˚C	300˚C
M-Package			
Vapor Phase (60 seconds)	215˚C	215˚C	215˚C
Infrared (15 seconds)	215˚C	215˚C	215˚C

See AN-450 "Surface Mounting Methods and Their Effect on Product Reliability" for other methods of soldering surface mount devices.

	LM741A	LM741	LM741C
ESD Tolerance (Note 8)	400V	400V	400V

Electrical Characteristics (Note 5)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Input Offset Voltage	$T_A = 25˚C$										
	$R_S \le 10\ k\Omega$					1.0	5.0		2.0	6.0	mV
	$R_S \le 50\Omega$		0.8	3.0							mV
	$T_{AMIN} \le T_A \le T_{AMAX}$										
	$R_S \le 50\Omega$			4.0							mV
	$R_S \le 10\ k\Omega$						6.0			7.5	mV
Average Input Offset Voltage Drift				15							µV/˚C
Input Offset Voltage Adjustment Range	$T_A = 25˚C, V_S = \pm 20V$	±10				±15			±15		mV
Input Offset Current	$T_A = 25˚C$		3.0	30		20	200		20	200	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			70		85	500			300	nA
Average Input Offset Current Drift				0.5							nA/˚C
Input Bias Current	$T_A = 25˚C$		30	80		80	500		80	500	nA
	$T_{AMIN} \le T_A \le T_{AMAX}$			0.210			1.5			0.8	µA
Input Resistance	$T_A = 25˚C, V_S = \pm 20V$	1.0	6.0		0.3	2.0		0.3	2.0		MΩ
	$T_{AMIN} \le T_A \le T_{AMAX}$, $V_S = \pm 20V$	0.5									MΩ
Input Voltage Range	$T_A = 25˚C$							±12	±13		V
	$T_{AMIN} \le T_A \le T_{AMAX}$				±12	±13					V

Electrical Characteristics (Note 5) (Continued)

Parameter	Conditions	LM741A			LM741			LM741C			Units
		Min	Typ	Max	Min	Typ	Max	Min	Typ	Max	
Large Signal Voltage Gain	T_A = 25˚C, R_L ≥ 2 kΩ										
	V_S = ±20V, V_O = ±15V	50									V/mV
	V_S = ±15V, V_O = ±10V				50	200		20	200		V/mV
	T_{AMIN} ≤ T_A ≤ T_{AMAX},										
	R_L ≥ 2 kΩ,										
	V_S = ±20V, V_O = ±15V	32									V/mV
	V_S = ±15V, V_O = ±10V				25			15			V/mV
	V_S = ±5V, V_O = ±2V	10									V/mV
Output Voltage Swing	V_S = ±20V										
	R_L ≥ 10 kΩ	±16									V
	R_L ≥ 2 kΩ	±15									V
	V_S = ±15V										
	R_L ≥ 10 kΩ				±12	±14		±12	±14		V
	R_L ≥ 2 kΩ				±10	±13		±10	±13		V
Output Short Circuit	T_A = 25˚C	10	25	35		25			25		mA
Current	T_{AMIN} ≤ T_A ≤ T_{AMAX}	10		40							mA
Common-Mode	T_{AMIN} ≤ T_A ≤ T_{AMAX}										
Rejection Ratio	R_S ≤ 10 kΩ, V_{CM} = ±12V				70	90		70	90		dB
	R_S ≤ 50Ω, V_{CM} = ±12V	80	95								dB
Supply Voltage Rejection	T_{AMIN} ≤ T_A ≤ T_{AMAX},										
Ratio	V_S = ±20V to V_S = ±5V										
	R_S ≤ 50Ω	86	96								dB
	R_S ≤ 10 kΩ				77	96		77	96		dB
Transient Response	T_A = 25˚C, Unity Gain										
Rise Time			0.25	0.8		0.3			0.3		µs
Overshoot			6.0	20		5			5		%
Bandwidth (Note 6)	T_A = 25˚C	0.437	1.5								MHz
Slew Rate	T_A = 25˚C, Unity Gain	0.3	0.7			0.5			0.5		V/µs
Supply Current	T_A = 25˚C					1.7	2.8		1.7	2.8	mA
Power Consumption	T_A = 25˚C										
	V_S = ±20V		80	150							mW
	V_S = ±15V					50	85		50	85	mW
LM741A	V_S = ±20V										
	T_A = T_{AMIN}			165							mW
	T_A = T_{AMAX}			135							mW
LM741	V_S = ±15V										
	T_A = T_{AMIN}					60	100				mW
	T_A = T_{AMAX}					45	75				mW

Note 2: "Absolute Maximum Ratings" indicate limits beyond which damage to the device may occur. Operating Ratings indicate conditions for which the device is functional, but do not guarantee specific performance limits.

Electrical Characteristics (Note 5) (Continued)

Note 3: For operation at elevated temperatures, these devices must be derated based on thermal resistance, and T_j max. (listed under "Absolute Maximum Ratings"). $T_j = T_A + (\theta_{jA} P_D)$.

Thermal Resistance	Cerdip (J)	DIP (N)	HO8 (H)	SO-8 (M)
θ_{jA} (Junction to Ambient)	100˚C/W	100˚C/W	170˚C/W	195˚C/W
θ_{jC} (Junction to Case)	N/A	N/A	25˚C/W	N/A

Note 4: For supply voltages less than ±15V, the absolute maximum input voltage is equal to the supply voltage.

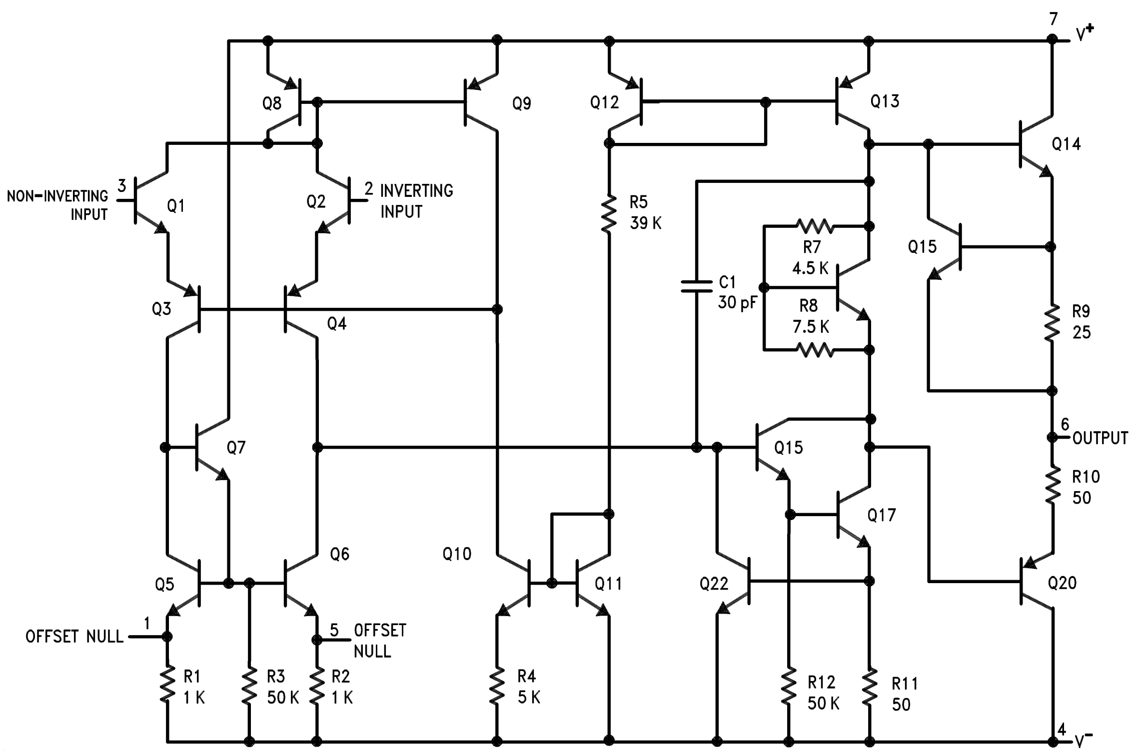
Note 5: Unless otherwise specified, these specifications apply for V_S = ±15V, −55˚C ≤ T_A ≤ +125˚C (LM741/LM741A). For the LM741C/LM741E, these specifications are limited to 0˚C ≤ T_A ≤ +70˚C.

Note 6: Calculated value from: BW (MHz) = 0.35/Rise Time(µs).

Note 7: For military specifications see RETS741X for LM741 and RETS741AX for LM741A.

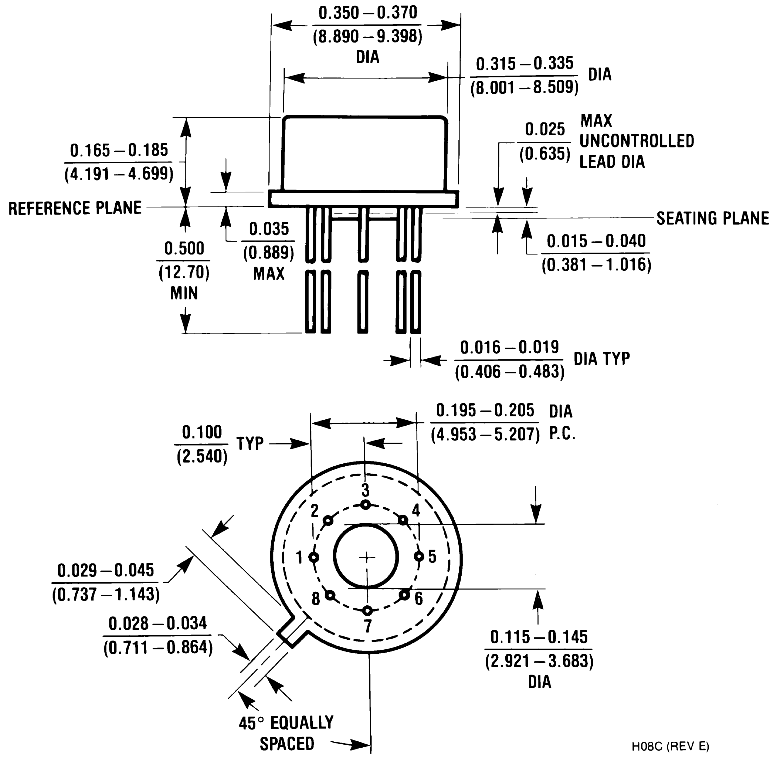
Note 8: Human body model, 1.5 kΩ in series with 100 pF.

Schematic Diagram

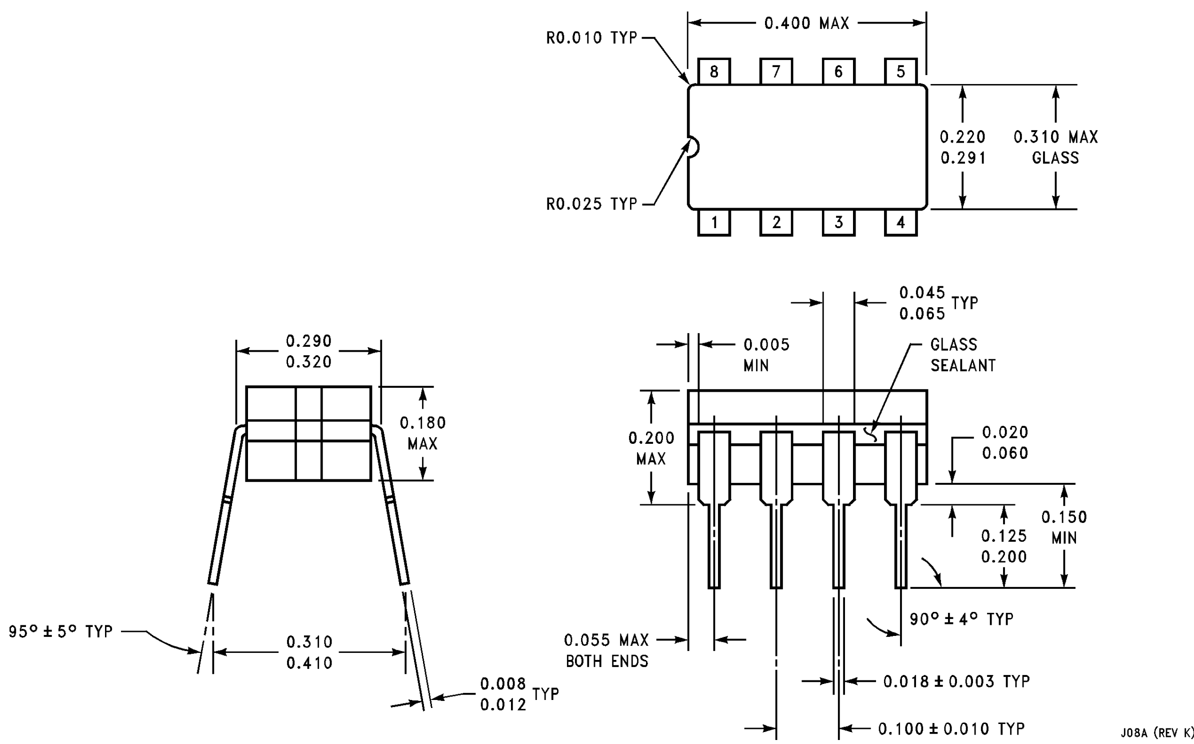


DS009341-1

Physical Dimensions inches (millimeters) unless otherwise noted

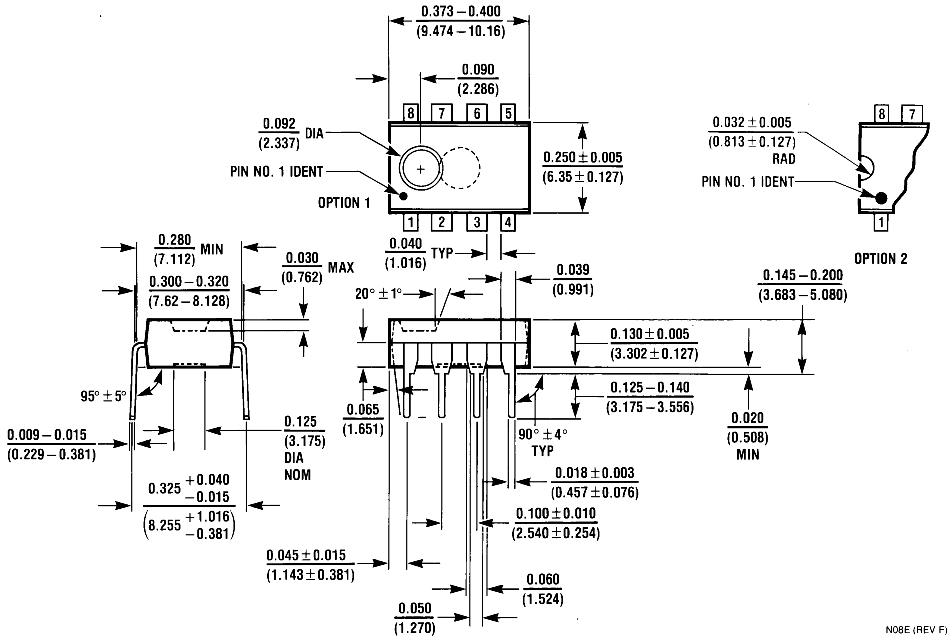


Metal Can Package (H)
Order Number LM741H, LM741H/883, LM741AH/883, LM741AH-MIL or LM741CH
NS Package Number H08C

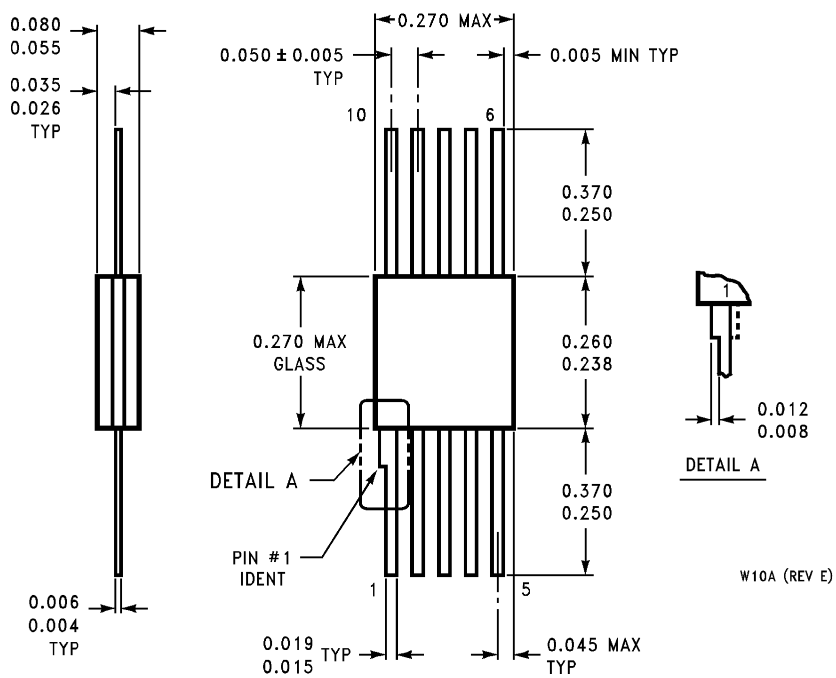


Ceramic Dual-In-Line Package (J)
Order Number LM741J/883
NS Package Number J08A

Physical Dimensions inches (millimeters) unless otherwise noted (Continued)



Dual-In-Line Package (N)
Order Number LM741CN
NS Package Number N08E



10-Lead Ceramic Flatpak (W)
Order Number LM741W/883, LM741WG-MPR or LM741WG/883
NS Package Number W10A

Notes

LIFE SUPPORT POLICY

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2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

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