Laboratory Manual

OHIO NORTHERN UNIVERSITY

Fundamentals of Electricity and Electronics - TECH 261

Ohio Northern University
Department of Technological Studies
Dr. Adam W. Stienecker

Table of Contents

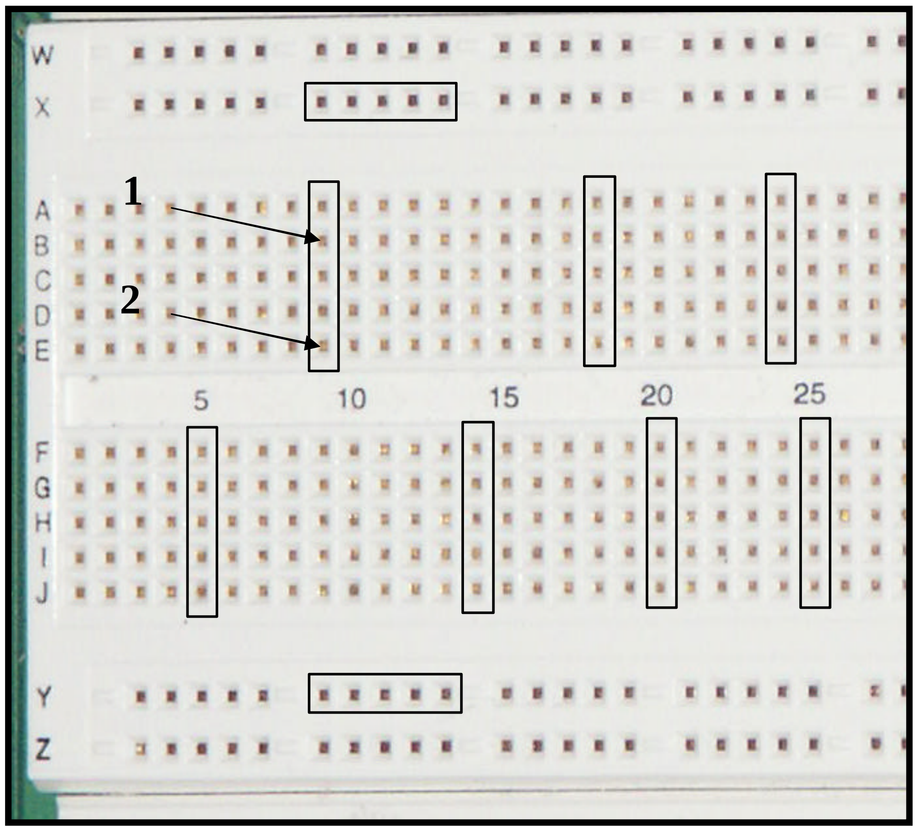
1. Intro to The NI ELVIS — Page 1
2. Changing a fuse in NI ELVIS — Page 5
3. Lab 1 – Measuring Simple Circuits — Page 6
4. Lab 2 – Simple circuits with ELVIS — Page 7
5. Lab 3 – AC Circuits — Page 8
6. Lab 4 – Resonance and Filtering — Page 10
7. Lab 5 – Transistors — Page 12
8. Lab 6 – Motor Controls — Page 17
9. Lab 7 – Op-amp Basics — Page 20
10. Lab 8 – Measuring Op-amp Parameters — Page 22
11. Lab 9 – Cascading Op-amps — Page 25
12. Example Lab Report — Page 27
13. Lab reports guidelines — Page 30
14. PN2222 Datasheet — Page 31
15. TL3472 Datasheet — Page 39

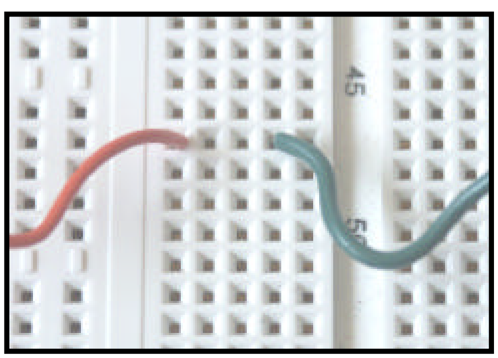
Introduction to The NI ELVIS

In order to experiment with electronics we need a place to house and facilitate the activities associated with the experiment. This requires measuring instruments, power supplies, signal generators, and digital controls and indicators. In the electronics lab we will be doing the majority of our experiments on the National Instruments Educational Laboratory Virtual Instrumentation Suite or NI ELVIS, referred to herein as ELVIS.

ELVIS has the ability to supply DC power to our experiment at +5V, +15V, -15V, as well as a ± 12V variable supply. The system can also generate a sine, triangle, and square wave at a range of frequencies, DC amplitudes, and DC offsets. We can also use the system to control and verify digital signals as well as read analog signals. Most important to the system is its ability to facilitate the connection of wires or components to one another through a series of hundreds of small holes. Each hole in the board has a series of other holes that are electrically connected to one another internally. Studying the following pictures should clarify this.

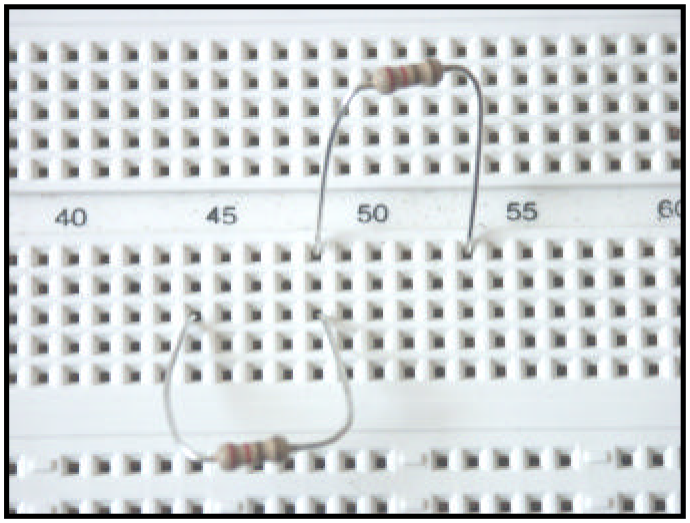
The picture to the right shows a small section of the breadboard part of the ELVIS system. As mentioned above one ability that the system gives us is the ability to connect wires together. Shown in the figure are several boxes each surrounding five holes within the board. These five holes are internally electrically connected to one another. In other words, plugging one wire into the hole labeled 1 and one into the hole labeled 2 would cause the two wires to be electrically connected. Each hole within a grouping on the ELVIS breadboard is connected to the other holes in the grouping. There are also sections of five holes that are connected together. In the rows labeled W, X, Y, and Z there are five sections of five holes that are connected to one another. This allows the user to connect up to 25 wires to one another.



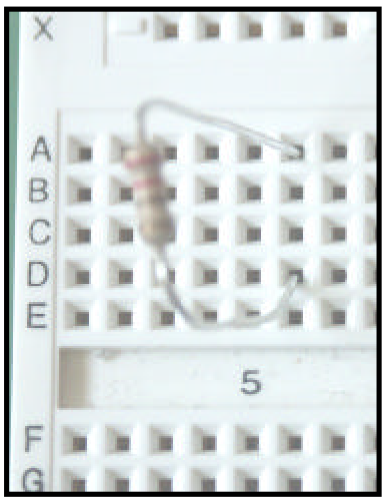


The picture to the left shows two wires plugged in to one grouping. These two wires are electrically connected because they are plugged in to the same grouping. On the next page you will find a series of pictures detailing how to connect different components to the board. Don't worry if you don't yet know what the components are, we'll get to them later in the quarter.

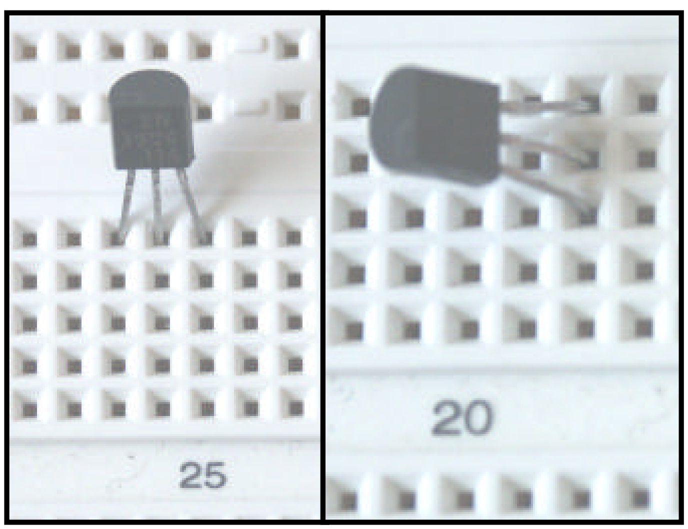
Introduction to The NI ELVIS



To resistors connected together in column 48.

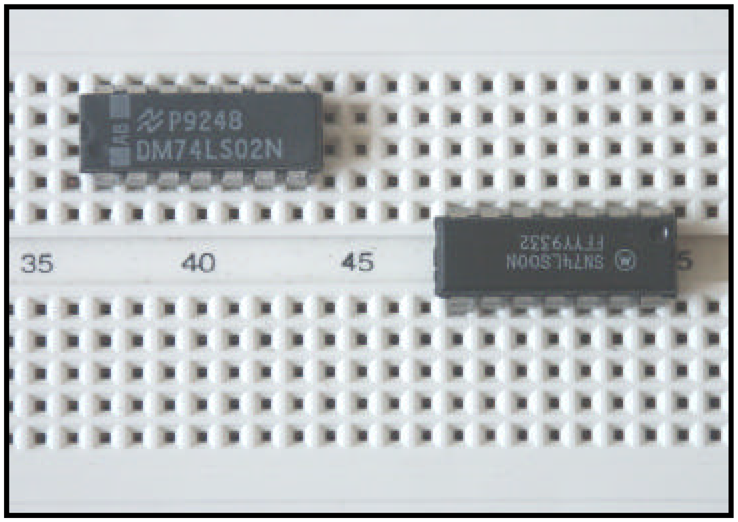


A common mistake; a resistor with both leads connected together.



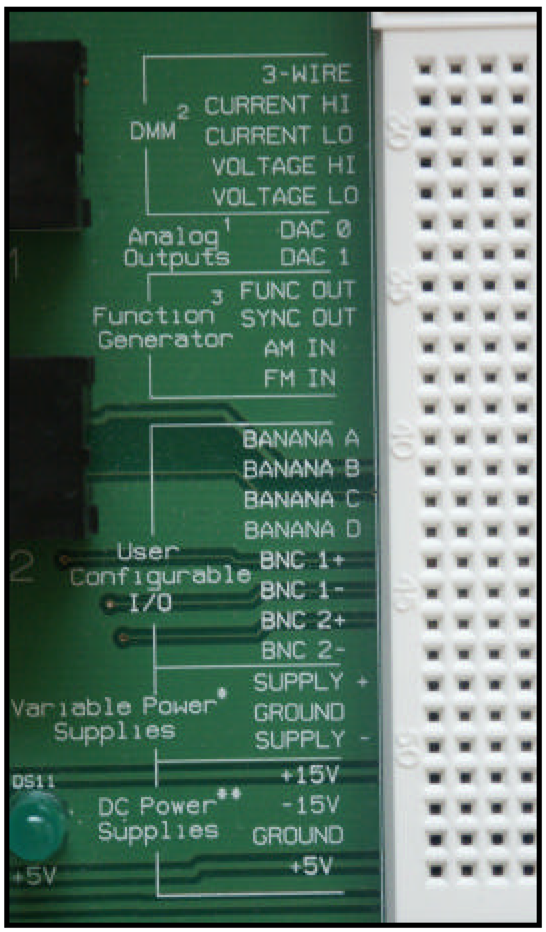
The transistor on the left is correctly installed. Note that each lead of the device has its own grouping in which to connect other wires or devices. The transistor on the right is installed incorrectly as all three of its leads are electrically connected together.

Introduction to The NI ELVIS



This picture shows two chips. The one on the left is installed incorrectly. Notice that on the correctly installed chip on the right each lead has its own grouping of five to connect to.

Also on the ELVIS board are connections to the other features in the system. These connections are located on both the left and right sides of the board. The white strip board with the square '3M' label contains the connections to all these features. Below is a series of pictures detailing some of the more utilized connections.



On the left, starting from the top, is the Digital Multimeter (DMM) section. This section allows the user to measure parameters such as voltage or current on the computer screen. Voltage HI, Voltage LO, Current HI, and Current LO are the four predominant connections you will utilize throughout the quarter.

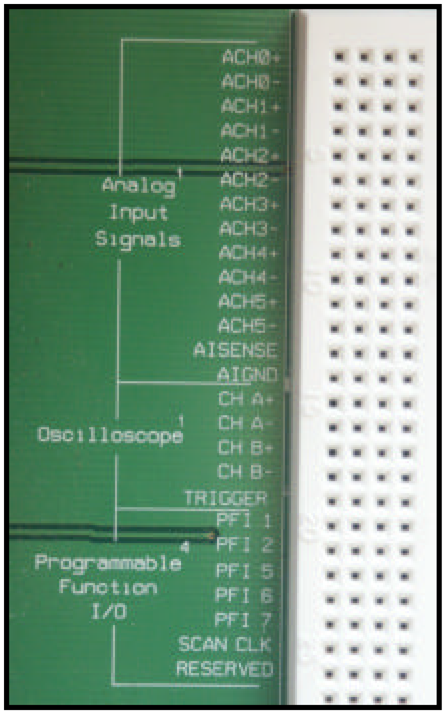
Continuing down under the Function Generator section we find the FUNC OUT connection. This connection will be used to produce sine, triangle, and square waves for use in our circuits.

The Variable Power Supplies section contains connections to the variable power supplies which can be varied via computer control.

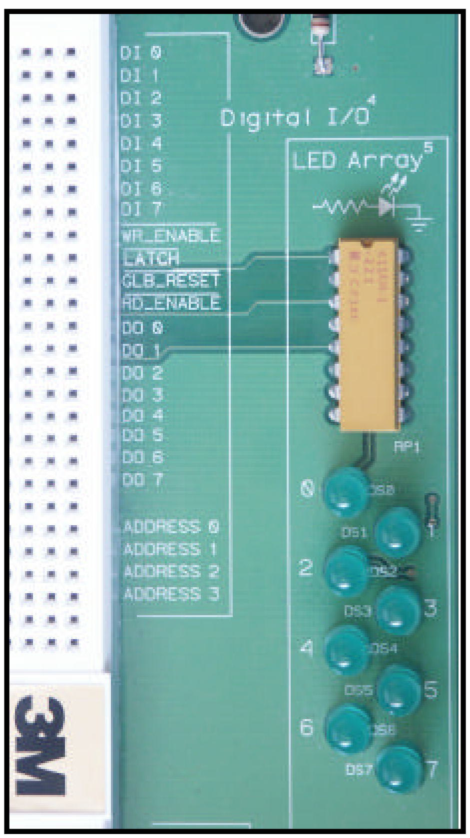
Finally, under the DC Power Supplies section you will find +15V, -15V, and +5V connections to power your circuits.

This entire section of connections is located on the lower left of the ELVIS breadboard.

Introduction to The NI ELVIS



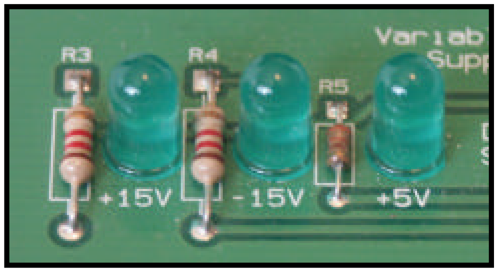
Also located on the left side of the board are the Dual channel Oscilloscope connections. The Oscilloscope allows you to see the waveform that is connected to it. It will plot the voltage level versus time with many different on screen controls. The remainder of the connections here will not be utilized in class.



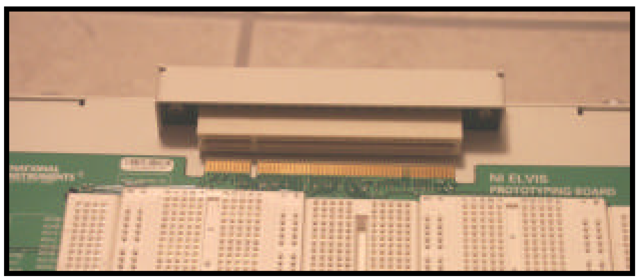
On the right side of the board are the digital connections. Starting from the top is DI0 through DI7. These connections are digital inputs to your circuit. They allow you to control your digital circuit via computer software. Below that is another set of eight; DO0 through DO7. These are outputs from your circuit to the computer. These allow you to monitor a digital output on the computer screen. On the lower right of the picture is a series of eight Light Emitting Diodes (LEDs). When their associated connection (on the lower right section of the board, not shown here) is connected to a '1' or a high signal they light up and if they are connected to a '0' or a low signal or not connect at all they do not light up. These connections are labeled LED0 through LED7.

Changing a fuse in NI ELVIS

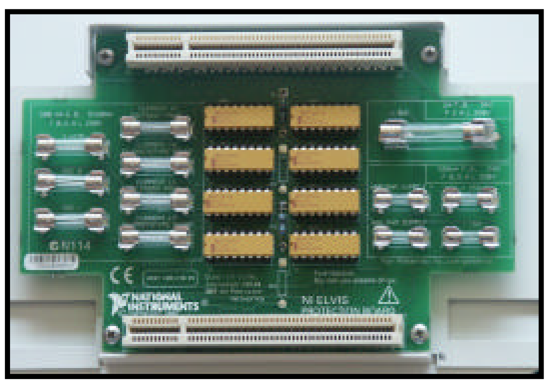
Located on the board in the lower right corner are three LEDs that function as power supply indicators. One of the inherent problems in experimenting with electronics is creating a short circuit that draws more current than can be supplied through the internal fuses. When this happens a fuse is blown and must be changed. If, at any time, any or all of the three LEDs, as shown below, goes out then the following procedure must be followed to change the fuse.



1. Take note of the LEDs are out by noting the label underneath the LED.
2. Turn off both power switches and remove both cables at the rear of the ELVIS system.
3. As in the picture below, remove the breadboard by pulling down on the board.



4. Loosen the four thumbscrews on the back of the system and remove the back by pulling out, away from the system. You should see the following.



5. Locate the fuse labeled the same as the LED that turned off, remove it, and replace it with a new one. Before continuing, discard the blown fuse.
6. Reattach the back, tighten the thumbscrews, reattach the cables, reinsert the breadboard, and turn on the power. You should be back in business.

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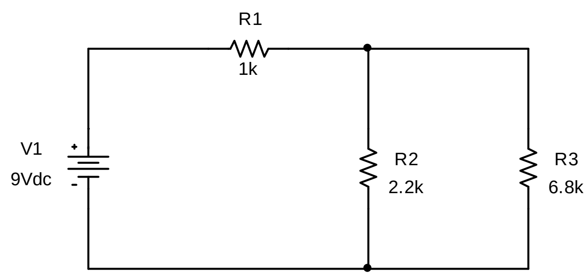
Lab 1 - Measuring Simple Circuits

Name:________________________________

1. Build the circuit below using five alligator clip wires, one power supply set to 9V, and three resistors.



2. Using a multimeter, measure the following values.

V_{R1} (the voltage across R1) = ____________ I_T (the current through R1) = ____________

V_{R2} (the voltage across R2) = ____________ I_{R2} (the current through R2) = ____________

V_{R3} (the voltage across R3) = ____________ I_{R3} (the current through R3) = ____________

V1 (the voltage of the power supply) = __________

3. Disassemble the circuit and measure the value of the resistors with the multimeter and compare the measured value to the color coded value on each resistor. Are all three resistors within tolerance?

R1: Measured Value _____ Color Code Colors _____ _____ _____ _____ Value/Range ______ __________

R2: Measured Value _____ Color Code Colors _____ _____ _____ _____ Value/Range ______ __________

R3: Measured Value _____ Color Code Colors _____ _____ _____ _____ Value/Range ______ __________

4. Using only the measured value of the power supply and the measured value of the resistors, calculate the expected values of V_{R1}, V_{R2}, V_{R3}, I_T, I_{R2}, and I_{R3} that you measured in number 2 above. Are they the same or similar to your measured values? Why or why not?

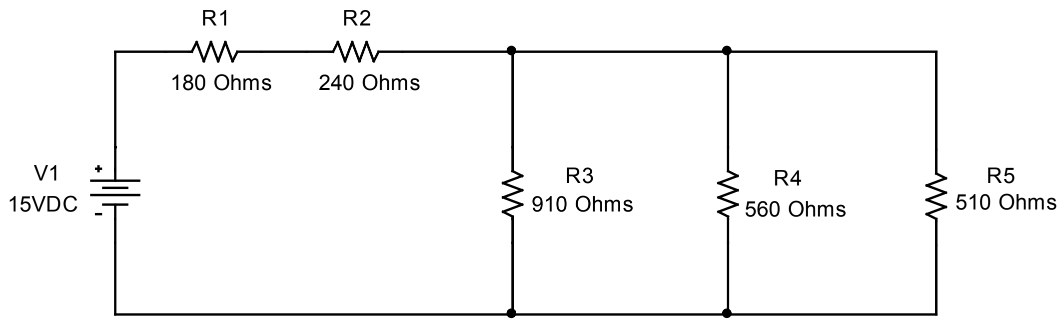
5. Calculate the power dissipated in each resistor as well as the total power consumed by the circuit. At $0.10 per kWh how much would this circuit cost to run for one year?

6. If your power supply was a battery with a capacity of 1500mAh how long would the battery last in this circuit? (Assume a linear battery capacity curve, i.e. $C_{1.5} = C_{0.01}$).

Lab 2 - Simple circuits with ELVIS

Name:_______________________________

1. Build the circuit below using the NI ELVIS system.



2. Using the NI ELVIS computer software, measure the following values.

   To measure voltage, use VOLTAGE HI and VOLTAGE LO, to measure current (disconnect your circuit) and use CURRENT HI and CURRENT LO. To measure resistance, put the resistor in CURRENT HI and CURRENT LO.

   V_{R1} (the voltage across R1) = ___________ R1 = ___________

   V_{R2} (the voltage across R2) = ___________ R2 = ___________

   V_{R3} (the voltage across R3) = ___________ R3 = ___________

   V_{R4} (the voltage across R4) = ___________ R4 = ___________

   V_{R5} (the voltage across R5) = ___________ R5 = ___________

   V1 (power supply voltage) = ____________

   I_T (power supply current) = _____________ I_{R3} (the current through R3) = ___________

   I_{R1} (the current through R1) = ___________ I_{R4} (the current through R4) = ___________

   I_{R2} (the current through R2) = ___________ I_{R5} (the current through R5) = ___________

3. Calculate the expected values that you measured in number 2 above. Use the measured value of the power supply given above as the expected value. Use the measured value of the resistors in your calculations as well.

4. Calculate the power dissipated in each resistor as well as the total power consumed.

5. If the electric company charged $0.05 per kWh, what would be the charge to power this circuit for one year?

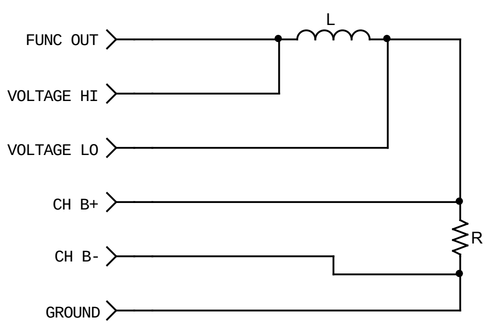
Lab 3 - AC Circuits

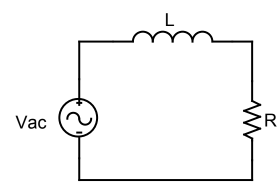
Name:______________________________

1. Obtain the provided inductor and a 240 Ohm resistor.
2. Turn on the NI ELVIS hardware (both front and rear switches).
3. Open NI ELVIS (START / All Programs / National Instruments / NI ELVIS 1.0 / NI ELVIS)
4. Click on the Digital Multimeter and select resistance, Ω.
5. Plug the resistor into CURRENT HI and CURRENT LO and record the resistance on the multimeter.
6. Remove the resistor and replace it with the inductor. Click over to Inductance (looks like a coil).
7. Measure the inductance of the inductor and record it below.
8. Click back to resistance and measure the resistance of the inductor and record it below.
9. Remove the inductor from the board and close the "Digital Multimeter."

Resistor's Resistance ______ Inductor's Resistance _______ Inductor's Inductance _______

10. Construct the following circuit (on the left) on your board. This is the same as the circuit on the right. FUNC OUT and GROUND are your AC Voltage Source, VOLTAGE HI and VOLTAGE LO are used to measure the voltage drop across the inductor, and CH B+ and CH B- are used to measure the voltage drop across the resistor.





The following is a procedure to measure the phase difference between the voltage and the current in the circuit. The connection to the inductor from the VOLTAGE HI and the VOLTAGE LO will cause a display of the voltage, V_L, waveform on your screen. The voltage, V_R, across the resistor is out of phase with V_L but in phase with the current; therefore, we can display the waveform of V_R (given by CH B+ and CH B-) on the screen to find the phase difference between the current and the voltage.

11. Open the "Function Generator" in NI ELVIS.
12. Click "ON" to turn it on (the manual switch on the front panel in the function generator box must be in the down position before it will turn on).
13. Change "Peak Amplitude" to 2.5V.
14. Set frequency to the first frequency in the chart below (100 Hz)
15. Record the actual frequency of the function generator in the chart below. Use this number for the calculations.

16. Open the "Oscilloscope" so that both the Oscilloscope and the Function Generator can be seen on the screen.
17. Click "OFF" under "CHANNEL B" to turn it on.
18. Change the "CHANNEL A" "Source" to "DMM Voltage" (your voltage between VOLTAGE HI and VOLTAGE LO).
19. Change "TRIGGER" to "SYNC_OUT."
20. Set "TIMEBASE" to 1mS.
21. Click "OFF" under "CURSORS."
22. Change "C2" to "CH B."
23. On the graph, click and hold C1 and drag it to the peak point of the waveform from CHANNEL A.
24. Do the same for C2 on the waveform for CHANNEL B nearest to C1 as possible.
    Be very very accurate with your positions. Remember ELI the ICE man; Voltage comes before current in an inductor. This means that C2 should be placed on the peak immediately after C1 and not before. C2 is the voltage across the resistor and is in phase with the current in the circuit while C1 is the voltage across the inductor and is out of phase with the current. Therefore the phase difference between C1 and C2 is the phase between the current and the voltage in the inductor.
25. Record "dT" as given on the screen in the chart below.
26. Change the frequency in the "Function Generator" to the next frequency in the chart.
27. Change the "TIMEBASE" to 500uS.
28. Repeat steps 15, 23 – 26, and 28 until the entire chart is complete.

Desired Frequency	Actual Frequency	dT	θ = dT x f x 360
100 Hz			
500 Hz			
1000 Hz			
1500 Hz			
2000 Hz			

Now that the phase difference has been measured, calculate the phase shift that you expected. Copy the measured values for the components from earlier in the lab in the provided space.

Resistor's Resistance ______ Inductor's Resistance _______ Inductor's Inductance _______

Resistor's Resistance + the Inductor's Resistance = Total Resistance = R = _______

Recall the following and complete the chart below: $X_L = 2\pi f \cdot L$ $\quad Z = \sqrt{R^2 + X_L^2}$ $\quad \theta = \cos^{-1}\frac{R}{Z}$

Don't forget to use whole units on each calculation. L is a small value!

Actual Frequency (from above)	X_L	Z	θ

Lab 4 – Resonance and Filtering

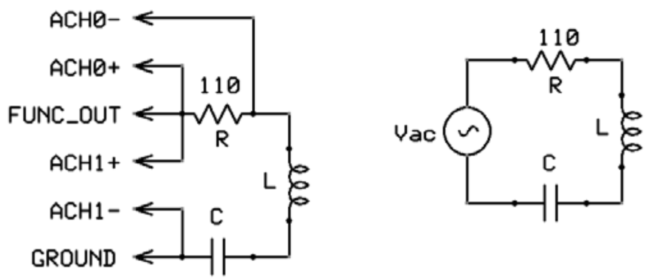
Name:______________________________

1. Obtain the provided inductor, a 1000pF capacitor, a 43k Ohm resistor, and a 110 Ohm resistor.
2. Turn on the NI ELVIS hardware (both front and rear switches).
3. Open NI ELVIS (START / All Programs / National Instruments / NI ELVIS 1.0 / NI ELVIS)
4. Click on the Digital Multimeter and measure the resistance of the resistor and of the inductor.
5. Measure the inductance of the inductor and the capacitance of the capacitor.

110 Ohm Resistor's Resistance _____43k Ohm Resistor's Resistance _____ Inductor's Resistance _______

Inductor's Inductance _______ Capacitor's Capacitance ______

6. Calculate the resonant frequency ________. Now calculate (f-5000) = ______ and (f+5000) _______. This is going to be the frequency range over which we will test the circuit.
7. Construct the following circuit (on the left) on your board. This is the same as the circuit on the right. FUNC OUT and GROUND are your AC Voltage Source, ACH0+/ACH0- is used to measure the voltage drop across the resistor and ACH1+/ACH1- is used to measure the total input voltage.

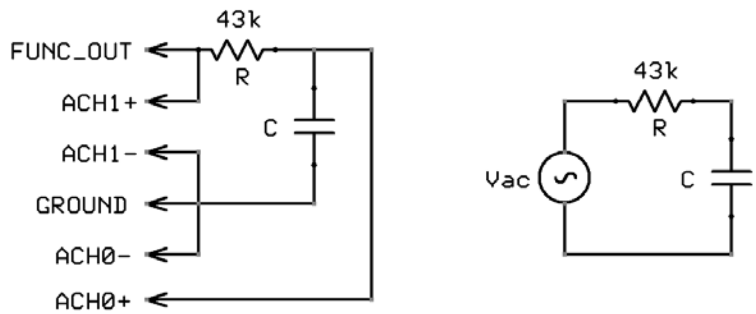


The following is a procedure to obtain the gain of the circuit over a range of frequencies. We will use a frequency sweep analyzer called a Bode Analyzer in NI ELVIS. This will automatically change the frequencies for us over a range and take measurements along the way. After the test it will display a graph of the results and allow us to export the data to excel. One additional thing to note about the Bode Analyzer is that its display uses a logarithmic graph so the distance between 100Hz to 1000Hz is the same as the distance from 1,000Hz to 10,000Hz. This is commonly used when a wide range of data is plotted on one graph so that detail in all ranges can be seen.

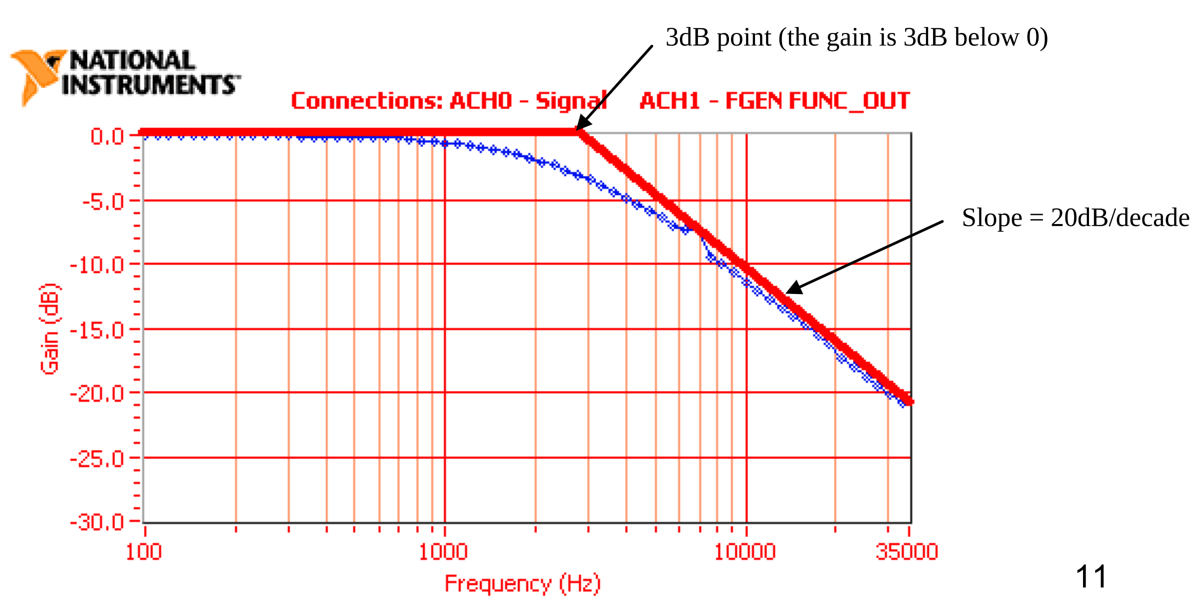
8. Open the "Bode Analyzer" in NI ELVIS. (Be sure that the multimeter is closed)
   a. Set the Start and Stop frequencies to the range you calculated in 6 above. Set steps to 500.
   b. Set Peak Amplitude to 2.0V and polarity to normal.
   c. Set the Y scale to Gain with a max of 0.5 and a min of 0. Click the green dB button so it changes to linear (may already be in the linear mode).
   d. Click run and wait.
   e. After the Log button is no longer grayed out it is ready to save the data, click Log and save the file.
9. Open the file in Microsoft Excel, delete the phase column and add columns for the inductive reactance, the capacitive reactance, impedance, total current (voltage is 2.0V), voltage drop across the resistor, and gain. All of these columns should be populated using the associated equations for each value. The

equation for gain in this case is voltage drop across the resistor divided by input voltage (Peak Amplitude = 2.0V).

10. Plot the measured gain alongside the calculated gain in one graph inside excel and paste the results into your lab report.
11. Now disconnect your circuit and build the low-pass filter pictured below.



12. Calculate the corner frequency of the filter __________.
13. Using the Bode Analyzer set with a range of 100Hz – 35kHz, steps 25, 2.0V peak amplitude, polarity normal, Y Scale set to Gain (dB), maximum = 0, minimum = -30.
14. The gain in this test is the voltage drop across the capacitor (or the output voltage of the filter) divided by the input voltage. It is a measure of how the circuit treated the input voltage. In this case the input voltage is a constant amplitude therefore the gain is proportional to the output voltage. In this test we are displaying gain in dB format. This is the same as taking each gain value and applying the 20log(gain) equation to it. The
15. After the test has completed, instead of exporting to excel, (drag the bode analyzer to the upper left side of the screen) take a "print screen" of the results and paste it into paint.
16. Inside paint, select Image/Invert Colors and copy/paste just the graph of the gain into a new paint document.
17. The corner frequency we calculate for a low-pass filter is an estimate for the frequency at which the gain begins to decrease. This equation is designed to match the frequency point in your test where the gain has dropped 3dB below the 0dB line. The second part of the estimate was not covered in the lecture, but it is estimated that from that corner frequency on up the gain drops at 20dB/decade. One decade (frequency) is the distance from 10 to 100 or from 100 to 1,000 or from 1,000 to 10,000, etc.
18. In paint draw a line of this estimate and include this image in your lab report. An example is shown below.
19. Is this a good estimate for the performance of your filter?

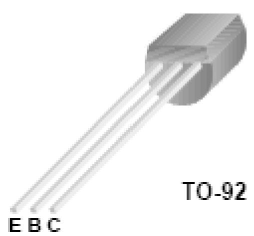


Lab 5 - Transistors

Name:______________________________

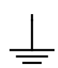
1. Obtain the following parts
   - (1) PN2222 NPN Transistor
   - (2) IRF530N N-Channel MOSFET
   - (1) 0.1μF Capacitor (Green)
   - (1) 33μF Capacitor (Yellow)
   - (2) 1kΩ Resistors
   - (4) 10kΩ Resistors
   - (1) Yellow Multimeter
   - (1) ELVIS Station

2. Measure the β of the transistor with the Yellow Multimeter. Turn the dial to h_{fe} and insert the transistor into the NPN black socket according to the following diagram. Record your measurement below.

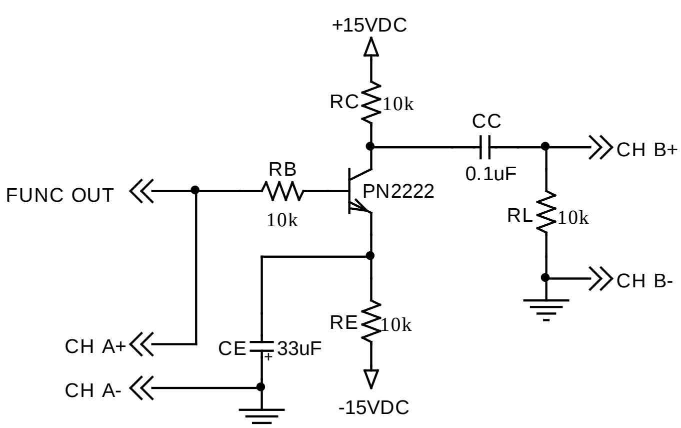


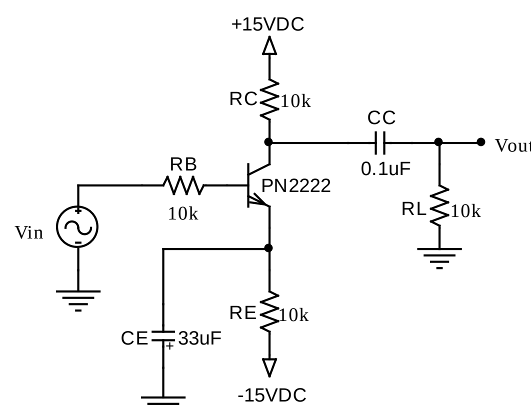
β = ________ It should read greater than 200

3. Construct the following circuit (on the left) on your board. This is the same as the circuit on the right.



Means Ground





The following is a procedure to measure the voltage gain of this amplifier. Channel B on the Oscilloscope will display the output voltage and Channel A will display the input voltage. You will then be able to determine the Peak-to-Peak voltage of both input and output. The ratio of these two numbers will then be the voltage gain of the amplifier.

1. Turn on the NI ELVIS hardware (both front and rear switches).
2. Open NI ELVIS (START / All Programs / National Instruments / NI ELVIS 1.0 / NI ELVIS)
3. Open the "Function Generator."
4. Click "ON" to turn it on (the manual switch on the front panel in the function generator box must be in the down position before it will turn on).
5. Change "Peak Amplitude" to 0.01V.
6. Set frequency to 2kHz.
7. Open the "Oscilloscope" so that both instruments can be seen on the screen.
8. Click "OFF" under "CHANNEL B" to turn it on.
9. Change "TRIGGER" to "SYNC_OUT."
10. Set "TIMEBASE" to 500µS.
11. Change the "SCALE" of channel A to 10mV and the "SCALE" of channel B to 500mV.
12. Two waveforms should be on the screen, Vin (Green) and Vout (Blue).
13. Use the controls to move one of the waveforms up or down so both can be seen clearly.
14. Measure the Peak-to-Peak voltage of both waveforms. Click on "MEASURE" on channel B and record the value given below (Vout). It should read around 1.3V. Now measure Channel A (Vin). It should be between 15mV and 20mV. Record the measured value below.
15. Calculate the Gain and record it in the chart below. Gain = Vout/Vin
16. Now use your yellow multimeter to measure V_{BE}, (the transistor should remain in the circuit) the DC voltage between the Emitter and Base of the transistor. It should measure around 0.6-0.7V.
17. Measure the -15VDC and +15VDC supply voltages. The measure of the -15VDC should be negative.
18. Next, measure V_C, the DC value of the Collector Voltage. Measure between the collector and ground.

Vin(CHA)	Vout (CHB)	Gain	V_{BE}	-15VDC	+15VDC	V_C

19. Close the function generator and the oscilloscope and open the Digital Multimeter.

20. Remove and measure (insert into CURRENT HI and CURRENT LO) each resistor using the Digital Multimeter. Be sure you know which resistor you are measuring as they all look the same. Once measured and recorded below remove the resistor and set it aside.

R_E	R_B	R_C	R_L

21. CALCULATION - Now calculate the expected DC value of the collector voltage, V_C, and the gain from your measured values above. The following equations have been derived for you and apply only to this amplifier. Use the measurement of -15VDC for V_{EE} (this will be a negative value) and your measurement of +15VDC for V_{CC} (this should be a positive value). Remember V_T=25mV or 0.025V. I_C should be around 1mA, V_C should be around 1V, and the gain should be around 80V/V.

$$I_C = \frac{-\beta(\beta+1)(V_{EE}+V_{BE})}{R_B(\beta+1)+\beta^2 R_E} = \_\_\_\_\_\_\_\_ \qquad V_C = V_{CC} - I_C R_C = \_\_\_\_\_\_\_\_$$

22. CALCULATION - Now calculate the expected gain, using the equations on the previous page if R_L, the load resistance, is changed to 5kΩ. How about 20kΩ.

$$Gain = \frac{V_{out}}{V_{in}} = \frac{-\beta}{\frac{\beta V_T}{I_C} + R_B} \cdot \frac{R_C \cdot R_L}{R_C + R_L} = \_\_\_\_\_\_\_\_$$

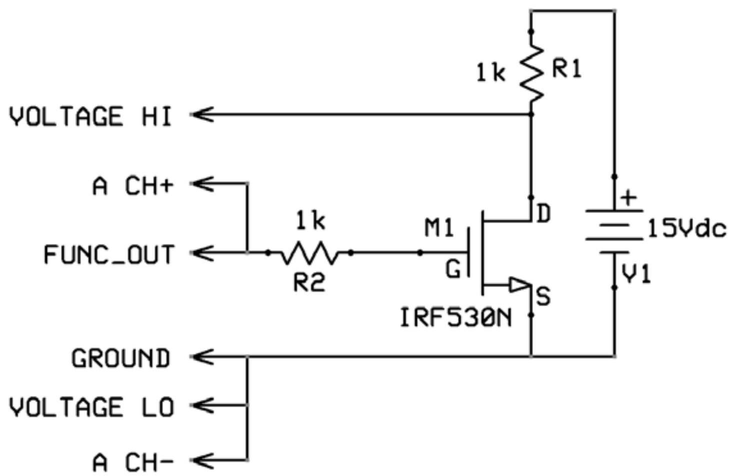
Gain at 5kΩ ________ Gain at 10kΩ (from above) ________ Gain at 20kΩ ________

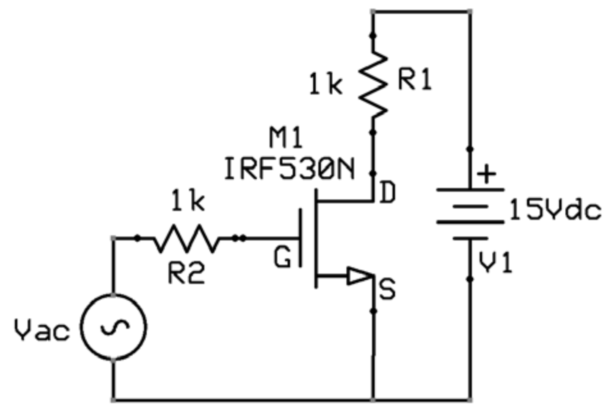
23. CALCULATION - Notice that when the load resistance changes (this is equivalent to changing the size or resistance of a speaker if this was applied to an audio system) the gain of the amplifier changes. Explain the problem this could cause in your car audio system knowing that stereo volume is directly related to voltage.

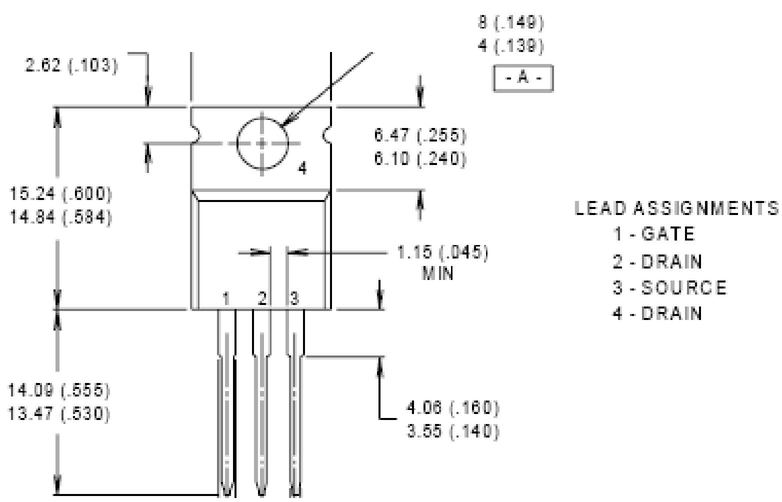
24. Now continue on to the next circuit, but before construction measure the resistance of R_1 with the yellow multimeter.

R_1 = __________

25. Construct the following circuit on your board. The circuit on the left is the connect diagram. The circuit on the right is the conceptual diagram. Use the diagram below the circuits to determine which leg is which on the transistors.







26. Set your function generator frequency to 100Hz, Peak Amplitude to 2.5V, DC Offset to 1.5V, and Waveform to Square. This generators a square wave at 100Hz with a voltage that ranges from 4V to -1V.

27. Put both waveforms onto the oscilloscope screen and set the trigger to SYNC_OUT.

28. Decrease the DC Offset in the function generator until V_D begins to rise above zero. This indicates that the transistor is no longer fully switching. Record this switching voltage below (Peak Amplitude + DC Offset). Now switch to another transistor and re-measure.

MOSFET 1 Switching Voltage ___________ MOSFET 2 Switching Voltage ___________

29. Now move R2 from FUNC_OUT to +5V so that the MOSFET remains on and measure (with the yellow multimeter) V_{DS}. To do this, set the meter to DC volts and place the red lead on the drain and the black lead on the source. This value will be between 1mV and 2mV.

V_{DS} ________________

30. Measure the current flow through the resistor, R1 (I_D), the power supply voltage, V1, and the voltage drop across R1, V_{R1}. Does $V1 = V_{R1}+V_{DS}$?

I_D ______________ V1 ______________ V_{R1} ______________

31. CALCULATION - Calculate the power dissipated in R1.

P_{R1} __________________

Lab 6 – Motor Controls

Name:______________________________

Obtain the following

1. DC motor
2. A MOSFET
3. A 6.8k ohm resistor
4. A 10k ohm resistor
5. Two alligator clip wires
6. A hall-effect sensor
7. A small magnet

Motor windings: Red and Black leads are connected to the brushes and into the rotor (the rotating part). The Brown and White leads are connected to the field winding (the stationary part).

1. Connect the motor in series by twisting the white and black wires together and connecting the red wire to +60VDC and the brown wire to ground. Record the direction of the motor (clockwise or counterclockwise). To connect to 60VDC use the power supply with the SERIES button pushed and the LEFT SIDE black connection used with the RIGHT SIDE red connection along with both sides set to 30VDC. Get this set up and measure the voltage with your yellow meter before connecting to the motor.

   Direction_______________

2. Switch the power supply connections such that the brown wire is now connected to +60VDC and the red wire is now connected to ground. Do not alter the twisted together wires at this time. Once again record the motor direction.

   Direction_______________

3. Now disconnect the motor and untwist the wires and reconnect as follows. Twist the black and brown wires together and connect the red wire to +60VDC and the white wire to ground. Record the direction.

   Direction_______________

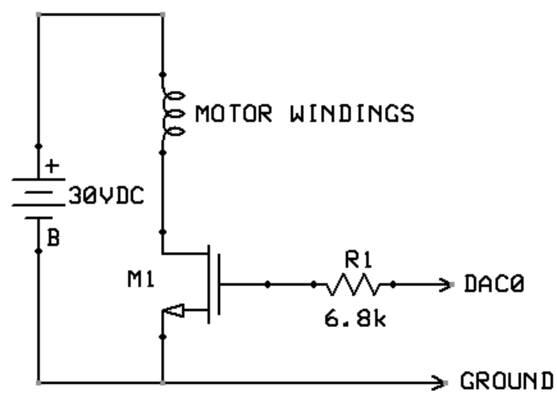
4. Leave the black and brown wires twisted and now connect the white wire to +60VDC and the red wire to ground. Record the direction.

   Direction_______________

In your lab report explain the reason you obtained the directions you did above and draw a schematic diagram for each using an inductor to represent each of the two motor windings. You should have four schematic diagrams.

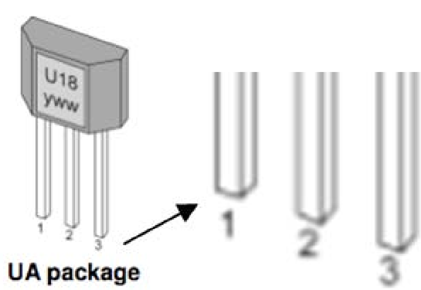
Now connect the motor in shunt by twisting together the red and brown wires and by twisting together the black and white wires. Remove the gearbox by removing the four 5/16" bolts from the back end of the gearbox. THE GEARBOX IS FULL OF OIL, PLEASE DO NOT DUMP IT ALL OVER! Place the small magnet on the shaft of the motor.

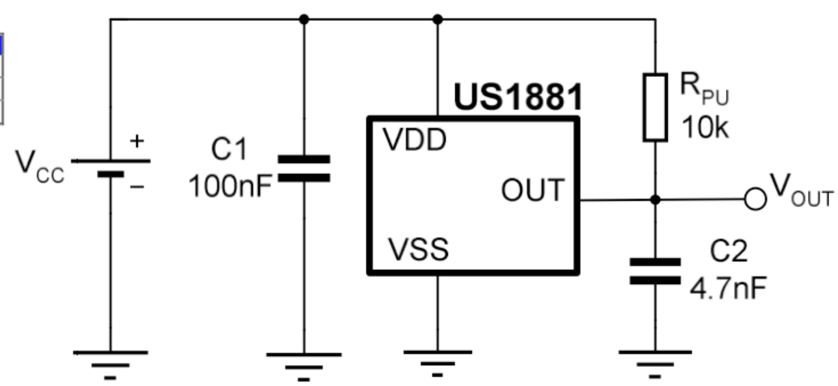
Build the circuit below using your motor, a MOSFET, and a resistor. You'll need two alligator clips to connect the motor to your NIELVIS board.



We will be using the NIELVIS system to generate a PWM waveform that controls the speed of the motor. In order to determine what the speed of the motor is we will need to measure the rotation of the motor shaft. Connect up the hall-effect circuit below based on the pin layout diagram. You will not need to install the capacitors in this circuit as they are there only to filter out high frequency noise, which isn't all that critical in our tests. Use 5VDC as V_{CC}. Be sure to connect this in such a way that you can get the magnet on the rotating shaft to pass very near the sensor.

UA Pin №	Name	Type	Function
1	VDD	Supply	Supply Voltage pin
3	OUT	Output	Open Drain Output pin
2	GND	Ground	Ground pin





Once you have the circuit connected, you must connect the oscilloscope to the V_{OUT} on the above circuit so that we can use the NIELVIS oscilloscope to see when the sensor senses the magnet and when it does not sense the magnet. To do this connect the V_{OUT} to CHA+ and connect CHA- to GROUND. We will use the oscilloscope to measure the time it takes for the shaft to make one complete revolution. From there we will be able to calculate RPMs.

Once your system is completely setup, open the NIELVIS software and follow directions below.

1. Open the Arbitrary Waveform Generator and click the Waveform Editor Icon at the bottom left of the black section of the screen.
2. Inside the waveform editor, click New Segment and then New Component.
3. In the Function Library on the right choose square and set the frequency to 1000Hz.
4. Now select segment 1 on the left in the white scroll box and change the duration to 0.005 on the right.
5. Select segment 2 and do the same.
6. Select File/Save As and then select Waveform File (.wdt) and click Next.
7. Leave the sample rate and number of samples alone and select Next again.
8. Save it to your desktop as 50.
9. Now return to the Waveform Editor and change the duty factor of the waveform to 60% through 100% by changing the segment 1 length and segment 2 length as indicated below. Save each file along the way as 60,70,80, etc.
    a. 60% Segment 1 = 0.006, Segment 2 = 0.004
    b. 70% Segment 1 = 0.007, Segment 2 = 0.003
    c. 80% Segment 1 = 0.008, Segment 2 = 0.002
    d. 90% Segment 1 = 0.009, Segment 2 = 0.001
    e. 100% Segment 1 = 0.01, Segment 2 = 0
10. Now close the waveform editor and select the File Open icon to the left of the Gain box in the DACO section of the screen.
11. Navigate to the 50.wdt file you created and double click it.
12. Now select the run or play button in the DACO section and change the gain to 4.00V.
13. The motor should now be running.
14. Open the oscilloscope and set the trigger source to CH A, set the TIMEBASE to 100ms and the level to 3V. Select measure and turn the cursors on. Adjust the cursors so they measure the period of the wave and record it in the chart below.
15. Repeat steps 10-14 for each of the files you created.

Duty Factor	Period(time for one rotation)	RPMs (60/Period)
50%	_____	_____
60%	_____	_____
70%	_____	_____
80%	_____	_____
90%	_____	_____
100%	_____	_____

Lab 7 – Op-Amp Basics

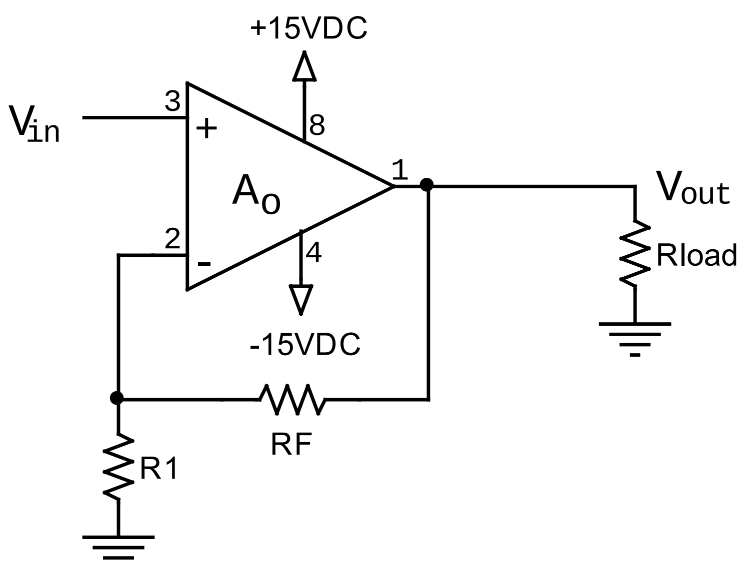
Name:______________________________

1. Obtain the following parts
   - (1) TL3472 Op-Amp
   - (2) 10kΩ Resistors (R_1 and R_F)
   - (1) 6.8kΩ Resistor (Load Resistor)
   - (1) Yellow Multimeter
   - (1) ELVIS Station

2. Before construction measure the resistance of R_1 and R_F with the yellow multimeter.

   R_1 = __________ R_F = __________

3. Construct the following circuit on your board. CONNECT V_{in} TO +5VDC as the input voltage. V_{out} has been labeled for your convenience but SHOULD NOT CONNECT ANYWHERE except to the resistor R_{load}.



4. What is the expected gain of the system (refer to your notes)? Gain = _________

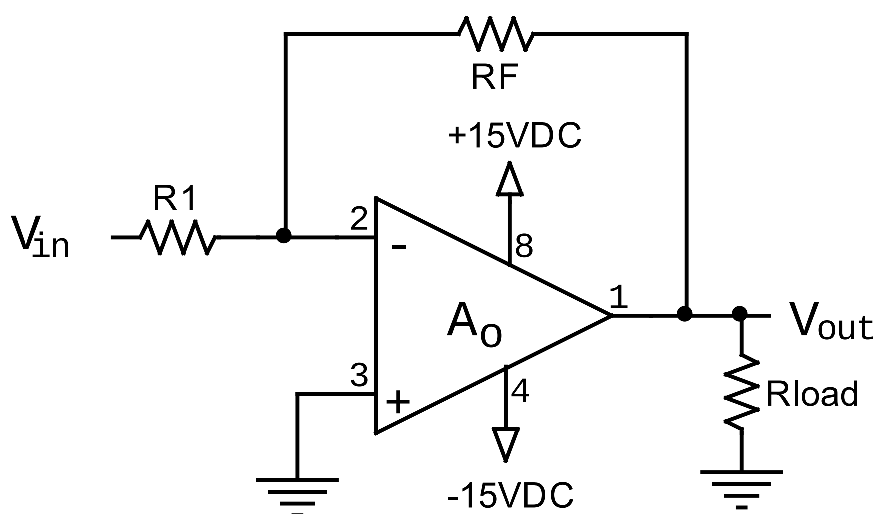
5. With your Yellow Multimeter, measure the +5VDC at V_{in}. +5VDC = __________

6. With your Yellow Multimeter, measure the V_{out}. Measured V_{out} = __________

7. Given the calculated gain above, what is the expected V_{out}? Expected V_{out} = __________

8. What is the actual measured gain of the system? Measured V_{out} / Measured V_{in} = __________

9. Construct the following circuit on your board. Connect V_{in} to +5VDC as the input voltage. V_{out} has been labeled for your convenience but SHOULD NOT CONNECT ANYWHERE except to the resistor R_{load}.



10. What is the expected gain of the system (refer to your notes)? Gain = _________

11. With your Yellow Multimeter, measure the +5VDC at V_{in}. +5VDC = __________

12. With your Yellow Multimeter, measure the V_{out}. Watch the sign! Measured V_{out} = __________

13. Given the calculated gain above, what is the expected V_{out}? (Sign??) Expected V_{out} = __________

14. What is the actual measured gain of the system? (Sign??) Measured V_{out} / Measured V_{in} = _______

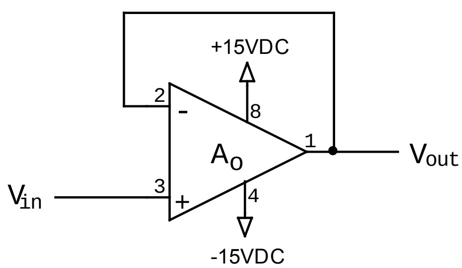
Lab 8 - Measuring Op-amp Parameters

Name:____________________________

1. Obtain the following parts

(1) TL3472 Op-Amp	(1) 100kΩ Resistor	(1) Yellow Multimeter
(2) 100Ω Resistors	(2) 220kΩ Resistors	(1) ELVIS Station
(2) Alligator Clips		

2. First we will measure the Output Voltage Limit. Begin by constructing the voltage follower below.



3. Start by connecting V_{in} to +15VDC in order to force V_{out} to the maximum positive value it can attain, or the High Output Voltage Limit.
4. Measure the High Output Voltage Limit by measuring, with the yellow multimeter, between V_{out} (pin 1) (positive, red lead) and ground (negative, black lead).

   V_{OH} = ____________

5. Disconnect V_{in} from +15VDC and move it to -15VDC. This forces V_{out} to attain its negative maximum value or the Low Output Voltage Limit.
6. Measure the Low Output Voltage Limit by measuring, with the yellow multimeter, between V_{out} (pin 1) (positive, red lead) and ground (negative, black lead).

   V_{OL} = ____________

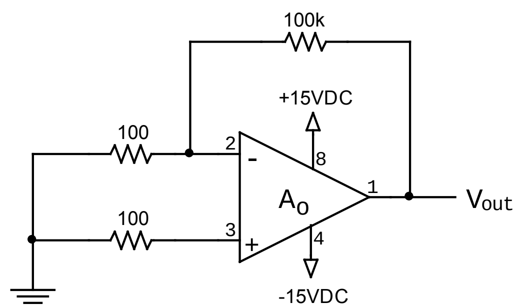
7. Next we will measure the Output Short-Circuit Current of the op-amp. We will use the circuit you already have constructed. However, remove V_{in} from -15VDC and move it to SUPPLY+. This is the connection to the positive variable power supply with a dial on the front of the white ELVIS box. The manual switches on the variable power supply should be in the up position.
8. Measure the voltage V_{in} with the yellow multimeter by connecting the red lead to V_{in} and the black lead to ground. While you are measuring it turn the dial on the front of the white ELVIS box labeled SUPPLY+ Voltage until V_{in} reads 1.00V or as close as you are able to get it. It may be easier to connect the multimeter with alligator clips so you can turn the dial easily.
9. Remove the positive (red) lead and set the multimeter to read DC Current (200m setting). Connect the red lead to V_{out} (pin 1) and record the current below. This procedure is shorting the output to ground and you've just measured the Output Short-Circuit Current in sourcing mode.

   I_{OS} (Sourcing) = _____________

10. Now you'll need to measure the Output Short-Circuit Current in sinking mode. Do this by disconnecting the positive (red) lead from the multimeter and setting it to measure voltage. Move the connection to V_{in} from SUPPLY+ to SUPPLY-. Connect the positive lead to V_{in} and turn the dial on the front of the ELVIS module labeled SUPPLY- Voltage until the meter reads -1.00V or as close as you are able to get it.
11. Remove the positive (red) lead and set the multimeter to read DC Current (200m setting). Connect the red lead to V_{out} (pin 1) and record the current below. This procedure is shorting the output to ground and you've just measured the Output Short-Circuit Current in sinking mode.

I_{OS} (Sinking) = ____________

12. Now you'll measure the Input Offset Voltage. Begin by constructing the following circuit.



13. The gain of this amplifier is 1000 V/V. Since the input is grounded, 0 volts, the output voltage will be equal to the Input Offset Voltage x 1000. Therefore, measure V_{out} (positive lead on pin 1, negative lead on ground) and divide by 1000 to obtain the Input Offset Voltage.

V_{IO} (with +15VDC and -15VDC power supplies) = ____________

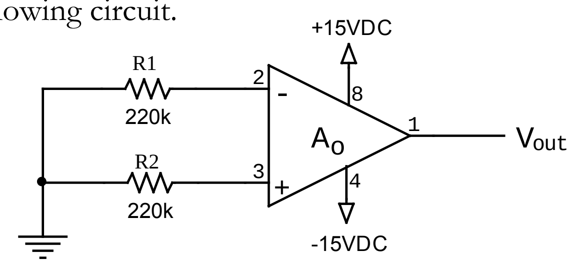
14. The Power Supply Rejection Ratio is a ratio between the change in Power Supply Voltage and the change in the Input Offset Voltage, V_{IO}. You just measured the Input Offset Voltage with ±15VDC power supply voltage. Change the power supply voltage to ±12VDC and measure it again. To do this move the connection from +15VDC to SUPPLY+ and move the connection from -15VDC to SUPPLY-. Measure the voltage at SUPPLY+ and ground while turning the dial on the front of the ELVIS module labeled SUPPLY+ Voltage until the meter reads +12.00V or as close as you are able to get. Now measure the voltage at SUPPLY- and ground while turning the dial on the front of the ELVIS module labeled SUPPLY- Voltge until the meter reads -12.00V or as close as you are able to get.
15. Repeat Number 13 now that you have a ±12VDC power supply voltage.

V_{IO} (with +12VDC and -12VDC power supplies) = ____________

16. Calculate the PSRR.

$$PSRR = 20\log\left|\frac{\Delta V_{DC}}{\Delta V_{io}}\right| = 20\log\left|\frac{6V}{V_{IO(\pm 15VDC)} - V_{IO(\pm 12VDC)}}\right| = \underline{\hspace{3cm}}$$

17. Next you will measure the Input Bias Current and the Input Offset Current. Begin by constructing the following circuit.



18. The Input Bias Current is the average of the currents flowing into the inputs. This current will also be flowing through the resistors, R1 and R2. Since the positive and negative inputs will be at the same voltage there will be no current flowing through R_i, the input resistance. Therefore, the voltage that is measured across the resistor is directly proportional to the Input Bias Current. Using the yellow multimeter measure the voltage across R1 (positive lead on pin 2 and negative lead on ground). In the same manner measure the voltage across R2 (positive lead on pin 3 and negative lead on ground).

V_{R1} = ____________ V_{R2} = ____________

19. Now calculate the input current on each input.

Input Current (negative input) = $I_{IB-} = V_{R1}/R1$ = ____________

Input Current (positive input) = $I_{IB+} = V_{R2}/R2$ = ____________

20. Now calculate the Input Bias Current. This is the average value of the two currents in number 19.

Input Bias Current = $I_{IB} = (I_{IB-} + I_{IB+})/2$ = ____________

21. The Input Offset Current is the absolute value of the difference between I_{IB-} and I_{IB+}.

Input Offset Current = $I_{IO} = |I_{IB-} - I_{IB+}|$ = ____________

22. Copy all parameter measurements from above into the chart below. Refer to the datasheet and fill in the remaining three columns. Not every parameter will have a maximum, typical, and minimum value. How do the measured values compare with the datasheet? Is anything "out-of-spec."

	Measured Value	Datasheet Min.	Datasheet Typ.	Datasheet Max.
V_{OH}				
V_{OL}				
$I_{OS(Sourcing)}$				
$I_{OS(Sinking)}$				
V_{IO}				
PSRR (k_{SVR})				
I_{IB}				
I_{IO}				

Lab 9 - Cascaded Op-amps

Name:______________________________

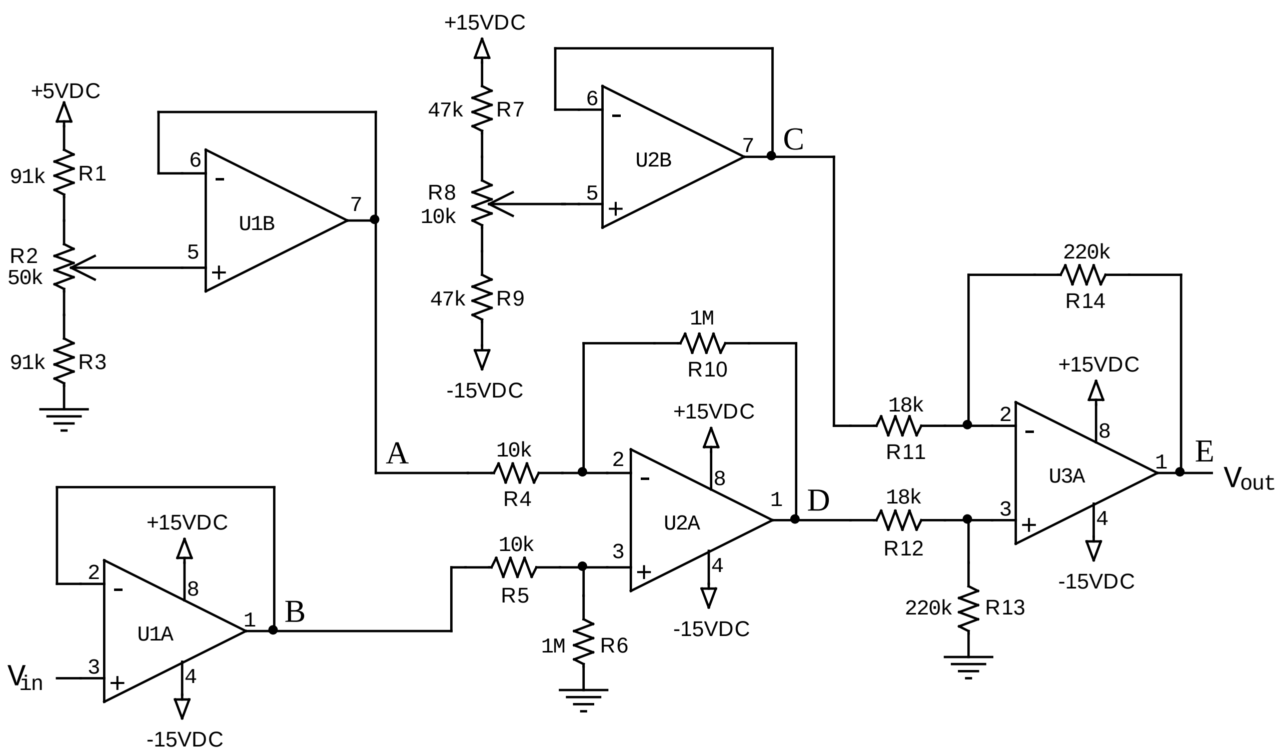
1. Obtain the following parts

(3) TL3472 Op-Amps	(2) 47kΩ Resistors	(1) 50kΩ Variable Resistor
(2) 91kΩ Resistors	(2) 18kΩ Resistors	(1) Yellow Multimeter
(2) 10kΩ Resistors	(2) 220kΩ Resistors	(1) Phillips Screwdriver
(2) 1MΩ Resistors	(1) 10kΩ Variable Resistor	(1) ELVIS Station

2. Begin by constructing the circuit below. **U1A and U1B are contained within one chip. U2A and U2B are contained within one chip. U3 is a separate chip.** This entire circuit seems complex but is a very simple combination of five circuits we've discussed in class. Before beginning, be sure that power is turned off to prevent a blown fuse.

3. The variable resistors have three leads. The third lead, opposite the two at the back of the variable resistor, is the lead that is signified by the arrow in the schematic diagram below. The other two leads, the top and bottom, are interchangeable.

4. **Connect V_{in} to FUNC OUT and V_{out} to VOLTAGE HI. Connect VOLTAGE LO to ground.**



5. Bring up the function generator on the computer and set the frequency to 20Hz, set the amplitude to 0.01V, and set the offset to +2.5V.
6. Open the Oscilloscope and set CHANNEL A to DMM VOLTAGE. Set the Scale to 5V/div and the TIMEBASE to 10ms/div. Set the TRIGGER Source to SYNC_OUT.

7. U2A is configured to be a difference amplifier so that the 2.5VDC offset from the function generator can be cancelled out with the input coming from U1B. The input to U1B is a common voltage divider circuit. This circuit contains a variable resistor so that the input to U1B can be tuned between 2 and 3 volts. This allows adjustment for any resistors that aren't perfect and the Input Voltage Offset that is inherent in the op-amps. Therefore, if the input to pin 5 of U1B is between 2 and 3 volts what do you expect the voltage to be at the output of U1B at "A"?

   Expected range of voltage at "A" = ________________

8. Similarly the input to U2B is a voltage divider containing a variable resistor. The voltage to pin 5 of U2B can vary between -1.4 and 1.4 volts. What is the expected range at the output of U2B at "C"?

   Expected range of voltage at "B" = ________________

9. In order for the circuit to work properly the two variable resistors need to be tuned. Variable resistor R2 can be thought of as course tuning and variable resistor R8 can be though of as fine tuning. Begin by observing the output voltage on the oscilloscope while carefully tuning R2. You should notice that the output is either +15 or -15 (or close). If the output switches from +15 to -15 or vice versa you've gone too far, turn it the opposite way. Once you see an alternating wave use R8 to fix the remaining DC offset such that the wave is alternating around 0 volts.

10. Click on the measure button on Channel A of the Oscilloscope and record the peak-to-peak voltage of the output below.

    Output peak-to-peak voltage = ________________

11. The input voltage peak-to-peak was set to 0.02V. Calculate the gain of the system.

    System Gain = ________________

12. When amplifiers are cascaded, one right after another, the gain is multiplied. For example if an amplifier with a gain of 2V/V was followed by an amplifier with a gain of 8 V/V the total system gain would be 16 V/V. Each of the five amplifiers in the circuit has a gain that can be calculated by referring to your notes. Calculate these individual gains and multiply them together to obtain the total expected system gain.

    Gain of U1A = ________________

    Gain of U1B= ________________

    Gain of U2A= ________________

    Gain of U2B= ________________

    Gain of U3A= ________________

    Total Expected System Gain = ________________

TECH-261 – Fundamentals of Electricity and Electronics
Ohio Northern University
Department of Technological Studies

Laboratory Experiment 1: Measuring Simple Circuits

Mr. Joe A. Student

<u>Laboratory Report</u>

Abstract:

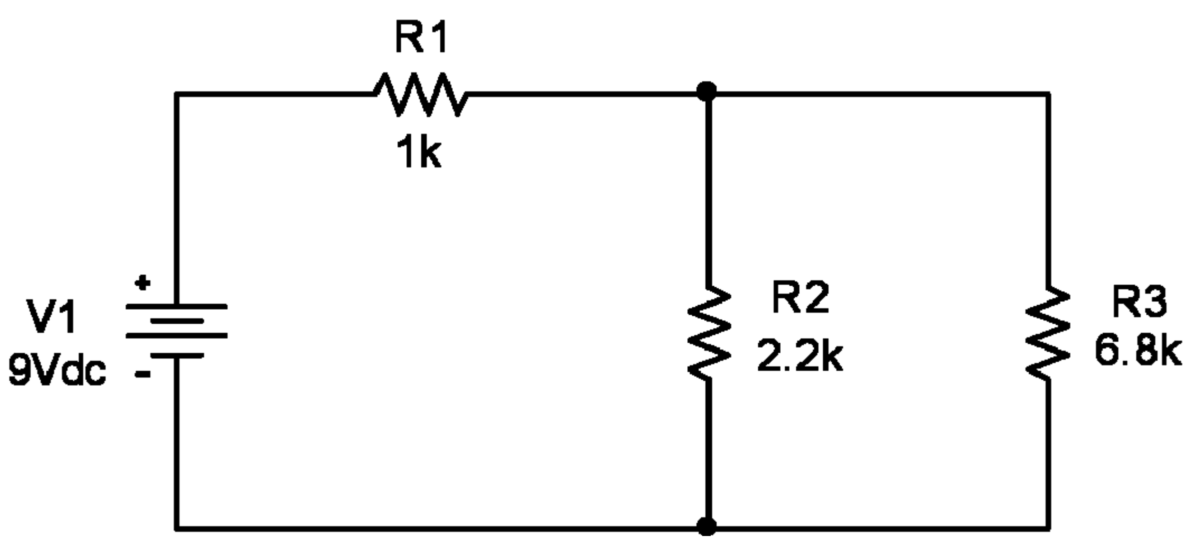
The "Measuring Simple Circuits" experiment was an exercise in the use of the Digital Multimeter. With the use of the multimeter we measured voltage, current, and resistance. Also Ohms law, Kirchhoff's voltage law, and Kirchhoff's current law are used to calculate expected results to verify our measurements.

Materials:

1. 1 9V power supply
2. 1 1kΩ resistor, ¼ Watt
3. 1 2.2kΩ resistor, ¼ Watt
4. 1 6.8kΩ resistor, ¼ Watt
5. 3 red alligator clips and 2 black alligator clips

Procedure:

1. The circuit was connected per the following diagram



2. The battery voltage and voltage across R_1, R_2, and R_3 were measured with the DMM.

   V1 = 8.8 Volts
   V_{R1} = 3.3 Volts
   V_{R2}= 5.5 Volts
   V_{R3}= 5.5 Volts

3. The current of R_1, R_2, and R_3 were measured with the DMM

   $I_{T(R1)}$ = 3.36 mA
   I_{R2} = 2.54 mA
   I_{R3} = .82 mA

4. The resistance of the resistors was determined based on their color code

   R_1 = Brown, Black, Red, Gold = $10 \times 100 \pm 5\%$ = 1000Ω (1kΩ) $\pm 50\Omega$
   Range = 950Ω to 1050Ω
   R_2 = Red, Red, Red, Gold = $22 \times 100 \pm 5\%$ = 2200Ω (2.2kΩ) $\pm 110\Omega$
   Range = 2090Ω to 2310Ω
   R_3 = Blue, Gray, Red, Gold = $68 \times 100 \pm 5\% = 6800\Omega \pm 340\Omega$
   Range = 6460Ω to 7140Ω

5. The resistance of the resistors was measured with the DMM

   R_1 = 985Ω
   $R_2 = 2170\Omega$
   $R_3 = 6740\Omega$

Discussion:

1. Values for V_{R1} , V_{R2} , V_{R3} , $I_{T\,(R1)}$, I_{R2} , and I_{R3} are calculated using the measured values of the power supply and resistors.

$$R_T = R_1 + \frac{R_2 \times R_3}{R_2 + R_3} = 985 + \frac{2170 \times 6740}{2170 + 6740} = 985 + 1640 = 2625\Omega\ OR\ 2.6k\Omega$$

$$I_T = \frac{V_T}{R_T} = \frac{8.8}{2625} = 0.00335A = 3.35mA$$

$$V_{R1} = I_T \times R_1 = 0.00335 \times 985 = 3.3V$$

$$V_{R2} = V_{R3} = V1 - V_{R1} = 8.8 - 3.3 = 5.5V$$

$$I_{R2} = \frac{V_{R2}}{R_2} = \frac{5.5}{2170} = 0.00253A = 2.53mA$$

$$I_{R3} = \frac{V_{R3}}{R_3} = \frac{5.5}{6740} = 0.000816A = 0.816mA$$

Some of the measured values are slightly different from the calculated values due to the accuracy of the volt meters and the finite, albeit small, resistance of the conductors used in the experiment.

2. The power dissipated in each resistor along with the total power dissipated is as follows.

$$P_{R1} = I_{R1} \times V_{R1} = .00335 \times 3.3 = 0.0111W = 11.1mW$$

$$P_{R2} = I_{R2} \times V_{R2} = .00253 \times 5.5 = 0.0139W = 13.9mW$$

$$P_{R3} = I_{R3} \times V_{R3} = .000816 \times 5.5 = 0.00449W = 4.49mW$$

$$P_T = I_T \times V_1 = .00335 \times 8.8 = 0.02948W = 29.48mW$$

3. If the power supply was replaced with a battery with a capacity of 1500mAh its life expectancy is calculated as follows.

$$T = \frac{Ah}{I_T} = \frac{1.5}{0.00335} = 447.76\ hours$$

Conclusion:

The "Measuring Simple Circuits" lab demonstrated the proper measuring methods for DC voltage, current, and resistance with a multimeter. Ohm's law and Kirchhoff's voltage law were also used to verify the measurements. The resistor color code learned in the lecture was utilized to calculate the expected values of the resistors and to verify that the resistors were within their manufacturing tolerance. The power dissipated in each resistor and total power dissipated was calculated along with the life expectancy of a battery utilized to power the given circuit.

General guidelines for generating lab reports

1. All equations must be shown first in equation form (with the letters), then with the equivalent values of all the variables in place, then finally with the answers. Look at the example lab in the discussion section for an example. Use appropriate subscripts when necessary. Use the Microsoft equation editor to generate these equations. Search online if you don't know how to use it or just ask.

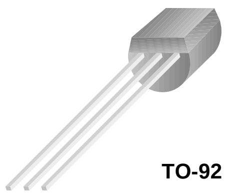
2. All circuits that are constructed must be drawn accurately by using an electrical cad package. DO NOT SCAN IN THE LAB HANDOUT AND COPY THE PICTURE. YOU MIGHT AS WELL NOT DO IT AT ALL! There is a free electrical cad program at http://www.expresspcb.com. You can install it on your own computer if you wish. Again, if you have trouble using it, just ask. Please do not use Microsoft Word to "draw" the circuits. I won't accept the lab report that way. However, any other electrical cad program is sufficient.

3. Each individual should create their own lab report. That means that each individual should draw their own circuit and generate their own equations. Your report should not look exactly the same as someone else in the class, especially your partner!

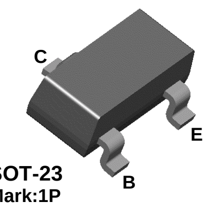
4. Please don't copy the abstract, discussion, or conclusion from the example lab report and use it as your own. Not only is that academic dishonesty, but it also won't suffice for subsequent lab reports as they are different.

FAIRCHILD SEMICONDUCTOR®

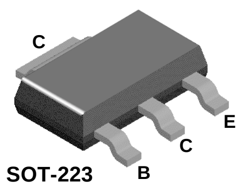
PN2222A MMBT2222A PZT2222A



TO-92



SOT-23
Mark:1P



SOT-223

NPN General Purpose Amplifier

- This device is for use as a medium power amplifier and switch requiring collector currents up to 500mA.
- Sourced from process 19.

Absolute Maximum Ratings * T_a=25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	75	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current	1.0	A
T_{STG}	Operating and Storage Junction Temperature Range	- 55 ~ 150	°C

* These ratings are limiting values above which the serviceability of any semiconductor device may be impaired

NOTES:
1) These ratings are based on a maximum junction temperature of 150 degrees C.
2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations

Electrical Characteristics T_a=25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
Off Characteristics					
$BV_{(BR)CEO}$	Collector-Emitter Breakdown Voltage *	I_C = 10mA, I_B = 0	40		V
$BV_{(BR)CBO}$	Collector-Base Breakdown Voltage	I_C = 10μA, I_E = 0	75		V
$BV_{(BR)EBO}$	Emitter-Base Breakdown Voltage	I_E = 10μA, I_C = 0	6.0		V
I_{CEX}	Collector Cutoff Current	V_{CE} = 60V, $V_{EB(off)}$ = 3.0V		10	nA
I_{CBO}	Collector Cutoff Current	V_{CB} = 60V, I_E = 0 V_{CB} = 60V, I_E = 0, T_a = 125°C		0.01 10	μA μA
I_{EBO}	Emitter Cutoff Current	V_{EB} = 3.0V, I_C = 0		10	μA
I_{BL}	Base Cutoff Current	V_{CE} = 60V, $V_{EB(off)}$ = 3.0V		20	μA
On Characteristics					
h_{FE}	DC Current Gain	I_C = 0.1mA, V_{CE} = 10V I_C = 1.0mA, V_{CE} = 10V I_C = 10mA, V_{CE} = 10V I_C = 10mA, V_{CE} = 10V, T_a = -55°C I_C = 150mA, V_{CE} = 10V * I_C = 150mA, V_{CE} = 10V * I_C = 500mA, V_{CE} = 10V *	35 50 75 35 100 50 40	 300 	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage *	I_C = 150mA, V_{CE} = 10V I_C = 500mA, V_{CE} = 10V		0.3 1.0	V V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage *	I_C = 150mA, V_{CE} = 10V I_C = 500mA, V_{CE} = 10V	0.6	1.2 2.0	V V

* Pulse Test: Pulse Width ≤ 300μs, Duty Cycle ≤ 2.0%

Electrical Characteristics Ta=25°C unless otherwise noted (Continued)

Symbol	Parameter	Test Condition	Min.	Max.	Units
Small Signal Characteristics					
f_T	Current Gain Bandwidth Product	I_C = 20mA, V_{CE} = 20V, f = 100MHz	300		MHz
C_{obo}	Output Capacitance	V_{CB} = 10V, I_E = 0, f = 1MHz		8.0	pF
C_{ibo}	Input Capacitance	V_{EB} = 0.5V, I_C = 0, f = 1MHz		25	pF
$rb'C_c$	Collector Base Time Constant	I_C = 20mA, V_{CB} = 20V, f = 31.8MHz		150	pS
NF	Noise Figure	I_C = 100μA, V_{CE} = 10V, R_S = 1.0KΩ, f = 1.0KHz		4.0	dB
$Re(h_{ie})$	Real Part of Common-Emitter High Frequency Input Impedance	I_C = 20mA, V_{CE} = 20V, f = 300MHz		60	Ω
Switching Characteristics					
t_d	Delay Time	V_{CC} = 30V, $V_{EB(off)}$ = 0.5V, I_C = 150mA, I_{B1} = 15mA		10	ns
t_r	Rise Time			25	ns
t_s	Storage Time	V_{CC} = 30V, I_C = 150mA, I_{B1} = I_{B2} = 15mA		225	ns
t_f	Fall Time			60	ns

Thermal Characteristics T_a=25°C unless otherwise noted

Symbol	Parameter	Max.			Units
		PN2222A	*MMBT2222A	**PZT2222A	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

* Device mounted on FR-4 PCB 1.6” × 1.6” × 0.06”.
** Device mounted on FR-4 PCB 36mm × 18mm × 1.5mm; mounting pad for the collector lead min. 6cm^2.

Spice Model

NPN (Is = 14.34f Xti = 3 Eg = 1.11 Vaf = 74.03 Bf = 255.9 Ne = 1.307 Ise = 14.34 Ikf = .2847 Xtb = 1.5 Br = 6.092 Isc = 0 Ikr = 0 Rc = 1 Cjc = 7.306p Mjc = .3416 Vjc = .75 Fc = .5 Cje = 22.01p Mje = .377 Vje = .75 Tr = 46.91n Tf = 411.1p Itf = .6 Vtf = 1.7 Xtf = 3 Rb = 10)

Typical Characteristics

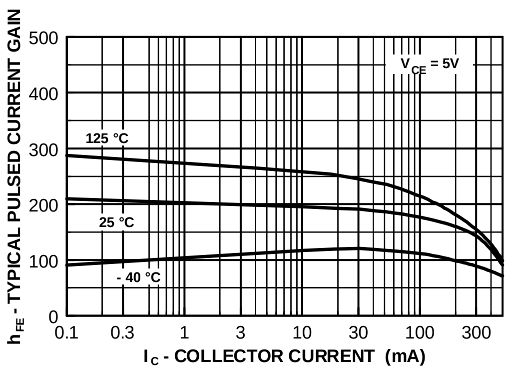


Figure 1. Typical Pulsed Current Gain vs Collector Current

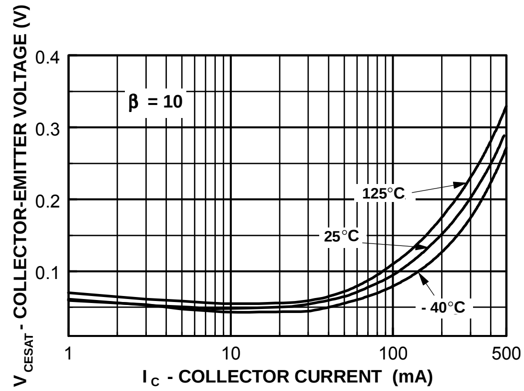


Figure 2. Collector-Emitter Saturation Voltage vs Collector Current

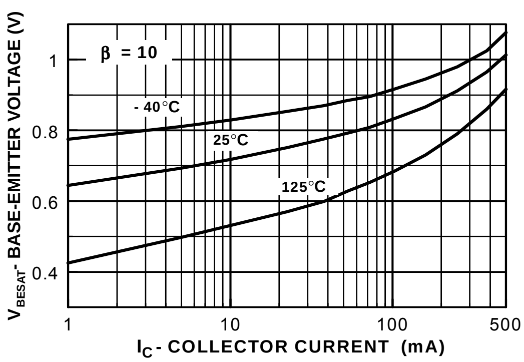


Figure 3. Base-Emitter Saturation Voltage vs Collector Current

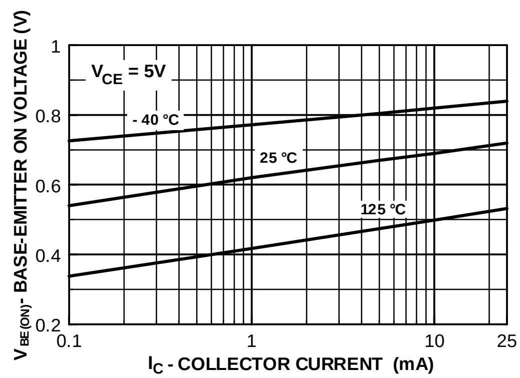


Figure 4. Base-Emitter On Voltage vs Collector Current

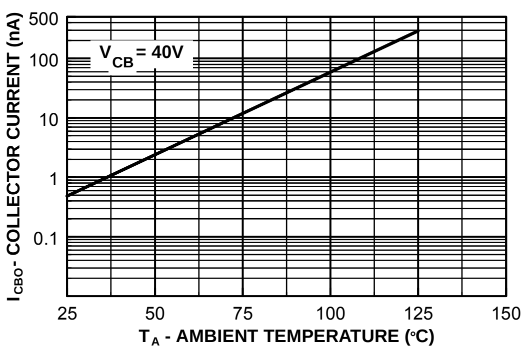


Figure 5. Collector Cutoff Current vs Ambient Temperature

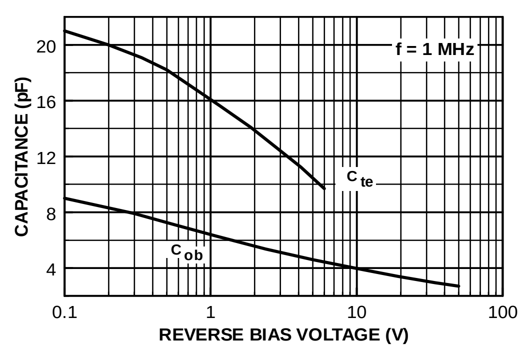


Figure 6. Emitter Transition and Output Capacitance vs Reverse Bias Voltage

Typical Characteristics

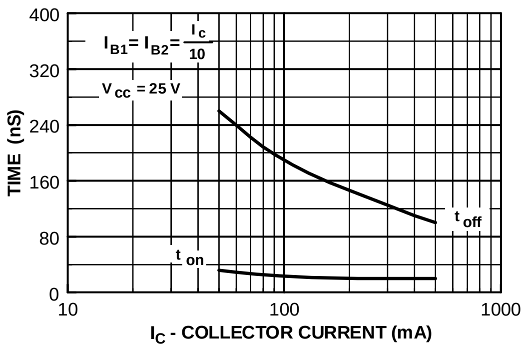


Figure 7. Turn On and Turn Off Times vs Collector Current

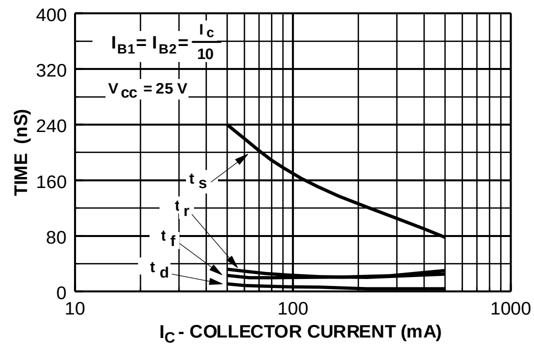


Figure 8. Switching Times vs Collector Current

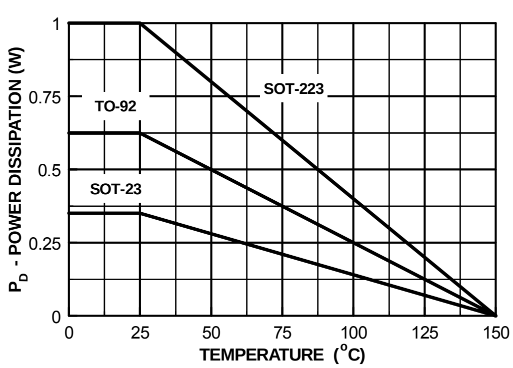


Figure 9. Power Dissipation vs Ambient Temperature

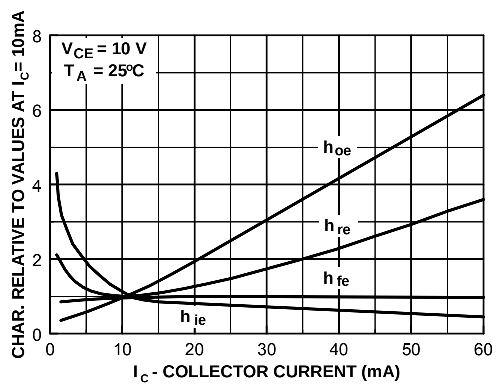


Figure 10. Common Emitter Characteristics

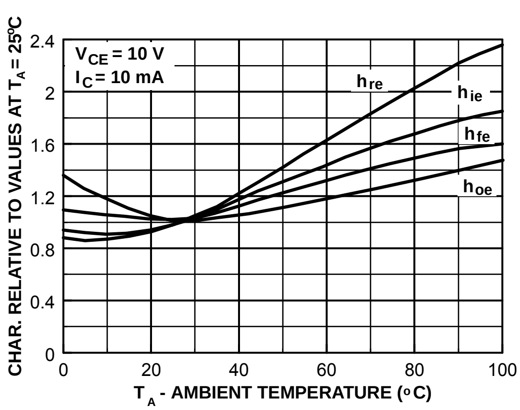


Figure 11. Common Emitter Characteristics

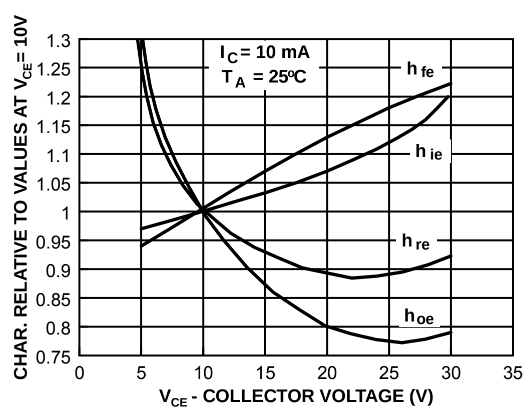
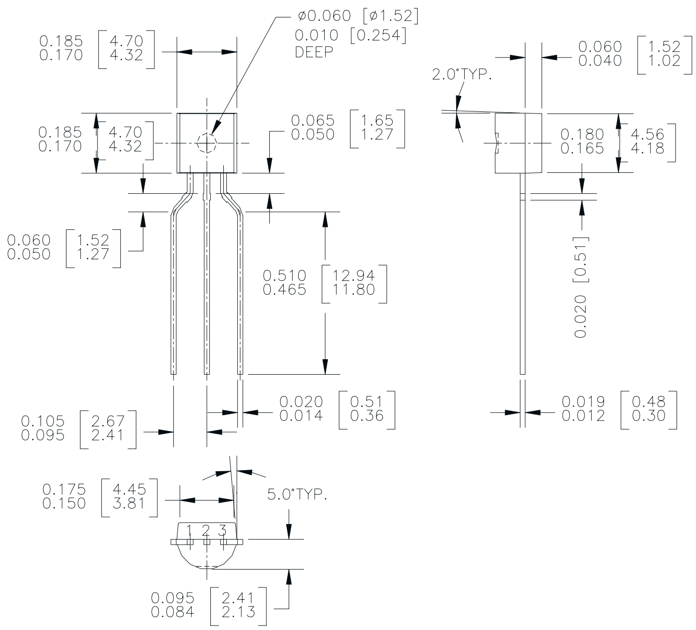


Figure 12. Common Emitter Characteristics

Package Dimensions

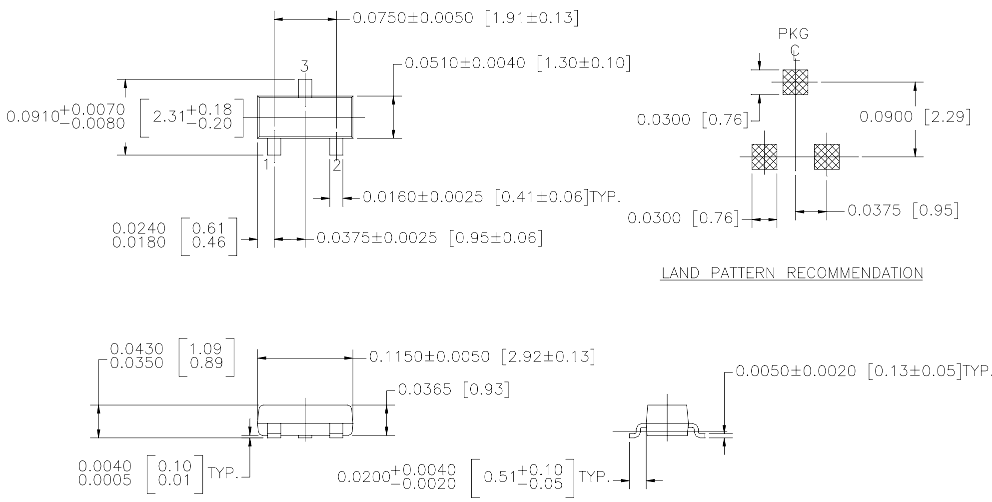
TO-92



Dimensions in Millimeters

Package Dimensions (Continued)

SOT-23



LAND PATTERN RECOMMENDATION

SOT 23, 3 LEADS LOW PROFILE

CONTROLLING DIMENSION IS INCH
VALUES IN [ ] ARE MILLIMETERS

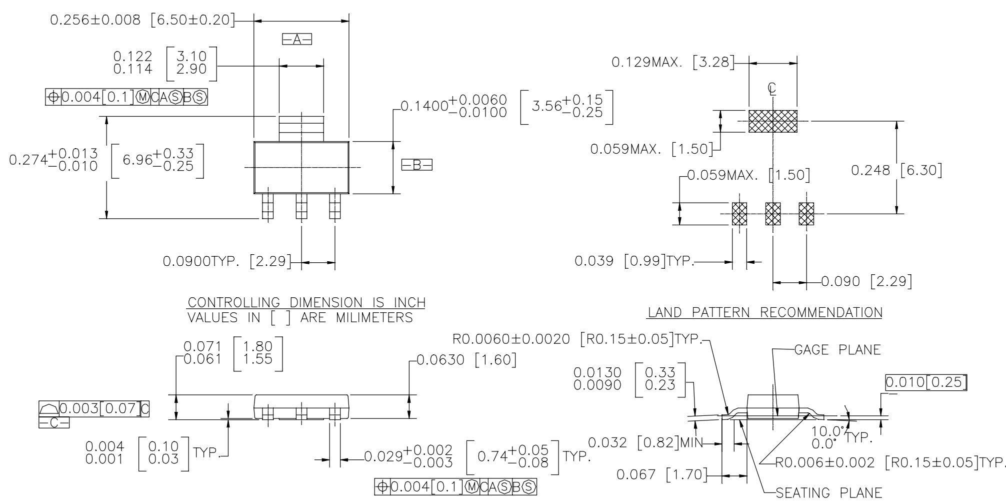
NOTE : UNLESS OTHERWISE SPECIFIED

1. STANDARD LEAD FINISH 150 MICROINCHES / 3.81 MICROMETERS MINIMUM TIN / LEAD (SOLDER) ON ALLOY 42
2. REFERENCE JEDEC REGISTRATION TO−236, VARIATION AB, ISSUE G, DATED JUL 1993

Dimensions in Millimeters

Package Dimensions (Continued)

SOT-223



NOTES : UNLESS OTHERWISE SPECIFIED
1. STANDARD LEAD FINISH TO BE 150 MICROINCHES/ 3.81 MICROMETERS MINIMUM TIN/LEAD (SOLDER) ON COPPER.
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SOT223, 4 LEADS

Dimensions in Millimeters

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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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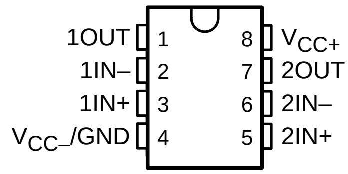
Definition of Terms

Datasheet Identification	Product Status	Definition
Advance Information	Formative or In Design	This datasheet contains the design specifications for product development. Specifications may change in any manner without notice.
Preliminary	First Production	This datasheet contains preliminary data, and supplementary data will be published at a later date. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
No Identification Needed	Full Production	This datasheet contains final specifications. Fairchild Semiconductor reserves the right to make changes at any time without notice in order to improve design.
Obsolete	Not In Production	This datasheet contains specifications on a product that has been discontinued by Fairchild semiconductor. The datasheet is printed for reference information only.

- **Wide Gain-Bandwidth Product . . . 4 MHz**
- **High Slew Rate . . . 13 V/μs**
- **Fast Settling Time . . . 1.1 μs to 0.1%**
- **Wide-Range Single-Supply Operation . . . 4 V to 36 V**
- **Wide Input Common-Mode Range Includes Ground (V_{CC-})**
- **Low Total Harmonic Distortion . . . 0.02%**
- **Large-Capacitance Drive Capability . . . 10,000 pF**
- **Output Short-Circuit Protection**

D OR P PACKAGE
(TOP VIEW)



description/ordering information

Quality, low-cost, bipolar fabrication with innovative design concepts is employed for the TL3472 operational amplifier. This device offers 4 MHz of gain-bandwidth product, 13-V/μs slew rate, and fast settling time, without the use of JFET device technology. Although the TL3472 can be operated from split supplies, it is particularly suited for single-supply operation because the common-mode input voltage range includes ground potential (V_{CC-}). With a Darlington transistor input stage, this device exhibits high input resistance, low input offset voltage, and high gain. The all-npn output stage, characterized by no dead-band crossover distortion and large output voltage swing, provides high-capacitance drive capability, excellent phase and gain margins, low open-loop high-frequency output impedance, and symmetrical source/sink ac frequency response. This low-cost amplifier is an alternative to the MC33072 and the MC34072 operational amplifiers.

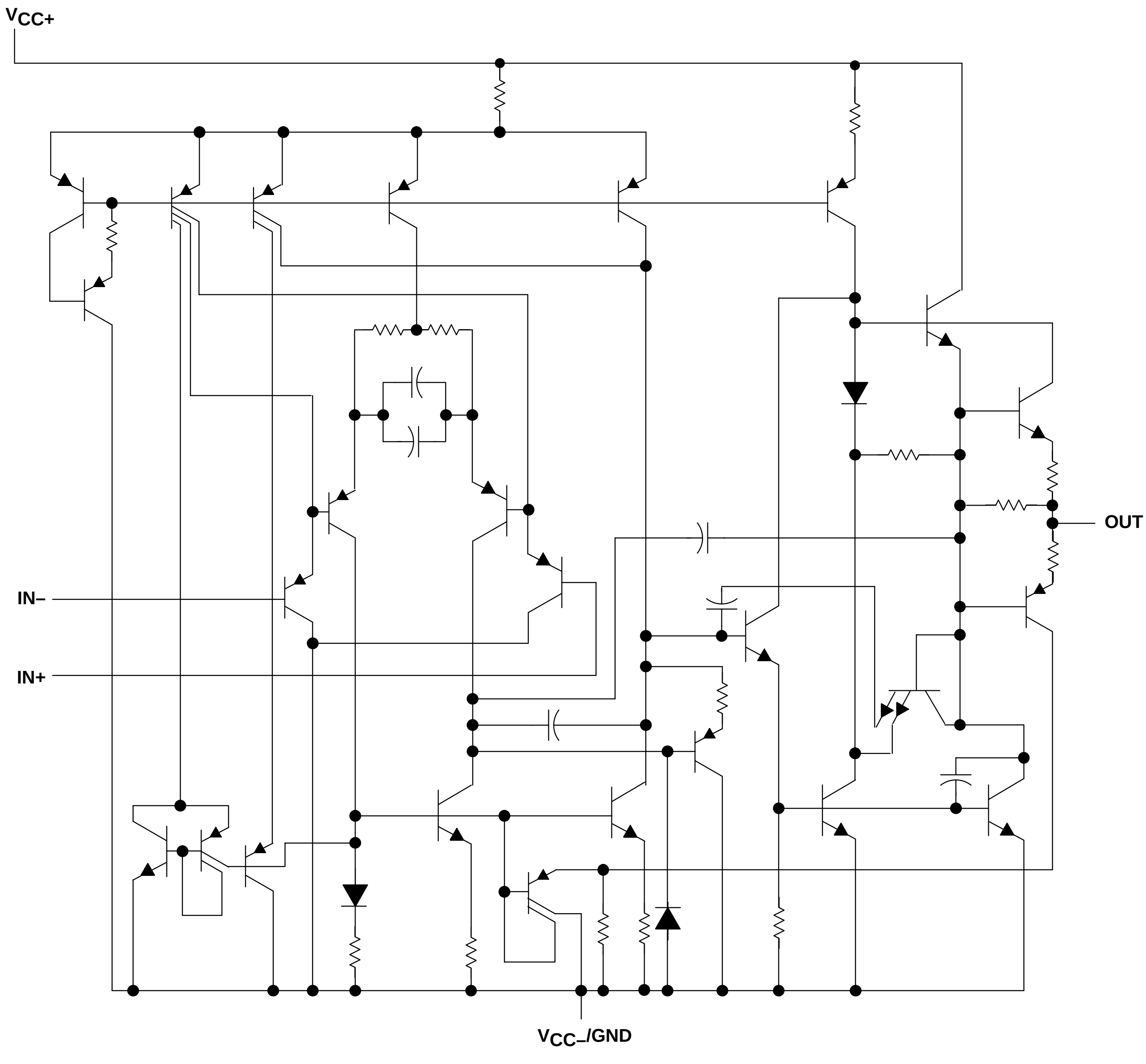
ORDERING INFORMATION

T_A	PACKAGE†		ORDERABLE PART NUMBER	TOP-SIDE MARKING
0°C to 70°C	PDIP (P)	Tube of 25	TL3472CP	TL3472CP
	SOIC (D)	Tube of 50	TL3472CD	3472C
		Reel of 2500	TL3472CDR	
–40°C to 105°C	PDIP (P)	Tube of 25	TL3472IP	TL3472IP
	SOIC (D)	Tube of 50	TL3472ID	Z3472
		Reel of 2500	TL3472IDR	

† Package drawings, standard packing quantities, thermal data, symbolization, and PCB design guidelines are available at www.ti.com/sc/package.

Please be aware that an important notice concerning availability, standard warranty, and use in critical applications of Texas Instruments semiconductor products and disclaimers thereto appears at the end of this data sheet.

schematic (each amplifier)



absolute maximum ratings over operating free-air temperature range (unless otherwise noted)†

Supply voltage (see Note 1): V_{CC+} . . . . 18 V
V_{CC-} . . . . –18 V
Differential input voltage, V_{ID} (see Note 2) . . . . ±36 V
Input voltage, V_I (any input) . . . . $V_{CC\pm}$
Input current, I_I (each input) . . . . ±1 mA
Output current, I_O . . . . ±80 mA
Total current into V_{CC+} . . . . 80 mA
Total current out of V_{CC-} . . . . 80 mA
Duration of short-circuit current at (or below) 25°C (see Note 3) . . . . Unlimited
Package thermal impedance, θ_{JA} (see Notes 4 and 5): D package . . . . 97°C/W
P package . . . . 85°C/W
Operating virtual junction temperature, T_J . . . . 150°C
Lead temperature 1.6 mm (1/16 inch) from case for 10 seconds . . . . 260°C
Storage temperature range, T_{stg} . . . . –65°C to 150°C

† Stresses beyond those listed under "absolute maximum ratings" may cause permanent damage to the device. These are stress ratings only, and functional operation of the device at these or any other conditions beyond those indicated under "recommended operating conditions" is not implied. Exposure to absolute-maximum-rated conditions for extended periods may affect device reliability.

NOTES: 1. All voltage values, except differential voltages, are with respect to the midpoint between V_{CC+} and V_{CC-}.
2. Differential voltages are at the noninverting input with respect to the inverting input. Excessive input current can flow when the input is less than V_{CC-} – 0.3 V.
3. The output can be shorted to either supply. Temperature and/or supply voltages must be limited to ensure that the maximum dissipation rating is not exceeded.
4. Maximum power dissipation is a function of T_J(max), θ_{JA}, and T_A. The maximum allowable power dissipation at any allowable ambient temperature is $P_D = (T_J(max) – T_A)/\theta_{JA}$. Operating at the absolute maximum T_J of 150°C can impact reliability.
5. The package thermal impedance is calculated in accordance with JESD 51-7.

recommended operating conditions

			MIN	MAX	UNIT
$V_{CC\pm}$	Supply voltage		4	36	V
V_{IC}	Common-mode input voltage	V_{CC} = 5 V	0	2.8	V
		$V_{CC\pm}$ = ±15 V	–15	12.8	
T_A	Operating free-air temperature	TL3472C	0	70	°C
		TL3472I	–40	105	

electrical characteristics at specified free-air temperature, $V_{CC\pm} = \pm15$ V (unless otherwise noted)

PARAMETER		TEST CONDITIONS		T_A	MIN	TYP†	MAX	UNIT
V_{IO}	Input offset voltage	$V_{IC} = 0$, $V_O = 0$, $R_S = 50\ \Omega$	$V_{CC} = 5$ V	25°C		1.5	10	mV
			$V_{CC} = \pm15$ V	25°C		1.0	10	
				Full range‡			12	
$\alpha_{V_{IO}}$	Temperature coefficient of input offset voltage		$V_{CC} = \pm15$ V	Full range‡		10		μV/°C
I_{IO}	Input offset current		$V_{CC} = \pm15$ V	25°C		6	75	nA
				Full range‡			300	
I_{IB}	Input bias current		$V_{CC} = \pm15$ V	25°C		100	500	nA
				Full range‡			700	
V_{ICR}	Common-mode input voltage range	$R_S = 50\ \Omega$		25°C		–15 to 12.8		V
				Full range‡		–15 to 12.8		
V_{OH}	High-level output voltage	$V_{CC+} = 5$ V, $V_{CC-} = 0$, $R_L = 2$ kΩ		25°C	3.7	4		V
		$R_L = 10$ kΩ		25°C	13.6	14		
		$R_L = 2$ kΩ		Full range‡	13.4			
V_{OL}	Low-level output voltage	$V_{CC+} = 5$ V, $V_{CC-} = 0$, $R_L = 2$ kΩ		25°C		0.1	0.3	V
		$R_L = 10$ kΩ		25°C		–14.7	–14.3	
		$R_L = 2$ kΩ		Full range‡			–13.5	
A_{VD}	Large-signal differential voltage amplification	$V_O = \pm10$ V, $R_L = 2$ kΩ		25°C	25	100		V/mV
				Full range‡	20			
I_{OS}	Short-circuit output current	Source: $V_{ID} = 1$ V, $V_O = 0$		25°C	–10	–34		mA
		Sink: $V_{ID} = -1$ V, $V_O = 0$			20	27		
CMRR	Common-mode rejection ratio	$V_{IC} = V_{ICR}$(min), $R_S = 50\ \Omega$		25°C	65	97		dB
k_{SVR}	Supply-voltage rejection ratio ($\Delta V_{CC\pm}/\Delta V_{IO}$)	$V_{CC\pm} = \pm13.5$ V to ±16.5 V, $R_S = 100\ \Omega$		25°C	70	97		dB
I_{CC}	Supply current (per channel)	$V_O = 0$, No load		25°C		3.5	4.5	mA
				Full range‡		4.5	5.5	
		$V_{CC+} = 5$ V, $V_O = 2.5$ V, $V_{CC-} = 0$, No load		25°C		3.5	4.5	

† All typical values are at $T_A = 25$°C.
‡ Full range is 0°C to 70°C for the TL3472C device and –40°C to 105°C for the TL3472I device.

operating characteristics, $V_{CC\pm} = \pm 15$ V, $T_A = 25°C$

PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
SR+	Positive slew rate	V_I = –10 V to 10 V, R_L = 2 kΩ, C_L = 300 pF	A_V = 1	8	10		V/µs
SR–	Negative slew rate		A_V = –1		13		V/µs
t_s	Settling time	A_{VD} = –1, 10-V step	To 0.1%		1.1		µs
			To 0.01%		2.2		
V_n	Equivalent input noise voltage	f = 1 kHz,	R_S = 100 Ω		49		nV/√Hz
I_n	Equivalent input noise current	f = 1 kHz			0.22		pA/√Hz
THD	Total harmonic distortion	$V_{O(PP)}$ = 2 V to 20 V, R_L = 2 kΩ, A_{VD} = 10, f = 10 kHz			0.02		%
GBW	Gain-bandwidth product	f =100 kHz		3	4		MHz
BW	Power bandwidth	$V_{O(PP)}$ = 20 V, R_L = 2 kΩ, A_{VD} = 1, THD = 5.0%			160		kHz
ϕ_m	Phase margin	R_L = 2 kΩ	C_L = 0		70		deg
			C_L = 300 pF		50		
	Gain margin	R_L = 2 kΩ	C_L = 0		12		dB
			C_L = 300 pF		4		
r_i	Differential input resistance	V_{IC} = 0			150		MΩ
C_i	Input capacitance	V_{IC} = 0			2.5		pF
	Channel separation	f = 10 kHz			101		dB
z_o	Open-loop output impedance	f = 1 MHz,	A_V = 1		20		Ω

PACKAGING INFORMATION

Orderable Device	Status [1]	Package Type	Package Drawing	Pins	Package Qty	Eco Plan [2]	Lead/Ball Finish	MSL Peak Temp [3]
TL3472CD	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472CDE4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472CDG4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472CDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472CDRE4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472CDRG4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472CP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type
TL3472CPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type
TL3472ID	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472IDE4	ACTIVE	SOIC	D	8	75	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472IDR	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472IDRE4	ACTIVE	SOIC	D	8	2500	Green (RoHS & no Sb/Br)	CU NIPDAU	Level-2-260C-1YEAR
TL3472IP	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type
TL3472IPE4	ACTIVE	PDIP	P	8	50	Pb-Free (RoHS)	CU NIPDAU	N / A for Pkg Type

(1) The marketing status values are defined as follows:
ACTIVE: Product device recommended for new designs.
LIFEBUY: TI has announced that the device will be discontinued, and a lifetime-buy period is in effect.
NRND: Not recommended for new designs. Device is in production to support existing customers, but TI does not recommend using this part in a new design.
PREVIEW: Device has been announced but is not in production. Samples may or may not be available.
OBSOLETE: TI has discontinued the production of the device.

(2) Eco Plan - The planned eco-friendly classification: Pb-Free (RoHS), Pb-Free (RoHS Exempt), or Green (RoHS & no Sb/Br) - please check http://www.ti.com/productcontent for the latest availability information and additional product content details.
TBD: The Pb-Free/Green conversion plan has not been defined.
Pb-Free (RoHS): TI's terms "Lead-Free" or "Pb-Free" mean semiconductor products that are compatible with the current RoHS requirements for all 6 substances, including the requirement that lead not exceed 0.1% by weight in homogeneous materials. Where designed to be soldered at high temperatures, TI Pb-Free products are suitable for use in specified lead-free processes.
Pb-Free (RoHS Exempt): This component has a RoHS exemption for either 1) lead-based flip-chip solder bumps used between the die and package, or 2) lead-based die adhesive used between the die and leadframe. The component is otherwise considered Pb-Free (RoHS compatible) as defined above.
Green (RoHS & no Sb/Br): TI defines "Green" to mean Pb-Free (RoHS compatible), and free of Bromine (Br) and Antimony (Sb) based flame retardants (Br or Sb do not exceed 0.1% by weight in homogeneous material)

(3) MSL, Peak Temp. -- The Moisture Sensitivity Level rating according to the JEDEC industry standard classifications, and peak solder temperature.

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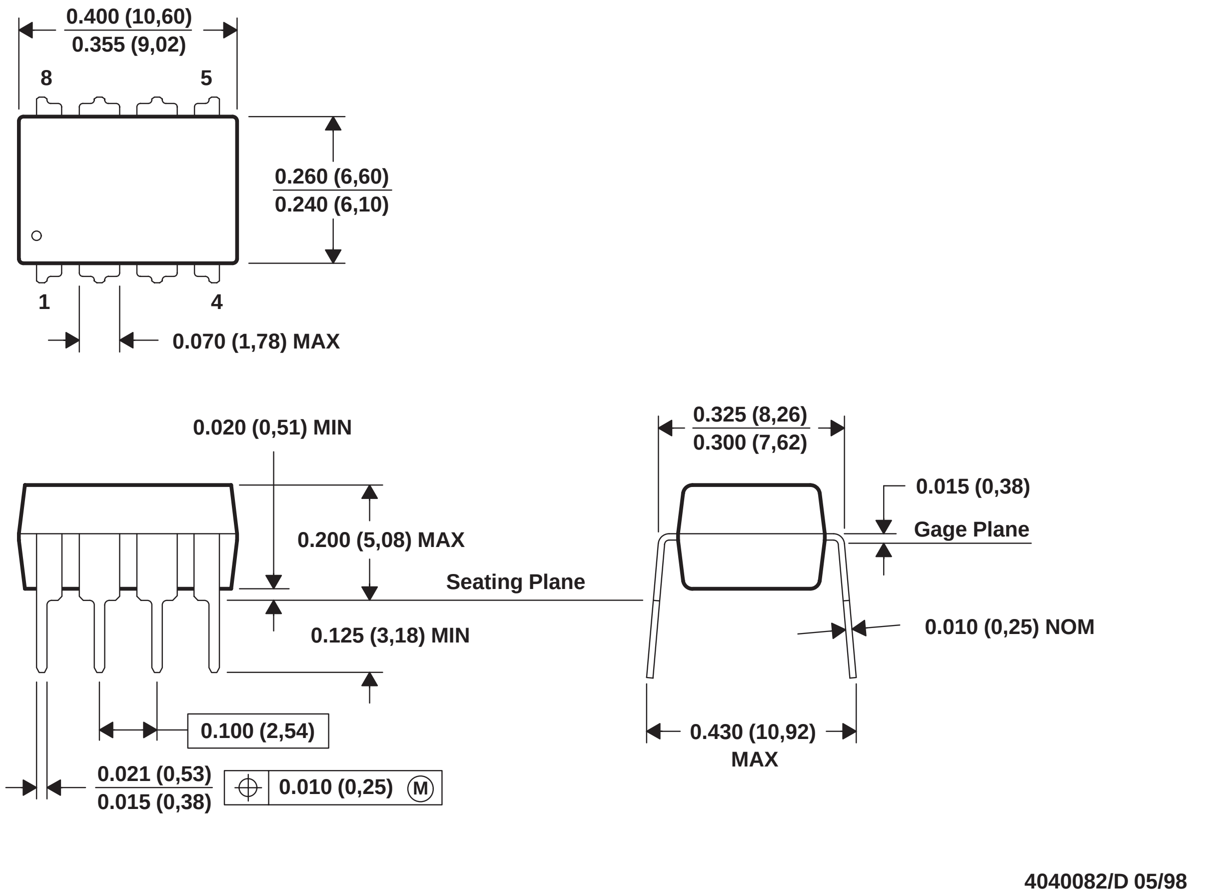
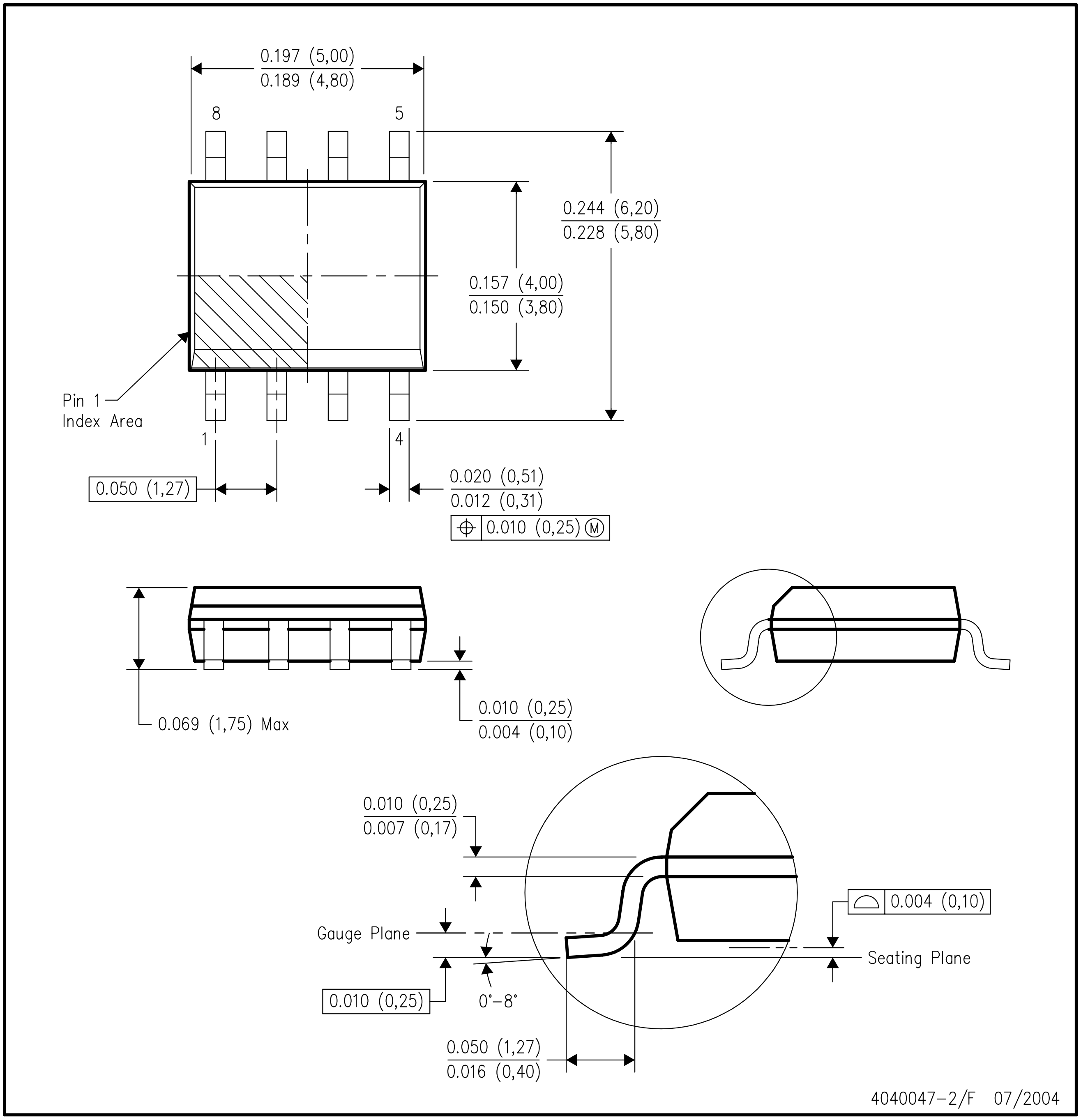
P (R-PDIP-T8) **PLASTIC DUAL-IN-LINE**



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Falls within JEDEC MS-001

D (R–PDSO–G8) PLASTIC SMALL–OUTLINE PACKAGE



NOTES: A. All linear dimensions are in inches (millimeters).
B. This drawing is subject to change without notice.
C. Body dimensions do not include mold flash or protrusion not to exceed 0.006 (0,15).
D. Falls within JEDEC MS–012 variation AA.

IMPORTANT NOTICE

Following are URLs where you can obtain information on other Texas Instruments products and application solutions:

Products		**Applications**	
Amplifiers	amplifier.ti.com	Audio	www.ti.com/audio
Data Converters	dataconverter.ti.com	Automotive	www.ti.com/automotive
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Interface	interface.ti.com	Digital Control	www.ti.com/digitalcontrol
Logic	logic.ti.com	Military	www.ti.com/military
Power Mgmt	power.ti.com	Optical Networking	www.ti.com/opticalnetwork
Microcontrollers	microcontroller.ti.com	Security	www.ti.com/security
		Telephony	www.ti.com/telephony
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Mailing Address: Texas Instruments
Post Office Box 655303 Dallas, Texas 75265