ELR 4202C
MEDICAL INSTRUMENTATION LABORATORY

Herman Watson
Malcolm Heimer
Nonarit O_Larnnithipong

GENERAL INSTRUCTIONS

1.   THE LABORATORY PROCEDURE

Assign one team member to record measured data while others work with the hardware. These roles should be rotated so all team members get "hands on" experience.
Record all measurements in a bound notebook. Be sure to identify all instruments you used in the procedure (the manufacturer and model as well as the serial number).
Record in the laboratory notebook descriptions of all procedures carried out. You should also make notations of observations and any conclusions based on the results.

2.   THE LAB REPORT

The lab report is due one week after the procedure is completed. The cover page must list the course title, the date, names of the team members and a title for the lab. The Table of Contents lists the first page number for all sections. The Procedure section will describe the steps taken, the data that was recorded and observations about the results. Questions posed in the lab handout should be answered within this section and/or in the Conclusions section. The Conclusions section will summarize the lab procedure. Some of the questions posed in the handout will be answered in this section. It should also include a section labeled "lessons learned" that describes the skills and knowledge gained from completing the lab. The Appendix should contain a photo-copy of the original entries in the lab notebook.

SCHEDULE

DATE	TEAMS
Week 2	**LAB ORIENTATION**
Week 3	**LAB #1**
Week 4	**LAB #2**
Week 5	**LAB #3**
Week 6	**LAB #4**

ELR 4202C
LABORATORY #1

I.   Layout of "proto-board"

The breadboard used in this procedure allows a circuit to be fabricated by inserting components into the socket holes. The figure on the next page shown the connections that exist between some of the socket holes. The terminology for this lab: the long rows of holes (marked by red and blue stripes) are called "bus strips". The "groups of 5" are the short columns of holes on both sides of a central "gutter".

Verifying the board connections:

Take a resistor and insert both ends into holes on the same bus strip. Set the digital meter to "ohms", touch the probes to both ends of the resistor and record the resistance reading. Move one end of the resistor to the other bus strip and repeat the measurement. Leave one end in a bus strip and move the other end to one of the groups of 5 holes and repeat the measurement. Remove the resistor and place both ends into holes within the same groups of 5. Measure the resistance between the ends. Move one end of the resistor to the group on the other side of the gutter and repeat. Does this verify the proto-board interconnections shown in the figure?

II.   Measure resistors

The resistors used in this laboratory are either metal film or carbon film.   They are manufactured by depositing the thin film on a cylindrical insulator and etching a helical pattern to attain the proper resistance. It is then covered with a resin and painted with a color code to indicate its nominal resistance value. The gold band indicates that these resistors have a tolerance of ±5% from the nominal value. These resistors have a power rating of ¼ watt. Obtain a copy of the resistor color code and use it to evaluate the resistor values in this procedure.

Your team has been given ten resistors: five each of two different values. Determine the nominal resistance values by interpreting the color code. Insert the resistors into the board and measure their exact values. Calculate the deviation from the nominal values and compare this to the ±5% guaranteed by the manufacturer. Do all of the resistors meet specifications?

Using the breadboard
(Socket board)
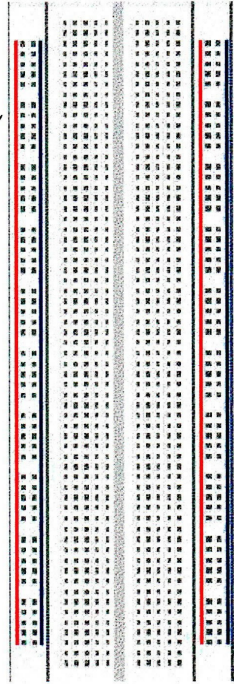
The bread board has many strips of metal (copper usually) which run underneath the board.
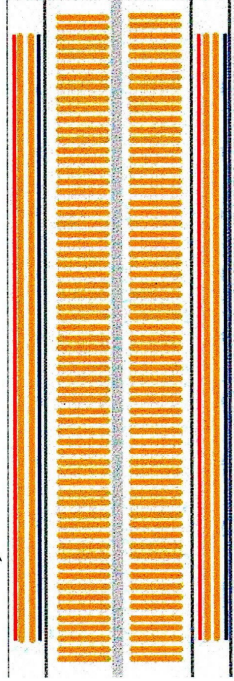
The metal strips are laid out as shown in orange. The long top and bottom row of holes are usually used for power supply connections.

To use the bread board, the legs of components are placed in the holes (the sockets). The holes are made so that they will hold the component in place. The circuit is built by placing components and connecting them together with jumper wires.
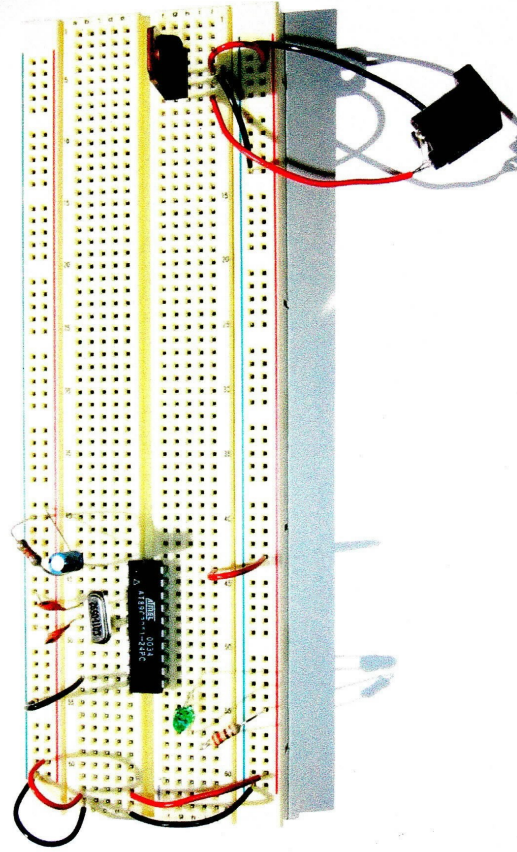
III.   DC resistor circuits

Set the digital meter to the DC volts mode and connect the probes to the output terminals of the power supply. Set the voltage to exactly 5.00 volts. Is there any discrepancy between the external meter and the meter in the power supply? If so, that is the percentage difference?

Turn off the voltage and connect the power supply to bus strips along the top and bottom edges of the board. Use a combination of the connections in the board and jumper wires to create the circuit shown below.
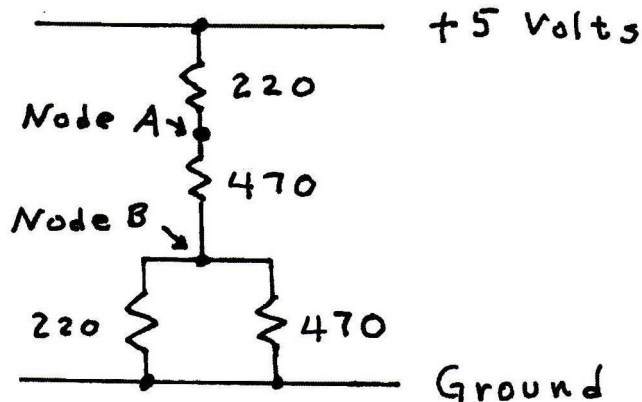
Turn on the power supply and measure the voltage (referenced to ground) on node A. Repeat for node B. For both cases, reduce the circuit to a 2-resistor voltage divider circuit by using the equations for series and parallel resistors. (For node A, the three resistors between node A and ground will be reduced to a single resistance.) Calculate the node voltages using the voltage divider formula and compare them to the measurements. Is the difference within the resistor tolerance?

Remove a jumper wire to open the circuit at either node A or node B. Set the meter to DC current mode and connect the probes to complete the opened circuit. Record the measured current and compare it to the calculated value. Is the difference within the resistor tolerance?

IV.   R-C low pass filter circuit

Remove the DC power supply connection to the board. Turn on the signal generator and the oscilloscope.   Connect the oscilloscope input to the output terminals of the signal generator. Set the signal generator to the sinusoidal mode and a frequency of 500 Hz. Adjust the output amplitude to 10 volts, peak-to-peak.

Connect the signal and ground from the signal generator to the top and lower bus strips previously connected to the DC power supply.
Insert a 10 Kilohm resistor and a 15 nanofarad capacitor to create the circuit shown below.
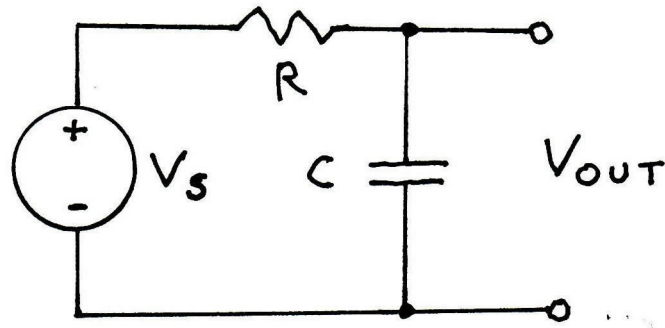
Set the oscilloscope to the 2-channel mode. Connect the top channel to the V_S from the signal generator and the lower channel to the V_{OUT} signal.

Classify this filtering circuit as either high pass or low pass and calculate the pole frequency in Hz. Sketch the Bode plot for this circuit based on the information covered in the lecture. Then, measure the response by observing the signals on the screen as the frequency is changed. Confirm that the input voltage on the upper trace has constant amplitude at all frequencies. Change the frequency over a range from 100 Hz to 10 Khz with three points per decade (e.g. 100, 200, 500, 1000, etc.). Take extra readings near the pole frequency to show more detail.

Calculate the gain in decibels at all frequencies and use this to generate a Bode plot. For the report, overlay both the calculated and measured Bode plots on the same graph and comment on the difference. Is it consistent with the tolerances of the resistor and capacitor values?

V.   Windkessel Model

For the last part of this laboratory you will characterize a circuit that simulates part of the cardiovascular system by modifying the RC circuit in part IV. The resistors and capacitors simulate fluidic parameters. The results allow some insight into the hemodynamic response of the physiological system. The applied voltage (V_S) will be a simulated aortic pressure waveform (AOP.tfw) that has been stored in the memory of the signal generator. To activate that waveform, do the following:

1. press ARBITRARY WAVEFORM button on front panel
2. select ARB. WAVEFORM MENU
3. select INTERNAL MEMORY
4. select USER 1 using knob
5. select OK

The following differential equation relates fluid flow (current) from a pump (the heart) into a flexible pipe (the aorta) and the aortic pressure (voltage) generated:

$$I(t) = \frac{P(t)}{R} + C\frac{dP(t)}{dt}$$

I(t) is the fluid flow out of the heart as a function of time measured in volume per time, P(t) is the water pressure as a function of time measured in force per area, C is equal to the ratio of pressure to volume, and R is the flow-pressure ratio. The same equation describes the relationship between the current, I(t), and the time-varying electric potential, P(t), in the following electrical circuit:

2-element Windkessel model
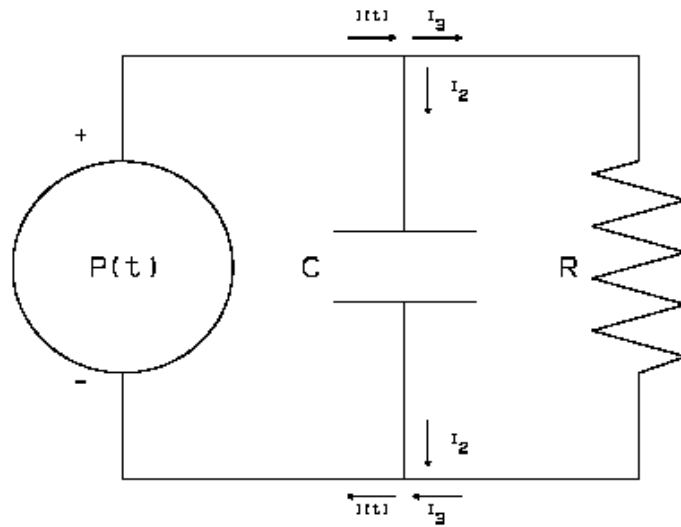
In terms of the physiological system, I(t) is the flow of blood from the heart to the aorta measured in cm^3/sec, P(t) is the blood pressure in the aorta in mmHg, C is the arterial compliance in the aorta in cm^3/mmHg, and R is the peripheral resistance in the systemic arterial system in mmHg.s/cm^3.

A modification of the 2-element model is the 3-element Windkessel model:

3−element Windkessel model
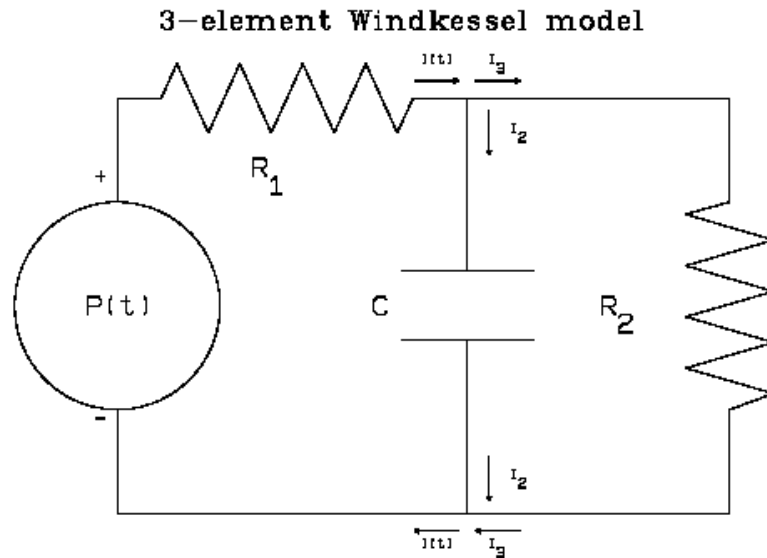
The differential equation for the 3-element Windkessel model is:

$$\left(1+\frac{R_1}{R_2}\right)I(t)+C*R_1\frac{dI(t)}{dt}=\frac{P(t)}{R_2}+C\frac{rP(t)}{dt}$$

where R_1 represents the resistance due to the aortic valve, and R_2 represents the peripheral resistance. I(t), P(t), and C have the same meanings as in the 2-element Windkessel equation.

Build the 2-element model by moving the resistor R in parallel with the capacitor C in the circuit in Part IV. Apply the simulated aortic waveform and record the voltage across the RC parallel network and the current from the voltage source I(t). Next, double the resistance R (simulating hypertension) and again record the voltage and current. What is the effect of hypertension on the pressure and current.

Next, build the 3-element model returning the R (now R_2) to its original value and placing a 1 Kohm resistor R_1 in series with the voltage source and the RC parallel network. Record the output voltage and current through R_1. Double the aortic valve resistance (R_1) and again record the voltage and current. What is the effect of increased aortic valve resistance on pressure and flow?

LABORATORY #2

BASIC OP AMP CIRCUIT

**I. Characteristics and pin-outs of an op amp TLC2274**
    1.) Study the attached datasheets before the lab meeting.
    2.) Mark up the schematic diagram with the pin numbers that will be connected.

II. Connecting power to the op amp
    1.) Designate the bus strips on the proto-board that you will use for power and ground connections. Suggest to use the red stripped bus for +5V and the blue stripped bus for -5V.
    2.) Use a jumper to connect together the two inner bus strips and connect them to ground. Turn off the power supply and insert the op amp IC in the center of the board, bridging the gutter. Then insert jumpers to connect the power pins of the IC to the power buses.

III. Non-Inverting Amplifier circuit
    1.) Connect the circuit diagram as shown below. **Use R_f = 20kΩ**

    2.) Adjust the signal generator to produce a sinusoidal signal at 100Hz with a peak amplitude of ±100mV and connect it to the board.
    3.) Turn on the power supply and record the waveforms of both V_{IN} and V_{OUT}

    4.) Calculate the voltage gain based on the measurement and compare the measured gain to the calculated value.
    5.) Change R_f to 200kΩ, 1MΩ and 10MΩ. Record V_{OUT} waveform and calculate the gain for each value of R_f. (Note that the power supply has to be turned off before modifying the circuit connection.)
    6.) Explain what happened when the value of R_f is changed. How do you expect to the waveform of V_{OUT} if the power supply to the IC is changed to be ±15V?
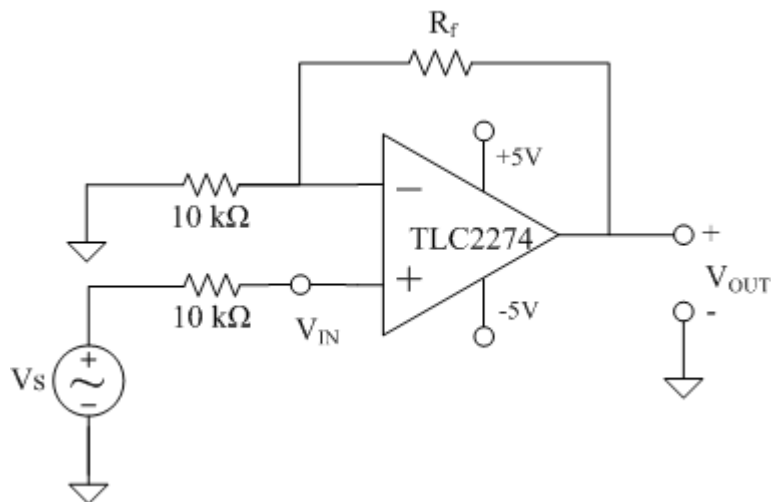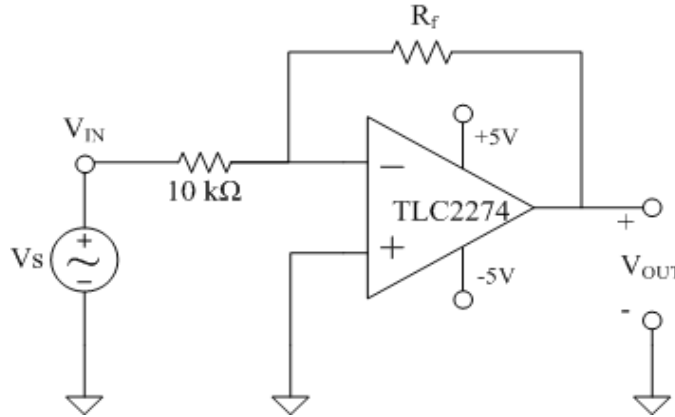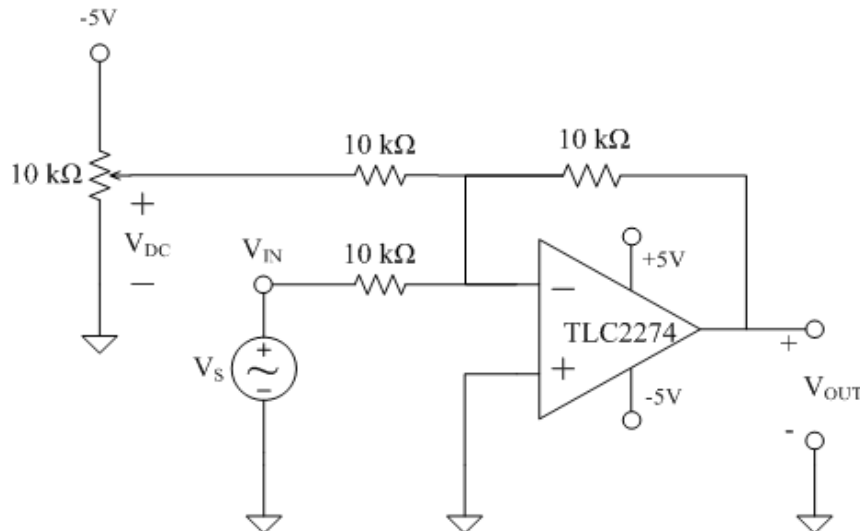
IV. Inverting Amplifier circuit

1.) Connect the circuit diagram as shown below. **Use $R_f = 200k\Omega$**

2.) Adjust the signal generator to produce a sinusoidal signal at 100Hz with a peak amplitude of ±100mV and connect it to the board.

3.) Turn on the power supply and record the waveforms of V_{IN} and V_{OUT}

4.) Calculate the voltage gain based on the measurement

5.) Repeat the steps for the different signal generator with a peak amplitude of ±200mV, ±300mV and ±400mV.

6.) Explain what happened to the outputs of this operation of the op amp.

V. Inverting summing amplifier circuit and its application in eliminating DC offset

1.) Connect the circuit diagram as shown below

2.) Adjust the signal generator (V_S) to produce a sinusoidal signal at 100 Hz with a peak amplitude of ±500 mV **with DC offset of +1 V** and connect it to the board.

3.) Turn on the power supply and adjust the potentiometer until the DC offset in op amp output voltage V_{OUT} is zero.

4.) Record the waveforms of V_{IN}, V_{DC} and V_{OUT}

5.) Explain how does potentiometer eliminate the DC offset in the input signal?

VI. Eliminating DC offset using non-inverting amplifier "High Pass Filter"

1.) Connect the circuit diagram as shown below

2.) Adjust the signal generator (V_S) to produce a sinusoidal signal at 100 Hz with a peak amplitude of ±500 mV **with DC offset of +1 V** and connect it to the board.

3.) Turn on the power supply and record the waveforms of $V_{IN\,1}$, $V_{OUT\,1}$ and $V_{OUT\,2}$

4.) Calculate the voltage gain based on the measurement of both op amp and compare the measured gain to the calculated value.
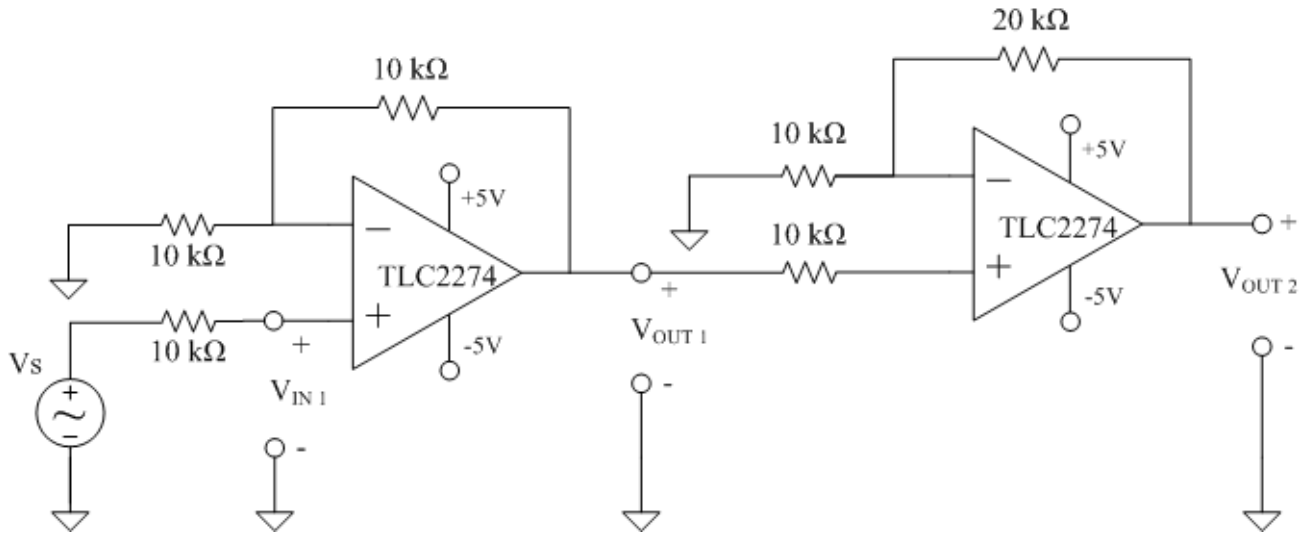
5.) Reconnected the circuit as shown in figure below using same signal generator settings.

6.) Calculate the value of C_1 used in the circuit to obtain the cutoff frequency of 10 Hz

7.) Turn on the power supply and record the waveforms of V_{IN}, V_2 and V_{OUT}

8.) Compare the output waveforms with the previous circuit connection.

9.) Discuss the effect of adding the capacitor into the amplifier circuit.
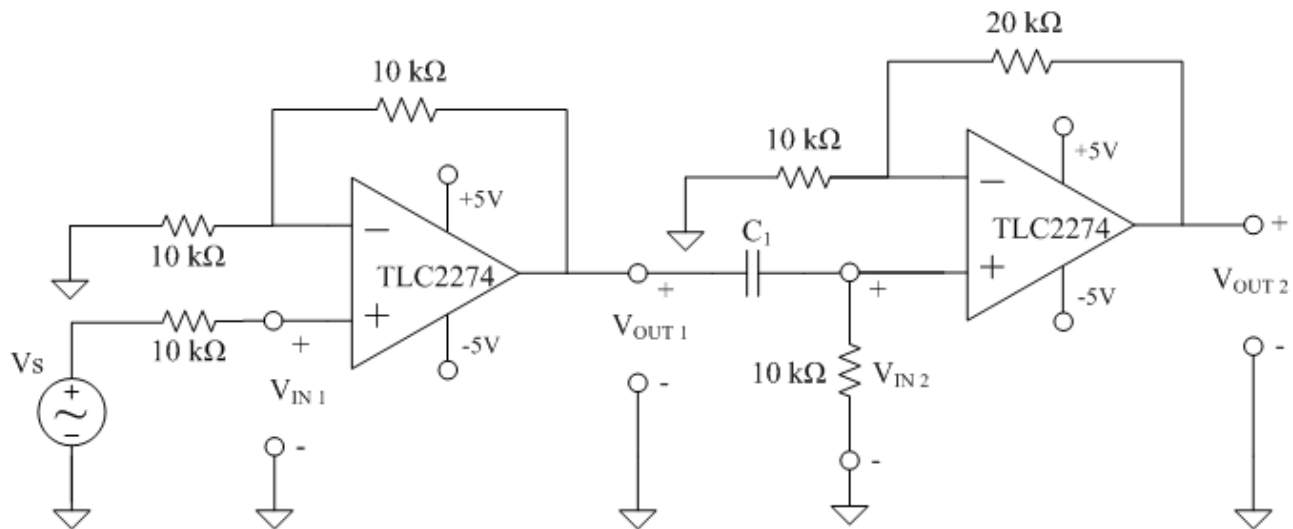
- **Qualified for Automotive Applications**
- **Output Swing Includes Both Supply Rails**
- **Low Noise . . . 9 nV/√Hz Typ at f = 1 kHz**
- **Low Input Bias Current . . . 1 pA Typ**
- **Fully Specified for Both Single-Supply and Split-Supply Operation**
- **Common-Mode Input Voltage Range Includes Negative Rail**

- **High-Gain Bandwidth . . . 2.2 MHz Typ**
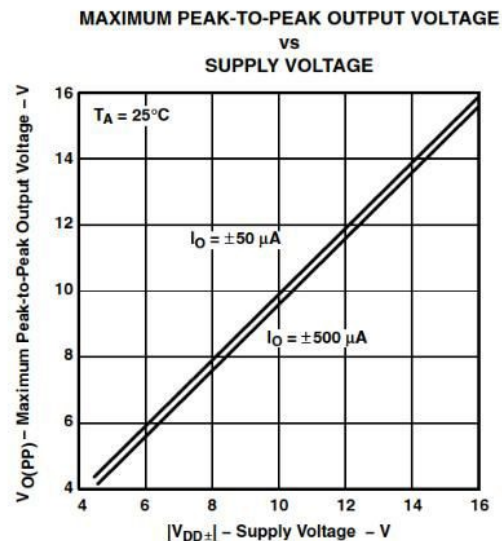- **High Slew Rate . . . 3.6 V/μs Typ**
- **Low Input Offset Voltage 950 μV Max at T_A = 25°C**
- **Macromodel Included**
- **Performance Upgrades for the TS272, TS274, TLC272, and TLC274**

description

The TLC2272 and TLC2274 are dual and quadruple operational amplifiers from Texas Instruments. Both devices exhibit rail-to-rail output performance for increased dynamic range in single- or split-supply applications. The TLC227x family offers 2 MHz of bandwidth and 3 V/μs of slew rate for higher speed applications. These devices offer comparable ac performance while having better noise, input offset voltage, and power dissipation than existing CMOS operational amplifiers. The TLC227x has a noise voltage of 9 nV/√Hz, two times lower than competitive solutions.

The TLC227x, exhibiting high input impedance and low noise, is excellent for small-signal conditioning for high-impedance sources, such as piezoelectric transducers. Because of the micropower dissipation levels, these devices work well in hand-held monitoring and remote-sensing applications. In addition, the rail-to-rail output feature, with single- or split-supplies, makes this family a great choice when interfacing with analog-to-digital converters (ADCs). For precision applications, the TLC227xA family is available with a maximum input offset voltage of 950 μV. This family is fully characterized at 5 V and ±5 V.

MAXIMUM PEAK-TO-PEAK OUTPUT VOLTAGE
vs
SUPPLY VOLTAGE

The TLC2272/4 also makes great upgrades to the TLC272/4 or TS272/4 in standard designs. They offer increased output dynamic range, lower noise voltage, and lower input offset voltage. This enhanced feature set allows them to be used in a wider range of applications. For applications that require higher output drive and wider input voltage range, see the TLV2432 and TLV2442 devices.

Advanced LinCMOS is a trademark of Texas Instruments.

TEXAS INSTRUMENTS

TLC2272
D, JG, P, OR PW PACKAGE
(TOP VIEW)

1OUT	1	8	$V_{DD}+$
1IN−	2	7	2OUT
1IN+	3	6	2IN−
$V_{DD}-$/GND	4	5	2IN+

TLC2274
D, J, N, PW, OR W PACKAGE
(TOP VIEW)

1OUT	1	14	4OUT
1IN−	2	13	4IN−
1IN+	3	12	4IN+
$V_{DD}+$	4	11	$V_{DD}-$
2IN+	5	10	3IN+
2IN−	6	9	3IN−
2OUT	7	8	3OUT

TLC2274
FK PACKAGE
(TOP VIEW)

TLC2272
FK PACKAGE
(TOP VIEW)
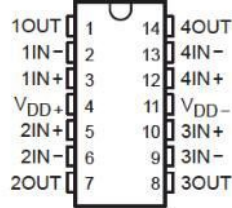
TLC2272
U PACKAGE
(TOP VIEW)

NC	1	10	NC
1 OUT	2	9	$V_{DD}+$
1 IN−	3	8	2 OUT
1 IN+	4	7	2 IN−
$V_{DD}-$/GND	5	6	2 IN+
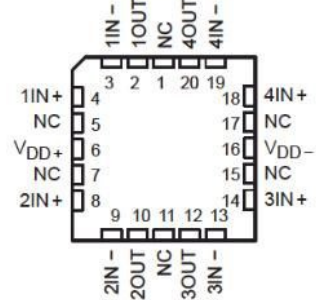
NC – No internal connection

TEXAS
INSTRUMENTS

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

Supply voltage, V_{DD+} (see Note 1) .... 8 V
Supply voltage, V_{DD-} (see Note 1) .... −8 V
Differential input voltage, V_{ID} (see Note 2) .... ±16 V
Input voltage range, V_I (any input, see Note 1) .... V_{DD-} − 0.3 V to V_{DD+}
Input current, I_I (any input) .... ±5 mA
Output current, I_O .... ±50 mA
Total current into V_{DD+} .... ±50 mA
Total current out of V_{DD-} .... ±50 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 (8 pin) .... 97.1°C/W
                                                   D package (14 pin) .... 86.2°C/W
  N package .... 79.7°C/W
  P package .... 84.6°C/W
  PW package (8 pin) .... 149°C/W
  PW package (14 pin) .... 113°C/W
Package thermal impedance, θ_{JC} (see Notes 4 and 5): FK package .... 5.6°C/W
  J package .... 15.1°C/W
  U package .... 14.7°C/W
Operating free-air temperature range, T_A: C suffix .... 0°C to 70°C
  I, Q suffix .... −40°C to 125°C
  M suffix .... −55°C to 125°C
Storage temperature range .... −65°C to 150°C
Lead temperature 1,6 mm (1/16 inch) from case for 10 seconds: D, N, P or PW package .... 260°C
Lead temperature 1,6 mm (1/16 inch) from case for 60 seconds: J or U package .... 300°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_{DD+} and V_{DD-}.
2. Differential voltages are at IN+ with respect to IN−. Excessive current will flow if input is brought below V_{DD-} − 0.3 V.
3. The output may 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 affect reliability.
5. The package thermal impedance is calculated in accordance with JESD 51-7 (plastic) or MIL-STD-883 Method 1012 (ceramic).

recommended operating conditions

	C SUFFIX		I SUFFIX		Q SUFFIX		M SUFFIX		UNIT
	MIN	MAX	MIN	MAX	MIN	MAX	MIN	MAX	
Supply voltage, $V_{DD\pm}$	±2.2	±8	±2.2	±8	±2.2	±8	±2.2	±8	V
Input voltage, V_I	V_{DD-}	V_{DD+} −1.5	V_{DD-}	V_{DD+} −1.5	V_{DD-}	V_{DD+} −1.5	V_{DD-}	V_{DD+} −1.5	V
Common-mode input voltage, V_{IC}	V_{DD-}	V_{DD+} −1.5	V_{DD-}	V_{DD+} −1.5	V_{DD-}	V_{DD+} −1.5	V_{DD-}	V_{DD+} −1.5	V
Operating free-air temperature, T_A	0	70	−40	125	−40	125	−55	125	°C

TEXAS INSTRUMENTS

ELR 4202C
LABORATORY #3

M. HEIMER
FALL, 2007

APPLICATIONS OF AN OP AMP

I.   Characteristics and pin-outs of op amp

Study the attached data sheets before the lab meeting. Mark up the schematic diagrams with the pin numbers that will be connected in the IC.

II.   Connecting power to the op amp

Designate the bus strips on the proto-board that you will use for power and ground connections. It is suggested to use the red stipped bus for +5 volts and the blue stripped bus for -5 volts. Use a jumper to connect together the two inner bus strips and connect them to ground. Turn off the power supply and insert the op amp IC in the center of the board, bridging the gutter. Then insert jumpers to connect the power pins of the IC to the power buses.

III.   Basic amplifier circuits

Insert resistors and jumpers to create the amplifier circuit shown below. Note that the signal generator connected with a series resistor of 10 kilohms simulates a signal source with high internal impedance.
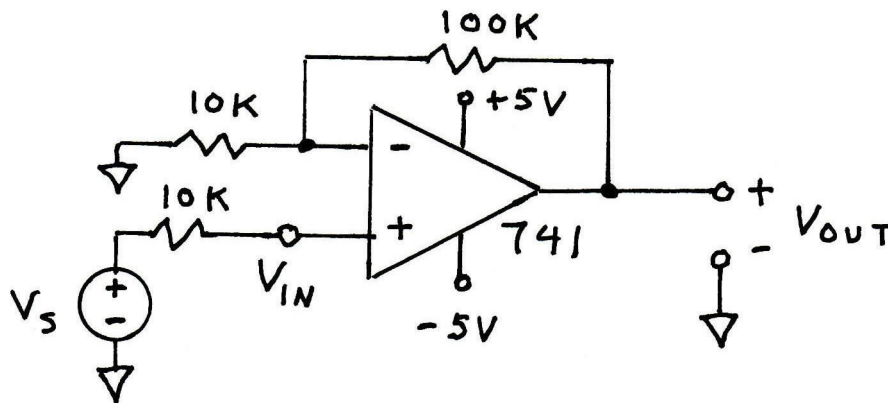
Adjust the signal generator to produce a sinusoid at 100 Hz with a peak amplitude of ±100 millivolts and connect it to the board.   Turn on the power supply and measure both V_{IN} and V_{OUT}. Based on these measurements, calculate the input impedance and the voltage gain for this circuit. Compare the measured gain to the calculate value. Increase the input signal amplitude to 200 mV, 500 mV and 1.0 volt. Record the V_{OUT} waveform and calculate the gain for each input. Explain what happened and relate it to the V_{SAT} parameter from the data sheet.
Turn off the power and modify the board to this inverting amplifier circuit.
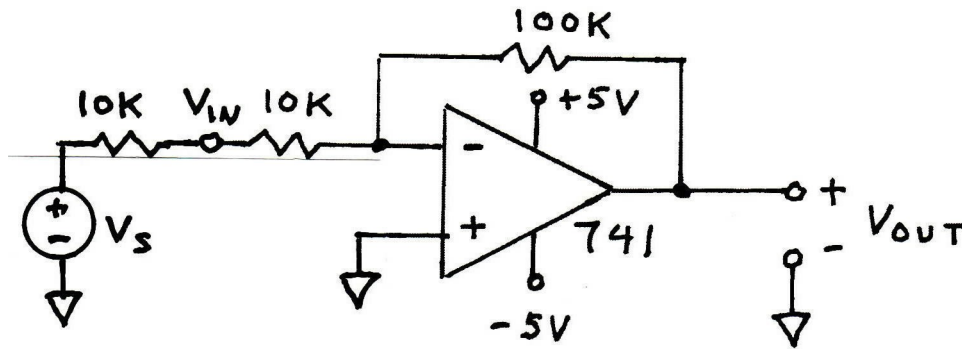
Adjust the signal generator to ±100 mV, turn on the power and measure V_{IN} and V_{OUT}. Based on these measurements, calculate the input impedance and voltage gain of this circuit. Compare to the calculated values.

IV.   ECG Amplifier

Turn off the power and modify the circuit to the one shown below.
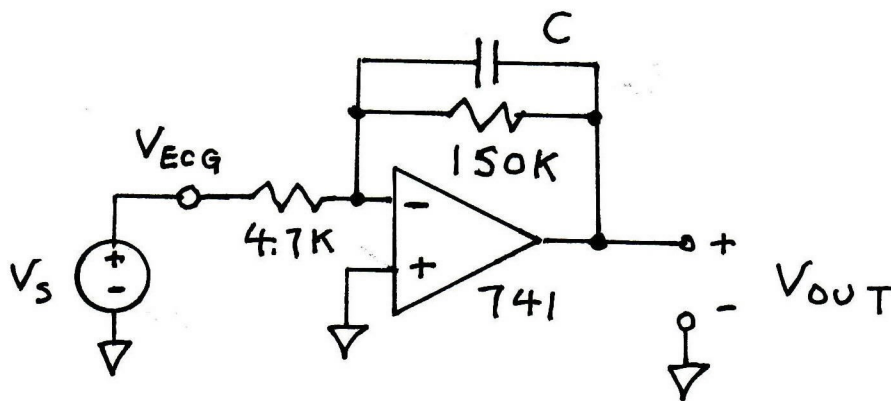
Insert the USB device into the signal generator so it produces the simulated ECG signal. Adjust the signal generator so the R-wave peak is 100 millivolts and the rate is 72 beats-per-minute. Note that this V_{ECG} signal simulates the signal from an instrumentation amplifier that is connected to bio-electrodes. Calculate the value for the capacitor C to produce a pole frequency of 500 Hz and insert the closest standard value into the board. Observe the signals at the input and output and calculate the voltage gain. Compare this to the expected voltage gain. Modify the value of C to create pole frequencies of 100 Hz, 50 Hz and 10 Hz. Capture both the input and output waveforms from the last trial and insert in your report. How does the R-wave from this last trial rate in terms of accuracy for clinical analysis?

V.   Detecting the R-wave

Turn off power and modify the board to the comparator circuit shown below.
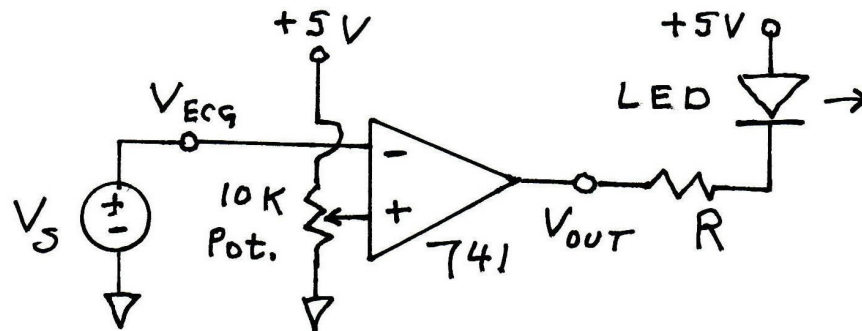
Adjust the amplitude of the signal generator so the peak amplitude of the R-wave is 1.0 volt. This simulates the output of a complete ECG amplifier. Note that now the output voltage from the op amp has only two possible levels: $\pm V_{SAT}$. Calculate the correct value for the resistor R so the LED current is 10 milliamperes when the output voltage is - V_{SAT}. Connect the voltmeter to read the voltage on the wiper of the potentiometer (the + input of the op amp). Adjust this voltage as instructed below and observe V_{OUT} on the oscilloscope screen and the LED.

Adjust the reference voltage to +2 volts and observe the results. Reduce the voltage to approximately +900 millivolts and repeat. Reduce the voltage to +50 millivolts and observe the effects on V_{OUT} and on the LED. What would be a suitable reference voltage so the LED marks the R-wave occurrence, taking into account the fact that the ECG amplitude undergoes changes with respiration?

FAIRCHILD
SEMICONDUCTOR®

February 2007

LM741
Single Operational Amplifier

Features

- Short Circuit Protection
- Excellent Temperature Stability
- Internal Frequency Compensation
- High Input Voltage Range
- Null of Offset

Description

The LM741 series are general purpose operational amplifiers. It is intended for a wide range of analog applications. The high gain and wide range of operating voltage provide superior performance in intergrator, summing amplifier, and general feedback applications..

8-DIP

1

8-SOP

1
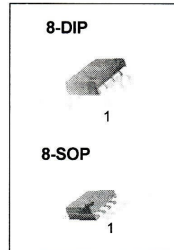
Ordering Information

Part Number	Operating Temp. Range	Pb-Free	Package	Packing Method	Marking Code
LM741CN		YES	8-DIP	Rail	LM741CN
LM741CM	0 ~ +70°C	YES	8-SOP	Rail	LM741CM
LM741CMX		YES	8-SOP	Tape & Reel	LM741CM

Internal Block Diagram

OFFSET NULL (1)
IN1 (-) (2)
IN1 (+) (3)
V_{EE} (4)

(8) NC
(7) V_{CC}
(6) OUTPUT
(5) OFFSET NULL

www.fairchildsemi.com
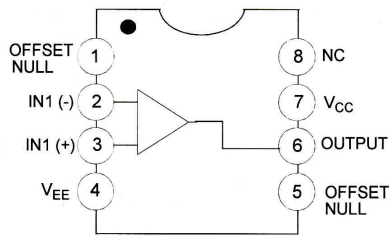
Electrical Characteristics

(V_{CC} = 15V, V_{EE} = -15V, T_A = 25°C, unless otherwise specified)

Parameter		Symbol	Conditions		Min.	Typ.	Max.	Unit
Input Offset Voltage		V_{IO}	$R_S \leq 10k\Omega$		-	2.0	6.0	mV
			$R_S \leq 50\Omega$		-	-	-	
Input Offset Voltage Adjustment Range		$V_{IO(R)}$	$V_{CC} = \pm20V$		-	±15	-	mV
Input Offset Current		I_{IO}	-		-	20	200	nA
Input Bias Current		I_{BIAS}	-		-	80	500	nA
Input Resistance (Note1)		R_I	$V_{CC} = \pm20V$		0.3	2.0	-	MΩ
Input Voltage Range		$V_{I(R)}$	-		±12	±13	-	V
Large Signal Voltage Gain		G_V	$R_L \geq 2k\Omega$	$V_{CC} = \pm20V$, $V_{O(P-P)} = \pm15V$	-	-	-	V/mV
				$V_{CC} = \pm15V$, $V_{O(P-P)} = \pm10V$	20	200	-	
Output Short Circuit Current		I_{SC}	-		-	25	-	mA
Output Voltage Swing		$V_{O(P-P)}$	$V_{CC} = \pm20V$	$R_L \geq 10k\Omega$	-	-	-	V
				$R_L \geq 2k\Omega$	-	-	-	
			$V_{CC} = \pm15V$	$R_L \geq 10k\Omega$	±12	±14	-	
				$R_L \geq 2k\Omega$	±10	±13	-	
Common Mode Rejection Ratio		CMRR	$R_S \leq 10k\Omega$, $V_{CM} = \pm12V$		70	90	-	dB
			$R_S \leq 50\Omega$, $V_{CM} = \pm12V$		-	-	-	
Power Supply Rejection Ratio		PSRR	$V_{CC} = \pm15V$ to $V_{CC} = \pm15V$ $R_S \leq 50\Omega$		-	-	-	dB
			$V_{CC} = \pm15V$ to $V_{CC} = \pm15V$ $R_S \leq 10k\Omega$		77	96	-	
Transient	Rise Time	T_R	Unity Gain		-	0.3	-	μs
Response	Overshoot	OS			-	10	-	%
Bandwidth		BW	-		-	-	-	MHz
Slew Rate		SR	Unity Gain		-	0.5	-	V/μs
Supply Current		I_{CC}	$R_L = \infty\Omega$		-	1.5	2.8	mA
Power Consumption		P_C	$V_{CC} = \pm20V$		-	-	-	mW
			$V_{CC} = \pm15V$		-	50	85	

Note:
1. Guaranteed by design.

Electrical Characteristics (Continued)

($0°C \leq T_A \leq 70°C$, $V_{CC} = \pm15V$, unless otherwise specified)
The following specification apply over the range of $0°C \leq T_A \leq +70°C$ for the LM741C

Parameter	Symbol	Conditions		Min.	Typ.	Max.	Unit
Input Offset Voltage	V_{IO}	$R_S \leq 50\Omega$		-	-	-	mV
		$R_S \leq 10k\Omega$		-	-	7.5	
Input Offset Voltage Drift	$\Delta V_{IO}/\Delta T$	-		-	-		$\mu V/°C$
Input Offset Current	I_{IO}	-		-	-	300	nA
Input Offset Current Drift	$\Delta I_{IO}/\Delta T$	-		-	-		$nA/°C$
Input Bias Current	I_{BIAS}	-		-	-	0.8	μA
Input Resistance (Note1)	R_I	$V_{CC} = \pm20V$		-	-	-	$M\Omega$
Input Voltage Range	$V_{I(R)}$	-		±12	±13	-	V
Output Voltage Swing	$V_{O(P-P)}$	$V_{CC} = \pm20V$	$R_S \geq 10k\Omega$	-	-	-	V
			$R_S \geq 2k\Omega$	-	-	-	
		$V_{CC} = \pm15V$	$R_S \geq 10k\Omega$	±12	±14	-	
			$R_S \geq 2k\Omega$	±10	±13	-	
Output Short Circuit Current	I_{SC}	-		10	-	40	mA
Common Mode Rejection Ratio	CMRR	$R_S \leq 10k\Omega$, $V_{CM} = \pm12V$		70	90	-	dB
		$R_S \leq 50\Omega$, $V_{CM} = \pm12V$		-	-	-	
Power Supply Rejection Ratio	PSRR	$V_{CC} = \pm20V$ to $\pm5V$	$R_S \leq 50\Omega$	-	-	-	dB
			$R_S \leq 10k\Omega$	77	96	-	
Large Signal Voltage Gain	G_V	$R_S \geq 2k\Omega$	$V_{CC} = \pm20V$, $V_{O(P-P)} = \pm15V$	-	-	-	V/mV
			$V_{CC} = \pm15V$, $V_{O(P-P)} = \pm10V$	15	-	-	
			$V_{CC} = \pm15V$, $V_{O(P-P)} = \pm2V$	-	-	-	

Note :
1. Guaranteed by design.

ELR 4202C
LABORATORY #4

Pressure Transducer Transient Response

Equipment:
1. Computer with "wxLaunchScope" software installed
2. MSP430 with USB adapter
3. MPX5100GP pressure transducer
4. Sphygmomanometer bulb and tubing with leur fitting added
5. Leur stopcock to isolate sphygmomanometer bulb
6. Tubing (size TBD) for catheter
7. Leur Fitting appropriate for above tubing
8. 60 mL syringe- modified with plunger removed and small leur adapter fitted in wall about 15 to 20 % of the distance to the bottom of the tube.
9. Leur tube fitting for pressure transducer.
10. A Second leur stopcock to bleed and seal downstream end of pressure transducer.
11. Syringe (1 mL) to introduce bubble near transducer.
12. Rubber glove, (expendable)
13. Three fingered Test tube clamp
14. Ring stand (any size that is convenient)
15. Creeper clamp to fit outside of 60 mL syringe body.
16. Scissors to cut disks from glove.
17. Exacto knife or scalpel.
18. Cigarette lighters

Prepare 100 mL deoxygenated water (100 mL) by boiling 250 mL of H_2O on a heating plate for at least 10 minutes. When the boiled water is cooled, you may fill a syringe with 60 ml by aspiration. Do not pour or stir or otherwise mix the water with air. Alternately, you may use vacuum pump to pump down on a vacuum flask of water having a rubber stopper in the top. Have the flask on a stir plate and stir vigorously with a stir bar. Mild heating is also useful but not required if you do this.

Refer to pp 30 to 35 and 302 to 305 of Webster, [1]

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[1] **Medical Instrumentation: Application and Design, 3rd Edition,** John G. Webster (Editor)
ISBN: 0-471-15368-0 Hardcover 720 pages August 1997

Experimental Setup
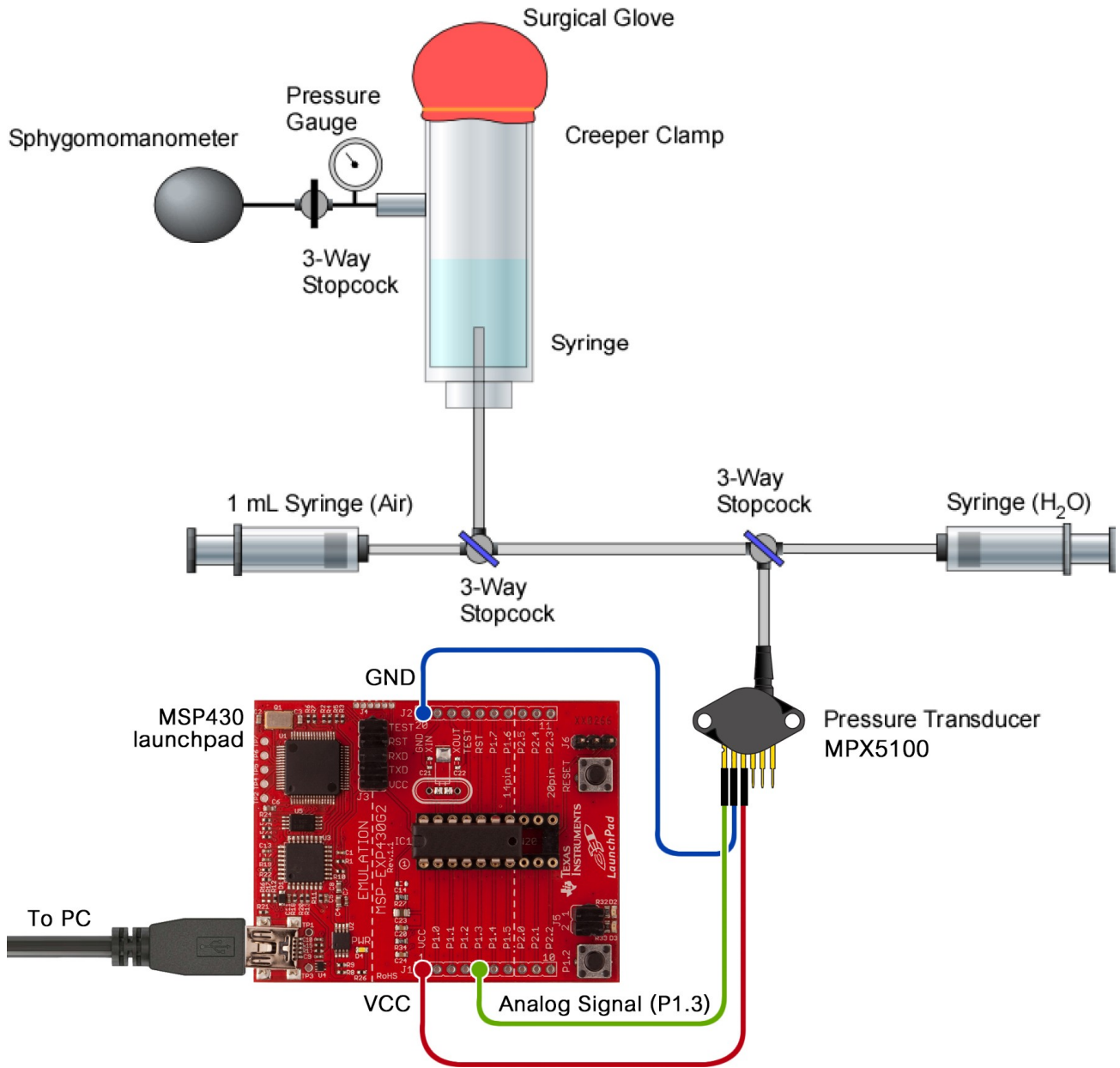
Integrated Silicon Pressure Sensor On-Chip Signal Conditioned, Temperature Compensated and Calibrated

The MPX5100 series piezoresistive transducer is a state–of–the–art monolithic silicon pressure sensor designed for a wide range of applications, but particularly those employing a microcontroller or microprocessor with A/D inputs. This patented, single element transducer combines advanced micromachining techniques, thin–film metallization, and bipolar processing to provide an accurate, high level analog output signal that is proportional to the applied pressure.

Features

- 2.5% Maximum Error over 0° to 85°C
- Ideally suited for Microprocessor or Microcontroller–Based Systems
- Patented Silicon Shear Stress Strain Gauge
- Available in Absolute, Differential and Gauge Configurations
- Durable Epoxy Unibody Element
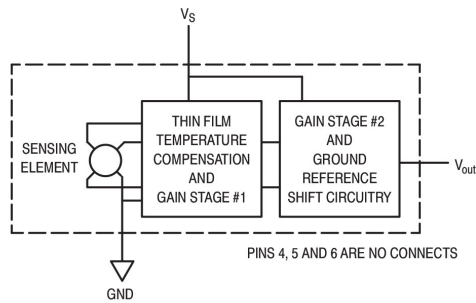- Easy–to–Use Chip Carrier Option

**MPX5100
SERIES**

**INTEGRATED PRESSURE
SENSOR
0 to 100 kPa (0 to 14.5 psi)
15 to 115 kPa
(2.18 to 16.68 psi)
0.2 to 4.7 Volts Output**

**MPX5100D
CASE 867**

**MPX5100DP
CASE 867C**

**MPX5100GSX
CASE 867F**

Figure 1. Fully Integrated Pressure Sensor Schematic

V_S

SENSING ELEMENT

THIN FILM TEMPERATURE COMPENSATION AND GAIN STAGE #1

GAIN STAGE #2 AND GROUND REFERENCE SHIFT CIRCUITRY

V_{out}

PINS 4, 5 AND 6 ARE NO CONNECTS

GND

UNIBODY PACKAGES

**MPX5100A/D
CASE 867-08**

**MPX5100AP/GP
CASE 867B-04**
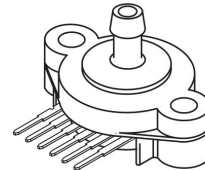
**MPX5100DP
CASE 857C-05**

PIN NUMBER			
1	V_{out}	4	N/C
2	Gnd	5	N/C
3	V_S	6	N/C

NOTE: Pins 4, 5, and 6 are internal device connections. Do not connect to external circuitry or ground. Pin 1 is noted by the notch in the lead.

REV 7

MOTOROLA

MPX5100 SERIES

MAXIMUM RATINGS(NOTE)

Parametrics	Symbol	Value	Unit
Maximum Pressure (P1 > P2)	P_{max}	400	kPa
Storage Temperature	T_{stg}	−40° to +125°	°C
Operating Temperature	T_A	− 40° to +125°	°C

NOTE: Exposure beyond the specified limits may cause permanent damage or degradation to the device.

OPERATING CHARACTERISTICS (V_S = 5.0 Vdc, T_A = 25°C unless otherwise noted, P1 > P2. Decoupling circuit shown in Figure 4 required to meet electrical specifications.)

Characteristic		Symbol	Min	Typ	Max	Unit
Pressure Range[1]	Gauge, Differential: MPX5100D Absolute: MPX5100A	P_{OP}	0 15	— —	100 115	kPa
Supply Voltage[2]		V_S	4.75	5.0	5.25	Vdc
Supply Current		I_o	—	7.0	10	mAdc
Minimum Pressure Offset[3] (0 to 85°C) @ V_S = 5.0 Volts		V_{off}	0.088	0.20	0.313	Vdc
Full Scale Output[4] Differential and Absolute (0 to 85°C) @ V_S = 5.0 Volts Vacuum[10]		V_{FSO}	4.587 3.688	4.700 3.800	4.813 3.913	Vdc
Full Scale Span[5] Differential and Absolute (0 to 85°C) @ V_S = 5.0 Volts Vacuum[10]		V_{FSS}	— —	4.500 3.600	— —	Vdc
Accuracy[6]		—	—	—	± 2.5	%V_{FSS}
Sensitivity		V/P	—	45	—	mV/kPa
Response Time[7]		t_R	—	1.0	—	ms
Output Source Current at Full Scale Output		I_{o+}	—	0.1	—	mAdc
Warm–Up Time[8]		—	—	20	—	ms
Offset Stability[9]		—	—	± 0.5	—	%V_{FSS}

NOTES:
1. 1.0kPa (kiloPascal) equals 0.145 psi.
2. Device is ratiometric within this specified excitation range.
3. Offset (V_{off}) is defined as the output voltage at the minimum rated pressure.
4. Full Scale Output (V_{FSO}) is defined as the output voltage at the maximum or full rated pressure.
5. Full Scale Span (V_{FSS}) is defined as the algebraic difference between the output voltage at full rated pressure and the output voltage at the minimum rated pressure.
6. Accuracy (error budget) consists of the following:
   - Linearity: Output deviation from a straight line relationship with pressure over the specified pressure range.
   - Temperature Hysteresis: Output deviation at any temperature within the operating temperature range, after the temperature is cycled to and from the minimum or maximum operating temperature points, with zero differential pressure applied.
   - Pressure Hysteresis: Output deviation at any pressure within the specified range, when this pressure is cycled to and from minimum or maximum rated pressure at 25°C.
   - TcSpan: Output deviation over the temperature range of 0° to 85°C, relative to 25°C.
   - TcOffset: Output deviation with minimum pressure applied, over the temperature range of 0° to 85°C, relative to 25°C.
   - Variation from Nominal: The variation from nominal values, for Offset or Full Scale Span, as a percent of V_{FSS} at 25°C.
7. Response Time is defined as the time for the incremental change in the output to go from 10% to 90% of its final value when subjected to a specified step change in pressure.
8. Warm–up Time is defined as the time required for the product to meet the specified output voltage after the Pressure has been stabilized.
9. Offset Stability is the product's output deviation when subjected to 1000 hours of Pulsed Pressure, Temperature Cycling with Bias Test.

MECHANICAL CHARACTERISTICS

Characteristics	Typ	Unit
Weight, Basic Element (Case 867)	4.0	grams

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Procedure:

Calibration:
1. Cut a disk of rubber from the glove large enough to fit over the end of the syringe with about ½ inch overlap
2. Stretch the rubber disk over the end of the syringe and fix it in place with the creeper clamp.
3. Apply pressure to the chamber at the top of the test tube until it reaches about 140 mm Hg.
4. Record the reading from the pressure transducer.
5. Release the air from the test tube until the pressure reading is zero.
6. Record the reading from the pressure transducer.

Exercise:
7. Cut a disk of rubber from the glove large enough to fit over the end of the syringe with about ½ inch overlap
8. Stretch the rubber disk over the end of the syringe and fix it in place with the creeper clamp.
9. Apply pressure to the air in the top of the test tube until it reaches about 140 mm Hg.
10. Light the match
11. Start recording of data at once.
12. Wait two seconds and use the match to pop the balloon.
13. Wait one second and stop recording.

Replace the rubber disk and repeat the experiment to complete the following matrix

Pressure Transducer	Trial	Natural Frequency ω	Damping Ratio ζ
Without bubble	1		
	2		
With bubble*	1		
	2		

.

* Add a 200 μL bubble to the transducer through the three way stopcock closest to the transducer.

Remark: With "wxLaunchScope" software, you can start capturing the reading from pressure transducer by choosing the active COM port and stop capturing by pressing "Stop". The recording screen will freeze the obtained recording when "Stop" was pressed. You can zoom in and out to see the measurement more clearly by holding "Ctrl" button and scrolling the mouse.

Data Analysis:

1. What is the initial value of the pressure, Pi?
2. What is the final value of the pressure, Pf?
3. Calculate the damping ratio, ζ, of the pressure transducer four all four experimental conditions.
4. Calculate the natural frequency of the experimental setup, ω_n for all four experimental conditions.
5. Explain the discrepancies between the calculated values among all experimental conditions. Keep in the mind the difference between changing system parameters versus changing data collection parameters.