Lab 3: Analog Electronics
BMEn 2151 “Introductory Medical Device Prototyping”
Prof. Steven S. Saliterman

Exercise 3.1: Familiarization with the Lab Box Contents

3.1.1 Team Lab Box

3.1.2 Multimeter (voltage, ohm and current) and Breadboard with 1660 tie points:
Breadboard “component” side for placing resistors, capacitors, transistors, integrated circuits, switches, screw terminals and other discrete devices:

3.1.3 Solderless Flexible Jumper Wire or 22 AWG hookup wire:
3.1.4 Wire cutter/stripper/plier and needle nose pliers:

3.1.5 Lead former:

3.1.6 Integrated circuit removal tool:
Use this tool when attempting to remove an IC from a breadboard. *Failure to do so could cause an IC to be imbedded in your finger!!*
3.1.7 Integrated Circuit Pin Straightening Tool
When inserting an IC into a breadboard, it is necessary to slightly squeeze the leads first so that the IC can be pushed in with minimal force and without crimping. Eyeball the chip from one end and be sure the leads are perpendicular. Use the IC Pin Straightening tool to make the pins perpendicular:

3.1.8 Component Box
Exercise 3.2: Familiarization with the Bench Power Supply

Objective: To acquaint you with the bench power supply. (If not already setup, obtain the triple source power supply from the course storage cabinet.)

1. TekPower Triple Voltage Power Supply:

These can be used as either a single or dual power supply source. You should limit current consistent with the load demands of your project. Consider the current requirements of the ICs, LEDs and other devices you have connected. This provides a measure of safety – with the power supply cutting off if the load is exceeded. Turn each current control fully counterclockwise and observe the red LED light. Now turn each knob about a 1/4 clockwise. This should be adequate current for your exercises. This also protects against short circuits. Remember to turn off the supply or disconnect it when actively wiring your breadboard or when through for the day.

Features:
1. Three DC outputs, two of them have a maximum output voltage of up to 30 VDC and current up to 5 amps, they may also be connected in series or in parallel for higher voltage or current; the last one has an output voltage fixed at 5 VDC and current up to 3 amps.
2. It comes with rotary switches for setting up the voltage and current.
3. It has current limiting protection.

2. Using the multimeter, power “on” and confirm the voltage across each of the three TekPower sources. (You can directly probe the banana jacks or use the test hook clips.) Confirm that you can adjust the voltage on the two power supplies.

For instructions on setting up and using the power supply as a single or dual power source, review the separate “Overview of Cables and Test Leads” document (self-review item).
Exercise 3.3: Familiarization with the Oscilloscope
Objective: To understand operation and uses of an oscilloscope. (YouTube tutorial: Oscilloscopes.)

1. The Hantek 100 MHz 2 Channel Digital Oscilloscope (model DSO5102B):
Features:
   100 MHz bandwidth
   Real time sample rate Giga Samples/s
   Record Length up to 1M
   Trigger mode: edge/pulse width/line selectable video/slop/overtime etc.
   USB host and device connectivity, standard
   Multiple automatic measurements
   Four math functions, including FFT standard
   Provides software for PC real-time analysis specifications:
   Display: 7" TFT 16K color LCD, 800 x 480 dots.
2. Review the front panel controls

3. Power “on” and confirm both traces are visible. Try positioning the traces along the x and y-axis by changing the vertical and horizontal position. Select channel one, and connect a probe to the channel one BNC connector. Clip the probe to the lower-right calibration signal (5 volt square wave). Adjust the vertical volts per division to 5, and the horizontal sweep (time base) to show five or six square wave cycles on the screen. Read the seconds per division necessary to do this. Read the voltage to confirm 5 VDC and the frequency and confirm it is 1 KHz. (If your square wave has over or under-shoots, the probe compensation should be adjusted to give a nice clean square wave.)

You may need to adjust the trigger to display a steady waveform. This allows the scope to start its trace at a particular threshold of voltage and direction of polarity movement. (There is also a means for delaying the trace or even triggering in advance in order to capture transient signals).

4. Explore the various menu functions. The “measure” function is very helpful, but you must momentarily turn off the channel not being measured to see the correct display. Be sure your probe and menu setting are set for “1X”. Also select “AC” vs “DC” depending on what you are measuring.

5. The “auto set” may or may not be helpful with these particular oscilloscopes.
Exercise 3.4: Familiarization with the Arbitrary Function Generator

Objective: To understand operation and uses of a function generator.

1. The Dual Channel Arbitrary Function Generators used in class

Features:
- Amplitude (voltage) up to 20Vpp
- Output Impedance: 50 ohm, ± 10V
- The instrument can output sine, square, triangle, ramp, pulse, staircase, DC voltage waveform.
- Pulse wave pulse width precision can be adjustable.

Click here for YouTube video: Function Generator.

2. Attach the output to the input of channel one of the oscilloscope. Select a frequency of 1 KHz and amplitude of 5 volts. You can cycle through the various waveforms by pressing the “wave” button repeatedly. Try different changing the amplitude (voltage) and frequency and see what happens.
Exercise 3.5: Series and Parallel Resistance
Objective is to measure the total resistance of two resistors in series and in parallel configurations.

Breadboard the following circuits and measure the resistance as shown for each circuit. Note that you are not connecting a power supply.

Record your measurements:

\[ \text{3.5.1 Series Resistance} \quad \underline{\ldots} \text{ohms} \]
\[ \text{3.5.2 Parallel Resistance} \quad \underline{\ldots} \text{ohms} \]
Exercise 3.6: Turning On a Light Emitting Diode (LED)

Objective is to use a voltage divider to reduce the voltage across an LED relative to the supply voltage.

Breadboard the following circuit without the meters shown, and verify that the LED lights. Be sure power is not connected until all wiring is done. Then using your multimeter measure the voltage across the LED (probes in voltage position). Finally take the current reading.

3.6.1 Did the LED turn on? ____________ (Yes or No)

3.6.2 What is the voltage across the LED? ____________ VDC

3.6.3 What is the current through the resistor and LED? ____________ mA

Your positive test lead should be moved to the multimeter 10AMP port, and the meter placed in series in your circuit. A soon as you are done, return the multimeter lead to the Volt/Ohm/Hz port. Failure to do this will harm other equipment and your circuit.
Exercise 3.7: Full-Wave Bridge Rectifier

Objective: Show how a full-wave bridge rectifier converts an AC to DC signal, and later the role of filtering capacitors.

The full-wave bridge rectifier has the above effect on an AC signal, effectively removing the negative voltage swing as shown below. This is insufficient for an adequate DC power supply, and some form of filtering to smooth out the ripples is necessary. We will next look at Zener diodes as a voltage reference, and an example of using capacitors to smooth out the ripple.

3.7.1 Breadboard a bridge rectifier with load resistor as shown below. You will be using the wall mount 12 VAC power supply with screw terminals for lead wire. Be careful when connecting the bridge leads! Your multimeter must be set to TRUE RMS to measure an AC voltage, and the multimeter positive lead in the Volt/Ohm/Hz port – not the 10A current port.

The peak value for the 12VAC RMS will be 12 times the square root of 2, less a small voltage drop across the bridge.
**Exercise 3.8: Zener Diode**

Objective: Operate a Zener diode in the reverse breakdown mode to show the Zener test voltage (use of a Zener diode to provide a voltage reference).

The IN4733A Zener diode is rated at 5.1 volts DC and 1 watt maximum. Breadboard this circuit (use the triple voltage DC power supply):

3.8.1 Measure the voltage across the Zener diode. _______________ VDC

3.8.2 What is the voltage across the resistor? _______________ VDC

3.8.3 If the load resistance were 1.5K ohms (in place of the meter), calculate the current through R1, the Zener diode and the load resistor.

_________________________________________________________________________

_________________________________________________________________________

Zener diode – the cathode is denoted by the dark band, and the opposite end is the anode.

Note that the supply voltage must be above the Zener reference voltage. Current is flowing in reverse through the diode as compared to a normal diode.
Exercise 3.9: Combining a Bridge Rectifier, Zener Diode and Capacitor
Objective: Creating a regulated DC power supply from an AC source, with simple filtering.

Breadboard this circuit using the 12 AC wall mount power supply, BR805D full-wave bridge rectifier and Zener diode.

3.9.1 What is the input voltage $V_{RMS}$? ____________________
(Your multimeter must be set to TRUE RMS to measure an AC voltage, and the multimeter positive lead in the Volt/Ohm/Hz port – not the 10A current port.)

3.9.2 What is the output voltage VDC? ____________________

3.9.3 Is this the voltage that you expected? ________________

3.9.4 Try swapping a 22 microfarad capacitor for the 1000 microfarad capacitor. What do you notice about the DC signal now?
Exercise 3.10: The 7800/7900 Series Voltage Regulators
Objective: Demonstrate the operation of the 7805 positive voltage regulator in a DC circuit.

Breadboard the following circuit:

3.10.1 Measure the output voltage ___________
Exercise 3.11: Transistor Amplifier

Objective: To construct a bipolar junction transistor (NPN) common emitter amplifier and observe amplification of an AC signal.

Breadboard and measure the actual gain of your circuit. Use your oscilloscope to obtain input and output waveforms as shown in the simulation above.

3.11.1 AC gain (show division)  \[ \frac{\text{Input}}{\text{Output}} = \]
Amplifier Circuit on Breadboard

Power Supply 15 VDC

Function Generator set at 1 kHz, 0.1 V pp (measures 80 mV pp below)
### Electrical Characteristics

Values are at $T_A = 25^\circ C$ unless otherwise noted.

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Parameter</th>
<th>Conditions</th>
<th>Min.</th>
<th>Max.</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{OFF}$</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$BV_{(BR)CEO}$</td>
<td>Collector-Emitter Breakdown Voltage</td>
<td>$I_C = 10 \text{ mA}, I_E = 0$</td>
<td>40</td>
<td>50</td>
<td>$\text{V}$</td>
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<tr>
<td>$BV_{(BR)CEO}$</td>
<td>Collector-Base Breakdown Voltage</td>
<td>$I_C = 10 \text{ mA}, I_E = 0$</td>
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<td></td>
<td>$\text{V}$</td>
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<tr>
<td>$BV_{(BR)CEO}$</td>
<td>Emitter-Base Breakdown Voltage</td>
<td>$I_C = 10 \mu\text{A}, I_E = 0$</td>
<td>50</td>
<td></td>
<td>$\text{V}$</td>
</tr>
<tr>
<td>$I_{CEO}$</td>
<td>Collector Cut-Off Current</td>
<td>$V_{CE} = 60 \text{ V}, I_E = 0$</td>
<td>10</td>
<td></td>
<td>$\mu\text{A}$</td>
</tr>
<tr>
<td>$I_{CEO}$</td>
<td>Collector Cut-Off Current</td>
<td>$V_{CB} = 60 \text{ V}, I_E = 0, T_A = 125^\circ C$</td>
<td>10</td>
<td></td>
<td>$\mu\text{A}$</td>
</tr>
<tr>
<td>$I_{BEO}$</td>
<td>Emitter Cut-Off Current</td>
<td>$V_{EB} = 3.0 \text{ V}, I_E = 0$</td>
<td>10</td>
<td></td>
<td>$\text{nA}$</td>
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<tr>
<td>$I_{EEO}$</td>
<td>Base Cut-Off Current</td>
<td>$V_{CE} = 60 \text{ V}, V_{EROT} = 3.0 \text{ V}$</td>
<td>20</td>
<td></td>
<td>$\text{nA}$</td>
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<table>
<thead>
<tr>
<th>$h_{FE}$</th>
<th>DC Current Gain</th>
<th>$I_C = 0.1 \text{ mA}, V_{CE} = 10 \text{ V}$</th>
<th>35</th>
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<tbody>
<tr>
<td>$h_{FE}$</td>
<td>$I_C = 1.0 \text{ mA}, V_{CE} = 10 \text{ V}$</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>$h_{FE}$</td>
<td>$I_C = 10 \text{ mA}, V_{CE} = 10 \text{ V}$</td>
<td>75</td>
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</tr>
<tr>
<td>$h_{FE}$</td>
<td>$I_C = 10 \text{ mA}, V_{CE} = 10 \text{ V}, T_A = -55^\circ C$</td>
<td>35</td>
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<td>$h_{FE}$</td>
<td>$I_C = 160 \text{ mA}, V_{CE} = 10 \text{ V}$</td>
<td>100</td>
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<td>$h_{FE}$</td>
<td>$I_C = 160 \text{ mA}, V_{CE} = 1 \text{ V}$</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>$h_{FE}$</td>
<td>$I_C = 500 \text{ mA}, V_{CE} = 10 \text{ V}$</td>
<td>40</td>
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</table>

<table>
<thead>
<tr>
<th>$V_{CE(sat)}$</th>
<th>Collector-Emitter Saturation Voltage</th>
<th>$I_C = 150 \text{ mA}, I_E = 15 \text{ mA}$</th>
<th>0.3</th>
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<tbody>
<tr>
<td>$V_{CE(sat)}$</td>
<td>$I_C = 500 \text{ mA}, I_E = 50 \text{ mA}$</td>
<td>1.0</td>
<td></td>
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<tr>
<td>$V_{BE(on)}$</td>
<td>Base Emitter Saturation Voltage</td>
<td>$I_C = 150 \text{ mA}, I_E = 15 \text{ mA}$</td>
<td>0.6</td>
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<td>$V_{BE(on)}$</td>
<td>$I_C = 500 \text{ mA}, I_E = 60 \text{ mA}$</td>
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<th>Small Signal Characteristics</th>
<th>$f_T$</th>
<th>Current Gain Bandwidth Product</th>
<th>$I_C = 20 \text{ mA}, V_{CE} = 20 \text{ V}, f = 100 \text{ MHz}$</th>
<th>300</th>
<th>$\text{MHz}$</th>
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<tr>
<td>Small Signal Characteristics</td>
<td>$C_{oib}$</td>
<td>Output Capacitance</td>
<td>$V_{CB} = 10 \text{ V}, I_E = 0, f = 1 \text{ MHz}$</td>
<td>8.0</td>
<td>$\text{pF}$</td>
</tr>
<tr>
<td>Small Signal Characteristics</td>
<td>$C_{oib}$</td>
<td>Input Capacitance</td>
<td>$V_{EB} = 0.5 \text{ V}, I_C = 0, f = 1 \text{ MHz}$</td>
<td>25</td>
<td>$\text{pF}$</td>
</tr>
<tr>
<td>Small Signal Characteristics</td>
<td>$\alpha' C_o$</td>
<td>Collector Base Time Constant</td>
<td>$I_C = 20 \text{ mA}, V_{CB} = 20 \text{ V}, f = 31.8 \text{ MHz}$</td>
<td>150</td>
<td>$\text{pS}$</td>
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<table>
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<tr>
<th>Switching Characteristics</th>
<th>$t_d$</th>
<th>Delay Time</th>
<th>$V_{CC} = 30 \text{ V}, V_{BE(on)} = 0.5 \text{ V}, I_C = 150 \text{ mA}, I_{B1} = 15 \text{ mA}$</th>
<th>10</th>
<th>$\text{ns}$</th>
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<tr>
<td>Switching Characteristics</td>
<td>$t_r$</td>
<td>Rise Time</td>
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<tr>
<td>Switching Characteristics</td>
<td>$t_f$</td>
<td>Storage Time</td>
<td>$V_{CC} = 30 \text{ V}, I_C = 150 \text{ mA}, I_{B1} = 15 \text{ mA}$</td>
<td>225</td>
<td>$\text{ns}$</td>
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<tr>
<td>Switching Characteristics</td>
<td>$t_f$</td>
<td>Fall Time</td>
<td></td>
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</tbody>
</table>

Note:
1. Pulse test: pulse width ≤ 300 µs, duty cycle ≤ 2.0%.
A DC biasing voltage is applied to the base to allow it to operate in its linear region. The transistor is then operating half-way between its cutoff and saturation voltages.

The output characteristic curves for a common emitter amplifier are shown above. These curves relate the output collector current, ($I_C$) to the collector voltage, ($V_{CE}$) for different values of base current, ($I_B$).

The DC load line shows all of the possible operating points when different base current values are applied.

$V_{CE}$ is set to allow the output voltage to swing positive and negative when amplifying an AC signal. This is referred to as setting the operating point or Quiescent point (Q-point).
Exercise 3.12: Operational Amplifier – Non-Inverting Amplifier

Objective: Construct a non-inverting amplifier using the 741 op amp.

Breadboard the following circuit. Configure the power supply as *dual supplies* and set the voltage for plus and minus 15 volts DC relative to the common (center) ground. You need to set only the right-sided supply (*master*) to 15 volts, and the left-sided supply will automatically read 15 volts (*slave*). Be sure your cables are correct!

\[
V_{out} = V_{in} \left( \frac{R_1 + R_2}{R_1} \right) = 2 \times \left( \frac{10 + 1}{1} \right) = 22 \text{ V}_{pp} \text{ or } 11 \text{ V}_{p}
\]

\[
\text{Voltage Gain} = \frac{V_{out}}{V_{in}} = \frac{22}{2} = 11 \text{ or } 1 + \frac{R_2}{R_1} = 11
\]

3.12.1 Breadboard this circuit, and using your oscilloscope measure the voltage gain:
Exercise 3.13: Operational Amplifier - Integrator

Objective: Construct an integrator using the 741 op amp.

Breadboard the following circuit:

3.13.1 Were you able to observe the above signals on your oscilloscope? _____ (yes or no)
Exercise 3.14: Astable Multivibrator – the LM555CN

Multivibrators can be used for “clocking” digital circuits. Breadboard the following circuit:

\[ t_{\text{high}} = 0.693R_1C_1 \]
\[ t_{\text{low}} = 0.693R_2C_1 \]
\[ f = \frac{1}{t_{\text{high}} + t_{\text{low}}} \]
\[ \text{Duty Cycle} = \frac{t_{\text{high}}}{t_{\text{high}} + t_{\text{low}}} \]
3.14.1 Calculate and measure the following:

Calculated duration of high voltage each cycle: ____________ ms

Calculated duration of low voltage each cycle: ____________ ms

Calculated frequency: ____________ Hz

Calculated duty cycle: ____________

Measured duration of high voltage each cycle: ____________ ms

Measured duration of low voltage each cycle: ____________ ms

Measured frequency: ____________ Hz

Measured duty cycle: ____________

End of Analog Electronics