Breadboard Circuit Techniques

- Circuit connections are made using the 5 hole vertical groupings of connections.
Breadboard Circuit Techniques

• Each of the top and bottom 2 rows forms a “bus”

Horizontal Groups (2 rows)

Vertical Groups (5 holes)

• In ME 360 use:
  – the top row for a +12V bus, (white wire)
  – the second row for a +5V bus, (red wire)
  – the next to the bottom row for a ground (GND) bus (black wire) and
  – the bottom row for a -12V bus (green wire)

DO NOT DEVIATE FROM THIS CONVENTION! (Not while in 360, at least.)
Breadboard Circuit Techniques

• A dual inline package (DIP), such as a 741 op-amp, is inserted across the “valley” in the center of the board

Tips for successful breadboarding

• Color-code your 22-24 gauge solid wires for different functions - don’t use 1 color for everything!

• Strip about 1/4 to 3/8 inch of insulation from each end of the wire

• Cut the end of the wire on a 45 degree angle for easy insertion into the holes
**Introduction to Signal Conditioning**

Webster’s online dictionary’s definitions for “conditioning:”

*tr.v. con·di·tioned, con·di·tion·ing, con·di·tions*
To make dependent on a condition or conditions.
To stipulate as a condition.
To render fit for work or use.
To accustom (oneself or another) to; adapt: had to condition herself to long hours of hard work; conditioned the troops to marches at high altitudes.
To air-condition.
To give the unsatisfactory grade of condition to.

Psychology. To cause an organism to respond in a specific manner to a conditioned stimulus in the absence of an unconditioned stimulus.
To replace moisture or oils in (hair, for example) by use of a therapeutic product.

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**Two-Port Devices**

- Consider the standard two port device
  - One port for an _input_
  - One port for an _output_

- Signal conditioning will be anything that we put inside the box that acts on the signal and modifies it from the input to the output.
Example #1: Miniature Shaker

- Given: Miniature piezoelectric shaker
  - Input: ±100 V
  - Output: 0.004 lb/V (0.018 N/V)

- How do you measure the voltage applied to the shaker?
  - 100 V WELL beyond the range of standard data acquisition systems

[Diagram: Function Generator → Amplifier → Shaker]

Attenuate the signal

Example #2: Temperature Measurement with Thermocouples

- Given: Type K thermocouple
  - -3.554 mV at -100°C (“Cold!”)
  - 54.138 mV at 1350°C (“Hot!”)

- You need to measure T/C voltage with a 0-5 V system
  - (54.138 - - 3.554)mV = 57.692 mV range of inputs
  \[\Rightarrow BADLY\] mismatched scales

[Diagram: Amplify the signal and… add to the signal.]
Example #3: Aliasing

- Given: Measuring with a fixed sampling-rate system.

From http://www.cyberresearch.com/cyb/cybtechtut.htm

Input: 10 rad/s, Sample @ 20 Hz

Sample @ 20 Hz
Input: 10 rad/s, Sample @ 15 Hz

Sample @ 15 Hz

Input -10 rad/s, Sample @ 10 Hz

Sample @ 10 Hz
Input -10 rad/s, Sample @ 5 Hz

Sample @ 5 Hz

Input -10 rad/s, Sample @ 2.5 Hz

Sample @ 2.5 Hz
Input -10 rad/s, Sample @ 2 Hz

Sample @ 2 Hz

Aliasing in Movies

• If you've ever watched a “Western” and seen the wheel of a rolling wagon appear to be going backwards, you've witnessed aliasing.
• Movie's frame rate isn't adequate to “sample” the true rotational frequency of the wheel – our eyes are deceived by the aliased frequency!
Aliasing in Digital Music

- Digital audio system typically sample at a rate of 48 KHz (although some WAV files are sampled at lower rates)
  - at a sound frequency of 24 KHz, only two sample points are available per cycle
  - a 25 KHz tone becomes indistinguishable from a 23 KHz tone
  - a 30 KHz tone becomes an 18 KHz tone
- Aliased components of music mix with the real frequencies to yield an obnoxious form of distortion

How do you prevent aliasing?

- Sample at a higher rate (at least 2x highest frequency in input)
  - can lead to “too much” data!
- Use a low pass filter to “attenuate” (or reduce) amplitude of high frequency signals
  - a simple RC low-pass filter is often included on data acquisition boards!
"Anti-aliasing" Filters

Typical Signal Conditioning

- Amplify or attenuate a signal
  - Use a two-port system with a specified gain
- Add or subtract two signals
  - Use an active circuit
- Filter signals
  - Low-pass to suppress noise or prevent aliasing
  - High-pass to remove DC and other low-frequency components
- Power amplification using an active circuit
  - Typical microchips capable of <10 μA of current
- Tough to drive a relay on 10 μA!
Signal Conditioning: Attenuation, Amplification, Addition and Subtraction

General Characteristics of Signal Amplification (p. 35)

- Gain is the relationship between change in input and change in output voltages,
  \[ \text{gain, } G = \frac{\Delta V_{\text{out}}}{\Delta V_{\text{in}}} \]
- Gain can be large (1000 or more)
- Gain can be less than 1
  - "___________" in this case
  - attenuation
What is the “gain” for this data?

\[ g = \frac{\Delta y}{\Delta x} = \frac{0.65 - 0.25}{10 \cdot 10^{-3}} = \frac{0.42}{0.01} = 420 \]

Example #1: Miniature Shaker

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  - Input: ±100 V
  - Output: 0.004 lb/V (0.018 N/V)

- **How do you measure the voltage applied to the shaker?**
  - 100 V *WELL* beyond the range of standard data acquisition systems

**Attenuate the signal**
Example #1 Continued

• Scale the ±100 V down to ±10 V \( R_1 = 9 \Omega \) \( R_2 = 1 \Omega \)
  - Use a voltage divider

Make sure that your measuring circuit does not draw too much current!
→ Make it’s impedance HIGH
→ Make the input impedance of the circuit measuring \( V_{out} \) even higher!

Limitation: you can only **attenuate** with a voltage divider.

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Operational Amplifier (op-amp)

Note the hole

Positive power supply (+12V)
Inverting input (V-)
Non-inverting input (V+)
Negative power supply (-12V)

Output (\( V_o \))
Inverting input
Non-inverting input

Electrical Schematic Symbol

Integreated Circuit
8 Pin DIP
(Dual In-line Package)
Single Input, Inverting amp

- Note: $V_i$ connected to inverting input (-)

$$V_o = -\frac{R_2}{R_1} V_i \quad \text{(Eq. 3.17)}$$

minus sign since $V_i$ connected to -

Inverting op-amp amplifier

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What is the gain of the op-amp that has this input/output?
To Maintain Ideal Relationships for all Op-amp Circuits!

- Input resistance $R_i$ should be fairly large
  \[ R_i > 10k\Omega \text{ in most cases} \]
  - minimizes current drawn from input side of op-amp circuit

Op-Amp Saturation

![Op-Amp Saturation Diagram]

- Ideal output $> 11$ V
  - "clipped" to 11 V
- Ideal output $< -11$ V
  - "clipped" to -11 V
Multiple input, summing amplifier

\[ V_o = -\left( \frac{R_2}{R_1} \right) V_1 + \left( \frac{R_2}{R_1} \right) V_2 \]

DON'T FORGET THE SIGN!

What is the gain of the op-amp that has this input/output?
Single input, non-inverting amplifier

\[ V_o = \left(1 + \frac{R_2}{R_1}\right)V_i \]

See anything interesting? Any limitation here?

What is the gain of the op-amp that has this input/output?
In-Class Exercise #1

- Design an op-amp circuit to give the input/output relationship shown in #1
  - make ALL necessary connections to op-amp chip
  - input connection is yellow, output is orange

- use the following resistors - 20kΩ, 56kΩ
In-class Exercise #1

Build a single input, inverting amplifier, gain of 2.8

\[ R_1 = 20 \, \text{k}\Omega \text{ (Red-Blk-Or)} \]
\[ R_2 = 56 \, \text{k}\Omega \text{ (Gr-Blue-Or)} \]

\[ +12V \quad \text{Out} \quad + \]
\[ \text{Com} \quad - \quad V_o \]
\[ -12V \]

What op-amp circuit does this? #2

![Graph showing input and output voltage over time.]
In-Class Exercise #2

• Design an op-amp circuit to give the input/output relationship shown in #2
  – make ALL necessary connections to op-amp chip
  – input connection is yellow, output is orange

• use the following resistors - 20kΩ, 56kΩ

In-Class Exercise #2

• Build a single input, non-inverting amplifier, gain of 1.36
• You have 20 kΩ and 56 kΩ resistors
Single input, non-inverting amplifier

\[ V_o = \left(1 + \frac{R_2}{R_1}\right)V_i \]
\[ = (1 + 0)V_i \]
\[ = V_i \]

What happens if...

This is called a **voltage follower**.

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Dual input, difference amplifier

\[ E_o = \frac{R_3}{R_1}(E_2 - E_1) \quad \text{assuming } R_4 = R_3 \text{ and } R_2 = R_1 \]
What is the gain of the op amp that has this input/output?

\[ V_o = \frac{-1}{RC} \int_0^t V_i \, dt + V_o(0) \]

(Eq. 3.32)
Differentiator

\[ V_o = -RC \frac{dV_i}{dt} \quad \text{(Eqn 3.33)} \]

Comparator

\[ V_o = \begin{cases} 
+12V & \text{if } V_i > V_{\text{ref}} \\
-12V & \text{if } V_i < V_{\text{ref}} 
\end{cases} \]

reference voltage

input voltage to be compared
Instrumentation Amp

\[ V_o = \frac{R_2}{R_1} \left( 1 + \frac{2R_3}{R_G} \right) V_i \]

Note - Formula in text is incorrect

“Buffered” Voltage Divider
Potentiometer - Schematic

1. Fixed Resistance \( R_{1-3} \)
2. "wiper"
3. Variable Resistance \( R_{2-3} \)

Potentiometer - Physical

Wiper Adjustment