Electronics Exam 2 Study Guide

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1 Diodes

A Diode is a two-lead semiconductor device that acts as a one-way gate to electric current flow. When a diode's anode is made more positive that its cathode lead (this is called forward biasing) current can flow. In the opposite instance, where the anode is more negative than the cathode, current does not flow. (The cathode is the pointy end the triangle.)

1.0.1 How do p-n junctions work?

We sandwich together a p-type region an n-type, the n-type region has extra electrons and the p-type region has holes. When the current is forward, such that the positive end is toward the p-type region, and vice versa for the negative region, current will flow. In the reverse scenario, all the electrons and holes are pulled away from the junction, and no current flows.

1.1 Types of Diodes

Diodes for high power applications (switching/power supplies) that draw lots of current or rectify high voltage are called **rectifier diodes**. Another type of diode is the **signal/switching/fast recovery/high speed diode** which have low internal capacitance, which have weaker junctions (can't take huge currents), however they have lower RC constants to switch faster, resulting in fewer time delays and lower signal loss. **Schottky diodes** have very fast switching (due to the metal-semiconductor interface) and drop very little (0.2V). These are very useful for low voltage, high frequency signals that ordinary diodes could not see. Useful for low voltage rectifiers/signal switching. Their high current density and low voltage drop make them useful in power supplies since they generate less heat. **Germanium diodes** are used for RF signal detection and low-level logic because of their low threshold voltage (0.2V). The reason they are not used for high-current rectifiers is because they are weaker and leak more than silicon diodes. **Zener diodes** have low breakdown potential that can allow backwards flow at a consistent voltage, called the zener voltage. LED's or **Light Emitting Diodes**, are diodes that require a specific potential difference across them to spit out photons, and a specific current to control the amount spit out.

1.2 Rectifiers

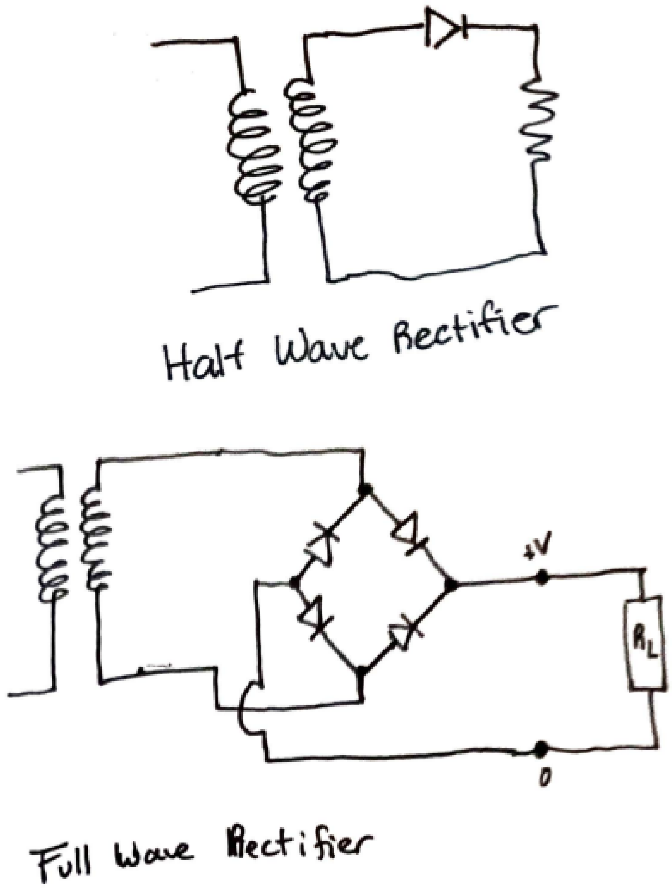

Figure 1: Half Wave Rectifier (Above) Full Wave Rectifier (Below)

2 OP Amps

2.1 Golden Rules

1. Open loop gain is infinite
2. Inputs draw no current (Very high input impedance)
3. Inputs are at the same potential

2.2 Inverting Amplifier

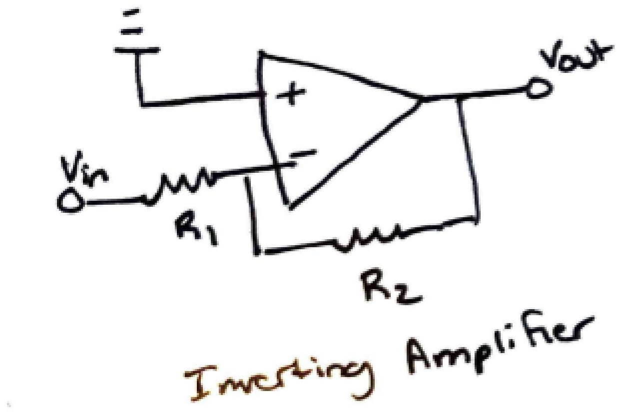

Figure 2: Inverting Amplifer

For amplifier, V_{in} drops to 0 over R_1, and since op-amps draw no current, this sets the current to be $\frac{V_{\text{in}}}{R_1}$. Thus, using ohms law, we get V_{out} to be:

$$V_{\text{out}} = \frac{R_2}{R_1} V_{\text{in}} \tag{1}$$

2.3 Non-Inverting Amplifier

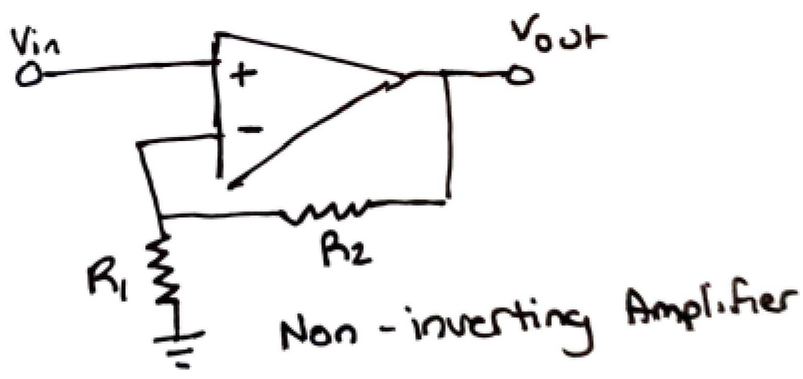

Figure 3: Non-Inverting Amplifer

For this amplifier, we jump up to V_{in} over R_1 from ground, setting the current to $\frac{V_{\text{in}}}{R_1}$. We then jump up further from V_{in} over R_2 a potential of $V_{\text{in}}\frac{R_2}{R_1}$. Thus we have the final V_{out} to be:

$$V_{\text{out}} = V_{\text{in}}(1 + \frac{R_2}{R_1}) \tag{2}$$

2.4 Difference Amplifier

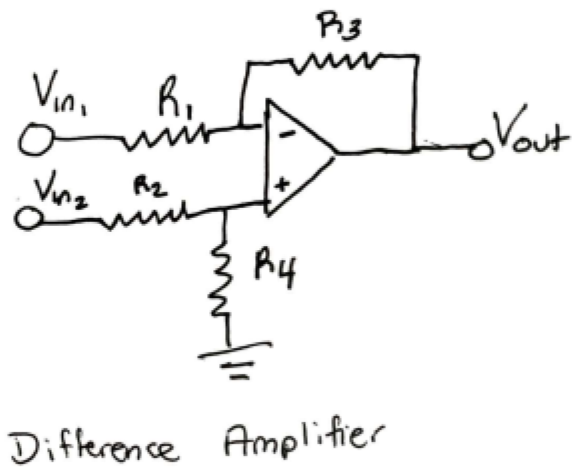

Figure 4: A Difference Amplifier

First, we can calculate the potential at the inputs of the op-amp by starting at the ground. Using the voltage divider equation, we find the voltage at the non-inverting input (and consequently the inverting input) to be $V_2\frac{R_4}{R_2+R_4}$. From this, We know the drop over R_1 has to take us from V_1 to this potential, so we can solve for the subsequent current:

$$I = \frac{1}{R_1}\Big(V_1 - V_2\frac{R_4}{R_2 + R_4}\Big)$$

Thus to find V_{out}, we take this current and drop over R_3 from the op-amp input. This then gives us an output potential of:

$$V_{\text{out}} = V_2\frac{R_4}{R_2 + R_4} - \frac{R_2}{R_1}\Big(V_1 - V_2\frac{R_4}{R_2 + R_4}\Big)$$

We can simplify this further to get our final V_{out}:

$$V_{\text{out}} = V_2\Big(\frac{R_4}{R_3 + R_4}(1 + \frac{R_2}{R_1})\Big) - V_1\frac{R_2}{R_1} \tag{3}$$

Further, in the case where $R_1 = R_3$ and $R_2 = R_4$ this becomes:

$$V_{\text{out}} = \frac{R_2}{R_1}\Big(V_2 - V_1\Big) \tag{4}$$

2.5 Comparators

We can use an op amp with a input reference voltage, to rail the output to either ground or positive rail depending on whether or not the input voltage exceeds the reference voltage.(Via Schmitt triggering).

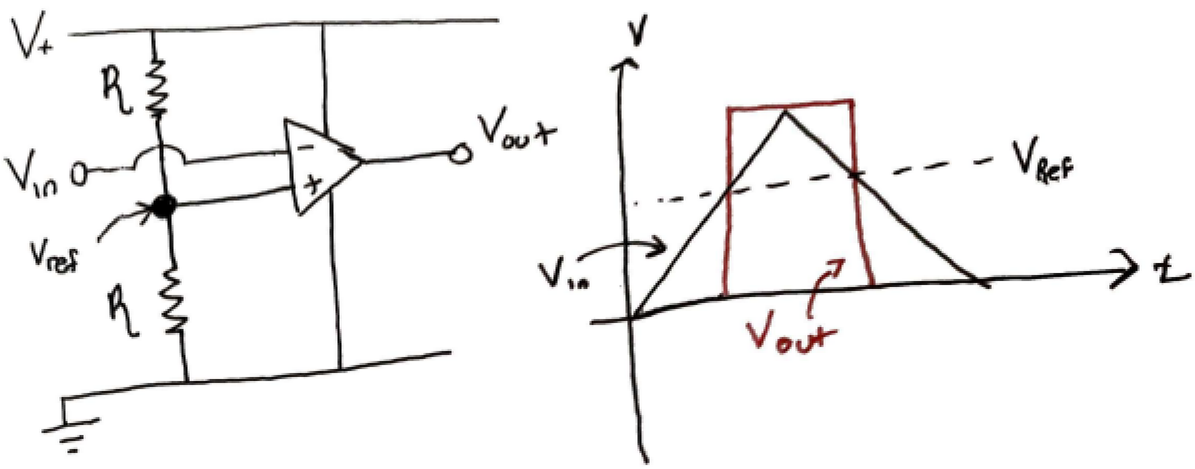

Figure 5: Comparator implemented using Schmitt triggering and an op-amp

Otherwise, we can use a specific comparator IC. This IC is very similar to an op amp, with inverting/non-inverting inputs, a output, power connections, and its schematic is very similar to an op amp. HOWEVER, comparator IC's are not frequency compensated, and consequently cannot be used as linear amplifiers. For comparators, we only use positive feedback, as negative feedback is rendered unstable. Comparators are designed with high-speed in mind, they have very high slew rates and small propagation delays compared to op-amps. Unlike op-amps, which use a push-pull output stage, a comparator uses an internal transistor whose collector is connected to the output and whose emitter is grounded. When the comparators non-inverting terminal is less positive(ie. $V_+ < V_-$), the output transistor turns on, which grounds the output (output of 0). When the opposite is true, the internal transistor is off and there exists a pull-up resistor connected to a positive voltage source (5V) that ensures the output pin is high when the transistor is off.

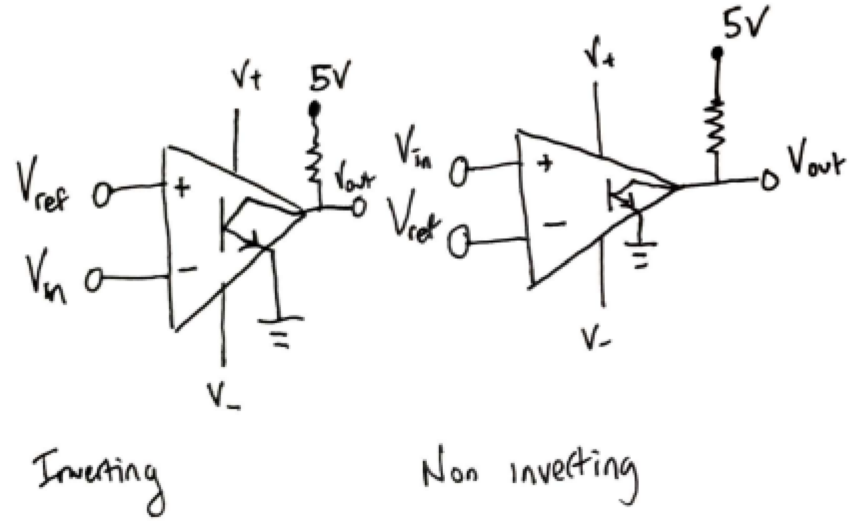

Figure 6: Comparator IC

2.6 Distortion

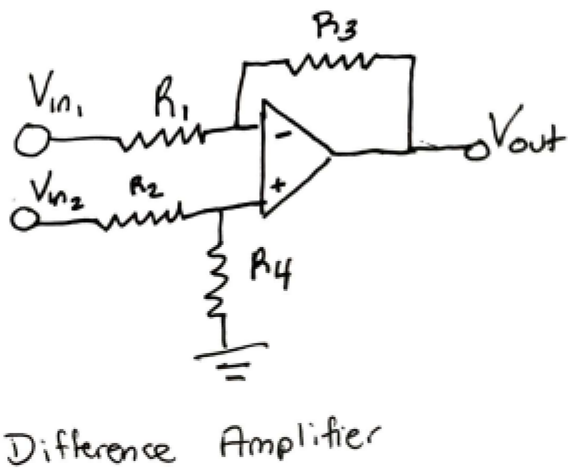

Figure 7: Clipping/Slew rate distortion

The Slew rate is the maximal rate of change (expressed in V/μs) that the op amp can jump up or down. It's essentially the max slope a wave can have before it gets distorted. Clipping is when the expected amplified output voltage exceeds that of the op-amp's capabilities. In essence, if an op-amp is only connected to +-18 volts, and the wave is amplifying to 20 volts, a chunk of the wave will be "clipped" off.

3 Transistors

The first type of transistor is a bipolar transistor. These consist of a collector, base, and emitter. There are two types of bipolar transistors, NPN and PNP.

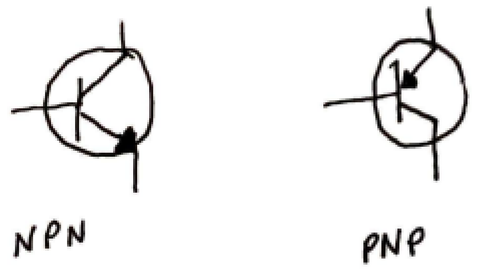

Figure 8: The types of BJT

These Transistors follow 3 rules:

1. The base draws very little current compared to I_e, so we can approximate $I_c \approx I_e$
2. The Base-Emitter junction is forward biased (Current only flows Base to Emitter)
3. The Collector-Base junction is reverse biased (Current from collector cannot go into the base connection)

3.1 Common Emitter Amplifer

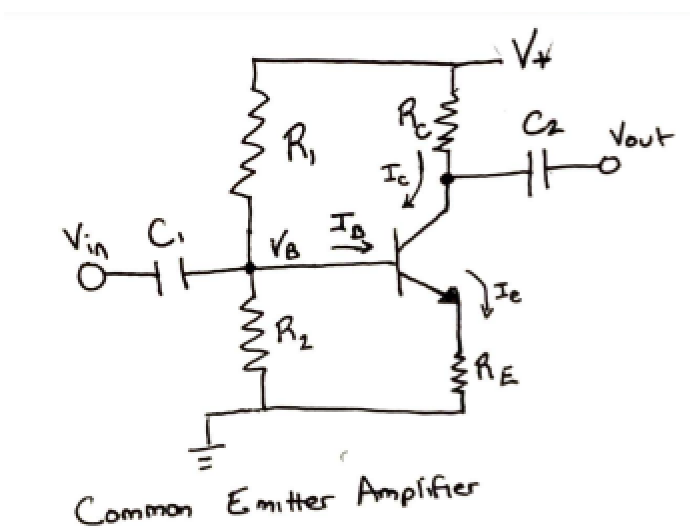

Figure 9: Common Emitter Amplifier

In order for the circuit to be stable and function properly, we introduce a constant DC voltage source V_+ to guarantee the required biases across the transistor, as well as greatly reduce the effects of varying β (Basically, this stabilizes the amplifier). This is where the voltage divider comes in (Components R_1 and R_2). Given we know the range of the input signal V_{in}, we divide the voltage such that it will never drop below the required bias of the Base-Emitter junction of the transistor, while still maintaining the necessary Collector-Base bias. This then gives us a constant base voltage V_b into the base, in addition to a constant base current. What happens is the AC voltage/current is superimposed on the DC. It does not change the amplification at all, it just guarantees the circuit will work properly. Thus, V_b is given by:

$$V_b = V_+\left(\frac{R_2}{R_1 + R_2}\right)$$

V_+ determines the maximum I_c when the transistor is fully 'on', ie. saturated, and no voltage drop across it (ie. $V_{ce} = 0$). Next, we look at the gain of this circuit. An important part of the circuit is the capacitors C_1, C_2, as they act as a **block to DC, but will pass AC**. These capacitors are called coupling capacitors, they separate AC signals from the DC biasing voltage. We will shortly see how this simplifies the calculations. *Without* C_2, We have the following:

$$V_{\text{out}} = V_+ - R_c I_c$$

Given that the base current is much smaller in comparison to the collector current, we make the approximation $I_e \approx I_c$. We then calculate I_e via the resistor value R_E.

$$I_e = \frac{(V_{\text{in}} + V_b - 0.6)}{R_E}$$

Thus, the gain then becomes:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = V_+ - \frac{R_c}{R_E}(V_{\text{in}} + V_b - 0.6)$$

Now, if add C_2, we can filter out all the DC parts! Thus, we can remove $V_+, V_b, -0.6$ effectively making the output gain of the circuit:

$$\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{R_c}{R_E}V_{\text{in}} \tag{5}$$

4 Logic

4.1 Logic Gates

AND

Input 1	Input 2	Logic Out
T	T	T
T	F	F
F	T	F
F	F	F

OR

Input 1	Input 2	Logic Out
T	T	T
T	F	T
F	T	T
F	F	F

XOR

Input 1	Input 2	Logic Out
T	T	F
T	F	T
F	T	T
F	F	F

NOR

Input 1	Input 2	Logic Out
T	T	F
T	F	T
F	T	T
F	F	T

NOT

Input 1	Logic Out
T	F
F	T

NAND

Input 1	Input 2	Logic Out
T	T	F
T	F	T
F	T	T
F	F	T

XNOR

Input 1	Input 2	Logic Out
T	T	T
T	F	F
F	T	F
F	F	T

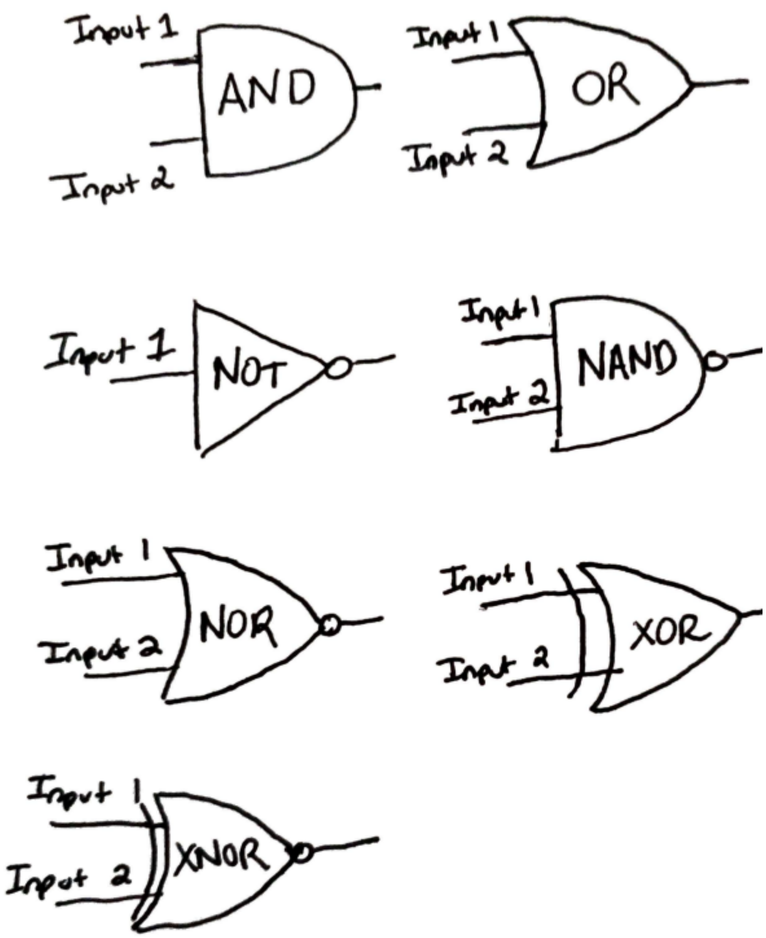

Figure 10: Logic Gate Symbols

4.2 TTL Logic Levels

A logic level is considered to be "off/low" when the voltage is between 0 to 0.8 Volts. A logic level is considered to be "on/high" when the voltage is between 2-5 Volts. (typically about 5 volts)

5 Sensors

5.1 Photo Diode

Photodiodes become a small current source in the presence of light. They are often used to detect fast pulses of near-infrared light used in wireless communication. They have a very linear light-current response.

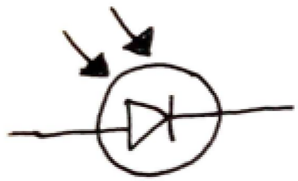

Figure 11: A photo diode

5.1.1 So, how do they work?

A photodiode is built by sandwiching a thin n-type region with a thick p-type region. The n-region has lots of electrons, the p-region has lots of holes. Here, the n-side is called the cathode and the p-side is the annode. When light hits the photodiode, some photons hit the p-region, which excites the electrons enough to knock them across the p-n junction. Now, the p-region has extra holes, and the n-region has extra electrons. This creates a potential difference, and thus if either end is connected via a wire, there will be a current!

5.2 Phototransistor

Phototransistors are light sensitive transistors. In bipolar phototransistors, the base is replaced with a light sensitive surface area. When there is no light, there is very little base current. When there is light, there is a small base current, that is amplified through to the collector-emitter current. PhotoFET's are another type, light generates a gate voltage that is used to control a drain-source current. This variation is very sensitive to small changes, but also fragile comparatively to bipolar transistors.

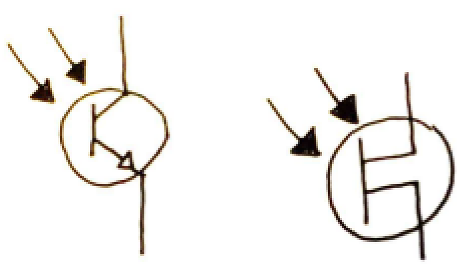

Figure 12: Photo Transistors (Left: Bipolar, Right: FET)

5.2.1 How do these transistors work?

There is a large p-type semi-conductor region in the base/gate region. Light hits this region and electrons gain enough energy to jump the p-n junction (provided the light is the correct energy / frequency). As electrons jump to the lower n-region, holes are created in the p-region, and the new electrons in the lower n-region are drawn towards the positive terminal of the battery. Electrons from the negative terminal of the battery are drawn into the upper n-type region and across the n-p junction, where they then fill the holes. Electron current from the emitter to the collector, which (in terms of conventional current) creates a positive current flow from collector to emitter. It is important to note, even when kept in the dark, phototransistors produce a "dark current", however this current is negligible.

5.3 Thermistors

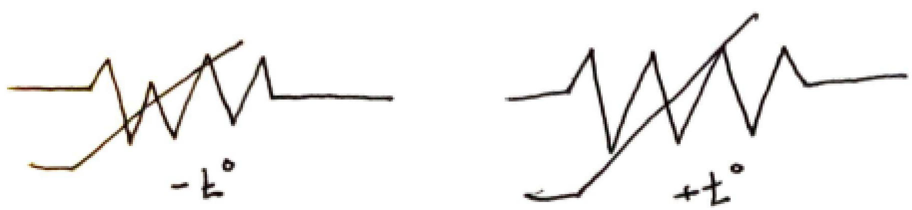

Figure 13: Thermistors (Left: NTC, Right: PTC)

These are resistors that chance their resistance with temperature. For these, they are grouped into two types: Negative Temperature Coefficients (NTC), where the resistance DECREASES as you increase the temperature, and Positive Temperature Coefficients (PTC), where the resistance INCREASES as temperature increases. The temp-resistance relationship is NOT linear, so we use the Steinhart-Hart (lol what a name) equation to get the resistance as a function of temperature (for either type). It is given as follows:

$$\frac{1}{T} = A + B\ln(R) + C\ln^3(R) \tag{6}$$

Where T is the temperature in Kelvin, R is the resistance of the thermistor, and A,B,C are specific given constants for that thermistor. Otherwise if we don't want to use this equation, we have an alternative, which is:

$$R(T) = R_0 e^{\beta(\frac{1}{T} - \frac{1}{T_0})} \tag{7}$$

Where R_0, β, T_0 are all given constants.

5.3.1 Thermocouples

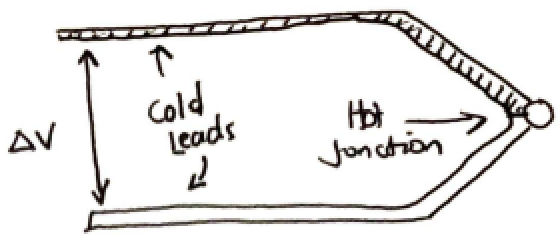

Figure 14: Thermocouple

Well, Thermistors are good for smaller temp ranges, what do you do if you have a large temp range? Thermocouples! When a conductor has a temperature gradient, it experiences the Seebeck effect, where it creates a small voltage depending on the material. Taking this further, when two different materials are joined together, the temperature of the hot junction can be measured using the potential difference on the cold leads and the temperature of the cold leads.

5.4 Resistive Temperature Detectors (RTD's)

Similar to thermistors, but these are made via a coil of wire (normally platinum) and a ceramic/glass core since the resistance of platinum chances more or less linearly over a range of 100 $°C$, and the core's resistance is 100Ω at $0°C$.

Say we wanted to find the resistance of a platinum RTD at $80°C$ with a resistance variance of 0.004 $°C^{-1}$

$$100\Omega + \left(80°C * 0.004°C^{-1}\right) * 100\Omega = 132\Omega$$