

Project conducted over spring semester of 2023

# Improvement of the IR thermometer For BetterBots—

Minnesota State University, Mankato

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## Abstract:

A differential amplifier is used in the BetterBots robot as an amplifier to the IR non-contact thermometer, a schematic of which can be shown in Figure 1. Our task was to improve some performance parameters of the circuit. The two parameters we had worked on were settling time and offset adjustment range. Improvements of settling time is closely tied to a value of compensation capacitance located in the second stage of the differential amplifier (differential amplifier and its second stage boxed in pink in Fig. 1). Decreasing the value of this compensation capacitor improves settling time without introducing sinusoidal behavior. The changes made was to decrease the value of the capacitance from an original value of 220pF to 1pF. Improvement of the adjustment voltage involved changing values of the resistance of the current sink at Q12 of Figure 1. Our changes to these values can be seen in Figure 4, achieving a compensation range of double the amount of the original, the new compensation range being  $\sim 20.8\text{mV}$  to  $\sim -21.5\text{mV}$ .

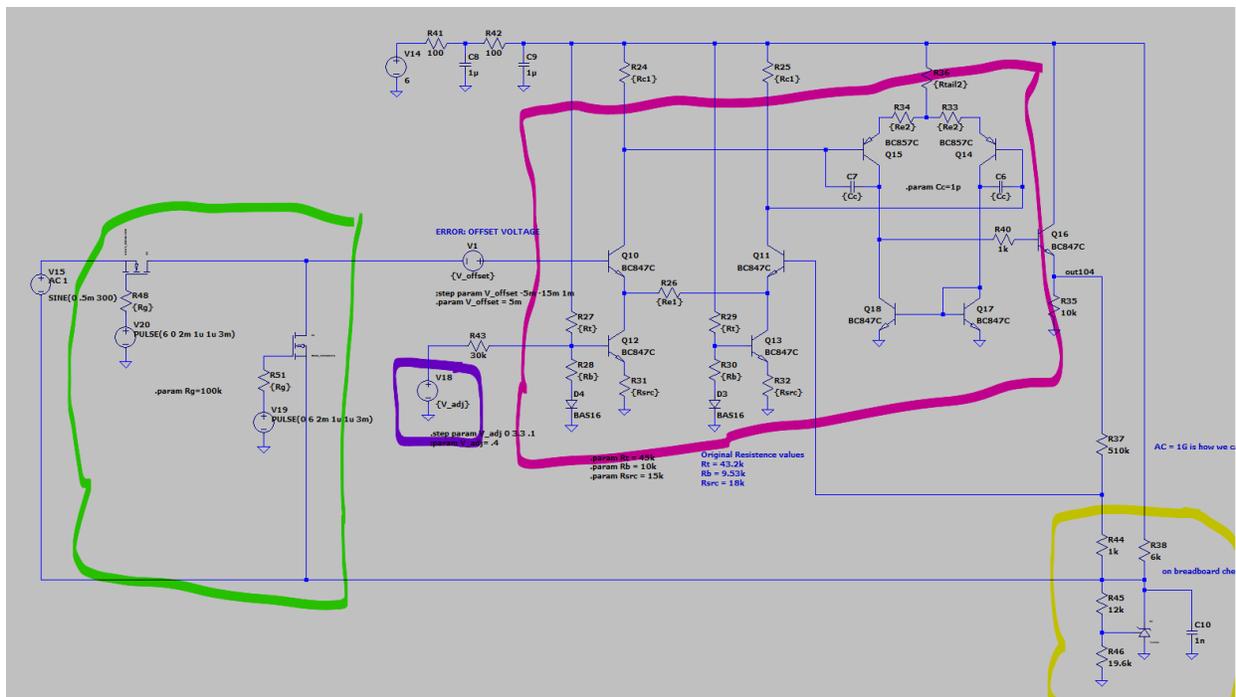


Figure 1. Schematic of the differential amplifier

## Improvements:

There were two main improvements to make over the course of time that the team had worked on the circuit, settling time and offset adjustment range. Both improvements are important aspects of an efficient circuit as they are performance parameters that determine how fast the circuit can transition from one input to another and how much offset voltage from mismatched transistors can be accommodated. In the case for settling time, the thermopile and common mode inputs need to swiftly change from one another when activating auto-zero calibration. Doing this ensures that the sensitive offset voltage between the differential pair can be measured with more accuracy. Compensation of the offset voltage can be adjusted using an adjustment voltage applied at the current sink of the differential pair (boxed in purple in Fig. 1). The adjustment voltage

Improvements on settling time:

The settling time is the amount of time it takes for the system to transition from the thermopile input to common mode input. It turns out that the main factor that determines this settling time is the compensation capacitors (labeled 'Cc' on Fig 1.). Originally this capacitance value was 220pF. As this value decreases, settling time improves, the figure below (Fig 2) shows a comparison of 220pF and 1pF.

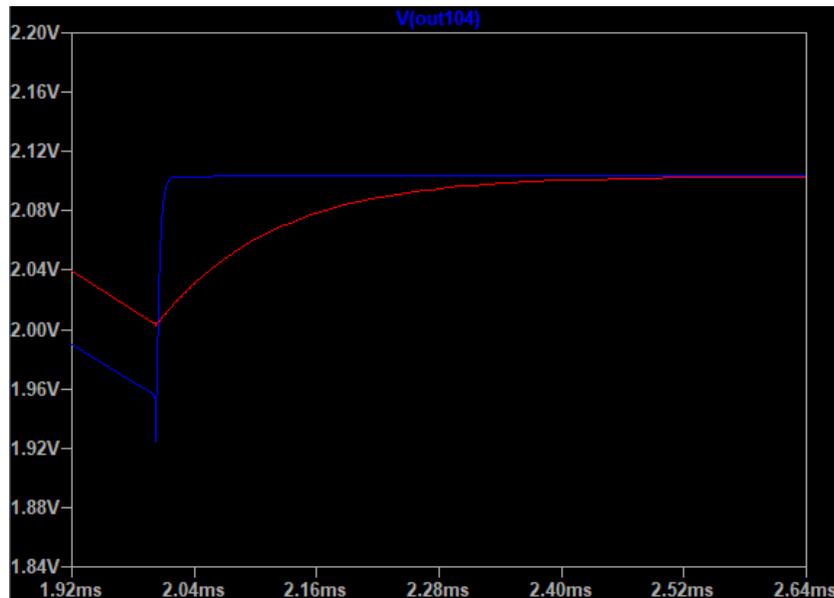


Figure 2. Comparison of settling time of 1pF in blue and 220pF in red

The graph shows a compensation capacitance of 1pF as a settling time of less than 0.04ms because the auto-zero switches at 2ms into the simulation. The compensation capacitance of 220pF of approximately 0.52ms. This improvement of settling time allows the device to sample at higher rates. High-rate sampling is important because it allows the device to get an offset fast enough before the offset has a chance to change too dramatically.

Improvements on adjustment voltage range.

A limitation to the circuit is the range of adjustment voltage that can produce a current in the current sink of Q12 and Q13 to compensate for the offset of the differential amplifier. This range is set by the resistor values of R27, R28, R43, and R31. These resistors form a current sink that can be modeled, as shown in Figure 3 as an ideal current sink.

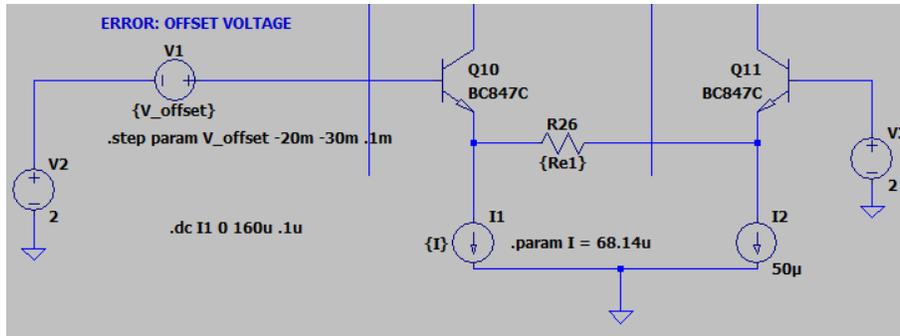


Figure 3. Ideal current sink

This simulation allows us to approximate the adjustment current needed for a given offset. With this simulation, we can generate another simulation to get these currents through the emitter of Q12. Figure 4 is the schematic of just the current sink of Q12.

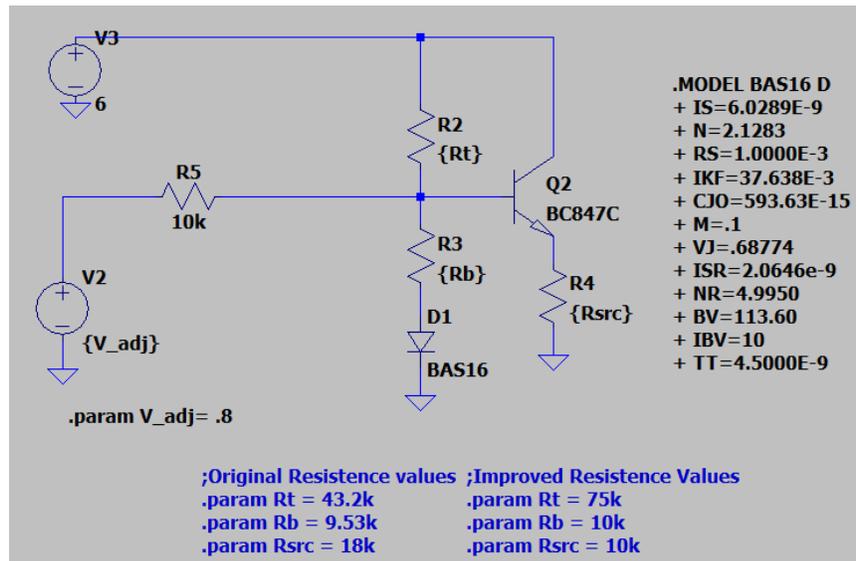


Figure 4. Current sink of differential amplifier

With this schematic, we can simulate changes in the resistor values to achieve a greater emitter current range of Q2 in figure 6. Remembering that the emitter current of Q2 in figure 6 is controlled by R4, the voltage contribution of V2 is controlled by R5, and the voltage at the base is set by the voltage divider made up by R2 and R3, we can adjust values in to achieve a improvement of adjustment range.

Because the voltage divider will be the minimum value (if no adjustment voltage is applied) the base can be, we want to set the voltage as low as possible to compensate for higher positive offset. Increasing R2 to 75kΩ allows the non-adjusted base voltage to be approximately 0.6V which is sufficient voltage to achieve the required 0.5V drop across the base to emitter for the transistor to remain in the active region. Since the emitter voltage is so low, we can achieve a smaller emitter current by reducing R4. To get a larger slope of the emitter current plotted against the adjustment voltage, a resistance of 10kΩ was chosen.

To get larger currents, reducing the value of R5 would be beneficial as it would mean more of a contribution from the adjustment voltage source. Supplying the base with higher voltage also increases the emitter voltage meaning a higher emitter current. Achieving more contribution from the adjustment voltage, R5 needs to be reduced, our design reduces this to a 10kΩ resistor.

Figures of the original and improved emitter ranges are Figures 5 and 6. The results of the simulations show a clear steeper slope over the same adjustment range of 0V to 3.3V. In the original design, the offset compensation range was from about -9mV to 9mV which have emitter currents 68.14μA and 32.14μA respectively. The improved design has an emitter current range of 7μA to 158μA which is compensating an offset between 21.5mV to -20.8mV



Figure 5. Original range of emitter current



Figure 6. Improved range of emitter current.

## Creating a PCB:

For this project, there was a PCB created to learn PCB design software, generating Gerber files, and following standards specific in our design. Even though we had made and ordered PCB's, we had never soldered components to them because of time restraints of the course. The intention of the PCB was to integrate it with the microcontroller instead of a breadboarded circuit for ease of construction and wiring. The team could not achieve integration; however, the process of the situation is still valuable and will be described in this report.

Using the schematic made in LTspice, a copy was made into the software EasyEDA which is a free tool to design PCB's and generate Gerber files. It also has a function to send the GERBER files to a partnered manufacturing company. A diagram of the schematic is shown with Figure D in the Appendix section. Copying the schematic is not simply copying the component one for one but rather it needs to be specified on which component that is going to be used and the packaging that the component will be of. Changing the components information is necessary as it is essential for accurate silk screens and pin layout. The Gerber file is shown on Figure 7, and the physical PCB is shown in Figure 8.

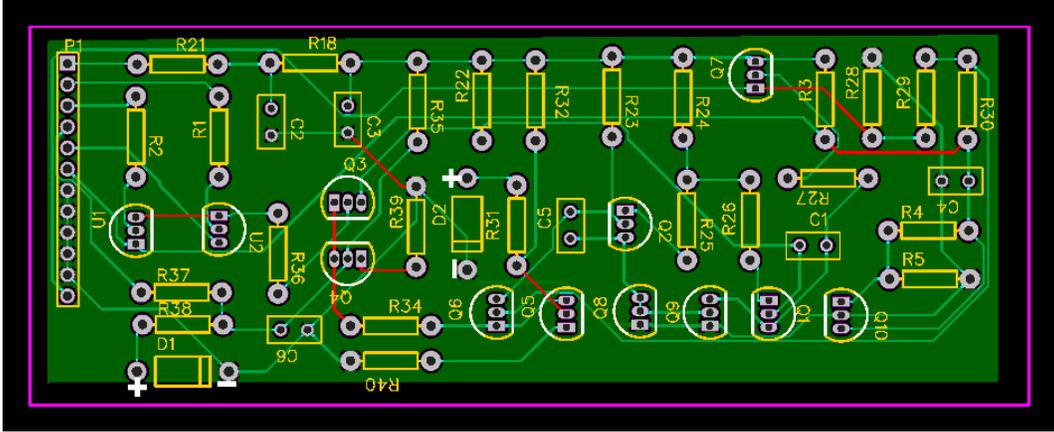


Figure 7. Gerber file generated

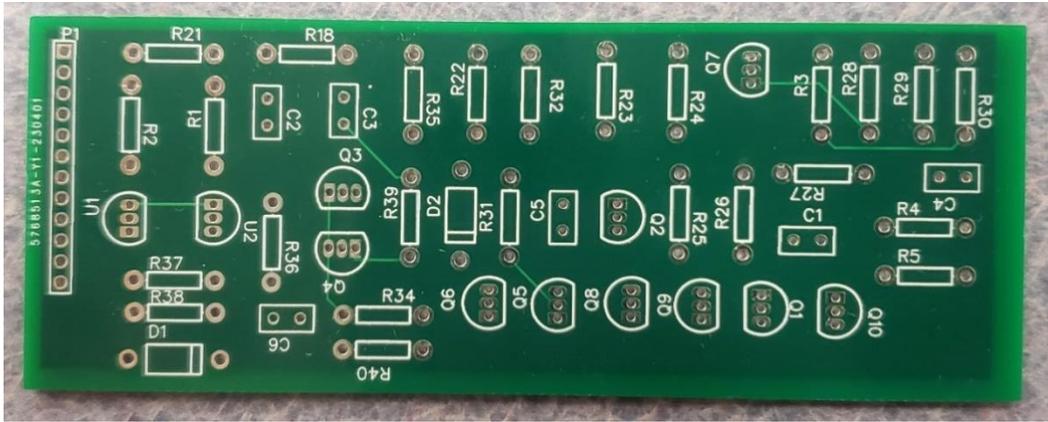


Figure 8. Physical PCB manufactured

## Testing the Circuit:

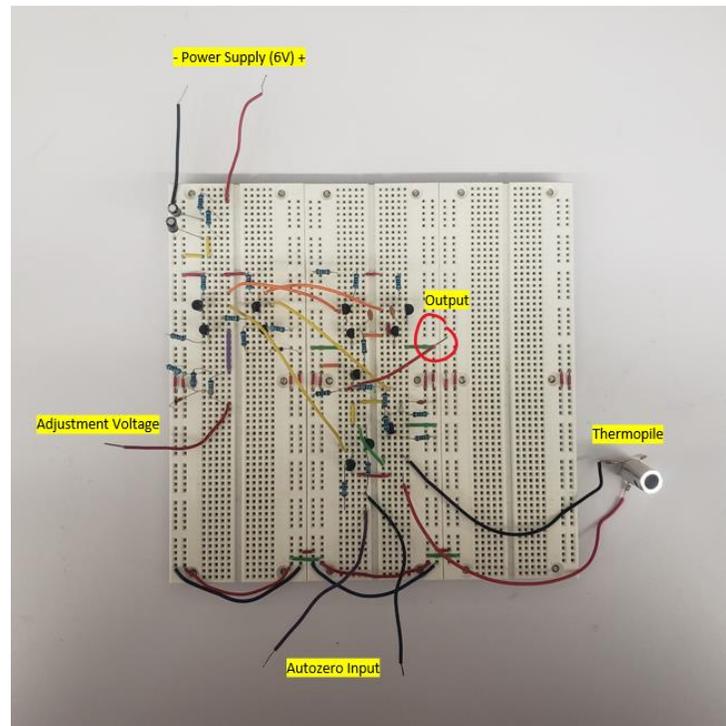


Figure 9. Breadboard of final circuit

Above is the circuit we used to test the design in real life. While the autozero is active, the adjustment voltage is a variable voltage that is swept till the output reaches its reference voltage. This reference voltage on the built circuit is  $\sim 1.8\text{V}$ . The value of the voltage supplied to R43 in Figure 1 is  $5.23\text{V}$  but the actual voltage applied to the base of Q12 is  $1.91\text{V}$ , this voltage is required to correct for the offset voltage between the differential amplifier's transistors. Testing the circuit involved measuring the thermopile output without the amplifier, then with the amplifier when it's adjusted. If the adjustment voltage is not tuned then the output of the amplifier is clamped to high/low voltage sticking to  $\sim 5\text{V}/\sim 0.3\text{V}$  respectively, this error matches the simulated behavior on LTSpice.

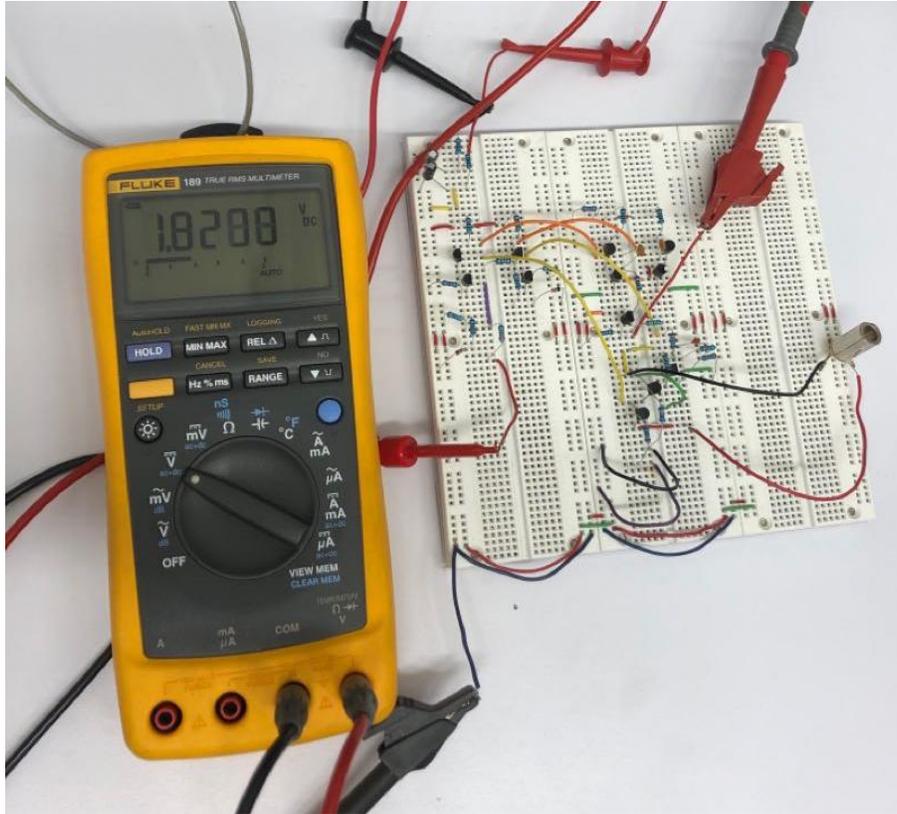


Figure 11. DMM reading output as Auto-Zero is active and adjustment voltage is tuned.

When activating the Autozero, the black wire (right) is connected to the power rail being 6V while the purple wire (left) is connected to the ground. In this state, the differential amplifier's inputs are shorted, allowing to measure and correct the offset voltage. We measured an offset of 0.5mV.

Testing the amplification of the amplifier involved measuring the unamplified output of the thermopile when reading ambient room temperature and when our hand was placed in front of the thermopile to capture a difference of readings. The following photos are of a DMM reading those values.

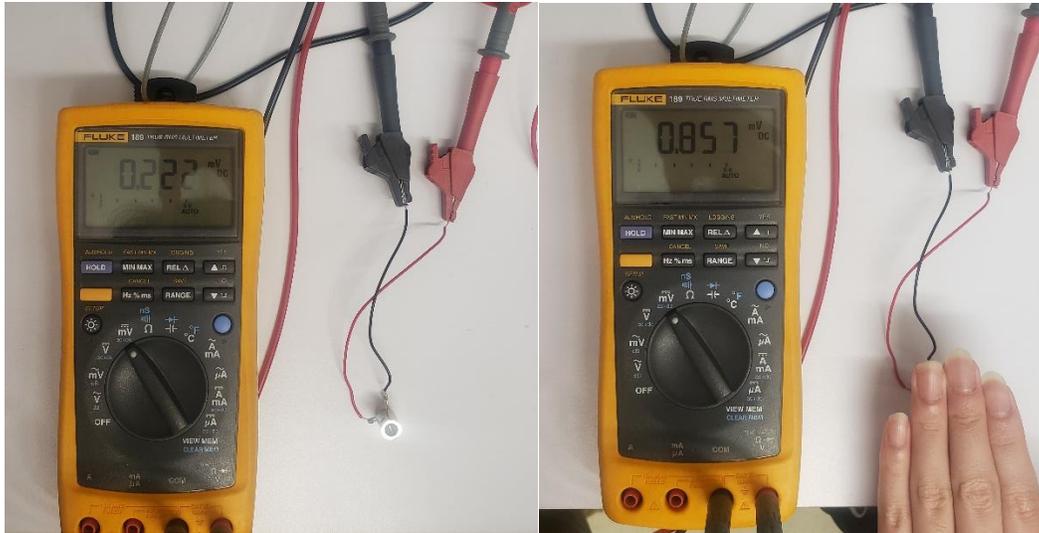


Figure 12. Unamplified thermopile reading ambient temperature (left) and reading hand temperature (right).

Notice the output of the unamplified thermopile being in millivolts. Attaching the thermopile to the differential amplifier and running the same tests show a significant amplification in voltage output. The following are photos of the DMM readings of those tests.

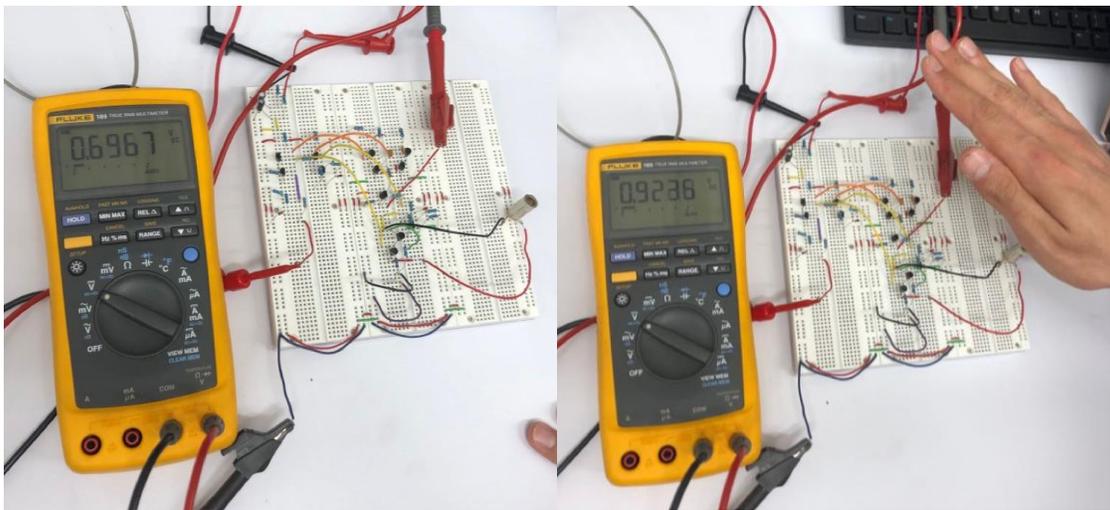


Figure 4. Amplified thermopile output of ambient temperature (left) and reading hand temperature (right).

The output of the thermopile running through the circuit does indeed amplify the output by a large factor (order of 1000). It is also of note that the ambient temperature reading comparing the unamplified vs amplified does have a difference. This difference could be due to the difference due to imprecise tuning leading to some offset being amplified as well as the thermopile input.

Another cause could be fluctuations of offset voltage that is not being corrected in real time.

Junior Engineering Design

# IR Room Temperature Scanner

Minnesota State University, Mankato

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5-2-2023

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## Abstract:

In this document, it is discussed on the importance of temperature regulation in a closed environment for different commercial uses like food storage. The document also goes on a purpose a solution to monitoring temperature by a IR room temperature scanner. Using a IR scanner previously designed or an educational robot called BetterBots, and a microcontroller, a device can be made to monitor the rooms temperature. Improvements to the differential circuit were made in the forms of setting time and offset adjustment range. Integration of the hardware and software proved to be too time-consuming as the team did not achieve a device that was functional but was able to prove that the circuit works and explain competently how the device would work.

## Background:

Temperature mapping involves using wireless data loggers or thermocouples to monitor and record temperature and humidity levels at various points in each environment, such as freezers, ovens, or storage areas. This data is then analyzed to identify areas of temperature deviation or hotspots, allowing you to take corrective action and maintain product quality.

Temperature mapping is critical for industries such as biotech and pharmaceutical development and manufacturing, where even small temperature variations can compromise product safety and quality. Well-documented validation processes are crucial for FDA and GxP compliance, and a large chunk of those processes usually involve temperature mapping.

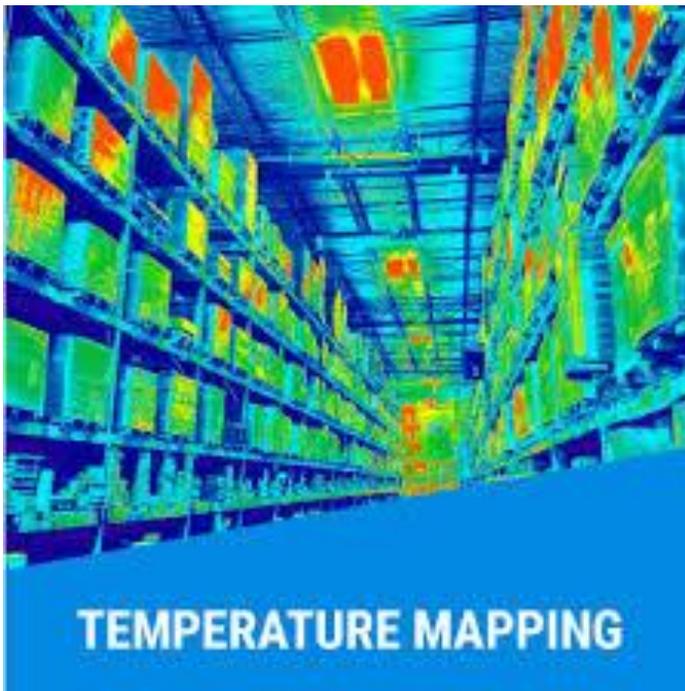


Figure 1. Visualization of temperature mapping

Our device will find the temperature difference while rotating 360 degrees and record and tell users the temperature which direction has high and low like (Fig 1).

The company is Ellab. like our project, Ellab provides world-leading validation, monitoring and calibration solutions and services, as well as GMP consulting, to life science and food manufacturing companies across the globe. One of the products they provide is Track View Pro PT1000 Smart Sensor. The Track View Pro system provides access to a wide variety of sensors including, but not limited to, temperature, relative humidity (RH), carbon dioxide (CO<sub>2</sub>), differential pressure (DP), door switches, 4-20mA inputs, 0-10V input, digital input, digital output and more, ideally suited for the

specific needs of the biopharmaceutical industry.

## Hardware:

For this project an emphasis on through hole components was made because of ease of use and possibility of breadboarding for prototypes and design purposes. Much of the hardware used was bought on Amazon.com for the bulk components like capacitors and resistors, the component kit acquires was the Mega Electronics Component Kit sold by 3PDT. The online component store, Digikey.com, was also used to buy extra and specialty components like the TLV431 Shunt Regulator. Simulations of the schematic were built and tested on LTSpice which is a free open-source CAD software for circuit schematics.

## Description:

The Differential Amplifier built on the Betterbots.com website is a complete circuit that is being implemented in the robot to take temperature readings. Using this circuit as reference, our device can start taking readings using the differential amplifier and send that data to be manipulated using the microcontroller used in this project.

Multiple subsystems are used in this circuit, but the main subsystems used in the project were the auto-zero system (highlighted green on Fig 2) and the voltage regulator system (highlighted in yellow). Both are integral systems to have as they allow the designer to capture error of the system and bias the differential amplifier generating our reference voltage. The Differential amplifier and its second stage are highlighted pink, the output of the entire circuit is the trace labeled “out104” which is the emitter of Q16.

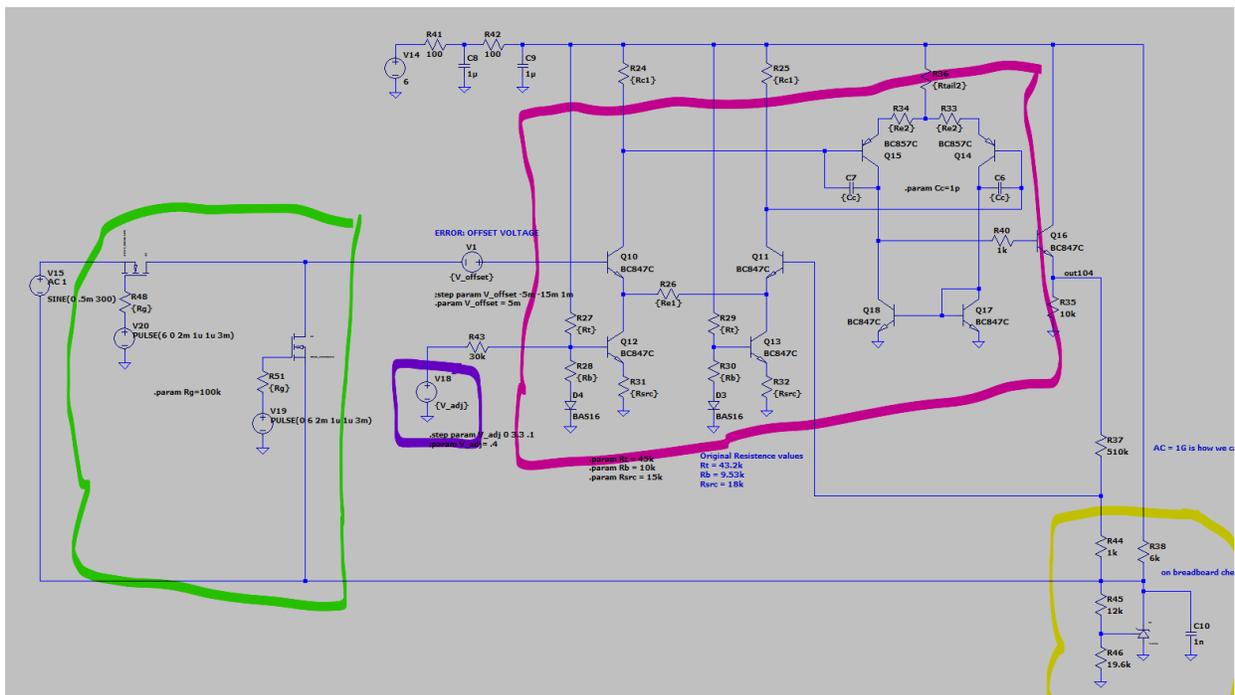


Figure 2. Schematic of Differential Amplifier

#### Auto-zero:

Auto-zeroing is the process of measuring your error when a differential amplifier's positive and negative inputs are short circuited. This results in an output that is equal to the reference voltage being applied to the inputs in an ideal case and a difference from that reference in a non-ideal case, this is also commonly known as "*common mode*". In the common mode, the margin of error from the output to the reference voltage is called the "*offset voltage*". This offset is caused by many different factors, the main one being the differences in manufacturing from part to part. Another reason for offset could be two different temperatures that each BJT is subjected to. The choice of using an auto-zero circuit is a key detail in later sections as this auto zero determines the offset. Once this offset is known, an adjustment voltage can be applied to the current sync of the active load of the differential amplifier (this voltage is highlighted purple in Fig 2). Doing such would compensate for the offset which allows the device to take accurate measurements.

Implementing the auto-zero is just two N-channel MOSFET's, the configuration of such MOSFET's is that to short the inputs of the differential amplifier and another to connect one of the inputs of the differential amplifier to the thermopile (simulated using a voltage source V15 in Fig 2). In the circuit shown in Figure 2, the resistor R48 sets current to the gate of a MOSFET (U1) that connects one of the inputs of the thermopile (base of Q10). R51 does the same (U2) but instead its task is to short the inputs of the differential amplifier.

Activating the auto-zero is simply applying a logical bit '1' (when breadboarding this is 6V) to the gate of U2 and ground the gate of U1. This disconnects the thermopile while shorting the inputs of the differential amplifier, this is when offset voltage can be measured. Getting back to measuring the Thermopile is simply switching the base voltages of U1 and U2 so the gate of U2 is ground and the gate of U1 is 6V or whatever is logical bit '1'

#### Voltage Regulator:

Highlighted in yellow is the voltage regulator system. This whole system depends on the TVL431 adjustable precision shunt regulator by Texas Instruments. This component has three pins, a reference pin and a cathode, anode pin that are the output and ground pin respectively. Setting a voltage to the reference pin allows the output to match this voltage by directing some current to ground. For more information on this component, the documentation is provided by Texas Instruments and linked in the Reference section.

The application of the circuit is simply generating the 2V reference by resistors R45 and R46. Wiring the output of the shunt regulator to the inputs of the differential amplifier applies the reference voltage.

#### Expected operation:

Below is a block diagram (Fig. 3) of how the microcontroller and circuit are interacting. From the diagram it is understood that the microcontroller generates the offset voltage and a clock pulse to the auto-zero. The microcontroller should run a calibration run to correct for offset and to activate the auto-zero. The differential amplifier block is the entirety of the hardware that was built by us. In expected operation, this calibration would sweep the adjustment voltage till offset is corrected by reaching the reference voltage value while the auto-zero is activated, and only after that is the IR Temperature Scanner taking accurate measurements.

## Block Diagram

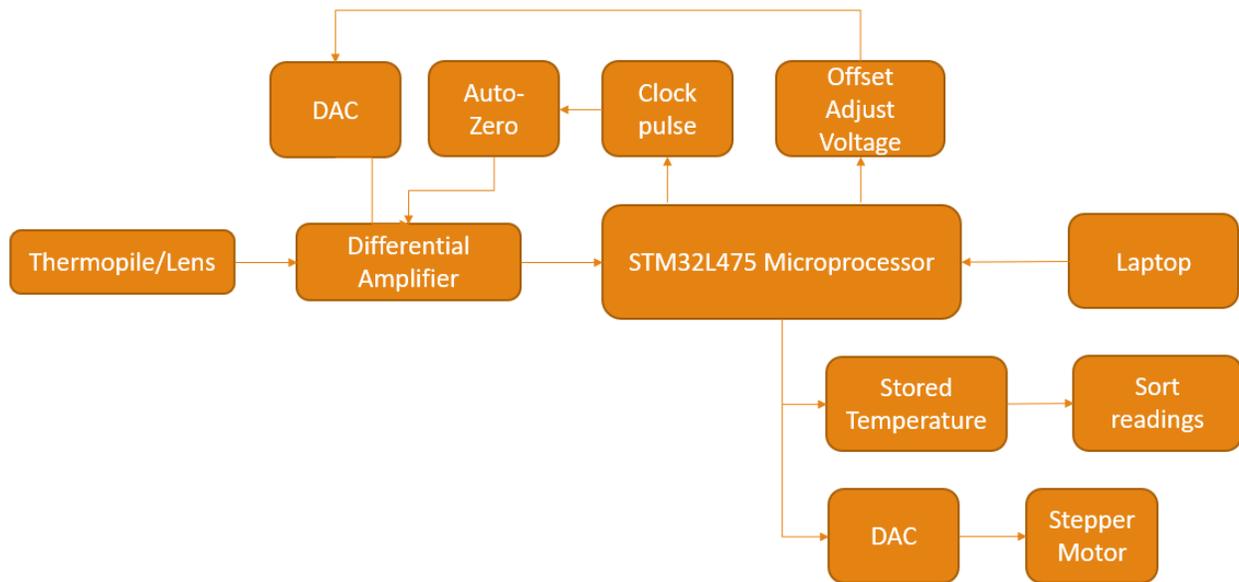


Figure 3 Block diagram of systems and signals

## Challenges:

There are setbacks in the design of the circuit that were well known by Daniel Walker, the creator of BetterBots and designer of the circuit. These setbacks are that the settling time of the circuit could be faster, and the adjustment voltage range where it's still compensating for an offset. These setbacks were taken by the team and while working closely with Mr. Walker to better understand the circuit by improving these parameters. The circuit was simulated on LTSpice and tested on a breadboard built in lab. The completed breadboard is Figure A in the Appendix section.

## Solutions:

Our multipackage design introduces a higher offset due to mismatching components. To reduce this offset, An IC containing multiple BJT's could reduce mismatch and in turn reduce offset in our differential amplifier. This would reduce the amount of voltage needed to fix offset, making a more efficient design.

Because of limitation of the current sink of the differential amplifier we can only get a certain range of adjustment voltage. We can change resistance values of the current sink to improve the adjustment voltage range, increasing the amount of offset we can correct.

Switching speed is determined by the settling time of the circuit. Settling time is determined by a compensation capacitor value. A resolution to this would be to decrease this value. We have already fixed this issue.

## Improvements on settling time:

The settling time is the amount of time it takes for the system to transition from the thermopile input to common mode input. It turns out that the main factor that determines this

settling time is the compensation capacitors (labeled 'Cc' on Fig 2.). Originally this capacitance value was 220pF. As this value decreases, settling time improves, the figure below (Fig 4.) shows a comparison of 220pF and 1pF.

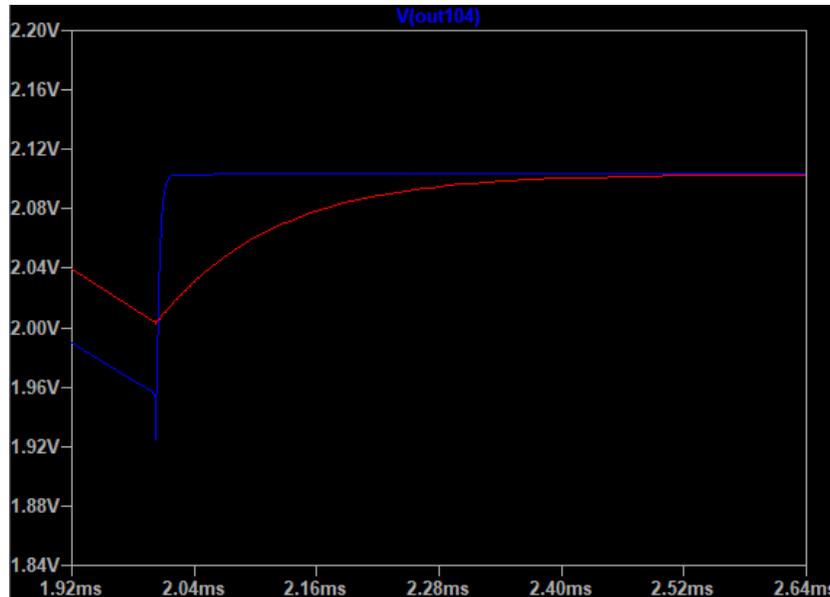


Figure 4. Comparison of settling time of 1pF in blue and 220pF in red

The graph shows a compensation capacitance of 1pf as a settling time of less than 0.04ms because the auto-zero switches at 2ms into the simulation. The compensation capacitance of 220pF of approximately 0.52ms. This improvement of settling time allows the device to sample at higher rates. High-rate sampling is important because it allows the device to get an offset fast enough before the offset has a chance to change too dramatically.

Improvements on adjustment voltage range.

A limitation to the circuit is the range of adjustment voltage that can produce a current in the current sink of Q12 and Q13 to compensate for the offset of the differential amplifier. This range is set by the resistor values of R27, R28, R43, and R31. These resistors form a current sink that can be modeled, as shown in Figure 5 as an ideal current sink.

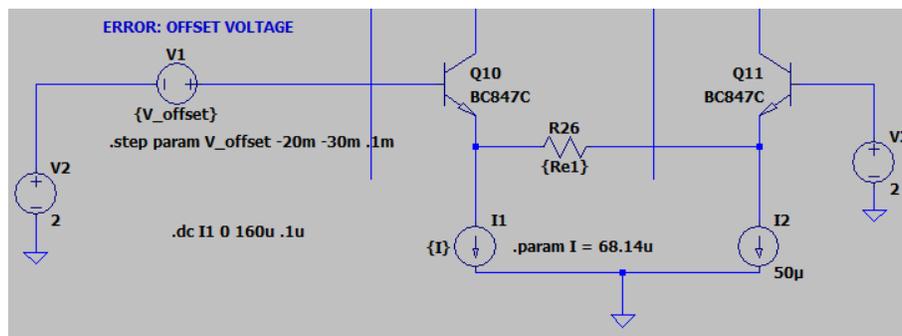


Figure 5. Ideal current sink

This simulation allows us to approximate the adjustment voltage needed for a certain offset. Because of this simulation we can generate another simulation to try and get these currents through the emitter of Q12. Figure 6 is the schematic of just the current sink of Q12.

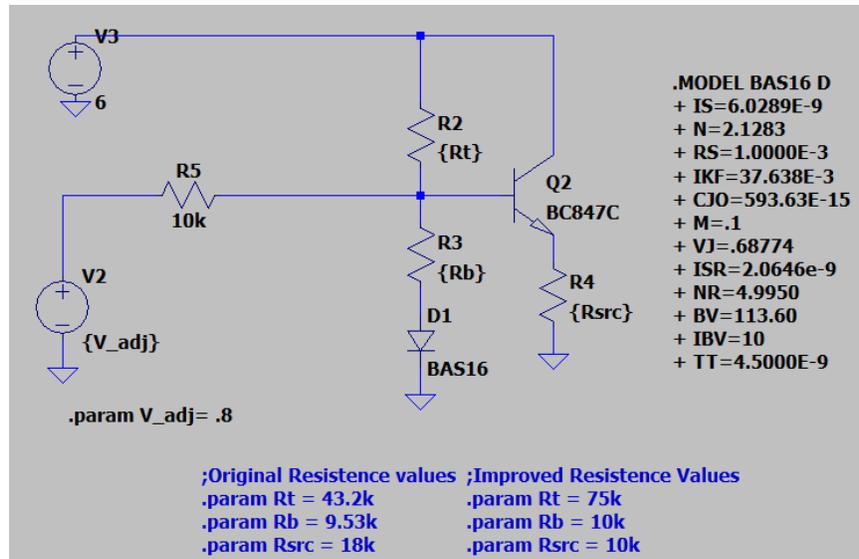


Figure 6. Current sink of differential amplifier

With this schematic, we can simulate changes in the resistor values to achieve a greater emitter current range of Q2 in figure 6. Remembering that the emitter current of Q2 in figure 6 is controlled by R4, the voltage contribution of V2 is controlled by R5, and the voltage at the base is set by the voltage divider made up by R2 and R3, we can adjust values in to achieve a improvement of adjustment range.

Because the voltage divider will be the minimum value (if no adjustment voltage is applied) the base can be, we want to set the voltage as low as possible to compensate for higher positive offset. Increasing R2 to 75kΩ allows the non-adjusted base voltage to be approximately 0.6V which is sufficient voltage to achieve the required 0.5V drop across the base to emitter for the transistor to remain in the active region. Since the emitter voltage is so low, we can achieve a smaller emitter current by reducing R4. To get a larger slope of the emitter current plotted against the adjustment voltage, a resistance of 10kΩ was chosen.

To get larger currents, reducing the value of R5 would be beneficial as it would mean more of a contribution from the adjustment voltage source. Supplying the base with higher voltage also increases the emitter voltage meaning a higher emitter current. Achieving more contribution from the adjustment voltage, R5 needs to be reduced, our design reduces this to a 10kΩ resistor.

Figures of the original and improved emitter ranges are Figures B and C in the appendix. The results of the simulations show a clear steeper slope over the same adjustment range of 0V – 3.3V. In the original design, the offset compensation range was from about -9mV to 9mV which have emitter currents 68.14μA and 32.14μA respectively. The improved design has an emitter current range of 7μA to 158μA which is compensating an offset between 21.5mV to -20.8mV

## Creating a PCB:

For this project, there was a PCB created to learn PCB design software, generating Gerber files, and following standards specific in our design. Even though we had made and ordered PCB's, we had never soldered components to them because of time restraints of the course. The intention of the PCB was to integrate it with the microcontroller instead of a breadboarded circuit for ease of construction and wiring. The team could not achieve integration; however, the process of the situation is still valuable and will be described in this report.

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The design specification for the PCB is that all components need to be through hole versions, and that there is proper heading space for all necessary pins. To get through hole version of components is that they need to be packaged as TO-92, A standard packaging size for through hole components. British Standards are a leading standard organization that recognizes TO-92 as a standard in their "Quick Reference Guide". This guide shows many different components following the package outline of the TO-92. Because of the recognition of standard packaging and the ease of installing and testing, TO-92 is default packaging that the circuit uses.

## Software:

### Description:

The focus of the software section is to use the circuit and implement it so that we can rotate a temperature sensor and get the readings.

We have used a stepper motor to make the rotations take place and get the reading of the thermometer sensor displayed on an LCD screen.

### Stepper motor:

A stepper motor is a type of electromechanical device that converts electrical pulses into precise rotational movements. It is used in a wide range of applications, including robotics, automation, CNC machines, and 3D printers.

The motor consists of a rotor (rotating part) and a stator (stationary part). The rotor typically has teeth on its surface, and the stator has several electromagnets arranged in a specific pattern. When current is applied to a particular electromagnet, it generates a magnetic field that attracts the rotor teeth to align with it. Once the rotor has aligned, the current is removed from that electromagnet, and another is energized to attract the next set of rotor teeth.

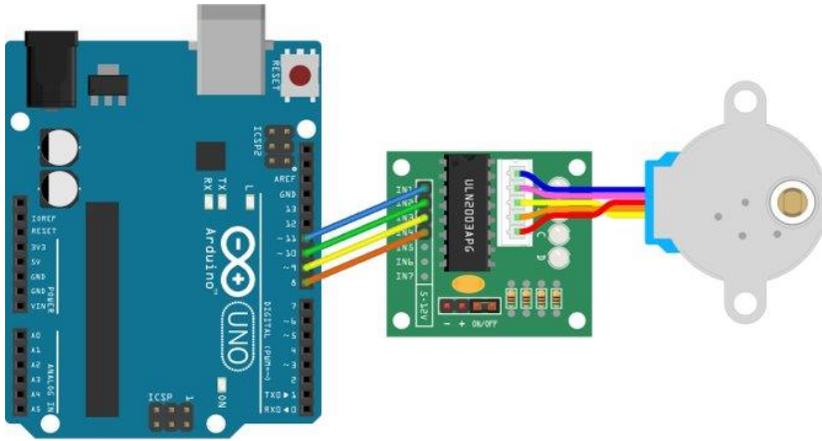


Figure 6. Stepper motor and Driver PCB

By repeatedly energizing and de-energizing the electromagnets in sequence, the rotor can be made to rotate in small, precise steps. (In our case we used a 15-degree interval) The number of steps per rotation is determined by the number of teeth on the rotor and the pattern of the stator electromagnets. Stepper motors can provide very precise positioning and speed control, making them ideal for applications that require high accuracy and repeatability.

LCD screen:

An LCD (Liquid Crystal Display) screen is a type of display technology that is commonly used to display temperature readings in various applications. LCD screens are thin and lightweight and can be made in various sizes and shapes.

To display temperature on an LCD screen, a temperature sensor is usually used to measure the temperature and send the data to a microcontroller or microprocessor. The microcontroller then converts the temperature reading into a digital format and sends it to the LCD screen for display.

The LCD screen can display the temperature in either Fahrenheit or Celsius and can be configured to show the reading in different formats, such as a numeric value or a graphical representation. Some LCD screens also have built-in backlighting, making them easy to read in low-light environments.

Overall, LCD screens are popular for displaying temperature readings because they are energy-efficient, easy to read, and can be customized to meet specific application requirements.

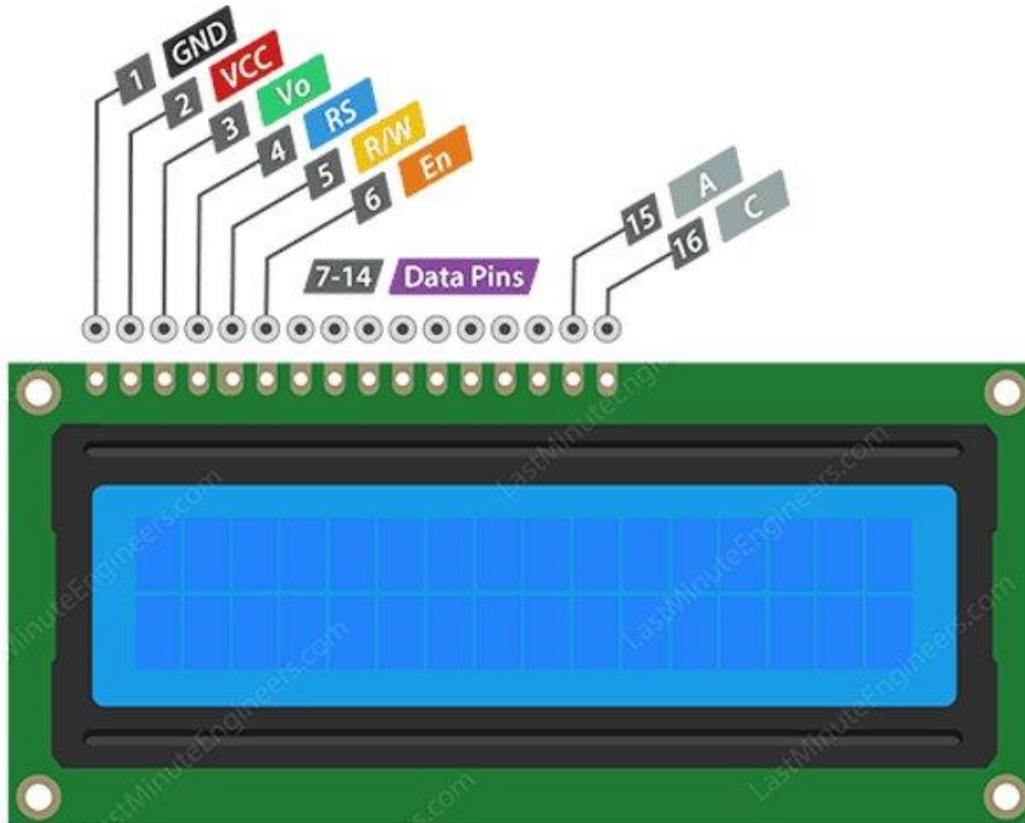


Figure 7: LCD screen setup

### Implementation:

To implement our ideas using a stepper motor we used Cube MX and stm32 using C language to get our code to work. Here are some snippets for the code.

```

void stepper_step_angle (float angle, int direction, int rpm)
{
    float anglepersequence = 0.703125; // 360 = 512 sequences
    int numberofsequences = (int) (angle/anglepersequence);
    for (int seq=0; seq<numberofsequences; seq++)
    {
        if (direction == 0) // for clockwise
        {
            for (int step=7; step>=0; step--)
            {
                stepper_half_drive(step);
                stepper_set_rpm(rpm);
            }
        }
        else if (direction == 1) // for anti-clockwise
        {
            for (int step=0; step<8; step++)
            {
                stepper_half_drive(step);
                stepper_set_rpm(rpm);
            }
        }
    }
}

```

```

/* USER CODE BEGIN WHILE */
while (1)
{
    /* USER CODE END WHILE */
    for(int i = 0; i< 3; i++)
    {
        stepper_step_angle(45,0,0);
        delay(1000);
    }
    /* USER CODE BEGIN 3 */
}
/* USER CODE END 3 */

```

```

/* USER CODE BEGIN 3 */
/* USER CODE END 3 */

```

Figure 8 Code snippet from cube MX

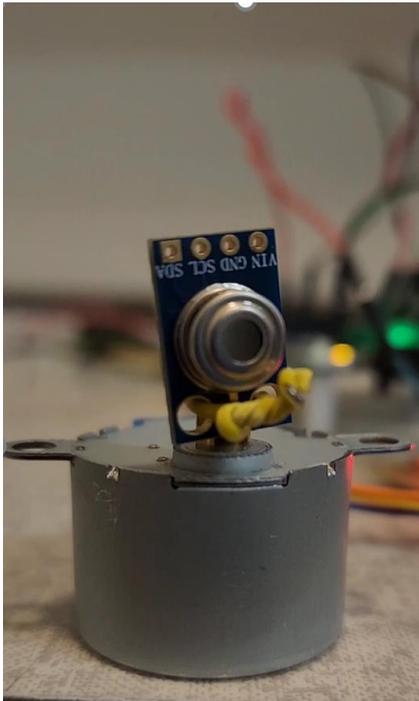
### Challenges:

Interfacing the Arduino I2C devices with STM32L475VGT6 in STM32CUBEIDE. We had errors with the clock configurations for using delay functions to halt and take temperatures. We

had a problem with pin configurations, we were not able to run all devices at once on the microcontroller. For example, stepper motor and lcd only work on GPIOA port. Also interfacing the PCB and thermopile setup with the microcontroller, problems encountered to read the data and calculate the offset and then writing it to the LCD.

### Solutions:

For the clock configuration issues, pin configuration issues we can use one microcontroller for the stepper motor and another microcontroller to take measurements from thermopile setup and output the temperature after adjusting the offset to the LCD monitor. By fixing the clock issues, we will be able to use FreeRTOS middleware(DAC) to control the stepper motor to stop at desired angle and let the thermopile take temperature reading. And then we can use ST-Link on STM32CUBEIDE to connect and transfer data between two microcontrollers in real-time. Which will almost eliminate the connection issues. The problem with interfacing the thermopile setup to microcontroller, is fixed by using the FreeRTOS middleware for analog to digital conversion.



*Figure 9: the stepper motor with the thermometer rotating in order to give output on display*

### Summary:

The design of a IR room temperature scanner for commercial and residential use was proved in this project. An outline of software to interconnect and operate the device was conceived and the design and realization of a differential amplifier was created. Using these two portions (software and hardware) it can be integrated together to come up with a product that monitors and displays temperature information and location to a user.

Major successes were achieved in this project, that being the improvement of differential amplifier circuit and the creation of a PCB that would be integrated into a microcontroller. A foundation of software was created to operate the device as well. However, there were many shortcomings in the project as well. The main shortcomings of the project were deadlines and not meeting those deadlines. Another shortcoming is that the team did not achieve a working product at the end of the project but rather a proof. Much of the year-long time spent on the project was spent on research and by the second half of the timeline, no product was envisioned. The second half of the year was spent on fitting a purpose to the device rather than coming up with a problem and trying to find a solution to that problem.

Future changes to the circuit can be made as well. More testing to find the optimal adjustment ranges can be found as the team's design accounts for offset way below -21mV but at lower offsets, the circuit will not have enough gain to reach reference voltage which is required for an accurate measurement. In the future, the current sink resistor values could be tuned to meet this limitation rather than account ahead of it. Another change we can add is adding multiple thermopiles in different directions to remove the stepper motor all together. Removing the motor would cut down on the complexity of coding the system which can be hard to implement, it is also unnecessary for the device to move if this change is included. Finally, a system for setting boundary temperatures could be included in future design iterations. A temperature boundary system could help users perform actions based on if the temperature readings are within or outside the boundaries. A temperature boundary system could help notify the user that the temperature in the room has fluctuated out of the specified ranges.

#### Acknowledgment:

We would like to acknowledge Daniel Walker with BetterBots as he took the time to contact us about interests in improving his circuits and continued correspondence throughout the duration of the project. Without him there would be no project to work on, so it is with great appreciation that we thank you Daniel Walker.

We would also like to acknowledge Dr Puteri S. Megat Hamari. The course instructor for Junior Engineering Design that had organized the class and helped with leadership, instruction, and wisdom on the project and how to look forward. We thank you Dr. Hamari for the experience you provided to the project.

## Appendix:

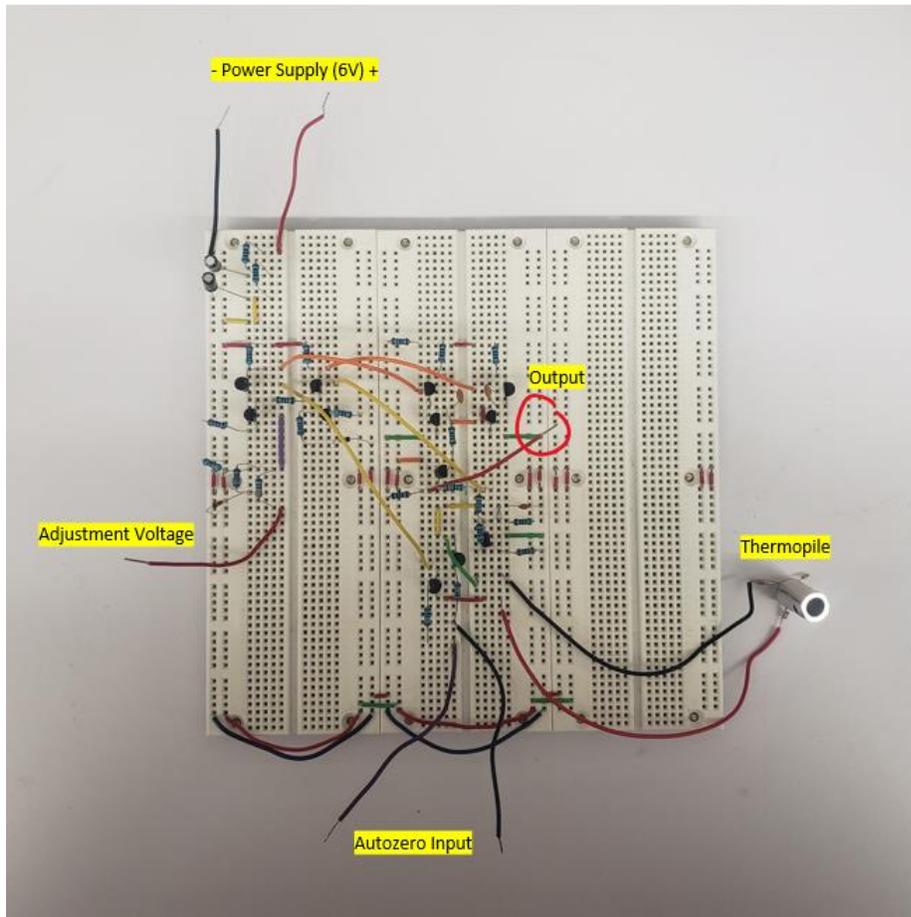


Figure A. Breadboard of final circuit



Figure B. Original range of emitter current

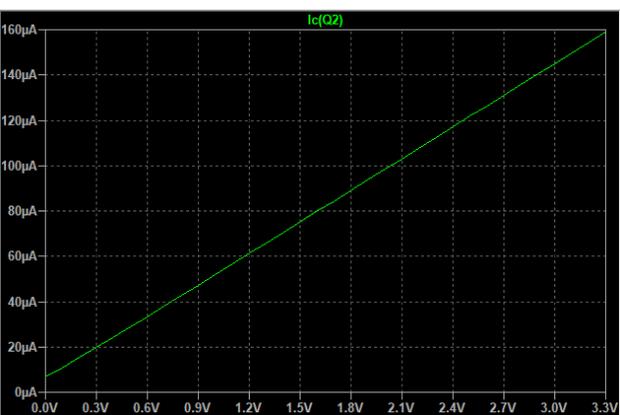


Figure C. Improved range of emitter current.



Part	Digi-key Part Model	Manufacturer	Price per part (\$)
NPN BJT	KSP2222ATACT-ND	Onesemi	0.39
PNP BJT	2N4403TARCT-ND	Onesemi	0.39
N-Channel MOSFET	TN2106N3-G-ND	Microchip Technologies	0.68
Shunt Regulator	296-10727-5-ND (TLV431CLP for MPN)	Texas Instruments	1.00
Thermopile	235-1330-ND	Amphenol Thermometrics	4.07
12-pin Header	S7045-ND	Sullins Connector Solutions	0.81

Table A. Parts list

## References:

BetterBots: <https://www.betterbots.com/>

EasyEDA: <https://easyeda.com/>

Ellab: <https://www.ellab.com/>

JLCPCB (EasyEDA manufacturing partner): <https://jlcpcb.com/?href=easyeda-home>

LTspice: <https://www.analog.com/en/design-center/design-tools-and-calculators/ltspice-simulator.html>

"Package Outlines". Quick Reference Guide (PDF). Ferranti Semiconductors. February 1983. p. PO14. Retrieved 2021-07-10.

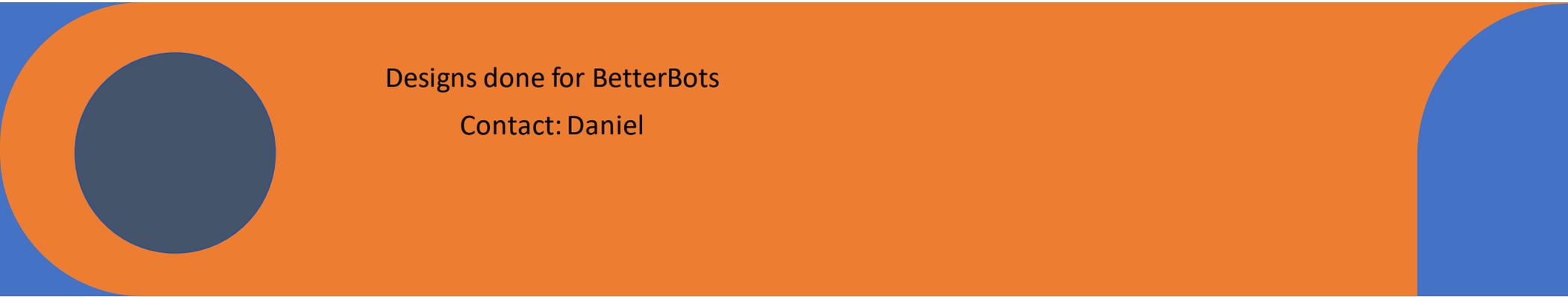
TLV431 Documentation by Texas Instruments: <https://www.ti.com/product/TLV431>



# Improving the Non-Contact IR Thermometer

By BotFix

Members: Zeynel Karagoz, Gyumo Yang, Siene Haq, Kavin Atmakur



Designs done for BetterBots

Contact: Daniel

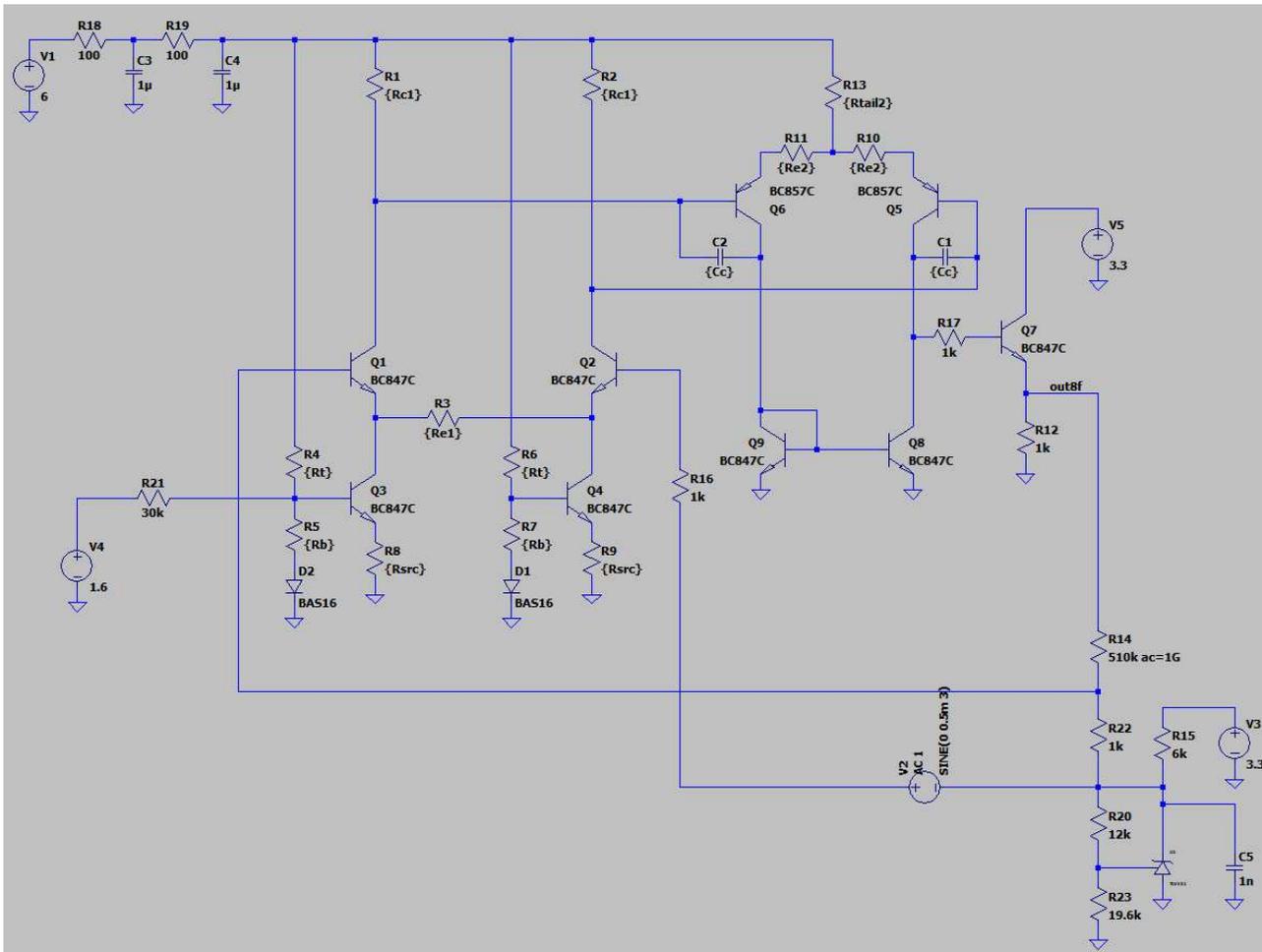
# Overview

- Background

The reasons we chose the differential amplifier in better bots is because it is clear to define the problem and it has a lot of options we can choose from.

- Goal/ Objectives

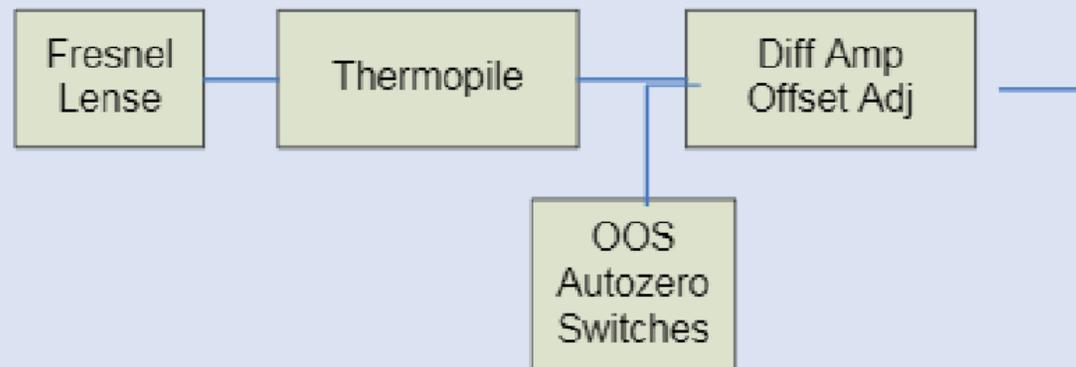
1. Increasing Amplifier bandwidth while keeping gain
2. Increasing switching speed.



The schematic for the differential amplifier

- Offset Variable voltage
- Second stage amplifier with compensation capacitance
- Gain dependence on  $R14/R22$

# Non-contact IR thermometer



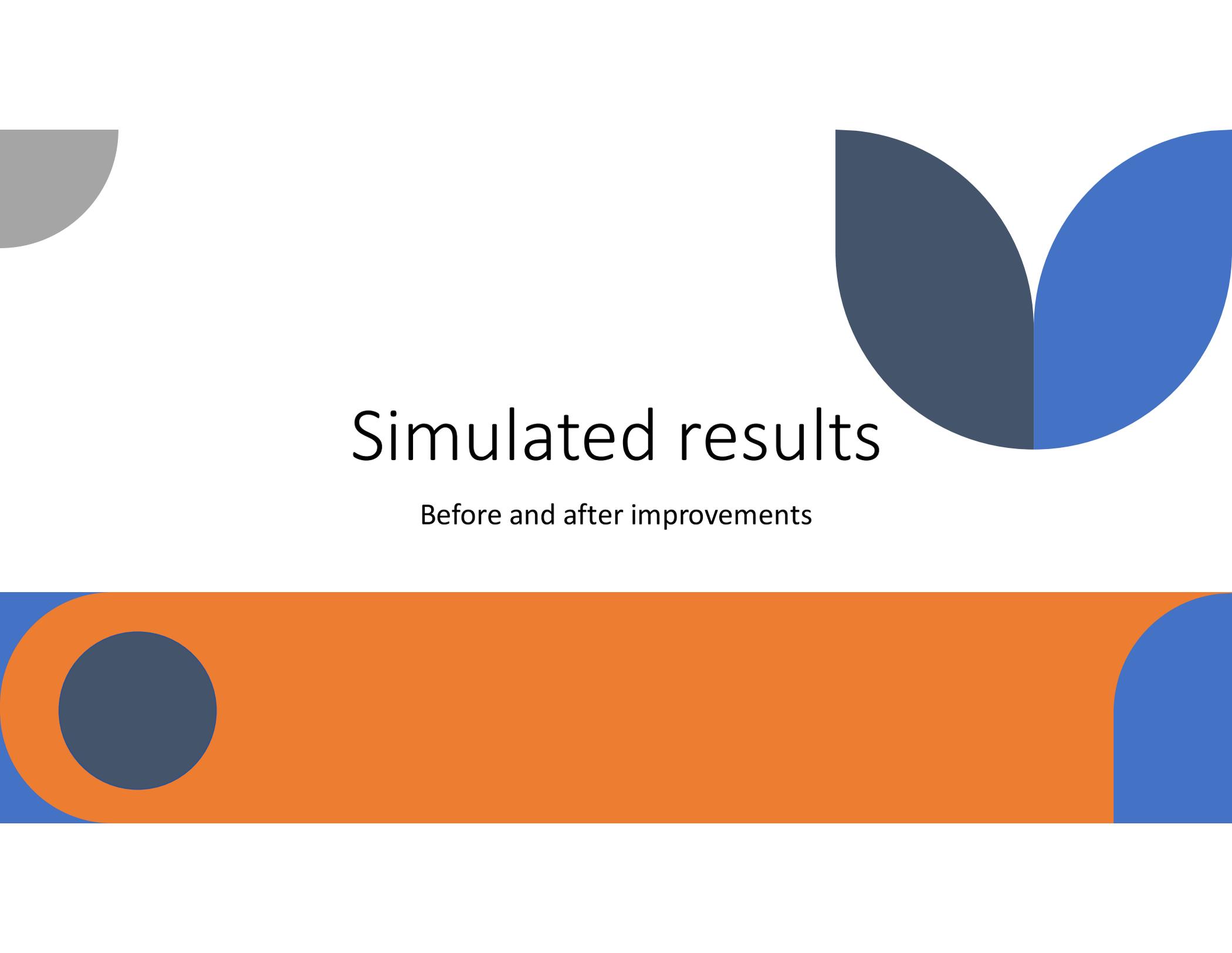
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systems involved in the IR thermometer

Diagram from BetterBots.com

- Offset voltage is similar magnitude as Thermopile output
- Offset and output is measurable
- Subtract offset from Output to get Thermopile input

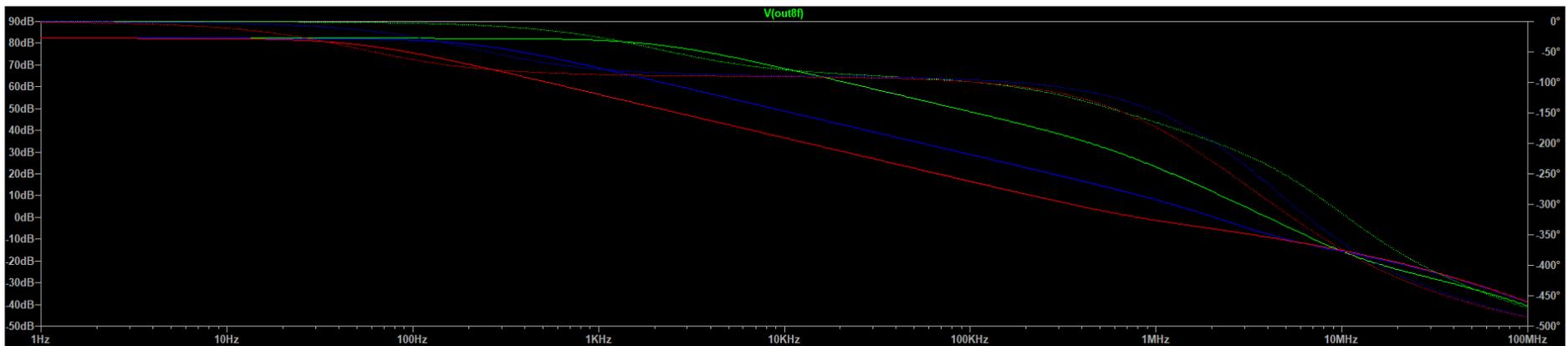
Auto Zero basics



# Simulated results

Before and after improvements

# Bandwidth improvements



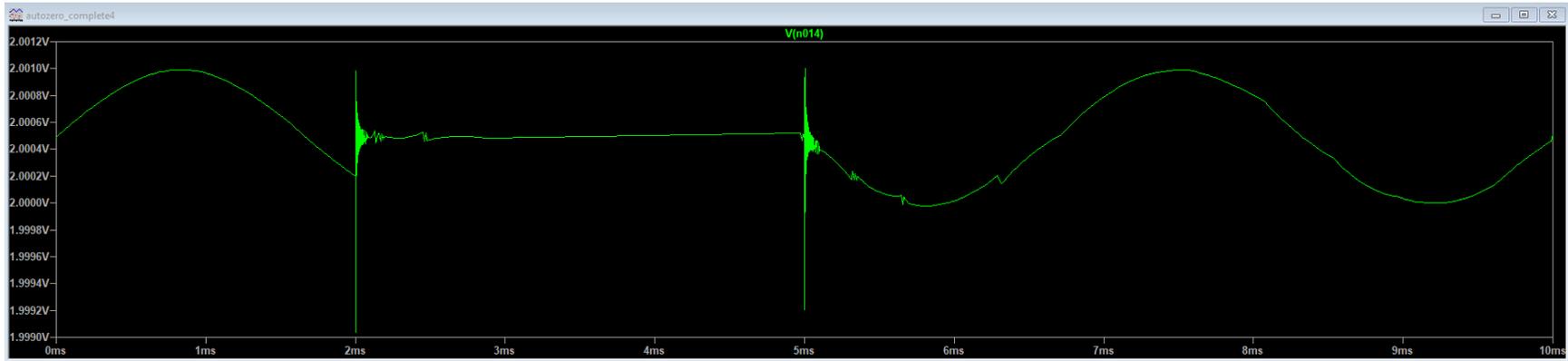
Red line – 220pF  
Blue line – 50pF  
Green line – 1pF  
Dotted line – Phase

## Amplifier vs Oscillator

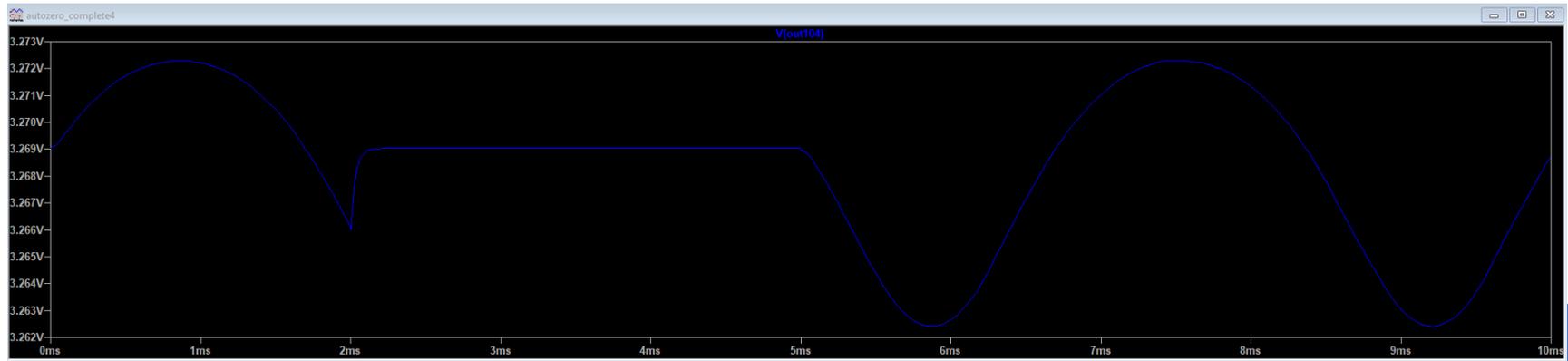
- Barkhausen Criterion
- Positive and Negative feedback

# Before improvements – transient response

Input signal

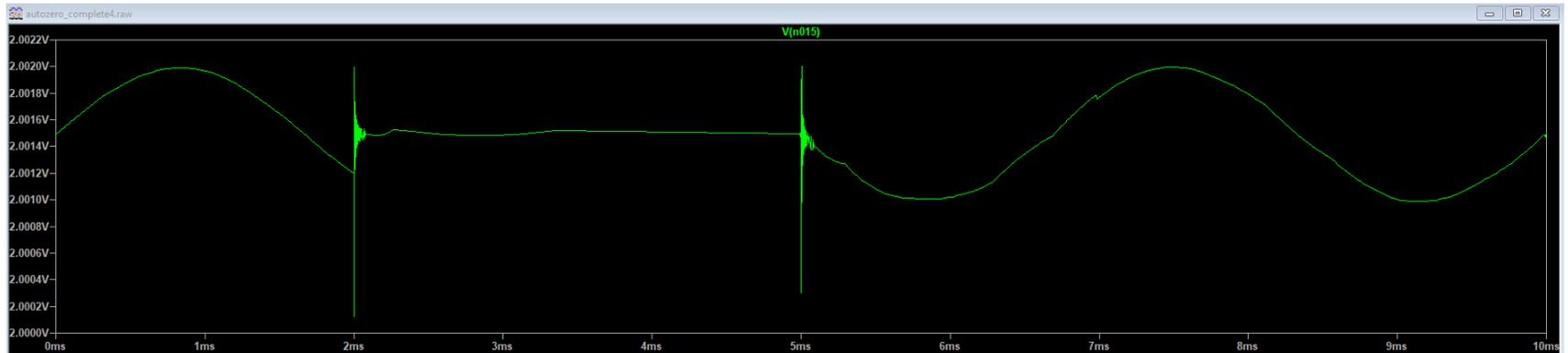


Output signal

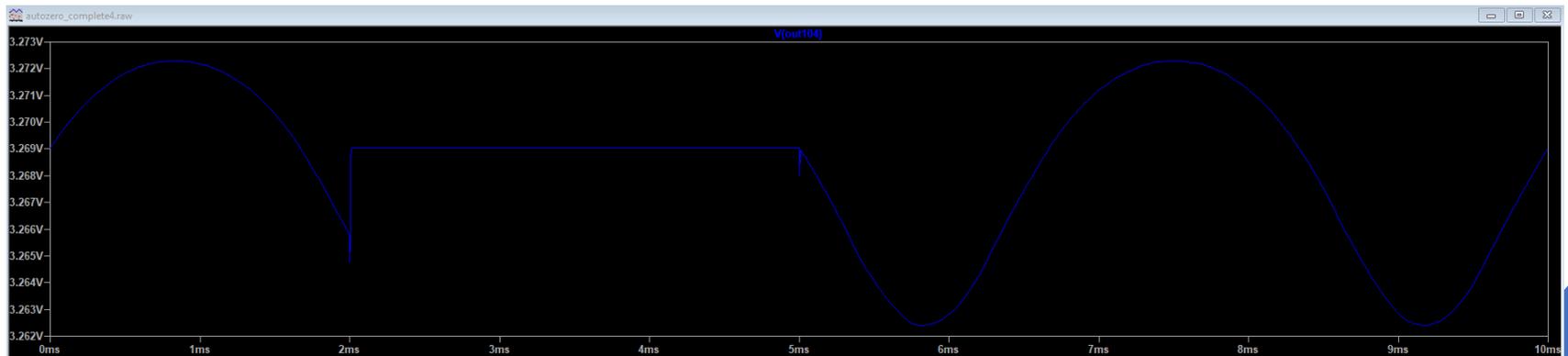


# After improvements – transient response

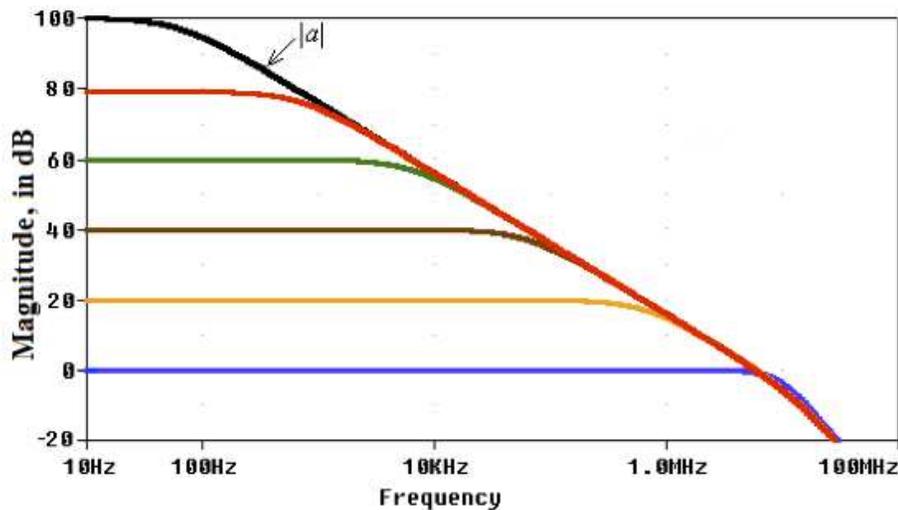
Input  
Signal



Output  
Signal



# Compensation Capacitances



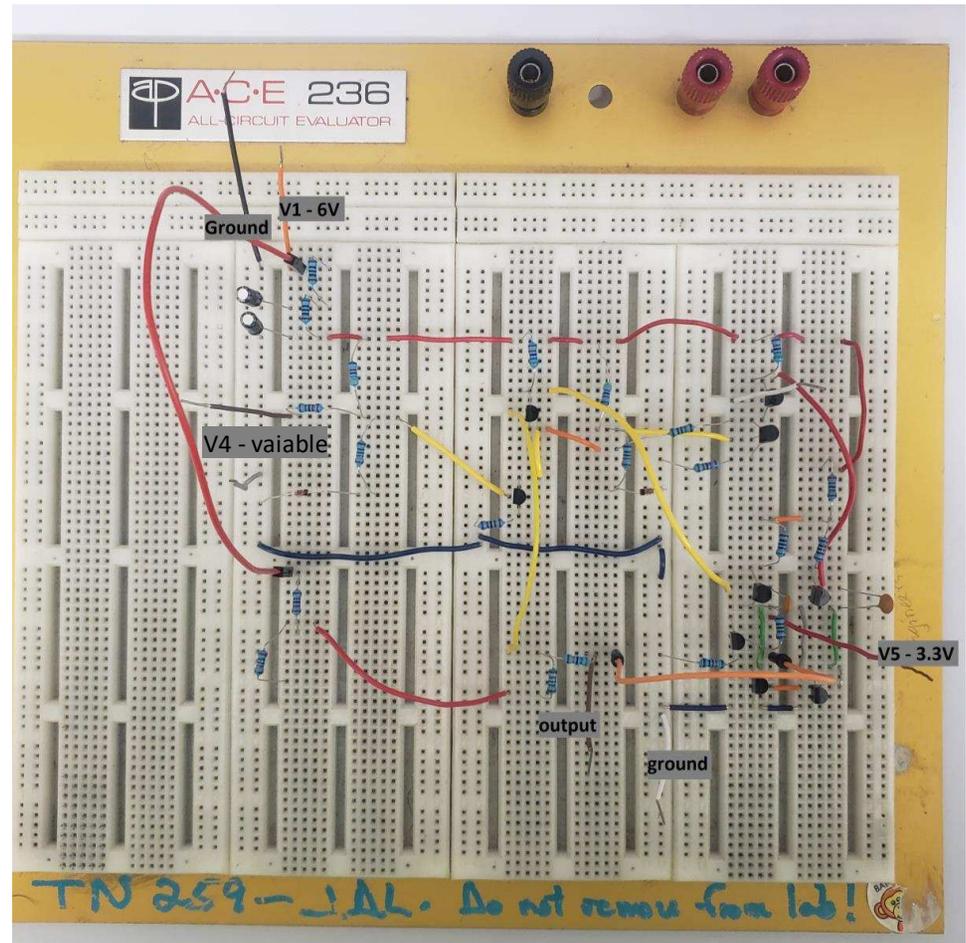
## What does it do?

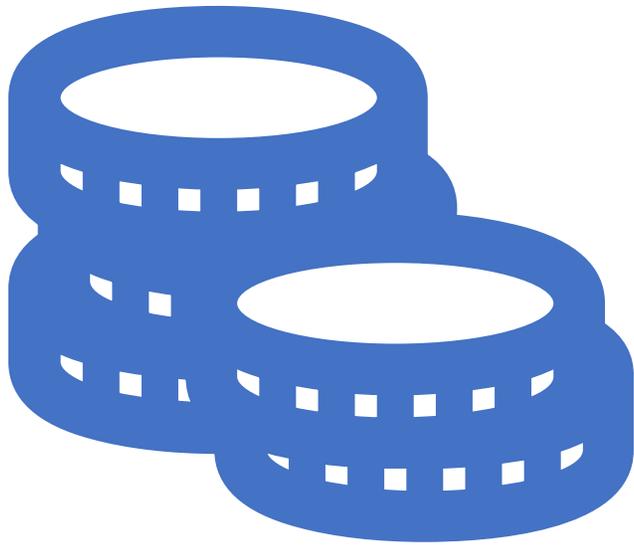
- “compensation capacitor improves the stability of the amplifier and as well as prevent the oscillation and ringing effect across the output”

- From circuitdigest.com

Figure taken from allaboutcircuits.com

# Breadboarded circuit





# Costs

component	amount needed	amount extra	total amount	cost of each component	total cost
<b>total with ceramic components</b>	<b>29</b>	<b>107</b>	<b>158</b>	<b>2.89267</b>	<b>25.78</b>
<b>total with aluminium and through hole resistor</b>	<b>29</b>	<b>97</b>	<b>148</b>	<b>2.87067</b>	<b>29.13</b>



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# Timeline

