# Capacitance Sensors for Mason Bee Activity Measurement

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# 1 Introduction

## 1.1 Objective and Background

The well-known loss of pollinators around the world has been a concern for ecologists, agriculturalists, farmers, and everyday citizens for several years now. While the exact reason for the infamous Colony Collapse Disorder affecting honeybees is unknown, there is interest in boosting their populations so that honeybees can be the thriving pollinators they were once. But what if we are focusing too squarely on the honey bees? What if there is a more effective way to pollinate crops and native plants with a bee population that is native to North America? That would be the mason bees, *megachilidae osmia*. Mason bees, solitary bees that don't live in hives, don't make honey, and usually don't sting, are a species of bee that can pollinate an area almost 100 times more efficiently than the western honeybee [7]. They are a good species for even amateur apiarists to keep near their homes to boost local native bee populations and participate in solving global ecological issues.

## 1.2 Problem

There are some key hurdles to keeping mason bees. Mason bees live in "tunnels"; in nature, this means they live in dark crevices found in trees, rocks, or in the ground, but kept bees live in tunnel homes. Please refer to Figure 1 to see examples of these tunnel nests.

Additionally, female bees will populate these tunnels with eggs for next year, and seal tunnels when they are done laying their eggs. Beekeepers must clean these tunnels, especially at the end of every season, and harvest the bee cocoons for the next year. It can be challenging to know when to clean a tunnel, especially if one is unable to tell if the tunnel is occupied by an alive adult bee. This difficulty arises from the fact that these tunnels are long and dark, and so bee activity deep inside the tunnels is hard to gauge. [5]

## 1.3 Solution

Our solution adds sensors to a mason bee house so that beekeepers can be confident their bees are active and healthy, and the house is clean. If they are alerted when unwanted visitors like parasites are entering the bee home, they can be proactive about preventing their spread. Additionally, by alerting the beekeeper when a tunnel is full of mason bee eggs, that tunnel can be removed and kept somewhere safe, away from mold and parasites.

Implementation: At the core of our solution are capacitive sensors that non-intrusively detect bee behavior in tunnels. These sensor readings will be interpreted to determine when bees are entering and exiting, how much of the tunnels are being actively used, and when unwanted intrusions occur. This data will be communicated so that beekeepers can view collected data at their leisure. A diagram illustrating the above use case can be found in Figure 2 .

Figure 1: Wood block with holes drilled in to make tunnels for mason bee nesting

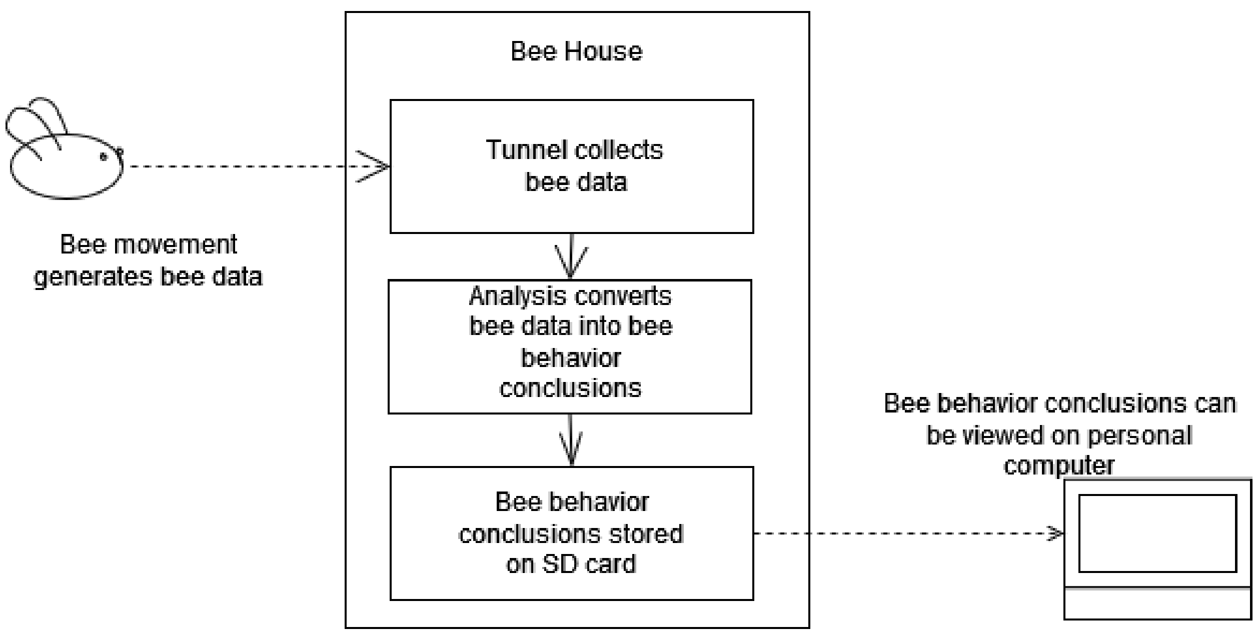


Figure 2: Putting our mason bee house in context. Dotted lines represent connections to external systems.

### 1.4 High Level Requirements List

1. Capacitor sensor setup shall differentiate between entering and exiting simulated bees (6mm ball) in each tunnel.

2. Sensor setup shall differentiate between simulated bee and simulated parasite (3mm ball to approximate the size of the Houdini fruit fly, a parasite that eats mason bee larvae).

3. An integrated SD card shall store data about how much of each tunnel is populated with simulated eggs(tunnel temporarily filled with 6mm balls).

### 1.5 Demonstration Plan

Our current demo plan is to simulate the behavior of bees using metal balls that are similar in size to mason bees. Previous research on bee sensors has used this testing method and shown it to be successful. To test whether the sensors can detect the presence and direction of bees, we will roll a 6mm ball in and out of the tunnel.

The balls we use to simulate bees in our demo will be made of the material that most closely resembles the dielectric constant a mason bee could be measured at in the wild, and will take the place of a live bee in our demo . A higher dielectric constant will lead to higher capacitance/ a higher change in capacitance. Some research was conducted into finding the dielectric constant of the western honey bees. [8]. Mason bees are roughly the same size as western honeybees and are of similar mass as well. So for our project, we will estimate that a mason bee's body will have a dielectric constant between 10.32[9] and 10.64 [8]. For our demo, we will aim to have spheres that have a radius of 6mm. We require the spheres to be conductive, as bees are made of mostly water, like humans.
To test whether the device can detect how much of a tunnel is filled with eggs, we will fill the tunnel to varying degrees of fullness with 6mm balls (to simulate the cocoons) , and roll a ball up and down the length of the tunnel (to simulate bee behavior in a partially filled tunnel). Our Analysis and Storage subsystem should be able to tell how full a tunnel is based on this simulation.

To test whether the device can differentiate between parasites and bees entering and exiting, we will roll a 6mm ball in and out of the tunnel, and roll a 3mm ball in and out of the tunnel. The data recorded on the SD card should reflect a bee for the 6mm ball and an unwanted intruder for the 3mm ball.

## 2 Design

### 2.1 Block Diagram

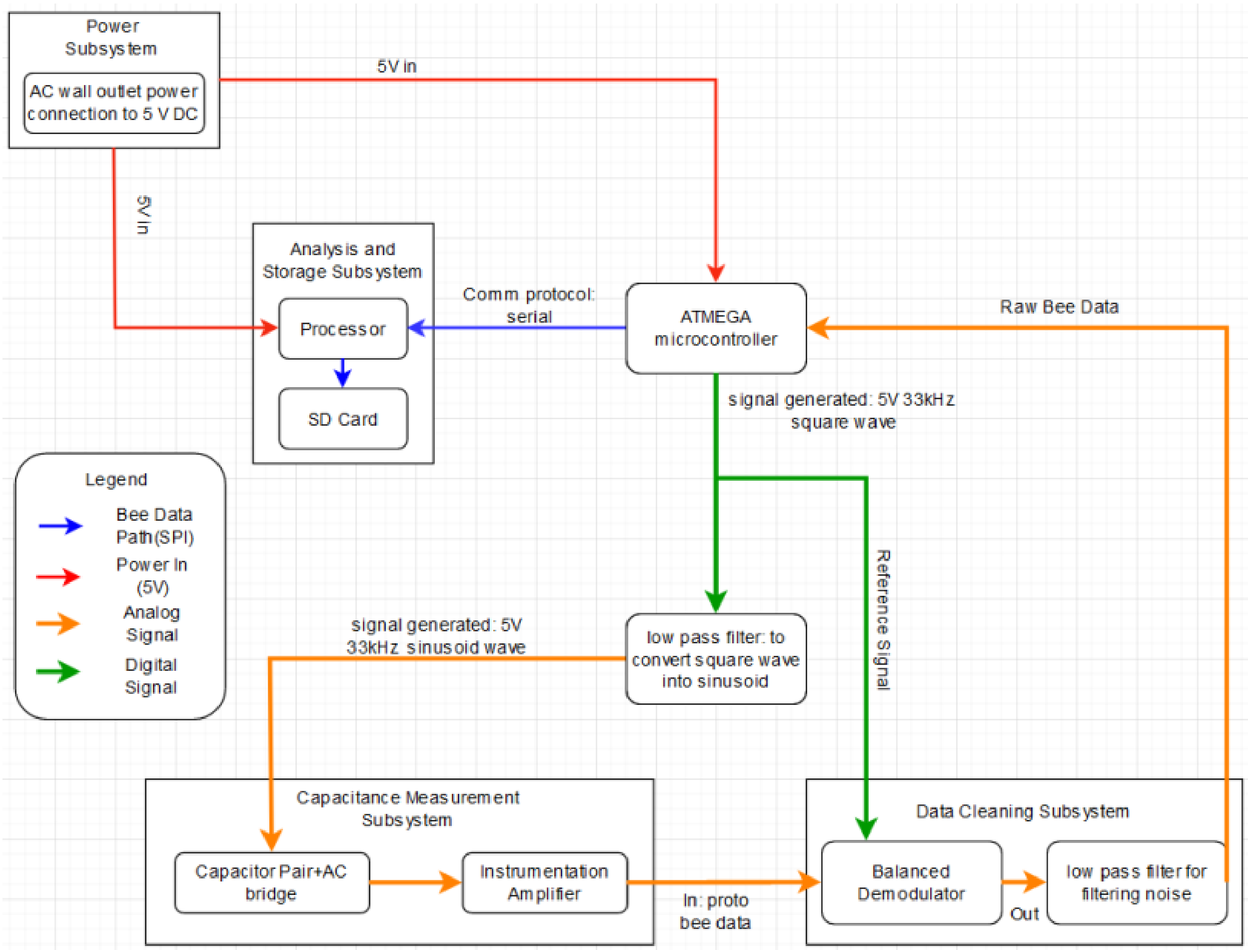


Figure 3: Block diagram of Circuit Design. See Figure 4 for Capacitor Pair set up.

## 2.2 Physical Design

Relevant Dimensions:

- Capacitor rings to be made of 9 Gauge copper wire (diameter 9mm). The inner radius of the ring should be 6mm due to the bee tunnel having 12mm outer diameter. Separation between pairs of rings is 8mm. Ring assemblies located at the beginning, middle, and end of bee tube. Shielding tube will be made of copper, with a thickness of 4mm and an inner diameter of at least 4cm.
- Bee tube will be 5.5 in. in length, and made of non-conductive material. Thickness of the bee tube should be between 1 mm and 3 mm depending on availability of material. It has an inner diameter of 8mm.
- End caps of tubes are squares with side lengths of 2 inches ( 5.08 mm) and a thickness of 0.5 in ( 1.26 mm).
- Eaves of mason bee house extend over the sides of the house by at least 1 cm to provide adequate protection from rain.

The dimensions above take into account many of the needs for mason bees along with needs and implications of our electrical design. Previous research [4] has determined that the sensor is most effective when the shield radius is at least 1.5 times the diameter of the rings, and that the width of the rings should be as thick as the sensor design allows. Additionally, the ring pairs should be between half the radius and the radius of the rings distance apart. Our design for the capacitor rings and shielding, shown in Figures 4, 5, and 6, takes all of this into account, with thick 9 gauge wire for the sensor rings, a distance of 8mm apart, and a shielding tube with a diameter of 4.8cm. Additionally, research on native bees [5] has determined that 8mm inner diameter of tubes of length at least 14 cm is ideal for the mason bee, so our tubes have this inner diameter to be as hospitable to the bees as possible, shown in Figures 7 and 8. This has driven the rest of the dimensions for our physical design.

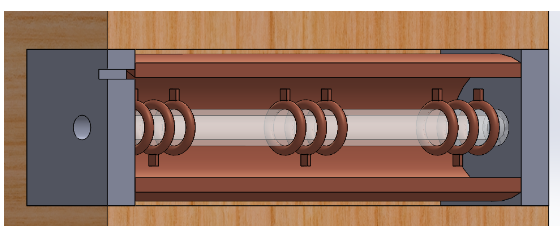

Figure 4: Cutaway of bee tunnel to show capacitor rings. Note the hole on the top of the left endplate for the connector.

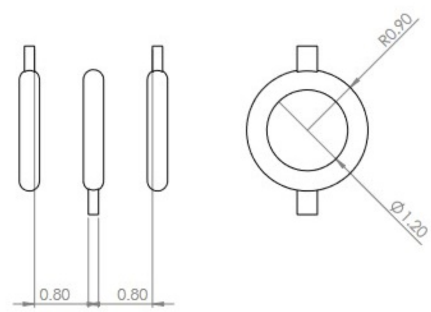


Figure 5: Dimensions of capacitor pairs for sensor

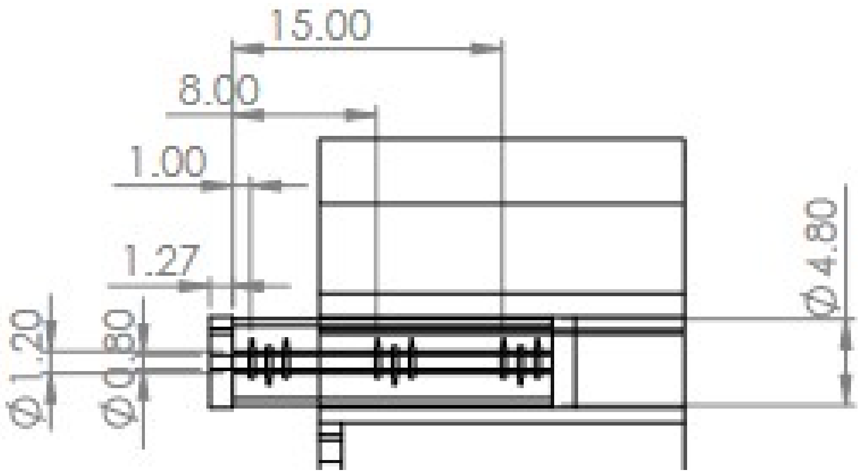


Figure 6: Dimensions of capacitance sensing tunnel

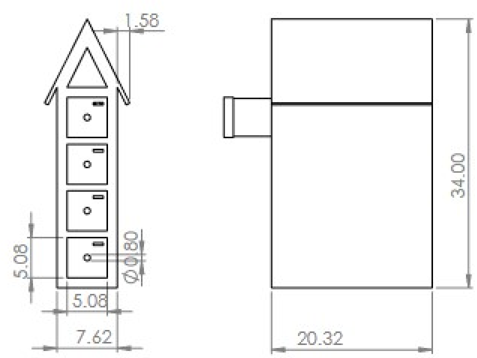


Figure 7: Dimensions of Bee House.

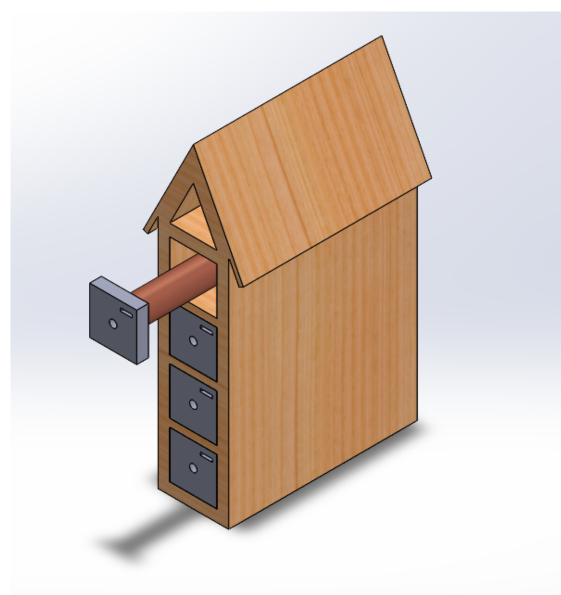

Figure 8: Mason bee house with one tunnel extended to show interior

## 2.3 Mason Bee Housing Subsystem

Subsystem Overview: For our mason bee house, we will be using a hollow wooden structure with holes drilled into it. Inserted into these holes we will have PVC or acrylic pipes which will function as the mason bee tunnels. The structure will house tunnels, and each tunnel will have multiple pairs of capacitors [see Figure 4 above for capacitor set up, Figure 8 for house structure]. Each tunnel will have a connector for the sensor wires to be sent to the rest of the design for analysis.

Subsystem Requirements:

1. Create a structure to hold the tunnels
2. Provide mounts for the electronics and connectors

## 2.4 Capacitance Measurement Subsystem

Subsystem Overview: The capacitor sensors that form the heart of our project are based on research done at the University of Prince Edward Island in 2005 [4]. In their paper "Capacitance-based sensor for monitoring bees passing through a tunnel", they describe a setup where they forced bumblebees to enter their hives through tunnels. In these tunnels they had set up a "two-capacitor set-up along with an ac bridge and phase-sensitive detection" which "produce an asymmetric double pulse for each bee passage". They then used this double pulse to estimate velocity, size, and direction of travel of the bumblebee. [4]

In our setup, we hope to adapt the sensor setup for use in mason bee tunnels. To accomplish this, we need to change the dimensions of the tunnel to accommodate the mason bee tunnels that they use as a nest. Additionally, by including a pair of capacitors at the entrance, midpoint, and back of the tunnel, not only will we get data about the entry and exit of bees, we can also determine how much of the tunnel is filled with eggs by analyzing how far down the tunnel the activity continues.

The sensor data will go to a microcontroller for processing so that we can identify which tunnels are occupied, how much of the tunnel is filled with eggs, and whether it is a mason bee or an unwelcome intruder entering the nest.

Subsystem Requirements: Sensors can record a bee's crossing and direction of travel. Sensors can collect data that can be analyzed to tell how full each tunnel is with eggs. Sensors can differentiate between different sizes of simulated insects.
Measurements: We have begun the prototyping process of this subsystem on a breadboard. Rather than implementing the sensors to detect a change in capacitance at this point, we simply included a series of capacitors in parallel with one arm to increase the capacitance of that arm. Thus, when pressing the button, the AC bridge becomes unbalanced by a known change in capacitance. This circuit design is illustrated in Figure 9. Our findings did not match up with our expectations, as we found that the smallest change in capacitance did not result in the smallest change in output voltage. This is illustrated in Figure 10 and Figure 11. However, we have determined that this is likely due to the choice in using parallel capacitors to create the change in capacitance in the prototyping circuit. Our next step is to take measurements with a circuit that does not use a parallel leg and buttons to change the capacitance. If that is confirmed to have proportional behavior, we can move forward with the PCB design.

Using the same circuit from Figure 9, we did confirm that using a higher input voltage to the AC bridge results in a more sensitive circuit that creates a higher output voltage change for the same change in capacitance. Based on this testing, we decided to use 5V as the input to this section of circuitry, as it has the ideal balance between sensor sensitivity and practical design considerations for the rest of the device.

To determine what amplitude of a waveform we should use to drive the AC bridge, we tested the output of this circuit with different input voltages and changes in capacitance. Our results are described in Figure 10. Here, we can see that with increased input voltage, the AC bridge becomes more sensitive to capacitance

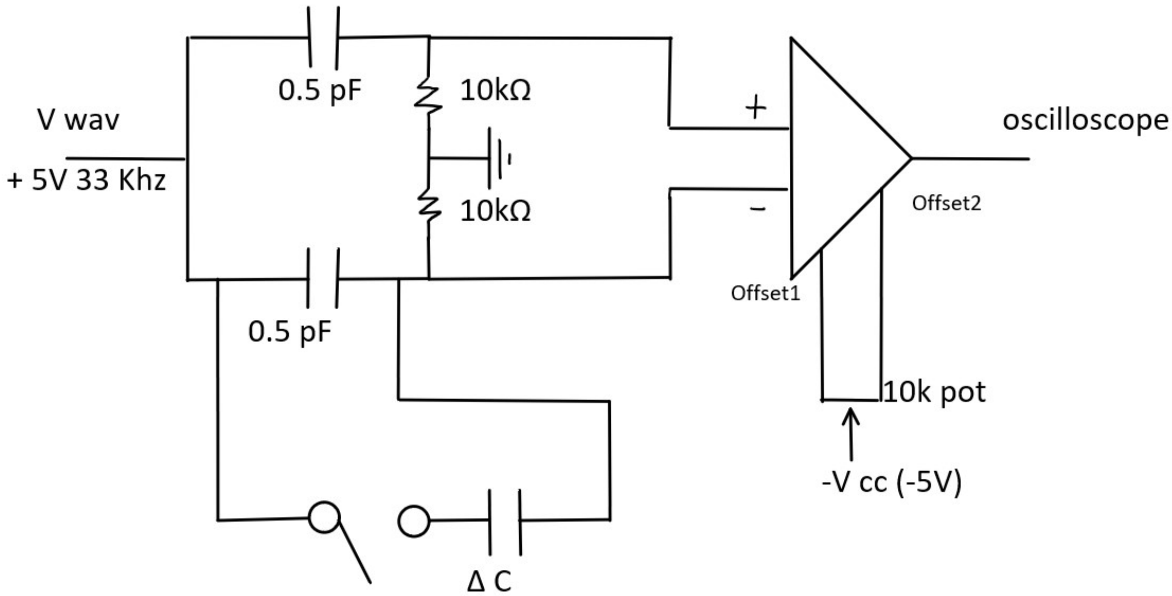


Figure 9: Circuit Diagram for initial testing of capacitance measurement subsystem

changes, creating a larger increase in the output voltage amplitude. This means that with a larger input voltage it will be easier for us to draw conclusions about bee activity. However, we saw that the increase in sensitivity from 5V to 6V input is not worth the extra parts and separate power supply that would be necessary to generate a 6V waveform to drive the AC bridge. To generate 5V or lower, we can make use of the microcontroller that will also take the initial data and convert it to serial, and we can make use of the same 5V supply that the rest of the device will run on. If we wanted to generate a 6V waveform, we would need to include a separate waveform generator and a 12V power supply that is stepped down to 6V just for this application. Currently, we conclude that the 5V input waveform will be sufficient to meet the requirements of our device.

## 2.5 Analysis and Storage Subsystem

Subsystem Overview: We would like for the identified bee behavior (which tunnels are occupied, entry and exit times recorded in different tunnels, any intruders detected) which is concluded using data from the capacitance measurement subsystem to be stored on an SD card that the beekeeper could remove from the mason bee house and look at on a personal computer. The data from the capacitance subsystem will be communicated using the SPI protocol.

Subsystem Requirements: Data is transferred from microcontroller to processor so that data can be analyzed. Data and analysis are stored in a file that is easy to read without specialized software (eg. txt file, .csv file, etc).

## 2.6 Power Subsystem

Subsystem Overview: Many mason bee keepers install mason bee houses on the outside walls of their own home. We plan to take advantage of exterior outlets that may exist on the home by using a commonly

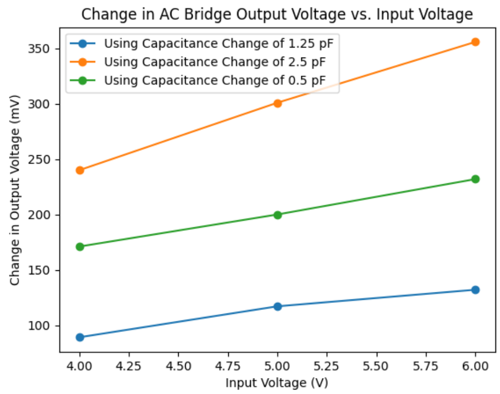


Figure 10: Graph of efficacy of circuit associated with capacitance sensors with different input voltages and amount of change in capacitance

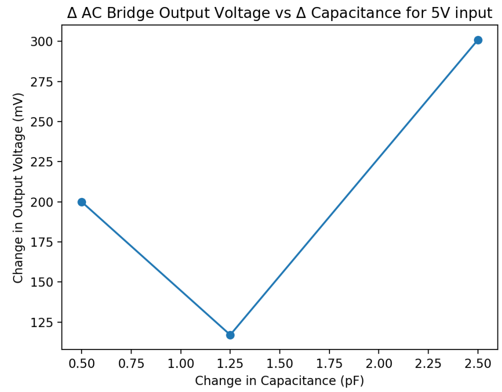


Figure 11: Graph of change in output voltage when different capacitance change applied, using input voltage of 5V

available 5V DC wall adapter. These 5 V will be fed to the microcontroller and the processor.

Subsystem Requirements: Provide power to the processor that will analyze and record the data. Provide power to the integrated circuits in the capacitive sensor setup. Provide power to the microcontroller.

## 2.7 Requirements and Verification Table

Mason Bee Housing Subsystem:

| Requirement | Verification |
|---|---|
| 1. Provide secure housing for tunnels and circuitry. | 1A. House will be shake tested to make sure no parts are unsecured and to ensure fit of connections. |
| 2. Shall be weather resistant. | 2A. Wooden structure of outside housing will be exposed to 100 ml of water from the top to simulate rain.<br>2B. Roll three glass balls into tunnels to simulate bee activity.<br>2C. Manually check [pull SD card out from housing, load into desktop, open file that the data has been written to] the data written to the SD Card and verify that activity has been recorded as expected [we see three spikes indicating entry and exit of simulated bees] |

Capacitance Measurement Subsystem:

| Requirement | Verification |
|---|---|
| 2. Square wave generated from ATMEGA with characteristics 5V amplitude and 33kHz frequency will be converted to sinusoidal wave with same characteristics using a low pass filter from resistors and capacitors. | 2A. Low pass filter functionality will be measured by oscilloscope measurements taken at input to filter and output from filter. Visual display on oscilloscope will show a square wave at input and a sinusoidal wave at output. |

| | |
|---|---|
| 3. AC bridge in sensor circuit is able to produce voltage spikes when a conductive ball is passed through capacitive sensor. Voltage pulse is greater than 15 percent of base reading. (at time of design document check this requirement is subject to further testing) | 3A. Oscilloscope measures input signal voltage and amplitude going into AC bridge on Channel 1<br><br>3B. Channel 2 of oscilloscope measures output from AC bridge , should show a voltage pulse.<br><br>3C. Signals captured on Channel 1 and 2 are measured and compared to show change in amplitude when simulated bee is passed between capacitor.<br><br>3D. The increase in measured amplitude when the simulated bee is passing through the sensor should be at least 150%. |
| 4. Instrumentation Amplifier will boost output from AC bridge by at least 100% | 4A. Oscilloscope measurements of voltage will be taken at input and output of amplifier.<br>4B. Comparison of taken measurements should show amplitude of waveform output measure at least doubled from initial measurement. |
| 5. Change in voltage / observed voltage spike must be reproducible for a given input voltage. | 5A. Input voltage to AC bridge will be measured with oscilloscope. It should measure 5V, within 5 percent accuracy.<br>5B. Oscilloscope measurements will be taken at the output of the AC bridge when no simulated bee is passed through sensor and when simulated bee is passed through sensor.<br>5C. Ratio of output to input is measured to understand consistency of circuit design. |

Analysis and Storage Subsystem:

| Requirement | Verification |
|---|---|
| 1. SD card will be able to store 2 days worth of data | 1A. Simulate 1 hour's worth of bee activity<br>1B. Write this data 48 times to the SD Card, make sure that SD card storage successfully stores all written data |

Power Subsystem:

| Requirement | Verification |
|---|---|
| 1. Provide 5V +/- 0.5% from a 4.9V - 5.1V DC Source. | 1A. Oscilloscope measurements (at time of design document check this verification procedure is not yet established) |
| 2. Minimum current operation should be in range 0 to 100 mA (at time of design document check this requirement is subject to further testing) | 2A.Ammeter measurements (at time of design document check this verification procedure is not yet established) |

## 2.8 Tolerance Analysis

One risk to the successful completion of our project is whether we can generate the necessary waveform for driving the AC bridge in the capacitance sensor setup, and the balanced demodulator, from our microcontroller. We will need a sine wave and a square wave of 5V and 33kHz frequency. The ATMEGA 168/368 generates PWM signals using three separate timers; it has a system clock of 16MHz and the timer clock frequency for PWM generation will be the system clock frequency divided by a prescale factor accepted by the ATMEGA. These prescale factors will let us subdivide clock steps into smaller increments and generate higher frequency signals as needed.

The biggest item of concern to consider is whether the generated output will be within the measuring capabilities of our microcontroller. The diameter of the tunnel entrance is 8 mm, and our testing plan involves using a 6mm ball bearing. With this in mind, we performed calculations to determine what the change in voltage in that scenario would be. The core of the sensor is an AC bridge, which can identify imbalance in the impedance of its legs. With plates with 8mm of separation, we would expect the capacitance to increase at most by a factor of 4 if metal 6mm in diameter is passed between the plates. We expect the data most immediately generated by the sensor is small, but to get some concrete expectations we did calculations to see the voltage for the proto-bee data. As you can see in the circuit diagram, the voltage value is dependent on the gain of the instrumentation amplifier. We can adjust that gain, along with the gain involved in the data cleaning subsystem in the block diagram, to be confident that that data is in the range of what is measurable by the microcontroller (between 0.5 and 5 V).

To mathematically verify the above statement, we calculated the gain of our circuit, ($\frac{V_{out}}{V_{in}}$). In order to do this, we conducted a circuit analysis of the AC bridge and instrumentation amplifier. Let $V_1$ be the voltage at the node connecting the first capacitor and 10K ohm resistor, and $V_2$ be the voltage at the node connecting the second capacitor and 10K ohm resistor. Converting the circuit to the s-domain and applying the voltage divider rule, we get:

$$V_1 = \left(\frac{\omega}{s^2+\omega^2}\right) V_{in} \left(\frac{R_1 s C_1}{R_1 s C_1 + 1}\right)$$

Similarly, for $V_2$, we get:

$$V_2 = \left(\frac{\omega}{s^2+\omega^2}\right) V_{in} \left(\frac{R_2 s C_2}{R_2 s C_2 + 1}\right)$$

According to the research paper which defines this circuit, the gain of the instrumentation amplifier is 50. Therefore, the output voltage $V_{out}$ is:

$$V_{out} = 50(V_2 - V_1)$$

Substituting in $V_2$ and $V_1$, this evaluates to:

$$V_{out} = 50V_{in} \left(\frac{s\omega}{s^2+\omega^2}\right) \left(\frac{R_2 C_2}{R_2 s C_2 + 1} - \frac{R_1 C_1}{R_1 s C_1 + 1}\right)$$

Plugging in $R_1 = R_2 = R$, $C_1 = C$, and $C_2 = C + \Delta C$ and simplifying, we get

$$V_{out} = 50V_{in} \left(\frac{s\omega}{s^2+\omega^2}\right) \left(\frac{-sR\Delta C}{(sRC + sR\Delta C + 1)(sRC + 1)}\right)$$

Assuming that $\Delta C << C$, we can get rid of the $\Delta C$ terms in the denominator. Dividing both sides by $V_{in}$, we see that $\frac{V_{out}}{V_{in}}$ is directly proportional to $\Delta C$ for one of the capacitors in the AC bridge.

$$V_{out} = 50V_{in} R \left(\frac{s\omega}{s^2+\omega^2}\right) \left(\frac{\Delta C}{(sRC + 1)^2}\right)$$

The output voltage of the whole circuit after filtering is a DC signal that can be negative or positive, depending on if the bee is traveling into the tunnel or out of the tunnel. However, the microcontroller only accepts analog inputs between 0.5V and 5V. To deal with this, we use a summing amplifier and add a 2.5V DC offset to the signal to make the input voltage positive. As seen in figure 12, the output voltage is inverted, so we need to connect an inverter to the output of the summing amplifier to make the voltage positive. One input to the summing amplifier will be the filtered signal which will contain the bee behavior, and the other

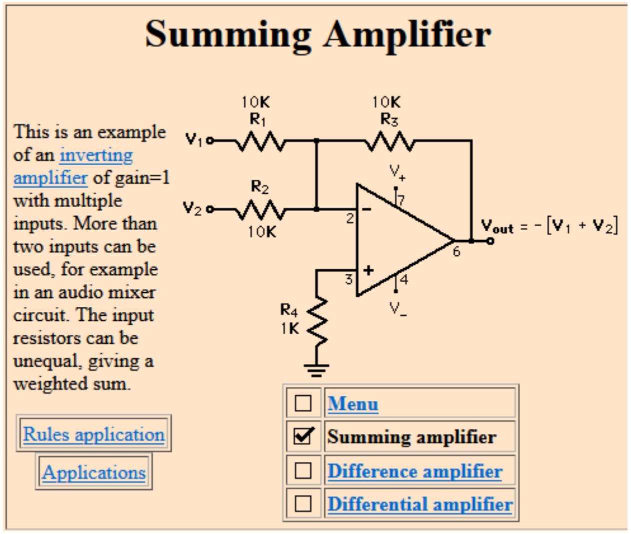


Figure 12: Operation of Summing Amplifier

input will be a 2.5V DC offset which will be generated using a voltage divider consisting of a 5V input and 2 10KΩ resistors.
An important point that came up while investigating the AC bridge calculation is that the instrumentation amplifier used with the capacitor pair is susceptible to a non-ideal common mode gain caused by a mismatch in the resistances of the internal resistors that make up the instrumentation amplifier. The signal we expect to receive is quite small, so this additional inaccuracy could cause the expected signal to be lost in noise. So we must make sure to use an instrumentation amplifier IC, since those are checked to make sure they meet ideal specifications, and they use precision matched resistors.

# 3 Cost and Schedule

## 3.1 Cost of Prototyping of Capacitance Sensor Investigation

Below is the estimated cost breakdown of the capacitance sensor prototyping, including but not limited to the prototyping described in Section 2.22 . We have obtained all the parts for free from the 445 lab or the Electronic Services Shop so far, but they are priced here according to their cost from the ECE Supply Shop and from Mouser. These parts

| Item | Cost/Item | Manufacturer | Quantity | Total Cost for Item |
|---|---|---|---|---|
| Hour of Member Labor | $35 | N/A | 6+4+2=12 | $420.00 |
| instrumentation amplifier | $8.59 | Texas Instruments | 2 | $8.59 |
| balanced demodulator | $36.57 | Analog Devices | 1 | $36.57 |
| op amp | $0.53 | Texas Instruments | 4 | $2.12 |
| MicroSD Card | $8.28 | SanDisk | 1 | $8.28 |
| ATMEGA 328 | $2.18 | AVR | 1 | $2.18 |

In total, the parts would cost us 66.33, $which, incombinationwithlabor, bringsthetotalto$486.33 per tunnel that we build. Please note that this base cost excludes standard parts such as wood, PVC piping, and common resistors/capacitors.

### 3.2 Schedule

| Week | Keerat | Piyush | Jyotsna | General |
|---|---|---|---|---|
| 22-Feb | Prototyping of initial circuit, Part numbers for cost analysis, Purchase parts for initial prototyping | Circuit analysis, ethics section of design document, figure out how demodulator circuit works | **Identify simulated bee options** | Block diagrams for each subsystem, finalize parts for Analysis and Storage Subsystem |
| 1-Mar | Identify potential connectors for connection between capacitive sensors and mason bee housing, prototype on breadboard with demodulator portion of circuit | Look at tutorials for using the ATmega microcontroller on a PCB, order parts to be soldered onto PCB | Requirements and verifications table, finalize power subsystem parts, identify materials for mason bee house construction | Tolerance analysis for design document, **initial PCB board design (3 / 8)** |
| 8-Mar | **Prototype wire-based capacitor sensors with breadboard setup** | Write code to test data logging onto sd card/text file with processor | Prototype plate-based capacitor sensors with breadboard setup | **Finalize machine shop design (3/7), sensor setup (capacitors) assembled and ready for testing** |
| 15-Mar | Plan the filesystem that the sensor data will be stored in | Test PCB to figure out if demodulator subsystem works with tube | Assemble capacitor pairs into single tube for testing | Assemble 1st round PCB, confirm functionality of single tube sensor system, confirm PCB works as expected |
| 22-Mar | Assemble and confirm one functioning tube with connector | Assemble and confirm one functioning tube with connector | Assemble and confirm one functioning tube with connector | Second Round PCB Board Design (3/24) |
| 29-Mar | **Confirm capacitive system works individually** | **Confirm analysis and storage subsystem works individually** | Confirm power and mason bee house system work individually | Have all tubes ready to install in mason bee house, all subsystems confirmed to work individually |
| 5-Apr | Investigate possibility of display (stretch goal), contribute slides about work to presentation | Investigate possibility of app or online dashboard, contribute slides about work to presentation | Investigate possibility of integration of temperature and humidity sensor, contribute slides about work to presentation | Initial construction of mason bee house complete, final report ready for feedback, presentation for demo ready for feedback |
| 12-Apr | Contribute writing about work to Final Report | Contribute writing about work to Final Report | Contribute writing about work to Final Report | Analysis and Storage subsystem confirmed to work with sensor subsystem(integration done) |
| | | | | **Be ready for mock demo** |

# 4 Ethics and Safety

The primary motivation of this project is to help boost native wild bee populations, which in turn will aid both agricultural and eco-conservation efforts.

For this project, we are not using real, live bees; we will be using metal balls to simulate bees going through the tunnels. Since no live bees will be used in the demo of this project, it will be safe and poses no obvious risks to bees. Additionally, we will not be using batteries, so this product is not likely to do damage to the environment or the user.

We will also do our utmost to prevent accidental harm done to mason bees that would eventually inhabit the device. This aligns with section 1.2 of the ACM Code of Ethics: avoid harm [1]. We did research to investigate whether living among electric fields affects the bees. While we did not find any relevant research on the effects of an electrical field on mason bees, we have found that leafcutter bees, which are in the same family as mason bees, were unperturbed by the electric field produced by a similar sensor's operation. We have also sized the mason bee tunnels in a way that reflects current research on healthy mason bee populations. Research published in the journal Apidologie in 2013 [7] concluded that tunnels of at least 15 cm produce the healthiest offspring and a suitable male-female larva ratio.

We also gave thought to whether this device would disenfranchise beekeepers, because it introduces technology that the layperson is not familiar with. If usage of this device became widespread, however, a layperson would still be able to keep mason bees easily. Even though the technology is complex, the portions that the beekeeper is asked to interact with are familiar. This lines up with ACM Code of Ethics section 1.4, where it is noted that technology should be as accessible as possible [1]. Most personal computers on the market can read SD cards, and we plan to store the data in an easily understandable and usable format like a .csv or .txt file. This keeps usage of the device within the skills of the typical beekeeper.

We do not need documented developer safety procedures because our device can not cause harm to the people who use it, even by accident. Our device has no moving parts or batteries, and we are not using real bees, only simulated bees. Even with real bees, however, mason bees do not sting and are not dangerous to health. Our electronics are all low voltage and will be covered by a housing, so there is no risk to people of accidentally getting shocked.

# References


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