

# ESE 1500 – Lab 02: Digital to Analog Conversion

## LAB 02

In this lab we will do the following:

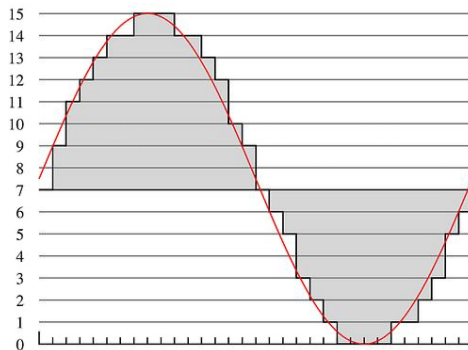
1. Learn how to write ItsyBitsy code that outputs voltages between 0 and 3.3V
2. Learn how to use the ItsyBitsy's serial monitor to SEND data to the ItsyBitsy
3. Have the ItsyBitsy behave as a basic D2A (digital to analog converter) to reconstruct your samples and produce sound on headphones

### **Background:**

Last week you used the ItsyBitsy to take an audio signal and turn it into a digital representation; you used an ItsyBitsy as an "A2D" converter (ADC, analog to digital converter). You should now have "samples" for the ItsyBitsy that you can use for reference today.

Today we will create waveforms in Excel. Next, we'll import the samples into the ItsyBitsy and attempt to reconstruct the signal you sampled last week!

Recall the meaning of this picture from class:



# ESE 1500 – Lab 02: Digital to Analog Conversion

## Lab Procedure:

### Prelab: Reconstructing Original Signal in Excel

- You should have sampled a 300 Hz signal at 500 Hz, 5000 Hz, and 50kHz (default rate with 20us total delay) at 10b of precision which is 1024 levels of quantization.
- In this section, you'll use a spreadsheet (e.g., Excel, Numbers, Google Docs spreadsheet (docs.google.com)) to construct equivalent signals.

Note: yellow, highlighted items mark question answers, code, data, and graphs that need to appear in your lab report.

1. What does Nyquist's theorem tell us about the sampling rates you recorded in lab 1 compared to the signal rate (i.e. frequency of the sine wave)? (Hint: Which (if any) of the cases are under sampled? What does that tell us about our ability to process the signal?)  
Select all cases that are under sampled.

- a. 300 Hz sample at 50KHz
- b. 300Hz+500Hz sampled at 50KHz
- c. 300 Hz sampled at 5KHz
- d. 300Hz sampled at 500Hz

2. What equation could you use to create the sample data for the sine wave mathematically? (a function of sine-wave frequency ( $f$ ), sample rate( $s$ ))

- a. Write an equation for a sine wave with a baseline at 2047 and an amplitude of 2048 (values ranging from 0 to 4095). Assume that there is no change in the x axis. Your equation should only be modifying the y values of the sine wave.
- b. Write an equation for the input into the sine function with frequency ( $f$ ), sample number ( $i$ ), and the sample rate ( $s$ ).

Hints:

- i. For the argument, you will want to use a formula in terms of  $f$  and  $t$  (time since  $t = 0$ ) that can be used to determine the number of cycles for the wave that has passed. (Hint: For a 300Hz wave, how many cycles in 0.5 seconds, 1 second, 2 seconds....).
- ii. We need to change the frequency to radians. (Hint: There are  $2\pi$  radians per cycle).
- iii. Sample Number is similar to time in other sine functions you've seen.
- iv. Look back through lecture, as you have seen equations like this in lecture.

## ESE 1500 – Lab 02: Digital to Analog Conversion

c. Combine (a) and (b) to write the formula for a frequency,  $f$  wave sampled at sample rate  $s$ , centered at 2047, and an amplitude of 2048 in terms of  $f$ ,  $s$ , and  $i$ .

i. Hint:  $i$  is the independent variables, the result of the formula is the amplitude, the dependent variable. Plotting this amplitude vs. discrete values of  $i$  should give you a sine wave like the one shown on page 2.

3. Create a Google Sheet or Excel file. Label column A as Sample Number, column B as SINE, column C as COSINE, column D as Frequency, and column E as Sample Rate.

a. In column A, you want your sample number to increase in increments of 1 from 0 to 1000.

b. In column B, use the equation you found in Problem 2, **set the frequency ( $f$ ) to  $\$D\$2$  and the sample rate ( $s$ ) to  $\$E\$2$** . To have spreadsheets output a number for the formula, add an equals sign (=) to the beginning of your formula. You need to encase the entire formula with ROUND() after the = sign. Finally, you need to set the sample number ( $i$ ) to its value in Column A. To do this you can set it to A(Current Row Number). Example: A2 for the function in row 2. Using the little box in the bottom right corner of the cell, you can drag it down to apply it to the remaining rows in the column.



i. Hint: It is useful to understand how  $\$A\$1$  behaves differently from A1 when referencing spreadsheet cells to setup these frequency and sample rate values. The  $\$$  tells sheets to not adjust that address while pasting the formula into new cells. This [link](#) may be quite helpful!

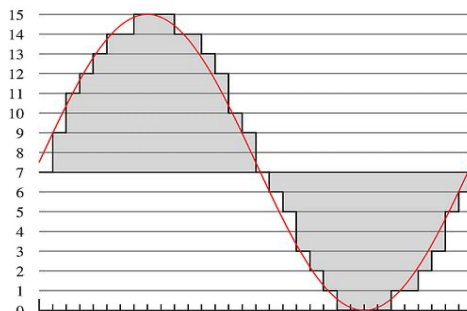
c. Input the frequency value into D2 and sample rate into E2.

i. Start with  $D2=f=300\text{Hz}$ ,  $E2=s=50\text{KHz}$

ii. You will change D2 and E2 for other frequencies and sample rates.

4. How can you further modify your equation to quantize the data to a different level of bit precision? Explain this in words.

a. Hint: Think about how the maximum quantization level changes as a result of changes in the bit resolution (number of bits).



## ESE 1500 – Lab 02: Digital to Analog Conversion

5. Copy your step 3 formula into column C and change the function from sine to cosine.
6. Complete the Prelab 2 quiz on canvas with your solutions to 1-4.
7. You will also upload the spreadsheet as part of your Lab 2 submission.
8. Include a graph for each sine and cosine in the spreadsheet for the lab writeup.

When you arrive in lab, compare your answers with your assigned partner. If your answers differ, discuss amongst yourselves and try to resolve your differences.

Early during the lab session, a TA will check you off the prelab. Go ahead and start working on the lab. It will take some time for the TAs to get around to all the groups.

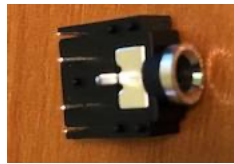
# ESE 1500 – Lab 02: Digital to Analog Conversion

## Lab – Section 1: Setting up the ItsyBitsy as a D2A

- In this section you will setup your ItsyBitsy to serve as a D2A.

1. Use the following items from your lab kit:

- (1) ItsyBitsy
- (1) Breadboard
- (1) 1 k $\Omega$  resistor
- (1) Female Stereo Jack (for headphones to plug into)

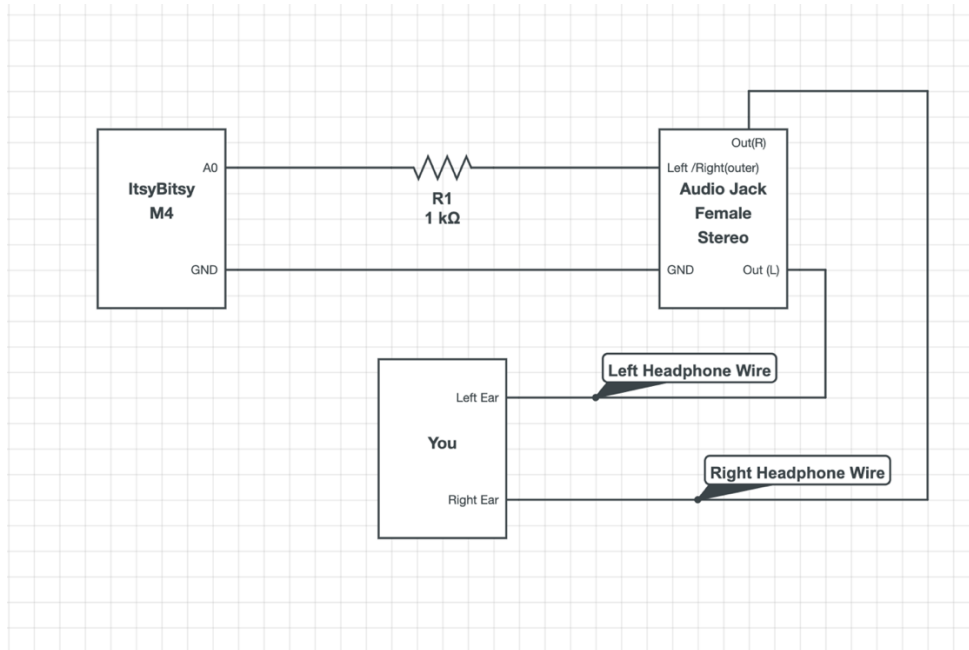


(1) Pair of headphones [we suspect if you use the headphones we provide, you will get more predictable/reliable results]

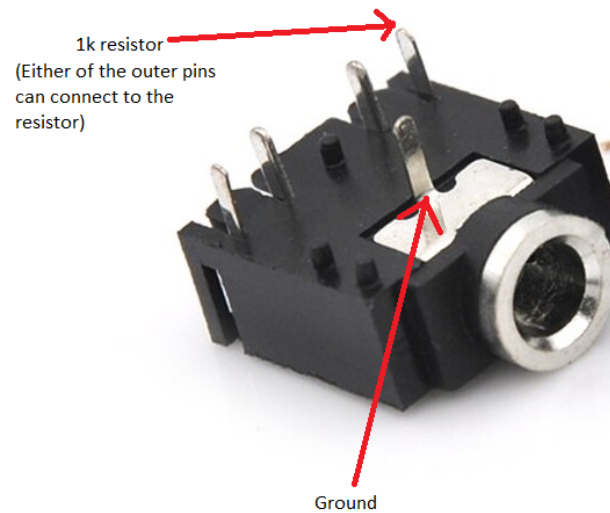
(1) Set of ears 😊

Wires to connect things

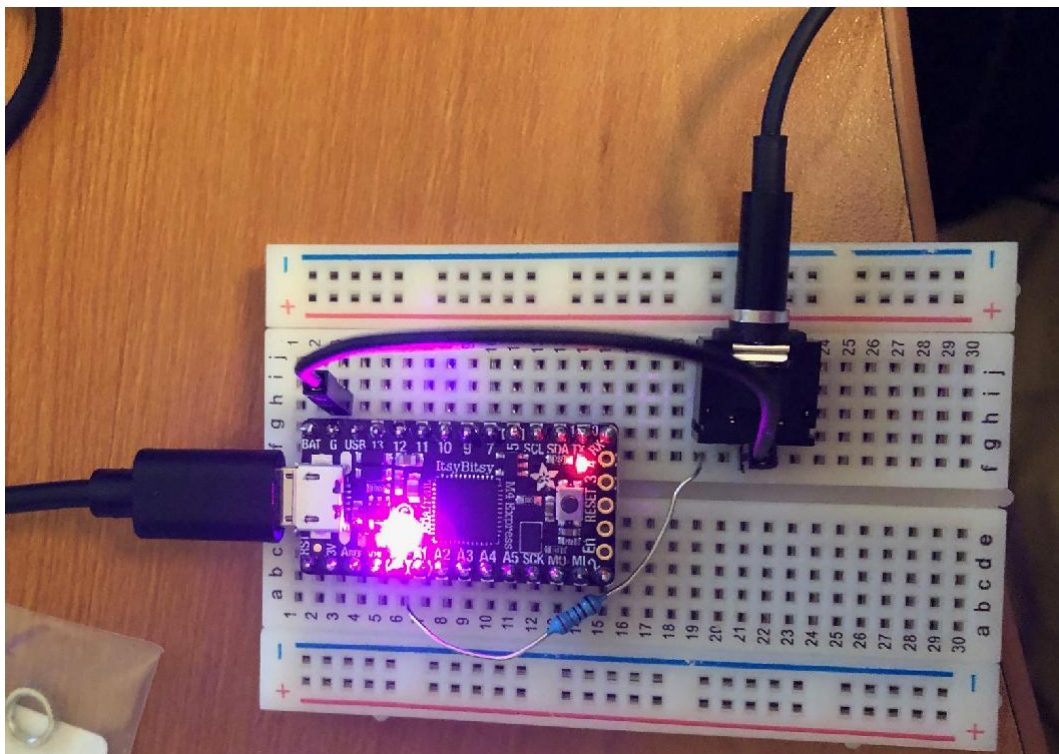
2. Using your ItsyBitsy and breadboard, connect the components above as shown in this schematic:



## ESE 1500 – Lab 02: Digital to Analog Conversion

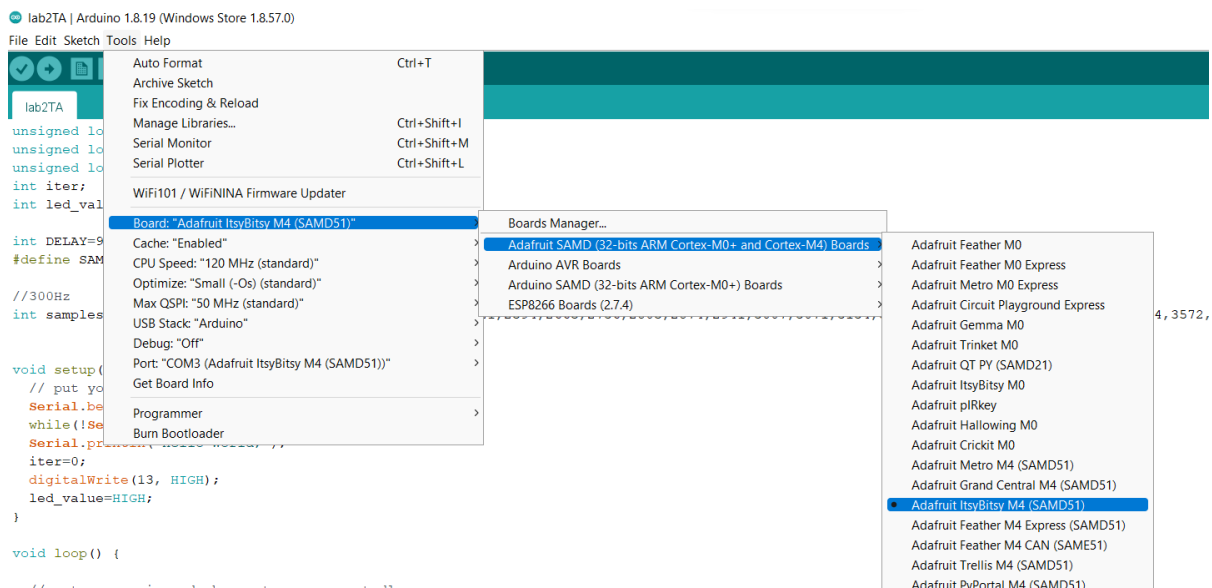


- Ensure that you connect the resistor to Analog Pin A0 on the ItsyBitsy, and either of the outer pins on the stereo. These outer pins will connect to either the left or right headphone. You'll have to figure that out later when sound is playing.
- Ensure that you connect the ground of the stereo jack (middle pin) to the Ground of the ItsyBitsy (G pin).
- Remember that Lab 1 instructions contained details about how the connection points on the breadboard are connected. Refer back to Lab 1 if you need a refresher.



3. Connect your ItsyBitsy to your computer via USB and open up the Arduino IDE software. Hint: Remember to select the correct board under Tools -> Board -> Adafruit ItsyBitsy M4

## ESE 1500 – Lab 02: Digital to Analog Conversion



4. Finally, run the code in “play\_samples\_50kHz.c” on your Itsy-Bitsy and plug your headphones into the female headphone jack. You’re not submitting anything for this question. The goal of this is for you to ensure that your circuit is working and that you can output voltages to the headphone jack and hear the result!

- Make sure to open the Arduino terminal port (aka the Serial Monitor); the code is written to wait on the serial port before playing any sound.
- If you are getting any undefined reference errors, try downloading Adafruit SAMD Boards with version 1.7.10 instead.

Hint: If you are not getting any sound, try moving the resistor connected to A0 to the other outer pin (in case one side of the headphones is broken).

- For the 300 Hz samples, you should compare what you hear to the same tone from the Lab 1 set when played from your phone or computer.
- Take a picture of your final, built circuit to include in your lab report.

## ESE 1500 – Lab 02: Digital to Analog Conversion

### **Lab – Section 2: Communicating with the ItsyBitsy through the Serial Monitor**

- We'd like to convert the samples generated in the prelab to voltage using the ItsyBitsy.
- We need to find a way to send the sample to the ItsyBitsy.
- For this we'll use the Serial Monitor to actually send data to the ItsyBitsy (instead of just receive it).

1. Create a new sketch and copy and paste the following code in your Arduino IDE:

```
#define MAX_SAMPLES 1000

// global variables
int samples [MAX_SAMPLES] ;
boolean samplesReceived = false ;
boolean samplesPrinted = false ;

void setup() {
  Serial.begin(9600); // setup serial monitor speed
}

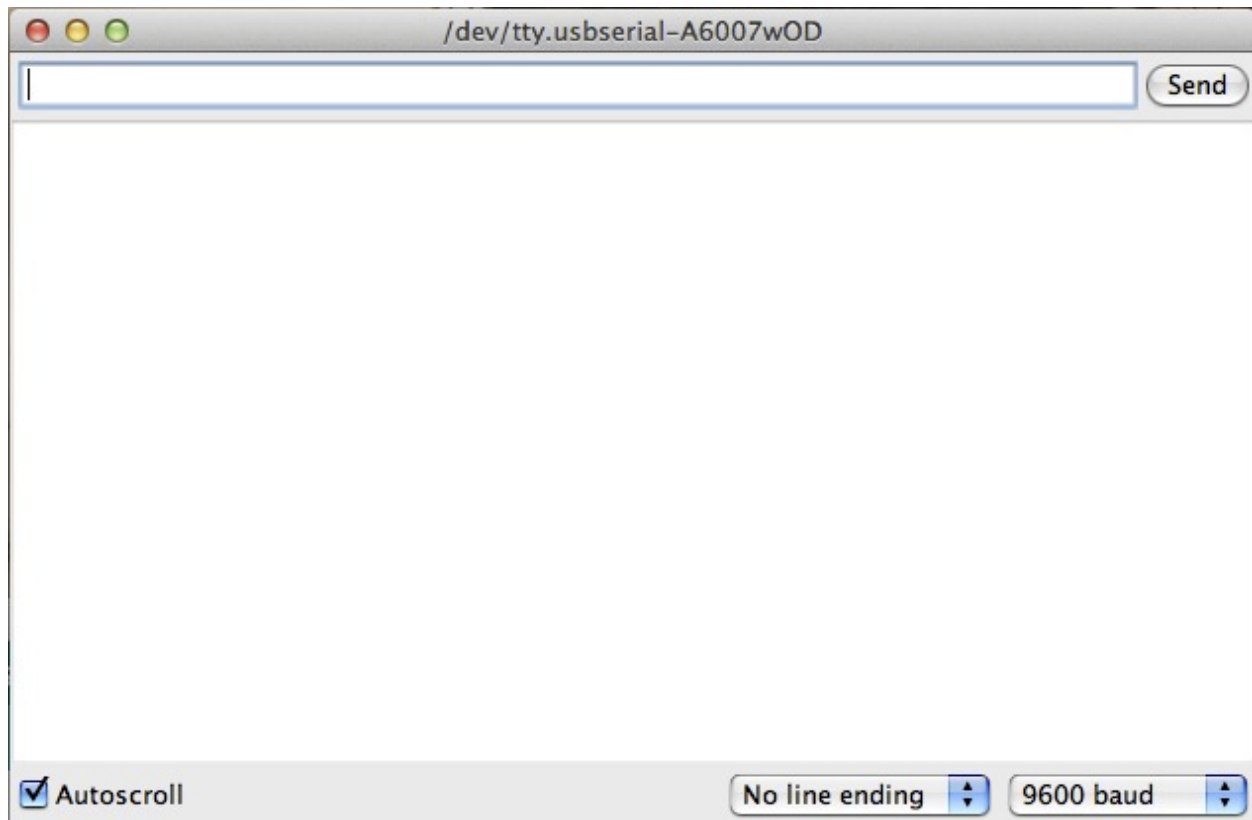
void loop() {

  int i = 0 ;
  while (Serial.available() && i < MAX_SAMPLES ) {
    samples[i] = Serial.parseInt();
    i++;
    samplesReceived = true ;
  }
}
```

2. Upload the code to your Arduino/ItsyBitsy.
3. Open the ItsyBitsy's Serial Monitor:



## ESE 1500 – Lab 02: Digital to Analog Conversion



4. In the top bar, type in the numbers: 100 200 300 400 1023, then press SEND.
5. Those numbers have now been sent to the ItsyBitsy, “parsed” and stored in an array.
6. Add a print statement to the Arduino code from part 1 so that whenever it **receives** samples it sends all the samples back to the Serial monitor (use `Serial.println()`).
  - a. Hint: This should be a single line of code. However, you need to be careful of how you are indexing through the array so that you are printing every element.
7. Try copying and pasting 1,000 samples from your Excel spreadsheet to the serial monitor and clicking SEND.
  - a. Note: In Excel, to select an entire column click on the letter denoting which column it is.
  - b. For this you can use any of your sample data sequences you generated in prelab.
8. Save your modified Arduino code.
9. Take a screenshot of both the top of your serial monitor and top of the associated column of DATA in your excel sheet. The goal is to demonstrate that you have successfully transmitted those samples to the ItsyBitsy.

## ESE 1500 – Lab 02: Digital to Analog Conversion

### Lab – Section 3: Putting it all together, ItsyBitsy as an D2A

- You have a spreadsheet setup to create quantized sinewave samples.
  - You now have a way of sending your samples to the ItsyBitsy.
  - You also have a way of putting voltages out to an ItsyBitsy output pin.
1. We're going to create a sketch that combines Section 1 and Section 2's Arduino code to output your samples through the ItsyBitsy's D2A using `analogWrite()`.
  2. **Your program should receive all 1,000 of the samples you generated in pre-lab.**
    - a. As you receive values, save that in the array.
    - b. For the waveform generation that follows, use the data from Prelab.
    - c. This input loop should run only once.
    - d. This is what you did in section 2 of this lab.
  3. It should then output all 1,000 samples to the output pin at the target sample rate.
    - a. Remember you need to set the delay between samples to match the sample rate; start with a sample rate of 50KHz to match the data generated in the prelab.
    - b. This output loop should repeat.
    - c. *You will have to think about the right delay in between analog writes.*  
*Remember from Lab 1, how you calculated the delay between samples depending on the sampling frequency (Prelab 1).*
      - i. **analogWrite has a delay of about 1.5 microseconds. However, for the purpose of this lab, do not consider it.**
    - d. Modify your code from Section 2 to include the loop and necessary variables from Section 1 (`play_samples_50kHz.c`) that indexes through the sample input arrays and outputs it to A0.
    - e. **Save this code for your writeup.**
  4. You will verify your output by listening on your headphones.
    - a. From your Excel spreadsheet, copy all 1000 data points of your 300Hz wave sampled at 50KHz into the serial monitor.
    - b. You should verify that your data sounds like the 300 Hz tone from last week played from your phone or computer.
  5. Hook up the A0 pin of your ItsyBitsy to the oscilloscope. Remember to hook up ground, too.
    - a. Turn on the oscilloscope and measure the frequency.
    - b. **Take a screenshot of the oscilloscope with the frequency and save it for your lab report.**
  6. Send the cosine data samples and compare how it sounds to the sine data.
    - a. **Can your hear tell the difference between the sine and cosine data sample sets?**

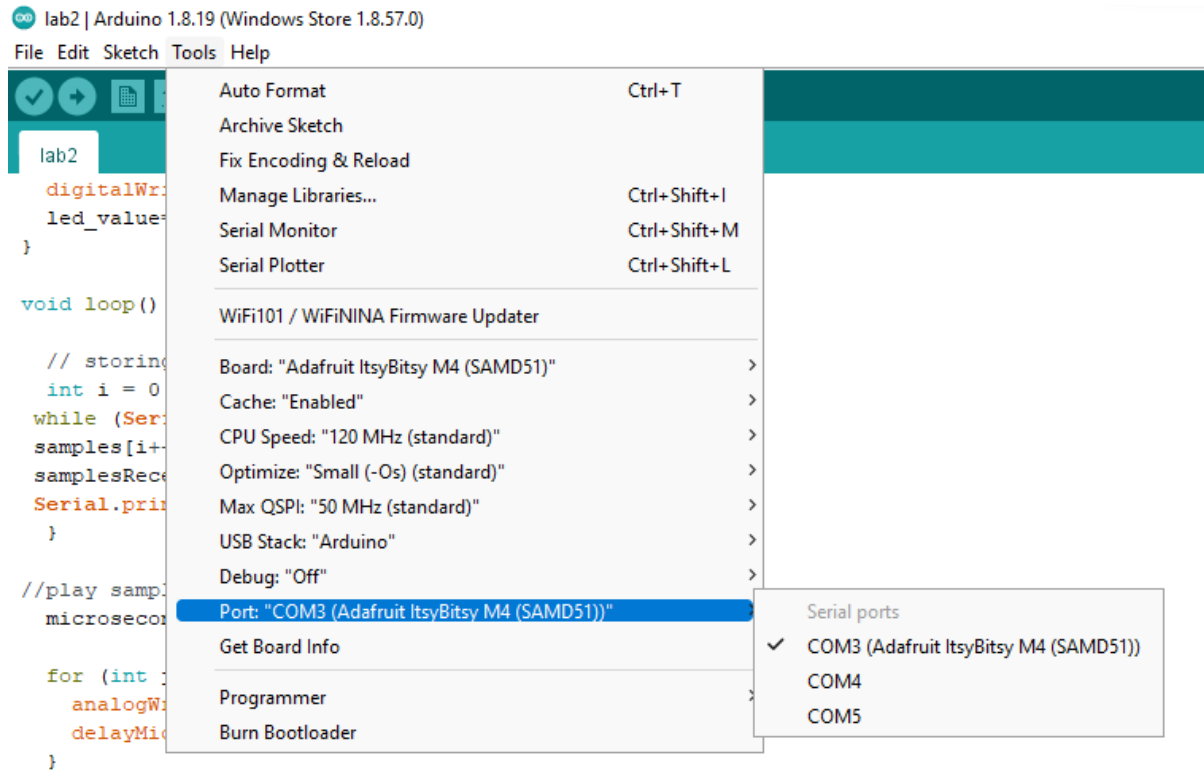
## ESE 1500 – Lab 02: Digital to Analog Conversion

7. Let's try changing to a sampling rate of **5000Hz**.
  - a. Modify your Excel spreadsheet's cell E2 to 5000.
  - b. Update your Arduino code to support a 5KHz sample rate.
  - c. From your Excel spreadsheet, copy all 1000 data points of your 300Hz wave sampled at 5KHz into the serial monitor and listen to the results.
  - d. Take a screenshot of the oscilloscope with this sample rate frequency and save it for your lab report.
  - e. Do you see anything beyond a clean 300 Hz tone on the oscilloscope? How might this be affecting the sound that you're hearing?
  - f. Now how might you be able to fix this issue? Try it out, do you see a difference on the oscilloscope?
    - i. Hint: Think about the data that was inputted and how sine/cosine waves work.
8. (optional, time permitting) How low can we make the sample rate and still represent the 300 Hz wave?
  - a. Repeat the steps a-e from 7 for the identified sample rate including the screenshot.
9. (optional, time permitting) Quantize the 300Hz wave sampled at 5000Hz to 11b, 10b, and 9b precision. Create screenshots of the DATA with associated plots.
  - a. Consider the original quantization level (12 bits = 0-4097 quantization). These give you values 0, 1, 2, ...
  - b. At 10b of resolution, you have values 0, 2, 4, ...; at 9b, 0, 8, 16, ...
  - c. How many quantization levels for n-bit resolution (n bits = .....)?
  - d. Make sure to ROUND() your answers (INTEGERS ONLY)
10. (optional, time permitting) Play these quantized samples on your ItsyBitsy. Describe the results:
  - a. Use the serial monitor to send the DATA as before.
11. Show code and describe sounds to TA for exit checkoff.
12. Make sure code and snapshots are available to both partners before you leave lab.
  - a. As we suggested last week, we recommend you put the data on a Google Drive shared between both partners **before** you leave the lab.

## ESE 1500 – Lab 02: Digital to Analog Conversion

### Code Upload troubleshooting:

1. Press the reset button on your ItsyBitsy twice, and wait for the light to turn green. This will reset the ItsyBitsy.
2. Press the reset button one more time. This should turn the light purple again.
3. Make sure you have the ItsyBitsy selected under Tools -> Ports



### Circuitry Troubleshooting:

1. Double check ground and A0 are connected to the correct pins on the jack
2. Check that the pins on the headphone jack are not bent. Make sure they are connected to the bread board!

## ESE 1500 – Lab 02: Digital to Analog Conversion

### **Postlab: Synthesis**

1. Describe the importance of Nyquist in your own words and how it applies to labs one and two.
  - a. If you need some guidance, try plotting and playing your 300Hz wave sampled at 500Hz (or, more likely, generating a 300Hz tone with a sample rate  $s=500\text{Hz}$ ).
  - b. Describe the difference between this and the original 300Hz tone.

# ESE 1500 – Lab 02: Digital to Analog Conversion

## **HOW TO TURN IN THE LAB**

- Upload a PDF document to canvas containing:
  - Prelab (Answers to Questions 1, 4, and 8 (2 plots))
  - Section 1 (picture of your final circuit)
  - Section 2 (revised Arduino code with serial monitor/excel screenshots)
  - Section 3 (final Arduino code 3e, 7b; answers to questions 6a, 7de; oscilloscope screenshots 5b, 7e)
  - Postlab (answer to Question 1)
- Please include adequate labels and text so it is clear where you have included each item requested in your report.
- Upload your prelab spreadsheet (prelab 3) to the designated canvas lab assignment.
- For your convenience, each item that is required to put in your report/demo is also highlighted within the lab writeup.
- Due by Monday 3pm.