

ESE 150 – Lab 02: Digital to Analog Conversion

LAB 02

In this lab we will do the following:

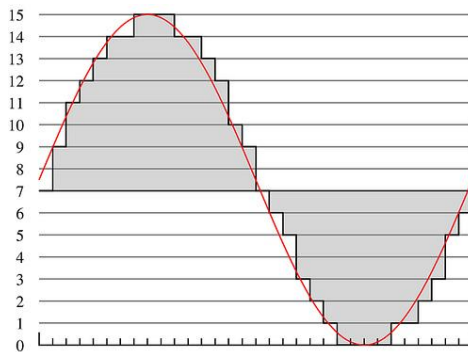
1. Learn how to write ItsyBitsy code that outputs voltages between 0 and 3.3V
2. Learn how to use the ItsyBitsy's serial monitor to SEND data to the ItsyBitsy
3. Have the ItsyBitsy behave as a basic D2A (digital to analog converter) to reconstruct your samples and produce sound on headphones

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:



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Lab Procedure:

Prelab: Reconstructing Original Signal in Excel

- It would be useful to have the output from your ItsyBitsy from Lab 1 before starting this section.
- You should have sampled a 300 Hz signal at 500 Hz, 5000 Hz, and 35,714.3Hz (default rate with 10us 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 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?)

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 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....)

b. How many radians is that? (assume 2π radians per cycle)

c. Assuming an amplitude of 2048 with a baseline centered at 2047, write the equation for the sine wave. Assume no phase shift.

d. This equation is great, but we're not done yet. With a sample rate of s , write a function for time $t(s, i)$ where i is the *sample number*.

e. Plug this function back into your formula from (c) in order to finalize your formula for the wave.

i. Hint: you have seen equations like this in lecture.

f. Using this general formula, write the formula for a 300Hz wave sampled at 5kHz centered at 2047 with an amplitude of 2048 in terms of f , s , and i .

3. Using the equation you found in Problem 2, develop a spreadsheet that produces a wave similar to the 10,000 samples for the 300Hz sine wave sampled at a 5000 Hz sample rate.

a. It will differ in that this wave will have a larger amplitude, with values between 0 and 4095, while you probably saw a wave centered at 800 that spanned 200 levels rather than 4096

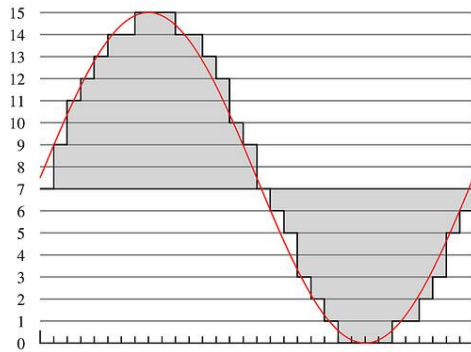
b. You will want to have frequency and sample rate (and later quantization) as separate cells in Excel and reference them in your Excel version of the equations. You

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should label these cells so that you know what they refer to. Try to put these constants far way from where your columns of DATA will go.

Hint: How does $\$A\1 behave differently from A1?

1. You can use a column in Excel for each sample number and apply your equation to each of those cells in a second column to get a column of datapoints. (If you are using AutoFill to apply the function to each sample while referencing the set parameter cells, this link may be quite helpful! <https://stackoverflow.com/questions/2156563/how-to-keep-one-variable-constant-with-other-one-changing-with-row-in-excel>)
2. **Remember, our samples must be discrete integers. Make sure to ROUND() your samples.**
3. How can you further modify your equation to quantize the data to a different level of bit precision? Explain this in words. **Hint: Think about how the maximum quantization level changes as a result of changes in the bit resolution (number of bits).**
4. Recall that you took 10,000 samples, so you should have 10,000 rows



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 on prelab. Go ahead and start working on the lab. It will take some time for the TAs to get around to all the groups.

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

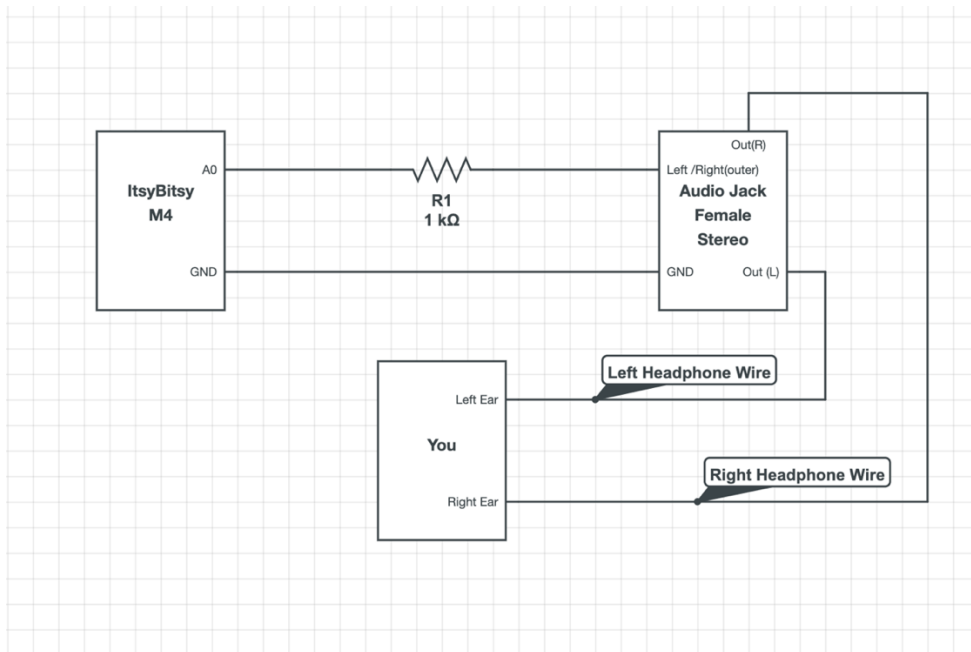
- In this section you will setup your ItsyBitsy to serve as a D2A.
 1. Obtain the following items from the lab bench stock (near the front of Detkin lab):

- (1) ItsyBitsy
- (1) Breadboard
- (1) 1 k Ω 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

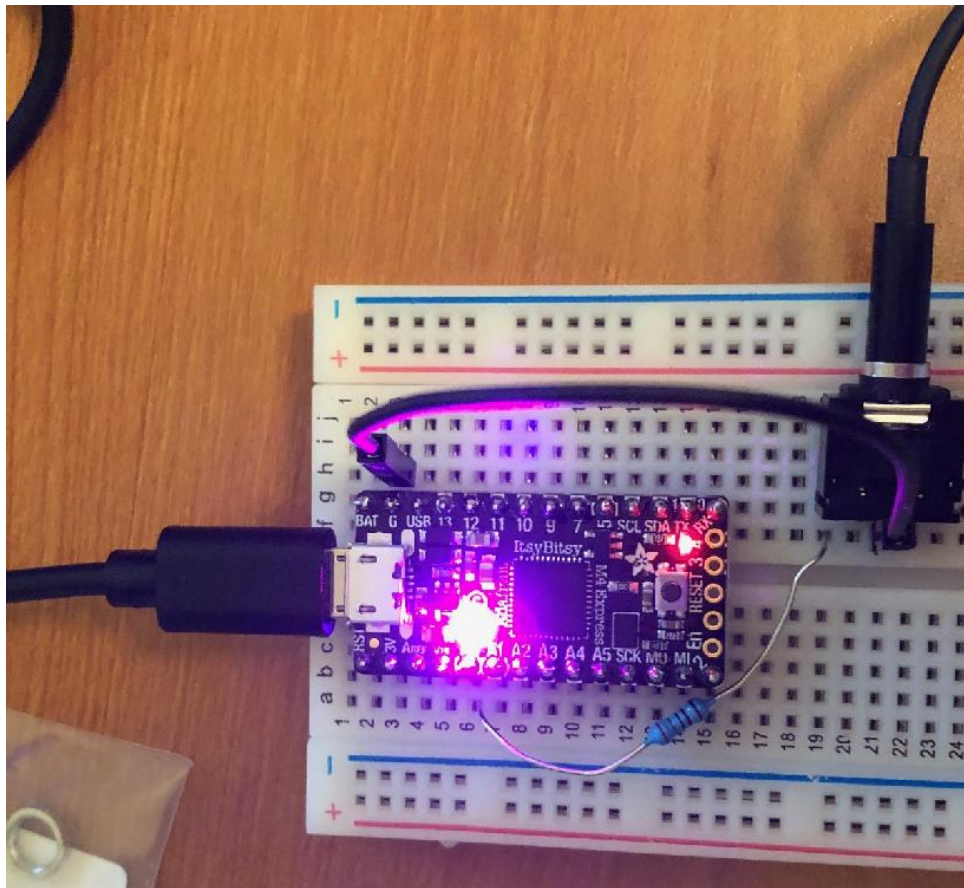
2. Using your ItsyBitsy and breadboard, connect the components above as shown in this schematic:



- a. 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.

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- b. Ensure that you connect the ground of the stereo jack (middle pin) to the Ground of the ItsyBitsy (G pin).
- c. 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.
4. Finally, run the code in “play_samples_50kHz.c” on your Itsy-Bitsy and plug your headphones into the female headphone jack. Comment and uncomment the three arrays at the top to determine what kind of wave you would like to listen to. 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!
5. 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.
6. Take a picture of your final, built circuit to include in your lab report.

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

- We'd like to convert the samples you took last week, back to a voltage using the ItsyBitsy
- We need to find a way to send the sample BACK 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 10000

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

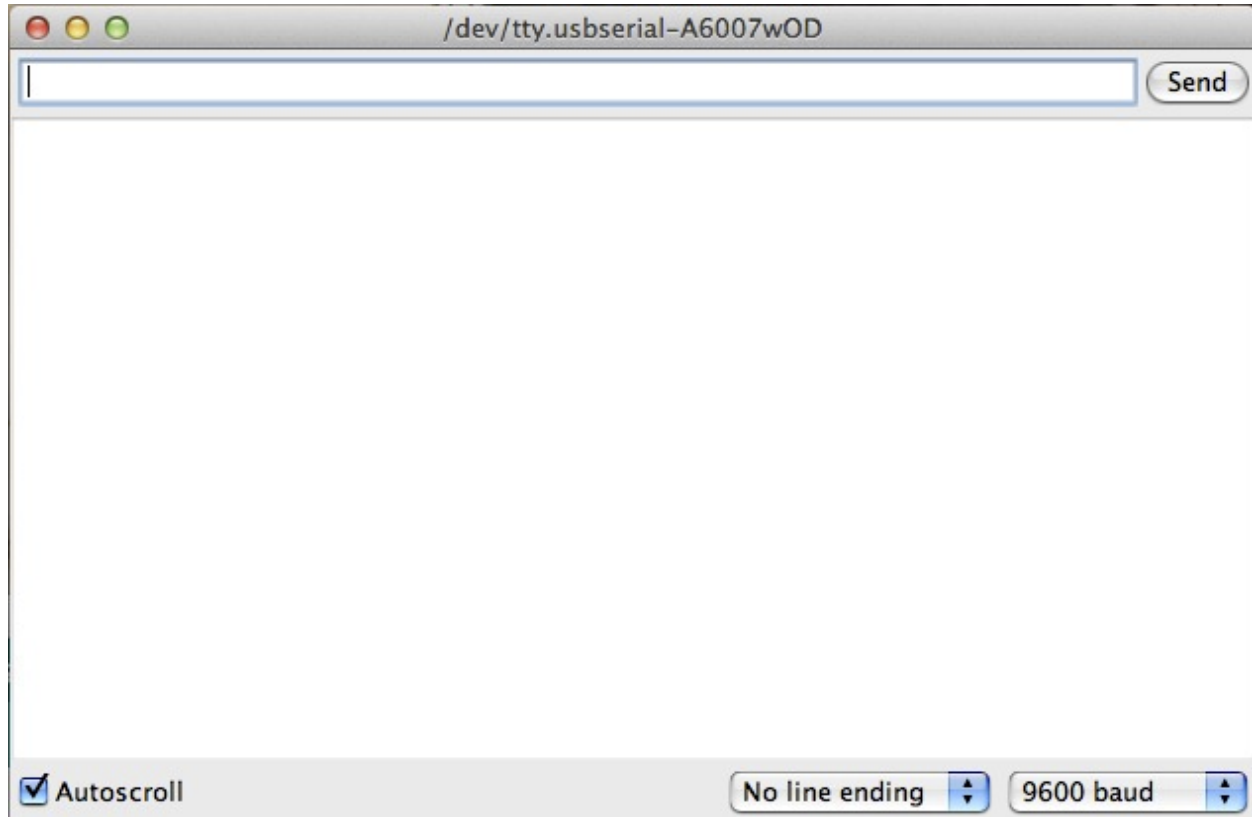
void setup() {
  Serial.begin(9600); // setup serial monitor speed
}

void loop() {

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

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

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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 to the Arduino code so that whenever it receives samples it sends back all the samples back to the Serial monitor (use `Serial.println()`).

Note: In the past, students have had difficulty getting the correct data written back. We have found that first recording the values in a loop and then printing them in a second loop is the most reliable way to achieve the desired results. You can use the ***samplesReceived*** variable to control whether or not you go into the print loop after parsing the serial input. You can also use ***samplesPrinted*** to control whether or not you print the samples more than once. In this case, you probably just want to print the samples once.

7. Try copying and pasting 10,000 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 from last week.
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.

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Lab – Section 3: Putting it all together, ItsyBitsy as an A2D

- 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. Create a new sketch that combines Section 1 and Section 2's Arduino code to output your samples as voltages.

2. **Your program should receive all 10,000 of the samples you generated in pre-lab.**

- a. As you receive values, your program should convert each sample to a PWM value using the conversion factor found in Question 1 and save that in the array.
- b. For the waveform generation that follows, use the data from the highest sampling frequency you collected.
- c. This input loop should run only once.

3. It should then output all 10,000 samples to the output pin.

- a. Remember you need to hold each output long enough for the ItsyBitsy to drive the output to the target voltage.
- b. This output loop should repeat.
- c. *You'll have to think about the right delay in between analog writes. Keep in mind that the ItsyBitsy takes around 12 microseconds to execute `analogWrite()`. Ensure you are driving voltage at the sample rate for which you generated. (Should be 5kHz)*

Hint: Think back to Lab 1 when the delay for `analogRead()` was 18us. How did you correctly determine the delay then? (also look at the `play_samples_50khz.c` code)

- d. This loop should not start until after completing the input loop.
4. You will verify your output by listening on your headphones.
- a. You should verify that your data sounds like the 300 Hz tone from last week played from your phone or computer.
5. Show code and describe sounds to TA for exit checkoff.
6. 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.

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Postlab: Synthesis

1. Quantize the 300Hz wave sampled at 5000Hz to 2, 4, and 8 bits of precision. Create screenshots of the DATA with associated plots.
 - a. Consider the original quantization level (12 bits = 0-4097 quantization)
 - b. How many quantization levels for n-bit resolution (n bits =)
 - c. Linearly scale from quantization of part a to quantization of part b
 - d. Make sure to ROUND() your answers (INTEGERS ONLY)
2. Play these quantized samples on your ItsyBitsy. Describe the results:
 - a. Use the serial monitor to send the DATA as before
3. 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 playing your 300Hz wave sampled at 500Hz.
 - b. Describe the difference between this and the original 300Hz tone.

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HOW TO TURN IN THE LAB

- Upload a PDF document to canvas containing:
 - Prelab (Answers to Questions 1 and 2 plus Spreadsheet for generated DATA)
 - Section 1 (picture of your final circuit)
 - Section 2 (revised Arduino code with DATA screenshots)
 - Section 3 (final Arduino code and screenshots)
 - Postlab (answer to Question 1, 2 and 3, in PDF)
- Please include adequate labels and text so it is clear where you have included each item requested in your report.
- Upload your postlab spreadsheets (postlab Question 2&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 Friday 5pm.