Lab 3: Relative Humidity

Tuesday, March 2, 2021 4:24 PM

Lab3-RelativeHumidi...

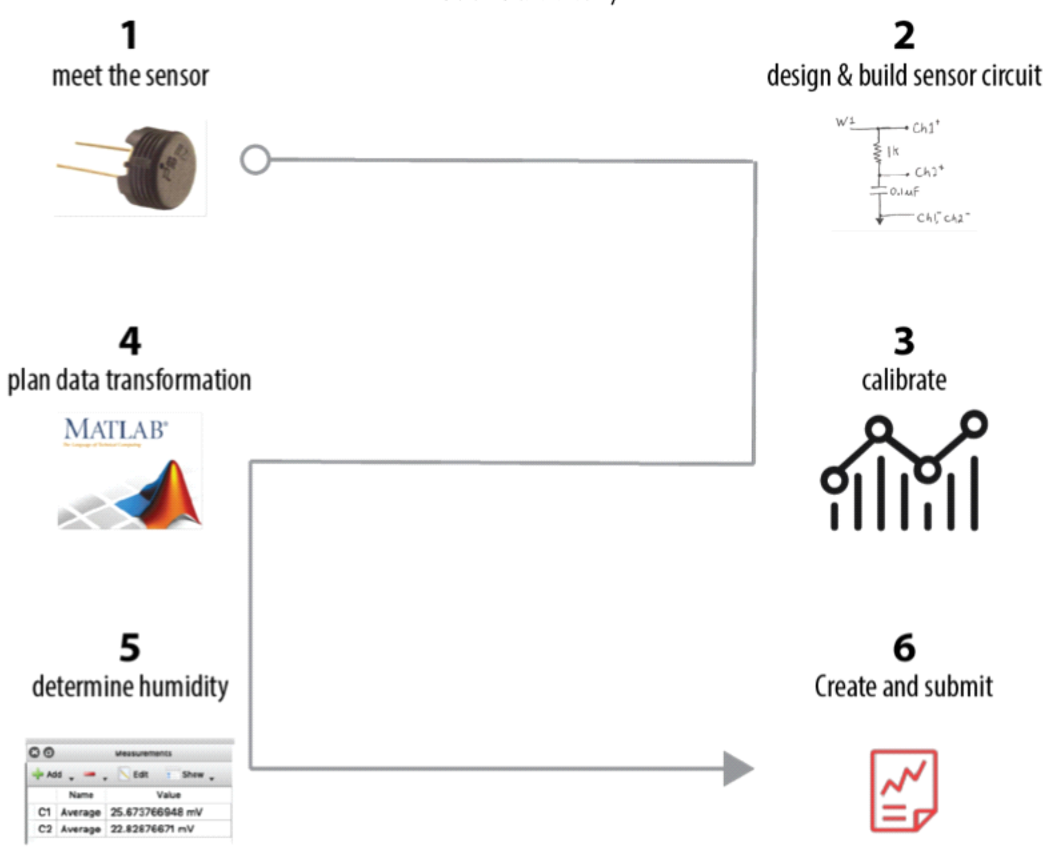
Lab 3: Using Capacitors to Measure Humidity

Goal: Build a circuit to sense and compute relative humidity by measuring capacitance.

Learning objectives

- Employ the concepts from the capacitor PSet to design a sensor circuit ;
- Use the specification sheet for a sensor to determine the frequency and voltage inputs for the sensor;
- Construct a transfer graph (ΔV to %RH) from the data on the specification sheet;
- Calibrate your sensor circuit.

Visual Summary



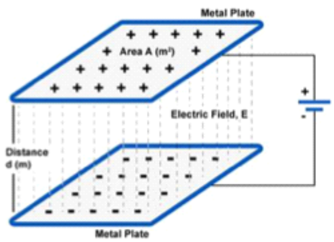
1. Meet the sensor

How can we sense humidity with a capacitor?

Now that you've been in Needham, Massachusetts for a few weeks, you've experienced humidity!

%RH *Relative humidity* is the percent of water vapor in the air *relative* to how much water vapor the air can hold before the water condenses—that is, before it rains or snows, depending on the temperature.

A capacitor is something that has the "capacity" to store charge. Often the charge is stored across parallel plates of metal, like so:



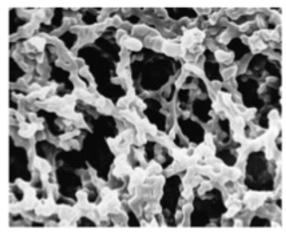
Source: https://sites.google.com/site/nithinjoseph2066/electromagnetics/parallel-plate-capacitor

We normally refer to separated + and - charges as "electric potential differences" or "Voltage differences."

$$\text{Capacitance} = \frac{charge\ stored}{\Delta V}$$

It turns out that we can increase the charge stored in a parallel-plate capacitor by placing a non-conducting material between the plates.

In the case of this lab, for the humidity sensor, the material between the capacitor plates is a water-sensitive polymeric (i.e., plastic) material, likely cellulose ester.



Source: https://www.labsupply.co.nz/

It's made from sugar molecules and looks like this in an electron microscope: The cellulose ester scaffolding is about 10,000 times smaller than the thickness of a human hair.

Water vapor from the air attaches to the surface of the cellulose ester fibers, enabling more charge to be stored in the capacitor:

Capacitance (C) ↑ with ↑ %RH

The %RH sensor

You are going to create a circuit that uses this humidity sensor (click link for specification sheet) as the *transducer.*

transducer: a device that converts one physical quantity to another

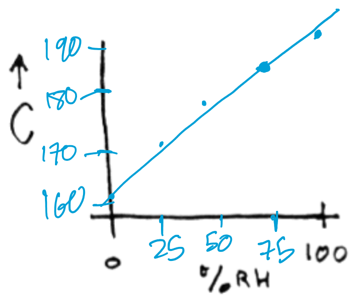
e.g.

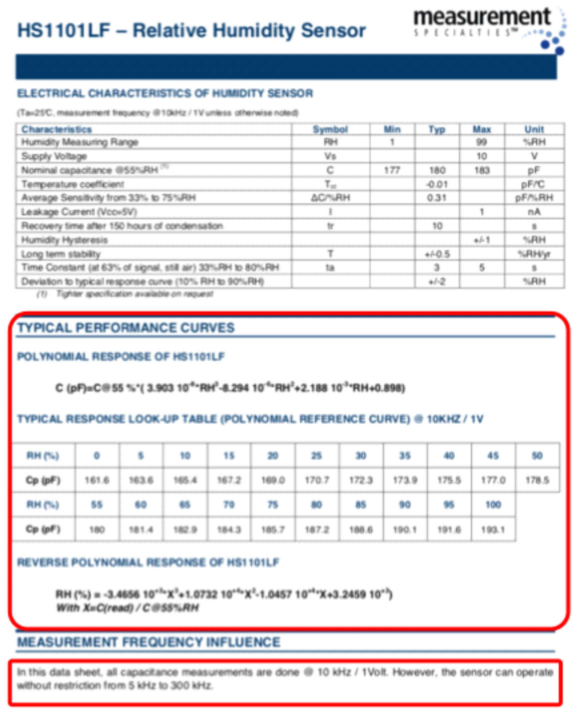
What is our transducer converting the humidity to?

Capacitance (NOT charge)

The product specification sheet states how it will *perform* in a circuit and under what *circuit conditions.*

<u>Roughly</u>, what does the *transfer* or *reference* curve for your sensor look like?





HS1101LF – Relative Humidity Sensor

measurement SPECIALTIES™

ELECTRICAL CHARACTERISTICS OF HUMIDITY SENSOR

(Ta=25°C, measurement frequency @10kHz / 1V unless otherwise noted)

Characteristics	Symbol	Min	Typ	Max	Unit
Humidity Measuring Range	RH	1		99	%RH
Supply Voltage	Vs			10	V
Nominal capacitance @55%RH [1]	C	177	180	183	pF
Temperature coefficient	T_{cc}		-0.01		pF/°C
Average Sensitivity from 33% to 75%RH	ΔC/%RH		0.31		pF/%RH
Leakage Current (Vcc=5V)	I			1	nA
Recovery time after 150 hours of condensation	tr		10		s
Humidity Hysteresis				+/-1	%RH
Long term stability	T		+/-0.5		%RH/yr
Time Constant (at 63% of signal, still air) 33%RH to 80%RH	ta		3	5	s
Deviation to typical response curve (10% RH to 90%RH)			+/-2		%RH

(1) *Tighter specification available on request*

TYPICAL PERFORMANCE CURVES

POLYNOMIAL RESPONSE OF HS1101LF

$C\,(pF) = C@55\,\% * (3.903\ 10^{-8} * RH^3 - 8.294\ 10^{-6} * RH^2 + 2.188\ 10^{-3} * RH + 0.898)$

TYPICAL RESPONSE LOOK-UP TABLE (POLYNOMIAL REFERENCE CURVE) @ 10KHZ / 1V

RH (%)	0	5	10	15	20	25	30	35	40	45	50
Cp (pF)	161.6	163.6	165.4	167.2	169.0	170.7	172.3	173.9	175.5	177.0	178.5
RH (%)	55	60	65	70	75	80	85	90	95	100	
Cp (pF)	180	181.4	182.9	184.3	185.7	187.2	188.6	190.1	191.6	193.1	

REVERSE POLYNOMIAL RESPONSE OF HS1101LF

$RH\,(\%) = -3.4656\ 10^{+3} * X^3 + 1.0732\ 10^{+4} * X^2 - 1.0457\ 10^{+4} * X + 3.2459\ 10^{+3})$

With X=C(read) / C@55%RH

MEASUREMENT FREQUENCY INFLUENCE

In this data sheet, all capacitance measurements are done @ 10 kHz / 1Volt. However, the sensor can operate without restriction from 5 kHz to 300 kHz.

2. Design and build the sensor circuit

Recall that throughout ISIM, we are simply taking a proxy measure using an instrument and transforming it through the wonders of math to our desired sensing goal.

Let's work backwards from our goal, using the image, right.

We desire to sense %RH (1). We know that the sensor will change capacitance with changes in %RH (2). We need a circuit that allows us to relate changes in capacitance to voltage (3).

You could *calibrate* the circuit (3) by simulating the circuit test conditions used to develop the REFERENCE CURVE (2).

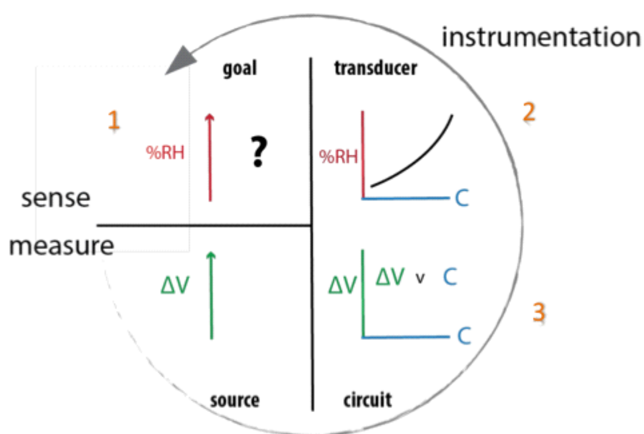


Figure 1. Concept of measuring to get sensing goal.

Both of the circuits below could work for the sensor, using a 10KΩ resistor. Build the circuit below using a 120 pF capacitor in the place of the sensor.

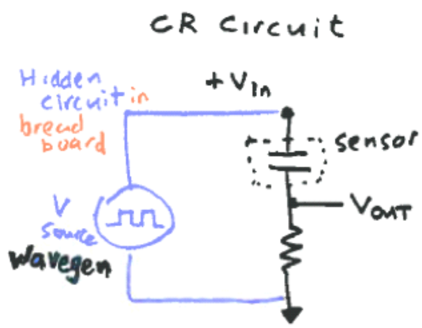


Figure 2. A CR circuit that will work with the %RH sensor.

3. Calibrate your circuit

If your sensor is powered and exposed to environments with a range of %RH, it would have different capacitances, as we can see from the TYPICAL RESPONSE LOOK-UP TABLE (specification sheet, page 2).

*If we want to duplicate the circuit conditions that produced the REFERENCE curve, what frequency (Hz) and voltage (Volts) should we input to the sensor? **Hint:** Check the specification sheet.*

To create a calibration curve for your circuit, you can use capacitors of known values in the range of the transducer's response (100-220 pF) to simulate the sensor in differing %RH environments.

Connect the O-scope and take the calibration data

There are several, equally-usable ways to connect to your sensor your circuit for the calibration. Connect your O-scope so that it meets these functional requirements:

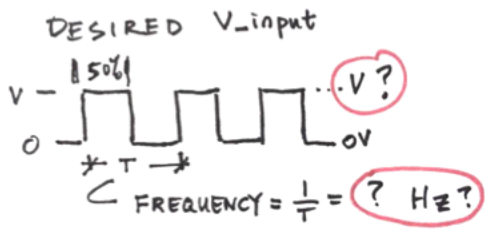
1. The O-scope and sensor circuit share a ground;
2. The WaveGeneration produces V_{in} as a square wave with the same amplitude and frequency used to develop the performance curves in the technical specifications (p. 3);
3. You can monitor the input V_{in} ;
4. You can measure the V_{out} as the calibrated signal.

Suggestion: *Sketch your circuit and O-scope connections to include with your report.*

Where in your circuit will you connect Ch1- and Ch2-?

Set up WaveGen to power the sensor circuit

(check the Technical Specification sheet, p.3, to see the conditions used to determine the Performance Curves)



2V

10 KHZ

Once you have determined the conditions for the waveform, collect the scope signal. Use the mean Voltage reading on the O-scope.

As a rule of thumb, your sampling rate should be ~twice the maximum frequency in the signal in order to get an accurate measure of the time-varying signal. But to measure an accurate waveform, you will need 100xf.

For those interested, this rule of thumb is called the [Nyquist rate](). It is the minimum sampling rate required to get a true measure of the signal.

Your voltage measurement is probably jumping around. You can use a single cycle to get a single voltage average.

Make sure you choose to measure the $V_{RootMeanSquare}$ (V_{RMS}) by selecting the button to the left of the V (;

Once you have recorded the measurement in the table below, replace the capacitor with a 100 pF capacitor. Note that the signal decays faster and the RMS voltage has decreased significantly. Mathematically, your sensor circuit has a large sensitivity, $\frac{dV}{dC}$.

ΔV of resistor

Capacitance value (R=10K)	Measured RMS Voltage amplitude
100 pF	84.84mV
120 pF	102.7mV
150 pF	118.4mV
180 pF	123.5mV
220 pF	150.4mV

4. Plan data transformation

Generate the plot of the C v. V-RMS relationship for your lab report from your measured data.

In the next step you'll replace the capacitor with your %RH sensor. Make a plan of how you will use the data that you have to get the relative humidity from the voltage output of your sensor circuit.

You'll need the data sheet for the humidity sensor.

5. Measure relative humidity

Replace the capacitor in your circuit with the humidity sensor. Take the measurement of the RMS amplitude. From your calibration data, determine the relative humidity of the room. 124.9 mV

Check your result to the relative humidity of the day (which you can check at www.weather.com).

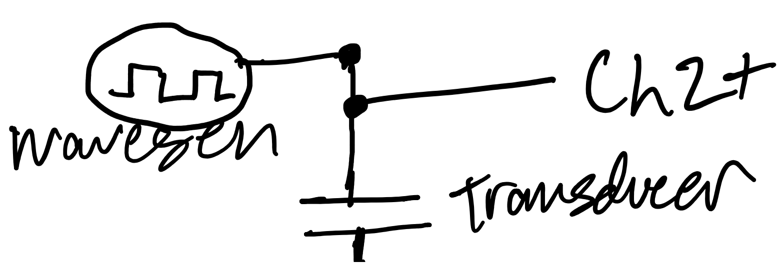
RH: 23% @ C=171pF

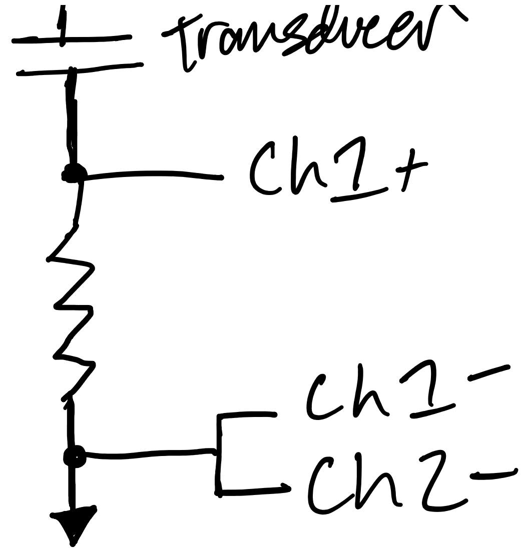
6. Create and submit report

The results you need to include are highlighted in **RED** above. They include

- A plot of the measured voltage versus time data from the 1-volt square wave at 10 kHz into your circuit for your sensor.
- A sketch of the circuit you used and the O-scope connections
- Compare your measurement to the *analytical solution*. Note that the analytical solution will be the same for the CR circuit as the RC circuit in the book, just with a minor adjustment.
- Plot your calibration data for the capacitance meter that you created (i.e. a plot of the table data). Plot a reasonable linear fit, overlaid on the data points and report what your calibration equation is.
- Report on your results of using the capacitance meter you built to measure the relative humidity. Comment on the "official" humidity for the day whether your results make sense.

**analytical solution* = The value that you would get if you used the equations for an idealized RC or CR circuit.


wavegen
Ch2+
transducer



ISIM_Lab_3

ISIM Lab 3: An Analysis of the Humidity in Needham, MA, USA

Ari Porad

March 9, 2021

Abstract

A humidity transducer, which functions as a capacitor with a defined relationship between capacitance and relative humidity, was installed as the upper element in a voltage divider. The lower element of the voltage divider was a $10k\Omega$ resistor, and the input was an 10kHz square wave with a 0.5V amplitude centered at +0.5V. The circuit was calibrated by replacing the transducer with various capacitors of known capacitance, measuring the voltages, and calculating a line of best fit accordingly. This calibration line was then used to derive the capacitance of the humidity transducer from the measured voltage across it. From there, the calibration table provided in the transducer's data sheet was used to determine the actual measured humidity from the capacitance.

1 Methodology

A humidity transducer is a capacitor who's capacitance changes with a defined relationship to relative ambient humidity. We measured the capacitance of the circuit using a voltage divider, with the transducer as the upper element and a $10k\Omega$ resistor as the lower element, with the measurement leads of the O-Scope connected to either lead of the transducer. The input to the voltage divider was the O-Scope's wave generator, which was configured to produce a square wave of 0.5V amplitude, centered at 0.5V with a frequency of 10kHz (as prescribed by the transducer's data sheet). For comparison, the measurement leads of the other channel of the O-Scope were connected to the output of the wave generator and to ground. See Figure 1.

1.1 Calibration

While our circuit directly measured voltage drop across the transducer, the transducer's data sheet provided humidity measurements in terms of capacitance. Consequently, we needed to determine the relationship between measured voltage across the transducer and capacitance. To do this, we replaced the transducer with several capacitors of known capacitance and measured the resulting voltage. We used this data to calculate a line of best fit between measured voltage and capacitance.

2 Results

2.1 Calibration

We calibrated our system using five capacitors, with the following known capacitances and measured voltages:

From this data, we calculated the following linear regression, which represents our system's relationship between measure voltage (V) and capacitance (pF). A visual comparison between our data and the regression can also be seen in Figure 3

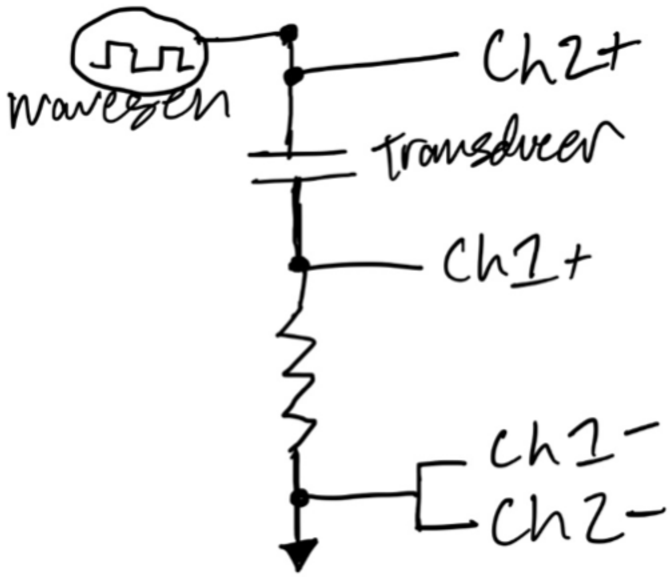


Figure 1: Our measurement circuit. We connected the relative humidity transducer as the upper element in a voltage divider, with the lower element as a $10k\Omega$ resistor. The input to this voltage divider was the O-Scope's wave generator, while the output was to ground.

Known Capacitance (pF)	Measured Voltage (mV)
100pF	84.8mV
120pF	102.7mV
150pF	118.4mV
180pF	123.5mV
220pF	150.4mV

Table 1: Measured voltages and known capacitances of our calibration capacitors.

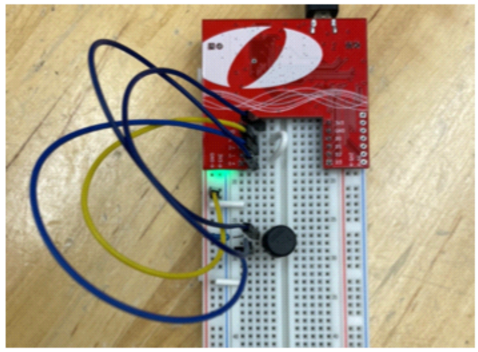


Figure 2: Our breadboard, as used to measure the voltage across the transducer using a voltage divider.

$$C = 1.92V - 68.45 \quad (1)$$

2.2 Humidity Measurement

After calculating our calibration trend line, we reconnected the humidity transducer and measured the voltage across it. We then used the calibration trend line to calculate the capacitance of the transducer, and the transducer's data sheet to derive the measured humidity from its capacitance. The measured capacitance of the transducer was 171.13pF (see Figure 4). The actual relative humidity at the time (as provided by Weather.com) was 25%. The data sheet of the transducer specifies that its capacitance will be 169.0pF at 20% RH, 170.7pF at 25% RH, and 172.3pF at 30% RH, meaning that the closest value would be 25% RH (exactly the same as the known humidity). While the precision of the data sheet doesn't permit a precise evaluation of the measurement's accuracy, it's safe to say that this system was highly accurate—especially considering that the humidity in the room may have deviated slightly from the measured humidity of all of Needham, MA, USA.

2.3 CR Circuit vs. RC Circuit

Because this circuit—unlike many of the circuits we've previously covered in class—is a CR circuit instead of an RC circuit, our system measures the voltage drop across the resistor instead of across the capacitor. As a result of this, the voltage across the transducer is shown to spike at the start of a wave cycle before immediately degrading. Half way through the cycle, when the voltage of the wave drops to 0, the voltage of the transducer again spikes in the negative direction, before degrading towards zero (Figure 5). This is the mirror image of what we'd expect for an RC circuit.

3 Finishing Remarks

This experiment demonstrated that a transducer is a highly accurate method for measuring relative humidity. More experimentation is required to test this system under a wider range of circumstances

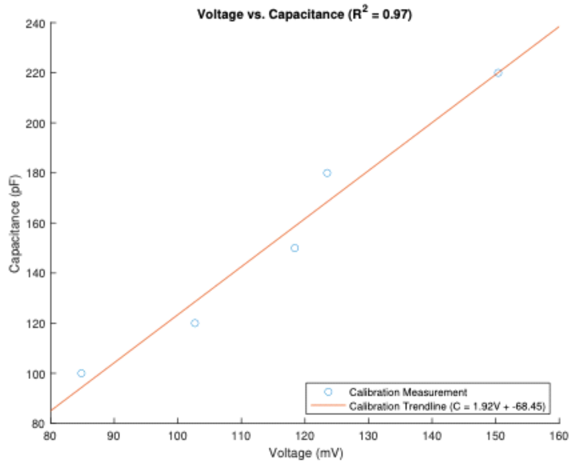


Figure 3: Voltage vs. capacitance, showing our five calibration capacitors and our calculated calibration trend line. $R^2 = 0.97$

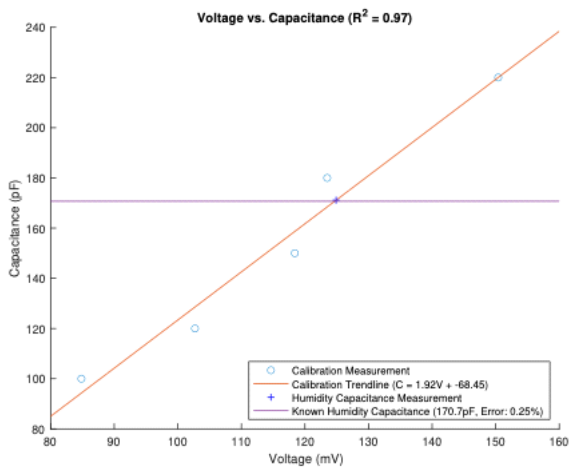


Figure 4: Voltage vs. capacitance, showing the humidity transducer's measured and true capacitance in addition to our calibration capacitors and our calculated calibration trend line.

and with a higher degree of precision.

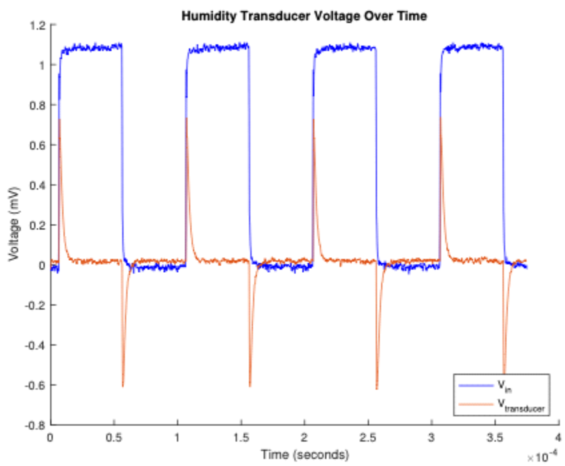


Figure 5: Voltage vs. time, showing the square wave produced by the O-Scope (blue) and the voltage across the transducer (orange)