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# Snap Circuits Part 4: The Snapino

Introduction

I've been using the Arduino Uno R3 microcontroller for over a decade, and like, I sometimes need to come up with innovative ways to mount and interface it to external circuits. Elenco Electronics Snap Circuits version called the "Snapino" (Figure 1, next page) solves the mounting problem nicely by encapsulating an R3 in a specially designed snap housing with the most commonly used pins connected via short, insulated #26 wires to external snaps. This allows you to easily build circuits in three dimensions by mounting the Snapino module on any snap base then using various snap components to build outwards. The top of the case (clear acrylic) still allows for standard Arduino shields to be stacked on top plus they can be inter-connected to other snap components by using Elenco's optional snap-to-DuPont wires.

"Making Coding a Snap"

The Snap Circuits Snapino kit provides a basic introduction to microcontrollers, interfacing to electronic components and coding to get the components to do something under control of the Snapino. Used in combination with other snap components and Arduino compatible shields, you can easily expand the complexity of the coding, circuits and experiments. As supplied, the Snapino communicates and exchanges data with the outside world tethered by a USB-to-serial cable to your laptop/desktop. The Arduino integrated development environment (IDE) supports the Windows, Linux and Macintosh OSX operating systems.

Figure 1: Snapino Kit and Components
Credit: Elenco Electronics.
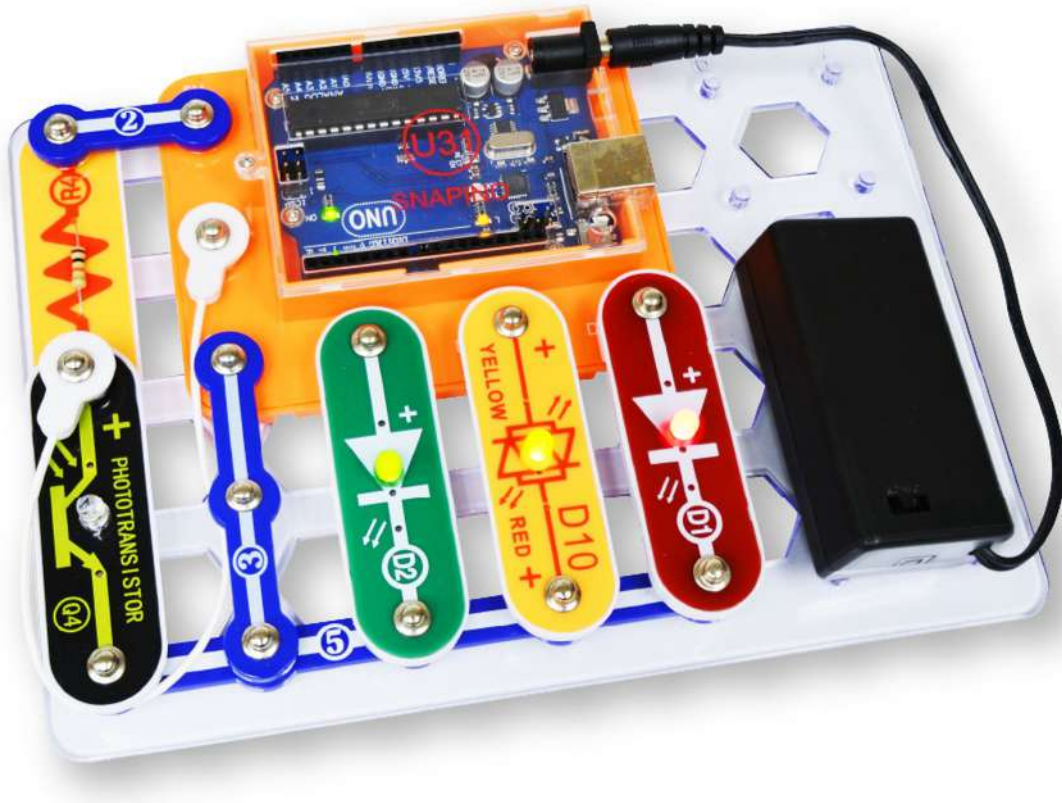
Years ago, I wrote two articles about the Uno that you can reference for more details (See *TCA* Nov-Dec 2014 and Jan-Feb 2015). Not much has changed in the interim until the recent release in mid 2023 of the far more powerful and versatile Uno R4—at long last! While working on this article, I also found a really nice piece of Arduino code that turns any Uno, Nano or Mega microcontroller into a fairly decent small value capacitor capacitance meter without needing any ancillary components.

The Capacitor

Capacitors are truly amazing passive analog devices that work the way they work because of the negatively charged electron, electric fields and opposing charges (positive/negative). They're used in resister-capacitor (RC) audio and radio frequency filter circuits, power supply ripple filtering, phase-shift, timing, tuning, oscillator and decoupling circuits, camera flashes and strobes, defibrillators, computer memory, and also as a low DC voltage/current main or backup power source ("supercapacitors").

In the case of parallel plate capacitors, whenever you connect an external voltage source across two metal plates separated by an insulator or "dielectric" (having the property of transmitting electric force without conduction) be it air, ceramic, mica, glass, et al (Figure 2) electrons are pushed on the plate connected to the negative side of the power source and pulled away from the other plate connected to the positive side of the power source building up opposite charges that increases the strength of the electric field between the two.
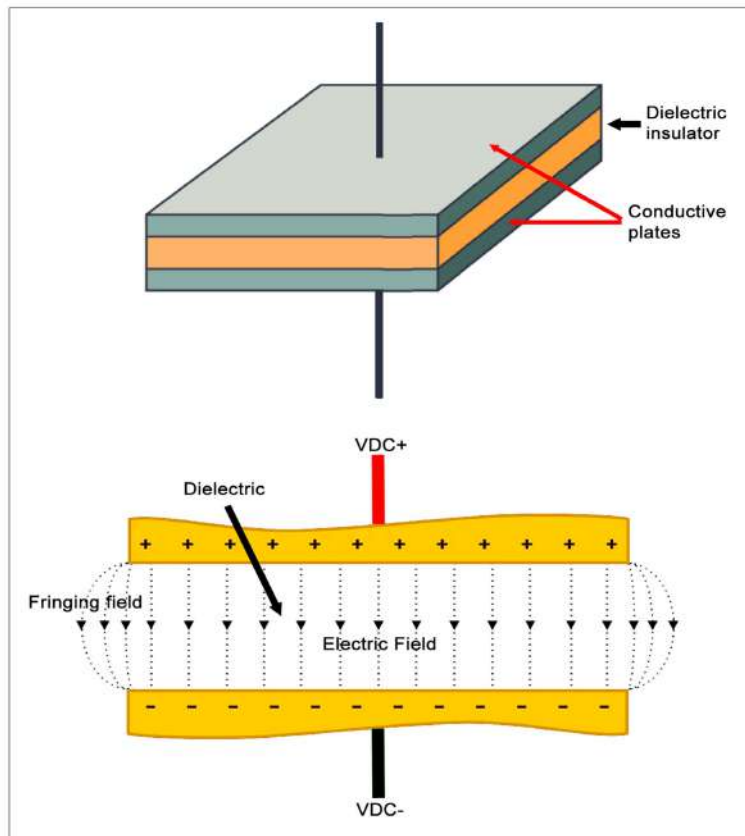

Figure 2: Capacitor Design and Physics
This depicts a simple parallel plate capacitor design. Credit: HowStuffWorks.com and Biologic.net.

We can measure this electrostatic or electric field effect as a brief charging current in the case of direct current (DC) or as a continuous charging/discharging current in the case of alternating current (AC). Electrons really, really want to travel over to the other plate, but they can't cross the dielectric barrier without damaging or destroying the capacitor, which will happen if the dielectric's breakdown voltage is exceeded.

Capacitor work the way that they do because of something called the electrostatic or electric force ("Fe"). Fe is also known as the Coulomb force (also abbreviated "Fe") named after Charles-Augustin de Coulomb, who formulated Coulomb's law (eerily similar to Newton's law of gravity). It's responsible for attraction/repulsion between charged objects, and it's one of the fundamental components of the electromagnetic (EM) force or "electromagnetic interaction" combining the once thought separate electric and magnetic forces into one of four known universal forces along with the strong, weak nuclear forces and gravity.

The EM force is responsible for keeping electrons in their "proper" places ("shells" or energy levels) while they swarm like bees around atomic nuclei creating stable atoms, elements and molecules. If this wasn't the case, the negatively charged electrons would repel each other out of their shells or even eject electrons out of the atom altogether while other electrons would be attracted to and smash into the positively charged proton(s) in the nucleus of atoms. The EM force between two charged particles is 10^{39} times (that's 10 followed by 39 zeroes) stronger than the force of gravity attraction between two masses on Earth or even the Universe! For example, you can easily lift a one kilogram steel hammer away from the Earth's gravity's grip on it, but try to do the same thing when an electromagnet holds it and that's not going to happen.

Charging (filling) or discharging (emptying) any capacitor is akin to filling/emptying a bucket with water, and the water analogy of electricity is often used to explain various actions because electricity was once believed to be an invisible "fluid" (one and two fluid models were once used); this is the reason why capacitors were called "condensers". Their capacity is measured in farads, in honour of Michael Faraday, a natural born genius with a grade school education who revolutionized the study and knowledge of electricity, magnetism, electromagnetism and electro-chemistry from the early to mid 19th century. And he proposed something that almost no one in science could believe, simply based on his famous experiments and his amazing Sherlockian powers of observation, deduction and reasoning that an invisible, mysterious medium must exist in the space surrounding all charged objects and magnets. He introduced the concept of electric and magnetic "lines of force" to explain how one object exerts a force (with a slight but measurable propagation delay) over a considerable distance on another object without needing any physical contact or intermediary to do so.

The Tau and Why

Charging/filling a capacitor occurs in a finite unit of time called tau (t), where one tau equals the circuit resistance times capacitance (t = RC). While a capacitor's internal resistance isn't zero, for DC use it's small enough to ignore so we only consider the external circuit resistance in series with a capacitor. Figure 3 depicts a handy Digikey.ca web tool that let's you play around with voltage, capacitance and resistance to calculate any tau, and the lower right of that image depicts the charging curve. At one tau (1RC), whether measured in micro, milli or whole seconds, and regardless of their capacity in farads, all capacitors naturally charge to exactly 63.2% of the value of the external voltage source in a non-linear, exponential curve. In most radio and electronics applications, a capacitor is considered fully charged at 5RC, but in some cases, a slightly shorter or slightly longer value of tau is used. Once fully charged, capacitors naturally block DC (steady) voltages but they naturally pass AC (changing) voltages. The same tau factor applies to discharging/emptying a capacitor.

Figure 3: Tau Calculator and Capacitor Charging Curves
Credit: Digikey.ca.
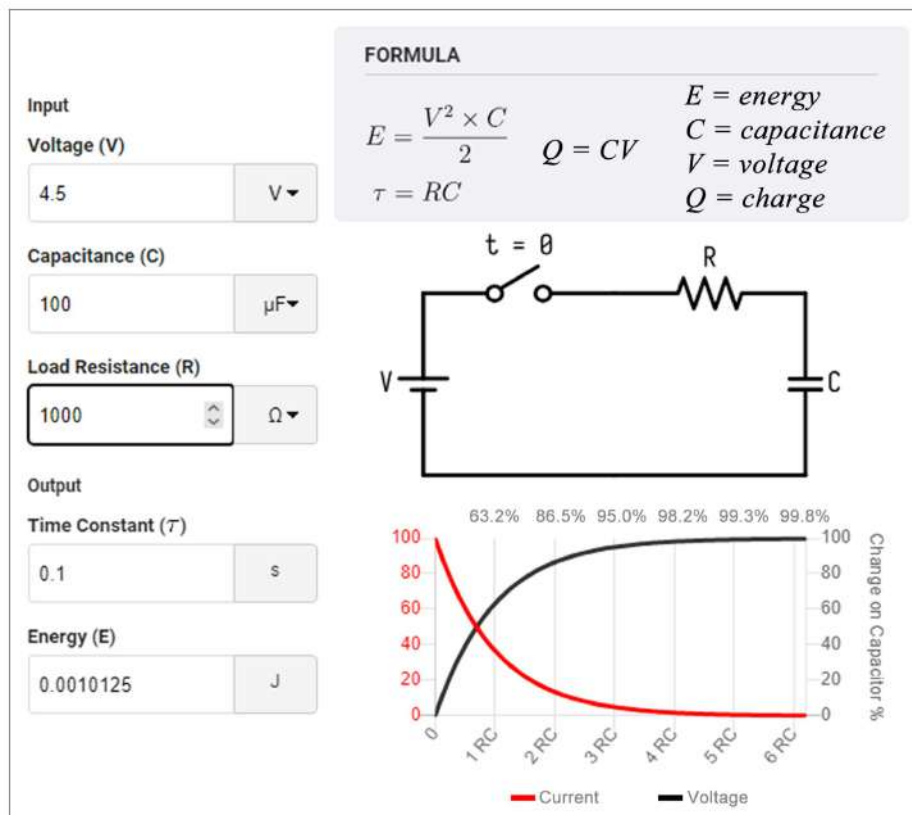
Capacitors are non-linear or "non-ohmic" devices, meaning that they don't have a 1:1 (linear) voltage to current relationship as we have with resistors (linear/ohmic devices). Whenever a discharged capacitor charges, the charging current starts at maximum and charging voltage is at minimum. At full charge, the charging voltage is now at maximum and equal to the external voltage source while the charging current is at minimum. In a capacitor, the charging current leads the voltage ("ICE") by 90 degrees.

Demonstration Capacitor Charge/Discharge Circuit
To keep things simple, I'll only talk about DC from now on. Figure 4 depicts the snap build using components from a couple of Snap Circuits kits, but you can use a solderless breadboard and parts from your parts box to replicate the circuit or you can also purchase Snap Circuits kits and/or parts from Robotshop.ca. *Note: Snap Circuits light emitting diodes (LEDs) are "resistorized" so we don't need external current limiting resistors.*
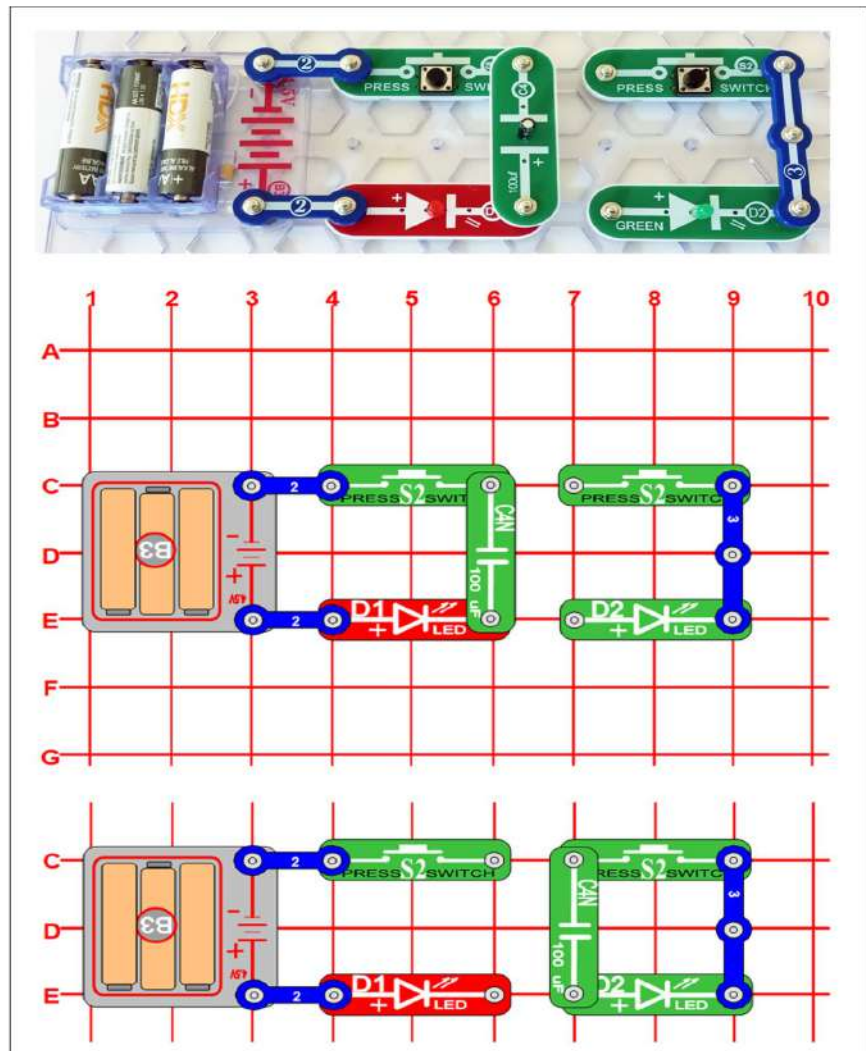

Figure 4: Capacitor Charge/Discharge Snap Circuits Build

1. Our capacitor (bucket) has a capacity to 100 microfarads. You charge/fill it by pressing and holding the left-hand pushbutton S2. This allows the energy (water) produced inside the battery pack to flow into our capacitor.

The red light emitting diode (LED) will briefly flash then fade out in about one-half second. Once full, no more energy/water can flow from the battery pack and the red LED returns to its dark/off state. Release the pushbutton.

2. Now move the capacitor over to the right hand circuit. You discharge/empty the energy/water inside it by pressing and holding the right-hand pushbutton. The green LED will briefly flash and fade in about one-half second. Once emptied, no more energy/water can flow from the capacitor/bucket and the green LED returns to its dark/off state. Release the pushbutton.

3. If you have a couple of snap resistors (try 5100 or 10000 ohms) to see how they affect tau. Or you can use the web tool to calculate what should happen.

Snapino Capacitance Meter

The original Arduino source code for making a small value (1 picofarad/pF to 1 nanofarad/nF) capacitance meter is at https://rb.gy/7y6ek. My modified version is included in this article's supplement zip file and available for downloading from my Radio Magic webpage (https://rb.gy/65aue). I removed the liquid crystal display (LCD) code, fixed a logic bug that only showed up when the program was used with the R4, and also added a smoothed moving average routine for both the Arduino IDE serial display (numbers) and the serial plotter display (graphs). The code and mathematics are not that complicated to understand so I didn't bother adding additional comments to the original code.

Making and Measuring "Gimmick" Capacitors

Any small value capacitor you want to measure is inserted into the Snapino's analog pins A0 and A2, which provides a convenient five millimetre lead spacing. After testing a few standard value disc capacitors, I went "old school" and made a "gimmick" capacitor by twisting together two 50 mm lengths of #22 insulated solid copper wires (Figure 5, next page). It's a variation of the parallel plate capacitor design depicted in Figure 2, but the gimmick capacitor is better for experimenting and demonstrating various capacitor characteristics and concepts because you can vary its capacitance simply by loosening or tightening the wire winding or by trimming the twisted pair of wires. Gimmick capacitance for this insulated wire gauge is roughly 0.4 pF per centimetre or 1 pF per inch (easier to use Imperial Units, in this case).
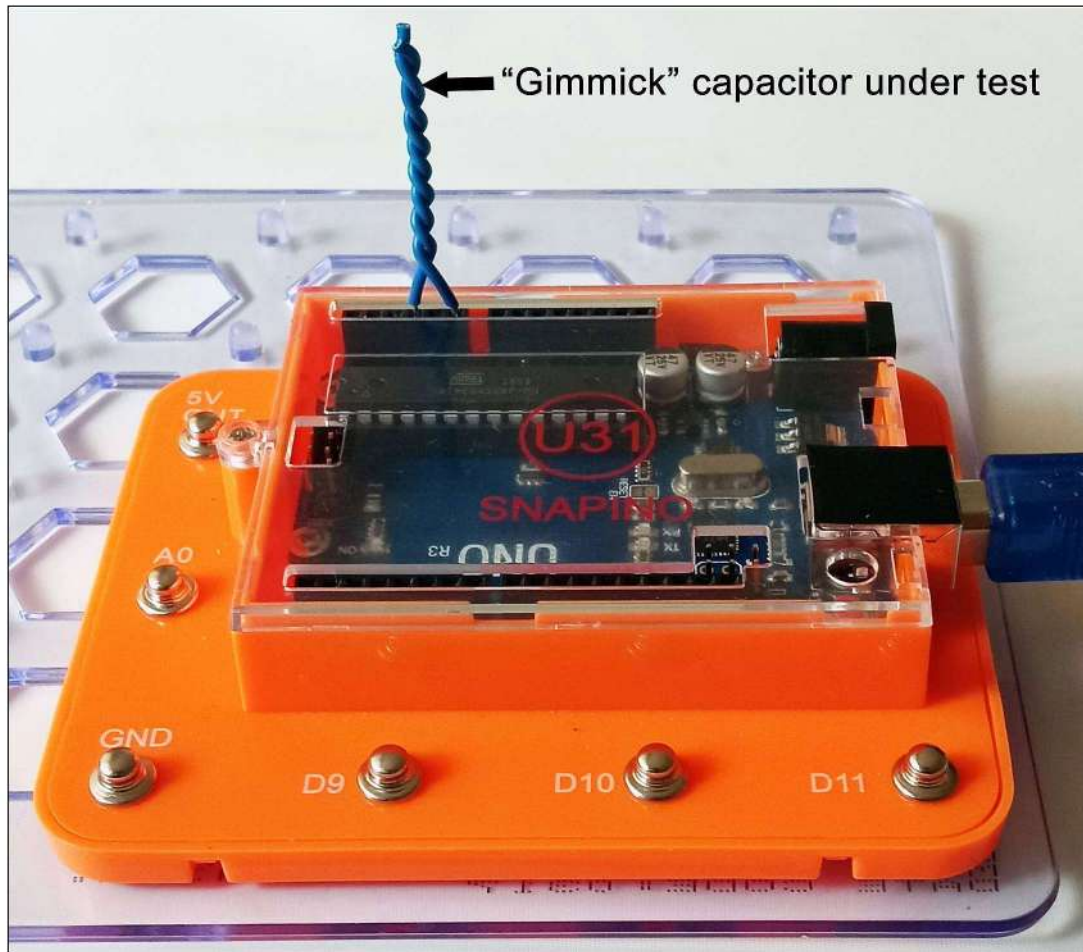
Figure 5: Snapino Capacitor Meter and Gimmick Capacitor

In the early days of Amateur Radio, gimmicks were widely used especially with regenerative (positive feedback) radio circuits, but they still come in handy when you need a very small capacitor of an unknown value to reduce or eliminate stray circuit capacitance or fine tune/stabilize an oscillator or amplifier. Figure 6 (next page) depicts the output of the Arduino IDE serial plotter output with the real time measurements in a light blue plot line that fluctuate rapidly up/down around a mean value as we take hundreds of analog readings per second and convert them to digital (ADC).

Note: You can use a Snapino or any handy Uno that you have on hand. This Uno gadget isn't specific to the Snapino.

Figure 6: Snapino Plotter Gimmick Capacitor Graph

The red (straighter with less variation) plot is the smoothed moving average of the real-time Snapino capacitor measurements (blue plot line). The insert (lower right) shows the Arduino IDE serial monitor real-time digital results alongside the smoothed moving average values.
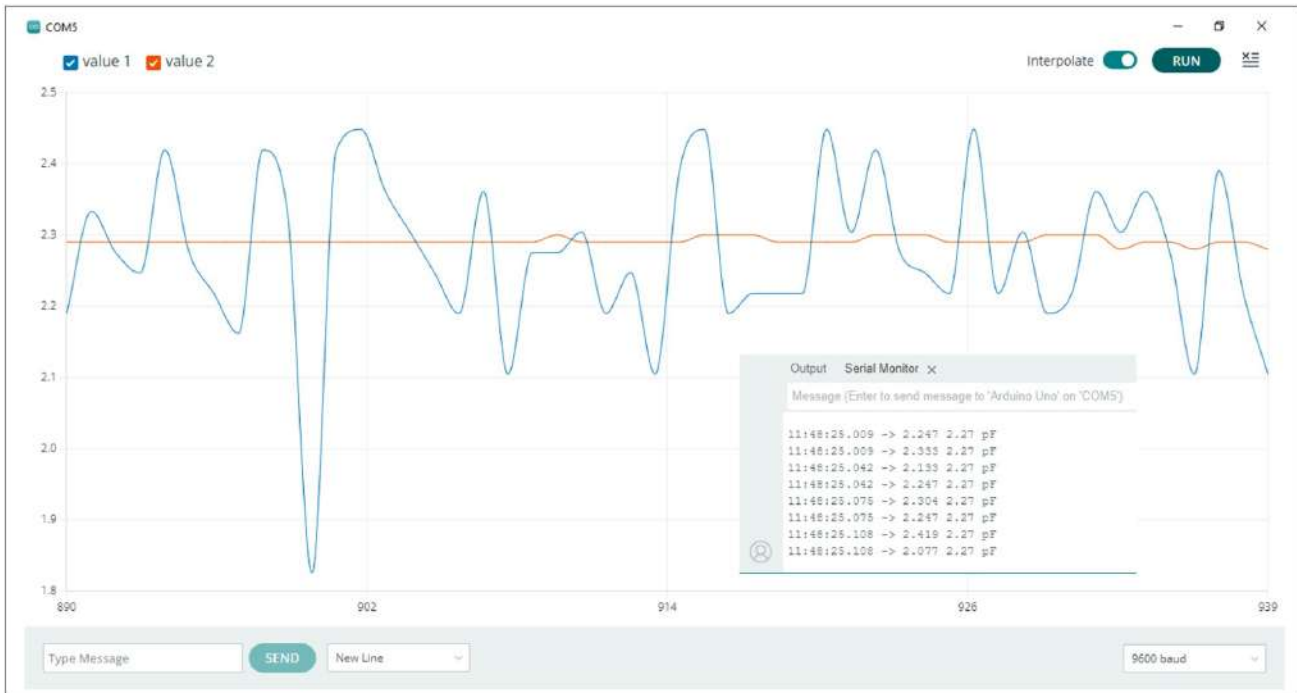
The Uno R3 can only meter/measure values using four microsecond increments, which is the reason for the "jitter" in the data (blue plot line) but we can overcome this limitation by using a smoothed moving average (red plot line). In Figure 7 (next page), the same gimmick is measured using an inductance, capacitance and resistance (LCR) meter. The LCR has the added ability to zero out almost all stray inductance and capacitance, which isn't possible with the Snapino/Uno capacitance meter, but we're still well within a nominal plus/minus tolerance range.

Note: Some readers may be wondering why no external series resistor is used. Well, that's because it's already built inside the microcontroller chip with each programmable pin having one that can be switched in/out using code.

Experimenting with Gimmicks

Here're few ideas to help get you started:

1. Try making both a loose and tight twist gimmicks.
2. Lightly touch the gimmick with your fingers while watching the serial plotter results and note any change.
3. Do right-hand and left-hand twists change the capacitance?
4. Alter the shape of the gimmick. Put a 90 degree bend in the middle and see what happens.
5. Trim the gimmick in small increments to see how this affects capacitance.

igure 7: LCR Meter and Gimmick Capacitor
I measured the same gimmick capacitor with my LCR meter and there's only a +0.1 pF capacitance difference (+4%) between the LCR and Snapino capacitance meter. Depending on their cost, design and where they are used, most mass produced commercial capacitors can have tolerances ranging from +/- 0.1% to +/-20%.

6. If you have a larger and/or small gauges of insulated copper wire make a few gimmicks of the same lengths and compare the results.
7. Does stranded wire of the same gauge and insulation produced the same gimmick results as solid wire does?

8. Try using enamelled magnet wire and repeat the experiments to see if there're any differences.
9. If you have scrap lengths of coaxial cable (50 or 75 ohm) handy, cut them to 50 millimetre lengths and measure their gimmick capacitances (Hint: Solder a short solid #22 copper wire to the coax shield so it can fit the your Snapino's or your Uno's pin (A0 or A2).

My Final

Over this past year (2023), I've become quite the adult fan of Elenco's Snap Circuits kits covering various areas of science, technology, engineering, arts and science ("STEAM"). There's something about their sizes, three dimensional shapes and colours that stimulates your mind in different ways than more conventional teaching methods do (at least in my case). And I no longer wonder why so many adult fans of LEGO (AFOLs) "play" with LEGO Bricks, which you can also interface into Snap Circuits and vice versa!—73

References and Resources

Capacitor Tau/Time Constant Calculator https://rb.gy/1ufac

Elenco Manuals https://elenco.com/manuals

Gimmick Capacitors https://rb.gy/u7s90

Maker's Space Series Part 1: Introducing Snap Circuits Jr., Snapino and Careers in Electronics https://rb.gy/3vkqp