SAINTCON 2022
Hardware Hacking Community

Analog Circuits Learning Workbook

Introduction

Hello!

The goal of this set of mini-badges is to allow you to learn something about analog circuits. I feel that analog circuits tend to be overlooked these days of Arduino-this, Raspberry Pi-that. Sometimes going back to the basics can help you combine with the new fancy-pants digital circuits to make something truly special.

I invite you to get a kit from the HHC and get started - or at least read through this workbook and perhaps learn something new.

Thanks, and I hope you enjoy!

-hamster

Assembly Instructions
github.com/hamster/SAINTCON

Reading Schematics

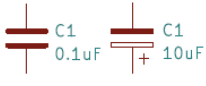
These are power symbols.
3.3v is plus, or positive.
GND is ground, or negative.

Note that the symbols have a letter and a number.
The letter is the type of component. This is a Resistor.
The number is uniquely identify the part on the schematic.
Together, this is called the 'Reference Designator' or 'RefDes'.
Sometimes a component value is present as well.

This is a resistor. A resistor impedes the flow of electricity
They are measured in 'ohms'.
Values less than 1000 usually have an R at the end to help denote less than 1000.

This is a special resistor that is variable. You twist a knob to change the value.
Terminals 1 and 3 measure 50k ohms on this one, and are constant.
Terminal 2 is a wiper that moves along the fixed part.
As you twist the knob, resistance at 1–2 goes in one direction,
and resistance at 2–3 goes to the other direction.

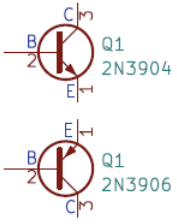
This special resistor is also variable.
However, the resistance across it varies as the amount of light it 'sees' changes.
Shine more light, and the resistance goes down.



These are capacitors. A capacitor stores energy and smooths changes in voltage.
Some capacitors have a polarity. They are 'polarized'.
Connecting a polarized capacitor backwards can damage them.

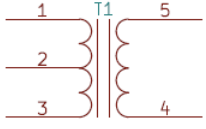
This is a LED, or Light Emitting Diode.
It converts electricity into light.
Note that has a polarity and will only light in one direction.

Reading Schematics



This is a transistor. It allows a very small current to 'switch' a much larger current.
The transistor is the cornerstone of our modern electronics.
These bi-polar transistors are two different kinds, NPN and PNP
The 2N3904 is a NPN. An easy way to remember this is 'Not Pointing In'
The 2N3906 is a PNP.
The P and N refer to the layers inside the transitor. An N is negatively doped.
A P is positively doped.
The 3 terminals of a transistor are the Base, Collector and Emitter.

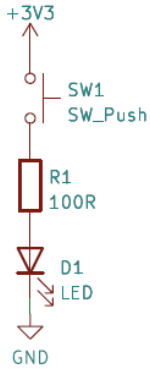
These are switches. A switch interrupts the flow of current.
The one on the left is a 'push button', it will open when you let go.
This is called 'Normally Open' or 'NO'
The other switch latches closed or open. It has a single 'pole'.
It is a 'Single Pole, Single Throw', SPST.



This is a transformer. It transforms the magnitude of the signal from the 'primary' to the 'secondary' winding.
The voltages at the two sides are magnetically coupled. They are not directly coupled.
This is called 'galvantic isolation'.

This is a speaker. It converts an alternating voltage into sound.
A thin membrane is wrapped with a magnetic coil, and the magnetic field moves the coil.
The moving membrane pushes air to make sound.

Reading Schematics

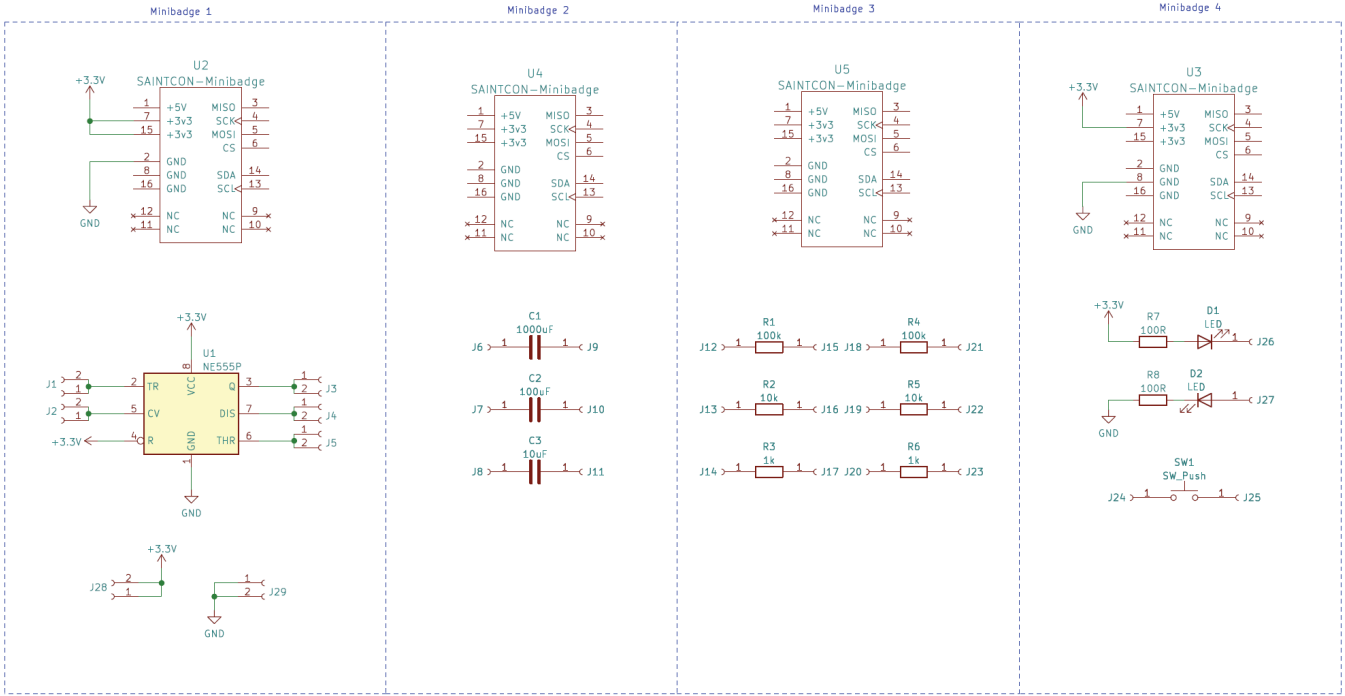


Let's look at a schematic. It is a visual diagram that shows how a circuit is wired.
To wire this circuit up, you simply use wires to replicate the lines.

Lines that have a dot indicate they are tied together.

Lines that cross without a dot are not connected. Be careful of this!

Minibadge Schematics



Special Notes

Note from the minibadge schematics on the previous page that we've pre-wired some items for you. This means in the following projects, you won't have to wire up some parts of the circuit. We'll indicate where this is happening with a note.

We highly suggest that you turn off your badge when wiring up a circuit. It is possible to short out your badge if you are not careful. Carefully evaluate that you have wired it properly before turning your badge back on. If your badge won't turn on, turn it off and check your wiring again!

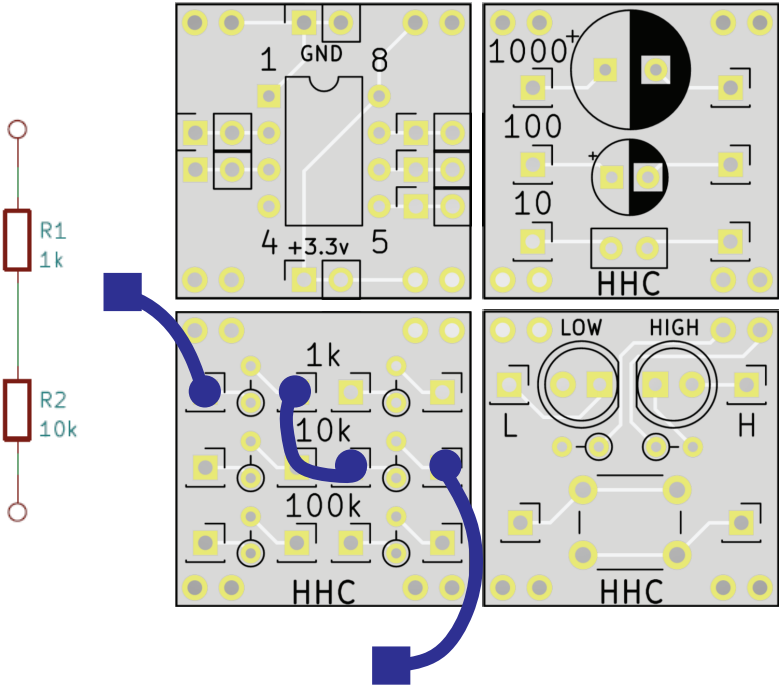
If you have minibadge sockets that are being turned on and off by the main badge, you may have issues with the following circuits. There will likely be an update at SAINTCON if there is an issue. Follow @hamster on Twitter or come by the HHC for any errata or check the github repo.

Series Wiring

When two devices are connected one after the other, it is said they are wired in series.

With resistors, series wiring means that the total resistance is added together. Get a multimeter and measure the resistance in the circuit. It should be about 11k ohms.

What happens if you change the resistor you have wired up?



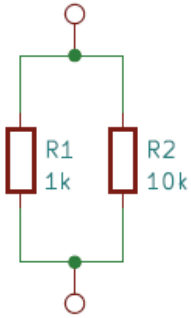
Note: the square denotes a floating wire

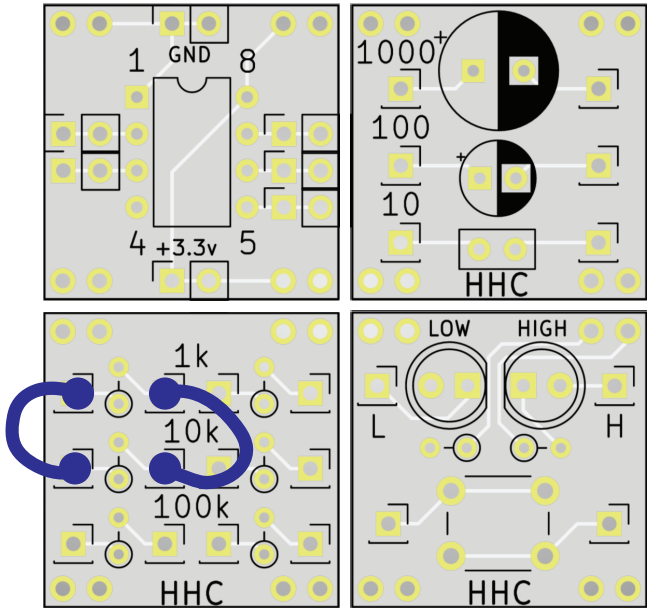
Parallel Wiring

When two devices are connected across each other, the circuit is said to be wired in parallel. When resistors are in parallel, something special happens: the total resistance is less than the resistance of one of the resistors by itself.

There is a special formula for calculating the resistance. What happens to the value if you change the resistors? Can you get a resistance of 50k ohms?

$$R_T = \frac{1}{(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + etc...)}$$





Note: you will have to measure to the sockets since we did not give you a spare socket for a floating wire

Light the LED

The first circuit is really simple. Light the LED!

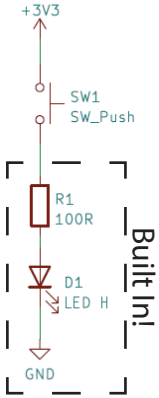
Wire up the circuit as shown.

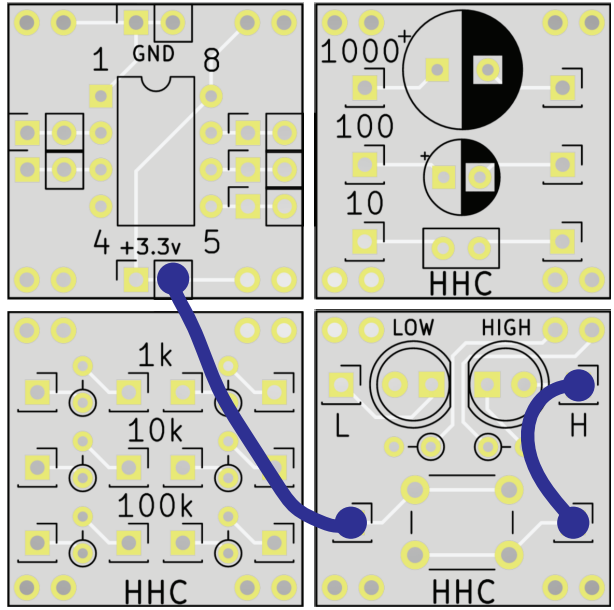
Then, press the button.

What happens to the H LED when you press the button?

What happens if you connect the L LED instead?

What if you also move the switch to GND?



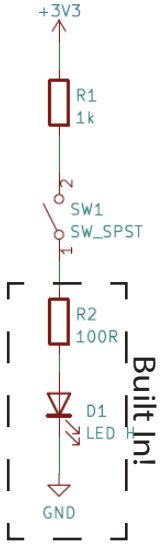


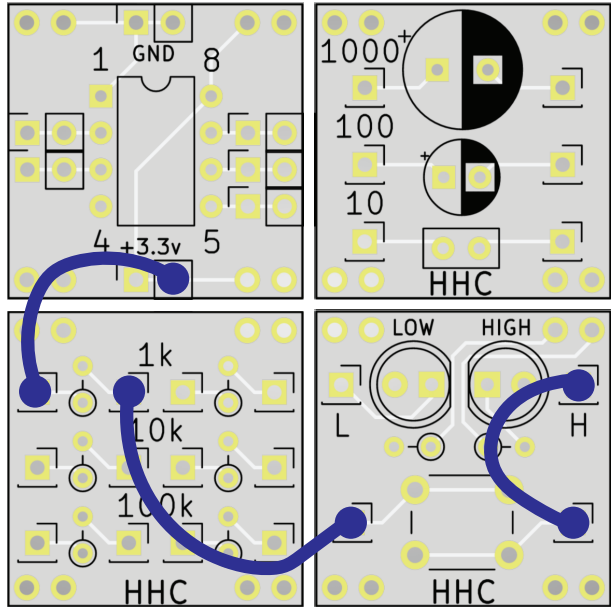
LEDs and Resistors

A resistor impedes the flow of current. You can use an LED to control thr brightness of an LED.

LED circuits typically require a resistor. This resistor limits the amount of current the LED gets so that the LED does not burn out. In our case, the 100 ohm resistor is that current limiting resistor.

What happens if you use a larger value resistor in this circuit?



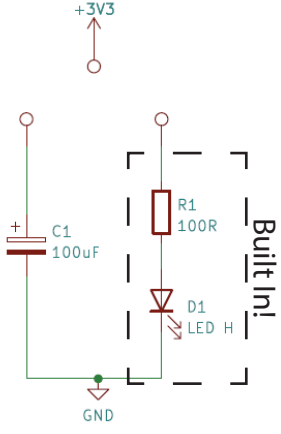


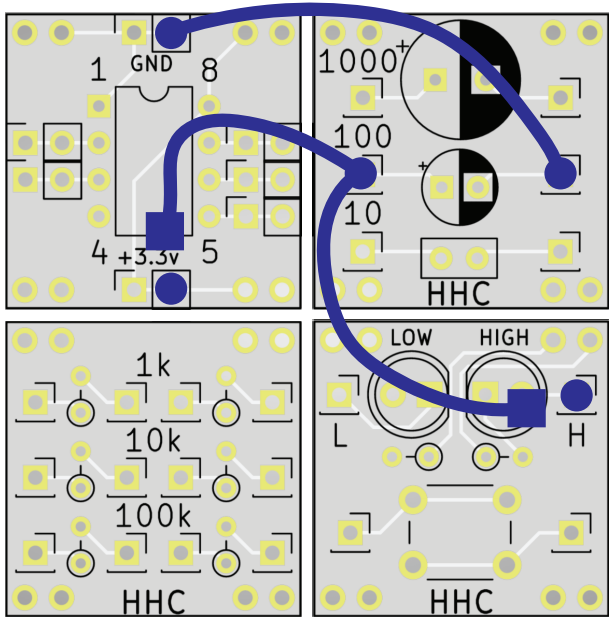
Capacitors

A capacitor is like a storage tank of energy. And just like a tank, you have to fill it.

In this circuit, connect one side of the cap to ground, and then connect a wire to the other side of the cap. Touch this floating wire to +3.3v for a short while. Then touch the wire to the H LED. What happens?

The time it takes to fill a capacitor to 63% full is called the Time Constant. Try using different caps. How long do the LEDs stay lit? What if you add another resistor in series with the capacitor?





Note: the square denotes a floating wire

The 555 Timer

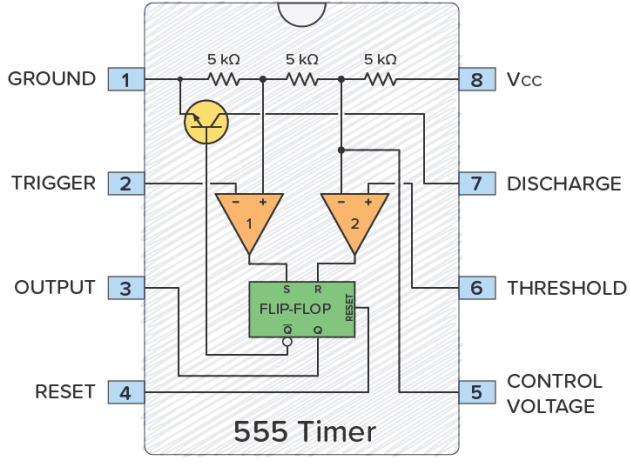
The 555 timer is a special little chip that came out 1971. This little circuit makes use of RC (resistor-capacitor) time constants to allow you to make all kinds of little timing functions.

In astable mode the chip produces regular pulses. This can be used as a 'function generator' to produce square waves with a specific on and off time. Both the on and off times can be set.

In monostable mode the chip will produce single pulses of a specific length. This can be used for 'pulse stretching', to make very short triggers last longer.

You can even use the chip as a flip-flop, though that's for you to find out on your own.

We've pre-wired the Vcc, GND and RESET signals for you.



The 555: Astable Mode

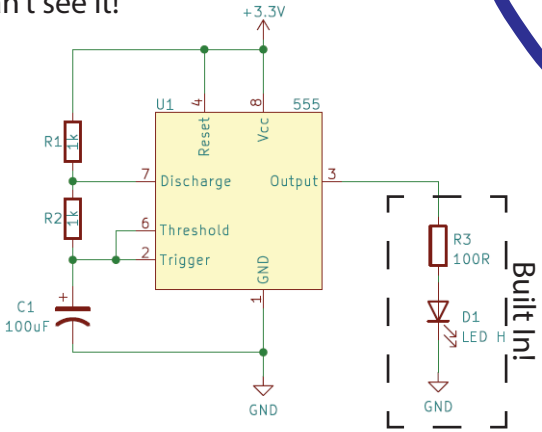
In astable mode, the chip produces pulses, like this:

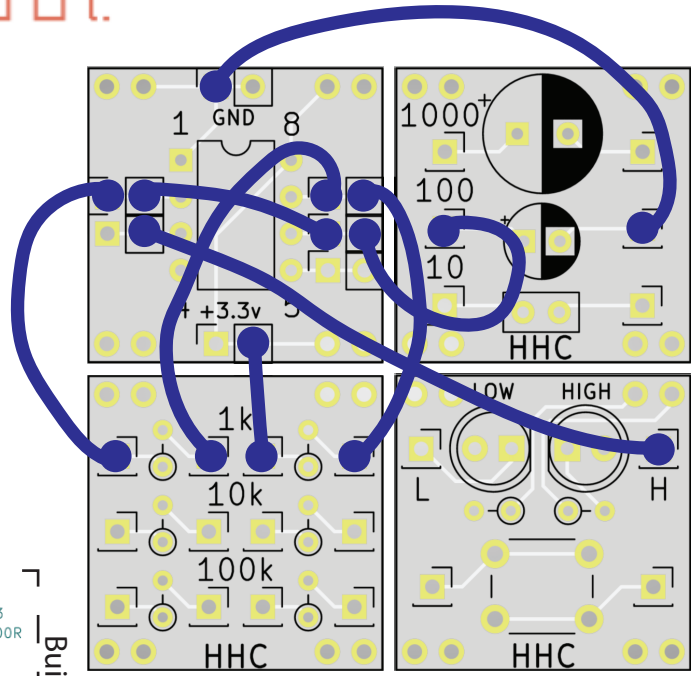
Wire up the circuit as shown. What happens to the LED?

What happens if you change the value of the resistors? What if you use the L LED instead? What if you use both the L and H LEDs?

Note that some values make the LED look like it is on constantly. In reality, you've just picked a mode that is toggling so fast you can't see it!

Find an online 555 calculator to dial in specific timing.





Further Learning

The 555 supports other modes of operation. Can you find a way to configure your badge in a different mode?

What other circuits can you make with your minibadges?

We hope you had fun and learned something interesting!