DIY Synthesiser Workshop

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This workshop is a crash-course in creating sound-making electronics! We're going to use some inexpensive parts to make some insane, noisy synthesisers and think about some ways to use them in performances.

The key parts we're using are two integrated circuits (ICs) which are (big versions of) some of the building blocks of computers. In digital electronics, signals are either on ("high" or connected to positive voltage) or off ("low" or connected to ground or 0 volts). One IC contains inverters or NOT-gates that output the opposite of their input (so high becomes low). The other contains NAND-gates which have two inputs and are only high if both inputs are low. Both of these elements can be easily used to make circuits that oscillate (go from high to low and back) at audio frequencies. Connect the oscillating signal to a speaker and BAM you've got a synthesiser.

The cool part is that with one chip we can make not one but SIX inverter synth voices and the other can make four voices of NAND oscillators. By mixing the voices together or using them to control each other we can make some very interesting sonic results.

Each kit contains a project box, battery and some parts. We'll do a few experiments together to figure out the possibilities of these parts but at the end of the workshop, you'll have a hackable synthesiser built into the project box ready for your next experimental music session.

Schedule

- 10am: General Electronics, Making a Sound
  - Making circuits on a breadboard
  - A one oscillator synth
  - Making a volume control
  - Controlling Pitch
- 11:15am: Coffee!
- 11:30am: Making a CD40106 Synthesiser
  - Controlling Pitch with light sensors
  - Mixing signals

- 1pm: Lunch!
- 2pm: Oscillators that Control Oscillators
  - Sound with the CD4093
  - Making rhythms with a Low Frequency Oscillator
- 3pm: Make a personalised instrument
  - Combine parts from the day to make a personal instrument
  - Make a custom prototype enclosure from cardboard and plastic containers.
- 4:30pm: Mini-Concert
  - Play a solo or ensemble piece with your new instrument.

Parts in your DIY Synth Kit

- breadboard
- 9V battery
- 9V battery lead
- strip of header pins
- alligator clips
- jumper leads
- 40106 - hex inverter IC (one little chip)
- CD4093 - quad nand gate IC (other little chip)
- Potentiometers: 10KOhm, 100KOhm, 1MOhm (knobs)
- Light Dependent Resistors (LDR)

Other Parts available to take

- bunch of resistors (esp. 1K, 10K, 100K)
- bunch of diodes
- extra LDRs
- extra potentiometers
- breadboard wire (thin solid core wire for making breadboard connections)

Tools available

- soldering irons
- pliers
- wire cutters
- mini speakers

Parts we need

Battery

We're all familiar with batteries - they store electrical power and when you connect the + terminal to the - terminal electrical current will flow between the two terminals until the power in the battery is consumed. 9V batteries are convenient because they're small and have a lot of volts (useful for powering complicated circuits) - but they don't have a high capacity so they can't supply a high current for a long time.

(In contrast, AA batteries have much higher capacities, but can only supply 1.5V each, so devices typically use more than one.)

Resistors

Resistors slow down the flow of electrical current. If you connect the + and - terminals of a 9V battery you might find that the wire will quickly get too hot to touch - too much current is flowing, which causes the metal to heat up, and the battery to run down quickly.

Resistors are used for slowing down electrical current in circuits. Some reasons to do this are: so that other components aren't damaged by excessive current, so we don't run down batteries too quickly!

Two resistors can also form a simple circuit called a voltage divider that converts from a high to lower voltage. And we can also use resistors to create a simple mixer! They're all around good guys.

Resistance is measured in Ohms and you can find out the value of a resistor by decoding the coloured bands or by measuring it with a multimeter. 1Ohm is a very small amount of resistance, so we usually use resistors with values between a few hundred and a few hundred thousand Ohms. For making our synthesisers it usually doesn't matter *exactly* what value the resistors are, so I've got a huge number of 1kOhm, 10kOhm and 100kOhm resistors to use!

Capacitors

Capacitors are like little rechargeable batteries. They've got lots of uses in electronics, but they're a key component in the synthesisers we're going to make. Capacitors are measured by how much charge they can contain, a value in Farads. 1F is a huge amount, so we usually see caps that contain between 0.1uF and 220uF that is millionths of a Farad!

Higher valued capacitors have a + and - terminal and need to go in the right way. These ones are usually little tubes and have a big arrow on the side with minus signs. Little caps sometimes look like little yellow discs or blobs and it doesn't matter which way you put them in. The tube caps usually have a marked value, while the little ones use a code. “104” is a common type, which means 0.1uF.

Capacitors are also useful for filtering signals - removing high or low frequencies so that we can focus on a particular part of the sound.

Potentiometers, LDRs

Potentiometers and LDRs (Light Dependent Resistor) are both resistors that change their value. Potentiometers change when you turn the knob and LDRs change when they are exposed to more or less light.

LDRs are easy to deal with because they have two leads - just like a regular resistor. Potentiometers can be confusing because they have three leads. Inside the potentiometer there’s a long windy trace of resistive material connected to each of the outer leads, and the inner lead is connected to a bit of metal that brushes over this trace as you turn the potentiometer. So as you turn, the connection between one of the outer and the middle leads increase resistance, while the other decreases.

Integrated Circuits

Little black caterpillers with 14 legs. These guys will do the work in our synthesisers! These devices are electronic swiches with inputs and outputs. On the “inverter” if the input is on, the output is off and vice versa. On the NAND gate, there are two inputs and one output, the output is only on if both inputs are off. Both of the chips actually contains several of these switches, there are six inverters and four NAND gates on each.

ICs always need to be powered before they can be used. On both of these pin 14 is connected to +ve and pin 7 (diagonally opposite) is connected to -ve.

Project 0 - set up the breadboard

The breadboard has lots of little holes to plug in components. They’re connected in a fairly simple pattern (see below). The long connections at the top and bottom are designed for the + and - connections of the battery (you would normally connect these to several places in a circuit). The slot in the middle is for ICs to sit.

As a first step, lets connect the battery snap to one side of the breadboard and then use some jumper wires to connect the power rails on both sides togther.

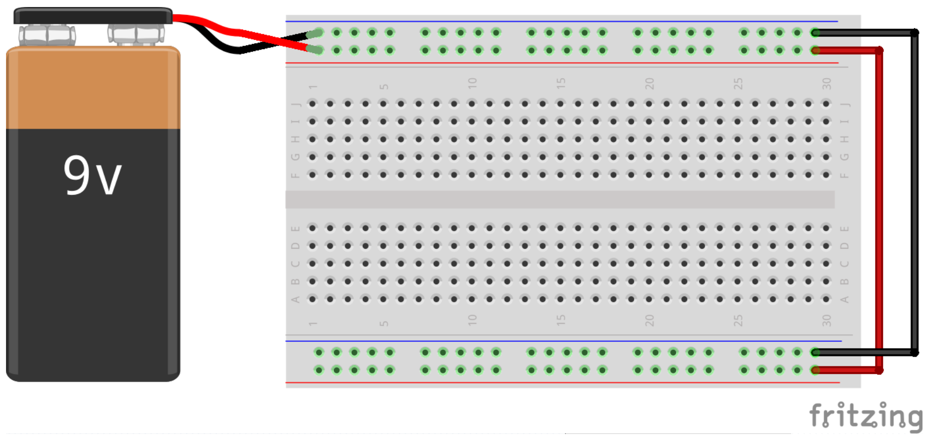

Figure 1: The breadboard ready for circuits!

Project 1 - making one inverter-oscillator

Let's get started by making one sound. We'll use the 40106 hex-inverter. Put it in the middle of the breadboard and use a jumper to connect pin 14 to the + rail and pin 7 to the - rail. Each inverter-section of this chip has one input and one output. If the input has a high voltage, the output is low and a low input results in a high voltage. Our circuit will connect the output to the input in such a way that the voltage on the output continues to oscillate from high to low - if we connect this signal to a speaker, we will hear the change as sound.

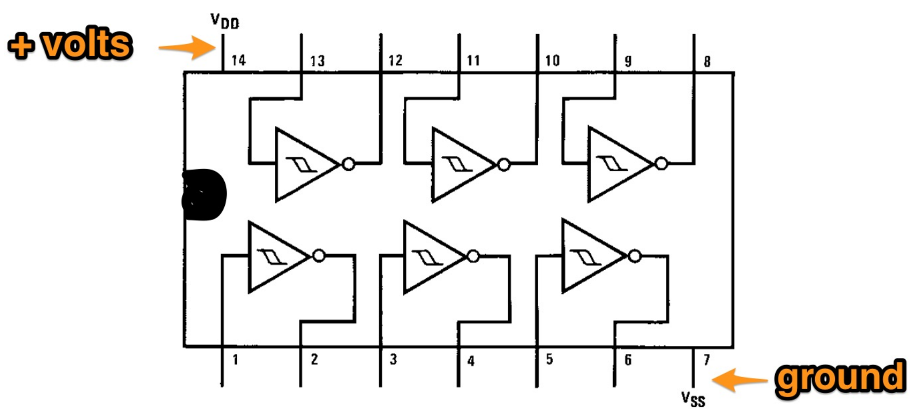

Figure 2: Diagram of the CD40106 hex-inverter

Grab a resistor and a capacitor and connect like so:

Now, get some alligator clips and connect them to a speaker, and we can probe around to find the sound. Connect the ground to ground and the speaker input

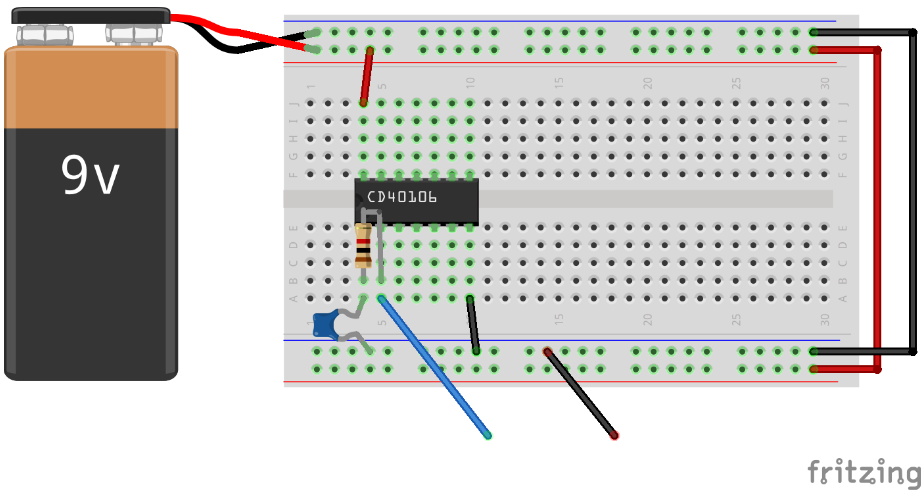

Figure 3: Breadboard layout for one oscillator. The blue wire connects to the signal part of the amp and the black wire connects to the ground.

to the leg of the IC connected to the resistor. In the diagram, the blue loose connection goes to the tip of the speaker plug and the black connection goes to the sleeve. Loud!

This little circuit relies on how long it takes to charge the capacitor for the frequency of the sound. Larger valued caps will charge more slowly (lower sound), and smaller valued resistors will allow more current through, charging them more quickly (higher sound). Try out some different capacitors and resistors!

Project 2 - controlling the volume

The output from the oscillator moves from 0-9V - way louder than a typical line output. This little circuit will change it to move from -0.5 - 0.5V - a much lower output. You can wire one of the 100K potentiometers as a volume control as well if you like. If your amp has a volume control, this probably isn't needed right now.

The example has two parts. First, the signal is sent through a 10uF electrolytic capacitor. This changes the signal from being 0V to 9V to -4.5V to 4.5V. That is, the changing signal moves around 0 instead of +4.5V. The second part is two resistors organised as a "voltage divider". This reduces the voltage to go between 0.5V and -0.5V which is a bit quieter than full-volume line level (i.e. still pretty loud).

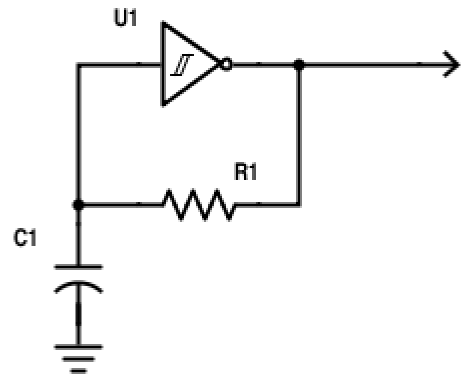

Figure 4: A circuit diagram of one oscillator showing just one section of the CD40106, a capacitor, and a resistor. The arrow made of lines means “earth”, which in this case is the negative side of the battery.

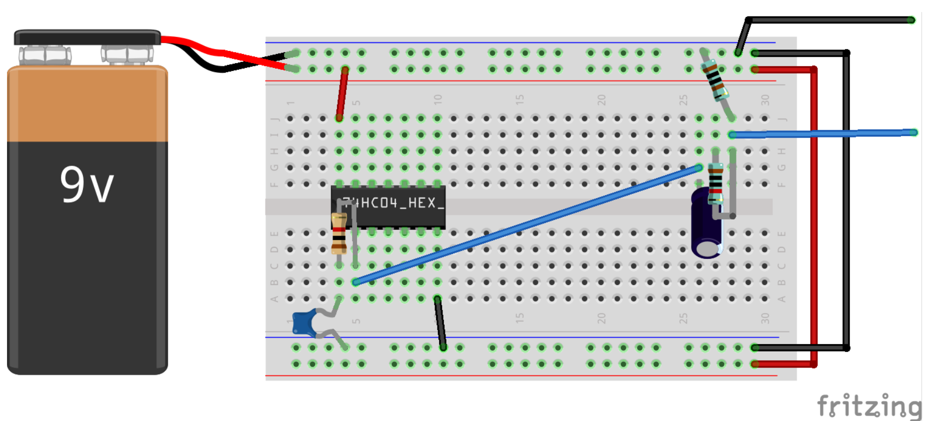

Figure 5: Adding a voltage divider and a coupling capacitor to lower the volume. Again, blue wire to signal, black wire to ground on the amp. You could also add a 100K potentiometer after the blue wire to make a volume control.

Project 3 - controlling the pitch

We've got two kinds of variable resistors - LDRs that change in react to light, and potentiometers. If you replace the resistor across the two pins of the IC with an LDR, you can use a shadow to change the pitch.

You can also use a potentiometer for this, you might want to attach some jumper wires to alligator clips so you can plug into the breadboard with one end and clip to the potentiometer legs with the other.

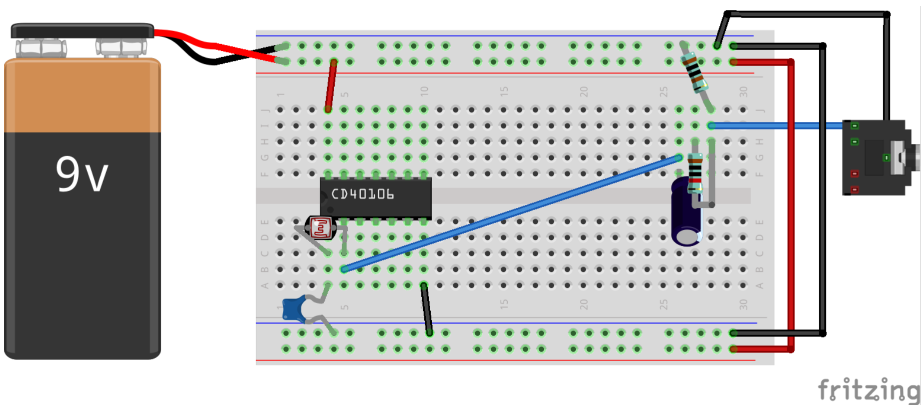

Figure 6: The light-dependent resistor will control the pitch. (A potentiometer will also work!) In this diagram, I've put in a headphone-style jack, but again, blue wire to signal, black wire to jack.

Project 4 - mixing synths together

The "hex-inverter" has six not-gates on one chip, so you can have up to six oscillators working together. To mix these oscillators, just put a 10K resistor between each output and the main output on the breadboard. This is a typical design for a simple passive mixer and is very useful for lots of applications!

You can also mix oscillators with diodes and one resistor arranged as follows. In this circuit, the audio signals can interact in an interesting way, blocking each other. Try mixing some super slow oscillators with normal sounding ones.

Project 5 - a NAND synth

Now let's try some experiments with the other IC. The CD4093 contains four NAND gates - short for the Boolean logical operator "not-and" or in english, "neither". You can see how the gates are arranged in the connection diagram,

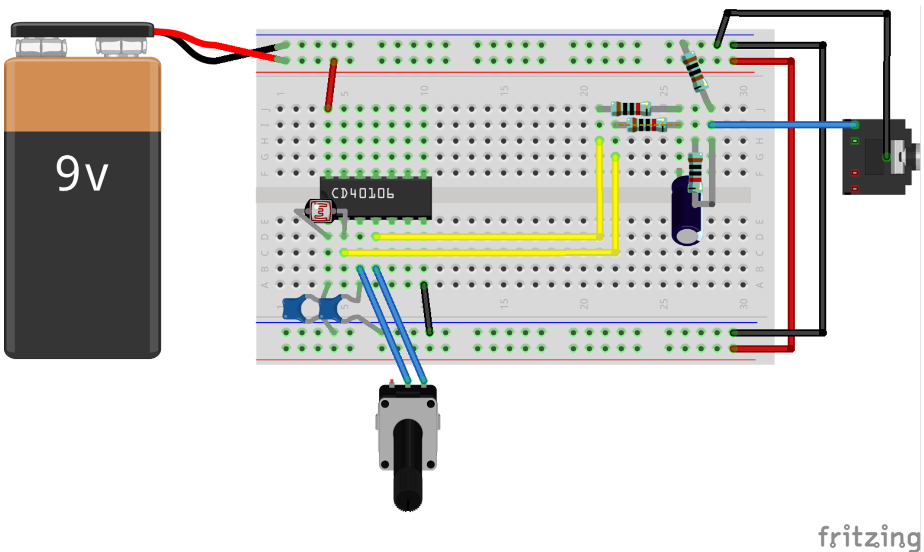

Figure 7: Using two resistors to mix the outputs of two oscillators.

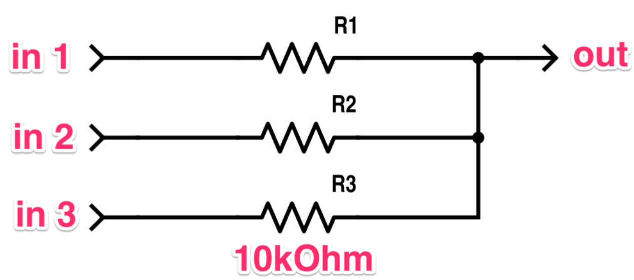

Figure 8: Circuit diagram for a passive mixer. Using 10kOhm resistors would be a good choice, many kinds will work, but if the values are different, the voices will be different volumes.

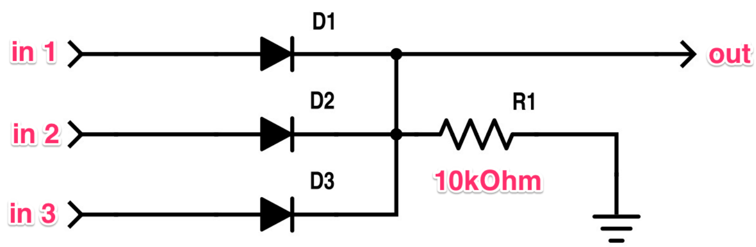

Figure 9: Mixing with diodes - the signals interact and block each other (sounds cool!) Use a 10kOhm resistor between the output point and ground. Diodes are one-way devices, the little black stripe on the diode should point towards the output (the direction of the arrow in the diagram).

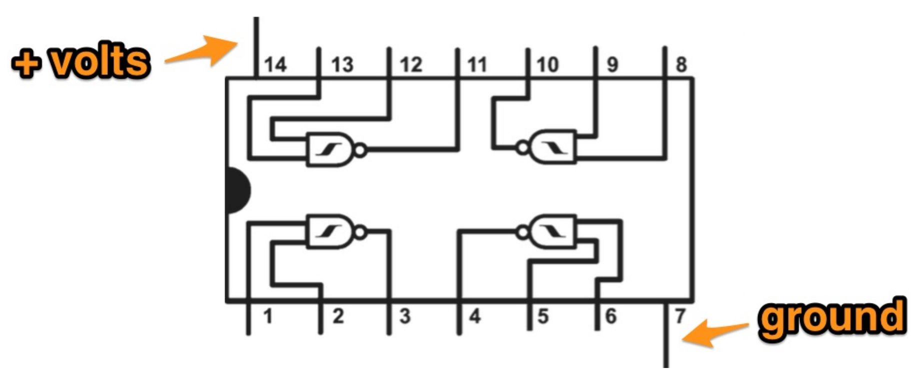

Figure 10: The connections for the CD4093 - note that the gates on each side are mirror images of each other.

each has one output and two inputs. For each gate, the output is low only if BOTH inputs are high.

With this chip, we can make an oscillator that you can turn on and off without disconnecting the battery. The output is connected to one input as with the hex-inverter synth and the other input is either connected to ground (no sound) or the battery +ve rail (sound!).

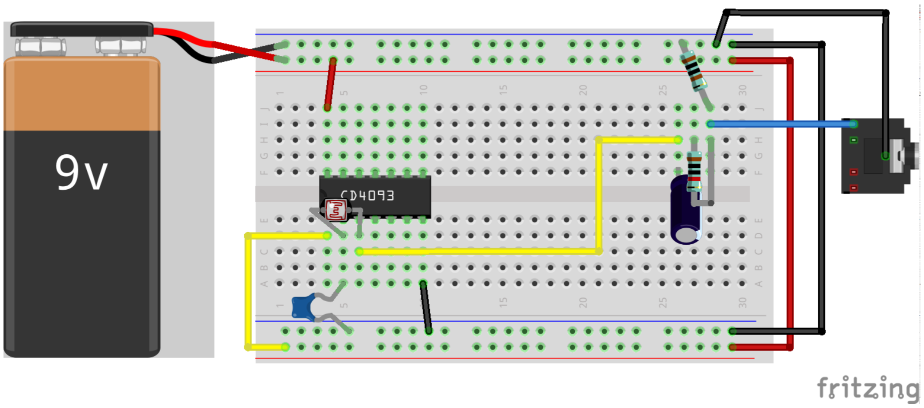

Figure 11: Building a basic oscillator with the CD4093 IC. If pin 1 of the IC is connected to +ve voltage, the oscillator will run, if it's connected to ground, it will stop.

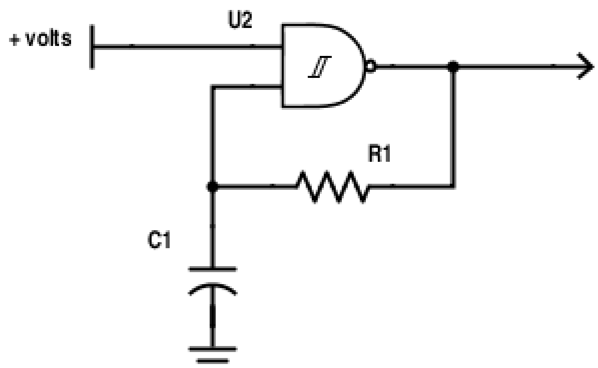

Figure 12: Circuit diagram of a NAND oscillator - this shows just one section of the CD4093 IC with a capacitor and resistor. The first input of the NAND gate can be used to turn the oscillation on and off.

Project 6 - oscillators that control oscillators

If we set up two oscillator circuits, we can control one of them with the output of the other. In the following circuit, the output of one is connected to the first input of the other. If the first oscillator is very slow, it will change from high to low in a simple on-off rhythm, which cause the other oscillator to play alternating notes and rests. If both oscillators are fairly fast, the sounds will interact and become complex and interesting!

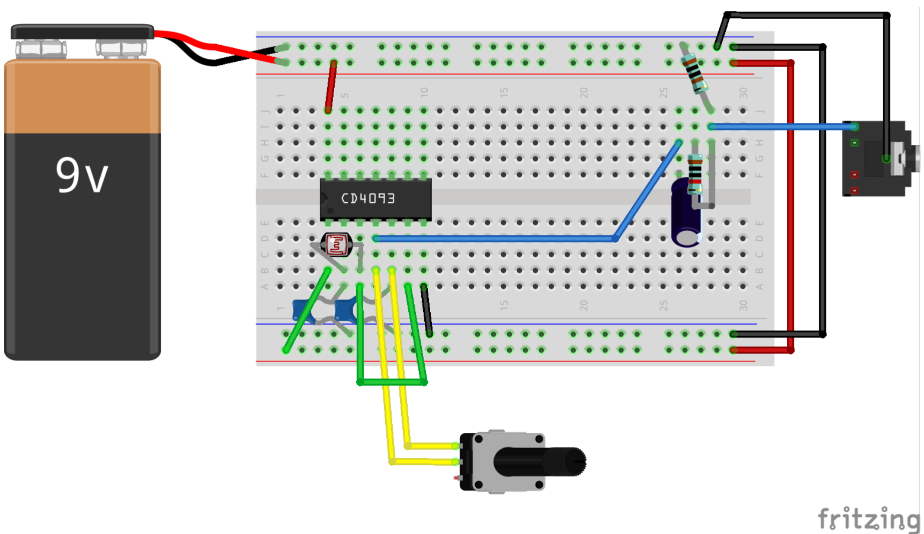

Figure 13: Using the output of one NAND oscillator to control the next. Use a big cap and resistor on the first oscillator in the chain to cause a rhythmic effect, if both oscillators are running at audio frequencies, it will have an interesting modulated sound.

With the CD4093, you can connect up to four oscillators in a chain for maximum fun. Or perhaps, you could have two groups of two for stereo effects or mixed with resistors or diodes.

Project 7 - putting together a unique synthesiser

Now you've gotten the hang of a few basic synthesise components: hex inverter oscillators, NAND oscillators, mixing, LDRs and potentiometers.

Now's the time to put together a unique instrument from these parts. For example, you might mix together a few oscillators with the same controllers (all pots or all LDRs) but different capacitors - the result will be different frequency ranges!

Project 8 - getting it all into a project box

Once you've got a synthesiser that you would like to work with, it's a good idea to get it into some kind of case to keep it together in performance. There's lots of options for "professional" enclosures, repurposing boxes or cases, or manufacturing new cases with laser-cutter, 3D printers and other techniques. It's worth trying out a simple prototype in cardboard or with tupperware first just to figure out what will work.

Similarly, once you have a circuit you like, it's a good idea to solder it onto a prototype board, rather than using up a breadboard.

Resources for further exploration:

- Nicolas Collins ([http://www.nicolascollins.com]) has a great book called "Handmade Electronic Music: The Art of Hardware Hacking". It's the basis of a lot of this workshop and well worth the price.
- If you're cheap, the class notes that preceded "Hardware Hacking" is available on Collins' website.. Check these out for the basics, and for the helpful lists of required parts.
- There's a series of articles on Hackaday about DIY Synths called "Logic Noise".
- There's a famous DIY synth called the "Atari Punk Console" that uses two 555 timer ICs (or one 556 dual timer). Easy to put together and lots of crazy sounds!
- Just go search on Youtube for "NAND Synth" or "555 Timer Synth"
- There's series of Youtube videos called "Collin's Lab" made by Collin Cunningham and published by Make Magazine and then Adafruit, these feature some general electronics but also a few musical projects.
- If you're hungry for more electronics videos try "The Ben Heck Show" or "EEVBlog", both on Youtube.

Buying more parts for MORE synthesisers:

- Jaycar is the only big store left, there's one in Fyshwick and Belconnen. They have a decent range, but some things are weirdly expensive and all ICs are held behind the desk which is tedious to ask for.
- Core Electronics is a decent Australian online store for parts (based in Newcastle). Good multi-packs of capacitors and resistors. They resell Sparkfun boards and parts as well as knockoff Arduinos etc from China but are more convenient than ordering from the USA or Ebay.
- Element 14 is a huge online electronics store. The search mechanism is daunting and you have to use a filter dialogue to find what you want. If you order about $50, the shipping is free, many things show up overnight if it's in stock in Australia, otherwise it takes about a week.

- Ebay is a great source for super-cheap parts from China. The shipping is slow and quality can be a bit dodgy, but there's bargains to be had.

Academic Resources

Doing a 3rd Year/Honours/Masters project using electronic music? There's lot of great work out there to check out and cite, and lots of opportunitites to publish as well.

- NIME (New Interfaces for Musical Expression) is a great modern conference covering all kinds of sound/music hacking. The proceedings are available online for free and it's in Brisbane next year. You should definitely show up.
- Computer Music Journal
- Organised Sound
- Leonardo Music Journal