Circuit Bending 101

A comprehensive guide for electronic modification

Dec. 13, 2018 – Design for Journalist – Professor Jason Das

Ben B. Burge

The Historical Context of Circuit Bending

"The creation of something new is not accomplished by the intellect but by the play instinct acting from inner necessity. The creative mind plays with the objects it loves."

- Carl Jung

Electronic instruments have become largely accepted in almost all modern genre of music. Primarily used to simulate real instruments: strings, horns, pianos, sometimes you may not even realize you're listening to a synthesizer! Too, we've come to celebrate synths for their unique musical properties, and otherwise impossible sounds. Early electronic music equipment paved the road for its own genre, leading artists to create new sounds and styles. Sounds and styles still being iterated to this day.

In the '60s, analog synthesizers could cost as much as a car, and were almost as big. These complex and complicated rigs appealed to a pretty slim audience, and never quite saw mass production. Still, these new sounds caught and inspired many musicians. See, synths may have first been embraced to replace traditional instruments, but more and more as musicians began to experiment, synthesizers were used to create strange and otherworldly sounds.

The 80s' digital revolution completely changed the electronic music scene. Circuitry grew dramatically smaller. The transistor replaced the need for clunky tube electronics, and overall, circuit boards became easier to manufacture. Analog synths were largely left in the past, as musicians and lay people alike moved to more reliable, less expensive, digital alternatives.

Digital devices were everywhere, despite many artists less than impressed by their performance. Sampling culture would gravitate back towards the analog devices of the '70s, seemingly rejecting digital tech, but the consumer market was hungry for affordable instruments.

One of my all time favorite albums, Ruth White's *Flowers of Evil* (1969), submerges classical and folk elements in a deep, sinister new electronic sound.

The circuit bending community grew out of mass produced electronic "student" standard and toy instruments laying around from the '80s and '90s. By modifying existing circuitry, circuit benders produce unique and often unintended sounds. By today's standards, these devices have relatively simple (and similar) designs, and can be found second hand cheaper than ever.

Circuit bending is a national phonenomon with dozens of dedicated fourms online documenting, exploring, and chatting about bending circuits. Whether used to make music, or simply to amuse, circuit bending offers an interesting repurposing of otherwise obsolete electronics.

Two Things + Tools

Circuit bending is largely about play. Tinkering, and trying. In fact, circuit bending as a culture has always embraced randomness and chance. It's part of the fun! Circuit design may seem complicated or intimidate you, but the best way to relieve that fear is diving in. We need not always completely understand what we're doing, or why it works-- but as we spend time inside electronics we discover we understand them better. What we understand better, we fear less.

Have you ever stuck your tongue to a nine volt battery? Keyboards, toys, and other low voltage devices do not have anywhere near enough power to harm us.

Important to note: I'll often reference toy keyboards, as with these I've had the most experience circuit bending, but by you should by no means feel restricted by the type of device you modify. The methods we'll explore have application for many electronic devices! There has always been a connection between circuit bending and music production, but this likely stems from audio being a common/simple output interface for circuits. For example, some circuit benders may use a screen to visualize their results, rather than listen to them. No matter what you're modifying, or how/which signals you interpret, you're taking a step towards a creative, ever expanding form of glitch art.

Tools

You'll need:

- **Drill/dremel**
- **Screw driver(s)**
- **Soldering iron + solder**
- **Wire strippers + wire**

Tools

That'd help:

- **Flux**
- **Multimeter**
- **Solder sucker**
- **Soldering wick**
- **Tray for screws**
- **Aligator clips**

Common Parts

Audio jacks
1/8" and 1/4" jacks are the most common. Learn to tell the difference between mono and stereo jacks. Aside from sending an audio signal, jacks can also be used for patch bays and external controllers/triggers.

Buttons
Many toy keyboards use soft buttons, which push a rubber spacer to a contact pad, which then passes currents to the board's logic circuits. Buttons differ from switches, in that they're momentary, only passing current when pressed. Most useful for effects you want fine control over, or entering temporary states.

Capacitors
Have two electrodes (legs) and stores electricity between them. Caps can be polar (they only flow one way) or non-polar (flow freely). Most polar caps are cylindrical, with symbols for negative and positive terminals. Non-polar caps are typically smaller, often round. A capacitor is constantly charging and depleting electricity across its plates.

Circuit board
This is the brown, green, yellow board in which all the components are attached. When handling be careful not to flex the board, as this could damage solder joints.

IC
Integrated circuit. A tiny black box that holds the device's logic. Made up of a bunch of transistors. In many toys this component is hidden in a blob of resin/plastic because it

Common Parts Cont.

is a cheaper than properly soldering it. ICs have a lot glitch potential, but the wrong pin in the wrong place could fry the chip.

Potentiometers
Variable resistors. A knob we can turn to change the resistance value. Typically, potentiometers have three electrodes: the two on either side will gain/lose voltage flow as the knob is turned.

Resistors
Have two electrodes and impede current. Resistors are designed to a specific values, which are coded in colored stripes along the element. Resistors come in different power ratings, but for low power applications even the lowest (1/8 W) rating will do us fine.

Switch
A switch differs from a button in that it toggles a state change. They're most useful for bends that you want to prolong, but can also be flipped rapidly to strange effect.

Transistors
Act as gates. A black component with three electrodes. Transistors have many different applications in circuits: logic and amplification both rely very heavily on transistors. There are many specific kind, but generally are either PNP and NPN type.

Dealing with Plastic

Opening Your Device

Clear an area to work on your device. No matter what you're working on, make sure your screwdriver has the right bit/bit size by testing its grip, to prevent screw stripping. Keep track of where your screws come from; I like to draw a diagram of my device on paper, and punch the screws through relative to where they go. Also consider taking pictures to keep track of the parts you remove.

Once you've unscrewed, slowly lift the back off from the front— be weary of any cables that connect the two sides. Most often the battery compartment will be on the back, with two wires connecting to the front. In fancy devices, ribbon cables may connect multiple boards. Usually these cables are long enough either side to sit on flush on the table, but if not, follow the cable to its end and find its connecting latch. Be gentle with these connections, and careful lining up pins when reconnecting.

Adding internal compoients

Before we talk about wiring, let's discuss adding interfaceable components to our keyboard. Buttons, potentiometers, and switches are all available in packages that mount through a hole. These are nice and easy to mount— simply drill a hole where you want your knob, switch, or button, slide the component through, then screw the washer and bolt over the hole. Old toy keyboards are notorious for big plastic cases with lots of room.

Be sure to plan and test your part placement before drilling holes. If you're short a drill, you could get away with a dremel. I've even seen people melt holes in their gear with soldering irons, but I highly discourage this.

Poking Around

It's very likely that once you get the back off, enough of the board will be exposed to start poking around. It's also very likely the boards themselves are screwed into to the front. Remove these screws using similar precaution. If your device has multiple boards, identify the one with the most visible components. If you have a keyboard, it's likely the same board that holds the contact pads for your keys. This is where the logic circuitry lives, and it's a great place to start poking around.

When poking around your circuit, it can be helpful to identify some constant sources. Start by locating your ground. Any trace that connects to the negative terminal of the battery is grounded. Often these traces are wide and take up a lot of area on the board. The ground makes a great line to compare voltages to. Follow the positive battery terminal wire, to where it connects on the board. Measure the voltage. This is the V+, likely ~3.7-5v.

Use these lines to experiment! For example, consider soldering one side of a wire to a ground contact, then tapping other contacts with the open side of this wire. How does this change the circuit's operation? How does it change the sound?

The goal now is finding interesting connections that enhance or create neat sounds. It may take some time to find something you like that is repeatable. Analyze the actions you're taking to produce an effect. Consider how you could implement components: do I want a button, or a switch connecting these junctions? Could I change the value of that resistor? What would happen if between these two points I put a solar cell?

Hard Restart

Particularly adventurous circuit benders may find themselves crashing their device often. This is usually harmless to the electronics, unless you find yourself need to remove the batteries after a crash. These situations can be stressful on our circuits. To best protect them, we want to be able to hard reset our device as quickly as we can.

By intercepting our battery's ground wire with a button, we can force our device to reset when we press it.

Make sure the button you use is designed to be normally closed (that is, current can flow through it). This way, when its pressed it severs the ground connection.

Warning Signs

While most noise is good, there are a few signs you're bending too hard! Avoid connections that cause any of the following:

- Sparks
- Speaker pops and hums
- Signs of surging (dimming lights, volume drop)
- Excess heat produced on the board

Adding an Audio Jack

The most obvious reason to add a headphone jack is that there isn't already one on your device. When recording, a tiny speaker doesn't always do our sound justice. Here are some options:

1. Wire a headphone jack in series with the speaker

Once you locate the speaker, solder a wire to both of its contacts on the board. You can attach the other end of these wires to a jack as is, but I recomend adding a resistor, or potentiometer, in between your jack and the speaker to control the volume. I also like to add a switch between one of the wires running to the speaker so I can toggle it on and off. For extra-credit, consider finding a jack with a "switching" feature built in. This switch will connect the speaker when no phones are plugged into it.

2. Wire a headphone jack from sound source

Sound quality can be diminished by old amplifiers in vintage devices. If your quest is for the sharpest sound possible, you may want to bypass these circuits. Bypassing the amp will lower the volume overall, but produce much less buzz. When searching for a unamplified signal, look near the volume potentiometers. This mod is often referred to as “Pro Sound.”

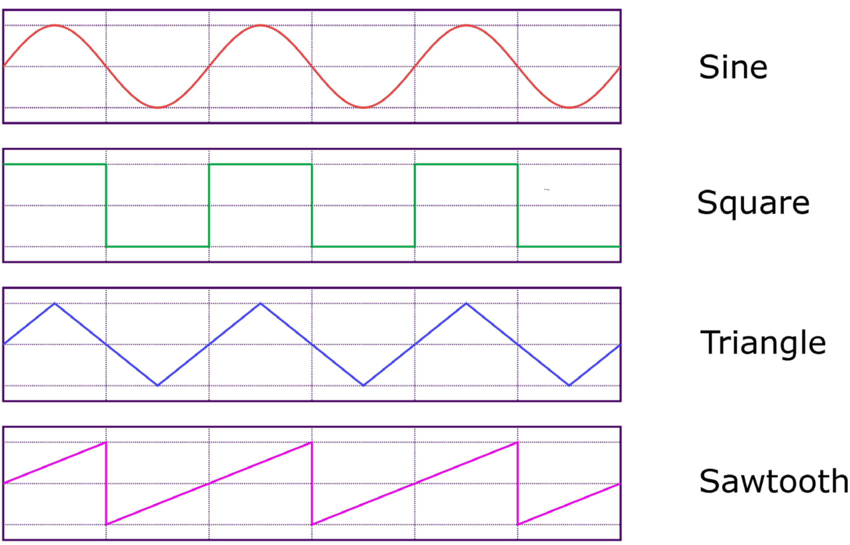
3. Creating patch bay sockets

A Patch bay is an arrays of input jacks that an be connected with standard audio cables. Maybe you’ve found a contact on your board that always gives interesting results. A Patch bay is an accessible way to modify your connections, even when the unit is closed (read: reasembled).

Oscillators

Though some instruments used electricity to produce music in the 18th century, these machines relied on traditional means for producing the sound. It was 1876, when working on a telephone setup, Elisha Gray accidently created the "Musical Telegraph" a contraption that harnessed electromagnets to vibrate steel reeds. Gray noticed he could control the output frequency by changing the voltage. In this way, the Musical Telegraph touched upon the discovery of electronic oscillation.

Oscillators create waveforms within a circuit. The signal is one of the four basic waves, shown below.



Older synths would have contained an oscillator for each voice-- that is, if a keyboard was "polyphonic" (can play more than one note at once) each note would be played on a single oscillator.

Digital circuitry relies on oscillators too, but in a different way. Oscillators build the foundation of a clock, using their waves to count along thousands of times a second, triggering the circuit's logic.

The two kinds of oscillators you'll encounter most while circuit bending are:

Crystal Oscillators

Tiny components made from quartz or other piezoelectric materials, tuned to specific frequencies. Renowned for consistency, crystals live for a metal oblong casing, and often have their frequency inscribed on top of the part.

Resistor-Capacitor Oscillators

A circuit that charges a capacitor at specific intervals. R-C oscillators are usually cheaper to produce, but don't inheitry have a fixed frequency like crystals. These are the most common oscillators for toys, and very easy to bend. The circuit may vary board to board, but almost always you'll find the resistor that controls the speed exposed, often near two transistors or a capacitor.

No matter the type of oscillator, the job is the same. It provides a stable timeline for the circuitry to map. Circuit designers intend for the oscillator to always run at a certain speed. For electronic instruments this is especially important, so that they are in tune with the standard 12 note chromatic scale.

Pitch Bend

Pitch Bending is a technique where were one modifies the oscillator, or injects a new clock pulse to run the circuit at unintended frequencies. By adjusting the values we can sweep our sounds up and down in frequency, crafting lower and higher pitched sounds. Typically this mod uses a potentiometer so that frequency can be adjusted on the fly. This means reaching new octaves, or bending notes played live, all by turning a knob.

You can think of oscillators operating this way like the engine in your car. The engine must be idling, so that when you're ready to drive, the car will move. When you step on the gas you're increasing the RPM of the engine-- raising its operating frequency-- the car will speed up. High performance engines are designed to live in these high frequencies, but go too fast and the engine may overheat. Inversely, you can slow down the RPM, but slow it down too much and you'll stall the vehicle.

Just as the engine has it limits within the confines of a car, so too does an oscillator within a circuit. Circuits can crash if run too fast, and can drop data if run too slow.

Each device is different. Play around with resistor values until you get it right. It's important to find values that keep your device *relitively* stable. Instability can sound cool, but is often unpredictable. With this in mind, I will recomend some good starting values for each pitch bend method.

R-C Oscillators

If your device has no crystal, its oscillator has its circuity exposed. This is great news! Your job is to find the resistor that controls the oscillator speed. It will be near, or connected to a capacitor. Make note of the resistor's value.

The Pitch Mod replaces this resistor with a potentiometer, but we can also add a switch, so that we can toggle between our potentiometer, and the original resistor. Make sure your switch is a Single Pole Double Throw switch so that we can use both positions!

Crystal Oscillators

Alright, you've got a crystal oscillator, maybe you're working on a GameBoy, or a decent keyboard. Unfortunately, the crystal is set to a specific frequency we have no way of changing. To change our speed we'll need to inject a new clock pulse. This calls for an external circuit.

For this bend, you'll need an LTC1799, a resistor, a capacitor, and your potentiometer-- also a switch if you'd like one! The LTC1799 only comes in a SMD (surface mount diode) package, which means it's really tiny! Consider buying a breakout board for the LTC.

If you'd like to add a switch, use a SPDT to toggle between the crystal and your clock output.

Dec. 13, 2018
Design for Journalist
Jason Das

For the wicked wave chart on page nine, I'd like to thank Wikipedia user: Omegatron. I moved the words, but all the line drawing was his.