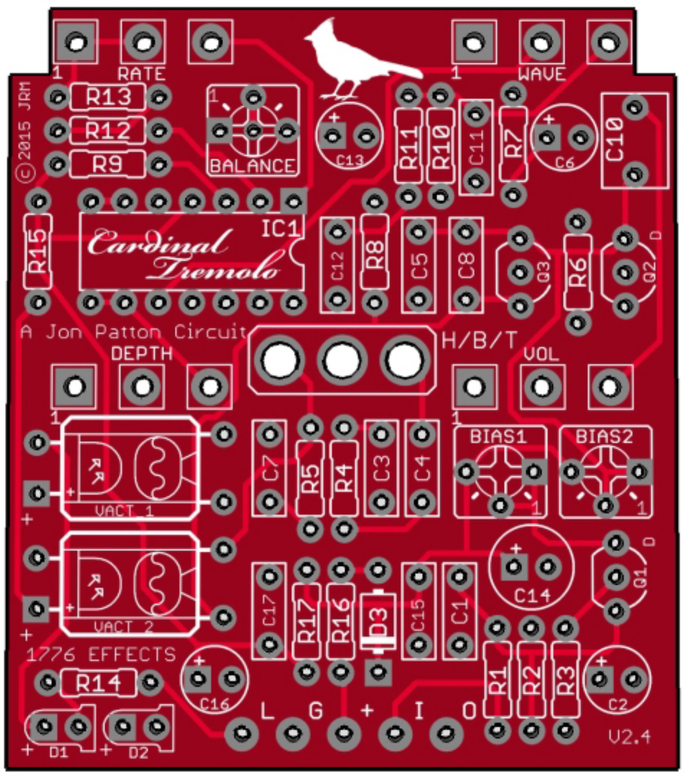
Cardinal Tremolo

PCB by 1776 Effects/JRM ©2015
Circuit Design by Jon Patton



The Cardinal Tremolo is a transistor and vactrol implementation of the Harmonic Tremolo. It resembles the harmonic tremolo from Fender's 1960-1963 amps; the Super, Pro, Twin, Showman, and Concert models.

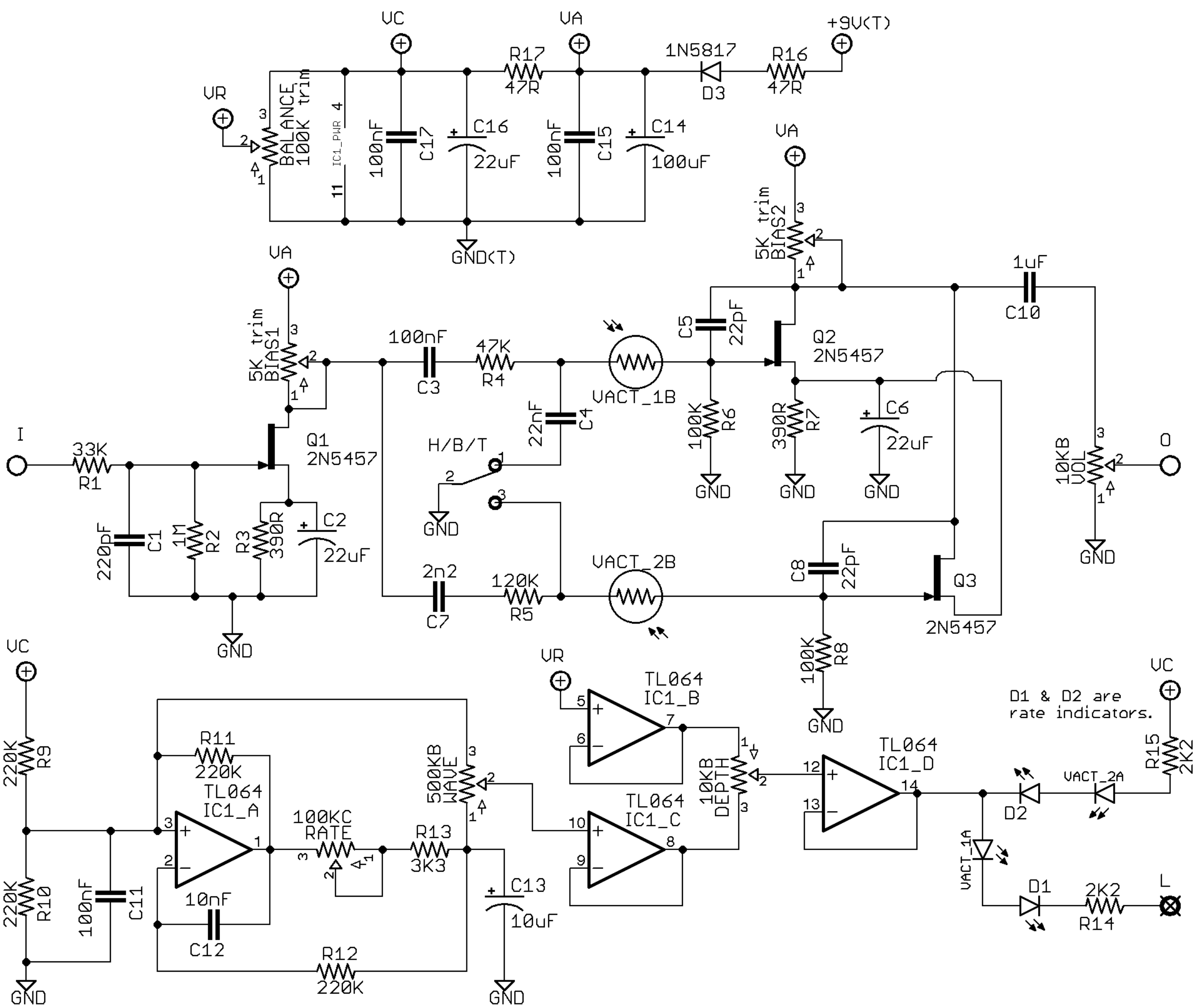
Thanks to Jon Patton for the circuit design. Jon also provided all the text and information in the build doc.

Parts List

Resistors				Capacitors		Diodes	
R1	33k	R12	220k	C1	220pf	D1-D2	3mm LED's
R2	1M	R13	3k3	C2	22uF	Red, orange, or yellow	
R3	390R	R14	2k2	C3	100nF	D3	1N5817
R4	47k	R15	2k2	C4	22nF	Transistors	
R5	120k	R16	47R	C5	22pF	Q1	2N5457
R6	100k	R17	47R	C6	22uF	Q2*	2N5457
R7	390R			C7	2n2	Q3*	2N5457
R8	100k			C8	22pF	Potentiometers	
R9	220k			C10	1uF	VOL	10kB
R10	220k			C11	100nF	WAVE	500kB
R11	220k			C12	10nF	DEPTH	10kB
				C13	10uF	RATE	100kC
Vactrols				C14	100uF	Trimmers	
VACT 1		VTL5C1		C15	100nF	BIAS 1	5K
VACT 2		VTL5C1		C16	22uF	BIAS 2	5K
Mode Switch				C17	100nF	BAL	100K**
SW1	SPDT	ON/ OFF/ ON		IC's		** Multi-turn recommended	
				IC1	TL064		

*Q2 and Q3 must be matched transistors

Schematic



VC
VA
+9V(T)
R17
47R
1N5817
D3
R16
47R
VR
BALANCE
100K trim
IC1_PWR
100nF
C17
C16
22uF
C15
C14
100uF
GND(T)
5K trim
BIAS2
1uF
C10
Q2
2N5457
BIAS1
100nF
C3
47K
R4
C5
22pF
VACT_1B
I
33K
R1
Q1
2N5457
22nF
C4
H/B/T
100K
R6
390R
R7
C6
22uF
10KB
VOL
O
GND
220pF
C1
1M
R2
R3
390R
C2
22uF
2n2
C7
120K
R5
VACT_2B
C8
Q3
2N5457
100K
R8
TL064
IC1_B
D1 & D2 are
rate indicators.
220K
R9
R11
220K
IC1_A
100KC
RATE
500KB
WAVE
R13
3K3
IC1_C
DEPTH
IC1_D
R15
2K2
VACT_2A
D2
R10
100nF
C11
10nF
C12
C13
10uF
VACT_1A
D1
R14
L
R12

About:

The Cardinal Harmonic Tremolo is a transistor and vactrol implementation of the tremolo effect found on Fender amps in the 1960s. It has a waveform control (for square and sine-ish waveforms), a switch to go between harmonic and normal tremolo modes, and a “bright” mode in the middle that modulates only the bass frequencies. The Harmonic mode is an unusual, and beautiful, combination of mild filtering and amplitude modulation with a very slight phase shift.

Version 1 of the Cardinal suffered from some finicky parts choices and low input headroom, making it difficult to achieve consistent results. Version 2 of the Cardinal features a re-designed dry path which is simpler than the original, with more headroom, a more balanced tone, and a newly-designed LFO that elegantly allows Version 2 to operate closer overall to the original amps.

Controls:

- The H/B/T toggle selects between harmonic (H), “bright” (B), and full-range (T) tremolo modes.
- The Rate control sets the speed of the effect.
- The Depth control sets the intensity of the effect.
- The Wave control alters the waveform. Counterclockwise the wave is a softened triangle and sounds more like a sine wave. Turned clockwise, the wave becomes more square. Harmonic mode has the most crossover on the sine wave side of the control. The full-range mode will have the most chop on the square wave side.
- Volume is the output level. There is a little bit of boost available.
- Internal trimpots:
    - Bias1 and Bias2 set the bias of Q1 and the Q2/Q3 differential pair.
    - Balance: This trimmer sets the reference voltage for the LFO and its setting affects the balance between the bass and treble bands when the depth is turned down in harmonic mode.

Notes & Mods

➤ **I recommend optical bypass with this effect.** This version of the PCB will fit with the 1776 Optotron in a 1590B.

➤ **The LED pad connects the cathode of D1 to ground to let the LED flash.** This can be wired to the footswitch where your bypass indicator's cathode would normally be wired, so you can use D1 as your bypass indicator, or you can connect the pad to ground to have both LEDs flashing all the time. If you are using the optical bypass, to wire D1 through the Optotron PCB when not using a separate bypass indicator, connect it to BOTH pads for the LED on the Optotron PCB.

➤ **Bias Q1-Q3 to 6V on the drains.** Alternatively, you can bias them to 4.5V for more output if you are omitting both C2 and C6 or if your FETs are lower gain than the 2N5457. Bias1 trim sets Q1. Bias2 sets Q2 and Q3.

➤ **Important: Q2 and Q3 must be MATCHED** so that they can be trimmed to the same voltage for correct harmonics and amplification. You want to find two 2N5457s that will bias to approximately 6V with the same amount of resistance on the drain. The final drain voltage will be set using the bias trim pots, so you don't need to worry about any other characteristics. The easiest thing to do is socket at least one of the transistors (or breadboard Q2, R5, R6, and use a 2.7K in place of the trimpot), set the trimpot to halfway, and measure the drain voltage. Then you simply have to swap transistors until you find any two that have the same drain voltage. Anything within a few tenths of a volt is fine. If you simply don't have access to enough FETs to match a pair closely enough, in a pinch you can adjust R7 (use a socket) to set the gain of the treble band.

➤ **If you are unable to obtain 2N5457s**, good substitutes are 2N5485, 2N5952, BF245A, or 2SK30. Be sure to check the pinout of any substitute transistors against the datasheet. J201s are not a good substitute without altering most of the parts as they will create a lot of distortion.

➤ **Important: Use the VTL5C1 for both vactrols.** I realize that these are more expensive than most other photocouplers and LDRs, but they this is the only photocoupler from which I was able to obtain an acceptable range of depth and which has a reaction time fast enough for the effect at higher rates.

➤ **How to balance the LEDs.** Matching: This step is not critical, but I highly recommend it to get the smoothest possible waveform. Similar to how you will need to match FETs for the ideal build, it is also a good idea to match the forward voltage of the pairs of LEDs in the LFO section. The VTL5C1 is fairly consistent, but there is still some inevitable variance. It would be prohibitively expensive to buy a lot of vactrols and match them. Fortunately, the LFO in this effect actually works best when you have an LED in series with the Vactrols' LEDs, and this provides a perfect opportunity to match the total forward voltage of the rate indicator LEDs (D1 and D2) PLUS the vactrol they are in series with. D1 and VACT_1 are one pair, and D2 and VACT_2 are the second pair. To match them, simply measure the LED forward voltage of each vactrol, and then find two red, orange, or yellow LEDs which will make up the difference between them. Example: If your vactrols' forward voltages measure 1.6V and 1.5V, find a pair of LEDs that measure 1.7 and 1.8V. You could then use the 1.6V VTL5C1 and a the 1.8V LED for VACT_1 and D1, and the 1.5V VTLC51 and 1.7V LED for VACT_2 and D2, respectively.

➤ **Setting the balance trim:** Regardless of whether you decide to match the LEDs, the next step for balancing the LEDs comes after the PCB is complete. The Balance trimpot sets the voltage reference for the op amp output of the LFO. The LEDs swing across this center point. At the highest depth settings this doesn't matter, the LEDs will swing fully between our 9V supply voltage and ground, but at lower depth settings and especially when the wave form is set to "sine wave," we want to maximize the amount of swing to keep the waveform smooth. **Set the depth to minimum and measure the resistance across the LDR side of each vactrol**. They will be a little different unless you are very lucky. For example: If the resistance across VACT_2's LDR is lower, that means that the balance needs to output a slightly lower bias voltage. This lower bias voltage will be translated by the op amp into a slightly higher voltage on pins 7 and 14. That higher voltage will dim the LED for VACT_2, which will raise the resistance of the LDR. There is a very, very small range where the LDRs will become perfectly balanced. Move the balance trim until the LDR's resistance matches closely. The PCB can accommodate a multi-turn trimpot and is recommended. If using a testing rig the L pad must be grounded to balance the vactrols.

➤ **The most important components for the harmonic effect are C4 and C7.** C4 forms the low-pass filter for the "bass" side of the effect. C7 forms the high pass filter for the "treble" side of the effect. The specified caps give my personal preference, after lots and lots of experimenting of the Brownface Twin's crossover frequencies (153Hz for the bass band and 723Hz for the treble band), but this is not necessarily what will sound best to you. If you want to experiment, you can use sockets for these two capacitors. I highly recommend soldering them once you have settled on their values or they might fall out. Ask me how I know.

➤ **C2 and C6 are optional.** These increase the gain of each stage, and in part are meant to imitate the tube stages in the preamp of the amplifiers. I generally omit C2 but I find that C6 is usually necessary especially with lower gain FETs to allow any boosted output in Harmonic mode. It also adds a little something extra. If you are using particularly low-gain FETs, you may need both.

➤ **C5 and C8 are optional.** These create a small treble cut in one or both audio bands, to mimic miller capacitance. I leave them out.

➤ **Higher voltage? Don't do it!** First, it's likely to have the opposite effect from what is intended. Running a FET higher voltage increases the available gain, but the headroom of a FET is limited by the device, not the supply voltage. While you could make modifications to the circuit to use lower-gain, higher-headroom FETs, there is another more important problem: The LFO will drive the LEDs harder, which will completely ruin the effect. The effect is created by the vactrols turning "off," so higher voltage makes for a shallower effect.

➤ **Alternate Bypass - as an amp sim/preamp!** You can zero out the depth to "bypass" the tremolo effect, to mimic hitting the tremolo switch on the amp. To do this, wire lug 3 of the depth control through the foot switch like this:

1: Depth pot lug 1
2: PCB connection to Depth pot lug 1
3: Ground
4: Bypass LED
5. Ground

6. Wire the effect input (pad 1) and output (pad 6) directly to the jacks.

With a low-gain overdrive or simple booster stage before or after the Cardinal circuit and a cab simulator on the output, this would make a pretty good amp-in-a-box effect! If you put a booster with a volume pot (and tone stack) in front of the Cardinal, you could use the booster's volume as the gain control. This would result in something topologically close to the Pro amp up to the phase inverter. Neat, huh?

How it works and other tidbits…

Introduction

The harmonic tremolo effect works by modulating two bands, one high-passed and one low-passed, 180° out of phase. The effect is fairly unique, though it sounds similar to a mix between a very mild phaser, vibe, and tremolo. Unlike a phaser or vibe however, there is no phase cancellation (and thus no frequency notching or pitch shifting) because the bands are in phase with each other.

Input stage

The input stage is a basic FETzer valve, as designed by Runoff Groove, with a couple very minor changes. R1 and C1 create a low-pass filter with its cutoff at 20KHz, to reduce noise in the circuit. R1 (plus the series resistance of the H11F1 with the optical bypass) imitates the 34K of resistance on the grid of a 12AX7 tube in most Fender amplifiers. It also reduces the chance of pops appearing when the circuit is switched. I have added the familiar 22uF (C2) bypass capacitor to increase the output of the stage, but depending on how much output or headroom is needed, this may not be a necessary inclusion for some builders. I omit it.

I recommend 6V as the bias point for all three FETs, even though ROG notes that including the bypass capacitor changes the harmonic structure and makes 6V less, for want of a better term, "magical."

From there, the circuit is split from the drain for the bass and treble bands, respectively.

Bass/Full-Range Tremolo Path

Q2 and Q3 are again based loosely on the FETzer valve, but with some notable deviations. The signal level is reduced by R4 and R5 in conjunction with the light dependent resistors (LDRs), which provide the tremolo effect.

In the 6G5 amp, the treble side is attenuated by 220K||220K (-6dB divider before the 250pF) || 1M (grid bias resistor), and the bass band's input is attenuated by a 470K before the grid bias resistor (1M). I've used smaller value resistors with different ratios to rebalance the bands, but the principle is the same. You could fiddle with the gain of each band by changing these; just remember that if you change R4, you need to change C4 as well. E.g. if you use 33K for R4, you'll need 33nF, or for a 68K, you'll need ~16nF (not a standard value ...). Here's the calculator I use.

On the Q2 side, R4 and C4 form our low pass filter for the "bass" band in harmonic mode; in normal tremolo mode, this is an all-pass stage. On the Q3 side, C7 and R5 form the high pass filter for the "treble" side of the effect.

In amplifiers, the bass band's cutoff (68Hz) is almost exactly a full decade lower than that of the treble band (636Hz in the amp, 723Hz in the Cardinal), creating a mild midrange scoop. You can alter the values to shift the response, reduces the midrange scoop, or simply get a different flavor of effect. After much experimentation, I settled on 22nF for C4 and left C5 alone. This is more like the Twin, and it has a slightly more "bubbly" and "wah-ish" effect that sounds more obvious. The effect becomes less obvious as the capacitance goes up. Using 47nF will give you the cutoff from the Pro and other "really big" brown amps, but I ultimately found this value too subtle in the cardinal.

The gate bias resistors (R6 and R8) are 100K, which is low for a FET stage. These resistors have to be small enough to result in a good effect but big enough to make variations in the vactrols less important. The LDR forms a voltage divider with the 100K to create the effect. The specified vactrol, VTL5C1, will easily become over 1M with the values chosen for the LED drivers at Q4 and Q5, which results in a very, very deep cut to the volume in each band, particularly in square wave mode (which will do a full stutter). However, the vactrols tends to measure 40-80K at 0 depth, which means that the signal is about -6dB after stage 1 when using the 100K, and then it's reamplified. If you reduce R6 and R8 to 47K, you'll lose another 6dB! The effect would then be very low output.

C5 and C8 are there to provide small treble cuts if needed, whether to reduce noise or simply to soften the sound. I prefer to omit them.

The outputs of both FETs are mixed at the drains before decoupling. (Thanks to RG Keen and teemuk on DIYSB for teaching me this arrangement.) This was probably the biggest improvement from the original Cardinal; in the original design, the drains were separately decoupled and then the outputs were directly connected, which resulted in a low-pass filter being formed between the two stages! This resulted in a loss of treble at lower depth settings, which was particularly distressing in full-range mode. The drawback is that Q2 and Q3 must matched so that they draw similar amounts of drain current and produce the same gains. They just have to match each other; you're not looking for a particular characteristic. Ten transistors should give you multiple pairs.

The original Cardinal had some distortion. This was both intentional and unavoidable with the devices used. This version has less distortion overall, but I think that a little bit of distortion can enhance the harmonic tremolo effect and I consider it a worthwhile ingredient. The amplifier uses a pair of tubes with the cathodes bypassed (the cathodes are connected … similar to what I've done with tying the drains together), coming after two gain stages. Despite some signal attenuation beforehand, the amp at typical playing levels is creating quite a bit of distortion before, during, and after the tremolo stages.

<u>LFO</u>

The LFO has its origins in the Tremulus Lune, and more directly in CultureJam's version of the Lune's LFO, which used some more common parts values, but it has been adapted to drive the two LEDs out of phase with an improved depth pot.

IC1A is a positive feedback loop. Self-noise from the op amp is fed back into the op amp's inputs. A voltage divider, R9 and R10, sets the center point of the LFO's wave swing to half of the supply voltage for a symmetrical waveform. C11 provides some filtering and helps stave off ticking.

At the output of IC1A (pin 1), a low-pass RC filter is created by the rate pot and R13 in series (together they are the "R") and C13 going to ground. When the rate pot is at its lowest setting, the total resistance is 103.3K, resulting in a period of .15Hz, or one cycle every ~6.6 seconds. The highest possible setting is 4.8Hz, or almost five cycles a second. This range expands what is found on the amplifiers slightly without getting unusably crazy at the highest speeds like the original Lune LFO.

The signal at pin 1 is almost a perfect triangle. The signal at pin 3 is a pulse, also known as a square wave. We can connect a pot (Wave) to pan between those outputs to set the wave shape.

Our output will work as a control voltage, but there's a problem: It's the full swing of the op amp's rails! This would be fine if we always wanted our tremolo all the way on, but we need a depth control. This isn't a Repeat Percussion. The waveform is also very "hard" sounding, too, but we want access to something that sounds like amps with a sine wave. The solution to the depth pot will actually take care of the second problem incidentally.

The first step is to buffer the op amp output. The output pin, through the rate pot and R13, is DC coupled to the non-inverting input of IC1C. This is a simple unity gain buffer, but it actually smooths out the waveform slightly.

Our depth pot must be wired so that we can keep our signal swinging across the center point, or 4.5V. This means wiring the depth pot to a voltage reference. We can't use the one created by R9 and R10, though, because we know that Pin 3, which is connected directly to that point, is outputting a square wave. So we need a new voltage reference. We could use a voltage divider, or the Balance trimpot by itself, but these actually work kind of poorly, and a very steady, low impedance reverence voltage would be best. We're going to have to buffer the depth pot from the LEDs anyway, which means another op amp stage is involved. Moving to a quad op amp from the dual op amp that was in the Lune gives us two more op amps with very, very little extra space required on the PCB. We don't even need any extra parts to buffer the "Balance" reference voltage, just a trace between the op amp pins. Now the depth control pans between a steady voltage (pin 7) and the oscillator output (pin 8).

There are some nice things about this depth control setup. One is that the pot value is not very important, and a B taper pot works very well, with a very smooth transition from "no effect" to full depth. So we can use the same value pot as the volume control. Another benefit is that at minimum depth the voltage controlling the LEDs will be similar to the voltage the see on average when oscillating -- resulting in the volume sounding constant throughout the depth sweep. (This would have meant an external volume control was unnecessary, but there is a volume difference among the modes.)

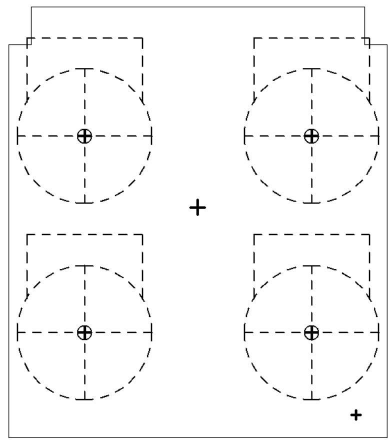
The last step is to buffer the depth control from the LEDs. A final op amp unity gain buffer is connected to lug 2, and then the LEDs get connected to the supply voltage and ground through a pair of 2k2 resistors. The op amp is, remember, half the supply voltage, so the LEDs on top see half the voltage on their cathode as their "low" voltage, and the ones on the bottom see half voltage on their anode as their "high" voltage. When the op amp's voltage swings up while oscillating, the top LEDs will see less voltage difference between the +9V rail and their "low" voltage, so less current flows, and the LED dims until no current flows at all and the LED is off. The opposite happens to the bottom LEDs. Putting D1 and D2 in series with the vactrols gives us one or two external rate indicators.

Vactrols

In the past, I have recommended substitutes for optical devices due to the cost of the VTL5C1s. However, I've been unable to achieve satisfactory results with anything else in any version of the Cardinal. You MAY be able to get the effect to work with the Smallbear Macron "workalike" for the 5C1, but part of the problem is that those devices use a super bright LED internally, whereas the VTL5C1 uses an infrared LED. There is a very large difference in forward voltage and current consumption between the devices. You might be able to adjust R14 and R15 to get the Macron devices to work. I couldn't get them to work right, but I didn't do an exhaustive experiment, either.

The spec sheet for the VLT5C3 has very similar characteristics to the 5C1, but I've had some trouble in the past with them not being able to handle faster speeds. Again, you can try them if you have them around, but I was unable to get them to work properly.

Drill Guide



Print this document 100% scale.

Board Dimensions: 1.97” x 2.25” (50mm x 57mm)

The Cardinal Tremolo PCBs can be used for small quantities of commercial pedal building. You may not however, offer these PCBs as part of a “kit” or redistribute the PCB’s for sale as a commercial endeavor. All PCB artwork is property of 1776 effects.

If using PCB’s for commercial building please rename your project so there is no confusion to the end user and it will be clear I offer no official support to those you sold your pedal to :)