aion DIY GUITAR EFFECTS

PROJECT NAME

APEX

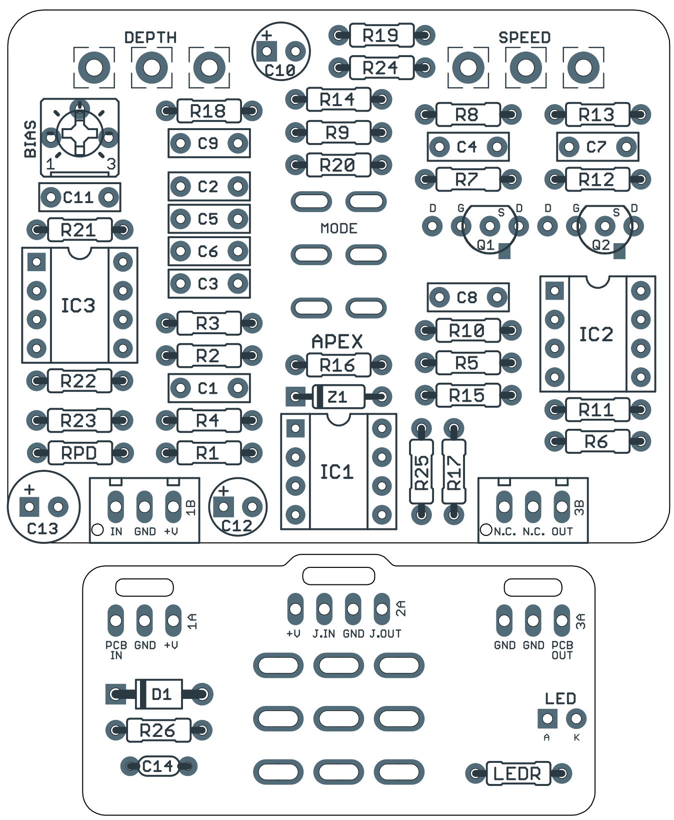
BASED ON
MXR® Phase 45

BUILD DIFFICULTY
Intermediate

EFFECT TYPE
2-stage phaser

DOCUMENT VERSION
1.0.0 (2024-04-19)

PROJECT SUMMARY
A simplified two-stage version of the classic Phase 90, using matched JFETs to produce a swept phase effect.



Actual size is 2.3" x 2.42" (main board) and 1.78" x 0.86" (bypass board).

TABLE OF CONTENTS

INTRODUCTION

The Apex JFET Phaser is based on the MXR Phase 45, a short-lived "little brother" to the MXR Phase 90 that was released in 1975, the next year after the more famous circuit.

The design is very similar to the Phase 90, but as the name implies, there are only half of the phase stages (two instead of four). While it was certainly cheaper to produce than the Phase 90, and that was probably the motivation for its release, it does have a milder character of its own that many people prefer to the original.

In 2017, MXR released a mini pedal called the Phase 95 that has a switch to activate a Phase 45 mode by bypassing two of the phase stages. We considered combining the 45 and 90 into one project in a similar way, but if you compare the schematics, there are enough differences between the two circuits that a single switch can't cover both with 100% accuracy to the original circuits.

The phase stages themselves are constructed differently, particularly the extra components around the JFETs, and the Phase 90 also includes an active transistor stage that mixes the dry and wet signals differently at the output.

The Apex is a direct copy of the Phase 45 circuit, with two added modifications. A Depth control allows the intensity to be dialed back, a modification that we also added to our version of the Phase 90. And by using a toggle switch to change the phase-frequency capacitors to a 10:1 ratio, it gives a warbly phase-shift sound that's more reminiscent of a Univibe.

USAGE

The Apex has two knobs and one toggle switch:

- **Speed** sets the speed of the phaser effect.
- **Depth** sets the intensity of the phaser effect.
- **Mode** (toggle switch) selects between two different sets of phase frequency capacitors. The "down" position is stock mode, and the "up" position is more like a Univibe.

PARTS LIST

This parts list is also available in a spreadsheet format which can be imported directly into Mouser for easy parts ordering. Mouser doesn't carry all the parts—notably potentiometers—so the second tab lists all the non-Mouser parts as well as sources for each.

View parts list spreadsheet →

PART	VALUE	TYPE	NOTES
R1	10k	Metal film resistor, 1/4W	
R2	470k	Metal film resistor, 1/4W	
R3	10k	Metal film resistor, 1/4W	
R4	20k	Metal film resistor, 1/4W	
R5	10k	Metal film resistor, 1/4W	
R6	10k	Metal film resistor, 1/4W	
R7	10k	Metal film resistor, 1/4W	
R8	10k	Metal film resistor, 1/4W	
R9	470k	Metal film resistor, 1/4W	
R10	10k	Metal film resistor, 1/4W	
R11	10k	Metal film resistor, 1/4W	
R12	10k	Metal film resistor, 1/4W	
R13	10k	Metal film resistor, 1/4W	
R14	470k	Metal film resistor, 1/4W	
R15	10k	Metal film resistor, 1/4W	
R16	10k	Metal film resistor, 1/4W	
R17	150k	Metal film resistor, 1/4W	
R18	510k	Metal film resistor, 1/4W	
R19	3M9	Metal film resistor, 1/4W	
R20	150k	Metal film resistor, 1/4W	
R21	150k	Metal film resistor, 1/4W	
R22	150k	Metal film resistor, 1/4W	
R23	150k	Metal film resistor, 1/4W	
R24	7k5	Metal film resistor, 1/4W	
R25	10k	Metal film resistor, 1/4W	
R26	47R	Metal film resistor, 1/4W	Power supply filter resistor.
RPD	2M2	Metal film resistor, 1/4W	Input pull-down resistor. Can be as low as 1M.
LEDR	10k	Metal film resistor, 1/4W	LED current-limiting resistor. Adjust value to change LED brightness.
C1	10n	Film capacitor, 7.2 x 2.5mm	
C2	47n	Film capacitor, 7.2 x 2.5mm	
C3	10n	Film capacitor, 7.2 x 2.5mm	Part of the "Mode" switch mod. See build notes.
C4	10n	Film capacitor, 7.2 x 2.5mm	

PARTS LIST, CONT.

PART	VALUE	TYPE	NOTES
C5	47n	Film capacitor, 7.2 x 2.5mm	
C6	100n	Film capacitor, 7.2 x 2.5mm	Part of the “Mode” switch mod. See build notes.
C7	10n	Film capacitor, 7.2 x 2.5mm	
C8	47n	Film capacitor, 7.2 x 2.5mm	
C9	47n	Film capacitor, 7.2 x 2.5mm	
C10	15uF	Tantalum capacitor, 044A	
C11	10n	Film capacitor, 7.2 x 2.5mm	
C12	47uF	Electrolytic capacitor, 5mm	Reference voltage filter capacitor.
C13	100uF	Electrolytic capacitor, 6.3mm	Power supply filter capacitor.
C14	100n	MLCC capacitor, X7R	Power supply filter capacitor.
D1	1N5817	511-1N5817	
Z1	1N5231B	512-1N5231B	May need to use a 3.9V, 4.3V or 4.7V zener instead. See build notes.
Q1	2N5952	JFET, N-channel, TO-92	Q1-2 must be matched to Vgs(off) or Vgs(10k). See build notes.
Q2	2N5952	JFET, N-channel, TO-92	Q1-2 must be matched to Vgs(off) or Vgs(10k). See build notes.
IC1	TL072	Operational amplifier, dual, DIP8	See build notes for IC selection.
IC1-S	DIP-8 socket	IC socket, DIP-8	
IC2	TL062	Operational amplifier, dual, DIP8	See build notes for IC selection.
IC2-S	DIP-8 socket	IC socket, DIP-8	
IC3	TL022	Operational amplifier, dual, DIP8	See build notes for IC selection.
IC3-S	DIP-8 socket	IC socket, DIP-8	
BIAS	250k trimmer	Film capacitor, 7.2 x 2.5mm	Bourns 3362P or similar.
SPEED	500kC	16mm right-angle PCB mount pot	
DEPTH	500kB	16mm right-angle PCB mount pot	
MODE	DPDT on-on	Toggle switch, DPDT on-on	
LED	5mm	LED, 5mm, red diffused	
IN	1/4" stereo	1/4" phone jack, stereo	
OUT	1/4" mono	1/4" phone jack, mono	
DC	2.1mm	DC jack, 2.1mm panel mount	
FSW	3PDT	Stomp switch, 3PDT	
ENC	125B	Enclosure, die-cast aluminum	Can also use a Hammond 1590N1.

Matching Q1 and Q2

The JFETs in the two phase stages must be matched for the phasing effect to occur. If you don't want to mess with matching your own JFETs, you can pick up a matched pair from Aion FX that will perform the same as those in the original Phase 45 and you don't have to give it a second thought. However, if you do want to match your own JFETs or you're just interested in the process, technical details are provided further down.

Theory of JFET matching

JFETs can be used as variable resistors controlled by the gate voltage. When used as soft switches, the gate voltage is changed instantly to make the *channel resistance* (the resistance between the source and drain pins) switch between very low, in the hundreds of ohms, and very high, in the megaohms. In the "off" state, the resistance is high enough that for all practical purposes the connection is interrupted.

The exact "on" and "off" resistance is not important for JFET switches. In the case of phasers, though, we need a set of JFETs that have roughly the same channel resistance when the same gate voltage is applied. This way, all four of the phase-shift stages will respond the same way to the LFO voltage.

The trouble is, JFETs have historically had an inexact manufacturing process, and because of this the datasheet parameters are very broad. If four JFETs were randomly pulled from a batch, even if it's the same manufacturer and lot code, they likely would not produce a phasing effect when used together.

This means that for phasers and other applications where the exact resistance is important, the JFETs must be measured and sorted. Historically, most manufacturers graded JFETs according to their $V_{GS(off)}$ parameter, the voltage at which the channel resistance is highest, also called pinch-off voltage.

However, some luminaries in the DIY scene have suggested that it's actually better to match the phaser JFETs to their $V_{GS(10k)}$ parameter, the voltage at which the channel resistance is 10k, which is within the normal operating range of a phaser. This leads to better "real world" matching, since the correlation between $V_{GS(off)}$ and $V_{GS(10k)}$ isn't always exact.

Measuring the V_{GS} values

The most straightforward way of measuring JFETs is to use an electronic component tester such as the Peak Atlas DCA75. This will give you all of the standard datasheet parameters of a particular JFET, including $V_{GS(off)}$. These testers won't give you the $V_{GS(10k)}$ value, but it's very simple to breadboard a circuit that can test either the OFF value or the 10k value. For that, check out the article on JFET matching from Geofex, which includes the test circuit and information on using it.

How closely should they be matched?

We measured the JFETs in an original block-logo Phase 90 and found that they tested as follows:

- **Q1:** $V_{GS(10k)}$ -1.78V, $V_{GS(off)}$ -2.32V
- **Q2:** $V_{GS(10k)}$ -1.71V, $V_{GS(off)}$ -2.21V
- **Q3:** $V_{GS(10k)}$ -1.72V, $V_{GS(off)}$ -2.30V
- **Q4:** $V_{GS(10k)}$ -1.80V, $V_{GS(off)}$ -2.35V

BUILD NOTES, CONT.

We can see that they were not matched very closely, with a spread of 0.09V at 10k. Presumably the Phase 45 used the same JFET specs. So if you are matching your own, it should work fine with anything inside of a 0.1V spread, though you should try for 0.05V if you can. The matched sets from Aion FX are typically within 0.01V of each other, about as close to ideal as you can get.

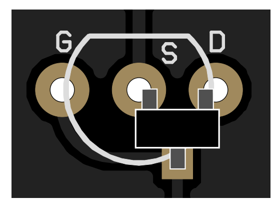
Setting the bias

The bias trimmer adjusts the LFO voltage sweep so it is best suited to the JFETs being used. It can easily be set by ear. With the Depth control set to maximum and Rate to medium speed, adjust the trimmer until you've got the best phasing sound with a wide sweep range and no audible distortion.

Analogman has a nice short video demonstrating the biasing of a vintage Phase 90 where you can hear the difference in the swept frequency as the bias trimmer is adjusted. The Phase 45 is less intense, but the biasing works the same way. Ultimately it comes down to personal preference.

Using SMD JFETs

Most TO-92 through-hole JFETs have been discontinued, and of the few that are still active, none are very well-suited to the Phase 45 circuit. There are still plenty of SMD types though. The Toshiba 2SK208-GR and Fairchild/ONSemi MMBF5485 (2N5485) are great choices, though matching can be difficult due to the small size.



This PCB uses a hybrid through-hole/SMD outline for each JFET. A SMD "G" (gate) pad is included to accommodate surface-mount devices without the need for adapters. SMD JFETs should be oriented as shown in the diagram to the right.

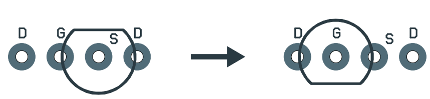
All surface-mount JFETs use the same pinout, so this configuration will fit any type that we're aware of. But always check the datasheet if you're uncertain—they're difficult to desolder if you make a mistake.

Using old-stock JFETs

Original through-hole 2N5952 JFETs are very difficult to find today, particularly in quantities that would allow for matching. But, the Toshiba 2SK30A-GR can still be found without too much trouble. This is a close substitute that BOSS used in their PH-1 and PH-1r circuits.

Be aware that these follow the Japanese pinout conventions, whereas the PCB layout is set up for the USA convention used in the Phase 90.

For those using original Toshiba through-hole JFETs or BJTs, an extra pad has been added to the left of the transistor outline (drain for JFETs, emitter for BJTs) so that the Japanese pinout can be easily used without needing to twist the legs around. In both cases, the transistor should be rotated 180 degrees from the silkscreen and shifted by one pad, as shown:



Note that for the row of matched JFETs, the extra "D" pad is to the left of the corresponding JFET.

Zener diode

The zener diode sets the bias voltage at a fixed value, ensuring that the bias is stable as the battery voltage decreases, or if you power it with a different supply voltage (e.g. going from 9.6V to 9.0V).

Since the ideal bias voltage depends on the characteristics of the JFETs being used, the value of the zener diode has changed throughout the manufacturing run of the Phase 90. In the very earliest Phase 90 pedals, it was 3.9V, but at some point was later changed to 5.1V. The Phase 45 wasn't produced long enough to have the same variations, but if it had lasted, it likely would have.

We recommend starting with 5.1V for Z1, but if you're having a hard time getting the JFETs to phase properly, you might need to change it to 4.7V (1N5320B), 4.3V (1N5229B) or 3.9V (1N5228B).

If using a different brand or series, make sure it's a 500mW type and not a 1W, since the higher wattage will not produce the nominal voltage at the low currents in this circuit.

IC selection

The original Phase 45 circuit has four op-amp stages in total, made up using two dual op-amps.

For the Apex, we used three duals. The reason is that a good-quality op-amp will not have the low current draw that works best for LFOs, and vice versa—an ideal LFO op-amp is not great for audio.

If you use two duals, then there is necessarily a compromise between audio quality and LFO suitability. Additionally, the LFO would share an IC package with either the input buffer or one of the phase stages, when you would ideally want it to be as far from the audio path as possible in order to prevent ticking.

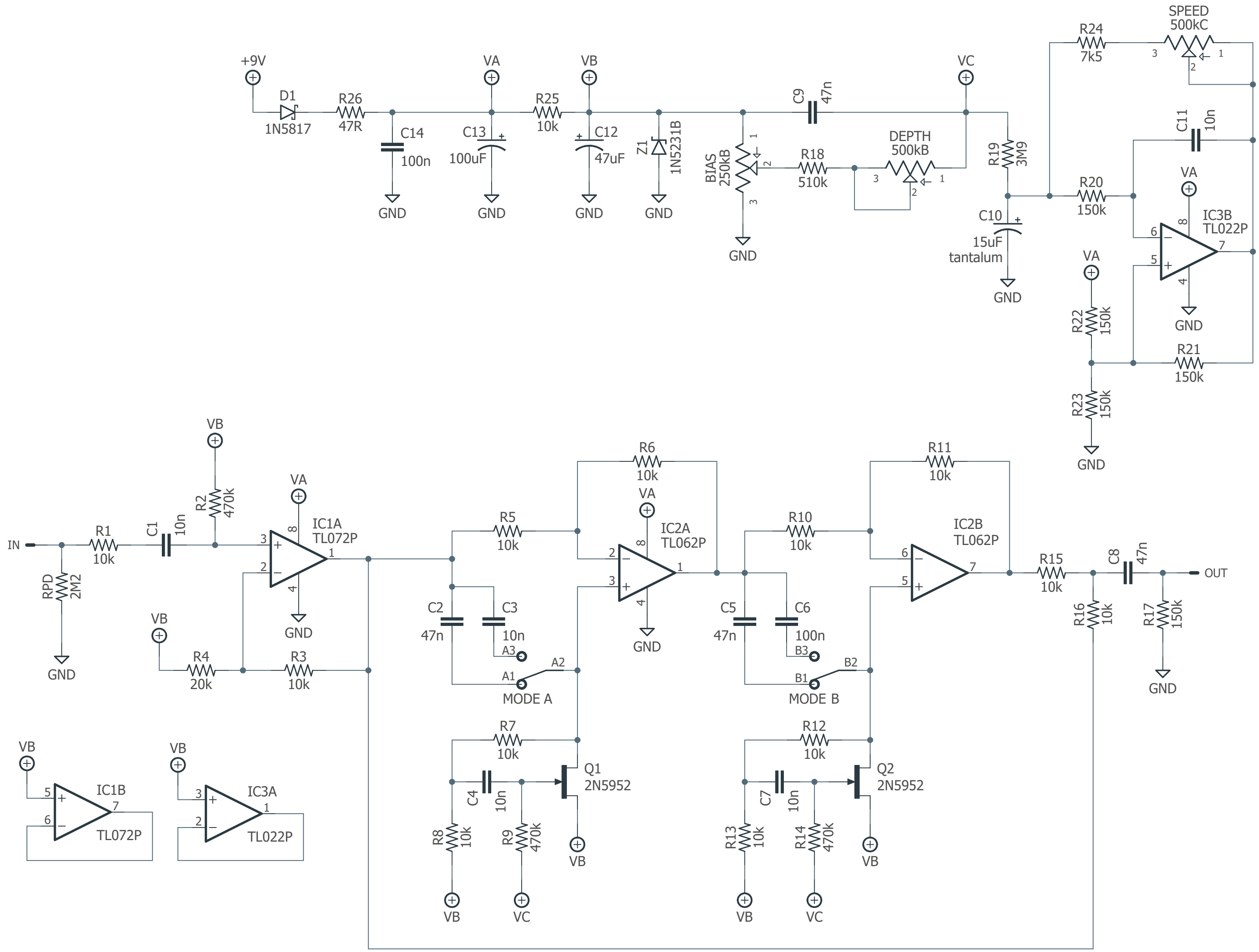
So in this project, the input buffer has its own IC so you can use something good-quality like the TL072. The LFO has its own IC so you can use something low-current like the TL022 or LM358, and it is also positioned far away from the others. And the two phase stages have their own IC, so you can use something that balances current draw and quality like the TL062.

The two unused stages are disabled by connecting them to the bias voltage, so there is no risk of runaway oscillation.

C3 and C6

The Shin-ei Univibe was the first phaser, though it was described as vibrato. Part of its characteristic sound came from using different capacitor values for the phase stages, leading to a more imbalanced phase sweep. We've incorporated a similar modification to this project, with both phase-frequency capacitors being switchable using a DPDT switch.

It's recommended to use 10n and 100n for C3 and C6, which gives a 1:10 capacitor ratio when in the alternate mode, similar to the Univibe's last two stages. But, you can experiment with different combinations to see what you like best.


+9V
D1
1N5817
R26
47R
C14
100n
GND
VA
C13
100uF
R25
10k
VB
C12
47uF
Z1
1N5231B
BIAS
250kB
C9
47n
R18
510k
DEPTH
500kB
VC
R19
3M9
C10
15uF
tantalum
R24
7k5
SPEED
500kC
C11
10n
R20
150k
IC3B
TL022P
R22
150k
R21
150k
R23
150k
IN
R1
10k
RPD
2M2
C1
10n
R2
470k
IC1A
TL072P
R4
20k
R3
10k
R5
10k
R6
10k
IC2A
TL062P
C2
47n
C3
10n
A1
A2
A3
MODE A
R7
10k
Q1
2N5952
C4
10n
R8
10k
R9
470k
R10
10k
R11
10k
IC2B
TL062P
C5
47n
C6
100n
B1
B2
B3
MODE B
R12
10k
Q2
2N5952
C7
10n
R13
10k
R14
470k
R15
10k
C8
47n
R16
10k
R17
150k
OUT
IC1B
TL072P
IC3A
TL022P

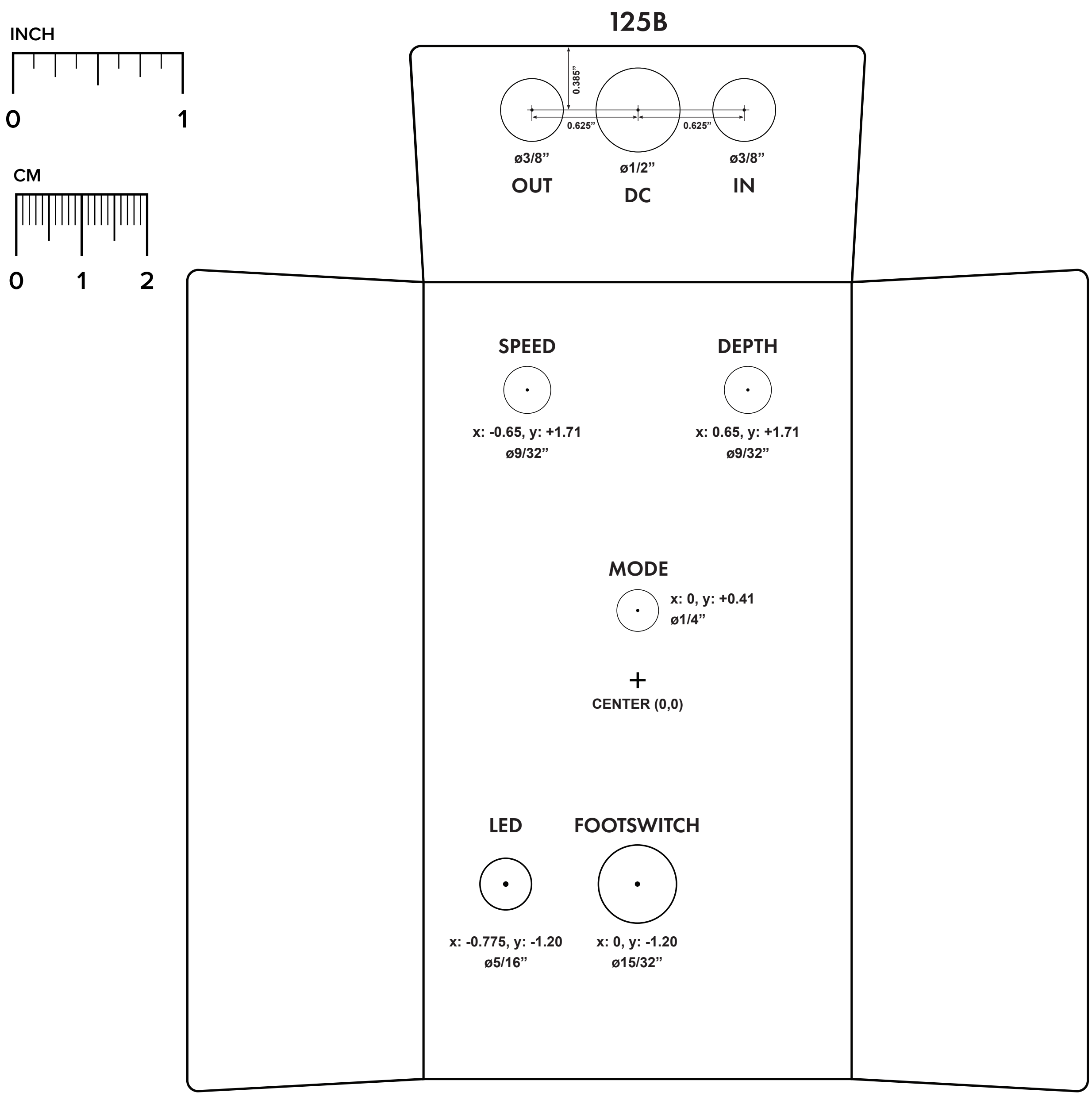
DRILL TEMPLATE

Cut out this drill template, fold the edges and tape it to the enclosure. Before drilling, it's recommended to first use a center punch for each of the holes to help guide the drill bit.

Ensure that this template is printed at 100% or "Actual Size". You can double-check this by measuring the scale on the printed page.

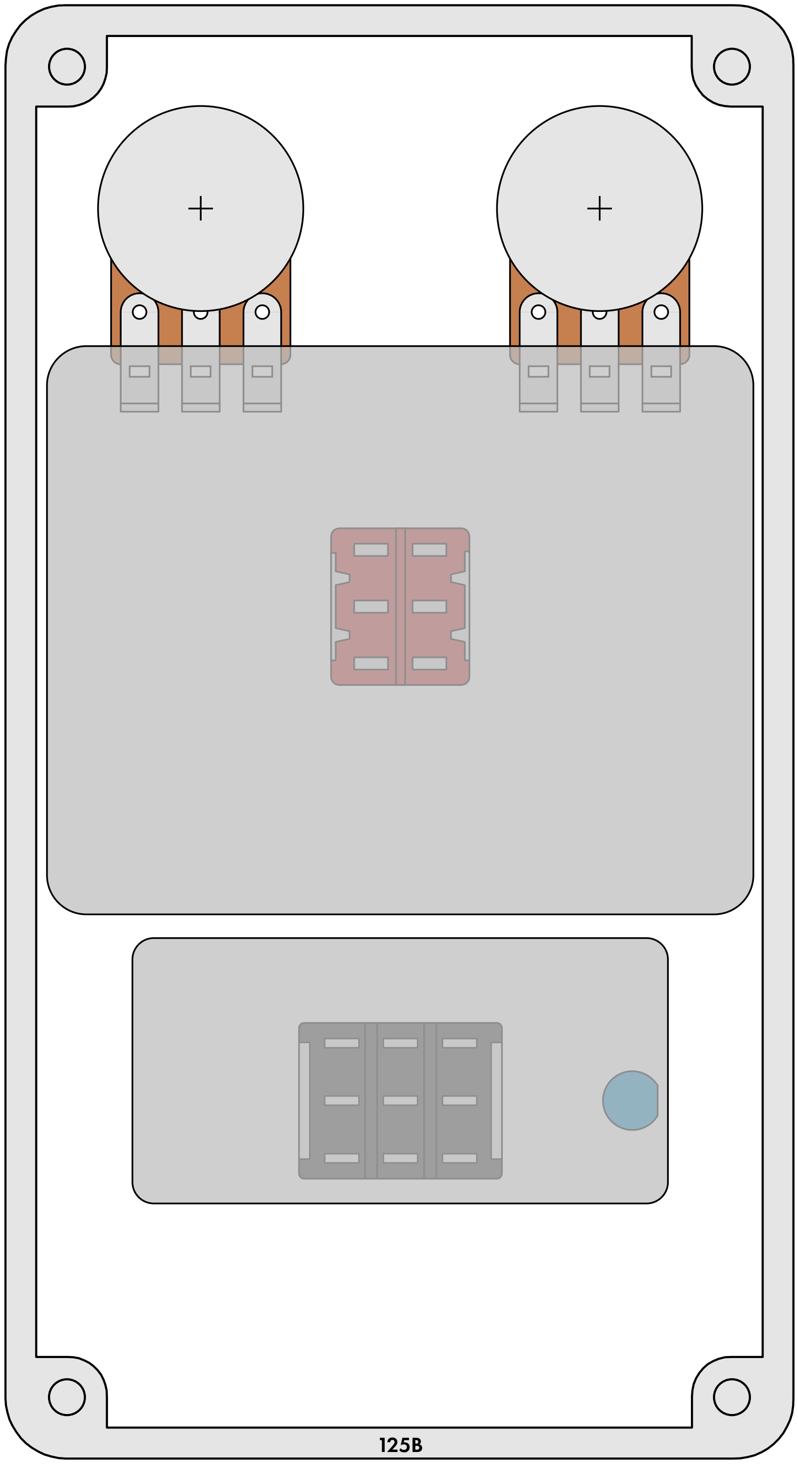
Top jack layout assumes the use of closed-frame jacks like the Switchcraft 111X. If you'd rather use open-frame jacks, please refer to the Open-Frame Jack Drill Template for the top side.

LED hole drill size assumes the use of a 5mm LED bezel, available from several parts suppliers. Adjust size accordingly if using something different, such as a 3mm bezel, a plastic bezel, or just a plain LED.

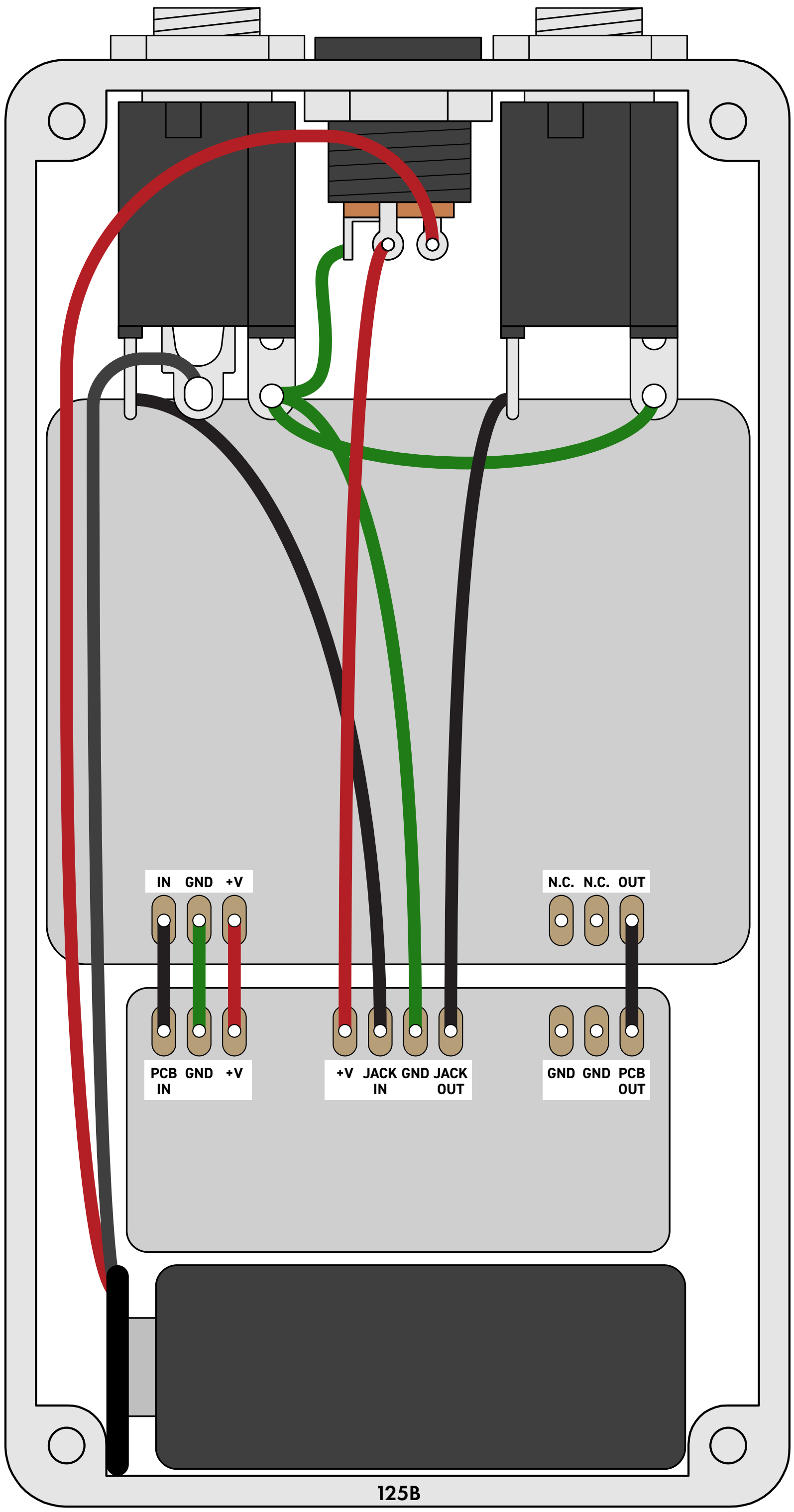


ENCLOSURE LAYOUT

Enclosure is shown without jacks. See next page for jack layout and wiring.



WIRING DIAGRAM



LICENSE & USAGE

No direct support is offered for these projects beyond the provided documentation. It's assumed that you have at least some experience building pedals before starting one of these. Replacements and refunds cannotbe offered unless it can be shown that the circuit or documentation are in error.

All of these circuits have been tested in good faith in their base configurations. However, not all the modifications or variations have necessarily been tested. These are offered only as suggestions based on the experience and opinions of others.

Projects may be used for commercial endeavors in any quantity unless specifically noted. No attribution is necessary, though a link back is always greatly appreciated. The only usage restrictions are that **(1) you cannot resell the PCB as part of a kit without prior arrangement**, and **(2) you cannot "goop" the circuit, scratch off the screenprint, or otherwise obfuscate the circuit to disguise its source**. (In other words: you don't have to go out of your way to advertise the fact that you use these PCBs, but please don't go out of your way to hide it. The guitar effects industry needs more transparency, not less!)

DOCUMENT REVISIONS

1.0.0 (2024-04-19)
Initial release.