PROJECT NAME

ZENITH

aion DIY GUITAR EFFECTS

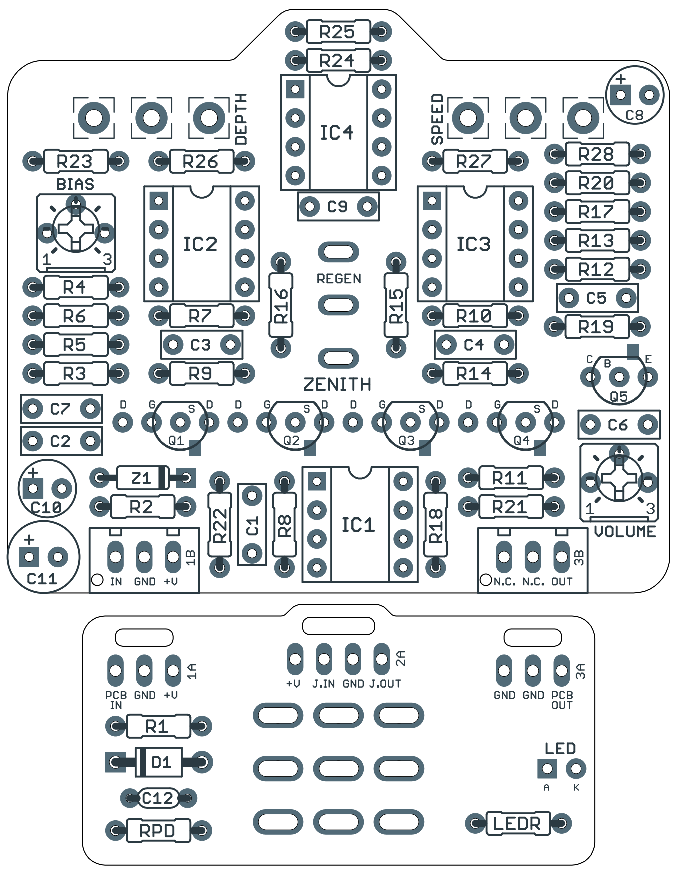
BASED ON
MXR® Phase 90

BUILD DIFFICULTY
Intermediate

EFFECT TYPE
4-stage phaser

DOCUMENT VERSION
1.0.0 (2024-04-19)

PROJECT SUMMARY
A legendary four-stage phaser that uses matched JFETs to create a moving phase-shift effect. Most notably used by Eddie Van Halen.



Actual size is 2.3" x 2.02" (main board) and 1.78" x 0.91" (bypass board).

TABLE OF CONTENTS

1 Project Overview
2 Introduction & Usage
3-4 Parts List
5-8 Build Notes
9 Schematic
10 Drill Template
11 Enclosure Layout
12 Wiring Diagram
13 Licensing
13 Document Revisions

INTRODUCTION

The Zenith JFET Phaser is adapted from the MXR Phase 90, unquestionably the most popular phaser pedal of all time. Originally released in 1974, the Phase 90 was most famously used by Eddie Van Halen, particularly on "Eruption". Other contemporary users in the 1970s included Robin Trower, Jimmy Page and David Gilmour, but both the originals and the later Dunlop reissues have been used by scores of others notable guitarists over the past 50 years.

The control scheme of the original pedal is as simple as it gets: a single knob for Speed. Despite this external simplicity, there's a lot going on inside, particularly for its size. The Phase 90 uses JFETs as voltage-controlled resistors to vary the frequency of four phase-shifted stages, which produces a moving filter effect. As such, the JFETs must be matched so that they produce a similar drain-source resistance with the same gate voltage, keeping the filters of all four stages moving at the same rate.

In 1977, the pedal was redesigned, both cosmetically and internally. The original pedal used a cursive or "script" typeface. The new design used the now-familiar "block" logo which is still in use today. Right around the same time, a feedback resistor was added to mix some of the output of the phase stages back into the input, which creates a more pronounced resonant peak. Some people like this effect and some don't. Many guitarists began their DIY journey by cutting out the "R28 resistor" (as it was labeled on the MXR PCB, not this project) to convert their block logo to script logo specs.

Our adaptation adds a Depth knob and puts the regen (feedback) resistor onto a toggle switch so you can go between Script and Block modes without the use of wire cutters. A third position has been added so you can change the intensity of the regeneration.

We also added a volume trimmer at the output, since these modifications can impact the perceived output volume. The build notes contain suggestions for how to make the most of these modifications.

USAGE

The Zenith has two knobs, one toggle switch, and two internal trimmers:

- **Speed** sets the speed of the phaser effect.
- **Depth** sets the intensity of the phaser effect.
- **Regen** (toggle switch) selects between two different regen or feedback settings, or no regen.
- **Volume** (internal trimmer) sets the output volume of the effect.
- **Bias** (internal trimmer) sets the bias voltage of the JFETs.

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	10k	Metal film resistor, 1/4W	
R5	22k	Metal film resistor, 1/4W	Some units used 24k. See build notes.
R6	10k	Metal film resistor, 1/4W	
R7	10k	Metal film resistor, 1/4W	
R8	22k	Metal film resistor, 1/4W	Some units used 24k. See build notes.
R9	10k	Metal film resistor, 1/4W	
R10	10k	Metal film resistor, 1/4W	
R11	22k	Metal film resistor, 1/4W	Some units used 24k. See build notes.
R12	10k	Metal film resistor, 1/4W	
R13	10k	Metal film resistor, 1/4W	
R14	22k	Metal film resistor, 1/4W	Some units used 24k. See build notes.
R15	18k	Metal film resistor, 1/4W	Regen resistor (modded value). See build notes.
R16	22k	Metal film resistor, 1/4W	Regen resistor (stock value). See build notes. 24k or 27k in some units.
R17	150k	Metal film resistor, 1/4W	
R18	150k	Metal film resistor, 1/4W	
R19	220k	Metal film resistor, 1/4W	Part of the output volume mod. 150k in original. See build notes.
R20	56k	Metal film resistor, 1/4W	
R21	100k	Metal film resistor, 1/4W	
R22	10k	Metal film resistor, 1/4W	
R23	510k	Metal film resistor, 1/4W	
R24	3M9	Metal film resistor, 1/4W	
R25	150k	Metal film resistor, 1/4W	
R26	150k	Metal film resistor, 1/4W	
R27	470k	Metal film resistor, 1/4W	
R28	4k7	Metal film resistor, 1/4W	Jumpered (0R) in some units, 10k in others. See build notes.
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	

PARTS LIST, CONT.

PART	VALUE	TYPE	NOTES
C3	47n	Film capacitor, 7.2 x 2.5mm	
C4	47n	Film capacitor, 7.2 x 2.5mm	
C5	47n	Film capacitor, 7.2 x 2.5mm	
C6	47n	Film capacitor, 7.2 x 2.5mm	
C7	47n	Film capacitor, 7.2 x 2.5mm	
C8	15uF	Tantalum capacitor, 044A	
C9	10n	Film capacitor, 7.2 x 2.5mm	
C10	47uF	Electrolytic capacitor, 5mm	Reference voltage filter capacitor.
C11	100uF	Electrolytic capacitor, 6.3mm	Power supply filter capacitor.
C12	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	Q1-4 must be matched to Vgs(off) or Vgs(10k). See build notes.
Q2	2N5952	JFET, N-channel, TO-92	Q1-4 must be matched to Vgs(off) or Vgs(10k). See build notes.
Q3	2N5952	JFET, N-channel, TO-92	Q1-4 must be matched to Vgs(off) or Vgs(10k). See build notes.
Q4	2N5952	JFET, N-channel, TO-92	Q1-4 must be matched to Vgs(off) or Vgs(10k). See build notes.
Q5	2N3906	BJT transistor, PNP, TO-92	Substitute. Original used 2N4125.
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	TL062	Operational amplifier, dual, DIP8	See build notes for IC selection.
IC3-S	DIP-8 socket	IC socket, DIP-8	
IC4	TL022	Operational amplifier, dual, DIP8	See build notes for IC selection.
IC4-S	DIP-8 socket	IC socket, DIP-8	
BIAS	250k trimmer	Film capacitor, 7.2 x 2.5mm	Bourns 3362P or similar.
VOL.	50k trimmer	Film capacitor, 7.2 x 3.5mm	Bourns 3362P or similar. Part of output volume mod. See build notes.
SPEED	500kC	16mm right-angle PCB mount pot	
DEPTH	500kB	16mm right-angle PCB mount pot	
REGEN	SPDT on-off-on	Toggle switch, SPDT center off	
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-Q4

The JFETs in the four 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 set of four from Aion FX that will perform the same as those in the original Phase 90 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

We can see that they were not matched very closely, with a spread of 0.09V at 10k. 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.

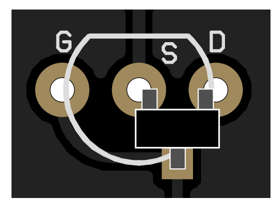
Setting the bias

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. Ultimately it comes down to personal preference and what sounds best to your ears.

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 90 circuit. There are still plenty of SMD types though. The Toshiba 2SK208-GR and Fairchild/ONSemi MMBF5485 (2N5485) are great choices, though measurement 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.

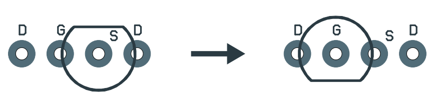
All surface-mount JFETs use the same pinout, so this configuration will fit any type that we're aware of. But always check the datasheet if you're uncertain—they're difficult to desolder if you make a mistake.

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.

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.

Resistor variations

There are several resistor values in the Phase 90 circuit that have changed very slightly throughout the production run.

- **R5, R8, R11, R14 (**parallel JFET resistors): Some versions use 24k instead of 22k. Likely related to JFET specifications. Recommended to use 22k.
- **R16** (block logo regen/feedback resistor): Some versions use 24k or 27k instead of 22k. See next section for more on selecting the feedback/regen resistors.
- **R28** (minimum speed resistor): Some versions use 10k or a jumper instead of 4k7. Recommended to use 4k7. Lower value gives slower minimum speed, higher value is faster.

Feedback/regen resistors

The block logo version of the circuit added a feedback resistor from the output of the 4th phase stage to the input of the second, which adds resonance and color.

The resistor has been 22k, 24k or 27k at different times during production. It's recommended to use 22k for R16 since that seems to be the value that MXR/Dunlop has most commonly used.

For R15, it depends on whether you want the second setting to be more intense or less intense than the stock feedback setting.

If you want even more intensity than the block logo circuit, then use a lower value for R16, such as 18k. Note that below around 16k, the amount of feedback will cause oscillation. It's possible that this could happen at even higher resistances depending on how the unit is biased, so if you notice oscillation on one of the switch settings, the feedback resistor should be increased until it goes away.

Some find the block logo circuit to be too colorful and prefer the circuit with this resistor removed, so you may want to make it a higher value such as 27k or 33k for a less intense option that falls in between stock and disabled.

Output volume modification

This project adds a depth control and switchable feedback, both of which can impact the perceived output volume slightly as they are adjusted, with the result that the effect mode is either slightly lower or slightly higher than unity.

We replaced the 150k resistor at the output with a 50k trimmer and 100k resistor. It's not a full volume control as it doesn't get down to zero, but it allows for small adjustments. Along with this, we recommend increasing the R19 resistor from 150k to 220k, which boosts the volume by a small amount in the output mixer stage. If you do this, unity gain is found between 10:00 and 11:00 on the trimmer.

The internal volume control is still a bit inconvenient to adjust, but it's fine for most use cases where you eventually settle on a favorite setting for your rig.

If you would rather move the volume control to an external knob, you can solder wires to the three pads of the trimmer and wire it offboard. Just be sure you know where it's going to go before you drill anything. We recommend using a mini 9mm potentiometer because it's small enough to fit under the PCB or on the side of the enclosure. If you do this, it's better to use a 100kA audio taper pot and reduce the R21 resistor to 51k.

If you want to omit the volume control entirely, then keep R19 at 150k and jumper all three pads of the volume trimmer together.

IC selection

The Phase 90 circuit has six op-amp stages in total. The earliest Phase 90s used six LM741s, which are single op-amps. The later block redesign collapsed this down to three TL062 duals, and most DIY adaptations follow this configuration in order to save on PCB space.

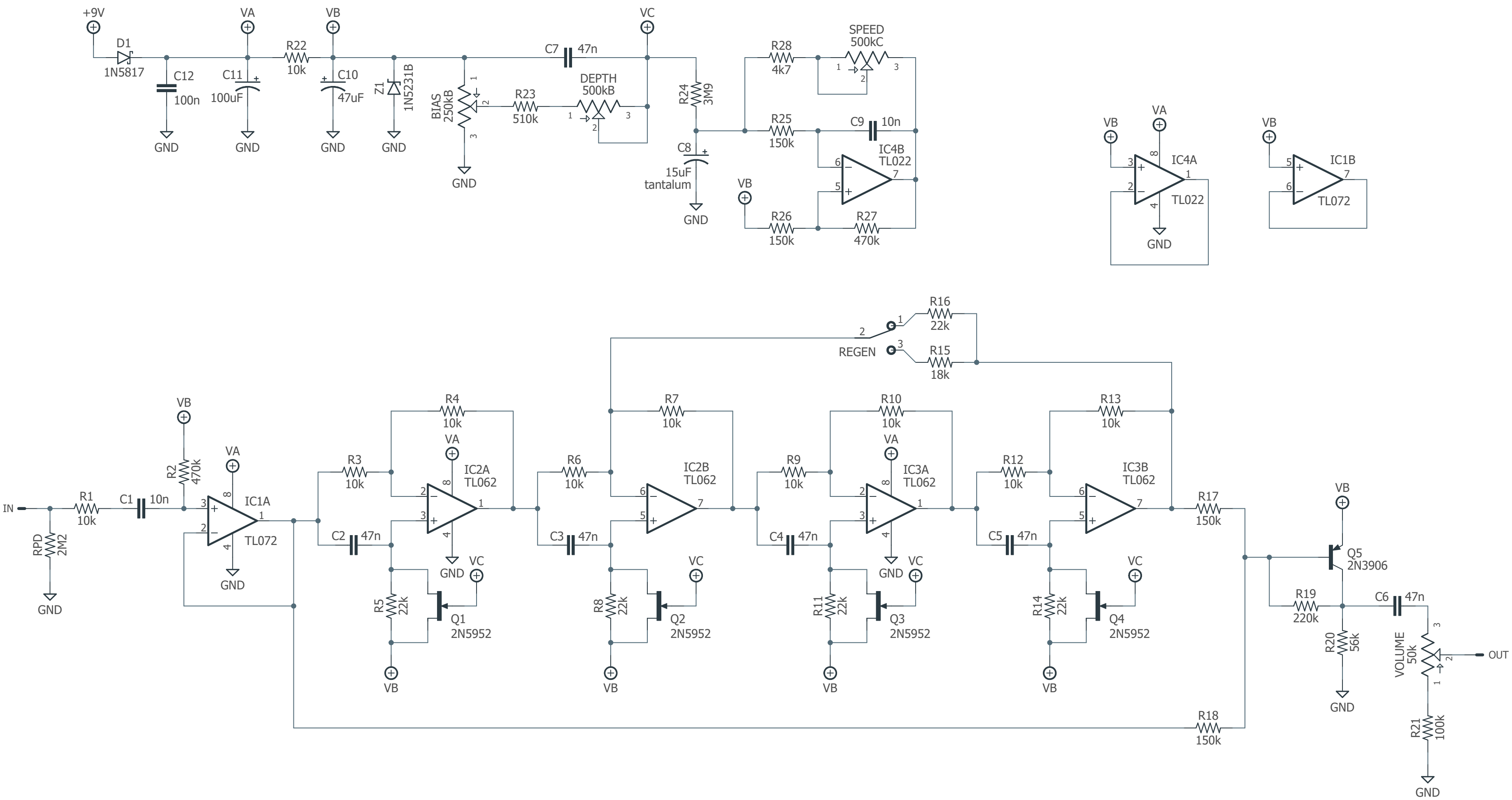
For the Zenith, we used four duals. The reason is that a good-quality op-amp will not have the low current draw that works best for LFOs, and vice versa—an ideal LFO op-amp is not great for audio.

If you use three 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 four phase stages are made with two ICs, 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.

You can experiment with other IC combinations if you want, but just be aware that the circuit can be finicky if you stray from these recommendations. During prototyping, we encountered some issues with unstable bias voltages using TL072s for the phase stages when either of the regen modes was engaged, but it was fixed when we swapped them for TL062s as used in the original Phase 90.



+9V
D1
1N5817
C12
100n
GND
VA
C11
100uF
VB
R22
10k
C10
47uF
Z1
1N5231B
BIAS
250kB
R23
510k
C7
47n
DEPTH
500kB
VC
R24
3M9
C8
15uF
tantalum
R28
4k7
SPEED
500kC
R25
150k
C9
10n
IC4B
TL022
R26
150k
R27
470k
IC4A
TL022
IC1B
TL072
R16
22k
REGEN
R15
18k
IN
RPD
2M2
R1
10k
R2
470k
C1
10n
IC1A
TL072
R3
10k
R4
10k
IC2A
TL062
C2
47n
R5
22k
Q1
2N5952
R6
10k
R7
10k
IC2B
TL062
C3
47n
R8
22k
Q2
2N5952
R9
10k
R10
10k
IC3A
TL062
C4
47n
R11
22k
Q3
2N5952
R12
10k
R13
10k
IC3B
TL062
C5
47n
R14
22k
Q4
2N5952
R17
150k
R18
150k
Q5
2N3906
R19
220k
R20
56k
C6
47n
VOLUME
50k
OUT
R21
100k

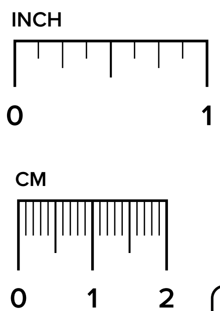
DRILL TEMPLATE

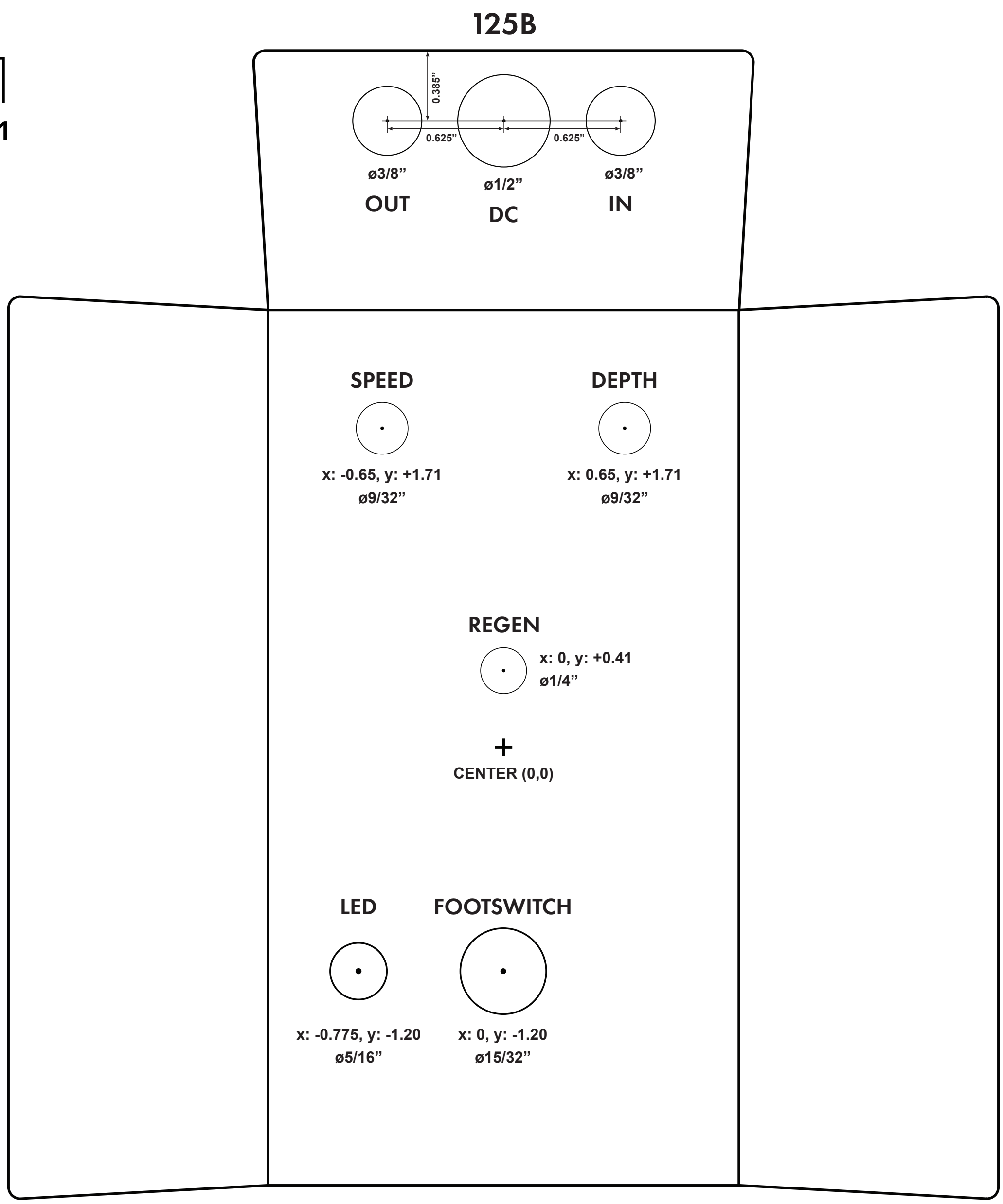
Cut out this drill template, fold the edges and tape it to the enclosure. Before drilling, it's recommended to first use a center punch for each of the holes to help guide the drill bit.

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.

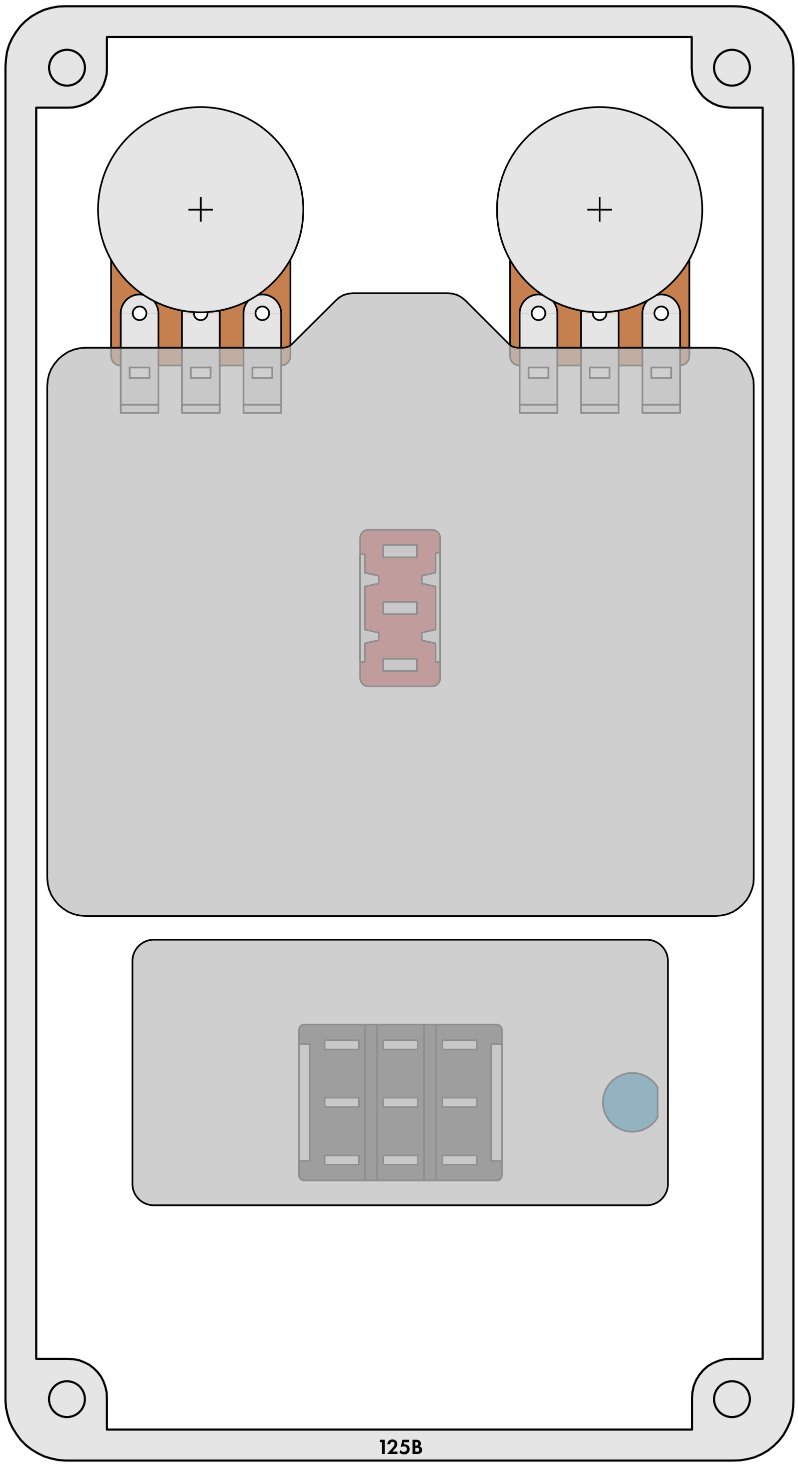
LED hole drill size assumes the use of a 5mm LED bezel, available from several parts suppliers. Adjust size accordingly if using something different, such as a 3mm bezel, a plastic bezel, or just a plain LED.



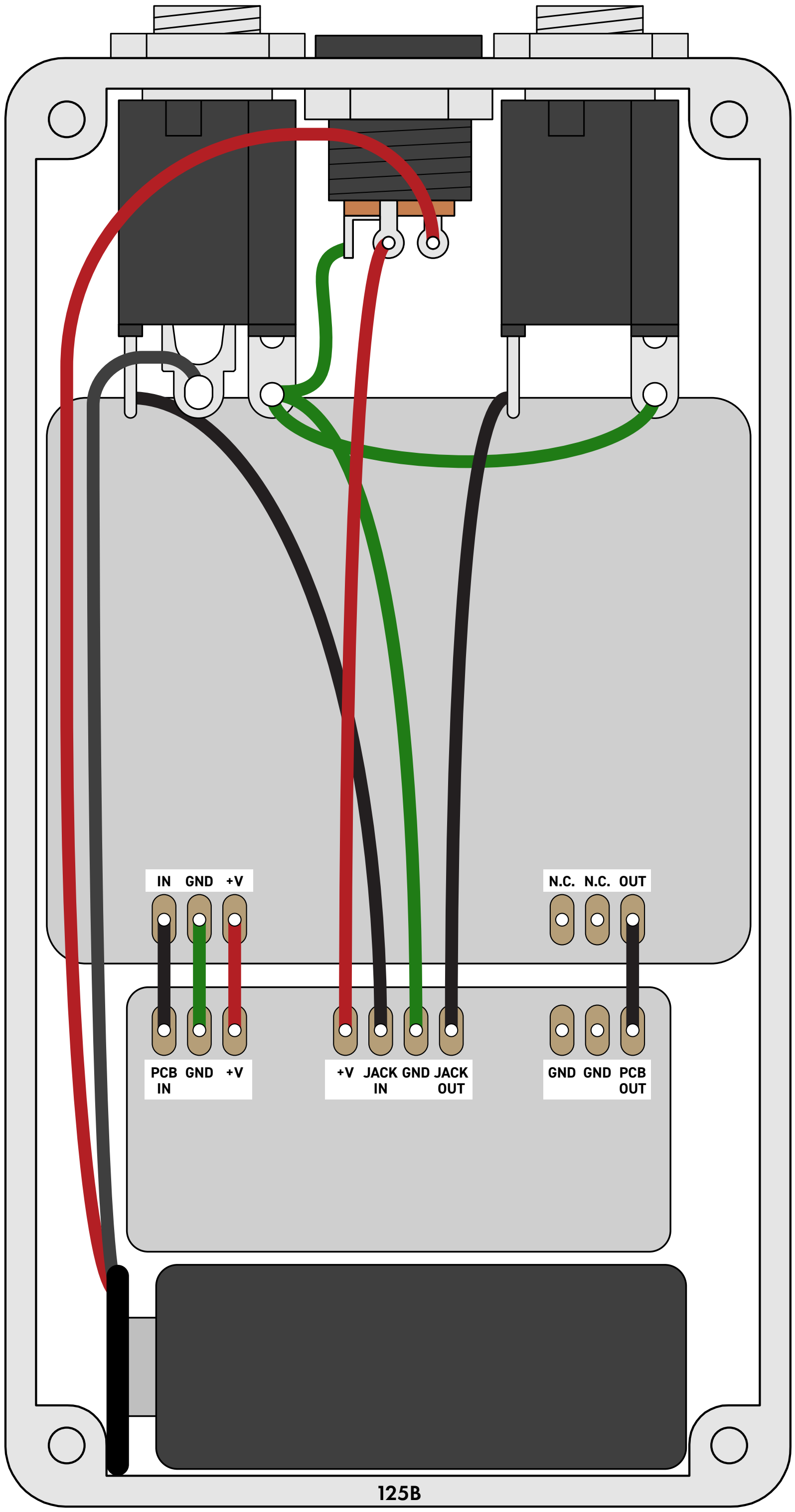


ENCLOSURE LAYOUT

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.