PROJECT NAME
EMERALD

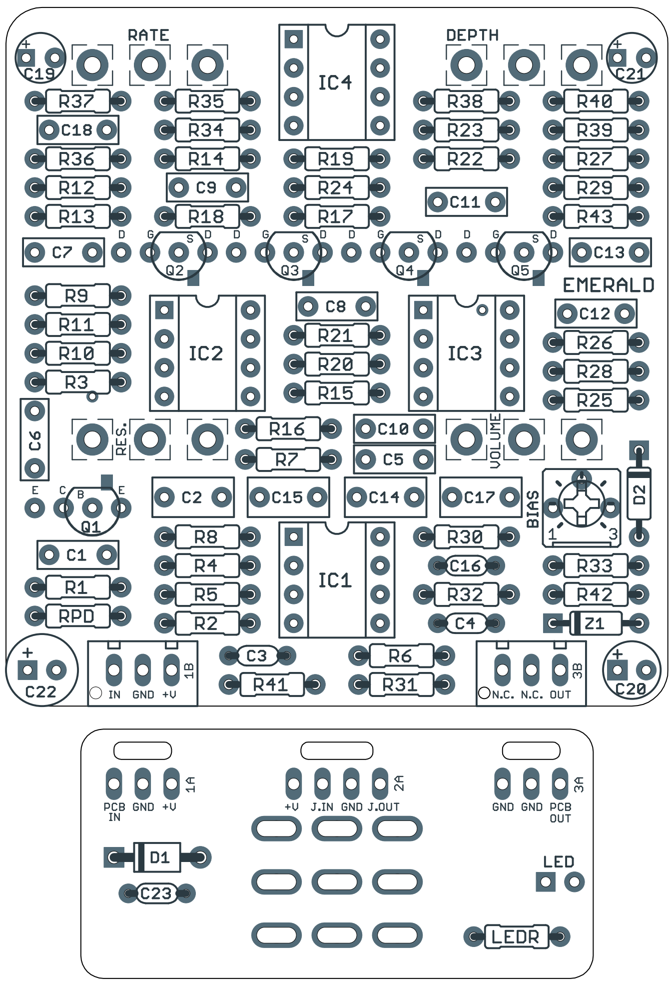
BASED ON
BOSS® PH-1r Phaser

BUILD DIFFICULTY
Intermediate

EFFECT TYPE
4-stage phaser

DOCUMENT VERSION
1.0.0 (2021-11-26)

PROJECT SUMMARY
A four-stage JFET-based phaser similar to the Phase 90, but with with a frequency-dependent feedback control that accentuates the phase effect.



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

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INTRODUCTION

The Emerald Resonant Phaser is based BOSS® PH-1r, a four-stage JFET phaser first released in 1980. The PH-1r is itself a slightly updated version of the PH-1, which was one of the first three BOSS pedals released in 1977 alongside the OD-1 OverDrive and SP-1 Spectrum.

The PH-1r changed the PH-1 circuit enough to warrant a new name, but not a full version number increase. The "r" stands for Resonance (also called "regen" in other similar circuits) which mixes some of the phased output back to an earlier stage, increasing the midrange resonance and making it a much more colorful effect. With the resonance control turned down, it is almost identical to the original PH-1, but it adds another dimension to the tonal palette.

The Emerald is an adaptation of the PH-1r, converting it to true bypass and adding a volume control so that it can be adjusted to perceived unity gain regardless of setting. Other than these changes, it's an exact replica of the original pedal.

The PH-1r uses four matched 2SK30A-GR JFETs for the phase stages. These are similar to the 2N5457, but not identical. For convenience, Aion FX offers matched sets of 2SK208-GR JFETs, which are the SMD version of the 2SK30A and are still in production. They are pre-soldered to through-hole adapter PCBs so they can be used with no SMD experience.

USAGE

The Emerald has four controls:

- **Rate** sets the speed of the phaser effect, from 100 milliseconds to 16 seconds.
- **Depth** sets the intensity of the phaser effect.
- **Resonance** adjusts the amount of frequency-dependent feedback which is fed from the output of the phase stages back to the input.
- **Volume** sets the overall output of the effect signal.

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	47k	Metal film resistor, 1/4W	
R5	47k	Metal film resistor, 1/4W	
R6	47k	Metal film resistor, 1/4W	
R7	12k	Metal film resistor, 1/4W	
R8	1k5	Metal film resistor, 1/4W	
R9	1k5	Metal film resistor, 1/4W	
R10	10k	Metal film resistor, 1/4W	
R11	10k	Metal film resistor, 1/4W	
R12	100k	Metal film resistor, 1/4W	
R13	330k	Metal film resistor, 1/4W	
R14	330k	Metal film resistor, 1/4W	
R15	10k	Metal film resistor, 1/4W	
R16	10k	Metal film resistor, 1/4W	
R17	100k	Metal film resistor, 1/4W	
R18	330k	Metal film resistor, 1/4W	
R19	330k	Metal film resistor, 1/4W	
R20	10k	Metal film resistor, 1/4W	
R21	10k	Metal film resistor, 1/4W	
R22	100k	Metal film resistor, 1/4W	
R23	330k	Metal film resistor, 1/4W	
R24	330k	Metal film resistor, 1/4W	
R25	10k	Metal film resistor, 1/4W	
R26	10k	Metal film resistor, 1/4W	
R27	100k	Metal film resistor, 1/4W	
R28	330k	Metal film resistor, 1/4W	
R29	330k	Metal film resistor, 1/4W	
R30	22k	Metal film resistor, 1/4W	
R31	47k	Metal film resistor, 1/4W	
R32	47k	Metal film resistor, 1/4W	

PARTS LIST, CONT.

PART	VALUE	TYPE	NOTES
R33	470R	Metal film resistor, 1/4W	
R34	150k	Metal film resistor, 1/4W	
R35	470k	Metal film resistor, 1/4W	
R36	4k7	Metal film resistor, 1/4W	
R37	150k	Metal film resistor, 1/4W	
R38	68k	Metal film resistor, 1/4W	
R39	10k	Metal film resistor, 1/4W	
R40	2M2	Metal film resistor, 1/4W	
R41	1k8	Metal film resistor, 1/4W	
R42	47k	Metal film resistor, 1/4W	
R43	1M	Metal film resistor, 1/4W	
RPD	2M2	Metal film resistor, 1/4W	Input pulldown resistor. Can be as low as 1M.
LEDR	4k7	Metal film resistor, 1/4W	LED current-limiting resistor. Adjust value to change LED brightness.
C1	47n	Film capacitor, 7.2 x 2.5mm	
C2	1uF	Film capacitor, 7.2 x 3.5mm	
C3	47pF	MLCC capacitor, NP0/C0G	
C4	100pF	MLCC capacitor, NP0/C0G	
C5	33n	Film capacitor, 7.2 x 2.5mm	
C6	10n	Film capacitor, 7.2 x 2.5mm	
C7	10n	Film capacitor, 7.2 x 2.5mm	
C8	10n	Film capacitor, 7.2 x 2.5mm	
C9	10n	Film capacitor, 7.2 x 2.5mm	
C10	10n	Film capacitor, 7.2 x 2.5mm	
C11	10n	Film capacitor, 7.2 x 2.5mm	
C12	10n	Film capacitor, 7.2 x 2.5mm	
C13	10n	Film capacitor, 7.2 x 2.5mm	
C14	1uF	Film capacitor, 7.2 x 3.5mm	
C15	1uF	Film capacitor, 7.2 x 3.5mm	
C16	47pF	MLCC capacitor, NP0/C0G	
C17	1uF	Film capacitor, 7.2 x 3.5mm	
C18	10n	Film capacitor, 7.2 x 2.5mm	
C19	15uF	Tantalum capacitor, 044A	
C20	47uF	Electrolytic capacitor, 5mm	Reference voltage filter capacitor.
C21	0.1uF	Tantalum capacitor, 044A	Bias voltage filter capacitor.
C22	100uF	Electrolytic capacitor, 6.3mm	Power supply filter capacitor.
C23	100n	MLCC capacitor, X7R	Power supply filter capacitor.
Z1	1N5231B	Zener diode, 5.1V, DO-35	

PARTS LIST, CONT.

PART	VALUE	TYPE	NOTES
D1	1N5817	Schottky diode, DO-41	
D2	1N914	Fast-switching diode, DO-35	
Q1	2N5088	BJT transistor, NPN, TO-92	Subsitute. Original uses 2SC732TM-GR.
Q2	2SK30A-GR	JFET, N-channel, TO-92	Q2-Q5 must be matched to Vgs(off) or Vgs(10k). See build notes.
Q3	2SK30A-GR	JFET, N-channel, TO-92	Q2-Q5 must be matched to Vgs(off) or Vgs(10k). See build notes.
Q4	2SK30A-GR	JFET, N-channel, TO-92	Q2-Q5 must be matched to Vgs(off) or Vgs(10k). See build notes.
Q5	2SK30A-GR	JFET, N-channel, TO-92	Q2-Q5 must be matched to Vgs(off) or Vgs(10k). See build notes.
IC1	JRC4558D	Operational amplifier, DIP8	
IC1-S	DIP-8 socket	IC socket, DIP-8	
IC2	JRC4558D	Operational amplifier, DIP8	
IC2-S	DIP-8 socket	IC socket, DIP-8	
IC3	JRC4558D	Operational amplifier, DIP8	
IC3-S	DIP-8 socket	IC socket, DIP-8	
IC4	TL022	Operational amplifier, DIP8	
IC4-S	DIP-8 socket	IC socket, DIP-8	
BIAS	100k trimmer	Trimmer, 10%, 1/4”	Bourns 3362P or similar.
DEPTH	100kB	16mm right-angle PCB mount pot	
RATE	1MC	16mm right-angle PCB mount pot	
RES.	10kB	16mm right-angle PCB mount pot	
VOLUME	100kA	16mm right-angle PCB mount pot	
LED	5mm	LED, 5mm, red diffused	
IN	1/4" mono	1/4" phone jack, closed frame	Switchcraft 111X or equivalent.
OUT	1/4" mono	1/4" phone jack, closed frame	Switchcraft 111X or equivalent.
DC	2.1mm	DC jack, 2.1mm panel mount	Mouser 163-4302-E or equivalent.
FSW	3PDT	Stomp switch, 3PDT	
ENC	125B	Enclosure, die-cast aluminum	Can also use a Hammond 1590N1.

Matching Q2-Q5

Like the Phase 90 and similar circuits, 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 identically to those in the original PH-1r 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.

Setting the bias

The bias trimmer adjusts the LFO voltage range 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, just adjust the trimmer until you've got the best phasing sound with a wide sweep range and no audible distortion.

If you've got an oscilloscope, the PH-1r service manual gives the full factory setup procedure.

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.

BUILD NOTES, CONT.

How closely should they be matched?

In the original PH-1r, the JFETs were painted with a color code on the top corresponding to their $V_{GS(off)}$ value. We measured the JFETs in three original PH-1r units with the following color codes:

- **Orange:** $V_{GS(off)}$ -1.71V to -1.73V
- **Green:** $V_{GS(off)}$ -1.78V to -1.83V
- **Blue:** $V_{GS(off)}$ -1.92V to -1.96V

We've also seen photos of pink and yellow units, but it's not known whether these ranges are higher than blue, lower than orange, or in between the colors we've tested.

Based on the above, and accounting for differences in equipment and testing conditions, it seems likely that orange is intended to be -1.70 to -1.79V, green -1.80 to -1.89V, and blue -1.90 to -1.99V.

Green did have one outlier, but if you shift all of them up by 0.02V to allow for test conditions or calibration differences, it fits the theory. With that said, though, the maximum spread in any of the three PH-1r units was only 0.05V, so it's also possible that pink and yellow are in between the other three.

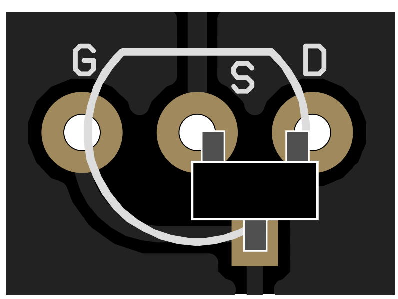
Whatever the case, if you do match your own, it should work fine with anything inside of a 0.1V spread, though you should try for 0.05V if you can. The matched sets from Aion FX are typically within 0.01V of each other, about as close to ideal as you can get.

Using SMD JFETs

The 2SK30A-GR JFET is no longer available in through-hole format. The 2SK208-GR is the SMD equivalent and is still in production.

This PCB uses a hybrid through-hole/SMD outline for each JFET. An extra "G" (gate) pad is included to accommodate surface-mount devices without the need for adapters.

SMD JFETs should be oriented as follows:



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

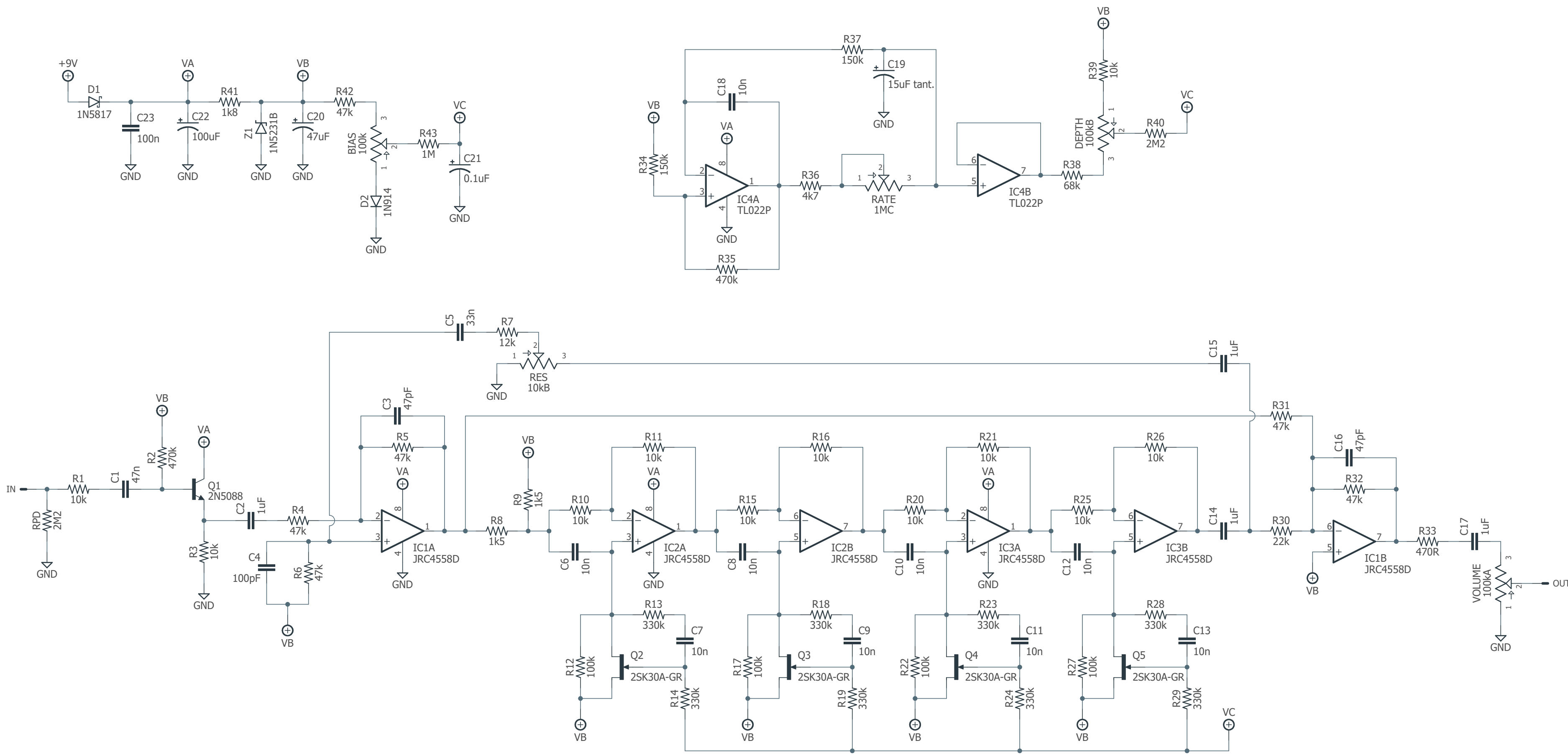
Using old-stock transistors

Toshiba has not manufacturered through-hole transistors and JFETs in many years, but it's still possible to find the 2SK30A-GR as well as the type of BJT transistor used in the original. However, be aware that these follow the Japanese pinout conventions, whereas the PCB layout is set up for USA conventions since there are a lot more widely-available substitutes in this format.

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.

SCHEMATIC



+9V
D1
1N5817
C23
100n
GND
VA
C22
100uF
R41
1k8
Z1
1N5231B
VB
C20
47uF
R42
47k
BIAS
100k
D2
1N914
R43
1M
VC
C21
0.1uF
R37
150k
C19
15uF tant.
C18
10n
R34
150k
IC4A
TL022P
R36
4k7
RATE
1MC
IC4B
TL022P
R38
68k
R35
470k
R39
10k
DEPTH
100kB
R40
2M2
C5
33n
R7
12k
RES
10kB
C15
1uF
IN
R1
10k
RPD
2M2
C1
47n
R2
470k
Q1
2N5088
R3
10k
C2
1uF
R4
47k
C4
100pF
R6
47k
C3
47pF
R5
47k
IC1A
JRC4558D
R8
1k5
R9
1k5
R10
10k
C6
10n
R11
10k
IC2A
JRC4558D
R13
330k
C7
10n
Q2
2SK30A-GR
R12
100k
R14
330k
R15
10k
C8
10n
R16
10k
IC2B
JRC4558D
R18
330k
C9
10n
Q3
2SK30A-GR
R17
100k
R19
330k
R20
10k
C10
10n
R21
10k
IC3A
JRC4558D
R23
330k
C11
10n
Q4
2SK30A-GR
R22
100k
R24
330k
R25
10k
C12
10n
R26
10k
IC3B
JRC4558D
R28
330k
C13
10n
Q5
2SK30A-GR
R27
100k
R29
330k
C14
1uF
R30
22k
R31
47k
C16
47pF
R32
47k
IC1B
JRC4558D
R33
470R
C17
1uF
VOLUME
100kA
OUT

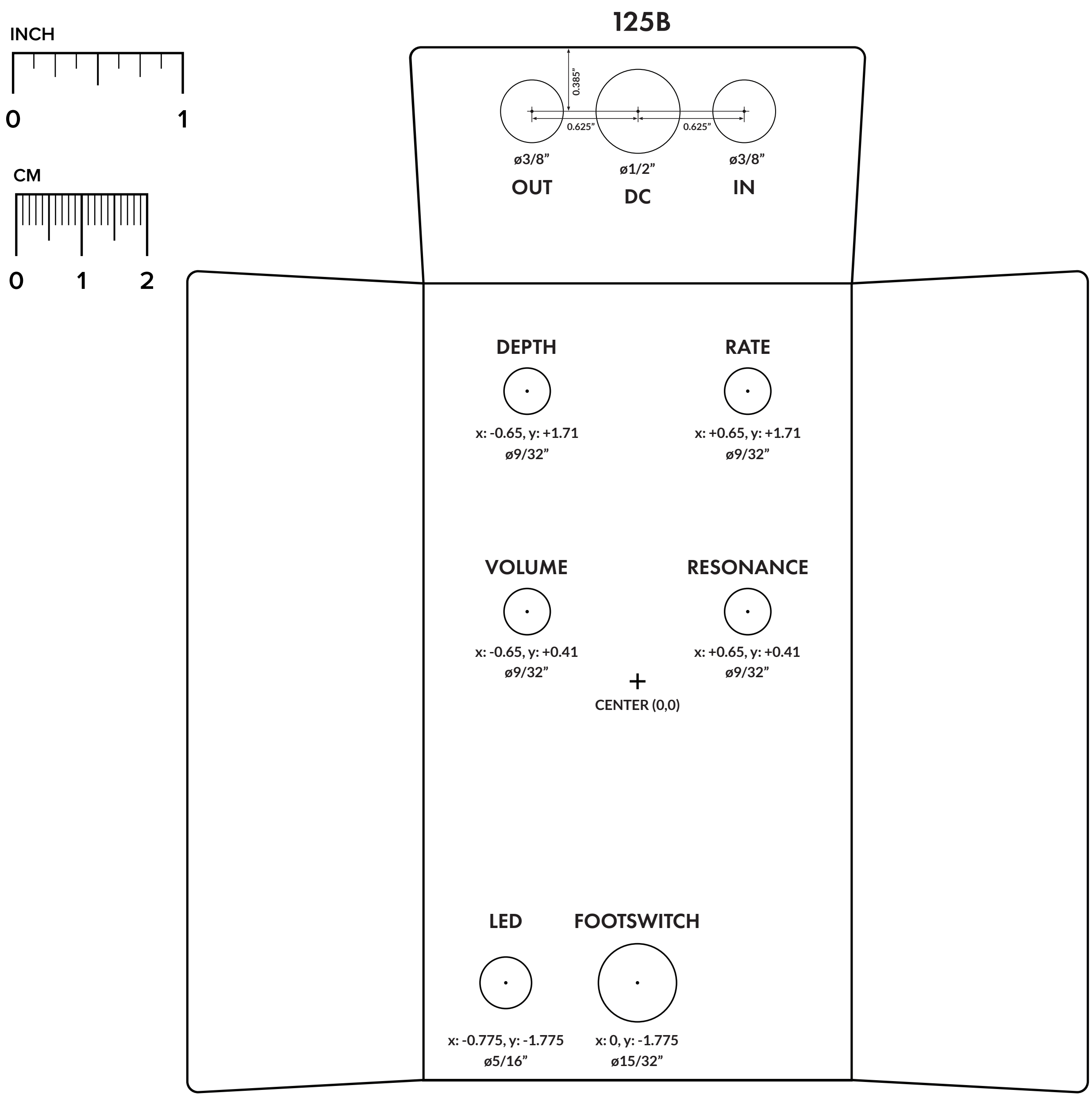
DRILL TEMPLATE

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.

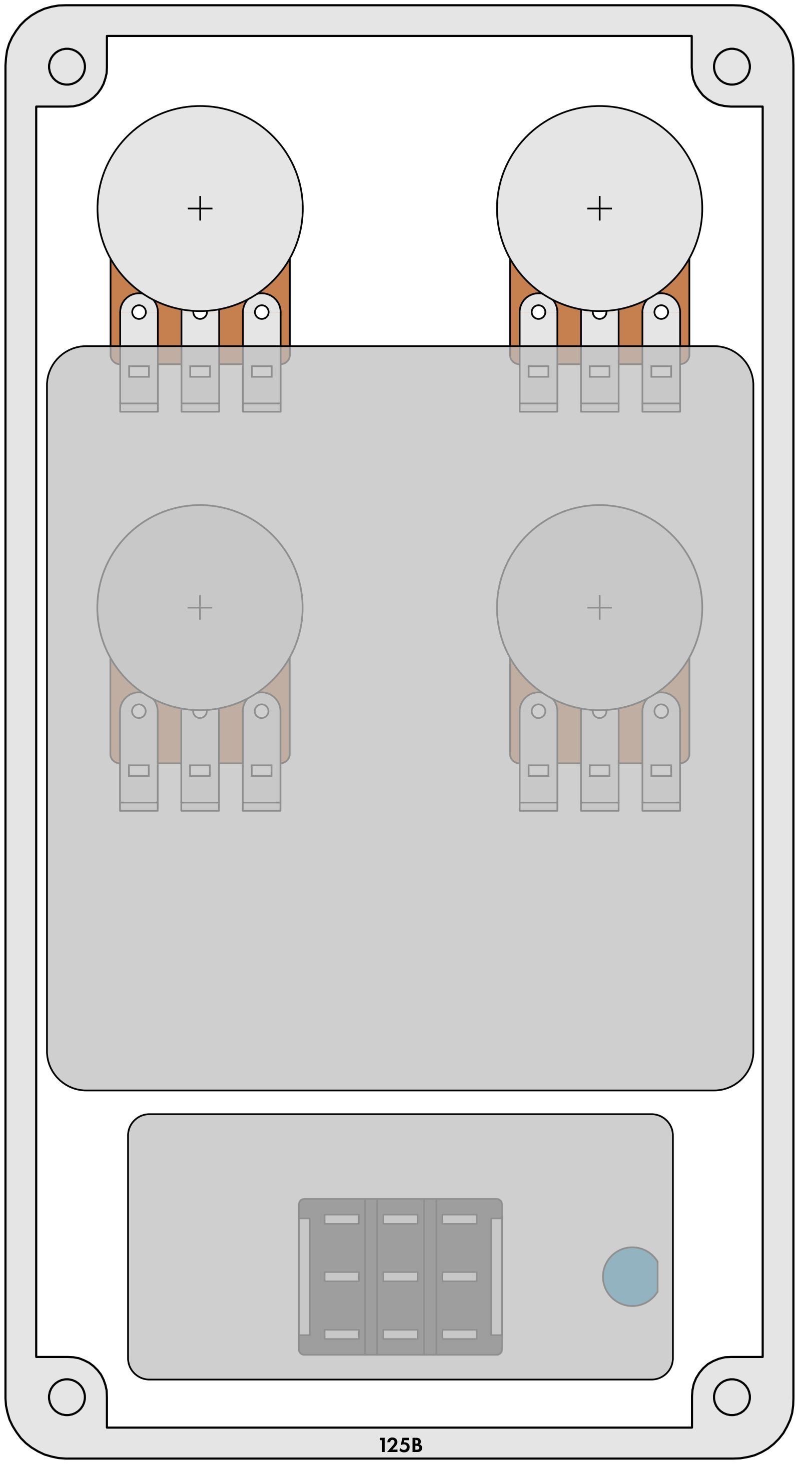
Top jack layout assumes the use of closed-frame jacks like the Switchcraft 111X. If you'd rather use open-frame jacks, please refer to the Open-Frame Jack Drill Template for the top side.

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.

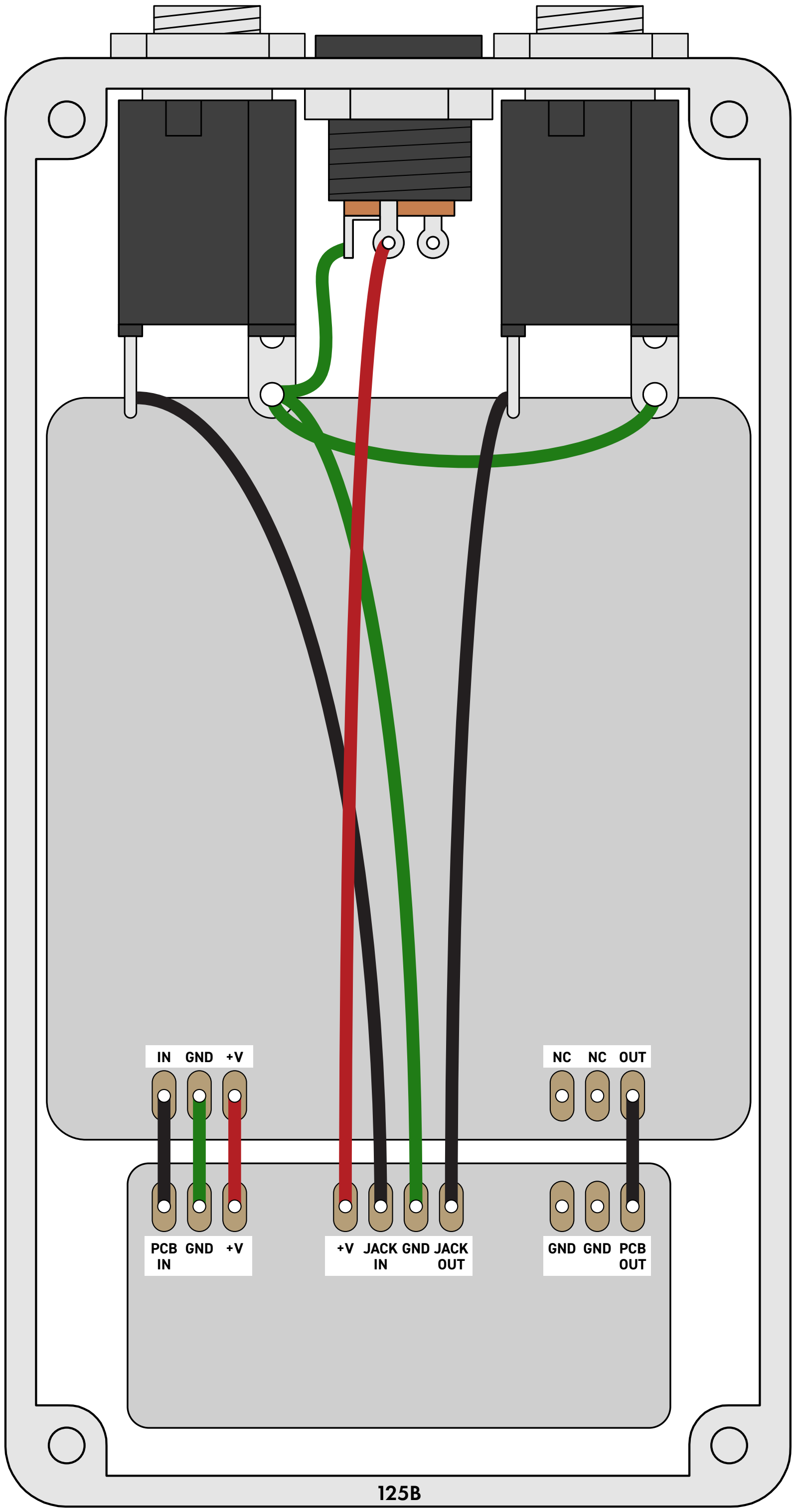


ENCLOSURE LAYOUT

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 (2021-11-26)
Initial release.