# POLARITY PROTECTOR
# CONSTRUCTION AND TESTING

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April 2021

DISCLAIMER

***Construct and/or use this protection device at your own risk.***

This is a non-professional *kit*, and the design, parts, and construction have not been evaluated to the same degree that a fully produced commercial kit might have been. You are encouraged to carefully follow the testing procedures included here-in to develop your own understanding of how much trust to place in this protection system and to verify that you have constructed it properly with properly-operating parts-- BEFORE connecting it to a valuable radio.

It is very important not to have a means for reversing the wires AFTER this protective device, before reaching the valuable radio.

While this design is a well-described and very commonly used by many, because of the variations in devices, and the lack of formal sensitivity analysis, and the unknown quality of manufacturer the designer nor the kit producer can guarantee that the device will perform satisfactorily. Nevertheless, we believe this is an effective way to protect valuable radios from many user-errors that would otherwise destroy radios by reverse polarity connections.

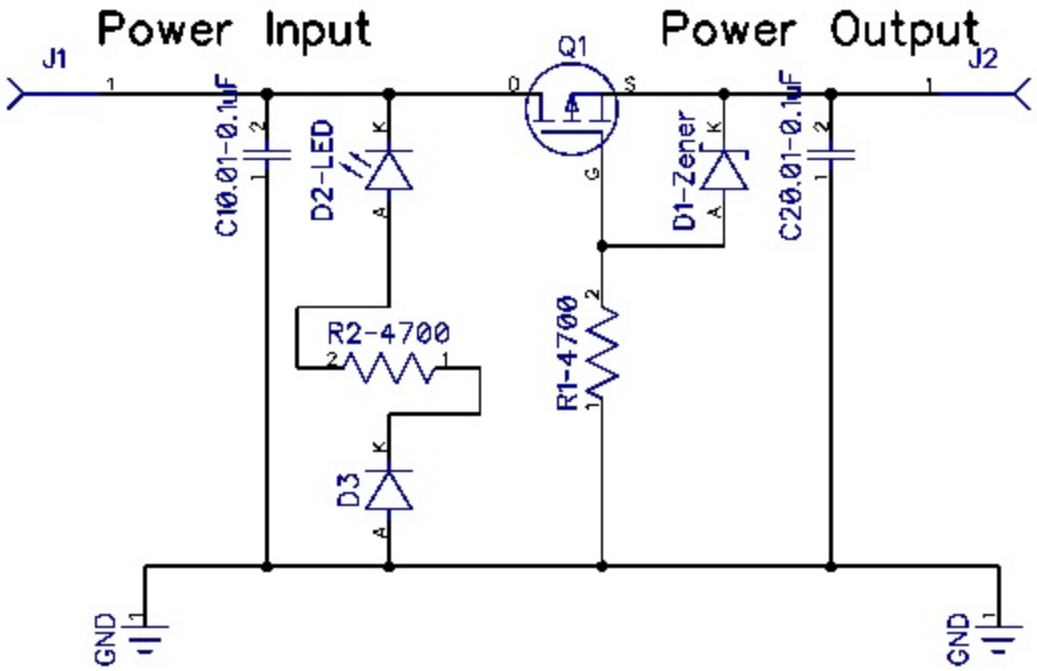
Avoid exposing this device to excessive heat such as unprotected exposure to sunlight in a vehicle dash board or similar.

- Please READ and UNDERSTAND all of these instructions, and the Disclaimer above, before beginning construction. This is an UNSUPPORTED kit intended for construction by persons with suitable knowledge and experience to solder and test a kit, or those with sufficient mentoring to succeed. The author cannot provide guaranteed mentoring for persons who experience difficulties with this kit.

PCBWAY Printed Circuit Board is now SHARED -- making it easier for you to purchase:

https://www.pcbway.com/project/shareproject/13_8VDC_Polarity_Protector.html

# SCHEMATIC




| Component | Specification | Comment/ Substitution |
|---|---|---|
| C1, C2 | 0.1 uF >= 25VDC | Used for RF bypass. Any value from 0.01 to 0.1 uF is likely to work well. |
| D1 | Zener Diode, 10-12 VDC | Any value zener from 10-12 volts likely to work well, 1/2-1W |
| D2 | Amber LED | Indicates reverse input polarity. Any type LED will likely work well. |
| D3 | 1N4007 | Almost any diode with a reverse breakdown voltage > 25V will work adequately. |
| R1, R2 | 4700 ohms, 1/4 watt. | Almost any value of resistor from 2-10K will likely work well, 1/2 - 1/4 W |
| Q1, (or Q2, or Q3, or Q4) | Infineon P-channel enhancement mode MOSFET,<br><br>**IPP80P03P4L04AKSA2**<br>or<br><br>**IPP120P04P4L03AKSA1** thru-hole, 40V, 120A rating, ON resistance 3.1 | SEPT 2022 UPDATE<br>AVAILABLE PART AT MOUSER:<br>IPP80P03P4L04AKSA2<br>https://www.mouser.com/ProductDetail/Infineon-Technologies/IPP80P03P4L04AKSA2?qs=GBLSl2AkirtPy%252BfkEHgmyQ%3D%3D<br><br>The number of high power **thru-hole** power MOSFETS is shrinking. Almost all of the P-channel enhancement modes are similar and conduct well with |

| | | |
|---|---|---|
| | milliohms. Limited stock, not recommended for new designs<br><br>https://www.digikey.com/en/products/detail/infineon-technologies/IPP120P04P4L03AKSA1/5960348<br><br>A second-best choice (6.7 milliohms, twice as much voltage drop and power dissipated) is the Vishay **SQP90P06-07L_GE3** https://www.digikey.com/en/products/detail/vishay-siliconix/SQP90P06-07L-GE3/9861092 | a gate voltage 10V below the source voltage. The pin out is almost always the same. There are possible substitutes for this device; be sure to check for a voltage rating >= 40 V and an ON resistance below 7 milliohms for reasonable performance Higher ON resistances will require additional devices in parallel to avoid significant voltage drop and heating. |

# OBTAINING PARTS IF YOU DID NOT PURCHASE AS A FULL PARTS KIT
# TWO EASY METHODS

1) SHARED DIGIKEY CART: https://www.digikey.com/short/w55b2dv5

Click on this cart and then proceed as appropriate to purchase. The current cost of the cart (without shipping / handling) is under $8. This cart is for TWO MOSFETs. You might wish to increase the quantity of some of the items to have spares or additional parts for your future building projects.

2) Comma-separated cart (suitable for uploading to Digikey)

```
"Index","Quantity","Part Number","Manufacturer Part Number","Description","Customer
Reference","Available","Backorder","Unit Price","Extended Price USD"
"1","1","1N4742AFSCT-ND","1N4742ATR","DIODE ZENER 12V 1W
DO41","","1","0","0.32000","0.32"
"2","2","IPP120P04P4L03AKSA1-ND","IPP120P04P4L03AKSA1","MOSFET P-CH 40V 120A TO220-
3","","2","0","3.13000","6.26"
"3","2","S4.7KCACT-ND","RNMF14FTC4K70","RES 4.7K OHM 1/4W 1%
AXIAL","","2","0","0.10000","0.20"
"4","1","C5SMF-AJE-CU0V0342CT-ND","C5SMF-AJE-CU0V0342","LED AMBER CLEAR 5MM OVAL
T/H","","1","0","0.15000","0.15"
"5","2","399-9859-1-ND","C315C104M5U5TA7303","CAP CER 0.1UF 50V Z5U
RADIAL","","2","0","0.23000","0.46"
"6","1","641-1312-1-ND","1N4007-G","DIODE GEN PURP 1KV 1A
DO41","","1","0","0.22000","0.22"
```

Save the above comma-separated parts in a .csv file, which can be done with Windows Notepad.

Go to https://www.digikey.com/
Click "BOM MANAGER" from top menu
Upload the above comma-separated file.
Proceed as appropriate to purchase.

**Parts can be obtained more cheaply by purchasing as a club or group in larger quantities.**

# PARTS IDENTIFICATION

- ❑ Review all of the parts by comparison to the photograph below

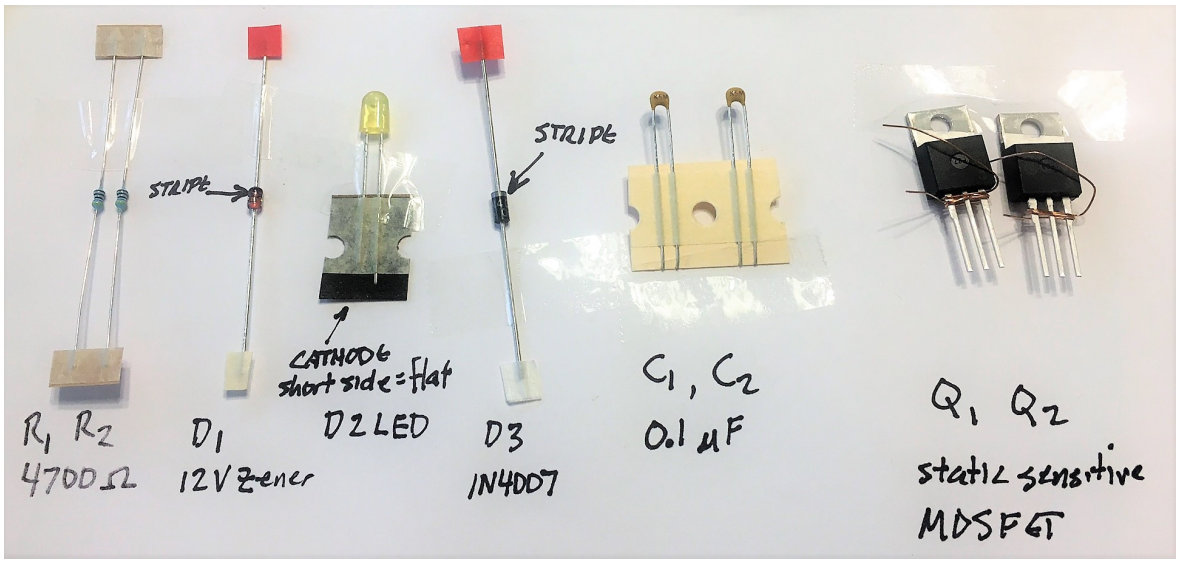



Figure: Parts required for this project, laid out left to right in the suggested order of installation.

- ❑ Note that there may be 2, 3, or 4 MOSFETs in your kit or construction, depending on your purchase and choice of current to design for.

| Transmitter Watts / Amperes to support | Recommended # of 3-5 milliohm $R_{DSon}$ MOSFETS in parallel |
|---|---|
| <=50Watts / 10 A | >= 2 MOSFETS |
| <=100 Watts / 20 A | minimum 3, recommend 4 |

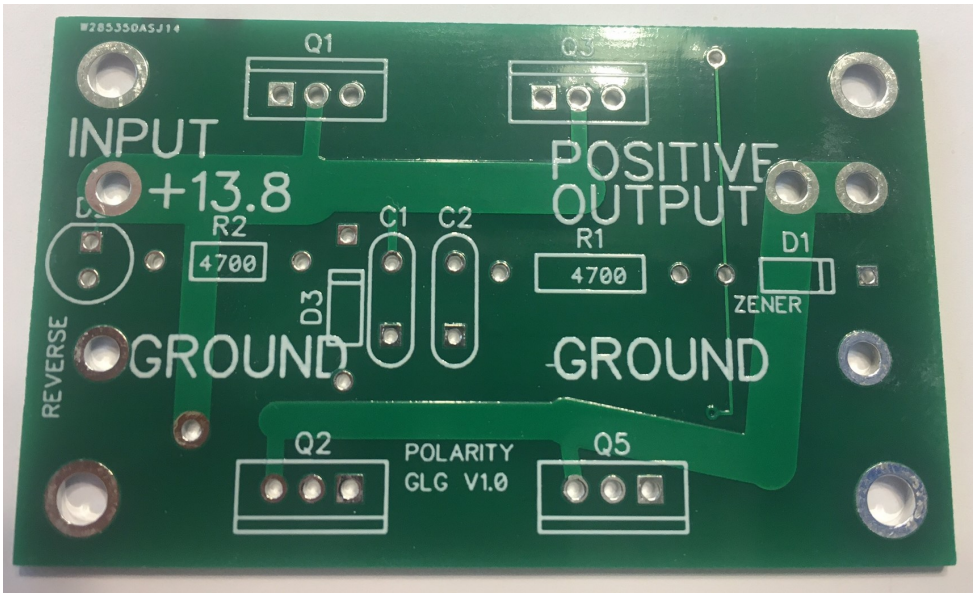
- ❑ CAUTION: The MOSFETS are static sensitive, with a limit of 20 volts maximum (or less) between gate and source; a static discharge may easily blow the delicate insulation between the gate and the channel. AVOID STATIC. Avoid dry cold days with low humidity & use very careful procedures to avoid static.

- ❑ CAUTION: A small bit of wire may be wrapped around the leads; this is for static protection. Do not solder this wire to the pins when you insert and solder the MOSFET!! Instead, either insert the MOSFET into the proper component holes (taking note of the position of the heatsink tab) and then remove the wire before soldering, or carefully solder so as not to solder the wire and then remove it.

- ❑ Take special note of the polarized parts: The Zener diode is typically in a glass package and has a STRIPE to indicate the cathode end, which must match the stripe (band) on the printed circuit board. The 1N4007 rectifier has the same type stripe, but the package is typically black plastic. The light emitting diode (LED) has a shorter lead, which corresponds to the cathode end, and must match the FLAT end of the printed circuit board image. The MOSFETS have a certain pin out, and the HEATSINK TAB must match the image on the printed circuit board for them to be installed correctly.

- ❑ The capacitors and resistors are not polarized.

**Circuit Board:** The board is a 2-layer printed circuit board, and has a silk-screened side, on which all components are placed and soldered on the bottom side. For the high power handling solder joints (the positive input and output leads, and the leads to the MOSFETs, be sure that the top connection is also displaying some solder, Electrical solder with rosin core is required, not acid-based plumbing solder. While either leaded or non-lead containing solder can be used, some persons find that traditional 60/40 tin/lead solder works at a lower temperature and provides easier soldering. BE CAREFUL with soldering iron to avoid burns or a fire.



## PARTS INSTALLATION

- ❑ Insert one or more components, with a slight bend to their leads on the underside of the board to make them stay in position, and then carefully solder so as not to create solder bridges, nor to burn the pad or board. Typically 1-4 components are installed, soldered, and the excess leads snipped off, before proceeding. When snipping off excess leads, avoid creating a risk of a flying wire harming someone.

- ❑ Proceed to install the components in order as shown in the above figure of the components, from left to right. This is so that all the other components are installed BEFORE the static-sensitive MOSFETs.

- ❑ Install the first MOSFET in the position Q1 on the board. If you installed all the other components first, as instructed above, as soon as you place the pins into the MOSFET position, it is largely protected, even before soldered. If your MOSFETS came inserted in a protective foam, simply carefully move the first one directly into the circuit pads, and then solder. If your MOSFET came with a small shorting strand, DO NOT SOLDER THAT STRAND; you can remove it before or after soldering, but after inserting the device into the pinholes. Don't forget to remove the shorting strand! POLARITY: The screenprint shows which side the heatsink tab should be on (always to the OUTSIDE of the board); this must be followed. Complete the TESTING described below before adding the next MOSFET, so that you can verify proper operation of each MOSFET individually as added to the circuit.

  *If Testing is done after adding each MOSFET, you could more easily recognize one that is improperly added, or damaged.*

- ❑ If there are TWO MOSFETS, they should be placed in the Q1 and Q2 positions; if three, in the Q1, Q2, and Q3 positions. If four, use all the positions. The circuit board has parallel tracks in order to reduce total voltage losses, so using both "tracks" will best take advantage of this feature.

## CIRCUIT TESTING

- ❑ Do NOT have the circuit board powering a radio for this testing.
- ❑ Have the circuit board on a NON-conductive surface.
- ❑ Be certain that you have removed any "shorting strands" of wire if there were any on the MOSFETS.
- ❑ Connect a source of +13.8VDC properly to the input terminals (plus to plus, and negative to the ground terminal). This doesn't have to be a permanent connection, and can be done with simple alligator clip test leads. Verify with a voltmeter that +13.8 VDC appears on the output terminals. There should be NO discernible voltage loss in the circuitry in this no-load test.

  *Under load, the traces of the circuit board may actually create more resistance than the combined parallel resistance of the MOSFET switches. The goal is to keep the MOSFETs cool so that they don't need any heatsinks, and thus aiming for individual MOSFET heat dissipation <= 0.5 W. Since W = I2R, keeping the current on each MOSFET at or below 5 Amps causes this requirement to be satisfied if the MOSFET on resistance is less than 20 milliohm. The devices used have ON resistances far lower than 20 milliohm and thus stay cool. At 5A maximum through each 5-milliohm device, the voltage loss of the paralleled MOSFETS will be less than or equal to 25 millivolts, a very negligible loss of voltage and FAR less than can be achieved with a Shottky diode.*

- ❑ With the negative probe of your voltmeter touching a "ground" pin, touch your positive voltmeter probe to the pad shown in the photo below as the "test point" and verify that the voltage is 1-4 volts positive. (This voltage should be limited in its ability to approach the negative power supply terminal voltage by the reverse avalanche conduction of the zener.)

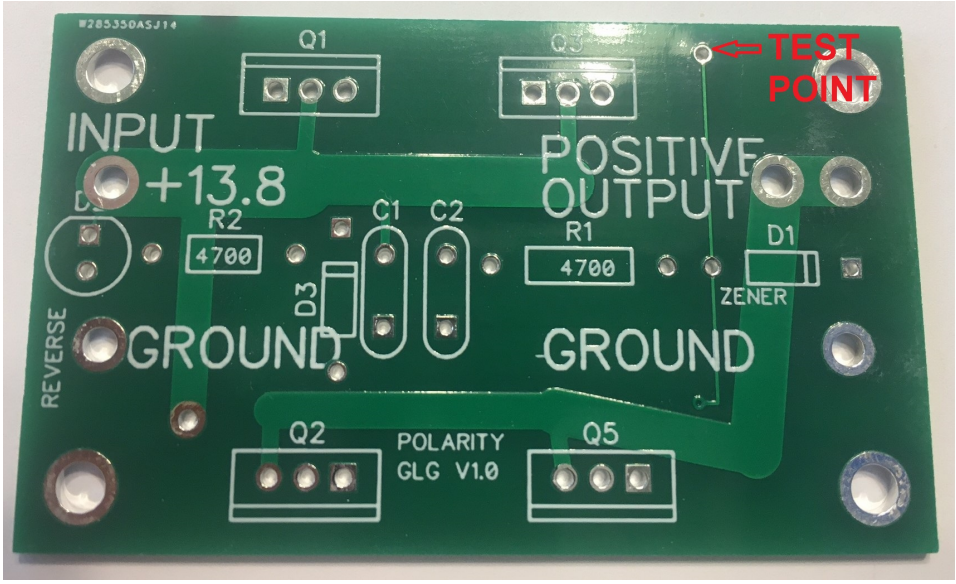



***FIGURE: Test Point Location -- allows measurement of the GATE***

***voltage on the MOSFETS, which is limited to safe values by the zener diode.***

*If this voltage measures only 0.6-0.7 volts different than the negative lead of the power supply, the zener diode may have been installed backwards.*

- ❑ Reverse the polarity of the <u>input</u> to the WRONG input polarity and confirm that (a) the LED illuminates, and (b) there is ZERO output voltage (or < 2 millivolts) present at the output terminal with respect to ground (positive terminal of your power supply).

  *If there is any significant output voltage, a MOSFET may have been inserted backwards or may be defective (shorted).*

- ❑ With the negative probe of your voltmeter connected to the negative terminal of your power supply, verify that the voltage on the "test point" pad, when touched by your voltmeter positive probe, is between 0 and 1 volt positive.

  *This voltage should be limited by the forward conduction of the zener diode. If greater than +2 volts positive, the zener may have been installed backwards.*

## FINAL WIRING TO PROTECT RADIO EQUIPMENT

- Connection to Radio: Most recently manufactured radios have a polarized connector for their power input, and come with a properly fitting polarized plug to match, to prevent accidental reversal of polarity at the very power input to the radio. BE CERTAIN TO USE THE MANUFACTURER'S SPECIFIED POWER CABLE.

- Most recently manufactured radio power cables may have two fuses installed in the proper power cable, typically farther from the radio in order to be closer to the battery or other power source. The typical goal for these fuses is to blow and interrupt current before the wiring would become hot enough to support combustion of the insulation.

- The polarity protector circuit should be installed on the RADIO side of any such fuses, and there should NOT be any other connectors (not even Power Pole connectors) between the polarity protector circuit and the radio. This is an important point and must be emphasized. ANY type of connector other than the manufacturer's back-panel polarized connector, raises the possibility of some mis connection beyond the control of the polarity protection circuit.

- It is fine to have any desired connectors between the battery or other power source and the power protector circuit. Power Pole or suitable polarized connectors are suggested. A frequent cause of destroying radios is accidentally applying connectors to a BATTERY in a reverse fashion due to confusion of the batter terminals or connectors. As long as the erroneous connection is on the INPUT side of the polarity protector circuit, it should protect your valuable radio from damage, and indicate a reversed polarity by illuminating the LED.

- The power wiring should be of a suitable size for the current to be handled. The solder points on the board are suitable for up to #12, and stranded (flexible) wiring is suggested.

- The POSITIVE wire from the power source should be connected to the INPUT 13.8V terminal.

- The POSITIVE wire from the radio input should be connected to the POSITIVE OUTPUT terminal. Very important to get this connection correct. There are TWO solder points provided in case you need to provide power to more than one radio.

- GROUND WIRE: It is actually preferable NOT to interrupt the power cable's negative (ground) wire, because the resistance of the ground path on the circuit board is likely more than that of a suitably sized power cable. It is sufficient to provide a short connection of #16, or #18 AWG stranded wire from the negative (ground) power cable NEAR THE RADIO INPUT (NOT on the battery side of any fuses) so that the circuit will be able to sense the polarity of the ground cable. IF you choose to interrupt the negative cable by connecting to the input and output of this circuit, you may wish to parallel the circuit board trace with a #18 or #16 short length of wire to reduce the loss in the circuit board ground trace.

- ❑ Please RE-TEST the polarity protection by observing the voltage protection at the manufacturer's polarized cable plug BEFORE connecting to the valuable radio. See the Testing section above.

- ❑ Mount the polarity protector inside a suitable enclosure so that the METAL TABS of the MOSFETS will NOT SHORT OUT to any metal, and the wiring and soldering will also not short out. The mounting solder holes are NOT connected to any of the wiring of the circuit, and can pass 4-40 screws or 3mm screws, or can be slightly drilled out to pass 6-32 x 1/2" or 5/8" or 3/4" screws.

- ❑ An easy way to mount the circuit board is to mark where the screws should be with a felt tip marker thru the mounting holes, then drill to easily pass a 6-32 x 1/2" or 5/8" or 3/4" screw, put a nut on the INSIDE of the box and tight down the screw from the outside, then place the circuit over the remaining portion of the screw length and use another nut to gently tighten down and secure the circuit board.

- ❑ Suitable enclosures could include a shallow Carlon flanged old-work utility electrical box (https://www.homedepot.com/p/Carlon-Blue-PVC-1-Gang-8-cu-in-Flanged-Shallow-Old-Work-Electrical-Outlet-Box-B108R-UPC/100404058, typical price $1.58 ) with a blank cover, or a suitably sized plastic box of a different manufacture.

# THEORY OF OPERATION

MOSFET Q1 (possibly formed from 2-4 devices paralleled) will conduct heavily if the gate is brought to a voltage 10V negative with respect to the Source. If the gate is near zero volts or positive, the device becomes basically non-conductive....except for the BODY DIODE, which is an intrinsic (un-avoidable) part of the device that will conduct as a normal diode if the DRAIN is more than 0.6 volts positive with respect to the SOURCE. For this reason, it is important that the MOSFET be installed in the circuit so that the Source is connected to the load. If it were the other way, even an improper polarity input would be conducted to the output terminal, by the intrinsic diode.

The gate-source voltage limit of the device may be as low as 16V. To avoid damaging this delicate gate insulation, zener diode is connected from the Source to the Gate so that the Gate can never go more negative than the avalanche voltage of the diode (selected to be 10-12V) In the case of a reversed input polarity, the Gate may rise to a higher voltage than the source, but the forward conduction of the Zener diode (in its normally conductive diode mode) will limit that excursion to only 0.6VDC.

Resistor R1 protects zener diode from excessive current flow.

Resistor R2, and the LED diode and rectifier diode are in series to allow the LED to illuminate if the input polarity is reversed to the improper polarity. This gives the operator some indication why the connected radio will not turn ON.

RF bypass capacitors C1 and C2 are added merely to attempt some suppression of RF voltages that might otherwise impact the operation of the circuit.

# TROUBLESHOOTING

| No. | Issue | Possible Causes / Suggestions |
|---|---|---|
| 1 | No output voltage when proper polarity is provided at the input. | MOSFET installed backwards. Heatsink tab must be to the outside.<br><br>Ground connection not made to the power supply.<br><br>Resistor R1 open or not suitably soldered<br><br>Bad solder joint<br><br>MOSFET failed open (unlikely unless output was short circuited and fuses failed to blow)<br><br>Zener diode installed backwards.<br><br>Inadvertent solder bridge from a MOSFET gate pin to another drain or source pin. |
| 2 | More than negligible voltage on output with reversed polarity input. | Shorted MOSFET, or damaged due to static electricity before added to circuit.<br><br>Shorting wire was not removed after installation.<br><br>MOSFET installed backwards. |
| 3 | Amber LED does not light when reverse polarity input is tried. | Amber LED installed backwards<br><br>Diode 1N4007 installed backwards<br><br>Resistor R2 open or not suitably soldered |
| 4 | Test point voltage goes all the way to ground voltage when 13.8 VDC proper polarity used as input. | Open zener diode. |
| 5 | Test point voltage only reaches 0.7 volts below 13.8 VDC (i.e. 13.1 VDC) proper polarity input voltage instead of going all the way down to 1-4 volts. | Zener diode installed backwards |