DC protection Circuit v1.0 Documentation

TolisDIY.com (v1.1 doc)

Intro:

The following document is aimed at providing a detailed circuit description to the operation of the DC protection circuit v1.0. The circuit can do more than just a simple DC protection, a quick overview of what it enables is:

- DC protection for 1-2 channels
- Support single ended, 3-channel (active ground), and balanced amplifier
- Adjustable sensitivity to DC level
- Independent DC detection per channel for a more robust design
- Wide supply voltage support (dual rail +-12V - +-75V, or a single 24 - 150V supply)
- Wide input voltage support (up to +-55V)
- Support 2 outputs (A/B/A+B)
- Visual notification of active output (LED)
- Visual notification of protection state (LED)
- Delayed start-up to allow amplifier settling
- Accelerated shut-down to reduce chance of "popping" noise

The supply range and input voltage range can be extended further with a few simple modifications if required. However, the default values are sufficient for almost all headphone/speaker amplifiers. While the default build supports all of the functions above, the circuit can be stripped down of some parts if not all these functions are required. For instance, LED's can be omitted, sensitivity can be made non-adjustable, and so on.

Main specifications:

Supply voltage – min:24V(+-12V) max:150V(+-75V)

Supply current – 40mA max with single relay active, 60mA max with two relays active.

Input voltage – 55V maximum in either polarity

Load current – 8A max, derived from relay limits – an off-board relay can extend this value further

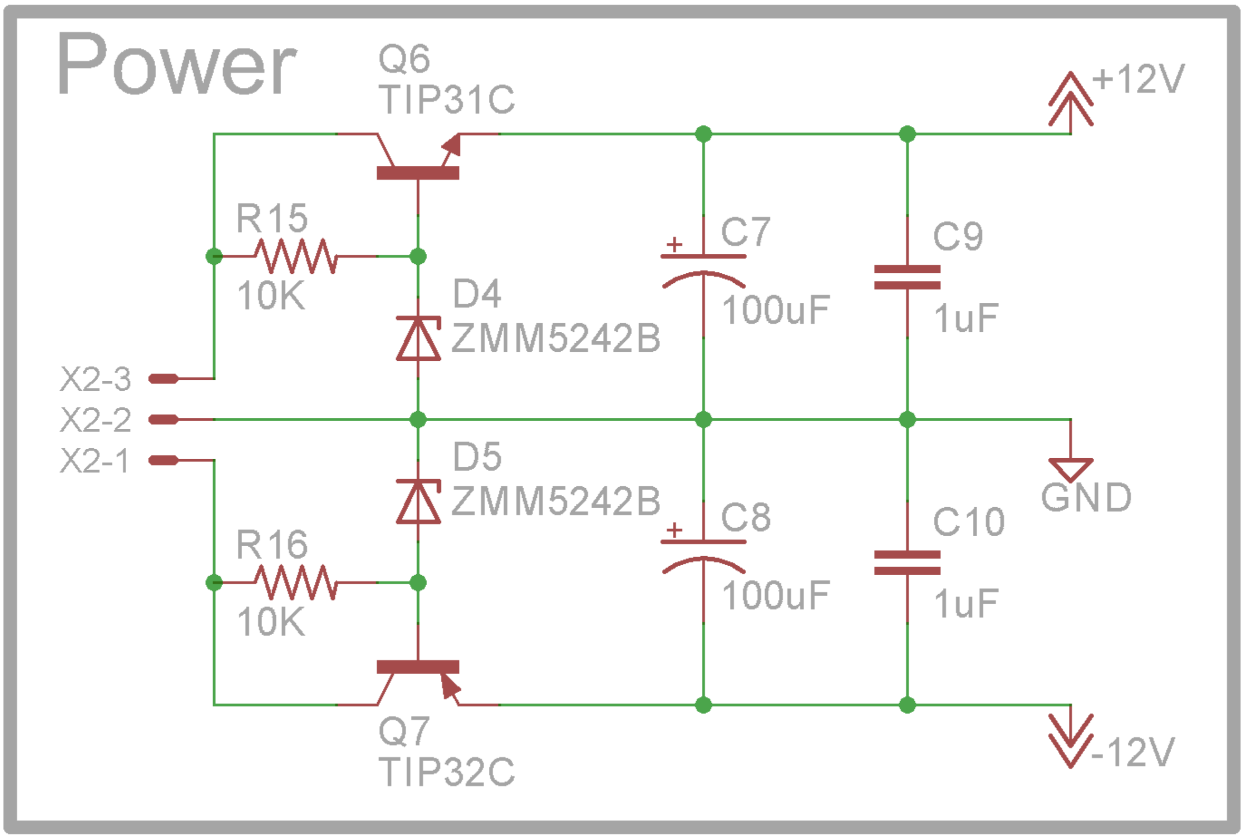
DC sensitivity – adjustable 75mV – 270mV. Can be extended further by replacing a single resistor

Circuit schematic and operation:

The circuit can be broken down into 3 main parts: power supply, signal filtering and detection, and switching circuit.

Power supply:

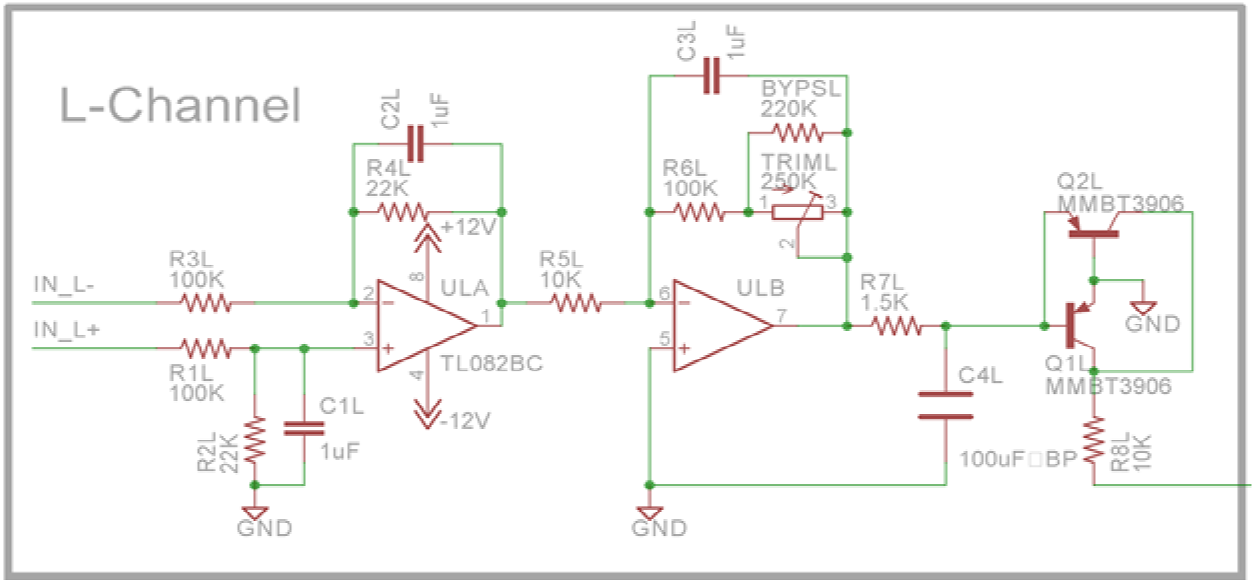
The power supply section is a simple implementation of the Zener follower circuit:



The Zener diodes D4/D5 generate a voltage of +-12V, which is then buffered by the transistors Q6/Q7. The value of R15/R16 is 10K to support high supply voltage range up to 75V (82V if it is operated at its maximum allowed power dissipation value which isn't recommended). The transistors Q6/Q7 are rated for 100V, and there don't pose a limit for this circuit. The output capacitors will be operated at a voltage of ~11V, therefore a capacitor with a voltage rating of 16V or over is recommended.

Signal filtering and detection:

The signal filtering and detection signal is based on a differential amplifier structure implemented with an operational-amplifier, with further filtering after it. Overall a 3rd order filter is implemented before feeding the detection circuit, to enable high selectivity between DC and low frequency music content:



The left channel is included in the figure above, with the right channel being an identical copy. The only difference is the use of a suffix *R* instead of *L* for part names.

The circuit starts with a differential amplifier with an input impedance of 100Kohm which is also used as a low pass filter. This amplifier has a gain of 0.22, which allows for input signals of >50Vin either polarity to be supported despite the fact it is operated from a dual 12V supply. The filtered and attenuated signal after the first stage is fed into an inverting amplifier structure with an adjustable DC gain, and an additional low-pass filter. To support adjustment of the sensitivity, the circuit accommodates a trimmer. However, if it isn't desired, it can be left out of the circuit, and bypassed using resistor *BYPSL* with the desired value. After this stage, the signal passes a 3rd filter and then fed into the decision circuit. If the signal at this point is >0.6V, Q2L will conduct. If it is <-0.6V Q1L will conduct. Otherwise, none of these transistors will be active. This current from Q1L/Q2L the flows out of the circuit where it will be combined with the current from the right channel circuit, and fed into the switching circuit.

The determine the value of the DC protection level, we can do the following calculation. Q1L/Q2l will need ~0.6V for them to conduct. The DC gain from input to output is:

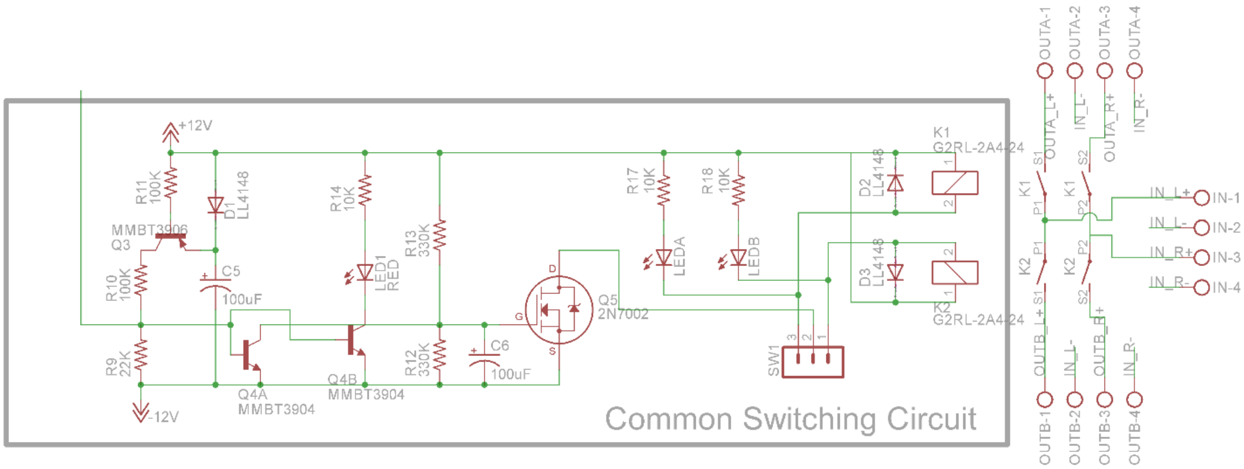
$$DCgain = \frac{R2}{R1} * \frac{R6 + TRIM(BYPS)}{R5}$$

Therefore, the desired value of the trimmer/bypass resistors be selected. Using a 250K trimmer will allow the sensitivity to be adjusted in the range of 75mV – 270mV. Please note that either BYPASL resistor, or TRIML trimmer are used, not both of them. The board layout prevents such a mistake.

<u>NOTE:</u> R8 changed to 10K instead of 100K, to guarantee full brightness for LED1 under Q4A/B mismatch. Using a 100K resistor might result in reduced LED1 brightness. Protection will still be fully operational.

Switching circuit:

The switching circuit is where the current from both the left and the right channel are used to switch the output on/off. It is also where the delayed start-up, accelerated shut-down, output selection, and visual notification are implemented:



To explain the operation of this circuit it should be broken down further. To simplify it even more, we'll follow it from end to beginning.

K1/K2 are the relays used to connect the desired output (A/B/both). With SW1 used to select which of them is active – SW1 is an off-board switch. LEDA/LEDB and their series resistors are also routed to the same switch, this enables visual notification of the active output. You can leave these LED's out if you don't wish to have this feature.

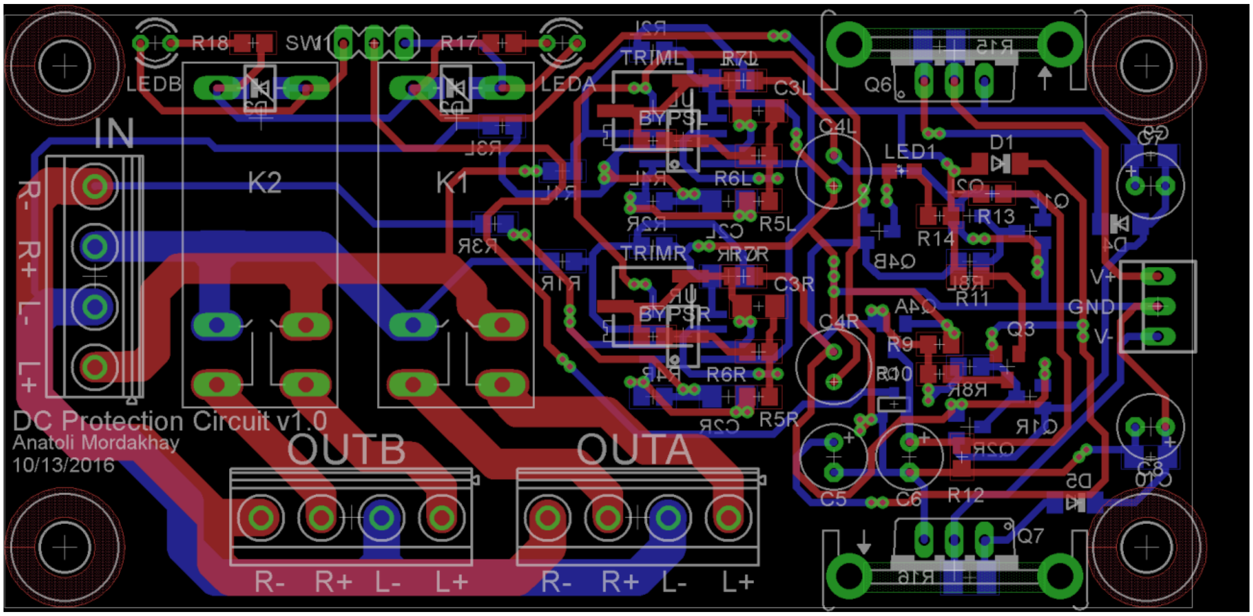
Q5 is a switching transistor which enables/disables the current to the relays coils. At the gate of Q5 is a low-pass filter of R12/R13/C6. This filter both limits the DC voltage at the transistor gate to keep it well within its operating rating, and to delay the start-up of the circuit.

The line on the left is where the current from the left and right channels enters the circuit. When this current is 0A (no error was detected) – transistors Q4A and Q4B are turned off, and no action should be taken. When there is a current in this line, the base voltage of Q4A/Q4B will rise and they will conduct. Q4A will discharge the gate of Q5, which will stop it from conducting. This will then disengage the relays. Q4B is used for visual notification of this state of protection, by means of LED1.

The final circuit is the one around Q3. During normal operation, this transistor is turned off, and isn't doing anything. However, as soon as the supply voltage drops to within 0.6V below its default value (~11V), Q3 will start conducting from the charge stored in C5. This will feed current into the switching circuit, just as if it is sourced from one of the signal channels. Therefore, once this happens, the relays will disengage. This circuit will reduce the chance of a "popping" noise from the circuit, but it isn't mandatory. You can leave out R10/R11/D1/C5/Q3 if you don't wish to implement this function.

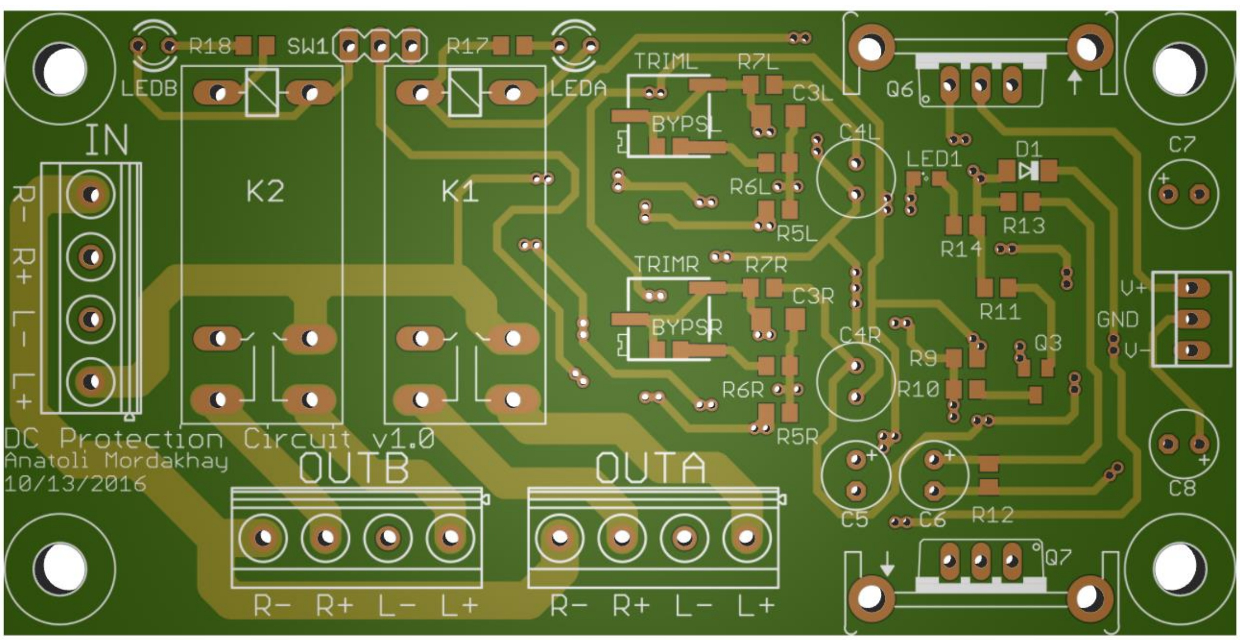
Board layout:

The board layout is shown in the next figure:



It is a 2-layer board. The signal lines are wide to support high current, and all of the filtering/switching elements are placed far from the signal lines. This is done to minimize any interference to the signal lines.

A more realistic rendering of the board can be seen here:



BOM:

The Batch-Of-Materials is listed next. For some parts, an exact part number is given, although it can be modified in many occasions if you know what you are doing. For other parts, such as resistors and capacitors, the size and value are given, and you can choose your own. These parts not-critical to performance/durability, and there you can choose which even you like/is cheapest.

Part Name	Value	Quantity	Part #	Notes
R1, R3, R6, R10, R11	100K	8	-	0805 SMD resistor
R2, R4, R9	22K	5	-	0805 SMD resistor
R5, R8, R14, R17, R18	10K	7	-	0805 SMD resistor
R7	1.5K	2	-	0805 SMD resistor
R12, R13	330K	2	-	0805 SMD resistor
R15, R16	10K*	2	-	1210 SMD resistor – *if the supply voltage is in the range of +-12V to +-24V, use 2.2K value
TRIM	250K	2	3361P-1-254GLF	SMD trimmer, can be omitted and replaced by BYPS resistor
BYPS	-	2	-	0805 SMD resistor, value of your choice, optional to replace TRIML/TRIMR
C1, C2, C3, C9, C10	1uF	8	-	1206 SMD capacitor, voltage rating 16V or over, X7R type is sufficient
C4	100uF	2	ECEA1AN101X	Any other BP capacitor of similar size will work
C5, C6, C7, C8	100uF	4	ECA1VM101	Voltage rating 25V or over, any other capacitor of similar size will work
D1, D2, D3	-	3	LL4148	Any other diode of similar size will work
D4, D5	-	2	ZMM5242 or BZV55-C12	Any other 12V Zener of similar size will do
LED1	-	1	-	0805 SMD LED – color of your choice
LEDA, LEDB	-	2	-	3mm through-hold LED – color of your choice
Q1, Q2, Q3	-	5	MMBT3906	SOT23 SMD transistor
Q4	-	2	MMBT3904	SOT23 SMD transistor
Q5	-	1	2N7002	SOT23 SMD transistor
Q6	-	1	TIP31C	TO220 transistor
Q7	-	1	TIP32C	TO220 transistor
UL/UR	-	2	TL082BCD	TL082 in SOIC8 SMD package
Heatsink	-	2	242-125ABE-22	Any other heatsink that will fit the board will work
Relay	-	2	G2RL-24A	Can be replaced with other relay if current rating is sufficient
Switch	-	1	-	Switch of your choice On-On (A/B), or On-Both-On (A/A+B/B) -mounted off board (panel)

Other than that, you can choose connectors of your choice or solder wires directly to the board for inputs, outputs, and power. Additionally, you will need to choose how you will mount the board, and use appropriate spacers/screws.

Additional notes:

There are a few additional modifications that can be made to the circuit, if you have a need for it:

Single channel build:

If you only need a single channel to be supported, for instance when building a mono-block or an amplifier for a sub-woofer, there is some gain to be had. First, you can leave out all of the parts that are used in the right channel (have a suffix *R* in their name). Second, you can use the input and output connectors of the right channel in parallel with these of the left channel. This will reduce the relay resistance by half, and will support double the current of a single contact.

Single channel build for balanced build with single ended output support:

If you are building an amplifier that supports both balanced and single ended outputs, there are additional fault conditions that should be detected for complete protection:

- To protect the balanced output, the protection circuit should observe the voltage between out+ and out- of the amplifier.
- To protect the single-ended output, the protection circuit should observe the voltage between out+ and ground of the amplifier.

Please note, any protection circuit that will not observe both of these conditions and monitor them, can fail to protect under specific conditions for either the balanced output, or the single-ended output. Again, this is only relevant if you are using a balanced amplifier, but would also like to support single-ended output such as TRS headphone jack. If you are using only a single configuration (balanced/active-ground/single-ended), this discussion isn't relevant for you.

If you are building a single channel protection circuit (or 2 such circuits for dual mono/mono-blocks), you can reuse the right channel circuitry, which you would otherwise leave un-populated, to support this additional protection of the single-ended output.

To do this you will need to:

- Use all inputs of the board, meaning L+ and R+ inputs should be shorted, and L- and R- inputs should be shorted. This is described in "single channel build" section of the document, and is beneficial for reduce contact resistance as well.
- Populate the right channel circuitry, with the exception of R1R. By leaving this resistor unpopulated, the right channel detection circuitry will look at the difference of L-/R- and ground. The fact we are using L-/R- instead of L+/R+ is irrelevant, since the circuit already monitors the difference between the two. Therefore, the only condition that is recognized as no-fault detected is when both outputs (+/-) are close to 0V, and close to each other. This guarantees all types of fault are detected, and both single-ended and balanced outputs are properly protected.

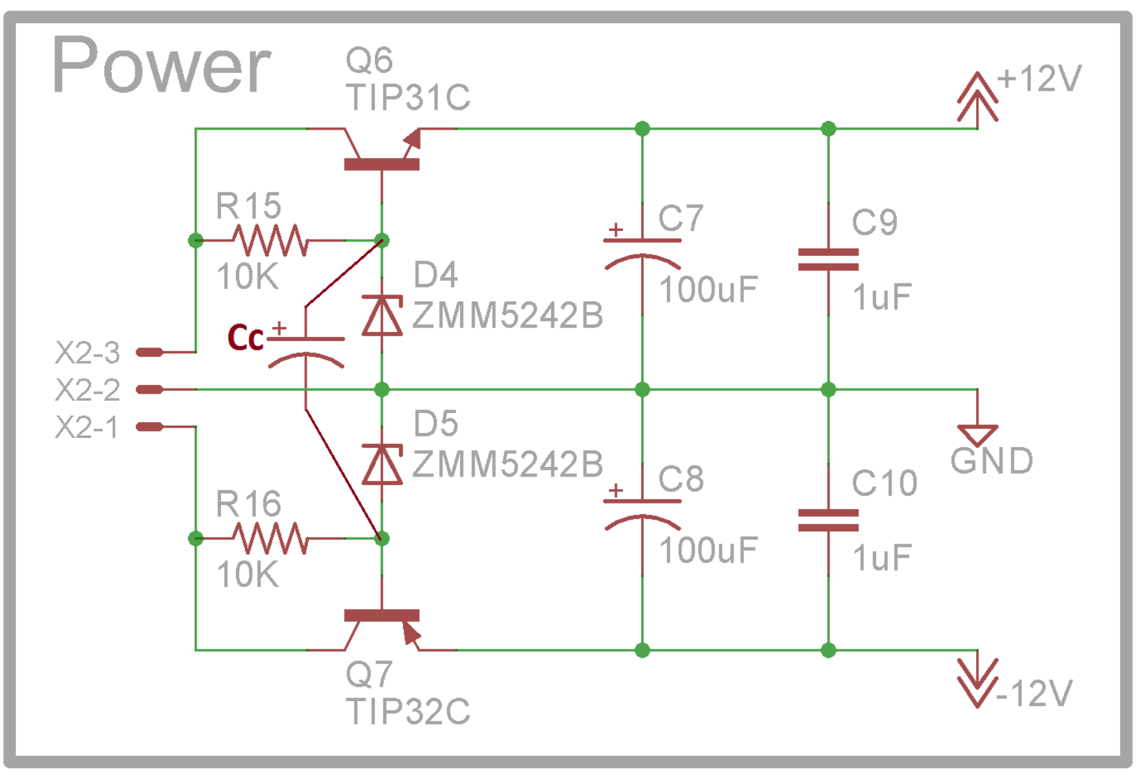
Multi-trigger at low supply:

The combination of the Zener follower supply and the accelerated shut-down circuit, can, in some cases, create an event of multiple triggering of the relay where it opens and closes a few times during supply power down. To understand how this happens, consider the following case:

The supply voltage is low, under the minimum rated 12V, and the Zener diodes are not conducting. This means the supply output impedance is on the order of a couple of 100's of ohms. When the relay is switched on, an additional 20mA is being drawn from the supply. This is sufficient to make the supply voltage droop by >1V, which is being detected by the accelerated power-down circuit, and disengages the relay. The supply voltage will then ramp slowly to the original value, and the relay will engage again, and so on. While this will eventually settle (after a few seconds), this is undesired.

I have been able to created such a scenario on my bench when using my test gear by operating it at a constant voltage below the minimum rated 12V. However, whenever I've simulated a real-life power-on or power-off slope on the supply, this effect wasn't observed. Therefore, this isn't expected to happen when used inside of an amplifier.

If you ever encounter such a phenomenon inside of an amplifier, I'd appreciate it if you let me know by email or PM. There is obviously an easy fix for this, and its as simple as adding a single capacitor to the circuit. A capacitor of 100uF (identical to C5/C6/C7/C8 will do) should be added between the bases of Q6/Q7. There is no accommodation for this capacitor on the board, therefore you will have to solder it off board using a piece of wire.



The capacitor Cc will be used as a charge reservoir in the event of switching, and will stop this multiple triggering effect from occurring.