Simple Speaker Protection Circuit for Power Amplifiers with Balanced Outputs Version 2

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Why the revised version, the SSP-2

Due to a recent project to design and build a balanced, high-voltage amplifier for electrostatic headphones, we had to revise the design of the Simple Speaker Protection board to suit the more demanding requirements of the former. These changes can also be used beneficially for normal power amplifiers for dynamic speakers, or for tube circuits. So an update to the SSP was implemented as below.

The Differences to Version 1

One of the first issue of using the SSP for a HV amplifier is of course the high signal voltage involved (up to +/- 400V). Not only is the high voltage level a problem, but the protection circuit also needs to detect a DC voltage which is some 100x lower than the dynamic signal. To make things worse, an electrostatic headphone amplifier has limited driving current capability, typically < 40mA. So the input impedance of the protection circuit has to be high ohmic, in the mega-ohm range.

This means that the DC detection diff-pair needs to be preceded by a 1:10 potential divider to get the voltage down (1:1 in Version 1). Note that most of the AC signal will have an attenuation much higher than 1:10, because of the input low-pass filter at ~0.1Hz. So the 1:10 ratio applies only to DC. The new version also has to have a steeper LP filter (2^{nd} order) to further improve rejection of large amplitude AC signals. And a much higher input impedance (2M ohm differential) is necessary in order not to overload the amplifier with low output current.

The above-mentioned requirements were quite easily achieved by simply changing the input series resistor of the diff pair from 100k in Version 1 to 1M. But this change created some other challenges. Assuming that one would want to detect a differential DC of say 10V, the DC current flowing through the diff pair input potential divider would be in the order of 4.5µA. If one would continue to use the PNP transistors in Version 1, with a hfe of about 500 and a bias current of 1mA, this would mean that the base current alone would already be 2µA. The input potential divider would then be overloaded and would result in inaccurate trigger point.

The obvious solution is to replace the PNP with a FET. While one can use a P-MOSFET for that purpose, our experience with small signal MOSFETs is that they tend to drift quite a lot with temperature. A few years back, we would not have hesitated to use a 2SJ109 dual P-JFET instead, but these have now become unobtainium. Still, 50V N-JFET such as 2SK209 is still easily available. So it was decided to use those for the diff pair and simply reversed the polarity of the rest of the circuit to suit. The gate current of the 2SK209 is typically at nA level.

In addition to the JFET gate current, it would also be necessary to reduce leakage currents in the rest of the diff pair input circuit. These included the over-voltage protection diodes, and the LP filtering capacitors. For the former, one could use a low-leakage Zener diode such as the DDZX6V2. On the other hand, since the input impedance of the diff pair is now so high, the maximum gate current cannot exceed 0.5mA even when the JFET were to go into positive bias. So it can be argued that the input protection diodes are no longer necessary.

For the input LP filtering caps of 20µF, no electrolytic capacitor we could find has a leakage current below 3µA. It was therefore decided to use 3x WIMA MKS2 6.8µF 63V in parallel to make up 20µF. These typically have a total leakage of < 20nA. Polypropylene caps would have even lower leakage current, but they would take up much more space. Further to the above mentioned measures, low leakage diodes such as BAS416 could also be used for D1, D2. And an additional capacitor in parallel with R9 provided additional LP-filtering.

The rest is basically the same as SSP-1 but with reversed polarity (NPNs replaced by PNPs, etc.). As we are using a much higher attenuation at the input, the sensitivity of the diff pair has to be increased accordingly (from ~2x in Version 1 to ~10x). For the relay driver, the use of high-hfe BJTs would keep the base current low. So it was decided to parallel up to 4 of them to allow up to 80mA driving current (only one is shown in the schematics below). This should be sufficient even for 16A SPDT relays with 12V coils. Should less current be required, one could simply use less number of devices. A maximum current of 20mA per PNP is recommended.

To ensure that the protection relay would remain off after a fault detection, a simple latch (R12, D6, D10) to the relay-off trigger Q3 was also added. The latch could be disabled by pressing the reset push button S1. In case of a fault, one should first remove the speakers anyhow before carrying out any further investigation. So the latch is considered to be essential.

Overall Circuit Description

To avoid answer questions, for which we have no time, here is a detailed description of the Version 2 circuit.

The balanced output of an amplifier is connected to Vin+ & Vin--. These are attenuated by a factor of 10 by R5,6,7,8 so that the maximum voltage level seen by the diff pair is at a safe level. The input impedance of the protection circuit is 2.2M. C1,2 together with the input attenuators form a low-pass filter with a time constant of about 2 second. As already explained above, each of the capacitors is made up of 3x WIMA MKS2 6.8µ to ensure low leakage current. Should you wish to have a faster response time, you may reduce the amount of capacitors used.

The filtered, attenuated, balanced amplifier outputs are then used to drive the diff pair detection circuit, formed by Q1,2, R1,2,3,4. The JFETs used for Q1,2 have high Vds ratings, and are easily available. They need to be matched to about 10% Idss, or else the trip voltage for positive and negative signals would become asymmetrical. The resistor values chosen for R1,2,3,4 gives a gain of 10 to recover the attenuation, but this now only applies to the LP-filtered difference. Furthermore, over-voltage to the diff pair is limited by D8,9 to 6V nominal. Should you wish to choose an even lower voltage, you may of course change the voltage of the low-leakage Zener's accordingly.

R13 sets the current through the diff pair, which should be 2mA in total, giving 2.5V nominal across R3,4. One should aim for a positive tolerance, such that this voltage should be about 2.5~3V when both inputs are shorted to Gnd. D1,2 form a hardware "OR" gate, so that both positive and negative DC would trigger the protection relay.

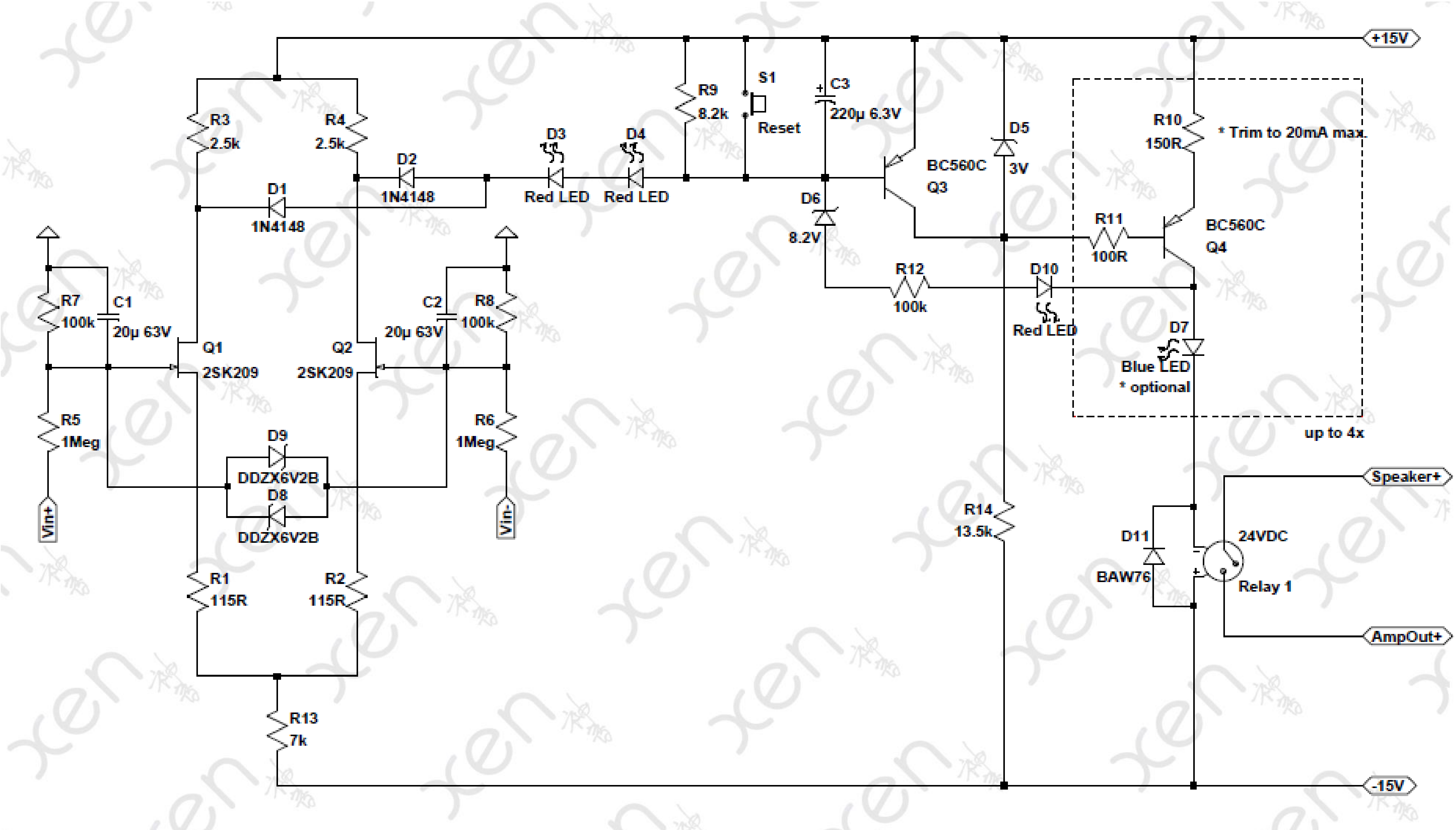
The protection relay triggering circuit works as follows. The relay is normally open, so that in case of a power failure, the amplifier is disconnected from the loudspeaker, and the latter is in a "safe" state. Under normal operation, D5, biased by R14, will put the base of Q4 at 3V below the top rail, or +12V. D5, R10 & Q4 form a constant current source to drive the relay. To limit dissipation on Q4, the current should not exceed 20mA. This means R14 should not be smaller than 120R. If the protection relay (with 24V coil) consumes more than 20mA, one can simply parallel multiple units of Q4, R10,11. D7 is an optional LED to indicate normal operation. When connected as shown, it will pass the entire 20mA of one Q4, and you may find this to be too bright. In that case you can dim it by putting a resistor in parallel to shunt some current from the LED. A good starting value is 200R 0.5W.

In case a fault (DC voltage) is detected, one of D1,2 will pull the cathode of D3 to 4.3V below the top rail. D3,4 will raise this by another 3.6V, such that the base of Q3 is at 0.7V below top rail, switching Q3 on and shorting D5 in the process. This in turn shuts off the relay and hence disconnecting the speaker from the amplifier. Some red LEDs might have forward voltage higher than 1.8V. In that case you may either replay D3 & D4 by a single 3.3V Zener, or replace D4 by 2x 1N4148. Reducing the value of R13 by 10% will also solve any triggering problems. R9 limits the steady current of D1,2,3,4. And C3 provides a further LP-filter in case some high-amplitude AC signal does get through the input attenuation filter. You may find this to be unnecessary for your particular application, in which case you may reduce its value or leave it out altogether.

As already mentioned, R12, D6, D10 form a latch to keep the relay off until it is manually disabled by the reset push button S1. D10 is another optional LED and acts as a fault indicator in this case. You may of course choose to you a blinking LED in this position.

PCB Layout

A small PCB including on-board 7815 / 7915 regulators was designed which incorporated all the improvements described within a 72x78mm foot print. This has two DC detection circuits, two relay drivers, but a common triggering circuit. So a DC offset appearing at any one of the two stereo channels would disconnect both speaker outputs. One can always leave out one detection circuit and one relay driver in case of mono-blocks. The circuit still functions fully without any changes.



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