Elliott Sound Products

Project 33

# Loudspeaker Protection and Muting


Updated November 2022



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**Please Note:** PCBs are available for the latest revision of this project (Rev-B). Click the image for details.

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## Introduction

Please note that the PCB version is different from the circuit shown in this article. It is actually simpler, but achieves the same functions. Full details are available when you purchase the board. The latest boards are Revision-A, and are slightly different from the previous version. The basic circuit arrangement is shown in Figure 5. This doesn't include the regulator that's on the Rev-B board at this time.

The latest incarnation of P33 is Revision-B, which now includes a simple regulator. The PCB dimensions are unchanged, and the PCB can be used in exactly the same way as the previous Rev-A board by bypassing the regulator transistor. The board is now double-sided to accommodate the extra circuitry. The price is unchanged.

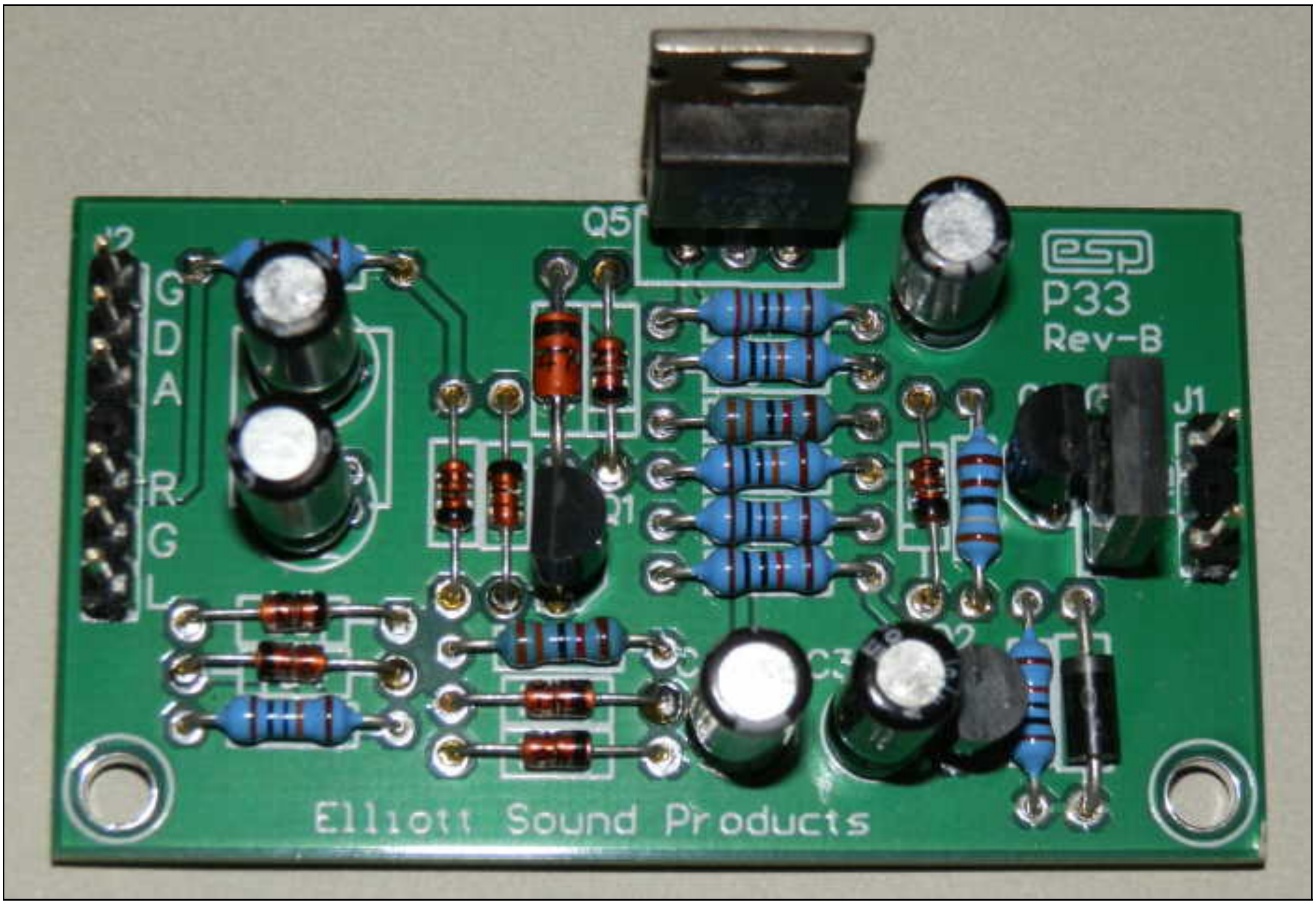


**Photo Of P33-Rev-B Board**

The P33 PCB can be used with a pair of Project 198 MOSFET relays, which is especially useful if you amplifier has supply voltage of more than ±35V. At high voltages, the relay contacts *will* (not might) arc, and if the fault voltage is around 60V or more the relay will be incapable of extinguishing the arc. See Relay Failure below for graphic evidence of this. I've also run many tests on relays, and a destructive arc is almost guaranteed with a voltage of 60V at 10A or more (assuming a voicecoil resistance of 5.6Ω). A new sub-section has been included to show how to use P198 MOSFET relay boards with P33.

Many hi-if amplifiers and professional power amps (and loudspeaker systems) provide some of protection, either to protect the speakers from an amp fault, and/or vice versa. Some of these are implemented at a very basic level - for example the use of a 'poly-switch'. The poly-switch is a non-linear resistor, having a low resistance at normal temperatures and a much higher resistance at some designated temperature. Unlike 'ordinary' thermistors whose characteristics are more or less linear, the poly switch has a rapid transition once the limit has been reached.

I don't like poly-switches, because I know that the introduction of a non-linear element is going to add some degree of distortion, and because of a finite resistance, will degrade damping. This (i.e. damping) is usually not an issue IMO, but to many audiophiles it is of prime importance. (I shall not pursue this argument here, however - see Impedance for more info.)

The basic requirement of a speaker protector requires that any potentially dangerous DC flow to the speakers should be interrupted as quickly as possible. There are a few issues that need to be solved to ensure that this will happen fast enough to stop the loudspeaker drivers from being damaged, and this becomes more critical if a biamped (and even more so with triamped) system is being used.

Naturally, one can simply rely on fuses. Although these also have finite resistance it is small, and use of fast blow fuses can be quite effective. The rating is quite critical, and fast blow types are essential. The problem with this approach is that if the fuse is of a suitable value to provide good protection, it will be subjected to considerable thermal stress since it is operating at close to its limits. Metal fatigue will create the problem of nuisance blowing, where the fuse blows simply because it is 'tired' of the constant flexing caused by temperature variations. I know this from personal experience with loudspeakers I had many years ago - they used fuses to protect the tweeters. Nuisance fuse failures were common (and very annoying).

This project explains the principles, and shows a suitable detection method that may be applied. The speed of the relay used is another critical factor, and we shall see that the conventional method of preventing the relay's back-EMF from destroying the drive transistor also slows down the response to a potentially unacceptable degree.

The circuit also includes a mute function, which leaves the speakers disconnected until the amplifier has settled, and disconnects the speakers as quickly as possible after power is removed to prevent the turn-off noises that some amps generate. These can range from a low level thump 5 to 10 seconds after power is turned off, to whistles, squeaks and other strange noises that I have heard from amps over the years.

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**Please Note:** While the circuit shown here and the PCB version can both be made to work just fine with high supply voltages (such as ±70V as might be used with some amplifiers), be aware that the majority of relays will be totally incapable of breaking that voltage and the resulting current under fault conditions. The DC causes a significant arc, and this is more than capable of simply burning off the relay contacts.

If you are lucky, the fuse(s) will blow before the relay is destroyed, but I wouldn't count on it. While relays capable of breaking perhaps 10A or more at 70V DC are available, they will be expensive and probably hard to get. Unfortunately, there are few options for an alternative method. The relays article does offer some solutions.

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Using the relays as shown below (with the normally open contact connected to ground), the arc will be diverted from the speaker and will be to ground, but the relay will almost certainly be destroyed unless a specialised component is used. Despite their apparent simplicity, relays are actually rather complex devices. A great deal of engineering goes into the development of the contacts, but operating them in excess of the manufacturer's ratings means that nothing is certain. For more information, see the two-part article about Relays.

Please make sure that you understand the limitations of any such circuit (not just mine - the same applies to all loudspeaker protection circuits). The circuits themselves are not limited, but the relays most certainly are.

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**MOSFET Relay**

If your amplifier has supply voltage above ±35V, you may want to consider using Project 198 MOSFET relays. You simply wire up a couple of the PCBs with MOSFETs suitable for your requirements, plus the IC and a few other parts. With the optimum choice of MOSFETs, disconnecting an amplifier with ±100V DC supplies is not a problem - that's a 600W/ 8Ω (1.2kW/ 4Ω) amplifier, and there can be no arc because the switching is done with MOSFETs, not electromechanical contacts.

For a stereo amp, you'll need two P198 boards (and no-one else has *anything* that comes close), and you only need about 10mA to drive them. The two input sections are simply wired in series with a limiting resistor to suit the P33 board's supply voltage. The MOSFET relay is perfectly suited to any amplifier voltages you'll encounter, and it's fully isolated so there can be no unwanted interactions.

If you use MOSFETs with an 'on' resistance ($R_{DS\text{-}On}$) of less than 10mΩ, the average dissipation will be less than 1W each, even at an output current of 10A RMS (a power of 400W/ 4Ω continuous - highly unlikely with *any* normal programme material). This is a new PCB from the ESP line-up, and it's the only one of its type that you can buy. It's specifically designed for AC - most of those you can buy are DC only, and the few AC versions available have *very* slow turn-on and may be unable to support high current. If there's enough interest I'll be able to get more made and reduce the price.

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### Why DC Kills Speakers

There are innumerable misconceptions as to what happens to a loudspeaker drive when it's subjected to DC. Small levels of DC (less than 1V) usually do no more than displace the cone slightly, and it's generally accepted that ±100mV DC offset is the maximum that should occur. This represents a power of 2.5mW into a 4Ω load. A 100W/ 8Ω amplifier will typically use ±42V supplies, although some will use up to ±56V DC.

When the amp is providing its maximum power, the output voltage is 28V RMS, assuming a steady tone. We don't listen to steady tones (especially at 100W!), and music has a peak to average ratio of around 10dB (although some has less - 5dB is the minimum generally achievable. We'll stay with 10dB, meaning that the average power from the amp is 10W, with 100W peaks. Most decent drivers can handle that easily, so there's no problem. Even if the average power is increased to 20W (probably with some severe clipping), that's still ok.

Now, if the amplifier should fail, we can see what happens. Complete failure is nearly always a shouted output transistor, so the amp's output jumps from around 9V RMS (10W into 8Ω) to 42V DC. That's a power of 294W, and it's *continuous* (the speaker only has resistance at DC, assumed to be 6Ω). This forces the voicecoil out of the magnet gap and because it's not moving there is no effective cooling. The voicecoil will reach a dangerous temperature in a few seconds, and if the DC isn't disconnected quickly, the speaker will fail. This can include catching on fire!

The answer is a DC detector with a relay, which will disconnect the DC fault current. This will be in the order of 7A, which is more than sufficient to cause almost *all* miniature relays to sustain a continuous arc. If the speaker isn't shorted by the relay, the arc current will be in the order of 4A or more directly to the speaker (arcs have impedance, but it's highly variable). With a sustained power of somewhere between 100W and 250W and no cone movement, very few speakers will survive.

The vast majority of published circuits do *not* show the relay shorting the speaker, and protection is only afforded with DC voltages of 30V or less.  Higher powered amplifiers are far worse, and there is no common relay known that can break a 70V DC arc at a current of more than a few hundred milliamps at most.  More than twenty years have passed since the design shown here was published, and almost no-one else has updated their flawed circuits.  To be able to break a 70V DC arc at any likely current requires a relay with *at least* 1.6mm contact clearance - this is extremely uncommon!

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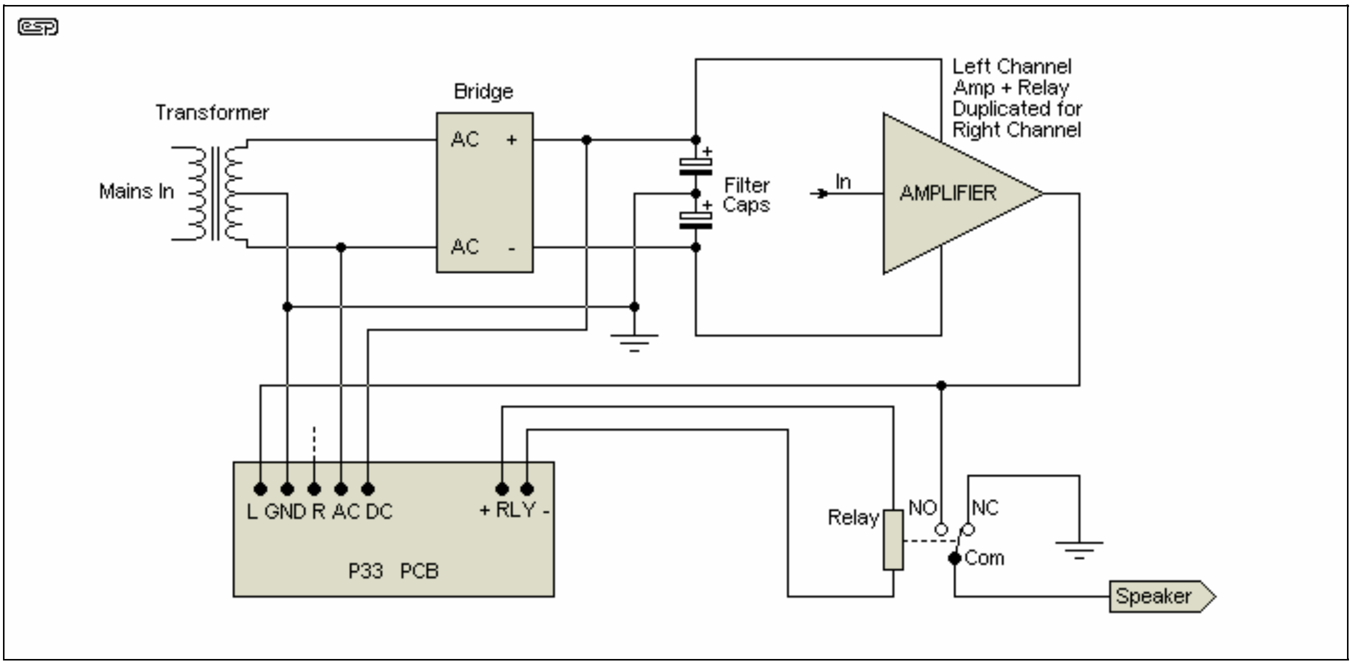
### The Circuit

It is important to identify the lowest frequency likely to be passed to a speaker, because this determines the delay that must be introduced to prevent low frequencies from triggering the protection circuit (nuisance tripping).  For practical purposes, a low frequency limit of 20Hz is satisfactory for a full range system, and this means that a minimum 25ms delay is essential.  In reality, due to the combination of low frequencies, and asymmetrical waveforms at higher frequencies, a greater delay will normally be required.  Unfortunately, the greater the delay, the greater the risk of drivers being damaged.  In a full range system (i.e. using passive crossovers), midrange and tweeters will be offered some protection by the capacitors used in the crossover network, but these are missing in a biamped or triamped system.  For this reason, it is important that the circuit can be easily modified to change the initial time delay before the system detects the DC and disconnects the speakers.

Be aware that you will need to use higher voltage transistors throughout if the amplifier is operated at more than ± 60V.  The transistors shown are rated for 65V, but using any transistor close to its voltage limit is unwise.  Provided you understand the circuit and know what you are doing, it's simple enough to run the circuit from a lower voltage if it's available.  Alternatively, a simple zener regulated supply can be created to power the circuit itself (but *not* the relays, as they draw too much current).  Relay selection becomes critical for high voltage supplies!




**Wiring Of Protection Circuit And Amplifier**

The drawing above shows how the circuit is wired into an amplifier. There will usually be a separate relay for each channel, and the P33 board will often be able to use the main amplifier power supply as shown. If an auxiliary supply is used, it needs to be around 12V to suit the relay coils. The power supply must be able to provide enough current for the detector (only a few milliamps) and the relays (typically around 45mA each, but it depends on the relays you use). Relays must be double-throw, with both normally open (NO) and normally closed (NC) contacts, with the NC contacts connected to the power amplifier ground. Without this connection, the ability of the relays to protect your speakers ranges from minimal to zero!

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### The Detector

This is the most important of the functions. It must be capable of detecting a DC offset of either polarity, and be immune to the effects of asymmetrical waveforms and low frequencies. This is a common requirement, and it is most expedient to use a simple (single pole) filter to keep the complexity to a minimum. With this arrangement, a low frequency cut-off of about 1Hz is about right. Without boring you with the mathematics behind this, it works out (eventually) that a filter having a time constant of 1.0s will still provide the ability to detect high level DC reasonably quickly, but allow low frequencies through without triggering. With this, the relay could have its supply removed within about 50ms from the time the output voltage reaches the supply rail (this is supply voltage dependent) - due typically to a shorted transistor in the output stage. By changing the time constant of the filter, we can adapt the circuit for operation at other higher frequencies to suit a biamped (or triamped) system.

The detector can be built using an opamp and will work very well, but this introduces the need for low voltage supplies within the power amp. This is not always possible (or desirable), so the design uses discrete transistors throughout to allow for the different supply voltages found in typical power amplifiers.

The detector circuit shown in Figure 1 [1] is simple and works well, and as shown will not trigger with a 30V RMS signal at 5Hz, but operates in 60ms with 30V DC applied, and in 50mS with a 45V DC supply. This should be sufficient for most applications, and allows the use of a non-polarised electrolytic capacitor in the filter. These are cheap, small and quite adequate for this purpose.

**NOTE:** *The power supplies (+ve and -ve) shown in these diagrams will normally be derived from the power amp supply rails. Do not try to substitute different supplies unless you know exactly what you are doing, or the circuit may not work properly. This is especially true of the muting circuit, but incorrect supplies will (may) also affect the DC detection circuit. Like most of my projects, this is intended for experienced constructors.*

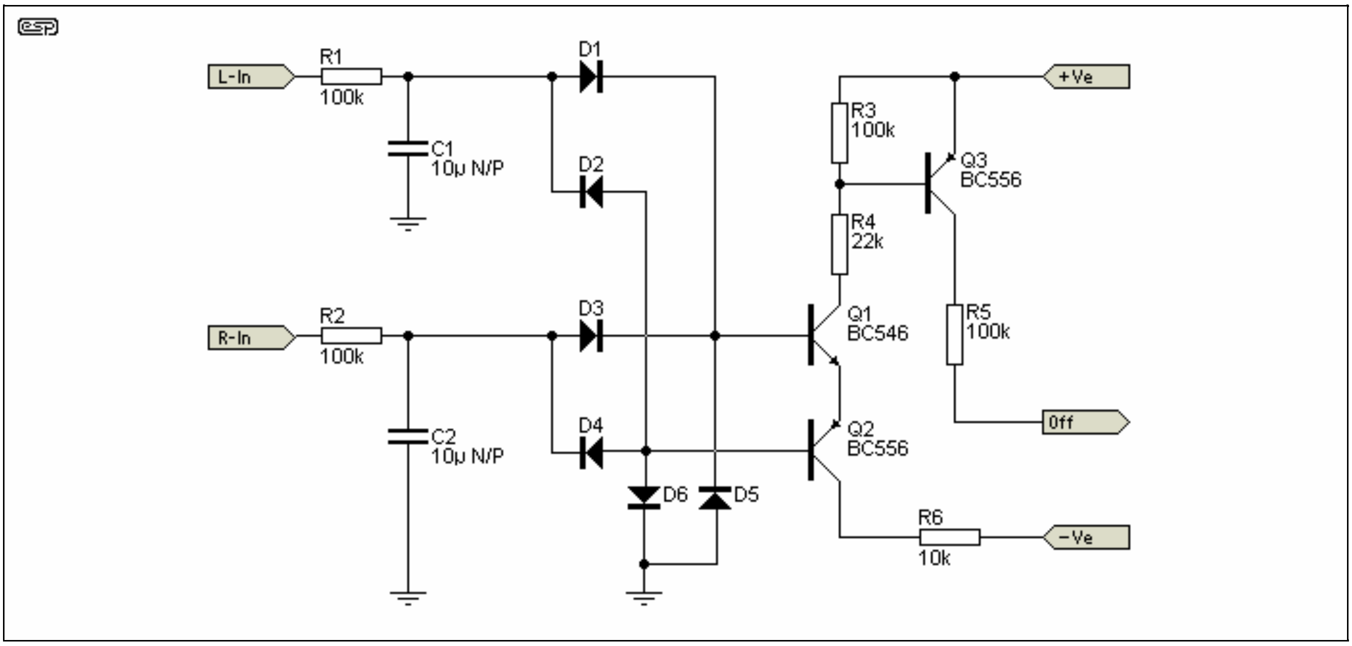

**Figure 1 - Basic DC Detector Circuit**

The input filter is a simple single pole (6dB/ octave) version, and although it would seem that a 'better' filter would be preferable, a two pole (or more) filter will actually degrade the DC detection. This basic circuit is not new (see reference), and has actually existed in one form or another for some time. It is ideally suited for our requirements, as it is symmetrical, and with the input diodes as shown, a single detector can be used with multiple amps and different input time constants for each individual filter. The unit itself can operate on a separate supply if desired, so the complete protection circuit can be in a separate enclosure. Regulated supplies are not needed, and no hum or other artifacts are introduced into the speaker lines. (Please see NOTE above.)

Table 1 (below) shows some suggested values for the filter, for use in bi- and tri-amped systems. You will need one filter and two diodes for each amplifier channel connected, and a suitable number of relay contacts to handle them all. In some cases, this will mean multiple relays.

| Frequency (Hz) | C1 Value |
|---|---|
| Full Range | 10 µF (non-polarised) |
| 100 Hz | 1 µF |
| 300 Hz | 330 nF |
| 1 kHz | 100 nF |
| 3 kHz | 33 nF |

**Table 1 - Capacitance Vs. Minimum Frequency**

The input resistors (R1 and R2) should be left at 100k for all frequencies. While it is possible to reduce the detection threshold by using a lower value, that makes the requirements of the filter more critical, and can easily make detection *worse* rather than 'better'. Do not use a conventional electrolytic capacitor for C1, because any small reverse bias will eventually ruin it. You may discover that with some types of music (especially if at high volume) may cause the circuit to false trigger. If this happens, increase the value of C1, up to a maximum of 47µF. Anything higher than this will slow down the response unacceptably. The voltage across the filtering cap can never exceed ~±2.5V, because it's clamped by the diodes.

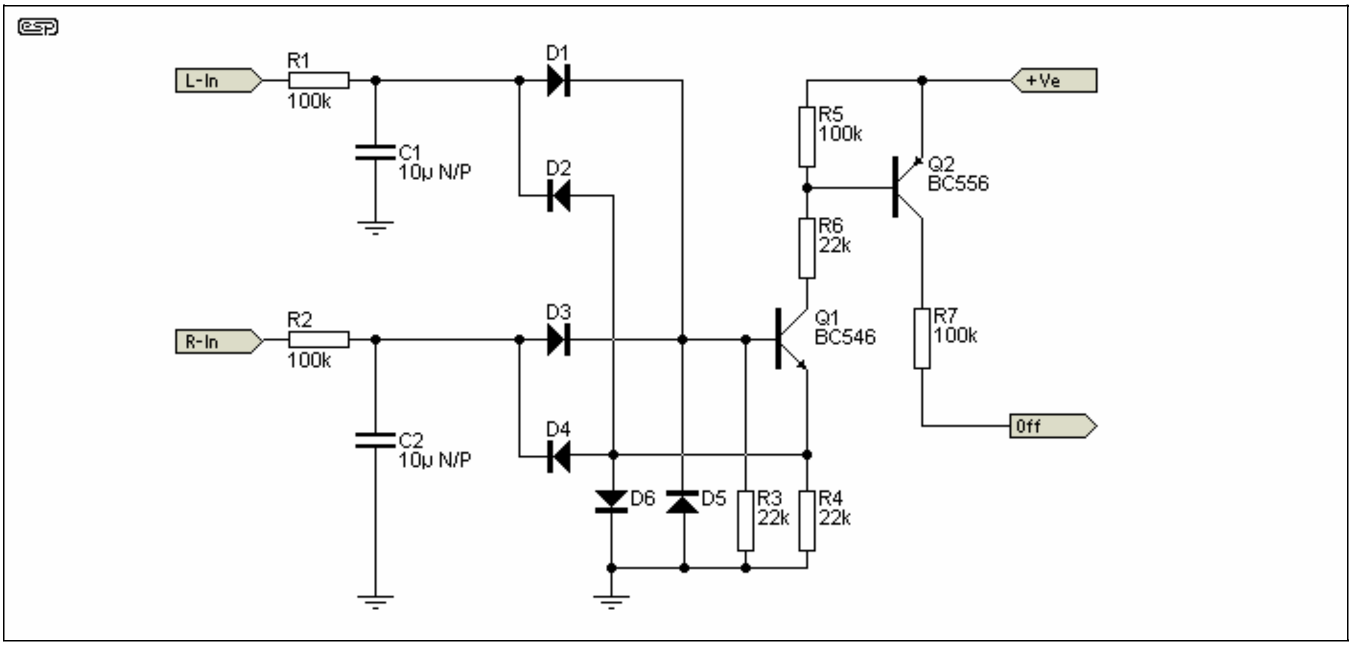


**Figure 1A - Basic Single-Supply DC Detector Circuit**

The circuit shown above is designed to use a single supply. Q1 can be turned on by a positive voltage at its base, or a *negative* voltage applied to the emitter. This is the basis of the PCB version, and it is a 'tried and true' solution. Everything said above (about the two transistor version) applies here as well. The values shown in the table remain applicable, as are all other comments and notes. The only difference is the removal of any need for a negative supply. When C1/ C2 are selected for full-range, detection time is under 60ms for positive or negative fault voltages of 25V, and it's faster with higher fault voltages.

There is no reason not to use much more complex circuits of course. However, they won't necessarily work any better, and some I've seen are not as good - despite the added complexity. Aiming for very low voltage detection thresholds might *seem* like a good idea, but in reality it simply means that the filter must be more complex, and it will react more slowly to a DC 'event'. Remember that any DC detector must never activate with the lowest frequency of interest present, at any voltage up to full power (and potentially allowing for some degree of clipping). However, it must still detect DC quickly enough to save your loudspeaker(s).

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## Relay Specifications

The relays should be easy enough to obtain. At least one of the Australian component suppliers has relays that are quite suitable, but they are not particularly cheap. The current rating is very important, and assuming a supply voltage of +/-40V, this will cause a current of about 6A in an 8 ohm speaker if a transistor shorts. Although 6A may not sound like much, it is at DC, and because there are no periods of 0V as with AC, the arc is longer, fatter, and far more destructive of contacts than the same current using AC.

Do not be tempted to use miniature relays, because if the normal AC speaker signal is too far in excess of the relay contact rating, the contacts may become welded together - this will almost certainly happen if the DC rating is too low. You also need to consider that contact resistance is additional resistance in the speaker lead and may affect damping (albeit very marginally) and will introduce some small power loss, and the miniature types will not be suitable in this regard.

I had a look in the catalogue of one Australian supplier, and they have several relays with a 10A contact rating. I would suggest that anything lower is unwise for long term reliability. Most of the commonly available relays will have a 12V coil, and this will cause problems if the supply voltage is 30V or more. Power relays often draw significant current (typically > 60mA), and it will usually be best to connect the coils in series.

Be aware that in some areas there is significant sulphur content in the air, and this causes heavy tarnishing of silver contacts. If you live in such an area, it would be advisable to obtain hermetically sealed relays if possible, to prevent the contacts from tarnishing.

It is well known that the current required to activate a relay is far greater than that needed to keep the contacts closed, and a common trick is to use an 'efficiency' circuit to minimise the relay holding current. I do not feel that the additional complexity is warranted, and have not included this facility. If you really want to do this properly, see reference 1 (below). It has been claimed that an efficiency circuit also speeds up relay drop-out time because of the lower stored magnetic field. I conducted some tests, and the savings are marginal at best, although this could be different with different relays.

Figure 2 shows the relay activation circuit, and includes the connection for the mute and protection signals. No components are critical, but some will need to be modified based on the relays used. I have assumed that a minimum of two relays will be needed (one for each channel), and this increases the total relay coil voltage to 24V. If you are going to use more than two (for example, four single pole relays are needed for a biamped system), then if the supply voltage is 48V or more, all 4 relays can be connected in series. In most cases you will need to work out the value of a suitable dropping resistor from the formula below.

The terminal labelled 'Off' is common to all three modules, and these points are simply joined together, as are the +ve and -ve supply connections. A positive current into the Off terminal will de-energise the relays, by turning on Q1. This steals all the base current for Q2, which then turns off, as does Q3.

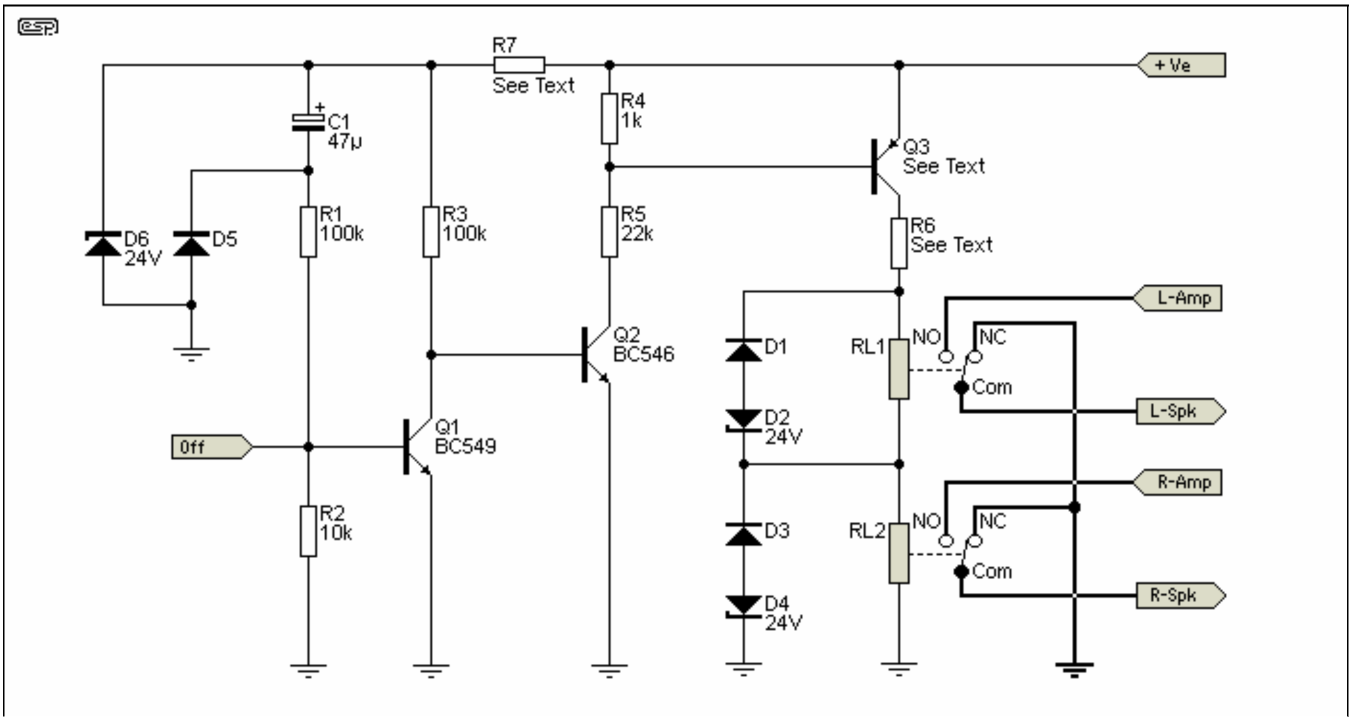

**Figure 2 - Relay Activation Circuit**

R7 and D6 are optional. A reader used this circuit on a P68 subwoofer amplifier, and found that the circuit occasionally false-triggered. It was finally discovered that with some signals, the supply collapsed enough to re-start the mute timer. By adding the resistor and zener, this is avoided. R7 and D6 won't normally be needed, but if you get false triggering they will have to be added. To leave this section out simply means that D6 is not installed, and R7 is replaced by a link.

The value for R7 (if needed) is determined by the supply voltage. The mute circuit draws very little current, so R7 can be calculated by ...

$V_{R7} = V_{supply} - 24$ (where 24 is the zener voltage)

R7 can then be calculated, based on a zener current of 10mA ...

$R7 = V_{R7} / 0.01$ (Ohms)
$P = V_{R7}^2 / R7$ (Watts)

For example, with a 56V supply, R7 would be 3.2k, and will dissipate 0.32W (a 1W resistor is recommended).

The relays must be turned off in the shortest possible time, so the use of the normal protection diode across the coil should not be used, as it slows the response considerably. Instead, the arrangement shown still protects the driver transistor, but allows the relay magnetic field to collapse without generating a current in the coil (this the what slows the relay's release). I cannot predict the exact delay you will achieve, since the choice of a suitable relay is outside my control. You will have to pester and annoy your local suppliers to find a relay that has suitable characteristics, and be prepared to pay what will seem like an obscene amount of money for a simple electro-mechanical device.

D5 discharges C1 as the supply collapses. It will not help much in the case where someone switches the power off then straight back on (not that anyone would do that !), but will reset the circuit much faster than would otherwise be the case.

The DC arc can (and does) destroy even 10A relays under some circumstances. To provide greater speaker protection, the relay wiring in Figure 2 is designed to short the speaker to earth in case of a fault. This way, even if the contacts do arc it will be directly to earth. This is much safer (for the speakers), and the arc to earth will blow the fuse a lot faster than if an 8 ohm load is a part of the circuit. It is strongly recommended that this scheme is used as a matter of course. It is worth noting that any DC protection system that does *not* use this method will almost certainly fail to protect the speakers with a medium to high powered amplifier. (My thanks to Phil Allison for the information.)

You may want to consider using double pole relays for RL1 and RL2, with the contacts wired in series. Most common relays have a 10A, 30V DC rating, and by using two sets of contacts in series this (theoretically) increases the voltage rating to 60V DC. The normally closed (NC) contacts should be connected to the DC ground for maximum protection.

Note also that this circuit cannot be used as shown with the 12V relays in series if the supply voltage is less than +/-24V (but you knew that already 😃)

In order to work out the value of R6, subtract the combined relay voltage from the supply voltage (you must know the relay coil current!). To calculate the coil current from its resistance, use the following (I have assumed a 40V supply for the examples):

$I = V / R$ Where V = coil voltage and R = coil resistance

So for a 180 ohm coil (fairly typical) this works out to

$I = 12 / 180 = 67mA$

The resistor value is worked out with:

$R = V / I$ Where V = the 'left over' voltage from the subtraction and I = coil current

You will also need to work out the power rating for the resistor:

$P = V^2 / R$ Where V is the voltage and R is the resistance

Again, for the above example, this works out to

$R = ( 40 - 24 ) / 67mA = 16 / 0.067 = 239$ Ohms (220R should be fine)
$P = ( 16 \times 16 ) / 220 = 1.16W$

So for an adequate safety margin, a 2 Watt resistor should be considered the minimum (5W would be better).

To determine the transistor for Q3, add the supply voltage and the zener voltages to give the maximum collector to emitter voltage. In this case it is 40 + 48 = 88 Volts, and I would suggest that a transistor with a breakdown voltage of at least 100V be used to give some safety margin. The MJ350 (300V rated) will be suitable in nearly (if not) all applications, or you can use a MPSA92 - lower current, but still has a 300V rating.

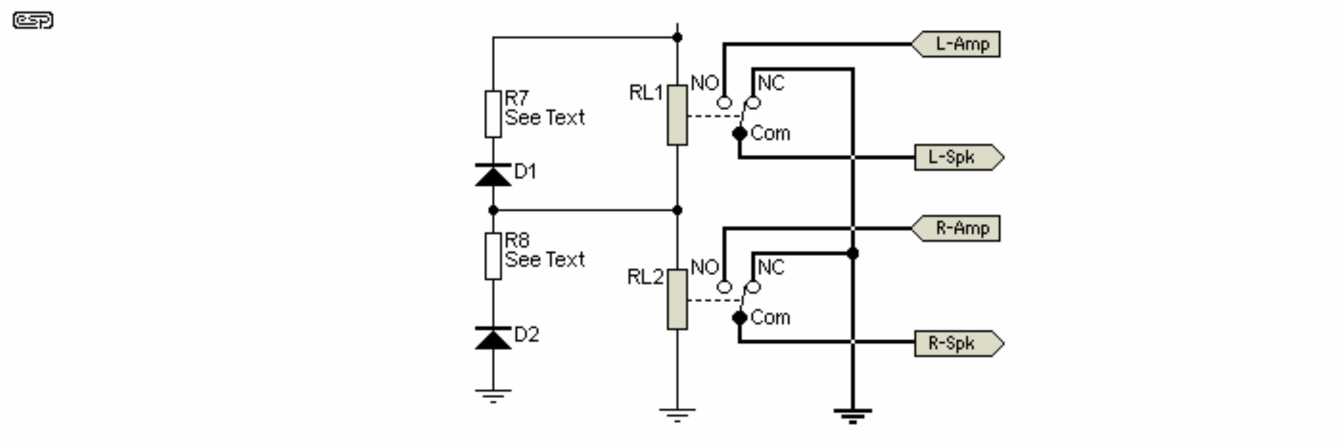


**Figure 2A - Alternative Back-EMF protection**

Figure 2A shows an alternative method you can use to damp the back-EMF from the relay, but to implement it properly, access to an oscilloscope is helpful (if not essential). If the resistors have approximately the same resistance as the relay coils, the back-EMF should (!) be limited to about the normal relay voltage, give or take 50% or so. In the tests I carried out (see Tests, below) using a 24V relay, the back-EMF was limited to about -30V, which would be fine in most cases.

This method is slightly cheaper than using zeners, but is less predictable. An additional alternative is to use a catch diode to the -ve power supply. A 1N4004 between the top of the relay string and the -ve amp supply will limit the back-EMF to the voltage of the -ve supply, so for the example case this would be -40V. I expect that this would be quite acceptable, but have not tried it. Make sure that the diode is connected the right way around - the cathode goes to the top of the relays, and the anode to the negative supply.

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## Muting

Since we have all this new circuitry, it is most worthwhile to incorporate a muting function, so that when power is removed from the system, the relay will open to stop turn-off transients from being heard. Likewise, we will normally want to mute the system for about 2 seconds after power is applied to stop the turn-on transients as well. C1 and R1 in the circuit of Figure 2 provide the turn-on delay, by supplying current to the 'Off' terminal as C1 charges. Once charged, the current falls to zero, and Q1 turns off, allowing Q2 and Q3 to turn on, thus energising the relays. (Note that this timer will not be reset if the power is turned off and back on again quickly, but since this is a procedure that should be avoided anyway, no provision has been made for it.)

To be able to do this effectively, we must have access to the AC from the power amp's transformer, or have the external unit controlled by the main power switch in the system. In some hi-if installations, there will be a multiplicity of different units to turn on (and off) each time the system is used. I will leave it to the reader to decide which unit to use as the control, but would suggest that where a separate preamp is used, this could be an ideal controller for the entire system. It is unfortunate that hi-if has not followed the sensible approach of a lot of computers, with a switched IEC connector on the back of the preamp to control power amps and other outboard devices. (I did this on my preamp, and it is most useful. 🙂 )

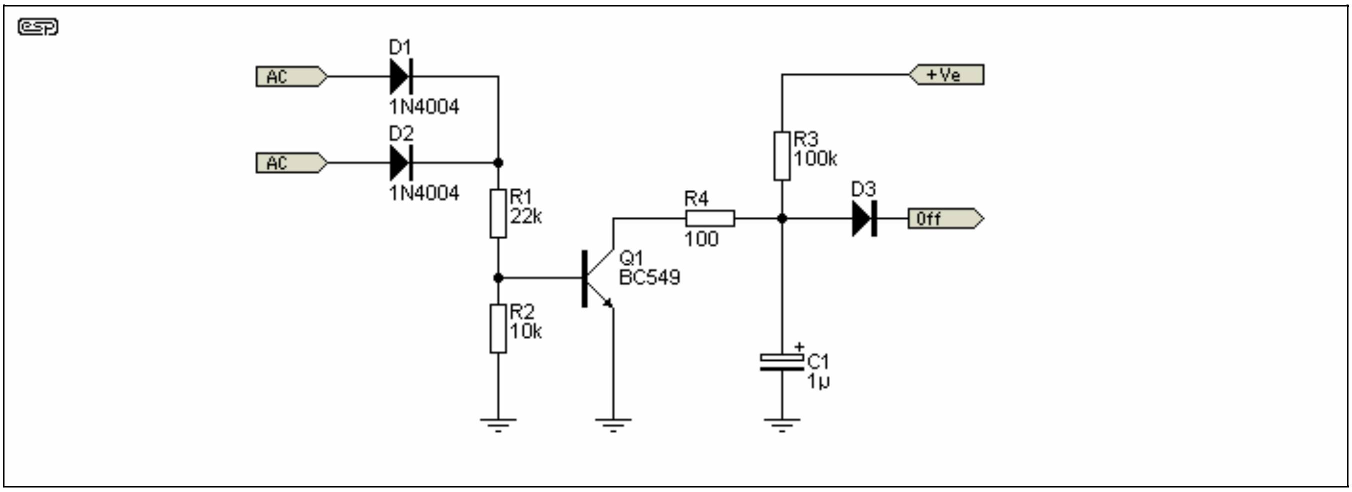


**Figure 3 - Loss of AC Detector**

The power detector cannot rely on the DC supply, as this may take a considerable time to collapse. The common approach is to use a rectified but unsmoothed output from the transformer secondary. Because it is not smoothed, this disappears instantly when power is removed, and is ideal. Figure 3 shows the basic circuit, and this will remove relay drive within about 50ms of the power being turned off. We could make it faster than this, but there is little point.

The circuit simply uses the current pulses to keep a capacitor discharged via Q1.

When the pulses stop, the cap charges until the threshold voltage of the 'Off' terminal is reached (0.65V), and the relays are turned off. After power is first applied, the timer circuit will activate the relays after about 4 seconds (typical). This can be increased if desired, by increasing the value of C1 in Figure 2.

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## Tests

I carried out some tests to see just how quickly the relays could be operated. The results were something of an eye-opener (and I *knew* about the added delay caused by a diode!). The relay I used was a small 24V coil unit, having a 730 Ohm coil and with substantial contacts (at least 10 Amps). With no back-EMF protection, the relay opened the contacts in 1.2ms - this is much faster than I expected, but the back-EMF went straight off the scale on my oscilloscope, and I would guess that the voltage was in excess of 500V. When a diode was added, the drop-out time dragged out to 7.2ms, which is a considerable increase, and of course there was no back-EMF (Ok, there was 0.65V, but we can ignore that). Using the diode / resistor method described above, release time was 3.5ms, and the maximum back-EMF was -30V, so this seems to be a suitable compromise.

I did not test the zener method prior to publication, but I know that it performs much like the diode/ resistor combination. The graphs below show the behaviour of the circuit with and without the resistor and diode. The estimated 500V or more is quite typical of all relays, which is why the diode is always included. This sort of voltage will destroy most transistors instantly. It is exactly the same process used in the standard Kettering ignition system used in cars, but without the secondary winding, or the 'flyback' transformer used in the horizontal output section of a CRT TV set.

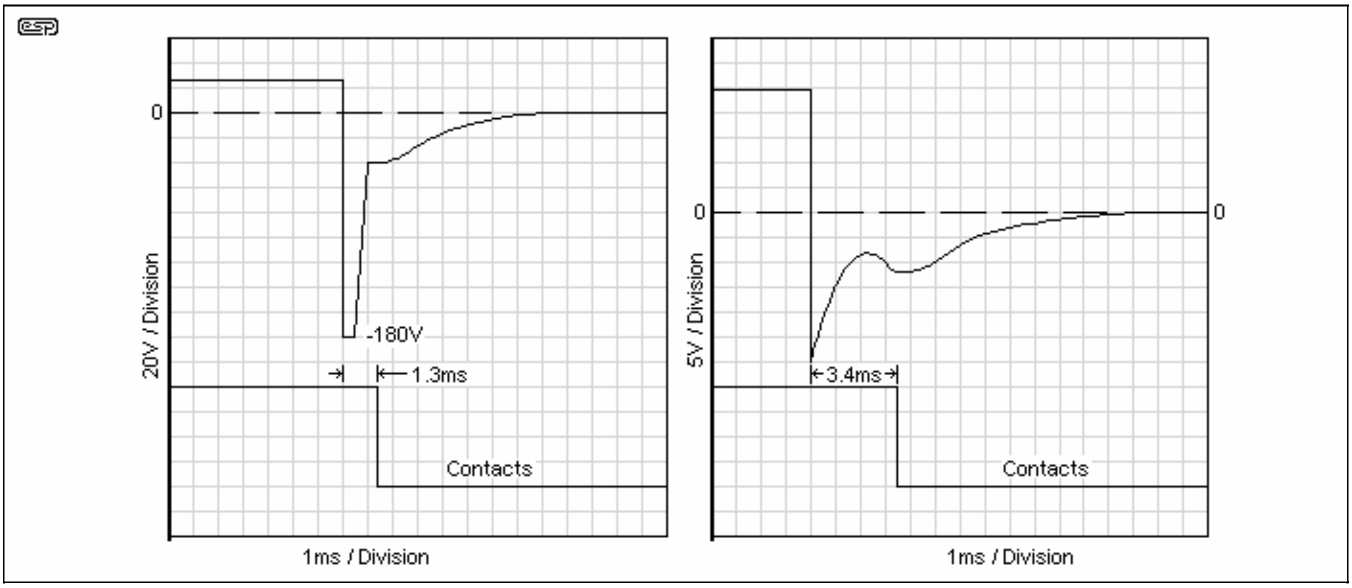


**Figure 4 - Relay Voltages**

The trace labelled 'Contacts' is representative only, and is not to scale. The peak relay voltage (above left) exceeded my oscilloscope's input range (and I was too lazy to set up an external attenuator), and as shown is cut off at my measurement limit. I estimate that the voltage is greater than 500V.

Note that the kink in the relay voltage curve is caused by the armature (the bit that moves) coming away from the relay pole piece, and reducing the inductance. This causes the stored magnetic charge to try to increase the voltage again, but it is absorbed by the resistance and dissipated quickly. The contacts open at the point where the previously closed magnetic field is opened as the armature moves away from the pole piece. As can be seen, this is 3.4ms after the relay supply is disconnected.

These graphs are representative only, as different relays will have different characteristics. As noted above, I cannot predict what sort of relay you will be able to obtain, but the behaviour can be expected to be similar to that shown. All tests were conducted using a 24V relay, having 10A contacts. Upon contact closure, I also measured 2.5ms of contact bounce. Provided your amplifier is stable by the time the contacts close, this will be completely inaudible.

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## PCB Version

The PCB version is slightly different from the circuits shown, but it still does everything. It includes a 'loss of AC' detector to mute the power amp when power is turned off, which is very helpful for amps that insist on making a loud 'thump' a few seconds after turn-off. None of the ESP designs do this (at least none that have a PCB available), but quite a few amps do.

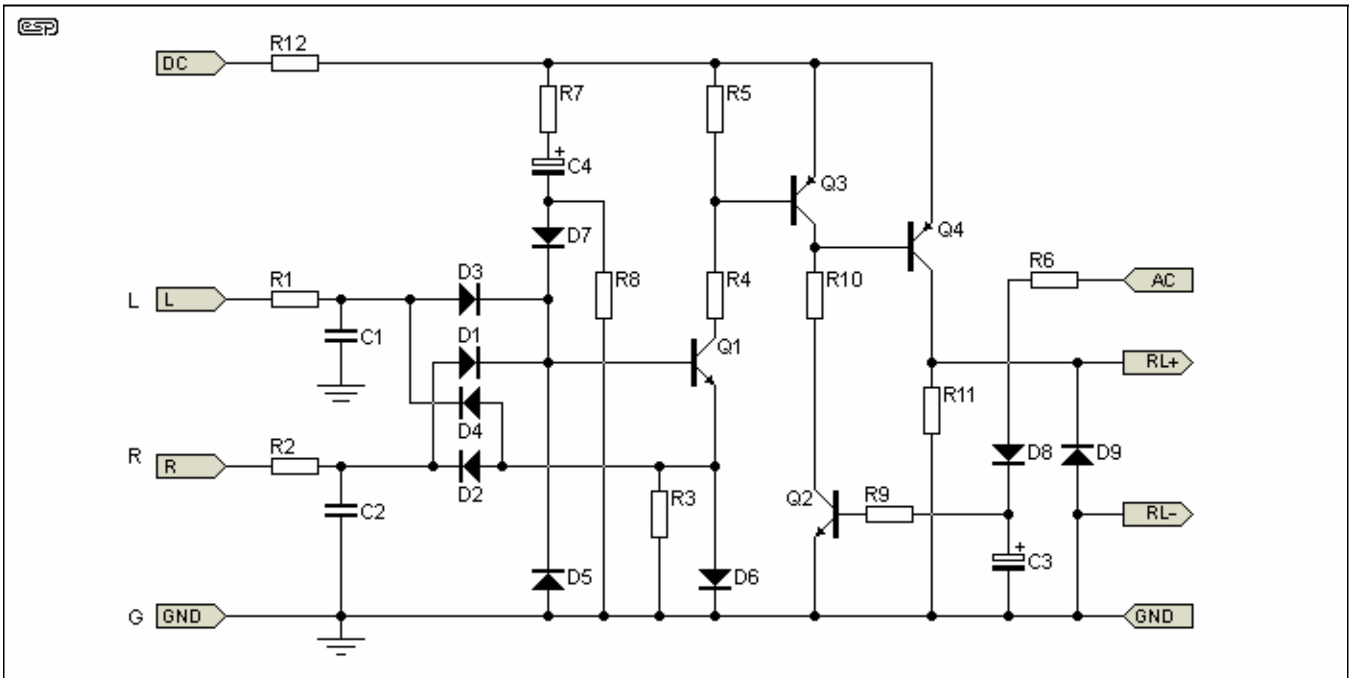


**Figure 5 - PCB Version Of The Circuit (Rev-A Version)**

The circuit is shown without the component values, but the full details are provided in the secure site available to those who purchase the board. It uses a small handful of cheap parts, and has proven itself to be very reliable in use. The PCB is very small, but does not include the relay(s), as they should be as close to the output terminals on the chassis as possible. The Revision-B board includes a simple regulator, so there's no need to mess around with series resistors for the relay(s). This is seen in the photo at the beginning of this article.

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## Relay Failure

The likelihood of the relay failing is illustrated below. When there is a DC arc, the temperatures reach well beyond that which any normal metal can withstand, and a meltdown is common. The photo shown was sent by a reader, and is not from a

P33 circuit. However, the process is identical, and the relay may easily end up looking like the one in the photo.

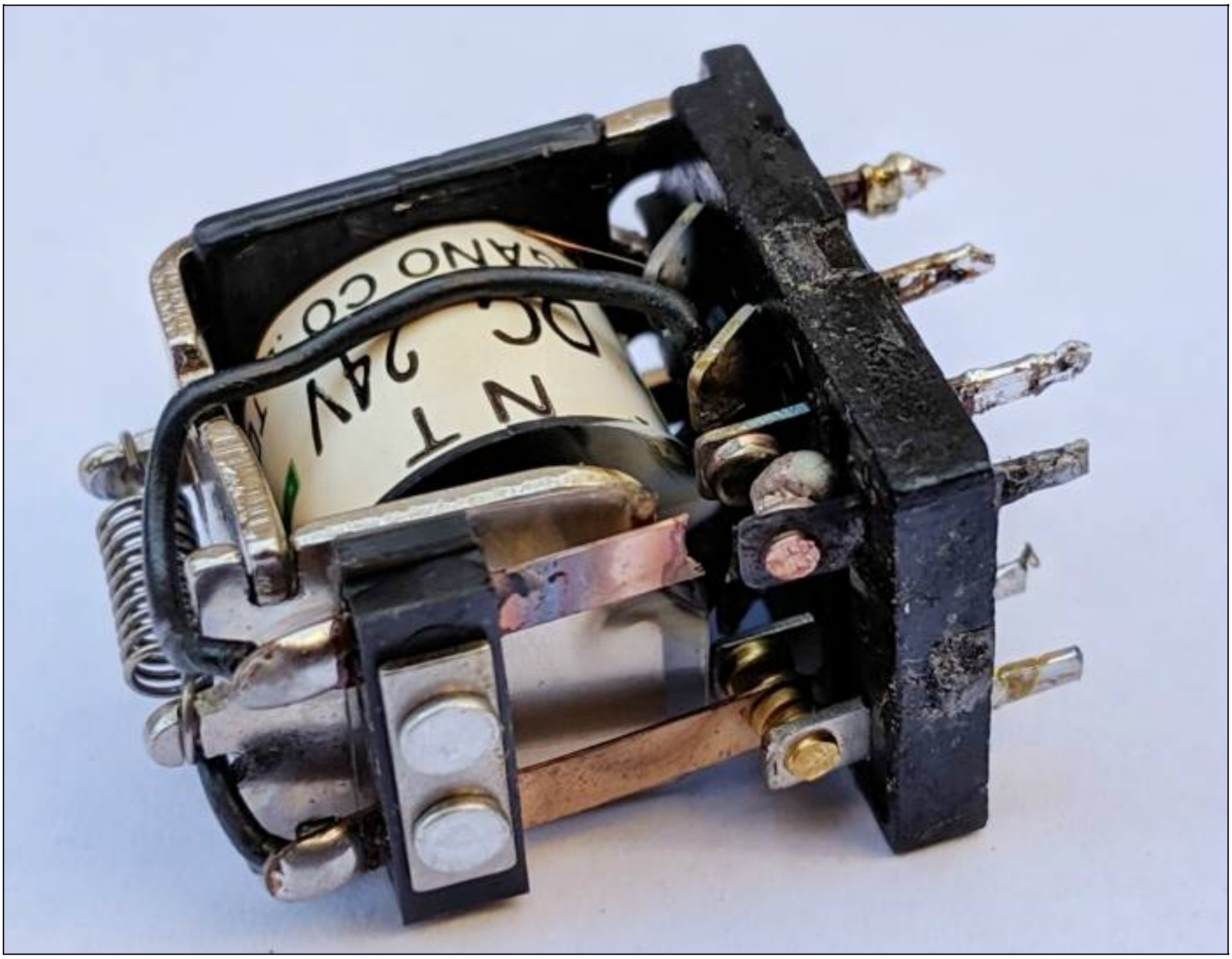

**Figure 6 - Relay Meltdown Due To DC Arc**

If the power amplifier(s) are fitted with fuses, the damage should be a lot less. Provided the fuse opens quickly enough, the energy in the arc will still be fairly high, but with greatly reduced duration. This limits the damage to the relay. However, a relay is still a great cheaper than a new loudspeaker driver (or drivers), so it doesn't matter that much if the relay is sacrificed for the 'greater good'.

A tried and tested solution is to use two sets of contacts in series. Most relays have a maximum voltage of 30V DC at rated current, so two sets in series can interrupt 60V DC. A capacitor (even 1µF is enough) across the normally open contacts can ensure there's either minimal (or no) arc, even at voltages above the relay's maximum. I've tested a relay with 1µF across the contacts at 60V with close to 15A (4 ohm load) without an arc, but you need to run your own tests. Bear in mind that the capacitor (if used) will allow some signal 'leakage' to the speaker. It's *imperative* that a resistor is used in series with an arc-suppression capacitor. The cap will never hold a charge, but it will connect the amplifier's output to ground.

So, you need to be aware (and preferably *very* aware) that a capacitor connected across the contacts ends up being connected directly from the amplifier's output to ground. A great many amplifiers will oscillate if you do that, so thorough testing is essential.  In general, a 3.9Ω resistor will help quench any arc, without causing amplifier damage.  A protection circuit that damages the amplifier is not helpful.  This doesn't happen if the relay's normally closed contact is not grounded, but that reduces the ability of the circuit to protect the speakers.  I strongly recommend that you read the Relays articles (Part I and Part II).

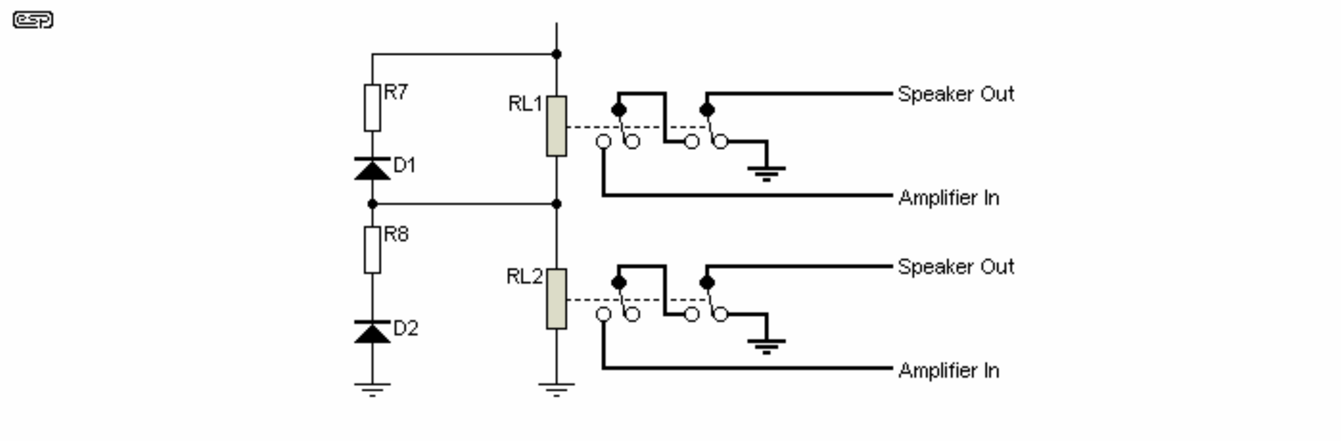


**Figure 7 - Relay Contacts In Series**

If you use a DPDT industrial class relay (with 0.8mm contact spacing) wired as shown (the same class of relay shown in Figure 6), I've verified that it can withstand up to 60V DC with around 16A of fault current.  A single set of 0.8mm separated contacts will simply arc (*violently*), and this has also been verified by bench testing.  Standard miniature relays generally have a contact separation of not more than 0.4mm, and that cannot withstand the arc produced.  The relay contact assembly will be vaporised!

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### P33 With P198 MOSFET Relays

As described above, high voltage arcs are very destructive, and while you *might* have success with a pair of contacts in series, this still limits the supply voltage to around ±60V.  This will be enough for most ESP designs, as I don't recommend using more than that for any of the published designs.  However, it's likely that many people will like the idea of a solid-state relay that *can't* arc, regardless of voltage.

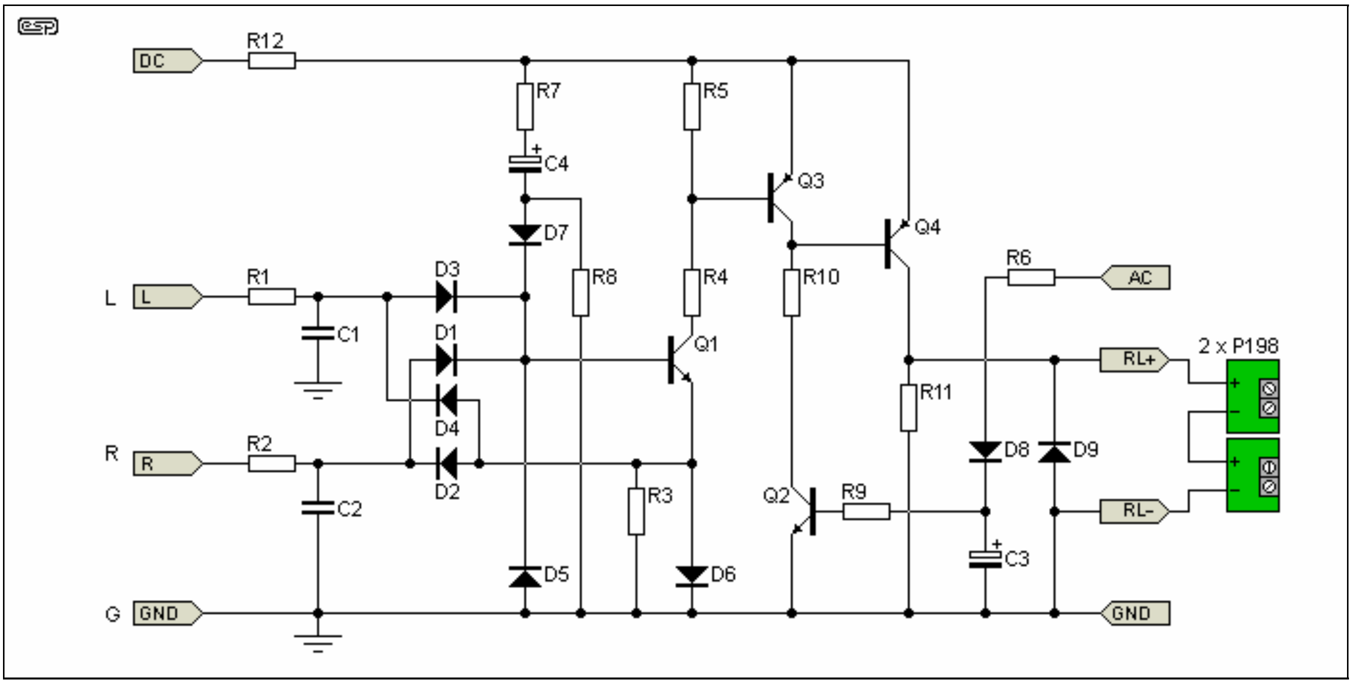


**Figure 8 - PCB Version Of The Circuit With P198 MOSFET Relays**

The recommended IC for the P198 boards is the Si8752, which uses 'diode emulation', and the limiting resistors need to be selected for a current of 10mA. Because the two are in series, each P198 board will receive half the total supply voltage. For example, the recommended current is 10mA, so if the supply to the P33 is 12V, each P198 module would use a 390Ω resistor in the R3 position (only one resistor is used for the Si8752 driver IC). You could also use 330Ω which will provide a little more current).

This will also work with higher voltages, and the formulae shown above can be used. The only difference is that the total voltage is reduced by 4.4V (2.2V for each Si8752), and the current is set for 10mA (±2mA). Using more current through the Si8752 only makes it turn on faster - it does not affect overall performance in a muting/ protection circuit. The low current drain (compared to a relay) makes the job of the main switch (Q4) much easier, and also reduces overall current drain. Otherwise, the P33 circuit behaves normally.

## References


1. D. Self - Muting Relays, Electronics World, Jul 1999
2. Relays, Selection & Usage (Part 1) - ESP (also see Part 2 which deals specifically with contact arcing)
3. Relay photo submitted by Bob



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