Soft-Start Circuit For Power Amps

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Updated 24 Sep 2003

WARNING: This circuit requires experience with mains wiring. Do not attempt construction unless experienced and capable. Death or serious injury may result from incorrect wiring.

Update - 03 Apr 2000
When I wrote this, I originally selected 50% of the full power as the optimum. While this will be quite OK in most cases, there are some instances where an amplifier may flatly refuse to settle to its normal working condition if so limited.

As a result, all calculations have been revised to allow for 125% of full power. This is still a useful limitation, but will ensure that all amps (including most Class-A) will start and settle correctly. Experiment by all means, but I advise that the new figure be used unless the power supply is so over-rated that you are sure it will not cause a problem.

Update - 24 Sep 2003
PCBs are available for a somewhat modified version of the soft-start project. Rather than the MOSFET switch, the PCB version uses a cheap opamp, and provides power and soft start switching. Full details are available when you purchase the PCB, but the schematic and a brief description is shown below.

Introduction

When your monster (or not so monster) power amplifier is switched on, the initial current drawn from the mains is many times that even at full power. There are two main reasons for this, as follows ...

- Transformers will draw a very heavy current at switch on, until the magnetic flux has stabilised. The effect is worst when power is applied as the AC voltage passes through zero, and is minimised if power is applied at the peak of the AC waveform. This is exactly the opposite to what you might expect
- At power on, the filter capacitors are completely discharged, and act as a short circuit for a brief (but possibly destructive) period

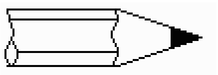
These phenomena are well known to manufacturers of very high power amps used in PA and industrial applications, but "soft start" circuits are not commonly used in consumer equipment. Anyone who has a large power amp - especially one that uses a toroidal transformer - will have noticed a momentary dimming of the lights when the amp is powered up. The current drawn is so high that other equipment is affected.

This high inrush current (as it is known) is stressful on many components in your amp, especially ...

- Fuses - these must be slow-blow, or nuisance fuse blowing will be common
- Transformer - the massive current stresses the windings mechanically and electrically. It is not uncommon to hear a diminishing mechanical buzz as the chassis reacts to the magnetic stress
- Bridge rectifier - this must handle a current way beyond the normal, because it is forced to try to charge empty filter capacitors, which look like a short circuit until a respectable voltage has been reached
- Capacitors - the inrush current is many times the ripple current rating of the caps, and stresses the internal electrical connections

It should come as no surprise to learn that the majority of amplifier failures occur at power on (unless the operator does something foolish). This is exactly the same problem that causes your lights at home to "blow" as you turn on the light switch. You rarely see a light bulb fail while you are quietly sitting there reading, it almost always happens at the moment that power is applied. It is exactly the same with power amplifiers.

The circuit presented here is designed to limit inrush current to a safe value, which I have selected as 125% of the full load capacity of the power transformer. Please be aware that there are important safety issues with this design (as with all such circuits) - neglect these at your peril.



NOTE: Do not attempt this project if you are unwilling to experiment - the relay operation must be 100% reliable, your mains wiring must be to an excellent standard, and some metalwork will be needed. There is nothing trivial about this circuit, despite its apparent simplicity.

See Construction Notes, Class-A Amplifiers, Special Warning and Update for more information on the implications of this project.

Description

As an example, a 300VA transformer is fairly typical of many high power domestic systems. Assuming an ideal load (which the rectifier is not, but that is another story), the current drawn from the mains at full power is ...

$\mathbf{I = VA / V}$ (1) Where VA is the VA rating of the transformer, and V is the mains voltage used

Since I live in a 240V supply country I will use this for my calculations, but they are easy for anyone to do. Using equation 1, we will get the following full power current rating from the mains

$I = 300 / 240 = 1.25A$

I said that I was going for 125% of full power current limiting, so this is 1.56A AC. The resistance is easily calculated using Ohm's law ...

$\mathbf{R = V / I}$ (2)

so from this I will get ...

$R = 240 / 1.56 = 154$ Ohms

Not really a standard value, but 3 x 470 Ohm 10W resistors will do just fine, giving a combined resistance of 156 Ohms. A single 150 Ohm resistor could be used, but the power rating of 384W is a little daunting. We don't need that for normal use, but be aware that this will be the dissipation under certain fault conditions.

To determine the power rating for the ballast resistor, which is 125% of the transformer power rating at full power ...

$\mathbf{P = V^2 / R}$ (3)

For this resistance, this would seem to indicate that a 374W resistor is needed, a large and expensive component indeed.

In reality, we need no such thing, since the resistor will be in circuit for a brief period - typically about 5 seconds, and the amp will (hopefully) not be expected to supply output power until stabilised. The only thing we need to be careful about is to ensure that the ballast resistor is capable of handling the inrush current. During testing, I managed to split a ceramic resistor in half because it could not take the current - this effect is sometimes referred to as 'Chenobyling", after the nuclear disaster in the USSR some years ago, and is best avoided.

It is common for large (> 1kW) amps to use a 50W resistor, usually the chassis mounted aluminium bodied types, but these are expensive and not easy for most constructors to get. For the above example, 3 x 10W ceramic resistors in parallel (each resistor is 470 Ohm) will give close to what we want, and is comparatively cheap.

For US (and readers in other 110V countries), the resistance works out to be 32 Ohms, so 3 x 100 Ohm 10W resistors should work fine (this gives 33 Ohms - close enough for this type of circuit).

Typically, the ballast resistor power rating should be not less that 1/10 (0.1) of the VA rating of the transformer, so for a 1kVA transformer, I would suggest 100W resistance as appropriate - although I have it on good authority that typical 1000W amps use a 50W resistor. From the same source, I also know that if the control circuit fails, they go off with an almighty bang!

Updated 18 Aug 2000

I have been harangued by a reader who tells me that the resistance should normally be between 10 and 50 ohms, and that higher values (such as those I suggested above) should not be used. I shall leave this to the reader to decide, since there are (IMO) good arguments for both ideas. As always, this is a compromise situation, and different situations call for different approaches.

A 10 ohm resistor is the absolute minimum I would use, and the resistor needs to be selected with care, as the surge current is likely to demolish lesser resistors, especially with a 240V supply. While it is true that as resistance is reduced, the resistance wire is thicker and more tolerant of overload, worst case instantaneous current with 10 ohms is 24A at 240V. This is an instantaneous dissipation of 5,760W, and it will require an extremely robust resistor to withstand this even for short periods. For 120V operation, the peak current will "only" be 12A, reducing the peak dissipation to 1,440W.

In reality, the worst case peak current will never be reached, since there is the transformer winding resistance and mains impedance to be taken into account. On this basis, a reasonable compromise limiting resistor will be in the order of 33 ohms for 240V, or 15 ohms for 120V operation. You may decide to use these values rather than calculate the value from the equations above, and it will be found that this will work very well in nearly all cases, and will still allow the fuse to blow in case of a fault.

This is in contrast to the use of higher values, where the fuse will (in all probability) not blow until the relay closes. Although the time period is reasonably short, the resistors will get very hot, very quickly.

Another good reason to use a lower value is that some amplifiers have a turn-on behaviour that may cause a relatively heavy current to be drawn for a brief period. These amplifiers may not reach a stable operating point with a high value resistance in series, and may therefore cause a heavy speaker current to flow until full voltage is applied. This is a potentially disastrous situation, and must be avoided at all costs. If your amplifier exhibits this behaviour, then the lower value limiting resistors ***must*** be used.

Update 08 Oct 2001: Due to comments from several readers, I have modified the circuit to allow a much faster relay release time. If flaky mains are a "feature" where you live, then I would suggest that you may need to set up a system where the amplifier is switched off if the mains fails for more than a few cycles at a time. The AC supply to a toroidal transformer only has to "go missing" for a few of cycles to cause a substantial inrush current, so care is needed.

Bypass Circuit

Many of the large professional amps use a triac (bi-lateral silicon controlled rectifier), but I intend to use a relay for a number of very good reasons ...

- Relays are virtually indestructible
- They are easy to obtain virtually anywhere
- Useful isolation is provided so control circuitry is not at mains potential
- No RF noise or harmonics of the mains frequency are generated. These are low level, but can be very troublesome to eliminate from triac circuits
- No heatsink is needed, eliminating a potential safety hazard should there be an insulation breakdown between triac and heatsink

They will also cause their share of problems, but these are addressed in this project. The worst is providing a suitable coil voltage, allowing commonly available devices to be used in power amps of all sizes and supply voltages.

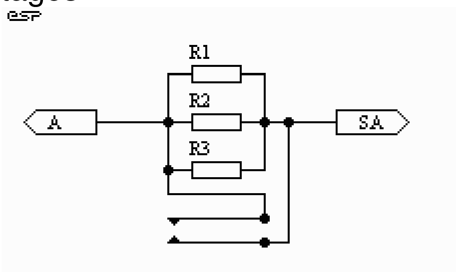


Figure 1 - Soft-Start Resistors and Relay Contacts

Figure 1 shows how the resistors are connected in series with the supply to the transformer, with the relay contacts short circuiting the resistors when the relay is activated. This circuitry is all at the mains voltage, and must be treated with great respect.

A represents the Active (Live or Hot) lead from the mains switch, and SA is the "soft" Active, and connects to the main power transformer. Do not disconnect or bypass any existing wiring, simply place the resistor pack in series with the existing transformer.

Do not attempt any wiring unless the mains lead is disconnected, and all connections must be made so that accidental contact to finger or chassis is not possible under any circumstance. The resistors should be mounted using an aluminium bracket that shrouds the connections preventing contact. All leads should be kept a safe distance from the chassis and shroud - where this seems impossible, use insulation to prevent any possibility of contact. Constructional notes are shown later in this project. The safety aspect of this project cannot be stressed highly enough !

The relay contacts must be rated for the full mains voltage, and at least the full power current of the amplifier. The use of a relay with 10A contact rating is strongly recommended.

HINT: You can also add a second relay to mute the input until full power is applied. I shall leave it to you to make the necessary adjustments. You will have to add the current for the two relays together, or use separate supply feeds if utilising the existing internal power supply voltage.

Control Circuits

If a 12V supply were to be available in all power amps, this would be very simple, but unfortunately this is rarely the case. Most amps will have DC supplies ranging from +/-25V to about +/-70V, and any attempt to obtain relays for these voltages will be met with failure in the majority of cases.

An auxiliary supply can be added, but this means the addition of a second transformer, which will be quite impossible due to space limitations in some cases. It is still a viable option (and is the safest way to go), and a control circuit using this approach is shown in Figure 2. This is the simplest to implement, but the added cost of the second transformer may be hard to justify. It is pretty much mandatory for Class-A amps though (See Class-A Amplifiers).

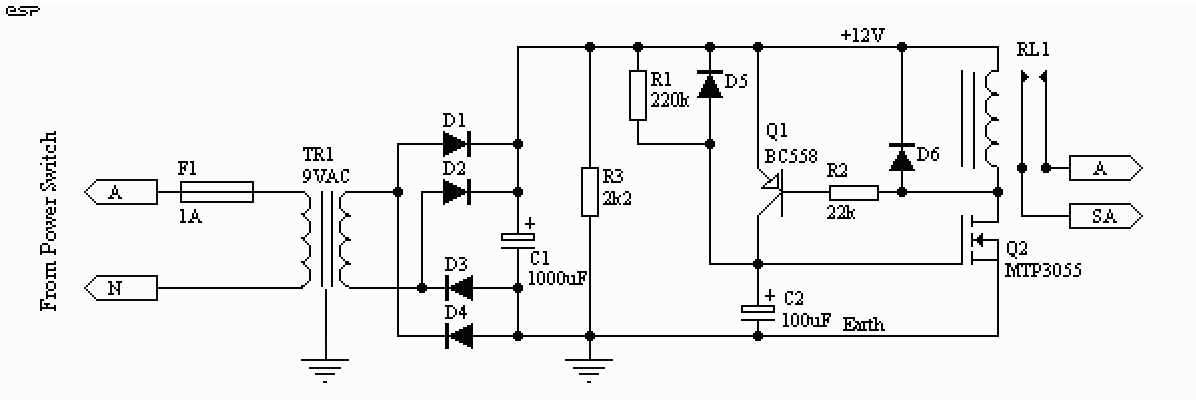


Figure 2 - Auxiliary Transformer Control Circuit

This uses simple bridge rectifier, and a small but adequate capacitor. The control circuit uses readily available and low cost components, and can easily be built on Veroboard or similar. All diodes can be 1N4004 or equivalent. Use a transformer with a 9V AC secondary, which will supply close enough to 12 Volts for this circuit. No regulation is needed, and the controller is a simple timer, activating the relay after about 5 seconds. I have chosen a MOSFET for the switch, since it has a defined turn-on voltage, and requires virtually no gate current. With the component values shown, the relay should activate in about 6 seconds. This can be increased by increasing the value of R1 (220k). The transformer need only be a small one, since current is less than 100mA.

Q1 is used to ensure that power is applied to the relay quickly. When a voltage of 0.65V is sensed across the relay, Q1 turns on, and instantly completes the charging of C2. Without the "snap action", the circuit will be sluggish, and is not suited to some of the other variations below.

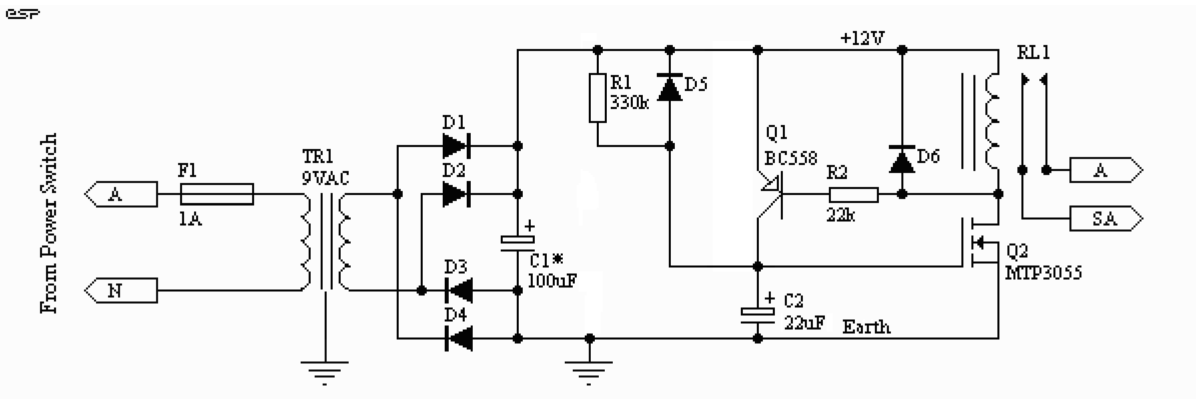


Figure 2a - Alternate Fast Acting Version

Figure 2a shows an alternate version. The circuit configuration is the same, but component values are changed to speed up the operation. Activation time is faster, but will still be in excess of 1 second, which will be fine for the vast majority of amplifiers. The main difference is the drop-out time, and this version will release the relay very quickly. As shown, and with a relay coil resistance of 120 ohms, the relay will release within about 300 ms. With a 285 ohm coil (such as the one I used for my experiments), a value of 47uF is suitable for C1.

NOTE: C1 should be rated at a minimum of 50V to ensure that the ripple current rating is sufficient to prevent capacitor heating. Be warned that if the cap gets warm (or hot), then its reliability and longevity will be compromised.

It is possible to make it much faster again, but at the expense of circuit complexity. A simple logic system could ensure that the circuit was reset with a single AC cycle dropout, but this would be too fast for normal use, and quite unnecessary. C1 (marked with a *) will have to be selected based on the relay. If the value is too small, the relay will chatter or at least buzz, and will probably overheat as well, due to eddy currents in the solid core used in DC relays. The capacitor should be selected based on the value that makes the relay quiet, but still releases quickly enough to prevent high inrush current if there is a momentary interruption to the mains supply.

You may want to consider using a mains switch with an additional set of contacts, so that the second set will short circuit the 12V supply when power is turned off. Make sure that the switch has appropriate ratings, and be sure to mark and insulate all connections.

Where it is not possible to use the transformer for any reason, then the circuit in Figure 3 can be used. This uses a resistor to drop the supply voltage for the relay, and has a simple zener diode regulator to supply the control circuit. The method of determining the resistor values and power for Rx and Ry is shown below.

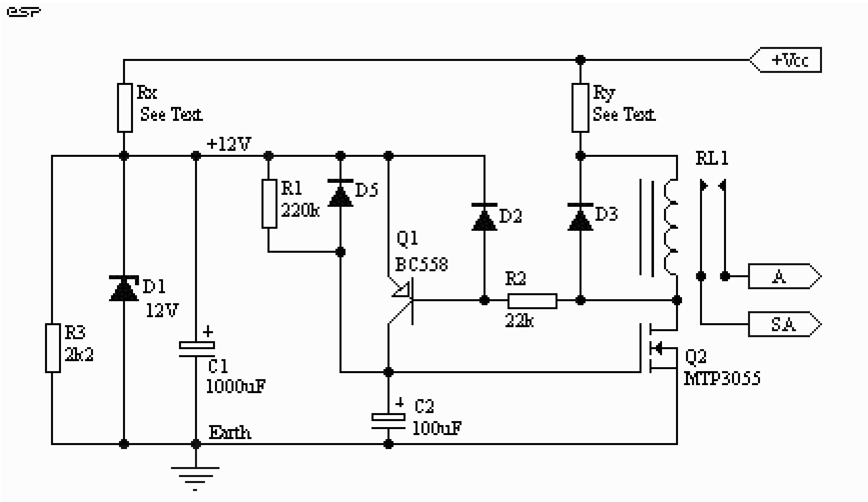


Figure 3 - Control Circuit Using Existing Supply

WARNING: In the event of an amplifier fault at power-on, the fuse will not blow with this circuit installed, since there may be no power to operate the relay. The current is limited to 125% that at normal full power, so the fuse will be perfectly safe - at least for long enough for it to destroy the resistor(s)! The ballast resistors will overheat very quickly, and if you are lucky they will fail. If you don't like this idea - USE THE AUXILIARY TRANSFORMER.

I very strongly suggest the auxiliary transformer - it is MUCH safer!

The first calculation is based on the supply voltage, and determines the current available to the zener. This should be about 20mA (it is not too critical). Since the zener is 12V, use the following formula to obtain the value for Rx ...

R = (Vcc - 12) / I (4) Where Vcc is the voltage of the main positive supply rail, I is current

Example. The Vcc (the +ve supply rail) is 50V, so

R = (50 - 12) / 0.02 = 1900 Ohms (1.8k is quite acceptable)

Power may now be determined as follows

P = (Vcc - 12)² / R (5)

Again, from the example above

P = (50 - 12)² / 1800 = 38² / 1800 = 1444 / 1800 = 0.8W

A 2W resistor (or two 3k6 1W resistors in parallel) is indicated to allow a safety margin. Where possible, I always recommend that a resistor be at least double the expected power dissipation, to ensure long life and cooler operation. It may be necessary to select different resistor values to obtain standard values - not all calculations will work out as neatly as this. Remember that the 20mA is only approximate, and anything from 15 to 25mA is quite acceptable.

The relay coil limiting resistor (Ry) is worked out in a similar manner, but first you have to know the resistance of the relay coil. This may be obtained from specifications, or measured with a multimeter. I have details of a suitable relay that has a 12V DC coil, and has a claimed resistance of 285 Ohms. Coil current is therefore

$I = Vc / Rc$ (6) Where Vc is coil voltage and Rc is coil resistance

$I = 12 / 285 = 0.042A$ (42mA)

Using the same supply as before, formula 4 is used to determine the "ballast" resistance

$R = (50 - 12) / 0.042 = 904$ Ohms. 1k Ohms will be fine here (less than 10% variation)

Power is determined using equation 5 as before

$P = (50 - 12)^2 / 1000 = 38^2 / 1000 = 1444 / 1000 = 1.4W$

If the coil current is calculated with the resistor in place, it is found that it is 39mA - this is a variation of about 7%, and is well within the tolerance of a relay. A 5W resistor is indicated, as this has a more than generous safety margin. These resistors will be very much cheaper than a transformer, and require less space. Wasted power is not great, and is probably less than that lost in a transformer due to internal losses (small transformers are not very efficient).

With relays, it is often beneficial to use a power saver circuit, where an initial high current pulse is used to pull the relay in, and a lower holding current is then used to keep it energised. This is very common in relay circuits, and can provide a saving of about 50%. The basic scheme is shown in Figure 4 with some typical values for the relay as mentioned in the text. I have based my assumptions on the relay I have - I tested this part thoroughly, since it is very difficult to make calculations based on an electro-mechanical device such as a relay - there are too many variables. If you want to use this method, then I suggest that some experimentation is in order. Typically, the relay holding current will be between 20% and 50% of the pull-in current - generally at the lower end of the scale.

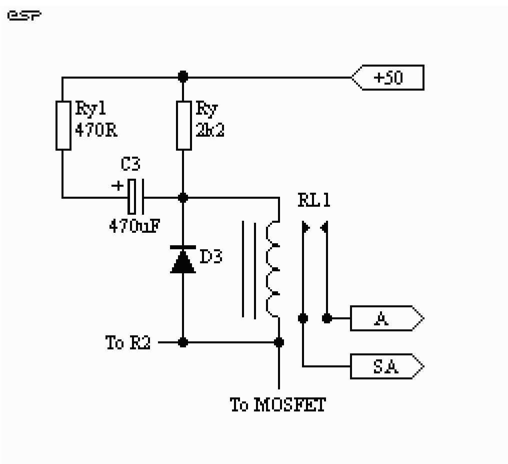


Figure 4 - Power Saving Relay Circuit

The values shown are those estimated for the 12V 285 Ohm relay - yours will be different! Do not mess about with this method if you are unsure of what you are doing. Failure of the relay to operate will cause the ballast resistors to overheat, with possibly catastrophic results (See below). This method can also be used with Class-A amps, as it is possible to make sure that the relay activates even on the lower voltage present while the ballast resistors are in circuit. (Although I strongly suggest the separate power supply circuit for Class-A, see Class-A Amplifiers, below.)

Notice that the power savings are across the board. The relay feed resistor now will dissipate 0.8W instead of 1.4W, and the auxiliary limiting resistor can be a 0.5W type - instantaneous dissipation is only 0.7W, and that is for a very short time. The feed resistor is now 2k2 instead of 1k, but an extra capacitor and resistor are the price you pay. The capacitor can be used in the circuit of Figure 3 too, and will force a large current at turn on. This will not save any power, but will most certainly ensure that the relay pulls in reliably.

A Few Test Results

The relay I used for testing is a 24V type - this in itself is of little consequence, since it can easily be re-calculated or re-measured for a 12V unit. A coil resistance of 750 Ohms means that at nominal supply voltage the relay needs 32mA. I measured the pull-in current at 23.5mA (typically about 65% of the nominal rating), and drop-out current was 7.5mA, or about 25% of rated current.

Using the 12V relay mentioned above, this would translate to (approximately - these are educated guesses)

- Nominal current - 42mA
- Pull-in Current - 28mA
- Drop-out Current - 10mA

Most (all?) relays will hold in perfectly well at 1/2 rated current, and I would suggest that this is as low as you should go for reliability. If you don't feel like including it, the resistor in series with the electro can be omitted. Sure this will pulse a 12V relay with 50V, but it won't care. Personally I suggest that a series limiter be used, calculated to provide an instantaneous current of 150% of the relay's nominal rating - this will protect the cap from excessive current. For a 12V unit (as above), this would mean a maximum current of 60mA and a holding current of 20mA.

Because of the vast number of variables, I shall leave this to your experimentation - Please do not ask me to calculate the values for you, because I won't. It is entirely the reader's responsibility to determine the suitability of this (or any other) project to their individual needs. If in any doubt, use the auxiliary transformer method.

Construction Notes

As described above, electrical safety is paramount with a circuit such as this. Figure 5 shows a suggested method of mounting the input ballast resistors that ensures that the minimum of 5mm creepage and clearance is maintained when the resistors are mounted, and still provides good thermal contact with the case and protection from fingers or other objects coming into contact with the mains.

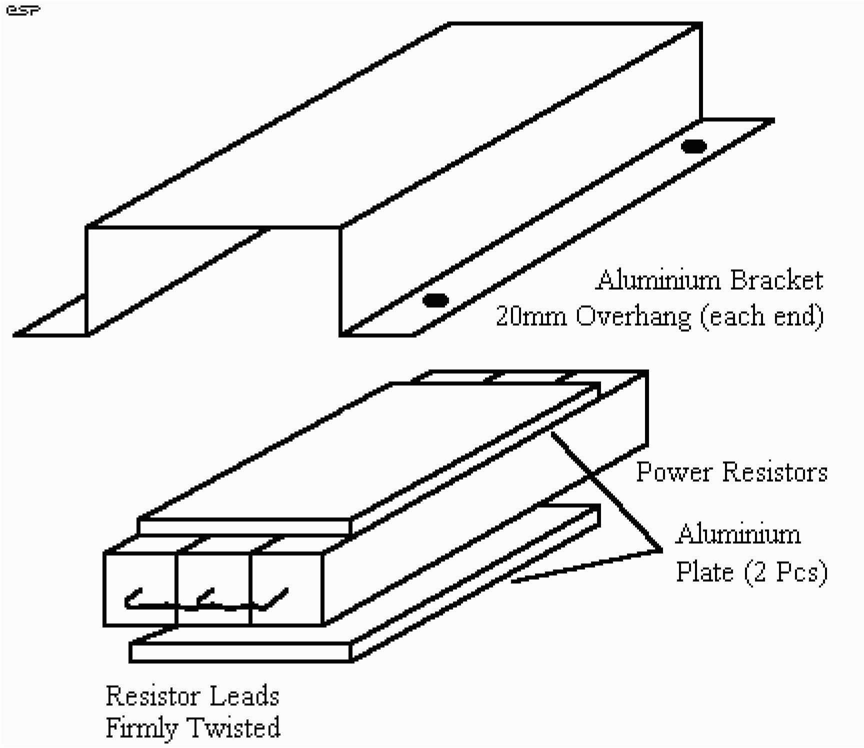


Figure 5 - Suggested Resistor Mounting

The aluminium bracket clamps the resistors firmly in position, and the plate above and below (which needs to be 5mm shorter than the resistor bodies) maintain clearance distances. It is imperative that the resistors cannot move in the bracket, and a good smear of heatsink compound will ensure thermal conductivity.

The alternative is to obtain one of the bolt-down aluminium bodied resistors if you can. This is obviously much simpler than making up a bracket. In case you are wondering why all this trouble for resistors that will be in circuit for 6 seconds, the reason is safety. The cover will keep fingers away, and stops the resistors moving about. It also provides a measure of safety if the relay does not operate, since dissipation will be very high. Since the resistors will get extremely hot, simply wrapping them in heatshrink tubing will do no good at all because it will melt. The idea is to prevent excessive external temperatures until the resistors (hopefully) fail and go open circuit.

The relay wiring is not critical, but make sure that there is a minimum of 5mm between the mains contacts and any other part of the circuitry. Mains rated cable must be used for all power wiring, and any exposed connection must be shrouded using heatshrink tubing or similar. Keep as much separation as possible between any mains wiring and low voltage or signal wiring.

The connections to the ballast resistors are especially important. Since these may get very hot if the relay fails to operate, care must be taken that the lead will not become disconnected if the solder melts, and that there is sufficient solder to hold everything together and no more. A solder droop could cause a short to chassis, placing you or other users at great risk of electrocution. An alternative is to use a screw-down connector, which must be capable of withstanding high temperature without the body melting.

Do not use heatshrink tubing as insulation for the incoming power leads to the ballast resistors. Fibreglass or silicone rubber tube is available from electrical suppliers, and is intended for high temperature operation.

Class-A Amplifiers

NOTE: I strongly suggest that the auxiliary transformer method is used with a Class-A amp, as this will eliminate any possibility of relay malfunction due to supply voltages not being high enough with the ballast resistors in circuit.

Because of the fact that a Class-A amp runs at full power all the time, using the existing supply you must not go below the 125% suggested inrush current. In some cases, it will be found that even then there is not enough voltage to operate the relay with the input ballast resistors in circuit.

If this is found to be the case, you cannot use this method, or will have to settle for an inrush of perhaps double the normal full power rating. This is still considerably less than that otherwise experienced, and will help prolong the life of the supply components, but is less satisfactory. The calculations are made in the same way as above, but some testing is needed to ensure that the relay operates reliably every time. See note, above.

Special Warning

In case you missed this the first time: In the event of an amplifier fault at power-on, the fuse will not blow with this circuit installed, since there may be no power to operate the relay. If you don't like this idea - USE THE AUXILIARY TRANSFORMER. The fuse will only blow after the relay closes, but at least it will blow.

This circuit by its very nature is designed to limit the maximum current at power on. If there is no power to operate the relay, the ballast resistors will absorb the full mains voltage, so for my example above will dissipate over 380W. The resistors will fail, but how long will they last? The answer to this is a complete unknown (but "not long" is a good guess).

The reliability of the relay circuit is paramount. If it fails, the dissipation across the ballast resistors will be very high indeed, and will lead to them overheating and possibly causing damage. The worst thing that can happen is that the solder joints to the resistors will melt, allowing the mains lead to become disconnected and short to the chassis. Alternatively, the solder may droop, and cause a short circuit. If you are lucky, the ballast resistors will fail before a full scale meltdown occurs.

Make sure that the mains connections to the resistors are made as described above (Construction Notes) to avoid any of the very dangerous possibilities. You may need to consult the local regulations in your country for wiring safety to ensure that all legalities are accounted for. If you build a circuit that fails and kills someone, guess who is liable? You!

It is possible to use a thermal switch mounted to the resistor cover to disconnect power if the temperature exceeds a set limit. These devices are available as spare parts for various household appliances, or you may be able to get them from your normal supplier. This is a highly recommended option.

WARNING: The small metal bullet shaped non-resetting thermal fuses have a live case (it is connected to one of the input leads). Use this type with great caution !!

PCB Version

The circuit diagram for the PCB version of this project is shown below. It uses a small transformer, and mains switching is only required for the small transformer, and the circuit takes care of the rest. The relays have a standard footprint, and should be available (almost) everywhere.

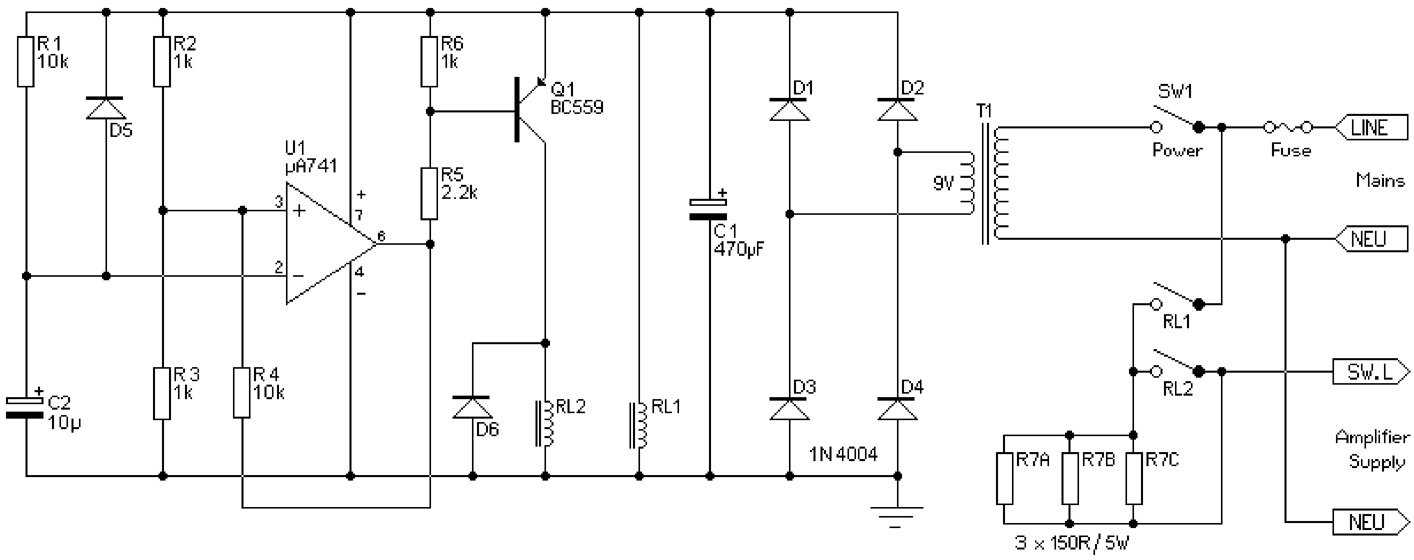


Figure 6 - PCB Version of Soft Start/ Mains Switch

A 9V transformer is needed, having a rating of around 5VA. The DC output is close to 12V, and will activate the relays reliably. The circuit has a reasonably fast drop-out and stable and very predictable timing (approx 300ms as shown). The PCB has space for 3 x 5W resistors, and the circuit has been used on a 500VA transformer with great success. The other comments above still apply (of course), but this circuit simplified the construction process considerably.

Full details, bill of materials, etc. are available on the secure server, along with detailed construction guide and mains wiring guidelines.