ICE Amplifiers Bench Power Supplies

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2. Table of Contents

1. Legal Stuff i
2. Table of Contents ii
3. Introduction 1
4. Circuit Diagram 2
5. AC to DC conversion 4
   5.1. Single Polarity Half Wave Rectifier 6
   5.2. Dual Polarity Half Wave Rectifier 8
   5.3. Single Polarity Full Wave Rectifier 9
   5.4. A Second Single Polarity Full Wave Rectifier 9
   5.5. Dual Polarity Balanced Full Wave Rectifier. 10
   5.6. Multiple Floatable Output Voltage Full Wave Rectifier 11
   5.7. Summery 11
6. Capacitive Smoothing 12
   6.1. Example Calculation 12
7. Earthing Grounding and the Common Terminal 14
   7.1. Definition of Terms 14
   7.2. An Example of Confusing Terminology 14
   7.3. Connecting the “earth” 14
   7.4. Audio and other Hum Sensitive Systems 15
   7.5. Situations Requiring Forethought 15
8. Valve Power Supplies 17
   8.1. Valve (Hard Vacuum) Rectifiers 17
   8.2. Filtration 17
9. Switching, Fusing & Indicators 19
   9.1. Switching 19
   9.2. Fusing 19
   9.3. Indicators 21
10. Construction Tips 23
   10.1. Mains 23
   10.2. Transformers 23
   10.3. Fuses 24
   10.4. Wiring 24
   10.5. Capacitors 24
11. Pictures 26
12. References 27

3. Introduction

A bench power supply for testing all kinds of electronics projects is a necessity. A ‘no frills’ linear design is presented here, providing ±5, ±12 and ±15 Volts @ 375mA max. Terminals are also provided directly from the filter capacitors. When used in conjunction with a variable autotransformer (0 - 240 VAC) DC voltages from 0 to approximately 40 Volts may be obtained. The only limitation is that the transformer continuous VA rating is not exceeded.

While 3/8ths of an Ampere may not be substantial, it is enough to test the functionality of a class B amplifier of any power rating. It is not enough to load test such an amplifier at its maximum power, nor is it possible to idle test a class A amplifier of any considerable power. However when building projects that are intended to have a high power output it is usual to provide a purpose built supply. This is a bench supply to make sure projects work before building a supply for them or scrapping them as ideas that “looked good on paper”.

4. Circuit Diagram

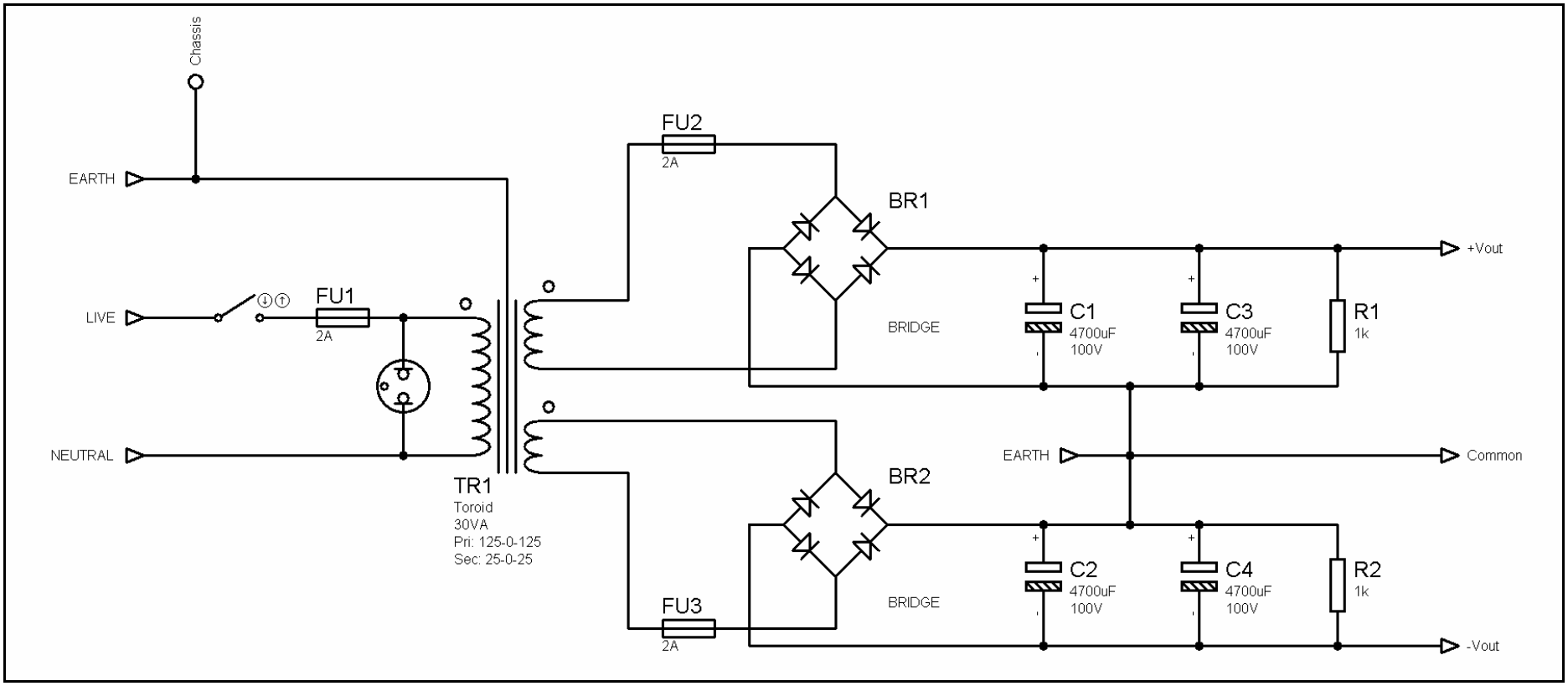


Figure 1: Main Power Supply Circuit

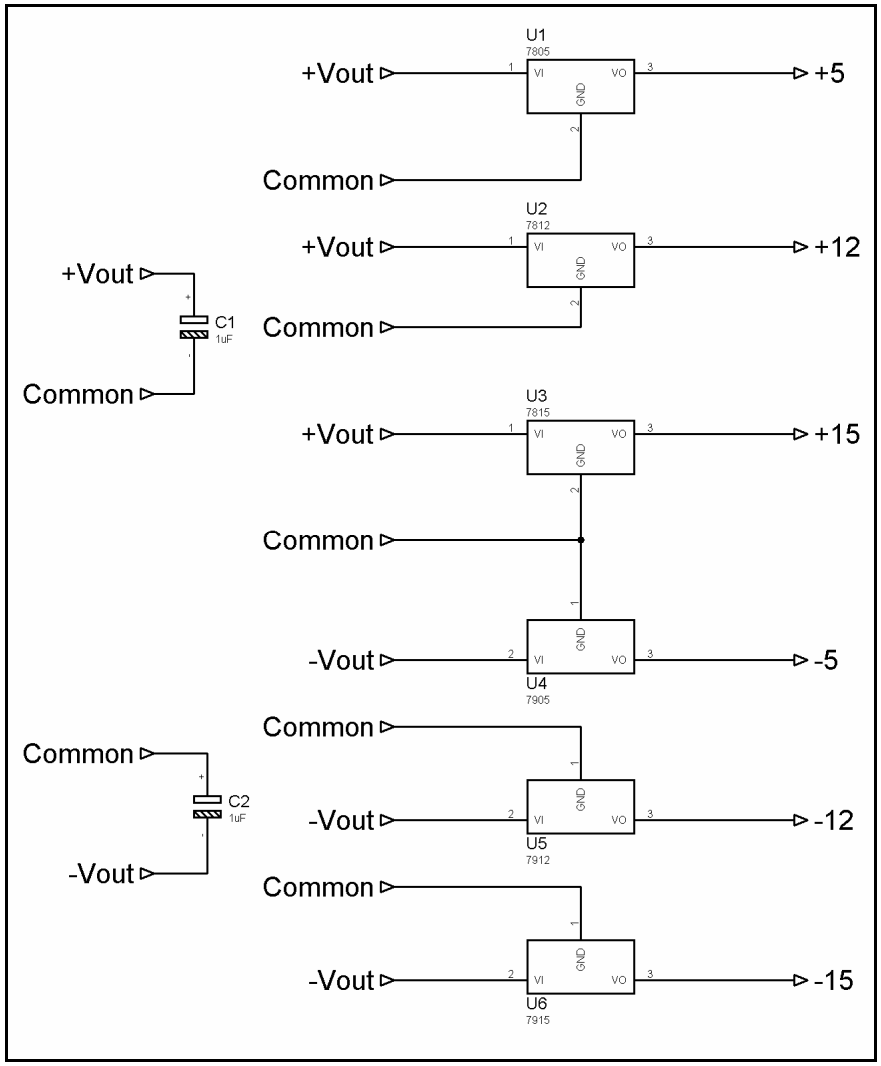


Figure 2: Regulation Circuit Diagram

5. Transformers

The transformer is usually the most expensive part of a power supply. Manufactures of consumer electronics go to great lengths to use the smallest VA transformer possible. It is common in some makes of audio power amplifier to find a power transformer capable of supplying 70% of the rated *output* power. Considering that a class B amplifier under perfect conditions (which can not be physically realised) is about 70% efficient, it is clear that the product could not be sine wave tested at maximum power for a considerable period before overheating. (This is also true of the heatsink in most cases, another expensive component)

When choosing a transformer for a bench supply, the 'rule' is fairly simple. The transformer should be rated for an absolute minimum of 100% of the maximum output power of the supply. This leaves nothing to account for inefficiencies. If the supply is moderately rated then the losses will become quite significant and ignoring them reduces the rated life.

Audio amplifiers very rarely deliver the maximum rated power, and when this power is delivered to the load the charge transferred will likely be (at least in part) from the smoothing capacitors. The thermal inertia of the transformer is very large compared to the likely length of time of maximum power delivery, so in this case it may be acceptable to under rate the transformer substantially.

In the case of a bench supply, the designer has no information about the likely load presented to the supply. The designer must assume that the supply will be required to develop maximum power in its load continuously for a time period significantly greater than the time taken for all components to reach thermal equilibrium.

In the power supply shown in section 4, the maximum power the supply should develop in a load is 26.52 Watts which is approximately 88.4% of the transformer VA. While the linear voltage regulation has low efficiency this is

not part of the calculation. The power flowing into the regulator first flows through the transformer; whether it then becomes useful (electrical) or wasted (heat) in the regulator is the concern of the regulator designer.

6. AC to DC conversion

The principles of operation of rectifiers are well established and can be found in several undergraduate text books [1] [2] [3] and also in [4] which is excellent if a copy can be found. Rectification relies on the non linear operation of the diode. The common silicon junction diode passes current in the forward bias direction when the built in voltage is exceeded. The forward bias current is exponentially proportional to the voltage across the terminals. Under reverse bias a very small current (the saturation current) flows. The built in voltage for silicon is approximately 0.7 Volts. Diodes are commonly configured as half bridges or full bridges of two or four diodes respectively.

Reviewing the material available free of charge on the internet, no general survey of rectifier circuits was available. There is plenty of information on driver bridges, matrix converters and phase controlled rectifiers etc. but a basic collection of common power supply circuits employing standard PN junction diodes seems to be lacking. Such a review is helpful in understanding the more general concepts in these circuits, which may be missed if they are studied in isolation. The circuits presented here are not a definitive set, many other configurations are possible, and all the circuits follow the same principles. The complexity increases with each example. The final circuit is generalised. In the following circuits non critical components have been removed for clarity. These components are still required.

Engineers and students may wonder why capacitive smoothing has been chosen, it is more instructive to analyse rectifier circuits using inductive loads. This is deliberate; the reason is simply that the circuits presented are intended to be building blocks. Further consideration of phase controlled rectification or DC-DC converters would warrant analysis using inductive loads. In linear power supply situations there is no advantage in complicating the problem.

6.1. Single Polarity Half Wave Rectifier

This is one of the simplest circuits for AC to DC conversion, consisting of one diode and one capacitor. The analysis should be done for two conditions.

Firstly the peak of an AC waveform with the dot end positive (wrt the non dot end), secondly for the peak of an AC waveform with the dot end negative.

Windings are in phase if the dot end of the lower is connected to the non dot end of the upper. Secondary windings connected in series have their voltages summed. E.g. two 6Vrms windings connected in series and in phase (dot to non dot) act as one 12Vrms winding. In anti-phase the result is zero.
Referring to Figure 4, at the dot end of the upper secondary assume that the (AC) voltage has just reached a maximum. In this case D1 and is conducting and C1 is charged. A DC current flows in R1. Half a cycle later the dot end of the upper secondary of TR1 is at its minimum voltage i.e. below that of the other end of the transformer. Current would usually flow from the point of high potential (the non dot end of the secondary) to the point of lower potential (the dot end). The saturation current flows through D1 in this case because it is reverse biased, it can be ignored. On the next half cycle the state of affairs returns to current flowing through the forward biased diode charging C1.

The lower portion of the AC waveform present across the transformer secondary has had its negative portions removed and is now DC. The capacitance stores charge supplied by the transformer and diode, and maintains a current in the load resistor when the diode is reverse biased. This circuits ability to maintain a stable DC voltage is a function of the capacitance across its output and the load current drawn. The preferable situation is to have the charge drawn into the load in one cycle significantly less than the total charge stored in the capacitor. The depletion of charge from the capacitor manifests a drop in voltage across its terminals. This is ‘ripple’, it can be considered a voltage, a current or a power, and is a measure of merit. The ‘ripple voltage’ is more usually quoted.

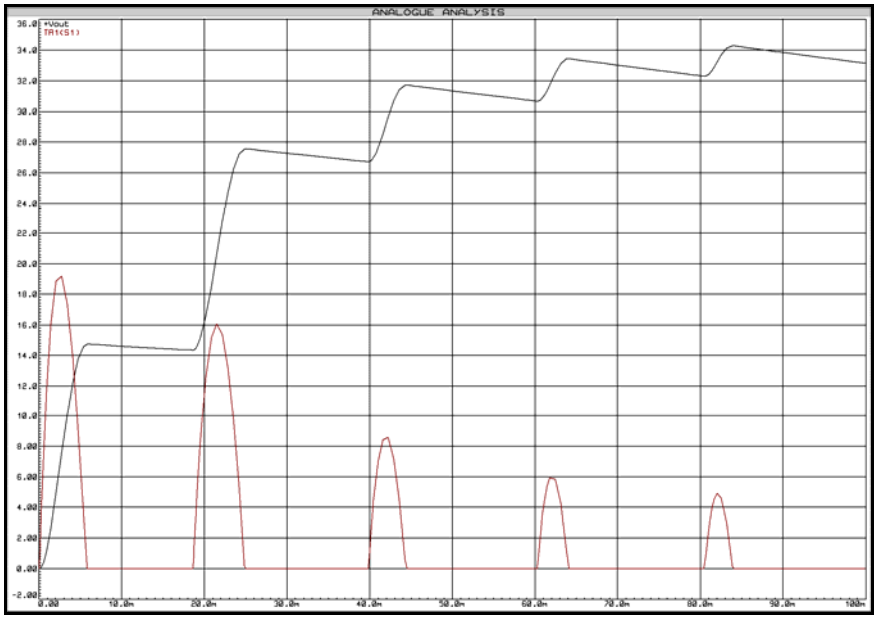


Figure 3: Current and voltage waveforms at the load

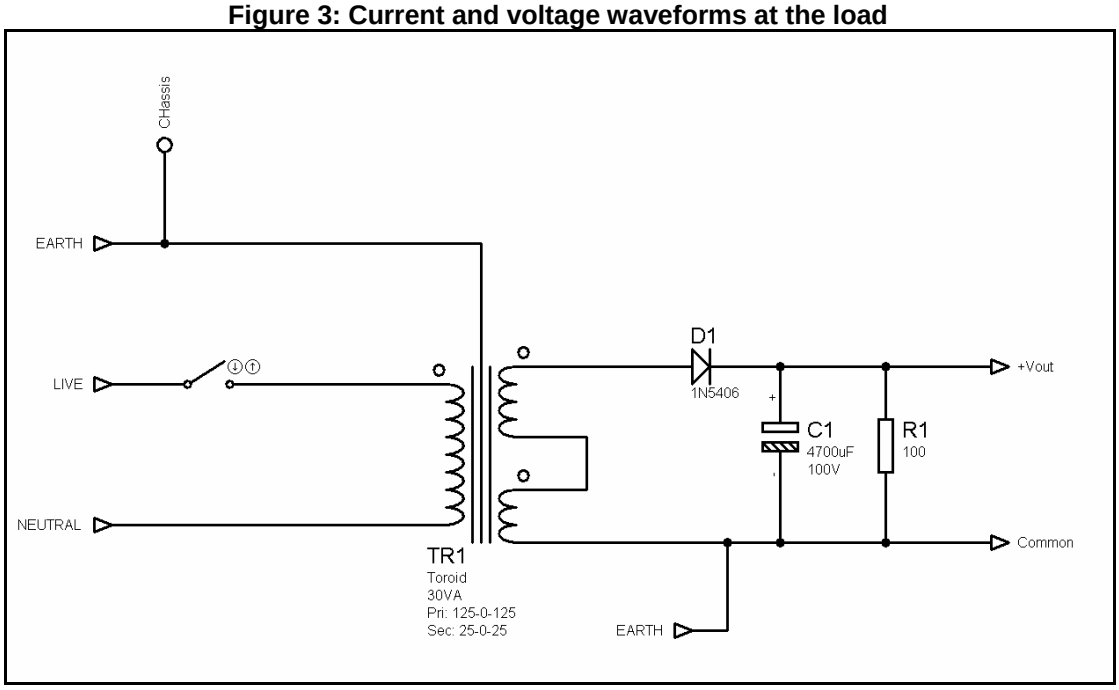


Figure 4: Single Polarity Half Wave Rectifier Supply

6.2. Dual Polarity Half Wave Rectifier

The dual polarity half bridge makes use of two diodes. The circuit requires two secondary taps because the common terminal must come from between the two supplies. This point is treated as the reference and all other voltages are relative to this. There is little advantage to analysing this circuit; it is left as a thought exercise for the reader. The operation is similar to the previous circuit. Superior dual supply circuits follow.

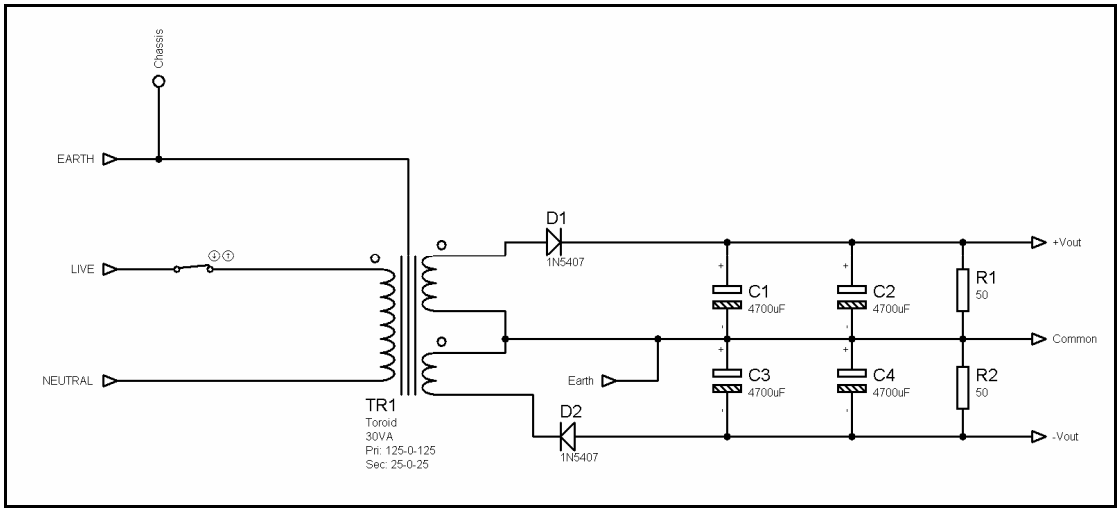


Figure 5: Duel Polarity Half Wave Rectifier Supply

6.3. Single Polarity Full Wave Rectifier

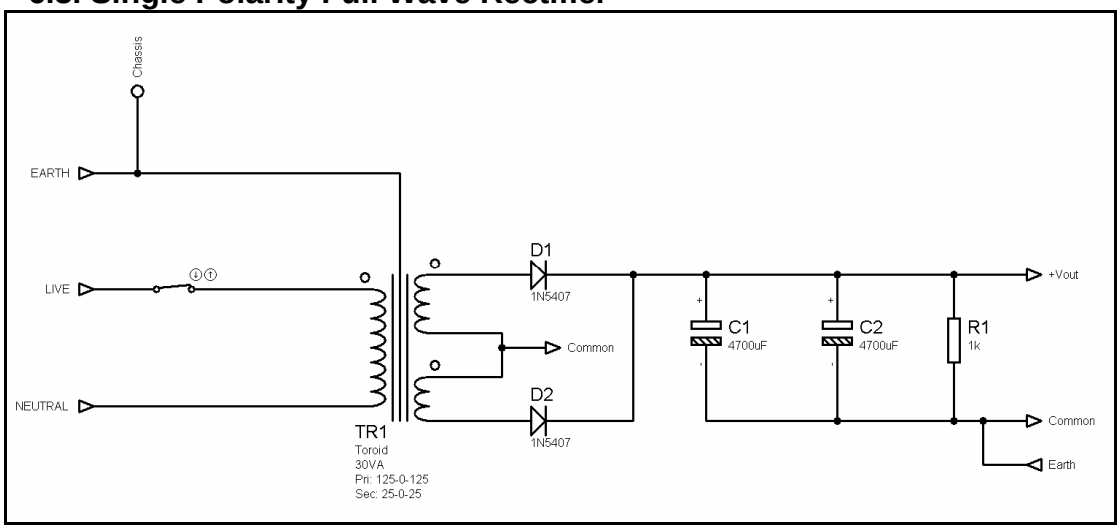


Figure 6: Full Wave Single Supply

The above circuit looks quite similar to the previous half wave rectifier; however it is a full wave rectifier circuit. The output voltage is the peak value of one of the secondary windings. The secondary windings should have the same voltage rating. If differing voltages are present on the secondary windings the capacitors C1 and C2 will be charged to the higher voltage, (assuming enough charge is available in a half cycle) every other half cycle. Any ripple calculation must account for this. It is reasonably rare to find a new stock transformer with differing secondary windings unless it is specifically for use in valve equipment.

6.4. A Second Single Polarity Full Wave Rectifier

This circuit is commonly used. It is a full wave circuit using a bridge of four diodes. The diodes conduct in pairs. The upper right and lower left diodes

conduct when the dot ends of the secondary windings are positive with respect to the non dot end. Conversely when the secondary polarity reverses, the other two diodes conduct and the first two are reverse biased. This circuit is found regularly in consumer electronics. This circuit is popularity because rectifiers are often manufactured in packages containing four diodes. These packages are ready to be bolted to a chassis or heatsink by a single fixing, they are convenient and cheep, and the package completely surrounds the diodes maximising heat transfer. Although it uses more components to achieve the same result as the previous circuit, it is ubiquitous.

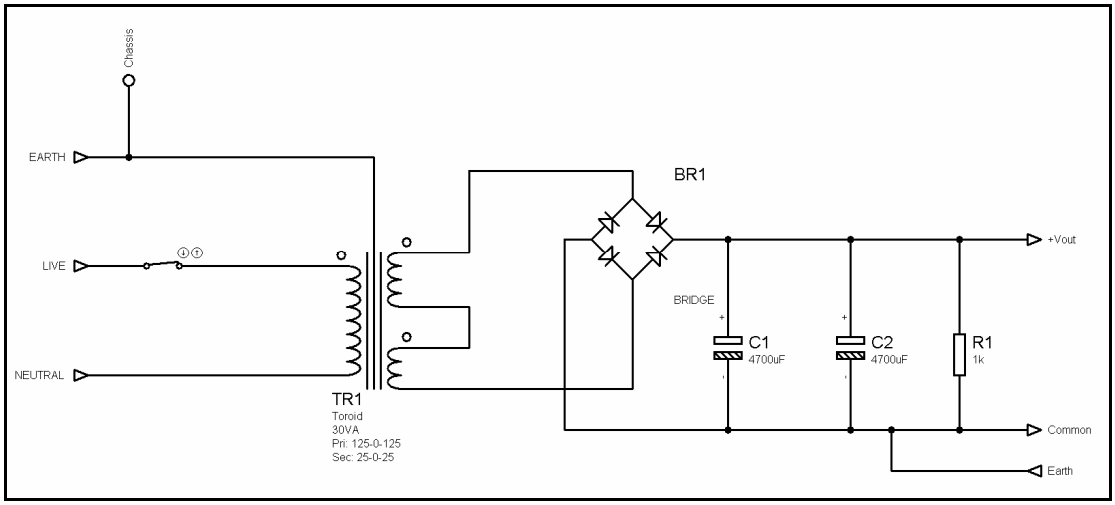


Figure 7: Single Supply Four Diode Bridge

6.5. Dual Polarity Balanced Full Wave Rectifier.

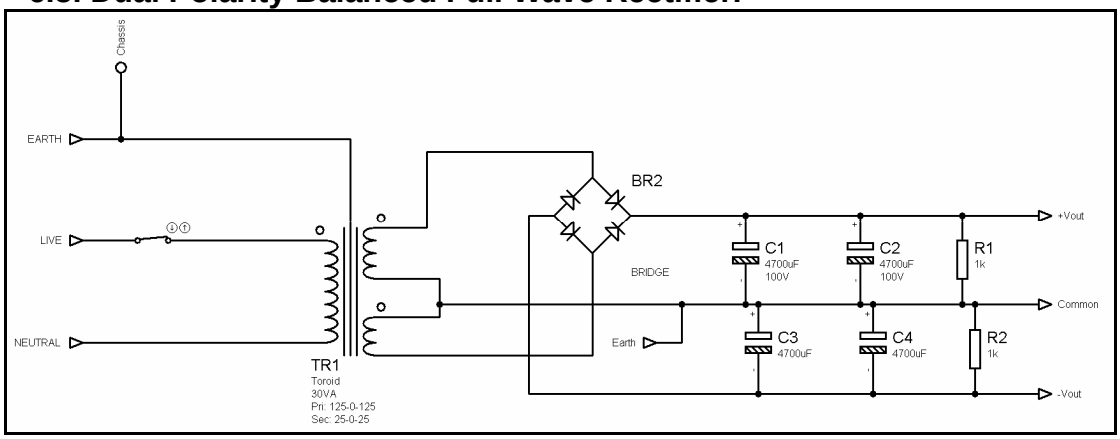


Figure 8: Dual Output Full Wave Single Bridge Circuit

Figure 8 is a dual output full bridge circuit. If the output from this circuit is measured with –Vout as the reference and +Vout is probed, the observed behaviour is the same as Figure 7. The sum of the positive and negative output voltage for this circuit is equal to that of Figure 7 if the transformer has the same windings and is run from the same supply voltage.

6.6. Multiple Floatable Output Voltage Full Wave Rectifier

This circuit (section 4) is more versatile than the circuit in section 6.5. Externally it functions similarly. The advantages are that two rectifiers are used so, assuming balanced load, the I^2R losses in any diode will be half that of the circuit above. The supplies need not necessarily be connected to each other to form a +/- supply. The two could be used separately as + to ground and + to ground. If a different number of turns was wound onto each secondary different output voltages would result. If one supply is heavily loaded the other will be less affected in this arrangement than in section 6.5. To ensure better immunity to supply interaction two transformers could be used at considerable extra cost[1], this would produce two essentially separate supplies. Even then the two supplies would share a mains lead to the wall outlet which (were a large enough current drawn) would represent a significant voltage drop. It is common to place 100nF capacitors in parallel with the rectifier diodes.

6.7. Summery

It should be clear to the astute reader that the placement of the earth connection with respect to the common connection is the controlling factor in determining relative polarities of power supplies. This is especially clear in the four diode bridge designs of 6.4 & 6.5. To take one example, consider that moving the “earth” connection to the Vout+ rail in Figure 7 would form a single supply with negative polarity with respect to the common terminal.

[1] Thurlby Thandar Instruments made some PSUs with two transformers; they were surprisingly heavy for their size…

7. Capacitive Smoothing

The “smoothing” of the rectified DC into a relatively constant voltage is achieved by placing a large capacitance across the output terminals. This results in a substantially constant DC voltage with a smaller ripple (AC component) at twice the supply frequency in the full wave case and at the supply frequency in the half wave case. The equation normally used in calculating ripple voltage is given by considering the change in charge of a capacitor in terms of the voltage across its electrodes and the charge flowing onto and off of its electrodes. It is usually given as a differential equation. In this case it is simple enough to dispense with that nomenclature and use:

$$Vr = \frac{I \cdot T}{C}$$

Where Vr is the ripple voltage (volts) I is the maximum current demand from the supply (Amps) T is the period between recharging of the capacitor(s) (0.01 Seconds for the British (50Hz) system using a full wave rectifier) and C is the capacitance in Farads. It is also possible to compute the value of ripple in volts using I in mA T in mS and C in µF. It is not possible to mix the two sets of units.

7.1. Example Calculation

Assume that a full wave rectifier circuit with capacitive smoothing is required to power a 20 Watt into 8Ω class B audio amplifier supplied from 25V rail. The maximum peak current drawn is 2.237Amps. The maximum ripple voltage is about 5 Volts, because the peak voltage required to deliver 40 watts (the peak power) is $V = (P \cdot R)^{1/2}$ giving V = 17.89 V. Then include a small voltage drop across each power transistor say 2.11 volts (to make the numbers round) subtract the sum of those (20V) from the supply (25V) to leave the maximum permissible worst case (highest current) ripple voltage. What is the minimum required capacitance to meet these criteria?

Ans: 4474µF

In practice one would choose 4700µF or 6800µF.

It is common to place a “bleed resistor” across the capacitor(s) to discharge them in a reasonable time period after the supply is switched off.

8. Earthing Grounding and the Common Terminal

There is considerable inconsistency in terminology between writers when discussing earthing in power supplies. The “ground” the “earth” and the “common terminal” take different meanings depending on the author, along with a host of unnecessary, confusing terms.

8.1. Definition of Terms

In this document the “earth” is the semi oblate spheroid with a radius of approximately 6300km upon which we live. The “common terminal” is the output from the supply to which other output voltages produced by the supply are referenced. In this document the “ground” and the “earth” are identical

8.2. An Example of Confusing Terminology

Terms such as HQG (High Quality Ground) are only confusing. This particular term arises (in at least one instance) because the author in question calls the “earth”, “ground”. And also wishes to refer to the “common terminal” as the “ground”. However, they wish to denote that the “earth” and “common terminal” (both of which are termed “ground”) are lifted (by a small resistance) from each other, thus reducing circulating currents. In order to have enough terms with the word ground in they invent the idea of a “high quality ground”.

All “common terminals” should be high quality (i.e. low noise) the use of “HQG” implies that there are situations where a “low quality common terminal” is permissible, presumably at a smaller economic penalty than a “HQG”. The terminology is confusing and is to be avoided.

8.3. Connecting the “earth”

Some authors advocate the connection of the “earth” to the “common terminal” in supplies. Others prefer only to connect it to the chassis for example. Some authors like to have a small resistance between earth and the point that they usually label “high quality ground” or similar. This is a matter for *your* judgement. When producing the supply that begun this document the “earth” was of course connected to the chassis as this is a piece of class I equipment. However the “earth” was initially not connected to the “common terminal”. A nearly sinusoidal voltage of peak magnitude 160 Volts was

observed between the “common terminal” and the “earth” connection. The “earth” was taken as the toggle part of the mains switch; this is bolted to the case which is in turn connected to the IEC input socket “earth” terminal. This point was chosen for accessibility. A user placing a finger on the “common terminal” while switching the supply on or off would experience this voltage. The current flowing into the earth terminal from the common terminal when the two are connected is about 60uA RMS (measured).

8.4. Audio and other Hum Sensitive Systems

In audio systems the connection of a resistor between the earth and the common terminal is to be avoided. Limiting the current flow into the earth mitigates the effectiveness of the “earth” connection. Adding components between the earth and any point that must be near to the earth voltage, however highly rated or specified they may be, invites trouble. It is preferable to use the following arrangement (Figure 9) in all permanent hum sensitive systems.

8.5. Situations Requiring Forethought

The connection of the “earth” to the “common terminal” advocated throughout this document is not always a good idea. For example a 0 to 30Volt variable linear regulated supply is designed and constructed with the “common terminal” connected to the “earth”. This supply is then floated on a high voltage unregulated supply having its “common terminal” also connected to “earth”. This will short the high voltage power supply output voltage. On most commercial bench power supplies that do not have a specific application in mind, the *option* of connecting the “earth” to the “common terminal” is provided. The supply may be floated in any arrangement if desired. An example of when this would be a good idea might be when testing the high side driver circuitry in a half or full H bridge driver / inverter type circuit.

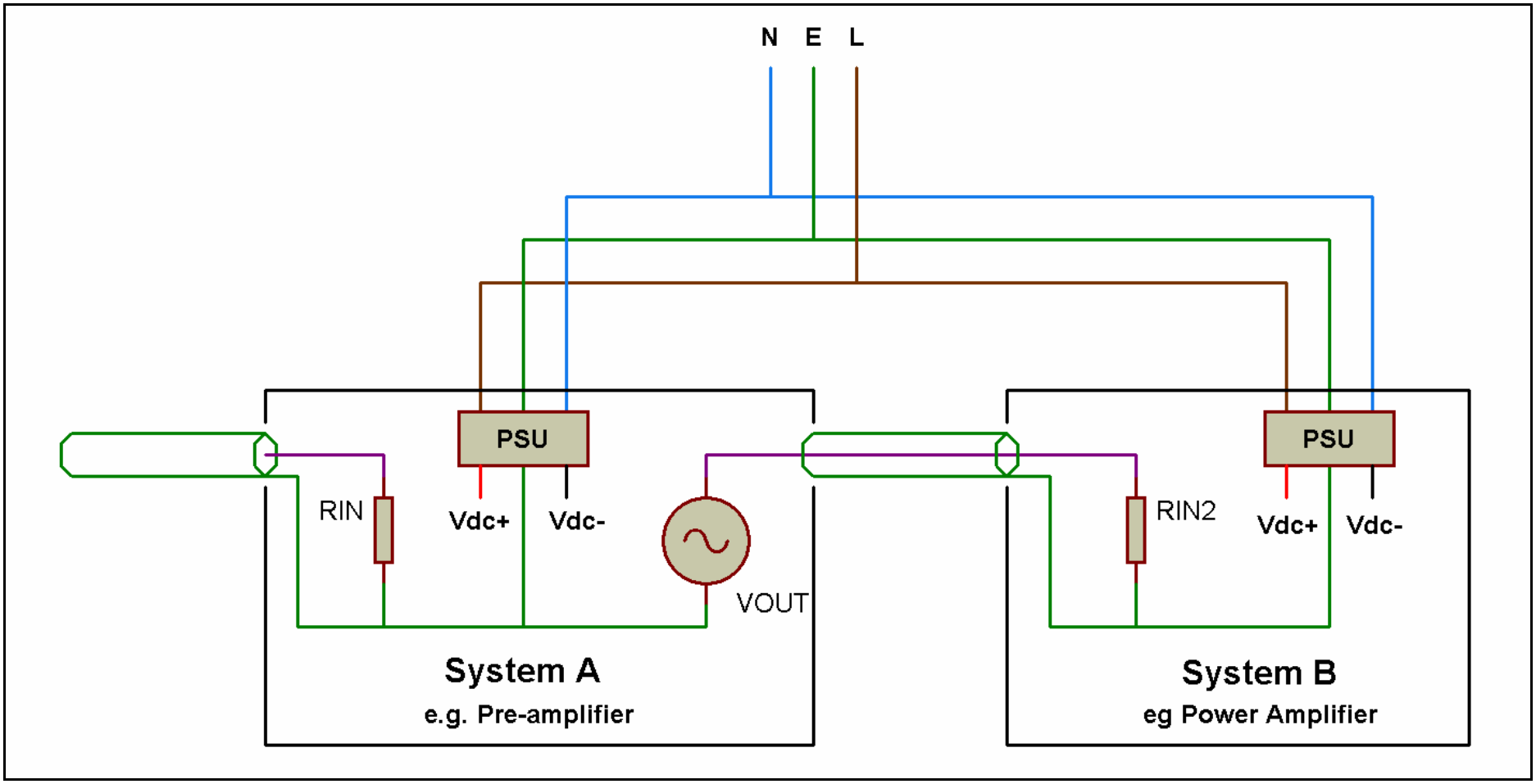


Figure 9: Preferable solution for maintaining safety while avoiding "hum loops"

9. Valve Power Supplies

Certain circumstances may require a valve power supply. For example one may have a piece of equipment requiring restoration to a period style. It is not usually economical to have a valve power supply in a new piece of equipment. Semiconductor rectifiers are more reliable, physically smaller, more efficient, have longer rated life etc. The following discussion assumes that there is a situation that demands a valve power supply. There are several differences between modern (silicon) and valve designs, but the concept of rectification is the same.

9.1. Valve (Hard Vacuum) Rectifiers

An indirectly heated hard vacuum rectifier such as the popular GZ34 or 5AR4 'full wave rectifier'[2] will require a 5 volt supply to the heater. This will mobilise a 'space charge' (free electrons) in the region of the cathode. Some of these free electrons will be accelerated towards the anode (by the electric field that exists across the plates due to the external voltage) and will flow in the external circuit.

9.2. Filtration

If this power supply is a traditional[3] valve supply it will have a bulky iron cored "choke"[4] instead of a large filter capacitor. The use of an inductor to smooth the supply instead of large capacitors was a necessity. High voltage, high capacitance devices were either not available, were prohibitively expensive and/or physically cumbersome. The author possesses a 4uF 500Vdc paper in oil capacitor manufactured around 1953 which is approximately 2.5" by 2" by 2". Surprisingly it still measures at 4uF +/- 20%. It was common to use a choke and a capacitor in an L-Section filter arrangement to smooth the rectified DC. Standard circuit analysis can be used to design for a required ripple voltage or current. Hard Vacuum rectifiers have considerable series resistance when compared with silicon. It is not uncommon to drop 20 to 30

[2] When valve data refers to full wave it almost always means that two diodes are in one glass envelope. The cathodes will sometimes be connected together in the indirectly heated case. This will definitely be the case in a directly heated model such as the 5R4-GY

[3] Traditional implies the use of component technology from a particular time period e.g. 1950s.

[4] Choke is another word for inductor which has fallen out of usage in the same way that a capacitor could also be called a condenser.

volts across a valve rectifier. Large inductors also have significant series resistance; this should be included in calculations if possible. A typical circuit diagram is given below.

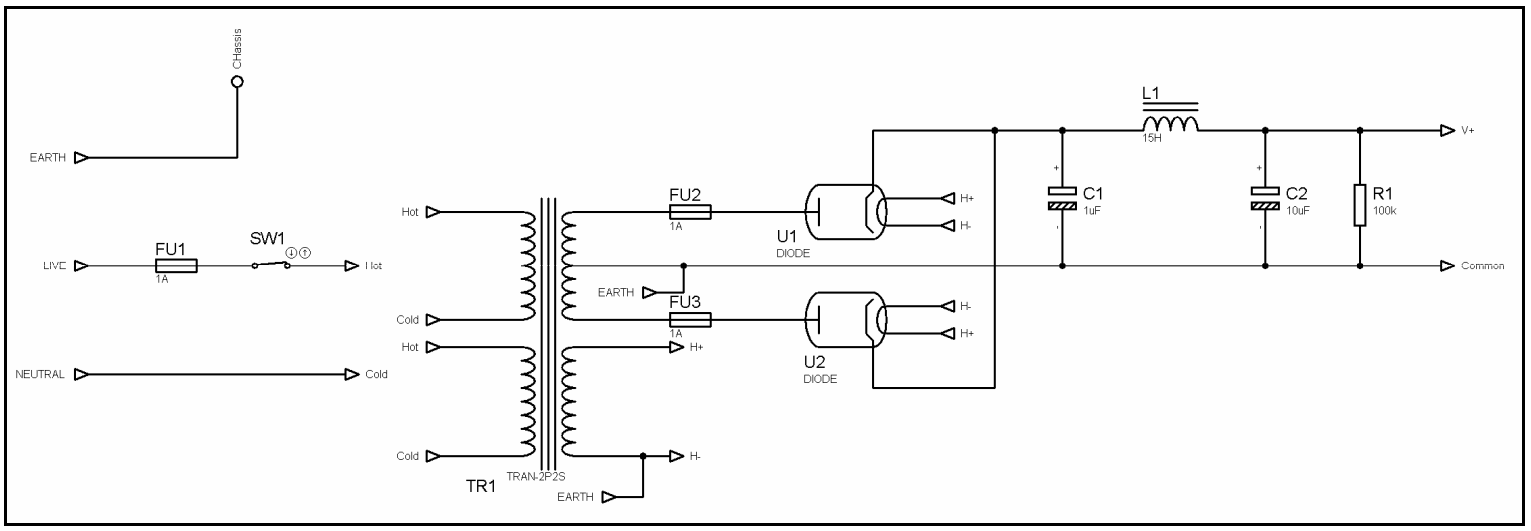


Figure 10: Simple Full Wave Valve PSU

The filter network is third order. It appears from calculations that the internal resistance of any physicaly realisable valve rectifier is such that the third order coefficient in the denominator of the transfer function is several orders of magnitude weaker than the second order coefficient. In physicaly realisable situations it can be treated as second order. Terman[5]. treats C1 as part of the rectifier circuit and L1 and C2 as an L section filter.

The designer intends to attenuate frequencies above DC, specifically one would wish to attenuate segnificantly frequencies aproachting 100Hz. Achiveing 40dBV attenuation at 100Hz is equivelent to 1% ripple (assuming a full wave design).

It is possible to use a valve to regulate a power supply by the same principles that IC regulators such as the L78xx and L79xx series regulators operate. In this case a suitable valve presently in production would be the EL34 or EL84 (for a smaller supply) configured as triodes. In the past cirtain valves such as the now rare (and beautiful) 13E1 were designed specificaly to be used as the series pass element in a linear regualted supply.

10. Switching, Fusing & Indicators

10.1. Switching

The preferred method for switching is a single pole single throw switch in the "live" wire before the transformer primary and after the fuse. Many power supply circuit diagrams found on the internet use linked SPST switches one pole and throw in the "live" and the other "neutral". This is to be avoided, it is potentially dangerous. If a fault develops with the switch in the live wire, mains will be applied to all the circuitry up to the transformer primary winding. This will not be manifested because the return path will still be open circuit by virtue of the still functioning switch. If someone should open the case to service the equipment while it was plugged in, they may act carelessly (believing the unit to be in a state equivalent to switched off, and therefore 'safe') when in fact there will be live wires running round the inside of the box. Should this person accidentally touch some bare wiring, they will expose themselves to the mains voltage.

This situation can not arise if only one switch is used. If the switch should fail closed, the equipment will become powered, and the fault will be detected quickly. It is important that the switch used is rated to actuate even under the maximum expected current drawn from the supply and has the necessary standards ratings to be used to switch mains equipment. In the UK "British Standards" are used in conjunction with the "International organisation for standardisation" ratings.

10.2. Fusing

20 & 25mm 250V equipment fuses are used to protect the equipment from further damage, to protect the power company's hardware from damage and to avoid the power company having to supply the fault current for a significant period. Fuses are not designed to protect the operator, they have nothing to do with the operator. I was once questioned at length in a popular high street consumer electronic and component store about my request for a pack of 10A, 20mm, glass, time delay fuses. The sales assistant instructed me somewhat forcefully that fuses were there for my safety. And that if one had

blown in my equipment; I should not replace it with a higher value, but should contact the manufacturer [myself in that case…] for service, he ended with some drivel about ‘fuses save lives’ or similar. This is of course totally wrong. Fuses can’t save an output stage transistor, much less a life. Relying on them is equivalent to putting on a blind fold, getting hideously drunk, and, without informing anyone of your intentions, going on a long cliff top walk in the rain and fog, on a freezing moonless winter night. If you’re lucky enough not to fall off the edge, the exposure will kill you eventually.

Under a fault condition (for example the transformer primary shorts, because the supply is being over loaded and the inter-winding insulation overheats and fails) a large current flows in the live wire to neutral. The fuse blows. This prevents further heating of the transformer and the possibility of an electrical fire. It also avoids the power grid having to supply the fault current until the fault is recognised.

If the fault current flowed to earth (e.g. through the operator) one would hope that an RCD or RCCBO or another residual current switching device would save them. The trip current for these devices is usually determined by the manufacturer. Use of residual current switching devices is not mandatory in all countries. This kind of equipment can be installed into the house or workshop wiring installation (by a qualified professional) or can be purchased as an in line “wall wart” style plug adaptor. Example parameters might be a 30mA maximum trip current and a maximum trip speed or 30mS. A quick calculation shows that if the supply was 320Volts for the full 30mS and the current was 30mA also, the hapless operator would dissipate 0.288 Watts. This is just about in the region that is thought to be harmless (~0.25W max). However it is recorded that ventricular fibrillation has occurred from power supplies as low as 16 Volts.

The use of residual current switching equipment is most strongly recommended, however its use should not replace complete concentration, vigilance and forethought when working on mains or high voltage supplies.

Given the opportunity current will always flow, providing an opportunity ensures disaster.

It is common to fuse the secondary windings on the transformer. This is not a requirement, but it is sensible. Fuses are very cheep, transformers are expensive by comparison. If a fault occurs and a secondary is shorted while the primary is being driven the circulating current will be very large. The fuse in the primary side should blow if it is properly rated. If there are fuses in each of the secondary windings and not all of the secondary winding fails, the rest of the equipment will continue to function to some degree. This allows quick isolation of the problem.

Secondary fuses do not add an extra layer of protection. In the more usual step down transformer case, the secondary fuses will be a higher current rating than the primary. The secondary fuses will take longer to reach their vaporising temperature because they have more thermal mass, owing to the thicker wire required in their construction.

An example situation which the author encountered involved accidentally shorting the secondary of a 500VA transformer. Both 8A time delay secondary fuses completely vaporised. The 3A line fuse went open circuit also. The 3A fuse in the plug survived the ordeal, but it was changed as a matter of course. In the time it took to heat up the 8A fuses the 3A line fuse was also destroyed, so there was no extra protection in this case.

It is easy to forget that currents are referred through transformers as well as voltages. The line fuse will need to be proportionally lower rating than the secondary fuses if it is to be effective.

10.3. Indicators

Indicators are used to convey information. In power supplies it is usually that power is on, or that a particular supply is on its current limit or similar. In the case where a high voltage is available a neon indicator is attractive due to its long life and efficiency. Neon lamps are inductive and noisy. If a supply needs

to be particularly quiet or have some special transient response an unfortunately positioned neon lamp may be the unexpected source of trouble. In any normal scenario they are entirely acceptable.

The LED is rather tacky and the blue or rainbow variety seems to be appearing everywhere these days. Has no one seen blue before? Look up at the sky on a clear day. If the LED is to be avoided on aesthetic grounds, but a neon lamp is not compatible with the circuit voltages (e.g. the indicator is on a secondary winding and the voltage is not great enough for a neon lamp to strike) consider the tungsten filament lamp. They have quite a short life compared to a neon lamp or a LED, but this can be circumvented.

The service life is a function of power dissipation and hence voltage squared. If a very long life is required choose (for example) an 8 Watt max dissipation type and use it in a circuit delivering only a few Watts. If the colour is an issue when running at a lower than rated power, a range of plastic mouldings are available to enclose the lamp and produce a range of colours. It is a question of personal taste and the style of the equipment. Valve supplies are a suitable place for a tungsten lamp, the age of the piece is right and the 6.3 heater voltage is commonly used to power an “on light”. 6.3V lamps are presently in production.

When considering the required voltage to obtain a given power in the lamp do not use the cold resistance in calculations. The resistance of the filament will change considerably with temperature. A preferable method is to run it briefly at its rated voltage and measure current and voltage. Then reduce the voltage until the I V product gives the required power. Filament lamps have unity power factor.

11. Construction Tips

This is not a definitive list of best practice, but some general ideas that may be helpful. This list is written with a class I product in a metal case in mind.

11.1. Mains

- Use an IEC connector. These can be purchased with line filters to attenuate noise entering or leaving the equipment. IEC sockets with integrated fuse holders can be found.
- If a fuse holder separate from the IEC is to be used, place it directly after the IEC. Then, if a fault occurs in the wiring, the likelihood is that the fault will be after the fuse.
- **Use a separate bolt with locking washers and a locking nut and solder tag for the earth connection to the case. This bolt must not be used for any other purpose than earthing the case.**
- **Heat shrink all bare wires. Use the 3:1 heat shrink. Ensure that it is practically impossible for someone (even with baby sized hands) to touch a point which will be at a lethal potential when the unit is operating with the lid/back/cover off. Think about the location of any air vents or grills which could permit access to the circuitry.**
- If there is any doubt at all, consult someone qualified.

11.2. Transformers

- In the case of toroidal transformers (which are superior to EI in almost every respect, ensure that the central bolt can not form a closed turn (have its ends connected). This inevitably leads to the destruction of the transformer.
- Place the transformer and rectifier as far as possible from circuits sensitive to interference. Use snubbing capacitors if it is deemed necessary.
- Use an X2 suppression cap in parallel with the primary if the IEC does not have a line filter.
- Higher rated transformers have ‘better’ regulation.

11.3. Fuses

- If possible choose “time delay” or “slow blow” when buying fuses (for PSUs), this type will not be degraded so quickly by repeated inrush.
- Use fuse holders which mount onto the outside of the case, it will be easier in the long term.
- If internal fuse holders are unavoidable (for space reasons for example) ensure that an insulating cover is available for the type used.

11.4. Wiring

- Colour code the wiring sensibly.
- Over rate all wires current carrying capacity. This reduces wiring resistance and hence heating, increases lifetime and attempts to mitigate fire risk if the equipment is used outside its design specification.
- Obey insulation voltage ratings
- Heat shrink looms of wires together. If this requires too much patience cable ties may be used, however cable ties tend (having been trimmed to length) to catch on clothes and hands, they can be very annoying.
- When heat shrinking looms place aluminium foil behind the loom to protect the rest of the equipment from the heat of the hot are gun. Do not contract heat shrink with a soldering iron, this will un-tin the iron.
- Colour code the wiring sensibly!
- Where possible run power looms and signal looms in opposite directions around a case.
- Keep rectifiers and fast switches away from noise sensitive circuitry.
- The mutual capacitance of two parallel conductors in a loom is approximately 100pF/Meter.
- The mutual inductance of two parallel conductors in a loom is approximately 1nH/cm.
- Avoid running digital e.g. (clock signal) in the same loom as analogue.
- …the wiring… sensibly!

11.5. Capacitors

- Electrolytic capacitors are far from perfect. It is advisable to use a range of capacitors in parallel having decreasing values to ensure a

low impedance path at high frequencies. (A standard electrolytic will have its impedance rising significantly by 100 kHz). For example if a 4700uF capacitor is used a 1uF & 100nF may be added in parallel. There is little point in adding smaller values on the supply rail. It is much more effective to add these decoupling caps (~100pF) close to the device being decoupled.

- Add bleeder resistors to ensure that the smoothing capacitors discharge within a reasonable time period.

12. Pictures



Figure 11: Front (top to bottom: + / common / -) (left to right: 15V/12V/5V)



Figure 12: Back (red: +35, green: common, blue: -35)

13. References

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