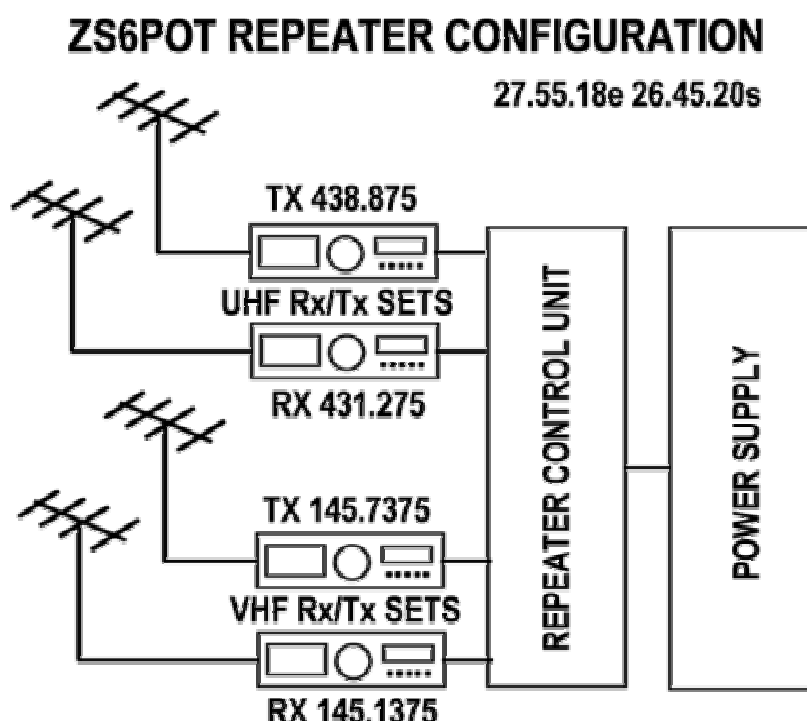


Building a High Power PSU.

Getting to grips with switched mode power systems.

By Mike Brink ZS6MEG.

This article deals with the battery backed up power supply for the Potchefstroom Repeater ZS6POT.



A [necessity](#) for most amateurs is a decent power supply. The problem is that these things are usually, either inflexible, of poor design or horrifically expensive. I know, I recently paid R 2000.00 for a dual power supply with a delivery capability of 3A per channel, 6A total if both power supplies are switched into parallel. I did not mind paying the R 2000.00 because it is a quality item but, it prompted me to look at the power supply issue a little more closely.

We (the members of the Potchefstroom Amateur Radio Klub (PARK)) decided that it was time to consider a battery backup for our repeater on the hill just outside of town. The ZS6POT repeater for the Potchefstroom area is configured as follows :

So, it is all fine and well having a repeater so that one can have a wider coverage area but, what if there is an emergency, disaster or plain old power failure. That is when the comms go down and that is when we will need the repeater most of all. Not only that, the most likely scenario is the worst case scenario. Lets say for example we are faced with a situation like they had in the USA. A cascade of power failures led to power outages that lasted for up to 4 days in certain places.

It is at a time like that, that the only comms system will become the most used comms system. Just like when 911 happened ... the emergency control center was in the basement of the tower. And so, it was radio amateurs who stepped in and provided the backbone of the communications network with their little handheld VHF and UHF sets and of course, their repeater network.

So, in designing the backup power supply for the repeater, it is necessary to consider the operational profile of the installation in both best and worst case scenarios. The following parameters were measured.

Current drawn when active : 10 Amps. Current drawn while in standby : 1 Amp

So, what we need is a battery capacity that would handle a 15% active cycle. (Realistically, I don't see the ten of us hogging the repeater for more than 3.6 hours of the day. 3.6 hour of continual transmission is a lot of talking. - Currently the repeater doesn't operate for more than about half an hour a day in terms of total active time.) That would enable us to go and swap batteries around every day under extended power outage conditions. (Some of us have generators that we can use to recharge batteries with so that's no problem.) So, we are looking at 10 Amps times 3.6 hours equals 36 ampere hours at 12 volts. In standby mode, drawing 1 Amp equates to 1 Amp per hour, equates to 24 Ampere hours capacity needed per 24 Hours.

So, I decided that to start off with, we would go with 3 x 12 AH sealed lead acid gel batteries and if the capacity was not quite adequate, we would get another battery which would take us up to 48 AH.

Charging and discharging.

Lest start off by taking a look at what the experts say.

Charge/discharge rates: Glass matte, gel-cell & wet lead acid batteries have a high internal impedance (resistance), so they will stay in a charged condition longer than nicad batteries before they self discharge, though glass matte & gell-cell lead acid batteries don't self discharge as quickly as wet lead acid batteries. Unfortunately this high internal impedance also means that lead acid batteries can't put out as much current (Amperage) over a short period of time as a similarly sized nicad battery, plus glass matte or gel-cells can take longer to charge than nicad batteries. A rough rule of thumb is that a wet lead acid battery can only accept a charge of no more than 25% of it's Amp/hour rating up to about the 80% charge level (called the "bulk charge"), then charge more slowly from 80-100% (called the "equalization" or "absorption" or "acceptance" stage)(i.e. take a minimum of 4-5 hours to charge a fully discharged wet cell battery). A glass matte or gel-cell lead acid battery accepts a higher discharge/charge rate than liquid lead acid because of it's thin close together plates & can be charged at an average of up to 40% or more of

it's Amp/hour rating up to the 80% charge level, then charge more slowly from 80-100% (i.e. take a minimum of 2.5 - 3.12 hours to charge a fully discharged glass matte or gel-cell battery using an intelligent charger). The charge pattern isn't linear & a lead acid battery will accept more of a charge when it is nearly empty (sometimes at a 60 - 70% rate) & the charger must gradually taper off that current charge or pulse charge as the battery starts to fill up (over 80% full) as well as limit the Voltage, or it will overcharge causing the battery to get warm & gas, which damages the battery. A slightly warm battery during heavy discharge or charging is ok, but a really hot glass matte or gel-cell battery indicates that damage is being done to the battery. The maximum safe temperature to the battery is 125 degree F (52 degrees C). A lead acid battery requires a charger with a slightly different Voltage charge level & different end of charge methods than a nicad charger. Because Glass matte or gel-cell batteries are so easily damaged by overcharging compared to nicad batteries, the charger must intelligently limit the Voltage level & taper or pulse the current (Amperage) level when topping off of the charge. Voltage levels on a lead acid battery during charge should typically be regulated to be between 13.6 & 13.8 Volts for the float level, sometimes going as high as 14.2 Volts (maximum 14.4 Volts) for pulsing or end of bulk charge stage. Once a gel-cell is almost charged, the "float" level can drop to 13.2 - 13.6 Volts & can be trickle charged or pulse charged with very little current for several hours or days using a quality intelligent charger, without damage. Using a proper intelligent charger, glass matte or gel-cell batteries do not give off a corrosive vapour (no explosive gases). Remember that 40% of the Amp/hour rating is the ideal textbook maximum a glass matte or gel-cell battery should take, so a 6 Amp/hour glass matte or gel-cell should never be fed more than 2.4 Amps from the charger Try to choose an automatic transformer charger that will automatically taper down the current (Amperage) right to zero, so that it will never feed more current (Amps) than the battery can take.

So, in a nutshell, we do not want to charge a gel battery at more than 40% of its equivalent Ampere/Hour rating. ie Charge current = AH / 2.5 and the trickle charge rate should be around AH / 200. Our 36 AH battery should not be charged at more than 14.4 Amps during the initial charge period and then, when fully charged, our battery should not consume more than 180 mA on an ongoing basis.

What we are going to do is design a charger that incorporates a constant current / constant voltage circuit. In other words, we have current limiting and voltage limiting. When the battery voltage is below 13.8 V, the charger will deliver the maximum current as set by the operator / installer and when the peak voltage is reached, the current will then start to taper off until the battery is fully charged and is no longer drawing any current.

Bearing in mind that this is the minimum configuration, and taking into consideration that we are making a controller / power supply / charger that should be suitable for other installations with a higher power requirement, we are going to set the design spec to support a battery capacity of 100 Ampere Hours. (The equivalent of 2 car batteries.) That makes our total current delivery 40 Amps. Also, some installations more than 12

Volts, some use 24 and even 36 Volts so we are going to cater for a maximum of 41.4 (13.8 x 3) Volts.

With a current supply capability of 40 amps at a maximum of 40 Volts, we have a 1.6 KVA power supply and it is going to cost a fraction of any other commercial unit that may be available on the market.

When things fail.

The next consideration is ... what when things go wrong. This is the most important aspect of any design and it is usually the aspect of the design that is most neglected by designers. When working with expensive and mission critical equipment such as this, it would be almost criminal to design a system with a component whose failure would lead to the sequential destruction of everything else connected to it. One has to make provision for the failure of any given component.

Things can go wrong in two ways. Either the controller/charger may fail or the mains power supply may fail. If the mains fails, then the batteries must seamlessly take up the function of supplying power to the equipment. If the power does not come back, the batteries will discharge to a point that would be considered the minimum safe battery level. When this level is reached, the batteries must be disconnected in order to protect them, because, as is seen above, over discharging the batteries, especially gel batteries may damage them.

If on the other hand, the controller fails, it can fail in one of two possible ways. The failure may cause the output power devices to fail into either an open circuit or closed circuit state. In the event of an open circuit state, the controller will treat the failure in the same way as a mains failure. The batteries will supply power until the low voltage cutoff level is reached and then it will disconnect the battery, protecting it.

In the event of a closed circuit state, the controller will go out of regulation and will attempt to over supply the battery and equipment. In this case, a 'loss of regulation' detection circuit will kick in and immediately disconnect the battery and the equipment.

In the final state, should the controller disconnect due to a mains / low level of charge / loss of regulation condition, the relay that disconnects the external equipment from the controller will automatically connect the external equipment to a backup power supply providing the ability to implement a second and even third level of redundancy to installations with critical power supply requirements.

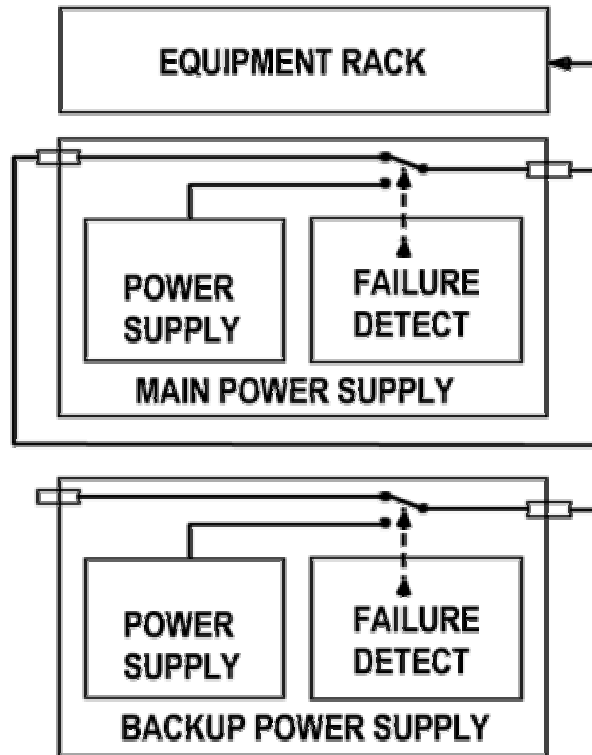
The following features are incorporated into the design.

- Constant current mode

- Constant voltage mode

- Battery low detect, cutout, and changeover to an auxiliary power supply

Controller fail detect, cutout and changeover to an auxiliary power supply.



As can be seen from the above circuit, the failure detect will monitor the power supply and if everything is OK, it will engage the relay allowing the power supply to supply power to the equipment rack. In the event of a power failure, for whatever reason, a fail to safe orientation will release the relay routing the power from the backup PSU to the equipment rack and when that PSU goes down, well then everything shuts down.

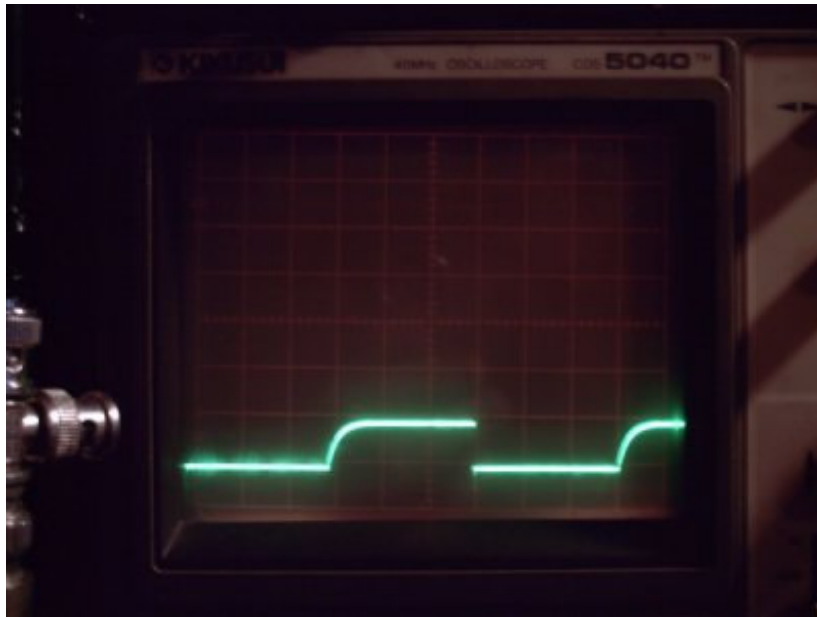
The Circuit.

A basic description of the key features of the circuit. This is a switched mode power supply. One cannot use analog regulation for high power systems of this nature, as too much heat is generated. We use a switching frequency of 20 KHz. High enough to be above the hearing range and low enough not to generate RF interference.

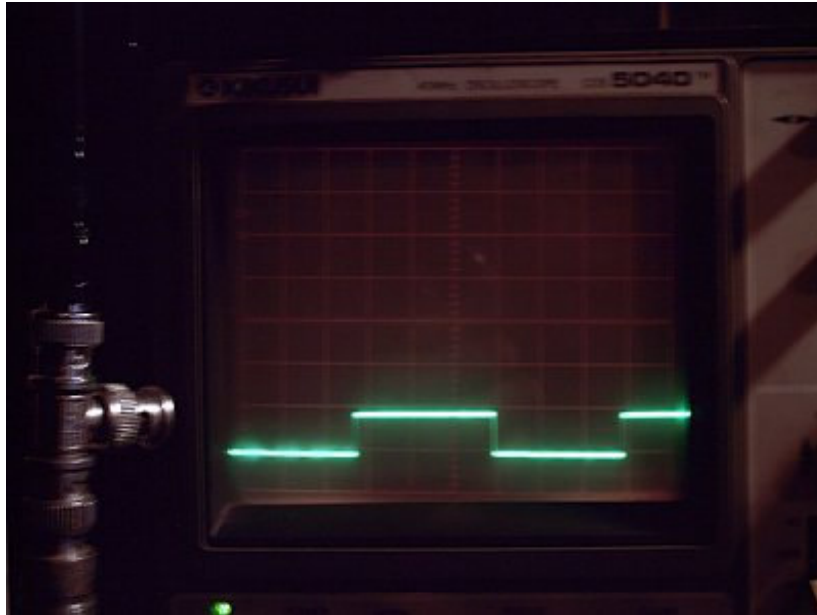
The comparison works like this :

A 24 V supply regulated to 12V running at 10 amps will have to waste $12 \times 10 = 120$ Watts of heat. A switched mode power stage will dissipate $0.6 \times 10 = 6$ watts of heat. Three driver devices are used in parallel so at 10 amps, each device is only dissipating 2 watts of heat.

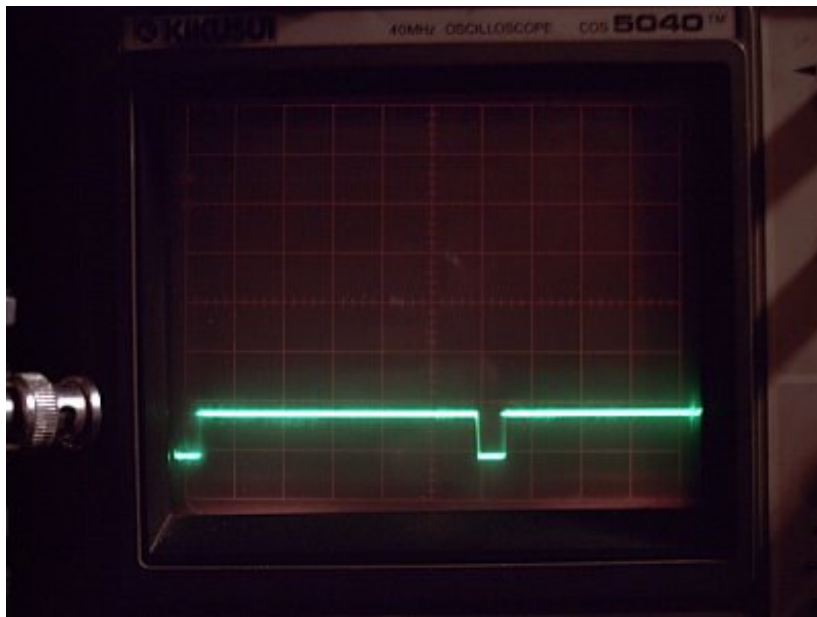
So, this is how we do it. :



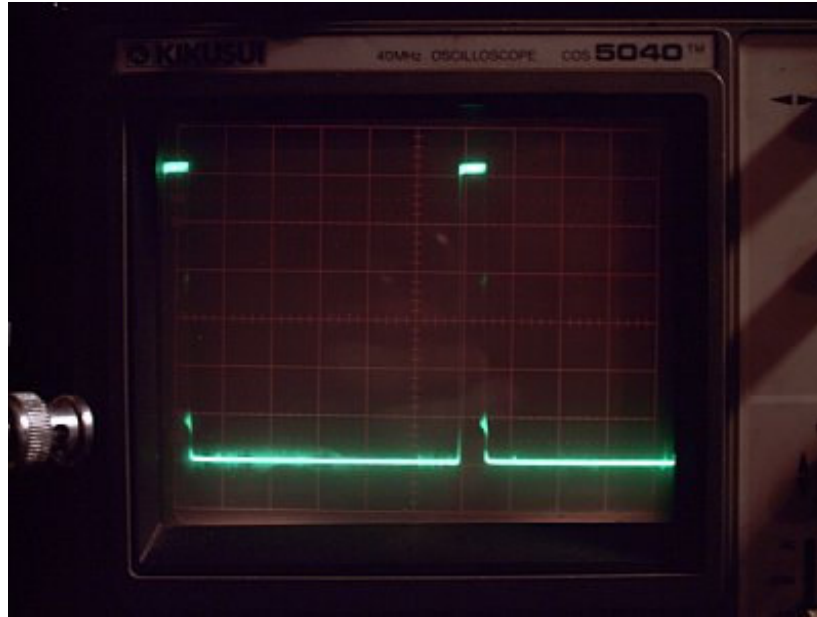
We begin with a 20 KHz fundamental frequency which is generated by a free running astable multi-vibrator.



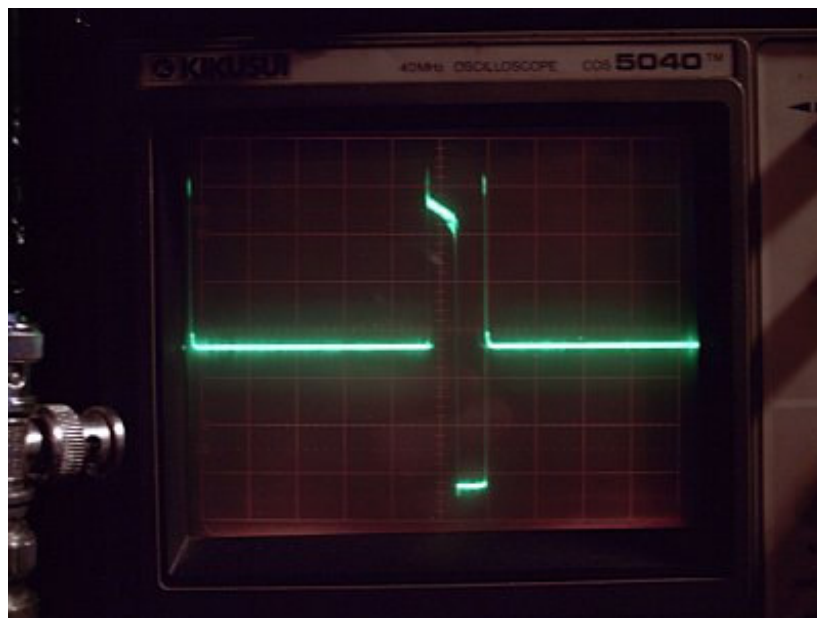
This signal is then passed through a wave shaper to provide a perfect 5V, 50% duty cycle square wave. This is the reference signal for the control electronics. This square wave is converted into a triangular wave. It is this triangular wave that generates the required duty cycle as the load is increased. .



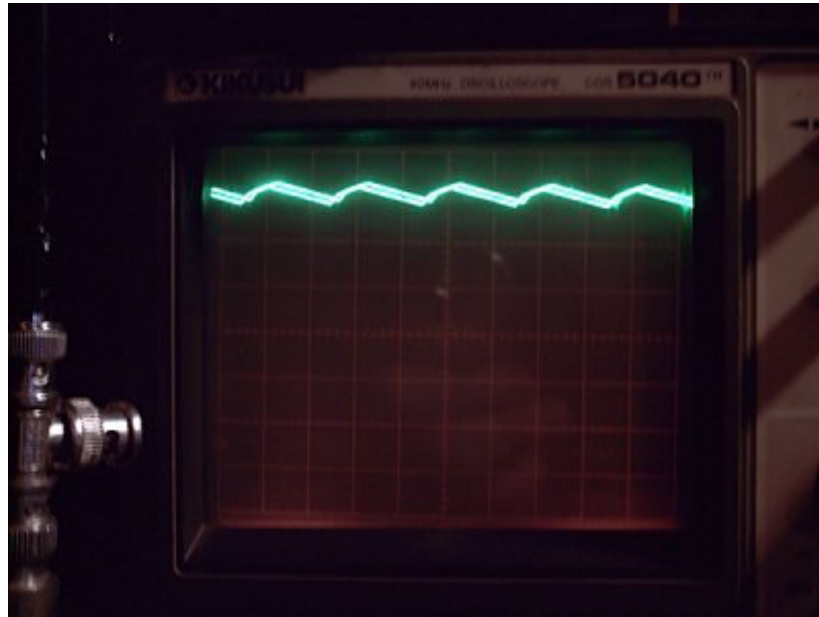
As a load is presented, the PWM (Pulse Width Modulator) changes the duty cycle to maintain a constant output voltage. This is an inverted signal at the output of the PWM.



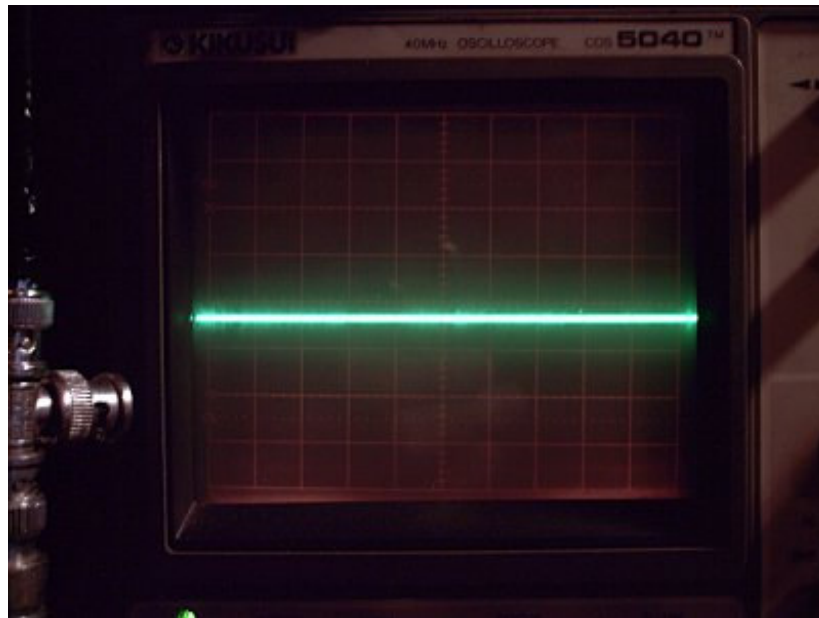
This signal is then inverted and a pulse is derived from the supply voltage. Here you see a 20V signal being pulsed at a 10% duty cycle. We derive the PSU loading % from the ratio of this duty cycle. This means the power supply is running at 10% of capacity.



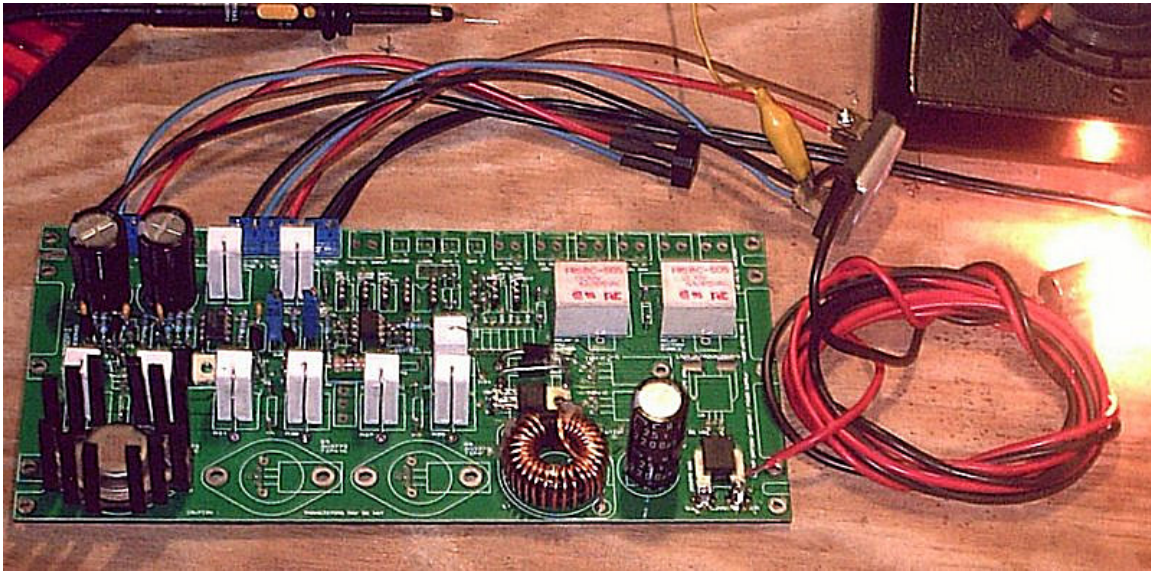
This is the output of the power stage. A 24 V pulse is used to charge an output cap through an inductor. When the cap is charged to 13.8V, the control electronics turn off the drive. 0.5 mSec later, the drive stage is turned on again and the capacitor is recharged maintaining constant output voltage of 13.8V. Diodes clamp the flyback caused by the inductor to the rails so that it cannot feed excessive voltages back into the transistor.



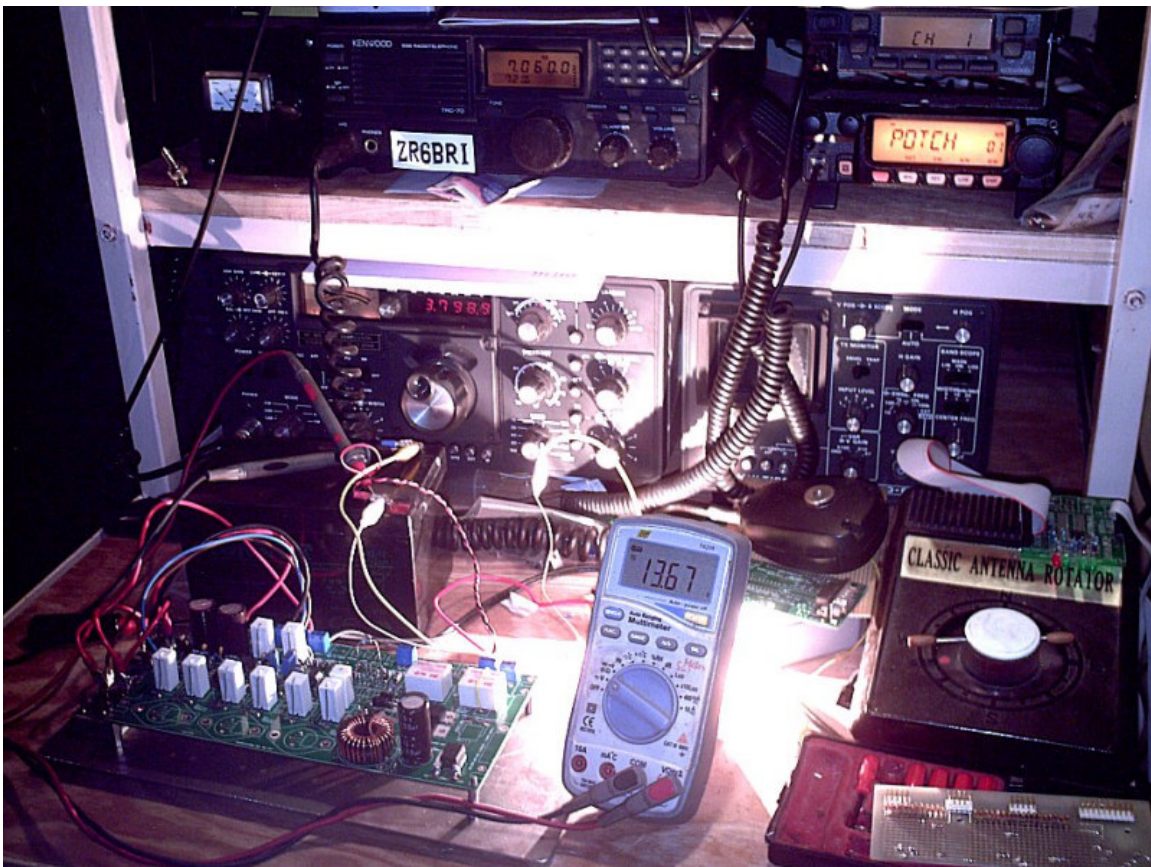
As you can see, the supply voltage from the transformer, when rectified and smoothed, shows a 50 Hz ripple. On the 50Hz ripple there is a 20 KHz ripple as pulses are fed through to the driver.



At the output, the supply, the output is perfectly smooth at 13.8 V



This shows the power supply running at 1.7 amps powering a 24 Watt automotive bulb. Up to 3 amps everything can be on board.



Now I am powering a 100 watt bulb at 8 amps. Output is holding steady at 13.67 volts. Current drain is around 8 amps. The power transistors have been mounted to a steel plate underneath which is at ambient temperature. Trannies run at ambient + 3 degrees.

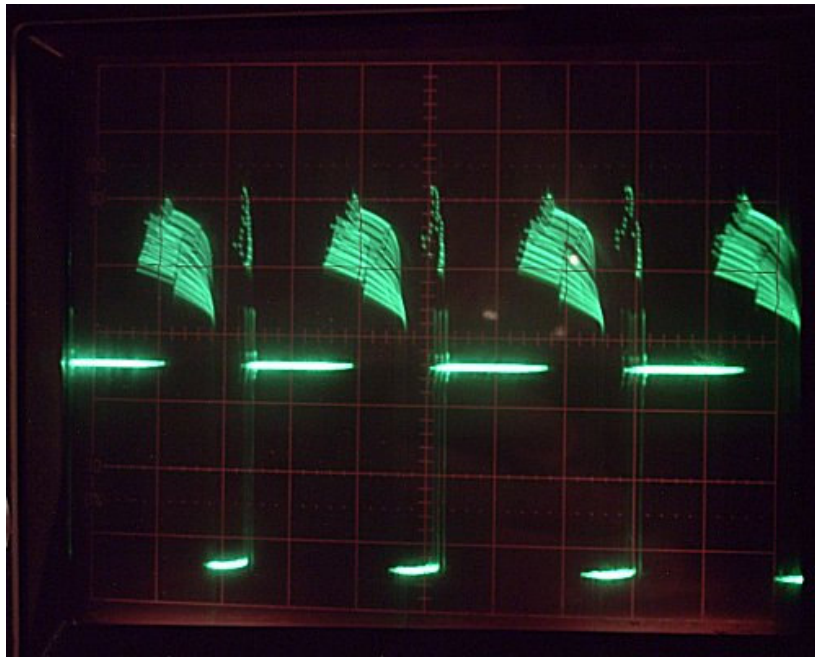
Do you know how junction temperature is determined?

We take the temperature above ambient. Then there is a thermal resistance from the casing to the junction. This factor is the de-rate factor and is factored in at temperature above ambient. So, for the 2n3773, the factor is 0.855. This means that we must derate the junction temperature of + 200 degrees Celsius.

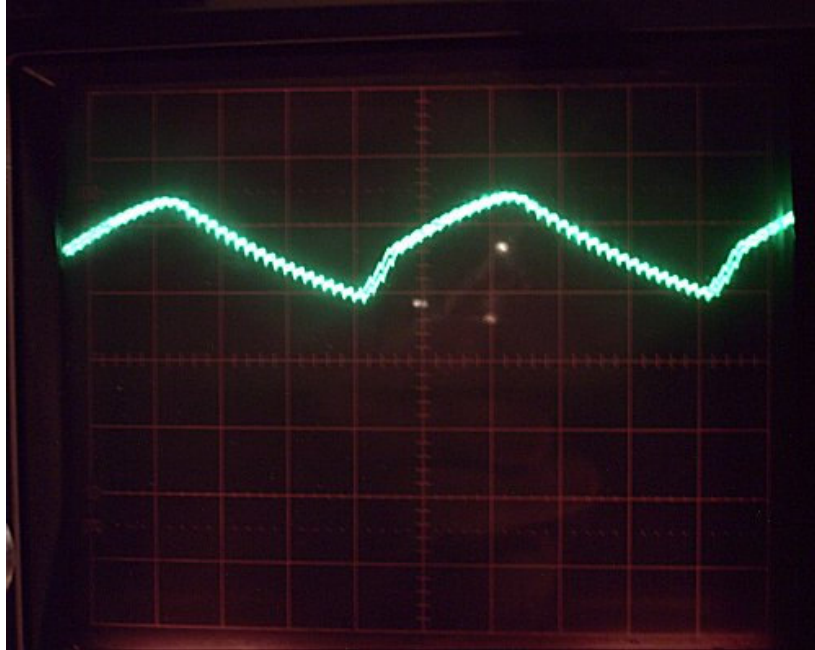
200 multiplied by .855 is 171 degrees. One can therefore not allow the temperature of the casing to exceed 171 degrees because then the junction will be at 200 degrees. That's the absolute limit. Now we are using a good heat sink which means that we can really push the power tranny to the limits.

So we have 15 amps times .6 volts (the junction voltage) which means that the junction is dissipating 9 watts of heat (max), In our case, we are only pushing 3.3 amps and that's 2 watts of heat.

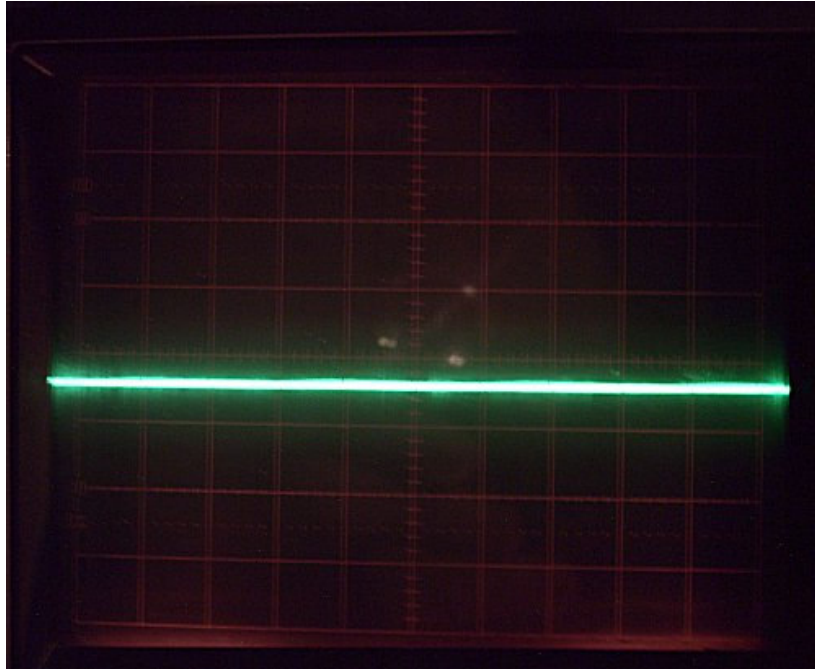
This 2 watts causes the casing to rise by 3 degrees. But as the casing gets hotter, so the junction gets hotter and this heat builds up over time. So we connect the transistor to a heat sink which channels this heat away, keeping us at a constant 3 degrees over ambient.



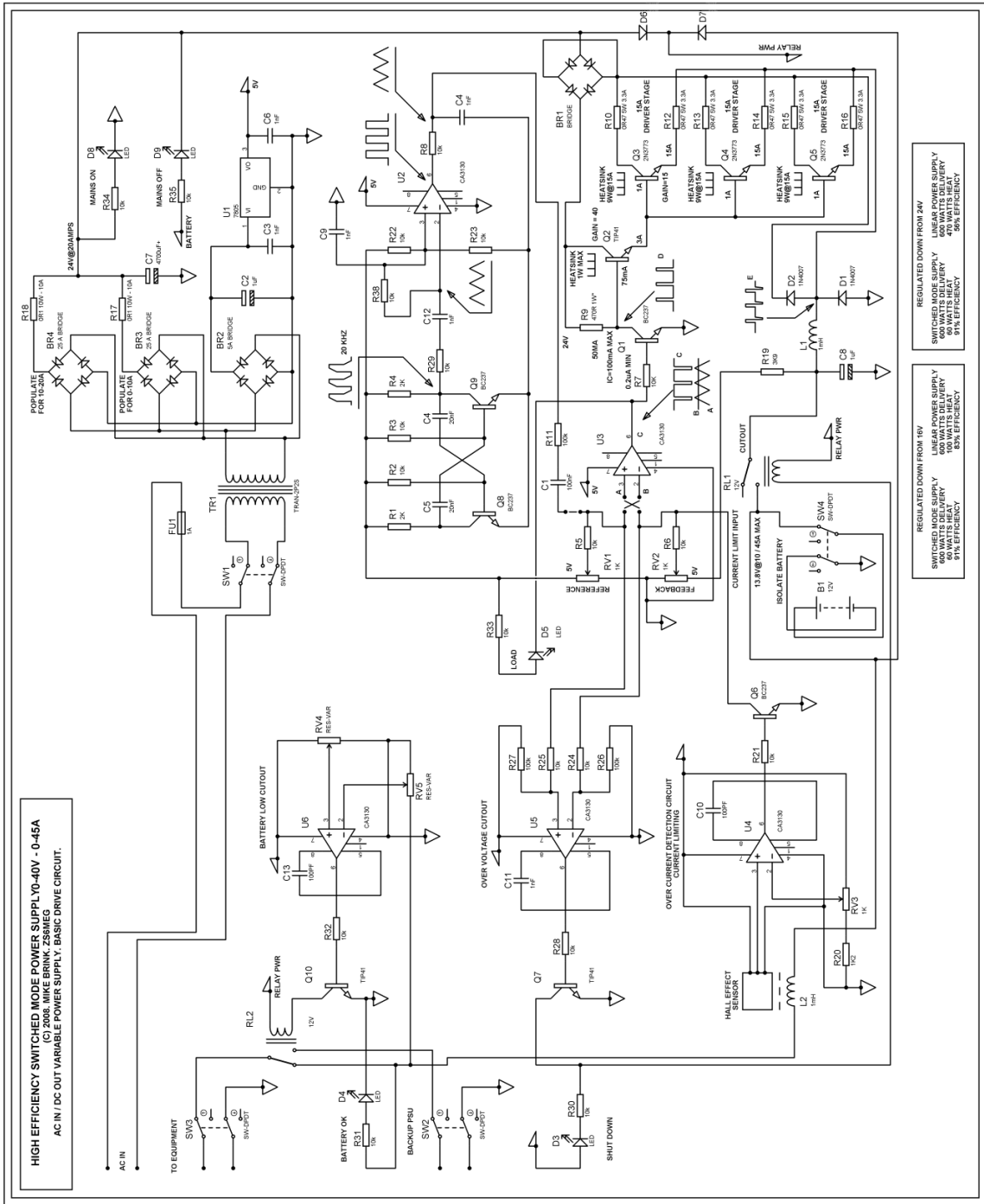
Under load, the signal degrades a little amplitude wise but the timing remains perfect.



This is because the amplitude on the drive stage is reflecting the un-smoothed 50 Hz ripple on the smoothing cap. You can see the fine ripples as the drive stage takes small bites out of the charge, causing the cap to discharge. The cap is recharged by the next cycle of the 50 Hz input.

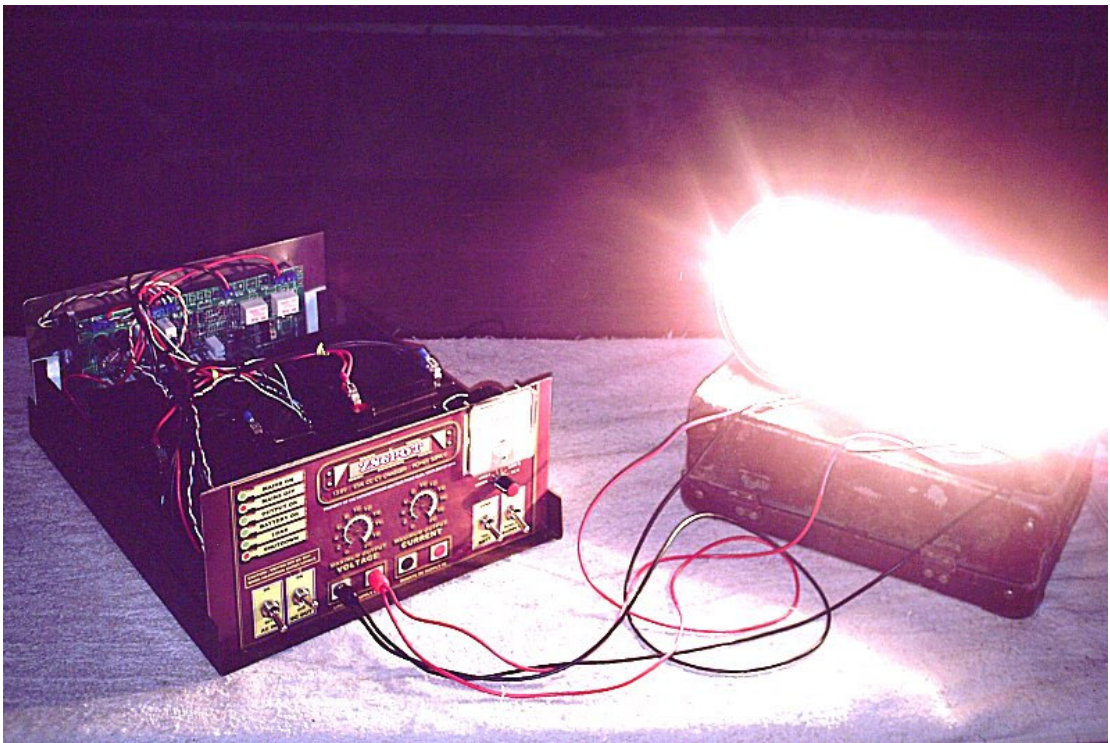


The output is of course dead smooth.



Circuit diagram of the power supply in 10 amp configuration.

Here are some pictures of the final unit.



Running the power supply into a 10 Amp, 120 watt load with two 60 watt spotlights.