**DESIGN THIS FOR DOUBLE THE POWER FOR PROTECTION OF THE PSU ITSELF!!!!!!!!!** (Or at least to 1.5x the maximum wanted power.)

Marker colors on the document:

* Red – to do, very important
* Yellow – to do, less important or on hold
* Green – done

# Power supply to do list

* DC power supply
* 0-35 V (or 30 V at minimum)
* 0-2.7 A, but design for 4 A (except the fuse and current limiting)
* Try to make it as efficient as possible
* Protection fuse
* Short-circuit protection for at most 1 A (the less the better, but that at most)
* Maximum current limiting in normal functioning (the current range above)
* Output voltage ripple at most 5% of the output voltage, but ideally 1-2%, or better yet, less than 1%. "For a 5 vdc supply 50mv ripple is an acceptable figure." (Quora). I saw on another answer that for CPU voltages, 1% at mega most, and inferior would be ideal, and I saw too that DC-DC PSUs have 1% of ripple. Check this for various loads.
* The supply must be fast enough to change the current to keep the voltage in case the load changes quickly. 🡪 Needs physical testing
* Check what happens in case there’s component failure. The load must remain safe!
* Implement some sort of oscillations detector to know if the ripple is too big on the output – do it with an Arduino checking the voltage at all times
* Implement a crowbar circuit: shorts the supply line in case there is some surge in voltage and so protects the rest of the circuit from overvoltage/surges.
* Implement reverse polarity protection on the output
* Overvoltage protection: imagine one or more power transistors gets shorted. Full voltage will appear on the output. As mega soon as that happens the supply must shut down. 🡪 It’ll be the fuse

# Unregulated module

This module is the full-wave rectifier with smoothing capacitor to result in an unregulated DC power supply.

We have 24 VAC max. at the input, which means 34 V pk-pk. The transformer will also have to be 0-12-24 VAC to be possible to switch voltages and, therefore, reduce the power consumption of the power supply. See on Transformer the one chosen (since we need its maximum electrical ratings to know which components to choose).

Thus, a bridge rectifier will be used, and in this case, the full-wave version for more efficacy. Each diode will have to withstand, in this case, 35 V minimum. As it’s good practice to go get at least 50% above of the value, then at minimum we have 42.5 V.

The maximum current of the power supply will be 3 A for both windings (100 VA / 24 VAC = 100/34 = 2.95. 50 VA / 12 VAC = 50 / 17 = 2.95), as per the transformer maximum ratings. But as we’re designing for 4 A, 4+4/2 = 6 A minimum maximum current rating for all power components.

## Fuse

The PSU will have to be able to work with stable 2.95 A max, so 3.15 A should be a good idea. And a slow fuse, for spikes in current not to blow it (shouldn’t be bad either if they happen).

## Transformer

This one seems like a good candidate: <https://adajusa.pt/pt/transformadores-em-fase-unica/12486-transformador-100va-e-230-s-12-24v-ip-00-8445340124863.html>.

* 230 VAC – 0-12-24 VAC
* 100 VA
* 4.17 A RMS

Those voltages translate to 0-17-34 VDC (which is what matters here).

The maximum current after rectification is 50/17 = 2.95 A and 100/34 = 2.95 A (the power gets divided by 2 on each winding. In series it’s 100 VA, but each one is 50 VA). That means the maximum output current can’t be 2.95 A – must be less, because there’s current also being distributed on the rest of the supply. So I chose 2.7 A to be the maximum output current and leave the remaining 250 mA to the rest of the supply.

## Rectifier diodes

Checking, for example, the datasheet of the power diode SR5100 (just to have one as a reference of the values to pay attention to), we see we must pay attention to the following maximum values, being the project values in parenthesis:

* Peak Repetitive Reverse Voltage (34 V)
* Working Peak Reverse Voltage (34 V)
* DC Blocking Voltage (34 V)
* RMS Reverse Voltage (24 V)
* Average Rectifier Forward Current (6 A)
* Non-Repetitive Peak Surge Current (see below)
* Operating and Storage Junction Temperature Range (to be calculated – hint, it’s related to the power dissipated on the cooler and fans of the PSU box, and there are also specifications of ºC/W dissipated on coolers, so that can help knowing the temperature)

Above, we have the Non-Repetitive Peak Surge Current, which we don’t have a value for. There is, however, a formula for that, just below. This is the version for the full-wave rectifier, as that’s the worst case. Formula:

, having assumed Vr = 3 V, just because I’d like to get the PSU to 30 V, so the least ripple the better (knowing it goes at most to 34 V).

So, at most 124 A (theoretically) will be put through the power diodes.

If possible, I’ll get Schottky-barrier diodes (SBDs), because of their 0.2-0.3 V drop, compared to the normal 0.7 V drop – more efficient.

YOU ASSUMED WRONG!!!! SHOULD HAVE CHECKED WITH THE DIODES YOU WERE BUYING!!!!! NTC RESISTOR IS \*\*\*MANDATORY\*\*\*!!!!! THE MAXIMUM OF THE DIODES YOU BOUGHT IS 150 A!!!!!!!!!!

## Capacitor

The formula to calculate its value is:



Supposedly I’d calculate the value for the worst case, which is when one of the bridge branches breaks down (half the frequency). Though, to make this as cheap as possible (and as better functioning as I can, though never ignoring maximum component ratings – this here would just be a just commodity to have it fully functioning with only one branch working), I’ll go for the full-wave case:



Though on LTspice with 30 V on the output, 13 mF are not enough and so I decided to go to 45 mF.

As I’m calculating for the full-wave case, if one of the branches goes down, a warning must be issued. So I’ll think of some LEDs to do it somehow.

One must also pay attention to the maximum surge current that capacitors can handle. To help reducing it, I will consider using a NTC thermistor, which decreases its resistance with increasing temperature (meaning it will become a short-circuit moments after current passes through it, which warms it up, and hence reduces the peak current through the capacitor).

See how to do this above, and then correct the diode ratings when the current is lowered. Also pay attention that this dissipates near 0.3 \* 4^2 = 5 W… Think on something else, or go ahead…

## Automatic relay winding switch

If the PSU has the transformer at its maximum at all times and it’s requested 5 V / 4 A at the output, the power transistor will have to take 25 V of drop, which will result in 25 \* 5 = 125 W of dissipated power (wtf).

To reduce the power consumption, something I thought on is that one could use a transformer with multiple windings (which seems is actually used in linear PSUs) and use a rellay to choose which winding to use.

For this, I’ve thought on a little switch circuit that compares the output voltage with a fixed voltage not too far from the 17 V.

### Circuit schematic

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Descrição gerada automaticamente

### Relays

The one on 12 VAC must be On by default, and the one on 24 VAC must be Off by default. This is because one must be conducting when the circuit starts from 0, while the other cannot not be conducting.

They must be able to carry at least 6 A minimum, use as little current to switch (so that I can ease my life with using an op-amp to provide the current), and at most need 10 V to switch (since from the op-amp, about 15 V will come out, and that will be compared to GND, so 10 V seems a good value not too close to the 15 V switching voltage).

Because when these things switch there’s “infinite” voltage generated due to the coil inside them, one must use a flyback diode so that the maximum voltage drop is low (VD, in this case). I’m not sure it’s really needed, but I don’t really like the idea of infinite voltage on a circuit that’s supposed to handle with 34 VDC max., so… flyback diode. Any diode should suffice, I believe. So will be any that I have in the components box.

### Op-amp

LM358, as suggested on Discord, as opposite to uA741 because it seems to outperform the latter (can go to VSS, for example).

### Zener diode

The Zener diode must have a voltage near the primary winding voltage, so that when the output is near that voltage, it switches to the other winding. 15 V seems a good choice. Greater than 15 V will switch the output to the higher winding; less than that will switch back to the lower winding.

### Schmitt trigger

It can’t be as simple as described on the Zener diode section. Can’t just switch based on one voltage. What happens at exactly 15 V then? Or at 14.9-15.1 V? (noise) Instability will happen 🡪 one must use a Schmitt trigger. The formula for the width of the hysteresis is

VSS is 34 V. A good width seems to be around 3.5 V. That’s

So the upper winding will be activated when the voltage rises to , and the lower winding will be activated when the voltage lowers to .

## Discharge circuit

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Descrição gerada automaticamente

To help discharge the capacitors when the voltage is lowered on the output (for example, it was set to 30 V and then we lowered it to 16 V. Or 0 V), I added the underlined circuit of the picture.

The TIP142 is because I don’t know about transistors that can withstand 0.6 mA, so I chose the one I was going to choose as the pass transistor.

The op amp compares the OUT voltage with Vref. If OUT is lower than Vref, the op amp goes HIGH and activates the TIP142 which pushes current from Vunreg to GND.

At what speed? Is it fast enough to not take seconds and seconds to discharge, especially with load current variations? There are these 2 formulas below, which I used to calculate the resistor value.

The total amount of charge in Coulombs in the capacitors at 30 V (max) is

I want it to discharge at maybe 1-2 seconds, so 1.5 seconds. So . Now I have the current and the voltage, so let’s get the resistance:

The power rating for this resistor must be a bit more than . A bit more would be 35-40 W. This seemed like an exaggeration (because on an online store I’m buying stuff there’s 30 W and then 50 W, nothing in-between), so instead, now having an idea of the value of the resistor (initially I thought 1 kOhm would be fine – sure thing, very near 33 Ohm), I went on the store and tried with 47 Ohm.

A bit more than 20 W is at least 25 W. I’m not going for 1.5-2 times more because will be for 2 seconds and rarely used. So 25 W should be just fine.

# Regulator module

## Power transistor(s)

The maximum output current is 2.7 A. Therefore, we need a transistor capable rated for at least 1.5-2x 2.7 A which gives 4-5.4 A.

The maximum output voltage is 30 V. This way, we need a transistor capable of handling at least 45-60 V on VCE.

The maximum power on the transistor is , so a transistor capable of handling 120-160 W is needed.  
Or, since that’s “too infinite”, a few transistors in parallel with lower power ratings. This also means that resistors must be added in series with each transistor, all in parallel with each other, to normalize the currents going on each transistor or else one might conduct more than the others and heat up a lot more (components are never exactly equal).

We’re also going with a BJT:  
Uma imagem com texto, Tipo de letra, captura de ecrã

Descrição gerada automaticamente  
(From <https://www.eevblog.com/forum/beginners/bjt-vs-mosfet-for-linear-power-supply-output/msg812441/?PHPSESSID=5jcesoeqncrh9mfehrlvegabaq#msg812441>)

I was also told the TO247 is a good package to use.

So I chose the TIP142. And I chose to use 4 of them. That gives 45 W dissipated on each.

EDIT: I got a BDY20 already screwed to a PSU metal case. I’ll use that one.

## Reference voltage

Initially a Zener was going to be used, but as pointed out to me on Discord, there can be drifts in the Zener voltage depending on the ripple from the unregulated part of the PSU.

So, instead of using a Zener diode, I decided to use the TL431 programmed to output between 2.5 V and 30 V with a potentiometer. Its output voltage is programmed through a resistor and a potentiometer with the following formula taken from its datasheet:

Fixing the potentiometer at 22k (because of previous experiments with the TLV431 and before that with a voltage divider at the output of the supply) and knowing VREF is 2.5 V, .

## Comparator op amp

The op amp must withstand the unregulated supply’s voltage and must output enough current to the power transistors.

Therefore, we need one capable of handling 34 V. The output current from the op amp is the necessary one to make the power transistors output the chosen current. The maximum current is 2.7 A, so dividing that by the gain of the BDY20 which is 20-70 at 4 A and I’ll assume 20 (should be higher though, at lower currents than 4 A, so this is the worst case scenario), gives 2.7/20 = 135 mA – this is the current on the base of the transistors needed.

So, an op amp with current output of 135 mA is needed. I chose the LM6171 which has a maximum output current of exactly the needed current and maximum VS of 36 V.

## Circuit protections

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Descrição gerada automaticamente

### Overcurrent protection

There are at least 2 types of protections: constant current limiting and foldback protection.



The foldback protection is the green one; the constant current limiting is the blue one; the red one is no protection at all.

We could use the foldback one, and initially I was going to use it, but aside from it progressively limiting the circuit current, the short-circuit protection is not complete: with 4 A max, LTspice said 2.8 A would be the short-circuit protection current – not cool. Also, the resistor it requires has a higher value than the constant current limiting protection one, so it steals less voltage from the output (4 V vs 0.9 V after testing on LTspice).

So we could go instead for the constant current limiting option, which allows to have full voltage and full current at the same time. Though I also wanted to be able to adjust the current limiting.

So I tried to think on a solution and arrived at one that separates the short-circuit and the overload protection.

There’s the short-circuit protection and the adjustable current limiting one (idea taken from <https://freecircuitdiagram.com/215-variable-adjustable-current-limiter-circuit/>). The first protects when the output is shorted; the second protects whenever the output current tries to go above 2.7 A when on overload.

The OCP works by comparing the voltage on R16 and activating Q6 whenever it goes above 0.66 V (the necessary to activate the transistor), again stealing whatever current is necessary to keep the current on 2.7 A at most and whatever we choose as the maximum – because it can be chosen with RPot1.  
I didn’t want to bother making the calculations, so instead I went by trial and error until the maximum was 2.7 A. Keeping RPot1 at 1 kOhm that resulted in R17 being of 1 kOhm. I also set R16 to be 1 Ohm. The minimum current to limit is given by:

Power rating needed for R16:

So we need at least 24-32 W for R16.

### Short-circuit protection

Uma imagem com captura de ecrã, texto, software, ecrã

Descrição gerada automaticamente

The SCP (Short-circuit protection) works by comparing output voltage to a fraction of the reference voltage and stealing the pass transistors current to disable them in case there’s a short-circuit.

The op amp is mounted in the inverting configuration and is by default Off, disabling the stealer transistor.

Whenever OUT is lower than Vref/something chosen with a potentiometer (if it’s below the requested it’s an overload and can be allowed (potentiometer), or if it’s very much below it’s a short (which can also be allowed for certain cases, again with the potentiometer)), the op amp will get enabled and will enable the stealer transistor and the pass transistors will stop conducting.

There’s also a pull-down capacitor C5 to push the signal to LOW on the first run (adds some delay but should be fine. It’s a very small delay) so that the transistors can conduct at the beginning, or else if they wouldn’t conduct the protection would start immediately because there would be 0 V at the output (a short). After that, the capacitor will be full and won’t do anything anymore – good, because it’s just there for the first run. This is useful because the circuit begins at 0 V everywhere and in case Vref rises faster than OUT, the SCP will get triggered, right at the beginning which is not too useful. The capacitor overrides whatever output the op amp has and forces the output to be deactivated. After some small period of time (16 ms according to LTspice) it’ll be full and will have no effect anymore, leaving the output to the comparison between Vref and OUT.

### Overvoltage protection

Uma imagem com software, texto, Software de multimédia, Software gráfico

Descrição gerada automaticamente

The OVP (Overvoltage protection) works similarly to the SCP on detection matters: it compares the output voltage with a fraction greater than the reference voltage (in this case 1+1k/20k – the gain of the op amp). If it’s above, the protection will get triggered and will short the supply, blowing the fuse.

The way it shorts the supply is by activating a thyristor which shorts the output of the supply, requesting maximum current and blowing the fuse simply by stealing to GND the current that the SCP is giving to the relay, thus shutting it down, getting it back to GND.

There’s also a pull-down capacitor C6 for the same reason as C5 on the SCP: to pull-down the signal at t=0 so that the current can pass to the relay and activate it at the beginning (since it all starts at 0 and it’s not stable there).

Check this again

## Output ripple

Uma imagem com texto, captura de ecrã, software, Software de multimédia

Descrição gerada automaticamente

Uma imagem com texto, captura de ecrã, software, Software de multimédia

Descrição gerada automaticamente

The maximum ripple is of 545 mV when on 23.5 V @ 2.5 A. The percentage of ripple is:

When not on maximum current but on maximum voltage, the ripple is of 138 mV (30 V @ 300 mA). The percentage of ripple is:

When not on maximum voltage nor on maximum current, the ripple is 0.

This fulfills the ripple ranges. At most 2.5% of ripple, sometimes 0.46%, majority of the time 0%.

# Efficiency

We’ll go for the minimum and maximum efficiency. The maximum one is when the output has full voltage and full current, so we’ll start there. The minimum one is when the output is on minimum voltage and minimum current.

The efficiency is calculated by:

Where Itotal accounts for the output current + current consumed by the supply itself, which by the limit set is (doesn’t mean it’s actually 250 mA, but at most can be that, hopefully – that’s what the limit supposes).

## Maximum efficiency

On maximum efficiency:

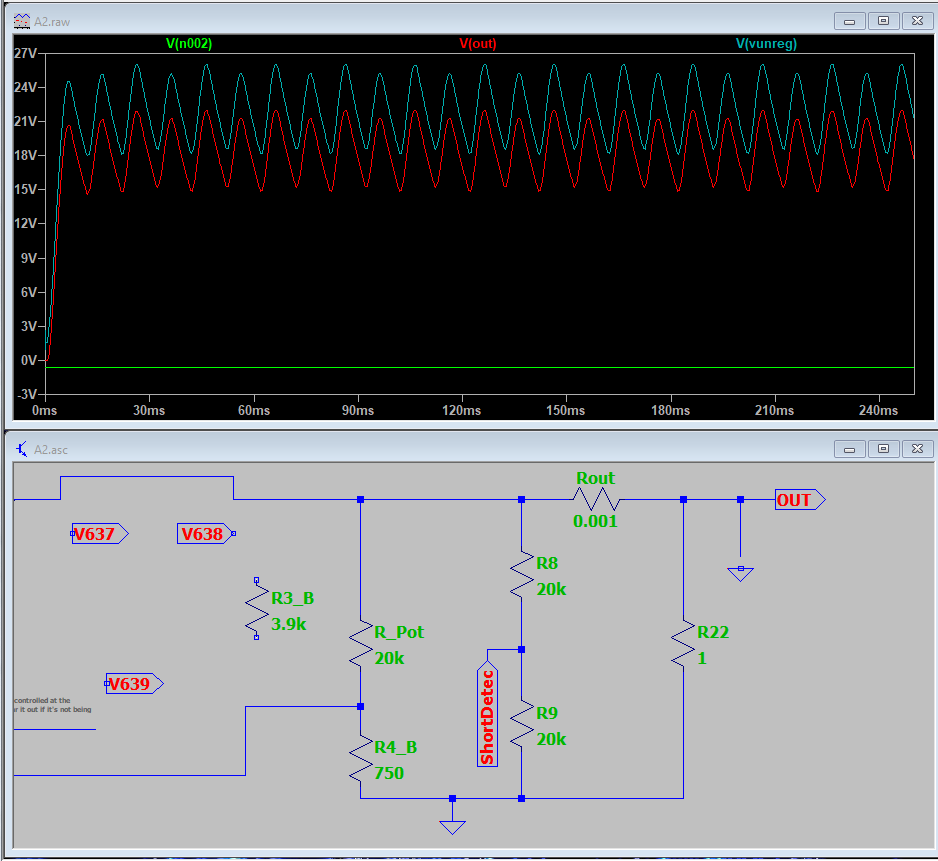
* the input voltage is 34 V and the output voltage is 30 V
* the current is the maximum that can be limited with the OLP: 3 A

## Minimum efficiency

On minimum efficiency:

* the input voltage is 17 V and the output voltage is 1.24 V
* the current is the minimum that can be limited with the OLP: 0.66 A

In this case the current consumed by the supply won’t be the maximum current because the power transistors will not be conducting as much, but the result with 0.1 A is 6.3% so it’s basically the same.



PUT THE LMV431 NEAR THE POWER TRANSISTOR!!!!!

One of the graphs in the datasheet says that the reference current gets lower as temperature increases 🡪 the power transistor is the hottest thing in there.

EDIT: do NOT do this. Vref changes with temperature, so if the PSU is being put at max, it will be hotter inside. Else, will be cooler. Get it as away from heat sources as possible (even if it has to be outside the board or something, connected with wires (or maybe not because of parasitic inductance on the wires and with such small currents that could affect stuff?).

Uma imagem com texto

Descrição gerada automaticamente

Uma imagem com texto

Descrição gerada automaticamente

ZKA won’t change. The cathode voltage won’t change because it’s connected to the reference, which also won’t change because the temperature supposedly won’t change (too much? Hopefully at all). The current won’t change either, because this thing is connected to an op-amp, which requires almost no current, and almost or no current changes at all. So none will change, and therefore ZKA won’t change either.

The LM358 has 2.5-5 pF of input capacitance, so from the picture below, the chip will be perfectly stable (0 F almost, meaning no capacitive load – 2nd picture below).

READ THE LAYOUT GUIDELINES OF THE LM358 IN THE DATASHEET!!!!!

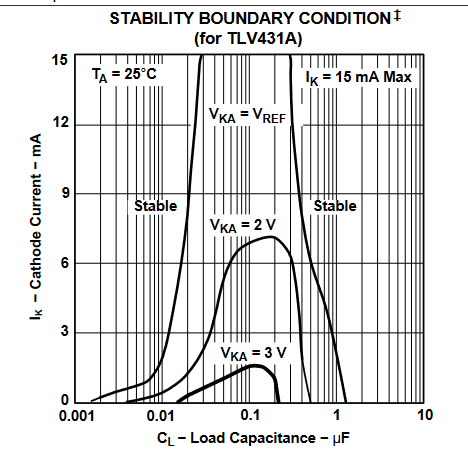
Example of guideline:



CHECK WHICH OP-AMP YOU BOUGHT!!!!!!!!!!

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As the LMV431 is functionally equivalent to the TLV431, and the TLV431 datasheet is more complete, I’ve used TLV431 datasheet and its application notes PDF.

Uma imagem com texto

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See about emitter degeneration technique in BJTs.

Various in parallel for less “You have to keep in mind that semiconductor devices tend to obey the general Arrhenius law, meaning a failure rate ~doubling for every 10°K (or C) increase.”?

<https://www.electronics-tutorial.net/analog-integrated-circuits/schmitt-trigger/non-inverting-schmitt-trigger/>

In the end, check <https://www.instructables.com/10Amp-Linear-Power-Supply/> and see everything he thought of that you didn’t.