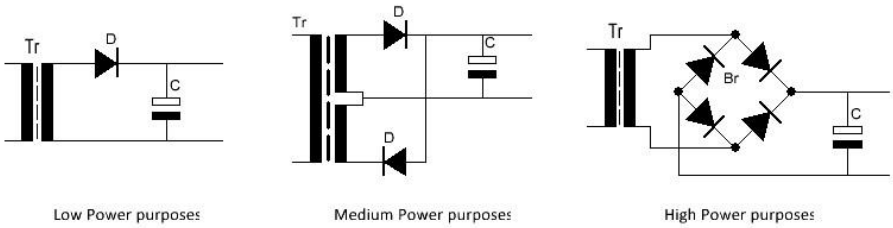
History and evolution of Power Supplies

From several new DIY-ers we got questions about how a symmetric power supply works as we use in about all our amplifier designs and what advantage(s) they have, so we wrote this document.

In the early days of audio electronics, tube amplifiers were used to transfer small audio (mostly microphones and ceramic phono cartridges) into larger signals capable of driving speakers. Due to a required output transformer (transforming very high output impedance of the tube amplifier itself into lower impedances for speakers), nobody thought of DC voltages at the output, since it simply wasn't there. Also ignored was the constant DC current flowing through this transformer, being not good, since the core becomes magnetised this way, as an electromagnet does > saturation effects. Power supplies schematics were/are like this:

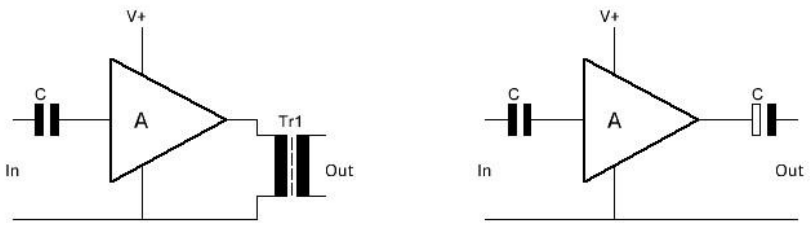


In the very early tube days, only the most left schematics was used where the diode was a rectifying tube. Only a half sine is rectified and charging the storage capacitor, causing quite some hum. The transformer is only loaded on the positive sines, so used very inefficiently.

After the diode was discovered more and more the middle one was used. By adding an extra secondary coil on the transformer, the full 50Hz could be rectified by two diodes/tubes > less hum. A disadvantage was that an extra secondary transformer winding was/is required in order to rectify full 50Hz sines. Still an inefficient use of the transformer, since each winding only is loaded every half sine.

Already 1896 the diode bridge was developed by Polish Karol Polak (patents) and a year later independently by German physicist Leo Graetz. Due to him the diode bridge is also known as a Graetz circuit/bridge. This development had significant advantages: just a single secondary winding required, yet rectifying full sinewaves into 100Hz half sines. Way less hum and/or less capacitance required. For many years already, this diode bridge is available as a single component in lots of varieties, used about everywhere and costing about nothing, not even large ones. This simple bridge solution was one of the smartest ideas for long time, follow the (AC) current through this bridge and "see" what happens exactly -) Clever indeed!

All three types of supplies above feeding a power amplifier have the same disadvantage, namely: as well this input as the output of the amplifier circuit carries DC as well as AC (signal) voltages, since their DC- level is "somewhere" between ground and supply voltage. However, we don't want DC on the input nor at the output. At input side it could damage connected equipment or even hurt people (f.e. microphones held by a human….) and at the output it can't work at all, since a DC signal there would cause a severe and constant shift forward of the woofer cone(s) AND weakening of their magnets due to the constant current flowing. These problems were "solved" by using output transformers and later in solid state circuits capacitors:



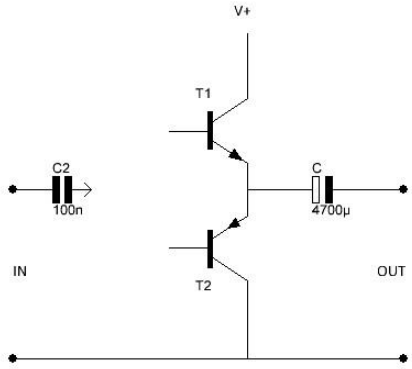
Even today, about 90% of (especially cheap) amplifier modules we find on Ebay, Alibaba, etc. still use an output capacitor in the speaker line, required since they about all use a single voltage supply. Due to the low impedance speaker load this capacitor has to be a significant value, say 4700uF. These kind of values are only available as electrolytic POLARISED capacitors. None of them is designed for use as done here, so they will significantly degrade the audio signal AND have a short lifespan due to the fact that half the time the polarity is wrong! Most of the time also a very cheap POLARIZED input capacitor is used causing similar mishaps.

One of the solutions invented by the audio industry avoiding these output capacitor is the class-D design, being very fast (yet not fast enough for true high-end audio quality) switching amplifiers where this switching is PWM modulated, an ANALOG conversion by the way as "modulating" always is! More easy to manufacture with less components and since it is sold as "*DIGITAL*" people are prepared to pay more for less quality in sound and facing a shorter lifespan due to permanent overloaded parts. **Switching ≠ digital** !

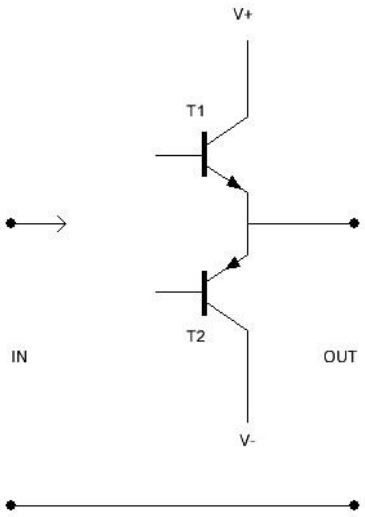
As planned by a specific group of class-D marketeers, somehow a huge number of audio enthusiasts stopped developing here believing that class –D is the top and fed by the audio community convinced that an amplifier at least needs a preferably high quality input capacitor (as we have lots of by the way). NOT true, since all my working life there are solutions where NO capacitors are required in the signal path at all!

We primarily sell high quality audio caps for use in passive speaker crossover networks and tube circuits.

With the development of push-pull output stages where two transistors (or tubes/mosfets!) swing the output signal, the signal quality significantly improved due to the fact that the amplifier could control woofer movements better due the its way higher damping factor compared to single ended (one active power component) designs. In the early 1970's the first designs were still built while using a single supply voltage, so still and input- and output capacitor were required, see left picture.



Then, late 1970's somebody had a very good idea how to solve this capacitor thing while using a push-pull amplifier design in combination with a symmetric power supply. Strange enough, nor Google or Wikipedia tells more about this circuit we know all our life (> 50 years) and bringing a very good sounding amplifier into the champions league. In a circuit like this, where the DC-level of the output is at ground level, the output capacitor is of no use any more and so left out, so again damping factor and overall sound quality dramatically increases.

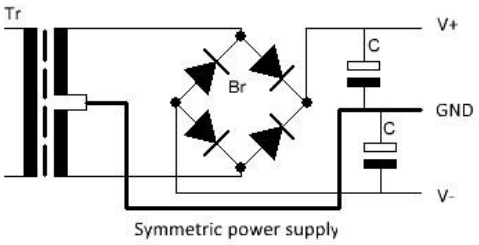


The amazing increase of quality and reliability of most modern Mosfets as we use today are not specifically relevant in this article. For that we wrote another document explaining more.

As we understand (and as we had ourself in the past), a lot of people have troubles in how a NEGATIVE voltage is achieved and how to deal with it. At the next pages we give it a try.

Symmetric Power Supply Principle

Actually, a symmetrical power supply schematics is a mix of the middle and the right drawing at the beginning of this article, see the picture at right:



Symmetric power supply

Look closely and "see" that two diodes rectify the positive half sines into V+ and two are used to rectify negative half sines into V-. Without doing anything else, it would act as in the right picture at first page.

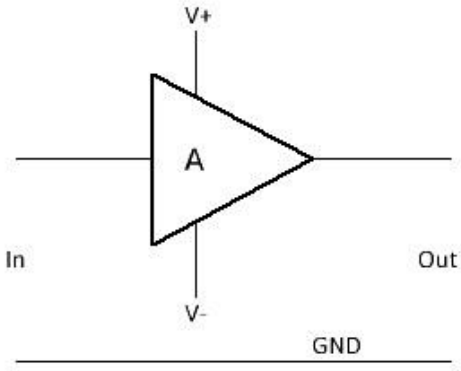
Then, just by relocating the ground connection to a centre tab on the transformer, we obtain a symmetric supply voltage, meaning a V+ (higher than ground) and a V- (lower than ground) voltage. With same voltage secondary windings, this ground level is exactly between V+ and V- or in other words, V- has the same voltage as V+ except for reversed polarity.

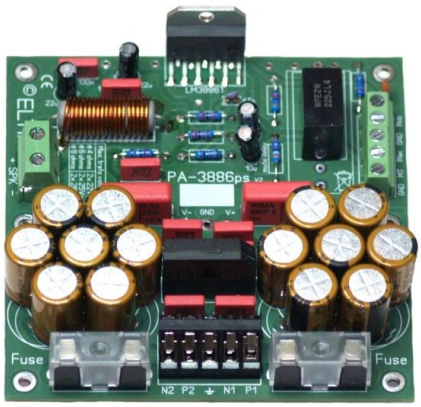
This "reversed" thing could be hard to understand if you are only used to positive voltages where current flow out of the supply circuit. The only difference actually is that with a V- the currents flow IN the supply circuit, just the way as currents flow back in the ground contact in a single voltage power supply! With this fact in mind, follow the currents from V- back to the transformer and see that it works this way indeed. It even can't in another way, because both left diodes only allow currents flowing from V- to the transformer, exactly as a positive V+ current only can flow from the transformer to the V+ output due to the direction of both right diodes.

So, unlike common single supplies where the current flows from V+ to Ground, in a symmetric power supply the current flows from V+ through the load and back again via V-. The ground contact of this power supply in principle only leads the (AC) speaker and input signal currents actually. Due to slight differences in supply capacitor values and behaviour it still runs some current mostly though. Also, these capacitors help the transformer to keep this ground level exactly between V+ and V-. Since these capacitors show a very small impedance (Electrical SERIES Resistance, ESR value) for AC-signals, they are in the speaker signal path and so like connectors, cables, etc. part of the audio quality chain! This means that the better capacitors you use, the more "solid" this ground level will be and are part of the resulting sound quality. That's why you can choose several supply capacitor types with most of our designs. Select the quality/pricing what fits you best.

Another advantage of this symmetrical design is that both secondary windings are now loaded ALL the time, so the full potential of the transformer is used. Due to this, compared to some circuits above it can be a smaller transformer.

Connecting this symmetrical power supply to a power amplifier, we see some interesting facts:





100x100mm, 80W amplifier module with integrated symmetric power supply using audio grade NICHICON 'Fine Gold" supply capacitors

Since also here the in- and output leads are at half the total supply voltage (being V+ to V-), both are at ground level (= (V+) + (V-) / 2), so there is NO DC voltage at the output we have to block by capacitors at all ! The speaker is directly connected to the output stage, dramatically improving the damping factor and sound quality of the total. So, in our ELTIM amplifiers you won't find a signal degrading output capacitor, since about all use a superior, symmetric power supply as described here.

In most of our designs there still is an input capacitor, but this is mounted because there are lots of equipment showing a DC-signal on their output signals. Since most of our amplifiers do their job from DC on, this DC input signal would also appear amplified on the output causing a huge woofer shift.

So, on most of our designs you'll find an ACin as well as a DCin lead. The latter bypasses the built in reasonable quality (MKP) input capacitor mounted on board.

Nice indeed, but the disadvantages of a symmetric power supply have to be named as well:

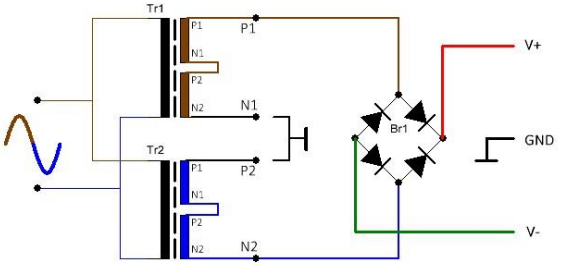
- More parts required (capacitors)
- More wiring required
- Larger PCB area required
- Double secondary windings transformer required
- Due to above, costing more.

Please note that a power supply is part of the AC signal chain, just as parts, cable and connectors are. Preferably its impedance (AC behaviour) should be close to zero ohms over the full audio band. Especially cheap Switched Mode Power Supplies (SMPS) do NOT meet these requirements and are mostly meant to feed more or less constant current drawing devices like Notebooks, PC monitors, etc.

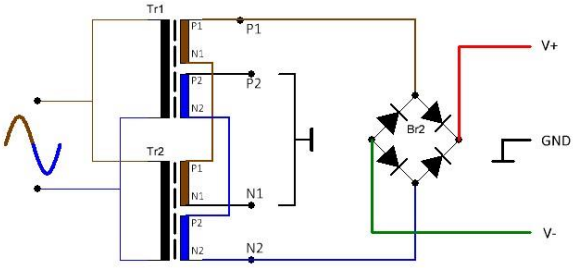
Low price equals low (sound) quality! It's like giving an top athlete fast-food every day. Won't work either.

***TIP 1**: Since electrolytic capacitors show worse behaviour at higher frequency loads, we and our professional colleagues recommend to use some high quality MKP capacitors over the voltage rails. You will be rewarded with better vocals and way less (to) sharp "s" and "t" sounds. Even cymbals, triangles, etc. start to sing (again).*

***TIP 2**: In cases where there is little space for transformer(s) or very high output power is required, use of two transformers instead of one could be the solution. For high power purposes about everywhere the upper schematics is recommended. Due to differences in transformer data, it could result in overloaded transformers, since you believe you can drain full double core capacity (in VA), being NOT the case sometimes. The higher voltage transformer could become overloaded AND there could be a difference between V+ and V- due to this as well. This event would result in a slight DC voltage at the speaker output.*



2x1000VA ≠ 2000VA !



2x1000VA = 2000VA !

We do it different and as we believe in the only correct way, where both transformer cores are loaded ALL the time and in exactly the same manner, see the lower picture. In our solution also problems caused by slight differences in transformer output voltages are solved. BUT: know what you are doing. With larges sized transformers like this, things can go really wrong if wired incorrect. Triple check !!