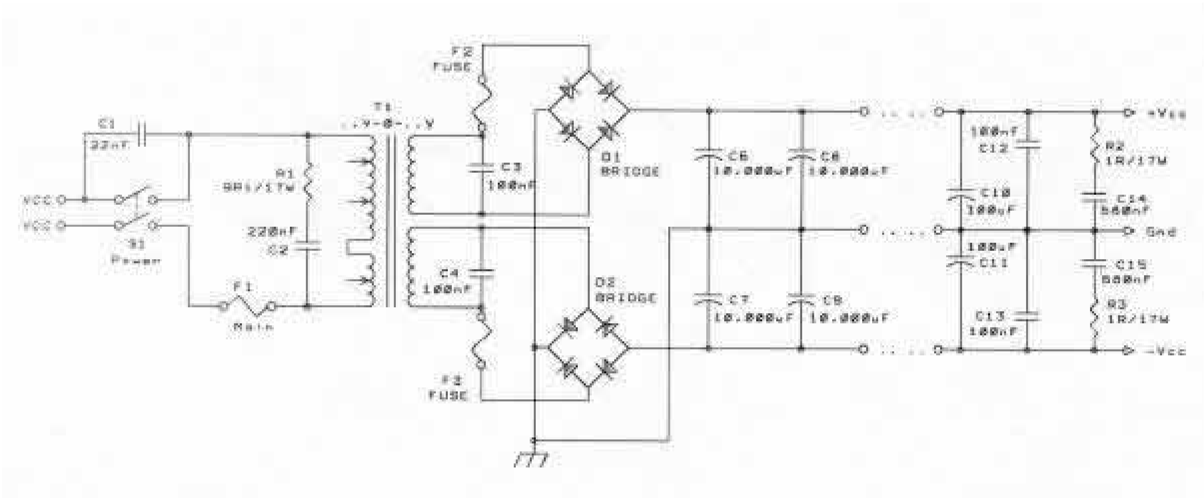
Solid State Power Amplifier Supply

Part 2

[Italian version]



Lastly, Figure 4 illustrates a serious power supply. For a start, we see that each half of the supply has its own full wave bridge rectifier. This allows for significantly improved rectification, as well as offering the designer greatly increased power handling capabilities, since two rectifiers now share the work load of one. This approach is quite common in American High End units, and has during the last several years begun to trickle downwards, into higher middle class units. A welcome change indeed.

But the real reason why this is done is twofold. First, this allows for much better channel separation, since each supply line is independent, and is therefore much less likely to transmit signal from one channel to the other. The other reason is essentially the same, but with regard to ground planes - this method produces more ground planes, but avoids mixing them, thus once again minimizing possibilities of crosstalk and improving our signal to noise ratios. For this to be so, one also needs dedicated transformer secondary windings, for a stereo amp a total of four, rather than the classic two. Obviously, while good and with many advantages, this is a considerably more expensive design.

Also, please note the two symmetrical RC networks. They serve to get rid of the residual capacitor inductance, which should improve high frequency performance. In my experience, it always does, though to what extent remains open to debate, trial and error. No matter how good the capacitors may be, they always have some inductance left over; the better they are, the lower the value, and vice versa. Therefore, this is always good to have, even if its greatest effects will show up with the worst of capacitors. A side benefit is that the amp will tend to be even more stable with complex loads, although this is primarily something the amp design should deal with.

Incidentally, do not be daunted by the power rating of the resistors shown, depicted as 1 Ohm 17W here; the actual required rating of the resistor will depend on many factors, but with a 17W rating, you're not likely to go wrong with any amplifier up to some 150W/8 Ohms and corresponding increases of power with lower loads.

Also, let me add that I use the same principle as shown on Diagram 4 for my own projects, however, for each channel, i.e. my totals are twice those shown. I have experimented much with all this and experience has shown me quite clearly that the last shown case will produce by far the best results. I typically use KBPC04-25 metal cased full wave bridge rectifiers, mounted on the case for additional cooling, followed by Siemens Sikorel capacitors. Which brings me to ...

Sizes

Well, by now you have surely realized that proper dimensioning or determining of sizes is of paramount importance. Right - now I could hit you with a slew of formulas, but I'm not going to do that. Instead, I'll give the peasant view, as referred to by mediocre engineers, or the simple method, as referred to by wiser and more knowledgeable engineers.

Transformer

First, you must decide - one transformer for all, or a separate transformer for each channel? To help you decide, work out the required power rating first. Let's assume you want the ultimate, a true voltage source - this is a fancy but technically correct way of saying you want an amplifier which will behave as a true voltage source and will deliver the same VOLTAGE into any load down to - what? Holy cow, now we have to consider the damn load as well.

We can do it. We can hog it Krell-style and say we want it to work down to 0.5 Ohms - then we're going to need some really massive power supplies. But we can also try to be reasonable and think. Say you want to drive only one pair of speakers; say they have a nominal impedance of 4 Ohms (the bad case), and say they are hell to drive because they exhibit a -60 degree phase shift.
To the amp, this is like having a 2 Ohm load. OK, so let's draw the line at 2 Ohms, let's say the amp must be a true voltage source down to 2 Ohms (watch out, this is going to cost you! But it will also show you why Krells, Levinsons, etc simply must be expensive). Finally, let's say you're happy with 50W into 8 Ohms, as you should be in most cases, if you have real world watts at your command. First, let's see what we have in terms of voltage:

Square root of: (Power x 2) x load impedance = peak voltage, or in our case

Sq. Root of: (50 x 2)x8 = 28,284271V, or simply 28.3V peak.

To obtain a mean figure, we must divide our result with the sq. root of 2:

28.3 : 1.41 = 20Vrms.

Power-wise, what this means in practice in case of a true voltage source amplifier down to 0.5 Ohm loads, is outlined in the list below:

50W/8 Ohms = 28.3 V peak / 3,53 Amperes peak

100W/4 Ohms = 28.3 V peak / 7,07 Amperes peak

200W/2 Ohms = 28.3 V peak / 14,14 Amperes peak

400W/1 Ohm = 28.3 V peak / 28.28 Amperes peak

800W/0.5 Ohm = 28.3 V peak / 56.57 Amperes peak

So, 50W/8 Ohms equals 28.3V peak. Good. It follows that with 8/4/2 Ohms loads, our required currents will be (20:8/4/2) 3.54/7.07/14.14 A. Small wonder, since we want our amp to provide 50/100/200W into 8/4/2 Ohms. Remember, this is in terms of the power supply only, and it completely disregards the capabilities of the output stage and heat sinking, which, for 200W/2 Ohms, will need to be massive.

Load impedances of 0.5 Ohms are in fact ridiculous, since they represent effectively short circuits - you might as well be using your audio power amp to drive a welding arch. It is even less ridiculous to consider driving this "load" on a continuous basis. Even for peak power outputs, 1 Ohm loads represent the worst loads which could be considered as realistic, in terms of power, but not in terms of absolute stability. However, that is a question of amp design, not power supplies.

So, our transformer ratings should be 200W per channel. To obtain a VA rating, we need to multiply this by 1.41, and we get (200x1.41) 282VA, or 300VA, which is a common manufacturer transformer rating. This is per channel, mind, and only if you want CONTINUOUS power outputs into 2 Ohms; for PEAK outputs into 2 Ohms, you can manage quite well with a smaller transformer, like a 200-220VA one.

Now, if you're going to have separate transformers for each channel, two 300VA units will be just fine, with power a-plenty even for worst cases - in fact, with supplies like that, you should be thinking about loudspeaker guarantees, not the amp's. This is sufficient to cater for transients as well. In reality, manufacturers use 300-360VA transformers to feed amplifiers TWICE our nominal power.

If you're going for a single transformer, you again have two choices. One is to use a straightforward unit with two secondaries and feed both channels from a single bank of capacitors, or you could use separate bridge rectifiers and capacitors for each channel - that's up to you. Or you could order a transformer with a single primary and separate secondaries for each channel - in that case, you will have something very near to a dual mono supply, though of course, nothing beats two separate, totally independent transformers.

Finally, should you use toroidal, or some variation on the theme of frame transformer? In many ways, your choice has already been made up for you - if you want custom building, I would venture a guess that 99.9% of all suppliers offering that service will use toroidal transformers. They are much easier to custom wind, are more compact and are definitely more weight/energy efficient. Over the last few years, we've witnessed their fall in terms of price, so they now cost about what a frame transformer would cost as well, thus shedding the last real disadvantage. And they are incomparably more quiet in operation, plus they theoretically radiate less, since they theoretically concentrate their magnetic field in its center.

I keep saying "theoretically" as whether and to what extent this will be true greatly depends on both transformer materials and equally to its winding. If wound properly, so that a secondary ends on the spot where it begins, if good quality rings are used and if good quality wire is used, then it will display all of its benefits to a considerable degree. In practice, unfortunately, I have seen far too many toroidal transformers which were poorly made, despite bold manufacturer claims.

Actually, you can check up on this rather easily. Using all necessary safety precautions, connect the transformer to the mains, then connect your multi meter across the secondary and measure its quiescent current consumption (the current it uses up with no load). Remember that by default, larger capacity transformer will use more current than a smaller one, and in all cases, you are in the milliampere range, below 30.

Two years ago, I measured a toroidal transformer made by a well known British company, rated at 300VA - it used up 17 mA. That is a reasonable, but hardly outstanding result. Then I measured a custom ordered and made transformer from a respected Yugoslav source - I got 14 mA, but that was an 800VA toroid. So, you work it out: 2.7 times the capacity uses up 17% less quiescent power - which one is better? Uncle Julije still beats the pants off mass production manufacturers, and to add insult to injury, he has better prices too.

Rectifier(s)

A full wave bridge rectifier consists of four diodes. It may be built using discrete (standalone) diodes, or may be purchased ready made, in a plastic or metal package. Here you need to make several decisions.

Decision one - will you construct your own rectifier, or will you go for single package? Both approaches offer advantages and disadvantages. Going discrete allows you to use very fast Schottky diodes not readily available in a single package. However, most such diodes were never meant for heavy duty rectification, so they will do just fine for low current, low voltage rectifiers in preamps, but are not very convenient for high current, high voltage applications. Single package rectifiers, on the other hand, are intended precisely for that - high power applications, so obtaining units with ratings such as 25-35A, 100-600V is very easy and not very expensive. In addition, such high power units already have handy holes which enable you to screw them on to additional cooling surfaces, thus extending their useful range and improving their reliability. A 25A 400V bridge, such as KBPC04-25, typically costs around 4-5 Euros in Germany.

A note may be in order here. Lately, some manufacturers are moving towards using ultra fast Schottky diodes even in heavy duty rectifiers, claiming this improves the sound. The theory is that since these diodes are so fast, their recovery time is inherently shorter than in case of typical, slower rectifier diodes; also, their noise floor is lower. Then there is the other group, which says that while speed is no doubt good, Schottky diodes do not offer current capabilities of rectifier diodes, and worse still, their voltage ratings are not anywhere near those of rectifier diodes. For example, Nelson Pass states very plainly in several of his projects that in his experience, classic heavy duty bridge rectifiers will in fact produce better results than ultra fast Schottky diode rectifiers.

Personally, I agree with Mr. Pass. I cannot say I spent much time on experimenting, but I did do some experiments and according to my results, I would never go for ultra fast diodes in current amplifier rectification stages - fine for preamps, fine for voltage gain stages, but not good for current gain stages. You could partly compensate their current capabilities using the circuit from Diagram 4 - that way, you would effectively double overall capacity by making two bridges share the load, but you would also double the not so insignificant price as well. Lastly, while it's not often said but is still true, diode matching in bridge rectifiers is not an insignificant sideline, but a very important characteristic - and here, block rectifiers, in which all four diodes are built on the same substrate and are matched by default, carry the day hands down.

Choosing the right bridge is really very easy. You have to carefully consider the specification, which will, or at least should, show you the voltage and current capacity with two numbers. One, the smaller one, applies with no additional cooling, the so-called free air capacity, and the second, the larger number, applies with additional cooling. So, if you know you will be working with transformer secondary voltages of say 30V, after rectification that will become (30x1.41) 42V, and you should be home and dry with an 80V rectifier rating. However, as you will easily see, 100 or 125V rated units cost hardly anything extra, so go for higher voltages - standardize, so to speak, adopt one unit and don't change unless forced to.

As for the current, simply read off the current rating of your power transformer - it will be something like "30-0-30, 2x5A" for a 300VA unit. Obviously, you need a 5A unit as a bare minimum, 7A is better and 10A is good. Again, you will soon discover that a 25A 400V rectifier costs very little more, so common sense tells you that it's best to have a very powerful bridge on hand - go for the metal cased unit, your reliability will increase greatly, you can use the amplifier case for additional cooling, and the only price you must pay are the wire connections to the filter capacitors or their board.

Another reason why a much more powerful rectifier is preferred are the following capacitors. If you want to have large banks, you have to consider what's available to charge those banks - less current means slower charging. Also, upon turning on, those caps are in effective short-circuit, which places some heavy stress on the rectifier; again, the more powerful, the better.

So, your bridge must be more powerful than your transformer - how much more powerful depends also on the following filter banks, your budget and your preferences.

Capacitors

As noted before, electrolytic capacitors serve two functions - to filter out the rectified supposedly DC voltage and to act as energy storage for those peaks which may require very large currents. Hence, they also stabilize the voltage by acting as energy reservoirs which offload the transformer, but this function is not of prime importance (however, it is far from being unimportant). I have set the priority list here: 1) filtering and 2) energy reserves.

In practice, manufacturers tend to use them as a panacea or cure-all for all other in-built power supply shortcomings. There is no doubt that filter capacitors have crucial influence on the sound obtained - that much is agreed upon by all, no matter what school they belong to. Therefore, they require special consideration.

First and foremost, their capacities. If you're willing to overlook their cost, a simple rule of thumb is to say that you need 1,000uF per every RMS Ampere of current. In practice, this will keep your amp working well even into lower loads. However, just to be on the safe side, it's better yet to say you need 1,000uF per every PEAK Ampere of current - this effectively increases your filter capacity by a factor of 1.41.

Using our example amplifier, delivering 50/100/200W into 8/4/2 Ohms, obviously we need bother only with the largest figure, that of 200W/2 Ohms. So, our RMS current will be as follows:

Sq. Root of (power:load impedance) = Sq.Root (200:2) = 10A.

Therefore, we would require 10,000uF per supply line at the very least. If we want to be really safe, we'd cater for our PEAK current, which is 1.41 times greater:

10A x 1.41 = 14.1 Amperes.

The nearest standard value is 15,000uF, so we'd use that for every supply line. If using just one transformer, you'd need four such capacitors; if using separate supplies for each channel, you'd put 2x15,000uF for each channel.

There is another approach. It is accepted that one needs 1-2 joules of energy per every 10W of output power. For a 50W/8 Ohms amplifier, we need 10-20 joules of energy to be stored. We can use a formula, 1/2CVsquared (where C equals capacitance and V equals voltage, the voltage being squared) to calculate that 15,000uF, fed by say 33V (worst case, full load on) allows for 8.16 joules per capacitor, or 16.3 joules per channel - enough to fry quite a few unsuspecting speakers in the low end class, and even some in the midrange class. If 33V is our worst case, we can assume 36-38V supplies with the load off (say 37V), which means that just before a transient, we will in fact have some 20.5 joules stored in each channel's capacitors.

Here you need to make another decision. Will you use single large capacity caps, or will you put two or more caps in parallel to obtain the proper value? Smaller capacity caps charge and discharge faster by their nature, all other things being equal, which is good, but they also have larger impedance and inductance values, which is not well.

To decide, use the following approach as one possibility. Look up all relevant values for say 15,000uF and say 6,800 uF caps from the same series (8,200uF is better yet!). Placing two in parallel will divide their impedance - disregard inductance for the moment. If such two caps together produce an impedance value smaller than one 15,000uF cap can do, then go for two smaller caps. ALWAYS go for lower impedance value, as this will have significant influence on your damping factor either way.

Next, repeat the above procedure with some really high quality caps, such as those made by Elna and Siemens. However, you may find that one manufacturer or the other has no near values - for example, Siemens Sikorel is easily available only in its 10,000uF/40 or 63 V guise. Then compare your notes. Pay special attention to impedance values.

Of course, you'll soon see that high quality caps produce some impressive values, but at a price. So, compare your prices to see if you can handle that. Answering that question will clearly point the way to go - always go for the best you can afford. In this case, you may well find that the most reasonable overall set would consist of two Elna caps, each rated at 8,200uF/50V, in parallel - this will give some impressive impedance values and would increase your capacity as well, both of what you want and need.

More or less same procedures apply to any case you care to name - the method is the same, only absolute values differ. A note is in order here - the above method stands true for real audiophile applications, as it assumes worst case requirements, such as driving 2 Ohm loads under continuous outputs. This is not likely to really happen in practice, so the above is really a worst case scenario which assumes reserves for even lower load impedances in short term bursts. I would expect 1 Ohm bursts of some 350+W to be readily available, and that is over 26 Amperes of current. The supply can do it - I'm not so sure of the amp, though, we're in some really serious waters here.

Another issue not often addressed is whether to use printed circuit mounted caps, or free standing caps with wire connections. Again, each type has their advantages and disadvantages.

PCB mounted capacitors allow you to place them near the output stage and to avoid any wiring whatsoever. This is good, we want that. On the down side, they are rather large and relatively heavy, so they tend to vibrate, and we don't want that. If you go for this type, use generous amounts of silicon paste/glue to affix them to the board as well as you can, and you can never do too much.

Freely standing caps, preferred in the professional group which, with all due respect, peddles much better electronics than most audiophile companies, famous brand components notwithstanding, are considerably larger, heavier and costlier. They are harder to implement since they require mounting hardware, but in return, well implemented mounting hardware will kill off vibration to a point one simply cannot achieve with PCB mounted caps. Glue and solder are nice, but they cannot begin to compare with heavy duty screws. Large sized caps also tend to have lower impedances than similar, smaller sized PCB versions, and their surge current specifications also tend to be better than PCB versions'. We want all of this. Their drawbacks are that you have to use wiring, which in itself costs money, is not elegant and causes the need for additional contacts.

Some years back, there was an text in Britain's Hi-Fi & Record Review by Mr Martin Colloms, in which he tested some filter capacitors. If memory serves, he did so by using various makes, shapes and types on well known audiophile products, and found that larger capacitors tended to sound better than smaller ones. By implication, free standing types with same specifications will tend to sound better than similar PCB types. But they will cost more and will be harder to implement, as they will require more real estate space inside the case.

Go to Part 3
Go back to Part 1

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