Calculating HiEnd-Audio supplies

… too small is not so good, but too big again limits performance

Part 1: Standard supplies

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Some designers tend to offer supplies that show too big capacitance.
When comparing vintage schematics we always find caps with a value that is too small.
What is the right value, and is it possible to calculate performance?

Basically there are two different kinds of loads …

Any power supply has to work well in relation to its load. Also, equipment's performance can only be as good as the quality of its supply. First we have to determine whether the load is a static one, or does it show dynamic behavior.

For example:

- A DC-heater supply is a static load as there is no change of the load current vs. time.
- The opposite is a class-AB amp as it shows really dynamic behavior in the load current. Load current could show a ratio of 1 : 5 vs. time.
- In the middle, with nearly static load, we find class-A circuits like pre-stages of amps, pre-amps and SET-A amps.

Both groups have one common requirement - they need to show a minimum of residual ripple at the load.

A dynamic load has one more requirement – we have to calculate the internal impedance of the supply as it must respond to big changes of current quickly. Before presenting these calculations, I wanted to recommend a small program you can download for free from the website "Duncan Amps". It is called "PSU Designer II". This program can help you to calculate standard supplies and it gives you a scope-like picture of the results.

The link -> http://www.duncanamps.com/psud2/psud2_setup.exe

The DC-heater-supply

We already characterized this type of supply as a static one. We need to know its values and then we could easily figure out its requirements.

Let us focus on a heater supply for 4 heaters in parallel using four 6SN7GT dual triodes, requiring a total of 6,3VDC at 2,4A.

If you try to convert an existing AC supply to DC, the results will be poor. First consider a separate heater winding from an existing transformer providing 6,3V @ 3A. Here only a bridge rectifier and capacitive filtering is possible. We use a 10.000µF/16V and a resistor of 0,1Ω in front of the el. cap. The big el. cap is needed to filter the output to acceptable ripple limits.

The result will be 6,3Vrms with a residual ripple of 1,7Vpp (app. 0,6Vrms). This residual ripple is app. 10% of the intended supply voltage. This is the worst case we could tolerate, as app. 10% is the limit to keep the heater quiet.

Well, but we have to observe one more limit too: the rms-current drawn from the transformer. Its value will be app. 4Arms. Generally speaking, that is too much! But because many transformer heater windings have thicker wire than necessary, it could work. You could experiment with your own transformer. You had to try out and believe in your transformer.

If we were able to use a higher voltage the results will be better. If we had a winding providing 9VACrms @ 3A, the filter could be a C-L-C with C1 = 2.200µF/25V, L = 50mH/3A/1Ω, C2 = 10.000µF/16V. Due to the choke, the result will have a residual ripple of app. 32mVpp at a heater voltage of 6,4VDC – OK, values we could live with! But in this case too, the current drawn from the transformer will be app. 3,9Arms, which is again too large and we will need a bigger transformer, one capable of 4Arms.

You can try out these results using the "PSUD II" program mentioned above. In my simulation I used 10% voltage regulation of the heater secondary winding (no load <-> rated load).

Internal impedance [Zi] plays a minor role because we have to face no variation in load current.

If you compare the effort and the expense needed - to achieve a proper DC-heater supply - to the SMPS solution, which I shall explain in the SMPS article, you will see why the use of a SMPS is so convenient!

The B+ -supply

This supply can be a nearly static one (like described from above) or a dynamic one.

I shall present two examples. Let us first calculate the nearly static one and focus on a preamp with 4 triodes, type 6SN7GT all working in class-A. B+ shall be 300VDC and load current shall be 50mA total with a variation of ±5mA.

The general equation for calculating the needed capacitance in parallel to the load is:

$$C = \frac{2 * P}{fu * U^2} \quad \text{or} \quad C = \frac{2 * I}{fu * U} \qquad (1)$$

We can calculate P as 300V x 50mA = 15W; fu = 10Hz -3dB (20Hz -1dB).

The result for C is = 33,3µF. As a rule of thumb, we increase this value by factor 2 to compensate for the ±5mA (±10%) of load current change. The new result is now 68µF. Such a supply is sometimes called a "battery replacement". We have to calculate the ESR (equivalent series resistance) of the el.cap to find its maximum load current ability. The formula reads:

$$ESR = \frac{\tan \delta}{2 \pi f C} \qquad (2)$$

tan δ (called "dissipation factor" or "tangent of loss angle") can be found in datasheets, and for this el. cap it is app. 0,3 (depending on brand and quality). We have to insert f = 100Hz (120Hz in the US) and get the result -> ESR = app. 7Ω. If we discharge the cap, an maximum peak current of 300V / 7 Ω = 42A will be possible. To increase the instantaneous current ability, a foil cap of 0,01 times (or 1%) the main cap's value is a good choice in parallel with the load. In our case we choose 680nF. Only good quality MKP or FKP should be used here. Keep the wires in between load and foil cap short - it is best to place it as close as possible to where it is actually needed.

If your amp uses a so-called "resistor ladder" to supply several serial stages, you have to do this calculation for every step. If the first triode in your amp draws 3mA and voltage has dropped to 250VDC, the cap's value will be 2,4µF. As before we choose 4,7µF and parallel a 47nF foil. Since the first triode will do most of the amplification, you can increase the el.cap to 10µF and parallel a foil of much bigger 220nF to increase the dynamic abilities.

Will bigger el. caps show any benefit? No – not really! As you can see from the formulas, you will only decrease the lowest frequency possible and that makes no sense in a tube-amp. You can try to increase the dynamic performance by increasing the foil caps, but better wiring (shorter wires of bigger diameter) will help the most. Simply try it out …

To define the C-L in front of this "battery replacement" we can again use the PSUD II program:

Considering a transformer's secondary of 480V CT @ 100mA, diodes 1N4007 (or even better use UF4007), C1 = 22µF/400V, L = 7H/50mA/200Ω and the already calculated C2 = 68µF/350V, we get a result of:

B+ = 306VDC, residual ripple = 78mVpp (app. 28mVrms) and secondary current of the transformer of 66mArms. A truly good result. Because of the small el.cap C1 the increase in secondary current is not too big and because of the relatively big choke, the smoothing effect is good. The "battery replacement" C2 feeds the load and decouples the load well from the C-L-assembly in front of it. Internal impedance [Zi] again plays a minor role because the variation in load current is small here.

Now we shall investigate the dynamic load configuration. We again assume a voltage of 300VDC and an idling current of 30mA vs. a maximum current of 100mA (1 : 3,3). What will change relative to the above calculation? Well, we just insert the maximum current in equation (1), and we increase the calculated el. cap's value by factor 3.

The result from (1) is: C = 66,6µF =>> we use 200µF

To achieve a lower ESR, we connect two 100µF caps in parallel along with a foil in parallel with a value of 2000nF (or 2µF). As you can see from most datasheets, tan δ is directly related to the volume of an el.cap. That's also true of its ripple current ability. If we use 2 pieces of half the capacitance instead of 1 piece of full capacitance, we generally increase the total volume –> leading to a lower total ESR-figure.

The rest of the supply can be calculated as before:

Considering a transformer's secondary of 480V CT @ 150mA, diodes 1N4007 (or even better use UF4007), C1 = 47µF/400V, L = 5H/100mA/100Ω and the already calculated C2 = 2x 100µF/350V in parallel, we get a result of:

<u>Full load, 100mA</u>: B+ = 296VDC, residual ripple = 39mVpp (app. 14mVrms) and transformer secondary current of 122mArms. Again a truly good result.

<u>When idling only, 30mA</u>: B+ = 336VDC, residual ripple = 15mVpp (app. 5mVrms) and transformer secondary current of 50mArms. The increase of the B+ voltage adds app. 13%. When reproducing a music signal, the B+ supply voltage will be somewhere in between. Note that the residual ripple decreases the most when at idle, so the hum at the output should stay inaudible during breaks without signal.

The internal impedance of the supply can be calculated as:

$$Zi = \frac{U_{id} - U_{fl}}{I_{fl} - I_{id}} \qquad (3)$$

-where index *id* denotes operation at idle, and index *fl* denotes operation at full load.

Our example -> (336V - 296V) / (0,1A – 0,03A) = 40V / 0,07A -> <u>Zi = app. 570Ω totally</u>

If we build such a supply using a SMPS, we will not gain as large benefits as we did from the heater supply. Benefits will be to keep the B+ regulation to a smaller ratio (less internal impedance!), and to keep the residual ripple at the output in the inaudible, higher frequent range. But the biggest benefit will be its difference in cost and needed space!

Further information on the mentioned supplies can be found in the separate articles on **“SMPS Heater supply”** and **“SMPS B+ supply”**. In these other articles I describe the design and calculation of such a perfect supply.

If you have further questions or advices on improvements that you feel should be published here, please contact me via eMail.