SMPS-Tube-Supply

… the way to a perfect solution

Part 2.1: The heater supply

By Barbara E. Gerhold "TUBECLINIC"

In this article I shall explain the design and calculation of a perfect tube heater supply.

The DC-heater-supply

Like from the former article, we already characterized this type of load as a static one. We need to know its values and then we could easily figure out its requirements.

Let us focus again on a heater supply for 4# of 6SN7GT, rated at 6,3VDC and 2,4A.

At first we had to decide for a Buck (step-down) -module from the market. There are many offers at ebay or Chinese taobao. You should look for modules with high switching frequency and proper rated output current. Most modules offered, show their maximum current and if the module has no heat-sink applied, you have to divide this value by app. 2. There are many modules rated 3A, but you should be aware, that they will only be capable of app. 1,5A without attaching an extra heat-sink. That's not difficult, because you can attach a heat-sink intended for power LEDs, saw it to fit and apply it by the use of "super-glue".

I decided for a Buck-module, rated at 5A max., switching frequency of 300kHz and already including a heat-sink. The SMPS regulating chip is a XL4005 by XLSEMI. It promises an efficiency of typ. 90%. The XL4005 datasheet can be downloaded here:

http://www.xlsemi.com/datasheet/XL4005%20datasheet.pdf

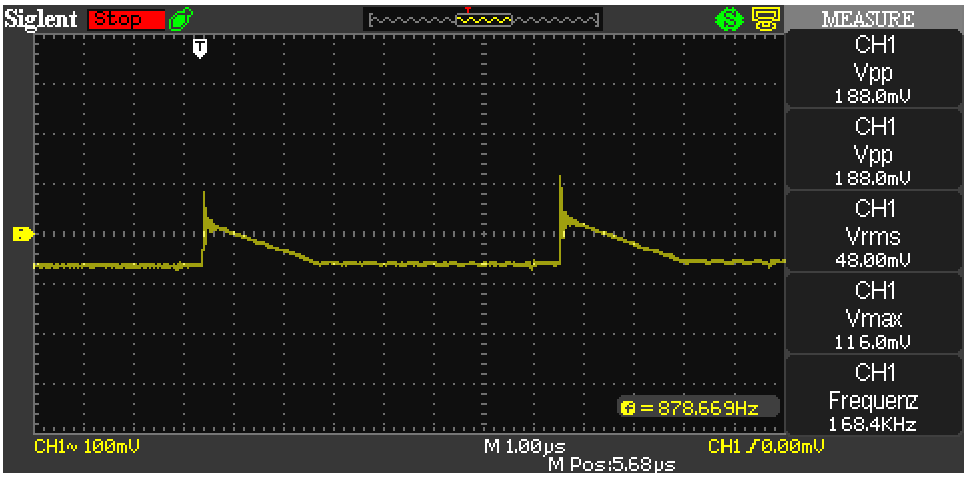
This is the module I used; you can purchase it from here ->

http://www.icstation.com/icstation-constant-current-voltage-step-down-module-cccv-p-3255.html - as well as from many other dealers from the web. It shows an adjustable current limit too, which is not common with other brands. This current limit is helpful, as the tube heaters will not become over-powered when switching on the supply! The heater wires show a heavy PTC (positive temperature coefficient) effect and would draw a big cold inrush current. An efficient soft-start, so to say …

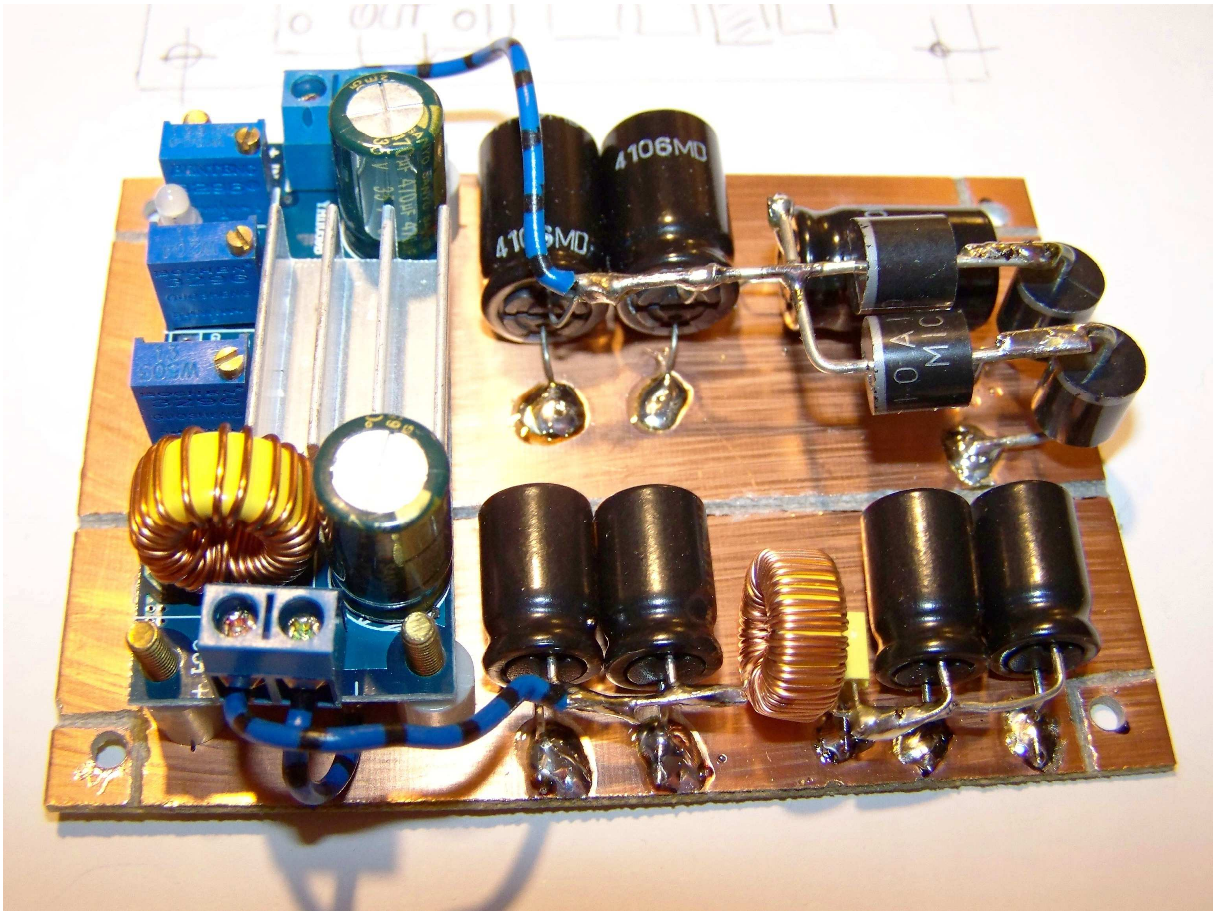
My tests showed that efficiency is extraordinary, while power loss limits the module to app. 3A in our application. If your heater supply needs more power, simply install one module per channel.

I used a small toroidal mains transformer prim. 230VAC, sec. 2x 18VAC @ 80VA. The other secondary winding was used for the B+ SMPS. The raw DC-voltage (input of the SMPS-module) was app. 24VDC, showing huge ripple of more than 2,5Vpp. But that does not matter anyway, because the switching frequency of the module is 300kHz and that will regulate-off this entire ripple.

As a first test, supplying 2# 12AX7 + 3# 6SN7GT in my existing pre-amp "Tequila MkII" (total heater current = 2,4A) was absolutely satisfying from its sonic performance. I took a screenshot from my DSO ->



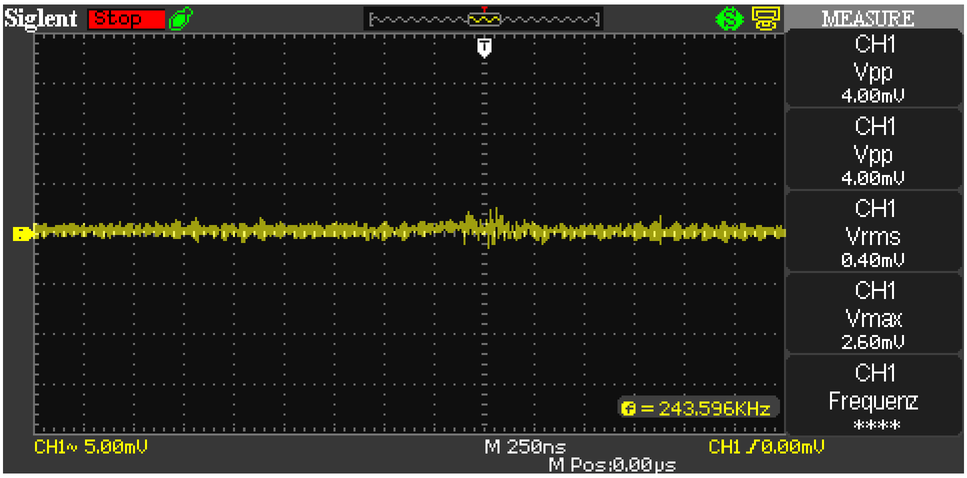
Because some (though inaudibly small) residues of the switching could be found too at the plate of the first triode when idling, I needed to reduce the ripple at the output. So the next step was to build an additional filter. I decided to use a small piece of FR4 (raw PCB material) to place the rectifier, the module and the additional output filter on it. You can see the finished part from this picture ->



The module is at the left side. I installed 4# 1.000V/10A diodes (10A10) for the bridge rectifier (top right). Not really necessary that big, but I had them on hand. They have stiff leads too, which compliments this way of building. Max. ripple current calculation required 2.100µF at the input filter. I installed 3# 1.000µF/35V (Panasonic type FR). The additional filter (bottom right) is built of 2# 100µF/25V Nichicon + ring-choke 100µH/3A + 100nF/100V MKT + 2# 100µF/25V Nichicon. Configuration therefore is C-L-C. After making some tests I found out, that only 1# of the 100µF/25V in front and in behind of the choke would have done it too, but there was enough space to place them. The MKT foil cap helps widely with reducing the small but high frequent spikes found prior without the additional filter.

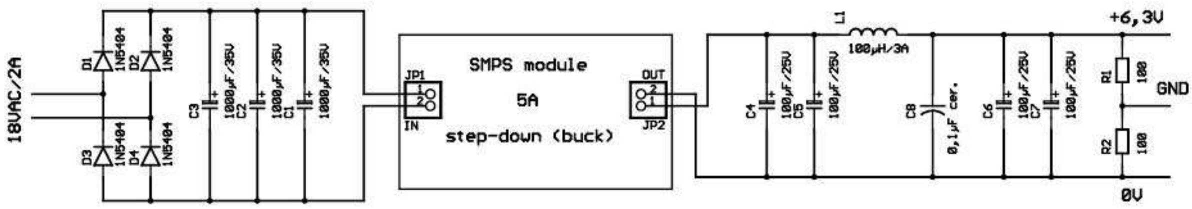
Please remind the grooves I cut to the FR4 board: They are necessary to separate both GND-planes. As you can see, the copper foil was used as a ground-plane. Because there is a current sensing resistor of 20mΩ in between both of the module's GND, both input-GND and output-GND have to be separated! This groove was milled by hand with my Dremel MotoTool. The holes for the fixing screws were separated too for to isolate them …

I took a screenshot of the resulting heater-SMPS too ->



The situation is 6,3VDC, residual ripple is 0,4mVrms @ 300kHz and load current is 2,46ADC. Current limit was set to 2,6ADC.

This the final schematic of the heater supply like from the above picture:



The calculation of the additional filter:

The bare module showed a residual ripple of app. 125mVrms @ 2,46ADC. Inside the module, a ring-choke of unknown value (33µH ???) and an el.cap of 470µF/35V are installed. So I decided to make the el.cap bigger in first place. That reduced the ripple to app. 70%. Now I had to calculate a choke, which is able to drop the ripple. That was not so easy, because Nichicon does not publish data of peak ripple current for their KZ series nor their up-rating for bigger frequency than 120Hz. Tan δ of these el.caps is shown as 0,12 for 25VDC rated voltage. So I could calculate the ESR (equivalent series resistance) as per ->

$$ESR = \frac{\tan\delta}{2\pi f C} \qquad (1)$$

The result for ESR = 1.59Ω per 1# 100µF, therefore <u>0,8Ω for two pieces</u>. In the real world, the ESR will be somewhat better, but I calculated from 120Hz-figures published by the manufacturer.

The foil cap will even lower this value, but it shall not be considered in this calculation. Now we need a choke, which is able to drop "99%" of the ripple in front of 0,8Ω @ 300kHz.

The formula reads ->

$$X_L \geq 100 * ESR \qquad (2)$$

where XL is the impedance of the choke.

Resulting in 0,8Ω *100 = <u>80Ω @ 300kHz</u>. The inductance of a choke is

$$L = \frac{X_L}{2\pi f} \qquad (3)$$

inserting X_L as 80 Ω and f = 300kHz we find L ≥ 42,4µH. OK – a ring choke of 100µH/3A was on hand, so I used it.

<u>Finally my additional C-L-C filter showed -></u>

2# 100µF/25V Nichicon + ring-choke 100µH/3A + 100nF/100V MKT + 2# 100µF/25V Nichicon

Using other el.caps than the mentioned ones will need other values, therefore carefully calculate their ESR and the needed choke.

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

Anyway - it can be calculated as:

$$Zi = \frac{U_{id} - U_{fl}}{I_{fl} - I_{id}} \qquad (4)$$

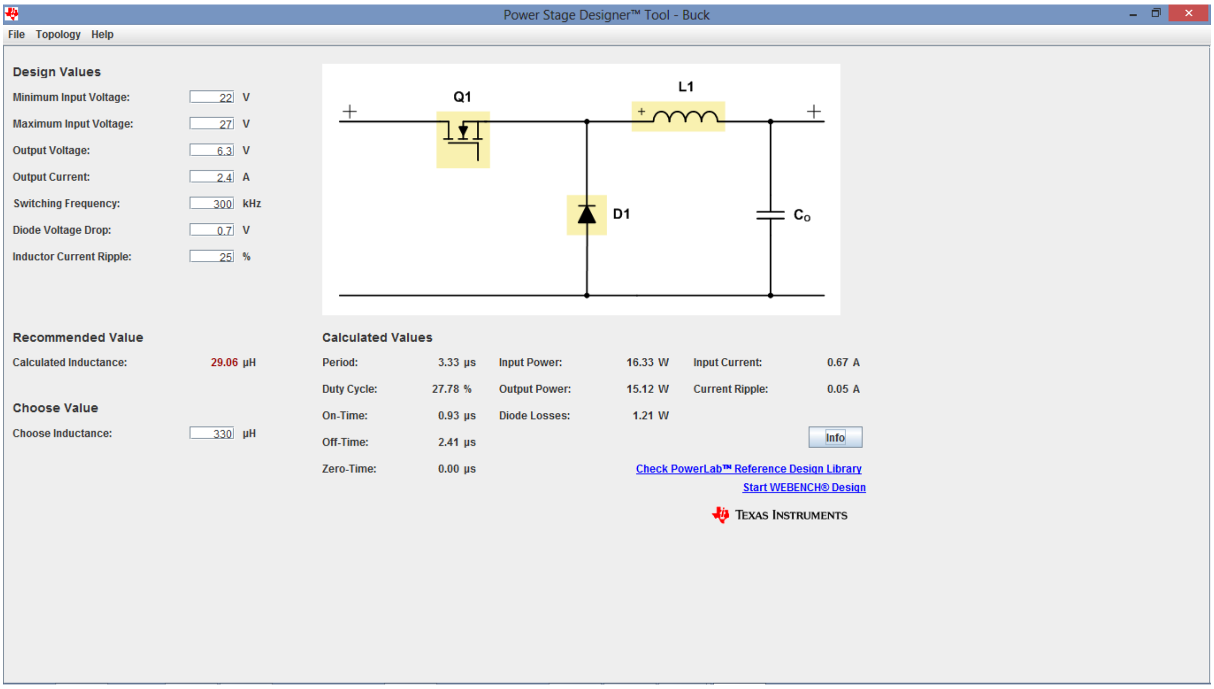
- where index *id* denotes voltage resp. current at idling only and index *fl* denotes voltage resp. current at full load.

My assembly measured -> (6,45V – 6,3V) / (2,46A – 0A) = 0,15V / 2,46A -> <u>Zi = app. 0,06Ω totally</u>

BTW – you can download for free a program which calculates all needed power stage parameters for SMPS design from the Texas Instruments (TI) website. Its name is "Power Stage Designer™ Tool". You can find it here ->

http://www.ti.com/tool/powerstage-designer?keyMatch=power_stage_designer&tisearch=Search-EN-Everything

I filled in my parameters and the result looks like this ->



The difference between input- and output-power is shown as 1,2W. They are the losses of the diode only. In the real world, there will be losses from the switching transistor and the R_{dc} of the choke too. But over the thumb the efficiency should be in the range of 90%.

A useful article about the basically function of Buck-converters can be found here too ->

http://www.ti.com/lit/an/slva057/slva057.pdf

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