The complete FETishizator V3.0   *NEW revision*

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After having done some elementary research for a late project of Mr. Lukasz Fikus – to find a method of matching and amplifying the output signal of a DAC using solid-state products – I found a proper way to achieve tube-like sound, which cannot be determined easily from that of real glass tubes.

The background for this project was, that for a non-tube version of his highly acclaimed "Lampizator" there would be no need for a plate-voltage DC-supply and there would be no heater consumption. Overall, we could spare the separate DC-supply.

I sent my opinions to Lukasz and he tried my quick applied hand drawings and published them on his website. Because my hand drawings based only on a computer-designed circuit, I made my own real-life experiments and designed the complete project including a "quiet DC-supply". There were some problems with crosstalk.

REVISION: Unfortunately, I developed this circuitry along a CD-player using PCM63P for DACs. Don't know why nobody discovered until today, that there is a mistake in my approach of I/U-conversion with the TDA1541 chip, I used to give an example. Well, some days ago, Mr. Darko Marijan from Sweden (many THX again!) alerted me, that this chip sends negative current (!!!) to the I/U-conversion resistor – but pls. see the following **revision** … well, unless its datasheet does not say anything about negative output current! Sorry folks, I did not try with a TDA1541 but I shall promise to get better for the future …

To make the "Real-McCoy" complete, I also designed a PCB, for to make the building of this stage easy – even ready for beginners.

About sound:

During my experiments I found out, that – contrary to Lukasz believing - the MOSFET cathode follower (Q_3) in my schematic is essentially necessary, if you want this tube-like, nasty triode sound. JFETs have the belonging, that they sound just like pentodes in triode mode (a little bit crispier than a triode, but with the same distortion characteristics). This leads from the fact, that the gate of a JFET shows higher impedance than the grid of a triode and less gate capacity while the output characteristics of the JFET is more that of a current source. The distortion products are nearly the same (almost only k_2 and k_4), which will guaranty this triode sound at low drain current values. To reduce this typical crispy sound, a small capacity should be brought into the circuit. This is done by using a small signal MOSFET as a source-follower. It has also the advantage, that the output of the circuitry shows only some few tens of Ohms.

OK now - my schematic <FET_CDout.pdf> shows a circuitry, which is very similar, because it almost shows my original hand drawing:

I used a BF245A, because the maximum input voltage (leading from +4mA of the current output DAC-TDA1541) will be only 400mV$_{pp}$, if used with the input resistor $R_2 = 100\Omega$ (4mA*100Ω = 400mV).

REVISION: The current output of the TDA1541 is -4mApp, so the converted output-voltage, using 100Ω as I/U-conversion resistor will be -400mV maximum!

The gate/source voltage of the BF245A is typically -1V at 1mA drain-current. Digitally Null output of the DAC (digital silence, only MSB = 1) will result in +2mA output current, which will reflect an input voltage of the JFET of +200mV. Full-scale output of the DAC will result in – positive half-wave – +400mVDC (4mA * 100Ω), while - negative half-wave – in 0VDC; all peak-to-peak AC - seen as DC-voltage.

Therefore, we can presume a Null input voltage of +200mV as our design point. If the BF245A had 0V at its gate, it would show a drain current of 1mA, if we put a 1kΩ resistor into the source path. Because we have + 200mV as design point, we have to raise the value somewhat to around 1200Ω to achieve the same drain current. JFETs are at their best performance at this 1mA drain-current, so do not change this value!

REVISION: Null input voltage or "digital silence" from the TDA1541 will be -200mV as the design point. For best performance and the statements from above, the best source resistor Rs will become 820Ω to achieve the above-mentioned 1mA of drain current. Please note, that everything said above (underlain blue) is still true also for this revision, except that you had to change the <**+**> for a <**–**> on all given input values!

To all folks, who already built this circuitry using TDA1541 -> you had to change only this one resistor to improve the sound widely. For all other DAC-chips with positive output current, the version remains unchanged!

The drain resistor R_5 (5k6) has to settle half the remaining supply voltage across it, to give fully symmetrical operation.

In my given example, I presume a supply voltage (L/R_B+) of +12VDC. So we have to lower this value by 1,2V (the gate/source voltage) => 10,8V and then we have to divide it by 2 => 5,4V. 5,4V / 1mA leads to 5,4kΩ. The closest value is 5k6, which is close enough for our circuitry.

REVISION: U across Rs = 0,8VDC -> so 12V – 0,8V = 11,2V / 2 => 5k6 exactly.

The common formula reads:

$$R_5 = \frac{(V_{B+} - V_{GS})}{2 * I_D}$$

Note:

*You could improve the performance of this circuit, if you raised the B+ voltage until close to +30V (breakdown voltage of any BF245), but be sure, **never** to exceed this value! Use the above formula to make the needed dimensioning! Keep proper spares in your calculation! If B+ is close to +30VDC, a value of 12k … 15k (R5) will be a good point to start with. R15, R18 should settle to 5k6 each.*

REVISION NOTE: Tests showed, that a B+ of +24 … +26VDC and values of 10k (R5) as well as 4k7 (R15, R18) will give superior performance. I received eMails from many, many readers stating this fact!

JFET breakdown will never destroy the DAC, because its gate is isolated from the channel and even channel (source/drain) breakdown will be held-back by the "quiet

DC-supply" circuit. Nevertheless, you had to replace the JFET, because it would not operate any more!

Since the current through R$_3$ (1200Ω -> <u>revision -> 820Ω for TDA1541</u>) will cause a current feedback, we have to bypass this resistor by some capacitance. As I wrote in my "Music Angel Mod article", bigger electrolytic caps show an immeasurable phase problem, we have to bypass also by foil capacitors (C$_4$, C$_5$, C$_6$). By this means, the current-feedback only remains for DC (for a stable DC operating point) but not for AC current. The AC amplification factor will therefore be much higher. The common formula for the dimensioning of caps reads:

$$C_{RS} = \frac{1}{2 * \pi * f_u * R_S}$$

You should settle f$_u$ to about ≤5Hz to get low phase-shift and satisfactory results. This formula can also be used for all input and output caps! Only substitute input resistance or output resistance instead of R$_s$.

At the drain of the JFET the MOSFET (BS170) is coupled. It cannot do any good or bad to the overall audible sound, it matches only impedance while it reduces high frequent dirt in the signal (above 0,5MHz) by its gate capacitance.

Please note: Tubes do the same by their grid- and Miller-capacitance!

The "quiet DC-supply" - flanking each audio channel - consists of a very high gain Darlington transistor in connection with some passive parts, which overall form a "gyrator". The function of this stage is very versatile and can be seen "like a choke - built of sand". The input voltage (VCC) may be as high as 120VDC if you use the mentioned BD651. Not all parts on the schematic drawing are used in common for all applications. I enclosed some typical dimensioning for VCC => ~ 12V, 15 … 20V, 24V … 30V, bigger (50V) in the back of this article. The BD651 stabilizes the supply voltage, while it decouples both audio channels to a maximum and while it smoothes B+ like a serial choke.

Theory tells, if you connect a cap to the inverting input (here: transistor base) of a current amplifying part, the complete circuit acts like an inductance. Big bargain in this small and sophisticated circuit!

I also enclosed the copper layout in real life size (1:1), from which you can easily make your on PCBs. The parts' drawing is also enclosed.

<u>Possible and/or some needed mods in the audio circuit:</u>

➢ For use with the above-mentioned current-output DACs (TDA1541 e.g.) the input caps C$_{25}$ and C$_{26}$ are not used. They are substituted by wire bridges.

➢ If you have a voltage output DAC, you should have a look at the manufacturer's datasheet of the sample. If the output voltage is smaller than 400mV$_{pp}$ (peak to

peak), you can stay with the given schematic and you have to use the above mentioned input capacitors, if the output voltage is not symmetrical (pure AC). See the above formula for dimensioning of C_{25}. Input resistor R_2 should be about 10 times the value of the specified inner resistance, mentioned in the datasheet as "output resistance" f.e.

> Some math:
>
> Datasheet says V_{out} is < 400mV$_{pp}$, while R_{out} is < 10kΩ =>
>
> $R_2 \geq 100$kΩ and according to the above formula $C_{25} = \dfrac{1}{2 * \pi * f_u * R_2}$ =>>
>
> $C_{25} = 1 / (2*PI*5*100.000)$ ➔ 318nF ➔ you can use 0,33µF or bigger.

> ➢ If the output voltage is bigger than 400mV$_{pp}$ but smaller than 2V$_{pp}$, you should use a BF245C and change R_3 to 3k9.

> ➢ If the output voltage is bigger than 2V$_{pp}$, you should use a BF245C and change R_3 to 3k9. Additionally you have to divide the output voltage of the DAC in a way to get about 2V$_{pp}$.

Possible and/or some needed mods in the gyrator circuit:

> ➢ VCC is around +12V:
>
> $R_8 = 10\Omega$; $R_9 = 10\Omega$; R_{11} = omitted; D_1 = omitted

> ➢ VCC is +15 … 20V:
>
> $R_8 = 10\Omega$; $R_9 = 2$k2; $R_{11} = 4$k7; D_1 = omitted

> ➢ VCC is +24V … 30V:
>
> $R_8 = 10\Omega$; $R_9 = 3$k9; R_{11} = omitted; D_1 = 12V-Zener (e.g. BZX55C12)

> ➢ VCC is bigger (e.g. +50V):
>
> $R_8 = 1$k5; $R_9 = 3$k9; R_{11} = omitted; D_1 = 12V-Zener (e.g. BZX55C12)

Some hints on mounting and wiring:

> ➢ Keep wires from DAC to the PCB as short as possible.

> ➢ Always look for the highest DC voltage inside your CD player. It is the best for VCC supply!

> ➢ The PCB is not subject to EMI/RFI catching (tested!) because of its proper copper ground-plane-design. Thus in fact try to keep it some inches away from mains transformers and digital chips. In serious cases, you had to insert the PCB into a shielding metal case.

> ➢ Only connect GND one (1) time to the remaining circuitry of the player. Try to find the best/quietest point for this connection. Use an AC mV-meter at the audio output to determine this connecting point!

If you use this circuit with solid-state amplifiers, capable of very high upper frequency limits (>500kHz -3dB), you should not use it without a radio frequency trap (AM-coil) in series with the audio output. <u>Tube power-amps are generally not critical.</u>

Caution: This circuit has no built-in trap for the residual radio frequency dirt of the D/A conversion, which could become almost as high as 50% of the maximum audio signal. It is designed and built along the ideas of Lukasz's "Lampizator". It could damage your valuable solid-state amps and tweeters!

Although I could not find this fact during my in-circuit tests, you had to be aware of it!

BF245 have a transition frequency of about 700MHz! The MOSFET lowers this particular value a lot, but in any case – be careful!

<u>You will not hear it first moment, but your amps and tweeters might burn after all!</u>

APPENDIX:

Design example for the TDA1541:

Datasheet values:		Your design values:
Current output(pin 6, 25):		
I_{out} (at pos. full scale)	-4mA	C_{25} = omitted; jumper
I_{out} (at dig. silence)	-2mA	R_2 = 100Ω (V_{in} = -200mV at dig. silence);
I_{out} (at neg. full scale)	0mA	output is designed for short circuit use!
		R_3 = 820Ω; Q_1 = BF245A

Design example for the PCM61:

Datasheet values:		Your design values:
Voltage output (pin 9):		
V_{out} (at full scale)	±3V	In the place of C_{25} => 10k (C_{25} omitted); R_2 = 2k2 (V_{in} = 1082mV$_{pp}$); R_3 = 3k9; Q_1 = BF245C
I_{out}	±2mA	Do not care!
Output impedance	0,1Ω	
Current output(pin 13):		
I_{out} (at full scale)	±1mA	C_{25} = omitted;
Output impedance	1,2kΩ	R_2 = 150Ω (V_{in} = 300mV$_{pp}$); output is designed for short circuit use! R_3 = 1k; Q_1 = BF245A

<u>For best audio results, you should always use the current output!</u>

Please also read the article about the **DAB** (Digital-Audio-Balun), which is also available from my website. You can find it in connection with the **NITRO**-project at the chapter on "Russian-Submin-tubes". This DAB-idea may also be used successfully in connection with this FETishizator circuitry, if any time-slice DAC-chip like PCM1798 or similar, will be used!