

## FYS4260 Project

### Operational Amplifier / Head Phone Amplifier

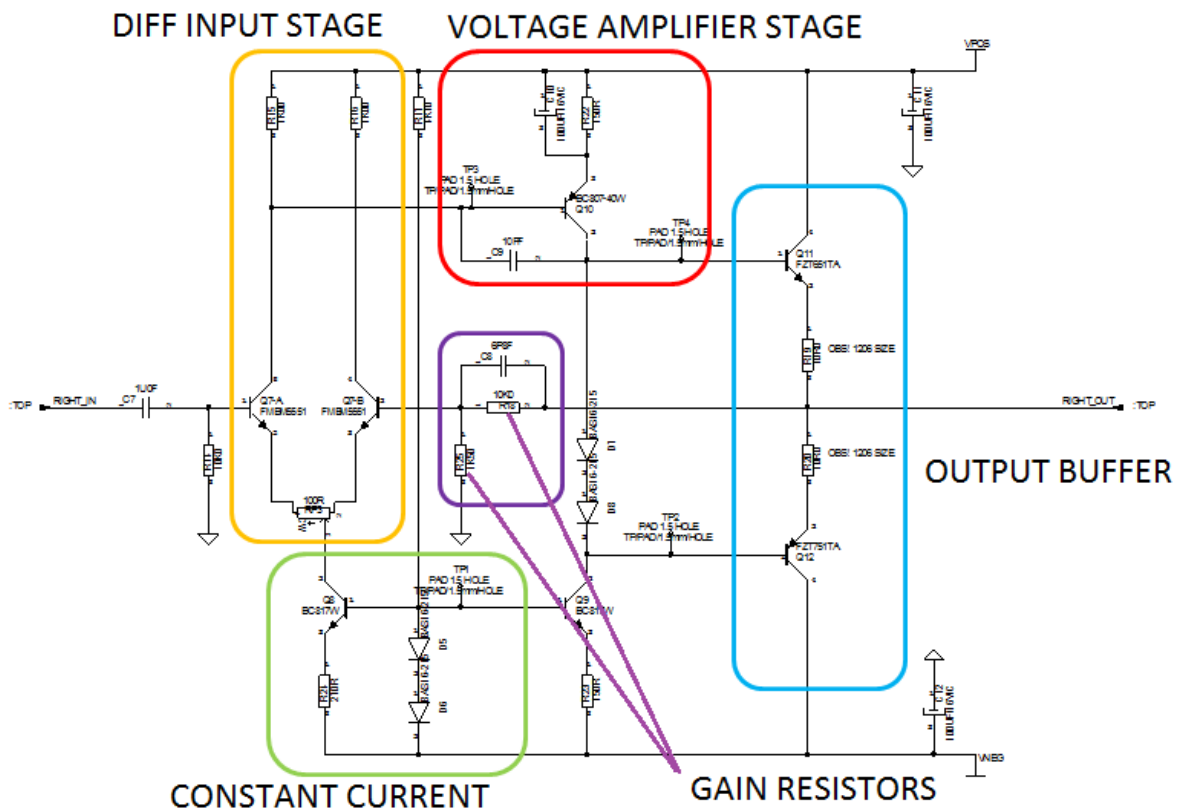
The design consist of a dual channel amplifier built with discrete components, and a switcher for selecting either a dual channel switching power supply or battery as power source.

#### Power

The switching power supply takes 5V in and converts to +12V and -12V, ~150mA each. A slider switch is added to select between this switcher and battery.

#### Amplifier circuit

Each channel in the circuit can be divided into a DiffAmp stage, a constant current stage, a voltage amplifier stage and an output buffer. A thorough description can be found in the printout from ELEKTOR magazine in the end of this document.



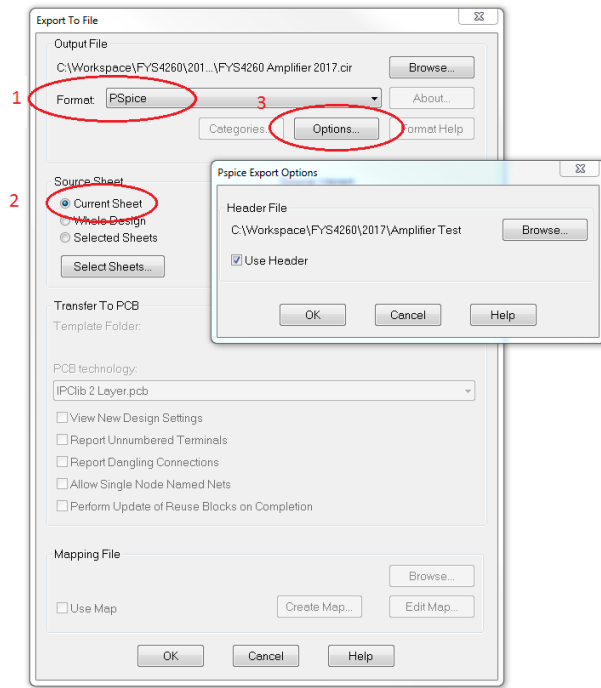
Your assignment will be the following:

- 1) Create a schematic drawing in CadSTAR based on the schematics in this document.
- 2) Select the power and audio connectors you want to use from the alternatives given in the schematics.
- 3) Do a SPICE simulation in either LTSpice or PSpice, see guide on this further down.
- 4) Create a layout.
- 5) Assemble one board at ELAB on assembly day
- 6) Test, verify, do repairs/modifications, and do a simple measurement to compare with your simulations.

## SPICE Simulations

### Export SPICE Netlist from CadSTAR

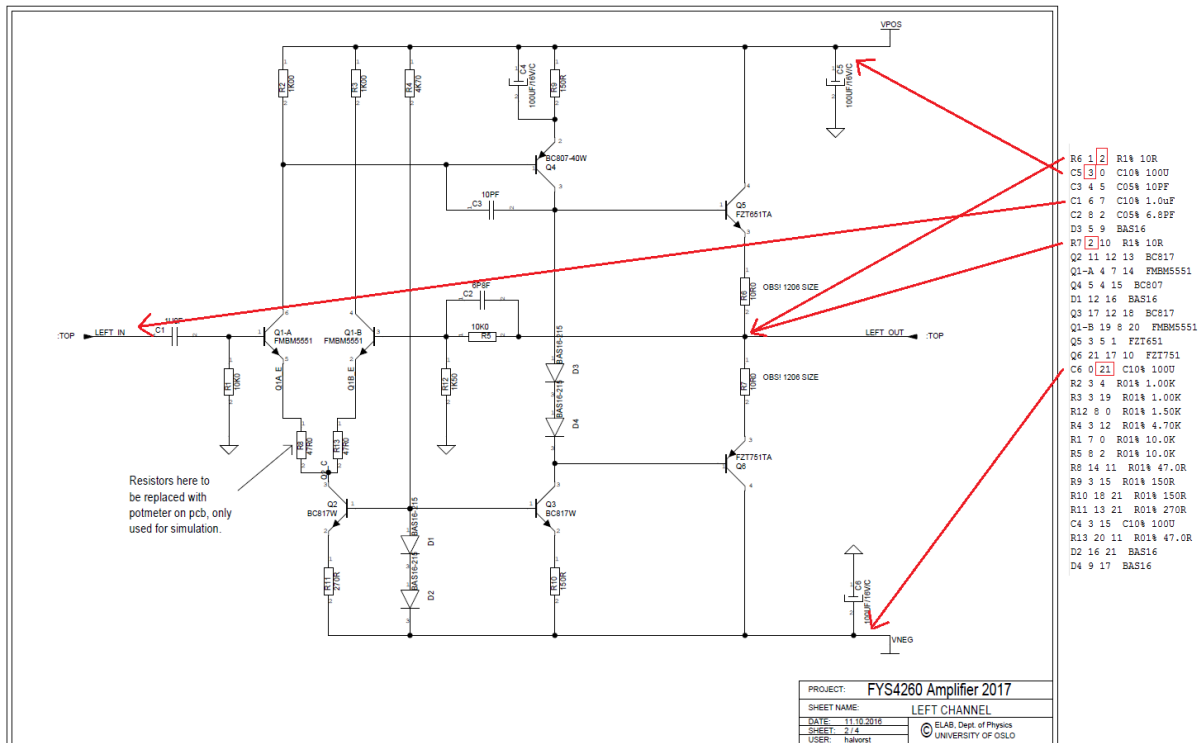
File -> File Export



1. Select Format PSpice
2. We only simulate on channel, make sure you have the correct sheet active or use “selected sheets”
3. Click options and select header file  
“FYS4260\_Amplifier\_Spice\_Header\_LTSpice.in” located in the project folder on FELT/ELAB/FYS4260
4. Click Browse and select name and destination folder for the exported netlist.

### Edit SPICE Netlist

The header file inserts the necessary generators and power supplies to successfully run the simulation, but we need to tell which nodes they are connected. Open the exported netlist in a text editor and located the Generators and Power Supply sections in the beginning of the netlist. From CadSTAR we now need to locate the names of the VPOS, VNEG, Vin and Vout nodes in the netlist, and replace the XX in the generated netlist with the correct node numbers. NOTE, the node numbers and component names are going to be different in your design, this is just an example!



VPOS Is f.ex. the positive node of the C5 capacitor (GND is always node 0 is SPICE). This tells us that VPOS is node 3 in this design.

VNEG Is the negative node of C6 -> Node 21. Replace XX in VNEG Power Supply with 21

Vin Is terminal 2 of C1 -> node 7

Vout is the common node of R6 and R7 -> node 2.

This gives

Vin 7 0 AC 1 SIN ( 0V 0.1V 1KHZ 0 0 0 )

VDC1 3 0 9V

VDC2 21 0 -9V

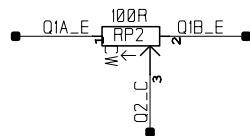
Rload 2 0 10R

Simulate in LTSpice

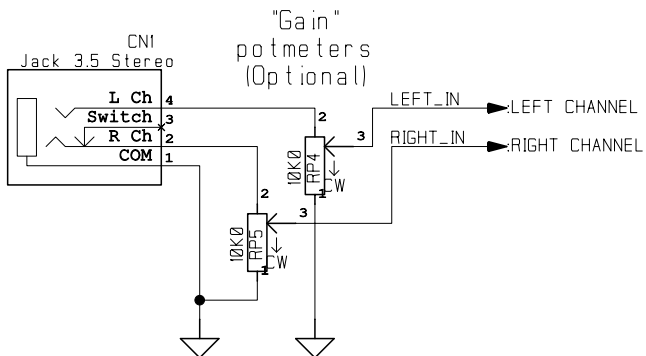
Open LTSpice, select File -> Open and locate your modified netlist. Run simulation, right click and select add trace. Add your Vout node. To see other simulations just comment out the AC Sweep.

To use PSPICE follow the same procedure, but use the \_PSIPCE header file when exporting from CadSTAR.

Potmeter to replace fixed resistors used only for simulation on left channel. Remove resistors from pcb.



3.5mm Jack or Phono connector for signal in.

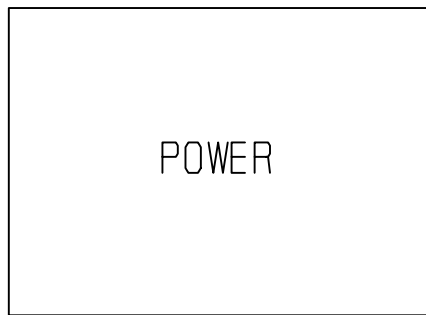
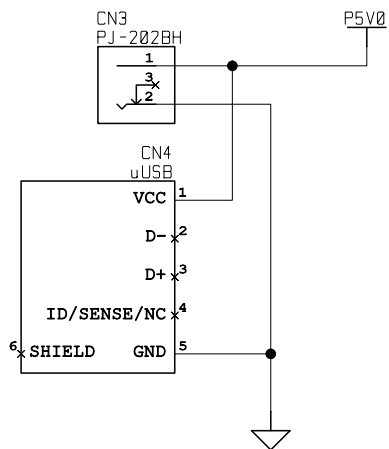


Left Channel  
(for simulation)



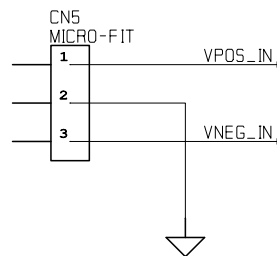
Right Channel

5V0 Input to Switcher Either USB or 2.1mm (Select one)

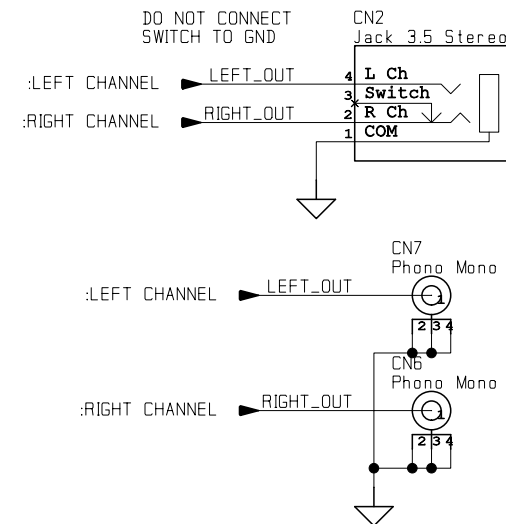


POWER

MicroFit Pinheader for battery



3.5mm Jack or Phono connector for signal out (Select one)



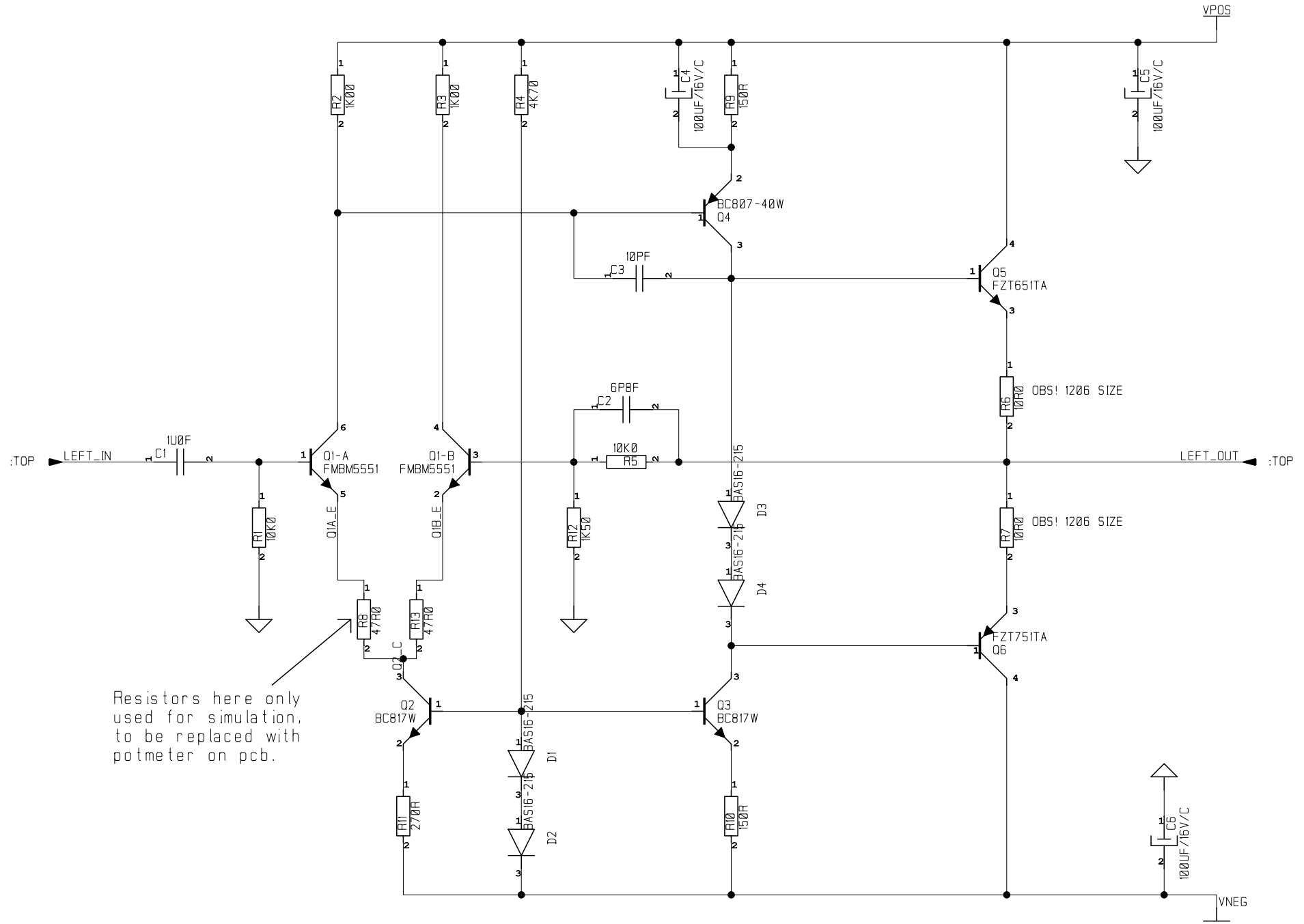
MountingHoles 3.2mm

Fiducial Marks

MH[1-2] MH/3.2mm

MARK[1-3] IDUCIAL MARK

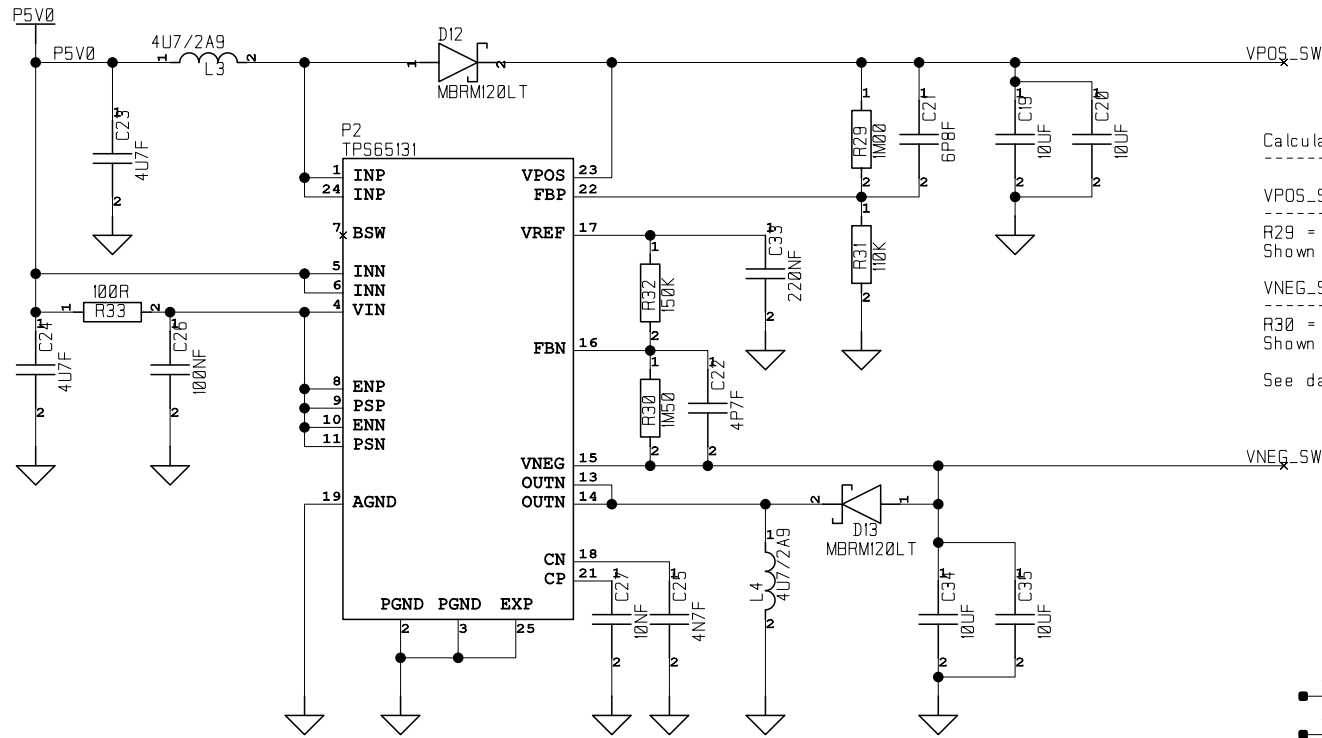
|                                 |  |
|---------------------------------|--|
| PROJECT: headphone amplifier v2 |  |
| SHEET NAME: TOP                 |  |
| DATE: 29.01.2018                | ELAB, Dept. of Physics<br>UNIVERSITY OF OSLO |
| SHEET: 1 / 4                    |  |
| USER: halvorst                  |  |



Resistors here only used for simulation, to be replaced with potentiometer on pcb.

|  |              |
|--|--------------|
| PROJECT: headphone amplifier v2              |              |
| SHEET NAME:                                  | LEFT CHANNEL |
| DATE:  | 29.01.2018   |
| SHEET:                                       | 2 / 4        |
| USER:  | halvorst     |
| ELAB, Dept. of Physics<br>UNIVERSITY OF OSLO |              |

# Switcher circuit 5V -> +/-12V

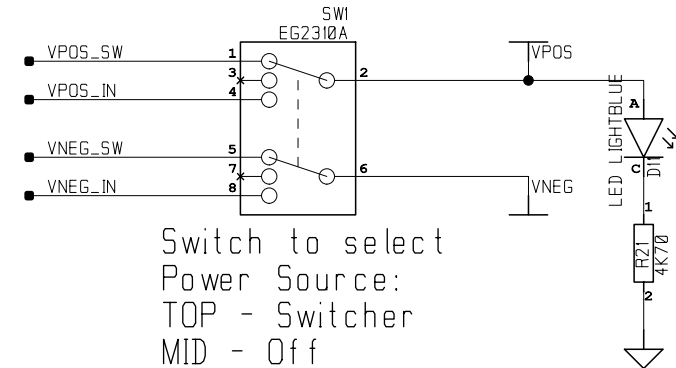


Calculate output voltage

VPOS\_SW  
 $R29 = R31 \times (VPOS\_SW/Vref) - 1$   
 Shown values gives approx VPOS\_Sw = 12.25V

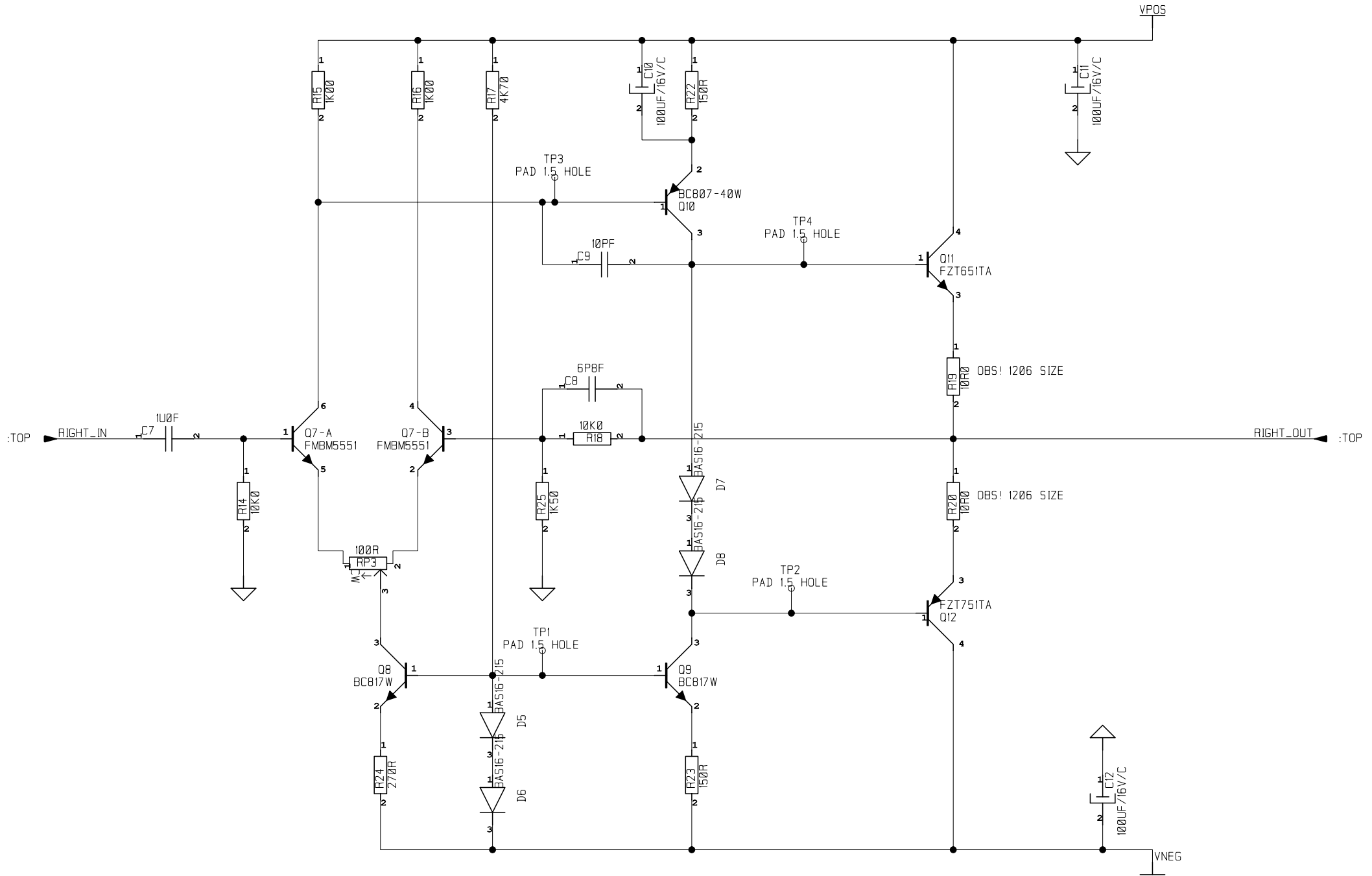
VNEG\_SW  
 $R30 = -R31 \times (VNEG\_SW/Vref)$   
 Shown values gives approx VNEG\_SW = -12.13V

See datasheet P 12-13 for details



Switch to select  
 Power Source:  
 TOP - Switcher  
 MID - Off  
 BOT - Direct

|                                 |  |
|---------------------------------|--|
| PROJECT: headphone amplifier v2 |  |
| SHEET NAME:                     | POWER  |
| DATE: 29.01.2018                | ELAB, Dept. of Physics<br>UNIVERSITY OF OSLO |
| SHEET: 3 / 4                    |  |
| USER: halvorst                  |  |



|             |                        |
|-------------|------------------------|
| PROJECT:    | headphone amplifier v2 |
| SHEET NAME: | RIGHT CHANNEL          |
| DATE:       | 29.01.2018             |
| SHEET:      | 4 / 4                  |
| USER:       | halvorst               |

ELAB, Dept. of Physics  
 UNIVERSITY OF OSLO

MINI PROJECT



By Stefan Dellemann (Germany)

There have of course been numerous designs for headphone amplifiers before this one, either more or less successful and simpler or more elaborate. The design presented in this article is straightforward, sounds quite good and can be built using well-established components.

### Specifications (output load: 33 $\Omega$ , supply voltage: $\pm 9$ V)

|   |  |
|---|--|
| • Input impedance (without P1)                    | 10 k $\Omega$                          |
| • Bandwidth                                       | 3.4 Hz – 2.4 MHz                       |
| • THD + Noise (1 kHz, 1 mW/33 $\Omega$ )          | 0.005 % (B = 22 kHz)                   |
| • THD + Noise (20 Hz - 20 kHz, 1 mW/33 $\Omega$ ) | 0.01 % (B = 80 kHz)                    |
| • Signal to noise ratio (ref. 1 mW/33 $\Omega$ )  | 89 dB (B = 22 kHz)<br>92 dBA           |
| • Max. voltage (into 33 $\Omega$ )                | 3.3 V (THD+N = 0.1 %)                  |
| • Max. input voltage                              | 0.57 V (with P1 set to maximum volume) |
| • Current consumption                             | 19 mA                                  |

These days it's not that easy to find a separate headphone amplifier in the shops. They do exist, especially in the hi-fi world, but they come with a matching price tag. The design presented here comes in a bit below these high-end circuits, but can be built using easily obtainable components and still manages to have quite a good sound quality.

### The circuit

The circuit could be described as a type of power-amp, built with discrete components (see Figure 1). At the input we find a volume control (P1, which is connected via a header) and a coupling capacitor (C1), followed by a differential amplifier (T1, T2) with a constant current source (T3) in the

emitter branch. The preset between T1 and T2 (P2) is used to set the symmetry, or in other words, the output voltage is set to 0 volt DC compared to ground. For the best sound quality we should have the same collector current flowing through both transistors. This can be seen from voltages at test points F and G in the circuit diagram, which are nearly equal. The input offset across R1 is caused by the base current flowing into T1. This causes the voltage at point A ( $V_A$ ) to be slightly negative. A quick measurement of the prototype showed that the base current into T1 was about 3  $\mu$ A. Without the offset compensation provided by trimpot P2 the output offset voltage  $V_O$  would exceed 0.2 V:

$$V_O = (1 + R_6/R_5) \times V_A$$
$$V_O = (1 + 10/1.5) \times 0.028 = 0.215 \text{ V}$$

The offset can therefore be removed by setting the differential amplifier to operate



slightly asymmetrically. Although this isn't the best method as far as the sound quality is concerned, it does keep the circuit much simpler.

**Constant current settings**

The current source in the emitter branch (T3) is set to about 3 mA with diodes D1, D2 and resistor R4, which results in T4 being driven as linearly as possible.

The audio signal then makes its way to the driver stage, T4, which drives the more powerful output transistors (T6 and T7). C4 has been added to provide a greater internal gain. The quiescent current in the output stage is set to about 5 mA with T5 and R9. Assuming a gain ( $h_{FE}$ ) of 50 in the output transistors, this 5 mA could theoretically provide a linear  $0.005 A \times 50 \times 32 \Omega = 8 V_{peak}$  into  $32 \Omega$ . However, some limitations are introduced by constant current source T5 and the voltage drop across the base-emitter junction of T7 (about 1.5 V). We should also take account of the voltage divider around R11 and R12 (R10 and R12) in the calculations. The maximum voltage  $V_{max}$  across the load ( $R_L$ ) then becomes

$$V_{max} = R_L / (R_L + R11 + R12) \times (9 - 1.5)$$

$$V_{max} = 4.6 V_{peak}$$

This corresponds to about  $3.26 V_{rms}$ , which is what we measured, as you can see in the specifications. This means that the circuit can deliver  $(3.26^2/32) = 330 mW$  into  $32 \Omega$ , which should be enough to keep most pop and rock fans happy.

Resistor R12, which follows the output stage, limits the output current and keeps the circuit stable when a capacitive load is connected, such as a long shielded cable to the headphones. This prevents the output transistors from overheating when there is a short circuit. R10 and R11 keep things symmetric. Despite the value of C2 in the feedback circuit, the bandwidth is still much greater than the audio bandwidth (see the specifications). To obtain a low corner frequency at the input we used  $4.7 \mu F$  for C1. A capacitor of  $2.2 \mu F$  (which is easier to obtain) still results in an acceptable corner frequency of 7 Hz (-0.6 dB at 20 Hz).

The measurements from one of our prototypes are shown in the circuit diagram. These should be seen as guideline values

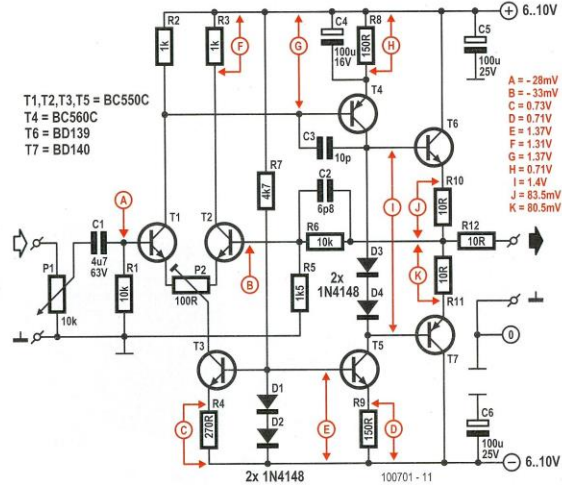


Figure 1. The circuit for the simple headphone amplifier uses easy to get components (one channel shown).

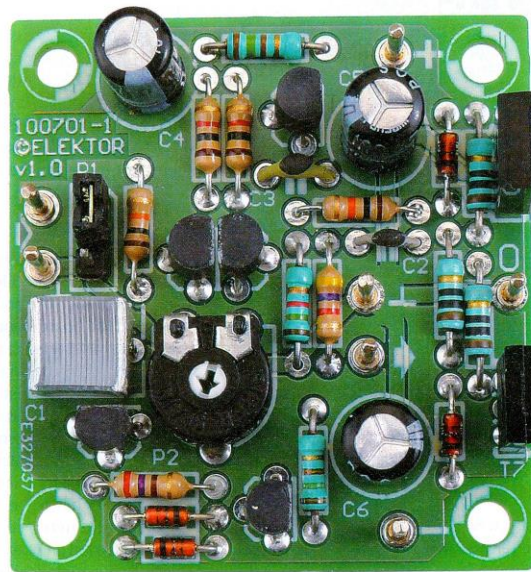


Figure 2. The completed circuit is still compact despite the lack of SMDs.

## COMPONENT LIST

## Resistors

R1,R6 = 10k $\Omega$   
 R2,R3 = 1k $\Omega$   
 R4 = 270 $\Omega$   
 R5 = 1.5k $\Omega$   
 R7 = 4.7k $\Omega$   
 R8,R9 = 150 $\Omega$   
 R10,R11,R12 = 10 $\Omega$   
 P1 = 10k $\Omega$   
 P2 = 100 $\Omega$  trimpot

## Capacitors

C1 = 4.7 $\mu$ F, lead pitch 5mm or 7.5mm  
 C2 = 6.8pF, lead pitch 5mm  
 C3 = 10pF, lead pitch 5mm  
 C4,C5,C6 = 100 $\mu$ F 16V radial

## Semiconductors

D1,D2,D3,D4 = 1N4148  
 T1,T2,T3,T5 = BC550C  
 T4 = BC560C  
 T6 = BD139  
 T7 = BD140

## Miscellaneous

Connection for P1 = 3-pin pinheader, lead pitch 0.1"  
 Connection for P2 = 3-way socket strip, lead pitch 0.1"  
 7 pcs 1.3mm diam. solder pin  
 PCB # 100701, see [1].

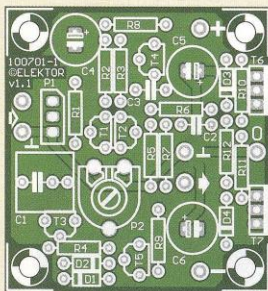


Figure 3. The component layout for the no-frills headphone amplifier.

rather than as exact requirements. The PN junctions and the gain of the transistors can of course vary depending on the manufacturer (this also applies to the current consumption given in the specifications).

## Experimenting

For those of you who don't mind a little bit more noise (although it will still be inaudible with most headphones), you can increase the impedance of the feedback loop to about 10 k $\Omega$ . This can be achieved by increasing R5 and R6 in the parallel cir-

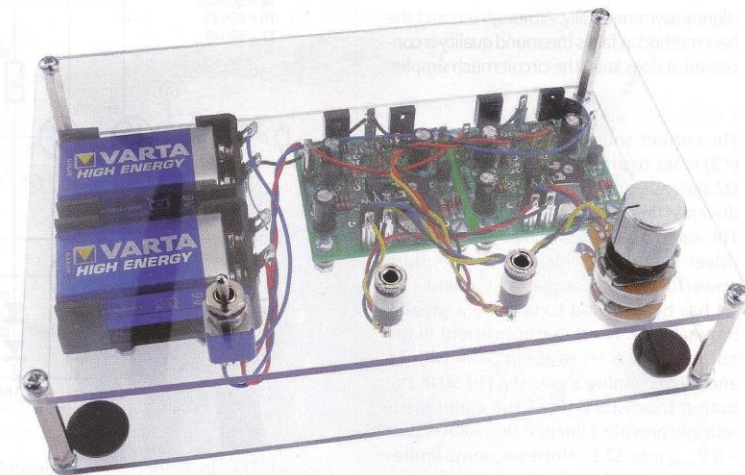


Figure 4. The circuit has a distinctive appearance when it's built into a ProjectCase.

cuit to 10 k $\Omega$ . In this case the base currents of T1 and T2 will compensate each other. If you like experimenting you can replace R5 with a resistor of 12 k $\Omega$  and R6 with a resistor of 68 k $\Omega$  (perfectionists should use 11.5 k $\Omega$  and 76.8 k $\Omega$  from the E96 series). It is unlikely that this offers an audible improvement, but there may be a smaller offset this way.

## Construction

A small printed circuit board has been designed for this circuit (see Figure 2), which can be ordered via [1]. From here you can also download the board layout in PDF format. The component layout is shown in Figure 3. As usual, construction is easiest if you start soldering the lowest components (resistors, diodes) and then continue mounting increasingly higher components (capacitors, transistors, connection pins). You will need two boards for a stereo version, in which case P1 has to be replaced with a stereo potentiometer, so that the volume can be controlled on both channels simultaneously. If your audio source already includes a volume control, you can leave out P1 (put a jumper on the header or solder a wire link on the board from pin 1 and pin 2

of the header instead of the actual header). The input impedance of our suggested circuit (which includes P1) has a minimum of 5 k $\Omega$  (P1 set to maximum volume). This shouldn't be a problem for most modern audio sources. Take note of the pin spacing of decoupling capacitor C1; the board accommodates 5 mm and 7.5 mm versions. For the power supply you could use two 9V batteries. Alternatively, a 2x6 V, 5 VA transformer with a 1.5 A bridge rectifier and 8200  $\mu$ F/16 V per supply rail is another option. This could optionally be supplemented with a pair of voltage regulators. The output transistors (T6 en T7) probably don't need heatsinks in practice, although a small heatsink will make sure that they will be short circuit proof.

We decided to build this circuit into an Elektor ProjectCase [2]. This is very easy to do and it gives it a distinctive look and a good view of the electronics (see Figure 4). (100701)

## Internet Links

- [1] [www.elektor.com/100701](http://www.elektor.com/100701)  
 [2] [www.elektor.com/100500](http://www.elektor.com/100500)