AEM600 Lateral MOS-FET Power Audio Amplifier

This amplifier design is based on the famous AEM5000 Audio, designed by David Tilbrook back in January 1981. This series of amplifiers was built around new (at the time) Hitachi lateral power MOSFETs. Most amplifiers at the time (and now as well) used bipolar output drivers. Bipolar transistors are cheap and plentiful. But they have relatively high transconductance, and can operate reasonably fast. However they have some drawbacks when used at high power. The main one is thermal runaway. The gain of a bipolar transistor increases as it gets hotter. That means that if there's any imbalance between output transistors, the hottest one will pass most of the current, getting hotter until it ultimately fail. MOSFETs don't have this problem. Their gain decreases with temperature, so they share the load well. Most power MOS-FET's (VMOS, trench-FET's, Hex-FET's, etc) use a vertical structure, where the current flows vertically. This has the advantage of a very low R_{ds} and hence high efficiency, but poor linearity or capacitance. Lateral MOS-FET's are a much simpler structure, where the gate oxide is formed on a flat substrate, and the current flows across the substrate. This results in well defined, controllable device parameters, good linearity, and relatively low gate capacitance. However, the R_{ds} of lateral MOSFETs has larger values than the vertical ones. MOSFETs also have a high input impedance at low frequencies, and are capable (when driven by a suitable source) of extremely high slew-rates. Of course this very attribute makes them rather prone to HF oscillation when improperly compensated, but with careful design they're capable of impressive performances.

Figure1: Complete assembled AEM6000 Audio Amplifier and mounted on the heatsink.

Amplifier Specifications:

- Continuous Output Power: 100W at 8Ω load impedance or 200W at 4Ω load impedance.
- Maximum Output Power with TDH values below 0.1% is 126W at 8Ω or 247W at 4Ω.
- Very low THD values, of 0.001% from 0.01W to over 100W.
- Very wide frequency response, from 10Hz up to 1MHz.
- Better than 0.1dB linearity from 10Hz to 24KHz and 3dB from 5Hz to 160KHz.
- Very Good S/N Ratio, of at least 116dB with an output noise of maximum 50uV.
- No Output Feedback Class AB Audio Amplifier offer very good linearity.
- Completely assembled PCB and on request, mounted directly onto the heat sink.
- Power supply filtering capacitors are added on-board for better performances and space saving.
- Power supply requirements: +- 54V for an output Power level of 100W at 8Ω.

The schematic of this amplifier is based on the famous AEM5000 Audio, designed by David Tilbrook back in January 1981. However, since the original design was made almost 30 years ago, it was using components available at that time, and which were just new released. In the meantime, there was a huge progress in the semiconductors industry and many new parts were released, with much better parameters than the original ones used in the first design. This allows to improve the original design and add even more performance that it hat at that time.

First update was made with the input stage, where linearity and extremely low noise was a very important issue. Instead of the original transistors, ECG461, SST404 differential input J-FET Amp was chosen. The SST404 series of high-performance monolithic dual JFETs features extremely low noise, tight offset voltage and low drift over temperature specifications, and is targeted for use in a wide range of precision instrumentation applications. This series has a wide selection of offset and drift specifications with the SST404 featuring a 5-mV offset and 10 μV/°C drift.

Next parts which were replaced are the MMBTA06 and MMBTA56 low power Bipolar Transistors, in SOT23 Case. The original was BC547 and BC557.

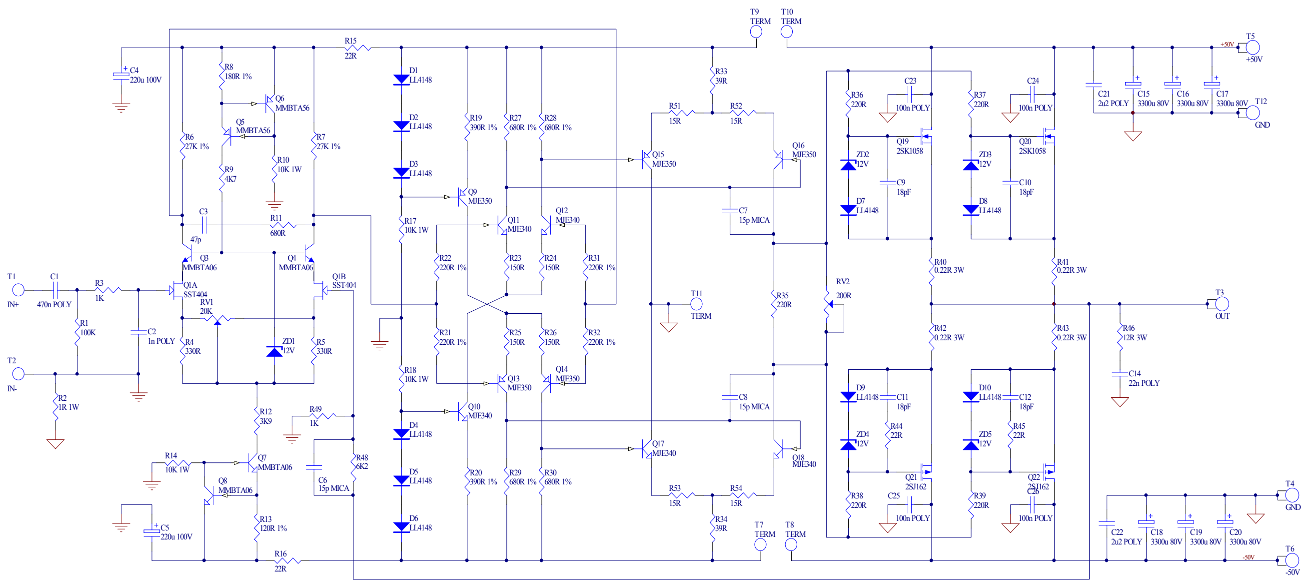

Figure 2: AEM6000 Audio Amplifier Schematic Diagram

Next replaced parts were the Power MOS-FET Transistors, instead of 2SK176 and 2SJ56 it uses the newer ones, 2SK1058 and 2SJ162, in insulated TO-3P case, which allows more easy installing and insulation on the heat sink. They also have better parameters than the original ones, and this contribute to the increased amplifier overall performance.

Besides the improvements which were brought by updating some parts, others were made by adding few more components and by designing a tight and balanced Printed Circuit Board, which allows the amplifier to operate with high performances with a very wide frequency response and without any risk of instability or degrading performances. For this reason, large electrolytic capacitors were added on each supply rail, mounted on board, close to the power MOS-FET transistors. In addition to this, some high quality mica capacitors and polystyrene capacitors were added as bypass for the electrolytic capacitors and on the Power Transistors Gates. Using this capacitors ensure minimal distortion creeps in through capacitor nonlinearities. The PCB Layout has a major contribution to the overall performance, minimizing the Ground Loops and making the High Current carry tracks as short as possible and as wide as possible. Wherever was enough space, copper pour was used. Also the thickness of the copper foil on the PCB is 3 Oz thick, which is 3 times the normal thickness, of just one Oz used on most of the PCB's. To help designing the schematic for this amplifier, an important contribution was brought by Linear Technology's SPICE Simulator, which is a powerful tool in design and analysis of the electronic circuits behavior. Using this tool, allows to chose and simulate various components and values for them, so the result can be improved.

One very important aspect which have to be considered is the **thermal design**. A class AB Power Audio Amplifier has maximum theoretical Efficiency of about 70%. This value is almost impossible to achieve in practice with good THD values and linearity. So, a compromise should be made, in favor of the sound quality. This will lead to a lower electrical efficiency, especially at low Output Power. The main reason for lower efficiency is the idle current and losses which occur in the signal and driving stages of the amplifier. The maximum dissipated power, will occur at High Output Power Levels, when the amplifier drives low impedance loads with high signal amplitude. It was calculated that with +/-56V supplies, worst case dissipation occurs at 150W into 4Ω load Impedance, of 155W. Most of this dissipated power is dissipated by the output transistors, which share equally the dissipated power. However, audio signal power spectrum is much poorer than the pure sine wave signal, usually just ⅛ of the power of the pure sine wave and with peaks of ⅓ of the pure sine wave. In order to remove the heat generated by this power dissipation, an external heat sink with thermal resistance of maximum 0.5 ˚C/W is required. A good choice is an extruded aluminum heat sink profile with vertical fins and with the size of at least 160x100x40mm, or horizontal fins option, if is intended to be mounted inside amplifier housing and use forced air cooling. Test results proved that the maximum temperature rise of the heat sink when the amplifier is used to play moderate volume of music on 8Ω load impedance is maximum 36˚C. This means that on an ambient temperature of 20˚C the heat sink temperature will be 56˚C. For higher power levels or 4Ω load impedance, forced air cooling may be required, to maintain the heat sink temperature under 85˚C

To be able to take advantage of the full performances of this amplifier, the short-circuit and over-current protection was not included. The reason is because this may trip at the peak levels of the sound, and also can introduce distortions. In fact, most of the High-End audio amplifiers doesn't have the over-current and short-circuit protection included onto the amplifier board, but it has on an external board dedicated for this purpose. When using this amplifier, special care should be taken to not overload the amplifier with very low load impedances, the minimum load impedance should be 4Ω, but is preferable to use 8Ω load impedance, since the amplifier will have the best performances .

Installation Guide:

To set-up and run this amplifier, need to follow some basic steps. First the amplifier module need to be installed into a case, preferable on the side of the case with each heat sink exposed for natural convection cooling. Note that should avoid covering the top and bottom of the heat sink fins, by the case cover or by stacking the amplifier in an audio system. In some cases, if the amplifier is used to play high level of audio signal for long time, the heat sink may get very hot, too hot to be touched. In this case, forced air cooling may be an option, using a small DC Brushless Fan, like those used on the computer power supply.

Next step is wiring the amplifier to the power supply, signal source, and output to the protection board and loudspeakers output. First of all, need to use a rectified and well filtered Linear DC Power Supply. A good choice can be either **Power Supply 6x10000uF at 63V** or **Power Supply 6x15000uF at 63V** or even **Power Supply 6x18000uF at 71V**. All this Linear Power Supplies are available for purchasing on the www.connexelectronic.com. The Linear DC Power Supply should be powered from a mains transformer, preferable Thoroidal type, since this type of transformers have improved performances for Audio Amplifiers. The size and power rating of this transformer depends on the required Output Power Lever. For 100W at 8Ω load impedance the transformer should have at least 360VA Power rating and have two identical windings of 40V AC at 5 A. After rectification and filtering this will be +- 54V DC. If the amplifier is intended to be used on 4Ω load impedances, the Power rating of the transformer should be double. Using two identical transformers instead of one, one for each channel, is a good choice, will enable better performances and a better channels separation. An alternative to the linear supply is to use a **SMPS** (Switched Mode Power Supply). The main advantage is that the SMPS is more compact and lightweight compared with classical linear supply and have load and line regulation. Some of them, those who have active PFC will allow universal mains input voltage as well, which is good to take into account when the amplifier is used in various places, with different mains voltages available. Few models of SMPS are available on the www.connexelectronic.com website.

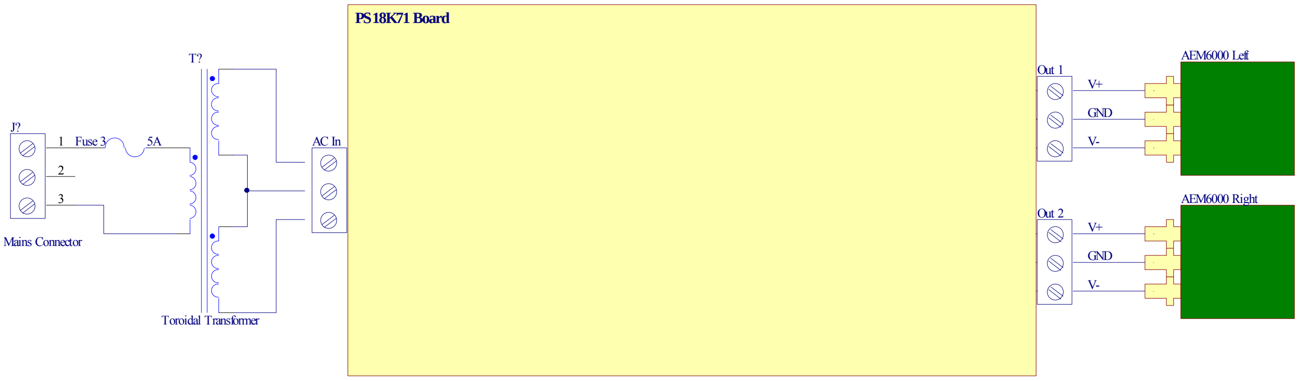

Figure 3: AEM6000 Audio Amplifier Linear Supply Connection Diagram

The input signal path should pass thru a volume potentiometer, to be able to adjust the output power, and volume to the desired value. The signal cables and connectors should be very good quality, shielded, and with shield connected to Signal GND in a single point, avoiding Ground loops which will drastically decrease performances, increase noise, and make the amplifier unstable. The input signal cables should be very short, and routed far from the mains transformer or the output section or wires to avoid interferences which will lead to noise and instability.

The output signal from the Power Amplifier Module should be routed thru a speaker protection board who has the role to delay the amplifier connection to the loudspeaker to prevent the click and pop noise when power ON or OFF the amplifier, and to protect the loudspeakers in case of amplifier malfunction when DC component may be present on the amplifier output. To use the **Speaker Protection Circuit**, just connect the outputs of the amplifier to the inputs of the Speaker Protection Circuit for both Left and Right Channels. The Speaker Protection Circuit requires an auxiliary voltage to be provided from a winding of the mains transformer, the value of this voltage should be between 9V AC to 12V AC. For higher voltage values, some components from the Speaker Protection Circuit board need to be replaced. The schematic of the Speaker Protection Circuit can be seen in the Figure 4.

Another useful module for the amplifier will be Power Soft Start Circuit, which will allow the slow start the mains transformer until the Filtering Capacitors are charged and also remote control the amplifier startup. For more information about the Power Soft Start Circuit, please visit the product page at www.connexelectronic.com.

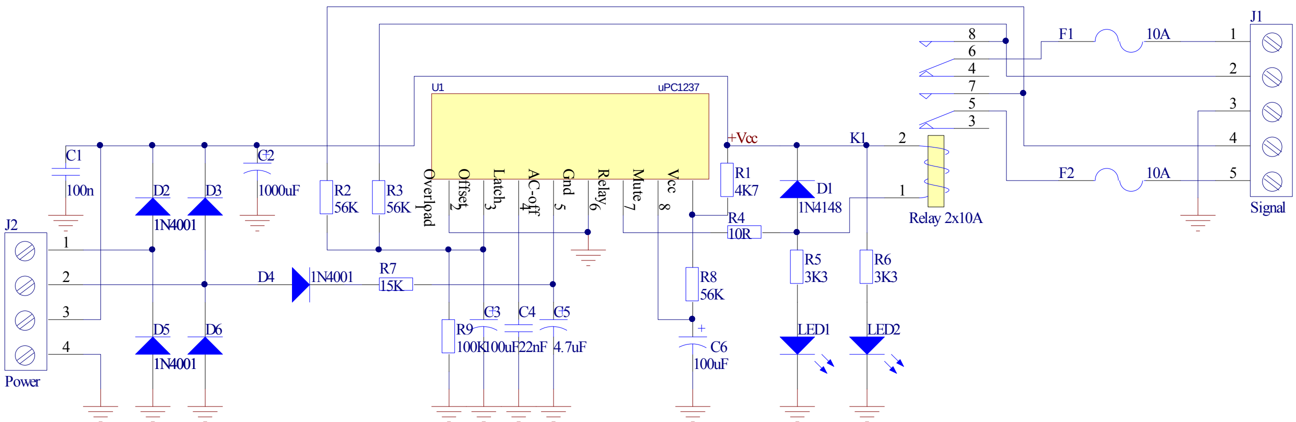

Figure 4: Speaker Protection Circuit Schematic.

For more information about the AEM6000 Audio Amplifier, do not hesitate to contact me thru www.connexelectronic.com website.

Disclaimer:

The AEM6000 Audio Amplifier Module shall be used according with the instructions provided in this document. The user should NOT attempt to modify or change any of the parameters of this product, which can lead to malfunction. The manufacturer of the product, **PCBstuff**, and the official distributor, **Connexelectronic**, will not be liable for any kind of loss or damage, including but not limited to incidental or consequential damages. Due to the high level of voltages on this board, the user should take all the caution measures needed when working with high voltage levels, should not touch any unisolated part of the board or connectors, or short-circuit any part of the board or connectors. Any misusage will be made on user responsibility.

The manufacturer **PCBstuff** reserve the right to make changes or modifications on both the product functions and performances without notice. The AEM6000 Audio Amplifier Module schematic and PCB design is based on a freeware project which is public on the internet.