You Can DIY!

The TERESA Amplifier

TERESA is an acronym for the manufacturers Texas Instruments (TE) and Renesas (RESA) because these companies provided the parts for the core of this amplifier. In this article, I used the latest Audio-MOSFETs from Renesas and a relatively new high-end drive component from National Semiconductor (now part of Texas Instruments). The result is worth seeing and hearing! This simple and cascadable Class-AB design with professional audio qualities does not require any special experience in detailed analog circuit technology to build.

Photo 1: The TERESA amplifier is a simple and cascadable Class-AB design.

By
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The initial idea for this amplifier came from my own wish, as an engineer, to build an amplifier at least once in my life. But if you have spent all your working life in the world of microcontrollers and their programming, you are no better prepared for such an adventure than any other analog layman. In total, I spent about two years researching, building, and improving my TERESA amplifier (see **Photo 1**).

For my first attempt, I used classic Hitachi MOSFETs—the 2SK1058 (N-Channel) and the 2SJ162 (P-Channel). I also used a National Semiconductor (now Texas Instruments) LM4702 high-end stereo drive part. This worked quite well. You can find the circuit in the examplary application notes for the LM4702 (AN1490, AN1645). Jack Walton's article "High-End 120-W MOSFET IC Driven Amp," (*audioXpress,* July 2007) also provides information on the LM4702 (see Resources).

During my second attempt, I used techniques that I learned from the first build, coupled with my natural curiosity. Apparently, no one has combined Renasas's relatively unknown audio MOSFETs 2SK2221/2SJ352 with Texas Instruments's LME49811 premium mono drive part (see **Figure 1**). I also found that the oscillation tendencies often attributed to MOSFET amplifiers seem significantly less with this combination. If you are fond of loud music, I should mention that the new driver part delivers about double the gate drive power to the MOSFET output stage (per channel). This is less important for an amplifier with one or two pairs of output MOSFETs but if you use three or more pairs, you have enough gate drive power to easily exceed 500-W output power.

The new MOSFETs can also deliver slightly higher output currents of 8 A vs. 7 A for the previous types. However, TERESA's quality should not suffer from the power specifications. The LME49811, with its 0.00035% distortion specification, is well suited for this application and will help the amplifier reach professional audio quality (i.e., the amplifier's relevant parameters). High-quality connectors, capacitors, trimmers, resistors, and wiring also make this a successful project. Several output pairs can be cascaded. The choice depends on the amplifier's expected use.

The basic amplifier with a single output pair configuration will have about 10-to-15-W idle dissipation, and can, with ±50 V supplies, deliver about 200-W sine wave power in 8 Ω (see **Photo 2**).

The goal is to produce an affordable high-quality project with the simplest possible design. With only a few exceptions, all the resistors are 1%, 0.25-W metal film types. In a few places, silver-mica capacitors have been used. These have good properties for

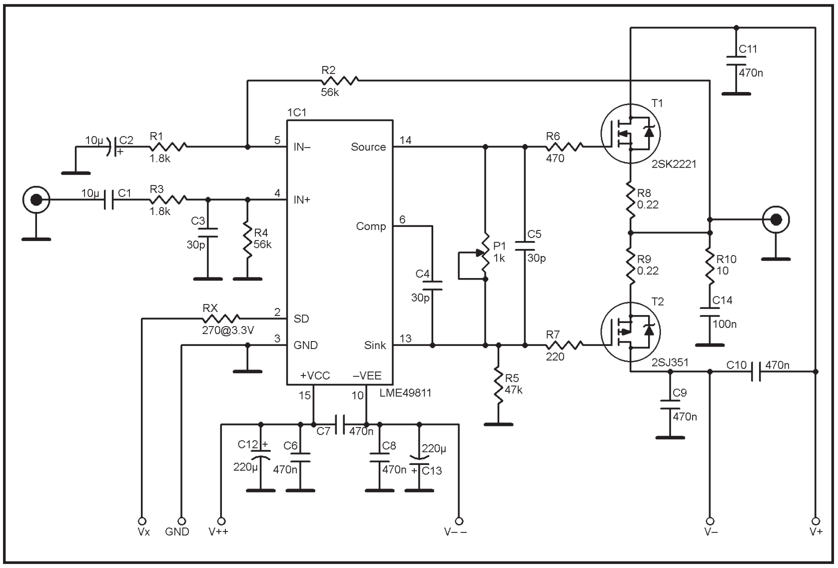

Figure 1: This design combines Renasas's 2SK2221/2SJ352 MOSFETs with Texas Instruments's LME49811 premium mono drive part.

audio applications. All the silver-mica capacitors are 30 pF, which will make sourcing easier. Also, all the capacitors on the LME49811 should be placed as close as possible to the IC pins.

The Concept

Using a coupling capacitor for the input signal to the LME49811 (C1) is safe, but it might also slightly lower the performance. However, in protecting the input from DC, such a capacitor significantly improves reliability. This capacitor could be left out if you are sure the source provides a DC-free signal. But, if you have to use one, it should be high quality. I decided to use a 10-µF upper-mid-class Mundorf capacitor. These capacitors are specially manufactured for crossover filter and coupling capacitor applications.

In the process, I learned a lot about capacitors. For example, they must be "broken in" to reach and maintain their full sound spectrum. So, use two identical capacitors for the two amplifier channels in a stereo setup.

The principle of the TERESA amplifier is simple and easy to understand. If necessary, the input signal can be attenuated with a high-quality volume control-type potentiometer. The signal is routed to the LME49811 +IN (noninverting) input via the coupling capacitor C1 and the resistor R3. The feedback is connected from the output via R2 to the –IN (inverting) input. The gain is calculated with the equation N = R2/R1. This value should be adapted to the expected input signal level and the power supply voltage to avoid clipping. For this amplifier, the gain should be between 20 and 35. Resistors R3 and R4 should be similarly dimensioned.

The LME49811 drives the gates of the MOSFETs, configured as source followers, from its SINK- and SOURCE- outputs, through gate stopper resistors. Any unsymmetries in the MOSFETs of a single pair will be compensated for by the feedback. Therefore, it is not necessary to match them. An RC-snubber is used at the output to suppress high-frequency signals. For bandwidth measurements, this snubber should be temporarily disconnected because the resistor can become very hot with prolonged high-frequency high-level measurements.

Power Supply and Power Supply Voltages

The ground (GND) connection should be wired to a star point with large-gauge wire (see **Photo 3**). The power supply's dimensioning can vary with the specific application. I recommend using a panel-mounted mains entry block consisting of a DP switch, a fuse holder, and a mains filter. This immediately solves several mechanical and electrical problems. The toroid mains transformer (which has less electromagnetic stray field) ideally should have extended secondary windings. In my amplifier, it is a 280 VA, 2 × 38 V and 2 × 43 V. You can find these and similar reasonably priced transformers on the Internet.

There are four main voltages, V+, V–, V++ and V–– (see **Figure 2**). Voltages V++ and V–– are for LME49811's symmetrical supply. They should be about 10 V above V+ and V– for the output MOSFETs. Otherwise, you lose 10-V output level because the MOSFET gates need to be driven 10 V above their source voltage. Voltages V–– and V++ should, according to the LME49811's specifications, range between 20 and 100 V. The MOSFET supply voltages V– and V+ should be 10 V less than that. This is a relatively large range that can be set to personal preference or a specific application. For V++ and V––, I recommend a reservoir capacitor of approximately 10,000 µF. For V+ and V–, I recommend a reservoir capacitor of approximately 30,000 to 40,000 µF. The LME49811 suppresses voltage variations on the supply lines rather well (see **Photo 4**). Therefore,

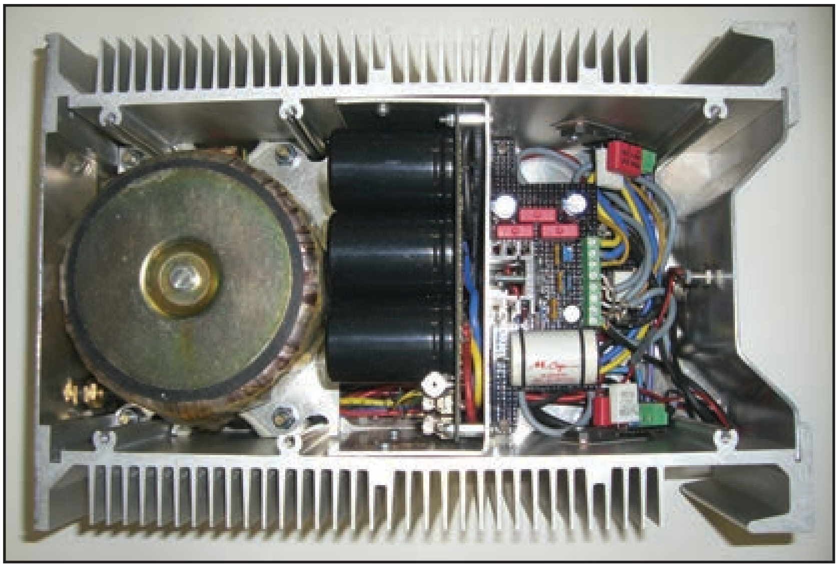

Photo 2: The completed amplifier is shown prior to buttoning up the enclosure.

Photo 3: The TERESA amplifier can drive three pairs of transistors.

you could connect V– to V–– and V+ to V++ if that would make your power supply simpler (but it would have a lower maximum output level).

Anti-Plop Provision

I have put an extra diode (D3) after the rectifier for the V+ voltage to create a fast decaying voltage. This feeds a low-value reservoir capacitor (C17) and is limited with a Zener diode. This Zener diode is only required if the voltage will be above 50 V because the following regulator (IC2) can accept input levels up to 50 V. To ensure the Zener diode correctly operates and the reservoir capacitor discharges relatively quickly, a discharge load is required. The discharge load is usefully combined with the Power-ON LED. About 5 to 10 mA will be sufficient here.

For the regulator, I have selected an S-1142B33 from Seiko Instruments, which can withstand a 50 V_{IN}, and delivers 3.3 V at up to 200 mA. This regulator has a Schmitt-trigger ON/OFF input (we need the –B part here, which has a positive going ON/OFF switching logic). A simple trimmer at this input provides a well-defined regulator switch-off point after the mains has been switched off. The regulator's output is connected through a carefully dimensioned resistor to the LME49811's shutdown-input. So, the whole amplifier is cleanly switched on or off through the regulator ON/OFF input voltage, with no switching pops or crackling (see **Photo 5**). It is simple and effective!

Important note: The LME49811 SD-input is quite sensitive and can, when overdriven, damage the chip. It is important to limit the current flowing into this input to between 1 and 2 mA. The SD signal should also have a reasonable rise time and not change levels too slowly. The combinations for the supply voltages, the input currents, and the LME49811's operational status are shown in **Figure 3**.

You can calculate the required series resistor or determine it through trial and error. Keep the input current as close as possible to 1.5 mA. The equation for this is: R_{SERIES} = (input voltage – 2.9 V)/1.5 mA. However, when you work with changing voltage levels during the test phase or when you're not sure what the input voltage will be exactly, the circuit and values shown in **Figure 1** and **Figure 2** will provide fail-safe operation.

Bias Adjustment

With this driver part, the bias generation is really simple. It consists of a single trimmer potentiometer between the LME49811's SINK and SOURCE pins, which is shown as P1 in **Figure 1**. Normally, you would use a VBE-multiplier circuit to generate the bias voltage and temperature-compensation to bias the output MOSFETs. However, the lateral structures in the Renesas audio MOSFETs show a change from positive-to-negative temperature coefficient at a specific bias point. The amplifier's operating point should be set at exactly this point, which would be between 80 and 100 mA. At this point, the amplifier will be temperature stable and show no runaway. When the amplifier heats up, it will move into the negative-temperature coefficient range, which will result in a reduction of the bias current and avoid thermal runaway.

Compensation is effected through a 30-pF capacitor between the compensation input and the SINK output. Use a high-quality mica capacitor and solder it as close as possible to the pins. Before switching on the amplifier, the bias trimmer should be set to minimum resistance. The amplifier input should also be shorted and and then the bias should

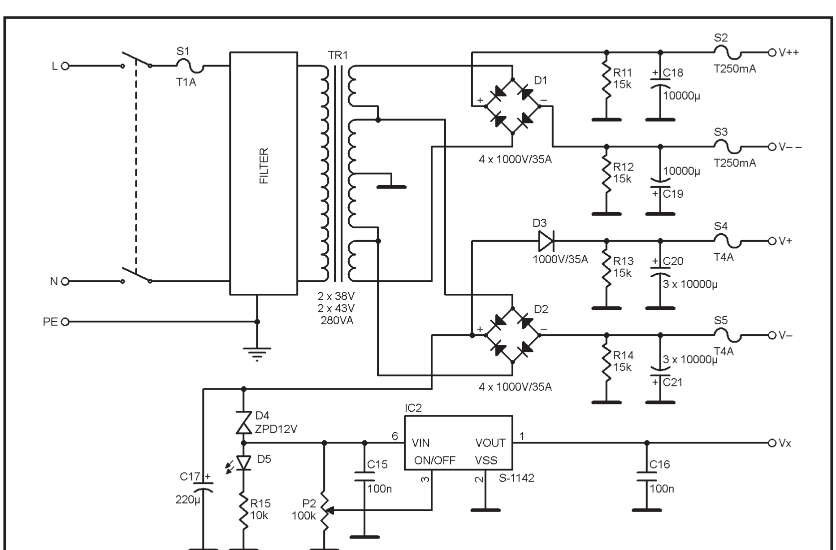

Figure 2: The TERESA amplifier has four main voltages: V+, V–, V++, and V––.

be slowly turned up. You can measure the bias current by measuring the voltage drop across the output emitter resistors (R8, R9, 0.22 Ω). Set the current through the P-Channel MOSFET to 100 mA.

Author's Note: At this point, I recommend that you purchase an inexpensive multimeter if you don't have one. Multimeters are available for approximately $30 and are worth the money. You can then verify supply voltages and correctly set the bias.

Physically Separate Construction

You can also physically split the amplifier at the point where the MOSFET gates are connected to the LME49811's SINK and SOURCE pins. You can easily use some screened cable between the output stage and the LME49811 to enable a decentralized construction layout (see **Photo 6**). In this case, the connection cable's screen should only be grounded at the LME side to avoid any ground loops that could cause hum. You would need three wires inside this cable for SINK, SOURCE, and the feedback connection to R2.

You can further decentralize this if you want to mount the P- and N-Channel output MOSFETs on separate heatsinks. You need to use three separate, screened cables, all with the screen connected on one side to the same ground point. Use them to connect the three sub-assemblies. Of course, you also need to connect the MOSFETs to build the output node but you can do that with a single heavy wire. The various signal cables should be connected to the gate stopper resistors and the driver outputs. This configuration enables you to build rather unconventional amplifier assemblies. There is another good reason to build the circuit as separate assemblies—any oscillation tendencies are also dependent on the distance of the high-impedance input to the low-impedance output and how the signal routings are implemented. So, the more separated these routes are, the better.

I determined the value for the gate-stopper resistors on the MOSFETs by trial and error. If, with a square-wave signal input, the output signal's rising and leading edges show instabilities around their mid-points, the gate stopper resistor values should be adjusted. If you don't have access to an oscilloscope, use the values in the schematic. With a single MOSFET pair, you could even do without the emitter resistors R8 and R9 (0.22 Ω) although the correct bias adjustment would become more difficult.

Most knowledgeable DIYers recommend Futaba MPC74 5-W resistors for the emitter resistors. When using several parallel output pairs, emitter resistors are required to ensure correct power sharing

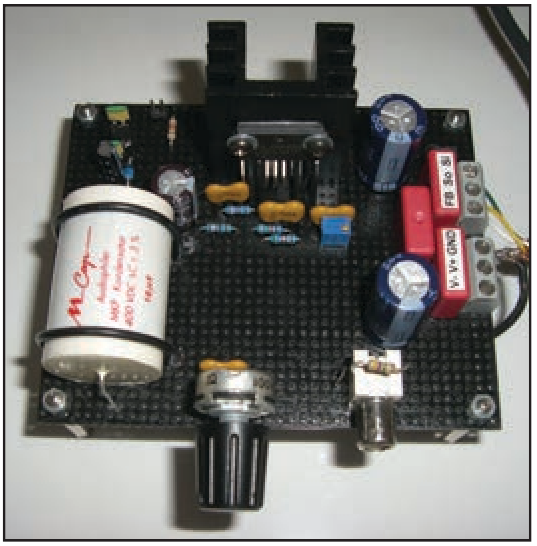

Photo 4: The LME49811 stage is shown without the power stage.

between pairs. Matching the MOSFETs for a single pair is not very useful because the LME49811 will flatten out any differences in parameters. However, with several parallel pairs, matching between same-polarity (N- or P-Channel) MOSFETs in an amplifier, ensures a better sharing of output power. Finally, a high-frequency damping combination of R10 and C14 is connected across the amplifier output.

Heatsinking

With a 100-mA bias current and a ±50 V MOSFET power supply voltage, there will be about 5 W idle dissipation per output MOSFET (in a single output pair), so adequate heatsinking must be provided. During actual operation, a single MOSFET pair can provide an output power of 150 to 200 W, and this should also determine the required heatsinking. The LME49811 should be mounted on a heatsink, which can be much smaller. The part has an internal temperature protection circuit that should only be activated with insufficient cooling. Both the MOSFETs

Photo 5: The LME49811 stage is shown in the front with the power stage at the back.

About the Author

Harald Frank studied in Duisburg, Germany, and became an Engineer in 1989. He started working as a field application engineer (FAE) for microcontrollers. He now works as an FAE and as the office manager for GYLN in Germany.

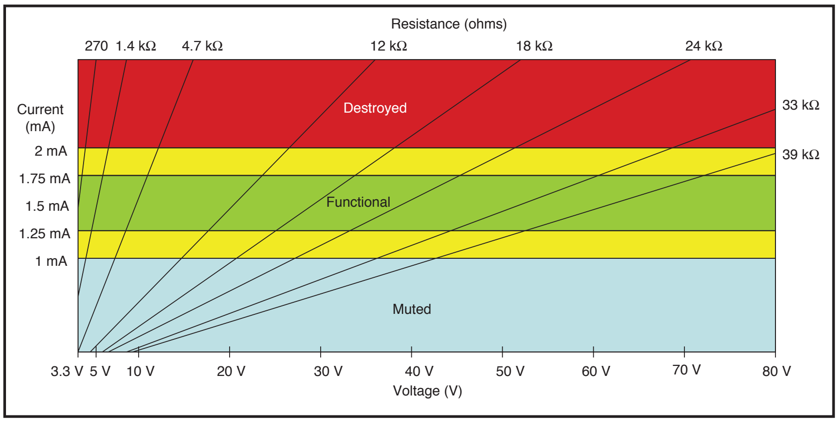

Figure 3: The LME49811 SD input diagram shows the current, voltage, and resistance.

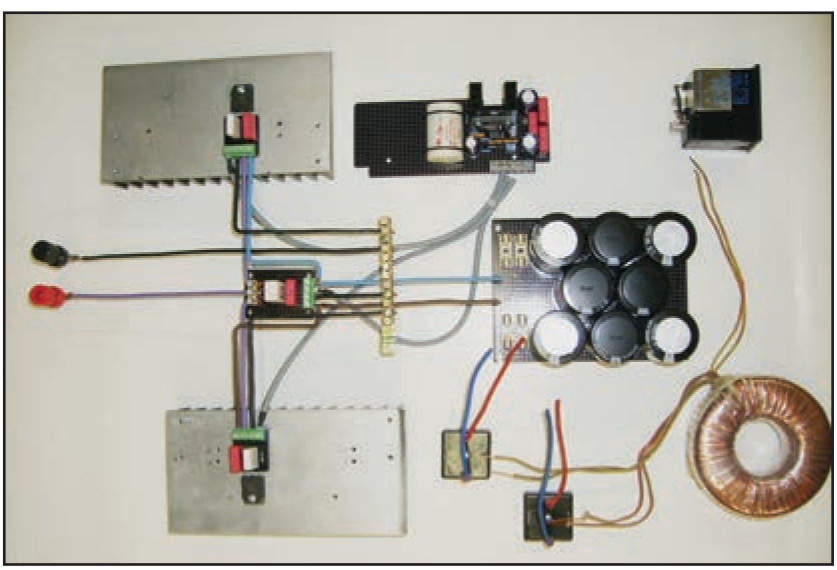

Photo 6: I recommend a decentralized construction, especially for the output transistors.

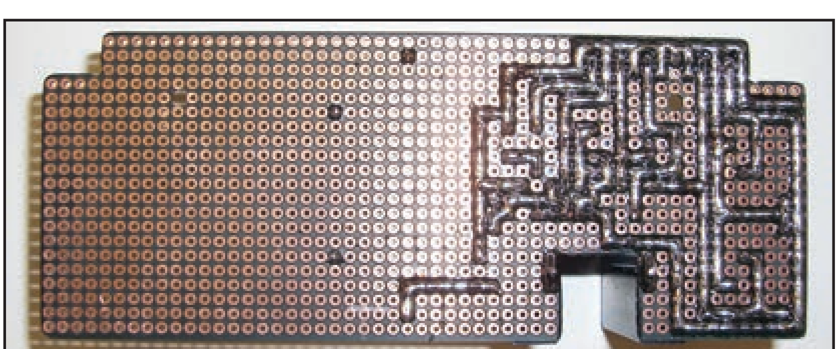

Photo 7: My PCB shows one practical way to design the heart of the amplifier.

and the driver chip have non-isolated metal heat transfer surfaces, which should be isolated from the metal heatsinks with heat-conducting isolation pads.

DC Protection

In many amplifiers, a lot of effort is put into ensuring that no DC can reach the speaker. In the TERESA amplifier, there is only one high-quality input coupling capacitor to ensure no DC enters the amplifier. Actually, DC at the output can only result from defective parts (which is not likely with a newly built amplifier). Destroyed parts, in my experience, are possible when an LME malfunctions or has the wrong voltage. However, good DC protection is worthwhile and I will propose such a system in a follow up article.

Short-Circuit Protection

TERESA has no problems with either a 4- or 8-Ω load. Builders should match the number of required MOSFET pairs, the expected speaker load, the heatsinking, and the power supply parameters so the combination results in a reliable amplifier system. A sufficient protection against short circuiting can be provided by a fuse at the power supply output. With all my tests so far, not a single MOSFET has been destroyed.

Assembly

I recommend a decentralized but classic assembly in a metal enclosure. Bridge rectifiers with a central mounting hole can simplify wiring and cooling. For the star GND point, I used a length of mains earth rail. All cabling is flexible with the largest diameter possible. The heatsinks are from an old amplifier. Each MOSFET has its own heatsink and doesn't really get warm at room listening levels. All the other metal parts for the assembly and the enclosure sides are 2-mm aluminum, which are easily sourced and can be easily worked.

In analog designs, PCBs are seldom perfect on the first try and usually require several iterations. Therefore, PCBs only make sense for this amplifier if they are compact and modular enough to enable a decentralized assembly (see **Photo 7**).

I used proven technology with the well-known matrix experimenter PCBs to find the optimum parts placement. This helped me quickly find a good solution. I painted the top surface of the boards black with lacquer paint before assembly, which gives them a professional look. The traces are built from thick solder layers, which work well after some trials. However, silver wire or anything similar will work as well. The advantage of using this technology is a clear layout that can easily be

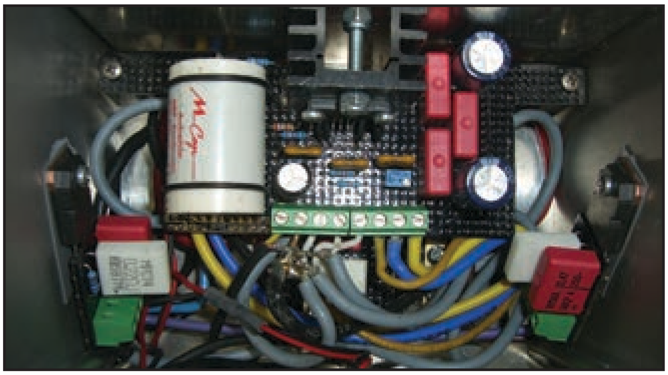

Photo 8: The TERESA amplifier mechanicals and electrical details are in place.

planned. The thick connections are also advantageous, especially for GND connections. Here, too, you should star-wire all GND connections and traces. If you have hum, it often is a result from GND loops (see **Photo 8**).

If the amplifier is built in a closed box its performance can slightly change for better or worse. For example, if you have hum or oscillatory tendencies, it may be possible to connect the open input to GND with a resistor. This resistor value should be as high as possible and as low as necessary. An important point is the connection of GND to the enclosure. It is necessary for the enclosure to have a single GND point and all metal parts connect together. Some amplifiers have an external option to connect the enclosure to the amplifier GND to fix problems. A 1-kΩ resistor from GND to enclosure can often work miracles.

Final Observations

This amplifier circuit is not perfect and surely harbors some significant improvement possibilities. However, it functions well and can provide an excellent starting point for many applications. An amplifier is only as good as its parts. Use good quality parts and you will reap the benefits.

The cascading options with several output MOSFET pairs make it difficult to design an efficient PCB for all the possibilities, and at this point, none is available. Also, I don't have the necessary test equipment to measure the TERESA's main parameters. This could be done by interested builders who have the necessary equipment. I would be very interested in your findings!

If, when listening to the TERESA, you hear sounds that you haven't previously heard, it could be because of the high cut-off frequency, which should be around 80 to 100 kHz with a resulting slew rate of about 18 to 22 V/µs. However, it could also be the speakers! Be aware of the power when you connect your speakers! A tweeter or other parts can be damaged when overdriven. I have discovered this the hard way.

If you have checked all of these factors, you can enjoy your music at the highest level. I would be very happy if this article helps improve the sound quality in as many listening rooms as possible! Constructive criticism, comments and improvement proposals are always welcome.

Editor's Note: In a follow-up article, Harald Frank will describe a protection circuit for this amplifier to guard against output DC, over current/short circuit, and temperature. The article will also feature level control, fade in/out, and switch-on delay options that are all controlled by a small microcontroller.

Resources

"LM4702 (ACTIVE) Stereo High Fidelity 200 Volt Driver with Mute," Texas Instruments, www.ti.com/product/lm4702.

J. Walton, "High-End 120-W MOSFET IC Driven Amp," *audioXpress*, July 2007.

Sources

MPC74 Resistors
Futaba Electric Co., Ltd. | www.fu-futaba.co.jp/english

2SK1058 N-Channel and 2SJ162 P-Channel MOSFETs
Hitachi Global | www.hitachi.com

2SK2221 N-Channel and 2SJ352 P-Channel audio MOSFETs
RENESAS Electronics Corp. | http://am.renesas.com

S-1142B33-E6T1U Voltage regulator
Seiko Instruments, Inc. | http://www.seikoinstruments.com

LM4702 Speaker amplifier and modulator and LME49811 audio power amplifier input stage
Texas Instruments, Inc. | www.ti.com

Bill of Materials

Capacitors	
C1	10 µF; 400 VDC; 3%; M-Cap audiophile MKP capacitor
C2	10 µF; 16 V; 10%; elektrolytic capacitor
C3, C4, C5	30 pF; 300 V; 5%; silver-mica capacitor
C6, C7, C8, C9, C10, C11	470 nF; 250 V; foil capacitor
C12, C13, C17	220 µF; 100 V; 10%; elektrolytic capacitor
C14, C15, C16	100 nF; 100 V; foil capacitor
C18, C19	10,000 µF; 80 V; elektrolytic capacitor
C20, C21	3 × 10,000 µF; 80 V; elektrolytic capacitor
Diodes	
D1, D2	Panel mount bridge rectifier 35 A/1,000 V
D3	Single diode 35 A /1,000 V
D4	Zener diode ZPD 12; 0.5 W (optional, voltage dependent)
D5	LED according to preference, approximately 5 mA
Fuses	
S1	Fuse, slow-blow, 1 A/250 V
S2, S3	Fuse, slow-blow, 250 mA/250 V
S4, S5	Fuse, slow-blow, 4 A/250 V
Potentiometers	
P1	1 kΩ; 0.25 W; Trimpot
P2	100 kΩ, 0.25 W; Trimpot
Regulators	
IC1	LME49811; ±100 V; Audio Power Amplifier (Texas Instruments)
IC2	S-1142B33-E6T1U Voltage regulator 50 V to 3.3 V (Seiko Instruments)
Resistors	
R1, R3	1.8 kΩ; 0.25 W; 1%; metal film
R2, R4	56 kΩ; 0.25 W; 1%; metal film
R5	47 kΩ; 0.25 W; 1%; Metal film
R6	470 Ω; 0.25 W; 1%; Metalfilm
R7	220 Ω; 0.25 W; 1%; Metal film
R11, R12, R13, R14	15 kΩ; 0.25 W; 1%; metal film
R15	10 kΩ; 0.25 W; 1%; metal film
R8, R9	0.22 Ω; 5 W; 5%; MPC74 metal band FUTABA
R10	10 Ω; 5 W; 5%; CWR-5 wire wound resistor FUTABA
Rx	270 Ω; 0.25 W; 1%; metal film at Vx = 3.3 V
Transformer	
Tr1	Toroidal mains transformer two 38 V/43 V; 280 VA
Transistors	
T1	2SK2221; 200V / 8A; N-Channel Audio-MOSFET (RENESAS)
T2	2SJ352; 200V / 8A; P-Channel Audio-MOSFET (RENESAS)

Note: The enclosure, heatsinks, fan (if needed), screw/solder terminals, PCB material, cabling, mains filter, mains switch, and other not-specified amplifier parts depend on individual implementation and should be determined by the builder. It is not always useful to spell everything out and suffocate all creativity!