DESIGNING AMPLIFIERS WITH TRIPATH'S HIGH-POWER CLASS-T DRIVERS

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Revised: March 24, 1999

Introduction

Although linear and Class-T amplifiers differ greatly in their operating principles, most of the circuits in the Class-T amplifier should be familiar to experienced designers. The Tripath Class-T driver products are designed to make the development of a high-quality amplifier a fairly straightforward process. In this application note, the Tripath TA0103A reference design (as supplied in the Tripath Audio Development Kit) is described in some detail to illustrate design techniques and the options available to the OEM.

Overview

The reference design is a stereo amplifier capable of (at it's maximum rated operating voltage into 4) over 150 Watts per channel with less than .1%THD+N. The sample amplifier is configured with two independent channels for stereo applications and can be used to drive a bridge-tied load for a single channel application (typically a subwoofer). The amplifier can also be used in a "2.1" application, where the amplifier outputs are tied to passive crossovers, and then to two satellite speakers and a subwoofer.

Some of the key benefits of the reference design include:

- High Efficiency. Inherent to a Class-T design, the high efficiency permits the use of a small heatsink and smaller power supplies.
- Simplicity. The design includes everything required for a full demonstration setup.
- Redundant protection circuits. In the case of a fault, the output FETs are turned off and a relay opens in the load line, protecting both the board and the load.
- All components are loaded on one side for easy test and analysis.

Architecture

A block diagram of one channel of the amplifier is shown in Figure 1. The major functional blocks of the amplifier are described below.

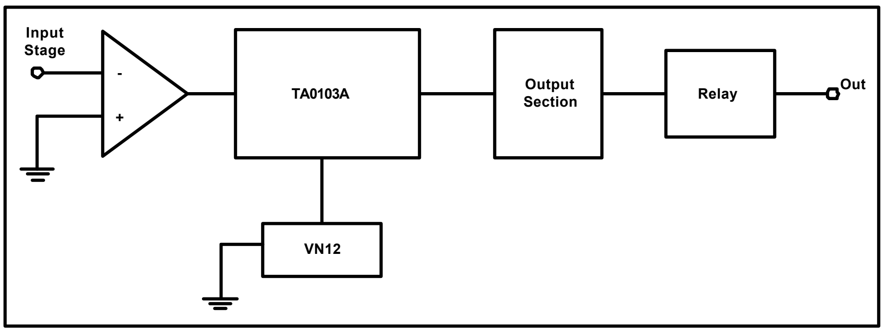

Figure 1: Amplifier Block Diagram

Input Stage

Figure 2 shows one channel of the input stage. The amplifier is designed to accept unbalanced inputs and provide an overall gain of up to 108, or approximately 41dB. In this application, the gain is set to approximately 7, or 17dB. The gain of the TA0103A is set by the value of resistor R_{IN}, according to the following formula: $Av = 538 \times 10^3 / (R_{IN} + 5000)$, where R_{IN} is in Ohms. In this design, R_{IN} is 75K . This value is a very good compromise between gain and noise, as decreasing the gain further results in a negligible increase in noise margin. For standalone applications without a preamplifier, however, this level of gain will usually not permit the outputs to be driven to full scale.

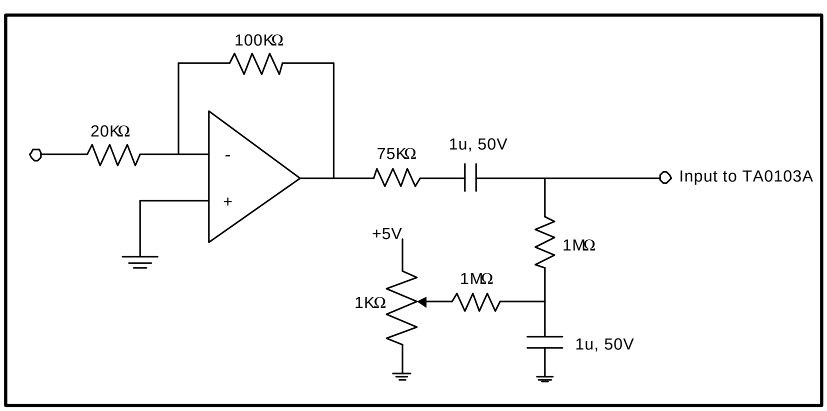

Figure 2: Input Stage

The value of the input capacitor, C_{IN} (C50/51), sets the –3dB point of the input high-pass filter. The frequency of the input high pass pole, F_P of the –3dB point can then be calculated as follows:

- $F_P = 1/(2\pi \times C_{IN})(R_{IN} + 5000)$
- where:

  C_{IN} = input capacitor value in Farads
  R_{IN} = input resistor value in Ohms

Output offset voltages are nulled in the input stage, and potentiometers are provided here for this purpose. Once set, the offset does not typically drift with temperature, so no tracking circuitry is required. Offsets can typically be set to +/- 25 mV.

Control Circuitry

Figure 3 shows the Tripath driver module and it's control circuitry.

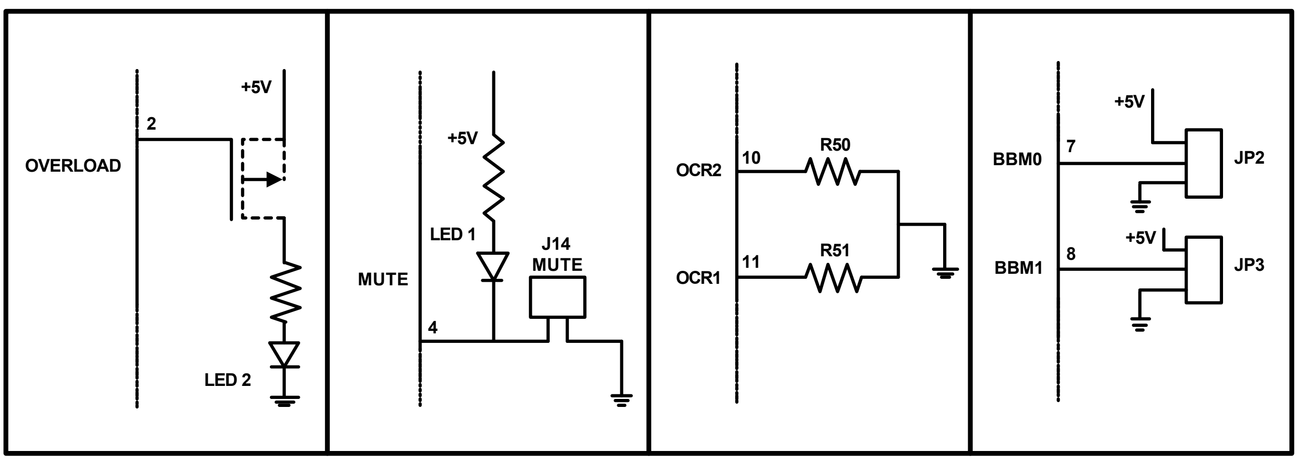

Figure 3: Overload, Mute, Over-Current and Break-Before-Make Circuitry

When a fault condition occurs, Q3 turns on LED 2 to provide an indication of this condition. When an OVERLOAD occurs, AC power must be cycled and the cause of the fault must be cleared before the normal operation can resume.

Voltage V5 drives the POWER LED (LED 1) directly to indicate "good" status of the internal 5V rail. If the LED 1 is off, the amplifier will be muted.

The MUTE pin is simply brought out to an external 2-pin header. When a jumper is installed on this header, the MUTE line is pulled to ground and the outputs are enabled. If the MUTE line is pulled high (to +12V through 1M), the outputs are muted. Note that if the MUTE jumper is simply removed, then MUTE pin floats high, the amplifier is muted, and the power LED will not be lit. This is done to remind the user of a possible "jumper off" condition if there is no output.

R50 and R51 set the overcurrent threshold for the output devices. Note that these are NOT the sense lines (the overcurrent sense resistors are in the output stage). Using these resistor values, the threshold at which the amplifier "trips" can be set, INDEPENDENT of the value chosen for the overcurrent sense resistors. The formula for determining the value for these threshold resistors follows:

- ISC x RS = (VTOC x 9100) / (9100 + ROCR)
- where:
  R_S and R_{OCR} are in Ω
  $I_{SC} = 3 \times I_{RMS} = 3 \times (P_{OUT}/R_L)^{0.5}$ (Over-current is typically set for 3 x RMS current)
  V_{TOC} = Over-current sense threshold voltage (in the range of .67 - .82V)
  = 0.75V typically
  when $R_{OCR} = 0\Omega$, $R_S = (0.75)/I_{SC}$

Here's an example that shows the value of being able to select the overcurrent threshold independently of R_S. First, note that R_S will dissipate approximately $(I_{RMS})^2 \times R_S$ of power. So, setting an I_{SC} of 30A with $R_{OCR} = 0\Omega$ means that $R_S = 25m\Omega$ and R_S must dissipate 2.5W on average. If, though, in this example $R_{OCR} = 9.1K\Omega$, then to set I_{SC} = 30A, R_S will be $12m\Omega$ and only have to dissipate 1.2W on average. Since high-wattage resistors are usually only available in a few low-resistance values ($10m\Omega$, $25m\Omega$ and $50m\Omega$), R_{OCR} can be used to adjust for a particular over-current threshold using one of these standard values for R_S. Also, overall amplifier efficiency is improved.

Finally, the Break-Before-Make (or "BBM") lines are used to control the "dead time" of the output FETs. The "dead time" is the period of time between the turn-off of one device and the turn-on of the opposite device on the same channel. If the two devices are both on at the same time, current "shoots through" from one supply to the other, bypassing the load altogether. Obviously, this will have a great impact on the overall efficiency of the amplifier. However, if the dead time is too great, linearity suffers. The optimum BBM setting will change with different output FETs, different operating voltages, different layouts and different performance requirements. For this reason, Tripath has provided a means to adjust the BBM setting among four preset levels by moving jumpers JP2 and JP3 on their 3-pin headers. These settings should be verified over the full temperature and load range of the application to ensure that any thermal drift of this timing does not impact the performance of the amplifier. Figure 4 shows the BBM values for various settings of the jumpers.

BBM1	BBM0	Delay
0	0	145nS
0	1	105nS
1	0	65nS
1	1	25nS

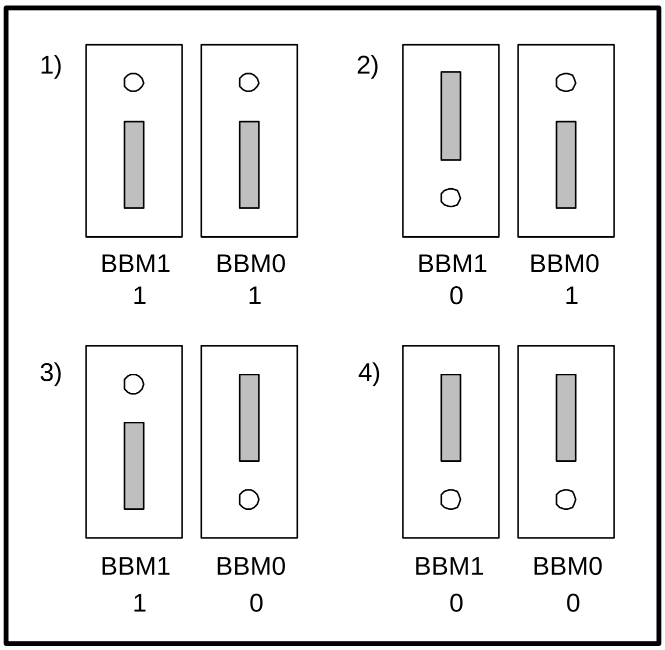

Figure 4: Break-Before-Make Jumper Settings

Output Section

The output section (Figure 5) includes the gate resistors, the FETs, the output filters, the previously mentioned overcurrent sense resistors, clamping diodes, a Zobel, and various bypass capacitors.

The gate resistors (R3, R4, R7, R8) are used to control MOSFET switching rise/fall times and thereby minimize voltage overshoots. They also dissipate a portion of the power resulting from moving the gate charge each time the MOSFET is switched. If R_G is too small, excessive heat can be generated in the driver. Large gate resistors lead to slower gate transitions resulting in longer rise/fall times and thus requiring a larger BBM setting. Tripath recommends using an R_G of 10Ω when the gate charge (Qg) of the output FET is less than 70nC and 5.6Ω when the Qg is greater than 70nC.

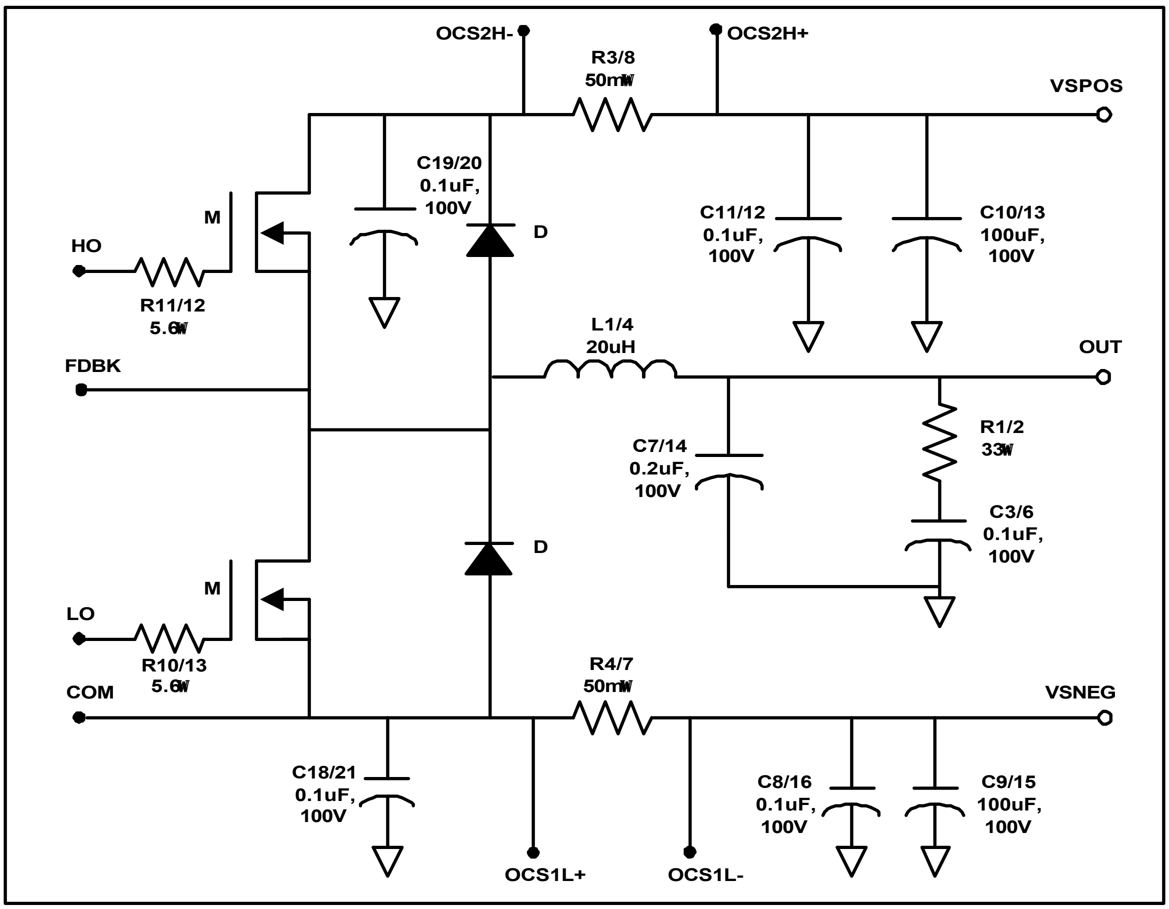

Figure 5: Output Section

The output FETs M1-M4 provide the switching function required of a Class-T design. They are driven directly by the TA0103A through the gate resistors. The devices used on the demo board are STP39NB20 from ST. There is extensive information on output FET selection in the data sheet for the TA0103A and in Tripath Application Notes 7 and 10: "Designing with Switching Amplifiers for Performance and Reliability" and "Efficiency and FET Selection" .

The output filters L1/C7 and L4/C14 are the low-pass filters that recover the analog audio signal. One of the benefits of the Class-T design is the ability to use output filters with relatively high cutoff frequencies. This greatly reduces the speaker interactions that can occur with the use of lower-frequency filters common in Class-D designs. Also, the higher-frequency operation means that the filter can be of a lower order (simpler and less costly).

The OEM may benefit from some experimentation in the filter design, but the values provided in the reference design, 20uH and .2uF, provide excellent results for most loads between 4 and 8 . As important as the values themselves, the material used in the core is important to the performance of the filter. Core materials which saturate too early will not provide acceptable distortion or efficiency figures. Tripath recommends a low-mu (10) type 2 iron powder core.

The clamping diodes D1-D4 are required to limit the reverse voltages seen by the output FETs as a result of normal operation. The diodes should be mounted with short leads, as close as possible to the FET. Only Schottky diodes should be used here due to their very low forward voltage drop and fast switching. The diodes should have a forward current rating of at least one Ampere.

The Zobel circuits R1/C3 and R2/C6 are there to account for the condition where the amplifier may be powered up with no load attached. The Q of the LC output filter, with no load attached, rises quickly out to 80 kHz. Resonant currents in the filter and ringing on the output could reduce the reliability of the amplifier. The Zobel eliminates these problems by reducing the Q of the network significantly above 50 kHz. Modifying the LC output filter should not require a recalculation of the Zobel values.

The bypass capacitors C18-C21 are critical to the reduction of ringing on the outputs of the FETs. These parts are placed as closely as possible to the leads of the FETs, and the leads of the capacitors themselves are as short as practical. Their values will not change with different output FETs.

VN12 Bias Requirements

The VN12 circuit (Figure 6) can be used to provide the voltage rail for the low side FET drivers on the TA0103A. This circuit is disabled in the Shielded Amplifier Module, but is provided in the EB-TA0103 standalone board for convenience. This supply must track the –Vs rail, and so, for simplicity, this supply is included on the amplifier circuit board (the corresponding +12V "floating" supply is generated internal to the TA0103A module and so is not shown). The VN12 circuit uses a National LM2594 "simple switcher" integrated circuit for all control. A few passive components complete the design. Tripath does not anticipate that there will be any reason to modify the operation of this circuit. Should the OEM wish to do so, there is reference data for the LM2594 at www.national.com/pf/LM/LM2594.html.

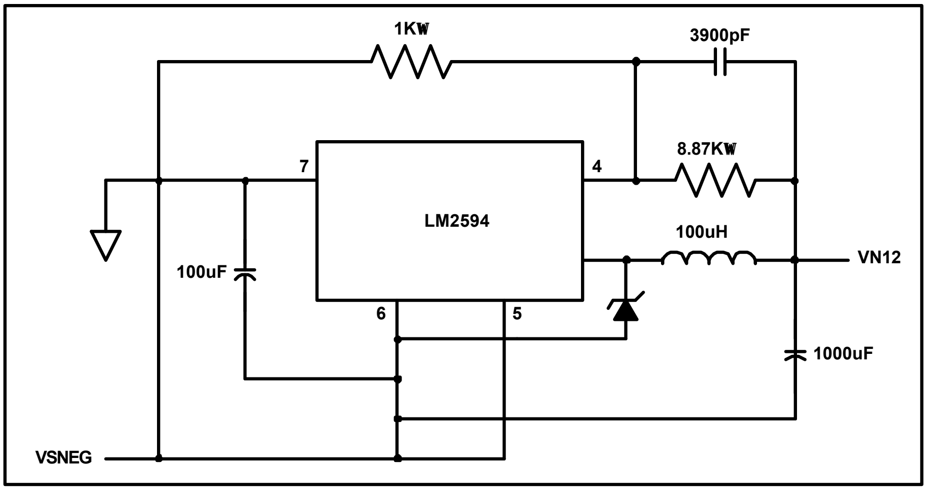

Figure 6: VN12 Circuit

Connection Diagram and Bridged Mode operation

The amplifier is connected to the power supplies and load(s) as shown in Figure 7. Note that in Figure 7 the stereo speakers appear to be connected out of phase. Actually, connecting the speakers in this way restores in-phase operation when the amplifier is used as recommended. Tripath recommends that one of the input channels be inverted, as this avoids a potential problem with switching power supplies (the "pumping" phenomenon), and it also simplifies the connections for bridged-mode operation. Assuming that the left and right channels are 180° out of phase, there are no external inverter circuits or switches required; simply connect the load between the "+" output terminal of the left channel and the "-" output terminal of the right channel. Since the theoretical power output of a bridge-tied load circuit is four times that of a single-ended channel, special care must be taken to ensure proper heat sinking of the MOSFETs.

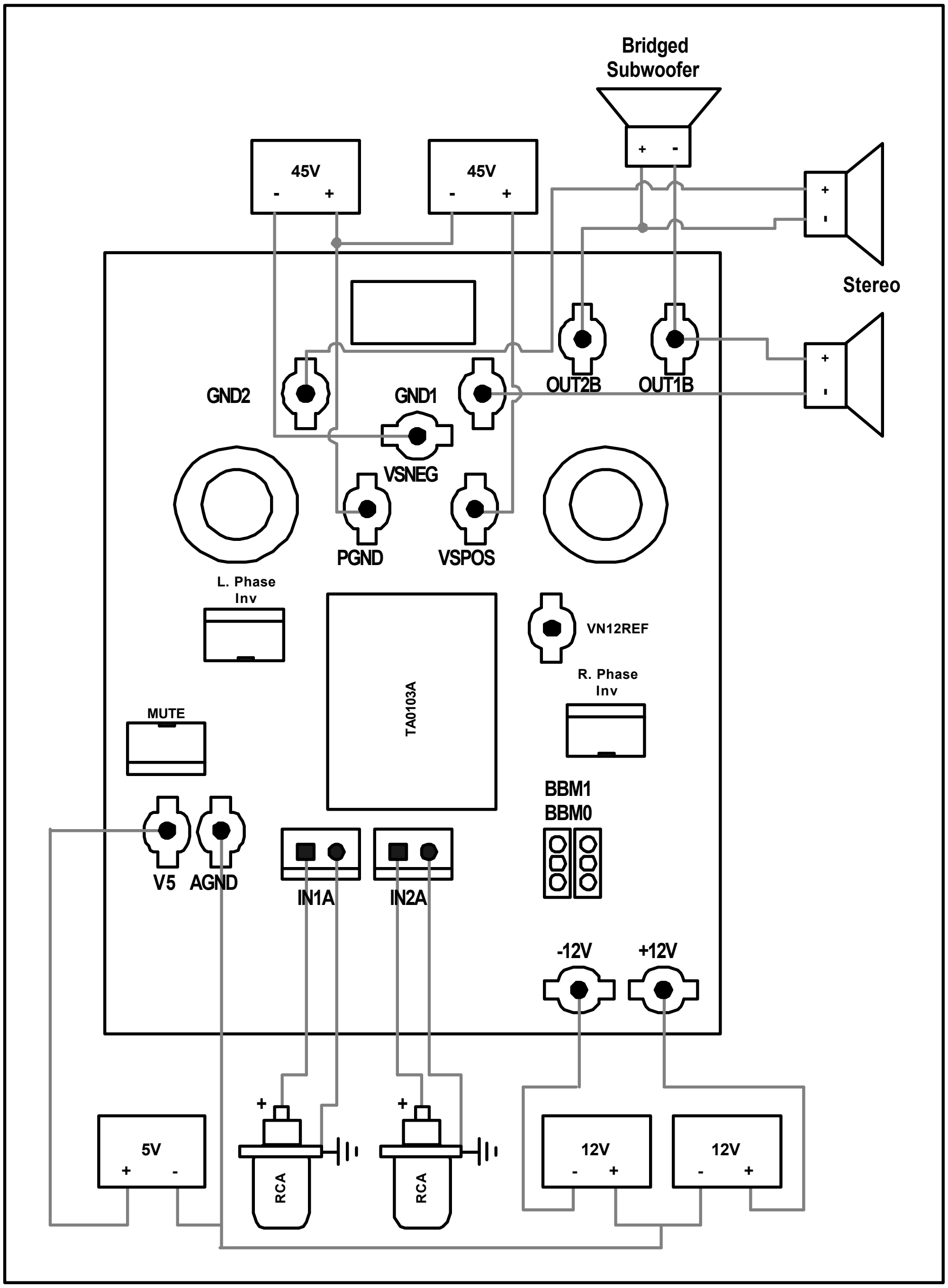

Figure 7: Amplifier connections to Power Supply and Loads