Application Report

SNAA057C – June 2008 – Revised June 2019

AN-1849 An Audio Amplifier Power Supply Design

ABSTRACT

This application report provides design information for a power supply for use with TI's newest offering of high-performance, ultra high-fidelity audio amplifier input stage ICs.

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Trademarks

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1 Introduction

Analog audio circuit power supplies can have an audible effect in listening tests and a quantifiable effect in bench measurement results. Power supply designs that operate from the power mains are of three common types: Switch mode (SMPS), regulated, and unregulated power supplies.

Switch mode power supplies have become very popular, common, inexpensive, and readily available. SMPS are used extensively in computer hardware. They are well-suited for such use providing good regulation with high efficiency in a small physical size. A drawback to SMPS is the switching nature of the design which creates EMI and RFI plus electrical noise on the supply rails. Small signal analog circuits are more susceptible to noise in the form of EMI or electrical noise on the supply lines. Certain classes of amplifiers, namely Class G and Class H, may be more easily realized with SMPS that are fast responding for full audio bandwidth signals. Using SMPS for audio circuits presents additional design challenges than when using a SMPS for non-audio circuits.

A regulated supply can be a simple linear regulator IC with the rectified voltage from the transformer as input and a handful of external components or any number of more complicated and often higher performance designs. There are the tradeoffs of complexity, cost, space, thermal design, reliability, and protection with any regulated design. It is common for regulated supplies to be used for the analog small signal portions and other sensitive circuits for the best performance. For an audio power amplifier, regulated supplies need high bandwidth for good audio performance. The complexity and cost for such a power supply design may not be acceptable. Most linear regulator ICs do not have high bandwidth and are slow compared to audio signals that can result in reduced audio performance.

For simplicity, good performance, and reasonable cost, an unregulated supply is the most common for an audio power amplifier. An unregulated supply uses a transformer, a bridge rectifier, and various rail capacitors. A drawback to the unregulated supply is the voltage fluctuations with load and power mains fluctuations. A design should allow for a minimum 10% high line condition on the power mains. Unregulated supplies may have only a fuse in the power mains input to protect against excessive current unlike more sophisticated regulated designs. Additionally, the power supply voltage rails may have inline fuses to add some additional protection.

The circuit and solution presented in this application note have not been tested to any industry standards. It is the responsibility of the reader to perform standard industry testing to assure safety when using the solution in part or in whole in any form. Texas Instruments does not provide any guarantees, written or implied, about the safety of the solution.

2 Overview

This application note covers the design of a ±72-V unregulated power supply specifically for audio amplifiers.

The power supply is an unregulated design with an option to allow connection to either 120-V or 240-V mains. The design uses toroidal transformers, a fully integrated bridge, and various rail capacitors for ripple voltage reduction, noise suppression, and to act as high current reservoirs. Additional circuitry to control inrush current on power up and power down Mute control are also included. A complete schematic, PCB views, and Bill of Materials are provided for the power supply design.

3 Schematic and Design

3.1 Power Supply

Figure 1 shows the complete schematic of the power supply design. The heart of the design is the basic power supply consisting of the transformers, the bridge, and various capacitors. Many of the capacitors used may not be commercially necessary or may have a minimal effect on performance. Because the design is not a commercial design where tight cost constraints must be taken into account, additional capacitors are freely used. For a commercial design, bench and listening test, or some other test, criteria is recommended to determine the exact number, size, and type of external components required. A short explanation of the purpose of each capacitor at the primary side of the transformers, around the bridge and on the supply rails follows. Some capacitors are doubled up on the PCB for flexibility or to achieve the desired total capacitance.

- C_1, C_2, C_4 protect against turn on and off spikes caused when the power switch changes positions. C_3

is not used and is redundant.

- C_{S1} and C_{S2} are low value, ceramic capacitors to filter higher frequency noise right at the DC output of the diode bridge.
- C_{S3} and C_{S4} are the large reservoir capacitors to supply large current demands and stabilize the supply rails to minimize low frequency fluctuations. These are very large value electrolytic capacitors. Two capacitors are used to achieve the desired 40 000 μF capacitance per rail.
- C_{S5} and C_{S6} are high quality film capacitors to filter higher frequency noise. Two footprints are used on the PCB for flexibility.
- C_{S7} and C_{S8} act in conjunction with R_{S1} and R_{S2} to decouple the large electrolytic capacitors and reduce impedance.
- C_{S9} and C_{S10} are low value, ceramic capacitors to filter higher frequency noise from the transformer secondary AC lines at the diode bridge.
- C_{S11}–C_{S14} are in parallel with the bridge diodes to reduce high frequency noise and ringing of the diode. An additional RC snubber in parallel with each diode of the rectifier will further reduce noise and ringing.

The values for the different capacitors were not chosen based on extensive bench work or research. The values were chosen based on general guidelines and commonly used values. Additional performance may be obtained through refinement of the capacitor values. The equations and methods to determine optimal values are beyond the scope of this application note.

Additionally, the supply rails have bleeder resistors, R_{BL1} and R_{BL2}, to drain the large reservoir capacitors (C_{S3} and C_{S4}). Two footprints per rail were placed on the PCB to allow for lower power resistors to be used and a wide range of bleeder current. More sophistication can be added by including an additional DPDT relay and controls to only connect the bleeder resistors below a set voltage and remain unconnected during normal operation.

The fully integrated bridge has a peel and stick heat sink attached. See Table 1 for robustness in use and higher ambient temperature conditions.

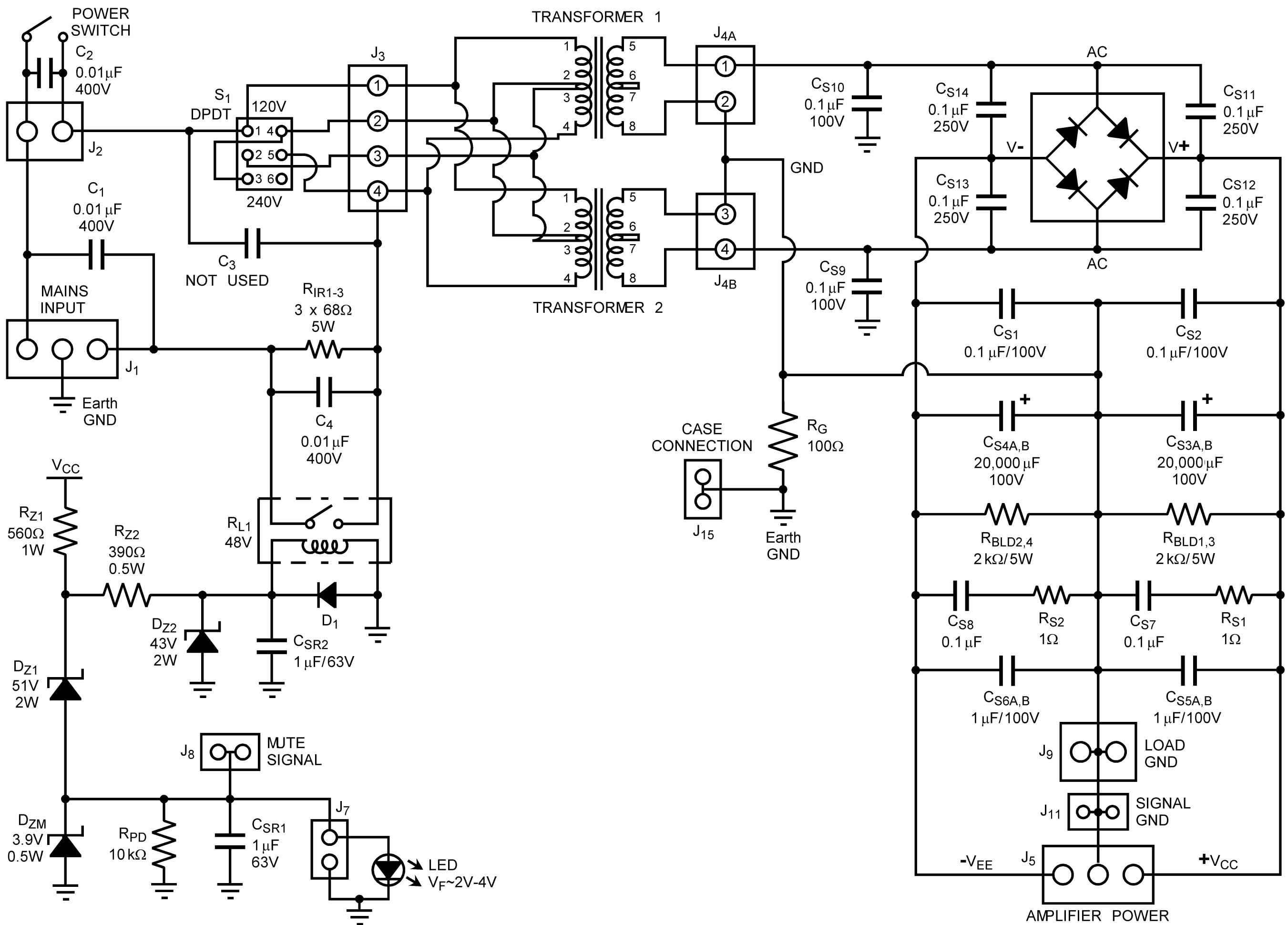

Figure 1. Complete Power Supply Circuit

4 Bill Of Materials

Table 1. Bill Of Materials

Reference	Value	Tolerance	Description	Manufacturer	Part Number
C1, C2, C4	0.01 µF	10%	400 V, metalized polyester film, 7.5-mm lead spacing	Panasonic	ECQ-E4103KF
C3			Not Used		
CS1, CS2, CS7, CS8, CS9, CS10,	0.1 µF	10%	100 V ceramic, X7R type, 200-mil lead spacing	AVX Corporation	SR211C104KAR
CS11, CS12, CS13, CS14	0.1 µF	10%	250 V, metalized polyester film, 7.5-mm lead spacing	Panasonic	ECQ-E2104KF
CS3A, CS3B, CS4A, CS4B	20 000 µF	20%	100-V electrolytic can	CDE Cornell Dubilier	DCMC203U100BC2B
CS5A, CS5B, CS6A, CS6B	1 µF	10%	100 V, metalized polyester film, 10-mm lead spacing	Panasonic	ECQ-E1105KF

Table 1. Bill Of Materials (continued)

Reference	Value	Tolerance	Description	Manufacturer	Part Number
CSR1, CSR2	1 µF	20%	63-V electrolytic radial, 2-mm lead spacing	Panasonic	EEU-EB1J1R0S
D1	1 A		400-V diode, DO-41	Vishay Semiconductor	1N4004-E3/54
DZ1	51 V	5%	2-W Zener diode, DO-41	Microsemi Corporation	2EZ51D5DO41
DZ2	43 V	5%	2-W Zener diode, DO-41	Microsemi Corporation	2EZ43D5DO41
DZM	3.9 V	5%	500-mW Zener diode, DO-35	Diodes Inc.	1N5228B-T
RBLD1, RBLD2, RBLD3, RBLD4	2 kΩ	5%	5-W metal oxide	International Yageo Corporation	SQP500JB-2K0
RFAN	1.2 kΩ	5%	5-W metal oxide	International Yageo Corporation	SQP500JB-1K2
RIR1, RIR2, RIR3	68 Ω	1%	5-W wire-wound silicone	Huntington Electric, Inc.	ALSR-5-68-1%
RS1, RS2	1 Ω	5%	¼ Watt carbon film	Panasonic	ERD-S2TJ1R0V
RG	100 Ω	1%	¼ Watt metal film	International Yageo Corporation	MFR-25FBF-100R
RZ1	560 Ω	5%	1 Watt metal oxide film	Panasonic	ERG-1SJ561
RZ2	390 Ω	5%	½ Watt carbon film	Panasonic	ERD-S1TJ391V
RPD	10 kΩ	5%	¼ Watt carbon film	Panasonic	ERD-S2TJ103V
RL1	16 A		48 V, 400-mW SPST, N.O., relay	Panasonic Electric Works	ALE15B48
U1	35 A		700-V bridge rectifier	Fairchild Semiconductor	GBPC3510W
S1	6 A		DPDT PCB mount, mini slide switch	C&K Components	1201M2S1CQE2
J1, J5			3 pin 156-mil header, right angle, tin plating	Molex/Waldom Electronics Corp.	26-60-5030
J2, J9, J4A, J4B			2 pin 156-mil header, right angle, tin plating	Molex/Waldom Electronics Corp.	26-60-5020
J3A, J3B			4 pin 156-mil header, right angle, tin plating	Molex/Waldom Electronics Corp.	26-60-5040
J7, J8, J11, J12, J13, J14, J15			2 pin 100-mil header, right angle, tin plating	Molex/Waldom Electronics Corp.	22-05-3021
Transformer1, Transformer2	24 V, 300 VA		Dual primary, dual secondary, torrid transformer	Plitron Manufacturing Inc.	77060201
	θ_{CA} = 16.5°C/W		Peel & stick heat sink for bridge, 1.21" square, 0.55" tall	CTS Electronic Components, Inc	BDN12-5CB/A01
RZ3, RZ4, DZ3, DZ4, CSF1, CSF2, CSF3			Option unused circuits		

5 Additional Circuit

5.1 120 V/240 V Selection Option

For multi-country operation, a switch is included to select between 120-V or 240-V input at the primary side of the transformers. The transformers are dual primary with the switch allowing the option to put the primaries into series or parallel. The primary side of each transformer is connected in parallel for 120-V operation with series connection used for 240-V operation. The schematics, Figure 2 and Figure 3, show the different connections with the switch set for either 120-V or 240-V input from the power lines.

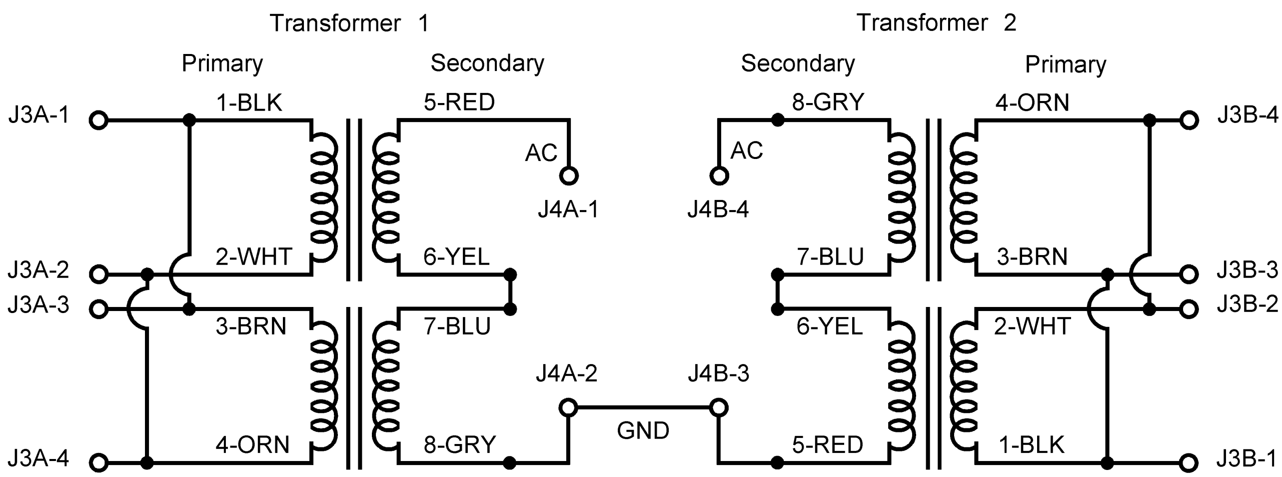

Figure 2. 120V Transformer Connections, Primaries in Parallel

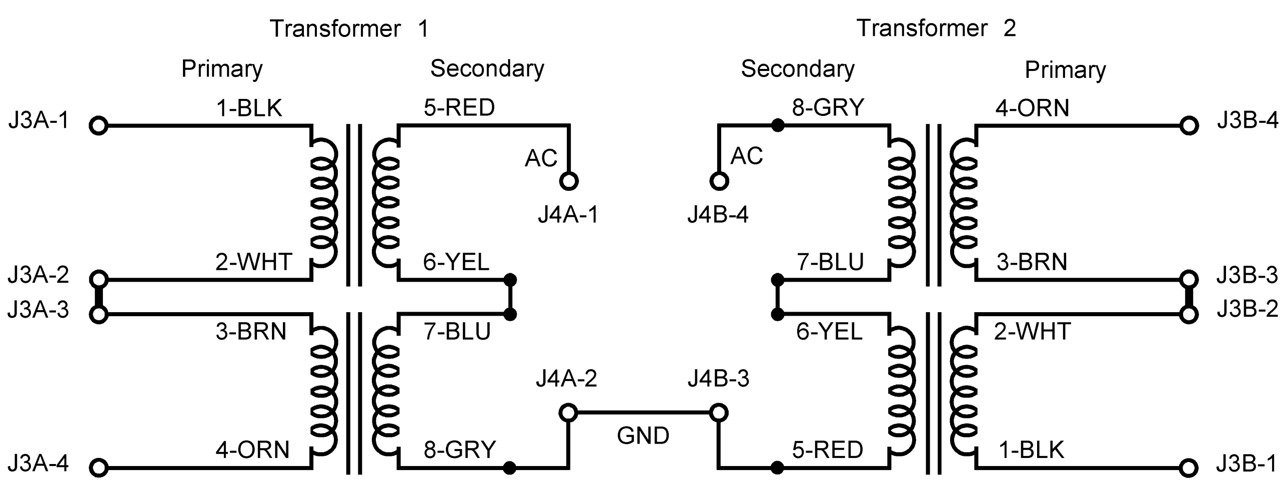

Figure 3. 240V Transformer Connections, Primaries in Series

5.2 Inrush Current Control

A simple inrush circuit is used to limit the high current that occurs at power up. The portion of the schematic that controls inrush current is shown in Figure 4.

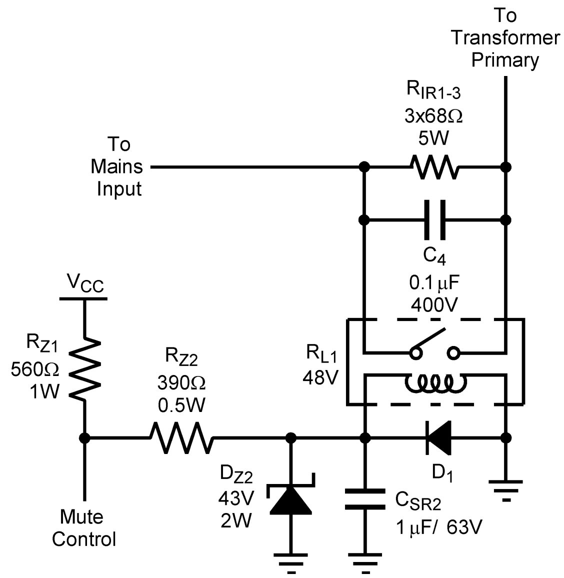

Figure 4. Inrush Current Control

The inrush circuit consists of three 68-Ω/5-W resistors (R_{IR1}–R_{IR3}, labeled just R_{IR} in Figure 1 and Figure 4) in parallel, a relay and the relay controls. The R_{IR} resistors limit transformer primary current flow and the resulting secondary current flow when the transformer is powered for a softer turn on. Once the V_{CC} rail voltage exceeds 33 V, the relay is activated, shorting out the resistors. The relay is deactivated when the V_{CC} voltage falls below 10 V, resetting the circuit. The circuit is very simple and does not limit inrush current if the mains power is switched on before the V_{CC} rail drops below 10 V. The relay control consists of the R_{Z1} and R_{Z2} resistors to limit current through the voltage clamping D_{Z2} Zener diode. D_{Z2} limits the relay voltage below the maximum 48 V rating. The D_1 diode is for the relay coil EMF and C_{SR2} is to remove ripple and stabilize the relay voltage. The oscilloscope view in Figure 5 shows how the positive rail charges up with the increase in charge rate once the relay is closed shorting out the inrush current limiting resistors. The R_{IR} resistors will get warm but they are only conducting for 500 ms each time the amplifier is powered on keeping the power dissipation well within the 5-W rating.

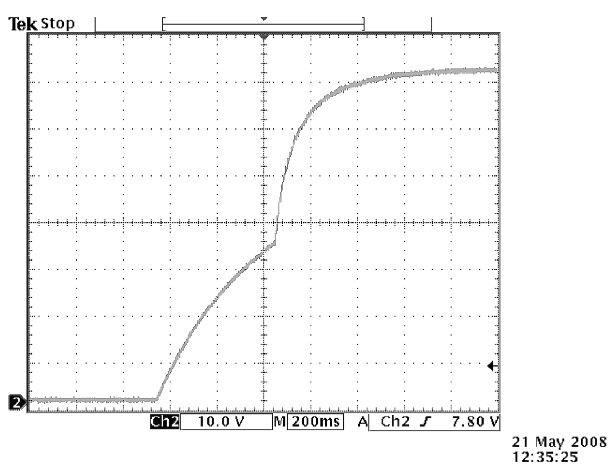

Figure 5. Supply Ramp at Power On

5.3 Power Up/Down Mute Control

The Mute function of the audio amplifier input stage IC is used for a completely quiet turn on and turn off. The amplifier is held in Mute mode until the voltage supplies are nearly stable and also goes into Mute mode once the supplies have collapsed below a determined voltage. With 40 000 μF of supply reservoir capacitance per rail ,the amplifier can continue operation for some time after the mains power has been removed. The mute control circuit removes the drive signal for a quicker turn off well before the supplies have collapsed down below the minimal operating voltages. The amplifier turns off quietly and smoothly without any undesired noise. The Mute control circuit portion is shown in Figure 6.

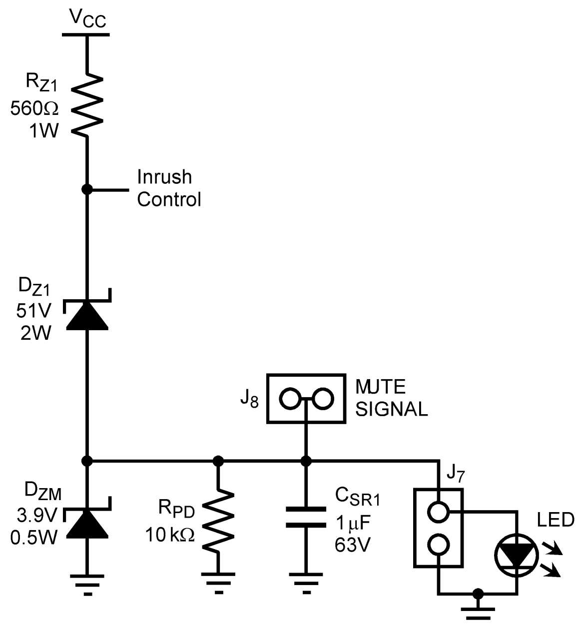

Figure 6. Mute Control

The voltage threshold is set by the value of the D_{Z1} Zener diode, the current limiting R_{Z1} resistor and the forward voltage on the LED. The circuit works by simply requiring a certain positive supply rail voltage before the LED turns on and the amplifier switches out of Mute mode. The D_{Z1} Zener diode begins to conduct once the positive supply rail exceeds the rated voltage. At this point, the LED begins to develop voltage across it. The forward voltage of the LED (typically 2 V ~ 4 V) is used as the Mute voltage of the amplifier. Setting the Mute resistor on the amplifier PCB module correctly allows the amplifier to go out of Mute mode once the forward voltage of the LED is high enough to supply the needed Mute current. The LED is also used as an indicator, lighting when the amplifier is in Play mode. The values shown set the Mute voltage threshold to 57 V on power up and 58 V on power down. Because of component tolerances, the threshold voltages varies. At power down, the forward voltage of the LED collapses quickly, putting the amplifier into Mute mode well before the supplies are discharged for a quiet and relatively quick power off. Figure 7 and Figure 8 show the Mute signal with supply voltage at power on and power off. There is additional delay from when the Mute signal reaches the Mute threshold (~1.80 V for the amplifier PCB) and when the amplifier enters PLAY mode as a result of the mute delay capacitor on the amplifier PCB.

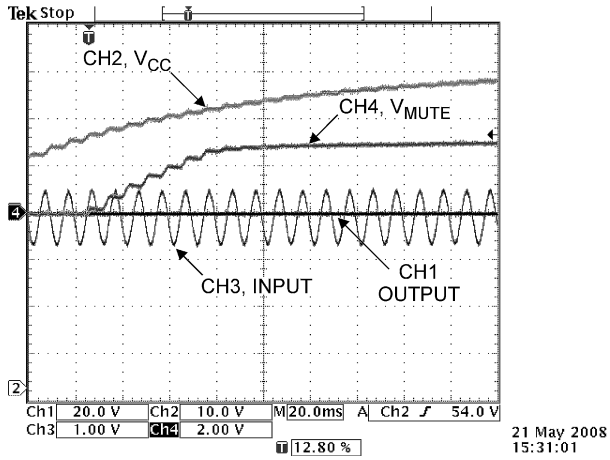

Figure 7. Mute at Power On

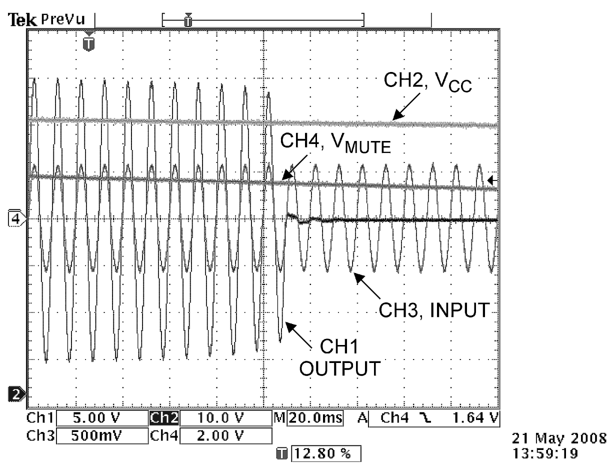

Figure 8. Mute at Power Off

The R_{ZM} Zener diode is for protection in the event of LED failure locking the Mute voltage so it does not exceed 4 V. The Mute resistor of the amplifier PCB module is sized for a maximum of 4 V safely limiting Mute current. R_{PD} is needed so D_{Z1} conducts and C_{SR1} is for a steady LED/Mute voltage.

A shortcoming of the simple Mute control circuit is that the brightness of the LED varies under a heavy amplifier load with the circuit values shown in Figure 6. Either the threshold of the Mute circuit can be lowered by changing the value of D_{Z1} for more consistent brightness in operation or a constant current circuit may be used. Figure 9 shows a basic constant current (LED brightness) circuit with similar threshold voltages as the Mute control circuit.

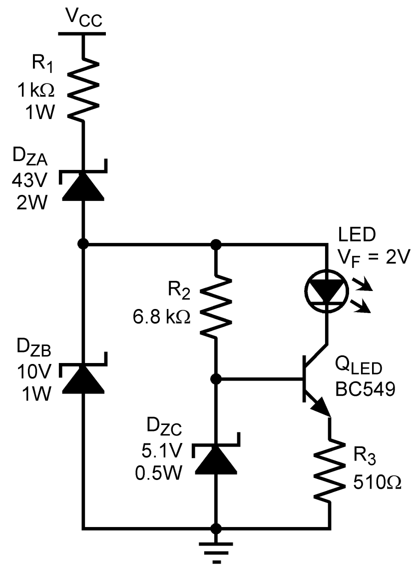

Figure 9. Constant Brightness LED Circuit

The LED first begins to light when the positive supply rail voltage exceeds 45 V. Once the positive rail reaches 60 V, the LED have 6.5 mA of current and only increase to 6.7 mA at 80 V with indiscernible change in brightness. Zener diode D_{ZA} sets the minimum threshold for first light of the LED. Combining the values of D_{ZA} and D_{ZB}, along with voltage drop across R_1 sets the voltage when the LED current reaches a constant value and constant brightness. R_3 and D_{ZC} set the LED current and R_2 is used to bias Q_{LED} and limit current through D_{ZC}. By using a 10-V Zener diode (D_{ZB}), the power dissipation in Q_{LED} is kept very low so that a small transistor can be used without power dissipation concerns. The trade-off is that the D_{ZA} Zener diode is required to dissipation about 1 W when the supply reaches 80 V. Figure 9 does not give both constant LED current and the Mute signal control as Figure 6, although the Mute control could be taken at the emitter of Q_{LED}. An alternate circuit to combine both Figure 6 and Figure 9 is shown in Figure 10.

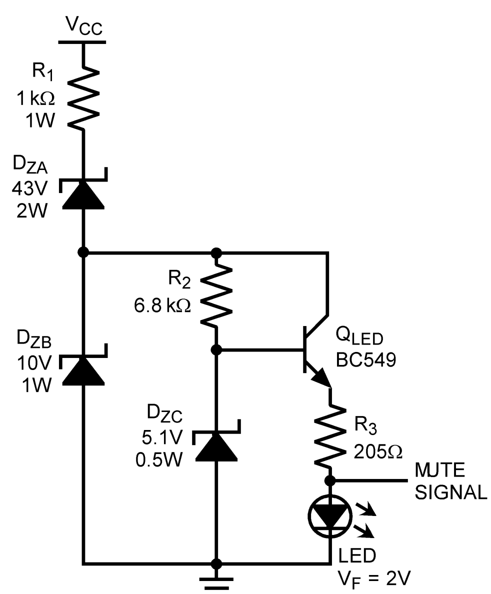

Figure 10. Constant Brightness LED and Mute Control Circuit

The circuit in Figure 10 has the same threshold voltages as in Figure 9 and similar Mute control thresholds as in Figure 6, but can also be used to control the Mute signal to the audio amplifier module. For a reduced supply voltage window from LED first light to constant brightness, D_{ZA} should be increased while D_{ZB} is reduced. This increases the LED first light threshold while reducing the additional voltage needed to reach the constant brightness threshold. The value of D_{ZC} may also be adjusted to achieve the designed circuit response.

6 Summary

The unregulated power supply presented gives very good performance while powering an audio amplifier. While circuit modifications and additions can improve performance, the solution presented has a relatively low part count and simplicity is maintained with all circuits. The power supply provides a ±70 V to ±73 V supply under quiescent conditions with full load voltage dropping to ±59 V to ±62 V.

7 Board Layer Views

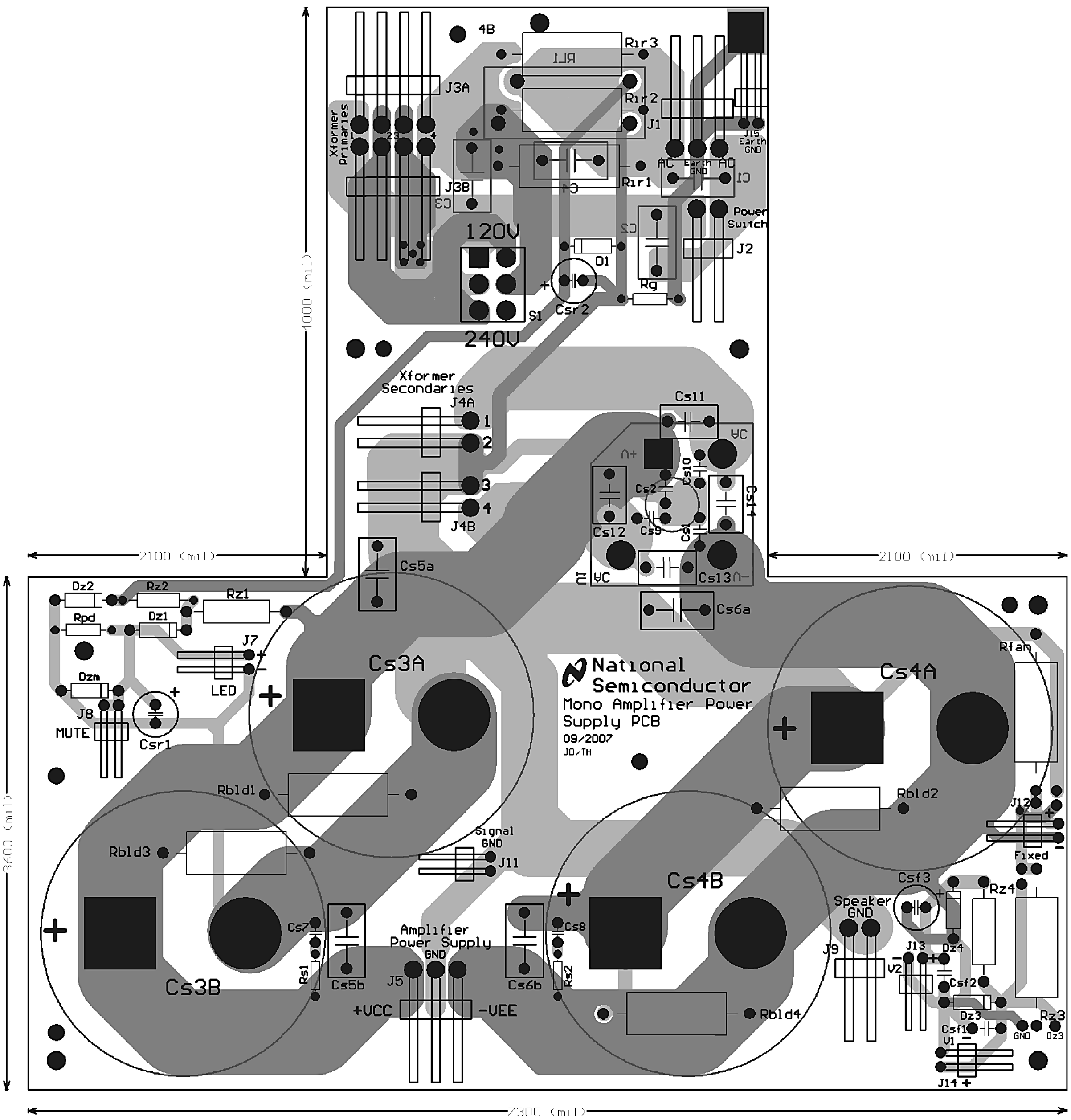

Figure 11. PCB Composite View From Top

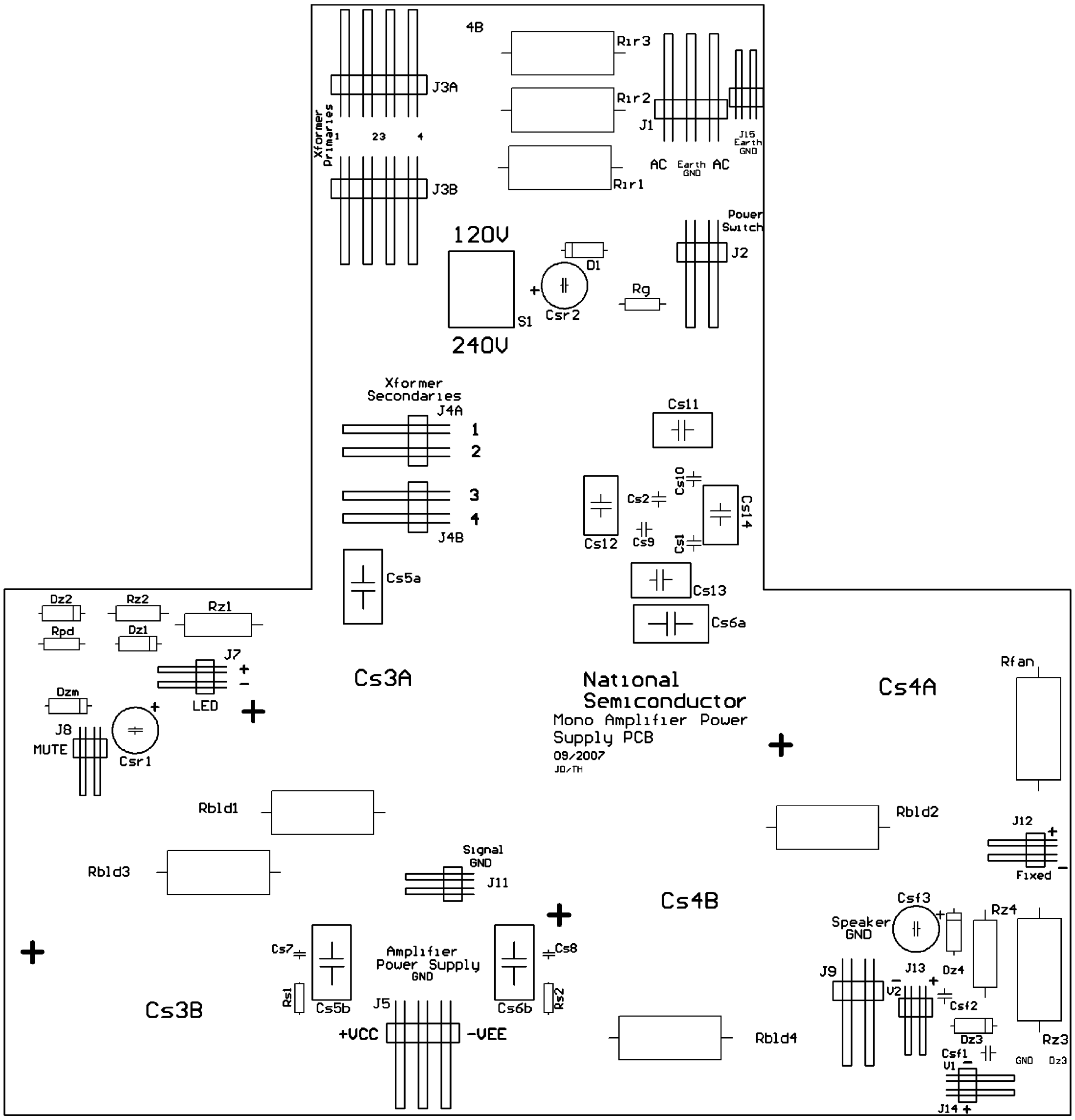

Figure 12. PCB Top Silkscreen View

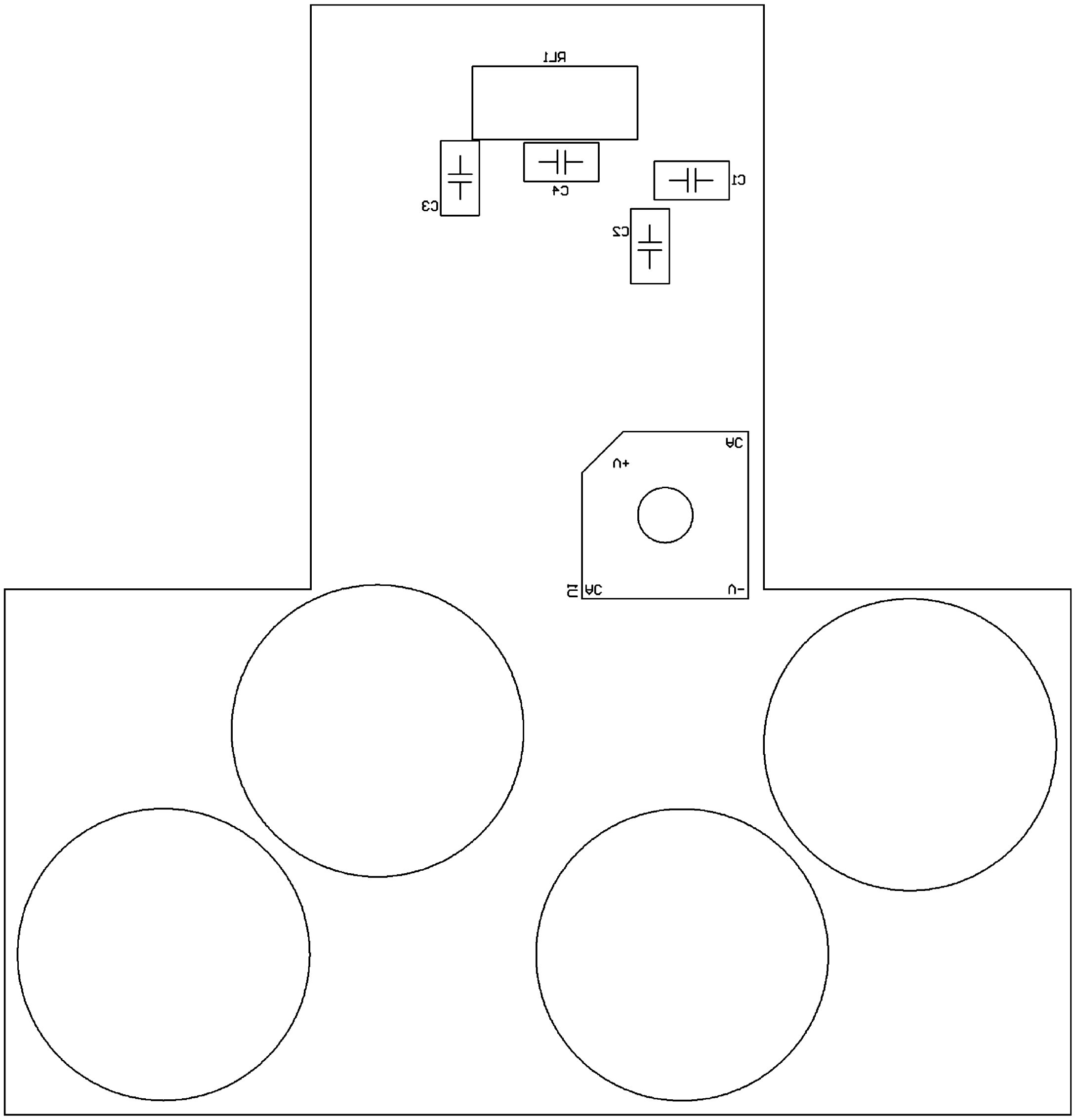

Figure 13. PCB Bottom Silkscreen View

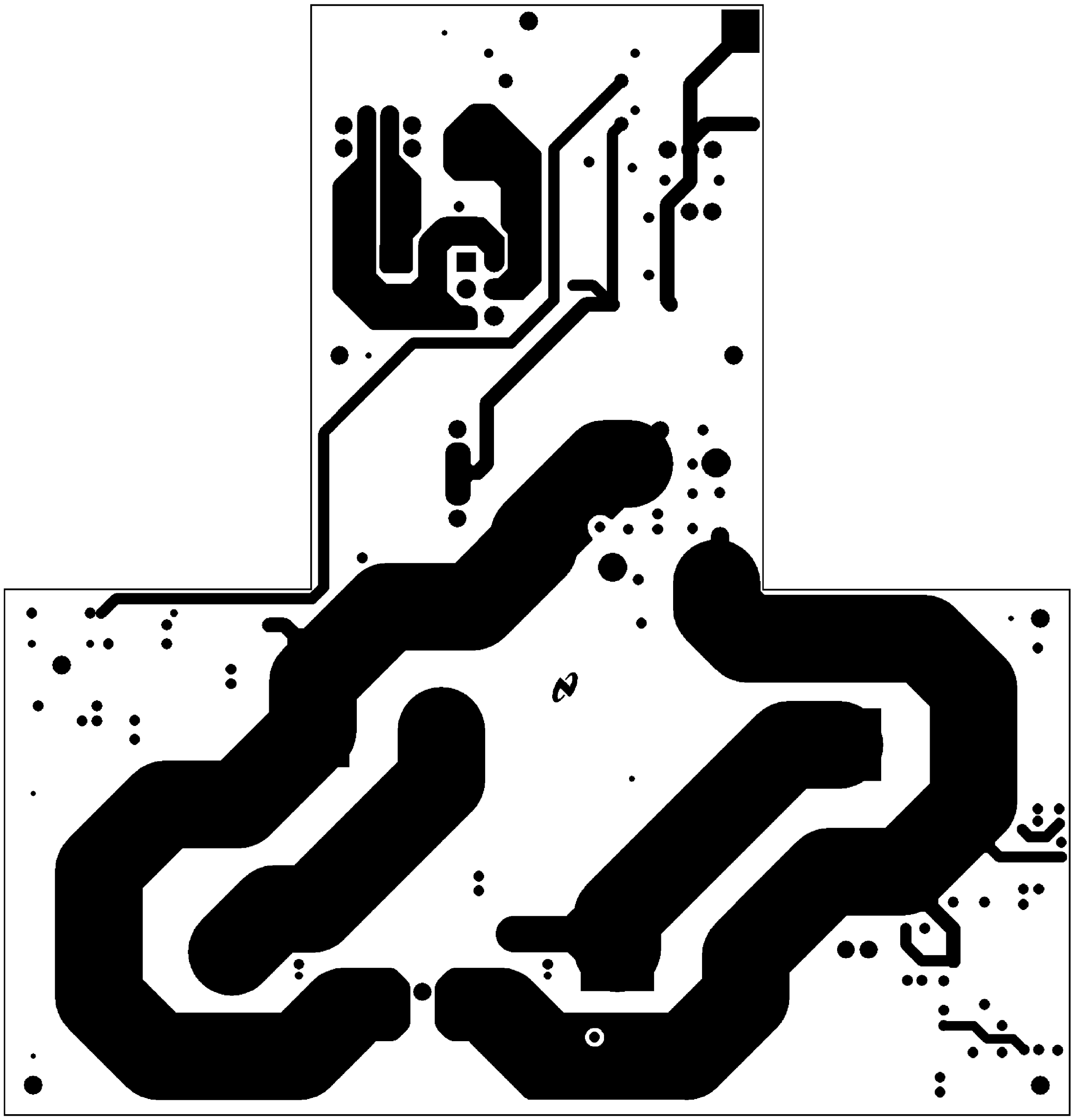

Figure 14. PCB Top Layer View

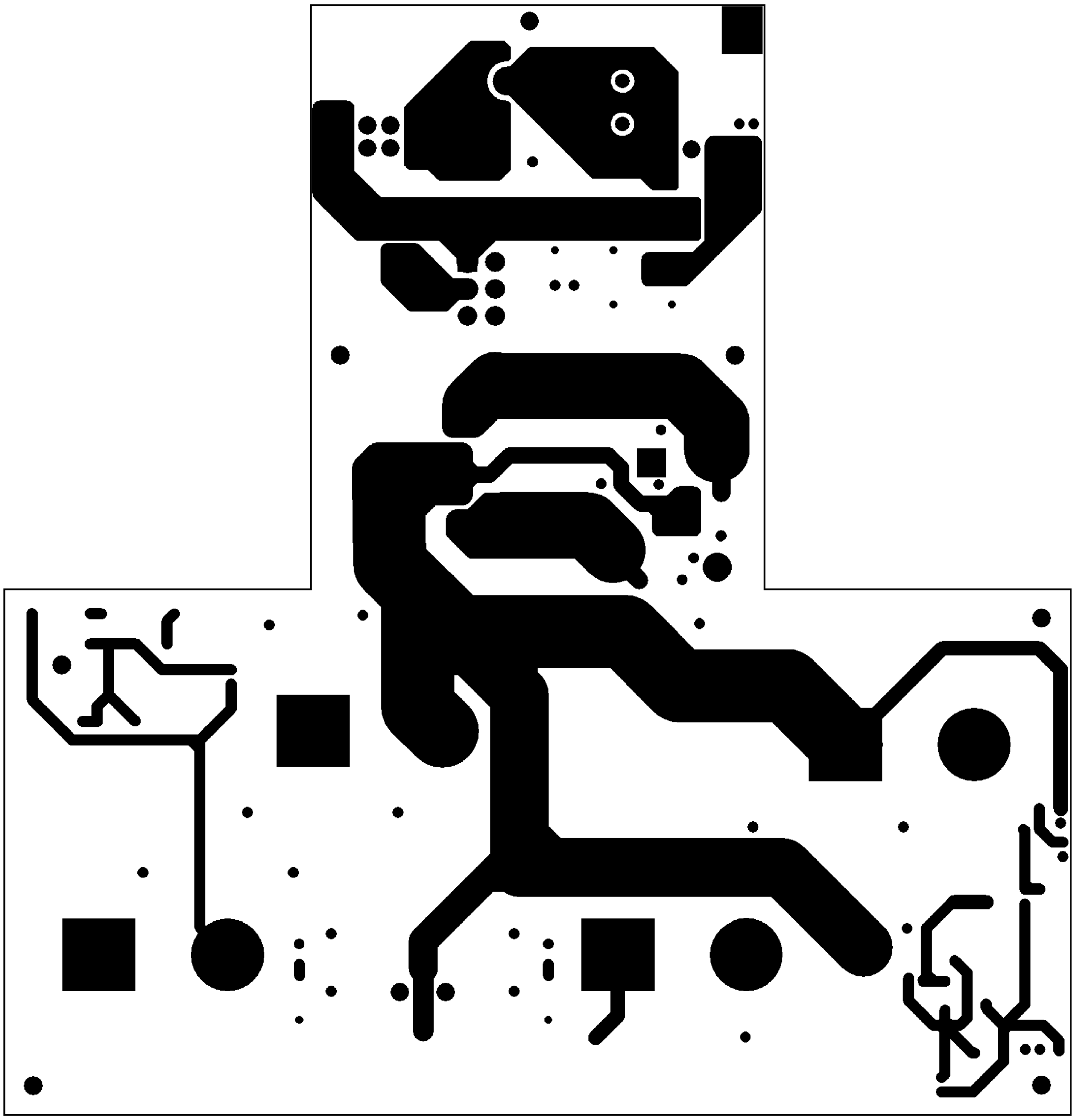

Figure 15. PCB Bottom Layer View

8 Revision History

Rev	Date	Description
1.0	06/03/08	Initial release.
1.01	03/15/10	Deleted all references to AN-1625.
2.0	06/27/19	Edited the Overview section. Edited application report for clarity.

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