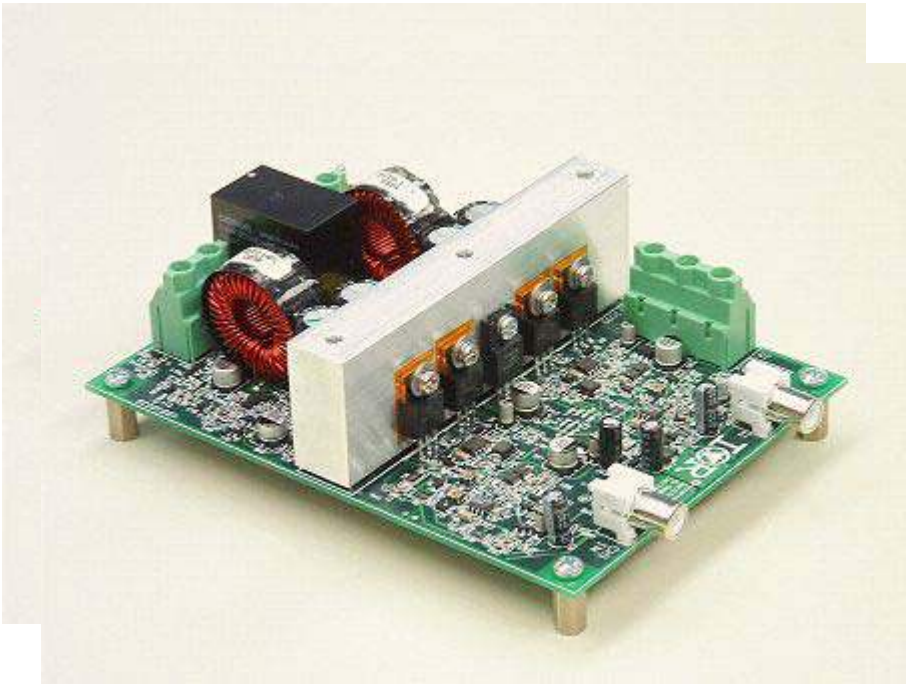
International
IOR Rectifier

REFERENCE DESIGN

IRAUDAMP1 revB

High Power Class D Audio Power Amplifier using IR2011S



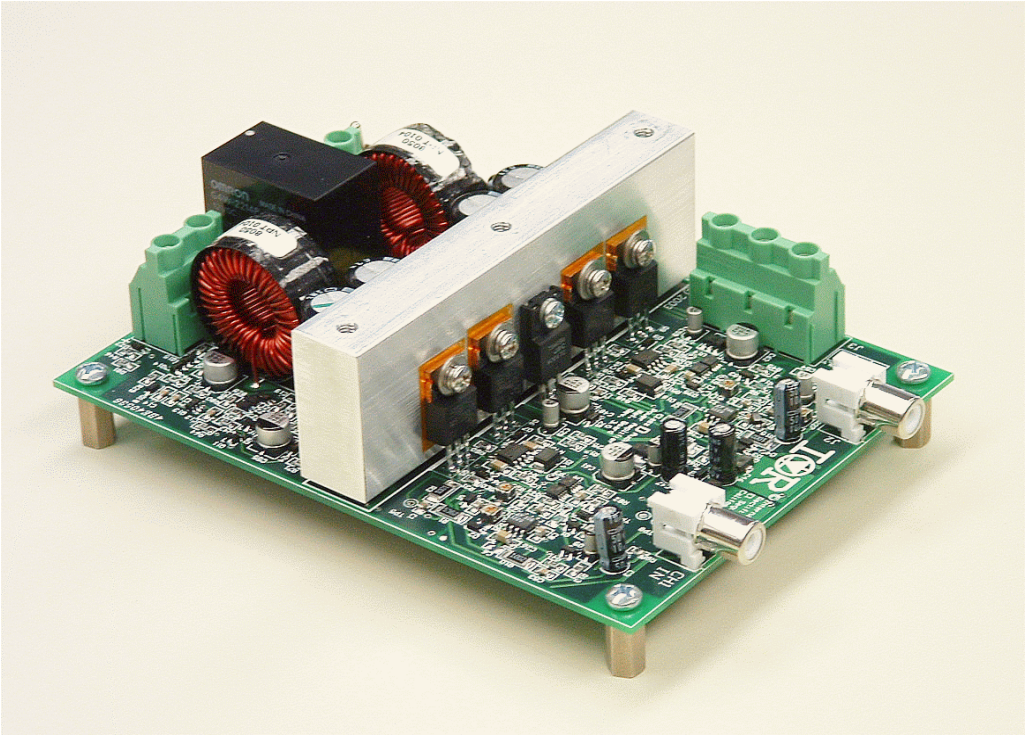
High Power Class D Audio Power Amplifier using IR2011S

Features

- Complete Analog Input Class D Audio Power Amplifier
- 500W + 500W Peak Stereo (2CH) Output
- THD+N=0.008% @1kHz, 100W, 4Ω
- High Efficiency 93% @350W, 1kHz, 4Ω
- Simple Self Oscillating Half-Bridge Topology
- Includes all Local House-keeping Power Supplies
- Protection Functions
- Wide Operating Supply Voltage Range ±25 ~ 60V
- Immune to Power Supply Fluctuations

Description

The IRAUDAMP1 is an example of a simple complete class D audio power amplifier design using the IR2011S, high speed high voltage gate driver IC. The design contains protection functions and house keeping power supplies for ease of use. This reference design is intended to demonstrate how to use the IR2011S, implement protection circuits, and design an optimum PCB layout.



Specifications

±Vcc=±50V, RL = 4Ω unless otherwise noted.

Output Stage Topology	**Half Bridge**	
Modulator	**Self Oscillating, 2nd order Sigma-Delta Modulation, Analog Input**	
IR Devices Used	**IR2011S Gate Driver** **IRFB23N15D MOSFET**	
Switching Frequency	**400kHz (Adjustable)**	**No signal**
Rated Output Power	**250W + 250W** **350W + 350W** **370W + 370W (Peak Power)** **500W + 500W (Peak Power)**	**1kHz, THD=1.0%** **1kHz, THD=10%** **1kHz, THD=1.0%, ±60V** **1kHz, THD=10%, ±60V**
THD+N	**0.008%**	**1kHz, 100W,** **AES-17 LPF**
Efficiency	**93%**	**1kHz, 350W,** **Class D stage**
S/N	**115dB**	**IHF-A Weighted,** **BW=20kHz**
Damping Factor	**200**	**8Ω, 1KHz**
Frequency Response	**3Hz ~ 40kHz (-3dB)**	
Channel Separation	**100dB** **80dB**	**100Hz** **10kHz**
Minimum Load Impedance	**4Ω**	
Power Supply	**±50V, (operational ±25V ~ ±60V)**	
Quiescent Current	**+75mA, -125mA**	
Dimensions	**4.0”(W) x 5.5”(D) x 1.5”(H)**	

Instructions

Connection Diagram

A typical test setup is shown in Fig.1.

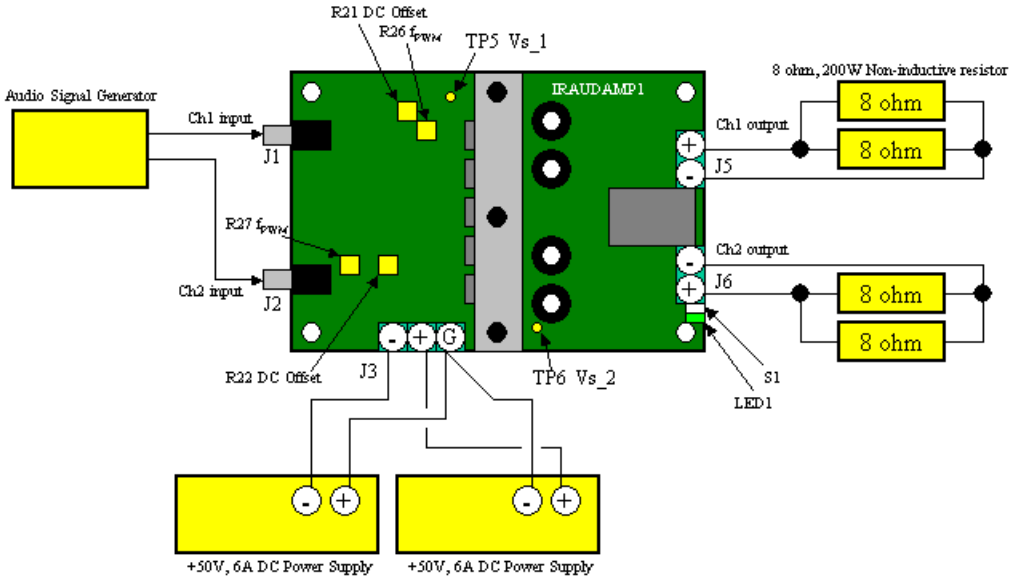


Fig.1 Test Setup

Pin Description

J1	CH-1 IN	Analog input for CH-1
J2	CH-2 IN	Analog input for CH-2
J3	POWER	Positive and negative supply
J5	CH-1 OUT	Output for CH-1
J6	CH-2 OUT	Output for CH-2

Resetting Protection

1. Turn off ±50V at the same time
2. Wait until supply voltage drops to less than 5V
3. Apply ±50V at the same time
4. Apply audio signal

Power Supply

The IRAUDAMP1 requires a pair of symmetric dual power supplies ranging from ±25V to ±60V. A regulated power supply is preferable for performance measurements, but not always necessary. The bus capacitor, C38-41 on the board along with high frequency bypass C31, C32, C35, and C36; are designed to take care only of the high frequency ripple current components from the switching action. A set of bus capacitors having enough capacitance to handle the audio ripple current must be placed outside the board if an unregulated power supply is used.

Bus Pumping

Since the IRAUDAMP1 is a half bridge configuration, the bus pumping phenomenon occurs when the amplifier outputs low frequency signal is below 100Hz. The bus pumping phenomenon is unavoidable; significant bus voltage fluctuations caused by a reverse energy flow coming back to the power supply from the class D amplifier. This might cause an unacceptable instablility condition in the feedback system of a power supply.
The bus pumping becomes worse in the following conditions.

- lower the output frequency
- lower the load impedance
- higher the output voltage
- smaller the bus capacitance in bus capacitors

If the bus voltage become too high or too low, the IRAUDAMP1 will shutdown the switching operation, and remain in the off condition until resetting the protection using the method described above.
One of the easiest countermeasures is to drive both of the channels out of phase so that the reverse energy from one channel is consumed by the other, and does not return to the power supply.

Input Audio Signal

A proper input signal is an analog signal below 20kHz, up to 5Vrms, having a source impedance of less than 600 Ω. A 30-60KHz input signal can cause LC resonance in the output LPF, resulting in an abnormally large amount of reactive current flowing through the switching stage. The IRAUDAMP1 has a C-R network to dump the resonant energy and protect the board in such a condition. However, these sub-sonic input frequencies should be avoided.

Load Impedance

The IRAUDAMP1 is designed for a load impedance of 4Ω and larger. The frequency response will have a small peak at the corner frequency of the output LC LPF if the loading impedance is higher than 4Ω. The IRAUDAMP1 is stable with capacitive loading, however, it should be realized that the frequency response will be degraded by a heavy capacitive loading of more than 0.1µF.

Adjustments of DC offset and Switching Frequency

Component Number	Adjustment
R10	DC offset for CH-1
R26	Switching Frequency for CH-1
R22	DC offset for CH-2
R27	Switching Frequency for CH-2

Adjustments have to be done at an idling condition with no signal input.

Note: The PWM switching frequency in this type of self oscillating scheme greatly impacts the audio performances, especially in the case where two or more channels are in close proximity.

Thermal Considerations

The IRAUDAMP1 unitlizes a relatively thick aluminum block heatsink for peak power output handling capabilities. It can handle continuous 1/8 of the rated power, which is generally considered to be a normal operating condition in safety standards, for a considerable length of time such as one hour. The size of the heatsink, however, is not sufficient to handle continuous rated power.
Fig.2 shows the relationship between total power dissipation and temperature rise at equilibrium. If testing requires running conditions with continuous power a higher than 1/8 of the rated power, then, attach extensions to the top of the heatsink using three M4 screw taps prepared for this purpose. Please note that the heatsink is electrically connected to the GND pin.

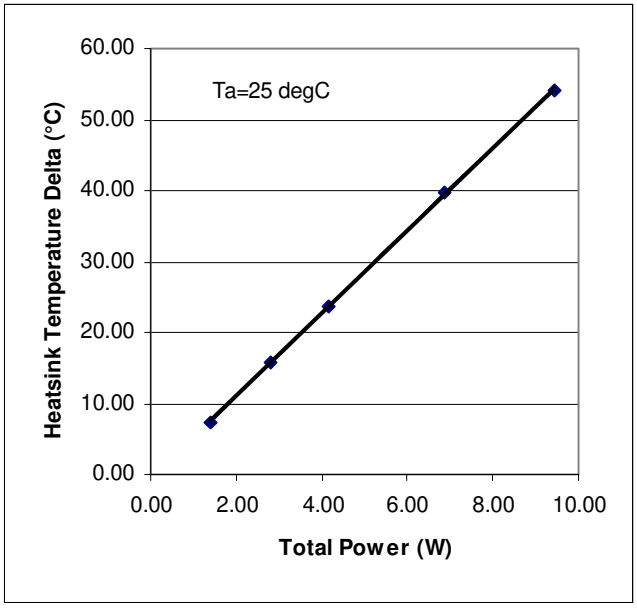


Fig.2 Heatsink Thermal Characteristic at Equilibrium

Functional Description

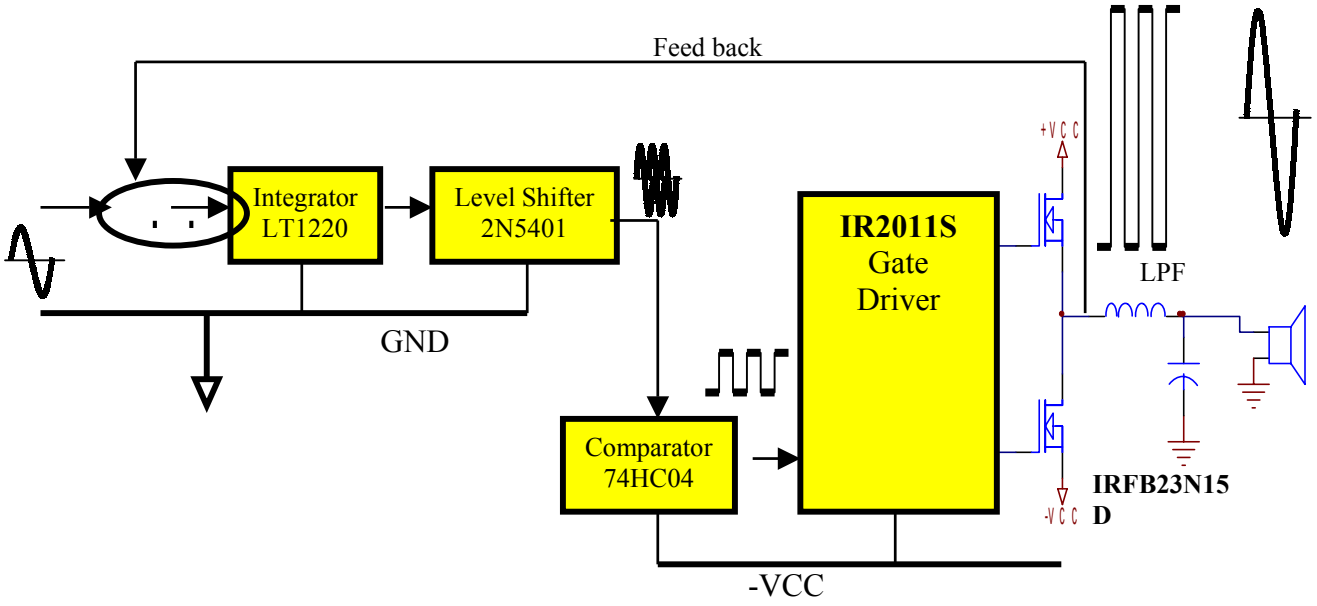


Fig. 3 Simplified Block Diagram of Amplifier

Self Oscillating PWM modulator

The IRAUDAMP1 class D audio power amplifier is based on a self oscillating type PWM modulator for the lowest component count and a robust design. This topology is basically an analog version of a 2nd order sigma delta modulation having a class D switching stage inside the loop. The benefit of the sigma delta modulation in comparison to the carrier signal based modulator is that all the error in the audible frequency range is shifted away into the inaudible upper frequency range by nature of its operation, and it can apply a sufficient amount of correction. Another important benefit of the self-oscillating modulator is that it will cease operation if something interrupts the oscillating sequences. This is generally beneficial in a class D application because it makes the amplifier more robust.

Looking at CH-1 as an example, OP amp U1 forms a front end 2nd order integrator with C17 & C18. This integrator receives a rectangular waveform from the class D switching stage and outputs a quadratic oscillatory waveform as a carrier signal. To create the modulated PWM, the input signal shifts the average value of this quadratic waveform, through R10, so that the duty varies according to the instantaneous value of the analog input signal. The level shift transistor Q1 converts the carrier signal from a voltage form into a current form and sends it to the logic gates sitting on the negative DC bus via the level shift resistor R44, which conerts the signal back into a voltage form. The signal is then quantized by the threshold of the CMOS inverter gate U2. The PWM signal out of the inverter is split into two signals, with opposite polarity, one for high side MOSFET drive signal, the other for the low side MOSFET drive signal. The dual AND gates of U4 are used to implement the shutdown function, a high shutdown signal will ensure the outputs of the AND gates are low which in turn ensures the inputs to the gate driver are low.

Under normal conditions the SD signal is low and the drive signal are passed directly through the AND gates to the IR2011S gate driver.
The IR2011 drives two IRFB23N15D MOSFETs in the power stage to provide the amplified Digital PWM waveform.
The amplified analog output is recreated by demodulating the amplified PWM . This is done by means of the LC Low Pass Filter formed by L1 and C51, which filters out the class D switching signal .

Switching Frequency

The self oscillating frequency is determined by the total delay time inside the loop. The following parameters affect the frequency.

- Delay time in logic circuits
- The gate driver propagation delay
- MOSFET switching speed
- Integration time constant in the front end integrator, e.g. R1, R23, R26, C17, and C18 for CH-1.
- Supply Voltages

Gate Driver

The IRAUDAMP1 uses the IR2011S gate driver IC which is suitable for high speed, high speed switching applications up to 200V. In this design, the difference between ton and toff is used to generate a dead-time (a blanking time in between the on state of the two MOSFETs). Because of this, there is no gate timing adjustment on the board.

MOSFET Gate Resistor

In order to add a little more dead-time and compensate for the finite switching transient time in the MOSFET, a schottky diode is added in parallel with the gate resistor. The gate resistor (R31 and R50 in CH-1) adds about 10nS of delay time at turn on by limiting the gate charging current to the IRFB23N15D. The schottky diode bypasses the gate resistor in the gate discharge path, so that there is no falling edge delay. The delay at the rising edge adds dead time.

Startup Circuit

A self oscillating scheme contains class D switching stage that requires a start-up triggering signal to charge the high side bootstrap capacitor . The starter circuits, Q9 and Q10, detect the rising edge of –Vcc and turn the low side MOSFETs on for about 200mS to charge the bootstrap capacitors C23 and C24, then release the loop allowing the oscillation to start.

Housekeeping Voltage Regulators

The IRAUDAMP1 contains following regulators to accommodate all the necessary functions on the board.

Regulator	Component #	Usage
+5V	Q18	OP Amps in the modulator
-5V	Q17	OP Amps in the modulator, Startup circuit
-Vcc+5V	U13, U14	Logic ICs
-Vcc+12V	U11	Gate driver IC, Protection circuits

Protection

The IRAUDAMP1 includes protection features for overvoltage (OVP), overcurrent (OCP), and DC current protection. All of the protection uses OR logic so that any of the protection features when activated will disengage the output relay to cut off the load and protect the speakers. OCP and OVP functions are latched, DC protection is unlatched. To reset the protection, the bus voltage has to be reset to zero volts before re-applying power. The protection circuitry will also shutdown the amplifier if a fault condition is detected.

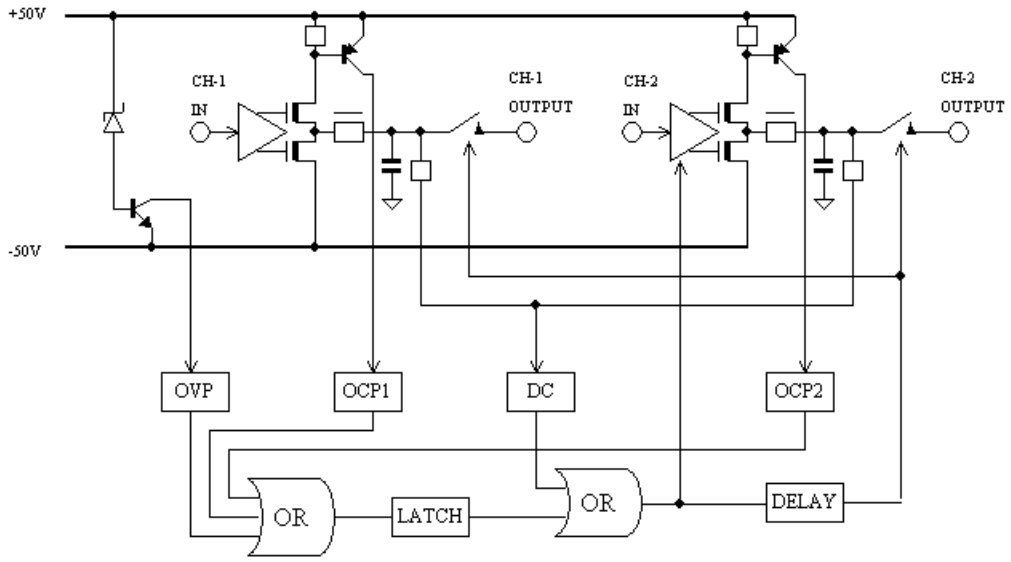


Fig.4 Functional Block Diagram of Protection

DC protection

DC voltage output protection is provided to protect the speakers from DC current. This abnormal condition occurs only when the power amplifier fails and one of the MOSFETs remains in the ON state. DC protection is activated if the output has more than ±3V DC offset. DC protection is unltached, and the amplifier will resume normal operation about 2 seconds after a fault condition has been removed.

Over Current Protection

Over Current Protection will activate and shut down the entire amplifier if the amount of current sensed at the positive power supply in either channel exceeds the preset value. If an overcurrent condition occurs, the voltage generated across a shunt resistor turns on the OCP detection transistors, Q2 and Q4 to send a signal to the protection logic.

Over Voltage Protection

Over Voltage Protection shuts down the amplifier if the bus voltage between –Vcc and +Vcc exceeds 126V, the threshold is determined by the sum of the zener voltages of Z1, Z2, and Z3. OVP protects the board from the bus pumping phenomena which occurs at very low audio signal frequencies by shutting down the amplifier.

Power On/Off Sequence Timing

The IRAUDAMP1 is a robust design that can handle any power up/down sequence. However, symmetrical power up is recommended to properly initiate the self oscillation. In order for the unit to startup correctly, the negative power supply has to be initialized from zero volts.
Fig.5 shows a preferred power up sequence. At start-up, a DC output voltage appears at the output of the LPF due to the charging of the bootstrap capacitors. To avoid this unwanted DC output signal being to fed to the load, the output relay RLY1 engages approximately 2 seconds after the startup condition is completed. Fig 6 below shows the start-up timing with the audio output not being activated until approximately 2 seconds after the power supplies are stable and the amplifier has reached steady state operation.

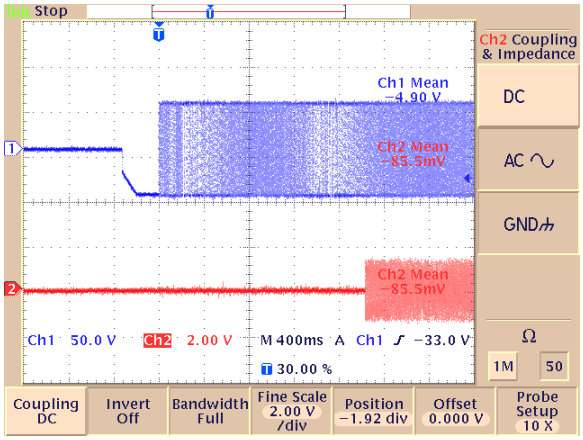


Fig.5 Start-up Timing
(BLU: Switching, RED: Audio Output)

Typical Performance

±Vcc=±50V, RL = 4Ω unless otherwise noted.

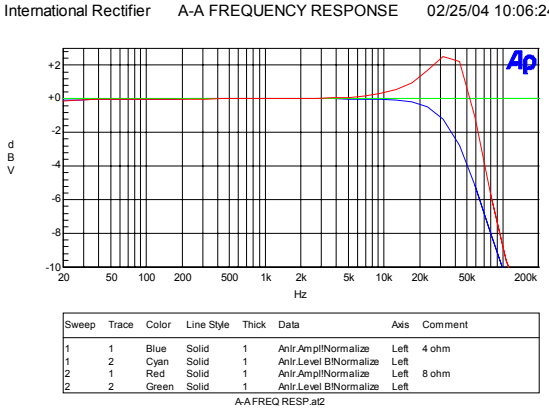


Fig.6 Frequency characteristics Frequency

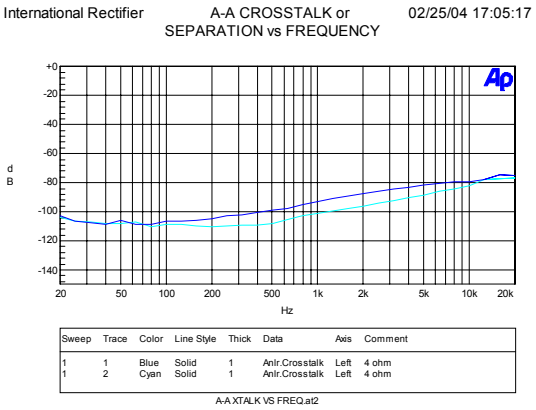


Fig.7 Channel Separation v.s.

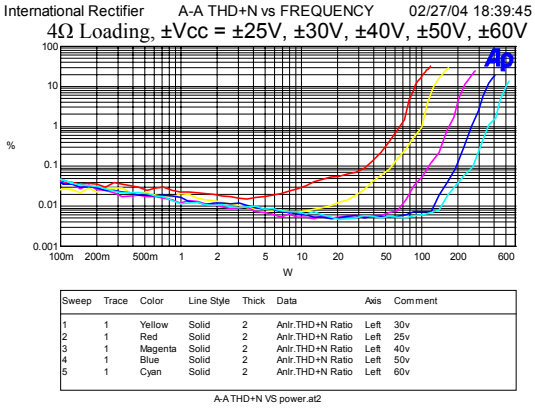


Fig.8 THD+N v.s. Output Power

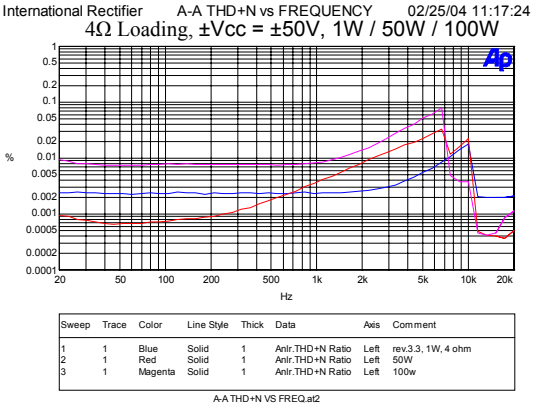


Fig.9 THD+N v.s. Frequency (4Ω)

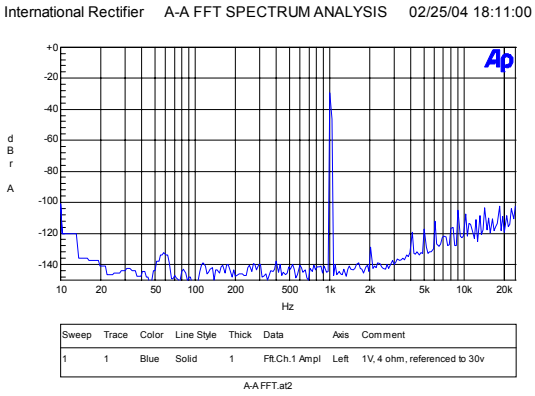


Fig.10 Spectrum
(1kHz, 1V, 4Ω, f_{SW}=400KHz)

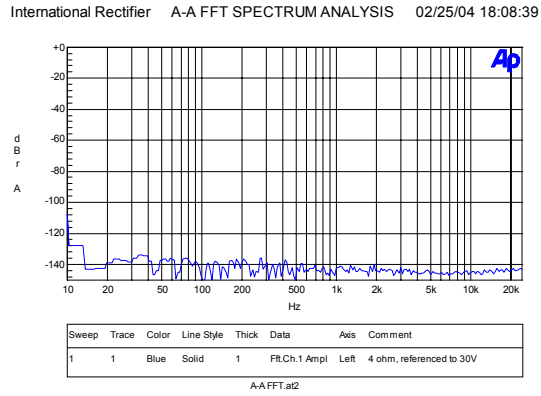
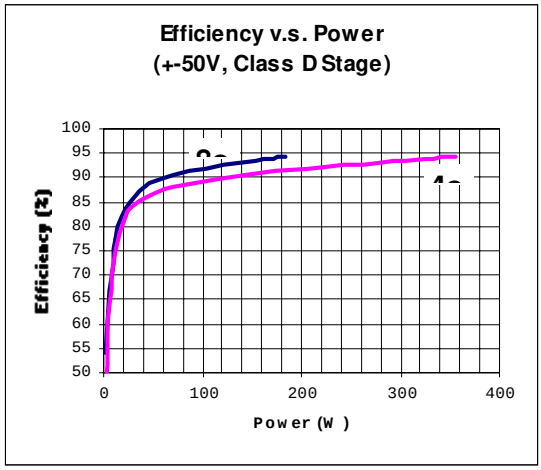


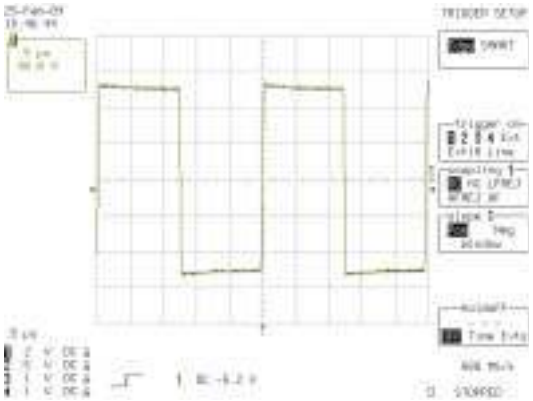
Fig.11 Residual Noise Spectrum
(no signal, 4Ω, f_{SW}=400KHz)



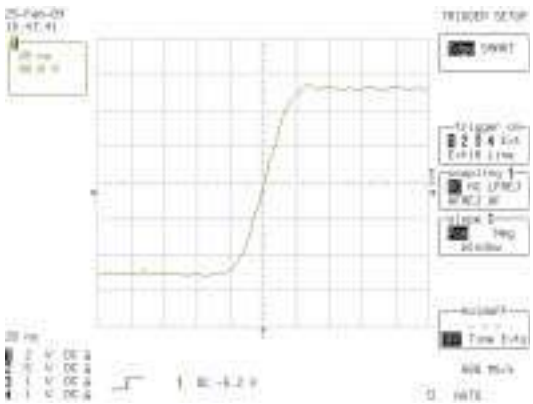
±Vcc = ±50V, f_{SW}=400kHz

Fig.12 Efficiency v.s. Output Power

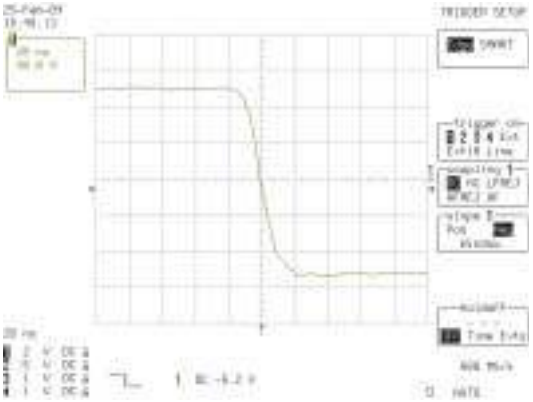
Typical Switching Waveforms



(a) 20v/div, 0.5µS/div

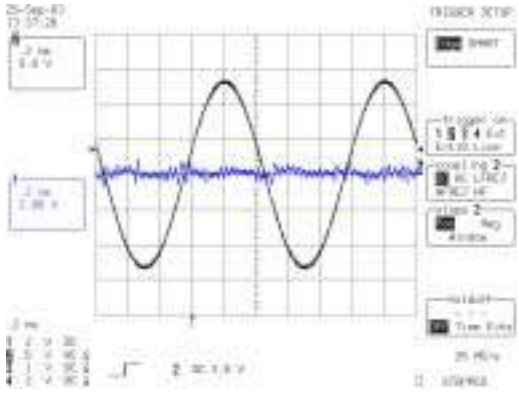


(b) 20nS/div, Rising Edge

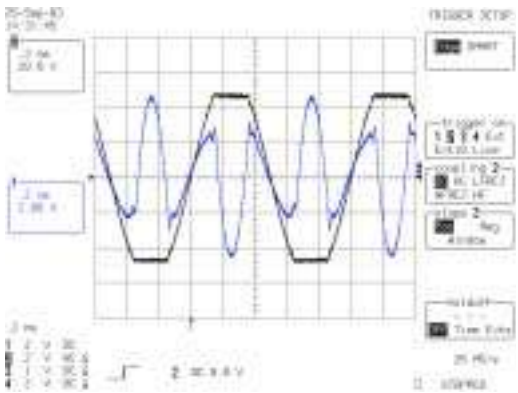


(c) 20nS/div, Falling Edge

Fig.13 Switching Waveform at Output Node (TP5)



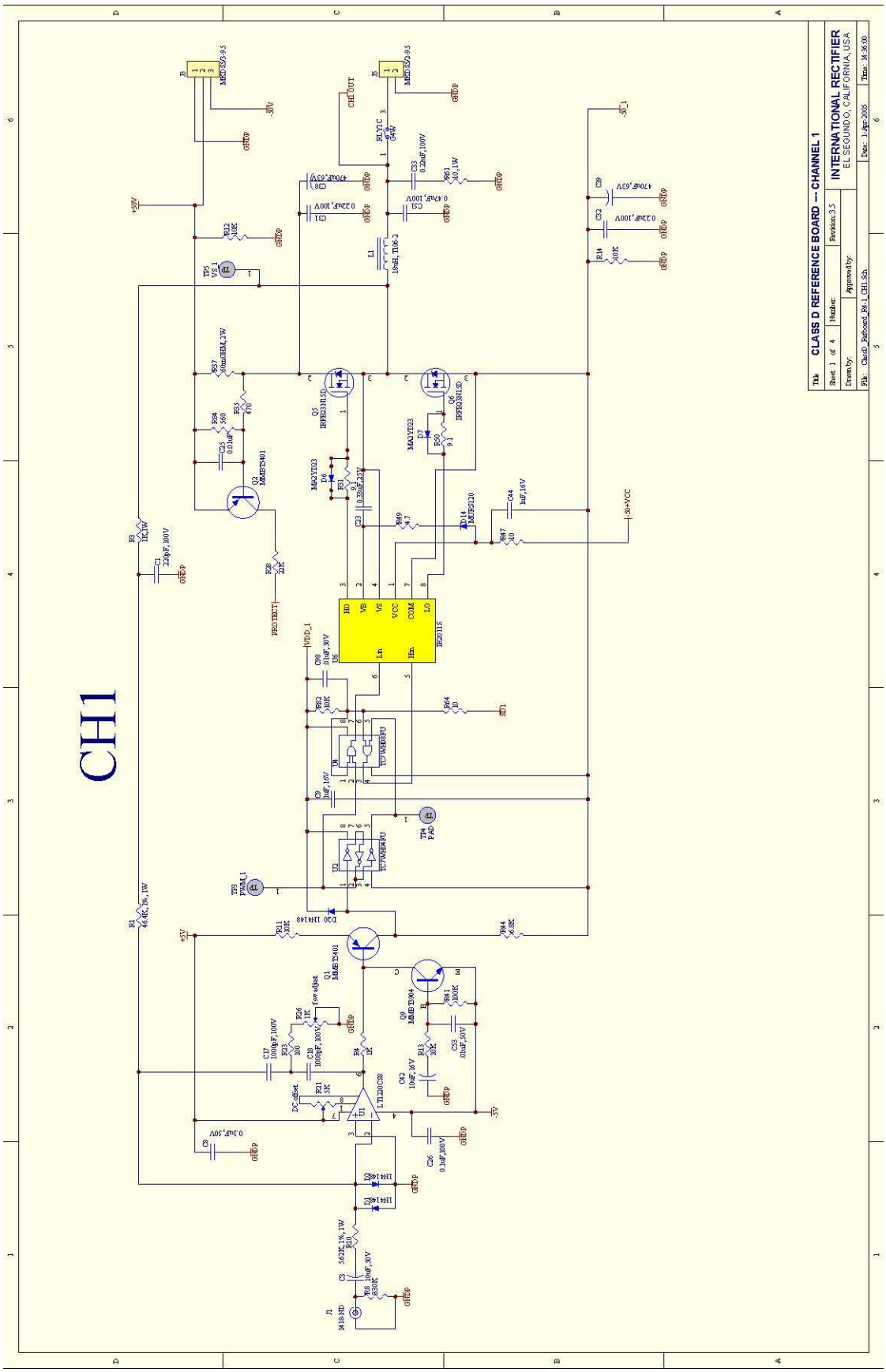
(a) 50W / 4Ω 1KHz, THD+N=0.0078%

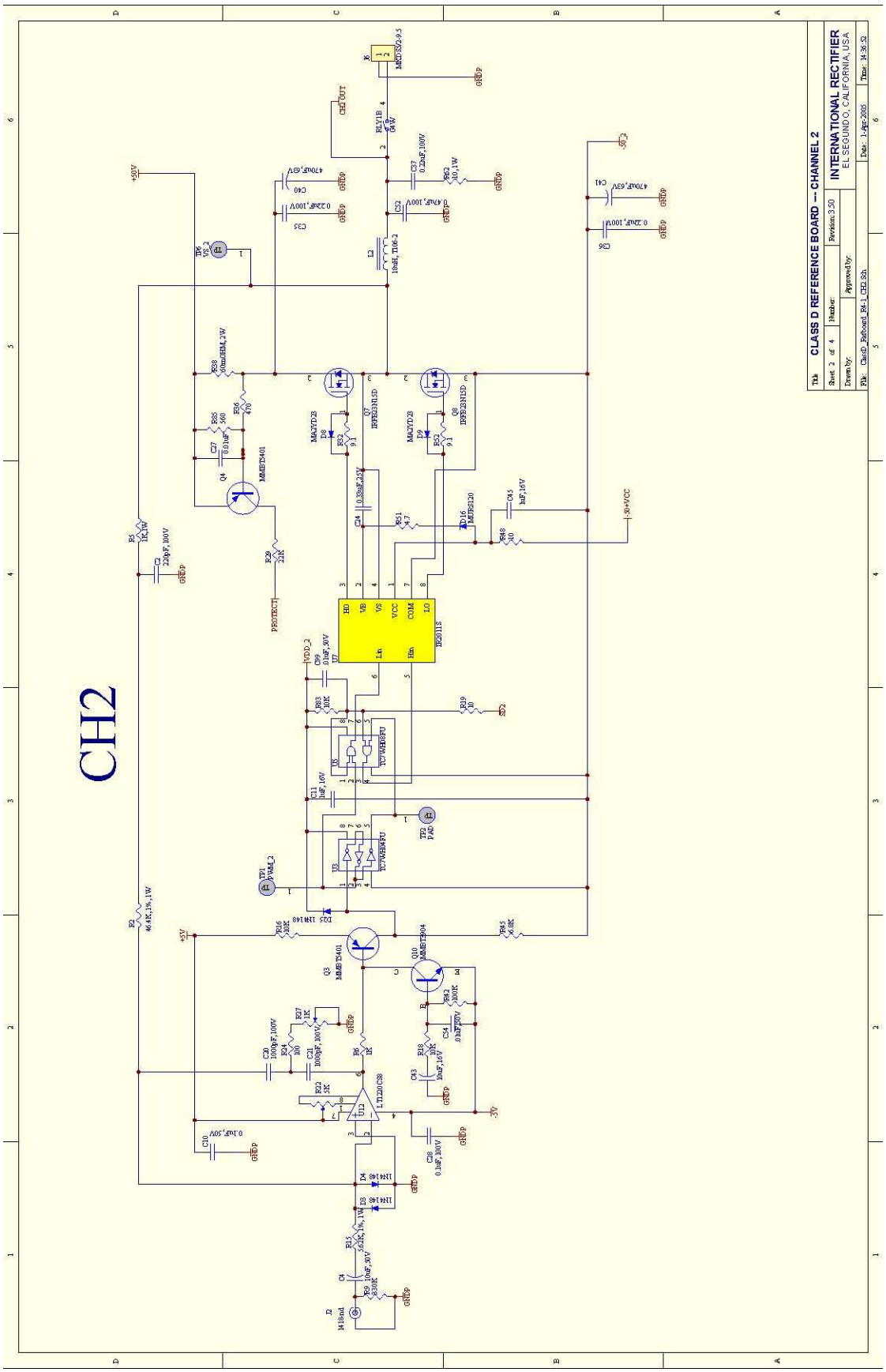


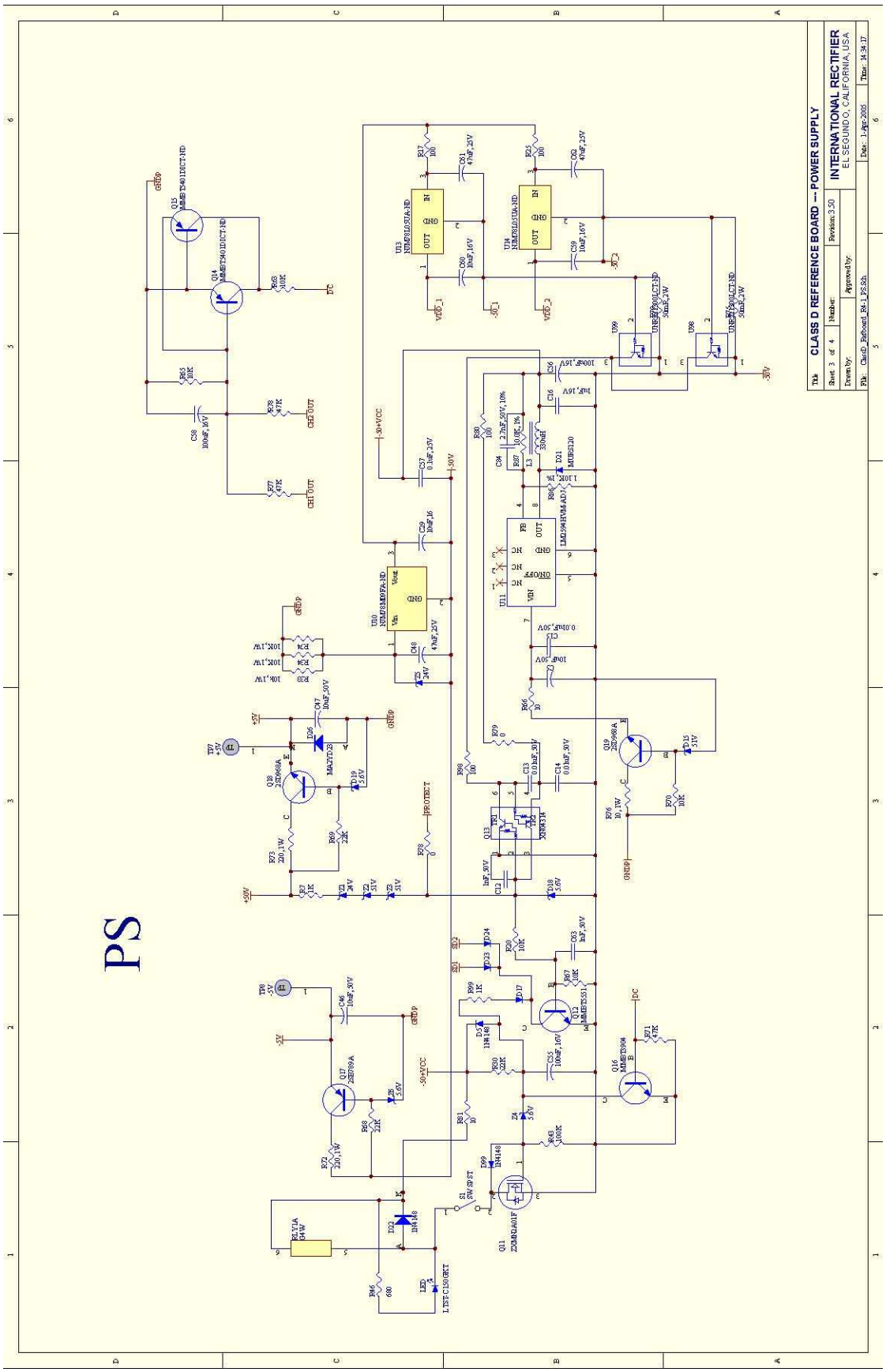
(b) 352W / 4Ω, 1KHz, THD+N=10%

Fig.14 Distortion Waveform

Schematic Diagrams




CH2
CLASS D REFERENCE BOARD -- CHANNEL 2
INTERNATIONAL RECTIFIER
EL SEGUNDO, CALIFORNIA, USA


PS
CLASS D REFERENCE BOARD -- POWER SUPPLY
INTERNATIONAL RECTIFIER
EL SEGUNDO, CALIFORNIA, USA

IRAUDAMP1 Bill of Materials

Qty	Manufacturer	Manuf. Part#	Designator	Part Type	Description
2	IR	IR2011S	U6,U7	IR2011S	High and Low Side Driver
4	IR	IRFB23N15D	Q6,Q5,Q8,Q7	IRFB23N15D	N-Channel MOSFET
3	IR	MURS120DICT	D14,D16,D21	MURS120DICT	fast recovery diode
1				Heatsink	Heatsink
2			L2,L1	18uH	inductor, T-106-2, t=37, AWG18
1	Lite-On Trading USA, Inc.	LTST-C150GKT	LED1	LTST-C150GKT	LED, SMD
12	Diodes Inc.	1N4148W-7	D1,D2,D3,D4,D5,D17,D20,D23,D24,D25, D22,D99	1N4148WDICT-ND	DIODE
2	Phoenix Contact	1714971	J6,J5	MKDS5/2-9.5	terminal 2P
1	Phoenix Contact	1714984	J3	MKDS5/3-9.5	terminal 3P
1	Panasonic	2SB0789A0L	Q17	2SB789A	2SB789A, SMD
2	Panasonic	2SD0968A0L	Q18,Q19	2SD968A	2SD968A, SMD
2	Panasonic	UNR4223	U99,U98	UNR4223	UNR4223,
2	Diodes Inc.	BZT52C24-7	Z5,Z1	24V	zener diode, SMD
3	Diodes Inc.	BZT52C51-7	D15,Z3,Z2	51V	zener diode
4	Diodes Inc.	BZT52C5V6-7	D19,Z6,D18,Z4	5.6V	zener diode, SMD
2	CUI Inc	RCJ-041	J1,J2	CP-1418-ND	CONN_RCA JACK
3	Building Fasteners	INT LWZ 008		Washer	washer lock int tooth #8 zinc
1	Building Fasteners	PMS 440 0050 PH		Screw	Screw, 4-40 Philips, L=0.5"
4	Building Fasteners	PMS 632 0025 PH		Screw	6-32 x 1/4, Philips
3	Building Fasteners	MPMS 004 0012 PH		Screw	Screw, M4 Philips, L=12mm
1	National Semiconductor	LM2594HVM-ADJ	U11	LM2594HVM-ADJ	Step-Down Voltage Regulator
2	Linear Technology	LT1220CS8	U12,U1	LT1220CS8	OP AMP
1	J W Miller Magnetics	PM3316-331M	L3	330uH	inductor, SMD
5	Panasonic	MA2YD2300L	D9,D6,D7,D8,D26	MA2YD23	DIODE
3	Diodes Inc.	MMBT3904-7	Q10,Q9,Q16	MMBT3904DICT-ND	2N3904, SMD
6	Diodes Inc.	MMBT5401	Q14,Q15,Q2,Q3,Q4, Q1	MMBT5401DICT-ND	2N5401, SMD
1	Diodes Inc.	MMBT5551DICT-ND	Q12	MMBT5551DICT-ND	2N5551, SMD
2	NJR	NJM78L05UA	U13,U14	NJM78L05UA-ND	Positive Voltage Regulator

Qty	Manufacturer	Manuf. Part#	Designator	Part Type	Description
1	NJR	NJM78M09FA	U10	NJM78M09FA-ND	Positive Voltage Regulator
2	Panasonic	ERJ-6GEYJ102V	R7,R99	1K	resistor, 0805
6	Panasonic	ERJ-6GEYJ101V	R17,R25,R23,R24,R80,R98	100	resistor, 0805
3	Panasonic	ERJ-6GEYJ104V	R43,R41,R42	100K	resistor, 0805
7	Panasonic	ERJ-6GEYJ100V	R47,R19,R66,R48,R64,R66,R81	10	resistor, 0805
12	Panasonic	ERJ-6GEYJ103V	R70,R43,R18,R20,R12,R14,R13,R65,R83,R82,R63,R67	10K	resistor, 0805
5	Panasonic	ERJ-6GEYJ223V	R68,R69,R30,R29,R28	22K	resistor, 0805
2	Panasonic	ERJ-6GEYJ334V	R8,R9	330K	resistor, 0805
2	Panasonic	ERJ-6GEYJ4R7V	R49,R51	4.7	resistor, 0805
2	Panasonic	ERJ-6GEYJ471V	R35,R36	470	resistor, 0805
3	Panasonic	ERJ-6GEYJ473V	R71,R77,R78	47K	resistor, 0805
1	Panasonic	ERJ-6GEYJ681V	R46	680	resistor, 0805
2	Panasonic	ERJ-6GEYJ561V	R84,R85	560	resistor, 0805
4	Panasonic	ERJ-6GEYJ9R1V	R32,R31,R50,R52	9.1	resistor, 0805
10	Panasonic	ECJ-2VB1H103K	C27,C25,C14,C15,C12,C13,C54,C53,C99,C98	0.01uF, 50V	capacitor, 0805
3	Panasonic	ECJ-2VB1E104K	C57,C10,C8	0.1uF, 25V	capacitor, 0805
3	Panasonic	ECJ-3YB1C105K	C16,C45,C44	1uF, 16V	capacitor, 1206
2	Panasonic	ECJ-3VB1E334K	C24,C23	0.33uF, 25V	capacitor, 1206
2	Panasonic	ECJ-2VC2A221J	C1,C2	220pF, 100V	capacitor, 0805
4	Panasonic	ECJ-2VC2A102J	C20,C21,C17,C18	1000pF, 100V	capacitor, 0805
1	Panasonic	ECJ-2VB1H102K	C63	1000pF, 50V	capacitor, 0805
2	Panasonic	ECJ-3YB2A104K	C28,C26	0.1uF, 100V	capacitor, 1206
2	Panasonic	ECJ-2FB1C105K	C11,C9	1uF, 16V	capacitor, 0805
1	Panasonic	ECJ-2VB1H272K	C84	2.7nF, 50V	Capacitor, 50v, 0805
5	Panasonic	ECE-V1CS100SR	C59,C60,C29,C43,C42	10uF, 16V	aluminum cap, SMD
3	Panasonic	ECE-V1CA101WP	C56,C58,C55	100uF, 16V	aluminum cap, SMD
3	Panasonic	ECE-V1EA470UP	C62,C48,C61	47uF, 25V	aluminum cap, SMD
4	Panasonic	ECW-U1224KC9	C31,C36,C32,C35	0.22uF, 100V	capacitor, 2820
3	Panasonic	ERJ-1TYJ103U	R34,R74,R33	10K, 1W	resistor, 2512
3	Panasonic	ERJ-1TYJ100U	R61,R62,R76	10, 1W	resistor, 2512
2	Panasonic	ERJ-1TYJ221U	R73,R72	220, 1W	resistor, 2512
2	BC Components	ST32TB102	R26,R27	1K	POTENTIOMETER

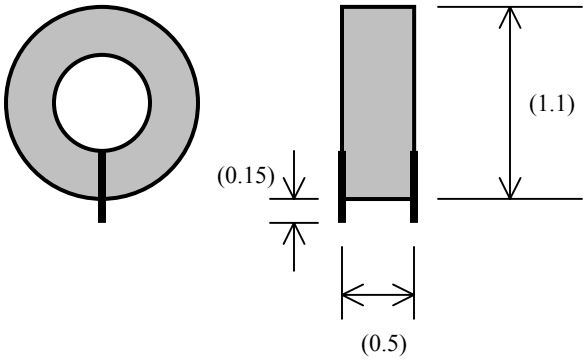
Qty	Manufacturer	Manuf. Part#	Designator	Part Type	Description
2	BC Components	ST32TB502	R22,R21	5K	POTENTIOMETER
2	Toshiba	TC7WH04FU(TE12L)	U3,U2	TC7WH04FU	TRIPLE INVERTER
2	Toshiba	TC7WH08FU(TE12L)	U5,U4	TC7WH08FU	DUAL 2-INPUT AND GATE
1	Panasonic	XN0431400L	Q13	XN04314	NPN-PNP Transistor
1	Omron Electronics, Inc	G4W-2214PUSHP-DC12	RLY1	SP Relay	DPST-NO RELAY, 15A
1	Zetex Inc.	ZXMN2A01FTA	Q11	ZXMN2A01	MOSFET, Nch
1	McMaster	98370A009		Flat Washer	flat washer for heat sink spacer
2	Vishay / Dale	CRCW20104642F100	R1,R2	46.4K, 1W	resistor, 2010
2	Vishay / Dale	CRCW20105621F100	R10,R15	5.62K, 1%, 1W	resistor, 2010
2	United Chemi-Con	SMG50VB10RM5X11LL	C46,C47	10uF, 50V	aluminum cap
3	United Chemi-Con	SMG50VB10RM5X11LL	C3,C4,C5	10uF, 50V	aluminum cap
1	TYCO ELECTRONICS-EM/T&B	TT11AG-PC-1	S1	switch	SPDT 3P Switch
4	Vishay / Dale	WSR-2 .05< 1%	R38,R37,R75,R79	50mOHM, 2W	power resistor, 2W
4	SPC Technology	WLS-04-017-SZ		Lock Washer	Lock Washer, #4
2	AVX	BF074E0224J	C33,C37	0.22uF, 100V	capacitor, box
2	AVX	BF074E0474J	C51,C52	0.47uF, 100V	capacitor, box
4	Aavid Thermalloy	4880		To-220 mounting kit	To-220 mounting kit, Type4880
2	Vishay / Dale	CRCW20101001F100	R5,R3	1K, 1W, 1%	resistor, 2010
4	HH Smith	8423		Standoff	standoff, HEX threaded, L=0.5"
2	Vishay / Dale	TNPW08051001BT9	R4,R6	1K, 0.1%	resistor, 0805
2	Vishay / Dale	TNPW08051002BT9	R16,R11	10K, 0.1%	resistor, 0805
1	Vishay / Dale	TNPW08051101BT9	R86	1.10K	resistor, 1%, 0806
1	Vishay / Dale	TNPW08051022BT9	R87	10.2K	resistor, 1%, 0805
2	Vishay / Dale	ERJ-6GEYJ682V	R45,R44	6.8K	resistor, 0805
4	United Chemi-Con	SME63VB471M12X25LL	C39,C40,C38,C41	470uF, 63V	aluminum cap
1				PWB	Printed Wiring Board
1					
0			R40,R39,R53,R54,R55,R57,R58,R59,R56,R60,C50,C49,C30,C34,C22,C19,C7,C6,D10,D11,D13,D12		

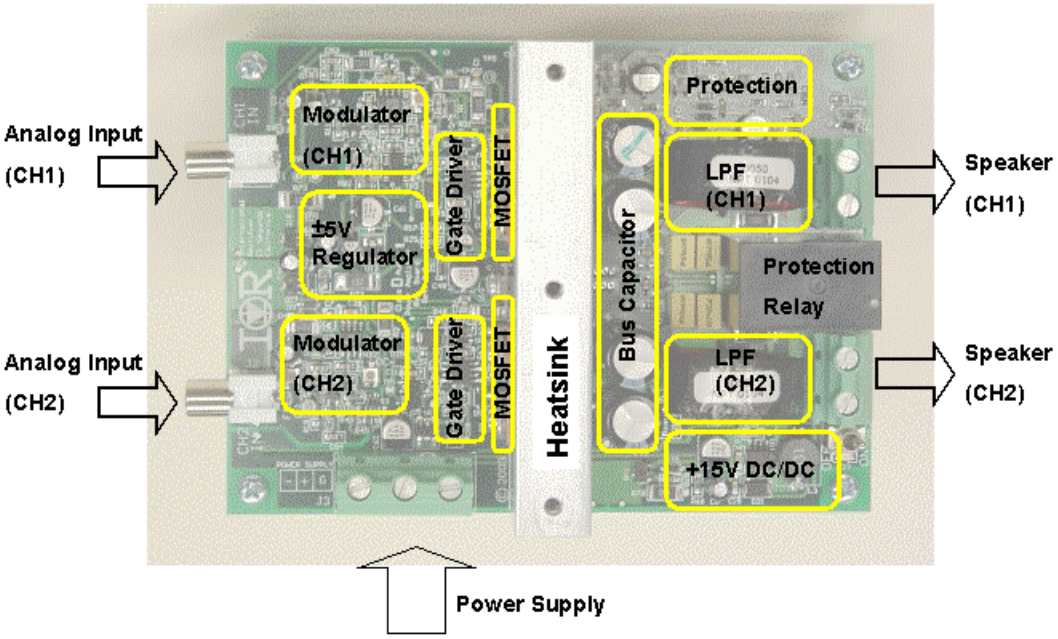
Inductor Spec

Part number: NPT0104
Inductance: 18uH
Rated Current: 10A
Core: T106-2, Micrometals
Wire: AWG18, magnet wire
# of Turns: 37
Finish: Varnished

Mechanical Dimensions:

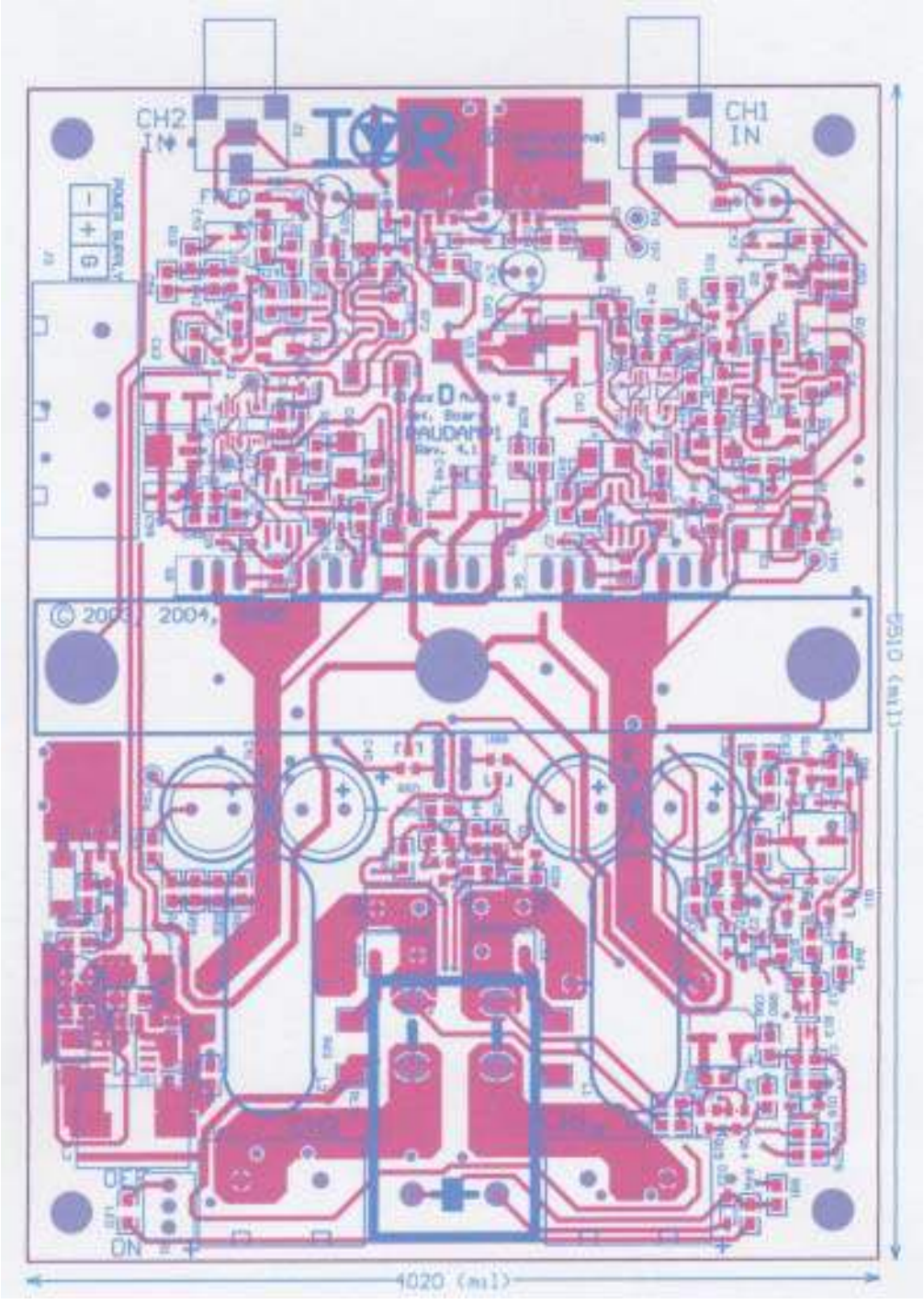
PCB layout

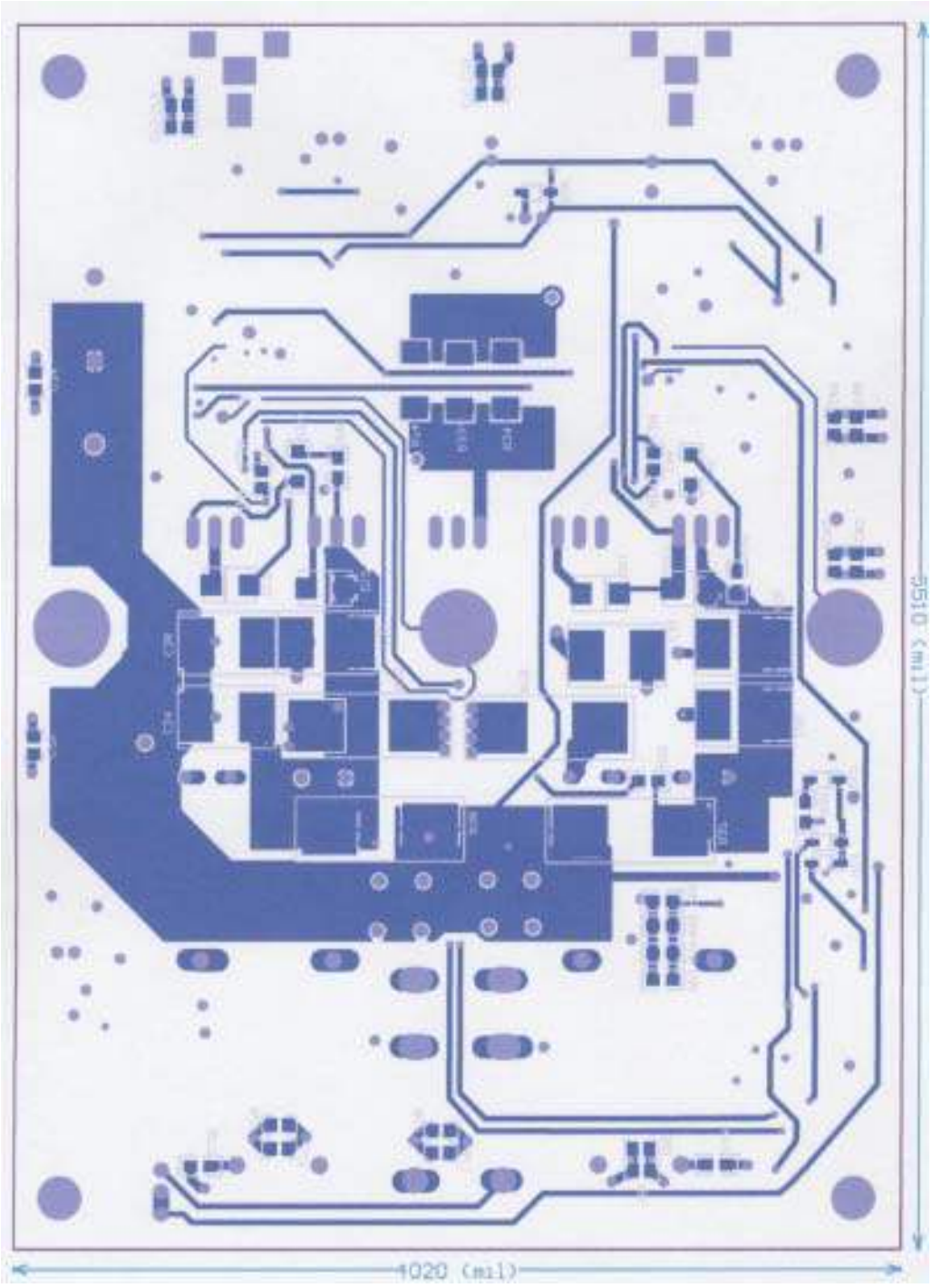




Functional Allocation

Mechanical Drawings




4020 (mil)
5510 (mil)