ECE 445 Design Review
Lightweight Hybrid Guitar Amplifier

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Objectives:

The goal of this design is to create a guitar amplifier head with output power between 35W and 75W, and a matching speaker cabinet with good dispersion characteristics.

The amplifier head will accept a high-impedance audio signal from an electric guitar and amplify it for connection to a speaker cabinet. It will include an entire low-power tube amplifier presented with a resistor load in the preamplifier section, and a solid-state class-D power amplifier for the speaker output, as well as a switching power supply. The preamplifier section will also have controls for gain, equalization, and volume. The speaker cabinet will use lightweight neodymium speakers to convert the electrical energy to acoustic energy, which will disperse in an even way at several angles of incidence and with a frequency response flattering to the guitar sound.

Benefits:

- Improve sound quality over commercially available hybrid amplifier designs
- Reduce weight from conventional tube amplifier designs
- Increase efficiency over conventional tube amplifier designs
- Reduce weight from conventional speaker cabinet designs
- Improve sound dispersion over conventional speaker cabinet designs

Features:

- Versatile "piggyback," "head and cabinet" design
- Controls for amount of distortion, equalization, and volume
- Approximately 50W power output from "head"
- 2 x 10" speaker cabinet

Schematics and Designs:

A block diagram for the project is shown in Figure 1.

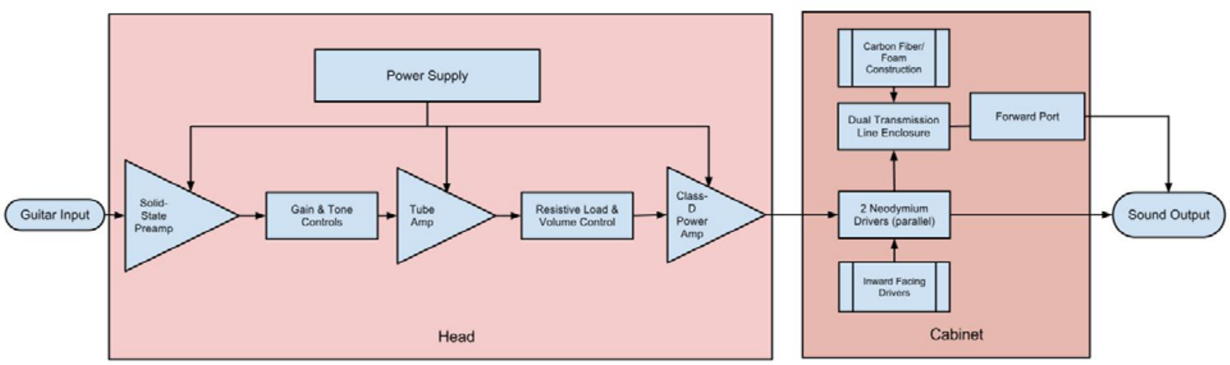

Fig. 1: Block Diagram

The project is made up of two components: an amplifier head (head) which amplifies the electrical guitar signal and provides equalization and distortion, and a speaker cabinet (cabinet) which turns the amplified electrical signal into acoustic energy. Each component will be discussed in turn, along with its internal circuits.

Head

Power Supply

The power supply converts the 120V RMS AC voltage input into four different output voltage rails, as well as a fifth voltage supply for its own circuity. Its schematic is shown in Figure 2.

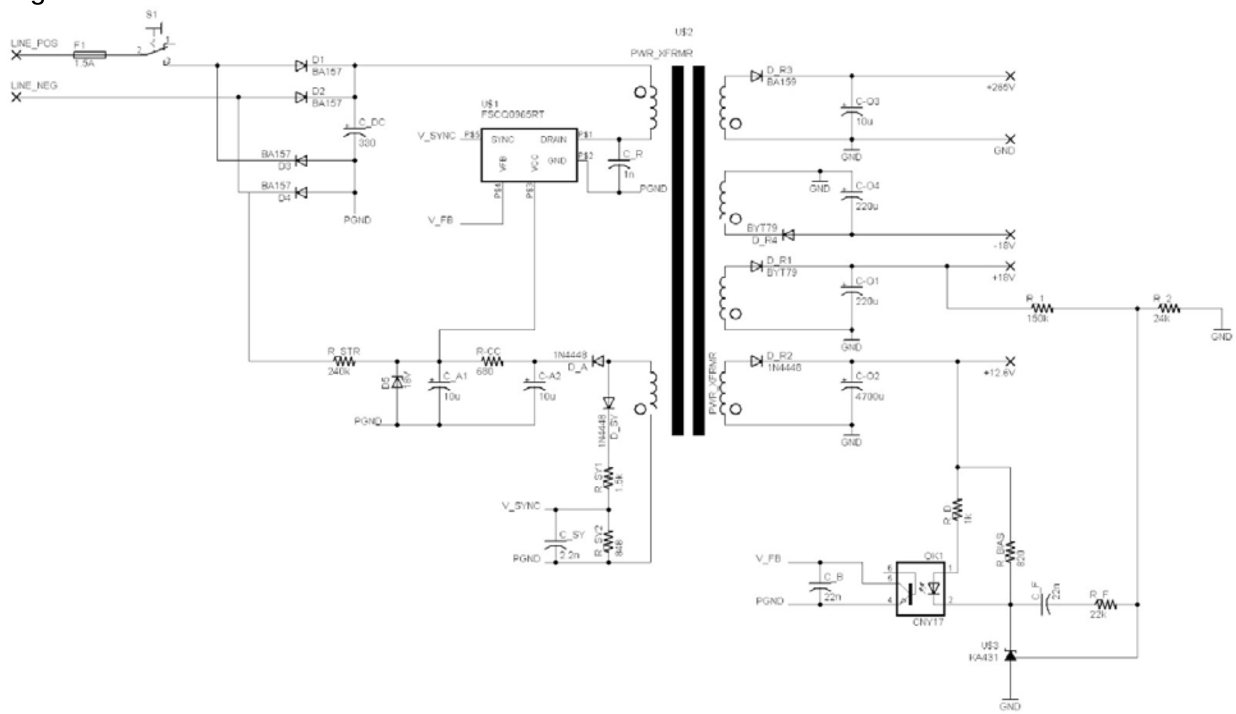

Figure 2: Power Supply Schematic

The topology of this circuit is that of a Quasi-Resonant Flyback Converter. The circuit itself was largely designed according to an application note for the switch IC, made by Fairchild Semiconductor [1]. With the application note was a software tool which provided most of the calculations to determine component values [2].

Among the figures required to fill out the software tool are the voltage outputs and currents required, which are shown in the table below.

1st Output (Vo1)	18V	2.5A
Vo2	12.6V	150mA
Vo3	265V	30mA
Vo4	-18V	2.5A

Table 1: Power Supply Voltages

The circuit functions as follows: The AC voltage input is rectified with a diode brigde (D1 - D4), then filtered in C_DC. The IC periodically interrupts the DC current in the primary of the coupled inductor, which causes current to flow in the secondaries, through the secondary rectifier diodes D_A and D_r1 through D_R4. When the current flows through the secondaries, current goes through D_SY causing V_SYNC to have a significant voltage. This voltage lowers as the inductors dispel their energy. When it drops lower than 2.6V, the MOSFET switch in the IC turns on, drawing more current into the coupled inductor. The frequency of this cycle is set by how long it takes for the inductor to charge and discharge with energy, so the frequency changes as a function of the input voltage and load current. Component values were chosen to keep the frequency above the audio range in the worse case, when the input voltage is low and the load current is high.

The voltage of the first output, Vo1, is fed back to the IC and modifies the duty cycle of the switching function to keep a steady 18V. A simulation of the feedback loop's frequency response is provided by the software tool, and the results for this design are copied below in Figure 3.

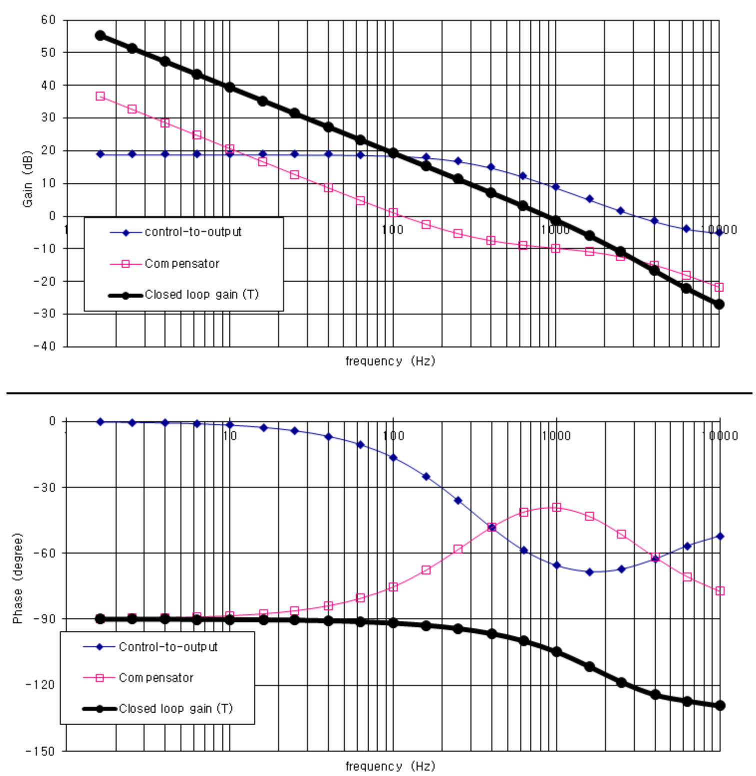

Figure 3: Power Supply Feedback Loop Frequency Response

The closed-loop gain rolls off at high frequencies to avoid having the IC react to its own switching action, and maintains high gain at low frequencies for good DC accuracy.

Solid-State Preamplifier

The schematic for the Solid-State Preamplifier (Preamp) is shown in Figure 4.

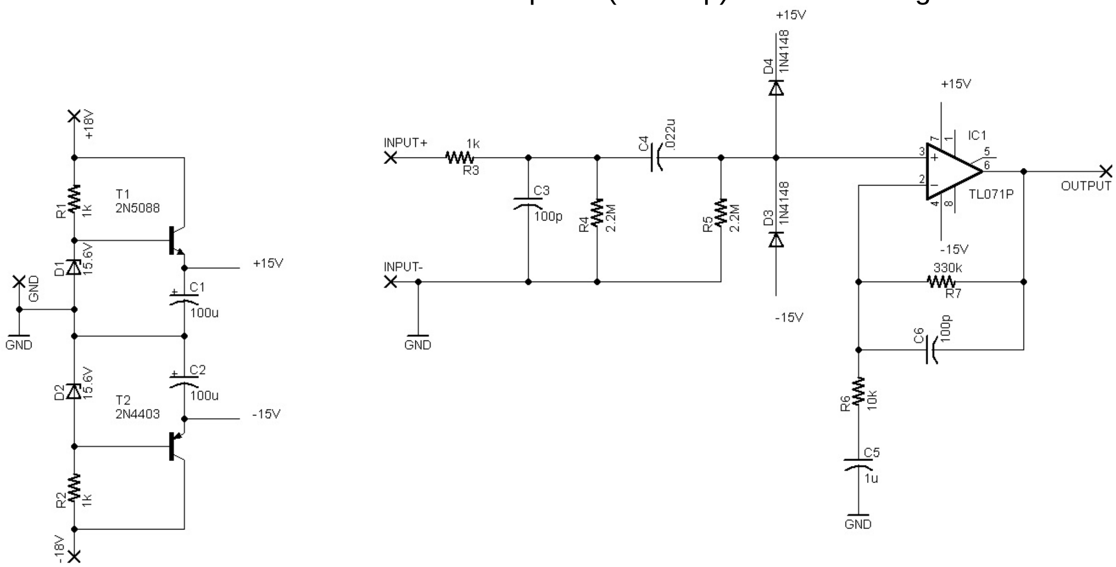

Figure 4: Solid-State Preamp Schematic

The subcircuit on the left is a pair of simple voltage regulators to make sure that the TL071 op-amp has a safely limited bipolar voltage supply, while also ensuring that variations in the positive and negative 18V supply rails caused by the power amplifier do not feed back to this earlier part of the circuit. The current through each zener diode stays close to $\frac{18V - 15.6V}{1k\Omega} = 2.4mA$, providing a stable voltage reference for the emitter followers made up of T1 and T2.

R3, in series with the impedance of the electric guitar, and C3 form a low pass filter to attenuate radio frequencies, or else demodulation may occur in the nonlinear tube amplifier, resulting in an AM radio. The maximum crossover frequency f_c is $\frac{1}{2\pi \cdot R3 \cdot C3} = 1.6MHz$. C6 and the parallel combination of R6 and R7 further reduce frequencies above 160kHz.

At frequencies of interest for electric guitar, which is between 82Hz and 5kHz, the voltage gain of this circuit is calculated with (1) to be 34, or 30.6dB.

$$A_v = 1 + \frac{R7}{R6} \quad (1)$$

Simulations of the frequency response and voltage gain of this circuit are shown in Figure 5.

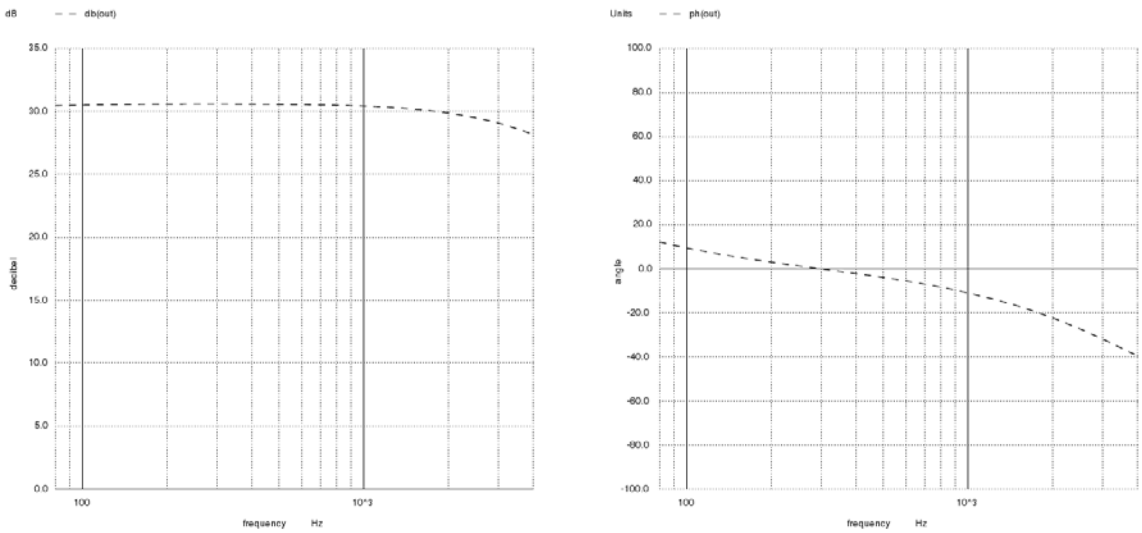

Figure 5: Amplitude (dB) and Phase (º) Simulations of Solid-State Preamp Circuit

The gain is very close to that calculated by (1) throughout the range of frequencies considered.

Gain & Tone Controls

The equalization circuit, often called a "tone stack," chosen for this amplifier is based on the one used in old Fender-brand tube amplifiers, but has been used in many other amplifiers. Its schematic is shown in Figure 6.

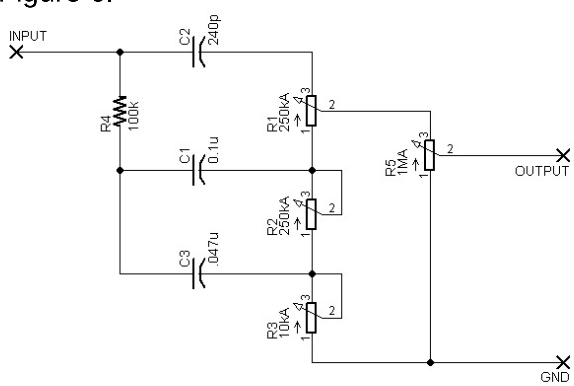

Figure 6: Gain & Tone Control Circuit Schematic

Being a passive circuit, the tone stack results in some loss of signal. When its frequency response is set as flat as possible, with the gain knob and mid knob at full and treble and bass at minimum, the insertion loss of this circuit can be approximated as a voltage divider between R4 and R3. The voltage gain of this circuit, then, is

$$A_v = \frac{R3}{R3+R4} = 0.091, \qquad (2)$$

or -20.8dB. Frequency response simulations for the condition described are in Figure 7.

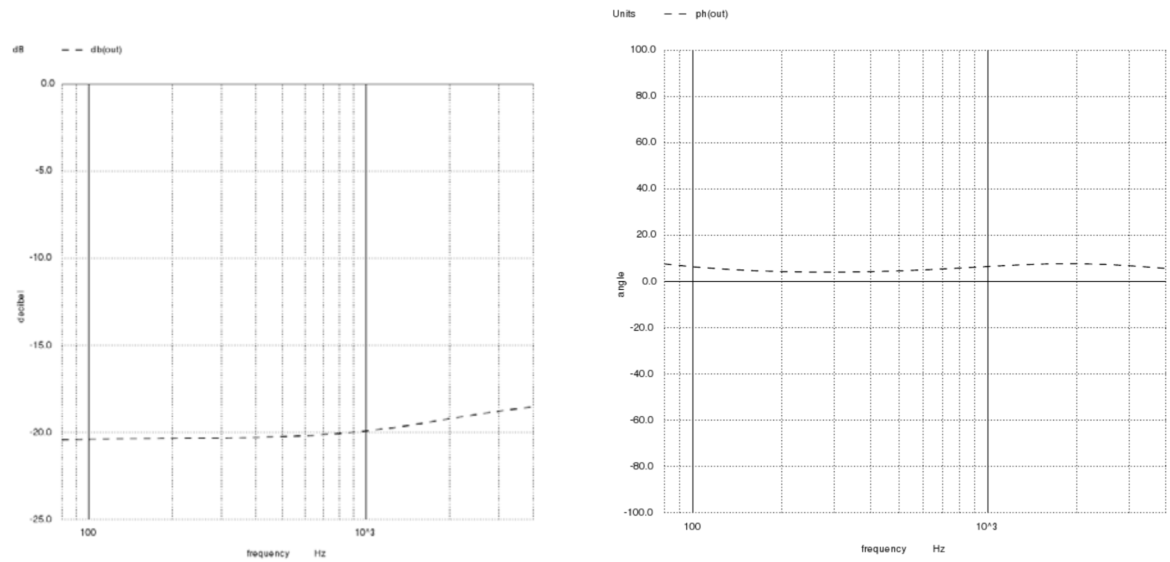

Figure 7: Amplitude (dB) and Phase (º) Simulations of Tone Control Circuit

Tube Amp

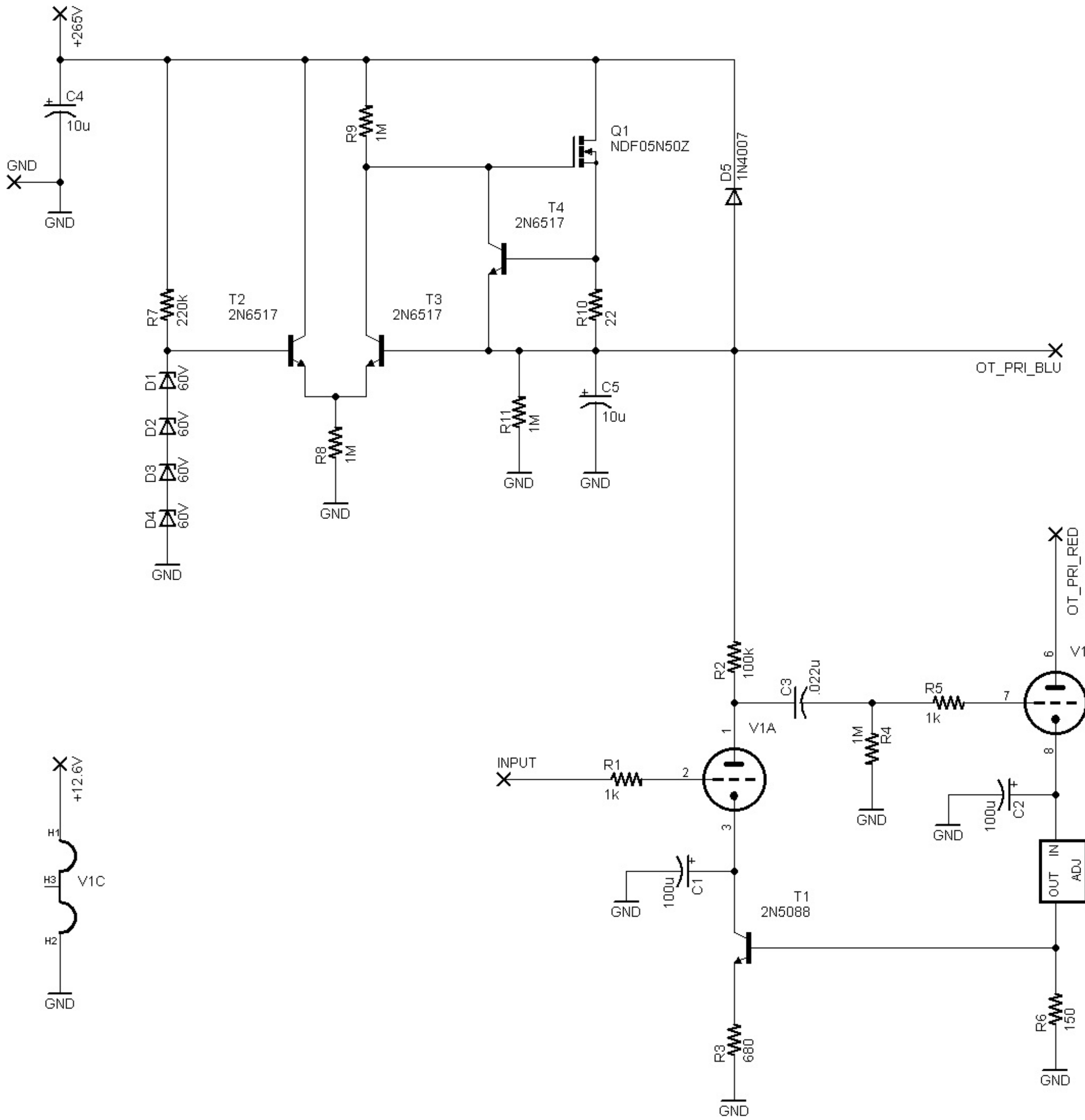

Figure 8: Tube Amplifier Schematic

A preliminary tolerance analysis of the amplifier showed that voltage ripple on the supply for the tube amplifier circuit exceeding 141mV peak would be amplified enough to bring the noise above 1% at the amplifier's output. Since voltage regulators for high-voltage applications are expensive and difficult to find, a discrete series voltage regulator was designed to reduce power supply noise.

In this circuit, T4 in conjunction with R10 acts as a current limiting device for the voltage regulator; when the voltage across R10 exceeds the base-to-emitter voltage needed to turn T4 on, the transistor reduces the gate-to-source voltage of the pass MOSFET, Q1. This occurs when the current through the MOSFET reaches about $\frac{0.6V}{22\Omega} = 27mA$.

V1A and V1B are both common-cathode amplifiers, similar in operation to common-source amplifiers using depletion-mode MOSFETs. The bias current is set in V1B by the low drop-out voltage regulator, which maintains 1.2V at its output. The bias current is then

$\frac{1.2V}{150\Omega} = 8mA$. Similarly, T1 forces the voltage at its emitter to be about 0.6V, so that the bias current of V1A is $\frac{0.6V}{680\Omega} = 0.9mA$.

The load on the anode of V1B is the output transformer, which is not shown. It presents an impedance of about 11kΩ. Therefore, the largest voltage swing at the plate of V1B is $8mA \cdot 11k\Omega = 88V$. If the input signal to the amplifier is a guitar with a peak voltage output of about 100mV, and if the gain control is turned all the way up, then there is enough gain in this amplifier that the peak voltage swing at the plate of V1B ought to be 396V. Being limited at 88V, the amplifier distorts. This is a desirable effect because the distortion produced by this type of circuit is usually considered pleasant, when combined with taste.

The 12.6V supply provides power for the heater filaments in the vacuum tube.

Resistive Load & Volume Control

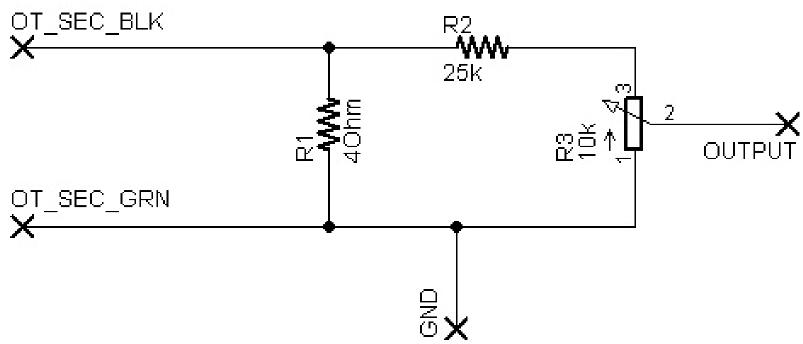

Figure 9: Resistive Load and Volume Control Schematic

At the secondary of the output transformer the 4 Ohm resistor R1 serves as the load for the tube amplifier. R2 and R3 form a voltage divider to limit the amount of voltage that the input of the solid-state power amplifier will receive.

The result of a frequency response simulation done on the tube amplifier, with the output transformer, the resistive load, and the volume control is shown in Figure 10.

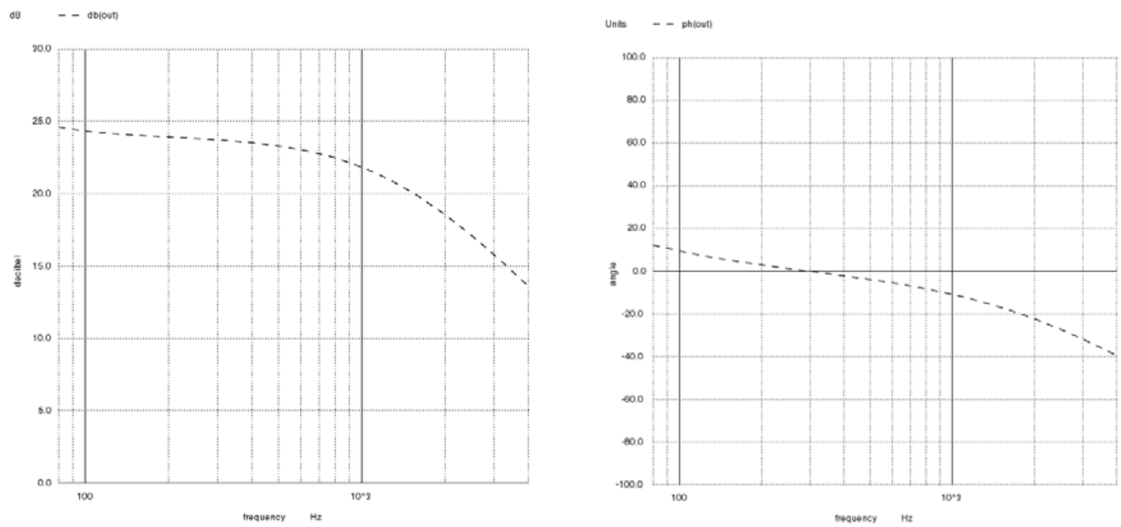

Figure 10: Amplitude (dB) and Phase (º) Simulations of Tube Amplifier Circuit

Solid-State Power Amp

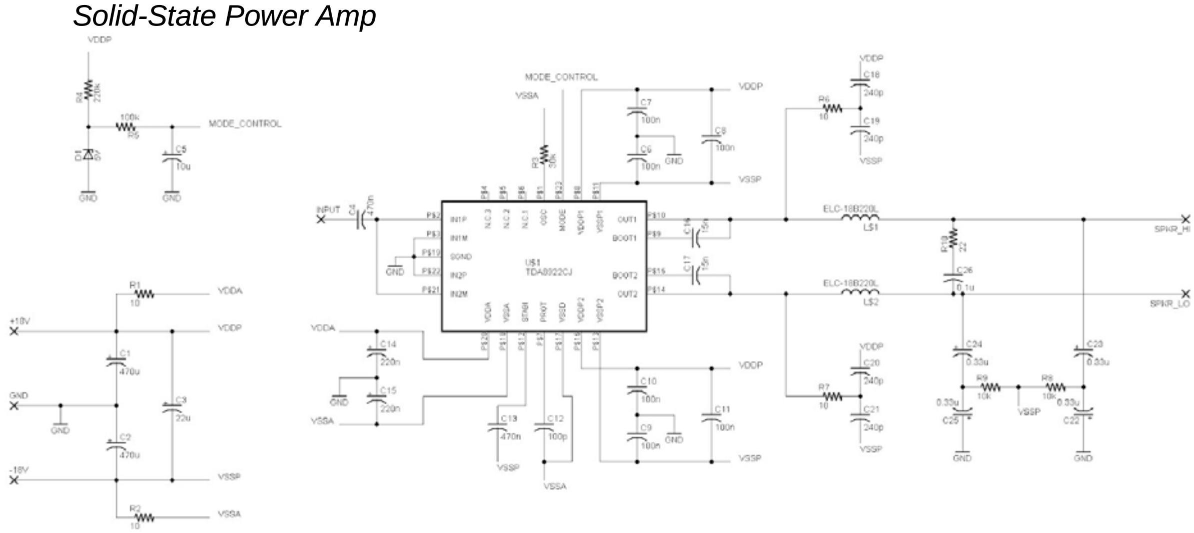

Figure 11: Solid State Power Amplifier Schematic

The solid-state power amplifier was largely designed according to the application notes in the datasheet for the TDA8922CJ IC [3]. The MODE_CONTROL signal prevents the amplifier from popping upon startup; when the power supply voltage is applied, the MODE_CONTROL voltage raises toward 5V with a time constant determined by R5 and C5. The application notes suggest a time constant of at least 500ms. The time constant of this circuit is 1s.

The IC outputs a PWM signal at about 325kHz, which is filtered by the L-C lowpass filters made up of L$1, C23, and C22; and L$2, C24, and C25. The crossover frequency of this circuit is

$$f_{lc} = \frac{1}{2\pi \cdot \sqrt{L \cdot C}}. \qquad (3)$$

In this circuit, that is 41.8kHz, well above the range of the electric guitar. Frequency response plots of a simulation of the solid-state amplifier and the output filter, along with the Zobel network and a model for a 10 inch speaker, are shown in Figure 12. The low-pass filter acting at about 42kHz is evident.

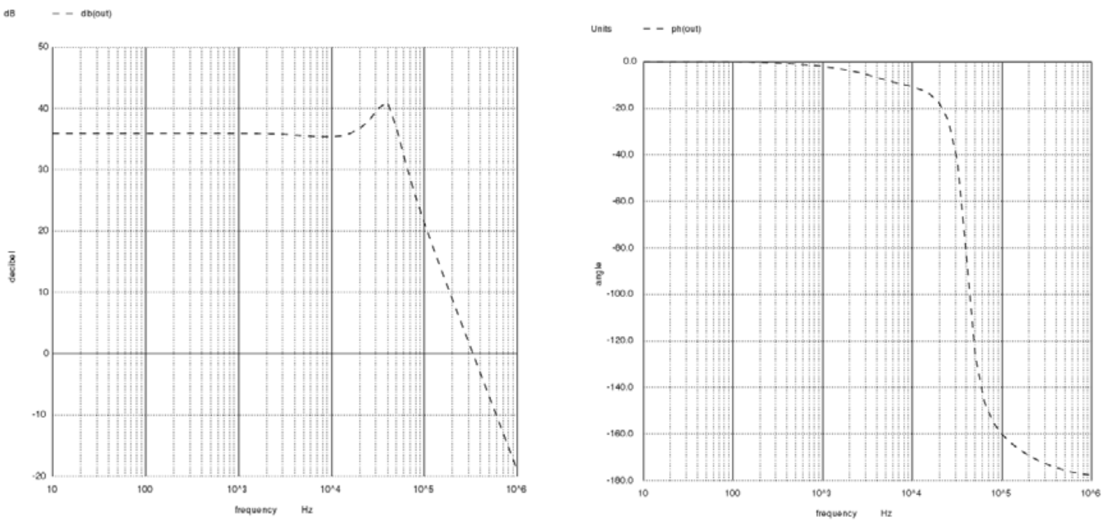

Figure 12: Frequency Response Plots of Loaded Solid State Amplifier

Cabinet

Speakers

The cabinet speakers will be 2 Jensen Neo 10-100 guitar 10 inch guitar speakers[4] and are the only electrical component situated in the cabinet. These speakers were chosen based on their lightweight neodymium based design and moderate cost. For a input impedence of 8 Ohms, the 16 Ohm speakers will be mounted in parallel as shown in Figure 13.

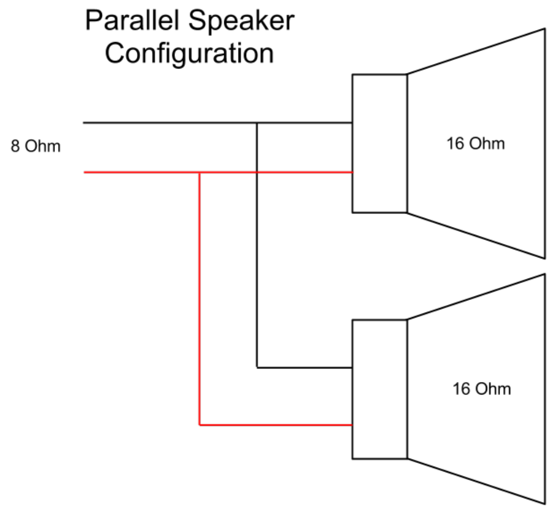

Figure 13: Speaker Wiring Scheme

Both of the speakers will be mounted on separate baffle boards and positioned such that the directivity is directed inward at an angle of 17 degrees perpendicular to the cabinet front. Figure 14 shows the mounting configuration.

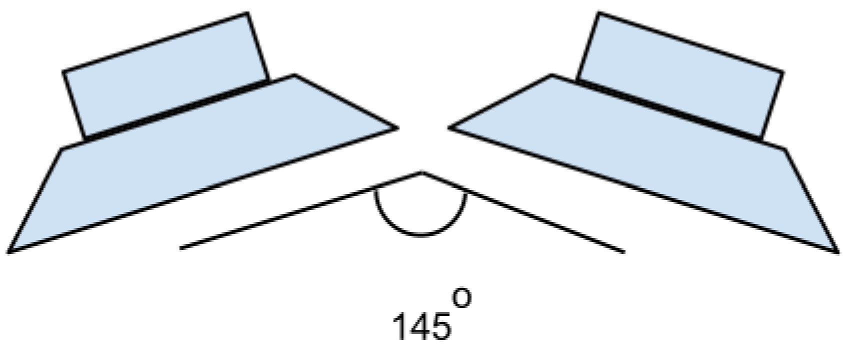

Figure 14: Mounting Configuration of the Two Loudspeakers

While the tilting of the speakers will not be of great effect at lower frequencies, when the sound begins to beam at the higher frequencies our design will facilitate a more even sound field. This is shown in figure 15 where a sound field is simulated using Mathematica with a sampling of frequencies. The equation used is that of a baffled piston[5]:

$$p = jca^2 U_o \frac{k}{2r} e^{j(wt-kr)} [\frac{2J_1(ka\sin\theta)}{(ka\sin\theta)}]$$

where, a=0.127 m
ρ=1.21 kg/m^3
c=343 m/s^2
U_o=244 m/s

This demonstrates how the sound field becomes more directional as the frequency increases and how this configuration aids in creating a more even sound field.

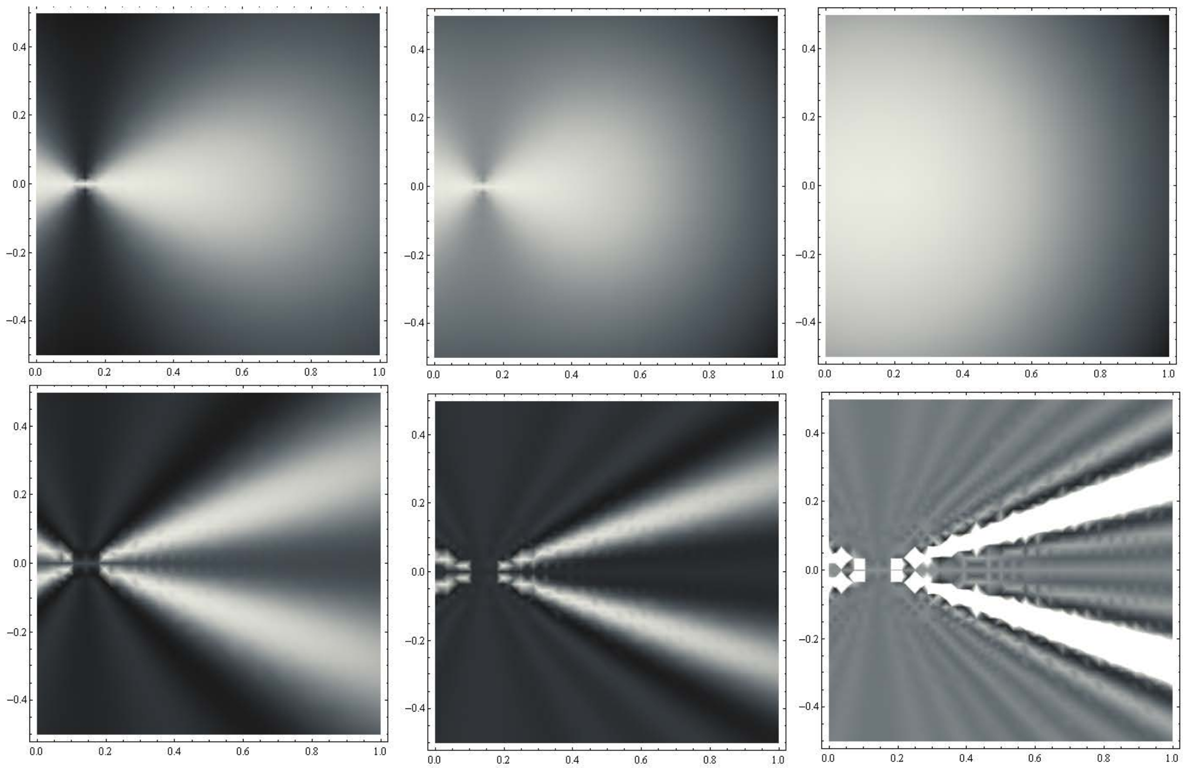

Figure 15: Directivity of Current Speaker Configuration using Frequencies of 1000(top left), 500(top middle), 80(top right), 5000(bottom left), 10000(bottom middle), 20000(bottom right).

The cabinets design is that of a tapered transmission line cabinet, as shown in Figure 16. The typical application for this style of cabinet is for high fidelity home stereo systems. While a complicated and often mystified topology, when executed correctly the waves passing from the back of the speaker are absorbed along the tapered path and allows for a flat frequency curve[6].

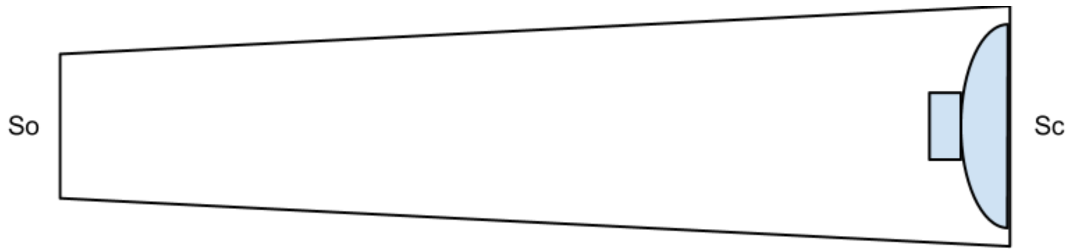

Figure 16: Transmission Line Topology

The design parameters for a transmission line are based around the resonant frequency of the drivers Fs and the driver's surface area Sd. A speaker baffle area, Sc, and port area, So, are devised through trial and error until an appropriate cabinet size is developed. For our design Sc/Sd=1.68 and So/Sd= 0.6. According to Martin King, these ratios should lie inbetween 2 and 0.5 [6]. To configure the transmission line, the resonant frequency is used to calculate the quarter wavelength, which will be the overall length of the line as shown in green in figure 17. Our transmission line cabinet has been folded to create a more compact cabinet as well as have a forward facing port, which will output sound waves in phase with the output of the speaker. This is used to increase the low frequency response of the drivers below their normal operating parameters.

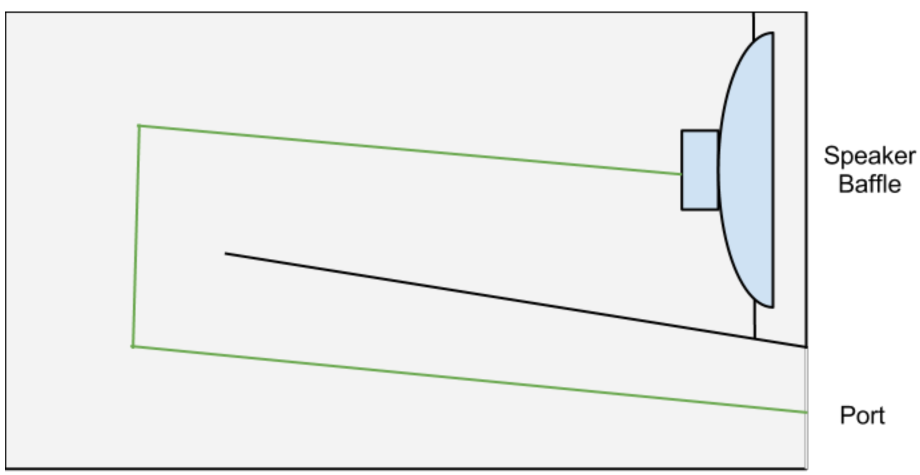

Figure 17: Folded Transmission Line Cabinet

The cabinet will be constructed of carbon fiber wrapped around a polystyrene core. From this method, the cabinet will be lightweight, less than 15 lbs, stiff and durable. Safety will be taken into account with respirators, safety glasses, safety gloves and proper ventilation being used at all times of manufacturing.

Requirements and Testing:

<table>
<tr><td>Requirement</td><td>Verification</td></tr>
<tr><td>
1. The power amplifier's power output, when loaded with 8Ω at 1kHz, will exceed 35W with less than 1% total harmonic distortion plus noise.
 a. Voltage is applied to power input pins
 b. Signal input is applied to input pins
 c. PWM signal is present at output pins
 d. Output power exceeds 35W
 e. THD+N is less than 1%
</td><td>
1. The Solid-State Power Amplifier will be supplied power with a bench supply and loaded with an 8Ω, 50W or greater power resistor. With a 1kHz input signal of 375mV peak, THD+N will be measured with an oscilloscope. If it is less than 1%, lower-level troubleshooting is unneccessary.
 a. With above setup, use DMM to check voltages at these pins, and expect these voltages:
<table>
<tr><td>Pin Name</td><td>Pin Number</td><td>Voltage Expected</td></tr>
<tr><td>SGND</td><td>19</td><td>0V</td></tr>
<tr><td>VSSD</td><td>17</td><td>-18V</td></tr>
<tr><td>VDDP2</td><td>16</td><td>18V</td></tr>
<tr><td>VSSP2</td><td>13</td><td>-18V</td></tr>
<tr><td>VSSP1</td><td>11</td><td>-18V</td></tr>
<tr><td>VDDP1</td><td>8</td><td>18V</td></tr>
<tr><td>MODE</td><td>23</td><td>5V</td></tr>
</table>
 b. With above setup, use oscilloscope to verify 375mV input signal at pins 2 and 21, zero voltage at pins 3 and 22.
 c. With above setup, use oscilloscope to verify PWM signal is generated at pins 10 and 14.
 d. With above setup, use power meter to verify power output of 35W.
 e. With above setup, use oscilloscope to verify THD+N less than 1%.
</td></tr>
<tr><td>
2. Resistive load & volume control module will have input impedance near 4Ω and will pass signal unless volume is at minimum.
 a. Input impedance is close to
</td><td>
2. A 2V pk 1kHz sine wave will be applied to the input of the module through a power meter. An oscilloscope will be connected to the output. If the power meter shows within 20% of 1W, and the output voltage
</td></tr>
</table>

4Ω. b. Impedance from output to negative input is close to 7.15kΩ with volume set to full. c. Impedance from negative input to ground is less than 1Ω. d. Signal voltage gain should have a maximum of at least 0.2.	measured with the oscilloscope is at least 400mV peak when the potentiometer is set to maximum, then no further testing is necessary for this module. a. With module disconnected from circuit, use DMM to measure impedance between the positive input and negative input. It should be within 10% of 4Ω. b. With module disconnected from circuit and volume set to maximum, use DMM to measure impedance between the negative input and output. It should be within 20% of 7.15kΩ. c. With module disconnected from circuit, use DMM to measure impedance between the negative input and ground pad. It should be less than 1Ω. d. A 2V pk 1kHz sine wave will be applied to the input of the module. An oscilloscope will be connected to the output. The output voltage with the volume set to full should exceed 400mV peak.
3. Gain & Tone Controls Module will pass signal.	3. 1kHz 10V pk sine wave will be presented to input. Output will be monitored with oscilloscope, and should be between 30mV and 300mV pk when mids & gain are full, treble & bass are off.
4. Solid-State Preamp module will have voltage gain of about 34, or 30.5dB. a. Voltage regulators will drop ±18V bipolar supply to ±15V bipolar supply, within 1V. b. Signal will pass through input filters to the IC input. c. Gain of module should be between 20 and 52.5.	4. Preamp will be removed from circuit and powered with a ±18V bench supply. Input of preamp will be presented with a 1kHz, 100mV peak sine wave. Output will be monitored on an oscilloscope, and should be near 3.4V peak, between 2V and 5.25V peak. If this is verified, then no further testing is needed on this module. a. Remove input signal. Use DMM to measure voltages at pin 7 and 4 of the TL071. They should be within 1V of +15V and -15V, respectively. b. Reapply input signal. Inspect voltage at pin 3 of the TL071 with an oscilloscope. It should have a value within 10% of 100mV. c. With input signal applied, inspect

<table>
<tr>
<td></td>
<td>output voltage with an oscilloscope. Its peak value should be between 2V and 5.25V.</td>
</tr>
<tr>
<td>
5. Power Supply will provide the following voltages, with these tolerances and ripple requirements:
<table>
<tr><th>Output</th><th>Vmin</th><th>Vmax</th><th>Vripple ≤</th></tr>
<tr><td>+265V</td><td>+250V</td><td>+280V</td><td>15V p-p</td></tr>
<tr><td>-18V</td><td>-28V</td><td>-14V</td><td>8V p-p</td></tr>
<tr><td>+18V</td><td>+14V</td><td>+28V</td><td>8V p-p</td></tr>
<tr><td>+12.6V</td><td>+11.3</td><td>+13.9</td><td>6V p-p</td></tr>
</table>
Table 2: Power Supply Specifications
a. DC input voltage must be provided to switching circuit
b. DC supply voltage must be provided to switching circuit
c. Switching supply circuit should be switching at frequency of at least 25kHz
d. Feedback voltage should be applied
e. The feedback optocoupler should be receiving input current
f. The output voltages should be as shown in Table 2 above.
</td>
<td>
5. Power supply will be loaded with nominal loads. Each output will be inspected in turn with a DMM to measure DC voltage and an oscilloscope to measure voltage ripple. Results will be checked against Table 2 at left. If this is verified, then no further testing is needed on this module.
a. DC voltage at the positive terminal of C_DC should be between +130V and +170V, as read by DMM
b. DC voltage at the positive terminal of C_A1 should be between +17V and +19V, as read by DMM
c. When viewed in an oscilloscope, the waveform of the voltage at pin 5 of the FSCQ0965RT should have a frequency of at least 25kHz
d. DC voltage at pin 4 of the FSCQ0965RT should be between 0V and +18V as measured with a DMM. It should be close to +18V if 5b is verified and the +12.6V output has no voltage
e. The DC voltage between pin 1 and pin 2 of the CNY17 should be between 1V and 1.65V
f. Each output will be inspected in turn with a DMM to measure DC voltage and an oscilloscope to measure voltage ripple. Results will be checked against Table 2 at left.
</td>
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<td>
6. Tube Amplifier module with Resistive load & volume control module together should have maximum voltage gain at 1kHz of between 3 and 24.
a. Heater filaments must work
b. Quiescent voltages must be correct, according to the following table.
<table>
<tr><th>Node</th><th>Vmin</th><th>Vmax</th></tr>
</table>
</td>
<td>
6. The Tube Amplifier module will be connected to the +265V and +12.6V outputs of the Power Supply module. The other outputs of the Power Supply module will be loaded with nominal loads. The output of the Tube Amplifier module will connect to the primary of the Output Transformer, whose secondary will connect to the Resistive Load & Volume control Module. A 10mV peak 1kHz sine wave will be presented to the input of the tube amplifier. With the volume knob
</td>
</tr>
</table>

C4 +	255V	275V
T2 Base	230V	250V
C5 +	230V	250V
R8	229V	249V
Tube pin 1	+90V	+190V
Tube pin 2	-1V	+1V
Tube pin 3	+1V	+4V
Tube pin 4	0V	0V
Tube pin 5	+11.3V	+13.9V
Tube pin 6	+230V	+240V
Tube pin 7	-1V	+1V
Tube pin 8	+1V	+4V
R3	+340mV	+1V
R6	+1V	+1.4V

Table 3: Tube Amp Quiescent Voltages

c. Gain of first tube stage should be between 40 and 70
d. Peak voltage at secondary should be between 75mV and 600mV.

turned up all the way, the output of the Resistive load and Volume Control module will be inspected with an oscilloscope. Its output should have a peak voltage between 30mV and 240mV. If this is verified, no further testing is needed on the Tube Amp module.

a. The tube will be touched with a forefinger. If it is hot, the heater filaments are working correctly.
b. With no input signal, DC voltages will be checked at nodes listed in Table 3 with a DMM. Voltages should lie between Vmin and Vmax for each node.
c. With 10mV pk-pk 1kHz input signal, the voltage at pin 7 of the tube should have a peak value of between 400mV and 700mV, when viewed in an oscilloscope.
d. With 10mV pk-pk 1kHz input signal, the voltage at pin 7 of the tube should have a peak value of between 400mV and 700mV, when viewed in an oscilloscope.
e. With 10mV pk-pk 1kHz input signal, the voltage at the input of the Resistive Load and Volume Control Module should have a peak value of between 75mV and 600mV, when viewed in an oscilloscope.

7. Drivers are undamaged and work as intended
    a. Cone does not have defects
    b. No short or open circuit in voice Coil

7. Driver will be installed onto test baffle.
    a. Visually inspect cone with magnifying glass
    b. Connect speaker to separate amplifier and check for sound production

8. Check that Thiele/Small Parameters Provided by the manufacturer are accurate
    a. Parameters must have a tolerance of 5% otherwise design must be adjsuted

8. Connect Speaker to 1V sine wave input signal with sweepable frequency in series with a ½ watt, 10 ohm resistor. View the voltage across the resistor with a multimeter.
    a. Measure the resonant frequency of the speaker, where the voltage across the resistor reaches a

	minimum. Use this to calculate the -6dB voltage of the speaker. Find the low and high frequencies where the voltage equals the -6dB voltage[7]
9. Test Frequency Response of Speaker Cabinet a. No Antiresonances -20 dB below average SPL	9. Connect Speaker Cabinet to Spectrum Analyser with white noise output resulting in even frequency output and record output using lock in amplifiers. a. Attach only cabinet to Spectrum analyser
10. Cabinet will withstand hostile work environment. a. Capable of withstanding vertical compression without deflection.	10. Take Cabinet to Talbot and connect to compressive testing machine. a. Apply Loading characteristics of large human being of approximately 300 lbs.

Cost Analysis:

Labor:

Dream Salary of each team member:		$40	per hour	
$40 x 2.5 x 150 hours		=	$15,000	per member
$15,000 x 2 members	=	$30,000	total	

Materials:

Item	Spec	Quantity	Unit Cost	Total
Head				
Vacuum Tube	12AT7	1	$10.00	$10.00
Output transformer	Hammond 1750A	1	$19.01	$19.01
Power Transformer				$15.00
Chassis				$20.00
Tube socket	9-pin, PC mount	1	$2.45	$2.45
Power Switch		1		$15.00
Fuse Holder	Fender style, Conical	1	$2.25	$2.25
Power cable		1	$8.95	$8.95
Power cable strain relief		1	$0.45	$0.45
Jacks		3	$2.50	$7.50
Potentiometers		5	$2.50	$12.50
PCBs		4	$0.00	$0.00
Misc. Hardware		1	$4	$4
Metal Film Resistors - Through Hole 150Kohms 1% 100PPM	660-MF1/4DCT52R1503F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 221K 1% 100PPM	660-MF1/4DC2213F	3	$0.06	$0.18

Metal Film Resistors - Through Hole 240K 1% 100PPM	660-MF1/4DC2403F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 330K 1% 100PPM	660-MF1/4DC3303F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 1/4W 1M ohm 1%	660-MF1/4DCT52R1004F	4	$0.06	$0.24
Metal Film Resistors - Through Hole 1/4W 2.21M ohm 1%	660-MF1/4DCT52R2214F	2	$0.06	$0.12
Metal Film Resistors - Through Hole 10ohm 1% 100PPM	660-MF1/4DC10R0F	4	$0.06	$0.24
Metal Film Resistors - Through Hole 22ohm 1% 100PPM	660-MF1/4DC22R0F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 150ohm 1% 100PPM	660-MF1/4DC1500F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 680ohm 1% 100PPM	660-MF1/4DC6800F	2	$0.06	$0.12
Metal Film Resistors - Through Hole 1/4W 825 ohm 1% 826 OHM 1%	660-MF1/4DCT52R8250F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 845ohm 1% 100PPM	660-MF1/4DC8450F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 1Kohms 1% 100PPM	660-MF1/4DCT52R1001F	6	$0.06	$0.36
Metal Film Resistors - Through Hole 1/4W 1.5K ohm 1% 1.5K OHM 1%	660-MF1/4DCT52R1501F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 10K 1% 100PPM	660-MF1/4DC1002F	3	$0.06	$0.18
Metal Film Resistors - Through Hole 1/4W 22.1K ohm 1% 22.1K OHM 1%	660-MF1/4DCT52R2212F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 1/4W 24.3K ohm 1% 24.3K OHM 1%	660-MF1/4DCT52R2432F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 1/4W 24.9K ohm 1% 24.9K OHM 1%	660-MF1/4DCT52R2492F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 30K 1% 100PPM	660-MF1/4DC3002F	1	$0.06	$0.06
Metal Film Resistors - Through Hole 100K 1% 100PPM	660-MF1/4DC1003F	3	$0.06	$0.18
Audio Amplifiers 1CH Mono/2CH Stereo Audio Amp Speaker	771-TDA8922CJN1112	1	$5.27	$5.27
Metal Oxide Resistors 2W 22 5%	660-MOS2CT52R220J	1	$0.13	$0.13
Polyester Film Capacitors .47uF 50V 5%	667-ECQ-V1H474JL	2	$0.4	$0.8
Aluminum Electrolytic Capacitors - Leaded 50volts 22uF 8X7mm L/S=5.0mm Ammo Crmp	667-EEA-GA1H220B	1	$0.65	$0.65
Ceramic Disc Capacitors 20NF 1Kvolts 20%	594-S203M75Z5UN63J0R	1	$0.24	$0.24
Transistors Bipolar (BJT) PNP Transistor General Purpose	512-2N4403TF	1	$0.06	$0.06
Transistors Bipolar (BJT) NPN Transistor General Purpose	512-2N5088TAR	2	$0.08	$0.16
Op Amps Single Lo-Noise JFET	511-TL071CN	1	$0.52	$0.52
Soft Switching PWM Controllers POWER_CONVERSION	512-FSCQ0965RTYDTU	1	$2.32	$2.32
Fuses SMALL DIM. FUSE	504-BK/GMD-1.5-R	1	$0.78	$0.78
Shunt Regulator 2.5V Programmable	512-KA431AZTA	1	$0.14	$0.14

Transistor Output Optocoupler	638-CNY171M	1	$0.21	$0.21
Aluminum Electrolytic Capacitors - 16V 4700uF	140-REA472M1CBK1625P	1	$0.95	$0.95
Aluminum Electrolytic Capacitors - 25V 220uF	140-REA221M1EBK0811P	2	$0.13	$0.26
Diodes 1.0 Amp 1000 Volt	625-BA159-E3	1	$0.06	$0.06
Diodes Ultra-Fast 600V 15A	771-BYT79-600,127	2	$1.49	$2.98
Polyester Film Cap 100V 2.2nF	647-QYX2A222KTP	1	$0.08	$0.08
Zener Diodes 18V	771-1N4746A,133	1	$0.04	$0.04
Electrolytic Capacitor 50V 10uF	871-B41827A6106M000	2	$0.06	$0.12
Diodes 100V	833-1N4448-TP	3	$0.05	$0.15
Polyester Film Cap 1000V 0.001uF	80-MMK5102K1000J01L4	1	$0.2	$0.2
Aluminum Electrolytic Cap 200Volts 330uF	647-UCS2D331MHD	1	$2.62	$2.62
Diodes 1.0 Amp 400 Volt	625-BA157-E3	4	$0.06	$0.24
Aluminum Electrolytic Capacitors - 100volts 0.33uF	647-UFW2AR33MDD	4	$0.08	$0.32
Polyester Film Capacitors 50V 0.015uF 5%	647-QYP1H153JTP	2	$0.15	$0.3
Aluminum Electrolytic Capacitors - 50V 0.22uF	140-REAR22M1HBK0511P	2	$0.06	$0.12
Multilayer Ceramic Capacitors (MLCC) - Leaded .1uF 50volts	21RZ310-RC	7	$0.08	$0.56
Aluminum Electrolytic Capacitors - Leaded 16V 10uF	140-REA100M1CBK0511P	1	$0.06	$0.06
Zener Diodes VREG 500MA 5%	771-1N4733A-T/R	1	$0.04	$0.04
Aluminum Electrolytic Capacitors - 25volts 470uF	871-B41827A5477M000	2	$0.17	$0.34
Metal Oxide Resistors MOSX2 3.9 5% 2W	660-MOSX2CT52A3R9J	1	$0.13	$0.13
Rectifiers Vr/1000V Io/1A	512-1N4007	1	$0.09	$0.09
Transistors Bipolar (BJT) NPN Si Transistor Epitaxial	512-2N6517CTA	3	$0.06	$0.18
MOSFET NFET T0220FP 500V 5A 1.5R	863-NDF05N50ZG	1	$0.69	$0.69
Zener Diodes 60 Volt 0.5 Watt	78-1N5264B	4	$0.07	$0.28
Aluminum Electrolytic Capacitors - 350V 10uF	140-REA100M2VBK1020P	3	$0.31	$0.93
Low Dropout (LDO) Regulators 800MA LDO LINEAR REG	926-LM1117T-3.3/NOPB	1	$1.49	$1.49
Polyester Film Capacitors .047uF 50V 5%	667-ECQ-V1H473JL3	1	$0.13	$0.13
Ceramic Disc Capacitors 50V 240pF SL 5% Tol	140-50S5-241J-RC	5	$0.07	$0.35
Polyester Film Capacitors .022UF 100V	667-ECQ-V1223JM	4	$0.31	$1.24
Polyester Film Capacitors ECQVStack Met Poly Film Cap	667-ECQ-V1H104JLW	1	$0.14	$0.14
Aluminum Electrolytic Capacitors - 1uF 25Volt	539-SN010M025ST	1	$0.31	$0.31
Diodes 100V Io/150mA T/R	78-1N4148	4	$0.08	$0.32
Ceramic Disc Capacitors 50V 100pF SL 5% Tol	140-50S5-101J-RC	3	$0.06	$0.18
Aluminum Electrolytic Capacitors - 25volts 100uF	871-B41828A5107M000	4	$0.08	$0.32
Zener Diodes 16 Volt 0.5W 10%	78-TZX16A	2	$0.07	$0.14
Power Inductors 22UH RADIAL COIL CHOKE	667-ELC-18B220L	2	$1.7	$3.4
			TOTAL	**$150.49**
Cabinet				
High Density Insulation Foam	8'x4'x1"	2	$12	$24
Jensen NEo 10-100	10" -16 Ohm	2	$112.65	$225.3
Neutrik Locking jack	black	1	$6	$6

carbon fiber part kit	2 yard kit	1	$142	$142
10-32 Machine Screws with T-nuts	50	1	$18.04	$18.04
			TOTAL	**$415.34**
			GRAND TOTAL	**$565.83**

Total Cost: Parts and Labor

Labor	$30,000.00
Parts	$565.83
Total	$30,565.83

Schedule:

Week	Task	Lead
2/6	• Read Material On Transmission Line Design	Thomas
	• Determine configuration for switching power supply • Finalize audio signal path design	Jeremy
2/13	• Finalize Transmission Line Design • Create Sound Field Simulation	Thomas
	• Sign up for Design Review • Finalize power supply design • Draw electrical schematics	Jeremy
2/20	• Purchase Cabinet Materials	Thomas
	• Design component layouts • Purchase electrical components	Jeremy
2/27	• Create small mock up of Cabinet	Thomas
	• Acquire PCBs • Acquire amplifier enclosure	Jeremy
3/5	• Begin Carbon Fiber cabinet manufacture	Thomas
	• Wind and test transformers • Assemble power supply	Jeremy
3/12	• Finish Individual Progress Report	Thomas
	• Finish Individual Progress Report	Jeremy

3/19	• Sleep in, camping, travel, playing instruments	Thomas
	• Spring Break	Jeremy
3/26	• Sign up for Mock-up Presentation	Thomas
	• Test & troubleshoot power supply • Assemble audio signal chain	Jeremy
4/2	• Finish Cabinet Construction	Thomas
	• Test & troubleshoot power supply • Test & troubleshoot audio signal chain	Jeremy
4/9	• Test Frequency Response of Cabinet	Thomas
	• Test & troubleshoot power supply • Test & troubleshoot audio signal chain	Jeremy
4/16	• Test Thiele small parameters inside and outside of cabinet	Thomas
	• Sign up for Demo and Presentation times • Test & troubleshoot power supply • Test & troubleshoot audio signal chain	Jeremy
4/23	• Create Presentation	Thomas
	• Create Presentation	Jeremy

Ethical Questions:

Re: 1, Playing amplifier at loud volumes can damage hearing if the acoustic factors are correct.

Re: 2, Many of the materials used in this project's construction are harmful to people and the environment and have no degradation over time. More responsible material choices will be pursued in the future

References

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3. *TDA8922B Datasheet;* Phillips Electronics
   http://www.nxp.com/documents/data_sheet/TDA8922B.pdf
4. *Neo 10-100;* Jensen Speakers
   http://www.jensentone.com/sites/default/files/spec_sheets/Neo10-100_Specification_Sheet.pdf
5. *Fundamentals of Acoustics*; Kinsler, Frey, Coppens, Sanders
6. *Pearls from Martin J. King Quarter Wave Design*, Bjorn Johannesen
   http://www.t-linespeakers.org/design/MJK-for-dummies/index.html
7. *Measuring Loudspeaker Driver Parameters*, Rod Elliot
   http://sound.westhost.com/tsp.htm