

AN1308

100 and 200 Watt High Fidelity Audio Amplifiers Utilizing a Wideband-Low Feedback Design

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INTRODUCTION

Over the past two decades many types of solid state, high fidelity audio amplifier design approaches have been tried. Many of these designs have used large amounts of negative feedback to ensure low closed-loop harmonic distortion. The main contributors to this type of distortion are the output devices. Other contributors to this harmonic distortion are the drivers, or devices preceding the output devices and the high voltage gain stage, also referred to as the transconductance stage. A side effect of a high open-loop gain is that wide bandwidth is very difficult to achieve with two gain stages, therefore most of these high gain designs have an open-loop bandwidth of less than a few kilohertz. This means there is a need for even more than necessary gain mid-band (referring to the audio band) to get a low distortion number at 20 kHz in the closed-loop condition. The audio band is defined as 2 Hz to 20 kHz with the mid-point from 1 kHz to 2 kHz. It was found that large amounts of negative feedback increased TIM (transient intermodulation distortion).

The approach to dealing with this problem in amplifiers is to use lower open-loop voltage gain sections and increase the open-loop bandwidth to 20 kHz. The loss of feedback (and increased closed-loop distortion) has inspired different solutions for the output section as well as the voltage gain section. One approach is to change the distortion specification; however, this may not produce optimal results. A better solution is to use multiple output devices to keep the current excursion low for each device, so as to stay within a linear range of gain. This has been a popular approach with some manufacturers; however, it is a more costly solution. Other approaches use high feedback, linearized, unity gain output stages. This is done with either bipolar devices or with power MOSFETs.

This note focuses on the use of a new pair of complementary Motorola bipolar power output transistors,

the 2SC3281 and 2SA1302. These devices have better linearity than devices previously targeted for this type of application. The amplifier circuits presented use a topology that is fully complementary in design with a dual differential input. Other parameters sought after are a wide open-loop bandwidth, (greater than the audio band) and a minimal amount of negative feedback, (25 dB or less).

BASIC AMPLIFIER DESIGN PHILOSOPHY

A conservative design approach was taken with effort made to keep the circuitry design simple. The purpose of this note is to show that a low feedback design with wide bandwidth can yield quite low distortion without any special distortion cancelling circuitry or localized feedback loops.

Design Description of the 100 Watt Amplifier

A block diagram of the 100 watt amplifier is shown in Figure 3. This design begins with the MPS8099 and MPS8599 complementary pair for the input stage. These devices are rated at 80 volts, giving them adequate margin on a nominal 52 volt supply. These devices are arranged as dual differentials. For simplicity, no current sources are used. A ± 24 volt zener with 10K ohm resistors supplies approximately 2.25 mA of current to each pair. This scheme supplies enough current to achieve the bandwidth necessary in the first stage while keeping the bias currents low enough for an acceptable amount of input voltage offset error. In an attempt to eliminate a coupling capacitor in the feedback loop, low offset is important when trying to DC couple the feedback. The input impedance of the amplifier is primarily determined by the 33.2K ohm resistor used as the input return path to ground. That, coupled with the 2.2 μ F coupling capacitor, sets the low corner frequency at approximately 2 Hz.



Figure 1. 100 Watt High Fidelity Audio Amplifier

Figure 2. 200 Watt High Fidelity Audio Amplifier

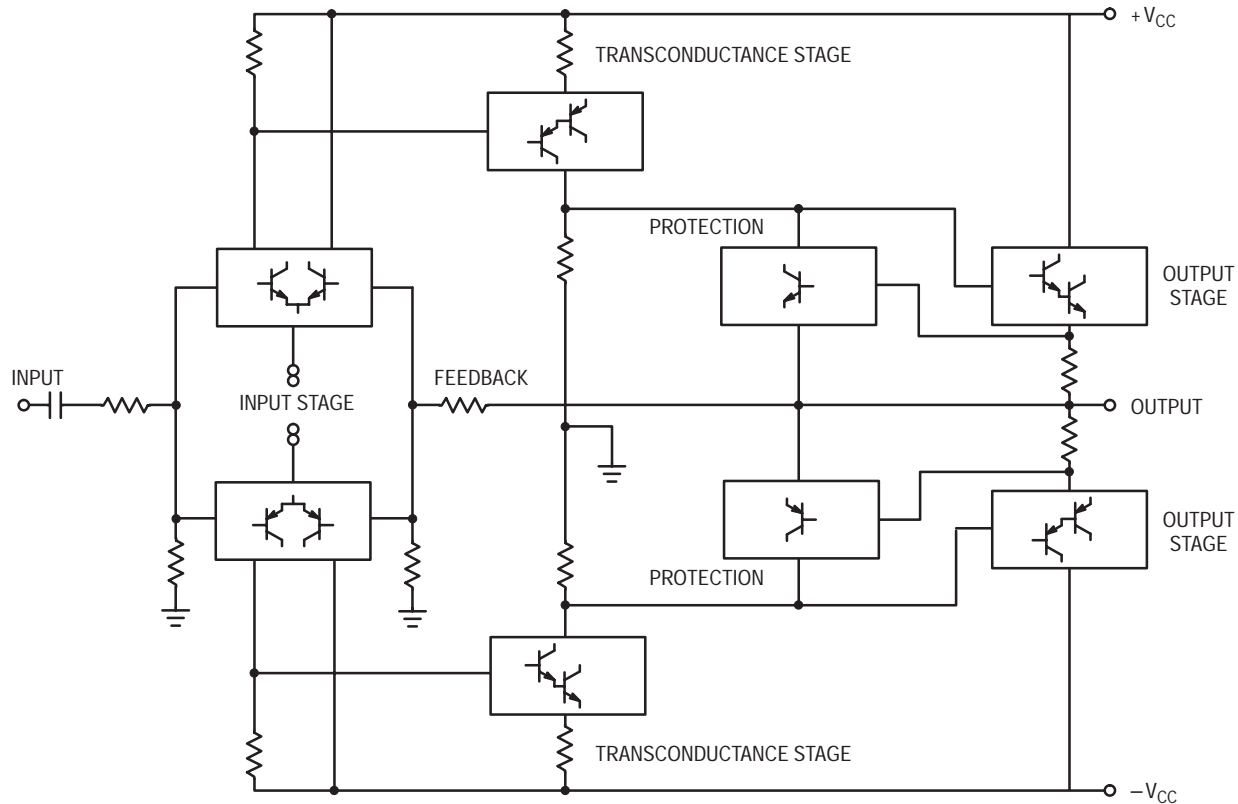


Figure 3. Block Diagram of 100 Watt Amplifier

The second stage of voltage gain, sometimes referred to as the transconductance stage, is made up of a darlington pair. The input devices of the darlington pairs are the MPSW06 and MPSW56 respectively. Both of these devices are also rated at 80 volts. These devices are operated in a common collector mode with their collectors grounded to minimize the Miller effect. Idling current is approximately 3.5 mA with 511 ohm emitter resistors which in turn set the idling currents for the 2SC3298B and 2SA1306B. Because the idling currents are set at approximately 50 mA or 2.4 watts in each of these devices, a small heat sink is required to keep the case temperatures down. The 2SC3298B and 2SA1306B devices are rated at 200 volts which is more than adequate to handle the nominal voltage swings of 100 volts for this stage of the amplifier. The transconductance stage is loaded by both the output stage and a pair of 2.7K ohm resistors. These resistors set the voltage gain at this stage. Looking at the input stage and the second stage respectively, their gains are approximately

18.5 dB for the input stage and 34 dB for the second stage thus giving an overall gain of about 52.5 dB. Compensation networks are used on the outputs of both stages to provide good gain and phase margin for the closed-loop condition. The closed-loop gain is set for approximately 1 volt sensitivity giving the amplifier a closed-loop gain of 27.8 dB.

The output stage is a complementary darlington configuration. This stage utilizes three 2SC3281 NPN devices and three 2SA1302 PNP devices connected in parallel. These are driven by the complementary pair consisting of an MJF15030 and MJF15031. The output devices are rated at 15 amps and 200 volts with power dissipation ratings of 150 watts. The drivers are 8 amp, 150 volt transistors with power dissipation ratings of 36 watts. The voltage ratings are adequate to handle the 100 volt nominal supply voltage. The drivers and output devices have excellent gain linearity which helps to minimize the amount of feedback needed to achieve a low distortion number.

The MPS650 and the MPS750 devices are used for current limit protection. Both devices are rated at 2 amps giving them excellent saturation and gain characteristics at 100 mA. A discussion on how the current limiters are set and the choice of the number of output devices used is discussed in the Output Transistors section.

Design Description of the 200 Watt Amplifier

A block diagram of the 200 watt amplifier is shown in Figure 4. The design of the 200 watt gain stages is very similar to the 100 watt amplifier with a few minor exceptions. Due to higher power supply voltages, a cascode configuration was used for the input stage. The level shifter portion of the cascode is tied to the 33 volt zener supplies which are used for the input current resistors. An additional change is the use of paralleled pre-drivers, or transconductance stage transistors. This accommodates the increased

current needed to bring the dual 2.7K ohm load and increased base current requirement of the output stage to the higher supply voltage. The benefit is a small increase in the voltage slew rate. The extra device also increases the open-loop gain by approximately 4 dB. This in turn helps the closed-loop distortion that was increased because of a 3 dB increase in closed-loop gain. This was done to keep the sensitivity of the amplifier for full power at 1 volt. Another change is the use of a cascode (series output stage). By effectively doubling the number of output devices without increasing the voltage seen in operation, second breakdown will not be a concern. The outside, or slave devices, are driven by a series resistive divider network tied to the output of the amplifier. This divider network forces the string of output devices to share the voltage and power delivered to the load.

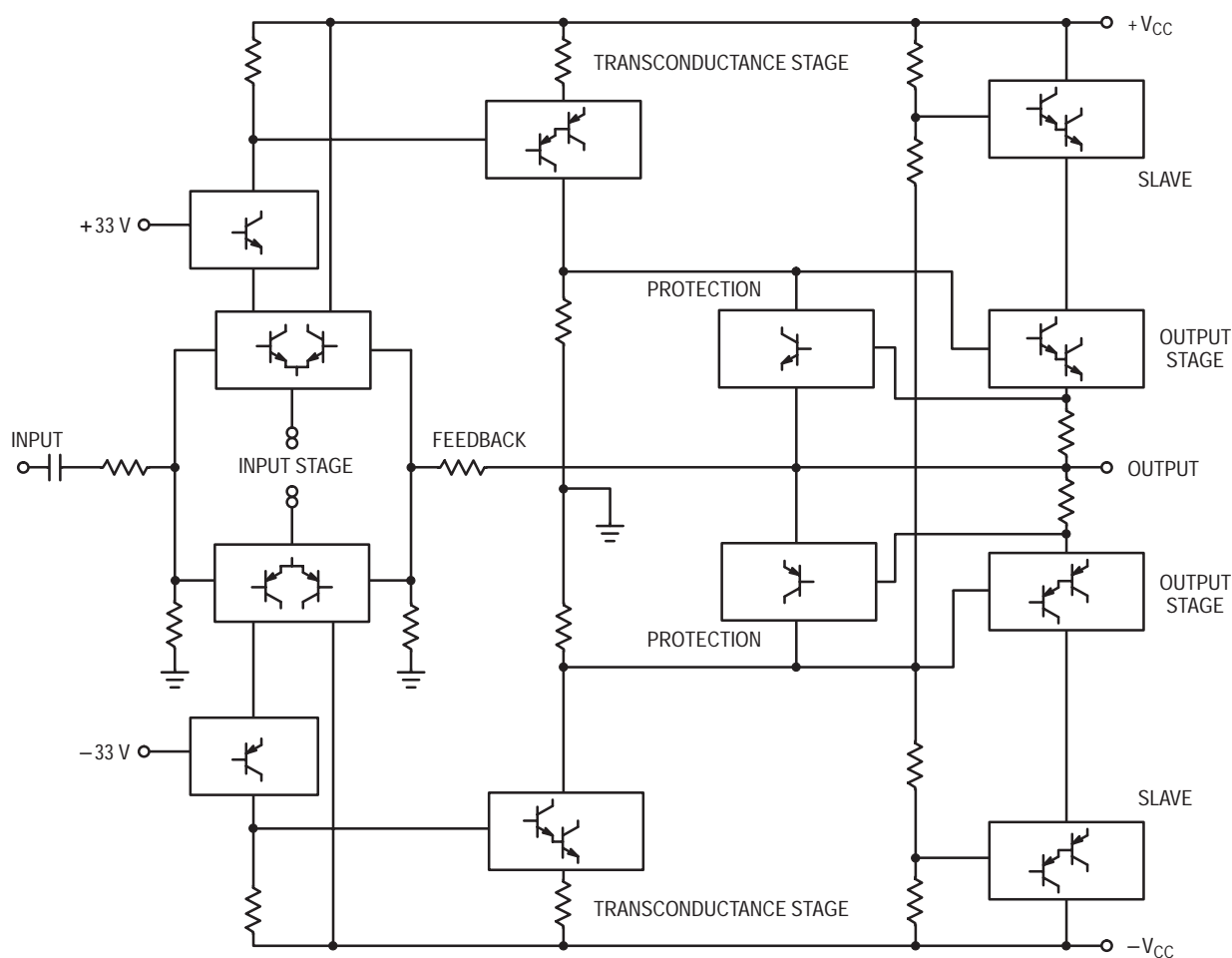


Figure 4. Block Diagram of 200 Watt Amplifier

POWER SUPPLY DESIGN

There are a number of formulas and philosophies pertaining to the selection of the size of a power transformer and the supply filters for use in an audio amplifier. The selection of these components affects the supply regulation and the amount of ripple the amplifier will see under varying load conditions. One specification that has come into widespread use over the past decade is a concept called dynamic headroom. Dynamic headroom is a measure of the difference in the RMS power an amplifier can deliver continuously and the power it can deliver dynamically as defined by the Federal Trade Commission. It is measured in dB, and can range from 0 dB for an amplifier operating in a full class A mode to 3–4 dB for a class AB type amplifier with poor supply regulation. Over the years designers have found that they prefer a lower dynamic headroom, which make certain “rules of thumb” work well and provides acceptable performance. For transformer selection, take the expected 4 ohm full power performance in watts, for example, 180 watts for the 100 watt amplifier, and double it. This could be considered a worst case load for the power supply even though under typical operating conditions this level of output will never be seen. By doubling the power rating, a VA (Volt-Ampere) rating of 360 becomes the rating for the transformer to be selected. VA ratings typically are based on a temperature rise of +55° to +65°C, which equates to a regulation of approximately 5% for a resistive load equal to the VA rating of the transformer. This does not equate to the regulation performance in the amplifier application. DC supply voltages are derived by the rectified diodes that charge the supply filters and these only occur during the voltage peaks of the sine wave input. 360 VA and 600 VA transformers were chosen for the 100 watt and 200 watt amplifiers respectively. To avoid the cost of custom transformers, standard off-the-shelf toroidal transformers were chosen. These transformers were then modified. To achieve the exact voltage required for the designs, several extra turns were added to the secondary winding (see Figures 25 and 34).

Cost becomes an issue in choosing the amount of filtering needed. In practice, the amount of filtering can be looked at in terms of stored energy, or joules. Typically 1 to 2 joules of stored energy per 10 watts of output power is sufficient. In the 100 watt amplifier, the maximum output power is 180 watts at 4 ohms. This equates to 18 to 36 joules of stored energy. The power supply in the 100 watt amplifier has a pair of 10,000 μ F filter capacitors with 52 volts across each capacitor. Using the formula $1/2CV^2$, this equates to 26

joules of stored energy. The 200 watt amplifier has a maximum output power at 4 ohms. Based on the previous discussion, 30 to 60 joules of stored energy is required. The power supply for the 200 watt amplifier contains four 4,700 μ F filter capacitors with 80 volts across each capacitor. This equates to 60 joules of stored energy.

OUTPUT TRANSISTORS

There are a number of considerations to be addressed when selecting output transistors for use in a high fidelity audio amplifier design. Two key considerations are the use of a complementary pair and the type of device packaging, i.e., plastic or metal. Newer designs are using plastic packages due to their simplicity in mounting and thermal performance equalling the older metal packages such as the TO-204 (TO-3). Other areas of design importance include breakdown voltage, power dissipation, safe operating area (SOA), current gain linearity, and f_T . At present, there are a limited number of complementary devices rated at 100 volts in plastic packages. Additionally, very few of these devices have good current gain linearity beyond one amp. Most of these devices have second breakdown points that usually fall between 20 and 40 volts. They may be classified as 150 watt transistors, but operate efficiently only up to 40 volts; then their power handling capability drops off rapidly.

The output devices that were selected are the 2SC3281 and 2SA1302 NPN and PNP transistors. These complementary devices are rated at 200 volts, 15 amps, and have power dissipation ratings of 150 watts. They are packaged in the TO-3PBL package, a high power plastic package with an isolated mounting hole and excellent thermal characteristics. The thermal resistance junction-to-case of this package is less than 0.83°C/watt with a maximum junction temperature, T_J equal to 150°C. The current gain is adequate beyond 3 amps of collector current, the f_T is greater than 20 MHz and the second breakdown point is greater than 70 volts. With these specifications these devices are ideal for use under the type of load conditions and voltages expected to be seen in low distortion wideband linear amplifier designs. Operating characteristics for these devices are shown in Figures 5 through 10.

Setting the Current Limits

Setting the current limits of an output stage in an audio amplifier is not an easy task. Calculation can be used to find a starting point, however the actual results must be determined through experimentation. There are two limitations to consider when dealing with the power handling

OPERATING CHARACTERISTICS FOR OUTPUT DEVICES

2SA1302 — PNP

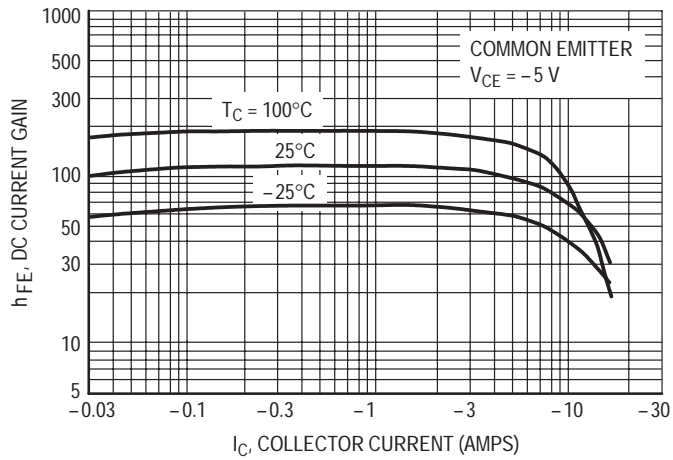


Figure 5. DC Current Gain

2SC3281 — NPN

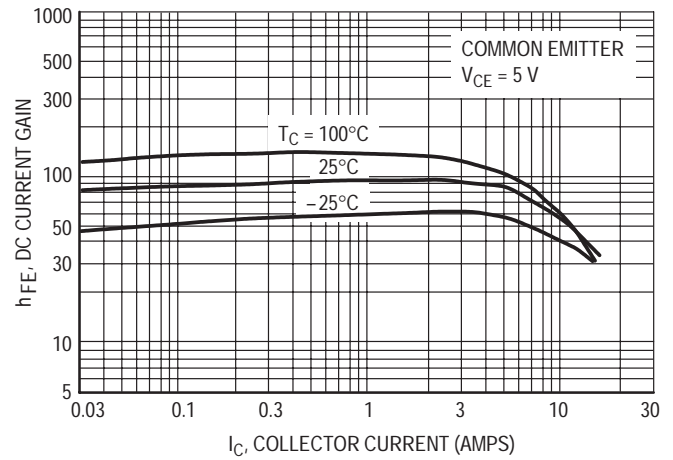


Figure 6. DC Current Gain

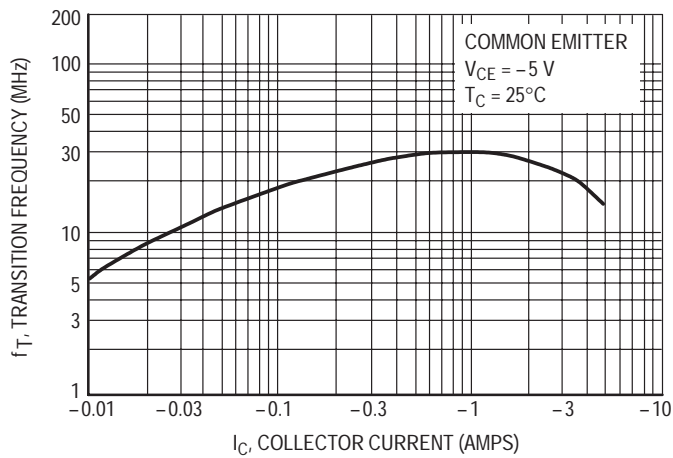


Figure 7. Current-Gain Bandwidth Product

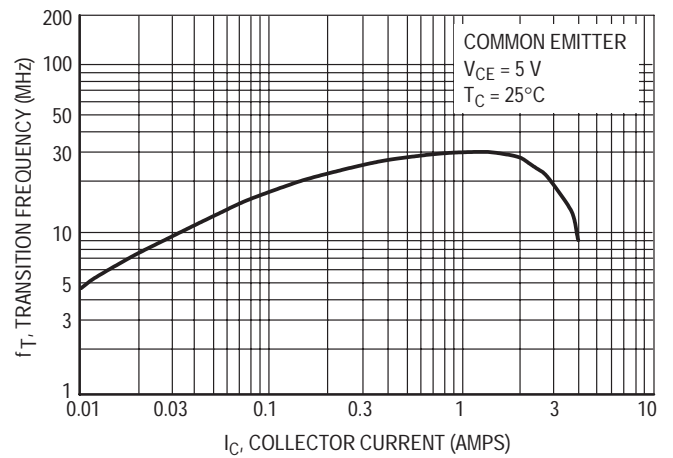


Figure 8. Current-Gain Bandwidth Product

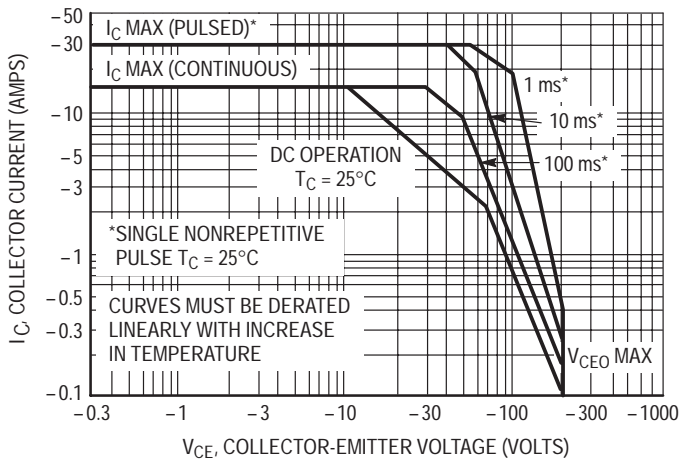


Figure 9. Active Region Safe Operating Area

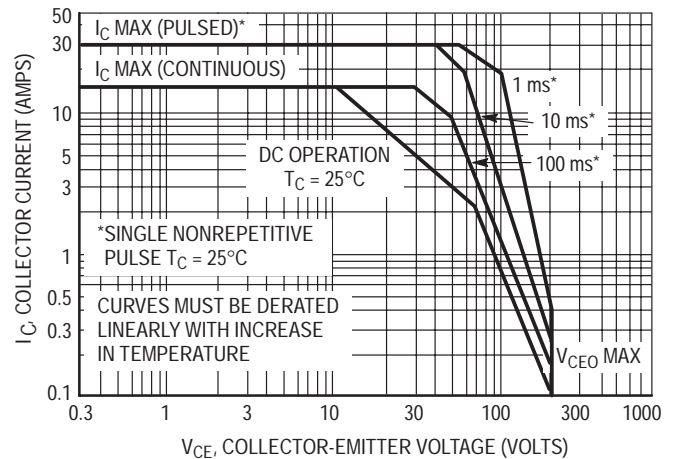


Figure 10. Active Region Safe Operating Area

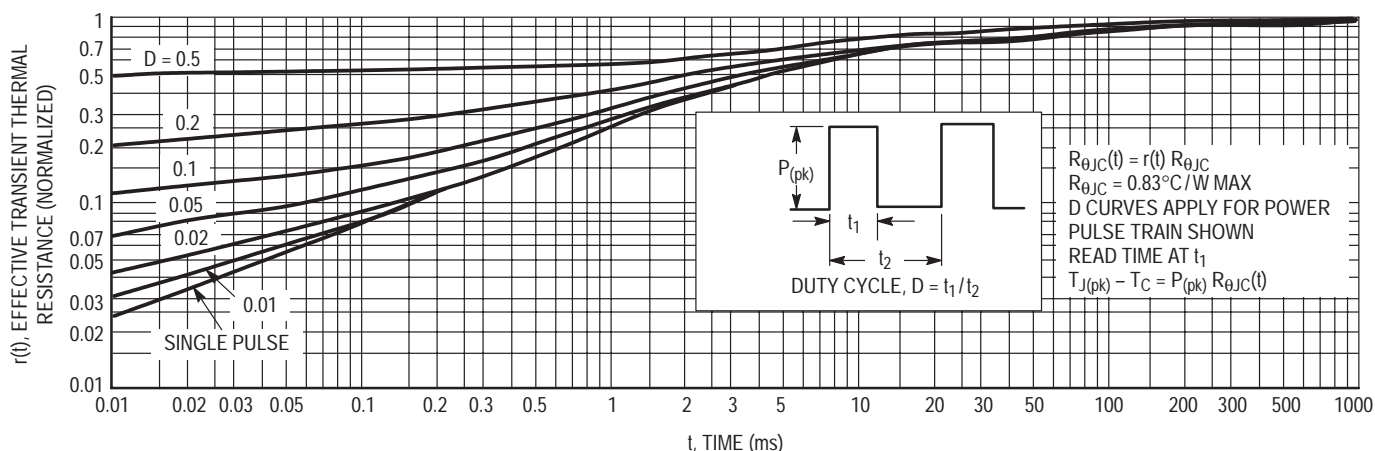


Figure 11. Thermal Response of Output Devices

ability of a transistor: the average junction temperature and second breakdown. In a class AB output stage, the output devices are not really in a 50% duty cycle situation. The bias current needs to be added to the calculated current that the load may present to the device. At higher frequencies the peak power can be considerably higher than the average power. At low frequencies the duration that one side of the output stage may endure during a load condition may be several hundred milliseconds, which nearly constitutes a DC condition. By examining the thermal response curve of the output devices in Figure 11, the actual value of $R_{\theta JC}$ for the low frequency condition can be determined by multiplying the specified value of $R_{\theta JC}$ by $r(t) = 0.9$. With this information, there are three more parameters that connect the transistor junction to its surroundings — the thermal resistance from the transistor junction to the case of the transistor, the thermal resistance of the mounting interface, and the thermal resistance of the heat sink to air.

Figure 12 shows the load conditions for the entire output stage of the 100 watt amplifier. The load line for an 8 ohm, 45 degree load indicates the need for 6 amps of collector current dropping to 4 amps of collector current when the collector voltage drops to 50 volts. Figure 12 also shows the peak currents at lower resistive load conditions. Most loudspeakers present a load impedance of less than 8 ohms; however, most don't present a reactive load of less than 8 ohms. As shown in Figure 12, a 90° reactive 8 ohm load is handled easily and resistive loads as low as 2 ohms do not present a problem. The constant power curve shown at 375 watts is drawn along the line where the current limits were set for this amplifier. If this power is shared between 3 devices, they will each be required to dissipate 125 watts at the point where the power will be limited by the current limiters.

By limiting the power linearly from 150 watts at 25°C to 0 at 150°C, the case temperature can rise to approximately 60°C. This is determined from Figure 14, the power derating curve. By allowing the case temperature to rise to this limit, the power output will have to be limited to 75% of 150 watts,

or 112.5 watts. With this number and the information known about the thermal response of the device, one can allow the peak power dissipated by each transistor to reach 125 watts. This means that under operating conditions where the temperature is less than 60°C, the output devices will be operating safely. Examining the safe operating area curves in Figures 9 and 10, it can be seen that above 70 volts, the power the output devices can dissipate, begins to drop. Using 100 volts as a reference, the power dissipation has dropped from 150 watts at 70 volts to about 800 mA at 100 volts, or 80 watts. The power derating curve (Figure 14) shows a reduction in power dissipation as temperature is increased with the derating factor dropping even lower for the second breakdown derating. The 60°C point on this curve is 85%, or 68 watts. This implies that the output devices are only safe for a total power dissipation of 204 watts when operating the three devices at the full supply voltage of the 100 watt amplifier. This is where the current limiters do not fully protect the output devices. As shown in the load line plots in Figures 12 and 13, the protection provided by the current limiters allows the power to reach 375 watts at 100 volts. A fully reactive load of 90 degrees will never be seen in a loudspeaker and the current limits need to be set by experimentation. Figures 15 and 16 show photos of the current limit, or protection circuit tested into a capacitor. Although Figures 15 and 16 show that the output devices are capable of more than their published specifications, it is recommended that one not exceed published limits as shown on the manufacturer's data sheets in the interests of achieving long term reliability.

Measurements of the protection circuit shown in Figures 15 and 16 show the actual current limit points of the amplifiers when driving large capacitive loads at a frequency of approximately 100 Hz. As measured, the limits are set about 25% higher than needed for the load conditions outlined. The type of current limiters used begins to limit the current slightly lower than their final value causing substantial distortion in the form of compression before the final limit value is reached.

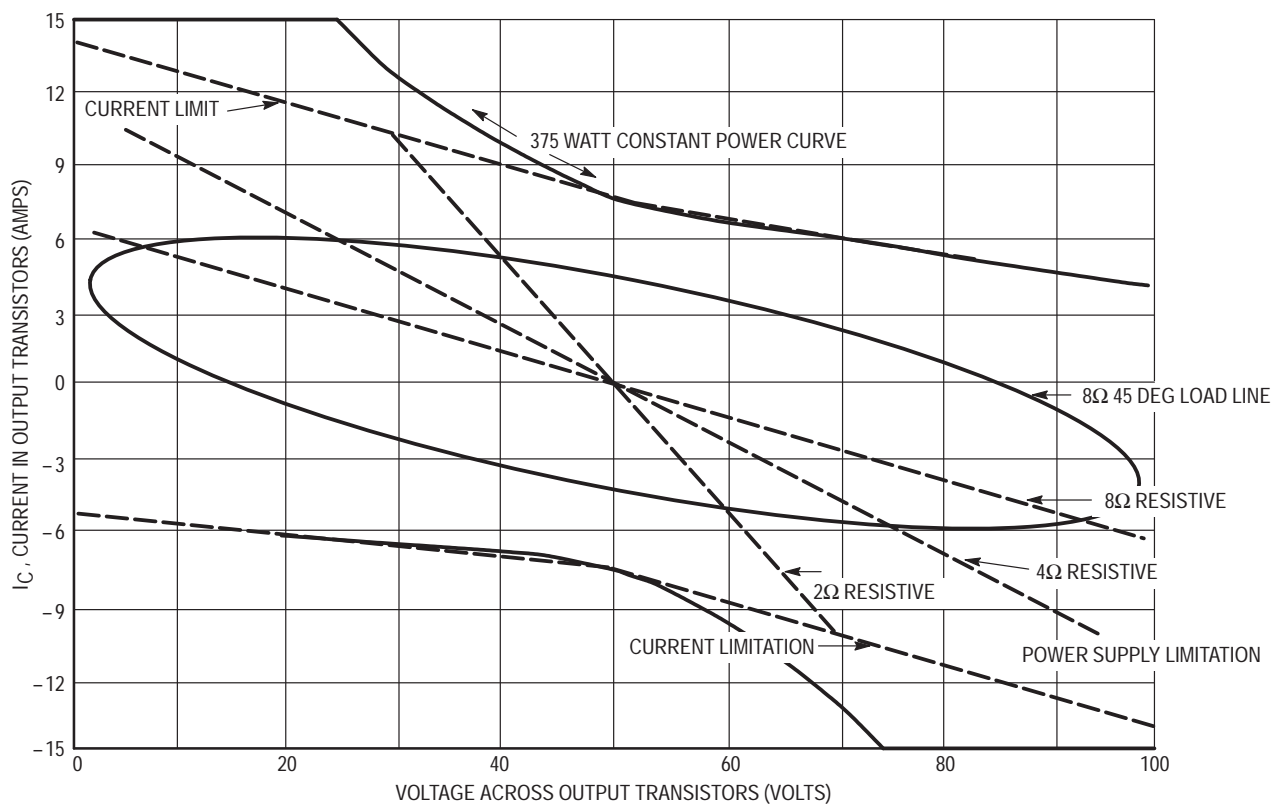


Figure 12. Load Lines of 100 Watt Amplifier

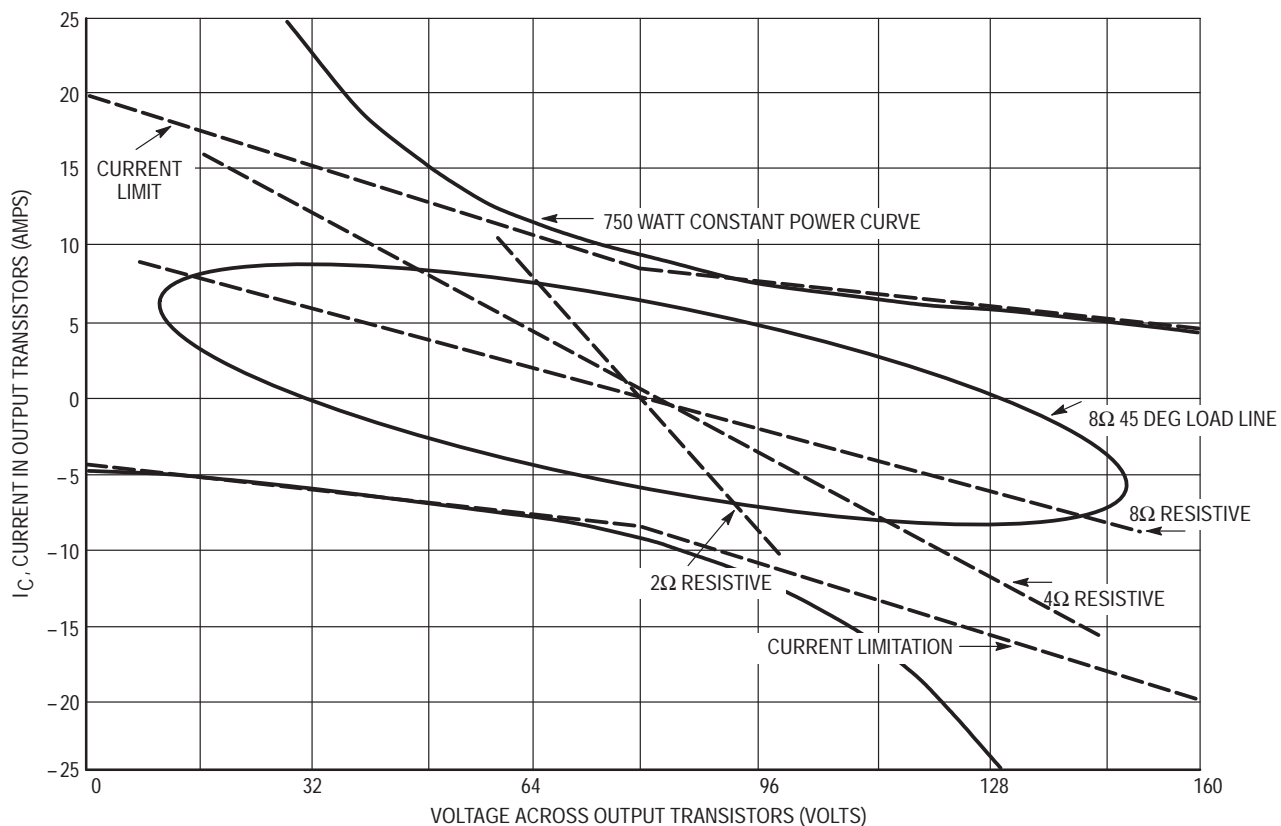


Figure 13. Load Lines of 200 Watt Amplifier

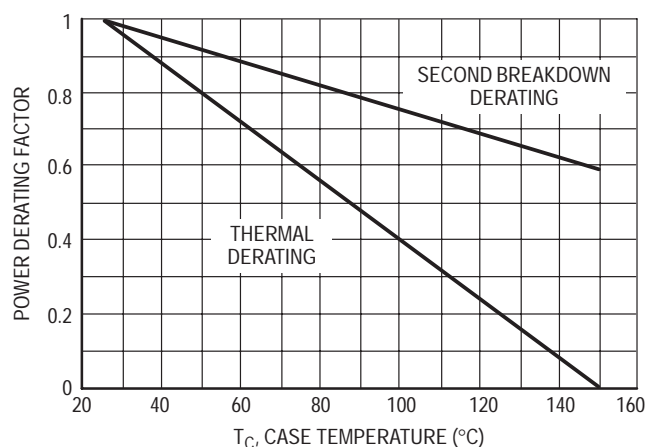


Figure 14. Power Derating Factor for Output Devices

Series Connected Output Devices

As discussed previously, the second breakdown of a transistor can severely limit the power dissipation capability of that device. When the supply voltages of an amplifier are greater than 100 volts, the output devices are pushing their limits. By configuring the output devices in a series-parallel configuration one can obtain an increase in output power from a set of devices rather than configuring them all in parallel. The load lines of the 200 watt amplifier indicate a constant power curve of 750 watts, which is twice that of the 100 watt amplifier. There are twice the number of output devices connected in a series-parallel configuration resulting in the same 125 watt criteria for each as in the 100 watt amplifier. Since these devices do not see more than 80 volts each in operation, second breakdown is of no concern. Although the devices can be operated in a series connected output stage, its operation is similar to a bridge configuration but the low impedance performance is diminished. This amplifier does current limit when driving a 2 ohm load where the 100 watt amplifier does not.

HEATSINK REQUIREMENTS

Choosing the right heatsink is very important. Regardless of the requirements of size, shape, form factor and cosmetics, the bottom line is heat transfer in terms of degrees centigrade per watt (°C/W). The heatsink chosen for these two amplifiers is a standard aluminum extrusion made by AHAM TOR INC., model #6071 as shown in Figure 17. It is a tree shaped extrusion weighing 2.2 pounds per foot. It has a surface area of 31.7 square inches per linear inch and a convection heat transfer rating of 1.8°C/W per 3 inch piece. The design of this heatsink lends itself well to the configuration used for mounting the output and driver devices. By using the PC board to clamp the devices to the heatsink, mounting hardware is eliminated. Another advantage to having the heatsinks board mounted is that the output transistors need not be electrically isolated from their mounting. This allows for nothing but thermal compound

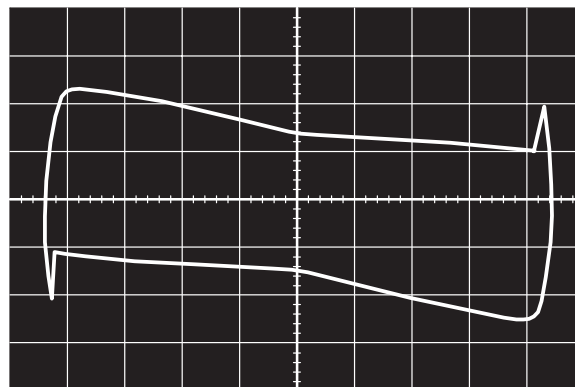


Figure 15. Output Current Limit of 100 Watt Amplifier

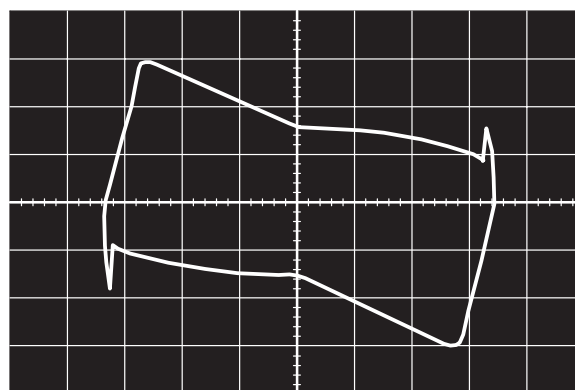


Figure 16. Output Current Limit of 200 Watt Amplifier

between the devices and the heatsink. This allows for optimum heat transfer (less than 0.1°C/W). The use of two 7 inch extrusions in the 100 watt amplifier gives the output stage the ability to dissipate about 90 watts while keeping a temperature rise of less than 35° above room temperature ($T_A = 25^\circ\text{C}$). This is based on 1.8°C of rise for a 3 inch piece making a 7 inch piece about 0.77°C/W. Tests run have shown that with the 100 watt amplifier running at full power, the heatsinks stayed below 60°C. Operation with air flowing across the heatsinks will give improved performance over the convection numbers published by the heatsink manufacturer. The addition of a fan blowing across the heatsinks will allow the amplifier to operate at a 4 ohm load continuously.

EVALUATION BOARD DESCRIPTIONS

100 Watt Amplifier

The 100 watt amplifier was constructed on a double-sided 0.062" G10 glass epoxy printed circuit board measuring 7 inches x 12 inches. All components are included on the PC board with the exception of the power transformer and bridge rectifier. Grounding is done with the star method; each point in the circuit that is connected to ground has its own trace running to the input connection. This helps to reduce ground loops and give optimum noise performance. The power supply center tap is connected as close to the center between the supply filter capacitors as is physically possible.

This keeps the power supply ripple balanced and as low as possible. The input devices and transconductance stages are grouped as close as physically possible on the board. This helps to reduce parasitics. Table 1 shows the actual measured performance of the 100 watt amplifier. Plots of the measurements are shown in Figures 18 through 23. The DC stability of this amplifier measured at the output of the amplifier is ± 100 mV at room temperature. All measurements were made at room temperature. If this parameter is critical, a DC servo loop could be added to reduce the DC output offset. The schematics of the power supply and amplifier are shown in Figures 25 and 26. The components used in the construction of this amplifier are listed in Table 3.

200 Watt Amplifier

The 200 watt amplifier was also constructed on a double sided 0.062" G10 glass epoxy printed circuit board measuring 13.5 inches x 12 inches. Other than the addition of the additional output devices and the two additional heatsinks, this board is identical to the 100 watt amplifier. Table 2 shows the actual measured performance of the 200 watt amplifier. Plots of the measurements are shown in Figures 27 through 33. The schematics of the power supply and amplifier are shown in Figures 34 and 35. The components used in the construction of this amplifier are listed in Table 4.

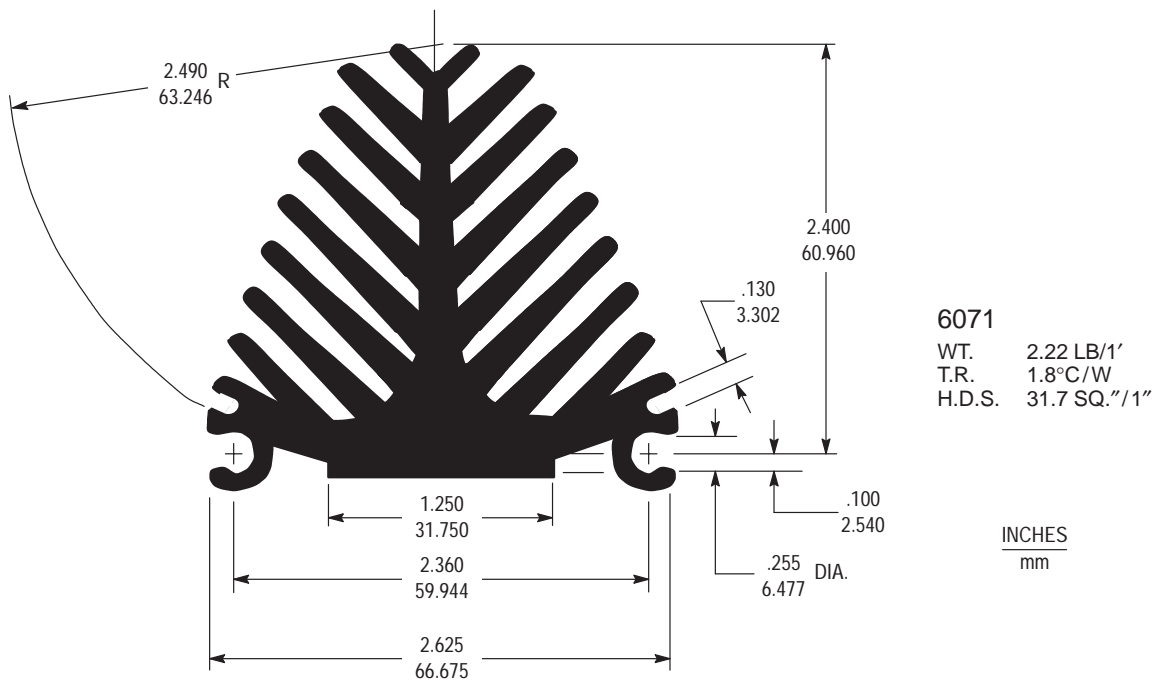


Figure 17. Heatsink Profile

Table 1. Specifications — 100 Watt Amplifier

Parameter	Performance	Notes
Output Power into an 8 ohm load	100 watts	20 Hz to 20 kHz
Output Power into a 4 ohm load	175 watts	20 Hz to 20 kHz
Power bandwidth @ 8 ohms +0 dB, -3 dB	2 Hz–210 kHz*	Source impedance = 600 ohms
Total Harmonic Distortion + Noise @ 8 ohms	< .03%	20 Hz to 20 kHz, 1 watt to 100 watts
Total Harmonic Distortion + Noise @ 4 ohms	< .05%	20 Hz to 20 kHz, 1 watt to 175 watts
Voltage Slew Rate	125 V/μs	
DC output offset voltage	< ±50 mV	@ 25°C
Rise time	< 1.8 μs	50% of full scale output voltage with 8 ohm load
Input Impedance	> 32 k ohm	20 Hz to 20 kHz
Input Sensitivity for rated output	1.18 volts RMS	100 watts @ 8 ohms or 28.3 volts RMS
Input Sensitivity for 1 watt out @ 8 ohms	118 mV RMS	
Output Impedance	< 80 milliohms	20 Hz to 20 kHz
Damping Factor	100	Referred to 8 ohms
Output Noise A weighted	< 75 μV	Input shunted with 600 ohms
Output Noise C weighted	< 150 μV	Input shunted with 600 ohms
Signal to Noise A weighted	90 dB	Referred to 1 watt out @ 8 ohms or 2.83 volts RMS
Signal to Noise C weighted	105 dB	Referred to 100 watts @ 8 ohms or 28.3 volts RMS
Short Circuit current	7.5 A	Peak
Peak output current	13 A	Resistive load
Open-loop bandwidth	5 Hz–21 kHz	No load, source impedance = 600 ohms, (small signal, inside output termination network)
Open-loop voltage gain	52.5 dB	No load (small signal)
Closed-loop voltage gain	27.8 dB	No load

*Output power above 10 kHz must be limited to 10% duty cycle to prevent over stressing the output termination network.

Table 2. Specifications — 200 Watt Amplifier

Parameter	Performance	Notes
Output Power into an 8 ohm load	200 watts	20 Hz to 20 kHz
Output Power into a 4 ohm load	300 watts	20 Hz to 20 kHz
Power bandwidth @ 8 ohms +0 dB, -3 dB	2 Hz–190 kHz*	Source impedance = 600 ohms
Total Harmonic Distortion + Noise @ 8 ohms	< .04%	20 Hz to 20 kHz, 1 watt to 200 watts
Total Harmonic Distortion + Noise @ 4 ohms	< .09%	20 Hz to 20 kHz, 1 watt to 300 watts
Voltage Slew Rate	125 V/μs	
DC output offset voltage	< ±50 mV	@ 25°C
Rise time	< 1.9 μs	50% of full scale output voltage with 8 ohm load
Input Impedance	> 32 k ohm	20 Hz to 20 kHz
Input Sensitivity for rated output	1.07 volts RMS	200 watts @ 8 ohms or 40 volts RMS
Input Sensitivity for 1 watt out @ 8 ohms	0.076 mV RMS	
Output Impedance	< 80 milliohms	20 Hz to 20 kHz
Damping Factor	100	Referred to 8 ohms
Output Noise A weighted	< 100 μV	Input shunted with 600 ohms
Output Noise C weighted	< 200 μV	Input shunted with 600 ohms
Signal to Noise A weighted	89 dB	Referred to 1 watt out @ 8 ohms or 2.83 volts RMS
Signal to Noise C weighted	106 dB	Referred to 200 watts @ 8 ohms or 40 volts RMS
Short Circuit current	9 A	Peak
Peak output current	14 A	Resistive load
Open-loop bandwidth	5 Hz–18 kHz	No load, source impedance = 600 ohms, (small signal, inside output termination network)
Open-loop voltage gain	56.7 dB	No load (small signal)
Closed-loop voltage gain	31.3 dB	No load

*Output power above 10 kHz must be limited to 10% duty cycle to prevent over stressing the output termination network.

100 WATT AMPLIFIER MEASUREMENTS

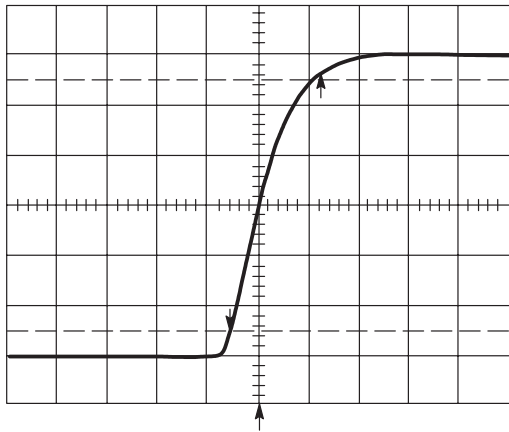


Figure 18. Square Wave Rise Time Full Scale — 8 Ω

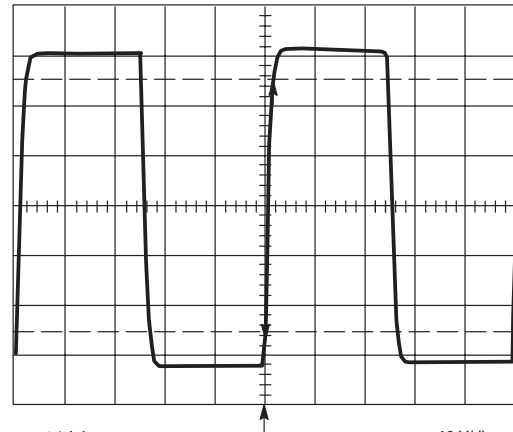


Figure 19. 20 kHz Square Wave Full Power — 8 Ω

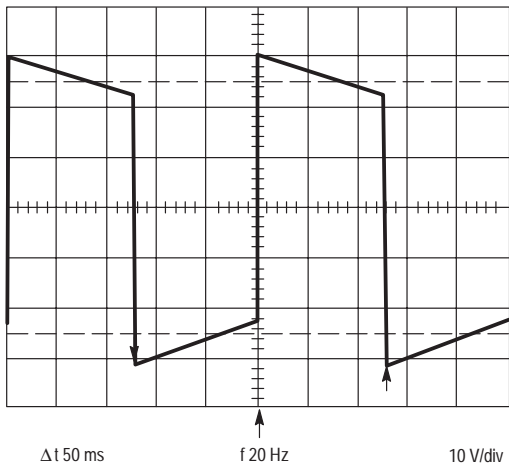


Figure 20. 20 Hz Square Wave Full Power — 8 Ω

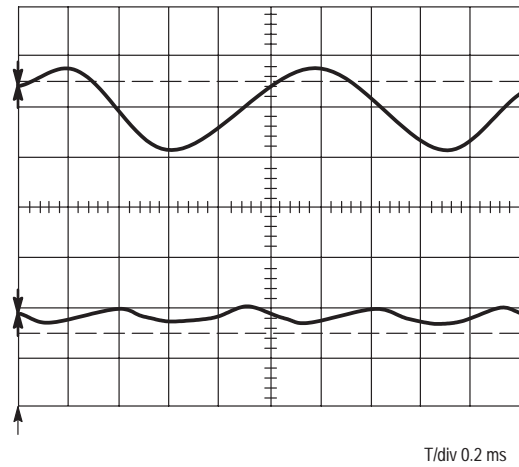


Figure 21. 1 kHz, Full Power, 8 Ω Harmonic Distortion = 0.018%

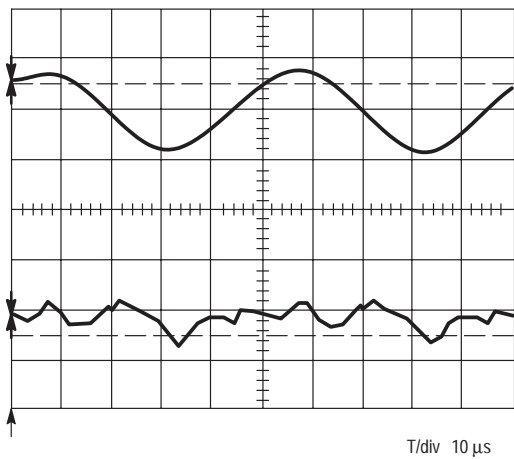


Figure 22. 20 kHz, Full Power, 8 Ω Harmonic Distortion = 0.028%

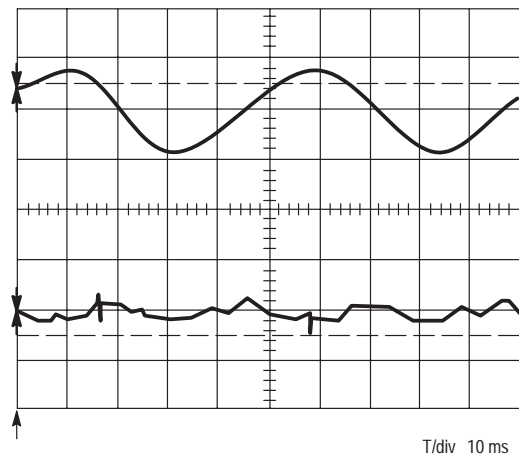


Figure 23. 20 Hz, Full Power, 8 Ω Harmonic Distortion = 0.016%

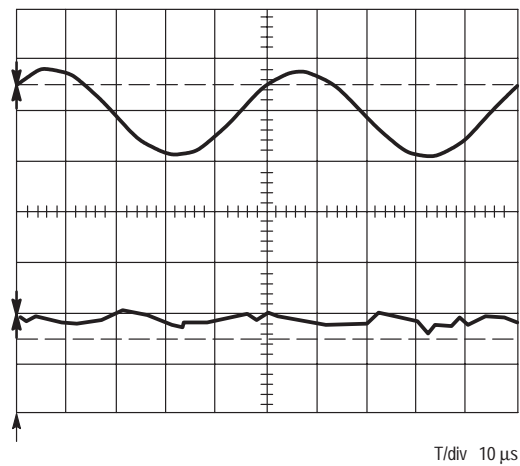
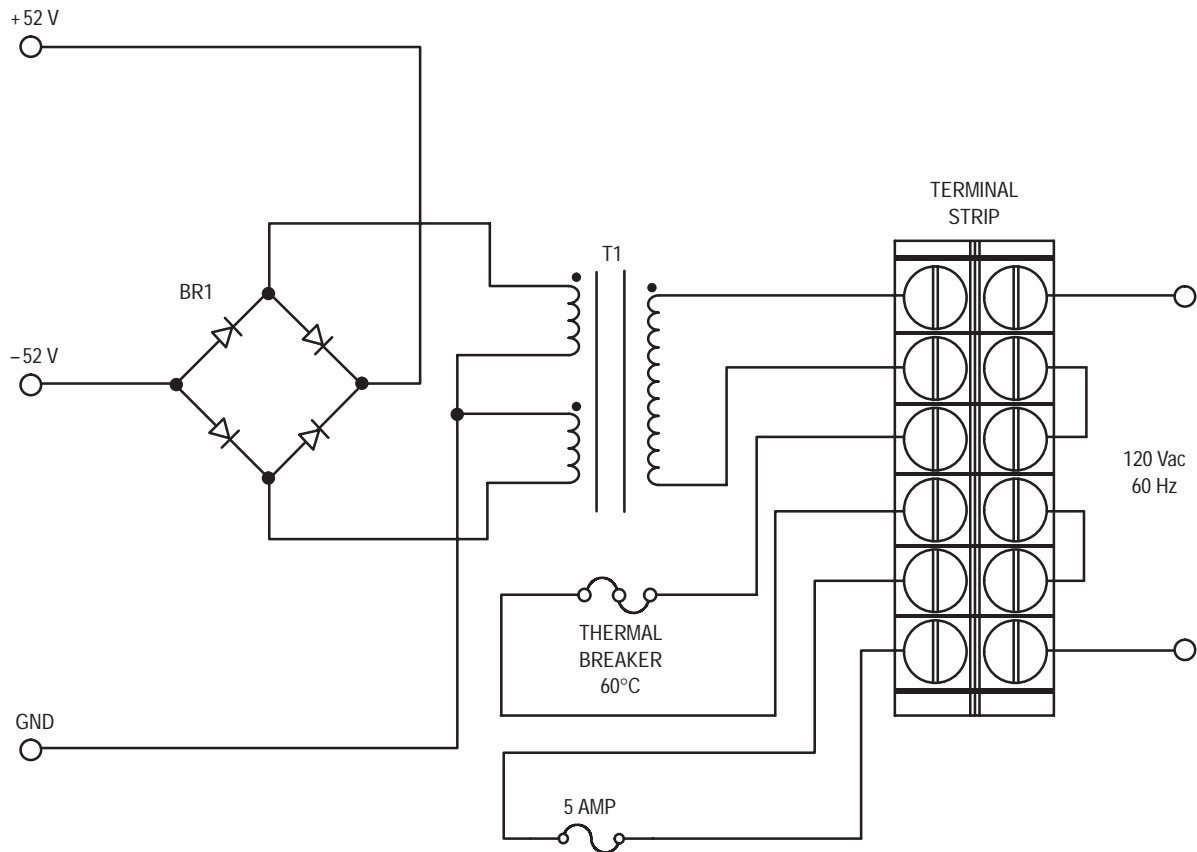


Figure 24. 20 kHz, 1 Watt, 8 Ω Harmonic Distortion = 0.014%



Notes: 8 Bifilar turns of #15 magnet wire are added to the secondary of the transformer to increase the voltage needed to obtain the required dc voltage.

Figure 25. 100 Watt Amplifier Power Supply Schematic

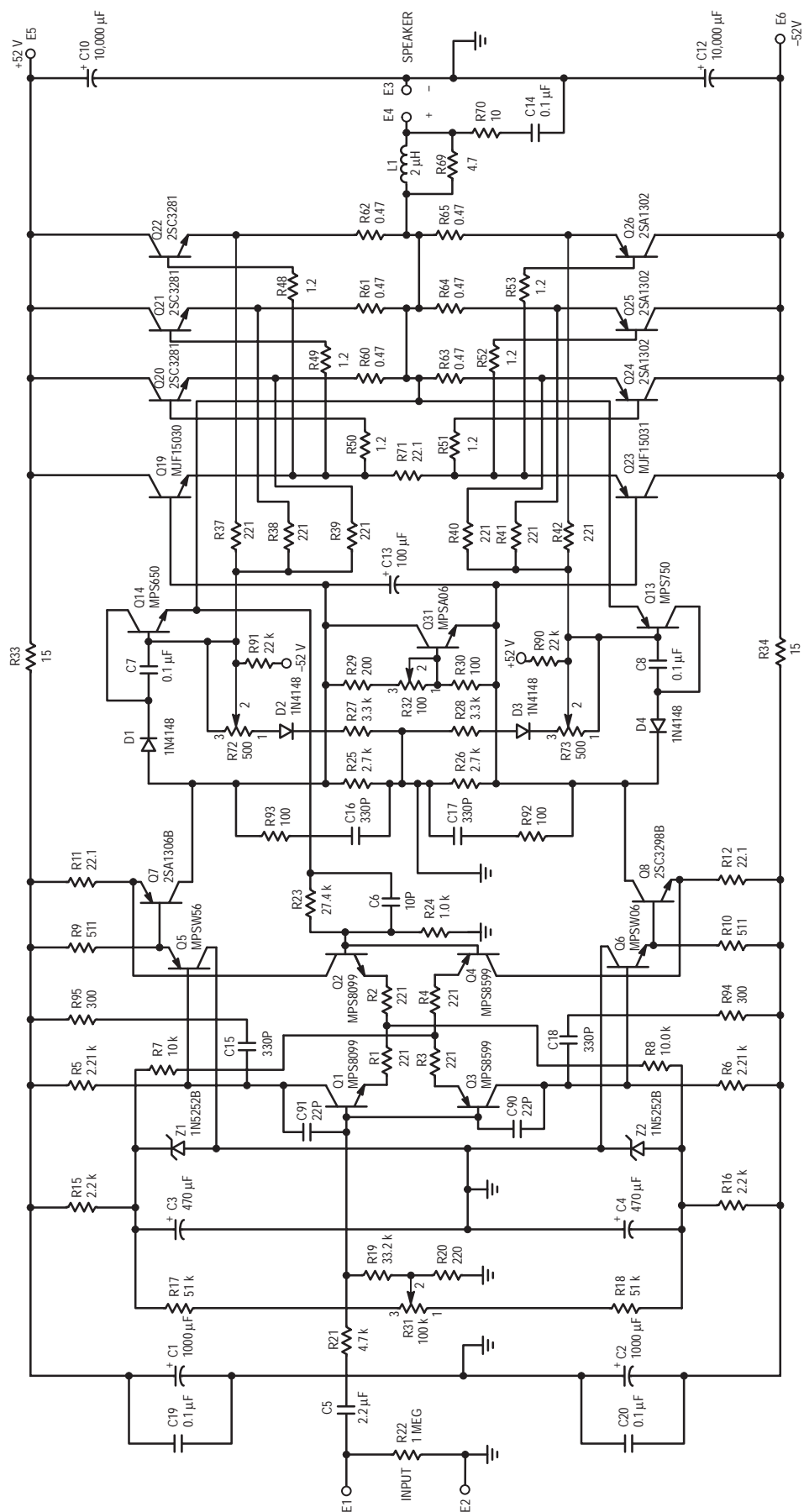


Figure 26. 100 Watt Amplifier Schematic

200 WATT AMPLIFIER MEASUREMENTS

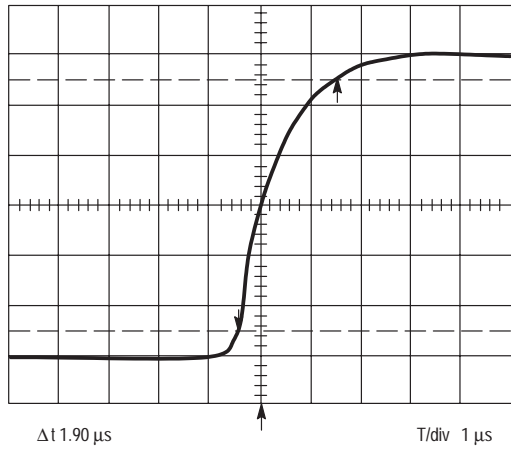


Figure 27. Square Wave Rise Time Full Scale — 8 Ω

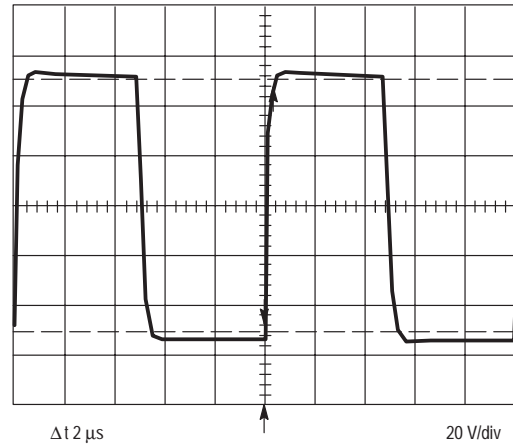


Figure 28. 200 kHz Square Wave Full Power — 8 Ω

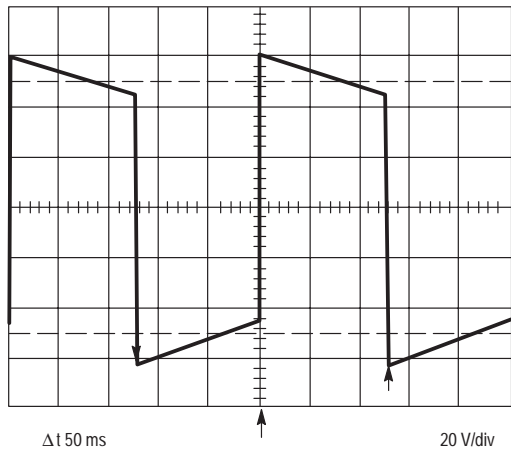


Figure 29. 20 Hz Square Wave Full Power — 8 Ω

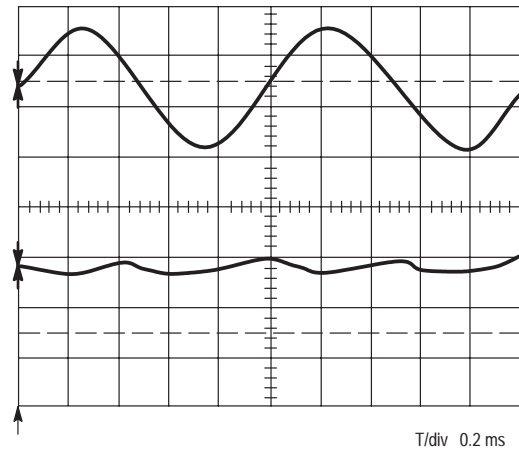


Figure 30. 1 kHz Full Power — 8 Ω Harmonic Distortion = 0.019%

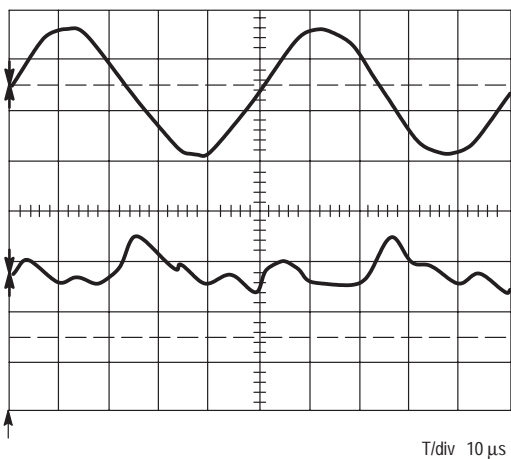


Figure 31. 20 kHz Full Power — 8 Ω Harmonic Distortion = 0.037%

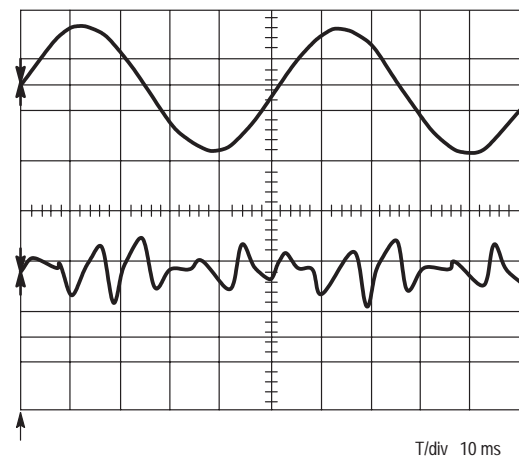


Figure 32. 20 Hz Full Power — 8 Ω Harmonic Distortion = 0.023%

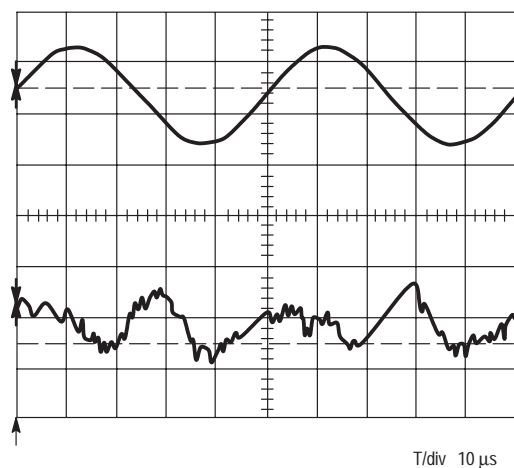
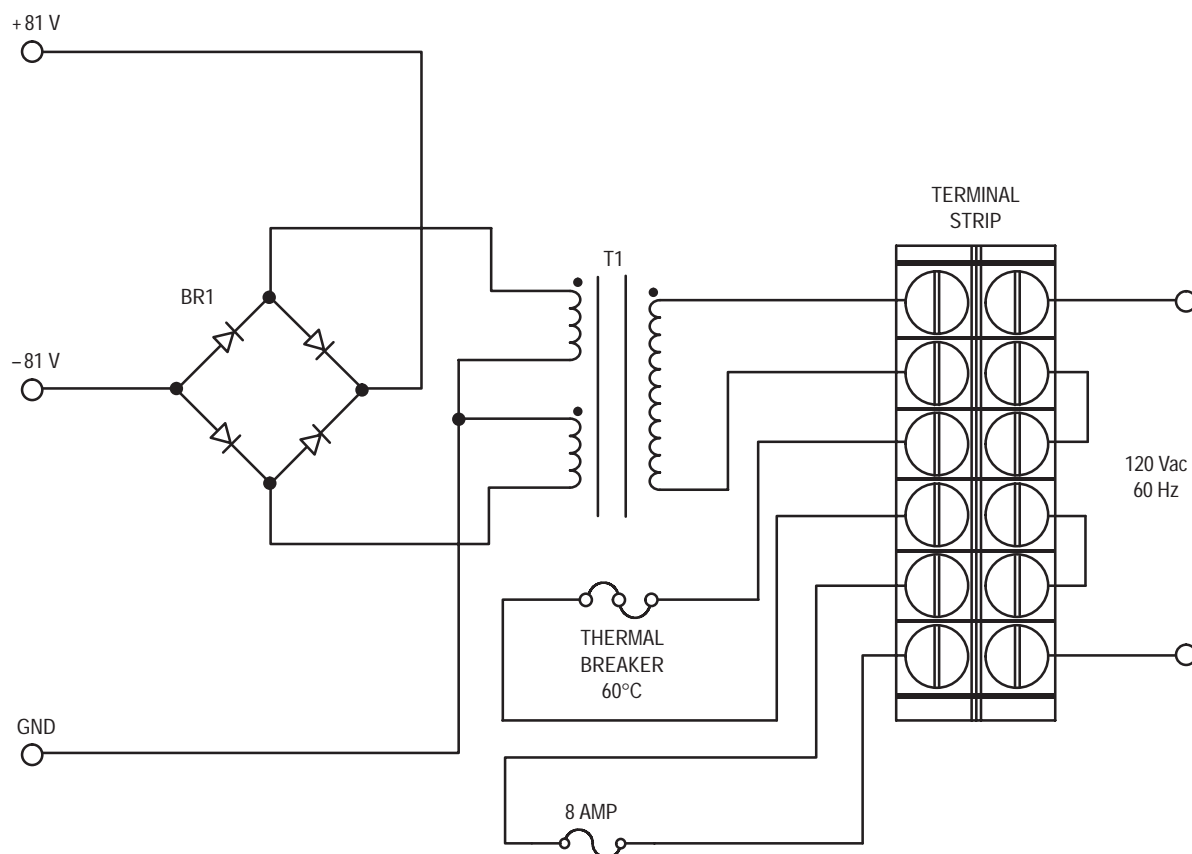


Figure 33. 20 kHz, 1 Watt, 8 Ω Harmonic Distortion = 0.026%



Notes: 13 Bifilar turns of #15 magnet wire are added to the secondary of the transformer to increase the voltage needed to obtain the required dc voltage.

Figure 34. 200 Watt Amplifier Power Supply Schematic

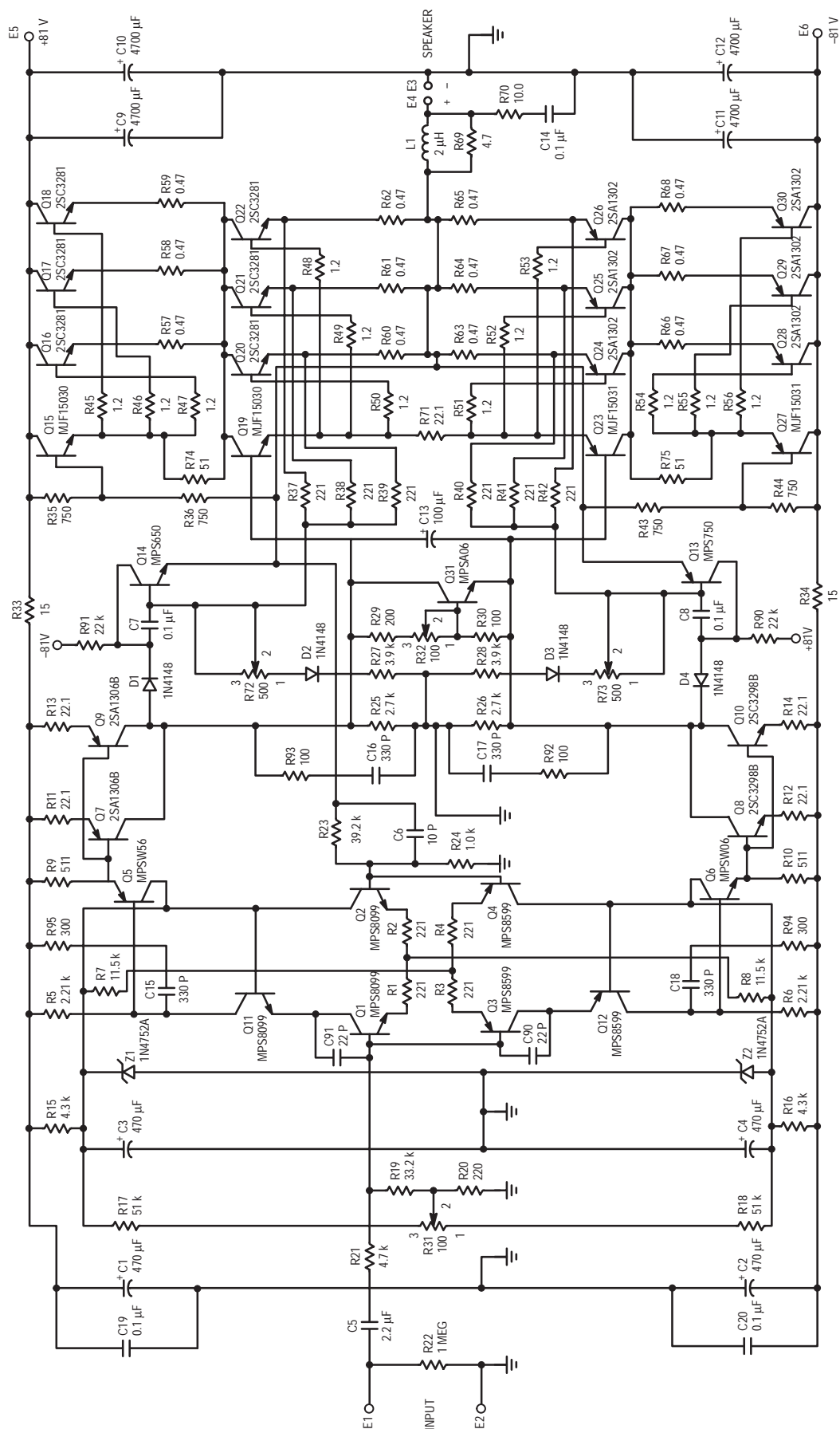


Figure 35. 200 Watt Amplifier Schematic

Table 3. Electrical Parts List for 100 Watt High Fidelity Amplifier Board

Designators	Qty	Description	Rating	Manufacturer	Part Number
BR1	1	General Purpose Bridge Rectifier		General Instruments	KBPC35-02
C1, 2	2	1000 μ F, \pm 20%, Electrolytic Capacitor	63 volt	Panasonic	ECE-A1JGE102
C3, 4	2	470 μ F, \pm 20%, Electrolytic Capacitor Low Leakage, Less than 50 μ A	50 volt	Panasonic	ECE-A50Z470
C5	1	2.2 μ F, Polypropolyne Capacitor			
C6	1	10 pF, Mica Capacitor	500 volt		
C7, 8, 14, 19, 20	5	0.1 μ F, X7R Ceramic Capacitor			
C10, 12	2	10,000 μ F, \pm 20%, Electrolytic Capacitor (35.5 mm x 51 mm x 10 mm)	63 volt	Panasonic	ECE S1JU103Z
C13	1	100 μ F, \pm 20%, Electrolytic Capacitor	10 volt	Panasonic	ECE-A1AGE101
C15, 16, 17, 18	4	330 pF, Mica Capacitor	500 volt		
C90, 91	2	22 pF, Mica Capacitor	500 volt		
D1, 2, 3, 4	4	Signal Diode			1N4148
L1	1	2 μ H — 6 turns airwound #16 wire, 1.625" diameter			
Q1, 2	2	NPN Transistor	80 volt	Motorola	MPS8099
Q3, 4	2	PNP Transistor	80 volt	Motorola	MPS8599
Q5	1	NPN Transistor	80 volt	Motorola	MPSW56
Q6	1	NPN Transistor	80 volt	Motorola	MPSW06
Q7	1	PNP Transistor	200 volt	Motorola	2SA1306B
Q8	1	NPN Transistor	200 volt	Motorola	2SC3298B
Q13	1	PNP Transistor	40 volt	Motorola	MPS750
Q14	1	NPN Transistor	40 volt	Motorola	MPS650
Q19	1	NPN Transistor	150 volt	Motorola	MJF15030
Q20, 21, 22	3	NPN Transistor	200 volt	Motorola	2SC3281
Q23	1	PNP Transistor	150 volt	Motorola	MJF15031
Q24, 25, 26	3	PNP Transistor	200 volt	Motorola	2SA1302
Q31	1	NPN Transistor	80 volt	Motorola	MPSA06
R1, 2, 3, 4, 37, 38, 39, 40, 41, 42	10	221 Ω , Resistor			
R5, 6	2	2.21 k Ω , Resistor			
R7, 8	2	10 k Ω , Resistor			
R9, 10	2	511 Ω , Resistor			
R11, 12, 71	3	22.1 Ω , Resistor			
R15, 16	2	2.2 k Ω , 5%, metal oxide Resistor	3 watt	Panasonic	ERG-3SJ222
R17, 18	2	51 k Ω , 5%, carbon film Resistor			
R19	1	33.2 k Ω , Resistor			
R20	1	220 Ω , 5%, Resistor			
R21	1	4.7 k Ω , 5%, carbon film Resistor			
R22	1	1 M Ω , 5%, carbon film Resistor			
R23	1	27.4 k Ω , Resistor			
R24	1	1 k Ω , Resistor			
R25, 26	2	2.7 k Ω , 5%, metal oxide Resistor	3 watt	Panasonic	ERG-3SJ272
R27, 28	2	3.3 k Ω , 5%, metal oxide Resistor	2 watt	Panasonic	ERG-2SJ332
R29	1	200 Ω , 5%, Resistor			
R30, 92, 93	3	100 Ω , 5%, Resistor			
R31	1	100 k Ω , 20%, Trim Potentiometer	1/2 watt	Panasonic	EVM-QOGA01B15
R32	1	100 Ω , 20%, Trim Potentiometer	1/2 watt	Panasonic	EVM-QOGA01B12
R33, 34	2	15 Ω , 5%, metal oxide Resistor	1 watt	Panasonic	ERG-3SJ150
R48, 49, 50, 51, 52, 53	6	1.2 Ω , 5%, carbon film Resistor	1/2 watt		

Note: All resistors are 1/4 watt with a tolerance of 1% unless otherwise noted.

All capacitors are 100 volt with a tolerance of 10% unless otherwise noted.

Table 3. Electrical Parts List for 100 Watt High Fidelity Amplifier Board (continued)

Designators	Qty	Description	Rating	Manufacturer	Part Number
R60, 61, 62, 63, 64, 65	6	0.47 Ω , 5%, non-inductive Resistor	5 watt	RG Allen Co.	
R69	1	4.7 Ω , 5%, metal oxide Resistor	3 watt	Panasonic	ERG-3SJ47R
R70	1	10 Ω , 5%, metal oxide Resistor	3 watt	Panasonic	ERG-3SJ100
R72, 73	2	500 Ω , 20%, Trim Potentiometer	1/2 watt	Panasonic	EVM-QOGA01B52
R90, 91	2	22 k Ω , 5%, carbon film Resistor	1/2 watt		
R94, 95	2	300 Ω , 5%, Resistor			
T1	1	120 V toroidal power transformer	360 VA	Toroid Corp. of MD	636.332
Z1, 2	2	24 volt, Zener Diode	1/2 watt	Motorola	1N5252B
Fuse	1	5 amp slo-blo 250 volt			
Breaker	1	60°C thermal breaker	15A	Elmwood Sensors	
Heatsinks, Output	2	Aluminum Extrusion, 7 inches long		Aham Tor Inc.	#6071
Heatsinks, pre-drivers	2	Aluminum Extrusion, 2.5 inches long		Aham Tor Inc.	#4405
—	1	14 pin IC socket tin plated			

Note: All resistors are 1/4 watt with a tolerance of 1% unless otherwise noted.

All capacitors are 100 volt with a tolerance of 10% unless otherwise noted.

Table 4. Electrical Parts List for 200 Watt High Fidelity Amplifier Board

Designators	Qty	Description	Rating	Manufacturer	Part Number
BR1	1	General Purpose Bridge Rectifier		General Instruments	KBPC35-02
C1, 2	2	470 μ F, \pm 20%, Electrolytic Capacitor	100 volt	Panasonic	ECE-A1JGE470
C3, 4	2	470 μ F, \pm 20%, Electrolytic Capacitor Lo Ω Leakage, Less than 50 μ A	50 volt	Panasonic	ECE-A50Z470
C5	1	2.2 μ F, Polypropolyne Capacitor	100 volt		
C6	1	10 pF, Mica Capacitor	500 volt		
C7, 8, 14, 19, 20	5	0.1 μ F, X7R Ceramic Capacitor	100 volt		
C9, 10, 11, 12	4	4,700 μ F, \pm 20%, Electrolytic Capacitor 35.5 mm x 51 mm x 10 mm)	100 volt	Panasonic	ECE S1JU472Z
C13	1	100 μ F, \pm 20%, Electrolytic Capacitor	10 volt	Panasonic	ECE-A1AGE101
C15, 16, 17, 18	4	330 pF, Mica Capacitor	500 volt		
C90, 91	2	22 pF, Mica Capacitor	500 volt		
D1, 2, 3, 4	4	Signal Diode			1N4148
L1	1	2 μ H — 6 turns airwound #16 wire, 1.625" diameter			
Q1, 2, 11	3	NPN Transistor	80 volt	Motorola	MPS8099
Q3, 4, 12	3	PNP Transistor	80 volt	Motorola	MPS8599
Q5	1	NPN Transistor	80 volt	Motorola	MPSW56
Q6	1	NPN Transistor	80 volt	Motorola	MPSW06
Q7, 9	2	PNP Transistor	200 volt	Motorola	2SA1306B
Q8, 10	2	NPN Transistor	200 volt	Motorola	2SC3298B
Q13	1	PNP Transistor	40 volt	Motorola	MPS750
Q14	1	NPN Transistor	40 volt	Motorola	MPS650
Q15, 19	2	NPN Transistor	150 volt	Motorola	MJF15030
Q16, 17, 18, 20, 21, 22	3	NPN Transistor	200 volt	Motorola	2SC3281
Q23, 27	1	PNP Transistor	150 volt	Motorola	MJF15031
Q24, 25, 26, 28, 29, 30	3	PNP Transistor	200 volt	Motorola	2SA1302
Q31	1	NPN Transistor	80 volt	Motorola	MPSA06
R1, 2, 3, 4, 37, 38, 39, 40, 41, 42	10	221 Ω , 5%, Resistor			
R5, 6	2	2.21 k Ω , Resistor			
R7, 8	2	11.5 k Ω , Resistor			
R9, 10	2	511 Ω , Resistor			
R11, 12, 13, 14, 71	5	22.1 Ω , Resistor			
R15, 16	2	4.3 k Ω , 5%, metal oxide Resistor	3 watt	Panasonic	ERG-3SJ432
R17, 18	2	51 k Ω , 5%, carbon film Resistor			
R19	1	33.2 k Ω , Resistor			
R20	1	220 Ω , 5%, Resistor			
R21	1	4.7 k Ω , 5%, carbon film Resistor			
R22	1	1 M Ω , 5%, carbon film Resistor			
R23	1	39.2 k Ω , Resistor			
R24	1	1 k Ω , Resistor			
R25, 26	2	2.7 k Ω , 5%, metal oxide Resistor	3 watt	Panasonic	ERG-3SJ272
R27, 28	2	3.9 k Ω , 5%, metal oxide Resistor	2 watt	Panasonic	ERG-2SJ392
R29	1	200 Ω , 5%, Resistor			
R30, 92, 93	3	100 Ω , 5%, Resistor			
R31	1	100 Ω , 20%, Trim Potentiometer	1/2 watt	Panasonic	EVM-QOGA01B15
R32	1	100 Ω , 20%, Trim Potentiometer	1/2 watt	Panasonic	EVM-QOGA01B12
R33, 34	2	15 Ω , 5%, metal oxide Resistor	1 watt	Panasonic	ERG-3SJ150
R35, 36, 43, 44	4	750 Ω , non-inductive Resistor	5 watt		

Note: All resistors are 1/4 watt with a tolerance of 1% unless otherwise noted.


All capacitors are 100 volt with a tolerance of 10% unless otherwise noted.

Table 4. Electrical Parts List for 200 Watt High Fidelity Amplifier Board (continued)

Designators	Qty	Description	Rating	Manufacturer	Part Number
R37, 38, 39, 40, 41, 42	6	221 Ω , Resistor			
R45, 46, 47, 48, 49, 50, 51, 52, 53, 54, 55, 56	12	1.2 Ω , 5%, carbon film Resistor	1/2 watt		
R57, 58, 59, 60, 61, 62, 63, 64, 65, 66, 67, 68	12	0.47 Ω , 5%, non-inductive Resistor	5 watt	RG Allen Co	
R69	1	4.7 Ω , 5%, metal oxide Resistor	3 watt	Panasonic	ERG-3SJ47R
R70	1	10 Ω , 5%, metal oxide Resistor	3 watt	Panasonic	ERG-3SJ100
R72, 73	2	500 Ω , 20%, Trim Potentiometer	1/2 watt	Panasonic	EVM-QOGA01B52
R74, 75	2	51 Ω , Resistor			
R90, 91	2	22 k Ω , 5%, carbon film Resistor	1/2 watt		
R94, 95	2	300 Ω , 5%, Resistor			
T1	1	120 V toroidal power transformer	600 VA	Toroid Corp. of MD	660.502
Z1, 2	2	33 volt, Zener Diode	1 watt	Motorola	1N4752A
Fuse	1	5 amp slo-blo 250 volt			
Breaker	1	60°C thermal breaker	15A	Elmwood Sensors	
Heatsinks, Output	4	Aluminum Extrusion, 7 inches long		Aham Tor Inc.	#6071
Heatsinks, pre-drivers	4	Aluminum Extrusion, 2.5 inches long		Aham Tor Inc.	#4405
—	1	14 pin IC socket tin plated			

Note: All resistors are 1/4 watt with a tolerance of 1% unless otherwise noted.

All capacitors are 100 volt with a tolerance of 10% unless otherwise noted.

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