AN-483B
Application Note

15 TO 60 WATT AUDIO AMPLIFIERS USING COMPLEMENTARY DARLINGTON OUTPUT TRANSISTORS

Prepared by
Richard G. Ruehs
Applications Engineering

The use of monolithic power darlington transistors can simplify the design of high-fidelity power amplifiers. Circuit and performance information are provided to facilitate the design of 15 watt to 60 watt amplifiers utilizing the power darlington devices.

MOTOROLA Semiconductor Products Inc.

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INTRODUCTION

Recently developed silicon monolithic darlington power transistors permit significant simplification of audio power amplifier circuitry. The amplifiers described in this note use complementary power darlington output transistors, eliminating the two driver transistors used in previous methods. A significant cost savings should be realized since, in addition to the driver devices, the driver heat sinks and output biasing resistors are also eliminated. Also, the printed circuit board for the amplifier could become very compact.

Three circuits will be discussed: a 15 to 20 watt, medium performance amplifier, a 15 to 60 watt high performance amplifier with ac-coupled output, and a 15 to 60 watt high performance amplifier with dc-coupled output.

15-20 WATT AMPLIFIER

The circuit of the 15-20 watt amplifier is shown in Figure 1. To ensure maximum signal swing, the dc "center" voltage (the point between R8 and R9) must be one-half of V_{CC}. This is accomplished by dc feedback from this point to the base of Q1, through R3. Resistors R3 and R2 also form a voltage divider which provides dc bias to the base of Q1. Loading of this divider by the base current of Q1 could cause the center voltage to vary with changes in

TABLE I

Parts List

RMS Power	15 W		20 W	
Load	4 Ω	8 Ω	4 Ω	8 Ω
V_{CC}	32 V	40 V	36 V	46 V
R2	4.3 k	5.6 k	5.1 k	4.3 k
R3	82 k	120 k	100 k	130 k
R6	3.3 k	3.9 k	3.3 k	4.7 k

Typical Performance

Idle Current (Adj. with R_V)	20 mA
Nominal Input Sensitivity for Full Rated Output	1 Vrms
Total Harmonic Distortion @ Rated Output, 50 Hz to 20 kHz	0.5%
Total Harmonic Distortion @ 1 W Output, 1 kHz	0.2%
Input Impedance	10 kΩ

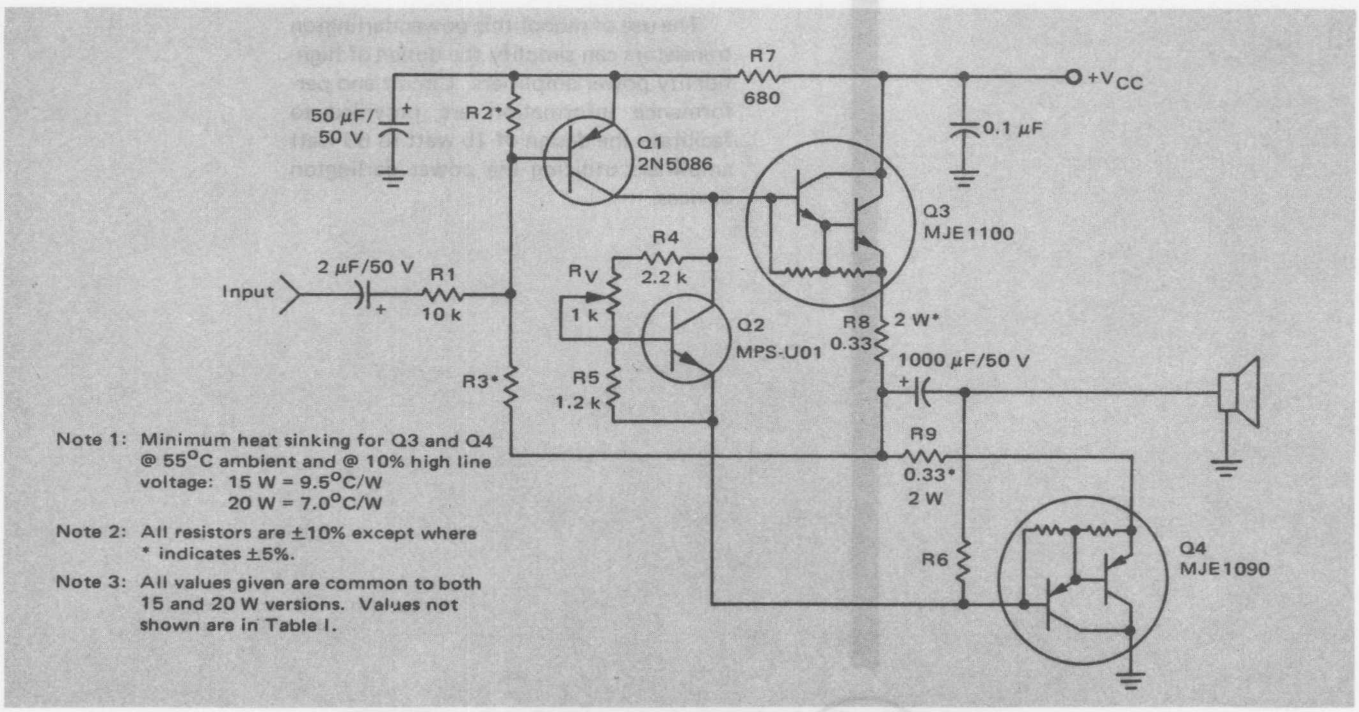


FIGURE 1 — Four Transistor Audio Amplifier for 15 to 20 W Output

h_{FE} of Q1. To prevent this change, the direct current in the R2, R3 divider is made at least ten times greater than the maximum base current of Q1.

Transistor Q2 is used to forward bias the output darlington devices. Resistors R4, R_V and R1 form a resistive divider which sets the collector to emitter voltage of Q2 at approximately 2.4 V for biasing of the output. R_V is made variable so that the I_C of Q2 can be adjusted and consequently the dc "idle current" in the output transistors can be set to minimize cross-over distortion. Twenty milliamps of idle current is sufficient to eliminate this distortion.

The V_{CE} voltage of Q2 tracks the $V_{BE(on)}$ temperature characteristics of Q3 and Q4 adequately. Therefore, if Q2 were mounted on the heat sink with the output transistors, the dc idle current would remain within practical limits over the temperature range.

To ensure maximum swing during peak negative signal excursions, R6 is connected to the speaker side of the output coupling capacitor. This makes use of the dc charge on the output coupling capacitor to provide drive current to the base of Q4 thru R6 (bootstrapping).

Parts values and typical performance characteristics for the 15 to 20 watt circuit are shown in Table I.

THE 15-60 WATT AC COUPLED CIRCUIT

The 15 to 60 watt ac-coupled circuit is shown in Figure 2. As in the previous circuit, the center voltage must be one half V_{CC} for maximum output swing. Resistors R1, R2 and R3 form a voltage divider which sets the dc voltage on the base of Q1 at approximately 1.5 volts above 1/2 V_{CC}. This will maintain the center voltage at 1/2 V_{CC} since there is a constant 1.5 volt drop from the base of Q1 to the output center point. This drop is caused by the base-emitter diode voltage of Q1 and the voltage drop across R6 due to the emitter current of Q1. The dc voltage across R4 is set by the $V_{BE(on)}$ voltage of Q2. The collector current of Q1 and the current thru R6 is thus

$$\frac{V_{BE(on)}\,Q2}{R4} \approx \frac{0.6}{1.8\ k\Omega} = 0.33\ mA$$

The ac closed-loop gain of the circuit is

$$A_V = \frac{R6}{R5}$$

The input impedance is set by the parallel equivalent resistance of R2 and R3.

Transistor Q2 has approximately 60 dB of voltage gain and determines the dominant pole in the amplifier. A 50 pF capacitor is used in this stage to compensate the amplifier to prevent high frequency oscillations.

Transistor Q3 is used, as in the previous circuit, to forward bias the output devices to prevent cross-over distortion.

A constant current source, Q4, is used to eliminate the need for bootstrapping the base of Q6. This eliminates the effects of the bootstrap capacitor on frequency, providing

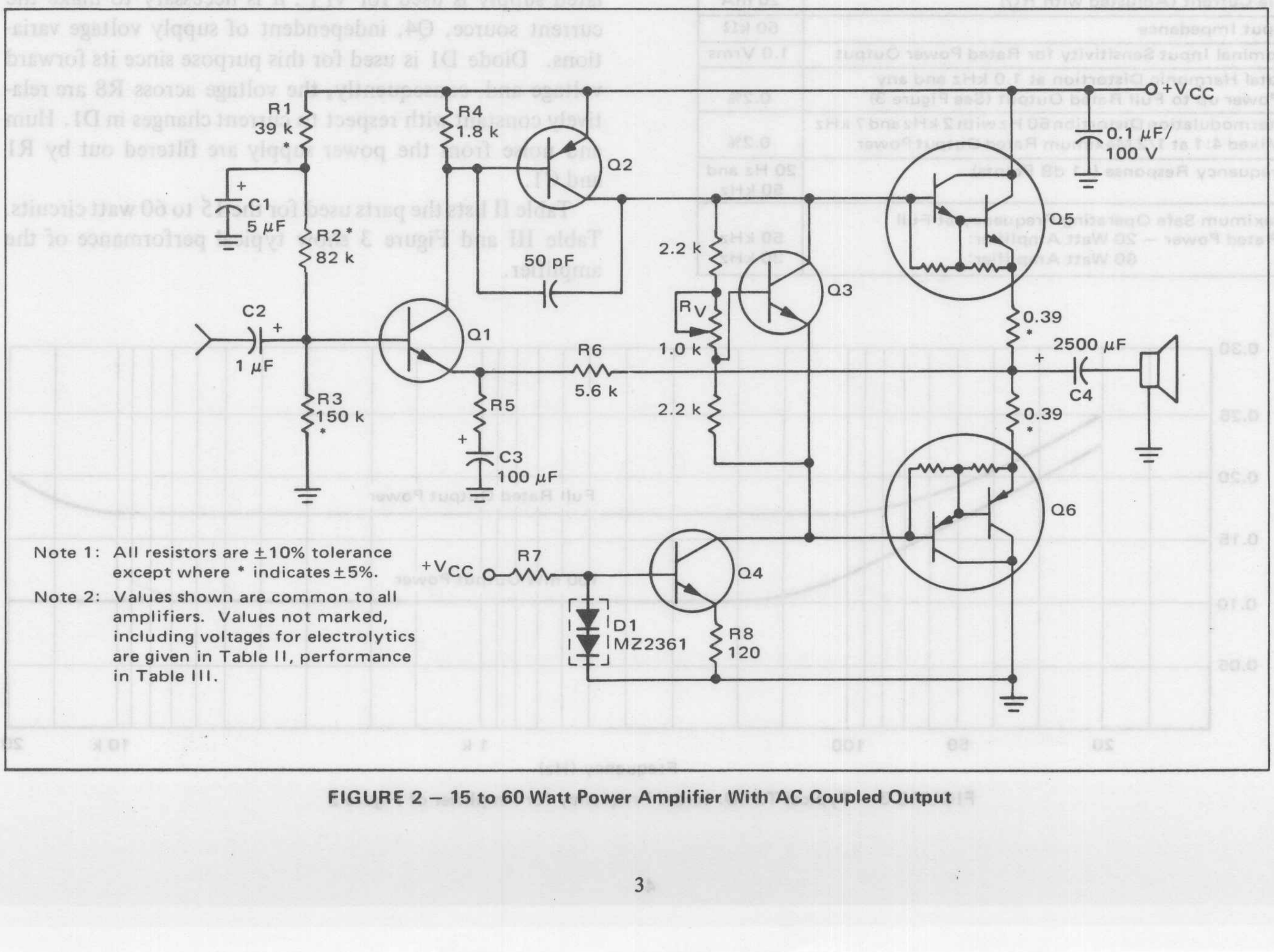


FIGURE 2 — 15 to 60 Watt Power Amplifier With AC Coupled Output

TABLE II – Parts List of 15 to 60 Watt Circuit of Figure 2

Power Watts (RMS)	15		20		25		35		50		60	
Load Impedance	4	8	4	8	4	8	4	8	4	8	4	8
V_{CC}	32 V	38 V	36 V	46 V	38 V	48 V	44 V	56 V	50 V	65 V	56 V	72 V
R5 (ohms)	620	510	560	470	560	390	470	330	390	270	330	220
R7 (ohms)	33 k	39 k	39 k	47 k	39 k	47 k	47 k	56 k	47 k	68 k	56 k	68 k
Q1	MPS A05	MPS A05	MPS A05	MPS A05	MPS A05	MPS A05	MPS A05	MPS A06	MPS A05	MPS A06	MPS A06	MPS A06
Q2	MPS A55	MPS A55	MPS A55	MPS A55	MPS A55	MPS A55	MPS A55	MPS A56	MPS A55	MPS A56	MPS A56	MPS A56
Q3	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13
Q4	MPS A05	MPS A05	MPS A05	MPS A05	MPS A05	MPS A05	MPS A05	MPS A06	MPS A05	MPS A06	MPS A06	MPS A06
Q5	MJE 1100	MJE 1100	MJE 1100	MJE 1100	MJE 1102	MJE 1100	MJ 3000	MJ 1001	MJ 3000	MJ 3001	MJ 3001	MJ 3001
Q6	MJE 1090	MJE 1090	MJE 1090	MJE 1090	MJE 1092	MJE 1090	MJ 2500	MJ 901	MJ 2500	MJ 2501	MJ 2501	MJ 2501
Voltage rating on C1	35 V	40 V	40 V	50 V	40 V	50 V	45 V	60 V	50 V	65 V	60 V	75 V
Voltage rating on C2, C3	20 V	25 V	25 V	30 V	25 V	30 V	25 V	35 V	30 V	35 V	35 V	40 V
Voltage rating on C4	40 V	45 V	45 V	55 V	45 V	55 V	50 V	65 V	60 V	75 V	65 V	80 V
Min. heat sink for outputs @ 55°C ambient temperature and 10% high line voltage	9.5°C/W		7.0°C/W		5.0°C/W		6.0°C/W	5.5°C/W	4.0°C/W		3.0°C/W	

TABLE III – Typical Performance of Circuit in Figure 2

Idle Current (Adjusted with R_V)	20 mA
Input Impedance	50 kΩ
Nominal Input Sensitivity for Rated Power Output	1.0 Vrms
Total Harmonic Distortion at 1.0 kHz and any Power up to Full Rated Output (See Figure 3)	0.2%
Intermodulation Distortion 60 Hz with 2 kHz and 7 kHz Mixed 4:1 at 1/2 Maximum Rated Output Power	0.2%
Frequency Response (–1 dB Points)	20 Hz and 50 kHz
Maximum Safe Operating Frequency at Full Rated Power – 20 Watt Amplifier: 60 Watt Amplifier:	50 kHz 30 kHz

lower distortion at low frequencies. The collector-emitter voltage of Q3 is a function of its collector current. Therefore, to eliminate cross-over distortion when a poorly regulated supply is used for V_{CC}, it is necessary to make the current source, Q4, independent of supply voltage variations. Diode D1 is used for this purpose since its forward voltage and, consequently, the voltage across R8 are relatively constant with respect to current changes in D1. Hum and noise from the power supply are filtered out by R1 and C1.

Table II lists the parts used for the 15 to 60 watt circuits. Table III and Figure 3 show typical performance of the amplifier.

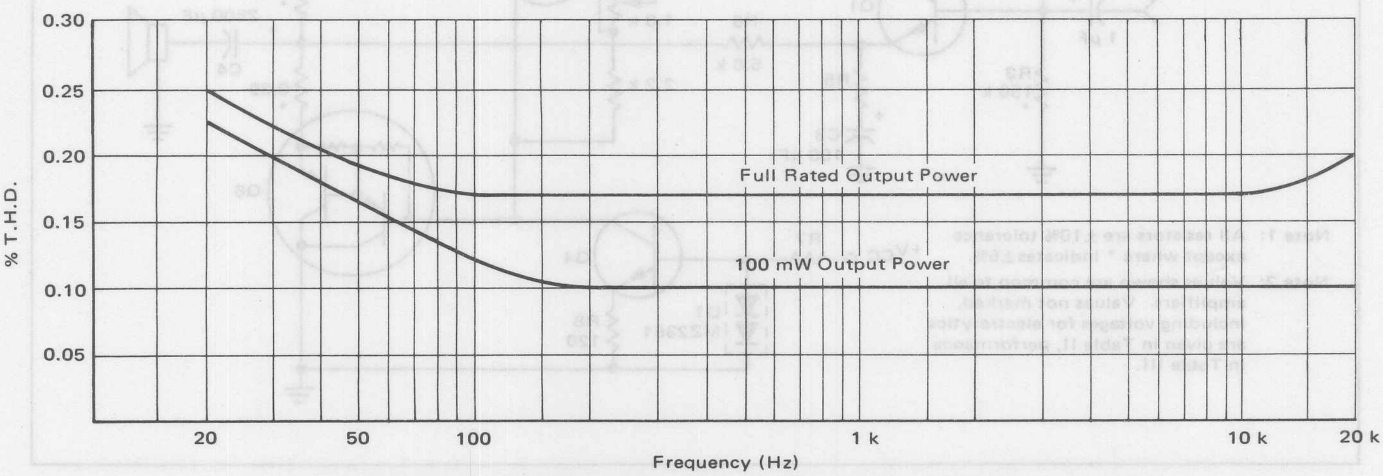


FIGURE 3 – Typical T.H.D. versus Frequency for Amplifier of Figure 2

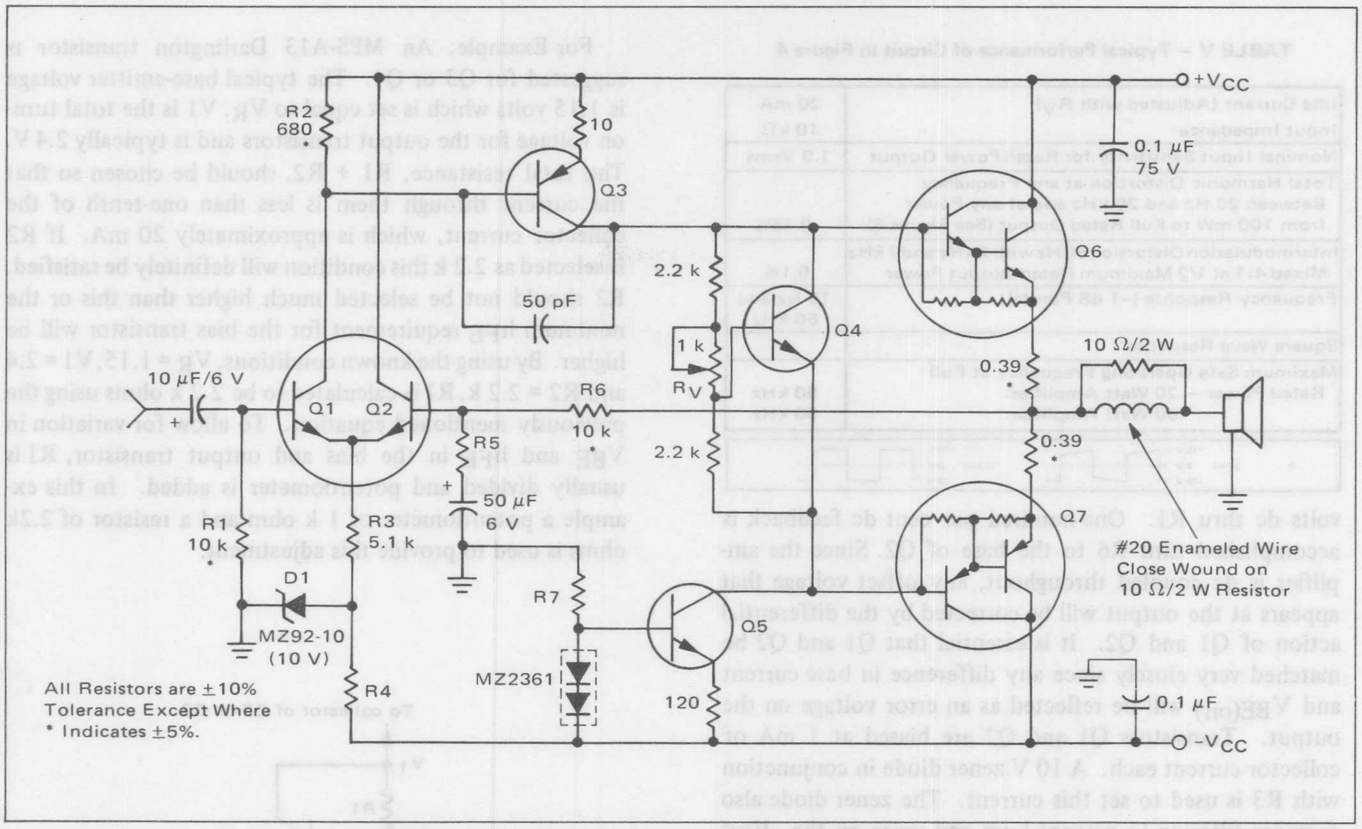


FIGURE 4 – 15 to 60 Watt Power Amplifier with DC Coupled Output

THE 15 TO 60 WATT DC-COUPLED CIRCUIT

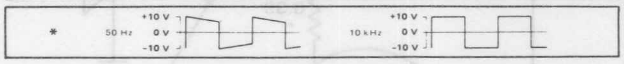
The 15 to 60 watt dc-coupled circuit is shown in Figure 4. The output center voltage must be maintained at zero volts dc not only to ensure maximum signal swing but also to prevent dc from appearing at the speaker. The zero center voltage is obtained by using a split power supply and a differential amplifier on the input of the circuit. The signal input base of the dif-amp (Q1) is referenced to 0

TABLE IV – Parts List for 15 to 60 Watt Circuit of Figure 4

Power Watts (RMS)	15		20		25		35		50		60	
Load Impedance	4	8	4	8	4	8	4	8	4	8	4	8
V_{CC}	± 16 V	±19 V	±18 V	±23 V	±19 V	±24 V	±22 V	±28 V	±25 V	±33 V	±28 V	±36 V
R4 (ohms)	1.5 k	2.2 k	2.0 k	3.3 k	2.2 k	3.3 k	3.0 k	3.9 k	3.6 k	5.6 k	3.9 k	6.2 k
R5 (ohms)	1.2 k	820	1.0 k	750	1.0 k	680	820	560	680	470	620	430
R7 (ohms)	15 k	18 k	18 k	22 k	18 k	22 k	22 k	27 k	22 k	33 k	27 k	33 k
Q1,Q2 Dual Transistors	MD 8001	MD 8001	MD 8001	MD 8001	MD 8001	MD 8001	MD 8001	MD 8001	MD 8001	MD 8002	MD 8001	MD 8002
Q3	MPS A55	MPS A55	MPS A55	MPS A55	MPS A55	MPS A55	MPS A55	MPS A56	MPS A55	MPS A56	MPS A56	MPS A56
Q4	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13	MPS A13
Q5	MPS A05	MPS A05	MPS A05	MPS A05	MPS A05	MPS A05	MPS A05	MPS A06	MPS A05	MPS A06	MPS A06	MPS A06
Q6	MJE 1100	MJE 1100	MJE 1100	MJE 1100	MJE 1102	MJE 1100	MJ 3000	MJ 1001	MJ 3000	MJ 3001	MJ 3001	MJ 3001
Q7	MJE 1090	MJE 1090	MJE 1090	MJE 1090	MJE 1092	MJE 1090	MJ 2500	MJ 901	MJ 2500	MJ 2501	MJ 2501	MJ 2501
Min. heat sink for outputs @ 55°C ambient temperature and 10% high line voltage	9.5°C/W		7.0°C/W		5.0°C/W		6.0°C/W	5.5°C/W	4.0°C/W		3.0°C/W	

TABLE V – Typical Performance of Circuit in Figure 4

Idle Current (Adjusted with R_V)	20 mA
Input Impedance	10 kΩ
Nominal Input Sensitivity for Rated Power Output	1.0 Vrms
Total Harmonic Distortion at any Frequency Between 20 Hz and 20 kHz and at any Power from 100 mW to Full Rated Output (See Figure 5)	0.15%
Intermodulation Distortion 60 Hz with 2 kHz and 7 kHz Mixed 4:1 at 1/2 Maximum Rated Output Power	0.1%
Frequency Response (–1 dB Points)	10 Hz and 50 kHz
Square Wave Response	*
Maximum Safe Operating Frequency at Full Rated Power – 20 Watt Amplifier: 60 Watt Amplifier:	50 kHz 30 kHz



volts dc thru R1. One-hundred per cent dc feedback is accomplished thru R6 to the base of Q2. Since the amplifier is dc coupled throughout, any offset voltage that appears at the output will be corrected by the differential action of Q1 and Q2. It is essential that Q1 and Q2 be matched very closely since any difference in base current and $V_{BE(on)}$ will be reflected as an error voltage on the output. Transistors Q1 and Q2 are biased at 1 mA of collector current each. A 10 V zener diode in conjunction with R3 is used to set this current. The zener diode also provides filtering to prevent hum and noise on the $-V_{CC}$ line from getting into the input stage. The value of R4 is chosen for 4 mA; 2 mA of current for the zener diode and the diff amp's 2 mA:

$$\left(R4 = \frac{V_{CC} \ -10\text{ V}}{4\text{ mA}}\right)$$

The closed-loop ac gain of the amplifier is determined by:

$$A_V = \frac{R6}{R5}.$$

The remainder of the circuit operation is identical to the previously described ac coupled approach of Figure 2.

The choke used on the output is to prevent high-frequency oscillations that might occur with capacitive loading.

Table IV lists the parts used for the dc-coupled amplifiers. Table V and Figure 5 show the typical performance of these amplifiers.

OUTPUT STAGE BIASING

The output stage biasing for the circuits in Figures 2 and 4 is controlled by Q3 in Figure 2 and Q4 in Figure 4. Q3 or Q4 should have an h_{FE} greater than 100 so that the current through R1 and R2 can be made less one-tenth of the collector current. If this condition is satisfied the base-emitter drop of Q3 or Q4 can be considered a reference voltage and the values of R1 and R2 can be calculated from

$$\frac{V1}{V_R} = 1 + \frac{R1}{R2} \quad \text{(See Figure 6)}$$

For Example: An MPS-A13 Darlington transistor is suggested for Q3 or Q4. The typical base-emitter voltage is 1.15 volts which is set equal to V_R. V1 is the total turn-on voltage for the output transistors and is typically 2.4 V. The total resistance, R1 + R2, should be chosen so that the current through them is less than one-tenth of the collector current, which is approximately 20 mA. If R2 is selected as 2.2 k this condition will definitely be satisfied. R2 should not be selected much higher than this or the minimum h_{FE} requirement for the bias transistor will be higher. By using the known conditions, $V_R = 1.15$, $V1 = 2.4$ and R2 = 2.2 k, R1 is calculated to be 2.2 k ohms using the previously mentioned equation. To allow for variation in V_{BE} and h_{FE} in the bias and output transistor, R1 is usually divided and potentiometer is added. In this example a potentiometer of 1 k ohm and a resistor of 2.2k ohms is used to provide this adjustment.

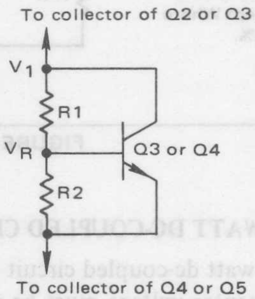


FIGURE 6 – Bias Circuit for Output Stage

OVERLOAD PROTECTION

A circuit for overload protection applying to all the darlington amplifiers discussed in this note, is shown in Figure 7. This circuit holds the darlington output devices within their dc safe-operating area in the event the output is accidentally shorted.

Resistors R1 and R2 form a voltage divider which senses the peak current flowing through the output transistor and R_E. This divider is set to turn Q1 and Q2 "ON" when the output current goes above the maximum normal operating level. When Q1 and Q2 conduct, they limit the amount of drive to the base of the output and, consequently, limit the amount of output current. Transistor Q1 and its associated circuitry function for the positive half of the waveform; Q2 and its associated circuitry, for the negative half of the waveform. Diode D1 prevents the collector-base junction of Q1 and Q2 from being forward biased during normal signal conditions and creating distortion in the output waveform.

During shorted output, the average power dissipation in the output devices increases about four times over the normal operating dissipation. The length of time a shorted

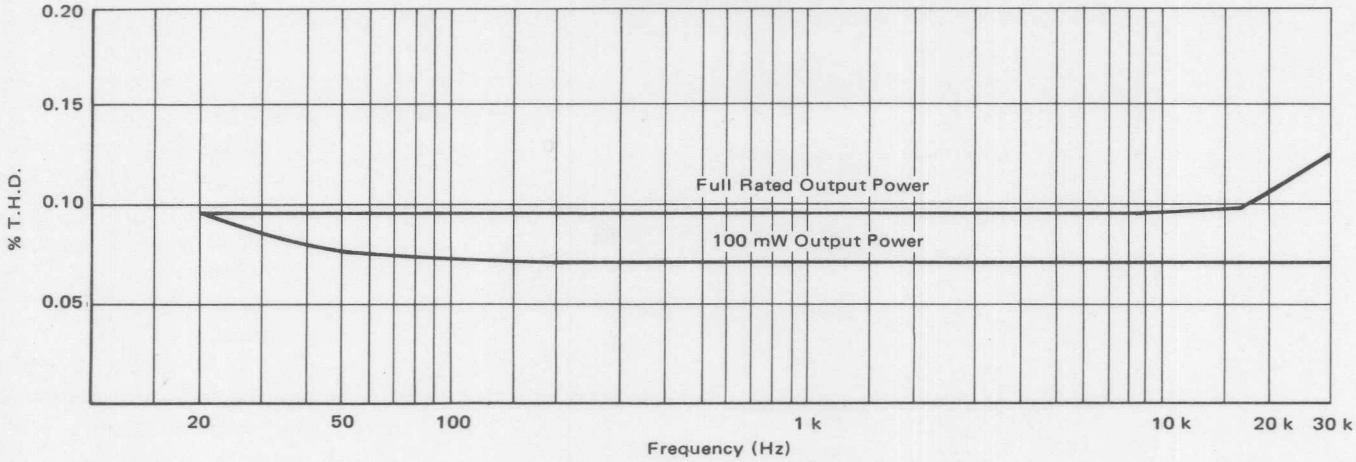


FIGURE 5 – Typical T.H.D. versus Frequency for Amplifier of Figure 4

condition can be tolerated is strictly a function of the size and capability of the output heat sinks. When the minimum heat sinks specified in Tables I, II and IV are used, and the circuit is operated in a 25°C ambient, the output devices can drive a shorted load for a few minutes without any damage. "Load line" protection circuits can also be used with the darlington amplifiers for long term overload protection.

Table VI gives the values of R1 in Figure 7 which, in the event of an overload, provide adequate safe operating area protection on the output devices for all of the amplifiers described in this note.

CONCLUSION

This note has described 15 watt to 60 watt audio power amplifiers using silicon monolithic darlington power output transistors.

TABLE VI

Power Watts (RMS)	Load Impedance (ohms)	Value of R1 (ohms)
15	4	330
	8	150
20	4	470
	8	180
25	4	510
	8	220
35	4	750
	8	390
50	4	910
	8	560
60	4	1.0 k
	8	620

The circuits illustrate the simplification resulting from the use of these darlington devices. The achievable performance of these amplifiers is equal to that previously obtained using the best silicon discrete devices.

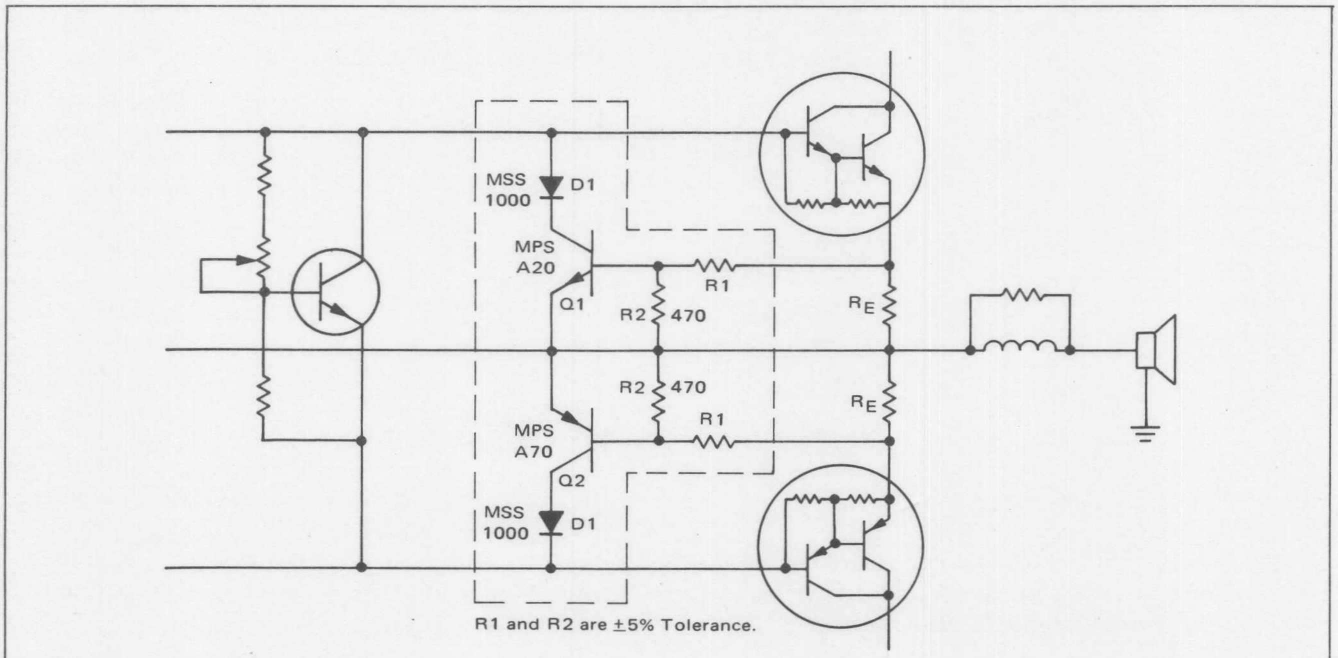


FIGURE 7 – Overload Protection Circuit for Amplifiers of Figures 1, 2 and 3