AN-209
Application Note

A 4 WATT WIDE-BAND AMPLIFIER

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The use of complimentary transistors in the output and/or driver stages of class B amplifiers eliminates the need for a separate phase inversion stage and offers the opportunity for the design of a simple, direct-coupled wide band amplifier. The amplifier to be discussed in this report uses two complimentary stages — driver and output, is completely direct coupled, and provides 4 watts into an 8 ohm load from 35 Hz to 100 K Hz with less than 1% harmonic distortion to 20 K Hz.

MOTOROLA Semiconductor Products Inc.

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INTRODUCTION

The initial ground rules for the amplifier were that it be wide-band, have low distortion, and provide reasonable output power. The design goals were 100 K Hz, less than 1%, and a minimum of 2 watts, respectively. In addition, it was desirable that the amplifier design be simple, using as few components as possible, and that it be efficient thus keeping power supply requirements to a minimum.

The latter dictated that the output be class B. There are many possible approaches in the design of class B amplifiers: transformer coupled, capacitor coupled, direct-coupled, and various combinations of the three. All have their limitations. Transformer coupled amplifiers can be made relatively simple, but wide-band operation puts fairly stringent requirements on the transformer design. Feedback can be a definite problem with regard to ac stability. Capacitor coupled amplifiers offer fewer ac stability problems but their design is generally less than simple since more components are required for biasing and more stages are usually needed because of impedance mismatch between stages and the resultant power loss. Direct coupled stages have relatively good ac stability but can cause some difficulty in the area of dc stability resulting in circuit complexity. Amplifiers using combination approaches will enjoy the benefits and suffer the limitations of the three.

Getting back to the original ground rules, it would appear that the wide-band requirement would eliminate transformer coupling, at least from an initial consideration, and the desire for circuit simplicity would tend to rule out capacitor coupling. Low distortion, reasonable output power, and efficiency were not initial considerations in the decision as to which way to go since any amplifier designed with reasonable care will result in their attainment. Direct coupling was decided upon as the approach to use, but then the big question was how to do it and keep it simple. The almost obvious choice was complimentary transistors.

AMPLIFIER CIRCUIT

Complimentary transistors lend themselves very readily to direct coupling and because they are what they are, that is, complimentary, there is no need for a separate stage of phase inversion. In order to use them to their fullest, two complimentary pairs were used—one pair as drivers and one pair in the output stage. The resultant amplifier is shown in Fig. 1. The input stage, consisting of transistors Q_1 and Q_2, is a differential amplifier. The collector of Q_2 drives into the emitter of Q_3, a common base amplifier. Diode D_1 in the base of Q_3 overcomes the base-emitter drop of transistor Q_4 thereby maintaining a reverse bias on the collector-base junction of Q_3. This assures operation of Q_3 in the linear region. Without D_1, Q_3 would operate in the saturation region resulting in very non-linear amplification.

One of the basic difficulties encountered with class B amplifiers is the elimination of crossover distortion. Generally the amplifier is biased somewhere between class A and class B (class AB) but this results in reduced efficiency due to the amount of quiescent power required. A more practical way,[1] is to drive from a high impedance, or current, source. This gives low crossover distortion with a minimum of quiescent current. The amplifier in Figure 1 operates somewhere between the two. Diodes D_2 and D_3 provide enough voltage to bias Q_4 and Q_5 just into conduction. In order to keep the quiescent current of Q_6 and Q_7 at a reasonable value (3-10 milliamps) from the standpoint of crossover distortion and efficiency, the combined voltage drop of D_2 and D_3 at 0.5 milliamps diode current should be between 1.05 and 1.15 volts. (Diodes D_2 and D_3 provide an added benefit since their variation over temperature will approximately match the base-emitter voltage changes of Q_4 and Q_5.) The source impedance for Q_4 and Q_5 is effectively the value of R_5, or 20 K, since the output impedance of Q_3, the common base amplifier, is several megaohms. A higher impedance source could be derived by the addition of another transistor and diode as shown in Figure 2. Transistor Q_8 is a common base stage and D_4 serves the same purpose as D_1, namely, it keeps the collector-base junction of Q_8 reverse biased. Since the 20 K ohm source impedance was found to be adequate, however, and in the interest of minimizing components, only R_5 was used. The value of R_5 is fixed primarily by the amount of base drive required by Q_5. This, in turn, sets the value of R_4 since it must provide sufficient base current for Q_4 plus the current flowing through D_2, D_3, and R_5. If a higher source impedance had been required, it would have been necessary to modify the circuit as shown in Figure 2.

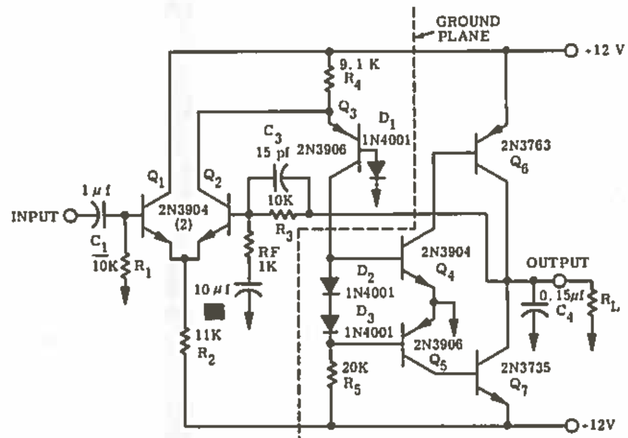

FIGURE 1 — 4 WATT WIDE-BAND AMPLIFIER

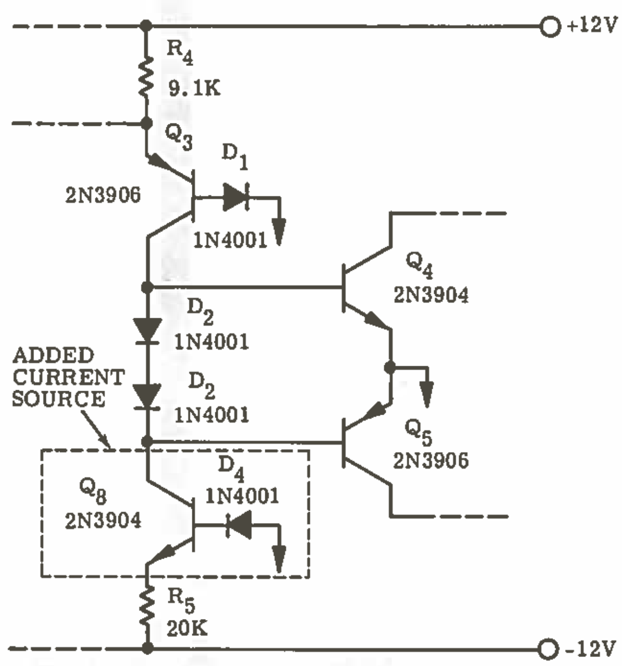

FIGURE 2 — MODIFIED CIRCUIT

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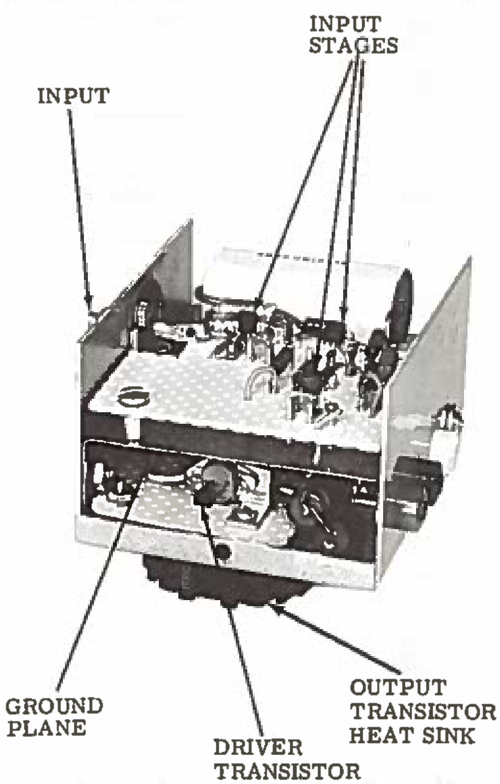
[1] Faran and Fulks, "High Impedance Drive for the Elimination of Crossover Distortion," IRE Transactions on Audio, Vol. Au-10, No. 4, pp 99--105.

Transistors Q_4 and Q_5 form the complimentary driver circuit and they are coupled directly to Q_6 and Q_7, the complimentary output pair. Since the amplifier works from plus and minus power supplies and the output is at approximately 0 volts dc, the load can be directly coupled to the amplifier output.

Negative feedback is carried from output to input via feedback resistor R_3. This reduces the amount of distortion at the output, including that caused by crossover, resulting in a very clean output waveform. The ac gain of the amplifier is adjusted by resistor R_F which is dc decoupled from ground by capacitor C_2. The large amount of dc feedback gives a closed loop dc gain of approximately unity and results in exceptional dc stability of the output. This is an important consideration when driving speaker loads since any dc current in the speaker will cause an offset in the speaker cone and may result in a distorted speaker output.

In order to assure a low dc offset at the amplifier output and to keep distortion low, the beta product of the Q_4-Q_6 and Q_5-Q_7 pairs should be matched. The degree of matching required will depend upon the limits set for dc offset and distortion; i. e. the closer the beta product match, the lower the offset and the distortion.

It should be noted at this point that certain precautions should be taken when building this amplifier. Because of the high gain-bandwidth of the transistors used, there is a definite tendency for the amplifier to oscillate. To help minimize this tendency, all leads should be kept as short as possible. Also, an attempt should be made to isolate the input stages from the output by the use of a ground plane. Capacitors C_3 and C_4 will also generally be necessary to provide sufficient ac stability to prevent oscillation. Figure 3 is a picture of the completed amplifier and serves to indicate the method of construction required.



PERFORMANCE

The response of the amplifier is indicated in Figure 4. This shows that the amplifier is capable of delivering 4 watts output from 45 Hz to 100 K Hz within +0, -1.0 db. Harmonic distortion from 35 Hz to 20 K Hz (the limit of the test equipment used) at 4 watts out is less than 1 per cent.

IM (intermodulation) distortion is shown in Figure 5. From this it can be seen that the amplifier is more than adequate for hi-fi purposes at 4 watts output.

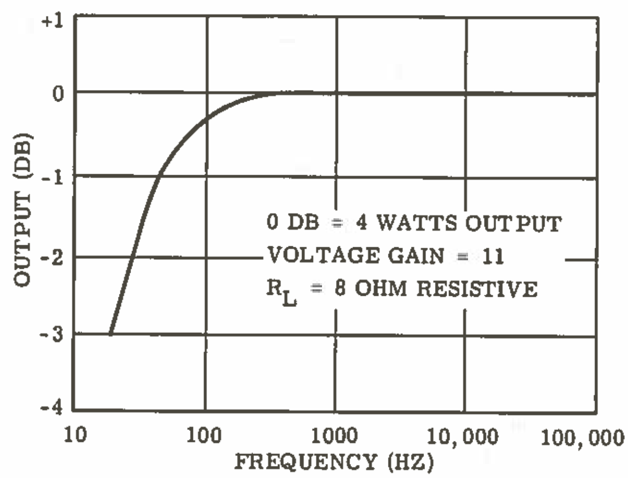


FIGURE 4 — FREQUENCY RESPONSE CURVE

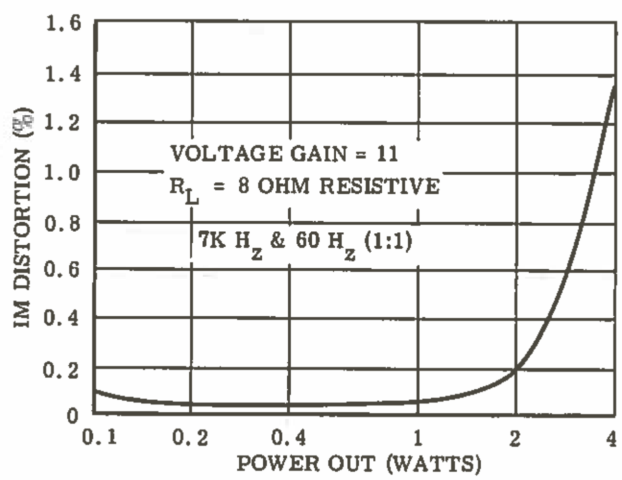


FIGURE 5 — IM DISTORTION

The input impedance is approximately 10 K from 35 Hz to 100 K Hz. The output impedance is less than 0.25 ohm up to 20 K Hz and approximately 0.5 ohm at 100 K Hz.

The ambient operating temperature range of the amplifier, at an output power of 4 watts, and based upon a junction to ambient thermal resistance for Q_6 and Q_7 of 70°C/watt, is -25°C to +50°C. The junction to case thermal resistance of the power output limiting devices, Q_6 and Q_7, is approximately 50°C/watt, putting the required case to ambient thermal resistance at 20°C/watt. No special heat sinking provisions are necessary for transistors Q_1 through Q_5.

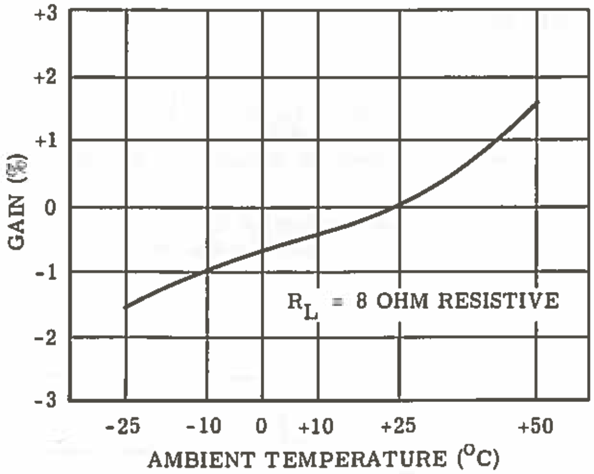


FIGURE 6 — A GAIN VS. TEMPERATURE

Figure 6 is a plot of ac gain versus temperature. The variation from the 25°C reference is about ±1.6 per cent or less than ±0.15 db.

The variation in the dc output voltage and the quiescent currents of Q_6 and Q_7 versus temperature are shown in Table 1. The dc offset at the output and the imbalance between the quiescent currents is due primarily to the mismatch (V_{BE} and h_{FE}) between transistors Q_1 and Q_2 in the differential amplifier.

All of the preceding data was taken with the gain set at 11. The gain can be increased by merely decreasing the value of R_F. Lowering the resistor value to 250 ohms will increase the gain to approximately 41. Although performance will be sacrificed somewhat, it still should be quite satisfactory for most applications.

Also, all measurements were taken with an 8 ohm load. Use of a higher value, such as 16 ohms, will result in improved amplifier performance, particularly in the area of distortion. For example; the IM distortion at 4 watts output is 1.35 per cent with an 8 ohm load, whereas a 16 ohm load will reduce this to 0.93 per cent. Of course, increasing the load resistor will necessitate an increase in the power supply voltages in order to realize 4 watts output. In no event should the supplies be set higher than 20 volts, and the peak current in the output transistors should be limited to 1 amp.

Another word of caution should be injected here. The voltage at the base of Q_2 should not exceed approximately 1.2 volts positive with respect to ground. If this occurs, the collector-base junction of Q_2 will be forward biased and Q_2 will saturate. This sets a maximum value for the feedback ratio, namely:

$$\frac{RF}{RF + R_3} \leq \frac{1.2}{V_{out}\ Peak}$$

D.C. AMPLIFIER

One final aspect of the amplifier should be mentioned. By removing capacitors C_1 and C_2, direct coupling to the input, and connecting the bottom of resistor R_F to ground, the amplifier can be used as a dc amplifier. The excellent dc stability of the amplifier indicates that it should be quite satisfactory for this type application.

CONCLUSION

A direct coupled ac amplifier using complimentary transistors has been designed that offers wide-band operation to 100 K Hz, provides 4 watts at less than 1% THD to 20 K Hz, and uses a minimum of components. In addition, the dc stability of the amplifier offers excellent possibility for its application in the area of dc amplifiers.

TEMPERATURE (°C)	V_{OUT} DC (VOLTS)	$I_{QUIESCENT}$ Q_6 (MILLIAMPS)	$I_{QUIESCENT}$ Q_7 (MILLIAMPS)
-25	.0543	6.80	0
0	.0525	6.57	0
+25	.0502	6.33	0.05
+50	.0471	5.95	0.05

TABLE 1