

4.7 LM386 LOW VOLTAGE AUDIO POWER AMPLIFIER

4.7.1 Introduction

The LM386 is a power amplifier designed for use in low voltage consumer applications. The gain is internally set to 20 to keep external part count low, but the addition of an external resistor and capacitor between pins 1 and 8 will increase the gain to any value up to 200.

The inputs are ground referenced while the output is automatically biased to one half the supply voltage. The quiescent power drain is only 24mW when operating from a 6V supply, making the LM386 ideal for battery operation.

Comparison of the LM386 schematic (Figure 4.7.1) with that of the LM380 (Figure 4.5.1) shows them to be essentially the same. The major difference is that the LM386 has two gain control pins (1 and 8), allowing the internally set gain of 20V/V (26dB) to be externally adjusted to any value up to 200V/V (46dB). Another important difference lies in the LM386 being optimized for low current drain, battery operation.

4.7.2 General Operating Characteristics

Device dissipation vs. output power curves for 4, 8 and 16 Ω loads appear as Figures 4.7.2-4.7.4. Expected power output as a function of typical supply voltages may be noted from these curves. Observe the "Maximum Continuous Dissipation" limit denoted on the 4 and 8 Ω curves as a dashed line. The LM386 comes packaged in the 8-pin mini-DIP leadframe having a thermal resistance of 187°C/W, junction to ambient. There exists a maximum allowed junction temperature of 150°C, and assuming ambient temperature equal to 25°C, then the maximum dissipation permitted is 660mW ($P_{DMAX} = [150^{\circ}\text{C} - 25^{\circ}\text{C}] / [187^{\circ}\text{C/W}]$). Operation at increased ambient temperatures means derating the device at a rate of 187°C/W. Note from Figure 4.7.3 that operation from a 12V supply limits continuous output power to a maximum of 250mW for allowed limits of package dissipation. It is therefore important that the power supply voltage be picked to optimize power output vs. device dissipation.

Figure 4.7.5 gives a plot of voltage gain vs. frequency, showing the wideband performance characteristic of the LM386. Both gain extremes are shown to indicate the narrowing effect of the higher gain setting.

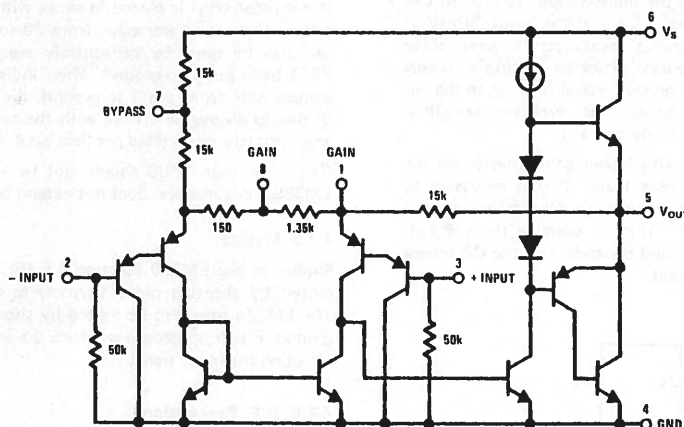


FIGURE 4.7.1 LM386 Simplified Schematic

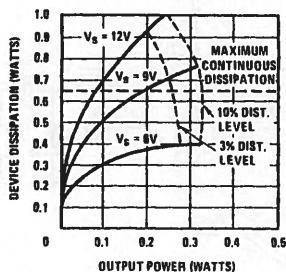


FIGURE 4.7.2 Device Dissipation vs. Output Power — 4 Ω Load

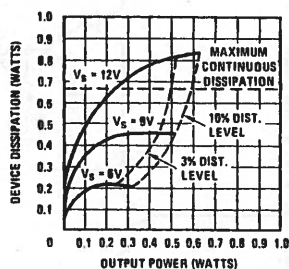


FIGURE 4.7.3 Device Dissipation vs. Output Power — 8 Ω Load

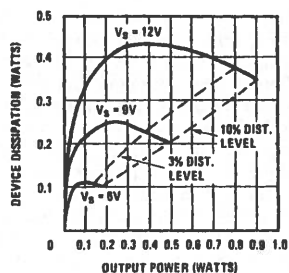


FIGURE 4.7.4 Device Dissipation vs. Output Power — 16 Ω Load

4.7.3 Input Biasing

The schematic (Figure 4.7.1) shows that both inputs are biased to ground with a 50k Ω resistor. The base current of the input transistors is about 250nA, so the inputs are at about 12.5mV when left open. If the DC source resistance driving the LM386 is higher than 250k Ω it will contribute very little additional offset (about 2.5mV at the input, 50mV at the output). If the DC source resistance is less than 10k Ω , then shorting the unused input to ground will keep the offset low (about 2.5mV at the input, 50mV at the output). For DC source resistances between these values we can eliminate excess offset by putting a resistor from the unused input to ground, equal in value to the DC source resistance. Of course all offset problems are eliminated if the input is capacitively coupled.

When using the LM386 with higher gains (bypassing the 1.35k Ω resistor between pins 1 and 8) it is necessary to bypass the unused input, preventing degradation of gain and possible instabilities. This is done with a 0.1 μ F capacitor or a short to ground depending on the DC source resistance on the driven input.

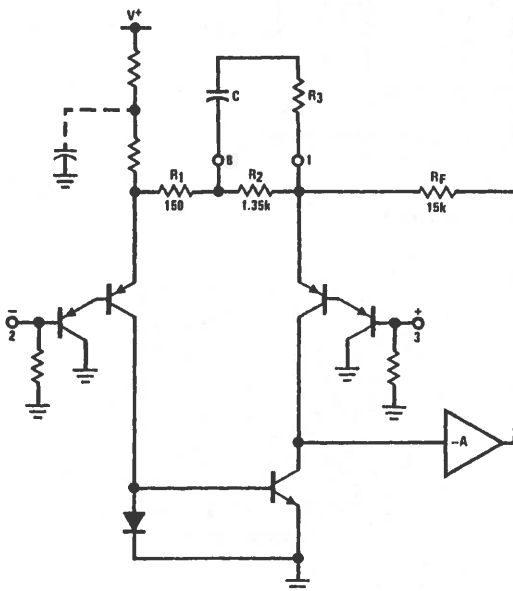


FIGURE 4.7.6 LM386 AC Equivalent Circuit

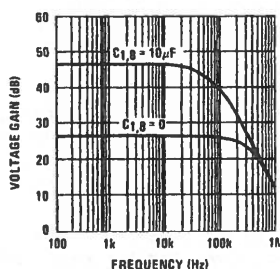


FIGURE 4.7.5 Voltage Gain vs. Frequency

4.7.4 Gain Control

Figure 4.7.6 shows an AC equivalent circuit of the LM386, highlighting the gain control feature. To make the LM386 a more versatile amplifier, two pins (1 and 8) are provided for gain control. With pins 1 and 8 open the 1.35k Ω resistor sets the gain at 20 (26dB). If a capacitor is put from pin 1 to 8, bypassing the 1.35k Ω resistor, the gain will go up to 200 (46dB).

If a resistor (R_3) is placed in series with the capacitor, the gain can be set to any value from 20 to 200. Gain control can also be done by capacitively coupling a resistor (or FET) from pin 1 to ground. When adding gain control with components from pin 1 to ground, the *positive* input (pin 3) should always be driven, with the negative input (pin 2) appropriately terminated per Section 4.7.3.

Gains less than 20dB should not be attempted since the LM386 compensation does not extend below 9V/V (19dB).

4.7.5 Muting

Similar to the LM380 (Section 4.5.15), the LM386 may be muted by shorting pin 7 (bypass) to the supply voltage. The LM386 may also be muted by shorting pin 1 (gain) to ground. Either procedure will turn the amplifier off without affecting the input signal.

4.7.6 R.F. Precautions

In AM radio applications in particular, r.f. interference caused by radiated wideband noise voltage at the speaker terminals needs to be considered. The pole splitting compensation used in monolithic audio power amplifiers to preserve a wide power bandwidth capability means that there will be plenty of excess

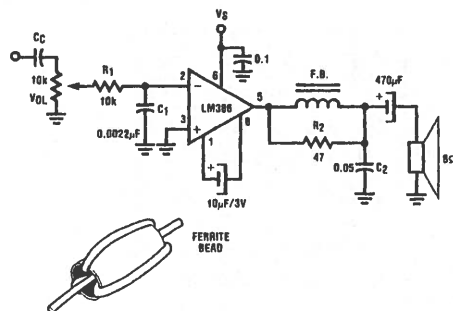


FIGURE 4.7.7 AM Radio Application

gain at frequencies well beyond the audio bandwidth. Noise voltages at these frequencies are amplified and delivered to the load where they can be radiated back to the AM radio ferrite antenna.

Any p.c. board should be laid out to locate the power amplifier as far as possible from the antenna circuit. Extremely tight twisting of the speaker and power supply leads is a must if optimum sensitivity for the radio is to be obtained.

If r.f. radiation still causes a reduction in sensitivity the circuit can be modified as shown in Figure 4.7.7. A typical radio application will use fairly high gain (200V/V) so the device gain is increased by connecting a $10\mu\text{F}$ capacitor between Pins 1 and 8. To band limit the input signal to 5-10kHz, a two pole filter configuration is used. The first pole is determined by the radio detector circuit and a second pole is added by the R_1C_1 network at the input to the LM386. Any r.f. noise is substantially reduced by placing a ferrite bead (F.B.) at the output. A Ferroxcube K5-001-001/3B with 3 turns taken through the bead is suitable for this application. The R_2C_2 network is necessary to stabilize the output stage (Section 4.5.5) but R_2 will also load the ferrite bead, reducing the level of r.f. attenuation. In this instance, a 47Ω resistor is optimum — a smaller value will simply degrade AM sensitivity and a larger value will not ensure stability for all parts. If other ferrite beads are used, a new value for R_2 that will guarantee stability and minimize degradation of AM sensitivity can be found by a few trials.

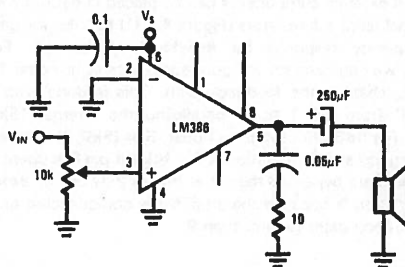


FIGURE 4.7.8 Amplifier with Gain = 20V/V (26dB) Minimum Parts

4.7.7 Typical Applications

Three possible variations of the LM386 as a standard audio power amplifier appear as Figures 4.7.8-4.7.10. Possible gains of 20, 50 and 200V/V are shown as examples of various gain control methods. The addition of the $0.05\mu\text{F}$ capacitor and 10Ω resistor is for suppression of the "bottom side fuzzies" (i.e., bottom side oscillation occurring during the negative swing into a load drawing high current — see Section 4.5.5).

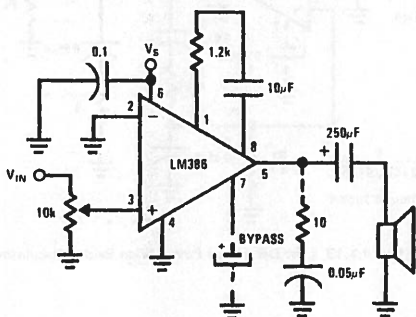


FIGURE 4.7.9 Amplifier with Gain = 50V/V (34dB)

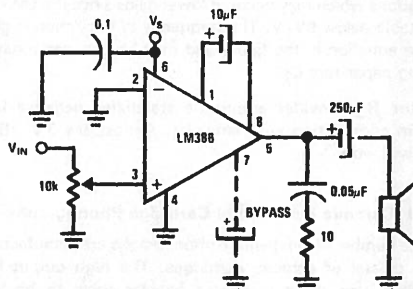
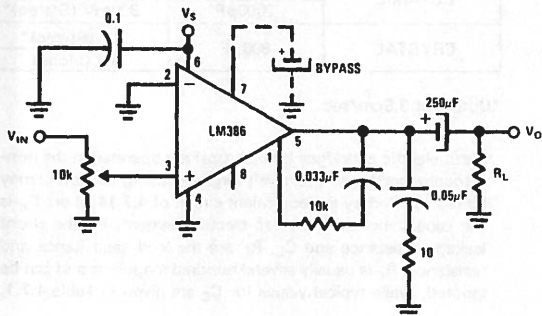
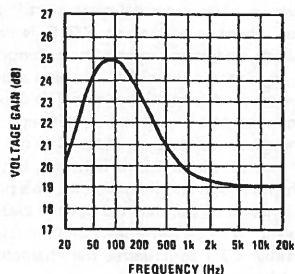


FIGURE 4.7.10 Amplifier with Gain = 200V/V (46dB)



(a) Amplifier with Bass Boost



(b) Frequency Response with Bass Boost

FIGURE 4.7.11 LM386 with Bass Boost

Additional external components can be placed in parallel with the internal feedback resistors (Figure 4.7.11) to tailor the gain and frequency response for individual applications. For example, we can compensate poor speaker bass response by frequency shaping the feedback path. This is done with a series RC from pin 1 to 5 (paralleling the internal 15k Ω resistor). For 6dB effective bass boost: $R \approx 15k\Omega$, the lowest value for good stable operation is $R = 10k\Omega$ if pin 8 is open. If pins 1 and 8 are bypassed then R as low as 2k Ω can be used. This restriction is because the amplifier is compensated only for closed-loop gains greater than 9.

4.7.8 Square Wave Oscillator

A square wave oscillator capable of driving an 8 Ω speaker with 0.5W from a 9V supply appears as Figure 4.7.12. Altering either R_1 or C_1 will change the frequency of oscillation per the equation given in the figure. A reference voltage determined by the ratio of R_3 to R_2 is applied to the positive input from the LM386 output. Capacitor C_1 alternately charges and discharges about this reference value, causing the output to switch states. A triangle output may be taken from pin 2 if desired. Since DC offset voltages are not relevant to the circuit operation, the gain is increased to 200V/V by a short circuit between the pins 1 and 8, thus saving one capacitor.

4.7.9 Power Wien Bridge Oscillator

The LM386 makes a low cost, low distortion audio frequency oscillator when wired into a Wien bridge configuration (Figure 4.7.13). Capacitor C_2 raises the "open loop" gain to 200V/V. Closed-loop gain is fixed at approximately ten by the ratio of R_1 to R_2 . A gain of ten is necessary to guard against spurious oscillations which may occur at lower gains since the LM386 is not stable below 9V/V. The frequency of oscillation is given by the equation in the figure and may be changed easily by altering capacitors C_1 .

Resistor R_3 provides amplitude stabilizing negative feedback in conjunction with lamp L_1 . Almost any 3V, 15mA lamp will work.

4.7.10 Ceramic and Crystal Cartridge Phonographs

A large number of inexpensive phonographs are manufactured using crystal or ceramic cartridges. The high output level available from these cartridges enables them to be used without pre-amplifiers in low power phonographs. Because the power amplifier is the only active gain element in such systems, the amplifier design should take into account the unique characteristics of piezo-electric cartridges.

Crystal cartridges are typically made from a single crystal material known as Rochelle Salt (Sodium Potassium Tartrate) which, like quartz, exhibits a natural piezo-electric action — when the crystal is bent or twisted an E.M.F. is developed. Despite a limited operating temperature range and a susceptibility to high relative humidity, the high sensitivity of Rochelle Salt has ensured its continued use. The development of modern ceramic titanates has solved many temperature and humidity problems but the ceramic material is not naturally piezo-electric. To obtain piezo-electric behavior, the ceramics are "poled" at high voltage and temperature. This produces a permanent deformation of the material but the piezo-electric action after "poling" is much lower than that obtainable from Rochelle Salt. Table 4.7.1 summarizes the characteristics of typical crystal and ceramic cartridges.

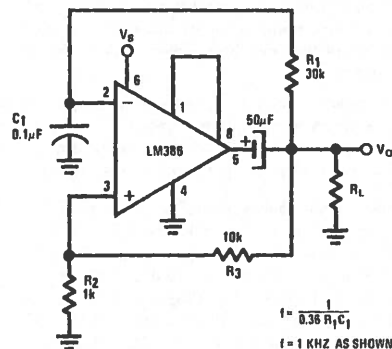


FIGURE 4.7.12 Square Wave Oscillator

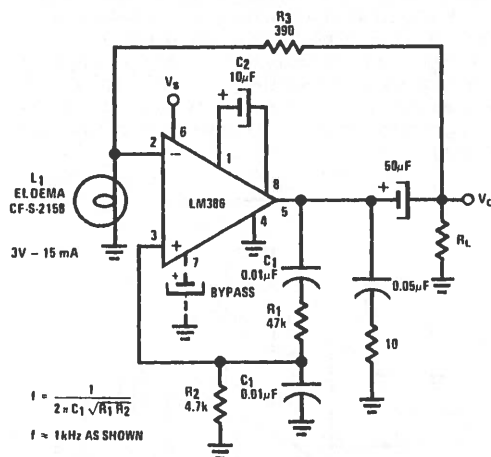


FIGURE 4.7.13 Low Distortion Power Wien Bridge Oscillator

TABLE 4.7.1

CARTRIDGE TYPE	CAPACITANCE	OUTPUT AT 5cm/sec (f = 1kHz)
CERAMIC	800pF	500mV
	2000pF	300mV (Stereo)*
CRYSTAL	800pF	2V (Stereo)*
		3V (Mono)

*Output at 3.5cm/sec

Piezo-electric cartridges (or pick-ups) are operated in the non-resonant mode over a relatively large frequency range and may be represented by the equivalent circuit of 4.7.14 where C_C is the capacitance of the piezo-electric element, R_C the shunt leakage resistance and C_L , R_L are the load capacitance and resistance. R_C is usually several hundred megohms and can be ignored, while typical values for C_C are given in Table 4.7.1.

The E.M.F. generated by any piezo-electric cartridge depends on the amplitude of the movement of the stylus. If discs were recorded with a constant amplitude characteristic, above the cut-off frequency determined by the cartridge capacitance and the load resistance, the response would be essentially flat with frequency, Figure 4.7.15. Note that any load capacitance reduces the output at *all* frequencies above cut-off and that the cut-off frequency moves lower since

$$f_c = \frac{1}{2\pi C_T R_L}$$

where C_T is the paralleled capacitance of the cartridge and the load capacitance.

Since discs are not cut with a constant amplitude versus frequency characteristic (See Section 2.11), when an ideal piezo cartridge plays back a R.I.A.A. recorded disc, there will be a 12.5dB drop in response between 500Hz and 2.1kHz. Before an amplifier response is designed to accommodate this, the designer should realize that crystal cartridges have mechanical compensation to provide relatively flat response through this region, so that a flat amplifier response is all that is required. Ceramic cartridges however, may or may not have mechanical compensation and the decision to compensate electronically will probably depend on the cost objectives (See Section 4.8.7).

4.7.11 LM386 Crystal Cartridge Amplifiers

Where a crystal cartridge is used, the most economical design with the LM386 is shown in Figure 4.7.17. The input stage configuration is the result of a trade-off between cartridge load R_L (which together with the cartridge capacitance will set the low -3dB frequency) and the need to mask variations of input impedance presented by the LM386.

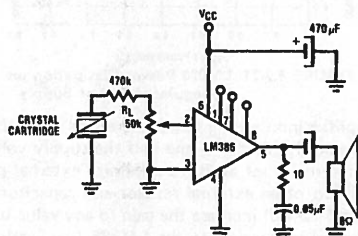


FIGURE 4.7.17 Low Cost Phono Amplifier

The resistor R_L is large enough to define the cartridge load for all settings of the volume control, but a signal attenuator is also formed by this resistor and the input resistance of the LM386 (50k) in parallel with the volume potentiometer. With a large valued potentiometer, the amount of signal attenuation will depend of the input resistance of the LM386 which can change by -30% to +100% from device to device. A 50k volume control will mask this variation to less than 4dB for worst case device input resistance change. A smaller volume control will give even less possible variation in output level but the signal become correspondingly more attenuated. Decreasing R_L to restore more signal input to the LM386 will cause further degradation in the cartridge bass response.

4.7.12 Ceramic Cartridge Amplifiers

While the circuit of 4.7.17 can provide a reasonable compromise of output power and bass frequency response with crystal cartridges, the lower output level of ceramic cartridges will require some changes.

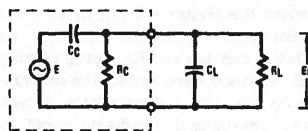


FIGURE 4.7.14 Cartridge Equivalent Circuit

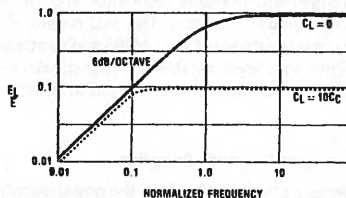


FIGURE 4.7.15 Cartridge Frequency Response

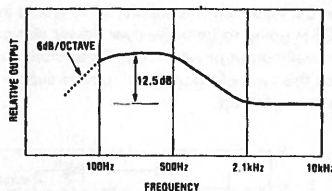


FIGURE 4.7.16 Cartridge Response to RIAA Recorded Disc

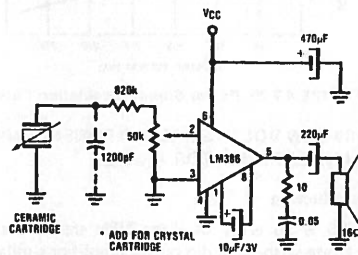


FIGURE 4.7.18 Ceramic Cartridge Amplifier

In the circuit of 4.7.18 the gain of the LM386 has been raised to 200V/V by connecting a capacitor between pin 1 and pin 8. This will also allow R_L to be increased to 820k Ω , which for a 2000pF capacitance cartridge will give a bass cut-off frequency of under 100Hz. This circuit can be used to accommodate the higher output crystal cartridges without overload simply by adding a 1200pF capacitor across the cartridge terminals. This reduces the crystal cartridge output by

$$\frac{800}{800 + 1200} = 0.4 \text{ or } 8\text{dB}$$

and extends the bass response down to 100Hz (compared to the usual bass cut-off of 200Hz). However, for either ceramic or crystal cartridge, extended bass response should be approached with caution, since problems can result from low frequency mechanical feedback between the speaker and the tone arm in complete phonograph units.

This is no problem for stereo units with separated speakers, but for more compact monaural phonographs the circuit of Figure 4.7.18 may cause a low frequency resonance at higher

4.7.13 Phonograph Power Supplies

A typical plot of supply voltage versus output current for a half wave rectified, capacitive input filter power supply is given in Figure 4.7.20. The equivalent internal resistance of the supply (contributed mainly by the winding) is approximately 26 Ω . Using this supply regulation curve to plot the internal power dissipation of the LM386 as the load current increases (Figure 4.7.21) shows that at no time does the power dissipation exceed 600mW. Nevertheless, it is important to check that the peak supply voltage under no-load conditions does not exceed the maximum supply voltage rating for the device.

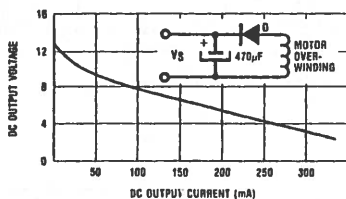


FIGURE 4.7.20 Power Supply Regulation Curve

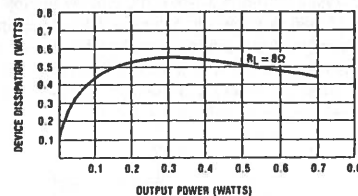


FIGURE 4.7.21 LM386 Power Dissipation on Unregulated Power Supply

4.8 LM389 LOW VOLTAGE AUDIO POWER AMPLIFIER WITH NPN TRANSISTOR ARRAY

4.8.1 Introduction

The LM389 is an array of three NPN transistors on the same substrate with an audio power amplifier similar to the LM386 (Figure 4.8.1).

The amplifier inputs are ground referenced while the output is automatically biased to one half the supply voltage. The gain is internally set at 20 to minimize external parts, but the addition of an external resistor and capacitor between pins 4 and 12 will increase the gain to any value up to 2.7. Gain control is identical to the LM386 (see Section 4.7.4).

