# Experiment No. 3
# Audio Components

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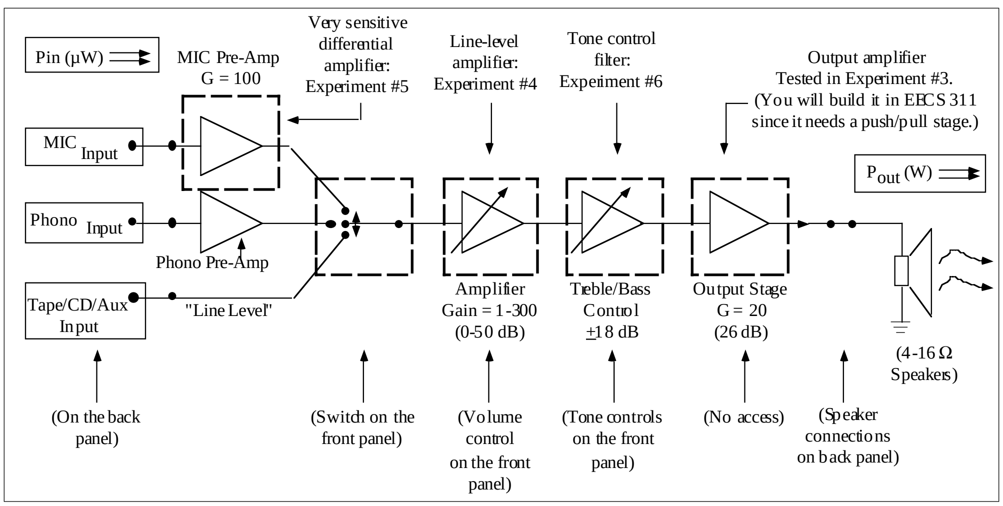
You have been measuring and measuring but not yet building anything. I hope that you are now comfortable with the equipment. Well, Good News! You will now design, build and test some essential components of an audio amplifier. A schematic of an audio amplifier is shown in Fig. 1.




Experiment #3: We will test a 2 W audio amplifier and determine its gain, bandwidth, power consumption, ideal and non-ideal response. This is the “output driver” in audio terms and home versions deliver power from 20 – 200 W!

Experiment #4: The easiest amplifier of all: A variable gain amplifier based on the LM 741 op-amp. We will spice it up by making a two-channel summer, as in the audio mixer of a D.J. or a recording studio. We will also look at intermodulation products when the amplifier is driven into non-linearity.

Experiment #5: A nice one: We will build an amplifier which is immune to noise (waoo!) and which can amplify very low level signals (µV-mV). Similar amplifiers are used as a hi-fi MIC pre-amp or a phono pre-amp.

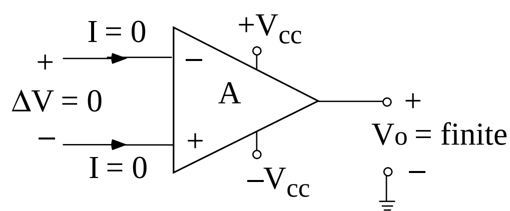
Experiment #6: Capacitors in action: We will design and build tone control circuits which can amplify/attenuate the bass and treble frequencies up to 20 dB.

Open Audio Lab: You will assemble an audio system from your circuits built in Lab Experiments #4 and #6, and the circuit you tested in Experiment #3. You will design and build voltage dividers between these amplifiers, connect the system to your CD player, and listen to your favorite music!

# Experiment No. 3.
# Ideal and Non-Ideal Amplifiers: Part 1

We have studied in class that an ideal amplifier follows the Golden Rules. To review, the Golden Rules are:

1. Input currents are equal to zero.
2. The voltage difference between the (+) and (–) inputs (ΔV) is zero since the amplifier has a very large (infinite) open-loop gain.




Using these rules, we analyzed several circuits (inverting amplifier, non-inverting amplifier, etc.) and obtained expressions for the transfer function ($V_o/V_i$) with no regards to the limitations of the ideal op-amp model. In this experiment, we will discuss some of these non-idealities and how they affect the performance of the amplifier.

1. Power Consumption of the Amplifier

The amplifier is composed of resistors and several transistors (typically 10-50) and therefore requires DC power to bias and operate the transistors. The DC power consumed in the op-amp is obviously delivered by the $+V_{CC}/-V_{CC}$ power supply. The amplifier delivers power to the load and this power also comes from the power supply (but passes through the amplifier first). For example, an audio amplifier may be delivering 10 W to a speaker but also consuming 4 W internally. The resulting power drain from the source is therefore 14 W.

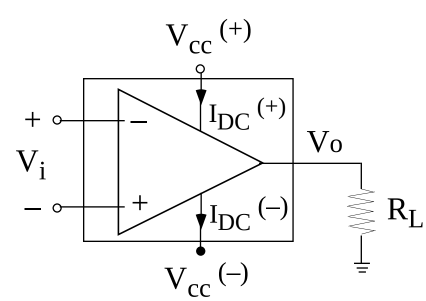
It is easy to calculate the power consumed by the amplifier. First, calculate the power delivered to the load. Then calculate the power delivered from the DC source. The difference between these powers is the power consumed in the amplifier.

$$P_{amp} = P_{DC} - P_{Load}$$

with $$P_{Load} = \frac{V_0^2(pk)}{2R_L} = \frac{V_0^2(rms)}{R_L}$$

$$P_{DC} = V_{cc}(I_{DC})$$

for single power supply connection



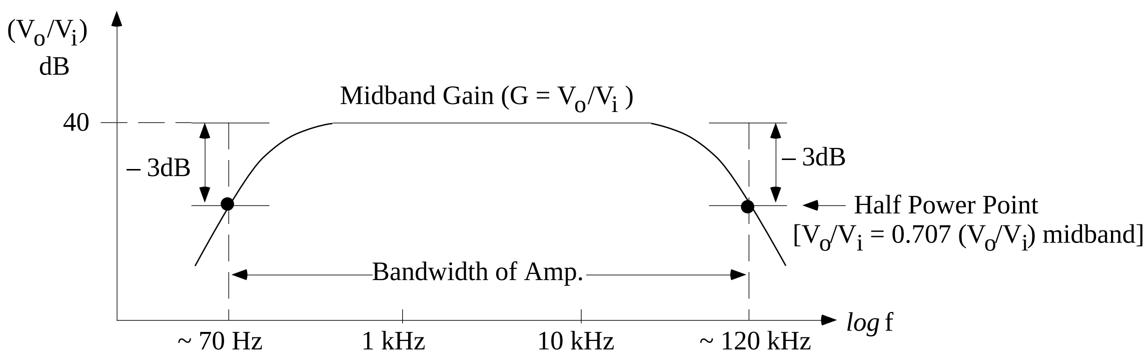
*or*

$$P_{DC} = V_{cc}^{+}\left(I_{DC}^{+}\right) + V_{cc}^{-}\left(I_{DC}^{-}\right) \approx 2V_{cc}^{+}\left(I_{DC}^{+}\right) \qquad \left(I_{DC}^{+} = I_{DC}^{-}\right)$$

for dual power supply connections.

2. Bandwidth of the Amplifier

All amplifiers operate up to a certain high frequency limit. Beyond this, the amplifier gain drops uniformly at –20 dB/decade (or even faster). Also, most amplifiers have a low-frequency limit imposed by internal, or external, components. Between the low and high frequency points, most amplifiers have a constant gain which is referred to as the “midband gain”. Actually, one can design an amplifier with nearly any gain response and the gain need not be flat. However, for now and up to Experiment #4, the transfer function $V_0/V_i$ will have a flat gain response (up to the high frequency limit). The high frequency and low-frequency limits are referred to as “corner” frequencies and define the “bandwidth” of the amplifier. They are taken as the half-power points (–3 dB), where the gain drops by 3 dB of its value at midband (or the output voltage drops by 0.707 of its value at midband for a constant input voltage).




xample: The 3-dB bandwidth is from 70 Hz to 120 kHz. The midband gain is 40 dB.

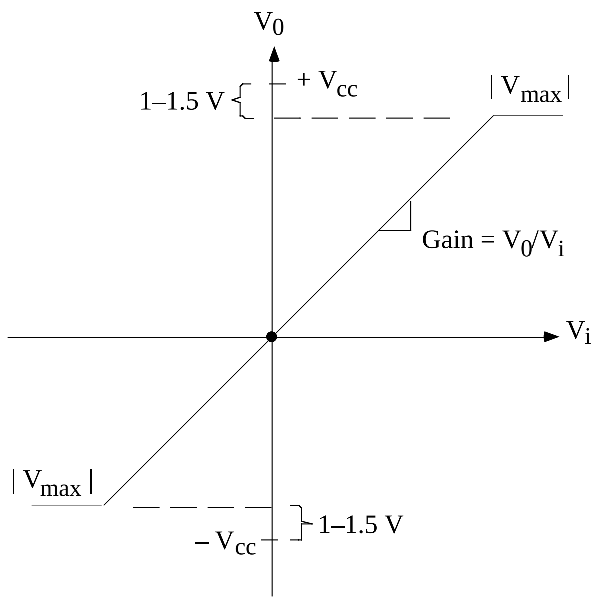
3. Gain Bandwidth Product

Amplifiers are typically rated by their Gain•Bandwidth product, a fundamental quality of amplifier design (you will study this in EECS 311). Here Bandwidth means the high-frequency point only. The Gain•Bandwidth product of any amplifier is constant. If an amplifier has a Gain•Bandwidth product of 20 MHz, this means that it will have a bandwidth of 200 KHz for a gain of 100, a bandwidth of 2 MHz for a gain of 10 and a bandwidth of 20 MHz for a gain of 1.

The LM 380 has a typical gain of 50 and a typical bandwidth of 100 KHz. This means that its Gain•Bandwidth product is 5 MHz. However, do not be surprised if you measure a Gain•Bandwidth product of 15 MHz. The ratings are generally quite conservative to allow for fabrication process variations. The LM 741 (or LM 747, used in Experiments 4, 5, 6) has a Gain•Bandwidth product of 0.44 MHz minimum and 1.5 MHz typical. This means that for a gain of 40, the bandwidth should be 11 KHz minimum and most probably will be around 35 KHz.

4. Maximum Output Voltage Swing (Output Voltage Saturation)

The maximum output voltage delivered to the load cannot be higher than $V_{CC}$ (or lower than $-V_{CC}$ for negative voltages). Actually, the maximum output voltage is 1.0–1.5 V lower than ($V_{CC}$) due to the small voltage drop in the output section of the op-amp. If a higher output voltage is requested, the amplifier will simply saturate (or clip the output signal). This generates a lot of high-order harmonics and deteriorates the sound quality in an audio-amplifier.




5. Maximum Output Current (Short Circuit Current)

Another amplifier rating is the maximum current it can deliver (or sink in the negative portion of the waveform). This quantity can vary a lot between different types of op-amps. For example, the LM 380 can deliver up to 1.3 A, while the LM 741 can deliver only 25 mA.

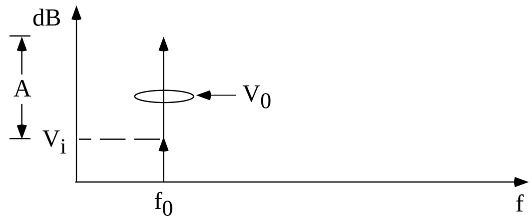
The maximum output current determines which load resistor one should use with the op-amp. For example, using the LM 741 and an output voltage swing of $\pm$ 6 V, one cannot choose a 100 Ω load resistor. At +6 V, the required output current is 60 mA which is far higher than the rated short circuit current of 25 mA. In this case, the amplifier will clip at 2.5 V (25 mA x 100 Ω)! A better choice would have been a 240 Ω resistor or higher. The short circuit current is a nice protection for the amplifier in case of an accidental short-circuit at the output. It will just deliver $I_{SC}$ and will not burn the amplifier.

Question: When do I know if an amplifier is voltage or current clipping?

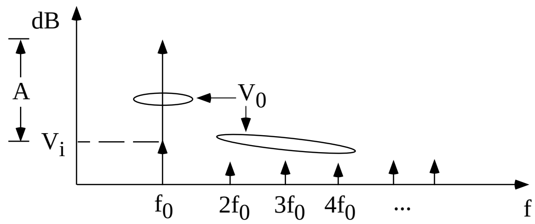
Answer: If the output voltage swing is limited by $V_{max}$, then it is voltage clipping. If it is lower than $V_{max}$, then most probably it is current clipping.

6. Total Harmonic Distortion

The total harmonic distortion (THD) is a figure of merit describing the linearity of the amplifier. Most amplifiers are not perfectly linear, and even with small input signals, generate a small amount of higher order harmonics. The LM 380 has a THD rating of 0.2% up to 10 KHz and 0.4% at 20 KHz. However look closely at the THD rating vs. output power in the LM 380 data sheet (page 41). When the amplifier starts clipping, the THD skyrockets from 0.2% to 10%. High performance audio amplifiers have a THD of 0.01–0.04% at midband.

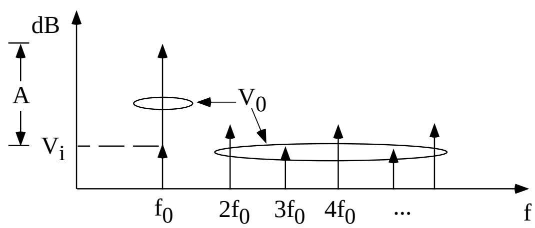



Perfect Linear Amplifier
$V_0 = A\,V_i$




"Linear" amplifier with a small non-linear component

$V_0 = AV_i + \beta V_i^2 + \gamma V_i^3 + \delta V_i^4 + V_i^5 + \ldots$
$\beta, \gamma, \delta, \ldots$ = small




Non-Linear Amplifier (clipping)

$V_0 = AV_i + \beta V_i^2 + \gamma V_i^3 + \delta V_i^4 + V_i^5 \ldots$
$\beta, \gamma, \delta, \ldots$ = large

The THD is defined as:

$$\mathrm{THD}(\%) = \sqrt{\frac{\sum(P_{harmonics})}{P_{signal}}} \text{ x } 100$$

where

$$\sum P_{harmonics} = \left(\frac{V_{2f_0}^2}{R_L}\right) + \left(\frac{V_{3f_0}^2}{R_L}\right) + \left(\frac{V_{4f_0}^2}{R_L}\right) + \left(\frac{V_{5f_0}^2}{R_L}\right) + \ldots$$

V in rms!

$$P_{signal} = \left(\frac{V_{f_0}^2}{R_L}\right)$$

7. Input Currents/Offset Voltage/Input Resistance:

We will cover these in Experiment #5. For this experiment, assume that $I_i = 0$, $\Delta V = 0$ and that the amplifier has an infinite input resistance ($R_i = \infty$). These are the "Golden Rules" of an ideal amplifier.

# Experiment No. 3.
# The LM 380 Audio Power Amplifier

The LM 380 is an audio amplifier developed expressly for low distortion amplification. It has an internally set gain of 50 and can drive 1.2 W into an 8 Ω speaker with a power supply voltage of 12 V. It can also drive 0.5 W into an 8 Ω load a power supply voltage of 9 V. As you will see in the lab, 1 W results in a loud sound at 0.5 – 1 m from the speaker. The LM 380 can be operated from a single supply and the output voltage will automatically be set at half the supply voltage. A very nice feature of the LM 380 is that it is current limited. This means that the LM 380 will not burn if an accidental short circuit occurs at its output.

The LM 380 is inserted into a 14-pin package with the pin connection shown in Fig. 1. Note the multitude of ground connections. These are used to reduce the inductance to ground and therefore to result in a better frequency response. Pins 3, 4, 5, 10, 11, 12 are for the return ground of the load current (which can be large). It is good practice to connect them all to the common DC ground. Pin 7 is the DC ground of the input transistors and must be used for the input lines.

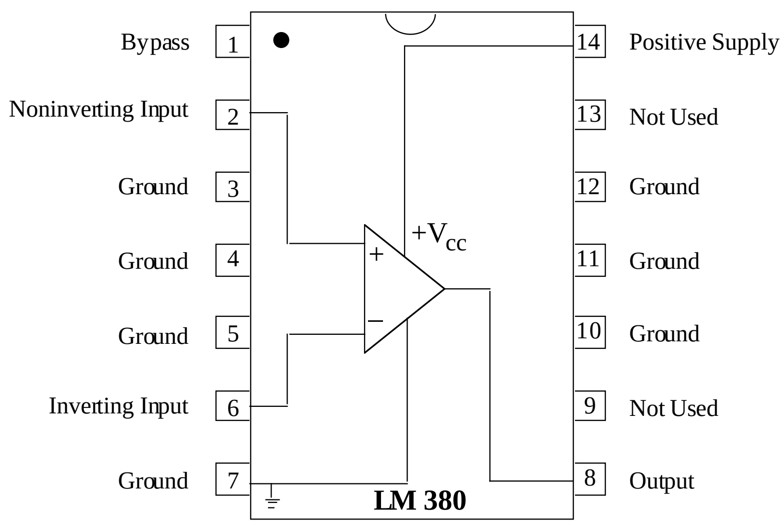



Fig. 1: Pin connections for the LM 380 audio amplifier.

Max. Output Power of the LM 380:

The output voltage swing of the LM 380 is limited by the DC supply voltage (0-$V_{cc}$). The output voltage will saturate ~1.3 – 1.5 V below/above the $V_{cc}$/0 V level (Fig. 2). This means that the $V_{cc}$ level sets the maximum undistorted output voltage swing (no clipping), and therefore the maximum power delivered to the load. For a $V_{cc}$ of 9 V, the maximum voltage swing is ~6 V ppk. For a $V_{cc}$ of 12 V, the maximum voltage swing is ~9 V ppk. As discussed in class:

$$V_{pk} = -\frac{V_{ppk}}{2} \text{ and } P = \frac{(V_{pk})^2}{2R_L} = \frac{(V_{rms})^2}{R_L}.$$

This means that the maximum undistorted power delivered to an 8 Ω load (speaker) is 0.56 W for a $V_{CC}$ of 9 V, 1.26 W for a $V_{CC}$ of 12 V, and 3.5 W for a $V_{CC}$ of 18 V. Above these voltage (or power) levels, the amplifier saturates (clipping) and generates a lot of harmonic signals.

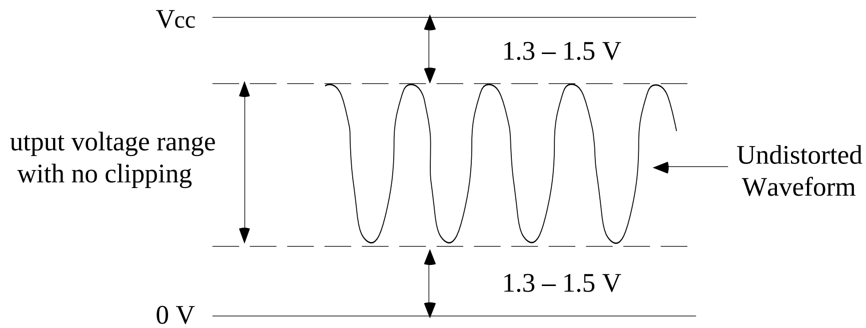



Fig. 2: The maximum voltage swing of the LM 380 amplifier. It uses a single positive supply.

The essential electrical characteristics of the LM 380 are presented below. The manufacturer's data sheet is also attached.

| | |
|---|---|
| Supply Voltage: | +9, +12 V typ., +22 V max. |
| Gain x Bandwidth: | 10 MHz typ. (Gain = 1, BW = 10 MHz)<br>Gain = 50, BW = 200 KHz) |
| Output Power: | 0.5 W into 8 Ω with +9 V<br>1.2 W into 8 Ω with +12 V<br>3.5 W into 8 Ω with +18 V |
| Total Harmonic Distortion: | <0.2% at 1 kHz up to 1 W with a 12 V supply. |
| Input Resistance: | 150 kΩ |
| Input Bias Current: | 100 nA |
| Output Short-Circuit Current: | 1.3 A |

National Semiconductor

# LM380 Audio Power Amplifier

## General Description

The LM380 is a power audio amplifier for consumer application. In order to hold system cost to a minimum, gain is internally fixed at 34 dB. A unique input stage allows inputs to be ground referenced. The output is automatically self centering to one half the supply voltage.

The output is short circuit proof with internal thermal limiting. The package outline is standard dual-in-line. A copper lead frame is used with the center three pins on either side comprising a heat sink. This makes the device easy to use in standard p-c layout.

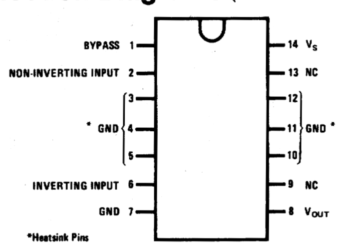
Uses include simple phonograph amplifiers, intercoms, line drivers, teaching machine outputs, alarms, ultrasonic drivers, TV sound systems, AM-FM radio, small servo drivers, power converters, etc.

A selected part for more power on higher supply voltages is available as the LM384. For more information see AN-69.

## Features

- Wide supply voltage range
- Low quiescent power drain
- Voltage gain fixed at 50
- High peak current capability
- Input referenced to GND
- High input impedance
- Low distortion
- Quiescent output voltage is at one-half of the supply voltage
- Standard dual-in-line package

## Connection Diagrams (Dual-In-Line Packages, Top View)

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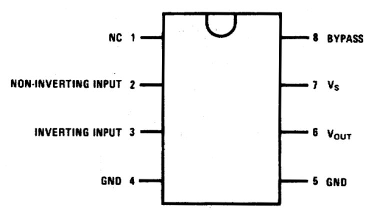
**Order Number LM380N**
**See NS Package Number N14A**

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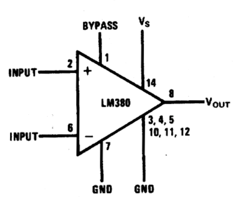
**Order Number LM380N-8**
**See NS Package Number N08E**

## Block and Schematic Diagrams

**LM380N**

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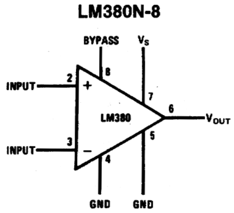
**LM380N-8**

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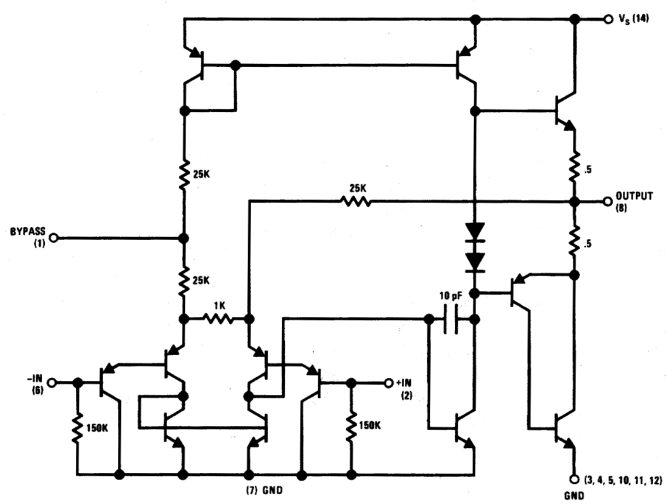


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Taken from National Semiconductor–Application Specific Analog Products Databook, 1995 Edition.

## Absolute Maximum Ratings

**If Military/Aerospace specified devices are required, please contact the National Semiconductor Sales Office/Distributors for availability and specifications.**

| | |
|---|---|
| Supply Voltage | 22V |
| Peak Current | 1.3A |
| Package Dissipation 14-Pin DIP (Notes 6 and 7) | 8.3W |
| Package Dissipation 8-Pin DIP (Notes 6 and 7) | 1.67W |
| Input Voltage | ±0.5V |
| Storage Temperature | −65°C to +150°C |
| Operating Temperature | 0°C to +70°C |
| Junction Temperature | +150°C |
| Lead Temperature (Soldering, 10 sec.) | +260°C |
| ESD rating to be determined | |
| Thermal Resistance | |
| $\theta_{JC}$ (14-Pin DIP) | 30°C/W |
| $\theta_{JC}$ (8-Pin DIP) | 37°C/W |
| $\theta_{JA}$ (14-Pin DIP) | 79°C/W |
| $\theta_{JA}$ (8-Pin DIP) | 107°C/W |

## Electrical Characteristics (Note 1)

| Symbol | Parameter | Conditions | Min | Typ | Max | Units |
|---|---|---|---|---|---|---|
| $P_{OUT(RMS)}$ | Output Power | $R_L = 8\Omega$, THD = 3% (Notes 3, 4) | 2.5 | | | W |
| $A_V$ | Gain | | 40 | 50 | 60 | V/V |
| $V_{OUT}$ | Output Voltage Swing | $R_L = 8\Omega$ | | 14 | | $V_{p\text{-}p}$ |
| $Z_{IN}$ | Input Resistance | | | 150k | | Ω |
| THD | Total Harmonic Distortion | (Notes 4, 5) | | 0.2 | | % |
| PSRR | Power Supply Rejection Ratio | (Note 2) | | 38 | | dB |
| $V_S$ | Supply Voltage | | 10 | | 22 | V |
| BW | Bandwidth | $P_{OUT} = 2W$, $R_L = 8\Omega$ | | 100k | | Hz |
| $I_Q$ | Quiescent Supply Current | | | 7 | 25 | mA |
| $V_{OUTQ}$ | Quiescent Output Voltage | | 8 | 9.0 | 10 | V |
| $I_{BIAS}$ | Bias Current | Inputs Floating | | 100 | | nA |
| $I_{SC}$ | Short Circuit Current | | | 1.3 | | A |

**Note 1:** $V_S = 18V$ and $T_A = 25°C$ unless otherwise specified.

**Note 2:** Rejection ratio referred to the output with $C_{BYPASS} = 5\ \mu F$.

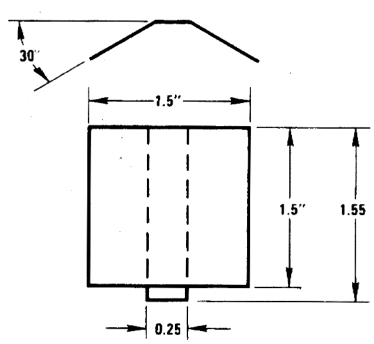
**Note 3:** With device Pins 3, 4, 5, 10, 11, 12 soldered into a 1/16" epoxy glass board with 2 ounce copper foil with a minimum surface of 6 square inches.

**Note 4:** $C_{BYPASS} = 0.47\ \mu fd$ on Pin 1.

**Note 5:** The maximum junction temperature of the LM380 is 150°C.

**Note 6:** The package is to be derated at 15°C/W junction to heat sink pins for 14-pin pkg; 75°C/W for 8-pin.

## Heat Sink Dimensions




Staver Heat Sink #V-7
Staver Company
41 Saxon Ave.
P.O. Drawer H
Bayshore, NY 11706
Tel: (516) 666-8000
Copper Wings
2 Required
Soldered to
Pins 3, 4, 5,
10, 11, 12
Thickness 0.04
Inches

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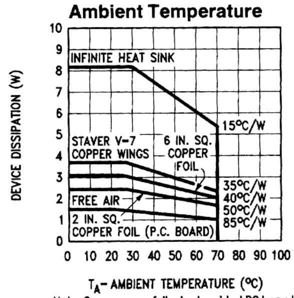
Taken from National Semiconductor–Application Specific Analog Products Databook, 1995 Edition.

## Typical Performance Characteristics

**Maximum Device Dissipation vs Ambient Temperature**




Note: 2 oz. copper foil, single-sided PC board.

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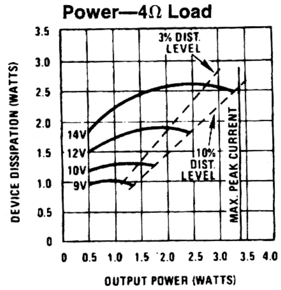
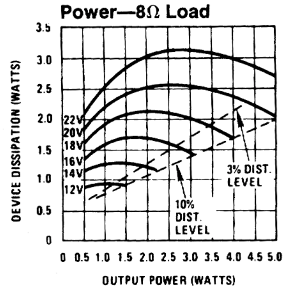
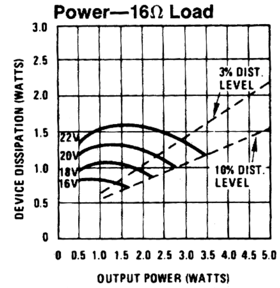
**Device Dissipation vs Output Power—4Ω Load**



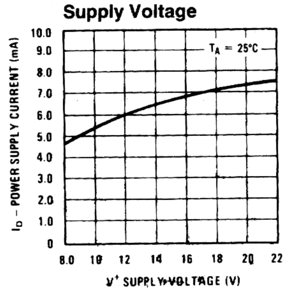

**Device Dissipation vs Output Power—8Ω Load**



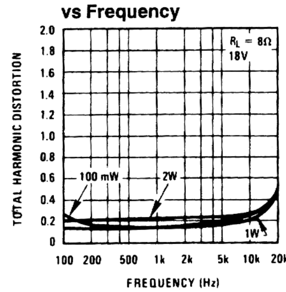

**Device Dissipation vs Output Power—16Ω Load**



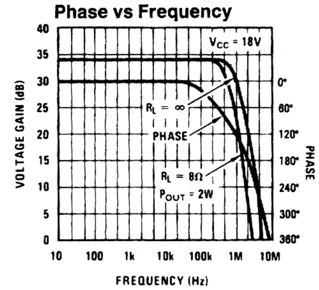

**Power Supply Current vs Supply Voltage**



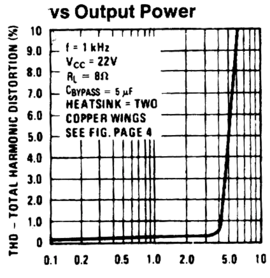

**Total Harmonic Distortion vs Frequency**



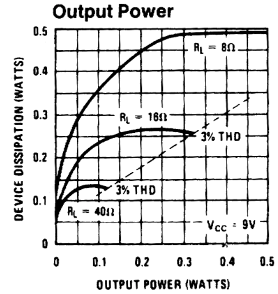

**Output Voltage Gain and Phase vs Frequency**



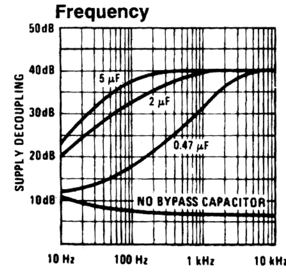

**Total Harmonic Distortion vs Output Power**




**Device Dissipation vs Output Power**




**Supply Decoupling vs Frequency**

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Taken from *National Semiconductor–Application Specific Analog Products Databook, 1995 Edition*.

# Experiment No. 3.
# Audio Amplifier Frequency Response, Distortion and Clipping

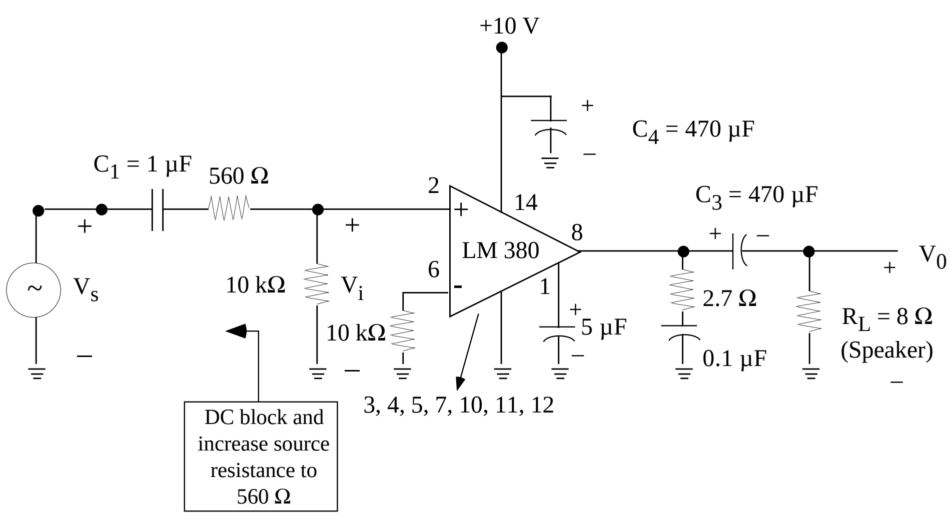
**Goal:** The goal of Experiment #3 is to test an audio power amplifier and determine its gain, bandwidth, power consumption and total harmonic distortion for different input levels.

- ❑ Read Chapters 1 and 2 in the additional course notes (Audio Electronics)
- ❑ Read this experiment and answer the pre-lab questions before you come to the lab.
- ❑ This experiment is relatively short, because you do not have to build the circuit: you will simply test amplifiers built by lab instructors. Therefore this experiment is combined with the Lab Lecture.

## 3.1 Audio Amplifier Frequency Response and Clipping:

**Equipment:**
- Agilent E3631A Triple output DC power supply
- Agilent 33120A Function Generator
- Agilent 34401A Multimeter
- Agilent 54645A Oscilloscope

The LM 380 audio amplifier circuit is shown below:




Explanation of Components:

1. The power supply capacitor ($C_4$ = 500 µF) attenuates the noise picked up by the power supply leads.
2. The large capacitor at the output ($C_3$ = 500 µF) blocks the DC voltage (~4.5 V) at the output terminal of the op-amp from the load resistor $R_L$.
3. The medium capacitor at the input ($C_1$ = 1 µF) results in a low-frequency cutoff frequency around 100 Hz and blocks any DC from the source to the input of the op-amp.

4. The 5 µF capacitor connected to pin 1 is needed for low frequency stability.

5. The 2.7 Ω/0.1 µF components are needed to help the LM 380 deliver high currents to the load. Basically, the 0.1 µF discharges into the load under high current conditions ($|V_0|$ is large). It will then charge back under low output currents ($|V_0|$ is small).

You have in front of you an Audio amplifier capable of delivering ~0.8 W into an 8 Ω load from a +10 V supply. Care was taken to lay it out in a clear manner so as to show you how circuits should be built. This amplifier is rated as:

| | |
|---|---|
| Frequency Response: | 20 Hz – 20 kHz (or more). |
| Gain: | 50 (34 dB) and flat over the frequency range. |
| Max. Output Power: | ~0.8 W into an 8 Ω load for $V_{cc}$ = 10 V. |
| Total Harmonic Distortion: | <0.4% up to 0.5 W. |

You will learn later how to design such an amplifier and the role of the resistors and capacitors in the circuit. The goal now is to treat it as a black box and test it.

- ❑ Draw the circuit in your notebook. NOW!

Experiment Set-Up:

1. Connect +10 V to the $+V_{cc}$. Connect the (–) terminal of the power supply to the LM 380 amplifier ground. (Again, make sure that the (–) terminal of the Agilent E3631A power supply is connected to the ground pin on the power supply.)
   - ❑ Measure the DC voltage at the output terminal (pin #8) and at the input terminal (pins #2 and 6). You should measure ~5 V at pin #8 and ~0 V at pins #2 and #6.
2. Set the Agilent 33120A function generator to deliver 100 mV ppk at 1 kHz. Look at it on the signal scope (on Channel 1) in time and frequency domain.
3. Connect the output of the function generator to the input of the audio amplifier.

GAIN AND DISTORTION/CLIPPING MEASUREMENTS:

4. Using the oscilloscope, measure the output of the audio amplifier across the 8 Ω load (connect it to Channel 2). The voltage should be around 4.5 $V_{ppk}$ since the amplifier gain is set at 50 ($V_o/V^+$) and there is a $10/10.56 \approx 0.95$ voltage divider at the input ($V_i/V_s$). The delivered power to the resistor is around $P_L = V_{pk}^2/2R$ = 0.40 W.
   - ❑ Plot the time and frequency domain signal (of $V_o$). Measure $V_{ppk}$ and $V_{rms}$ in time domain (using the scope Softkeys at the bottom of the screen under the Measure [Voltage] menu). Measure the fundamental ($f_o$) harmonics (up to $5f_o$) in the frequency domain (they may be very small and not measurable). DO NOT MEASURE ANY HARMONICS IF THEY ARE 40 dB BELOW THE PEAK.
   - ❑ Measure the DC current supplied by the Agilent power supply (see p. 7 to see how to do it easily).

5. ❑ Increase the input waveform to $V_S$ = 200 $mV_{ppk}$. The output waveform *should* be around 10 $V_{ppk}$ for an ideal amplifier with no clipping. However, due to clipping, it will actually look more like a square-wave and the harmonic levels should skyrocket!

   ❑ Plot the time and frequency domain signals (of $V_O$). Measure $V_{rms}$ and $V_{ppk}$ in the time domain. Measure the fundamental and harmonic levels (up to $9f_O$) in the frequency domain. Measure the ± clipping voltages at the output.

   ❑ Measure the DC current supplied by the Agilent power supply.

Explanation: The clipping at $V_i$ = 130 mV and above is due to the DC power supply of 10 V. If we increase the DC voltage to +15 V, the maximum output voltage swing will be ~ $V_{ppk}$ (max) = 12 V (with a maximum power output of 2.25 W into an 8 Ω load). The maximum allowable input voltage for no distortion will therefore be $V_{i\ ppk}$ (max) = 240 mV. The chip is rated at this power and will work well. But then, we need to worry about proper heat sinking of the LM 380. DO NOT BIAS THE LM 380 AT +15 V!

FREQUENCY RESPONSE MEASUREMENTS:

6. Set the Agilent 33120A function generator to deliver $V_S$ = 100 $mV_{ppk}$ and connect the signal output of the Agilent function generator to the input of the LM 380 amplifier.

7. Connect the output of the LM 380 amplifier to Channel 2 of the scope. Make sure that you are in the linear region (no clipping).

8. ❑ Measure the transfer function (gain vs. frequency) from 20 Hz – 1 MHz in a logarithmic fashion (1, 2, 5 frequency hops). This is done by choosing 20, 50, 100, 200, ... Hz and measuring $V_O/V_S$ ($V_S$ = 100 $mV_{ppk}$ = constant). Determine the 3-dB bandwidth. Remember, the 3-dB bandwidth is when $V_O$ in Volts drops to 0.707 of its value at midband in Volts (or by -3 dB from its value at midband in the frequency domain).

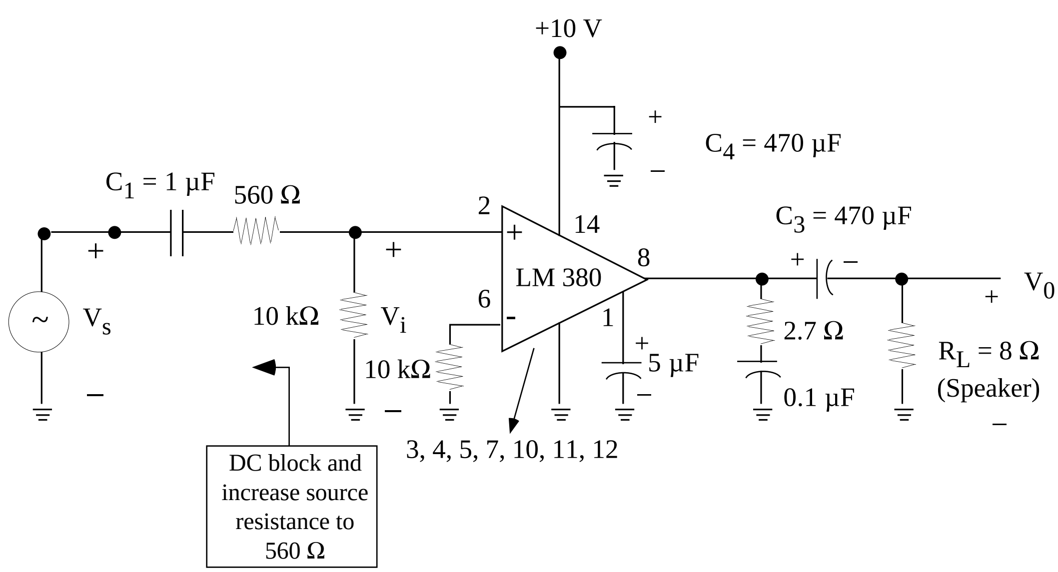
9. The LM 380 will operate well to around 60 KHz. After this, you will starting noticing “glitches” in the output voltage at the zero crossings. These glitches will become more pronounced as the frequency increases and may dominate the waveform above 300 KHz. The glitches are commonly called “cross-over distortion” and are a characteristic of class AB push-pull amplifiers. This type of amplifier is used at the output stage of the LM 380 (look at the two diodes and two output transistors in the schematic). You will study push-pull amplifiers in EECS 311/413.

NOTE: The op-amp has a very wide frequency response from 1 Hz to 10 MHz. Some of the resistors/capacitors in the circuit are used to limit the frequency response from ~100 Hz to ~300 kHz. This is done so that the amplifier does not pick up a lot of 60 Hz noise or computer switching noise. This noise, when amplified, could cause the amplifier to break into oscillations.

**You have finished your lab now. If you wish, take the speaker and connect it to the amplifier and listen to clean signals and distorted (clipped) signals. If you choose a fundamental frequency of 400-600 Hz, I guarantee you that you will clearly hear the higher harmonics!**

# Experiment No. 3
# Audio Amplifier Frequency Response, Distortion and Clipping

### Worksheet/Notes



# Experiment No. 3.
# Audio Amplifier Frequency Response, Distortion and Clipping

## Pre-Lab Assignment

1. An amplifier with a gain of 100 is connected to a +12 V single power supply and draws 5 mA at $V_i$ = 0 $V_{rms}$ and 100 mA for $V_i$ = 35 $mV_{rms}$. Take $R_L$ = 16 Ω.
   a. Calculate the power delivered to the load for $V_i$ = 0 and $V_i$ = 35 $mV_{rms}$.
   b. Calculate the power consumed by the amplifier for $V_i$ = 0 and $V_i$ = 35 $mV_{rms}$.
2. A measured audio spectrum across an 8 Ω speaker is:

   $V_{(fo)}$ = 17 dB at $f_o$ = 1 KHz

   $V_{(3fo)}$ = 0 dB

   $V_{(5fo)}$ = –5 dB

   $V_{(7fo)}$ = –10 dB

   a. Calculate $V_{rms}$ of the fundamental and each harmonic.
   b. Calculate the power delivered to the load at each frequency.
   c. Calculate the THD present in the signal.
3. The gain bandwidth product of the LM 741 op-amp is between 0.4 MHz and 1.5 MHz. What is the 741 op-amp high-frequency bandwidth for a gain of 20? Can we build a hi-fi audio amplifier with the 741 op-amp with a gain of 400?
4. An audio amplifier is connected to a $\pm V_{CC}$ dual power supply and can deliver an undistorted output voltage up to $|V_{CC}|$-2 V into an 8Ω load. Calculate the minimum $\pm V_{CC}$ required for an undistorted output power of 5W, 20W and 100W.

# Experiment No. 3
# Audio Amplifier Frequency Response, Distortion and Clipping

## Lab Report Assignment

1. ❑ For the two cases:

   $V_S$ = 100 mV ppk    $V_S$ = 200 mV ppk

   do the following:

   a) Using the measured DC input current from the Agilent power supply ($V_{CC}$ = 10 V), calculate the input DC power to the amplifier circuit. This power is delivered to the op-amp circuit and to the load.

   b) Using the measured $V_O(t)$, calculate the power dissipated in the 8 Ω load ($P_{load} = V_{rms}^2/8\Omega$).

   c) Calculate how much power is dissipated in the op-amp.

   d) Calculate the total harmonic distortion (THD) in % present at the output

2 ❑ Using the measured data, plot the transfer function (y-axis: dB scale from 0 to +40 dB, x-axis logarithmic scale: from 20 Hz to 1 MHz. Determine the midband gain in dB and the 3-dB bandwidth.

3. a. The output of the non-linear amplifier which is clipping symmetrically is given by:

   $v_O = Av_i + \gamma v_i^3 + \xi v_i^5$    where $v_i = V_i \cos(\omega t)$.

   where A ≡ gain of amplifier and β, γ << A ≡ non-linear components

   Calculate $v_O(t)$ and put it in the form:

$$
\begin{aligned}
V_o(t) = {} & f_1(V_1, A, \gamma, \xi)\cos(\omega t) \\
& + f_3(V_1, A, \gamma, \xi)\cos(3\omega t) \\
& + f_5(V_1, A, \gamma, \xi)\cos(5\omega t) \quad \text{where } f_1(\ ), f_2(\ ), f_3(\ ) \text{ are functions of } V_1, A, \gamma, \xi.
\end{aligned}
$$

   For doing so, you have to replace powers of cos (ωt) with harmonics such as cos (2ωt).

You need the following formulas:

$$\cos^2(x) = \frac{1+\cos(2x)}{2}$$
$$\cos(-x) = \cos(x)$$
$$\cos(x)\cos(y) = \frac{1}{2}\cos(x+y) + \frac{1}{2}\cos(x-y)$$

This is simple trigonometric calculations. You will find that the non-linear amplifier "creates" components at $3\omega$ and $5\omega$. The expressions for $f_3$ and $f_5$ will give you amplitudes of the harmonics.

b. For A = 30, $\gamma$ = 3, $\xi$ = 1, calculate the resulting output spectrum in $V_{rms}$ (and also in dB) for $V_i$ = 200 mV $V_{rms}$. Calculate the THD.

(This problem has nothing to do with your lab measurements.)