



ALTOIDS TIN HEADPHONE AMPLIFIERS

Stephen Zajac
IEEE / AEE
October 19th 2010

TOPICS OF DISCUSSION

○ This Week

- Audio Basics
- Amplifier Design Basics

○ Next Week

- Cmoy Headphone Amplifier Design
- Modifying the Cmoy Design to Drive Speakers

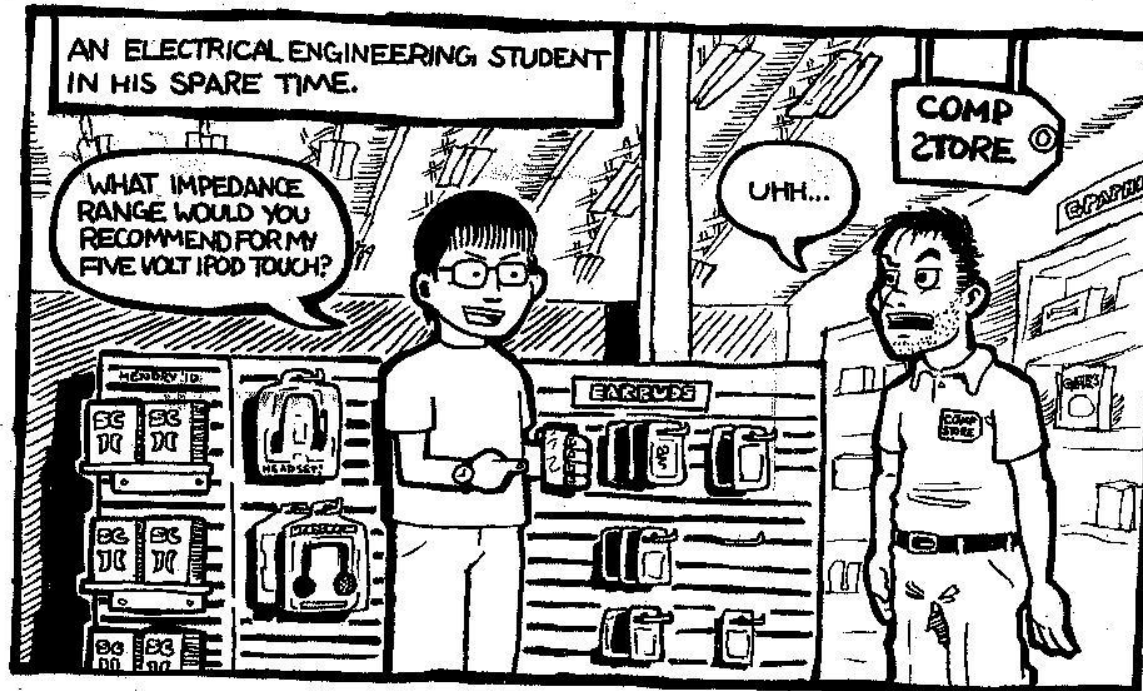


TOPIC 1: AUDIO BASICS



**Austin
Hendry**

Is the State
News editorial
cartoonist.
Reach him at
hendryau@
msu.edu.



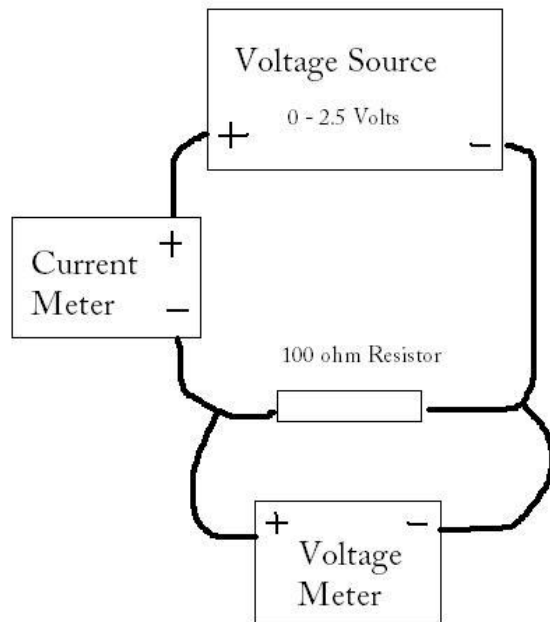
WHAT IS IMPEDANCE?

- First you must ask the question what is resistance?
- Ohm's Law-published by Georg Simon Ohm in 1827.
- $V = I * R$
- Voltage is equal to current times resistance.



GREAT IDEA... BUT PROVE IT

Experimental Setup



Results

Voltage (V)	Current (mA)
0.50248	5.04
1.00351	10.05
1.50419	15.05
2.0045	20.05
2.5045	25.05

Measured Resistance: 100.005 Ω



OTHER USEFUL FORMULAS

- $V = I * R$

- $P = V * I$

- $I = V / R$

- $P = (I * I) * R$

- $R = V / I$

- $P = (V * V) / R$

- Resistance is the ratio of voltage to current.

- Power is the square of voltage or current times a scale factor.



SO WHAT IS IMPEDANCE THEN?

- Resistance is the ratio of voltage to current at a frequency of 0 Hz (Direct Current or DC).
- Impedance is the ratio of voltage to current at any frequency higher than 0 Hz (Alternating Current or AC).
- For DC circuits you only need to consider one type of element: resistors. For AC you need to add on the effects of capacitors and inductors.



IMPEDANCE OF SPECIFIC ELEMENTS

- Resistor

$$Z_R = R$$

- Capacitor

$$Z_c = \frac{1}{j * \omega * C}$$

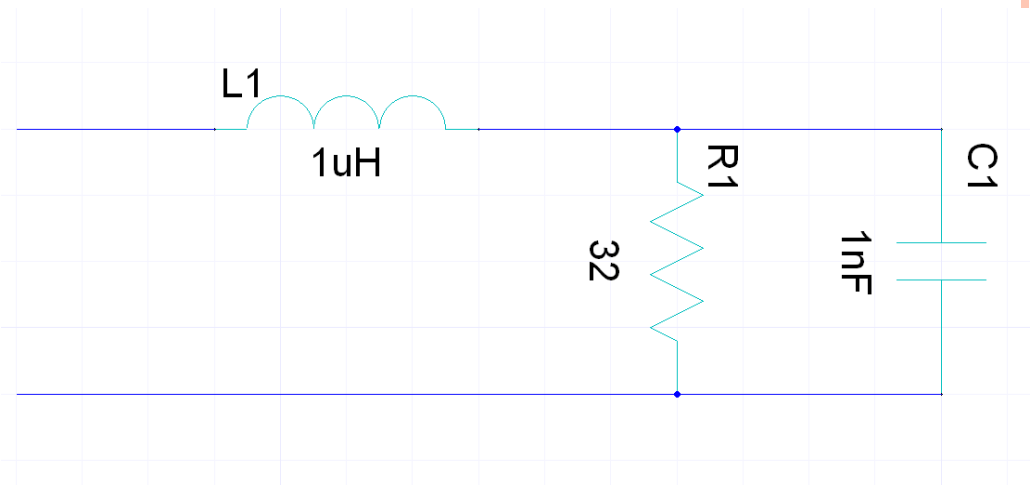
- Inductor

$$Z_L = j * \omega * L$$



CONSIDER THE FOLLOWING CIRCUIT

- At a frequency of 1 kHz: $Z_L = j6.3 \text{ m}\Omega$ and $Z_C = -j159 \text{ k}\Omega$
- In other words...
 $Z_L = 0.0063 \text{ }\Omega$ and
 $Z_C = 159000 \text{ }\Omega$
- $32 \text{ }\Omega \parallel 159 \text{ k}\Omega = 32 \text{ }\Omega$
- $32 \text{ }\Omega$ in series with $6.3 \text{ m}\Omega = 32 \text{ }\Omega$



At low frequencies with small values of capacitance and inductance, impedance is equal to resistance.



IMPEDANCE OF HEADPHONES/SPEAKERS

- Speaker Impedance:
(2 Ω ~ 16 Ω)
- Headphone Impedance
(32 Ω ~ 600 Ω)
- Resistance Measured at DC:
Apple Earbuds: 30.2 Ω
Sennheiser HD497: 35 Ω
Sennheiser HD650: 286.3 Ω
Small Speakers: 3 Ω
Big Speakers: 7 Ω



Demo



WHAT DETERMINES VOLUME?

- Three Things:

 - Voltage output of your amplifier.

 - Impedance of your load.

 - Efficiency of your load.

- The first two can be combined into one (Power).
- The second gives you a number in decibel output with a given power input.
- So a high voltage across a high impedance load produces less volume than a high voltage across a low impedance load.



How LOUD IS TOO LOUD?

TABLE G-16 - PERMISSIBLE NOISE EXPOSURES (1)

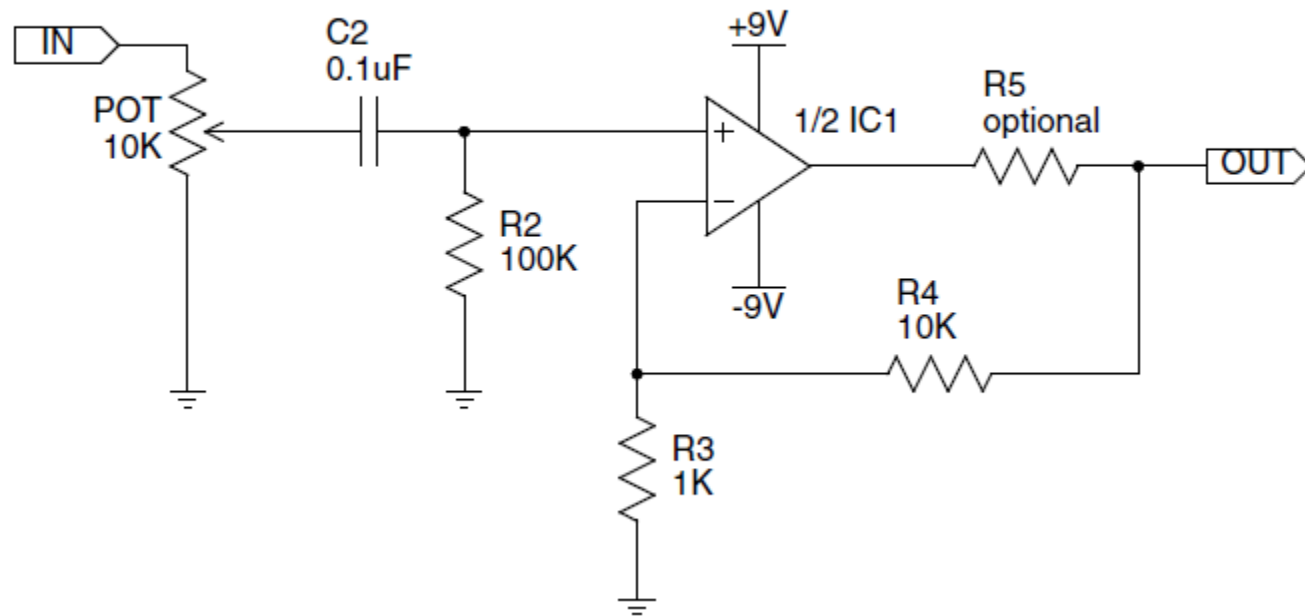
Duration per day, hours	Sound level dBA slow response
8.....	90
6.....	92
4.....	95
3.....	97
2.....	100
1 1/2	102
1.....	105
1/2	110
1/4 or less.....	115

Footnote(1) When the daily noise exposure is composed of two or more periods of noise exposure of different levels, their combined effect should be considered, rather than the individual effect of each. If the sum of the following fractions: $C(1)/T(1) + C(2)/T(2) + C(n)/T(n)$ exceeds unity, then, the mixed exposure should be considered to exceed the limit value. C_n indicates the total time of exposure at a specified noise level, and T_n indicates the total time of exposure permitted at that level. Exposure to impulsive or impact noise should not exceed 140 dB peak sound pressure level.

Source: <http://www.osha.gov/>



AMPLIFIER DESIGN BASICS



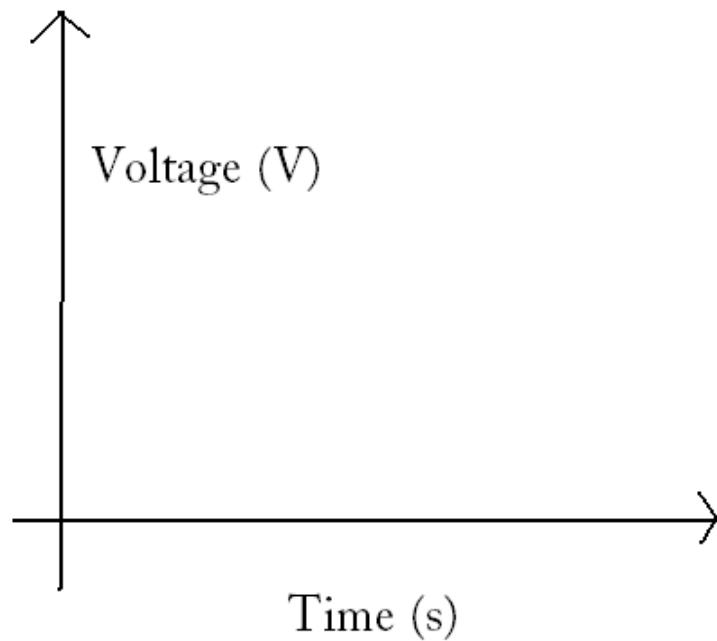
WHAT DETERMINES A GOOD AMPLIFIER?

- Distortion
- Noise
- Efficiency
 - Battery Life
- Power Output
 - Size

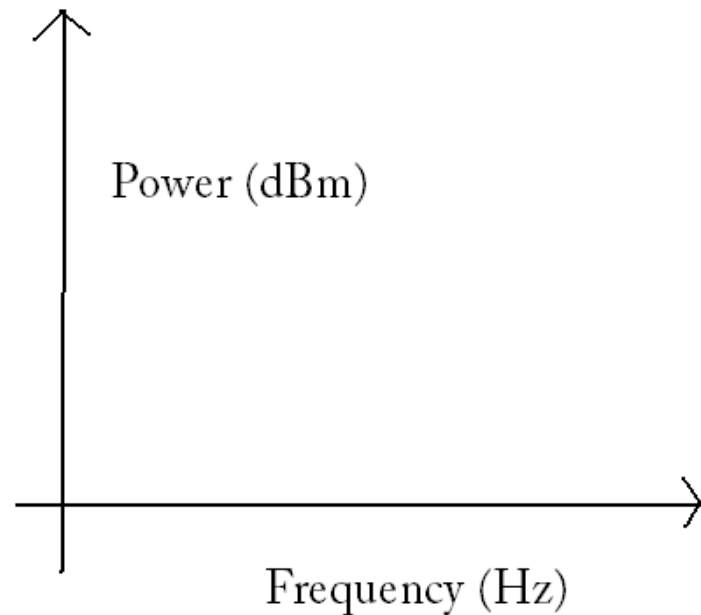


TIME DOMAIN VS. FREQUENCY DOMAIN

Voltage vs. Time



Power vs. Frequency

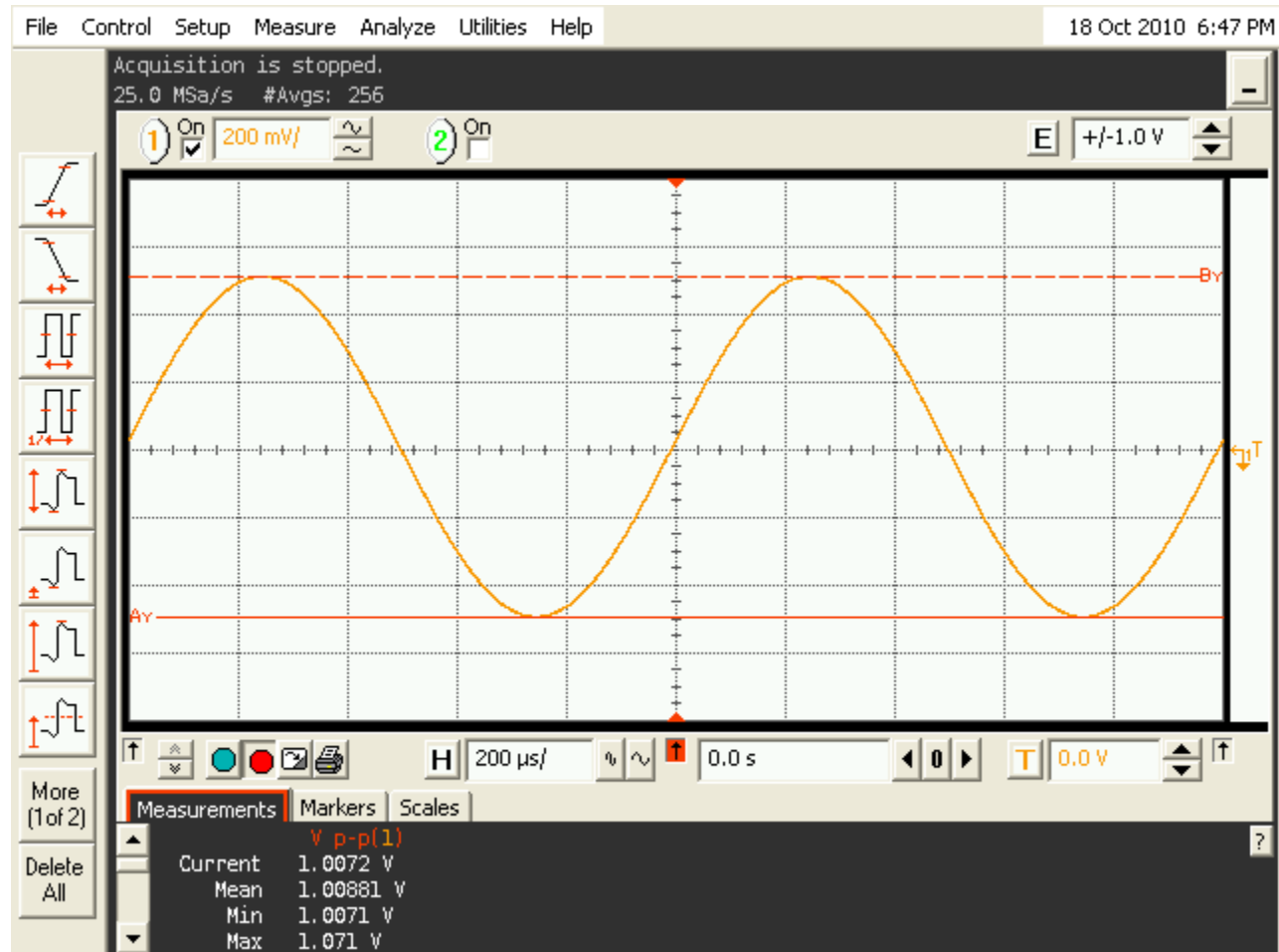


DISTORTION

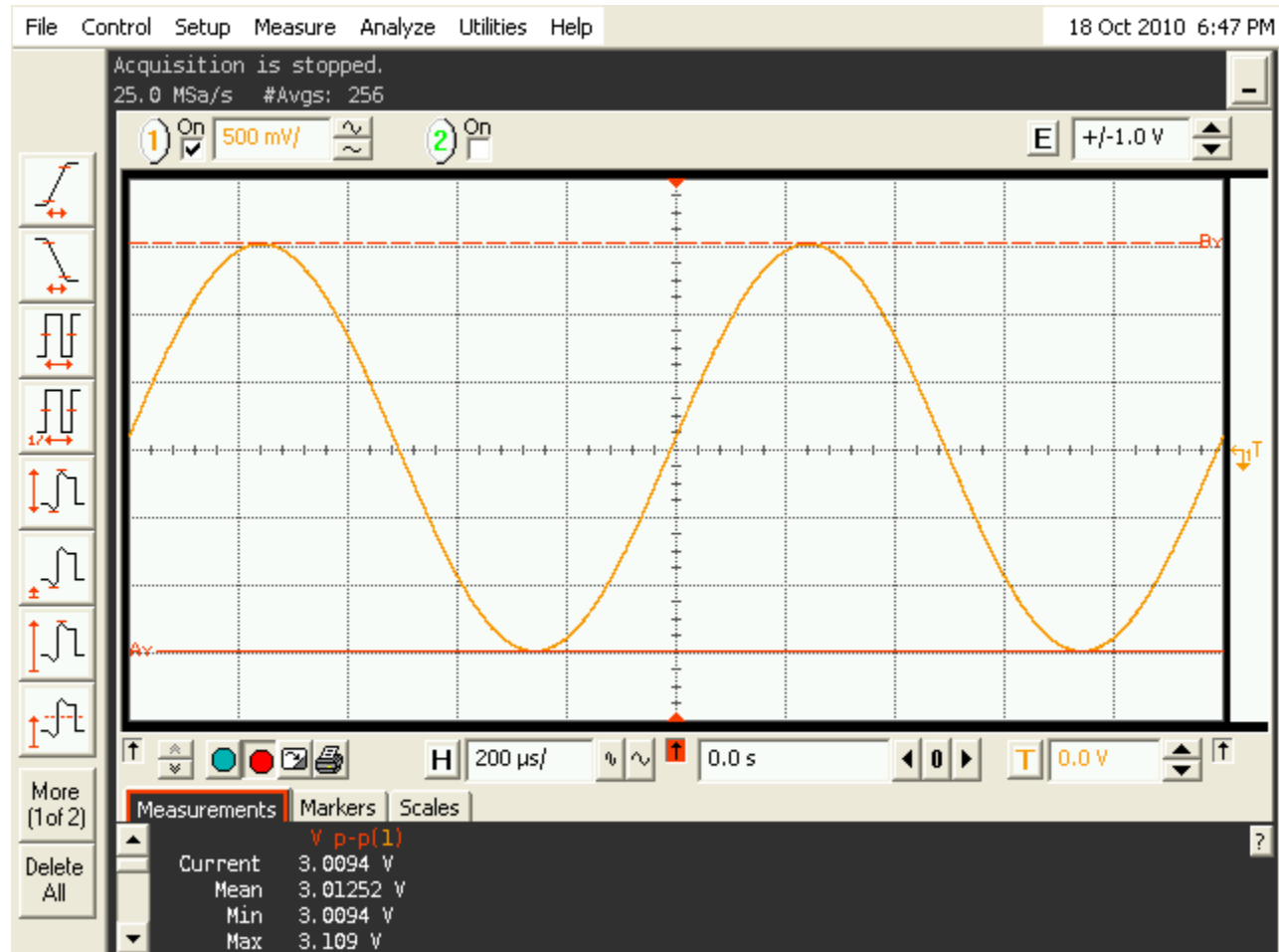
- In a normal amplifier the output is equal to the input time a linear scale factor (the gain).
- Distortion occurs when the output is no longer proportional to the input.
- This normally happens when you ask too much of a specific amplifier design, for example, when you try to get 30 mA out of a amplifier that can only give you 20 mA, you will get distortion.
- The next four plots show voltage vs. frequency of an amplifier design with a battery voltage of 9V. The output voltages are 1V, 3V, 6V, and 9V.



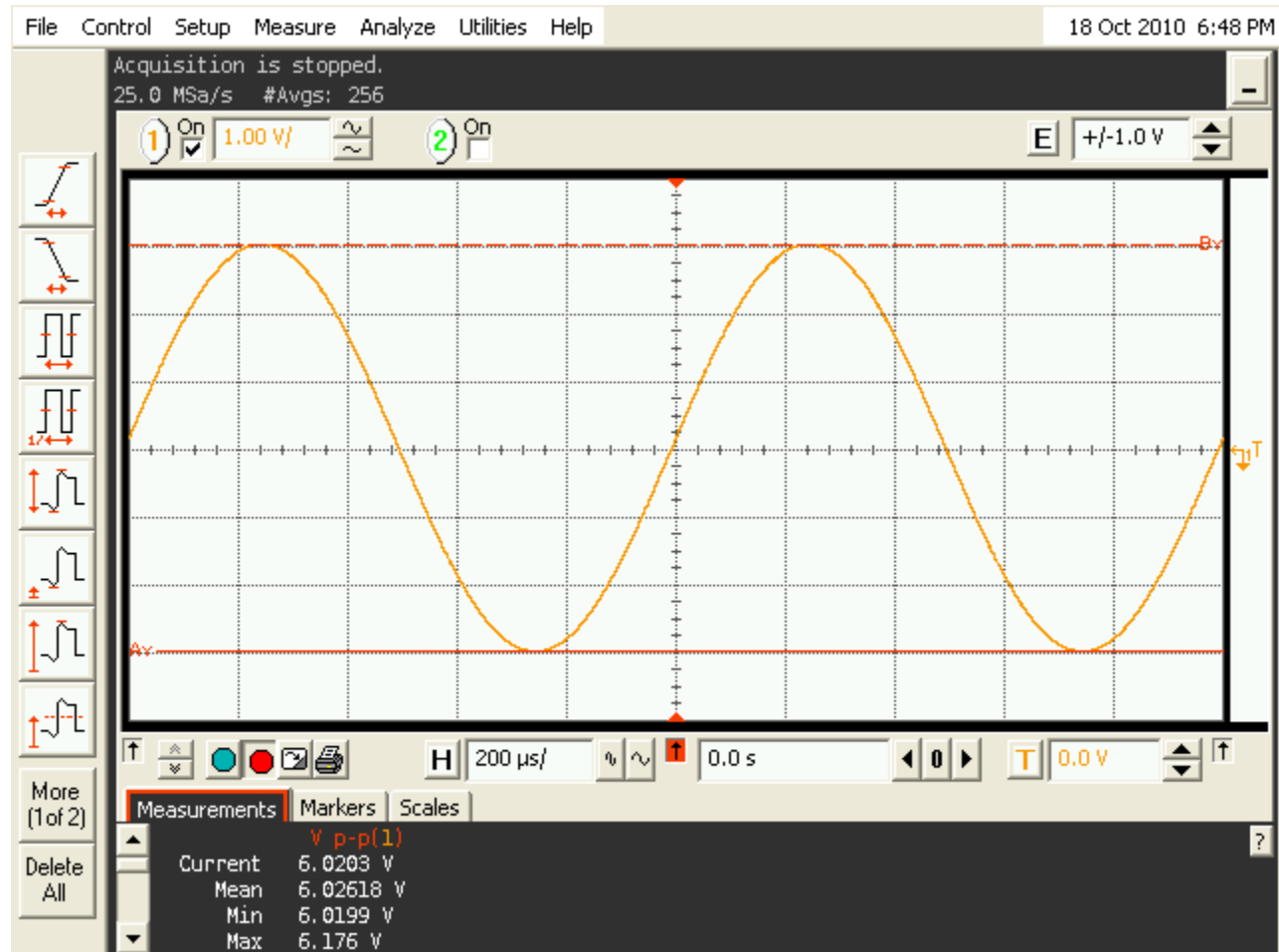
1 V OUT (1 KHZ SINE WAVE INPUT)



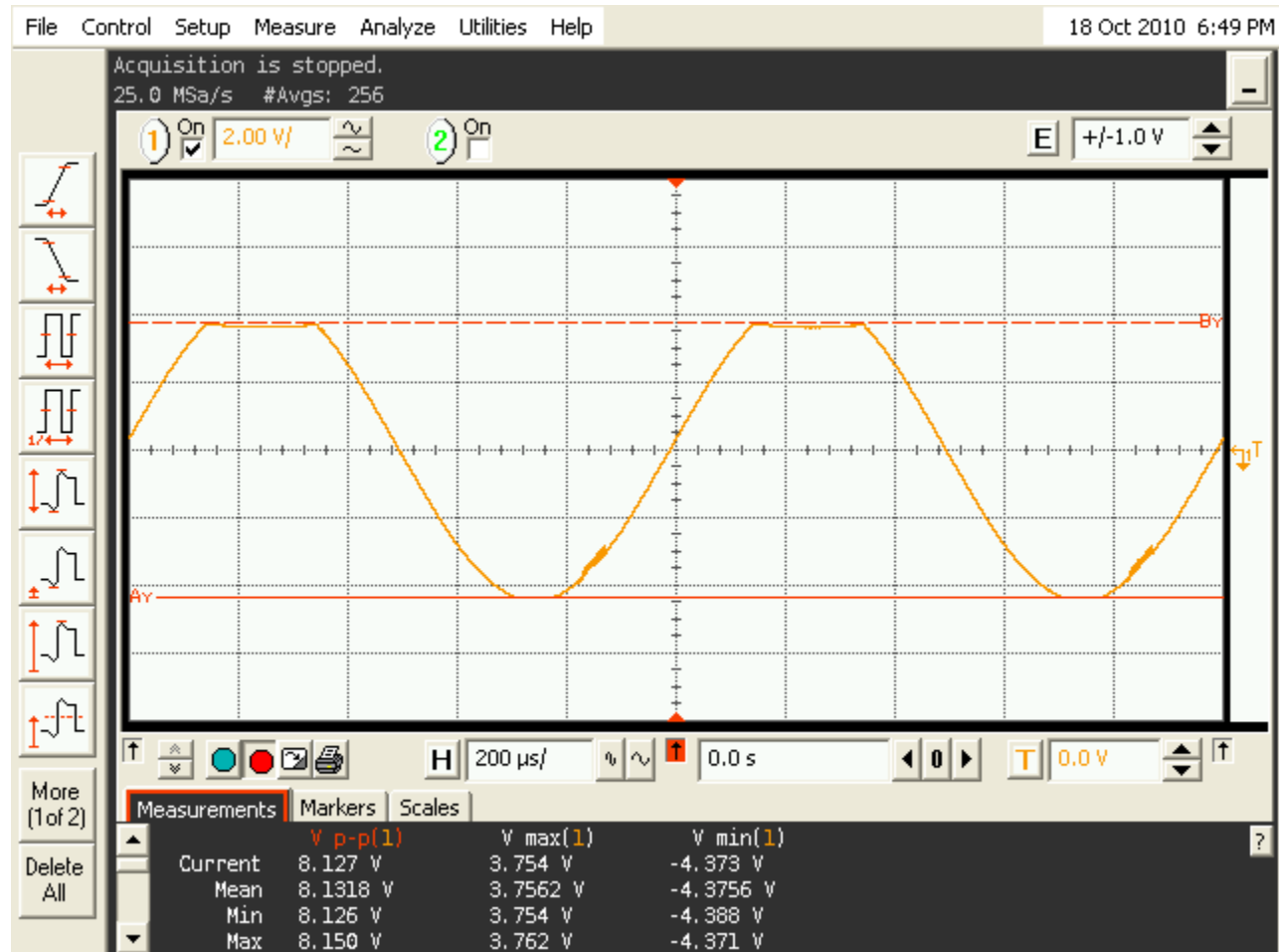
3 V OUT (1 KHZ SINE WAVE INPUT)



6 V OUT (1 KHZ SINE WAVE INPUT)



9 V OUT (1 KHZ SINE WAVE INPUT)



OBSERVATIONS

- If you have very little current draw, you can get high output voltages without distortion.
- The output voltage of the amplifier can never be greater than the battery voltage.
- In this case the output could swing within 0.45 V of each battery voltage without distortion.



HARMONIC DISTORTION

- If you send a pure 1 kHz sine wave into an amplifier, you would expect to get one single sine wave at 1 kHz at the output.
- In reality what you get is a 1 kHz sine wave (fundamental) in addition to very small sine waves at multiples of the fundamental (2 kHz, 3 kHz, 4 kHz, etc...).
- This is called harmonic distortion.

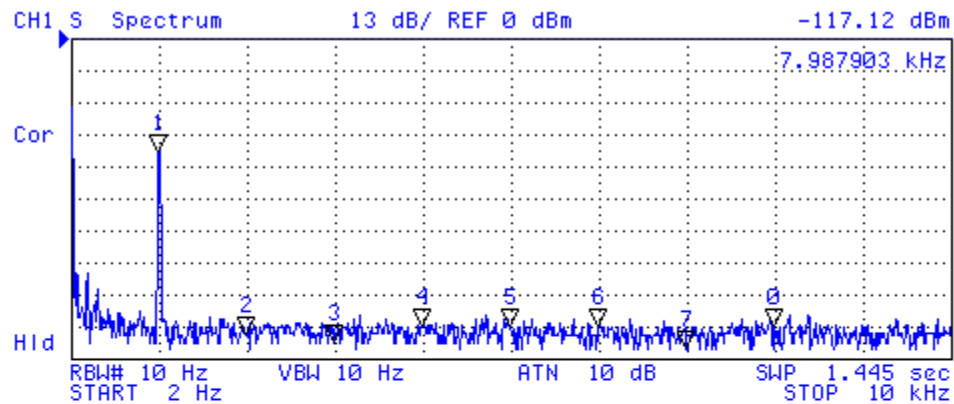


HARMONIC DISTORTION (CONTINUED)

- Intermodular distortion (IMD) is another type.
- The next four slides show the harmonic content of the previous 4 sine waves at 1V, 3V, 6V, and 9V output.

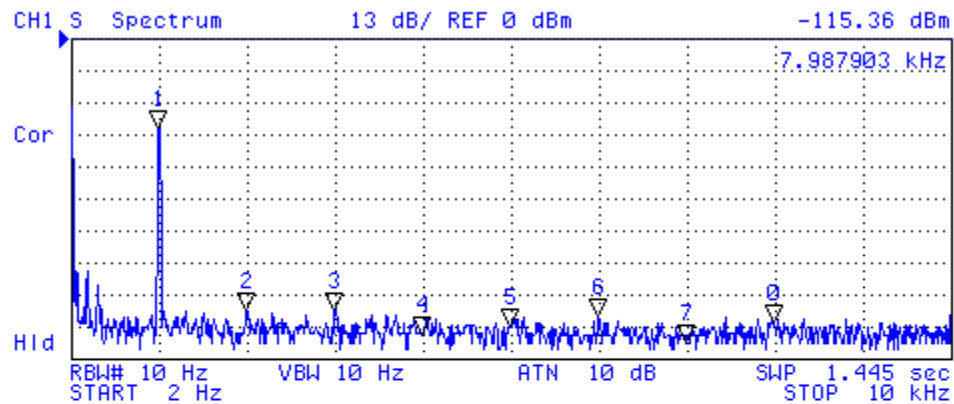


SPECTRUM OF A 1 V SINE WAVE



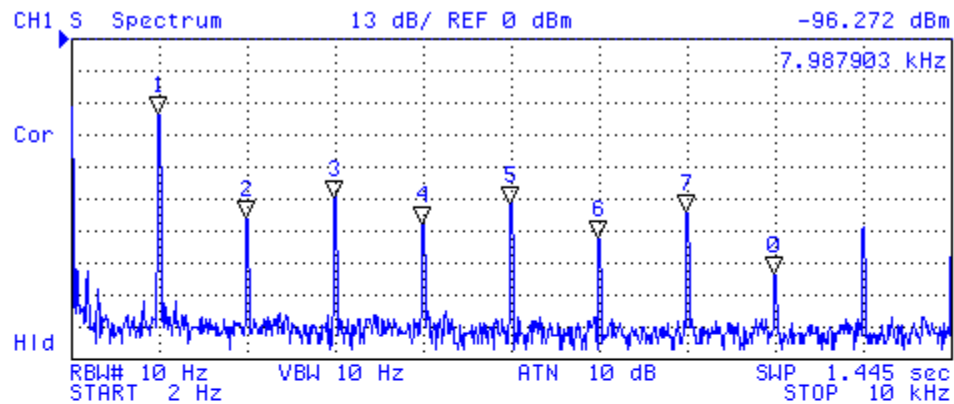
N	SWP PARAM	VAL
0	7.987903 kHz	-117.12 dBm
1	989.303 Hz	-46.18 dBm
2	1.989103 kHz	-120.13 dBm
3	2.988903 kHz	-123.14 dBm
4	3.988703 kHz	-117.12 dBm
5	4.988503 kHz	-116.61 dBm
6	5.988303 kHz	-116.61 dBm
7	6.988103 kHz	-126.15 dBm

SPECTRUM OF A 3 V SINE WAVE



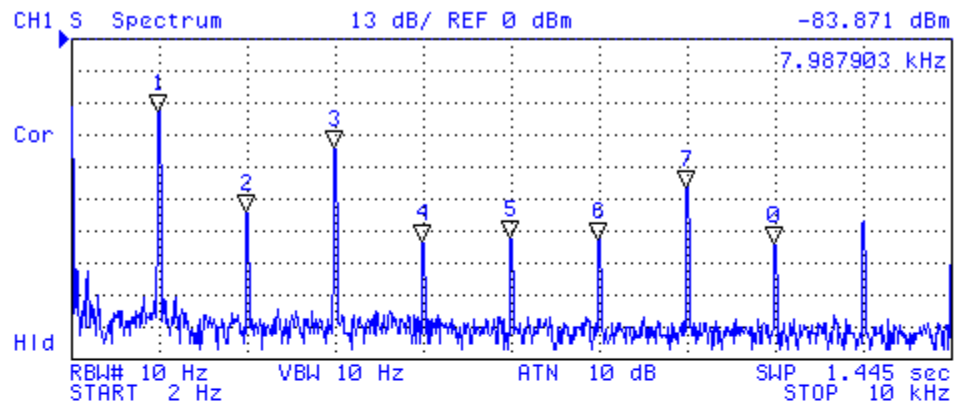
N	SWP PARAM	VAL
0	7.987903 kHz	-115.36 dBm
1	989.303 Hz	-36.632 dBm
2	1.989103 kHz	-110.24 dBm
3	2.988903 kHz	-110.13 dBm
4	3.988703 kHz	-120.13 dBm
5	4.988503 kHz	-116.61 dBm
6	5.988303 kHz	-112.53 dBm
7	6.988103 kHz	-123.14 dBm

SPECTRUM OF A 6 V SINE WAVE



N	SWP PARAM	VAL
0	7.987903 kHz	-96.272 dBm
1	989.303 Hz	-30.804 dBm
2	1.989103 kHz	-73.285 dBm
3	2.988903 kHz	-64.723 dBm
4	3.988703 kHz	-75.509 dBm
5	4.988503 kHz	-67.087 dBm
6	5.988303 kHz	-81.274 dBm
7	6.988103 kHz	-70.855 dBm

SPECTRUM OF A 9 V SINE WAVE



N	SWP PARAM	VAL
0	7.987903 kHz	-83.871 dBm
1	989.303 Hz	-29.752 dBm
2	1.989103 kHz	-70.707 dBm
3	2.988903 kHz	-45.003 dBm
4	3.988703 kHz	-83.094 dBm
5	4.988503 kHz	-81.407 dBm
6	5.988303 kHz	-81.739 dBm
7	6.988103 kHz	-60.801 dBm

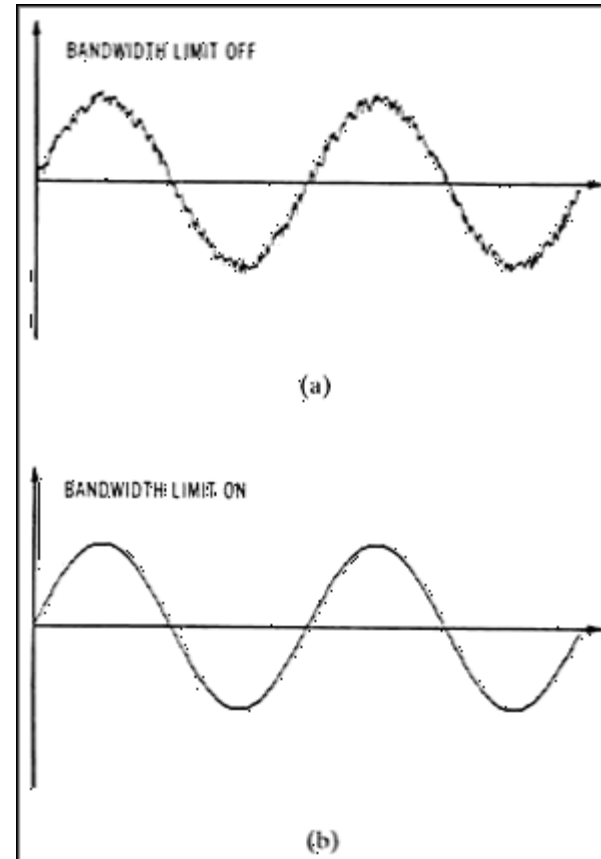
OBSERVATIONS

- For this test the load was 50 ohm. A 350 mA current buffer was placed on the output of the amplifier to ensure that any clipping that took place was due to voltage limiting and not current limiting.
- At 1 V and 3 V out the harmonic distortion is well below the noise floor of the instrument.
- At 6V and 9 V out the harmonic distortion is significant.

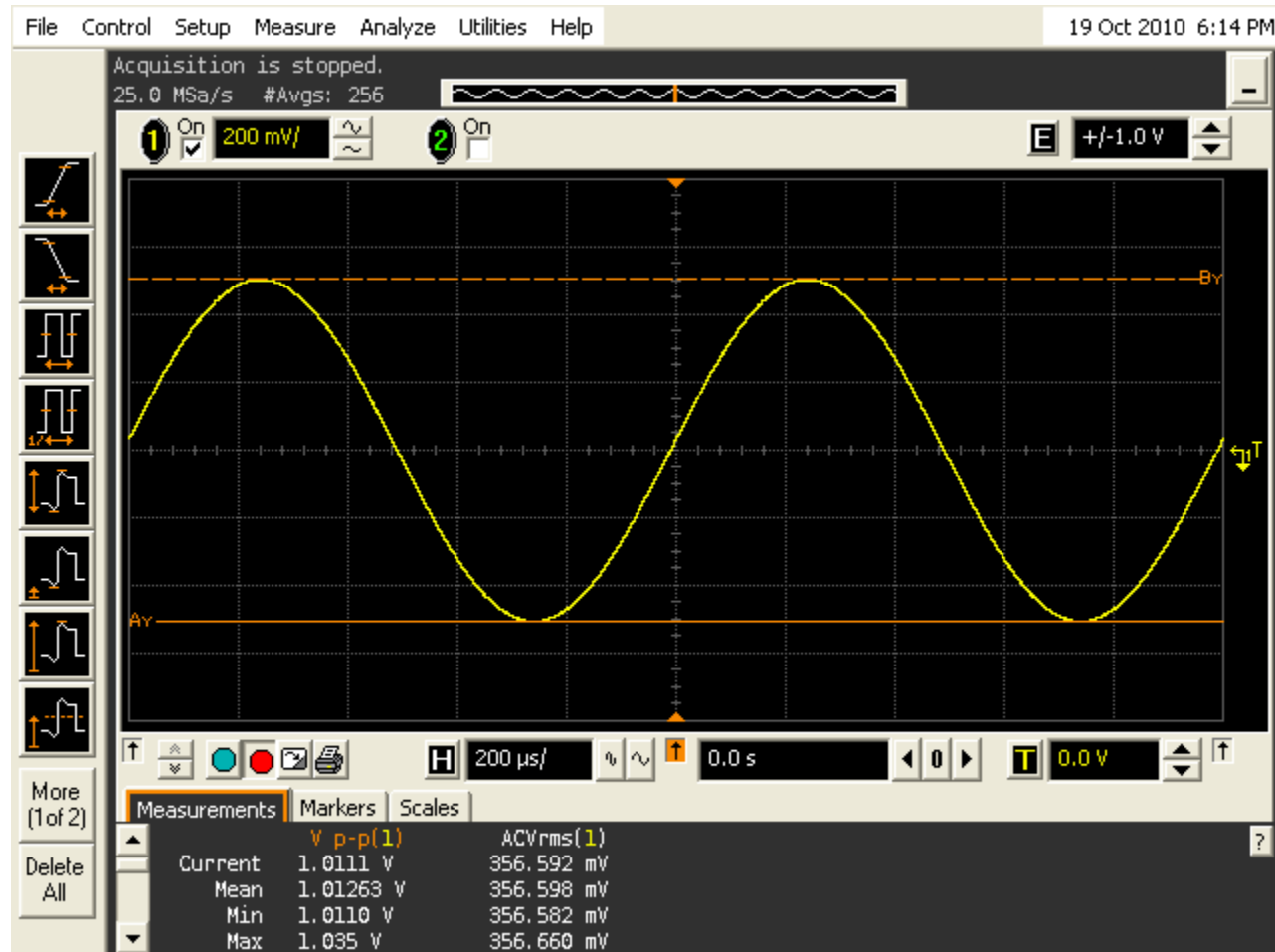


NOISE

- Noise is simply random information distributed across all frequencies.
- Any amplifier will add a certain amount of noise, so you want to design amplifiers that will keep this amount to a minimum.



VOLTAGE PEAK-TO-PEAK VS. VOLTAGE RMS



EFFICIENCY

- The input power is the power drawn from the battery.
- The output power is the RMS value across the load.
- Efficiency is the ratio of these two times 100%, and can never be greater than 100%.

- Formulas:

$$Efficiency = \frac{Power\ Out}{Power\ In} * 100\%$$

$$Efficiency = \frac{V_{rms}^2 / R}{I_{batt} * V_{batt}} * 100\%$$



EFFICIENCY OF THE POCKET SPEAKER AMP

- Driving a $7.5\ \Omega$ Load
- $V_{p-p} = 3V$, $V_{rms} = 1.06V$
- $V_{batt} = 9V$, $I_{batt} = 76\text{ mA}$
- Efficiency = 21.9 %
- Driving a $300\ \Omega$ Load
- $V_{p-p} = 3V$, $V_{rms} = 1.06V$
- $V_{batt} = 9V$, $I_{batt} = 15\text{ mA}$
- Efficiency = 2.7 %



BATTERY LIFE

- Battery capacity is given in amp*hours.
- For example, a 9 V 200 mAh battery can supply 200 mA at 9 V for an hour, or 100 mA at 9 V for two hours, and so on.
- Calculated Battery Life
- Driving Speakers, current draw is 76 mA, so $200/76 = 2.63$ hours of battery life.
- Driving Headphones, current draw is 15 mA, so $200/15 = 13.3$ hours of battery life.
- This assumes full volume, so actual battery life will be much higher.

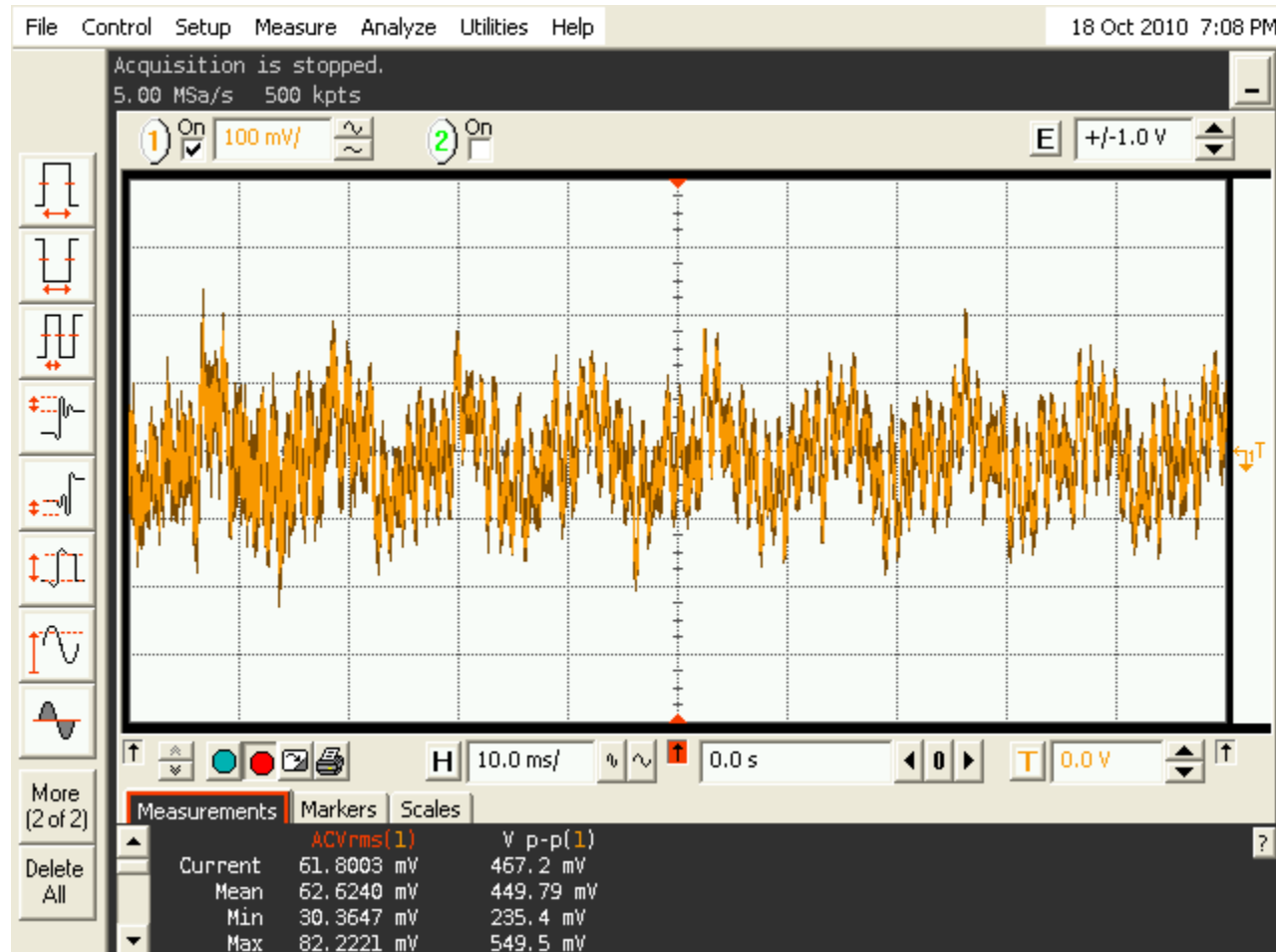


POWER OUTPUT

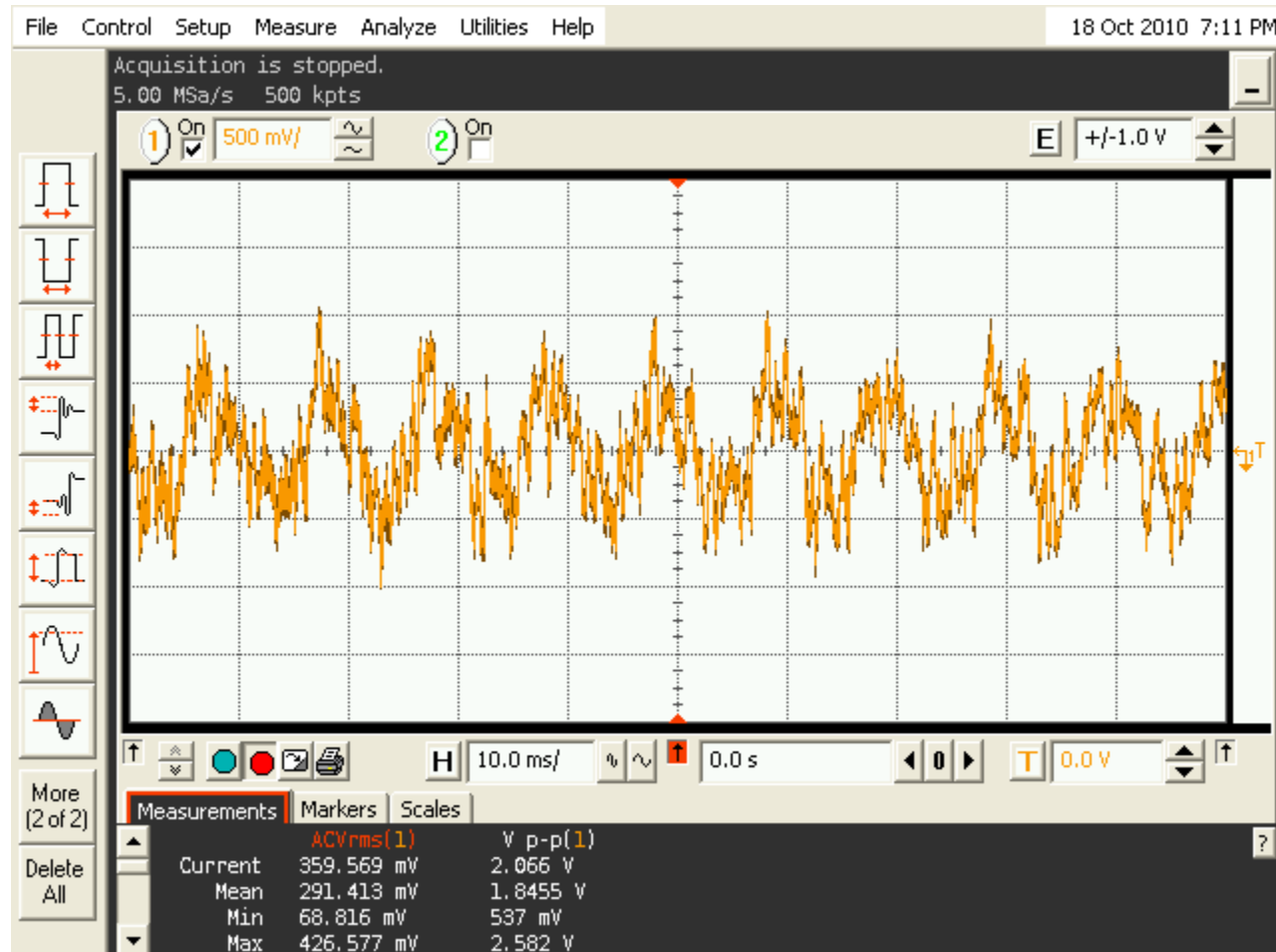
- Since $P = (V * V) / R$, the same voltage level with different loads will produce different output powers.
- But Power is also equal to $(I * I) * R$, so with a given output load, either the maximum voltage or maximum current will determine the maximum power.
- The Pocket Speaker Amp uses 350 mA current buffers, so max power is $350 \text{ mA} * 350 \text{ mA} * 8 = 1 \text{ Watt/Channel}$, or 2 W total.



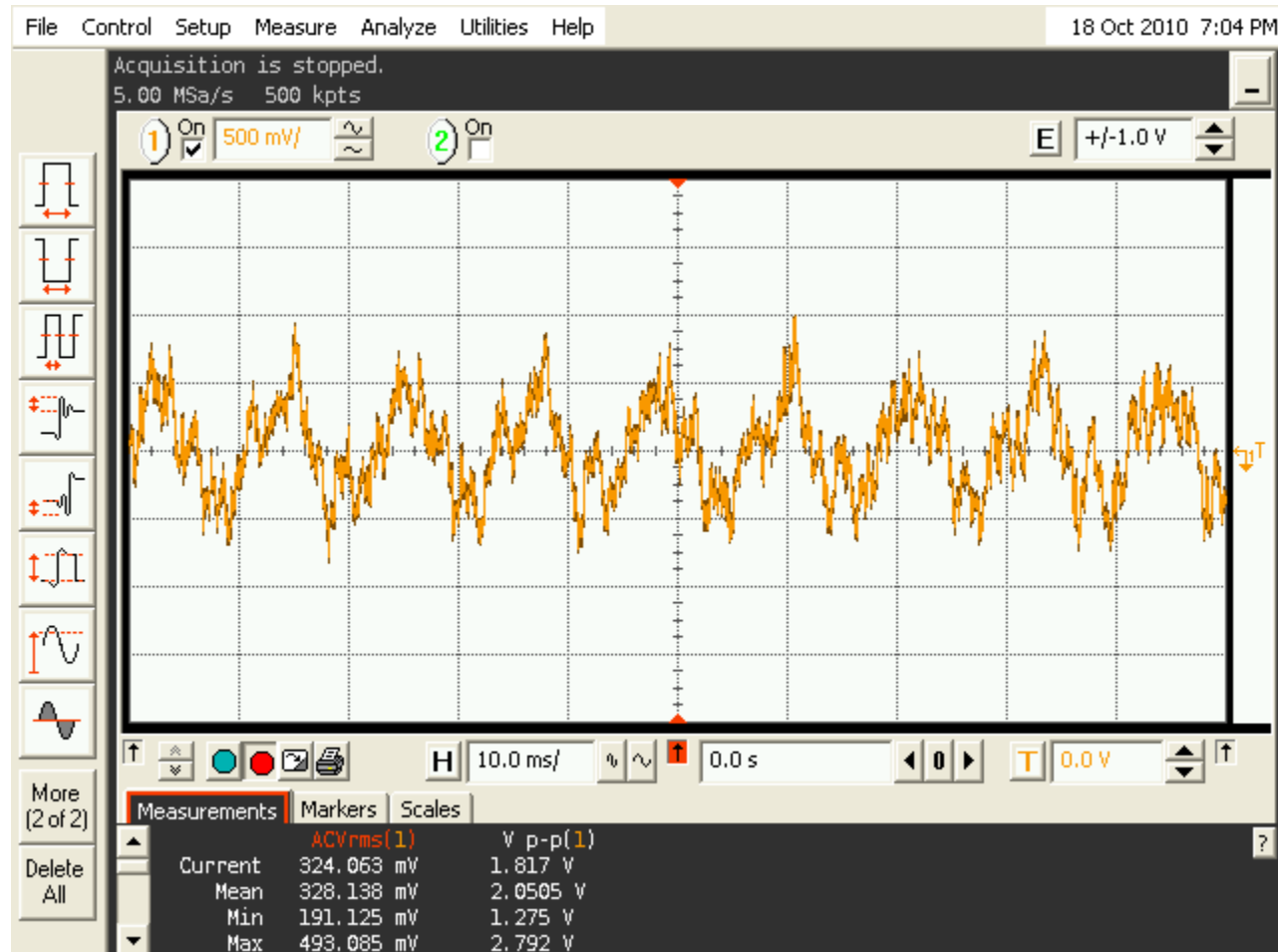
VOLTAGE ACROSS 32 OHM HEADPHONES



VOLTAGE ACROSS 300 OHM HEADPHONES



VOLTAGE ACROSS 8 OHM SPEAKERS



COMPARISON OF ACTUAL POWER OUTPUTS (PER CHANNEL)

Peak Output Power

- 32 Ω Headphones
 - 9.45 mW
- 300 Ω Headphones
 - 22.2 mW
- 8 Ω Speakers
 - 0.974 W

Average Output Power

- 32 Ω Headphones
 - 120 μ W
- 300 Ω Headphones
 - 282 μ W
- 8 Ω Speakers
 - 13 mW

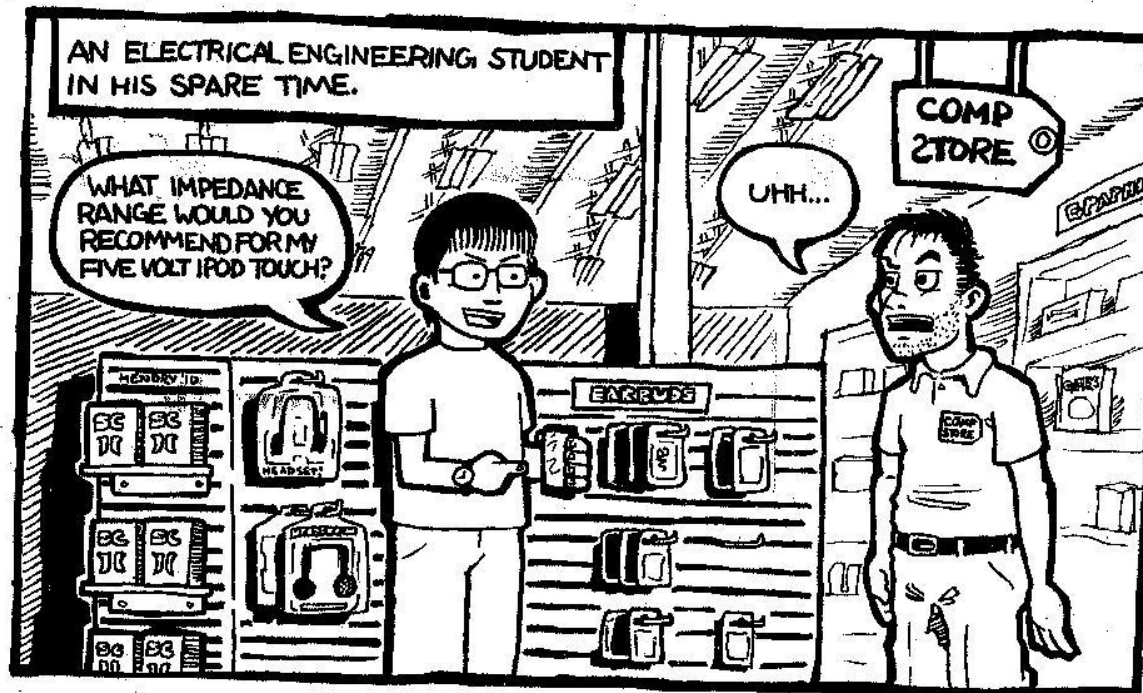


BACK TO THE ORIGINAL QUESTION



**Austin
Hendry**

Is the State
News editorial
cartoonist.
Reach him at
hendryau@
msu.edu.



IPOD SHUFFLE MAX VOLUME



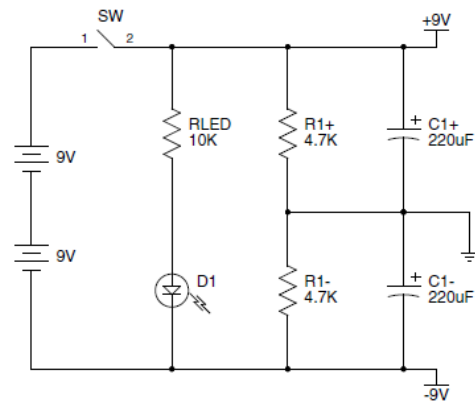
IMPEDANCE RANGE

- 2.3 V of Voltage Swing, which is $3.7V - 0.7V - 0.7V$. This is 0.813 V_{rms}.
- Assume that the maximum current output of the iPod shuffle is 20 mA (rms), and you want 10 mW of power for a reasonable listening volume.
- $P = (V * V) / R$ and $P = (I * I) * R$
- This Gives you an impedance range of
25 Ω to 66 Ω

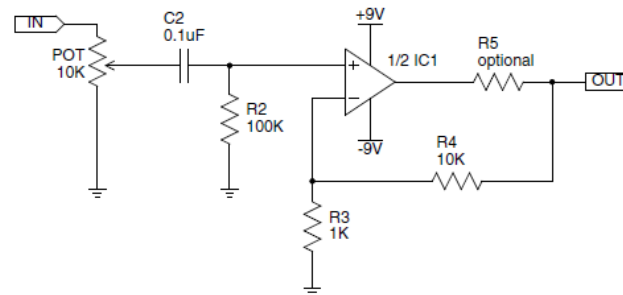


CMOY HEADPHONE AMPLIFIER

POWER SECTION

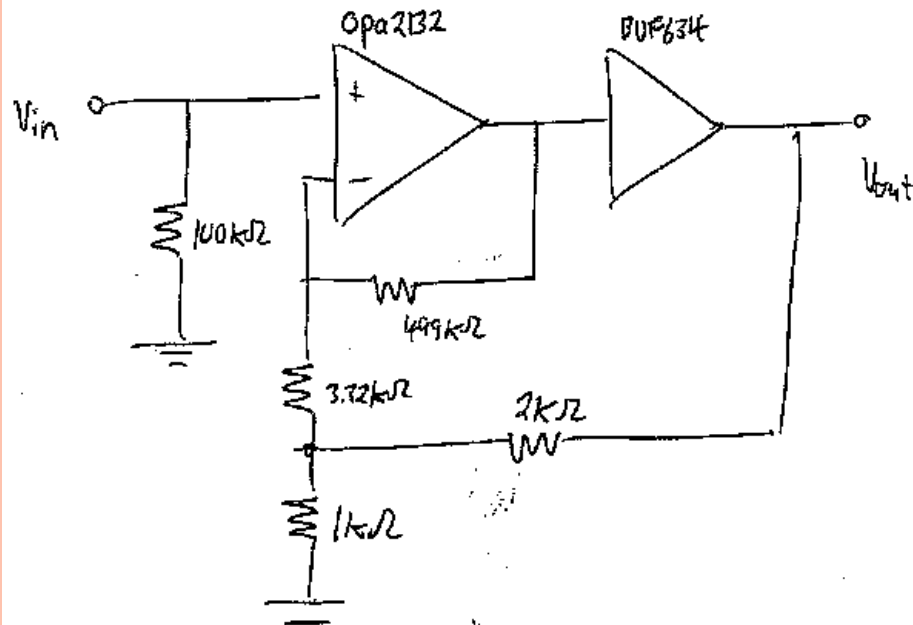


AMPLIFIER SECTION

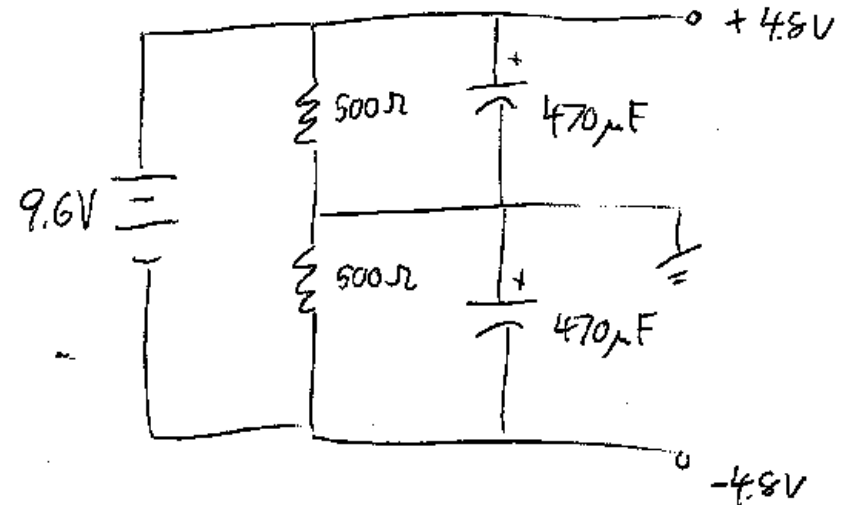


POCKET SPEAKER AMP

Amplifier Section



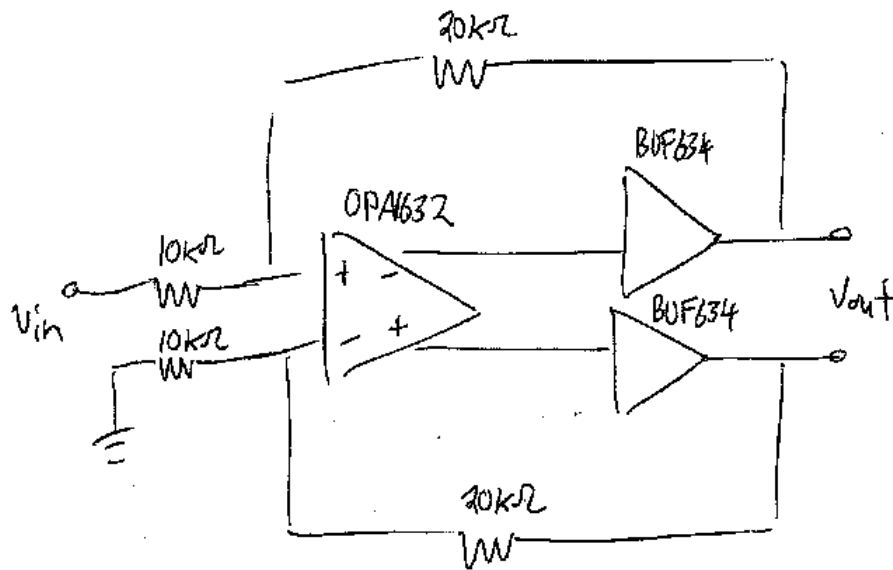
Power Section



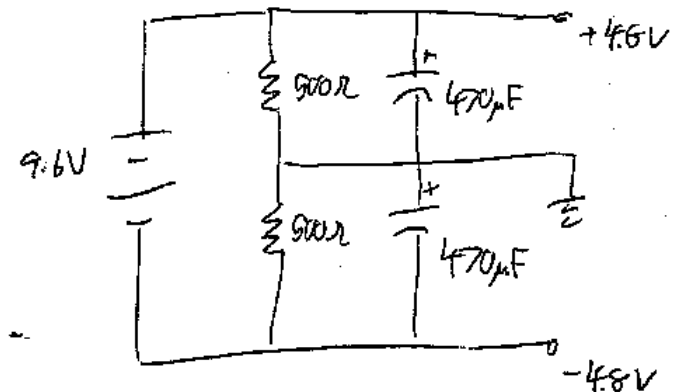
NEW IDEA

8 Watt Pocket Speaker Amp

Amplifier Section



Power Section



Questions?

