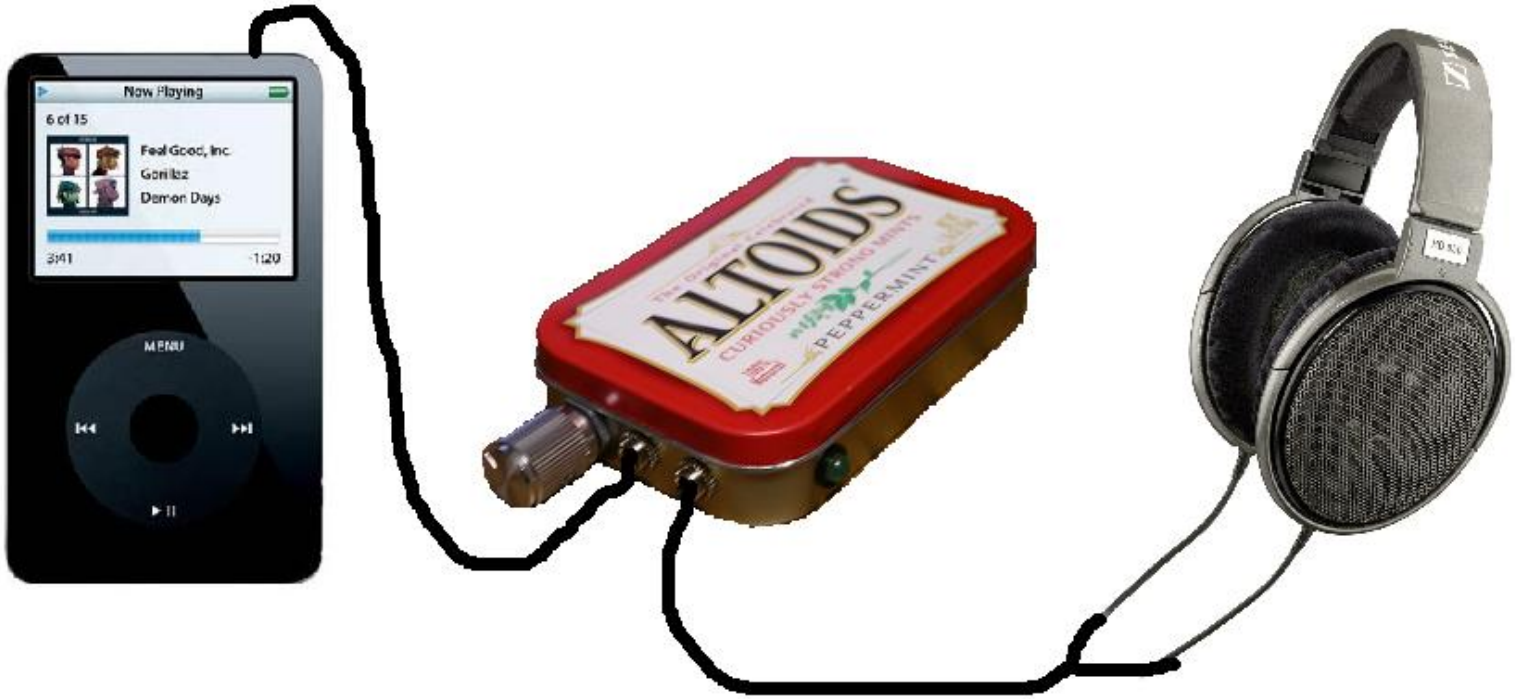
Altoids Tin Headphone Amplifiers

Stephen Zajac
IEEE / AEE
October 18th 2011

What Is A Headphone Amplifier?



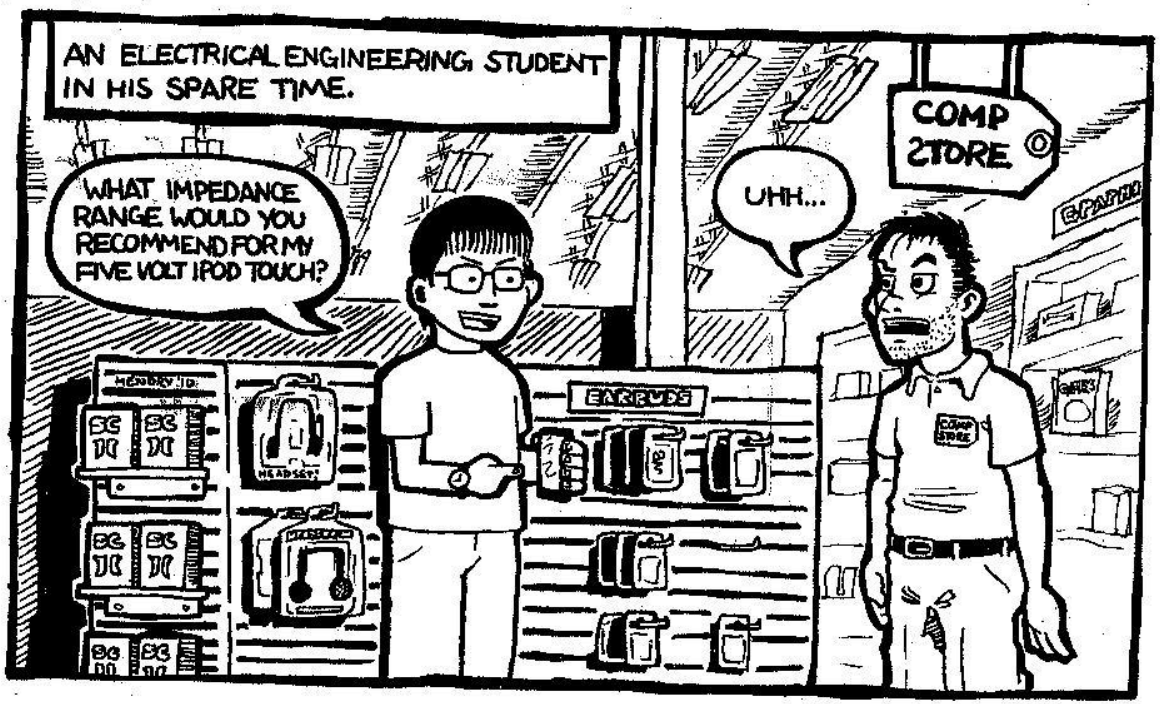
Why Do I Need A Headphone Amplifier?

- Two Main Reasons:
  - (1) Impedance Matching
  - (2) Lowering Distortion

Impedance Matching Example

Austin Hendry

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



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

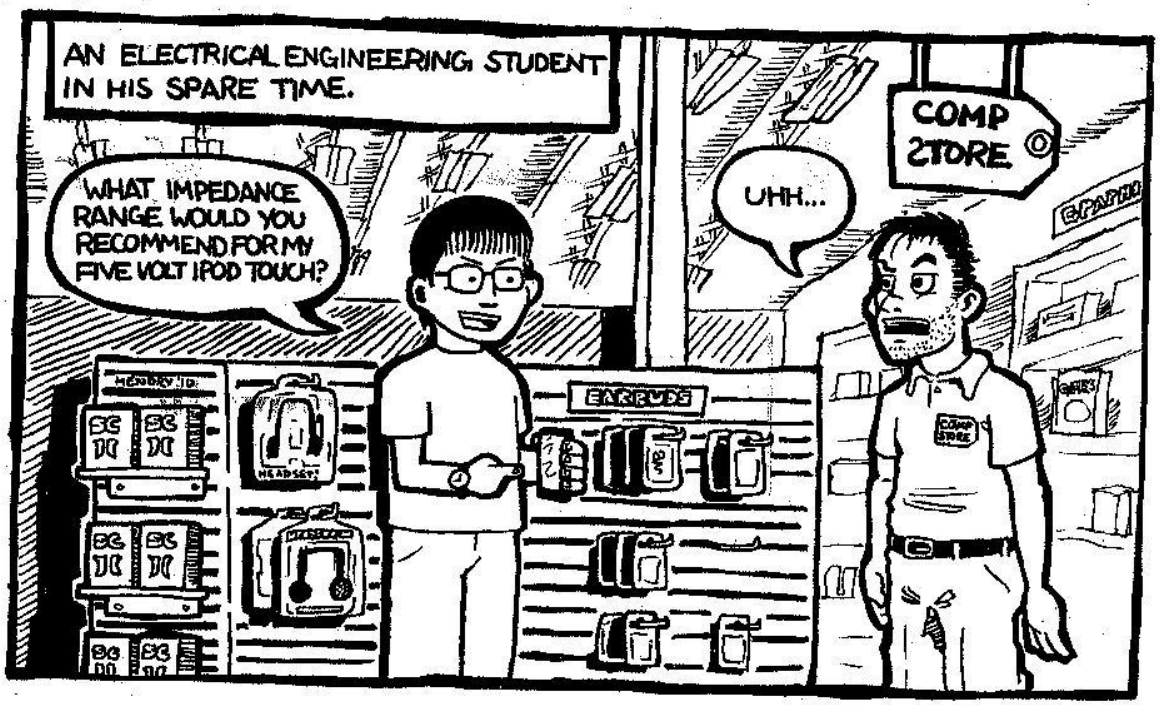
Useful Formulas

- V = I * R
- I = V / R
- R = V / I
- Resistance is the ratio of voltage to current.
- P = V * I
- P = (I * I) * R
- P = (V * V) / R
- Power is the square of voltage or current times a scale factor.

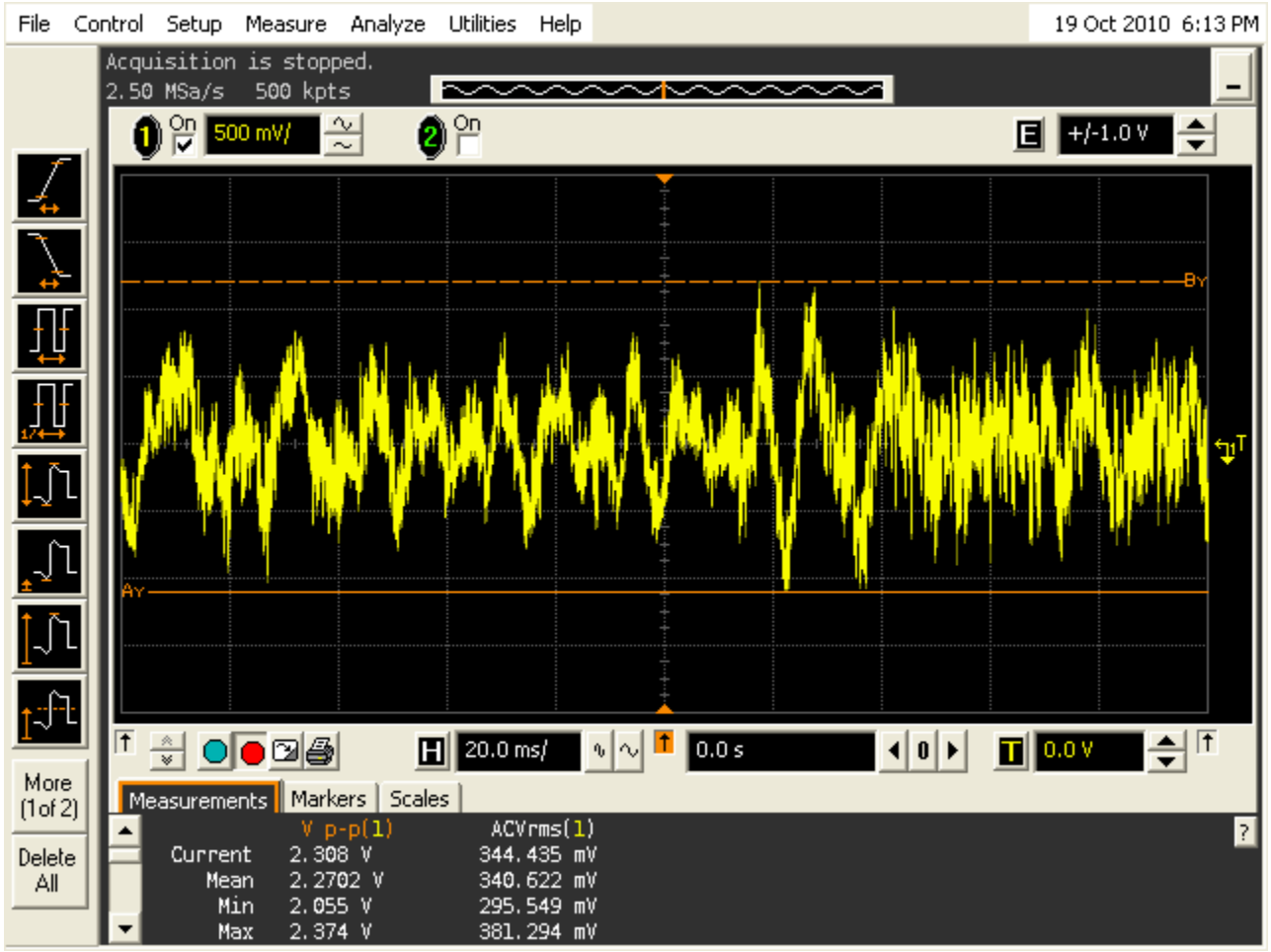
Back to the Original Question

Austin Hendry

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



IPOD SHUFFLE MAX VOLUME



Impedance Range

- 2.3V 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

What Determines Volume?

- Three Things:

  Voltage output of your amplifier.

  Impedance of your load.

  Efficiency of your load.

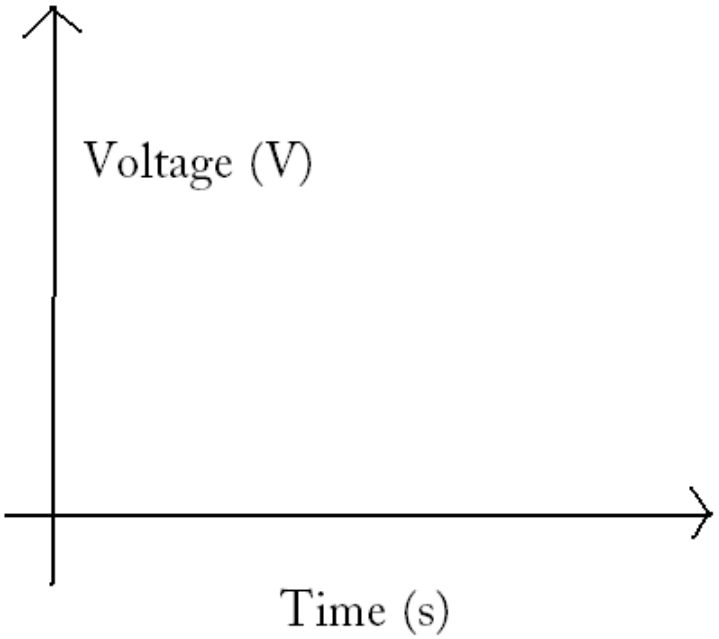
- The first two can be combined into one (Power).
- The second gives you a number in decibel output with a given power input.
- So a high voltage across a high impedance load produces less volume than a high voltage across a low impedance load.

Distortion

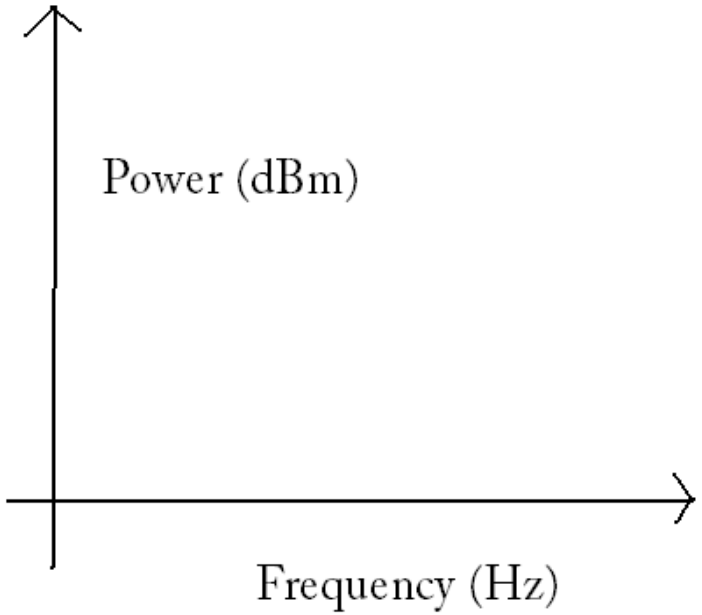
- In a normal amplifier the output is equal to the input time a linear scale factor (the gain).
- Distortion occurs when the output is no longer proportional to the input.
- This normally happens when you ask too much of a specific amplifier design, for example, when you try to get 5V out of a amplifier that can only give you 3.7V, you will get distortion.

Time Domain vs. Frequency Domain

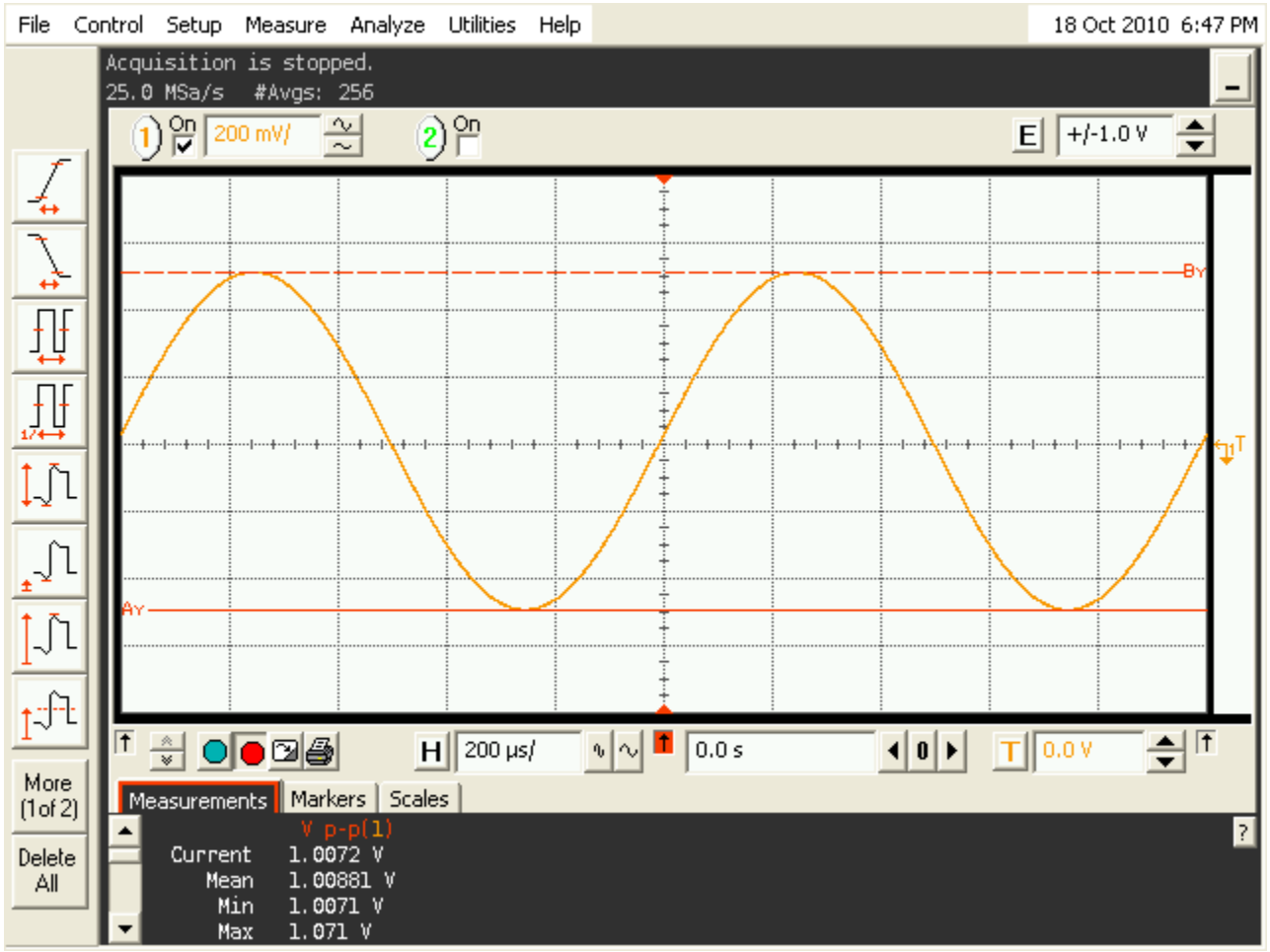
Voltage vs. Time



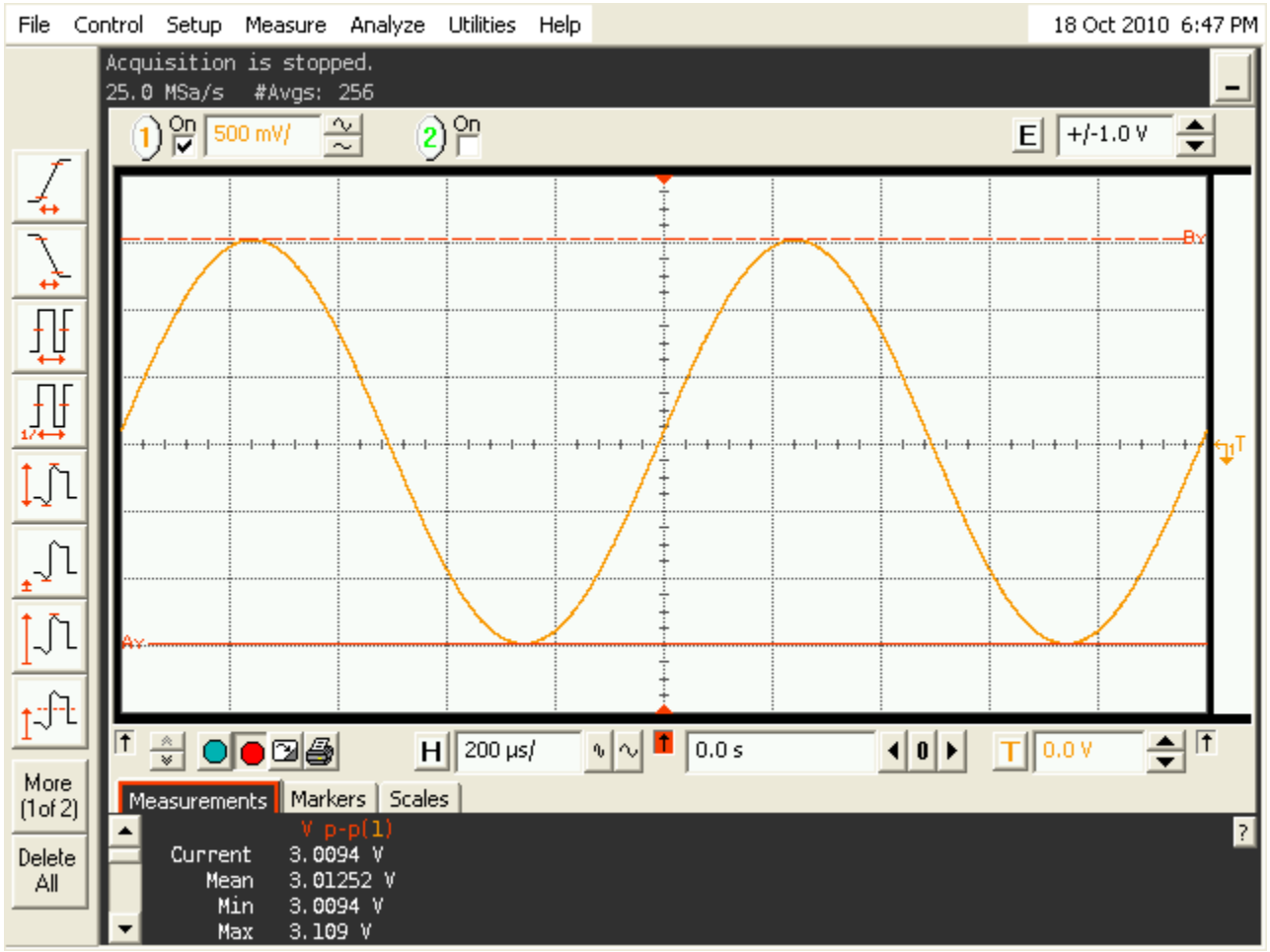
Power vs. Frequency



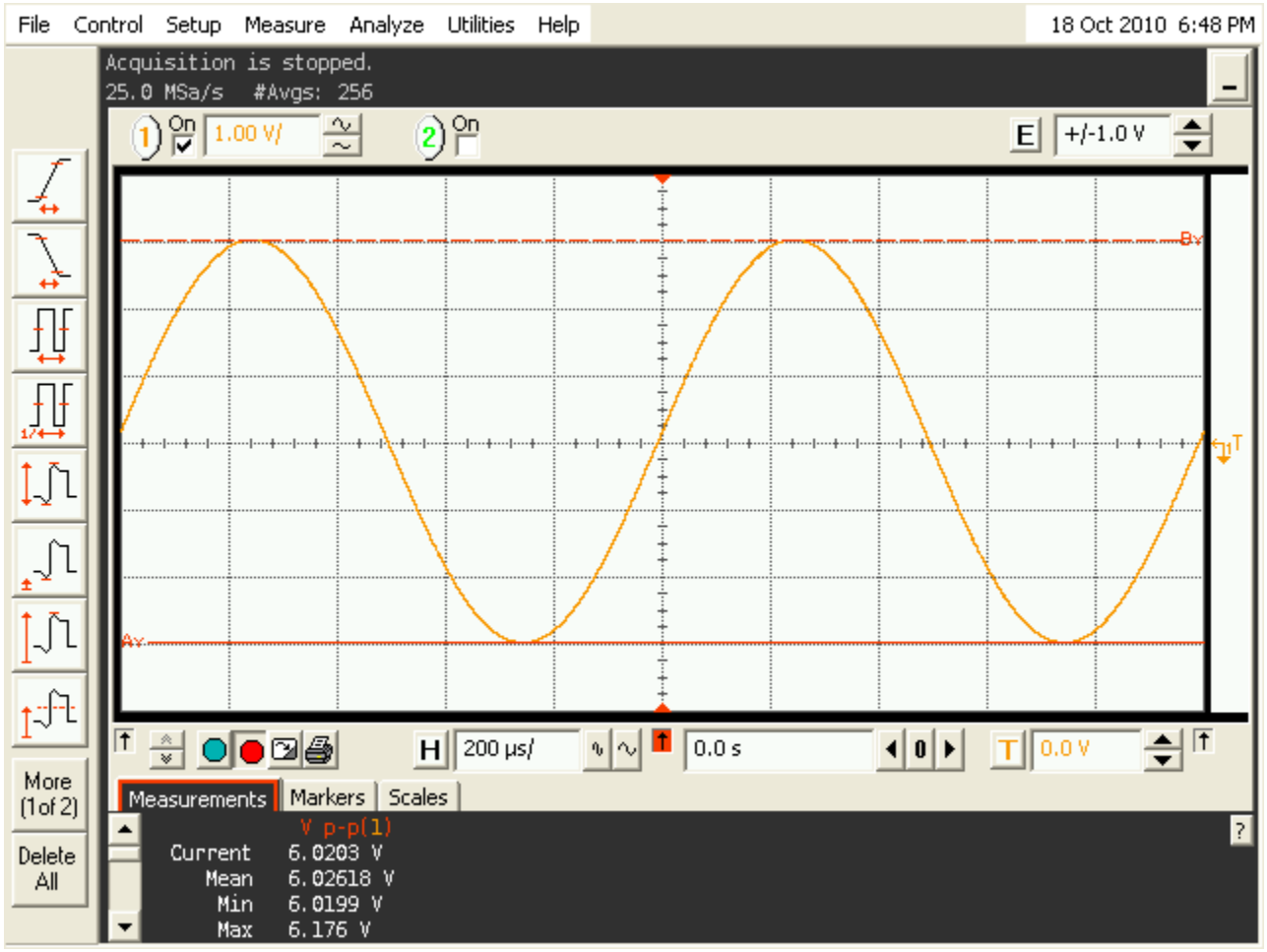
1 V Out (1 khz sine wave input)



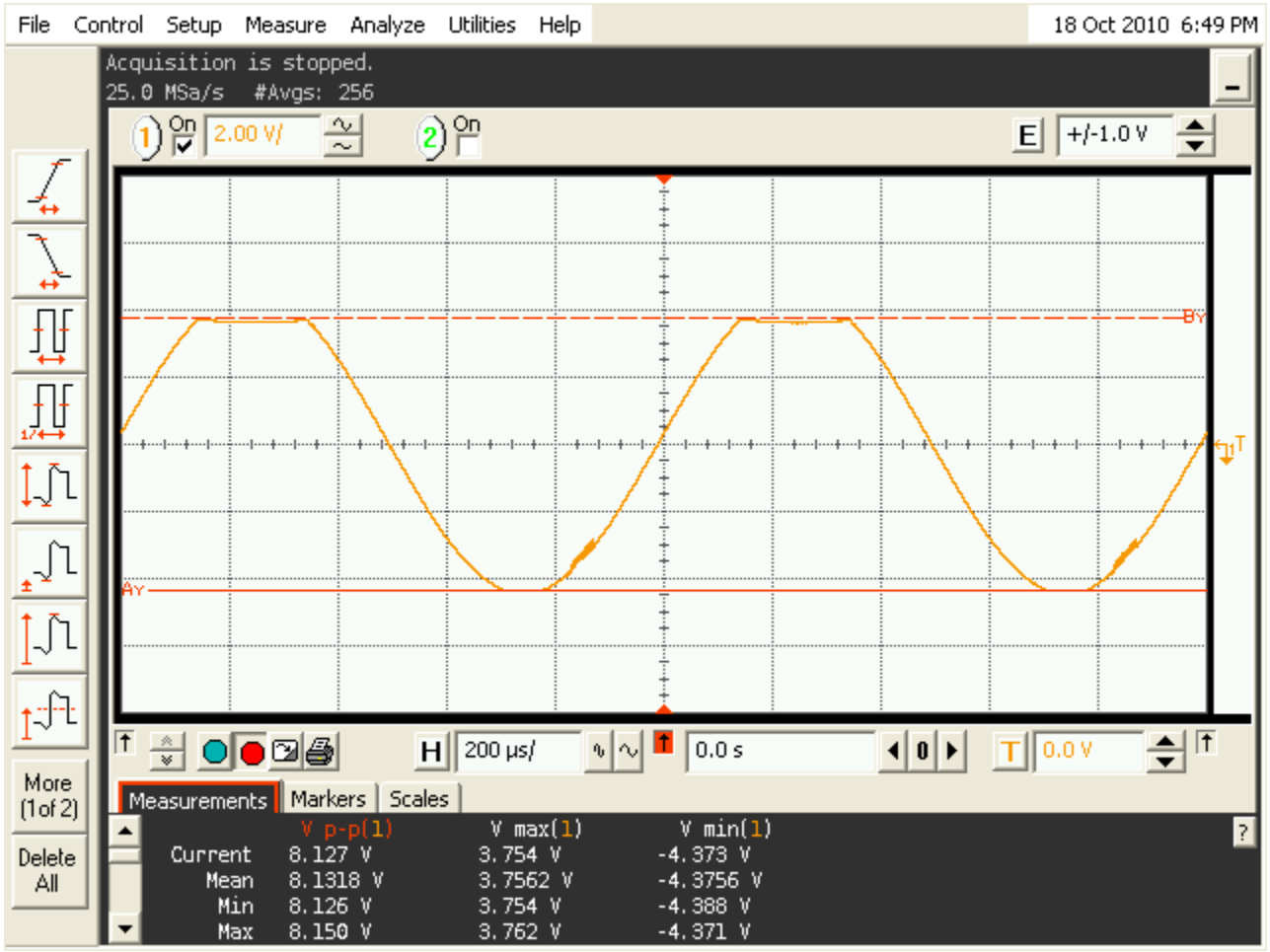
3 V Out (1 khz sine wave input)



6 V Out (1 khz sine wave input)



9 V Out (1 khz sine wave input)



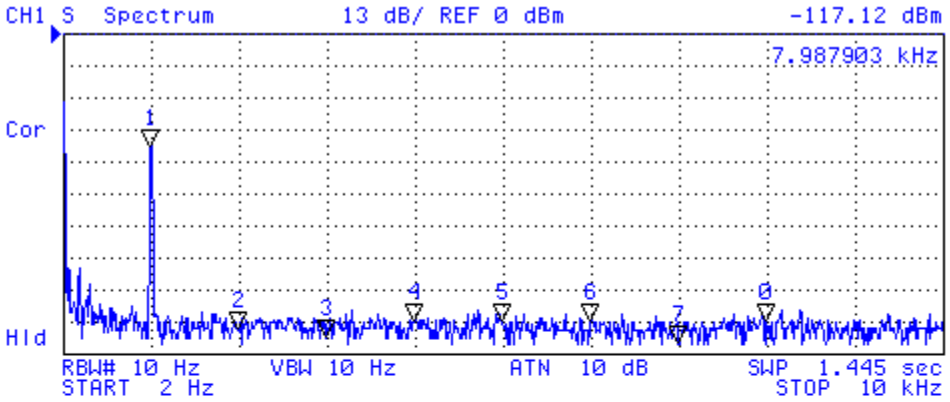
Observations

- 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

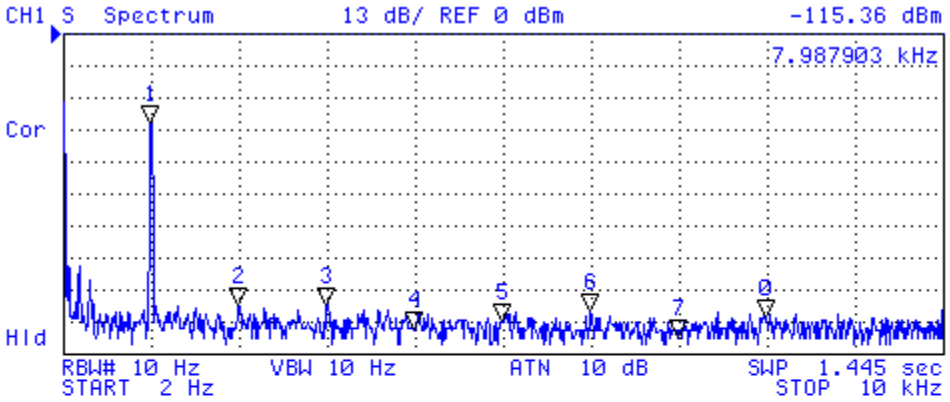
- If you send a pure 1 kHz sine wave into an amplifier, you would expect to get one single sine wave at 1 kHz at the output.
- In reality what you get is a 1 kHz sine wave (fundamental) in addition to very small sine waves at multiples of the fundamental (2 kHz, 3 kHz, 4 kHz, etc…).
- This is called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

Spectrum of A 1 V Sine Wave



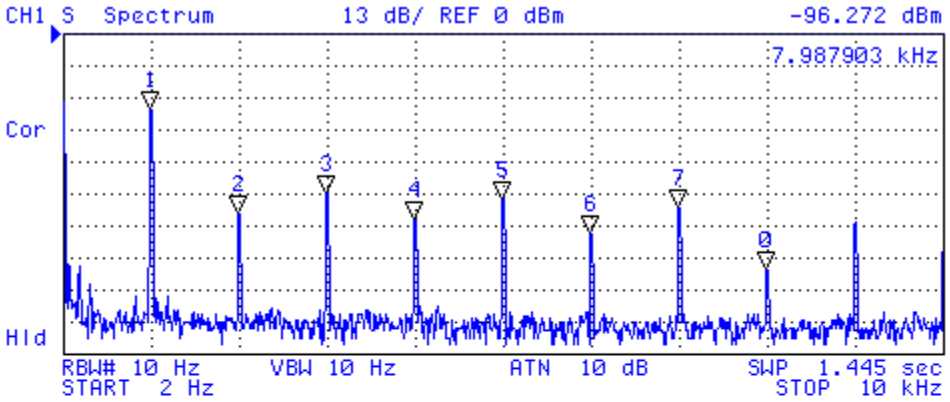
N	SWP PARAM	VAL
0	7.987903 kHz	-117.12 dBm
1	989.303 Hz	-46.18 dBm
2	1.989103 kHz	-120.13 dBm
3	2.988903 kHz	-123.14 dBm
4	3.988703 kHz	-117.12 dBm
5	4.988503 kHz	-116.61 dBm
6	5.988303 kHz	-116.61 dBm
7	6.988103 kHz	-126.15 dBm

Spectrum of A 3 V Sine Wave



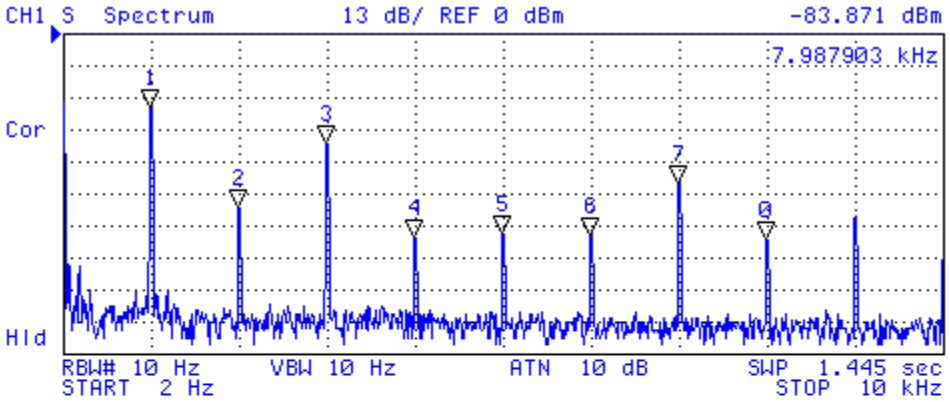
N	SWP PARAM	VAL
0	7.987903 kHz	-115.36 dBm
1	989.303 Hz	-36.632 dBm
2	1.989103 kHz	-110.24 dBm
3	2.988903 kHz	-110.13 dBm
4	3.988703 kHz	-120.13 dBm
5	4.988503 kHz	-116.61 dBm
6	5.988303 kHz	-112.53 dBm
7	6.988103 kHz	-123.14 dBm

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

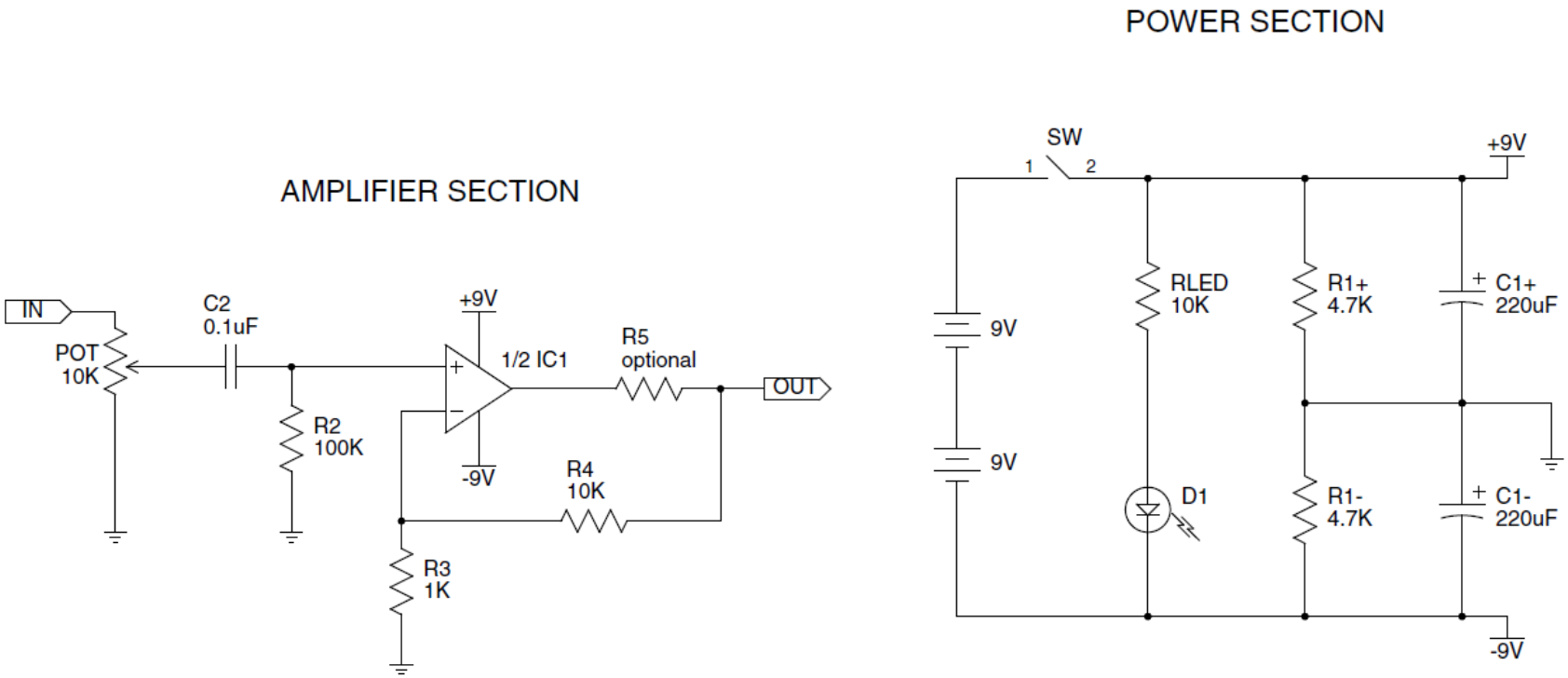


N	SWP PARAM	VAL
0	7.987903 kHz	-83.871 dBm
1	989.303 Hz	-29.752 dBm
2	1.989103 kHz	-70.707 dBm
3	2.988903 kHz	-45.003 dBm
4	3.988703 kHz	-83.094 dBm
5	4.988503 kHz	-81.407 dBm
6	5.988303 kHz	-81.739 dBm
7	6.988103 kHz	-60.801 dBm

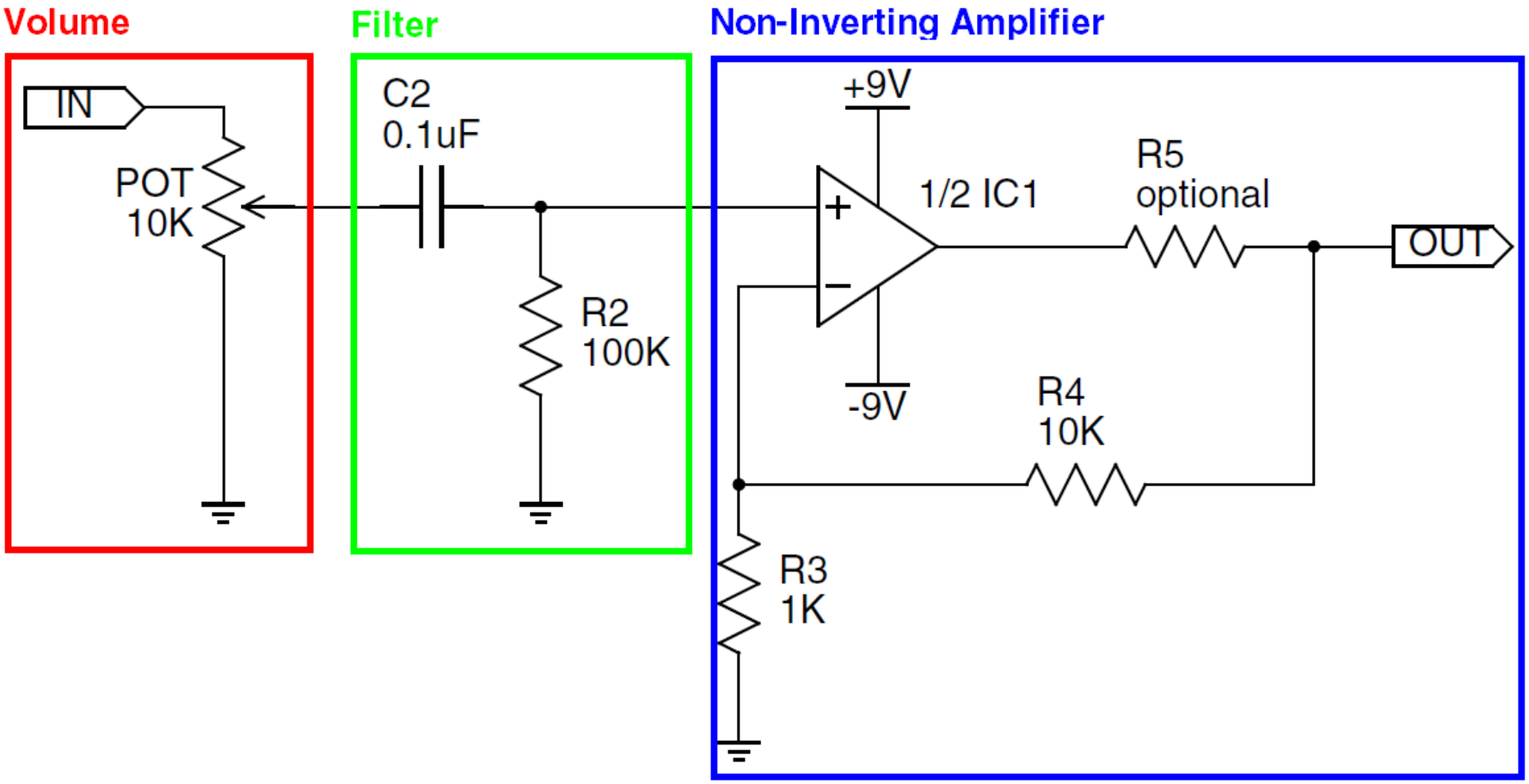
Observations

- 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.

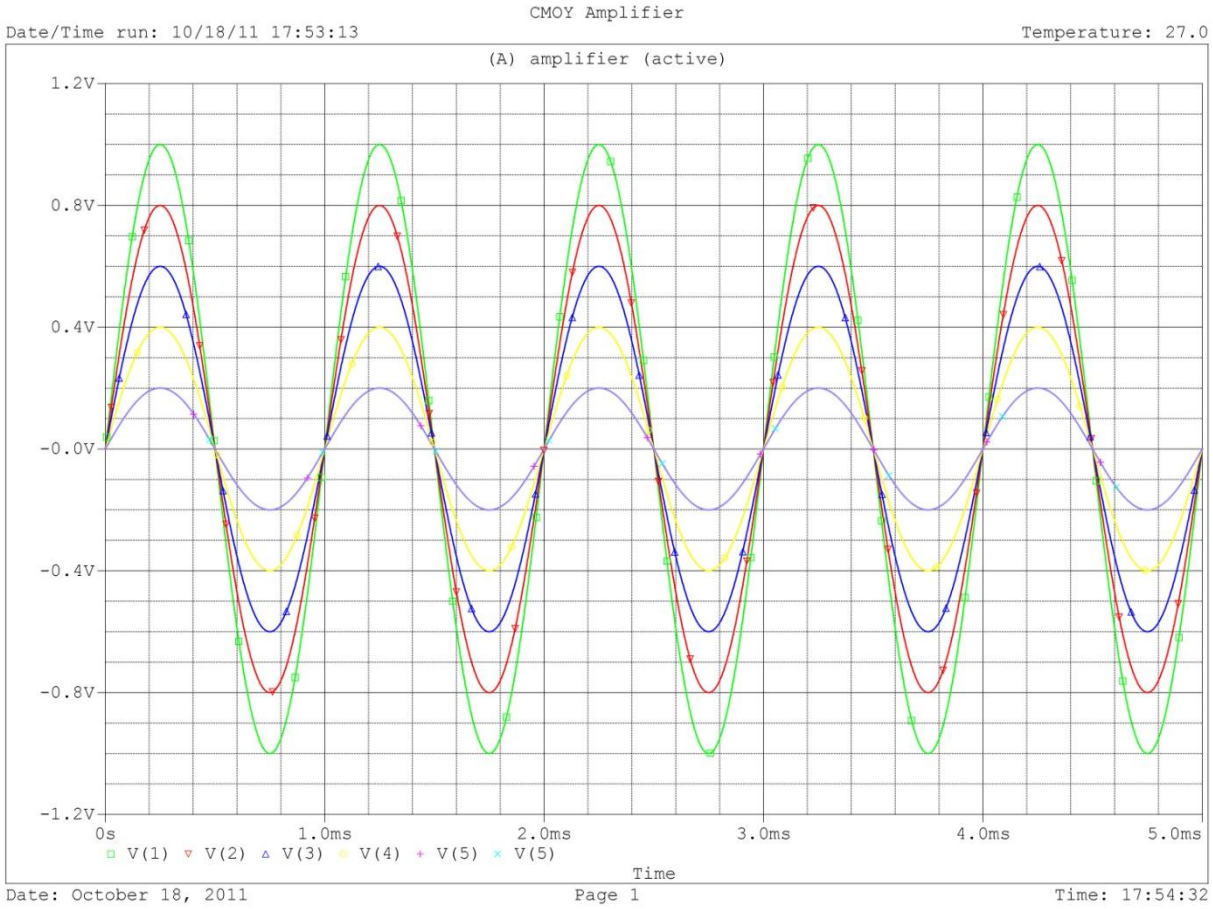
CMOY Headphone Amplifier Schematic



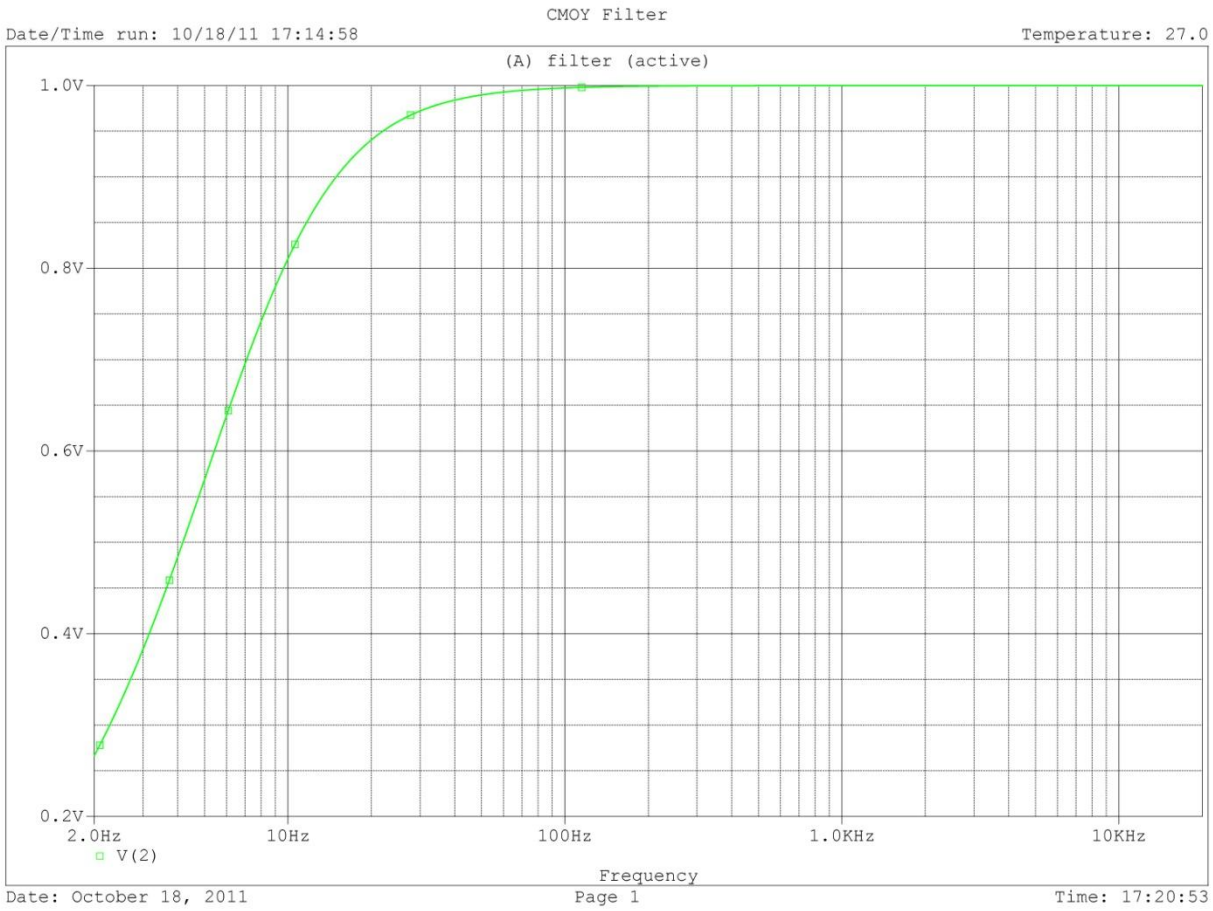
AMPLIFIER SECTION



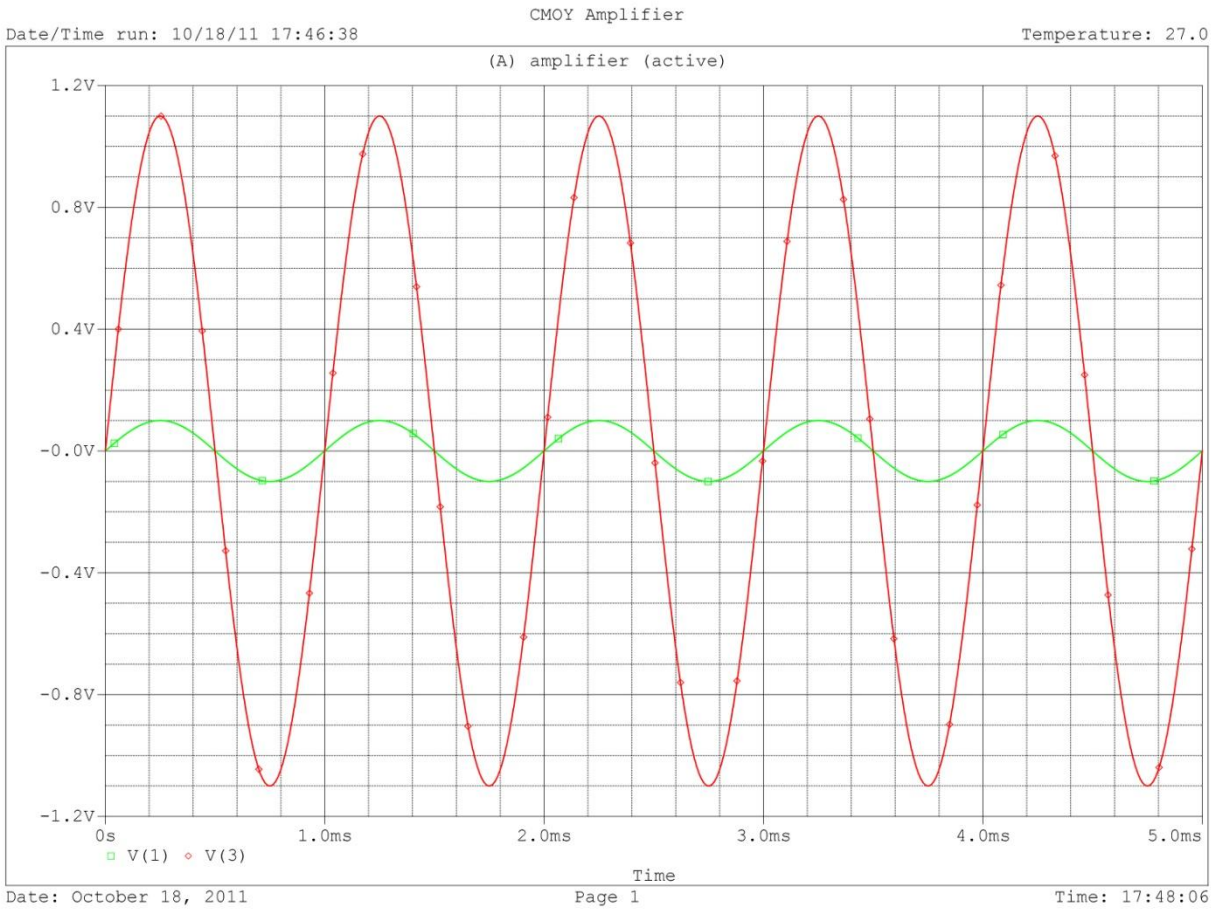
Volume


CMOY Amplifier
Date/Time run: 10/18/11 17:53:13
Temperature: 27.0
(A) amplifier (active)
1.2V
0.8V
0.4V
-0.0V
-0.4V
-0.8V
-1.2V
0s
1.0ms
2.0ms
3.0ms
4.0ms
5.0ms
V(1) V(2) V(3) V(4) V(5) V(5)
Time
Date: October 18, 2011
Page 1
Time: 17:54:32

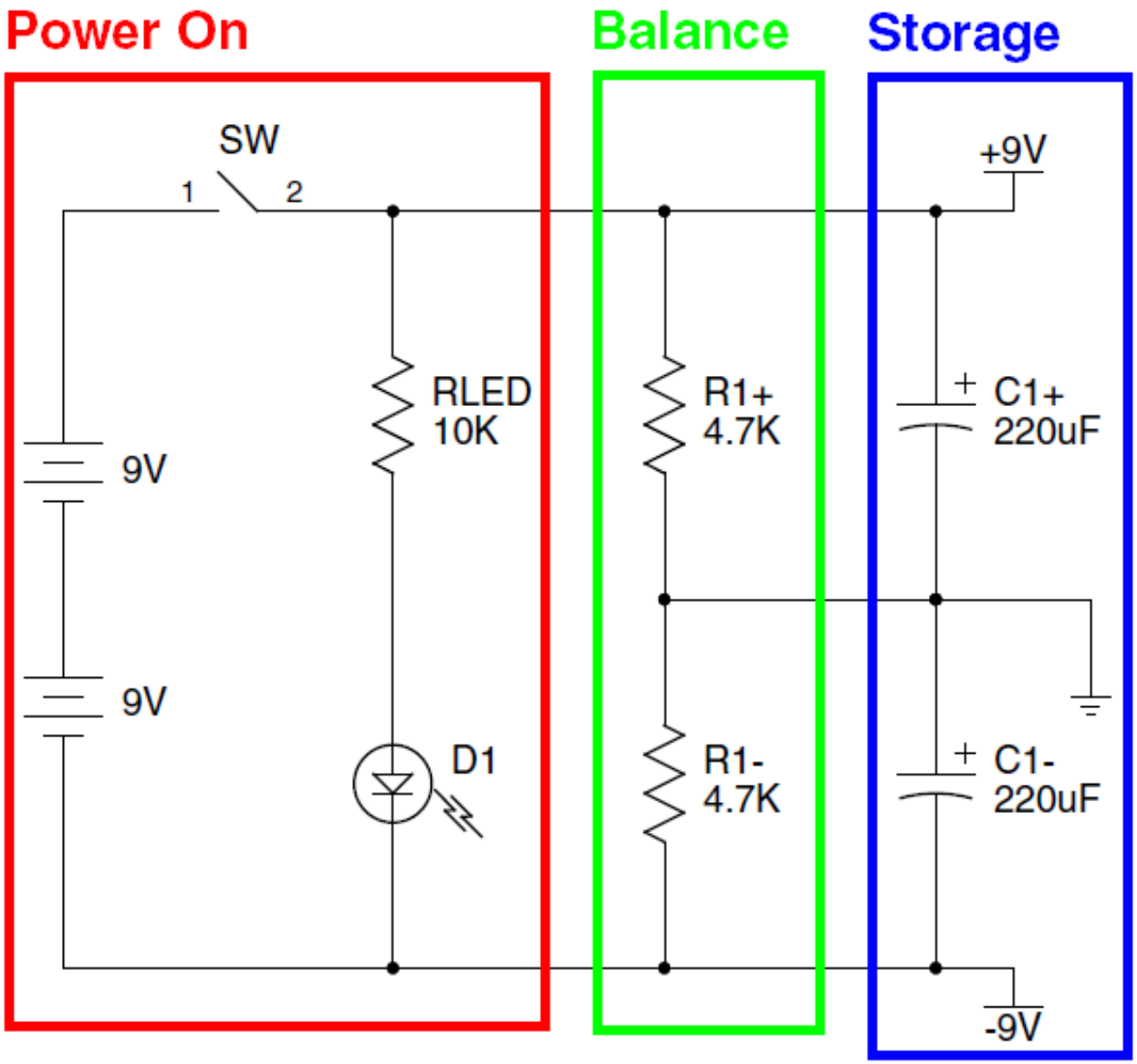
Filter


CMOY Filter
Date/Time run: 10/18/11 17:14:58
Temperature: 27.0
(A) filter (active)
1.0V
0.8V
0.6V
0.4V
0.2V
2.0Hz
10Hz
100Hz
1.0KHz
10KHz
V(2)
Frequency
Date: October 18, 2011
Page 1
Time: 17:20:53

Non-Inverting Amplifier



POWER SECTION



Questions?