Acoustas
AC650

Evaluation and Testing

Done by

Willow Electronics Labs

Okemos, MI

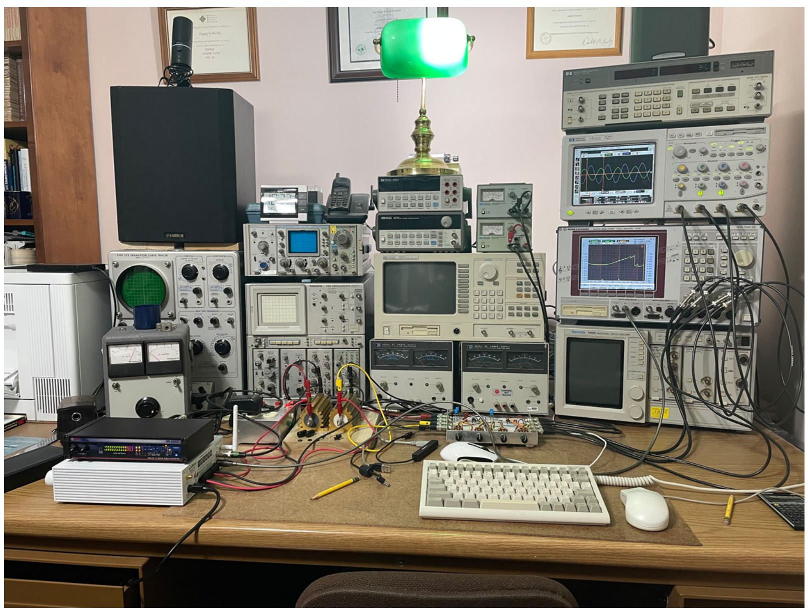
Rev 040324

Foreword

This document covers the testing of the Acoustas AC650 DSP Amplifier. The document explains and illustrates some of the features of the amplifier. It also tries to explain the advantages of the settings available through the Acoustas App.

The best way to navigate the document is to use the Bookmarks or the Table of Contents with Links.

Below is a photo of some of the lab equipment used to take the measurements of the amplifier included in this document.

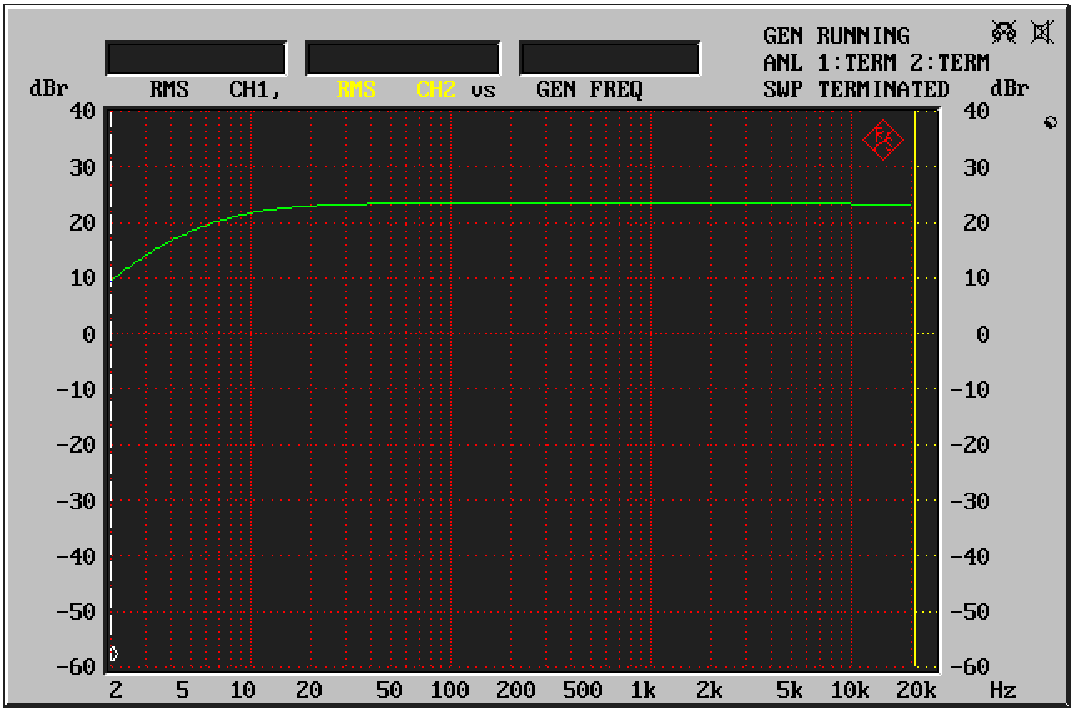


We are pleased to be the first company to test the Acoustas AC650 DSP Amplifier and look forward to working with the engineers at Acoustas in the future.

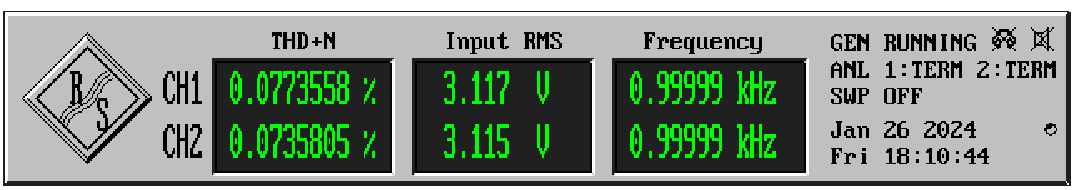
Gregory M. Wierzba
President
Willow Electronics, Inc.
Okemos, MI 48864
CustomerSupport@WillowElectronics.com

Highlights

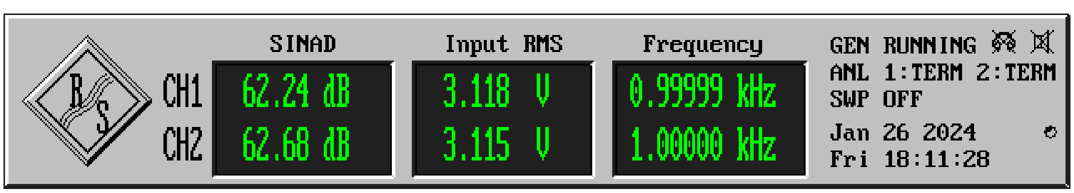
A flat Magnitude Response in the audio band:



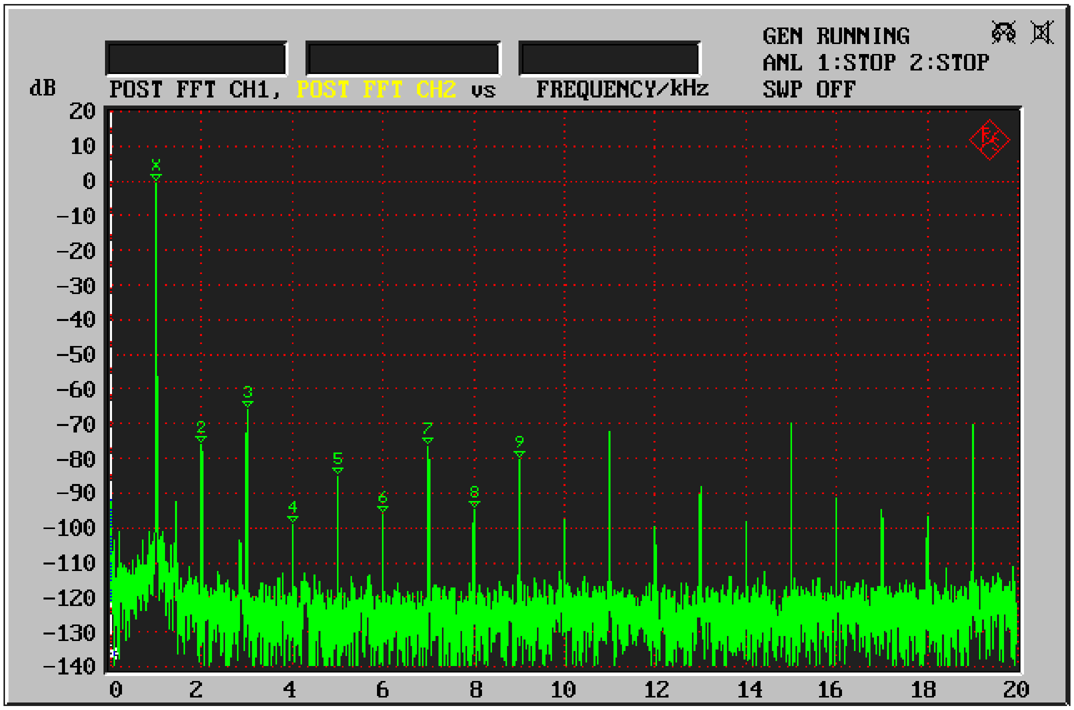
Low THD+N:



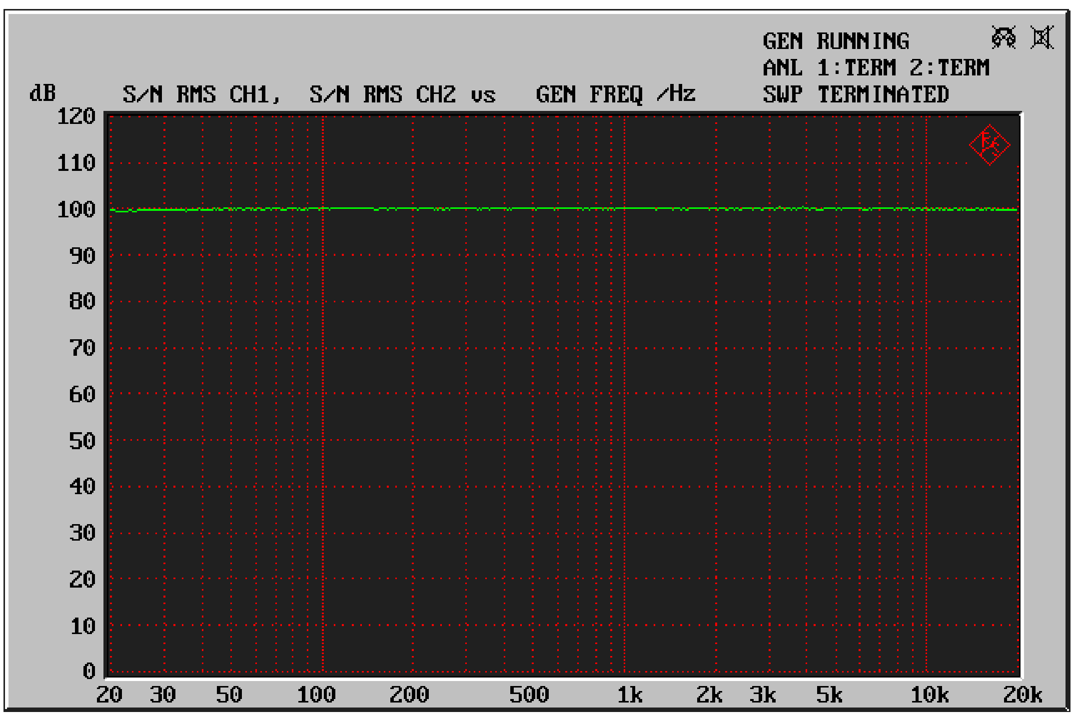
Large SINAD:



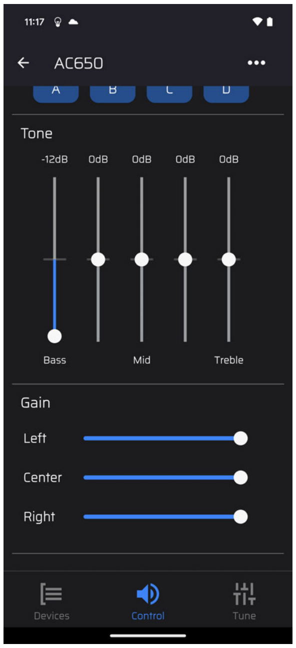
FFT of the output with the largest harmonic at least 60 dB below the fundamental (marked with an X):

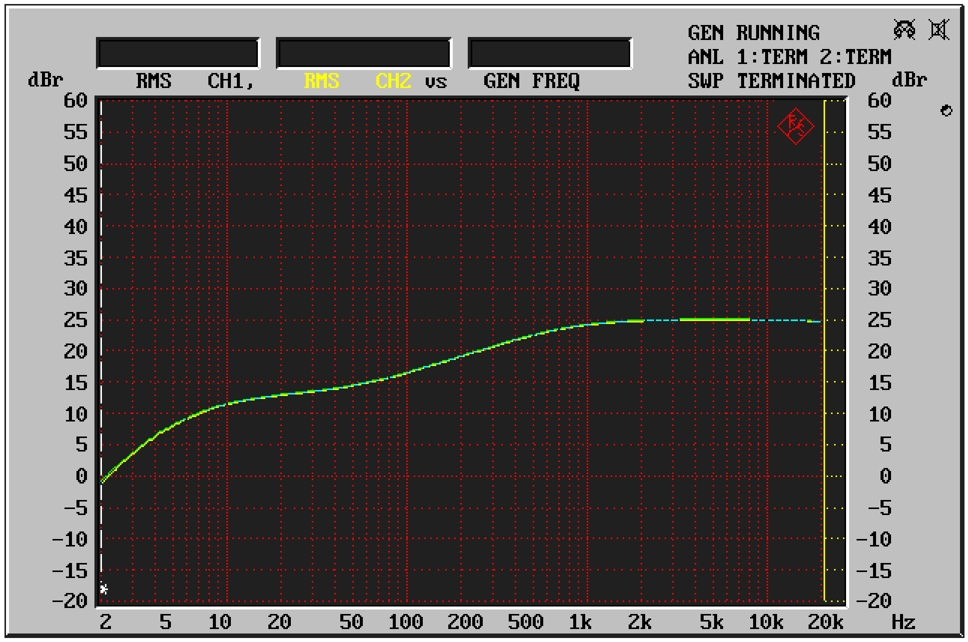


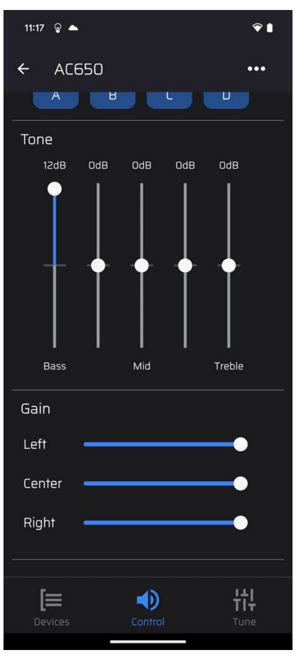
Large Signal-to-Noise Ratio over the entire audio band:

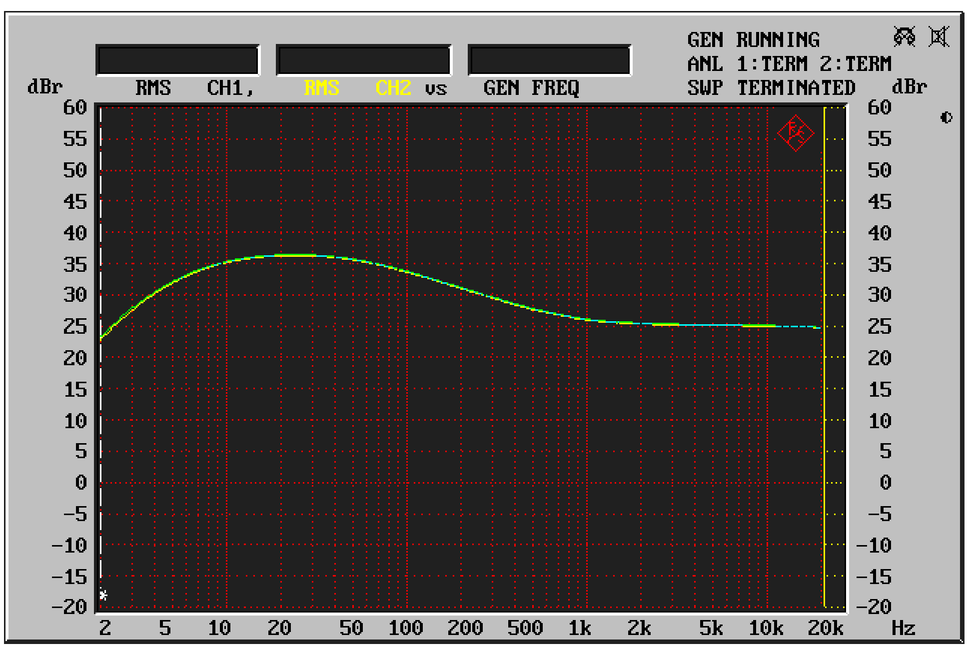


Acoustas App selected Tone Controls:

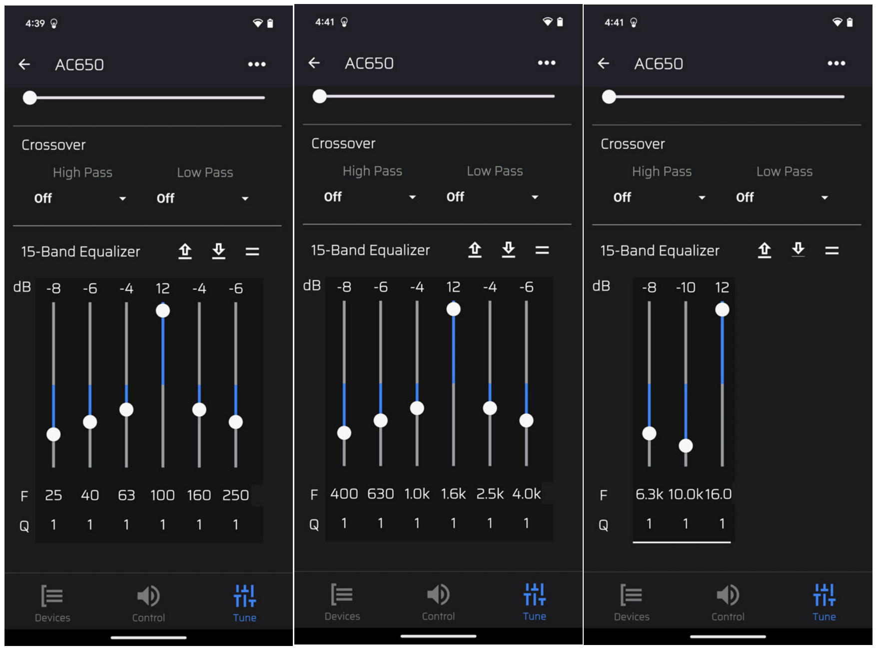


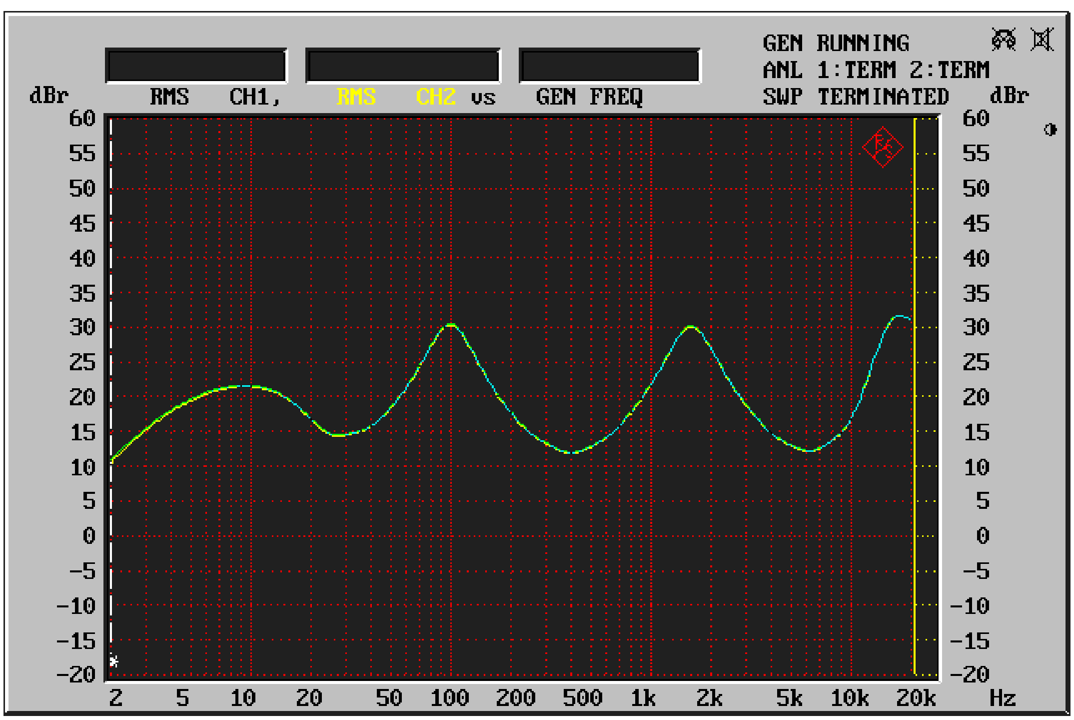




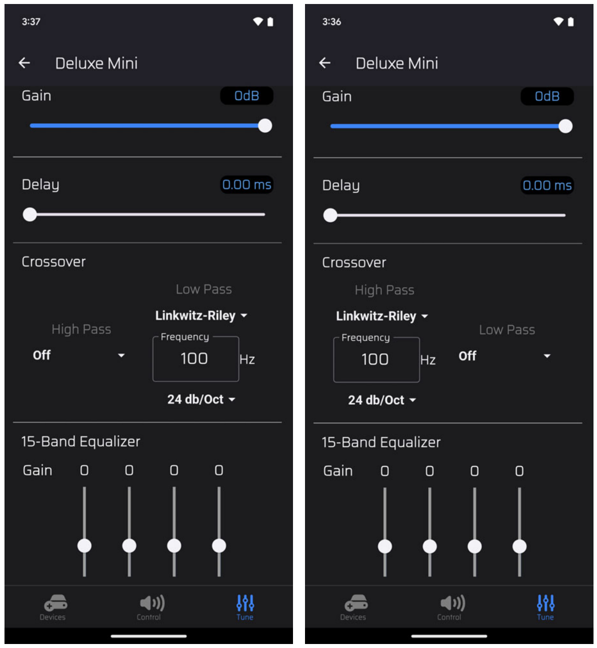


Acoustas App selected 15-Band Equalizer:





Acoustas App selected Crossovers:



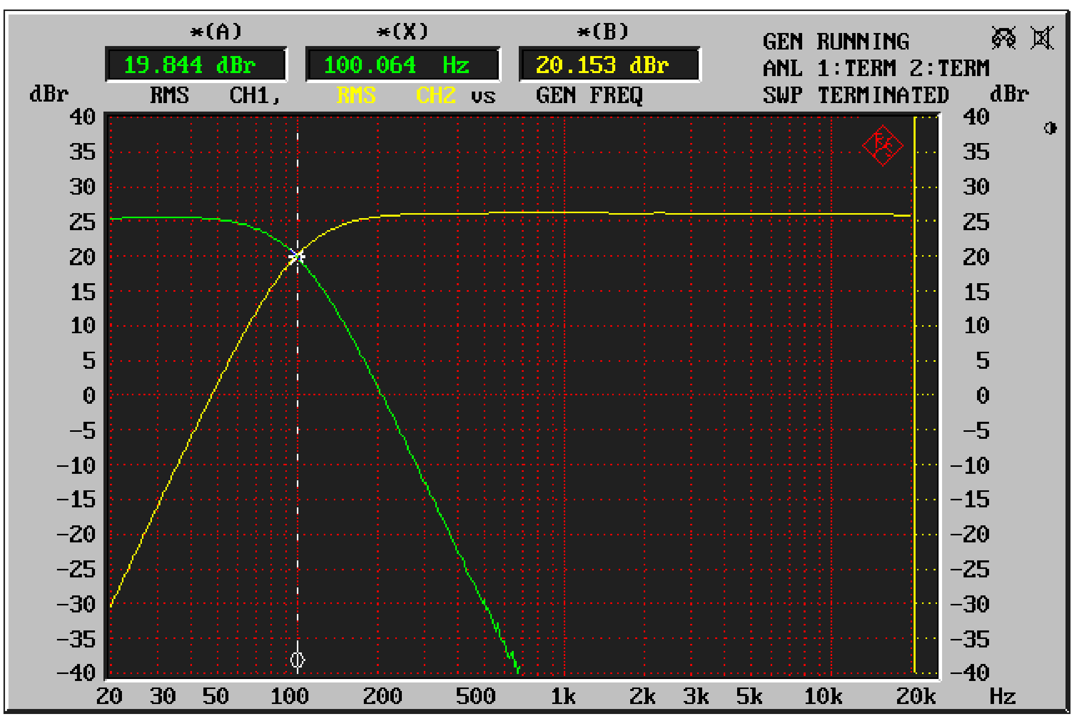
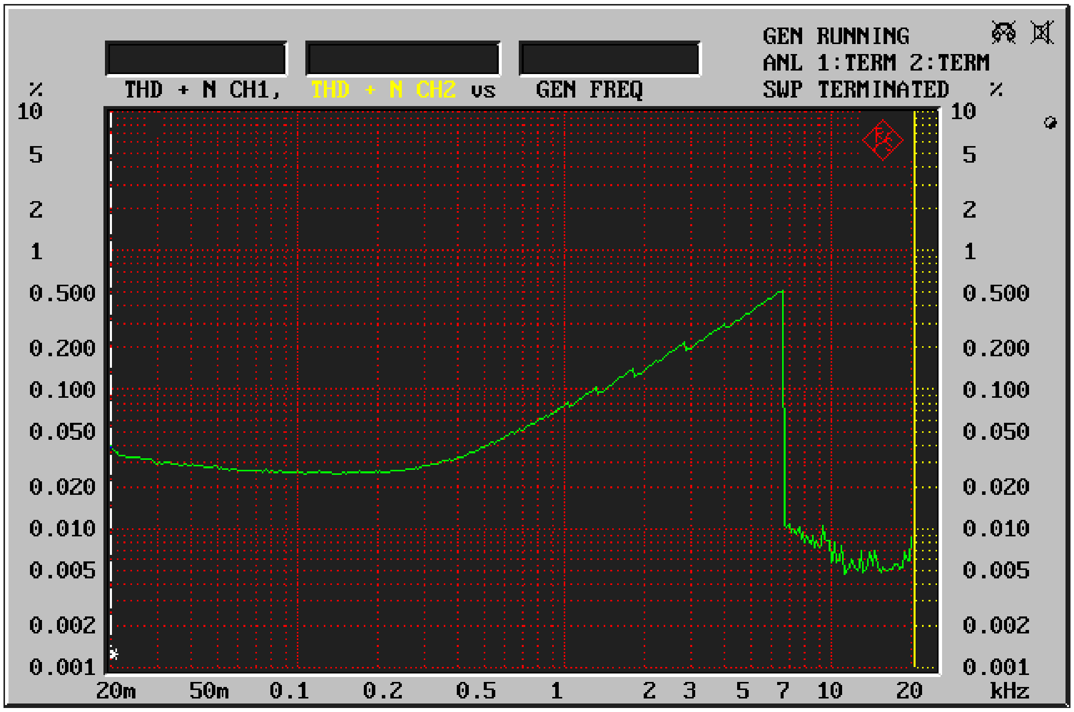


Table of Contents with Links

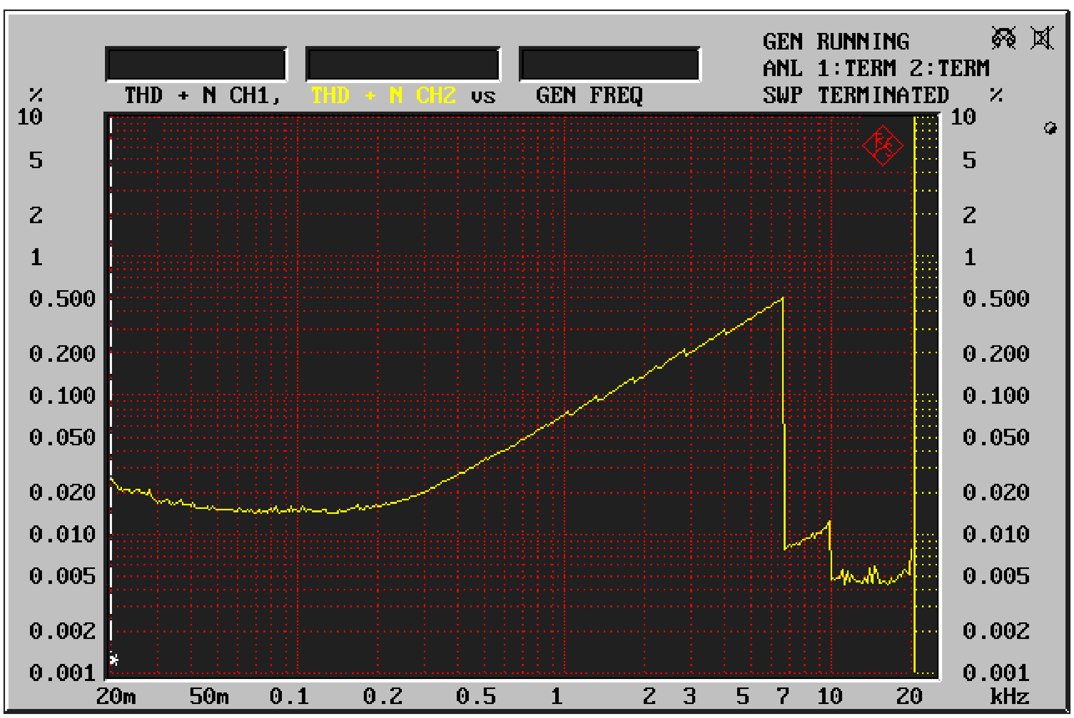
Crossovers

- Linkwitz-Riley
  - ±12 dB/Oct f_o = 100 Hz
    - Time Domain Phase Plots
  - ±24 dB/Oct f_o = 100 Hz
    - Time Domain Phase Plots
  - ±36 dB/Oct f_o = 100 Hz
    - Time Domain Phase Plots
  - Issues with 12 dB/Oct and 36 dB/Oct Crossovers
  - ±12 dB/Oct Revisited with Invert On for Ch 4
- Butterworth
  - ±6 dB/Oct f_o = 100 Hz
  - ±12 dB/Oct f_o = 100 Hz
  - ±18 dB/Oct f_o = 100 Hz
  - ±24 dB/Oct f_o = 100 Hz
  - ±30 dB/Oct f_o = 100 Hz
  - ±36 dB/Oct f_o = 100 Hz
- Bessel
  - ±6 dB/Oct f_o = 638 Hz
  - ±12 dB/Oct f_o = 638 Hz
  - ±18 dB/Oct f_o = 638 Hz
  - ±24 dB/Oct f_o = 638 Hz
  - ±30 dB/Oct f_o = 638 Hz
- Time Domain Step Response
  - Butterworth Low-Pass 12 dB/Oct f_o = 3 kHz
    - Pspice Step Response
  - Linkwitz-Riley Low-Pass 12 dB/Oct f_o = 3 kHz
    - Pspice Step Response
  - Linkwitz-Riley Low-Pass 24 dB/Oct f_o = 3 kHz
    - Pspice Step Response
  - Butterworth Low-Pass 30 dB/Oct f_o = 3 kHz
    - Pspice Step Response
  - Bessel Low-Pass 30 dB/Oct f_o = 3 kHz
    - Pspice Step Response
  - Butterworth Low-Pass 36 dB/Oct f_o = 3 kHz
  - Linkwitz-Riley Low-Pass 36 dB/Oct f_o = 3 kHz
  - Bessel Low-Pass 36 dB/Oct f_o = 3 kHz

THD+N for CH1 (Right) with 2.5 Watts Out into 4Ω:

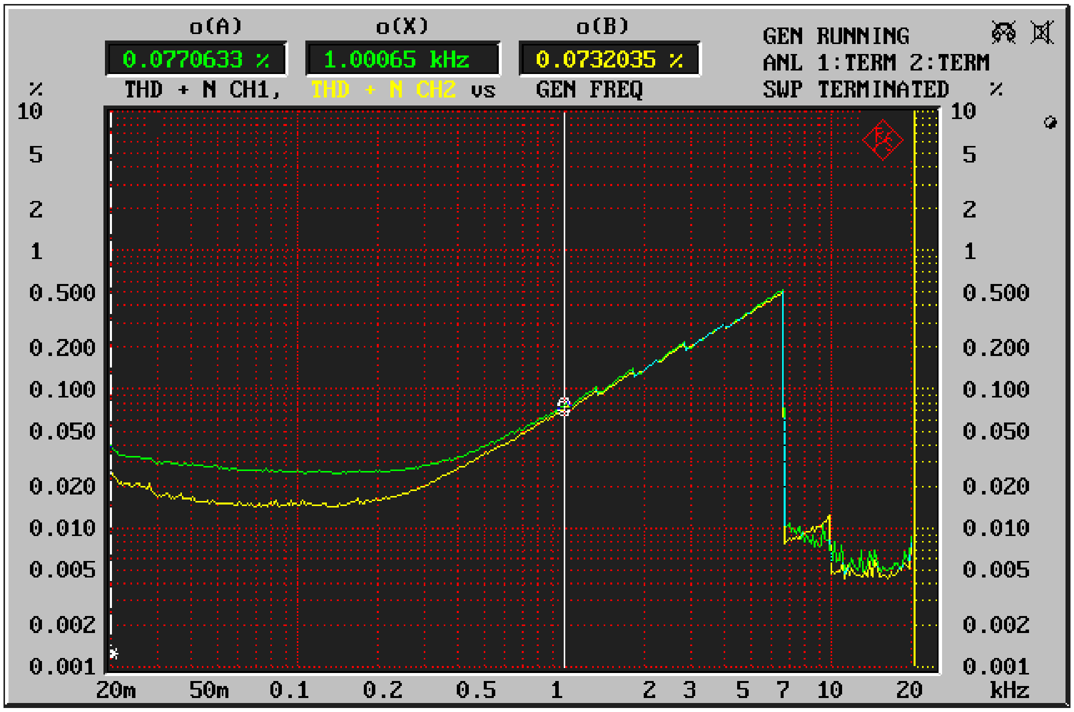


THD+N CH 4 (Left) with 2.5 Watts Out into 4Ω:

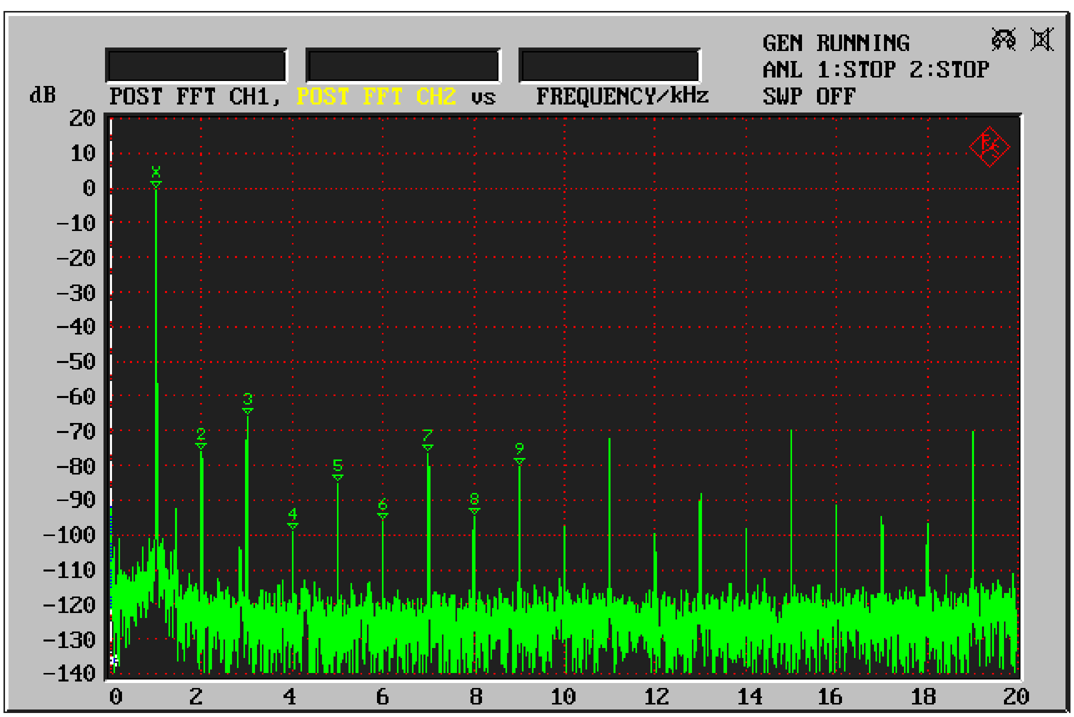


The Acoustas AC650 uses 6 Texas Instruments TAS5828M Class D Switching Power Amplifiers. The output is a filtered square-wave which contains odd harmonics. The THD+N is calculated up to 20 kHz. A frequency of 6666 Hz would have a 3rd harmonic at 20 kHz and so would not be included in the THD+N calculations. This is why the curve dips at 6666 Hz.

THD+N for both Channels with 2.5 Watts Out into 4Ω:

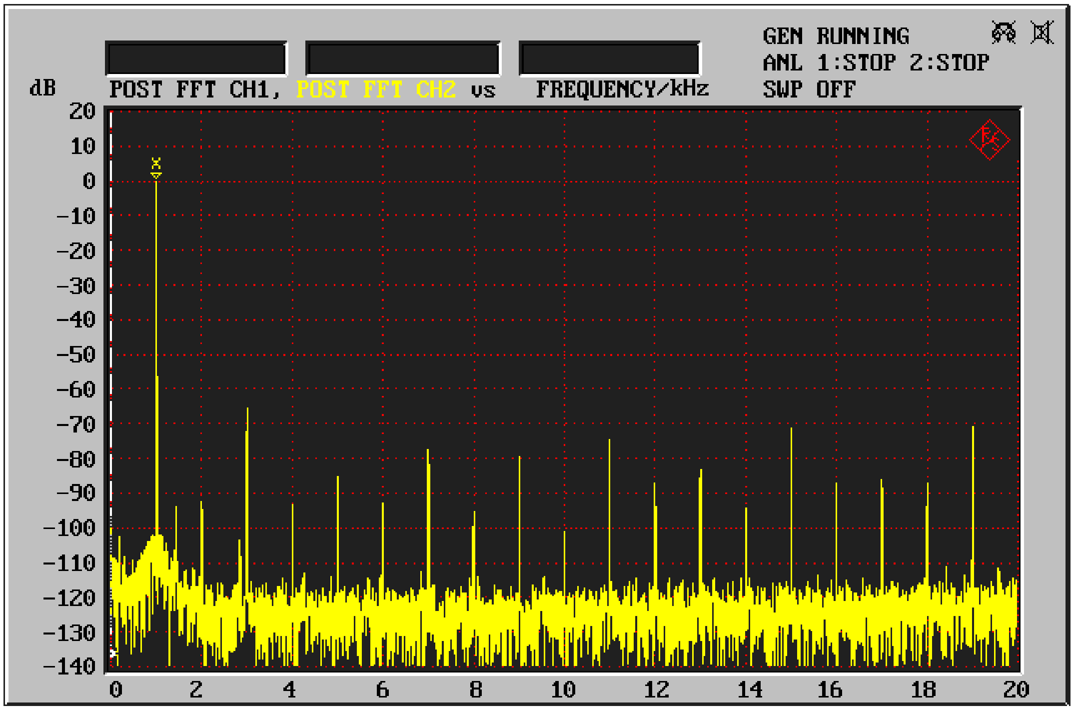


FFT for CH1 (Right) with 2.5 Watts Out into 4Ω at 1 kHz:

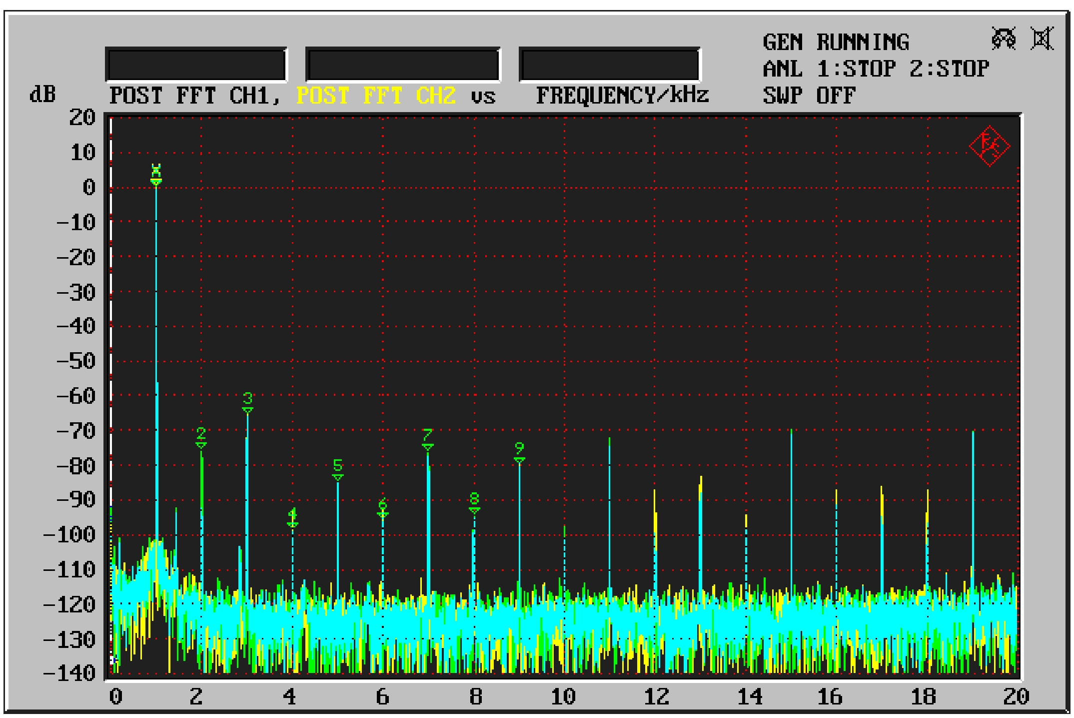


The analyzer numbers the first 9 harmonics for CH1. The two largest non-harmonics are -92 dB at 1.32422 kHz and -103 dB at 2.61914 kHz.

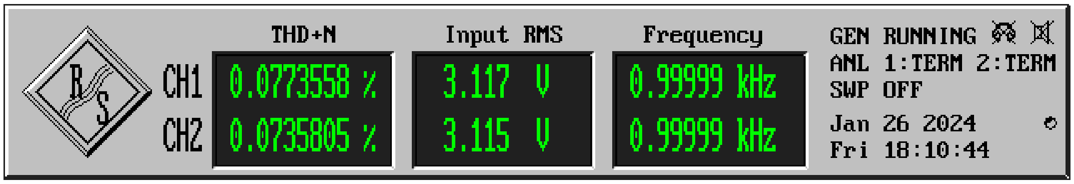
FFT for CH4 (Left) with 2.5 Watts Out into 4Ω at 1 kHz:



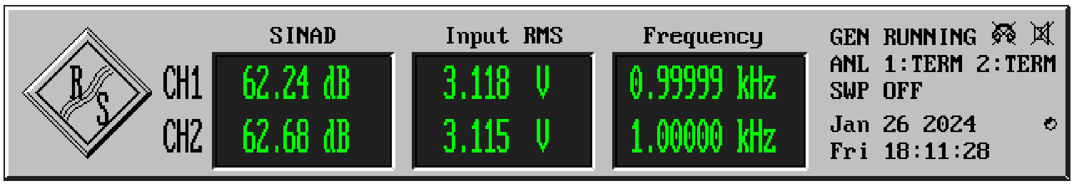
FFT for both Channels with 2.5 Watts Out into 4Ω at 1 kHz:



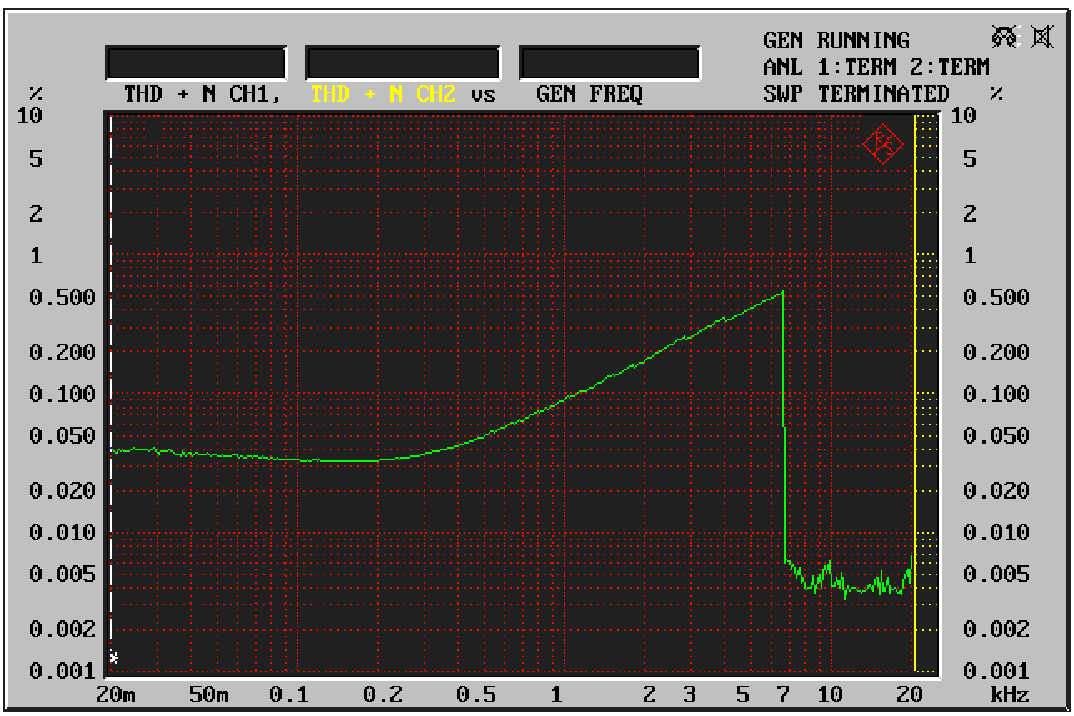
THD+N for both Channels with approximately 2.5 Watts Out into 4Ω at 1 kHz:



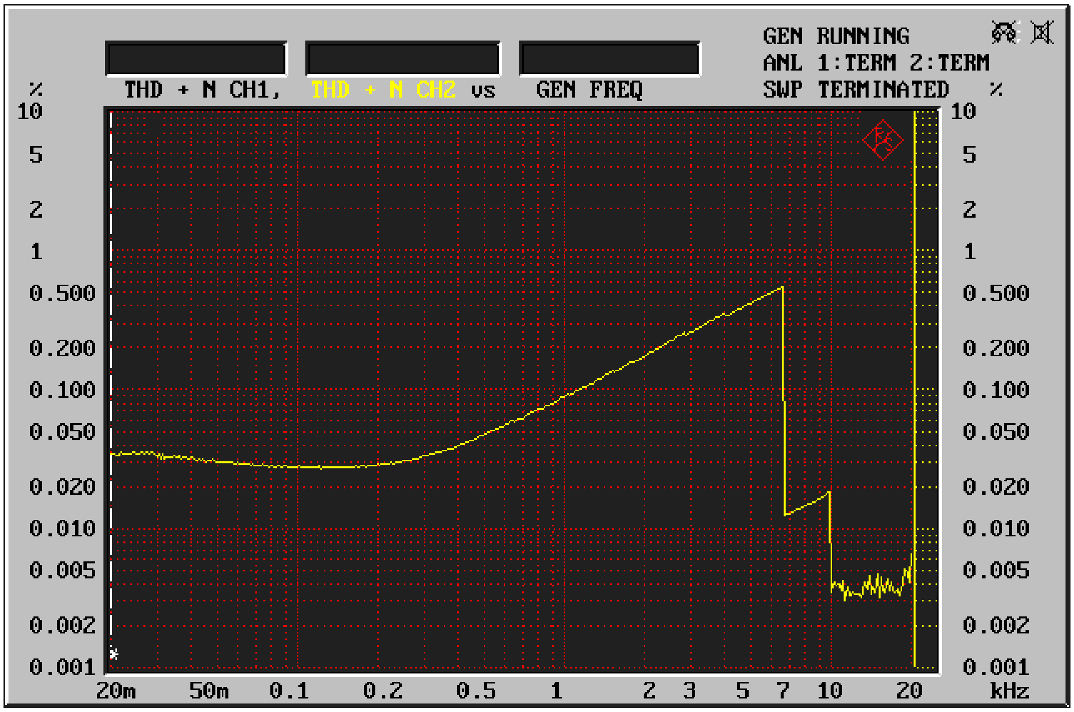
SINAD for both Channels with approximately 2.5 Watts Out into 4Ω at 1 kHz:



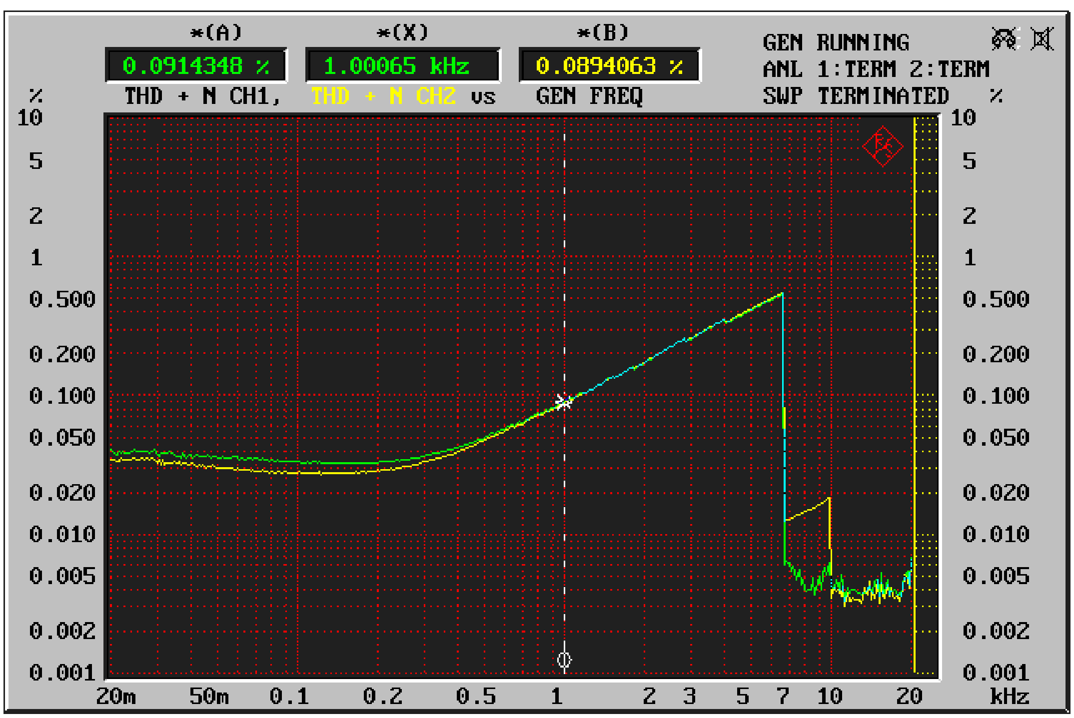
THD+N for CH1 (Right) with 5 Watts Out into 4Ω:



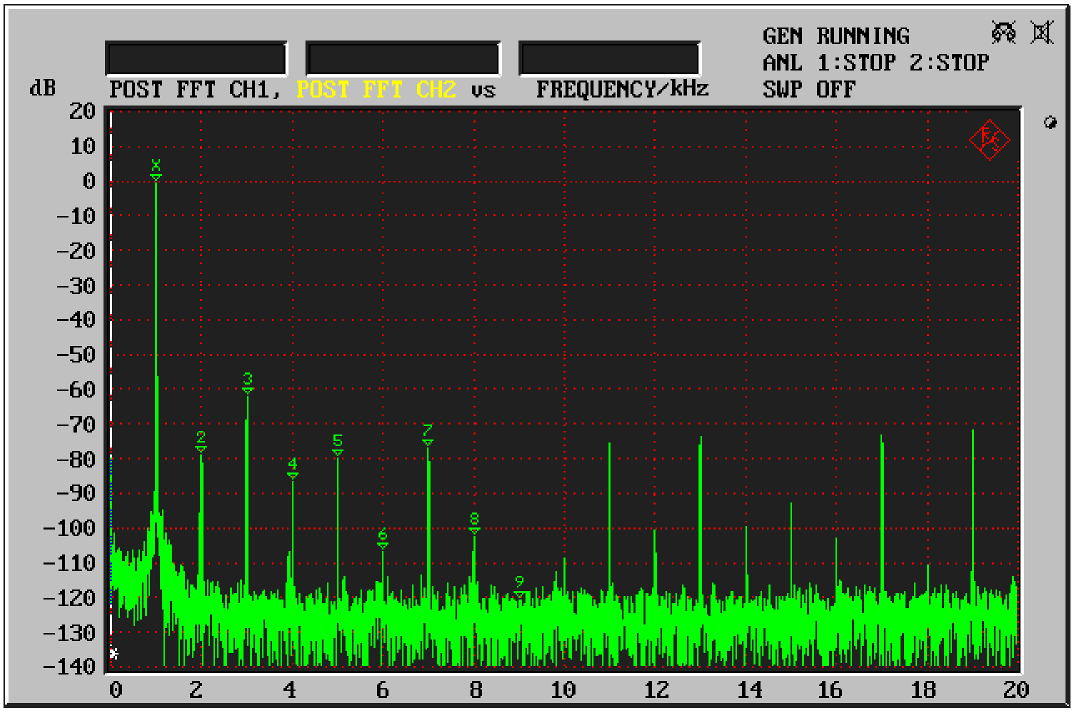
THD+N CH 4 (Left) with 5 Watts Out into 4Ω:



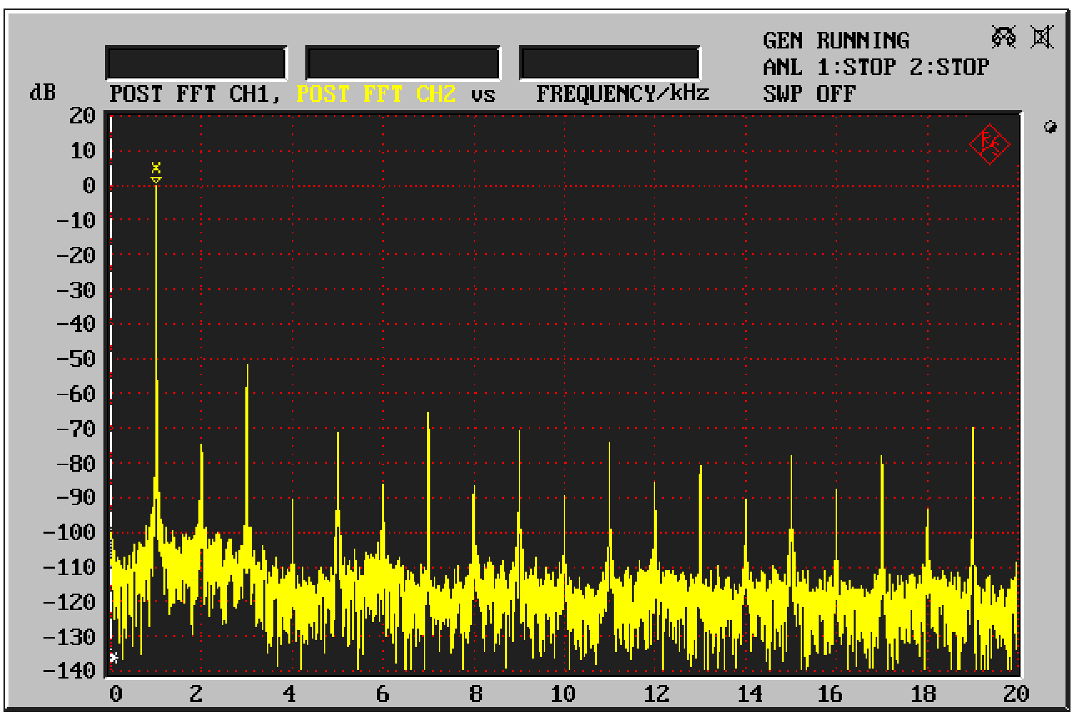
THD+N for both Channels with 5 Watts Out into 4Ω:



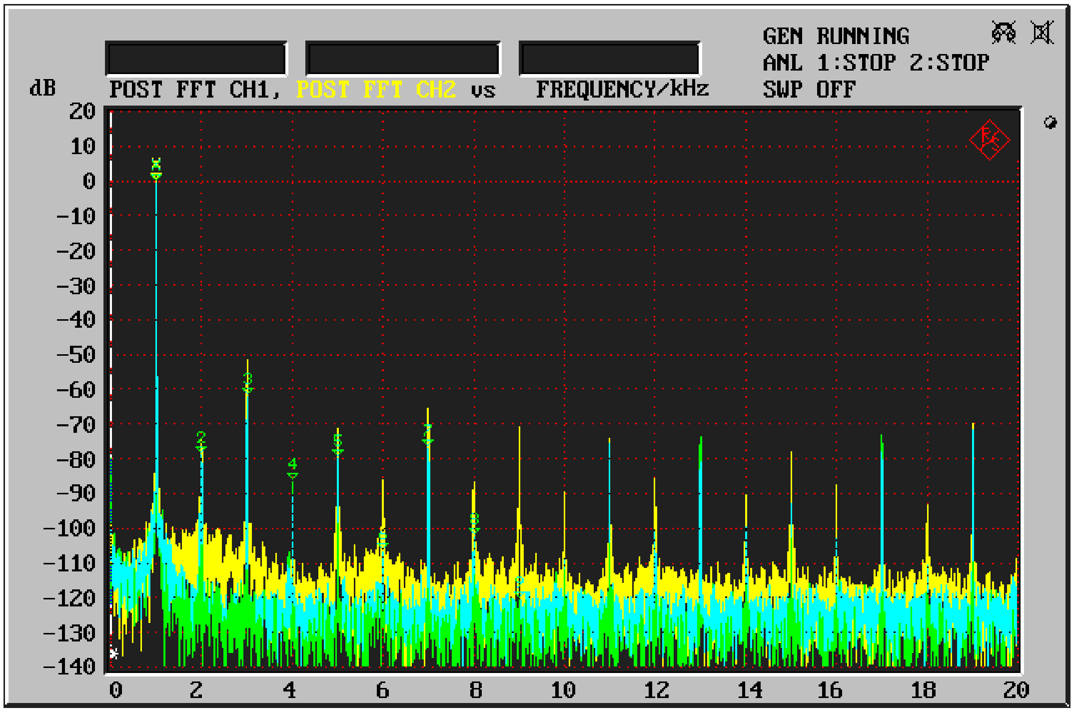
FFT for CH1 (Right) with 5 Watts Out into 4Ω at 1 kHz:



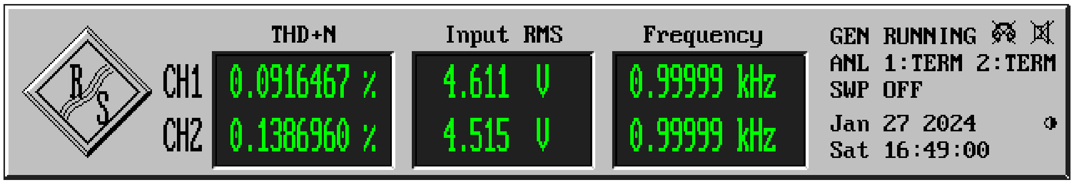
FFT for CH4 (Left) with 5 Watts Out into 4Ω at 1 kHz:



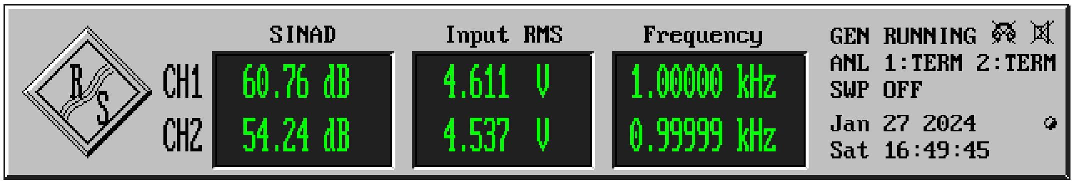
FFT for both Channels with 5 Watts Out into 4Ω at 1 kHz:



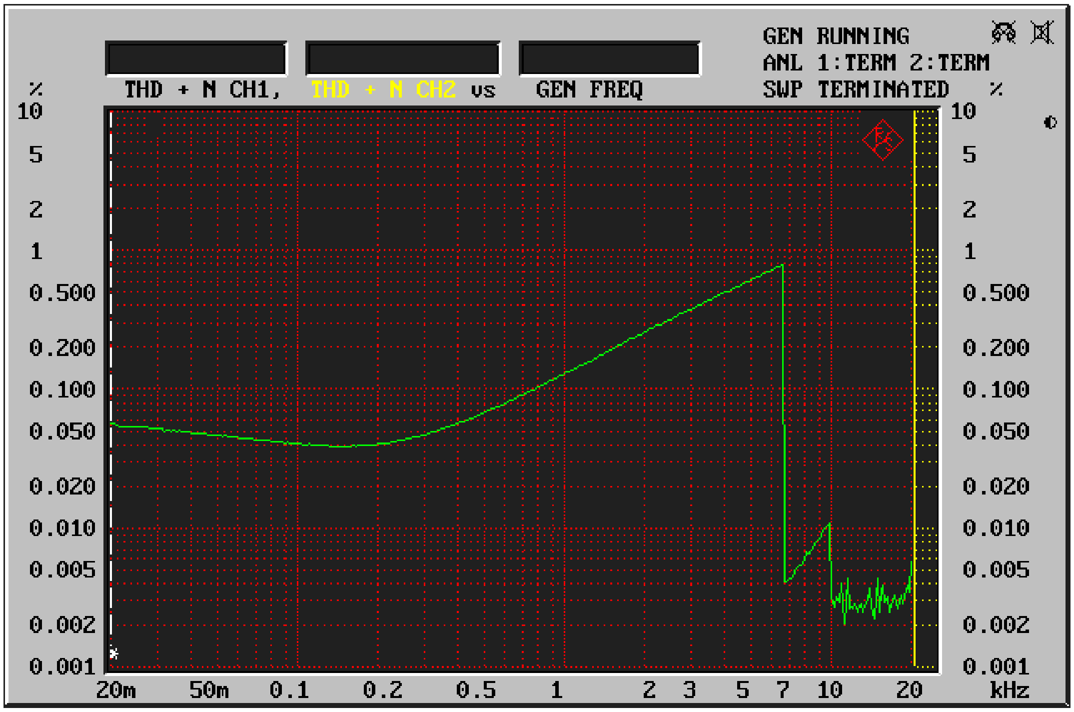
THD+N for both Channels with approximately 5 Watts Out into 4Ω at 1 kHz:



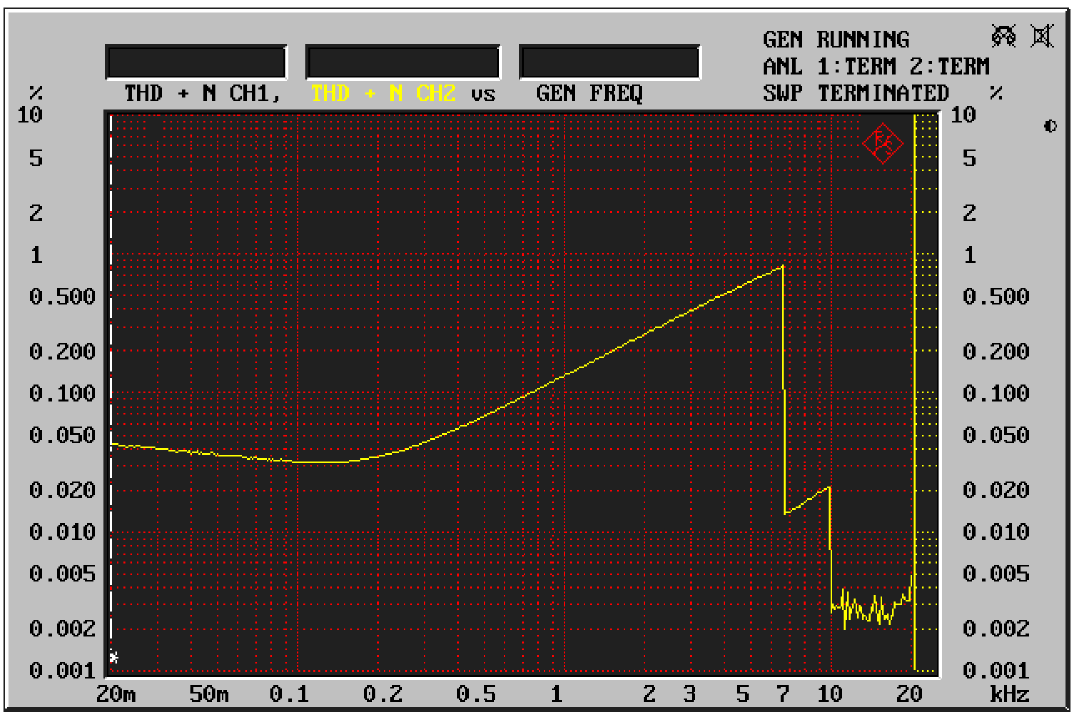
SINAD for both Channels with approximately 5 Watts Out into 4Ω at 1 kHz:



THD+N for CH1 (Right) with 10 Watts Out into 4Ω:

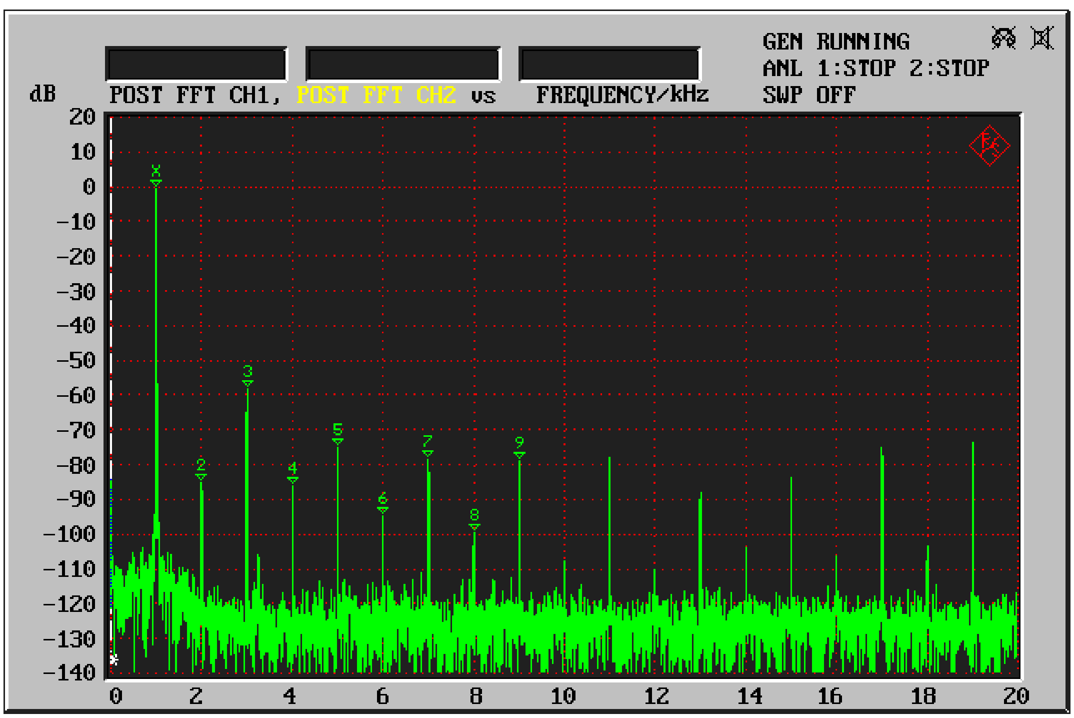


THD+N CH 4 (Left) with 10 Watts Out into 4Ω:

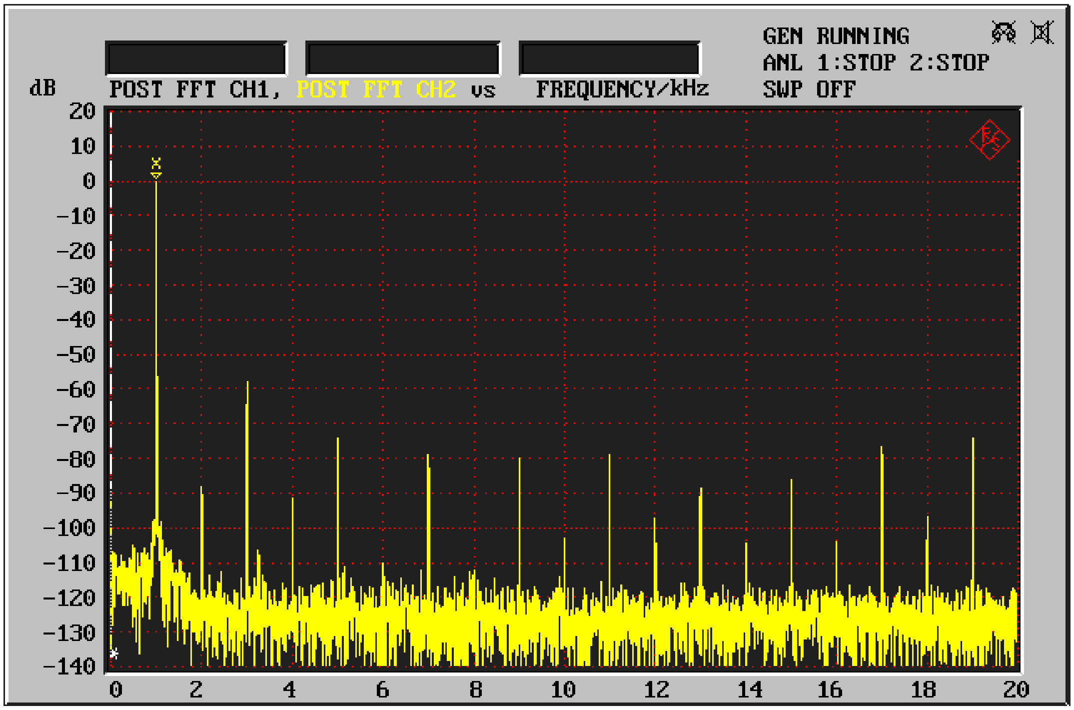


THD+N for both Channels with 10 Watts Out into 4Ω:

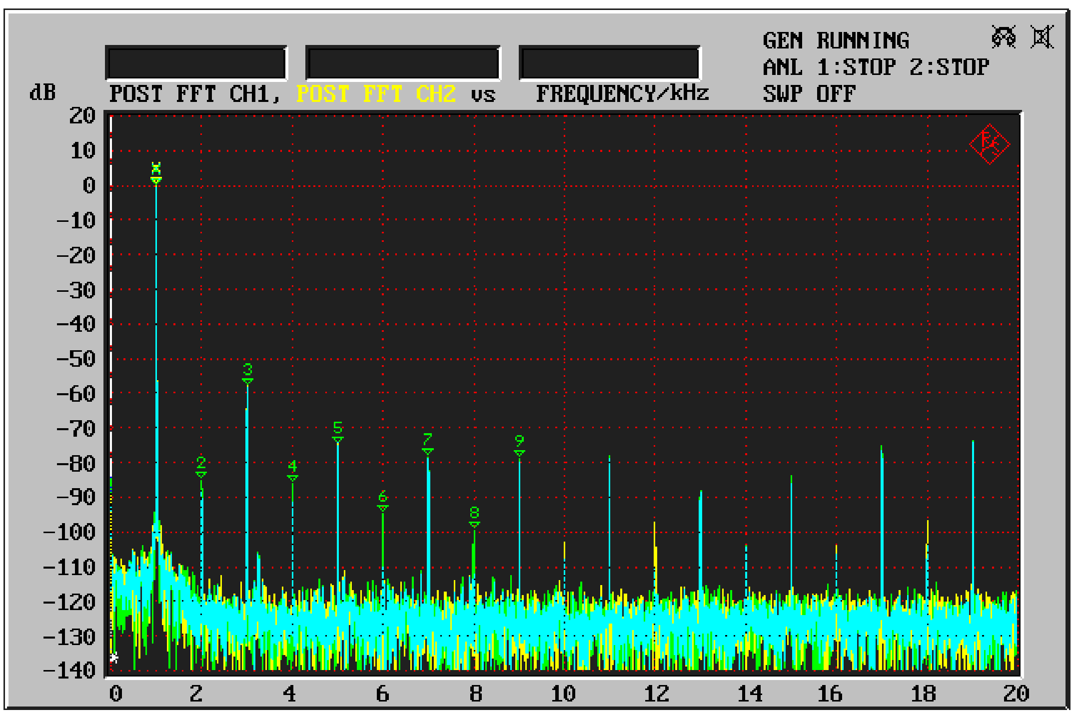
FFT for CH1 (Right) with 10 Watts Out into 4Ω at 1 kHz:



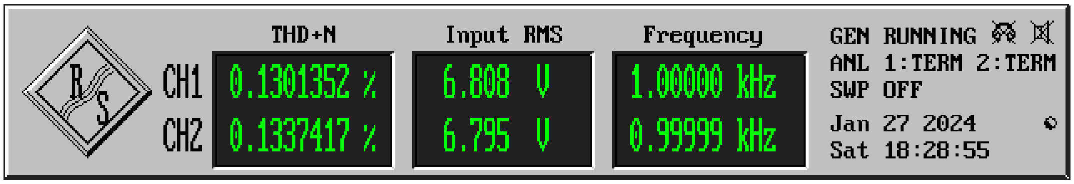
FFT for CH4 (Left) with 10 Watts Out into 4Ω at 1 kHz:



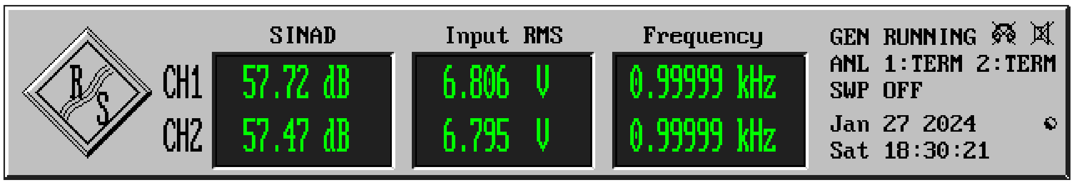
FFT for both Channels with 10 Watts Out into 4Ω at 1 kHz:



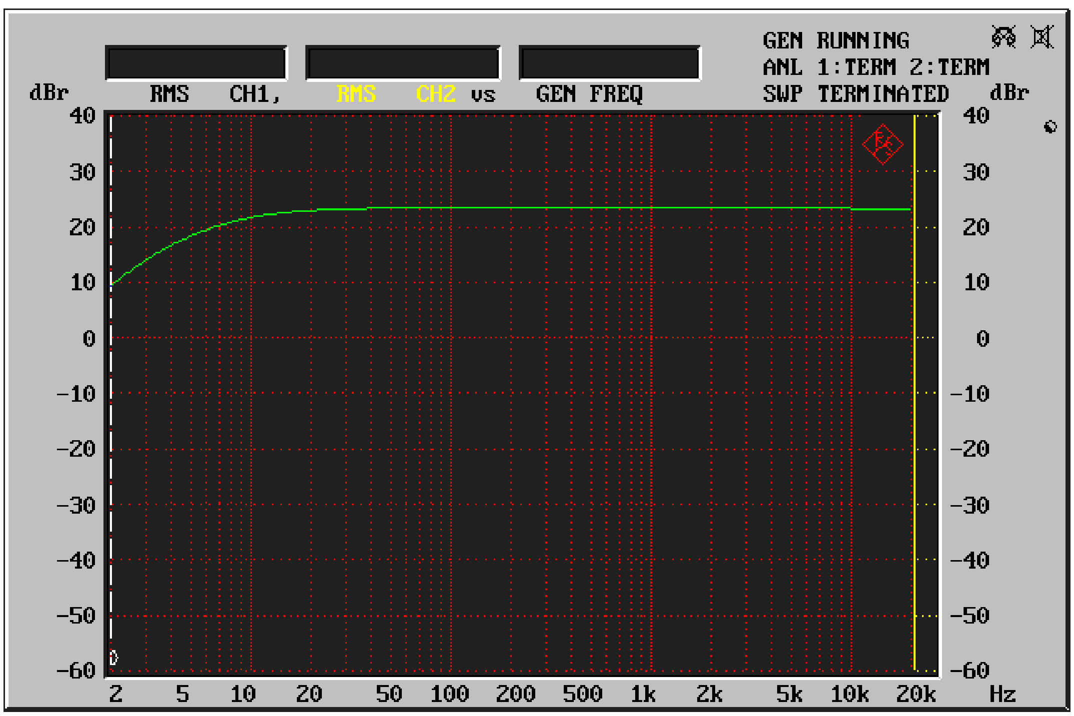
THD+N for both Channels with approximately 10 Watts Out into 4Ω at 1 kHz:



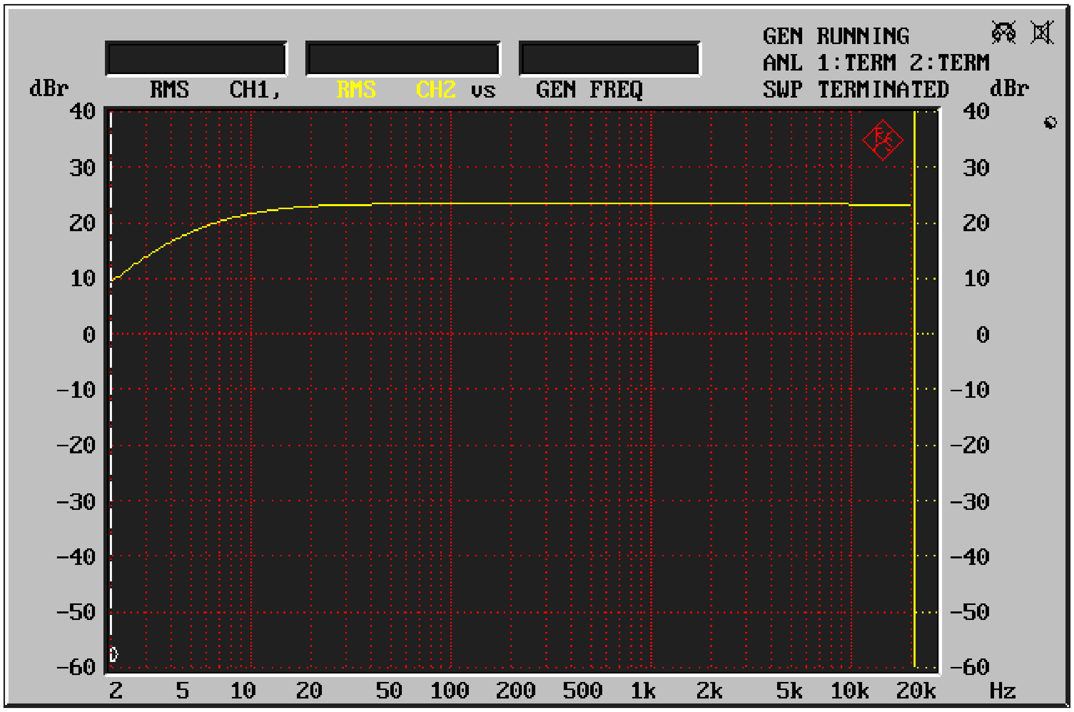
SINAD for both Channels with approximately 10 Watts Out into 4Ω at 1 kHz:



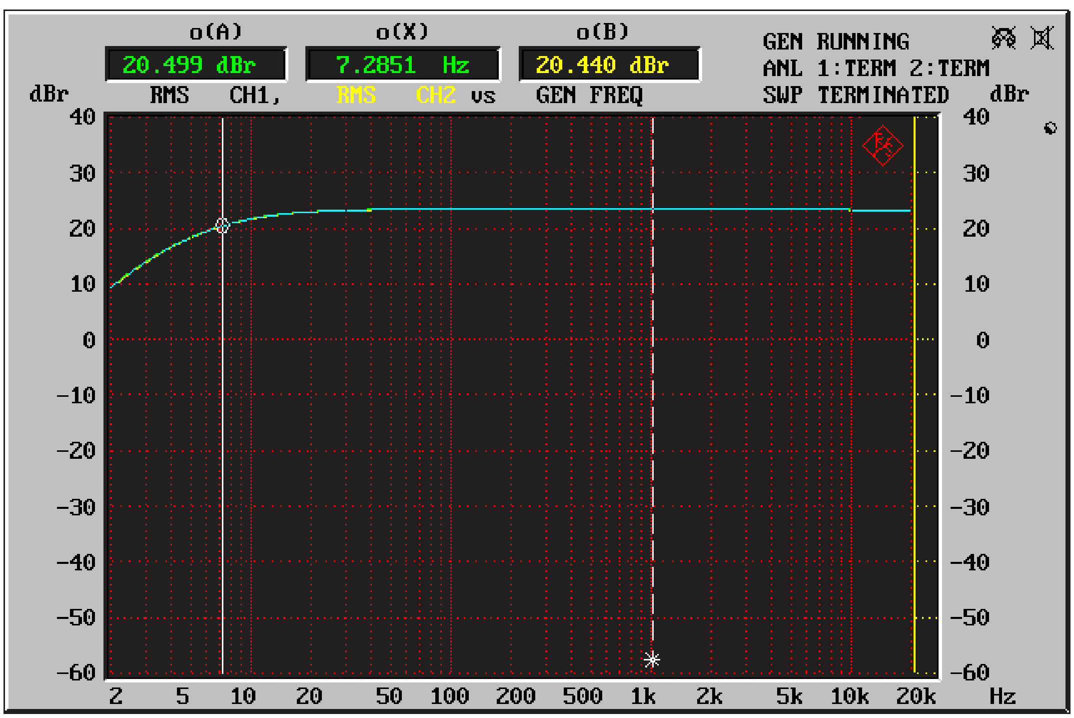
Magnitude Response for CH1 (Right) with 2.5 Watts Out into 4Ω at 1 kHz:



Magnitude Response for CH4 (Left) with 2.5 Watts Out into 4Ω at 1 kHz:

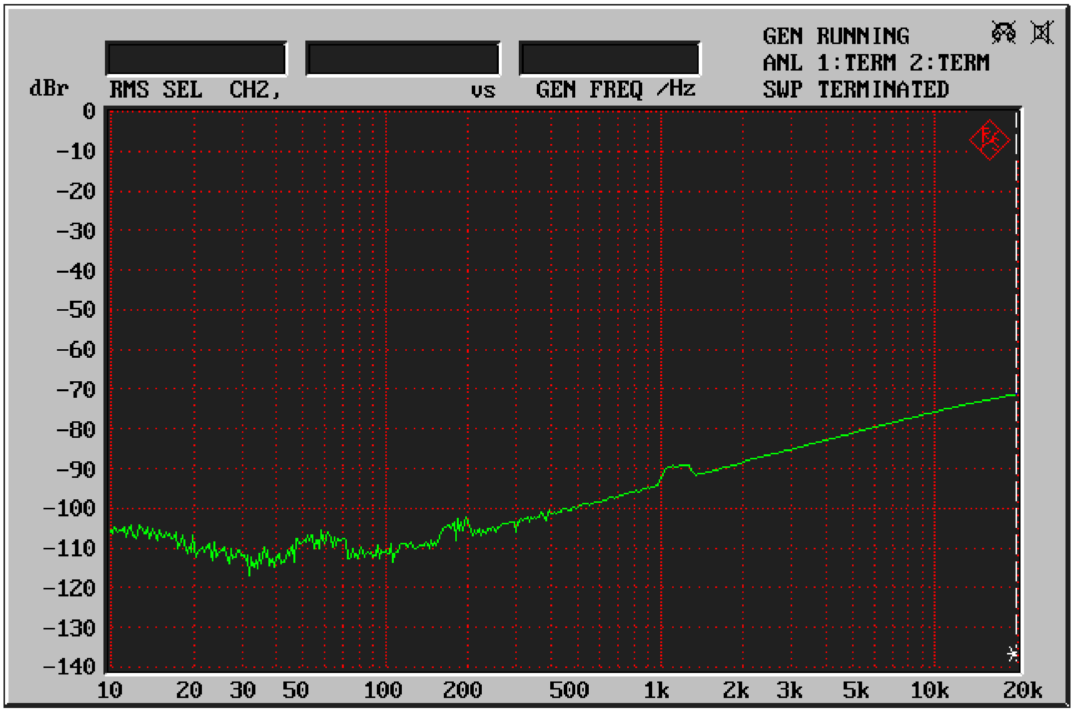


Magnitude Response for both Channels with 2.5 Watts Out into 4Ω at 1 kHz:

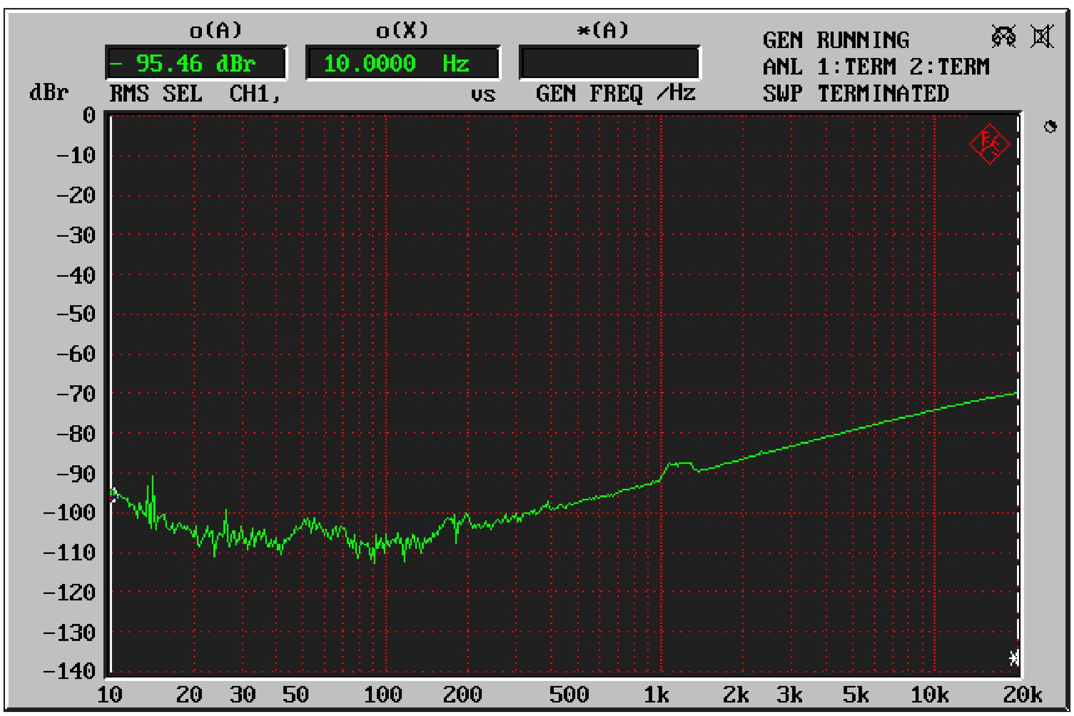


The -3 dB frequency is marked above at 7.2851 Hz.

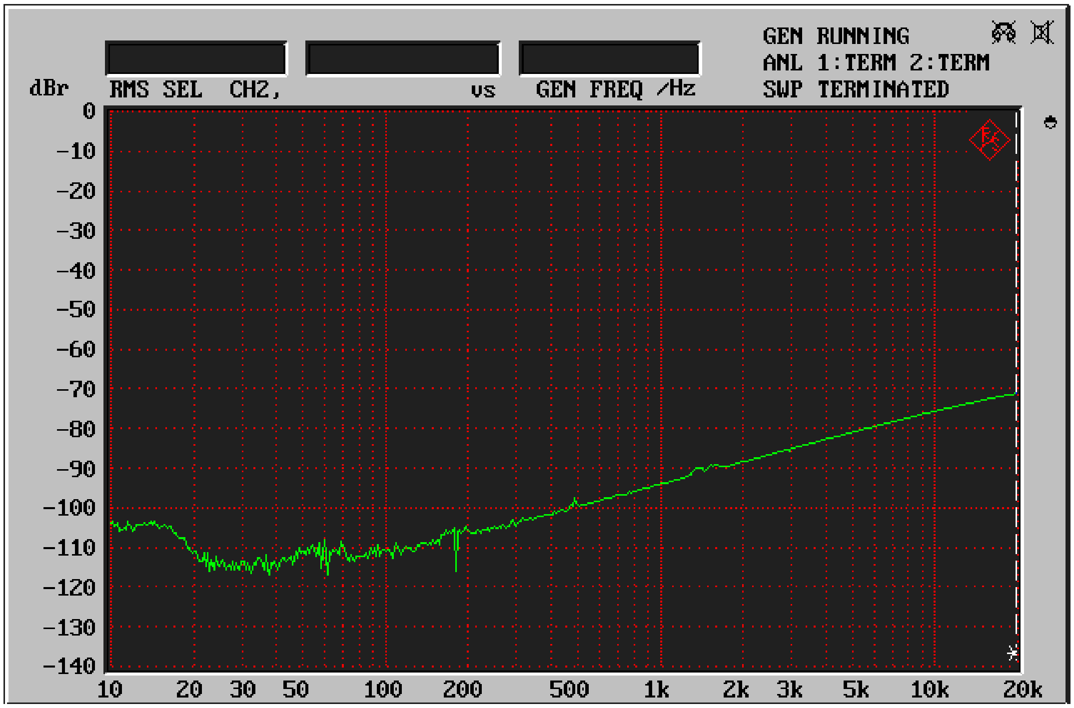
Below is the Crosstalk from Channel (Right) 1 to Channel (Left) 4 with 2.5 Watts Out into 4Ω (Vo = 8.9 Vp-p):



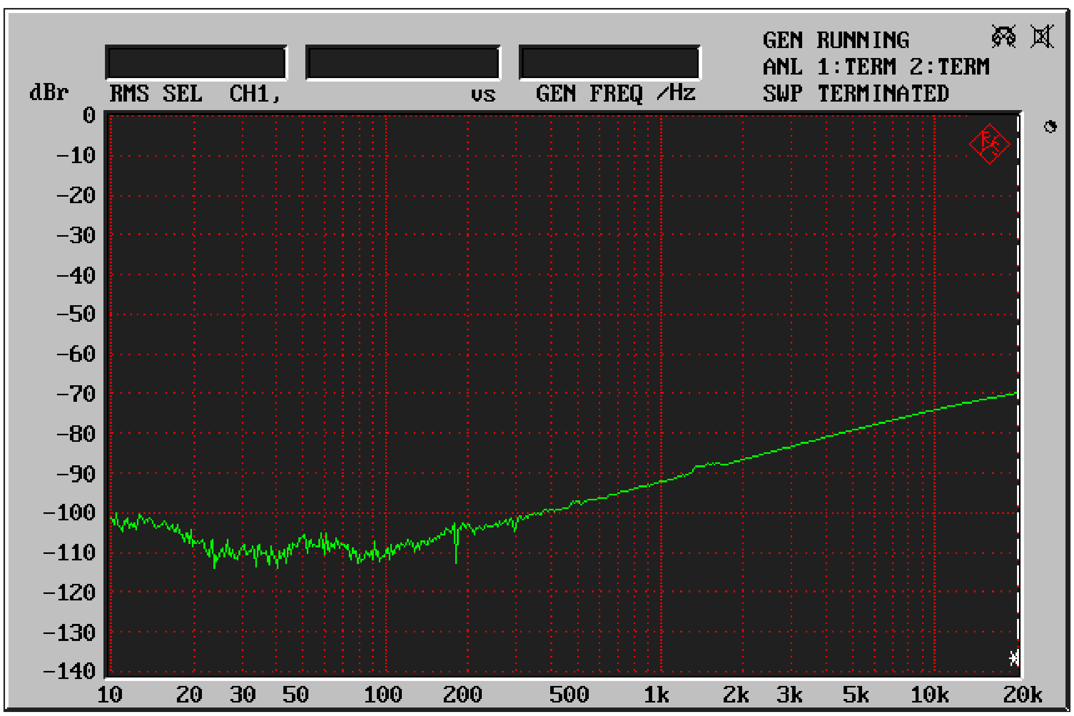
Below is the Crosstalk from Channel (Left) 4 to Channel (Right) 1 with 2.5 Watts Out into 4Ω (Vo = 8.9 Vp-p):



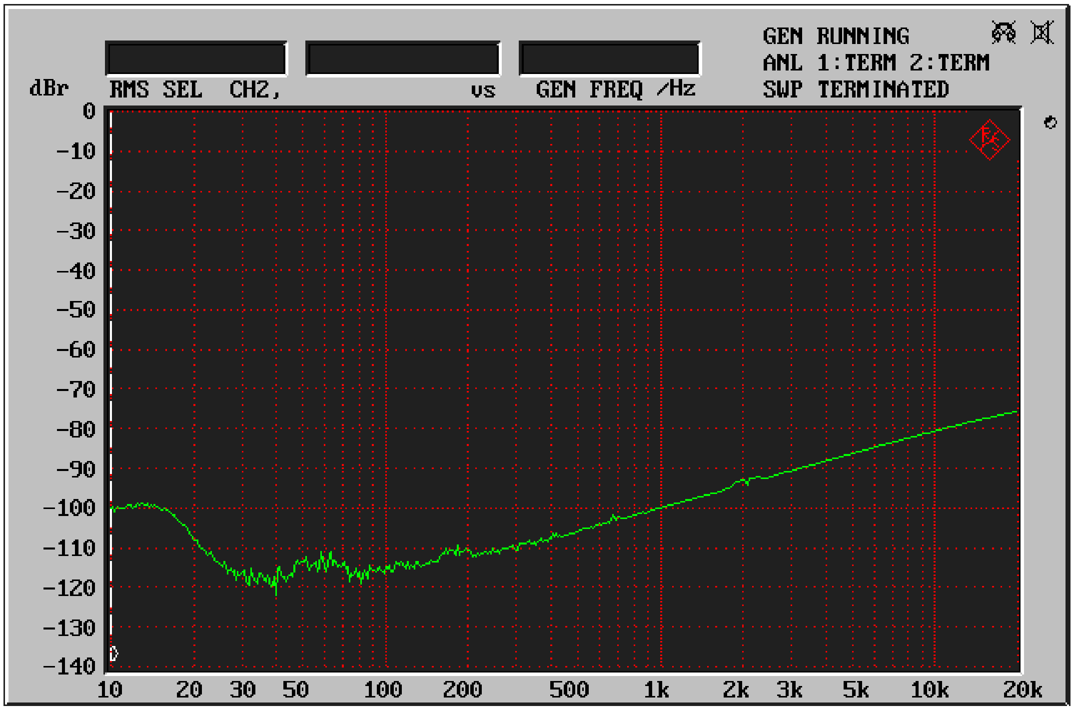
Below is the Crosstalk from Channel (Right) 1 to Channel (Left) 4 with 5 Watts Out into 4Ω (Vo = 12.6 Vp-p):



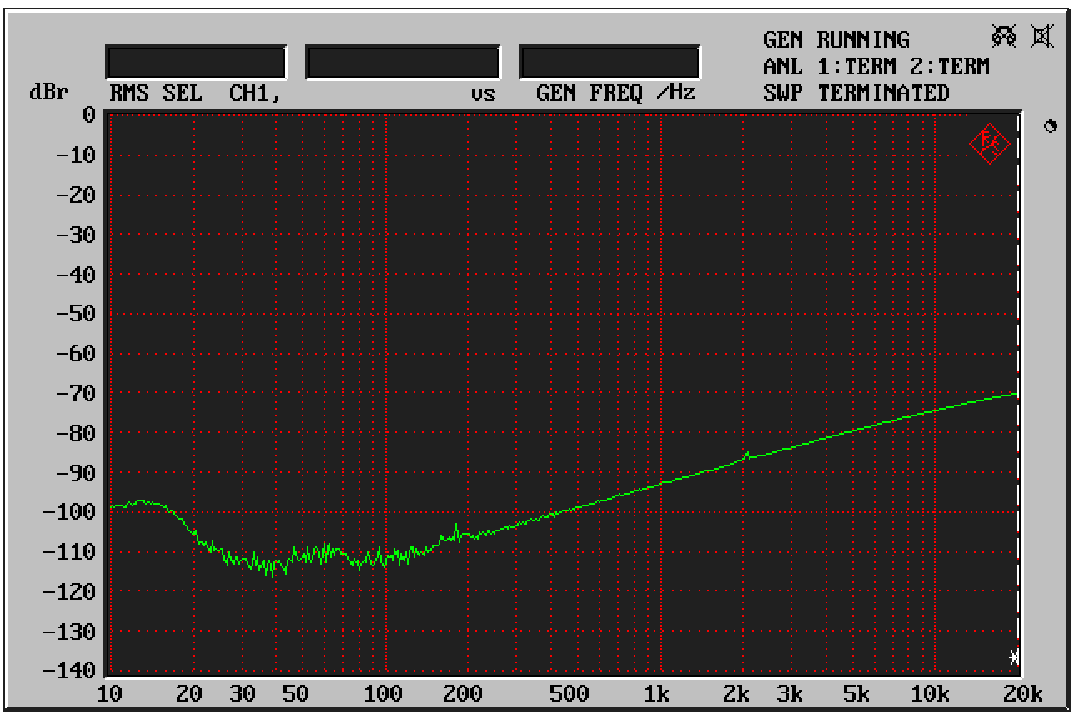
Below is the Crosstalk from Channel (Left) 4 to Channel (Right) 1 with 5 Watts Out into 4Ω (Vo = 12.6 Vp-p):



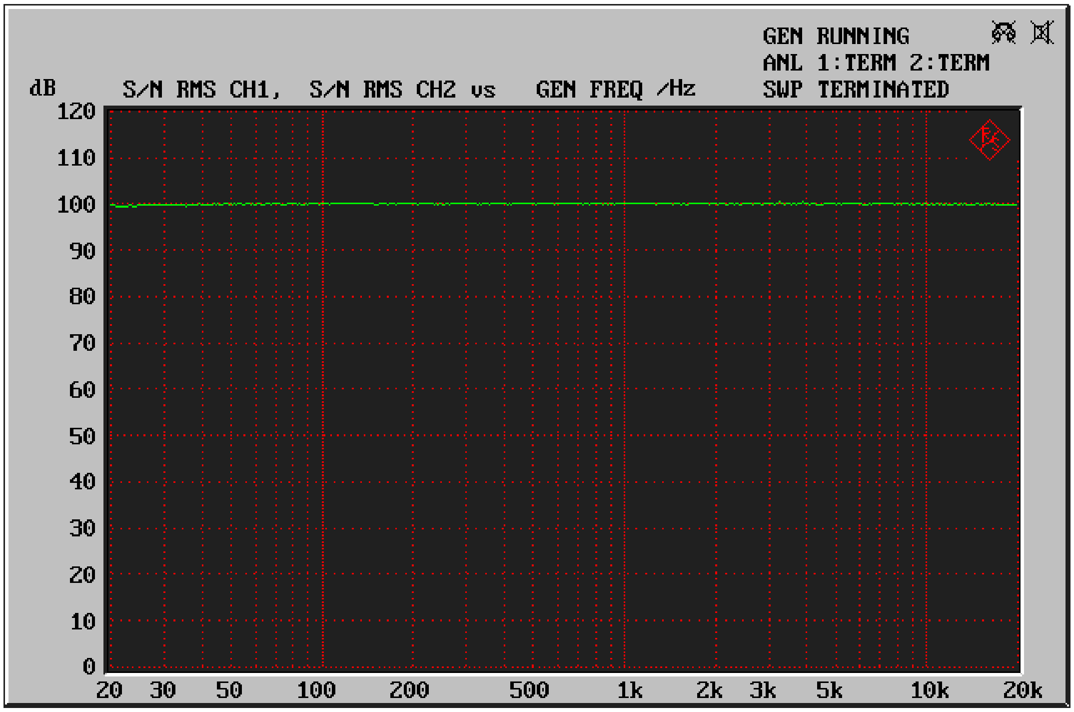
Below is the Crosstalk from Channel (Right) 1 to Channel (Left) 4 with 10 Watts Out into 4Ω (Vo = 17.9 Vp-p):



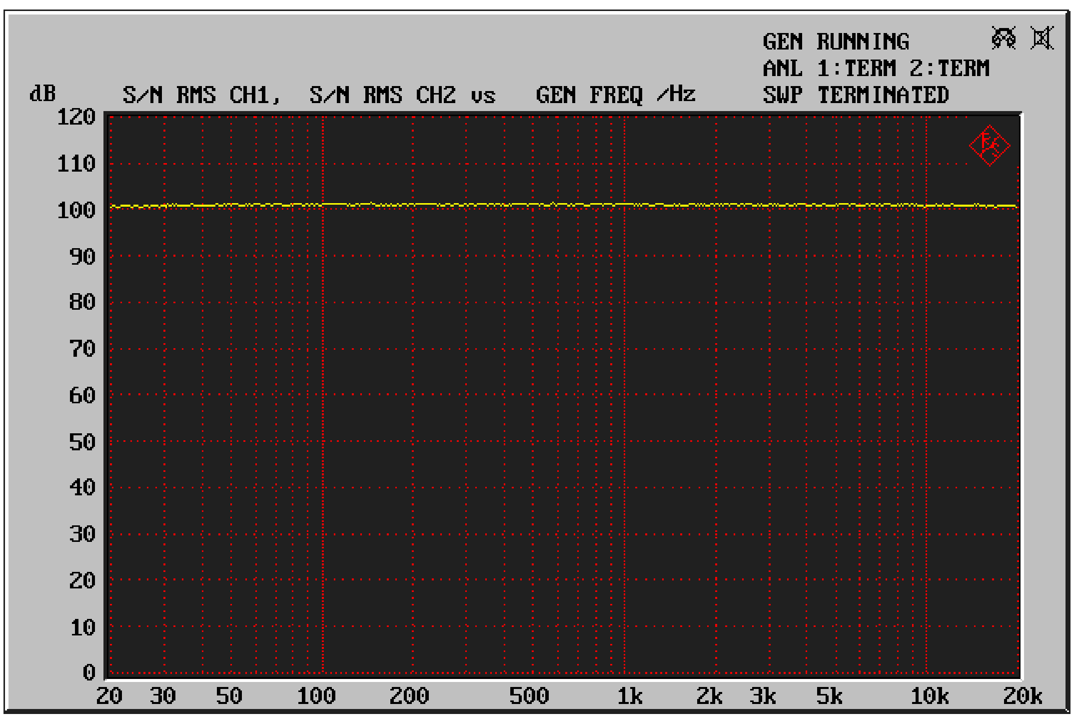
Below is the Crosstalk from Channel (Left) 4 to Channel (Right) 1 with 10 Watts Out into 4Ω (Vo = 17.9 Vp-p):



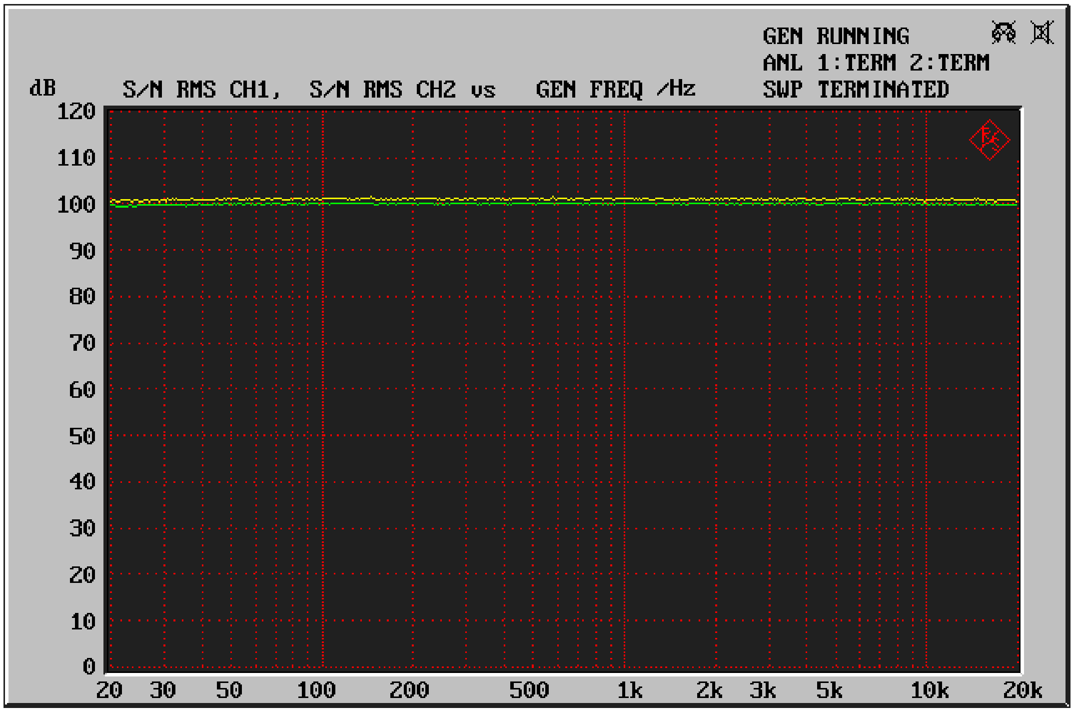
Below is the Signal-to-Noise Ratio with an A-Weighted Curve for CH1 (Right) with 36 Watts Out into 4Ω (Vo = 34 Vp-p).

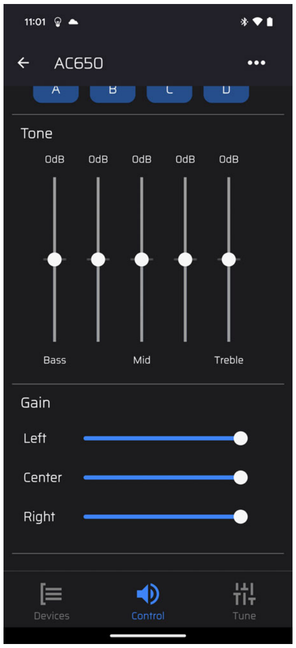


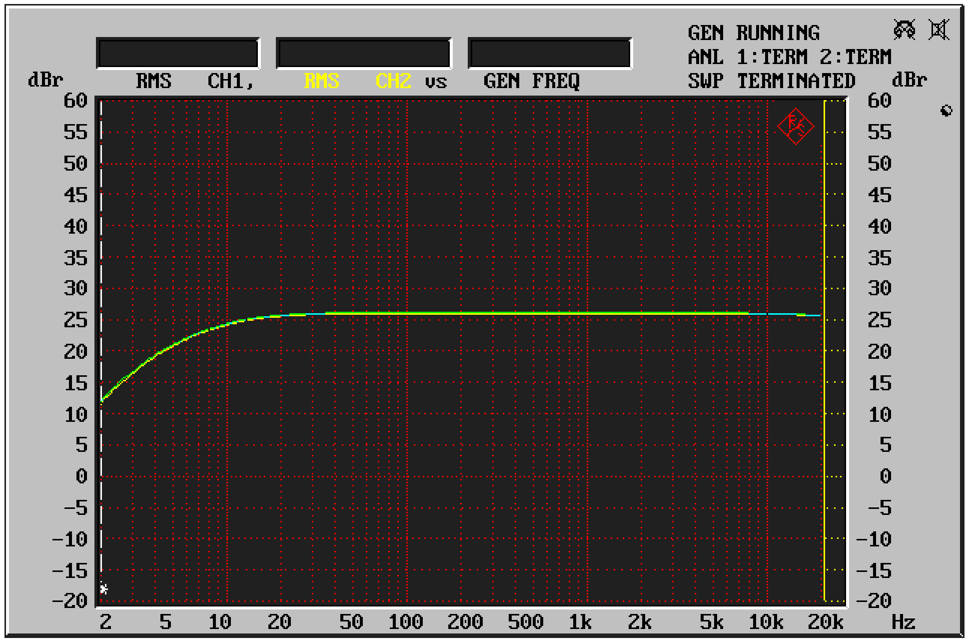
Below is the Signal-to-Noise Ratio with an A-Weighted Curve for CH4 (Left) with 36 Watts Out into 4Ω (Vo = 34 Vp-p).



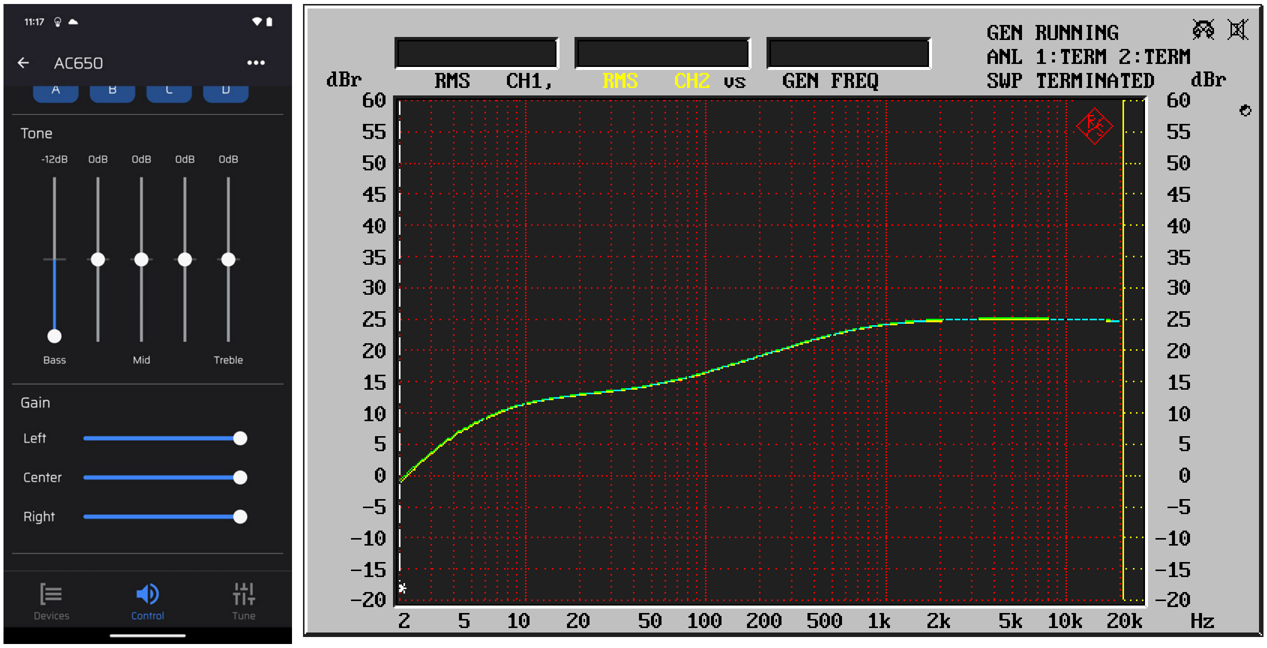
Below is the Signal-to-Noise Ratio with an A-Weighted Curve for both with 36 Watts Out into 4Ω (Vo = 34 Vp-p).



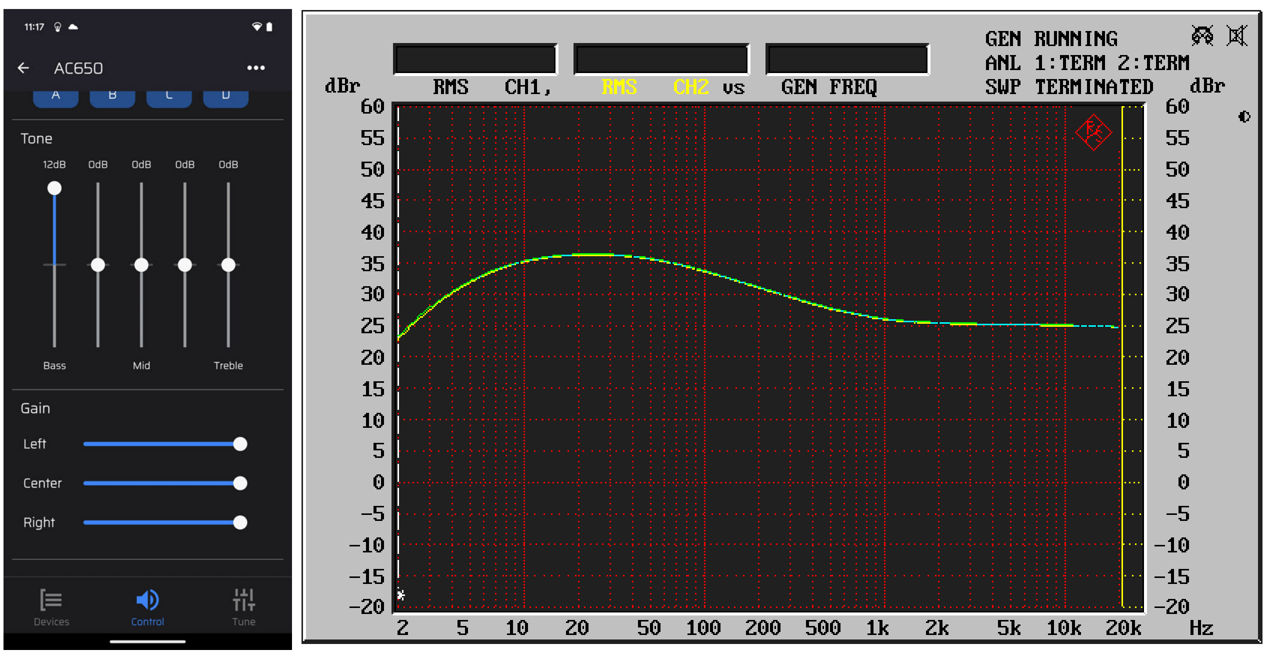




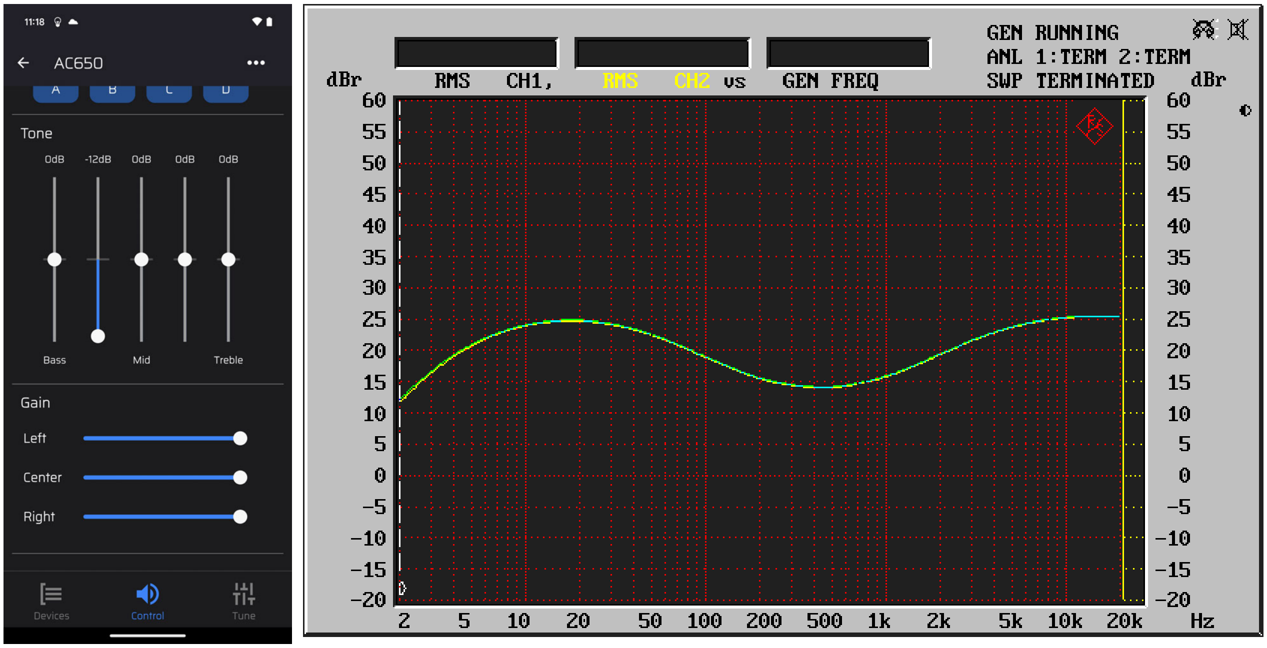
Volume Max, Channels 1 & 4 Selected, Invert Off. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



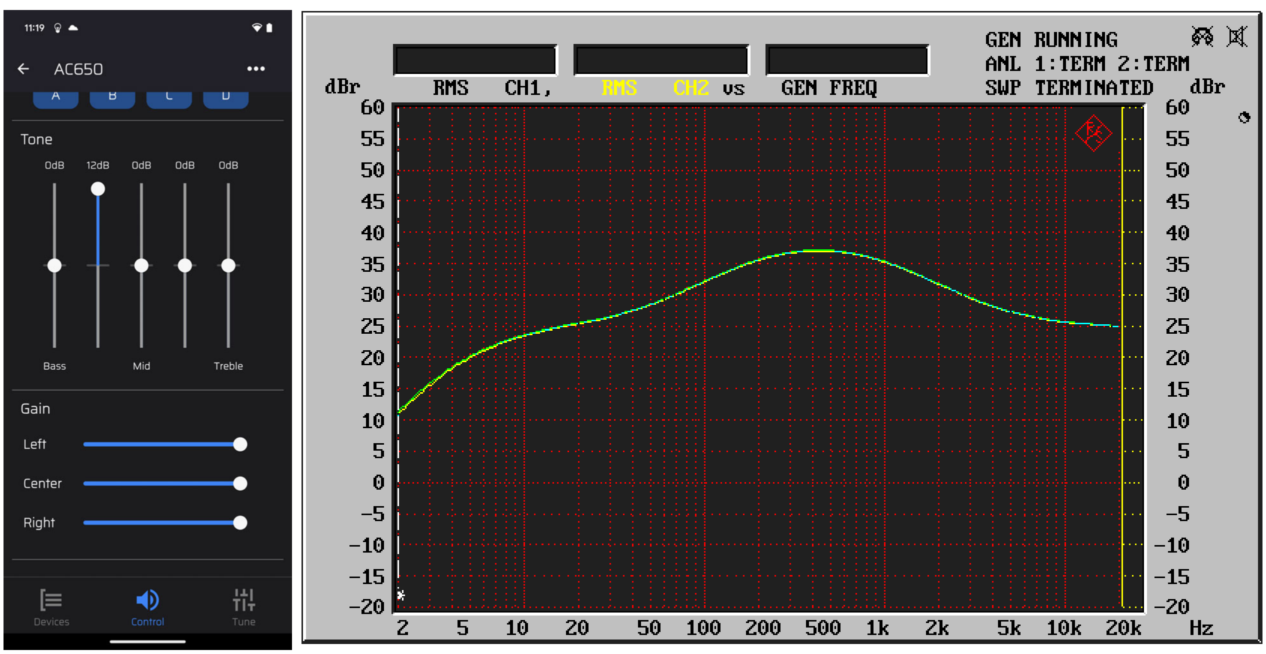
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.566 Vp-p = 0.2 Vrms; Vout(max) ≈ 11.5 Vp-p.



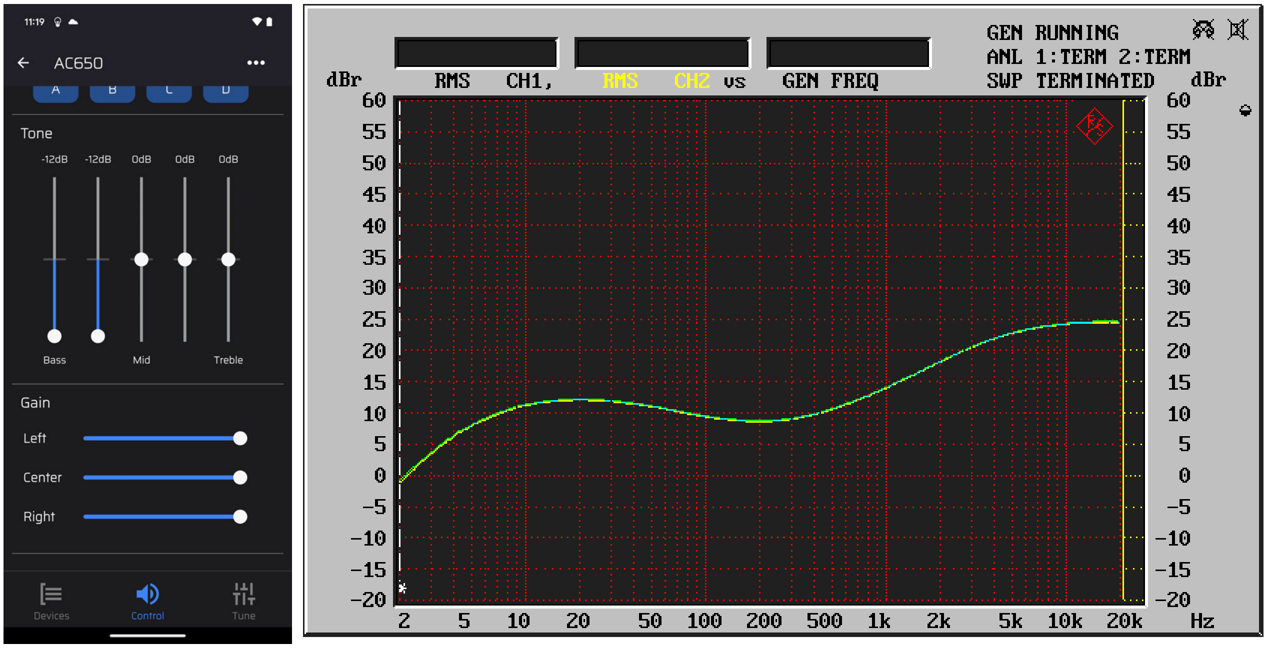
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 18.7 Vp-p.



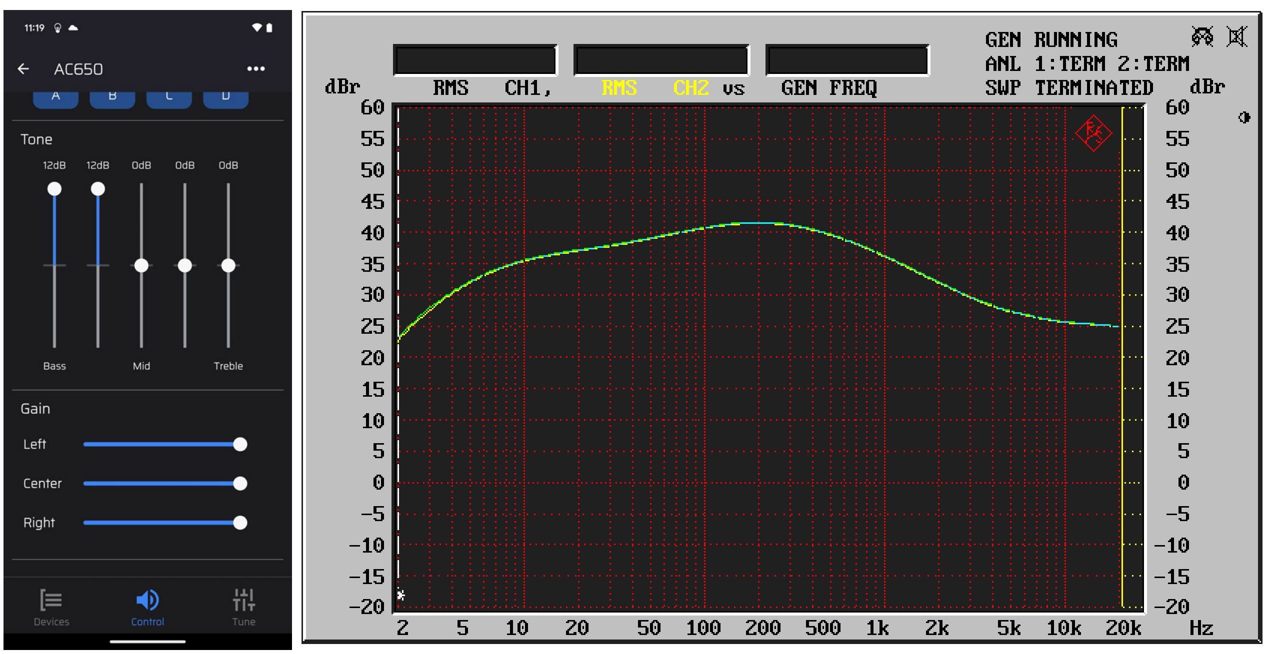
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.566 Vp-p = 0.2 Vrms; Vout(max) ≈ 11.5 Vp-p.



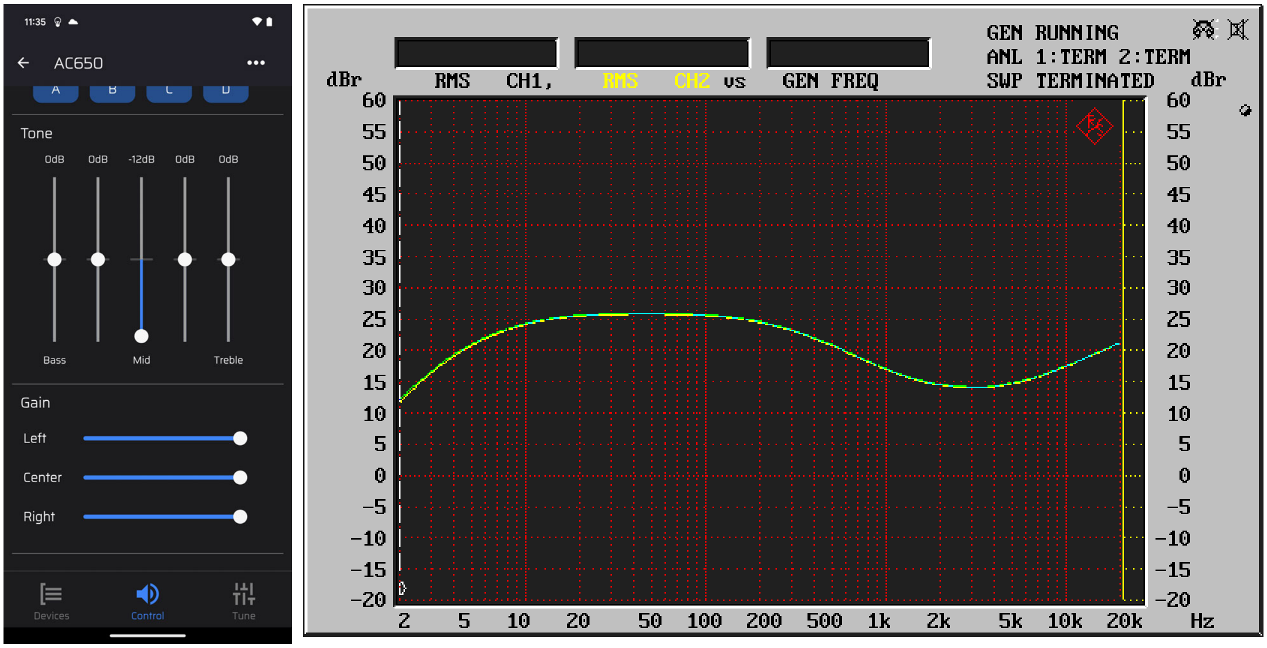
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 20.4 Vp-p.



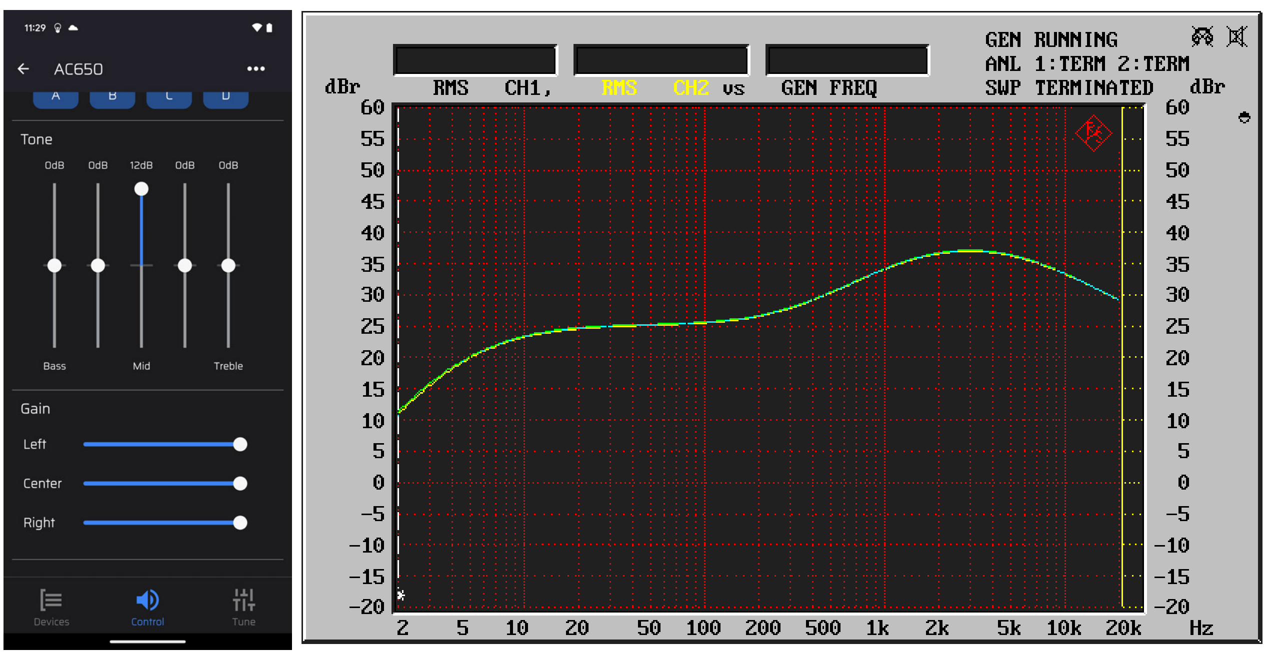
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.566 Vp-p = 0.2 Vrms; Vout(max) ≈ 11.5 Vp-p.



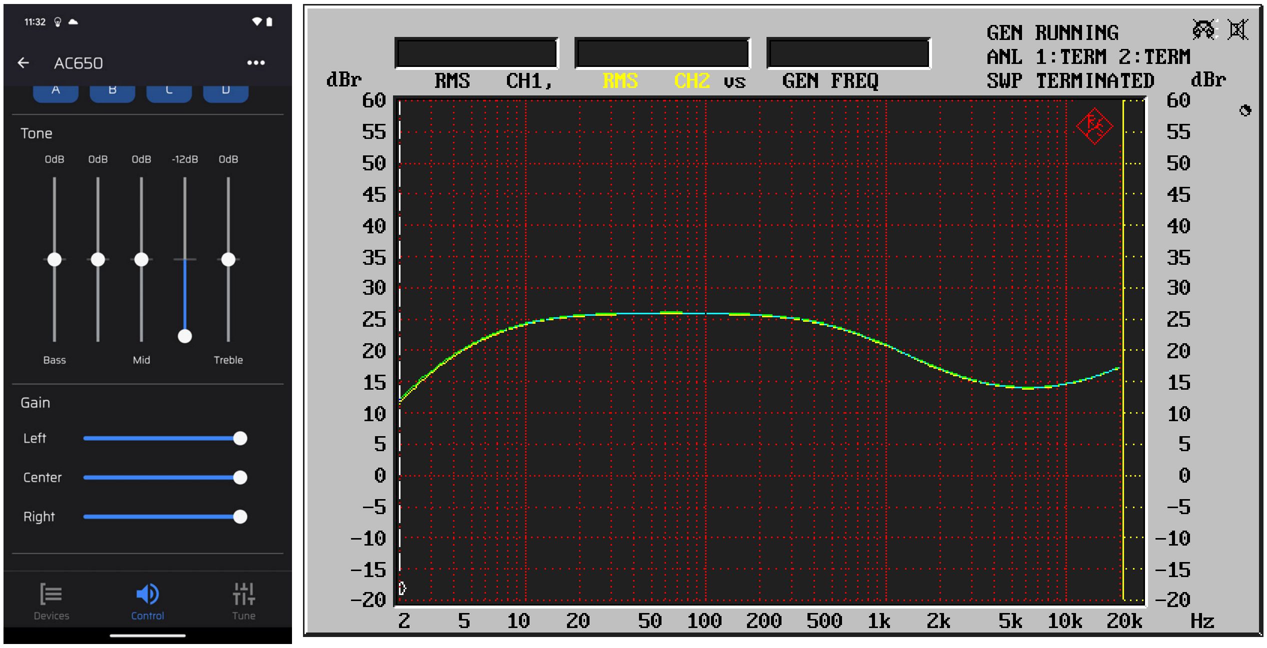
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 33.9 Vp-p.



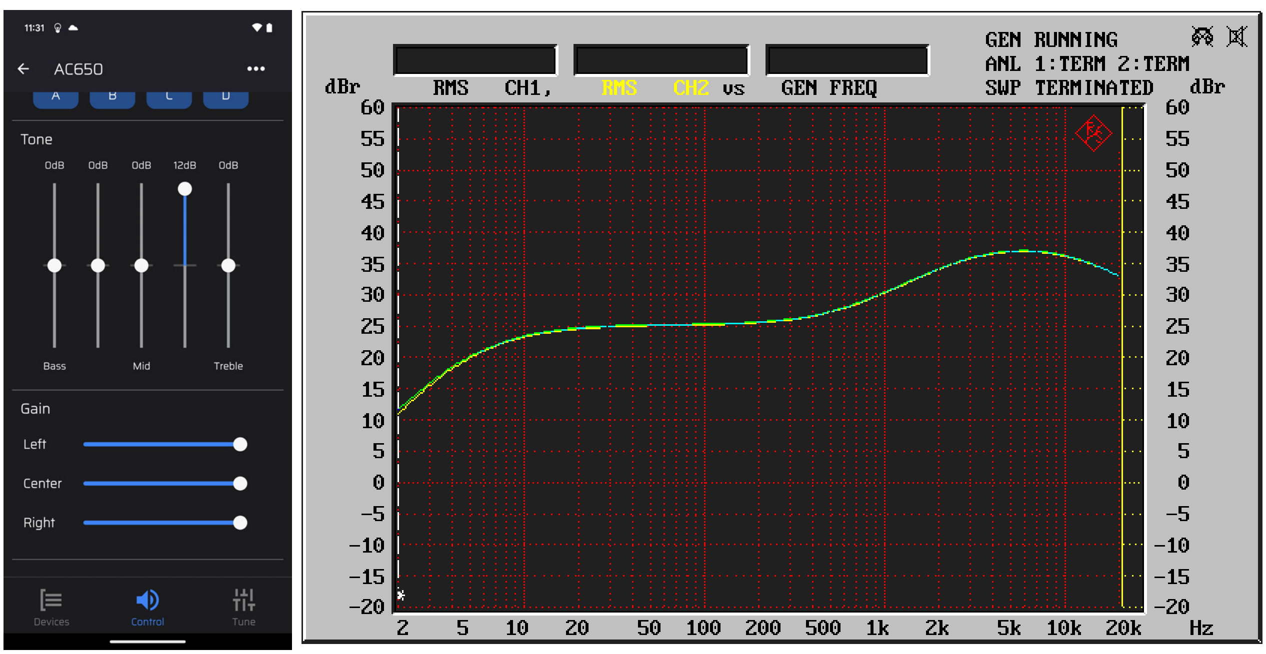
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.566 Vp-p = 0.2 Vrms; Vout(max) ≈11.5 Vp-p.



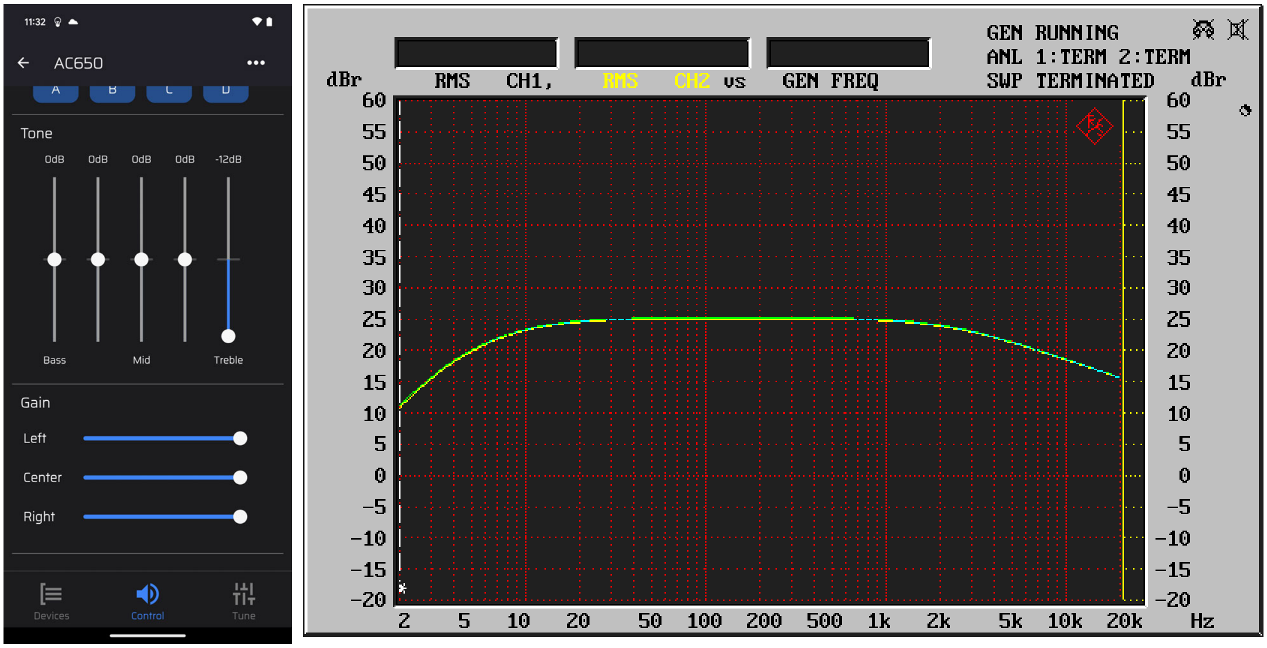
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 20.3 Vp-p.



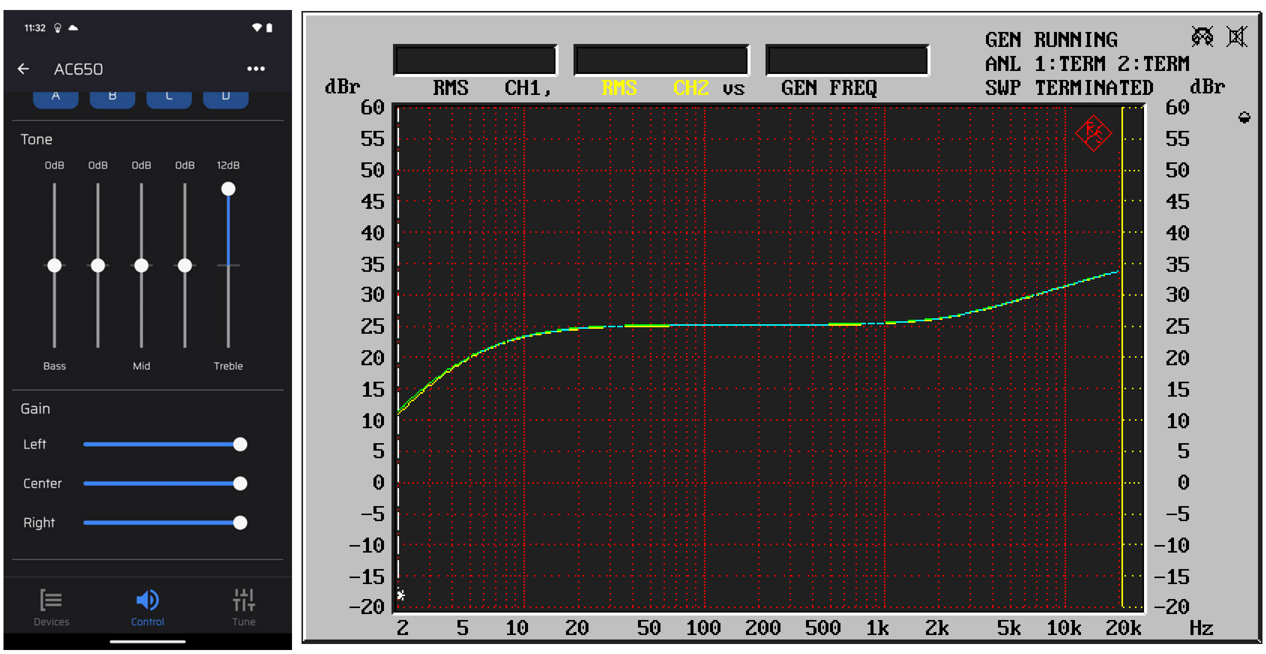
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.566 Vp-p = 0.2 Vrms; Vout(max) ≈11.5 Vp-p.



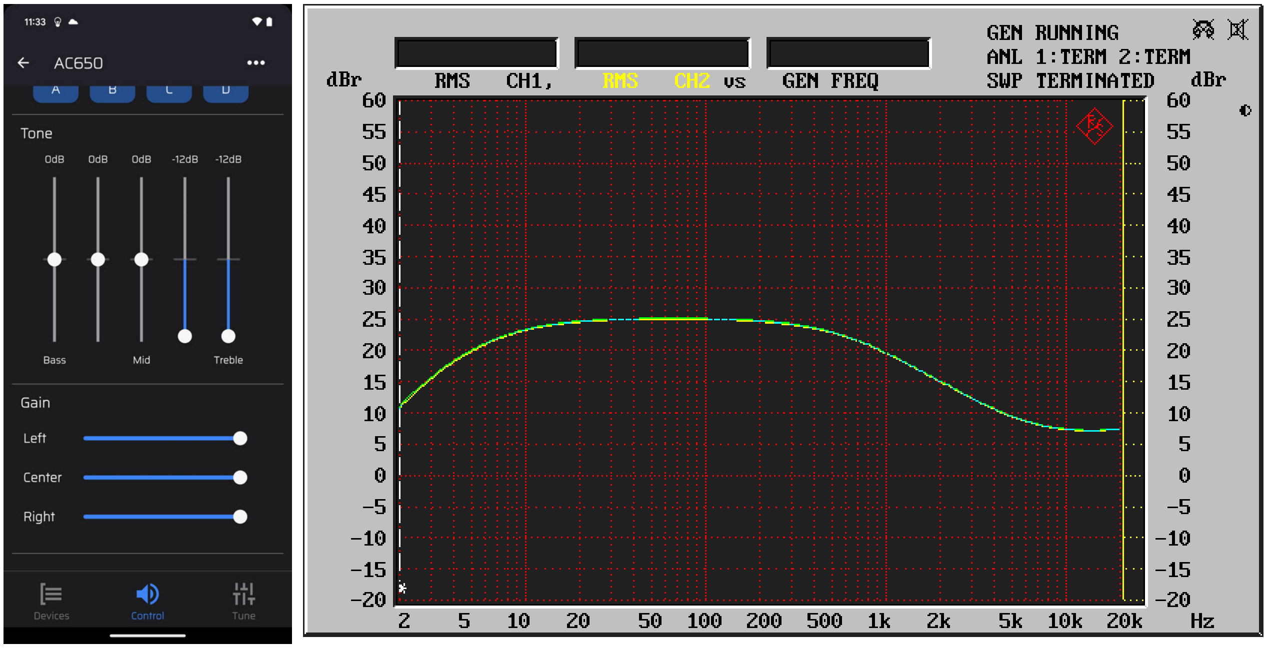
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 20.2 Vp-p.



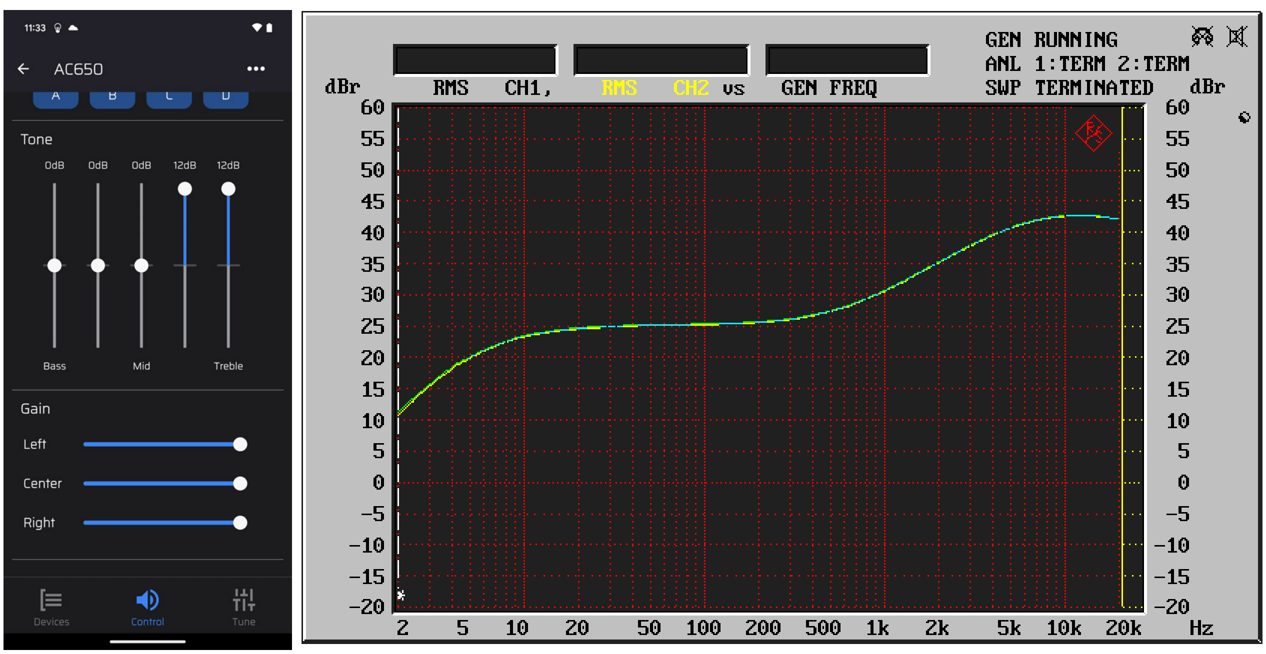
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.566 Vp-p = 0.2 Vrms; Vout(max) ≈ 11.5 Vp-p.



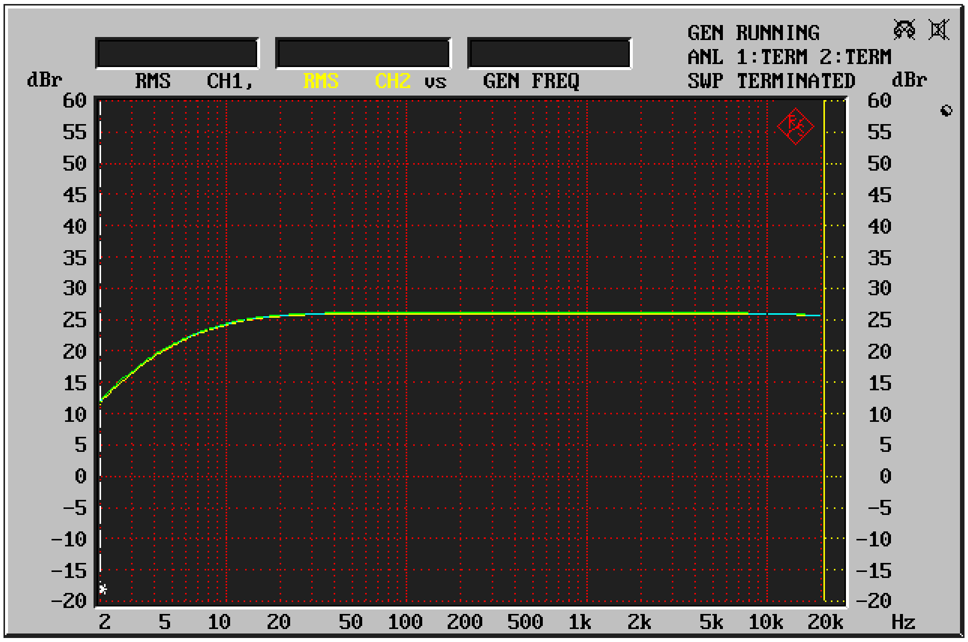
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 13.8 Vp-p.



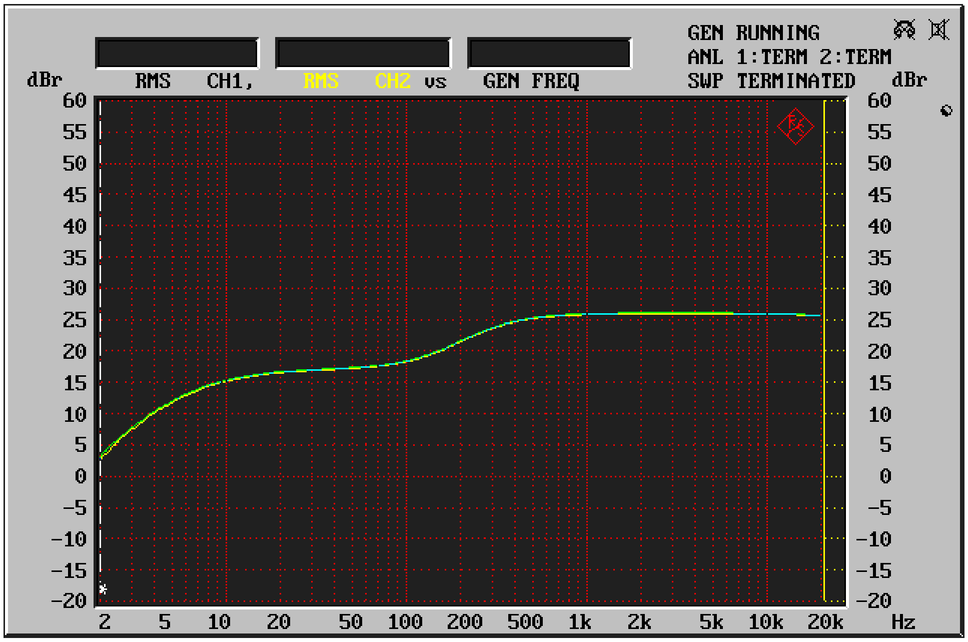
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.566 Vp-p = 0.2 Vrms; Vout(max) ≈ 11.5 Vp-p.



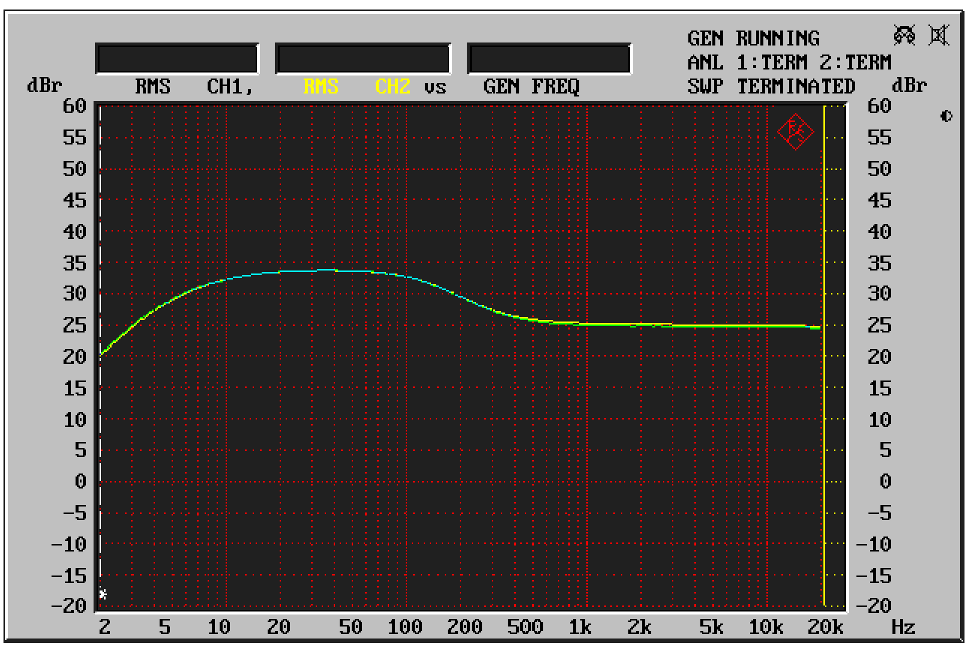
Volume Max, Channels 1 & 4 Selected, Invert Off, Gain 0 dB. Front tone controls in middle position. Vin = 0.141 Vp-p = 0.05 Vrms; Vout(max) ≈ 19.45 Vp-p.



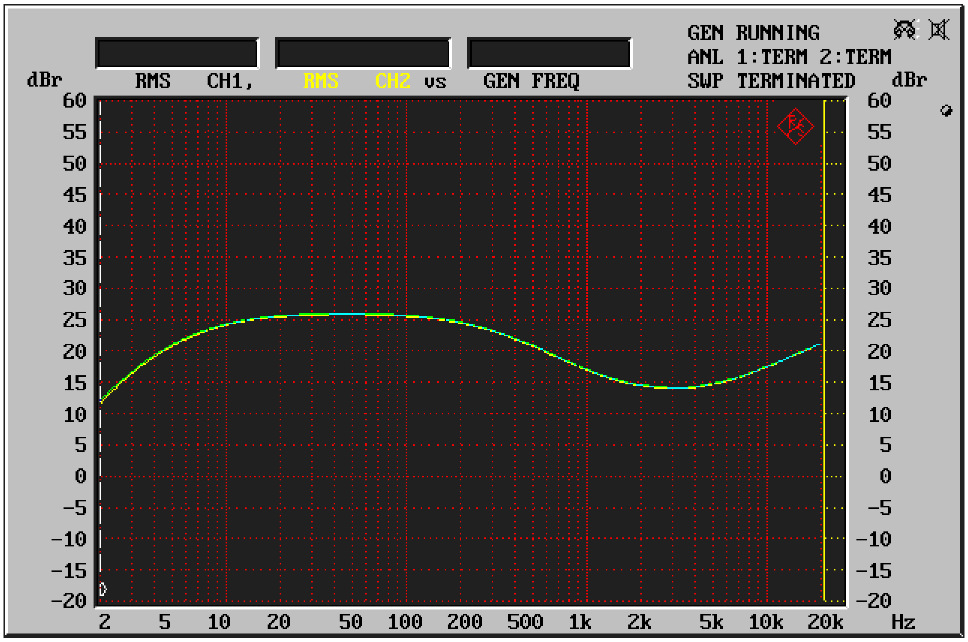
App tone controls are all at the center position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



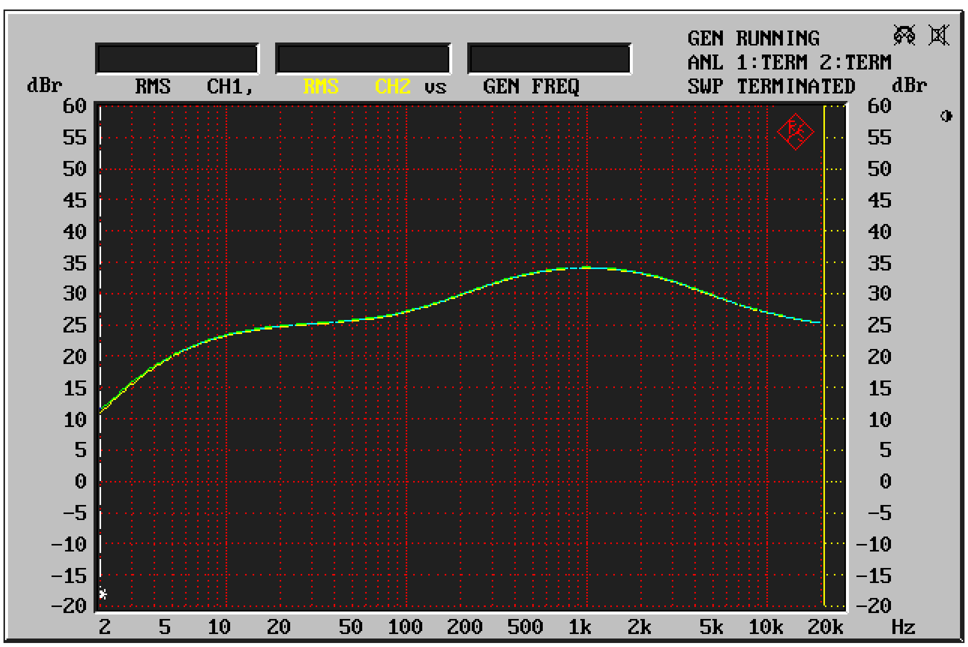
App tone controls are all at the center position. The Bass tone control is set in the fully CCW position, the Mid tone control is in the middle position and the Treble tone control is in the middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



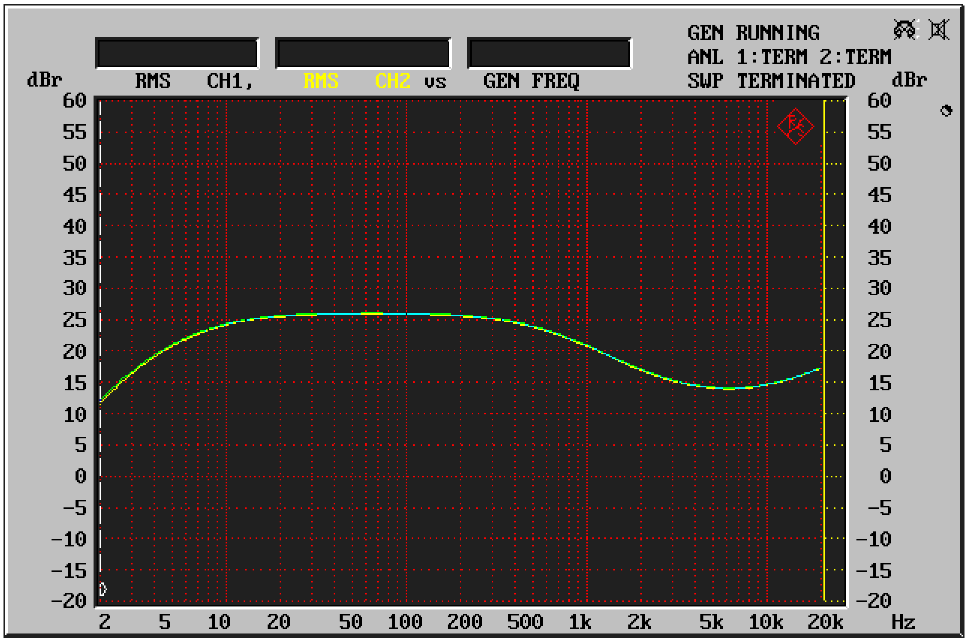
App tone controls are all at the center position. The Bass tone control is set in the fully CW position, the Mid tone control is in the middle position and the Treble tone control is in the middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 14 Vp-p.



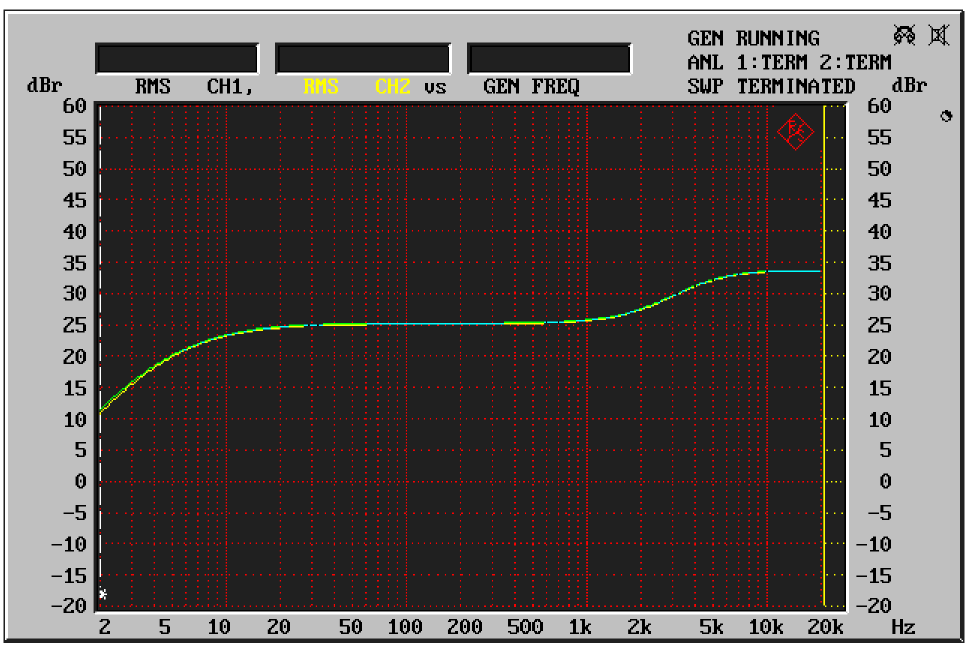
App tone controls are all at the center position. The Bass tone control is in the middle position, the Mid tone control is set in the fully CCW position and the Treble tone control is in the middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



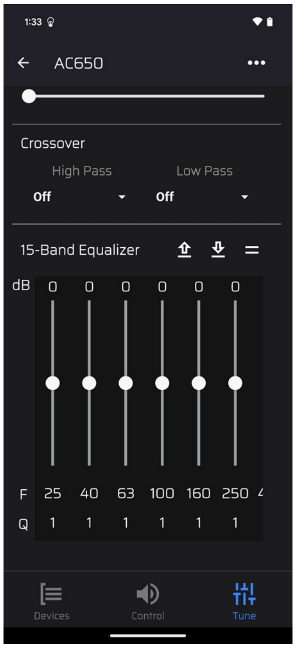
App tone controls are all at the center position. The Bass tone control is in the middle position, the Mid tone control is set in the fully CW position and the Treble tone control is in the middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 14 Vp-p.

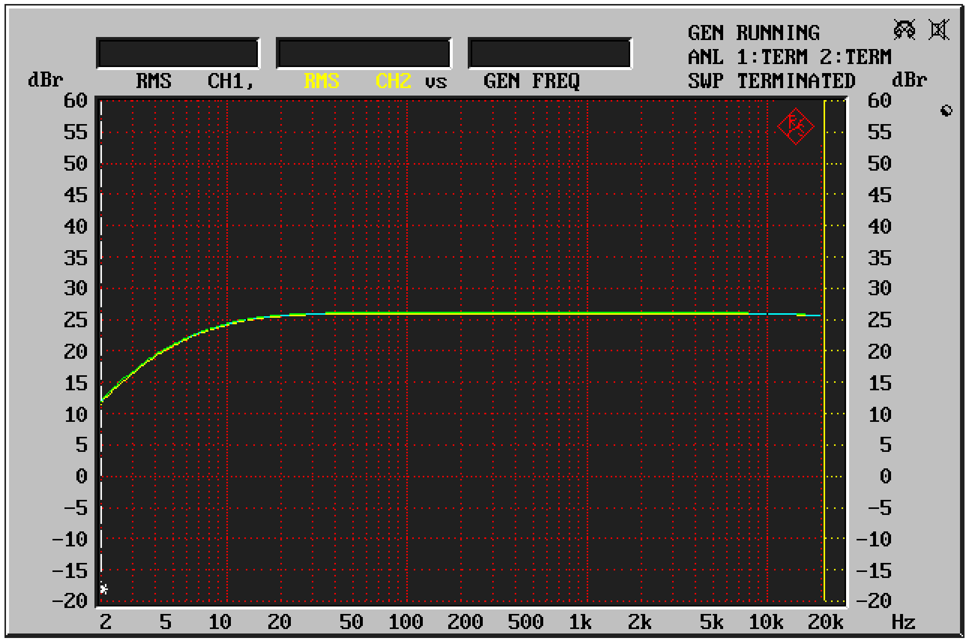


App tone controls are all at the center position. The Bass tone control is in the middle position, the Mid tone control is in the middle position and the Treble tone control is set in the fully CCW position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.

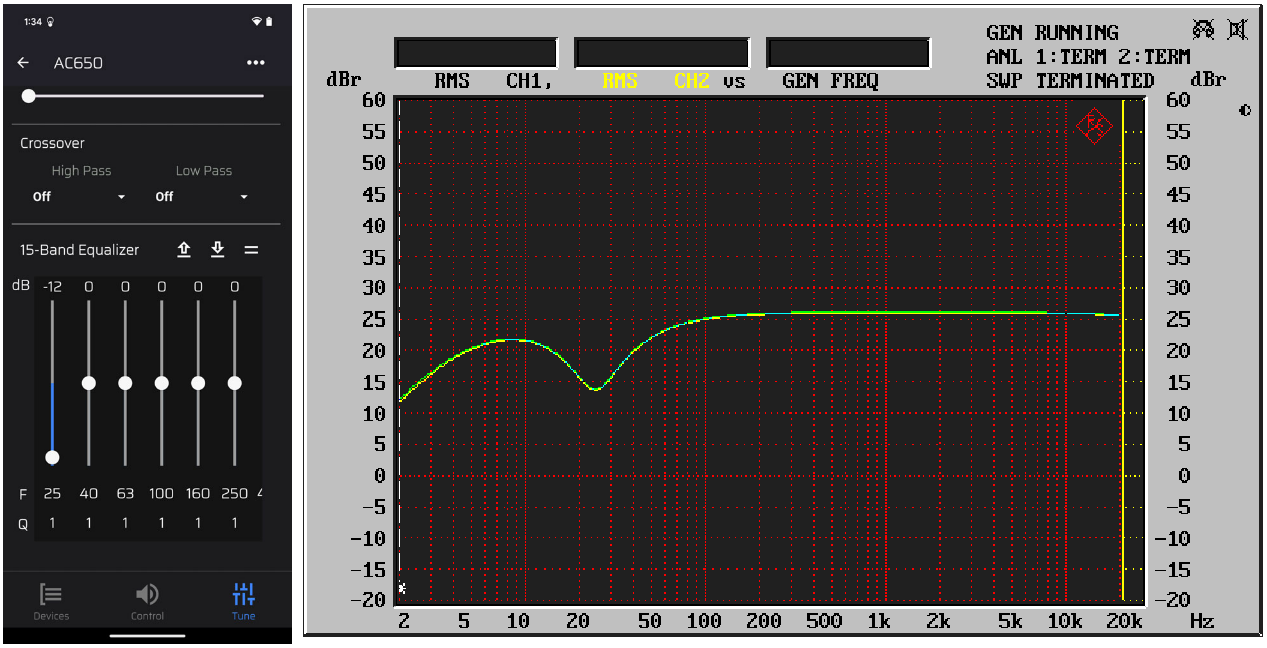


App tone controls are all at the center position. The Bass tone control is in the middle position, the Mid tone control is in the middle position and the Treble tone control is set in the fully CW position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 14 Vp-p.

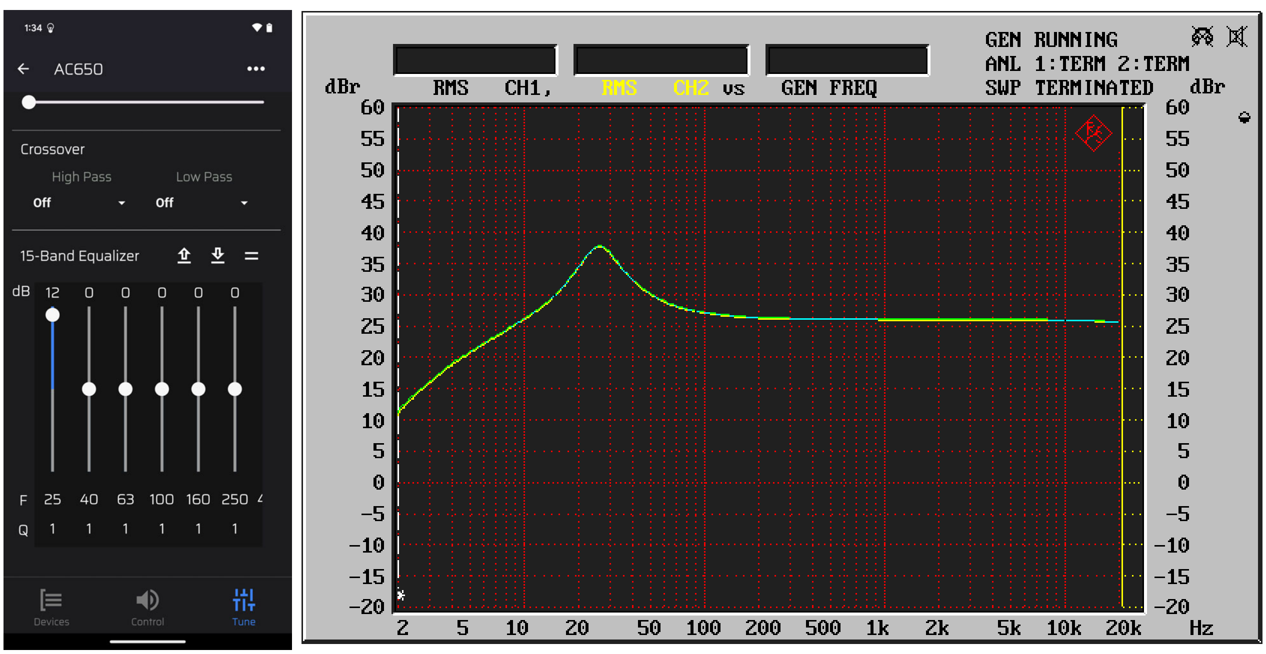




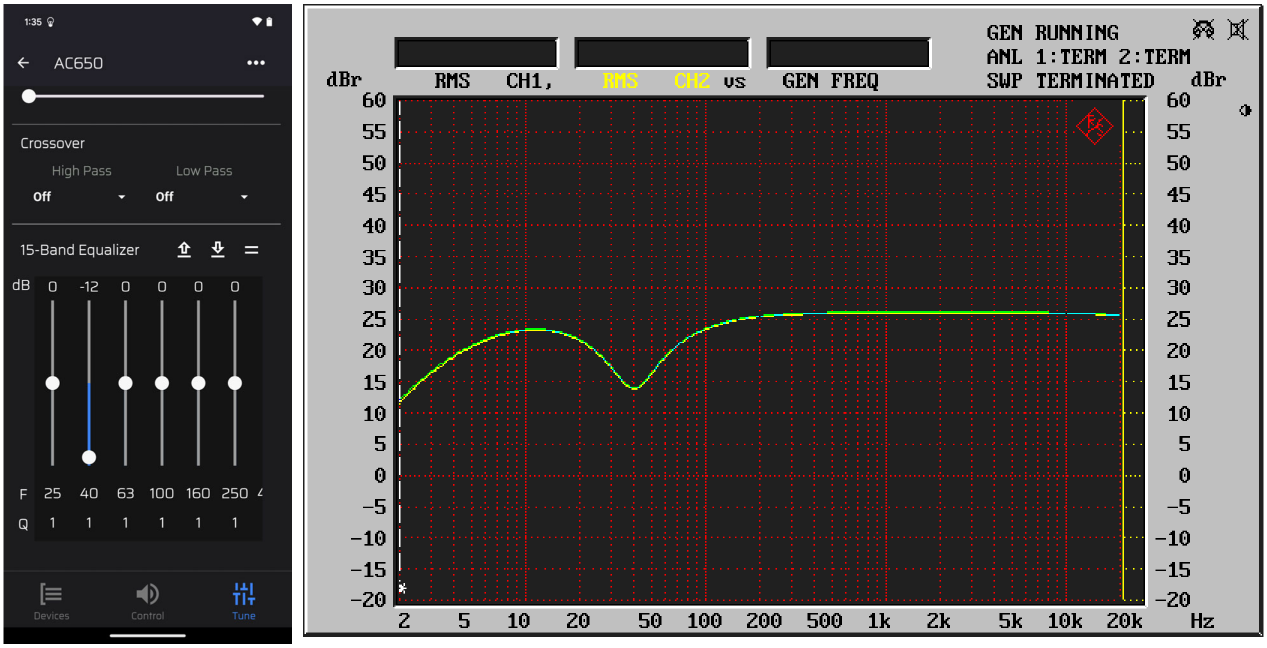
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



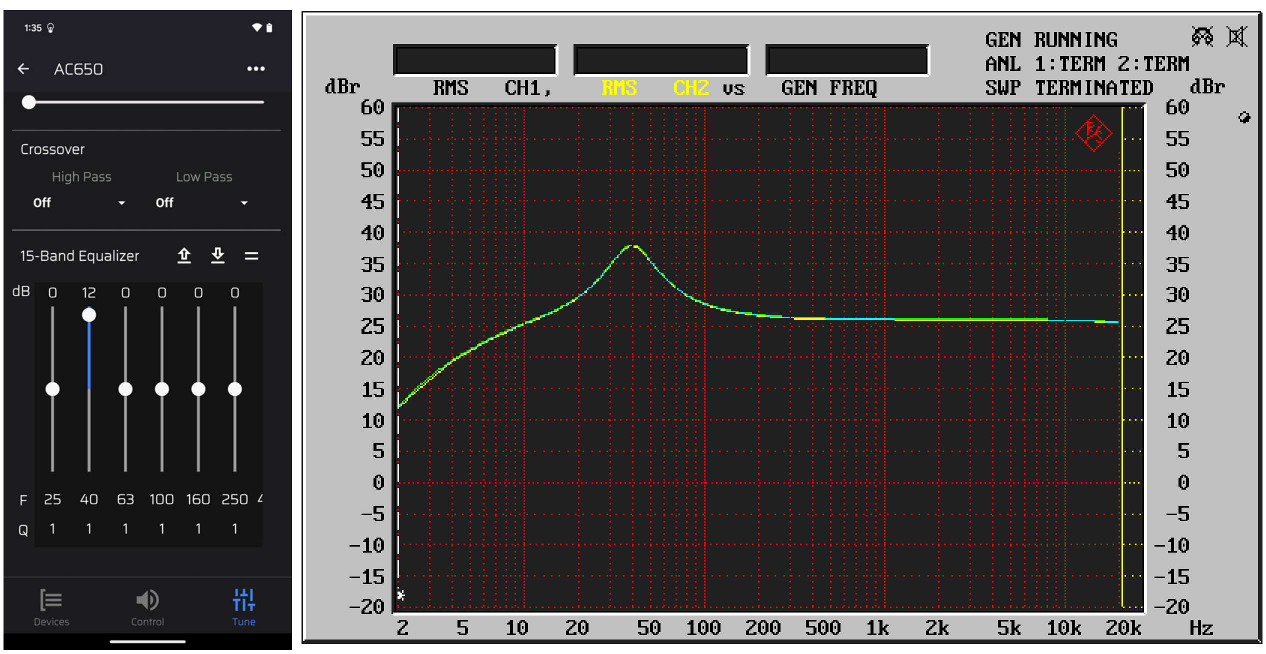
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



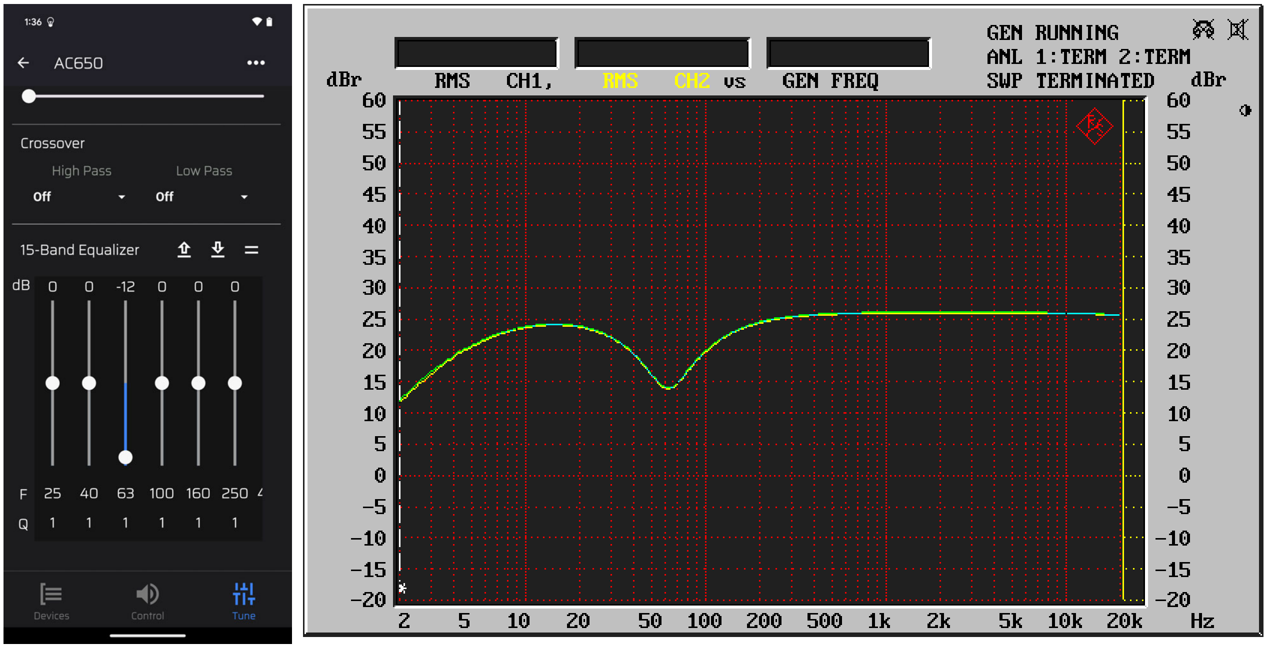
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



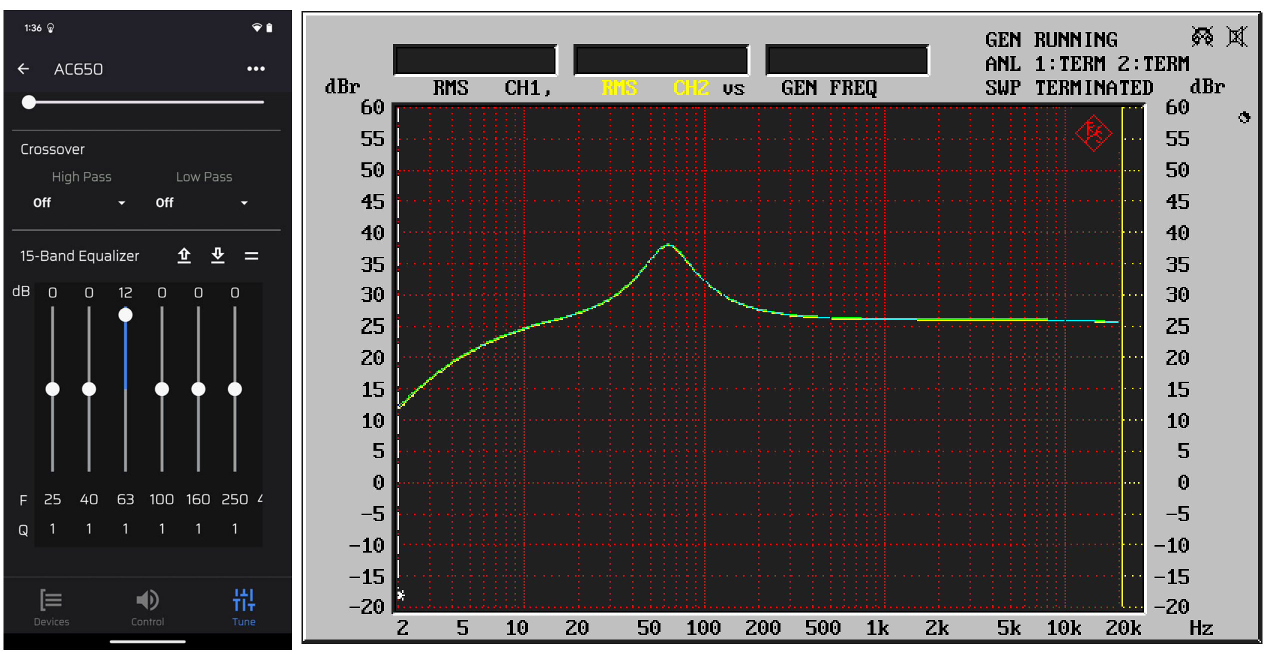
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



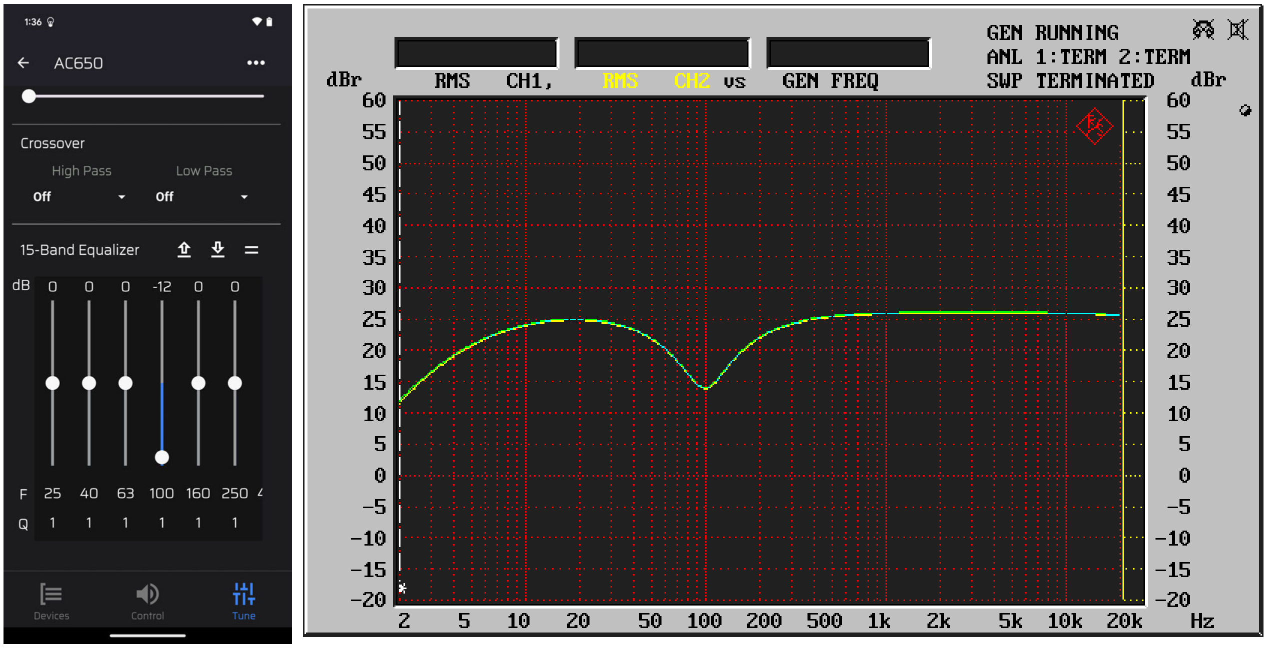
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



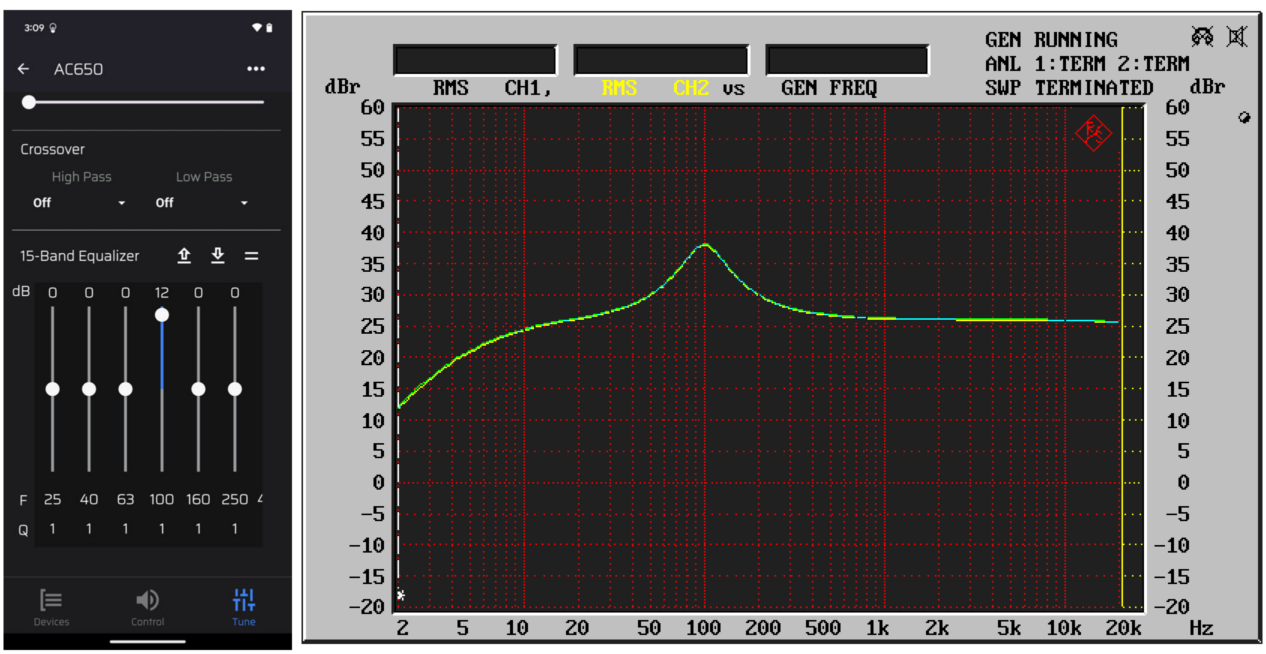
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



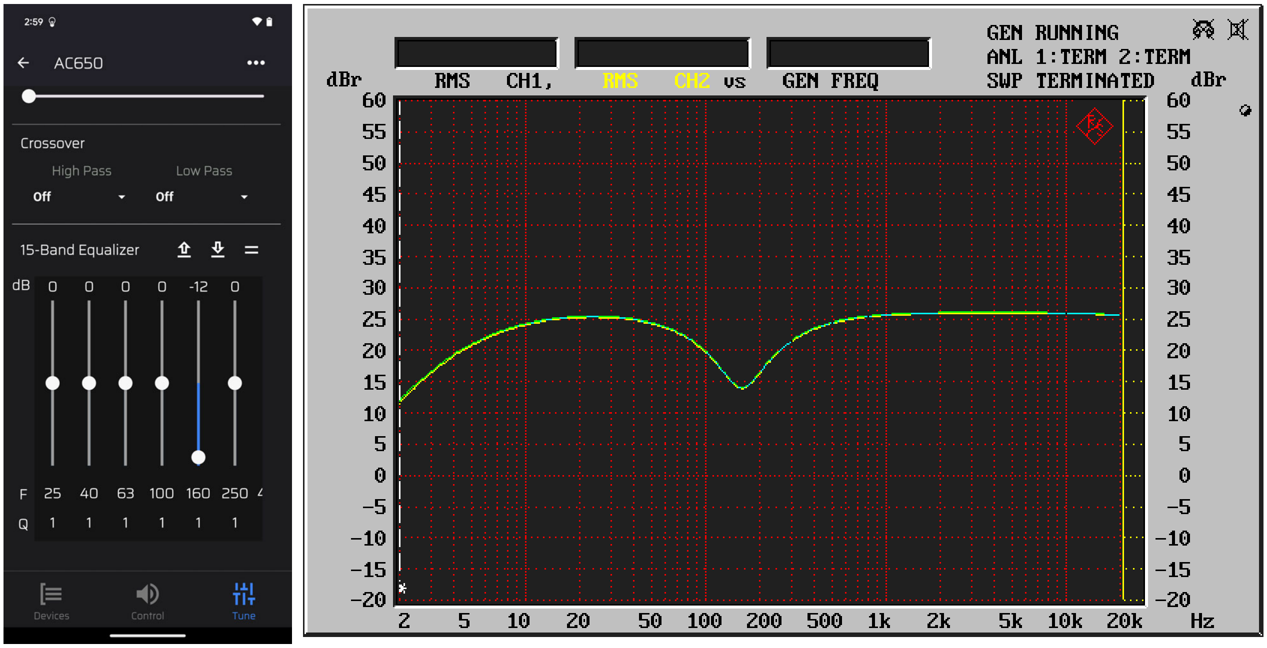
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



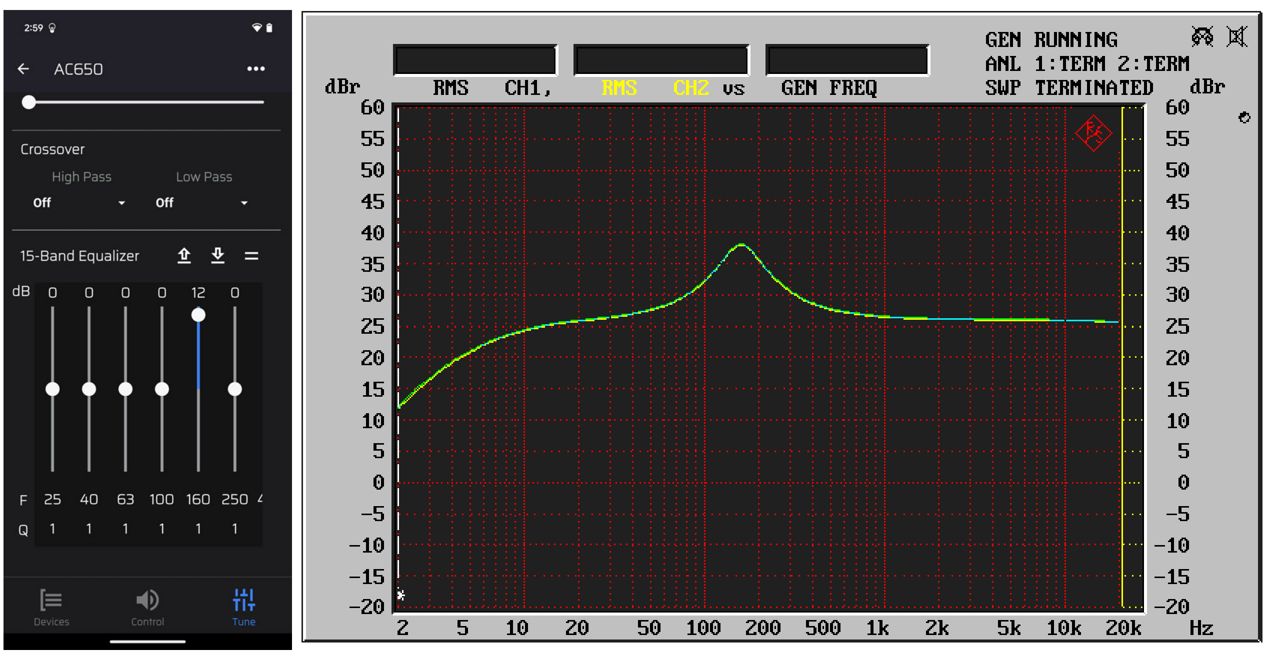
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



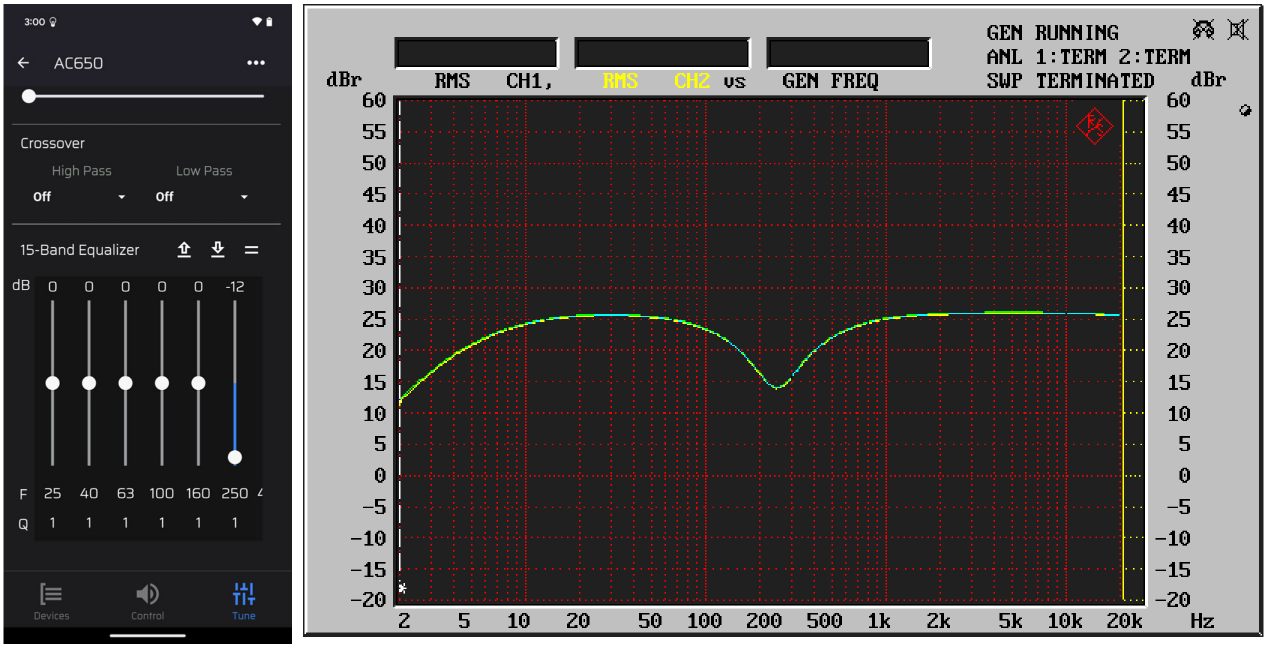
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



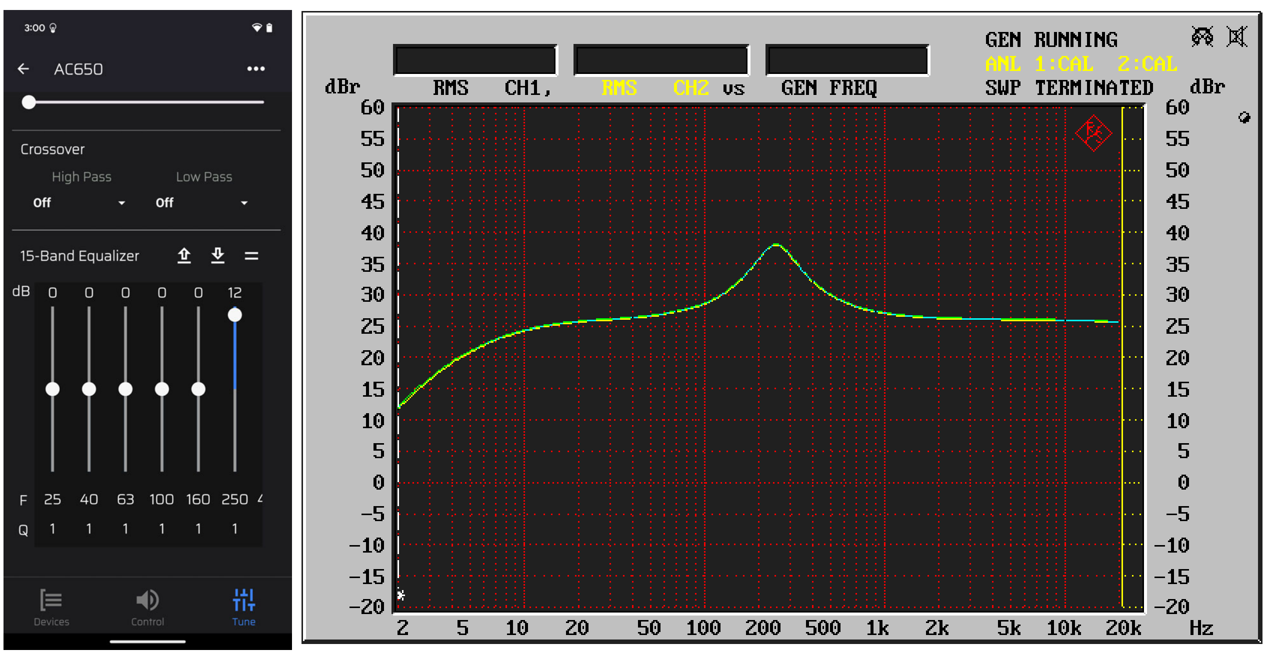
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



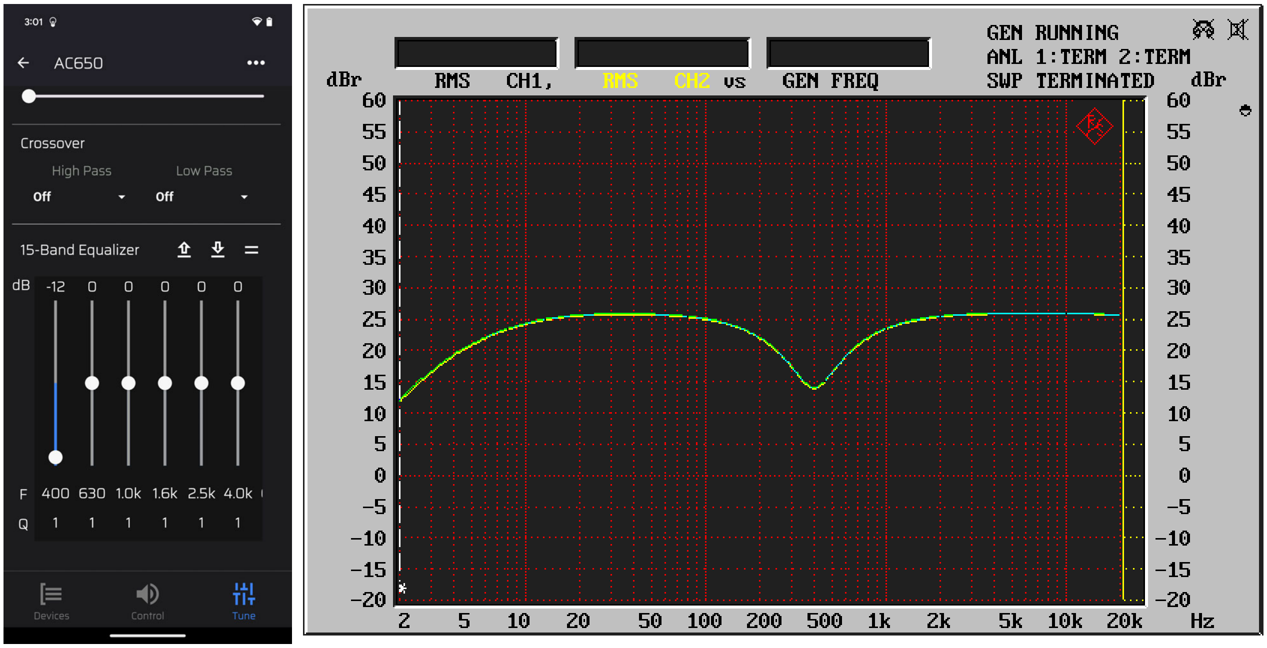
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



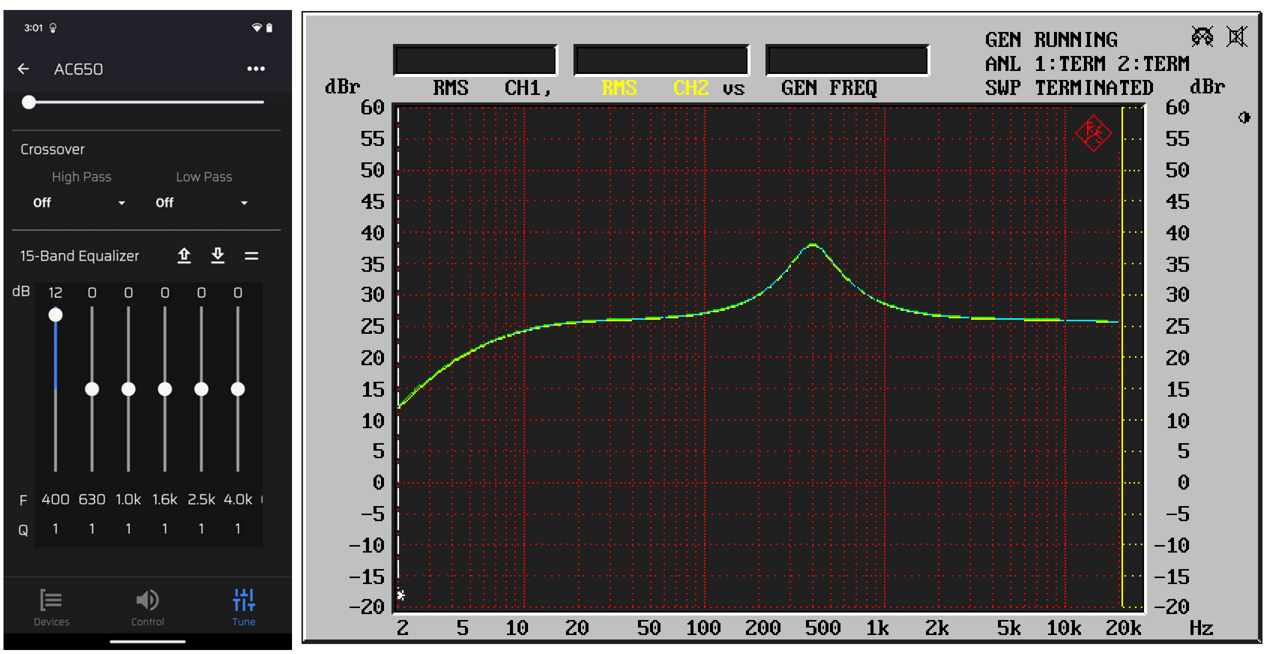
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



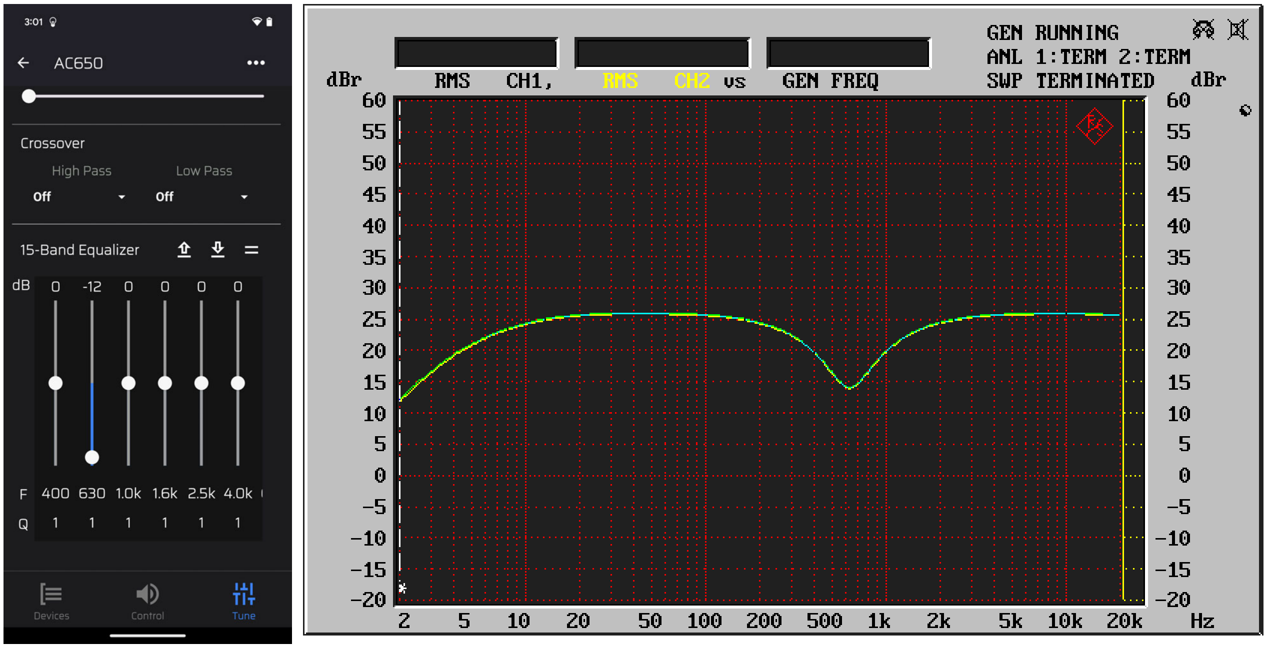
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



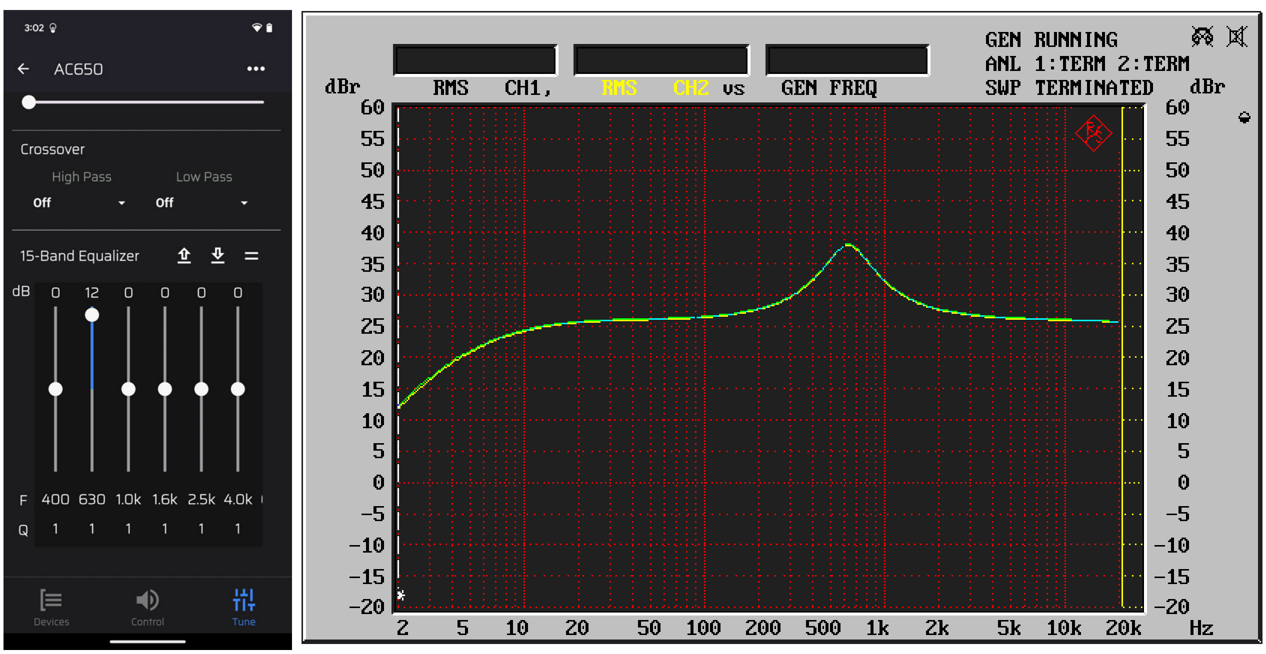
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



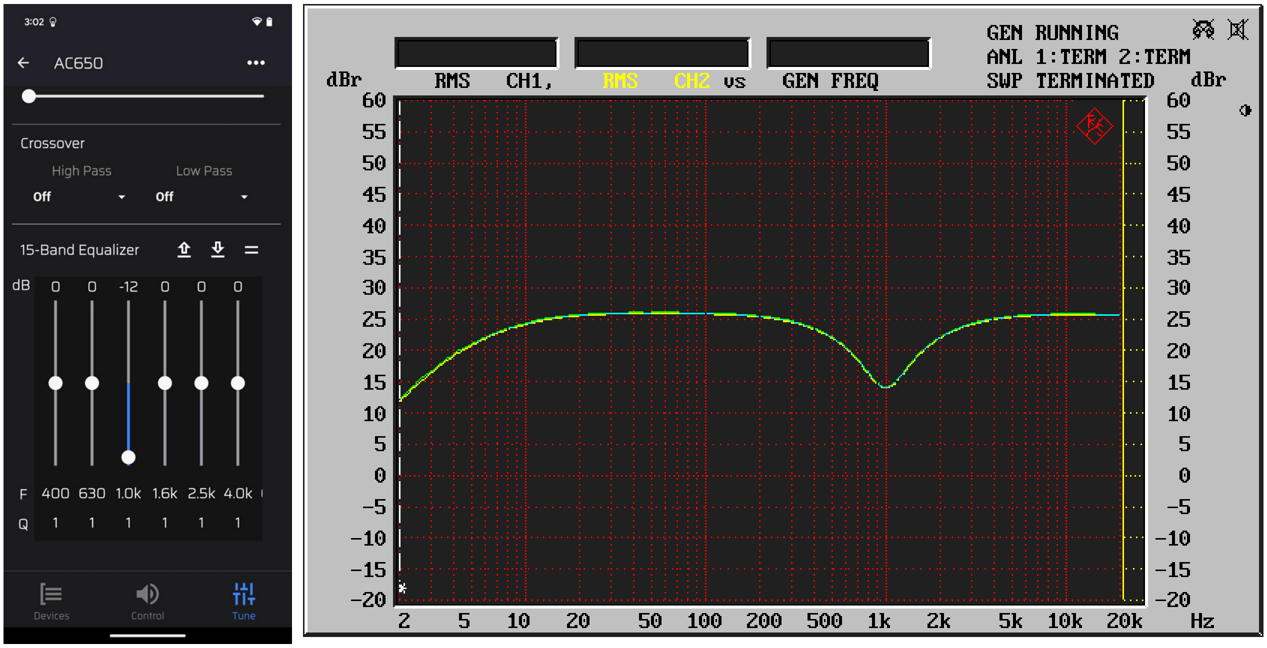
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



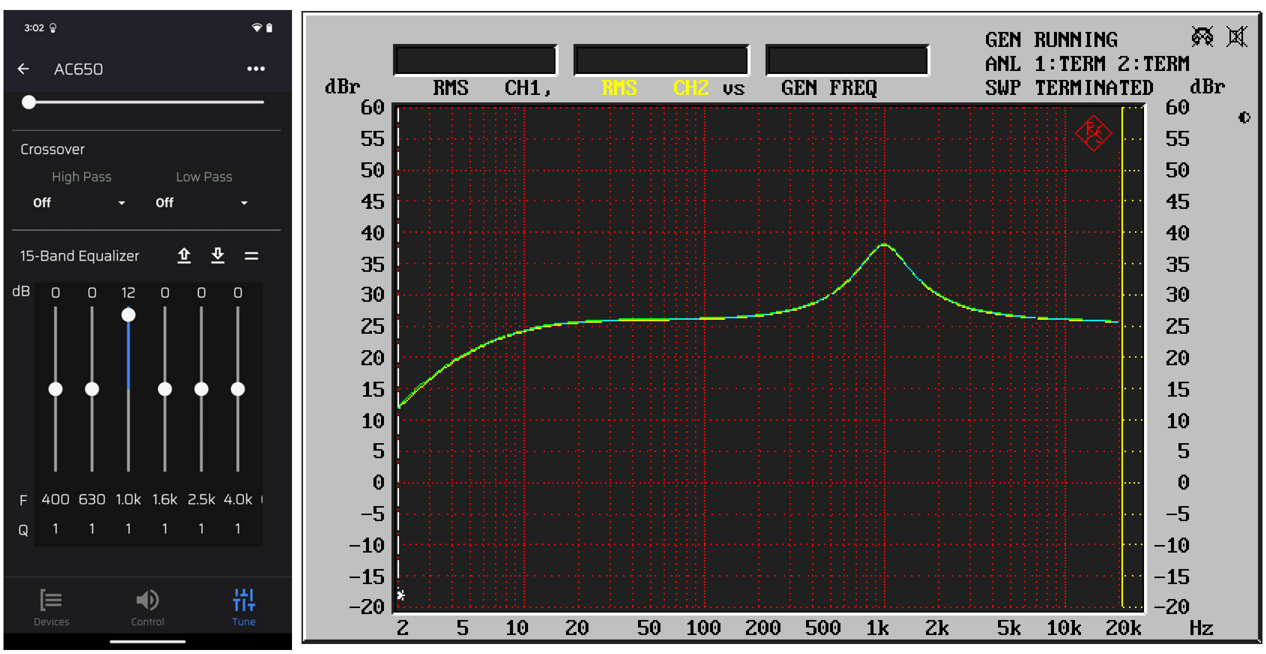
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



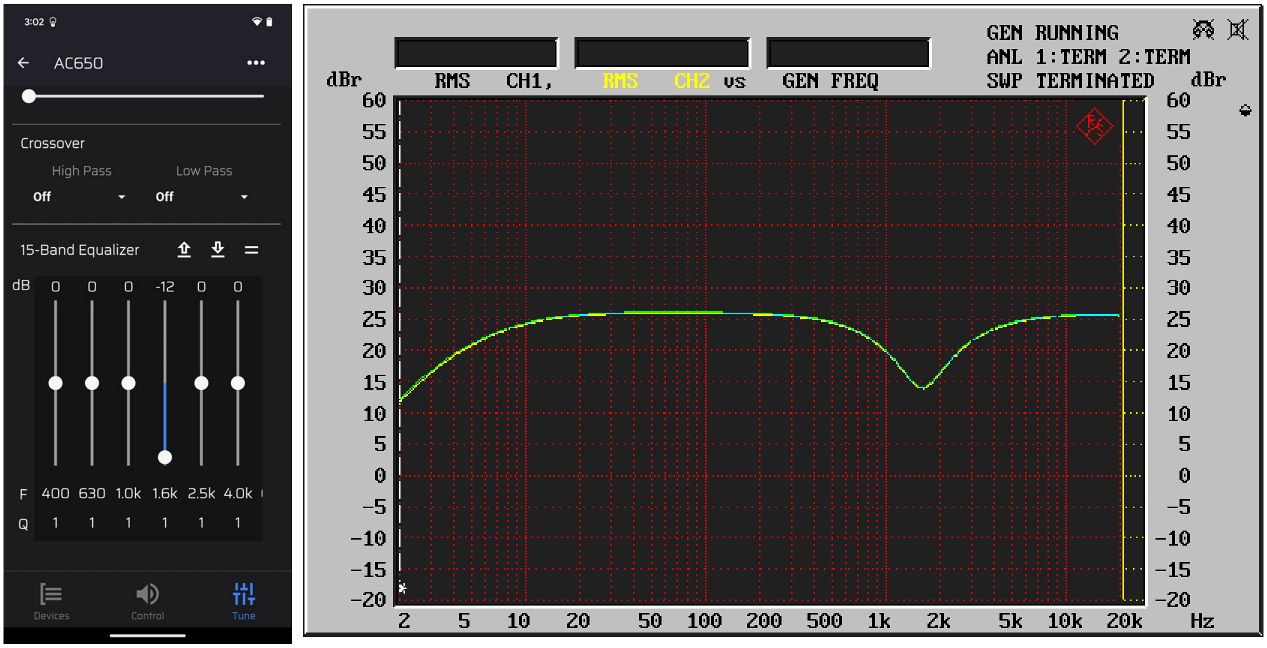
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



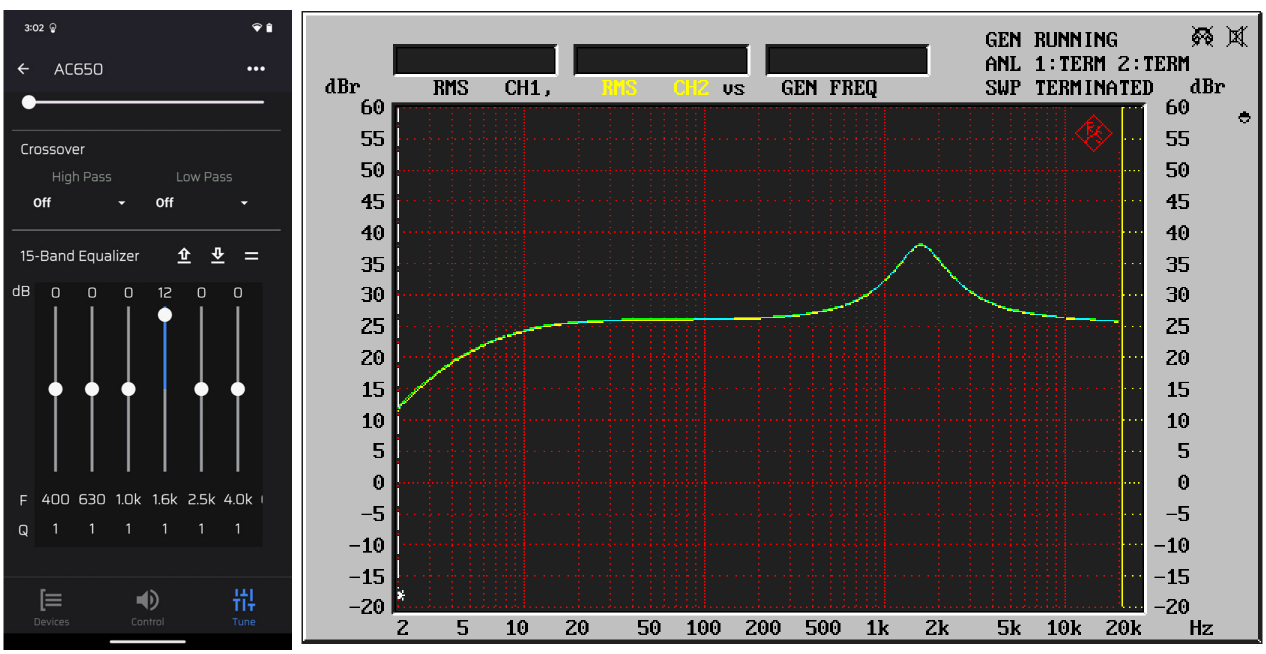
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



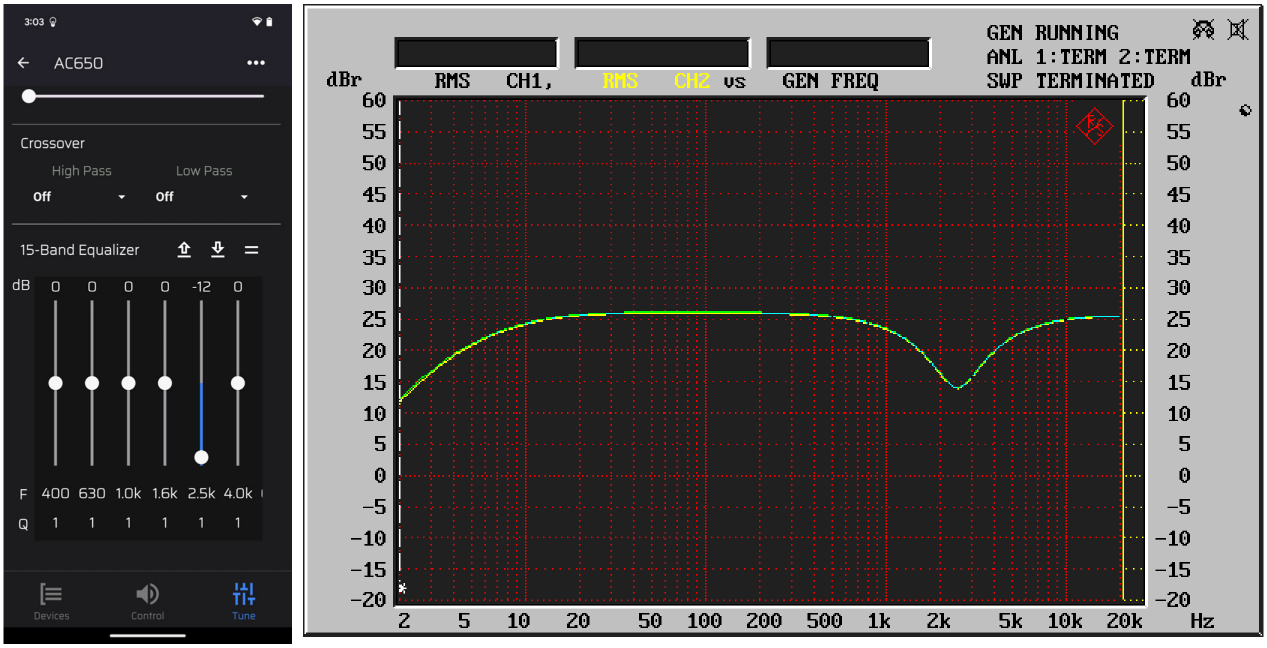
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



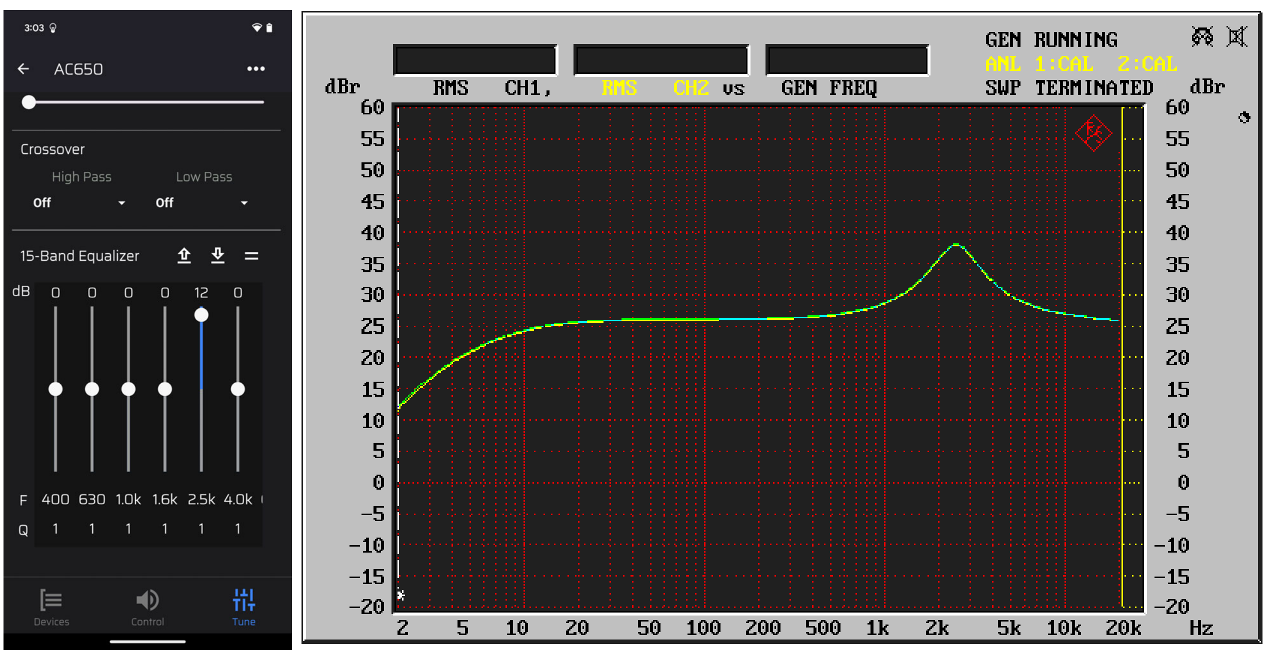
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



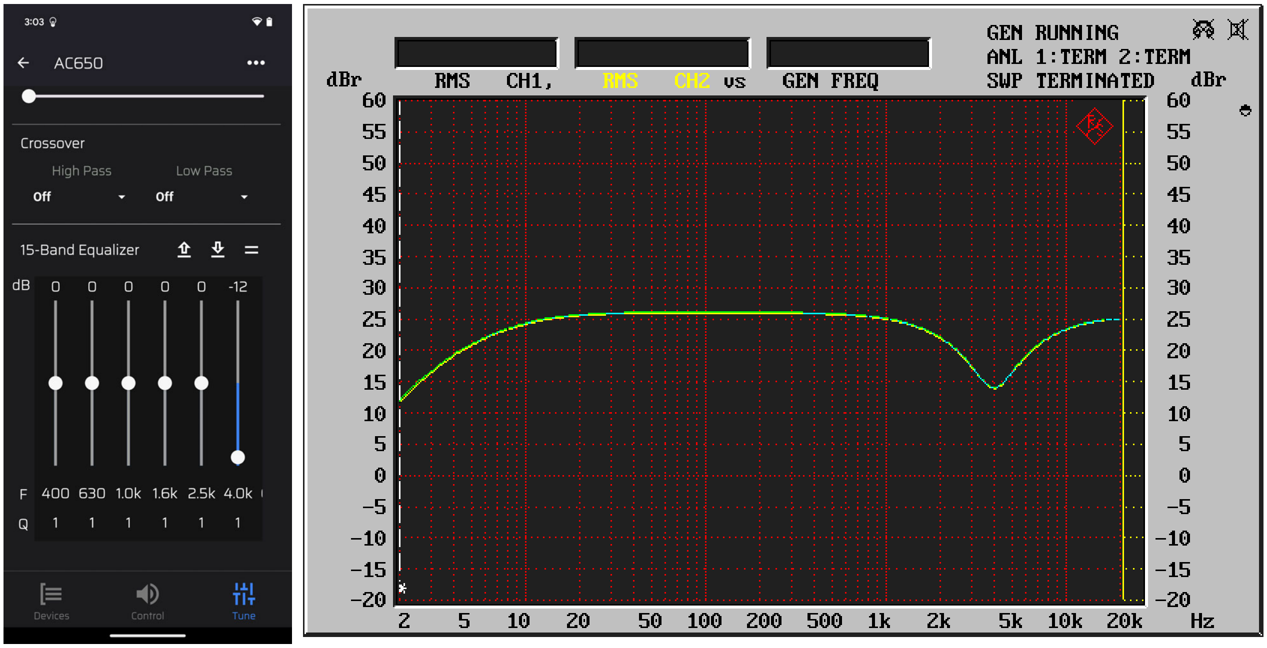
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



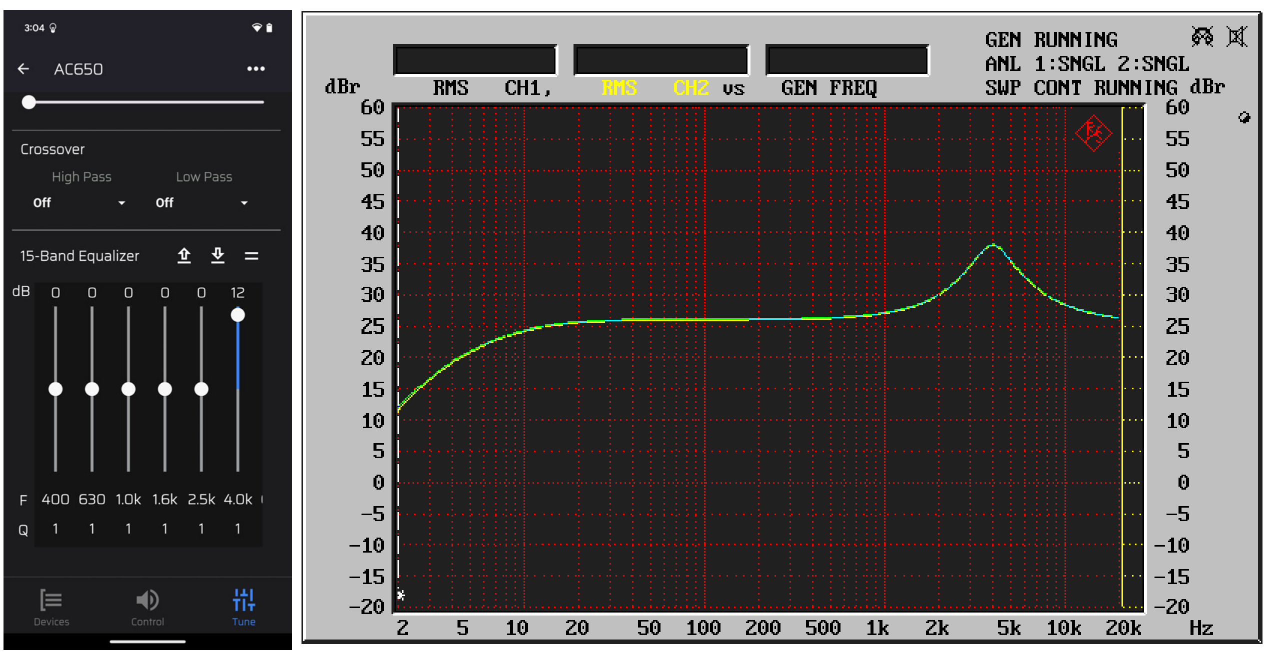
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



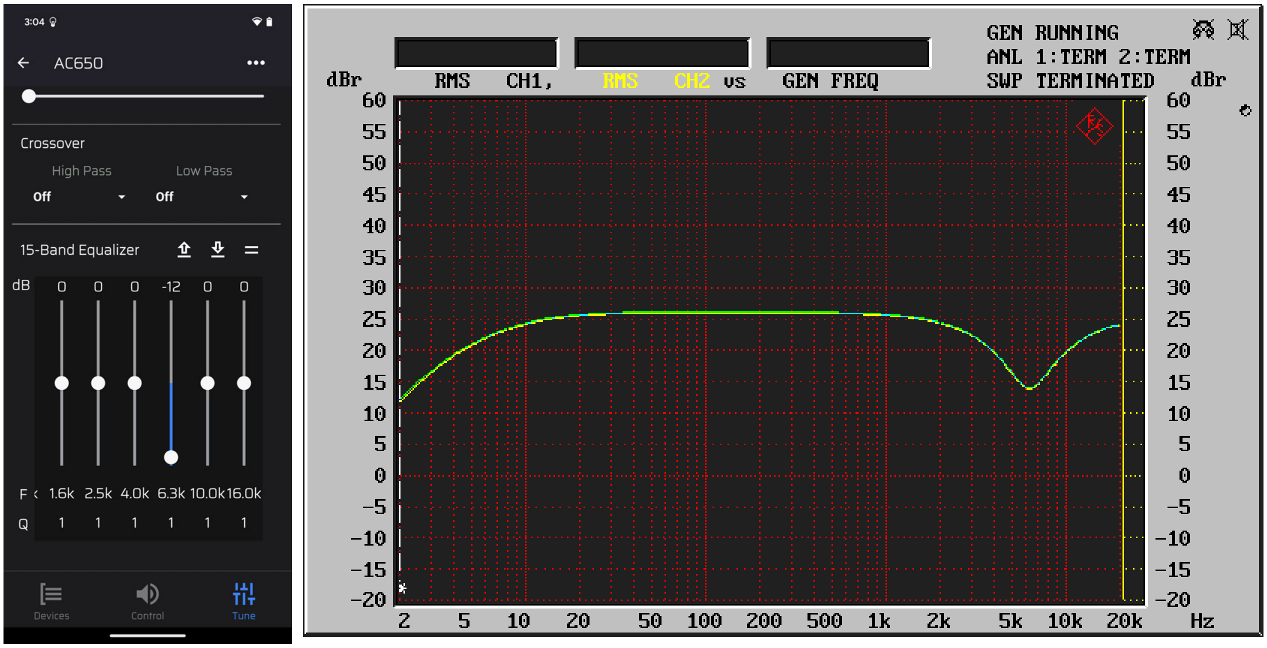
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



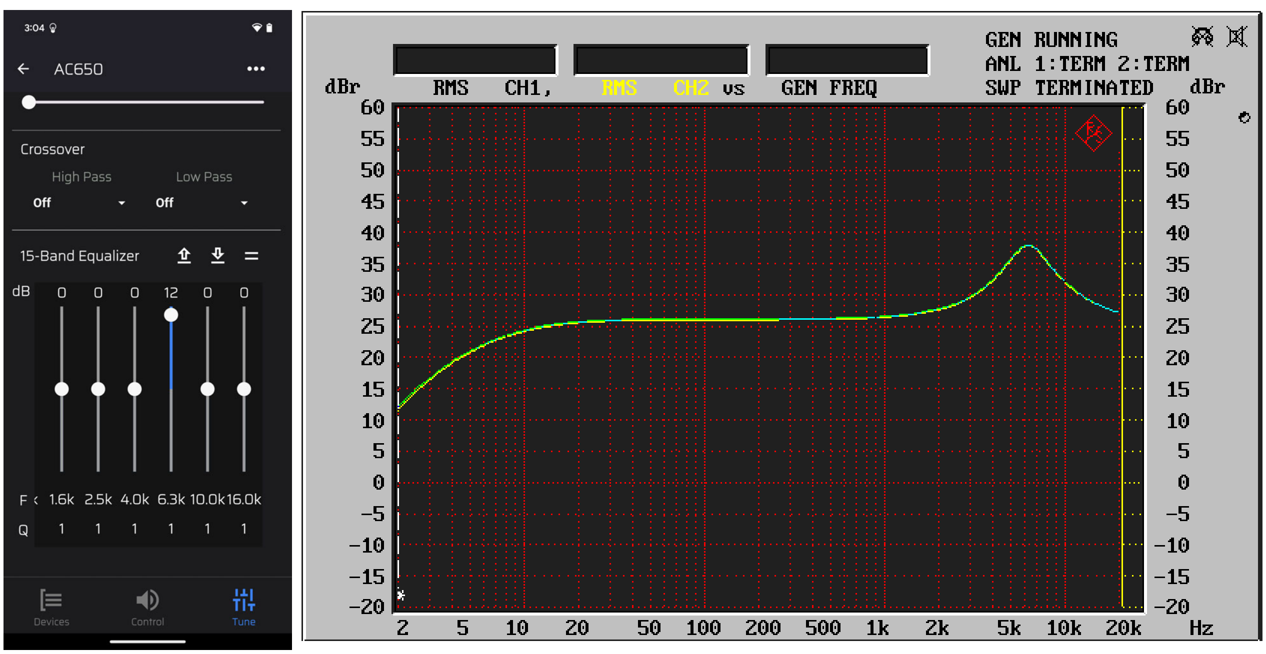
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



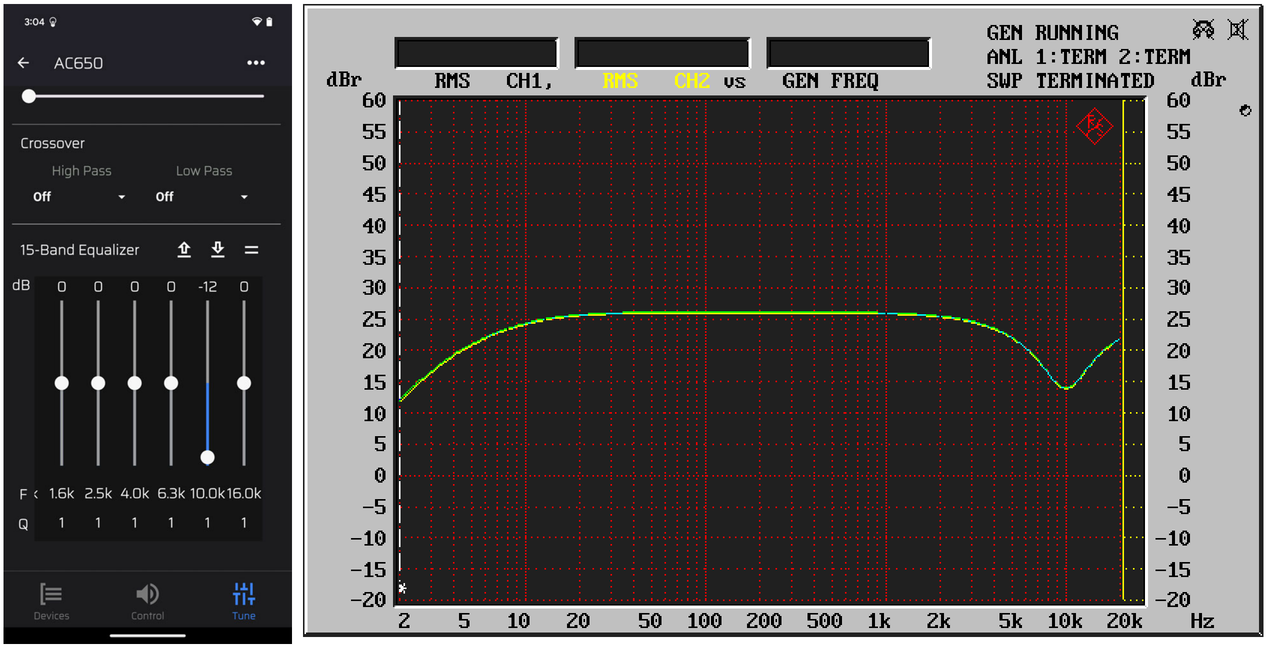
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



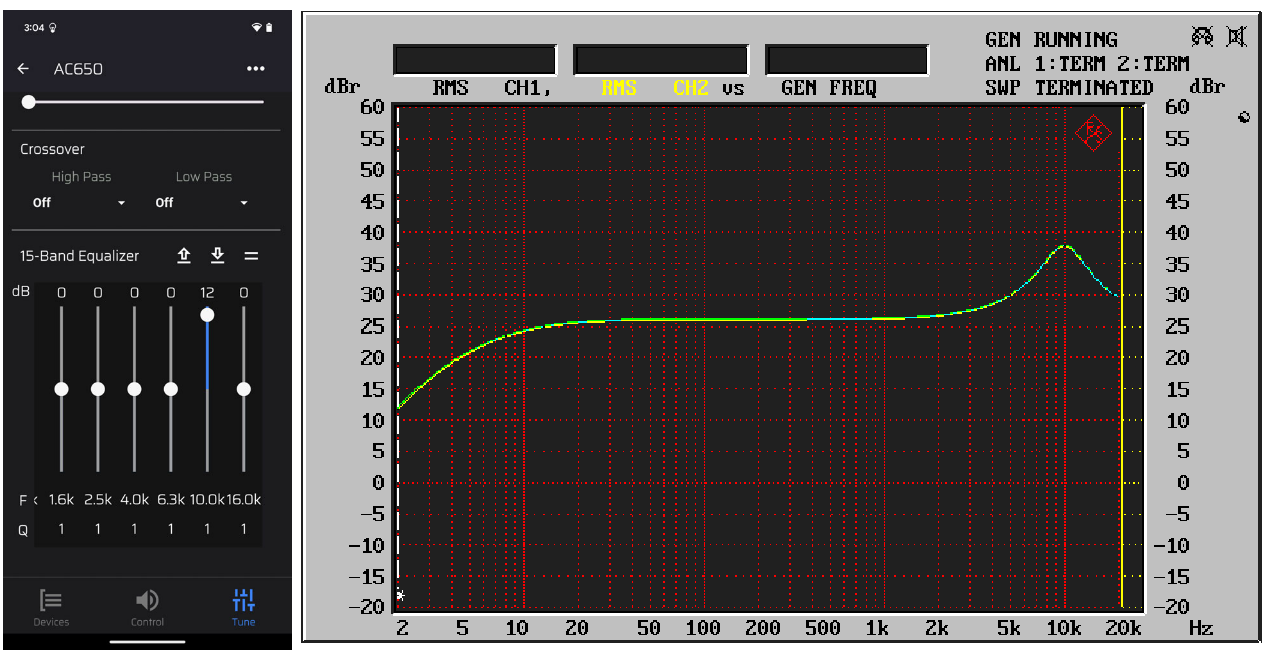
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



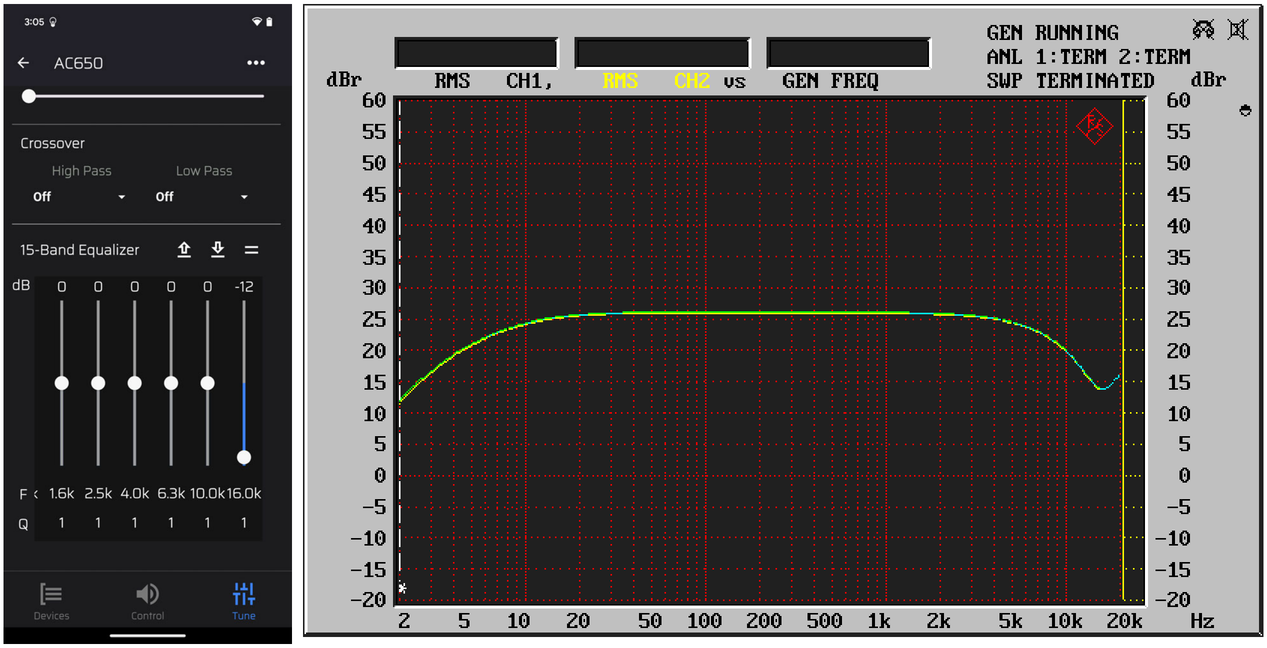
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



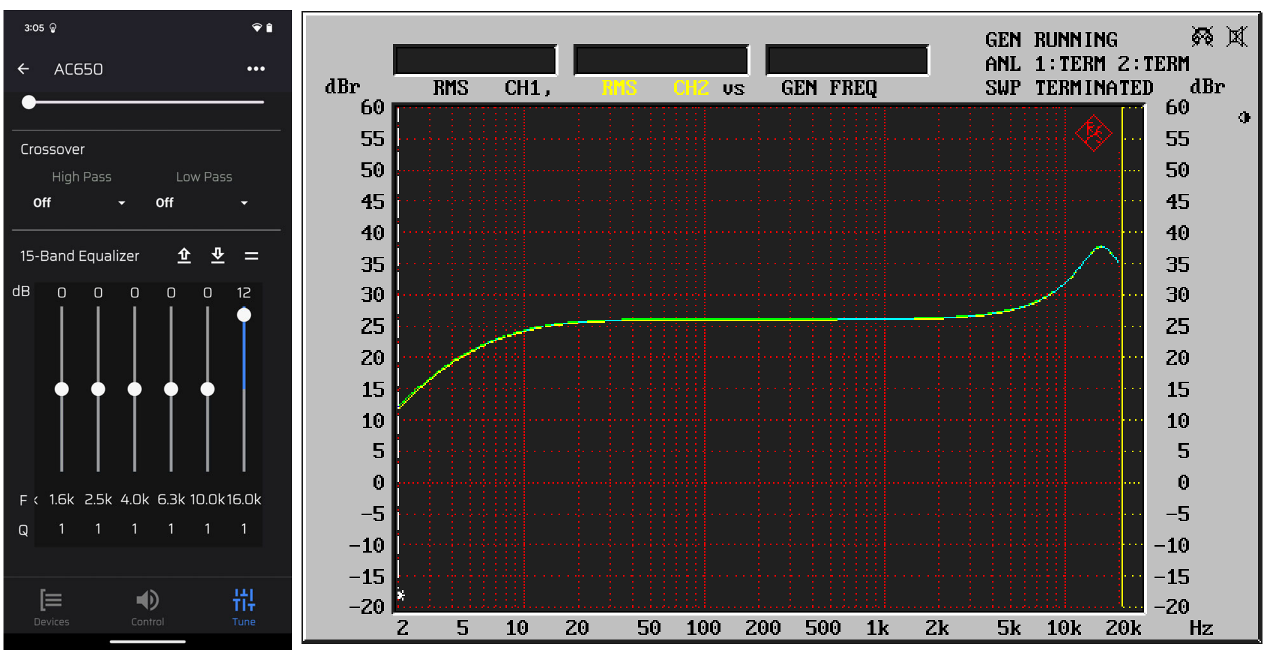
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.



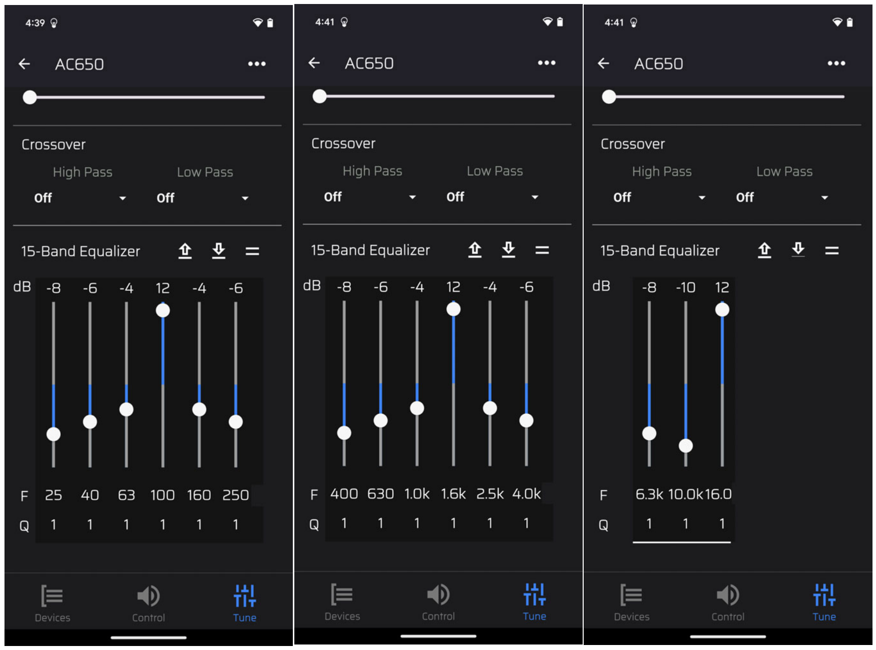
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.

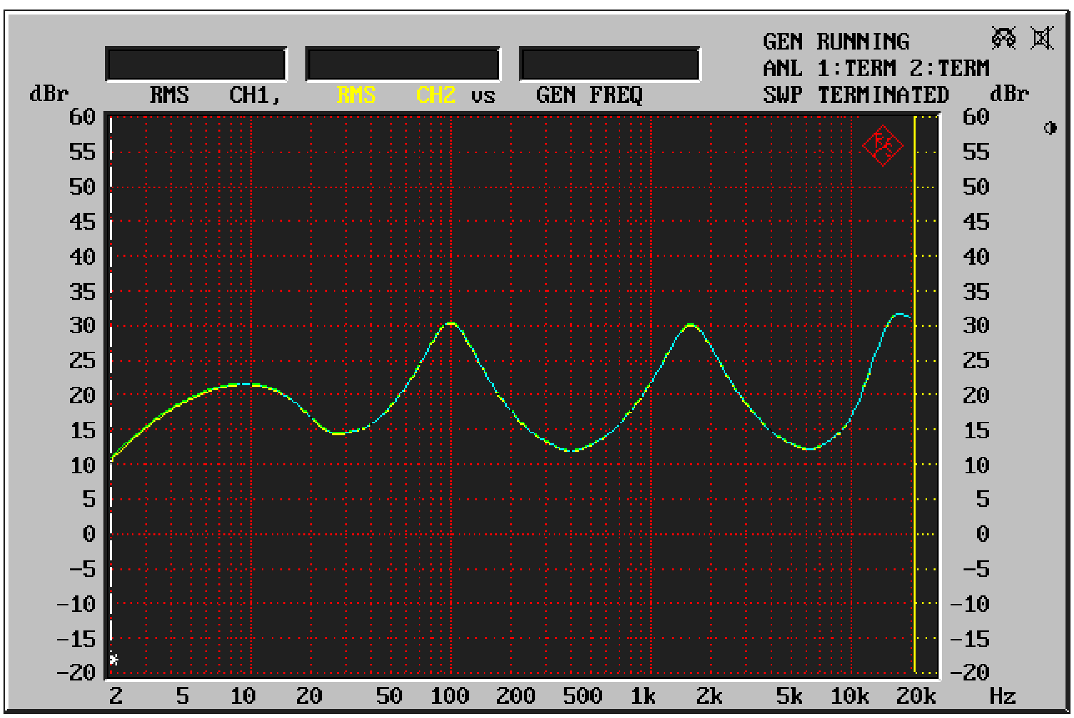


Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 5.7 Vp-p.

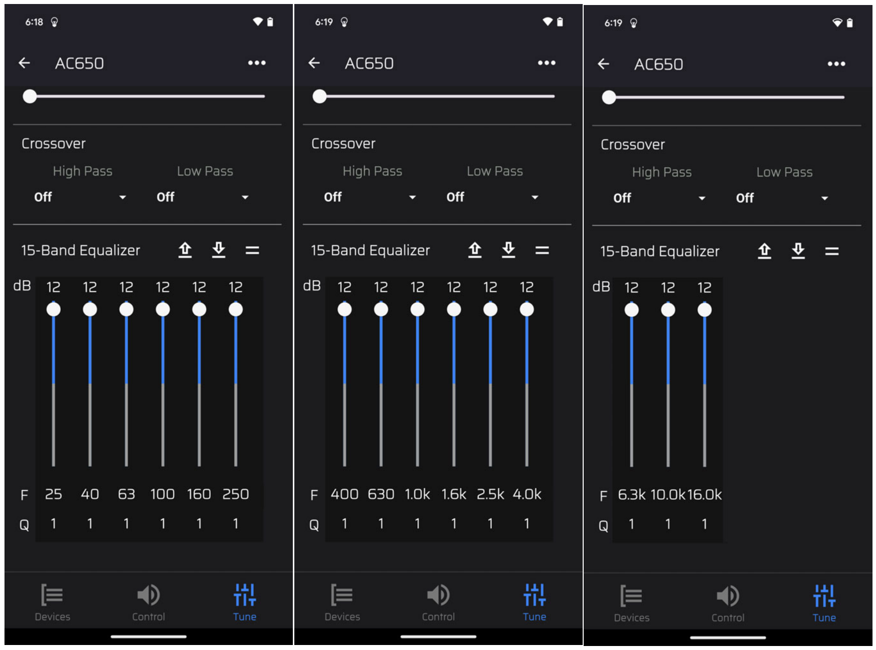


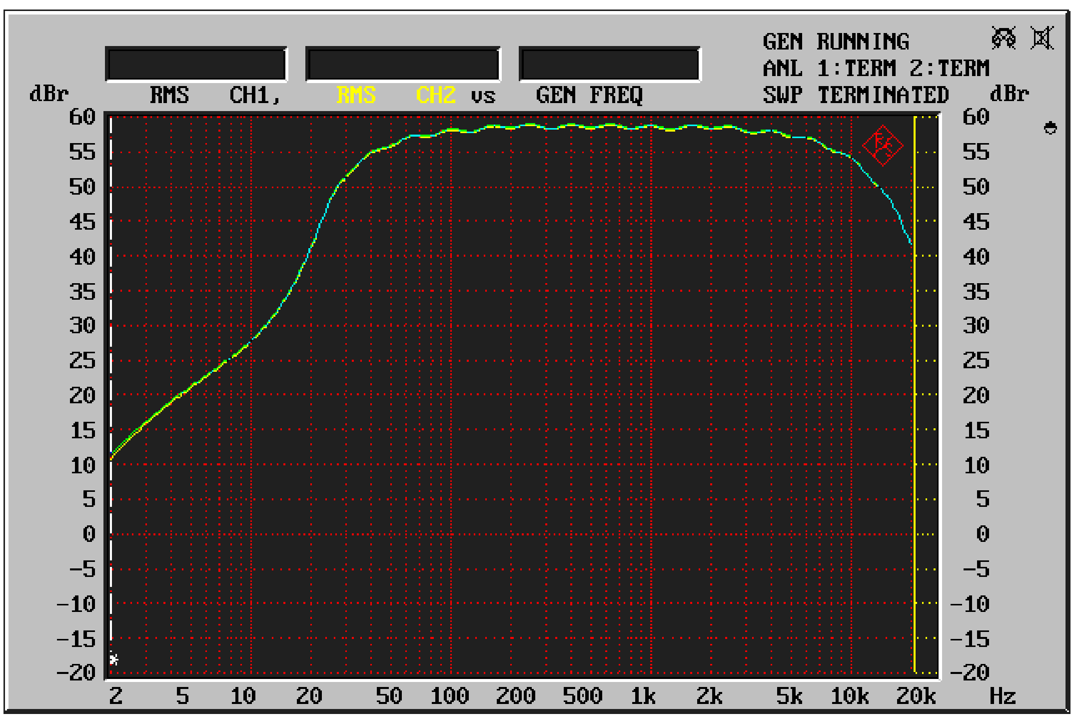
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.283 Vp-p = 0.1 Vrms; Vout(max) ≈ 22 Vp-p.



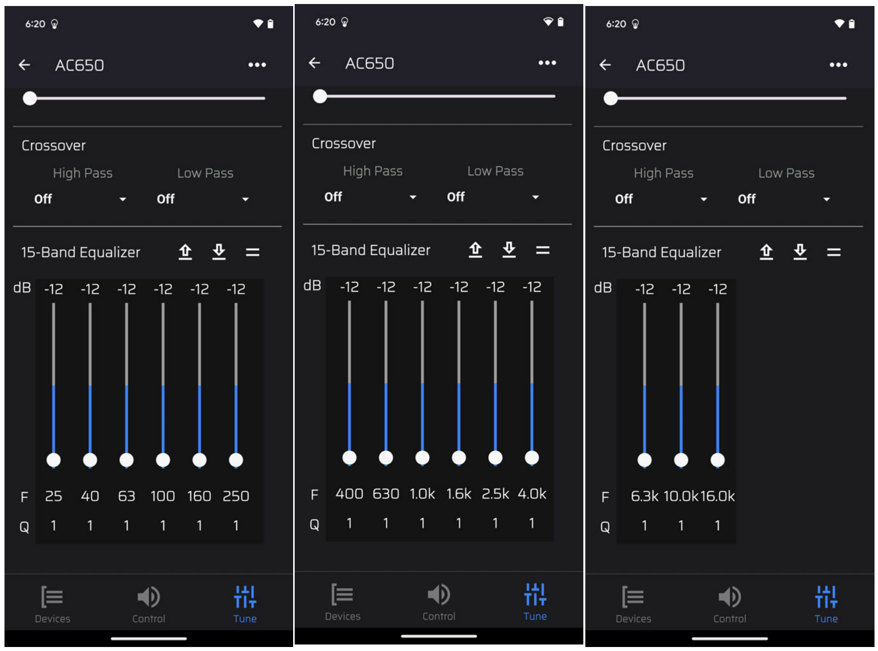


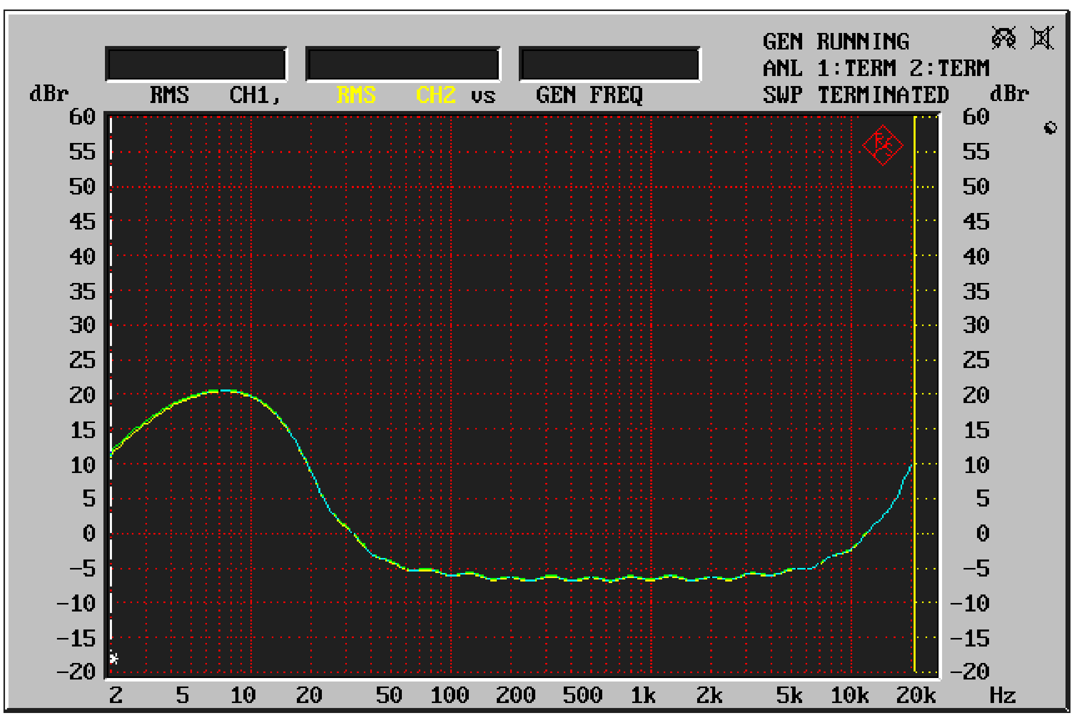
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.0283 Vp-p = 0.01 Vrms; All sliders set as shown above.





Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.0283 Vp-p = 0.01 Vrms; All sliders set to maximum (12 dB).

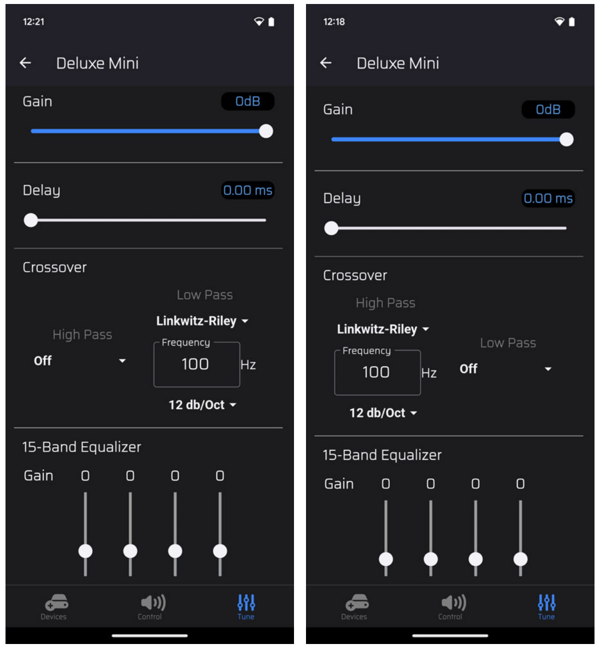




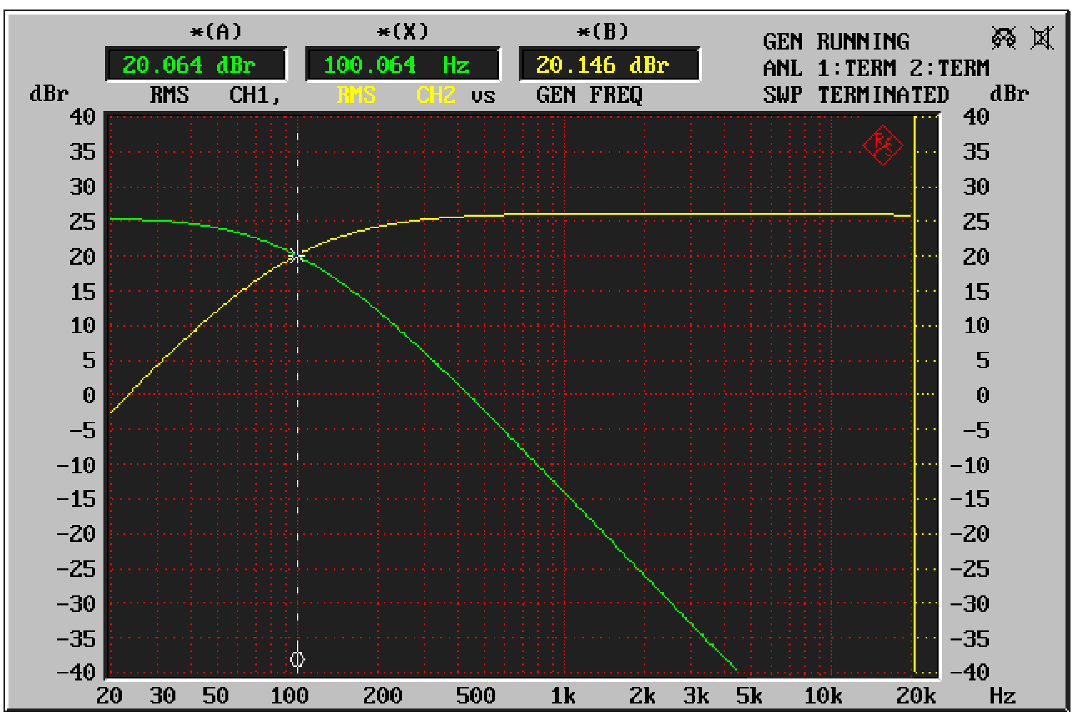
Volume Max, Channels 1 & 4 Selected, Invert Off. Front tone controls in middle position. Vin = 0.0283 Vp-p = 0.01 Vrms; All sliders set to minimum (-12 dB).

Linkwitz-Riley Crossovers

1) 12 dB/Oct Ch1 Ch4

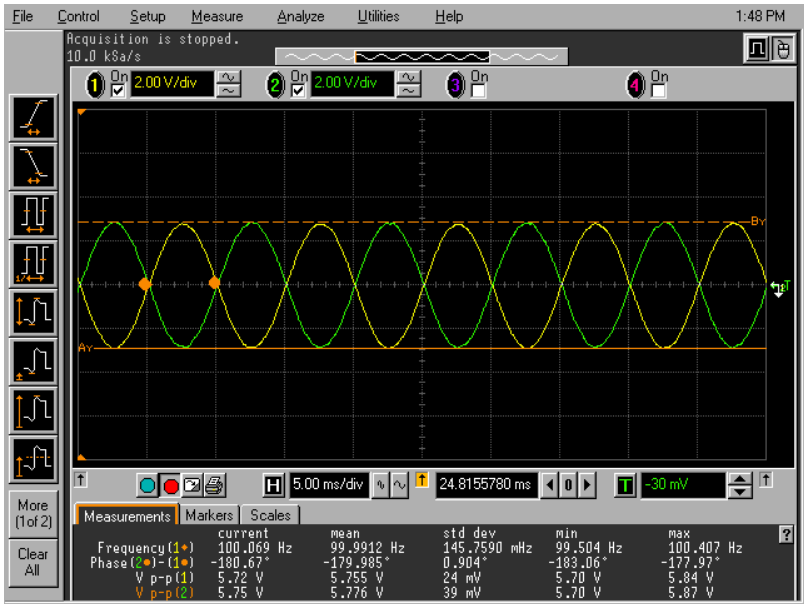


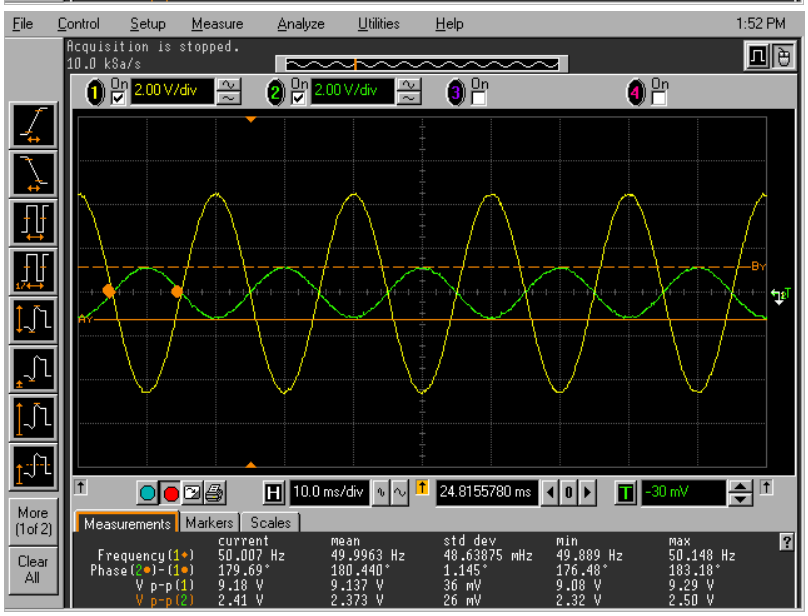
Volume Max, Channels 1 & 4 Selected, Invert Off.

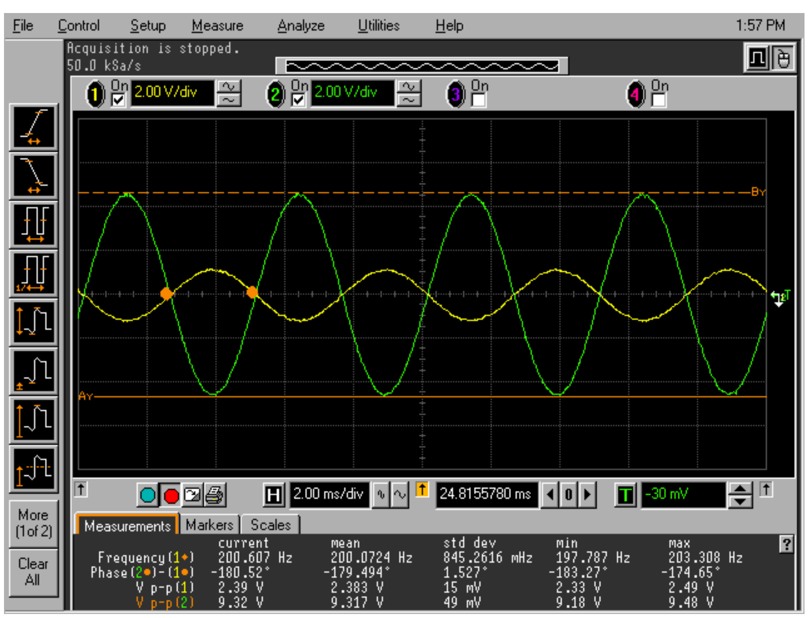


Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4.

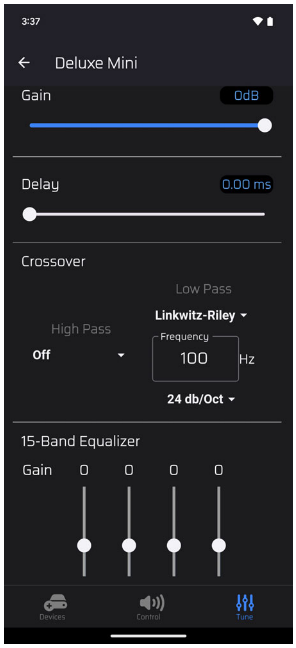
The 12 dB/Oct Linkwitz-Riley Crossover has a constant phase difference of 180° for all frequencies. Shown below are scope pictures of phase difference for 100 Hz, 50 Hz and 200 Hz where scope Ch 1 = amp Ch1 and scope Ch 2 = amp Ch 4.

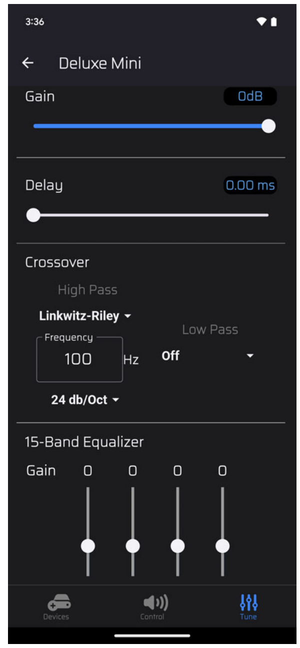




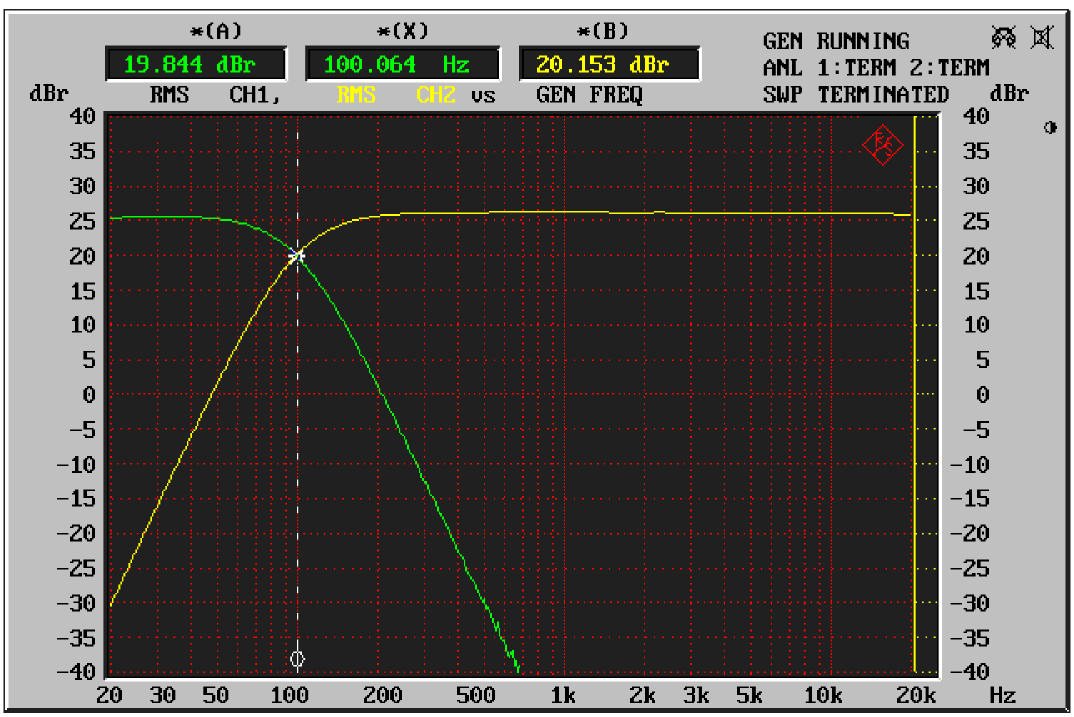


2) 24 dB/Oct Ch1 Ch4



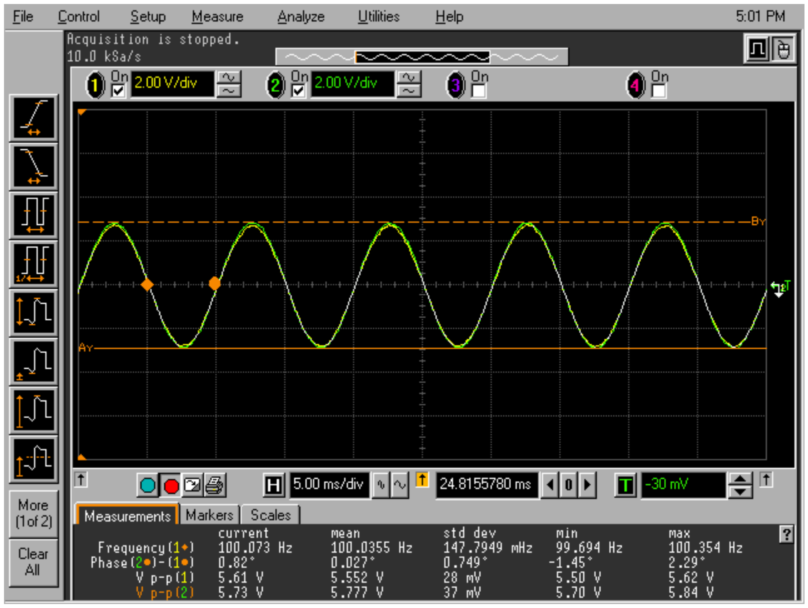


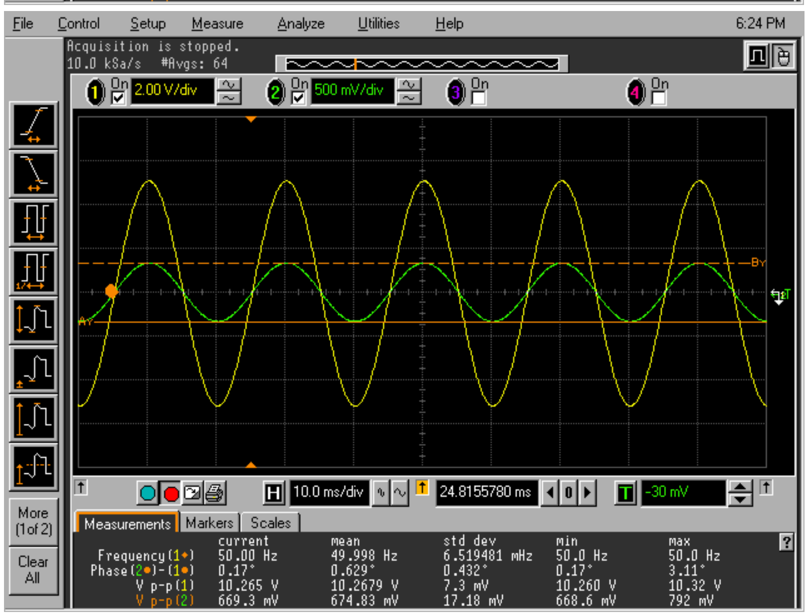
Volume Max, Channels 1 & 4 Selected, Invert Off.

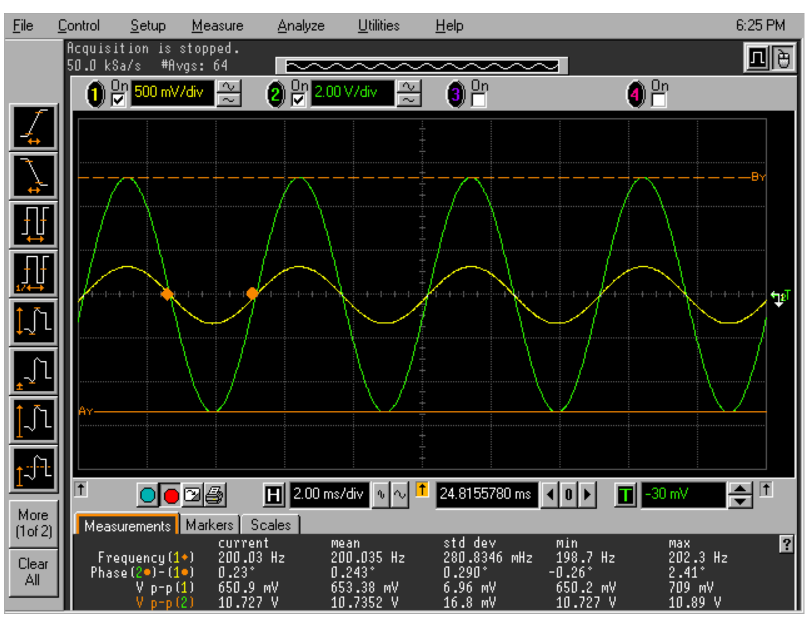


Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4.

The 24 dB/Oct Linkwitz-Riley Crossover has a constant phase difference of 0° for all frequencies. Shown below are scope pictures of phase difference for 100 Hz, 50 Hz and 200 Hz where scope Ch 1 = amp Ch1 and scope Ch 2 = amp Ch 4.

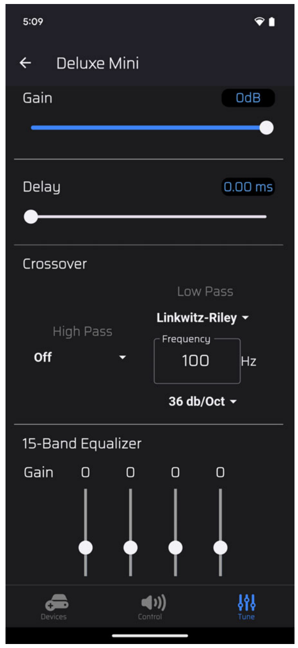




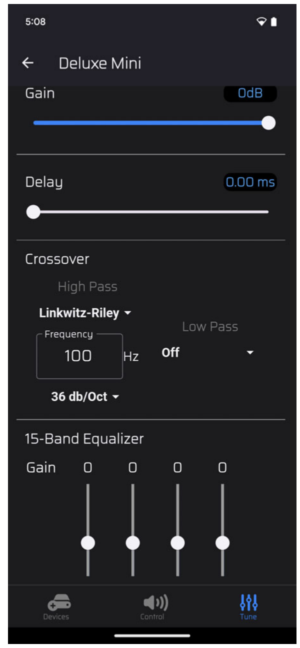


3) 36 dB/Oct

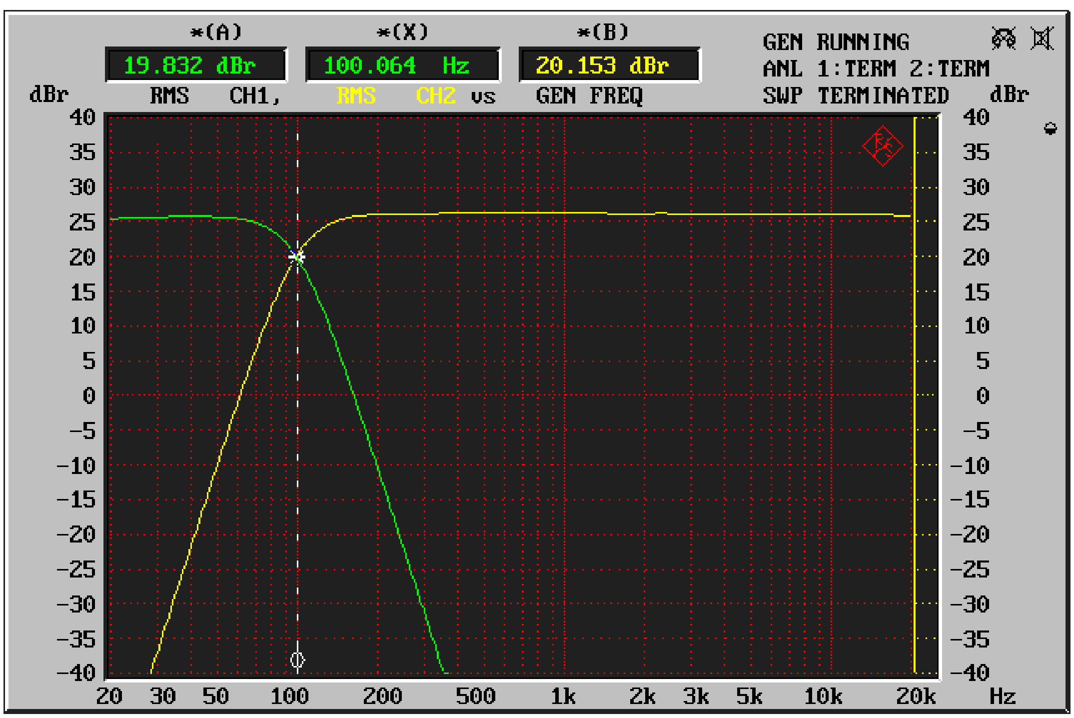
Ch1



Ch4

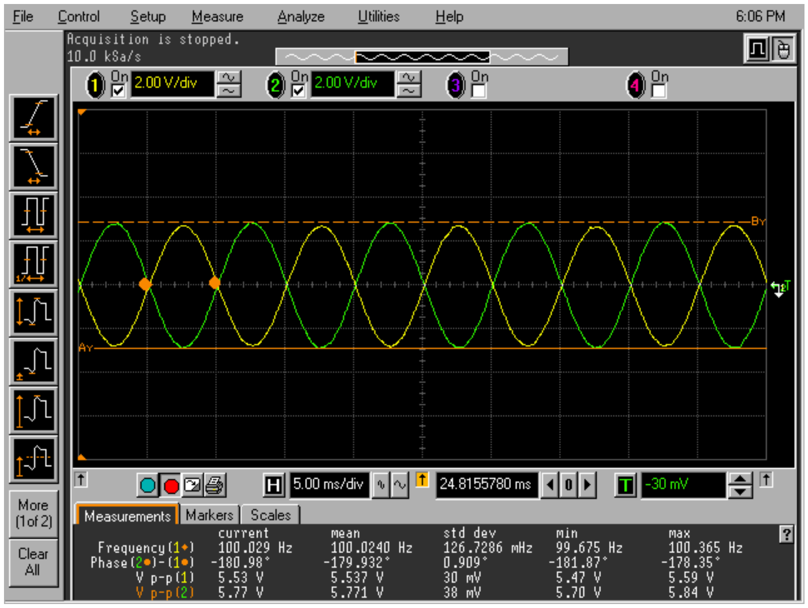


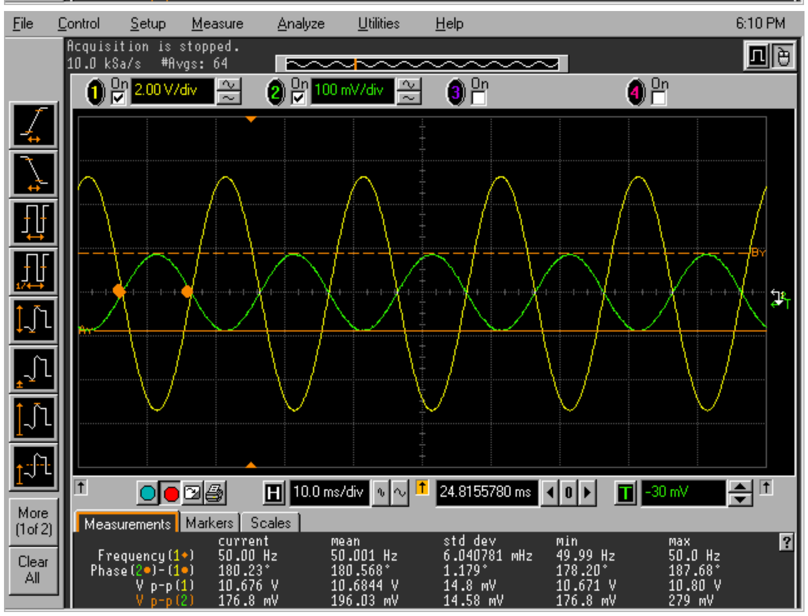
Volume Max, Channels 1 & 4 Selected, Invert Off.

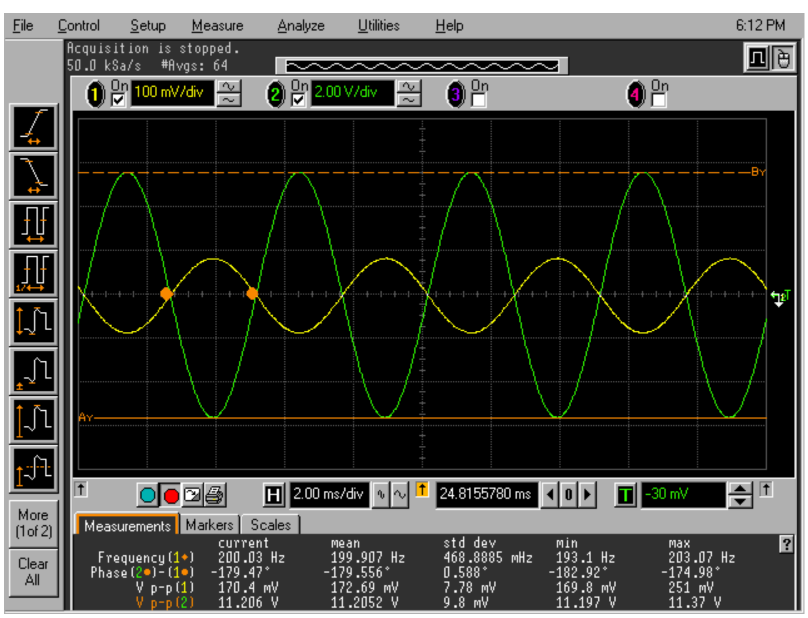


Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4.

The 36 dB/Oct Linkwitz-Riley Crossover has a constant phase difference of 180° for all frequencies. Shown below are scope pictures of phase difference for 100 Hz, 50 Hz and 200 Hz where scope Ch 1 = amp Ch1 and scope Ch 2 = amp Ch 4.



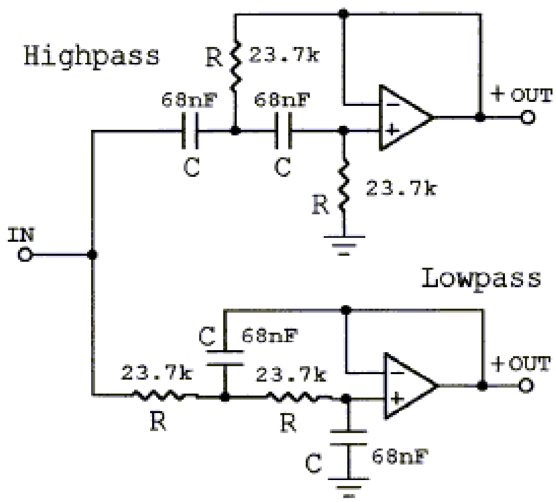




4) Issues with 12 dB/Oct and 36 dB/Oct Linkwitz-Riley Crossovers

a) From Linkwitz's web site: https://www.linkwitzlab.com/filters.htm

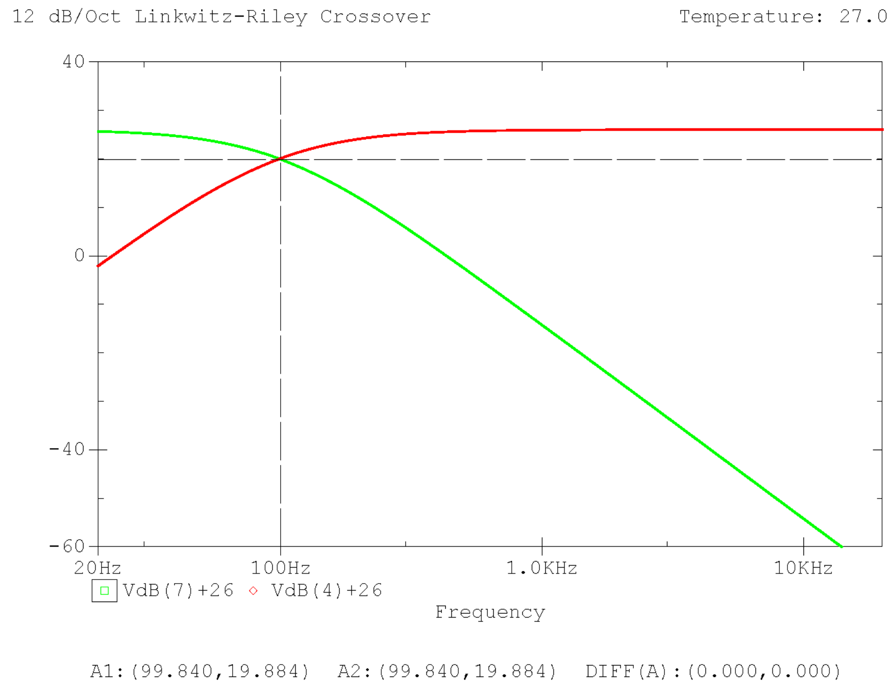
b) Here is his 12 dB/Oct Crossover:

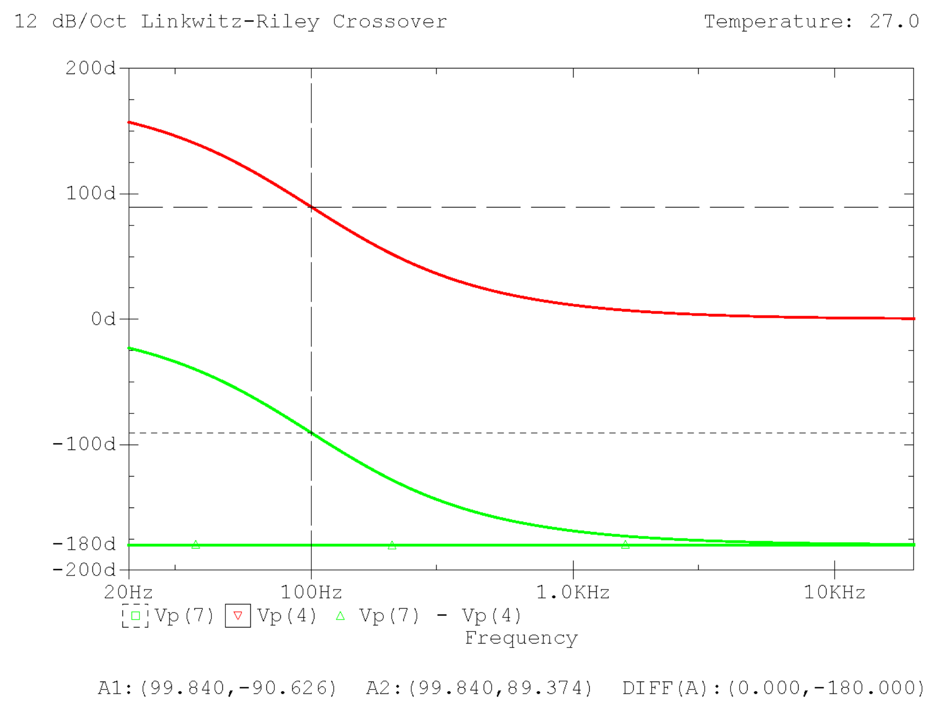


c) Pspice file:

```
12 dB/Oct Linkwitz-Riley Crossover
VIN 1 0 AC 1
C1 1 2 68N
C2 2 3 68N
C3 5 7 68N
C4 6 0 68N
R1 2 4 23.7K
R2 3 0 23.7K
R3 1 5 23.7K
R4 5 6 23.7K
XHP 3 4 4 OPAMP
XLP 6 7 7 OPAMP
.SUBCKT OPAMP 1 2 3
RI 1 2 100MEG
EA 3 0 1 2 100MEG
.ENDS OPAMP
.AC DEC 400 20 20K
.PROBE
.END
```

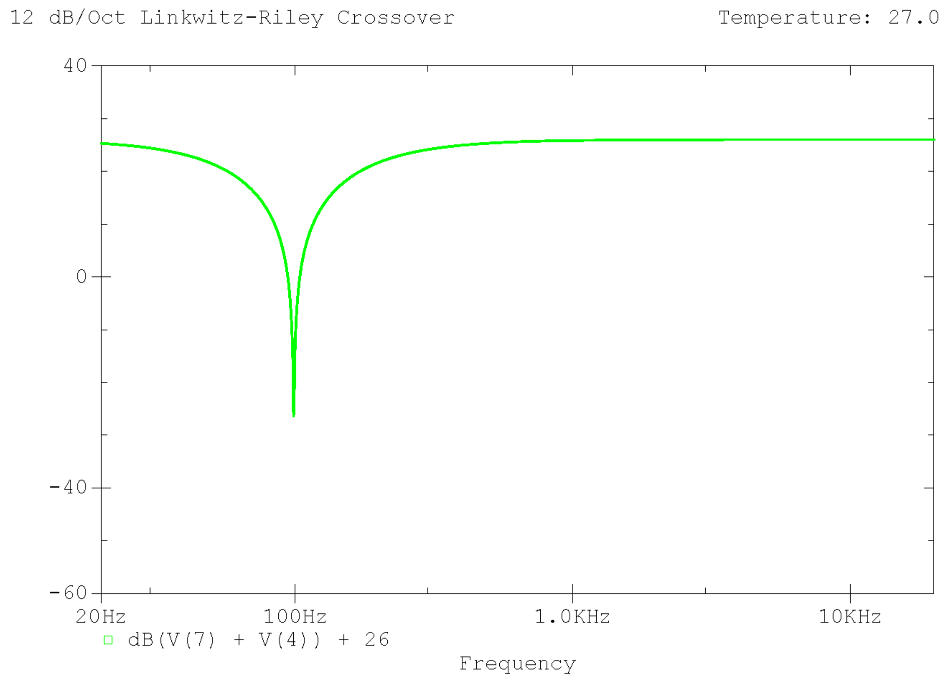
The Acoustas AC650 has ≈26 dB of gain with the volume turned up. So adding 26 dB to the output voltages will shift the curve up to match page 1.



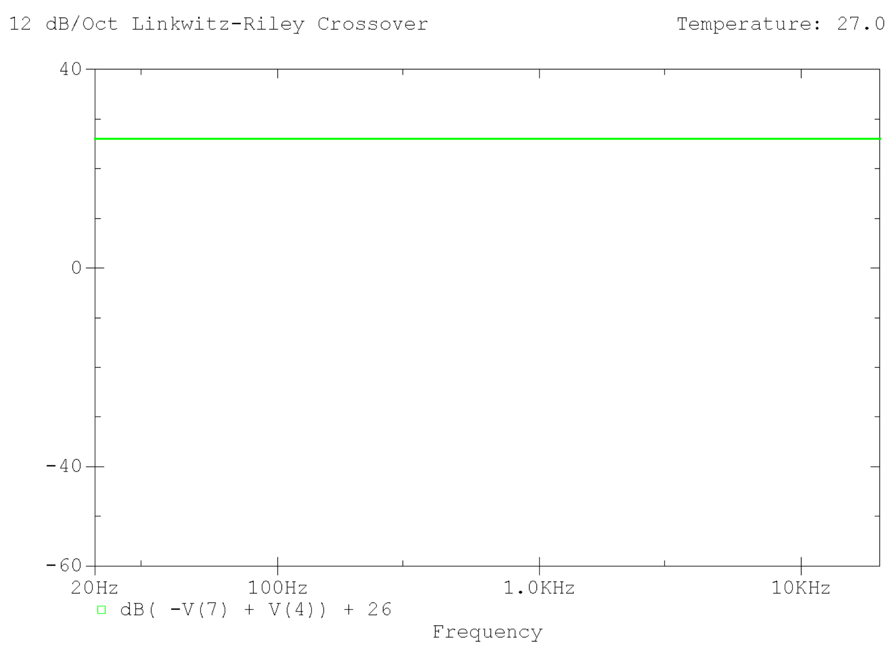


The simulated results match the measured results.

The down side of using 12 dB/Oct or 36 dB/Oct is that at the crossover frequency the magnitude of both channels are equal and their phase angles are equal but opposite in sign. *The vector sum is 0 or the vector sum approaches minus infinity dB*. To illustrate this, let's plot what your ear would hear versus frequency. This is done by adding the two phasor outputs and plotting their magnitude in dB.



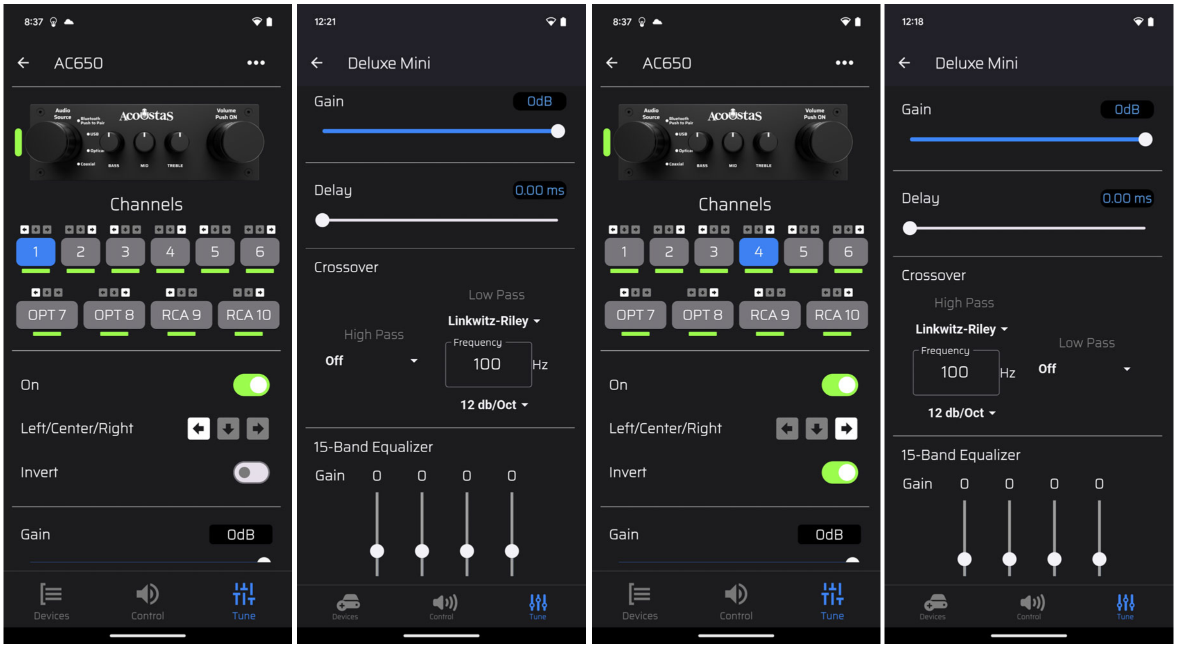
There is "hole" in the audio band at the crossover frequency. However there is a "cure" if we could invert one of the channels but not both. We can do this in the app or in Probe by changing the sign of one output:



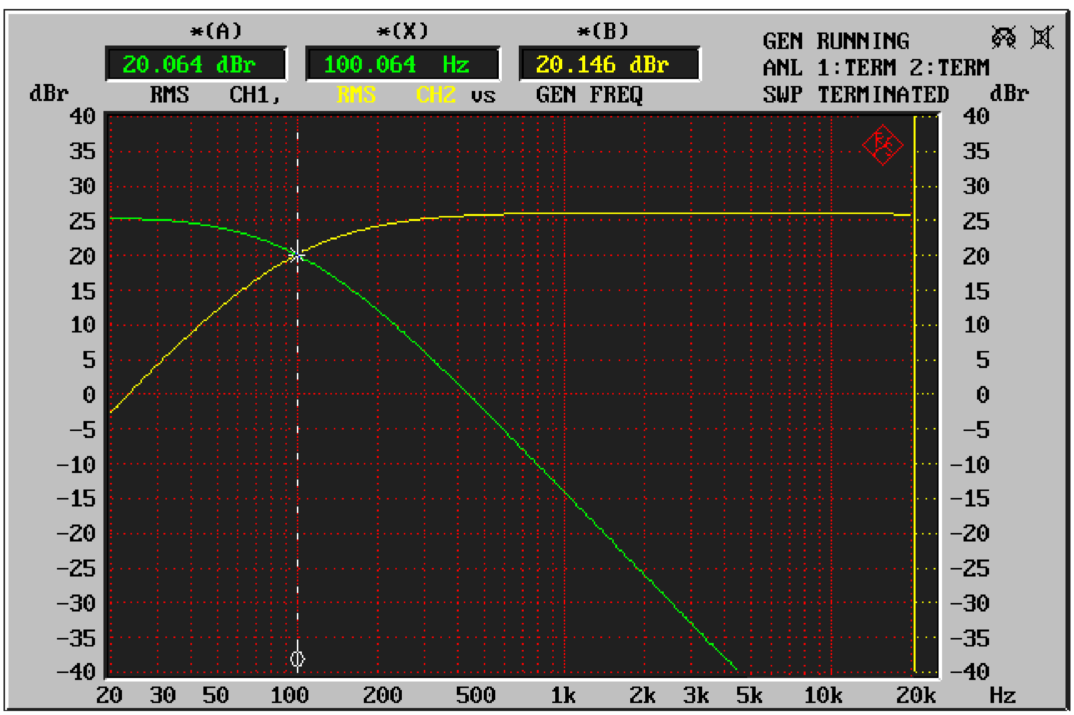
This is also the response of the 24 dB/Oct Linkwitz-Riley crossover.

4) 12 dB/Oct - Revisited with Invert On for Ch 4

Ch1 Ch4

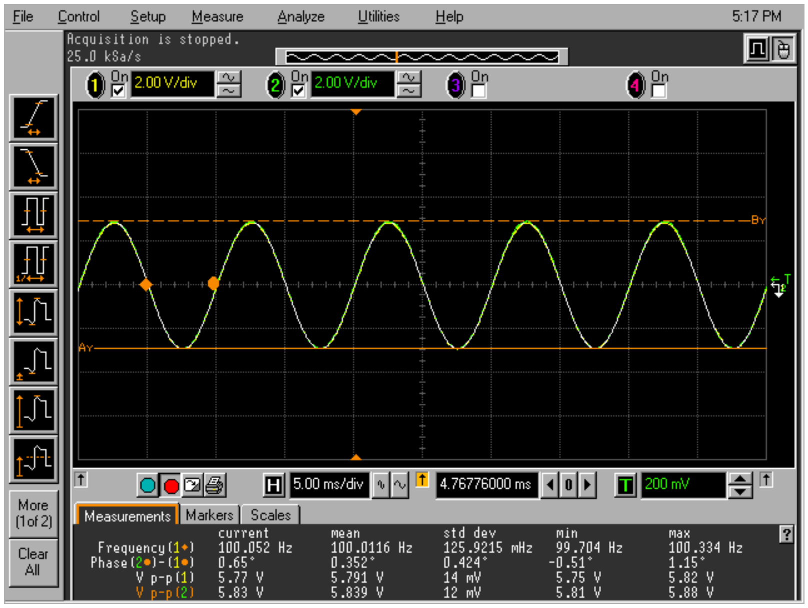


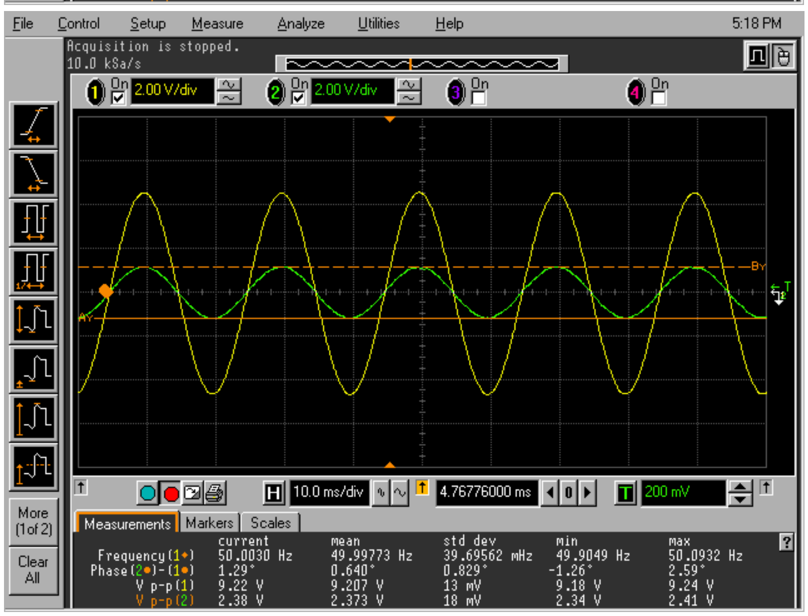
Volume Max, Channels 1 & 4 Selected.

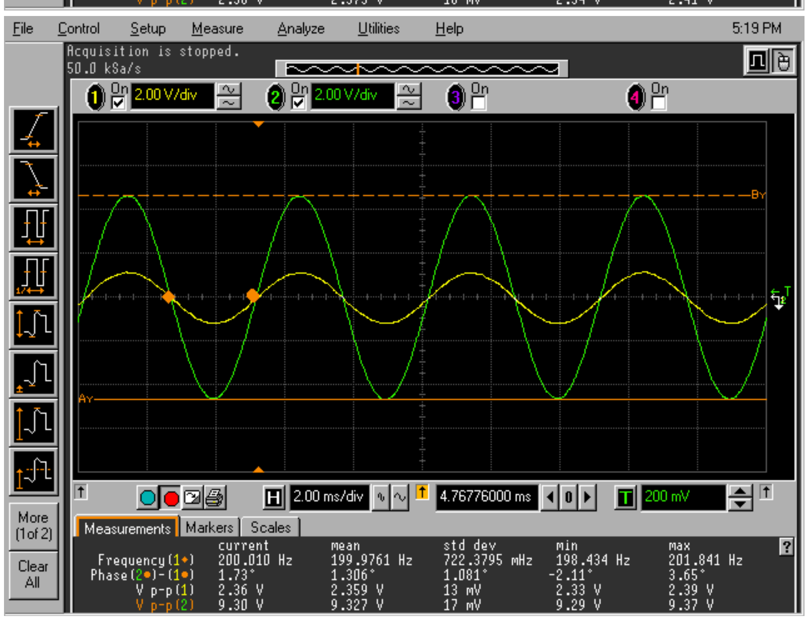


Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4.

The 12 dB/Oct Linkwitz-Riley Crossover **now** has a constant phase difference of 0° for all frequencies. Shown below are scope pictures of phase difference for 100 Hz, 50 Hz and 200 Hz where scope Ch 1 = amp Ch1 and scope Ch 2 = amp Ch 4.



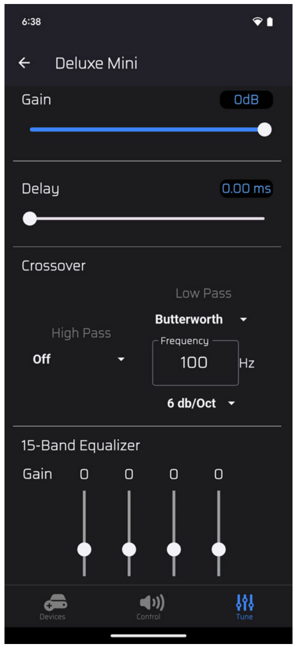




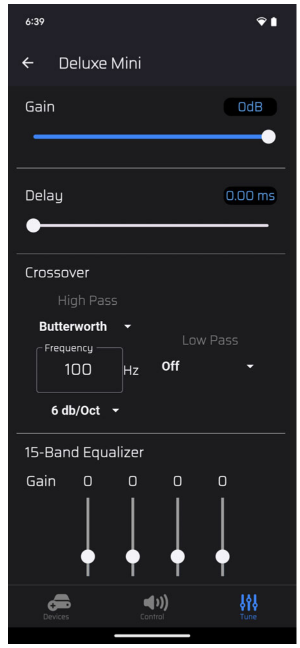
Butterworth Crossovers

1) 6 dB/Oct

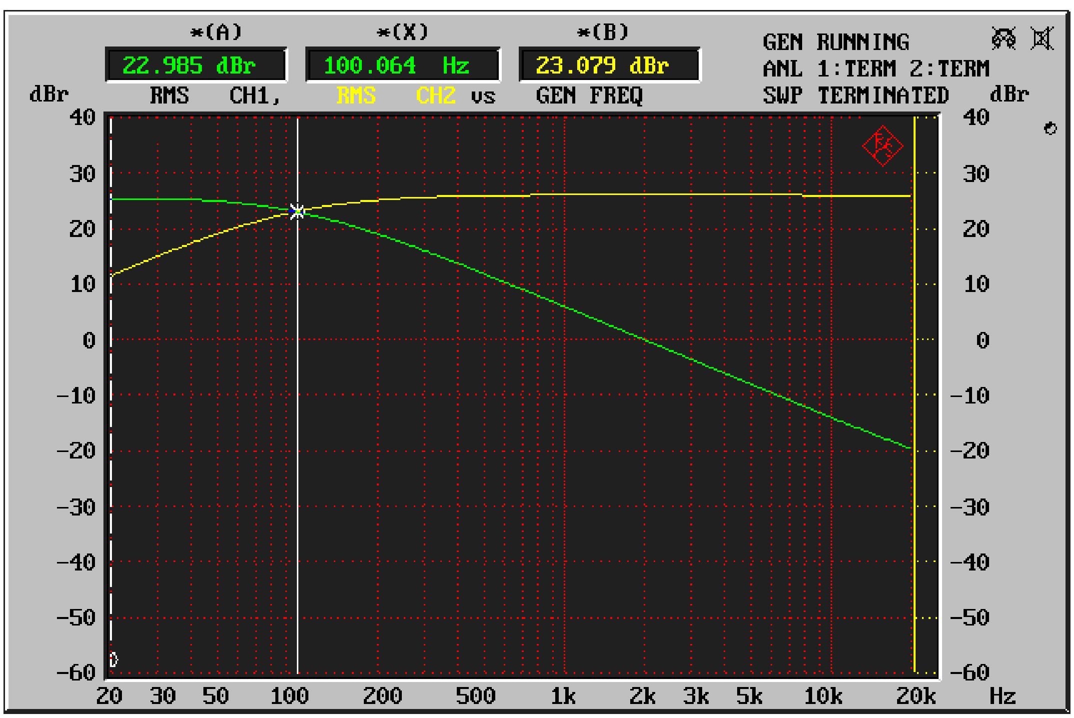
Ch1



Ch4



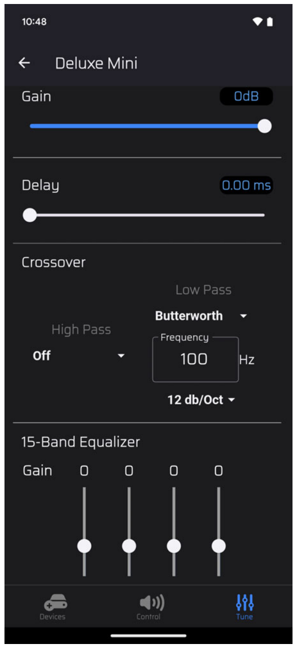
Volume Max, Channels 1 & 4 Selected, Invert Off.



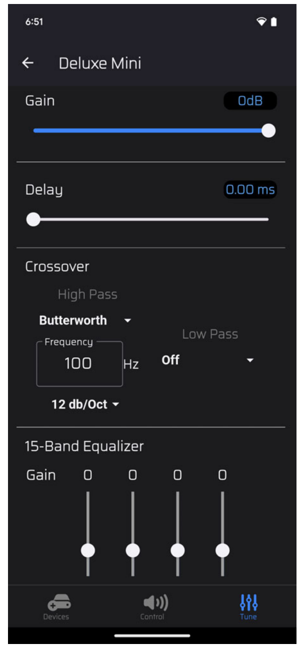
Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The 6 dB/Oct Butterworth Crossover has a constant phase difference of 90° for all frequencies.

2) 12 dB/Oct

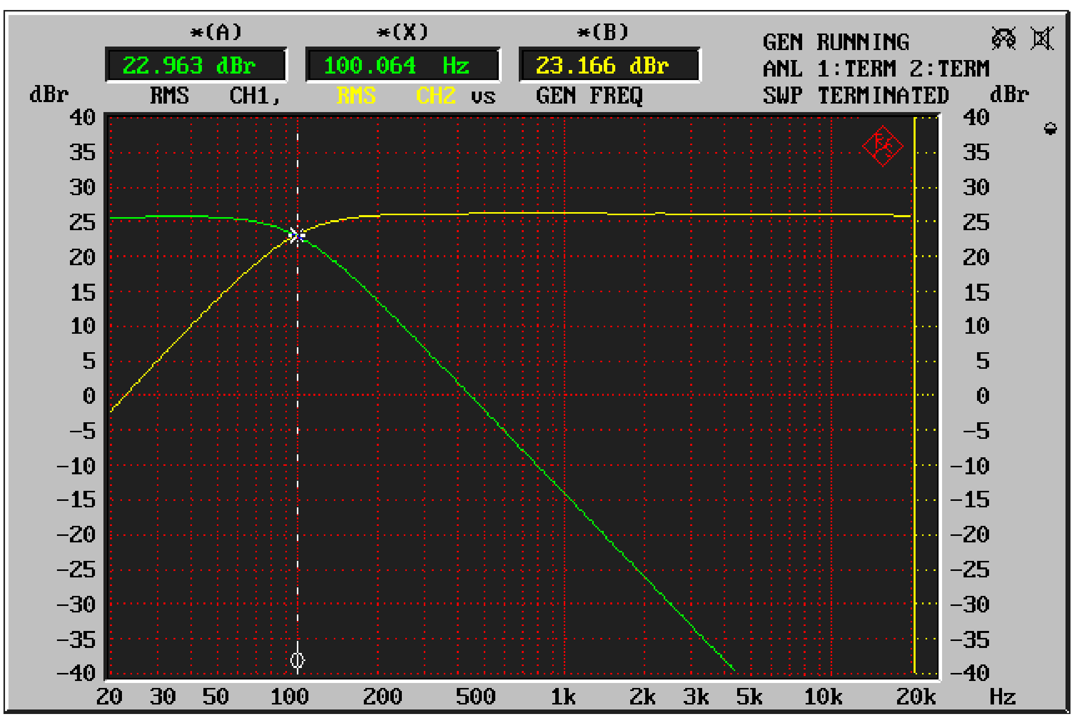
Ch1



Ch4

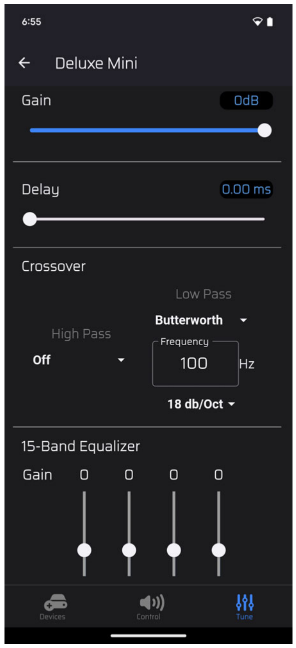


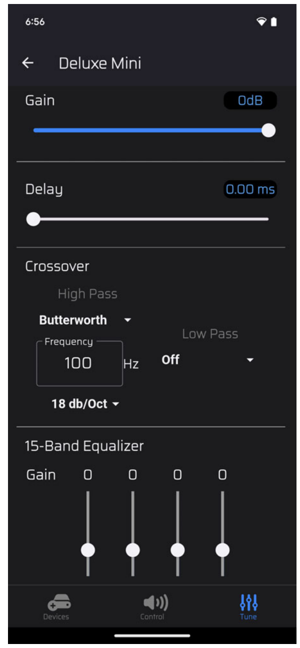
Volume Max, Channels 1 & 4 Selected, Invert Off.



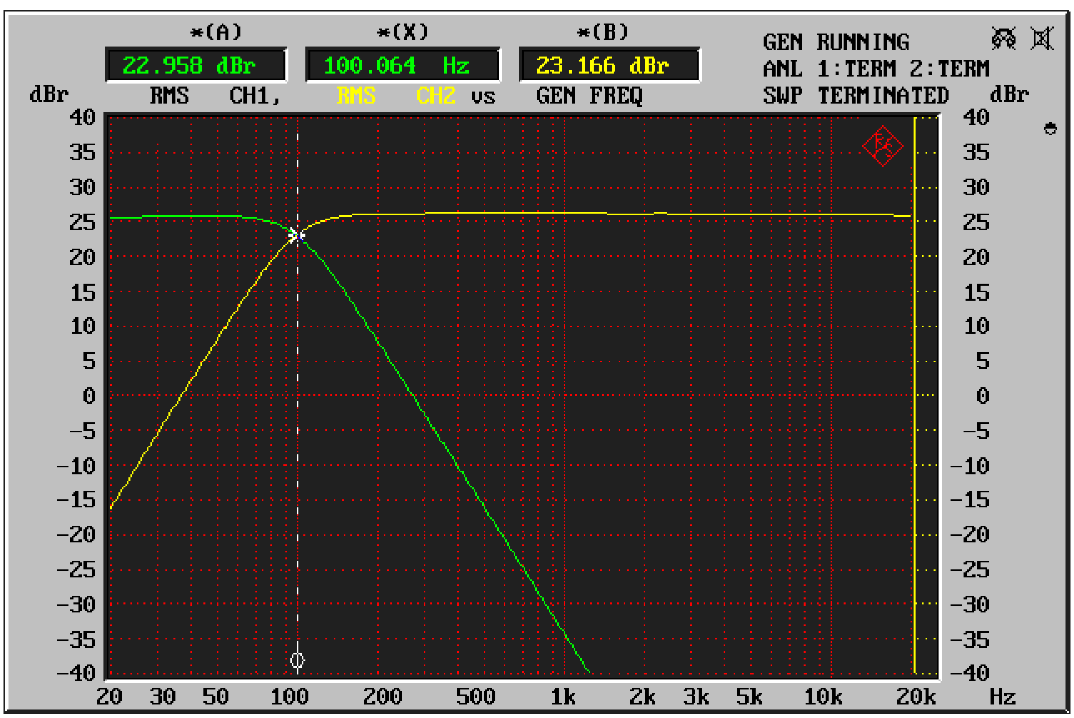
Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The 12 dB/Oct Butterworth Crossover has a constant phase difference of 180° for all frequencies. This creates a notch at the crossover frequency for the listener.

3) 18 dB/Oct Ch1 Ch4



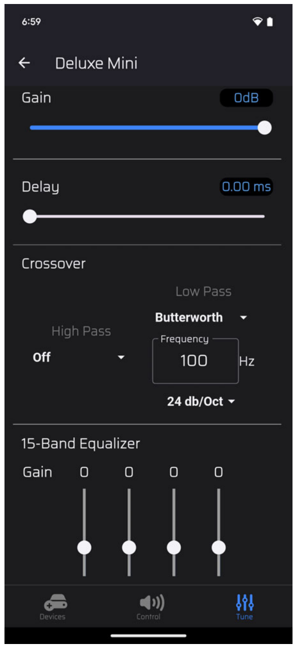


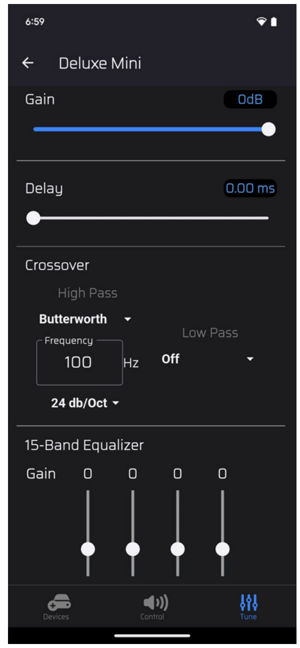
Volume Max, Channels 1 & 4 Selected, Invert Off.



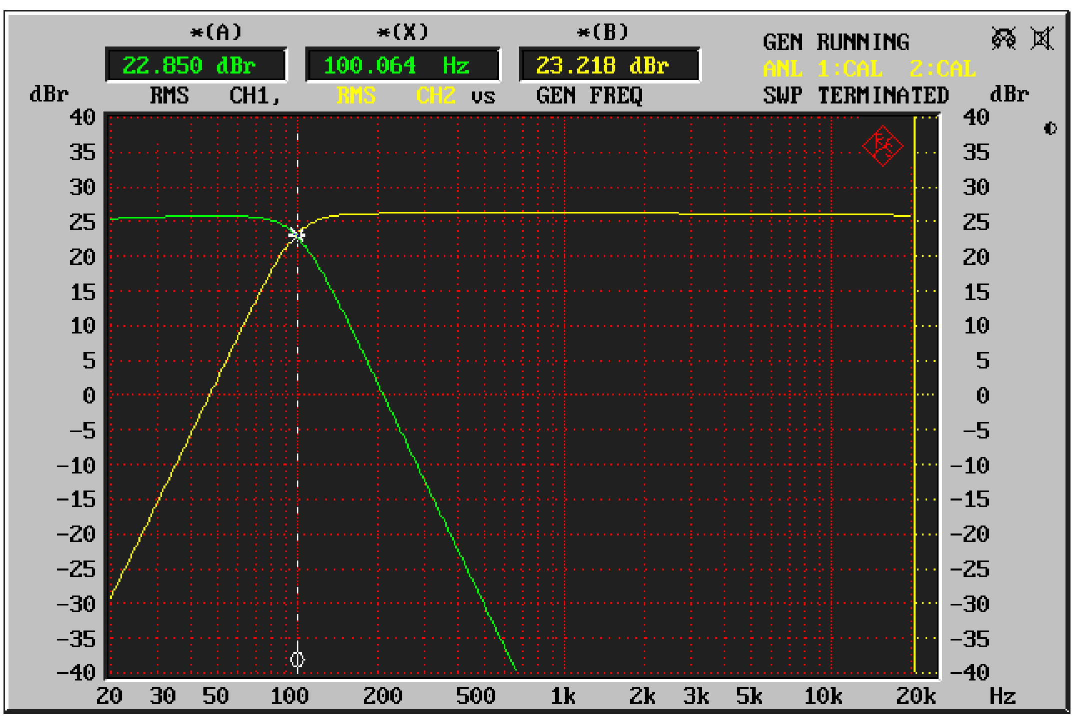
Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The 18 dB/Oct Butterworth Crossover has a constant phase difference of 90° for all frequencies.

4) 24 dB/Oct Ch1 Ch4



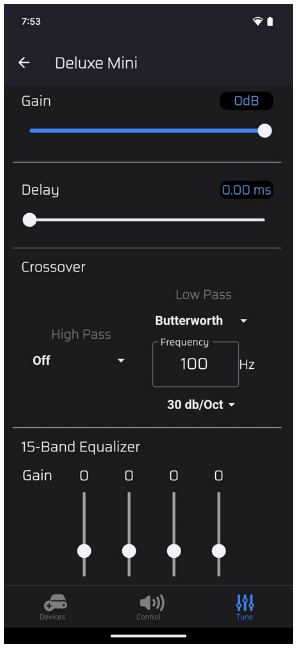


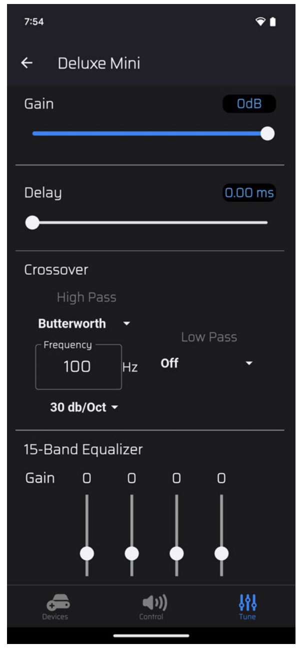
Volume Max, Channels 1 & 4 Selected, Invert Off.



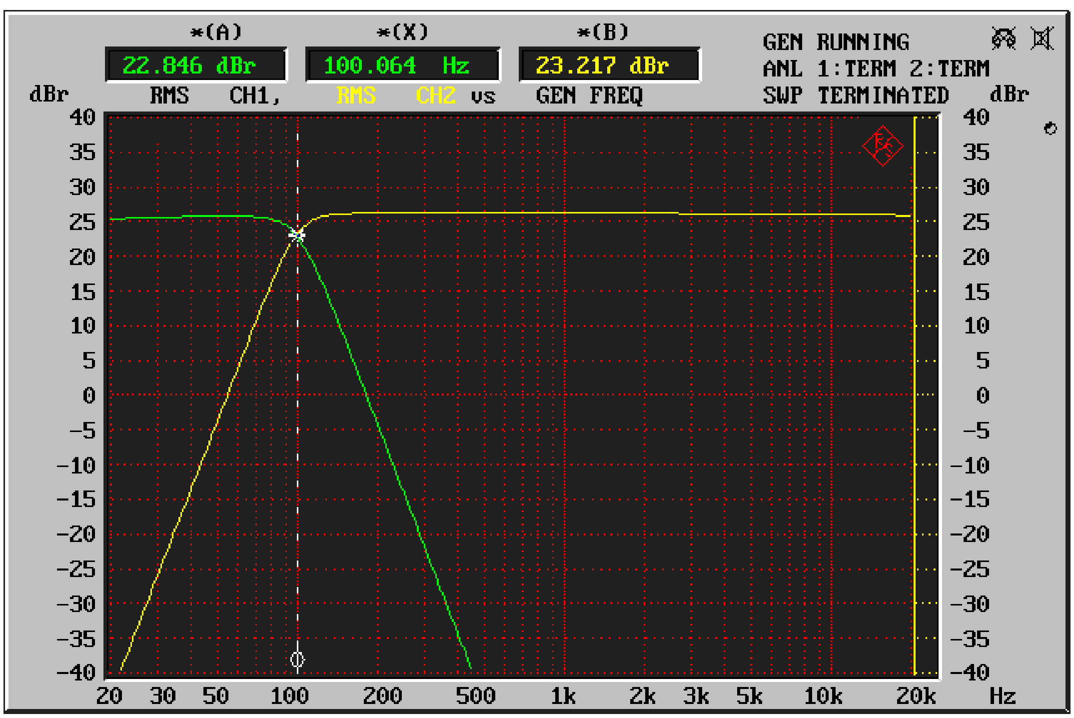
Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The 24 dB/Oct Butterworth Crossover has a constant phase difference of 0° for all frequencies. This is best in that both speakers are in phase with each other.

5) 30 dB/Oct Ch1 Ch4





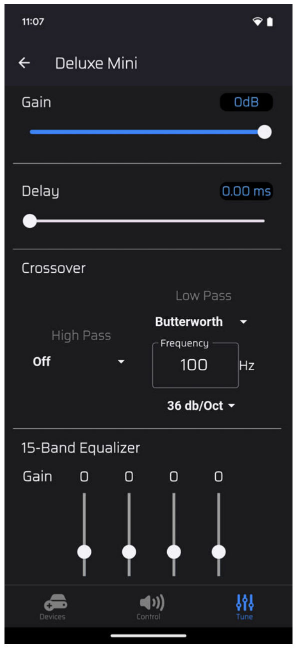
Volume Max, Channels 1 & 4 Selected, Invert Off.



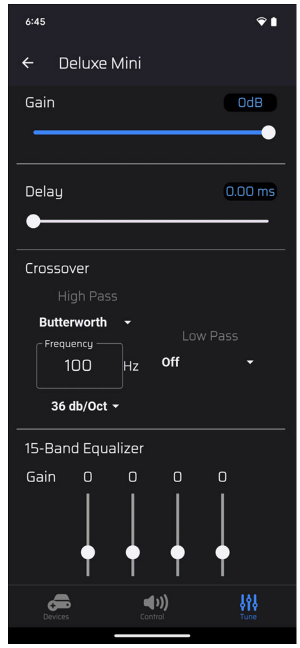
Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The 30 dB/Oct Butterworth Crossover has a constant phase difference of 90° for all frequencies.

6) 36 dB/Oct

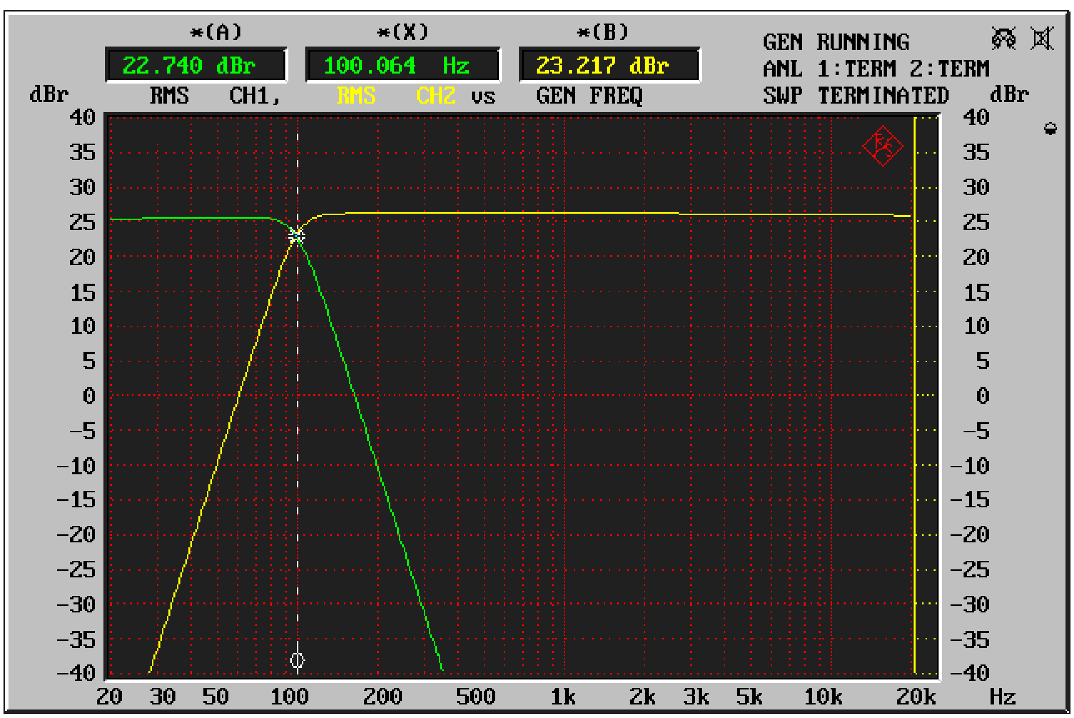
Ch1



Ch4



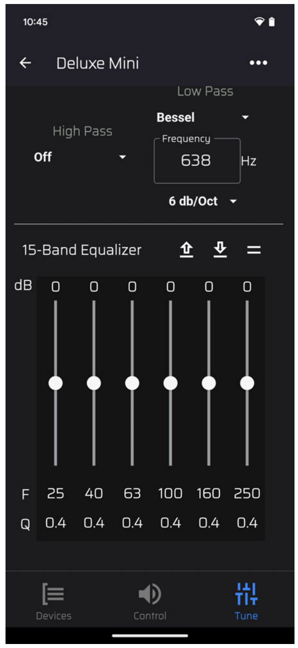
Volume Max, Channels 1 & 4 Selected, Invert Off.

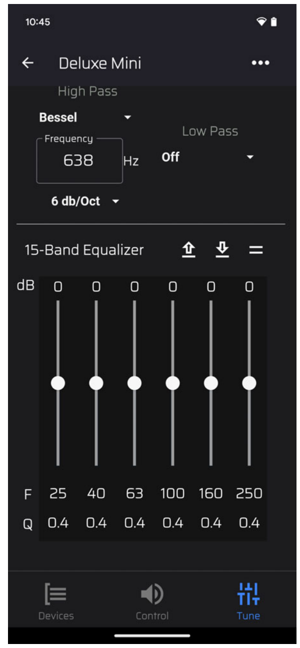


Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The 36 dB/Oct Butterworth Crossover has a constant phase difference of 180° for all frequencies. This creates a notch at the crossover frequency for the listener.

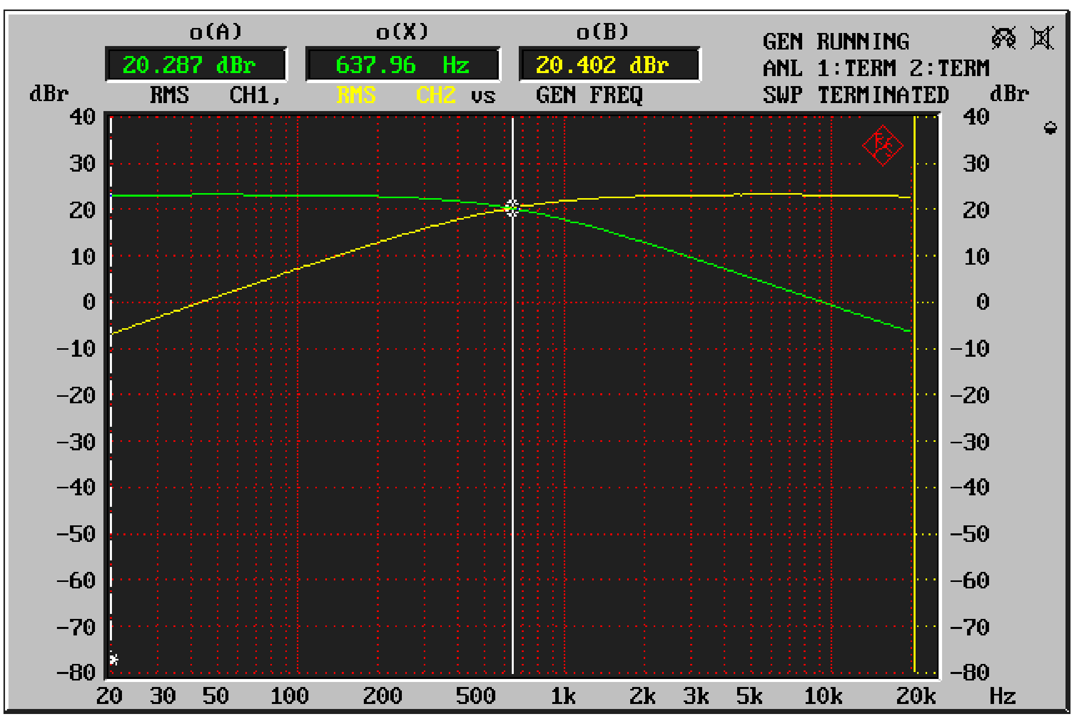
Bessel Crossovers

1) 6 dB/Oct Ch1 Ch4



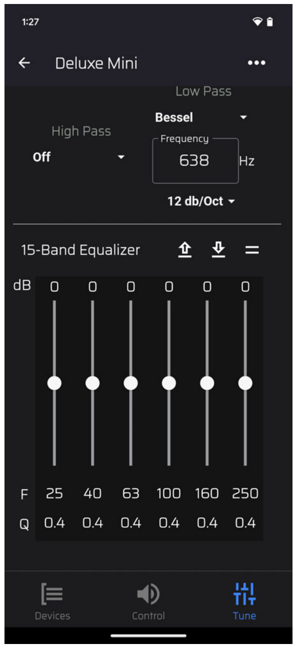


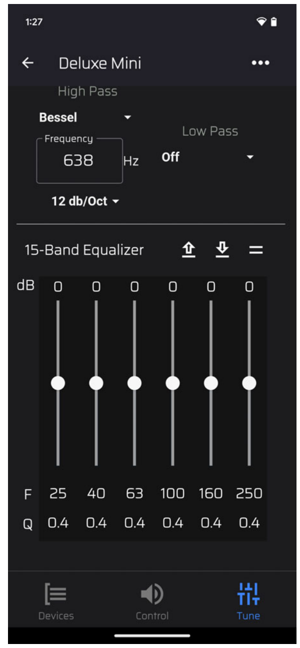
Volume -26 dB, Channels 1 & 4 Selected with Max Volume, Invert Off.



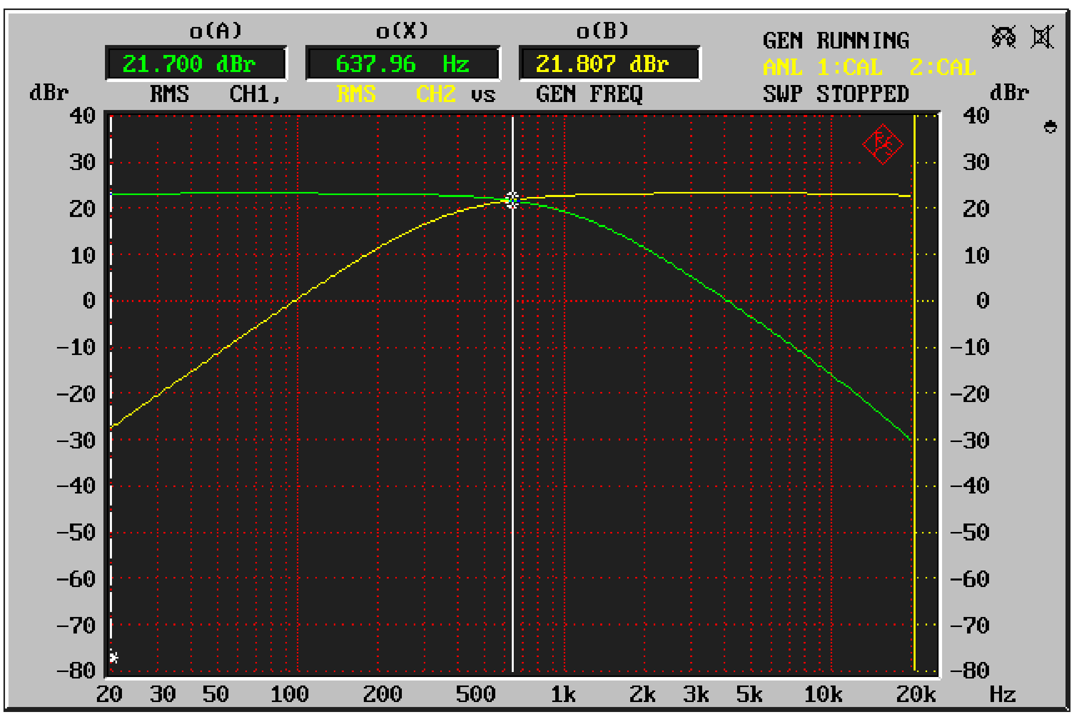
Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The magnitude is approximately -3.0 dB down at the crossover frequency of 638 Hz which is correct.

2) 12 dB/Oct Ch1 Ch4



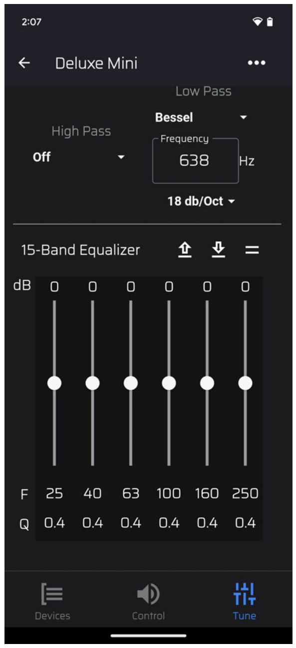


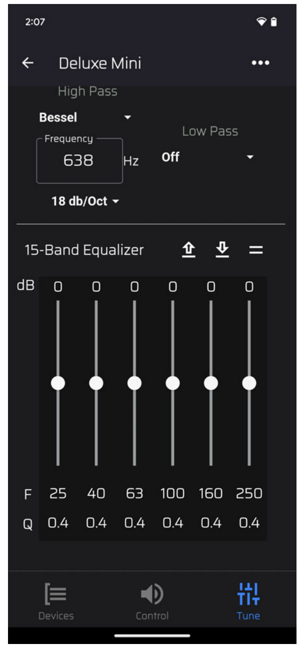
Volume -26 dB, Channels 1 & 4 Selected with Max Volume, Invert Off.



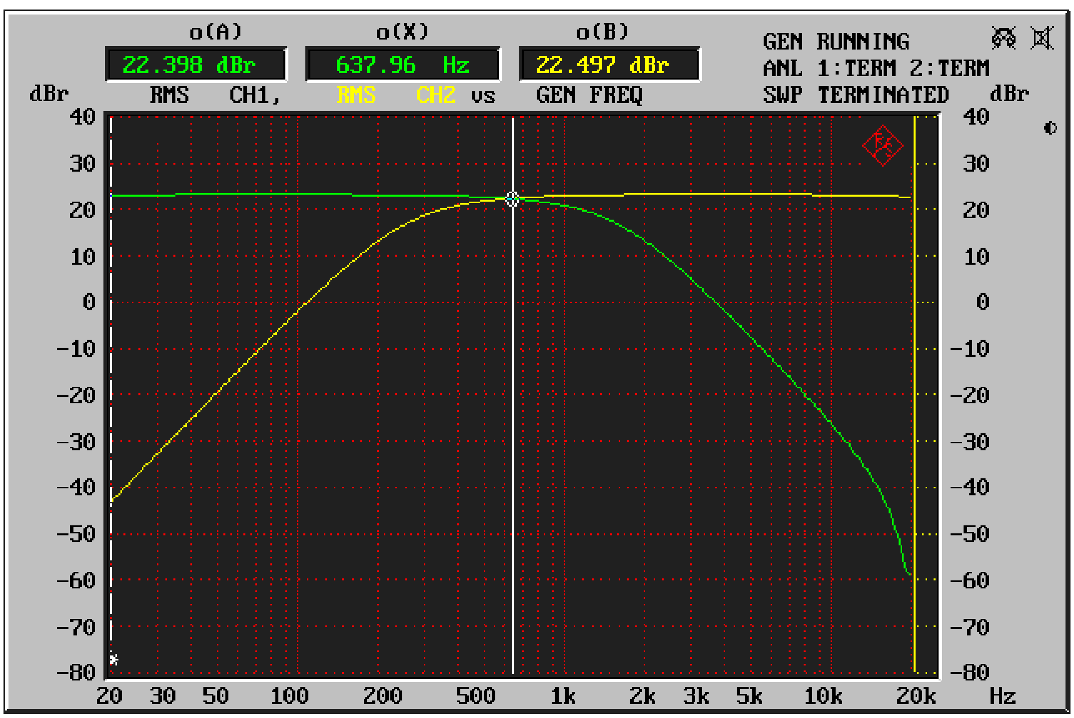
Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The magnitude is approximately -1.6 dB down at 638 Hz which is correct.

3) 18 dB/Oct Ch1 Ch4



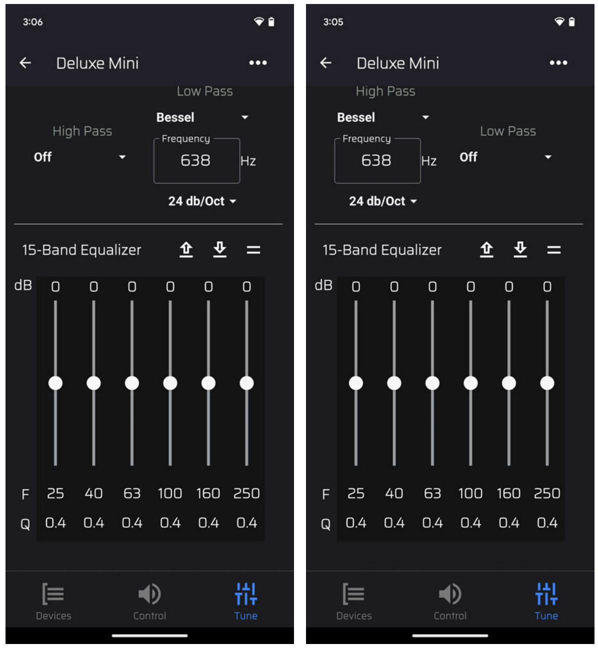


Volume -26 dB, Channels 1 & 4 Selected with Max Volume, Invert Off.

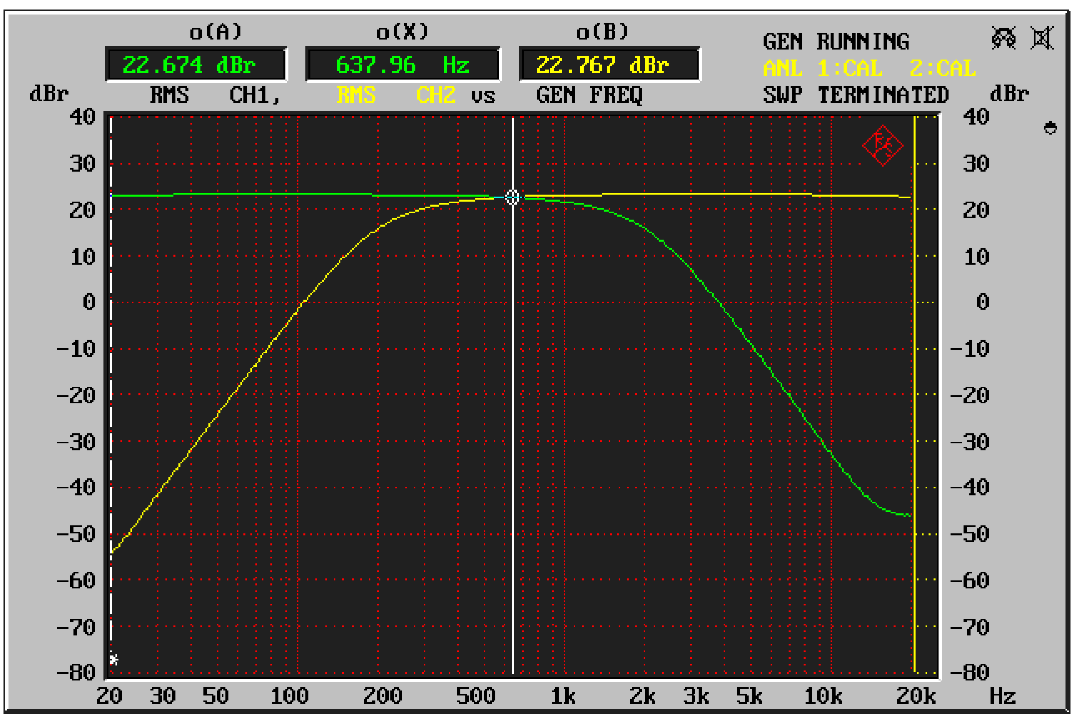


Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The magnitude is approximately -0.9 dB down at 638 Hz which is correct. The Low Pass slope change around 16 kHz is due to the non-ideal Class D Amplifier.

4) 24 dB/Oct Ch1 Ch4

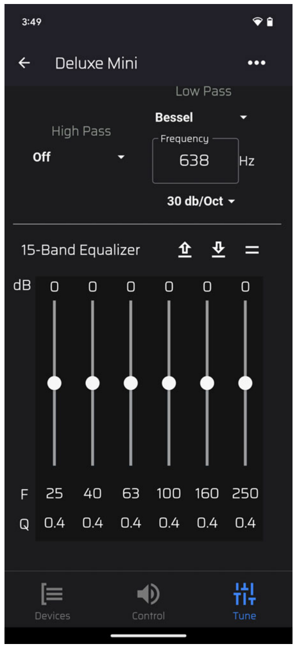


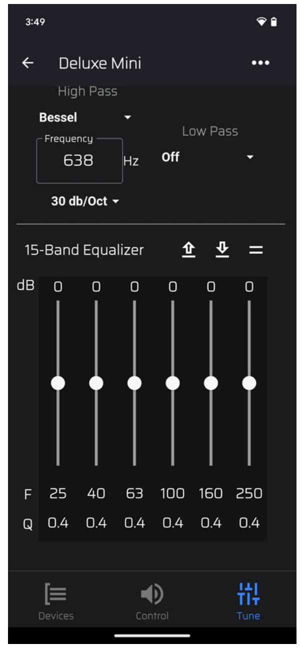
Volume -26 dB, Channels 1 & 4 Selected with Max Volume, Invert Off.



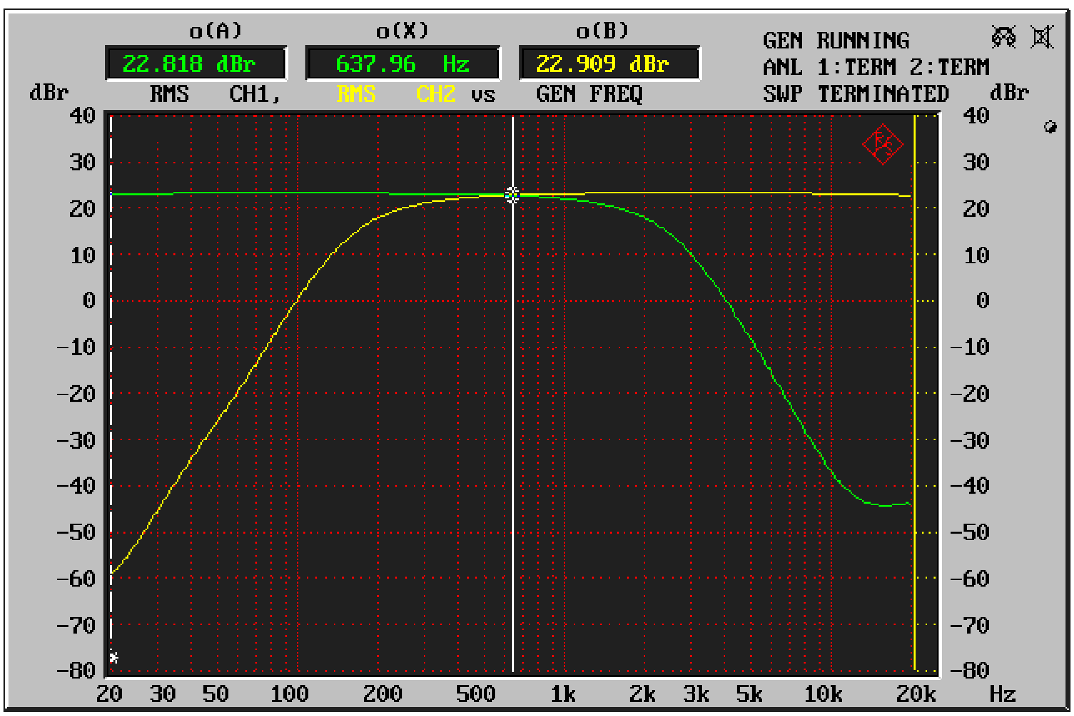
Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The magnitude is approximately -0.63 dB down at 638 Hz which is correct. The Low Pass slope change around 14 kHz is due to the non-ideal Class D Amplifier.

5) 30 dB/Oct Ch1 Ch4





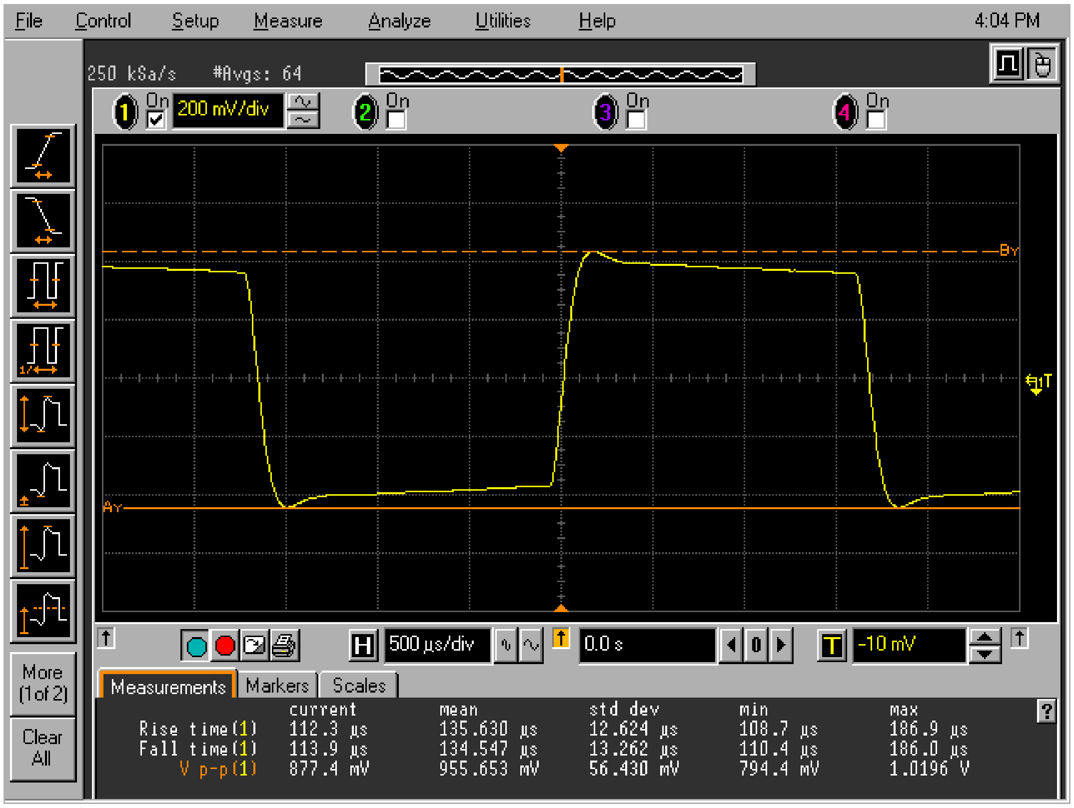
Volume -26 dB, Channels 1 & 4 Selected with Max Volume, Invert Off.



Low Pass is on the analyzer CH1 = amp Ch 1 and the High Pass is on the analyzer CH2 = amp Ch 4. The magnitude is approximately -0.49 dB down at 638 Hz which is correct. The Low Pass slope change around 12 kHz is due to the non-ideal Class D Amplifier.

Crossovers in the Time Domain

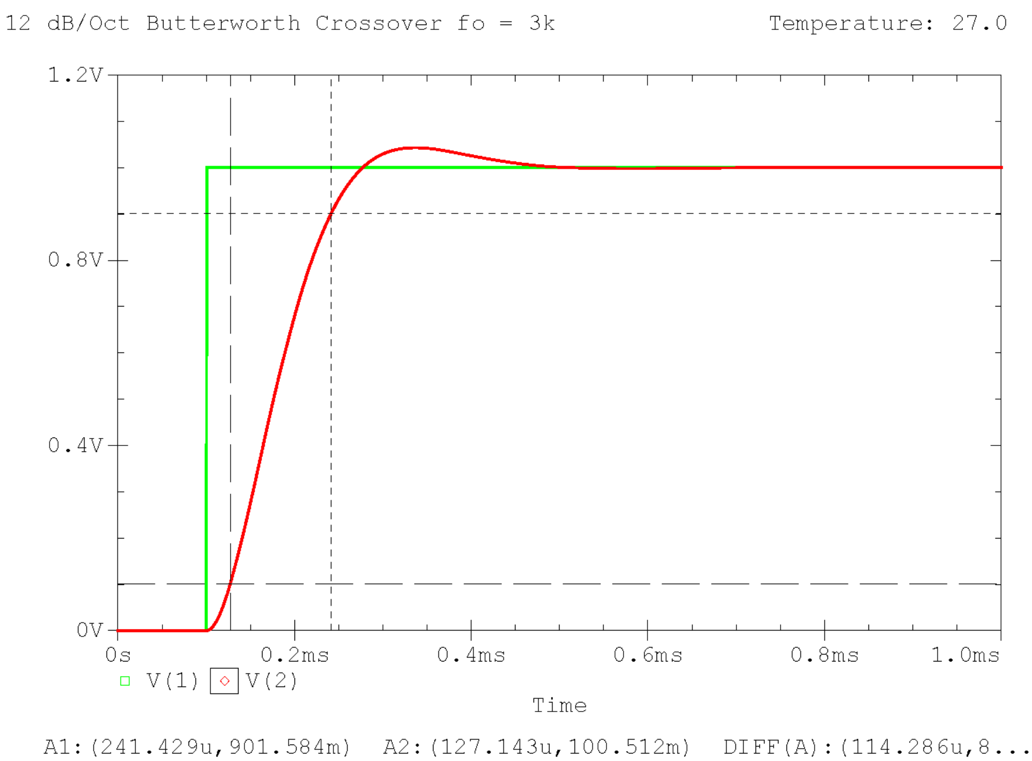
1) 12 dB/Oct Butterworth Low Pass Step Response for fo = 3 kHz



The output of the amp (Ch1) is on Ch 1 of the scope and the Generator's Output passing through the amp (Ch 4) with crossovers off is shown on Ch 2 of the scope.

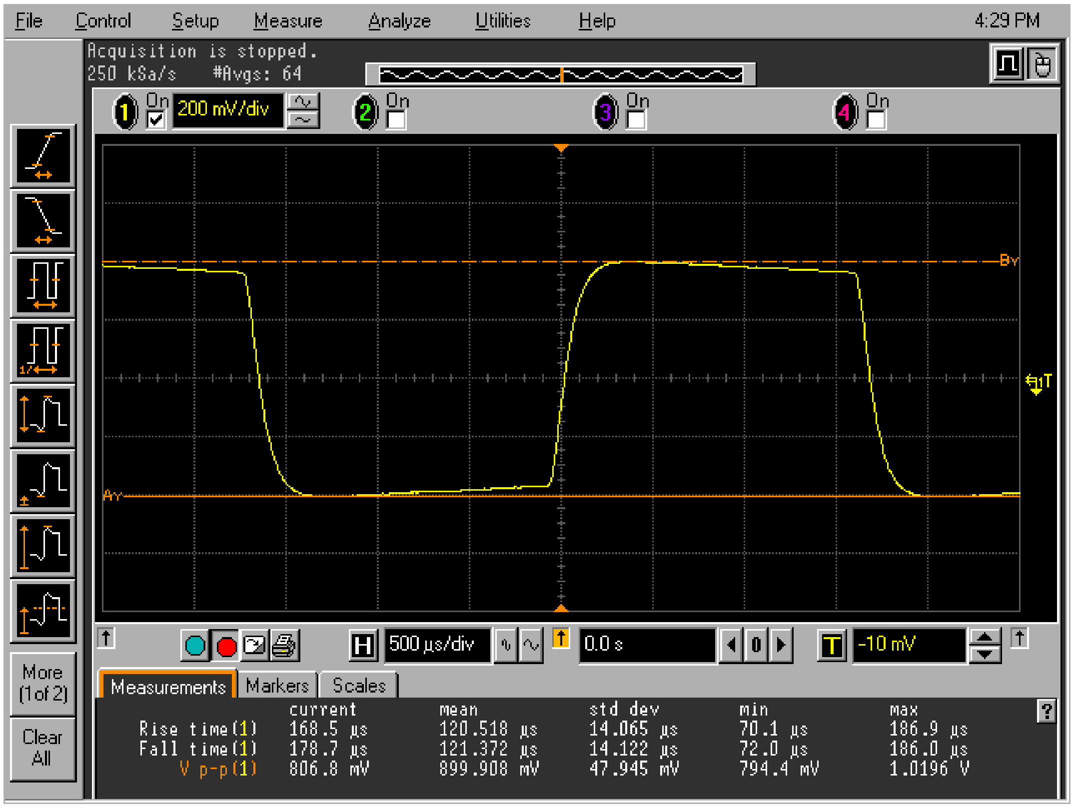
Pspice file for the Step Response of the Low Pass Butterworth Crossover:

```
12 dB/Oct Butterworth Crossover fo = 3k
Vin 1 0 PULSE (0 1 0.1M)
R1 1 4 10K
R2 4 5 10K
R3 6 3 3.75132K
R4 7 0 7.50264K
C1 4 2 7.50264N
C2 5 0 3.75132N
C3 1 6 10N
C4 6 7 10N
X1 5 2 2 OPAMP
X2 7 3 3 OPAMP
.SUBCKT OPAMP 1 2 3
RI 1 2 100MEG
EA 3 0 1 2 100MEG
.ENDS OPAMP
.TRAN 0.5U 1M 0 0.5U
.PROBE
.END
```

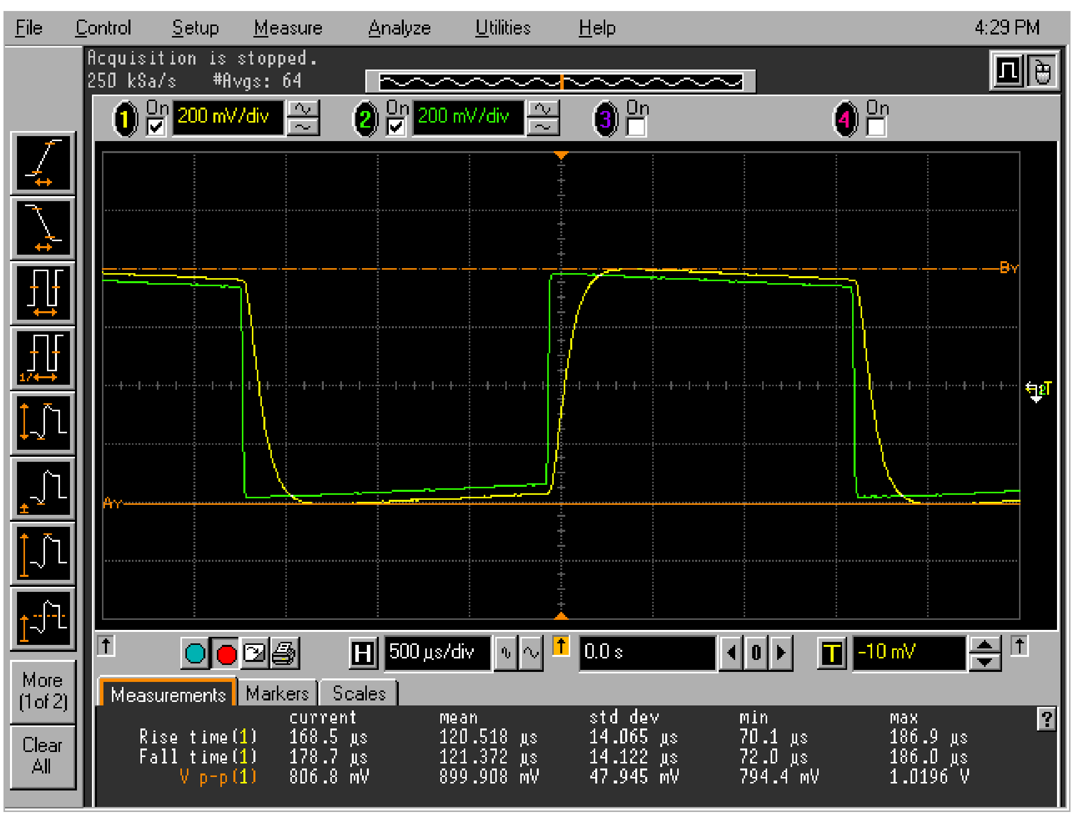


The simulated rise time is 114.286 μsec which is in the vicinity of the measured rise time of 112.0 μsec.

2) 12 dB/Oct Linkwitz-Riley Low Pass Step Response for fo = 3 kHz

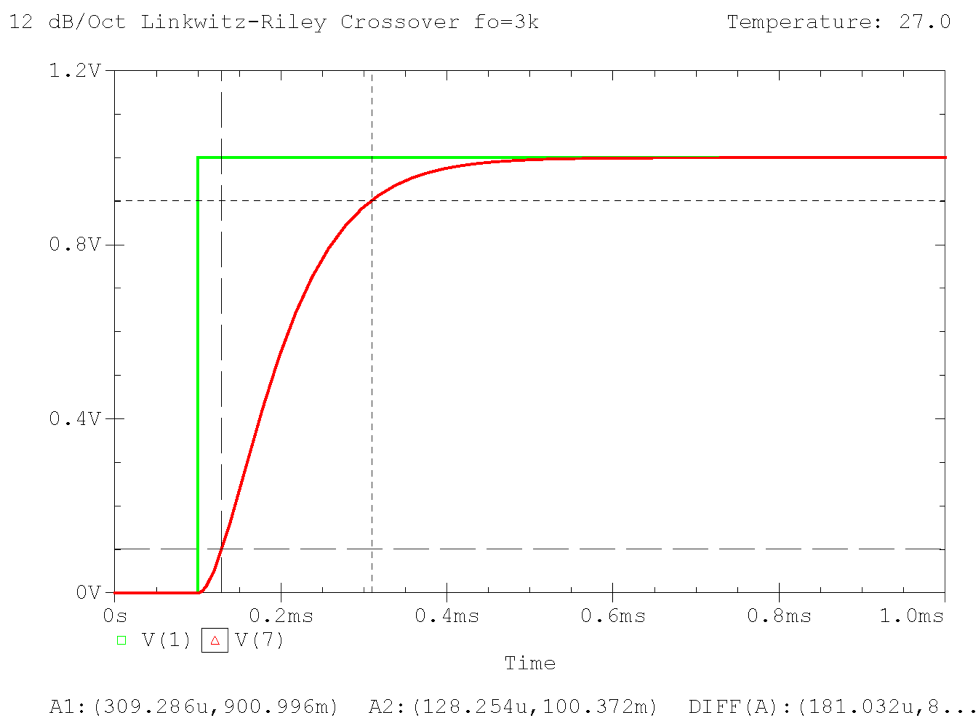


The output of the amp (Ch1) is on Ch 1 of the scope and the Generator's Output passing through the amp (Ch 4) with crossovers off is shown on Ch 2 of the scope.



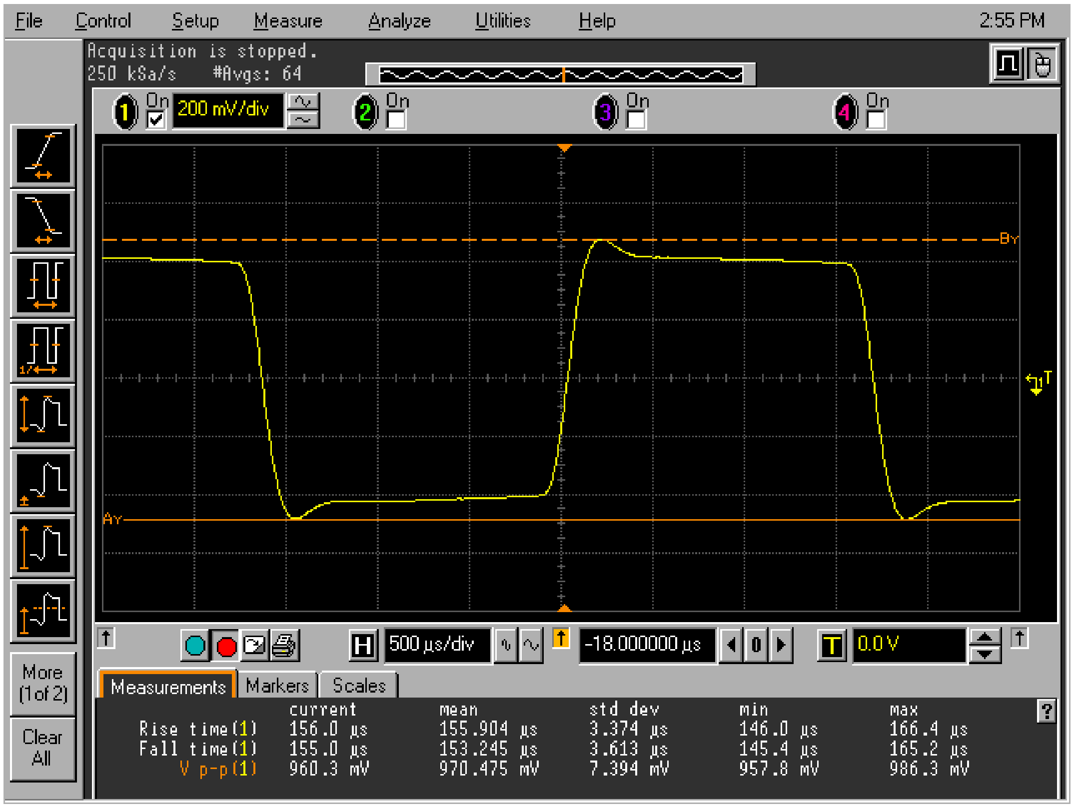
Pspice file for the Step Response of the Low Pass Linkwitz-Riley Crossover:

```
12 dB/Oct Linkwitz-Riley Crossover fo=3k
Vin 1 0 PULSE (0 1 0.1M)
C1 1 2 2.2666N
C2 2 3 2.2666N
C3 5 7 2.2666N
C4 6 0 2.2666N
R1 2 4 23.7K
R2 3 0 23.7K
R3 1 5 23.7K
R4 5 6 23.7K
XHP 3 4 4 OPAMP
XLP 6 7 7 OPAMP
.SUBCKT OPAMP 1 2 3
RI 1 2 100MEG
EA 3 0 1 2 100MEG
.ENDS OPAMP
.TRAN 0.1U 1M 0.1U
.PROBE
.END
```

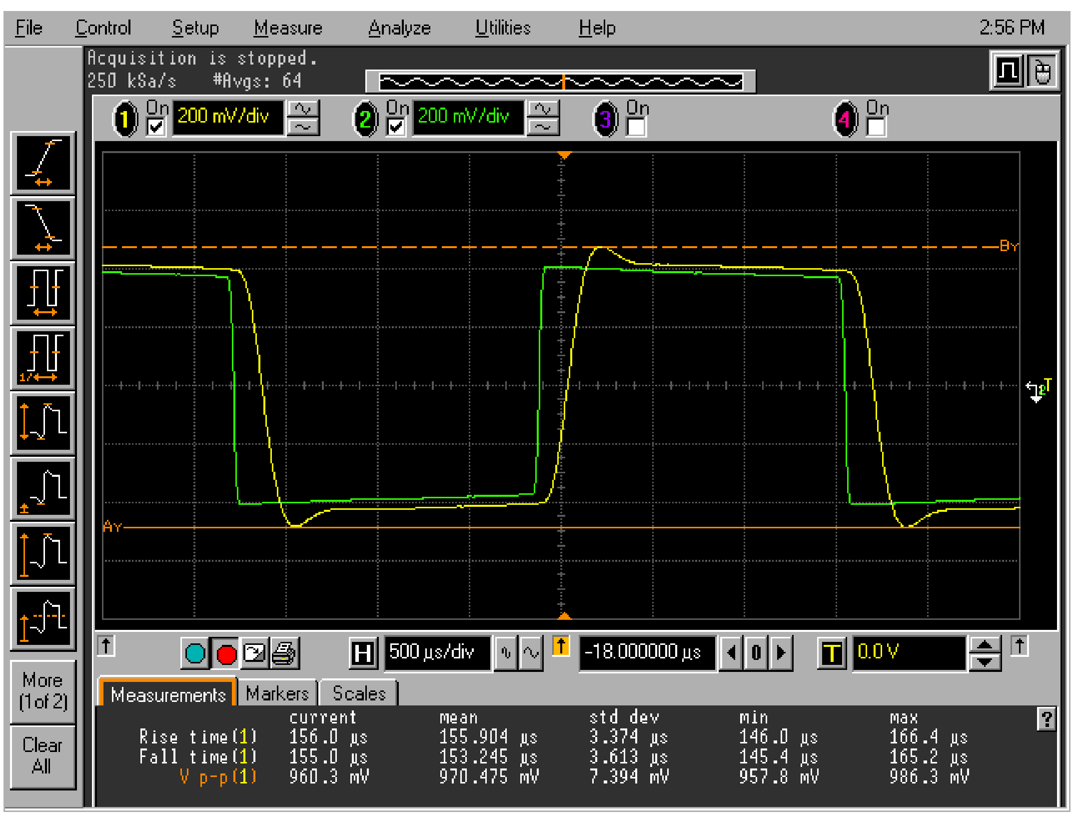


The simulated rise time is 181.032 µsec which is in the vicinity of the measured rise time of 168.5 µsec.

3) 24 dB/Oct Linkwitz-Riley Low Pass Step Response for fo = 3 kHz

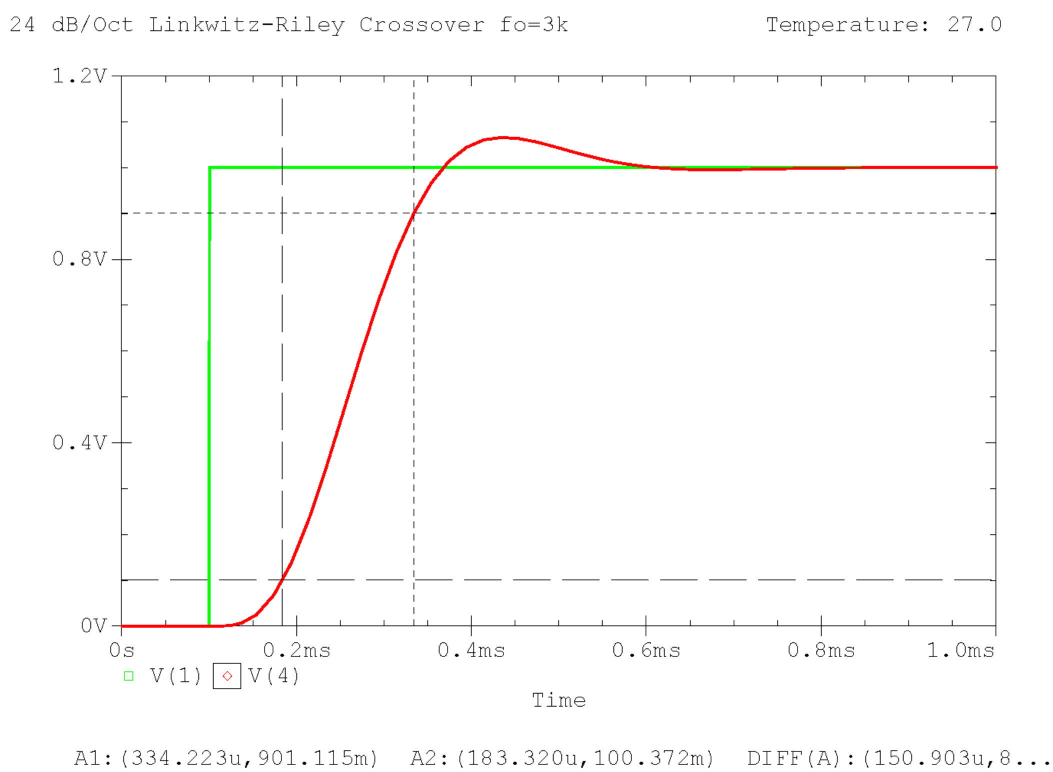


The output of the amp (Ch1) is on Ch 1 of the scope and the Generator's Output passing through the amp (Ch 4) with crossovers off is shown on Ch 2 of the scope.



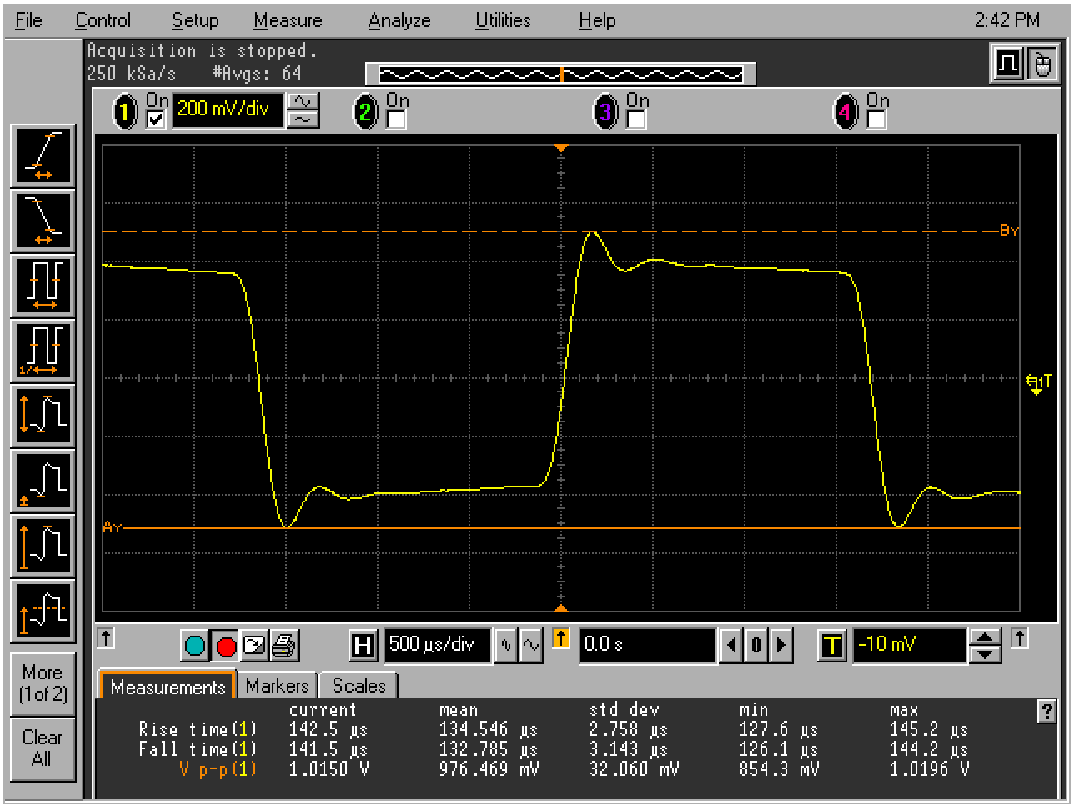
Pspice file for the Step Response of the Low Pass Linkwitz-Riley Crossover:

```
24 dB/Oct Linkwitz-Riley Crossover fo=3k
Vin 1 0 PULSE (0 1 0.1M)
C1 2 4 31.65N
C2 3 0 15.825N
C3 5 7 31.65N
C4 6 0 15.825N
R1 2 7 2.37K
R2 2 3 2.37K
R3 1 5 2.37K
R4 5 6 2.37K
X2 3 4 4 OPAMP
X1 6 7 7 OPAMP
.SUBCKT OPAMP 1 2 3
RI 1 2 100MEG
EA 3 0 1 2 100MEG
.ENDS OPAMP
.TRAN 0.5U 1M 0.5U
.PROBE
.END
```

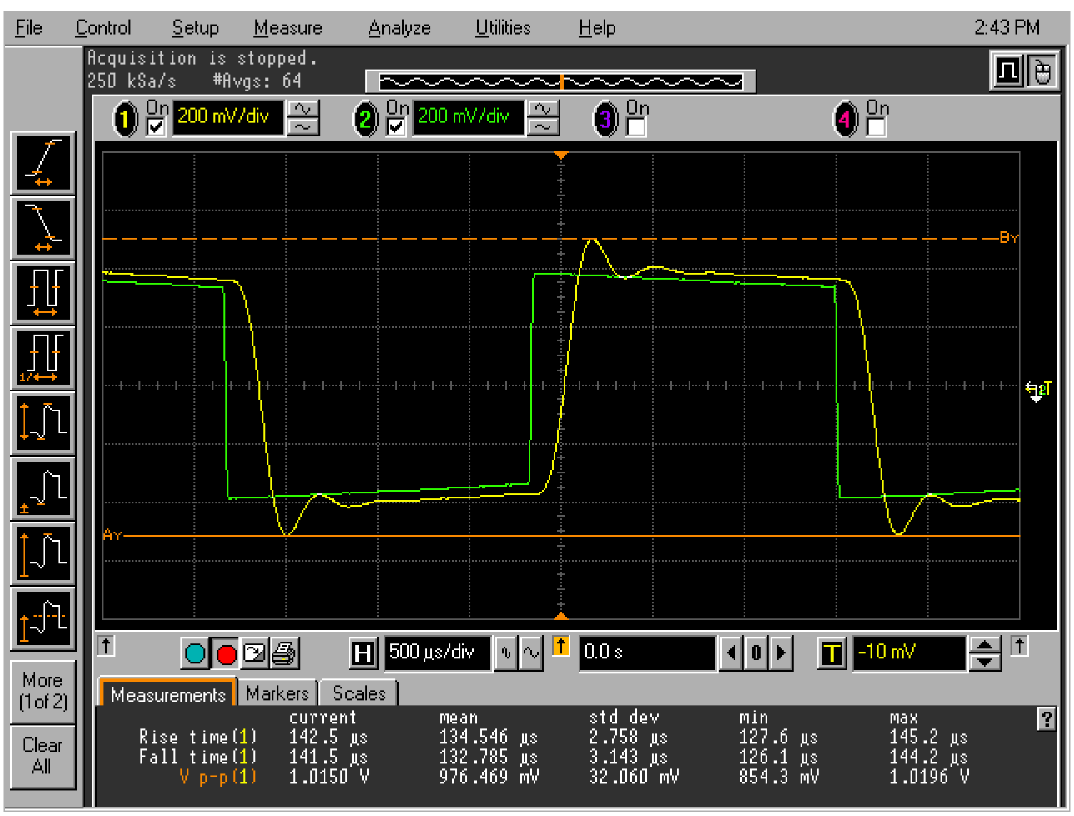


The simulated rise time is 150.902 μsec which is in the vicinity of the measured rise time of 156.0 μsec.

4) 30 dB/Oct Butterworth Low Pass Step Response for fo = 3 kHz

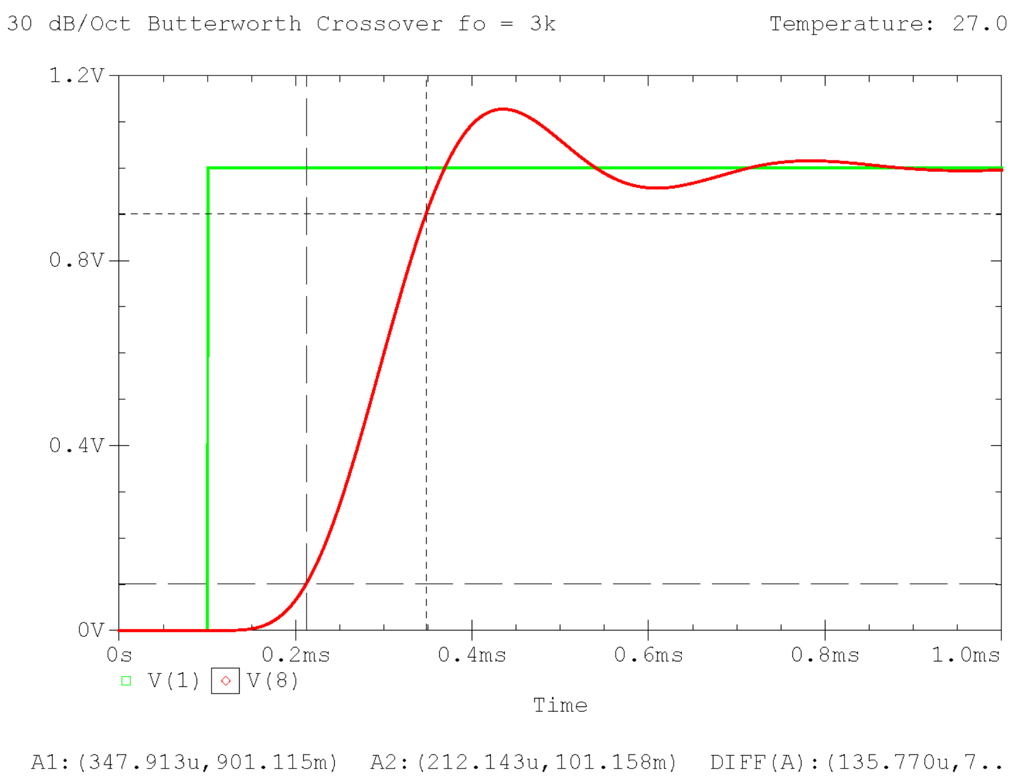


The output of the amp (Ch1) is on Ch 1 of the scope and the Generator's Output passing through the amp (Ch 4) with crossovers off is shown on Ch 2 of the scope.



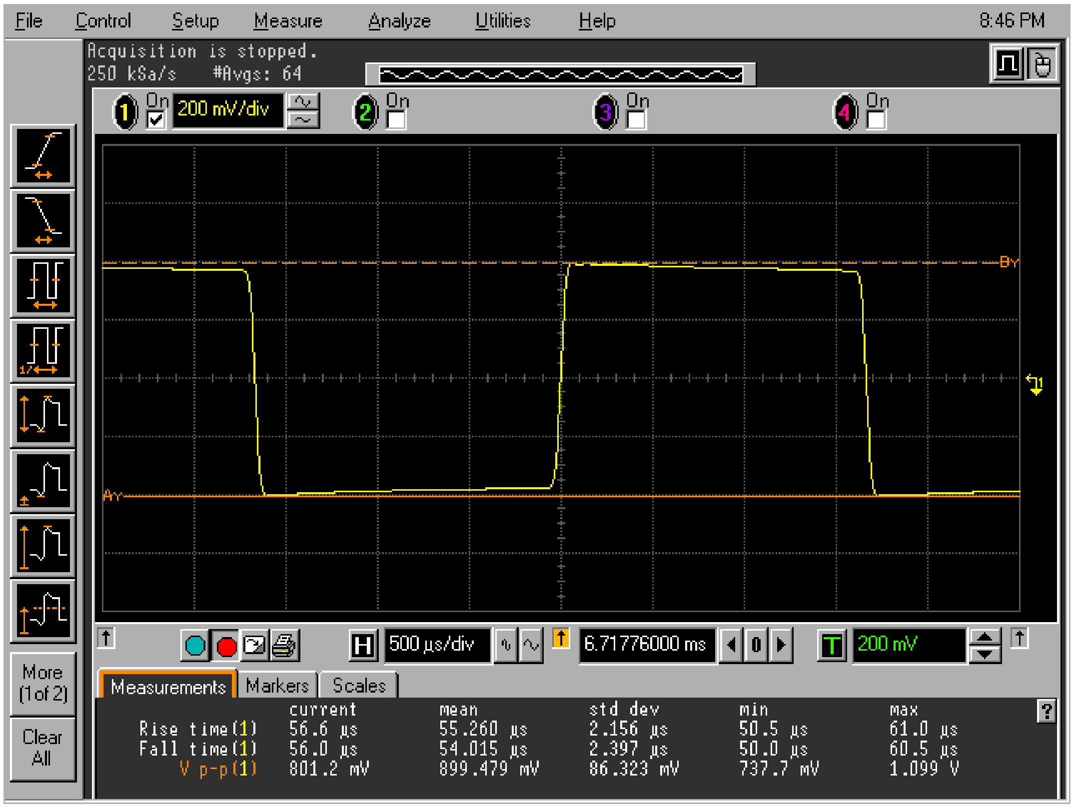
Pspice file for the Step Response of the Low Pass Butterworth Crossover:

```
30 dB/Oct Butterworth Crossover fo = 3k
Vin 1 0 PULSE (0 1 0.1M)
R1 1 2 12K
R2 2 3 12K
R3 3 4 12K
R4 5 6 12K
R5 6 7 12K
C1 3 5 7.75N
C2 2 0 5.987N
C3 4 0 1.863N
C4 6 8 14.3N
C5 7 0 1.365N
X1 4 5 5 OPAMP
X2 7 8 8 OPAMP
.SUBCKT OPAMP 1 2 3
RI 1 2 100MEG
EA 3 0 1 2 100MEG
.ENDS OPAMP
.TRAN 0.5U 1M 0 0.5U
.PROBE
.END
```

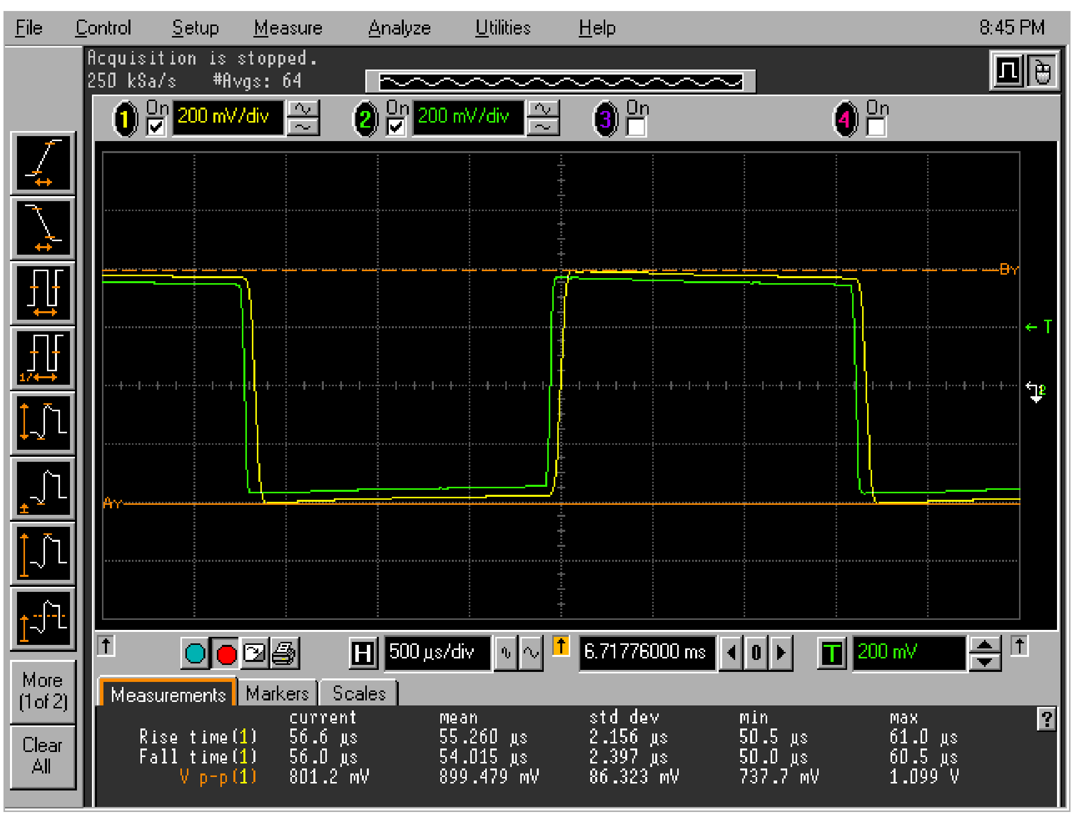


The simulated rise time is 135.77 µsec which is in the vicinity of the measured rise time of 142.5µsec.

5) 30 dB/Oct Bessel Low Pass Step Response for fo = 3 kHz

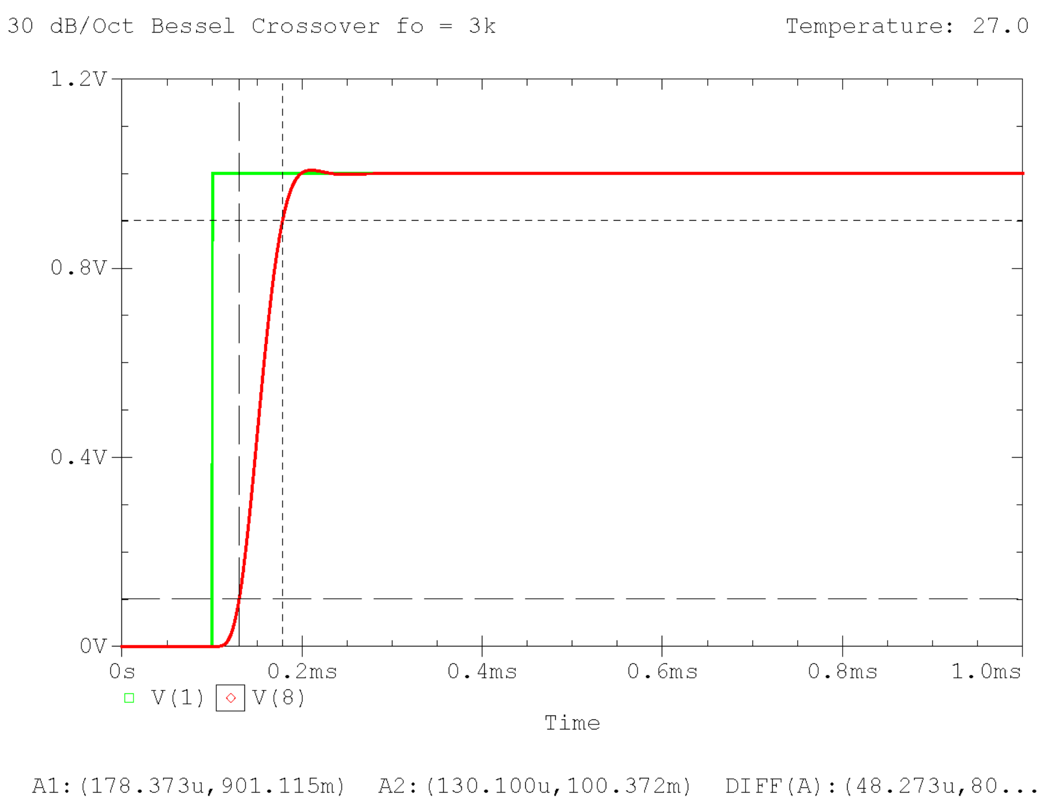


The output of the amp (Ch1) is on Ch 1 of the scope and the Generator's Output passing through the amp (Ch 4) with crossovers off is shown on Ch 2 of the scope.



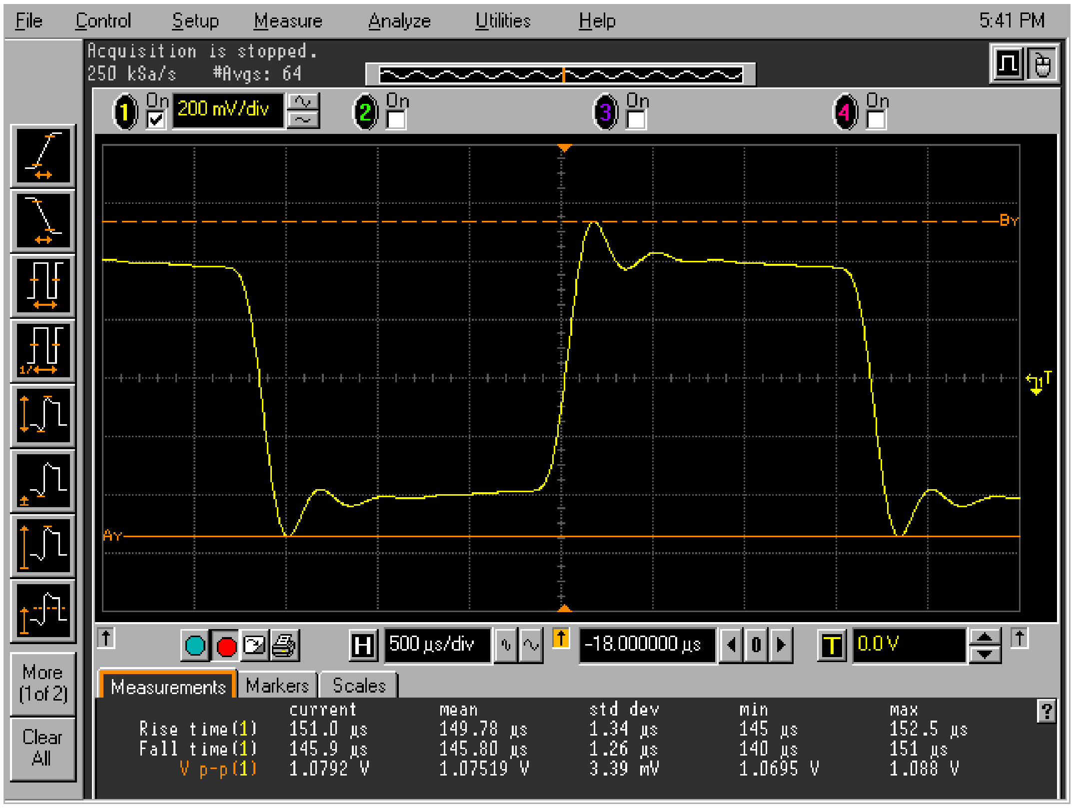
Pspice file for the Step Response of the Low Pass Bessel Crossover:

```
30 dB/Oct Bessel Crossover fo = 3k
Vin 1 0 PULSE (0 1 0.1M)
R1 1 2 12K
R2 2 3 12K
R3 3 4 12K
R4 5 6 12K
R5 6 7 12K
C1 3 5 3.254N
C2 2 0 1.587N
C3 4 0 252.9P
C4 6 8 1.317N
C5 7 0 1.039N
X1 4 5 5 OPAMP
X2 7 8 8 OPAMP
.SUBCKT OPAMP 1 2 3
RI 1 2 100MEG
EA 3 0 1 2 100MEG
.ENDS OPAMP
.TRAN 0.5U 1M 0 0.5U
.PROBE
.END
```

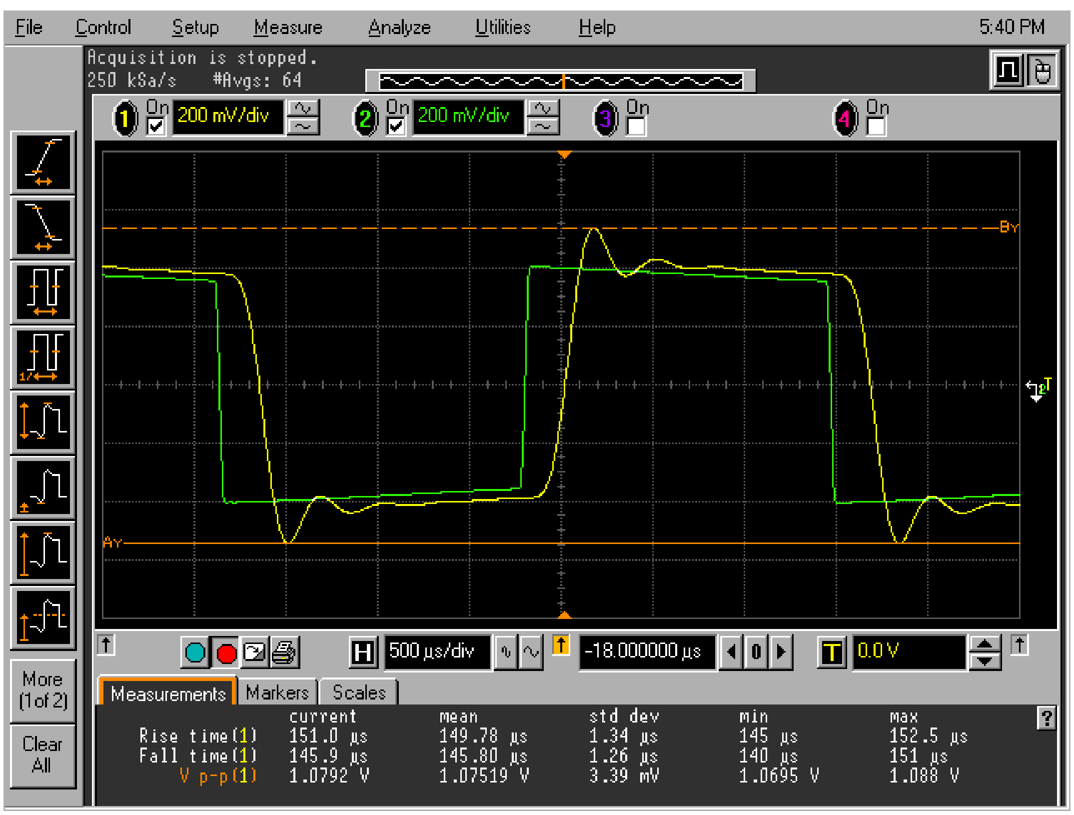


The simulated rise time is 48.273 μsec which is in the vicinity of the measured rise time of 56.6 μsec. The Bessel Crossovers are the fastest to respond to a jump in sound.

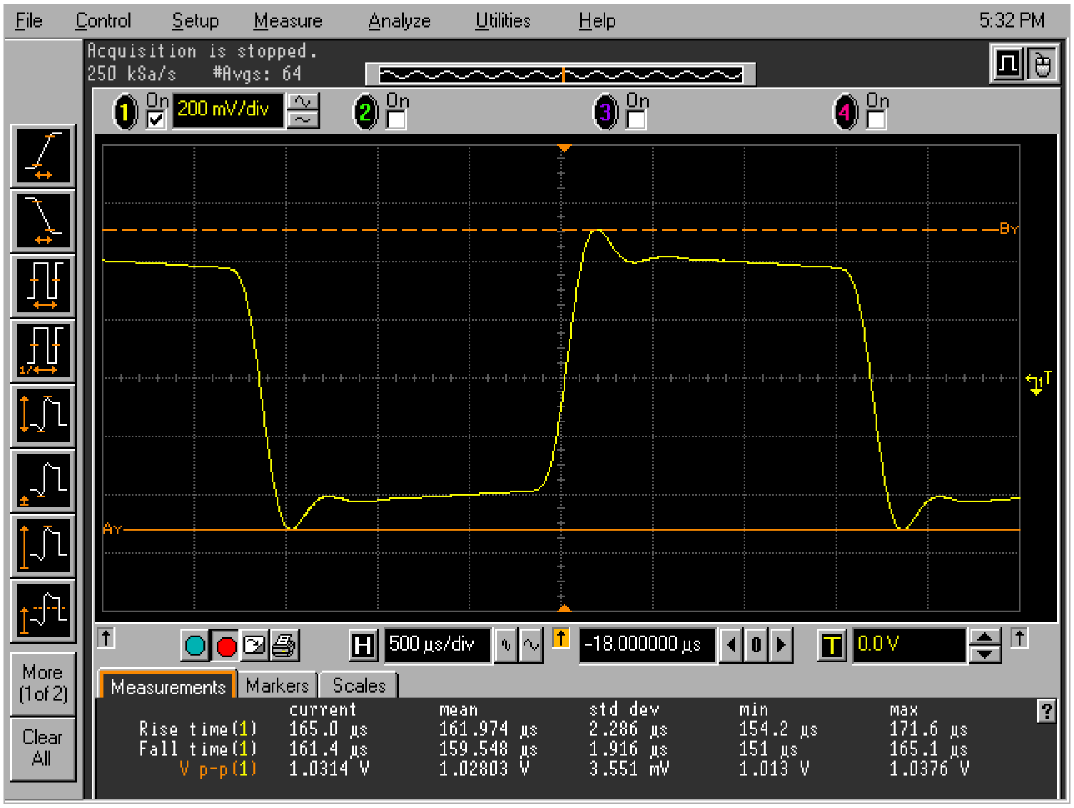
6) 36 dB/Oct Butterworth Low Pass Step Response for fo = 3 kHz



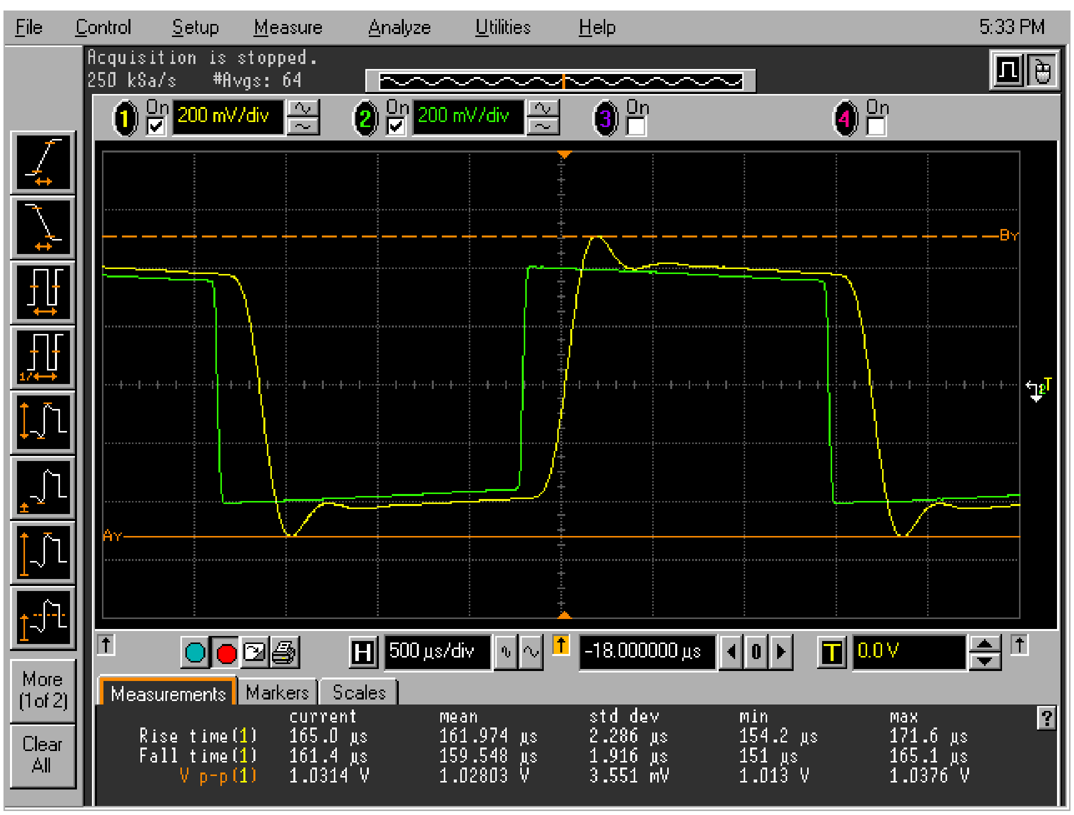
The output of the amp (Ch1) is on Ch 1 of the scope and the Generator's Output passing through the amp (Ch 4) with crossovers off is shown on Ch 2 of the scope.



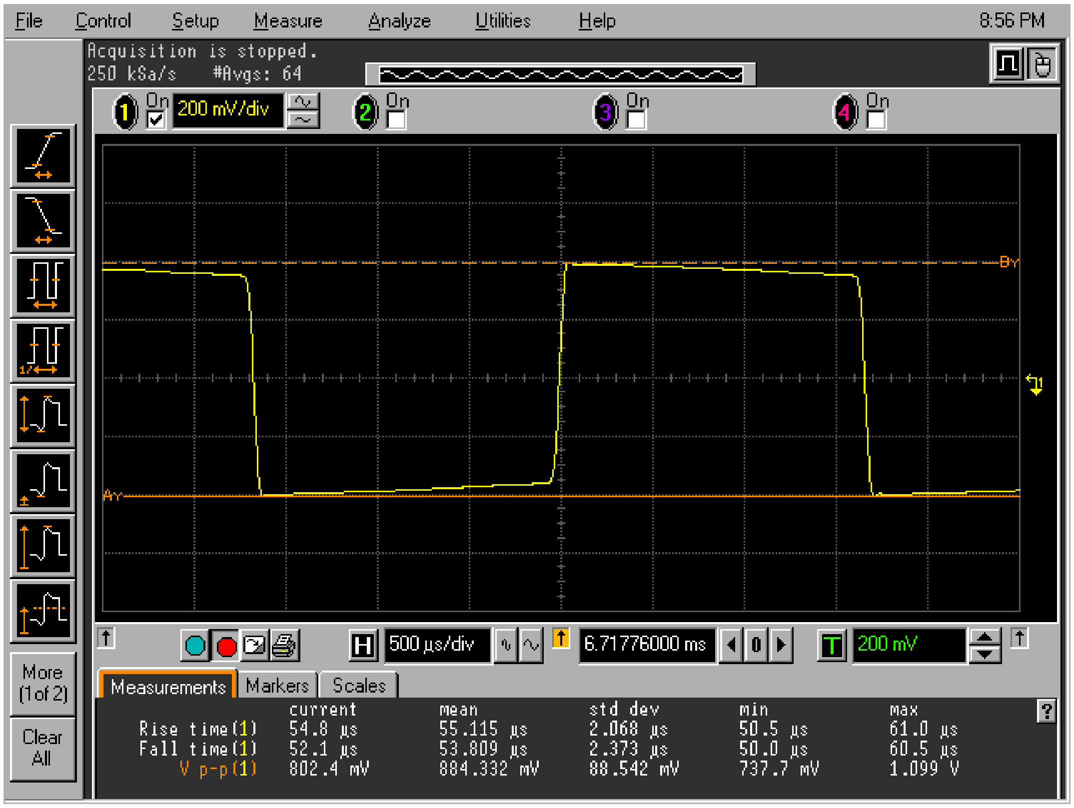
7) 36 dB/Oct Linkwitz-Riley Low Pass Step Response for fo = 3 kHz



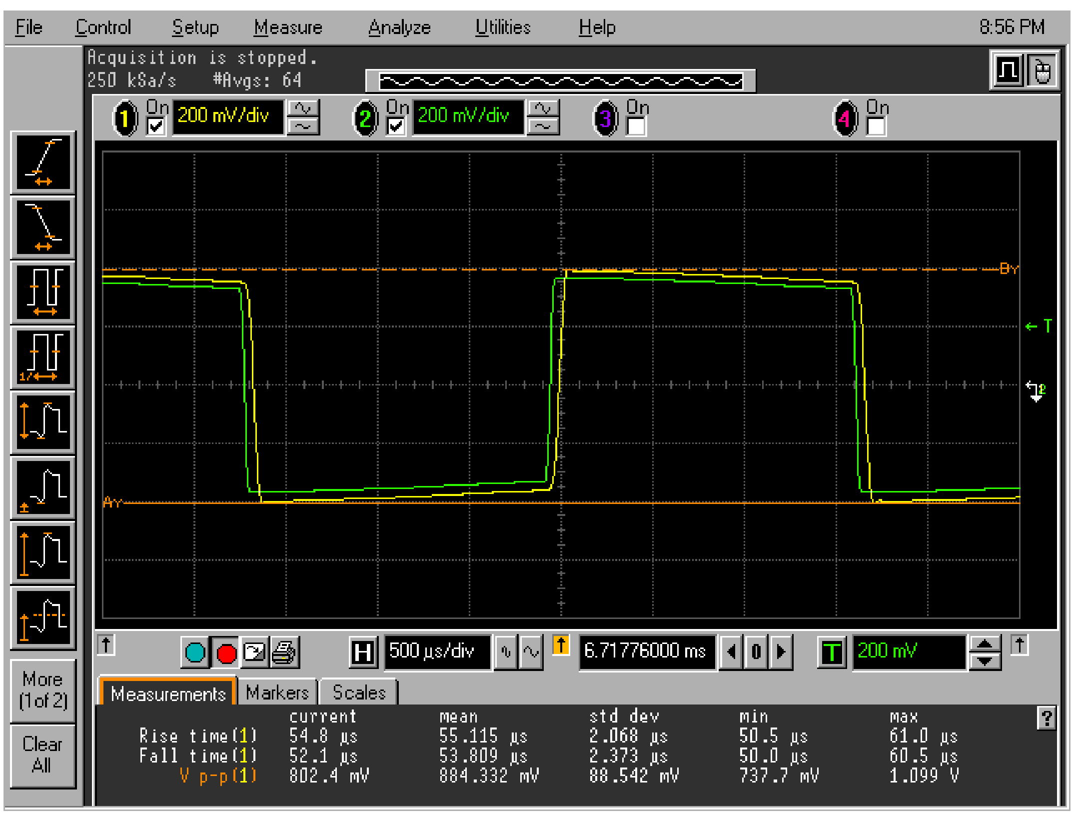
The output of the amp (Ch1) is on Ch 1 of the scope and the Generator's Output passing through the amp (Ch 4) with crossovers off is shown on Ch 2 of the scope.



8) 36 dB/Oct Bessel Low Pass Step Response for fo = 3 kHz



The output of the amp (Ch1) is on Ch 1 of the scope and the Generator's Output passing through the amp (Ch 4) with crossovers off is shown on Ch 2 of the scope.



The Bessel Crossovers are again the fastest to respond to a jump in sound.