A Precision Audio Attenuator Using the MAX502

This article describes a precision audio attenuator circuit using the MAX502 digital-to-analog converter (DAC). Included is the circuit schematic, theory of operation and lab test data results for frequency response and various distortion parameters.

Digital control over audio voltage levels requires low noise and low total harmonic distortion (THD) circuitry. For consumer-grade audio, digital pots are often used. However, if you need professional-level audio performance, the MAX502 12-bit multiplying DAC is an ideal choice.

Why the MAX502?

The MAX502 is a multiplying DAC. This refers to both the internal circuit topology and the transfer function of the DAC.

The output of a multiplying DAC is a direct function of the input digital word multiplied by the reference voltage. What is important to note is that the internal circuitry of the DAC is such that the reference voltage passes to the output without modification, except for the signal amplitude. Multiplying DACs are usually in the form of an R-2R ladder network. See Figure 1 below.

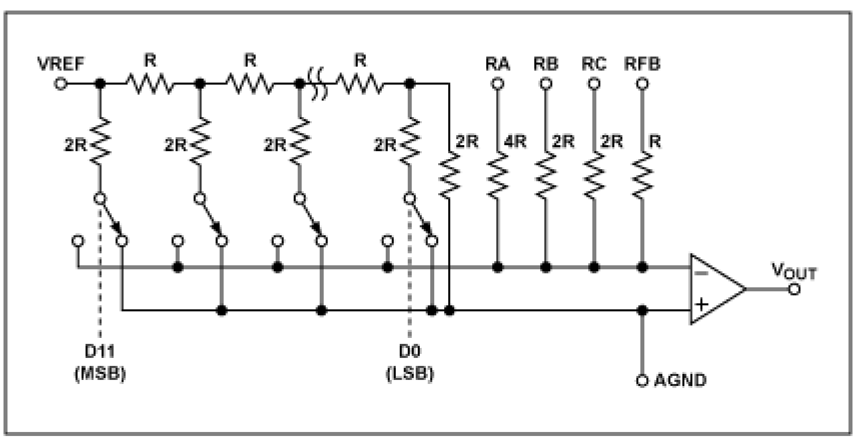

Figure 1. The MAX502 internal R-2R structure

There is no internal circuitry between the R-2R divider network and the output amp. This allows the external voltage reference pin, VREF, to be used as the *audio input*, which further allows the digital input to control the amount of attenuation, or the volume. Exceptional audio performance and very low distortion are achieved over the full audio range of frequencies with this configuration, partially due to the fast settling time (5ms) of the MAX502. This is supported by the following test data.

Test Circuit

The setup used to generate the test data is shown in Figure 2. The audio input was set to 1VRMS, which is the industry de facto standard for "full volume." The MAX502 can handle much larger inputs, but for audio measurements, the 1VRMS standard is used.

The audio test set used is the Audio Precision System Two, an extremely accurate audio measuring device. Four MAX502BENG devices were tested. The graphs are for the worse case part, although the variation between parts was less than 1%.

The input consists of a precision inverter U1, a MAX427 low offset, low-noise op amp. The two resistors R1 and R2 are matched to 0.1% to keep the gain error small. Since the audio input and DAC output is bipolar, the DAC input code word is from 40H (full off) to 7FH (full on). All of the tests are at full-scale volume, with an input code of 7FH.

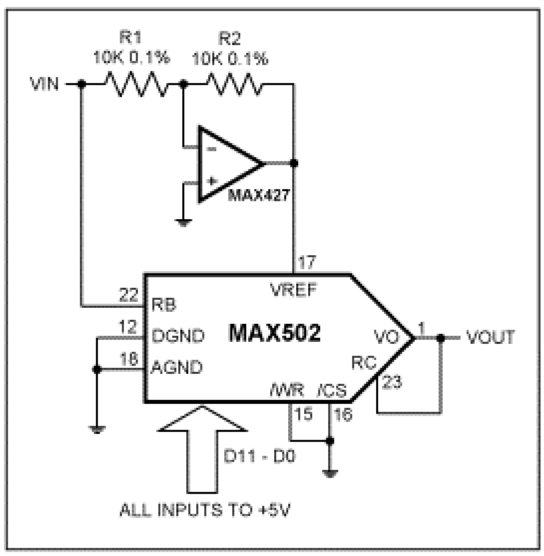

Figure 2. The MAX502 test circuit

Test Results

The first test that was performed is frequency response. Our goal was to achieve a very flat (within ±0.25dB) response from 20Hz to 20KHz. Since the response of the MAX502 extends to well over 50KHz this is easily accomplished as evidenced by Figure 3. The nominal output level is slightly less than 0dB (1VRMS reference) because the absolute gain is untrimmed, and to a much lesser degree caused by the fact that the maximum output occurs at a digital count of 2047 vs the ideal maximum count of 2048. Adjusting the values of the gain setting resistors R1 and R2 can eliminate this gain error. In this case, increasing the value of R2 by 292 ohms normalizes the gain to exactly 0dB.

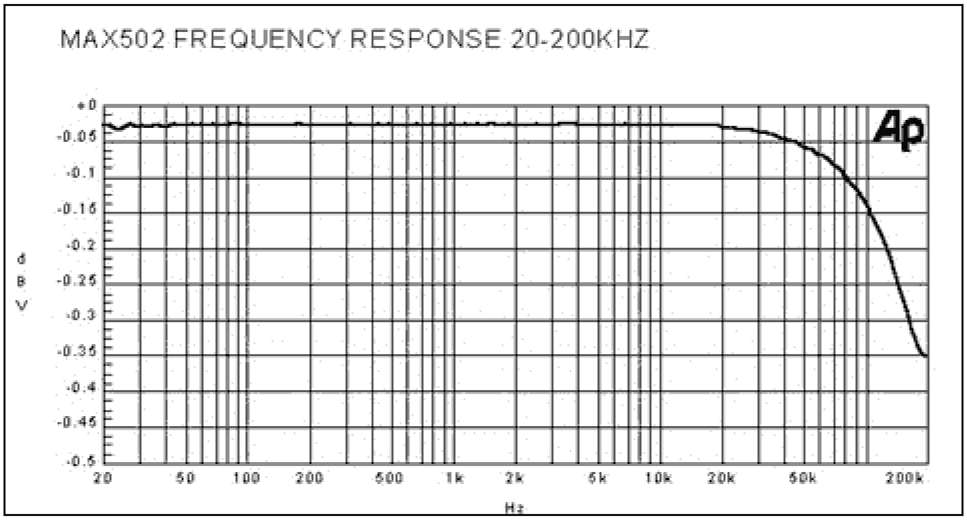

Figure 3. Frequency response

The next most important tests are the harmonic distortion and noise tests. These tests prove that the MAX502 does not degrade the quality or add noise to the output signal. A single test shows both results at once, the FFT. The input to the DAC is a 1KHz, ultra-pure sine wave. The output is digitized (to 24-bit accuracy) and the FFT algorithm is run on the data. The FFT plot should show only the original 1KHz tone, and nothing else. In order to be "CD quality", all of the harmonics and the noise floor must be below 96dB. As Figure 4 indicates, the highest component is the third harmonic (3KHz), which is -115dB down at the output, and the noise floor is around -120dB down. This is superb audio performance!

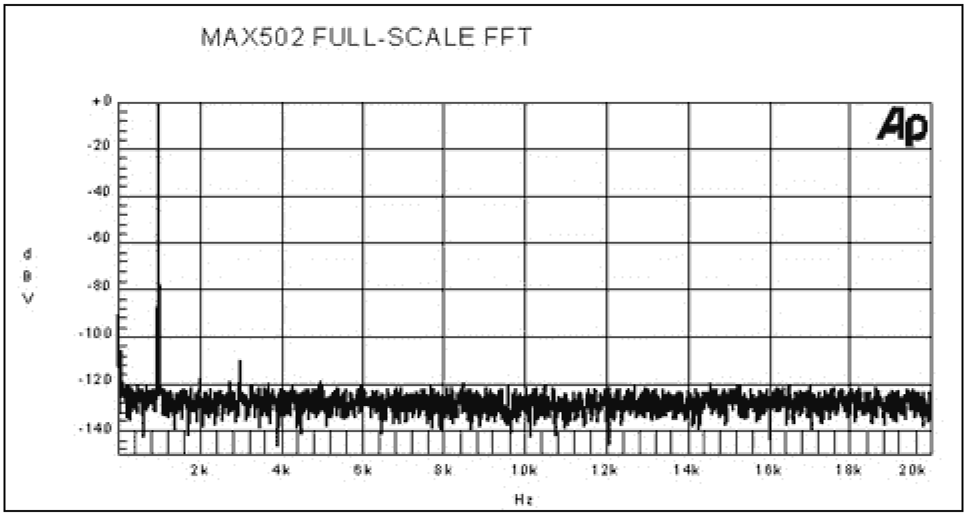

Figure 4. The MAX502 FFT plot

The ideal volume control should not alter the sound as the volume changes. The THD at lower volume levels should not be substantially different for full-scale, and there must be "headroom" for transient peaks without clipping. The standard test is to plot the THD versus audio level. As a general rule, the curve is in the shape of a "V." At very low levels (-50dB), the THD starts with a large number, then rapidly drops until a minimum point is reached. Ideally, this low point on the curve is between Ð10dB and +6dB, where the music volume is from moderate to loud. Distortion would be the most objectionable (and noticeable) at this range of amplitude. At levels below Ð30dB, the music is quiet and the human ear cannot easily detect objectionable distortion.

The MAX502 exhibits extremely low distortion, as first indicated by the FFT plot. The lowest point in the curve is actually closer to the +15dB point, which indicates it can work with much larger signals than standard audio levels. For any audio path, a THD of less than 0.025% is professional quality and the MAX502 easily beats that figure. At the 0dB reference, the THD is 0.002%, which few other solutions can match. The sharp upwards increase past +16dB indicates the onset of clipping and slew rate at the larger input levels, but these levels would never be used in the application.

The THD curve in Figure 5 is for a single frequency, 1000Hz. Another benchmark of audio performance is the THD versus frequency (at full-scale level), shown in Figure 6. This shows whether the circuit adds distortion based on sensitivity to frequency. Ideally, this plot should be fairly flat in the manner of the frequency response plot.

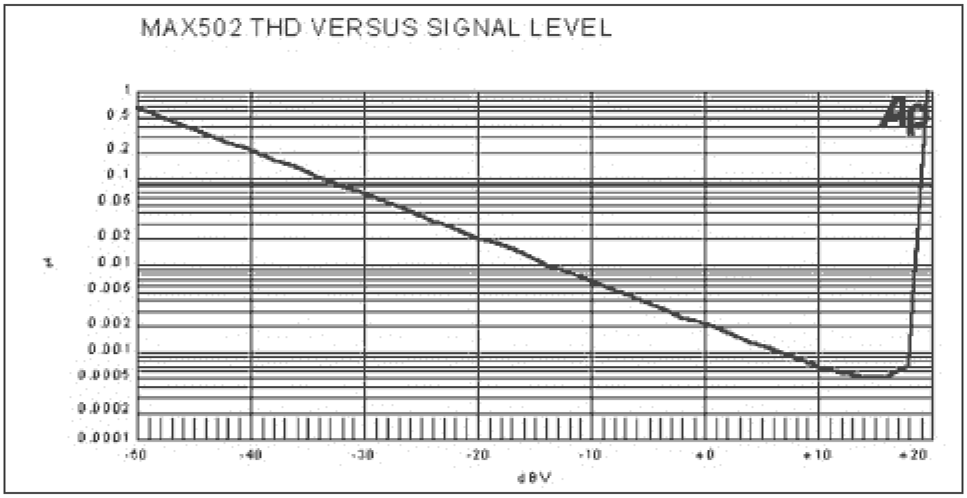

Figure 5. The MAX502 THD versus level

The last audio test is a standard measure of distortion, using a set of 30 different tones added together. This test was authored by SMPTE (Society of Motion Picture and Telephone Engineers) as a test for inter-modulation distortion (IMD). The early IMD test tone was two sinewaves of 60Hz and 7KHz. If IMD is created by the circuit, there will be added frequencies based on the sum and difference of the two frequencies. The IMD products are of the form:

$$mF1 \pm nF2$$

Where m and n are all possible integers, F1 = 60Hz and F2 = 7KHz.

Modern DSP-based audio test sets allow the test tone to have 30 different individual frequencies, and therefore detect a broader range of potential IMD distortion. If the audio circuit is linear, there should be no difference between the multi-tone plot shown in Figure 7 versus the single-tone THD plot shown in Figure 6.

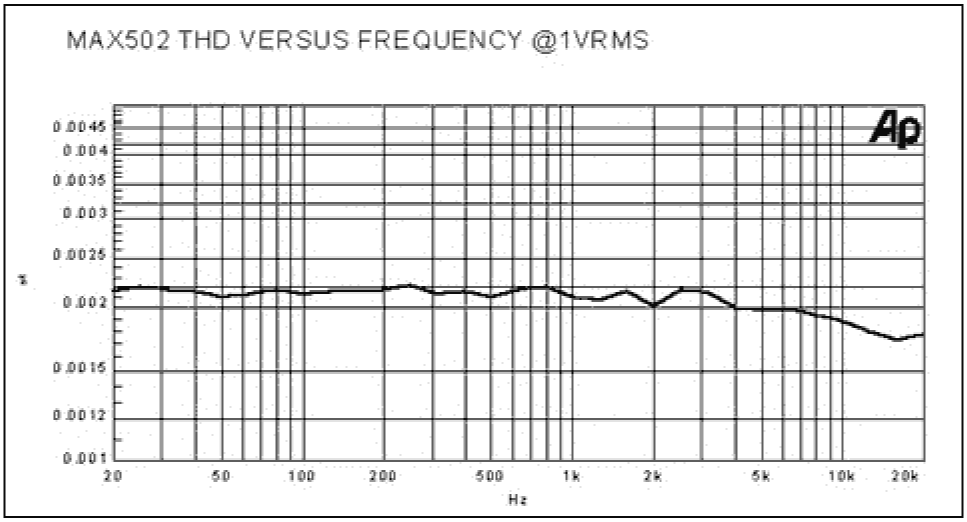

Figure 6. The MAX502 THD versus frequency

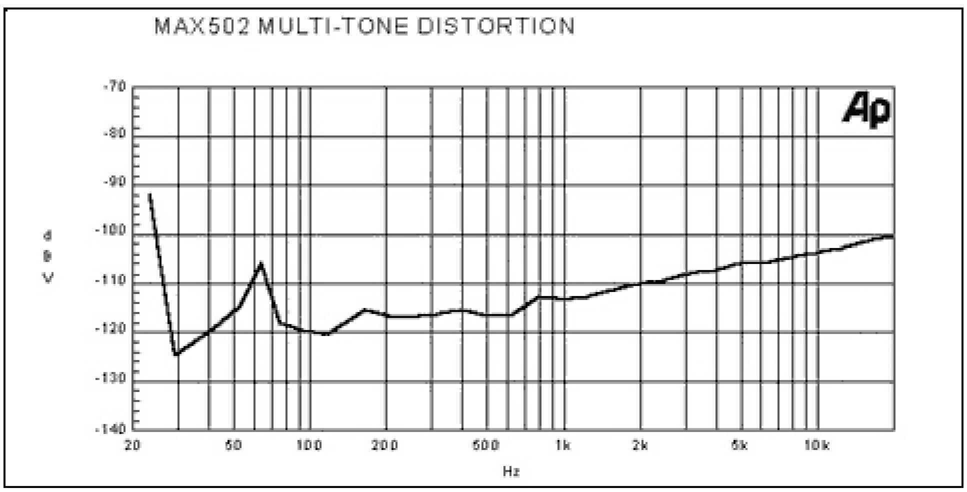

Figure 7. SMPTE IMD, 30-tone signal

The IMD plots shows that all distortion levels are Ð100dB are better, and in the frequency band the ear is most sensitive to (200Hz Ð 1KHz) the IMD products are below Ð110dB, an outstanding result.

Conclusion

The MAX502 exhibits true professional audio performance when used as an attenuator. Requiring only one external op amp and two matched resistors, better than CD quality audio is obtained with a minimum of parts.

For further reading, see the Audio Measurement Handbook by Bob Metzler, available from Audio Precision at http://audioprecision.com/techsupport/audio_measurement_handbook.html.

MORE INFORMATION

MAX427: QuickView -- Full (PDF) Data Sheet (416k) -- Free Sample

MAX502: QuickView -- Full (PDF) Data Sheet (376k) -- Free Sample