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APPLICATION NOTE 3877

ALC Improves Sound Quality While Protecting Speakers

Abstract: A problem for current notebook computers and portable DVD audio is the limited dynamic range of available speakers. The speakers are typically small due to size restrictions, and therefore capable of producing only modest levels of sound pressure over restricted frequency ranges. This application note explains how automatic level control (ALC) can help eliminate the audio problem posed by small speakers.

Introduction

For an operating-system alert or similar audio source, the typical dynamic range is sufficiently limited so that a user can turn up the volume with no concern that the dynamic peaks will cause distortion. However, the limited dynamic range of notebook computer speakers presents quite apparent problems for a DVD soundtrack with a relatively wide dynamic range. The difference in volume between dialog and sound effects can be significant, compelling users to increase the volume to hear dialog and reduce the volume to prevent clipping during loud scenes.

Without adjusting the volume, the user must compromise. You either pick a setting too high for the dynamic peaks and live with the distortion, or pick a setting that is too low for understanding the dialog. For notebook computers with small speakers, this audio problem can render the computer almost useless for watching DVDs.

Theory of Automatic Level Control

An amplifier with automatic level control (ALC) can help eliminate the audio volume problem posed by small speakers. The amplifier can not increase its maximum output voltage without increasing the supply voltage, and can not increase the power-handling capability of a small speaker. The amplifier can, however, make dynamic changes in the RMS output voltage while playing audio. If peaks in the audio waveform (above a predefined threshold) are reduced to a level more closely matching the rest of the audio signal, you can then increase the overall signal volume without clipping the peaks. Known as compression or limiting, depending on the compression ratio, this technique is commonly practiced throughout the audio industry.

A small compression ratio (2:1, for instance) reduces a 4dB increase at the input to a 2dB increase at the output for signals above the compression threshold. Larger compression ratios (20:1 or greater) are referred to as limiting, because once the threshold is reached, the output waveform remains at the same amplitude regardless of increases at the input. Compression is typically applied at the recording and mixing stages, but can also be applied later in the audio stream.

As implemented in an amplifier like the MAX9756, ALC acts essentially like a limiter. It detects output signals above a set threshold, and reduces gain to keep the output below that threshold. The MAX9756's gain response above the threshold is nearly flat, indicating a nearly infinite compression ratio (**Figure 1**).

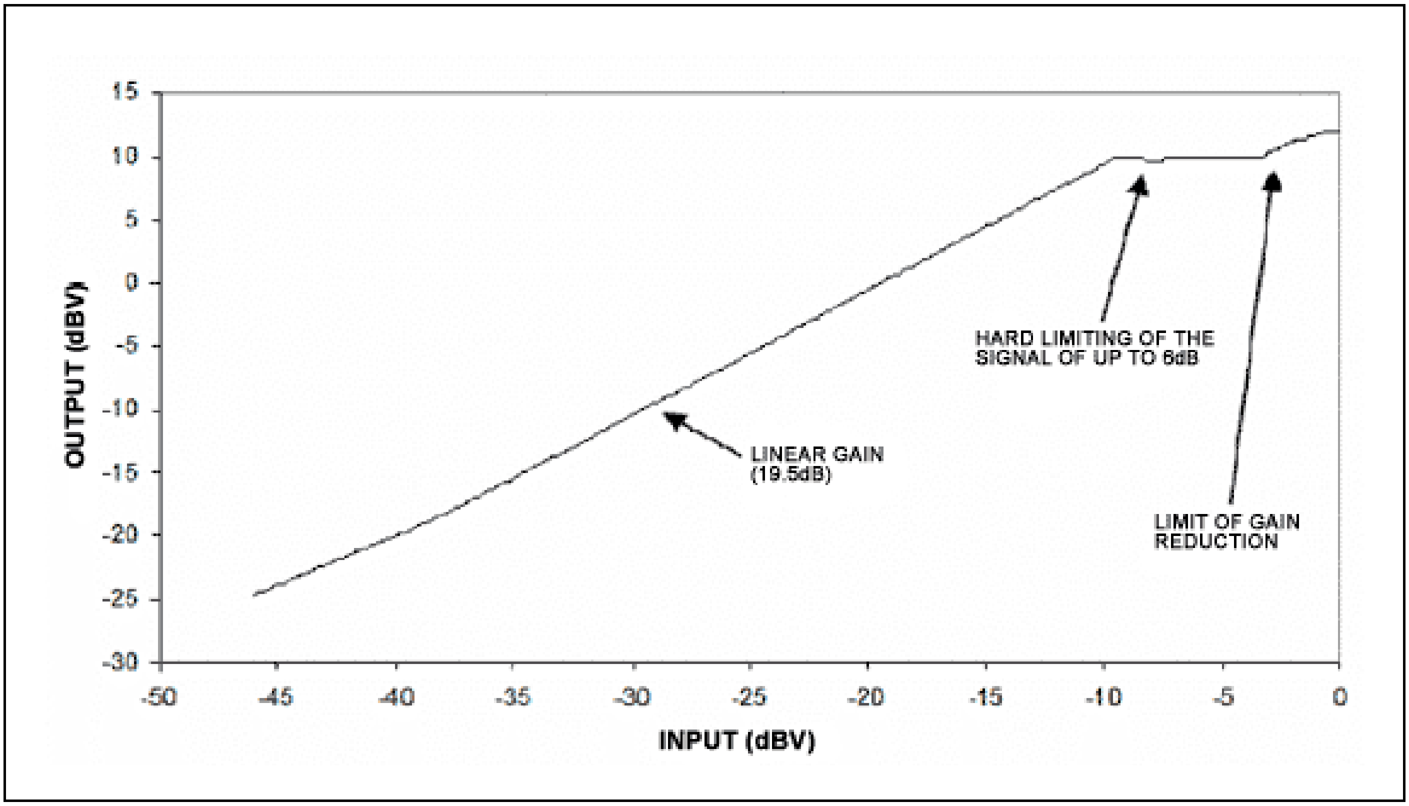

Figure 1. For low levels of volume, the amplifier operates as a normal linear amplifier. For levels above the threshold, it reduces gain to prevent the output from exceeding the threshold. It limits this gain reduction to 6dB maximum, after which the output voltage increases above the threshold.

Automatic Level-Control Timing

The speed at which a limiter reacts to changes in signal amplitude can dramatically affect the sound. When the output signal surpasses its threshold, the amplifier reduces gain at the rate specified by the attack time. Gain is then held at a reduced level until the signal amplitude decreases. Release time specifies the rate at which the amplifier increases the gain, eventually reaching its original value. For amplifiers like the MAX9756, attack time is specified by the value of the capacitor connecting the CT pin to ground. The following equation derives attack time from that capacitor value:

$$\tau = 1500 \times C \text{ SECONDS}$$

Release time is calculated as a ratio to the attack time, and is adjusted by varying the voltage applied to the DR pin. One of three ratios can be selected by applying V_{DD}, V_{BIAS}, or GND to the DR pin. The MAX9756 adds a fixed hold time of 50ms to all release-time values. No gain adjustments are made during the hold time.

Figure 2 shows the effect of a large signal pulse occurring during an otherwise small-amplitude signal. The amplitude of the large pulse in the output waveform is clearly reduced as the gain ramps down. The gain-reduction control voltage is the voltage across the capacitor at CT, which sets the attack time. That voltage is proportional to the gain reduction (in dB) at a given time.

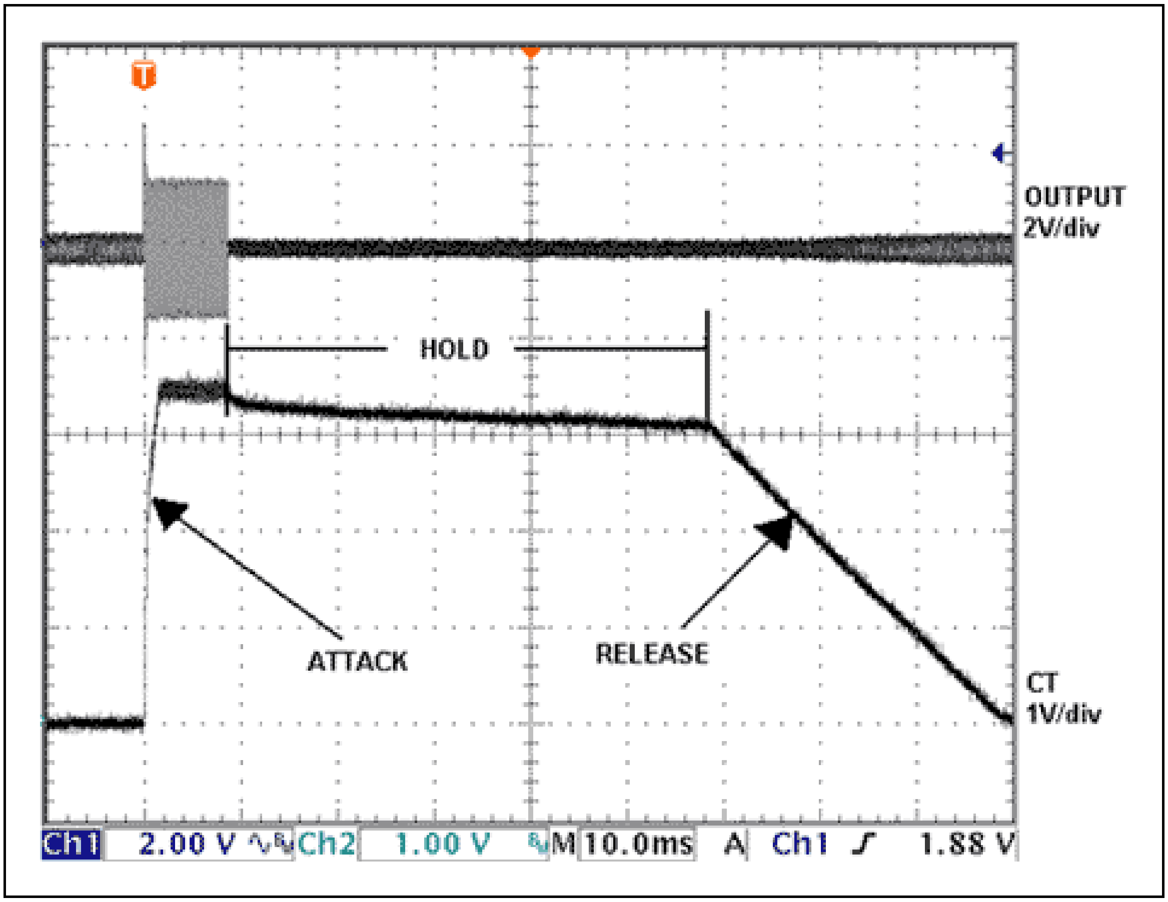

Figure 2. The full cycle of ALC can be seen by applying a brief large signal. The hold time of a MAX9756 amplifier is set at 50ms, and the attack and release times can be adjusted by external components.

The length of attack and release times should correspond to the source material and the desired effect. For example, short time constants cause the ALC to rapidly follow changing signal levels and thus protect against even the shortest spikes in signal level. This action ensures that large signals do not damage loudspeakers, but it can also allow audible artifacts like 'pumping' and 'breathing' as the gain rapidly adjusts to follow the signal dynamics.

For a movie soundtrack with constantly changing signal levels, longer time constants prevent artifacts and maximize the sound quality. The gain in that case is held relatively fixed during rapid changes in signal level, and adjusts only when a long-term change gives the amplifier sufficient time to react. Speaker protection remains intact, because the ALC still reduces most of the signals that could cause damage.

You can observe the effect of long vs. short attack and release times by monitoring the gain-reduction control voltage and the signal waveform (**Figure 3**). To produce representative waveforms, the input signal is a full-volume audio signal. Short attack and release times cause frequent gain adjustments during a passage that, overall, has relatively constant signal strength. Longer attack and release times maintain a smooth gain response that prevents the amplifier from overreacting; the overall signal level is thus maintained and more of the signal dynamics preserved.

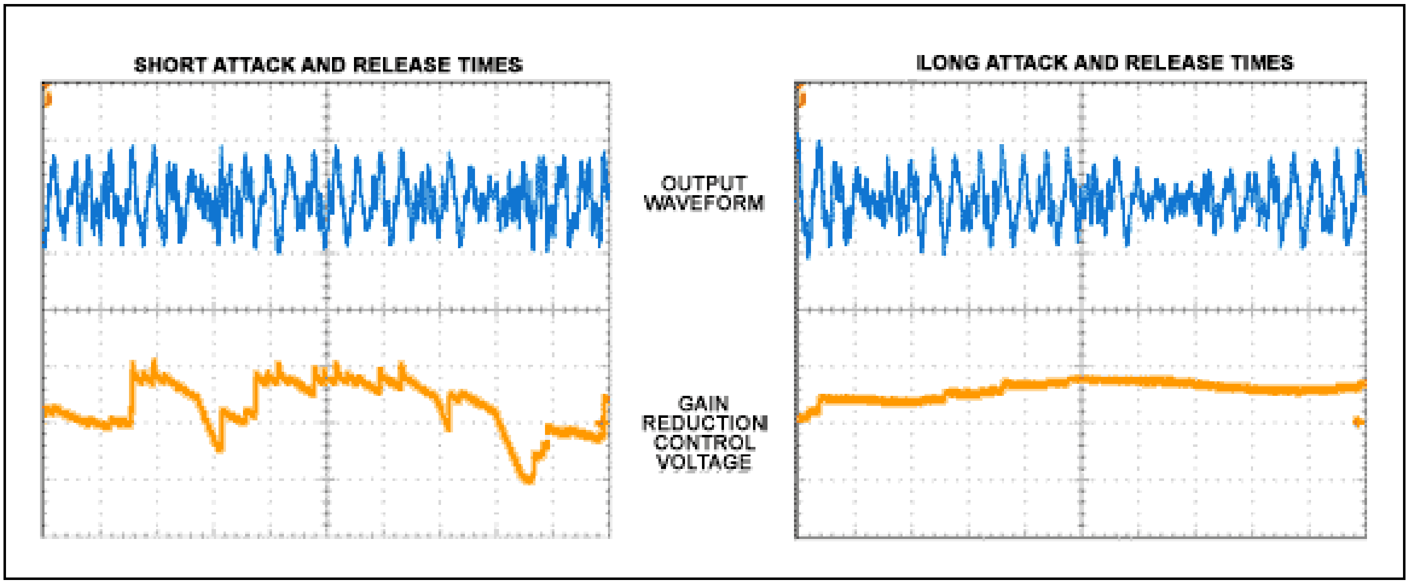

*Figure 3. Short attack and release times (**a**) cause frequent gain changes that can degrade the sound. Longer attack and release times (**b**) produce a smoother gain response.*

ALC Threshold

The speaker amplifiers in notebook computers often operate from a 5V supply. With an 8Ω speaker driven in a bridge-tied load (BTL) configuration, the maximum available continuous power is theoretically:

$$P_{OUT} = \left(\frac{\left(\frac{V_{P-P}}{\sqrt{2}}\right)}{R_{SPEAKER}}\right) = \left(\frac{\left(\frac{5}{\sqrt{2}}\right)^{2}}{8}\right) = 1.56W$$

Because of the 5V supply, any attempt to deliver more power to the load produces a clipped waveform. Amplifiers like the MAX9756 let you adjust the gain-reduction threshold by selecting the resistor connecting the PREF pin to ground. (The MAX9756 injects a constant current of 12µA into the resistor.) You can calculate the value of this resistor (for a 1.4W threshold in this case) by:

$$R_{PREF} = \sqrt{P_{OUT}}\ \mathrm{X}\ \frac{180000}{\sqrt{1.16}} = 198K\Omega$$

You can change the threshold to any desired level by adjusting the value of R_{PREF}. In some cases the sound system is limited by the loudspeaker's power-handling capability. In those instances, you can set the threshold considerably lower than the amplifier's maximum output power and thus ensure that the power-handling capability is not exceeded. If the loudspeaker can handle the amplifier's full output power, then setting the threshold just below the clipping level maximizes sound quality and protects the loudspeaker from long-term damage. Clipped waveforms not only sound bad, but they can eventually cause permanent damage to a loudspeaker. The sharp edges of a clipped waveform are difficult for the mechanical elements of a loudspeaker to reproduce, and over time can cause failure.

Figure 4 shows the effect of setting the threshold just below the amplifier's maximum power output. The input signal is a sinusoidal burst that alternates between high and low levels. The output waveform clearly is clipped during the attack time, but clipping ceases as soon as the gain reduction is complete.

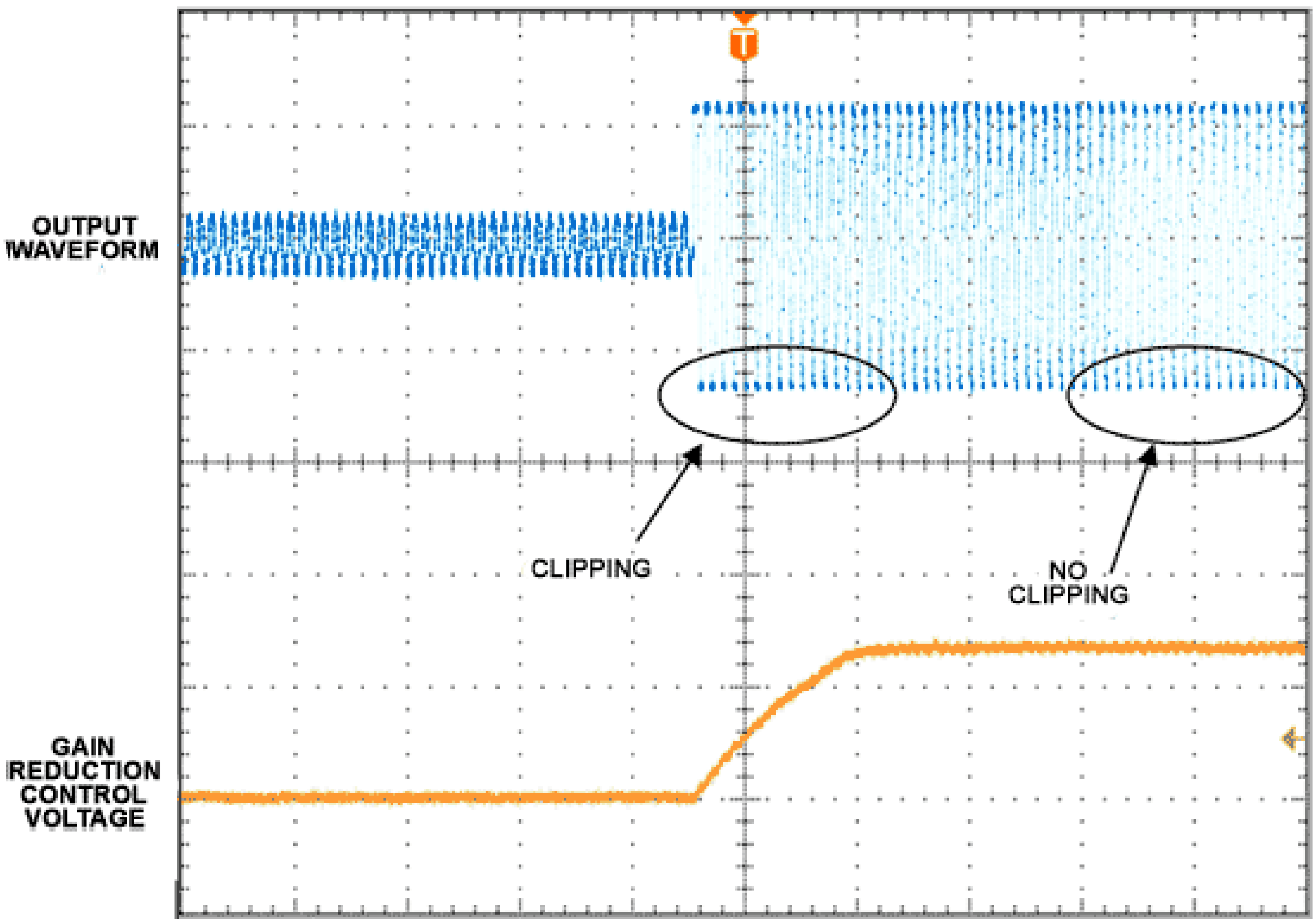

Figure 4. During this transition from small signal to large signal the output waveform initially clips. As gain reduction ramps up, the output waveform returns to the desired unclipped state.

Reducing the Compression Ratio

Limiting, as provided in the MAX9756, can be useful for protecting speakers and preventing clipping, but it completely eliminates dynamic changes while ALC is in effect. The infinite compression ratio means that an increase in the input signal strength has no effect on the output, thereby producing a lifeless and monotone audio sound. If strict control of the output waveform is not required, a lower compression ratio can help prevent clipping while maintaining some dynamic content. Lower compression ratios reduce the audio-signal dynamics rather than completely eliminating them. The MAX9756 compression ratio can be lowered by adding external circuitry, as shown in **Figure 5**.

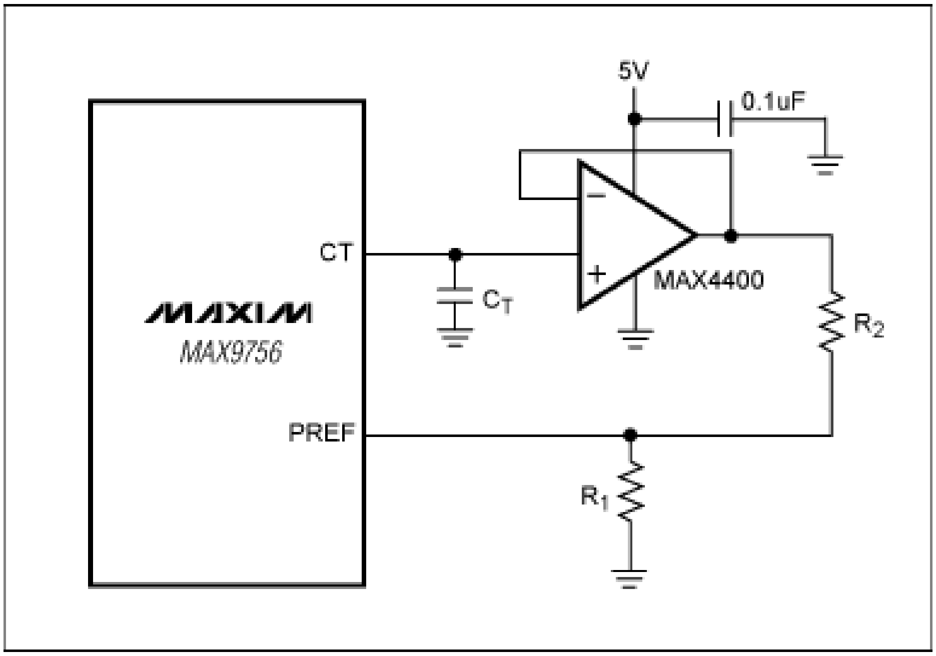

Figure 5. Adding an op amp like the MAX4400 and a resistor, R_2, to the external circuitry of the MAX9756 reduces the ALC compression ratio.

The MAX4400 op amp buffers the MAX9756 CT output, thus ensuring that the added circuitry does not affect the CT voltage and, hence, the release time. The MAX4400 features a typical input impedance of 1000GΩ, which eliminates leakage current that could discharge the capacitor prematurely. The op amp output is fed into PREF through R_2. Thus, the parallel combination of R_1 and R_2 determines the new ALC threshold. The following equation determines the threshold in this configuration:

$$\frac{R_1 \times R_2}{R_1 + R_2} = \sqrt{P_{OUT}} \times \frac{180000}{\sqrt{1.16}}$$

Just before the threshold is reached, the impedance seen by the PREF pin is the parallel combination of R_1 and R_2, because both are connected to GND at that time. Thus, setting this parallel combination sets the threshold for ALC in this configuration. The right side is the previous formula (Equation 3) for calculating R_{PREF}, and the left-hand side is the equation for resistance of the parallel combination of R_1 and R_2 (Equation 4).

The ratio of R_2 to R_1 contributes to the new compression ratio. When R_2 is much larger than R_1, the ALC has a high compression ratio similar to that of the MAX9756's standard hard-limiting configuration. When R_2 is less than R_1, the ALC has a low compression ratio and maintains most of the original dynamic range in an audio signal. Therefore to achieve a useful compression ratio of 3:1, set R_2 to 2.5 times the value of R_1. **Figure 6** shows the effect on voltage gain of the MAX9756 with standard limiting and the compression ratio resulting from $R_2/R_1 = 2.5$.

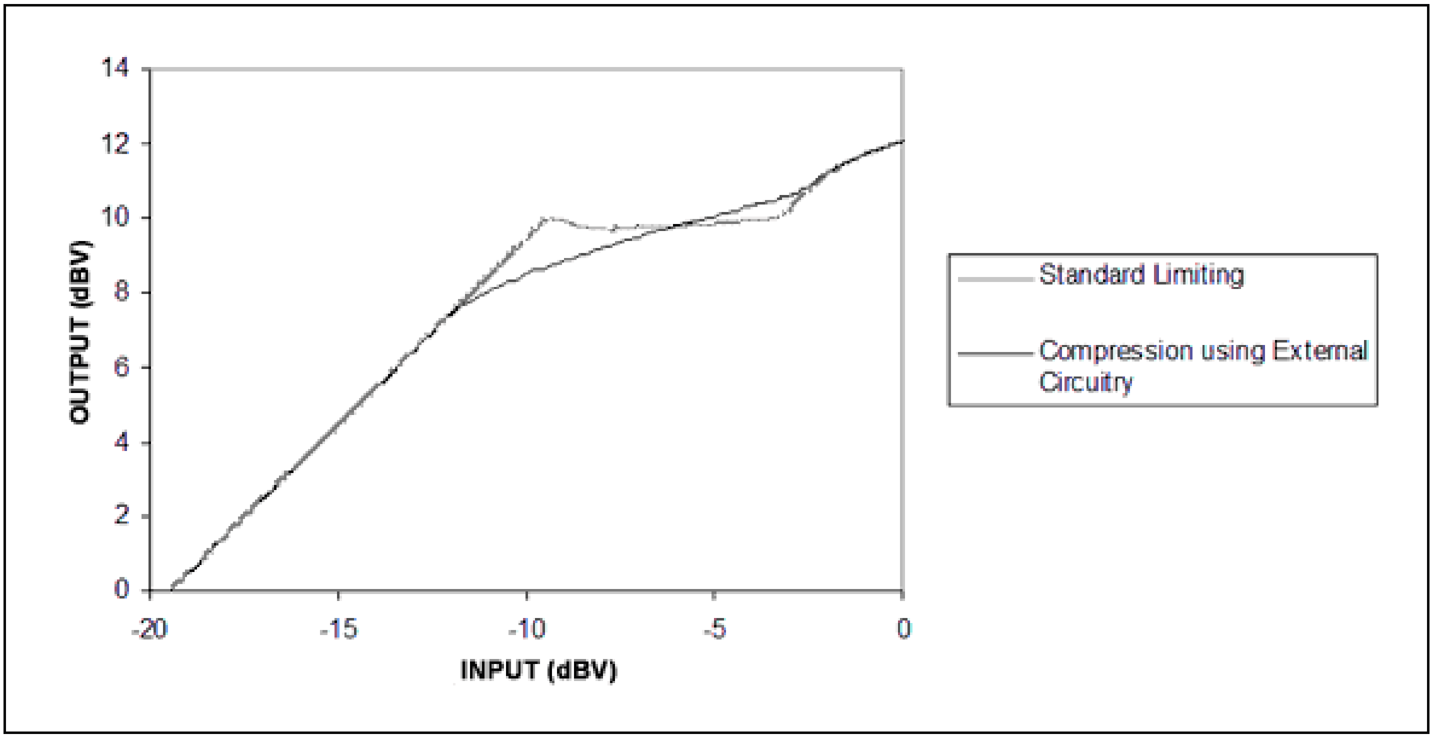

Figure 6. Comparing the MAX9756 standard limiting with the compression achieved with external circuitry shows a more gradual adjustment of gain, and elimination of the horizontal portion.

Improvements Offered by ALC

The improvements contributed by ALC are significant (**Figure 7**). Plot (a) shows the output waveform during a particularly loud passage from a DVD movie without ALC, and plot (b) shows the output waveform for the same input and the same volume setting with ALC enabled.

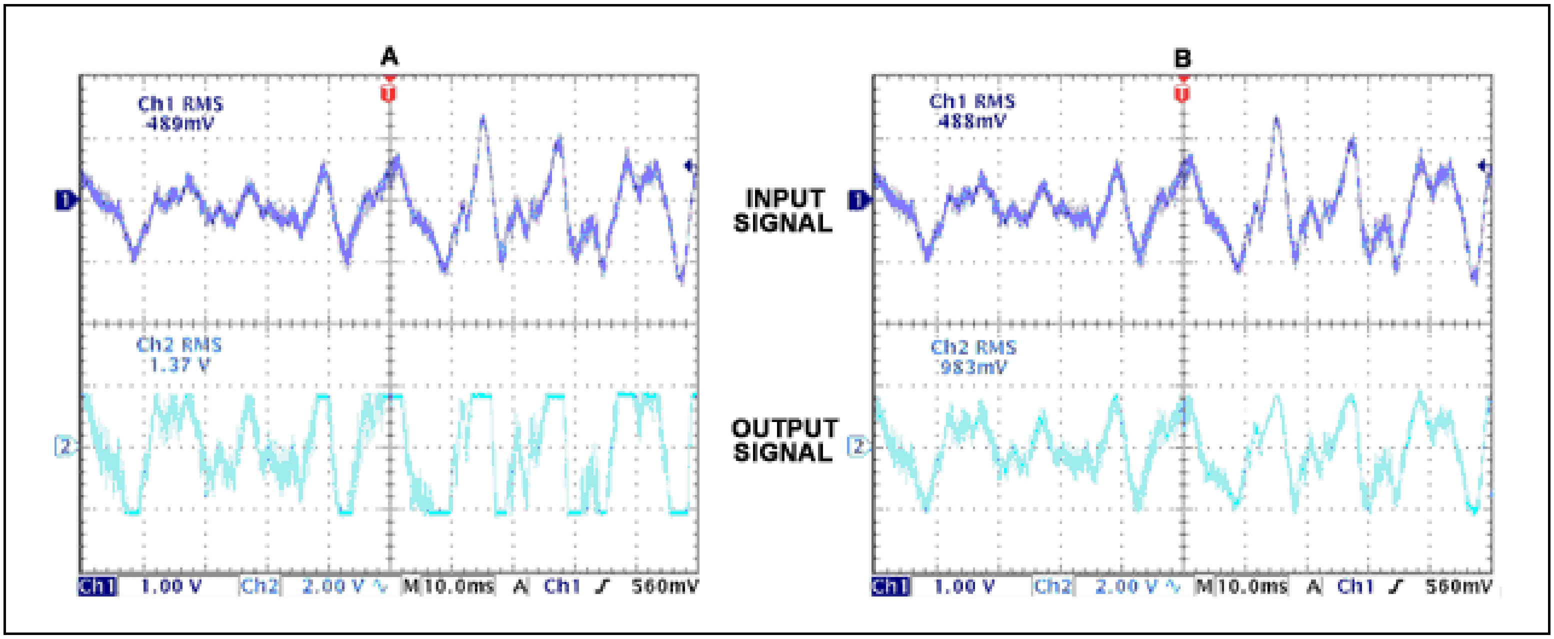

*Figure 7. Without ALC (**a**), the output is severely clipped due to a strong input signal. For the same input waveform with ALC enabled (**b**), clipping of the output waveform is eliminated.*

Users can turn up the volume to acceptable levels for dialog and not worry about other passages being too loud. The sound quality, moreover, is better because clipping is less likely. In addition, ALC extends the life of speakers (less clipping) and aids in protecting low-power speakers. The maximum volume setting is 6dB higher than that of the same system without ALC.

ALC can also be implemented digitally. ALC can possibly be achieved with existing DSP hardware, which can further improve sound quality and speaker protection by performing sophisticated processing such as multiband compression. Though convenient, ALC in the digital domain burdens a DSP system by requiring more cycles and potentially more power.

Incorporating analog ALC into the speaker amplifier, as demonstrated above, is an excellent compromise for notebook computer and portable DVD players, where battery life is at a premium and sound quality traditionally suffers.

A similar article appeared in the November, 2005 issue of *Portable Design*.

Application Note 3877: www.maxim-ic.com/an3877

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