**Amplifier considerations for driving ceramic (piezoelectric) speakers (Part 2 of 2)**

Mark Cherry, Applications Engineer, Maxim Integrated Products Inc. - January 18, 2008

(Part 1 of this article is available at [www.planetanalog.com/features/showArticle.jhtml;?articleID=205801069](http://www.planetanalog.com/features/showArticle.jhtml;?articleID=205801069)).

**Amplifier requirements when driving a ceramic speaker**

Ceramic speaker manufacturers specify a maximum voltage of 14 to 15 V\textsubscript{p-p} to produce the highest levels of sound pressure. The question quickly becomes how to generate these voltages from a single battery supply.

One solution is to use a switching regulator to boost up the battery voltage to 5 V. Armed with a regulated 5-V supply, the system designer could choose a single-supply amplifier that requires a bridge-tied load (BTL). Bridge tying the load automatically doubles the voltage that the speaker sees. But supplying a BTL amplifier with 5 V will allow the output to theoretically only swing to 10 V\textsubscript{p-p}. This voltage will not allow the ceramic speaker to output its highest SPL level. To create the higher sound pressure levels, the power supply would need to regulate to a higher voltage.

Another approach is a boost converter to regulate the battery voltage up to 5 V or more, but has its own set of issues, namely the size of the components needed. Large peak inductor currents can quickly limit how small a total solution can be, because the inductor ends up having to be physically large so that the core doesn't saturate. High-current, small-profile inductors are available, but the saturation-current rating of the core may not be high enough to handle the load current needed to drive the speaker with high voltage at high frequency.

High current drive and current-limit avoidance are needed to drive the ceramic element. This is due to the fact that the ceramic speakers have very low impedance at high frequencies. The amplifier chosen to drive the ceramic speaker must have enough current drive available to not go into a current-limit mode when a lot of high-frequency content is being driven into the speaker.

**Figure 4** shows an applications circuit using a Class G amplifier.
Class G amplifiers have multiple voltage rails available, one high voltage and one low. The low-voltage rail is used when the output signal is small. The high-voltage rail is switched onto the output stage when the output signal demands higher voltage swing.

As a consequence, the amplifier is more efficient than a Class AB amplifier when the output signal is small, due directly to the lower power-supply rail. The Class G amplifier can still handle peak transients because of the higher available rail.

The MAX9788 shown in the figure uses an on-chip charge pump to generate a negative rail that is the inverse of $V_{DD}$. This negative rail is only applied to the output stage when the output signal demands the higher rail. This device provides a more efficient method of driving a ceramic speaker over traditional Class AB with boost converter methods.

The speaker manufacturers always recommend a fixed resistance ($R_L$) in series with the ceramic speaker, as shown in Figure 4. This resistor acts to limit the current out of the amplifier when the signal contains a lot of high-frequency content.

In some applications, the fixed resistance may not be needed if the frequency response of the audio passed to the speaker can be bandwidth-limited to ensure that the speaker does not look like a short circuit to the amplifier. Current ceramic speakers available on the market have a capacitance on the order of 1 μF. The impedance of the speaker is 20 Ω at 8 kHz and 10 Ω at 16 kHz. Future ceramic speakers may have a larger capacitance that will force the amplifiers to deliver even more current for the same signal frequency.

**Efficiency in ceramic vs dynamic applications**

Efficiency in a traditional dynamic speaker application is easy to calculate. The voice coil windings can be modeled electrically as a fixed resistance in series with a high-value inductance. Calculating power delivered to the load is an Ohm's law problem, using the resistance value of the speaker: $P = I^2R$, or $P = V \times I$. This power is dissipated as heat in the speaker coil.

Ceramic speakers don't generate very much heat when they dissipate power due to their capacitive nature. The speaker dissipates a so-called, "blind" power. This is a very small amount of power based on the dissipation factor of the ceramic element. Very little heat is generated when "blind" power is dissipated. Calculating "blind" power is not as straightforward as $P = V \times I$. *(Reference 1)*
The "blind" power is calculated as:

\[ P = \left( \pi f CV^2 \right) \times (\cos \varphi + Df) \]

Where:
- \( c \) = capacitance value of the speaker
- \( V \) = is the rms drive voltage
- \( f \) = the frequency of the drive voltage
- \( \cos \varphi \) = the phase angle between the current through the speaker and the voltage across the speaker
- \( Df \) = the dissipation factor of the speaker. This is quite low and depends on the frequency of the signal and the ESR of the ceramic speaker.

Since the phase angle between the voltage and current is 90° in an ideal capacitor, and the ceramic speaker is mostly capacitive, \( \cos \varphi \) is equal to zero, thus resulting in no power dissipation in the capacitive portion of the ceramic speaker. The imperfections in the ceramic material cause the voltage across the speaker to lag the current through the speaker by a phase angle that does not quite equal 90°. This small difference between the ideal 90 degree phase shift and the actual phase shift is the dissipation factor, \( Df \).

\( Df \) in a ceramic speaker can be modeled as a small resistance, ESR, in series with the ideal capacitor. The series resistance is not be confused with the isolation resistor that is placed in between the amplifier and the speaker. Dissipation factor is the ratio of the ESR to the capacitive reactance at the frequency of interest (Reference 2 and Reference 3).

\[ Df = \frac{R_{ESR}}{X_C} \]

For example, a ceramic speaker with a capacitance of 1.6 μF and ESR of 1 Ω being driven by a 5 V\text{rms}, 5 kHz signal would have a blind power of:

\[ P = \left( \pi \times 5000 \times 1.6 \times 10^{-6} \times 5^2 \right) \times (0 + .05) \]

or 31.4 mW.

**Real power dissipation**

Thus, although the ceramic speaker itself doesn't dissipate real power as heat like dynamic speakers do, heat is generated in the output stage of the driving amplifier and in the external resistor (\( R_L \)) placed between the amp and the speaker (Figure 4, again). The larger the external resistor, the more power dissipation is moved off of the amplifier at the expense of low frequency response.

When driving a ceramic speaker with a 10 Ω series resistor, one can see that "blind" power is a small contribution to the overall load power. Most of the power is dissipated in the external resistor, as
shown by the required amplifier power delivery versus frequency graph, **Figure 5**.

Better low-frequency response will require a smaller external resistor, but that will cause the output stage of the amplifier to dissipate more power. Amplifier efficiency will dictate how much power will be dissipated in the output stage of the amp. The need to dissipate power in the amplifier drives the need for more efficient solutions including Class D and Class G amplifiers. The load consists of some series resistance, which will lead to some power dissipation in the load network and not the speaker. Even with a 100% efficient amplifier, the series resistor will burn power that is intended for the speaker.

![Figure 5: Power delivery needed vs frequency](Click on image to enlarge)

In this simple example, at 5 kHz the total power delivered to the load is 515 mW. An amplifier with 53% efficiency will dissipate 457 mW. The amount of power that the amplifier needs to dissipate will dictate what size package the application can use. A significant amount of power dissipation will be required if high-frequency sine waves need to be driven into the speaker.

**Conclusion**

Thinner and thinner portable devices are driving a need for low-profile ceramic speakers. These speakers are different than traditional dynamic speakers so a different set of design considerations apply. The capacitive nature of the ceramic speaker requires the amplifier to have high output-voltage drive and a large output-current capability, so that the high voltage can be maintained over frequency. An amplifier chosen to drive a ceramic speaker must be able to deliver both blind and real power to the complex load. Amplifier efficiency must be high enough to allow for a small solution size and low cost. Such demands require the use of different amplifier topologies than the traditional Class AB. More efficient solutions such as Class G or Class D amplifiers become more attractive, with Class G offering the best efficiency.

(Editor's note: the x-axis in Figure 2 originally was labeled in "Hz", instead of "kHz"; we regret the error.)

**References**

About the author

Mark Cherry is an Audio Corporate Applications Engineer in the Multimedia Business Unit at Maxim Integrated Products Inc., Sunnyvale, CA. He joined Maxim in 2001 after earning a BSEET degree from Arizona State University East. Prior to Maxim he worked as an intern at MTX audio in Phoenix, Arizona building car audio power amplifiers. In his current role at Maxim, Mark is a product definer in the multimedia business unit, working on products for the portable audio market including cellphones and mp3 players. He can be reached at Mark.Cherry@maxim-ic.com, or (408) 737-7600 x 6800.