RF Filtering for Audio Amplifier Circuits

Is DC Resistance Robbing Power From Your Circuit?

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Introduction

Nearly every device that sends sound to a speaker requires an audio amplifier. With the explosive growth of consumer electronic devices, usage has increased dramatically. Audio amplifiers are used in everything from car and home stereos, personal digital assistants (PDAs), cell phones and portable music devices such as CD and MP3 players.

An important aspect of the audio amplifier circuit is the output RF filter, required to suppress RF interference produced by fast output transitions of the amplifier.[1] Early techniques for filtering the amplifier output in car stereos used traditional through-hole type feedthru capacitors. Over time, circuit designers have changed from through-hole type to surface mount chip feedthru capacitors or chip ferrite beads to lower costs. These new components add DC resistance to the audio circuit, which can increase power consumption and shorten battery life in handheld devices.

This article will show how to use a single X2Y® bypass capacitor to improve audio amplifier output performance by removing the DC resistance. The solution also lowers system cost through component reduction.

Car Audio

In the past, many in the automotive industry used multilayer ceramic through-hole feedthru capacitors to filter the audio amplifier output in car radios. RF filtering prevents electro-magnetic interference (EMI) from corrupting other electrical components in the car by using speaker wire or main power leads, or as a launch point for radiated noise. The through-hole feedthru capacitors provided insertion loss with no effect on the power output of the audio amplifier because the power and return wires to the speaker were fed through a hole in the center of each feedthru capacitor. The capacitor was mounted to a grounded plate so undesirable EMI could be shunted to the circuit ground reference (see Figure 1).

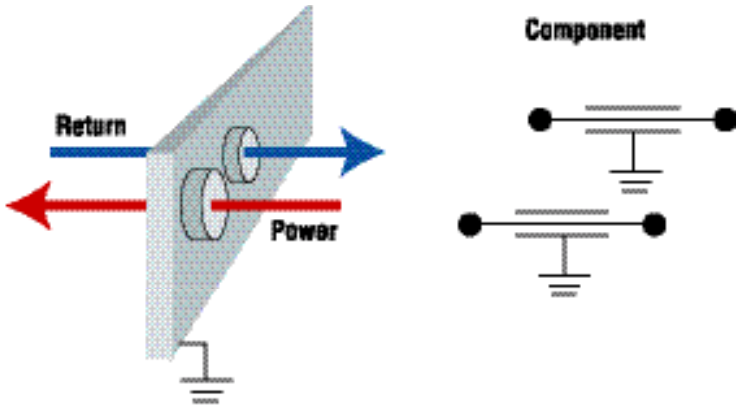

Figure 1: Standard "through-hole" capacitors

Eventually, OEM price pressures began fueling the demand for alternative solutions. Ongoing research by passive component manufacturers led to the development of the four terminal surface mount chip feedthru capacitor. The new type chip feedthru seemed a natural replacement for its cousin, the through-hole feedthru capacitor, and could offer lower costs in a number of ways:

1. A simplified component design lowers production costs.
2. No need for a mounting plate for the chip feedthru, which can be surface mounted on the PC board.
3. Labor costs are lowered through the use of automated pick and place machines during production.

Although both capacitors are called "feedthru", the method by which the DC current is fed through the two devices differs dramatically. The chip feedthru does not

have a hole-through for the wire lead and instead must carry the current through the internal electrode plates. In doing so, DC resistance is added to the circuit (see Figure 2).

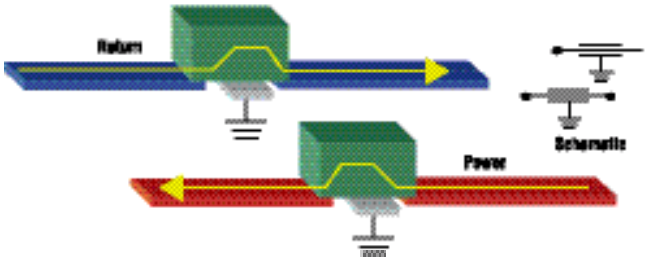

Figure 2: Chip "feedthru" capacitors give resistance to the DC current in a circuit

DC Resistance

When current is fed through a chip feedthru device, the DC resistance associated with the component reduces the power output of the audio amplifier. This is not just true for a chip feedthru capacitor, but for any filter component that offers resistance to the circuit. Figure 3 shows the application of two feedthru capacitors to an amplifier output.

The DC resistance rating of a typical for a typical 0805 or 1206 ceramic chip feedthru capacitor is approximately < 0.6W and for an equivalent size chip ferrite bead device ≤0.4W (both rated for 300mA current). The Power Formula [2] box describes the relationship of power to resistance and shows the dissipated power that is otherwise intended for the circuit, as shown in the two examples. For the following example, the lower resistance of 0.4W will be used.

Power Formula

Bridged-output amplifier Pd_{max} Equation
(National Semiconductor LM4862 Boomer)

$PD_{max} = [4(V_{dd})^2] / [2\pi^2 R_L] = [2(V_{dd})^2] / [\pi^2 R_L]$

Example 1: Amplifier Without Filter DC Resistance

LM4862:
Vdd = 3V, $R_L = 8\Omega$
$PD_{max\ w/o\ resist} = [4(V_{dd})^2] / [2\pi^2 R_L] = [4(3)^2] / [2\pi^2 (8\Omega)] =$ **228mW**

Example 2: Audio Amplifier And Filter With DC Resistance

LM4862:
Vdd = 3V, R_{filter} = Typical 0.4Ω per filter
$R_L' = R_L + 2\ R_{filter} = 8\Omega + (0.4\Omega + 0.4\Omega) = 8.8\Omega$
$PD_{max\ w/resist} = [4(V_{dd})^2] / [2\pi^2 R_L'] = [4(3)^2] / [2\pi^2 (8.8\Omega)] =$ **207.2mW**

Note: Adding a 0.4W DC filter resistance per side (Figure 3) will cause a loss of output power (228mW -207.2mW = 20.8mW [9.12%] loss of output power).

After calculating the reduced power output of the amp because of the higher load impedance, you can then calculate the percentage of output power loss to the speaker:

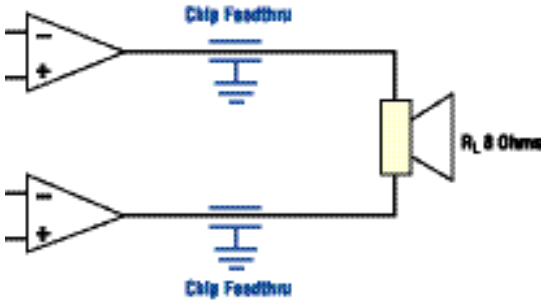

Figure 3: Filter portion of typical amplifier circuit showing feedthru capacitors.

Speaker output power with filter = (Speaker Resistance/Total Resistance) x Total Output Power = (8/8.8) x 207.2mW = **188.36mW**

% of power loss to speaker = [1-(Speaker output power with filter / $PD_{max\ w/o\ resist}$ x 100 = [1- (1.88.36mW / 228mW)] x 100 = **17.5% loss of power to speaker**

Another factor affected by the DC resistance is damping of the loudspeaker, which affects the sound quality of the bass.

Damping Factor is calculated by the following formula:

Damping = $(R_{ls} + R_{out})/R_{out}$
R_{ls} = loudspeaker resistance
R_{out} = amplifier output resistance/impedance.

Audio enthusiasts are often "tuned" in to the sound quality associated with bass. When resistance is added to the R_{out}, it decreases the damping factor. A high series resistance and hence a low damping factor will give a "boomy" bass, in contrast with a "tense" sounding bass for a high damping factor.

X2Y Bypass Filter

When using an X2Y device the component is placed in bypass between the power and return lines, and the two center ground terminations of the component are attached to the circuit ground reference, offering no DC resistance or power loss to the amplifier circuit (see Figures 4 & 5).

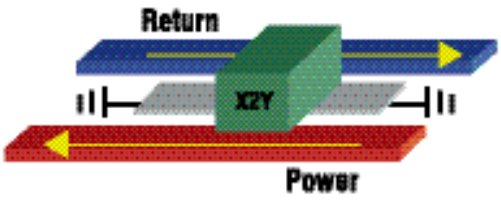

Figure 4: The X2Y bypass capacitor is low impedance to RF noise.

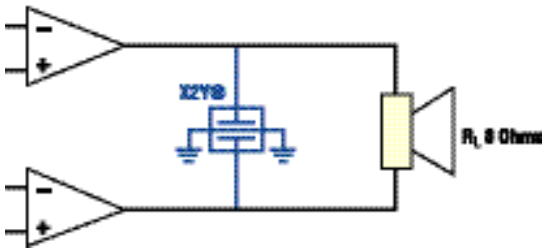

Figure 5: Example showing application of a single X2Y bypass capacitor.

Example 3: Amplifier with X2Y Filter

Since the X2Y chip filter is in bypass (Fig. 4, 5), the series DC resistance in the circuit is 0. Hence the bridged-output amplifier power is the same as the example shown earlier without a filter in the circuit.

$PD_{max} = [4(V_{dd})^2] / [2\pi^2 R_L] = [4(3)^2] / [2\pi^2 (8\ \Omega)]$ = **228mW**

Comparing Filter Performance

A natural question is "how can a bypass capacitor attenuate noise in a manner equal to a feedthru capacitor?" The parasitic inductance of a standard two-terminal capacitor is an order of magnitude higher than a chip feedthru capacitor.[3] It has been documented that by careful placement of two standard capacitors, some flux cancellation can be achieved to improve circuit performance.[4][5] The X2Y improves upon the concept of flux cancellation because the internal electrode design forces opposing current flow into a single component body. Spacing from opposing electrodes to a nearby shared ground layer is only a dielectric layer apart. The flux cancellation reduces the internal mutual inductance of the component and is achieved whether the X2Y is applied single-ended or differentially. The net result is a bypass capacitor with improved broadband and high frequency performance yielding a significant reduction of the common mode noise (see Figure 6).

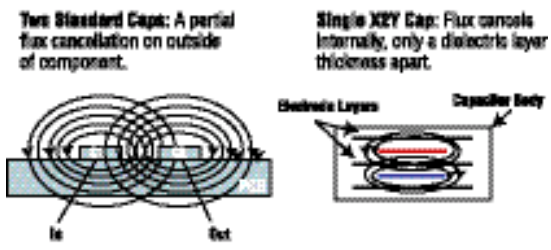

Figure 6: Flux cancellation: Two standard caps vs. one X2Y.

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An added benefit to the X2Y design is that differential mode noise is also filtered simultaneously due to the internal "X" capacitor connection between the power and return lines. Two feedthru capacitors can only filter the common mode noise and require an additional "X" capacitor or choke for differential mode filtering. The common and differential mode noise attenuation of a single 1206 size X2Y component is measured in a microwave test fixture from Inter-Continental Microwave and plotted in Figure 7. For this example, a higher cap value (0.1uF) is shown, a typical value used for filtering the main power leads for the car stereo.

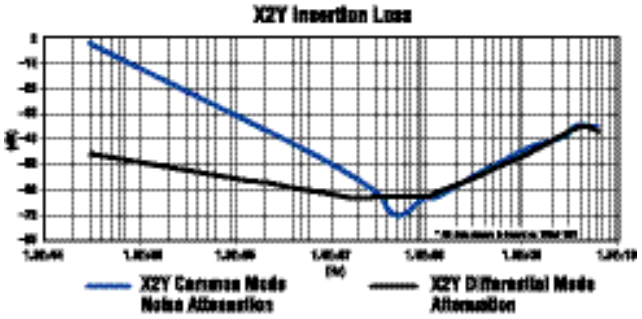

Figure 7: X2Y differential and common mode noise reduction.

Other advantages of a single X2Y component solution include:

- Using one bypass device versus two or more resistive devices reduces component count.
- Better balance between power and return lines to ground: capacitance tolerance between the internal line to ground capacitors is typically 3% or less. This means matched suppression of common mode noise.[6]
- The capacitor maintains balance over time; equal aging and temperature tracking side to side.

We have now established that DC resistance can be removed from a circuit and filter performance actually improved using fewer components.

Portable Audio Devices

Resistive devices are used extensively in consumer electronic products, where smaller, better and cheaper are constant goals. A typical MP3 portable music device may use as many as 10 devices for filtering the different internal components such as audio amplifiers, memory, microprocessor and DSP devices. These devices can rob precious battery life, reducing playing time for the consumer and lowering customer satisfaction for the product (see Figure 8).

Headphone cables like speaker wires are a source of radiated noise from higher harmonics produced by digital processors in the circuit. Standard resistive filtering is shown and require either one component per line

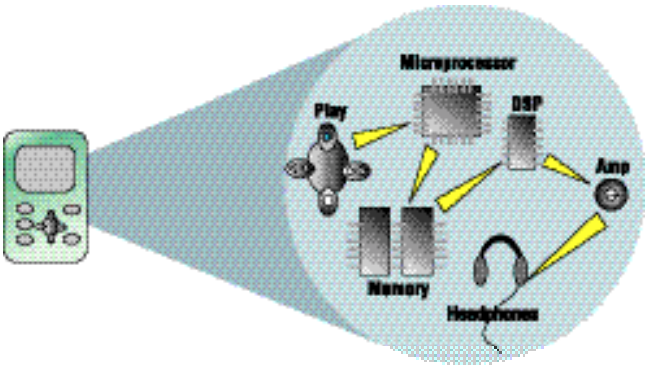

Figure 8: Typical MP 3 player.[7]

or a single device that can filter all three lines at once (see Figure 9). Both scenarios reduce circuit power.

A single X2Y component in bypass can be used in the

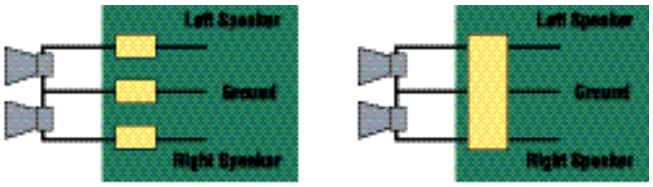

Figure 9: Standard resistive components applied to the headphone jack.

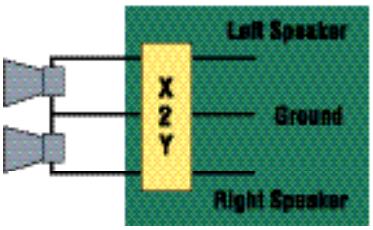

Figure 10: A single X2Y bypass capacitor applied to the headphone jack.

same application by placing the end terminations of the X2Y device on the right and left speakers, while the center ground terminations of the component are placed on the ground of the jack (see Figure 10). In this manner the full intended power goes to the headphone.

The chart in Figure 11 compares the different attributes

Filter Devices	Form Factor	DC Resistance?	Circuit Power Loss?	# Required for Common Mode Noise Filtering	Differential Mode Noise Filtering?
X2Y		No	No	One	Yes
Feedthru or Ferrite Bead		Yes	Yes	Two	No
Multi-pole Feedthru		Yes	Yes	Two	No

Figure 11: Comparison Chart

of selected components used for filtering.

Conclusion

Using the X2Y bypass capacitor for filtering audio amplifiers will result in no power loss because of DC resistance. Power loss is inherent in the design of feedthru chip or ferrite bead components because signal and noise must pass through the device.

References

[1] Maxim App Note: Class D Audio Amplifier Output Filter Optimization, APP 624: Apr 01, 2002 ❑

Technical Paper

[2] Data Sheet, National Semiconductor LM4862 Boomer.

[3] AVX Multilayer Ceramic Feedthru Chip Capacitors And Arrays, http://www.avxcorp.com/docs/masterpubs/feedthru.pdf

[4] Decoupling Strategies for Printed Circuit Boards Without Power Planes, Hwan W. Shim, Theodore M. Zeef, Todd Hubing, EMC Laboratory, University Missouri-Rolla, Presented at the August 2002 IEEE EMC Symposium, Minneapolis, MN - TU-PM-G-5, Volume 1, page 258

[5] Dell Patent #6,337,798

[6] Differential-to-common-mode conversion, By Howard Johnson, PhD, http://signalintegrity.com/Pubs/edn/DifftoCommonMode.htm, (Originally published in EDN Magazine, October 17, 2002)

[7] Source, "How Stuff Works", http://static.howstuffworks.com/gif/mp3-player .gif ❑