APPLICATION NOTE 3171
Do Passive Components Degrade Audio Quality in Your Portable Device?
Jun 16, 2004

Abstract: In an audio circuit, passive components define the gain, provide biasing and power-supply rejection, and establish DC-blocking from one stage to the next. Portable audio, for which space, height, and cost are usually at a premium, forces the use of passives with small footprints, low profiles, and low cost. The audible effect of these devices is worthy of some examination, because poor component choice can significantly degrade the measured performance. Some designers assume that resistors and capacitors have no measurable effect on audio quality, but the nonlinear characteristics of many common passives used in the audio signal path can seriously degrade total harmonic distortion (THD). In some cases, the nonlinear contribution of passives exceeds that of active devices such as amplifiers and DACs, which are assumed by many designers to be the limiting factor in audio performance.

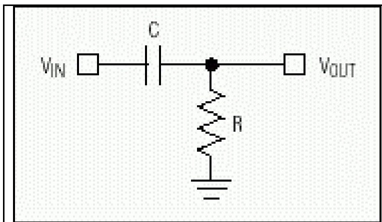
Sources of Nonlinearity

Il valore di resistenza e capacità dei componenti passivi dipende dalla tensione applicata ai loro morsetti.
(voltage coefficient). Per esempio un resistore da 100K può diventare da 101K con 10 V applicati.
Alcuni costruttori mostrano questa caratteristica nelle specifiche.
I moderni resistori a strato metallico non presentano problemi. I condensatori invece ne hanno molti.

- Voltage coefficient:
- Assorbimento del Dielettrico (DA) o effetto memoria
- Resistenza serie (dipendente dalla frequenza)
- Microfonicità: effetto piezoelettrico
- Bassa tolleranza

Tutti questi difetti sono rilevabili attraverso le normali misure di Distorsione.

Test Description



In questo filtro passa alto:
ad alta frequenza l'impedenza del condensatore è piccola rispetto al resistore ma le non linearità si sommano all'uscita.
La distorsione tende ad un picco attorno alla frequenza –3dB

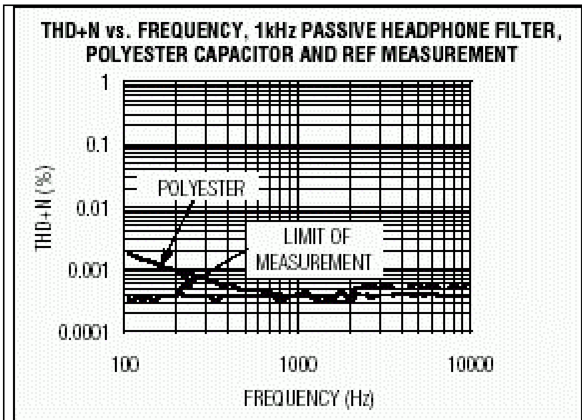


Figure 2. THD+N vs. frequency for a 1kHz highpass passive filter with polyester capacitor, compared to a reference measurement.

Si nota l'incremento di Distorsione a bassa frequenza.

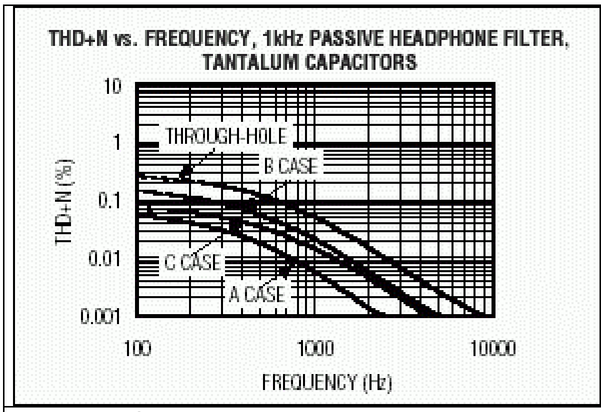


Figure 3. Comparison of THD+N vs. frequency for various tantalum capacitors in a 1kHz highpass passive filter.

Value	Case Size L x W (mm)	Voltage Rating (V)
1µF	A (3.2 x 1.6)	25
1µF	B (3.5 x 2.8)	35
1µF	C (6.0 x 3.2)	50

Condensatori al tantalio

Table 1. Comparison of SM tantalum capacitors tested in Figure 3.

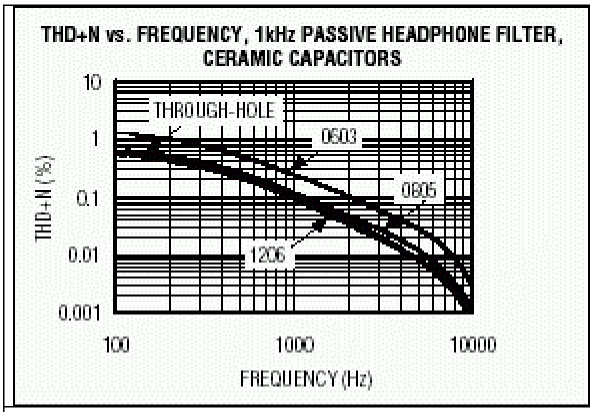


Figure 4. Comparison of THD+N vs. frequency for various ceramic capacitors in a 1kHz highpass passive filter.

Value	Case Size	Voltage Rating (V)	Dielectric Type
1µF	0603	10	X5R
1µF	0805	16	X7R
1µF	1206	16	X7R

Condensatore ceramico

Table 2. SM ceramic capacitors tested in Figure 4.

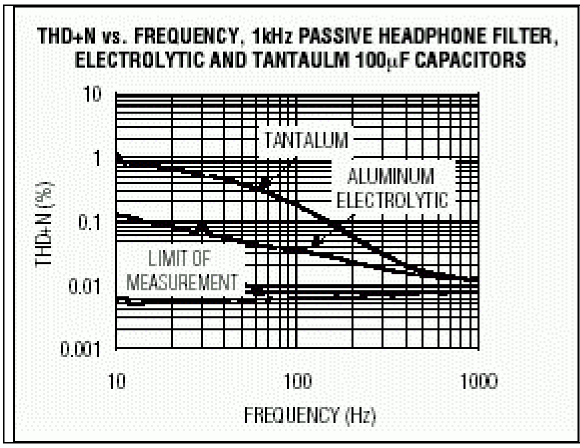


Figure 8. THD+N vs. frequency for large-valued, 100µF capacitors driving a 16Ω load. Both types (tantalum and aluminum electrolytic) contribute heavily to THD at the nominal -3dB point of 100Hz. No such output-coupling capacitors are required with Maxim's DirectDrive headphone amplifiers.

Condensatore elettrolitico da 100 uF

How to Avoid Capacitor Voltage-Coefficient Effects

Figure 5 shows a line-input topology whose novel AC-coupling configuration allows a much lower valued input capacitor than that of a traditional configuration. The input capacitor in this example (C1) is 0.047µF, which can be specified as a ceramic with C0G dielectric in a 1206 case size—a configuration that minimizes the THD contribution from voltage-coefficient effects. DC feedback for the op amp (which should be a device with low input-bias current, such as the MAX4490) is provided by the two 100kΩ resistors. The effect of the DC-feedback path at audio frequencies is attenuated by C2 and R5, so the majority of the feedback is from R1 and R2 through C1. With the values shown, the -3dB point is set at 5Hz.

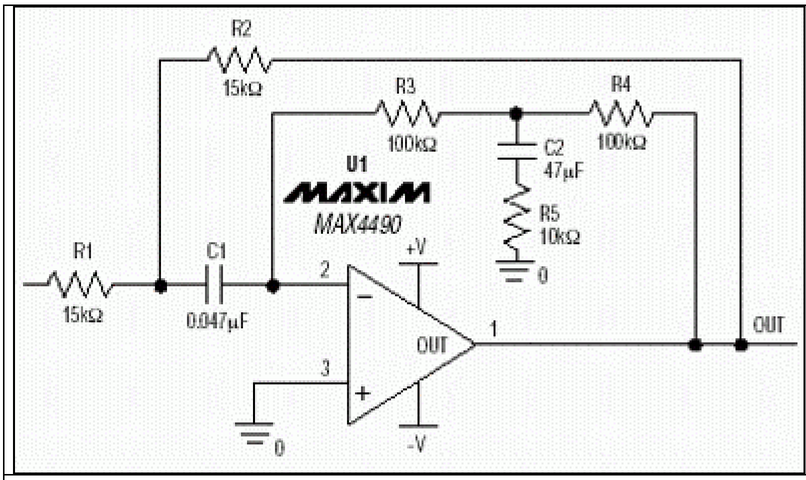


Figure 5. This novel line-input stage reduces degradation due to voltage-coefficient effects. Including the traditional AC-coupling capacitor inside the amplifier's error path lowers the value of that capacitor, and enables the use of C0G capacitors in portable designs.

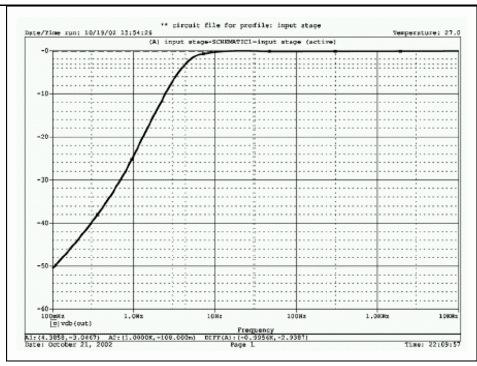


Figure 6. Frequency response for the circuit in Figure 5 shows a smooth rolloff below 10Hz with the -3dB point at 5Hz. The ultimate rolloff rate with decreasing frequency is 20dB/decade.

This type of compound feedback ultimately has a first-order LF rolloff, but can be tuned for a 2nd-order response around the highpass cutoff frequency. Consequently, pay careful attention to overshoot and peaking when adjusting the component values from those shown in Figure 5. Values in the example approximate a maximally flat highpass function. This circuit principle can easily be adapted to quasidifferential (ground-sensing) and fully differential input stages.

The stereo headphone driver IC shown in **Figure 7** (MAX4410) features an innovative technology called DirectDrive®, in which the output bias, powered from a single positive supply, is set at 0V to allow direct DC-coupling to the headphones. Several advantages follow:

- Large DC-blocking capacitors (100µF–470µF, typ) are eliminated, which removes a significant THD contribution based on voltage coefficients.
- The lower -3dB cutoff, now defined by the input capacitor and input resistor, is around 1.6Hz with the values shown in Figure 7, but a -3dB point of 1.6Hz in standard AC-coupled headphone drivers for 16Ω headphones requires about 6200µF. In addition, the low-frequency response is no longer load dependent.
- Eliminating the large-case capacitors saves a significant amount of PCB area. Such capacitors are expensive when compared with the 1µF and 2.2µF ceramic compacitors required by MAX4410 charge-pump circuitry.

To enable the outputs to sink and source load current with a ground-referenced load, the chip generates an internal negative supply for the amplifier. Because that supply (P_{VSS}) is an inverted version of the positive supply (V_{DD}), the available voltage swing at the output (almost $2V_{DD}$) is twice that of a traditional single-supply, AC-coupled headphone driver.

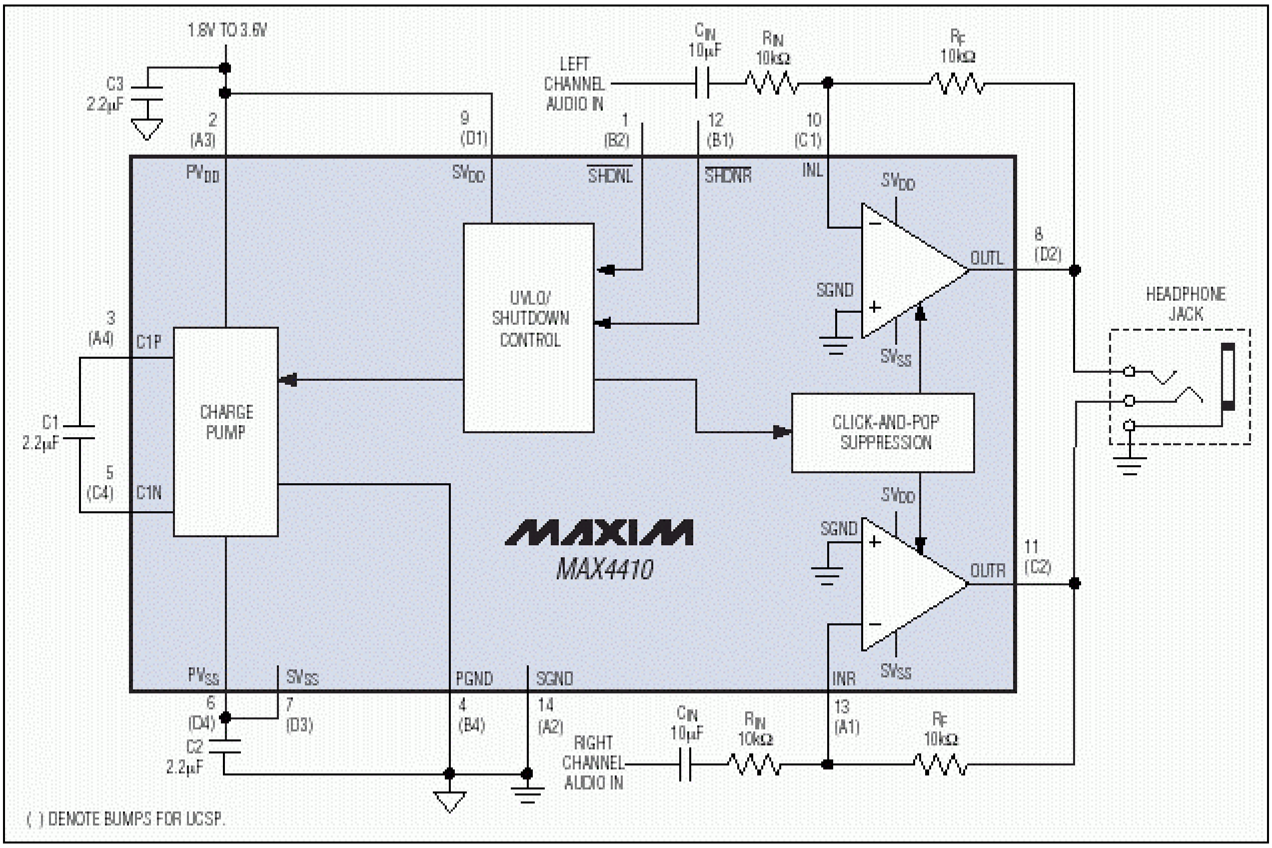


Figure 7. In this typical application circuit for the MAX4410 stereo headphone driver, setting C_{IN} to 10µF restricts any voltage-coefficient effects to subaudible frequencies. Large-valued coupling capacitors at the output are not necessary.

In this example, it has been a relatively simple matter to minimize the voltage-coefficient effect of input capacitors on audio bandwidth by oversizing those capacitors. Given a 10kΩ input resistor, choose a 10µF ceramic for C_{IN}. That combination places the -3dB point at 1.6Hz, so the worst effects due to voltage-coefficient nonlinearity are at least an order of magnitude below the lowest audible frequencies being reproduced.
Regarding larger valued capacitors, **Figure 8** compares two types of 100µF capacitors used with a 16Ω resistor in forming a passive highpass filter. At the 100Hz, -3dB frequency, both types contribute significant THD due to the capacitors' voltage coefficient. The 100µF tantalum contribution to THD+N is 0.2% at the -3dB cutoff, which is equal to the worst-performing ceramic device in Figure 4. Eliminating those devices from the audio path using Maxim's DirectDrive components, or similar techniques, improves the audio quality significantly and notably at low frequencies. In Figure 8, a MAX4410 is used to derive the reference plot (limit of measurement).

Summary

Passive components can add real, measurable degradation to an analog audio path. Those effects can be easily examined and assessed using standard audio test equipment. Of the capacitor types tested, aluminum-electrolytic and polyester capacitors give the lowest THD. X5R ceramics give the poorest THD.

When choosing active components, take care to minimize the number of AC-coupling capacitors in analog audio stages. For example, use differential signal paths or DirectDrive components for headphone feeds (e.g., MAX4410). When possible, design audio circuitry with low capacitance values in which C0G or PPS dielectrics can be used. To reduce voltage-coefficient effects in AC-coupled audio stages, restrict potential problems to the subaudio frequencies by lowering the -3dB point much more than necessary, by 10x, for example.