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APPLICATION NOTE 4525

"Linkwitz Circuit" Equalizes a Closed Box

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Abstract: The Linkwitz equalizer, intended for complex-pole systems in which Q > 0.5, neutralizes the original response by compensating the original poles with zeros, and then creates a new highpass response as specified by the designer. Like the original, the new circuit provides a 2nd-order response.

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The linearity and high power-handling capability of modern low-frequency loudspeakers have made it easy to electronically extend the bass response. This extension is especially useful in second-order systems like a closed box, where cone excursions are limited by the box.

Many such circuits are available, but the most popular today is the so-called Linkwitz equalizer[1] intended for complex-pole systems in which Q > 0.5. The circuit neutralizes the original response by compensating the original poles with zeros, and then creates a new highpass response as specified by the designer. Like the original, the new circuit provides a 2^{nd}-order response.

Figure 1 shows the basic circuit for one channel (two are required for stereo). The circuit must be driven by a low-impedance source, so you should provide a buffer stage in front of it. Because the **Figure 1** circuit inverts the signal, this buffer should be an inverting type to maintain the original signal phase.

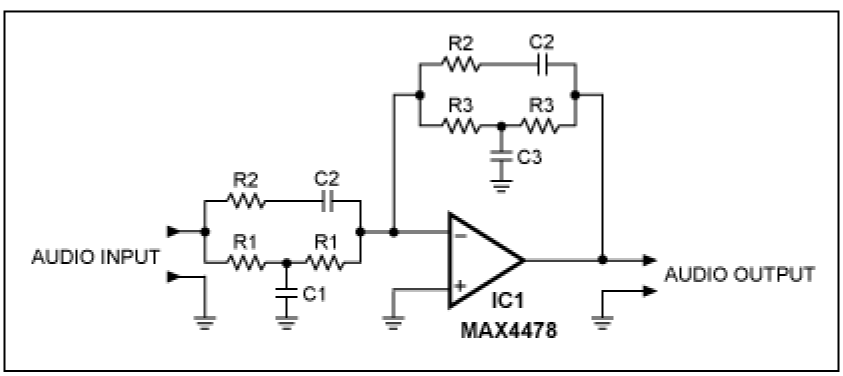

Figure 1. This "Linkwitz transform circuit" lets you neutralize the original response of a bass circuit, and substitute new complex poles that improve the bass response.

Following is the design procedure suggested by Mr. Linkwitz:

First, specify f_o, Q_o, f_p, and Q_p:

f_o and Q_o are determined from the frequency response of the original, unequalized system. f_o is the -3dB frequency, and Q_o is the system Q. **Figure 2** helps to determine the Q_o value.

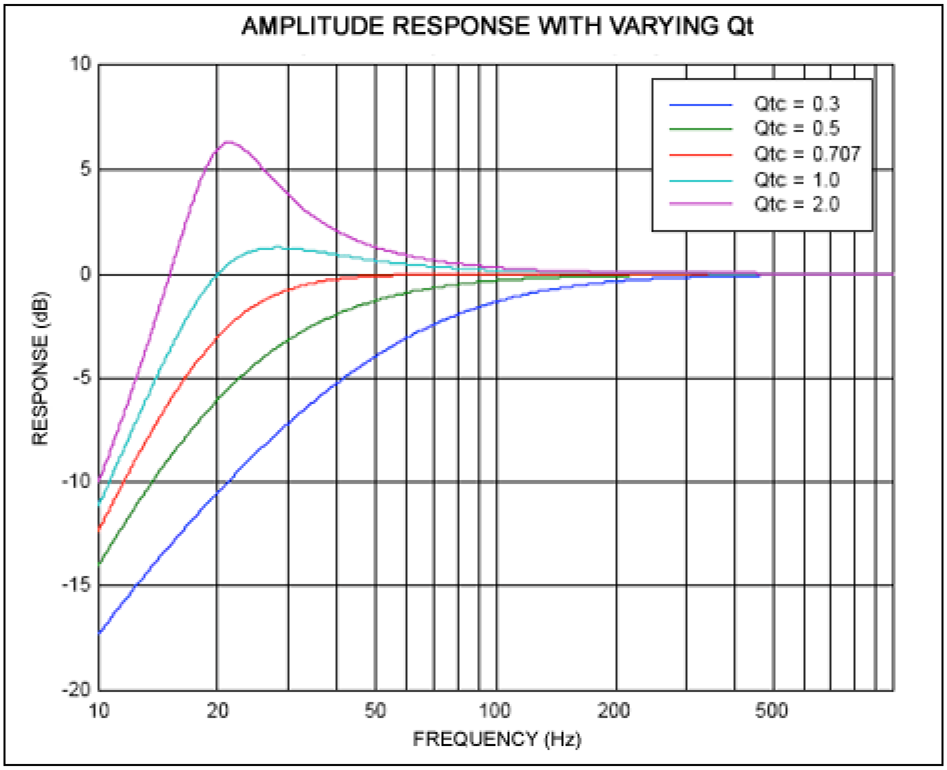

Figure 2. The amplitude response in Figure 1 varies with the system Q as shown.

f_o and Q_o specify the exact compensation for existing poles, and are determined by the existing closed-box design. f_p and Q_p are target specifications for the transformed system. As an aid in finding the correct values for f_p and Q_p, Figure 2 shows the response for various Q_o values.

Next, calculate the constant "k," which should be positive to ensure realizable equations modeling this circuit topology:

$$k = \frac{\frac{f_o}{f_p} - \frac{Q_o}{Q_p}}{\frac{Q_o}{Q_p} - \frac{f_p}{f_o}}$$

Choose C2. A good start is 470nF, which gives a reasonably low impedance level with low noise.

Calculate R1:

$$R1 = \frac{1}{2\pi f_o \times C2 \times [2Q_o \times (1 + k)]}$$

Calculate R2:

$$R2 = 2k \times R1$$

Calculate C1:

$$C1 = C2 \times [2Q_o \times (1 + k)]^2$$

Calculate C3:

$$C3 = C1\left(\frac{f_p}{f_o}\right)^2$$

Calculate R3:

$$R3 = R1\left(\frac{f_o}{f_p}\right)^2$$

If the calculated resistor values are too large (much over 100kΩ, for instance), you should increase the value of capacitor C2 and then re-calculate the other component values.

The frequency ratio f_o/f_c sets the DC gain and low-frequency boost for the circuit. It is recommended that boost not exceed 20dB, because the increase in power and cone excursion at that level becomes extreme. (For most music, on the other hand, the energy level for signals below 40Hz is relatively low.)

Because the op amp selected in Figure 1 must handle the entire audio band, it should have low noise, high slew rate, and low distortion. Op amps MAX4478 and MAX4495 are suitable for low-voltage, single-supply designs. For higher supply voltages, consider the dual MAX412 (to provide a buffer on each channel, you will need two of these). Or, you can use a single quad op amp such as the MAX4478 or MAX4495.

An Example

To illustrate the procedure we equalize an existing closed box, which transforms the existing f_o = 80Hz and Q_o = 1.2 to f_p = 30Hz and Q_p = 0.707 (a Butterworth response). Going through the calculations above gives the following component values, rounded to the closest standard values: R1 = 10kΩ, R2 = 15kΩ, R3 = 75kΩ, C1 = 0.82µF, and C3 = 0.12µF.

Figure 3 shows the original response, the equalizer response, and the desired combination of those two, which nicely matches the target. **Figure 4** shows the time delay before and after equalization. Although peak delay is higher in the equalized system, the delay over those frequencies that are important for music is improved.

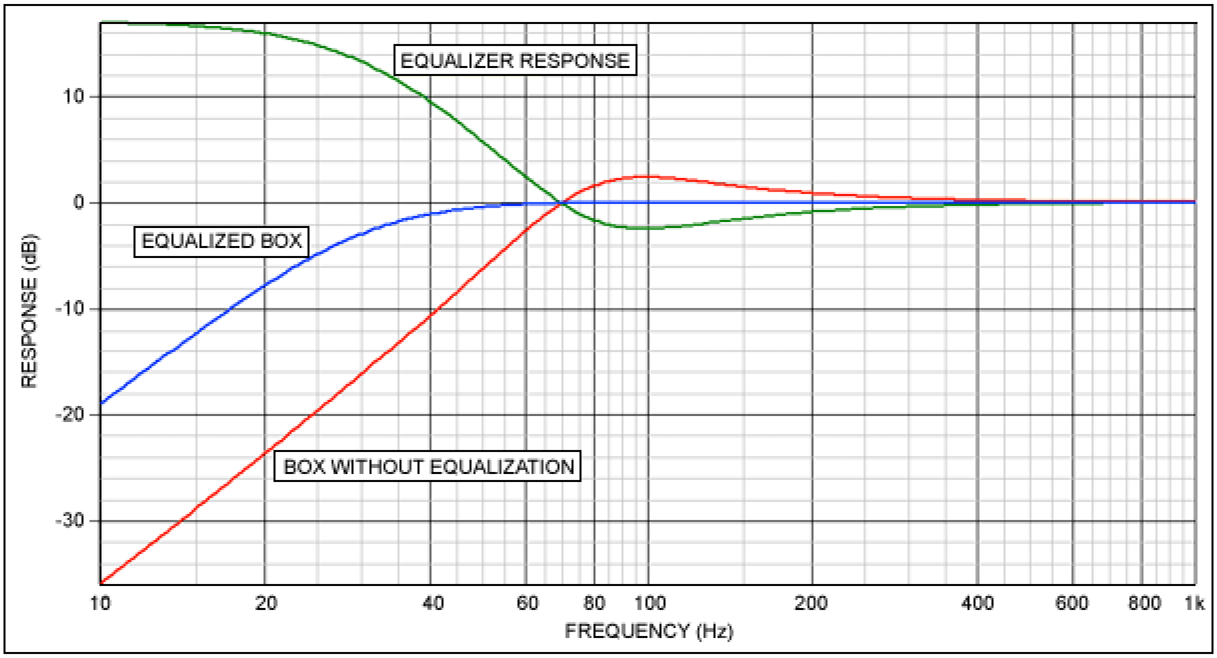

Figure 3. These curves illustrate how the equalizer improves an existing system.

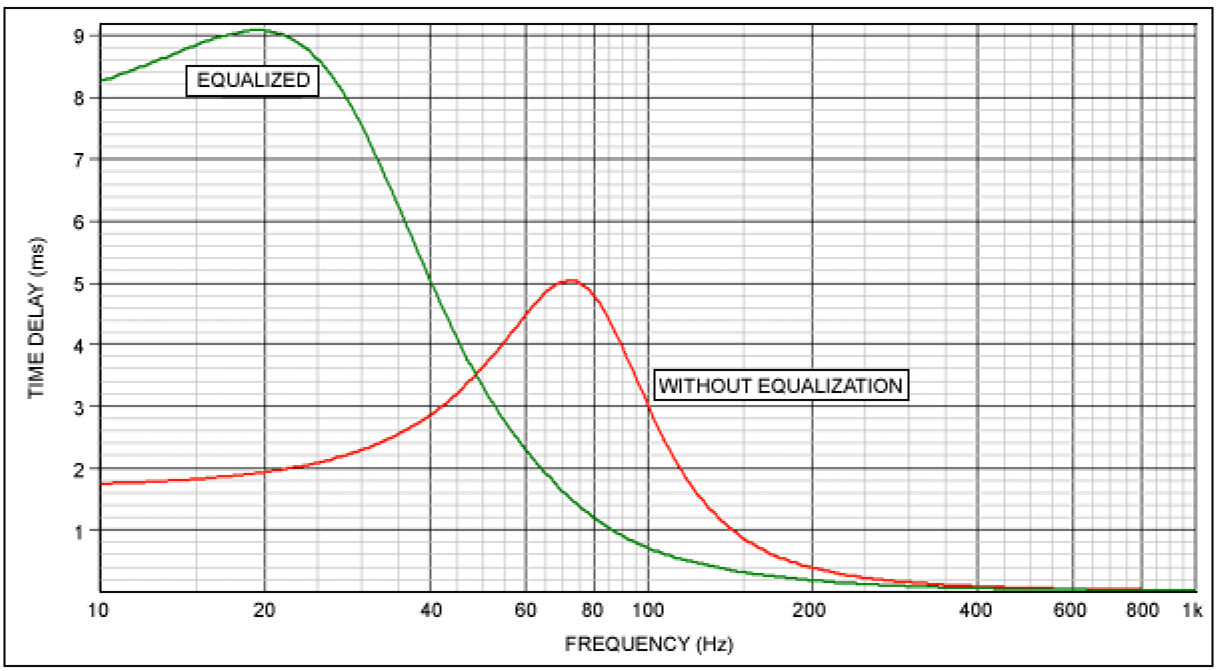

Figure 4. For most music, the equalized system also provides a more favorable delay time.

[1]S. H. Linkwitz, "Loudspeaker system design," *Wireless World*, December 1978, p. 80.

Related Parts		
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