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Equalizers and Constant-Q

by

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Equalizers and Constant-Q

The graphic equalizer is no stranger to the audio world. I'm not real sure which came first, but the second edition of the Audio Cyclopedia1 documents two designs; one passive and one active.

A Little History

I can still remember setting foot in a local studio sometime in the late 1960's and discovering a Langevin EQ-252 in the studio's console. The engineer replied that it was a graphic equalizer; a line drawn through the knobs was an approximation of the frequency response created by the equalizer. It didn't take too long for a situation to arise that required this specialized equalizer (at $600 a pop, the console only had one that was patched in where needed). The engineer was having trouble equalizing the bass guitar so that it could be heard out of a four-inch speaker. I was awestruck at how useful it was to be able to control the entire audio spectrum with one device. I wanted one, bad. Unfortunately, there was no way that I could afford one, so I had to wait for several years. A few years later, Advent (the loudspeaker folks) brought out the Frequency Balance Control, a crude (by today's standards) but workable, affordable equalizer. I was the first kid on my block to own one. Bass and treble controls: phooey. Here was my first exposure to sonic nirvana.

At the same time, a few folks had started experimenting with equalizers as a means of improving the relationship between a sound system and the room in which it was installed. Previous applications just used the equalizer as a sophisticated tone control. These experimenters were using the equalizer as a means of exactly tailoring a sound system to a given room. Mind you, this is no cure for a rotten room or an inadequate sound system. But it is a way to make a good system in a reasonable room sound better. For some rooms, careful equalization was the difference between acceptable and unacceptable.

In the 1960's, Don Davis, then at Altec Lansing, developed and patented a method of equalizing sound systems which he called Acousta-Voicing. Don also used the term combining to describe the way that the filters in a sound system interact (in a beneficial manner) to allow equalization at points between their band centers. Unfortunately, Don didn't describe in very exact terms just what he really meant; consequently the term has been subject to almost as many interpretations as the Bible. We'll revisit this subject later on in this paper.

Since that time, the graphic equalizer has become commonplace in every make, manner and form of audio equipment. No longer $600 a crack, you can find a two-channel, octave-bandwidth unit at a discount store for under $100. Ah, technology.

The purpose of this paper is to explore the ramifications of one aspect of equalizer design: constant-Q vs. non constant-Q. If you don't understand the meaning of the term Q, have no fear; you will when you finish reading this paper. The bottom line is that both designs will help you solve the problem of interfacing a sound system to a given acoustical environment. We feel that for one-third octave equalizers, a constant-Q design will help you get the job done sooner with less difficulty. And we feel that with a one-third octave constant-Q design, the graphic settings for different frequencies will track the actual frequency response better.

Terms

No study of equalizers can be complete without at least a starting vocabulary.

amplitude — A measure of the strength, voltage-wise, of a signal.

attenuate — The reverse of *equalize*, an amplitude loss at the center frequency, relative to the loss at other than the center frequency. In any other words: cut.

bandpass filter — A combination of a lowpass and highpass filter. The bandpass filter has rapidly decreasing output above or below its -3dB frequencies. The bandpass filters usedin most equalizers for tonal correction have bell-shaped curves (Figure 1). Another type of bandpass filter has rather straight skirts, and a flat response characteristic in its passband (the area between the lower and upper -3dB points). Such bandpass filters are very commonly used for midrange loudspeakers (Figure 2).

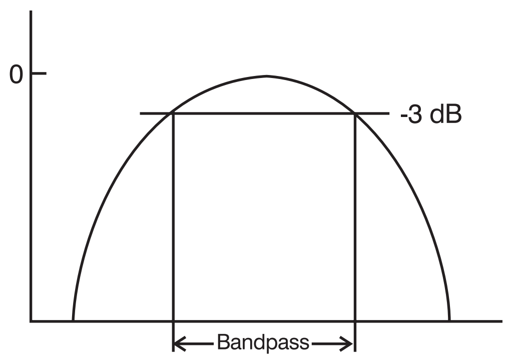


Figure 1. Bandpass Filter

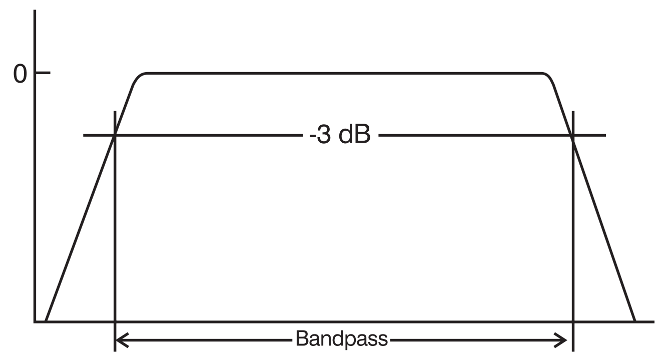
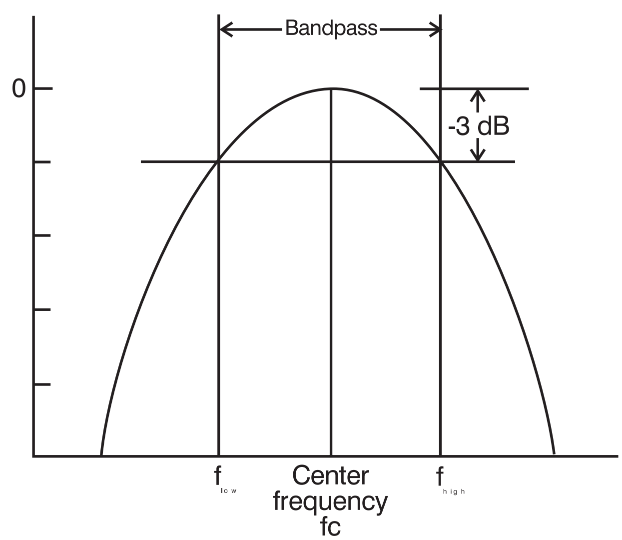


Figure 2. Bandpass Filter

bandwidth — A measure of the amount of the audio spectrum effected by the equalizer. Bandwidth is usually measured in fractions of an octave across the -3dB points (Figure 3).

center frequency — The frequency at which the output signal from the equalizer is the highest (maximum boost), or the lowest (maximum cut). Refer to Figure 3.



$$Q = \frac{fc}{f_h - f_l}$$

Figure 3. Bandwidth, Center Frequency and "Q"

equalize — To apply equalization so that the amplitude of signals at the center frequency of the equalizer is higher than that for signals that do not fall at the center frequency. In any other words: boost.

equalizer — An electrical filter network that effects the transmission of alternating current with respect to frequency.

highpass filter — A special sort of equalizer that has rapidly decreasing output below it's -3dB frequency. Eventually, there is no output. This sort of filter is very commonly used to keep low frequencies out of a tweeter (Figure 4).

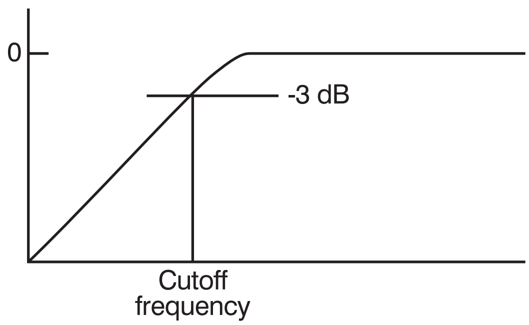


Figure 4. Highpass Filter

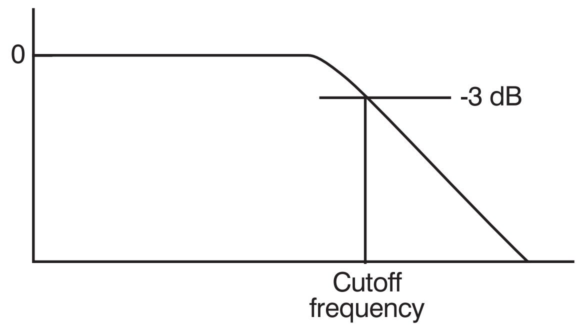


Figure 5. Lowpass Filter

lowpass filter — The opposite of a highpass filter. The lowpass filter has rapidly decreasing output above it's -3dB frequency. If you go high enough in frequency, there is no output. This sort of filter is very commonly used to keep high frequencies out of a woofer (Figure 5).

octave — A musical term representing a pitch ratio of 2:1. Thus, A-440 (A above middle-C on a piano, or 440Hz) is one octave lower than A-880.

Q — Another word for bandwidth. Q is measured differently. It is the center frequency divided by the difference of the upper -3dB frequency and the lower -3dB frequency (Figure 3). Don't confuse this usage of the term with the usage relating to a loudspeaker's directivity index, or to the Q of the moving system (a Thiele-Small parameter)

skirt — Nope, not the things that women buy at a boutique. The skirts of an equalizer are those frequencies that lie above and below the center frequency.

What is an Equalizer?

Very simply, an equalizer is an electrical filter network whose output characteristics vary with frequency. The equalizers that you are probably most familiar with are amplitude equalizers; their primary characteristic is that the output signal varies in strength, or amplitude, with frequency, given a constant amplitude, variable frequency input source (or pink noise and a real time analyzer at the output).

Equalizers are used in many places: telephone lines, broadcast transmitters and receivers, phonograph record recording and production, tape recording and reproduction, sound systems, and many, many more. In many cases, the equalizer is used to overcome a loss in a storage system; such is the case in magnetic recording. Substantial amounts of treble boost are applied to the input signal when recording. On playback, a complementary curve restores the frequency response to flat and in the process, reduces some of the high frequency content of the tape hiss. In this case, the record and playback curves are not completely complementary; somewhat more boost is applied in record because of losses inherent in the recording process. These losses are worse at lower speeds which is why a cassette recorder doesn't have as much high frequency headroom as a studio machine running at 15 ips.

In sound system usage, there are two primary uses for equalizers: altering the tonal characteristics of a source (tone controls) and improving the interface between the system and the room (overall system equalization). Optimally, these two functions should be separate. Most of the time, for economic reasons, the same equalizer is used to compensate for shortcomings in the acoustical environment and to apply the signature of the owner's taste to the overall sound.

Sophisticated autosound systems can take this notion one step further by providing an equalizer in the passenger compartment for the owner to use as a tone control. Another equalizer, mounted safely away in the trunk, and (hopefully) set by the installer using pink noise and a real-time analyzer, helps compensate for the vagaries of car interiors and helps the installer achieve some measure of consistency in his installations.

Other types of equalizers may effect phase relationships rather than amplitude. Many times, such equalizers are used to compensate for the differences in time caused by loudspeakers that do not have their acoustic centers aligned. The misalignment results in an arrival-time difference between the two loudspeakers, and results in differences in the way the system produces (or doesn't produce) a stereo image. Such equalization is beyond the scope of this paper. From this point on, the term equalizer will apply to amplitude equalizers only.

How Equalizers Do Their Magic

As mentioned earlier, an equalizer is an electrical filter network. Such networks consist of resistors, capacitors, and sometimes inductors. Generally speaking, an equalizer has a bandpass filter characteristic. That is, is has usable response (output) both above as well as below its center frequency. The capacitors (and inductors, if used) have characteristics that are frequency dependent. Used in combination with inductors, operational amplifiers, and resistors, virtually any sort of frequency characteristic can be created. Since inductors tend towards bulk, are somewhat sensitive towards magnetic fields (they love to pick up hum), and aren't cheap, most modern equalizers have replaced them with active circuits that generate equivalent response shapes using only resistors and capacitors. Figures 6 and 7 illustrate two approaches to equalizer design.

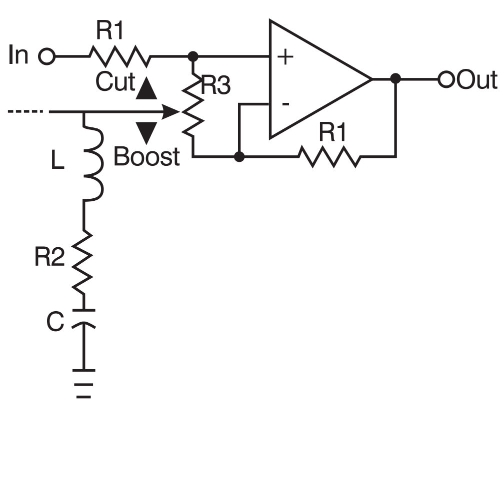


Figure 6. LRC Equalizer

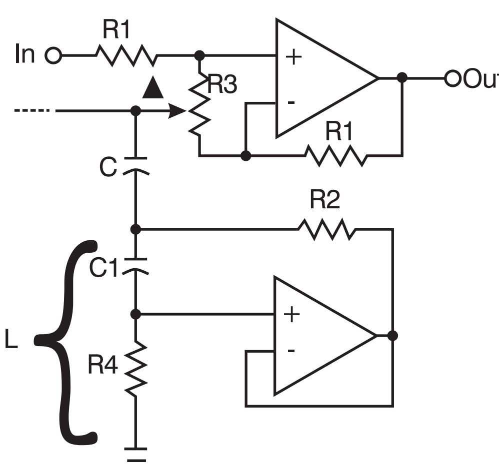


Figure 7. Gyrator Equalizer

The magic occurs because our ears are sensitive to amplitude as well as pitch. By making changes in the relationships of various parts of the audio spectrum, we can change the way that the overall sound is perceived by our brains. Increasing the amplitude of lower frequency sounds, say...below 70Hz gives the sensation of power and fullness. Excessive energy around 180 to 250Hz is perceived as boominess. The 1000Hz region is nasal sounding, and the 3000Hz region adds shrillness. The frequencies above 8000Hz add sparkle and life.

What Kinds of Equalizers are there?

As many as there are seconds between now and eternity. Fortunately, for sound system work, a few basic types dominate:

active	An equalizer that requires an external power source (besides the input signal) to function. This generally means that the frequency-dependent circuitry was built without the use of inductors. Active equalizers dominate the audio scene today.
passive	An equalizer that requires no external power source to function. A loudspeaker crossover is a good example of a passive equalizer.
graphic	An equalizer containing multiple bandpass filters, spaced at regular intervals across the audio spectrum, allowing control of the entire audio spectrum. Originally, graphic equalizers used slide controls, and got their name for the graphical nature of the layout of the controls. Today, graphic equalizers used both rotary as well as slide controls. While the user interface is perhaps not quite as visual, the results are certainly the same. Most graphic equalizers have fixed bandwidth filters for each control.
parametric	An equalizer that allows control over all fundamental equalizer parameters: amplitude, frequency, and bandwidth. Although this seems like it would be the cat's meow, and it is for certain applications, for the most part, it's best used as a problem solver, when nothing else will do.
non-adjustable	An equalizer used to apply a constant correction, such as the RIAA equalizer used during the recording and playback of a phonograph record.

There are also equalizer types that are a hybrid of two or more of the types mentioned above, like the paragraphic (graphic EQ with adjustable center frequencies) or the sweep equalizer (a parametric, hold the Q control).

Constant-Q and Non Constant-Q

A recent development in equalizer design is constant-Q. Look at the frequency response curves for a non constant-Q (variable Q) equalizer in Figure 8. Note that the bandwidth, or Q of the equalizer changes with the amount of boost or cut used. You can see that the equalizer only achieves its specified bandwidth at one boost setting. At all others, the bandwidth is wider (lower Q value). This means that for boost or cut amounts that are less than maximum, a far greater number of frequencies are effected. Thus, if you need a subtle correction centered at 1000Hz, you'll have to settle for correction at frequencies far removed from 1000Hz (you may be able to compensate somewhat by dialing in a small amount of cut using the sliders adjacent to 1000Hz). The problems here are, first, it takes more time and effort to get the desired results and secondly, the control settings are different than the actual response. Enter constant-Q.

Figure 9 shows a family of curves for a typical constant-Q equalizer section. Looking at the frequency response curves, you can see that even for small amounts of boost or cut, the equalizer maintains its specified bandwidth. This means that if you need 3dB of equalization at 1000Hz, you can get it with minimal effect on the adjacent 1/3 octave bands. So you can get what you want, where you want it, quickly.

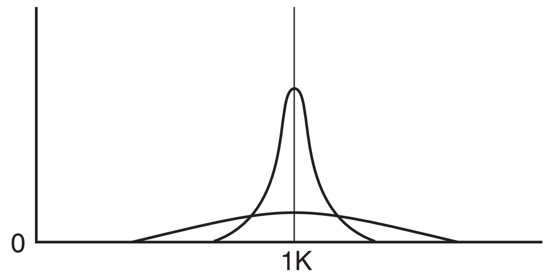


Figure 8. Variable (non-constant) Q

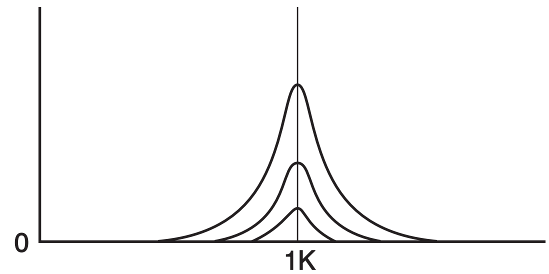


Figure 9. Constant Q

Interactions between Controls and Constant-Q

For better or worse, Don Davis used the word “combining” to describe the manner in which adjacent controls effect the overall, composite frequency response. Originally, I believe that the term was coined to help Altec’s marketing department sell equalizers...if your equalizer didn’t combine, you couldn’t use it in an Acousta-Voiced installation. Since no on understood what combining really meant, it was pretty difficult to say conclusively whether or not your equalizer combined.

Later on (15 years), a reasonable definition surfaced: the combined effect of two adjacent equalizer controls should be the sum of their response characteristic. For example, two one-third octave equalizers, both set for -10dB attenuation, should give a composite response that is -14dB down at the geometric mean of the two equalizer’s center frequencies. A non-combining equalizer is said to have ripple (uneven frequency response) in the region between the two band centers. Figures 10 and 11 illustrate these points.

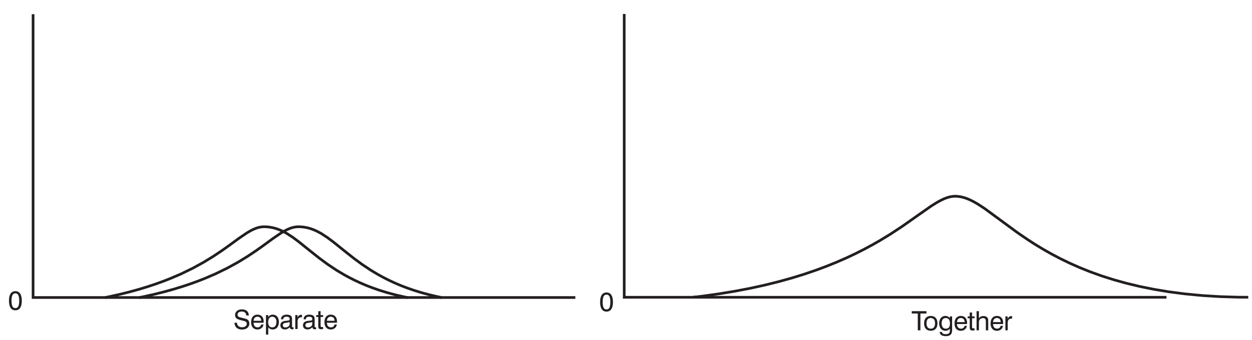


Figure 10. Variable Q Effecting Broad Area

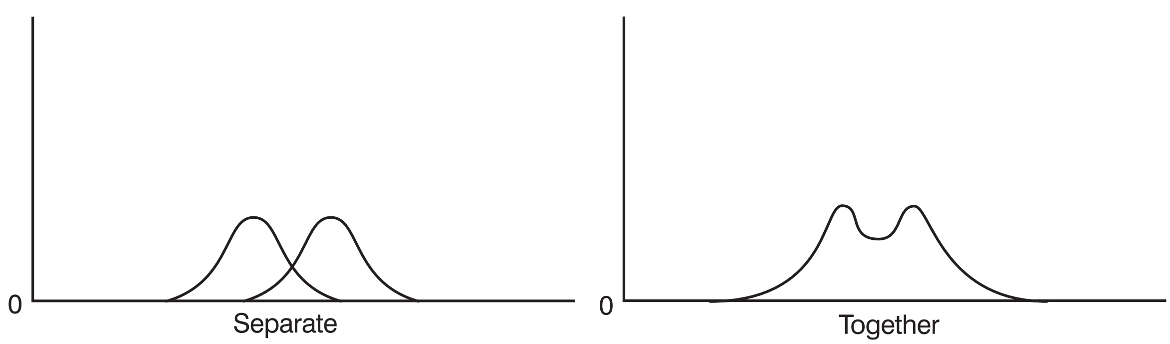


Figure 11. Non-combining Ripple Response

What this really means is that for a graphic equalizer, combining filters (using Don's definition) will interact with each other to the extent that the "graphical" representation of the front panel is a lie. That is, the front panel "graphic" settings are different from the actual frequency response. This means that you may have to make several passes with the equalizer to arrive at a correct (least amount of equalization required) group of settings. Often, the multiple passes take quite a bit of time. Constant-Q equalizers combine in a different manner. Two adjacent filters set for the same amount of boost or cut provide a smooth bandpass characteristic at the same amount of boost or cut (Figure 12). This helps keep the front panel representation of the response curve much more accurate. Furthermore, the interaction between adjacent controls is minimized, which allows you to arrive at the correct settings much more quickly, and with less repetition.

Figure 13 makes these points even more dramatically. With the adjacent controls set at +6dB, 0dB and +6dB, the variable Q (non-constant Q) equalizer is no longer functioning as a one-third octave unit. The center (0dB) control is essentially ineffective, servicing only to reduce the peak amplitude of those adjacent. The result clearly is not true to the front panel control settings. While with constant-Q, the frequency response does display the expected (and desired) results for these control knob settings.

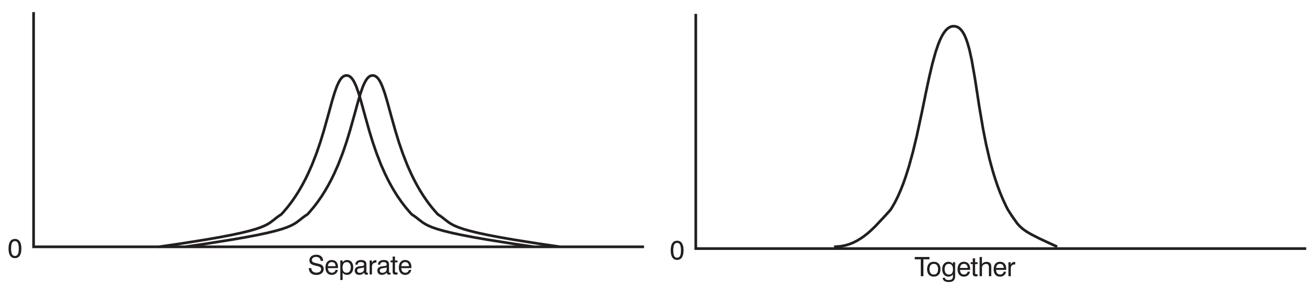


Figure 12. Constant Q Showing Smooth Bandpass

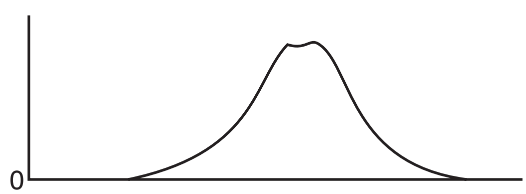


Figure 13a. Variable Q. +6, 0, +6 Adjacent Controls

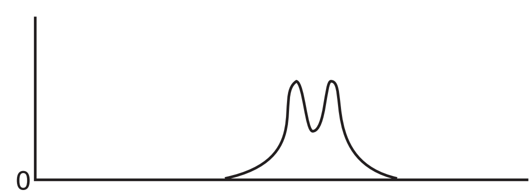


Figure 13b. Constant Q, +6, 0, +6 Adjacent Controls

Conclusions

The constant-Q equalizer represents an advance in equalizer technology. For a given situation, a constant-Q equalizer will help you arrive at the correct setting in less time, and with less guesswork on your part. This is especially true for one-third octave bandwidth equalizers.

While there is no clear-cut good/bad relationship between constant-Q designs and non constant-Q designs and both will do most jobs, there is a distinct difference between the two designs. It is a situation of how much effort you wish to expend to do the job and how closely you want the front panel controls to match the results. Constant-Q will give you a true one-third octave equalizer where the expected results are indicated by the front panel controls and will get you there faster.

1. The Audio Cyclopedia, Howard Tremaine, Howard W. Sams & Co., Copyright1969.

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