Designer Notebook: The Quest For True Graphic EQ

The back-story on the evolution of equalization and the Rane DEQ 60

By Ray Miller & Rick Jeffs, with Dennis Bohn (all of Rane Corp.)


Front-panel view of the DEQ 60...

One day out of the blue, Rane Senior Design Engineer Rick Jeffs approached Senior Software Engineer Ray Miller with an idea: "We need to design an analog-controlled, digital graphic equalizer with unsurpassed accuracy."


...and a view of the back of the unit.

Having studied this problem before, Miller replied that he thought he could reduce adjacent band interaction a little, but Jeffs shot back, "That's not good enough - we need to eliminate it."

Five years earlier, Miller had investigated a primary Achilles' heel of graphic equalizers, namely, that the front panel controls do not accurately show the output response. However, he'd resigned himself to the problem of adjacent band interaction being nonlinear, which prevented a simple and effective solution.

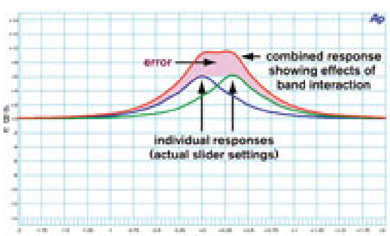

Figure 1: Band interaction of Proportional-Q.

With the subject in front of him again, Miller found himself interested enough that it started occupying his spare time on weekends. If only it could be treated as a linear system, he mused. Finally he hit on an idea - what if he could make it linear?

Miller knew that a filter's Q value (a measure of selectivity) affected the level away from the center of the band of frequencies being changed, so it occurred to him that Q could possibly be adjusted to make the problem linear (that is, a change of x-dB to the center would always produce a predictable change of y-dB at the skirts).

A linear solution was important because linear problems are straightforward to solve mathematically.

BIRTH OF AN ALGORITHM

A nonlinear problem forces compromise by either ignoring the non-linearity or finding a solution using approximations that converge toward a solution; however, that requires lots of computing time. He spent weeks trying to use standard linear approximation techniques and other methods before realizing that they were not going to get the job done, and that he was going to have to create his own solution - which he did on a Seattle rainy weekend. Thus was born the Perfect-Q algorithm. (The term "Perfect-Q" was coined by fellow engineer Michael Rollins, who combined "perfect filter response" and "adjustable Q.")

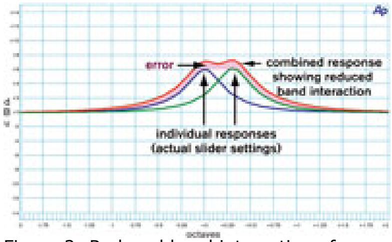

Figure 2: Reduced band interaction of Constant-Q.

Similar attempts to solve this non-linearity problem relied on trial-and-error iterative methods, where adjustments are made, the error analyzed, then adjustments are made again, and so forth, until the error is sufficiently small. This is what a person who could see the amplitude vs. frequency response result would do. Although a computer does it much faster, this equalizing-the-equalizer procedure still results in an undesirable time lag between changing settings and the desired response.

Miller's method for linearizing the filter band interaction uses Variable-Q techniques that effectively allow a real-time solution. He proceeded to write the code. The tricky part was writing it in Motorola 56000 DSP assembly language so that it would run extremely fast, resulting in no perceptible delay in control adjustment. Sure enough, it worked.

GRAPHIC REALITIES

The advantages of a true graphic equalizer go far beyond yielding a more accurate picture; it provides a very high degree of adjustment. In fact, to our knowledge, this level of adjustment has never been possible before. Crucial subtle refinements of frequency response are also unique, allowing for an extreme ease of operation and clarity of sound reproduction. Changing a one-third-octave setting alters only that setting, and this is most certainly unlike any other graphic EQ available.

Figure 3: Elimination of band interaction in Perfect-Q.

True graphic equalizer adjustments produce tighter, more defined sound that is predictable, clearer and more precise with no surprising characteristics. A true graphic equalizer lets the sound professional modify only what they want, without offensive side effects.

There is irony in knowing that our well-regarded Constant-Q technology required switching to Variable-Q technology to perfect the response-versus-slider position problem. Constant-Q interacted less than Proportional-Q, and now Perfect-Q eliminates the problem.

Ever since RCA's John Volkman pioneered the use of equalizers for improving reproduced sound in the 1930s, graphic equalizers have been the preferred choice due to their ease of use and convenience. The down side is the limitation of fixed one-third-octave bands and filter response overlap resulting in significant interaction between controls as shown in **Figure 1**. The display shows the result of boosting two adjacent sliders 6 dB, which produces a combined curve greater than 9 dB.

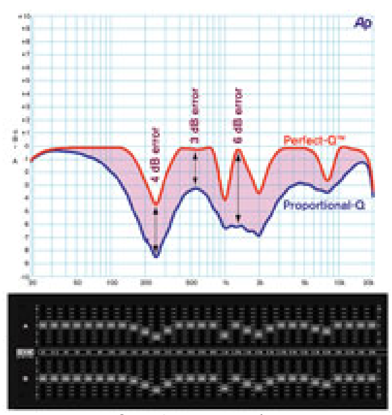

Figure 4: Perfect-Q compared to Proportional-Q frequency responses, and also note the correspondence with the DEQ 60 slider positions.

It is this adjacent band interaction that makes parametric equalizers the preferred choice of professional audio users despite their limited number of bands and difficulty of use. Band interaction makes graphic equalizers difficult to use for "ringing out a room," often resulting in a hollow sounding performance due to gain changes in more than the desired one-third octave bands.

And it is difficult for sound engineers to adjust system response using a real time analyzer, as several iterative passes are required to get it right.

Constant-Q designs, pioneered by Rane in 1981, provided significant improvement as shown in **Figure 2**. Here it is seen that the combined response is reduced to 7 dB - better, but not perfect.

Throughout the years, Rane continued to study and evolve graphic equalizer technology, first with Constant-Q, then interpolating Constant-Q, MIDI-programmable interpolating Constant-Q, THX Home Cinema EQ and first-generation digital signal processing (DSP) based graphic equalizers. However, none of these advancements provided a slider-based adjustable equalizer with the flexibility, accuracy, immediacy and ease of use possible with a true graphic EQ.

DSP finally freed designers from the constraints of analog design. The tools were in place for the next major step forward. Using Miller's Perfect-Q technology, Jeffs designed the first analog-controlled graphic equalizer to eliminate band interaction in real time, the Rane DEQ 60. It virtually eliminates band interaction and ripple between bands as shown in **Figure 3**. The output response precisely matches the slider settings. The DEQ 60 is the long sought true graphic equalizer.

WHAT YOU SEE...

Figure 3 and **Figure 4** demonstrate the main principles of a true graphic equalizer; namely that what you see is (really) what you get - all slider settings exhibit constant bandwidth behavior, and each band is independently adjustable from its neighbor. There are no overload problems caused by band interaction gain increases, and the always narrow-band correction guarantees minimum phase response.

Figure 5: A look inside – the DEQ 60 digital (below) and the GE 60 analog (above).

In addition to the above response characteristics, the DEQ 60 contains auxiliary features necessary for a complete professional equalizing tool. These include adjustable high- and low-cut filters for band-limiting the overall frequency response, a set of three-band tone controls with steep roll-off rates and full-off operation for timbre control, and separate input and output level controls with independent input and output metering.

A novel ability is being able to choose either A or B channel as the control assignment. This handy function allows stereo linking, A/B curve comparison, or even acts as two analog memories.

And because we live in a complicated world where no one solution fits every occasion, the DEQ 60 includes choice between Perfect-Q or Proportional-Q responses, ±12 or ±6 dB range selection, and separate channel bypass switches (selectable between bypassing just the filter sections or bypassing everything).

Figure 4 demonstrates an example of DEQ 60 slider positions lined up with the frequency responses corresponding to the Perfect-Q and Proportional-Q settings. There's a scoop around 250 Hz to remove some low-mid "woof," a few notches around 1 kHz and 2 kHz for feedback control, and a dip in the 8 kHz region to tame a pesky high-frequency hot spot.

Note the difference between the two curves, especially the interactions between adjacent bands in the low-mids and the 6 dB offset at 1.25 kHz. The Perfect-Q response exactly matches the slider setting while the Proportional-Q response shows as much as 6 dB error. Note that the maximum intended change in any one band was only 4.5 dB.

CONSTRUCTION DETAILS

DSP provides many benefits beyond creating the desired graphic response. All analog graphic equalizers suffer from susceptibility to magnetic and radio frequency interference due to the large number of high impedance slide controls connected directly to summing amplifiers. Digital designs isolate the analog signal, mitigating susceptibility problems. **Figure 5** compares the internal construction of Rane's analog GE 60 versus the new DSP DEQ 60.

Figure 6: Closed steel pan shields front panel controls.

In the analog design the audio signals must run throughout the chassis and all along the front panel, while in the digital design the analog signals are confined to the small PC board at the back of the chassis and to a small area on the digital board.

Another important factor is the elimination of the resistors and capacitors required to create the analog filters - and their real world value tolerances.

Even 1 percent resistors and 2 percent capacitors allow great variations between the same bands on different channels and from unit to unit.

In the DEQ 60 DSP implementation all bands are exactly the same, every time, in every unit. This is valuable in applications where it is necessary to set several units with the same curve - something very difficult with analog designs. Lastly there is the obvious reduction in the number of active parts required to complete a finished unit, and fewer active parts means greater reliability.

Figure 5 also shows the chassis differences between Rane analog and digital products. Pro audio products containing microprocessors, DSP and digital audio sig- nals mandate redesigned chassis. Both are manufactured from cold-rolled steel, as has always been Rane's standard for strength and shielding, but digital circuits mandate a tighter fit than analog.

The new chassis creates a secure shielding environment so that RF (radio frequency) components generated inside the box do not leak outside, and simultaneously prevent RF signals outside the box from getting inside. This is what compliance engineers call satisfying the emission and immunity requirements.

And an analog-controlled DSP solution like the DEQ 60 presents tougher shielding problems because all the slide controls cut slots into the front panel, breaching its shielding integrity. This required adding the steel pan attached behind the slider controls as shown in **Figure 6**. And making the rack mounting ears separate pieces that bolt to the chassis sides makes for a stronger, more road-worthy touring unit.

The DEQ 60 is manufactured at Rane headquarters in Mukilteo, Washington, where every unit is tested to rigorous limits using Audio Precision test equipment and - to catch what computers cannot - listened to by real humans.

A SINGLE PASS

The advantages of a true graphic equalizer are many. With the elimination of band interaction, it is possible to adjust a graphic equalizer based on real time analyzer (RTA) readings in a single pass.

It also is possible to compensate for room-ring modes in several bands without creating a "hollow" sounding performance. Professionals are able to "draw" a predictable and accurate response with front panel sliders. Musicians, live sound and recording engineers are able to make large or small changes in a single band without affecting neighboring bands.

While they still have their place, many difficult tasks previously reserved for parametric equalizers are now easily addressed by a new generation of true graphic equalizers.

Editor's Note: *All techniques and algorithms discussed in this article are covered by applications filed by its inventor, Ray Miller, and Rane Corporation with the U.S. Patent and Trademark office and other international patent agencies.*

*Rick Jeffs is senior design engineer and Ray Miller is senior software engineer with Rane Corp. Dennis Bohn is a principlal partner and vice president of research and development at Rane. He is author of numerous in-depth technical articles and complied the Rane Pro Audio Reference Book, where he also wrote many chapters. It's available on-line at **www.rane.com/library.html** and is also available for purchase in book form.*

July 2003 Live Sound International