How to Choose Equalizers for Professional Recording Applications

By Robert Orban

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At the current state of the art there are a number of practical techniques for achieving musically useful equalization of audio program material. The state of the art has changed greatly in the last twenty years: the old classical passive LC equalizers have given way to techniques using active devices, like transistors and integrated circuits. The advent of low-cost integrated circuit operational amplifiers, in particular, has resulted in a revolution in equalizer circuit design, and a dramatic improvement in the cost/performance ratio achievable.

The purpose of this paper is to provide an overview of the different types of equalizers available today, and to clarify some of the important performance characteristics which can make or break an equalizer design. Because we manufacture the Orban Parametric Equalizers, you will find a great deal of information on the characteristics of these units. Hopefully, this information will help you determine if our equalizer is the best one for your particular needs, of if another type of equalizer might be more appropriate. We have tried to include enough basic material to inform the newcomer, and enough more challenging material to provide some insight for the more experienced user.

We will be discussing four basic types of equalizers found in modern sound equipment: tone controls, "three knob" and "four knob" console equalizers, graphic equalizers, and parametric equalizers. Each equalizer function can be achieved electrically in various ways, each with associated compromises. Each technique has relative advantages and disadvantages in a given situation.

Back to Basics: Tone Controls

The simplest form of equalizer found in professional use is simple bass and treble tone controls. While their lack of flexibility and control limits their usefulness, they have definite and often unappreciated advantages over more elaborate equalizers.

Typically, tone controls are *shelving* equalizers with a maximum *slope* of 6 dB per octave, and *reciprocal* characteristics. What do we mean, exactly?

By *shelving*, we mean that the frequency response of the equalizer has a shape similar to figure (1). The gain of a treble control starts out at 0 dB at low frequencies. Then it starts to slope upwards (or downwards, depending on whether you are boosting or cutting). Finally, it reaches a new level at some higher frequency, and stays there. It doesn't slope downward (or upward) again — at least not until the frequency is outside the audible range. The curve shape resembles a shelf — thus, "shelving."

Because the electrical network which produces this curve is "first order" (has only one capacitor or one inductor), the maximum rate at which the voltage gain can change is to double (or halve) every time the frequency doubles — a 6 dB per octave slope. Higher order networks (containing more than one capacitor or inductor, or combination thereof) can produce steeper slopes, and more complicated curves.

One advantage of a first order (6 dB/octave) response is that it can't ring under any circumstances. Ringing occurs when some higher order networks are hit with transients. The transient forces the network to produce a tone, which may decay slowly or rapidly, depending on the degree of "damping" or the "Q." This tone can cause nasty coloration of speech or music. [See figs. (2)-(6).]

Finally, our tone control is *reciprocal*. This means that if we take two identical tone controls, connect them in series, and adjust one for a given amount of boost and the other for the same amount of cut, that the overall frequency response is flat, and square waves are not degraded by passage through both tone controls. The effect of the second control has entirely nullified the effect of the first.

Reciprocal curves are highly desirable in equalizers without adjustable bandwidth, because they permit an engineer to "undo" equalization that he may have performed when a track was originally cut. However, as we'll see later, reciprocal curves may not *always* be desirable.

The Hard Facts about Ringing, Phase, and Frequency Response

It is often heard in the studio that such-and-such equalizer sounds bad because it has *phase shift* or *ringing*. The subject is often treated like black magic. The truth is very simple: with one qualification (below), knowledge of either an equalizer's phase response, square wave response, or frequency response *uniquely determines* the other two characteristics. Therefore, if an equalizer is ringy, it means that the frequency response is excessively peaky, and that there is a rapid change in the phase response around the peak. Any other equalizer with the same frequency response will have the *same* phase shift and the *same* amount of ringing.

There are two qualifiers. First, the frequency response outside the audible range can have substantial effect on the phase shift and ringing inside the audible range. Just looking at one section of the frequency response isn't enough. Second, the equalizer must be "minimum phase." This is of little practical importance, since practically every equalizer is minimum phase, just because minimum phase circuits are simplest and least costly.

In general, it can be said that the ear is *far* more sensitive to the frequency response than to phase response, so that the shape of the frequency response curves that an equalizer produces are of paramount importance in determining its musical utility.

"Three Knob" and "Four Knob" Console Equalizers

The next most complex equalizers found in contemporary studio practice are so-called "three knob" and "four knob" equalizers. These equalizers, true to their name, have either three or four sections of equalization. The highest and lowest frequency ranges are often switchable between shelving and *peaking* response.

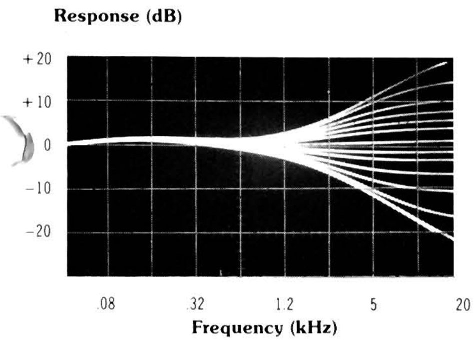

Fig. 1: This is the frequency response of a treble tone control at various control settings. Note the shelving shape and the fact that the curves are reciprocal — the boost and cut responses are mirror images of each other.

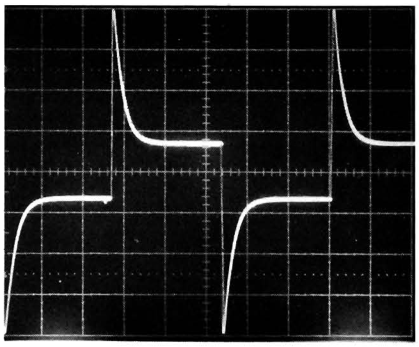

Fig. 2: This is the output of a second-order equalizer adjusted for 12 dB boost and a "Q" of 0.29 when a square wave like fig. (7) is applied to its input. Note that the very low "Q" (associated with a family of frequency response curves shown in fig. (9) results in a very large "overshoot" (degree to which the initial response exceeds the final flat-topped level), and that it takes a relatively long time for the overshoot to decay to the final level. No ringing is present.

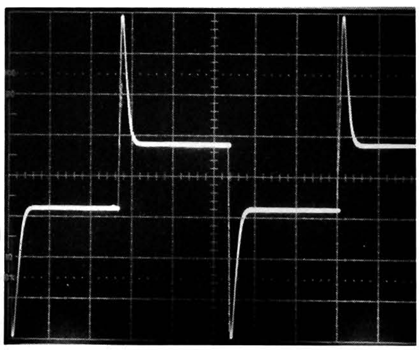

Fig. 3: Output of the same equalizer as fig. (2) with 12 dB boost and a "Q" of 0.5 (critical damping). This "Q" produces the frequency response family of fig. (10), which can be seen to be narrower than the family of fig. (9) — "Q" = 0.29. Because the overshoot in the "Q" = 0.5 case is less than in the "Q" = 0.29 case, we have raised the gain to preserve the same height in both waveforms. The overshoot decays much faster than in the "Q" = 0.29 case; there is no ringing, but ringing would start to appear were we to increase the "Q" beyond 0.5.

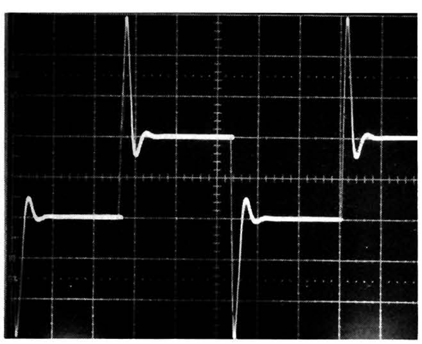

Fig. 4: Output of the same equalizer as fig. (2) with 12 dB boost and a "Q" of 1.0. Once again, we have increased the gain, as the overshoot once again decreases. However, ringing is now visible, although it is rapidly damped out and would not tend to be audible.

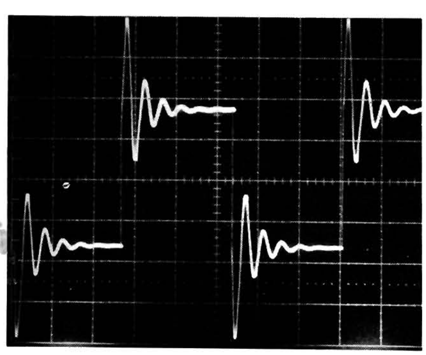

Fig. 5: Output of same equalizer as fig. (2) with 12 dB boost and a "Q" of 3.2. The overshoot is decreased, so we once again raise the gain in the equalizer for the photo. This time, the ringing takes a much longer time to damp out, and would tend to be very audible. The corresponding family of frequency response curves is shown in fig. (11).

A *peaking* response is produced by a *second-order* network, and is generally the most musically useful equalizer response because it is capable of far more selectivity over the frequency range it affects when compared to a first-order shelving equalizer. This selectivity is not without its drawbacks. If too much selectivity (too narrow a bandwidth) is attempted, the equalizer will ring, and can introduce bizarre and highly unpleasant coloration into the signal. Therefore, the peaking equalizer must be used with more care and taste than the shelving equalizer. In addition, if the bandwidth is not user-adjustable, then the manufacturer must be trusted to provide musically useful characteristics at *all* degrees of boost or cut. Too often, the same circuitry used to produce reciprocal curves also results in an increasingly sharply peaked frequency response as equalization is increased towards maximum boost. This can make large peak boosts musically intolerable. [See figs. (12)-(16).] This tends to be less of a problem in those "three-knob" etc. equalizers which employ stepped switches to determine the amount of peak or boost, and more of a problem in those equalizers with continuously variable adjustment. In addition, nearly all such equalizers provide switches in several of the equalization sections to vary the frequency at which the maximum equalization occurs. This switching is in discrete steps. The shape of the equalization curve usually stays constant as these switches are operated, and varies only in frequency.

Certain "three-knob" etc. equalizers also provide switchable lowpass and highpass filters. These filters sharply discriminate between frequencies in the "passband" (perhaps 100 to 8000 Hz), and frequencies in the "stopband" (perhaps above 8 kHz or below 100 Hz), rolling off stopband frequencies at a rate of 12 dB per octave or greater. They are useful for noise reduction in cases where the dominant frequency of a sound being recorded lies in the passband, and interference exists in the stopband.

Graphic Equalizers

A graphic equalizer provides a series of peaking equalizers whose center frequencies are equally spaced according to musical intervals. Therefore, an "octave band" graphic equalizer might have eleven equalization controls spaced at octave intervals: 20, 40, 80, 160, 320, 640, 1.25k, 2.5k, 5k, 10k, and 20k Hz for example. The equalization controls for the various bands are usually linear slide controls, and are arranged side-by-side. Therefore, the physical positions of the controls gives a rough approximation of the actual frequency response of the overall equalizer — thus "graphic."

Note that we said rough. The graphic's controls are almost invariably reciprocal, and graphic equalizers seem particularly prone to the problem of excess ringing due to narrow bandwidth when large amounts of peak boost is used. While it is possible to minimize this sort of behavior by careful design, the most inexpensive graphic equalizer circuits are particularly prone to it. The practical result is that it is not possible, with many graphics, to obtain broadband boosts of more than 6-7 dB. Beyond this, the responses of the individual equalizers which must be boosted in tandem to obtain the broadband response begin to peak excessively, and the curve becomes uneven ("ripply"), eventually becoming intolerably colored and ringy.

Graphic equalizers are manufactured commercially with bandwidths as wide as two octaves, and as narrow as one-third octave. Octave-wide bandwidths seem most accepted for equalization "by ear." One-third octave graphics are utilized to correct the frequency response of loudspeakers, and to a certain extent, of rooms. They are particularly useful in sound reinforcement, where flattening the frequency response of the entire sound system can result in striking gains in intelligibility, and in the availability of far more gain before feedback than would be the case were the system unequalized. In addition, very narrow-band notch filters are sometimes utilized in sound reinforcement systems to damp "ring modes," which are narrow bands of frequency where the gain of the sound reinforcement system is high, and where feedback would otherwise occur.

It is generally considered impractical to adjust one-third octave band graphic equalizers by ear, and it is therefore customarily done with a "real-time analyzer." This instrument provides an approximate measure of the acoustical frequency response of an entire sound system, averaged over one-third octave intervals. Because the frequency response is read out graphically, and updated practically continuously, it is easy to adjust a one-third octave graphic equalizer to secure the desired frequency response. However, these instruments are not foolproof, as they can be fooled by unfavorable acoustics, and a practiced ear is still the final judge of the success of a system equalization. In particular, the equalizers used in a one-third octave graphic are particularly prone to ringing, and it is often necessary to perform rough equalization using wider bandwidth equalizers (even tone controls!), and then perform the final detailed trimming with the third-octave graphic, using minimum amounts of equalization.

There are two varieties of third-octave graphic. One type provides both boost and attenuation, while the other type provide attenuation only. The attenuation-only type is favored by many practitioners because its broadband curves tend to be smoother than the boost/attenuate type.

Parametric Equalizers

A second-order equalization curve can be described by three parameters:

(1) The maximum amount of boost (or dip) in dB;

(2) The frequency at which the maximum amount of boost (or dip) occurs (in Hz);

(3) The "bandwidth," which defines the shape of the equalization curve. The "bandwidth," as used here, has no precise engineering meaning, but is related to the "Q" of the circuit. The meaning of "Q" is well-defined. Most generally, it determines the speed with which the ringing in a circuit is damped out. As the "Q" increases beyond 0.5, the ringing hangs on for more and more cycles and the bandwidth becomes narrower and narrower. At Q = 0.5, the circuit no longer rings, and is said to be "critically damped." As the "Q" goes below 0.5, the bandwidth continues to increase, with no ringing. The shape of the peaking curve approaches a flat top with skirts falling at 6 dB per octave — like a pair of tone-control shelving responses. [See figs. (2)-(11).]

In general, the term "Parametric Equalizer" means what an individual manufacturer wants it to mean. It tends to imply that the center frequency is continuously adjustable, rather than switchable in steps. Some control over the bandwidth or "Q" is provided, although some manufacturers provide only two discrete choices of bandwidth, rather than making the bandwidth continuously variable. Finally, the amount of boost or cut is usually continuously variable, rather than stepped.

The Orban Parametric Equalizers provide *independent* and *non-interacting* control over all three parameters. It can be shown that in order to provide constant "Q" as the *equalization* control is varied, that the peaking and dipping curves are

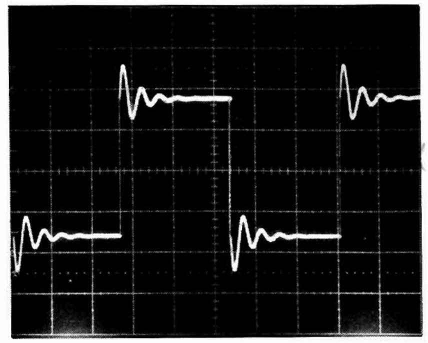

Fig. 6: Output of the same equalizer as fig. (2) with 6 dB boost and a "Q" of 3.2. Because this is a "constant Q" design (like the Orban Parametric Equalizer), the magnitude of the overshoot decreases, but the ringing takes exactly as long to damp out as it does in fig. (5), where 12 dB of boost is used.

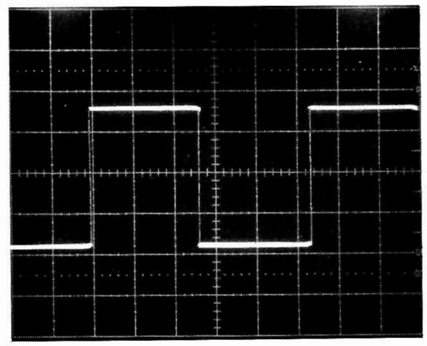

Fig. 7: Output of same equalizer with no equalization applied, showing shape of input square wave.

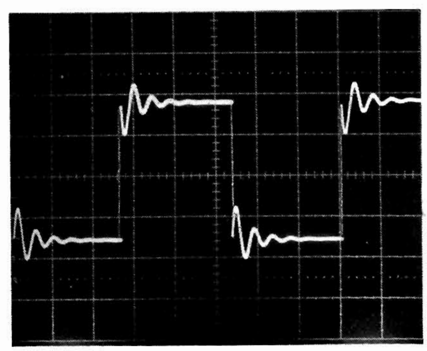

Fig. 8: Output of same equalizer with infinite dip and "Q" = 3.2. The polarity of the ringing is inverted compared to fig. (6), but because of the "constant Q" design, the ringing still takes the same time to damp out.

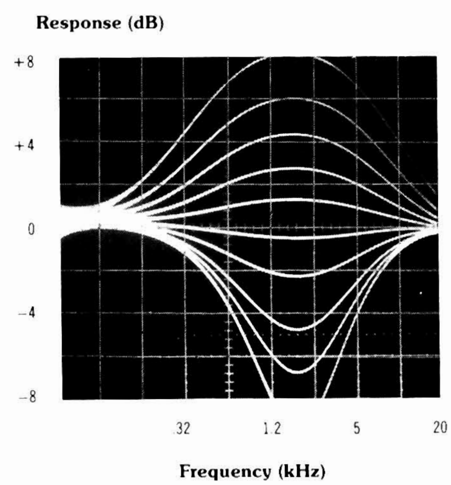

Fig. 9: A set of frequency response curves for a "constant Q" equalizer (like the Orban Parametric Equalizer) for a "Q" of 0.29. Note that the bandwidth is broadest for maximum boost, and continuously decreases as the equalization is moved towards maximum cut. This characteristic tends to result in curves whose tolerability to the ear stays relatively constant as equalization is varied.

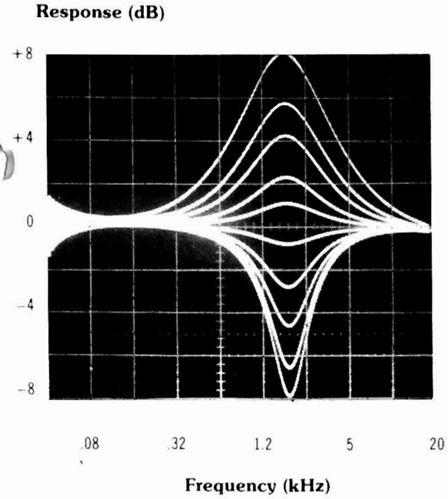

Fig. 10: A set of "constant Q" frequency response curves for a "Q" of approximately 0.5.

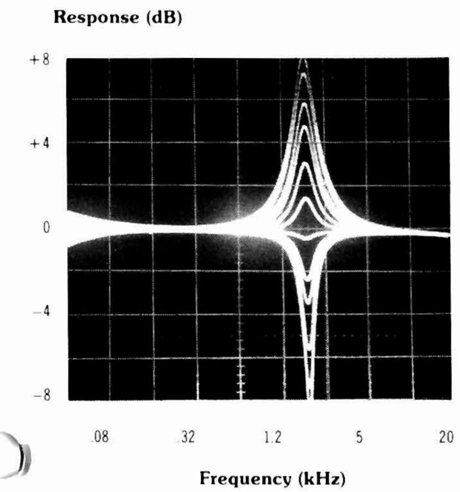

Fig. 11: A set of "constant Q" frequency response curves for a "Q" of approximately 3.2. Note how the bandwidth of the curves has decreased as the "Q" is increased. Curves with this narrow bandwidth tend to cause objectionable coloration when used in boost mode, and are useful only for special effects, like telephone filters, simulation of "old-time" recordings, etc. When used in the dip mode, these curves tend to be essentially inaudible (despite the ringing introduced), and are useful as notch filters to eliminate hum, camera whine, etc. with negligible effect on the overall sound quality. These are the narrowest bandwidth curves available on the Orban Parametric Equalizer.

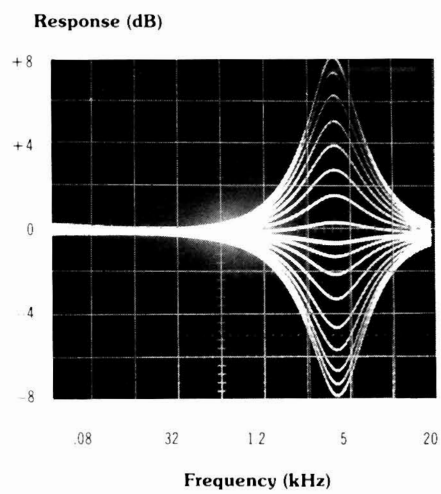

Fig. 12: A set of "reciprocal" (nonconstant "Q") frequency response curves. The curve shape tends to become "peaky" and the bandwidth increasingly narrow as boost is increased. Compare these curves to the "constant Q" family of fig. (10).

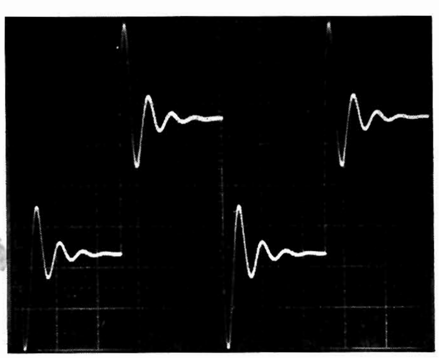

Fig. 13: Square wave response of the reciprocal equalizer of fig. (12) at maximum boost (10 dB). Note the large amount of ringing, and the time necessary to damp the ringing out.

not reciprocal. *However, because the curves are all second order, reciprocal curves are easily generated by readjusting the bandwidth control,* if such curves are desired.

The use of the "constant Q" characteristic in both peaking and dipping modes was prompted by musical and practical considerations. The reciprocal circuit most often used increases the "Q" as the amount of boost is increased. Therefore, equalization extremes become extremely colored and ringy. In contrast, the "Q" of the Orban equalizer remains constant, thereby reducing or eliminating the need to readjust the bandwidth control as equalization is increased. [See figs. (9)-(11).]

The constant "Q" characteristic has several other advantages. First, it is possible to provide an infinite depth notch, which is invaluable in removing interference of fixed pitch, such as hum or camera sprocket noise. Second, the utility of the infinite depth notch is augmented by the fact that the constant "Q" characteristic results in wider peaking curves than dipping curves, thus permitting the notch to be introduced with negligible effect on most sound passed through the equalizer, and making most effective use of the approximately 10:1 ratio of "Q" control available on the equalizer. Simultaneously, the widest bandwidth (minimum "Q") results in very gentle, totally non-ringing (Q = 0.29) peak equalization, which can be as subtle and innocuous as simple tone controls, with the added advantage of continuously variable control over the frequency at which the control begins to act. Attempts to get the same effect with a graphic equalizer are doomed to failure, as the graphic equalizer's simulation of the curve consists of a large number of higher-"Q," ringy peaks.

The Orban Parametric uses a series connection of its four equalization sections — each section is cascaded with the next. Most graphics use a parallel connection. Parallel connections raise the possibility of interaction between adjacent bands because of phase additions and cancellations around the skirts of the individual bands' curves. In the series connection, such interactions are totally absent: the total equalization is simply the sum (in dB) of the equalization contributed to each of the sections.

Extensive thought was given to the "feel" when packaging the Orban Parametric. Accordingly, the equalization control is tapered so that the first ±4 dB of equalization occurs in the first ±25% of the control rotation, to achieve fine control in the area most often used. Each band's center frequency adjusts over a 25:1 range, which gives excellent range without excessive touchiness. In addition, the wide overlaps in frequency coverage which result give great versatility in the available frequencies of narrowband notches. The parametric is highly useful in sound reinforcement work, as the notches can be exactly tuned to the desired frequencies to suppress feedback. A useful variation is the use of a dual-channel Parametric Equalizer with both sections cascaded: one section providing broadband equalization to correct the "sound" of the system, and the other section providing narrowband notches to suppress feedback.

An input level control provides complete control over the 12 dB available gain, and also permits correction of overloads, which are sensed by a "peak-stretching" overload lamp which monitors all points in the equalizer circuitry that are subject to clipping.

Check List for Comparing Parametric Equalizers

When comparing "parametric" equalizers, the potential buyer should check several things:

(1) How many sections of equalization are available, and over what range do they operate? In the Orban there are four sections, operating 20-500 Hz, 68-1700 Hz, 240-5850 Hz, 800-20,000 Hz.

(2) Is the range of the *tuning* controls broad enough so that the user doesn't have to shift constantly from one section to another in order to find the sound he needs?

(3) Does the shape of the equalization curve stay constant as the center frequency is tuned?

(4) Is overload monitoring provided?

(5) What is the interaction between "Q" and the *equalization* control? The Orban has the advantages of "constant Q" design, as described.

(6) Is shelving provided? In the Orban, tuning bands 1 and 4 to their frequency extremes and operating with low "Q" provides the equivalent of shelving curves whose characteristics are adjustable by means of the *bandwidth* control.

(7) Is an input attenuator control provided? How much gain is available?

(8) What is the output capability? The Orban can drive +20 dBm into 500 ohms or greater. While some competitors offer increased headroom, the combination of the Orban's input attenuator and overload light results in positive identification and easy correction of overload for *any* equalization curve — even those which would overload a +28 dBm output stage.

(9) What is the dynamic range (between clipping and noise)? The Orban offers 106 dB dynamic range (typical).

(10) Is the equalizer constructed with quality parts to high standards of workmanship? We invite anyone to open the covers of the Orban equalizers to verify this for themselves.

(11) Are the inputs and outputs balanced or unbalanced? The Orban Parametric Equalizer has an electronically balanced input, and an unbalanced output, with an output transformer optionally available. Balancing the input or the output provides a convenient way to break ground loops in complex installations; only in the most severe cases (such as high RF fields) are both balanced input and balanced output required to prevent hum. In general, our design philosophy avoids transformers, as they tend to unnecessarily reduce sonic definition.

(12) What are the power requirements? Orban equalizers are provided with AC power supplies capable of operating from 115/230 volt 50/60 Hz power for the convenience of international users and travelling shows.

(13) Are any parameters voltage-controllable? This is of interest only for automated operations or remote control. The Orban is a manually operated device.

(14) What are the distortion and slew rate characteristics? Very recently, a new generation of IC opamps have become available. These devices incorporate field-effect transistor inputs, and exhibit improved slew rate characteristics compared to IC opamps used in earlier generations of Orban equalizers. The slew rate of the new Orban equalizers is typically in excess of 7 volts/microsecond. This performance, coupled with the improved linearity of the FET input stages, renders any "transient intermodulation distortion" totally negligible. We can perceive no reason for use of faster, much costlier discrete amplifiers. This is particularly true since recent research has proven the older rule of thumb for avoiding TIM ("the open loop bandwidth of the amplifier must exceed the bandwidth of the material being amplified") to be incorrect.

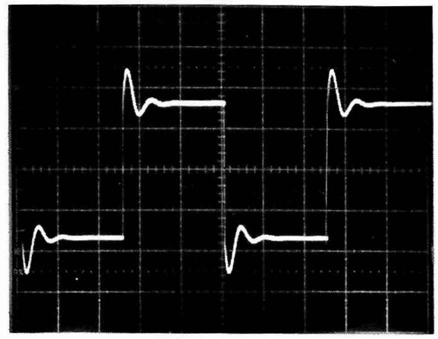

Fig. 14: Square wave response of reciprocal equalizer of fig. (12) at 5 dB boost. The ringing damps out much faster, indicating that the "Q" has been lowered. While the characteristic in fig. (13) would tend to be audibly offensive, the curve in this figure would tend to be acceptable.

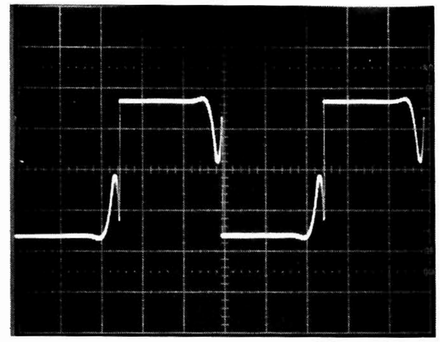

Fig. 15: Square wave response of the reciprocal equalizer at maximum cut. The "Q" has once again been reduced, resulting in even faster damping of the ringing. The reciprocal equalizer cannot produce infinite depth notches (because the reciprocal boost curve would have infinite boost, and would be unstable). In addition, the width of the dip curve (see fig. [12]) results in audible removal of program material when notch filtering is attempted.

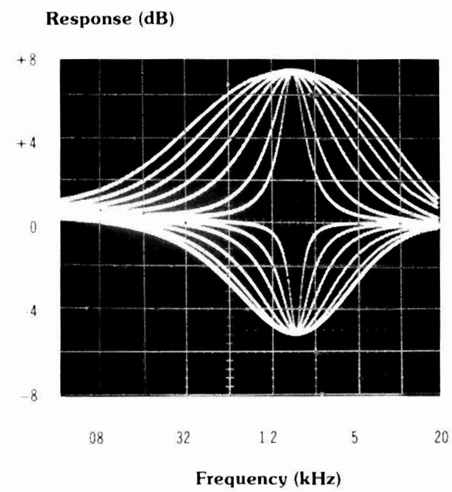

Fig. 16: Frequency response of the Orban Parametric Equalizer for one peaking setting, and for one dipping setting, of the "equalization" control, as the "bandwidth" control is varied. The gain at the maximum peak (or dip) remains constant, and the skirts of the curves move in and out.

Quasi-Parametric Equalizers

The "Quasi-Parametric" equalizer, like the true Parametric, provides control over bandwidth, center frequency, and amount of peak or dip. However, unlike the true Parametric, in "Quasi-Parametrics," these parameters can interact. In particular, changing the tuning and/or changing the amount of peak or dip will also cause a change in the "Q". In addition, the Orban "Quasi-Parametric" equalizers provide reciprocal curves which are carefully controlled so that the "Q" does not change in "peak" mode (although, as it must, the "Q" does change in "dip" mode).

The reason for providing "Quasi-Parametric" characteristics is simple — they are considerably less costly to provide than true Parametric characteristics. The user trades the convenience of true Parametric operation for substantially lower cost per channel of equalization. Also, because the user still has control over all three parameters, he can eventually obtain the same curves and same flexibility as with a true Parametric — he just has to work harder. The only exception to this is that infinite-depth notches are not available because of the reciprocal characteristics.


OVER LOAD
INPUT
LF
MLF
EQ, dB
MHF
HF
OUT IN
TUNING, Hz
ON
POWER
MODEL 622B


ORBAN/PARASOUND PARAMETRIC EQUALIZER
OVER LOAD
INPUT
LF
MLF
EQ, dB
MHF
HF
TUNING, Hz
ON
POWER
MODEL 622B