THE LEDE CONCEPT

DON DAVIS

The Live-End Dead-End (LEDE) concept evolved from an insight I had during the mid-1970s while measuring the acoustic response of monitor loudspeakers in recording studio control rooms. I was using analyzers that had been converted to do the Heyser Transform, which is the frequency-domain portion of Time-Energy-Frequency or TEF measurements. Most obvious to me was the inability of a monitor, in a typical control room of that period, to reproduce accurately the composite record of the signal delays recorded in the studio. I saw that the LEDE room could be a neutral playback environment that would allow the recording environment to be heard with correct temporal imaging of the recorded material.

The LEDE effect is a psychoacoustic effect. The original design goal for recording control rooms was to give the mixing engineer's ears the acoustic clues of a larger space, thus allowing the perception of hearing the studio rather than the control room. Those readers familiar with the illusive nature of the five physical senses should not be surprised to find that hearing is easily

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TO OPTIMIZE POLAR PATTERNS, MAKERS OF ELECTROSTATICS HAVE TRIED USING MULTIPLE DIAPHRAGMS, SIGNAL DELAYS, AND CURVED ELECTRODES.

er amp, a more convenient solution to the problem of drive voltage is to use a step-up transformer to feed the electrodes. The design of such a transformer is very difficult, but because the electrode current is very low, it is not impossible. So we can move on to tackle the distortion problem. The force error we encounter is the result of the physical laws governing the behavior of our system. Therefore, we must explore an alternative system to solve our problem. Cleverly borrowing from other people's work, we realize that if we could use some sort of push-pull arrangement, constant force could be achieved and distortion would be eliminated.

Figure 7 shows a method of combining the use of a transformer with a push-pull approach. The stepped-up audio is applied to acoustically transparent electrodes which attract and repel a central membrane biased to a high voltage with a separate power supply. The use of a high-value resistor to isolate the center electrode results in a form of operation known as "constant charge," referring to the fact that the number of electrons on the electrode remains essentially fixed as it moves. Constant-charge operation became popular in the '50s, pioneered in England by Peter Walker, the inventor of the landmark Quad ESL, and in the U.S. by Arthur Janszen. Constant-charge operation provides very low distortion and is now universally accepted by designers.

Another of Janszen's important contributions to the development of the modern electrostatic loudspeaker was the introduction of what he called "sheathed conductor" technology. This was invented to address the issue of sparking, mentioned earlier. In Janszen's approach, now used by Acoustat, a grid of insulated wires comprises the fixed electrodes. This sounds like a trivial advance, but it is, in fact, very difficult to find insulation techniques that can withstand the voltages required and yet allow the complex system of fields and charges to operate correctly. There are many other ways to construct the fixed electrodes and prevent electrical arcing. Various conductor and insulator combinations have been or are now in use, including inert insulating gases filling the region between the various electrodes. In Walker's recent Quad ESL-63, an internal antenna rapidly detects electrical discharges, shutting off the drive voltage in response. This technique, combined with an input-limiting circuit, eliminates the need for insulated electrodes altogether.

Even with all the advances realized over the last few years, today's electrostatics are not the first choice for providing high-volume sound. It's true that they have finally shed their predecessors' propensity for catastrophic failure every time a stylus was dropped or a bass drum was hit too hard; in fact, modern units can be very reliable and are capable of high output. However, partly due to the transformers used, they are not efficient nor are they easy loads to drive. For a while, it seemed that manufacturers were making an effort to integrate high-voltage, transformerless amplifiers into electrostatic designs, but this trend seems to have waned, probably for a combination of technical and marketing reasons.

More than any of the designs discussed so far, electrostatic drivers are adaptable to full-range use (within the inherent low-frequency limitations of dipoles). By three-dimensional shaping of the diaphragm; by tall, narrow geometry, or by using a phased array of radiators, polar patterns can be optimized over a very wide range of frequencies. This is an important advantage over those planar approaches which are not so easily suited to these alterations. In the Quad ESL-63, an array of vertically oriented independent radiators are fed from a series of delay lines to maintain a very constant horizontal dipole figure-eight pattern over the audible spectrum. In this way, an essentially flat radiator can be made to combine many of the benefits of a point source with those of a dipole. In the ESL-63, multiple full-range drivers are used, so none of the usual crossover troubles appear.

Martin-Logan has refined a different approach to controlling directivity. By using a large, curved electrode-and-diaphragm assembly, their loudspeakers can produce a semi-cylindrical wavefront similar to that of a vertical line source. Although the shape is not inexpensive to manufacture, floor, ceiling, and wall reflections are reduced without sacrificing coverage. The curved shape is used in a single-driver, full-range speaker as well as one using an electrodynamic subwoofer. Acoustat too produces full-range speakers that have a vertical line-source characteristic, using instead a tall and narrow flat electrode.

Electrostatic loudspeakers have long held captive a core of fanatical devotees. Even at a time when listening to electrostatics invariably meant clamping your head in the right position to hear the highs, settling for background-music sound levels and thin bass, and making frequent trips to the repair shop, there were those who would have nothing else. Electrostatics do have a sound of their own, even if only due to their dipolar operation and lack of crossover effects. And something about transparent, high-voltage speakers seems to hint at communication beyond the sensory norm.

Contrary to common belief, though, electrostatics—especially full-range ones—do not have extraordinarily extended top ends nor fast rise-times. There are many high-quality dynamic tweeters that can easily outperform them in these areas. Transient response can be excellent from the point of view of damping and phase, but the truth is that the air-load mass on a large diaphragm requires a very large force to accelerate quickly. Since there is virtually no scientific evidence to support the audible need for response much above 20 kHz, this should not be considered a problem, just an interesting fact.

All things considered, there are many things that make sense about flat loudspeakers. As a group, they have really come into their own over the last decade or so, and I have every reason to believe they will continue to improve. We might expect to eventually see a resurgence of interest in direct-drive, high-voltage amplification for electrostatics, and new magnetic materials applicable to ribbons and planar magnetics are appearing regularly.

At some point in the future, the use of cones as we know them will probably be confined to the bottom three or four octaves of the audible spectrum, where I think they do what they do best. And, of course, we'll still use them for ice cream.

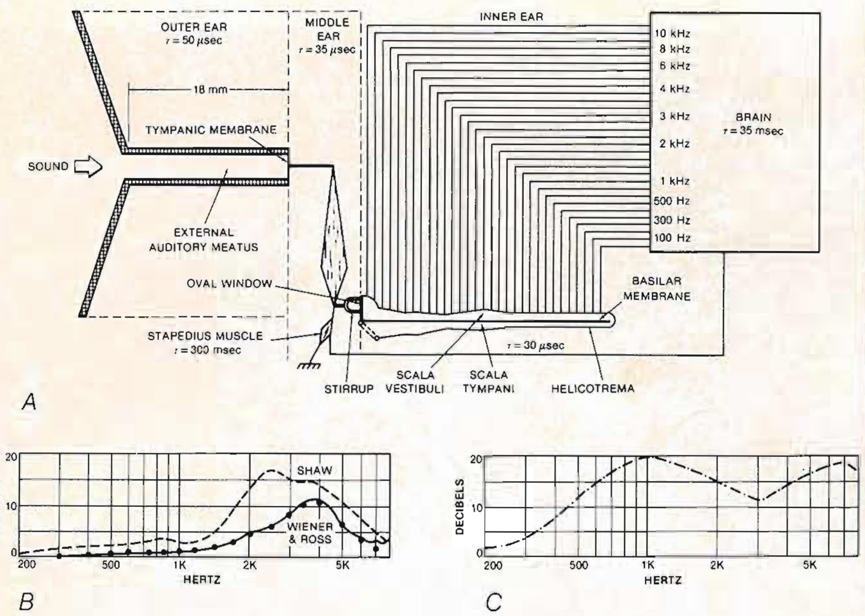


Fig. 1—Schematic of the human ear with the teletransmission system's most important time constants (A), and the transmission characteristics of the outer (B) and middle ear (C). (Courtesy of Brüel & Kjaer.)

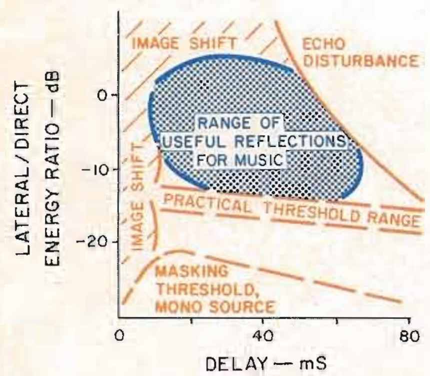


Fig. 2—Illustration (redrawn from Barron) showing the effect of reflections on the perception of music. The practical threshold for a stereo source was added by Marshall and Hyde. (Courtesy of Peter D'Antonio.)

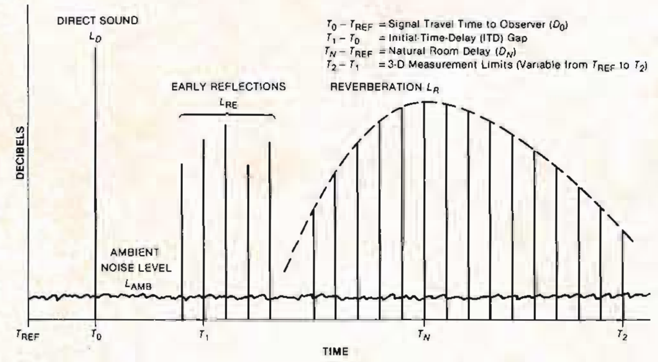


Fig. 3—A depiction of acoustic energy vs. elapsed time. In small, well-damped rooms, such as home living rooms, only the direct sound level, L_D, and early reflections, L_{RE}, are present. Reverberation, L_R, while theoretically present, is below the ambient noise level, L_{AMB}. In large rooms, such as concert halls, L_R actually develops. It is the reverberation in the recording that we would like to hear reproduced over the speaker before it is masked by the listening room's early reflections.

fooled. Human hearing is little understood even by those studying its complexities, despite the many devoted and talented workers in this field. As simple a subject as the integration time of the human hearing mechanism is under question as the newest measurement techniques reveal serious anomalies in the older data. Because LEDE theory and practice deal primarily, though not totally, with the time domain, understanding the various time relationships shown in Figs. 1 and 2 is important. The top portion of Fig. 1 is a schematic drawing of the temporal behavior of the ear/brain, with graphs of the amplitude response of the outer and middle ear below.

Sound Fields

To better understand the importance of the theoretical and practical work now being done, we should first discuss a few fundamentals of sound fields in small rooms—small in the acoustical sense.

Figure 2 illustrates some key time-domain characteristics of human hearing. The useful range of reflections is such that signal delay and signal level combine to create the Haas effect, but it does not evoke false imaging. This illustration encourages the belief that a "Haas-kicker" (i.e., a strong reflection which triggers the Haas effect following an initial signal delay gap) should be within 20 to 30 mS at a level optimally 5 to 10 dB below the direct sound. This would place it within the range of useful reflections and well past the danger of "image shift." The directivity of such returns is also a critical factor.

Initial Signal Delay Gap: A fundamental error often committed by those unfamiliar with small-room acoustics is to believe that classical statistical methods can be used. Let's first view the sound field as a record of signal delays using a chart with vertical coordinates of level, in dB, and horizontal coordinates of delay, in seconds, from some arbitrary zero point.

As shown in Fig. 3, the first signal to arrive is the direct sound, L_D. This is followed by the initial signal delay gap, ISD, well known in concert-hall acoustics as the initial time delay gap, ITD. (Since time can't be delayed, I prefer the term "signal," which can be delayed.) The conclusion of the ISD is signalled by the arrival of the first significant reflection (i.e., the first reflection that is higher in level than 30 dB) below the L_D, which is usually the highest level in its group of early reflections. Following the early reflections will be the reverberant sound field, if present. In small rooms, this reverberant sound field normally never appears above the ambient noise level, L_{AMB}, in the room, and consequently we are concerned only with the direct sound level, L_D, and the early reflected level, L_{RE}, and not at all with the reverberant sound level, L_R.

The kind of reflected energy capable of triggering the Haas effect can come from a single discrete reflection or from a cluster of returns, such as those from a quadratic residue diffusor like the ones discussed in Manfred R. Schroeder's 1984 *JAES* paper. A first significant reflection can be broadly defined as the first appreciable level of energy to arrive after the direct sound from the source. The first significant return also has constraints of coming from the proper direction (or containing the comb filtering that mimics the proper direction) and having the correct frequency content (i.e., containing the higher frequencies that provide the correct pinnae clues).

The primary goal of an LEDE listening space is to extend the ISD that occurs acoustically in the listening room to a value greater than that present in the performer's area, such as a recording studio (see Fig. 4).

Leo Beranek has written in *Music, Acoustics and Architecture*, "Persons trained in listening—for example, blind people, who receive all their clues about the environment around them through the senses other than the eye—can 'measure' the size of a room or judge the distance to a wall behind them by the length of the time interval between the direct sound and the first reflected sound." Beranek goes on to note that this capability is not restricted to the unsighted, but that "experienced music listeners . . . sense the approximate size of a hall . . . by the length of the 'initial time delay gap.' "

The LEDE technique, by virtue of the distance the direct sound must travel to encounter a first reflection, adjusts the initial time delay gap to the same figure that Beranek judged as desirable in the best concert halls, namely 20 mS. It is no coincidence that the same 20 mS is the optimum delay for the maximum Haas effect in good, diffuse, semi-reverberant spaces.

William B. Snow, of Bell Labs fame, in 1957 wrote in *Application of Acoustical Engineering Principles to Home Music Rooms*, "The direct sound alone carries the information giving the sense of direction, by allowing the listener to observe initial transients clearly during the short time interval before the many-directioned reflections begin to arrive at his ears."

Haas Effect: The Haas effect is the inability of the brain to discriminate between echoes and delays of sounds that arrive approximately 10 to 20 mS after the original waves. The reflected sound is still present but psychologically does not exist so far as the listener is concerned. The auditory system temporarily fuses sounds in this 20-mS zone. This ability to fuse sounds is what allows us to blend the direct sound, early reflections, and reverberation into one sound perception.

Critical Frequency: We can also generate a graph, as in Fig. 5, with the sound pressure level, in dB, as the vertical scale and the frequency, in Hz, as the horizontal scale. The key to this graph is the critical frequency, f_c, which is the frequency at which the wavelength is roughly comparable to the largest dimension of the room. Because the equation for f_c is merely a handy approximation for the point where the room modes begin to overlap, it can be condensed to this relatively simple form, 3 c/D, where c is the velocity of sound in air and D is the smallest room dimension. The rever-

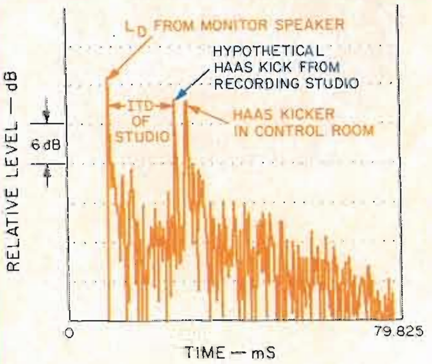


Fig. 4—An energy-time curve or ETC. The horizontal axis is 0 to 80 mS; the vertical axis is 6 dB/div. This ETC shows the actual distribution of acoustic energy vs. time in an LEDE control room. The increased density is created by the generation of deliberate specular reflections which repeatedly redrive through the quadratic residue diffusors, QRD.

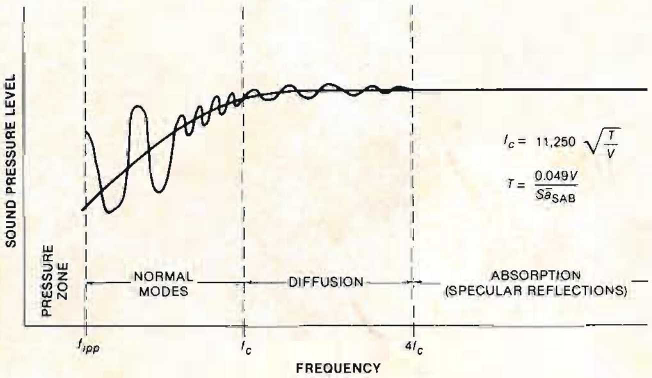


Fig. 5—Sound energy (sound pressure level) vs. frequency. The frequency dependency of the total sound field is the determining factor in the variations in room treatment vs. frequency. Soft absorptive material is useful only above $4f_c$, the specular reflection region. It would be difficult to overemphasize the importance of understanding these basic frequency zones in terms of handling a room's sound field. (Courtesy of BBN.)

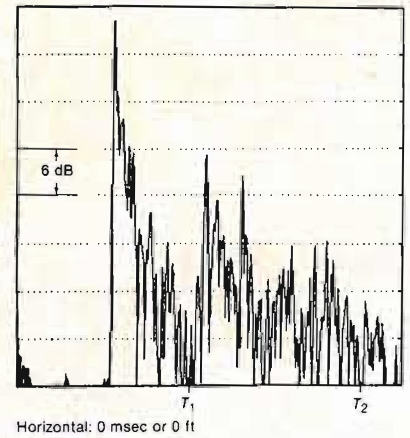


Fig. 6A—The ETC of a small, well-damped room. Note in particular the location of T_1 and T_2 on the horizontal scale. These indicate the start and stop points on the "3-D" view of Fig. 6B.

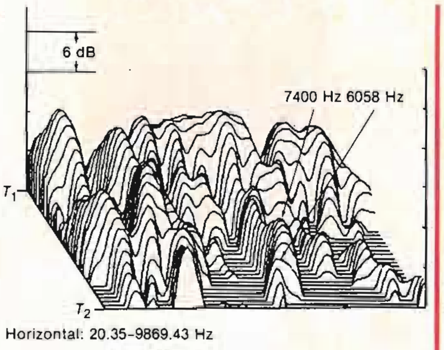


Fig. 6B—A "3-D" view of the energy depicted in the ETC of Fig. 6A. The horizontal axis is 20 to 10,000 Hz; the vertical axis is 6 dB/div. The oblique axis is time, with T_2 being later than T_1. Note here how rapidly the energy divides into room modes, definitely not a statistically random sound field.

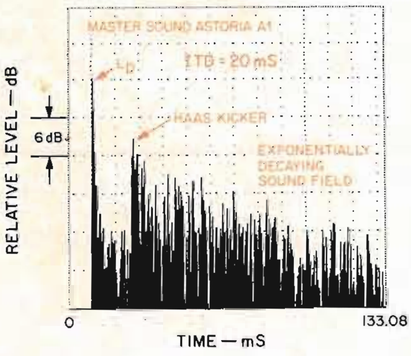


Fig. 7A—An ETC of the control room at Master Sound Astoria in Astoria, N.Y., designed by acoustician Charles Bilello.

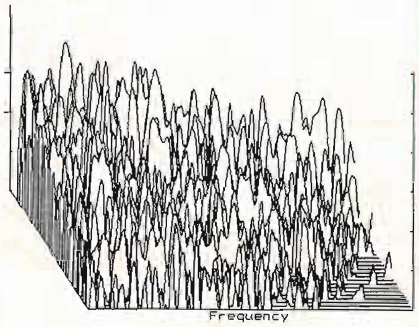


Fig. 7B—A perfect example of what a "3-D" sound field should look like, an exceptional LEDE control room. (Courtesy of Charles Bilello.)

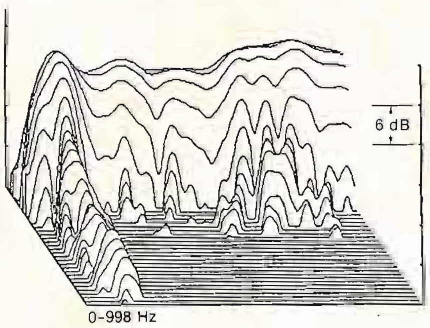


Fig. 8A—Here we have a small room with a pronounced low-frequency mode at 125 Hz, which causes a boomy sound.

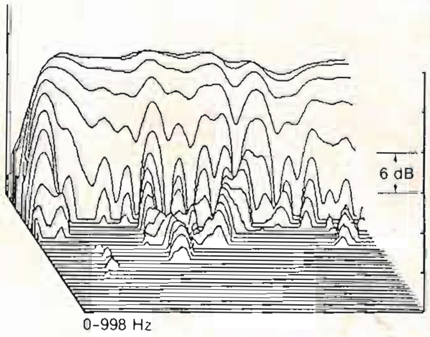


Fig. 8B—This is the same small room as in Fig. 8A, after the installation of a Helmholtz resonator. Note that the low frequencies cannot be absorbed by soft, fuzzy materials. (Courtesy of Doug Jones and WFMT, Chicago.)

beration time, RT_{60}, is simply the apparent rate of decay, in dB per second, converted to an equivalent RT_{60}. See Fig. 5 for a typical conversion.

Room Modes: In a room that has a decay of 300 dB per second, i.e., a room where a line drawn across the peak energy of the early reflections mimics a reverberant decay, the apparent reverberation time would be 0.2 S. Let's have a look at the actual density of the sound field in such a room; see Fig. 6. Note that T_1 and T_2 at the bottom of Fig. 6A indicate the time span of the oblique scale on Fig. 6B. It can be clearly seen that the modes do not overlap. Figure 7 shows what the sound field in a superb LEDE control room looks like.

Once again, looking at the frequency-versus-level graph, Fig. 5, we can see that below f_c there are standing waves, so that movement of the listener about the room can result in major changes in level as the listener's ears leave a peak and enter a null. The change in level can be in excess of 40 dB. Through the use of tuned resonators, these modes can be both broadened and damped. See Fig. 8 for an example of the effects of damping.

Pressure Zone: The pressure zone is that region of the room where the encounter of energy with a boundary is still adding to nearly 6 dB. If we accept a phase shift of 60° as still near enough to coherent addition (i.e., 5.5 dB), then the pressure zone you associate with the floor, for a frequency of 20 Hz, is:

$$\frac{60^\circ}{360^\circ} \times \frac{1{,}130 \text{ feet/S}}{20 \text{ Hz}} = 9.4 \text{ feet deep.}$$

This formula takes the fraction of a complete wave that is still adding coherently (i.e., 60°/360°) and multiplies that fraction by the wavelength for the specific frequency, which is calculated by dividing the speed of sound, 1,130 feet/S, by the frequency, in this case 20 Hz.

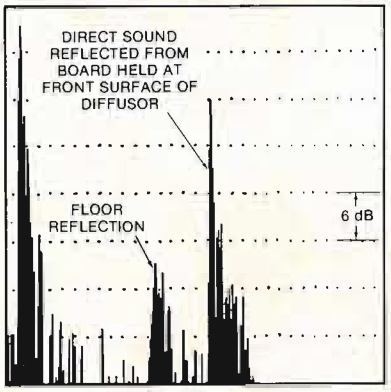
Diffusion Zone: In Fig. 5, the region from f_c to $4f_c$ is the diffusion zone. The diffusion problem has been elegantly solved through the mathematics of Manfred R. Schroeder; Peter D'Antonio of RPG Diffusor Systems has made the equations into practical products. The creativity of D'Antonio (known in the industry as Dr. Diffusor) is shown in Fig. 9. In AES Preprint No. 2365 from the 81st Convention, D'Antonio writes:

> The primary purpose of reflection phase grating (RPG) diffusion is to 1) provide uniformly high density of closely spaced reflections at the listener position, without any density gradients or discontinuities; 2) provide a dense pattern of uniformly distributed, irregularly spaced frequency notches, and insure that any inadvertent reflection combinations with slight time differences, which could result in broadband frequency anomalies, are minimized; 3) uniformly backscatter a broad frequency bandwidth over a wide angle, and 4) reduce the backscattered energy to minimize frequency coloration and image shifting, resulting from interference with the direct sound.

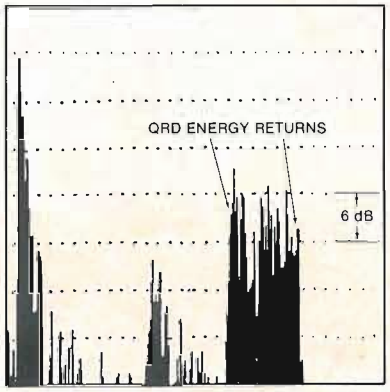
Frequency Dependency: Sometimes it seems that only polarity is not frequency dependent; indeed, polarity is defined in the IEEE Dictionary as "not frequency dependent." The question naturally arises, "What frequencies are pertinent to the LEDE concept?" The answer is, "The specular frequencies, those frequencies which can be modelled by light rays." The beauty of using reflections instead of absorption is that, once above the frequencies of diffusion, the result of reflecting the energy is non-frequency dependent. This frequency range is in the center of the ear's sensitivity, and the higher frequencies provide the pinnae with its directional clues.

Specular reflections occur in the region above $4f_c$, and it is in this region that LEDE must be applied. If the term LEDE is to be applied correctly, then the following rule must be satisfied: Control of frequencies between f_c and $4f_c$ by means of diffusors is such that no reflected energy departs dramatically from exponential decay or exhibits energy voids over time.

Reflection-Free Zone: The original *JAES* paper on LEDE in September 1980 stated that to qualify as an LEDE room there had to be "an effectively anechoic path between the monitor loudspeakers and the mixer's ears which extends for at least 2 to 5 mS beyond the studio's initial time delay gap." Note that no limitations were placed on how this was to be accomplished, inasmuch as it was realized at the time that the end result could be accomplished either by absorption or



A



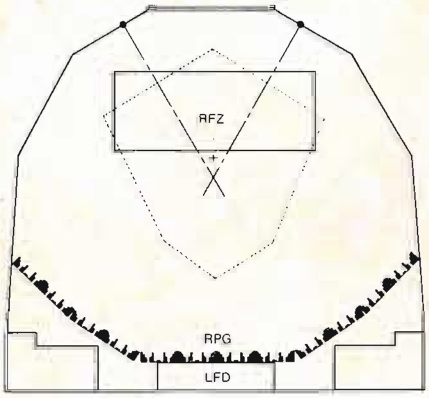
B

Figs. 9A and 9B—The temporal effect of a well-designed diffusor, before (A) and after (B) one is installed. Note that it lowers the level of the reflected energy by spreading reflections out over a wider angle, and that it spreads the energy in time because it is spread in distance travelled.

C

Fig. 9C—A control-room installation of diffusors like those of Fig. 9B, at Master Sound Astoria. (Courtesy of Charles Bilello.)

Fig. 10—Plan view of an RFZ/RPG control room with low-frequency diffusors. Limiting reflections from surface boundaries forms a symmetrical six-sided RFZ. (Courtesy of Peter D'Antonio.)



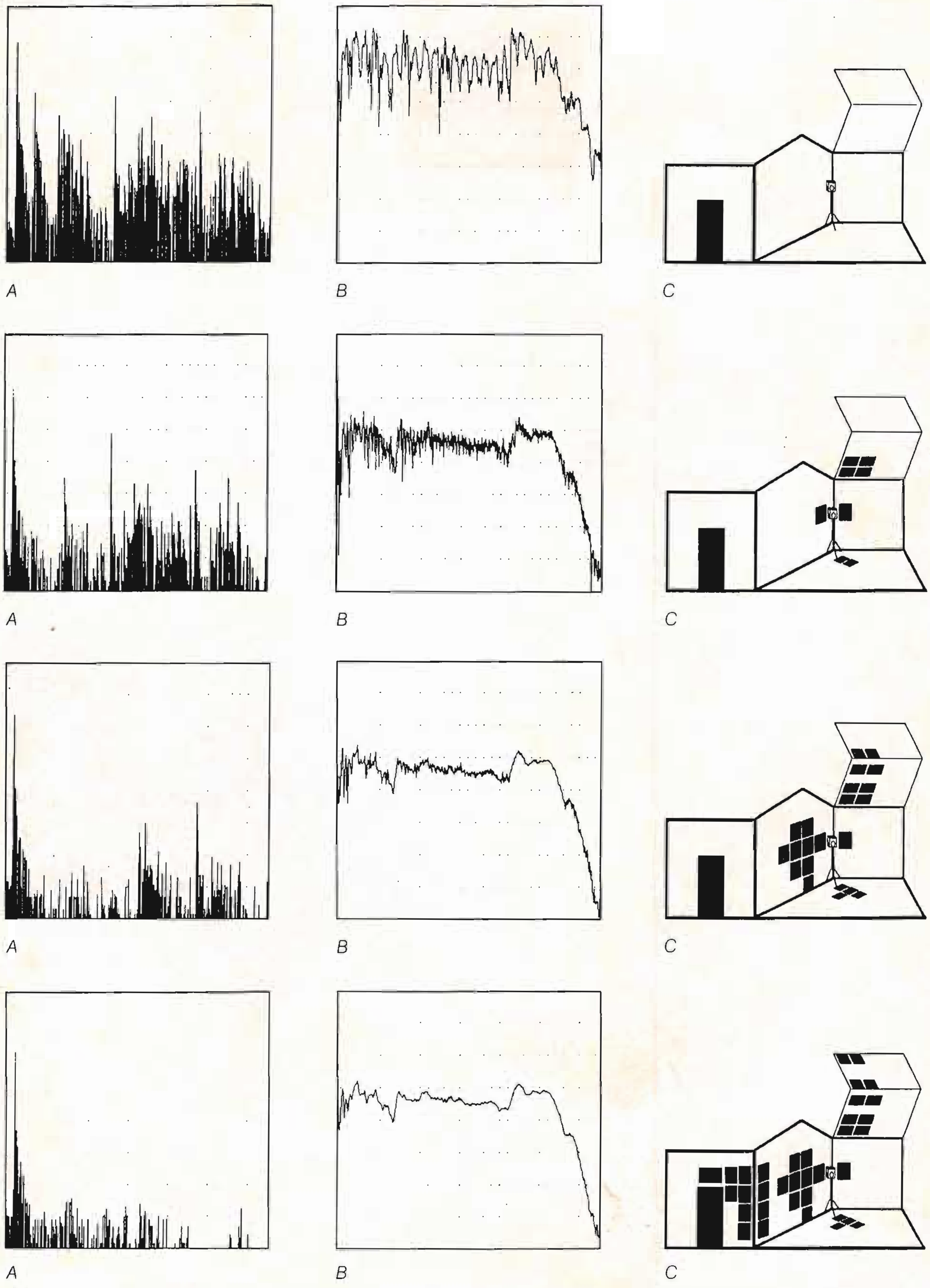


Fig. 11—The step-by-step identification of individual specular reflections and their interception by use of absorptive material. In each trio of drawings, (A) is the ETC, (B) is the frequency response with the filter window equal in time to the ETC display, and (C) is the specific room treatment made at each step. (Courtesy of Doug Jones.)

by the loudspeaker's directivity in combination with the room geometry, i.e., a highly directional loudspeaker in a wide room (see Fig. 10). An excellent example of the former approach is shown in Fig. 11, which illustrates how Doug Jones of Electro Acoustic Systems made an ordinary room meet this particular part of the LEDE criteria.

When this technique is employed, it allows the designer to use specular surfaces at the front of the room as sources of energy spaced later in time to again "drive" the rear wall diffusors, thus adding to the total energy density present over a longer time interval. In control-room design, taking advantage of source directivity has always been the way to avoid reflections from the control room window.

Monitor Loudspeakers

At frequencies below f_c, an LEDE room is a "live" room. If the room construction has been massive enough so that bass frequencies stay in the room, the wall in which the monitors are mounted lends substantial support. Loudspeakers should not be left standing outside of a wall surface in an LEDE room. They should be mounted on shock mounts inside the wall and should use the wall at low frequencies. Fortunately, at the specular frequencies above $4f_c$, there are loudspeakers available that approach reasonable control of their polar responses. In accurately engineering an LEDE listening space, the loudspeakers chosen must be measured carefully through the critical region from 500 to 2,000 Hz for their directional responses (see Figs. 12 through 14).

Bipolar and similar designs are not optimum choices for LEDE rooms. If one is used, the LEDR tape, discussed later, can reveal to the listener the audible compromise encountered.

Characteristics of a good loudspeaker include:

1) The fewer crossovers, the better (two-way systems are usually best);
2) Full signal alignment;
3) Identical amplitude and phase responses for *both* speakers;
4) Identically controlled polar responses for *both* speakers;
5) Ability to produce sound pressure levels of at least 130 dB SPL at 10 feet;

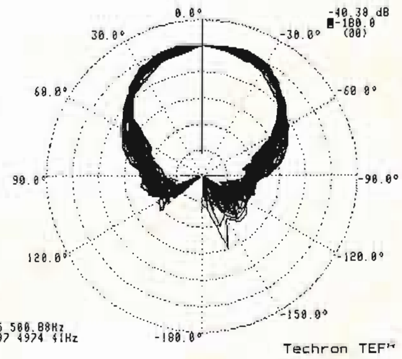


Fig. 12A—Overlaid polar responses, every 250 Hz from 500 to 5,000 Hz, for a high-quality loudspeaker for home or studio. With a device of this quality, it is easy to assign meaningful coverage angles and a meaningful directivity index or Q.

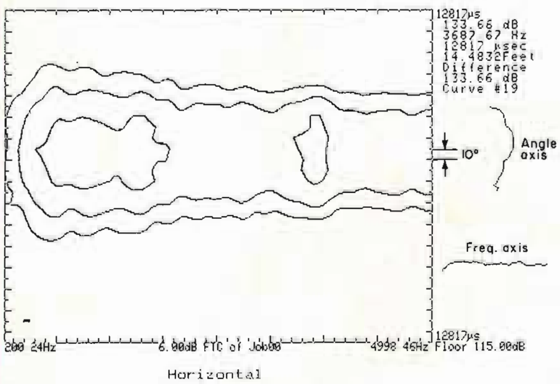


Fig. 12B—The same loudspeaker as in Fig. 12A but analyzed as a frequency-vs.-angle curve. The contours are in 6-dB increments; each vertical division is 10°. Note that the side plots show relative directivity and on-axis frequency response.

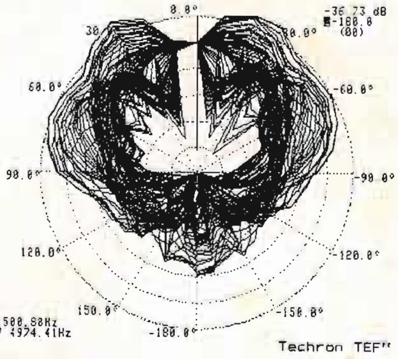


Fig. 13A—The identical measurement as in Fig. 12A but with a loudspeaker that has much poorer directivity.

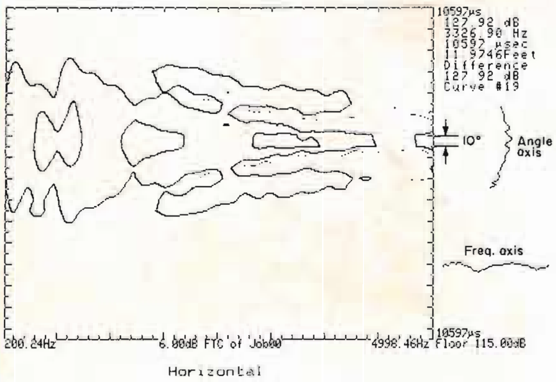


Fig. 13B—The same loudspeaker as in Fig. 13A, analyzed as a frequency-vs.-angle curve. Note that the three major lobes are present over a very wide frequency range.

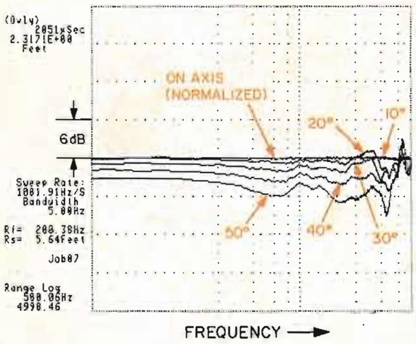


Fig. 14—A quick but efficient way to view on- and off-axis response, here from 0° or directly on-axis to 50° off-axis.

6) Sufficiently well-damped enclosures which, once shock mounted, radiate little spurious energy;

7) A reasonable impedance to match the narrow range of stable amplifiers capable of driving such loudspeakers to the sound pressure level specified above;

8) Harmonic distortion below 2% at all frequencies above 50 Hz;

9) Directivity factor of at least 5, with a Q of 10 the most useful, for the frequency band from 500 to 5,000 Hz, and

10) Time-domain behavior for each individual driver which is the conjugate of a network at the crossover frequency, and which adjusts the frequency-dependent behavior of the drivers back to uniformity.

Imaging

The work of Carolyn "Puddie" Rodgers has shown that the pinnae transform incoming signals, superimposing upon the original signal a comb filter-like spectrum. Recent evaluations of misaligned loudspeakers and early reflections (i.e., those from less than 3 feet away) reveal that they can generate pseudo-pinnae clues, resulting in dramatic image shifts. Directional clues to a large degree reside in comb filter information at high frequencies. Signal delays that generate comb filters cause specific and predictable directional effects.

Misalignment of loudspeakers causes comb filters. This effect can be devastating in an LEDE room designed for aligned loudspeakers, because the misalignment causes a change in polar response (see Fig. 15).

LEDR Tape

Researchers at Northwestern University have developed a special tape recording that, when played in an LEDE room over signal-aligned loudspeakers, causes the listener to perceive the sound as rising straight up out of the right loudspeaker almost to the ceiling, and then going in back of the listener, circling around the listener, moving forward, and finally dropping back down from the ceiling area into the left loudspeaker. Any aberration in either the loudspeakers or the room mars this remarkable imaging. (The LEDR tape can be purchased for $250 in two formats: Quarter-inch, 15-ips open-reel analog or Sony Beta F1 digital, from Doug Jones, Electro Acoustic Systems, 715 Monroe St., Evanston, Ill. 60202.)

LEDE in the Home

Where loudspeakers cannot be built into the wall, I suggest that great care be taken to avoid diffraction effects around the enclosure. "Wings" made of material such as Sonex mounted on plywood panels can be very effective. The greatest difficulty I encounter in consumer loudspeakers is their claim to be aligned when they're not. The high-resolution energy-time curves (ETCs) which the late Richard Heyser included in his loudspeaker reviews have been a totally reliable way to inspect loudspeaker alignment. Particular care needs to be exercised with regard to the vertical polar response of loudspeakers for use in the home, as the ceiling is quite often too low and highly reflective. Floors can be handled adequately with heavy carpeting and pads.

Paul Klipsch's advocacy of corner placement for the past 50 years is still correct. Corner placement has the following advantages: The entire audience-coverage angle is within 90°, polar control is excellent at specular frequencies, and the best low-frequency modal response in acoustically small rooms is obtained.

It is absolutely necessary to introduce diffusion behind the listener. Where the budget allows, quadratic

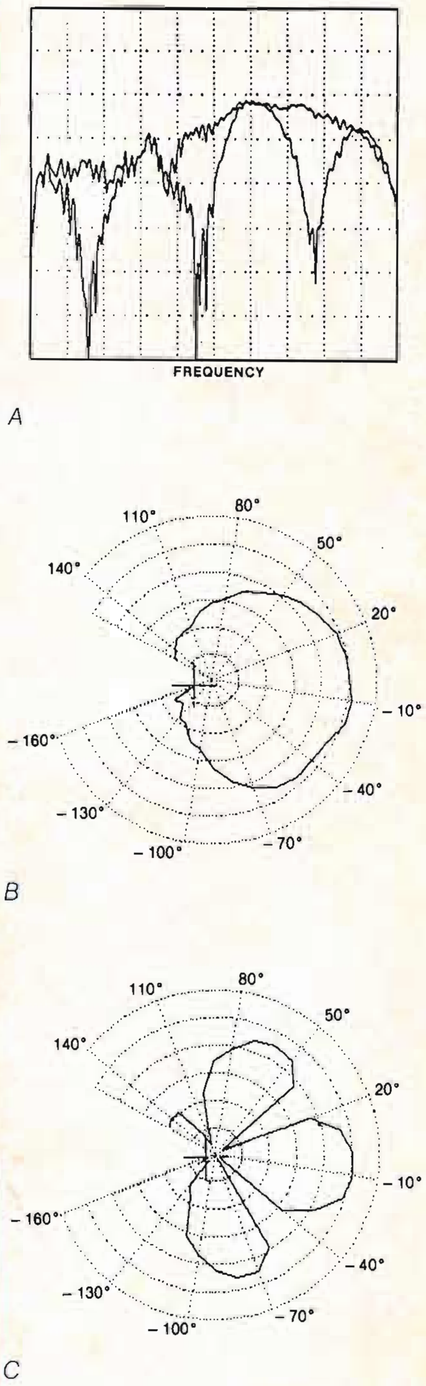


Fig. 15—What can happen when two loudspeakers covering the same frequency range are misaligned by 4 inches: (A) is the response both aligned and unaligned, (B) is the aligned polar response, and (C) is the unaligned polar response.

residue diffusors are best. Bookcases can also be useful. Just make certain that the rear surface is not a hard, flat wall. In addition, make certain that it is *not* absorptive.

Whatever absorptive material is chosen, it can and should be hidden behind acoustically transparent grille cloth-like material. I prefer using Sonex panels because the wedges of this material scatter sound at the higher frequencies, and they smooth the transition to acoustic transparency near the critical frequency, f_c, normally encountered in small rooms. Whatever material is chosen, the designer needs to know its behavior at specific angles of incidence, not its statistical behavior in a reverberation chamber.

Absolute Polarity

Figures 16 and 17 illustrate the phase measurement of a loudspeaker, in polarity and out of polarity. Energy-time curves and energy-frequency curves do not show any effect of being out of polarity, yet it is audible. Only phase measurements reveal absolute polarity.

Ed Long's MDM near-field monitors allow front-panel switching of polarity, as do a few preamplifiers. On a recent demonstration Compact Disc, I observed the need to switch absolute polarity on both channels for every selection. Incorrect absolute polarity manifests itself as sounding like two holes in the wall. When switched, the result is a solid curtain of sound with correct imaging between the two loudspeakers. These minor changes become quite audible when one is listening to good loudspeakers in an LEDE environment.

What does an LEDE room sound like? You shouldn't hear it at all. What you should hear is the characteristic acoustic signature of the room in which the recording you are listening to was made. Most good classical recordings include the sound of the original room on the disc, but the small listening room usually masks it. When the physically and acoustically small room is converted into a physically small, acoustically large room by LEDE means, then this signature is heard from the loudspeakers.

When the recordings are essentially multi-channel mono (often up to 32 channels), it makes little difference what kind of a room you listen in. Many folk, country-western, and some contemporary recordings are properly recorded, in terms of being useful to reproduce the ambience of the recording space over the playback system. Many recording engineers, upon first hearing one of their non-LEDE recordings played back in an LEDE environment, say "That's terrible!" Only after time elapses do they realize that what's terrible is the mix and not the environment. LEDE rooms are harsh critics of technically deficient recordings. On the other hand, technically proficient recordings are a sensuous reward in an LEDE room.

There are presently more than 200 Techron TEF analyzers in the field, mostly in the hands of professional sound contractors and acoustical consultants. These consultants typically charge $500 for a day of measurement, which includes an operator for the TEF analyzer. If five audio enthusiasts were to contract for such measurements to be made in a hi-fi dealer's showroom, choosing a loudspeaker would become an easily documented task—for just $100 per person. Use of the LEDR tape in their own listening rooms would reveal if they needed further TEF analysis of those rooms. Eliminating the loudspeaker as a variable by means of TEF analysis makes playing the LEDR tape in the home an acid test of a listening room's quality. You would be astounded to see how easy it is to find interfering reflections in a home listening room using the TEF analyzer (see Fig. 18). The direction from which reflections come has an important bearing on how that energy is perceived. Thanks to the creativity of Farrel Becker, we can now easily plot the direction as well as the travel time of each and every reflection. I am willing to predict that by the mid-1990s, no serious home system will be made without TEF analysis.

Kurt Graffy of Paoletti/Lewitz in San Francisco has recently started working with custom installers of high-quality music systems. Graffy's firm is hired to find the offending surfaces in the music room and suggest the placement of absorption and/or diffusors to establish a clean ISD gap and precise stereo imaging.

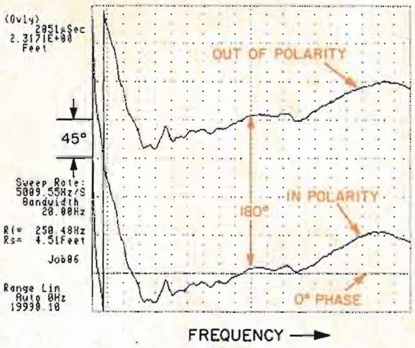


Fig. 16—The difference between phase response and polarity. Phase is frequency dependent; it varies with frequency. Polarity is not frequency dependent. Signal at each frequency has been changed exactly 180°.

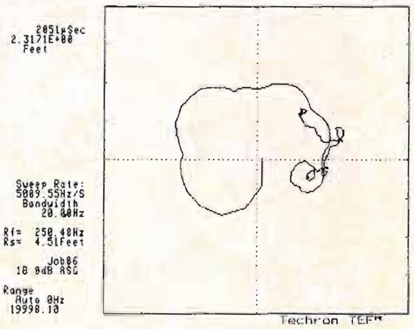


Fig. 17A—An "in-polarity" Nyquist curve. The vertical axis is the imaginary part, i.e., the kinetic energy; the horizontal axis is the real part, i.e., the potential energy. This plot is the tip of a rotating vector of the analytic signal traced out as a curve. Plato said, "God ever geometrizes." God must love modern analysis.

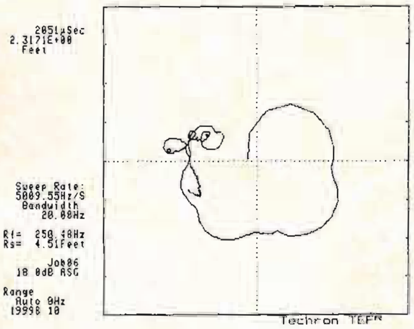


Fig. 17B—A Nyquist curve of the same loudspeaker as in Fig. 17A, this time out of polarity.

THE LEDE CONCEPT

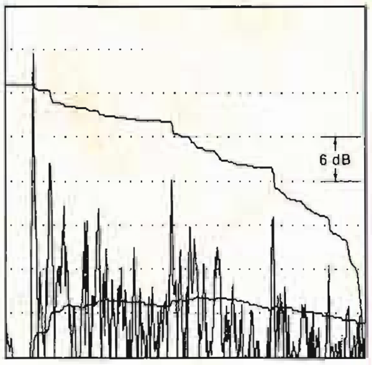


Fig. 18A—The ETC of a flutter echo with a conventional integration in the bottom curve and a Schroeder integration in the top curve.

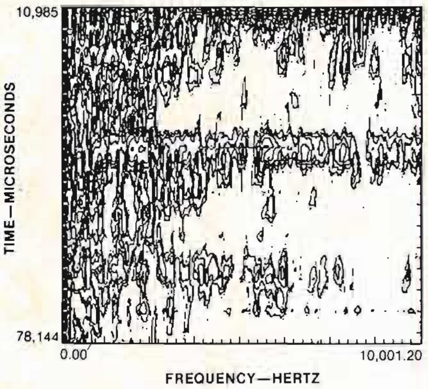


Fig. 18B—A frequency-vs.-time curve or FTC of the same flutter echoes as in Fig. 18A, showing the first, second, and third reflections and their frequency dependency.

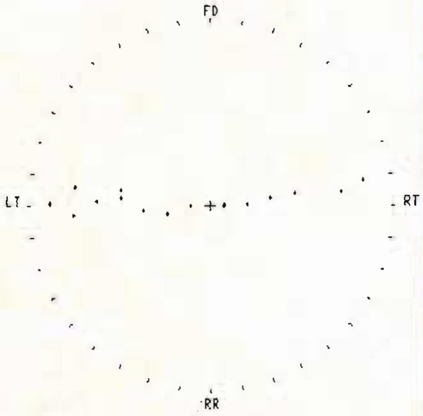


Fig. 18C—A polar ETC of a flutter echo, showing the direction from which each flutter came. Supporting the flutter are the side walls. (Courtesy of Farrel Becker.)

Ideally, the consultant should be engaged at the time a listening room is being designed, just as with a control room. Doug Jones, for example, has been engaged to design and supervise the building of several home listening rooms in recent months. His wedding of psychoacoustics and TEF has enabled him to make valuable contributions to the design of home entertainment rooms.

I can't resist presenting the measurement shown in Fig. 19. It is a TEF-RASTI measurement (RASTI stands for rapid speech transmission index). We now are able to measure speech intelligibility objectively, with as great an accuracy as live listening groups can do with carefully constructed intelligibility tests. How long do you suppose it will be until we can do the same for music?

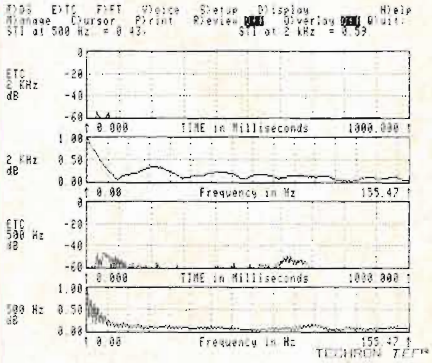


Fig. 19—Will there ever be a musical equivalent of the RASTI or rapid speech transmission index? How about an MPC or music preference curve? ("MTF" means modulation transfer function; overall STI = 0.51, which is fair intelligibility.)

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