Standing Waves—An Audio Booby Trap

WILLIAM D. BELL[*]

The acoustics of the listening room have always been considered important, but the analysis and cure have not often been discussed. The author describes one type of trouble and tells how to correct for it.

NOT LONG AGO I witnessed an impressive static rocket-engine test. The test stand was nestled in a ring of hills in a remote, isolated spot. When the engine was fired, it shot a column of fire, smoke, and steam blistering down a canyon, and the tremendous energy shook the very ground of the distant hill where I stood. Sound levels? 180 db and more at the engine—enough to burst your eardrums, or worse, if you were close. As I watched this awesome demonstration, the terrifying sound level rose higher and higher and then abruptly weakened, suddenly reversed itself and grew stronger again. The wavering sound effect continued. Later, I asked one of the test engineers how they controlled the rocket engine to make it change its power setting. The engineer laughed. "What you were hearing," he said, "wasn't a change in the sound of the engine; it was just *standing waves* in the valley."

This rocket-engine demonstration was probably as impressive a display of standing waves as anyone could ever hope to hear. The same phenomena can make a perfect hi-fi rig sound mediocre. What are standing waves? How do you know if they exist? And what can you do about them?

Take the case of Ed Goldenears.[1] Ed built his own amplifier and preamplifier. He designed his speaker box and had it made by a first-class cabinetmaker. He put a great deal of care and expense into the selection of all components of the system. When he was done, his wife said, "It sounds wonderful!" All of his neighbors and friends agreed. Ed, being a genuine golden-ear, said, "It just doesn't sound right!" He had listened to reproduced sound in some of the best recording studios in Hollywood and he knew just how good reproduced music could sound.

Our friend Goldenears diligently checked his system; he ran frequency tests, power-level tests, distortion tests, and speaker-box tests. So far as he could tell, he had an exceptionally fine system. But it just didn't sound right!

Remembering the long-standing argument between the triode purists and the pentode advocates, he revamped the output stage of his amplifier. Triodes were substituted for the pentodes formerly used. Again he ran extensive listening tests. He played the same passages over and over, at low level, MEDIUM level, and HIGH level. Over and over and over. This sort of thing almost drove Mrs. Goldenears, who didn't have golden ears, crazy. Fortunately, she didn't know that worse was yet to come.

So far as Ed could tell, the change in tube types made no difference—it still just didn't sound right. The next step was to change output transformers and try the Ultra-Linear circuit. This didn't help, either.

Ed was both diligent and persistent. He took his expensive speakers out of the cabinet and took them to the manufacturer. "They're no good," he stated, belligerently. The manufacturer ran frequency-response tests on the speakers and compared them with new speakers coming off the line. Ed's speakers were excellent. Their self-resonance was way down where it should be. Nevertheless, he had the manufacturer remagnetize the permanent magnets, just to make sure nothing was wrong. Remounted, the speakers still didn't sound right.

A speaker box plays a large part in any high-fidelity system. It was natural that Ed next directed his attention to his lovely mahogany bass-reflex speaker enclosure with its twenty coats of hand-rubbed lacquer. He placed a resistor in series with the lead to the speakers, used an oscillator to feed his amplifier, and by measuring the voltage across the series resistance, located the resonant peaks of both the box and the speaker. He sawed out the bass-reflex ports in the speaker box to make them larger. He covered the holes to make the ports smaller. He increased the internal bracing of the box for better rigidity. He converted the bass reflex to an infinite baffle. He converted the infinite baffle to an exponential horn.

For every change made in the speaker box, a complete set of response curves was taken. Our friend Goldenears was nothing if not a perfectionist. Moreover, he was not going to be misled by taking too wide spacing in his frequencies and thus miss pertinent information. The sine-wave oscillator alternately made the big woofer boom, shaking the pictures on the walls, and then shrieking until Ed's wife held her ears. And so Ed, testing and checking, went on—day after week after month. Two years elapsed. The system still just didn't sound quite right! Ed was aging rapidly, and his wife was getting old twice as fast.

One weary night, Ed was for the umpteenth time running response curves on the system. The familiar bedlam of groans, moans, and shrieks began to issue from the powerful speakers. Ed's wife stood in the doorway, her lips moving as she pantomimed an ultimatum which neither she nor her husband could hear. The door slammed behind her, and Ed was alone for another night of research into the mysteries of High Fidelity.

Standing Waves Discovered

About half an hour later, a strange thing occurred. Ed Goldenears was crossing the room, intending to change the setting of the oscillator. Halfway across he suddenly stopped with a shocked, surprised look upon his face. In the spot where he was standing he could hear absolutely no sound! Hurriedly, he backed across the room and slowly, inch by inch, worked his way forward again. This time he hadn't found a dead spot. He slapped the side of his foggy head the better to clear his ears and tried it again. This time he found the dead spot again. Standing stiffly in the mysterious spot, he slowly rotated his head from side to side. He found that he could make the sound come and go by the position of his head. Exploring further, he found that there were spots in the living room where the sound was much

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[*] *Route 2, Box 923, Tucson, Arizona.*

[1] Not his real name.

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louder than it was in other locations. He tried shifting the frequency of the signal generator from 190 cps. A change of just a few cycles in either direction, and the phenomenon he had discovered disappeared. However, every time the oscillator stood at 190 cps, he could find spots of sharp silence and other locations of shockingly loud sound. Edward Goldenears had discovered standing waves—and the source of all his troubles!

The quality of sound reproduction depends not only upon turntables, preamplifiers, amplifiers, and speakers, but upon the acoustical environment of the hi-fi rig. In words of one syllable, the calibre of sound reproduction depends also upon the room in which the equipment is located.

This is why a hi-fi system that sounded wonderful at the dealer's may sound only mediocre in your own home. Or vice versa!

We are all familiar with reverberation, which we recognize as the "liveness" or "deadness" of a room. When we visit an empty house, our footsteps are loud as we walk across the bare floor, and speech is often muffled and garbled. This is because there is nothing in the house to damp the sound—no rugs, no draperies, no furniture. Instead, the hard surface of plaster wall and hardwood floors cause the sound to bounce in multiple, continuous reflections. Such empty rooms have very long reverberation time constants.

At the other extreme are the acoustical "dead" rooms that have been built for making accurate sound measurements in an area free of reflections. Stand quitely for a moment in such a completely dead test area. You are soon conscious of a feeling of pressure in your head; your breathing is abnormally loud, and the pounding under your shirt sounds like Poe's *Telltale Heart.*

Sound waves follow the same laws of reflection as light waves. Under normal circumstances, a sound bounces around randomly within a room and is rather quickly absorbed by damping materials in the room. There remain the special circumstances that create standing waves. This occurs in small rooms with parallel reflecting surfaces. Unfortunately, this is a perfect description of the rooms in which we live and play our high-fidelity systems. We have ceilings exactly parallel to the floor, at least in most houses. The four parallel walls of each room are hard, reflecting plaster or glass.

Causes

What causes the standing wave? To answer this question, we must first remember the nature of sound. Sound travels in waves from either the source of the sound or from a reflection. A sound wave exists as a compressional wave motion in an elastic medium, the air. *Figure* 1 illustrates how a simple sine wave consists of a series of successive areas of compression and rarefaction. When a reflected wave exactly matches compression with a rarefaction area of the original sound, cancellation occurs. When the reflected signal is in the same phase as the original, the sound waves reinforce themselves, and as they reflect back and forth the amplitude of the sound increases. These are standing waves! Sound reinforcing at such critical frequencies can amount to 20 to 25 db or more! Thus, the standing-wave frequency may actually be heard ten to twenty times as loud as other frequencies. The whole room resonates at some critical frequency, just as a bass-reflex speaker box resonates to reinforce the low-frequency range.

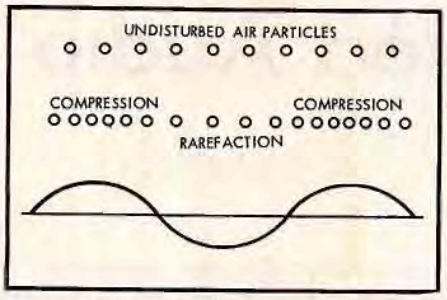

Fig. 1. Particle distribution along a sound wave.

Understanding a little about standing waves, it is obvious why Ed Goldenears' hi-fi system didn't sound right to him. All of the effort of producing a really superior reproducing system is aimed at securing linear reproduction—all frequencies are reproduced at the same sound level. And yet, in Ed's case, one frequency — 190 cps — was amplified twenty times louder than any other frequency—*amplified by the room itself!*

Typically, serious reinforcement of a critical frequency will occur when the wave length of the sound is twice the height of the ceiling. Standing waves can also occur at a harmonic of the fundamental. In one case of a living room that was carefully measured, the fundamental frequency of standing waves was related to the height of floor to ceiling and the fourth harmonic of that fundamental to the wall-to-wall dimensions within the room.

How can you tell if there are standing waves in your hi-fi area?

Finding and Curing the Trouble

The best solution is to follow the example of our old friend, Ed Goldenears. Get a sine-wave oscillator and start experimenting. Your primary requirements are a lot of patience and the ability to maintain diplomatic relations with the woman in your house. The human ear is, after all, a very sensitive sensory device. Attempting to explore a typical room with a microphone is very difficult, or impossible, because of the multiple reflections.

What do you do if you find that standing waves are affecting the quality of your reproducing system? The best answer is to move, and this time make certain that your new hi-fi quarters involved rooms of adequate dimensions, with no parallel walls or floors and ceilings, and with optimum reverberation characteristics. If such an upheaval in your domestic life poses problems, there is another answer.

What must be done is to insert a deliberate nonlinear characteristic into your amplifier response. Thus, at the critical frequencies, your hi-fi rig will put out less energy, but this lesser energy will be amplified by the room resonance to make the over-all response approximately correct. (It's things like this that make high fidelity an art and not a science!)

Ed Goldenears followed the first plan of action, moving not because of the hi-fi system, but because of his job. He soon discovered that his new home had standing-wave resonances, also! He then

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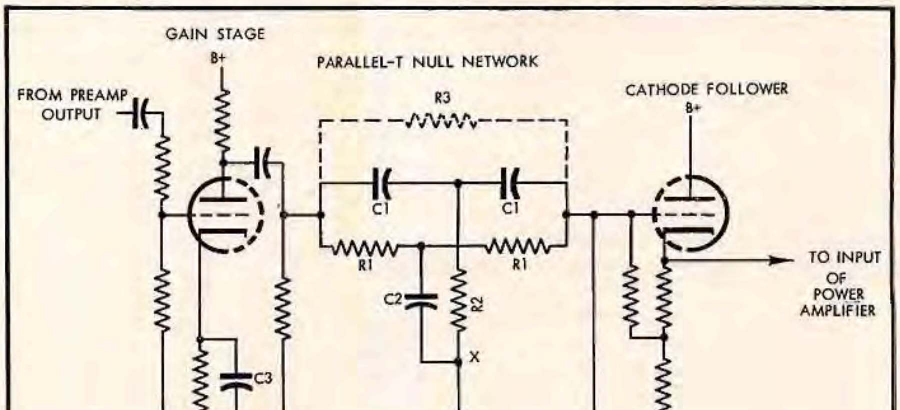

Fig. 2. Standing-wave neutralizing circuit.

mal circumstances, a sound bounces
height of the ceiling. Standing waves
(Continued on page 65)

BOOBY TRAP

(from page 23)

tried the second plan of inserting a dip filter in the system. It worked, too. Now Goldenears is all smiles because his hi-fi system sounds good to his golden ears.

What kind of a circuit will compensate for standing-wave resonances? The answer to this problem depends upon your ingenuity in designing circuits and the kind of hi-fi rig you have. First, of course, you must find the resonant frequency to be damped, using the experimental techniques described before. Once the frequency is known, a corrective circuit must be designed. Attempting to make the correction within the power amplifier is difficult because feedback loops prevent introducing nonlinear characteristics. Similarly, tone controls and equalization circuits within the preamp cause difficulties. Because minimum distortion will be created at lower signal levels, one acceptable plan is to use a special equalizing stage between the preamplifier and the power amplifier.

Figure 2 shows one possible circuit for neutralizing the effect of standing waves. Such a circuit can be built using a single dual triode with B-plus voltages taken from either the preamp or the power supply. To understand the operation of this circuit, consider the parallel-T null network which is redrawn in *Fig*. 3, along with its response curve. This circuit is capable of achieving a complete null at a selected frequency, using only RC components. Assuming the resonant frequency f_o to be known, the design procedure is to calculate values of the components in the

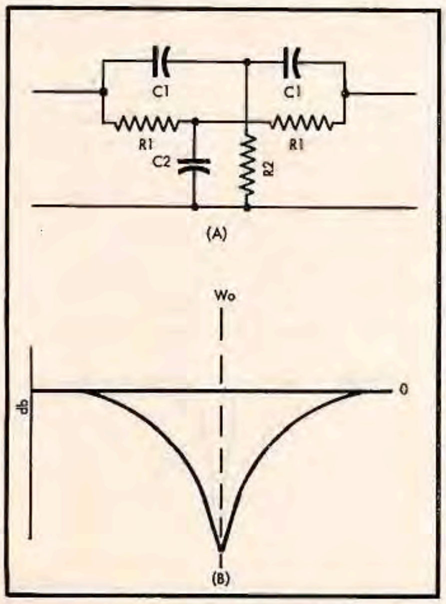

Fig. 3. Parallel-T null network, and typical response curve.

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parallel-T network from the following equations:

$$\omega_o = 2\pi f_o \quad (1)$$

$$R_2 = 2R_1 \quad (2)$$

$$C_1 = \frac{1}{2R_1\omega_o} \quad (3)$$

$$C_2 = 2C_1 \quad (4)$$

Knowing f_o, a value can be assumed for any one of the four components and the remaining three values calculated. Reasonably high impedances should be used to avoid undue loading of the triode stage that drives the parallel-T network. The attenuation achieved with this circuit is the conventional 6 db per octave possible with a single stage RC circuit. It is obvious, therefore, that attempting to use the parallel-T circuit directly would attenuate a wide band of frequencies. What we seek is the attenuation of a narrow band of frequencies. This result is achieved by taking the output from the parallel-T network and applying it as feedback to the input amplifier stage, as shown in *Fig.* 2. At first consideration, this circuit is confusing, since the effect of placing the equalizing network inside the feedback loop is to cause the feedback to attempt to minimize the equalization.

Sharpening the Null

Figure 4 shows the effect of the overall circuit. Curve A, when the loop gain is zero, is the conventional 6-db-per-octave attenuation curve. Curve B shows the output with a loop gain of 20, and Curve C shows the results with a loop gain of 100. Thus, we see that the feedback is doing exactly what we anticipated, trying to correct the nonlinearity.

The reason that attenuation exists at the selected frequency is simply that the parallel-T circuit is null at that frequency. Regardless of the amplification ahead of the parallel-T circuit and regardless of feedback—the null network still produces a null output at the selected frequency. Therefore, the response curves of *Fig.* 4.

In order to balance our room acoustics properly, we have three variables under our control: selection of the resonant frequency, the rejection band width, and the amount of attenuation.

The rejection frequency is determined by the design of the parallel-T network as explained earlier. Accuracy of the rejection must be checked with a signal generator. Practically, it is very difficult to design the parallel-T circuit of *Fig.* 3 so that an exact null is achieved. This result can be approached only by very accurately matching the components with a high-precision bridge. This requirement for accurate matching of components for a true null need not concern us in the present application, however, because we don't want a complete null. Instead, we would like to attenuate a narrow band of frequencies by possibly 10 db.

The rejection band width is controlled by the gain of the triode stage, as *Fig.* 4 demonstrates. The tube type employed and the value of the plate load resistor can be selected for greater or lesser gain. Also, the cathode by-pass capacitor C_3 can be eliminated for reduced gain.

The amount of attenuation is affected by the loop gain and by the mismatch in the components of the parallel-T. A bridging resistor, shown dotted as R_3 on *Fig.* 2, will also reduce the attenuation. So will a series resistor inserted at point X on *Fig.* 2.

Unfortunately, it is impossible to design our equalizing circuit so that opti-

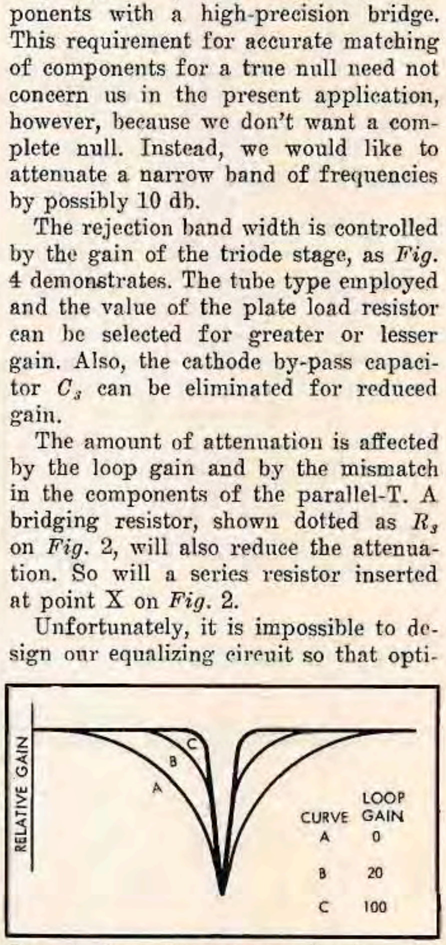
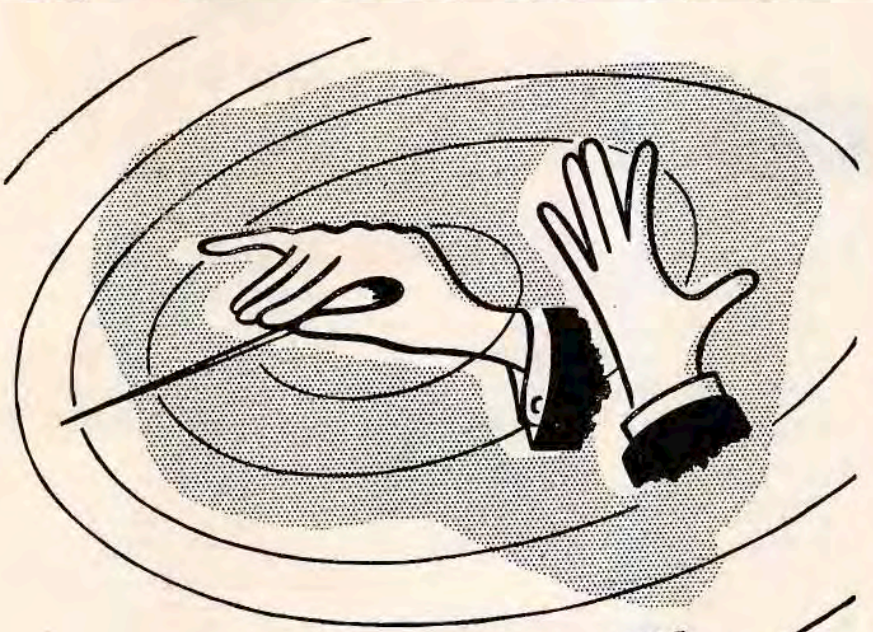


Fig. 4. Response curves showing the effect of placing the null network within the feedback loop.



The amount of attenuation is affected

mum results are guaranteed. Instead, the empirical approach must be used. Once an attenuating circuit has been built and proved to be operating with the desired attenuation at the resonant frequency, it is then necessary to try the circuit with your high-fidelity system and judge with your own two ears if the results are better. Narrowing the band of frequencies and varying the attenuation by one of the devices described above will produce different results. It is up to you to select by trial-and-error methods the circuit configuration that does the best job for your room. The final criterion is what sounds best. If standing waves of significant amplitude are generated in your listening area, you will find the time and effort spent in matching your hi-fi system to its environment is well invested. Æ

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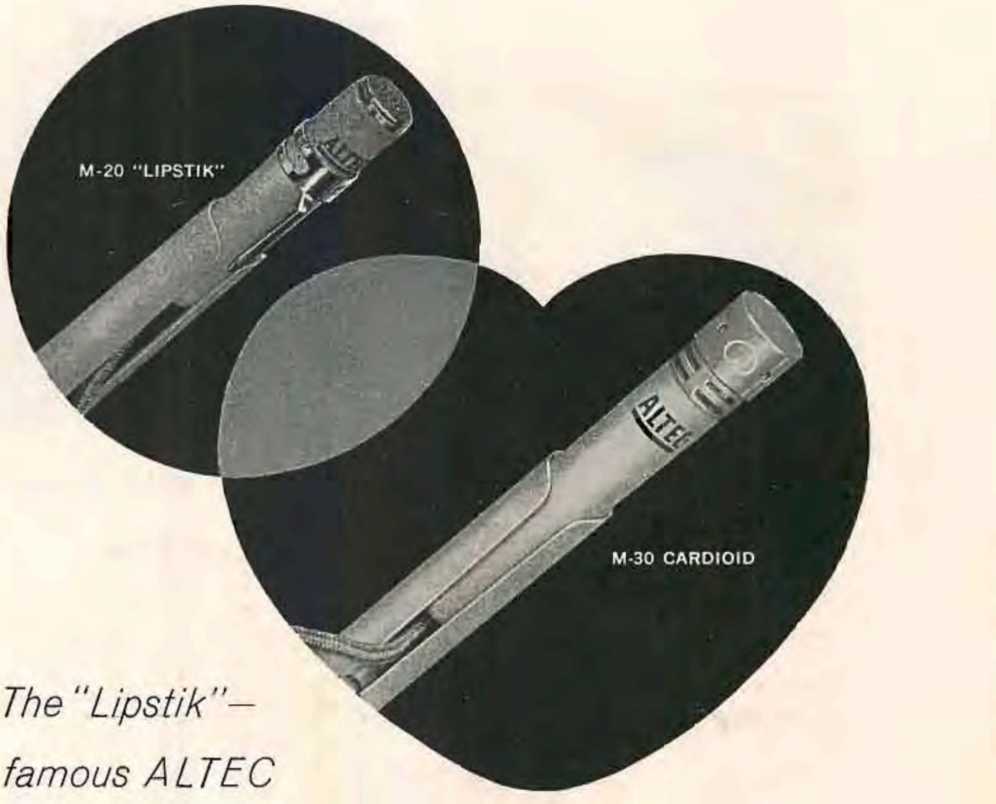

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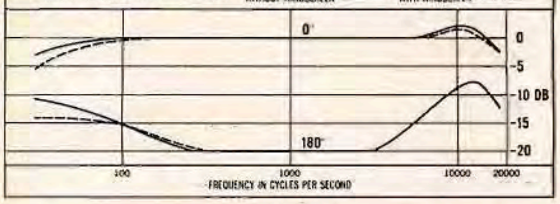

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