how it works

A NEW SOUND-REPRODUCTION TECHNOLOGY USES ULTRASONIC ENERGY TO CREATE AUDIBLE, HIGHLY DIRECTIONAL SOUND BEAMS OUT OF THIN AIR.

Directional beams refocus sound science

By Warren Webb, Technical Editor

ALTHOUGH THE SETUP WAS SIMPLE, the demonstration was almost unbelievable. A portable CD player fed a small amplifier that in turn drove a special speaker. I stood beside the 7×7 flat speaker, and yet the sound seemed to emanate from the far wall. I could change the apparent point of origin of the sound by simply changing the direction of the speaker. And still I heard no direct sound from the speaker beside me. When I walked directly in front of the speaker, the sound felt as though it was created right at my ears or inside my head. If I moved a foot to either side, the sound was gone. Spooky. Ultrasound energy and the nonlinear properties of the air around us made possible this demonstration, which seemed to defy the laws of physics and the science of sound.

I was in the San Diego offices of ATC (American Technology Corp), which is working on the equipment to focus sound for a variety of incredible applications. For example, international gatherings, such as the United Nations, could have translations beamed directly to individuals—Spanish at one seat and Arabic at the next—all without interference or earphones. A coach could use a directional megaphone to beam verbal instructions to a single player on the field. Or the kids in the back seat of the car could listen to hip-hop while the parents played oldies in the front—without headphones. Tomorrow's multichannel surround-sound entertainment systems will be able to beam virtual speakers to any point on the walls or ceiling. Simpler applications will enable shoppers to hear private product promotions at locations in grocery stores or museum patrons to hear audio descriptions within a few feet of each exhibit.

According to Elwood "Woody" Norris, ATC's chairman, the company's goal is to direct and focus sound in a manner similar to what we can do with light. Although this statement seems to contradict our high-school-physics notion that sound waves travel in spherical waves from the source, speaker designers have for years struggled with sound-directivity problems. As the frequency increases, sound becomes more directional, so manufacturers add horns and other mechanical devices to their tweeters to spread high frequencies over the listening area. As frequencies continue to increase into the ultrasound region, sound waves become so directional that they can find use in 3-D

A parametric bullhorn would allow users to communicate to a person or area without creating noise pollution in the surrounding environment.

An overhead emitter can advertise a special sale in a grocery aisle without disturbing other shoppers.

medical-imaging and ranging applications. And don't forget that bats use their high-frequency sonar to catch flying insects while flying full speed in total darkness.

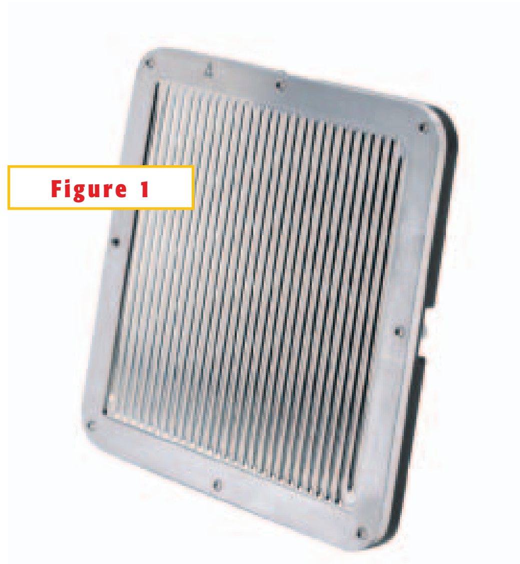
NONLINEAR AIR

Although the concept has been around for years, ATC has refined an ultrasound-to-audio parametric generator that uses the nonlinear properties of air to translate a set of ultrasonic frequencies into sound that we can hear. Early parametric-generator experimenters used arrays of hundreds of discrete ultrasound emitters, although results were often poor because of mismatched amplitude and phase responses. The latest ATC parametric sound generator is a monolithic, thin-film structure that maintains coherent amplitude and phase across the entire device in a package measuring less than a half-inch thick (**Figure 1**). Because the emitter is larger than the wavelength of the frequencies involved, it emits the ultrasound wave as a pure plane wave with virtually no expansion in the beam diameter with distance. In general, the dispersion is less than 3° in either direction or a total of 6° overall. ATC calls this ultrasonic beam *hypersonic sound*.

The real magic of hypersonic sound occurs when modulated ultrasound energy hits the air in front of the emitter. Under certain conditions, the air acts as a mixer that combines signals to produce sum and difference products like a downconverter in a radio receiver. Variations in the speed of sound cause this phenomenon. At normal atmospheric pressure and a temperature of 20°C, a small audio signal travels through air at approximately 343m/sec. As the amplitude of the sound signal increases to more than approximately 100 dB, the speed of sound changes over the course of a single cycle. The upper part of the waveform sufficiently compresses air molecules to increase the local temperature and pressure and, therefore, slightly boost the speed of sound. Likewise, the negative portion of the waveform slows sound propagation. These speed variations result in a distorted waveform that resembles a triangular wave (**Figure 2**). Because triangular waves are rich in harmonics, the speed variations demodulate the ultrasound signal.

To review heterodyne fundamentals in the frequency domain, assume that the modulated ultrasound signal contains 50- and 51-kHz tones. If you pass this signal through a detector or a nonlinear device, your output will contain both of the original signals plus a sum signal at 91 kHz and a difference signal at 1 kHz (**Figure 3**). Additional harmonics also exist at much higher frequencies. The interesting output is the difference tone at 1 kHz, the only signal in the human audible range of 20 Hz to 20 kHz. To extend the example, you can substitute a complex audio waveform for the 51-kHz tone to produce any audible sound anywhere along the beam of ultrasonic energy. In general, 100 to 110 dB of ultrasonic-sound-pressure level produces an average 90 dB of audible sound. The actual conversion efficiency in air depends on frequency, distance, and modulation parameters.

Figure 1



Unlike a conventional loudspeaker, a parametric emitter projects no sound from the sides or rear. You can focus sound where you want and no place else.

$600 BEAMER

Although inherent distortions exist in the process due to unwanted harmonics, emitter inefficiencies, frequency variations, and modulation losses, ATC has developed an amplifier-and-emitter product that delivers clear audio with minimum power consumption. The model R220A uses single sideband-modulation techniques along with distortion-correction preprocessing to increase parametric-conversion efficiency without increasing bandwidth (**Figure 4**). A proprietary power converter provides amplification and modulation in a single process. The self-contained unit requires only a source of audio and ac power to function. The model R220A is available now for $600.

The R220A operates in both direct and virtual

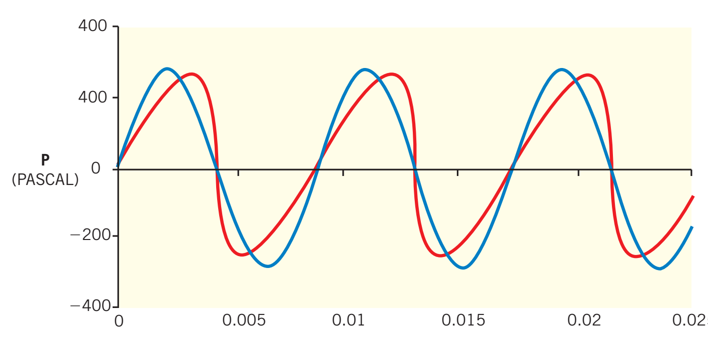
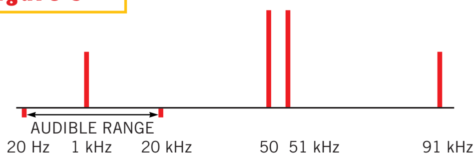


Figure 2

At high amplitudes, the speed of sound changes over the course of a single cycle. The blue line is a pure sine wave, and the red represents the same waveform after it has propagated through the nonlinear air for a time.

Figure 3

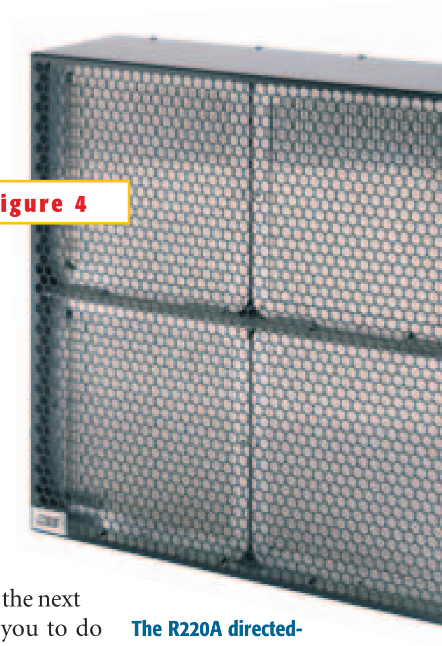


The output of a nonlinear device contains the original 50- and 51-kHz signals plus a sum signal at 91 kHz and a difference signal at 1 kHz.

modes. In the direct mode, the unit points directly toward a listener, and the listener hears the sound because he or she is standing in the ultrasound beam. Other listeners standing off to the side or to the rear of the unit hear no sound from the emitter. However, if the listener is outside the sound beam and the ultrasound column strikes a hard surface, the audible sound reflects back into the environment. The listener perceives the sound as originating from the reflective surface, not the hypersonic sound unit, and the reflective surface acts as a virtual-sound source. In addition, hypersonic sound does not follow the traditional loudspeaker-inverse-square law, which dictates that you have a 6-dB decrease in level for every doubling of the distance from the source. This fact means that hypersonic sound can travel much greater distances while maintaining intelligibility than the sound from conventional speakers.

Although ATC has a 15-Mbyte demonstration video, along with other technical information on its Web site (www.atcsd.com), you cannot get the full impact of hypersonic-sound technology without experiencing it for yourself. You will not believe your ears. As with any new technology, it offers benefits and possibly entails unforeseen headaches. So, the next time that little voice in your head tells you to do something, go somewhere, or buy something, take a look around to see whether this new ultrasonic technology is pointed in your direction.□

Figure 4



The R220A directed-audio-sound system targets museum displays, retail environments, point-of-purchase, and kiosk applications.

Acknowledgments

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