December Meeting: Loudspeaker Design & Physics

Note our new web address: http://www.torontoaes.org

Toronto AES Section Meeting
Loudspeaker Design and Physics
Presenters: John Vanderkooy (University of Waterloo) Paul Barton (PSB Loudspeakers)
Date: Tues 7 Dec 2004
Time: 7:30 PM
Location: Harris Institute for the Arts
118 Sherbourne Street, Toronto, Ontario

John Vanderkooy spoke on the Basic Acoustics of Loudspeakers. His tutorial outlined the essential acoustics needed to understand direct-radiator loudspeakers. Topics ranged from the gas law to the diffraction of a loudspeaker cabinet. Acoustic pressure and particle velocity concepts for plane waves and for spreading 3D waves were explained. Demonstrations of some acoustic effects for speakers were shown. A major conclusion was that the acoustic output is related to the acceleration of the diaphragm for a baffled system. These points were illustrated with experiments and measurements with a MLSSA system.

Some highlights of his presentation are described in a relatively nonscientific style. His talk was infinitely more sophisticated than the summary here:

Professor Vanderkooy began his discussion with a short talk about the atmosphere which loudspeakers are built to manipulate for our listening pleasure!

The atmosphere weighs 1.2 Kg/Cubic meter, or about 10,000 KG of air per each square meter in a column of air 8 Kilometers high, which is what we think of as the atmosphere around us. It's heavy but you can still see through it. The gas law is PV=RT; pressure or density is inversely proportional to volume. The gas molecules are moving, the pressure rises as the square of the speed. As sound waves propagate, the air changes density and temperature. This makes sense as, if heat were not dispersed as a by-product, sound would never lose energy and therefore never decay. It would be a loud world indeed and it's loud enough as it is!

Using a 25-liter sealed speaker box as an example, Professor Vanderkooy explained if an 8" round active speaker cone moves 1mm, the SPL inside the box would be 134 dB. This is subject to many phenomena.

Resonance: As the cone moves, air inside the box is compressed. A 25-liter box with an 8" (20cm) driver (say a 20g moving mass ignoring the driver surround) would have a resonant frequency of 84 Hz, too large a driver for a modest box. The resonant frequency in a speaker box (not considering ports and chambers and so forth) will determine the Low Frequency characteristic of that loudspeaker system.

As sound occurs in waves, velocity and pressure are proportional, manifesting in the atmosphere as a series of moving high and low pressure fronts. In a free wave (or a free field without boundaries) the wave fronts remains clean. Introduce any kind of reverberation and "all bets are off."

Pressure does not change the speed of sound, temperature does. In air the typical speed of sound is 340 meters/sec. If we took an "infinite wall" and moved it 1mm at 100Hz, 139 dB SPL would be created. The wall moving at 1000Hz would need 100 times the force or 20dB more sound energy. Since sound moves faster in hotter temperatures, in the small throat of a horn where there is great pressure, the heat created actually speeds up the sound it is producing, while on rarefactions it is retarded – the wave literally "catches up" with itself in one place, "loses ground" at others, creating distortion.

As sound emanates from its source, it will travel in an expanding spherical wave, keeping its shape but lessening in amplitude. In a 1 dimensional wave, pressure and velocity will be in phase. In a 3 dimensional wave, sound travels out in all directions, but pressure and velocity are no longer in phase near the source. The closer one is to the source, the more the pressure is in phase with the acceleration, not the velocity. It is the acceleration of the cone which makes "sound" by creating the pressure outside the sound source. Ears hear pressure, not velocity! If you are closer to the source than the wavelength of 100Hz, you are in the "near field". There will be a lot of "whoosh", but further away will be the "wham", in which pressure and velocity are in phase like a plane wave. The motion of the wave in front of the speaker is in fact 90 degrees out of phase from what you would think.

Professor Vanderkooy demonstrated the MLSSA system, which measures impulse response by using a broadband pseudo-noise signal transmitted through the speaker and picked up by a microphone. Inside the sealed speaker box, of course, the reading is loud, and the pressure is proportional to the cone displacement. Outside of the test speaker box, the pressure is constant at frequencies down to 80 Hz below which it drops off at 12dB per octave, consistent with the box's resonant frequency of about 85 Hz. The pressure outside the box is proportional to the acceleration of the cone. When we compare the SPL inside and outside the box we see that they differ as frequency squared. The pressure inside and outside a loudspeaker box is always related that way at lower frequencies. Above the resonance frequency, inertia takes over, and the acceleration is independent of frequency. There is no way to accurately fight the resonance of the box, though there are ways to compensate for it and manipulate it.

A further aspect of loudspeaker design is Huygens principle, which states that each point on a wave front will act as a new source of spherical waves. This means that a larger driver will not disperse sound well as frequency rises. HF tends to beam from the driver, which is commonly dealt with using MF and HF drivers and crossovers so that each frequency range is dealt with by a tailored component in the system. Since LF pressure inside the box will influence midrange and HF units, the components must be isolated. Usually the MF driver can have a smaller box, and the HF driver doesn't really need a box to reproduce those frequencies, since the space under the cone is sufficient as an air spring.

Diffraction is also an issue unless the box is, for example, a sphere, and we have seen this design utilized recently by several manufacturers.

Certainly Professor Vanderkooy could have gotten in to greater depth, but chose to wrap up the talk there, turning the floor over to PSB Loudspeakers' founder Paul Barton. Mr. Barton spoke about the history of PSB, and the challenges of designing a loudspeaker for consumer use which overcomes a good number of the difficulties inherent to loudspeaker design - as we saw in Professor Vanderkooy's presentation.

PSB Loudspeakers started in a factory in St. Jacobs in 1972. Mr. Barton was the first loudspeaker designer to use the anechoic chamber at the National Research Council's location in Montreal, designing the first speaker from start to finish in its facilities. In 1988 PSB participated in the National Research Council's "Athena Project", a study of loudspeaker and room interface. Mr. Barton he gave us a virtual tour of the "Athena Project" room and the NC's anechoic chambers using Power point and Quick time footage.

The "Athena Project" chamber allows the listening room's dimensions to be tailored in real time for testing and analysis. The largest anechoic chamber at the NRC boasts 6 foot deep sound absorbing wells in a suspended chamber which is totally floated. The ambient sound level in the room is 20 dB below threshold.

Mr. Barton also described some of the sophisticated measurement tools used in loudspeaker design. An Audio Precision system one test unit allows resonances to be separated from diffraction in analyzing a design. A laser vibrometer provides analysis of the motion on the surface of the cone. The vibrometer reveals resonance and indicates where bracing is necessary.

Cabinets for the speakers have to be stiff and the material should resonate at a frequency high enough that an LF driver can't excite it. Ports are designed with curved entrances and exits to keep the air turbulence down to prevent distortion. Fiberglass cones are used, injection molded rather than vacuum formed in order to attempt to reduce resonances up and down the cone. The boxes are damped with open cell foam.

Subs usually are designed with a circuit which squashes dynamics, though PSB designs its subwoofers to preserve or restore the dynamics of the original signal. Subwoofers have their own design challenges with issues such as noise from the spider being much more audible. Amplifiers provided with the PSB subwoofers are a differential voltage design, using class A/B circuitry, with a digital amplifier driving an analog amplifier for high efficiency and accurate dynamic reproduction.

Mr. Barton presented several speaker measurement charts for various speakers on the market at all price ranges. It has been proven through research that the average consumer finds a speaker with a "flat" frequency response most pleasing to listen to. Many of these charts, presented anonymously (!), show that the average speaker on the market is anything but flat. The PSB speakers are certainly very close in a design field where perfection is still purely imaginary.

In showing us the latest line of PSB speakers, Mr. Barton pointed out that one of his primary design considerations is integration into real listening environments. Speaker designs must be modified to suit 3 main consumer needs – in room, in wall, and in cabinet. "In room" designs are ideal of course, where the speaker box is built for optimum performance and ideal installation is more or less expected. "In cabinet" designs are optimized for home entertainment units where the speakers might be mounted similar to a television set, and lastly, "in wall" designs are for modern (or particularly tidy!) installations where the speakers are not to be seen at all!

After the presentation was the AES Christmas social. We were treated by the AES to some fine beer choices, and some darn good pizza, courtesy the efforts of Garrick Filewod and Dan Mombourquette. Thanks to the Harris Institute for the Arts for their hospitality and meeting space.

ABOUT THE PRESENTERS:

John Vanderkooy was born in The Netherlands in 1941, but received all of his education in
Canada, with a B. Eng. degree in engineering physics in 1963 and Ph.D. in physics in 1967, both
from McMaster University in Hamilton, Ontario. For some years he followed his doctoral interests in low- temperature physics of metals at the University of Waterloo, where he is currently a professor of physics. However, since the late 1970s, his research interests have been mainly in audio and electroacoustics. A fellow of the AES, current member of its Board of Governors, and a member of the IEEE, Dr. Vanderkooy has contributed a variety of papers at conventions and to the Journal. Together with his colleague Stanley Lipshitz and a number of graduate and undergraduate students, they formed the Audio Research Group at the University of Waterloo.
Dr. Vanderkooy's current interests are digital audio signal processing, measurement of transfer functions with maximum-length sequences, transducers, diffraction of loudspeaker cabinet edges, and most recently sub-surface analysis techniques using maximum-length sequences.
http://audiolab.uwaterloo.ca/john.htm

Paul Barton, founder and chief designer of PSB Speakers, began designing speakers more than 30 years ago for a Grade 10 Physics project. His engineering bent coupled nicely (for speaker designer purposes) with his abilities as a violinist who as a young musician played with Canada's National Youth Orchestra and the University of Toronto's Repertoire Orchestra. His two passions converged permanently in 1972, when he founded PSB Speakers. www.psbspeakers.com
One of the first to use the anechoic chamber at Canada's renowned National Research

Council facilities in Ottawa and other facilities there, Paul has combined research into the correlation of measurements and audible performance with testing of successive modifications of every speaker-in process. In the mid 1980s, PSB became part of the Lenbrook Group of Companies whose expertise in marketing specialized electronic products along with their widespread distribution in North America has established PSB Speakers as one of the most respected loudspeaker manufacturers in the North America as well as in 43 other countries around the world. http://www.psbspeakers.com/