Panphonics Audio Transducer Technology

Panphonics Oy manufactures electrostatic audio transducers having a patented structure consisting of porous surface layers and a diaphragm in between them. As an electric voltage is applied to the stator plates, an electric field is produced between them. As the electric field moves the diaphragm in same phase over the transducer area, the element transmits acoustical plane waves with dipole radiation characteristics. Conversely, the element may also be used as audio receiver, as diaphragm movement in relation to the stators caused by incident sound can be detected as electric signal.

The one-piece construction of the transducer enables high-volume manufacturing of elements of variable sizes and shapes. As the distances between the diaphragm and the stators are small, low voltage is used compared to traditional electrostatic loudspeakers. Due to their light weight and high directivity, the Panphonics audio panels are used in growing numbers in locations where traditional cone speakers can not serve the audio reproduction needs.

In the following, the basic theory behind the Panphonics transducer is briefly reviewed, after which the specific characteristics of the transducer are discussed in more detail.

Sound Radiation from a Piston

Sound radiated by a loudspeaker element of any kind, set in a plane baffle, can be estimated by a plane piston set in an infinite plane baffle [Kinsler et al. 2000]. This estimation is especially useful for panel loudspeakers such as the Panphonics audio transducer, as its radiating surface is effectively flat.

An important measure in this estimation is the source's capacity to convert the piston motion into acoustic sound power, or the acoustic radiation resistance. It is the ratio of pressure [N] to the volume velocity of the piston [m^3/s]. At high frequencies, all pistons have the same ability to produce real acoustic power per unit surface area.

The the acoustic load developed by a baffled piston depends on the relation between frequency and piston dimensions. The acoustic resistive load exerted on a vibrating diaphragm is constant in the piston band, which consists of all frequencies above the piston band cutoff frequency:

$$f_{bp} = \frac{c}{\pi D},$$

where ***c*** is the sound velocity [m/s] and is the piston diameter [m]. Below the piston band, as the wavelength of produced sound approaches the size of the piston, the radiation resistance starts to decrease at the rate of 12 dB / octave or the square of the decreasing frequency. The value of the acoustical load can be calculated by

$$R_D = \rho_0 c S_D,$$

where R_D is the piston band diaphragm resistance [Ns/m], $\rho_0 c$ is the characteristic resistance of air [Ns/m^3], and S_D is the diaphragm area [m^2] [Kuttruff 2000]. The force exerted by the diaphragm is calculated by

$$F_D = R_D v_D,$$

where v_D is the diaphragm movement velocity [m/s], related to the frequency ***f*** and displacement ***d*** by

$$v_D = 2\pi f d .$$

Radiation efficiency of a piston depends on its size and the size of the baffle around it [Morse & Ingard 1968]. As seen in Fig. 1, even an infinite baffle has little effect when piston sizes comparable to those of typical Panphonics audio panels are considered. The theoretical limit for low frequency cutoff is also seen from these plots. If maximal efficiency is aimed for at the high frequencies, -6 dB relative attenuation will be perceived around 100...200 Hz.

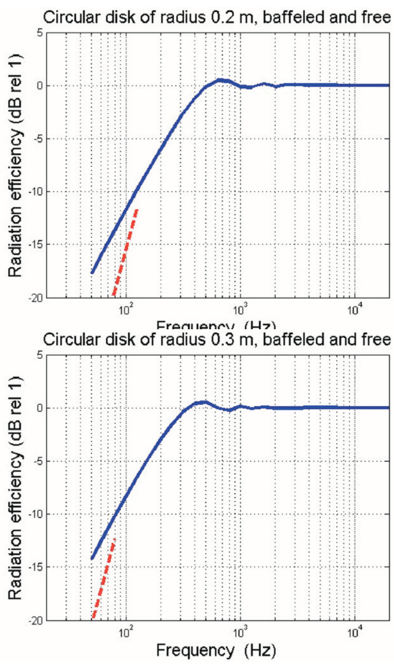

Figure 1: Radiation efficiency of a piston: baffeled (solid line) and unbaffeled (dashed line, low frequency asymptote).

Directivity of a piston source depends of its size and shape. At frequencies above the piston band cutoff frequency the radiation pattern narrows and produces side lobes. In the piston band, the directivity index and the on-axis gain increase by 6 dB/octave, ie. the beam angle is approximately halved for each octave increase in frequency.

Acoustical Plane Waves

For a plane wave, the acoustic variables have constant amplitudes and phases on any plane perpendicular to the direction of propagation. Any acoustical wavefront resembles a plane wave, when observed at a location far from the source.

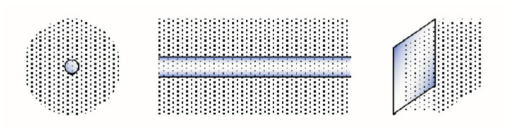

Figure 2: Point, line and area sources and their radiation patterns. [Peltonen 2003]

A traditional loudspeaker typically has characteristics varying from a line source to a point source depending of the construction and the radiated frequency. In contrast, due to the large diaphragm area radiating in same phase, the Panphonics audio element functions as area source producing plane waves at high frequencies, gradually changing to a point source at low frequencies as the wavelength reaches the element dimensions.

Acoustical plane wave as a physical phenomenon has been known for a long time. In contrary to spherical waves, ideal plane waves have no geometrical attenuation, as the wavefront does not spread to areas larger than the source area. Thus, the pressure amplitude is independent of distance if losses in the propagation media are neglected.

In practice, some geometrical spreading is observed due to boundary effects and unideal accuracy of the movement of the sound source. Also, some frequency dependent attenuation is always present in sound propagation in air.

Electrostatic Loudspeaker Principle

An electrostatic loudspeaker is basically a parallel plate capacitor, one plate being a flexible diaphragm. A push-pull operation, essentially linearizing the operation of the transducer, includes two air-permeable stator plates between which the diaphragm is moving, as depicted in Fig. 3. Applying a signal voltage to the two plates produces a uniform electric field in the space between them. A charge placed anywhere in this space will experience a force causing it to accelerate towards the stator with opposite sign voltage.

The electrostatic principle enables the construction of loudpeakers with lower coloration, better transient response, lower distortion and higher directivity in comparison to other techniques. The advantages of the electrostatic loudspeakers have been known for decades. The first commercial products appeared in the 1920s and 1930s and development of the materials made it possible to produce full-frequency-range electrostatic loudspeakers in the 1950s [Walker 1979, Borwick 2001].

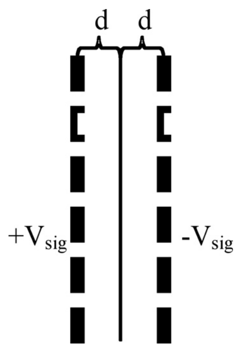

Figure 3: Basic structure of a push-pull electrostatic transducer.

To make the diaphragm react to the changes of the electric field caused by the signal voltage, it needs to be charged. In electrosatic loudspeakers, this is most often solved by applying a constant bias voltage to the diaphragm. This enables the use of inexpensive materials. The bias voltage causes the electrical force to be non-linear at very high amplitudes, but this has no noticeable effects when the transducer is designed properly to keep the diaphragm movement in linear range.

Panphonics audio element characteristics

Panphonics' proprietary electrostatic transducer technology provides large scale manufacturing of thin, light weight loudspeakers and microphones [Kirjavainen 1997, Kirjavainen 2002]. They are easy to install and to use due to their exceptional one-piece structure. The high directivity and the plane wave characteristics of the produced sound field enable many novel audio usages.

Mechanical Structure

The elements consist of porous stator plates and a metallized diaphragm. Each stator is less than 2 mm thick and has one metallized surface with 160 m grooves to allow the diaphragm movement. At the same time, the construction is kept stable and relatively rigid by joining the layers together at multiple locations in and around the element. Porous plastic plates enclose the charged surfaces to provide perfectly safe operation.

Audio Source Usage

When the Panphonics audio transducer is used as a loudspeaker, the diaphragm is connected to DC bias voltage, while signal voltage is applied to the stators.

Directivity Characteristics

The directivity of the transducer panel depends of its dimensions and of the output frequency. For example, the isobar plot of a square shaped element is shown in Fig. 4. At low frequencies, the radiation pattern is a wide figure-of-eight. At frequencies between 500 Hz and 2 kHz the main lobe gets narrower and noticeable side lobes exist. At higher frequencies also the side lobes diminish remarkably.

The directivity pattern can be affected for example with surface treatments or with electric means – by changing the local magnitude or phase output characteristics over the element area. Both narrower and wider main lobes can be achieved depending of the customer needs.

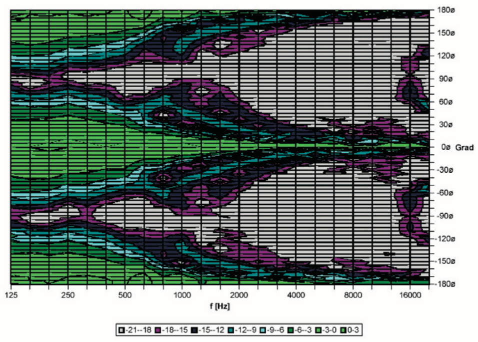

Figure 4: Directivity of a 60 cm x 60 cm loudspeaker panel. Sound pressure is plotted in dB relative to the on-axis level.

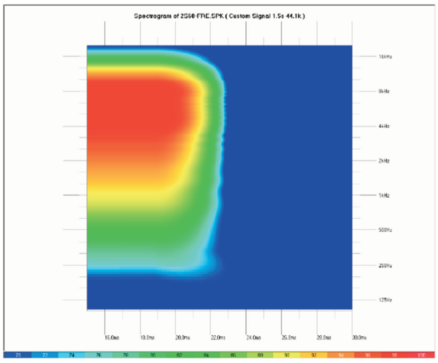

Figure 5: Panphonics transducer impulse response depicted as a spectrogram of the radiated sound pressure in dB.

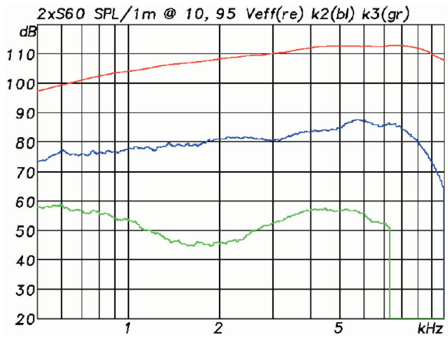

Figure 6: Radiated sound pressure level at 1 m distance (red) and two distortion products measured at constant voltage of 10.95 V_{rms}. Measurement distance was 8 m, all levels are recalculated to 1 m standard.

Frequency Response and Signal Accuracy

As the moving mass per area of the Panphonics audio transducer is very low compared to traditional cone speakers, the coupling from the diaphragm to the air is very good. Because of the low inertia, transient response is exceptionally accurate and minimal distortion levels are obtained. An impuse response is depicted in Fig. 5.

The size and shape of the transducer drastically affect the frequency response as predicted by the piston radiation theory. As an example, the sound pressure level and the levels of two distortion products are shown in Fig. 6.

Audio Receiver Usage

When used as a microphone, the transducer may be connected in several manners. Movement of the biased diaphragm causes measurable changes in the capacitances measured between the diaphragm and the stators. Thus, the signal may be recorded from the stators, for example. Another option is to apply opposite bias voltages to the stators and to measure the voltage at the moving diaphragm. To protect the circuit from electromagnetic disturbances, an extra counductive layer can be manufactured on the element surfaces for shielding.

Test results of three different sizes of receiver elements are shown in Fig. 7. Sound sources located straight in front of the element and 45 degrees to the side were used. Comparison with Figs. 4 and 6 shows that similar directivity characteristics apply to the transducer whether it is used as a source or as a receiver. In combination with its flatness, this enables interesting usage possibilities for audio interfaces in vehicles and teleconferencing systems, for example.

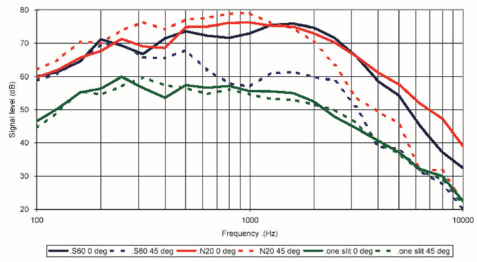

Figure 7: Frequency response of transducers of three sizes when used as audio receivers: S60 = 60 cm x 60 cm, N20 = 20 cm x 60 cm, and one slit = 2 cm x 60 cm.

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