# EFA Loudspeakers

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*Abstract* — **Loudspeakers developed by Kronos Air Technologies use the same physical phenomenon as an electrostatic fluid accelerator (EFA). This ionic wind technology provides virtually inertialess air oscillations by applying a force directly to the air without the use of a membrane and creates high linear displacement. As a result, Kronos EFA loudspeakers deliver accurate sound production across a wide acoustical range.**

## I. Introduction

A loudspeaker is a device that converts electrical signal to acoustic waves, i.e. sound. There are different types of loudspeaker. The most popular and widely used is a moving coil type. This type itself has many variations such as electrodynamic, permanent magnet, and horn speakers. A coil is attached to a diaphragm or cone and is placed in a magnetic field created by an electro- or permanent magnet. An electric current through the coil forces the diaphragm to move back and forth generating acoustic waves. Electrostatic speakers have a thin charged membrane placed between two conductive stationary panels. An electric potential proportional to the acoustic signal is applied between the panels and membrane, creating electrostatic forces that induce movement in the membrane. Advantages of electrostatic speakers include a low mass membrane and the resulting flat frequency response expecially at high frequencies [1]. The planar-magnetic type speaker is similar to the electrostatic one except that it uses a very thin metal ribbon placed between two magnets where magnetic forces between the ribbon and magnets are controlled by electric current through the ribbon.

All of the above described loudspeakers have some fundamental limitations related to their method of electrical to acoustic transduction. One common limitation is the presence of a diaphragm or membrane that has non-zero mass, limited maximum displacement, and suspension stiffness. In contrast, plasma loudspeakers do not have a membrane or moving parts. In plasma speakers, acoustic waves are excited by partially ionized gas that works as a transducer. The ionization is created by a gas discharge, which is generally produced by application of high voltage between electrodes with different curvatures. A good review of plasma loudspeakers as well as principles of operation and applications can be found in [2,3].

Plasma loudspeakers can be divided into two classes: "hot-plasma" and "cold-plasma" [3]. Hot-plasma loudspeakers use heat as an acoustic source and are based on thermal expansion of the gas surrounding the plasma to produce acoustic waves. The plasma induced heat is generated by the interaction of ions with neutral molecules, allowing for rapid heating of the gas. High voltage varying with radio frequency is applied between electrodes and modulated with an acoustic frequency signal. The gas temperature changes with time according to the acoustic signal, leading to changes in gas pressure and thus generating acoustic waves. One of the first loudspeaker based on this operational principle was developed by S. Klein in 1954 [4]. Originally it was called "Ionophone", later it was commercially produced and sold as the "Ionovac" [5]. Ackerman *et. al.* built "hot-plasma" speaker for animal research that could generate sound pressure levels up to 132 dB at 3 kW power [6].

Cold-plasma speakers use Columbic force as an acoustic source and are based on momentum transfer between ions and the fluid medium. Their principle of operation is the same as one of electrostatic fluid accelerators [7]. In the case of cold-plasma speakers, also known as EFA or ionic wind speakers, dc high voltage is applied between electrodes arranged such that resulting corona discharge creates ions moving from the high curvature corona electrode to the low curvature collecting electrode. On their way ions collide with neutral gas molecules creating a net gas flow in some particular direction or so-called "ionic wind". Modulation of high voltage with acoustic frequency creates forces changing with the applied frequency, which act on neutral gas molecules and generate acoustic waves. Although the cold-plasma loudspeaker has been investigated more intensively than the hot-plasma loudspeaker [2] with many different models describing its operation [2,3,8-11] no EFA loudspeaker has been produced commercially to date.

The main advantage of plasma loudspeakers is the absence of membrane and moving parts, which makes them essentially inertia-free. This results in a near-perfect transient response, i.e. the ability to instantaneously respond to an infinitesimally short pulse, and frequency response free of resonance. The former allows creating acoustic generators that can produce very short impulses with wide spectrum [12], and the later allows creating acoustic generators with high fidelity output up to 150 kHz [9] and higher. In addition, plasma speakers can be made very small in size and can work as true acoustic point-source with uniform directivity curve [9,13,14]. However, there are also some difficulties associated with plasma loudspeakers that limit their wide exploitation. The main problems are the following: poor signal output at lower frequencies from devices produced to date, ozone production as a byproduct of corona discharge, longevity of high curvature electrodes, and low electric to kinetic transduction efficiency. The purpose of this paper is to present a model of EFA loudspeakers that overcomes many problems mentioned above while keeping all advantages of plasma loudspeakers.

## II. KRONOS EFA LOUDSPEAKER

Schematic representation of the Kronos acoustic system using EFA loudspeakers is shown in Fig. 1. The stereo system consists of two Kronos EFA loudspeakers powered by a proprietary Kronos switching high voltage power supply (HVPS) connected through an amplifier to an acoustic signal source such as CD player.

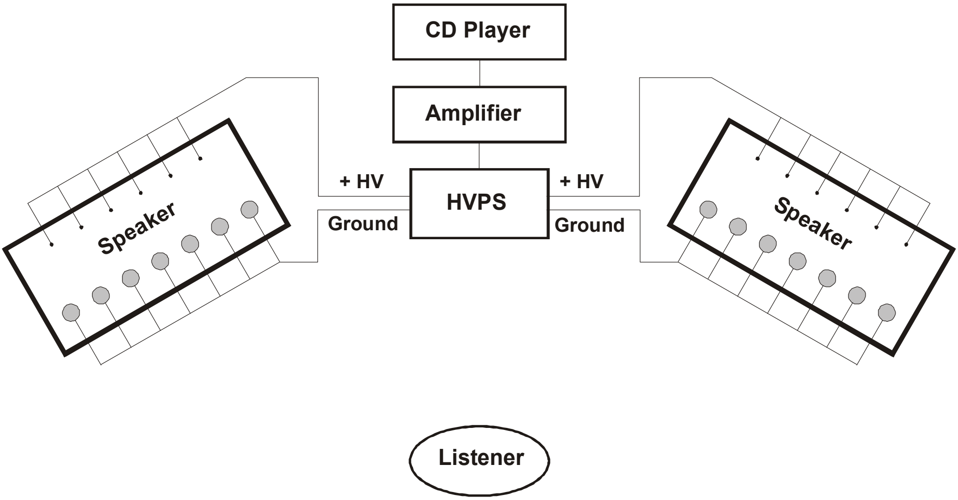



**Fig. 1.** *Schematic representation of Kronos acoustic system that uses two Kronos EFA loudspeakers.*

Kronos EFA loudspeaker is shown in Fig. 2. High curvature corona electrodes consisting of an array of metallic wires are placed parallel to an array of attracting electrodes made of hollow aluminum rods. High electric potential is applied at wires while aluminum rods are kept at ground potential. The whole assembly of wires and rods can be wrapped in a fabric or put in a box.

Dimensions of Kronos EFA loudspeaker shown in Fig. 2 (a) are 14” by 22” by 2”. The geometry and the material choice of the loudspeaker have several advantages. First of all, the loudspeaker is very light, weighting only 1.6 lb, and is comparatively thin. This allows for flexible mounting options such as hanging it on a wall or to a ceiling. Second, the loudspeaker has a high transparency, so it can be installed, for example, in a window where both sun and air may come through the window. Third, Kronos EFA loudspeaker can work simultaneously as an air purifier and/or an electrostatic fluid accelerator, i.e. fan, as their geometry and principle of operation are similar. In addition, the loudspeaker geometry makes it possible to change its directivity by controlling magnitude and phase of high voltage applied to each wire according to concept of wave field synthesis that is based on a Huygens principle on wave propagation.

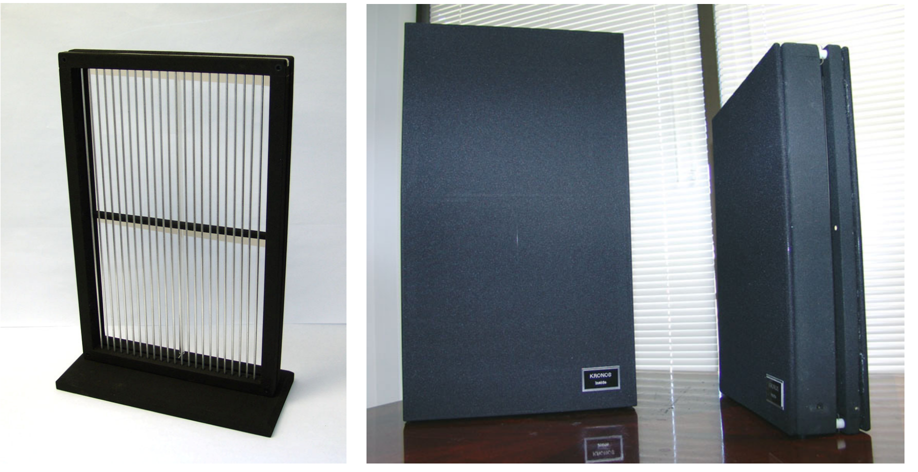


**Fig. 2.** *Kronos EFA loudspeaker: (a) without enclosure and (b) put in a box and wrapped in a fabric.*

One of the main concerns associated with plasma loudspeakers is ozone generation as a byproduct of corona discharge. Although the Kronos EFA loudspeakers produce a small amount of ozone, it is possible to reduce ozone level to natural background level. For example, Kronos EFA loudspeakers shown in Fig. 2 (b) retain majority of ozone produced within their enclosure, where it is allowed to naturally decay back to oxygen.

For the following experimental results a high voltage of 14 kV was applied to the corona electrodes and a time dependent acoustic modulated HV signal was applied to the collecting electrodes with maximum amplitude of approximately 3 kV. During operation of Kronos EFA loudspeaker, the electric potential difference between arrays was bounded by the corona onset voltage and corona breakdown voltage.

## III. Results and Discussions

Kronos EFA loudspeakers produce high fidelity crisp sound. It is currently possible to achieve a sound level of 130 dB measured in the near field without audible distortion or spark evens. The acoustic signal from each speaker has a maximum intensity along its centerline.

Frequency response of Kronos EFA loudspeaker is shown in Fig. 3. Acoustic signal was measured at a distance of 1 ft from the speaker. One can see that frequency response is almost flat over a full range up to 24 kHz.

Frequency response of a waterfall test is shown in Fig. 4. Again, one can see an almost abrupt decay of the signal, when compared with results from the same test conducted with a generic moving coil-type speaker.

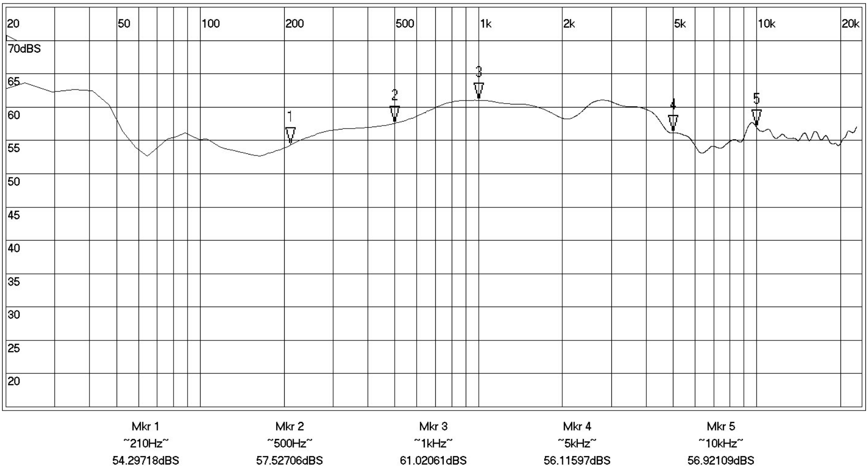
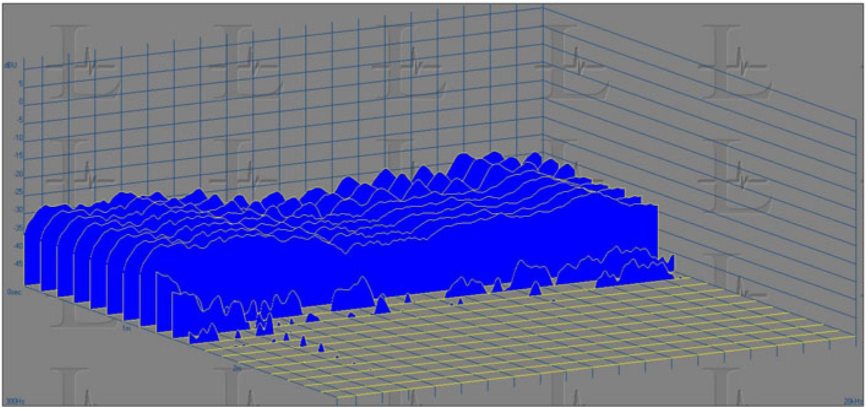



**Fig. 3.** *Frequency response of Kronos EFA loudspeaker.*

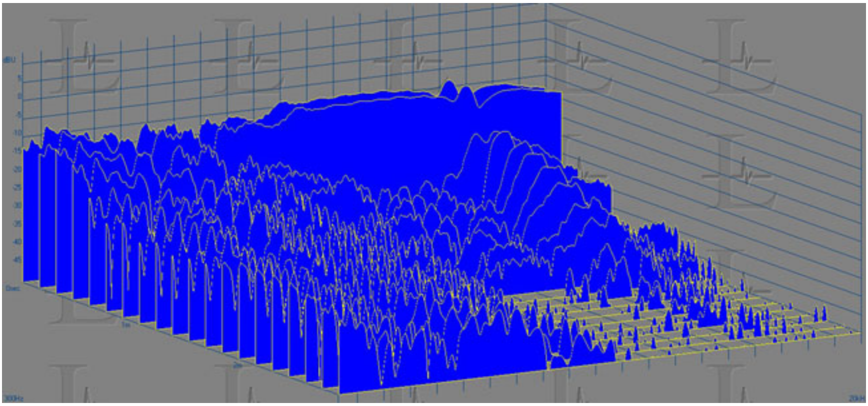
In addition, Kronos EFA loudspeaker was investigated for the potential application of active noise cancellation device. Experimental setup for active noise cancellation tests is shown in Fig. 5. A box with walls covered by sound absorption foam imitates a closed volume where noise is to be eliminated. The dimensions of the box used were 3 ft by 2 ft by 2 ft. One wall of the box was replaced by EFA speaker 2, which was used to cancel sound generated by EFA speaker 1 placed outside of the box. Both speakers were oriented such that generated airflow was directed toward into the box. The distance between speakers was approximately 24 inches.

Both speakers were driven by a HVPS connected through a Yamaha amplifier to an acoustic signal generator. Amplitude of the acoustic signal for both speakers was independently controlled by the Yamaha amplifier. Time delay of the signal for the second speaker was controlled by an AD 22d Audio Delay device. Sound level at different locations inside the box was measured using a RS 232 Sound Level meter. The background noise level was approximately 40 dB.

Cancellation of a simple sinusoidal wave was investigated for three individual frequencies, 1, 2, and 3 kHz. The signal of the second speaker had an opposite phase with respect to the first speaker. It was found that at all three frequencies proper time delay and amplitude adjustment of the acoustic signal of the second speaker decreased sound level by 20 dB, 27 dB, and 24 dB, at any point inside the acoustically insulated box. By adjusting the time delay while maintaining the same amplitude of both speakers, it was possible to provide sound level reduction by 14 dB at any point inside the box for all three frequencies.



(a)



(b)

**Fig. 4.** *Waterfall test: (a) Kronos EFA loudspeaker and (b) generic moving coil-type speaker.*

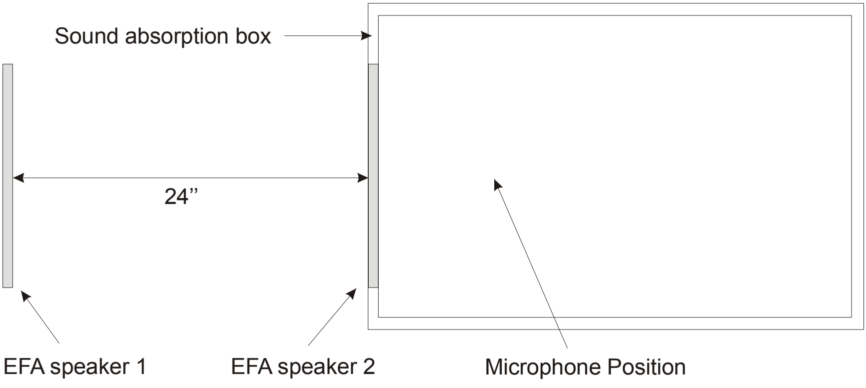



**Fig. 5.** *Experimental setup for active noise cancellation tests.*

## IV. Conclusion

Kronos has successfully demonstrated a proof of concept full range EFA loudspeaker with near flat frequency response up to 24 kHz, and a maximum acoustic output of 130 dB. Future work will further characterize the Kronos EFA loudspeaker including directivity curve and signal destruction analysis. Further work will also investigate the developments in active noise cancellation and dynamic magnitude and phase to ray directivity control.

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