

Ferro-electret nanogenerators as flexible microphones

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Abstract—Research on flexible transducers capable of sensing acoustic signals has become increasingly important due to its implications in human interfaces with wearable electronics. The proof-of-concept for a flexible microphone/loudspeaker based on the use of a ferro-electret nanogenerator (FENG) was recently presented. Following that, this work characterizes FENG-based microphones, showing the sensitivity of a 5 cm x 5 cm, single layer FENG to be $\sim .015$ mV/Pa. The variance of sensitivity based on surface area is also studied and presented. Polar patterns or directivity is emphasized in this work by studying how various shapes (i.e. flat, concave and convex) affect the output. The spectral information of the output of FENG-based microphone to typical voice input is compared with a commercially available microphone.

I. INTRODUCTION

Microphones are transducers that convert sound pressures (acoustic input) to electrical signals. These usually find wide range of applications by enabling voice and audio human interface with multimedia. The traditional and most common types are Electret Condenser Microphones (ECM) [1]. These consist of an electrostatic capacitor and eliminate the need for a polarizing power supply by using a permanently charged material. The next line of microphone design is the piezo-type, which are also known as contact microphones. These are typically impervious to air vibrations but transduce only structure-borne sound [2]–[5]. Recent times have seen a growing interest in wearable electronics [6]–[10], which has led to a greater research focus on flexible electronics. Along with flexible screens and flexible PCBs comes a larger demand for research and development of flexible acoustic sensors. One of the recent approaches in flexible acoustic sensors involve the use of triboelectric nanogenerators (TENGs), which was deployed on a robot for voice activation and also used as an energy harvester [11]. Another approach consists of the use of a Ferro-electret Nanogenerator (FENG), which had a bi-directionality capability that allowed for its use as a microphone or speaker [12]. One of the demonstrated applications that shows the potential use of FENG-

based microphones included the instance where the device was used to recognize the owner and unlock a personal computer. The objective of this manuscript is to demonstrate the different parameters of interest in FENG-based microphone devices and to form a base for future microphone designs. The specifications and their dependancies discussed are intended to help designer with fabrication of microphones based on FENG. It is also demonstrated that the testing environment plays a role in device performance as a microphone.

II. EXPERIMENTAL SETUP

All the experiments were performed inside an acoustic anechoic chamber as shown in Figure 1. This chamber was characterized following procedures shown in prior art [13]. The setup consists of a standard baffle (International Electrotechnical Commission (IEC)) on which the FENG-based microphone is mounted. Although most of the microphone characterization in industry/commercial environments do not involve using a baffle [14], [15], the baffle is required to maintain constant sound pressure over the entire area of the FENG since the microphone size can be comparable to or larger than a wavelength. The FENG is attached to the copper back-plate using double-sided tape completely covering the FENGs surface. The back-plate is fixed to the baffle using tape on all sides. The other components placed inside an anechoic chamber include the surface microphone from PCB Piezotronics (130B40), which has a sensitivity of 8.5mV/Pa, which is placed close to the DUT so as to record sound pressures. A wireless speaker is placed at a distance of 30 cm from the DUT with the center aligned with the DUT's geometric center. Sounds ranging from 20 Hz to 20 kHz are played through the speaker via a bluetooth transmitter. The output from the FENG is amplified using a voltage pre-amplifier (SR560) and then recorded along with the output from the surface microphone using data acquisition (NI-DAQ 6003). LabVIEW is used to perform FFT on the recorded signals to obtain spectral information which allows for power levels from

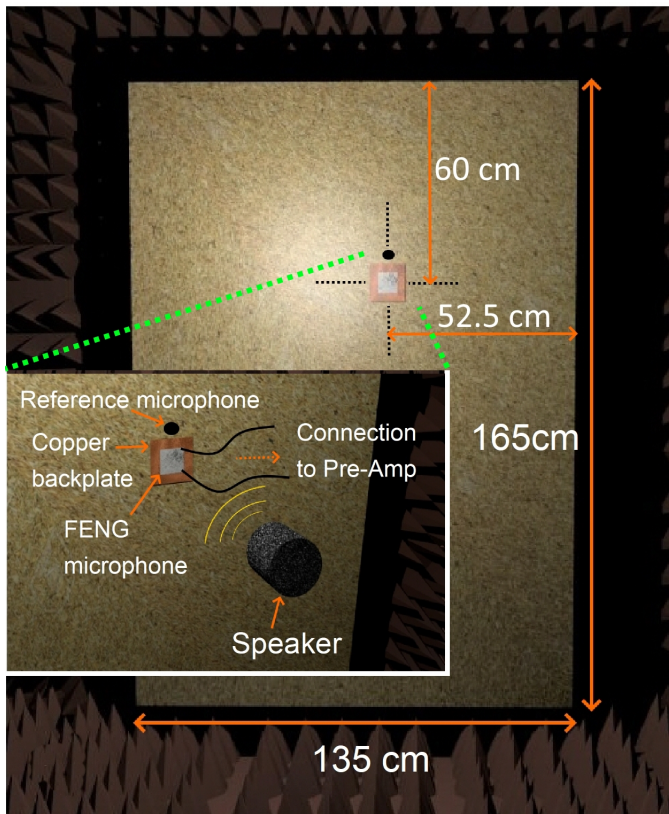


Fig. 1. Baffle with FENG mounted and dimensions; the insert shows a more detailed view of the components.

frequency bins of interest to be read. This information translates to the sensitivity of the microphone in the all the experiments described below.

III. RESULTS AND DISCUSSION

Sensitivity of a microphone is usually defined as the ratio of output voltage to Sound Pressure (Pa) at the microphone position without the microphone present. This is under the assumption that the microphone is small when compared to a wavelength. The variation of sensitivity with area of the FENG is certainly an important aspect for design since many applications include a concealed microphone. This is studied by testing 3 FENG samples: 1 cm x 1 cm; 2 cm x 2 cm; 3 cm x 3 cm as shown in Figure 2. The speaker was placed at a distance of 30 cm from the FENG for this experiment. The results are as shown in Figure 3. It is observed that the frequency response for all the FENGs remain almost flat throughout the frequency range (20 Hz to 20 kHz). It is also observed that the sensitivity increases linearly with increase in area of the FENG; i.e. the measured average sensitivities are approximately -94, -82, -75 dBV/Pa for devices with surface areas of 1, 4, and 9 cm², respectively. This result agrees with observations made while characterizing the FENG for energy harvesting applications [16].

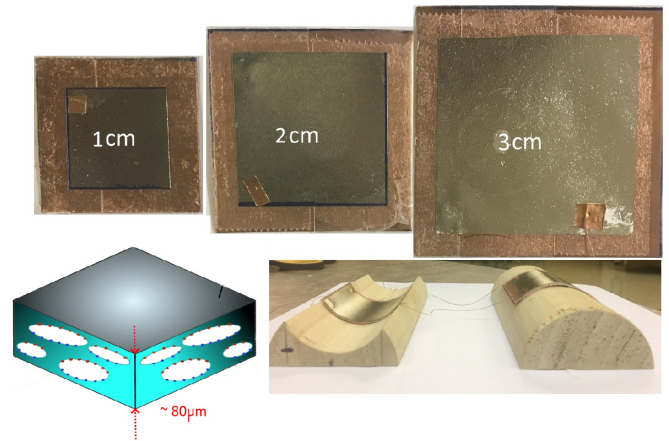


Fig. 2. Samples used to study area dependency on the sensitivity and directivity; The inset shows a cross-section diagram of FENG, which consists of dipoles of different sizes.

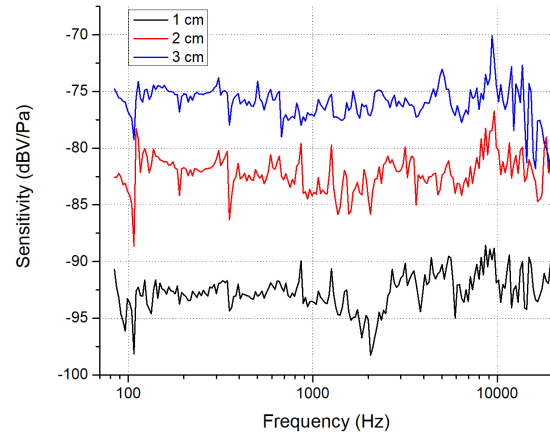


Fig. 3. Frequency response of 3 samples.

The polar pattern or directivity of a microphone is another important performance parameter for a microphone, which describes the sensitivity to sound pressure relative to the direction or angle from which it arrives. There exists several commercially available microphones that are categorized based on its polar patterns; e.g. cardioid, super/hyper cardioid, omnidirectional [17]. The polar patterns for FENG-based microphones are studied next for 3 different shapes: flat (square), concave, convex as shown in Figure 2. In order to make a fair comparison of the different shapes, the surface area of all the 3 FENG-based microphones remained the same (4 cm x 4 cm). The speaker is again placed at a distance of 30 cm from the FENG and frequency is swept for angles from 0° to 180°. As a reference, 90° would correspond to the angle where the speaker is facing the FENG-microphone's top surface.

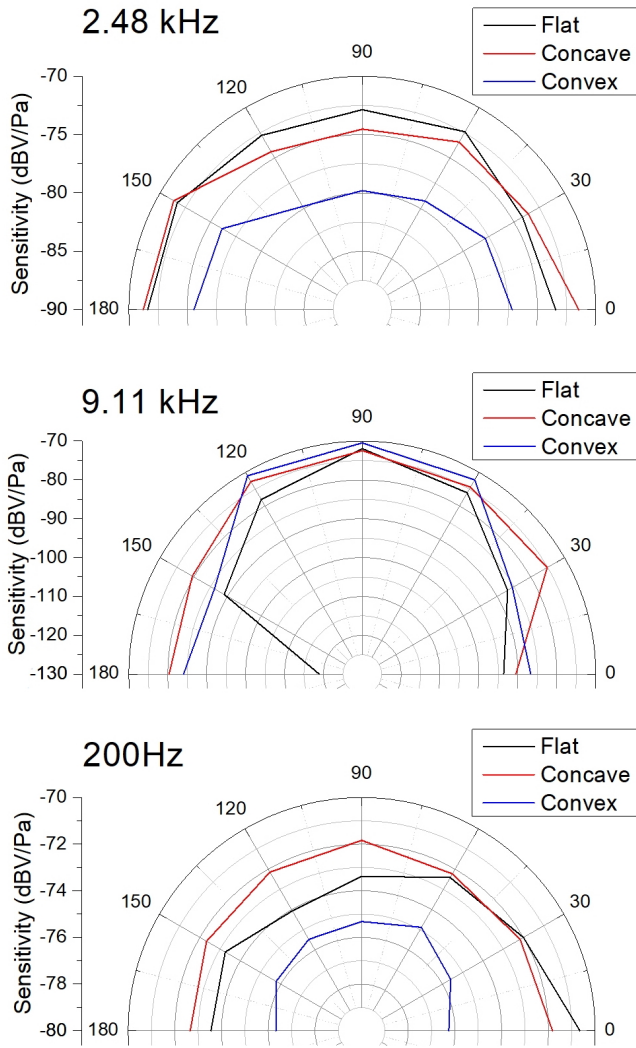


Fig. 4. Measured directivity for different shapes.

The results for selected frequencies are shown in Figure 4. The microphone tends to be nearly omnidirectional (or isotropic) at lower frequencies. Directionality increases with frequency, but this will also be dependent on the characteristic length of the FENG —when the FENG becomes comparable to a wavelength then it begins to become directional.

In order to compare FENG-based microphones with commercially available microphones, simultaneous recordings of voice through both FENG microphone and reference microphone were carried out. The spectral comparison of both recordings are shown in Figure 5. Voice and impulsive noise are clearly represented in front of background noise on a reference microphone, but the same were highly masked by background noise; i.e. the FENG microphone has lower signal to noise due to its low sensitivity. Moreover, the 60 Hz noise and harmonics are also clearly visible in FENG-based

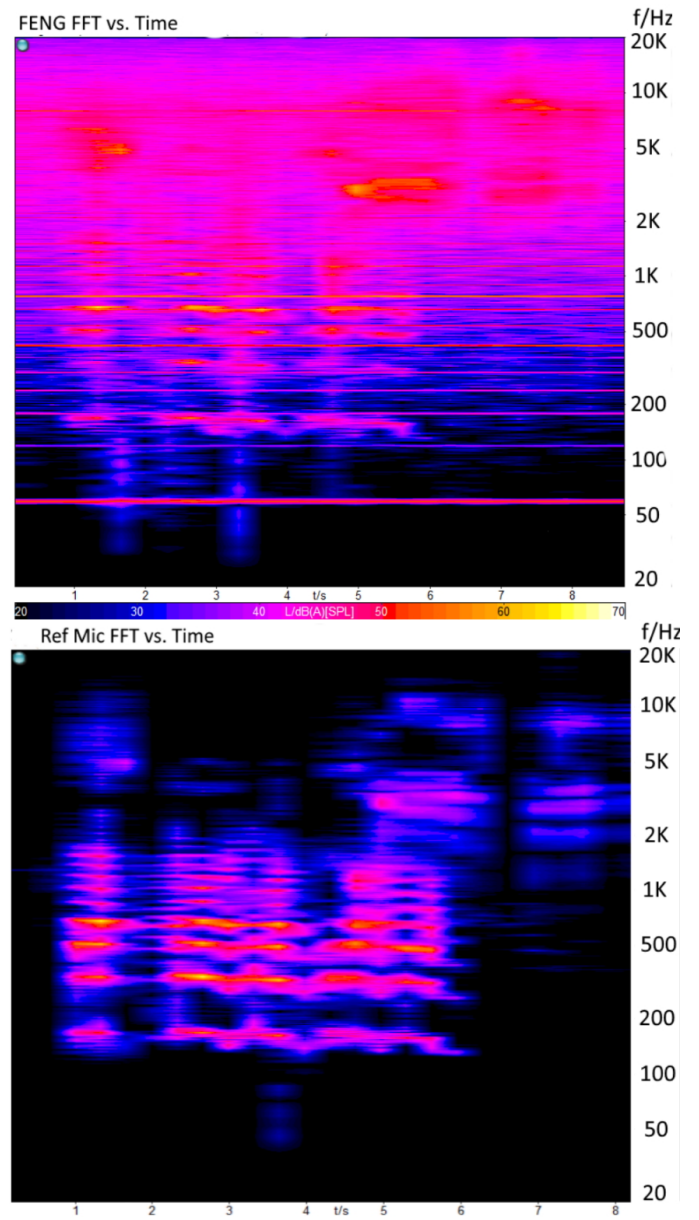


Fig. 5. Spectral comparison between FENG microphone and a traditional microphone

microphone.

IV. CONCLUSION

This work shows the performance of ferro-electret nano generators when used as microphones. Although they have lower sensitivity than commercially available microphones, yet comparable with SATURN [18] (~ -90 dBV/Pa). Also, the frequency response and directivity characteristics stand out. Furthermore, due to their flexibility, FENG-based microphones can be configured into different shapes, enabling a reconfigurable tuning. Also, different fabrication techniques can be explored to increase the dipole density in the FENG which will help

increase the sensitivity. Thus, FENG-based microphones show potential to be used in smart fabrics and wearable technologies.

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