Ultrasonic Transducer for Matching the Performance of Natural Sonar Systems

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Introduction

Inspired by the bat's wellknown proficiency in ultrasonic sensing, the CIRCE (Chiroptera - inspired Robotic Cephaloid) project [1] is building a robotic reproduction of a complete biosonar system found in these animals. The hereby extracted knowledge should then be applied in robotics or the field of automated object recognition. A specially developed mechanical motion system incorporating multiple free axis allows realistic movement of the ears and the mouth of the bionic head (Fig. 1). Due to the difficult realization of an appropriate ultrasonic transducer which has to cover the whole frequency range from 20 to 200 kHz, earlier projects with similar objectives often failed, because the echo sounding systems could be realized only with much smaller bandwidths. The assembly as well as initial measurements using such a wide bandwidth ultrasonic transducer will be described in more detail in this paper.

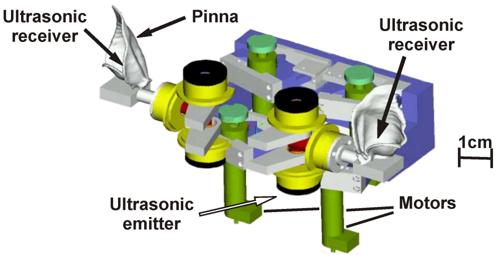

Figure 1: Design of artifical bat head

Transducer Specifications

In order to investigate the sounds as produced by a wide variety of bat species, the following transducer specifications have to be fulfilled (Table 1).

Table 1: Emitter and receiver specifications

	Emitter	Receiver
Bandwidth	$20-200\ kHz$	$20-200\ kHz$
max. Transducer size	$2\ cm^2$	$1\ cm^2$
Sound Pressure Level (at $1\ m$)	$80-100\ dB$	
Equivalent acoustic noise level		$< 50\ dB$

Apart from the acoustical properties, the mechanical requirements are also of importance. The ultrasound receivers which have to be moved with the ears, should not be heavy or large. A transducer material which meets these requirements is the “Ferroelectret” [2].

As a result of its manufacturing process, this polymer has the cellular structure shown in Fig. 2a. Through subsequent heating and application of a voltage of $U > 10\ kV$ the polymer is polarized. This results in the formation of macroscopic dipoles (Fig. 2b) which are retained after the polymer is cooled down to room temperature. The cellular structure and the macroscopic dipoles result in a high piezoelectric constant of $d_{33} = 250\ pC/N$. The piezoelectric constant can be further increased up to $d_{33} = 600\ pC/N$ by means of improved polarization techniques [3]. Since the measurements on the artificial chiroptera cephaloid should be conducted under normal environmental conditions, the disadvantage of the material's temperature sensitivity [4] has no influence because the permissible temperature range between -40 and + 50 °C is not violated.With a resonance frequency of about 500 kHz, the polymer can be used as emitter material as well as receiver material.

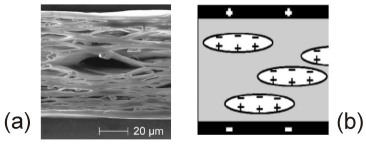

Figure 2: (a) Scanning electron micrograph of the cross section of a charged piezoelectric polymer foam. (b) Schematic representation of the nonsymmetric charge distribution in the foam.

Broadband Ultrasonic Emitter

By utilizing the ferroelectric foil presented, above different emitters were assembled and their performance measured. The foil was fixed on one side on top of a printed circued board (PCB) with adhesive paste so that the ferroelectric material can oscillate in thickness mode. To contact the top electrode of the polymer very flexible bond wires were used (Fig. 3).

In order to avoid the build-up of a standing wave field between microphone and transducer, the foil was exited by a sine burst voltage signal lasting 5 periods with a maximum amplitude of $U = 600\ V_{pp}$. The sound pressure level (SPL) was measured with a Brüel & Kjaer

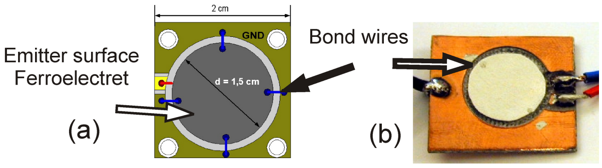

Figure 3: (a) Schematic representation of the ultrasonic emitter. (b) Picture of the ultrasonic emitter.

1/8 inch condenser microphone. Its protection grid was taken off to improve the sensitivity at high frequencies. Points of measurement were placed on the principal axis at a max distance of 1 m (Fig. 4). It can be seen, that the single foil ultrasonic transducer with a diameter of $d_t = 1.5\ cm$ does not fulfill the required specifications of a SPL value of $> 90\ dB$ at 1m distance for low frequencies $f < 65\ kHz$. One option to also meet specifications at low frequencies is building up a stack actuator. Here, two or three ferroelectric foils with opposite directions of polarization are sticked together and are jointly excited. The resonant frequency is shifted down to about 75 kHz for two layer and down to 45 kHz for a three layer stack (Fig. 4). Due to the shift of the resonance frequency to lower frequencies a gain of about 10 dB (two layer stack compared to a single foil) is obtained within the frequency range 20 to 80 kHz. Beyond the resonance peak the influence of the two layer stack design decreases, so that the two curves approach each other.

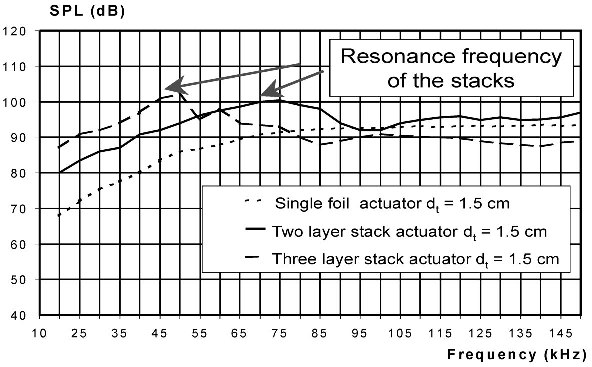

Figure 4: Sound pressure level of different emitter designs.

Broadband Ultrasonic Receiver

A simple pinna shape in conjunction with a broadband receiver based on the "Ferroelectret" foil is used for the artificial bat head (Fig. 5a). In order to minimize the size of the receiver, the low noise preamplifier circuit is implemented with SMD technology on the bottom PCB of the sandwich structure (Fig. 5b) The "Ferroelectret" film was fixed on the top PCB with adhesive paste. Thereby, the transmission line between transducer material and preamplifier can be kept short and the noise can be minimized. Another problem is electromagnetic disturbance, which can be mostly suppressed by connecting the top electrode of the sensor to ground and by an appropriate housing of the electronics. The receiver preamplifier combines a broad bandwidth (20 kHz - 200 kHz) with a very low noise.

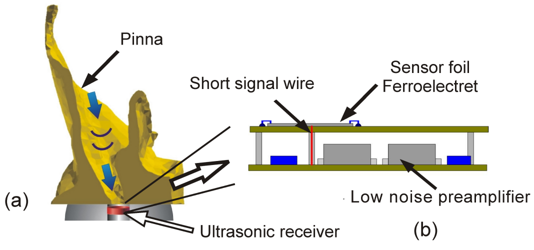

Figure 5: (a) Cut trough bat ear with ultrasonic receiver. (b) Schematic of the sandwich structure of the ultrasonic receiver (front view).

For the acoustic measurements, the two layer stack actuator with an diameter of 1.5 cm was used as emitter. As receiver a single foil and a double foil transducer with a diameter of 1 cm was used. The SPL, which arises at the location of the receiver, was calibrated by a measurement with a 1/8 inch Brüel & Kjaer condenser microphone mounted right next to the receiver. Fig. 6 shows the measured sensitivity of the receivers. As can be seen the sensitivity is very flat between 20 kHz and 150 kHz. With an equivalent acoustic noise level of $SPL_{noise} = 45\ dB$ and a sensitivity of about 25 mV/Pa, the receiver meets the required specification very good.

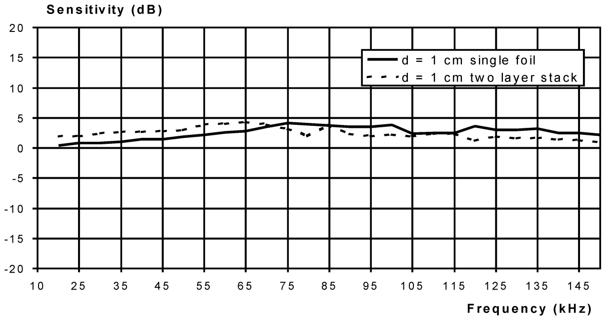

Figure 6: Sensitivity of the receiver $0dB = 25\ mV/Pa$

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Conclusion

We presented the major acoustical components of the bat head, i.e. the emitter and the receiver. Both were realized with a new material, the "Ferroelectret", which allows to meet all proposed specifications. A stack actuator with two ferroelectric foils was used as an emitter, allowing to generate a SPL of more than 90 dB for frequencies of 50 - 150 kHz in a distance of 1m. With the ferroelectret an broadband ultrasonic receiver with a sensitivity of 25 mV and an low equivalent acoustic noise level of 45 dB was build up.

References

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