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Microbial Fuel Cells Based Sonic Transducer for Bio Robotics

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Introduction

Environmental sensing is an important evolved functional aspect of multicellular organisms in nature. Detection of sound (both abiotic and biotic) in particular helps increase the survival rate (e.g. reflex or behaviour to move away from danger or communicate with family or similar friendly species) and/or aid in finding food. In multicellular organisms in nature, the sound obtained by anatomical structures, is processed by neurological pathways, and finally perceived by cognitive processing. The living cells use electrical signalling to achieve this. Functionally, this process is the same in conventional electro-mechanical devices and in robotics; in which an electromechanical transducer converts the acoustic waves into an electrical signal.

Traditionally used as power sources for energy autonomous robots (Ecobots), Microbial fuel cells (MFC) enable the utilisation of microbial metabolism, consuming organic matter, as an engine of power generation providing building blocks for building artificial bio robotics.

In this work, we demonstrate specifically designed MFCs that operate in steady state under continuous feed conditions that can function as a far field sonic transducer (MFCST) which behaves like a microphone, with the ability to sense sound from the environment. We demonstrate identification of sound source direction using two MFCST, which enable sonotaxis (Krivonosov et al., 2016), similar to that of animals in nature. With these MFC sound sensors, we aim to enable increased functionality and bio-inspired behaviour for future bio-robotics.

Figure 1. MFCST Sensor in operation. Front view (left), left side from top (right). MFCST is continuously fed using the feed lines at the back, red and back wires connect to the anode and cathode, the output of the sensor.
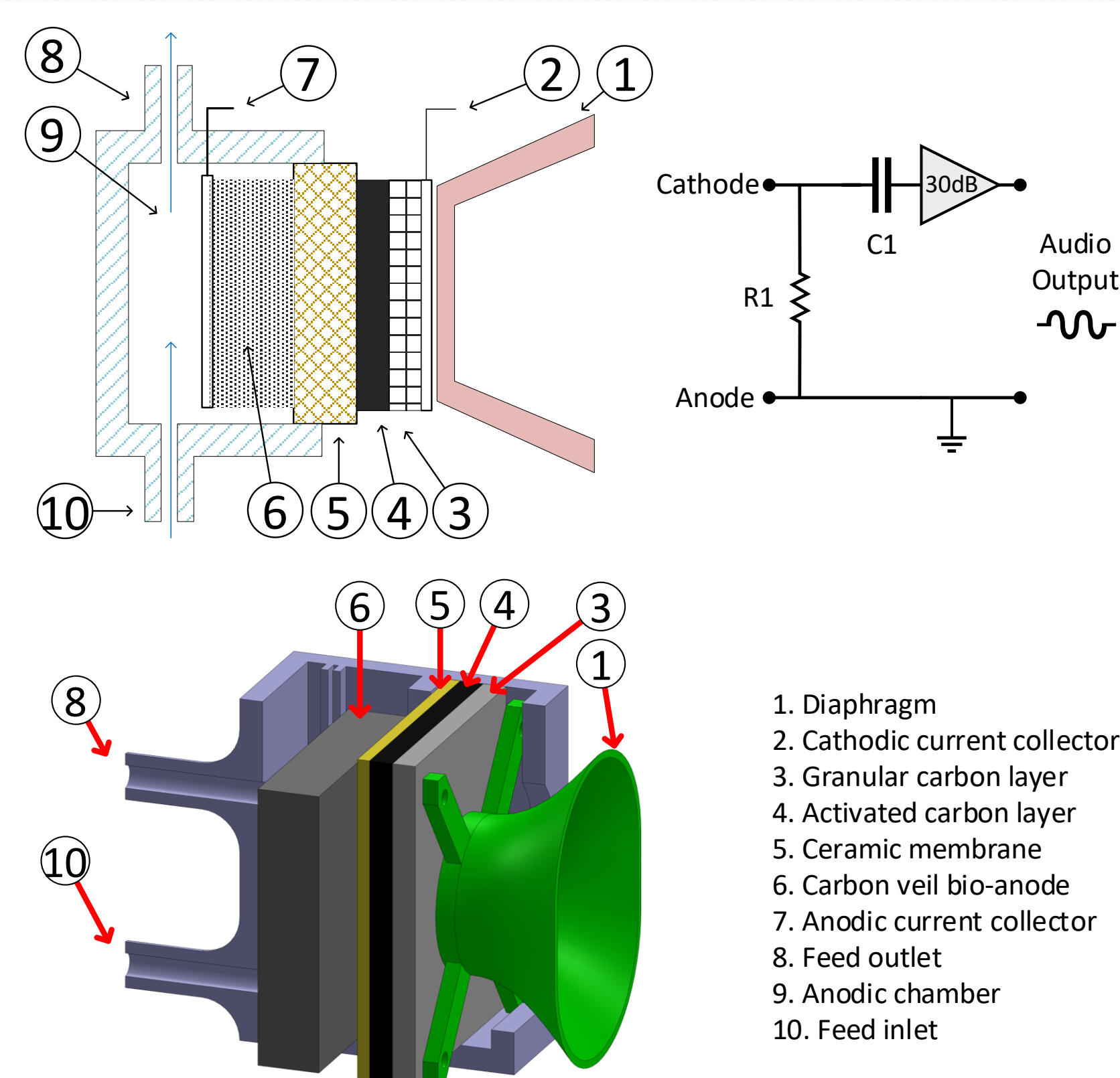
Materials and Methods

MFCST Operation

- MFCST output (from anode and cathode) was fed to a pre-amplifier, which amplified the signal by a gain of +30dB. The Capacitor between block DC voltages generated by the MFCST and let the audio frequency signal pass through to the amplifier.

- A resistor bridge across electrodes (1kOhm) which is mandatory for operation droped the open-circuit-voltage from 630mV to 450mV.

- The MFCST was continuously fed with artificial media (TYE) at a flow rate of 250 μL/min.

1. Diaphragm
2. Cathodic current collector
3. Granular carbon layer
4. Activated carbon layer
5. Ceramic membrane
6. Carbon veil bio-anode
7. Anodic current collector
8. Feed outlet
9. Anodic chamber
10. Feed inlet

Figure 2. MFCST sensor module. (left) MFCST Component Layout, (right) Audio output connection, (bottom) 3D CAD illustration.

- Sensor construction follows the principle of a carbon granule microphone (Jones, 1931). The vibrations caused by acoustic waves received at the horn, compress and decompress the carbon granules in the cathode electrode material, change the impedance of the electrode which in turn changes the power output of the MFCST.

Results and Discussion
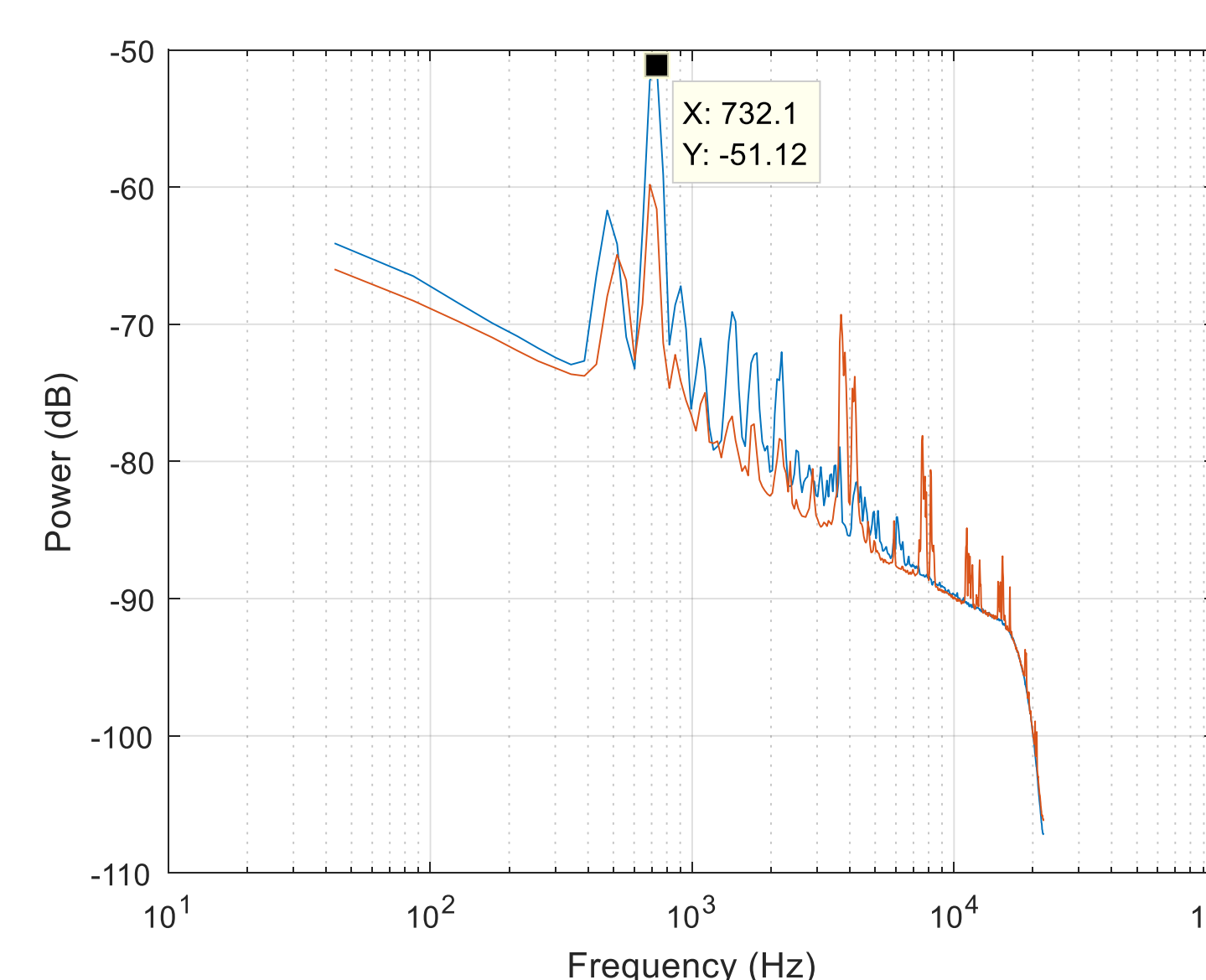
MFCST Frequency Response and Sensitivity

Figure 3. MFCST frequency response. Showing a spectrogram for frequency sweep from 100Hz to 22kHz.
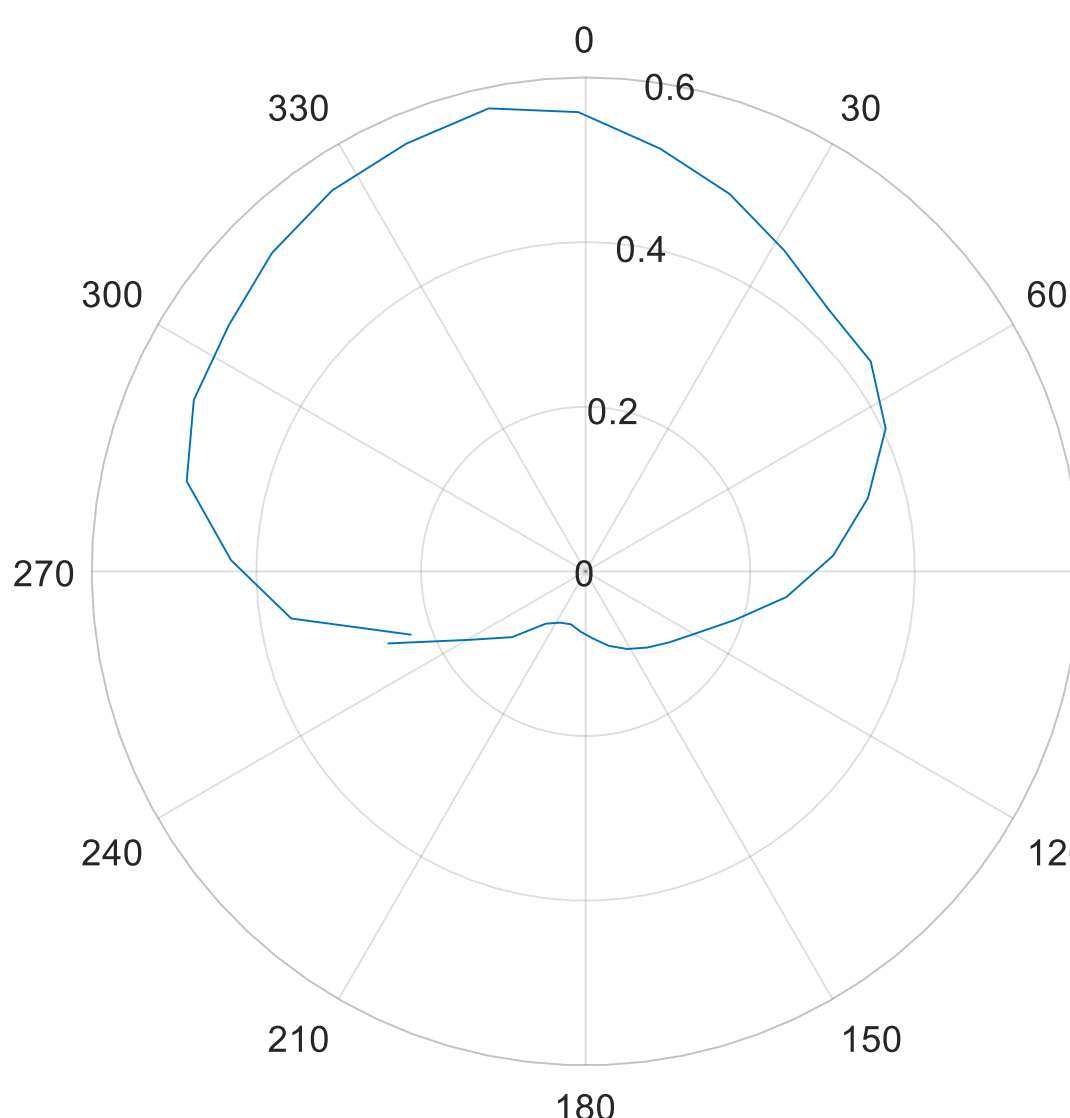

Figure 4. MFCST off-axis response. Showing the off axis gain response at 700 Hz.

- The frequency response spectrogram shows the MFCST is most sensitive at the 100Hz to 3000Hz region. The MFCST diaphragm (horn) sensitivity was at its maxim at ~732Hz.
- A high noise level of -65~-90dB from 100Hz to 10kHz, was observed without a filter
- The off-axis gain plot shows the depicted sensor has maximum gain sensitivity at the front of the sensor and the sensitivity minimum sensitivity at the back.
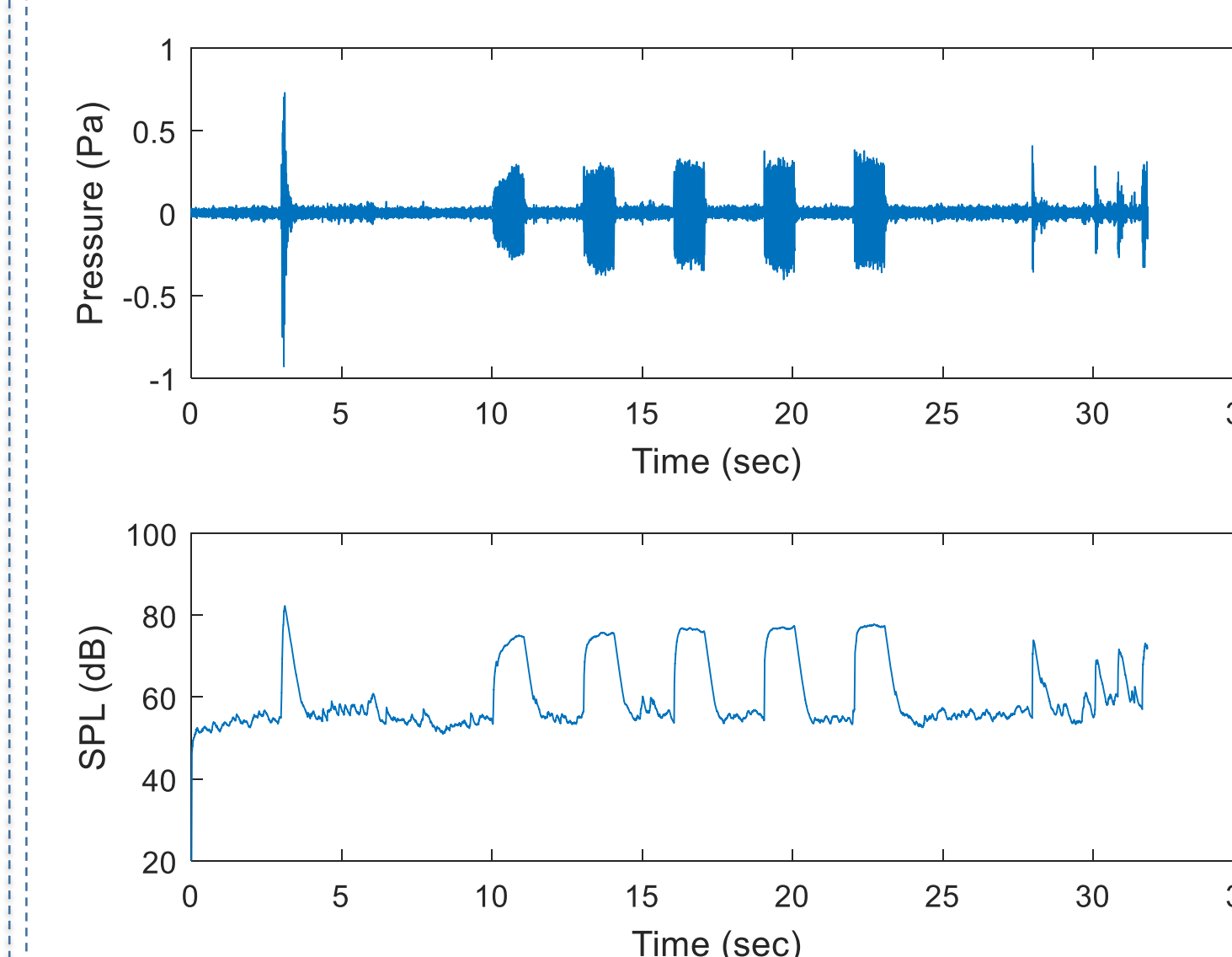
Signal Detection

Figure 5. Detection of 4 pulses at 700 Hz. Time Vs sensor output amplitude (top), and Time Vs. detected pulses (bottom)

- Pulse detection used a band-pass filter at 650-800 Hz.

- A detection of sound bound a fixed threshold was detected as an input pulse (see figure 5)

Source Direction Detection Using Two MFCST

- Sound direction can be determined using non-uniform off-axis gain properties of the MFCST.

- In a simple test rig, 2 MFCTS placed horizontally, with a gap of 10cm, facing 60° apart was given 700Hz pulse inputs from a distance of 50 cm, left and right of the test rig.
- Pulses were given in the order {right, left, right, left} (figure 6.)
- The comparison of normalised amplitudes, for each input enables one to determine the direction of the sound source as seen in figure 6 (bottom)
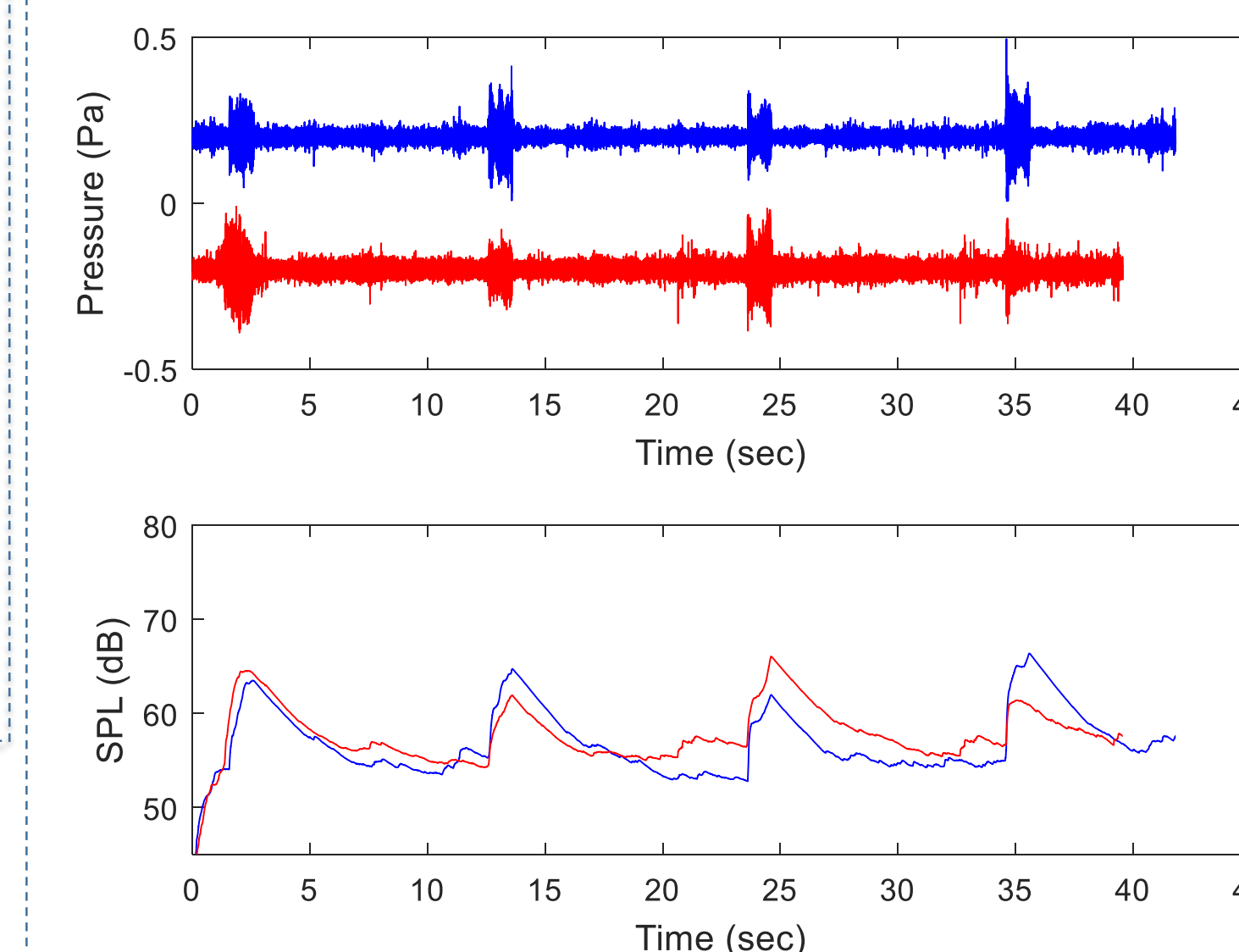

Figure 6. Sound source direction detection using two MFCST 10cm, 60° apart . Blue – MFCST on left, Red – MFCST on the right. Sensor output vs. time (top), and detected signal (bottom). Input are alternating pulses of 700 Hz, from the directions {right, left, right, left} corresponding to amplitude of detected signal amplitude (bottom)

Conclusions

The results show that it is indeed feasible to use MFCs for sensing sound. The simple MFCST tested in this work is sensitive within the region of 400 to 3000Hz. The sensor operated energy autonomously using the energy produced within the MFCSTs MFC core. It is also demonstrated that using two sensors it is feasible to implement a robotic sonotaxis mechanism.

We aim to use sensors such as the MFCST within a bio-robot, in which all the critical robotic functions such as power generation, sensing, processing and actuation are performed by artificial bio-robotic elements.

References:
[1] Krivonosov, M., Denisov, S., and Zaburdaev, V. (2016). Lévy robotics. *arXiv Prepr. arXiv1612.03997*.
[2] Jones, W. C. (1931). Condenser and carbon microphones—their construction and use. *J. Soc. Motion Pict. Eng.* 16, 3–22.