# Dual-Band 3D Multiferroic Antenna Stack for Passive Telemetry Sensors

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***Abstract*—Multiferroic antennas can operate at lower frequencies with smaller dimensions as they scale with the acoustic resonance wavelength of the transducer. This has specific advantages such as antenna miniaturization and operation at lower frequencies. In this paper, we investigate multiferroic antennas for dual-band operation to enable passive backscattering telemetry-based antennas and sensors. Fabrication and testing results demonstrate the dual-band operation. A 3D antenna stack concept is described to combine the antenna pair into as integrated multiband antenna.**

## I. Introduction

Low frequency (LF) radio antennas have several benefits. As compared to higher frequency signals, low frequency signals propagate across longer distances and through obstacles. Further, low frequency transmitters require less power, making them energy efficient. However, a major challenge in designing low frequency antennas is the size reduction and the antenna efficiency at LF radiation. To overcome the efficiency issue, use of magnetoelectric (ME) and multiferroic antennas are introduced in this paper [1, 2]. A key functioning element of piezo-magnetoelectric devices is the harmonic variation of magnetic fields, through an applied voltage to the piezo material layer, leading to radiation.

Multiferroic antennas are well suited for underground mines and underwater communications. Additionally, these are useful in a variety of applications, including neural activity monitoring, implantable biomedical devices, and energy harvesting systems. One such application is passive recording via telemetry sensors. In this approach, a dual-band antenna in conjunction with an antiparallel diode pair (APDP) is employed. The latter acts as a sub-harmonic mixer and frequency-doubler to receive the incoming signal at frequency f, and transmit at frequency 2f as described in [3]. Such sensors have the unique advantages of 1) complete passive mode operation for neural signal recording at zero power, b) minimal bill of materials or components as the sensor only comprises the anti-parallel diodes without other passive matching components, c) multiferroics can pick up electrical signals from vibrations or magnetic fields variations. A key building block of such sensors is the realization of the dual-band antenna. This paper demonstrates that such multiband antennas using 3D stacking of multiferroics and their operation at multiple frequencies.

## II. Fabrication

Magnetoelectric (ME) antenna operation relies on the coupling between magnetic and electric fields within magnetoelectric material. The associate bimorph laminate structure consists of piezoelectric and magnetoelectric to create the active element. In the transmitting mode of the ME antenna, an alternating voltage is applied on the piezoelectric layer, producing an oscillating strain in the magnetostrictive layer. In turn, this generates alternating magnetic and (by virtue of Maxwell's equations) electric fields. In the receiver mode, the reciprocal operation takes place. Specifically, an incident time varying magnetic field is captured by the magnetostrictive layer that in turn induces oscillating voltage signals at the terminals of the piezoelectric layer via mechanical coupling.

The multiferroic antennas describe above, can be integrated within a package to utilize the dual-band function as illustrated in Fig. 1. The shown antenna stack is assembled with the vertical interconnects of silver adhesives. Notably, the bottom layer of Fig. 1 shows the PVDF that acts as the package substrate to support wiring for diode assembly and sensor signal inputs. The top antenna ground is interconnected to the bottom antenna ground with a flex interconnect.

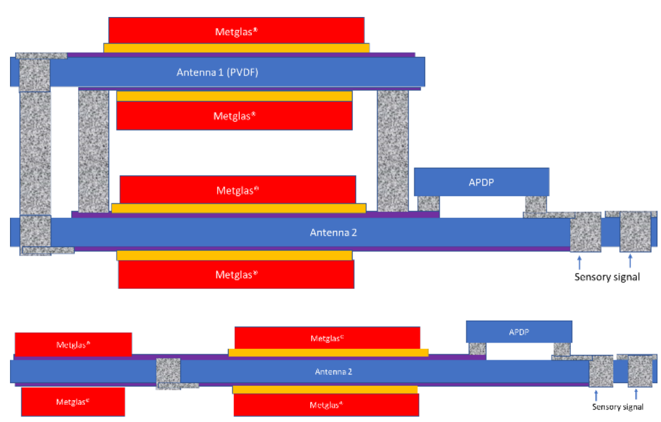


Fig. 1: 3D package integration, showing the multiferroic antennas and sub-harmonic mixers.

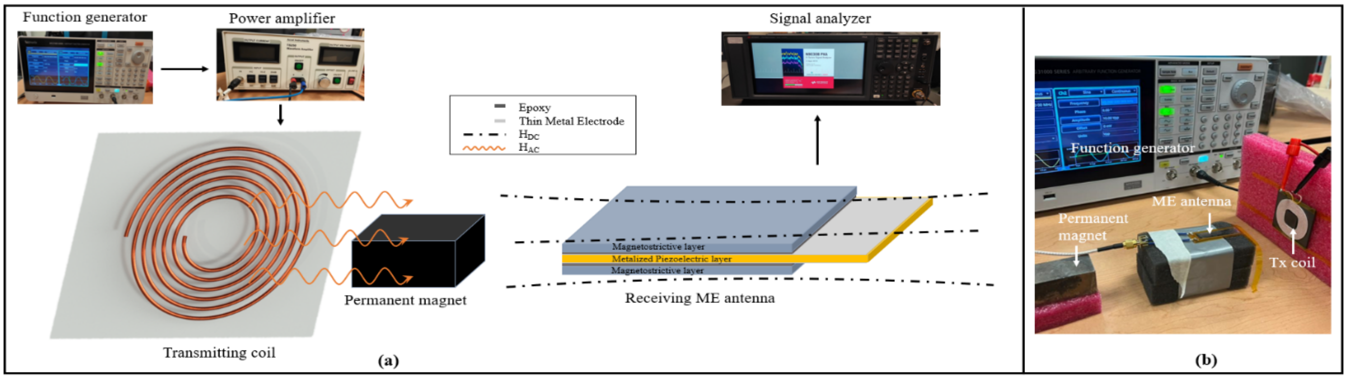


Fig. 2. a) Illustration of the low frequency communication link with the piezo-magnetoelectric (ME) receiving antenna. b) Fabricated ME sample as a receiving node.

## III. CHARACTERIZATION

In this study, two different types of ME heterostructures were used to demonstrated low frequency links. Namely, PZT/ Metglas® and PVDF/ Metglas® layers were used for realizing the antennas. Specifically, a 23-µm thick Metglas® 2605SA1 was used as a magnetostrictive layer in all structures. The PZT piezoelectric layers was formed by a macro fiber composite of piezofibers, encapsulated in polyimide. The dimensions of PZT-1 are 40 mm × 10 mm × 300 µm, PZT-2 are 25 mm × 3 mm × 300 µm and PVDF are 40 mm × 10 mm × 200 µm. Notably, the Metglas® sheets were cut and bonded using epoxy on both sides. The test set-up and fabricated samples are shown in Fig. 2. Also, Fig. 3 shows the resonant frequency bands of the interconnected antennas. Notably, the resonances are per design and do not contain additional dampening in the output power, providing confidence for multiband operation. In the future, the multiband operation will be achieved with a single magnetoelectric antenna as in [3].

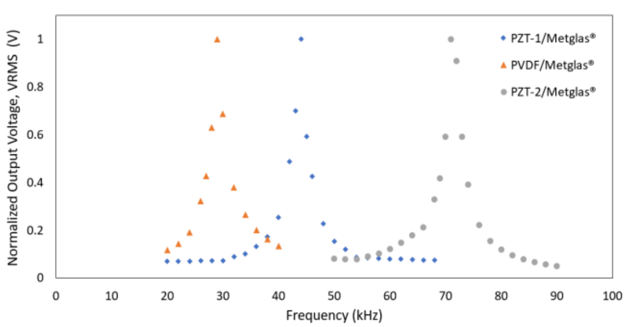


Fig. 3. Normalized open circuit voltage of differerent ME heterostructures at different frequencies.

At our ME's resonating frequency of 44 kHz (PZT-1/ Metglas®), the transmitting coil was found to have an impedance of nearly $Z_{Tx} = 3.15e^{j\pi/2}\ \Omega$. Also, the input power ($P_{in}$) was calculated from the following formula: $P_{in} = \frac{{V_{RMS}}^2}{|Z_{Tx}|}\cos\theta$. That is, an amplitude of input 2V RMS delivers 22 mW of power, with the received power at 2cm distance being -30dBm, Also, when the distance is increased to 15 cm, the received power is -65dBm. Future work will integrate such antennas with the diode structures for complete system/sensing performance and analysis.

## IV. CONCLUSIONS

Piezo-magnetoelectric antenna stacks were built and characterized to show operation at multiple bands. Specifically, the multi-stack fabricated antennas showed operation at 29, 44 and 71 kHz. A 3D package integration concept was shown with telemetry sensors at these low frequency antennas.

## ACKNOWLEDGMENT


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