SAND2021-11432C

Detachable Dry-Coupled Ultrasonic Power Transfer Through Metallic Enclosures

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***Abstract*—Ultrasonic waves can be used to transfer power and data to electronic devices in sealed metallic enclosures. Two piezoelectric transducers are used to transmit and receive elastic waves that propagate through the metal. For an efficient power transfer, both transducers are typically bonded to the metal or coupled with a gel which limits the device portability. We present an ultrasonic power transfer system with a detachable transmitter that uses a dry elastic layer and a magnetic joint for efficient coupling. We show that the system can deliver more than 2 W of power to an electric load with 50% efficiency.**

***Index Terms*—Acoustic power transfer, ultrasonic power transfer, dry coupling**

I. Introduction

Sensitive electronics are usually sealed inside metallic enclosures to protect them from electromagnetic interference and block external contaminants. This presents a challenge in powering the electronics inside since not only feedthroughs but also electromagnetic power transfer cannot be used. Ultrasonic waves, by contrast, propagate through metals with little attenuation and are commonly used in this situation [1]–[3]. In an ultrasonic power transfer (UPT) setup, two piezoelectric transducers transmit and receive elastic waves that carry power from the source to the receiving transducer. For efficient UPT operation, there must be good mechanical contact between the transducer and the barrier, which is typically achieved by permanently bonding them using an adhesive layer [4]–[6] or by using gel couplant [7]. However, in many applications, it is desirable to have a fully removable outer transducer that does not rely on the use of gel couplant at the barrier interface. The transducer is only attached when used to supply power to the internal device and removed otherwise.

In this work, we develop an efficient UPT system with a bonded receiving piezoelectric transducer and an external detachable transmitter that does not require a gel or liquid couplant. Good mechanical contact is achieved between the barrier and the detachable transmitter through a soft elastic layer with low ultrasonic attenuation (glued to the transmitter).

II. Experimental setup

The setup shown in Fig. 1 shows the proposed detachable dry-coupled UPT system. The transmitter assembly consists of an air-backed piezoelectric transducer (SMD30T21F1000R supplied by Steminc) glued to a soft elastomer (Aqualink supplied by Innovation Polymers inc.). The transducer is a disc transducer with a thickness of 2.1 mm and a 30 mm diameter with a first thickness mode around 1 MHz. The transducer is mounted in a 3D-printed casing that encloses an alkaline battery as the main power source and a custom printed circuit board used to drive the transmitter near its resonant frequency.

Ultrasonic coupling between the transmitter and the metallic wall is achieved by compressing the soft elastomer using an

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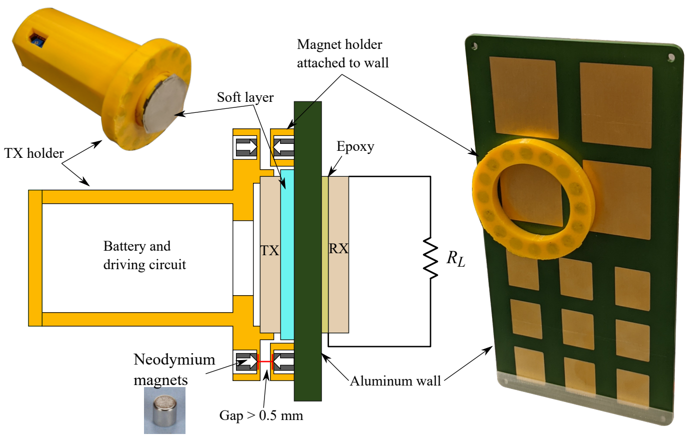

Fig. 1. The developed detachable setup for realizing dry coupled ultrasonic power transfer through a metallic enclosure.

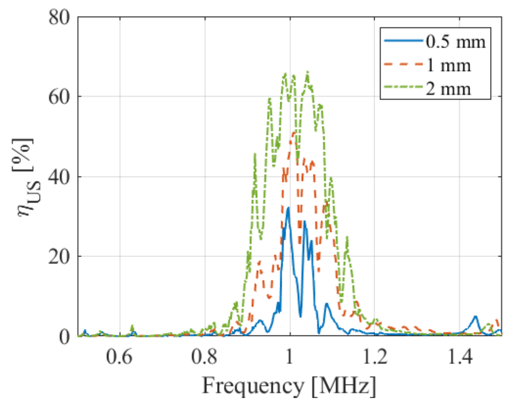

Fig. 2. Ultrasonic (AC-to-AC) efficiency of the system versus frequency for elastomer layers with a thickness of 0.5 mm, 1 mm, and 2 mm.

array of magnets as shown in Fig. 1. The attraction forces between two arrays of magnets attached to both the transmitter and the wall are used to compress the soft elastomer to eliminate any air gaps present and ensure efficient dry coupling. This setup eliminates the need for any liquid coupling and the inconvenience associated with it.

The thickness of the elastomer layer is varied to determine the value that would yield the highest efficiency for the dry-coupled system. The ultrasonic efficiency μ_{US} of the system, defined as the ratio between the output AC power delivered to a 50 Ω resistor to the input AC power supplied to the piezoelectric transmitter, is measured for 0.5 mm, 1 mm, 2 mm, and 3 mm elastomer layers. The ultrasonic efficiency is measured using a chirp excitation that spanned the frequency range between 0.5 MHz and 1.5 MHz. The applied voltage to the piezoelectric transmitter and the current supplied to it are measured using a voltage and current probe connected to an oscilloscope. The measured time signals are then converted to the frequency domain, and used to calculate the input power to the transmitter. The output power is calculated using the relation V_o^2/R were V_o is the output voltage and $R = 50\Omega$.

As shown in Fig. 2, the ultrasonic efficiency of the 2 mm layer yielded the highest efficiency of the system (around 63%). The added compliance of the thicker layer helped ensure a good contact between the transmitter and the barrier under the compressive force applied by the magnetic setup. The thicker layer, however, introduces an added rotational degree of freedom for the transmitter while attached to the wall. This reduces the reliability of the system as the efficiency becomes sensitive to the exact orientation of the transmitter. The efficiency of the system with a thicker elastomer (3 mm) is even more sensitive to the orientation of the transmitter to the barrier, and could not be measured reliably with this setup.

III. DC-to-DC system performance

The overall DC-to-DC performance of the UPT system is measured using the setup shown in Fig. 3a. A DC power supply is used to supply different DC voltage levels to the signal generation and amplification circuit connected to the piezoelectric transmitter. A Raspberry Pi Pico microcontroller is used to generate a square wave signal to drive class E power amplifier connected to the supply voltage. An AC-to-DC full bridge rectifier is connected to the piezoelectric receiver to rectify the output AC voltage and supply DC power to a 50 Ω resistor.

The output AC voltage waveform (without the rectifier) and DC voltage waveform (with the rectifier) delivered to the load resistor are shown in Fig. 3b for different power supply voltage levels. Clean AC and DC signals are observed at the output with a peak-to-peak voltage of 36 V.

The DC-to-DC efficiency of the system as well as the output DC power delivered to the resistive load are shown in Fig. 3 for different DC power supply levels. The DC-to-DC efficiency accounts for all the losses in the system including the efficiency of the amplifier, mechanical system, and full bridge rectifier. It also accounts for the power needed to drive the signal generator. A peak DC-to-DC efficiency of 50% was achieved for a dry coupled system operating at 1 MHz while delivering 2.7 W of power to the resistive load as shown in Fig. 3c.

IV. Conclusion

A detachable dry-coupled ultrasonic power transfer system was developed to deliver power through sealed metallic enclosures. The portable transmitter could be used to send power ultrasonically through metal without the need of the application of any liquid couplant yielding fast, reliable, and convenient portable operation. Experimental results showed that the portable system can deliver more than 2 W of power through a 3mm aluminum barrier to a 50 Ω load with a total DC-to-DC efficiency of 50% near the resonance frequency of the piezoelectric transducer (1 MHz). Applications of the developed system include wireless power transfer (as well as data transmission) to inaccessible electronic components in sealed enclosures.

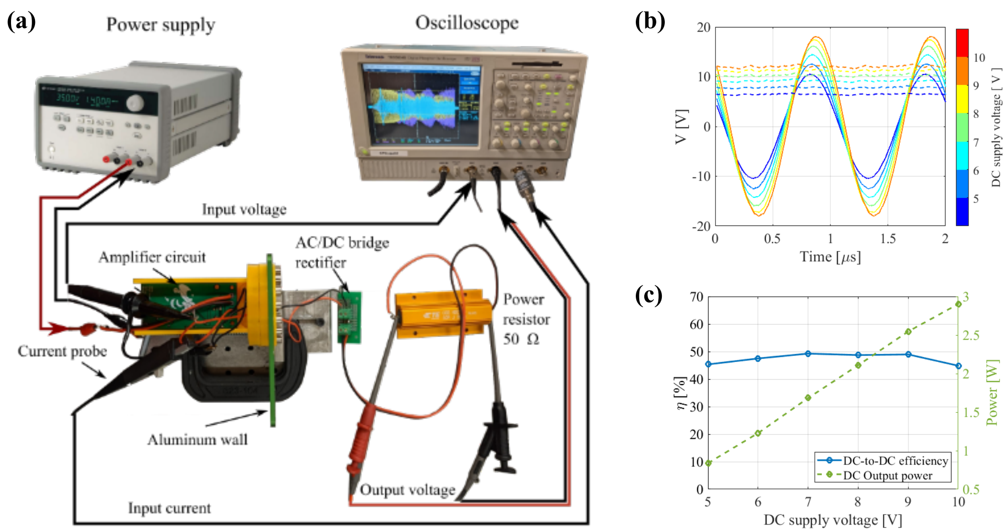

Fig. 3. (a) Experimental setup for measuring the performance of the developed system. (b) The output AC and rectified (DC) voltage waveforms for different supply voltage levels. (c) The output power and DC-to-DC efficiency of the system for different supply voltage levels.

Acknowledgment

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