Architecture of an Ultrasonic Experimental Platform for Information Transmission Through Solids

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***Abstract*— An ultrasonic signal is seldom used for information transmission because it attenuates, scatters, disperses and reverberates in the channel. In some environments, the ultrasonic signal is the only option for communication since radio frequency (RF) electromagnetic waves cannot propagate in the solid and metallic media. This paper presents the feasibility of using an RF ultrasonic signal as the energy source for communication through elastic solids. A testbed platform based on the Field Programmable Gate Array (FPGA), high speed data and signal converters, low noise amplifier, power amplifier, and transducers are assembled to conduct ultrasonic communication experiments. This paper focused on the frequency of 2.5 MHz signal. Amplitude Shift Keying (ASK) and Phase Shift Keying (PSK) are tested using the testbed platform. The objective is to design and examine a reliable system for the ultrasonic communication in solids having diverse geometrical configurations.**

***Keywords*— RF Ultrasonic Signal, Configurable Communication Systems, Solid Channel**

I. Introduction

Using an ultrasonic signal as a carrier of information is widely adopted for the non-destructive testing (NDT), medical imaging and other applications. Ultrasonic signals are rarely used for communication purposes because it has a relatively low bandwidth compared to the higher frequency radio signals. In some environments, such as underwater or underground, ultrasound is a better carrier for transmitting signals compared to radio signals [1] [2] [3]. In this paper, we present a discussion about using the ultrasonic signal for communication. A testbed platform with a programmable arbitrary function generator and a digital oscilloscope is assembled for experimental studies. Also, a Field Programmable Gate Array (FPGA) based Software Defined Radio (SDR) platform is designed to test the performance of the communication using ultrasonic signals. Different modulation methods are tested with this system and the results are compared and discussed.

Section II presents a testbed built with an arbitrary function generator (Agilent 33220A) and a digital oscilloscope (Agilent MSO6032A). Both units allow sampling rates in the MHz range and users have the full control over the units' configuration allowing different experiments for communications. With this experimental platform, the user can gain a better understanding of ultrasonic signals and channel conditions with different geometry for communications.

Section III demonstrates an FPGA based communication platform using the concept of SDR. This type of configuration is adaptive and reliable to transfer information across the solid channels with different structures.

II. Experiment Setup

Before designing a complete communication system, a test platform that can excite transducers and capture the received signal is necessary for experimental studies. Figure 1 shows the system diagram of an ultrasonic communication platform. As shown in this figure, an arbitrary function generator is used to excite the transmitting transducer. The signal is picked up by the receiving transducer and amplified before acquired by a digital oscilloscope. Both arbitrary function generator and digital oscilloscope are interfaced to the computer through an Ethernet cable. MATLAB is used for configuring the system, generating the waveform for the arbitrary function generator and analyzing the received signal from digital oscilloscope. For this study, an application software is developed to send a modulated message signal and to capture and process the received signal. The acquired data is then analyzed to assess the communication channel performance. This communication test platform is adequate for a variety of experiments.

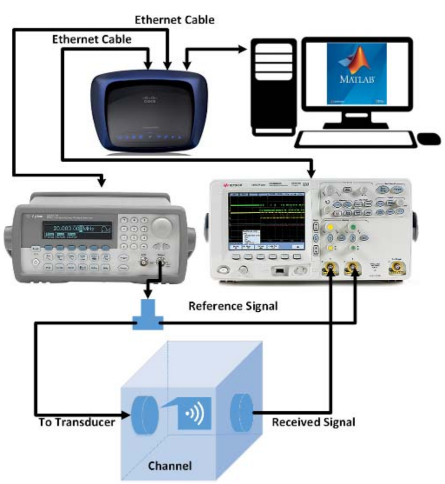

Figure 1. Ultrasonic Communication Experimental Setup

Piezoelectric (PZT) transducers [4] are utilized throughout the experimental studies that can convert electrical energy to mechanical energy or vice versa. This type of transducer can be used as both the transmitter and receiver. Several transducers

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with different shapes and frequencies are used in our experimental studies. In particular, this paper discusses the experimental results using the 2.5 MHz ultrasonic transducer.

As shown in Figure 2, three channel configurations are used to conduct experiments. *Configuration A* (see Figure 2) is when the transmitting and receiving transducers are connected in loop back mode. The transmitting and receiving transducers are connected back to back, to ensure the maximum reception of the sound energy. This configuration is used to test the feasibility of using the ultrasonic communication under the ideal condition. *Configuration B* uses a solid bar for the channel. In this configuration, the transducers are connected perpendicularly to the surface on two sides of the solid bar (see Figure 2). In *Configuration C*, the ultrasonic signal is transmitted through a solid bar with oblique angle wedges [5]. Sliding fixtures are designed to move the transducers and wedges along the solid bar. In each configuration, ultrasonic coupling gel with medium viscosity is used to ensure a better transmission and reception of ultrasonic signal in the solid bar.

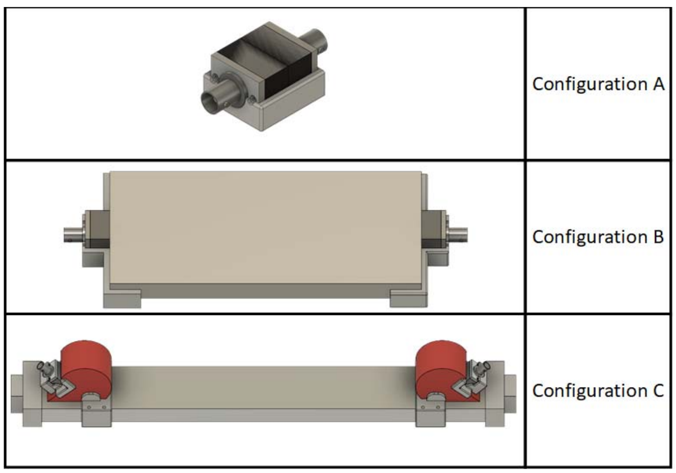

Figure 2. Test Configurations

Ten sinusoidal waves at 2.5 MHz are generated and transmitted towards the receiving transducer. Figure 3a is the frequency spectrum of the transmitted signal consisting of 10 cycles of sinusoidal signal with a frequency of 2.5 MHz that is transmitted through the solid bar channel. Figure 3b is the received signal in the frequency domain. The received signal exhibits distortion due to a multipath effect. This result suggests that ultrasonic pulsed sine waves may not be the best choice to be used for communications.

In communication systems, sine waves are often used as the carrier signal. Figure 4 shows the frequency response of the 2.5 MHz ultrasonic transducer using continuous sweeping frequencies from 0 to 5 MHz. In this experiment, a continuous sine wave is transmitted toward the receiving transducer and the signal is recorded by the oscilloscope at the receiver. The amplitude of the received signal is plotted in Figure 4 which represents the actual frequency spectrum of the ultrasonic transducer.

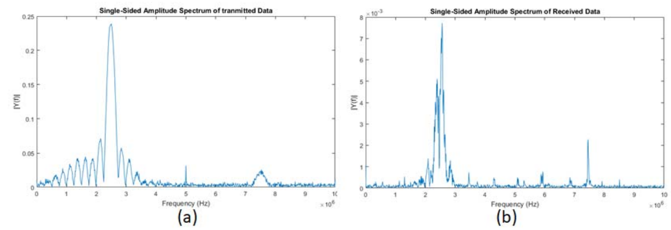

Figure 3. (a) Transmitted Signal in Frequency Domain; (b) Received Signal in Frequency Domain.

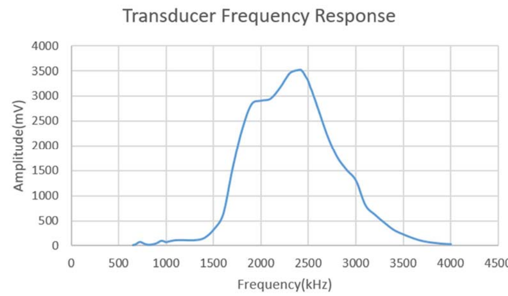

Figure 4. Transducer Frequency Response

By using the *Configuration C*, the reflection, refraction and mode conversion exist at the solid boundaries. Figure 5a shows the reflection, refraction and mode conversion when the wave is transmitted from plexiglass to metal with an oblique angle [6]. This figure also shows the energy is split into three components. The reflection of the input sound wave is absorbed and attenuated by the wedge special geometry. The other two components of the energy enters the metal and splits into longitudinal (L-wave) wave and shear wave (S-wave). Figure 5b shows the splitting of sound wave at the boundary of metal/plexiglass for reception.

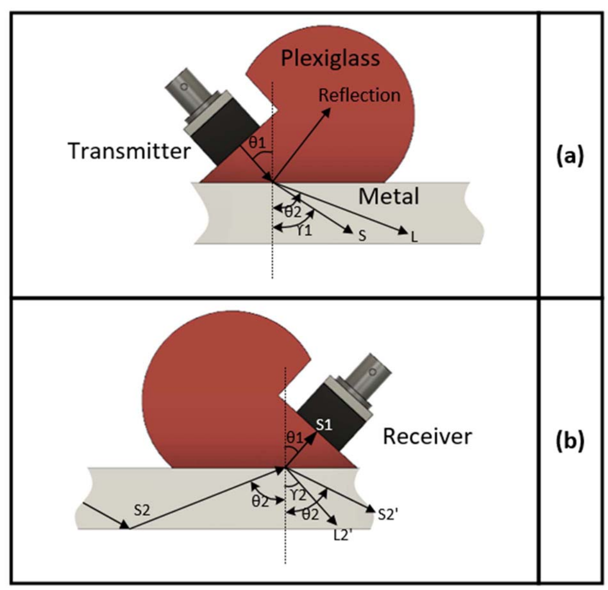

Figure 5. Geometrical Representation of Refracted and Reflected Waves (a) Transmitting Transducer from Plexiglass to Metal; (b) Receiving Transducer from Metal to Plexiglass

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III. FPGA BASED SDR SYSTEM SETUP

To make the system more compact, efficient, and highly adaptive to communication channel characteristics, and to allow multiple frequency band communications for high computational throughput, we use a ZYNQ SoC which includes dual core ARM processors and FPGA fabric for our application specific design. In our previous published papers [7] [8], we have discussed the efficiency of using ZYNQ SoC to design a reconfigurable system for high speed signal processing applications. For this study, a ZYNQ SoC is configured to function as an SDR system based on the IQ (In-phase and Quadrature) modulation technique. Figure 6 illustrates the IQ modulation and demodulation by multiplying the in-phase component *I(t)* and quadrature component *Q(t)* with sine and cosine signals. The baseband signal is shifted by IQ modulation to the high frequency band for transmission. The demodulation is exactly the reverse operation of the modulation (see Figure 6). By mixing the received signal with local signals in quadrature, based band signals can be retrieved from the high frequency band. Since the transmitter and receiver does not have a synchronized clock, further processing is required after the IQ signal is obtained from the IQ demodulation.

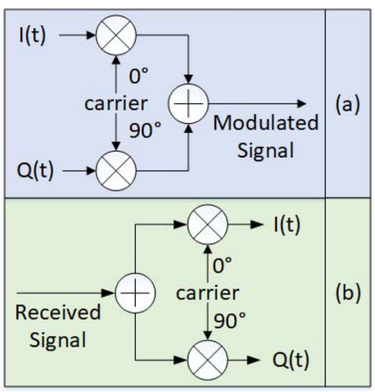

Figure 6. (a) IQ Modulation; (b) IQ Demodulation

An SDR system can be conveniently implemented on the ZYNQ SoC. The IQ modulation and IQ demodulation are computationally heavy due to the high frequency of the carrier signal. Therefore, they are implemented on FPGA for parallel high-speed structure. As shown in Figure 7, the IQ modulation output is connected to the Digital to Analog Converter (DAC). By connecting through a power amplifier, the DAC output is amplified. This is desirable to drive the ultrasonic transmitting transducer. After the signal travels through the channel, the ultrasonic signal will be picked up by the receiver transducer. A Low Noise Amplifier (LNA) adds a 20-dB gain which significantly enhances the SNR of the signal. The received signal is sampled by the Analog to Digital Converter (ADC) and IQ demodulated using the FPGA. The entire process is controlled by the ARM processor embedded in the ZYNQ SoC. At the back-end, a computer running GNURadio software generates, receives, and processes the IQ data.

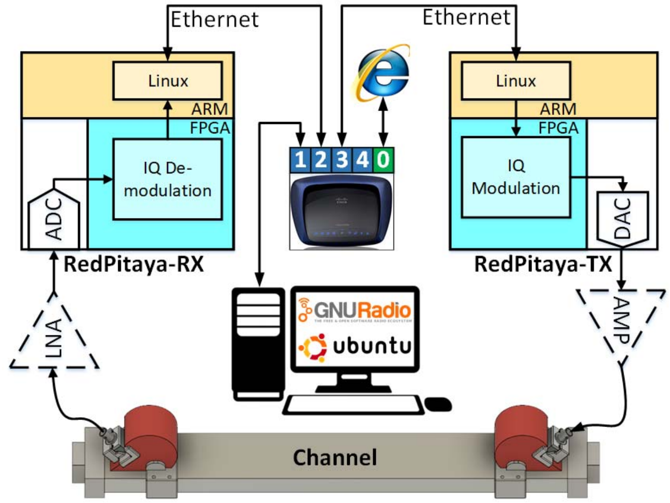

Figure 7. Configurable SDR System Diagram for Ultrasonic Signal Communications

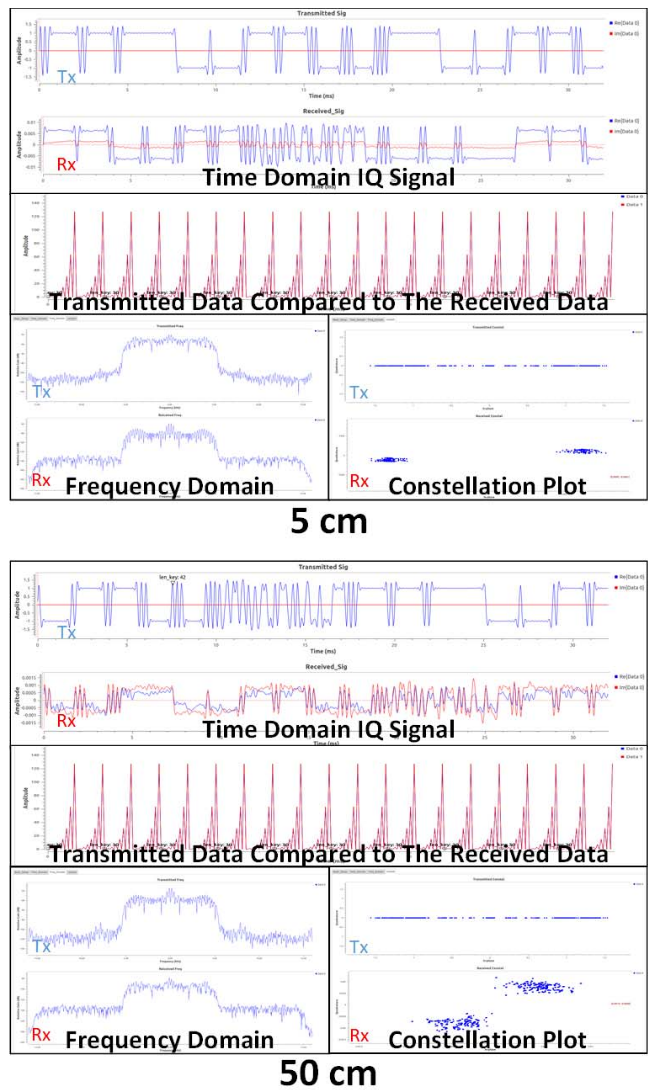

Figure 8. BPSK Result at Distance of 5cm and 50cm

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As discussed in the previous section, the frequency responses of the ultrasonic transducer and channel do not favor the frequency modulation. Therefore, mainly Amplitude Shift Keying (ASK) and Phase Shift Keying (PSK) modulations are tested and compared using *Configuration C* (see Figure 2) is used to conduct experiments. Wedges made of plexiglass with angles of 30 degrees, 45 degrees and 60 degrees are tested to find the optimal angle for transmitting and receiving ultrasonic signals in the solid bar. Two 60-degree angle wedges are used to guide the ultrasonic signal into the channel since it exhibits a better signal quality. The solid bar is made of aluminum and has dimensions of 6.5cm × 1.9cm × 60cm. The transmitting and receiving transducers operate at the frequency of 2.5 MHz.

Figure 8 shows experimental results using the communication system described in Figure 7. The modulation method used in this experiment is Binary Phase Shift Keying (BPSK). The upper section of this figure is the result obtained when two transducers are 5 cm away from each other and the bottom section is the results obtained for 50 cm channel distance. Results include IQ signals in the time domain, time domain message, frequency domain signal and constellation plot for both the transmitted and received signals. These results clearly support the feasibility of using configurable SDR system for ultrasonic signal communications in solids.

IV. Conclusion

Using an ultrasonic signal for communication is useful in certain environments where other options for information transmission are not practical. In this paper, two system configurations for ultrasonic communications are introduced. The first configuration is a setup with typical arbitrary function generator and oscilloscope. With this system, we will be able to precisely control, monitor and evaluate the ultrasonic communications. The second system configuration is based on an SDR platform built on FPGA. This system simplifies the experiments with different modulation techniques, different testing environments with adverse effect of scattering, attenuation, mode conversion, dispersion, and reverberation which are common phenomena in transmitting sound waves in solids. This architecture can be expanded to allow experiments with multiple transmitters and receivers operating simultaneously at different frequencies.

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