Design and Construction of an ultrasound transmit pulser system for non-destructive testing

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Abstract. The design and construction of an ultrasonic pulser is part of a multichannel ultrasonic system, for the analysis, monitoring and characterization of heterogeneous and highly dispersive materials. The pulser has been built on the FPGA platform and allowed to modify the pulse repetition rate, the pulse width and the number of pulses of a burst. This open architecture is a basic module for a more complex ultrasonic pulser, such as arbitrary pulse generator. The results show the ultrasonic transducer responses under the above parameters.

1. Introduction
The acoustic wave propagation throughout the heterogeneous and highly dispersive media is very complex, due to scattering, dispersion and mode change of the energy, causing the phase velocity and attenuation coefficient becomes frequency dependent [1-3]. In a non destructive testing, the received ultrasonic signals, that contain information about microstructure and embedded defects of the tested media, are an attenuated, slower down and shifted version of the transmit pulse. In order to enhance the defect information from the microstructural noise it is necessary to design the transmit pulse that able to work with the 6-dB bandwidth of the transducer, and also with the power of the excitation pulse. These can be done by varying the rectangular pulse width and designing a train of pulses, respectively.

The ultrasonic pulser proposed in this work is the basic excitation module of a multichannel system for non-destructive testing. It is based on FPGA architecture, is a single channel with configurable parameters such as pulse width, train of pulses (burst), pulse repetition rate, to avoid second-fire echoes, and the delay of the excitation pulse. The latter is for the multichannel implementation of beamforming, to focus the energy to a certain region depending on the user needs. The design of this open architecture is based on rectangular pulses as many commercial systems work, such as US Ultracek [4], Advanced OEM Solutions [5], Ultrasonix [6], among o

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2. The ultrasonic pulse generator system
A single channel ultrasonic pulser generation system is shown in Figure 1. The system is composed of the main pulse generation module, voltage driver and ultrasonic transducer. The pulse generation module is responsible for rectangular excitation signals and it is controlled using USB connection. It has been designed and built on a FPGA Xilinx Spartan-6 (model LX45) architecture, the main structure of the Digilent Atlys development module [7].

![Diagram of the ultrasonic pulse generation system]

The FPGA Spartan 6 has an embedded Picoblaze microcontroller that is in charge of reading the input data, from the user via the UART and sending to the generation pulse module. Once a specific transmit pulse is built and voltage adjusted is fitted for the ultrasonic transducer to generate the transmit pulse.

2.1 Pulse Generation Module
This module is composed by the control architecture and pulse generation circuit. The control architecture sends the bytes coming for the microcontroller to each of the internal configuration registers of the pulse generation circuit through an 8-bit bus. This operation has been done in assembly language based on the flow chart shown in Figure 2.

2.1.1 Pulse Generation Circuit
The circuit has been developed on a Finite State Machine with Datapath (FSMD). This circuit has five configuration registers; one register for the time delay, other for the operational frequency, a third is for the number of pulses, the fourth and fifth are dedicated to the burst and the pulse repetition rate, respectively. The FSMD load the initial parameters values in the registers, and wait for the enable signal. If a time delay is greater than zero, the machine is on hold until the value of the parameter is reached, then a logic “1” is generated in the circuit output followed by a logic “0”. The time taken between this to finite machine states define the frequency given as initial parameter. This process is repeated depending on the input value respect to the number of pulses. Once the pulses are generated, the FSMD must halt long
enough to fulfill the requirement of the pulse repetition rate, as shown in Figure 3. This can be an interactive process depending on the initial parameters given by the user.

2.2 Voltage Adjustment

The amplitude of the FPGA output signal is 3.3 V, that for non-destructive testing of heterogeneous media is very low. Therefore, the digital output data of the pulse generation circuit is voltage adjusted by an optocoupler 6N137, which amplified the signal up to 5V (TTL level), and then it is transfer to a voltage driver SN75472 which produces an amplified ultrasonic pulse in the range of 12-50 V. (see Figure 4). The excitation amplitude is limited by the transducer construction and the electronics capabilities. At this stage this procedure is manually operated, however we are working on automatic amplification to control the gain of the output voltage.

![Flowchart](image)

**Figure 2.** Flow of the input parameters from the Picoblaze microcontroller to the pulse generation circuit
3. Control software

The user Graphic Interface (GUI), developed in Python platform, allow the input of the transmit pulse parameters by the user, as shown in Figure 5. As you can see it is not restricted to the operating frequency of the transducer, the user can choose any frequency of interest depending on the application, also this open architecture able to decide whether to use a single pulse or a train of pulses and the pulse repetition rate, which depend on the tested material elastic parameters and dimensions.

![Figure 5. Single-channel GUI.](image_url)
4. Results and future work

The ultrasonic transmission module has been implemented and experimentally validated. The experimental setup in Figure 6 is an immersion through transmission ultrasound, the distance between the transmitter and the receiver is 45 cm. This configuration has been chosen under the following considerations: the slowest tested media is water, therefore the time taken for the wave to travel is the longest time we going to study, that give us the maximum pulse repetition rate, the maximum dimension of the tested material is 30 cm, this can be related to the minimum power needed of the transmit pulse.

The results, shown from Figure 7a to Figure 9b, highlight the responses of the transmitter and receiver transducers of several pulses configuration.

Figure 7. (a) Pulse parameters, given by the user (upper), and the transmitter response (lower).

Figure 8. (b) The received signal for a single emitted pulse.

Figure 9. Immersion through transmission testing. The transmit system is connected to a transmitter and an oscilloscope acquired the received transducer response.
As can be seen from the results a single pulse produces a narrow ultrasonic signal with low amplitude, as the number of pulses increases the width of the detected pulse and its power increases. This open system gives us the possibility of studying an heterogeneous material from several points of view, for a narrow pulses at different frequencies able to highlight microfractures embedded in granular noise, on the other hand broader transmit pulses can give information about the effective elastic properties of the tested media.

It is worth to mention that the ultrasonic pulser is not restricted to the immersion through transmission experimental setup, it can also be used for contact transmission system. Also the lower and maximum frequencies are 127 KHz and 5 MHz, respectively. This single channel pulser is the basis for a multichannel ultrasonic system, the future work leads to have 8 independent transmitter channels and 8-receivers to generate a 2D image of the tested material, including an arbitrary signal generator.

Figure 8. Two pulses generation for a given width and pulse repetition rate. (a) Pulse parameters, given by the user (upper), and the transmitter response (lower). (b) The received signal for a two consecutive emitted pulses. (c) Output of two burst fired a 2.25ms apart.
Figure 9. A train of three consecutive pulses: (a) the parameters given by the user (upper) and the transmitter response (lower). (b) The received signal due to a burst under the characteristics of (a).

5. Reference

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