Stepped-frequency software-defined Ground Penetrating Radar

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1. INTRODUCTION

Ground Penetrating Radar (GPR) is an electronic system capable of producing high resolution images of the subsurface. It generates electromagnetic waves and analyses the echoes resulted from the reflections of these waves at discontinuities of the studied medium[1]. The resulted images provide valuable information for a multitude of scientific fields like geology[2] and archeology[3].

In this paper, an experimental implementation for a low-cost, software-defined Ground Penetrating Radar is presented. The proposed system uses a general purpose low-cost SDR platform with minimal external components. The SDR platform is USRP N200 equipped with WBX RF daughterboard. The only external additions are two off-the-shelf RF switches, an Arduino Uno microcontroller board, a fixed RF attenuator and two Vivaldi antennas. The system implements stepped-frequency radar operation with a bandwidth of 1500 MHz achieving a resolution of 10 cm in air. It works by sweeping this frequency band transmitting sine waves and storing the amplitudes and phases of the scattered waves. Then, this frequency-domain information is translated into time-domain by means of Inverse Fast Fourier Transform (IFFT). The time-domain responses are plotted in an A-scope image. Then, these images are combined to create the classic B-scope image used in ground penetrating radars.

2. EXPERIMENTAL SETUP

The proposed hardware consists of a PC and a USRP N200 platform fitted with a WBX RF daughterboard. This configuration provides a full-duplex transceiver. The transmitter and the receiver sections of the system are connected to Vivaldi antennas and a fixed attenuator through a couple of RF switches. The choice for this particular antenna is motivated by its wide-band and ease of fabrication. The switches are controlled by the computer through an Arduino Uno board as depicted in figure 1.

The baseband signal processing is divided between the USRP motherboard, mainly the FPGA module, and the personal computer connected to it, which also serves as the system's human interface device. The most extensive part of the signal processing is performed on the computer and is coded, for simplicity, in LabVIEW. The FPGA uses factory firmware.

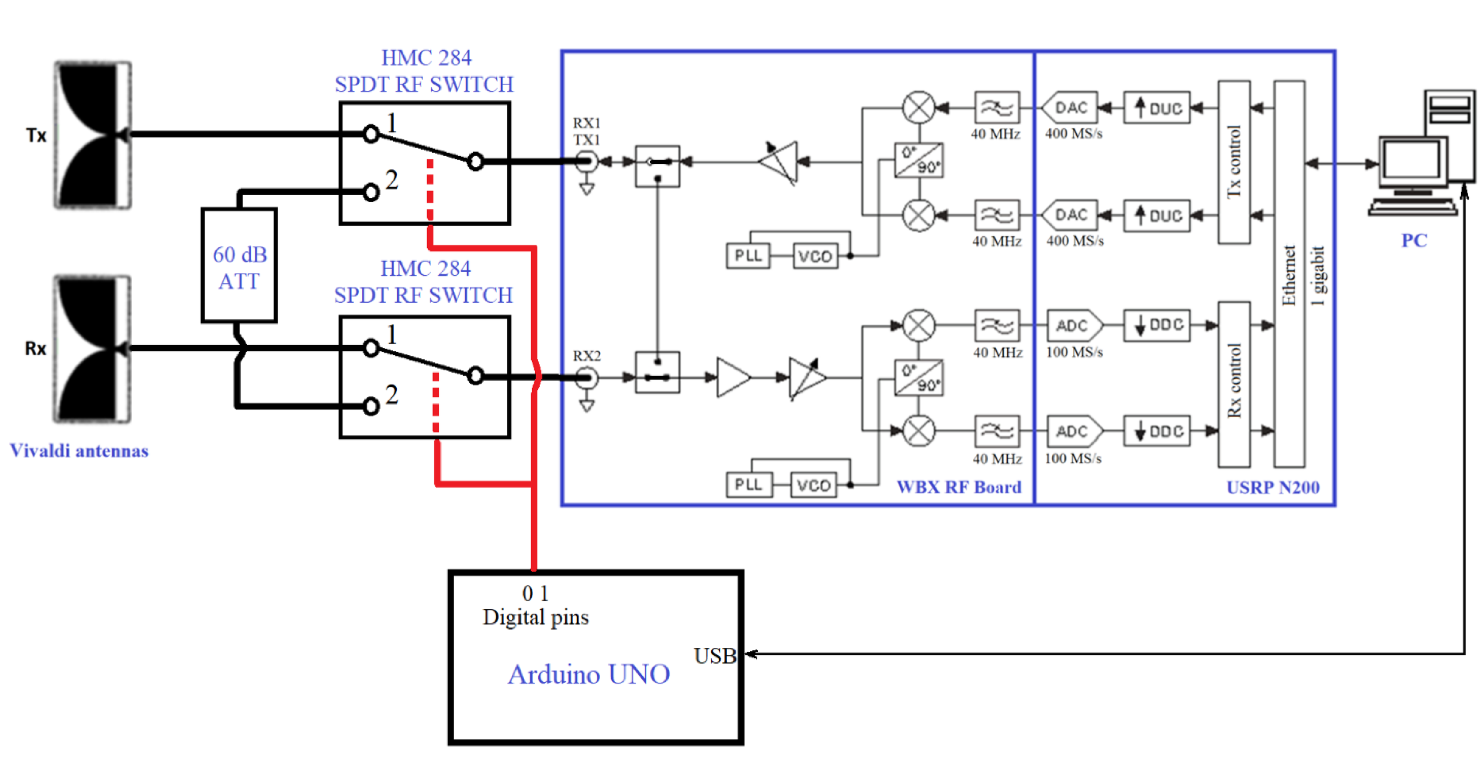

Fig. 1. Experimental setup – block diagram.

3. OPERATION

The main difficulty in implementing radar operation on low-cost, general purpose software-defined radio transceiver platforms stems from the lack of coherence between the transmitter and receiver sections of the device. This translates in a random phase shift between the transmitter and the receiver sections. In order to successfully implement radar operation, it is imperative to correct this fundamental problem. The proposed solution is to continuously measure and subtract this random phase shift from the acquired signal.

The second essential correction is the parasitic antenna coupling. This unwanted effect is corrected by subtracting a previously stored target-less measurement from each scan.

The complete algorithm for the operation of the proposed system is presented in the flowchart in figure 2.

For simplicity, the Arduino platform is controlled using LabVIEW Interface for Arduino (LIFA) driver.

The program also stores the acquired data in multiple files, a file for each scan location, in 3 columns format. The first column stores the frequency, the second column the amplitude in dB and the last column the phase in degrees. This makes the data available for further processing, like applying the synthetic aperture algorithm for focusing the data in azimuth.

If the program cannot find the antenna-coupling correction file named Correction.txt in its directory / Data it automatically creates one using the data obtained in the first scan, which becomes the reference for correcting the antenna coupling from all the following scans.

The device has to be manually moved from a scan position to the next and the new scan is triggered by clicking the NEXT MEASUREMENT button.

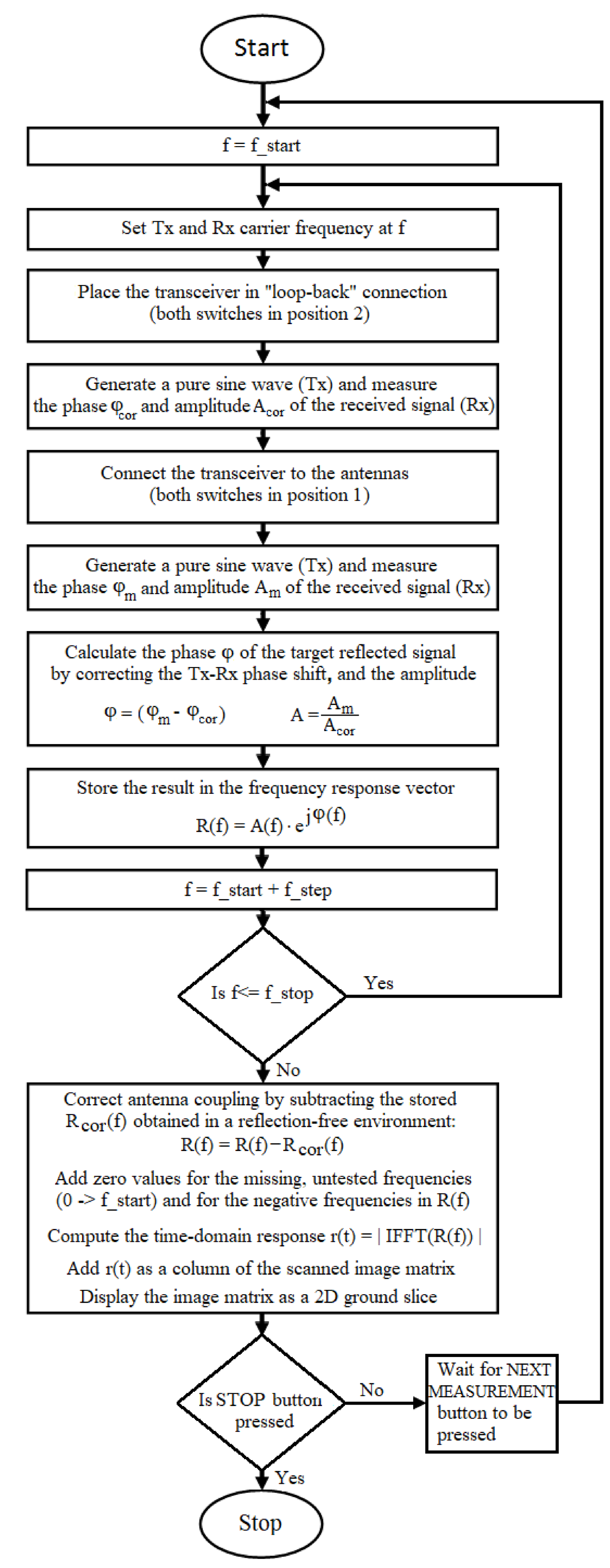

Figure 2. The proposed scanning algorithm.

4. RESULTS

The system was tested using the configuration in figure 3. The target was a coper plated PCB 30 cm x 20 cm, situated at a depth of 50 cm from the table top. The GPR was moved on a straight line over the target area with a step of 5cm between successive scan points. The resulted image is depicted in figure 3. The depth resolution is:

$$\delta_d = \frac{c}{2\cdot Bandwidth} = \frac{3\cdot 10^8}{2\cdot 1.5\cdot 10^9} m = 10\ cm \quad (1)$$

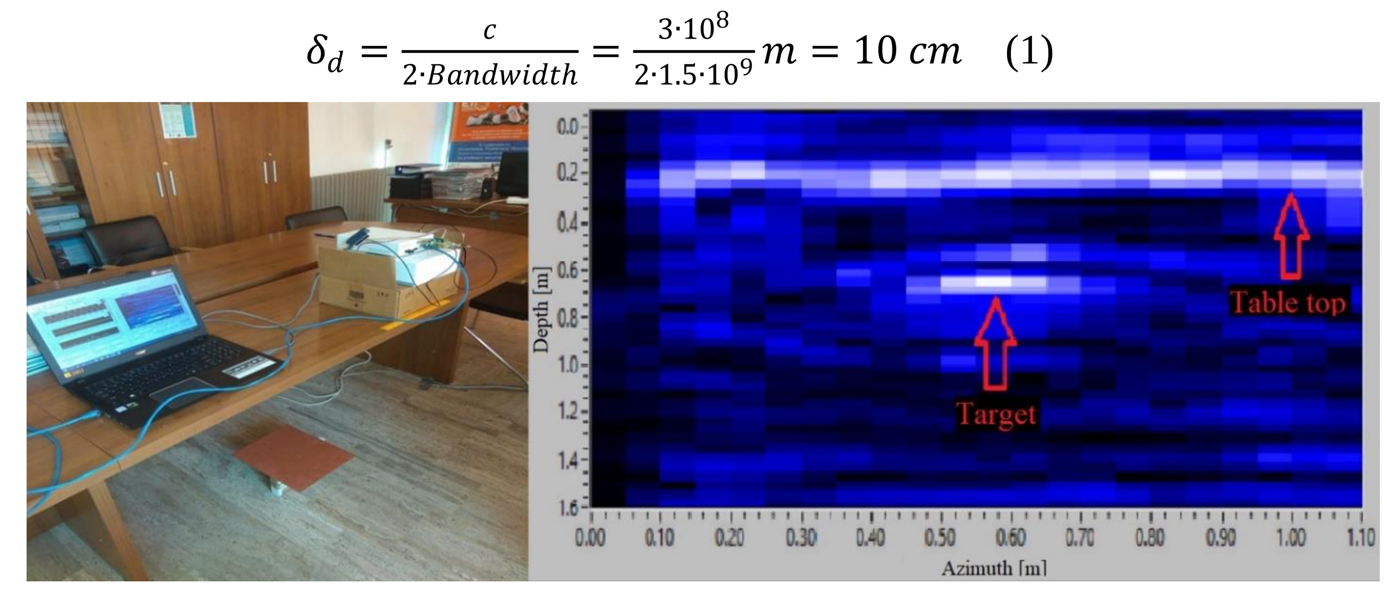

Fig. 3. Experimental results.

5. CONCLUSIONS

The system proposed in this paper implements a high-resolution (10 cm in air) ground penetrating radar using a low-cost software-defined radio and a minimum number of external components.

The proposed implementation overcomes the instantaneous bandwidth limitation of the software-defined radio by employing frequency sweeping over the entire operating bandwidth of the device and correcting phase shifts and amplification variations. The only disadvantage is the slower scanning speed.

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