Enhanced Adaptive Equalization for High-Rate Ultrasonic Communication through Solid Channels

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***Abstract*— This paper presents an adaptive equalizer design for high-rate ultrasonic communication through solid channels. Ultrasonic communication through solid channels is prone to multipath effects, dispersion, refractions, and reverberations. These effects cause severe intersymbol interference (ISI), resulting in a high Bit Error Rate (BER) and overall deterioration of communication performance. Thus, an adaptive decision feedback equalizer (DFE) based on the fast Kalman filter algorithm is used for the equalizer design. The Kalman filter algorithm has fast convergence and good tracking ability, which is essential to reverse the distortion incurred by the ultrasonic solid channel. The performance of the proposed equalizer design is examined using simulated data to train and evaluate the efficiency of the algorithm. Simulation results confirm that adaptive equalizer improves bit rate and lowers BER.**

Keywords—Ultrasonic Communication, Solid Channels, Adaptive Equalizer, Kalman Filter

I. Introduction

Ultrasonic communication through solid channels is prone to severe intersymbol interference (ISI), resulting in a high Bit Error Rate (BER) [1-5]. The ISI, due to the multipath effect, limits the capacity and reliability of ultrasonic communication significantly. The adaptive equalizer is a promising solution to combat the ISI-infested time-varying multipath channels. Our recent papers using piezoelectric transducers (PZT) and electromagnetic acoustic transducers (EMAT) [6-9] examine the foundation of ultrasonic communication through solid channels where an FPGA-based software-defined ultrasonic communication platform is developed for studying the challenges that impact the bit rate and the bit error rate (BER) in channels of different configurations. The issue of channel equalization has been studied [10-12] using the time-reversal concept and pulse shaping matched filter for improved signal quality and higher bit rate.

In this paper, we present the design of an adaptive equalizer using a fast Kalman filter to suppress the ISI caused by the time-varying multipath solid channels. Section II presents the architecture of the ultrasonic communication system and the technical details of the equalizer design for improved signal quality and a higher bit rate. Section III presents the experiment setup and results of the proposed equalizer design. Finally, Section IV concludes and summarizes the key design issues for the equalization of ultrasonic solid channels.

II. System Design

A. Solid Channel Communication

The solid channel communication system used in this research is shown in Fig. 1. Two identical ultrasonic transducers function as the transmitter and receiver and are attached to the solid channel (aluminum bar) with ultrasonic gel.

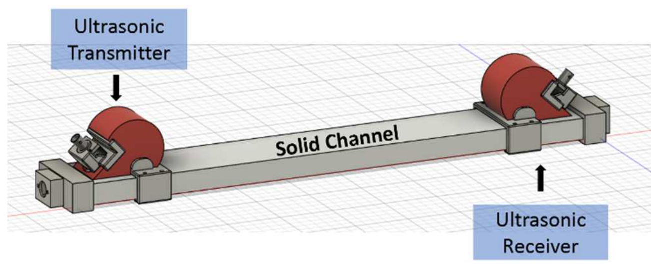

Fig. 1. The Layout of the Solid Channel Communication.

B. Decision Feedback Equalizer

This research uses Decision Feedback Equalizer (DFE) for the equalization of the ultrasonic communication channel. As shown in Fig. 2, the decision feedback equalizer uses a feedback filter (FBF) to mitigate the ISI from the output of the feedforward filter (FFF). The estimated ISI is then sent before the decision device and deducted from the subsequent outputs of the FFF.

C. Adaptive Algorithms

Adaptive algorithms are used to update the coefficients of the equalizer to keep track of the changing situation of the channel. Least Mean Squares (LMS) and Recursive Least Square (RLS) are two classic algorithms in this category.

A predetermined sequence of bits, or training sequence, is used to train our adaptive equalizer. When designing the training sequence, two factors are considered: the exact length and the relative size compared to the actual payload. The former would affect how efficiently the equalizer converges, and the latter would impact the transmission efficiency of the whole communication.

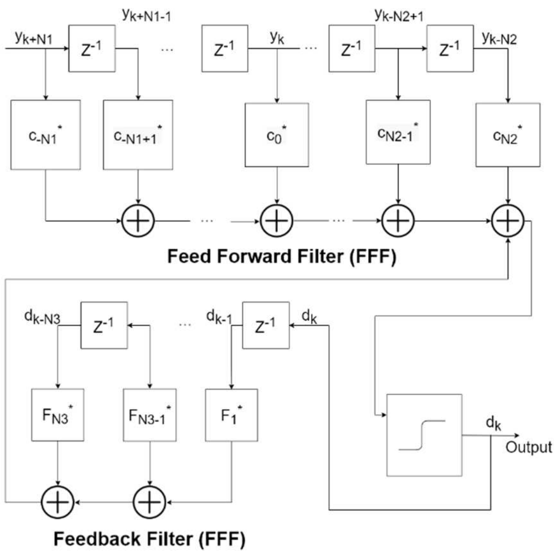

Fig. 2. Decision Feedback Equalizer.

The data flow will resend the training sequence periodically to keep the tracking consistent. This scheme is demonstrated in Fig. 3, where the payload and the training sequence are sent sequentially. The equalizer has prior knowledge of the training sequence and will start the training process every time the training sequence reaches the equalizer. The method to determine the training sequence on the receiver end will be discussed next.

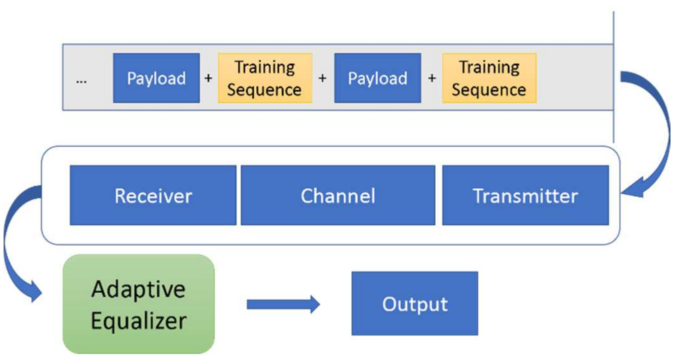

Fig. 3. Data Flow of the Adaptive Equalizer.

D. *Equalization and BER Calculation*

The system diagram of the communication and equalization is shown in Fig. 4. The data consists of the training sequence and the payload, both in fixed length. Data bits go through PSK modulation, and the symbols are modulated to the carrier frequency at 2.5MHz using IQ modulation.

To determine the training sequence in a simulation, we can calculate the exact delay introduced by the communication, especially the channel. Once the total delay is determined, the training sequence can be easily found in the receiver end. However, this method is not viable in real life as the channel delay cannot be readily determined. Instead, a correlation estimator can solve this problem by estimating the delay introduced by the entire communication system.

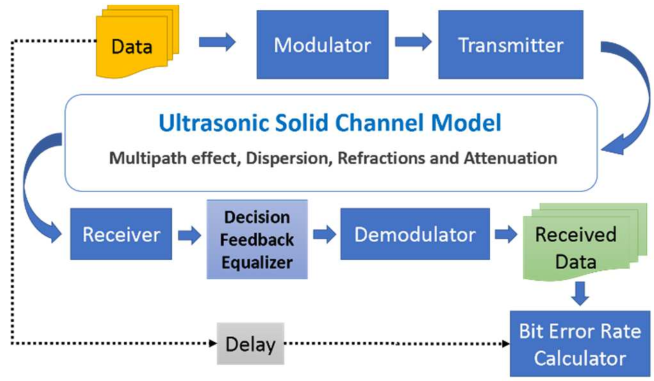

Fig. 4. System Diagram of the Equalization and BER Estimation.

III. SIMULATION RESULTS

Simulation results are used to examine the performance of the proposed equalizer. The feedforward filter and the feedback filter are designed to have 24 taps for allowing a balanced convergence speed and tracking capability. The training sequence is 300 bits, and the payload is 700 bits (see Fig. 3). Free space path loss through the channel is set to 30 dB, and the channel signal-to-noise ratio is set to 25 dB. Five paths with various delays and gains are used to simulate the multipath effect. The symbol rate is set to 10 Msps (symbol-per-second).

Fig. 5 shows the constellation of Rx signals both before and after the equalization. Comparing the constellations before and after the equalization, we can conclude that the equalizer is working as intended. Fig. 6 shows the BER curves when LMS and RLS are used to update the weights in the decision feedback equalizer (see Fig. 2). As shown in Fig. 6, RLS algorithm has a better convergence time and lower BER.

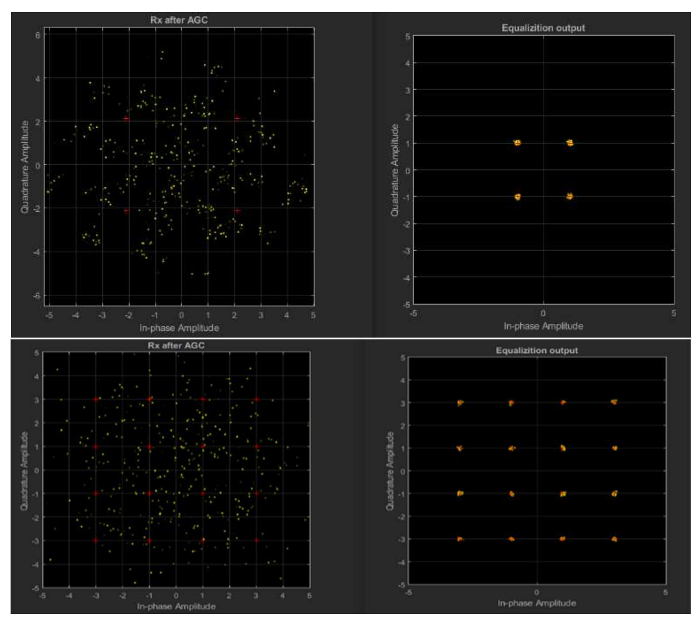

Fig. 5. The Constellation of Rx Signals Before/After Equalization.

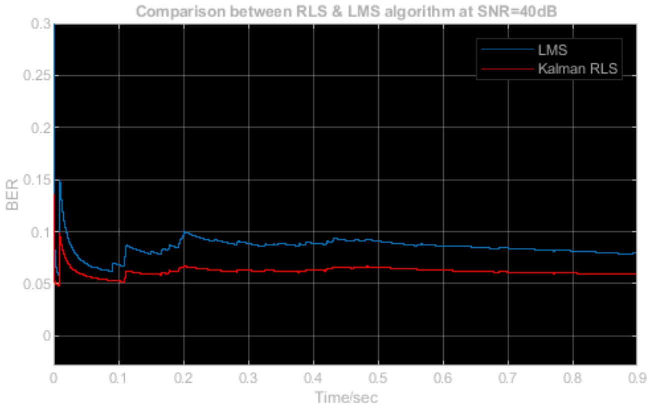

Fig. 6. Bit Error Rate Comparison of LMS and RLS

IV. Conclusion

In this research, we presented an adaptive equalizer for ultrasonic communication through a solid medium. RLS is used as the adaptive algorithm, and DFE is picked as the overall equalizer design. In the end, the proposed equalization method is shown to achieve a high data rate (10Msps) in a practical SNR of 40dB and BER of 5%. Thus, the proposed method can be concluded as efficient for its intended use.

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