Advances in Computer Science Research, volume 74
2nd International Conference on Computer Engineering, Information Science & Application Technology (ICCIA 2017)

Identification and Communication Simulation of an Ultrasonic Through-metal-wall Channel

Dong Tian[a], Dingxin Yang[b] and Baojian Hou[c]

Science and Technology on Integrated Logistics Support Laboratory, National University of Defense Technology, Changsha 410073, China

[a]13378012090@163.com, [b]yangdingxincn@163.com, [c]hbjian23@163.com

Keywords: wireless communication, ultrasonic, system identification, echoes cancellation.

Abstract. Many industrial applications need the technologies of power and data transmission through metal barriers without physical penetrations. The reverberation of the acoustic signals in the channel can produce multipath distortion with a significant delay spread that introduces severe inter-symbol interference into the signal. To overcome this shortage, we did a more detailed study of the channel's characteristics. The voltage transfer function and impulse response of the same channel were obtained. The response signal was used for system identification, and then a more accurate model of the ultrasonic channel was built. An equalizer was directly derived based on the identified model. The equalizer's superb results on echoes cancellation is simulated and verified using ASK modulation schemes in Simulink. The results show that data rates on the order of 100kbps at least. By choosing a discrete time representation of the system, the resulting equalizer is readily implemented on FPGA.

1. Introduction

The ability to steadily communicate through thick metal walls without physical penetration would provide great potential benefit to many sensing and condition monitoring applications in rugged environments [1]. These matters may be avoided by using ultrasonic to transmit both power and data. Due to the unique acoustic characteristics of the ultrasonic channel, the effects of echoes lead to large delay spread and a highly frequency selective, which severely limits the channel's coherence bandwidth [2].

Prior research has shown that echoing of acoustic energy within the channel leads to significant inter-symbol interference when transmitting at a high data rate [3]. An echo cancelation technique was developed that uses a predistortion filter at the transmitting to cause destructive interference and partial cancelation of echoes at the receiver [4-6]. In this paper, we first studied the channel's characteristics in detail. The voltage transfer function and impulse response of the same channel were obtained. An accurate model of the ultrasonic channel was identified based on these characteristics and we derived a better equalizer using the identified model.

2. Ultrasonic Communication Channel

The ultrasonic communication channel, shown in Fig.1, consists of two ultrasonic transducers separated by a metal barrier. Between each of the transducers and the metal plate is a layer of epoxy resin in order to maximize the acoustic power transfer efficiency between the two parts. Two experiments were performed to obtain the characteristics of the communication channel.

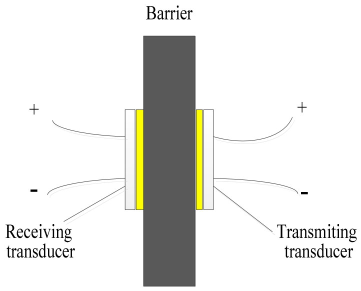


Fig. 1 Ultrasonic communication channel

Fig. 2 Channel gain magnitude measurement Experimental setup

2.1 Channel Gain Magnitude Estimation.

The channel gain magnitude measurement experimental setup is illustrated in Fig.2. The transmitting transducer is driven by a function generator and the receiving transducer is connected to a resistance box and an oscilloscope which captures the received signal. Both the generator and oscilloscope are connected to a PC which controls the transmitter and receiver in Matlab.

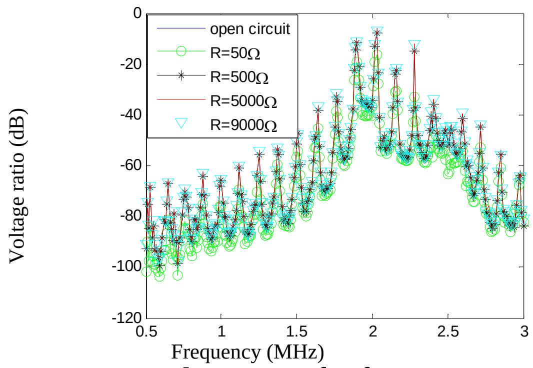


Fig. 3 Voltage transfer function magnitude

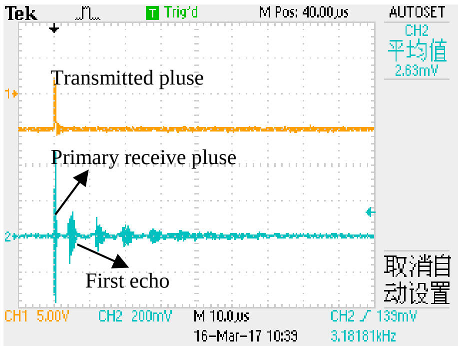


Fig. 4 Impulse response of the channel Of the channel

The frequency sweeping results of the magnitude response for the channel with the ultrasonic channel connected to different loads are shown in Fig.3. It is clear that the transfer function varies significantly with frequency. The voltage transfer function magnitude will increase with the increasing of load resistance, while the peak frequencies nearly remain unchanged. In this way, these peak frequencies can be used as the carrier to modulate the digital baseband signal simultaneously, so as to increase the data rate.

2.2 Impulse Response.

In this test, we excited the transmitting transducer with a pulse signal which amplitude is 5V, and pulse width 220ns, one half of the piezoelectric transducer resonant period. This pulse width was chosen to maximize the ringing amplitude at the receiver.

The coherence bandwidth is defined as the frequency range over which the channel is correlated [7]. These two characteristics have a relationship as

$$F_c = \frac{1}{D} \tag{1}$$

Where D is the delay spread, and F_c is the coherence bandwidth.

From Fig.4 we observe that D is about 50 μs . According to Eq. (1), F_c should be 20 kHz. So if a signal with a bandwidth larger than 20 kHz is transmitted through the channel, a severe inter-symbol interference will occur. In the following sections, the echo cancelation equalizer will be introduced to solve this problem.

3. Channel System Identification

The echo cancelation equalizer is based on the transfer function of the channel. So the key point is to identify the model of the ultrasonic channel.

3.1 Channel Modeling.

According to the reference [4], the barrier is further decomposed into forward and reverse paths Br, B_f, which accounts for the echoes observed in Fig.5. The transfer function of the channel in Fig.5 is:

$$H = \frac{T_t T_r B_f}{1 - B_r B_f} \tag{2}$$

It is evident that the transducer transfer characteristics have no effort on the channel's echo. Meanwhile, the Eq. (2) can be simplified as follows:

$$H = \frac{P}{1 - E} \tag{3}$$

The practical model H has additional denominator 1-E as shown in Eq. (3), which accounts for the generation of echoes. An equalizer should be placed between the source and the channel for compensation of 1-E, it will cancel the echoes. The block diagram of Fig.6 shows the overall system, where we refer to as estimates of the actual function E.

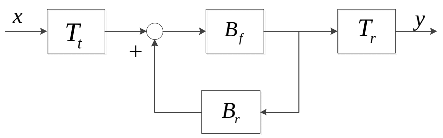


Fig. 5 Channel block diagram

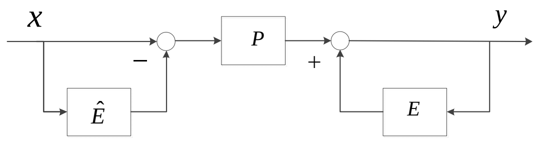


Fig. 6 Construction of the equalizer

3.2 System Identification Algorithm.

In order to tune the equalizer, the transfer function of the channel has to be determined first. System identification techniques have been developed to estimate model parameters based on input-output data. Due to the linearity of the system, we use ARX structure polynomial model as the channel model.

The transfer function of the channel requires two steps corresponding to the two components of Eq. (3). The transfer functions of main path and echo path are obtained separately.We have developed a method of modeling the main signal path as a cascade of a rational transfer function and a pure delay [4], expressed as follows:

$$P(z) = P_l(z) z^{-d} \tag{4}$$

The lumped element portion of the transfer function, $P_l(z)$, accounts for the frequency selective effects of the transducers and barrier, while z^{-d} accounts for the acoustic delay contributed by those components. The form of $P_l(z)$ is given by Eq. (5).

$$P_l(z) = \frac{bp(1) + bp(2)z^{-1} + \cdots + bp(M_p + 1)z^{-M_p}}{ap(1) + ap(2)z^{-1} + \cdots + ap(N_p + 1)z^{-N_p}} \tag{5}$$

Using system identification techniques, the coefficient vectors bp and ap and the time delay d can be determined from channel input-output data.Following the same procedure that was used to model the main signal path, the echo path is assumed to be the cascade of a rational and an ideal delay.

The goal of system identification is to minimize the error between the model's response, and that of the actual systems. In this paper, the model parameters are estimated using the least squares complex exponent method (LSCE), and the model orders are determined using the final prediction error (FPE) criterion. The most accurate model has the smallest FPE, and the form of FPE is given by Eq. (6) and (7).

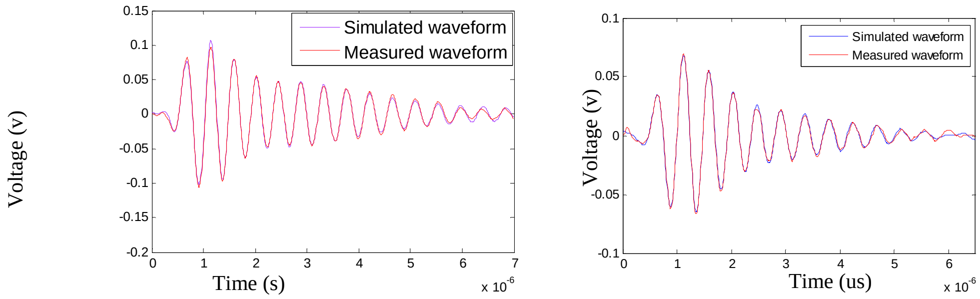
$$FPE(k) = \frac{n + k + 1}{n(n - k - 1)} \sigma^2(k) \tag{6}$$

$$\sigma^2(k) = \frac{1}{n} \sum_{i=1}^{n} (x_i - \hat{x}_i(k))^2 \tag{7}$$

3.3 Model Result.

In order to estimate , the transmitted pulse and primary received pulse as shown in Fig.4 are extracted from the channel impulse response and used as the input and output for identification. The echo transfer function relates successive echoes to one another. So the primary pulse and the first echo are used as the input and output. The estimated round trip delay of the barrier is estimated by measuring the time between the primary pulse and the first echo.

The goodness of fit to practical situation is up to 93.03% and 92.25%, while FPE is 5.811×10^{-6} and 2.78×10^{-6}. The simulation model's waveform and the actual waveform are compared in Fig.7. The frequency response of the estimated channel model is shown in Fig.8. Though there is a small move for the resonant frequencies, the null-to-null spacing is as the same as which in Fig.3.



(a) (b)

Fig. 7 Measured and simulated model output. (a) The primary pulse; (b) the first echo

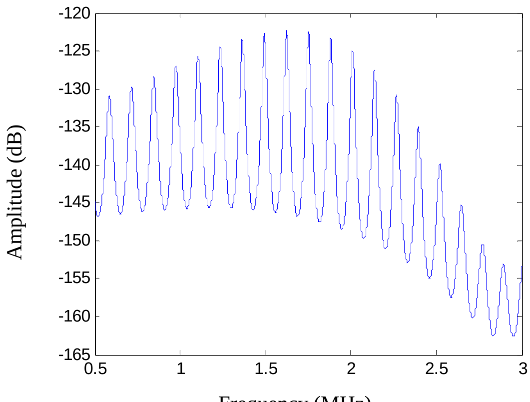


Fig. 8 Frequency response of the estimated model

4. Channel Communication Simulation

In this section, the ultrasonic channel model developed in Section 3 is simulated. Using such a model, the channel's response to arbitrary inputs can be simulated, including the response to digital signal. The basic modulation schemes used in the current work are simple Amplitude Shift Keying (ASK). For transmitting symbols in high frequency channel with limited bandwidth, the corresponding carrier need to be modulated by the signal for high transfer efficiency. At the receiving port, the signal can be recover through demodulation, filtering and decoding. As can be seen by the figures below, the output waveform of the module without equalizer is serious distortion with several echoes. The comparison between Fig.9 (b) and (d) is the vivid reflection of the ISI and multipath effect. With the equalizer, the task of detecting data sequence is simplified and data rate can be increased substantially.

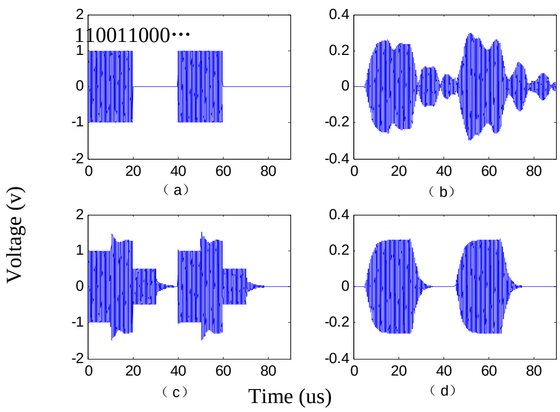


Fig. 9 The waveform of the simulintion model

5. Conclusion

In this paper, we did a more detailed study of the channel's characteristics. The voltage transfer function magnitude and impulse response of the same channel were presented. In order to cancel echoes, we used the system identification technique tune the channel model. By choosing a discrete time representation of the system, the resulting equalizer is readily implemented on FPGA. The model was validated by ASK in Simulink. The equalizer plays an important role in canceling the echoes and greatly increasing the data rate no matter which modulation scheme used. However, in the process of building the model, we found that the model identified by the method is sometimes unstable, and the modulation result is diverging, but it's not clear why the situation occurred. So the system identification algorithm needs to be improved in the future.

Acknowledgments

The authors would greatly appreciate the support provided by National Nature Science Foundation of China No.51375485 and Hunan Province Natural Science Foundation No.2017JJ2300 for this work. The corresponding author: Dingxin Yang, E-mail: yangdingxincn@163.com

References

[1]. J. D. Ashdown, G. J. Saulnier, H. A. Scarton, A full-duplex ultrasonic through-wall communication and power delivery system, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 60 (2013), 587-595.

[2]. M. Bielinski, K. Wanuga, R. Primerano, M. Kam and K. R. Dandekar, Application of adaptive OFDM bit loading for high data rate through-metal communication, Global Communications Conference, 263 (2011), pp. 1-5.

[3]. T. J. Lawry, K. R. Wilt, J. D. Ashdown, H. A. Scarton, and G. J. Saulnier, A high-performance ultrasonic system for the simultaneous transmission of data and power through solid metal barriers, IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control, 60,1, pp. 194-203 (2013).

[4]. R. Primerano, M. Kam, K. Dandekar, High bit rate ultrasonic communication through metal channels, Conference on Information Sciences and Systems, Ciss 2009, 2009, pp. 902-906.

[5]. R. Primerano, K. Wanuga, J. Dorn, M. Kam and K. Dandekar, Echo-cancellation for ultrasonic data transmission through a metal channel, Conference on Information Sciences and Systems, Ciss 2007, 2007, pp. 841-845.

[6]. Y. Z. Sun, D. X. Yang, Z. Hu, H. F. Hu and B. J. Hou, Study on energy transmission through metal wall based on piezoelectric material, METEC Web of Conference, 61 (2016), pp.05018.

[7]. J. N. Zhang, Z. Y. Yu, H. X. Yang, M. Wu, and J. Yang, Wireless communication using ultrasound through metal barriers: Experients and analysis, International Conference on Information, Communication and Signal Processing, 2015, pp. 1-5.