Design and Performance Evaluation of Single Antenna SSD (Simultaneous Single Band Duplex) System Using Turbo Equalizer

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Abstract— In this paper, we propose a single antenna SSD (simultaneous single band duplex) system using turbo equalizer. The proposed system communicates simultaneously on single band. That is the proposed system is full-duplex system. The proposed system uses balanced feed network circuit to improve isolation in single antenna structure. Also, the proposed system uses RF cancellation and digital cancellation to cancel self-interference. Additionally, the proposed system uses turbo equalizer to equalize ISI by harsh multipath fading and to collect bit errors by residual self-interference signals. By using turbo equalizer, the proposed system guarantees more QoS (quality of service). In this paper, we uses Simulink simulation program to analyze performance of the proposed system. The simulation results confirm that proposed system can communicate simultaneously by using balanced feed network, RF cancellation, digital cancellation and turbo equalizer in harsh multipath channel on single band.

1. INTRODUCTION

Recently, the use of small wireless terminal device is suddenly increasing. These wireless communication devices use duplex to exchange information. The duplex is a communication system to exchange information with each other while transmission and reception between devices. There are frequency-division duplex (FDD) and time-division duplex (TDD) in these duplex system [1, 2]. TDD is a system for transmission and reception by dividing time-domain. FDD is a system for transmission and reception by dividing frequency-domain. However, TDD requires guard interval that is a period that does not any transmission and reception. Further, it is impossible to use frequency band specified for complete transmit or complete receive. In FDD, there is a drawback that double frequency band is required in order to communicate duplex. Recently, research on SSD system that to solve the drawback of TDD and FDD is performing [3, 4].

SSD system improves the spectrum efficiency because SSD system uses single frequency band for transmission and reception simultaneously. But, SSD system that has these advantages causes self-interference because SSD system communicates simultaneously in the single band. That is, transmission signal of own station is received in receiver of own station. Power of self-interference by transmission signal of own station is larger than power of desired signal from distant station in SSD system. Therefore, the desired signal can be distorted completely by self-interference. If desired signal is distorted by self-interference, then it is impossible to receive information of distant station. Therefore, SSD system requires additional self-interference cancellation technic to cancel huge self-interference.

Generally, well known self-interference cancellation methods are RF cancellation and digital cancellation [5, 6]. RF cancellation is performed for self-interference cancellation in RF stage. RF cancellation cancels direct self-interference that moves directly from transmitter of own station to receiver of own station. Antiphase signal for self-interference cancellation is made by using transmission signal of own station in RF cancellation. Digital cancellation is performed for self-interference cancellation in digital stage after ADC. Digital cancellation cancels multipath self-interference and residual direct self-interference that is self-interference signal after RF cancellation. In these SSD system using RF cancellation and digital cancellation, in order to design RF cancellation circuit, amplitude and phase of self-interference is measured. And then attenuator and phase shifter are designed by using the measured amplitude and phase data. But, this RF cancellation method can be incorrect by change of antenna position and design. If RF cancellation circuit design is not satisfied with condition of same amplitude and antiphase, then performance of RF cancellation is degraded highly. Also, even though this SSD system cancels self-interference effectively by RF cancellation and digital cancellation, performance of SSD system can be degraded by multipath fading from distant station.

Therefore, in this paper, in order to solve this drawback of SSD system using two antennas, we design SSD system using single antenna and balanced feed network. And we propose and analyze single antenna SSD system using turbo equalizer to overcome performance degradation by harsh multipath fading.

2. SYSTEM MODEL

The SSD system is a system for simultaneous transmission and reception on the single band. In this paper, the proposed system is single antenna SSD system using turbo equalizer. In this paper, we use RF cancellation and digital cancellation for SSD communication. And then, we combine SSD system and turbo equalizer to overcome harsh multi-path channel.

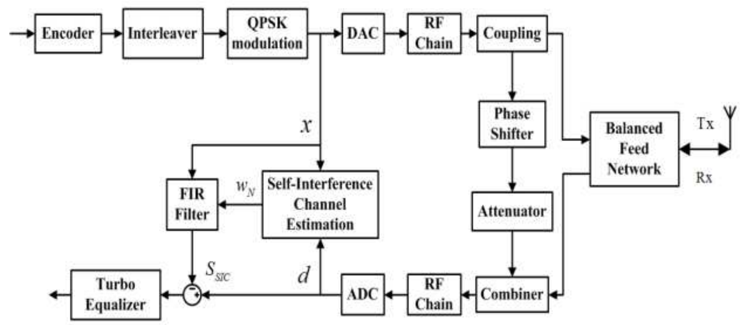


Figure 1: Block diagram of the proposed SSD system.

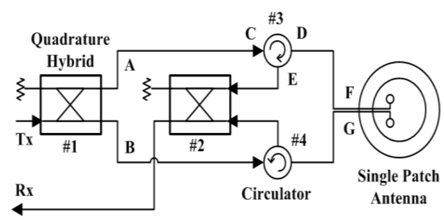


Figure 2: Block diagram of balanced feed network.

Figure 1 shows block diagram of the proposed SSD system using turbo equalizer. In signal flow of the proposed system, In this paper, the proposed system uses RF cancellation to cancel the leakage signal of balanced feed network. But, even though RF cancellation circuit cancels the leakage signal, residual leakage signal exists. Therefore, it is difficult to receive desired signal from distant station because this residual leakage signal and returned signal by multi-path is larger than desired signal from distant station. For this reason, the proposed system needs self-interference cancellation of digital-stage. In this paper, we use digital cancellation with LMS algorithm to cancel residual self-interference.

In this paper, the proposed system model of Fig. 1, it is possible to use the mobile terminal and a base station. The proposed system can increase spectral efficiency in the base station and the mobile terminal.

3. SELF-INTERFERENCE CANCELLATION AND TURBO EQUALIZER

3.1. Balanced Feed Network

Figure 2 shows block diagram of balanced feed network. In this paper, the proposed system uses single patch antenna. It is important to isolate transmit signal and receive signal in a transceiver with single antenna. In general, the transceiver with single antenna uses a circulator to isolate transmit signal and receive signal. Transmit signal from RF chain move to antenna and receive signal from antenna move to receiver by circulator. That is, the circulator prevents the leakage signal to receiver from transmitter. But, using the circulator, it is difficult to completely isolate transmit signal and receive signal. This leakage signal is larger than desired signal from distant station. Therefore, the leakage signal must be cancelled to receive the desired signal. In this paper, the proposed system uses balanced feed network circuit for efficient cancellation of transmit signal by leakage [7].

The balanced feed network isolates transmit signal that leaks to receiver by 40 dB [7]. The self-interference by the transmit leakage signal is $80 \sim 90$ dB larger than the desired signal. Therefore, even though the self-interference is cancelled 40 dB by the balanced feed network, a residual self-interference is larger than the desired signal. If the residual self-interference distorts the desired signal, then it is impossible to decode the desired signal. To solve this drawback, additional self-interference cancellation method is required.

3.2. RF Cancellation

In this paper, the proposed system uses a RF cancellation to cancel the residual self-interference from the balanced feed network. The RF cancellation uses principle that signals which has phase difference of 180 degrees and same amplitude is cancelled by combination each other. In this paper, the proposed system should generate a signal which has phase difference of 180 degrees and same amplitude with the residual self-interference. To generate the cancelling signal, a transmit signal after RF chain in own transmitter go through attenuator and phase shifter.

3.3. Digital Cancellation

Even though the proposed system cancels the self-interference by the balanced feed network and RF cancellation, a portion of the self-interference is remained. Therefore, the proposed system uses a digital cancellation to cancel this residual self-interference.

The digital cancellation is a self-interference cancellation method that estimates a coefficient of self-interference and cancels self-interference by using estimated coefficient in the digital stage. In this paper, the proposed system uses adaptive algorithm for self-interference estimation. In this paper, we use a LMS (least mean square) algorithm as adaptive algorithm. The LMS algorithm is to minimize an error of a desired signal and output signal of FIR filter. That is, the LMS algorithm updates coefficients of FIR filter to minimize the error continuously [8]. In the LMS algorithm, the error of input desired signal and output signal of FIR filter is given by

$$e_k = d_k - W_k^H X_k \tag{1}$$

where d_k is the desired signal, X_k is input signal. W_k^H is estimated coefficient that apply to FIR filter. Therefore, $W_k^H X_k$ is the output signal of FIR filter. The error is calculated by subtracting the output signal of FIR filter from the desired signal. In Equation (1), the desired signal is a receive signal that is combined with self-interference after ADC. The input signal is transmit signal of digital stage before DAC. An equation to update the coefficient of FIR filter is given by [8]

$$W_{k+1} = W_k + 2\mu e_k X_k \tag{2}$$

where μ is step size. Firstly, LMS algorithm estimates coefficient to minimize the error by using Equation (2). Next, the estimated coefficient is applied to a FIR filter. Next, the transmit signal pass through the FIR filter, thereby output of the FIR filter becomes similar to the self-interference. Finally, the self-interference is cancelled by subtracting the output signal of FIR filter from the receive signal in digital stage.

3.4. Turbo Equalizer

In this paper, we use a turbo equalizer to equalize ISI channel and correct bit error by the residual self-interference. The turbo equalizer increases a performance of communication system by combining with equalizer and decoder and by iterating LLR value [9].

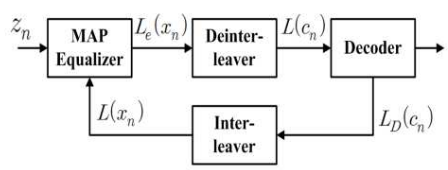


Figure 3: Block diagram of turbo equalizer.

Figure 3 shows block diagram of turbo equalizer. The turbo equalizer consists of MAP equalizer, deinterleaver, decoder and interleaver. The MAP equalizer shows to perform best. The deinterleaver restores mixed bit sequence by the interleaver. The decoder corrects bit error of encoded bit stream. Output of the MAP equalizer is given by [9]

$$L_e(x_n) \cong \ln \frac{P(x_n = +1 | z_1, \ldots, z_{K_c})}{P(x_n = -1 | z_1, \ldots, z_{K_c})} - \log \frac{P(x_n = +1)}{P(x_n = -1)} \tag{3}$$

where Output of the MAP equalizer is calculated by subtracting a prior probability LLR value from a posterior probability LLR value. z_n, $n = 1, 2, \ldots, K_c$ is receive symbol. The prior probability

$L(x_n)$ that is output of the interleaver shows prior information by generation probability of x_n. $L(x_n)$ is calculated by the decoder. In initial equalization step, $L(x_n) = 0$ because there is a prior information. In the decoder, a posterior probability $P(c_n = x|L(c_1, \ldots, L(c_{K_c})),\ x \in B$ is calculated by using $L(c_n)$. Output of the MAP decoder is given by [9]

$$L_D(c_n) = \ln \frac{P(c_n = +1|L(c_1), \ldots, L(c_{K_c}))}{P(c_n = -1|L(c_1), \ldots, L(c_{K_c}))} - \ln \frac{P(c_n = +1)}{P(c_n = -1)} \tag{4}$$

where $L(c_n)$ is output of the MAP equalizer. And $L(c_n)$ is calculated by passing $L_e(x_n)$ through the deinterleaver. Output of the MAP decoder feed back to the MAP equalizer through the interleaver. In the MAP equalizer, output of the MAP decoder is used as a prior probability. The turbo equalizer improves the equalization performance by iterating this mechanism. Finally, the MAP decoder decides data bits. Decision equation of data bits is given by [9]

$$\widehat{b}_i = \arg\max_{b \in \{0,1\}} P(b_i = b|L(c_1), \ldots, L(c_{K_c})) \tag{5}$$

4. SIMULATION RESULTS AND ANALYSIS

In this paper, we use the Simulink simulation program to analysis performance of the proposed SSD system using turbo equalizer. In this paper, we consider that power of transmit signal is 20 dB. And, we consider that power of self-interference by multi-path fading is −40 dB. We consider that balanced feed network that isolates transmit path and receive path has phase shift error of 0.5 degrees. In this paper, for digital cancellation, we use a LMS algorithm which has 32 taps. A step size of the LMS algorithm is 0.001. In this paper, we consider that power of transmit signal is 20 dB. We consider that power of receive signal from distant station is −70 dB.

Table 1: Simulation parameters.

Parameters	**Values**
Modulation	QPSK
Adaptive algorithm	LMS
Number of taps	32
Step size	0.001
Channel	Proakis A, Proakis B, Proakis C
Channel coding	Convolution code
Code rate	3/4
Equalizer	Turbo Equalizer
Number of iteration	0, 1, 2, 3, 4

Table 1 shows simulation parameters.

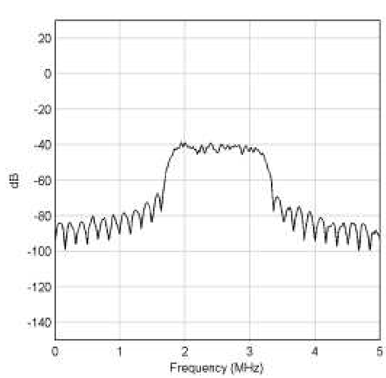


Figure 4: Spectrum of multipath self-interference signal.

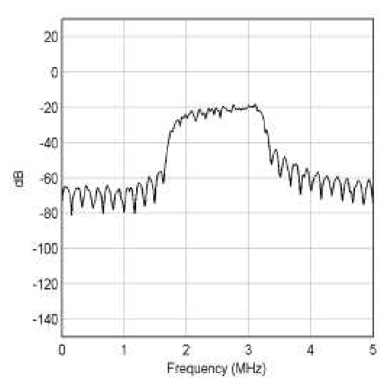


Figure 5: Spectrum of receive signal after balanced feed network.

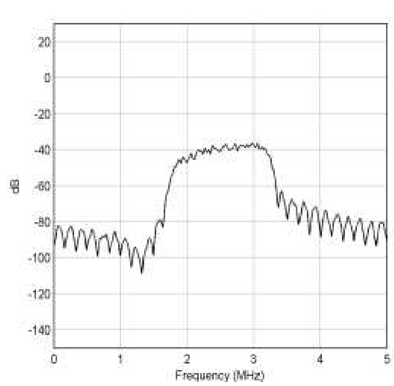


Figure 6: Spectrum of signal after RF cancellation.

Figure 4 shows spectrum of self-interference by multi-path fading. In this paper, we consider that power of self-interference by multi-path fading is −40 dB.

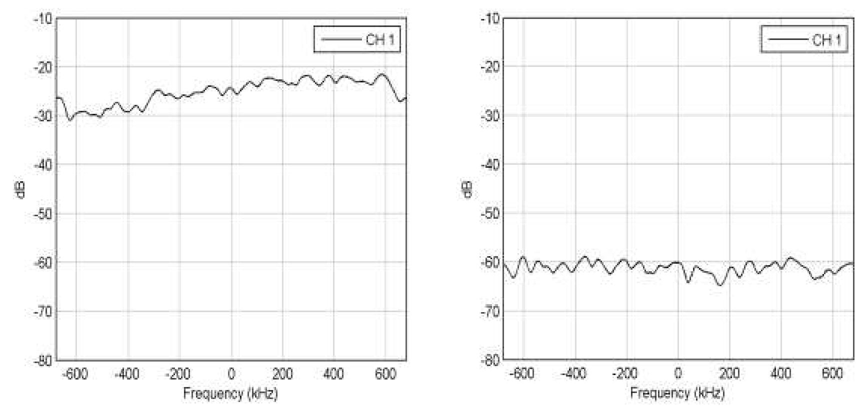
Figure 5 shows spectrum of a receive signal after it has passed through balanced feed network. We can confirm that power of the receive signal after balanced feed network. This signal consists of desired signal, self-interference by multi-path fading and leakage signal of transmit signal from balanced feed network. In receiver path, leakage signal of transmit signal after balanced feed network is larger than desired signal from distant station. Therefore it is impossible to decode desired signal information in receive signal. Therefore, for decode desired signal information, the proposed system requires additional self-interference cancellation method.

Figure 6 shows spectrum after RF cancellation. RF cancellation cancels leaked self-interference signal from balanced feed network. In Fig. 6, we can confirm that self-interference of 20 dB is additionally cancelled by RF cancellation. But, self-interference signal after RF cancellation is larger than desired signal which has power of -70 dB. Therefore, it is impossible to decode desired signal information in receive signal. Therefore, for decode desired signal information, the proposed system requires additional self-interference cancellation method.

Figure 7 shows spectrum of signal after and before digital cancellation. We can confirm that power of signal before digital cancellation is -25 dB ~ -30 dB. We can confirm that power of signal after digital cancellation is -60 dB ~ -65 dB. We can confirm that self-interference is cancelled 30 dB $\sim$ 35 dB additionally.

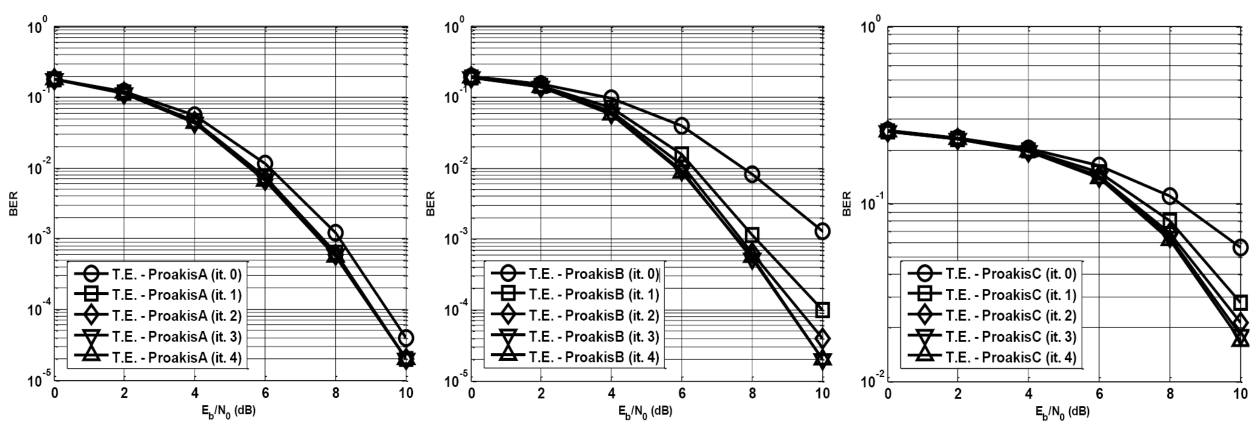
Figure 8(a) shows performance of the proposed system according to iteration of turbo equalizer in Proakis A. Multi-path fading of Proakis A channel is worse than multi-path fading of Proakis B and Proakis C channel. In Proakis A channel, when the number of iterations of turbo equalizer is 1, performance of the proposed system is saturated. In this paper, we can confirm that performance of the proposed system is 2×10^{-5} at 10 dB when the number of iterations of turbo equalizer is 1 in Proakis A channel.

Figure 8(b) shows performance of the proposed system according to iteration of turbo equalizer in



(a) (b)

Figure 7: Spectrum of signal after digital cancellation, (a) before (b) after.



(a) (b) (c)

Figure 8: BER performance of proposed system according to global iteration in Proakis A, Proakis B and Proakis C channel. (a) Proakis A channel. (b) Proakis B channel. (c) Proakis C channel.

Proakis B. In Proakis B channel, when the number of iterations of turbo equalizer is 3, performance of the proposed system is saturated. In this paper, we can confirm that performance of the proposed system is 2×10^{-5} at 10 dB when the number of iterations of turbo equalizer is 3 in Proakis B channel.

Figure 8(c) shows performance of the proposed system according to iteration of turbo equalizer in Proakis C. Proakis C channel is harsh multi-path fading channel. In this paper, we can confirm that performance of the proposed system is 2×10^{-5} at 10 dB when the number of iterations of turbo equalizer is 4 in Proakis C channel.

5. CONCLUSION

In this paper, we propose the SSD system using turbo equalizer. In the proposed system, self-interference is cancelled 40 dB by balanced feed network, and self-interference is cancelled 20 dB by RF cancellation. Finally, self-interference is cancelled 30 dB $\sim$ 35 dB by digital cancellation. Totally, performance of self-interference cancellation of the proposed system is 90 dB $\sim$ 95 dB. That is, we can confirm that it is possible to decode desired signal through turbo equalizer in the proposed system. In the proposed system, self-interference is cancelled 90 dB totally in Proakis A, Proakis B and Proakis C channel.

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