別紙４－１（課程博士（英文））

Date of Submission: Jan. 7th, 2021

Department of Electrical and Electronic Information Engineering	Student ID Number	D143229
Applicant's name	Kazuki Komatsu	

Supervisors	Hideyuki Uehara Takashi Ohira Shuichi Ichikawa

Abstract (Doctor)

Title of Thesis	Nonlinear Self-Interference Cancellers for In-Band Full-Duplex Radios

Approx. 800 words

As the demand for wireless communications is increasing unabated, the achievement of efficient frequency utilization is an ongoing challenge. In-band full-duplex (IBFD) technology, which simultaneously transmits and receives on the same frequency band and can theoretically achieve twice the spectral utilization efficiency of conventional half-duplex systems, is an emerging technique in recent wireless communications. However, self-interference (SI) interferes significantly with the desired signal propagated from another terminal and disturbs the system capacity, as the distance between the transmission and reception antennas is extremely close compared to the distance between the terminal and another terminal. Unfortunately, orthogonal frequency division multiplexed (OFDM) modulation, which is commonly used in numerous systems at present, causes a high peak-to-average power ratio and the nonlinearities of the terminals have a significant impact on the signals. Furthermore, SI is distorted by other transceiver non-idealities, such as imbalances of the I/Q mixers and the phase noise of the local oscillators. Thus, the IBFD literature includes reports of nonlinear SI cancellers that have been developed to achieve improved cancellation performance. However, nonlinear cancellers exhibit certain problems, such as high computational complexity, the requirement of large training data, and vulnerability to the nonlinearity of low-noise amplifiers (LNAs). Moreover, no theoretical studies have been conducted on the performance of IBFD radios with nonlinear cancellers. This thesis presents studies on nonlinear cancellers with regard to the above problems.

Chapter 1 provides a general introduction to and summary of this thesis. It contains the background of the studies in this thesis and details of time-domain parallel Hammerstein cancellers, which are among the most well-studied SI cancellers.

In Chapter 2, a frequency-domain Hammerstein canceller is proposed, which achieves low computational complexity while taking into account the nonlinearity of I/Q mixers and power amplifiers (PAs). In the training period of the proposed canceller, discontinuities are produced in the OFDM symbols without destroying the cyclic prefix structure, and the parameter estimator can estimate the discontinuities of the SI signal with high accuracy in the frequency domain. In the cancellation period, the time-domain SI signal is regenerated with the estimated frequency response by the overlap-save method. The performance of the proposed scheme is assessed by equivalent baseband signal simulations of an IBFD transceiver. As a result, the proposed scheme achieves as high SI cancellation as time-domain parallel Hammerstein cancellers with a low computational cost. Furthermore, the results demonstrate that the convergence performance of the proposed scheme is faster than that of the time-domain scheme.

In Chapter 3, a basis function selection technique is presented to reduce the computational cost further and to improve the convergence performance of the frequency-domain Hammerstein canceller, which is presented in Chapter 2. The power spectral density (PSD) of the nonlinear SI signal is

theoretically analyzed in detail and a nonlinear SI PSD estimation method is developed. The proposed selection technique determines the basis functions that are necessary for cancellation and relaxes the computational cost of the frequency-domain Hammerstein canceller based on the estimated PSD of the SI of each basis function. Thereafter, the simulation results are presented, demonstrating that the proposed technique can achieve similar cancellation performance to the original frequency-domain Hammerstein canceller and a time-domain parallel Hammerstein canceller. It is also shown that the proposed technique improves the computational cost and convergence performance of the original frequency-domain Hammerstein canceller.

In Chapter 4, an iterative nonlinear SI canceller is proposed to consider the nonlinearities of not only the PA and I/Q mixers, but also the LNA. The estimation process of the proposed scheme consists of three stages: the channel response estimation, I/Q imbalance estimation, and PA and LNA nonlinearity estimation. The channel response is estimated in the time domain, whereas the I/Q imbalance and nonlinearities are estimated in the frequency domain by using features of OFDM modulation for a more straightforward estimation and superior accuracy. In the cancellation process of the proposed scheme, the received signal is compensated for with the estimated parameters of the LNA and receiver I/Q imbalance prior to cancellation, because the desired signal is received with a high-power SI and is distorted by the radio frequency impairments of the receiver. The simulation results reveal that the proposed technique can achieve higher cancellation performance than the Hammerstein canceller when the LNA is saturated by SI. Moreover, the performance of the proposed canceller converges much faster than that of the time-domain parallel Hammerstein canceller.

In Chapters 2 to 4, the development of cancellers that can achieve higher cancellation performance and a lower computational cost is presented, but a more detailed discussion of nonlinear cancellers is required to improve the performance of IBFD radios further. For a more in-depth discussion, Chapter 5 presents a theoretical analysis technique that takes into account the PA and LNA nonlinearities for IBFD radios with parallel Hammerstein SI cancellers. The envelope of an OFDM signal with a sufficiently large number of subcarriers can be assumed to follow a complex Gaussian distribution according to the central limit theorem. Thus, the nonlinear characteristics of the system can be expanded by a generalized Fourier series using orthonormal Laguerre polynomials. Subsequently, the canceller performance and system symbol error rate (SER) are analyzed using the obtained Fourier coefficients. The analytical results are compared with the simulation results, demonstrating strong correlation in various situations, from extremely nonlinear cases to good linear cases. Furthermore, the results demonstrate that the SER of the IBFD system is reduced by moderately nonlinearizing rather than linearizing the amplifier.

Chapter 6 concludes this thesis and provides a discussion on future works.