Effective Self-Interference Cancellation for IBFD (In-Band Full Duplex) Communication System

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Abstract **- As the technology has been evolved from 4G to 5G, data traffic growth has been explosively increasing due to the emergence of various applications. In order to satisfy the tremendous required traffic, it is necessary to improve the frequency bandwidth or the signal-to-noise ratio (SNR) in accordance with Shannon's law. However, since there is a limit in the frequency resource, it has become very important to improve the spectral efficiency. In-Band Full Duplex (IBFD) systems can improve spectral efficiency up to 2 times. In this IBFD system, the Self-Interference (SI) occurs inherently, so the desired received signal cannot be demodulated. Self-Interference Cancellation (SIC) must be required to solve this problem. In this paper, a Balanced Feed Network (BFN) based system is designed and evaluated to improve SIC performance at the target frequency 2.45GHz. Simulation results show that the SIC performance is improved by 3 dB compared to the existing system. However, it is also confirmed that the transmission power is decreased by 3 dB.**

Keywords - IBFD, SIC, Spectral Efficiency, Balanced Feed Network, Self-interference

I. INTRODUCTION

Mobile communication started from 1G has come to the age of commercialization of 5G due to technological advancement over time. Of these, data network-based communication started from 4G and data traffic began to explode as various applications and platforms appeared. Therefore, it is essential to improve the throughput in order to satisfy the traffic requirement. Throughput is defined by Shannon's law[1-2].

$$C = W \cdot log_2(1+S/N) \tag{1}$$

Equation (1) represents Shannon's law. Where W is bandwidth, S is signal power, and N is noise power. According to Shannon's law, throughput is determined by the frequency bandwidth and the SNR. It is difficult to increase the bandwidth and the SNR by more than a certain amount. Because of the lack of frequency resources, the millimeter waveband was adopted as standardization in 5G. In order to increase the SNR, the signal output must be increased. However, considering the nonlinearity of the HPA, it is difficult to raise the SNR more than a certain power. As a result, increasing the spectral efficiency has become a way to improve throughput.

There are many ways to increase spectral efficiency. Use waveform design to narrow the guard band width between adjacent channels by reducing spectral out-of-band (OOB) power. When the guard band width is narrowed, the bandwidth occupied by each channel is narrowed. As a result, the spectrum can be efficiently used. Waveform design methods include WR-OFDM, FBMC, and UFMC.

Another method is to transmit / receive simultaneously in the same time, same band using IBFD, or to increase bps per Hz using MIMO technology. In this system, Shannon's law can be modified as follows.

$$C = a \cdot W \cdot log_2(1+S/N) \tag{2}$$

Equation (2) is modified from Shannon's law. a is a constant 2 in the IBFD system in the ideal environment and min (Tx, Rx) in the MIMO system[3].

This paper deals with SIC performance, which is the biggest problem of IBFD. In the IBFD system, the power of the SI is about 110 dB larger than that of the signal transmitted from the other station. Without SIC, it is impossible to distinguish signals received from other stations and communication is impossible. Or you need to use the highly-efficient Analog-Digital Converter(ADC), which increases the price of the system exponentially. Therefore, SIC must be essential for using the IBFD system[4-9].

In this paper, a BFN based SIC system is designed and its performance is evaluated. In order to compare the performance, the existing single-BFN and double-BFN systems are designed and compared with the system designed in this paper.

II. BFN BASED SIC SYSTEM

A. Self-Interference Cancellation

Since the intensity of the SI is about 110 dB higher than the intensity of the signal transmitted from the other station[7], it is most important to remove the interference. As shown in Figure 1, the signal transmitted from the transmitting antenna enters the receiving antenna portion, and the SI occurs. The SI is divided into a case of being generated by the LoS (Line of Sight) and a case of being reflected by the antenna peripheral structure.

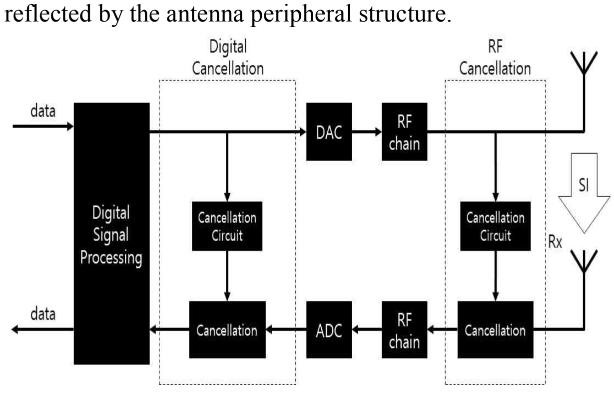

Fig. 1. Block diagram of SI generation and removal.

RF cancellation generally uses an attenuator and a phase shifter to remove SI. After the signal is attenuated by the amount of attenuation while the SI intensity is propagated from the transmitting antenna to the receiving antenna, the signal is shifted to the opposite phase and then the two signals are summed to eliminate the SI.

Digital Cancellation has various methods such as a method of using deep learning or an adaptive algorithm- based method[5].

B. Balanced Feed Network

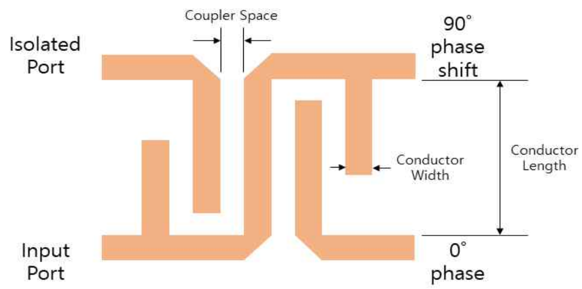

Fig. 2. Structure and parameters of lange coupler

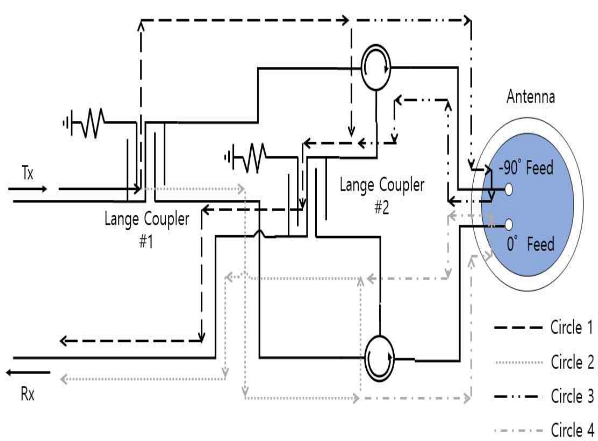

Fig. 3. Configuration diagram of BFN

Figure 2 shows the structure and parameters of the Lange Coupler[9]. The Lange Coupler is a four-port circuit that operates the same function as the Quadrature Hybrid circuit. When the signal enters the input stage, it outputs a signal whose phase is the same as that of the output and a shifted by 90 degrees.

Figure 3 shows the BFN configuration[8]. When the transmission signal passes through the first Lange Coupler, the signal is split and transmitted in the form of Circles 1, 2. At this time, the power of each signal is reduced by 3dB from the original signal. In Circle 1, a signal whose output is 90 degrees out of phase reaches the antenna through the circulator. In Circle 2, the phase of the output is intact and reaches the antenna through the circulator. The antenna uses a patch antenna and a special antenna with two feedlines. If the transmitter / receiver has an antenna, the SI due to the LoS is generated. If only one antenna is used, it can be removed originally. Each feed consists of a feed with a 0 ° phase and a feed with a -90 ° phase. Since the signal flowing in Circle 1 is rotated by 90 degrees, when the antenna is connected to the feed having the phase of -90 degrees, the phase becomes 0 degree. Since the signal flowing in Circle 2 is the same in phase, if the antenna is connected to a feed having a 0-degree phase, the phase of the signal coming into the antenna in both circles is 0 ° both, so the power of the transmitted signal is directly transmitted to the antenna.

The SI occurs in two cases. The first case is caused by Isolation of Circulator. At this time, SI occurs in the path of circles 1 and 2. The second case is caused by the S-parameter characteristics of the antenna. At this time, SI occurs in the path of Circle 3 and 4.

The principle of SI cancellation is removed in the same way regardless of the two previous cases. The method is as follows. The signal from the first Lange Coupler is divided into two parts, and it enters the second Lange Coupler through each Circulator. The signals of Circles 1 and 3 enter the port of 90 degrees phase of the second Lange Coupler and the signals of Circles 2 and 4 The signal enters the port with a zero degree phase. In this case, since the signals of Circles 1 and 3 have already shifted in phase by 90 degrees, the second lange coupler is shifted by 90 degrees and becomes a signal having a phase of 180 degrees. The signals of circles 2 and 4 go into and out of the 0 degree port of two Lange Couplers, so there is no phase rotation. Therefore, when the signals of Circles 1, 3 and Circles 2, 4 are added together in the second Lange Coupler, the signals having the same power but opposite phases are added together. In this paper, we design the system using the principle of BFN.

C. BFN based SIC system

In this paper, we constructed the system based on the above-mentioned BFN. Figure 4 shows the configuration of a triple-BFN system as an example of a BFN-based system configuration. The transmitted signal is divided into equal parts of the BFN by the power splitter, and the signal is transmitted to the antenna only at the upper BFN 1. The received signal goes through the first BFN and then goes into the Power Combiner without going through the Phase Shifter. In the two BFNs below, the SI is generated, and then each phase is rotated by the Phase Shifter, and the signals from the three BFNs are summed to remove the SI.

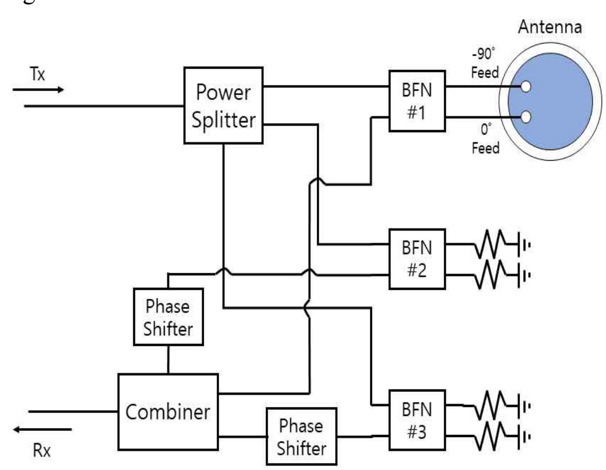

Fig. 4. Example of BFN based system

III. Simulation Configuration and Results

TABLE I. SIMULATION PARAMETERS CONDITION

Parameters		***Value***
Lange Coupler	W	0.0406mm
	S	0.0381mm
	L	40.1mm
	Hw	15mil
	W1	25mil
SIC Target Frequency		2.45GHz
Terminal Impedance		50 Ohm

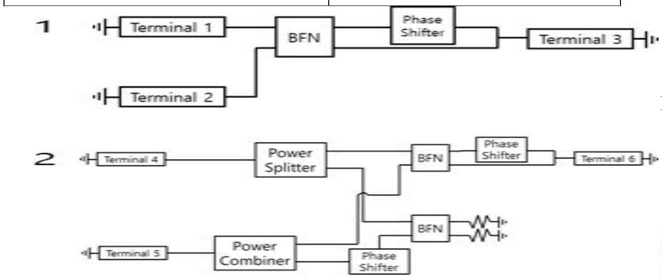

Fig. 5. Simulation diagram of signal power attenuation in existing system

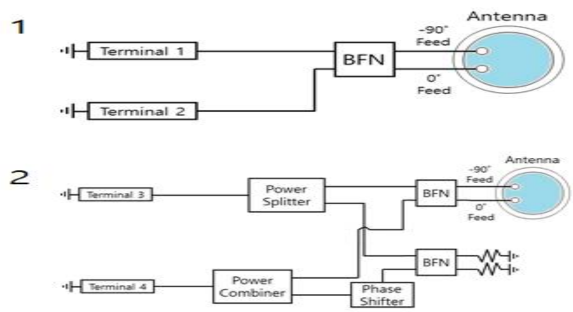

Fig. 6. SIC performance evaluation diagram in existing system

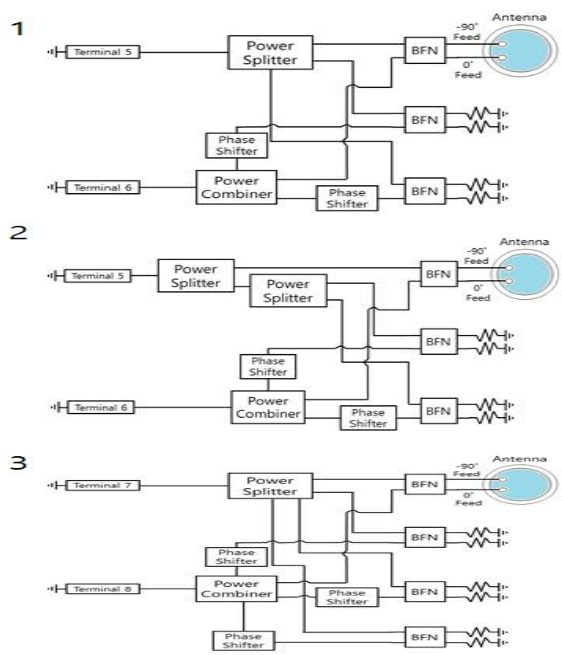

Fig. 7. Block diagram of each designed system

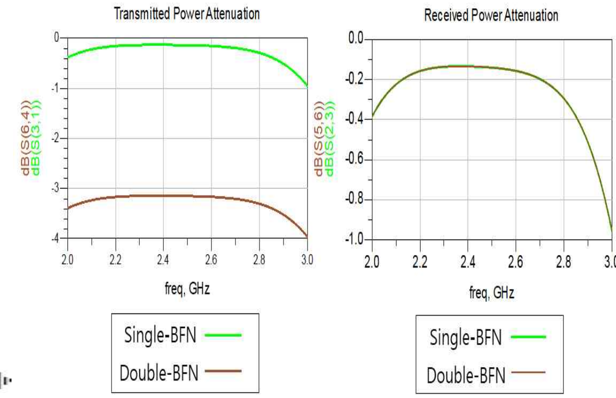

Fig. 8. Evaluation of attenuation of signal power of existing system

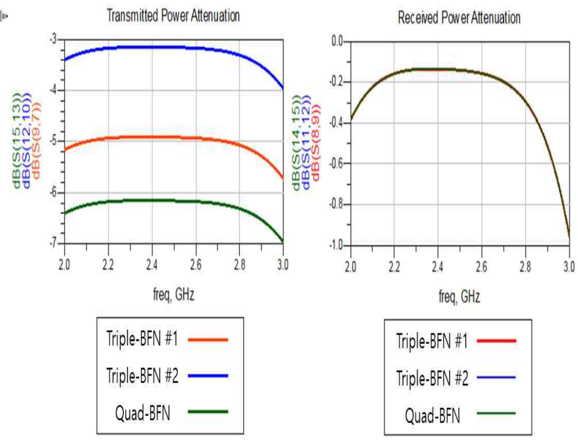

Fig. 9. Evaluation of attenuation of signal power of designed system

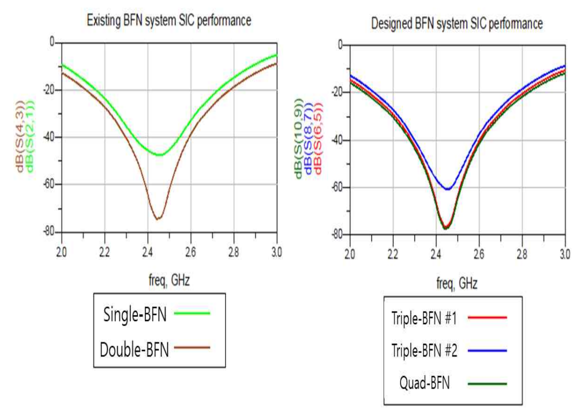

Fig. 10. SIC performance evaluation result of existing and designed system

In this paper, the conditions of the simulation parameters are shown in Table 1 to design the BFN-based system and evaluate its performance. All of the simulations conducted in this paper were conducted using the Advanced Design System tool.

In this paper, we evaluate the performance of a single-BFN system and a double-BFN system before evaluating designed system performance. Figure 5 is a schematic diagram for simulating attenuation of transmit / receive signal power of the system. 1 indicates Single-BFN, and 2 indicates Double-BFN system. Figure 6 shows the SIC performance evaluation of the system. After that, all the designed systems are configured as shown in Figures 5 and 6, and the performance evaluation is carried out. The impedance of all the terminals was 50 ohms.

Figure 7 shows the structure of the system designed in this paper. 1 and 2 are composed of three BFNs, and three are composed of four BFNs. The difference between systems # 1 and # 2 is that two power splitters are used in transmission system # 2 to improve the transmission signal strength attenuation performance. The receiver Power Combiner was configured identically.

Figure 8 shows the performance evaluation of the transmit / receive signal power attenuation of the existing system. Single-BFN attenuates transmission signal strength by about -0.1dB and Double-BFN by about -3.1dB. In both systems, the received signal strength attenuation was equal to -0.1 dB.

Figure 9 shows the performance evaluation of the transmit / receive signal power attenuation for the designed system. Triple-BFN # 2 has the best transmission signal power attenuation performance and Quad-BFN performance is worst. In all three systems, the received signal power attenuation was -0.1dB.

Figure 10 shows the SIC performance evaluation of the existing system and the system designed in this paper. The SIC performance of Single-BFN is -47dB and the performance of Double-BFN is -74dB at 2.45GHz frequency. Triple-BFN # 1 and # 2 performances are -76dB and -60dB, respectively. Quad-BFN performance is -77dB, which is the best performance of each system.

TABLE II. SIC PERFORMANCE EVALUATION RESULT OF EACH SYSTEM

System	***Tx Power***	***Rx Power***	***SIC performance @ 2.45GHz***
Single-BFN	-0.1dB	-0.1dB	-47dB
Double-BFN	-3.1dB	-0.1dB	-74dB
Triple-BFN #1	-4.9dB	-0.1dB	-76dB
Triple-BFN #2	-3.1dB	-0.1dB	-60dB
Quad-BFN	-6.1dB	-0.1dB	-77dB

Table 2 summarizes the simulation results of each system. The SIC performance of the Quad-BFN was -77dB at the frequency of 2.45GHz, but the attenuation of the transmitted signal strength was the largest at -6.1dB. The received signal strength attenuation was the same at -0.1 dB for all systems.

IV. CONCLUSIONS

In this paper, a BFN-based system is designed and evaluated to obtain effective SIC performance. In this paper, we evaluate the performance of each system by constructing a single-BFN system and a double-BFN system to evaluate and compare the performance of the designed system. After evaluating the performance of the designed system, we compared the performance with the existing system. Simulation results show that the received signal strength attenuation is equal to -0.1 dB in all systems. The transmit signal strength attenuation was -6.1 dB for Quad-BFN, which was 3 dB lower than the conventional double-BFN. However, the SIC performance is improved to -77 dB for the best performance, which is -3 dB better.

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