Enhanced Security Communication System Using Digital Retrodirective Array Antenna

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Abstract

Fast beam tracking and beamforming technology are essential for the communication signal quality of high-capacity and high-quality. In this paper, we design a digital retrodirective array antenna (RDA) system possible for beamforming technology without any prior location information for signal quality improvement and security improvement. Simulation results show phase conjugation scheme has better BER performance about 1dB and 3dB at the source than that of without phase conjugation, when phase delay is 15° and 30°.

Keywords: *Digital retrodirective array antenna, phase lock loop, bandpass sampling, phase detector, phase conjugation*

1. Introduction

Interest in communication security is increasing due to development of communication technology. The communication system for improved security has been studied. Especially, interest in retrodirective array antenna (RDA) technique is increasing as one way for improving security. RDA can transmit signal toward the source without any priori information of the arrival direction [1-3]. RDA has more simple structure than smart antenna technique and it is possible to do automatically beam-tracking. Also, RDA has merit such as high link gain, easy interference elimination, and high energy efficiency.

The design of phase conjugation in RDA is important in order to estimate correct direction of arrival (DOA). Various schemes have been studied to design efficient phase conjugation. Above all, Corner reflector and Atta Array methods are well known as analogue phase conjugation method [4-6]. The Corner reflector scheme is contributed by placing two intersecting flat reflectors perpendicular to each other. Van Atta Array is a planar or linear array in which the elements with equidistance from the array center are interconnected in pairs with lines of equal length. The implementation of passive RDA systems is easy. But, this technique is difficult to modify or upgrade.

Another RDA system using heterodyne mixer is already well known [7-8]. This technique is using local oscillator ($w_{LO} = 2w_{RF}$) of twice RF frequency.

$$\begin{aligned} V_{IF} &= V_{RF}\cos(w_{RF}t+\theta_{RF})\times V_{LO}(\cos w_{LO}t) \\ &= \frac{1}{2}V_{RF}V_{LO}[\cos((w_{LO}-w_{RF})t-\theta_{RF})] \\ &\quad +\cos((w_{LO}+w_{RF})t+\theta_{RF}) \end{aligned} \tag{1}$$

where θ_{RF} is phase information. When the frequency of local oscillator has twice RF frequency ($w_{LO} = 2w_{RF}$), the output signal has opposite sign phase $-\theta_{RF}$ of input signal θ_{RF} as you can see in $\cos(w_{RF}t - \theta_{RF})$. But, Heterodyne RDA scheme has disadvantage like required additional RF device such as mixer and local oscillator.

Digital RDA system using direct down-conversion scheme is proposed for resolving these problem. But, this scheme has disadvantage that the system has sensitivity to frequency offset and DC offset because of using direct conversion. To solve the problem of digital RDA based on direct conversion, Digital RDA system based on bandpass sampling (BPS) is proposed [9-11].

To improve communication security, a variety of technique has been studied. Most of study of the improved communication security has been investigated at the network layer. This paper, we study the security of communication from at physical layer. To enhance communication security at physical layer, we adapt digital RDA system based on bandpass sampling. Digital RDA system has strong characteristics to eavesdropping or wiretapping because of making automatically the beam forming. Also, Digital RDA system can efficient communicate using beamforming scheme.

In this paper, we design and analyze BER performance of digital RDA system based on bandpass sampling for security communication.

2. System model

Figure 1 shows system model using digital RDA system. Here, Transmitter at the source can transmit Tx.signal to retrodirective antennas. Digital RDA can retransmit Tx.signal toward to at the source. The Tx.signal is received with a progressive phase shift across a retrodirective aperture that is an antenna array. The progressive phase shift contains the information of direction of the received beam.

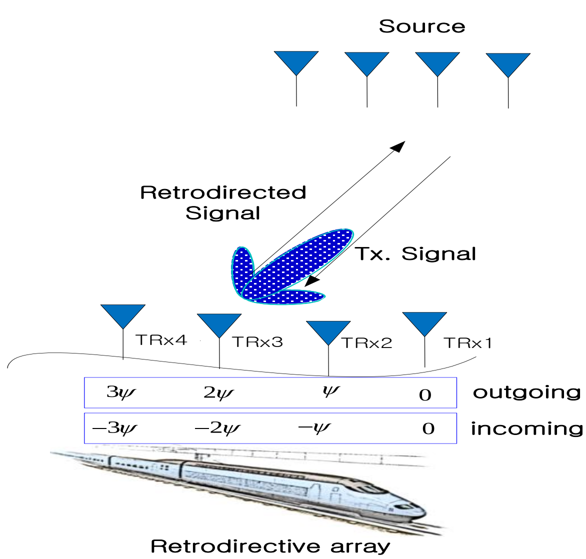


Figure 1. Retrodirective antenna for fast beam tracking

The incoming signal at TRx 2 is generated phase delay $-\psi$ compare to that of TRx 1, when each antenna received Tx.signal. The outgoing signal at TRx2 is transmitted after processing phase conjugated. In this paper, we consider two retrodirective array antenna cases.

3. Digital retrodirective array antenna

A direct RF-undersampling retrodirective array system is proposed. We analyze the reception performance of this system in AWGN channel. This paper, we assume that there are two receive array element. Each array element receives the signal with different phase delay. This system is doing down-converting using bandpass sampling scheme to IF band and then doing AD converting. Bandpass sampling rate of A/D converter need to satisfy the following condition:

$$f_s \geq 2B \qquad (2)$$

where B is signal bandwidth, f_s is the sampling frequency. Digital phase lock loop (DPLL) is used to estimate phase difference between different arrays in digital retrodirective array system. It consist three components which are phase detector, the loop filter, Numerically Controlled Oscillator. Phase detector is to estimate difference the incoming signal and the reference signal.

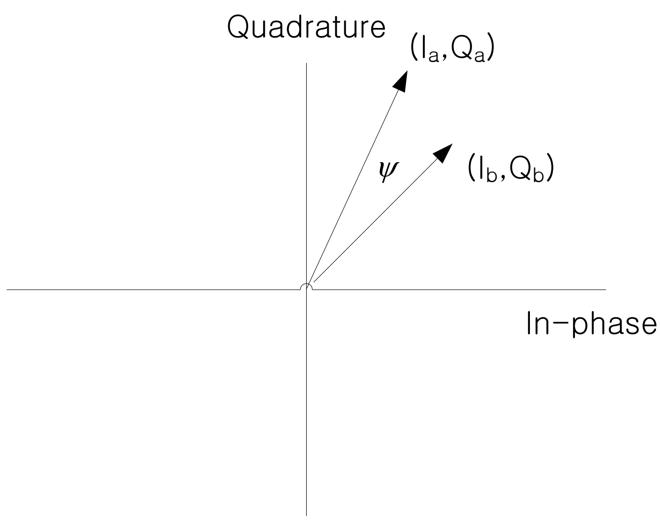


Figure 2. Phase difference between data (I_a, Q_a) and correct point (I_b, Q_b)

The phase error θ between receive data (I_a, Q_a) and the correct point (I_b, Q_b) given by

$$\begin{aligned} e^{j\psi} &= e^{(\psi_a-\psi_b)} = \cos(\psi_a-\psi_b) + j\sin(\psi_a-\psi_b) \\ &= \cos\psi_a\cos\psi_b + \sin\psi_a\sin\psi_b \\ &\quad + j(\sin\psi_a\cos\psi_b - \sin\psi_b\cos\psi_a) \\ &= \frac{I_a}{\sqrt{I_a^2+Q_a^2}}\frac{I_b}{\sqrt{I_b^2+Q_b^2}} + \frac{Q_a}{\sqrt{I_a^2+Q_a^2}}\frac{Q_b}{\sqrt{I_b^2+Q_b^2}} \\ &\quad + j\left(\frac{Q_a}{\sqrt{I_a^2+Q_a^2}}\frac{I_b}{\sqrt{I_b^2+Q_b^2}} - \frac{Q_b}{\sqrt{I_b^2+Q_b^2}}\frac{I_a}{\sqrt{I_a^2+Q_a^2}}\right) \end{aligned} \qquad (3)$$

The constellation of correct point is $\sqrt{I_b^2 + Q_b^2} = \sqrt{2}$. Since $|\psi| \leq 30^o$, the phase difference θ can be approximated as

$$\psi \approx \sin\psi = \frac{1}{\sqrt{2(I_a^2 + Q_a^2)}} \cdot (I_b Q_a - I_a Q_b) \quad (4)$$

Normalize equation can be further simplified to be

$$\psi = (I_b Q_a - I_a Q_b) \quad (5)$$

Phase detector can be search phase information between antenna arrays by equation (5). Phase information between antenna arrays pass Loop filter block and Voltage controlled Oscillator (VCO) is shown Figure 3.

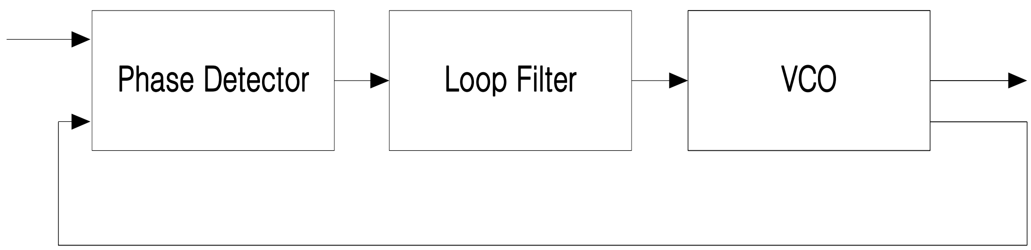


Figure 3. The Block Diagram of PLL

Phase Lock Loop (PLL) is closed-loop feedback control system that generates and output a signal in relation to the frequency and phase of an input signal. Retrodirective system can send data signal from retrodirective system to source conjugated phase signal.

4. Simulation

In this paper, we design the digital retrodirective array system based on bandpass sapling using MATLAB Simulink tool. Figure 4 shows Simulink model of the digital retrodirective array system. The signal of data rate with 25ksym/s is generated and passes through modulated as QPSK signal. Modulated data signal is pass thought up-converter, AWGN channel, and under-sampling processing block. Phase detector block can search phase information between at 1st (reference plan) and 2th- array element.

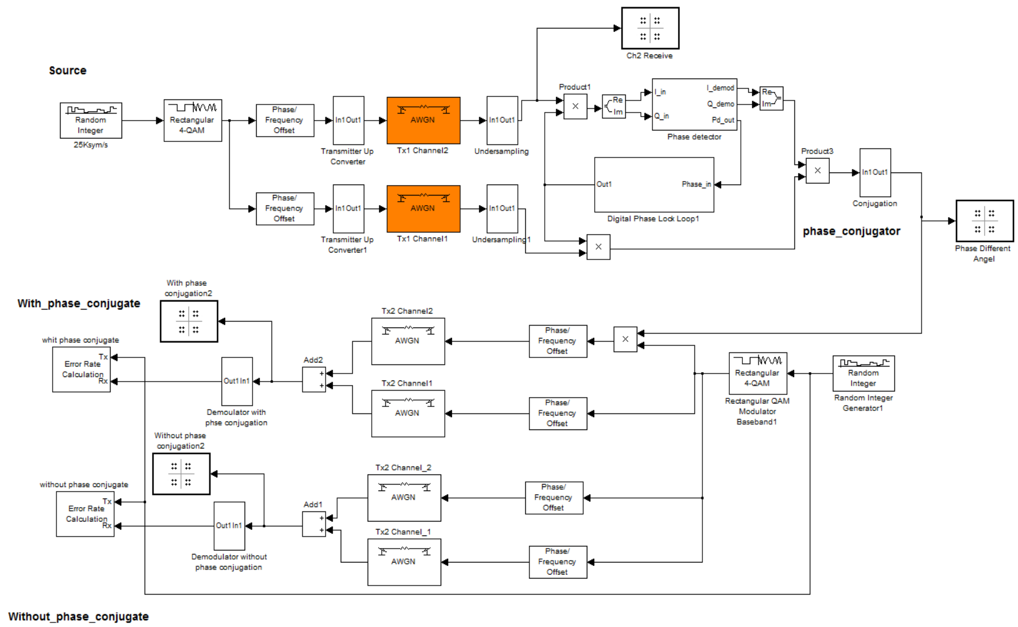
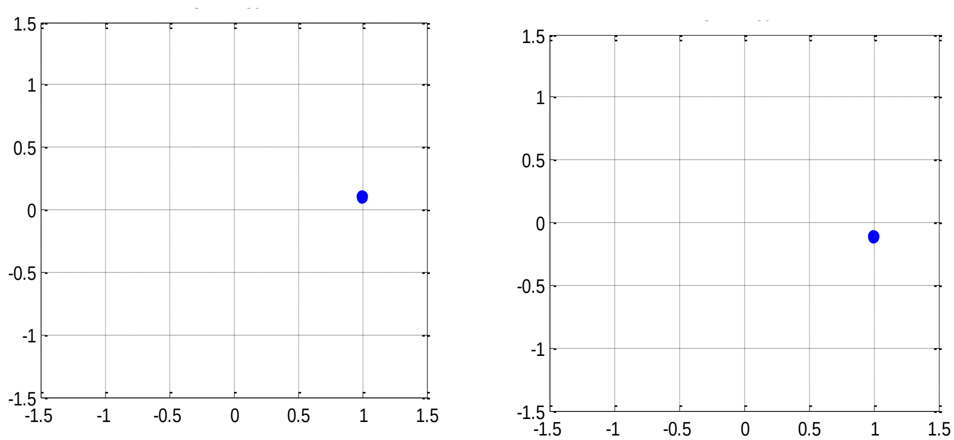


Figure 4. Simulink Model for the Digital RDA



(a) The output of phase detector (b) The output of phase conjugator

Figure 5. The Output of Phase Detector and Phase Conjugator

Figure 5(b) shows the output of phase conjugator. Figure 5(b) and Figure 5(a) is related by conjugation. We confirm that digital RDA can retransmit to direction of source by using the block of phase detection and phase conjugation. As a result, Figure 5(a) and Figure 5(b) shows the output phase detector and phase conjugator when phase delay is 10 degree and SNR of AWGN is 18dB.

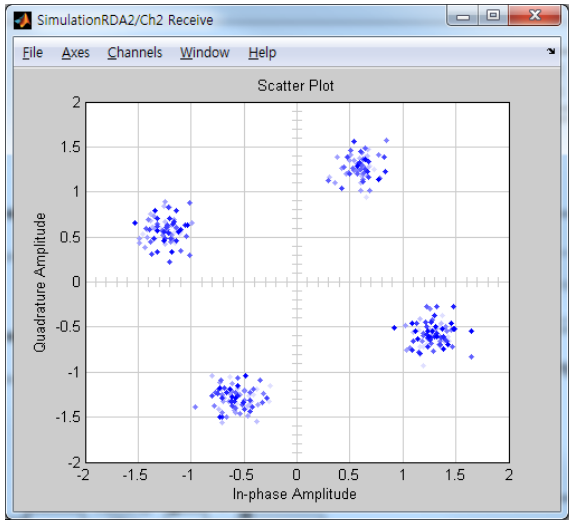


Figure 6. The Constellation of Received Signal at 2th Array Element

Figure 6 shows signal constellation when phase delay is 20°, SNR 15dB. The constellations of received signal at 2th antenna array are effected on phase rotation by time delay. The constellation of received signal at 1st antenna array cannot change comparing transmission signal.

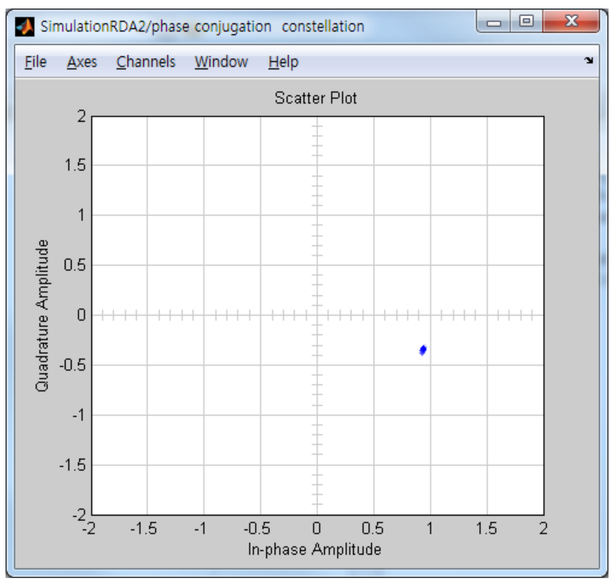
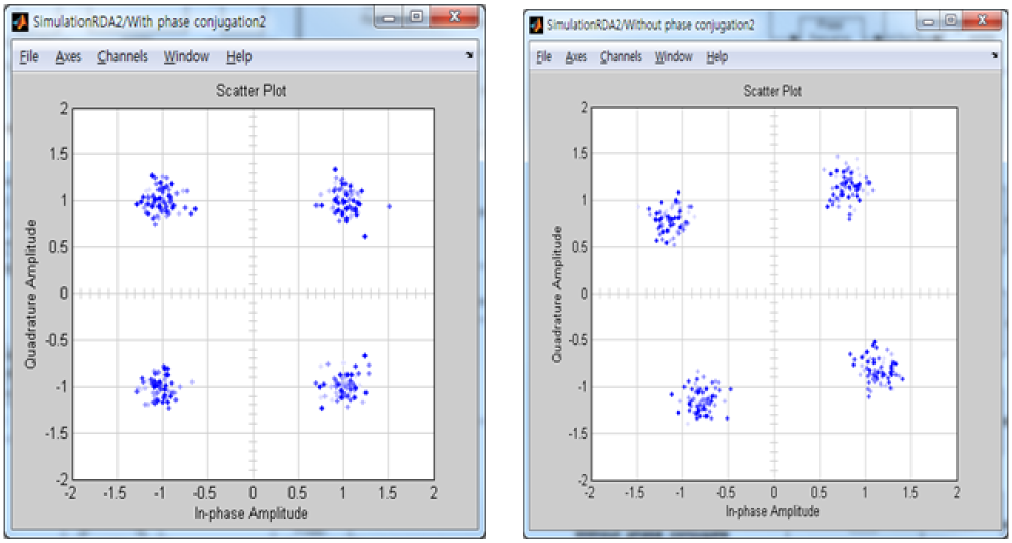


Figure 7. Phase information after phase conjugation

Figure 7 shows information about conjugated phase (-20°) by retrodirective system. Retrodirective array system can be found phase information between antenna arrays and set conjugated phase for transmission to source.



(a)w/ phase conjugation (b)w/o phase conjugation

Figure 8. The signal constellation by digital retrodirective array antenna

Figure 8(a) and (b) shows the received signal constellation at source. Phase conjugation scheme has correct constellation compare to without phase conjugation scheme.

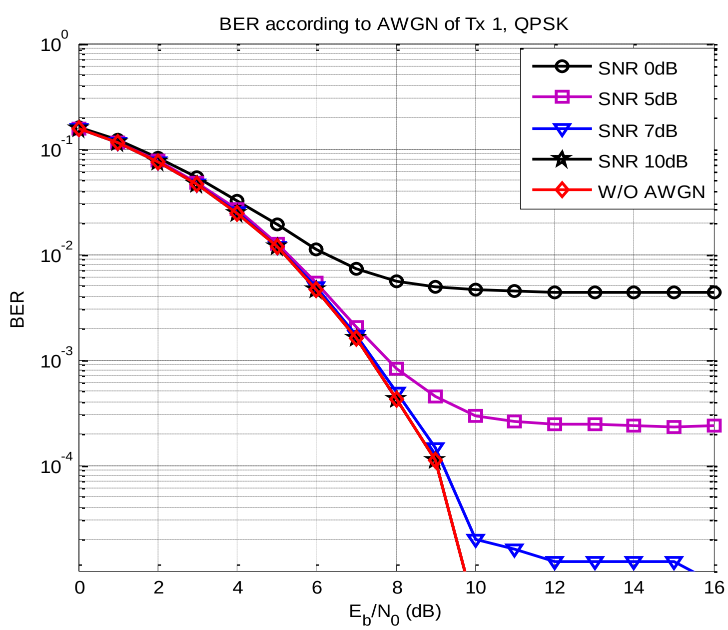


Figure 9. Comparison of BER performance according to Noise Level

Figure 9 shows BER performance at source according to noise level at retrodirective system. Error of phase detector is generated by noise signal when SNR is low. Retrodirective array system needs to operate over about SNR 10dB for correct phase detection.

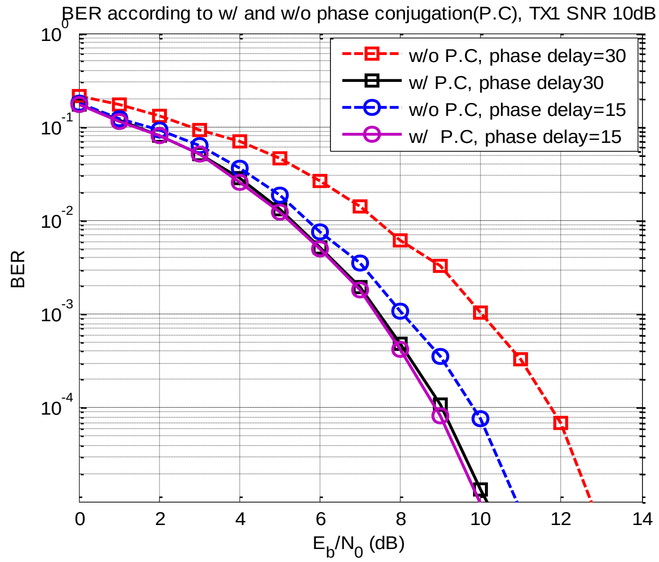


Figure 10. Comparison BER performance with and without Phase Conjugation

Figure 10 shows comparison BER performance at the source with and without phase conjugation. Phase conjugation scheme has better BER performance about 1dB and 3dB at source without signal processing than that of without phase conjugation when phase delay is 15 and 30.

5. Conclusion

In this paper, we analyze BER performance of digital retrodirective array system based on bandpass sampling considering noise environment of retrodirective system. Digital retrodirective array system does not require the RF analog circuit. Simulation results shows correct phase conjugation when the SNR of each source to retrodirective array is 10dB. Phase conjugation scheme has better BER performance about 1dB and 3dB at source without signal processing than that of without phase conjugation when phase delay is 15 and 30.

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