Analysis of Digital Retrodirective Array System Considering Multipath Signal

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***Abstract*— Retrodirective array antenna is possible to do automatically beam-tracking because it can control the phase information of the output signal toward opposite direction to input signal without a priori knowledge of the arrival direction. The receive performance of retrodirective array system is degraded considering multipath signal in wireless communication system. In this paper, we analyze the system performance of digital retrodirective array system using digital phase conjugation under multipath signal. Simulation results show that the error about phase and magnitude of direct signal direction occur in the present of multipath signal.**

***Keywords*— Retrodirective antenna, multipath signal, phase detection, phase conjugation.**

I. INTRODUCTION

The retrodirective array antenna can retransmit toward input direction without previous information about location of source. First, Van Atta in the United States proposed retrodirective system in 1959. Heterodyne mixing technique for retrodirective array system is proposed by Pon. in 1964[1-2]. The retrodirective array antenna has merits such as self beam tracking, high energy efficiency, high- link gain because transmission energy is concentrated in one direction. There have been many researches about retrodirective array system as the possibility that replaced a smart antenna which is using complex phase shifter and signal processing algorithms [3].

An analogue retrodirective array system using heterodyne mixer is already well known. 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 the $\cos(w_{RF}t-\theta_{RF})$. Analogue retrodirective array system has advantage that you can easily implement without complex signal processing. But, analogue retrodirective array antenna system has disadvantage required additional RF device such as mixer and local oscillator. Also, upgrade and modify of retrodirective array system is difficult because of using analogue device. Local oscillator which has twice RF frequency is required. It is difficult to design local oscillator has twice frequency of RF frequency.

In order to solve this problem, digital retrodirective array antenna using direct conversion is proposed [4-5]. This technique has the advantage that it is easy to modify and variable frequency. But, this technique has disadvantage that the system has sensitivity to frequency offset and DC offset by because of direct conversion method. Recently, the study was conducted about retrodirective array system using band pass sampling based on SDR in order to solve the problem with directive conversion method [6-7]. Retrodirective array system based on band pass sampling solves the problem with direct conversion method and is easy to update and modify.

Receive performance is degraded by multipath signal in the presence of the multipath signal in communication system. It is important to improve communication system quality through analysis of multipath signal. Multipath signals are exist when the signal arrived at different direction by reflection and scattering object such as mountains and buildings in wireless communication channel.

In this paper, we analyse the receive performance of digital retrodirective array antenna system based on band pass sampling under multipath signal. Direct signal is affected by indirect signals in presence of multipath signal. We design the digital retrodirective array system based on bandpass sampling by using Matlab Simulink and analyse the beam pointing error of retrodirective array system under multipath signal. Also, we analyse the effect on the BER performance of retrodirective array system under multipath signal.

II. DIGITAL RETRODIRECTIVE ARRAY SYSTEM

A. Retrodirective Array System

Figure 1 shows phase lag by incident wave when incident wave is θ. The phase lag of receive signal at each antenna can be expressed as

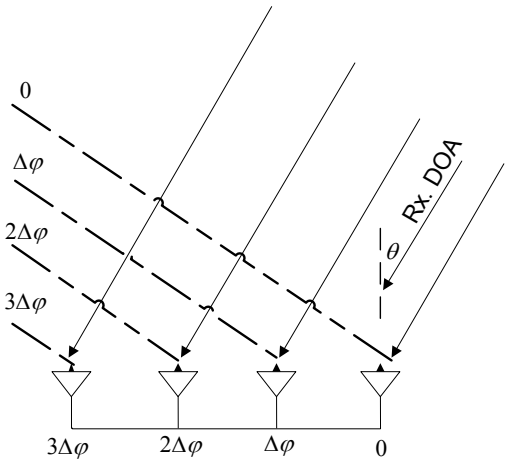

Figure 1. Phase lag by incident wave.

$$\triangle\varphi = 2\pi fd \sin\frac{\theta}{c} \tag{2}$$

where $\triangle\varphi$ phase lag between antenna arrays, f is incident wave frequency, c is light speed, d is distance between antenna arrays, θ is incident wave angle. In order to transmit in the same direction from which the retrodirective array is receiving. It is must meet following conditions:

$$\varphi_{Tx} = -\varphi_{Rx} \tag{3}$$

Input phase lag are output phase lag of signal are related by conjugation.

B. Phase Detector

It is important to detect the phase lag between array antennas to correctly configure the retrodirective array antenna. Retrodirective array system can find direction of arriving signal by detecting the phase difference between the array antennas.

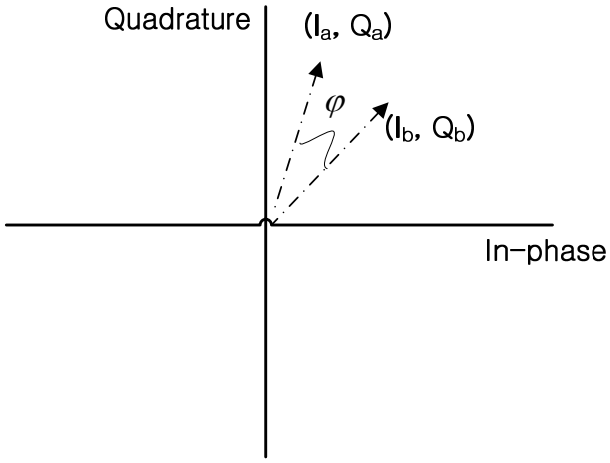

Figure 2. Phase different between received signal(I_a,Q_a) and correct signal(I_b,Q_b).

Figure 2 shows phase different between received signal at array antenna. In the case of QPSK modulation, we can calculate phase lag by comparing received signal with correct point signal. The constellation of correct point (I_b,Q_b) and received signal (I_a, Q_a) is shown in figure 2.

The phase difference of the two signals can be expressed as follows

$$\begin{aligned} e^{j\varphi} &= e^{(\varphi_a-\varphi_b)} = \cos(\varphi_a-\varphi_b)+j\sin(\varphi_a-\varphi_b) \\ &= \cos\varphi_a\cos\varphi_b+\sin\varphi_a\sin\varphi_b \\ &\quad + j(\sin\varphi_a\cos\varphi_b-\sin\varphi_b\cos\varphi_a) \\ &= \frac{I_a}{\sqrt{I_a^2+Q_a^2}}\frac{I_b}{\sqrt{I_b^2+Q_b^2}}+\frac{Q_a}{\sqrt{I_a^2+Q_a^2}}\frac{Q_b}{\sqrt{I_b^2+Q_b^2}} \\ &\quad + j\left(\frac{Q_a}{\sqrt{I_a^2+Q_a^2}}\frac{I_b}{\sqrt{I_b^2+Q_b^2}}-\frac{Q_b}{\sqrt{I_b^2+Q_b^2}}\frac{I_a}{\sqrt{I_a^2+Q_a^2}}\right) \end{aligned} \tag{4}$$

where the magnitude of QPSK signal with correct point is $\sqrt{I_b^2+Q_b^2}=\sqrt{2}$, we assume $(|\varphi|<20)$, φ can be approximation $\sin\varphi$ ($\varphi \simeq \sin\varphi$).

(4) can be reformed as

$$\varphi \simeq \sin\varphi = \frac{1}{\sqrt{2(I_a^2+Q_a^2)}}\cdot(I_bQ_a-I_aQ_b) \tag{5}$$

Finally, the phase information between two signal can be express as

$$\varphi = (I_bQ_a-I_aQ_b) \tag{6}$$

It is possible to detect the phase different between received signals through at two array antenna using equation (6) .

III. RETRODIRECTIVE ARRAY SYSTEM CONSIDER MULTIPATH SIGNAL

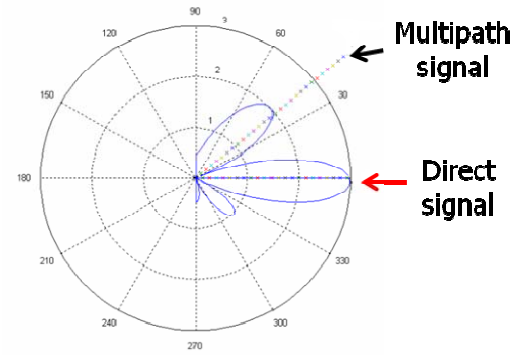

Figure 3. Beam pattern in the case of receiving direct signal and indirect signal.

Figure 3 shows beam pattern in the case of receiving direct signal and indirect signal. If angle and amplitude rate between direct and indirect signal are 40 degrees and 0.5. Phase and amplitude error about direction of direct signal occurs when retrodirective array system is affected by interference signal and multi-path signal. Beam pointing error is generated by these phase and amplitude variation.

Phase variation can be expressed as

$$\psi_e = \tan^{-1}(K\sin(\theta)/1+K\cos(\theta)), \tag{7}$$

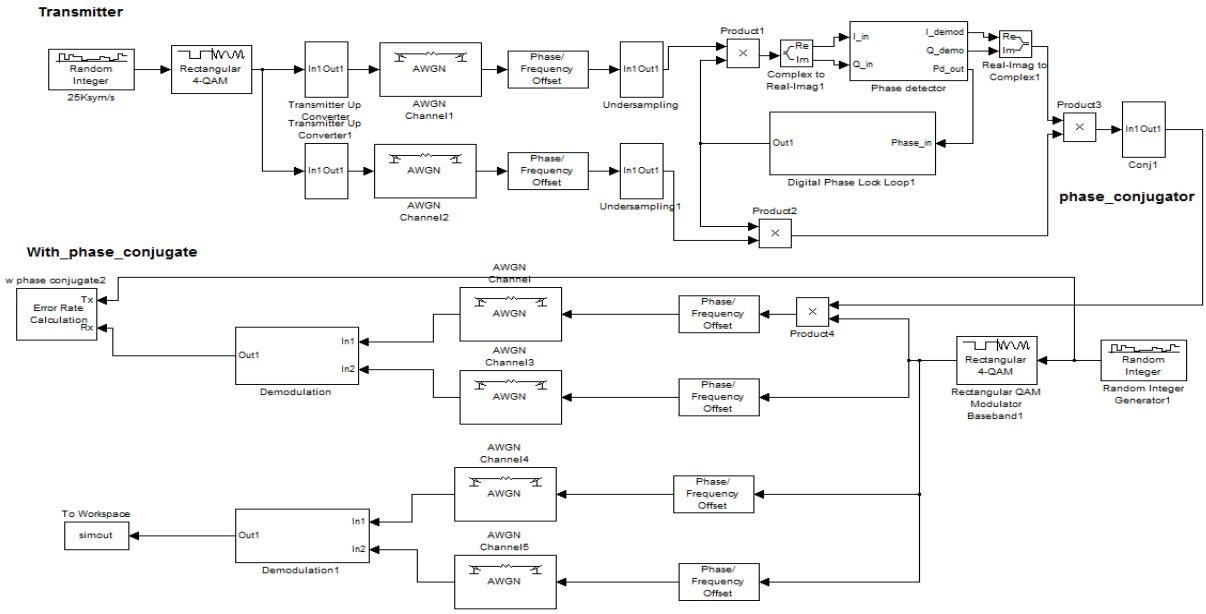

Figure 4. Digital Retrodirective array system based on band pass sampling.

where K is amplitude rate between indirect and direct signal ($K = |Indirect| / |direct|$), θ is angle difference between indirect and direct signal.

Amplitude variation can be expressed as

$$K_e = \sqrt{1 + 2K\cos(\theta) + K^2}. \quad (8)$$

Amplitude and phase variations have the same effect as a set of complex weights multiplying each element of the array in shown [7]. The effect of this complex weight is split the radiation pattern into a direct beam pointed in direction of the source and secondary beam pointed in direction of the multipath signal [8].

IV. SIMULATION

Figure 4 shows block diagram of digital retrodirective array system based on band pass sampling using Matlab/Simulink. In this paper, we assume only two array antennas which have different phase lag(first antenna is 0°, second antenna is 5°). On the transmitter side, the signal of data rate is 25Ksym/s with QPSK modulation. We assume that SNR of the AWGN from transmitter to retrodirective array system is 15dB and signal power was selected to be 1W.

On the receiver side, band pass sampling was applied to the received RF signals. The sampling rage is fs=25MHz, which is much lower than RF frequency.

On the retrodirective array side, the signal received by the 1st and 2st antenna element is conjugated phase different between 1st and 2st antenna element like (3).

Figure 5 shows analysis of magnitude variation by incident waves which are between direct and indirect signal, when Rician factor K is 0.5, 0.25, and 0.15. Magnitude of multipath signal has higher, error of the direction of array antenna toward direct signal is increase. The magnitude of multipath signal has higher the more error of direction of array antenna toward direct signal increase. We confirm that the magnitude of variation has smaller than 1 in the case of larger angle between direct and indirect signal than 110°. This effect arise because direction of direct signal is changed by multipath signal.

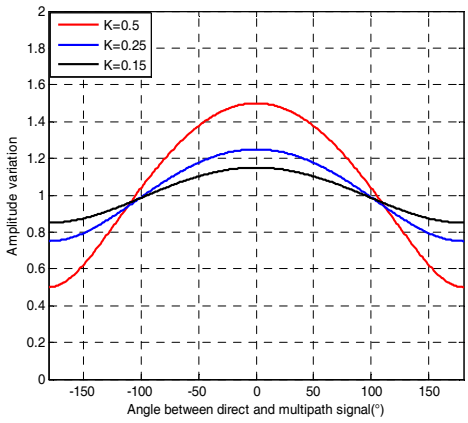

Figure 5. Amplitude variation by different angel between indirect and direct signal.

Figure 6 shows analysis of phase error by incident waves which are between direct and indirect signal when Rician factor K is 0.5, 0.25, and 0.15. Amplitude of multipath signal has higher, phase perturbation is larger. Also, you can see that phase perturbation is the symmetric in the case of the positive direction and negative direction of angle difference of incident wave. We confirm that phase information of direct signal is changed by indirect signal.

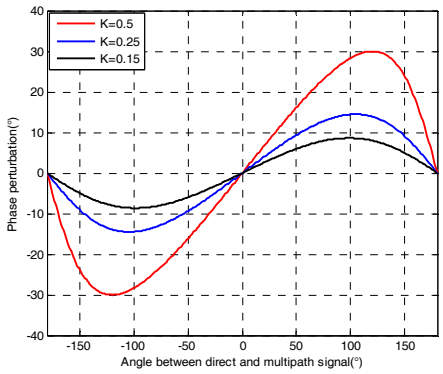

Figure 6. Phase variation by different angle between indirect and direct signal.

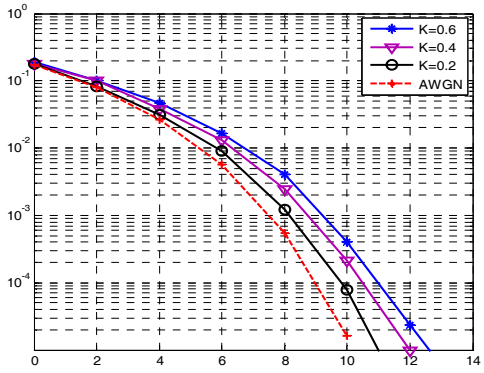

Figure 7. Comparison of BER performance at source by amplitude difference between indirect and direct signal.

Figure 7 shows BER performance at source by amplitude difference between direct and indirect signal (phase difference between direct and indirect signal =15°). We analyse the BER performance in the case receiving data signal which retransmitted signal from the retrodirective array system to source. We assume that channel is AWGN when Rician factor K is 0.6, 0.4, and 0.2. We ensure that the receive performance is degraded when Rician factor K is increase. Simulation results shows that beam pointing error occur by multipath signal effect.

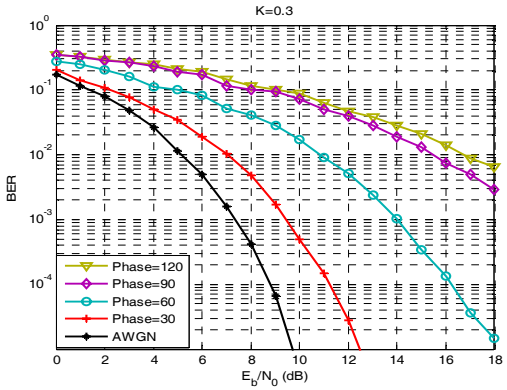

Figure 8. Comparison of BER performance by phase difference between indirect and direct signal (K=0.3).

Figure 8 shows BER performance at the source by phase differences between direct and indirect signal (K=15°). We confirm that the BER performance is more degraded, the phase difference between indirect and direct signal is larger when the indirect signal amplitude divided by direct signal amplitude is 0.3 under AWGN. Beam pointing error has sensitivity phase variation than amplitude compare with results of in Figure 7.

V. Conclusion

In this paper, we analyse receive performance of digital retro directive array system under multipath signal. Beam pointing error at retrodirective array antenna arise by multipath and interference signal. Numerical results show amplitude and phase information about direction is changed by multipath signal in shown figure 5 and 6. We confirm that receiver performance at source by beam pointing error according to amplitude and phase difference between indirect and direct signal in shown figure 7 and 8. We ensure that beam pointing error is more severely affected by phase difference between indirect and direct signal than that of amplitude ratio.

Acknowledgment

This research was supported by the KCC(Korea Communications Commission), Korea, under the R&D program supervised by the KCA(Korea Communications Agency)"(KCA-2012-11-921-04-001)

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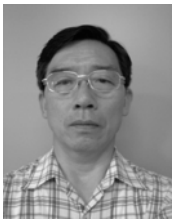

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