Phased Array Antenna Using Directional Modulation with Sum & Difference Pattern for Secure Communication

Authors: *Tasuku Kuriyama* and Jun Goto**

1. Introduction

In radio communications, information is transmitted and received in open spaces using radio waves. Therefore, communication radio waves may be intercepted by unintended people and the contents may be wiretapped and decrypted. To prevent such risks, common key cryptosystems and other cryptographic techniques are widely used.

Other measures proposed by researchers include physical layer security techniques in which radio waves and signal processing are used to enhance security.(1) In one such technique, the channel characteristics are used to share secret keys only among legitimate users, and in another human-made noise known to legitimate users is introduced to the desired signals to prevent the signals from being noticed.(2) This paper introduces the phased array antenna—a physical layer security technique—for which a directional modulation technology that can control the ranges in which signals can be demodulated (hereafter, "directional modulation array") is used.

This paper reports the principle of the method to calculate the excitation distribution of directional modulation arrays and the results of evaluating the communication performance.

2. Directional Modulation Arrays

2.1 Directional modulation technologies

In the directional modulation method, carrier signals are modulated using phase shifters and variable attenuators installed on phased array antennas to form modulating signals which are then transmitted from each element antenna.(3) By carefully designing the excitation distribution of phase shifters and variable attenuators, modulating signals radiated from each element antenna become meaningful signals only after being combined in the communication direction; in other directions they are irregular signals.

Methods to calculate the excitation distribution of phase shifters and variable attenuators that realize directional modulation have been studied. Conventionally, optimization methods using genetic algorithms are used to calculate the excitation distribution(3), but this makes the calculation volume large. One way to solve this problem is the sum and difference patterns synthesis method—a simple excitation distribution calculation method that does not rely on the calculation processing capability of communication systems.(4), (5)

2.2 Sum and difference patterns synthesis method

Figure 1 shows the principle of the sum and difference patterns synthesis method. In the method, a desired signal beam to send the desired signals is formed at the same time with an interference signal beam to send the interference signals.

The desired signal beam is formed in a shape such that the beam pattern peak is in the communication direction. This beam pattern is called a sum pattern. On the other hand, the interference signal beam is formed in a shape such that the null of the beam pattern faces the communication direction and the gain of the interference signal beam is higher than that of the desired signal beam in other directions. The beam pattern for which the communication direction is null is called a difference pattern. By forming sum and difference patterns at the

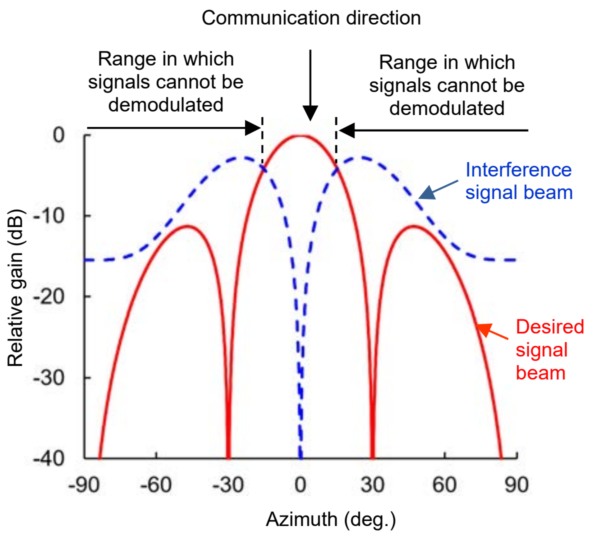

Fig. 1 Principle of sum and difference patterns synthesis method

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same time, the power ratio between the desired and interference signals can be changed depending on the transmit direction and the angle width in which signals can be demodulated can be limited only near the communication direction. Specifically, desired signals are transmitted with a stronger signal power than the interference signals near the communication direction, so they can be demodulated. On the other hand, in the sidelobe direction of the desired signal beam, interference signals are transmitted with a stronger signal power than the desired signals, so the desired signals cannot be demodulated.

Figure 2 illustrates the configuration of a directional modulation array using the sum and difference patterns synthesis method. The excitation distribution which forms the desired signal beam shown in Fig. 1 is multiplied by the desired signals, and that which forms the interference signal beam is multiplied by the interference signals. They are combined to calculate the excitation distribution. Based on this excitation distribution, the phase shifter and variable attenuator control the amplitude phases of the carriers transmitted from each element antenna.

3. Evaluation of Characteristics

Table 1 lists the simulation parameters. The communication performance when a 4-element phased array antenna is used for communication in quadrature phase shift keying (QPSK) is evaluated.

3.1 Beam patterns

Figure 3 shows amplitude characteristics of the beam patterns sending QPSK symbols, and Fig. 4 shows their phase characteristics. The beam patterns were obtained by multiplying each beam shown in Fig. 1 by the desired signals or interference signals and combining in consideration of phase values. The legends in Figs. 3 and 4 indicate the phase value of each QPSK symbol. The four types of beam pattern shown in the figures are switched according to desired signals. When focusing on the amplitude phase in the communication direction with the azimuth of 0 degrees, the amplitude is equal amplitude for each symbol as shown in Fig. 3 and the phase values are 45, 135, −135, and −45 degrees as shown in Fig. 4. They match the QPSK constellation. Figure 5 shows the constellations received in the communication direction (0-degree direction) and a direction other than the communication direction (30-degree direction). This figure shows the amplitude phase value of each azimuth in Figs. 3 and 4 on the complex plane. As shown in the figure, the constellation in the communication direction is that of QPSK, but in the direction (30-degree direction) other than the communication direction, the symbol points concentrate to a point and are disordered. Thus, the directional modulation technology can allow constellations to have angular dependence.

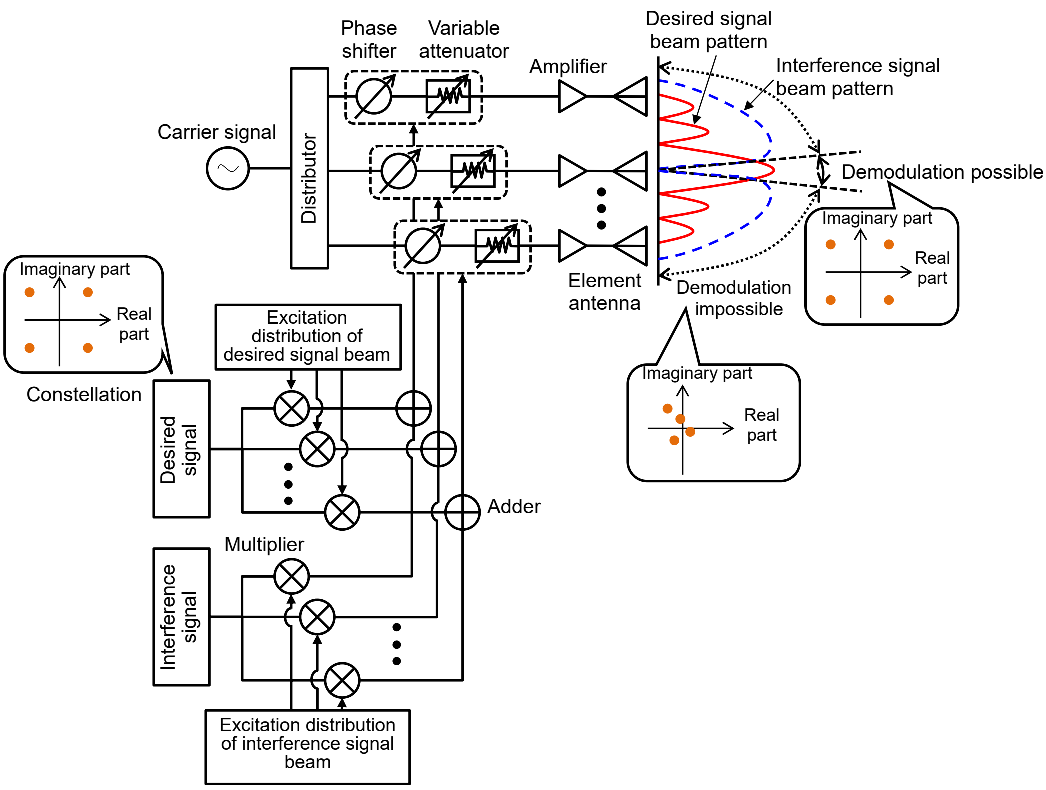

Fig. 2 Configuration of array antenna using directional modulation

3.2 Angle characteristics of bit error ratios

Next, to check how the angular dependence of the constellations affects communication performance, bit error ratio (BER) characteristics in an environment with additive white Gaussian noise were evaluated. Figure 6 shows the BER characteristics when the signal to noise power ratio (SNR) in the communication direction (0-degree direction) is 20 dB and the receiving point is changed in a semicircle with a certain distance from the transmitting station. For comparison, the figure also shows the angle characteristics of a conventional array antenna at the time of beam scanning in the communication direction (0-degree direction).

For the conventional array antenna, the SNR at the receiving point changes according to changes in the beam pattern amplitude, so the BER gradually deteriorates as the direction moves away from the communication direction and it becomes local minimum in the direction of the sidelobe peak. The BER improves in the sidelobe direction like this, thus allowing the communication contents to be demodulated even in azimuths other than the communication direction. On the other hand, the figure shows that for the directional modulation array, the BER remains deteriorated in the sidelobe direction of the conventional array antenna and the angle range in which the BER is good can be limited near the communication direction. When the angle width

Table 1 Simulation parameters

Item	Description
Antenna configuration	4 elements, half-wave length interval, linear array antenna
Element antenna	Omnidirectional
Communication direction	Antenna boresight (0-degree direction)
SNR in the communication direction	20 dB
Modulation	QPSK
Interference signal	Phase: 0 degrees

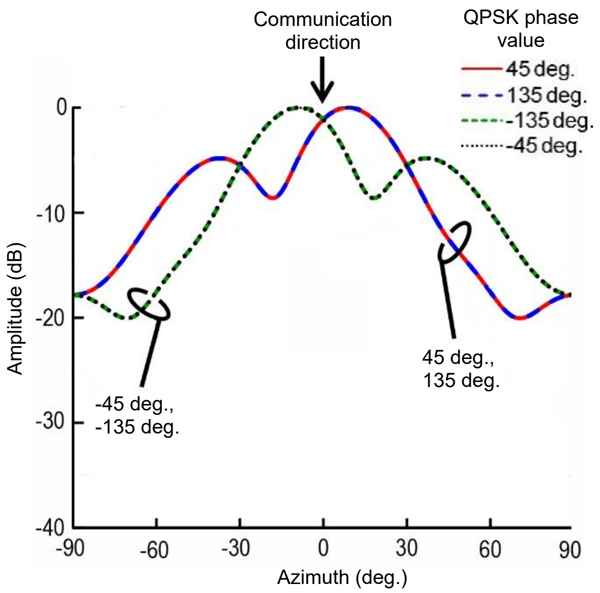

Fig. 3 Far-field amplitude pattern

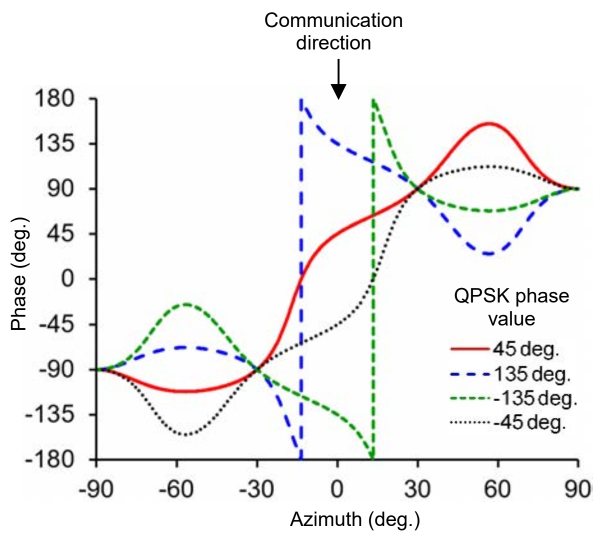

Fig. 4 Far-field phase pattern

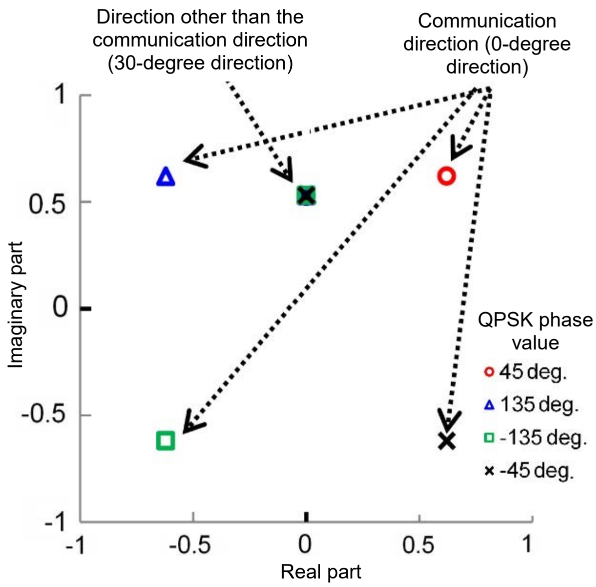

Fig. 5 Constellation diagram of received signal

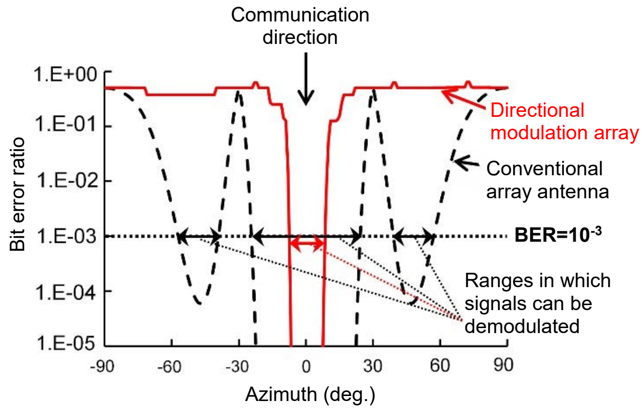

Fig. 6 BER spatial distribution

in which the BER is 10^{-3} or lower is defined as the range in which the contents can be demodulated, the range is 84 degrees for the conventional array antenna and 15 degrees for the directional modulation array. Thus, we have confirmed that using a directional modulation array can limit the range in which contents can be demodulated to approximately one fifth of the conventional value, and that communication is possible only in a limited direction.

4. Conclusion

This paper proposed directional modulation arrays using the sum and difference patterns synthesis method as a technique to limit the range in which contents can be demodulated using phased array antennas and evaluated the communication performance. The results showed that the range in which the contents can be demodulated can be narrowed using this type of antenna compared to conventional array antennas and that communication is possible only in a limited direction. We will study combining this technology with cryptographic techniques in the future, and work to enhance the safety of radio communication systems.

5. References

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