A Reduction Method of Quantization Error of Excitation Coefficient for Phased Array Antenna

#Tasuku KURIYAMA, Kazunari KIHIRA, Toru TAKAHASHI, and Yoshihiko KONISHI
Information Technology R&D Center, Mitsubishi Electric Corporation
5-1-1 Ofuna, Kamakura, Kanagawa, 247-8501, Japan,
E-mail: Kuriyama.Tasuku@ea.MitsubishiElectric.co.jp

1. Introduction

Phased array antennas (PAA) enable to form a main beam in the direction of a desired signal and nulls in the direction of interference signals by adjusting excitation coefficient (amplitude and phase) of each antenna element. One method to form nulls in the direction of interference is sidelobe canceller [1]. The signals received by the auxiliary antennas are adjusted to be the conjugate of the interference signal received by the main antenna. The adjusted signals are combined with the signal received by the main antenna. One method to conjugate the signals is the analog beam forming (ABF) using variable attenuator and digital phase shifter. ABF has a large quantization error when antenna elements are few. The quantization error causes the null to shift, so the interference signal is not fully suppressed. Therefore, to form null in antenna pattern, highly precise ABF is required.

In this paper, we propose a reduction method of quantization error of excitation coefficient for phased array antenna employing ABF. The proposed method is a method of combining a number of the quantized excitation coefficients.

2. Effect of quantization error

Figure 1 shows a configuration of conventional PAA. The desired and interference signals are received by main and auxiliary antennas, respectively. These signals are amplified by low noise amplifier (LNA). Next, the signal received by the auxiliary antenna is adjusted to be the conjugate of the interference signal received by the main antenna. Finally, these signals are combined with a combiner. Figure 2 shows an example of an antenna pattern by the conventional configuration. The directions of the desired and interference signal are 0 deg. and 60 deg., respectively. Signal-to-interference power ratio (SIR) before receiving by the main and the auxiliary antenna is -40dB. ‘Ideal’ in Fig. 2 is due to the ideal excitation coefficient with no quantization error. The ideal excitation coefficient is calculated by power inversion criteria [2]. ‘Quantized’ is the excitation coefficient quantized by using variable attenuator of 0.5dB resolution and 5-bit digital phase shifter. It can be found from Fig.2 (b) that a deep null can be formed in the direction of the interference when the ideal excitation coefficient is applied. On the other hand, it can be seen that the null is shifted from the direction of the interference when the quantized excitation coefficient is applied. Thus, when the quantization error of the excitation coefficient is taken into account, the interference signal is not fully suppressed.

3. Proposed Method

3.1 Configuration

Figure 3 shows a configuration of PAA employing the proposed method. The signal received by each antenna is amplified by LNA. The signal received by the auxiliary antenna $x_a(t)$ is divided into N signals by a power divider. The divided signals are excited with digital phase shifters and variable attenuators. Note that the quantization resolution of each digital phase shifter is equal, and that of each variable attenuator is equal. These signals are combined with the signal received by the main antenna $x_m(t)$ at the combiner. The combiner output $y(t)$ is given by

$$y(t) = x_m(t) + \frac{1}{\sqrt{N}} \sum_{k=1}^{N} W_k^* x_a(t) \tag{1}$$

where,

$$W_k = a_k(m) e^{j\theta_k(n)} \tag{2}$$

$a_k(m)$ is the *m*th quantized amplitude of variable attenuator of the *k*th divided signal, $\theta_k(n)$ is the *n*th quantized phase of digital phase shifter of *k*th divided signal. $(.)^*$ denotes complex conjugate operation. $a_k(m)$ and $\theta_k(n)$ are determined so as to minimize the output power $|y(t)|^2$.

3.2 Principles

Figure 4 shows the principle of the proposed method. This figure represents an excitation coefficient on a complex plane. The quantized excitation coefficient is a vector on a grid. The proposed method is a method of obtaining the excitation coefficient equivalent to the ideal excitation coefficient by the vector composition of a number of quantized excitation coefficients. Although Fig. 4 is an example of two vector compositions, the excitation coefficient equivalent to the ideal excitation coefficient may not be obtained depending on the quantization resolution. In this case, the quantization resolution can be improved by increasing the number of vectors to be combined. Note that the quantized phases must be determined so that the phase of the ideal excitation coefficient is among the quantized phases. Fig. 4 is an example using the quantized phases like θ_2 and θ_1. The quantized phases like θ_3 and θ_1 can be also set to digital phase shifter.

4. Simulation Results

The simulation parameters are given in Table 1. Then the quantized phases and amplitudes are determined as follows. First, the quantized phases of each digital phase shifter are set in order from fewer errors compared with the ideal excitation coefficient. Next, the quantized amplitudes of each variable attenuator are set to minimize the output power at the combiner. Figure 5 shows simulated output signal-to-interference plus noise power ratio (SINR) between the proposed method ('Proposed') and conventional PAA ('Conventional'). 'Ideal' represents the performance utilizing ideal excitation coefficient which has no quantization error and is calculated by power inversion criteria [2]. Moreover, 'Conventional' represents the performance utilizing the quantized excitation coefficient. It can be found from Fig. 5 that output SINR in the conventional method decreases as the input SIR becomes low. This is because null is shifted to the different direction from the interference direction because of the quantization error. On the other hand, the output SINR in the proposed method is improved in case of lower input SIR. This is because the excitation coefficient with few errors from the ideal excitation coefficient is obtained by carrying out the vector composition of two quantized coefficients. For example, in case of input SIR = -40dB, the output SINR in the conventional method is 11.1dB, and that in the proposed method ($N = 2$) is 18.8dB. Furthermore, it can be found that the output SINR in the proposed method improves as the number of division N increases. This is because the quantization error becomes lower by combining a number of the excitation coefficients.

5. Conclusions

For the phased array antennas employing ABF, a reduction method of quantization error was proposed, which combines a number of quantized excitation coefficients. In computer simulations, the output SINR was greatly improved in comparison with the conventional method. Moreover, it was found that the output SINR was improved as the number of division increases.

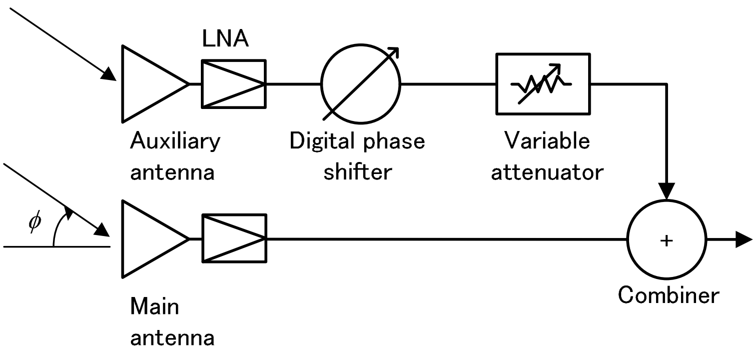

Figure 1: Configuration of the conventional method

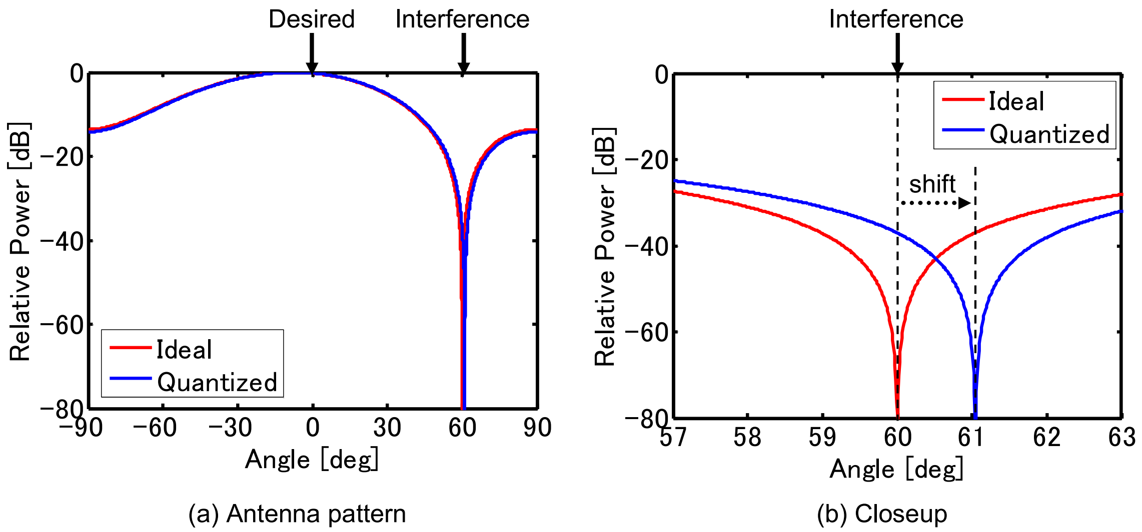

Figure 2: Quantization error effect on antenna pattern

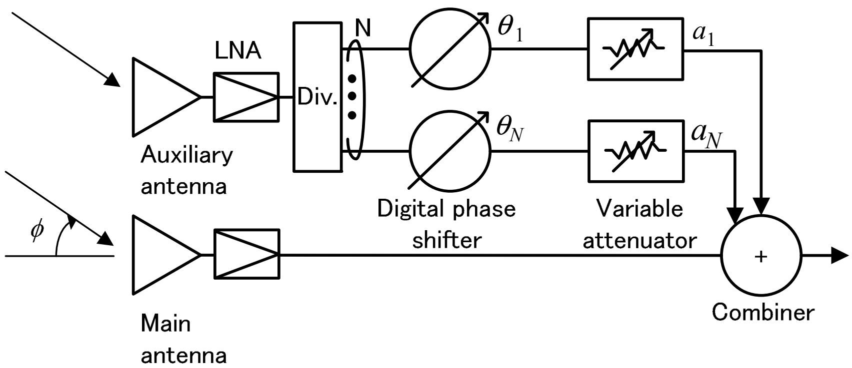

Figure 3: Configuration of the proposed method

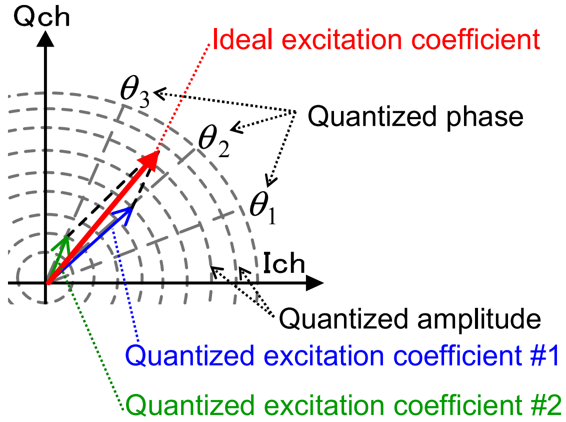

Figure 4: Principle of proposed scheme

Table 1: Simulation parameters

Space of antenna element		half of wavelength
Direction (Desired / Interference)		0deg. / 60deg.
Antenna gain (Desired / Interference)	Main antenna	15dBi / -5dBi
	Auxiliary antenna	0dBi / 0dBi
Input SNR at main antenna		20dB
Quantization resolution	Amplitude	0.5dB
	Phase	11.25deg.(5bit)
Division number		2 to 4

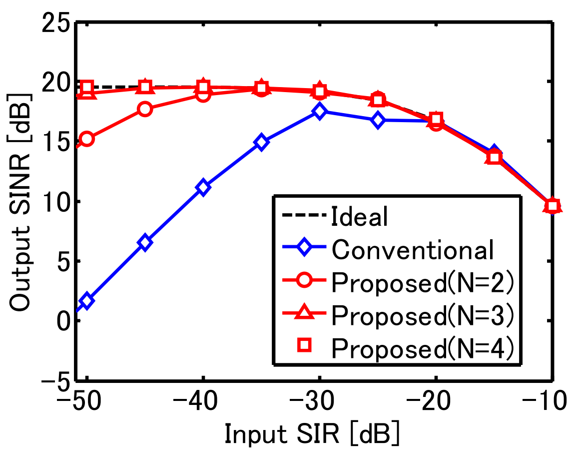

Figure 5: Simulated Output SINR

References

[1] S.P.Applebaum, “Adaptive arrays”, IEEE Trans. Antennas & Propag., vol. AP-24, No. 5, pp. 585-598, Sept. 1976.

[2] R.T.Compton, Jr. : “The Power Inversion Adaptive Array : Concept and Performance”, IEEE Trans. Aerosp. & Electron. Syst., vol. AES-15, No. 6, pp. 803-814, Nov. 1979