A Method to Measure the Antenna Mode and Structural Mode for Antenna RCS reduction Using Circulator and Phase Shifter

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***Abstract* - An antenna RCS reduction using circulator and phase shifter is one of promising RCS reduction techniques. In this RCS reduction method, the antenna mode scattered field, which is the re-radiated field of antenna, is controlled by the phase shifter to cancel out the structural mode scattered field. In this paper, a method is proposed to measure the amplitude and phase relationship between the antenna mode and structural mode for the deterministic RCS reduction. The effectiveness of the proposed method is verified by experiments using an array antenna with circulators and digital phase shifters.**

***Index Terms* — Antennas, RCS, circulator, phase shifter.**

I. INTRODUCTION

It is known that the scattered field by antenna consists of two components: the structural mode and the antenna mode [1]. The structural mode is due to the interaction between the incident field and the antenna structure. The antenna mode is due to the reradiation of antenna, and which is associated with the antenna radiation property and loaded impedance.

The reduction of radar cross section (RCS) of antennas has recently received more attention [2]-[4]. The impedance loading is a popular technique in which the antenna mode is adjusted to cancel out the structural mode by the loaded impedance. Thus, it is not so effective when the structural mode is much larger than the antenna mode.

The in-band RCS reduction method using circulator and phase shifter is also a promising method [5]. In this method, an antenna is connected to a circulator with a phase shifter as shown in Fig. 1. The incident field to the antenna circulates through the circulator and the phase shifter, and then is reradiated from the antenna as the antenna mode. For the RCS reduction, the phase of the antenna mode is adjusted by the phase shifter to cancel out the structural mode. This method has a potential to achieve the perfect reduction of RCS by utilizing an amplifier. In [5], however, experiments using a single dipole antenna with a circulator and a phase shifter (line stretcher) have only been reported to show the effectiveness of this RCS reduction method.

In this paper, a method is proposed to measure the amplitude and phase relationship between the antenna mode and the structural mode for the deterministic RCS reduction using circulators and phase shifters. The proposed method is based on the rotating element electric field vector method [6] and the amplitude and phase of each mode can be determined without any phase measurements. The proposed method is verified by experiments using an array antenna.

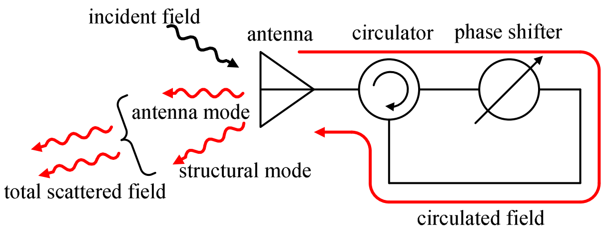

Fig. 1. Antenna RCS reduction using circulator and phase shifter.

II. MEASUREMENT THEORY

In the proposed method, the amplitude variation of the scattered field by an antenna is measured while the phase of phase shifter is shifted from 0 to 360 degrees. This amplitude variation becomes sinusoidal and the antenna mode and the structural mode can be determined as follows.

The amplitude and phase of the total scattered field by the antenna in an initial state are denoted by E_0 and ϕ_0, and those of the antenna mode and the structural mode by E_a, ϕ_a, E_s, and ϕ_s, respectively. When the phase of phase shifter is shifted by Φ_i, the total scattered field E_i is given as

$$E_i = E_s e^{j\phi_s} + E_a e^{j(\phi_a+\Phi_i)} \\ = E_0 e^{j\phi_0} - E_a e^{j\phi_a} + E_a e^{j(\phi_a+\Phi_i)}. \quad (1)$$

We now define the relative amplitude and phase of the antenna mode to the initial total scattered as $k_a = E_a / E_0$ and $X_a = \phi_a / \phi_0$. The relative amplitude k_a and phase X_a of the antenna mode can be determined as [6]:

$$k_a = \frac{\Gamma}{\sqrt{1+2\Gamma\cos\Phi_0+\Gamma^2}} \quad (2)$$

$$X_a = \tan^{-1}\left(\frac{\sin\Phi_0}{\cos\Phi_0+\Gamma}\right) \quad (3)$$

where $\Gamma = (r-1)/(r+1)$, r is the ratio of the maximum and the minimum of the amplitude variation of the scattered field, and $-\Phi_0$ is the phase that gives the maximum of the amplitude variation.

Dividing (1) by the initial total scattered field, we obtain

$$1 = k_s e^{jX_s} + k_a e^{jX_a} \tag{4}$$

where k_s and X_s are the relative amplitude and phase of the structural mode to the initial total scattered field and are defined as $k_s = E_s / E_0$ and $X_s = \phi_s / \phi_0$. From (4), the relative amplitude k_s and phase X_s of the structural mode can be easily determined as follows:

$$k_s = \left|1 - k_a e^{jX_a}\right| \tag{5}$$
$$X_s = \arg\left(1 - k_a e^{jX_a}\right). \tag{6}$$

When the antenna is an array, the phase of each element in the array is successively shifted and the antenna mode of each element is determined by the same procedure. The total structural mode of the array is also determined in a similar way as in the case of a single element.

III. Experimental Results

Fig. 2 shows a schematic diagram of the measurement system in the experiment. The array consists of 8 patch antenna elements, 5-bit digital phase shifters, and circulators. We first measure the antenna mode and structural mode by the proposed method, and then adjust phase shifters to reduce the RCS of the array.

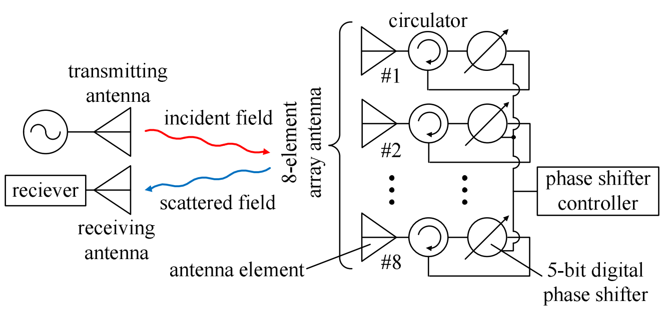

Fig. 2. Schematic diagram of the measurement system.

Fig. 3 shows the measured relative amplitude and phase of the antenna mode and structural mode. It can be seen that the amplitude of the structural mode is larger by about 19 dB than that of the antenna modes. In order to minimize RCS at $0.99f_c$, f_c, or $1.01f_c$, we adjust the phase shifters based on the results in Fig. 3 so that the antenna mode and the structural mode have an opposite phase at respective frequencies.

Fig. 4 shows the measured RCS after adjusting the phase shifters. In Fig. 4, the abscissa is the frequency normalized by the center frequency f_c. It can be seen that each RCS curve almost has the minimum RCS at the intended frequency.

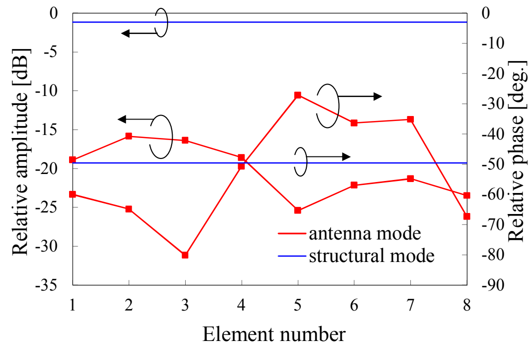

Fig. 3. Measurement result of the antenna mode and the structural mode.

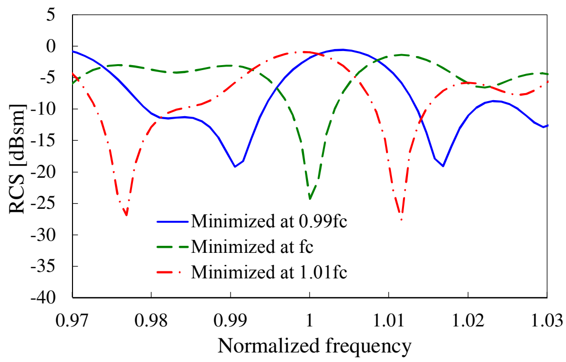

Fig. 4. Measured RCS of the array antenna.

IV. Conclusion

We have proposed the method to measure the antenna mode and the structural mode for the antenna RCS reduction using circulators and phase shifters. In the proposed method, the amplitude and phase of each mode can be determined without any phase measurements. The effectiveness of the proposed method has been verified by experiments using the 8-element array antenna. By utilizing the proposed method, we can deterministically reduce the antenna RCS.

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