Measurement method of axial ratio using only the reflection coefficient of waveguide circular polarizer

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Abstract: A circularly polarized feed circuit in a primary radiator of a reflector antenna is often required to have a low axial ratio. Therefore, it is necessary to accurately evaluate the axial ratio. The left- and right-handed circular polarized components are numerically obtained from the complex coefficients measured for dual linear polarized waves. The transmission phase measurement is difficult to measure accurately, particularly at high frequencies such as Ka band. Authors proposed a method to measure the axial ratio of the circular polarization feeding circuit from the reflection coefficient only, and the proposed method has been validated by the numerical simulation.

Keywords: axial ratio, circular polarization, feed circuit, measurement

Classification: Antennas and Propagation

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1 Introduction

A horn antenna and a waveguide feed circuit are often used as a primary radiator for a reflector antenna. A circularly polarized feed circuit in a primary radiator of

a reflector antenna is often required to have a low axial ratio. Therefore, it is important to accurately measure the axial ratio of a circularly polarized feed circuit.

In order to measure the axial ratio of the waveguide feed circuit, two orthogonal polarization components are measured. The transmission coefficients of the feed circuit can be measured directly or by space propagation connecting with a horn antenna [1]. In both methods, the left- and right-handed circular polarized components are numerically obtained from the complex coefficients measured for dual linear polarized waves. It is difficult to accurately measure the transmission phase by space propagation. A spinning linear source method is known as a method for measuring an axial ratio while avoiding phase measurement. The axial ratio measurements were conducted with the feed circuit aligned with the linear polarized source and rotated in ϕ (polarization). The axial ratio is the difference between the top and bottom envelopes of the measurements [2]. Although this method can reduce the effect of errors due to phase measurement, the effect of space propagation is inevitable.

In the method of directly measuring the complex transmission coefficients of the feed circuit, it is necessary to separate the circularly polarized wave into the dual linearly polarized wave components. An OMT (Orthogonal Mode Transducer) with good performance or a circular-to-rectangular waveguide transition is required for polarization separation. Inaccurate OMT characteristics affect the axial ratio measurement results. Although it is relatively easy to realize good performance of the circular-to-rectangular waveguide transition, orthogonal polarization causes cut-off resonance, so measurement of frequency characteristics is limited. There are intrinsic problems in evaluating the axial ratio by the transmission characteristics, as mentioned. As a method for measuring the full matrix of OMT, a method based on five measurements and calculation processing has been proposed [3]. This method has a slightly complicated measurement process.

Therefore, the authors propose a method of measuring the axial ratio from the reflection characteristic in which the output port on the horn side is short-terminated without measuring the transmission characteristic [4]. The transmission phase measurement is susceptible to cable bending, and it is difficult to measure it accurately, particularly at high frequencies such as Ka band. In the method of measuring from the transmission coefficient, since it is necessary to measure at two linear polarization ports at 90 deg-rotated positions. Accurate phase measurement is difficult due to different cable conditions. Reflection coefficient is relatively easy to measure by keeping cable condition. In the first proposed method, the axial ratio is evaluated from reflection amplitude only. Further, in the method using the reflection phase, the influence of the phase measurement error is reduced by the averaging process. Although the proposed method is typically suitable for waveguide circuit, it can be an effective method for other circuits. Since this method uses the fact that circularly polarized waves are converted to reversely polarized waves by a short plate, it is limited to measuring the axial ratio of a circularly polarized wave feeding circuit. It can be measured very simply and easily.

Short Plate

Fig. 1. Circular Polarization Feeding Circuit to be evaluated.

2 Measurement theory

Fig. 1 shows a circularly polarized feed circuit for measuring the axial ratio. The feed circuit has two linearly polarized input ports and two circularly polarized output ports. The input ports correspond to RHCP (Right Hand Circular Polarization) and LHCP (Left Hand Circular Polarization) at the output port, respectively. The output ports are virtual ports corresponding to orthogonal circular polarization components. In practice it is a common circular waveguide or square waveguide. When the output port is short terminated, it is reflected as a reverse circular polarization with round-trip phase shift.

The axial ratio is obtained from the measurement of the reflection coefficient in which the output port is shorted. The reflection coefficients are measured while changing the distance s to the short position. The reflection coefficients at the port #1 with the shorted output port can be approximately expressed as follows if multiple reflection is ignored.

$$S_{11,s} = S_{11} + 2S_{41}e^{-j2\beta s} + S_{44}e^{-j4\beta s} \quad (1)$$

Here, the phase constant β is known value.

$$\beta = \frac{2\pi}{\lambda_0} \sqrt{1 - \left(\frac{\lambda_0}{\lambda_c}\right)^2} \quad (2)$$

λ_c is equal to $\pi d/\chi'_{11}$ ($\chi'_{11} = 1.8412$ for circular waveguide with diameter of d) and λ_0 is free space wavelength. β may be known because it can be correctly calculated from the exact diameter. S_{11} is a reflection coefficient of the circularly polarized feed circuit with a load-terminal at output port, and S_{44} is a reflection coefficient of LHCP at the output port #4. S_{41} is an LHCP output when input to the RHCP port #1. The XPD (Cross Polarization Discrimination) is exactly the ratio of S_{41} to S_{31} . The axial ratio is assumed to be sufficiently good, and S_{41} is regarded as XPD, which can be converted to the axial ratio. Strictly speaking, XPD is a positive value, but here it is treated as a negative value. Relationship between axial ratio ζ in antilogarithm and XPD ρ in antilogarithm is following equation.

$$\zeta = \frac{\rho + 1}{\rho - 1} \quad (3)$$

Tracing of reflection coefficient when changing short position is shown in Fig. 2. Each term in Eq. (1) continuously changing short position s is illustrated. The first term S_{11} is depicted in the orange-colored point. The second term

Fig. 2. Tracing of reflection coefficient when changing short position

$2S_{41}e^{-j2\beta s}$ is depicted in the light blue-colored line. The third term $S_{44}e^{-j4\beta s}$ is depicted in the green-colored line. The whole $S_{11,s}$ is depicted in the red-colored line. In practice, the short position s is discrete and show as same colored points in Fig. 2 (6 points for each line are shown as an example). In the average of $S_{11,s}$ when the short position s is changed, the second and third terms on the right side of Eq. (1) are cancelled. Therefore, the average value of $S_{11,s}$ can be regarded as load-terminated reflection S_{11} . A value obtained by subtracting the average value of $S_{11,s}$ from $S_{11,s}$ corresponds to S_{11} , as shown in Fig. 2(b). From the Fig. 2(b), the difference between the maximum and minimum amplitude of the red line of $S'_{11,s}$ is corresponding to $4|S_{41}|$, then XPD can be calculated (Method 1).

S_{41} can be calculated by simultaneous equations from the measurement value of $S_{11,s}$ in which the short position s is changed in the Eq. (1). Since S_{11} corresponds to the average of $S_{11,s}$, it is a known value obtained from the measurement of $S_{11,s}$. S_{41} and S_{44} become complex unknowns. A simultaneous equation for S_{41} and S_{44} can be constructed in which the square of the difference between both sides is minimized (Method 2). Since the real and imaginary part become unknowns, four or more measurements with different s are required.

Fig. 3. Evaluation example of axial ratio in simulation

Similarly, S_{41} can also be calculated from an equation in which S_{11} is not known and is one of unknowns (Method 3). In this method, five or more measurements with different are required. Both methods are essentially equivalent to the complex Fourier series expansion.

3 Evaluation example

Fig. 3 shows a verification of the proposed method by the simulated values in the circularly polarized waveguide feed circuit.

In order to validate the proposed method, we simulated the same situation as the measurement and calculated the axial ratio. Although transmission characteristics can also be calculated, axial ratio obtained only from reflection characteristics are verified using the axial ratio calculated from transmission characteristics as a reference value. The exact value is the axial ratio calculated from the transmission coefficient. Six kinds of s of 0, 30, 60, 90, 120 and 150 deg as electrical length at the center frequency are used. The evaluated axial ratio by each method is compared with the calculated axial ratio from the transmission coefficients (exact value). Also in method 1 which is a very simple method, axial ratio can be calculated in the range of $\pm 4\%$ of the center frequency. In the methods 2 and 3, the axial ratio can be accurately calculated in a wide frequency range.

4 Conclusion

We proposed a method to measure the axial ratio of the circular polarized feed circuit from the reflection coefficients only, and the proposed method has been validated by the numerical simulation.