THREE-ANTENNA METHOD ON A GROUND PLANE FOR MEASURING COMPLEX ANTENNA FACTOR

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ABSTRACT

In order to measure the complex antenna factor (CAF) of a dipole antenna, a three-antenna method on a ground plane is proposed. In this method, the transmission S-parameter between transmitting and receiving antennas in free space is estimated from a value measured on a ground plane. To estimate the S-parameter in free-space, the method of moment is employed. Experimental results are compared with the CAF calculated from the effective length and circuit parameters of the balun. The agreement shows the usefulness of the proposed method.

INTRODUCTION

The antenna factor is an important characteristic of antennas for field measurements. It is necessary for EMI tests to certify the normalized site attenuation (NSA) of the used EMI test site. In order to evaluate the NSA, the antenna factors of transmitting and receiving antennas are needed. Usually, the antenna factors are measured or calibrated on a ground plane. Then the determined values depend on the antenna height.

In the time domain measurement of transient electromagnetic fields of natural and manmade noises, the complex antenna factor (CAF) is proposed [1]. The CAF is a receiving characteristic of both magnitude and phase, while the conventional scalar antenna factor is of magnitude only. The CAF is defined for an incident plane wave in free space.

The three-antenna method can be used to measure the CAF of any antenna system [2]. However, a large full anechoic chamber is necessary in the measurements in order to exclude the errors due to ambient reflections and near field effects. The purpose of this paper is to develop a method for measuring the CAF of dipole antennas at an open site on a ground plane that is actually obtainable.

CAF AND THREE-ANTENNA METHOD

When a dipole antenna receives a plane wave as shown in Fig.1, the CAF is defined as,

$$F_c(\omega) = \frac{E(\omega)}{V_o(\omega)} \quad , \tag{1}$$

where ω is an angular frequency, $E(\omega)$ is the incident complex electric field of the plane wave with the polarization giving the maximum output, and $V_o(\omega)$ is the complex voltage of the load with the impedance Z_0 matched to the coaxial cable (transmission line).

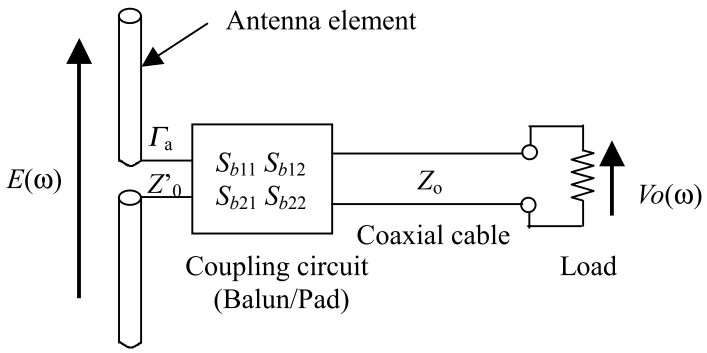

Fig.1 Dipole antenna with a coupling circuit

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In previous publications, antenna receiving transfer function has been used [3]. Fundamentally, the CAF is equivalent to the reciprocal of the transfer function. It should be noted that CAF is defined for a non-reflecting load. A mismatched load is not adequate for the waveform measurements. Not only the magnitude but also the phase of CAF varies with the reflection coefficient of the load.

When the CAF is measured by the usual three-antenna method, as shown in Fig.2, two (#*i* and #*j*) of three dipole antennas (*i,j*=1,2,3) are set so as to satisfy the far-field condition in free-space. In this figure, R is a far-field distance between the two antennas. Then, the transmission S-parameter $S_{21}(R)$ between transmitting antenna #*i* and receiving antenna #*j* are measured. The suffixes with $A(R)$ are corresponding to the antenna numbers,

$$A_{ji}(R) = \left[S_{21}(R)\right]_{\#i\rightarrow\#j} \quad . \tag{2}$$

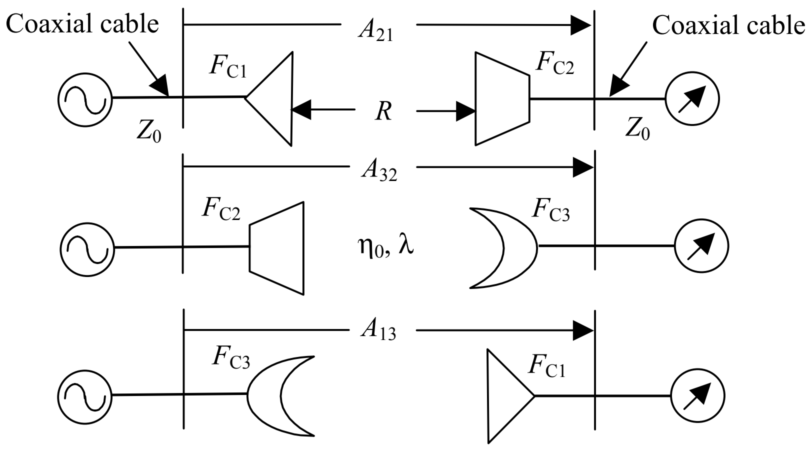

Fig.2 Three antenna method

The all sets of two antennas among three give three equations to calculate the CAF of each antenna in terms of $A_{ji}(R)$. If the load of the receiving antenna is matched to the coaxial line, the CAF of each antenna can be calculated from the measured $A_{ji}(R)$. For example, the CAF of the antenna #1 can be obtained from

$$F_{c1} = \sqrt{\frac{\eta_0 A_{32}(R)}{jZ_0 A_{21}(R) A_{13}(R)} \cdot \frac{e^{-jkR}}{R}} \quad , \tag{3}$$

where η_0 (=120 π) is the wave impedance of free-space, and β (=2 π / λ) is the wave number of the wavelength λ.

FIELD TRANSFER FACTOR

A transmission S-parameter between the transmitting and receiving antennas is measured in near field on a ground plane as shown in Fig.3 (a). In order to estimate the free-space transmission S-parameter satisfying the far-field condition, field transfer factor (FTF) is introduced as shown in Fig.3 (b). The FTF is defined as the ratio of the far-field free-space $A_{ji}(R)$ to the near-field $A_{ji}^{GP}(r)$ on the ground plane,

$$q(r,R) = \frac{A_{ji}(R)}{A_{ji}^{GP}(r)} \quad . \tag{4}$$

The estimation from the near-field data $A_{ji}^{GP}(r)$ to the far-field value $A_{ji}(R)$ using the FTF can reduce the effects of undesired reflection or that of the ambient noise at an open site.

If the reflections of the baluns are small, the FTF can be approximated as [4],

$$q(r,R) \cong \frac{\left[S_{e21}(R)\right]_{\#i\rightarrow\#j}}{\left[S_{e21}^{GP}(r)\right]_{\#i\rightarrow\#j}} \quad , \tag{5}$$

where $S_{e21}(R)$ is the far-field free-space S-parameters between the transmitting and receiving antenna “elements” and $S_{e21}^{GP}(r)$ is the corresponding the near-field S-parameter on the ground plane. These parameters can be calculated from the self- and mutual- impedances of the elements. The impedance values are calculated using the method of moment.

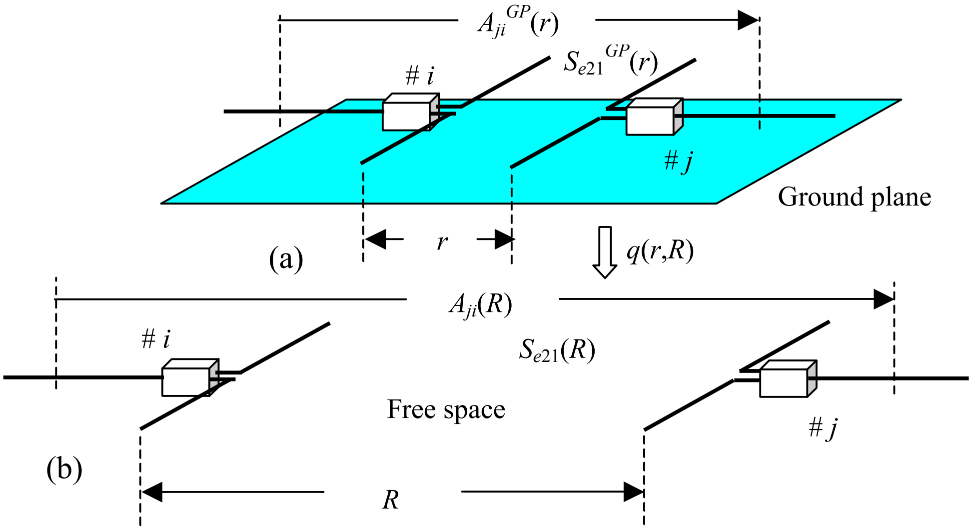

Fig.3 Measurement of transmission S-parameter and field transfer factor

MEASUREMENT AND COMPARISON

Three dipole antennas with transformer baluns are constructed. The half wavelength frequency is 300 MHz. The S-parameters $A_{ji}^{GP}(r)$ were measured on a ground plane (size: 50m x 30 m). The distance, *r,* between two antennas was 3 m. The antenna heights were selected as 1 m to avoid null detection. The far-field distance, *R*, for the FTF estimation is 100 m. The magnitude and phase of CAF are shown as the thin red lines in Fig.4 and Fig.5, respectively.

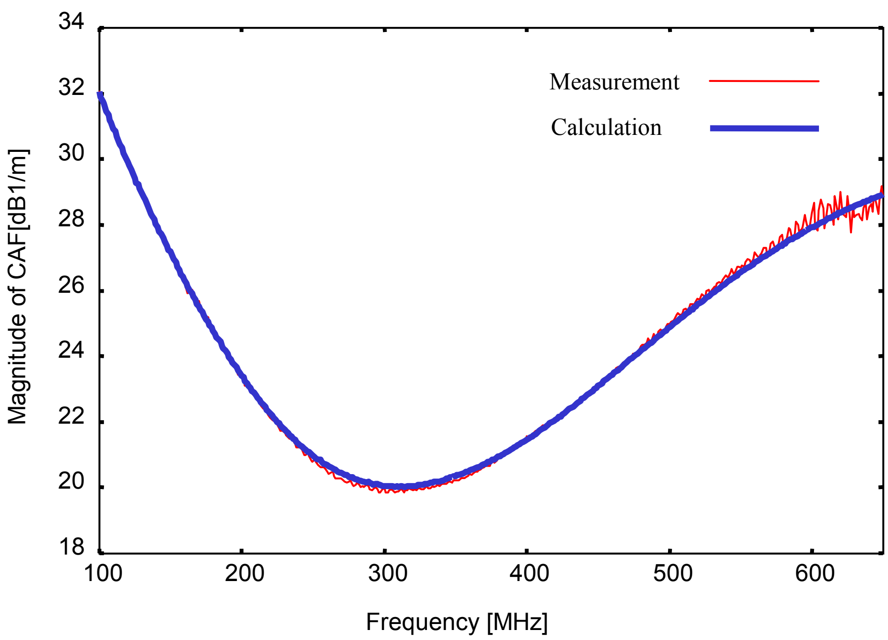

Fig.4 Measured and calculated CAF magnitude

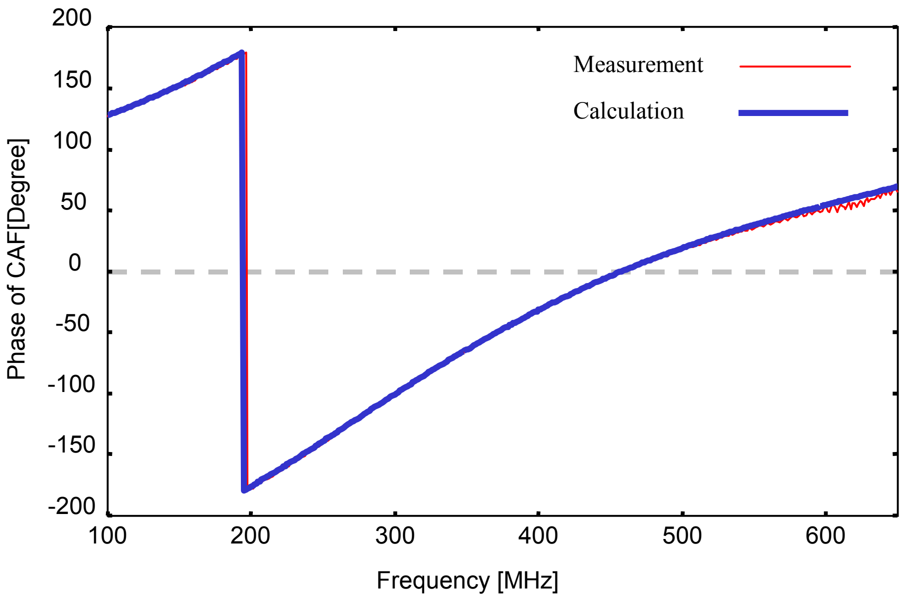

Fig.5 Measured and calculated CAF phase

This antenna has a structure in which the dipole elements and the balun can be separated. In this case, the CAF can be also calculated by the following equation [5],

$$F_c = -\frac{1}{l_e} \cdot \frac{Z_0 + Z_0'}{\sqrt{Z_0 Z_0'}} \cdot \frac{1 - S_{b11}\Gamma_a}{S_{b21}} \quad . \tag{6}$$

In this equation, l_e is the equivalent length of the dipole element, Z'_0 is the characteristic impedance of the two-wire line, S_{b11} and S_{b21} are S-parameters of the balun, and Γ_a is the reflection coefficient looking into the dipole at the two-wire line (see Fig.1).

The two-wire line dimensions are determined to be $Z'_0 = 200\ \Omega$. The parameters l_e and Γ_a are calculated by the method of moment. The S-parameters of the balun, S_{b11} and S_{b21}, are measured by a network analyzer with its TRL calibration of a two-wire line [6]. The thick blue lines in Figs.4 and 5 show the results obtained by (6). In these figures, the results measured using FTF (thin red lines) agree with the calculated results (thick blue lines).

CONCLUSIONS

The field transfer factor (FTF) has been introduced to measure the free-space CAF of a dipole antenna on a ground plane. The FTF was calculated using the moment method. A comparison of the calculation and measurement results shows the validity of the proposed method. By using the proposed method, the CAF of dipole antennas can be obtained, even though the baluns and elements cannot be separated.

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