Accurate Complex Antenna Factor by Broadband Calculable Dipoles over 10 MHz to 1000 MHz

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***Abstract*—The complex antenna factor (CAF) is accurately generated based on a pair of ultra-wide-band calculable dipole antennas (CDAs) from 10 MHz to 1000 MHz. The differences of both amplitude and phase of the transmission coefficient S21 between CDAs are verified experimentally; for example, for dipoles resonated at 400 MHz, the difference is less than 0.52 dB and 9 Deg between measurements and simulations from 10 MHz to 1000 MHz. CAF is calculated from the verified simulations, and the phase is unwrapped and normalized to the starting frequency. More dipoles can be used as standard antennas for more accurate results and for higher frequency, since the differences of S21 between measurements and simulations are less than 0.2 dB at resonant frequencies.**

Keywords—antenna factor; dipole antenna; OATS

I. Introduction

CAF is useful in recovering both the amplitude an phase information for the incident electromagnetic field, especially for the electromagnetic pulse field. The simulation and measurement of CAF has been made for wire-cage biconical dipoles from 30 MHz to 300 MHz [1] and calculable dipole antennas [2] based on the S-parameters from 30 MHz to 1000 MHz. However, more accurate results and broader frequency band are required in some applications. This paper focuses on the CAF via a complex transfer function (CATF) [3]. Special attention is given to the normalization of phase and precise verification. The achievements in this paper are the ultra-broadband frequency and precise verification; e.g. A single dipole can cover 10 MHz to 1000 MHz.

II. Principle of Generating CAF

A. Relationship between CAFand S-parameter

Supposing a plane wave E_i is incident upon a dipole antenna (in polarization) in free space, and the voltage induced in the load Z_c (=50 Ω) is U_r. There will be [3]:

$$\frac{U_r}{\sqrt{Z_c}} = H_n \frac{E_i}{\sqrt{Z_0}} \tag{1}$$

Where $Z_0 = 120\pi$ is the wave impedance in free space; and H_n is the normalized CATF.

According to the definition of CAF (F_c), there will be:

$$F_c = \frac{E_i}{U_r} \tag{2}$$

Eq. (3) can be derived from Eq. (1) and Eq. (2) :

$$F_c = \frac{\sqrt{Z_0}}{\sqrt{Z_c}} \frac{1}{H_n} \tag{3}$$

The normalized H_n can be calculated with slightly modified Eq. (4) [3],

$$H_n(j\omega) = \pm\sqrt{\frac{j}{r\lambda} S_{21}(j\omega) e^{+jkr}} \tag{4}$$

Where r is the separation between two identical dipoles; k is the wavenumber, and ω is the angular frequency. S21 is the transmission coefficient between the reference plane 1 and 2. The ± can be determined according to the fact that the phase shall be changed continuously with the increasing of frequency.

Usually, we only want to know the F_c in the boresight direction, which is the default parameter in this paper.

Eq. (1) ~ (4) is valid in free-space environment.

B. Calculable dipole antennas

A calculable dipole antenna consists of a separable balun and wire element [4, 5]. The balun is such specially designed that the port can be connected to a port of a vector network analyzer (VNA) via a coaxial cable with standard connector. Basically, a balun is a 3-port network, which can be converted into a 2-port one. Let the S-parameter matrices for the transmit and receive antenna baluns are ***L*** and ***N***. The transmit and receive antenna elements can be regarded as a virtual 2-port network, and let its S-parameter matrix be ***M***, which can be accurately modelled by Method of Moments (MoM) [6]. Then one will have Eq. (5) [4] by cascade combining of the three 2-port networks with S-parameter matrices ***L***, ***M*** and ***N***:

$$S_{21} = \frac{l_{21}m_{21}n_{21}}{(1-m_{22}n_{11})(1-l_{22}m_{11}) - l_{22}m_{12}m_{21}n_{11}} \tag{5}$$

Where $l_{i,j}$, $m_{i,j}$ and $n_{i,j}$ ($i, j = 1,2$) are the S-parameter elements of Matrixes ***L***, ***M*** and ***N*** respectively.

The phase error of the CAF will be dominated by S21, if one compares Eq. (3) and Eq. (4).

III. Experimentally Verification

Fig. 1 and 2 shows the comparison between measurements, S_{21}^{m}, and calculation, S_{21}^{c} for a pair of CDAs whose dipole resonated at 400 MHz; the height of transmit dipole (Tx) is h_{Tx} =170.4 cm; the height of receive dipole (Rx) h_{Rx} =170.7 cm; r =21.0 cm. The phase differences in Fig2. (b) are corrected for by 360 degrees at several frequencies, since it is a periodic function with the period of 360 degrees. The difference in the amplitude is less than 0.6 dB from 10 MHz to 1000 MHz. At resonant frequency 400 MHz, the difference is less than 0.2 dB.

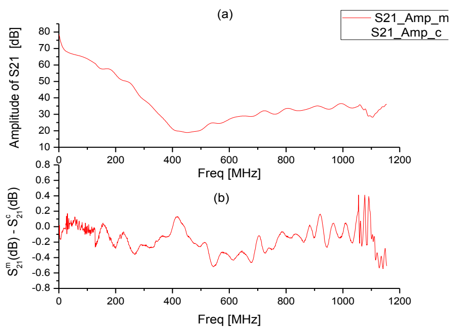

Fig. 1 The comparison of amplitude of S21 between measurements and simulation by the MoM code NEC2++ (r =21.0 cm, Dipole resonated at 400 MHz)

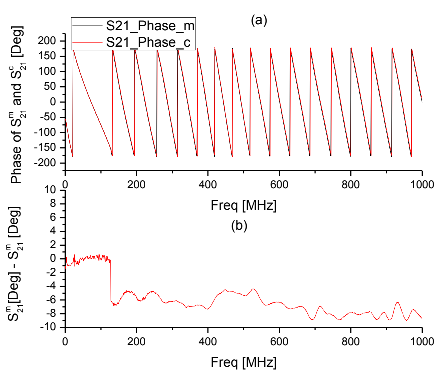

Fig.2 The comparison of phase of S21 between measurements and simulation by the MoM code NEC2++ (r =21.0 cm, Dipole resonated at 400 MHz)

At large separation, model dipoles without baluns in free space, and calculate S21 with Eq. (5). Then calculate CAF with Eq. (3), shown in Fig. 3 for dipoles resonated at 400 MHz. The calculation is repeated at two separations for different pair of dipoles, and is summarized in Table 1.

When calculate CAF, the amplitude and phase shall be calculated separately, and unwrap the phase in order to avoid phase ambiguity since a square root is involved. Also, the phase is normalized to 0 at the beginning frequency. If use more than one pair of dipoles as the reference antenna to get more accurate results and wider bandwidth, the phase can be normalized in this way: normalize all phases of one dipole with the phase at the stop frequency of the preceding dipole.

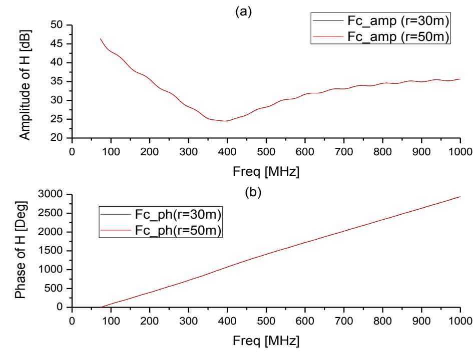

Fig. 3 The calculated amplitude and phase of CATF of a CDA with dipole resonated at 400 MHz. (r = 30 m and 40 m respectively)

TABLE I. The Difference of Fa at Different Separations

Dipole Resonant frequency [MHz]	Frequency range [MHz]	Separation r [m]	Difference at different r	
			Amplitude [dB]	Phase [Deg]
30	10 to 100	250, 500	0.030	1.36
400	80 to1000	30, 40	0.0029	3.79
700	400 to 1500	30, 40	0.0014	4.39

IV. Conclusion

The phase response, as well as amplitude of CDAs are calculated and accurately verified experimentally from 10 MHz to 1000 MHz. The difference of S21 could be less than 0.52 dB and 9 Deg in amplitude and phase respectively for a pair of dipoles resonated at 400 MHz, which shows good performance in ultra-wide bandwidth. Based on the calculable property of CDAs, CAF is generated accurately at different separation, which shows little effect on the results for CAF at free-space. The CDAs can be used for verifying the accuracy of the antenna measurement system, as well as the standard antenna to measure other antenna's CAF. More accurate results and broader band frequencies can be acquired by more dipoles.

References

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