Complex Antenna Factors of EMI Antenna with Coaxial Cable Balun for Measuring Electromagnetic Fields

Chang-Hyun Ju · Dae-Hwa Jun · Ki-Chai Kim

Abstract

The purpose of this paper is to present the complex antenna factor of an EMI dipole antenna with a balun consisting of two coaxial feeders(coaxial cable balun) for measuring electromagnetic fields. A new formula of complex antenna factors for an EMI antenna with coaxial cable balun is derived using by power loss concepts. The complex antenna factor shows that the present result in this study was identical with that of the result from S-parameters. The theoretical complex antenna factors derived by power loss concepts are in good agreement with the experiments.

Key words : EMI Antennas, Complex Antenna Factor, Power Loss Concepts.

Ⅰ. Introduction

The EMI antennas for measuring electromagnetic interference are necessary to measure radiated emission from electronic equipments and systems or site attenuations of an open-area test site. Measurements of radiated emissions from equipment under test are usually made with resonant dipole antennas, biconical antennas, and log-periodic dipole antennas(LPDA) in the frequency range from 30 to 1,000 MHz. The various kinds of antennas have been already developed and used for EMI antennas, but a half-wavelength(half-wavelength resonance) dipole antenna is most basic[1]~[4]. Extensive work has been performed in the development of broadband, V-dipole antennas for pulse-receiving[5]. In transient field measurements, an antenna with wide-band performance both in amplitude and in phase is desired. The complex antenna factor(CAF) is an appropriate parameter of such an antenna. The complex antenna factor has been defined by Ishigami *et al.*[6], who computed and measured complex antenna factors for linear antennas using by S-parameters[7].

In this paper, a new formula of complex antenna factors for a general EMI antenna with a balun consisting of two coaxial feeders(coaxial cable balun) using by power loss concepts is derived and an EMI dipole antenna with the coaxial cable balun for measuring electromagnetic fields is presented. The previous work dealing with the analysis of a complex antenna factor using by S-parameters for a dipole antenna with a coaxial cable balun[7]. Bennett is considered the conventional scalar antenna factor using by power loss concepts[8]. This paper presents the complex antenna factor using by the power loss concept. We show that the present analysis was identical with the expression from the S-parameters. In the calculation of the complex antenna factor for the EMI dipole antenna, the integral equation for the current distribution on the dipole element is derived and solved by applying Galerkin's method of moments.

To check the validity of the theoretical analysis, the complex antenna factor was measured using by reference antenna methods. It is shown that the calculated complex antenna factor is good agreement with experimental results.

Ⅱ. Derivation of Complex Antenna Factors

Fig. 1 shows the basic structure of a general EMI antenna with a coaxial cable balun. The antenna with balanced elements is placed in the incident electric field. The coaxial feeder balun consist of two coaxial line with length l is connected to the antenna terminal as shown in Fig. 1. The inner conductors of the two coaxial lines are connected to the balanced dipole element. The outer conductors of the coaxial cable are in contact with each other electrically. As shown in Fig. 1, a matched terminal load is connected to one coaxial line, and a matched measuring instrument is connected to the other coaxial cable. If this structure is perfectly symmetrical, the two matched output voltages will have the same amplitude and a phase difference of π radian. Therefore, this structure works as a balun with 3 dB of loss at one port. This antenna is used only for receiving purposes.

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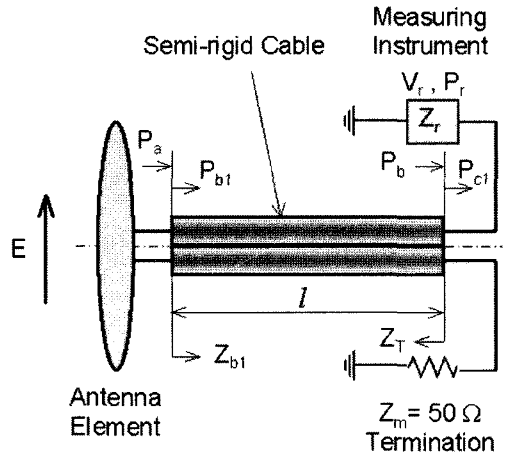


Fig. 1. A general EMI antenna with a coaxial cable balun.

When the EMI antenna receives a plane wave as shown in Fig. 1. If h_e is the effective length of a receiving antenna with a coaxial cable balun, and $Z_a=R_a+jX_a$ is the antenna input impedance, then the complex power available from receiving antenna can be expressed as

$$P_r^{ava} = \frac{(h_e E)^2}{4R_a} \tag{1}$$

where E is the incident electric field.

If the structure is perfectly symmetrical, the two matched output voltages will have the same amplitude and a phase difference of π. Therefore, this structure works as a balun with 3 dB of loss at one port. And, if V_r is the input voltage to a measuring receiver which is connected to the antenna, and $Z_r=R_r+j0$ is the input impedance of that receiver, then the complex power delivered to measuring receiver including the 3 dB of loss at one port and the phase difference of $exp(j\beta l)$ can be expressed as

$$P_r = \frac{(V_r)^2}{R_r}\left(\sqrt{2}e^{j\beta l}\right)^2 \tag{2}$$

where β is the phase constant of the coaxial cable.

Assuming only passive devices lie between the receiving antenna and measuring receiver, and a cable loss is zero, the total complex power losses can be represented as follows:

$$\frac{P_r^{ava}}{P_r} = \frac{E^2 h_e^2 R_r}{4R_a V_r^2\left(\sqrt{2}e^{j\beta l}\right)^2} = L_A L_B L_C \tag{3}$$

where

$$L_A = \frac{P_a}{P_{b1}} \tag{4}$$

$$L_B = \frac{P_{b1}}{P_b} \tag{5}$$

$$L_C = \frac{P_b}{P_{c1}}. \tag{6}$$

In (4), (5), and (6), P_a is the power available from antenna, P_{b1} is the power delivered to the coaxial cable balun, P_b is the power available from the coaxial cable balun, and P_{c1} is the power delivered to receiver input terminal as shown in Fig. 1. These powers can be expressed as

$$P_a = \frac{V_{oc}^2}{8R_a} \tag{7}$$

$$P_{b1} = \frac{1}{2}\frac{V_{oc}^2 Z_{b1}}{(Z_{b1}+Z_a)^2} \tag{8}$$

$$P_b = \frac{V_o^2}{8R_T} \tag{9}$$

$$P_{c1} = \frac{(Z_T+R_r)^2}{4R_r R_T} \tag{10}$$

where $Z_{b1}(=Z_B)$ is the input impedance seen from the input terminal of the coaxial cable balun into the receiver and $Z_T=R_T+jX_T$ is the impedance of the coaxial cable balun seen from the output terminal of the coaxial cable balun into the antenna as shown in Fig. 1. V_{oc} and V_o are the open circuited voltages of the Thevenin's equivalent circuits.

When the EMI antenna receives a plane wave as shown in Fig. 1. The complex antenna factor is defined as

$$K_C = \frac{E}{V_r} \tag{11}$$

where E is the incident complex electric field and V_r is the complex voltage of the receiver.

From (3), the desired complex antenna factor can be expressed as

$$K_C = \frac{2}{h_e}\sqrt{\frac{R_a}{R_r}}\sqrt{L_A L_B L_C}\sqrt{2}e^{j\beta l}. \tag{12}$$

If the coaxial cable balun is lossless, then the product $L_A L_B L_C$ can be calculated either by noting that P_b is the same as P_a, i.e., $L_A L_B=1$, and calculating L_C, or by noting that L_{c1} is the same as L_{b1}, i.e., $L_B L_C=1$, and calculating L_A. Clearly the result will be the same either way. L_A and L_C can be derived as

$$L_A = \frac{(Z_B+Z_a)^2}{4R_a Z_B} \tag{13}$$

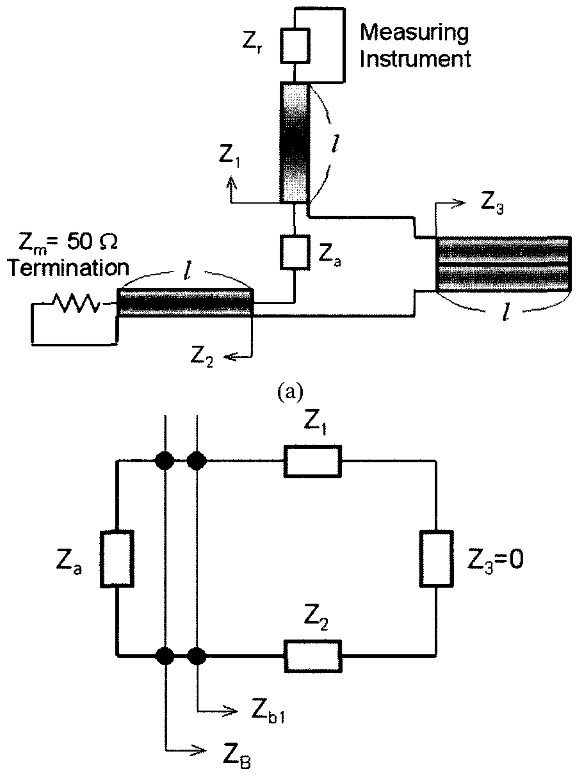


Fig. 2. An equivalent circuit of the balun for the purpose of studying its impedance characteristics.

$$L_C = \frac{(Z_T + Z_r)^2}{4R_T R_r} \tag{14}$$

In this paper, we choose the L_A, then the complex antenna factor can be expressed as

$$K_C = \frac{2}{h_e}\sqrt{\frac{R_a}{R_r}}\sqrt{\frac{(Z_B + Z_a)^2}{4R_a Z_B}}\sqrt{2}e^{j\beta l}\,. \tag{15}$$

where $Z_B(=Z_{b1})$ is calculated from the equivalent circuits as shown in Fig. 2. Fig. 2 illustrates the equivalent circuit of an EMI antenna with the coaxial cable balun as shown in Fig. 1. As shown in Figs. 1 and 2, Z_B is expressed as

$$Z_B = Z_{b1} = Z_1 + Z_2 + Z_3\,. \tag{16}$$

In Fig. 2, the three series impedances Z_1, Z_2, and Z_3 can be expressed as follows:

$$Z_1 = Z_0\frac{Z_r + jZ_0 \tan\beta l}{Z_0 + jZ_r \tan\beta l} \tag{17}$$

$$Z_2 = Z_0\frac{Z_m + jZ_0 \tan\beta l}{Z_0 + jZ_m \tan\beta l} \tag{18}$$

$$Z_3 = 0 \tag{19}$$

where Z_0 is the characteristic impedance of the coaxial cable and Z_r is the input impedance of the measuring receiver.

Ⅲ. Comparison of Complex Antenna Factors

For purposes of comparison, the published complex antenna factor derived using S-parameters is also showed.

If Z_r=R_r=Z_0, Z_m=Z_0, the input impedance $Z_B(=Z_{b1})$ of the coaxial cable balun seen from the input terminal of the coaxial cable balun into the receiver for the unloaded antenna can be expressed as

$$Z_B = Z_{b1} = Z_1 + Z_2 + Z_3 = 2Z_0\,. \tag{20}$$

From which the complex antenna factor (14) can be expressed as

$$K_C = \frac{1}{h_e}\left(2 + \frac{Z_a}{Z_0}\right)e^{j\beta l}\,. \tag{21}$$

This equation is identical with that of the expression in the reference [7] for the complex antenna factor derived by S-parameters. Thus, (21) gives the same result of the complex antenna factor derived from S-parameters for an EMI antenna with a coaxial cable balun.

Ⅳ. Transfer Function

In order to study the dependence of the sensitivity and fidelity(bandwidth of the flat zone) of the antenna, we present the normalized transfer function[5] given by (22) versus the frequency when the antenna length changes.

$$T_N = \frac{V_r}{EL} = \frac{h_e}{2\sqrt{2}}\sqrt{\frac{R_r}{R_a}}\sqrt{\frac{4R_a Z_B}{(Z_B + Z_a)^2}}\frac{e^{-j\beta l}}{L} \tag{22}$$

where L is the length of the EMI antenna.

Ⅴ. Numerical Results and Discussion

Fig. 3 shows the structure and coordinate system of an EMI dipole antenna with a coaxial cable balun. The dipole antenna with length L, radius a is placed along the z-axis. The coaxial feeder balun consist of two coaxial line with length l is connected to the antenna terminal as shown in Fig. 3.

Assuming the radius of the antenna is much smaller than wavelength and the antenna is fed by a delta-gap generator as the voltage source, the integral equation for the current distribution can be written as

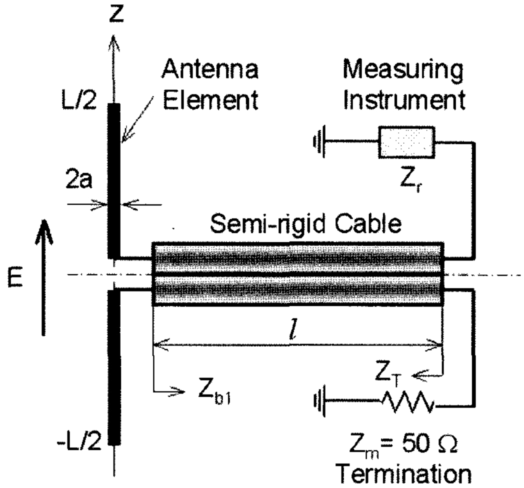


Fig. 3. An EMI dipole antenna with a coaxial cable balun.

$$\frac{1}{j4\pi\varpi\varepsilon_0}\int\left(k_0^2+\frac{\partial^2}{\partial z^2}\right)\frac{e^{-jk_0R}}{R}I(z')dz' = -V\delta(z) \tag{23}$$

where $R=\sqrt{(Z-Z')^2+a^2}$, k_0 is the wave number in free space, ω is the angular frequency, ε_0 is free space permittivity, $\delta(*)$ is the Dirac delta function.

The current distribution $I(z)$ in integral equation (23) can be expanded as

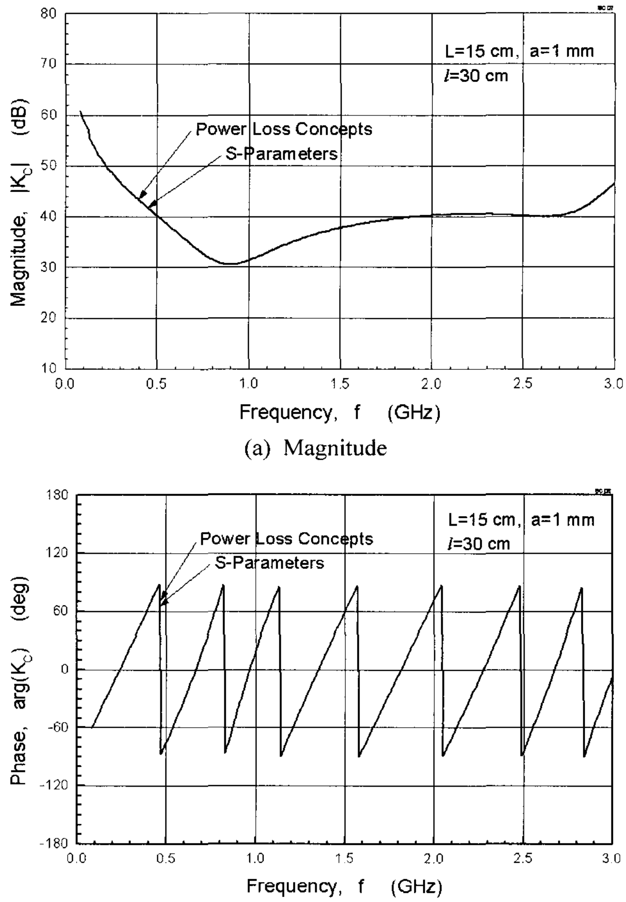
$$I(z)=\sum_{n=1}^{N} I_n F_n(z) \tag{24}$$

where I_n is the unknown current coefficients and $F_n(z)$ is the piecewise sinusoidal function on the segmented wire. Substituting the current distribution (24) into the integral equation (23) and employing Galerkin's method of moments, we obtain a set of linear equations for the unknown expansion coefficients.

In the numerical calculation, standard thin wire kernel approximation and segments length of 0.0125 λ per dipole length is used to the method of moments model for dipoles. The dipole length was chosen to be 15 cm and the nominal value 50 Ω is used for the characteristic impedance Z_0.

Fig. 4(a) and (b) show the frequency characteristics of the complex antenna factor. As shown in Fig. 4(a) and (b), the calculated result of complex antenna factors using by power loss concepts was coincident with the result from S-parameters[7]. In Fig. 4 and the others, the discontinuity of the magnitude at low frequencies is due to the different values of N-segment in order to satisfy the equal length segments of 0.0125 λ per dipole length at a given frequency.

Fig. 5 presents the normalized magnitude transfer function T_N for the EMI dipole antenna. As shown in Fig. 5, this antenna presents a sensitivity of 0.15. It also becomes apparent that as the frequency is increased, the antenna's sensitivity decreases.



(a) Magnitude

(b) Phase

Fig. 4. Frequency characteristics of complex antenna factors.

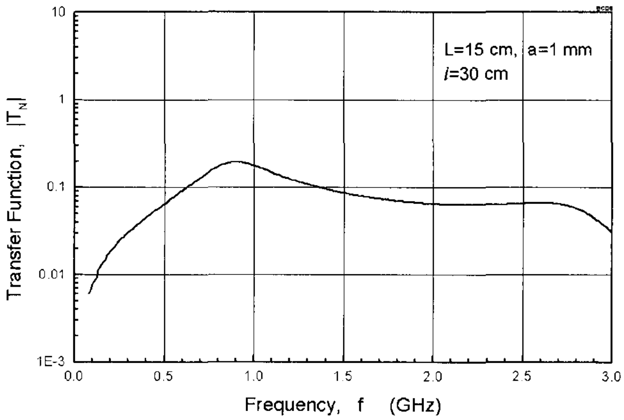


Fig. 5. The normalized magnitude transfer function.

To check the validity of the theoretical analysis presented in this paper, the complex antenna factor of the dipole antenna derived by the power loss concept was compared with those of experiments using by the

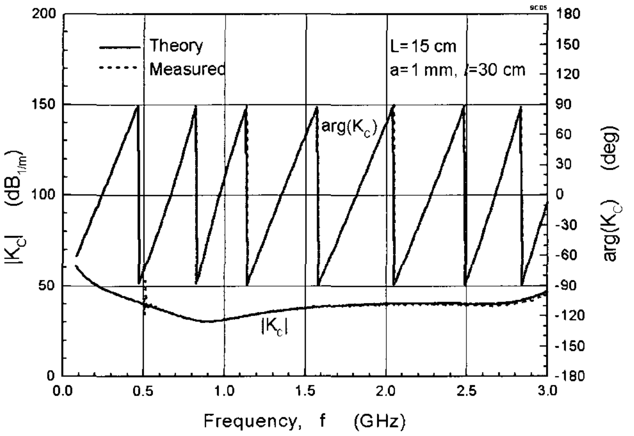


Fig. 6. The measured and calculated results of complex antenna factors.

reference antenna method. The experimental setup comprised of Wiltron 37225A network analyzer and a broadband double-ridged horn antenna made by ICU (Model No. ICU-MA-04-2, 0.75~6 GHz) for the field generation in the anechoic chamber. Its measured result is shown in Fig. 6. As the Fig. 6 indicates, it is shown that the calculated complex antenna factor by the power loss concept is good agreement with experimental results. At the low frequencies below 750 MHz, the magnitude of the complex antenna factor is just a major disagreement. The cause of the disagreement is due to the lower frequency limit of the anechoic chamber and the double-ridged horn antenna.

Ⅵ. Conclusions

In this paper a new formula of complex antenna factors for a general EMI antenna with a coaxial cable balun for measuring electromagnetic fields is derived using by power loss concepts and an EMI dipole antenna with a coaxial cable balun is presented. In the evaluation of the complex antenna factor for the dipole antenna, the integral equation for the current distribution on the dipole element is derived and solved by applying Galerkin's method of moments. The numerical results show that the result of complex antenna factors using by power loss concepts was identical with the result from S-parameters. The theoretical complex antenna factors derived by power loss concepts are in good agreement with the experiments.

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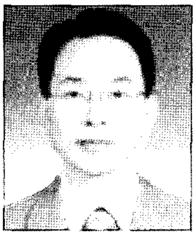

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