ANTENNA FACTORS OF EMI DIPOLE ANTENNA WITH COAXIAL CABLE BALUN FOR MEASURING RADIATED EMISSIONS

Chang-Hyun Ju, Eun Jung Park, and Ki-Chai Kim

Department of Electrical Engineering, Yeungnam University
214-1 Dae-dong, Kyeongsan, 712-749, Korea
ele0853@yumail.ac.kr, ahah66@yumail.ac.kr, kckim@yu.ac.kr

1. **Introduction**

The various kinds of antennas have been already developed and used for the EMI antennas and the antenna factor is an appropriate parameter of such an EMI antenna [1~3]. Measurements of radiated emissions from equipment under test, in the frequency range from 30 to 1000 MHz, are usually made with half-wavelength resonant dipole antennas. The wire biconical is the most common configuration in use between 20 and 300 MHz, with either log-periodic dipole arrays used from 200 to 1000 MHz.

In this paper, the dipole length of 150 cm with a balun consisting of two coaxial feeders (coaxial cable balun) is used in the frequency range between 30 and 300 MHz, with either 30 cm dipole length with a coaxial cable balun used from 300 to 1000 MHz. The antenna factor of the EMI dipole antennas with the coaxial cable balun for measuring radiated emissions is considered to be a function of the length of the dipole. The previous work dealing with the analysis of the complex antenna factor using by S-parameters for a dipole antenna with a coaxial cable balun [5]. The new formulation presented this paper is derived by using power loss concepts [4].

From the result of theoretical analysis, we realize two kinds of EMI dipole antennas with appropriate antenna factors in the frequency range from 30 to 1000 MHz: 150 cm dipole length (30~300 MHz) and 30 cm dipole length (300~1000 MHz). To check the validity of the theoretical analysis, the antenna factor was compared with those of experiments.

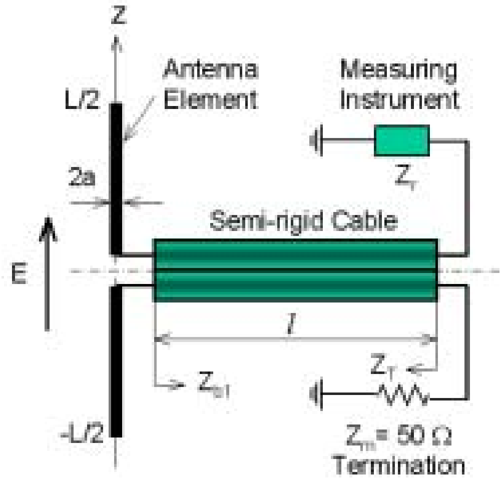


Fig. 1 An EMI dipole antenna with a coaxial cable balun.

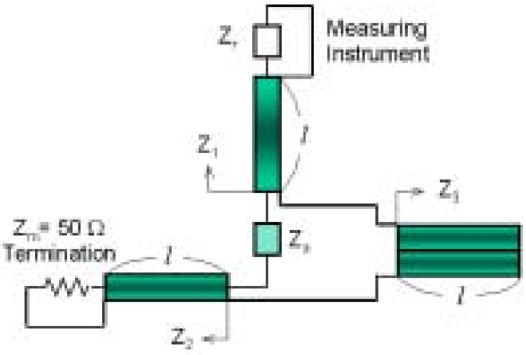


Fig. 2 An equivalent circuit of the EMI dipole antenna with a coaxial cable balun.

2. Dipole Antenna with Coaxial Cable Balun

Figure 1 shows the structure and coordinate system of the EMI dipole antenna with a coaxial cable balun. The dipole antenna with length L and 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. 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 [5]. This antenna is used only for receiving purposes.

3. Derivation of Complex Antenna Factor

An 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 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 the measuring receiver can be expressed as

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

where β is the phase constant of the coaxial cable.

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

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

where

$$L_A = \frac{P_a}{P_{b1}} \text{ (4a)}, \quad L_B = \frac{P_{b1}}{P_b} \text{ (4b)}, \quad L_C = \frac{P_b}{P_{c1}} \text{ (4c)}.$$

In (4a~4c), 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.

From (3), the desired antenna factor E/V_r can be expressed as

$$K_C = \frac{2}{h_e}\sqrt{\frac{R_a}{R_r}}\sqrt{L_A L_B L_C}\sqrt{2}e^{j\beta l}. \tag{5}$$

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 P_{c1} is the same as P_{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

$$L_A = \frac{(Z_B + Z_a)^2}{4R_a Z_B} \tag{6}$$

$$L_C = \frac{(Z_T + Z_r)^2}{4R_T R_r} \tag{7}$$

where $Z_B\,(= Z_{b1})$ is the input impedance seen from the input terminal of the coaxial cable balun into the receiver and Z_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.

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

$$K_C = \frac{2}{h_e}\sqrt{\frac{R_a}{R_r}}\sqrt{\frac{(Z_B + Z_a)^2}{4R_a Z_B}}\sqrt{2}e^{j\beta l}. \tag{8}$$

where Z_B is calculated from the equivalent circuits as shown in Fig. 2. As shown in Fig. 2, Z_B is expressed as

$$Z_B = Z_{b1} = \mathrm{Z}_1 + \mathrm{Z}_2 + \mathrm{Z}_3 . \tag{9}$$

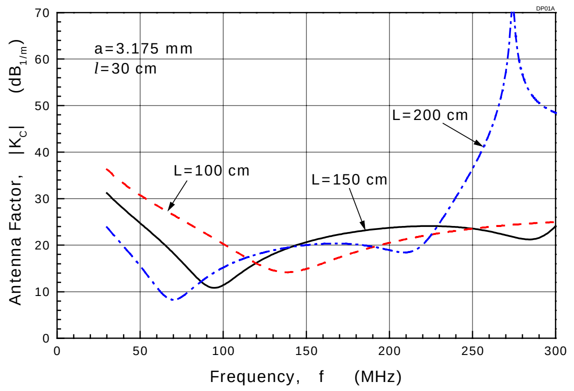
In Fig. 2, the three series impedances Z_1, Z_2, and Z_3 can be expressed as follows:

$$Z_1 = Z_0 \frac{Z_r + jZ_0 \tan\beta l}{Z_0 + jZ_r \tan\beta l} \tag{10}$$

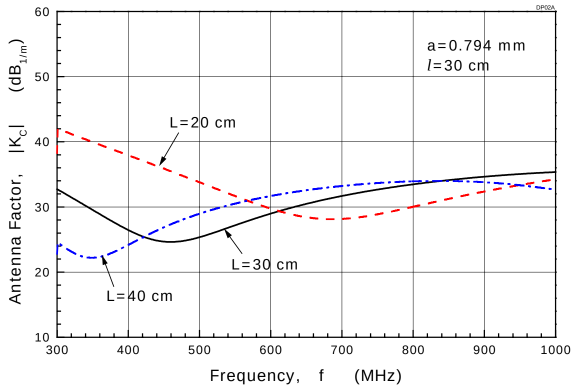
$$Z_2 = Z_0 \frac{Z_m + jZ_0 \tan\beta l}{Z_0 + jZ_m \tan\beta l} \tag{11}$$

$$Z_3 = 0 \tag{12}$$

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

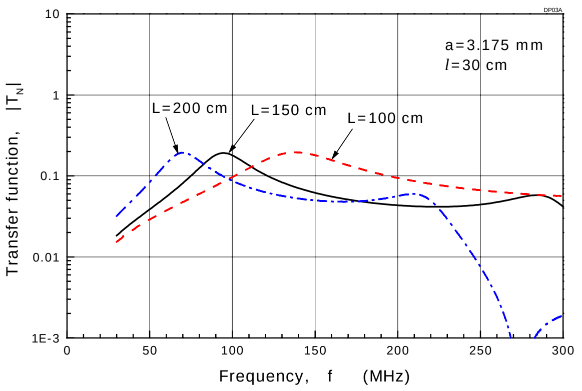


(a) 30 ~ 300 MHz

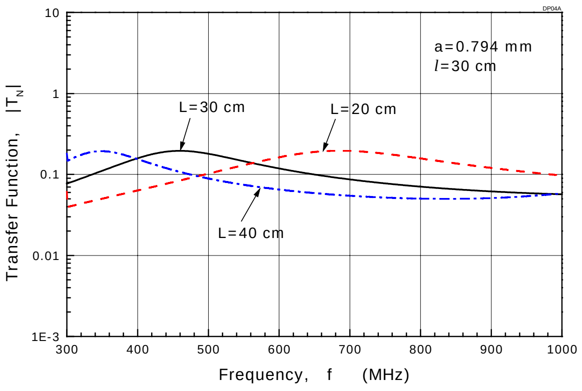


(b) 300 ~ 1000 MHz

Fig. 3 Frequency characteristics of antenna factors.



(a) 30 ~ 300 MHz



(b) 300 ~ 1000 MHz

Fig. 4 Frequency characteristics of transfer functions.

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 dipole can be expressed as

$$Z_B = Z_1 + Z_2 + Z_3 = 2Z_0 . \qquad (13)$$

From which the antenna factor (8) can be expressed as

$$K_C = \frac{1}{h_e}\left(2 + \frac{Z_a}{Z_0}\right)e^{j\beta l} . \qquad (14)$$

This equation is identical with that of the expression from S-parameters for the complex antenna factor [5].

In order to show the dependence of the sensitivity and fidelity (bandwidth of the flat zone) of the EMI antenna, we present the normalized transfer function given by (15) versus the frequency when the dipole length changes.

$$T_N = \frac{V_r}{EL} = \frac{h_e}{2\sqrt{2}}\sqrt{\frac{R_r}{R_a}}\sqrt{\frac{4R_a Z_B}{(Z_B + Z_a)^2}}\,\frac{e^{-j\beta l}}{L} \qquad (15)$$

where L is the length of the dipole antenna.

4. Numerical Results and Discussion

In the numerical calculation of the antenna impedance Z_a, standard thin wire kernel approximation with a radius of under 0.007λ and segments length of 0.0125λ per dipole length is used to the method of moments model for dipoles. The reference dipole length was chosen to be 150 cm in the frequency range from 30 to 300 MHz and 30 cm in the frequency range from 300 to 1000 MHz. The nominal value 50 Ω is used for the characteristic impedance Z_0.

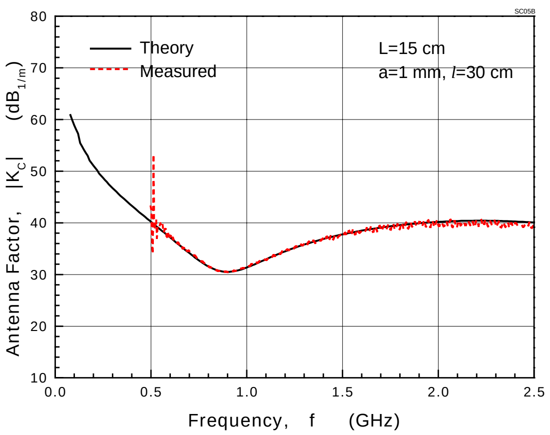


Fig. 5 The measured and calculated results of the antenna factor.

Figure 3 shows the frequency characteristics of the antenna factor as a parameter of a dipole length. As shown in Fig. 3, 150-cm dipole length in the frequency range between 30 and 300 MHz and 30-cm or 40-cm dipole length in the frequency range from 300 to 1000 MHz have an appropriate antenna factor.

Figure 4 presents the normalized magnitude transfer function as a parameter of a dipole length. As shown in Fig. 4, 150-cm dipole length and 30-cm or 40-cm dipole length are approximately 0.1 in sensitivity.

To check the validity of the theoretical analysis, the antenna factor of the dipole antenna was compared with those of experiments using by reference antenna methods. The dipole length for experiments was chosen to be 15 cm and the nominal value 50 Ω is used for the characteristic impedance Z_0. 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 results are shown in Fig. 5. As the Fig. 5 indicates, it is shown that the calculated antenna factor is in good agreement with experimental results. At the low frequencies below 750 MHz, the antenna factor is just a major disagreement. The disagreement is due to the lower frequency limit of the anechoic chamber and the double-ridged horn antenna.

5. Conclusions

The antenna factor of an EMI dipole antenna with a coaxial cable balun for measuring radiated emissions is considered in the frequency range between 30 and 1000 MHz. The new formulation of antenna factors presented this paper is derived by using power loss concepts. We can realize two kinds of EMI dipole antennas with appropriate antenna factors in the frequency range from 30 to 1000 MHz: 150-cm dipole length (30~300 MHz) and 30-cm dipole length (300~1000 MHz).

Acknowledgment

This research was supported by the EMERC (Electro Magnetic Environment Research center) in Chungnam National University, one of IT Research Centers.

References

[1] CISPR-16 part 1, “Specification for radio disturbance and immunity measuring apparatus and methods-Part 1, Radio disturbance and immunity measuring apparatus,” 1993.

[2] ANSI C63.4-1991, “American national standard methods of measurement of radio-noise emissions from low-voltage electrical and electronic equipment in the range of 9 kHz to 1 GHz,” 1991.

[3] K. C. Kim, “EMI dipole antennas with forced resonance by reactance loading for frequencies below 80 MHz,” IEICE Trans., on Commun., vol. E85-B, no. 11, pp. 2489-2494, Nov. 2002.

[4] W. S. Bennett, “Properly applied antenna factors,” IEEE Trans. Electromag. Compat., vol.EMC-28, no.1, pp.2-6, Feb. 1986.

[5] H. Hosoyama, T. Iwasaki, and S. Ishigami, “Complex antenna factor of a V-dipole antenna with two coaxial feeders for field measurements,” IEEE trans. on Electromag. Compat., vol.41, no.2, pp.154-158, May 1999.