Characteristics of the Sleeve Dipole Antenna Used for EMC Applications

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This work was supported by the 2016 Yeungnam University Research Grant.

ABSTRACT
This paper presents the antenna factor (AF) characteristics of a sleeve dipole antenna (SDA) with coaxial-cable balun for electromagnetic compatibility (EMC) applications. The AF characteristics are considered by varying parameters such as the length of the central dipole and the size and spacing of the sleeve elements. The coupled integral equations for the unknown current distributions on each element are derived and solved by applying Galerkin’s method of moments. A SDA with a 180 cm central dipole has similar characteristics as a conventional biconical antenna but with a physical volume 86% lower than that of the Schwarzbeck BBA9106 biconical antenna. Calculated antenna factors of the SDA are compared with measured results. A sleeve dipole antenna for electromagnetic interference (EMI) measurements with an appropriate antenna factor could be realized.

INDEX TERMS
Antenna factor, biconical antenna, EMC antenna, EMI/EMC measurement, fixed-resonant dipole antenna, sleeve dipole antenna.

I. INTRODUCTION
The use of a tuned dipole antenna in the electromagnetic compatibility (EMC) field is described in CISPR Publication 16-1 and ANSI C63.5 [1], [2]. The problem with using the tuned dipole antenna is that it has to be tuned at every measurement frequency. These days electromagnetic interference (EMI) receiver and spectrum analyzer are able to make the equivalent of swept frequency measurements. Therefore, the broadband antennas are necessary for the automation of EMC measurements. The broadband EMC antennas typically used in EMC measurements are the biconical antenna (30 ~ 300 MHz) and log-periodic dipole array antenna (300 ~ 1000 MHz and beyond). These broadband EMC antennas for the measurement of EMI have similar wire radiating structures and have been developed and reported on by many researchers [3]–[13]. A disk-loaded thick dipole antenna was also developed for the validation of an EMC test site using a thick cylindrical dipole to achieve broad-band characteristics [14]. Recently, broad-band sleeve antennas have been developed for application with a cross-borehole radar [15] and a high power ultra-high frequency (UHF) band [16].

The calculated antenna factors of SDA with CC balun are compared with measured results. We confirmed that a sleeve dipole antenna for EMI measurements with an appropriate antenna factor could be realized.

This paper presents the antenna factor (AF) characteristics of a sleeve dipole antenna (SDA), with coaxial-cable balun (CC balun), for use in EMI measurements in the frequency range of 30 MHz to 300 MHz. To calculate the AF, the coupled integral equations for the unknown current distributions on each element are derived and solved by applying Galerkin’s method of moments (MoM). We considered the frequency characteristics of the SDA AF in terms of central dipole length, size of sleeve elements, and sleeve spacing. In particular, various lengths of the central dipole were considered for comparison with the AF of a conventional 130 cm biconical antenna, a 130 cm fixed-length dipole antenna, and a resonant dipole antenna. When a central dipole lengths of 160 cm, 180 cm, and 200 cm were chosen for use in the frequency range of 30 to 300 MHz, the SDA has similar characteristics as the conventional biconical antenna, which has a volume 88%, 86%, and 85% lower than that of the commercial Schwarzbeck BBA9106 biconical antenna, respectively. Through proper adjustment of the parameters, a SDA with similar performance to the biconical antenna can easily be designed.

The calculated antenna factors of a SDA with CC balun are compared with measured results. We confirmed that a sleeve dipole antenna for EMI measurements with an appropriate antenna factor could be realized.
II. STRUCTURE OF SLEEVE DIPOLE ANTENNA

Fig. 1(a) shows the structure of a SDA with CC balun of length $d$ that is connected to the feeding terminal of a central dipole element. The matching impedance ($Z_m$) and receiver impedance ($Z_L$) are connected to the end of the CC balun. As shown in Fig. 1(b), a central dipole (#0) with length $L$ and radius $a$ is located on the z-axis. $N$ sleeve elements (#1, #2, · · · , #N) with length $S$ are arrayed on the circumference at a distance $R$ (sleeve spacing) from the central dipole element (#0).

III. ANTENNA FACTORS

The complex antenna factor of a SDA with a CC balun of length $d$ is expressed as follows [12]:

$$ AF = \frac{2}{h_e} \sqrt{\frac{R_a}{R_f}} \sqrt{\frac{(Z_B + Z_a)}{4R_aZ_B}} \sqrt{2}e^{\beta d} \tag{1} $$

where $h_e$ is the effective length of the antenna; $Z_a(= R_a + jX_a)$ is the input impedance of the antenna; $Z_B$ is the input impedance of the CC balun as seen from the input terminal of the CC balun into the receiver, and $Z_B$ is given as follows [12]:

$$ Z_B = Z_0 \frac{Z_{a} + jZ_0 \tan \beta d}{Z_0 + jZ_m \tan \beta d} + Z_0 \frac{Z_m + jZ_0 \tan \beta d}{Z_0 + jZ_m \tan \beta d} \tag{2} $$

where $Z_0$ and $\beta$ are the characteristic impedance and phase constant of the coaxial cable, respectively.

When voltage is excited from the central dipole, the simultaneous integral equations for the current distributions flowing in each element are derived. To obtain the solution of the simultaneous integral equations using Galerkin’s MoM, the current distribution on each element is expanded as a piecewise sinusoidal function. If the current distributions are obtained, the AF characteristics of the SDA can be calculated from Eq. (1).
IV. ANTENNA FACTOR CHARACTERISTICS OF THE SDA

Considering the structural robustness of the SDA, \( N = 6 \) or \( N = 8 \) is much stronger than \( N = 3 \). The AF characteristics are almost identical in \( N = 6 \) and \( N = 8 \) within 0.28 dB. In this study, \( N = 6 \) is fixed for structural robustness and symmetry, such as the six elbow-shaped wires on the biconical antenna [3]–[5], [17]. To calculate the AF characteristics of the SDA, we set the number of sleeves to \( N = 6 \), and the radii of the central dipole and sleeve elements are 3.175 mm. The length of the central dipole was set to \( L = 130 \) cm, \( L = 160 \) cm, \( L = 180 \) cm, and \( L = 200 \) cm, for comparison with the AF of the conventional 130 cm biconical antenna [4], the Schwarzbeck BBA9106 biconical antenna [17], a 130 cm fixed-length dipole antenna, and a resonant dipole antenna. The length of the CC balun is \( d = 43 \) cm, which is the same as the boom length of the 130 cm biconical antenna [4].

Fig. 2 presents a graphical comparison of the AF versus the sleeve spacing of the central dipole as a parameter of the frequency when \( N = 6 \), \( L = 180 \) cm, and \( S = 50 \) cm. The AF is minimal with a sleeve spacing of \( R = 7.7 \) cm (approximated to 8 cm).

Fig. 3 presents the frequency characteristics of the AF as a parameter of the sleeve length when \( N = 6 \), \( L = 180 \) cm, and \( R = 8 \) cm. The AFs are almost the same at frequencies below 130 MHz, but above 130 MHz the AFs are significantly different for various sleeve lengths. The sleeve length of 50 cm is the best for the AF because it exhibits the smallest AF fluctuation. The AF characteristics were found to be more strongly affected by the length of the sleeves than by the number of sleeves.

Fig. 4 shows the frequency characteristics of the AF as a parameter of the central dipole length for a selecting of length and sleeve spacing that give the best AF performance for the central dipole lengths compared. The conventional biconical antenna has a length of 130 or 131 cm. Thus, the SDA central dipole with \( L = 130 \) cm is first adopted for AF comparison with a 130 cm biconical antenna [4] and a 131 cm Schwarzbeck BBA9106 antenna [17]. We also considered the AF at \( L = 160 \) cm, \( L = 180 \) cm, and \( L = 200 \) cm. There are suitable characteristics of the AF at which the frequency on both ends (i.e., 30 MHz and 300 MHz) exhibits better characteristics when \( L = 180 \) cm than when \( L = 130 \) cm, \( L = 160 \) cm, and \( L = 200 \) cm. Therefore, the 180 cm SDA (with \( S = 50 \) cm and \( R = 8 \) cm) exhibits the most suitable AF characteristics and is similar to the 130 cm biconical antenna and the 131 cm Schwarzbeck BBA9106 as shown in Fig. 5. In addition, for a SDA with \( N = 6 \), the H-plane radiation pattern is very close to omni-directional.

Fig. 5 presents the frequency characteristics of the AF when the central dipole is fixed at \( L = 180 \) cm (with \( S = 50 \) cm and \( R = 8 \) cm), and also presents the AF of four different antenna types, for comparison. The four types are the 130 cm biconical antenna, 131 cm Schwarzbeck BBA9106 antenna, 130 cm fixed-length dipole antenna, and resonant dipole antenna. The 130 cm SDA is not suitable because its AF is larger than that of the 130 cm fixed-length dipole antenna at frequencies below 100 MHz as shown in Figs. 4 and 5.

Fig. 6 depicts the schematics of the SDA and Schwarzbeck BBA9106 antennas used to calculate the physical volume.

Table 1. Comparison of antenna volume disparity.

| Antenna length L (cm) | Sleeve Dipole Antenna (SDA) | Schwarzbeck BBA9106 [17] |
|-----------------------|----------------------------|--------------------------|
| 130                   | 16,300                     | 289,010                  |
| 160                   | 34,774                     |                          |
| 180                   | 39,121                     |                          |
| 200                   | 43,468                     |                          |
| Volume reduction (%)  | 94                         | 88                       |

FIGURE 5. Comparison of the antenna factors of four different antenna types.

FIGURE 6. Schematics of the Schwarzbeck BBA9106 and sleeve dipole antennas used to calculate the physical volume.
the antenna. Comparing the physical sizes of the antenna, (i.e., the volume of the antenna), a SDA with \( L = 160 \) cm, \( 180 \) cm, and \( 200 \) cm has a volume 88%, 86%, and 85%, respectively, lower than that of the 131 cm Schwarzbeck BBA9106 biconical antenna [17]. Table 1 presents the physical volumes of several SDAs and the Schwarzbeck BBA9106 antenna.

As shown in Figs. 4 and 5, the 180 cm SDA (with \( S = 50 \) cm and \( R = 6 \) cm) has similar characteristics as the BBA9106 biconical antenna but has a physical volume 86% lower than that of the Schwarzbeck BBA9106 biconical antenna, as shown in Table 1. As mentioned in Section IV, the AF characteristics with \( N = 6 \) and 8 are almost identical within 0.28 dB. Therefore, there is little difference in the physical volume between \( N = 6 \) and 8.

V. ANTENNA FACTOR MEASUREMENTS

To check the validity of the theoretical analysis, the AF of the SDA was compared with those from experiments conducted using the reference antenna method.

Fig. 7 shows the constructed SDA with \( N = 8 \), \( L = 200 \) cm, \( S = 60 \) cm, and \( R = 6 \) cm. The details of the driving point are also shown in Fig. 7. The copper flanges are soldered for a tight connection to the coaxial-cable balun.

Fig. 8 shows the AF measurement setup in an open area test site (OATS). A size of the OATS is \( 21 \) m in length and \( 18 \) m in width. The biconical antenna (Rohde & Schwarz HK116), calibrated by Korea Research Institute of Standards and Science (KRISS), was used as a reference antenna in a frequency range from \( 30 \) to \( 300 \) MHz. A transmitting antenna is fixed on a polystyrene block foam of which a height is \( 34 \) cm [17]. The distance between transmitting and receiving antennas is \( 3 \) m.

The frequency characteristics of the calculated and measured AFs of the SDA are shown in Fig. 9. Although loss was not taken into account in theoretical calculation, it can be seen in the figure that the calculated and measured AFs are in good agreement at high frequencies. The difference at low frequencies seems to be due to the coupling effect and reference antenna uncertainty. The SDA manufacturing errors are also affected in these deviations.

The thin disc-type frames can support the central dipole and sleeve elements and ensure the structural robustness of the SDA. However, thin disk-type frames with low permittivity should be employed to avoid affecting the AF characteristics. Research on this will be conducted in future work.

VI. CONCLUSION

This study presents the AF of SDAs for use in a 30–300 MHz frequency range. The flatness of the antenna factor is considered by varying the length and number of sleeve elements. The 180 cm SDA exhibits the most suitable AF characteristics and it is more similar to the 131 cm Schwarzbeck BBA9106 biconical antenna but with 86% less physical volume. We confirmed that a sleeve dipole antenna for EMC measurements with an appropriate antenna factor could be realized.

REFERENCES

[1] CISPR-16 Part 1, Specification for Radio Disturbance and Immunity Measuring Apparatus and Methods-Part 1, Radio Disturbance and Immunity Measuring Apparatus, CISPR Publication 16-1, IEC, 1993.

[2] American National Standard for Electromagnetic Compatibility–Radiated Emission Measurements in Electromagnetic Interference (EMI) Control–Calibration and Qualification of Antennas (9 kHz to 40 GHz), Standard ANSI C63.5-2017, 2017.
[3] B. A. Austin and A. P. C. Fourie, “Characteristics of the wire biconical antenna used for EMC measurements,” IEEE Trans. Electromagn. Compat., vol. 33, no. 3, pp. 179–187, 1991.

[4] S. M. Mann and A. C. Marvin, “Characteristics of the skeletal biconical antenna as used for EMC applications,” IEEE Trans. Electromagn. Compat., vol. 36, no. 4, pp. 322–330, Apr. 1994.

[5] M. J. Alexander, M. H. Lopez, and M. J. Salter, “Getting the best out of biconical antennas for emission measurements and test site evaluation,” in Proc. EMC, Austin Style. IEEE Int. Symp. Electromagn. Comput., Symp. Rec., Aug. 1997, pp. 18–22, doi: 10.1109/ISEMC.1997.667546.

[6] A. R. Mallahzadeh, R. Pazoki, and S. Karimkashi, “A new UWB skeletal sleeve dipole antenna,” in Proc. Int. Symp. Microw., Antenna, Propag. EMC Technol. Wireless Commun., Aug. 2007, pp. 543–546.

[7] Z. Kai, L. Wang, and C. Xiewei, “Study on the biconical antenna in the EMC test suitable for engineering machinery,” in Proc. WRI World Conge. Comput. Sci. Inf. Eng., 2008, pp. 81–84.

[8] J. L. McDonald and D. S. Filipovic, “Biconical antenna over ground plane,” IEEE Trans. Antennas Propag., vol. 60, no. 4, pp. 2093–2096, Apr. 2012.

[9] R. Wakabayashi, K. Shimada, H. Kawakami, and G. Sato, “Circularly polarized log-periodic dipole antenna for EMI measurements,” IEEE Trans. Electromagn. Compat., vol. 41, no. 2, pp. 93–99, May 1999.

[10] Z. Chen, M. Foegele, and T. Harrington, “Analysis of log periodic dipole array antennas for site validation and radiated emissions testing,” in Proc. IEEE Int. Symp. Electromagn. Computability, Symp. Rec., vol. 2, Aug. 1999, pp. 618–623.

[11] S. Z. Sapuan, A. Kazemipour, and M. Z. Mohd Jenu, “Direct feed biconical antenna as a reference antenna,” in Proc. IEEE Int. RF Microw. Conf., Dec. 2011, pp. 5–8.

[12] K.-C. Kim, “Complex antenna factors of resistor loaded dipole antennas with coaxial cable balun,” IEICE Trans. Commun., vol. E89-B, no. 4, pp. 1467–1471, Apr. 2006.

[13] L. Jian-Ying and G. Yeow-Beng, “Study on open sleeve dipole antenna,” in Proc. IEEE Int. Workshop Antenna Technol., Small Antennas Novel Metamater. (IWAT), Jul. 2005, pp. 7–9, doi: 10.1109/IWAT.2005.1461073.

[14] W.-S. Cho, M. Kanda, H.-J. Hwang, and M. W. Howard, “A disk-loaded thick cylindrical dipole antenna for validation of an EMC test site from 30 to 300 MHz,” IEEE Trans. Electromagn. Comput., vol. 42, no. 2, pp. 172–180, May 2000.

[15] J.-H. Jung, J.-H. Cho, and S.-Y. Kim, “Analysis of sleeve dipole antennas fed by ferrite-loaded coaxial cables for a scaled-down cross-borehole radar,” IEEE Trans. Antennas Propag., vol. 65, no. 11, pp. 6130–6133, Nov. 2017.

[16] R. Lewis, “Broadband optimization of a high power UHF band cylindrical sleeve dipole antenna,” in Proc. IEEE Int. Symp. Antennas Propag. USNC-URSI Radio Sci. Meeting, Jul. 2019, pp. 1239–1240.

[17] D. Meng and M. J. Alexander, “Calibration of biconical antennas by vertically stacking method,” IEEE Trans. Electromagn. Comput., vol. 56, no. 6, pp. 1262–1270, Dec. 2014.

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