Evaluation of a TEM horn antenna for radiated immunity tests in close proximity

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Abstract: We have proposed a transverse electromagnetic (TEM) horn antenna for radiated immunity tests in close proximity as specified in IEC 61000-4-39 and evaluated the main characteristics of the antenna required in the immunity tests. The TEM horn antenna has broadband radiation characteristics with a low VSWR and generates a homogeneous field over the entire test frequency range from 380 MHz to 6 GHz.

Keywords: immunity, TEM horn antenna, shortened exponential taper, radiated immunity test in close proximity

Classification: Electromagnetic Compatibility (EMC)

References

- [1] IEC 61000-4-39, Electromagnetic Compatibility (EMC) - Part 4-39: Testing and measurement techniques - Radiated fields in close proximity - Immunity test, 2017.
- [2] C. A. Grosvenor, R. T. Johnk, D. R. Novotny, S. Canales, B. Davis, and J. Veneman, "TEM horn antenna design principles," NIST Technical Note 1544, Jan. 2007. DOI:10.6028/NIST.TN.1544
- [3] H. Hirsch and R. Heinrich, "Simulation and experimental investigations of a TEM horn antenna for RF radiated immunity testing in close proximity," Proc. Int. Symp. Electromagn. Compat. (EMC EUROPE 2017), Angers, France, Sept. 2017. DOI:10.1109/EMCEurope.2017.8094739
- [4] K. Harima, T. Kubo, and T. Ishida, "Evaluation of a TEM horn antenna prototype for radiated immunity test in close proximity," Proc. 2019 Joint Int. Symp. Electromagn. Compat. and Asia-Pacific Int. Symp. Electromagn. Compat. (EMC Sapporo/APEMC 2019), Sapporo, Japan, pp. 581–584, June 2019. DOI:10.23919/EMCTokyo.2019.8893928
- [5] H. Choi and S. Lee, "Design of an exponentially-tapered TEM horn antenna for the wide broadband communication," *Microw. Opt. Technol. Lett.*, vol. 40, no. 6, pp. 531–534, Mar. 2004. DOI:10.1002/mop.20025
- [6] K. Harima, "Numerical estimation for TEM horn antennas with transmission line taper shapes," *IEICE Commun. Express*, vol. 6, no. 9, pp. 560–565, Sept. 2017. DOI:10.1587/comex.2017XBL0095
- [7] A. R. Mallahzadeh and F. Karshenas, "Modified TEM horn antenna for

- broadband applications,” *Prog. Electromagnetics Res.*, vol. 90, pp. 105–119, 2009. DOI:10.2528/PIER08123106
- [8] J. W. Duncan and V. P. Minerva, “100:1 bandwidth balun transformer,” *Proc. IRE*, vol. 48, no. 2, pp. 156–164, Feb. 1960. DOI:10.1109/JRPROC.1960.287458
- [9] M. Manteghi and Y. Rahmat-Samii, “A novel UWB feeding mechanism for the TEM horn antenna, reflector IRA, and the Vivaldi antenna,” *IEEE Antennas Propag. Mag.*, vol. 46, no. 5, pp. 81–87, 2004. DOI:10.1109/MAP.2004.1388832

1 Introduction

Recently, with the widespread availability of portable wireless services such as mobile phones, the situations in which these radio frequency (RF)-transmitting devices are used in close proximity to electronic equipment have become increasingly common. For this reason, immunity requirements for electronic equipment with the aim of ensuring protection against RF sources used in close proximity have been specified in the basic standard IEC 61000-4-39 [1].

The use of TEM horn antennas as radiating antennas is explicitly defined in the standard, and several types of antennas have been proposed for immunity tests [2, 3, 4]. For a linearly tapered TEM horn antenna, resistive tapers are often used for matching the characteristic impedance at the feeding point and to the aperture [2]. A TEM horn antenna with an exponentially tapered structure based on a tapered transmission line does not require resistive loading for impedance matching [5]. This type of antenna has the most suitable characteristics as a broadband antenna among typical tapered transmission lines [6]. However, it does not maintain a single main lobe in the radiation pattern over part of its frequency range. Modified exponentially tapered TEM horn antennas with improved directivity have been proposed [6, 7]. The TEM horn antenna is a balanced antenna such as a dipole and is usually connected to a balun circuit. For radiated immunity testing, the balun should have a broadband, low-loss, and high-power handling capability. For this purpose, a tapered coaxial balun [8] or a balanced feeding mechanism [9] is applicable.

In this work, we proposed a TEM horn antenna with a balanced feeding mechanism for use in close-proximity radiated immunity tests. The antenna characteristics and field uniformity of the exposure area required by the test standard were evaluated experimentally and numerically.

2 Design of the TEM horn antenna

A TEM horn antenna was designed for EMC measurements, especially for a radiated immunity test in close proximity. The close-proximity test is carried out in the frequency range of 380 MHz to 6 GHz, which is used in mobile wireless services [1]. A TEM horn antenna is used as the field-generating antenna; the use of a double-ridged guide horn, LPDA, and other antennas is not allowed in the standard. The TEM horn antenna consists of two metal plates tapered from the

feeding section to the aperture. The tapered structure has to be designed considering the impedance matching at the feeding section and to the aperture. For a linearly tapered TEM horn antenna, which is easy to construct, a resistively loaded taper is used to match the impedances [2]. On the other hand, by applying tapered transmission lines to the antenna shape, the characteristic impedance can be transformed continuously and smoothly from the feeding section to the aperture; that is, resistive loading for matching the impedance is not necessary [5]. The exponential taper has the most suitable radiation characteristics as a broadband antenna among typical tapered transmission lines [6].

Fig. 1 shows a proposed TEM horn antenna with an exponentially tapered shape. The plate of the antenna was made of brass of 0.6 mm thickness, and the spacing between the two plates was maintained using an expanded hard foam with a relative dielectric constant of 1.07. The configuration of these dielectric supporting objects was adjusted while taking into account its influence on the radiation characteristics by computer aided design (CAD) modeling and numerical simulations using CST Studio Suite based on the finite integration technique (FIT). As the antenna parameters for the exponentially tapered shape that we used, the antenna length (L) and aperture dimension ($h_L = w_L$) are set to a half wavelength (60 cm) at the lowest frequency (250 MHz). The characteristic impedance $Z(z)$, the separation $h(z)$ between the two plates, and the width $w(z)$ of the plate at the location z , $0 \leq z \leq L$, are expressed respectively as [5]

Fig. 1. (a) External view and (b) internal structure of proposed TEM horn antenna. Calculated surface current distribution on antenna plate of (c) 870 MHz and (d) 2.45 GHz.

$$Z(z) = Z_0 e^{z/L \ln(Z_L/Z_0)}, \quad (1)$$

$$h(z) = h_0 e^{z/L \ln(h_L/h_0)}, \quad (2)$$

and

$$w(z) = \frac{h(z)}{Z(z)} 120\pi, \quad (3)$$

where $Z_0 (= Z(0))$ is the input impedance at the coaxial feeding point of 50Ω and $Z_L (= Z(L))$ is the characteristic impedance at the square aperture of 377Ω . The TEM horn antenna with the exponentially tapered shape does not maintain a single main lobe in the radiation pattern over part of its frequency range. This directivity problem can be improved by shortening the plate, that is, the antenna plate was cut off at 10% ($dl = 0.1L$) of the antenna length from the aperture [6], as shown in Fig. 1(b).

Since the TEM horn antenna is a balanced antenna such as a dipole, it is usually connected to a balun circuit when feeding by an unbalanced coaxial cable. In particular, for radiated immunity testing, the balun should have a broadband, low-loss, and high-power handling capability. However, by considering the current distribution on the antenna, the common-mode leakage current flowing outside the outer conductor of the coaxial cable can be suppressed without using the balun circuit [9]. The surface current distribution on the tapered plate of the TEM horn antenna is calculated by the FIT solver. Some examples of the current distribution are shown in Figs. 1(c) and (d). It shows that there are high-current parts at the narrow portion and edge of the plate, and low-current parts at the center of the aperture side. A semirigid cable was attached to the plate from the antenna feeding point to a point in the low-current area.

3 Measured results

In a proximity radiated immunity test [1], the equipment under test (EUT) is placed at a distance of 100 mm from the antenna aperture. The field uniformity in the area illuminated by the TEM horn antenna is validated by measurements, and the usable window size of the uniform area of the E-field is defined to be in the range of 0 to 4 dB below the maximum field strength. The antenna is moved according to the window size to fully illuminate all surfaces of the EUT. Therefore, TEM horn antennas that generate larger uniform areas improve test efficiency by reducing the test time.

The experimental setup for the measurement of the field uniformity is shown in Fig. 2(a). The frequency-selective E-field probe was scanned on a test area in 2.5 cm steps using an XY-positioner, and the E-field distribution generated by the TEM horn antenna was measured. The measured field uniformities at frequencies for different mobile wireless services, which are 380 MHz, 870 MHz, 1,845 MHz, 2.45 GHz, and 5.85 GHz, are shown in Figs. 2(b) to (f), respectively. The maximum field strength was located on the antenna axis and at the center of the uniform area over the entire range of test frequencies. The uniform area tends to decrease as the frequency increases, which results in the minimum uniformity window size of 20 cm × 20 cm. The measured E_y , E_x , and E_z field distributions at 5.85 GHz are

Fig. 2. (a) Experimental setup. Measured field uniformities of (b) 380 MHz, (c) 870 MHz, (d) 1,845 MHz, and (e) 2.45 GHz, and (f) E_y , (g) E_x , and (h) E_z field distributions at 5.85 GHz at 100 mm distance from TEM horn antenna.

shown in Figs. 2(f) to (h), respectively. Although the cross-polarization level is not required in the close proximity test, its level is less than -20 dB in the on-axis direction. The E_z component appeared to increase at the upper and lower sides owing to the direction of the E-field vector. The measurement results are in good agreement with the results of numerical simulations using the antenna CAD model, as shown in Fig. 2(f).

The VSWR of the antenna should not exceed 3:1 as required in a proximity radiated immunity test. The measured VSWR of the TEM horn antenna is shown in Fig. 3(a). Considering that the reflection characteristic rapidly deteriorates at the lower frequency, the antenna geometry parameter in the design was adjusted to 250 MHz so that the VSWR satisfies the IEC requirement at the test frequency of 380 MHz. A good reflection characteristic within a VSWR of 2:1 is obtained owing to the effect of the exponentially tapered transmission line. The reflected wave from the EUT placed close to the antenna causes the deterioration of the VSWR. Assuming the worst-condition, i.e., an EUT with a huge metal surface, the aperture

Fig. 3. (a) Measured VSWR of TEM horn antenna and (b) required forward power for 300 V/m at 100 mm from antenna aperture.

of the TEM horn antenna was directed at a distance of 100 mm from the metal floor in a semi-anechoic chamber. The VSWR worsens owing to the reflection wave from the metal floor, yet it still satisfied the VSWR limit specified in all test frequency bands.

The test levels for RF fields are classified as 10, 30, 100, and 300 V/m according to the wireless communication equipment [1]. The forward power required to generate 300 V/m at a 100 mm distance from the aperture of the TEM horn antenna is shown in Fig. 3(b). The proposed antenna is highly efficient because it does not use resistive loading or a balun circuit. That is, a forward power of 100 W is required at low frequencies, and that of 40 W is required above 2 GHz.

4 Conclusion

We have presented a shortened exponentially tapered TEM horn antenna used for radiated immunity tests in close proximity. A TEM horn antenna was designed and fabricated using a numerical simulation based on the finite integration technique. The experimental results indicate that the proposed TEM horn antenna has broadband radiation characteristics covering a test frequency range from 380 MHz to 6 GHz and a low VSWR of less than 2:1, which satisfies the requirement of the test standard, and that it generates a homogeneous RF field area with less deformation over the entire test frequency range.