On the New Design of a 4-Port TEM Waveguide with a Higher Cutoff Frequency and Wider Test Volume

Sangbong Jeon, Jaehoon Yun, and Seungkeun Park

A new miniaturized 4-port waveguide generating a transverse electromagnetic wave is proposed. The waveguide presents enhanced performance of higher field uniformity in extended test volume up to an increased test frequency limit compared to that of the conventional 2-port waveguide. The advantageous features of the proposed waveguide have been obtained through a new design scheme based on effective miniaturization maintaining good impedance matching. Consequently, we can provide a more accurate electromagnetic compatibility test method, covering larger devices operating in higher frequencies, which is a marked improvement upon the conventional approaches.

Keywords: TEM waveguide, EMC test, field uniformity, cutoff frequency, far-field environment.

I. Introduction

A transverse electromagnetic (TEM) waveguide has become a popular test apparatus to evaluate the electromagnetic compatibility (EMC) properties of electric or electronic devices, which has been regarded as an alternative approach to a conventional far-field test in an Open Area Test Site [1]-[3].

A 1-port or 2-port waveguide with a single septum is a typical structure generating TEM waves, which is widely used in the practical field of EMC examinations [1], [2]. In our previous work, we presented a modified 4-port waveguide with two parallel septa, illustrating that the test volume of a waveguide could be enlarged [3]. However, the test volume and the test frequency of this 4-port waveguide are limited, which makes it difficult to cover larger emerging devices operating in higher frequencies. The Korean terrestrial digital multimedia broadcasting (T-DMB) receiver can be used as a typical example to show the limitations of conventional TEM waveguides. The T-DMB receiver, including antenna, measures about 25 cm and operates from about 170 MHz to 240 MHz. It is well known that we cannot characterize the EMC properties of the T-DMB receiver using conventional TEM waveguides because of its huge size and high operational frequencies. More specifically, the TEM waveguide should be equipped with a large enough test volume to completely encompass the T-DMB receiver and should resonate at much higher frequencies than 240 MHz.

In this letter, we present an advanced miniaturized 4-port TEM waveguide that provides greater test volume, frequency range capacity, and field uniformity than conventional waveguides, and these respective improvements are provided simultaneously, an achievement that is highly desirable and impossible to accomplish using conventional waveguides. Being able to extend the test volume and the test frequency range simultaneously is significant in broadening the territory of the current EMC test methodology [4].

Our design is in excellent accordance with an experiment verification, which shows the validity and usefulness of the proposed waveguide [5]-[7].

II. New Design Approach

The geometry of the proposed TEM waveguide is shown in Fig. 1. In our previous work [3], we used two parallel septa connected to four ports at each end. The proposed waveguide bears a different design. We have increased the widths of the outer shielding shell, *a*, and the two septa, *w*, to deal with larger equipment under test (EUT), which results in better field uniformity in the enlarged test volume, located between the

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Sangbong Jeon (phone: +82 42 860 6408, sbjeon@etri.re.kr), Jaehoon Yun (jhyun@etri.re.kr), and Seungkeun Park (seungkp@etri.re.kr) are with the Broadcasting & Telecommunications Convergence Research Laboratory, ETRI, Daejeon, Rep. of Korea.

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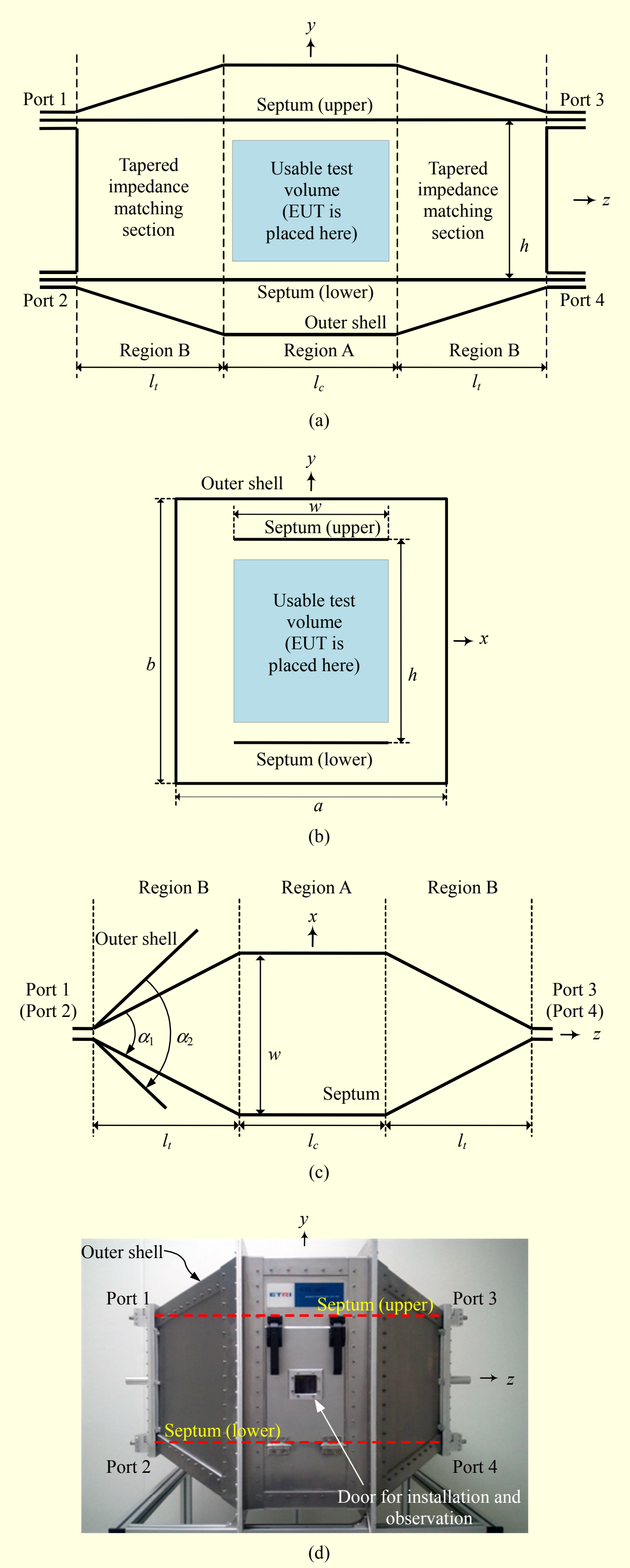

Fig. 1. Geometry of proposed TEM waveguide: (a) side view with h=450 mm, (b) cross-section view with w=435 mm, a=795 mm, and b=655 mm, (c) top view of septum with l_c=l_t=300 mm, α_1=67.8°, and α_2=104.5°, and (d) fabricated TEM waveguide.

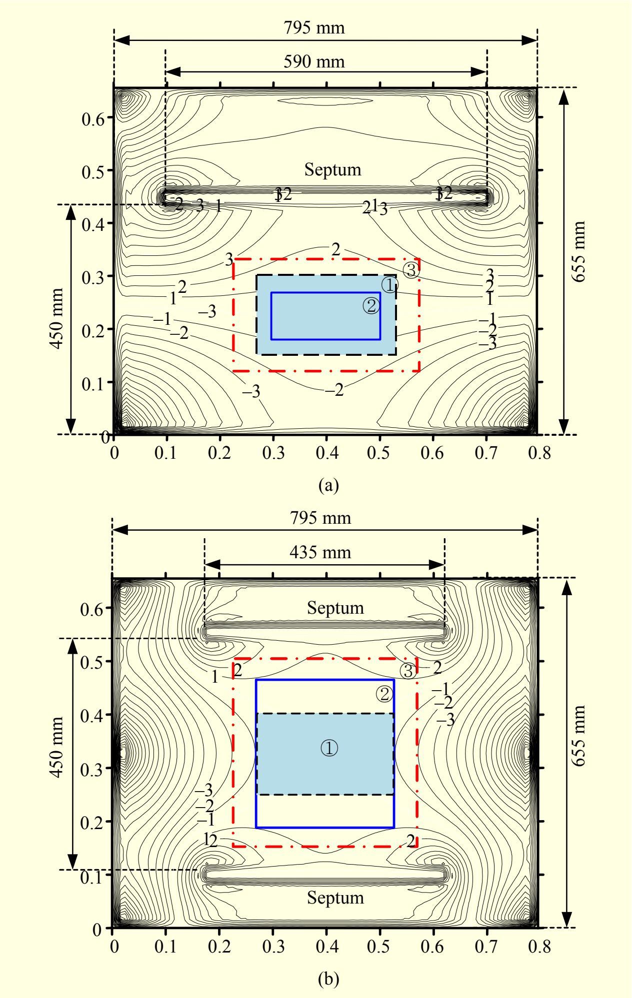

Fig. 2. Distribution of electric field intensity in (a) conventional 2-port TEM waveguide with asymmetric septum and in (b) proposed 4-port TEM waveguide with symmetric two parallel septa.

septa. Moreover, to further miniaturize the dimension along the z-axis (wave propagation direction) and to increase the usable frequency range, we reduce an unnecessarily long length (l_c) of the middle section of each septum, which was indispensably long in [3]. Because the long septa causes an undesired standing wave in a lower frequency region, we set the lengths of regions A and B to be equal, that is, l_c=l_t. In other words, the overall length (l_c+2l_t) of the waveguide and septa in the z-direction is reduced from 1,200 mm to 900 mm. According to overall changes in cell sizes, input impedance seen from each wave port is deviated from a desired value of 50 Ω. Therefore, we redesign the tapering angles of the septa and the outer shielding box, from the original values of α_1=69.1° and α_2=95° to the optimized α_1=67.8° and α_2=104.5°.

Consequently, we can effectively retard the appearance of higher-order modes, which means a remarkable increase in resonant frequencies of higher-order modes. In short, our main

Table 1. Comparison of test volumes, cutoff, and resonant frequencies.

	2-port waveguide	Previous design [3]	Proposed waveguide
Uniform area1)	±1.7 dB / 265 mm × 150 mm	±0.9 dB / 218 mm × 138 mm	±0.6 dB / 265 mm × 150 mm
±1 dB zone	170 mm × 100 mm	218 mm × 157 mm	260 mm × 280 mm
±3 dB zone	360 mm × 220 mm	348 mm × 328 mm	403 mm × 348 mm
Test volume2)	590 mm × 450 mm × 600 mm	413 mm × 450 mm × 600 mm	435 mm × 450 mm × 300 mm
f_{c_TE01}, f_{r_TE011} 3)	146.5 MHz, 203.5 MHz	187.4 MHz, 234.7 MHz	187.9 MHz, 272.1 MHz
f_{c_TE10}, f_{r_TE101}	188.7 MHz, 254.0 MHz	229.0 MHz, 278.9 MHz	188.7 MHz, 300.3 MHz

1) The shaded area numbered as ① in Fig. 2. 2) $w \times h \times l_c$ in Fig. 1. 3) f_c: cutoff frequency, f_r: resonant frequency.

objective of the design is to obtain greater field uniformity in the enlarged test volume and lessen the limitation on usable frequency while decreasing the overall dimension in the wave propagation direction, and this objective is obtained. The advantageous features of our design are all strongly required and important in a standard EMC test procedure.

It is important to note that despite the reduced length of the middle section of the septa (l_c) in region A, the test area ($w \times h$) increases about 10 percent compared to that obtained from the conventional design reported in [3]. It is also remarkable that the overall field uniformity is much enhanced.

Figure 2 shows the properties of the electric field uniformity in a conventional 2-port TEM waveguide with a single septum and in the proposed one. The field strengths are evaluated on each center (z=0) of the test volume. For a fair comparison in Fig. 2, dimensions of the outer shells are intentionally set to be equal and the input impedance of each waveguide is 50 Ω. Region ① is a "uniform area" defined in the IEC-61000-4-20 [2], and regions ② and ③ (enclosed by a blue solid line and a red broken line, respectively) are ±1 dB and ±3 dB deviation zones in the field uniformity, respectively. The enhanced performance of the proposed waveguide, which is accomplished by applying a new design approach, is summarized in Table 1. We find that our waveguide shows improved performance both in electrical and dimensional aspects.

III. Operation and Experiment Verification

The operation method to generate a TEM mode wave is shown in Fig. 3. To generate the TEM mode wave between the septa in region A (see Fig. 1), the input signal should be applied to ports 1 and 2 with a reversed phase, and a 50 Ω load resistance allows for termination at each other port, that is, 3 and 4. Because of the symmetry, ports 1 and 2 are interchangeable with ports 3 and 4, with no change in the generated TEM wave property.

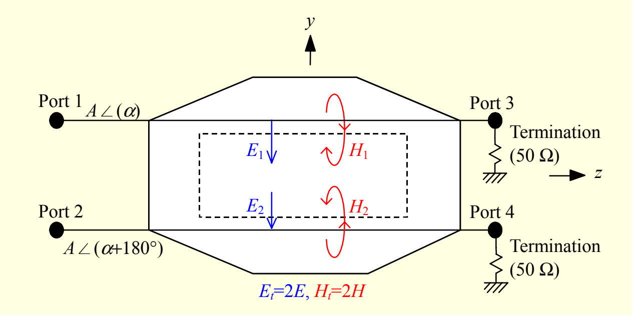

Fig. 3. Operational method to generate TEM mode by applying reversed-phase signal feeding method.

For the division of the signal with the phase reversal, we use the commercial 180° hybrid dividers, models H2979 (below 100 MHz) and H7683 (above 100 MHz), manufactured by Werlatone, Inc. The two input signals with the same magnitude and the reversed phase generate an E_y-field and an H_x-field in the waveguide, whose magnitude is the same with the applied original input signals.

The measured resonant properties of the proposed waveguide are shown in Fig. 4(a). The resonant frequencies are all much higher than the cutoff frequencies shown in Table 1. The measured E_y-field distribution is also shown in Fig. 4(b). The field intensity is measured on the yz-plane and xy-plane intersecting the center of the test volume. The interval between the measured data is 4 cm, which satisfies a standard experiment criterion specified in [2]. We find that all data is within a ±3 dB deviation region and is in accordance with the analysis shown in Fig. 2(b).

Finally, the measured wave impedance of the TEM mode wave is compared with the free space wave impedance, which is shown in Fig. 5. The wave impedance of the TEM mode is strongly dependent on the accuracy of a phase difference between the two split input signals. In our case, the maximum deviation range of the phase difference is within 180° ±2.5° in the frequency range of interest. The average of the wave impedance is about 350 Ω, which is a bit lower than the wave impedance in free space. We measure the E_y-field and the H_x-field using electric and magnetic probes. As for the electric probe, it is much smaller than the wavelength and the

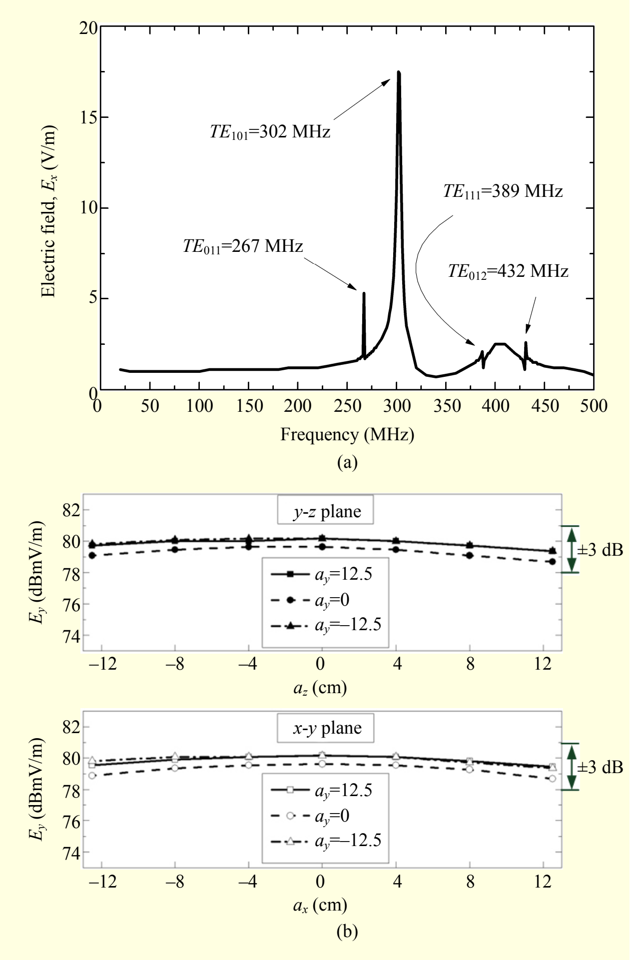

Fig. 4. (a) Measured resonant frequencies in TEM mode and (b) measured *E*-field intensity representing behavior of field uniformity.

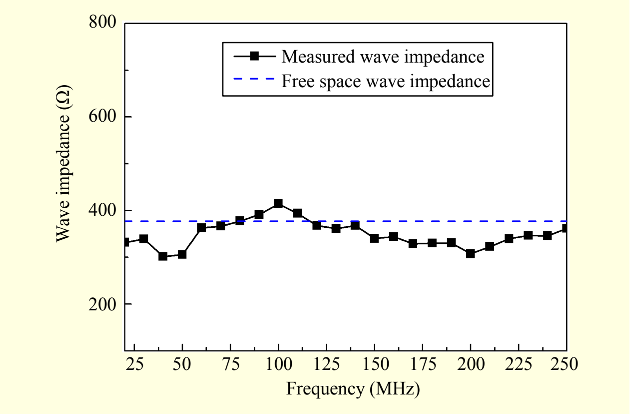

Fig. 5. Measured wave impedance of TEM mode.

dimension of the test area. However, in the case of the magnetic field, its diameter is 6 cm, which is not negligible compared to the dimension of the test area. A small discrepancy in the wave impedance may be caused by the less accurate measurement of the H_x-field including undesirable field disturbance, because we derive the wave impedance from the ratio of the measured E_y-field and H_x-field intensity.

IV. Conclusion

In this letter, a 4-port waveguide generating a TEM wave was proposed. The main contribution of this letter is the presentation of the advantageous features of our proposed waveguide, namely, enhanced performance and remarkable miniaturization, compared to conventional waveguides. We showed that our waveguide can simultaneously provide greater field uniformity in the enlarged test volume and lessen the limitation on usable frequency.

The proposed waveguide is currently under discussion to be included in the international standard of the EMC test, and we believe that our waveguide can broaden the applicable territory of the current EMC investigation.

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