FOUR-SEPTUM TEM CELL FOR IMMUNITY/SUSCEPTIBILITY TEST BY ROTATING EM FIELDS

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Abstract: For evaluating immunity/susceptibility characteristics against electromagnetic field of various directions, a four-septum TEM cell has been proposed. The cell is for generating the slowly rotating electromagnetic field inside. Thus, the cell must have properties of a transmission line system and an electromagnetic field generator. The transmission characteristics are studied from the multi-conductor transmission line theory and then the design method of the cell is discussed. The characteristics of the prototype four-septum TEM cell are clarified by comparing experimental results with the theory, and the rotating fields inside the cell are confirmed experimentally.

Key words: Four-septum TEM cell, immunity, susceptibility, transmission characteristics, rotating EM field.

1. Introduction

Three typical types of radiated immunity or susceptibility tests are adopted: vertical and/or horizontal antenna method, transverse electromagnetic (TEM) transmission line method and reverberation chamber method. TEM and GTEM cells, which are a sort of a coaxial transmission line system, are used to estimate immunity/susceptibility characteristics of electronics equipment against TEM-transmission-mode fields simulating radiated electromagnetic (EM) emissions. The cells generate only TEM-mode fields in a specific direction inside. Our newly proposed four-septum TEM cell, which has four plate-like conductors (septum), can generate EM fields of arbitrary direction inside at the transverse plane of the cell and the direction can be controlled electronically. We applied the following technique used in [1] to the four-septum TEM cell.

In the measurement system and mapping technique using rotating-EM-field for immunity/susceptibility test proposed in [1], the EM fields slowly rotate at the polarization plane by controlling electronically, and then knowing the field direction and combining a turntable, the characteristics of immunity/susceptibility of equipment of under test (EUT) can be depicted like as a three-dimensional map. Therefore, the weak/strong directions of the immunity/susceptibility characteristics of EUT would be revealed and the data would be useful at a phase of design of electronics enclosure, for example. This test method is done in an anechoic chamber. As the TEM and GTEM cell are developed as an alternating method without expensive anechoic chamber, we proposed the four-septum TEM cell, where the slowly rotating fields are adopted.

In this proposed cell, to generate the balanced EM field between facing septa, the septa are fed with sources of appropriate amplitude and phase, respectively. The TEM field rotating slowly is generated by compounding two EM fields of the two balanced mode due to two set of the face-to-face septa [2].

In this paper, the proposed four-septum TEM cell inherently has properties similar to a coupled multi-conductor transmission-line system, so that the transmission characteristics of the cell are here discussed on a basis of telegrapher's equation. By using these results, the design method is clarified. Next the transmission characteristics of the proto type cell are discussed by comparing the measured results with the computed. Moreover, the rotating EM field generated in the four-septum TEM cell is discussed from experimental results.

2. Transmission characteristics of a four-septum TEM cell

In the cross-sectional view of the proposed four-septum TEM cell, four plate-like septa exist in the internal space surrounded by an outer conductor as shown in Fig. 1. In a practical model, to put EUT into the inside space, the upper part of the cell separates from the lower part in the figure.

Let the septa be numbered clockwise with i = 1, 2, 3, 4, and the line direction be of z axis. The telegrapher's equations regarding line voltage V_i and current I_i are

$$-\frac{d}{dz}\begin{bmatrix} \boldsymbol{V} \\ \boldsymbol{I} \end{bmatrix} = \begin{bmatrix} 0 & j\omega L_{ij} \\ j\omega c_{ij} & 0 \end{bmatrix}\begin{bmatrix} \boldsymbol{V} \\ \boldsymbol{I} \end{bmatrix} \quad (1)$$

$$\boldsymbol{V} = [V_1,\ V_2,\ V_3,\ V_4]^T$$
$$\boldsymbol{I} = [I_1,\ I_2,\ I_3,\ I_4]^T\ . \quad (2)$$

Where superscript T denotes a transposed matrix.

In this paper, the four-septum TEM cell assumes that it is completely symmetrical and then independent

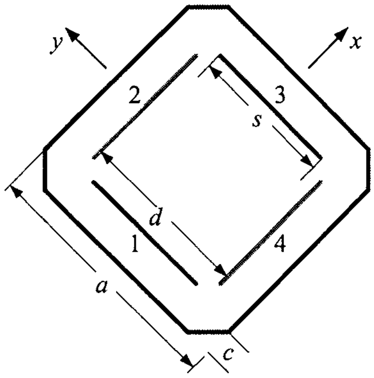

Fig. 1 Cross-sectional view of a four-septum TEM cell.

transmission modes as shown in Fig. 2 can be adopted, for example.

These modes are, here, named as $M = A, B, C, D$, respectively, and the voltage, V_M, and current, I_M, for M mode are expressed as

$$\boldsymbol{v} = [V_A,\ V_B,\ V_C,\ V_D]^T \tag{3}$$

$$\boldsymbol{i} = [I_A,\ I_B,\ I_C,\ I_D]^T\ . \tag{4}$$

Relations between the line voltages and mode voltages, and between the line currents and mode currents are obtained by taking account of the relations shown in Fig. 2.

$$\boldsymbol{V} = \begin{bmatrix} 1 & 1/2 & 1/2 & 1/2 \\ 1 & -1/2 & 1/2 & -1/2 \\ 1 & 1/2 & -1/2 & -1/2 \\ 1 & -1/2 & -1/2 & 1/2 \end{bmatrix} \boldsymbol{v}$$

$$\equiv [T_V]\,\boldsymbol{v} \tag{5}$$

$$\boldsymbol{I} = \begin{bmatrix} 1/4 & 1/2 & 1/2 & 1/2 \\ 1/4 & -1/2 & 1/2 & -1/2 \\ 1/4 & 1/2 & -1/2 & -1/2 \\ 1/4 & -1/2 & -1/2 & 1/2 \end{bmatrix} \boldsymbol{i}$$

$$\equiv [T_I]\,\boldsymbol{i} \tag{6}$$

Substituting the above equations into (1) leads the following equations for the independent modes:

$$-\frac{d\boldsymbol{v}}{dz} = j\omega[T_V]^{-1}\boldsymbol{L}_{ij}[T_I]\boldsymbol{i} \equiv j\omega\boldsymbol{L}_M\boldsymbol{i} \tag{7}$$

$$-\frac{d\boldsymbol{i}}{dz} = j\omega[T_I]^{-1}\boldsymbol{c}_{ij}[T_V]\boldsymbol{v} \equiv j\omega\boldsymbol{C}_M\boldsymbol{v}\ . \tag{8}$$

Since it is assumed that the septa are completely symmetrical, $\boldsymbol{L}_M$ of (7) and $\boldsymbol{C}_M$ of (8) becomes a diagonal matrix where there are zeroes except the diagonal entry corresponding to the mode inductances and capcitances. For example, $\boldsymbol{C}_M$ can be expressed as follows.

$$\boldsymbol{C}_M = \begin{bmatrix} C_A & 0 & 0 & 0 \\ 0 & C_B & 0 & 0 \\ 0 & 0 & C_C & 0 \\ 0 & 0 & 0 & C_D \end{bmatrix} \tag{9}$$

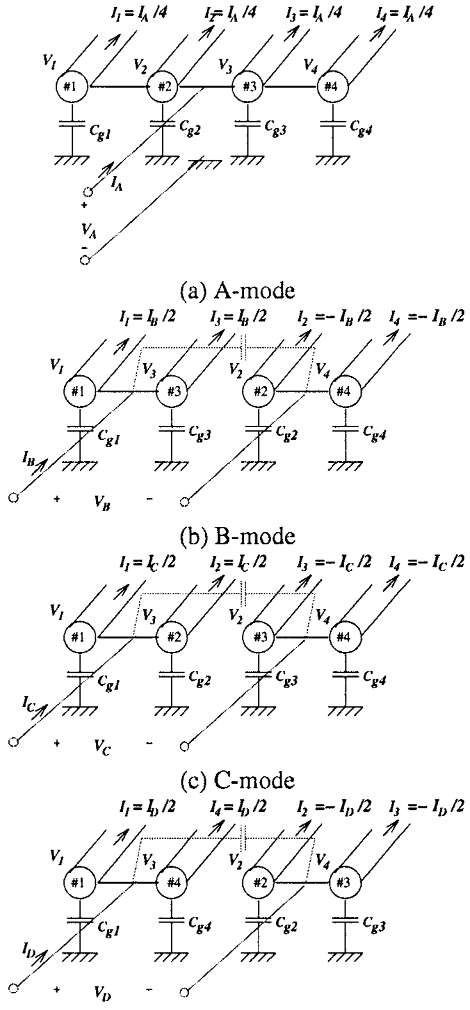

Fig. 2 Independent modes of the four-septum TEM cell.

Since the propagation of TEM mode is assumed, the characteristic impedances Z_M of M mode can be found from the following formulas.

$$Z_M = \frac{1}{v_0 C_M} \tag{10}$$

Where, v_0 is the speed of light. From a solution to telegrapher's equations, the impedance matrix of the cell is obtained as

$$\begin{bmatrix} \boldsymbol{V}(0) \\ \boldsymbol{V}(\ell) \end{bmatrix}$$

$$= \begin{bmatrix} [T_V] & [0] \\ [0] & [T_V] \end{bmatrix} \begin{bmatrix} \boldsymbol{Z}_{11} & \boldsymbol{Z}_{12} \\ \boldsymbol{Z}_{21} & \boldsymbol{Z}_{22} \end{bmatrix} \begin{bmatrix} [T_I]^{-1} & [0] \\ [0] & [T_I]^{-1} \end{bmatrix} \begin{bmatrix} \boldsymbol{I}(0) \\ -\boldsymbol{I}(\ell) \end{bmatrix}$$

$$\equiv \begin{bmatrix} \boldsymbol{Z}_{11}^T & \boldsymbol{Z}_{12}^T \\ \boldsymbol{Z}_{21}^T & \boldsymbol{Z}_{22}^T \end{bmatrix} \begin{bmatrix} \boldsymbol{I}(0) \\ -\boldsymbol{I}(\ell) \end{bmatrix} = [\boldsymbol{Z}_T] \begin{bmatrix} \boldsymbol{I}(0) \\ -\boldsymbol{I}(\ell) \end{bmatrix} \tag{11}$$

$$\boldsymbol{Z}_{11} = \boldsymbol{Z}_{22} = -j\cot\beta\ell \begin{bmatrix} Z_A & 0 & 0 & 0 \\ 0 & Z_B & 0 & 0 \\ 0 & 0 & Z_C & 0 \\ 0 & 0 & 0 & Z_D \end{bmatrix} \tag{12}$$

$$Z_{12} = Z_{21} = -j\csc\beta\ell \begin{bmatrix} Z_A & 0 & 0 & 0 \\ 0 & Z_B & 0 & 0 \\ 0 & 0 & Z_C & 0 \\ 0 & 0 & 0 & Z_D \end{bmatrix} \quad (13)$$

Since the characteristic impedance Z_c (= 50 Ω) of each port is equal, by considering $\boldsymbol{I}_8$ as a unit matrix, $\boldsymbol{S}$ matrix can be expressed as

$$\boldsymbol{S} = ([\boldsymbol{Z}_T] - Z_c\boldsymbol{I}_8)([\boldsymbol{Z}_T] + Z_c\boldsymbol{I}_8)^{-1} . \quad (14)$$

From (14), calculated reflection and coupling characteristics are shown in Fig. 3, for example.

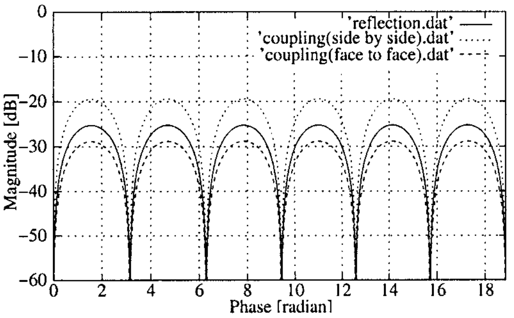

Fig. 3 Calculated reflection and coupling characteristics.

It is noted that these characteristics are cyclically changing at a specific frequency depending on the cell length. Furthermore the reflection characteristics are −25 dB or less, the coupling characteristics between the adjoining septa are −19 dB and the one between the opposite septa are −28 dB or less.

3. Design of the cell

Using (14) , when changing the width (= s) of septum, and the distance (= d) between septa for $\beta\ell = \pi/2$ equivalent to $\ell = \lambda/4$ to which the characteristics become the worst, the reflection and coupling characteristics are shown in Figs. 4 to 6. From these figures, it is noticed that the coupling characteristics become good as d becomes large almost regardless of s, and that reflection characteristics are the minimum at a certain d. From the results of Figs. 4 to 6, the size of optimal cell is determined as s = 120 mm and d = 246 mm and a = 300 mm.

4. Principle of rotating EM field generation

In reference [1], the rotating fields can be generated by supplying two double-side-band, suppressed-carrier (DSB-SC) waves to two antennas orthogonally arranged, respectively. When the face-to-face septa are excited with the same amplitude but in opposite phase voltage, i.e., in balanced mode, the electric field inside the cell generated by two sets of the face-to-face septa is in a specific direction depending on the magnitudes of the excited voltage. To rotate the resultant field, the septa should be applied with the following sources.

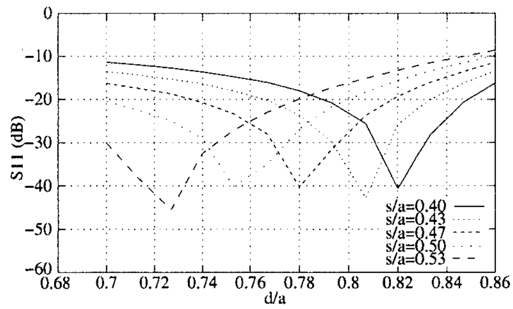

Fig. 4 S_{11} versus the distance between the opposite septa with the width of the septum as parameter.

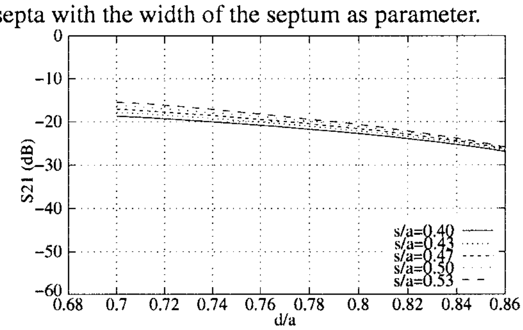

Fig. 5 Coupling between the adjacent septa versus the distance between the opposite septa with the width of the septum as parameter.

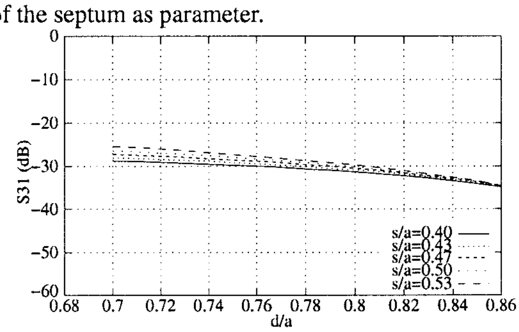

Fig. 6 Coupling between the opposite septa versus the distance between the opposite septa with the width of the septum as parameter.

$$V_1 = \sin\omega t\cos\Omega t = \frac{1}{2}\{\sin(\omega-\Omega)t + \sin(\omega+\Omega)t\} \quad (15)$$

$$V_3 = -\sin\omega t\cos\Omega t = \frac{1}{2}[\sin\{(\omega-\Omega)t+\pi\} + \sin\{(\omega+\Omega)t+\pi\}] \quad (16)$$

$$V_2 = \sin\omega t\sin\Omega t = \frac{1}{2}[\sin\{(\omega-\Omega)t+\pi/2\} + \sin\{(\omega+\Omega)t-\pi/2\}] \quad (17)$$

$$V_4 = -\sin\omega t\sin\Omega t = \frac{1}{2}[\sin\{(\omega-\Omega)t-\pi/2\} + \sin\{(\omega+\Omega)t+\pi/2\}] \quad (18)$$

The block diagraom to generate the rotating EM fields in the four-septum TEM cell is shown in Fig.7.

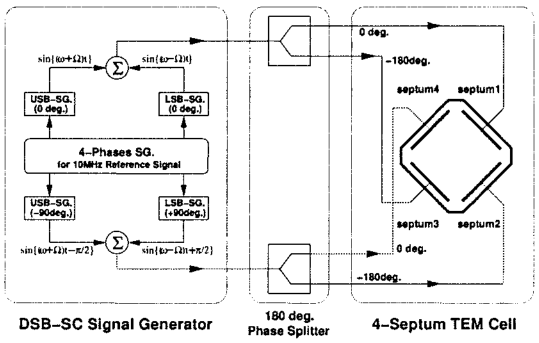

Fig. 7 Rotating EM field generating system for the four-septum TEM cell.

5. Experimental results

First, we discuss the transmission characteristics of the prototype cell. Fig. 8 shows the reflection coefficient characteristics, S_{ii}. The characteristics were of −18 dB or less in a frequency range less than 800 MHz. Moreover, unlike calculated results, the characteristics were not changing periodically. A resonance determined with the cross-section area of the cell was observed at about 560 MHz.

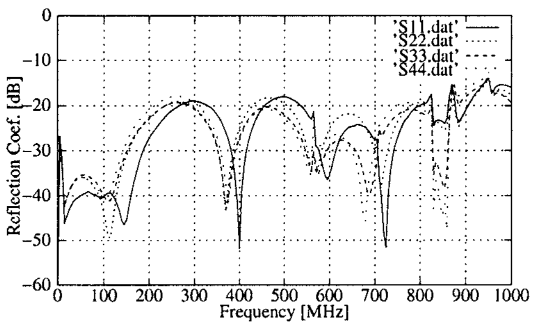

Fig. 8 Measured reflection coefficient characteristics of the prototype model.

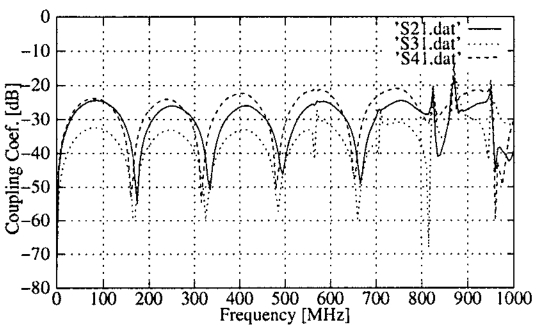

Fig. 9 Measured coupling coefficient characteristics of the prototype model.

Moreover, the same resonance was observed in the coupling coefficient characteristics, S_{ij}. In a frequency range below the resonance frequency, it is shown in Fig. 9 that S_{21} and S_{41}, the adjacent-septa coupling are of −25 dB or less, and that S_{31}, the opposite-septa coupling is of −33 dB or less. It can be known that the characteristics change at a cycle of about 170MHz, of which wavelength corresponds to twice of the cell length.

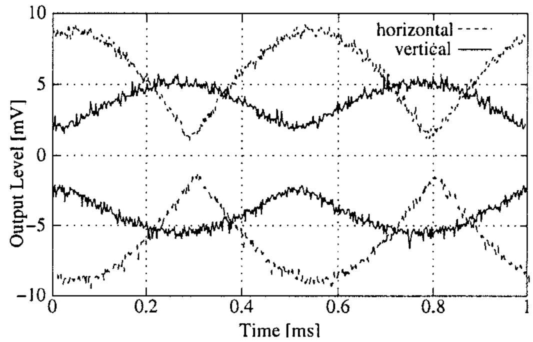

Fig. 10 Magnetic field inside the four-septum TEM cell.

To check whether the field rotates inside the four-septum TEM cell or not, the magnetic fields were measured using two orthogonal loop probes. Fig. 10 shows the measured results for the field at a frequency of 385 MHz, which rotate at the frequency of 1 kHz, of which frequency was selected to show on our oscilloscope, in practical case, it can choose more low frequency such as 1 Hz. The envelopes of the two signals appear alternately, having 90° phase difference. From the results, it can be concluded that the rotating EM field is generated in the proposed cell.

6. Conclusion

The basic characteristic of the four-septum TEM cell was clarified on a basis of multi-conductor transmission line theory, and the prototype cell was designed from the transmission characteristics of the cell. The transmission characteristics of the prototype cell were evaluated experimentally and theoretically. And to generate the rotating EM field inside the cell, we showed the technique and then confirmed it by measuring the magnetic fields in orthogonal directions in time domain.

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