5 Electromagnetic Environment

5-1 Recent Progress of Studies on EMC Relating to Various Equipment

Yukio YAMANAKA, Shinobu ISHIGAMI, and Katsushige HARIMA

In order to realize the further development of the advanced information society, R&D in EMC technologies between electric, electronic and communication equipment and/or systems are indispensable. The target of the EMC is to promote the electromagnetic environment in which those equipment can be used without mutual interference. In this paper, recent EMC studies on various equipment in CRL are explained. CRL/EMC group mainly focus its research area on measurement method. Research outline and outcome on some topics are summarized which include the radiated emission measurement method above 1 GHz, GTEM cell and reverberation chamber which are promising measuring instruments for both radiated emission measurement and radiated immunity measurement in the near future.

Keywords
Electromagnetic Compatibility (EMC), electromagnetic disturbance, immunity, reverberation chamber, GTEM cell

1 Foreword

With the popularization of electronic equipment such as computers, as well as the trend toward its fusion with various other forms of equipment and integration to create an integral system, a wide array of complex problems involving telecommunications and broadcasts caused by electromagnetic disturbances have arisen. Moreover, with the explosive increase in the use of cellar telephones and wireless equipment, concerns are increasing that the radio waves they emit may cause electronic and medical equipment to malfunction. In addition, the influences thereof upon the human body have received a great deal of media attention. As we enter the 21st century, to ensure the continued development of our advanced information society, it is absolutely necessary to conduct research and development of electronic equipment and communication equipment/systems that increase convenience and the quality of daily life, while conducting research and development of technologies to ensure a good electromagnetic environment that allows all equipment/systems to operate normally is also indispensable.

In the Communications Research Laboratory (CRL), research on electromagnetic environments has been underway since 1965 as one of basic technologies supporting wireless communication. In particular, as a research institute of the Ministry of Posts and Telecommunications (the current Ministry of Public Management, Home Affairs, Posts and Telecommunications) in charge of the administration of radio stations, CRL has conducted various studies to ensure electromagnetic compatibility (EMC) between radio stations and between radio stations and electronic equipment. For example, CRL has been conducting research on measurement methods for electromagnetic disturbances caused by electronic equipment for many years, and has contributed to the enactment of related standards in Japan and the planning of international standards such as CISPR. Further, CRL has determined the actual state of our country's electromagnetic environments, such as that in the neighborhood of a large RF-power radio stations, and has contributed to the enactment of guidelines for the protection of human health and the prevention of equipment damage. Moreover, since 1996 CRL has been researching the influences on the human body of radio waves emitted from equipment used in close proximity to the human body, such as cellar telephones, and is also conducting research on evaluation methods for compatibility with the radio-radiation protection guidelines. We have set as a goal the creation of electromagnetic environments in which various pieces of equipment can be used without mutual interference, and in which the influences thereof upon the human body are negligibly small, through a wide range of research, as exemplified above.

In July 1997, the EMC project was moved to the Yokosuka Radio Communications Research Center due to a revision of the internal organization. Since 2001 the project has been administrated on a consignment basis by the Ministry of Public Management, Home Affairs, Posts and Telecommunications, as part of the movement of the Communication Research Laboratory into an independent administrative institution. Though the frame work of CRL has changed, we feel it is necessary to further enhance and develop the contents of research activities, and to use them as a foundation for our ongoing work to accomplish our mission as a public institute.

In this special edition, EMC projects are divided into those that are equipment-related and those that are human-related. Also, and the most recent main research results and future research topics are introduced for each project. Among the subjects relating to the equipment, measurement methods for the EMC are chiefly being examined. Among the subjects relating to the measurement methods are "electromagnetic-disturbance measurement methods" whereby electromagnetic disturbances from the equipment are measured, and "immunity measurement methods" whereby the tolerance of the equipment against incoming electromagnetic waves is measured. Further, the measurement methods can be classified into those for radiated electromagnetic disturbances (immunity) whereby coupling of the electromagnetic wave from (or to) an enclosure of the equipment concerned is treated, and those for conduction disturbances (immunity) whereby coupling of the electromagnetic wave through a power-source line or communication lines is treated.

This paper will outline and discuss the research results concerning (1) a measurement method for radiated electromagnetic disturbances above 1 GHz, and (2) a GTEM cell and reverberation chamber that will be available in the near future for the measurement of radiated electromagnetic disturbances and radiation immunity, respectively.

2 Measurement method for electromagnetic disturbances above 1 GHz

(1) Introduction

In recent years, with the development and popularization of wireless communication systems in frequency bands above 1 GHz and the enhanced performance of digital circuits toward higher operating frequencies, the EMC problem in these frequency bands has grown in magnitude. CISPR (International Special Committee on Radio Interference) is currently examining a measurement method for radiated electromagnetic disturbances above 1 GHz, part of which (1-18 GHz) has already been standardized. CISPR16-1 2nd edition (1999) [1] prescribes measurement receivers, measurement antennas, and measurement sites as fundamental devices for measuring electromagnetic disturbances. Further, CISPR16-2 Amendment 1 (1999)[2] prescribes measurement methods such as measuring arrangements and measurement procedures. Outlines of these prescriptions are shown in Fig.1. It can be said that a basic structure has been built, but work remains to be done.

In this section, the problems with the spectrum analyzers commonly used as measurement receivers, measurement antennas, and measurement sites are discussed, along with CRL's efforts for the problems.

(2) Measurement apparatus

The basic requirements for the spectrum analyzer specified in CISPR are as follows[1].

1) Detection method: Peak detection
2) Resolution bandwidth (RBW): 1 MHz ± 10%
3) Video bandwidth (VBW): 1 MHz or more

Here, it should be noted that the RBW is defined with the impulse bandwidth B_{imp}. This is due to the fact that, in the measurement of the peak, the measured value for pulse noise is

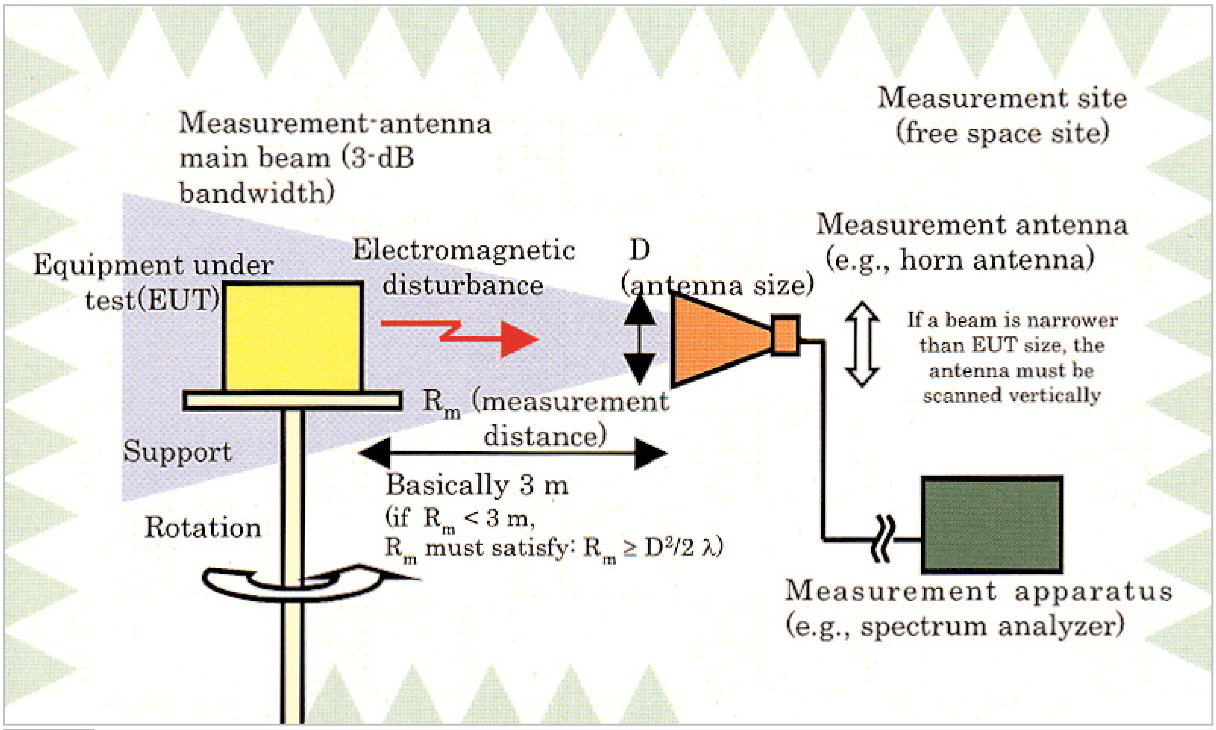


Fig.1 *Conceptual diagram of the measurement method for electromagnetic disturbances at 1-18 GHz*

Table 1 *Variations in measured values (peaks) by model and video bandwidth (VBW)*
RBW=1MHz B_3 : 3-dB Bandwidth B_6 : 6-dB Bandwidth

Spectrum analyzer	VBW (MHz)	$A(t)_{max}$ (dBm)	Difference (dB)
Company A, No.1 (B_3)	1 3	-21.5 -17.7	3.8
Company A, No.2 (B_3)	1 3	-19.7 -16.6	3.1
Company A, No.3 (B_3)	1 3	-19.4 -16.3	3.1
Company B, No.1 (B_3)	1 -	-30.2 -	-
Company B, No.2-1 (B_3)	1 3	-24.1 -21.6	2.5
Company B, No.2-2 (B_6)	1 3	-24.8 -23.5	1.3
Company C (B_3)	1 3	-31.2 -28.6	2.4

Table 2 Comparison of impulse bandwidth (Nominal Value: RBW=1MHz VBW=3MHz)

Spectrum analyzer	Method 1 (MHz)	Method 2 (MHz)	Average (MHz)	Peak measurement error when pulses are input (dB)
Company A, No.2	1.64	1.50	1.57	3.9
Company A, No.3	1.69	1.66	1.68	4.5
Company B, No.2-1	0.92	0.88	0.90	-0.9
Company B, No.2-2	0.74	0.79	0.75	-2.5
CISPR Standard of impulse bandwidth: 1MHz±10% (0.9～1.1MHz)				

in proportion to B_{imp}. However, the RBW of commercial spectrum analyzers is defined with an attenuation bandwidth of 3 dB or 6 dB, and no measurement is taken of the impulse bandwidth.

Moreover, arbitrary settings, such as 1 MHz, 3 MHz, and the like, can be made for the VBW. In addition, weighted measurement achieved by reducing the value of the VBW is also prescribed.

Thus, in EMI measurement using the spectrum analyzer at above 1 GHz, the characteristics of the RBW and VBW significantly affect the measurement results; therefore, we surveyed the characteristics of typical spectrum analyzers commercially available at present. The results are shown in Table 1[4].

As can be seen from the table, when the same pulse is input, the measured values (peak values) differ significantly by model (difference of up to 11.8 dB under a constant VBW of 1 MHz). This is due to the fact that the type and characteristics of each IF filter differ. Moreover, even with the same model, the peak measured value changes significantly (by up to 3.8 dB) when the setting of the VBW is changed. Therefore, in the actual measurement of electromagnetic disturbances as well, the VBW-dependence described above may be exhibited in the case of pulse electromagnetic disturbances. Moreover, the measured values of B_{imp} for company A and company B are shown in Table 2.

These results revealed that some models of commercially available spectrum analyzers achieve the impulse bandwidth of 1 MHz ± 10% prescribed by CISPR, whereas some models fall far short of that mark. Therefore, when a spectrum analyzer that does not satisfy that specification is used, the measured result may differ significantly from that of a specification-compliant spectrum analyzer, particularly in terms of impulse noise (wide-band noise having a bandwidth wider than the measurement bandwidth). It will therefore be necessary in the future for the spectrum analyzer used in the measurement of electromagnetic disturbances to explicitly indicate the value of the impulse bandwidth. Moreover, it is preferable to perform the measurement at the same VBW value (such as 3 MHz), due to the possibility that the measurements will yield different results only under the CISPR prescription directing that “the VBW shall be 1 MHz or higher.”

Here, it should be noted that when the video bandwidth VBW of the spectrum analyzer is set to a value lower than the modulation bandwidth of the measured signal, the measured value becomes a value corresponding to the average level of the measured signal, and weighted measurement can be performed in such a way that noise occurring continuously results in a high indicated value and noise occurring intermittently results in a low indicated value. The display indication of the spectrum analyzer features a Log mode and a Linear mode and, in the case of weighted measurement, the values in the Linear mode become greater than the values in the Log mode.

CISPR11[3] prescribes weighted measurement with the VBW set to 10 Hz in the measurement of radiated electromagnetic disturbances of 1 GHz to 18 GHz using a class-B, group-2 ISM device capable of operating at frequencies equal to or higher than 400 MHz, which is intended to be performed in the Log mode.

Consequently, we examined the factors that affect the measurement results in weighted measurement[4]. As a result, it was found that the values obtained in weighted measurement in the Linear mode were always greater than those obtained in the Log mode. For example, in the measurement of pulses with a duty ratio of 50%, the measured value in the Linear mode is decreased from the peak by 6 dB, whereas the measured value in the Log mode is decreased therefrom by as much as 30 dB. Incidentally, the weighted measured value in the Linear mode indicates the actual average; the corresponding value in the Log mode differs from the actual average and is difficult to define.

Therefore, when weighted measurement that uses the VBW is adopted, its application must be re-examined by a pertinent product committee (for each waveform to be measured). Moreover, as a weighted-measurement method that can be substituted for this measurement, Japan has proposed a measurement method using APD (Amplitude Probability Distribution)[6] based on research results[5] obtained by CRL and the like, which is now being examined.

(3) Antenna

As the antenna used for electromagnetic disturbances of 1-18 GHz, the following items are prescribed[1]:

- A calibrated antenna having linear polarization shall be used.

- The main lobe of the antenna (defined as a 3-dB width) shall cover the equipment under test.

- The maximum size D of the antenna, measurement wavelength λ, and measurement distance R_m shall satisfy the following condition:

$$R_m \geq D^2/2\lambda \qquad (1)$$

In the derivation of this formula, the main radiation for the equipment under test is considered to be that coming from a point source. Typical antennas include various horn antennas, such as a double-ridged guide horn, pyramidal horns, and a standard-gain horn. Although the basic measurement distance R_m is 3 m, measurement can be performed at a different distance if necessary due to the surrounding conditions and lack of measurement sensitivity. In such a case, the value is then converted according to the rule that the measured value is in reverse proportion to the distance.

Regarding the above conditions, the double-ridged guide-horn antenna that is generally also used in EMC measurement was evaluated [7]. As a result, it was confirmed that the main lobe had a minimum 3-dB width of 30 degrees up to 15 GHz, and that beyond this frequency the pattern changed and the 3-dB width decreased. Moreover, from the calculation of the size of the equipment under test that is covered by the main lobe when this antenna is used, it is shown that the maximum size of the equipment under test is 1.7 m for the basic measurement distance of 3 m and 0.6 m for a distance of 1 m up to 15 GHz, indicating that there is no problem in putting it to practical use, except in large equipment. Note that for frequencies exceeding 15 GHz, the standard gain horn has a wider beam width than the double-ridged guide horn and becomes advantageous in measurement. In addition, it was confirmed that the double-ridged guide horn fulfilled the conditions of Eq. (1) at the basic measurement distance, which was prescribed to be 3 m, for all frequencies from 1-18 GHz.

In general, the measurement of antenna characteristics is performed at a distance that satisfies the far-field condition which is shown in the next equation.

$$R'_m \geq 2D^2/\lambda \qquad (2)$$

Therefore, at a distance that satisfies Eq. (1), the antenna gain decreases from the gain in the far field. From our measurements, it was found that, when the gain at the far field was used as is in measurement at the distance specified in Eq. (2), there was the possibility of error of up to 2-3 dB. Consequently, even if Eq. (1) is satisfied, it is necessary to position the antenna apart from the equipment under test by at least 1 m.

(4) Measurement site

For the measurement site at 1-18 GHz, only the following have been specified:

- A standard test site shall be a free-space open site with no reflection.

- An arbitrary test site that fulfills the free-space conditions may be used as an alternative test site.

The allowable deviation for ideal free-space conditions and the compatibility confirmation procedure are under consideration. Outlines of the most recent draft[8] are given below.

- Free-space conditions and allowable deviation

The normalized site attenuation AN in an ideal free space is given by the following formula:

$$AN[dB]=20\log(D)-20\log(F)+32 \quad (3)$$

where D: distance [m] between the transmitting and receiving antennas and F: frequency [MHz]

In the measurement arrangement shown below, the normalized site attenuations at the site concerned (for horizontal and vertical polarizations) are measured and, if the difference between the value and the above-mentioned theoretical value is within ±4 dB, the site is determined to be in conformity with the free-space conditions.

- Measurement arrangement of normalized site attenuation

• Receiving antenna: The same antenna as is used to measure the electromagnetic disturbance

• Transmitting antenna: Antenna with a gradual directivity (3-dB width exceeding 40 degrees)

• Distance between transmitting and receiving antennas: Distance at which the electromagnetic-disturbance measurement is performed (normally 3 m)

• Heights of transmitting and receiving antennas: Both are set at an equal height, and no scanning is performed.

Specifically, the height is basically 1.0 m (from a metallic ground). However, in cases in which the receiving antenna is made to scan in the height direction when performing the measurement due to the beam width of the receiving antenna being narrower than that of the equipment under test, the space therebetween is scanned. For example, in cases in which the receiving antenna is made to scan for 1-3 m at the measurement distance of 3 m, the measurement is performed every 0.5 m over the measurement distance.

In the future, it will be necessary to confirm the validity of the above-mentioned draft. We are conducting an examination focusing on what type of antenna should be used as the transmitting antenna, how the antenna factors of the transmitting and receiving antennas will be obtained, whether it is necessary to perform the measurement with the position of the transmitting and receiving antennas changed, and the like, and are making pertinent proposals. Further, the uncertainty in the calibration of the measurement receiver and the measurement antenna must be evaluated. Moreover, how the free-space conditions will be satisfied for floor-standing equipment remains a problem.

(5) Future problems

The measurement system used to measure radiated electromagnetic disturbances above 1 GHz was evaluated and examined. First, since the results of the characteristics evaluation of the spectrum analyzers revealed that there are models satisfying the impulse bandwidth prescribed by CISPR, as well as models with characteristics that differ considerably from the prescription, the impulse bandwidth must be described explicitly in the specifications of the equipment. Further, since the measured level (peak) differs according to the setting of the video bandwidth VBW, it is preferable to unify the VBW in order to improve reproducibility. In the weighted measurement achieved by reducing the size of the VBW, the value in the Log mode becomes smaller than the value in the Linear mode and deviates significantly from the true average. Regarding weighting using the VBW, the characteristics cannot be fully understood and their relationship to its limit is not clear. In the future, it will be necessary to grasp the characteristics as much as possible and to investigate other methods as well.

Regarding the antenna, the procedure for using antennas in the near field and standardization and the like of the calibration method will be important issues in the future.

Regarding the measurement site, several problems remain to be solved, including the allowable deviation from the ideal free-space conditions and the compatibility confirmation procedure; therefore, further examination will be necessary in the future.

3 GTEM cell

(1) Introduction

The GTEM (giga-hertz transverse electromagnetic) cell, a type of TEM waveguide, is an apparatus designed to allow the immunity test and the radiated electromagnetic-disturbance test to be performed in the microwave frequency band. Its external appearance is as shown in the photograph in Fig.2. Other types of TEM waveguides include a TEM cell, a strip line, and the like. For the standardization of several test methods and the like that use these devices, these methods are presently under discussion at a Joint Task Force (JTF) of IEC SC77B and CISPR/A, where examination to make them an international standards is underway.

Fig.2 *External appearance of the GTEM cell*

To this point (December 2001), a committee draft for a vote (CDV) CISPR/A/343/CDV [9] continuing the international standard document IEC61000-4-20 has been sent to the national committees of the respective countries. Each country votes for or against the contents of this draft and, if the affirmative votes represent the majority, the draft makes great strides toward its establishment as an international standard document.

The GTEM cell has the structure as shown in Fig.3. The internal electric field becomes almost vertical between the septum and the floor conductor. In the immunity test and the radiated electromagnetic-disturbance test, the equipment under test (EUT) is placed between these two conductors. An EM-absorber and a resistor board on the rear side are installed for impedance matching and to absorb electromagnetic waves incident on the rear side.

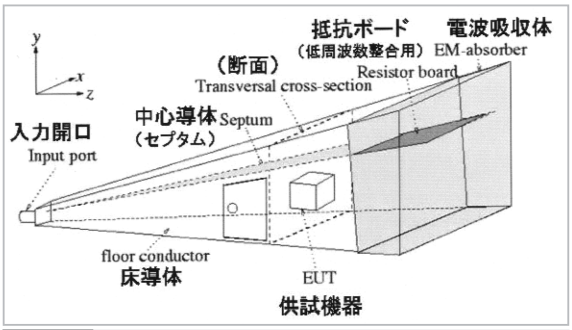


Fig.3 *Structure of the GTEM cell*

(2) Uniformity evaluation

To perform a reproducible test in the immunity test and the radiated electromagnetic-disturbance test, the electric field must be uniform in the space in which the EUT was placed. The CDV proposes the following requirements: (1) the space in which the test can be performed shall be $0.6W \times 0.33d$ (W: width of the septum; d: distance between the floor conductor and the septum); (2) the variation in the primary electric-field component (vertical component) within the above-mentioned region on the transversal cross section of the GTEM cell shall be -6 dB or less in an empty cell state in which no EUT is placed; and (3) electric-field components other than the primary component (components in a horizontal direction and in a propagation direction of the electromagnetic wave) shall be −6 dB or less than the primary component. To examine whether the region is appropriate, we have conducted an experimental and theoretical examination of each electric-field component on three axes[10] and proposed an evaluation method, part of which has been reflected in the CDV.

For a sensor for measuring the electric-field distribution of each axis in the above-mentioned area, an optical electric-field sensor (with a measuring frequency of up to 1 GHz) is used that, comparatively speaking, hardly disturbs the surrounding electric field. The results are shown in Fig.4. Calculation results obtained by the FD-TD (finite-difference time domain) method are shown in Fig.5. The region enclosed with a white line is that marked out by the measurement shown in Fig.4. It was confirmed that the measurement results were in fairly good agreement with the theoretically calculated results, and hence the maximum usable area proposed by the CDV was appropriate.

(3) Influence of EUT size

In the immunity test, the EUT is placed in the GTEM cell. When the EUT is loaded into the cell, the state of the electric field in the cell changes to the electric distribution measured when the cell is empty. On the other hand, there is an immunity test that uses a full anechoic chamber as the conventional method. In both the conventional method and a method using the TEM waveguide, such as the GTEM cell, the electric field is adjusted so as to have the same electric-field level as when the EUT is absent. However, when the EUT is placed in position, the influence of the EUT on the scattered wave differs between the two methods, and as a result the test results may differ between the two methods. Therefore, it is important to determine to what extent the immunity test results differ between the conventional method and the method using the GTEM cell, and whether there is any correlation between the two results. As such matters are considered to be dependent on the EUT size and the position within the cell at which the EUT is located, a theoretical examination is being conducted with these factors assumed as parameters.

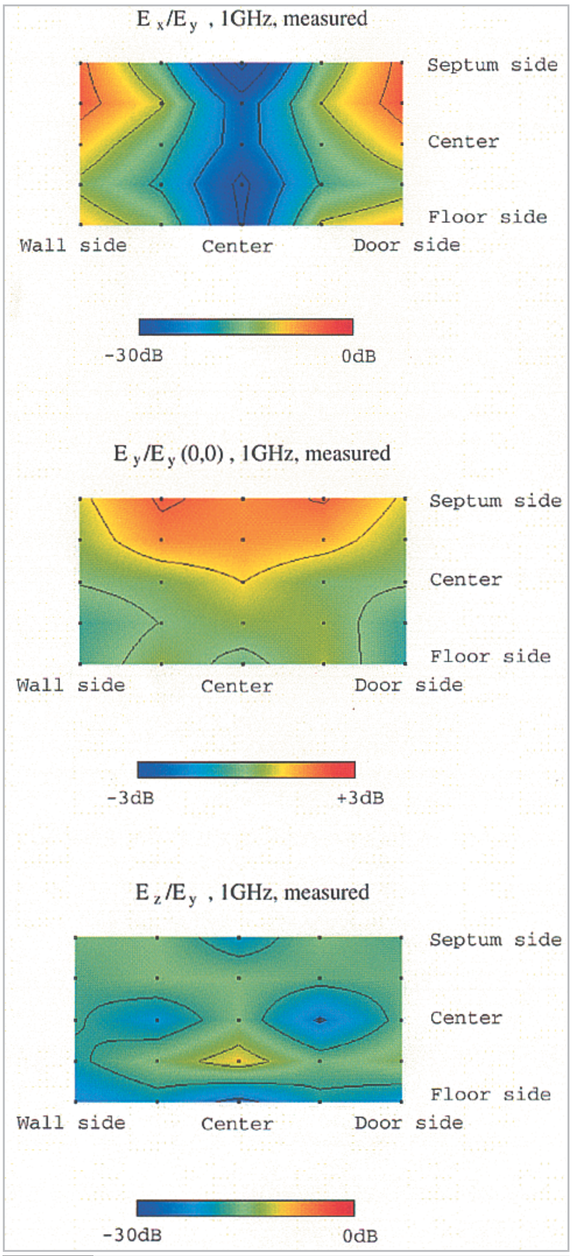


Fig.4 Measurement results for electric-field distribution

(Upper: Horizontal electric-field component Ex; Center: Primary electric-field component Ey; Lower: Electric-field component in propagation direction Ez)

Fig.6 shows the spatial distribution of the ratio of the electric-field value when the EUT

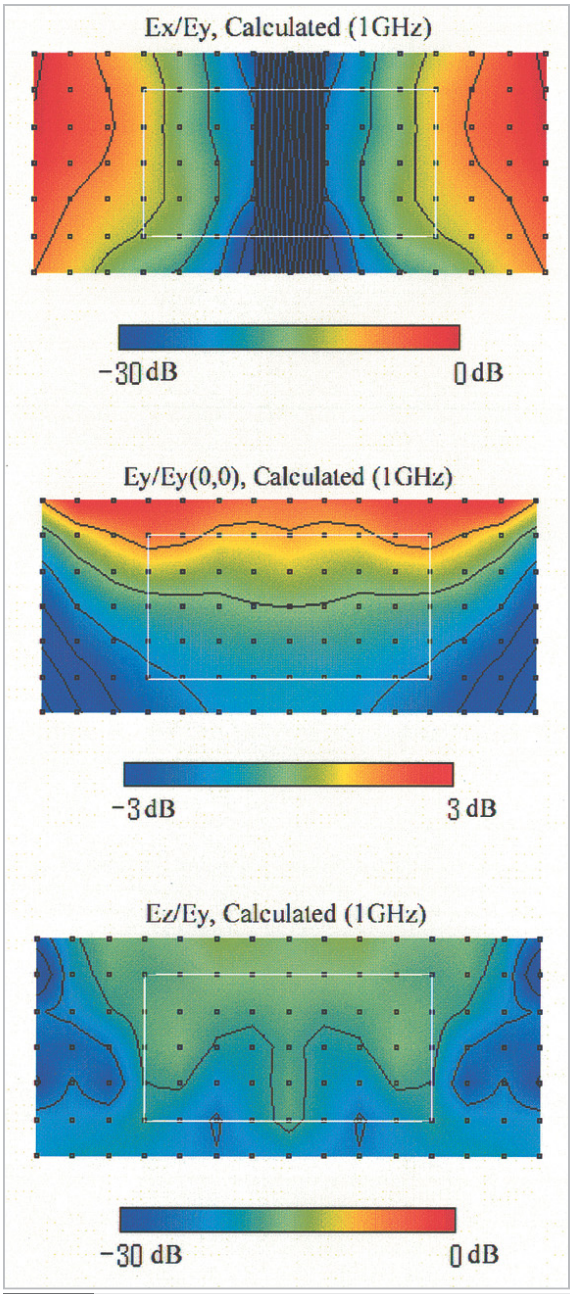


Fig.5 Calculation results for electric-field distribution

(Upper: Horizontal electric-field component Ex; Center: Primary electric-field component Ey; Lower: Electric-field component in propagation direction Ez)

is loaded and that when no EUT is loaded; the figures on the left indicate that the ratio (*a/d*) of the EUT size (a) and the distance between the septum and the floor conductor (d) is equal to 0.1, and the figures on the right indicate a ratio of 0.3. Here, the EUT is assumed to be a cube. The upper two figures are for the case of the anechoic chamber, and the lower two figures are for the case of the GTEM cell. From Fig.6, it is apparent that the manner in which the distribution of the normalized electric field changes spatially depends on the EUT size, and that it differs among measuring facilities.

Fig.7 is a graph showing the averages of the electric fields on all surfaces of the EUT as a function of the frequency (frequency response), for the case of the anechoic chamber and for the case of the GTEM cell. The case of $a/d = 0.2$ is shown as an example.

From the figure, it can be seen that the frequency characteristics of the anechoic chamber and of the GTEM cell are roughly identical, but that the characteristics of the GTEM cell exhibit greater fluctuations. The width of these fluctuations tend to grow with an increase in ratio *a/d*. Therefore, as the EUT size increases, the possibility grows that the test results obtained using the anechoic chamber will deviate from those obtained using the GTEM cell on a larger scale.

To this point, the EUT is placed in the middle between the septum and the floor conductor. Fig.8 shows how the difference between the average electric fields on all surfaces of the EUT in the anechoic chamber and that in the GTEM cell changes when the position of the EUT is changed vertically by plotting the difference against the positional height of the EUT. In the figure, h_{EUT} denotes the distance between the bottom surface of the EUT and the floor conductor. This parameter is that proposed in the committee draft (CD), which recommends $h_{EUT} \geq 0.05d$. From the figure, it can be seen that when $h_{EUT} = 0.05d$, the difference in the average of the electric fields between the anechoic chamber and the GTEM cell is larger than at any other position. Further, when $h_{EUT} = 0.85d$, which corresponds to a case in which the spacing between the septum and the upper side of the EUT is equal to $0.15d$, the difference is the second largest. Therefore, it was found from this result that the EUT shall preferably be set apart from both conductors by $0.15d$ or more.

(4) Future problems

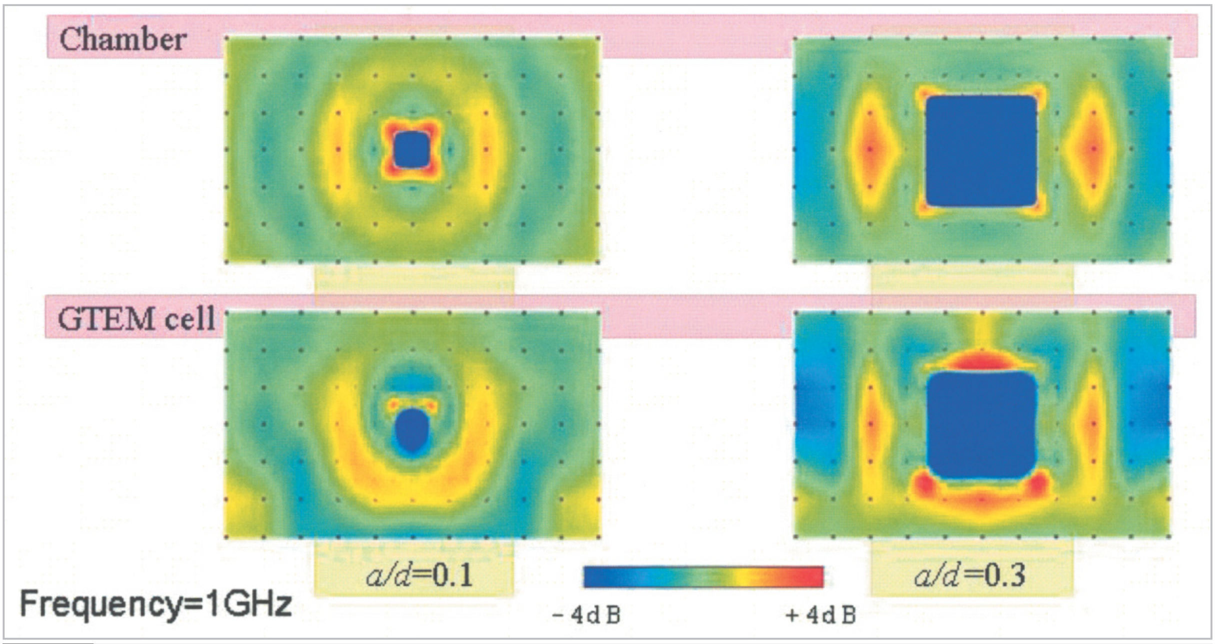


Fig.6 *Spatial distribution of the ratio of the electric field when EUT is loaded and when no EUT is loaded*

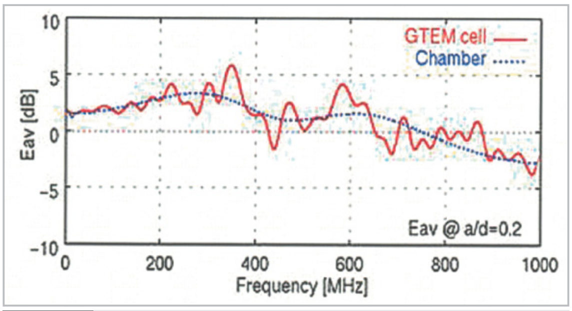


Fig.7 *Frequency characteristics of the average electric field on all surfaces of the EUT*

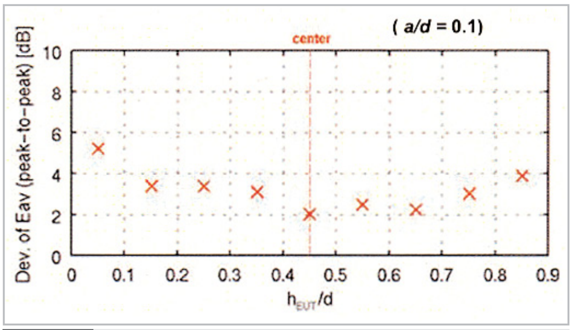


Fig.8 *Frequency characteristics of the average of the electric fields on all surfaces of EUT*

Regarding the EUT to which the electric field is applied by the GTEM cell, it is necessary to evaluate not only its surface electric fields but also other elements such as its current and magnetic field, and to investigate the difference from the conventional method and the correlation therewith. Further, if possible, it is also important to measure the electric fields and the like on the surfaces of the EUT in order to prove the validity of the theoretical calculation. Moreover, its application to measurement of electromagnetic disturbance requires further exploration in the future.

4 Reverberation chamber

(1) Introduction

Generally, measurements of the radiated electromagnetic disturbance and the radiation immunity of the electronic equipment[11] are performed primarily at open test sites and in anechoic chambers. In recent years, the use of the reverberation chamber and TEM waveguides such as a stripline or TEM cell is being examined by international organizations such as IEC/SC77B and CISPR, as an alternative to the conventional methods and as an independent method[12]~[15]. Further, as can be seen from the growing use of portable wireless equipment, the popularity of antenna-integrated wireless equipment is increasing exponentially. The use of the reverberation chamber is being examined as a new measurement method of the radiated power of such wireless equipment[16].

The reverberation chamber is an apparatus such that a stirrer composed of metallic impeller blades and the like is installed inside a metallic chamber[17] to establish a statistically uniform electromagnetic-field distribution therein, by changing the boundary condition inside the chamber using the stirrer [18][19][20]. In the measurement of radiated power using the reverberation chamber, the equipment under test (EUT) is placed in a test area of the reverberation chamber, and the radiated power is estimated based on the average received power obtained by continuously operating the stirrers. Further, in the measurement of radiation immunity, the performance of the EUT is monitored while the stirrers are being rotated stepwise. The uniformity evaluation is performed statistically based on the distribution obtained from the electric probe placed in the test area[14]. In any measurement, the non-uniformity of the electric-field distribution is a primary factor in the measurement error.

Therefore, in a basic-characteristics evaluation of the reverberation chamber, the following were investigated through a computer simulation using the FDTD (Finite-Difference Time-Domain) method; how the size of the reverberation chamber affects the uniformity of the electric field, the number of stirrers, the size of the stirrers, and the installation locations of the stirrers[21][22]. Further, the influences of the stirrer and the number of probe locations on the uniformity evaluation were examined through actual measurements [23][24][25].

(2) Evaluation by simulation

The reverberation-chamber method changes the boundary condition by rotating the stirrers, and generates a statistically uniform electromagnetic field. When the reverberation chamber is applied to the radiated electromagnetic-disturbance measurement and the immunity measurement, the spatial uniformity of the electromagnetic field that is intended to exist in the reverberation chamber becomes a problem. Therefore, the uniformity of the electric-field distribution in the reverberation chamber was examined by the FDTD method[21][22].

Fig.9 shows an analytic model of the reverberation chamber. To enable the FDTD method to be applied thereto, the analytic model is composed of a primitive (Yee's) cell [26]. As shown in Fig.9, the stirrer is made up of two metallic plates, and two stirrers are installed on the side walls. Incidentally, the Tx point in the figure denotes a transmitting point, and the Rx point denotes a receiving point.

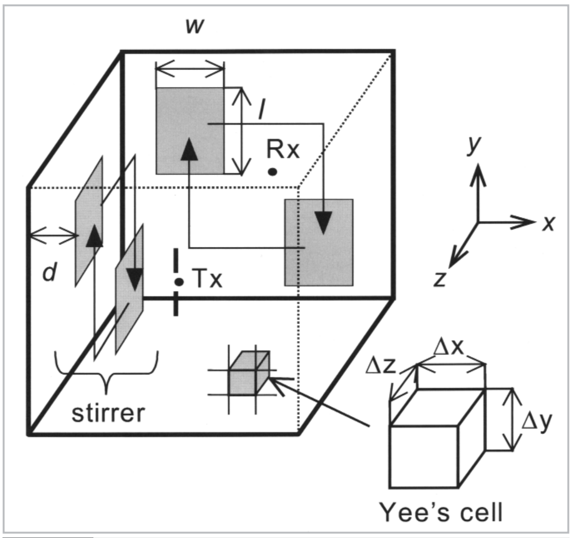


Fig.9 *Analytic model of the reverberation chamber*

The reverberation chamber is specified to be a rectangular parallelepiped chamber measuring 150 cm × 138 cm × 168 cm, and a dipole antenna is placed at the transmitting point as an excitation source. It is specified that the spatial discrete spacing of the primitive cell be 1.5 cm ($=\Delta x = \Delta y = \Delta z$), and that the time step thereof be 25 ps ($=\Delta t$).

In general, regarding the electromagnetic-field problem involved in the use of a metallic cavity with a loss-free interior, if the walls are assumed to be a complete conductor, convergence in numeral calculation becomes difficult to attain. Therefore, certain electric constants are given to the walls by arranging absorption boundaries around the outer peripherals of the walls, so that a reflection coefficient is set for the walls. The reflection coefficient R(θ) is shown as a value as in the case in which a plane wave is incident. Note that the metallic plates of the stirrer are assumed to be a complete conductor, and that the electric conductivity in of the medium is set to zero.

Fig.10 shows an example of the calculation results for the average electric-field distribution of Ey on the xz plane passing through the receiving point Rx for two cases in which the exciting frequencies are 1 GHz and 2 GHz, respectively. In the case in which the reverberation chamber is not sufficiently large compared to the wavelength of the measurement frequency, deterioration in the uniformity can be predicted. Fig.11 shows the cumulative distributions for the median of the received electric-field strength at point Rx for an x-direction component or a y-direction component of the electric field. From the results, it can be inferred that the instantaneous fluctuations in the electric field caused by the stirrers in the reverberation chamber follow a Rayleigh distribution.

Thus, by calculating the electromagnetic field in the reverberation chamber by the FDTD method, a basic examination was conducted on the influence of the size of the enclosure in the reverberation chamber and the stirrers on the electric-field uniformity in the reverberation chamber.

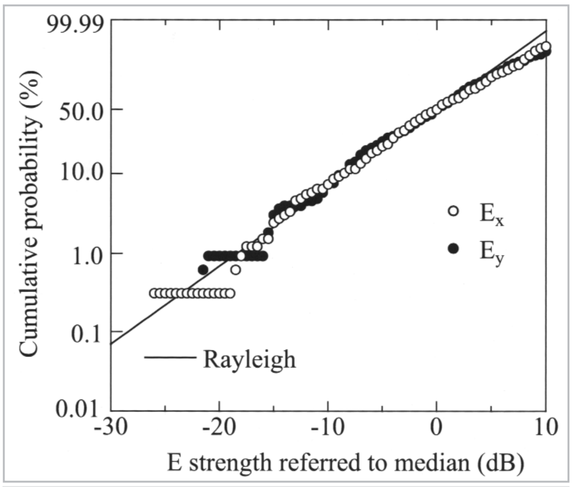


Fig.11 Cumulative distributions for the received electric-field strengths at receiving point (Rx) (at 2 GHz)

From the results, in order to minimize the non-uniformity of the electric field in the reverberation chamber, we are able to infer that the following are necessary: (1) the size of the reverberation chamber shall be set so as to be equal to 10 wavelengths or more; (2) two

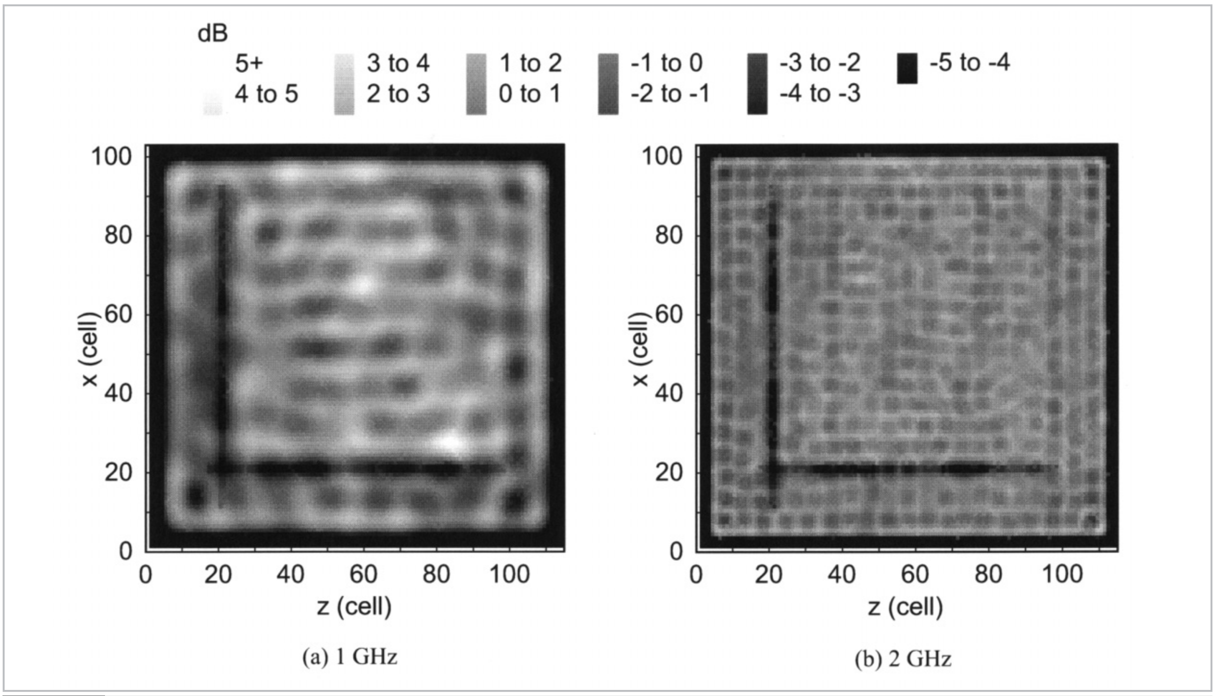


Fig.10 Average electric-field distribution of Ey in a cross section of the reverberation chamber (y = 67, | R(0) | = 0.97)

or more stirrers shall be installed, with each having a different rotation speed; (3) the size of each stirrer shall be as large as 3 wavelengths or more; (4) each stirrer shall be set apart from the walls by approximately 1 wavelength.

(3) Evaluation through actual measurements

In the radiated immunity measurement using the reverberation chamber, the equipment under test (EUT) is placed within the test area in the reverberation chamber, and the performance of the EUT is monitored while the stirrers are rotated stepwise. The evaluation of the electric-field uniformity is performed in such a way that the probe is placed within the test area and the electric-field uniformity is evaluated statistically from the maximum electric-field strengths obtained during one cycle of rotation of the stirrer[22]~[25]. At this time, the number of stirrers installed in the reverberation chamber and the setting of the number of steps of the stirrer influence the uniformity[21][22]. Moreover, it is expected that the number of probe locations affects the uniformity evaluation[13]. We have examined, through actual measurements, the influence of the number of stirrers installed in the reverberation chamber and the number of steps on the uniformity, and the influence of the number of probe locations on the uniformity evaluation [24][25].

The electric-field distribution within the test area in the reverberation chamber shown in Fig.12 was measured using an optical electric-field probe for each direction component (Ex, Ey, and Ez) from 200 MHz to 3 GHz. The probe locations are 125 (= 5×5×5) points within the area. The uniformity within the test area was evaluated on the basis of the deviation ($E_{75\%}$) of a 75% value (from 12.5% to 87.5%) of the cumulative distribution of the obtained data.

Fig.13 shows the variation in $E_{75\%}$ of the electric-field distribution obtained using three stirrers. The use of three stirrers provides the most uniform distribution. However, the effect obtained by the increase in the number of stirrers from two to three is not as great as the effect obtained by the increase in the number of stirrers from one to two. When the tolerance 6 dB of the uniformity in the immunity test like the same way conducted in the existing anechoic chamber method is applied, the available frequency of the used reverberation chamber becomes 200 MHz or higher.

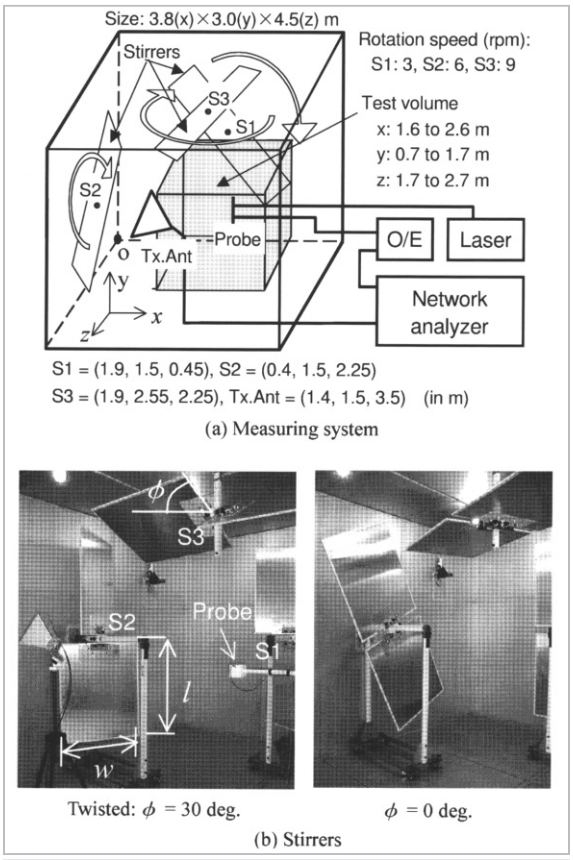


Fig. 12 *Schematic diagram of test arrangement*

The variation in the $E_{75\%}$ versus frequency when the number of steps necessary for the stirrer to return to the initial state is increased from 10 to 400 steps is shown in Fig.14. As the number of steps of the stirrer is increased, the uniformity is improved. However, when the number is 100 or more, the effect obtained by the increase in the number is small. Moreover, even with as few as 10 steps, the obtained uniformity satisfies the tolerance (6 dB) for frequencies above 400 MHz.

Fig.15 shows the variation in $E_{75\%}$ evaluated using the following number of probe locations in the measurement area: 125, 45, 27, and 8 points. The uniformity evaluated using

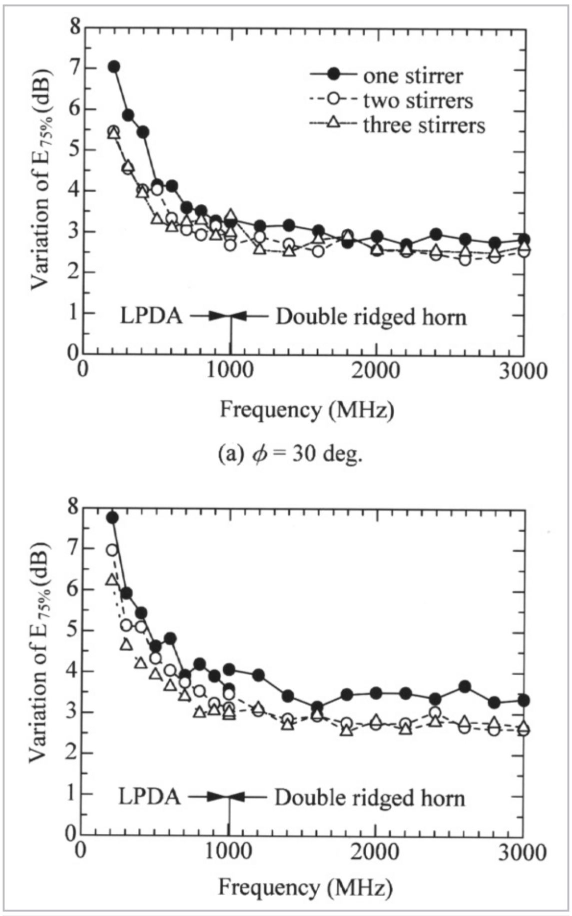


Fig. 13 Influence of the number of stirrers on uniformity

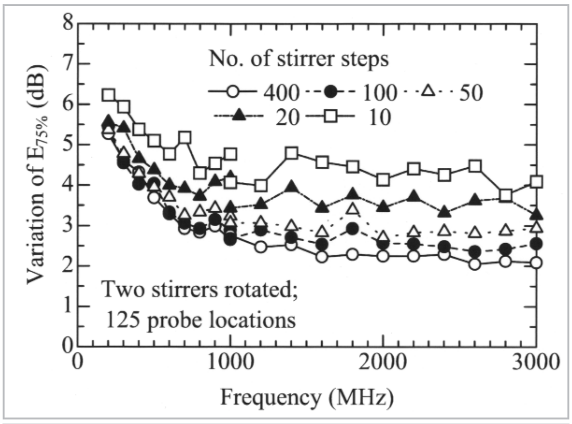


Fig. 14 Influence of the number of steps of the stirrer on uniformity

8 probe locations differed from the value obtained using 125 locations by ±1 dB. To evaluate the variation in $E_{75\%}$ with a difference of approximately 0.5 dB from the value obtained using 125 probe locations, probe locations at 27 points or more become necessary.

From the above results, we have experimentally confirmed the following : (1) the use of two stirrers can yield a sufficiently uniform distribution; (2) only a small improvement can be obtained in the uniformity even when the number of steps of the stirrer is increased to 100 or more; (3) the use of a smaller number of probe locations increases the uncertainty in the evaluation of uniformity.

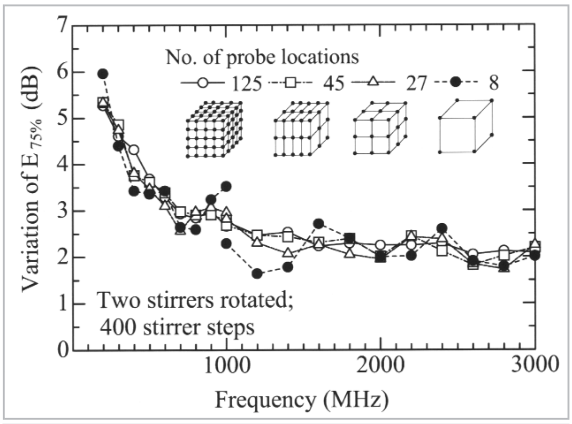


Fig. 15 Influence of the number of probe locations on uniformity evaluation

(4) Future problems

Regarding the evaluation standard of the electric-field uniformity in the reverberation chamber, further statistical examination must be conducted on the relationship between the 75% value and the standard deviation. Further, it is necessary to examine the relationship between the shape of the stirrer and the uniformity and the problems in the measurement of actual equipment. Moreover, the application thereof to the measurement of electromagnetic disturbances requires further investigation in the future.

5 Conclusions

Among the subjects of the equipment-related EMC research being conducted in the EMC group of CRL, the measurement method for radiated electromagnetic disturbances above 1 GHz, outlines of the GTEM cell and the reverberation chamber, the research results, and the like were introduced. We are considering investigating the remaining problems, and we also wish to properly address various EMC problems that will become more significant and complex in accordance with the trend in radio-wave utilization toward higher frequency and higher performance.

References

1 CISPR 16-1, 2nd Ed., 1999.

2 CISPR 16-2, Amend. 1, 1999.

3 CISPR 11, Amend. 1, 1999.

4 Hideaki Sugama and Yukio Yamanaka, "EMI measurement instrument above 1 GHz – Evaluation of Spectrum analyzers -", Tech. Rep. , EMCJ99-86,1999.

5 Yukio Yamanaka and Takashi Shinozuka, " Measurement and Estimation of BER degradation of PHS due to Electromagnetic Disturbance from Microwave Ovens", Trans. IEICE, Vol.J79-B-II, No.11, pp.827-834, Nov.1996.

6 CISPR/A/212/NP, "Amendment to CISPR 16-1 Clause 6.2: Spectrum analyzers for the frequency range 1 GHz to 18 GHz," Nov. 1997.

7 Hideaki Sugama and Yukio Yamanaka, "EMI measurement instrument above 1 GHz – Evaluation of Measuring Antennas -", Conference Rep. IEICE, Mar. 2000.

8 CISPR/A/342/CD, "Amendment to CISPR 16-1 Clause 5.12: Test sites for measurement of radio disturbance field strength for the frequency range 1 GHz to 18 GHz; Subclause 5.12.2 Validation of the test site," Nov. 2001.

9 CISPR/A/34X/CDV, "IEC 61000-4-20: EMC Part 4: Testing and Measurement Techniques: Section 20: Emission and Immunity Testing in Transverse Electromagnetic (TEM) Waveguides, " Dec. 2001.

10 S. Ishigami, K. Harima, and Y. Yamanaka, "TEM-Mode E-Field Uniformity in a GTEM Cell," IEICE Trans. Commun, Vol. E84-B, No. 9, pp. 2610-2617, Sep. 2001.Publication IEC 61000-4-3, "Radiated, Radio-frequency, Electromagnetic Field Immunity Test," 1998.

11 IEC 77B/273/CDV, 1999.

12 IEC 77B/260/CD, 1999.

13 CISPR/A/325/CD, 2001.

14 CISPR Publication 16-1, "Reverberation Chamber for Total Radiated Power Measurement," 1996.

15 A.Suzuki, T.Sugiyama, and T.Shinozuka, "Measuring of Radiated Power from Radio Equipment using a Reverberating Chamber, "Proc. C EEM'96, pp.53-56, Nov. 1996.

16 M. L. Crawford and G. H. Koepke, "Design, evaluation, and use of a reverberation chamber for performing electromagnetic susceptibility/ vulnerability measurements," National Bureau of Standards Technical Note 1092, Apr. 1986.

17 D. A. Hill, D. G. Camell, K. H. Cavcey, and G. H. Koepke, "Radiated Emissions and Immunity of Microstrip Transmission Lines Theory and Reverberation Chamber Measurements," IEEE Trans. Electromagn. Compat., Vol.EMC-38, No.2, pp.165-172, May 1996.

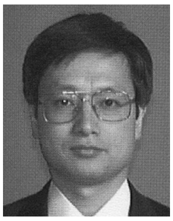
18 P. Corona, G. Ferrara, and M. Migliaccio, "Reverberating Chambers as Sources of Stochastic Electromagnetic Fields," IEEE Trans. Electromagn. Compat., Vol.EMC-38, No.3, pp.348-356, Aug. 1996.

19 M. O. Hatfield, "A calibration procedure for reverberation chambers," Proc. 2000 IEEE International Symposium on EMC, pp.621-626, Washington D.C., USA, Aug. 2000.

20 K. Harima, "FDTD Analysis of Electromagnetic Fields in a Reverberation Chamber," IEICE Trans. Commun, Vol.E81-B, No.10, pp.1946-1950, Oct. 1998.

21 K. Harima and Y. Yamanaka, "FDTD Analysis of the Effects of Stirrers in a Reverberation Chamber," Proc.

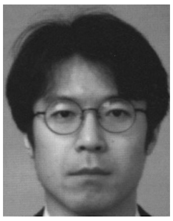
1999 International Symposium on EMC, pp. 260-263, Tokyo, JAPAN, May 1999.
22 K. Harima, and Y. Yamanaka, "Evaluation of E-field uniformity for immunity testing in a reverberation chamber," Proc. 2000 International Symposium on Antennas and Propagation, pp.1573-1576, Fukuoka, Japan, Aug. 2000.
23 K. Harima and Y. Yamanaka, "Evaluation of E-Field Uniformity for Radiated Immunity Testing in a Reverberation Chamber," Proc. 2001 IEEE EMC Symposium, pp. 768-770, Montreal, CANADA, Aug. 2001.
24 K. Harima and Y. Yamanaka, "Evaluation of Electric-Field Uniformity in a Reverberation Chamber for Radiated Immunity Testing," IEICE Trans. Commun, Vol. E84-B, No. 9, pp. 2618-2621, Sep. 2001.
25 K. S. Yee, "Numerical solution of initial boundary value problems involving Maxwell's equations in isotropic media," IEEE Trans. Antennas and Proppag., Vol.AP-14, No.3, pp.302-307, May 1966.
26 G. Mur, "Absorbing boundary condition for the finite-difference approximation of the time-domain electromagnetic field equation," IEEE Trans. Electromagn. Compat., Vol.EMC-23, No.4, pp.377-382, Nov. 1981.



Yukio YAMANAKA

Leader, Electromagnetic Compatibility Group, Yokosuka Radio Communications Research Center

EMC



***Shinobu ISHIGAMI**, Ph. D.*

Senior Researcher, Electromagnetic Compatibility Group, Yokosuka Radio Communications Research Center

EMC

Katsushige HARIMA

Researcher, Electromagnetic Compatibility Group, Yokosuka Radio Communications Research Center

EMC