STATISTICAL MEASUREMENT OF RADIO-FREQUENCY ELECTROMAGNETIC FIELDS IN A FUSION EXPERIMENTAL FACILITY

Jianqing Wang[1], Osamu Fujiwara[1] and Tatsuhiko Uda[2]
[1] Faculty of Engineering, Nagoya Institute of Technology, Japan
[2] Safety and Environmental Research Center, National Institute for Fusion Science, Japan
E-mail: wang@elcom.nitech.ac.jp

Abstract: In this study, the high frequency (HF) and microwave electromagnetic fields in fusion experimental facilities were measured, and the exposure levels were compared with the safety guidelines to ensure the workers' safety. As a result, for the HF generator of a heating device in the ion cyclotron range of frequencies (38.5 MHz), the electric field level was only 1/110 or less compared to the safety guidelines (61.4 V/m) even if the HF field could be generated in the whole period of 6 minutes, and for the microwave power source of a linear high-density plasma generator (2.44GHz) and the electron cyclotron resonance cleaning device in a compact helical system (2.45GHz), the electric field level was only 1/90 or less compared to the safety guidelines (137V/m) in a controlled environment. Moreover, statistical characteristics of the electric field intensity at the center frequencies were also given.

Key words: Electromagnetic environment, fusion experiment facility, exposure level, amplitude probability distribution.

1. Introduction

In a fusion experimental facility, in addition to a static magnetic field for confining the plasma, many devices such as plasma heating and discharge cleaning may also produce an electromagnetic field leakage ranged from several MHz to several hundred GHz. Fig. 1 shows a large-scaled helical device [1][2] in the National Institute for Fusion Science, Japan. As can be seen, the heating device in the ion cydotron range of frequencies (ICRF) acts at frequencies from 30 MHz – 100 MHz, and the radio-frequency (RF) system for discharge cleaning acts at 2.45 GHz, and so on. For protecting the workers from possible health hazards in such a special electromagnetic environment, it is essential to quantify the exposure level and evaluate the safety level with specified safety guidelines in Japan [3].

In this study, the HF and microwave electromagnetic fields were measured in fusion experimental facilities. Due to the specific characteristics of the electromagnetic fields that are generated intermittently and have time-varying amplitudes, statistical measurements were made for the cumulative amplitude probability distribution (APD) of electric fields. The measured exposure levels were compared with the safety guidelines to ensure the workers' safety.

2. Measurement

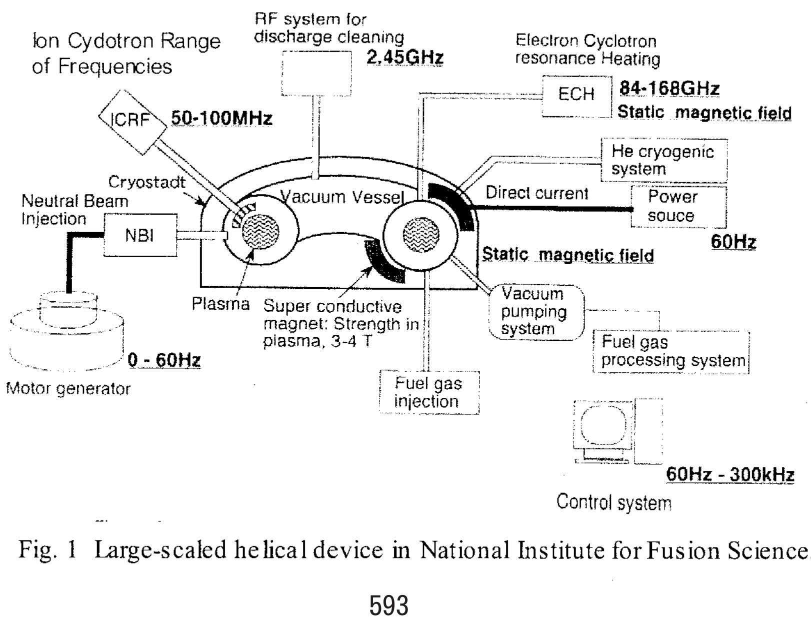

Fig. 1 Large-scaled helical device in National Institute for Fusion Science.

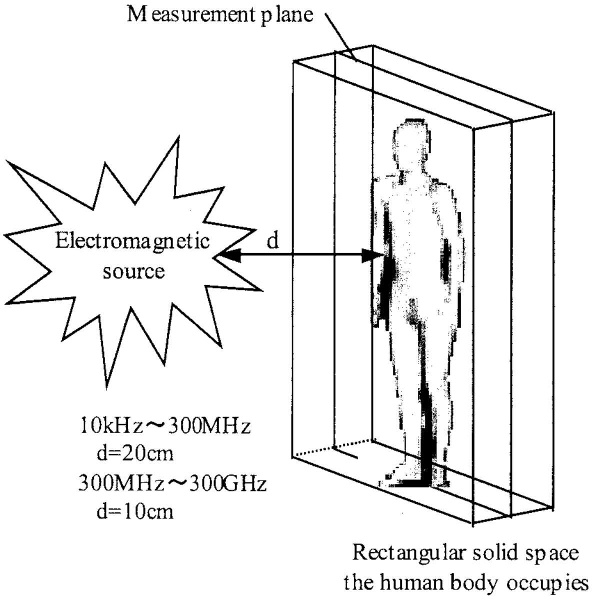

Fig. 2 Scenario of measurement for a non-uniform exposure.

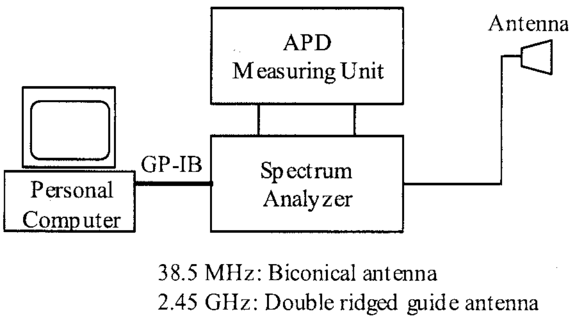

Fig. 3 Diagram of measurement.

The measurements were conducted for three devices: the HF generator of heating device in the ion cydotron range of frequencies (ICRF, 38.5 MHz), the microwave power source of a linear high-density plasma generator (HYPER-I, 2.45GHz) and the electron cyclotron resonance (ECR) cleaning device in a compact helical system (CHS). According to the measurement protocol in the safety guidelines, for the EM fields with a non-uniform distribution as shown in Fig. 2, the measurement should be conducted at a distance of above 20 cm from the radiation source between 10 kHz – 300 MHz, and above 10 cm between 300 MHz – 300 GHz. The field intensity has been defined as both the space average within the assumed human body region and the time average within 6 minutes. Following this protocol, we set the measurement distance at 20 cm for the ICRF heating device, and 10 cm for the HYPER-I and ECR. Since the leakage fields from these devices are time-varying ones, we measured not only the time-averaged electric field intensity but also their statistical characteristics. The latter should give a deeper insight to the field characteristics in the fusion experimental environment.

Fig. 3 shows the diagram of measurement for this aim. For the ICRF heating device that acts around 38.5 MHz, we employed a biconical antenna, and for the HYPER-I and ECR whose HF sources act around 2.45 GHz, we employed a double ridged guide antenna. The output of measuring antenna was connected to a spectrum analyzer including an amplitude probability distribution (APD) measuring unit. For an electric field $e(t)$ with a time-varying amplitude, the APD is defined as

$$APD(e) = \int_{e}^{\infty} p(e)de = \frac{1}{T}\sum_{n} \tau_{n} \qquad (1)$$

where $p(e)$ is the probability density, τ_n is the period of n-th measurement time in which the electric field exceeds e, and T is the total measurement time.

By using the measuring system shown in Fig. 3, both the electric fields versus the frequency and the APD of electric fields at the center frequency were measured. To obtain a time average within a period of 6 minutes for the measured field levels, data were sent to a personal computer in a time interval of 10 seconds via GP-IB interface during the 6-minute measurement period, and then the average was made in the computer. On the other hand, the APD measurement was conducted at each center frequency that was identified from the measured data with the spectrum analyzer, and the cumulative distribution was obtained in a period of 2 seconds, which was the maximum period for the APD measurement unit.

Since it is quite time-consuming to scan an assumed human body region to obtain the space-averaged field intensity, we first identified the maximum field location by moving the measuring antenna, and then fixed it at the identified location to conduct the measurement. That is to say, we used the maximum electric field levels in lieu of the average in the safety evaluation with safety guidelines. This should be a more rigorous evaluation.

3. Results and Discussion

3.1 ICRF Heating Device

The measurement was conducted at a distance of 20 cm from the device and a height of 2.8 m from the

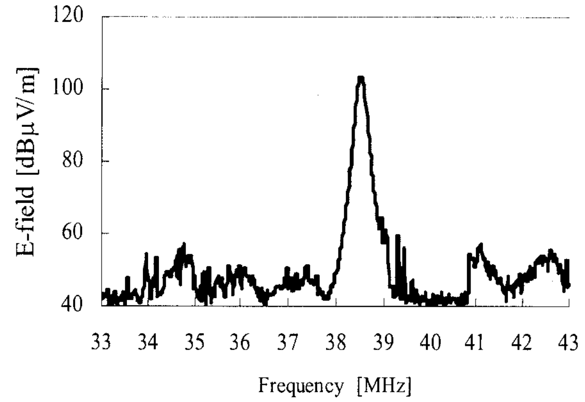

Fig. 4 Typical snapshot of measured electric field versus frequency.

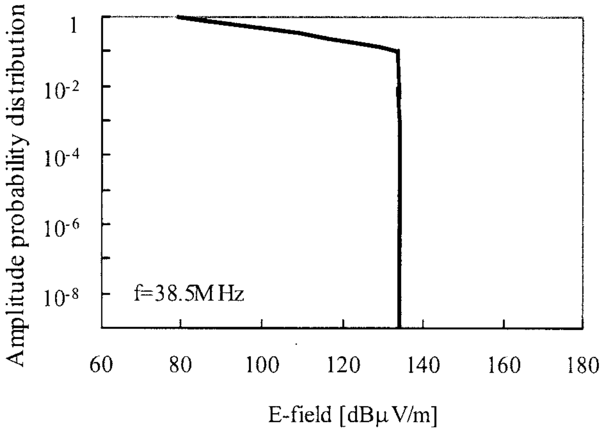

Fig. 5 APD of electric field leakage from the HF generator of a heating device in the ion cydotron range of frequencies (ICRF).

ground. In general, the HF field has a burst period of 100 ms at an interval of 5 seconds. In this measurement the HF field was set to be continuous for simulating a worst case. Fig. 4 shows a typical snapshot of measured electric fields as a function of frequencies. The peak electric field intensity was found to be 105 dBμV/m (0.18 V/m) at 38.5 MHz. Fig. 5 shows the measured APD for the electric fields at 38.5 MHz within a period of 2 seconds, which gave statistical characteristics of the time-varying electric field levels. As can be seen, the leaked electric fields with a level higher than 130 dBμV/m (0.32 V/m) is within 10% during the total measurement period, and the maximum field intensity does not exceed 135 dBmV/m (0.56 V/m). This result implies that the electric field level is only 1/110 compared to the safety guidelines (61.5 V/m) in a controlled environment even if the HF field may continue in the whole period of 6 minutes.

3.2 Microwave Power Source of HYPER-I

This power source generates microwaves with a power of 15 kW at maximum during a 30-second burst within each 120-second period. The

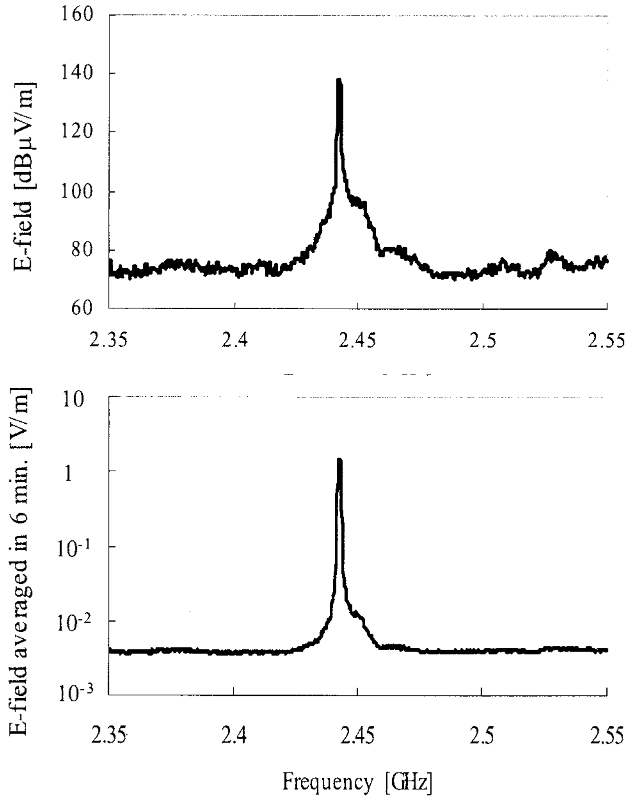

Fig. 6 (a) Typical snapshot of measured electric field versus frequency; (b) electric field averaged within 6 minutes for the microwave power source of a high density plasma generator.

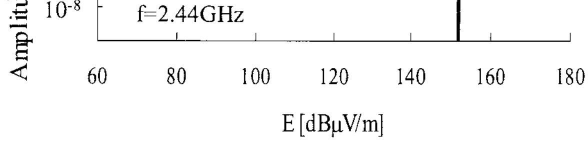

Fig. 7 APD of electric field leakage from the microwave power source of a high-density plasma generator (HYPER-I).

measurement was made at a distance of 10 cm from the front of the device. Fig. 6 shows a typical snapshot of measured electric fields and their average within 6 minutes, both as a function of frequencies. The instantaneous peak electric field intensity was found to be 140 dBμV/m (10 V/m) at 2.44 GHz, while the electric field averaged within 6 minutes at this frequency is only 1.5 V/m. This averaged electric field level was only 1/90 compared to the safety

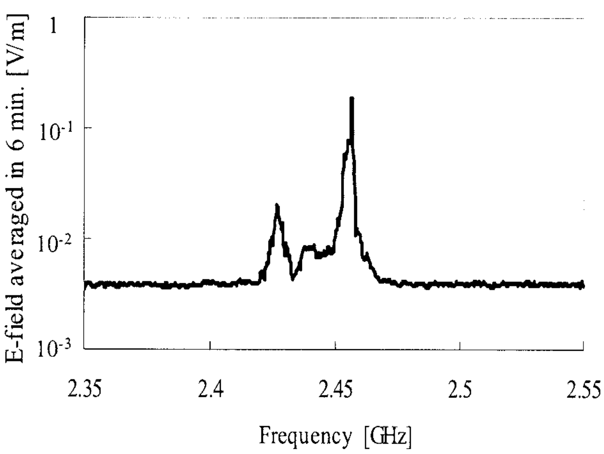

Fig. 8 Measured electric field averaged within 6 minutes for an electron cyclotron resonance (ECR) cleaning device.

guidelines (137 V/m) in a controlled environment. Fig. 7 shows the measured APD for the electric field at 2.44 GHz. As can be seen, the leaked electric fields keep at a level larger than 115 dBμV/m (0.56 V/m), and have only a possibility of 10^{-5} to exceed 150 dBμV/m (31.6 V/m). Using a commercially available electromagnetic field monitor (Wandel & Golterman EMR-300) we obtained a maximum power density of about 0.5 mW/cm^2 at the same location. This corresponds to an electric field intensity of 43.4 V/m under the assumption of far-field region, and is similar to our measurement results.

3.3 ECR Cleaning Device in CHS

This device also leaks EM fields around 2.45 GHz. Fig. 8 shows the measured electric fields averaged within 6 minutes as a function of frequencies. It was found that the averaged electric field level is 0.2 V/m at maximum, which is only 1/8 of leakage from the microwave power source of HYPER-I. In addition to the peak electric field fixed at 2.45 GHz, another peak was observed with a shifting frequency between 2.42 - 2.44 GHz. Moreover, the instantaneous value of the electric field is also low enough, i.e., only 2.2 V/m at maximum, which is in good agreement with the indicated value of 1.9 V/m on the commercially available electromagnetic field monitor.

4. Conclusion

The leakage measurement of HF and microwave electromagnetic fields has been conducted in a fusion experimental facility by using a spectrum analyzer including an APD measuring unit. As a result, for the HF generator of heating device in the ion cyclotron range of frequencies, the electric field level is only 1/110 or less compared to the safety guidelines (61.4 V/m) even if the HF field continues in the whole period of 6 minutes, and for the microwave power source of a linear high-density plasma generator and the electron cyclotron resonance cleaning device, the electric field level is only 1/90 or less compared to the safety guidelines (137 V/m) in a controlled environment. The APD measurement has also be shown to be a useful means to grasp the time-varying electromagnetic field characteristics.

A future subject is to quantify the electromagnetic absorption inside human bodies for the time-varying electromagnetic exposure.

References

[1] S. Imagawa, H. Tamura, K. Yamazaki, T. Satow, J. Yamamoto, O. Motojima, "Design analysis of electromagnetic forces on the Large Helical Devices," Fusion Eng. and Design, vol.20, pp.87-95, 1993.

[2] T.Uda, S Tanahashi, H. Ohbayashi, H. Nakatsuka and M. Ito, "Measurement of static and extremely low frequency magnetic fields around a large plasma experimental facility," Hoken Butsuri, vol.35, no.1, pp.53-63, 2000.

[3] Telecommunications Technology Council for the Ministry of Posts and Telecommunications, Deliberation no.38, Tokyo, Japan, 1990.