MEASUREMENTS OF ELECTROMAGNETIC WAVE RADIATION PATTERNS IN THE PRESENCE OF A HUMAN BODY AT 600MHZ

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1. INTRODUCTION

With a large number of radio devices in service, and an expected increase of them in the future, the potential biological hazards of electromagnetic (EM) radiation have become a public concern in recent years. When a biological body is illuminated by an EM wave, an EM field is induced inside the body and an EM wave is scattered externally by the body. For the understanding of biological effects caused by the EM wave, it is necessary to determine the energy absorption inside the body and radiation patterns outside the body. Some theoretical methods have been developed for the studies on interaction of EM fields with biological bodies [1]-[4]. Analyses of the so-called block model of man appear to be most promising in simulating a biological body and providing the specific absorption rate (SAR) distribution [3]-[6]. However, it is essential that theoretical data are verified experimentally. Furthermore, as the capabilities of analytical methods are limited in treating such complex structures as biological bodies, especially at high frequency region (above 200 MHz), measurements may offer useful means [7]-[9]. A radiation pattern measurement of living system is valid to understand and evaluate the interaction between a radio device and a human body.

In this paper, the case of a man working close to a radio device is considered. Measurements of EM field radiation patterns are conducted in the absence and in the presence of the man respectively by using a developed automatic measuring system of EM field pattern [10] at 600MHz. The measured radiation patterns in the presence of the man are compared with radiation patterns analytically obtained by using the so-called block model method with a large block size, and few differences between the experimental and analytical radiation patterns are observed. In view of this fact, the average SAR inside the human body is calculated by using the block model method with a large block size at 600MHz. The calculating result may be valuable.

2. MEASUREMENTS

A general view of the measurements is shown in Fig.1, simulating a man working close to a radio device. An exposure field was produced by a half-wave dipole antenna powered by a RF generator whose output was 1Vrms/50Ω at 600MHz. The antenna was located at 1.3 metre high from floor. A sitting
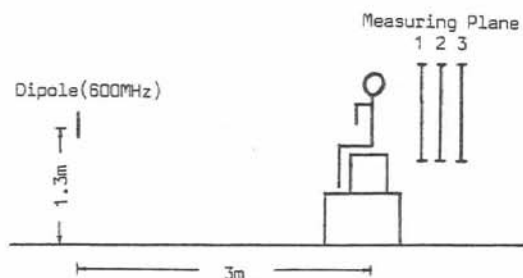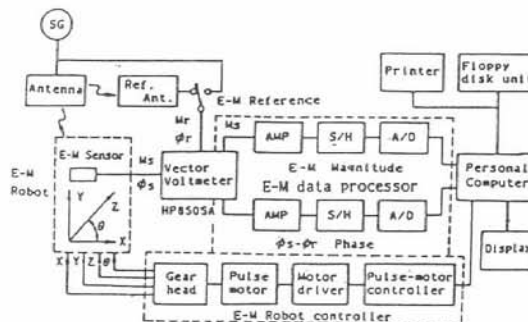

Fig.1 A View of Measurement

Fig.2 Measuring System

adult man was 3 metre far from the dipole antenna. An automatic measuring system of EM field pattern was used to scan measuring planes. The measuring system is mainly composed of an EM sensor, a robot controller and a data processor as shown in Fig.2. It can be used to measuring automatically a 3-dimensional EM field distribution and plot data of a arbitrary 2-dimensional plane as a pattern [10]. In the measurements shown in Fig.1, a half-wave dipole antenna was used as the EM sensor. It was moved by the robot controller to scan each measuring plane covering an area of $2\lambda \times 2\lambda$ with $\lambda/8$ space interval (λ : wave length in free space). The interested measuring planes 1, 2 and 3, as shown in Fig.1, were 7λ, 7.25λ and 7.5λ far from the antenna, respectively. A vector voltmeter was used to obtain both amplitude and phase difference information as DC voltages from the sensor. The data were A-D converted and then sent to a micro-computer. Except for the RF generator, the robot controller equipment and the micro-computer, the measuring system was placed in a semi-anechoic chamber with a metal floor, but the metal floor was covered by some absorptive materials to prevent reflection.

The automatic measuring system of EM field pattern shown in Fig.2 has been experimentally evaluated in Ref.10. The evaluation results showed that the scanning position error was smaller than 2mm when the scanning distance was 80cm and the measured signal variation was about 3mV when the input of data processor was 2.2V.

3. RESULTS

The measurements were conducted at each measuring plane as shown in Fig.1. The measured radiation intensity data at each measuring plane were uniformly divided into 10 levels between the maximum and the minimum value and then plotted as a radiation pattern by means of the combination of the contour line and tone picture.
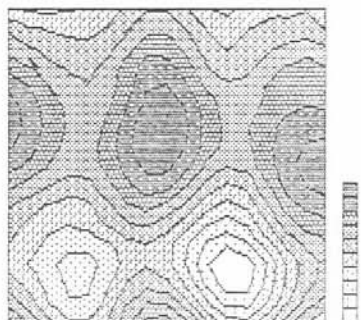

Fig.3 Radiation Pattern in the Absence of a Man

Fig.3 shows the radiation pattern at a plane of $2\lambda \times 2\lambda$ large and 6λ far from the antenna in the absence of the man. Although some absorptive materials had been used to cover the metal floor and the robot was wood structure, a few disturbances were still observed. Therefore, the radiation pattern was resulted from the transmitting antenna, the influence of the robot and the reflection from the floor. When the measurements in the absence of the man were conducted at the measuring plane 1, 2 and 3, respectively, the obtained radiation patterns were similar to Fig.3, though the intensity was different.

Fg.4 shows the radiation patterns in the presence of the man at the measuring plane 1, 2 and 3, respectively. The height of the transmitting antenna was corresponding to the location of chest of the sitting man. Compared with the radiation pattern in the absence of the man, dramatic differences can be observed, which are attributable to the large disturbance introduced by interaction of the EM wave with the human body. It is worth noticing that unpredictable contour lines appear, not only around, but away from the human body. Due to a scattering caused by the human body, the radiation intensity at some positions was stronger than that obtained in the absence of the man.

4. DISCUSSION

The measured results presented in the previous section have exemplified the complexity of EM radiation patterns in the presence of a human body, and also shown that the disturbance of EM field by a human body depends on the physical size and shape of the body. The so-called block model

Measuring Plane 1   Measuring Plane 2   Measuring Plane 3
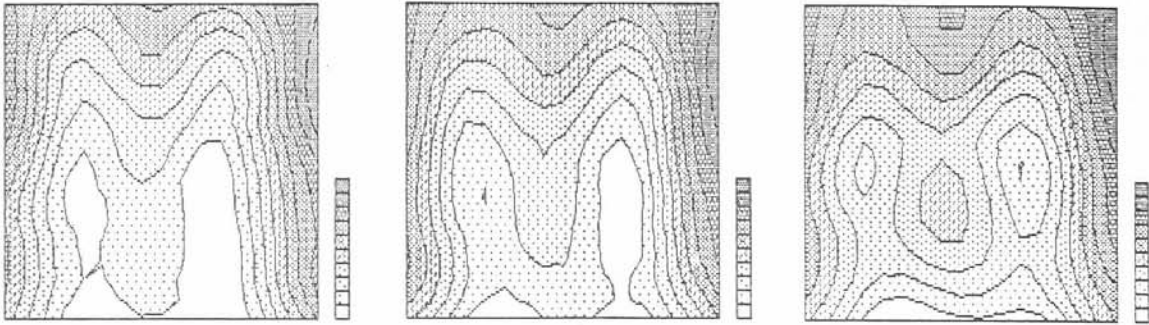

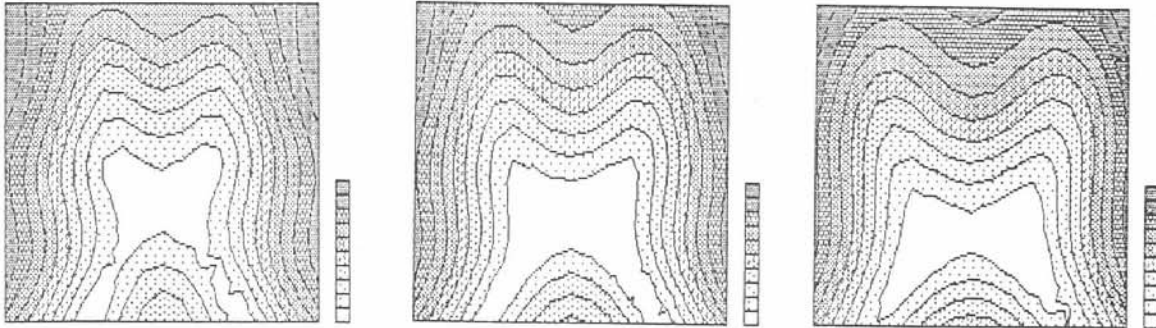Fig.4 Measured Radiation Patterns in the Presence of a Man

Fig.5 Calculated Radiation Patterns in the Presence of a Man

method [3] appears to be most promising in simulating such a complex structure as human body.

For a dipole-body system as shown in Fig.1, the total EM field $E(r)$ for all points in space exterior to the antenna can be considered to be the sum of two fields

$$E^a(r)=\int_{ant}I(s')\hat{s}'\cdot G(r,s')ds' \qquad (1)$$
$$E^b(r)=PV\int_{Vb}J(r')\cdot G(r,r')dV'-\overleftrightarrow{I}\cdot J(r')/(3j\omega\varepsilon_c) \qquad (2)$$

where $E^a(r)$ is the incident EM field of the antenna, $E^b(r)$ is the scattered EM field from the body, $I(s)$ is the antenna current, $J(r)$ is the equivalent current density replacing the induced current in the human body, $G(r,r')$ is the free space tensor Green's function, and the symbol PV denotes the principal value. For a point r exterior to the body, the scattered field $E^b(r)$ in Eq.(2) is given by the tensor integral only.

By using Eqs.(1),(2) and $J(r)=\tau(r)\cdot E(r)$, $\tau(r)$ is the complex permittivity, the following tensor integral equation can be obtained

$$[1+\tau(r)/(3j\omega\varepsilon_o)]E(r)-PV\int_{Vb}\tau(r')E(r')\cdot G(r,r')dV'$$
$$=\int_{ant}I(s')\hat{s}'\cdot G(r,s')ds' \qquad (3)$$

where r locates a point inside the body.

The basic principal of the block model method is to transform Eq.(3) into a matrix equation and solve it numerically by using the method of moments, based on partitioning the body into a lot of small block and assuming that $E(r)$ and $\tau(r)$ are constant in each block. It has been indicated that the block size is an important factor of determining the reliability of calculation. As a result of that the typical block size is on the order of $\lambda/25$, the upper limit on the frequency analysed by using the block model

method is about 200MHz [6]. Due to the restrictions on computer capacity and computing time, the theoretical analysis of a human body at 600MHz is difficult.

For reference, a calculated radiation pattern at each measuring plane by using the block model method with a large block size is shown in Fig.5. The sitting man as shown in Fig.1 was simulated by a high water content model of human body formed by 128 blocks as shown in Fig.6. The block size, i.e. side length of one block, was $\lambda/5$. It is thought generally that the block size had gone much beyond the typical order of $\lambda/25$, thus would result in an unreliable result. However, comparing Fig.4 with Fig.5, we find that few differences can be observed in the measured and the calculated radiation patterns. In view of this fact, we want to say that may be the calculating results with such a large block size as $\lambda/5$ are somewhat valuable. It is very known that the SAR within an exposed human body is an essential factor in quantifying biological effects. It can be obtained by following equation
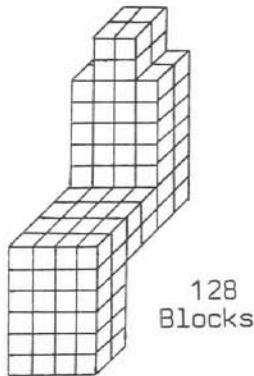
$$SAR = 1/(2\rho)\sigma(r)|E(r)|^2 \qquad (4)$$

Fig.6 Block Model of a Man

where ρ is the specific density and $\sigma(r)$ is the conductivity. As a reference result, when the input power to the antenna is 1W and $\rho = 1g/cm^3$, the average SAR in a human body as shown in Fig.1 obtained by using the block model method with a block size of $\lambda/5$ is shown as follows:

Average SAR (Whole body) = 0.01 mW/kg

The result shows that the absorped power with a dipole antenna illumination is quite weak in the Fresnel region. Furthermore, we found that the average SAR of torso is larger than that of head and smaller than that of leg in a dipole-body system as shown in Fig.1. The same conclusion has been obtained when a plane wave illuminates a model of man [4].

5. CONCLUSIONS

Radiation patterns were measured by using an automatic measuring system of EM field pattern for a dipole-body system in the Fresnel region. Dramatic differences in the presence and absence of a human body were observed in the radiation patterns. The results showed the complexity of EM radiation with a human body. In view of the fact that calculated radiation patterns by using the block model method with such a large block size as $\lambda/5$ were very similar to those measured, we showed the calculated average SAR inside the human body as a reference result and found that the average SAR of torso is larger than that of head and smaller than that of leg in the dipole-body system.

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