Fast Measurement of Radiation Efficiency of Mobile Handset Antennas

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***Abstract*—A simultaneous measurement method using parallel modulated probe array has been proposed to measure the electromagnetic radiation rapidly. Each modulated probe is excited by a local signal with individual frequency, so that the received IF signal contains different frequency components which indicate the relative magnitude of the RF signal at positions of the probes, and all the IF components are measured simultaneously by a broadband receiver. The configuration of the measurement system is described. The performance of the system is demonstrated by the measurement time and some experimental results such as the radiation pattern and the radiation efficiency of measured antennas. Even in the case of the model which includes human phantom, the radiation efficiency can be measured easily.**

I. Introduction

The radiation pattern of antennas is usually measured by rotating the antenna under test (AUT) on a turntable. This conventional measurement requires several tens of seconds to several minutes depending on the speed of the rotation and the number of sampling points. Measurement of the radiation efficiency of antennas by integrating the radiation power on a closed surface including measured antennas [1], may take more than ten minutes if the mechanical turntable and spherical scanner are used. However, in practical antenna designing, it is strongly required to reduce the measurement time to measure the 3-D radiation pattern of antennas as fast as possible.

In the EMC (Electromagnetic Compatibility) research, it is required to measure the electromagnetic radiation which is instant and irregular, such as the leaked electromagnetic radiation from the electric devices [2]. The radiated field should be measured simultaneously in several locations around electric devices in order to estimate the source locations. Therefore, a method which is able to measure the electromagnetic radiation simultaneously at several locations is necessary.

A measurement method using the modulated scattering technique (MST) has been proposed to measure the electromagnetic field rapidly [3]-[7]. The MST measurement employs array of the modulated scattering elements (MSEs) which are successively modulated by a low-frequency modulation signal. The electromagnetic field radiated by the AUT is received and modulated by the MSE. The modulated field is scattered by the MSE and is received by the AUT or by an auxiliary antenna to obtain the distribution of the incident electric field on each MSE. Since only a low frequency multiplexer and a power dividing network instead of expensive microwave switching networks are used to connect all the MSE, the MST measurement is a simple and economical method for measuring the electromagnetic field at a large number of observation points rapidly. The MST measurement is actually a rapid measurement but not a simultaneous measurement, because the low-frequency modulation signal is successively scanned electrically over the MSE to distinguish the observation points.

A simultaneous measurement method using the parallel modulated probe array has been proposed by our research group [8]. Each modulated probe element is modulated by a low-frequency modulation signal with different frequencies. The modulated signal is combined and received by a broadband microwave receiver.

In this study, the measurement precision is evaluated by measurement of the radiation efficiency and the radiation pattern of antennas. And, measurement of radiation efficiency of antenna located in the vicinity of head phantom is performed by the present measurement system. So, the accuracy and measurement time is given.

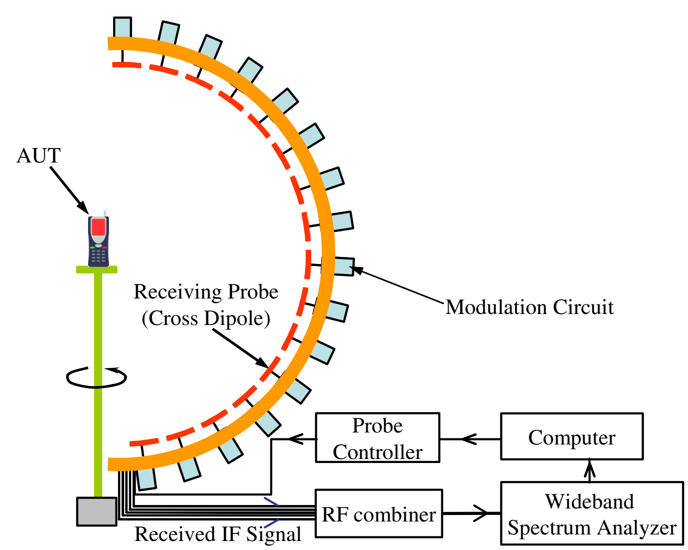

Fig. 1. Configuration of measurement system using modulated probe array.

II. Measurement system

Fig. 1 shows configuration of the measurement system using the parallel modulated probe array. The probe array consisting of 16 modulated probe elements is mounted on a semicircular arch with equally angular spacing from 0 to 168.75 degrees in zenith angle. The probe array, together with an azimuth turntable makes the measurement system possible to measure the radiation field on a spherical surface including the AUT located on the turntable. The modulatinon probe is composed of a cross dipole antenna and a shielding box which contains modulation circuits. Each probe has a crystal generating a local signal with individual frequency ranging from 20 MHz to 40 MHz for modulating the received RF signal. The modulated signals with different frequencies are combined by RF combiners and delivered to a wideband spectrum analyzer. The polarization of the modulated probe array can be switched electrically. The measurement system is located inside of the microwave anechoic chamber. The manufactured measurement system is shown in Fig. 2. The cross dipole antenna is shown in Fig. 3. Isolation between the horizontal antenna and the vertical antenna is greater than 30 dB. The shielding box of each modulated probe includes electric circuits for modulation and amplification. The gain of the modulated probe is 10 dBi at 1 GHz. Fig. 4 shows the spectrum of the received IF signal observed by wide bandwidth spectrum analyzer. 16 peaks of the spectrum correspond to the RF signal level received by the 16 modulated probes when the RF frequency is 1 GHz.

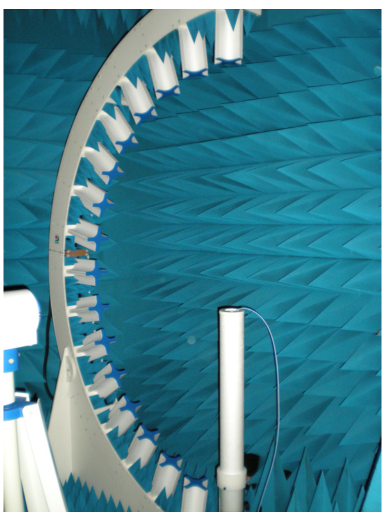

Fig. 2. Photo of measurement system.

The radiation efficiency of AUT can be also measured by this measurement system because this system can measure total radiation power. When the loss of the antenna conductor is negligible, the input power is partly radiated outside and the remaining part is absorbed by the nearby human body. The total radiation power can be obtained by integrating the radiation power over a spherical surface enclosing the antenna and human body [9]. The radiation power from the source antenna can be received by the modulated probes on the spherical surface which encloses the antenna under test. Therefore, the total radiated poewr P_r of the antenna can be

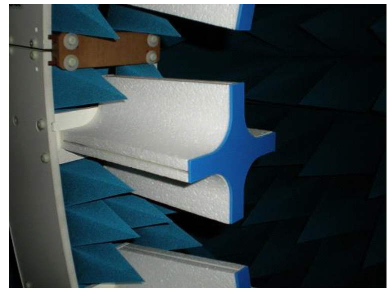

Fig. 3. Photo of modulated probe element.

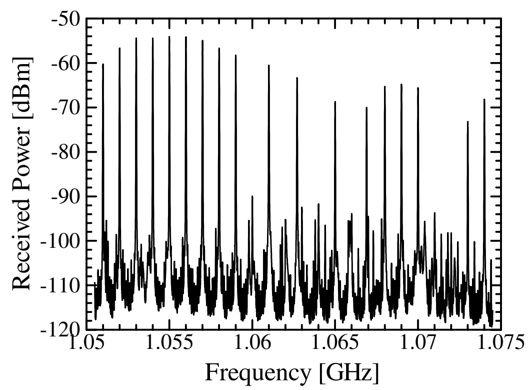

Fig. 4. Spectrum of received IF signal.

calculated by

$$P_r = \frac{r^2}{A_e}\int_0^{2\pi}\int_0^{\pi}(P_\theta + P_\phi)\sin\theta d\theta d\phi \quad (1)$$

where P_θ and P_ϕ indicate the vertically and horizontally polarized components of the received power, respectively, A_e is the effective aperture area of the modulated probe, and r is the radius of the scanning surface. Radiation efficiency can be given by the ratio of radiated power and input power as

$$\eta = \frac{P_{\mathrm{rad}}}{P_{\mathrm{in}}} \quad (2)$$

where η, P_{rad} and P_{in} indicate radiation efficiency, radiated power, input power to the AUT, respectively.

The power P_{a} absorbed by the human phantom is given by

$$P_{\mathrm{a}} = P_{\mathrm{in}} - P_{\mathrm{rad}} \quad (3)$$

Main parameters of the measurement system is shown in TABLE I.

TABLE I
MAIN SPECIFICATIONS OF THE MEASUREMENT SYSTEM.

Radius of semicircular arch	1.03 m
Frequency range	0.8 $\sim$ 2.5 GHz
Frequency step of local frequency	$>$ 2 MHz
Measurement time for spherical scan	16 sec.
Repeatability of measurement	$<$ 0.3 dB
$\vert S_{21}\vert$ between horizontal antenna and vertical antenna	$<$ 30 dB

III. Measurement results

A. Evaluation of measurement accuracy

Evaluation of measurement accuracy is performed by measurement of the radiation pattern of a monopole antenna and radiation efficiency of the monopole antenna located in the vicinity of saline water at the frequency of 1 GHz. The monopole antenna as the AUT is shown in Fig. 5. The length is 7 cm and the size of the ground plane is 30 cm × 30 cm. E-plane radiation pattern of the monopole antenna is measured and compared with the numerical analysis using FDTD (Finite Difference Time Domain) as shown in Fig. 6. This results show high accuracy of the measurement system.

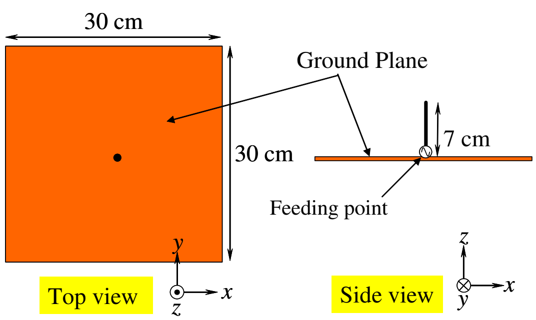

Fig. 5. Monopole antenna for the performance evaluation.

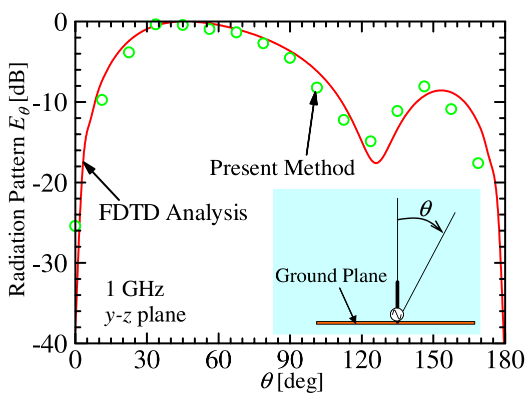

Fig. 6. Radiation pattern of the monopole antenna.

Fig. 7 shows a 3-D radiation pattern of a dipole antenna. The rapid measurement is one of the main advantages of using the present measurement system. It takes only about 16 seconds to measure the 3-D radiation pattern and to obtain the radiation efficiency of antennas.

The radiation efficiency of antennas can be obtained by measuring the 3-D radiation pattern and using the pattern integration method. The radiation efficiency of a monopole antenna located in the vicinity of a plastic box filled with a 1.0 % salt solution is also measured. FDTD analysis is also performed for comparison, where the dielectric parameters of ϵ_r = 74.8 and σ = 1.90 S/m are assumed for the 1.0 % salt solution. The complex permittivity is given by

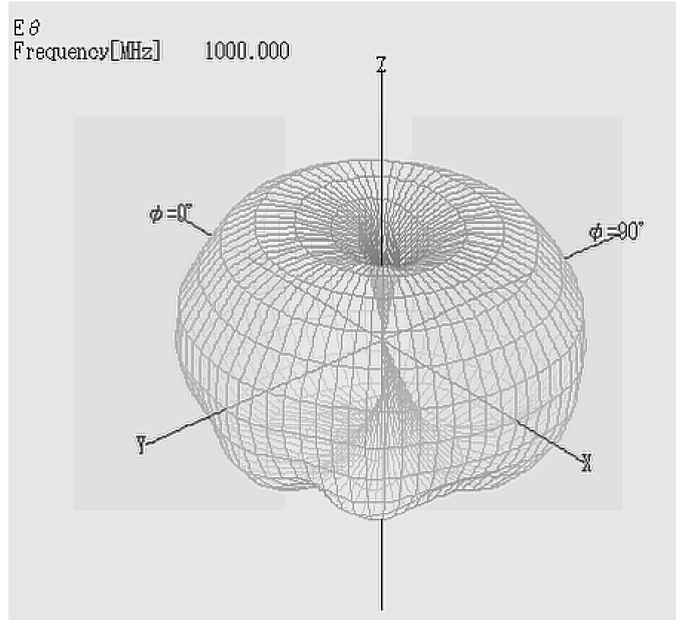

Fig. 7. 3-D radiation pattern of half-wavelength dipole antenna.

$$K = \epsilon_\infty + \frac{\epsilon_0 - \epsilon_\infty}{1 + j2\pi\tau f} - j\frac{\sigma}{2\pi\epsilon_0^* f} \tag{4}$$

where ϵ_0, ϵ_∞ and ϵ_0^* are the static, high frequency and vacuum permittivity, respectively. τ is the relaxation time and σ indicates ionic conductivity of the dissolved salts. [10].

The measured and calculated radiation efficiency versus the distance between the antenna and the surface of the box is shown in Fig. 8. Good agreement between the measurement and numerical analysis has been obtained.

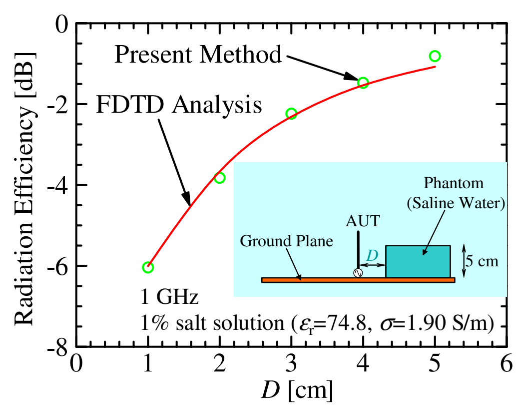

Fig. 8. Radiation efficiency of the monopole antenna located in the vicinity of the rectangular phantom.

B. Measurement of radiation efficiency of array antenna located in the vicinity of human head

The evaluation of the power absorption by the human body is important not only for the potential hazard problem from the viewpoint of the electromagnetic compatibility, but also for the research and design of the antennas for mobile handsets, since these antennas are usually used near the human body and the absorption by the human body could decrease the radiation efficiency of the antennas.

Fig. 9 shows the model of handset and monopole antenna located near the left ear of SAM (Specific Anthropomorphic Mannequin) phantom which is defined as the head model for SAR testing by the IEEE Standards Coodinating Comittee 34. Distance between the antenna and surface of the phantom is D. The measurement was performed at 2 GHz. Sugar based solution is used as the phantom solution and the relative permittivity and conductivity of the phantom are ϵ_r = 32.60 and σ = 1.933 S/m at 2 GHz, respectively. Although, the dielectric constant of the phantom solution differs from the standards for compliance SAR testing (e.g., CENELEC EN50361, IEEE P1528, etc.), it was used for the measurement of the radiation efficiency, which is not affected dielectric constant significantly. Fig. 10 shows the measured efficiency as a function of the distance of D. The radiation efficiency of the antenna can be measured easily.

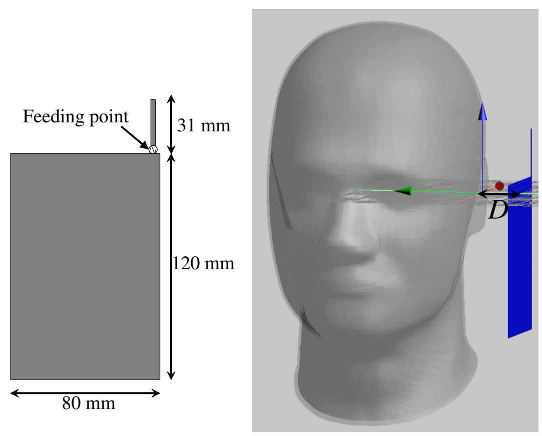

Fig. 9. Monopole antenna mounted on handset model and SAM.

TABLE II
SPECIFICATION OF SELF-PRODUCED PHANTOM SOLUTION.

	900 MHz		2 GHz	
	Expt.	IEEE Standard	Expt.	IEEE Standard
ϵ_r	40.77	41.5	32.60	40.0
σ [S/m]	0.930	0.97	1.933	1.4

IV. SUMMARY

A simultaneous measurement method using the parallel modulation technique has been proposed. The measurement of radiation efficiency can be performed within only about 16 seconds with high accuracy due to use of the parallel modulated probe array. Even in the case of the model which includes human phantom, the radiation efficiency can be measured easily.

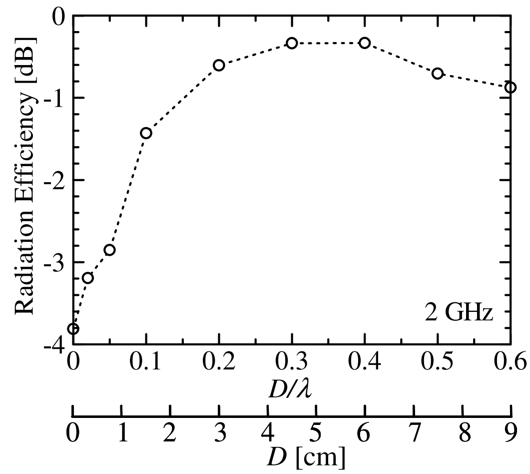

Fig. 10. Measured radiation efficiency of monopolea antenna located in the vicinity of human phantom.

ACKNOWLEDGMENT

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