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A Measurement Method Using a Modulated Probe Array for Phase of Electromagnetic Field

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Abstract A measurement method for phase of radiation field using modulated probe array is proposed. Experimental investigation of phase measurement is performed to confirm the validity of the proposed method. It is indicated that the measured phase almost agrees with theoretical data but improvement of the accuracy is required.

Key words Phase Measurement, EM Measurement, Radiation Efficiency, Modulation, Measurement Equipment

1. Introduction

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 [1] takes more than ten minutes when the mechanical turntable and spherical scanner are used. However, in practical antenna design, it is strongly required to reduce the measurement time to measure the 3-D radiation pattern and the radiation efficiency of antennas.

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

A measurement method using the modulated scattering technique (MST) has been proposed to measure the electromagnetic field rapidly [3]- [7]. A simultaneous measurement method using the parallel modulated probe array has been also proposed by our research group [8]. Each modulated probe element is modulated by a low-frequency modulation signal with different frequencies. The modulated signals are combined and received by a wideband spectrum analyzer. The measurement accuracy has been evaluated by measurement of the radiation efficiency of antenna located in the vicinity of head phantom and 3-D radiation pattern of antennas.

However, the measurement system described above is applicable only for the magnitude of the radiation field and the phase measurement method using modulated probe array is required.

In this paper, a phase measurement method using the modulated probe array is proposed. Experimental investigation is also performed with two modulated probes to confirmed the validity of the proposed method.

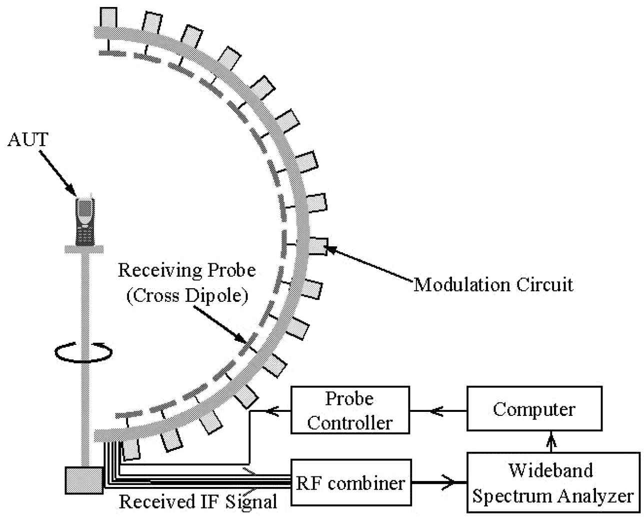

Fig. 1 Configuration of measurement system using parallel modulated probe array.

2. Measurement System Using Parallel Modulated Probe Array

Fig. 1 shows the configuration of the measurement system using parallel modulated probe array. The probe array consisting of 16 modulated probe elements is mounted on a semicircular arch with equal angular spacing from 0 to 168.75 degrees in zenith angle. Each the modulated probe is composed of a cross dipole antenna and a shielding box which contains modulation circuit having a crystal generating a local signal with individual frequency 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 electric circuit of each probe has also amplifier and the equivalent gain of the modulated probe is 10 dBi at 1 GHz. The probe array together with an azimuth turntable makes the system possible to measure the radiation field on a spherical surface including the antenna under test (AUT) located on the turntable. The measurement of a full 3-D radiation pattern can be performed within about 16 seconds. The measurement system is located in a microwave anechoic chamber. The manufactured measurement system and the cross dipole antenna are shown in Fig. 2 and Fig. 3, respectively. The specifications of the measurement system are shown in Table 1. The isolation between the horizontal antenna and the vertical antenna is greater than 30 dB.

Fig. 4 shows the spectrum of IF signals measured by the wideband spectrum analyzer, where 16 peaks of the IF signals at frequencies given by

$$f_{\mathrm{IF}} = f_{\mathrm{RF}} + f_{\mathrm{LO}} \tag{1}$$

are observed. Each peak corresponds to the RF signal level received by the 16 modulated probes when the RF frequency is 1 GHz.

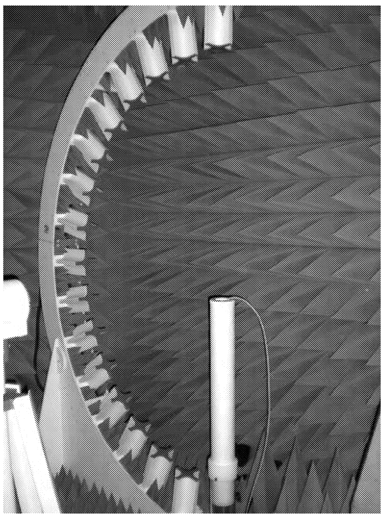

Fig. 2 Photo of measurement system using parallel modulated probe array.

3. Phase Measurement Method

Although the system described above can be used for the measurement of the magnitude of the radiation field, it can not be used for phase measurement. In this section, a method

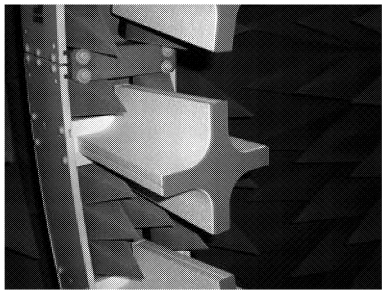

Fig. 3 Photo of a modulated probe element.

Table 1 Specifications of the measurement system.

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

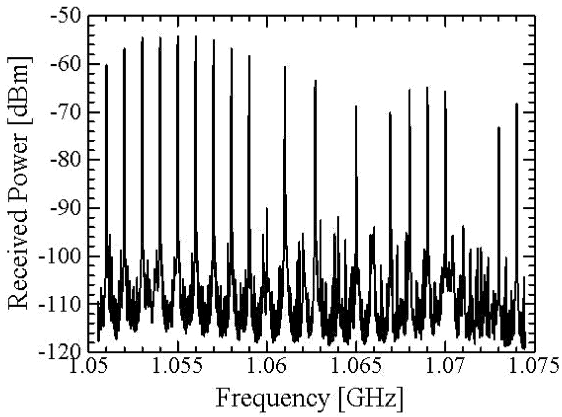

Fig. 4 Spectrum of received IF signal.

for phase measurement using modulated probe array is proposed.

The proposed phase measurement method is schematically illustrated in Fig. 5 for the case of two probes.

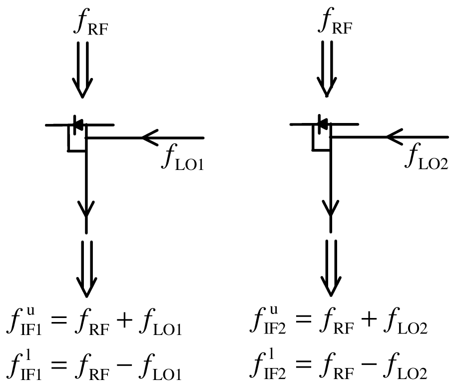

Fig. 5 Frequencies of upper and lower IF signals.

In this method, lower sideband of IF signal is used as well as upper sideband, although only upper or lower sideband is used for the magnitude measurement. The upper and lower IF signals have frequency shown in Fig. 5. The phase of IF signals at $f^{\mathrm{u}}_{\mathrm{IF1}}$ and $f^{\mathrm{l}}_{\mathrm{IF1}}$ is given by

$$\theta^{\mathrm{u}}_{\mathrm{IF1}} = \theta_{\mathrm{RF1}} + \theta_{\mathrm{LO1}} \tag{2}$$

$$\theta^{\mathrm{l}}_{\mathrm{IF1}} = \theta_{\mathrm{RF1}} - \theta_{\mathrm{LO1}} \tag{3}$$

where θ_{RF1} is the phase of RF signal received by probe #1 and θ_{LO1} is the phase of the local signal. By using eqs. (2) and (3), the phase of RF1 is given by

$$\theta_{\mathrm{RF1}} = \frac{1}{2}(\theta^{\mathrm{u}}_{\mathrm{IF1}} + \theta^{\mathrm{l}}_{\mathrm{IF1}}). \tag{4}$$

Similarly, the phase of RF signal received by probe #2 is given by

$$\theta_{\mathrm{RF2}} = \frac{1}{2}(\theta^{\mathrm{u}}_{\mathrm{IF2}} + \theta^{\mathrm{l}}_{\mathrm{IF2}}) \tag{5}$$

where

$$\theta^{\mathrm{u}}_{\mathrm{IF2}} = \theta_{\mathrm{RF2}} + \theta_{\mathrm{LO2}} \tag{6}$$

$$\theta^{\mathrm{l}}_{\mathrm{IF2}} = \theta_{\mathrm{RF2}} - \theta_{\mathrm{LO2}}. \tag{7}$$

The phase difference between RF signals of two receiving points is obtained by

$$\Delta\theta_{\mathrm{RF}} = \theta_{\mathrm{RF2}} - \theta_{\mathrm{RF1}}. \tag{8}$$

Although measured phases θ_{RF1} and θ_{RF2} are time-varying relative values, the phase difference between the RF signals is time-invariant.

4. Experimental Investigation

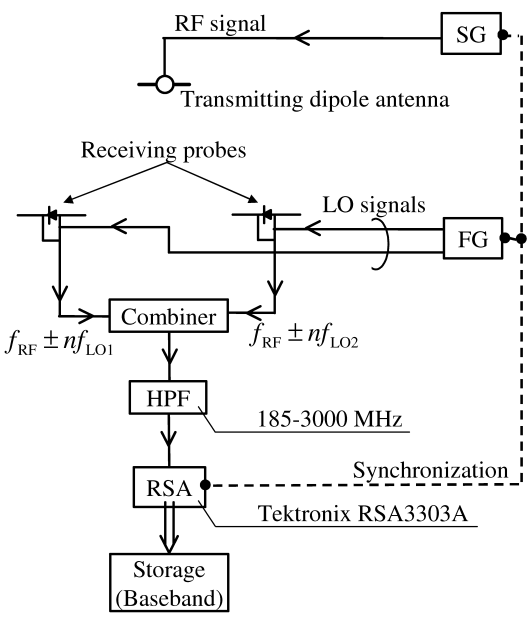

Fig. 6 Phase measurement system.

In order to investigate the validity of the proposed method, an experiment of phase measurement was performed by using the experimental setup illustrated in Fig. 6.

RF signal radiated by a dipole antenna is received by two modulated probe elements. Both modulated probe elements are modulated by low-frequency LO signals with different frequencies. Then, the received RF signal and LO signal are mixed by a silicon Schottky barrier diode loaded at each modulated probe element. IF signals are combined by a power combiner.

IF1 and IF2 signals are converted into baseband signals and are stored as a time domain data using A/D converter. The complex spectrum of IF signals is obtained by FFT and the phases $\theta^{\mathrm{u}}_{\mathrm{IF1}}$, $\theta^{\mathrm{l}}_{\mathrm{IF1}}$, $\theta^{\mathrm{u}}_{\mathrm{IF2}}$ and $\theta^{\mathrm{l}}_{\mathrm{IF2}}$ are evaluated. The magnitude of the complex spectrum is shown in Fig. 7.

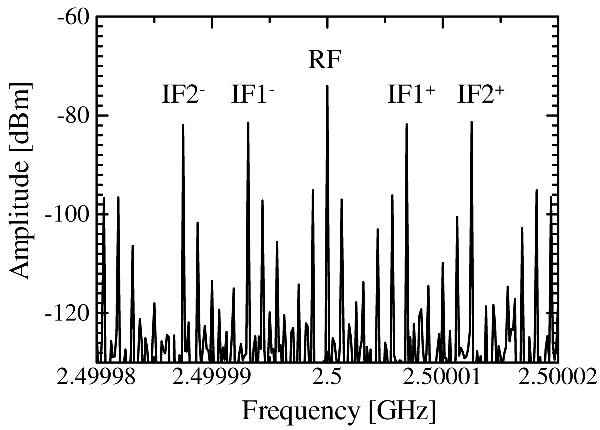

Fig. 7 Spectrum of measured IF signal.

The phase difference of RF signals was measured with changing the distance between the transmitting antenna and each modulated probe. A dipole antenna and the modulated probe elements were located inside an anechoic chamber as Fig. 8. The polarization of transmitting antenna and modulated probes were horizontal. The modulated probe element #1 was located 161.0 cm from the dipole antenna

The probe used in this measurement is shown in Fig. 9. This probe is half-wavelength dipole antenna with a silicon Schottky barrier diode. LO signal is supplied by lead wires. The specifications of the experiments are shown in Table 2. The frequency of RF signal is 2.5 GHz and the frequency of LO signals are 6.875 kHz and 12.5 kHz.

5. Results

The measured magnitude of the complex spectrum of IF signal obtained by FFT is shown in Fig. 7, where the horizontal axis is baseband frequency corresponding to the range around 2.5 GHz. The measured phase difference with respect to the fixed probe is shown in Fig. 10 as a function

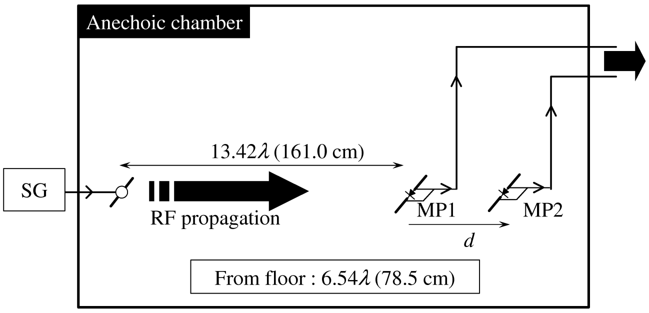

Fig. 8 Configuration of measurement systems.

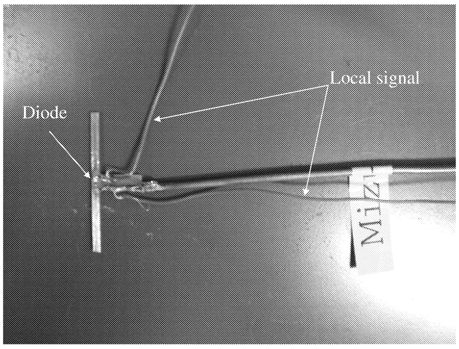

Fig. 9 Modulated probe element.

Table 2 Specifications of phase measurement.

Frequency of RF signal	2.5 GHz
Frequency of LO signal	6.875, 12.5 kHz
Amplitude of RF signal	0 dBm
Input voltage of LO signal	$V_{p-p} = 4$ V
Center frequency of receiving span	2.5 GHz
Receiving span	80 kHz
Num. of sampling points	1024
Aquisition time	6.4 msec.

of the distance between two probes. It is shown that the error from the theoretical value are less than 70°. This is reproducible. Therefore, the validity of the proposed phase measurement method is confirmed by the comparison of the measured phase difference and theoretical value. The error can be considered the mutual coupling effect between the probes.

6. Conclusion

A simultaneous measurement method of the phase of radiation field using the parallel modulation technique has been proposed. The experiment of the proposed method for two modulated probe elements was performed.

It is shown that the measured phase difference almost agrees with theoretical values except for the case around d =150 mm, where the maximum error of 70° is observed.

It is confirmed that experimental results almost agree with theoretical data. However, the accuracy of measured data is not satisfactory. And, improvement of the accuracy is the

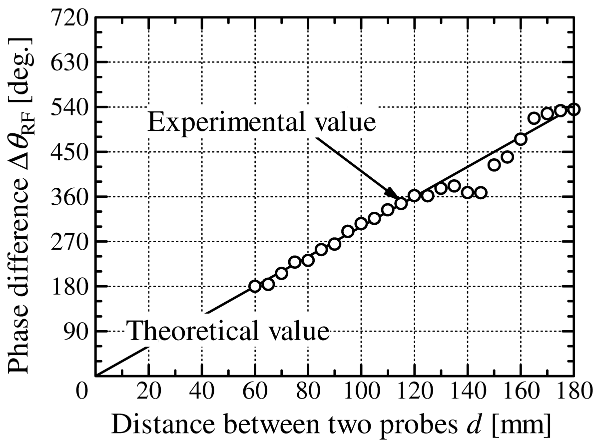

Fig. 10 Measured phase difference of RF signals received by two modulated probe elements.

remaining subjects to be solved.

Acknowledgments

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