第 528 回 伝送工学研究会

変調プローブアレーを用いた電磁界の位相の測定法

平成 22 年 6 月 16 日

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第 528 回 伝送工学研究会
2010 年 6 月 16 日

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.

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

1. Introduction

Recently, the EMC problem is becoming more and more seriously because of exponential increase of electronic devices and speed-up of clock frequency of IC (Integrated Circuit).

Thus, demand for the system which can measure the electromagnetic fields at plural point increases to evaluate the performance of electromagnetic sources rapidly. Then, it is advisable to measure not only the amplitude of radiation field but also the phase because for source position estimation. And it is required to obtain the radiation field on the whole spherical surface which surrounds the sources to evaluate the radiation efficiency and three dimensional (3-D) radiation patterns of the sources.

Additionally, it is prescribed to measure 3-D radiation fields of mobile handsets with over-the-air (OTA) to assess the total radio performances of the mobile handsets by CTIA (Cellular Telecommunications & Internet Association) and COST (European Cooperation in Science and Technology).

The sources under test are rotated by an azimuth turn table to measure the radiation fields to estimate the radiation pattern of horizontal directions conventionally. Furthermore, measurement of 3-D radiation pattern can be realized by scanning the receiving probe in zenith angles. This measurement is not simultaneous measurement and it requires several tens of minutes.

For the purpose of decreasing the measurement time, measurement method of 3-D radiation fields by rotating the sources under test on azimuth direction and zenith direction was proposed [1]. The TRP (Total Radiated Power) and RSCP (Received Signal Code Power) pattern can be measured in 4 minutes by this measurement method. This measurement time is 1/4 compared with the measurement by rotating 1 axis and the measurement accuracy is comparable to the measurement by rotation 1 axis.

A spherical EM measurement system for the purpose of reducing measurement time by supplying LO signal to the receiving probes aligning in elevation angle via the low-frequency switching network was proposed [2]. Actually, this measurement is not simultaneous measurement but it can measure the phase of radiation field by synchronizing between the transmitting and receiving instrument. However, this system has a weak point which it need an expensive switching network admitting that it is low-frequency type of it.

On the other hand, simultaneous measurement method which employing modulated scattering technique (MST) was proposed [3]. Additionally, a simultaneous electromagnetic measurement system using a parallel modulated probe array which is based on the MST was proposed by our research group [4]- [5]. This system can be composed at lower cost than other simultaneous electromagnetic measurement system. 3-D radiation pattern can be measured within only about 16 seconds by using this system.

Although this technique can be used for the measurement of the magnitude of the radiation field, it can not be used for phase measurement because phase of measured signal contains phase of LO signal components. Therefore, in order to make it possible, the phase of LO signal components must be canceled. This problem can be solved by simple signal processing arrangement.

A method of measuring phase of RF signal is proposed and its reliability and accuracy are validated by some experiments and numerical analysis in this paper. A phase measurement method is introduced in section 2. The reliability and accuracy of phase measurement method is discussed in section 3. Some results of simultaneous phase measurement using proposed method are shown in section 4. Finally, the conclusion is given in section 5.

2. 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 for phase measurement using modulated probe array is proposed.

The proposed phase measurement method is schematically illustrated in Fig. 1.

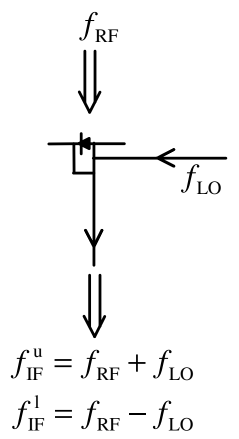

Fig. 1 Frequencies of upper and lower IF signals.

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. 1. The phase of IF signals at f_{IF}^{u} and f_{IF}^{l} is given by

$$\theta_{IF}^{u} = \theta_{RF} + \theta_{LO} \quad (1)$$

$$\theta_{IF}^{l} = \theta_{RF} - \theta_{LO} \quad (2)$$

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

$$\theta_{RF} = \frac{1}{2}(\theta_{IF}^{u} + \theta_{IF}^{l}). \quad (3)$$

This phase measurement method is realized by using experimental setup illustrated in Fig. reffig:measysver.

RF signal radiated by a dipole antenna is received by a modulated probe element. The modulated probe element is modulated by low-frequency LO signal. Then, the received RF signal and LO signal are mixed by a silicon Schottky barrier diode loaded at the modulated probe element. IF signal is converted into baseband signal and is stored as a time domain data using A/D converter. The complex spectrum of IF signal is obtained by FFT (Fast Fourier Transformation) and the phase θ_{IF}^{u} and θ_{IF}^{l} are evaluated.

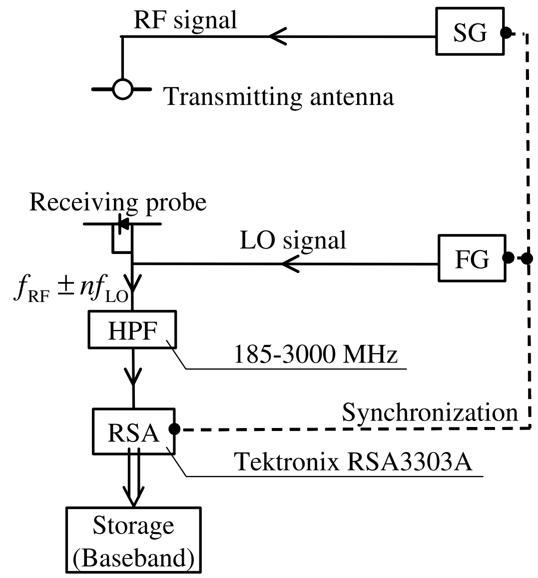

Fig. 2 Phase measurement system using modulated probe.

3. Experimental Discussion

3.1 Validation

In order to investigate the validity of the proposed method, an experiment of phase measurement was performed.

Phase of RF signal was measured with changing distance between a transmitting half-wavelength dipole antenna and a modulated probe. The transmitting antenna and the modulated probe were located on coolite blocks and located inside an anechoic chamber as Fig. 3. The distance between the transmitting antenna and modulated probe is 1670 mm. The polarization of transmitting antenna and modulated probe were horizontal. The probe used in this measurement is shown in Fig. 4. This probe is half-wavelength dipole antenna with a silicon Schottky barrier diode. LO signal is supplied by lead wires. The specifications of the experiment are shown in Table 1. The frequency of RF signal is 2.5 GHz and the frequency of LO signal is 12.5 kHz.

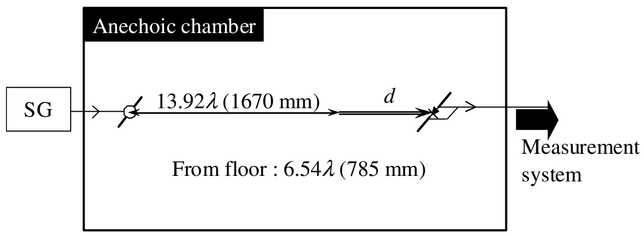

Fig. 3 Arrangement of transmitting antenna and modulated probe on validation experiment.

The measured magnitude of the complex spectrum of IF signal obtained by FFT is shown in Fig. 5, where the horizontal axis is baseband frequency corresponding to the range around 2.5 GHz.

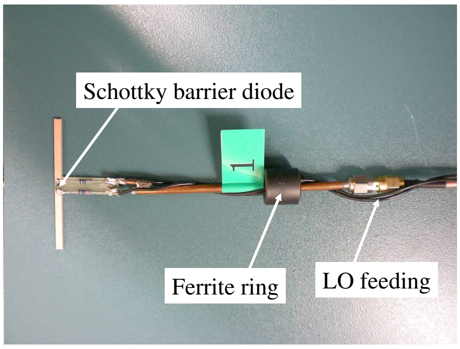

Fig. 4 Dipole type modulated probe.

Table 1 Specifications of validation experiment.

Frequency of RF signal	2.5 GHz
Amplitude of RF signal	0 dBm
Frequency of LO signal	12.5 kHz
Input voltage of LO signal	2 $V_{\text{p-p}}$
Center frequency of receiving span	2.5 GHz
Receiving span	80 kHz
Num. of sampling points	1024
Aquisition time	6.4 msec.

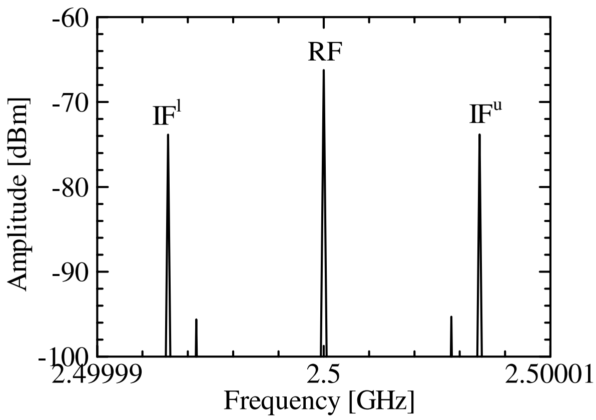

Fig. 5 Spectrum of measured modulated signal.

The measured phase is shown in Fig. 6 as a function of the distance between the transmitting antenna and modulated probe. It is shown that the mean error from the theoretical value are about 12°. The results are normalized to be 0° at $d = 0$ mm. Therefore, the validity of the proposed phase measurement method is confirmed by the comparison of the measured phase and theoretical value. It can be considered that the error is caused by instability of the basis of the transmitting antenna and modulated probe.

3. 2 Simultaneous Measurement

A simultanesous measurement was also performed by modulated probe array. As shown in Fig. 7, a transmitting 1/4 wavelength monopole antenna is located at the center of aluminium plate and 6 elements of a monopole type modulated probe array is located around the monopole antenna at 30 ° intervals in azimuth angle. The distances between the trans-

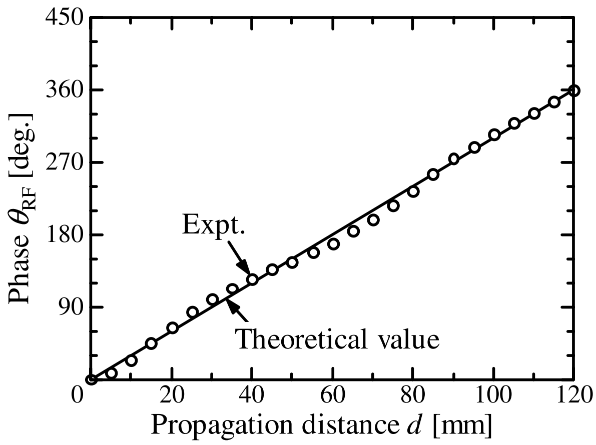

Fig. 6 Measured phase of RF signal respect to propagation distance.

mitting antenna and all modulated probes are 450 mm. At first, each signal received by each modulated probe is measured as reference value of following phase measurements. Next, position of the transmitting antenna is changed to position # 2 and # 3 in Fig. 7. Then, each phase of RF siganl respect to the reference phase received by each receiving point is measured and compared with the MoM simulation results. Thus, difference from the phase measured at the case of position # 1 is evaluated. Each signal received by modulated probes is combined by RF combiners and measured by a real-time spectrum analyzer. The specifications of the experiment are shown in Table 2.

The measured phases and amplitudes of radiation field are shown in Fig. 9 and Fig. 10 respectively. According to the results, the mean error of the measured phases from the MoM simulation results are 10.1° and the maximum error of the measured amplitudes from the MoM simulation results are 1.1 dB. It is shown that the simultanesous phase measurement by using 6 elements of a modulated probe is achieved and high degree of measurement accuracy is obtained. The cause of the error can be considered as mutual coupling effect of modulated probes and experimental error.

Table 2 Specifications of simultaneous measurement.

Frequency of RF signal	2.5 GHz
Amplitude of RF signal	0 dBm
Frequency of LO signal	0.4375, 1, 1.2656, 1.8125, 2.1406, 2.4531 kHz
Input voltage of LO signal	2 $V_{\text{p-p}}$
Center frequency of receiving span	2.5 GHz
Receiving span	10 kHz
Num. of sampling points	1024
Aquisition time	64 msec.

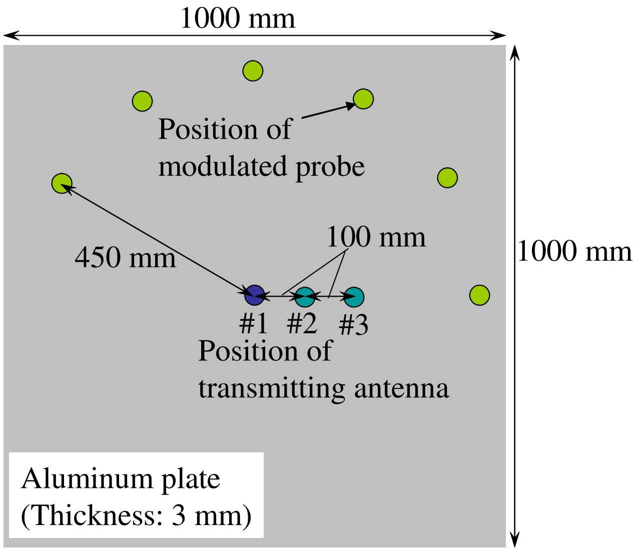

Fig. 7 Arrangement of monopole antenna and modulated probes of simultaneous measurement.

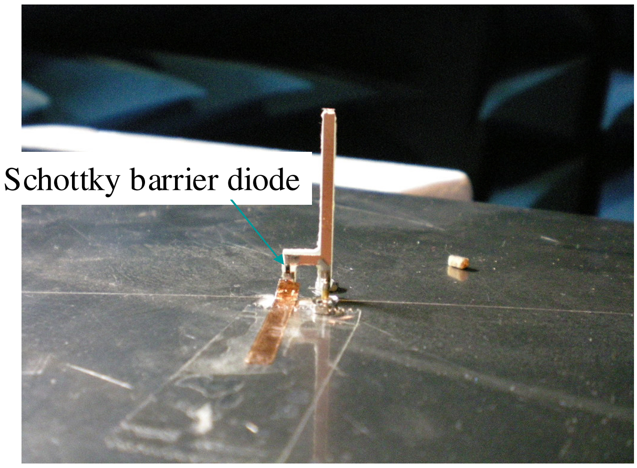

Fig. 8 Monopole type modulated probe.

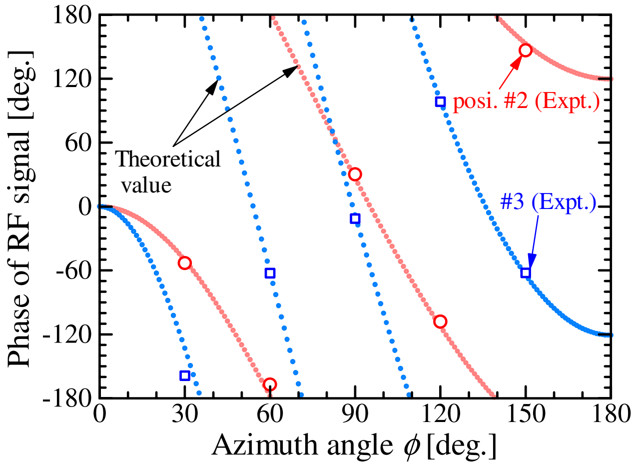

Fig. 9 Measured phase of monopole antenna at position #2 and position #3.

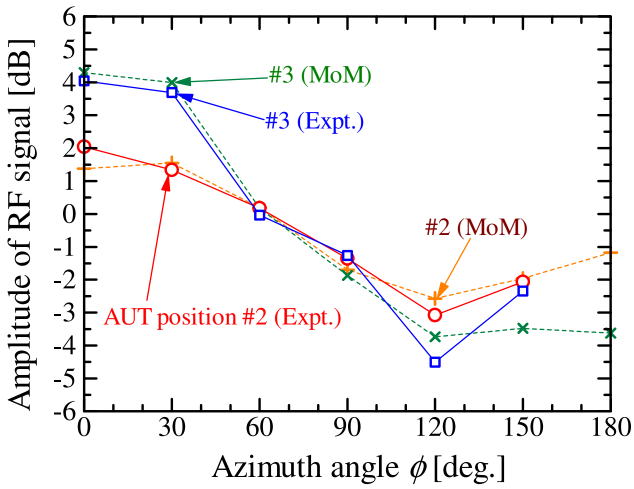

Fig. 10 Measured amplitude of monopole antenna at position #2 and position #3.

3. 3 Phase Pattern Measurement

A simultaneous phase pattern measurement of a directional antenna was also performed by 3 elements of a modulated probe array as more practical case. The experimental setup is shown in Fig. 11. A patch antenna is used as an antenna under test (AUT) and located perpendicular at the center of a coolite board so that its polarization becomes vertical and 3 elements of a dipole type modulated probe array is located around the AUT at 60 ° intervals in azimuth angle. The specifications of the experiment are shown in Table 3.

The measured phase pattern is shown in Fig. 12. The results are normalized to be 0° at $\phi = 0°$. The mean error of the measured phases from the finite element method (FEM) simulation results is about 7°. The measured radiation pattern is shown in Fig. 13. The results are normalized to be 0 dB at $\phi = 0°$. The maximum error of the measured amplitudes from the finite element method (FEM) simulation results is about 0.9 dB. It is shown that the simultanesous phase pattern measurement of directional antenna by using 3 elements of a modulated probe is achieved and high degree of measurement accuracy is obtained. The cause of the error can be considered as positioning error and diffraction effect of coaxial cable.

Table 3 Specifications of phase pattern measurement.

Frequency of RF signal	2.5 GHz
Amplitude of RF signal	0 dBm
Frequency of LO signal	6.875, 10, 12.5 kHz
Input voltage of LO signal	4 $V_{\text{p-p}}$
Center frequency of receiving span	2.5 GHz
Receiving span	100 kHz
Num. of sampling points	1024
Aquisition time	6.4 msec.

4. Conclusion

In this paper, a measurement method using a modulated

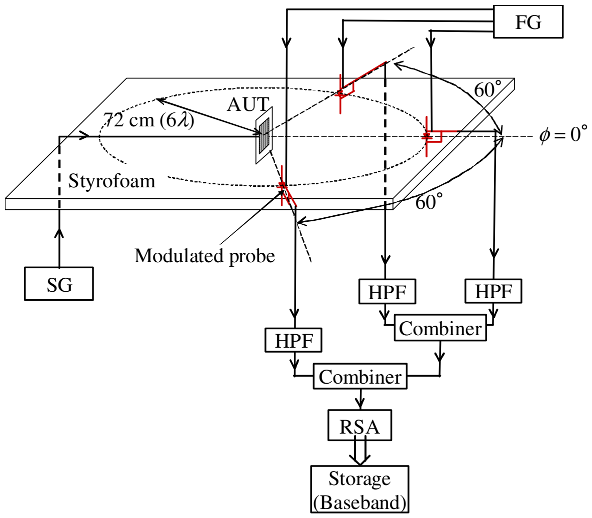

Fig. 11 Experimental system of phase pattern measurement.

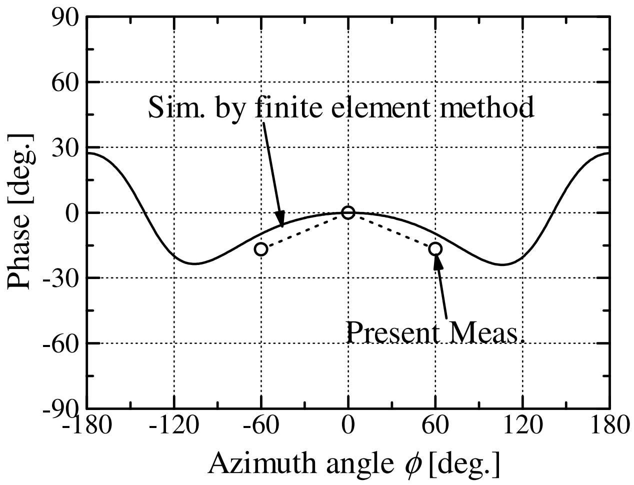

Fig. 12 Measured phase pattern of patch antenna.

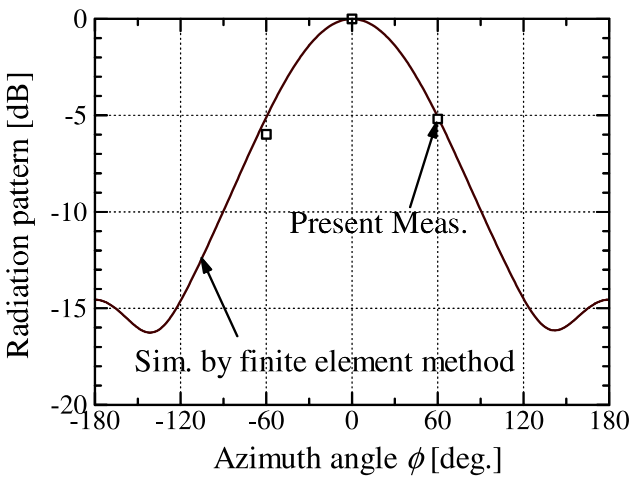

Fig. 13 Measured radiation pattern of patch antenna.

probe array for phase of electromagnetic field was proposed. The profile of measured phase respect to propagation distance was investigated to verify the validity of the proposed method. As the results, the measured phase difference almost agrees with theoretical values where the mean error of about 12° is observed. It is shown that the profile of measured phase is similar to theoretical values. Therefore, It can be said the validity of the proposed method was ascertained. A simultaneous phase measurement of radiation field of monopole antenna at different positions using 6 elements of modulated probes was performed. According to the results, it is shown that the simultaneous phase measurement by 6 elements of modulated probes was achieved. Additionally, a simultanesous phase pattern measurement of directional antenna was also performed by 3 elements of a modulated probe array as more practical case. As the results, the simultanesous phase pattern measurement of patch antenna was realized with high degree of accuracy.

Acknowledgments

This research was partly supported by Telecom Engineering Center (TELEC).

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