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Development of three-antenna method measurement system for low-sensitivity optical electric field sensor

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Abstract: A high-power three-antenna measurement system is successfully developed for calibrating the complex antenna factor of low-sensitivity sensors. First, the system is compared with a conventional three-antenna measurement system using double-ridged guide horn antennas, and the validity of the high-power system is confirmed. Then, the low-sensitivity optical electric field sensor is calibrated by this system and this result is compared with the standard field method. A good agreement between these results is obtained. The high-power three-antenna measurement system is therefore found effective for calibrating the complex antenna factor of low-sensitivity sensors.

Keywords: high-power three-antenna measurement system, optical electric field sensor, antenna factor, high-power amplifier

Classification: Electromagnetic compatibility (EMC)

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1 Introduction

With recent innovations in wireless communication, communication equipment has reached an incredibly high frequency range. Leakage of electromagnetic field radiation from this equipment often leads to serious electromagnetic interference (EMI) problems with other wireless devices [1]. It is therefore necessary to measure the equipment's emissions and perform immunity measurement at these frequency ranges. Accurately measuring the electric field strength near the equipment under test (EUT) is most important for these measurements. Electric field strength above 1 GHz is generally measured by a calibrated double ridged guide horn (DRGH) antenna with coaxial cables; yet this type of antenna is large and made of metal, and the electric field near the EUT would be disturbed by the antenna and cables [2]. Recently, electric field probes and optical electric field sensors are attracting a great deal of attention for these measurements [3]. These probes and sensors can measure electric fields up to several GHz. In comparison with these probes and sensors [3], the sensor heads of the optical electric field sensors are small, have high spatial resolution and are nonmetallic, except for their elements. Electric fields are scarcely affected by optical electric field sensors; thus they are best suited for emissions and immunity measurements near the EUT. Moreover, optical electric fields are frequency selectable. The sensitivity of the sensor can be calibrated both in the amplitude and phase ("complex antenna factor") as a function of frequency. Therefore the signal waveform can be evaluated in the time domain, which is calculated by both amplitude and phase information. Optical electric field sensors, however, have poor sensitivity. A high electric field is necessary when measuring their complex antenna factor. In general, this type of sensor is calibrated with a high-power amplifier using the standard field method, but this method can only evaluate amplitude; phase information cannot be evaluated. The conventional three-antenna method using a vector network analyzer (VNA) can evaluate the amplitude and phase information, but the output power is limited by the VNA [4]. It is difficult to measure an antenna factor with high accuracy when the receiver sensitivity is not sufficiently high. Simply connecting the power amplifier to the VNA can evaluate the amplitude, but cannot evaluate the phase information. In this study, a high-power three-antenna measurement system is developed for calibrating the complex antenna factor of low-sensitivity sensors. This system is based on testing for a high-power

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amplifier in cases where the output power of the network analyzer is not sufficiently high for measuring the performance of the high-power amplifier [5]. First, the high-power three-antenna measurement system is compared with the conventional three-antenna method using double-ridged guide horn antennas to confirm the method's reliability. Then, the low-sensitivity optical electric field sensor is calibrated by this method and the result is compared with the standard field method.

2 Measurement system and procedures

When using the conventional three-antenna method, the transmitting antenna is normally connected to port 1 of a VNA with a coaxial cable [6]. The output power of the transmitting antenna therefore depends on the VNA. The maximum output power of the VNA is generally 10 dBm [5], so it is difficult to use it to directly measure the low-sensitivity optical electric field sensor. The high-power amplifier can be inserted between port 1 of the VNA and the transmitting antenna, but full two-port calibration of the VNA cannot be carried out with a power amplifier. The phase information of the frequency characteristic of the optical electric field sensor therefore cannot be measured using the normal procedure of S-parameter measurement. The drift of the high-power amplifier also cannot be ignored when the power amplifier is installed. In this section, a high-power three-antenna measurement system is developed for calibrating the complex antenna factor of low-sensitivity sensors. The details are as follows.

2.1 Measurement system

In this study, a high-power three-antenna measurement system is developed based on reference [5]. Fig. 1 shows the schematic diagram of the measurement setup. Fig. 1 (a) shows the developed measurement system. The principles for measuring a low-sensitivity optical electric field sensor are as follows. The source power from the source-out of the VNA is connected to the high-power amplifier and the source power is amplified by this power amplifier. The amplified source power and reflected power from the transmitting antenna is turned to the VNA via a directional coupler and attenuators (RCVR R1 IN and RCVR A IN). These powers can be reflected as a reference signal of the VNA. Based on the reference signals, full two-port calibration of the VNA can be conducted for the high-power measurement system. And the attenuation and phase rotation between the transmitting and receiving antenna ports can be obtained. The amplitude and phase information of the low-sensitivity optical electric field sensor can therefore be measured, and without the effect of the drift of the power amplifier.

2.2 Complex antenna factor

The complex antenna factor of the optical electric field sensor is calibrated based on the three-antenna method [6] with the high-power measurement system described above. The optical electric field sensor is only for receiving,

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so two transceiving antennas are necessary for the high-power measurement system. In this study, two DRGH's are chosen. Fig. 1 (b) shows a diagram of the three-antenna method. Based on this method, the three-transmission coefficient and three-phase information can be obtained with this measurement system. The complex antenna factor of the optical electric field sensor is defined as follows:

$$AF_{OEFS} = \sqrt{\frac{\eta_0 A_{21}(d)e^{-jkd}}{jZ_0 A_{32}(d) A_{31}(d) d}} \tag{1}$$

where η_0 is the impedance of free space, A_{ij} (i,j = 1,2,3) is the transmission parameter, k is the wave number, Z_0 is load impedance, and d is the distance between the two antennas, respectively. In this study, Z_0 is 50 Ω and d is 3 m.

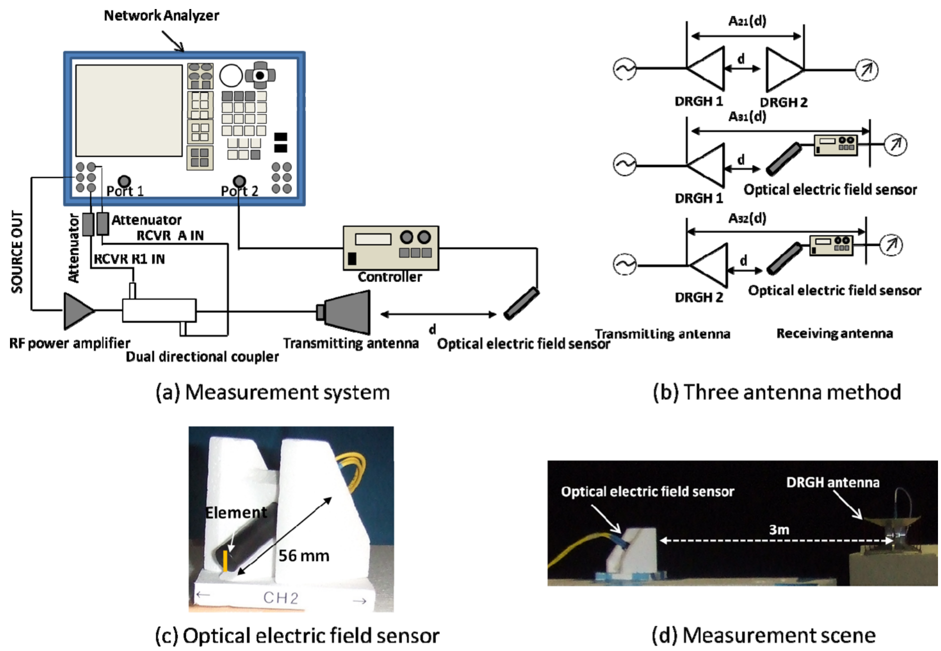

Fig. 1. Schematic diagram of measuring setup and sensor

3 Validity of measurement system

To confirm its reliability, the high-power three-antenna measurement system is compared with the conventional three-antenna measurement system [6] using double-ridged guide horn antennas of 1–4 GHz, limited by the characteristics of our power amplifier. First, we measure the transmission coefficient of DRGH antennas in the far field where the wave can be considered as a plane wave by the conventional three-antenna measurement system and calculate the antenna factor. Then, we calibrate the DRGH antennas using the high-power measurement system. The distance between the antennas is 3 m and their phase center is applied for this measurement [7]. Fig. 2 shows the comparison results between the conventional and high-power three-antenna measurement systems. The antenna factors of these methods resultantly

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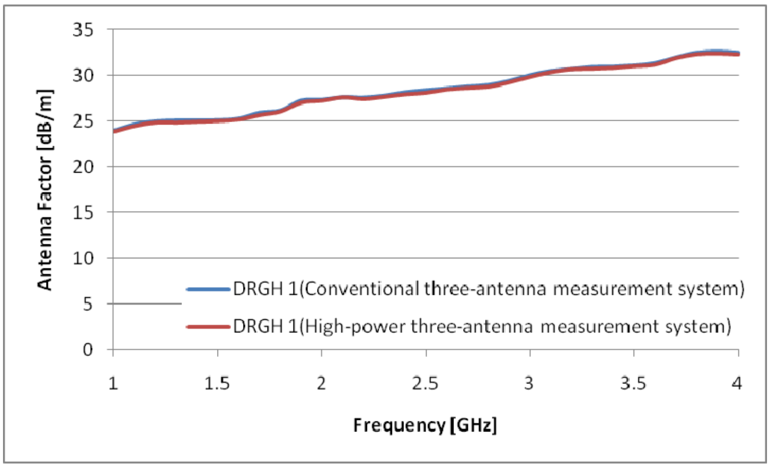

Fig. 2. Results of comparison of conventional and high-power three-antenna measurement systems

agree. The maximum difference between the antenna factors of the conventional and high-power systems is 0.2 dB. Therefore, the high-power system is as effective as the conventional one for calibrating antennas.

4 Calibration of optical electric field sensor

In this section, we calibrate the optical electric field sensor using the high-power three-antenna measurement system. One optical electric field sensor (Fig. 1 (c)) and two DRGH antennas are used. The optical electric field sensor has three elements, but in this study we only evaluate one. A special jig is constructed using polystyrene foam to align the probe along the diagonal of a cube, so that one element is aligned with the incident field and the other two elements are cross-polarized to the incident field as shown in Fig. 1 (d) [8]. The distance between the optical electric field sensor and DRGH antenna is 3 m. The optical electric field sensor has poor sensitivity. When the electric field near the sensor is too weak, the measured electric field will be unstable and fluctuate greatly. Therefore the input power of the DRGH antenna should be evaluated before calibrating the sensor. The receiving electric field of the optical electric field sensor will resultantly be stable when the input power of the DRGH antenna is 37 dBm ($\fallingdotseq$ 5 W). The input power of the DRGH antenna is therefore set to 37 dBm in this study. First, the low-sensitivity optical electric field sensor is calibrated by the high-power three-antenna measurement system and the calibration result is compared with the result by the standard field method, which compares the difference between the standard and measured electric fields [8]. Fig. 3 (a) shows the comparison results. The antenna factors of the elements of this sensor agree with the result by the standard field method. The maximum difference between the antenna factor of the standard field method and the high-power measurement system is 0.5 dB. Therefore, the high-power system can be used to effectively calibrate the optical electric field sensor, which has poor sensitivity. We also evaluated the phase information of the optical electric field sensor calculated

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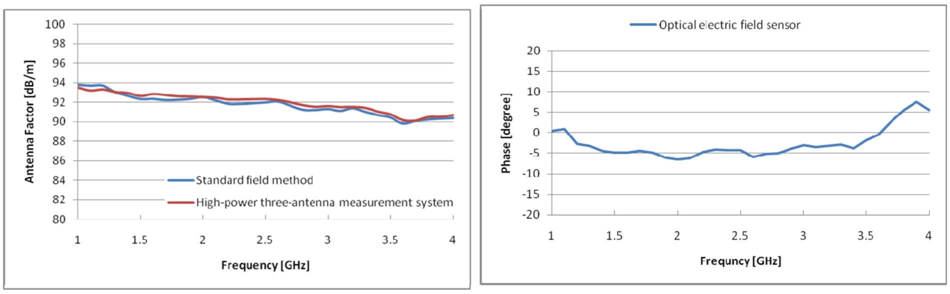
by equation (1). Equation (1) is calculated by the square root and the phase information of the optical electric field sensor only can show from $-90°$ to $90°$. Also, 20-m optical fiber is used in this measurement. The phase rotation may be too fast. Therefore the result of the phase information calculated by equation (1) should apply phase unwrapping [6] and the phase rotation equivalent of 20-m fixed delay optical fiber should be subtracted from the result. Fig. 3 (b) shows the phase information of the optical electric field sensor.



(a) Antenna factor of optical electric field sensor **(b) Phase information of optical electric field sensor**

Fig. 3. Calibration of low-sensitivity optical electric field sensor

5 Conclusions

In this paper, a high-power three-antenna measurement system is successfully developed for calibrating the complex antenna factor of low-sensitivity sensors, from 1–4 GHz. To confirm the reliability of the high-power three-antenna measurement system, this system is compared with the conventional three-antenna measurement system using double-ridged guide horn antennas. The antenna factors of these methods agree with each other. The maximum difference is 0.2 dB. The high-power measurement system is therefore as effective as the conventional three-antenna method for calibrating antennas. The low-sensitivity optical electric field sensor is then calibrated by the high-power three-antenna measurement system and this result is compared with the standard field method. Good agreement between these methods is obtained. The maximum difference is 0.5 dB. The high-power three-antenna measurement system is therefore also effective at calibrating the complex antenna factor of low-sensitivity sensors.

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