

## A PROBE CALIBRATION METHOD TO MEASURE ABSOLUTE GAIN BY SPHERICAL NEAR-FIELD MEASUREMENT SYSTEM USING PHOTONIC SENSOR

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### 1. Introduction

Near-field measurement techniques are useful to measure the patterns of various kinds of antennas in an indoor environment. To measure the 3D patterns of antennas on a portable terminal, we need a spherical near-field technique because the 3D patterns have complex shapes over broad angles. However the conventional equipment for the spherical near-field technique is so large and expensive that a special room or an anechoic chamber is required to accommodate it. To solve these problems, we have proposed a new spherical near-field measurement system using a photonic sensor as a probe and successfully measured the 3D antenna patterns of a X-band horn antenna and a MSA array [1].

By improving the structure of the system, we have developed a compact spherical near-field measurement system (SNFMS) to measure 3D antenna patterns from 1 GHz to 10 GHz. This system consists of a compact spherical scanner and a photonic sensor that is used for the probe of the spherical near-field measurements. In our system, only one probe can be used for the wide frequency range measurements, whereas the probe compensation is not needed.

To measure the absolute gain of antennas using this system, we need to calibrate the photonic sensor system. Conventionally, we can calibrate the system by measuring the output voltage of the system, of which photonic sensor is illuminated by the electromagnetic wave of known amplitude. However the calibration is troublesome because we must in advance know the radiation characteristics of the antenna that creates the electromagnetic wave.

In this paper, we propose a simple calibration method using a double-ridged horn antenna for the SNFMS with the photonic sensor. We calibrate the system by measuring the double-ridged horn antenna with the assumption that the antenna efficiency is 100 %, which means that the directivity and the gain are equal to each other. This assumption is practical because horn antennas have almost 100 % efficiency due to their little ohmic loss. Comparing the gain obtained by this calibration method with the absolute gain decided by the three-antenna method at far-field range about the double-ridged horn antenna, we have found that they agree with each other within 1 dB over the whole frequency range. Therefore it is proved that we can measure absolute gains of antennas within 1 dB by the proposed calibration method on the SNFMS with the photonic sensor.

### 2. Photonic sensor

The photonic sensor that we are using is shown in Fig. 1. The detailed explanations of the operation principle and the structure of the photonic sensor are given in Ref. [1]. The basic structure of the sensor is a type of Mach-Zehnder interferometer. The  $\text{LiNbO}_3$  substrate is of 3 mm width, 0.5 mm thickness, and 8 mm length. The antenna is a rectangular dipole antenna whose total length is 2.4 mm and its base width is 2 mm. Since a small mirror is made at the left side in Fig. 1, the sensor is called as a reflection type.

Because it consists of dielectric materials except for the metallic antenna and their sizes are very small compared to the wavelength (0.08 wavelengths at 10 GHz), the sensor can be considered to be an infinitesimal electric dipole antenna that does hardly disturb the original electromagnetic field to be measured. The infinitesimal electric dipole antenna makes us to obtain the far-field patterns using Ludwig's method because the measured  $S_{21}$ s are proportional to the theta and phi components of the electric field by the dipole moment being parallel to each electric field [1, 2].

To support the photonic sensor, we use the 50 cm glass pipe. This effect is negligible because the antenna patterns obtained by using the sensor agree well with those by the far-field measurement.

### 3. Spherical near-field measurement system

We made a spherical scanning system that consists of two rotators as in Fig. 2. One of them is used as the phi rotation and has the foam polystyrene block on it to support the antenna under test (AUT). The other is used as the theta rotation and has the arm to support the photonic sensor. The sensor is fixed on the top of a glass pipe that is fixed to the foam polystyrene arm. A screen of electromagnetic absorbers is set between the antenna and the theta rotator in order to prevent the radiated field of the antenna from being disturbed by the arm and other structures.

The locus of the sensor movement is a circle whose radius is 0.58 m and the scanning angle is from 0° to 150° by a few degree step, which is from 1° to 3° depending on the measurement frequencies. The top of the antenna is set at the position of  $r=0.42$  m and continuously rotated around the z-axis (the vertical axis in Fig. 2) from 0° to 360°. The vector network analyzer (VNA), HP8719D, was used for RF measurement. The IF bandwidth and the output power were set to 10 Hz and 0 dBm respectively. A power amplifier of about 30 dB was connected to the output port of the VNA to increase the sensitivity of the measurement system. The measured SNR was about 30 dB in all the measurements.

### 4. Simple calibration method of the total system

Calibration of the system is troublesome and inconvenient because we must measure the S parameters of the component consisting of cables and the amplifier, and the sensitivity of the photonic sensor system by illuminating an electromagnetic wave of known amplitude.

Therefore we propose a simple calibration method by treating the VNA, cables, the amplifier, and the control unit of the photonic sensor as one component. To use the calibration method, we must adopt the antenna of 100 % efficiency as a reference antenna. It is not so difficult to find such an antenna since antennas made of metals have usually the efficiency of almost 100 %, for example, standard horn antennas. In our system, the measured  $S_{21}$  is proportional to the inner product of the electric near-field  $\mathbf{E}(\mathbf{r})$  at the position of the sensor and the electric moment  $\mathbf{p}$  of the photonic sensor. That is

$$S_{21} = \text{const.} \cdot \mathbf{E}(\mathbf{r}) \cdot \mathbf{p} \quad (1)$$

When  $\mathbf{p}$  is parallel to the theta component of the electric field, the measured  $S_{21}$  is given as [2]

$$S_{21\theta} = \alpha \sum_{s=1}^2 \sum_{n=1}^N \sum_{m=-n}^n T_{smn} \vec{F}_{smn}^{(3)}(A, \theta, \phi) \cdot \hat{\theta} \quad (2)$$

where  $T_{smn}$  is the coefficient to be determined by Ludwig's method,  $\mathbf{F}_{smn}^{(3)}$  is a spherical wave function, and  $\alpha$  represents the system characteristics to be calibrated. The phi component of the electric field is measured by the same way as the above. Finally we obtain the absolute gain as [2]

$$G(\theta, \phi) = \frac{\left| \sum_{smn} \alpha T_{smn} \vec{K}_{smn}(\theta, \phi) \right|^2}{1 - |\Gamma|^2} \frac{1}{|\alpha|^2} \quad (3)$$

where  $\Gamma$  is the reflection coefficient of the AUT and  $\mathbf{K}_{smn}^{(3)}$  represents the far field deduced from  $\mathbf{F}_{smn}^{(3)}$  when the distance  $A$  is infinite.  $\alpha T_{smn}$  is obtained directly by the two measured  $S_{21}$ s and Ludwig's method. Therefore  $\alpha$  must be determined at first to obtain the absolute gain of the AUT.

To determine  $\alpha$ , we propose to use the reference antenna. Because the reference antenna is assumed to have 100 % efficiency, the directivity and the absolute gain are equal. It is not so difficult to decide the directivity because the directivity can be determined only by integrating the measured relative pattern over the unit sphere. Therefore  $\alpha$  is easily determined in order that the directivity is equal to the absolute gain, without any extra S parameter measurements on cables and the amplifier, and even without the calibration of the VNA.

### 5. Measured results

We used the Model 3115 (manufactured by EMCO) as the reference antenna. Because EMCO 3115 is almost made of metals, it is expected that it can be used as the reference antenna.

To check the equality between the absolute gain and the directivity, we measured the absolute gain by three antenna method at far-field range (about 5 m between two antennas). The directivity was calculated by the integration of the far-field pattern obtained by the SNFMS using photonic sensor. They are plotted in Fig. 3 with their difference. Figure 3 shows that they agree within 1 dB from 1 GHz to 2 GHz and within 0.5 dB from 3 GHz to 10 GHz. The relatively large differences at 1 GHz and 2 GHz are due to the pattern deformation by some unwanted reflecting waves from the surroundings in the measured results using the SNFMS, which is shown in Fig. 4. Therefore we can calibrate the system within about 1 dB.

Figure 4 shows the absolute gain patterns at 1 GHz in the E and H planes measured by the three-antenna method, and the directive patterns in the same planes obtained by the SNFMS using the photonic sensor. The difference becomes larger from  $90^\circ$  to  $270^\circ$ . Because the three-antenna method is more accurate than the SNFMS, this is due to unwanted reflecting waves from the environment in the measured results using the SNFMS. From these pattern differences, we can understand that the absolute gain and the directivity are different to the degree as shown in Fig. 3.

Figure 5 and Fig. 6 shows the same patterns as those in Fig. 4, at 5 GHz and 10 GHz respectively. In Fig. 5, the patterns agree well with each other in the range from  $-140^\circ$  to  $140^\circ$ . In Fig. 6, the patterns using the SNFMS are degraded by the lower SNR in the measurement. However the overall shapes of the patterns agree with each other. From these facts, we can expect that the absolute gain and the directivity are almost the same with each other as shown in Fig. 3.

## 6. Conclusion

We have proposed a simple calibration method using a double-ridged horn antenna to calibrate the spherical near-field measurement system (SNFMS) using the photonic sensor. Using the fact that the antenna of efficiency 100 % has the gain equal to the directivity, we can determine the necessary calibration constant in the proposed method. Comparing the gain by this calibration method with the absolute gain measured by three-antenna method at far-field range about the double-ridged horn antenna, we have found that they agree with each other within 1 dB from 1 GHz through 10 GHz. Therefore it is proved that we can measure absolute gains of antennas within 1 dB using the proposed calibration method combined with the SNFMS using the photonic sensor.

We have plans to make the measurement frequency lower than 1 GHz by designing a new system, to increase the sensitivity of the photonic sensor system, to correct the position and direction errors of the sensor, and to eliminate the deterioration of the pattern due to the lack of the measured data in the theta direction. We will treat these subjects in the forthcoming papers.

We would like to thank DEVICE Co. Ltd. for their support and cooperation of building the spherical scanning system.

## References:

- [1] M. Hirose, T. Ishizone, and K. Komiyama, "Antenna Pattern Measurements Using Photonic Sensor for Planar Near-Field Measurement at X Band", *IEICE Trans. Communications*, Vol.E87-B, No.3, pp.727-734, March 2004.
- [2] J. E. Hansen ed., *Spherical Near-Field Antenna Measurements*, IEE Electromagnetic waves series 26, 1988

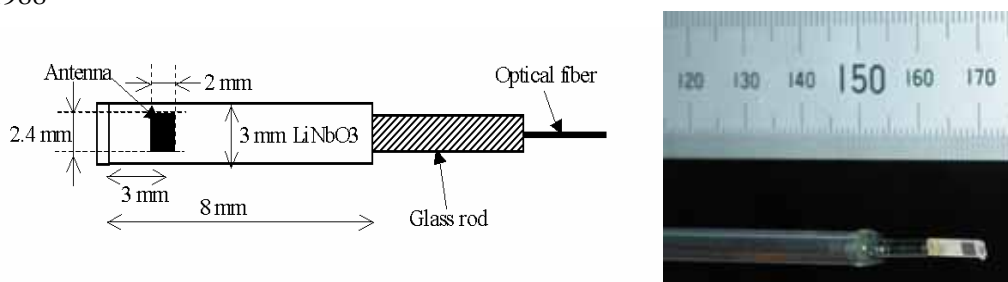


Fig. 1. Geometrical structure of the photonic sensor

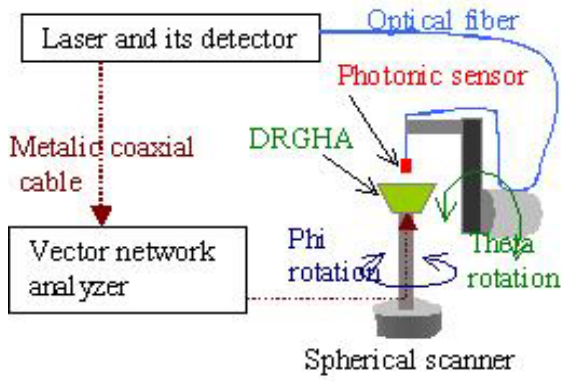


Fig. 2. Measurement setup

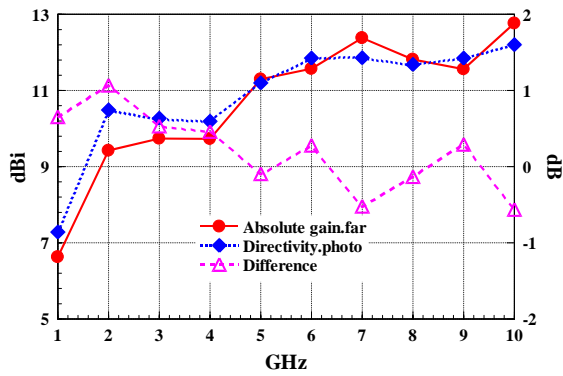


Fig. 3. Frequency characteristics of the absolute gain, the directivity, and their difference for EMCO 3115, which are measured by the conventional three-antenna method (far) and the SNFMS using the photonic sensor (photo).

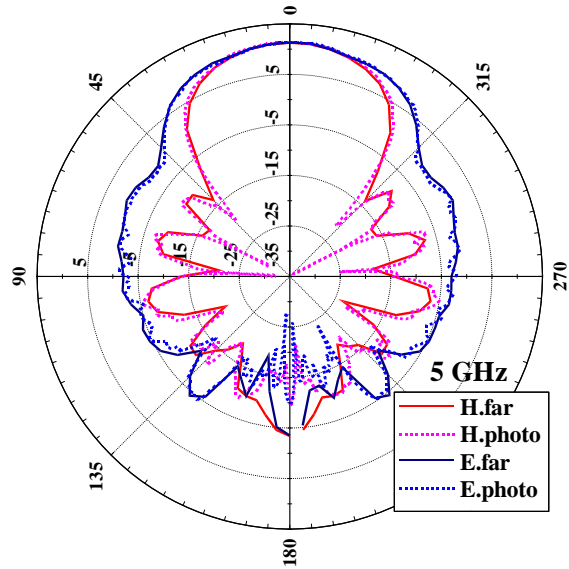


Fig. 5. Principal absolute gain patterns at 5 GHz, on the E and H planes for EMCO 3115.

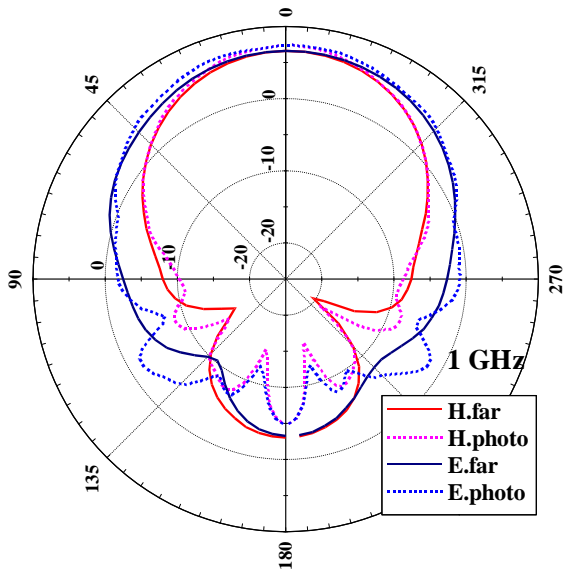


Fig. 4. Principal absolute gain patterns at 1 GHz (dBi in unit), on the E and H planes for EMCO 3115, measured by the three-antenna method (far) and the SNFMS using the photonic sensor (photo).

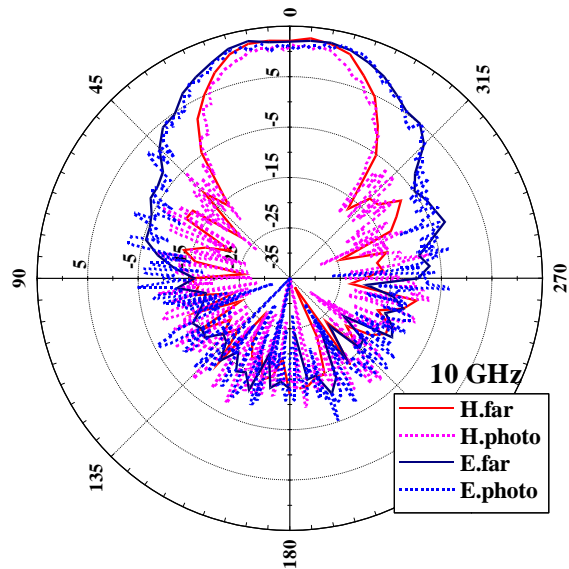


Fig. 6. Principal absolute gain patterns at 10 GHz, on the E and H planes for EMCO 3115.