High-Sensitivity Optically Modulated Scatterer for Electromagnetic-Field Measurement

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***Abstract*—The optically modulated-scatterer (OMS) technique is developed for electromagnetic-field-distribution measurement with minimum disturbance to the field under test. In this paper, an OMS with newly designed photoconductive-switching structure is proposed. The performances of the new OMS are evaluated with a monostatic-field-measurement system. Measurement results show that an improvement of 6 to 8 dB in sensitivity is achieved compared to previous OMS devices. The developed OMS was used in an electromagnetic-field-distribution mapping system to measure the field distribution in a cubic phantom radiated by a mobile phone. The results show the suitability of this OMS for specific-absorption-rate measurement application.**

***Index Terms*—Optically modulated scatterer (OMS), radiated field, specific absorption rate (SAR).**

I. INTRODUCTION

THE OPTICALLY modulated-scatterer (OMS) technique is developed to measure electromagnetic-field distribution with minimum disturbance to the field under test [1]. Such a technique has been successfully applied to the measurement of antenna pattern [2] and to the evaluation of the performance of microwave absorbers [3]. In this paper, an OMS with a new photoconductive-switching structure is proposed.

Performance of the OMS is evaluated and compared with previous OMS [2]. The results show significant improvement in sensitivity of the newly designed OMS.

The developed OMS is used in an electromagnetic-field-distribution mapping system to measure the field distribution in a cubic phantom radiated by a mobile phone. Measurement results show that this OMS is suitable for specific-absorption-rate (SAR) measurement application.

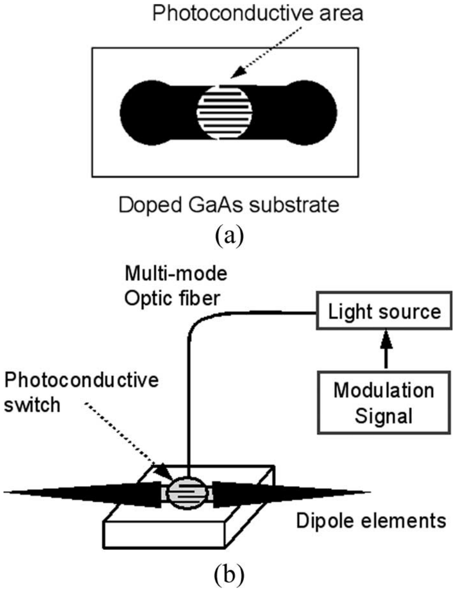

Fig. 1. (a) Circular-interdigit structure of photoconductive switch. (b) OMS probe with light source.

II. PROPOSED OMS

The OMS is composed of a small dipole with a photosensitive semiconductor switch at the center, as shown in Fig. 1. The switch is fabricated on a doped GaAs substrate with a newly designed circular-interdigit structure at the central photoconductive area. The circular-interdigit-structured design can effectively decrease the switch impedance when the optical signal is applied on it (the "ON" state). The impedance ratio between the "OFF" state (when the optic signal is off) and the "ON" state is then increased, which increases the dynamic range of the OMS probe. Three 10-, 20-, and 50-mm dipole elements were designed to cover the applicable frequency range from 0.5 to 14 GHz. An amplitude-modulated laser diode is used to provide the power to drive the photoconductive switch through an optical fiber. The impedance of the switch is modulated by the optical signal, and thus, the scattering cross section of the dipole is also modulated.

When the OMS is applied to field measurement, the OMS is placed in the position where the field is to be determined. A portion of the electric field incident upon the OMS is scattered by it. Since the scattering cross section of the OMS is changed by the modulated optical signal, the scattered signal is also modulated at the same rate. By detecting the received signal with a coherent homodyne receiver, the modulated scattering

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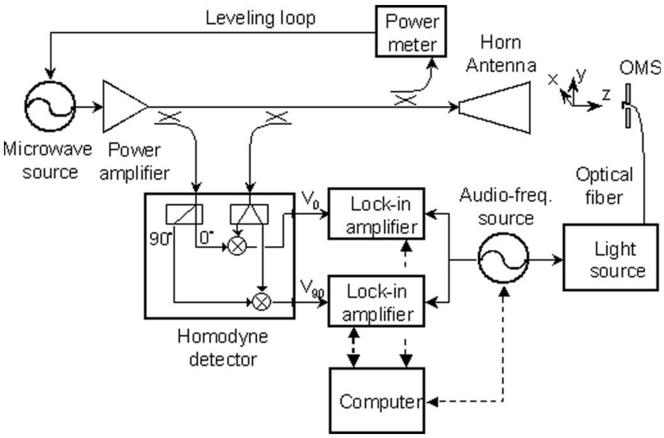


Fig. 2. Monostatic OMS field-measurement system.

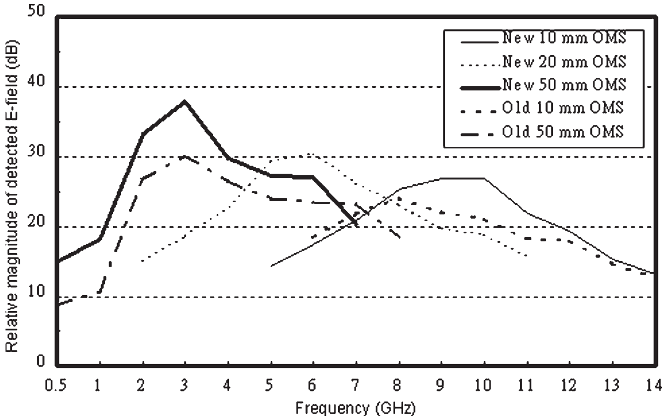


Fig. 3. Frequency response of new and old OMSs.

signal from the OMS can be recovered. All the other non-modulated scattering signals such as signals reflected from the antenna mismatch or from the environmental objects can be filtered out. The magnitude and phase information of the field at the location of the probe can be deduced from the modulated scattering signal.

III. CHARACTERIZATION OF THE PROPOSED OMS

At the National Physical Laboratory, the frequency response and sensitivity of the newly designed OMS was compared with the previous OMS [2] in a monostatic OMS system, as shown in Fig. 2. A horn antenna functions as the transmitting and receiving antenna. The OMS is mounted on a balsawood support at a distance of 30 cm in front of the horn antenna. A 10-kHz modulated optical signal is fed onto the photoconductive switch and modulates the OMS. The magnitude of the received scattered modulated signal indicates the detection capability and, thus, the sensitivity of the OMS. Fig. 3 shows the measurement results. Comparison between the newly designed OMS and the previous one shows that an improvement in sensitivity of about 6 to 8 dB is obtained at the resonant frequencies of 3 and 10 GHz for 50-mm OMS and 10-mm OMS, respectively.

Other measurement carried out was a scanning at a distance of 55 cm in front of the horn antenna by the 10-mm OMS probe, to observe the radiation-field pattern of this horn.

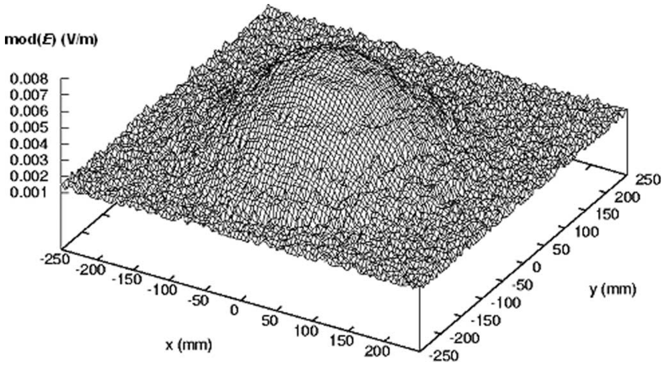


Fig. 4. Magnitude of electric-field distribution on the x–y plane measured with the old 10-mm OMS.

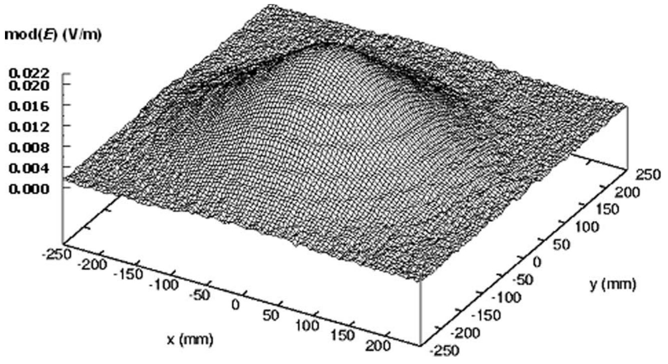


Fig. 5. Magnitude of electric-field distribution on the x–y plane measured with the new 10-mm OMS.

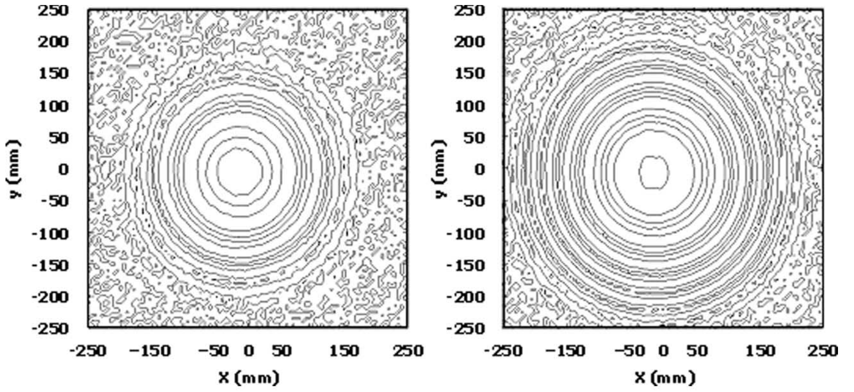
Figs. 4–6 show the magnitude and phase of the measured field distribution at 10 GHz. The measurements with the new OMS show higher resolution in both magnitude and phase due to the improvement in sensitivity of this OMS.

IV. APPLICATION TO SAR MEASUREMENTS

Here, the proposed OMS is applied to a field mapping system [4], which is used for SAR measurement in brain-simulation liquid. The system block diagram is shown in Fig. 7. Scanning measurements of the radiated-field distribution of a mobile phone was performed with the new 10-mm OMS in a cubic phantom.

The OMS was combined with a receiving dipole antenna in parallel at a distance of 20 mm. During the test, the combined OMS–Rx probe was put into a 20 × 20 × 20 cm cubic phantom filled with liquid of relative complex dielectric constant of $\varepsilon_r = 38.3 - j20.4$. A computer-controlled positioning system was used to control the location of the probe. The mobile phone under test was attached to the bottom surface of the phantom. It was controlled with an appropriate test SIM card to operate in the continuous-wave (CW) emission mode during the measurement. The OMS–Rx probe was made to scan at different heights above the bottom of the phantom. An area of 15 by 10 cm was scanned in 5-mm steps. Fig. 8 shows the position of the mobile phone and the scanning area.

The 650-nm CW optical-signal-controlling OMS is modulated by a 500-kHz square-wave signal. The modulated signal is fed to the OMS by an optic fiber. When the mobile phone



(a) (b)

Fig. 6. Phase of electric-field distribution on the x–y plane measured with the (a) old 10-mm OMS, and (b) new 10-mm OMS, respectively.

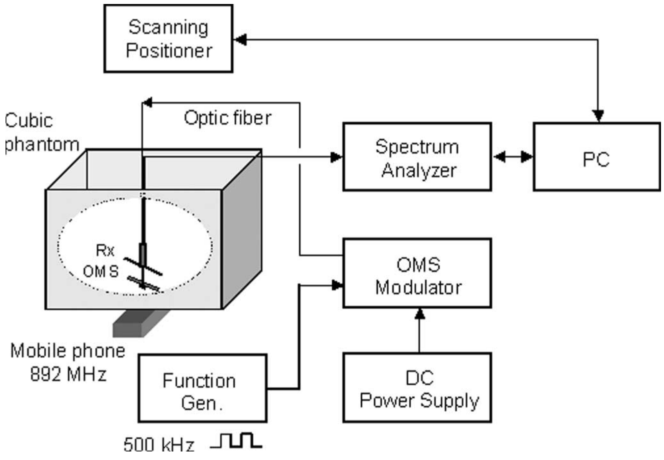


Fig. 7. Configuration of the OMS field mapping system.

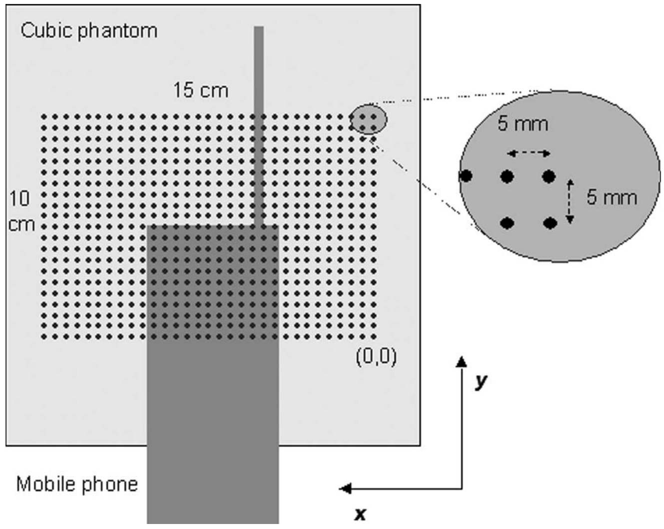


Fig. 8. Position of the mobile phone and scanning area.

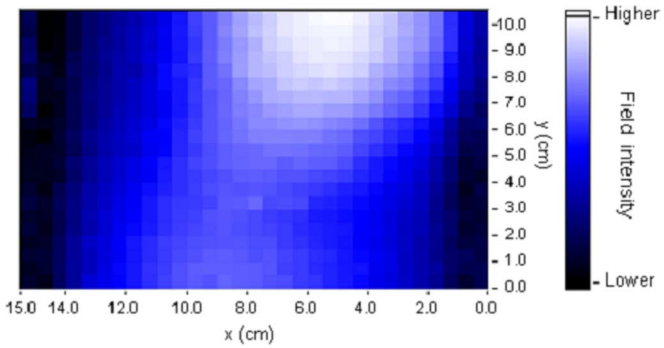


Fig. 9. E_y field distribution in the phantom measured with the OMS–Rx probe parallel to the mobile antenna (OMS–Rx probe in y-direction). E_y field radiates mainly from the mobile antenna.

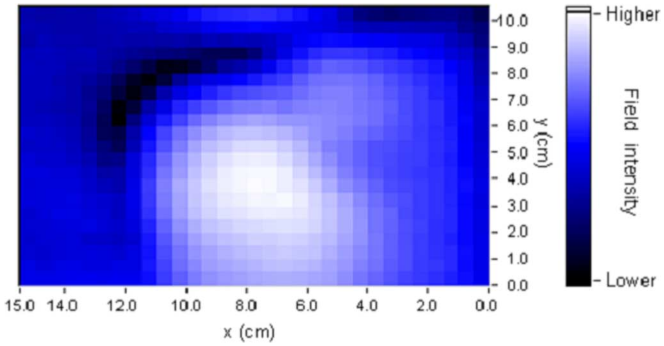


Fig. 10. E_x field distribution in the phantom measured with the OMS–Rx probe perpendicular to the mobile antenna (OMS-Rx probe in x-direction). E_x field radiates mainly from the body of the mobile phone rather than from the antenna.

transmits a CW signal at 892 MHz, part of the signal is scattered by the OMS. The receiving dipole behind the OMS would then receive an 892-MHz signal together with the modulated scattering signals at the frequencies of 892 ± 0.5 MHz. The magnitude of the modulated scattering signal reflects the magnitude of the 892-MHz signal at the location of the OMS. By scanning the area of interest, the field distribution of the 892-MHz signal can then be determined.

Figs. 9–11 show the field distribution in the phantom measured with the probe at the height of 4 mm above the bottom. From measurements obtained with the probe parallel to the mobile-phone antenna, the y-component of the radiated field E_y can be observed. Fig. 9 shows significant radiated field in the area above the phone antenna. When the probe is scanning cross polarized with respect to the mobile-phone antenna, the x-component of the radiated field E_x can be observed, as shown in Fig. 10. It is radiated mainly from the body of the mobile phone rather than from the antenna. The maximum value

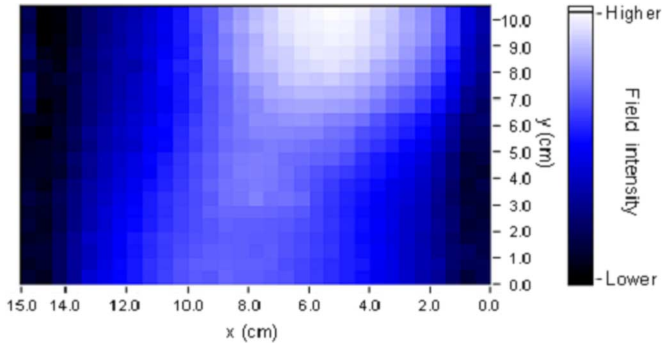


Fig. 11. Tangential field distribution in the phantom (the root-sum-of-squares of E_x and E_y fields), which indicates that most of the field is radiated from the mobile antenna.

of the measured E_x is smaller than that of E_y in about 7 dB. Fig. 11 shows the tangential field distribution (the root-sum-of-squares of E_x and E_y components), which indicates that most of the field is radiated from the mobile antenna. The 3-D field distribution can be obtained by scanning with the probe at different heights.

V. CONCLUSION

The newly designed OMS increases the resolution of the measured field level and makes the detection of slightly varying fields be possible. Measurement results show significant improvement in resolution of radiated-field pattern of a horn antenna compared with the previous OMS device. The present OMS can be applied to electromagnetic-field-measurement systems for antenna-pattern measurement, electromagnetic-compatibility field-uniformity mapping, or microwave-image reconstruction with minimum disturbance to the field.

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Richard P. Thompson, photograph and biography not available at the time of publication.

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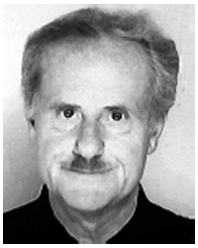

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Dr. Bolomey is the recipient of the Blondel Medal of the "Société des Electriciens et des Electroniciens" (SEE) in 1976, le Général Ferrié Award of the Academy of Sciences in 1984, and, with his research group, the Microwave Award of the European Microwave Conference in Nüremberg, in 1983. In 1994, he is the recipient of the Schlumberger Stitching Fund Award, in acknowledgment for his contribution to inverse-diffraction techniques in microwave imagery. From 1977 to 1982, he was the Chairman of the Group 25 (Waves and Signals) of the SEE and he received the "Grade Emérite" of this society in 1995. Between 1978 and 1984, he was the French delegate to the Commission B of the International Radio Scientific Union. He is Chairman of the "Club Rayonnement d'Electricité de France," and since 1994, a member of the Permanent Committee on high-power electromagnetism.

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