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Optical system for electromagnetic field measurement using modulated scattering technique

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In the paper, an optical system used in radio frequency (RF) electromagnetic field measurements is described. A new design of an optically powered and controlled modulated scatterer driven by a plastic optical fibre (POF) applied in modulated scatterer technique (MST) is presented.

Keywords: electromagnetic field measurement, optically modulated scatterer.

1. Introduction

Modulated scatterer technique (MST) is a very promising method of electromagnetic field testing [1]–[3]. Invented in the 1950s [4] this sophisticated method of electromagnetic radio-frequency field measurement is now more commonly used than in the past due to the current technological progress, which allows exploiting its advantages.

Weak influence on the distribution of the field under test is one of the most important features of MST. This is achieved thanks to the small size of the scatterer, which can be significantly smaller than that of an ordinary detecting probe [5]. This feature allows applying an array of probes (scatterers) with negligible mutual interaction. A precondition for using this advantage of the MST is lack of any resistive connection between the scatterers and the rest of the measuring setup. The application of an array of fixed scattering probes instead of a single mechanically scanned detection probe can cause a significant labour reduction in measurement of an electromagnetic RF field distribution. This is of concern in both, far- and near-field examination.

A broad area of use of the MST includes its employment for the field calibration in immunity testing according to IEC-61000-4-3 standard [2], [3], [5], [6].

1.1. MST principle

RF field measurement can be performed by direct measurement of the field at a point of interest or by measurement of the field scattered by a dedicated scatterer. In the second case, a scattering probe is placed at a point of interest and substitutes a classical detecting probe.

The principle of MST is based on extraction from the reflected signals received by the antenna the one caused by the scatterer placed at the point of interest. The voltage due to the presence of scatterer is proportional to square of the magnitude of the field at the position of the scatterer [1]. As the signal coming from the scatterer is by many orders smaller than other reflected signals, its detection is possible by using a homodyne method of detection.

There are two basic schemes of measurement of scattered fields – bistatic and monostatic. Both of them are illustrated in Fig. 1. In the first case, two measurement

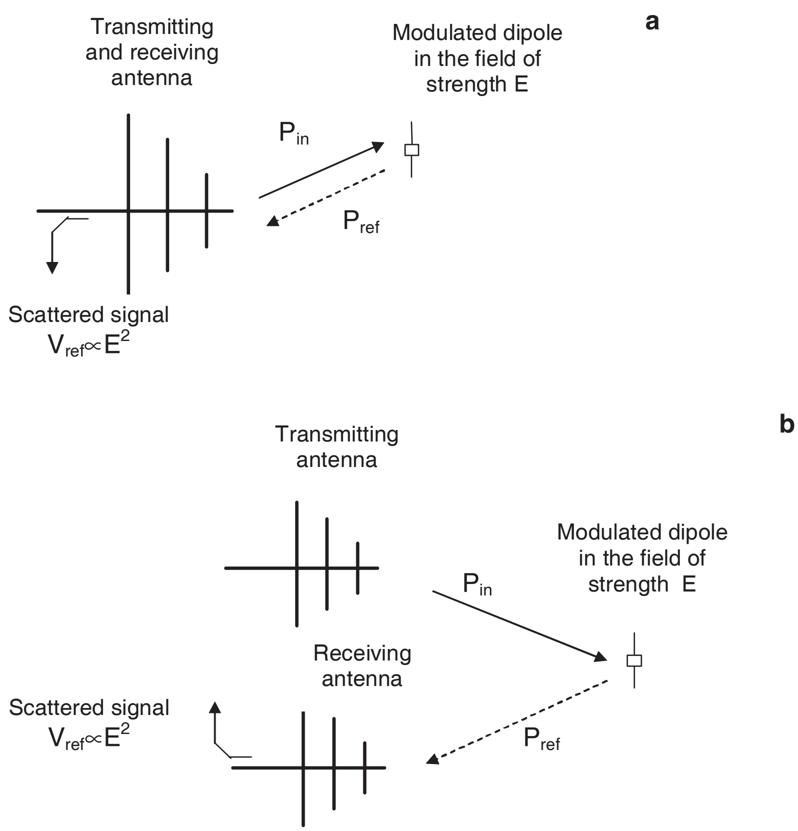

Fig. 1. Monostatic (**a**) and bistatic (**b**) configurations of the MST.

antennas (transmitting and receiving) are employed. In the second one the same antenna is both a transmitting and a receiving antenna.

2. Scatterer

In a MST measuring system either a dipole or a loop antenna can be used to measure the electric or magnetic field, respectively. So far, it is the short dipole antenna that is most often used. Modulation of the scatterer parameters usually consists in modulating its load. This load modulation should effectively cause modulation of the scattered fields. Its effectiveness depends on the scattering properties of the antenna. These properties can be analysed at the basis of a minimum scattering antenna approach [7]–[9].

A load switching between low impedance and high impedance is the simplest and the most effective method of scatterer modulation. In this case, the influence of any nonlinearity in electronic part of the system (from the modulating generator to the scatterer) is significantly limited.

In a MST setup, different types of switches can be used [1]. The most popular are diode switches (preferably Schottky diode) or diodes in bridge configuration that can ensure their better symmetry. In the case of optical modulation, a phototransistor can be used [10] with a strong modulating frequency limit (1 kHz). In both cases, relatively high power has to be delivered to the switch. The power can be delivered by a resistive connection between the scatterer and the rest of the testing set. Another solution, *i.e.*, the use of an autonomous battery features the disadvantage resulting from its significant size compared to the size of a classical detecting probe and its limited capacity.

As mentioned above, a full advantage of MST can be taken when there is no metallic connection between the scatterer and the rest of the setup and the scatterer is not powered by autonomous battery. The obvious solution of the problem is to make use of a fibre optic link to control the switch and to avoid the necessity of using any battery.

In paper [10], a "photoconductive switch" is suggested which can be modulated with the frequency 10 kHz or more, offering a high dynamic range. Unfortunately, this kind of element is not commercially available.

Taking the above into account, the authors put forward their own solution based on a MESFET switch. In the case of MESFET, thanks to a very small power demand, powering and controlling can be easily employed by means of a p-i-n photovoltaic cell set. When the switch is driven with the full amplitude, there is no necessity to separate polarisation and control signal. The same signal powers and controls the switch.

2.1. MESFET as a switch

The authors propose the use of a MESFET switch as the modulating switch of the scatterer. In this case, a very low impedance of the switch and symmetrical characteristics can be obtained (see Fig. 2). The switch demands a very low

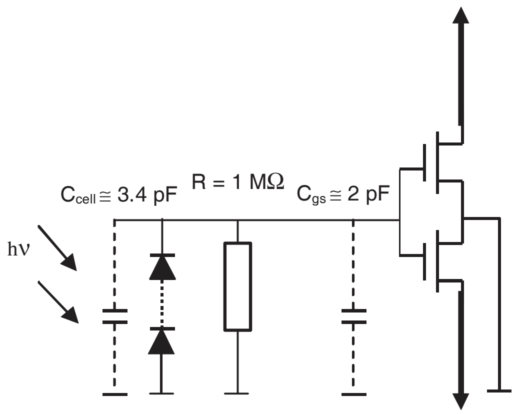

Fig. 2. Schematic diagram of a single (one dimensional) scatterer.

(incomparable with other solutions of scatterers) power to switch it on and off. A fibre with the use of a p-i-n photovoltaic cell can easily supply the necessary power. The voltage induced on the cell powers and controls the switch at the same time.

A MESFET as a switch can be used without drain-source DC polarisation. Its channel is switched on and off by adequate gate-source polarisation. The gate leakage current is very small.

The switch-on impedance is very small. In practice the resistance of a few ohms can be reached easily. The off-impedance is of the order of a few hundreds kΩ and bigger. Therefore, the modulation of short dipole parameters can be very effective. The impedance of the switch shows quite good symmetry. Moreover, the MESFET switch can switch effectively signals up to several GHz.

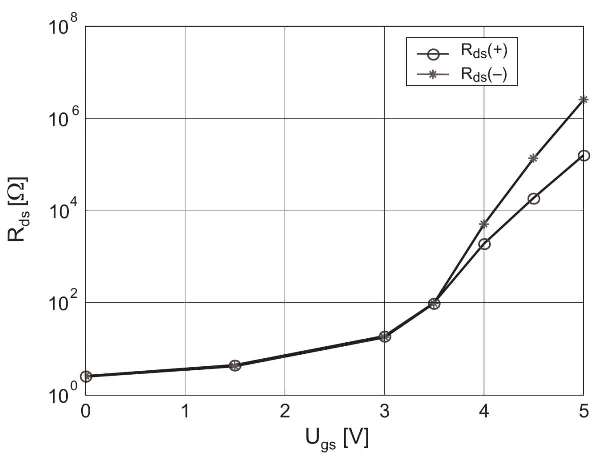

Fig. 3. Resistance of the MESFET switch *vs.* gate voltage for both drain-source polarisations.

Concluding, the MESFET switch seems to be an ideal solution in the case of a very low supply and control power capacity. A very high input resistance of the gate causes that the input is capacitive in the (practically) whole frequency range. This capacitance has to be considered when the transistor is AC driven. When the gate is driven by a current source the influence of the capacitance is very important. When necessary, the additional resistance discharging the capacitance should be connected across the input to achieve discharging time short enough (Fig. 2).

A chosen switch is a double symmetrical switch primarily designed for antenna switching in transmitting/receiving devices. The switch can switch signals up to 2 GHz. The drain is not DC polarised. The switch-on bias voltage is 0 V and switch-off is –5 V. The switch control is practically non-current. The static impedance of any switch transistor *vs*. gate-source voltage is shown in Fig. 3. As we can see, possible influence of switch asymmetry on the signals is smaller when the gate is driven with the full amplitude (from –5 to 0 V). The switch-on impedance of the switch is as small as about 4 Ω. The gate capacitance of 3.4 pF has forced the use of a discharging resistor of 1 MΩ to achieve the switching frequency limit higher than 10 kHz.

The above described features of the chosen switch allows using a p-i-n photovoltaic cell set as a source of power supply and control signals.

2.2. Light powering and controlling of the switch

2.2.1. Photovoltaic cell

The total voltage across the cell set terminals should be at least 5 V. The current capacity should exceed 5 μA. The total cell set area should be equal to or smaller than a circle with a 1 mm diameter (the diameter of the core of a plastic fibre). The optical power needed to obtain the required voltage/current parameters should not exceed 2 mW (the wavelength – red light, 630–670 nm). As there has been no adequate photovoltaic cell commercially available, the authors have decided to design their own cell matching their needs.

A p-i-n GaAs photovoltaic cell has been chosen. The voltage across one cell has been estimated at about 0.75 V.

2.2.2. Device fabrication

The battery was made as a series connection of planar p-i -n-based photovoltaic cells. The top view of this device is presented in Fig. 4. The diameter of the active area was set to 0.7 mm to match the plastic optical fibre.

Fabrication of this device was based on a typical GaAs technology used in our Semiconductor Device Laboratory (Wrocław University of Technology, Poland). The schematic cross-section of a single cell based on p-i-n GaAs structure is shown in Fig. 5. The growth of p-i-n structures was performed in atmospheric pressure MOCVD system equipped with AIX-200 R&D horizontal reactor made by AIXTRON. Trimethylgallium (TMGa), trimethylindium (TMIn), and arsine (AsH_3) were used as sources for GaAs or InGaAs epitaxial layers grown on semi-insulated (100) GaAs

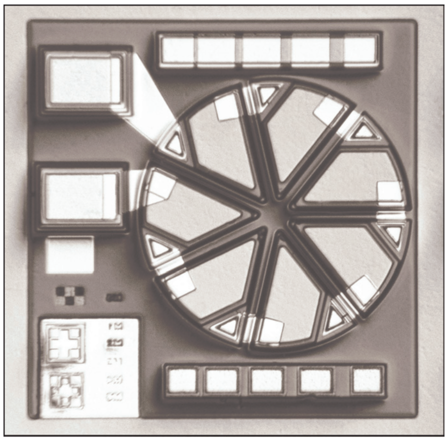

Fig. 4. Top view of a planar photovoltaic battery.

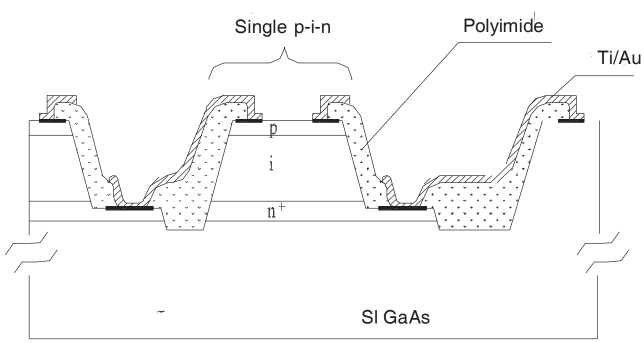

Fig. 5. Schematic cross-section of a single p-i-n photovoltaic cell.

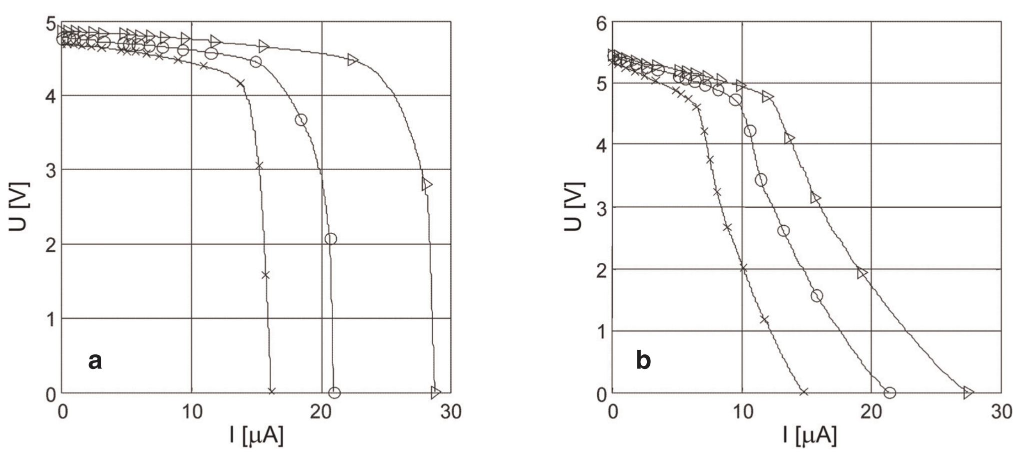

Fig. 6. Voltage-current curves for InGaAs (**a**) and GaAs (**b**) photovoltaic cells for 2 mW (–×–), 3 mW (–○–) and 4 mW (–▷–) of optical power at the end of POF fibre illuminating the cell.

substrate. Two types of absorption layers were used: i-GaAs (undoped) layer which allowed achieving the high open circuit voltage and i-InGaAs (undoped) layer which allowed the maximum absorption to be moved towards the longer wavelengths. The Si and Zn were used as dopants for n- and p-type GaAs, respectively. AuGe/Ni/Au metallization for n-type ohmic contact, Ti/Ni/Au metallization for p-type ohmic contact and Ti/Au as interconnection metalization were electron beam evaporated and patterned using "lift-off" photolithography. The n-type and p-type ohmic contacts were formed by thermal annealing at 450 °C and 350 °C, respectively, in a nitrogen atmosphere. The seven p-i-n cells have been separated by mesa wet etching technology. The surface was passivated by a polyimide layer, which allowed also connecting p-type and n-type contacts in series. The separated chips were mounted on TO18 package using ultrasonic bonding.

Voltage-current characteristics for both types of photovoltaic cells, with GaAs and InGaAs absorption layer, are shown in Fig. 6. The open circuit voltage is 4.6 V for the InGaAs-based photovoltaic cell and 5.3 V for GaAs-based one. The shape of the curve for the GaAs cell indicates the current leakage. Because of the higher open circuit voltage obtained from this device the GaAs array was chosen for application, despite the leakage. It fulfils the requirements of the MESFET switch supply.

3. Optical system

As the optical signal was to be carried on over a small distance – up to 10 m – the authors decided to use a plastic optical fibre (POF). The use of such a fibre results in a possibility of a very simple solution of an optical interface. A typical plastic fibre diameter is 1 mm. Thanks to the big diameter of the plastic fibre the interface can be constructed without any additional optical elements, by direct illumination of a photovoltaic cell set surface by a bare fibre (Fig. 7). The chip case is fixed in a small plastic tube. Then a bare grinded fibre end is adjusted in the tube against the cell dice for obtaining a maximum voltage across the battery terminals. Then the fibre

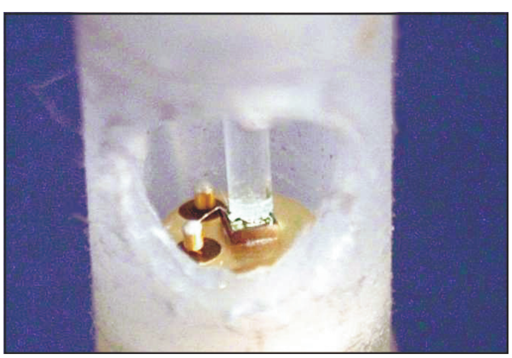

Fig. 7. Photovoltaic cell coupled to POF.

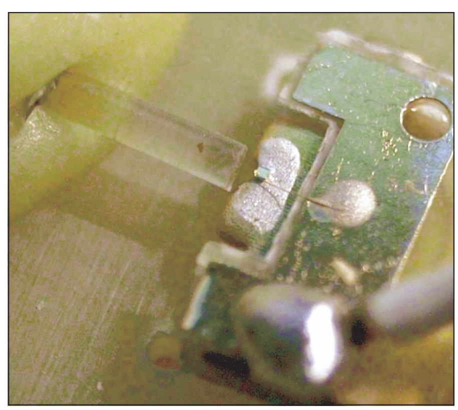

Fig. 8. Semiconductor laser coupled to POF.

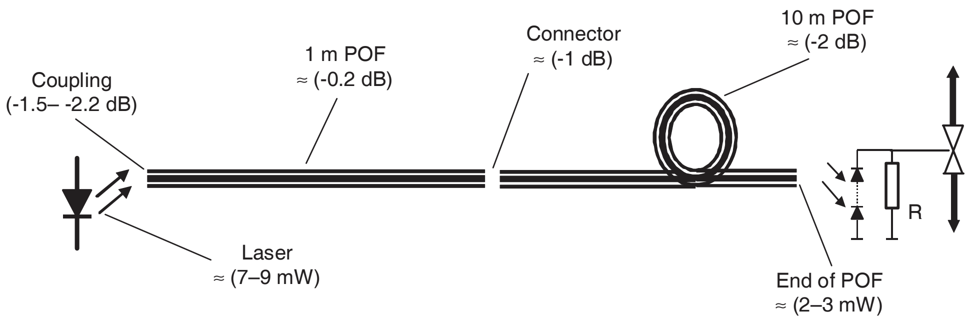

Fig. 9. Power budget of the optical system.

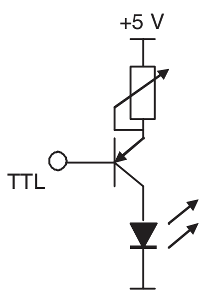

Fig. 10. Laser driver.

10 m long is bonded. The distance between the dice and the fibre end is fixed to ca. 0.3–0.4 mm.

A cheap semiconductor laser designated for a laser pointer was used as the light source. A direct coupling of the fibre to the laser, similar to the one described above, has been employed (Fig. 8). The length of the fibre coupled to the laser is ca. 1 m. This fibre and the 10 m long fibre ended with the battery can be joined together with a detachable connector.

The total power budget of the system is shown in Fig. 9. As can be seen, the power of the laser of 7 to 9 mW is sufficient to reach about 2–3 mW at the end of the fibre coupled to the battery. It allows fulfilling the power demands of the MESFET switch. The laser itself is driven by means of a transistor switch (Fig. 10). A variable resistance, which can be observed in the figure, allows adjusting the laser power.

3.1. Construction of the scatterer

According to the above description an optically modulated scatterer shown in Fig. 11 has been designed. The length of the dipole is 120 mm. The same model of the scatterer has been used to build a new three-axis scatterer (Fig. 12) proposed by the authors. The new scatterer enables a measurement of the total value of a field and each of x, y

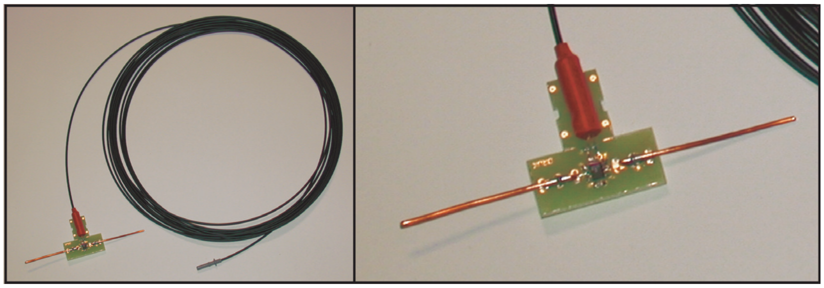

Fig. 11. One-dimensional scattering probe.

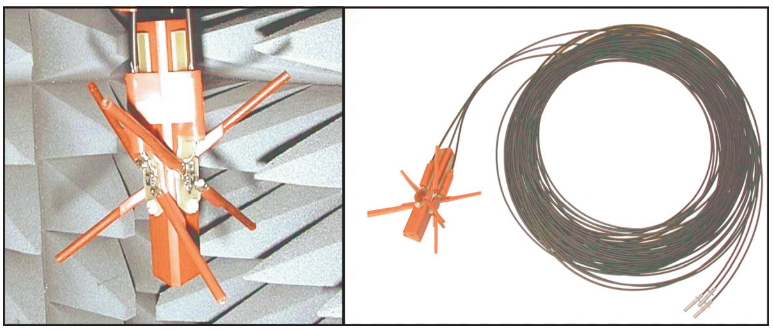

Fig. 12. Three-axis scatterer.

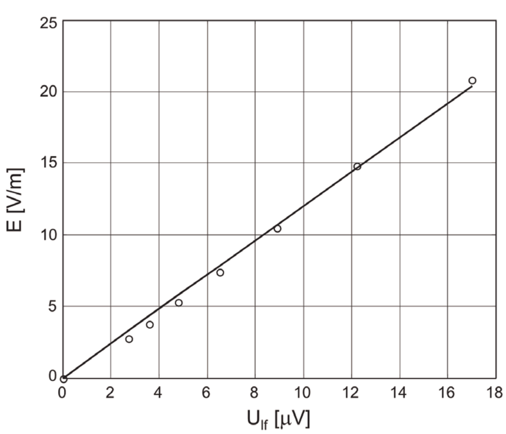

Fig. 13. Calibration curve of the probe designed; approximation follows the equation $E = 0.612\sqrt{U_{1f}}$ (where: E – field strength [V/m], U_{1f} – low frequency voltage [mV]).

and z components as well. The calibration curve obtained in the monostatic configuration of the MST system is shown in Fig. 13.

3.2. Optical driver

To make use of the above scatterers arranged into an array, for the field calibration according to IEC-61000-4-3, a special driver has been designed (Fig. 14). It consists of 48 lasers (16 three-dimensional scatterers). Each of 16 three-dimensional scatterers

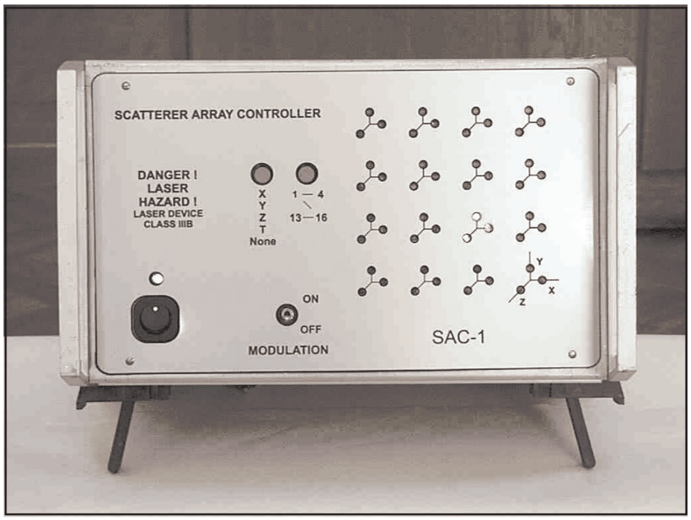

Fig. 14. Optical laser driver used in the field measurement with an array of 16 three-axis scatterers.

and each of *x*, *y*, and *z* dipoles of every probe can be controlled separately. This allows measuring all components and total value of the electromagnetic field. The driver can be controlled manually or automatically using the RS232 interface.

4. Conclusions

In the paper, an optically powered and controlled modulated scatterer used in electromagnetic field measurements by MST has been presented. An extremely low power consumption of a MESFET switch used as a scatterer modulator allows using an optically driven photovoltaic cell set as a source of power.

A plastic optical fibre has turned out to be cost effective and simple to employ. A coupling of a fibre to a laser source, and to a photovoltaic cell is very effective and no additional optics or expensive tools are required.

The optical system presented allows controlling an array of 16 three-dimensional isotropic scatterers (*e.g.*, intended for electromagnetic field calibration according to IEC-1000-4-3). Presented in the paper an optically driven array of scatterers guarantees field distortion significantly smaller than that observed in the case of a classical detecting probe. The use of an array of probes instead of mechanically scanned single sensor allows the time of measurements to be significantly reduced [6].

The idea of an optical system using a cheap laser source, a plastic fibre and a photovoltaic cell can have wide application for powering and controlling low power consuming electronic systems.

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