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Measurement of the electric field intensity in the near-field region with proposed electromagnetic field probe

Abstract. This paper deals with a measurement of the electric field intensity in the near field region with proposed autonomous electromagnetic (EM) field probe. This probe is specially designed to measure in the near distance from the sources of the EM field. The output from the probe is a voltage corresponding to the measured component of the electric field intensity. At the end we compared results from measurement of the components of the electric field intensity with the results from simulation based on the numerical method.

Streszczenie. Artykuł dotyczy pomiaru natężenia pola elektrycznego w strefie bliskiej za pomocą zaproponowanej autonomicznej sondy pola elektromagnetycznego (EM). Sonda ta została zaprojektowana specjalnie do pomiaru w strefie bliskiej źródła pola EM. Na wyjściu sondy otrzymuje się napięcie odpowiadające mierzonemu komponentowi natężenia pola elektrycznego. W artykule porównano rezultaty pomiarów komponentów natężenia pola elektrycznego z wynikami symulacji prowadzonych z wykorzystaniem metod numerycznych. (Pomiar natężenia pola elektrycznego w strefie bliskiej za pomocą proponowanej sondy pola elektrycznego).

Keywords: vector, sensor, electromagnetic field probe, near-field region, electric field intensity, numerical method
Słowa kluczowe: wektor, sensor, sonda pola elektrycznego, strefa bliska, natężenie pola elektrycznego, metoda numeryczna.

Introduction

A. Electromagnetic field

The EM field consists of an electric field and magnetic field. We focused on the electric field, strictly speaking measurement of electric field intensity. The electric field intensity consists of three vector components. These vector components are Ex, Ey and Ez in the Cartesian coordinate system. Because the electric field intensity is a vector we need to measure individual elements of these vectors. A value element of the vector depends on the distance from the source of EM field. Based on the distance from source of EM field we can subdivide the EM field into the several regions: far-field (Fraunhofer) region and near-field region [1]. Our paper deals with measuring electric fields intensity in the near-field region. This region can be divided into two parts: reactive and radiating near-field region [1]. In the immediate vicinity of the source of the EM field there is the reactive near-field region. In this region, the fields are a predominately reactive field, which means the phases of electric field intensity and magnetic field intensity are mutually shifted by 90 degrees (recall that for propagating or radiating fields, the fields are orthogonal (perpendicular) but are in phase). The boundary of this region is commonly given as [1]:

$$(1) \qquad r < 0.62\sqrt{D^3/\lambda}$$

where: r – distance from source of EM field; D – maximum linear dimension of the EM field radiator; λ – wavelength
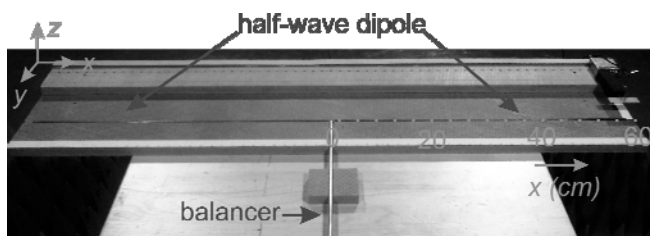

Fig. 1.   Fixture with half-wave dipole

The radiating near-field region is the region between the near and far field. In this region, the reactive fields are not dominated; the radiating fields begin to emerge. However, unlike the Far-Field region, here the shape of the radiation pattern may vary appreciably with distance. The region is usually defined by following formula [1]:

$$(2) \qquad 0.62\sqrt{D^3/\lambda} < r < 2D^2/\lambda$$

The source of EM field is half-wave dipole, length of the dipole is D = 1.2 m. Proposed half-wave dipole resonates near the frequency 125 MHz. This half-wave dipole is inserted into the fixture which is created from extruded polystyrene. Relative permittivity of extruded polystyrene is almost same as relative permittivity of air, εr = 1.03. In Fig. 1 we can see fixture with half-wave dipole.

Power supply of half-wave dipole is symmetrical therefore there were coaxial cable to half-wave dipole feeder through balancer connected. As a balancer the tubular folded dipole was used.

B. Autonomous EM field probe

Vector components of the electric field were measured with our proposed EM field probe. The probe is intended for measurement mainly in the range of EMC standard EN610000-4-3:2006. This EM field probe is designed to be used in the near-field region. Main parts of the probe are: electric small sensor(s), control electronics, power supply and optical input into the PC, Fig. 2.
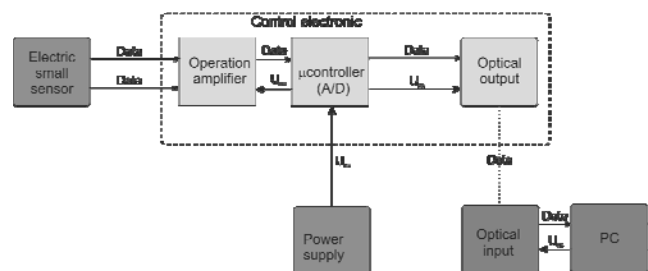

Fig. 2.   Autonomous EM field probe –block diagram

Electric small sensor(s) converts the measured vector components of the electric field intensity to inducted voltage on the it's terminals. This sensor consists of electric short dipole, Schottky detector diode and electronic components, see Fig. 3. The length of electric short dipole is 0.06 m. Schottky detector diode is placed on the terminals of the dipole; signal is rectified and devoid of HF noise. The

electronic components as a resistors and capacitor can remove LF noise. Signal from electric small sensor is transferred to the differential operational amplifier (OA). The OA amplifies the difference in voltage between its inputs. The output from OA is transferred to the microcontroller. It is used to digital conversion. Digital output is sent to the PC through the optical cable. The EM field probe is autonomous in terms of the power supply. Power supply is designed as a device taking (sucking) energy from measured EM field. The power supply device consists of dipole, Cockcroft-Walton multiplier and DC/DC converter [4]. Output from the power supply device is 3.3 V. Distance between EM field probe and the antenna input of power supply must be more than 10 cm [4]. Measured EM field is affected by the power supply for lower distance as 10 cm.
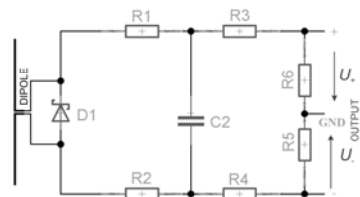

Fig. 3.   Electric small sensor – scheme

C. The enviroment in which we measure

If we want to compare the results from measurement with results from numerical model we need adjust environment. The have to be just one source of the EM field in the environment. We need suppress others source of the EM field therefore we performed the measurements in the semi-anechoic chamber. In **Błąd! Nie można odnaleźć źródła odwołania.** there is shown semi-anechoic chamber with a high-frequency absorbers on the floor. These absorbers prevent signal reflection of the floor. This chamber is used for different measurements not only EMC radiation [2] and [3].After removing the surrounding disturbances we can measure vector components of the electric field intensity.
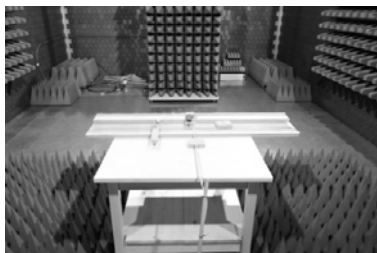

Fig. 4.   Semi-anechoic chamber and fixture with half-wave dipole

Measurement electric field intensity

Autonomous EM field probe measures vector components of the electric field intensity in the reactive near-field region. Distance between probe and source of the EM field (half-wave dipole) has to be less than 0.223 m (1). The EM field probe can measure 3 vector components of the electric field intensity Ex Ey and Ez. Correct positioning of electric small sensor is necessary for every vector components of the electric field intensity, Fig. 5.
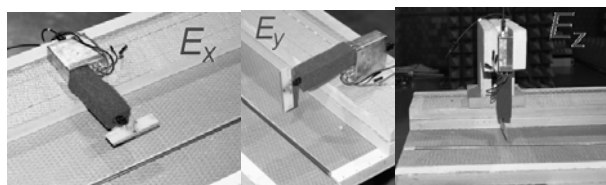

Fig. 5.   Measurement vector components of electric field intensity

The EM field probe was placed into the different position against the half-wave dipole. The position of probe was moved in x, y and z axis direction, **Błąd! Nie można odnaleźć źródła odwołania.**. Position probe center is marked as [x; y; z] cm. Position of probe in y and z axis was changed only once. We changed only position in x axis, **Błąd! Nie można odnaleźć źródła odwołania.**. The x axis was moved in direction from the middle of the half-wave dipole to the end of the half-wave dipole. The electric field intensity was measured only for one half of the half-wave dipole because half-wave dipole is symmetric. Half-wave dipole feed had frequency 125 MHz and input voltage 105.27 dB $_V$.

Output voltage from probe based on the vector component of the electric field intensity E_x is shown in 0 (red line). Output from the measurement with EM field probe is marked as U_{Xm} what represents the DC voltage. The distance between the EM field probe and source of EM field (half-wave dipole) had distance set to [x; 1; 3] cm. Position in x axis was changed from the middle of the half-wave dipole (0 cm) to end of the half-wave dipole (60 cm). In 0 we can see dependence of the output voltage from probe on the position of x axis. Output voltage of probe has highest amplitudes in the middle of the half-wave dipole and at the end of the half-wave dipole.
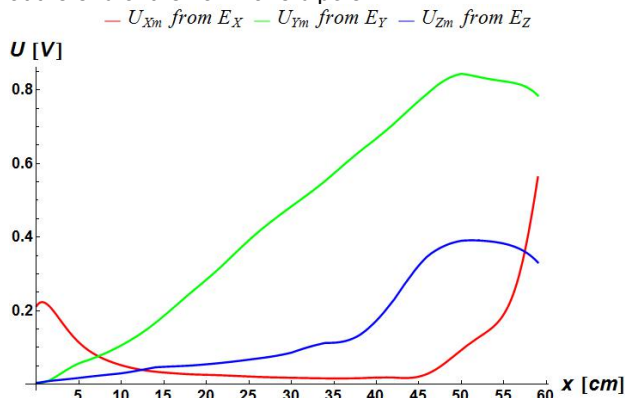

Fig. 6.   Dependence of the output voltage of probe on the position x axis, measurement

Vector component of the electric field intensity E_y is illustrated in 0 (green line). Output from the measurement with EM field probe is marked as U_{Ym} what represents the DC voltage. The distance between the EM field probe and source of EM field (half-wave dipole) had distance set to [x; 1; 4] cm. Position in x axis was changed ditto. Amplitude of probe voltage U_{Ym} was varied otherwise as during measurement of E_x. Output voltage of the probe was raising towards the end of the half-wave dipole. Output voltage started slowly and went down at the end of the half-wave dipole. This was caused because the current distribution is biggest in the middle of the half-wave dipole. Output voltage of the probe U_{Ym} had highest amplitude in the position on the x axis, x = 50 cm, 0.

Measured vector component of the electric field intensity E_z is in 0 (blue line). Output from the measurement with EM field probe is marked as U_{Zm} what represents the DC voltage. The distance between the EM field probe and source of EM field (half-wave dipole) had distance set to [x; 2; 1] cm. Position in x axis was changed from middle of the half-wave dipole (0 cm) to the end of the half-wave dipole (60 cm). The amplitude of probe voltage U_{Zm} was changed otherwise as during measurement of E_y. Output voltage of the probe was rising more slowly as voltage U_{Ym}. Output

voltage of probe U_{Zm} had highest amplitude in the position on the x axis x = 50 cm, 0.

Comparing the amplitude of the output voltages U_{Xm}, U_{Ym} and U_{Zm} we can notice that the highest amplitude is reached in case of the vector component $\boldsymbol{E}_y$. Output voltages are measured in the different position of the probe [x; y; z] cm. This is due the fact that we have not proposed fixture so that we can center of the probe EM field for measurement of all vector components of the electric field intensity. Therefore, we could not measure vector component of the electric field intensity in one place.

Numerical model

The results from measurement of the electric field intensity together with the results from numerical model were compared. Numerical model was created in simulation software called FEKO. Vector components of the electric field intensity were simulated in the same position as measured.

Dipole representing the EM field probe had length 0.06 m and impedance 150 kΩ. This is real impedance of the proposed EM field sensor. The vector components of the electric field intensity were simulated in the same place as it was measured. Source of the EM field was half-wave dipole with length 1.2 m. Frequency of the half-wave dipole feed was 125 MHz and amplitude was 105.27 dB V. Position in x axis was changed from middle of the half-wave dipole (0 cm) to the end of the half-wave dipole (60 cm).

The results obtained from numerical model of the vector component electric field intensity Ex are shown in Fig. 7 (orange line). As the output from the simulation the output voltage from EM field probe UXs was considered. The position of the simulated probe was the same as the position of probe during the measurement [x; 1; 3] cm. In Fig. 6 and Fig. 7 can see that waveform UXs is almost same as a waveform UXm. Output from simulation Ex had highest amplitudes in the middle of the half-wave dipole and at the end of the half-wave dipole.
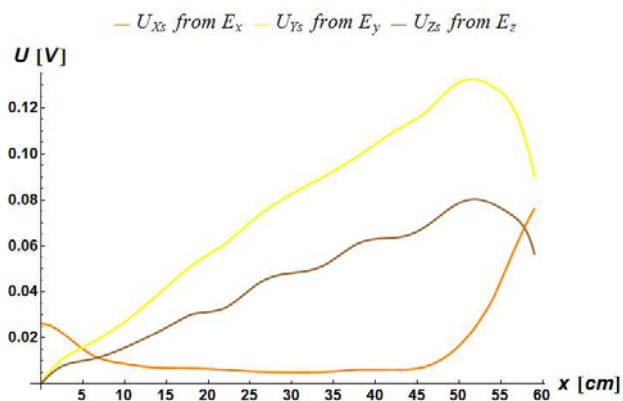

Fig. 7.   Dependence of the output voltage of probe on the position x axis, numerical model

Simulated vector component Ey is in Fig. 7 (yellow line). Output from simulation was voltage UYs. Simulated probe was placed in position [x; 1; 4] cm. The axis x was changed from the middle of the half-wave dipole to the end of the half-wave dipole. Waveform UYs is almost same as a waveform UYm. Output voltage of probe from simulation had highest amplitudes in the position on the x axis x = 50 cm.

Simulated vector component Ez is in Fig. 7 (brown line). Output from simulation was voltage UZs. Simulated probe was placed in position [x; 2; 1] cm. Comparing the amplitude of the simulated output voltages UXs, UYs and

UZs we can notice that the highest amplitude was reached in case of vector component Ey. We obtained the same results also from measurement.

Now it is necessary to compare the results obtained from the measurements with results obtained from the numerical model.

Results

In this part we will analyze result from numerical model and measurement. In Fig. 6 and Fig. 7 we can see that amplitude of the voltages is not the same. It is due to Schottky diode was placed on the terminals of the dipole. This situation was not simulated in our model. Transfer characteristic used Schottky diode is not linear in all range of diode. Next reason is that output voltage from the probe is amplified. Amplification of operation amplifier is 2.
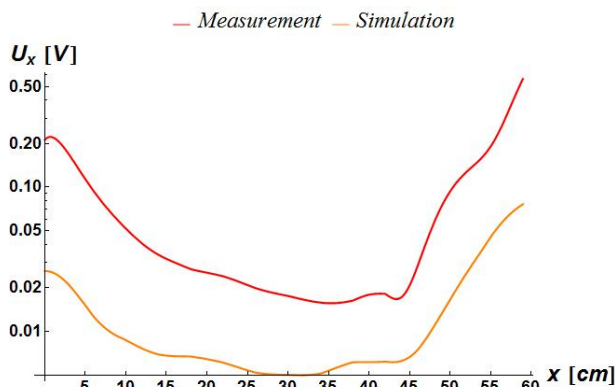

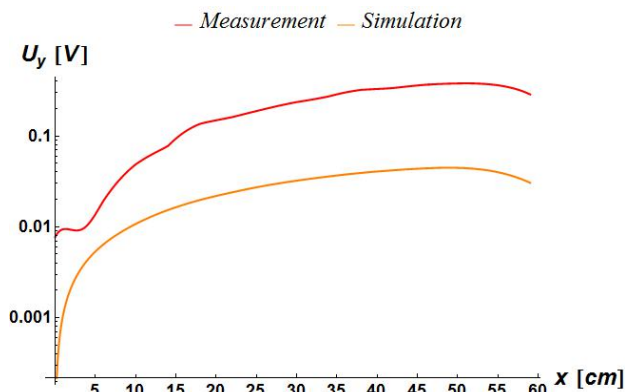Fig. 8.   Compare result from measuremnt and numerical model E_X

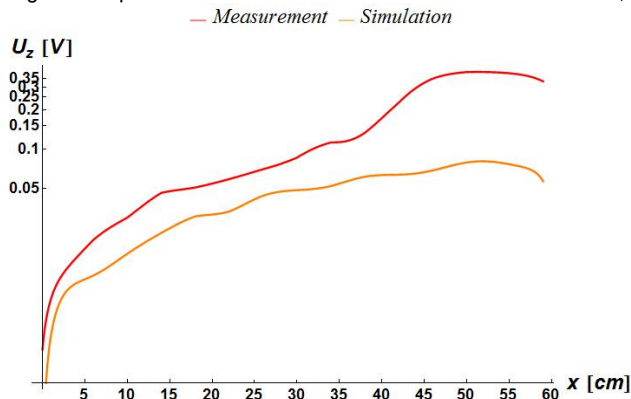Fig. 9. Compare result from measuremnt and numerical model E_Y

Fig. 10. Compare result from measuremnt and numerical model E_Z

Therefore, in case of comparing the results from measurement with result from numerical model we

investigated shape and course of the voltages. In Fig. 8, Fig. 9 and Fig. 10 we compared voltages from measurement to voltages from numerical model. The y axis of the graph was recounted in logarithmic scale for better comparison. Shape and course of the voltages form measurement were similar to the shape and course of voltages from numerical model. Therefore, we can argue that proposed EM field probe and numerical model confirmed the theoretical assumption.

Conclusion

In this article we had dealt with measurement vector components of the electric field intensity. Intensity was measured with proposed autonomous electromagnetic field probe. Probe was in near distance from the source of the EM field. Autonomous EM field probe measured vector components of electric field intensity in the reactive near-field region. The results from measurement were compared with numerical model. Our proposed probe was represented with dipole in numerical model. The Schottky diode and operation amplifier in numerical model were ignored. We compared shape and course of output voltage from probe. Conclusion is that proposed autonomous electromagnetic field probe and numerical model confirmed theoretical assumption.

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