

## **Prototyping of UHF antennas using simulation software**

Filip Polak, Wojciech Sikorski, Krzysztof Siodła

Poznań University of Technology

60–965 Poznań, ul. Piotrowo 3a, e-mail: filip.r.polak@doctorate.put.poznan.pl,  
{Wojciech.Sikorski; Krzysztof.Siodla}@put.poznan.pl

The method of ultra high frequency is being increasingly applied in the power transformer diagnostics. Using the probe (antenna) mounted inside the transformer tank it is possible to detect partial discharges occurring in defects of high-voltage insulation system. Such probes must be designed and optimized on several factors, such as frequency band, directivity, or the geometrical design etc. This paper presents parameters of two types of antennas (discone and microstrip patch) obtained through simulation. Calculations and simulations results will provide basis to construct the prototypes of the antennas, which will eventually find application in the measurement system used for localisation of partial discharges inside power transformers.

**KEYWORDS:** partial discharges, UHF antenna, antenna design, simulations

### **1. Introduction**

Power transformers are usually designed for the service life of approx. 30 years. It is estimated that the majority of transformers installed in Polish power system has already exceeded this age, therefore periodic diagnostic tests are being conducted (among others moisture determination and degradation of solid insulation system using polarization methods, examination of the mechanical conditions, tests for partial discharge occurrence), through which it is possible to take appropriate actions in order to extend the service life of power transformers and keep them in good condition. The aged insulation system is more susceptible to the occurrence of defects, and partial discharges (PD) which are appearing in their area are the most common cause of a possible transformer failure.

Worldwide carried researches are aimed primarily at improvement of the reliability of currently used methods of diagnosis and monitoring of power transformers based on the detection of the phenomenon of PD. Authors of this paper are focused on finding new theoretical and technological solutions that would significantly improve the accuracy of defects localisation in high-voltage insulation system.

The concept presented in articles [6, 9, 10] involves the use of sensor arrays technology to estimate the direction of arrival (DOA) of the acoustic emission signal or electromagnetic pulse generated by PD. The simulation results and reconnaissance studies confirm the validity of the chosen concept.

This paper presents the results of the recent work of the authors, which now focus on the design of sensory elements for measurement system in the form of antennas operating in the ultra high frequency (UHF) band.

The further part of this paper presents the results of simulations of two antenna structures. For the purposes of the article only some of the most important (from the point of view of the measurement system) parameters were selected.

## **2. Antenna parameters**

The space surrounding an antenna is usually divided into three regions: namely, (a) the reactive near-field, (b) radiating near-field (Fresnel) and (c) the far-field (Fraunhofer). Those regions are so determined, that in each of them the field structure can be identified. Crossing the boundaries of each zone does not affect in sudden changes in the characteristics of the field, but there are clear differences between them. The boundaries are determined by the number of approximations and are not the same for all types of antennas. Most commonly, in order to consider a zone, conditions which must be met are being used.

The reactive near-field is described as the area directly surrounding the antenna with a predominance of the inductive field. Analysis of electric and magnetic fields in this area is very complex – there is a 90° phase shift between them, and the energy is not radiated outside – it is stored within the electric and magnetic fields. For most of the antennas, it is assumed that this region is limited in the area with its radius less than

$$R < 0,62\sqrt{D^3/\lambda} \quad (1)$$

from the center of radiating surface (where  $R$  – distance from the center of the antenna,  $D$  – length of the antenna,  $\lambda$  – wavelength). For electrically short antennas it is established to apply the boundary equal to  $\lambda/2\pi$ .

With increasing the distance from the center of the antenna (outside the reactive near-field) the electric field components shift in phase, which appears in the flow of energy along the direction of propagation, radiation prevails over the induction field (which is still present) and the field distribution depends on the distance from the antenna. Such an area is called the radiating near-field, or Fresnel zone, and comprises in the area:

$$0,62\sqrt{D^3/\lambda} \leq R < 2D^2/\lambda. \quad (2)$$

The far-field (Fraunhofer) is considered the area within

$$R \geq 2D^2/\lambda \quad (3)$$

from the center of the antenna. The electric and magnetic field components are perpendicular to each other and the direction of propagation, which is characteristic for a plane wave. Assuming that the wave emitted by the antenna is spherical, considering it as a plane wave would be possible only in the

infinitely great distance from the source. However, some approximations are made, from which the basic assumption is that above the distance calculated with eq. (3) radiuses drawn from the emission source are locally parallel. As a result, the field distribution in the far-field zone is considered to be independent from the distance from the source [4, 5, 7].

To describe the operation of the antenna, it is necessary to define some of its parameters. Some parameters are interdependent and not all of them have to be specified for a full description of the antenna. Description of all parameters is included in the international standard *IEEE Std 145* [8]. A brief description of the selected parameters is given below.

### **Radiation pattern**

The energy radiated by the source of electromagnetic waves is different in different directions of propagation. Graphical representation of this feature is called a radiation pattern, which is defined as the electric field distribution on the surface of a sphere having a very large radius (in far-field zone) and the center coinciding with the center of the antenna.

Most often it is presented in the form of curves on 2D planes suitably selected in polar coordinate system (e.g. X-Y, Y-Z). A 3D graph may be illegible in the printed version, but as an editable simulation result can be a valuable source of information about the directionality of the antenna (Fig. 1). It is essential to properly orientate the antenna relative to the ground. In order to eliminate difficulties in comparing the characteristics of the different antennas, normalized values, obtained by dividing the current value by the maximum, are being used (most commonly a logarithmic scale is used in practice).

$$\mathbf{F}(\theta, \phi) = \frac{E(\theta, \phi)}{E_{\max}} \quad (4)$$

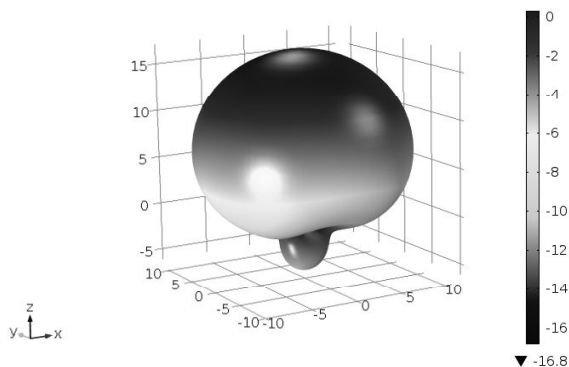


Fig. 1. Exemplary radiation pattern of a microstrip antenna shown in 3D space

### **SWR – Standing Wave Ratio**

Standing Wave Ratio (SWR), or Voltage Standing Wave Ratio (VSWR) is a measure of impedance mismatch between the transmission line (eg. Coaxial cable) to the load (antenna). If the load is matched to the transmission line, the whole energy is radiated by the antenna. If the load impedance different from the characteristic impedance of the line, a part of the energy is reflected back in the direction of the power source. As a result of the superposition of the outgoing wave and a return wave in the waveguide a standing wave is formed revealing in sinusoidal variations of the amplitude of the traveling wave along the transmission line. Most commonly, to determine the standing wave ratio, a reflection coefficient  $\Gamma$  is used:

$$VSWR = \frac{U_{max}}{U_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|}. \quad (5)$$

### **Antenna gain**

An antenna power gain is a ratio of the density of power radiated by the antenna in a given direction to the power density radiated by the reference antenna. In theoretical considerations most commonly as a reference antenna an isotropic antenna is applied, assuming that both antennas were fed with the same power. The unit of antenna gain is dBi and it is dependent on the radiation pattern and antenna efficiency:

$$G(\theta, \phi) = 4\pi \frac{U(\theta, \phi)}{P_{in}}. \quad (6)$$

## **3. Simulations results**

UHF sensors, dedicated to receive signals from defects in the insulation system are designed first and foremost in terms of matching frequency band and should be characterized by the highest possible to achieve sensitivity in this frequency range. On the basis of the frequency characteristics of different types of partial discharges published in [1], 800 MHz was chosen as the center frequency. A very important factor in the selection of UHF probes, which would apply to the PD detection in power transformers, is the geometrical design. Among many considered constructions two have been selected: a discone and a microstrip patch antenna. During the prototyping process, geometric parameters of antennas were determined on the basis of formulas available in the literature [2–5, 7, 11]. In Autodesk Inventor models of prototyped antennas were developed, which were then used to simulate the operating conditions in Comsol Multiphysics simulation software.

For the purpose of this paper it was decided to present only the most important (from the point of view of the designed measurement system) simulation results in form of their radiation patterns, VSWR characteristics and gain in function of frequency.

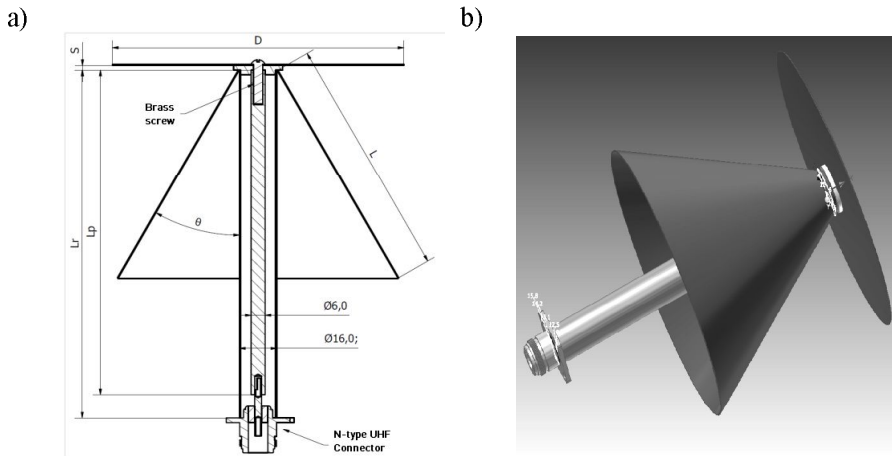


Fig. 2. Construction drawing (a) of a discone antenna and its model (b) made in Autodesk Inventor

The simulation results for the discone antenna, geometrically optimized for a resonant frequency of 800 MHz, are shown in Figures 3, 4 and 5.

The simulation results for the microstrip patch antenna, geometrically optimized for a resonant frequency of 800 MHz, are shown in Figures 7, 8 and 9.

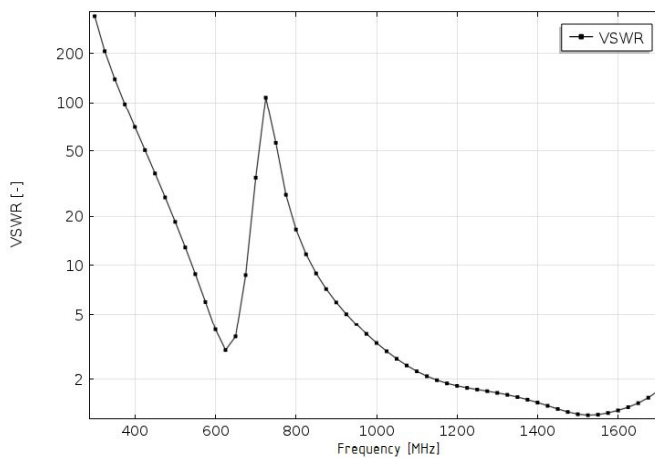


Fig. 3. SWR in function of frequency of designed discone antenna

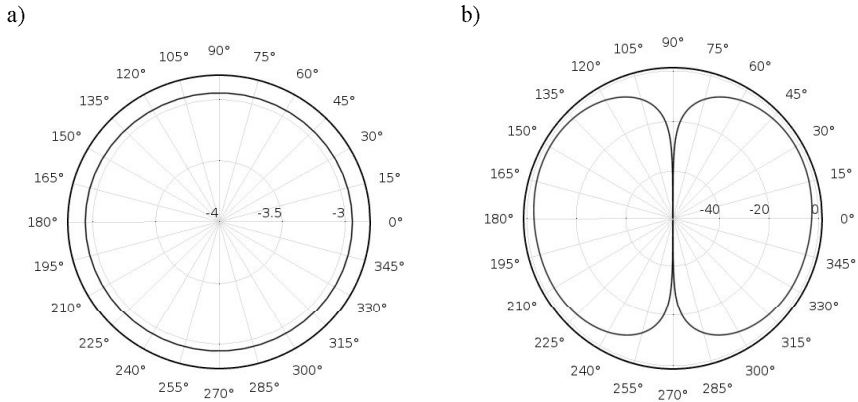


Fig. 4. Radiation pattern of designed discone antenna at 800 MHz in (a) horizontal and (b) vertical plane

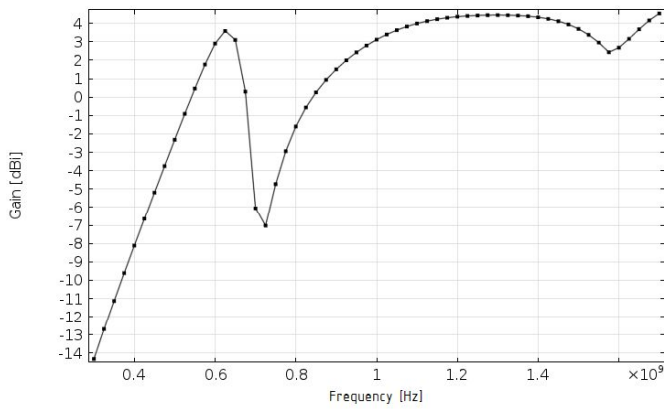


Fig. 5. Designed discone antenna gain in function of frequency (in reference to an isotropic antenna)

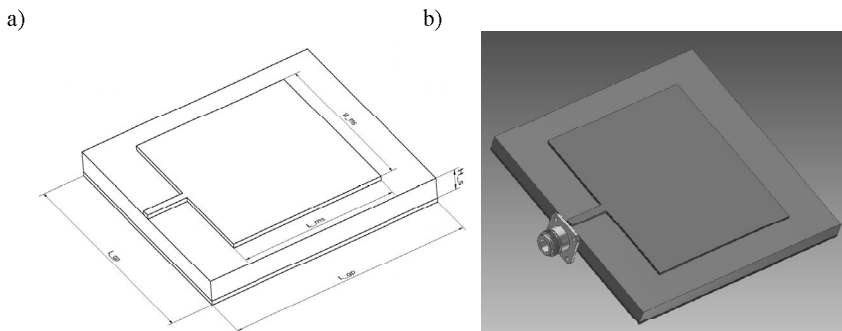


Fig. 6. Construction drawing (a) of a microstrip patch antenna and its model (b) made in Autodesk Inventor

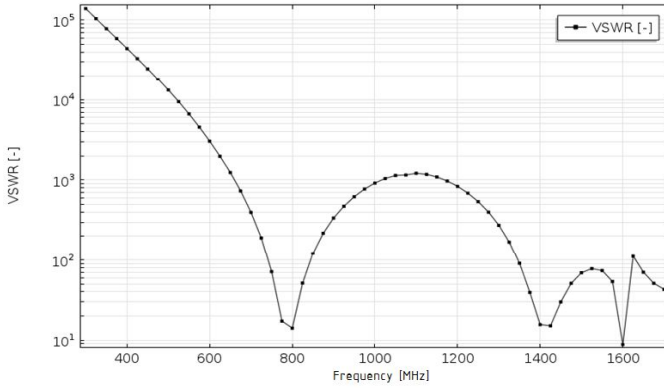


Fig. 7. SWR in function of frequency of designed microstrip patch antenna

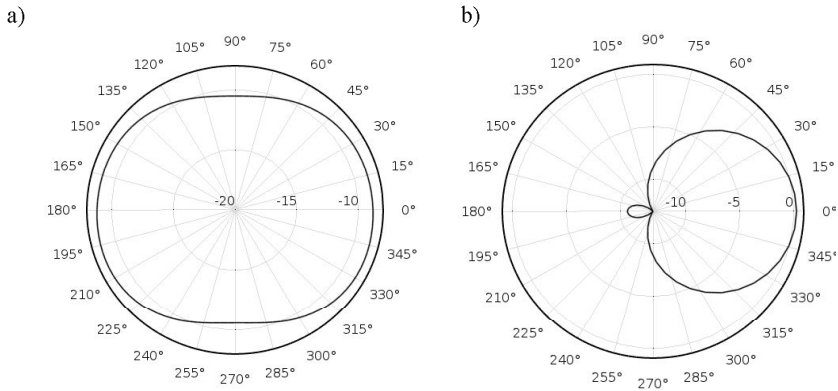


Fig. 8. Radiation pattern of designed microstrip patch antenna at 800 MHz in (a) horizontal and (b) vertical plane

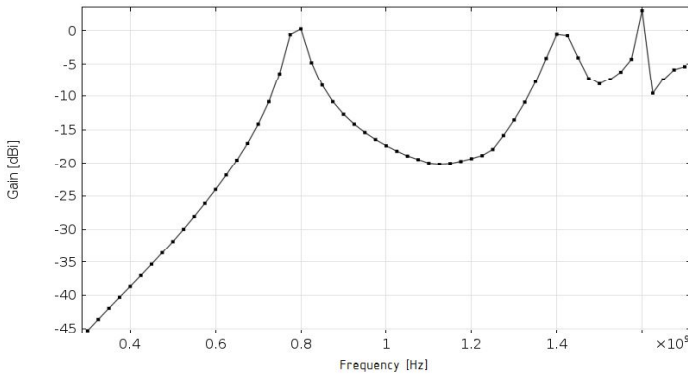


Fig. 9. Designed microstrip patch antenna gain in function of frequency (in reference to an isotropic antenna)

## **4. Conclusion**

The simulation results largely reflect the theoretical assumptions. Frequency response is clearly wider in the case of the discone antenna. It includes a range of approx. 800 MHz to 1700 MHz (frequency limit value in simulation), reaches a maximum at approx. 1250 MHz. For the microstrip patch antenna three useful ranges were observed, which are in the range approx. 760–820 MHz, 1380–1440 MHz and 1580–1610 MHz. On the basis of the values of gain it is also possible to definitively conclude that the microstrip patch antenna has several times lower sensitivity comparing to the discone antenna. Both antennas are characterized by a wide main lobe (beam) – almost omnidirectional.

For the purposes of this paper there were only two types of a wide range of available UHF antennas designs presented. In point of view of a measurement system for partial discharges localisation, which is actually designed, the application of microstrip patch antenna, due to the small geometric dimensions, would be an optimal solution. Further studies and simulations can allow finding more favorable geometry to improve the receiving parameters of sensor elements, and as a result, to improve general performance of the designed measurement system.

*The work was supported by Polish National Centre for Research and Development, within Applied Research Programme, grant No. PBS3/A4/12/2015*

## **References**

- [1] Raja K., Devaux F., Lelaidier S., Recognition of discharge sources using UHF PD Signatures, IEEE Electrical Insulation Magazine, Vol:18, Issue: 5, 2002, 8–14.
- [2] Sarkar B., Mishra D.K., Koley C., Roy N.K., Microstrip patch antenna based UHF sensor for detection of partial discharge in high voltage electrical equipments, Annual IEEE India Conference (INDICON), 2014, 1 – 6.
- [3] Verma S., Mishra A., Khan R., Analysis of variation of various parameters on design of discone antenna, IEEE Applied Electromagnetics Conference (AEMC), 2011, 1–6.
- [4] Milligan T.A., Modern antenna design, John Wiley & Sons, Hoboken, 2005.
- [5] Balanis C.A., Antenna theory, analysis and design, John Wiley & Sons, Hoboken, 2005.
- [6] Polak F., Sikorski W., Siodła K., Kowalczyk K., Zastosowanie matrycy mikrofonowej do lokalizacji wyładowań niepełnych, Między ewolucją a rewolucją – w poszukiwaniu strategii energetycznej, Tom I, Wydawnictwo Fundacja na rzecz Czystej Energii, Poznań 2015, 589–600.
- [7] Szóstka J., Fale i anteny, Wydawnictwa Komunikacji i Łączności, Warszawa 2006
- [8] IEEE Std 145™–2013, IEEE Standard for Definitions of Terms for Antennas, New York 2013.



- [9] Polak F., Sikorski W., Siodła K., Lokalizacja źródeł wylądowań niezupełnych przy użyciu matrycy przetworników, Poznan University of Technology Academic Journals. Electrical Engineering Issue: 78, ISSN: 1897-0737, Wydawnictwo Politechniki Poznańskiej, 2014, 157-166.
- [10] Polak F., Sikorski W., Siodła K., Lokalizacja źródeł wylądowań niezupełnych przy użyciu matryc sensorowych, Przegląd Elektrotechniczny, 10/2014, 74-77.
- [11] Sheets W., Graf R.F., Discone VHF-UHF Antenna, Poptronix Electronix Handbook, 1997, <http://educyclopedia.karadimov.info/library/discone.pdf>, dostęp: 14.01.2016.

*(Received: 11. 10. 2016, revised: 15. 11. 2016)*