Naval mine detection system based of FPGA circuit

Mirosław Wołoszyn, Jacek Łubkowski, Marek Chomnicki
Gdańsk University of Technology
80-952 Gdańsk, ul. Narutowicza 11/12, e-mail: mwoloszyn@ely.pg.gda.pl

1. Introduction

Electrochemical processes take place in a metal object immersed into sea water even if an anticorrosive coating is applied [1]. As a result, flowing field appears around the object. There are naval mines between many other objects situated in the sea. Naval mines can be put in the seabed in order to be more difficult to detect by sonars. Such a mine is located on the line demarking two environments of different electrical conductivity. The results of a computer analysis of the influence of seabed's electrical conductivity on the electric field's disposition around a mine model are shown below. Also, a naval mine detection system based on the FPGA circuit is presented.

2. Electric field of an object

Determination of the most effective electric field mine detecting sensors layout was one of the goals of a numeric electric field analysis or a naval mine model's electric potential disposition. A mine-shaped object was modeled with two sources (Fig. 1) of potential difference equaling U. The distance between the sources equals L. All the quantities are presented as dimensionless according to the following formulas:

$$V = \frac{\varphi}{U} \tag{1}$$

$$r = \frac{R}{L} \tag{2}$$

where: V – dimensionless potential, φ – electric potential, U – tension between electric field point sources, R – distance from measurement point to the middle of mine model, L – distance between the electric field sources equaling the length of the mine-shaped object, r – dimensionless distance measurement point to the middle of mine model.

The values of all the coordinates as well as the distance between the electric field sensors are given as dimensionless values referred to the distance between the L electric field sources equaling the length of the analyzed mine-shaped object. The simulations were performed for the tension between electric field point sources U = 1V and the distance between the sources L = 1m.

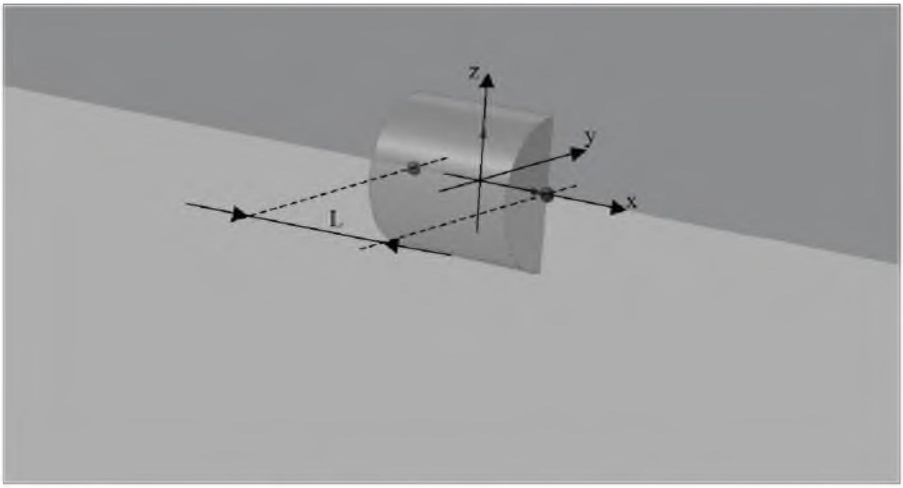

Fig. 1. Naval mine model in numeric analysis

A dimensionless electrical conductivity defined with the correlation below was applied in the research:

$$\sigma = \frac{\sigma_d}{\sigma_w} \tag{3}$$

where: σ_w – electrical conductivity of water, σ_d – electrical conductivity of the seabed.

On the basis of analysis of many computer simulation results it was stated that in the case where the electric field source is located above the seabed or on the borderline between the seabed and water, the seabed electrical conductivity value does not have a significant impact on the disposition of the potential in the water. Such an impact is observable when the electric field is located beneath the seabed. In Fig. 2 the dependence of maximum dimensionless potential value on the dimensionless "z" height above the object hidden on a dimensionless depth of $z = 0.25$ is presented.

As shown in Fig. 2 and Fig. 3, the influence of seabed's electrical conductivity is particularly relevant for short distances between the electric sensor and the object. For distances longer than three times maximal dimension of the object the influence of the seabed is not big. The influence of seabed's electrical conductivity on the electric field disposition in space is insignificant. If the flowing field source is placed on the borderline between the seabed and water or if it is placed above the seabed, the influence of seabed's electrical conductivity is not relevant for the values and the disposition of the potential above the object. The dependence of the dimensionless potential on the dimensionless depth "z" follows the curve shown in Fig. 2 for $\sigma = 1$.

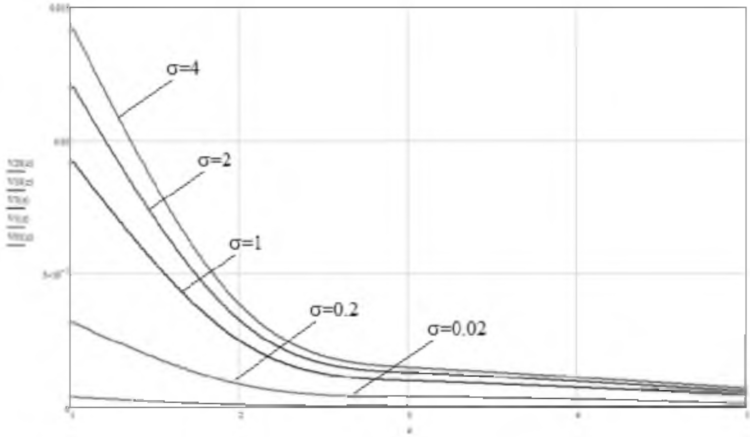

Fig. 2. Dependence of the maximum dimensionless electric potential value on the dimensionless "z" height above the object (the electric field source is located beneath the seabed for z=0.25)

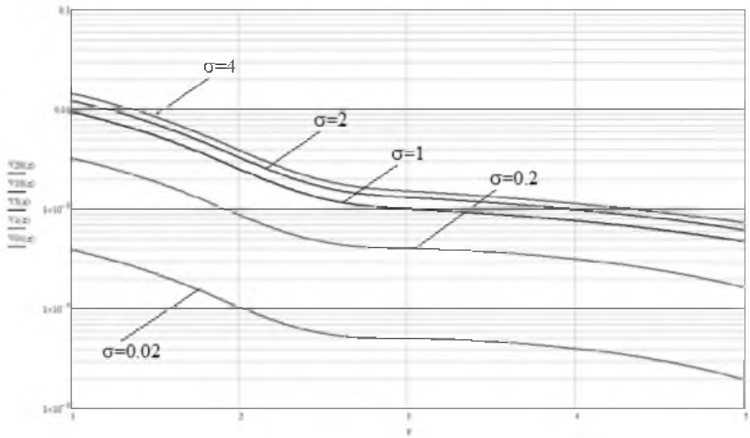

Fig. 3 Dependence of the maximal dimensionless electric potential value in logarithmic scale on dimensionless "z" height above the object, for an object located beneath the seabed

3. Analysis of electric potential disposition in sensors arranged in a circle

An analysis of electric potential disposition of a naval mine model was carried out for different sensor configurations. Eventually, as a result of the carried research, it has been stated that arranging the sensors in a circle is the most effective. A dimensionless electric potential disposition and the disposition of potential differences between each sensor set in a plane system where the sensors are located on a circle of dimensionless diameter equaling 2 is presented below.

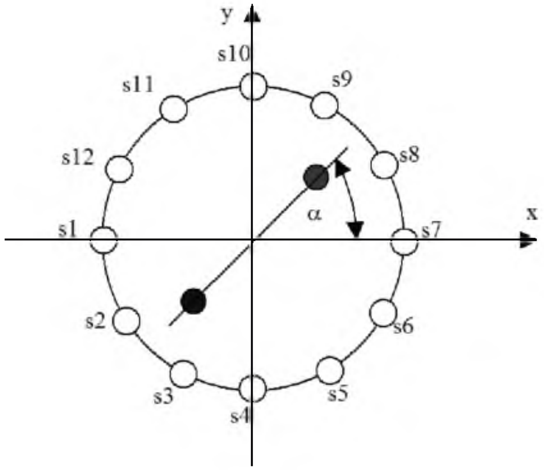

Fig. 4. The sensors' layout in a circle and explanation of the α angle

The dispositions of electric potential were made along straight lines parallel to the x axis. It was assumed that the electric field source lies in the middle of the coordinate system (x = 0, y = 0, z = 0), while the straight line linking the two spherical electric fields sources form a α angle with the x axis (Fig. 4). Examples of electric potential disposition in each sonar for angles $\alpha = 0°$ and $\alpha = 90°$ are presented in Fig. 5 and Fig. 6.

The following conclusions result from a numeric analysis of dimensionless electric potential disposition around a mine-shaped object located on the seabed or beneath the seabed:

- arranging sensors in a circle is the most effective for determining the location of a naval mine-shaped objects and for their identification;
- in order to localize and identify naval mine-shaped objects a sensor arrangement in two concentric circles set in one plane should be considered. The reference sensor should be placed in the middle of the two circles;
- the diameters of the circles where the electric field sensors will be arranged depend on the length L of the searched object. The suggested diameters should equal 2L and 4L, respectively. The sensor arrangement with the smaller diameter shall localize a mine from a shorter distance while the sensor arrangement with the bigger diameter shall localize a mine from a longer distance. The plane of the sensor arrangement should be parallel to the seabed. For technical reasons, the maximal diameter of the sensor arrangement must not be too big;

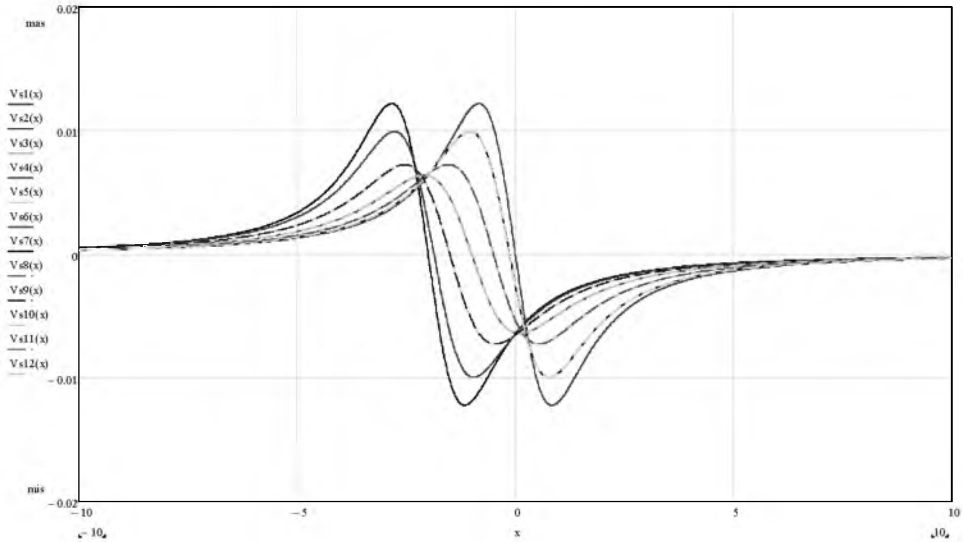

Fig. 5. Dispositions of dimensionless electric potential for each sensor in Fig. 55 for α = 0°, z = 1, y = 0

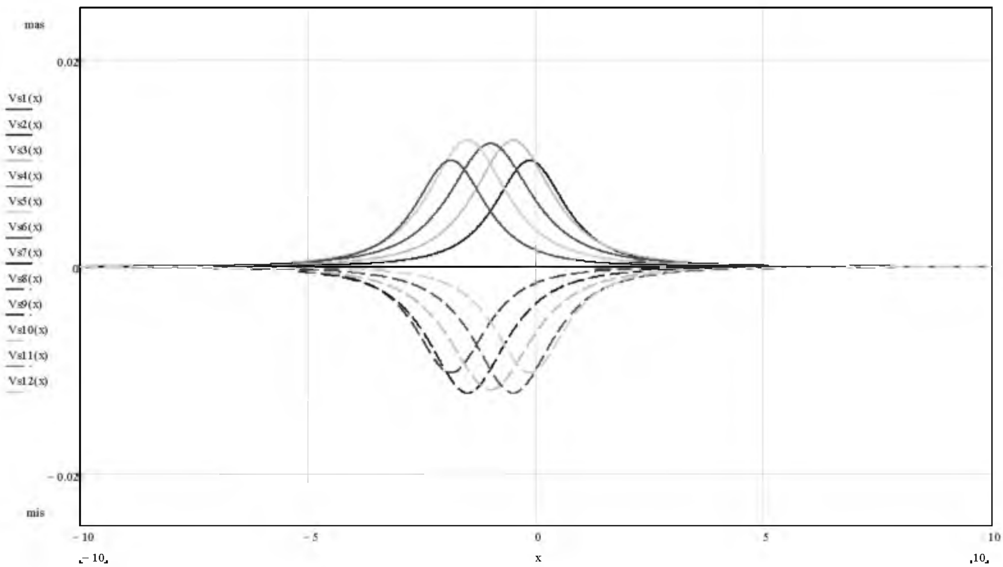

Fig. 6. Dispositions of electric potential for each sensor for α = 90°, z = 1, y = 0

- the distance from which a mine is possible to localize depends on the resolution of the measurement instrument (the resolution of the electric field sensor arrangement plus an amplifier);

- other than circular geometric configurations of the sensor arrangement, such as spherical or hemispherical etc., show worse properties for naval mine localization and identification possibilities.

4. Mine detection system based of FPGA circuit

Mine detection system requires a continuous and fast signal processing and operation of peripherals. These tasks can be performed by using an FPGA circuit. A parallel structure of such a circuit enables a fast hardware implementation of the introduced algorithms. Logic gate array with a possibility to reconfigure the connections between the gates is the basic element of the FPGA circuit (Field Programmable Gate Array). After programming the gates constitute a hardware version of the designed algorithm or function. VHDL of Verilog hardware description language is used to describe the gates. Besides the possibility to design parallel structures, the FPGA circuits also enable implementing complete microcontrollers and microprocessors together with cooperating digital peripherals. Every producer offers his own processor destined for his FPGA circuit, e.g. Xilinx company provides a 8-bit PicoBlaze or a 32-bit MicroBlaze [3]. The designer chooses the appropriate microprocessor, available as the so-called IP-core described with VHDL or Verilog language [2]. The company offers many other IP-cores easily addible to one's own project as a block.

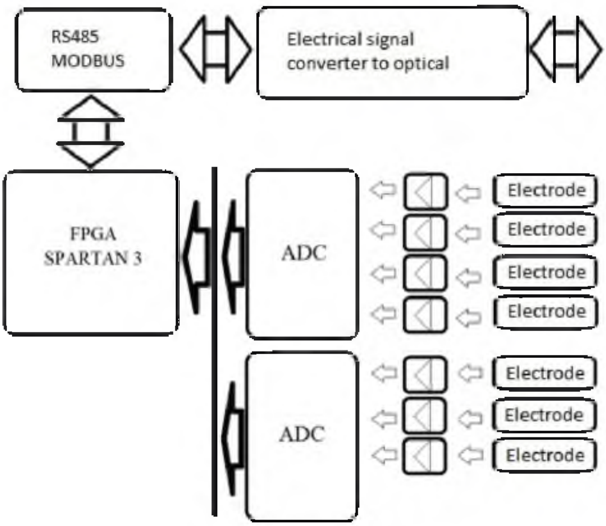

Fig. 7. Flowchart of the measurement system

A flowchart of a measurement system integrated into the naval mine detection system is presented in Fig. 7. The electric potentials of electric field sensors measured regarding the reference sensor potential after amplification with a high precision, small voltage offset, low noise amplifiers are measured with A/D converters of high resolution (24 bits). The voltage values are decoded by a FPGA processor, undergo a digital filtration to be sent to a computer on the water surface by a RS485 system. The FPGA circuit (Fig. 8) also enables implementation of object detection algorithm.

Electric field sensors are an important element of the measurement system. Metrological parameter values should be identical for all the employed sensors, particularly with regard to the changes of the parameters in time.

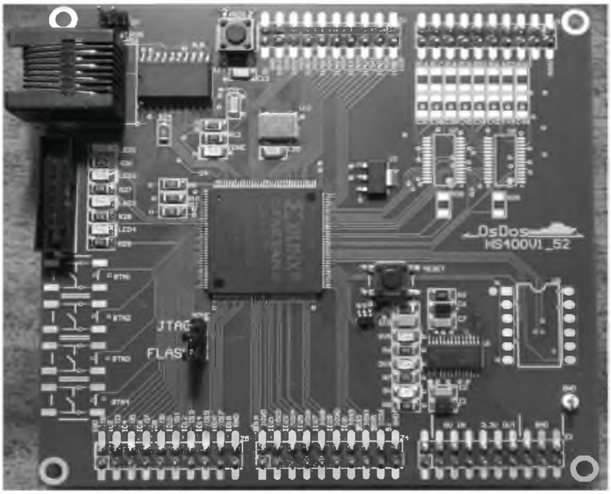

Fig.8. Photograph of FPGA circuit

Fig. 9. Electric field sensors in a measurement capsule

In Fig. 9 there are electric field sensors located in a small waterproof measurement capsule. Inside the capsule the FPGA circuit is installed together with other electronic devices. Fig. 10 shows the sensor disposition in two circles in a naval mine detection technology demonstrator. Fig. 11 presents the biggest measured potential difference between the sensors No 9 and No 14 (Fig. 10) of the object detected in the sea water.

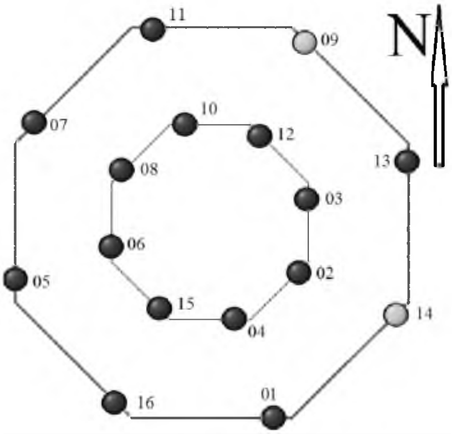

Fig. 10. Sensor disposition in the naval mine detection technology demonstrator

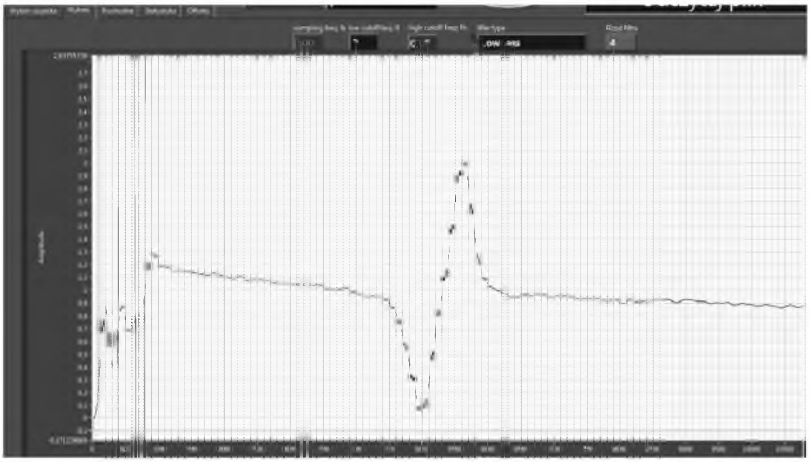

Fig. 11. Course of changes of the electric potential differences between the sensors No 9 and No 14

Silver chloride electrodes were used in the arrangement as the electric field sensors., that is metallic silver covered with a layer of silver chloride AgCl immersed in a saturated solution of potassium chloride. Chemical reactions occur in the electrode between the surface of the membrane and the solutions on both sides of the membrane under the influence of electric field changes. Besides a low value of the potential, the Ag-AgCl electrode also shows stability of the potential and lack of toxic effects.

5. Summary and final conclusions

The paper presents the results of a numeric analysis of the influence of seabed's electrical conductivity on the disposition of the electric potential around the electric field source hidden in the seabed and the electric potential disposition of the electric field. The structure of a naval mine detection measurement system with particular regard to the implemented PFGA circuit was described.

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