Simulation of the Near-field of a Ferrite Antenna

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Abstract. The paper presents results of simulation of the near-field radiation zone of ferrite antenna. It describes the HFSS model of the ferrite antenna consisting of a ferrite core, several turns of wire, and an excitation port. The paper also shows results of the antenna far-field boundary estimation and the near-field components visualization. The conclusions were made on the applicability of this configuration of the ferrite magnetic antenna in the area of ground penetrating radars.

Keywords: Ground penetrating radar, Near-field estimation, Ferrite antenna

1 Introduction

The ground penetrating radar is aimed at finding and visualizing the objects in concealment environments. The process of finding objects is often complicated due to the nature of the underlying surface (snow, ice, asphalt). A powerful masking reflection from the top edge of the underlying surface layer can completely suppress the reflection signal from the searched object because of the limited receiver dynamic range.

The authors hypothesis is that with specific restrictions on the ground penetrating radar, namely, the search and visualization of objects with high magnetic permeability, such as iron products, the following solution of the raised problem is possible. Due to the highly expressed magnetic properties of the searched objects made of iron, it is appropriate to use magnetic antennas, characterized by predominance of the magnetic field over electrical in the near-field zone. Thus, the hypothesis is that the use of magnetic antennas will allow one to receive the magnetic component of the field, reflected from the searched object undermining the influence of concealing effect reflect from the top layer of the concealment environment with high dielectric permeability [1].

The purpose of this work is to examine the characteristics of the electromagnetic field in the near zone of the magnetic antenna as a result of the ANSYS HFSS simulation. It is proposed to develop and use the ferrite antenna model as a magnetic antenna. The article is organized as follows. Chapter 2 examines the ferrite antenna model created in the ANSYS HFSS program. It also analyzes the input impedance of antenna. Chapter 3 shows the results of the field modeling in the near-field zone of the ferrite antenna. It also evaluates the long-range boundary of the radiation on the basis of the wave resistance approximation to the value of 120 ohm. Analysis of the influence of the amount of the wire turns on the antenna parameters is also given. Chapter 4 provides a brief discussion of the results.

2 Model of the ferrite antenna

The basis of the ferrite antenna is a ferrite core in the form of a solid rod or set of rings. Taking into account the frequency range used, the ferrite material must meet the broadband requirements. It also should have low losses. Therefore, on the basis of the minimum loss requirement in the specified frequency range (up to 100 MHz), we have chosen the ferrite ring Amidon FT-50-68. The size of each ring is 12.7 x 7.14 x 4.78 mm. The admissible frequency range is from 1 MHz to 150 MHz.

On the basis of known equations, the equivalent diameter of the ferrite rod is defined

$$d = \sqrt{d_{\text{outer}}^2 - d_{\text{inner}}^2} = \sqrt{12.7^2 - 7.14^2} = 10.5(mm). \tag{1}$$

Now the condition that the maximum efficiency of the ferrite antenna on the rod is achieved with a ratio of its length to the diameter being about 25–30, the required rod length can be calculated

$$L = d \cdot (25...30) = 10.5 \cdot 25 = 263(mm). \tag{2}$$

The specified ferrite rod has a wire winding with the following parameters: the number of coil turns *(turns)*, the diameter of the wire in millimeters (*wire_d*), and the pitch of the coil winding in times *(pitch)*. Ferrite rod with wire winding represents an inductor with ferrite core, or a ferrite antenna from another point of view.

The widely used design of a ferrite antenna in the form of a simple winding of the wire on the rod has a number of disadvantages. In particular, the power supply terminals of the coil are spaced apart from each other, causing a loop forming when connected. There is irregularity in the phase distribution of the field strengths because the coil is asymmetrical. Turning to the problem of suppressing a direct coupling signal by constructing a differential circuit of two or more receiving antennas [2], it is important to ensure the uniformity of wave propagation in the direction of each receiving antenna. Such a task might be solved by a modified model of a ferrite antenna with two in-phase coils connected at a common point. The 3D-view of the ferrite antenna with in-phase coils is shown in Fig. 1. It is seen that two coils are symmetric relative to the center of the rod. They are connected at a common point, and the coil ends are connected by an earth conductor (red line) and contact the power port at the center. Also, the coil has the mentioned parameters *turns*, *wire_d* and *pitch*.

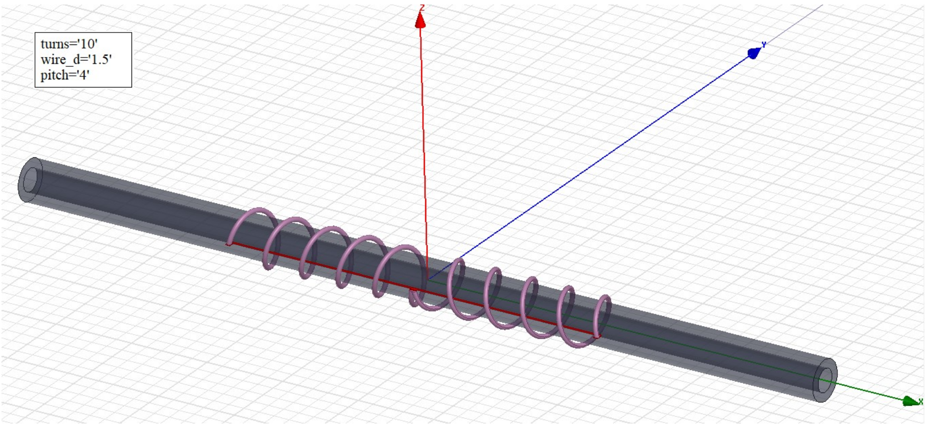

Fig. 1. 3D-view of a ferrite antenna model

Firstly, let us consider the input impedance of the antenna in the range 50-100 MHz (Fig. 2). In this case antenna parameters are the following: the number of wire turns is eight, the wire diameter is 1.5 mm, and the winding step is four wire diameters.

It can be seen that the real part of the input impedance is from 1.8 to 6.3 Ohm, and the imaginary part is from 142 to 406 Ohm. Positive reactance indicates the "inductive"nature of the input impedance in a given frequency range. It is seen that the graph of the reactance at the upper frequency becomes hyperbolic instead of the linear. It indicates that there is undesirable parallel resonance at an excess of 100 MHz.

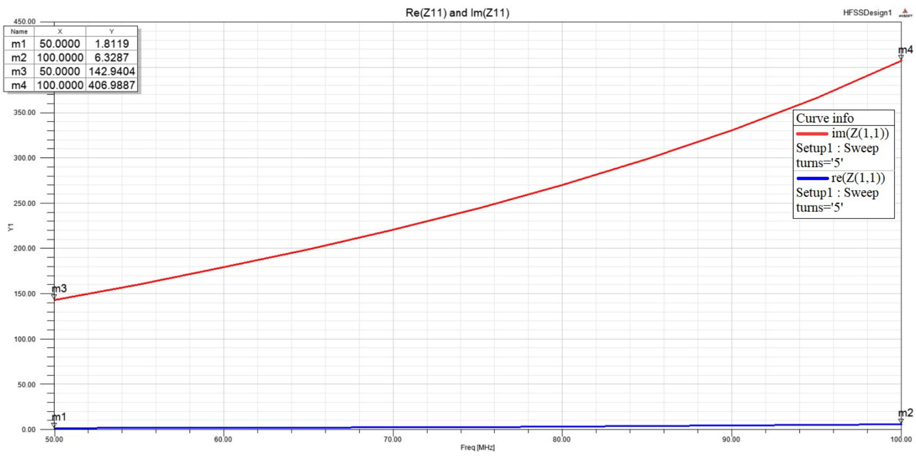

Fig. 2. Antenna input impedance: imaginary (red line) and real (blue line) parts

The cross-sections of the 3D-body of the radiation pattern by the azimuth plane at zero elevation and the angle plane at zero azimuth are shown in Fig. 3. In this case, the axis of the ferrite rod is directed along the X axis. The zero directional diagram in this direction is observed. It is seen that the greatest directionality of the antenna is 2.5 dB in the direction perpendicular to the direction of the axis of the ferrite rod. The directional pattern in this case has the form of a torus.

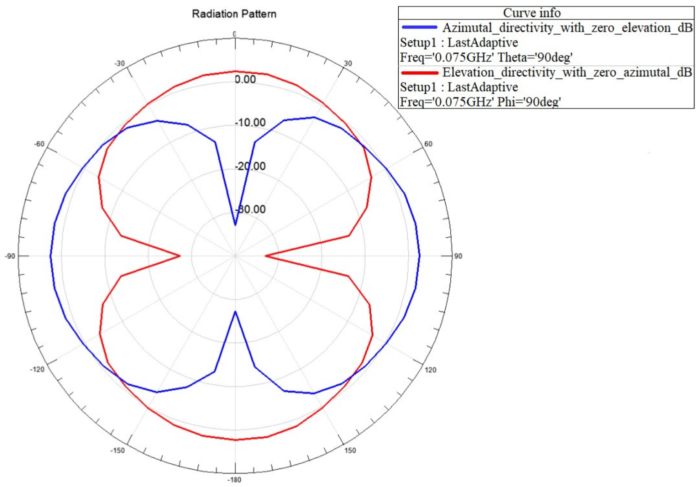

Fig. 3. Azimuth plane (blue line) and elevation plane (red line) radiation patterns

3 Near-field estimation

It is known that any induction coil has a parasitic intercoil capacity, which results in a parasitic parallel resonance. Let us analyze the antenna input impedance at 75 MHz when the number of coils is changed from 3 to 20. As it is seen in Fig. 4, with the number of coils between 7 and 8, a vivid resonance occurs. A more precise resonance level can be achieved by tuning the frequency.

We will consider the influence of the number of coil turns on the characteristics of the field in the near zone. For this purpose, we analyze the graphs of intensity of the electric and magnetic fields along a five-meter-long line emanating from the geometric center of the antenna. The number of turns in each half of the coil is two turns, five turns, or ten turns. Figure 5 shows that the curves practically coincide. It can be concluded that within a single design in a fixed frequency range, varying the number of turns of the coil significantly affects only the input impedance of the antenna. Wherein, it should not be forgotten about the different frequencies of a coil self-resonance.

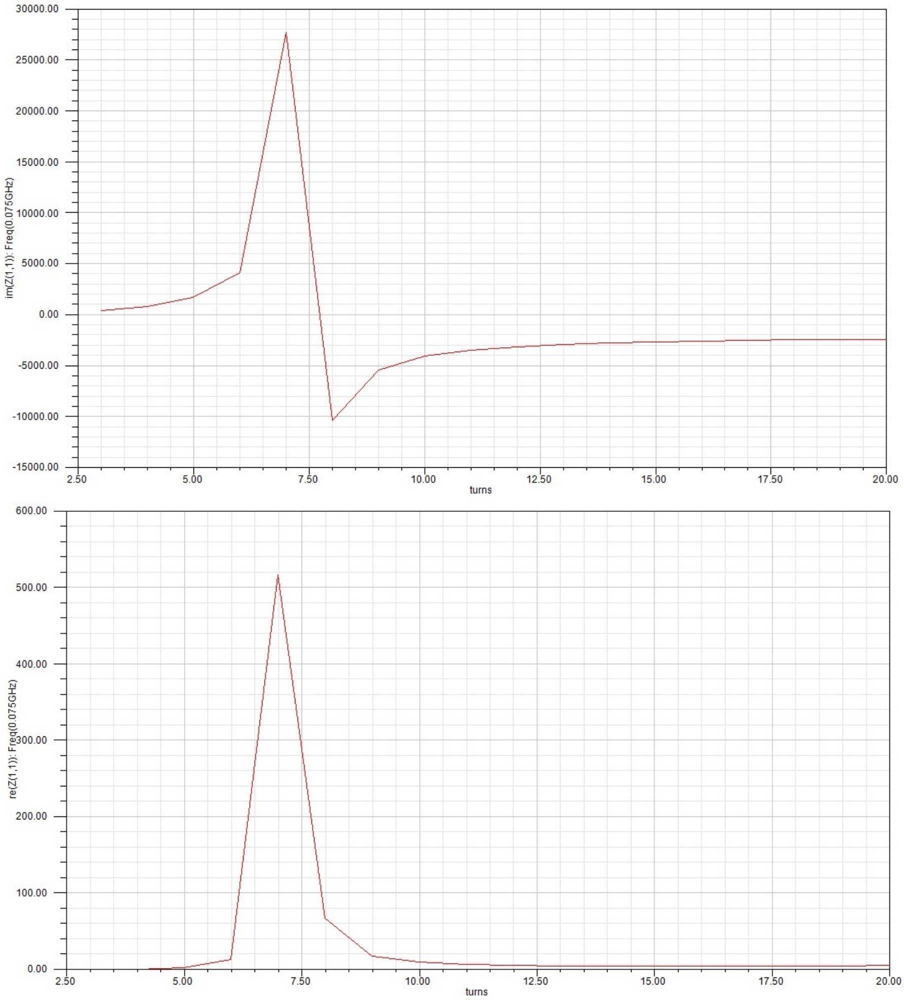

Fig. 4. Parasite resonance, depending on the number of wire turns at fixed frequency 75MHz: imaginary (above) and real (bottom) components of the antenna input impedance

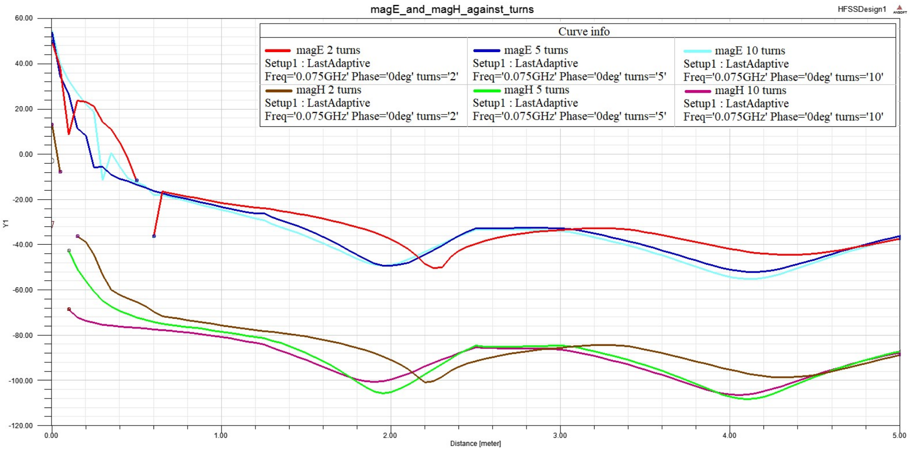

Fig. 5. Intensities of the electric (upper curves) and magnetic (lower curves) fields depending on the number of wire turns, dB

There are different approaches to divide the radiation field of the antenna into the near-field and far-field radiation zones, as well as there are different criteria for determining the boundary of far-field radiation. One of criteria is to consider the wave impedance, namely, the ratio between the intensities of electric and magnetic components of the electromagnetic field. When an exact ratio is established, then the intensity of an electric field is 120 times more than the magnetic field intensity. On one may say that the electromagnetic wave front has formed, which propagates in the environment. Let us consider the character of the wave impedance of a ferrite antenna in the near-field zone (Fig. 6). It can be seen that the wave impedance in the near-field zone has an inductive character, *i.e.* the magnetic field prevails over the electric one. As the oscillations of this curve settle around 377 Ohm, the presence of the far-field radiation boundary at this distance can be predicted. It can be said that this boundary is located at the 1–meter distance in case of the frequency equals to 75 MHz (wavelength equals to 4 meters). This result, with an error, corresponds to a theoretical estimate of the far-field radiation boundary for a full-size antennas

$$d_f = \frac{\lambda}{2 \cdot \pi} = 0.63(m). \tag{3}$$

Finally, the isosurfaces of intensities of the electric field (Fig. 7) and magnetic field (Fig. 8) in the azimuth plane of the antenna are shown, while the position of the antenna is displayed with a red dot at the center. The visible area of the field mapping is five by five meters, which is 1.25λ at an average wavelength equals to 4 meters. The maximum linear size of the antenna is 263 mm, or 0.066λ. The structure of the electric and magnetic fields forming in the near-field zone is clearly visible. We can say that the structure of the magnetic field in the near zone is more uniform and distinctly formed. This is one of the distinguishing features of magnetic antennas in comparison with electrical ones.

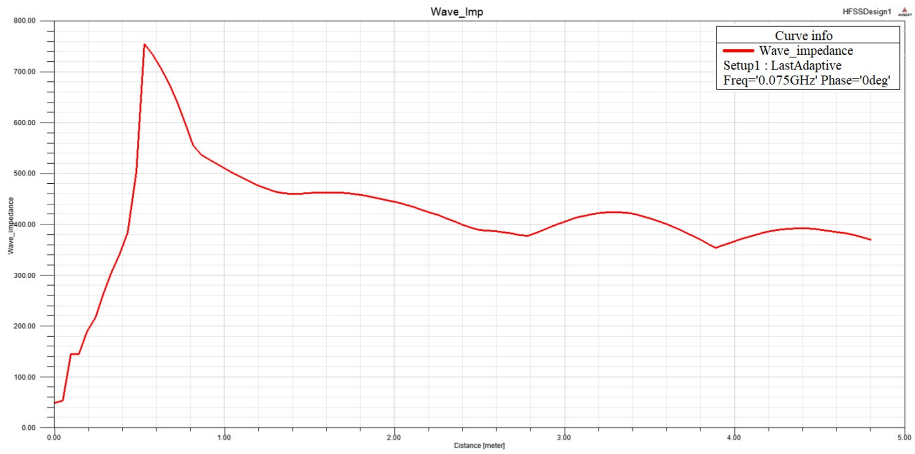

Fig. 6. Estimation of the far-field radiation boundary by wave impedance, Ohm

4 Conclusion

The modeling results show that it is reasonable to design short-range VHF antenna systems based on ferrite antennas. This will allow one to implement the discussed advantages that are impossible to radio-vision systems with shorter wavelength [3]. A small directivity and complicated impedance is a compromise with an extremely large reduction in the size of the antenna (up to 0.09λ). The boundary of the far-field radiation zone is at a range of about 1 meter according to the simulation results. Thus, at ranges up to 1 meter, the magnetic field emitted from the antenna dominates. In other words, surrounding objects and the underlying surface differently affect on the GPR antenna in the cases of using the magnetic or electric antennas.

Thus, the results of the research confirm the hypothesis of the authors that the use of magnetic antennas can allow one to receive the magnetic component of the field reflected from the searched object undermining the influence of concealing effect reflecting from the top layer of the concealment environment with high dielectric permeability. This results could be used for further research on evaluating the possibility of designing the GPR with a reduced influence of the underlying surface.

It should be noted that the ferrite antenna is an electrically small antenna with all the inherent disadvantages [4]. It is necessary to carefully design the matching circuits, since the impedance of the ferrite antenna has a large imaginary part and must be accurately matched [5].

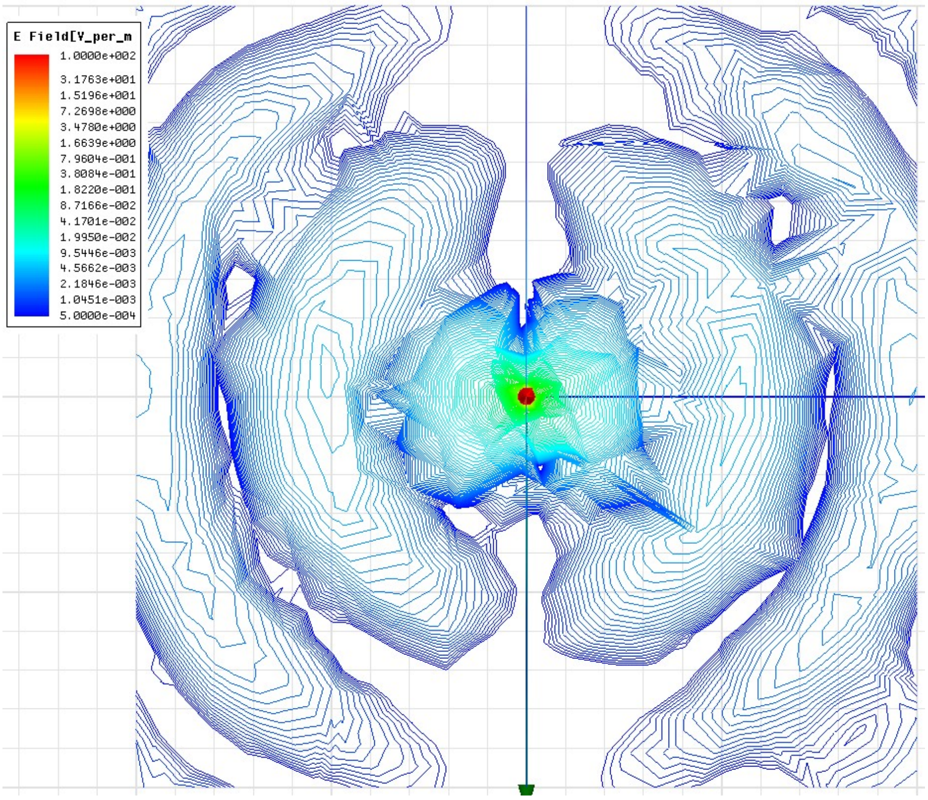

Fig. 7. Electric field intensity in the near-field zone, V/m

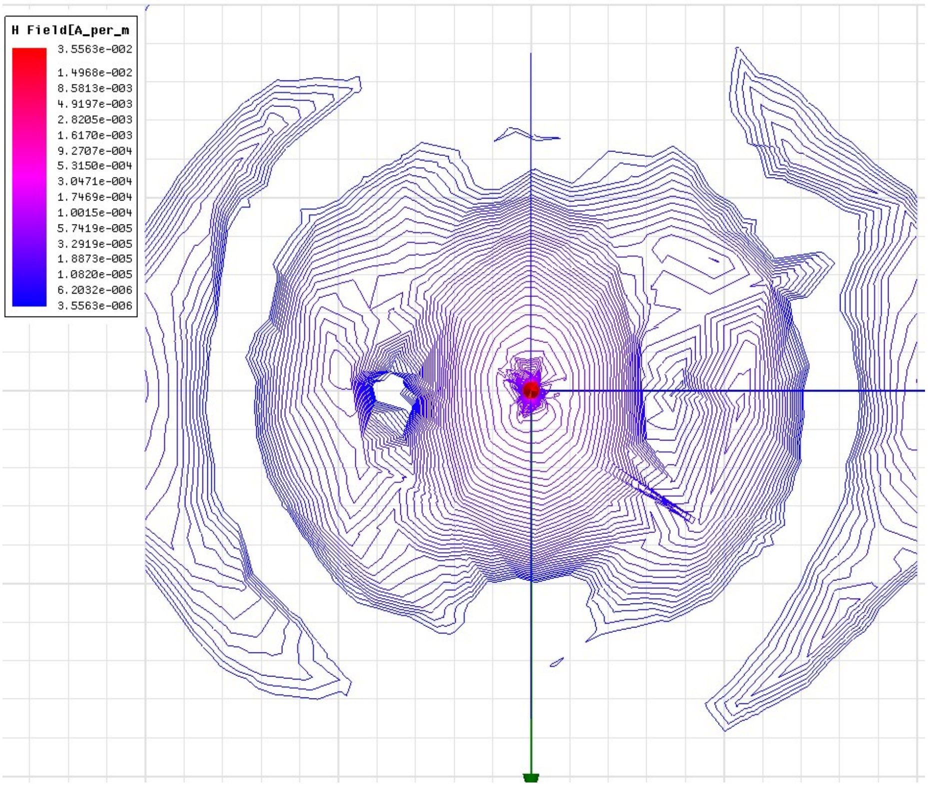

Fig. 8. Magnetic field intensity in the near-field zone, A/m

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