Influence of the underlying surface on the antenna system of the ground penetrating radar

E V Balzovsky, Yu I Buyanov and S E Shipilov

Tomsk State University, Tomsk, Russia

E-mail: shipilov@mail.tsu.ru

Abstract. Simulation results of the antenna system of the radar of subsurface sounding intended for contactless investigation of the road condition are presented. The elements of the antenna system of ground penetrating radar with extended bandwidth made as a combination of electric and magnetic type radiators have been designed. The transmission coefficient between the elements of the antenna array determining their mutual influence has been calculated. Despite the close arrangement of the elements in the array, the level of mutual influence of the elements is not critical. The developed antenna array can be used both for excitation with short ultrawideband pulses and for frequency steering in the range of 0.8-4 GHz.

1. Introduction

The use of ground penetrating radar (GPR) for the study of highways allows diagnosing hidden defects and preventing road surface damages in due time. Despite the existence of ready-made technical solutions of road scanners, a low scanning speed and high price of such devices are obstacles for their using in real application. Algorithms of radio vision of the objects hidden behind opaque obstacles can be applied when creating a new road scanner [1, 2].

Radiation of the surface layer and underlying layers of a highway with ultrawideband (UWB) nanosecond pulses provides high spatial resolution, and the presence of energy in the low-frequency part of the spectrum provides the deep penetration of electromagnetic waves in a lossy medium. The losses in the sounded medium increase with the frequency rise. To increase the depth of the sounding, the spectrum of the UWB pulses is shifted toward low frequencies and occupies the band of 0.5-2 GHz. To obtain radio imaging of the roadway heterogeneities, the technique of the synthetic aperture is used by moving the radar transceiver along the road. The array of the antennas is used to increase the width of the scanning area of a road. Antennas are connected in series to the generator or receiver by the switching unit [3].

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When creating an antenna array, it is necessary to calculate the mutual influence of the antenna elements. It is also necessary to take into account the effect of the substrate influence on the directional properties of the antennas. The results of modeling of a single antenna element and the elements within the antenna array are presented below.

2. Antenna array design

The element of the antenna array of GPR is made using the technology of combined antennas [4]. It is a combination of electric-type and magnetic-type radiators. It has small electrical dimensions, stable directional characteristics and slightly varying input impedance in the frequency band of 0.5-4 GHz [5]. An electric type radiator 6 is made by PCB technology on a 110×110×1-mm dimension fiberglass plate (1-4 in Figure 1) fixed in the aluminum corner 5 of the cross-section 120×120 mm and length 0.6 m. A metal-free part of the circuit-board 7 is the magnetic type radiator. The amplitude-phase relations for excitation of radiators of both types are determined by the dimensions of section 7 and the slot line 8.

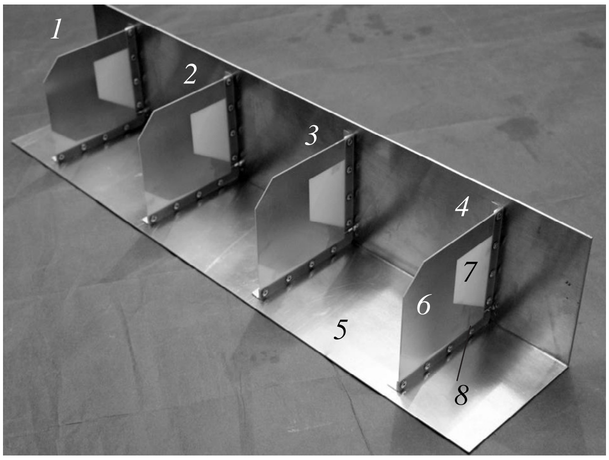

Figure 1. Antenna array physical configuration.

3. Antenna array simulation

Simulation of the antenna element and antenna arrays was carried out in the software product CST Studio Suite under an academic license. The calculated and measured standing-wave ratio (VSWR) of a single element does not exceed the value of VSWR = 2 in the frequency range of 0.6-4.3 GHz. The calculated and measured results practically coincide in the frequency range up to 2 GHz. At more higher frequencies, the discrepancy of measured and calculated VSWR dependences may be due to the fact that the losses in the antenna materials were not accurately taken into account during the antenna simulation. VSWR of the antennas composing an array deteriorates in the low-frequency region. The lower boundary of the matching band by the level of VSWR = 2 rises up to 0.78 GHz.

Simulation of the receiving and transmitting antenna arrays placed above the dielectric layer was carried out. Figure 2 presents the geometry of the simulation task. Antenna element 1 is excited by a bipolar voltage pulse of the duration of 0.4 ns. Antenna elements 2-4 in Figure 2 record the reflected pulses subject to the existence of plate 5 of the thickness 150 mm with dispersion properties corresponding to dry concrete: the value of dielectric permittivity is 5.5-6 at the frequencies of up to 4 GHz, dielectric loss tangent has the value of up to 0.25 at the frequency of 1 GHz.

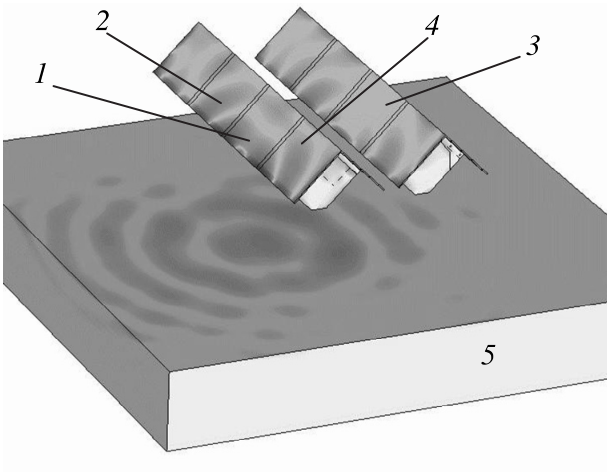

Figure 2. Distribution of electric field strength during layer sounding.

It was revealed that the directional properties of the antennas weakly depend on the distance to the dielectric layer when the antennas are located at a height of 100-300 mm above the layer. At the indicated distances, VSWR of the antennas increases to the value not exceeding 2.5 in the frequency ranges of 1.5-1.8 GHz and 2.6-2.9 GHz. Figure 2 presents the distribution of the electric field module at the frequency of 2 GHz in the gray color grading.

Calculations have shown that at the frequency range of 1-2.5 GHz, along the upper air-dielectric interface a surface wave is exciting. This resulting in parasitic radiation into the upper half-space at an angle of 30-50 degrees to the surface of the dielectric plate with the intensity of up to 0.5 of the maximum intensity of the wave radiated into the low half-space.

Calculation of the mutual influence of the array elements was carried out in the presence of a dielectric layer. Frequency dependence of the transmission coefficient module $|S_{21}|$ on antenna element 1 (Figure 2) to element 2 and $|S_{31}|$ to element 3 is presented in Figure 3. The greatest influence on each other is provided by the neighboring elements, for example, 1 and 2, as well as 1 and 4. In the presence of a dielectric layer, $|S_{21}|$ has an expressed maximum in the frequency range of 1.5-1.8 GHz. The exact position of the maximum depends on the distance between the antenna array and layer. If the properties of the dielectric layer corresponding to air are set in the numerical model (i.e., dielectric layer is absent), then the level of interaction between the elements 1 and 2 in this range decreases by 6-8 dB. The influence of the radiation field of element 1 on element 3 and more distant ones is much less. It can be assumed that the use of volumetric absorbing material will allow decreasing the mutual influence of the antenna array elements.

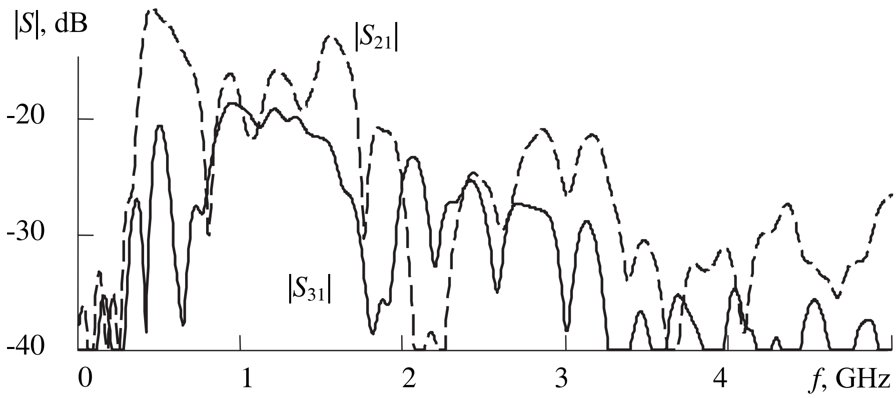

Figure 3. Mutual influence of antenna elements.

4. Conclusion

An ultrawideband antenna array designed for application in subsurface sounding radar has been developed and studied. The antenna elements matched to the 50-Ω feeder path in the frequency band of 0.8-4 GHz have expressed directional properties. Despite the close arrangement of the elements in the array, the level of the mutual influence of the elements is not critical. The developed antenna array can be used both for excitation with short UWB pulses and frequency steering in the range of 0.8-4 GHz.

Acknowledgments

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References

[1] Daniels D J 2004 *Ground-penetrating radar – 2nd ed.* (London: The Institution of electrical engineers) p 734
[2] Shipilov S E, Satarov R N, Fedyanin I S, Balzovsky E V and Yakubov V P 2016 *MATEC Web of Conferences* **79** 01079
[3] Satarov R N, Kuzmenko I Y, Muksunov T R, et. al. 2013 *Rus. Phys. J.* **55** 884
[4] Koshelev V I, Buyanov Yu I and Belichenko V P 2017 *Ultrawideband short-pulse radio systems* (Norwood: Artech House) p 432
[5] Balzovsky E V and Buyanov Y I 2016 *MATEC Web of Conferences* **79** 01036