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Radiotomographic system construction on the basis of multi-elemental reflective array

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Abstract. The authors propose a solution of the problem of radiovision using the reflective array, each element of which can change the reflection coefficient under the action of external control voltage. The focusing abilities of flat reflection array of monochromatic radiation were studied to solve the problem of radiovision. The array element based on waveguide with a controlled reflection coefficient was developed. The phase shift switching is 180°.

1. Introduction

Modern radiovision systems are applied for numerous purposes: to control the quality of materials, buildings and constructions as well as for medical applications. The development of computing technologies provided the application of the radiotomography techniques for the remote non-destructive testing and the diagnostics of the internal structure of radio-semitransparent media and the shape recovery of radio opaque objects. The task of radiotomography is the transformation of the data obtained from the multiangle scanning of target objects into the 3D visualization. The electronically and electromechanically scanned arrays are developed to obtain the multiangle projections of the wave field. However, the design and development of such arrays are complicated and expensive task, as it requires the development and control of numerous microwave transceiver channels.

The development of the electronically scanned arrays widely prevails nowadays over the electromecanically scanned ones. Together with conventional phased arrays, the arrays of elements with controllable phase of reflection are extensively applied. The reflection elements are usually based on ferrite phase shifters, micromechanical systems or varactor diodes [1].

The phase switching of the array reflection coefficients enables the simulation of the Fresnel zone plate that provides the focusing of feeder radiation at a certain point. The waves from two neighboring Fresnel zones are counter-phased. The electronic scanning can be performed in a certain angle sector with the change in geometrical arrangement of zone rings [2-3]. In this case, the only transceiver at fixed position can be used.

2. Formulation of the problem

In this research, the authors propose a solution of the problem of radiovision using the reflective array, each element of which can change the reflection coefficient by the external voltage control. The detailed task scheme presented in figure 1. A transmitted spherical wave be propagated in a free space defined in the Cartesian coordinate system. The transmitter (1) is placed at *Z* axis and at the h height from the reflective array (2). The test object (3) is placed above the array.

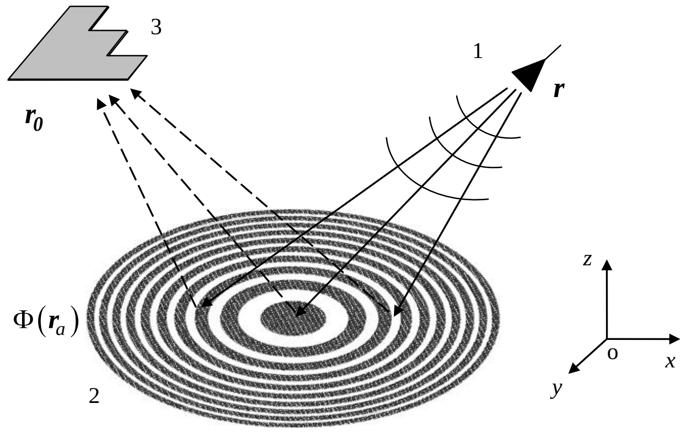


Figure 1. Task scheme.

Set the focusing point coordinates as (x_0, y_0, z_0). Then, the Fresnel zone boundaries are defined by the equation:

$$\sqrt{z_0^2 + (x - x_0)^2 + (y - y_0)^2} + \sqrt{h^2 + x^2 + y^2} = n\frac{\lambda}{2} \quad (1)$$

where n is the number of the Fresnel zone boundary, λ is the wavelength of the sounding signal.

Previously, two problems were solved [4]. The equation for reflection coefficient distribution was obtained, which provided the radiation focusing at the certain point. Also, the equation describing the field at the receiver point was obtained as well. The using of the 2D reflective array with controlled reflection coefficient to focus the monochromatic radiation for radiotomographic application were analyzed. This problem is solved by changing the focusing point, by switching the array elements. The numerical simulations with a test object approved the recovery of the test object shape.

3. Waveguide element of the reflection array

A waveguide was used as an element of the reflection array. The scheme of the waveguide array element and its pilot prototype are presented in figure 2.

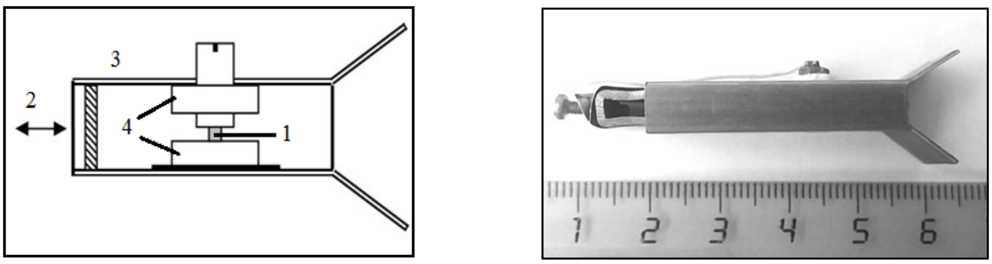


Figure 2. Array element structure (1- semiconductor diode capacitor, 2- shorting plunger, 3- waveguide, 4- impedance transformer) and its external view.

The varactor diode was installed into the waveguide section 11x5.5 mm in size. The waveguide impedance could be switched from low to high by altering the varactor capacity through the voltage adjustment. In that case, the installed varactor diode could either shunt the waveguide or transmit the propagated wave to the shortening plunger. In the latter, the phase shift to be set as 180° by the shorting plunger position.

The waveguide element is simply constructed that makes possible its volume production as well as provides its cost competitiveness with printed phase shifters.

4. The numerical and experimental results

In the program CST Microwave Studio, we were investigated the model of waveguide element of the reflective array. Figure 3 is an image of model and a graph, which illustrate the phase reconstruction of the reflection coefficient due to a change in the capacitance of the varactor.

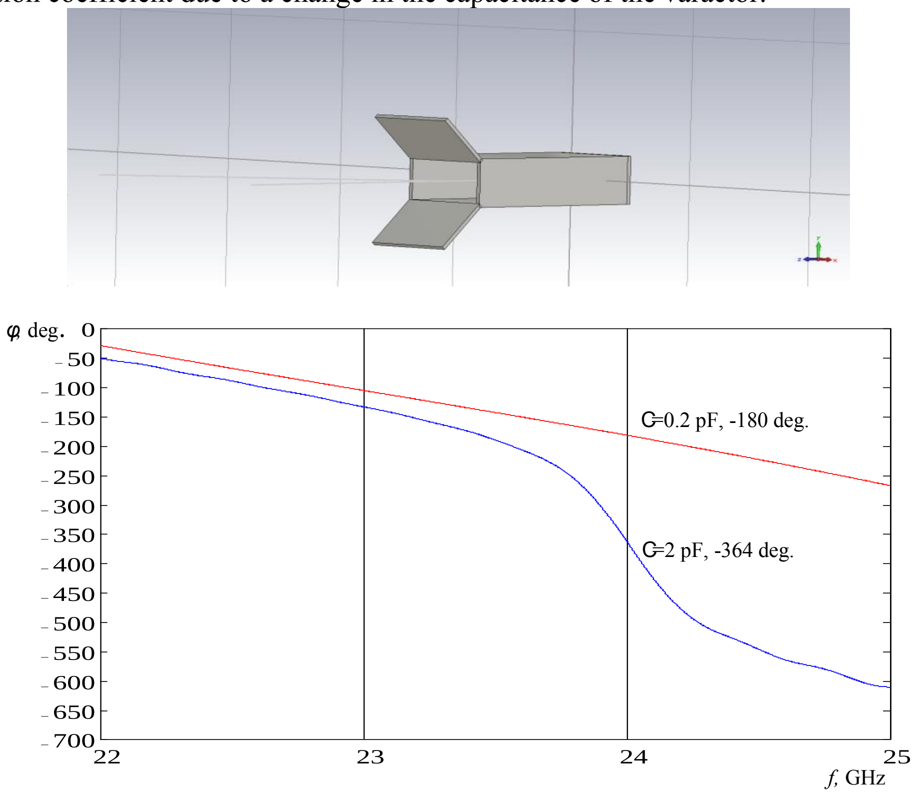


Figure 3. The numerical model of the waveguide element of the reflectance array and the result of simulation.

The array element experimentally demonstrated the reproducibility of characteristics. In figure 4 is an experimental plot that shows the phase shift of the reflection coefficient by 180° when the control voltage on the varactor changes (for 24 GHz frequency). Varactor capacity varies from 0.2 to 2 pF.

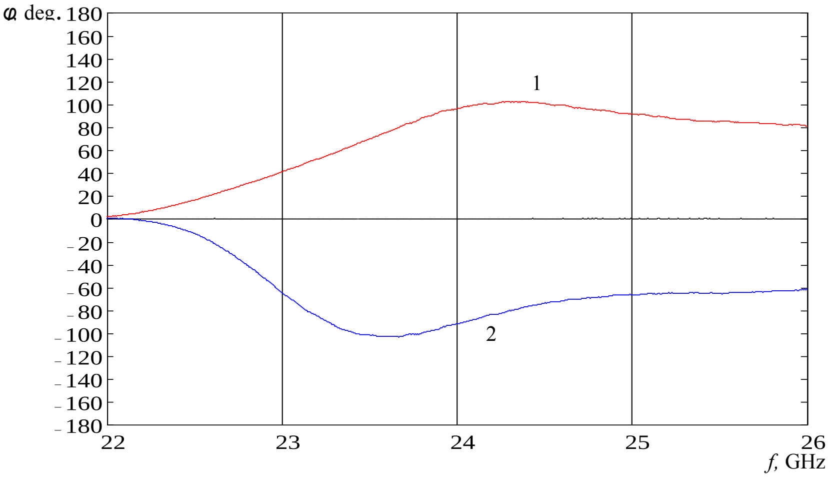
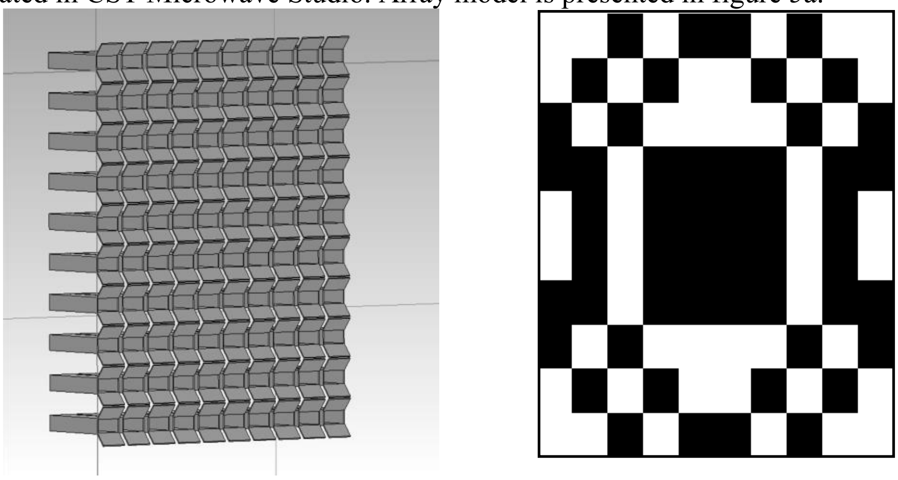


Figure 4. Change in the phase of the reflection coefficient (1 – voltage applied to varactor +5 V, 2 – varactor voltage -5 V).

To develop the experimental sample of the reflection array, the waveguide element and the array were simulated in CST Microwave Studio. Array model is presented in figure 5a.



a b

Figure 5. Numerical model of reflective array made of waveguide elements of size 10x10 elements, and the Fresnel zone distribution.

The distribution of the reflection coefficient $\Phi(\boldsymbol{r}_a)$ was predefined, which was calculated by the algorithms [4] corresponding to the array size. The calculations were performed for the frequency of 24 GHz. The distribution of the reflection coefficient, which provides the focusing at the coordinates $(0,0,10)$ sm is presented in figure 5b.

The field focused with the waveguide-based reflection array is presented in figure 6. It was calculated in CST Microwave Studio.

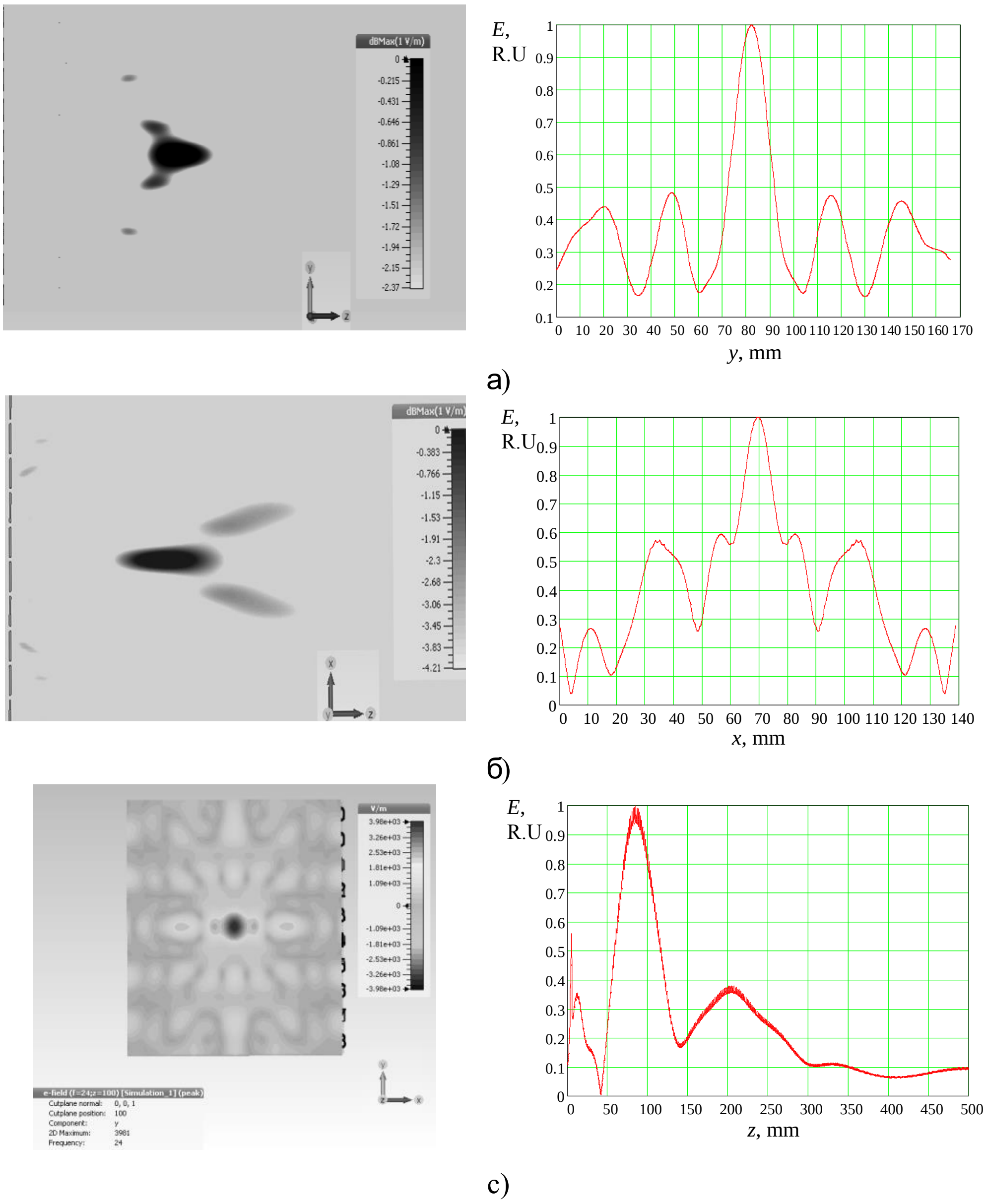


Figure 6. Radiation focusing with the reflection array.

The field distribution in the *yz* plane is presented in figure 6a. Figure 6b presents the field distribution in the *xz* plane. Figure 6c shows the field distribution in the *xy* plane as well as the field strength variation depending on the distance from the array. It is indicated that the field was focused at a certain point $(0,0,10)$ sm which the distribution of the reflection coefficient corresponded to (figure 5b).

An experiment was carried out with a array consisting of 100 elements (figure 7). The essence of the experiment was as follows: the transmitting antenna irradiated the array, the receiving antenna, which was installed in a two-coordinate scanner. The scanning was carried out in the focusing plane in the vertical and horizontal directions. The Agilent N5230C vector network analyzer was used as source and receiver. In this array, the distribution of the reflection coefficient was determined by means of a control voltage.

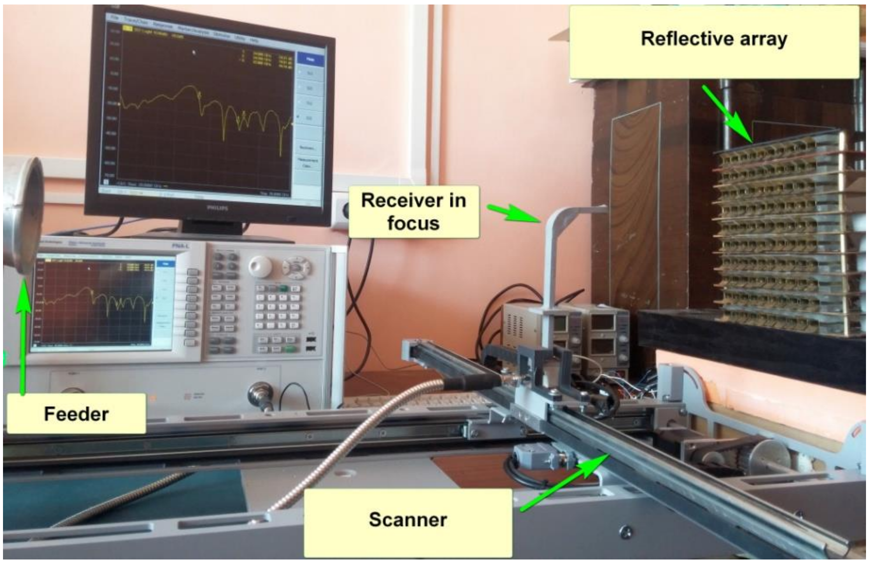


Figure 7. Automated experiment of focusing properties of a reflective array.

As a result, we obtained the field intensity distribution in the focusing plane (figure 8). For the reliability of the results obtained, a similar experiment was carried out, but only in this case the array was in the off state. In other words, no distribution of the reflection coefficient was specified. For electromagnetic radiation, the grating was represented as a metal plate.

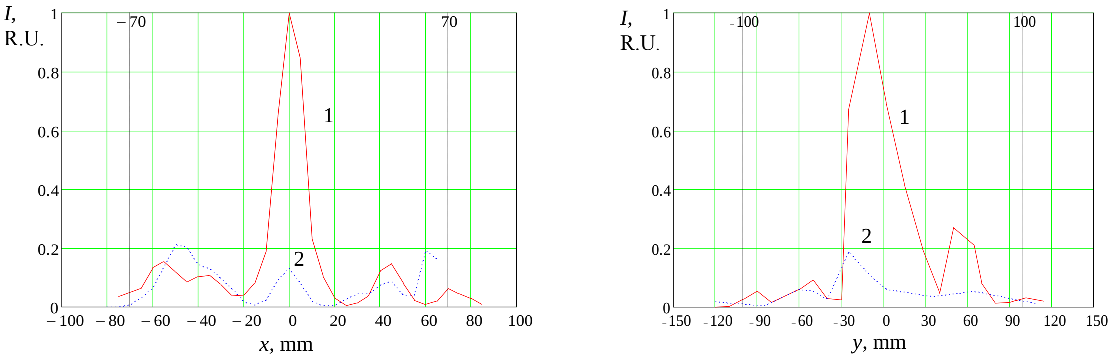


Figure 8. The distribution of the field intensity in the focusing plane in the vertical and horizontal directions (1 - the distribution of the reflection coefficient is given, 2 - the distribution of the reflection coefficient is not specified).

The bars show the geometric dimensions of the array. When the array was in the off state, the intensity of the reflected field decreased by approximately 10 times. In order to shift the focus point, it is necessary to change the distribution of the reflection coefficient. The distribution for the focusing point with coordinates $(6,0,20)$ sm is given. See the results of the experiment in figure 9.

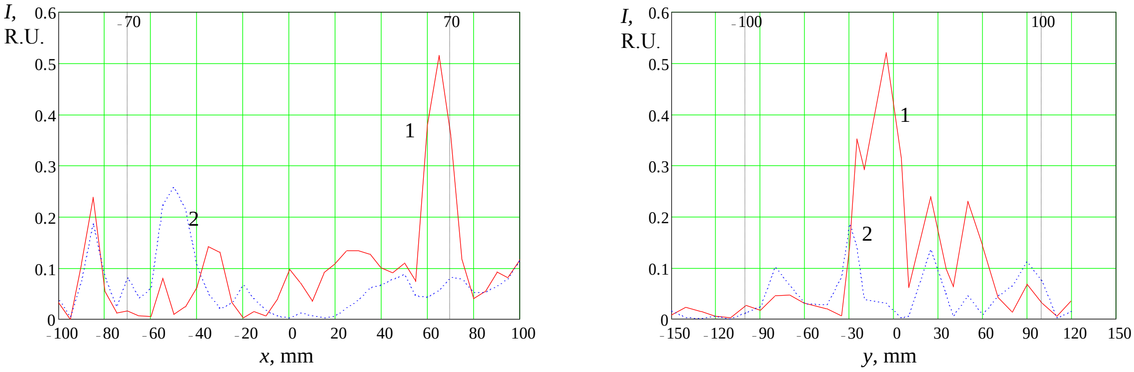


Figure 9. The distribution of the field intensity in the focusing plane in the vertical and horizontal directions (1 - the distribution of the reflection coefficient is given, 2 - the distribution of the reflection coefficient is not specified).

It can be seen from the results that when the focus point is shifted from the central position, the intensity of the field at the focusing point decreases, and the side-lobe level increases. This is due to the fact that the array has a low-density filling and a small aperture. Thus, carried out experiments with a reflective array based on waveguide elements confirm its focusing properties. Hence, with the help of such an array and one transceiver, you can scan a certain area of space. Electronic scanning is carried out. To obtain radioimages of objects in this area.

5. Conclusion

So, the capability of the flat reflection array to focus a monochromatic radiation at a certain point were studied. The element of the array based on waveguide with a controlled reflection coefficient was developed. The controlled phase shift is 180°. The array model based on waveguide elements was simulated in CST Microwave Studio. These simulations proved the monochromatic radiation focusing with the array made up of waveguide elements. Experimental studies of a reflective array consisting of 100 waveguide elements confirmed the focusing properties of such a array. A hardware and software complex to control the array is being currently developed. The proposed structure of the reflection array provides the high-rate focusing at a certain point.

Acknowledgments

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