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RADIOHOLOGRAPHY USING A SPHERICAL WAVE AS A REFERENCE SIGNAL[1]

It is proposed the radio-holographic method of the recovery of radio images based on measurements of the reference and object signals interference field of the intensity. As a reference source, a source of spherical waves is used. The results of numerical modeling and estimation resolution are presented.

Keywords: *radiotomography, radiovision, radioholography*.

Introduction

Radio tomography of the millimeter and submillimeter ranges is increasingly used in visualization systems of objects hidden behind radiotransparent obstacles [1]. In particular, radio tomography is used in security systems, access control and quality control.

The most high-quality radio images with a resolution close to the diffraction limit can get a system based on the technology of synthetic aperture using the measurement of the amplitude and phase of the wave field. Measuring the amplitude of the field is always technically much simpler task than the measurement of phase or associated with it, the quadrature components. That measure only the amplitude, without direct measurement of the phase allows significantly reduce the cost and simplify the system of radiovision. In some cases, e.g. when dealing with incoherent radiation phase measurement is impossible in principle. This situation arises when using thermal radiation or X-rays. Here we can speak only about the relative phase measurements by measuring the results of the interference of the so-called reference and object waves.

At present, the accuracy achieved, for example, in X-ray imaging is determined by the diameter of the holes collimation scanning nodes. Typically, the diameter of a few tenths and hundredths of a millimeter. Increasing the resolution when it requires reduction of the diameter, which inevitably leads to a loss of sensitivity of the energy system as a whole and, consequently, to an increase in radiation exposure to the test object. This dramatically increases the accumulation time at each point, and decreases overall performance. Note that the diffraction limit for the X-ray emission is of the order of nanometers or less. So it is clear that the recovery phase information, let indirectly, is the most urgent problem. In the long run, it will dramatically reduce the radiation dose and the objects of sensing and improve the performance of probing systems. The developed technology will help increase the accuracy of existing methods of X-ray tomography no less than 100 times.

Radio holographic methods [2] is a promising development of terahertz and subterraherz radio tomography systems, because they require only measure the intensity of the field without the phase measurement. They are due to the interference of the reference and object signals of possible partial preservation of phase information in the intensity of the interference pattern. This allows to restore the radio image with maximum resolution possible, as shown in [3, 4].

This paper proposes a method to recover narrowband radio holographic planar radio images, using a spherical wave as a reference signal.

Statement of the problem

The problem of narrow-band radiogolography by measuring the intensity of the field with the use of a source of spherical waves as a reference signal is considered (Fig. 1). It is assumed that the amplitude of the field measured by the filled matrix of sensors, disposed in increments less than half a wavelength, which are in a plane spaced from the plane of the emitter placement at h_2. The test object having a stepped shape of the polygon is at h_1 distance from the emitter plane. We believe that emitter is the point and isotropic. The source of probing radio waves, indicated in Fig. 1 as asterisk, is emits waves in the test object side and toward the measuring area. The investigated object scatters probe signal towards the measuring region. Field of the object falls to measure the intensity of which interferes with the field of the wave source probing signal, which acts as a reference signal.

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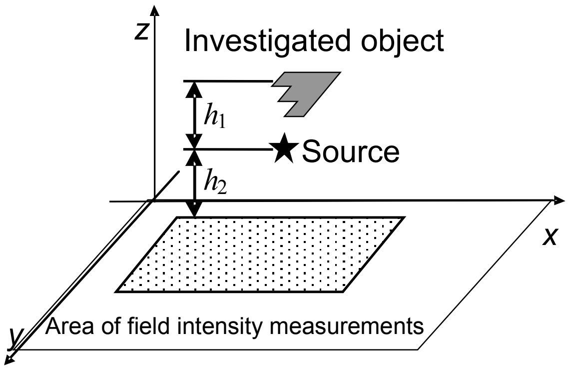

Fig. 1. Measurement scheme.

From the measured intensity of the interference field is necessary to restore the image of the object. We consider the problem in the scalar approximation. Write field in the measurement plane in the form:

$$U(\boldsymbol{r}) = A(\boldsymbol{r}) + B(\boldsymbol{r}), \quad (1)$$

where $A(\boldsymbol{r})$ – field, scattered by object (object wave); $B(\boldsymbol{r})$ – field of direct wave from the source to the measurement area (reference wave). Will consider, that magnitude of reference wave is much stronger than magnitude of object wave.

Consider that in this problem is measured by the intensity of the field, that is, the value of:

$$W(\boldsymbol{r}) = |U(\boldsymbol{r})|^2. \quad (2)$$

We write the object wave $A(\boldsymbol{r},\boldsymbol{r}_s)$ at the points of measurement $\boldsymbol{r}$ when using the transmitter at $\boldsymbol{r}_s$ a single scattering approximation [5]:

$$A(\boldsymbol{r},\boldsymbol{r}_s) = -\iint_{S'} p(\boldsymbol{r}')B(\boldsymbol{r}',\boldsymbol{r}_s)\frac{\partial G(\boldsymbol{r},\boldsymbol{r}')}{\partial n}d^2\boldsymbol{r}', \quad (3)$$

where $\boldsymbol{r} = (x, y, z = 0)$ – point of measuring field; $\boldsymbol{r}_s = (x_s, y_s, z_s = h_2)$ – coordinate of the emitter; $\boldsymbol{r}' = (x', y', z')$ – coordinate integration by point a facility, where it is assumed flat object at a distance $z = h_1 + h_2$; S' – the surface of the object to which the integration; $B(\boldsymbol{r}',\boldsymbol{r}_s)$ – field of the source on the surface of the object; $p(\boldsymbol{r}')$ –scattering coefficient of object points; $G(\boldsymbol{r},\boldsymbol{r}') = \exp(ik|\boldsymbol{r}-\boldsymbol{r}_s|)/(4\pi|\boldsymbol{r}-\boldsymbol{r}_s|)$ – Green's function of free space.

The field of the reference wave can be written on the basis of the Green's function of free space:

$$B(\boldsymbol{r},\boldsymbol{r}_s) = a\,e^{ik|\boldsymbol{r}-\boldsymbol{r}_s|}\Big/|\boldsymbol{r}-\boldsymbol{r}_s|, \quad (4)$$

where a – dimensionality coefficient that characterizes the magnitude of the source field.

Reconstruction of radioimages

For recovery of radio scattering objects consider the expression (2) with regard to the expression (1):

$$W(\boldsymbol{r}) = |U(\boldsymbol{r})|^2 = |A(\boldsymbol{r}) + B(\boldsymbol{r})|^2 = (A+B)(A+B)^* = |A|^2 + |B|^2 + AB^* + A^*B, \quad (5)$$

where consider that $|A| << |B|$, while; B – is priori known function. Also we can consider that $(AB^* + A^*B) >> |A|^2$, consequently we can calculate function:

$$C(\boldsymbol{r}) = (AB^* + A^*B)\big/(2|B|) \approx (W(\boldsymbol{r}) - |B(\boldsymbol{r})|^2)\big/(2|B|). \quad (6)$$

If rewrite complex numbers $A = a_1 + ia_2$ and $B = b_1 + ib_2$, then $(AB^* + A^*B) = 2(a_1b_1 + a_2b_2)$, in fact, is the twice scalar product (a_1, a_2) and (b_1, b_2), that is $C(\boldsymbol{r})$ – is the projection of vector (a_1, a_2) on unit vector $(b_1, b_2)/|B|$. Value $\tilde{C} = C\frac{B}{|B|}$ has two possible phases: $\arg(B)$ or $\arg(B) + \pi$. If we assume that the phase of the object wave *A* distributed homogeneously from $-\pi$ to π, then the phase of $\tilde{C}$ will have maximum distinction from the phase of *A* less than $\pm\pi/2$. This accuracy of the phase determination is sufficient to the method of space-match filter method of and restoration the image of the object. Equation (6) allows us to calculate from the measured intensity of the field, in fact, the C – is the quadrature of the signal at the point of measurement, the phase of which is measured from the phase of the reference signal *B*.

To restore the radio image of the object will use the method of spatially-matched filtering, where the value $\tilde{C}$ will be considered as a complex wave field in the area of measurement. The image is restored on the basis of measurements at work of source of spherical waves is given by:

$$P(x,y,x_s,y_s) = \iint \tilde{C}(x',y',x_s,y_s) G^*(\boldsymbol{r}',\boldsymbol{r}) G^*(\boldsymbol{r},\boldsymbol{r}_s) dx'dy', \quad (7)$$

where $|\boldsymbol{r}'-\boldsymbol{r}| = \sqrt{(x-x')^2 + (y-y')^2 + z^2}$ – distance from the point of measurement to the point of focusing on the object; $|\boldsymbol{r}-\boldsymbol{r}_s| = \sqrt{(x_s-x)^2 + (y_s-y)^2 + h_1^2}$ – distance from the source to the point of focusing on the object; $\boldsymbol{r}_s = (x_s, y_s, h_2)$ – coordinate of the source on the plane; $\boldsymbol{r}' = (x', y', 0)$ – position of receiver; $\boldsymbol{r} = (x, y, z)$ – point on the object; $\tilde{C}(x',y',x_s,y_s)$ – field in the plane of measurement; function $P(x,y,x_s,y_s)$ is the solution of radio image reconstruction task.

Numerical modeling of radioholographic system

The proposed method of radioholography was simulated numerically at 20 GHz. The form of the object is shown in Fig. 2, the step size is 5 cm. The distance from the receiver matrix to the object – 100 cm, the distance from the transducer to the object – 80 cm. With the help of formulas (1) – (3) was the forward task is solved, that is, determined the intensity of the interference field in the measurement area. Figure 3 shows the intensity of the field from the source of spherical waves. One can see a clear interference pattern formed by the field source and the field scattered by the object.

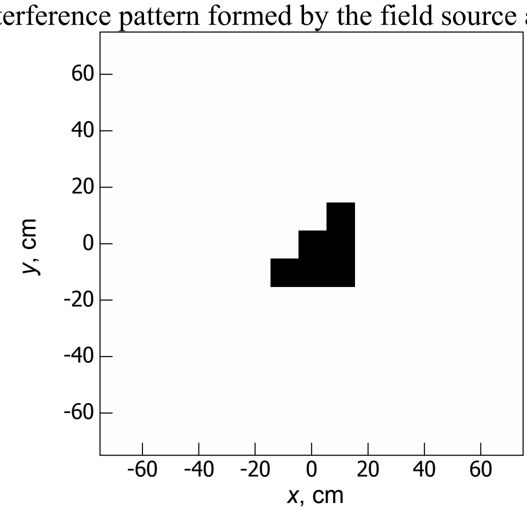

Fig. 2. Image of investigated object.

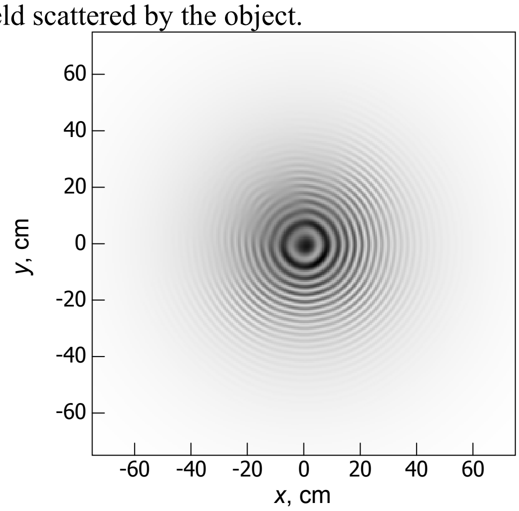

Fig. 3. Intensity of interference field of object and reference signals in the area of signal measurements.

The values of the field intensity, obtained by solving the forward task, have been treated with the help of (6), (7). As a result of the formula (7) was obtained image of the object based on the measurement data using a spherical wave as the reference signal (Fig. 4). Image of the object is clearly identified.

Note that the resolution of the image close to the diffraction limit for the system considered here is 15 mm.

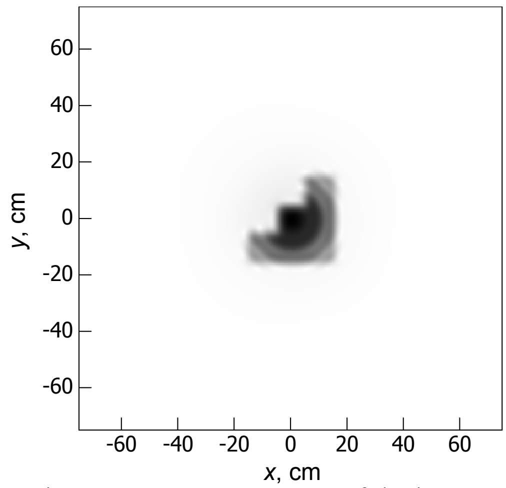

Fig. 4. Reconstructed image of the investigated object.

Conclusion

We propose a method of holographic radio-wave-based measurements of the intensity of the field with a filled matrix of receiving elements using a spherical wave source. A numerical simulation of the proposed system for radio-wave frequency of 20 GHz. Numerical results show that the proposed method allows radio holographic planar images of objects even at the same frequency without broadband scanning by measuring the amplitude of the wave field. The use of higher frequencies can improve the resolution of the reconstructed image. The resulting resolution is close to the diffraction limit, like systems that use phase information. This method can be used in radio-vision systems in the near field. It may also be used in case of passive radar, while using as the radiation source - solar radiation in terahertz range.

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