MATEC Web of Conferences **79**, 01040 (2016) DOI: 10.1051/matecconf/20167901040
IME&T 2016

RADIOTOMOGRAPHY BASED ON MONOSTATIC INTERFERENCE MEASUREMENTS WITH CONTROLLED OSCILLATOR

Dmitry Sukhanov[a], *Kseniya* Zavyalova

Radiophysics Faculty, Tomsk State University, 634050, Tomsk, Russia

Abstract. The method of three-dimensional tomography based on radioholography measurements with the reference signal transmitted by the transmitter in the near zone and the receiver near zone. We solve the problem of repairing the object signal phase due to the reference signal in the near field in a wide frequency band and the consideration of analytical signals. Here are presented results of experimental studies on application of a tunable YIG (yttrium iron garnet) oscillator in the frequency range from 6.5 to 10.7 GHz for radio tomography of metal objects in air. Holographic principle is applied on the basis of measuring of the interference field amplitude by the detector diode. The interference occurs with the direct wave and waves scattered by the object. To restore the radio images the method of aperture synthesis and extraction of quadrature components at all frequencies sensing are applied. Experimental study on test object shows resolution about 15 mm.

1 Introduction

Tomography at microwave frequencies allows to visualize different electrically inhomogeneous objects with high resolution [1–2]. Currently radio tomography systems are quite expensive and not available to the mass consumer. The most common method to recover the three-dimensional image is a method of aperture synthesizing [3] on the basis of the spatial scan by monostatic radar. Impulse ground penetrating radar (GPR) are widespread to study hidden underground objects and irregularities [1–2]. But the scope of the GPR is not limited, GPR actively used for inspection, monitoring of building structures state, roads and engineering structures. To capture short pulse signals highly stable sampling oscilloscope is required, which significantly increases the cost of the system. Alternative of short-pulse sensing is a sensing using monochromatic signal with scanning frequency. Scanning planar aperture with spatial steps less than a quarter wavelength provides the most complete information about the field scattered by objects. Measuring the amplitude and phase of the scattered waves at different frequencies allows to recover three-dimensional images with range resolution when scanning a wide frequency band and

---

[a] Corresponding author:sdy@mail.tsu.ru

without range resolution on probing at the single frequency. To obtain necessary amplitude and phase of the sine and cosine quadratures of the measuring signal. In fact, measurements of a set of quadrature on different frequencies content equivalent information to ultra-wideband short-pulse sensing. However, measurement of quadrature microwave signals is at least technically costly solution as the use of sampling oscilloscopes. Holographic approach is widely used for reconstruction of radio images on single frequencies or for frequency scanning measurements [4–8].

In [9] it was shown that for three-dimensional imaging is sufficient to measure only the cosine signal quadrature. In [9] proposed to use the measurement of the amplitude of the interference field of the direct wave and the wave scattered by objects in the environment. Besides the possibility of visualization of objects hidden underground has been demonstrated [2]. For these measurements, it is possible to apply a scalar network analyzer, but this solution is not applicable for measurements in practice.

In this paper we propose to use a compact microwave YIG oscillator with generated signals in the range from 6.5 to 11 GHz Hewlett-Packard 5086-7343 Oscillator (5.9 – 12.4 GHz) for tomographic measurements. Here is proposed to use the detector diode HSMS - 8101-BLKG. Experiment was conducted on the multi-position sounding of metal object at the distance of 20 cm. The three-dimensional image of the test object has been reconstructed by processing of experimental data. The proposed solution allows to reduce the cost of three-dimensional tomographic systems. The most expensive components of the developed system is a tunable microwave generator.

2 Measurement scheme

It is proposed to consider the scheme of measurements shown in Figure 1.

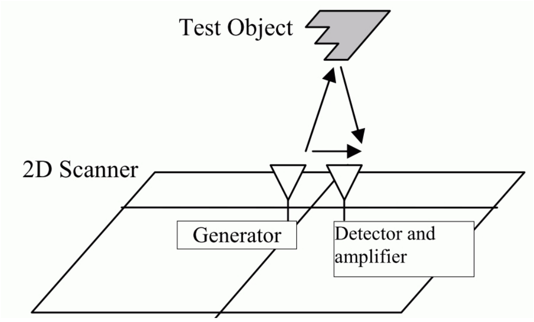

Figure 1. Measurement scheme.

On a two dimensional positioning device has been mounted a unit of the transmitting and receiving antennas (transceiving module). The transmitting antenna is connected to tunable oscillator. Receiving antenna is connected directly to the detector, which is connected to the amplifier. The source antenna irradiates directly receiver antenna and also irradiates the test object.

The scattered from the object wave enters the receiving antenna (object signal), which interferes with the direct signal from the transmitter (reference signal). Assume that the voltage from the detector is proportional to the intensity of the signal in the receiving antenna. Using the interference of object and reference signal the quadrature of signal can be extracted at a current sensing frequency.

We assume that the magnitude of reference signal is much grater than the magnitude of the object signal (at least 10 times). Let us denote $A = |A|\exp(i\alpha)$ – complex magnitude of object signal, $B = |B|\exp(i\beta)$ – complex magnitude of reference signal. Hence the full field in reciewer antenna can be written as the sum: $U = A + B$. Consider that only the intensity $|U|^2$ is measured. The quadrature of object signal has to be extracted from this value. Let us write the value:

$$|U|^2 = (A+B)(A^* + B^*) = |A|^2 + |B|^2 + AB^* + BA^* , \tag{1}$$

and consider that $|A| << |B|$, consequently:

$$|U|^2 - |B|^2 \approx AB^* + BA^* = |A||B|e^{i(\alpha-\beta)} + |A||B|e^{-i(\alpha-\beta)} = |A||B|2\cos(\alpha-\beta).$$

Denote value

$$C = \frac{|U|^2 - |B|^2}{2|B|}e^{i\beta} \tag{2}$$

– reconstructed complex magnitude of object wave in the receiver antenna, where multiplier $\exp(i\beta)$ provides the error of phase reconstruction relatively to reference signal less than $\pm\pi/2$. Assuming that the received signal is analytical applying Hilbert transformation we can recover complete phase of the signals. Hence the measurements are ultra wide band by frequency scanning we can make backward Fourier transformation (to time domain), set to zero negative time part of the signal and then make forward Fourier transformation. This operation allows recovering phase of signals on different frequencies.

The reference signal can be calculated as spherical wave: $B = |B|\exp(ikd)$, where d – distance between the source and receiver antenna, $|B|$ – magnitude of source, which is determined by calibration measurements for current sounding frequency. Besides the reference signal can be written as a solution of the forward task in approximation of the single scattering:

$$A(x, y, \omega) = \iiint\limits_V p(x', y', z')\frac{\exp(2ik|\mathbf{r} - \mathbf{r}'|)}{|\mathbf{r} - \mathbf{r}'|}dx'dy'dz' , \tag{3}$$

where ω – sounding frequency; $p(x', y', z')$ – distribution of scattering heterogeneities; $\mathbf{r}' = (x', y', z')$ – current point on the scattering object; $\mathbf{r} = (x, y, 0)$ – transceiver module coordinates, V – integration volume. In this solution we consider that receiver and source are combined in a single point.

3 Solution of inverse problem

A three-dimensional distribution of scattering heterogeneities has to be restored from the measured intensity in the measurement plane. To solve the inverse problem we use the method described in [9]. The essence of this method is to restore the three-dimensional spatial spectrum of scattering heterogeneities from the measured field plane-waves spectra at different frequencies, according to the formula:

$$\widetilde{P}(k_x, k_y, k_z) = \widetilde{C}\left(k_x, k_y, \frac{c}{2}\sqrt{k_x{}^2 + k_y{}^2 + k_z{}^2}\right), \tag{4}$$

where $\widetilde{P}(k_x,k_y,k_z)$ – spatial spectrum of scattering heterogeneities; $\omega = \frac{c}{2}\sqrt{k_x{}^2 + k_y{}^2 + k_z{}^2}$; $\widetilde{C}(k_x,k_y,\omega)$ – plane wave spectrum of reconstructed field of the object wave in the measurement area at the frequency ω .

Distribution of heterogeneities reconstructed using a three-dimensional Fourier transform:

$$P(x,y,z) = \iiint \widetilde{P}(k_x,k_y,k_z)\exp\left(ik_x x + ik_y y + ik_z z\right)dk_x dk_y dk_z \ . \tag{5}$$

For unambiguous reconstruction of three-dimensional images necessary grid of the frequency with step should be less then $\frac{c}{2R}$, R – distance to the farthest point in the investigated volume. For a larger frequency step with, images of objects will be doubled for different ranges.

4 Experimental studies

To perform experimental studies the laboratory setup has been built. The setup includes: two-dimensional scanner; transceiver module; oscillator YIG Hewlett-Packard 5086-7343 Oscillator (5.9 – 12.4 GHz); detector diode; HSMS – 8101-BLKG. The transceiver module consist of ultra wideband transmitting antenna and ultra wideband receiver antenna (logarithmic patch antenna). The detector diode is connected to low frequency operational amplifier LM 358. The transceiver module scheme is presented on the Figure 2.

Source antenna is located at a distance of 7 cm from the receiving antenna. The flat metal screen mounted between the emitting and receiving antenna allows to decrease and adjust the reference signal level. The excess of the reference signal over the subject signal reached about 10 times by adjusting of the screen position.

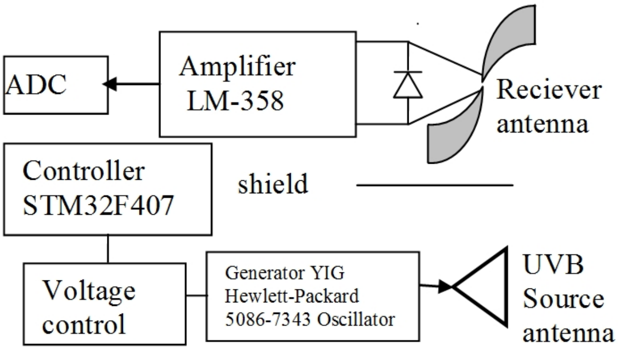

Figure 2. Transciever module scheme.

To start the generator YIG Hewlett-Packard 5086-7343 Oscillator the voltage of 6V is applied to it. The voltage applied to the control coil can be vary from 6 to 11 V to control the frequency. The coil resistance is 50 Ohms. Voltage 6 V provides generation at a frequency of 5.9 GHz, and voltage 12 V provides 1 generation at a frequency of 12.4 GHz. Variation of the voltage on the control coil is controlled by bipolar transistor 2N3055. The transistor base is connected to microcontroller throw optocoupler. By 100mkF capacitor the smoothes of the control voltage is provided. This scheme provides tuning of the frequency generator during the period of 10 ms from 10.7 GHz to 6.5 GHz. Figure 3 shows the frequency of the oscillator as a function of time.

The frequency depends on time nonlinearly, however, there is correspondence between the time and frequency. Therefore the generator frequency can be defined precisely by time. The antenna block is located on the two dimensional scanner, providing positioning region 36 cm on 36 cm with steps of 5 mm. The metal test object has a shape of polygon with the step size of 5 cm. The object has been placed at a distance of 20 cm from the antenna movement plane. Figure 4 shows a photograph of the experimental setup.

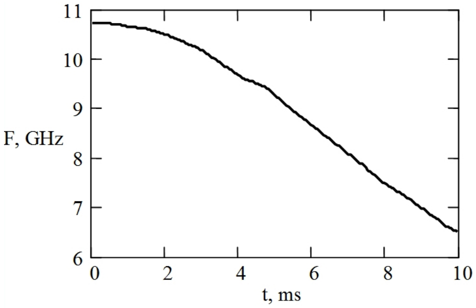

Figure 3. Dependence of oscillator frequency on time during adjustment.

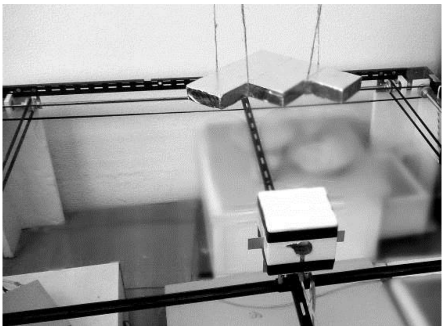

Figure 4. Photography of experimental setup.

Full scanning has been performed on area 36 cm on 36 cm during 10 minutes. As a result of measurements the magnitude of field on 256 frequencies from 10.7 GHz to 6.5 GHz has been acquired. From the measured magnitudes were calculated quadrature signals at different frequencies for the various provisions of the antennas according to the formula (3). Figures 5 and 6 shows a cosine signals quadratures at frequencies of 10 GHz and 6.5 GHz. An interference pattern is clearly observed that indicates the presence of information about the object. The noise level does not exceed the signal level and dynamic range of the measuring system, which is enough to restore quadrature.

Recovered quadratures were processed using the formulas (4 – 5), resulting in a three-dimensional reconstructed image of the investigated volume. In the distance section of 20 cm of 3D image the test object is observed, which is represented in Figure 7. Visual resolution of the reconstructed image by estimating the blurriness of the object edges is about 15 mm.

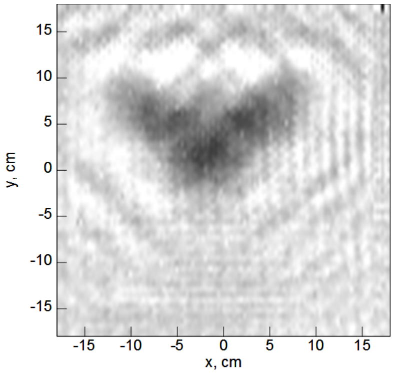

Figure 5. Cosine quadrature on 10 GHz frequency.

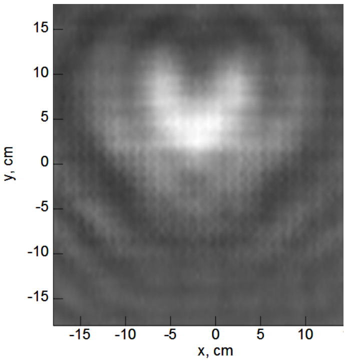

Figure 6.Cosine quadrature on 6.5 GHz frequency.

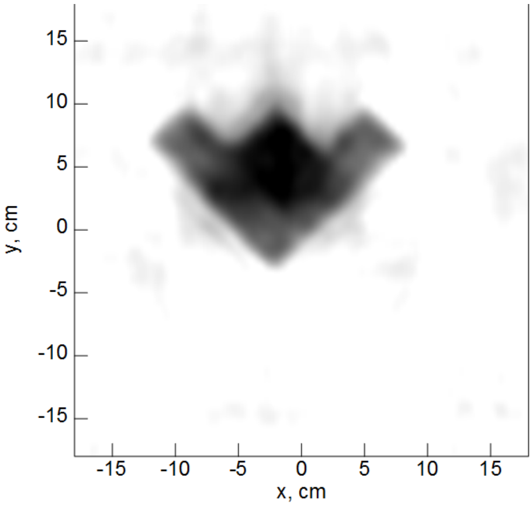

Figure 7.Reconstructed image of the test object.

In addition to the image of the object observed the noise and artifacts. The appearance of the noise associated with outside signals in a reception path circuits. Artifacts caused by the approach of monostatic sounding, but real antennas are not in the same point in space, and are separated by 7 cm. In addition curve of the oscillator frequency from time to time may slightly change according to the transistor 2N3055 temperature. The positioning precision of the two-dimensional scanner is 2 mm also leads to an increase in the noise level. Despite the presence of noise and measurement errors, the image of the test object was restored, which is clearly identified. This result provided by highly stable algorithm for solving of the inverse problem on the basis of the matched filter.

5 Conclusion

In this paper we propose a method of radiowave tomography based on a detector and tunable microwave generator. The result of an experiment of the metal object sensing test at a distance of 20 cm confirmed the presence of an acceptable level of signal-to-noise at all sounding frequencies. The processing of the measured data allowed to restore the image of the test object with a resolution of about 15 mm. Our research demonstrates that the three-dimensional tomography can be created on the basis of low-cost components.

Acknowledgment

The research is supported by Russian Science Foundation project No 16-19-10272.

References

[1] Joaquim Fortuny-Guasch, IEEE Transactions on Geosciences and Remote Sensing **40**, 443 (2002) doi: 10.1109/36.992808
[2] V. P. Yakubov, D. Ya. Sukhanov, Radiophysics and quantum electronics **50**, 299 (2007) doi: 10.1007/s11141-007-0026-8
[3] R.O. Harger, EARSeL Advances in remote sensing **2**, 269 (1993)
[4] E. C. Ngai, 2013 IEEE Antennas and Propagation Society International Symposium (APSURSI), 288 (2013) doi: 10.1109/APS.2013.6710805
[5] A. Popov; I. Prokopovich; V. Kopeikin; D. Edemskij, Proceedings of the 15th International Conference on Ground Penetrating Radar (GPR 2014), 655 (2014) doi: 10.1109/ICGPR.2014.6970507
[6] S.A. Wilson, R.M. Narayanan, M. Rangaswamy, IEEE National Radar Conference – Proceedings **2015**, 925 (2015) doi : 10.1109/RADAR.2015.7131127
[7] Yingzhi Kan, Yongfeng Zhu; Qiang Fu, MATEC Web of Conferences **56**, 02001 (2016) doi: 10.1051/matecconf/20165602001
[8] A. Zhuravlev, S. Ivashov, I. Vasiliev, V. Razevig, 2012 14th International Conference on Ground Penetrating Radar (GPR 2012), 62(2012)
[9] D. Ya. Sukhanov, K. V. Zav'yalova, Technical physics **57**, 819 (2012) doi: 10.1134/S1063784212060229