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RADIOPHYSICS

Remote Ultra-Wideband Tomography of Nonlinear Electronic Components

V. P. Yakubov[a], S. E. Shipilov*[a], R. N. Satarov[a], and A. V. Yurchenko[b]

[a] *National Research Tomsk State University, pr. Lenina 36, Tomsk, 634050 Russia*

[b] *National Research Tomsk Polytechnic University, pr. Lenina 30, Tomsk, 634050 Russia*

**e-mail: s.shipilov@gmail.com*

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Abstract—The efficiency of using ultra-wideband (UWB) signals for nonlinear radar is investigated. In the case at hand, it is necessary to see, based on scattered field disturbances, whether nonlinear inclusions are present in the field of view. The solution suggested is to compare the shapes of UWB signals reflected from the probe area under two conditions: an additional generator irradiating the probe area by intense monochromatic radiation is switched on and off. If a nonlinear electronic component is present in the probe area, the reflected UWB signals differ in shape. Thus, the difference in the shapes of the signals indicates the presence of a component with a nonlinear characteristic.

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INTRODUCTION

The problem considered in this work falls within the domain of so-called nonlinear radar. The aim of nonlinear radar is to locate nonlinear inclusions (if any) in the field of view based on scattered field disturbances. In a first approximation, all probe media are linear, because of which so are the constitutive equations. However, when the irradiation intensity grows, linearity is violated. Usually, this takes place in areas occupied by lumped electronic components (diodes, transistors, chips) or at leaky joints between metallic structures. In the first case, products of an even degree of nonlinearity arise; in the second case, the degree of nonlinearity is odd. This forms the ground for nonlinearity recognition techniques.

Consider how the problems of nonlinear radar are solved. Today, the main problem in this field is to withstand industrial and economic spying. Advanced transmitters and detectors are so small that they may be covered up anywhere, being camouflaged in different consumer devices and interior design items (building constructions). Battery cells with prolonged lifetime provide their operation for several months or even years. To locate such caches by radio radiation is extremely difficult, since many of them can be remotely switched off. Here, nonlinear radio locators come to the rescue [1–3]. They irradiate an object by a monochromatic microwave signal, and the rereflected (reradiated) probe signal at multiple probe frequencies (combination frequencies or harmonics) is then detected. Reradiation at multiple frequencies arises because a potential difference induced on a nonlinear object generates a current nonlinearly related to it. This current contains combination harmonics. The induced variable current is responsible for a reradiated electromagnetic field, which also contains these combination harmonics. Usually, the appearance of such harmonics indicates nonlinearity.

Apart from chance finding by inspection or using X-ray equipment, nonlinear radar remains so far the only means for location of nonradiating electronic components, including damaged components and those with burned *p*–*n* junctions.

Publications on the application of pulsed UWB devices in nonlinear radar are vary scarce. The reason is that a low energy of pulses cannot make nonlinear components show up.

1. UWB TOMOGRAPHY OF NONLINEAR INCLUSIONS

In this work, we study the feasibility of UWB signals for nonlinear radar. Investigation is based on the well-known Luxemburg–Gorky effect (LGE) [4]: the occurrence of cross modulation when radio waves propagate in a nonlinear medium. Under cross modulation conditions, radio waves from a master station operating at carrier frequency $f1$ are received together with a transmission from another station operating at carrier frequency $f2$ differing much from $f1$. This effect was first observed in Eindhoven (Netherlands), 1933, where a Swiss radio station was listened together with the powerful Luxemburg station. The same was observed in Gorky (now Nizhni Novgorod, Russia): stations located west of Moscow and powerful Moscow stations were listened simultaneously. The depth of cross modulation may reach 10% or even more, but usually it is no higher than 1–2%. It is believed that the LGE is a noise source for radio reception.

The LGE theory was proposed by Australian physicists Bailey and Martin (1934–1937), Soviet physicist Ginzburg (1948), and others. Another Soviet physicist, Bonch-Bruevich, was the first to indicate the possibility of cross modulation in the ionosphere (1932). The essence of this phenomenon is as follows: one powerful wave "heats up" the medium, whereas another wave propagates in this medium, transferring information. Both waves experience cross modulation, that is, can "see" each other. Here, we are dealing with the nonlinear cross modulation effect. Physically, this effect is similar to the well-known effect appearing in a mixer when two signals are applied to it simultaneously.

Consider whether this effect can be applied for UWB probing of nonlinear inclusions. Let $E_0(t)$ be a pulsed UWB signal incident on a nonlinear inclusion. Then, up to a factor, the scattered field can be written in the form

$$E_r(t) = E_0(t) + g[E_0(t)],$$

where $g(x)$ specifies the type of nonlinearity. Usually, one can put

$$E_r(t) \approx E_0(t).$$

If an illuminating field, e.g., a powerful microwave monochromatic wave,

$$E_1(t) = A\sin(\omega t + \varphi_1)$$

is added to the incident field, the total scattered field is represented as

$$E_r(t) = E_0(t) + A\sin(\omega t + \varphi_1) + g[E_0(t) + A\sin(\omega t + \varphi_1)].$$

The phase of the monochromatic microwave signal is by no means related to the UWB signal; therefore, we can write upon averaging

$$\langle \tilde{E}_r(t, A)\rangle = E_0(t) + \frac{1}{2\pi}\int_{-\pi}^{\pi} g[E_0(t) + A\sin(\varphi)]d\varphi.$$

This means that a nonlinear inclusion shows up as a truncated averaged scattered pulsed signal. If the illumination intensity is low, the effect will not manifest itself,

$$\langle \tilde{E}_r(t, A \ll |E_0|)\rangle \approx E_0(t).$$

The difference between the obtained signals is an information-carrying quantity in nonlinearity diagnostics. Computer simulation supports this conclusion [5]. It is this effect that is used in our developments.

It should be emphasized that here multiple frequencies are not observed unlike conventional nonlinear radar. Nonlinearity shows up as the distortion of the scattered UWB pulse. The method suggested by the authors is covered by a patent of the Russian Federation [6].

As a source of UWB signals, we used a pulse generator forming 0.2-ns-wide bipolar pulses. Signals were emitted by a UWB antenna into the space with a probed diode. The same UWB antenna received the reflected signal, which was applied to a UWB amplifier and then to a gate UWB detector. After digitization, the signal was applied to a computer. A nonlinear component was 100 cm distant from the receiving and transmitting UWB antennas. A monochromatic wave with a frequency of 850 MHz was applied to the probe zone. The monochromatic signal generator was switched on and off synchronously with the instant of UWB signal reception. When an odd (even) UWB signal was obtained, the generator was switched off (on). The power of the microwave generator at which the amplitude difference between received signals exceeds the statistical error, that is, suffices to locate a nonlinear component, was equal to 4–5 W.

Figure 1 shows typical waveforms of signals detected at UWB probing of a D20 diode in the absence (*1*) and presence (*2*) of microwave radiation, along with a difference signal (*3*). The diode was not terminated and represented a loose commercial component. The difference signal is seen to be 20–25%, which is a quite significant value and exceeds the noise level of the gate detector. Some sluggishness (delay) of the diode's nonlinear response is seen. Similar characteristics were observed for a number of other inclusions as well.

2. UWB TOMOGRAPHY DATA FOR NONLINEAR INCLUSIONS

The method of linear rf tomography was described at length elsewhere [7]. Data are obtained by 2D UWB radar scanning of a given scene with a preset step. At each point the scanner was stopped, the scene was probed with and without microwave radiation by an intense monochromatic radiation. Scanning was performed by automatically displacing the antenna unit. Tomographic data arrays were processed and nonlinear inclusions were located with appropriate software.

In the course of experiments, three inhomogeneities were placed in between two gas–concrete blocks 10 cm thick (Fig. 2). Two of them were 2 × 2-cm plane squares made of aluminum foil, and the third one atop

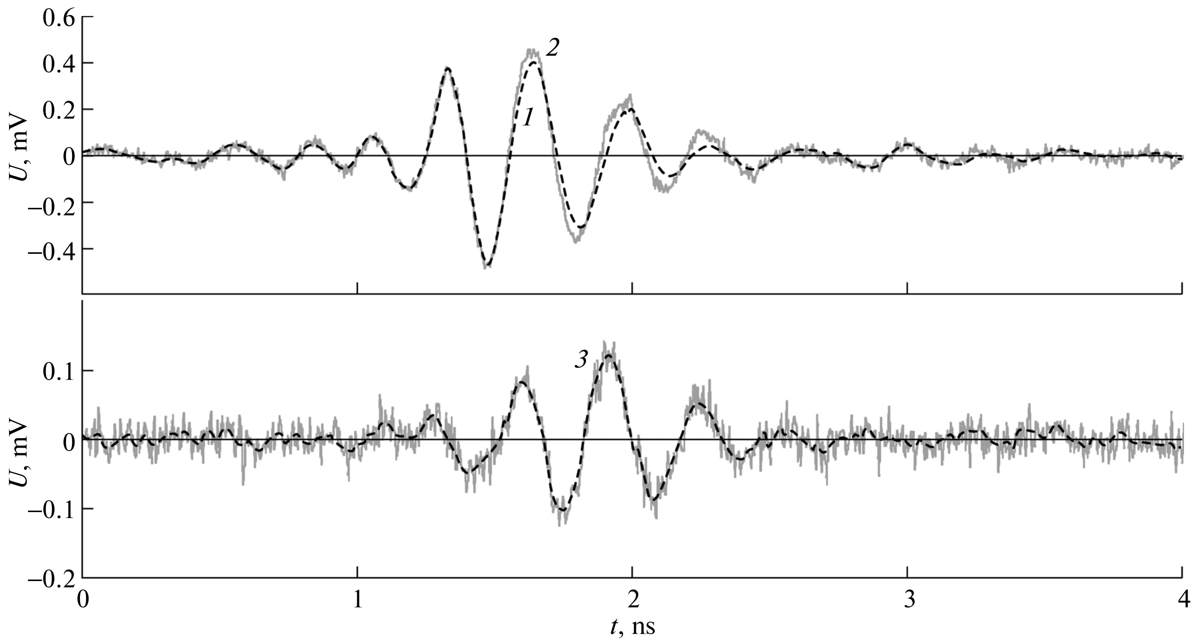

Fig. 1. Waveforms of the signals used in UWB probing of the D20 diode (*1*) without and (*2*) with microwave radiation. (*3*) Difference signal.

was a 2-cm-long microwave detector diode. The results of tomographic processing of experimental findings are presented in Fig. 3.

The reconstructed radio image represents a 33 × 33-cm field of vision at a depth of 10 cm from the surface. The radio image of the inhomogeneities that was obtained by linear rf tomography is shown in Fig. 3a. All three inhomogeneities are distinctly seen. Two lower inhomogeneities are 2 × 2-cm plane squares made of aluminum foil, and the upper one is the detector diode 2 cm long. Figure 3b is the radio image obtained using the method of tomographic location of nonlinear components. It is seen from this figure that the method developed in this work allows one to distinguish electronic components from different inhomogeneous inclusions. Thus, our experiments confirm the efficiency of the method suggested.

Fig. 2. Test scene of inhomogeneities placed in between gas–concrete blocks.

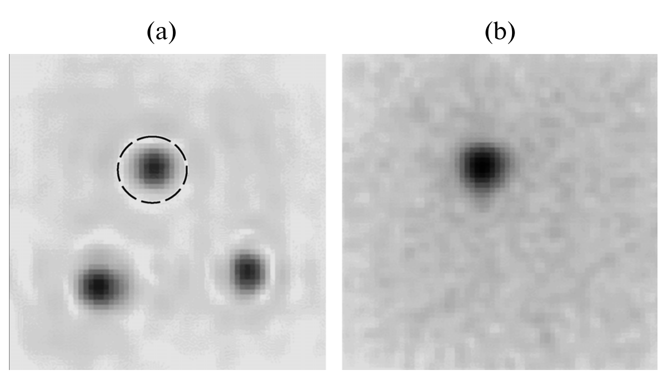

Fig. 3. 3D image taken at a depth of 10 cm inside the gas–concrete block using (a) linear rf tomography and (b) the method suggested.

CONCLUSIONS

The feasibility of UWB radiation for rf tomography of artificial nonlinear inclusions opens up wide possibilities in 3D tomography. Unlike conventional nonlinear radar, the new approach does not rely on combination frequency separation. However, it is necessary to additionally probe test objects by a powerful microwave radiation to highlight their nonlinear properties when UWB probe radiation is used.

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