

PARAMETRIC NONLINEAR LOCATOR

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Abstract. The device relates to the field of radar techniques for locating or objects detecting using reflection or reradiation of radio waves. This device can be used to detect and identify the objects containing non-linear electrical contacts. The non-linear radar contains two sources of signals that generate the signals in close frequency rangers, and a signal combining scheme associated with the antenna. The source of the first signal is provided with a low-frequency modulator. A vector reflectometer is included between the source of the second signal and the signal combining circuit. The design is simplified and the detectability of the non-linear radar is improved due to these design features.

1 Justification of the structural scheme

The device is intended for detecting and identifying the objects containing non-linear electrical contacts such as a metal-metal, a semiconductor-metal or a semiconductor-semiconductor, for example, the concealed weapons or the electronic devices for unauthorized retrieval of information. The operation of the most nonlinear radars is based on the reception of harmonics of a powerful probing signal. In contrast, the concept of parametric nonlinear location [1] implies a change in reflection from a nonlinear object under the action of an additional usually electromagnetic effect. A typical example is a two-frequency locator [2] containing two sources of signals that generate the signals with close-range frequencies f_1 and f_2 and the signal combining circuit associated with the antenna. This radar contains a receiver capable to receive the signals besides the harmonics of frequencies f_1 and f_2 at the sum and difference frequencies that do not coincide with the harmonics of frequencies f_1 and f_2 . As a result, the design is simplified by reducing the requirements for suppressing harmonics. Nevertheless the additional antennas of the appropriate ranges are needed to receive these signals since the sum and difference signals are far away from the transmitted signals by frequencies. This circumstance leads to a complication in the design. In addition a high level of both sounding signals is required for the formation of combinative (sum and difference) signals, and this requires a doubled number of powerful amplifying cascades. The radar's detectability is low under the limited power of the amplifiers.

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In this paper we solve the problem of combining the advantage of a simpler scheme for selecting of harmonics in a two-frequency locator and the advantage of a smaller number of powerful amplifying cascades in a single-frequency locator. The source of the first signal is provided with a low-frequency modulator for this in the nonlinear radar containing two signal sources that generate signals in close frequency rangers and a signal combining circuit associated with the antenna. And a vector reflectometer is switched between the source of the second signal and the signal combining circuit. The result is an improvement in the detectability of a non-linear radar and a simplification of its design.

In the circuit under study the low-frequency modulator of the first signal provides a time-dependent build-up of the nonlinear characteristic of the object. Wherein its averaged conductivity at different frequencies, including at the frequency of the second signal, is also modulated. The vector reflectometer in the second signal channel provides a formation of the modulated response in accordance with the modulation law of the first signal. It is unnecessary to increase the power of the second signal to the power level of the first signal to obtain a modulated response. Due to this the design of the nonlinear radar is simplified by reducing the number of powerful amplifying cascades. The design is also simplified at the expense of using the only antenna needed for transmitting the first and second signals as well as for receiving the reflected modulated signal at the frequency of f_2 .

The improvement of the detectability in comparison with the known scheme is due to the nature of the spectrum of the build-up of the nonlinear volt-ampere characteristic of the object by a powerful signal. The appearance of harmonics or combinative frequencies is associated with the effect of harmonic fluctuations on a nonlinear element. As a rule, semiconductor elements have an exponential volt-ampere characteristic. The harmonics of the current J_n are proportional to the modified Bessel functions of the first type $I_n(Z)$ under the influence of the harmonic signal with a relative amplitude Z . The conductivity G in the element with the exponential volt-ampere characteristic is proportional to the current, that is it contains harmonics, which are also proportional to the functions $I_n(Z)$. The second harmonic of the current, that responsible for the formation of the received signal in a conventional nonlinear radar, is proportional to $I_2(Z)$. In the scheme under study the average conductivity G , that is proportional to $I_0(Z)$ and receives a small increment δ under the influence of the first signal, is responsible for the formation of the signal entering the reflectometer. Considering the expansion of the functions $I_n(Z)$ into series in accordance with the well-known formula

$$I_n(Z) = \sum_{k=0}^{\infty} \frac{\left(\frac{Z}{2}\right)^{2k+n}}{k! \Gamma(k+n+1)} \quad (1)$$

one can see that the current component at the second harmonic is proportional to $\frac{Z^2}{8}$, while

the change of the average conductivity is proportional to $\frac{Z^2}{4}$, that is twice more then for the

second harmonic. Besides the detection efficiency is enhanced on account of the nature of signal processing in the vector reflectometer. The signal generated in the reflectometer is

proportional to $\frac{(1-\delta G)}{(1+\delta G)} \approx 1-2\delta G$ according to the relation between the conductivity of an

element and its reflection coefficient. Due to this circumstance the conductivity modulation appears in the reflected signal twice as effectively as in the case of a harmonic response in a

conventional nonlinear locator. In other words, the advantage of coherent detection is realized in comparison with quadratic detection. These considerations confirm an improvement in the detectability in the proposed scheme.

2 Experimental results

The model of the nonlinear radar based on laboratory radio measuring instruments was assembled and tested in accordance with the structural diagram (Figure 1).

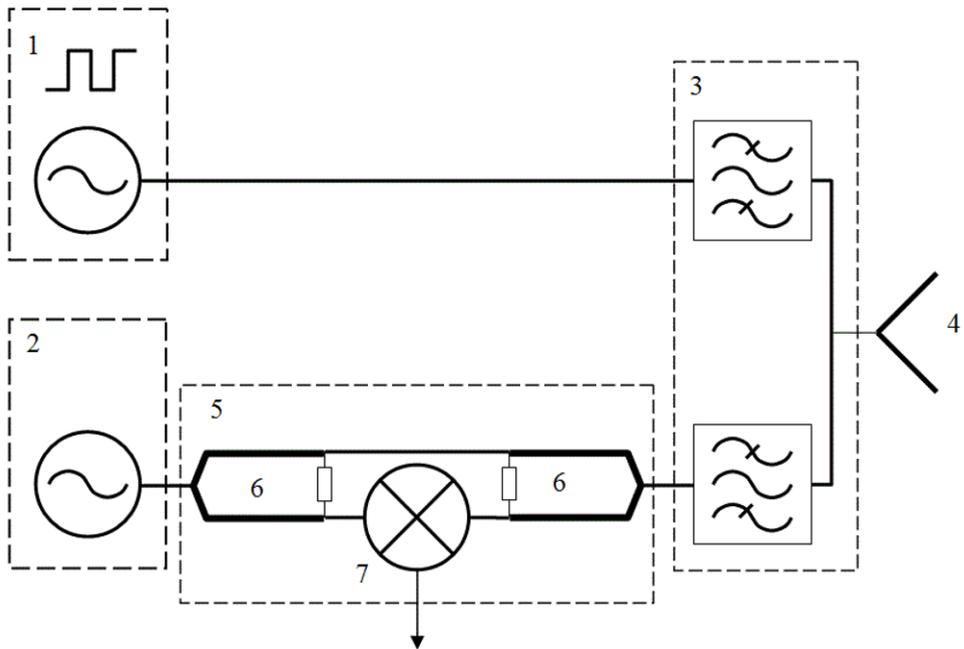


Fig. 1. Structural diagram of the model of the parametric nonlinear locator.

The generators of standard signals are used as the sources of microwave oscillations. The first generator 1 operates at the frequency of 1300 MHz in the mode of internal amplitude modulation of 1 KHz, the second generator 2 operates in continuous generation mode at the frequency of 1600 MHz. The power of the generators is 60-80 mW. The signal combining circuit 3 is made on five-link pintle filters and provides independent relation of the frequency channels with the antenna. The antenna 4 has the form of a vibrator above the plane, equipped with one director to expand band of reconciliation frequencies. The reflectometer 5 is represented by the combination of Wilkinson's three-decibel divisors 6 with the balance mixer 7. The output signal is amplified by a selective microvoltmeter and is observed on an oscilloscope. The antenna is directed to the object possessing the nonlinear volt-ampere characteristic. The reflection coefficient of the object at the frequency of the second source also turns out to be modulated in accordance with the law of modulation of the first generator. As a result, a low frequency signal indicating the presence of a nonlinear object in the antenna coverage zone is generated in the vector reflectometer.

With the indicated power values this scheme ensured the detection of typical test objects at a distance of up to 0.5 m, which is comparable with similar indicators of serially produced non-linear radars with power of about 1 W.

3 Prospects for characteristics improvement

The increase in the energy potential of the nonlinear locator is primarily connected with the increase in the power of the modulating signal of the frequency f_1 . The specificity of the parametric method of nonlinear location consists in the presence of two fundamentally different signals: the first signal must be powerful enough to change the conductivity of the nonlinear object, and the second one can have an arbitrary power, that would provide the excess of the noise threshold.

In accordance with the formula (1) the modulation effect of the average conductivity of the nonlinear object is proportional to the square of the amplitude of the field Z , respectively, this effect is inversely proportional to the square of the distance to the object D . We emphasize that for the nonlinear locator the key parameter is the extent of buildup, which is characterized by a certain "threshold" level for a semiconductor element. The Z_{cr} level is the critical for a reliable detection of nonlinearity. The specific gravity of the higher terms of the expansion in the formula (1) begins to increase at this level. The reflection coefficient of the object acquires a noticeable modulated increment if this level is exceeded.

We select in the field of view of sounding antenna the elementary cell possessing a nonlinearity and that has the reflection coefficient K_{neg} at the frequency f_2 . The possibility of registering the increments of the reflected signal at the frequency f_2 is limited mainly by its excess over the amplitude and phase noises of the generator. As a rule in the radius of the nonlinear locator action this excess remains big enough and weakening of the reflected sounding signal, that is proportional to the fourth extent of the distance, is easily compensated by amplification increase. Thus, within certain limits the threshold power of the modulating signal can remain proportional to the detection distance in the second extent, and not in the fourth extent or more, as it happens in the locators of traditional structure.

The above arguments are illustrated by the diagram in Figure 2.

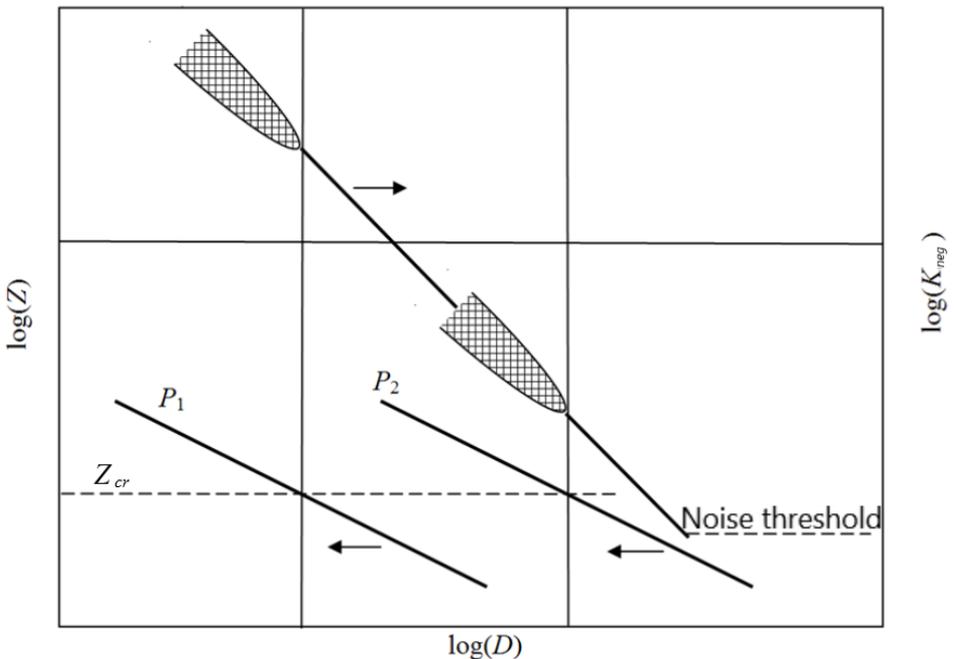


Fig. 2. The diagram of signal levels in the parametric nonlinear locator.

The distances D to the object are plotted along the horizontal axis on a logarithmic scale, and the characteristic levels of signals are plotted along the vertical axes as well on a logarithmic scale. The lines with the signatures of P_1 and P_2 correspond to two different power levels of the modulating signal, and relating to them the vertical axis from the left corresponds to the buildup level Z of the nonlinear element. The slope of the lines takes into account the weakening of the signal in proportion to the square of the distance. The Z_{cr} level corresponds to the threshold of nonlinearity demonstration. The line with the hatching areas, referring to the vertical axis to the right, corresponds to the transmission coefficient of the sounding signal K_{neg} . The hatching areas reflect the variations in the reflection coefficient observed under the action of the modulating signal at the powers P_1 and P_2 . The slope of the line corresponds to weakening of the signal in proportion to the fourth extent of the distance. The dotted line conditionally displays the noise threshold of the sounding circuit, determined mainly by the amplitude noises of the frequency generator f_2 . The location of the areas in which variations in the reflected signal are manifested under the action of the modulating signal, relative to the noise threshold, evidences that the detection distance which is far from this threshold depends solely on the efficiency of the build-up of the nonlinear element by the modulating signal, that is. This distance is proportional to the ratio of the power of the frequency generator f_2 to the square of the distance to the object.

We use the basic radar equation from [3] to estimate the relation between the signal levels and the noise threshold of the sounding circuit:

$$P_c = \frac{P_1 D_a S_{effc} S_{effa}}{(4\pi)^2 D^4}, \tag{2}$$

where P_c is the power of the received signal, D_a is the factor of directed action of the antenna. S_{effc} is the scattering area of the target, S_{effa} is the effective area of the antenna, D is the distance, herewith the factor of directed action and the effective area of the antenna at the wavelength of λ are related by (3):

$$D_a = \frac{4\pi S_{effa}}{\lambda^2}. \tag{3}$$

We substitute in these formulas the values of the wavelength equaled 0.19 m for the frequency $f_2 = 1600$ MHz, the antenna size is of the order of $\frac{\lambda}{2}$, the area of the tested object is of the order of 10^{-4}m^2 (1 square centimeter) and the distance is 1 m. Under these conditions the ratio of the received and emitted signals is -56 dB. Taking into account that the dynamic range of modern vector analyzers reaches 120 dB, it can be judged that the range of measured signals at the distances in units of meters is much higher than the noise threshold, so that the operability of the circuit under investigation is actually determined mainly by the power of the modulating signal. Thus, we can expect an increase in the distance detection of test objects in 4 times, that is up to 2 m if the power of the modulating signal is increased from the above value of 60 mW to 1 W, that is approximately in 16 times.

Improving the operational characteristics of the circuit under study is also associated with eliminating so-called "blind" distances in which the modulation of the reflection from the object is perceived in the mixer as phase modulation and does not produce the desired response. In connection with this the reflectometer in the diagram of Figure 1 should be equipped with a quadrature channel. In this case the "blind" distances will differ by a quarter of the wavelength and the signal will be detected at least in one of the channels.

The integrated microcircuits of generators, amplifiers and mixers as well as a planar antenna and miniature dielectric filters will be applied in the projected pilot sample of the parametric nonlinear locator.

4 Conclusion

The considered scheme of the parametric nonlinear locator with a relatively powerful modulating signal and a relatively low-power sounding signal differs significantly from the analogues of simple design. At the same time it is able not to concede in the detectability to known constructions and even probably to surpass them.

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