EVALUATION OF VISIBILITY PHENOMENON IN CLEARANCES OF CLUTTER IN THE SHORT-RANGE RADAR

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This work considers methods of pinpoint targets visibility improvement against the background of an underlying surface and terrain features with respect to advanced radars in case of increasing a spatial resolution. There have been revealed peculiarities of a radar image which are characteristic of short-range radars with a high spatial resolution. This work also illustrates the phenomenon of interclutter visibility (IV) for a practically important case of clutter from an underlying surface; it also introduced a quantitative evaluation (measure) of such phenomenon.

1. INTRODUCTION

Development of multifunctional radars (MFR) to meet manifold challenges, which are characteristic of earlier radar versions of various classes, is one of the main trends in the radiolocation development over the last decades. This trend leads to the necessity to ensure that MFR meets a range of conflicting requirements, for example, a simultaneous detection of dynamic airborne objects (which requires a high rate of surveillance) and low-speed land-based objects (which requires a long-time surveillance for a good moving target indication). Such trend is most pronounced in short-range radars (SRR) in view of the economic feasibility of solving their inherent problems (for example, sites protection) by a heterogeneous fleet of highly specialized radars. That is why SRR should be constructed as MFR.

Solving one of the most important problems concerning detection and tracking of low-flying objects with low values of radar cross section (RCS) (for example, remotely piloted aircraft RPA) against the background of the reflection from underlying surfaces and terrain features (TF) requires an increase in space surveillance rate (scanning rate). Depletion of the series of reflected echo signals, what becomes a factor determining a decreasing the scanning rate. Under conditions of a “lean” series of echo signals, what becomes a factor determining a reachable suppression depth for binomial-weight canceler (BWC) algorithms of various ratios in radar with mechanical antenna scanning in azimuth is the impact of an incidental amplitude modulation of the series by radiation pattern (in azimuth plane) [1].

A result of MTI procedures \( P_{c\text{out}} \) directly depends on the depth of a clutter at the input of MTI device.

\[
P_{c\text{out}} = P_{c\text{in}} / K_t ,
\]

where: \( K_t \) – echo signal rejection ratio from the underlying surface by MTI procedures.

With regard to most civil application of radars it is possible to withdraw from registering the power of jamming. In such case the power of clutter of MTI systems \( P_{c\text{in}} \) is determined basically by the main clutter signal caused by reflections from the underlying “background” surface \( P_b \). At the same time the given power directly depends on the spatial resolution of radar. This circumstance enables to reduce the power of the clutter signal from the underlying surface at the input of radar receiver, which is equivalent to an increase in MTI procedures efficiency, increasing a range resolution (reducing \( \Delta R \)). The power of background components (clutter) of the reflected echo signal is determined by the following expression:

\[
P_b = \frac{P_p G^2 \lambda^2 \Delta R \cdot \Delta \theta_{az} \cdot R \cdot \sigma_0 \cdot F \cdot K_e}{(4\pi)^3 \cdot R^4 \cdot \sin(\theta_{ea})} ,
\]

where: \( \Delta R \) – radar range resolution, \( \Delta \theta_{az} \) – radar azimuth resolution, \( \theta_{ea} \) – elevation angle (from nadir), at which a resolution element can be observed, \( F \) – attenuation at a propagation path, \( P_p \) – radar pulse power, \( \lambda \) – wave length, \( \sigma_0 \) – specific RCS of a resolution cell, \( G_a \) – antenna power gain.

One of the main ways of improving the selective identification properties of SRR, that is, resolution enhancement, has been formed for these purposes. This way of improving the selective identification properties of radar in combination with the absence of side lobes of discrimination function (DF) by range with an impulse probing signal (PS) was offered and researched within the framework of ultra-short pulse (USP) radar technology [2–5]. The area of the element, “covered” by the main lobe of discrimination function, serves as a resolving power measure as applied to a jamming signal from the underlying surface in USP radars. The use of probing pulses with duration (about 10 ns) twice as little as in traditional radars for USP radars enables to reduce the power of clutter at the input of MTI device. At the same time the radar images, obtained in the course of radars full-scale tests under USP radar technology [4], in most situations enable to view land-based and low-altitude small-size objects at a primary indicator even without an application of MTI procedures.

2. AN EXTENT OF THE INTERCLUTTER VISIBILITY (ICV) PHENOMENON

In line with the mentioned advantage of reducing the clutter power, we can observe the interclutter visibility (ICV) phenomenon in USP radars. The ICV phenomenon is mentioned in [1] as applied to the regions of space

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unoccupied by clutter. This phenomenon is mentioned in [6] as distinctiveness in passive interclutter (DPI), which is characteristic of radars with a high spatial resolution. Interclutter regions should be understood as: shadow areas; areas not occupied by clouds of hydrometeors (in case of an antenna beam separation from the surface), and other zones with a medium intensity of the echo signal at the level of self-noises of a receiving and recording equipment.

Thus, the factors of enhancement of small-size objects visibility against the clutter background in case of increasing the range resolution are determined by:

1. reduction of the area of a surface collector element (by space volume contraction), which affects the clutter power at the input (MTI devices) of radar receiver;
2. in case of an increase in the range resolution it is determined by dividing a continuous extended area, affected by clutter from the surface, into the areas with a reflection and the areas free from clutter (ICV phenomenon).

We are going to illustrate these factors by data from full-scale experiments obtained using USP radar [7]. An observation of wave-covered water can serve as an example, in case if the resolution capacity of radar enables to severally observe individual crests of waves and areas between them (refer to Figs. 1 and 2). In case of PP (probing pulse) duration of 10 ns, the amounts of echo signals which exceeded threshold (determinate by noises) in the presented area is 14 % of the total analyzed area. This is a percent of a radar image (RI) affected by clutter, whereas with duration of 100 ns the extent of threshold excess amounts to 74.1 % of the same area of analysis section.

Unfortunately, instability of the water surface prevents from confident division of threshold excess by echo-signals from a small-size object and from individual waves in accordance with obtained experimental data. (This limitation can be omitted for other types of radars). That is why it is necessary to concentrate on the analysis of echo signals reflection from the land surface, where dimensional stability of the position of reflecting elements groups exceeds analysis time.

Figures 3 and 4 presents the radar images (RI) of a terrain sector that includes a motorway bridge (2), a road and a forest edge (3), obtained using two types of probing signals: a short radio pulse 10 ns and linear frequency modulation (LFM) of a similar band signal (with the same base 100). Radar images have been obtained without changing the equipment parameters at an interval of 1 second (through the surveillance). As can be seen from Fig. 3 a significant part of RI area is not affected by clutter. The shadow area, formed behind the bridge (shown in Fig. 3 on RI) and obtained using LFM of a signal, is to a large degree closed by the side lobes of the selection function (SF).

Fig. 3 – Experimentally obtained RI with short pulse as a probing signal.

Fig. 4 – Experimentally obtained RI with LFM as a probing signal.

In [6] it is noted that although the ICV phenomenon has been known long ago no quantitative measure for its evaluation has been offered yet. That is why the article offers such a measure for a significant individual case, at which clutter is represented by reflections from the underlying surface.
In the capacity of such a measure we will introduce the concept of a fill factor of the initial RI array with respect to clutter $K_{fc}$ as the ratio of the number of elements ($N_c$) of the initial RI array discrimination, in which the average strength of a received signal exceeds the power of radar self-noise, to the general number of discriminated elements ($N_{Σ}$) expressed as a percentage:

$$K_{fc} = \frac{N_c}{N_{Σ}} \cdot 100\%.$$  \hfill (3)

The ICV measure, introduced in such a manner, turns out to be materially dependent on features and parameters of specific radar. Indeed, two different radars (different in the resolution capacity) in the course of surveying one and the same area of the underlying surface have different values of the fill factor. Won’t it become a hindrance to a practical use of $K_{fc}$? By no means! The ICV phenomenon itself does not exist in isolation from the radar observing it. Stability of a clocking angle and a time reference of formed RI to a locality is a key factor for determining the fill factor of the initial RI array with respect to clutter and a practical use of ICV phenomenon in radars with a high spatial resolution. This circumstance requires fulfillment of the condition that each reflecting element of a terrain should not be shifted between RI resolution cells during entire analysis time.

For experimental determination of the fill factor values for initial RI with respect to clutter a series of RI shots was taken (more than 100 shots). An averaged map of initial RI was formed by the given sequence of shots. It enabled to proceed from work with a casual fluctuating echo signal in each element of the resolution to the assessments of the expected values of the echo signal strength.

### 3. EXPERIMENTAL EVALUATIONS OF ICV PHENOMENON

Let’s consider values $K_{fc}$ using the example of RI of the land section, obtained by SRR from PS with duration of 10 ns (refer to Figure 5).

The values of the experimentally obtained fill factors of the primary radar image with respect to the clutter are presented in Table 1.

### Table 1

<table>
<thead>
<tr>
<th>No</th>
<th>Surface type</th>
<th>$K_{fc}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>trembling grass</td>
<td>53.3%</td>
</tr>
<tr>
<td>2</td>
<td>forest edge</td>
<td>49.0%</td>
</tr>
<tr>
<td>3</td>
<td>trees tops</td>
<td>23.1%</td>
</tr>
<tr>
<td>4</td>
<td>low-rise development</td>
<td>12.0%</td>
</tr>
</tbody>
</table>

The analysis of RIs, obtained in the course of experimental works, enabled to distinguish the peculiarities of the radar images that had been received by USP (ultra-short pulse) SRR:

- high refinement, contrast range and stability of RI,
- a considerable proportion of areas to the radio horizons that are free of clutter.

Due to the fact that the radar equipment, which is used for experimental works, enables to change the type and duration of the probing signals (PS) we have researched dependence $K_{fc}$ on PS duration. The relevant schedule is presented in Fig. 6.

As expected, after observing a number of RI (for example, Fig. 1) obtained from one and the same terrain sector with different PS duration, a reduction in the size of the spatial resolution element leads to the reduction in the share of RI elements affected by clutter.

The resolution cells division into clutter-affected and free of clutter is largely specific to SRR of high spatial resolution. This circumstance contemplates various processing individually for each RI element for the purpose of complete implementation of obtained high spatial resolution advantages. In particular, it contemplates elimination of MTI procedures in those spheres of RI, which are not affected by clutter, and enables to avoid unnecessary losses in the course of processing the received echo signal, which is equivalent to the advantage in radar potential [8].

The introduced ICV measure enables to optimize the used algorithms of radar data processing in SRR that solve problems, for example, of: provision of safety and security of territories, airfield surveillance [9] and etc.

### 4. CONCLUSIONS

Subject to the results of experimental research the peculiarities of RI have been revealed, which are characteristic of SRR with high spatial resolution: in particular, ICV phenomenon. The measure of that phenomenon was introduced in the form of the fill factor of the primary radio image with respect to clutter $K_{fc}$.  

![Fig. 5 – Original RI for determining the clutter fill factors for various types of surfaces.](image-url)
A one-to-one association of value $K_{fc}$ to the spatial resolution capacity of radar was revealed.

The necessity and efficiency of a pixel-by-pixel statistical analysis of RI was shown in SRR with high spatial resolution, as well as an elimination of MTI procedures for significant parts of RI. As a result a useful signal suppression is eliminated from objects in MTI procedure (including “blind” speeds), which enables to detect objects with lower values of RCS.

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