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ON SOME PROBLEMS OF THE IMPLEMENTATION OF MOVING TARGET INDICATION SYSTEMS IN SMOOTH SCANNING RADARS [+)]

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Abstract

The paper is dedicated to the problem for selection of passive noise correlation function form and the influence of antenna scanning on the improvement factor assessments of moving target indication systems in smoothly scanning radars.

Analysis

The design methodology of modern scanning radars is mainly directed to the problem of moving targets' effective detection. A number of fundamental monographs (see [1], [2], [3], [4]) and a persistently increasing number of papers are devoted to the theory and design of moving target indication (MTI) systems. Lately, permanent scientific interest in the problem is being witnessed.

An MTI system consists of (cf. Fig.1): phase detector (FD) with a noise phase correction device (NPCD), rejection filter (RF) and integrator (accumulator) with a threshold device.

The system's main unit is RF that plays a central role in interperiod processing. RF increases the signal-to-noise ratio and decorrelates noise in the compensation process.

The improvement factor ν is to be regarded as a universal quality index for the MTI systems [3]. The improvement factor ν also characterizes the quality of RF. The improvement factor ν is defined as a ratio of the

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ratios of the signal's average powers and noise in the RF's output and input, accordingly:

(1) $$\nu = \frac{\left(\overline{P}_s / P_N\right)_{out}}{\left(\overline{P}_s / P_N\right)_{in}},$$

where $\left(\overline{P}_s / P_N\right)_{out}$ and $\left(\overline{P}_s / P_N\right)_{in}$ are the output and input power ratios averaged by all target velocities.

We discuss problems affecting the value of the RF factor ν of the MTI systems in smoothly scanning radars, which are insufficiently highlighted in literature, namely: the selection of the interperiod correlation function form of passive noise and the influence of antenna beam scanning. Different authors are unanimous on the possibility for the form of the fluctuation interperiod correlation function to be approximately presented by an exponent (cf. [2], [6]):

(2) $$r_{k,l}^{s} = \exp\left(-\left|k-l\right|\frac{T_p}{\tau_s}\right),$$

where T_p is the period of the radar pulse sequence and τ_s is the correlation time of the reflected signal fluctuations. However, an uncertainty exists on the problem for the form of the passive noise interperiod correlation function. Some authors are advocates of the exponential approximation (cf. [2], [6], [8]), i.e.

(3) $$r_{k,l}^{N} = \exp\left(-\left|k-l\right|\frac{T_p}{\tau_N}\right),$$

where τ_N is the correlation time of the passive noise fluctuations. While other authors (cf. [1], [3], [7], [8]) recommend an approximation by a Gaussian curve:

(4) $$r_{k,l}^{N} = \exp-\left(\left|k-l\right|\frac{T_p}{\tau_N}\right)^2.$$

When the form of the correlation function is taken to be of form (3), the optimal RF consists of a device carrying out a one-time overperiod subtraction (OTOPS) with attenuation in the holding channel that corresponds to the coefficient of the noise interperiod correlation (cf. [2], [4]).

When using Gaussian correlation function, the RF structure that provides an optimal compensation is known only in a particular case $r_N \to 1$ and is coming to a OTOPS with maximal frequency rate $m = L - 1$, where L is the number of pulses in the package (see [2], [4]).

In coherent-pulse radars with frequency repetition (F_r) of the order of hundreds of Hz to units of kHz, OTOPS implementation devices with different frequency rates m are widely applied as RFs. At that, the value of v in the output is:

(5) $$v = \frac{\sum_{k=1}^{m+1}\sum_{l=1}^{m+1} C_m^{k-1} C_m^{l-1} (-1)^{k+l} e^{-i(k-l)(\Delta v - \Delta\varphi)} r_{k,l}^{s}}{\sum_{k=1}^{m+1}\sum_{l=1}^{m+1} C_m^{k-1} C_m^{l-1} (-1)^{k+l} e^{-i(k-l)(\Delta\psi - \Delta\varphi)} r_{k,l}^{N}},$$

where C_m^{k-1} and C_m^{l-1} are binomial coefficients, $(\Delta v - \Delta\varphi)$ and $(\Delta\psi - \Delta\varphi)$ are Doppler phase accumulation for the signal and the noise during the radar's time T_p. Making a correlation of the noise phase Doppler shift $\Delta\varphi = \Delta\psi = \Omega_{DN} T_p$, the denominator in (5) takes real value components.

Comparative assessment of v for two utmost forms is to be made under one and the same noise correlation time, i.e.

(6) $$\int_0^\infty e^{-\tau} d\tau = \int_0^\infty e^{-\beta^2 \tau^2} d\tau .$$

The condition is fulfilled at $\beta = \frac{\sqrt{\pi}}{2}$. We obtain:

(7) $$r_{k,l}^{e} = e^{-\frac{|k-l| T_p}{\tau_N}} \quad \text{and} \quad r_{k,l}^{G} = e^{-\left(\frac{\sqrt{\pi}}{2}\right)^2 \left(\frac{|k-l| T_p}{\tau_N}\right)^2}.$$

A diagram of the RF factor v at m = 1, 2, and 3 for the exponential and Gaussian approximation is given in Fig.2 (see $v_{\exp}$ and v_G). When increasing the RF elements number, the obtained computed v value for the Gaussian form is larger by 20 to 50 dB in comparison with the exponential one, all other conditions being equal. This fact could be attributed to the singularity of the Gaussian random processes.

Considering from the physical point of view the real form of the interperiod correlation function should be a compromise between two utmost forms. The experimental study (cf. [9], [10]) has shown that the correlation function is decreasing according to the dependence ~ $\frac{1}{\omega^4}$. An exponentially-parabolic function of the following type corresponds to the conditions mentioned:

(8) $$r(\tau) = (1 + b\tau)e^{-b\tau} = \left(1 + b|k - l|\frac{T_p}{\tau_N}\right)e^{-b|k-l|\frac{T_p}{\tau_N}}.$$

The condition for spectrum identification for the exponential and Gaussian functions is fulfilled for the value $b = 2$.

The curves corresponding the to RF factor v dependences for exponentially-parabolic form are also shown in Fig.2 at OTOPS frequency rate m = 1, 2, and 3 (cf. v_{ep}). In this case, computed v values take intermediate position being closer to those for Gaussian approximation and have to be considered as the most likely ones.

One of the basic factors determining the value of the passive noise interperiod correlation coefficient is the antenna motion while scanning (cf. [2], [3], [7]). While scanning, a renovation of the elementary reflectors composition takes place, so that their total number remains one and the same at times t and $t + \tau$. The bigger the τ, the lower the succession.

When the antenna beam diagram is approximated by a Gaussian curve, the corresponding correlation function can be presented as follows:

(9) $$r_a(T_P) = e^{-1{,}57\left(\frac{6\eta T_p}{\theta_{0,5}}\right)^2},$$

where η reflects the radar antenna revolutions per minute.

Taking into account the reflectors' chaotic shift and the renovation because of diagram scanning, as well as the independency of those two physical processes, the background correlation function can be presented as:

(10) $$r_{back}(\tau) = r_N(\tau).r_a(\tau).$$

Further on, an exponentially-parabolic approximation expression like (8) will be used when analyzing the influence of antenna beam diagram scanning. Fig.3 shows the dependence of the v factor for two-star RF (m =

2), that has been calculated using the expression (5) for strong ($\tau_N = 10ms$) and weak ($\tau_N = 25ms$) correlated noise at resolution velocities of $\eta = 3$ and $6\,\min^{-1}$. For the sake of comparison, the maximal attainable factor v values with motionless antenna are shown as well ($v_{\max\, reach}$).

It is seen from the diagram in Fig.3 that antenna motion results in decreasing of the v factor values. In this particular case, the decrease is 4 dB at $\eta = 3\min^{-1}$ and 10 dB at $\eta = 6\min^{-1}$.

An averaged v factor is most often used in practice that is calculated on the basis of expression (5). According to [3], the numerator in (5) is changing by a constant coefficient, as follows: 1 for $m = 1$; 3 for $m = 2$ and 10 for $m = 3$. Fig. 4 shows the dependence of the averaged v factor of a two-star RF on passive noise correlation time for the cases of motionless and moving antenna with $\eta = 6\min^{-1}$.

The exponentially-parabolic form determines again an intermediate position. When noise correlation time increases, scanning influence increases as well. The latter can be explained by decorrelation and widening of the noise spectrum.

Conclusion

The basic conclusion is that the advisable form of the passive noise interperiod correlation function is the exponential-parabolic form.

The computed values for the improvement factor v of the order of 40-50 dB are in good coincidence with the data published for smoothly scanning radars.

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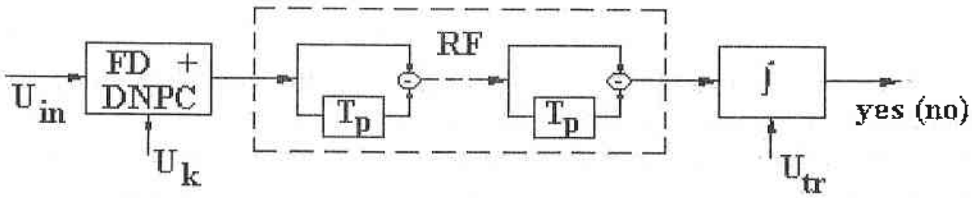


Fig.1

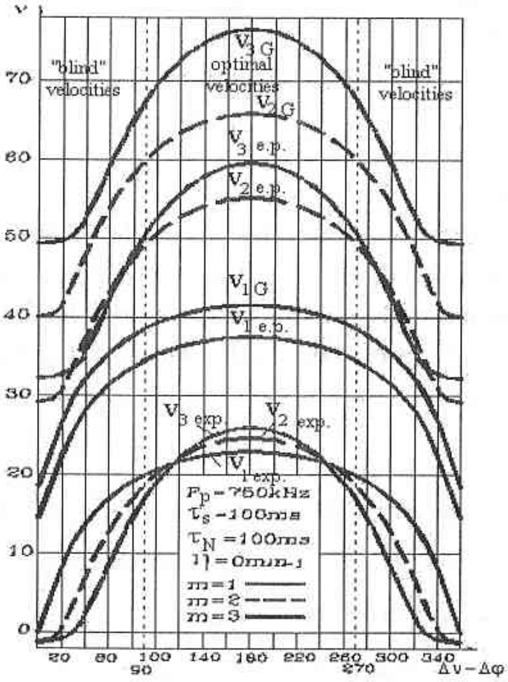
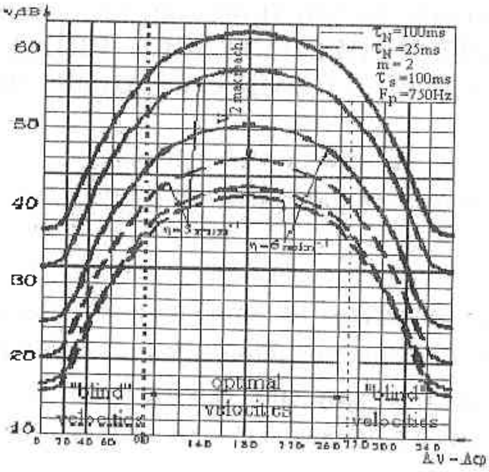
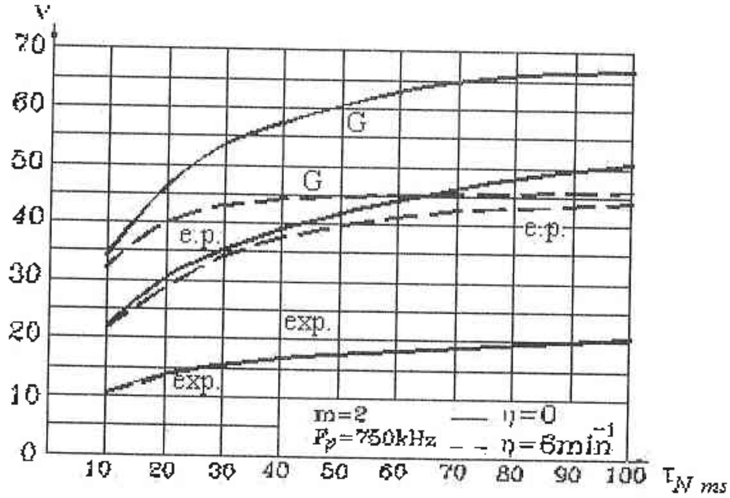


Fig.2



V,dB
60
50
40
30
20
10
τ_N=100ms
τ_N=25ms
m=2
τ_s=100ms
F_p=750Hz
"blind" velocities
optimal velocities
"blind" velocities
$\Delta v - \Delta\varphi$

Fig.3



V
70
60
50
40
30
20
10
0
G
G
e.p.
e.p.
exp.
exp.
m=2
F_p=750kHz
— η=0
– – η=6min^{-1}
10
20
30
40
50
60
70
80
90
100
$\tau_{N\ ms}$

Fig.4

ВЪРХУ НЯКОИ ПРОБЛЕМИ НА РЕАЛИЗАЦИЯТА НА ИНДИКАЦИОННИ СИСТЕМИ С ДВИЖЕЩА СЕ ЦЕЛ В РАДАРИ С ГЛАДКО СКАНИРАНЕ [+)]

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Резюме

Статията е посветена на проблема за избор на формата на корелационната функция на пасивния шум и влиянието на сканирането на антената върху оценката на фактора на усъвършенстване на индикационни системи с движеща се цел в радари с гладко сканиране.

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