RANDOM PHASED ANTENNA ARRAYS – THE NEW CHALLENGE FOR THE MULTISTATIC RADAR NETWORKS

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Abstract

In this report an effective solution of the “beam scan-on-scan losses” problem in Bistatic radars and Multistatic Radar Networks is proposed. It is based on random phased antenna arrays approach, as well as correlation signal processing in the radar receiver. Similar approach was proposed by the author to solve the antenna problems of the mobile satellite communications, named Spatial Correlation Processing – Random Phase Spread Coding. Matrix presentation of the signals in such radar systems is given, as well as the computer simulated Spatial Correlating Function, which is the virtual antenna patterns at baseband.

1. INTRODUCTION

Bistatic radars and Multistatic Radar Networks (MRN) are subject to problems and special requirements that are either not encountered or encountered in less serious form by monostatic radars [1]. One of the main problems are beam scan-on-scan losses. If high gain narrow-beam antennas are used by both the transmitter and the receiver in bistatic surveillance radar, inefficient use is made of the radar energy because only the volume common to both beams can be observed by the receiver at any given time. Several techniques have been proposed and used [1], but all of them suffer different disadvantages. Another problem, typical for all kind high gain antenna radar systems, is the sequential target search in the space due to the steering of the narrow antenna pattern. It leads to low illumination/scan period ratio and low probability of target detection.

The goal of this report is to propose effective solution of the above mentioned problems, based on Random Phased Antenna Arrays (RPAA) approach, as well as correlation signal processing in the radar receiver. Similar approach was proposed by the author to solve the antenna problems of the mobile satellite communications in Ku frequency band [2]. The name of the proposed new technical solution is Spatial Correlation Processing – Random Phase Spread Coding (SCP-RPSC).

2. SCP TECHNOLOGY – THE NEW APPROACH TO SOLVE THE MRN SCAN ON SCAN PROBLEMS

The basic SCP bistatic radar geometry is shown in fig. 1. It consists of transmitter site, radar target and receiver site. The last is given in more details in fig, 3. The transmitted by the radar transmitter CW signals are phase modulated with slow “coarse” PN-code *C* and fast “precise” PN-code *P.*

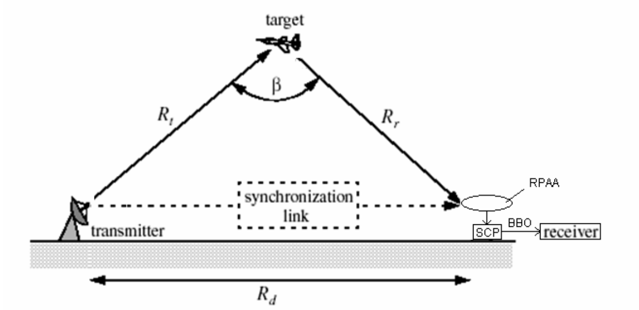

Figure 1. The basic SCP bistatic radar geometry

The frequency spectrum of the transmitted wave is shown in fig. 2.

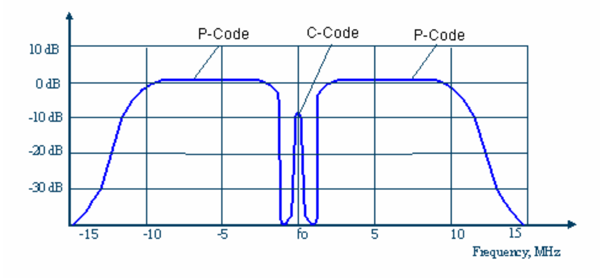

Figure 2. The frequency spectrum of a SCP bistatic radar system

3. BASIC MATRIX EXPRESSIONS OF THE SIGNALS IN A SCP BISTATIC RADAR SYSTEM

The receiver site of a SCP bistatic radar system can be represented by a block diagram, shown in fig. 3. It involves a radar target located in a position, given with its angular coordinates in the coordinate system, centred in the receiver RPAA [fig. 4]. To analyze such a system, the most suitable mathematical tools available involve matrix and vector algebra.

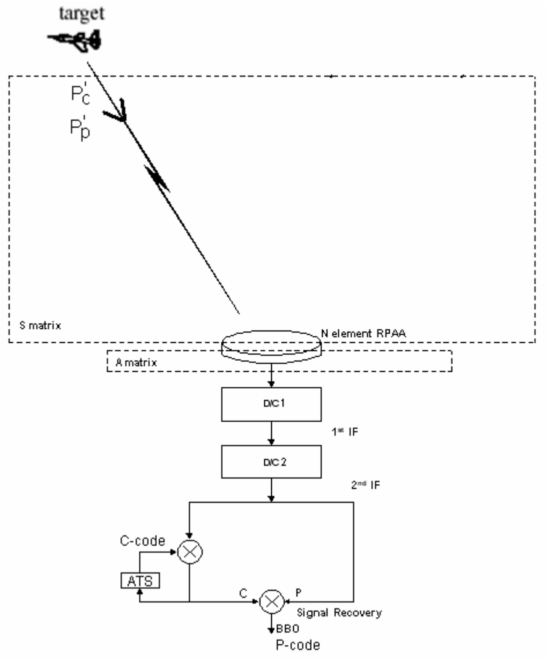

Figure 3. The SCP bistatic radar receiver site

The reflected by the radar target SCP signals involve both the coarse signal with power P_c' and precise P_p'. For simplicity target point scattering model is considered. These signals travel through space to reach the RPAA, where they are picked up by every antenna element and collected by the summing network to the input of the receiver. Here, after several steps of down-conversion, the collected random phase spread *P* signals correlate with the recovered phase spread in the same manner *C* signals for precise signal recovery. The radar target is located at angular coordinates ϕ_r, θ_r and distance R_r.

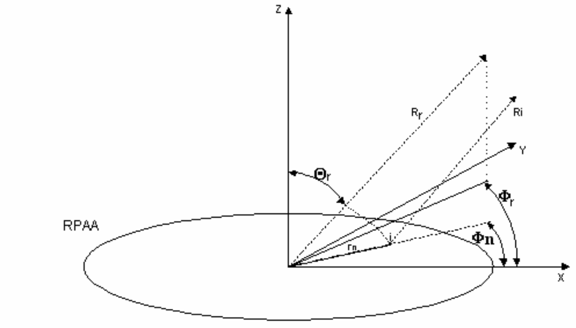

Figure 4. The SCP bistatic radar coordinate system

Each element of the N-elements RPAA pick up the reflected by the target signals and deliver them to its output. Let s_n be the transfer function between the radar target and the n-th element of RPAA. Then

$$s_n = L_{sn}.e^{-j\psi_n} \tag{1}$$

where L_{sn} are the space propagation losses, $\psi_n = kr_n \sin\theta_r \cos(\phi_r - \phi_n)$ is the phase of the signal received by n-th element of RPAA relative to its centre, $k = 2\pi/\lambda$ - free space phase constant, r_n, ϕ_n - the coordinates of the n-th element of RPAA, ϕ_r, θ_r - the angular coordinates of the radar target.

The transfer function for the *C* and *P* signals from the radar target to the RPAA will be given by:

$$\mathbf{s_c} = \begin{vmatrix} s_{c1} \\ s_{c2} \\ \cdots\cdots \\ s_{cn} \\ \cdots\cdots \\ s_{cN} \end{vmatrix} \text{ and } \mathbf{s_p} = \begin{vmatrix} s_{p1} \\ s_{p2} \\ \cdots\cdots \\ s_{p3} \\ \cdots\cdots \\ s_{pN} \end{vmatrix} \tag{2}$$

The signals, reflected by the radar target, at the RPAA elements will be given by:

$$x_{cn} = s_{cn}P_c', x_{pn} = s_{pn}P_p' \tag{3}$$

All RPAA elements will also receive the reflected *C* and *P* signals, as follows:

$$\mathrm{x_c} = \mathrm{s_c}\, P_c', \mathrm{x_p} = \mathrm{s_p}\, P_p' \tag{4}$$

The summing networks of the RPAA will transport all signals, received by the different elements, to its output and the SCP receiver. Let the transfer functions between all RPAA elements and its output be represented by the column vector $\mathbf{a}$:

$$\mathbf{a} = \begin{vmatrix} a_1 \\ a_2 \\ a_3 \\ \cdots\cdots \\ a_n \\ \cdots\cdots \\ a_N \end{vmatrix} \tag{5}$$

where $a_n = L_{an}.e^{j\varphi n}$, L_{an}- gain of a single element, internal propagation losses are included, $\varphi_n = 2\pi r_n / \lambda_g + \Delta\varphi_n$, where $2\pi r_n / \lambda_g$ -phase shift due to summing network, $\Delta\varphi_n$- phase shift due to the element inclination if Circular Polarization (CP) is used.

Due to the finite transfer function that exists between the input and output ports of the RPAA and the summing network, the signals appearing at the output, will be those at the input modified by the transfer function $\mathbf{a}$. The signal vectors, combining all *C* and *P* signals, will be given by:

$$C = \mathrm{ax_c} \quad (6)$$

$$P = \mathrm{ax_p} \quad (7)$$

The received by RPAA signals are amplified in Low Noise Amplifier (LNA), down converted, amplified and correlated in the Correlator unit. Consider for simplicity the process without math description of *C*- code spreading and dispreading. The total receiver gain G, product of the above mentioned procedures, will be:

$$G = G_{LNA}.G_{DC1}.G_{IFA1}.G_{DC2}.G_{IFA2} \quad (8)$$

where G_{LNA} is the gain of the LNA, G_{DC1} is the gain of the first down converter, G_{IFA1} is the gain of the first IFA, G_{DC2} is the gain of the second down converter and G_{IFA2} is the gain of the second IFA.

The output signal, product of the multiplication process, will be:

$$G(C.P) = G\begin{vmatrix} c_1.p_1 & c_2.p_1\cdots & c_n.p_1\cdots & c_N.p_1 \\ c_1.p_2 & c_2.p_2\cdots & c_n.p_2\cdots & c_N.p_2 \\ \cdots & \cdots & \cdots & \cdots \\ c_1.p_n & c_2.p_n\cdots & c_n.p_n\cdots & c_N.p_n \\ \cdots & \cdots & \cdots & \cdots \\ c_1.p_N & c_2.p_N\cdots & c_n.p_n\cdots & c_N.p_N \end{vmatrix} \quad (9)$$

A basic requirement of the SCP technology (in order to obtain smooth omnidirectional receiving pattern) is the sum of the off-diagonal terms of the matrix (9) to be zero. This requirement is fulfilled when the RPAA output signals phase probability density function (PDF) is uniform in the interval 0 – 360 degrees, the channel is real with AWGN and the signal processing is digital.. The real part of the n-th diagonal term of matrix (9) consists of:

$$\mathrm{Re}(c_n.p_n) = c.p.\cos^2[\omega_{II}.t - kr_n \sin\theta_r.\cos(\phi_r - \phi_n) + k_g r_n] \quad (10)$$

Equation (10) can be presented by means of eq. $\mathbf{cos}^2 A = 0{,}5.(1 + \mathbf{cos}\, 2A)$ as follows:

$$\mathrm{Re}(c_n.p_n) =^{+}_{-} 0{,}5.c.p + 0{,}5.c.p.\cos(2\omega_{II}.t + ...) \quad (11)$$

The second term of eq. (11) vanishes after Low Pass Filtering. The first term represents the demodulated reflected signal per antenna element at baseband for the precise PN-code, used later for precise distance measurement. The total baseband output signal will be N times more, equal to the trace of the matrix (9) (the N diagonal elements are in phase):

$$BBO_{cp} =^{+}_{-} 0{,}5.G.c.p.N \quad (12)$$

The formal mathematical way to describe the above mentioned correlation process and the result (12) in matrix form is:

$$\mathrm{BBO}_{cp} = \mathrm{timeaver}\, G.(c.\mathrm{p}) = G.\mathrm{Tr}(c.\mathrm{p^H}) \quad (13)$$

where $\mathbf{p^H}$ is the Hermitian (transpose and conjugate) matrix of $\mathbf{p}$.

If there is another radar target, interfering with the same reflected power over the system, the Spatial Cross - Correlation Function (SCCF) can be introduced for the spatial interference analysis, as follows:

$$SCCF(\phi,\theta)(dB) = 10\lg[\mathrm{BBO}_{c.inter.}(\varphi,\theta)/\mathrm{BBO}_{cp}] \quad (14)$$

The matrix simulations of the SCCF of a SCP system for $\lambda = 2{,}5cm$, $r_n = 5 - 28{,}5cm, \phi_n = 0 - 360^0$ are shown in fig. 5.

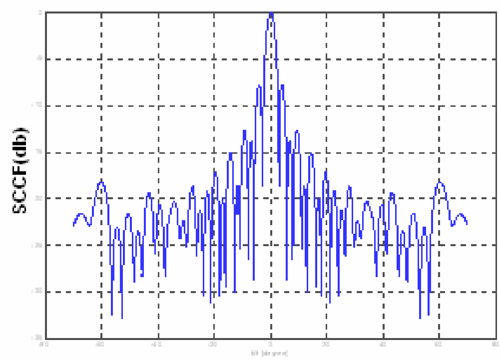

Figure 5. The SCCF for $\theta_r = 0$ deg.

The simulated SCCF, which is the virtual RPAA antenna pattern, is pointed to the radar target direction when the Acquisition and Tracking System (ATS) is locked to the reflected *C* signal. The interference, coming from targets with different directions and distances, will be attenuated with the corresponding value of the *P*-code autocorrelation function and SCCF.

4. CONCLUSION

The application of SCP-RPSC technology in radar bistatic and MRN,s, is proposed in this paper. Matrix presentation of the signals in a bistatic radar SCP systems is given too. The implementation of the RPSC technology in the transmitter site will give another important benefits and will be subject of future research work. A promising feature is the typical for the RPSC technology random space coding, which will improve the anti jamming resistance of the radar system in the case of jamming targets.

References

[1]. .J. Willis, *Bistatic Radar*. Artech House, Boston, 1991.

[2]. V. Demirev, Mobile and Personal Satellite Communications, TU-Sofia, 2010.