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Review of SCP-RPSC Technology

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Abstract – **The theory of SCP technology in transmit mode (SCP-RPSC) is considered in the report. The specific properties of the system are widely discussed. Equations for evaluating the system performances are derived too.**

Keywords **– SCP technology, SCP RPSC, S-DVB, Spatial cross correlation function**

I. INTRODUCTION

A new principle to realize the receiving satellite ground systems antennas was proposed in [1, 2, 3]. The name of the new radio technology is Spatial Correlation Processing (SCP). The idea to use the same principle in transmit mode [4] was born during the SCP project research. The transmitting antennas, as well as the receiving random phase antenna arrays in SCP technology are pure passive, without any active or nonreciprocal elements. The specific SCP processing is situated in the receiver. According to the basic electromagnetic antenna lows the replacement of the passive transmitting antenna with passive random phase antenna array in the transmitter, and vice versa in the receiver should not change the system working principles and system parameters.

The transmitted by the random phase antenna array signals have specific phase spread. It can be considered as random spatial coding. That is why the term SCP-RPSC (Random Phase Spread Coding) will be used instead SCP, transmit in the text below. The signals and the propagation matrix components in the SCP-RPSC case will be denoted with “t”.

II. THE MAIN SCP-RPSC FEATURES

The main features of the SCP technology in receive mode are listed in [1].

The proposed SCP-RPSC system will have the following additional features:

- Providing full duplex interactive system with one simple and cheap transmit-receive antenna.
- The transmitted random poly-phase spread signals will not cause significant harmful interference to the conventional satellites, using the same frequency channels. The interference will be similar to that, caused by the sidelobes of a phased antenna array with random inter elements spacing.
- The transmitted random poly-phase spread signals are uniformly radiated in the space above the antenna. Several satellites, equipped with the same SCP receivers and providing space diversity, receive them. The knowledge of the receiving satellites positions for the transmitting equipment is not necessary (as it is for a conventional satellite earth station).
- The transmitted random poly-phase spread signals have low detection probability for the conventional microwave receivers (due to the low spectral power flux density, similar to CDMA case), leading to low active jamming probability.
- The SCP-RPSC approach could be a breakthrough technology, leading to unpredictable increase of the frequency reuse factor in satellite and terrestrial wideband networks. Close situated subscriber terminals could communicate with terrestrial or satellite base stations, using the same frequency channel without interference. The isolation between the terminals will be provided by their specific random phase spread coding, due to their specific random design.
- The practical SCP principles implementations in transmit and receive mode will drastically change the existing paradigm in the satellite communication business in general. Many of the existing problems of the proposed LEO, MEO and GSO satellite systems, dealing with frequency and orbital resource sharing, beam pointing, beam shadowing, etc., will be solved successfully.

III. BACKGROUND OF THE SCP-RPSC TECHNOLOGY

A block scheme of a SCP-RPSC satellite system is shown in Fig.1, where:

- (1) is a transmitter of SCP signals (modulated information signals and CDMA-spread pilot signals).
- (2) is a Random Phase Antenna Array (RPAA) or Radial Line Slot Antenna (RLSA) in some particular cases .
- (3) is a conventional microwave receiving antenna.
- (4) is a conventional one channel receiver with IF output.
- (5) is a SCP Pilot recovery unit.
- (6) is a SCP Signal recovery unit (correlator).
- (7) is a baseband signal processing equipment.

Following the block-scheme, shown in Fig. 1, the RPAA transports the transmitted signals $c_{c,t};c_{p,t}$ from the antenna input (connected to the SCP transmitter) to the RPAA elements. Let the transfer functions between the input and the

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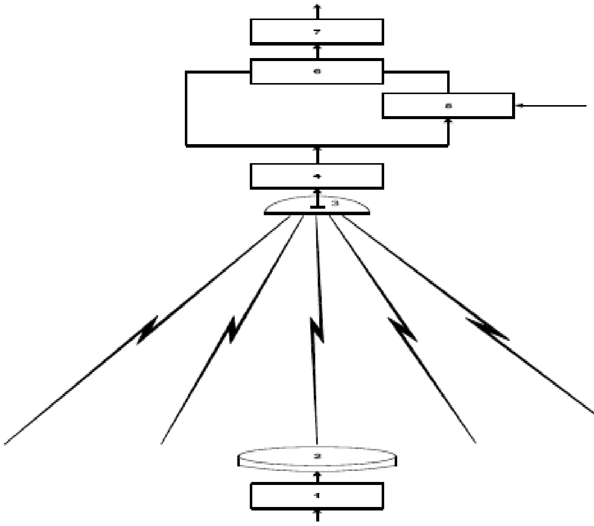

Fig. 1. Block scheme of a SCP-RPSC satellite system

outputs (the RPAA elements) be represented by the column vector a_t:

$$\mathbf{a}_t = \begin{vmatrix} a_{t1} \\ a_{t2} \\ a_{t3} \\ \cdots\cdots \\ a_{tn} \\ \cdots\cdots \\ a_{tN} \end{vmatrix} \tag{1}$$

Where $a_{t,n=L_{t,an}} .e^{j\gamma n}$, $L_{t,an}$ is the gain of a single RPAA element in transmit mode (propagation losses are included), $\gamma_n = 2r_n / \lambda_g + \Delta\gamma_n$, where the first term is the phase shift due to RPAA and the second – the phase shift due only to the inner elements and to the element inclination in the case of circular polarization of the receiving antenna (3).

Due to the finite transfer function that exists between the input and output ports of a RPAA, the signals appearing at its elements will be those at the input modified by the transfer function a_t. The signal vectors $c_{c,t}; c_{p,t}$, combining all transmitted signals appearing at the outputs of the RPAA elements, are:

$$\mathbf{c_{c,t}} = \begin{vmatrix} a_{t1}c_{c,t} \quad a_{t2}c_{c,t} \quad a_{t3}c_{c,t}\cdots \\ \cdots a_{t,n}c_{c,t}\cdots\cdot \quad a_{t,N}c_{c,t} \end{vmatrix} = \mathrm{a}_t\, c_{c,t} \tag{2}$$

$$\mathbf{c_{p,t}} = \begin{vmatrix} a_{t1}c_{p,t} \quad a_{t2}c_{p,t} \quad a_{t3}c_{p,t}\cdots\cdot \\ a_{t,n}c_{p,t}\cdots\cdot \quad a_{t,N}c_{p,t} \end{vmatrix} = \mathrm{a}_t\, c_{p,t} \tag{3}$$

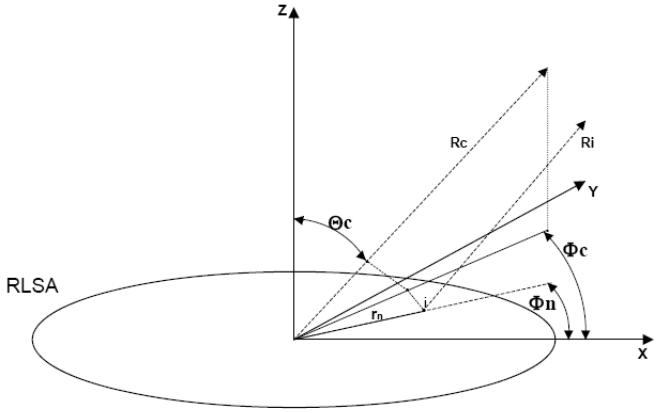

Fig. 2. The coordinate system, centred at a terminal

The receiving satellite (base station) is located at angular coordinates ϕ_c, θ_c and distance R_c to the cooperative signal source (subscriber terminal) (Fig.2). Each element of the transmitting RPAA can be considered as separate signal source, received by a conventional antenna (3). Thus the antenna (3) output will carry signals from all antenna elements. Let $s_{t,n}$ be the transfer function between n^{-th} RPAA element and antenna (3). Then:

$$s_{t,n} = L_{t,n} e^{-j\psi_n} \tag{4}$$

Where $L_{t,n}$ are the free space propagation losses, $\psi_n = kr_n \sin\theta_c \cos(\phi_c - \phi_n)$is the phase of the signal, received by antenna (3) and transmitted by n^{-th} RPAA element relative to its centre [5], circular antenna aperture is considered, $k = 2\pi / \lambda$ - free space phase constant, r_n, ϕ_n - the coordinates of the n^{-th} element. In this case:

$$\mathbf{s}_t = \begin{vmatrix} s_{t1} \\ s_{t2} \\ \cdots\cdots \\ s_{t,n} \\ \cdots\cdots \\ s_{t,N} \end{vmatrix} \tag{5}$$

Where s_t is called a column matrix or vector, representing the space transfer function between the terminal RPAA and the antenna (3).

In analogy the transfer functions for information and pilot signals are:

$$\mathbf{s}_{\mathbf{c},t} = \begin{vmatrix} s_{c,t1} \\ s_{c,t2} \\ \cdots\cdots \\ s_{c,t,n} \\ \cdots\cdots \\ s_{c,t,N} \end{vmatrix} \qquad \mathbf{s}_{\mathbf{p},t} = \begin{vmatrix} s_{p,t1} \\ s_{p,t2} \\ \cdots\cdots \\ s_{p,t,n} \\ \cdots\cdots \\ s_{p,t,N} \end{vmatrix} \tag{6}$$

The signal transmitted by the n^{-th} RPAA element, at the input of the receiving antenna (3) is:

$$x_{t,n} = s_{t,n} a_{t,n} c_t \tag{7}$$

And that for the cooperative and for the pilot signals are:

$$x_{c,t,n} = s_{c,t,n} a_{t,n} c_{c,t} ; x_{p,t,n} = \\ = s_{p,t,n} a_{t,n} c_{p,t} \tag{8}$$

Therefore the signal vector, combining the signals from all RPAA elements, at the input of the receiving antenna (3) is:

$$\mathrm{x}_t = \begin{vmatrix} x_{t1} & x_{t2} \ldots x_{t,n} \ldots x_{t,N} \end{vmatrix} = \\ = \begin{vmatrix} s_{t1} a_{t1} c_t & s_{t2} a_{t2} c_t \ldots s_{t,n} a_{t,n} \\ c_t \ldots s_{t,N} a_{t,N} c_t \end{vmatrix} \tag{9}$$

In analogy the signal vectors, combining the cooperative and pilot signals from all RPAA elements at the antenna (3) input are:

$$\mathbf{x}_{\mathbf{c},t} = \mathbf{s}_t \, \mathbf{a}_t c_c ; \mathbf{x}_{\mathbf{p},t} = \mathbf{s}_{\mathbf{p}} \, \mathbf{a}_t c_p \tag{10}$$

The signal vector, representing the output of antenna (3) is:

$$\mathbf{i}_{\mathbf{t}} = G_A \mathbf{x}_{\mathbf{t}} \tag{11}$$

Where G_A is the gain of the antenna (3). In analogy the vectors of cooperative and pilot signals are:

$$\mathbf{i}_{\mathbf{c,t}} = G_A \mathbf{x}_{\mathbf{c,t}} ; \mathbf{p}_{\mathbf{t}} = G_A \mathbf{x}_{\mathbf{p,t}} \tag{12}$$

The received by the receiving antenna (3) signals are amplified in Low Noise Amplifier (LNA), downconverted, amplified and correlated in the Correlator unit. Consider for simplicity the process without math description of CDMA pilot spreading and dispreading, which in principle will not change the investigated interference environment and thermal noise properties.

The total receiver gain G, product of the above-mentioned actions, will be:

$$G = G_{LNA} G_{DC1} G_{IFA1} G_{DC2} G_{IFA2} \tag{13}$$

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 Intermediate Frequency Amplifier (IFA), G_{DC2} is the gain of the second down converter and G_{IFA2} is the gain of the second IFA.

The signal vector, representing the receiving signal at the correlator input, will be:

$$\mathbf{i}_{\mathbf{t,IF}} = G \mathbf{i}_{\mathbf{t}} \tag{14}$$

In analogy the signal vectors, representing the cooperative and pilot signals at correlator input, will be:

$$\mathbf{i}_{\mathbf{c,t,IF}} = G \mathbf{i}_{\mathbf{c,t}} ; \mathbf{p}_{\mathbf{t,IF}} = G \mathbf{p}_{\mathbf{t}} \tag{15}$$

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

$$(\mathbf{i}_{c,t,IF} \mathbf{p}_{t,IF}) = G(\mathrm{i}_{c,t} \mathrm{p}_t) = \\ = G \begin{vmatrix} i_{c,t1} p_{t1} & i_{c,t2} p_{t1} \cdots & i_{c,t,n} p_{t1} \cdots & i_{c,t,N} p_{t1} \\ i_{c,t1} p_{t2} & i_{c,t2} p_{t2} \cdots & i_{c,t,n} p_{t2} \cdots & i_{c,t,N} p_{t2} \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ i_{c,t1} p_{t,n} & i_{c,t2} p_{t,n} \cdots & i_{c,t,n} p_{t,n} \cdots & i_{c,t,N} p_{t,n} \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ i_{c,t,1} p_{t,N} & i_{c,t,2} p_{t,N} \cdots & i_{c,t,n} p_{t,n} \cdots & i_{c,t,N} p_{t,N} \end{vmatrix} \tag{16}$$

Where the $j-k$ off-diagonal term consists of:

$$(i_{c,t,j} \, p_{t,k}) = \pm \, i_{c,t} e^{j\left[\omega_{II} t - k r_j \sin\theta_c \cos\left(\phi_c - \phi_j\right) + k_g r_j\right]} \\ e^{j\left[\omega_{II} t - k r_k \sin\theta_c \cos\left(\phi_c - \phi_k\right) + k_g r_k\right]} \tag{17}$$

In Eq. (17) $i_{c,t}$ is the amplitude of the information signal per RPAA element (BPSK modulation and uniform amplitudes of the antenna elements are considered), the same for the pilot is chosen to be 1(the pilot signal is considered as noise free because of the used high CDMA Processing Gain).

By means of

$$\cos A \cos B = 0{,}5 \cos\left(A - B\right) + 0{,}5 \cos\left(A + B\right),$$

Eq. (17) can be represented in real form as:

$$\begin{aligned}&\mathrm{Re}(i_{c,t,j}\,p_{t,k}) = \pm\ 0{,}5 i_{c,t}\\ &\cos\left[-kr_j \sin\theta_c \cos\left(\phi_c - \phi_j\right) + k_g\left(\ r_j - r_k\ \right) + \right.\\ &\left. + kr_k \sin\theta_c \cos\left(\phi_c - \phi_k\right)\right] \pm\\ &\pm\ 0{,}5 i_{c,t}\left(2\omega_{II} t + ...\right)\end{aligned} \qquad (18)$$

The second term of Eq. (18) is with double second IF and after Low Pass Filtering (LPF-typical for the correlation process) it cancels. The first part is a sample function of a random phase process, given by the matrix (16).

A basic SCP technology requirement (in order to obtain smooth omnidirectional cooperative pattern) is the sum of the off-diagonal matrix terms to be zero. This requirement is fulfilled when the signals phase probability density function is uniform in the interval 0 – 360 degrees, the channel is real with Additive White Gaussian Noise (AWGN) and the correlation process is digital. For this reason only the cases of pure diagonal matrices are considered in the text below.

The real part of the n^{-th} diagonal term of matrix (16) consists of:

$$\begin{aligned}&\mathrm{Re}(i_{c,t,n}\,p_{t,n}\ ) =\\ &= \pm i_{c,t} \cos^2\left[\omega_{II} t - kr_n \sin\theta_c \cos(\phi_c - \phi_n) + k_g r_n\right]\end{aligned} \qquad (19)$$

Eq. (19) can be presented as follows:

$$\begin{aligned}&\mathrm{Re}(\ i_{c,t,n}\,p_{t,n}) =\\ &= \pm\ 0{,}5 i_{c,t} \pm 0{,}5 i_{c,t} \cos\left(2\omega_{II} t + ...\right)\end{aligned} \qquad (20)$$

The second term of (20) vanishes after LPF. The first term represents the demodulated information signal per RPAA element at baseband. The total baseband output signal will be N times more, equal to the trace of the matrix (16) (the N diagonal elements of (16) are in phase):

$$BBO_{\ c,t} = \pm\ 0{,}5 G i_{\ c,t} N \qquad (21)$$

The physical explanation of the process, described above, is that the phase shifts for the pilot and information signals per RPAA element are equal (they use the same frequency and have the same propagation path and environment). During the process of coherent demodulation (correlation) the double frequency term of (20) vanishes after LPF, while the difference part is with zero phase. It means that all diagonal elements of the autocorrelation matrix (16) are with zero phases too (or they are in phase).

The formal mathematical way to describe the above mentioned correlation process and the result (21) in matrix form is:

$$\mathrm{BBO}_{\ \mathrm{c},t} = \mathrm{timeaver}\ \ G(\mathrm{i}_{\ \mathrm{c},t}\,\mathrm{p}_{\ t}) = G\ \mathrm{Tr}(\mathrm{i}_{\ \mathrm{c},t}\,\mathrm{p}_{\ t}{}^{\mathrm{H}}) \qquad (22)$$

Where p_t^H is the Hermitian (transpose and conjugate) matrix of p_t.

In order to evaluate the space interference rejection pattern (similar to the antenna pattern in classical antennas) between the cooperative terminal and a interference terminal, located in the same place, it is necessary to correlate the pilot signal, coming from the cooperative terminal, with the information signal from the interference terminal. The last should be shifted at small angles in azimuth and elevation step by step. In analogy with (22), we can determine the interference signals:

$$\mathrm{BBO}_{t,\mathrm{interference}} = \mathrm{timeaver}\, G(i_t\ \mathrm{p}_{\ t}) = G\,\mathrm{Tr}(i_t\ \mathrm{p}_{\ t}{}^{\mathrm{H}}) \qquad (23)$$

The Spatial Cross - Correlation Function, transmit (SCCF,t) can be introduced for the spatial interference analysis, as follows:

$$\begin{aligned}&SCCF_t\,(\phi,\theta)(dB) =\\ &= 10\,\mathrm{lg}\left[\mathrm{BBO}_{t,\mathrm{inter.}}\,(\varphi,\theta)/\mathrm{BBO}_{\mathrm{c},t}\right]\end{aligned} \qquad (24)$$

IV. CONCLUSION

In this paper the application of SCP technology in transmit mode is proposed. The particular features of the proposed system are defined. The matrix presentations of the signals at different system points are given. The Spatial Cross – Correlation Function in transmit mode is derived too.

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