Principles of Construction and Application of Modern Microwave Wireless Energy Transmission Systems

A.V. Gomozov, V.M. Shokalo, D.V. Gretskih, Sh.F.A. Al - Sammarraie, O.S. Lukavenko

Abstract – **results of investigations of construction principles of the modern wireless energy transmission (WET) microwave systems on the basis of the multi-position system of emitters (MSE) with focusing of single-stage discrete V-shape multi-frequency signals and double-layer microstrip rectenna with circumpolarization in KHNURE are shown.**

Two variants of such systems are considered: for the power supply of ground objects in remote areas, and for low-orbit small (LOS) space vehicles (SV).

Keywords – **wireless energy transmitting, rectenna, multi-position system of emitters, focusing of electromagnetic radiation, remote ground object, low-orbit small space vehicle.**

I. INTRODUCTION

WET systems proposed in 60th years of XX century were constructing on the basis of the use of transmitters with single-position antennas and focusing of microwave ray (for high efficiency obtaining) by means of rectenna placing in the Fresnel area. Investigations results of such systems in KHNURE are summarize in [1].

For the constructing of the modern WET systems by authors are proposed focusing of electromagnetic radiation (EMR) on the basis of interconsistency spatial-phase-frequency (SPF) control of the MSE's signals parameters.

For the last two decades the developed methods of EMR focusing with the combined methods of the emitter signals control along the MSE's apertures are published. WET to the remote objects must possess along with high power parameters also productivity and realization simplicity. Positions and central workings frequencies of transmitter and receiving subsystems must be beforehand known also in them. Compromise and the most effective solution of these requirements is possible at the using of single-stage discrete (SSD) V-shape multifrequency (MF) radio-frequency pulses in the MSE's transmitter subsystems with the SPF focusing [2]. These MSEs create a spectral density in maximums of EMR without scanning at ensuring of the required temporal parameters of focused impulse packs.

Principles of work and concrete variant of transmitter subsystem and rectenna construction for such WET systems were not expounded for the present. Partial liquidation of this gap is the purpose of this paper.

II. WET SYSTEM OF FOR THE REMOTE OBJECTS POWER SUPPLY

Distributing of initial frequencies of radiation sources in MSEs with focusing of V-shape SSD MF signals at the small number of radiation sources N, it is possible to write in the simplified view [2]:

$$f_{0n} = f_0 + |n|\Delta F_n \text{, where } n \in \left[-\frac{N-1}{2},...,0;\ 0,...,\frac{N-1}{2}\right]. \quad (1)$$

At the same condition the distribution of initial phases of emitters for coherent addition of EMR in the focusing point P_F, which is located on the OZ axis of the rectangular axes, it is also possible to write in the following simplified view [2]:

$$\phi_{0n} = -2\pi f_{0n}\left(\frac{z_F}{c} - \frac{R_{Fn}}{c}\right), \quad (2)$$

where $R_{Fn}=[(x_F-x_n)^2+(y_F-y_n)^2+(z_F-z_n)^2]^{1/2}$ – distance between the focus point and center of n emitter with the $P_F(x_F,y_F,z_F)$ and (x_n,y_n,z_n) coordinates accordingly, c – light speed.

Analysis of simulation results, obtained in [2] shows that at the selection of focus point on distance $z_F^M \le 4$ (where $z^M=z/L$ is MSE's coordinate which is reduced to the base of aperture) and using in MSE of the SPF focusing of the V-shape SSD MF signals with distributing of their frequencies and phases view (1) and (2) the single spatial-temporal pulse (STP) is formed only [2]. With increasing of the distance to the focus point the sequence of STP in space is creating, and the number of focused STPs in a periodic sequence increasing with the increasing of distance to the focus point z_F. At the same time duration and pulse period of STP in a periodic sequence is equal $\tau_{seq} \approx 1/\Delta F_{max}$, $T_{seq}=1/\Delta F_n$ (where ΔF_{max} и ΔF_n – maximal spacing and discreteness of frequency setting on emitters in MSE accordingly).

Specificity of the WET systems operating to the remote and mountain objects is causing feature of requirements to the structure and parameters of focused STPs. In particular to them belong: necessity of continuous long-time operating at a maximal spectral density of STP's power flux of the transmitter subsystem, exception of the possible inactivation of reception- rectifier elements (RRE) of rectenna and other semiconductor elements of radio electronic devices (RED) on an object by the sequences of focused STP of an own transmitter WET subsystem.

Taking into account abovementioned it is suggested to create structure of STP's packs as two parts which at a necessity the protracted influence can radiate s times in succession. First part, compared to grounded in [2], for the functional defeat of radio elements the number of STP in the pack $N_{inpack}=10^7$, duration of STP τ_{inpack} =10 ns, STP's period T_{inpack}=20 ns and time of total influence of the pack nonmetering of intervals between them $\tau_{inpack\Sigma}$=100 ms, for eliminating of inactivation by them of radio elements of rectennas and other RED on object, at least, with a tenfold power supply, must have a number of impulses in the STP's pack $N_{pack}= (N_{inpack}/10)=10^6$, STP's

Gomozov Andrey, Shokalo Vladimir, Gretskih Dmitriy, Shamil Al-Sammarraie, Lukavenko Olga - Kharkiv National University of Radioelektronics, Lenina Avenue, 14,
Kharkiv, 61166, UKRAINE.
E-mail: dvgretskih@rambler.ru

pulse period T_{pack}=80 ns (for implementation $T_{pack}<\tau_r$ condition, where to τ_r =22÷76 ns – time constant of establishment of characteristic vibrations of most receivers of different RED [2]) and at the chose τ_{pack} =20 ns (for implementation of $\tau_{pack}\geq\tau_K$ condition where τ_K =10 ns is actuation time of the best protection device on SHF input of real RED [2]) and accordingly STP's pack duration nonmetering of intervals between them $\tau_{pack\Sigma}=10^6\tau_{pack}$=20 ms. The second part of STP's structure must be as a free time (without STP impulses filling), equal to the maximal possible value permanent time of relaxation of thermal processes for semiconductor elements $\tau_{T.max}$=410 ns [2]. It provides reliable relaxation of thermal effects, caused influence of the first part of STP's structure. Complete duration of such STP'S packs structure is equal

$$\tau_{pack\Sigma S} = s\,[N_{pack}\cdot\tau_{pack}+\tau_{T.max}], \qquad (3)$$

where s – needed number of reiteration of both parts of STP's packs structure during the required influence time on rectenna of receiving WET subsystem for the transmission of the required electric power.

For the WET systems to the ground objects at a choice as emitters in MSE of the stations of missile-guidance stations (MGS) surface-to-air missile system (SAMS) «TOR-M1»-type, maximal focus distance at the height of phase centers of phased-array antennas (PAA) in SAMS h_a and height of rectennas h_r it is expedient to set no more than direct radar visibility D_{DRV}, expected on well-known simple formula:

$$z_F \leq D_{DRV}=4{,}12[(h_a)^2+(h_r)^2]^{1/2}, \qquad (4)$$

where D_{DR} has a dimension [km], h_a and h_r have dimensions [m].

It is possible to consider standard placing of MGS with PAA and rectenna on an earth surface in typical cabins at $h_a=h_r$=5 m, then maximal focus distance is equal:

$$z_F\leq D_{DRV}=4{,}12[(h_a)^2+(h_r)^2]^{1/2}=4{,}12[(5)^2+(5)^2]^{1/2}\approx 29\text{ km}$$

Expedient plan of placing of elements (top view) for the WET systems to the remote surface objects is shown on fig. 1.

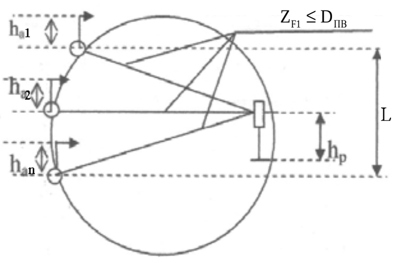

Fig. 1 WET system plan (top view)

On the basis of foregoing for WET transmitter subsystem to the remote objects the followings expedient parameters of MSE are grounded:

1. Transmitting MSE consists of SAMS with PAA, placed on an arc (fig. 1):

1.1 For WET to the surface objects base L=1 km, number of SAMS with PAA k=9, distance of focusing $z_F \leq D_{DRV}$ =29 km

1.2 PAA includes n_{SA}=4 rectangular subarrays with sizes and number of emitters $(L_{SA})^2$=(85×85) sm^2 and $n_{SP}=(nxm)=(12)^2=144$.

1.3. Wave-length and intervals between emitters in the rectangular subarrays with the sizes of their sides L_{SA}=0,85 m and number of emitters n=m=12 are $\lambda_0\leq(L_{SA}/n)$=(0,85/12)≈0,07 m and $d_{XSP}=d_{YSP}$≈0,07 m.

1.4. PAA's subarrays amplification coefficients during operating with the narrow round section ray G_{SP}≈3750.

2. Radiated signals are the V-shaped SSD MF LCHM (linear frequency modulated) coherent packs of radio-frequency pulse:

2.1. Initial frequencies of signals in k-th SAMS are equal to f_{0n}≈(4,3±0,1) GHz, maximal frequency spacing is ΔF_{max}=50 MHz and frequency discreteness ΔF_n = 12,5 MHz.

3. Power of the radio-frequency pulses for all emitters of each PAA's subarray are about P_{nm}=21,5 W, and complete power of impulsive radiation of every subarray $P_{SP}=n_{SP}\times P_{nm}$=144×21,5≈3,1 kW.

MSE's emitters of the suggested WET are subarrays of PAA from GMS SAMS "TOR-M1"-type. In this WET system their number is equal $N_{EM}=(k\times n_{SA})$=(9×4)=36.

As in suggested WET the peak distributing of the emitters' signals on the MSE's apertures is even, aperture emitters are identical and $z_F\leq z_{DП}$, then cophased addition of the fields is provided and expression for the calculation of maximal power densities of the V-shape SSD MF LCHM of the coherent packs of radio-frequency pulse looks like [2]:

$$S_{max} = N_{EM}^{\ 2}\, P_{SP}\, G_{SP} / (4\pi Z^2_F)$$

Calculation results of achievable values S_{max} on distances z_F are presented on fig. 2.

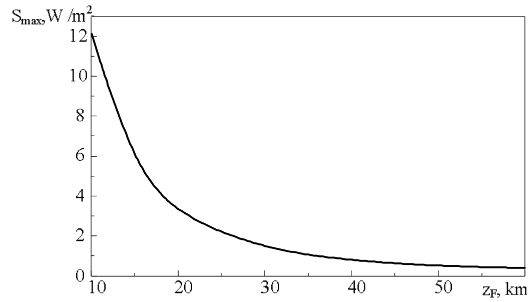

Fig. 2 Dependency of S_{max} on distance to the focus point

Suggested technical solutions of the rectenna realization consist of the following. For reducing of aperture area the rectenna is executed as double-layer microstrip construction (fig. 3) on dielectric substrate with $\varepsilon_r = 3{,}5$. Emitter system is executed as an aggregate of colinear band microstrip leads, in the breaks of which through equal spaces the Schottky diodes are connected (in our case a unpackaged 3A149A-3 diode is chosen) (fig. 3).

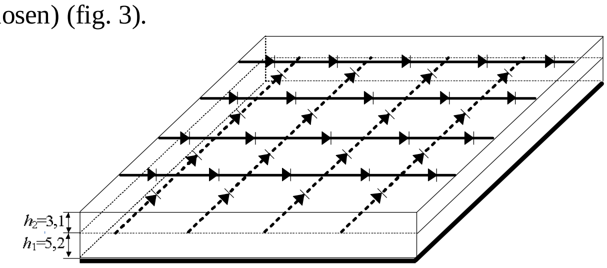

Fig. 3 Fragment of rectenna with circumpolarization

Using of such emitters is structural advantageously on two reasons. At first, easily realized serial-parallel schema of power collection of the direct current. For the obtaining of the specified power in loading of rectenna the defined EMF values E_r and resistances R_r on direct current of rectenna are needed [1]. The required value E_r is achieving by serial connection of RRE in a line, and R_r – by parallel connection of lines (fig. 3). Secondly, reliability of rectenna rises because as at failure of some lines, rectenna will reserve the operating (topically at the transmission of high power-levels).

In order that rectenna receive the field with circumpolarization the RREs which are operating on two ortogonal polarizations in relation to the planes of top and bottom layer of pay are used in such rectenna (fig. 3).

The calculation of rectenna performed on a method presented in [1]. At simulation the rectenna considered as an endless periodic array with the Floke cell sizes 13x13 mm$^{2.}$ On Fig.4. dependencies of efficiency of rectenna's rectification η_r (with the aperture area 9 m^2) and voltage on its loading U_{load} on distance to the focus point Z_F are shown.

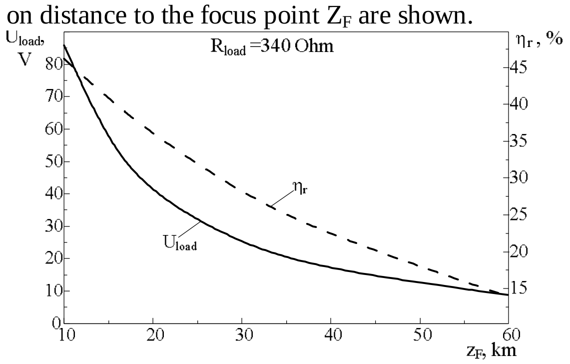

Fig. 4 Dependencies of rectification efficiency and voltage in loading of rectenna on focus distance

III. WET SYSTEM F FOR THE IMPROVEMENT OF POWER SUPPLY OF THE LOS SV

Last years LOS SVs are intensively using, which are operating on low orbits which are close to the circle sun-synchronous, 250...700 km high. In the complement of power supply subsystem (PSSS) of this class for the developed typical platform as an power source four frame-type solar arrays (SA) with gallium-arsenide (GaAs) solar cells (SC) are used and they are rigidly fixed relative to the SV's platform. As a power accumulation element a chemical battery (CB) are used. CB consisting of hermetic cadmium-nickel accumulators with CB's discharge voltage which change range is providing the required voltage for onboard equipment of SV.

Solar array have the limited overall dimensions determinated by the SV's platform design, therefore at the use of SCs certain type a value current, given by the solar arrays in load, is fixed and depends only on an orientation of SV on the Sun. However in new developments a power consumption of the desired composition of SV's scientific onboard equipment exceeds existent power possibilities of applied SV's PSSS for a regular platform developed on Ukrainian LOS SVs («EgyptSat-1», «MC-2-8» and «Microsat»).

One of an alternative method of an additional power receiving for the LOS SV's PSSS is suggested to use the WET system. Rektenna of receiving WET subsystem can be placed on the presently not-in-use back surfaces of SA's (total area of standard 4 SAs is 1,6 m^2). In addition, at using of this method of an additional power receiving for the PSSS for such class of the SVs in case of emergency complete or partial absence of CB's charge from SAs it is possible after the certain amount of circuit the SV to receive an additional electric power from the receiving WET subsystem for the CB charging to the minimal level which is needed for operating of the SV's command radio link in case of nonpermanent emergency situation of work of the SV's orientation system, for providing of correction realization possibility of a control system software SV from Earth.

The ground transmitter WET subsystem of SV must be placed near the positions of the ground SV's control REDs, because during being in the area of review of these facilities the SV is oriented by the back surfaces of the SA's on Earth.

The LOS SVs during orbital flight around of Earth depending on the angle of inclination of the orbit are within the limits of field of view of the ground SV's control REDs, for example for SV «MC-2-8»-type, from 4 to 6 circuits per day and depending on azimuthal direction on SV at included of it in a field of view on time is in field of view on every circuits within from 7 to 13 minutes (there is at distance of included in the field of view area from 2000 to 3000 km), that allows after a few circuits with help of the offered receiving SV's WET subsystem to accumulate an additional (along with SAs) electric power.

As a transmitting WET subsystem for realization of an additional power supply of LOS SVs in case of occurring of foregoing nonpermanent emergency situation, using of RT-70 radiotelescope is possible (Evpatoria). Thus after a few circuits of SV, it is possible to perform CBs charging to minimal level which is needed for brief operating of command radio link.

For realization of effective an additional power supply for LOS SVs it is expediently also to create of a transportable powerful transmitter WET subsystem by the using as emitters of MSE of the «Obzor-3» radar (1RL141), which is a part of the PRW-17 radio altimeter (frequency of radiation – 2,625 GHz with impulse power 2,5 MW which is developed by the Design Office «Iskra», Zaporozhe) with the spatially-phase focusing of their EMR or with focusing of V-shape SSD signals.

IV. CONCLUSION

Possibility of creation of the effective WET systems for the remote objects power supply with a transmitter subsystem on MSE, containing PAA of existent "TOR-M1"- type SAMSs with SPF focusing of the V-shape SSD MF coherent radiofrequency pulses and double-layer rectenna with circumpolarization, and also WET systems for the improvement of power supply of LOS SVs is shown.

REFERENCES

[1] Shokalo V.M., Luchaninov A.I., Rybalko A.M., Gretskikh D.V. Largeaperture antennas-rectifiers of the WET systems by a microwave beam – Kharkov: Kollegium. 2006. – 308 p (in Russian).

[2] Gomozov A.V., Gomozov V.I., Ermakov G.V., Titov S.V. Focusing of electromagnetic radiation and its application in SHF radio electronic devices/ Under redaction V.I. Gomozov– Kharkov: CE «City printery», 2011.– 330 p. (in Russian).