MATHEMATICAL SIMULATION OF THE MPSE FIELD IN THE POINT OF THE UAV MOTION TRAJECTORY Let us put down the expression for the power flux density in the fixed focusing point created by MPSE (Fig. 1) with the aperture dimensions in the planes XOZ and YOZ - Lx and Ly , correspondingly (taking into consideration the directional properties of its emitting elements)

$$S(x,y,z,t) = \left| \sum_{n=1}^{N_x} \sum_{m=1}^{N_y} \sqrt{\frac{P_{nm}\ G_{nm}}{4\pi\ R_{nm}^2}} \times \atop \times F_{nm}(\theta,\varphi)\ e^{-j\left[2\pi f_0 \left(t - \frac{R_{nm}}{c}\right) + \psi_{0nm}\right]} \right|^2 \quad (1)$$

Where $\psi_{0nm} = -2\pi f_0 \left(\frac{z_F}{c} - \frac{R_{Fnm}}{c} \right)$ are the initial phases of the emitters in MPSE for coherent summation of EMR in the point of focusing $P_F(x_F,y_F,z_F)$; $R_{Fnm} = \sqrt{(x_F - x_{nm})^2 + (y_F - y_{nm})^2 + (z_F - z_{nm})^2}$ - is the range between the focusing point $PF(xF, yF, zF)$ and the center of the nm–th emitter with the coordinates $R_{nm} = \sqrt{(x - x_{nm})^2 + (y - y_{nm})^2 + (z - z_{nm})^2}$ is the range to the observation point from the nm–th emitter; c is the light velocity, zF is the range between the focusing point and the central emitter of MPSE, and $F_{nm}(\theta,\varphi)$ – is the pattern normalized upon the field of the nm-th emitter of MPSE.

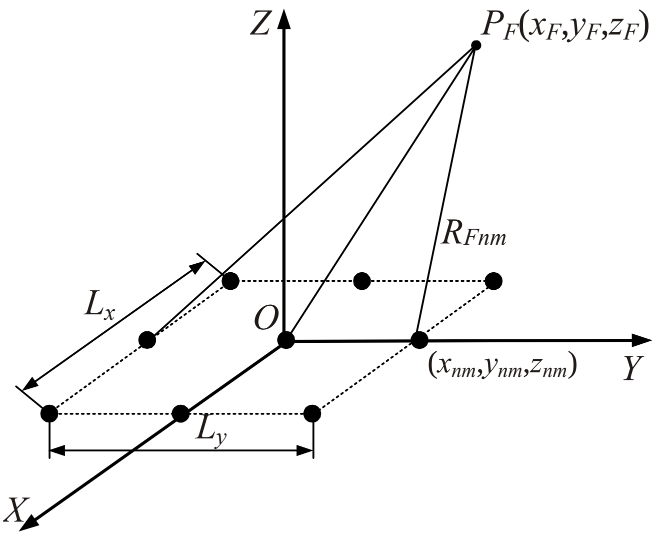

Figure 1: Multi-position system of emitters

For the purpose of the out-of-band disablement the frequency band of the FD facility is selected at an approximate consideration of the operating frequencies of the suppressed REM, based on the possibilities for realization of the acceptable parameters of weight and dimensions of the antenna array of the FD device and suppression of the largest number of the REM types. In this case, the wavelength of the influencing spatial and temporal pulse (STP) λ ≈ 2...2.5 cm can be accepted as the basic compromise value. The length of the focused STP upon the coordinates x and y (transversal linear dimensions of the focused bundle in the vicinity of the focusing point zF) are determined in the first approximation based on the known expressions for the co-phase antenna arrays

$$\Delta x_F \approx 2\left(\frac{\lambda}{L_x}\right) z_F\ ,\ \Delta y_F \approx 2\left(\frac{\lambda}{L_y}\right) z_F\ . \quad (2)$$

Table 1 provides the results of calculation based on the formula (2) for the apertures of MPSE at the given transverse dimensions of the FD zones ($\Delta x_F = \Delta y_F = 2$ m) at different focusing ranges. Figure 2 shows the results of mathematical modeling for the electromagnetic field in the vicinity of the focusing point at the frequency of 15 GHz under the assumption that the amplitude distribution upon MPSE is homogeneous, and its emitting elements are represented by the flat square PAA with horn emitters. The number of PAA in MPSE is 36.

Table 1: Results of calculation for the apertures of MPSE

z_F, km	5	10	15	20	25	30
$L_x = L_y$, m	100	200	300	400	500	600

From the provided above dependences it is evident that varying the dimensions of the MPSE aperture, we can provide for stability of the dimensions of the domain space for FD at different focusing ranges (Fig. 2(c)). This phenomenon plays an important role in providing for the electromagnetic compatibility thus excluding the cases of disabling friendly REM under the influence of powerful electromagnetic radiations. The levels of side lobe radiation can be decreased by application of amplitude distributions declining to the edges of the MPSE aperture. For effective FD the prescribed shapes of zones can be available by means the solution to the problem of MPSE structural synthesis. While performing FD of the maneuvering UAV it is necessary to envisage the possibility of focusing the EMR in MPSE into the moving point P_F (x_F, y_F, z_F) of the trajectory of their motion. In the general case new coordinates of such focusing point can be determined if at the given moment of time it is performed an extrapolation of the motion trajectory of the tracked UAV on the basis of the radar information received during the previous temporal counts.

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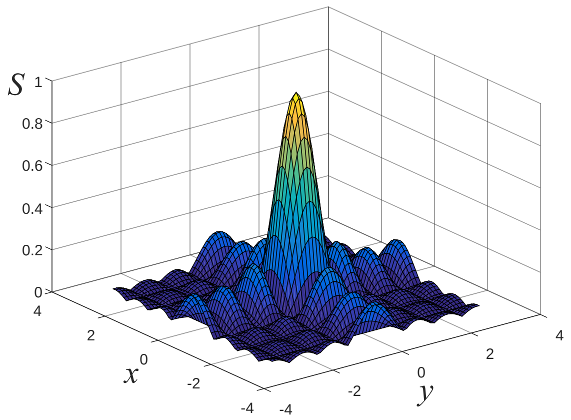
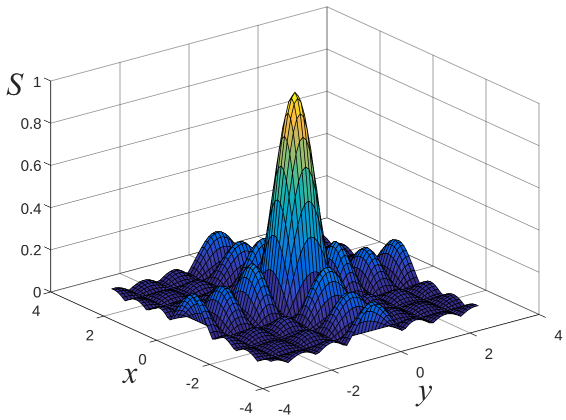
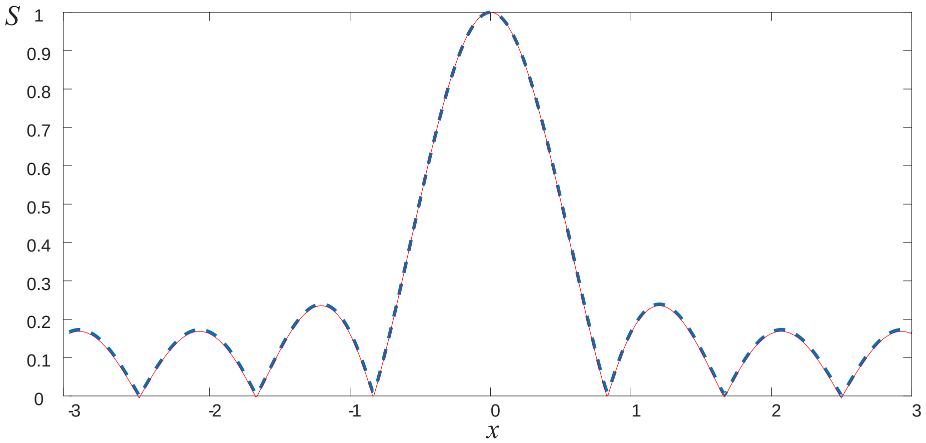


(a) z_F = 5 км, $L_x = L_y$ =50 м



(b) z_F = 30 км, $L_x = L_y$ =300 м



(c) distribution of the normalized power flux density within the XOZ plane, solid line z_F = 5 km, $L_x = L_y$ =50 m, dashed line z_F = 30 km, $L_x = L_y$ =300 m

Figure 2: Distribution of the normalized power flux density in the vicinity of the focusing point

Based on the known rectangular coordinates of the focusing point P_F (x_F, y_F, z_F) at the given moment of time their new values in the spherical system of coordinates related to the *nm*-th emitter of MPSE (Fig. 1) can be calculated using the following system of equations:

$$\begin{cases} R_{nm}(t) = \sqrt{(Xf(t) - Xnm)^2 + (yf(t) - ynm)^2 + (zf(t) - znm)^2}, \\ \Theta_{nm}(t) = \arccos \frac{ZF(t) - Znm}{Rnm(t)}, \\ \Phi_{nm}(t) = \arctan \frac{ZF(t) - Znm}{yF(t) - ynm} \end{cases} \quad (3)$$

Knowledge of the angular coordinates of the new focusing point allows setting an additional phase distribution in the form of an additive increment to the quadratic phase incursion providing for deviation of the focused beam from the direction of the normal to the emitter of MPSE. For the purpose of scanning it is necessary to add the linear phase distribution along the MPSE aperture. At independent scanning or split distribution the increment upon the elevation angle ξ0θ and azimuth ξ0φ in MPSE has the following representation:

$$\xi_{0\theta}\ x_{nm} = -a_{nm} x_{nm} \text{ и } \xi_{0\varphi}\ y_{nm} = -b_{nm} y_{nm},$$

Where $a_{nm} = \left\{\frac{\pi Lx}{\lambda}\right\} \sin\theta_{nm} \cos\varphi_{nm}$, $b_{nm} = \left\{\frac{\pi Ly}{\lambda}\right\} \sin\theta_{nm} \sin\varphi_{nm}$ is the steepness of the phase distributions.

In the case of focusing into a moving point the coefficients *anm* and *bnm* would depend upon time in accordance with the given law of the object motion, which is determined on the basis of (3). Therefore, the expression for calculation of the power flux density while focusing into a fixed point (1) must be modified by means of addition of the linear phase distribution determined by the law of the UAV motion and re-calculation of the quadratic increment □0*n* in the case of variation of the focusing range.

ASSESSMENT OF THE REQUIRED TEMPORAL AND POWER CHARACTERISTICS OF STP FOR FD

Special protective devices with the short actuation time and blocking receiving units at availability of not only the eigen receiver signal but also of a high level of any other input signals at their inputs can be applied in REM un a number of cases. The actuation time for the protection devices is of the order of 10 ns. Considering the foregoing the duration of the influencing focused STP must be selected based on the following condition

$$\tau_i \le \tau_r \quad (4)$$

where τ_i , τ_r are correspondingly the duration of the influencing STP and the actuation time of the device for protection against overloading at the receiver input of the suppressed REM. The transmission period for these influencing STP has to be selected in a way that the self-excitation oscillations in the receiving unit of REM would attenuate by not more than (50...70)% before arrival of each of the following influencing STP, the way they do:

$$Ti \le (0.7...1.2)\tau c \approx (0.7...1.2)\ \pi\Delta fb \approx (0.22...0.38)\ \Delta fb , \quad (5)$$

where Δfb and τc are the throughput bandwidth and the time constant for establishing of eigen oscillations of the suppressed REM receiver.

The required power of a single influencing STP in the case of the out-of-band influence at the inputs of the REM receiving units to perform their FD must be

$$P fd \ge P r \min \mathrm{K}dr\, \mathrm{K}\, cl. \quad (6)$$

The required power flux density of a single influencing STP in the set local focusing domain corresponding to the positioning of UAV, which is designated for FD, considering the relevant angular misalignment of the REM antenna patterns and the focused microwave beam of the FD facility has to be selected based on the following condition:.

$$\mathrm{S_{fd}} \ge \frac{\mathrm{Pfd}}{\mathrm{Aef}}\ \mathrm{Kam}. \quad (7)$$

The designations in the equations (6), (7) are the following: *Pr* min, K_{dr} is the sensitivity and the dynamic range of the REM receivers; *Kcl* is the coefficient of compensation of the losses occurred due to mismatch of the center frequencies of the influencing STP spectra and the throughput bandwidths Δfb of the suppressed REM; *Aef* = *Aga Kua* is the effective area of the antennas of the suppressed REM; *Kua* is the coefficient of efficient use of the antenna aperture geometrical area *Aga*, and *Kam* is the coefficient of compensation of the losses occurred due to angular misalignment of the pattern directions of the antennas of the disabled REM and the focused beam of the FD devices. The effective area of the antennas of the REM subject to FD can be approximately assessed on the basis of the following correlations:

- for the dipole antennas at $(L/\lambda) > 1$

$$\mathrm{A}_{ef} = \mathrm{K_{ua}} \frac{(2...4)L\lambda}{4\pi}, \quad (8)$$

- for the travelling-wave antennas $(L/\lambda) > 1$

$$\mathrm{A}_{ef} = \mathrm{K_{ua}} \frac{(7...8)L\lambda}{4\pi}, \quad (9)$$

- for the aperture antennas

$$Aef = Kua\ Aga , \quad (10)$$

where *L* is the wavelength of the disabled REM.

The power threshold necessary for attaining the degradation effect of the electronic elements is determined by the relaxation time of the thermal processes. For semiconductor devices and integral microchips that time amounts to $\tau rt \ge$ 10...100 ns [5]. At fulfillment of the condition (4) it appears that $\tau i < \tau rt$ and that periodic sequences of the focused STP are also required for the thermal degradation, while the required effect can be obtained, in this case, due to the aggregate time of influence of the entire STP package less the intervals between them if their transmission period is $Ti < \tau rt$ [7].

For degradation of the semiconductor device the required power at its input is determined from the following correlation:

$$P_{fd} = K_{td} \tau_{i\Sigma}^{-1/2} S_{p-n}, \quad (11)$$

where K_{td} is the thermal disablement constant for the relevant type of the semiconductor device, which constant has the dimensionality of $[\mathrm{kW}/(\mu\mathrm{s})^{1/2} \cdot \mathrm{cm}^{-2}]$; $\tau i\Sigma$ is the aggregate time of influencing upon the disabled REM by the periodic STP disregarding the intervals between them, and $Sp{-}n$ is the area of the *p-n* transition in cm^2. The required power of a single influencing STP at the outputs of the receiving units of REM for their FD in order to perform the out-of-band disablement must be:

$$P_{fd} = K_{td} \tau_{i\Sigma}^{-1/2} S_{p-n} K_{cl}. \quad (12)$$

Table 2 provides the calculation results of the required power *Pfd* at the inputs of the semiconductor devices for their degradation

Table 2: Power at the semiconductor in put for their degradation

Type of semi- conductor device	*Ktd*	*Sp-n*, cm2	*τiΣ*, ms	*Pfd*, mW	
				***Kcl*=30 dB *Kcl*=30 dB**	***Kcl*=40 dB *Kcl*=40 dB**
Diodes and transistors	0.1	$10^{-3}...5\cdot10^{-2}$	10^2	$316...1.6\cdot10^3$	$3160...1.6\cdot10^4$
Microwave diodes	0.01	$10^{-3}...5\cdot10^{-2}$	10^2	$31.6...1.6\cdot10^3$	$316...1.6\cdot10^4$
Integral circuits	0.1	$10^{-4}...2\cdot10^{-3}$	10^2	31.6...630	$316...6.3\cdot10^3$

Table 3: Power being needed for out-of-band disability

Type of semiconductor device	**Diodes and transistors**	**Microwave diodes**	**Integral circuits**	***Kam*, dB**
P_{fd}, mW	$316...1.6\cdot10^5$	$32...1.6\cdot10^4$	$32...6.3\cdot10^3$	
A_{ef}=13.5...27 см^2 (L=0.5м)	$12...1.2\cdot10^4$	$1.2...\ 1.2\cdot10^3$	1.2...470	0
	$23...2.3\cdot10^4$	$2.3...2.3\cdot10^3$	2.3...930	3
	$37...3.7\cdot10^4$	$3.7...3.7\cdot10^3$	3.7...1500	5
A_{ef} =54...108см^2($L_П$=2.0м)	$3...3\cdot10^3$	$0.3...3\cdot10^2$	0.3...120	0
	$5.8...5,8\cdot10^3$	0.58...580	0.58...230	3
	$9.2...9.2\cdot10^3$	$0.9...9.2\cdot10^2$	0.9...370	5
A_{ef} =135...271см^2(L=5.0м)	$1.2...1.2\cdot10^3$	0.12...120	0.12...47	0
	$2.3...2.3\cdot10^3$	0.23...230	0.23...93	3
	$3.7...3.7\cdot10^3$	0.37...370	0.37...150	5

The required spectral power flux densities S_{fd} for the out-of-band disablements are assessed on the basis of the correlation (7). The results of the assessments necessary for the out-of-band FD power flux densities S_{fd} (mW/cm^2) in the REM with the dipole antennas are provided in Table 3.

From Table 3 it follows that the out-of-band disability of the REM with the dipole antennas at the above-mentioned basic conditions is secured at the following power flux densities *Sfd* ≥ (0.12...3.7·104) mW/cm2.

Similar assessments used to be performed for the REM with the travelling-wave antennas, PAA and mirror antennas. The performed calculations showed that for the out-of-band disablement of the REM with the travelling-wave antennas the means of FD have to provide for the power flux densities within the limits of $S_{fd} \geq (0.12...3.3\cdot10^4)$ mW/cm^2, and for the REM with PAA and mirror antennas – of $S_{fd} \geq (4\cdot10^{-4}...830)$ mW/cm^2. Potential value of the FD range is determined from the functional disability equation [5].

CONCLUSIONS

The investigation results showed that at the accepted basic conditions, REM antenna types and the allowable angular shifts ±30^0 of the REM antenna patterns and the focused beam of the FD devices in the place of positioning of the UAV to be disabled, there must be created singular STP inside of their package with the duration of τ*i*Σ = 100 ms without taking into consideration of the intervals between the pulses with the possibility of variation of the values of *Sfd* within the limits from 4·10-4 to 4·104 mW/cm2. The required power flux density in the focusing point can be provided for with the help of varying of the number of emitters in MPSE.

Based on the information disclosed in the paper and the performed investigations we can point out that at the present moment the alternative means of FD with focusing of EMR in MPSE possess significant advantages over the traditional means of EWF and principally occupy a promising position in solving of the problem of FD for different classes of UAV.

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