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# Conditions For Reliable Transmission Of Information Over Long Distances Using a Powerful Electromagnetic Radiation

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## ABSTRACT

The paper draws attention to the transmission of useful information over long distances using radio equipment, GW power, with a duration shorter than ns.The estimation of the maximum breakdown strength of the electromagnetic radiation (EMR) pulse propagation in air space and the estimation of breakdown conditions in the discharge gap under the effect of microwave EMR range have been conducted.

The conditions under which the breakdown in the atmosphere will not occur regardless of the EMR power level have been determined.The spatial parameters of the EMR and the effect of the air on the EMR power loss and electron heating have been calculated.

**Key words**: radio electronic means, electromagnetic radiation, ultrashort pulse duration, plasma protection technologies, gaseous plasma media.

## 1. INTRODUCTION

Modern radiolocation media have the ability to generate GW power pulses, with a duration shorter than ns, in order to solve the problems of transmitting useful information over long distances.

For example, the use of broadband signals (BBS) in radiolocation or communications is considered in terms of protection of useful information.

The need to transmit information over long distances requires an increase in strength, which may lead to a breakdown in the atmosphere, which preconditions the study of the space-energy and spatiotemporal characteristics which are generated [1, 6, 13-17, 22, 24, 25].

The aim of the article is to determine the conditions for reliable transmission of information over long distances using a powerful EMR.

### 1.1 PROBLEM ANALYSIS

#### 1.1.1 Estimation of the maximum breakdown strength of the EMR pulse propagation in the air space

Under the influence of pulsed EMR its parameters are chosen so that there was no discharge (breakdown) during the propagation of the EMR pulse in the air space, that is, such conditions are chosen that until the end of the pulse duration $\tau$, the concentration of charged particles would increase to a value of no more than $n \le \frac{n_{кр}}{2}$.

For this, the pulse repetition rate is chosen such that before the start of each subsequent pulse after time T, the concentration of charged particle would decrease to a value $n_0$. Thus, we can write down the following:

$$\nu_i = \nu_в + \frac{\ln \frac{n_{кр}}{2n_0}}{\tau}. \qquad (3)$$

Taking into account (1), (2) we will present the expression (3) in the following form:

$$\nu_i = \nu_з \left( h + \frac{\ell^2}{3\Lambda^2} + \frac{\ln \frac{n_{кр}}{2n_0}}{\tau} \right),$$

or

$$\nu_i = \left( 1 + \frac{6.7 \cdot 10^2}{(pd)^2} + 5 \cdot 10^{-5} \frac{\ln \frac{n_{кр}}{2n_0}}{p\tau} \right) 2.12 \cdot 10^4 p. \qquad (4)$$

During a small pulse duration, when $\tau < 5 \cdot 10^{-5} \frac{\ln \frac{n_{кр}}{2n_0}}{p}$ and $\tau < 7 \cdot 10^{-8} \ln \frac{n_{кр}}{2n_0} \cdot pd^2$, the expression (4) can be greatly simplified and represented in the following form:

$$\nu_i = \frac{\ln \frac{n_{кр}}{2n_0}}{\tau}. \qquad (5)$$

The correlations (4), (5) allow to find $E_{кр}$ at given $p, d, \tau$, in accordance with the results of experimental studies [ 1, 2, 4, 11, 12, 13, 21, 24], in which by the end of pulse the concentration of charged particles of ionized air will be $n \approx \frac{n_{кр}}{2}$.

The results of the calculation of the breakdown strength of the air for $\omega = 2\pi \cdot 10^{10}$ for $\tau_1 = 5 \cdot 10^{-6}$s and $\tau_2 = 5 \cdot 10^{-8}$s are presented in tables 1, 2.

**Table 1:** Breakthrough strength of air at $\tau_1 = 5 \cdot 10^{-6}$s

| h, km | 30 | 60 | 70 |
|---|---|---|---|
| p, mm.mer.p | 10 | 0,2 | $8\times10^{-2}$ |
| $p/d^2$, W/sm² | $5\times10^2$ | $2.2\times10^3$ | $10^4$ |

**Table 2:** Breakthrough strength of air at $\tau_2 = 5 \cdot 10^{-8}$s

| h, km | 30 | 60 | 70 |
|---|---|---|---|
| p, mm.mer.p | 10 | 0,2 | $8*10^{-2}$ |
| $p/d^2$, W/sm | $3.3\times10^3$ | $3\times10^4$ | $5\times10^5$ |

The results of the calculations given in table 1, 2 show that at a distance of h >70 km at $\tau = 50$ns and $p/d^2 \approx 10^6$ the power transmission P =$10^{10}$ W without discharge in the atmosphere can be provided.

**1.1.2 Estimation of breakdown conditions in the discharge gap under the effect of microwave EMR range**

According to the results of research cited in [20, 25, 27], the electron loss under the influence of microwave EMR range is defined by the processed of diffusion, trapping and recombination. In terms of the inhomogeneous distribution of the microwave field in the discharge gap, the electron loss is determined by the directed motion of electrons under the action of the ponderomotive forces of the microwave field.
In order for a discharge to occur, the condition $\nu_i \geq \nu_в$ must be fulfilled. That is, thet ionization frequency $\nu_i$ must be greater than the electron loss rate $\nu_в$. The fulfillment of the condition $\nu_i \geq \nu_в$ is determined by the quantity of the amplitude of the microwave field tension, which is called the breakdown voltage $E_{пр}$.

In the case of a homogeneous microwave field $E_{пр}$ depends on the quantity of the atmospheric pressure p in the discharge interval and is determined by the Paschen law [20, 24, 26].

The minimum value $E_{пр}$ occurs at such a pressure p when $\omega = \nu_з$ ($\omega$ –microwave frequency, $\nu_з$ – frequency of electron collisions with air atoms).

In our case, for the implementation of the guaranteed REM protection, the pressure area where $\omega \ll \nu_з$ is important.

In this pressure range $\nu_П + \nu_Д \ll \nu_з$ and $\nu_в = \nu_П + \nu_Д$, where $\nu_П = h\nu_з$,

h–probability of trapping, and $\nu_Д = \frac{\ell^2}{3\Lambda^2}\nu_з$,

$\ell$ –length of the electron's mean free path,
$\Lambda$ –characteristic diffusion size of the microwave field.

Thus, the quantity $E_{пр}$ can be found by solving the following equation:

$$\nu_i = \left( h + \frac{\ell^2}{3\Lambda^2} \right) \nu_з. \qquad (1)$$

The solution of equation (1) does not exist in the analytic form. It happens due to the complex dependence $\nu_i$ from E of the microwave field. To find $E_{пр}$ we will use the results of experimental studies of the dependence $\nu_i$ on E of the microwave field, which are sufficiently given in many papers [2, 8,9,10, 25].

For the air $h = 4\cdot10^{-6}$, $\ell = \frac{1}{35}p$, $\nu_з = 5,3\cdot10^{9}p$.

Given that $\Lambda = d/\pi$, where d–is the smallest characteristic size of the area occupied by the microwave field, from (1) we will receive the following:

$$\nu_i = \left(4\cdot10^{-6} + \frac{2.7\cdot10^{-3}}{p^2d^2}\right)\cdot 2.12\cdot10^{4}p\,. \qquad (2)$$

From the analysis of equation (2) it can be seen that at $\omega > \nu_з$, or $p < \frac{\omega}{5.3\cdot10^{3}}$ and $pd > 25$ the electron losses are determined by the trapping process. In this case, the value $E_{пр}$ does not depend on both the pressure p and the size of the microwave field. For these conditions $E_{пр}$ = 650 V/sm.

When $pd < 25$, the electron losses are determined by the diffusion process, and the quantity $E_{пр}$ becomes dependent on both the pressure p and the size of the microwave field d.

In accordance with (2) for a fixed value $\omega$ $E_{пр} = const$ at $pd = const$.

In diffusion mode for air at $\omega = 2\pi\cdot10^{10}$ the quantity $E_{пр}$ = 950 V/sm ($pd = 1$) and $E_{пр}$ = 1,7кV/sm ($pd = 0.2$).

The diffusion mode is limited by conditions $pd < 25$ and $d \ge \ell = 1/35p$, or $3\cdot10^{-2} < pd < 25$.

In conditions where $d \ll \ell$ ($pd \ll 3\cdot10^{-2}$), the electron losses will be determined by their thermal motion:

$$\nu_в \cong \frac{\ell}{d}\nu_з\,,$$

where $\ell\nu_з = v_e$ –the speed of thermal motion of electrons.

Since $\nu_i/\nu_з \le 1$, then at $\frac{\ell}{d} \ll 1$ there will be no breakdown of the air gap at any values of the voltage of the electric field.

**1.1.3 Determination of conditions under when the breakdown in the atmosphere will not occur regardless of the EMP power level**

Since the EMR is characterized not only by the quantity of the EMR power but also by the pulse duration, we will find conditions under which, regardless of the power level of the EMR, no breakdown in the atmosphere will occur. This requires that the following condition is fulfilled:

$$\frac{1}{\omega} < \tau < \frac{1}{\nu_з} = \frac{1}{5,3\cdot10^{9}p}.$$

Thus, at $\omega = 2\pi\cdot10^{10}$ Hz and $p < 12$ mm.mer.pil. for altitude h=60 km $\tau \approx$ 1ns, for altitude h=85 km $\tau \approx$ 20ns, for altitude h=100 km $\tau \approx$ 200ns.

The condition $\tau < \frac{1}{\nu_з}$ is rather tough. It is enough to fulfil the following condition: $\tau < \frac{1}{\nu_i}$. This means that with the pulse effect of the microwave power the beam focus altitude can be reduced to 100 km.

**1.1.4 Determination of spatial parameters of EMR**

The radio frequency radiation is determined by the spatial parameters, the intersection of the EMR beam passing through the atmosphere in particular. The knowledge of the spatial dimensions of the EMR beam is important in terms of the possibility of simultaneous destructive effect on several objects at a short distance from each other. So let us determine under which EMR spatial parameters the breakdown of the air space will not occur but it will be possible to affect several objects at the same time. To do this, let us assume that the intersection of the EMR beam is a square whose side equals d.

It can be shown that at the altitude H the size of the intersection side of the EMR beam, which is determined by the dimensions of the beam across the intersection on Earth $d_3$ and at the altitude $H_Ф$ of the beam focus $d_Ф$,, will be determined by the following relation:

$$d = d_3(d_3 - d_Ф)(1 - \frac{H}{H_Ф}) + d_Ф\,.$$

Let us determine the parameters of the EMR beam, under which on breakdown in the atmosphere will occur and under which there will be a destructive effect on spatially spaced REM.

The solution to this problem with such known EMR parameters as EMR power P, $d_3$, $d_Ф$ and $\omega$, can be reduced to the definition $H_Ф$.

When solving the problem, it is necessary to consider that at different altitudes there will be different values d. It leads to the difficulties of building a dependency or dependency family that reflect the breakdown strength of the atmosphere at different altitudes at different values of d. But the laws of the similarity of the gas breakdown allow to solve this problem in a relatively simple way.

It has been stated above that the minimum breakdown voltage $E_{пр}$ will be at such altitude when $\omega = \nu_з$. Based on this, we will reformulate the problem in question as follows: it is necessary to find (select) the minimum value $H_Ф$, at which at altitudes $H < H_Ф$ there will be no breakdown in the atmosphere. To solve the problem, we will use the conditions under which the quantity $E_{пр}$ does not depend on the pressure p and the size of the microwave field, the conditions of the diffusion regime provided above, the ratio for determining d, as well as the results of experimental data on the breakdown strength of air at different values of pd, widely provided in the known literature [18, 19, 20]. As a result, for $\omega = 2\pi \cdot 10^{10}$ Hz at altitude $H < H_Ф$ there will be a breakdown if

$$pd = pd_з\left((1-\frac{H}{H_Ф})+\frac{d_Ф}{d_з}\right) > 25 .$$

In this case, the EMR energy density will be determined according to this expression:

$$\frac{P}{d^2\left((1-\frac{H}{H_Ф})+\frac{d_Ф}{d_з}\right)^2} > A = 5\cdot 10^2\,\frac{Вт}{см^2},$$

where A- is the energy density.

Thus, in accordance with the abovementioned considerations, the breakdown in the trapping area will occur at altitudes (at $\frac{d_Ф}{d_з} \ll 1$)

$$H \le H_{кр} = H_Ф(1-\frac{\sqrt{P}}{\sqrt{Ad_з}}), \qquad pd = p\sqrt{\frac{P}{A}} \ge 25.$$

In the diffusion area the conditions for the breakdown are as follows:

$$H_1 = H_Ф(1-\frac{\sqrt{P}}{\sqrt{A_1 d_з}}), \quad p\sqrt{\frac{P}{A_1}} \ge 1 \text{ at } A_1 = 10^3\, W/sm^2$$

and

$$H_2 = H_Ф(1-\frac{\sqrt{P}}{\sqrt{A_2 d_з}}), \quad p\sqrt{\frac{P}{A_2}} \ge 0.2 \quad \text{at}$$

$$A_2 = 3.5\cdot 10^3\, W/sm^2 .$$

Thus, by setting different values of $H_Ф$, it is possible to determine the possibility of the breakdown at different altitude $H_i$.

Let us consider the abovementioned conditions for the implementation of the breakdown in the field of trapping and diffusion area with respect to the following EMR parameters: $d_з = 3\cdot 10^5$ sm, $d_Ф = 10^2$ sm, $\omega = 2\pi\cdot 10^{10}$ Hz, and also $P = 10^{10}$ W and $P = 10^{12}$ W.

As shown above, for these parameters, the condition of realization of the breakdown in the trapping area will be fulfilled at the air pressure of less than 11 mm.mer.pil. at an altitude of $H \ge 30$ km, the diffusion breakdown area will be limited by the condition $3\cdot 10^{-2}$ <pd<25, that is will be realized at $d_Ф = 10^2$ sm, p> $3\cdot 10^{-4}$ mm.mer.pil. It means that there should be no breakdown at the altitude $H_Ф > 130$km (l>d). Next, let us find out at what altitude values the conditions of breakdown will be fulfilled.

Let us suppose that $P = 10^{12}$ W, $H_{кр} = H_Ф(1-0.15) = 0.85 H_Ф$ and $H_Ф = 100,\ 120$ and $150$ km.

Then $H_{кр} = 85,\ 102$ and $127$ km, at which the air pressure equals p=$10^{-2}$, $10^{-3}$ and $3\cdot 10^{-4}$ mm.mer.pil. Based on this, at the altitude $H_{кр} = 85$ km $pd_{кр} = 4.2\cdot 10^2$ >25 there will be a breakdown. At the altitude $H_{кр} = 102$ km there will be a breakdown as well. Yet, there will be no breakdown at the altitude $H_{кр} = 127$ km $pd_{кр} = 13.5$ <25. Thus, the breakdown in the trapping area determines the minimum value of the altitude $H_Ф \approx 150$km.

Let us find out if there will be a breakdown in the diffusion area at the altitude $H_Ф \approx 150$km.

$H_1 = H_Ф(1-0.1) = 135$ km at $d = 0.1 d_з$.

At this altitude, the air pressure is p=$1.5\cdot 10^{-4}$ mm.mer.pil. and $pd = 1.5\cdot 10^{-4}$.

Under these conditions, the breakdown will occur.

$H_2 = H_Ф(1-0.054) = 142$ km and $d = 0.054 d_з = 1.6\cdot 10^4$ sm. At this altitude p=$10^{-4}$ mm.mer.pil. and $pd = 1.6 > 0.2$. The breakdown will occur as well.

According to the abovementioned calculation approach, it is possible to determine more precisely the minimum value $H_Ф$, when all the breakdown conditions in the trapping area and diffusion area are fulfilled. Such an altitude equals $H_Ф = 170$ km.

If $P = 10^{10}$ W, based on the condition of breakdown in the trapping area, $H_Ф \approx 100$ km. Let us check the possibility of fulfilling the condition of functioning in the diffusion area. For these conditions $H_1 = H_\Phi(1-0.01) = 99$ km. At this altitude p=$10^{-3}$ mm.mer.pil. and $pd > 3$. The breakdown will occur.

$H_2 = H_\Phi(1-5.4\cdot 10^{-3}) = 99.2$ km , $pd = 1.6 > 0.2$. The breakdown will occur as well. Thus, it is necessary to choose $H_\Phi \approx 130$km.

But it has to be noted that at the altitude H > 150 km, even when a focus breakdown occurs (there will be one hundred percent ionization), the density of the plasma media $n \le 3\cdot 10^{11} sm^{-3} < \frac{n_{кр}}{2}$ is such that the fact of the breakdown will not affect the process of EMR propagation.

If the EMR is propagated along the Earth's surface at small angles of incidence, then the magnetic field of the Earth will be affected by the breakdown, under the influence of which the effective diffusion length in the direction perpendicular to the field will increase, as a result, the diffusion losses will be reduced. It means that the breakdown will not occur.

### 1.1.5. Determination of the effect of the air on the EMR power loss and electron heating

The passage of EMR through the air will result in the power loss due to electron heating. The power losses $\Delta P$ according to [19] are determined by the following ratio:

$$\frac{\Delta P}{P} = \frac{\nu_з}{c}\frac{\omega_0^2}{\omega^2}\Delta H,$$

where $\omega_0^2 = 3\cdot 10^9 n$; n – the plasma density at the length of the EMR beam, $\Delta H$, c– speed of EMR propagation.

It is known [18, 20], that at the altitude $H = 100...150$ km $n_0 = 10^5...10^6 sm^{-3}$.

For $\omega = 2\pi\cdot 10^{10}$ Hz we will receive:

$$\frac{\Delta P}{P} = 2\cdot 10^{-13} p n_0 \Delta H.$$

At $p = 1$ mm.mer.pil. , $\Delta H = 10^6$ sm and $n_0 = 10^3 sm^{-3}$ the power losses will equal $\frac{\Delta P}{P} = 0.02$ %. This estimation does not take into account the increase in the electron temperature.

The frequency of the electron collisions depends on their energy $\nu_з \sim W_e^{\frac{1}{2}}$.

Thus, as the electrons heat up, the fraction of absorbed power will increase. If the breakdown occurs and there is a one hundred percent ionization of the air, but $n < \frac{n_{кр}}{2}$, as the electrons heat up, the fraction of absorbed power will decrease. It is due to the fact that the frequency of electron collisions with ions equals $\nu_{ei} \sim \frac{1}{W_e^{\frac{1}{2}}}$.

Let us consider the effect of electron heating on the breakdown strength of the air.

In the diffusion area and the trapping area, the effect of electron heating can be disregarded because there is the quantity $P/d^2 \approx 5\cdot 10^2...3\cdot 10^3\ W/sm^2$.

But in the EMR focus $P/d^2 \approx 10^6...10^8\ W/sm^2$, which preconditions the necessity of consideration of electron heating.

In the known literature, the question of the effect of electron heating on the breakdown has not been addressed and requires appropriate research. But, in our opinion, it is sufficient to determine the value $P/d^2$ for estimation.

The estimations show that one electron in a volume $\frac{d^2}{\Delta H}$ can generate the following energy:

$$W_e(eB) \approx \frac{10^{18}}{1.6} P \frac{\nu_з \tau_ж}{\omega^2 d^2},$$

where $\tau_ж$ – the lifetime of the electron in the discharge volume.

Let us consider that $\nu_з = 20\nu_e p$ ($\ell\nu_з = \nu_e$), in terms of $\ell$ >d, $\tau_ж \approx \frac{d}{\nu_e}$. Then $W_e(eB) \approx 3\cdot 10^{-3}\frac{P\cdot p}{d}$.

At $p = 10^{-4}$ mm.mer.pil. , d=$10^2$ sm, $P = 10^{10}...10^{12}$ W the value $W_e(eB) = 30...3000$.

The proposed estimation is rough, but it indicates that at $P/d^2 > 10^6\ W/sm^2$ the heating can be significant.

Thus, the EMR beam that is propagating perpendicularly to the Earth's surface with power $P = 10^{10}...10^{12}$ W will pass through the air at minimum focal lengths $H_\Phi = 130$ and 170 km, respectively.

The pulse EMR with power $P = 10^{10}$ W ($\tau_i = 50$ns) passes through the air at $H_\Phi \ge 70$ km.

At $P = 10^{12}$ W ($\tau_i = 20$ns) the minimum focal length equals $H_\Phi \ge 85$ km.

## 2. CONCLUSION

1. It has been determined that for a breakdown to occur in the discharge gap under the influence of the EMR of the microwave field, it is necessary to fulfil the condition that can be represented in the following way: the frequency of ionization should be greater than the frequency of electron losses.

2. The estimation of the effect of pulse EMR and its parameters has been conducted. It has been determined that in the air space, when the EMR pulse is propagated over a distance of more than 70 km with a duration of 50 ns, it is possible to transmit GW power without discharge in the air space.

## REFERENCES


1 M. Iasechko. **Plasma technologies for the protection of radio electronic means from exposure to high-power electromagnetic radiations with ultrashort pulse duration**, *Proceedings of the 1-st Annual Conference*, Tallinn, Estonia, 2017, pp. 18–21. doi: /10.21303/2585-6847.2017.00480.

2 E. M. Bazelyan and U. P. Raizer. **Lightning attraction mechanism and the problem of laser lightning control**, *Physics–Uspekhi, 43:7,* Moscow, 2000, pp. 701–716. https://doi.org/10.1070/PU2000v043n07ABEH000768

3 V. L. Ginzburg and A. V. Gurevich. **Nonlinear phenomena in a plasma located in an alternating electromagnetic field**, *SOV PHYS USPEKHI, 3(1),* Moscow, 1960, pp.115–146. doi:10.1070/PU1960v003n01ABEH003261.

4 O. G. Sytenko. **Electromagnetic plasma fluctuations**, KhGPU, Ukraine, Kharkiv, 1965, pp. 1-183.

5 S.A.Gutsev, A.A. Kudryavtsev, R.Yu. Zamchiy, V.I. Demidov, and V.I. Kolobov. **Diagnostics and modeling of ashort (without positive column) glow discharge in helium with nonlocal plasma**, *Proc. 40th European Physical Society Conference on Plasma Physics*, Finland, 2013, N 06.502.

6 M.M. Iasechko, and O.M. Sotnikov. **Advanced technologies of radio electronic equipment (means) protection from powerful electromagnetic radiations with ultra short duration of pulses exposure,** *Published by Izdevnieciba Baltija Publishing*, Collective monograph, Riga, 2018, pp.356-385.

7 I. Mac-Daniel. **Collision processes in ionized gases**, *World*, Moscow, 1967.

8 O.Skoblikov and V. Knyazyev. **Properties of Conductive Shells Exposed to Electromagnetic Impulse of Lightning**, *International Conference on Lightning Protection (ICLP'2012)*, Vienna, Austrian, 2012, pp. 1-8. https://doi.org/10.1109/ICLP.2012.6344231

9 A. Tajirov, I. Cwhanovskaya, and Z. Barsova, N. Iluoykha. **Chemistry and technology of magnetite and barium-containing composite materials on its basis**, *European Science and Technology: materials of the II international research and practice conference*, Wiesbaden Germany, 2012, pp. 80-87.

10 V.A. Chernikov, S.A. Dvinin, A.P. Ershov, I.B.Timofeev, and V.M. Shibkov. **Experimental and Theoretical research of DC transversal gas discharge in a supersonic gas flow**, The 3rd workshop on Magneto-Plasma-*Aerodynamics in Aerospace Applications*, Moscow, 2001, pp. 129-134.

11 B. M. Smyrnov. **Low Ionized Gas Physics,** *The science*, Moscow, 1985.

12 S.A. Dvinin, and A.A. Kuzovnikov. **Plane ionization waves caused by diffusion in high frequency fields**, *XVII International Conference on Phenomena in Ionized Gases*, Belgrade, 1989, pp. 818-819.

13 O. Sotnikov, M. Iasechko, V. Larin, O. Ochkurenko, and D.Maksiuta. **The model of a medium for creation of electric hermetic screens of the radio electronic means**, *IJATCSE. 8(2)*, 2019, pp. 300-304. doi:10.30534/IJATCSE/2019/32822019.

14 M. Iasechko, O. Tymochko, Y. Shapran, I. Trofymenko, D. Maksiuta, and Y. Sytnyk. **Loss definition of charged particles in the discharge gap of the opening of the box-screens during the formation of a highly conductive channel,** *IJATCSE. 8(1.3)*, 2019, pp. 1-9. doi: 10.30534/ijatcse/2019/0181.32019.

15 M. Iasechko, V. Larin, O. Ochkurenko, S. Salkutsan, L. Mikhailova, and O. Kozak. **Formalized Model Descriptions Of Modified Solid-State Plasma-Like Materials To Protect Radio-Electronic Means From The Effects Of Electromagnetic Radiation,** *IJATCSE. 8(3)*, 2019, pp. 393-398. doi: 10.30534/ijatcse/2019/09832019.

16 M. Iasechko, V. Larin, O. Ochkurenko, A. Trystan, T.Voichenko, A. Trofymenko, and O. Sharabaiko. **Determining the function of splitting the charged particles of the strongly ionized air environment in the openings of the case-screens of radioelectronic means,** *IJATCSE. 8(1.3)*, 2019, pp. 19-23. doi: 10.30534/ijatcse/2019/0481.32019.

17 M.M. Iasechko, and O.M. Sotnikov. **Protecting of radio electronic facilities is from influence of powerful electromagnetic radiation,** *Published by Izdevnieciba Baltija Publishing*, Collective monograph, Riga, 2019, pp.283-299.

18 A. Syrotenko, O. Sotnikov M. Iasechko, V. Larin, S.Iasechko O. Ochkurenko, and A. Volkov. **Model of Combined Solid Plasma Material for the Protection of Radio-Electronic Means of Optical and Radio Radiation**, *IJATCSE, 8(4),* 2019, pp. 1241 — 1247. doi:10.30534/ijatcse/2019/33842019.

19 V. Gurevich. **Electromagnetic Terrorism**: *New Hazards. – Electrical Engineering and Electromechanics*, N 4, 2005.

20 Yu. P. Reiser. **Breakdown and heating of gases under the action of laser beam**, *The successes of the physical sciences*, 1965.

21 A.V. Bobylev, and V.A. Chuyanov. **On the numerical solution of the Landau kinetic equation**, *Journal of Computational Mathematics and Mathematical Physics, T. 16. № 2*, 1977, pp. 407 – 416.

22 O. Turinskyi, M. Burdin, M. Iasechko, V. Larin, Y. Gnusov, D. Ikaev, V. Borysenko, and V. Manoylo. **Protection of board radioelectronic equipment from the destructive powerful electromagnetic radiation with the use of natural technologies**, *IJETER, 7(11),* 2019, pp. 542 ― 548. doi: 10.30534/ijeter/2019/2371120 19.

23 M. Iasechko, V. Larin, D. Maksiuta, O. Ochkurenko, I. Krasnoshapka, Y.Samsonov, H. Lyashenko, A.Zinchenko, and R.Vozniak. **Model description of the modified solid state plasma material for electromagnetic radiation protection**, *IJETER, 7(10),* 2019, pp. 376 ― 382. doi: 10.30534/ijeter/2019/027102019.

24 O. Turinskyi, M. Iasechko, V. Larin, D. Dulenko, V. Kravchenko, O. Golubenko, D.Sorokin, and O. Zolotukhin. **Model and development of plasma technology for the protection ofradio-electronic means of laser emission**, *IJATCSE. 8(5)*, 2019, pp. 2429-2433. doi:10.30534/IJATCSE/2019/85852019.

25 M.Iasechko, Y. Gnusov, I. Manzhai, O. Uhrovetskyi, V.Manoylo, A. Iesipov,O. Zaitsev, M. Volk, and O. Vovk. **Determination of requirements for the protection of radio-electronicequipment from the terroristic influence by electromagnetic radiation**, *IJETER, 7(12),* 2019, pp. 772 ― 777. doi: 10.30534/ijeter/2019/077122019.

26 I.Ruban, H. Khudov, O.Makoveichuk, I. Khizhnyak, N.Lukova-Chuiko, G.Pevtsov, Y.Sheviakov, I.Yuzova, Y.Drob, and O.Tytarenko. **Method for determining elements of urban infrastructure objects based on the results from air monitoring**, *Eastern-European Journal of Enterprise Technologies, № 4/9(100),* 2019, pp.62-61. doi: 10.15587/1729-4061.2019.174576.

27 I.Ruban, H. Khudov, O.Makoveichuk, M. Chomik, V.Khudov, I. Khizhnyak, V.Podlipaiev, Y.Sheviakov, O.Baranik, and A.Irkha. **Construction of methods for contours of objects on tonal aerospace images based on the ant aigoritms**, *Eastern-European Journal of Enterprise Technologies, № 5/9(101),* 2019, pp.25-34. doi: 10.15587/1729-4061.2019.177817.