Development and justification of parameters of a microwave installation for pre-planting treatment of vegetable seeds

O V Mikhailova¹, G V Novikova², M V Belova³, A I Kotin³, A V Kazakov⁴ and A A Tikhonov⁴

¹Chair «Technology info-communications and connection systems», Nizhny Novgorod state engineering and economic university, 22a, Oktyabrskaia Str., Knyaginino, 606340, Russia
²Nizhny Novgorod state engineering and economic university, 22a, Oktyabrskaia Str., Knyaginino, 606340, Russia
³Chair «Electrification and automation», Nizhny Novgorod state engineering and economic university, 22a, Oktyabrskaia Str., Knyaginino, 606340, Russia
⁴Chair «Metal technology and car fixing», Nizhny Novgorod state agricultural academy, 97, Gagarina Prospect, Nizhny Novgorod, 603107, Russia

E-mail: NovikovaGalinaV@yandex.ru

Abstract. The article is devoted to the analysis of the dielectric parameters of potato and onion tubers for the development of a microwave installation that provides pre-planting treatment by means of a complex effect of electrophysical factors. The sources of energy were magnetrons, Ulтратrone or Darsonval. The originality of the research includes analysis of the volume of planting material for determination of the required plant performance; analysis of the dielectric parameters of potatoes depending on the frequency of EMF, humidity, and temperature for calculating the power of dielectric losses per unit volume. Theoretical studies of the dielectric parameters of onions presented their structure as a "capillary model". The development of the design of a microwave installation for provides a complex effect of electrophysical factors when calibrating onions. The justification of the corona discharge intensity of electric-gas-discharge lamps is in UHF EMF. There is the study of the dynamics of onion-sowing heating, justification of effective treatment modes. The dynamics of onion heating shows that with the power of the microwave generators of 3.4 kW and Darsonval of 80 W, the drum drive power of 0.25 kW, it is possible to ensure the installation capacity of 150-200 kg/h at an energy cost of 0.025 kWh/kg.

1. Introduction
In medium-sized farms in Russia, pre-planting processing of 125 tons of potato tubers is carried out. 20-30 days before planting, the onion is calibrated. For planting onion-sowing on 1 hectare, a small fraction (10-14 mm) of 960-1120 kg is required; an average fraction (14-17 mm) is 1714-2000 kg; a sample of onions (21-24 mm) is 4616-5385 kg [1, 2]. In order to prevent bolting, the sowing is warmed up 3-4 days before planting. In order to prevent diseases, pests, to accelerate germination and obtain a good harvest, they are treated with growth stimulants, i.e. various agricultural products. They protect the crop from diseases at all stages of growth, but do not exclude side effects on humans.

The main problem is to analyze the dielectric parameters of potato and onion tubers of the
developed microwave installation (patent no. 2703062) [3, p. 1–10], which provides pre-planting treatment of seeds by a complex effect of electrophysical factors.

The ultra-high-frequency (microwave) installation with a toroidal resonator for pre-planting processing of potato tubers provides for a complex effect of such electrophysical factors as: ultra-high-frequency electromagnetic field, corona discharge, ultraviolet rays, ozone. The sources are a microwave generator, an Ultraton or Darsonval [4, p. 1], and an induction cooker. Our research shows that the effect of their influence can be increased by placing electric-gas-discharge lamps connected to kilohertz frequency sources in an ultrahigh frequency electromagnetic field (UHF) [5, p. 89].

This unit can be used for calibrated planting material, including large-fraction onion-sowing, otherwise small fractions together with ectoparasites are subjected to induction heating. For effective complex influence of electrophysical factors, it is necessary to exclude induction heating and use pre-calibrated planting material, this will allow you to identify the exact dose of UHFEMF exposure for each fraction, including for onion-sowing. Therefore, we are developing a new installation that provides a complex effect of electrophysical factors on calibrated onions.

2. Materials and methods
When analyzing humidity, temperature, onion density, and the size of each fraction, GOST 30088-93 "Onion-sowing and onion-samples. Seed quality. General technical conditions was used [1]. The sources of the kilohertz frequency were the Ultraton "AMP-2 INT" (frequency 22 kHz) or the Darsonval "AMD-Igka-4", with a capacity of 80 VA with a scallop electrode. The frequency of pulse-modeled high-frequency oscillations is 110 kHz [4, p. 110-112]. The sources of microwave energy were magnetrons, powerful generators of electromagnetic waves in the centimeter range (frequency 2450 MHz, wavelength 12.24 cm), the principle of operation of which is based on the braking of electrons in crossed magnetic and electric fields. We used magnetrons with forced air cooling of the Galanz model (M24FA-410A, 800 W), JM002 (700 W), 2M210-M1 (900 W), 2M213 (700 W). The concentration of aeroions near the electro-gas discharge lamp was measured by light ion counters (MAS-01).

The algorithm of the research includes:
* analysis of the amount of planting material (potato tubers, onion-sowing) to determine the required productivity of the plant for farms;
* analysis of changes in the dielectric parameters of potatoes depending on the UHF frequency, humidity, and heating temperature to calculate the power of dielectric losses per unit volume;
* theoretical studies of the dielectric parameters of the onion-sowing by presenting its structure as a "capillary model”;
* development of a design version of a microwave installation with volumetric resonators that provide a complex effect of electrophysical factors in the process of onion-sowing calibration;
* theoretical justification of the corona discharge intensity when scallop electro-gas discharge lamps are located in the UHF;
* experimental studies of the heating dynamics of calibrated onion seeds;
* preliminary justification of effective modes of pre-planting processing of onion-sowing.

3. Results
In order to disinfect and activate the cells of the planting material in order to increase their sowing and productive indicators, we propose to perform pre-planting treatment of onion sowing and potato tubers in an installation with ultra-high frequency electromagnetic field sources (UHF) and electro-gas discharge lamps powered by Darsonval or Ultraton. The effect of ultra-ionizing or darsonvalization is manifested by the action of ionized and ozonized air on the raw material.

The paper analyzes the dielectric characteristics of early-grade potatoes "Priekulsky" depending on the frequency of EMF, temperature and humidity at a frequency of 2400 MHz (Fig. 1) according to I. A. Rogov [6, p. 92-93]. The analysis shows that with an increase in the UHF frequency from 433 MHz to 3000 MHz, the dielectric loss factor decreases from 33 to 15.5 at a temperature of 20°C and a
humidity of 81.3 %. The dielectric parameters of the EMF frequency are described by empirical expressions:

\[ \varepsilon = 66.788e^{-2E-05f}, \quad k = 34.17e^{-3E-04f}, \quad tg\delta = 0.5114e^{-3E-04f}. \]  

(1)

When the temperature changes from 20 °C to 95 °C, the dielectric constant (\(\varepsilon\)) decreases from 63.1 to 47.1, the coefficient of dielectric loss (\(k\)) increases from 16.9 to 18, that is, at 19.5 %, the tangent of the dielectric loss angle (\(tg\delta\)) increases from 0.268 to 0.38. These characteristics are described by empirical expressions:

\[ \varepsilon = 69.78e^{-0.004x}, \quad k = 17.66e^{0.0008x}, \quad tg\delta = 0.254e^{0.0046x}. \]  

(2)

The increase in the dielectric loss factor in the specified temperature range is explained by the fact that at a temperature above 30 °C, denaturation of proteins begins, accompanied by the release of moisture. Over 60°C, the dielectric loss factor decreases due to moisture evaporation and thermal movements of polar molecules that prevent their dipole orientation in EMF [6, p. 92-93].

Changes in the dielectric parameters of potatoes from humidity in the range of 70-80 % at a temperature of 20 °C are described by empirical expressions:

\[ \varepsilon = 9.415e^{0.023w}, \quad k = 0.408e^{0.046w}, \quad tg\delta = 0.0432e^{0.023w}. \]  

(3)

In the specified humidity range, the dielectric loss factor increases from 10.8 to 20.4. One of the main factors affecting the dielectric parameters of potatoes is humidity, which must be taken into account when justifying heat treatment modes.
The permittivity and the coefficient of dielectric loss depending on humidity are described by expressions [6, p. 64]:

\[
\varepsilon = 81 \cdot \left( \frac{\rho_s}{\rho_w} \right) \cdot (1 - m) \cdot \frac{W}{(1 - W)}, \quad k = 2 \cdot \left( \frac{\rho_s}{\rho_w} \right) \cdot (1 - m) \cdot \frac{\sigma}{\pi} \cdot \left[ \frac{W}{(1 - W)} \right],
\]

where \(\rho_s\) – density of dry substance, kg/m\(^3\); \(\rho_w\) – density of water, kg/m\(^3\); \(m\) – porosity of the onion; \(W\) – humidity of the onion, %; \(\sigma\) – specific conductivity of the liquid in capillaries.

With \(\rho_w = 10^3\) kg/m\(^3\), \(\rho_s = 1.5 \cdot 10^3\) kg/m\(^3\), \(m = 0.85\) and with the frequency of 2450 MHz these expressions look like this:

\[
\varepsilon = 81 \cdot \left( \frac{1.5 \cdot 10^3}{10^3} \right) \cdot (1 - 0.75) \cdot \frac{W}{(1 - W)} = 30.375 \cdot \frac{W}{(1 - W)},
\]

\[
k = 2 \cdot \left( \frac{1.5 \cdot 10^3}{10^3} \right) \cdot (1 - 0.75) \cdot \frac{\sigma}{2 \cdot \pi \cdot f} \cdot \left[ \frac{W}{(1 - W)} \right] = 0.75 \cdot \frac{\sigma}{6.28 \cdot 2450 \cdot 10^6} \cdot \left[ \frac{W}{(1 - W)} \right].
\]
If we take into account the specific conductivity of the liquid in the capillaries, equal to \(31.91 \times 10^{10}\) \(\text{sm/m}\), the following is obtained:

\[
k = 0.485 \times 10^{-10} \times 31.91 \times 10^{10} \left[ \frac{W}{1-W} \right] = 15.48 \left[ \frac{W}{1-W} \right], \quad k = 15.48 \left[ \frac{W}{1-W} \right]. \tag{6}
\]

The expression describing the change in the onion-sowing dielectric loss factor as a function of frequency is:

\[
k = 0.12 \cdot \frac{\sigma}{f} \left[ \frac{W}{1-W} \right]. \tag{7}
\]

If we take into account, the equation describing the change in the dielectric constant of water from the frequency of EMF [6, p. 30; 7, p. 318] \(\varepsilon = 2 \times 10^{-9} f + 79.53\) (fig. 2a), then you can get an approximate expression of the change in the dielectric constant of the onion from the frequency and humidity:

\[
\varepsilon = \varepsilon(f) \left[ \frac{1.5 \times 10^9}{10^3} \right] (1-0.75) \left[ \frac{W}{1-W} \right], \quad \varepsilon = \left(2 \times 10^{-9} \cdot f + 79.53\right) \cdot 0.375 \cdot \frac{W}{1-W}. \tag{8}
\]

![Diagram a)](image)

The static dielectric constant of water

![Diagram b)](image)

The static dielectric constant of water
Figure 2. Dielectric parameters of water depending on the EMF frequency (a, b) and heating temperature (b)

Since the permittivity of water depends on temperature, it means that for the studied frequency of 2450 MHz, the equation can be written as follows:

$$\varepsilon = \varepsilon(T) \cdot 0.375 \cdot \frac{W}{1-W} = \left(82.844 \cdot e^{-0.004T}\right) \cdot 0.375 \cdot \frac{W}{1-W}, \quad \varepsilon = 31.066 \cdot e^{-0.004T} \cdot \frac{W}{1-W}. \quad (9)$$

So, the behavior in the ultrahigh frequency electromagnetic field of the onion sowing becomes more clear as a result of the analysis of the dielectric parameters, their frequency, temperature and humidity dependence.

The technical task is to develop an installation for pre-setting processing of onion sowing by the complex influence of an ultrahigh frequency electromagnetic field and ionized air during calibration in a continuous mode. Taking into account the features of already developed microwave installations with different working chambers for heat treatment of raw materials [8, p. 57; 9, p. 64; 10, p. 55] another design is proposed.

Figure 3. Installation for calibration of onions: 1 – cylindrical shielding body; 2 – section perforated cylindrical resonator; 3 – crown from the drive sprocket on the motor shaft; 4 – collecting bottle with a valve; 5 – microwave generator; 6 – sections with different diameters of perforation holes of the cylindrical cavity; 7 – inverted truncated pyramidal cavities with dampers 9; 8 – magnetron emitters which are directed inside the pyramidal cavities; 10 – generators kilohertz frequency; 11 – scallop electric gas discharge lamps; 12 – support rollers
Installation for calibration and pre-planting processing of onion sowing under the influence of electrophysical factors (Fig. 3) contains a coaxially mounted sectional cylindrical perforated resonator 2 made of non-ferromagnetic material without bases in a cylindrical shielding housing 1 located at an angle to the horizontal plane.

The technological process of calibration and pre-planting processing of onions under the influence of electrophysical factors is as follows. Close the flap of the receiving container 4 and fill in the UN-calibrated onion. Turn on the electric motor to rotate the sectional cylindrical perforated non-ferromagnetic resonator 2 by engaging the leading sprocket with the crown 3. Turn on the generators of the kilohertz frequency 10, after which the electro-gas discharge lamps 11 begin to corona between the base of the shielding housing and the scallops. The air was ionized and ozonized. Open the flap of the receiving vessel 4 and turn on the microwave generators 5 to excite the ultra-high frequency electromagnetic field.

It is known that when placing electro-gas discharge lamps powered by a kilohertz frequency generator in an ultra-high frequency electromagnetic field, the corona discharge increases, and consequently, the concentration of ionized and ozonized air and the radiation of a bactericidal stream of ultraviolet rays increases. The onion of different fractions, falling into a sectional cylindrical perforated resonator when rotating at a speed less than the critical one, is calibrated. The critical speed of rotation is when the onion, pressed against the resonator shell by centrifugal forces, does not break away from it and begins to make a full revolution. The smallest onion-sowing passes through the perforation holes of the first section 6 of the resonator into the corresponding pyramidal resonator 7. Further, the raw material is moved to the second section due to the tilt and rotation of the cylindrical resonator, where the diameter of the perforation holes is larger than in the first section. Therefore, the onion is calibrated into fractions of the corresponding diameter in the next pyramidal resonator 7.

The calibration process continues until the last section, where the largest bulbs pass through holes of the corresponding diameter of the resonator 2 perforation. During the calibration process, the onion is endogenously warmed up, disinfected, and stored in ionized air of an effective concentration controlled by the gap between the base of the scallop electric-gas discharge lamp and the power of the kilohertz frequency generators. Ionized air is also distributed in pyramidal resonators, where it also acts effectively on a biological object. Radiation through the perforation holes of the cylindrical resonator sections towards the pyramidal resonators and vice versa occurs, while the power of the radiation flow is higher through the perforation holes of the last section of the resonator. Radiation outside the installation is limited by a cylindrical shielding housing made of non-ferromagnetic material (aluminum, copper, etc.) and the use of dampers on the receiving vessel and on small bases of pyramidal resonators. Calibrated, pre-heated, ionized and ozonated onion in pyramidal resonators is subjected to additional exposure to the electromagnetic field of ultrahigh frequency, different doses in each resonator 7, so the size of the onion in them are different. Thus, the implementation of a complex effect of electrophysical factors on raw materials in the calibration process is possible in an ultra-high-frequency installation with a sectional cylindrical perforated rotating resonator that provides calibration of the onion into fractions, disinfection due to ozonated air and treatment with ionized air of high concentration.

Experimental studies of the dynamics of heating of onion tubes of different calibrations were carried out (Fig. 4). The control of the heating temperature of the onion with the Testo 925 pyrometer after exposure to the EMP SHOWS that at the same specific power, the calibrated onion of different diameters is heated in the same way. If you do not calibrate, the onion tubes of different diameters is heated at different speeds, for example, for 10 seconds, the onion tubes with a diameter of 1.3-1.5 cm is heated 5-6°C higher.

Based on the known data of the positive effect of negative aeroions on a biological object, studies of the complex effect of EMF and ionized air by placing an electro-gas discharge lamp in it are conducted. The research was based on the scientific works of leading scientists [11, p. 49-50; 12, p. 154; 13, p. 93; 14, p. 321-322; 15, p. 103-104]. According to the results of experiments, the operating
modes of the microwave installation with a working chamber that provides heat treatment of onions in ionized air were corrected.

The corona discharge intensity is justified when placing a scallop electro-gas discharge lamp, when pulse-modeled high-frequency oscillations (110 kHz) are amplified due to an ultra-high frequency electromagnetic field of certain intensity.

An inhomogeneous electric field is created between the scallop electro-gas discharge lamps and the base of the cylindrical resonator, the intensity of which is maximum on the scallops. If you reduce the interelectrode gap, the electric field intensity reaches a value at which air ionization begins. Corona discharge is accompanied by the formation of ozone and electromagnetic radiation in the range from radio waves to UV rays. Let us consider the calculation of the main parameters of the corona discharge for a scallop electro-gas discharge lamp powered by a kilohertz frequency generator.

Figure 4. Dynamics of heating of the onion-sowing in different-caliber microwave oven with an equal specific power of 8.5 W/g: a) temperature on the surface of a large fraction; b) temperature on the surface of a small fraction

We determine the initial tension by the empirical Peak formula \( E_o \) corona discharge through atmospheric pressure \( p, \text{PA} \), air temperature \( T, \text{K} \), and air density \( \delta \) [16, p. 204]:

\[
E_o = 30.3 \cdot 10^4 \cdot \delta \cdot \left( 1 + \frac{0.298}{\sqrt{\delta r_o}} \right), \quad \delta = 289 \cdot 10^{-5} \cdot \frac{p}{T}
\]  

(10)

If \( p = 1.013 \cdot 10^5 \text{ Pa}, T = 293 \text{ K}, \) so \( \delta = 1 \).

Then the initial intensity of the corona discharge at the radius of the corona electrode \( r_o = 5 \text{ mm} \) is \( E_o = 30.3 \cdot 10^4 \cdot \left( 1 + \frac{0.298}{\sqrt{5 \cdot 10^{-5}}} \right) = 4.3 \text{ kV/cm} \), which is much lower than 30 kV/cm, i.e. the breakdown strength of the electric field at an atmospheric air pressure of 100 kPa [17. p. 62].

On the other hand, the corona discharge intensity depends on the geometric parameters of the corona electrodes (scallop electro-gas discharge lamps as high-potential electrodes) and the system of their location relative to the low-potential electrode (the base of the cylindrical resonator). Using the well-known expression [16, p. 206; 20, p. 37], describing the relationship of the initial electric field strength, geometric parameters of this system of electrodes, it is possible to determine the initial corona discharge voltage. For example, if the distance between high-potential electrodes and low-potential electrodes is 20 mm:

\[
U_o = E_o \cdot r_o \cdot \left[ \frac{2 \cdot \pi \cdot h}{d} - \ln \left( \frac{2 \cdot \pi \cdot r_o}{d} \right) \right].
\]

(11)

\[
U_o = 43 \cdot 10^4 \cdot 10 \cdot 10^{-3} \cdot \left[ \frac{2 \cdot \pi \cdot 20 \cdot 10^{-3}}{10 \cdot 10^{-3}} - \ln \left( \frac{2 \cdot \pi \cdot 10 \cdot 10^{-3}}{20 \cdot 10^{-3}} \right) \right] = 4.91 \text{ kV}.
\]

(12)
The mobility of negative ions at an electric field strength of 430 kV/m and a distance between the corona electrodes of 20 mm is $2 \times 10^{-4}$ (m$^2$/V·s) [16, p. 207]. The normalized parameters of ionized air are the concentration of light ions, which for a biological object is in the range of 10-25 thousand ions/cm$^3$.

Further, the known formula was used to calculate the thermal energy released per unit volume of raw materials because of heating in an ultra-high frequency electromagnetic field [14, p. 321-322; 19, p. 228].

Power:

$$P = 0.555 \cdot 10^{-10} \cdot k \cdot f \cdot E^2 = 0.555 \cdot 10^{-10} \cdot 17 \cdot 2450 \cdot 10^6 \cdot 2 \cdot 10^4 = 46231.5 \text{ W/m}^3$$ (13)

where $P$ – power, W/m$^3$; $k$ – dielectric loss factor equal to the product of the relative permittivity of the onion by the tangent of the loss angle; $E$ – electric field strength in the volume of raw materials, W/m.

Let us determine the speed of heating the onion at this specific power generated per unit volume [20, p. 536]:

$$\frac{\Delta T}{\Delta t} = \frac{P \cdot \eta}{\rho \cdot C} = \frac{46232 \cdot 0.7}{500 \cdot 1382} = 0.047 \text{ °C/s}$$, (14)

where $\rho$ – onion density, kg/m$^3$, $C$ – onion heat volume, kilo joule /kg·°C, $\eta$ – thermal efficiency of heating, taking into account the loss of heat to the environment.

According to GOST 10832-2009, the bulk density of onions was determined. It, depending on the fraction, is 490-520 kg/m$^3$. The specific heat capacity of the onion is 1382 kJ/kg·°C.

Effective heating rate of the pearl onion in APPSVC of 0.05 °C/s is possible at specific power of the microwave generator of 0.42 In/yr. If the total useful power of the microwave generators is 3400 watts at a time up to 8 kg onion sets will be in the resonators effects of APPSVC power density 0.42 W/g the exposure duration will be 3-3.3 minutes, the unit performance 145-150 kg/h.

4. Conclusion

The efficiency and productivity of the installation for the complex effect of electrophysical parameters on potato and onion tubers are provided by a high level of microwave energy transfer to the raw material and the choice of the design of interconnected resonators, such as a sectional perforated cylindrical resonator combined with pyramidal resonators. Due to the fact that the specific heat capacity, conductivity and dielectric properties of materials depend on moisture, temperature, to ensure stable operation of the microwave generator and the electric discharge lamp is recommended to maintain the ratio of raw material to the volume of the resonator, i.e., fill the cavity with raw materials 10-20%.

The technological process of pre-planting treatment of onions can be successfully carried out in a multigenerator installation with the appropriate choice of effective design, technological and operating parameters. Studies of the dielectric constant and the onion loss factor from frequency, temperature and humidity confirmed the possibility of transmitting microwave energy to raw materials with an efficiency of at least 0.7.

Experimental studies of the dynamics of heat onion sets show that when power microwave generators of 3.4 kW and Darsonval of 80 watts of drive power of the drum is 0.25 kW to ensure the plant capacity of 150-200 kg/h at energy costs of 0.025 kWh/kg.

5. Acknowledgments

We express our gratitude to the colleagues who participated in the publication of the article and note the fact that the work was carried out with the financial support of the grant-giver.

References

[1] GOST 30088-93 onion sowing and onion-samples. Seed quality. General specifications
[2] Semenov D A and Gugin M S 2019 Theory of electromagnetic compatibility of radio-electronic devices and systems (Knyaginino: NGIEU) p 278
[3] Kotin A I, Novikova G V, Shamin E A, Mikhailova O V and Belova M V, RF Patent No.
2703062 IPC AO1C1/08 Installations for pre-planting processing of potato tubers under the
influence of electrophysical factors (15 October 2019)
[4] Osokin V L and Kirillov N K 2013 Light engineering (Knyaginino: NGIEU) p 380
[5] Kotin A I and Zaitsev P V 2019 Research and development of an installation for pre-planting
processing of potato tubers under the influence of electrophysical factors Bull. of Kazan state
agrarian University 1(52) 89-93
[6] Rogov I A 1981 Electrophysical, optical and acoustic characteristics of food products
(Moscow: Light and food industry) p 288
[7] Lykov A V 1968 Theory of drying (Moscow: Energia) p 470
[8] Belova M V and Yershova I G 2016 Volumetric resonators in ultrahigh frequency technology
Innovation in agriculture 2(17) 115-119
[9] Belova M V, Yershova I G and Mikhailova O V 2016 In innovations in technologies of
agricultural raw materials processing ARPN J. of Engineering and Applied Sciences 11(6)
1269-1275
[10] Zhdankin G V, Zaitsev P V and Storchevov V F 2017 Development and justification of
parameters of a microwave installation for heat treatment of raw materials in the process of
grinding Scientific life 11 25-36
[11] Didenko A N 2003 Microwave energy: Theory and practice (Moscow: Nauka) p 446
[12] Ilchenko M E, Vzyatyshev V F et al 1989 Dielectric resonators (Moscow: Radio
communication) p 320
[13] Ivashov V I 2001 Technological equipment of enterprises of the meat industry (Moscow: Kolos)
p 551
[14] Azarov B M 1988 Technological equipment of food production (Moscow: Agropromizdat)
p 467
[15] Levitskiy S M 1974 Collection of problems and calculations on physical electronics (Kiev:
University) p 210
[16] Basov A I, Bykov V G, Laptev A V and Fain V B 1970 Electrotechnology (Moscow: Kolos) p
255
[17] Pchelnikov Yu N 1981 Electronics of ultrahigh frequencies (Moscow: Radio communication)
p 96
[18] Ginzburg A S 1985 Calculation and design of drying plants for the food industry (Moscow:
Agropromizdat) p 336
[19] Strekalov A V and Strekalov Yu A 2014 Electromagnetic fields and waves (Moscow:
RIORINFRA-M) p 375
[20] Listov P N 1974 Application of electric energy in agricultural production (Moscow: Kolos)
p 623