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EMI SOURCES FROM MICROWAVE ELECTRON DEVICE

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Theoretical and experimental studies of spurious in crossed-field devices is described. Ions of residual gases in vacuum tubes are responsible for oscillations. These oscillations affect the electromagnetic oscillation in those tubes. Thus both the breadth and the concentration of output spectrum from crossed-field devices take place. The theoretical study was proved by experimental tests. The theoretical investigation of dispersion characteristics of magnetrons for microwave oven was shown that the frequency band of the second group resonance's were in Direct Broadcasting Satellites band. Experimentally it is detected these oscillations in output spectrum, found their emission from cathode junction. Thus crossed-field devices influence for EMC.

INTRODUCTION

The study, control and suppression (or reduction) of spurious oscillations from microwave oven are actual problem.

The major requirements for the crossed-field devices used in microwave ovens are improvement of oscillation efficiency and reduction of noise. For the noise, studies on the mechanisms of its generation are sure to suggest some concrete methods of decreasing it.

Thus the predication of electromagnetic radiation from such devices during design stage is necessary.

It is well-known that crossed-field electron devices used in microwave ovens emit interference radiation in an extremely broad range of frequencies form audio frequency band to the seventh harmonic of fundamental frequency or more.

In order to proper further improvement of microwave oven or crossed-field devices design, it is necessary to analytically clarify the mechanisms of output spectrum.

Here we consider such mechanisms of noise generation: ion (relaxation, ion-plasma, hybrid), electron (electron-plasma, hybrid, oscillation of electron cloud) and slow-wave structure of electron devices.

1. ION OSCILLATIONS

Any vacuum tube contains residual atmosphere which consist of the various "technological" gases. During operating process residual gases' molecules are ionized by electron beam creating multicomponent plasma.

Existing direct electric and magnetic fields result in origin own plasma oscillations and nonlinear interaction ones with other oscillations in tube including fundamental oscillation and its harmonics.

The study of influence of wave electric field and plasma are in progress in operating crossed-field devices.

There are some theoretical approach which described interaction between ion oscillations and fundamental frequency. The modulation approach is preferred. Such an approach proved to be extremely helpful. The modulation approach was described separately every mechanism of ion oscillation origin and their interactions. Mathematically this approach was described the ordinary equations.

Here it will be considered such ion oscillation mechanisms as ion-relaxation, ion-plasma, ion-hybrid and their interaction.

Theoretical investigation of every process separately was found correlation between amplitude (or frequency) of oscillation process and operating condition (geometric sizes, pressure, kind and temperature of residual gases, and value of electric and magnetic fields).

1.1 Ion-relaxation oscillation

Here it will be considered low frequency oscillations. These oscillations exit due to the relaxation mechanism. Such mechanism is responsible for periodic effluent of ions which stored in the well to electrode with less potential.

As for frequency of ion-relaxation oscillations that allowing for neutralization time of ionization gas charge, ionization probability, ionization cross-section [1].

The amplitude of ion-relaxation oscillations is solution such equation [2]

$$U_{min} = \frac{m}{2e}\left(\frac{\delta k T}{p}\right)^2\left[\exp\left(\frac{2eU_{min}}{kT}\right) - 1\right]$$

As a result of a theoretical investigation it is got that relaxation oscillation exists when inner pressure in crossed-field device is less or equal dozens microtorr and frequency band stretches from some hertz to dozens kilocycles, amplitude - from some volts to some microvolts. Radiating from open feeder junction, these oscillations made parasitic oscillations in super long wave band and widen spectral lines of fundamental oscillation

1.2. Ion-plasma and ion-hybrid oscillations

There is space charge in crossed-field devices. This was responsible for electrostatic ion-plasma oscillations. There is took place energy exchange between electrical field and kinetic particles' energy in ion-plasma oscillations.

It is well known that frequency of ion-plasma oscillations is $f_p = \frac{1}{2\pi}\sqrt{\frac{n_0 e^2}{m_i \varepsilon_0}}$

There is magnetic field that is normal to electric one in crossed-field devices. This was responsible for existent ponderomotive Lorenz force which normal directed to direction of vectors magnetic field density $\vec{B}$ and velocity $\vec{V}$. Thus ion-hybrid oscillators had excited. Frequency of such oscillations is

$$f_h = \sqrt{\frac{pe^2}{\varepsilon_0 k T m_i} + \frac{e^2}{m_i^2}B^2}\,.$$

The amplitude both ion-plasma and ion-hybrid oscillations was obtained solving together Poisson, ponderomotive and continuity equations. Thus amplitude of these oscillations can be described such expression

$$u = \frac{ep}{4\varepsilon_0 kT} r_k\left(\frac{s_a^2 - 1}{\ln s_a}\ln s - s^2 + 1\right)\,.$$

Ion-plasma and ion-hybrid oscillations exist when inner pressure in crossed-field devices is from nanotorr to millitorr and frequency band stretches from some dozen kilocycles to some dozen megacycles, amplitude - from some millivolts to some hundred volts. These oscillations made parasitic oscillation in radio and TV range and modulate electron, fundamental oscillations and its harmonics, widened output spectrum.

1.3. Oscillations' interaction

The interaction space of crossed-field devices is strong nonlinear medium. Thus all oscillations which existing in crossed-field devices will be interacted one to other. Oscillations' interaction will be characterized modulation process [3] such as amplitude and frequency modulation. If frequency of interacting oscillations are close one to other it is took place excitement of oscillations on combination frequencies in output spectrum.

2. SLOW-WAVE STRUCTURE OSCILLATIONS

The minimizing of the oscillations at the frequencies of harmonics in the microwave tubes and especially in the high-power distributed-emission crossed-field amplifiers is the necessary and important condition of the designing of the good performance devices. It is well known that the reason of the appearance of harmonics in the output spectrum is a nonlinearity of the process of interaction of the electron beam and RF waves. The amplitudes of the input signal and harmonics at the output of tubes depend on a lot of factors of the process.

The 2.45 GHz magnetron used in a microwave oven emits interference radiation in an extremely broad range of frequencies from radio frequency bands to the 7-th harmonic or more.

Along with the vigorous trend toward an information based society, television broadcasting via satellite has become a practical reality. In this connection, there has been a move in Europe to strictly regulate noise at the higher frequency band, that is from 1 GHz to 18 GHz. This has given rise to the crucial task of providing effective measures to suppress electromagnetic interference from magnetrons and microwave ovens [4].

Here we discuss nontraditional source of EMI - magnetron cavity resonator.

2.1. Slow-wave structure design

Slow-wave structures, being used in electron devices, are intended interact to create conditions when propagating electromagnetic wave can the most intensively with moving electron beam.

It is found experimentally that the best conditions of electron interaction with field define in those causes when electron velocity and phase wave velocity close one to other.

The principal part of slow-wave structure is to accumulate the high-frequency energy and fixation of oscillation frequency. The slow-wave structure may become like filtre with narrow bandpass that from all frequencies connecting with electron beam discriminate definite one [5].

The most important characteristics of slow-wave structure are its dispersion characteristics, i.e. function of phase velocity propagating wave along this structure versus frequency.

Using dispersion characteristics it can estimate value of frequency separation between oscillation mode, possible width of magnetron's linear tuning, partial influence of structure constructive parameter to mode frequency separation and value of tuning where it is expected stability operation of magnetron and its EMC parameters.

The design and the simulation of characteristics of 2,45 GHz magnetron's slow-wave structure with strap-ring carry out using two essentially different methods:

- field theory method, which is based on the solution of Maxwell's equations for composite cavity. It is calculated resonance frequency spectrum and components of electromagnetic field in magnetron's interaction space;

- dual circuit method, which is based on the solution of Kirchhoff's equations for made circuit or resonators.

Dual circuit method isn't allowed to calculate the resonance frequencies to a high precision. This method is allowed only qualitative representation about frequency spectrum, that is about fundamental (first) resonance group.

Taking into account above-mentioned results the calculations of dispersion characteristics were used by field theory.

The investigation of magnetron's slow-wave structure is assumed to define the possible configuration of high-frequency in interaction space, to find frequency spectrum and to determine function versus geometry parameters of slow-wave structure [5].

Here we limit only determination of own frequency spectrum versus geometry parameters of slow-wave structure. To find such characteristic of slow-wave structure, using field theory, it is necessary to solve the resonance equation, which in general can be written as

$$Y_n + Y_r + Y_a = 0,$$

where Y_n - interaction space admittance;

Y_r - cavity admittance;

Y_a - complementary admittance, using that if it is necessary to allow admittance of rings, outer resonator etc.

Every addend of resonance equation has enough cumbrous entry, which is shown in [5,6]. Resonance equation was solved for different cavity assembly:

- "slot-aperture" type;
- "sector-aperture" type;
- wane type;
- wane type with rings.

Solutions of above-mentioned equation for different segments' pair define dispersion characteristic of magnetron slow-wave structure.

2.2 Analysis of theoretical results

The influence of two groups of constructive parameters has been investigated.

The first group is connected with the cavity assembly: cavity number, cathode, anode, wane diameter, wane thickness, anode height.

The second group connects with the strap-rings: average diameter, distance between rings, their thickness and height.

The calculations were provided for some ranges of dispersion characteristic.

The theoretical study of dispersion characteristic of 2.45 GHz magnetron with strap-rings showed that presence of strap-rings have not an influence on dispersion characteristic in even ranges and its behavior differ one. The behavior of dispersion characteristic in odd ranges is similar to one in the first range.

Thus for simplification the behavior of dispersion characteristics in even ranges may be investigated without regard to strap-rings.

The theoretical investigation was shown that the frequency domain of second and third ranges of dispersion characteristic coincides with the 12 GHz DBS band. Thus the frequency domain of the second range may be displaced by variations of wane diameter, wane thickness or cavity number. The frequency domain of the third range may be displaced by variations of the same parameters and yet the second group of constructive parameters.

However, all this will require modification of magnetron construction and preservation other parameters of dispersion characteristic [6].

The dispersion characteristic was calculated for magnetron for microwave ovens with N = 12, Ra = 10 mm, Rk = 5 mm.

The comparison between the dispersion characteristics found theoretically and the experimental results allows the discrepancy no more 8 %.

3. EXPERIMENTAL STUDY

As result of experimental study it is estimated power levels, analyzes spurious and extra waveguide emission spectrum of crossed-field device and compared with theoretical results. The experimental study was applied to mass- production type M-105-1.

It was made using substitution method, and as receiver it was used spectrum analyzer. According to this method to determine relative level of spurious and extra waveguide emission was compared with transmitting signal level.

The measurement of relative level was made in radiation maximum of angular pattern from cathode junction. The horn aerial is mounted before window of anechoic chamber where investigating device.

The absolute power level was measured by powermeter which connected to thermistor mount of the aerial. It is made after determination of extra waveguide maximum by spectrum analyzer. The search and determination of extra waveguide emission level was made by spectrum analyzer also as estimation of the spurious oscillation level.

Experimentally it is found that the extra waveguide spectrum is more varied then spurious spectrum. As a spectrum extra waveguide guide emission is determined by property of cathode junction, and theoretically all oscillation may be emitted in surrounding space.

4. CONCLUSIONS

Theoretically it is predicated possibility of existence of oscillations depending both residual atmosphere and space charge, and experimentally it is found correlation with some oscillations which influence on electromagnetic surroundings.

Relaxation oscillation strengs to frequency band from some hertz to some dozen kilohertz and amplitude - from some volts to some microvolts.

Ion plasma and ion hybrid oscillation strengs to frequency band from some dozen kilocycles to some dozen megacycles and amplitude - from some millivolts to some hundred volts.

Electron plasma, electron hybrid oscillation and oscillations of electron cloud strengs to frequency band from some megacycles to some gigacycles and amplitude - from some millivolts to some hundred volts.

Interactions of these oscillations are provided noise spectrum in wide frequency band.

Experimentally it was observed widen the frequency spectrum from 70 to 300 kHz, modulation of electron and fundamental oscillation by ion oscillations and spurious radiations on this frequency.

Comparison of theoretical and experimental results make possibility to identify some spectral lines and mentioned mechanisms of generation of noise oscillations. It can assist making concrete methods of decreasing noise.

Slow-wave structure of electron devices also is the source of EMI.

Cavity assembly of electron devices is band filter having some passbands.

The most important characteristic of cavity assembly is its dispersion characteristic which determine electron devices (particularly magnetron) operating.

Simulation of cavity assembly characteristics of 2.45 GHz magnetron with strap-ring carry out the method of field theory which is based on the solution of Maxwell's equations for composite cavity.

By magnetron operating the oscillations from the higher ranges which aren't the 5-th harmonic of fundamental frequency are arisen. Now the intensifications of designers and producers of magnetrons and microwave ovens direct to suppression of 5-th harmonic level, but it is necessary to mean that the EMC problem in 12 GHz DBS band must take into account not only the 5-th harmonic but also the oscillations from the second and third ranges.

The complementary influence sources in 12 GHz Direct Broadcasting Satellites band aren't the 5-th harmonic of 2.45 GHz magnetron for microwave oven but and oscillations from the second and third ranges.

Thus EMI from electron devices is responsible both residual atmosphere and slow-wave structure.

5. REFERENCES

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BIOGRAPHICAL NOTES

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