# Passing power sensors and multiprobe microwave multimeter on its base

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## ABSTRACT

The mathematical modeling of thin wall waveguide heating process allows to determine the law of temperature field distribution on their surface. The new physical models of sensors on the absorbing wall principle in the coaxial transmission line were proposed and dissipative losses dependence on frequency in one, two and three layer absorbing wall was analyzed. Methods of calculation and designing of the both quasipoint and extended sensors, located on the narrow and wide waveguide walls were proposed: minimization of effective reflection coefficient of sensors in a wide frequency range was reached. The multiprobe microwave multimeter (MMM) is designed for automated powerful transmission line checking.

## 1. INTRODUCTION

The theoretical and applied aspects of absorbing wall method allowes to define the perspective directions in their development by elaboration and investigation of sensors mathematical model which are adequate to physical models and directed at designing and technique research of sensors and devices with better frequency, dynamic and metrological characteristics and creation of more perfect construction and manufacturing technology. The task of dissipative losses of electromagnetic waves in the waveguide walls was investigated and researched. The applicability of theory of strong skin-effect for the purpose of attenuation in the absorbing wall calculation was grounded. Frequency properties of electro-magnetic waves dissipative losses in the waveguide were researched, the plausibility of development of measuring devices with weak dependence from frequency of sensor transformation coefficient was shown. The mathematical model of the absorbing wall in the rectangular waveguide was analyzed by different methods: by Laplas method formulas for sensors designing, including those which take into account their termophysical characteristics change were received, by variation methods the probability of calculation of absorbing wall thermo fields in the waveguide was shown with greater effectivity, than by Fourier methods; probability of calculation and analysis of physical models of differently shaped sensor unclosed forms was confirmed by numerical method, the most simple and precise enough formulas for sensor designing in the wave guide with uniform coordinate systems were received by integral transformation method.

The thin wall waveguide heating process mathematical modeling allowed to determine the law of temperature field distribution on their surface which is the same as electromagnetic wave distribution inside it, that open the opportunity of a new type measuring devices designing: a thermal measurement line, a reflection coefficient measurement gauge, a multiprobe microwave multimeter and so on with the properties, defined by the absorbing wall method.

The new physical models of sensors on the basis of the absorbing wall in the coaxial transmission line were proposed and dissipative losses dependence on frequency in one, two and three layer absorbing wall was analyzed, plausibility of designing of sensors with weak frequency dependence of transformation coefficient was shown; the mathematical models of temperature field of such sensors were elaborated and analyzed and formulas for calculation of coaxial sensor transformation coefficient were received.

Methods of calculation and designing of the both quasipoint and extended sensors, located on the narrow and wide waveguide walls were proposed: minimization of effective reflection coefficient of sensors in a wide frequency range was reached, the calculation method of transformation coefficient of single and twin sensors of arbitrary shape in the waveguide and coaxial tract was worked out. The calculation methods of extended sensor error, caused by out strip component and of components of general wattmeter error were designed and calculation was performed.

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## 2. MATHEMATICAL MODEL OF ABSORBING WALL

The mathematical model quasi point the sensor on effect absorbing walls is analyzed from the point of view of achievement of the maximal sensitivity, sensor installed in a narrow or wide wall of a wave guide transformation depending on the frequency calculation methodic is offered; manufacturing sensor certification on transformation coefficient base for standard wave guides of a centimeter wave band family is offered.

The sensor transformation coefficient is understood as a temperature increment in the center absorbing walls quasi point sensor [1] on unit of passing power.

Let's consider a problem about value of the stationary temperature of an absorbing wall of the round form. It consists in the decision of the heat conductivity stationary equation which are taking into account heat exchange with an environment

$$\Delta T - Ty = -\frac{I}{K\delta}, \quad (1)$$

where $\Delta$ - Laplas operator; $I$ – VHF power superficial density of capacity on a wall; $T$ – an increment of temperature relatively disk edge; $To$ – factor of heat conductivity of a material of a wall.

$$y^2 = 2\alpha / K\delta, \quad (2)$$

where $\alpha$ - factor of heat exchange; $\delta$ - thickness of a wall.

As a boundary condition we shall accept, that the increment of temperature on border is equal to zero.

In practice the round disk form sensor can be located in a wide or narrow wall of a rectangular wave guide.

The power superficial density can be calculated under the formula (3):

$$I = \frac{1}{2} R_S \,|\, H_{tg} \,|\, 2, \quad (3)$$

$H_{tg}$ - a tangential component of a magnetic field on a surface of a wall; Rs=0/2 $\sqrt{\omega\mu}$ $\tau$ - superficial resistance; $\mu$ - walls material conductivity.

Having substituted in the formula (3) expressions for a magnetic field in a rectangular wave guide, we shall find, that on a narrow wall the power superficial density is defined by low[3]

$I_y(y, z) = N_1 F^+(z) \cos^2(K_y y) + N_2 F^-(z) \sin^2(K_y y)$, (4)

where $F^+(z) = 1+\Gamma^2+2\Gamma\cos(2K_z z+\varphi_0)$; $F^-(z) = 1+\Gamma^2-2\Gamma\cos(2K_z z+\varphi_0)$; $N_1^H = H_0^2/2\sigma\Delta$;

$N_2^H = H_0^2/2\sigma\Delta(K_z(Ky/K_\perp^2))^2$; $N_1^E = 0$; $N_2^E = E/2_0^2\,\sigma\Delta((K_z/Z^E)(K_x/K_\perp^2))^2$; $K_x = m\pi/a$; $K_y = n\pi/b$;

$K_\perp^2 = K_x^2 + K_y^2$; $K_z^2 = K_0^2 + K_\perp^2 = 2\pi/b\lambda$; $K_0 = 2\pi/\lambda$; $Z^E = Z_0\sqrt{1-(\lambda/\lambda_{kp})}^2$;

$\lambda_{kp} = 2\sqrt{(m/a)^2} + (n/b)^2$; $\Delta = \sqrt{2/\omega\mu_0\sigma}$ - depth of a skin-layer; $\Gamma$, $\Phi_0$ – termination reflection coefficient the module and a phase; $a$ and $b$ - the sizes of wide and narrow walls of a wave guide (the axis $x$ is directed along a wide wall, an axis $y$ - along a narrow wall, an axis $z$ - along a wave guide); $\lambda$, $\lambda_b$, $\lambda_{\kappa p}$ – length of a wave in free space, in a wave guide and critical; $z_0$ – wave resistance of free space: $m$ and $n$ - indexes of the wave mode propagating in a wave guide; $E$ and $H$ - the indexes indicating type of a wave; $E_0$ and $H_0$ - amplitudes of electric and magnetic fields.

$E_0$ and $H_0$ are connected with waveguide passing power P by the following relations:

$$E_0^2 = \frac{8z_0P}{abz_0\sqrt{1-(\lambda/\lambda_{kp})^2}}(\lambda/\lambda_{kp})^2, \quad H_0^2 = \frac{4(2-\delta_{m0}-\delta_{n0})P}{abz_0\sqrt{1-(\lambda/\lambda_{kp})}^{-2}},$$

where $\delta_{m0}$ And $\delta_{n0}$ – Kroneker symbols.

For a wide wall the law of distribution of power superficial density looks so:

$$I_ш(x, z) = N_3F^+(z)\cos^2K_xx + N_4F^-(z)\sin^2K_xx, \quad (5)$$

where $N_3^H = H_0^2/2\sigma\Delta$ ; $N_4^H = H_0^2/2\sigma\Delta(K_z(K_x/K_\perp^2))^2$; $N_3^E = 0$;

$N_4^E = E_0^2/2\sigma\Delta((K_z/Z^E)(K_y/K_\perp^2))^2$.

The certain difficulty of the decision of the equation (1) at a kind of its right part determined by formulas (4) and (5), will be that the absorbing wall is a circle, $I_ш$ (x, z) and $I_y$ (y, z) are written down in rectangular coordinates. Therefore it is reasonable to use one of numerical methods, for example a method of grids. A grid from radiuses and circles thus to use it is inexpedient, as it is impossible to set a boundary condition in the center of a circle. - in fact value of temperature and its derivative there are unknown. Therefore we use a wall as a rectangular. The equation (1) for a wide wall we shall write down in the cartesian coordinates:

$$\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial z^2} - \gamma^2 T = -\frac{I_ш(x,z)}{K\delta}. \quad (6)$$

For a narrow wall type of the equation will be same, only derivative $\partial^2 T/\partial x^2$ it is replaced on $\partial^2 T/\partial y^2$, and $I_ш$ (x, z) on $I_y$ (y, z).

Derivatives in the equation (6) we shall present as final differences:

$$\frac{\partial^2 T}{\partial x^2} = \frac{T_{i+1,j} - 2Ti,j + T_{i-1,j}}{h_x^2}, \quad \frac{\partial^2 T}{\partial y^2} = \frac{T_{i,j+1} - 2Ti,j + T_{i,j-1}}{h_z^2}.$$

here $i$ and $j$ – numbers of units of grids along axes $x$ and $z$ accordingly, $h_x$, $h_z$ – steps of a grid along these axes. Derivatives are calculated for unit with indexes $i$ and $j$.

Substitution of these formulas in (6) gives:

$$\frac{T_{i-1,j} + T_{i+1,j}}{h_x^2} + \frac{T_{i,j-1} + T_{i,j+1}}{h_z^2} - \left[y^2 + 2(1/h_x^2 + h_z^2)\right]T_{i,j} = -\frac{I_{i,j}}{K\delta}, \quad (7)$$

where $Ii, j$ – value of function $I_ш$ (x, z) in unit with indexes $i$ and $j$.

Expression (7) represents system of the linear equations which decision are values of temperature in units of a wall. For its decision it is convenient to use a consecutive approximation method from (7) follows, that:

$$Ti,j = \frac{1}{y^2 + 2(1/h_x^2 + 1/h_z^2)} + \left(\frac{T_{i-1,j} + T_{i+1,j}}{2} + \frac{T_{i,j-1} + T_{i,j+1}}{2} + \frac{I_{i,j}}{K\delta}\right), \quad (8)$$

Initial value of temperature, for example $T=0$, is substituted in the right part of expression (8), and there is a first approximation of the decision. The received file of values $T_{i,j}$ it is again substituted the right part (8), the following approach is founding and so until the difference between two consecutive approximation does not be less than the given error of the decision.

To use values of temperature on a circle of a disk, used a rectangular grid, at which the step can vary.

On fig. 1 some units of such grid near to edge of a disk which here does not pass through one unit are represented. The meaning of factors $a_1, a_2, b_1, b_2$, which we will use, is clear from figure. Expressions for derivatives then will be written down so:

$$\frac{\partial^2 T}{\partial x^2} = 2\frac{\frac{T_{i+1,j} - T_{i,j}}{a_2} - \frac{T_{i,j} - T_{i-1}}{a_1}}{(a_1 + a_2)h^2}, \quad \frac{\partial^2 T}{\partial z^2} = 2\frac{\frac{T_{i,j+1} - T_{i,j}}{b_2} - \frac{T_{i,j} - T_{i,j-1}}{b_1}}{(b_1 + b_2)h^2},$$

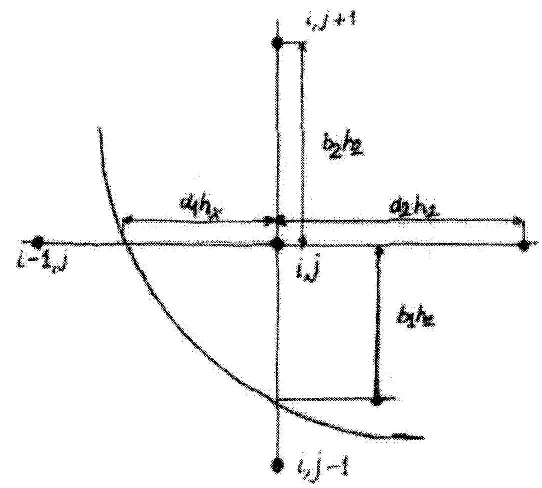


Figure 1 Application of method of grids

Here we consider, that steps of a grid *h* along an axis x and axes z are identical. The working equation for calculation of value of temperature in unit of a grid with indexes *i* and *j* looks so:

$$T_{i,j} = \frac{\frac{2}{h^2}\left(\frac{T_{i-1,j}/a_1 + T_{i+1,j}/a_2}{a_1 + a_2} + \frac{T_{i,j-1}/b_1 + T_{i,j+1}/b_2}{b_1 + b_2}\right) + \frac{I_{i,j}}{K\delta}}{y^2 + \frac{2}{h^2}\left(\frac{1}{a_1 a_2} + \frac{1}{b_1 b_2}\right)}. \quad (9)$$

If $a_1 = a_2 = b_1 = b_2 = 1$, the equation (9) passes in (8). At calculations for each unit of a grid factors $a_1, a_2, b_1, b_2$ are calculated. If the unit is far from edge of a disk, calculations are conducted under the formula (8). For the units close to edge of a disk some factors there are smaller units. Then as temperature in such "mixed" units the temperature on border of a disk, that is *T=0* undertakes.

## 3. MULTIPROBE MICROWAVE MULTIMETER

The new way for signal and tract parameter calculation and a gauge for frequency measurement were proposed, the algorithms of signal and tract measuring parameter were synthesized, the multimeter sensor frequency properties were analyzed. It was shown the stability is high enough in comparatively narrow frequency range, it remains high in wide frequency range with sensor commutation, the specific components of multimeter error were analyzed, so multimeter measuring method effectivity was confirmed, with the spectrum having out strip components, and requirements for sensor of no point shape were defined.

A technique was proposed for multimeter metrological support on the base of element after element attestation of sensors separately in manufacturing stage and processing and indication unit.

The extended and quasipoint sensors and the passing power wattmeters of high and very high passing power levels with weak frequency dependence of transformation coefficient and high speed of performance were created, researched and implemented, the heat measuring lines were worked out and researched, the multiprobe microwave multimeter for fixed frequency was created and implemented, the progressive technological solutions for sensor manufacturing were proposed and implemented into practice.

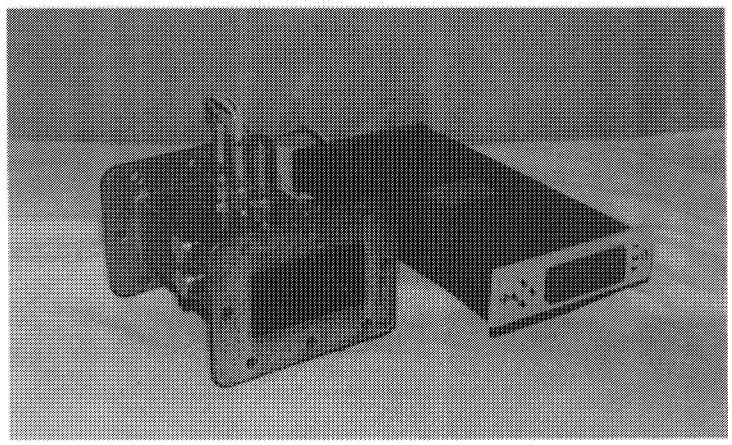

Figure 2. MMM for microwave oven checking (P=0.1-100 кW, waveguide 90x45 мм)

The multiprobe microwave multimeter (MMM) is designed for automated powerful transmission tract checking: charged corpuscle accelerators, radiolocation, navigation and communication stations, VHF heating and drying plants, testing VHF generators ( magnetrons, klystrons, travelling-wave tubes, backward -wave tubes) equipment.

MMM permits measurement of incident, reflected, passing power and a termination reflection coefficient module and phase executing in the wide frequency range of a waveguide or a coaxial line with a basic error ±(3-5)% or less than ±3% at the fixed frequency. Average value of measuring power level is from dozens W to hundreds kW, at pulse power of up to 100 MW, a reflection coefficient module is 0.01-0.8 and phase is ±180°. The built-in devices are compact, of high precision, of high performance speed, electrical and thermal noise stable, comparatively simple and cheap in the manufacturing.

The unified, changeable and calibrated during serial production sensors could be used in the waveguides of any cross section. Due to long time parameter stability, the device could be an standard one, for this purpose it is necessary to calibrate them with a more precise standard gauge. Calibrated correspondingly at the standard section waveguides, sensors could be sold and used by consumers at their discretion at the arbitrary range, for example, using microcontrollers and PCs.

The priorities are defined by importance for recourses saving technologies in radioelectronic industry.

The expediency is determined by the requirement of strict control over generator operation and termination in "hot" mode. The proposed devise is able to compete with Rohde&Schwarz (Germany) wattmeter NAUS6 , frequency range 25-1000 MHz, dynamic range 0.5-1000 W. In addition MMM allows to measure termination complex reflection coefficient and wavelength. It means that in addition to generator parameters the parameters of VHF circuit are measured as well.

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