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CALCULATION OF THE TEMPERATURE FIELD OF A PRINTED-CIRCUIT BOARD WITH ACCOUNT FOR CONVECTIVE AND RADIATIVE HEAT EXCHANGE ON THE BOARD SURFACE

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The temperature field of a printed-circuit board has been simulated numerically according to the two-dimensional thermal model with account for convective and radiative heat exchange on the board surface. The temperature fields in the actual printed-circuit board have been determined experimentally. The deviation of the results of the numerical analysis from the experimental data does not exceed $\pm 4^{o}$*C.*

In designing radioelectronic equipment, it is important to know the accurate distribution of temperature in a created device, unit, etc. [1]. This information is required for accurate evaluation of the reliability of radioelectronic equipment which this equipment will possess under operating conditions [2].

Analysis of the data currently available in the literature [3] has shown that at present there are no models allowing one to calculate the temperature fields in radioelectronic equipment with an error of the order of 2–4^{o}C in the range of its operating temperatures (–25 to +85^{o}C). Creation of mathematical models with three space coordinates and with account for radiation heat transfer should be considered as an efficient way to increase the accuracy. Nevertheless, it should be noted that the three-dimensional models require very large computational resources; therefore, it is of interest to compare them to much less laborious two-dimensional models wherein heat exchange from the upper and lower sides of a plane simulating the board is taken into account.

The present work seeks to create a two-dimensional thermal model of a typical printed-circuit board with radioelements in which the heat exchange by convection and radiation from the upper and lower sides of the printed-circuit board is considered.

Formulation of the Problem. We solve the problem of calculation of the temperature field in the plate with dimensions along the x and y axes that are equal to L_x and L_y. Inside the plate, a local heat source with heat release Q is placed. Boundary conditions the third kind without radiation are specified on the boundaries. Within the limits of the plate, there are several regions (zones) with differing thermophysical parameters; on the boundaries between these regions boundary conditions of the fourth kind are specified. The heat exchange by convection and radiation is specified on the upper and lower surfaces of the plate.

Figure 1 presents the geometry of the solution domain. The actual structure represents a printed-circuit board made of glass textolite of thickness 1.5 mm which is coated on both sides with copper. On the upper side of the board in regions 1 and 3 copper is removed; in region 1 the heat-release source (integral voltage stabilizer) is located.

In formulating the problem, we used assumptions. The first of them is as follows: the radiation heat exchange on the plate boundary is absent. This assumption is justified by the fact that for the printed-circuit board the contribution of radiation from the boundaries of the board to the total heat exchange is small because of the small surface area. At the same time, the problem is simplified considerably. The second assumption is as follows: the heat-release source has a plane shape. Here we must take into account the heat exchange from the lateral sides of the source whose total area is approximately equal to that of the upper side.

The problem in this formulation is reduced to solution of the nonlinear unsteady heat-conduction equation with the corresponding boundary and initial conditions:

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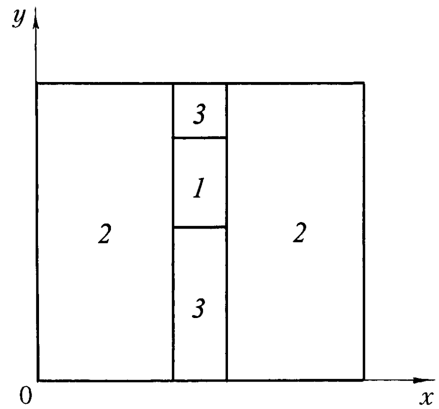

Fig. 1. Geometry of the solution domain (top view): 1) heat-release source; 2 and 3) regions with different thermophysical characteristics.

TABLE 1. Temperature of Region 1

Temperature, °C	Time, sec									
	0	20	40	60	80	100	120	140	160	180
Source power is 1.6 W										
Measured	29	38	47	54	59	66	69	74	76	78
Calculated	29	41	49	54	59	63	67	71	74	77
Source power is 2.1 W										
Measured	27	42	52	61	68	76	81	85	88	92
Calculated	27	43	53	60	66	72	77	82	86	91

$$C(x,y)\,\rho(x,y)\,\frac{\partial T}{\partial t}=\lambda(x,y)\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+\frac{Q(t,x,y)}{Sh}+\frac{2\alpha(T_{\text{ext}}-T)}{h}+\frac{2\sigma(\varepsilon_{\text{ext}}T_{\text{ext}}^4-\varepsilon_{\text{sur}}T^4)}{h}\,; \qquad (1)$$

$$0\le t<+\infty\,,\quad 0\le x\le L_x\,,\quad 0\le y\le L_y\,; \qquad (2)$$

$$t=0\quad T=T_0(x,y)\,; \qquad (3)$$

$$x=0\quad -\lambda\frac{\partial T}{\partial x}=\alpha(T_{\text{ext}}-T)\,,\quad x=L_x\quad \lambda\frac{\partial T}{\partial x}=\alpha(T_{\text{ext}}-T)\,; \qquad (4)$$

$$y=0\quad -\lambda\frac{\partial T}{\partial y}=\alpha(T_{\text{ext}}-T)\,,\quad y=L_y\quad \lambda\frac{\partial T}{\partial y}=\alpha(T_{\text{ext}}-T)\,. \qquad (5)$$

Method of Solution. Equation (1) can be solved by the method of finite differences on a uniform rectangular grid using the implicit scheme of splitting over coordinates [4]. The nonlinearity in temperature is resolved by the method of simple iterations.

Results of Calculations and Experiments. For calculations we used a 120 × 110 difference grid; the time step was 0.05 sec. The calculation results are given in Table 1. The temperature-field distribution is presented in Figs. 2 and 3.

To verify the accuracy of the results obtained, we carried out the experiments with the following initial data: dimensions of the printed-circuit board 60 × 55 mm; power of the heat-release source 1.6 and 2.1 W, and ambient temperature 300 K. The coefficient of convective heat exchange α was calculated according to the procedures of [1].

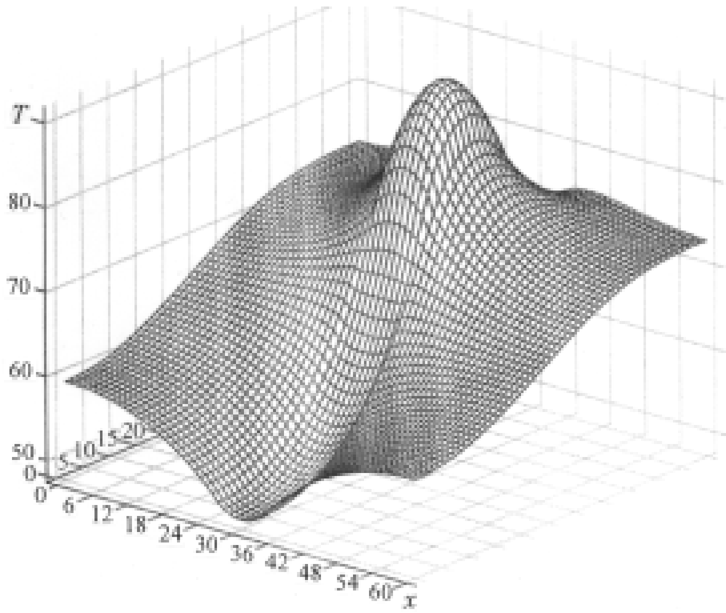

Fig. 2. Distribution of the temperature field for the source with a power of 2.1 W. T, ^{o}C.

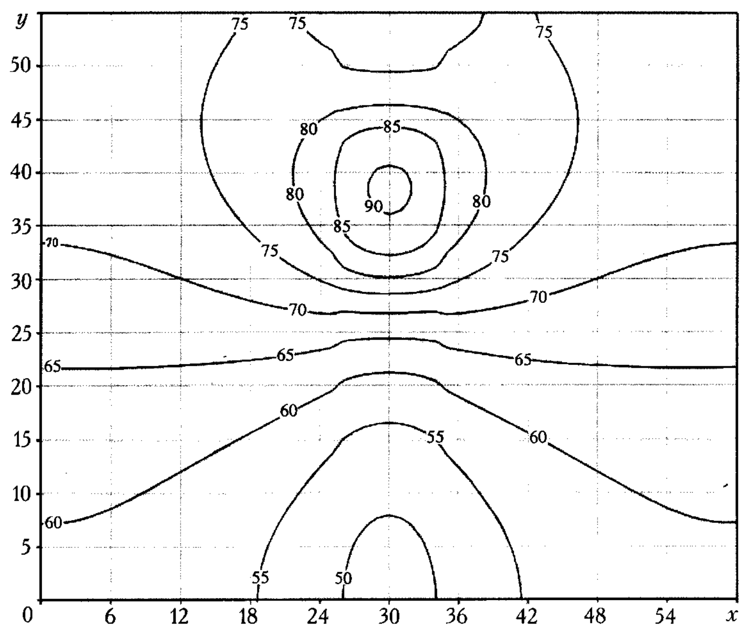

Fig. 3. Isotherms of the temperature field of the printed-circuit board for the source with a power of 2.1 W (temperature is given in ^{o}C).

TABLE 2. Thermophysical Characteristics for the Regions of the Printed-Circuit Board

Number of region	Density ρ, kg/m^3	Specific heat *C*, J/(kg·K)	Thermal conductivity λ, W/(m·K)
1	2500	1088	2.76
2	9000	406	365
3	2500	1088	2.76

The temperature was measured by a thermocouple in zone 1. The thermophysical characteristics of regions (zones) 1–3 are given in Table 2. The results of measurements of the temperature are presented in Table 1.

Comparison of the calculated and experimental data given in Table 1 allows the conclusion that by means of the mathematical model considered it is possible to calculate the temperature field for the typical printed-circuit board of simple structure with a deviation from the experimental values of no more than $\pm 4^{o}$C.

At the same time, numerous types of radioelements and methods of mounting them are used in the structural units of radioelectronic equipment (including printed-circuit boards). Since the model requires accurate thermophysical characteristics for an adequate calculation of the temperature field, it is necessary to have complete information on the thermophysical characteristics of every radioelement for all the methods used in its mounting.

Thus, on condition of the presence of accurately specified thermophysical characteristics, the model considered can be applied to calculation of the unsteady temperature field of a printed-circuit board in designing radioelectronic equipment.

NOTATION

x, y, coordinates; L_x and L_y, dimensions of the plate along the x and y axes, respectively; Q, heat release of the source; C, specific heat; ρ, density; T, temperature; t, time; λ, thermal-conductivity coefficient; S, source area; h, plate thickness; α, heat-transfer coefficient; T_{ext}, temperature of the external medium; σ, Stefan–Boltzmann constant; ε_{ext}, emissivity of the external medium; ε_{sur}, emissivity of the surface of the printed-circuit board; T_0, initial temperature. Subscripts: ext, external; sur, surface.

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