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ESTIMATION OF THE EFFECT OF TEMPERATURE ON THE TIME RESPONSE OF A MODAL FILTER BASED ON A MICROSTRIP LINE WITH TWO SIDE CONDUCTORS GROUNDED AT BOTH ENDS

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For the first time, the effect of temperature on the time response of a new modal filter (MF) based on a microstrip line with two side conductors grounded at both ends is estimated. The estimation was performed based on the results of quasi-static modeling, taking into account the temperature model and measuring the manufactured MF layout using the heat-cold chamber. The time responses to the ultrashort pulse at the MF output were analyzed. The results of modeling without taking into account losses, with taking into account losses, and measurements at temperatures of –50, 25, and +150°C are presented. Deviations of the delay and voltage amplitude are estimated. The consistency of the simulation and measurement results is shown. A small effect of temperature on the delay (about 1%) and a significant effect on the amplitude (up to 36%) of the first pulse were revealed.

Keywords: time response, microstrip line, modal filter, printed circuit board, ultrashort pulse, temperature.

Severe operating conditions (space, the Arctic, the tropics, etc.) of radio-electronic equipment (REE) impose on it the requirement of trouble-free operation in a wide temperature range (*T*). The study of the influence of *T* on various characteristics of transmission lines, as well as the use of the information obtained at the design stage make it possible to evaluate changes in these characteristics and their criticality for the operation of REE [1−4]. Microstrip lines (MSL) and their modifications are often used in REE [5−7]. In this regard, the authors previously studied the influence of temperature on the characteristics of MSLs with above conductors grounded at both ends [8]. Meanwhile, such MSLs can have the properties of a modal filter (MF) for protection against various conductive effects, for example, an ultrashort pulse (USP), due to its modal decomposition into a sequence of pulses of lower amplitude [9–12]. In the general case, this occurs due to the difference in the propagation delays of the pulses of the transverse wave modes in a segment of a multiwire transmission line. Such a difference is possible at a nonuniform (in cross section) dielectric filling of the line. As a result of modal decomposition, in particular by reducing the resulting voltage amplitude at the MF output, the risk from excitation by USP of REE components connected to the MF output can be significantly reduced. However, a change in temperature can affect the effectiveness of MF properties, and thus, its protective abilities. In order to obtain new original results in this context of MSL application, it is very important to analyze the distortion of the waveform of the time response of such MFs with changing *T*. The purpose of this work is to evaluate the effect of temperature on the time response of a modal filter based on MSL with two side conductors grounded at both ends.

Two approaches were used: measurements of the MF layout and its quasi-static modeling in the TALGAT system [13]. The cross section of the fabricated MF layout is shown in Fig. 1*a*. Its parameters are: t = 105 μm, w =

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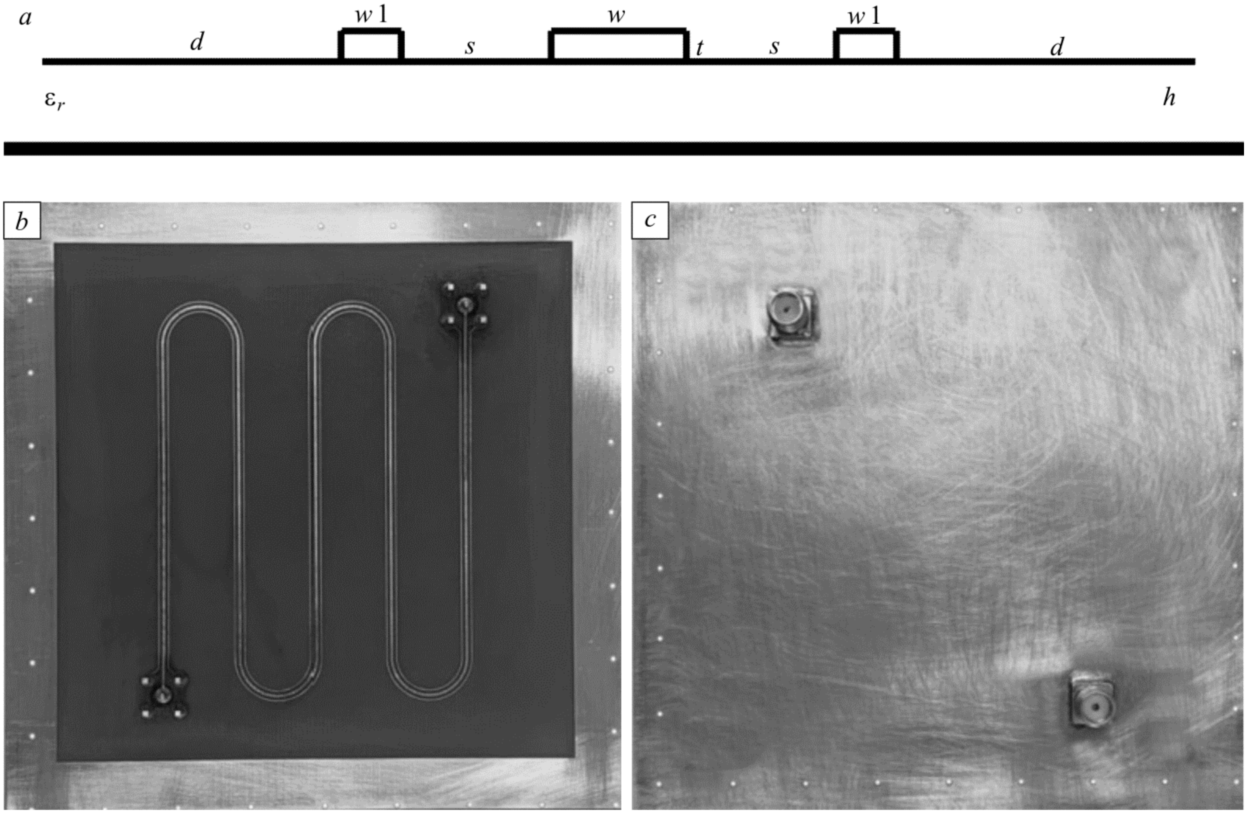

Fig. 1. Cross section (*a*), photos of the upper (*b*) and lower (*c*) layers of the MF layout.

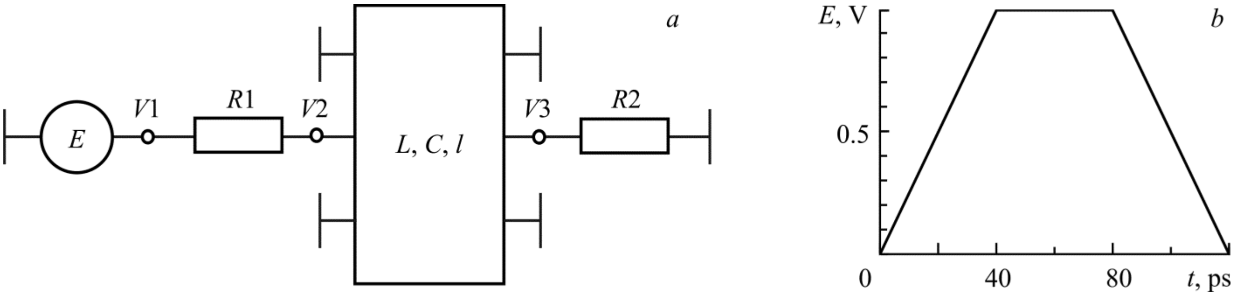

Fig. 2. Electrical circuit diagram (*a*) and the shape of the exciting EMF (*b*).

0.45 mm, $w1$ = 0.2 mm, h = 0.5 mm, d = 1 mm, s = 0.45 mm, ε_r = 4.7, tan δ = 0.03, and l = 328 mm. The layout material is STF-2-105-0.5. The overall dimensions of the layout are 100×100 mm.

Figures 1*b* and c show photos of the upper and lower layers of the layout. To reduce the length of the layout, it is bent into a meander. The connection between the half-turns of the meander is very weak, since the distance between them is 10 mm. The MF was connected to the measuring equipment with SMA-connectors.

The modeling was performed at T = –50, 25, and 150°C using the temperature model presented in [14]. The temperature coefficient of linear expansion of copper is assumed to be $17 \cdot 10^{-6}$ K^{-1}, and those of the dielectric base of the layout along the Z and Y axes are assumed to be $70 \cdot 10^{-6}$ and $17 \cdot 10^{-6}$ K^{-1}, respectively [15]. For the material STF-2-105-0.5 with $\varepsilon_r = 4.7$, the temperature coefficient is assumed to be $8.33 \cdot 10^{-4}$ K^{-1}.

The electrical circuit diagram shown in Fig. 2*a* was modeled where the signal conductor is connected to the USP source represented in the diagram by an ideal EMF source E and internal resistance $R1$. At the other end, the

TABLE 1. Relative Deviations (from $T = 25$°C) of Delays and Voltage Amplitudes of Pulse 1

Result	T, °C	Δt, %	ΔU, %
Modeling with taking into account changes of losses	– 50	–0.57	21.42
	150	1.15	–35.71
Measurement	– 50	–1.12	26.67
	150	1.12	–33.33

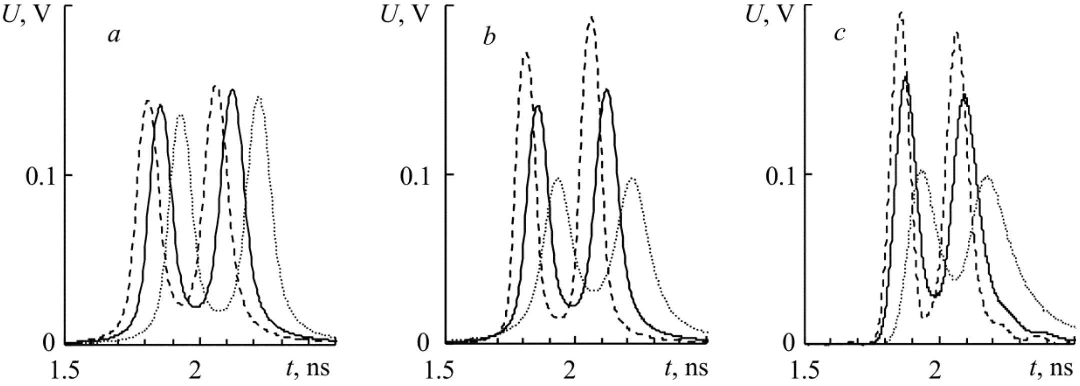

Fig. 3. Voltage waveforms at the MF layout output obtained by modeling without (*a*) and with (*b*) taking into account changes in the dielectric losses and by measurement (*c*) at $T = -50$ (– –), 25 (—), and 150 (· ·) °C.

conductor is connected to $R2$. The circuit parameters are: line length $l = 328$ mm, internal resistances of the USP source and load $R1 = R2 = 50\ \Omega$. In modeling and measurements, a trapezoidal pulse with an EMF amplitude of 1 V and rise, flat top, and fall times of 40 ps was taken as the USP (Fig. 2*b*).

The measurements were performed once at a temperature change from –50 to 150°C using a vector network analyzer (VNA) R&S ZVA 40. The errors in measuring the magnitude of the transmission and reflection coefficients (*S*-parameters) are 0.1–1.0 and 0.4–3 dB, respectively, depending on the frequency and value. The layout was placed in the climatic (test) heat-cold chamber ESPEC SU-262. Temperature fluctuations were ±0.3°C (–60 ... +100°C) and ±0.5°C (101.1–150°C). The VNA was connected to the SMA-connectors with R&S ZV-Z195 and Semflex 60637 test cables. The measured frequency responses of the *S*-parameters were then converted into time responses in the Advanced Design System. Thus, the measurement errors of the *S*-parameters determine the accuracy of the time response simulation.

Figure 3 shows the results of modeling and measurements at $T = -50$, 25, and 150°C. It can be seen that the USP is decomposed into 2 pulses. As the temperature increases, the pulse delays increase both during simulation and measurement, while the pulse amplitudes decrease. It can be seen from the simulation results without taking into account the change in losses (Fig. 3*a*) that the pulse amplitudes differ significantly from the measured ones. Since it is known that losses increase with increasing T, test simulation was additionally carried out taking into account the change in the dielectric losses by a factor of 2 at $T = -50$ and 150°C (Fig. 3*b*). It can be seen that the pulse amplitudes have decreased in the same way as during the measurement, since the losses affect the dispersion.

A quantitative estimation of the deviations of the delay and voltage amplitude of the pulse 1 was made (Table 1). It showed good agreement between the simulation and measurement results, as well as a small effect of temperature on the delay (deviation modulus of about 1%) and a significant effect on amplitude (deviation modulus of 21–36%).

For a clearer comparison of the simulation and measurement results, they are presented in Fig. 4 separately for $T = -50$, 25, and 150°C. Good agreement is observed between the simulation results in case of taking into account the

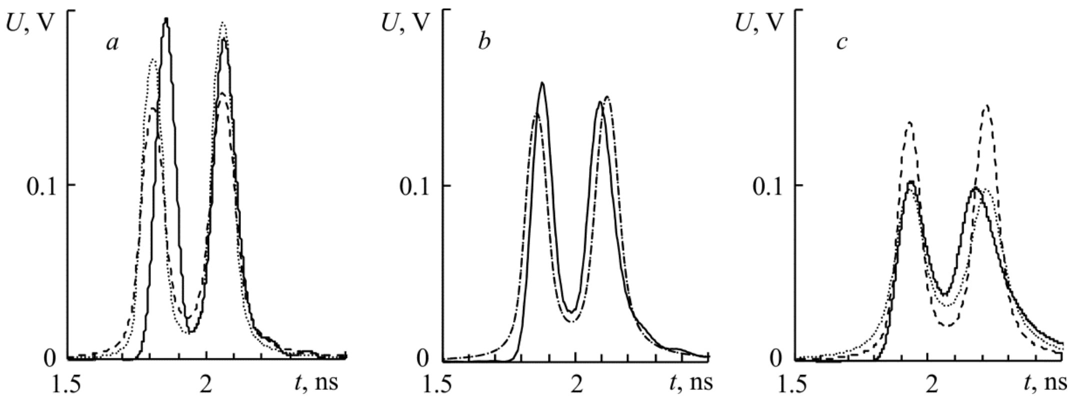

Fig. 4. Voltage waveforms at the MF layout output obtained by modeling without taking into account (– –) and with taking into account (· ·) changes in losses and by measuring (—) at $T = -50$ (*a*), 25 (*b*), and 150 (*c*) °C.

change in losses and the measurements of the pulse 1 delays (±3.55% at $T = -50$°C, ±1.72% at $T = 25$°C, and ±2.84% at $T = 150$°C). Simulation with taking into account the 2-fold change in losses for $T = -50$ and 150°C showed that the pulse amplitudes coincided with the measured ones.

Thus, the paper presents an estimation of the effect of temperature on the time response of MF based on MSL with two side conductors grounded at the ends. The estimation was carried out based on the results of quasi-static modeling taking into account the temperature model in the TALGAT system and the measurement of the manufactured MF layout using the ESPEC SU-262 heat-cold chamber. The results of modeling without taking into account losses, with taking into account losses, and measurements at temperatures of –50, 25, and 150°C are presented. A quantitative assessment of the delay and voltage amplitude deviations was performed, which showed the consistency of the simulation and measurement results. The results of the work can be useful for designing interference-proof transmission lines on printed circuit boards used under different climatic conditions.

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