To compare the measurement results for the circuit elements with the real heterostructure, the serial-parallel equivalent circuit is transformed into the serial equivalent circuit. This transformation is necessary to correctly apply the measurement results obtained by a device for the series-parallel EC. The parameters of this circuit can be calculated with the following formula (1):

$$C_{QW}^{\Sigma} = C''_{QW}\left(1+\omega^2\tau_{QW}^{\Sigma}\right)/\,\omega^2\tau_{QW}^{\Sigma 2},$$
$$R_{QW}^{\Sigma'} = R_{QW}^{\Sigma}\,/\left(1+\omega^2\tau_{QW}^{\Sigma}\right), \qquad (1)$$

where ω is the test signal frequency.

Conclusion. The model representing the physical processes in the heterostructure with QWs is proposed. It is a series-parallel EC that takes into account the QWs, the QW electron filling, and the flow of electric current through the barrier layers and the structure.

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THE INFLUENCE OF TEMPERATURE AND HUMIDITY ON FOUR-LAYER REFLECTION-SYMMETRIC MODAL FILTER PERFORMANCE

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The paper presents geometrical, schematic, and algorithmic models that take into account the influence of temperature and humidity on the four-layer reflection-symmetric modal filter performance. We obtained the time responses at the far end of the active conductor using the quasi-static approach.
Keywords: four-layer reflection symmetric modal filter, quasi-static simulation, temperature, humidity.

To protect radioelectronic equipment (REE) from the influence of high-power conductive electromagnetic interference (EMI), engineers use several schematic and design solutions. Ultrashort pulses (USP) are the most dangerous type of EMI [1]. The classic protection systems have a relatively low performance, which allows USP to damage the REE. A perspective type of protection against such EMI is the use of modal filtering techniques, modal filters (MF) in particular [2]. Previously, the authors proposed a four-layer reflection-symmetric MF, the frequency and time characteristics of which we have well studied in the full-scale and in the numerical experiments. However, an analysis of the influence of temperature and humidity on its performance has not been performed. This paper aims to conduct this study.

In this study, the authors used a temperature mathematical model from [4]. Figure 1, *a* presents a geometric model of the cross-section of the four-layer reflection-symmetric MF constructed in the TALGAT software, where conductor width w = 1 mm, distance between conductors s = 0.7 mm, conductor thickness t = 35 μm, core thickness h_1 = 510 μm, prepreg thickness h_2 = 206 μm, relative permittivity of core ε_{r1} = 4.6, and relative permittivity of prepreg ε_{r2} = 4.6.

Figure 1, *b* shows the schematic model of the MF (a trapezoidal pulse with an amplitude of 1 V and a rise time, flat top, and fall time of 100 ps; the length of MF equal to 1 m).

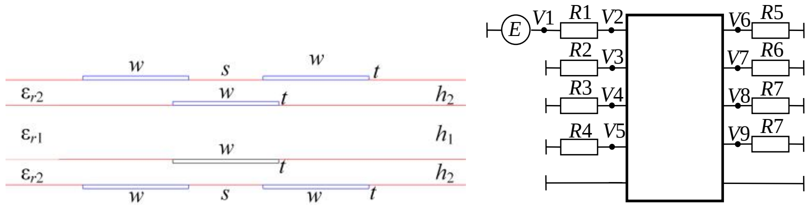


Fig. 1. Geometric model of the cross section (*a*) and schematic model (*b*) of the four-layer reflection-symmetric MF

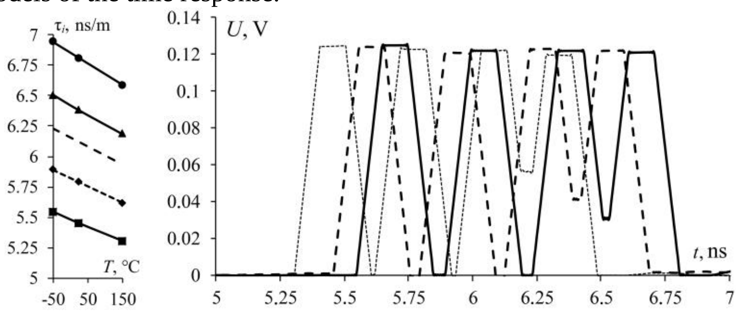
The developed algorithmic models for the four-layer reflection-symmetric MF are presented further as a sequence of steps. The algorithm for creating a geometric model of the cross section is the following: to set the finite ground, to set the parameters of the cross section according to the model of thermal extension, to set the boundary segmentation, to construct of conductor-dielectric boundaries for conductors, to construct of dielectric-dielectric boundaries for substrates, and to visualize the cross section and segmentation. The algorithm for creating models is: to calculate the matrices of primary and secondary parameters, to calculate the elements of the matrix of simultaneous linear algebraic equations, to calculate the matrix **C**, to calculate the matrix **L**, to set the zero matrices **R** and **G**, to calculate the delay matrix, and to calculate the matrix of characteristic impedance. The algorithm for creating a schematic model is: to set the transmission line segment and its parameters (**L**, **C**, **R**, **G** matrices, line length), to set elements with concentrated parameters, including the source of influences, and to set the ground. The algorithm for creating a simulation model to calculate the response is: to set the time step (the number of counts per front) and the number of counts per pulse repetition period, to calculate the time response $U(t)$, and to visualize the time response $U(t)$. Using the temperature model, we calculated the dependences of the cross section parameters of the four-layer reflection-symmetric MF on T (Table 1).

Table 1

Dependences of the cross section parameters of the four-layer reflection-symmetric MF on *T*

T,°C	*w*, µm	*t*, µm	*s*, µm	h_1, µm	h_2, µm	*d*, µm	ε_{r1}	ε_{r2}	*l*, m
–50	998.725	34.9554	699.107	497.375	204.918	2992.35	4.77	4.26	0.9987
–25	999.15	34.9702	699.405	498.25	205.279	2994.9	4.71	4.21	0.9991
0	999.575	34.9851	699.703	499.125	205.639	2997.45	4.65	4.15	0.9995
25	1000	35	700	500	206	3000	4.59	4.1	1
50	1000.42	35.0149	700.297	500.875	206.36	3002.55	4.52	4.04	1.0004
75	1000.85	35.0297	700.595	501.75	206.721	3005.1	4.46	3.99	1.0008
100	1001.28	35.0446	700.892	502.625	207.081	3007.65	4.41	3.93	1.0012
125	1001.7	35.0595	701.19	503.5	207.442	3010.21	4.34	3.88	1.0017
150	1002.12	35.0744	701.487	504.375	207.802	3012.76	4.28	3.82	1.003

Table 1 shows that the values of the parameters *w*, *t*, *s* and *h* increase as T increases, while ε_r decreases. Figure 2 shows the dependences of the values of the per-unit-length delays (τ_i) on T, as well as the simulation models of the time response.



a *b*

Fig. 2. Dependencies of $\tau_1 - \tau_5$ from T (*a*) and simulation model of time response for T = –50 (–), +25 (– –), +150 (--) °C (*b*)

Figure 2 shows that the values of τ_i decrease and T increases. The maximum values of the output voltage at the extreme values differ slightly *T* (0.125 V at –50 °C and 0.124 V at +150 °C). However, the lags decrease by about 5%, leading to a partial overlap of the pulses and breaking the equality of the intervals between them.

To take into account the effects of humidity, a layer of water (ε_{r1} = 81) or ice (ε_{r2} = 4) 1 mm thick was assumed to be present along the MF surface. T = 25 °C was assumed for water and –50 °C for ice. Figure 3 represents the geometrical model of the cross section of the four-layer reflection-symmetrical MF constructed in the TALGAT software. The schematic model of the MF is the same as in Fig. 1, *b*.

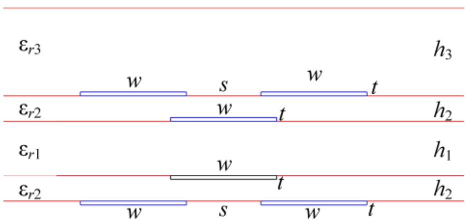


Fig. 3. Geometric model of the cross section of a four-layer reflection-symmetric MF to account for the influence of humidity

Table 2 shows the calculated per-unit-length delays and maximum voltage at the output of the MF with and without water and ice layers. Figure 4 shows the simulation models of the time response.

Table 2

Calculated per-unit-length delays and maximum voltage at the output of the MF with and without the layers of water and ice

Layer	τ_1, ns/m	τ_2, ns/m	τ_3, ns/m	τ_4, ns/m	τ_5, ns/m	U_{max}, V
Water	5.58	6.21	7.03	7.46	16.7	0.244
Ice	5.73	6.40	6.69	6.77	7.06	0.428
–	5.45	5.79	6.12	6.38	6.81	0.124

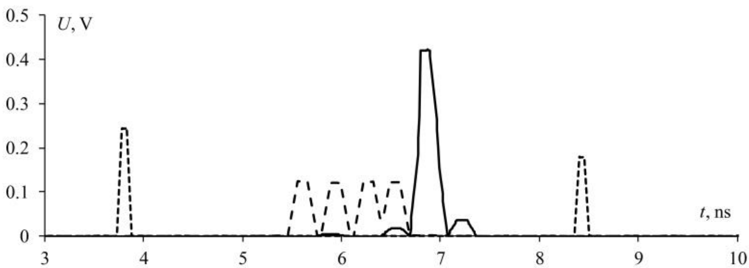


Fig. 4. Simulation models of time response with water layers (-), ice layers (– – – -) and without them (– –)

Figure 4 and Table 2 show that the maximum values of τ_i correspond to the water layer, but 2 rather than 4 pulses are obtained, whereas with ice the decomposition is almost not observed. Accordingly, the maximum output voltage values are: with an ice layer (U_2 = 0.428 V), without layers (U_3 = 0.124 V), and with a water layer (U_1 = 0.244 V).

Thus, the paper presents geometrical, schematic, algorithmic, and simulation models that take into account the influence of temperature and humidity on the four-layer reflection-symmetric modal filter performance. We obtained the time responses at the far end of the active conductor using the quasi-static approach for different temperatures and humidity.

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