Study of the Characteristics of a Modal Filter with Different Periodic Profiles of the Coupling Region

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***Abstract*—Improvement of protection against ultrashort pulse using modal filters (MF) is considered. A method for calculating the difference of the modes delays through the frequency characteristics without finding the time response at the MF output is proposed. On example of the interdigital, L-shaped and spiral structures simulation, the possibility of increasing the difference of the modes delay due to the application of the periodic profile of the coupling region is considered. The influence of a covering layer with a high dielectric constant in MF on the behavior of the frequency characteristics and the value of the difference of the modes delays is shown. The results showed the expediency of using the periodic profile of the MF coupling region in combination with inhomogeneous dielectric filling.**

Keywords*— Protective device, modal filter, electrodynamic simulation, difference of the modes delays.

I. Introduction

To protect the electronic equipment from an ultrashort pulse (USP), new protective devices have been proposed - modal filters (MF) based on modal filtering technology [1]. The principle of MF operation is based on the using of the modal decomposition of a pulse signal in multi-wire transmission lines due to the difference in the modes delays. The results of studies showing the effect of a nonuniform dielectric filling of a coupled line on the difference of the modes delays are presented [2]. For example, additional layers of dielectric or water-proof varnish are applied to the surface of the structure. Another way to control the modes delays is using of a periodic profile of the coupling region in the coupled structures [3]. In such structures, the path length of the odd mode is increased in comparison with the even one, since the odd-mode currents are forced out to the inner edges of the conductors in the coupling region, and the even one to the outer. However, the use of these opportunities in the MF has not been studied.

The purpose of this work is to study the frequency characteristics of MFs with different periodic profiles of the coupling region, as well as their effect on the difference of the modes delays.

II. Simulation Parameters

It is known that the difference of modes delays for a coupled line (Fig. 1) can be calculated as [4]

$$\tau_{even} - \tau_{odd} = 1/(2 \cdot f_{180}) \quad (1)$$

where f_{180} is the resonant frequency at which S_{21}=0, and S_{41}=1. In terminology [4], at the resonant frequency f_{180}, the electromagnetic coupling with the passive line is 100 % and the phase difference between the even and odd modes is 180 °.

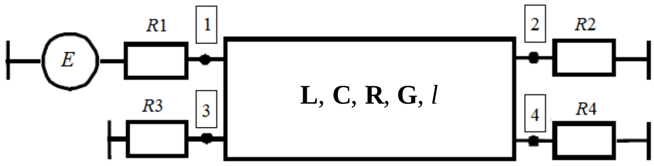

Fig. 1. Switching circuit of a coupled line

The study was based on the structure of MF for protection of Ethernet equipment (Fig. 2) with the following dimensions: conductor width w=0.3 mm, conductor thickness t=0.105 mm, distance between conductors s=0.4 mm, dielectric substrate thickness h_1=0.29 mm, coating layer thickness h_2=h_1. In this structure, the active (A) and passive (P) conductors are arranged mirror-wise with respect to the axis perpendicular to the reference (R) located on the axis of symmetry.

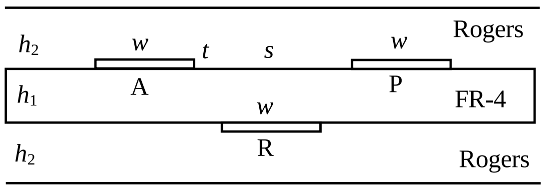

Fig. 2. Cross-section of original structure

The dielectric substrate material is FR-4, and the coating layer is Rogers RT6010. The use of Rogers RT6010 material will allow to increase the difference of the modes delays, since a dielectric constant of the material is 10.2. The simulation was performed taking into account the dispersion and losses. The length of the structure (l) is 0.1 m. The R_1–R_4 resistors have a resistance of 100 Ohms. The calculation of S_{11}, S_{21}, и S_{41} was performed in the frequency range from 0 to 10 GHz.

Three topologies of the periodic profile in a coupling region between the active and passive conductors of the MF are considered in the study: interdigital; *L*-shaped; spiral. Variants without a covering layer and with it were considered. The geometrical dimensions of the conductors and the distance between them during the construction of the periodic profile are the same as for the original structure.

Investigation was carried out at the expense of the Ministry of Education and Science of Russian Federation project No. 8.9562.2017/8.9.

The topology of the interdigital structure (Fig. 3) is created by adding pins of length *lp* in the coupling region. To study of the effect of complex periodic profiles of the coupling region on the difference of the modes delays, two other topologies of MF are proposed: L-shaped and spiral. The *L*-shaped topology (Fig. 4) was created by adding *L*-type conductors in the coupling region. The spiral topology (Fig. 5) was created by adding spiral branches in the coupling region.

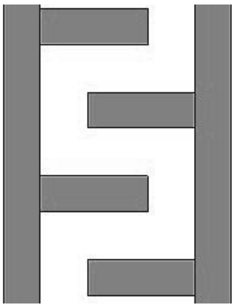

Fig. 3. Interdigital structure of conductors

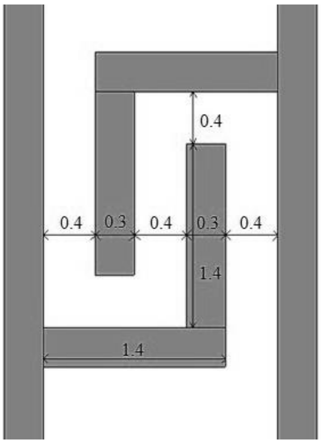

Fig. 4. *L*-shaped structure of conductors with sizes

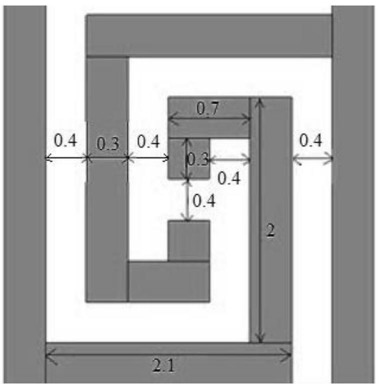

Fig. 5. Spiral structure of conductors with sizes

III. Simulation Results

A. Original structure

The simulation results are presented in Fig. 6. It is seen that for a structure without a covering layer f_{180}=6.135 GHz ($|S_{21}|$=-55 dB, $|S_{41}|$=-2dB), and when it was added, the resonance shifted to the frequency f_{180}=2.7 GHz ($|S_{21}|$=-21 dB, $|S_{41}|$=-2 dB).

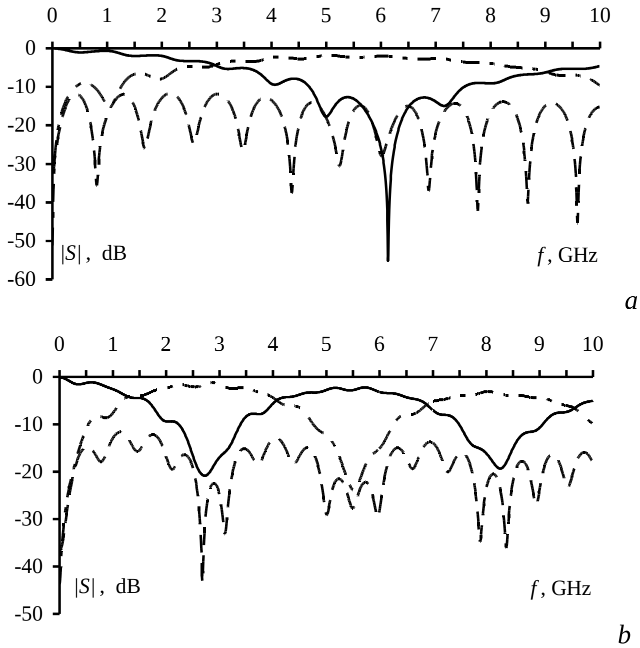

Fig. 6. Frequency dependencies of $|S_{11}|$(– – –), $|S_{21}|$(——), $|S_{41}|$(– · – · –) for uncoated (*a*) and coated (*b*) original structures

B. Interdigital structure

The simulation results are presented in Fig. 7 for *lp*=1.4 mm and Fig. 8 for *lp*=2.1 mm. From Fig. 7 it can be seen that for a structure without a covering layer f_{180}=2.995 GHz ($|S_{21}|$=-42.5 dB, $|S_{41}|$=-2 dB), and with its addition the resonance is shifted to the frequency f_{180}=0.919 GHz ($|S_{21}|$=-23 dB, $|S_{41}|$=-1 dB). From Fig. 8 it can be seen, that for a structure without a covering layer f_{180}=1.54 GHz ($|S_{21}|$=-34 dB, $|S_{41}|$=-2 dB), and when it was added, the resonance is shifted to the frequency f_{180}=0.549 GHz ($|S_{21}|$=-26 dB, $|S_{41}|$=-1 dB). As can be seen, the addition and extension of the pins reduce the resonant frequency.

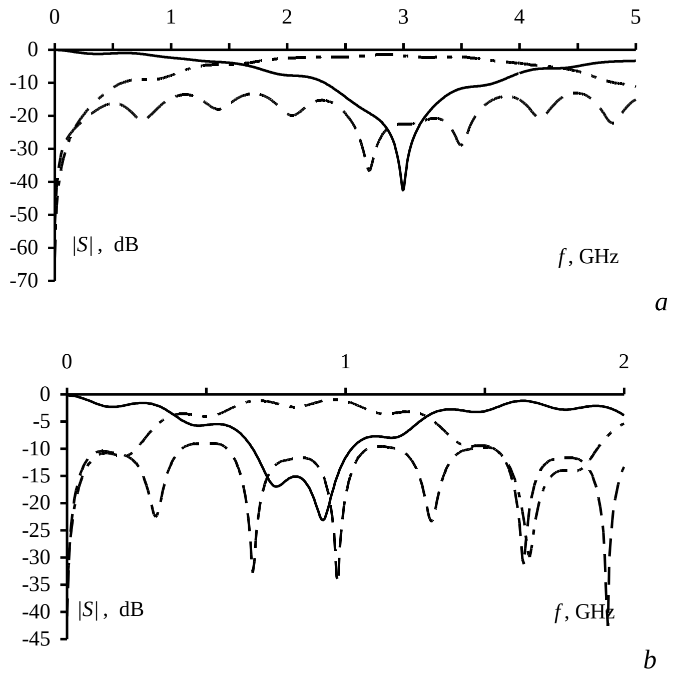

Fig. 7. Frequency dependencies of $|S_{11}|$(– – –), $|S_{21}|$(——), $|S_{41}|$(– · – · –) for uncoated (*a*) and coated (*b*) interdigital structures for *lp*=1.4 mm

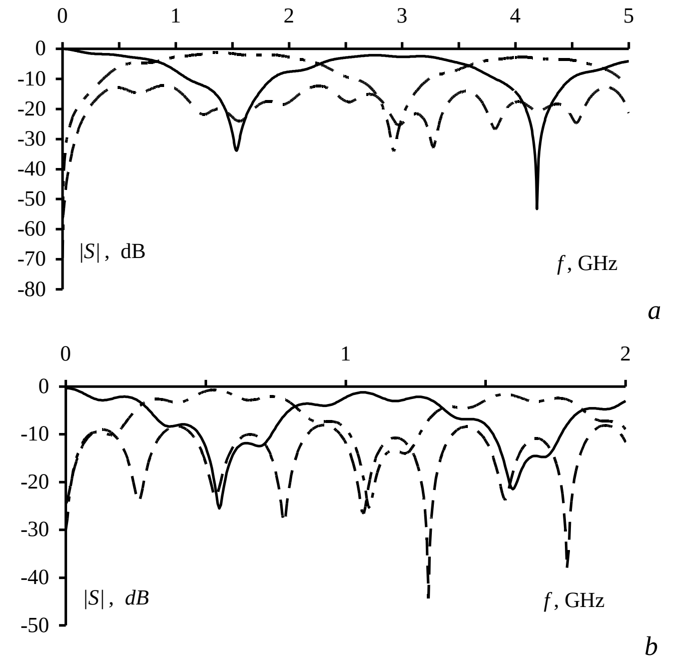

Fig. 8. Frequency dependencies of $|S_{11}|$(– – –), $|S_{21}|$(——), $|S_{41}|$(– · – · –) for uncoated (*a*) and coated (*b*) interdigital structures for *lp*=2.1 mm

C. L-shaped structure

The simulation results are presented in Fig. 9. It is seen that for a structure without a covering layer f_{180}=2.17 GHz ($|S_{21}|$=-32 dB, $|S_{41}|$=-1 dB), and when it was added, the resonance shifted to the frequency f_{180}=0.69 GHz ($|S_{21}|$=-20 dB, $|S_{41}|$=-1.5 dB). As can be seen, the resonant frequency is increased, in comparison with the previous structure.

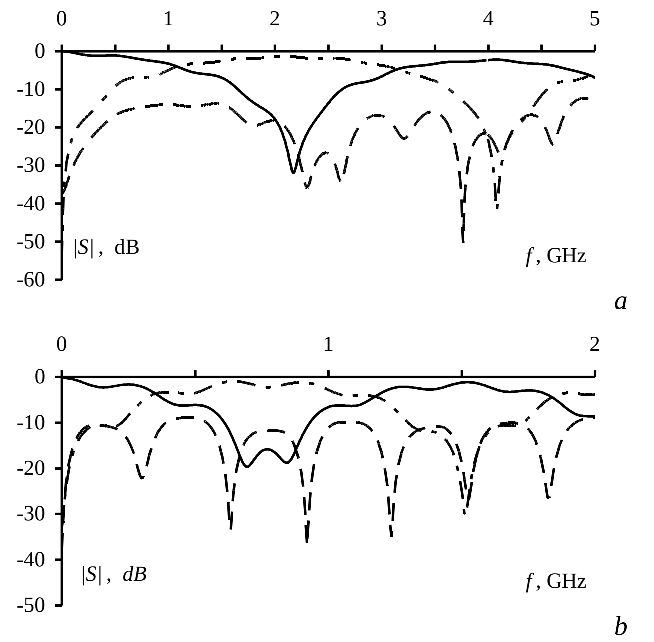

Fig. 9. Frequency dependencies of $|S_{11}|$(– – –), $|S_{21}|$(——), $|S_{41}|$(– · – · –) for uncoated (*a*) and coated (*b*) *L*-shaped structures

D. Spiral structure

The simulation results are presented in Fig. 10. It is seen that for a structure without a covering layer f_{180}=1.386 GHz ($|S_{21}|$=-22 dB, $|S_{41}|$=-1 dB), and with its addition the resonance is shifted to the frequency f_{180}=0.538 GHz ($|S_{21}|$=-16 dB, $|S_{41}|$=-1 dB).

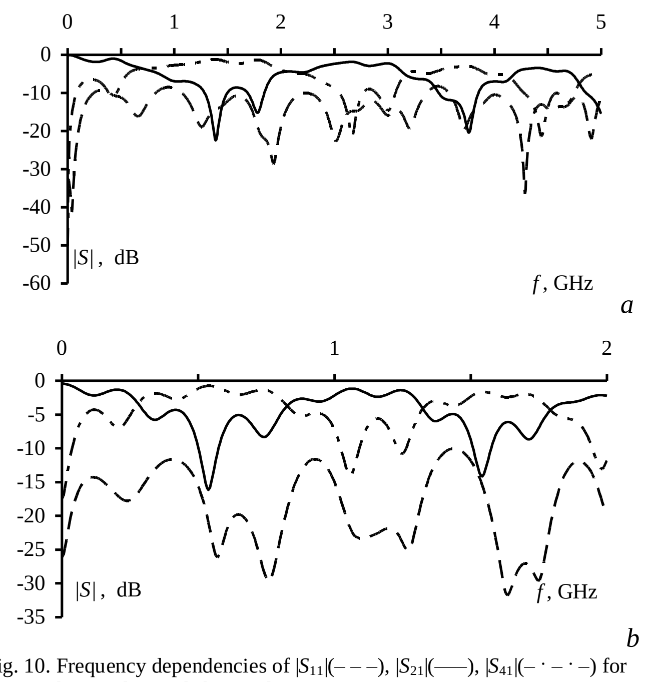

Fig. 10. Frequency dependencies of $|S_{11}|$(– – –), $|S_{21}|$(——), $|S_{41}|$(– · – · –) for uncoated (*a*) and coated (*b*) spiral structures

IV. Conclusion

On the basis of the obtained results, according to the formula (1), for each structure, the values of the difference of the modes delays are calculated. The values obtained are summarized in Table 1.

TABLE I. VALUES OF DIFFERENCE OF THE MODES DELAYS (NS) FOR STRUCTURES OF LENGTH 0.1 M

Fig.	Type of structure	
	Without covering layer	***With covering layer***
6	0.0815	0.1852
7	0.167	0.5441
8	0.3245	0.9107
9	0.23	0.7246
10	0.3655	0.9294

From Table 1, it can be seen that the use of interdigital topology makes it possible to increase the value of the difference of the modes delays in 2 (Fig. 7) and 4 times (Fig. 8). However, the distance between the active and passive conductors is increased to 1.8 and 2.5 mm, respectively. The application of the *L*-shaped topology leads to an increase in the difference of the modes delays by 2.8 times, and the distance between the active and passive conductors has increased to 1.8 mm. Consequently, the *L*-shaped topology in comparison with the interdigital one for *lp*=1.4 mm makes it possible to increase the mode delay difference by 1.4 times. The spiral topology increases the difference of the modes delays by 4.5 times, and the distance between the active and passive conductors up to 2.5 mm. Consequently, the use of this topology in comparison with the interdigital one at *lp*=2.1 mm allows to increase the difference in the mode delay by 1.13 times. In addition, the application of the cover layer leads to more wide stopband in the resonant frequency region.

References

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