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Evaluating the influence of the magnetic permeability of the microstrip modal filter substrate on its frequency characteristics

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Evaluating the influence of the magnetic permeability of the microstrip modal filter substrate on its frequency characteristics

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Abstract. This paper considers the possibility of improving the characteristics of modal filters by using composite materials with a relative magnetic permeability of $\mu_r>1$. The influence of the magnetic permeability of the microstrip modal filter substrate on its frequency characteristics is investigated. The paper presents the frequency dependences $|S_{21}|$ of the filter with lengths l=1, 0.5, and 0.2 m and with μ_r=1, 4, 7, and 10. It is shown that the increase of the the μ_r value leads to a decrease in the filter bandwidth.

1. Introduction

The nomenclature of radioelectronic devices (RED) used in radar systems, television, and radio is increasing every year. At the same time, because of the vulnerability of these devices to electromagnetic interference, the requirements for ensuring their electromagnetic compatibility (EMC) are being constantly tightened [1]. The interference that penetrates RED directly through the conductors, for example, through signal conductors or power circuits, is called conducted [2]. One of the types of conductive interference is ultrashort pulses (USP) [3]. They are particularly dangerous because of their short duration and wide spectrum [4, 5]. In addition, when a USP affects the equipment, the energy does not have time to be distributed across the structure elements, and therefore, due to the localization of the energy in one area, the probability of failure in sensitive areas increases [6].

To protect RED from the effects of USPs, it is proposed to use modal filters (MF), whose operation is based on the modal decomposition of the interference pulse into pulses of lower amplitude caused by the difference in mode delays. The simplest MF structure is a segment of connected transmission lines (TL) with the number of conductors N=2, where the USP is decomposed into 2 pulses of lower amplitude [7]. A complete decomposition of the pulse in a segment of length l takes place if the total pulse duration t_Σ is less than the minimum modulus of the delay difference in the propagation of modes in the line [8], i.e. if the condition is met

$$t_\Sigma<l\cdot\min|\tau_{even}-\tau_{odd}|,\quad i,\ k=1,\ldots,N,\ \ i\neq k,$$

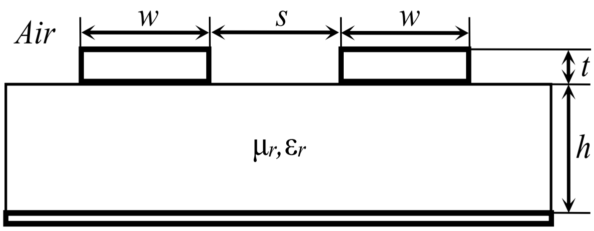
where τ_{even} and τ_{odd} – are the even and odd modes in the transmission line, respectively.

There are several ways to improve the efficiency of modal decomposition. First, a cascade connection can be used, which results in the sequential decomposition of each pulse into two more pulses of a lower amplitude [9]. There are also several modal filters under the development that differ in location of conductors and their number. A study of a multi-conductor MF has been performed, where it was shown that an increase in the number of passive MF conductors allows us to decompose the USP into a larger number of pulses [10]. A new approach to improving the MF structure based on mirror symmetry has been proposed [11]. It is shown that the use of the periodic topology of the MF allows increasing the difference in mode delays by 2 times compared to the original structure of the MF [12].

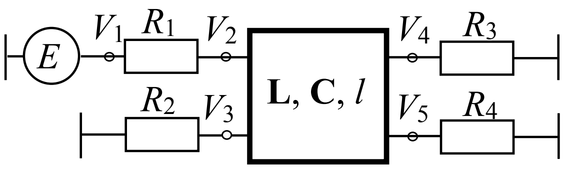
Modal decomposition in an MF is possible only in a non-uniform dielectric filling, and its efficiency increases with increasing the values of relative permittivity of the dielectric ε_r (for example, an MF on a ceramic substrate). If it is not possible, the effective decomposition of the USP into a sequence of pulses is provided by increasing the length of the line. However, this leads to an increase in the size of the MFs and limits the scope of their application. The paper [13] considers the possibility of improving the characteristics of the MF by using modern composite materials with a relative magnetic permeability of $\mu_r > 1$. It is also shown that increasing the value of μ_r allows increasing the time intervals between the decomposition pulses. Meanwhile, the effect of changing the μ_r value of the MF substrate on its frequency characteristics, in particular, on the bandwidth, has not been previously considered. Nevertheless, this effect is very important since the parameters of the transmitted useful signal depend on the bandwidth of the filter. The purpose of the work is to perform evaluating the influence of the magnetic permeability of the microstrip modal filter substrate on its frequency characteristics.

2. Structure under research

The microstrip MF structure was selected to investigate the influence of the μ_r value on frequency characteristics. Its cross-section is shown in Figure 1a with geometric dimensions s=200 µm, w=850 µm, t=35 µm, h=500 µm, ε_r=4.5, and the schematic diagram is shown in Figure 1b. The calculation of MF parameters and signal waveforms at its output under the harmonic influence of an EMF source 2 V was performed using a quasi-static approach in the TALGAT system [14]. The resistances of the resistors (R_1, R_2, R_3, and R_4) connected at the ends of the MF were set based on the condition of ensuring pseudo-agreement, i.e. when the resistances are equal to the mean geometric value of the Z_e and Z_o impedances (Z_e, Z_o are the impedances of even and odd modes, propagating in the line, respectively).



a



b

Figure 1. The cross-section (a) and the schematic diagram (b) of the microstrip MF.

3. The simulation results

The frequency dependencies of the MF with lengths l=1, 0.5, and 0.2 m and value μ_r =1, 4, …, 10 are obtained to estimate the bandwidth. The simulation results are presented in Figure 2. Figure 3 shows the dependence of the cutoff frequency (f_c) on the level of -3 dB, which determines the bandwidth of the MF and the time interval values between the decomposition pulses (Δt), taken from [13], on the change in the value of μ_r. Figure 3 shows that as the value of μ_r increases, the frequency of the first resonance and the cutoff frequency of the MF decreases.

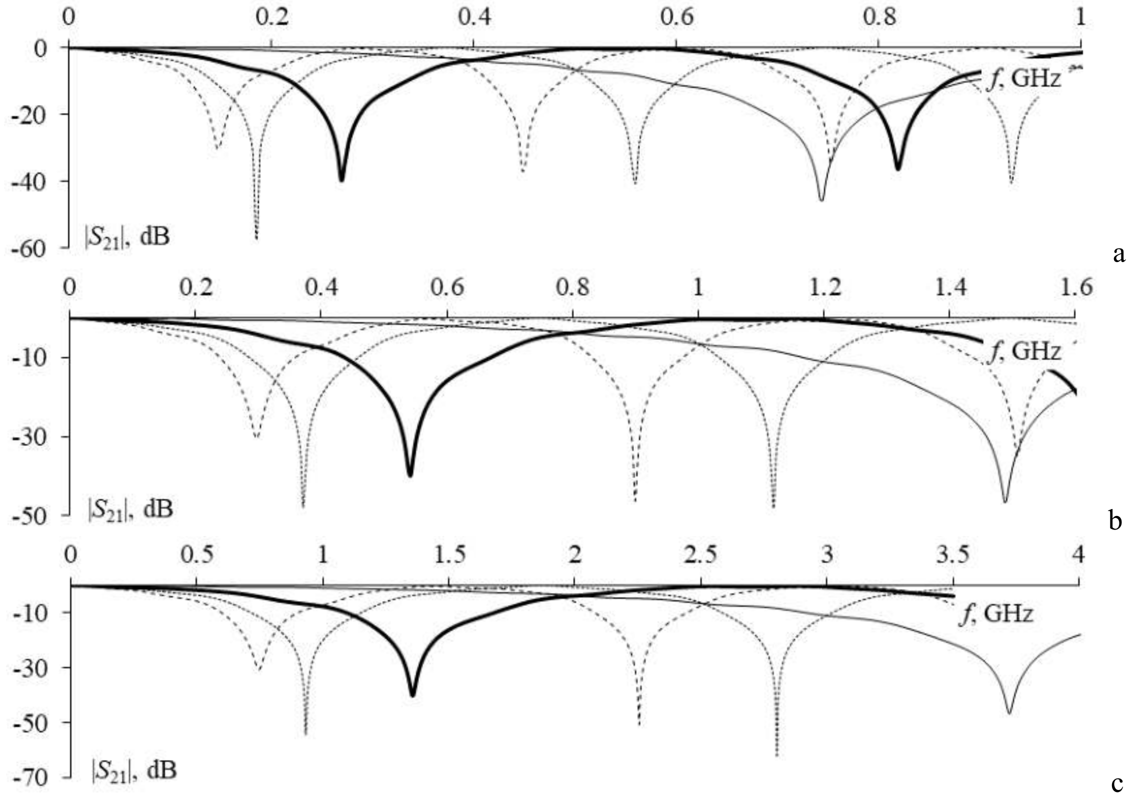


Figure 2. The frequency dependencies $|S_{21}|$ of the MF with lengths
a) l=1 m, b) l=0.5 m, and c) l=0.2 m with μ_r=1 (—), μ_r=4 (▬), μ_r=7 (·····), μ_r=10 (– –).

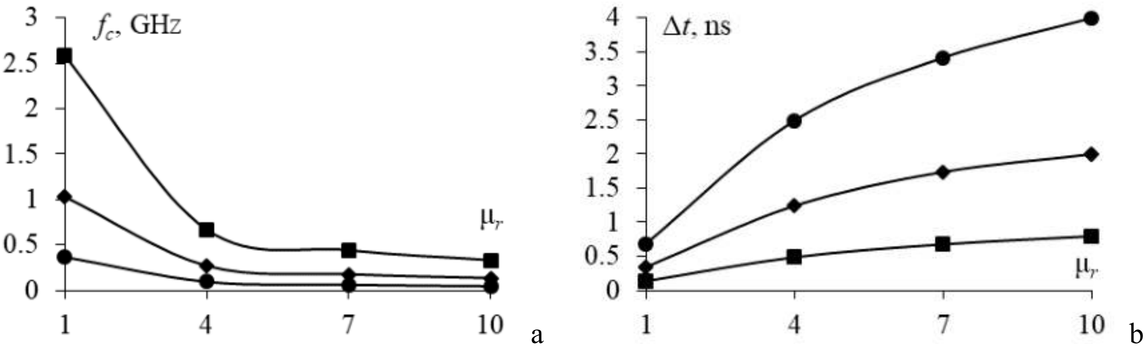


Figure 3. The dependence of a) the cutoff frequency f_c and b) the time interval between the decomposition pulses Δt on the μ_r value of the MF substrate with lengths l=1 m (–■–), l=0.5 m (–♦–), l=0.2 m (–●–).

The μ_r value directly affects the rate of propagation mode in the transmission line:

$$\nu = \frac{c}{\varepsilon_r \mu_r},$$

where υ – is the speed of propagation of modes in the line, c – is the speed of light. Based on the fact that the value of the linear delay τ is inversely proportional to the value of υ, i.e.

$$\tau = \frac{1}{\nu},$$

an increase in the value of μ_r will lead to an increase in the difference between the linear delays of the two modes or, in the case when the line length is taken into account, the time interval between the decomposition pulses. From the inverse relation between the value of τ and the frequency of the first resonance f_{res} [15]:

$$f_{res} = \frac{1}{2l(\tau_{\text{even}} - \tau_{\text{odd}})},$$

it follows that as the value of μ_r increases, the value of f_c decreases and, conversely, as the length of MF decreases, the value of f_c increases.

This statement is fully confirmed by the results of the simulation (Figures 2 and 3). Thus, a 0.2 m long MF on a substrate with μ_r=10 provides almost the same band as a 1 m long MF on a substrate without the use of a composite material. However, with an increase in the f_c value, there is a decrease in Δt, which can lead to a deterioration in the effectiveness of MF attenuation.

4. Conclusion

In conclusion, the frequency dependences $|S_{21}|$ for a microstrip MF on a substrate with μ_r=1, 4, 7 and 10 with the lengths of the MF l =1, 0.5 and 0.2 m are obtained. It is shown that the value of the cutoff frequency decreases as the value of the μ_r increases. Therefore, by varying the value of the substrate's μ_r, it is possible to achieve the required MF characteristics both in the bandwidth of the useful signal and in the required attenuation, including the duration of the USP.

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