Experimental Study of the Buried Vias Effect on Reflection Symmetric Modal Filter Performance

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***Abstract* – The paper considers the influence of buried vias in the reference conductor on time and frequency characteristics of a four-layer reflection symmetric modal filter (MF). The prototype of the reflection symmetric MF was developed in two versions: with and without buried vias. For the first time, the effect which buried vias has on the characteristics of reflection symmetric MFs was studied experimentally. The decomposition of an ultrashort pulse (USP) into a sequence of pulses of lower amplitude is shown. The influence of buried vias on the MF characteristic impedance was estimated. The frequency dependences of the transmission and reflection coefficients in the range from 0 to 32 GHz were obtained. Moreover, practical recommendations are given for the design of multilayer reflection symmetric devices based on coupled lines in this paper. The results are useful for further research because the configuration of a four-layer reflection symmetric MF without buried vias reduces its cost.**

***Index Terms* – buried via, reflection symmetric modal filter, coupled lines, protection devices, TDR, modal filtration, microwave measurements.**

I. Introduction

Modern radio electronic equipment (REE) is extremely sensitive to various electromagnetic interference (EMI). Increased speed, higher density of REE parts and miniaturization of electronic components reduce electromagnetic compatibility (EMC). The level of conducted and radiated emissions rises sharply. An ultrashort pulse (USP) is especially dangerous for signal and power circuits [1, 2]. The USP bypasses traditional protection systems and disables REE since it has a wide range, high amplitude and large power. Noise filters are used to achieve the specified EMC level [3]. They limit the level of conducted noises to a target value. There are filters based on coupled transmission lines [4, 5], lumped elements [6, 7] and hybrid structures [8, 9]. However, they do not completely suppress USP due to parasitic parameters and coupling. Such protection devices as modal filters (MF) and meander lines [10 – 12], which work is based on modal distortions, are promising. Particularly, the structures of coupled transmission lines with cross section having nonhomogeneous dielectric filling are selected. The signal modes propagate at different phase velocities, which consider strong coupling between the conductors, leads to distortions. The utilization of a dielectric substrate with a high value of ε_r and tgδ improves interference suppression. However, this type of dielectric is more expensive and more difficult to manufacture.

II. Problem Statement

In [13] the author has described a new device – a reflection symmetric MF (Fig. 1). In the proposed MF, interference suppression is improved by introducing symmetry and additional passive conductors. Conductor 1 is used for signal transmission, and it is active; conductors 2 to 4 are passive; conductor 5 is a reference. The original reflection symmetric MF version uses only one reference conductor. However, this configuration does not meet the standard requirements of PCB manufacturers and makes the production difficult.

In [14], a new design of a four-layer reflection symmetric MF was proposed (Fig. 2). A specific attribute is the fourth conductor layer and conductor 6, which is connected by buried vias to conductor 5. This creates a single combined reference conductor. In [15], an experimental study of the MF characteristics was carried out for the first time. Experimental verification was executed to prove the possibility of protecting REE from a USP by decomposing it into a sequence of pulses of lower amplitude. The comparison of measurement and electrodynamic simulation results was also made.

However, the presence of buried vias makes it difficult to

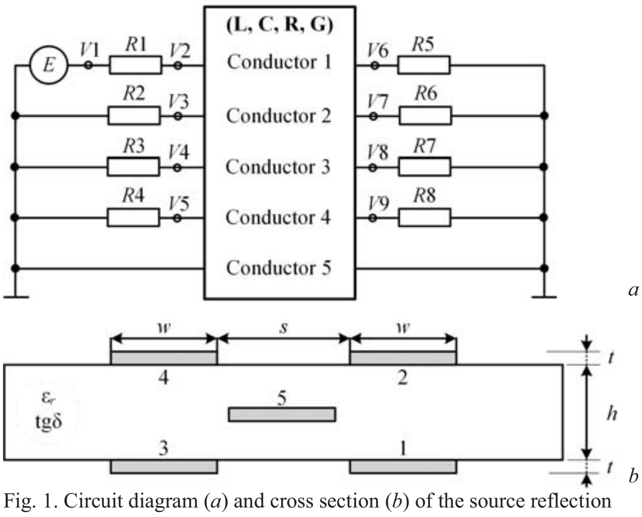

Fig. 1. Circuit diagram (*a*) and cross section (*b*) of the source reflection symmetric MF.

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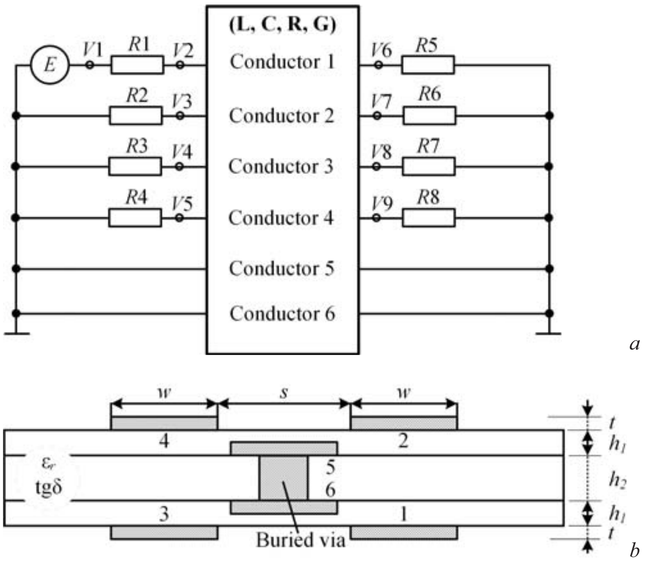

Fig. 2. Circuit diagram (*a*) and cross section (*b*) of the four layer reflection symmetric MF.

design and manufacture of MF. Removing buried vias makes the production easier and cheaper. The purpose of this research is to conduct an experimental study of the influence of buried vias on the characteristics of a four-layer reflection symmetric MF.

III. Approaches, Techniques and MF Structure

A modification of a previously manufactured MF prototype was used to study the effect of buried vias on the reflection symmetric MF performance in a wide frequency range (Fig. 3). We designed and implemented new connector pads for high-frequency coaxial-to-microstrip transitions. The new prototype of the reflection symmetric MF consists of two transmission lines with and without buried vias. In order to reduce the length of the PCB, the MF was modified into a meander. The distance between the turns was 6 mm, which sufficiently reduces the coupling of adjacent turns of the MF.

Fig. 4 shows the cross section of the connector pad for coaxial-to-microstrip transition. Fiberglass FR-4 with a dielectric constant of 4.3 and a dielectric dissipation factor of 0.025 was chosen as the core (h_2). Dielectric material H140AP 1080 with a dielectric constant of 4.4 and a dielectric dissipation factor of 0.018 was chosen as the prepreg (h_1 and h_3). The prototype parameters are presented for 1 MHz frequency. Sizes are the following: $s = 700$ µm, $w = 1000$ µm, $h_2 = 510$ µm, $h_1 = h_2 = 210$ µm, $t = 35$ µm. The diameter of buried vias is 600 µm.

In order to provide matching in the MF passband, conductors 2, 3 and 4 are connected to a reference conductor by 50 Ω resistors (chip size 0805).

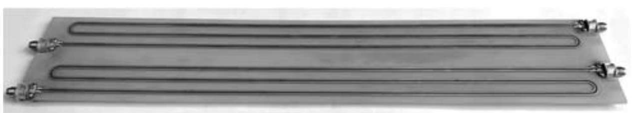

Fig. 3. Four layer reflection symmetric MF modified prototype.

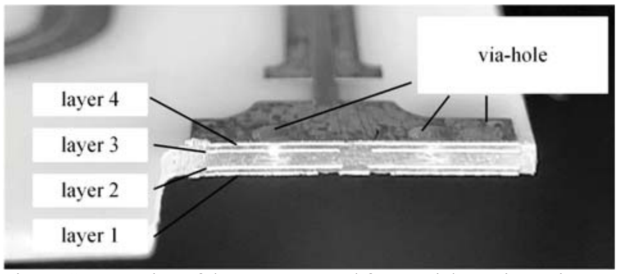

Fig. 4. Cross section of the connector pad for coaxial-to-microstrip transition.

The experimental study of the influence of buried vias on the reflection of symmetric MF performance was carried out in the frequency and time domains. To study the frequency response of the MF we used the vector network analyzer techniques from [16]. The reflection symmetric MF is a four-pole one, and as anisotropic elements are not included in its design, the device is reciprocal. This means that the MF has a symmetrical scattering matrix (formula (1)), so the measurements were made in only one direction.

$$\dot{S}_{12} = \dot{S}_{21},\ \dot{S}_{11} = \dot{S}_{22} \qquad (2)$$

Frequency dependencies of $|S_{21}|$ and $|S_{11}|$ were obtained by using vector circuit analyzer N9917A from Keysight Technologies.

To analyse the characteristic impedance of the MF, the TDR method was used with the DSA8300 stroboscopic oscilloscope and sampling module 80E04 from Tektronix. The characteristic impedance Z_0 was calculated using the expression (2)

$$Z_0 = Z_L \frac{(1-\rho)}{(1+\rho)} \qquad (2)$$

where Z_L is a reference impedance (50 Ω), ρ is a measured reflection coefficient.

It is necessary to consider the reflection coefficient on the matched load to obtain Z_0 values normalized to 50 Ω.

By using the GZ1117DN-35/1V pulse generator, a USP with a duration of 60 ps (defined by the level of 0.5) and an amplitude of 1.66 V was injected into the transmission line. A time response to a given excitation was observed at the MF output by using a DSA8300 stroboscopic oscilloscope.

High-frequency coaxial-to-microstrip and coaxial transitions (Fig. 5) were used in the experimental studies. Micran PKM1-32-13R-0.3P junctions were used to connect microstrip and coaxial paths. Coaxial transitions PK2-26-13-05 and PK2-26-13-05P were used for connecting it to measuring microwave equipment. By datasheet the total

Fig. 5. High-frequency coaxial-to-microstrip and coaxial transitions.

insertion losses caused by transitions do not exceed 1 dB in the frequency range from 0 to 32 GHz. The standing wave ratio in this case is not higher than 1.3.

The calculation of deviation of the experimental research results is performed as follows

$$\delta = \left| \frac{x_1 - x_2}{x_1 + x_2} \right| \times 100\% \quad (3)$$

where x_1 and x_2 are comparable variables.

Calibration provided by the manufacturer of microwave equipment is performed in the time and frequency domains before conducting the experimental studies. This is necessary to remove a systematic error. All results were obtained under normal environmental conditions.

IV. RESULTS

A. Time response

The experimental setup shown in Fig. 6 is used to analyze the effect of buried vias on pulse decomposition efficiency. Decomposition pulses can be seen on the stroboscopic oscilloscope screen. They have negative polarity, which is caused by the fact that GZ1117DN-35 generates negative pulses. In order to simplify the analysis, the decomposed pulses are presented in the positive plane in Fig. 7.

Ona can note from Fig. 7 that the voltage waveforms at the output of the reflection symmetric MF in different versions are similar, e.g. the maximum deviation of the pulse peaks is 10.81 %.

The values of the decomposition pulse amplitudes and the difference of per-unit-length time delays of each pulse for the prototype with and without buried vias are summarized in Table I.

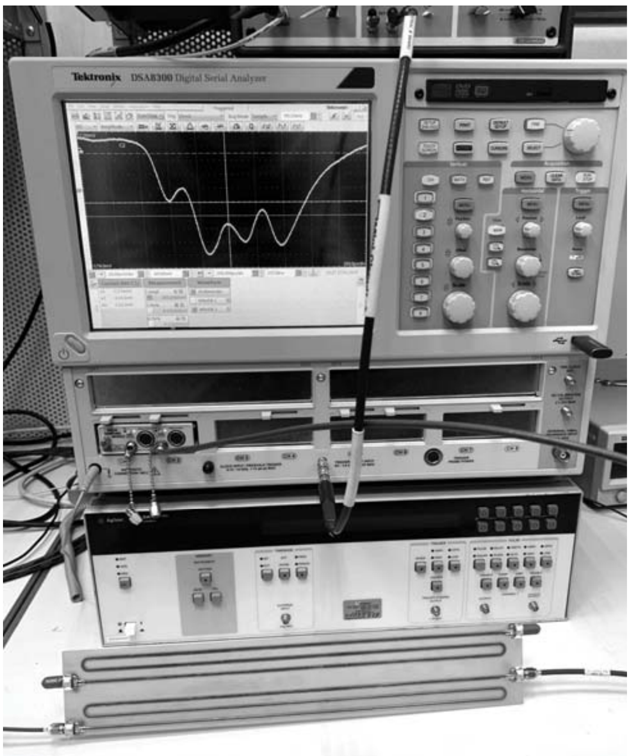

Fig. 6. Sampling oscilloscope DSA8300 and the reflection symmetric MF under study.

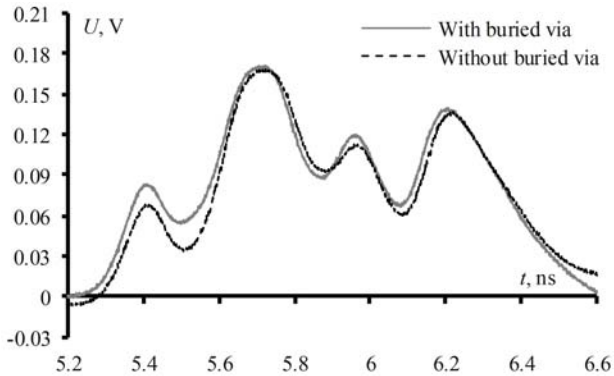

Fig. 7. Voltage waveforms at the output of the reflection symmetric MF with and without buried vias.

TABLE I
COMPARISON OF AMPLITUDES (U) AND DIFFERENCES OF PER UNIT LENGTH DELAYS ($\Delta\tau$) OF FOUR PULSES IN TWO VERSIONS

Parameters	With vias	Without vias	Deviation, %
U_1, V	0.082	0.066	10.81
U_2, V	0.169	0.166	0.895
U_3, V	0.119	0.111	3.478
U_4, V	0.138	0.135	1.098
$\Delta\tau_1$, ns	0.3		-
$\Delta\tau_2$, ns	0.25		-
$\Delta\tau_3$, ns	0.24		-

By using electrodynamic simulation results from [14] we obtained the per-unit-length time delays of each mode. Their differences are 0.26, 0.37 and 0.349 ns/m. The maximum deviation from the experimental study results is 19.35 %. We can conclude that buried vias have a weak effect on modal decomposition efficiency.

B Time-domain reflectometry

A time domain reflectometry was performed to analyze the effect of buried vias on the characteristic impedance. The reflectogram of the prototype of a reflection symmetric MF in two versions is presented in Fig. 8.

The reference plane of the stroboscopic module is given in region 1. At time t_1 = 1.9 ns, the reflection coefficient ρ

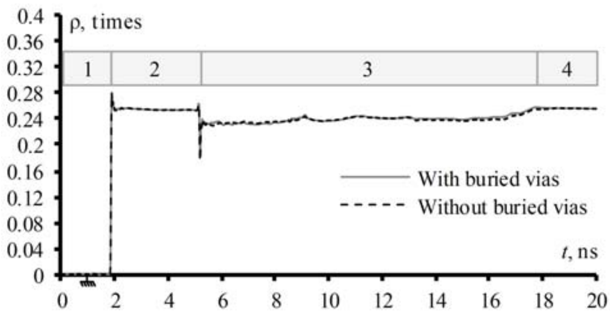

Fig. 8. Reflection symmetric MF prototype reflectogram.

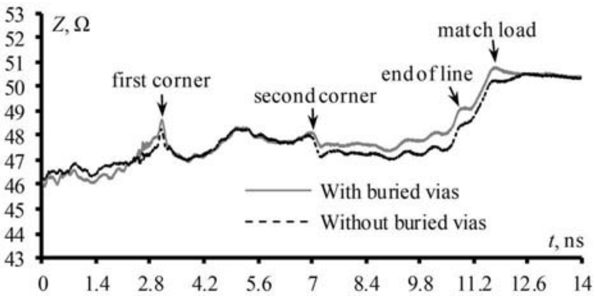

Fig. 9. Characteristic impedance of the reflection symmetric MF prototype.

rises sharply, which is caused by the propagation to a matched coaxial path (50 Ω) (region 2). At time t_2 = 5.1 ns, the reflected wave comes from the coaxial-to-microstrip transition. Region 3 characterizes the processes occurring in the reflection symmetric MF. After t_3 = 17.6 ns, the ρ value corresponds to region 2. This is due to the fact that when TDR is performed, the far end of the MF active line is matched by a high-frequency impedance of 50 Ω (region 4). The characteristic impedance of the MF is calculated basing on formula (2). The results are shown in Fig. 9.

The results for both MF configurations are well consistent. The minimal convergence is observed on the third turn, where the greatest deviation is 0.66 %. In general, it can be concluded that the transmission line impedance is independent or weakly dependent on buried vias. The maximum deviation of the measured characteristic impedance from the reference 50 Ω was 4.52 %.

C. Frequency response

The results of the study of the effect which buried vias have on the characteristics of the reflection symmetric MF in the frequency domain are shown in Fig. 10.

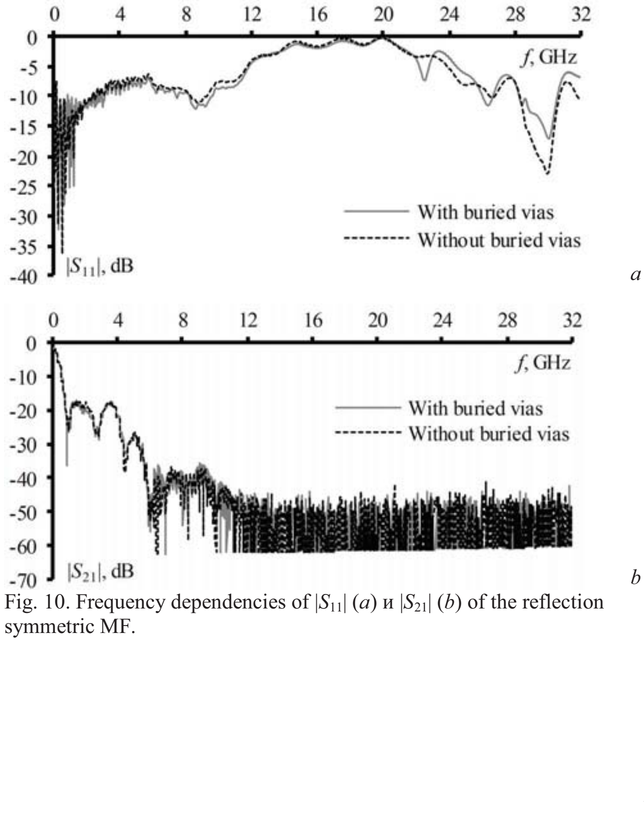

Fig. 10. Frequency dependencies of $|S_{11}|$ (*a*) и $|S_{21}|$ (*b*) of the reflection symmetric MF.

From the results of the experimental study of frequency dependencies $|S_{11}|$ and $|S_{21}|$ the forms of the obtained curves are seen to agree well. The maximum deviation of the reflection coefficient is observed at 29.82 GHz and is 6 dB. The resonance frequencies in the two versions are also well matched. Thus, the maximum deviation of the first resonance frequency is 5 %. The bandwidth for the version without buried vias is 245 MHz and with them 238 MHz. Thus, the deviation does not exceed 1.5 %.

IV. CONCLUSION

Thus, the paper considers the influence of buried vias in the reference conductor on time and frequency characteristics of a four-layer reflection symmetric modal filter (MF). The prototype of the reflection symmetric MF was developed in two versions: with and without buried vias. For the first time, the effect which buried vias has on the characteristics of reflection symmetric MFs was studied experimentally.

The decomposition of an ultrashort pulse (USP) into a sequence of pulses of lower amplitude is shown. The largest difference in the amplitudes of decomposition pulses was observed for the fastest mode. The deviation was 10.81 %.

The influence of buried vias on the MF characteristic impedance was estimated. The buried vias were found to have a small effect on the characteristic impedance of the reflection symmetric MF. The maximum deviation did not exceed 4.52 %.

The frequency dependences of the transmission and reflection coefficients in the range from 0 to 32 GHz were obtained. The measured frequency dependencies of the transmission and reflection coefficients were also well matched. Basing on the results of the experimental study, we can conclude that buried vias weakly affect the characteristics of a reflection symmetric MF.

While designing symmetric coupled lines, including reflection symmetric MFs, it is necessary to carefully control modal parameters. To simplify the design and implementation of such devices, it is possible to remove the buried vias. Disconnections of the reference conductors do not lead to significant changes in MF parameters.

Thus, the paper presents the results of the experimental study of the influence, which buried vias have on the characteristics of reflection symmetric MFs, for the first time. High convergence of results in the frequency and time domains is obtained for MF configurations with and without buried vias.

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