Modal Analysis of a Microstrip Line with Polygons in the Air

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Abstract – **A modal analysis of a microstrip line with polygons in the air is performed. The results of the analysis which takes into account modes and the one without them are compared. It is shown that the difference can be important for ultrashort pulses.**

Index Terms – **Printed circuit board, microstrip line, polygons, per-unit-length delay mode, sensitivity, modal analysis.**

I. INTRODUCTION

AN IMPORTANT factor ensuring electromagnetic compatibility (EMC) of electronic equipment (EE) is the correct design of printed circuit boards (PCBs). For this, it is desirable to use well-known transmission lines (TL), as well as their modifications, which make it possible to obtain more stable values of the characteristics, e.g. per-unit-length delays (τ). TLs are implemented on the PCBs in accordance with the production technology, the specified materials, the geometric dimensions of the conductors and other PCB components which can significantly affect the signal distortion. A strong influence on the signal distortion is provided by the dielectric filling [1], which in reality, as a rule, is non-uniform; e.g. in a microstrip line (MSL) [2–6]. The inhomogeneity of the dielectric filling does not equally affect the capacitive and inductive parameters of TLs, the ratios of which, in turn, determine their main characteristics. Interference arising from a constructive implementation should not exceed permissible values, and signal delays should provide a certain data transfer speed. Therefore, the reduction of signal distortions is carried out, first of all, by the appropriate choice of TL parameters. Also, when designing PCBs, if their nearest bottom layer acts as a circuit ground, it often requires a very narrow strip, thereby increasing the relative spread of its width, and, hence, the spread of τ. Therefore, in practice, the foil is etched under a strip on one or more layers, thereby using the lower layer as a circuit ground. According to the properties of a flat capacitor, increasing the distance from the strip to the ground allows you to increase the width of the strip. However, side grounded conductors (often called as PCB polygons) affect the characteristics of the TL [7].

Meanwhile, it is important to minimize the sensitivity of the characteristics of the strip lines in order to reduce the spread of their parameters during the manufacturing process.

Recently it has been proposed to use grounded polygons for this purpose [8]. However, the influence of these polygons remains unexplored when they are not grounded completely along the line, but only at the ends. At the same time, this study is important, because at certain values of the TL parameters, additional transverse-wave modes will be strongly excited, which can lead to a change in the sensitivity of the TL characteristics (in particular, per-unit length delays) and even distortion of the pulse signal. In this regard, an important task is to determine the boundaries of the regions of admissible values of TL parameters corresponding to the minimum sensitivity of the TL characteristics while maintaining the allowable signal distortion.

In order to achieve this, it is necessary to perform quasi-static modeling of the per-unit-length matrix coefficients of the electromagnetic (**L**) and electrostatic (**C**) induction of the multiconductor transmission lines (MTLs), which describes their real structure. Then, it is necessary to calculate the eigenvalues and eigenvectors of the product of these matrices. At last, it is necessary to calculated, the time response to the ultrashort pulse (USP) excitation.

A thorough analysis of the data will allow us to draw conclusions about the possibility of reducing the sensitivity of line characteristics.

The present work is devoted to building a more complete model of τ in MSL with end-grounded polygons above it and to compare it with the results of [8].

II. LINE UNDER INVESTIGATION

In the work, quasi-static modeling was made in the TALGAT system [9], which allows us to evaluate signal integrity for lines of various cross sections. Thus, using the TALGAT system, we constructed a cross-section of MTL (Fig. 1) and performed the corresponding calculations, the results of which are presented in the following sections.

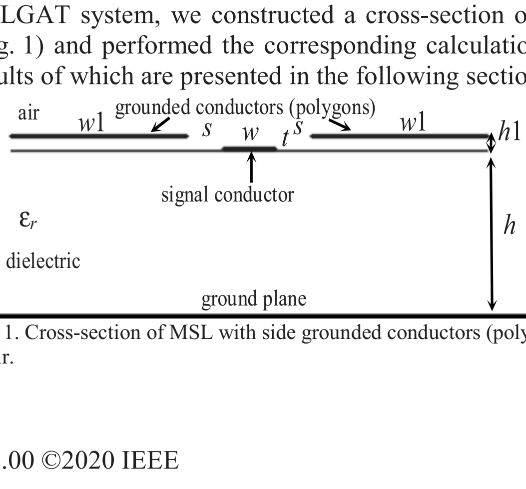

Fig. 1. Cross-section of MSL with side grounded conductors (polygons) in air.

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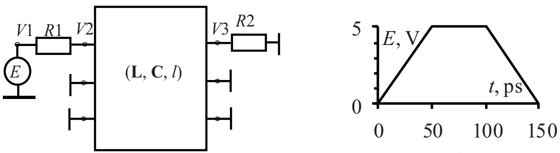
In order to evaluate and compare the corresponding sensitivity of τ, the parameters of the studied line were taken as in [8]: the width of the signal conductor was w=0.3 mm, the thickness of the signal and side grounded conductors was t=18 μm, the width of the side conductors is $w1$=1 mm, the thickness of the dielectric substrate was h=1 mm, and the relative permittivity of the substrate was ε_r=4.5.

The simulated circuit diagram of the TL segment from Fig. 1 is presented in Fig. 2*a*. The second and third conductors are polygons. The first (signal) conductor is connected to a pulse signal source, represented in the diagram by an ideal source of e.m.f. *E* and internal resistance *R*1. At the other end, the first conductor is connected to *R*2. The resistance values *R*1 and *R*2 are assumed to be the same and equal to 50 Ohms. Length (*l*) of the TL segment is 1 m.

The input excitation is a trapezoidal e.m.f. pulse, shown in Fig. 2*b* and having the following parameters: the amplitude of 5 V, the rise, flat top and fall times of 50 ps. Losses in conductors and dielectrics were not taken into account.



(*a*) (*b*)

Fig. 2. Simulated circuit diagram (*a*), waveform of the input excitation (e.m.f. vs time) (*b*).

III. EIGENVALUES AND EIGENVECTORS

This section presents the results of evaluating the sensitivity of the per-unit-length modal delays (τ), as well as their eigenvectors (*U*), which were obtained from calculations of the matrices **L** and **C**.

Similar studies have been presented in [10], but for other lines. To compare the results, the calculated delays shown in Fig. 3 were obtained using two methods.

The first method is used to estimate the per-unit length delay which is denoted by τ_0 and calculated in [8], (assuming the polygons are grounded) as follows:

$$\tau=(C/C_0)^{0.5}/v_0 \qquad (1)$$

where v_0 is the speed of light in air; *C* is the per-unit length capacitance of the line; C_0 is the per-unit-length capacitance in the air.

The second method is used to evaluate per-unit length delays of the modes (τ_1, τ_2, τ_3) of the line under study. They were calculated as the square root of the eigenvalues of the product of matrices **L** and **C**. Calculations based on both methods were performed with a change in the conductor spacing s=0.1–0.9 mm when the polygon height $h1$=0.1 mm. According to the results obtained, it can be seen that the values of τ_1, τ_2, and τ_3 smoothly increase with parameter *s*, while the dependence of τ_0 for a small value of s=0.1–0.4 mm increases more sharply.

Comparing the results of two methods, it can be noted that the difference in the values of τ reaches 15%, while $\tau_3 - \tau_2 \approx 0.2$ ns/m.

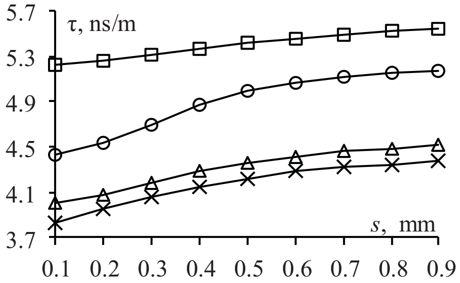
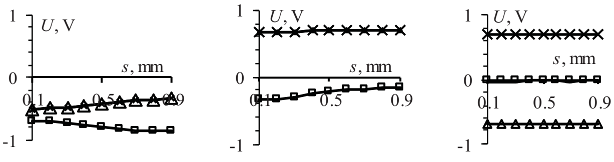


Fig. 3. Dependences of τ_0 (○), τ_1 (□), τ_2 (Δ), τ_3 (×) on *s* for *h*1= 0.1 mm.

Each of the per-unit-length mode delays has its voltage eigenvectors, whose entries are presented in Fig. 4. They can be seen to change smoothly with increasing *s*, and for τ_3 they are unchanged. The reliability of the results is confirmed by their comparison to the vectors presented in [10] in the form (2):

$$U_1=\begin{pmatrix} a \\ 1 \\ a \end{pmatrix},\ U_2=\begin{pmatrix} -b \\ 1 \\ -b \end{pmatrix},\ U_3=\begin{pmatrix} -1 \\ 0 \\ 1 \end{pmatrix} \qquad (2)$$

where parameters *a* and *b* are functions of the physical dimensions of the line.



(*a*) (*b*) (*c*)

Fig. 4. Dependences of U1 (□), U2 (Δ), U3 (×) on parameter s for corresponding delays τ1 (a), τ2 (b), τ3 (c), when h1=0.1 mm.

IV. TIME RESPONSE

This section presents the results of modeling time responses to the excitation of the USP for $h1$= 0.1 mm. Fig. 5 shows the time responses for s= 0.1–0.6 mm. The USP is noted to decompose into a series of pulses. A pulse with a maximum delay increasing from 5.2 to 5.4 ns/m is very small in amplitude. Therefore, the response essentially consists of two pulses with per-unit-length delays of about 3.8 and 4.0 ns/m. The interval between them first slightly decreases, and then increases again, in accordance with the behavior of the dependences of τ_2 and τ_3 on *s* in Fig. 3.

Fig. 6 demonstrates the convergence of two output pulses with increasing flat top duration (t_d), when s=0.1 mm and *h*1=0.1 mm. Obviously, when pulses are added, there will be time steps with a duration proportional to $(\tau_3-\tau_2)l$.

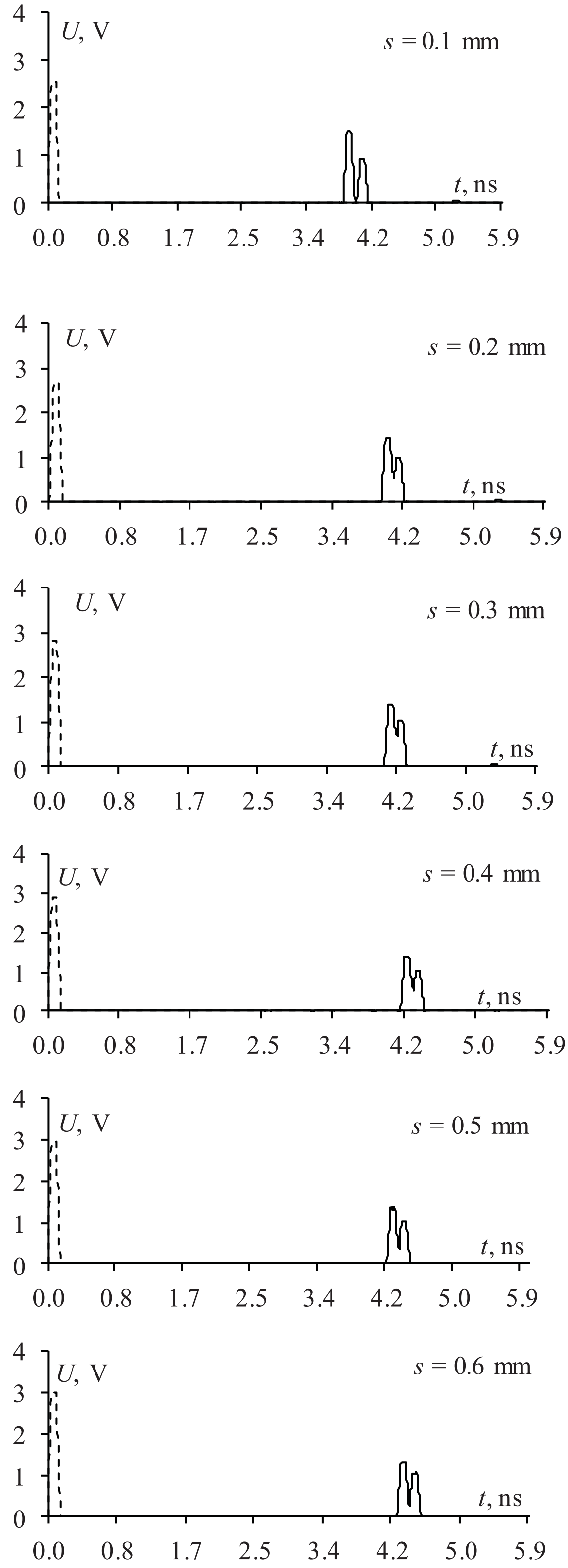


Fig. 5. Voltage waveforms at the input (- -) and output (—) when s=0.1–0.6 mm.

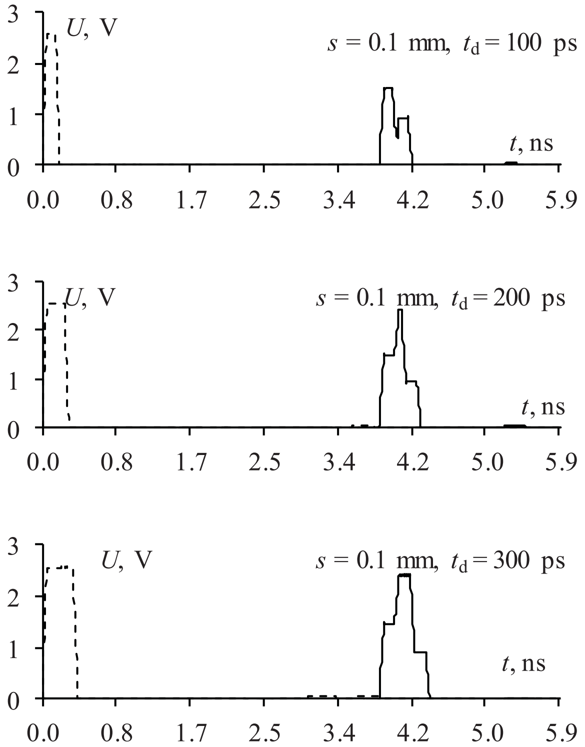


Fig. 6. Voltage waveforms at the input (- -) and output (—) when s = 0.1 mm, $h1$ = 0.1 mm and t_d = 100, 200, 300 ps.

V. CONCLUSION

A modal analysis of a MSL with polygons in the air has been performed. An estimate of the influence of parameter changes on the propagation characteristics has been performed using quasi-static simulation. For a more accurate assessment of sensitivity, the per-unit-length delays of the modes (τ_1, τ_2 τ_3), their eigenvectors and the time response of the investigated line for end-grounded case have been calculated. These results have been compared with the values of the per-unit-length delay (τ_0) for completely grounded case presented in work [8]. Comparing the results of the two cases, it can be noted that the difference in the values of τ reaches 15% and sensitivity changes considerably. As a result, pulse distortions are observed.

Thus, such a study is relevant for other lines presented in [8]. Particularly, their sensitivity to parameter variations can be completely estimated and compared for the both cases. Besides, similar study can reveal importance of complete polygon grounding for short pulse distortions.

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