Journal of Physics: Conference Series

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To cite this article: I Ye Sagiyeva and T R Gazizov 2018 *J. Phys.: Conf. Ser.* **1118** 012032

Modeling of microstrip line characteristics with side grounded conductors near air–substrate boundary

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Abstract. The modeling of the microstrip line with side grounded conductors located near air-substrate boundary is performed. The dependences of per-unit-length delay and the characteristic impedance on a distance between the grounded conductors are calculated with a change in the height above the boundary and the burying into the substrate. The change of the points of zero sensitivity of the per-unit-length delay to the position of the side grounding conductors over and under the air-substrate boundary is investigated. The possibility of obtaining a minimum (up to zero) sensitivity of the impedance to the height of the side grounding conductors near the air-substrate boundary is revealed.

1. Introduction

The electronics industry is one of the most important modern industries. The development of the electronics is impossible without improving its component base, in particular, interconnections based on transmission lines, which possess high reliability, speed, the stability of electrophysical parameters and characteristics that provide electromagnetic compatibility. For this, new design and technological solutions are needed, in particular, transmission lines with stable characteristics of per-unit-length delay (τ) and impedance (Z). Therefore, studies of these characteristics are relevant [1, 2].

One of the most widely used high-speed signal transmission lines is the microstrip line (MSL) [3]. An important task is to obtain stable line characteristics. In this regard, it is relevant to minimize the sensitivity of line characteristics to changing of the line parameters. Meanwhile, the possibilities of such minimization are limited by the simplicity of the construction of the classical MSL. Therefore, various modifications of MSL, such as suspended and inverted microstrip lines, allowing obtaining zero sensitivity of τ and Z to change in the thickness of dielectric layers are considered [4]. In the multilayer printed circuit boards (PCBs) the varieties of MSLs, for example, MSL with polygons on different layers allowing obtaining a stable value of the τ, are used [5]. Similar possibilities are revealed in MSL with side grounded conductors located over the substrate [6] and buried in the substrate [7]. A detailed analysis of modes and dispersion in such a line and its varieties is known [8]. The possibility of minimizing the sensitivity arises from the redistribution of the electric field in the layers of air and substrate. It was also revealed that the side grounded conductors influence specially near the air-substrate boundary. Therefore, it is useful to study in more detail the characteristics of MSL with side grounded conductors located near the air-substrate boundary.

The aim of this paper is to investigate for the MSL the dependence of τ and Z on the distance between the side grounded conductors located near the air-substrate boundary.

Investigation of microstrip structure characteristics, especially in the first stage, is advisable to perform through modeling, as it is less costly and may be more accurate than measurements. Two types of MSL are considered (Figure 1). Strict full-wave analysis of fields in the investigated lines is rather complicated. The parameters of the dielectric filling medium in the lines are nonhomogeneous over the cross-section so that only a part of the field is concentrated in the dielectric substrate, and the rest is in the air. Therefore, not pure TEM-mode but quasi-TEM-mode propagates in the lines. Nevertheless, for such lines, one can apply the quasi-static analysis based on the calculation of the per-unit-length capacitance.

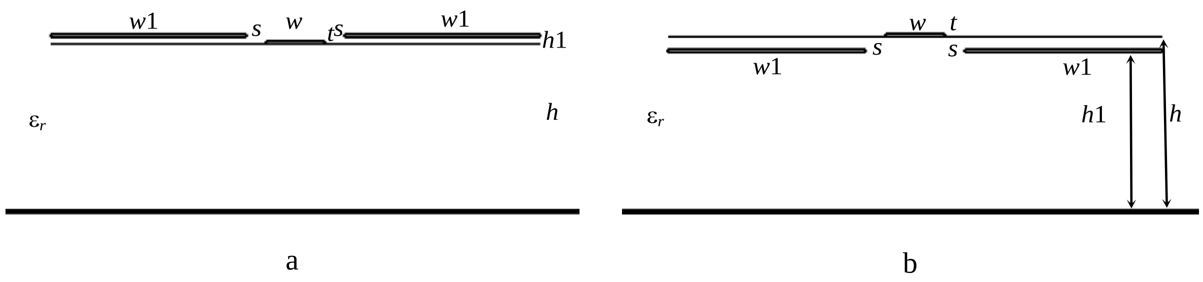


Figure 1. Cross-sections of MSLs with side grounded conductors:
a – over boundary; b – under boundary.

2. Modeling a line

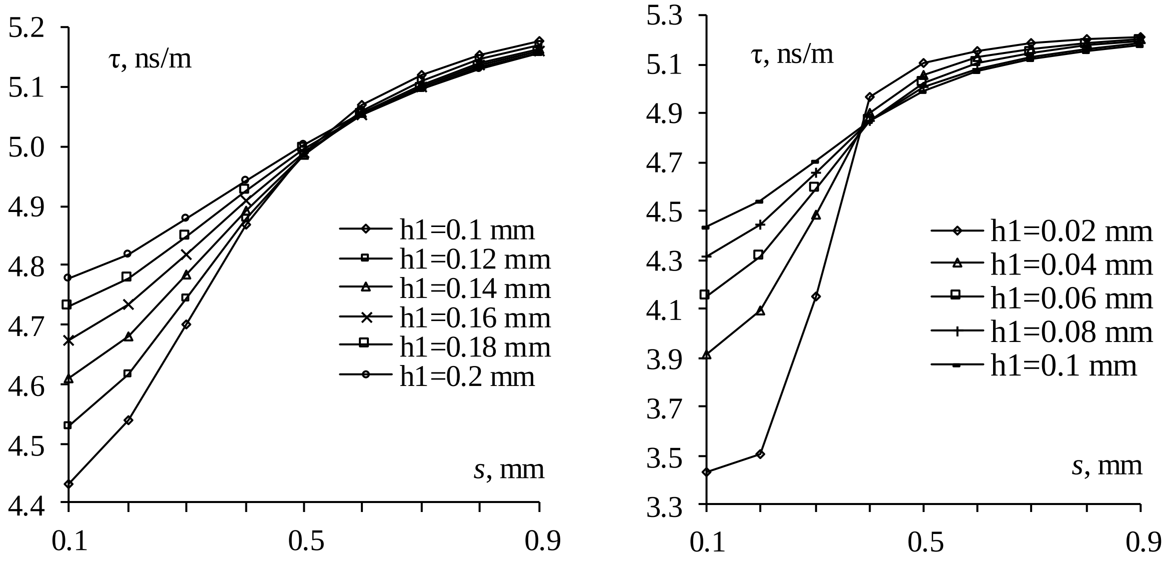
In the TALGAT [9, 10] software the geometric model of the line cross-section (Figure 1) are built and the matrixes (3*3) of per-unit-length coefficients of electrostatic induction, taking into account the dielectric and without it, are calculated. The values of some of parameters were chosen typical and did not change: the thickness of the signal and ground conductors t=18 μm, the thickness of the substrate h=1 mm, the relative dielectric constant of the substrate ε_r=4.5. From the matrices, the values (denoted below C and C_0) of the diagonal entry corresponding to the signal conductor were taken, and the values of τ and Z were calculated (v_0 is the speed of light in vacuum):

$$\tau=(C/C_0)^{0,5}/v_0,\ \ Z=1/(v_0(CC_0)^{0,5}).$$

The values of τ and Z are calculated with a change in the distance ($2s+w$) between the side conductors located near the air-substrate boundary. For clarity, the results are given for consequent lowering the grounded conductors in air to the boundary and burying in to the substrate. Figures 2 a and 3 a show the results for Figure 1 a with decreasing $h1$ from 0.2 mm to 0.1 mm [6], while Figures 2 b and 3 b a show from 0.1 mm to 0.02 mm. Figures 4 a and 5 a show the results for Figure 1 b with a decrease in $h1$ from 0.9 mm to 0.8 mm [7], and in Figures 4 b and 5 b from 0.98 mm to 0.91 mm. The behavior of the graphs from [6, 7] has been described in detail in these papers. Therefore, only the differences in the newly obtained dependencies are considered here.

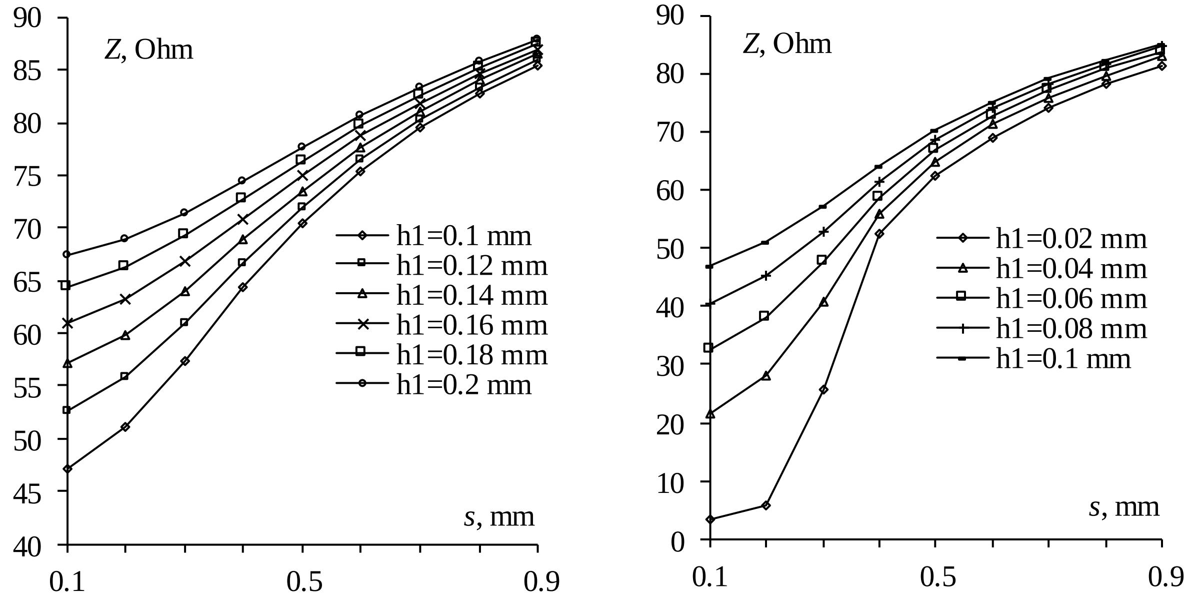
Comparison of Figures 2 a and 2 b shows increasing influence of the grounded conductors expressed in significant decreasing value of τ for small values of s. In addition, the dependence itself becomes sharper, and the point of zero sensitivity of τ to the change of $h1$ shifts from the value *s*=0.4 mm to *s*=0.5 mm. With regard to the values of *Z* in Figure 3 b, they decrease significantly with decreasing *h*1.

When the side grounded conductors are buried into the substrate, the values of τ do not decrease, but increase (to 6.9 ns/m) as the value of *s* decreases. Comparison of Figures 4 a and 4 b show that as the air-substrate boundary is approached, the increase in the value of τ becomes sharper, and the point of zero sensitivity of the τ to the change of the *h*1 shifts from the value *s*=0.4 mm to *s*=0.3 mm. With regard to the values of *Z* in Figure 5 b, they decrease with increasing *h*1 (up to 1 Ohm at *s*=0.1 mm). However, at *s*=0.4–0.9 mm, the sensitivity of *Z* to the change in *h*1 becomes minimal and even zero. Moreover, the point of zero sensitivity shifts to smaller values of *s* with increasing value of *h*1. It is representative active to show the dependences of the τ on *s* for both structures under study on a single graph (Figure 6). It can be seen that there is a position of the side grounded conductors relative to the air-substrate boundary, at which the sensitivity of the τ to the change of the *s* can be minimal, down to zero. Such behavior of the dependencies can by explained by changing of ratio of broad-side and edge coupling of conductors across air–substrate boundary. However, to obtain modeling results that support this conclusion, it is necessary to build geometric models of three other structures, which is beyond the scope of this paper.



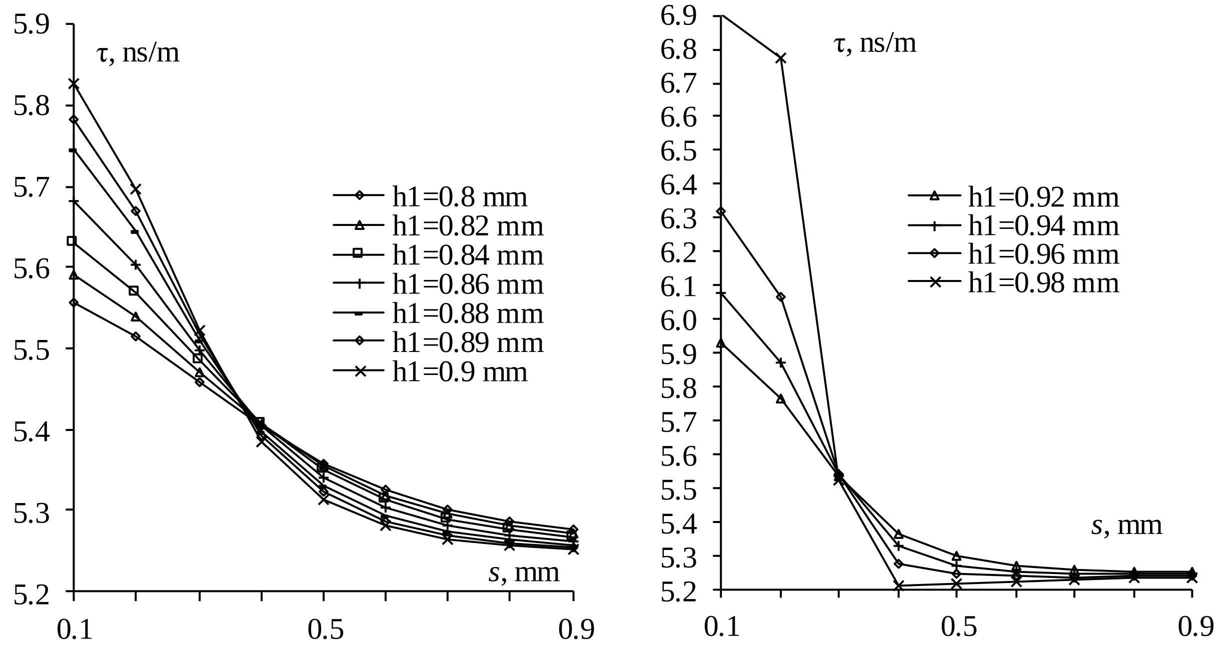
a b

Figure 2. Dependences of τ on *h*1 for MSL with side grounded conductors above when changing *h*1: a – from 0.2 mm to 0.1 mm [6]; b – from 0.1 mm to 0.02 mm.



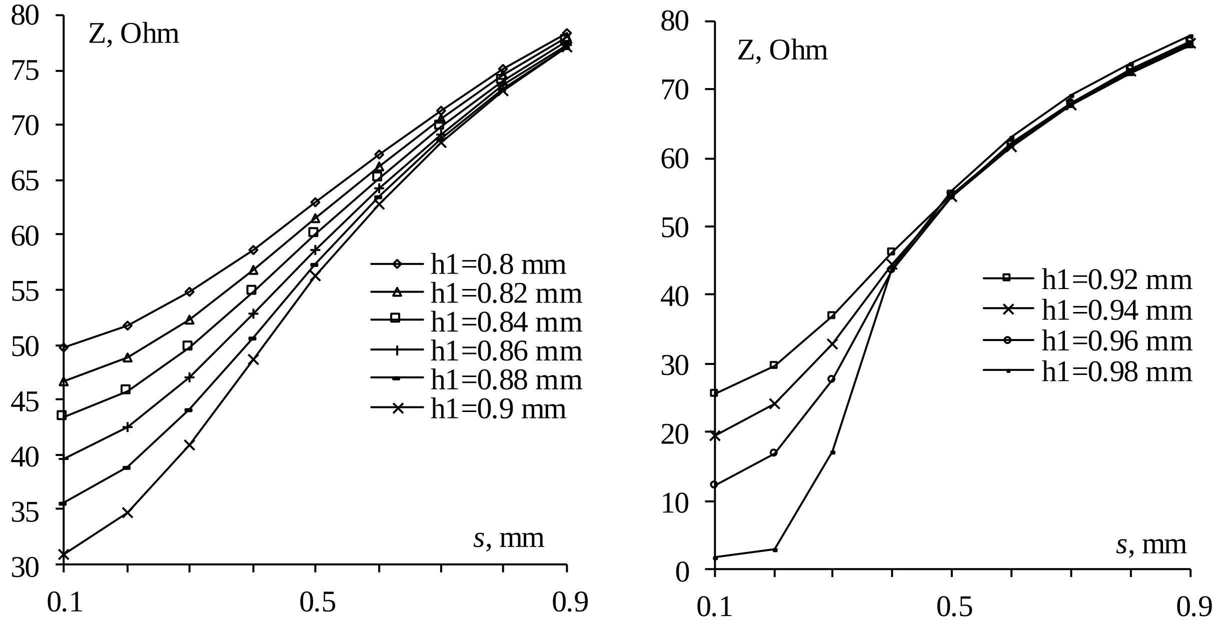
a b

Figure 3. Dependences of *Z* on *h*1 for MSL with side grounded conductors above when changing *h*1: a – from 0.2 mm to 0.1 mm [6]; b – from 0.1 mm to 0.02 mm.



a b

Figure 4. Dependences of τ on *h*1 for MSL with side grounded conductors buried in substrate when changing *h*1: a – from 0.8 mm to 0.9 mm [7]; b – from 0.91 mm to 0.98 mm.



a b

Figure 5. Dependences of *Z* on *h*1 for MSL with side grounded conductors buried in substrate when changing *h*1: a – from 0.8 mm to 0.9 mm [7]; b – from 0.91 mm to 0.98 mm.

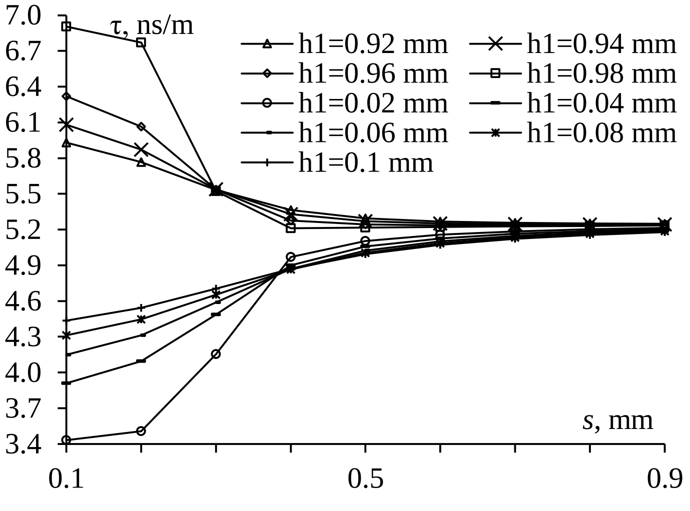


Figure 6. Dependences of τ on *h*1 for MSL with side grounded conductors near air-substrate boundary (for both structures of Figure 1)

3. Conclusion

The modeling of the microstrip line with side grounded conductors located near air-substrate boundary is performed. The dependences of per-unit-length delay and the characteristic impedance on a distance between the grounded conductors are calculated with a change in the height above the boundary and the burying into the substrate. The change of the points of zero sensitivity of the per-unit-length delay to the position of the side grounding conductors over and under the air-substrate boundary is investigated. The possibility of obtaining a minimum (up to zero) sensitivity of the impedance to the height of the side grounding conductors near the air-substrate boundary is revealed.

These results are obtained for specific values of the line parameters. However, it is easy to obtain similar dependencies for other values of the parameters. The results of this paper can be used to design transmission lines with stable characteristics.

4. Acknowledgments

This research was supported by The Ministry of Education and Science of the Russian Federation (project no. 8.9562.2017/8.9).

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