Symmetrical slot line with a dielectric insert in the slot

S B Klyuev¹, E I Nefyodov² and A A Potapov³,⁴,⁵,⁶

¹RPC «Istok», 2A, Vokzalnaya Str., Fryazino, Moscow Region 141190, Russia
²Fryazino branch of Kotel'nikov institute of radio engineering and electronics of RAS, 1, Vvedenskiy Sq., Fryazino, Moscow Region, 141195, Russia
³Kotel'nikov institute of radio engineering and electronics of RAS, 11, Mokhovaya St., Moscow 125009, Russia
⁴Jinan University (JNU), College of Information Science and Technology / College of Cyber Security, Guangzhou, 510632, China
⁵Cooperative Chinese-Russian Laboratory of Informational Technologies and Signals Fractal Processing, Guangzhou, 510632, China
⁶E-mail: potapov@cplire.ru

Abstract. The electrodynamic properties of a symmetric slot line with a dielectric insert are investigated. A numerical analysis of the transmission line is performed using the finite element method. The dispersion matrix elements of the transmission line are presented. It is shown that the model of a symmetric slot line with a dielectric insert can extend the operating frequency band more than 2 times.

1. Introduction

Nowadays the designing of microwave devices and systems is determined by a number of trends. One of them is an intensive mastering of millimeter (or EHF) range of wavelengths, for instance, in search of new applications of microwave engineering. Another one is the development of the element base of microwave and EHF equipment which should solve the problem of integrating devices using group technology methods (when all or most part of the product must be implemented in a single technological cycle) allowing the realization of all component parts including the antenna and beam-forming circuits, etc. as a single integrated circuit.

The aim of the paper is to provide physical, mathematical and technical basis for the engineering design of wide-band slot integrated circuits (ICs) of microwave and EHF bands. To achieve this aim the following objections were solved: creation of a slot line transmission design to use in a wide operating frequency band, the use of effective designing methods for calculating the slot transmission line, the study of the most typical physical phenomena of electromagnetic processes in the transmission line. Slot ICs are ICs based on a number of basic transmission lines, the most important of which is a symmetrical slot line (SSL).

Today the parameters of any of the classical (slot, symmetrical strip line, symmetrical coplanar) lines can be calculated using empirical formula, if the geometric dimensions of the line are known [1, 2]. Unfortunately, any change in the fundamentals of the geometry of the line and its symmetry leads to the revision of the methods and techniques.
2. Problem statement. Model. Method of analysis
In this paper we propose the option of extending the operating frequency band for SSL by placing a dielectric insert in the slot with $\varepsilon_{r2}$ exceeding the value of $\varepsilon_{r1}$.

The classical SSL model (figure 1) is an open guided structure with a narrow slot or a gap in a thin conducting layer made on one side of a dielectric substrate.

When using a slot line as a microwave transmission line, radiation should be minimal. This is achieved by using substrates with a high dielectric constant, which results in substantial decrease of the wavelength $\lambda_w$ in the slot compared to the wavelength $\lambda_0$ in free space and provides the concentration of field lines near the slot with negligible radiation losses.

![Figure 1. Symmetric slot line:](image)

*a* – cross-section of line, where 1- dielectric substrate with $\varepsilon_{r1}$; 2 – metal screens

*b* – distribution of the transverse electric field of the fundamental mode of the transmission line.

An electromagnetic wave propagating along the slot has an elliptical polarization of the magnetic field so it can be used, for example, to build non-reciprocal devices. In the symmetrical slot line one part of the electric field is in the air, the other part is in the dielectric substrate (figure 1b). As the wave in the slot line differs from the TEM-wave, its characteristic impedance $Z_0$ and phase velocity $v_{ph}$ are not constant but variable with frequency. This is how the slot lines differ from microstrip lines with quasi-TEM wave where $Z_0$ and $v_{ph}$ do not depend on frequency at a first approximation.

The finite element method was chosen as a calculation method.

![Figure 2. Cross-section of symmetric slot line:](image)

$h$ – thickness of dielectric substrate with $\varepsilon_{r1}$; $t$ – thickness of metal screens; $w$ – slot width.

The first step towards the implementation of the objective – determining the possibility of expanding the operating frequency band – was to consider a classic SSL model (figure 2). The slot width $w$ and the thickness of metal screens $t$ remained constant when performing calculations. After the calculations of the SSL model the geometrical dimensions of its dielectric substrate were determined and later on the value of the bandwidth of operating frequencies was also determined. Figure 3 shows the main SSL parameters: scattering matrix and characteristic impedance versus geometric dimensions of the line, dielectric substrate $\varepsilon_{r1}$ and frequency.

The model with the obtained calculated data was used as the basis for solving the problem in question: the expansion of the SSL operating frequency band. It should be noted that at frequencies above 160 GHz the SSL principal wave (figure 1b) with geometrical dimensions of figure 3 becomes the second mode and the TEM wave becomes the principal one.
Next, the dielectric inserts with their different positions on the substrate were inserted into the slot between the metal screens in SSL design. The versions of SSLs with dielectric inserts (SSLDI) considered in the work are presented in figure 4. For these models only the behavior of the principal SSL wave was considered depending on the position of dielectric inserts on the substrate of the guiding structure.

Figure 4. The versions of the symmetric slot line:
   a) the dielectric insert is placed on the substrate,
   b) the dielectric insert is placed into the recess of the substrate,
   c) the dielectric insert is placed onto the substrate pedestal.

As a result of SSLDI numerical simulation the best parameters were obtained for the transmission line with the dielectric insert on the substrate shown in figure 4a.

Figure 5 shows SSLDI model based on which further calculations were carried out. To obtain the maximum possible bandwidth of operating frequencies the dielectric constant of the insert was changed.
As a result of numerical calculations the dependencies of the scattering matrix and the characteristic impedance of SSLDI models shown in figure 6 were obtained. It should be noted that as in case of the classical SSL the slot wave is no longer the principal one for SSLDI (curve 5) at the frequencies above 160 GHz. Geometrical dimensions and SSLDI frequency band at which the calculation was conducted had the following values: \( h/t_1 = 1.25; \ t/t_1 = 1.25; \ w/h = 3.2 \) and \( f = 6 \div 200 \) GHz.

\[ S_{21}, \text{ дБ} \]

\[ Z_{pi}, \text{ Ом} \]

\[ S_{11}, \text{ дБ} \]

**Figure 5.** Cross-section of symmetric slot line with a dielectric insert (SSLDI):
- \( h \) – thickness of dielectric substrate;
- \( t \) – thickness of metal screens;
- \( h_1 \) – thickness of a dielectric insert in the slot, \( w \) – slot width.

**Figure 6.** Dependencies of SSLDI parameters of the scattering matrix and characteristic impedance with \( \frac{w}{h} = 3.2; \ \frac{t}{h} = 0.8; \ \frac{t_1}{h} = 0.64 \):
- \( a \) transmission coefficient,
- \( b \) reflection coefficient,
- \( c \) characteristic impedance

where 1 – SSL without dielectric insert with \( \varepsilon_r \) = 9.8;
2 - SSLDI with \( \frac{\varepsilon_r}{\varepsilon_{r1}} = 0.57 \);
3 - SSLDI with \( \frac{\varepsilon_r}{\varepsilon_{r1}} = 0.55 \);
4 - SSLDI with \( \frac{\varepsilon_r}{\varepsilon_{r2}} = 0.46 \);
5 - SSLDI with \( \frac{\varepsilon_r}{\varepsilon_{r2}} = 0.32 \).

The numerical results of SSLDI model calculations are shown in figure 6. Comparing the results of calculations of SSL and SSLDI shown in figures 3 a, b and figure 6, it is evident that a line with a significantly larger band of operating frequencies can be obtained due to the dielectric insert used in
SSL. The value of SSLDI operating frequency band exceeds the value of SSL operating frequency band more than twice.

3. Conclusion
The main advantages of the symmetrical slot line with a dielectric insert are the simplicity of manufacturing, low losses, suitable mounting of discrete elements, as well as broadbandness which is not achievable for other types of integrated waveguides.

The obtained data indicate the large possibilities of using this type of lines for building wideband and super wideband microwave devices.

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