Influence Coefficients of Constructive Parameters of Meander Slow-Wave System with Additional Shields

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Abstract – **Constructions of meander slow-wave systems with additional shields grounded at different positions are presented. The construction of meander slow-wave systems with additional shields grounded at both edges is investigated in detail. The influence of the main constructive parameters on the electrical characteristics of meander slow-wave systems with additional shields grounded at both edges is evaluated. The main constructive parameters of the investigated system are: the length of the conductor, the width of meander conductor, the width of additional shield, and the width of the gap between adjacent meander conductors.**

Sonnet® software package, which is based on the method of moments, has been used during the investigation. The results of the influence of constructive parameters to the phase delay time, input impedance, and the width of pass-band of the system are discussed.

Keywords – **Delay lines; Meander structures; Microwave devices; Parametric synthesis.**

I. INTRODUCTION

Modern microwave devices, including meander systems, are designed using computer-aided design systems in nowadays. Meander systems are widely used in the applications of wireless communication systems and antennas [1]–[3], biomedical field [4], [5], filter production [6]–[8], couplers and in-phase inverters [9], [10], slow-wave systems (SSs) [11]–[15], and traveling waves tubes [16]–[18].

A designer synthesizes an initial variant of the meander SS by applying his experience and synthesis techniques. The calculated characteristics of the meander SS are compared with technical requirements during the procedure of analysis. The parameters of the system are configured, and the procedure of analysis is repeated again if the comparison results are not satisfied. The last two procedures are referred to as the optimization of the meander SS [19].

The above-discussed automated design is called parame-tric synthesis [20]. The sensitivity of the changes in the parameters of the system must be analyzed before determining the changes in order to facilitate the process of synthesis, the analysis and optimization of the computer-aided design. Otherwise, the accuracy may be lost, and parametric synthesis will not benefit but will absorb the valuable study time.

Artificial neural networks are applied in such kind of tasks in recent years for the modelling of filters [21]–[23], antennas [24], [25], and for the analysis of signals [26], [27]. The use of neural networks can help to resolve the accuracy and time-consumption problems.

In order to properly synthesize the construction of meander slow-wave system with desirable electrical characteristics, the influence of the main constructive parameters on its electrical characteristics of meander slow-wave system is investigated in this article.

II. MODEL OF MEANDER SLOW-WAVE SYSTEMS WITH ADDITIONAL SHIELDS

The main electrical characteristics of the meander SS are as follows: the width ΔF of pass-band, phase delay time t_d, and characteristic impedance Z_C. In general, these characteristics (except ΔF) are determined or calculated in low-frequency domain. The monograph [18] states that the characteristic impedance Z_C and the input impedance Z_{IN} are the same in homogenous dielectric and differ very little in inhomogeneous dielectric of meander SS with additional shields; therefore, the term "input impedance Z_{IN}" will be used further in the text.

The main constructive parameters of meander SS with additional shields are (Fig. 1): the thickness h and the relative permittivity ε_r of dielectric substrate, the length $2A$ and the width w_1 of one meander conductor strip, the width w_2 of additional shield, and the width s of gap between adjacent strips [28].
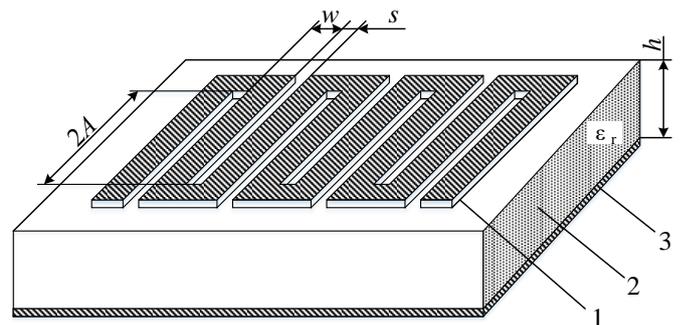
Fig. 1. Meander slow-wave system: 1 – meander-shape conductor; 2 – dielectric substrate of relative permittivity ε_r; 3 – external shield [19].

The influence of constructive parameters is not the same to different electrical characteristics of the meander SS with additional shields. Therefore, in order to achieve optimal results of synthesis it is necessary to investigate the influence of the main constructive parameter to the electrical characteristics of the meander SSs with additional shields. The results of investigation will allow improving the algorithms of the parametric synthesis of such systems. The parametric synthesis of meander SSs with additional shields is a part of

the process of computer-aided design during which constructive parameters are changed in order to get the desired electrical output characteristics of the system.

Four models of meander SSs with additional shields grounded at different positions are investigated (Fig. 2).

(a)

(b)

(c)

(d)

(e)
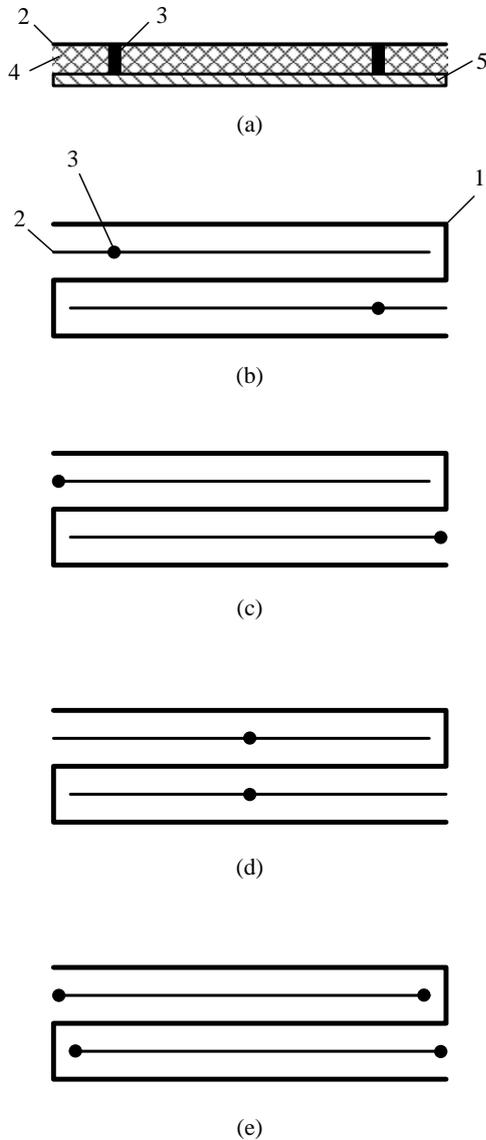
Fig. 2. (a) cross-section and the top views of meander slow-wave system when grounded via positioned at: (b) – the point between the edge and the center (like in cross-section view); (c) – one edge; (d) – center; (e) – both edges; 1 – meander-shape conductor; 2 – additional shield; 3 – grounded via; 4 – dielectric substrate; 5 – grounded external shield.

The model of meander SSs with additional shields grounded at both edges (Fig. 2e) is discussed in detail and is used in the numerical experiment.

The more detailed fragment of the topology of meander slow-wave systems with additional shields grounded at both edges is presented in Fig. 3. The initial dimensions of the analyzed system are: $2A = 20$ mm; $w_1 = 0.5$ mm; $w_2 = 0.25$ mm; $s = 0.65$ mm; $\varepsilon_r = 7.3$; and $h = 0.5$ mm.
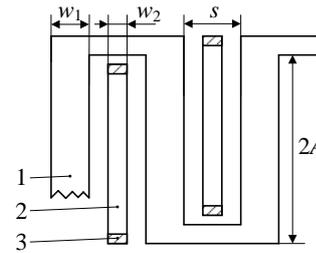
Fig. 3. The fragment of the topology of meander slow-wave system with additional shields grounded at both edges, where $2A = 20$ mm; $w_1 = 0.5$ mm; $w_2 = 0.25$ mm; $s = 0.65$ mm; $\varepsilon_r = 7.3$; $h = 0.5$ mm.

The evaluation of the influence of constructive parameters to delay time, input impedance and the width of the pass-band of meander slow-wave systems with additional shields is possible with determination of impact coefficients. The influence of the particular constructive parameter can be represented by formula

$$S = (\Delta p/p_0)/(\Delta d/d), \qquad (1)$$

where

Δp – the variation of the electrical characteristic of meander slow-wave system;

p_0 – the value of the electrical characteristic of meander slow-wave system with initial constructive parameters;

Δd – the change of selected constructive parameter;

d – the initial value of the constructive parameter or meander slow-wave system with additional shields grounded at both edges.

Constructive parameters were reduced by 1 % during the investigation and the determination of impact coefficients. For example, the change in phase delay time, which results from the reduction in the length $2A$ of the strip of the meander conductor from 20 mm to 19.8 mm, is shown in Fig. 4.

The value of the phase delay time decreases when the length $2A$ of the strip is reduced by 1 % (Fig. 4). Therefore, it is possible to calculate the impact coefficient of the constructive parameter $2A$ using the expression (1) after setting a change Δt_d of the phase delay time in the lower frequencies.
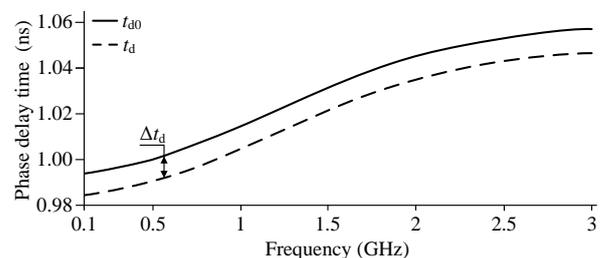
Fig. 4. Change in phase delay time when the length of a meander conductor is changed by one percent.

The calculation of the impact coefficients of the constructive parameters of meander slow-wave systems with additional shields grounded at both edges is provided in the next sections.

As well as the sensitivity of the phase delay time, the input impedance and the width of pass-band are evaluated to the changes in constructive parameters. Sonnet® software package, which is based on the method of moments, has been used during the investigation [29].

III. INFLUENCE OF CONSTRUCTIVE PARAMETERS TO THE PHASE DELAY TIME OF THE SYSTEM

The results of the sensitivity investigation of phase delay time because of the changes in the length $2A$ or the width w_1 of the conductor of meander slow-wave system with additional shields grounded at both edges are presented in Fig. 5.
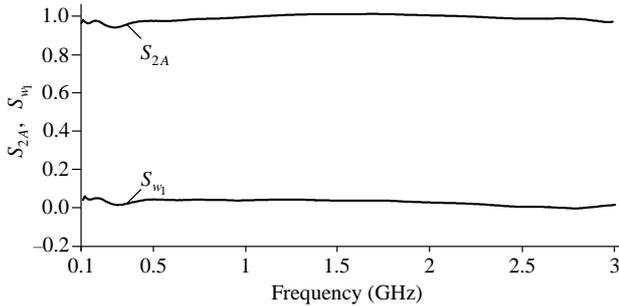
Fig. 5. Impact coefficients on the phase delay time of a system when changing: the length $2A$ of meander conductor, and the width w_1 of meander conductor.

The values of impact coefficients versus frequency are presented when the length $2A$ and the width w_1 of a conductor are reduced by 1 %. The curves, which are presented in the graphs, show that the value of the phase delay time of the meander SS with additional shields grounded at both edges reduces by about 1 % when the conductor length $2A$ reduces by 1 %. Changing the width of the meander conductor has a much lower impact on the phase delay time of the system. The value of the phase delay time reduces just by 0.06 % when the width w_1 is reduced by 1 % in this case.

The values of impact coefficients versus frequency are presented in Fig. 6 when the width s of the gap between adjacent meander conductor strips is reduced by 1 % (Fig. 6a), the width w_2 of the additional shields of the meander slow-wave system with additional shields grounded at both edges is reduced by 1 % (Fig. 6b).

The value of phase delay time decreases by 0.07 % in the lower frequencies when the width of the gap between adjacent meander strips is reduced by 1 %. Meanwhile, the change in the width w_2 of additional shield has almost no impact on the phase delay time. The value of the impact coefficient is close to zero in lower frequencies in this case.

The results of the sensitivity investigation of phase delay time because of the changing parameters of the dielectric substrate of meander slow-wave system with additional shields are presented in Fig. 7. The impact coefficients of relative permittivity ε_r (Fig. 7a) and the thickness h of the dielectric substrate (Fig. 7b) are presented in Fig. 7.

It is clear from the graphs that changing the relative permittivity ε_r has a greater influence on the phase delay time. The phase delay time is reduced by about 0.5 % when ε_r is

reduced by 1 %. Meanwhile, the impact coefficient of the thickness h of dielectric substrate is negative. This means that the value of the phase delay time is increased by approximately 0.1 % when the thickness h is reduced by 1 %.

Summarizing the results it can be stated that the change in the length $2A$ of the conductor has the greatest impact on the phase delay time of the meander slow-wave system with additional shields earthed at both edges. A smaller impact is observed when changing the relative permittivity ε_r and the thickness h of dielectric substrate.

(a)

(b)
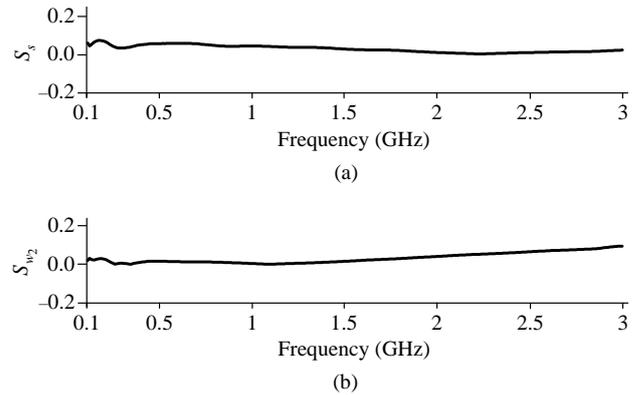
Fig. 6. Impact coefficients on the phase delay time of a system when changing: (a) the gap s between adjacent meander conductors; (b) the width w_2 of additional shield.
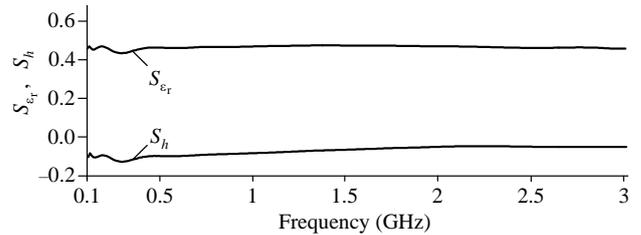
Fig. 7. Impact coefficients on the phase delay time of a system when changing: (a) the relative permittivity ε_r; (b) the height h of a dielectric substrate.

Meanwhile, the variation of the width w_1 of meander conductor, the width w_2 of additional shield, and the width s of the gap between adjacent meander conductors almost do not change the phase delay time. The length $2A$ of the meander conductor or the number of conductors, as well as the material of dielectric substrate must be changed in order to change the phase delay time.

IV. INFLUENCE OF CONSTRUCTIVE PARAMETERS TO THE INPUT IMPEDANCE OF THE SYSTEM

The investigation results of the sensitivity of input impedance to the changes in length $2A$ and the width w_1 of the conductor of meander slow-wave system with additional shields grounded at both edges are presented in Fig. 8. The values of impact coefficients versus frequency are shown when the length $2A$ (Fig. 8a) or the width w_1 (Fig. 8b) of the conductor are reduced by 1 %.

Impact coefficient is close to zero and the input impedance value is almost unchanged when the length $2A$ of the conductor is reduced by 1 % (Fig. 8, a). Changing the width of

the meander conductor has a greater impact on the input impedance of the system.

The value of the input impedance is reduced by 0.3 % in the lower frequencies when the width w_1 is reduced by 1 %. It is also appropriate that curves fluctuations occur in the higher frequencies. Curves fluctuations are caused by the incompatibility of the input impedance with the load resistance of the generator when the frequency increases.
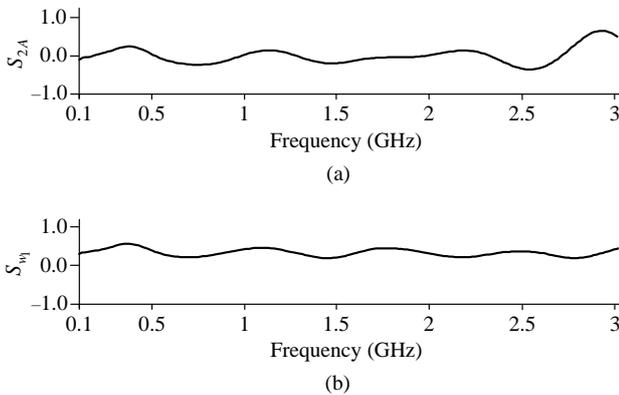
Fig. 8. Impact coefficients on the input impedance of a system when changing: (a) the length 2A of meander conductor; (b) the width w_1 of meander conductor.

The values of impact coefficients versus frequency are presented in Fig. 9 when the width s of the gap between adjacent meander conductors (Fig. 9a) and the width w_2 of additional shields of the meander slow-wave system with additional shields earthed at both edges (Fig. 9b) are reduced by 1 %.

The value of the input impedance is reduced by about 0.5 % in the lower frequencies when the width of the gap between adjacent meander conductors is reduced by 1 %. Meanwhile, changing the width w_2 of additional shield has a greater impact on the input impedance of the meander slow-wave system with additional shields earthed at both edges. The value of impact coefficient is close to one in the lower frequencies in this case; therefore, the input impedance of the system is reduced by about 1 % as well when w_2 is reduced by 1 %.

The investigation results of the sensitivity of the input impedance of the meander slow-wave system with additional shields earthed at both edges are presented in Fig. 9 when the parameters of dielectric substrate vary.

The impact coefficient of relative permittivity ε_r is presented in Fig. 10a, and the impact coefficient of the thickness h of the dielectric substrate of the meander SS with additional shields earthed at both edges is presented in Fig. 10b.

Changing the relative permittivity has a greater impact on the input impedance of the system (Fig. 10). The impact coefficient S acquires a negative value and the input impedance of the system increases by 0.5 % when ε_r reduces by 1 %. Meanwhile, the impact coefficient of the thickness h of the dielectric substrate is positive. This means that the value of the input impedance of the system is reduced by 0.2 % when thickness h is reduced by 1 %.

Summarizing the results it can be stated that the change in the width w_2 of additional shield has the greatest impact on the

input impedance Z_{IN} of the meander slow-wave system with additional shields earthed at both edges. A smaller impact is observed when changing the width s of the gap between adjacent meander conductors and the relative permittivity ε_r of dielectric substrate. The impact coefficients are even smaller and hardly reach 0.2–0.3 of other constructive parameters such as thickness h of the dielectric substrate and the width w_1 of meander conductors. Meanwhile, the variation of the length 2A of meander conductor does not change the input impedance Z_{IN} in the low frequencies. In addition, it should be noted that fluctuations are noticeable in the impact coefficients curves of input impedance during the variations of frequency.
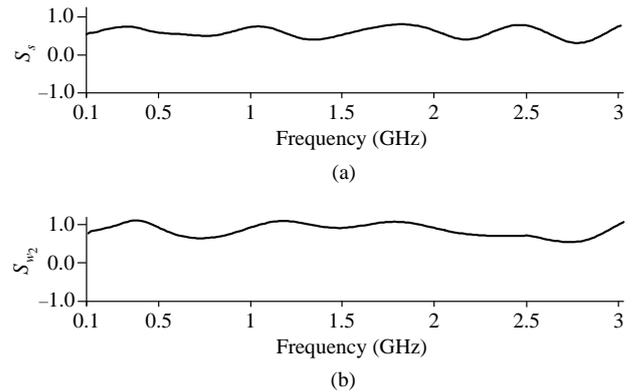
Fig. 9. Impact coefficients on the input impedance of a system when changing: (a) the gap s between adjacent meander conductors; (b) the width w_2 of additional shield.
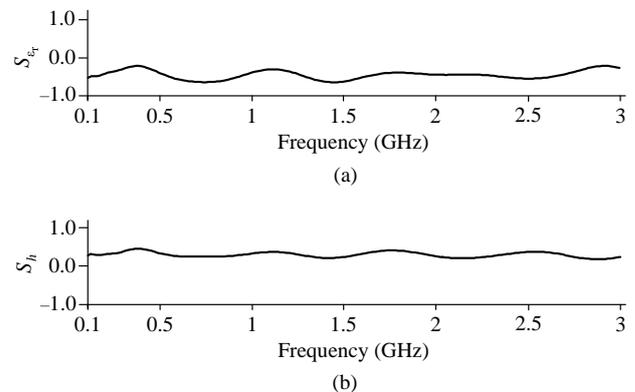
Fig. 10. Impact coefficients on the input impedance of a system when changing: (a) the relative permittivity ε_r; (b) the height h of a dielectric substrate.

Fluctuations occur due to the edges of the system, in which the size of the input impedance changes, and, therefore, inconsistency of signals tract arises.

V. Influence of Constructive Parameters to the Width of the Pass-Band

The survey results of the impact coefficients of constructive parameters to the phase delay time and the input impedance of meander slow-wave system with additional shields earthed at both edges are summarized in Table I.

The sensitivity of the width of pass-band depending on the change in constructive parameters expressed through the influence coefficients is also shown in Table I.

TABLE I

INFLUENCE OF THE CONSTRUCTIVE PARAMETERS OF MEANDER SLOW-WAVE SYSTEM WITH ADDITIONAL SHIELDS GROUNDED AT BOTH EDGES ON ITS ELECTRICAL PARAMETERS

Parameters of structure and topology	Impact coefficients when appropriate construction parameter decreases by 1 %		
Length $2A$ of meander conductor	0	1	–1.36
Width w_1 of meander conductor	0.3	0.06	–0.68
Width w_2 of additional shield	1	0	0
Width s of the gap between adjacent meander conductor	0.5	0.07	–0.68
Relative permittivity ε_r of dielectric substrate	–0.5	0.5	–1.36
Thickness h of dielectric substrate	0.2	–0.1	−0.68

Changes in the length $2A$ of meander conductor and the dielectric permittivity ε_r of substrate have the greatest impact on the width of the pass-band (Table I.). The width ΔF of the pass-band increases by about 1.36 % when these parameters are reduced by 1 %. Changes in the width w_1 of meander conductors, the width s of the gap between adjacent meander conductors and the thickness h of dielectric substrate have a significant impact on the width of the pass-band. The width ΔF of the pass-band increases by 0.68 % when these parameters are reduced by 1 %. Changing the width w_2 of additional shield does not affect the width of the pass-band.

VI. CONCLUSION

In summary it can be concluded that a certain electrical parameter of meander slow-wave systems with additional shields earthed at both edges depends on several constructive parameters. For example, the required values of the input impedance Z_{IN} can be obtained by changing the width s of the gap between adjacent conductors, the relative permittivity ε_r of substrate, or the width w_1 of meander conductor. The required value of the delay time can be obtained by changing the length $2A$ of the meander conductor or the parameters ε_r and h of the dielectric substrate.

However, not all of the above-mentioned parameters are changeable. Some constructive parameters could not be varied freely since the chosen technology of production limits their variation. These parameters are the thickness h and the relative permittivity ε_r of the dielectric substrate. The number of constructive parameters that can vary decline, and the process of synthesis becomes simpler in that case. Therefore, the basic parameters that vary during synthesis are the length $2A$ and the width w_1 of meander conductor, the width w_2 of additional shield, and the width s of the gap between adjacent strips of meander.

The algorithm of the synthesis of meander slow-wave systems with additional shields earthed at both edges can be realized when the influence of the constructive parameters to electrical characteristics is known.

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