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DETERMINATION OF THE TRANSMISSION LINE RESISTANCE MATRIX WITH DEVIATIONS OF DESIGN PARAMETERS FROM NOMINAL

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ABSTRACT

Context. UHF transmission systems make extensive use of transmission line segments, the characteristics of which have a significant impact on the performance of various information technologies. One of the problems of production of transmission lines is to obtain a given wave impedance, which significantly affects the electrical and information characteristics of the entire set of equipment. Currently, there is a burning issue of estimating the influence of disturbing factors on various electrical characteristics of long line segments. To date, the most fully developed methods for assessing the effect of disturbing factors on the wave impedance of a homogeneous line (the wave impedance is constant) under regular perturbations. In this case, the influence of perturbations on the reflection coefficient of matched lines was mainly considered. The effect of perturbations on the other characteristics of homogeneous and, especially, inhomogeneous lines has not been sufficiently studied.

Objective. The purpose of this paper is to determine the effect of wave impedance perturbations on the transmission line impedance matrix. Knowing the perturbed impedance matrix, it is possible to determine the distortion of the characteristics of any device built on transmission line segments.

Method. The paper uses the method of perturbation theory of linear differential operators applied to equations describing processes in inhomogeneous long lines.

Results. The obtained results make it possible to estimate the influence of regular and irregular perturbations of the wave resistance (wave conductance) on the transmission line matrix considered as a quadrupole. Such matrix can be any quadrupole matrix: resistance matrix, conductance matrix, circuit matrix. This makes it possible, according to the desired function of the circuit (gain, input impedance, reflection coefficient), to determine the allowable deviation of the wave impedance from the nominal value in order to select a tolerance for reproducing the wave impedance.

Conclusions. The proposed criterion for estimating line parameter deviations using the norm of the four-pole matrix is inherently an integral criterion and can be used to preliminarily estimate the frequency domain of the strongest distortions, regardless of the functional purpose of the transmission line segment. The developed approach is applicable to both homogeneous and heterogeneous transmission lines and covers both regular and irregular wave impedance perturbations.

KEYWORDS: transmission line, wave impedance, disturbance, impedance matrix, quadrupole, inhomogeneous line, reflection coefficient.

ABBREVIATIONS

UHF – ultrahigh frequencies.

NOMENCLATURE

W – impedance,

τ – current delay time;

$t_з$ – line delay time;

Γ – line reflection coefficient;

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$\widetilde{\Gamma}$ – the reflection coefficient of a line with perturbed impedance;

$\bar{u}$, $\bar{i}$ – respectively, the Laplace image of voltage and current in the line;

z_{in} , y_{in} – respectively, the input resistance and conductivity;

p – complex frequency variable;

$Y_0(\tau)$ – wave conductivity;

A, B – constant integrations;

$\Delta Y_0(\tau)$, $\Delta W_0(\tau)$ – respectively, a technological error in the implementation of wave conductivity and impedance;

$[z], [\widetilde{z}]$ – matrices of line resistances in accordance with the nominal and perturbed impedance;

H0 – the relative change in the norm of the matrix of the system of parameters of the quadrupole.

INTRODUCTION

In line production, due to imperfections in measuring tools and all kinds of technological inaccuracies, there is always an error in the realization of the wave impedance. $W(\tau)$ (τ – current delay time, $t_з$ – line delay time). In addition, for a number of designs the wave impedance has been determined with some error. Thus, errors in reproducing the required wave impedance, affecting the electrical parameters of the transmission line: input impedance, transfer functions, reflection coefficient, etc., inevitably occur during line fabrication. Obviously, the perturbation can be estimated from the change in parameters specific to the problem to be solved. For example, when considering negotiated transitions, the perturbation criterion could be $\left\| \widetilde{\Gamma} \right| - \left| \Gamma \right\|$, where $\left| \widetilde{\Gamma} \right|$, $\left| \Gamma \right|$ – the modulus of the reflection coefficient of the line with perturbed and undisturbed impedance, respectively. When considering the range resonators, we can compare the overlap coefficient in frequency and load. When designing filters, it is of interest to change the characteristics of the filter in the bandwidth and barrier, as well as the magnitude and direction of displacement of parasitic resonances. Thus, the choice of the criterion for assessing the impact of perturbation depends on the type of problem to be solved. Such criteria are partial.

A line is a linear system, the processes in it are described by a linear operator. Therefore, the question of the effect of small changes in impedance can be solved with the help of modern perturbation theory of linear operators. However, it is inconvenient to directly use the methods of this theory in solving problems of perturbed lines. This is due to the fact that the same segment of the line is usually used to solve a number of problems: to match how the resonators, filter elements and so on. Each of the above problems can be matched by one or more linear operators and for them to consider the perturbation problem. For example, if you take a filter containing three cascaded lines of line, then each of these segments on both sides will be loaded with different loads. Therefore, even with the same perturbations of the wave resistance of all three line segments, each of the segments will clearly correspond to its linear operator, since the boundary conditions for each of the three lines are different. Thus, in our example, one filter corresponds to three perturbation problems. You can describe the filter as a whole as a linear operator, but then the operator is quite complex and solve the problem of perturbation becomes almost impossible. From the above considerations, it is clear that in the general case, the direct use of methods of perturbation theory is unacceptable. From a practical point of view, it is necessary to have a method of accounting for perturbations, which would immediately answer the question of how much the parameters of the line will change when perturbation of the impedance, regardless of the type of problem (whether filtering, matching, etc.).

For this criterion, the article proposes to choose any matrix of four-pole, for example, a matrix of resistances. It is obvious that at perturbation of impedance the matrix of a line will change and then it is possible to define change of any characteristic of a line.

The aim of the article is to determine the effect of wave resistance perturbation on the resistance matrix of the transmission line. Knowing the perturbed resistance matrix, we can determine the distortion of an arbitrary line function as a quadrupole.

1 PROBLEM STATEMENT

Let an inhomogeneous line with a nominal characteristic impedance $W(\tau)$ have a resistance matrix $[z]$. Due to technological inaccuracies in the manufacture of the line, the characteristic impedance $\widetilde{W}(\tau) = W(\tau) + \Delta W(\tau)$, where $\Delta W(\tau)$ is the error (disturbance) in the implementation of the wave impedance. It is required to determine the resistance matrix $[\widetilde{z}]$ of the line with the disturbed characteristic impedance $\widetilde{W}(\tau)$ from the wave impedance $\Delta W(\tau)$, the matrix $[z]$, and the perturbation $\Delta W(\tau)$.

2 REVIEW OF THE LITERATURE

The question of influence of design parameter variation on electrical characteristics of transmission lines has become especially urgent at development of high-speed information transmission systems, for which it is necessary to develop new methods of calibration taking into account deviations of wave resistance from nominal value [1–7], statistical modelling W [8–11].

In particular, in the publication [9] the issues of the influence of regular and irregular deviations of the elements of line structures from the nominal values on the wave resistance are considered.

In the publication [10] the questions of methodology of calculation of electric parameters of lines of printed circuit boards of high-performance computing devices are considered. In these works, various methods of influencing existing technological processes on the parameters of

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the dielectric and the geometry of line conductors with a nominal constant wave resistance (homogeneous line) are considered. The influence of structural scatter on the reflection coefficient of transmission lines is analyzed.

The publication [11] considers the influence of technological errors on the output of suitable high-frequency devices on printed circuit boards. The method of calculation of tolerances on parameters of interconnections of printed circuit boards of high-speed units of digital information processing, forecasting of technological defect, algorithm of calculation of errors of impedance taking into account a scatter of geometrical sizes of conductors is offered. It is shown that with modern technologies for the manufacture of microstrip transmission lines, the deviations of the impedance within one layer of the multilayer substrate do not exceed 8%, and the total tolerance of the impedance as a whole is ± 10%.

The question of the influence of statistical perturbation on the wave resistance of an inhomogeneous line is devoted to works [12, 13], in which the authors propose to use the theory of Markov processes to estimate the statistical characteristics of wave resistance on the basis of which the probability density of wave resistance is determined *W*, the probability of not leaving the process *W* outside the given limits at a given standard deviation *W* (the percentage of suitable products).

3 MATERIALS AND METHODS

Consider the equation of inhomogeneous lines [14]

$$\bar{u}'' - \frac{W'}{W}\bar{u}' - p^2\bar{u} = 0;\ \bar{i}'' + \frac{W'}{W}\bar{i}' - p^2\bar{i} = 0. \qquad (1)$$

Then the input line resistance can be represented as

$$z_{in} = \frac{\bar{u}}{\bar{i}} = -\frac{1}{p}W\frac{\bar{i}'}{\bar{i}} = -pW\frac{\bar{u}}{\bar{u}'}. \qquad (2)$$

Similarly, you can write an expression for input conductivity

$$y_{in} = \frac{\bar{i}}{\bar{u}} = -pY_0\frac{\bar{i}}{\bar{i}'} = \frac{1}{p}Y_0\frac{\bar{u}'}{\bar{u}},\ Y_0 = \frac{1}{W}. \qquad (3)$$

Let $\bar{u}_1(\tau)$ – partial solution (1). Then the second partial solution can be represented as [15]

$$\bar{u}_2(\tau) = \bar{u}_1(\tau)\int\frac{\exp\left(\int\frac{W'}{W}d\tau\right)}{\bar{u}_1^{\,2}(\tau)}d\tau. \qquad (4)$$

Let's convert the exponential coefficient

$$\exp\left(\int\frac{W'(\tau)}{W(\tau)}d\tau\right) = \exp\left(\int\frac{d}{d\tau}\ln W(\tau)d\tau\right) = \\ = \exp\left(\int d\ln W(\tau)\right) = \exp\left(\ln W(\tau)\right) = W(\tau). \qquad (5)$$

We assume that the beginning of the line is at a point $\tau = 0$, and the edge is at a point $\tau = t_з$. Then a partial solution $\bar{u}_2(\tau)$ taking into account (5) can be written as a definite integral

$$\bar{u}_2(\tau) = \bar{u}_1(\tau)\int_0^{\tau}\frac{W(s)}{\bar{u}_1^{\,2}(s)}ds. \qquad (6)$$

Therefore, the general solution of equation (1)

$$\bar{u}(\tau) = A\bar{u}_1(\tau) + B\bar{u}_1(\tau)\int_0^{\tau}\frac{W(s)}{\bar{u}_1^{\,2}(s)}ds. \qquad (7)$$

Let us replace the wave resistance in the equation (1) with respect to the current with the wave conductivity $W(\tau) = 1/Y_0(\tau)$. Then

$$\frac{W'(\tau)}{W(\tau)} = -\frac{Y_0'(\tau)}{Y_0(\tau)} \qquad (8)$$

and the equation for the current will take the form

$$\bar{i}'' - \frac{Y_0'(\tau)}{Y_0(\tau)}\bar{i}' - p^2\bar{i} = 0. \qquad (9)$$

Equation (9) in appearance coincides with the equation for voltage (1). Therefore, its overall solution ($\bar{i}_1(\tau)$ – partial solution (9))

$$\bar{i}(\tau) = A\bar{i}_1(\tau) + B\bar{i}_1(\tau)\int_0^{\tau}\frac{Y_0(s)}{\bar{i}_1^{\,2}(s)}ds. \qquad (10)$$

Express the input resistance of the open line through the partial solution $\bar{i}_1(\tau)$, which satisfies the boundary conditions

$$\bar{i}_1(0) = 1,\ \bar{i}_1'(0) = 0. \qquad (11)$$

From (10) it follows $\bar{i}(0) = A$. So, the first derivative

$$\bar{i}'(\tau) = A\bar{i}_1'(\tau) + B\bar{i}_1'(\tau)\int_0^{\tau}\frac{Y_0(s)}{\bar{i}_1^{\,2}(s)}ds + B\bar{i}_1(\tau)\frac{Y_0(\tau)}{\bar{i}_1^{\,2}(\tau)}, \qquad (12)$$

where do we find $\bar{i}'(0) = BY_0(0)$.

Input line conductivity at points $\tau = 0$:

$$y_{вх}(0) = \frac{\bar{i}(0)}{\bar{u}(0)} = -pY_0(0)\frac{\bar{i}(0)}{\bar{i}'(0)} = -p\frac{A}{B}. \qquad (13)$$

Because when $\tau = t_з$ the line is open, then $\bar{i}(t_з) = 0$. Therefore, according to (10)

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$$\bar{i}(t_з) = 0 = \bar{i}_1(t_з)\left(A + B\int_0^{t_з} \frac{Y_0(s)}{\bar{i}_1^2(s)}ds\right). \quad (14)$$

Execution of equality $\bar{i}_1(t_з) = 0$ and conditions (11) are possible only at certain values p^2, which are eigenvalues of the boundary value problem under boundary conditions

$$\bar{i}_1(0) = 1, \ \bar{i}_1'(0) = 0, \ \bar{i}(t_з) = 0. \quad (15)$$

Therefore

$$\left(A + B\int_0^{t_з} \frac{Y_0(s)}{\bar{i}_1^2(s)}ds\right) = 0, \quad (16)$$

where

$$\frac{A}{B} = -\int_0^{t_з} \frac{Y_0(s)}{\bar{i}_1^2(s)}ds. \quad (17)$$

therefore,

$$y_{вх}(0) = -p\frac{A}{B} = p\int_0^{t_з} \frac{Y_0(s)}{\bar{i}_1^2(s)}ds. \quad (18)$$

The input resistance of the open line is an element z_{11} resistance matrix

$$z_{11} = \frac{1}{y_{вх}(0)} = \frac{1}{p\int_0^{t_з} \frac{Y_0(s)}{\bar{i}_1^2(s)}ds}. \quad (19)$$

The current equation (9) coincides in appearance with the voltage equation (1). Therefore, if we proceed from equation (1), we can immediately write the input resistance of the line closed at the point $\tau = t_з$:

$$z_{вх}(0) = -p\frac{A}{B} = p\int_0^{t_з} \frac{W(s)}{\bar{u}_1^2(s)}ds, \quad (20)$$

where $\bar{u}_1(\tau)$ – partial solution (1): $\bar{u}_1(0) = 1$, $\bar{u}_1'(0) = 0$. The element of the conductivity matrix of a closed line is equal to

$$y_{11} = \frac{1}{z_{вх}(0)} = \frac{1}{p\int_0^{t_з} \frac{W(s)}{\bar{u}_1^2(s)}ds}. \quad (21)$$

In deriving (20) it is taken into account that for a closed line the common solution satisfies the condition $\bar{u}(t_з) = 0$.

Let $Y_0(\tau), W_0(\tau)$ – nominal (calculated) values of wave conductivity and impedance $Y_0(\tau) = 1/W_0(\tau)$. Suppose that during the technological implementation of the line there was an error, as a result of which instead of the nominal wave conductivity $Y_0(\tau)$ realized wave conductivity $\tilde{Y}_0(\tau) = Y_0(\tau) + \Delta Y_0(\tau)$, where $\Delta Y_0(\tau)$ – technological error. Obviously, there is an error $\Delta W_0(\tau)$ in the implementation of impedance

$$\tilde{W}_0(\tau) = W_0(\tau) + \Delta W_0(\tau) = \frac{1}{\tilde{Y}_0(\tau)}. \quad (22)$$

From (22) we find

$$\tilde{W}_0(\tau) = W_0(\tau) + \Delta W_0(\tau) = \frac{1}{\tilde{Y}_0(\tau)} = \\ = \frac{1}{Y_0(\tau) + \Delta Y_0(\tau)} = \frac{W_0(\tau)}{1 + W_0(\tau)\Delta Y_0(\tau)}. \quad (23)$$

From here we find the impedance error

$$\Delta W_0(\tau) = -\frac{W_0^2(\tau)\Delta Y_0(\tau)}{1 + W_0(\tau)\Delta Y_0(\tau)}. \quad (24)$$

Let's estimate influence of an error of wave conductivity $\Delta Y_0(\tau)$ on the elements of the resistance matrix. We believe that the disturbance $\Delta Y_0(\tau)$ quite a few and, according to perturbation theory, an outraged decision $\tilde{\bar{i}}_1 \approx \bar{i}_1(\tau)$, $\tilde{\bar{u}}_1(\tau) \approx \bar{u}_1(\tau)$. Then the elements of the perturbed matrix

$$\tilde{z}_{11} = \frac{1}{p\int_0^{t_з} \frac{\tilde{Y}_0(s)}{\bar{i}_1^2(s)}ds} = \frac{1}{p\int_0^{t_з} \frac{Y_0(s)}{\bar{i}_1^2(s)}ds + p\int_0^{t_з} \frac{\Delta Y_0(s)}{\bar{i}_1^2(s)}ds}, \quad (25)$$

$$\tilde{z}_{22} = \frac{1}{p\int_0^{t_з} \frac{\tilde{Y}_0(s)}{f_1^2(s)}ds}, \ s = t_з - \tau, \quad (26)$$

$$\tilde{z}_{кз} = p\int_0^{t_з} \frac{W(s)}{\bar{u}_1^2(s)}ds + p\int_0^{t_з} \frac{\Delta W(s)}{\bar{u}_1^2(s)}ds = z_{кз} + p\int_0^{t_з} \frac{\Delta W(s)}{\bar{u}_1^2(s)}ds, \quad (27)$$

where $z_{кз}$ – resistance of undisturbed closed line, $f_1(\tau)$ – solving the equation

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$$f_1''(\tau)+\frac{Y_0'(t_3-\tau)}{Y_0(t_3-\tau)}f_1'(\tau)-p^2 f_1(\tau)=0,\ s=t_з-\tau. \quad (28)$$

under extreme conditions $f_1(0)=1,\ f_1'(0)=0.$

Enter the notation

$$\alpha_{11}=p\int_0^{t_з}\frac{Y_0(s)}{\bar{i}_1^2(s)}ds,\ \beta_{11}=p\int_0^{t_з}\frac{\Delta Y_0(s)}{\bar{i}_1^2(s)}ds. \quad (29)$$

Then

$$\tilde{z}_{11}=\frac{1}{\alpha_{11}+\beta_{11}}=\frac{1}{\alpha_{11}}-\frac{\beta_{11}}{\alpha_{11}(\alpha_{11}+\beta_{11})}=z_{11}+z_{11}\frac{-\beta_{11}}{\alpha_{11}+\beta_{11}}. \quad (30)$$

We find similarly

$$\tilde{z}_{22}=\frac{1}{\alpha_{22}+\beta_{22}},\alpha_{22}=p\int_0^{t_з}\frac{Y_0(s)}{f_1^2(s)}ds, \beta_{22}=p\int_0^{t_з}\frac{\Delta Y_0(s)}{f_1^2(s)}ds. \quad (31)$$

Marking

$$\Delta z_{11}=z_{11}\frac{-\beta_{11}}{\alpha_{11}+\beta_{11}},\ \Delta z_{22}\frac{-\beta_{22}}{\alpha_{22}+\beta_{22}},$$
$$\Delta z_{кз}=p\int_0^{t_з}\frac{\Delta W(s)}{\bar{u}_1^2(s)}ds, \quad (32)$$

we will receive

$$\tilde{z}_{12}^2=\tilde{z}_{22}(\tilde{z}_{11}-\tilde{z}_{кз})=(z_{22}+\Delta z_{22})(z_{11}+\Delta z_{11}-z_{кз}-\Delta z_{кз}). \quad (33)$$

Opening the brackets, write

$$\tilde{z}_{12}^2=z_{22}(\Delta z_{11}-\Delta z_{кз})+\Delta z_{22}(\tilde{z}_{11}-\tilde{z}_{кз}). \quad (34)$$

Thus, the matrix of line resistances with perturbed impedance can be represented as

$$[\tilde{z}]=\begin{bmatrix}\tilde{z}_{11} & \tilde{z}_{12}\\ \tilde{z}_{12} & \tilde{z}_{22}\end{bmatrix}=\begin{bmatrix}z_{11}+\Delta z_{11} & \sqrt{z_{12}^2+\Delta z_{12}^2}\\ \sqrt{z_{12}^2+\Delta z_{12}^2} & z_{22}+\Delta z_{22}\end{bmatrix}. \quad (35)$$

4 EXPERIMENTS

When designing high-speed digital signal transmission systems with a frequency above 1 GHz due to technological errors in the production process there is a problem of their distortion when passing along the conductors of a homogeneous transmission line on a printed circuit board. In this case, as follows from the requirements of international standards IPC-2221A [16] instability in obtaining a constant wave resistance can be described with a sufficient degree of accuracy by the perturbation of the wave conductivity $\Delta Y_0(\tau)=\alpha\sin(\beta\tau+\theta)$, where α,β,θ constant numbers that characterize the technological process.

5 RESULTS

According to the above formulas for a particular case of perturbation of the impedance of a homogeneous line, the dependence of the relative change in the norm was constructed (H0) chain matrix $[A]=[A_{11},A_{12},A_{21},A_{22}]$ from the electric length of Fig. 1

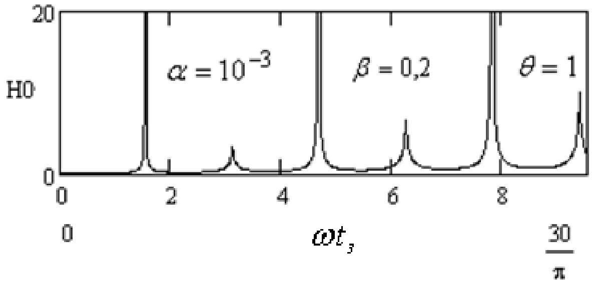

Figure 1 – Graph of the relative change in the norm H0 of the chain matrix from the electric length of the line with perturbed wave conductivity

6 DISCUSSION

From Fig. 1 it follows that this perturbation most strongly affects the frequency characteristics of the line in certain frequency bands, where there is a surge of H0. This conclusion is valid regardless of the functional purpose of the segment of the transmission line. The analysis of the dependences (Fig. 1) for various values of α,β,θ showed:

1. The oscillation frequencies of the wave conductance error $\Delta Y(\tau)$ depend on the parameter β and determine the frequency region of the strongest disturbance of the electrical parameters of the line. Outside this region, the perturbation of the parameters is small. The maximum distortion is observed at electrical lengths *nπ* / 2, *n* = 1,2,3,…. The higher the oscillation frequency of the wave impedance disturbance, the higher the frequency range in which the electrical parameters of the line are disturbed.

2. For lines operating in the frequency range up to the second harmonic open at both ends of the line, the most dangerous disturbances are monotonic deviations of wave conductivity.

3. The location of the disturbance $\Delta Y(\tau)$ a well as the initial phase of the disturbance θ does not affect the frequency domain of distortions, but only affects the nature of distortions in this domain.

4. An increase in the magnitude of the error of wave conductivity α leads to an increase in the deviation of electrical parameters from the nominal in the entire frequency range.

5. Existing methods for assessing the impact of technological inaccuracies in the manufacture of lines make it possible to determine the deterministic and statistical characteristics of the wave impedance of transmission

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lines [5–9, 11–14]. At the same time, the degree of distortion of the functional electrical characteristics (input impedance, reflection coefficient, various transfer characteristics) is difficult or impossible to determine using known methods. The approach developed in the work made it possible to estimate the influence of inaccuracies in the implementation of the wave impedance on the resistance matrix of the line, considered as a four-terminal network. The obtained relations (34, 35), in contrast to the known solutions, allow us to evaluate the influence of errors in the implementation of wave resistance on the deviation of an arbitrary functional parameter of the transmission line.

CONCLUSIONS

In this work, the problem of determining the influence of the deviation of the wave impedance of a transmission line from the nominal value on its elements of the resistance matrix is solved.

The scientific novelty of the results obtained lies in the fact that for the first time it was proposed to evaluate the results of the influence of production technological errors in the implementation of the line on the norm of the resistance matrix, which makes it possible to reasonably choose the accuracy of the reproduction of the wave resistance based on the functional purpose of the line.

The practical value of the results obtained is to substantiate the accuracy of the functioning of technological processes for the implementation of the wave impedance of the line, in which the functional parameters of the line are within acceptable limits. The results obtained make it possible to determine the minimum accuracy of production processes, which ensures the minimum cost of the production process.

The obtained results allow to estimate the influence of the perturbation of the wave resistance (wave conductivity) on the matrix of the transmission line, which is considered as a quadrupole. As such a matrix can be any matrix of four-pole: a matrix of resistances, conductivities, a chain matrix. This makes it possible for the required function of the circuit (transmission factor, input resistance, reflection coefficient, etc.) and its permissible deviation from the nominal value, it is reasonable to choose the tolerance for the accuracy of the reproduction of the impedance. The proposed criterion for estimating deviations of line parameters using the norm of the quadrupole matrix is essentially an integral criterion and can be used to pre-estimate the frequency range of the strongest distortions, regardless of the functional purpose of the segment of the transmission line. The developed approach is applicable to both homogeneous and inhomogeneous transmission lines and covers both regular and irregular perturbations of the impedance.

Prospects for further research are related to the substantiation of the accuracy characteristics of various technologies for the production of microwave equipment in order to ensure the minimum cost.

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ВИЗНАЧЕННЯ МАТРИЦІ ОПОРІВ ЛІНІЇ ПЕРЕДАЧІ ПРИ ВІДХИЛЕННІ КОНСТРУКТИВНИХ ПАРАМЕТРІВ ВІД НОМІНАЛЬНИХ

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АНОТАЦІЯ

Актуальність. У НВЧ системах передачі інформації широко використовуються відрізки ліній передачі, характеристики яких значно впливають на продуктивність різних інформаційних технологій. Однією з проблем виробництва ліній передачі є отримання заданого хвильового опору, що значно впливає на електричні та інформаційні характеристики всього комплексу обладнання. В даний час постає гостре питання оцінки впливу збурюючих факторів на різні електричні характеристики відрізків довгих ліній. На сьогоднішній день найбільш повно розроблені методи оцінки впливу збурюючих факторів на хвильовий опір однорідної лінії (хвильовий опір постійно) при регулярних збуреннях. У цьому випадку в основному враховувався вплив збурень на коефіцієнт відбиття узгоджених ліній. Питання впливу збурень на решту характеристик однорідних і, особливо, неоднорідних ліній вивчені недостатньо.

Мета. Метою статті є визначення впливу збурень хвильового опору на матрицю опору лінії передачі. Знаючи матрицю збурених опорів, можна визначити спотворення будь-якого пристрою, побудованого на відрізках ліній передачі.

Метод. У статті використано метод теорії збурень лінійних диференціальних операторів, застосований до рівнянь, що описують процеси в неоднорідних довгих лініях.

Результати. Отримані результати дають можливість оцінити вплив регулярних та нерегулярних збурень хвильового опору (хвильової провідності) на матрицю лінії передачі, що розглядається як чотириполюсник. Така матриця може бути будь-якою квадрупольною матрицею: матрицею опорів, провідностей, ланцюговою. Це робить можливим, відповідно до необхідної функції схеми (коефіцієнт передачі, вхідний опір, коефіцієнт відбиття) визначити її допустиме відхилення від номінального значення, щоб вибрати допуск для відтворення хвильового опору.

Висновки. Запропонований критерій оцінки відхилень параметрів лінії з використанням норми квадрупольної матриці за своєю суттю є інтегральним критерієм і може бути використаний для попередньої оцінки частотної області найсильніших спотворень, незалежно від функціонального призначення відрізка лінії передачі. Розроблений підхід застосовується як до однорідних, так і до неоднорідних ліній передачі та охоплює як регулярні, так і нерегулярні збурення хвильового опору.

КЛЮЧОВІ СЛОВА: лінія передачі, хвильовий опір, збурення, матриця опорів, чотириполюсник, неоднорідна лінія, коефіцієнт відбиття.

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ОПРЕДЕЛЕНИЕ МАТРИЦЫ СОПРОТИТВЛЕНИЙ ЛИНИИ ПЕРЕДАЧИ ПРИ ОТКЛОНЕНИЯХ КОНСТРУКТИВНЫХ ПАРАМЕТРОВ ОТ НОМИНАЛЬНЫХ

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АННОТАЦИЯ

Актуальность. В СВЧ системах передачи информации широко используются отрезки линий передачи, характеристики которых значительно влияют на производительность различных информационных технологий. Одной из проблем производства линий передачи является получение заданного волнового сопротивления, что значительно влияет на электрические и информационные характеристики всего комплекса оборудования. В настоящее время возникает острый вопрос оценки влияния возмущающих факторов на различные электрические характеристики отрезков длинных линий. На сегодняшний день наиболее полно разработаны методы оценки влияния возмущающих факторов на волновое сопротивление однородной линии (волновое сопротивление постоянно) при регулярных возмущениях. В этом случае в основном учитывалось влияние возмущений на коэффициент отражения согласованных линий. Вопрос влияния возмущений на остальные характеристики однородных и, особенно, неоднородных линий изучены недостаточно.

Цель. Целью статьи является определение влияния возмущений волнового сопротивления на матрицу сопротивления линии передачи. Зная матрицу возмущенных сопротивлений, можно определить искажения характеристик какого-либо устройства, построенного на отрезках линий передачи.

Метод. В статье использован метод теории возмущений линейных дифференциальных операторов, примененный к уравнениям, описывающих процессы в неоднородных длинных линиях.

Результаты. Полученные результаты дают возможность оценить влияние регулярных и нерегулярных возмущений волнового сопротивления (волновой проводимости) на матрицу линии передачи, рассматриваемой как четырехполюсник. Такой матрицей может быть какая-либо матрица четырехполюсника: матрица сопротивлений, проводимостей, цепной. Это делает возможным, в соответствии с требуемой функцией цепи (коэффициент передачи, входное сопротивление, коэффициент отражения) определить допустимое отклонение волнового сопротивления от номинального значения, чтобы выбрать допуск для воспроизведения волнового сопротивления.

Выводы. Предложенный критерий оценки отклонений параметров линии с использованием нормы четырёхполюсной матрицы по своей сути является интегральным критерием и может быть использован для предварительной оценки частотной области наиболее сильных искажений, независимо от функционального назначения отрезка линии передачи. Разработанный подход применим как к однородным, так и к неоднородным линиям передачи и охватывает как регулярные, так и нерегулярные возмущения волнового сопротивления.

КЛЮЧЕВЫЕ СЛОВА: линия передачи, волновое сопротивление, возмущения, матрица сопротивлений, четырехполюсник, неоднородная линия, коэффициент отражения.

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