Synthesis of the meander microstrip and helical delay lines
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Abstract

The mathematical models of the meander microstrip line and helical line as a four-layered printed board were applied to expose the connection between the electrical properties and the constructional parameters of the above mentioned lines. The algorithm and the programme in PASCAL for synthesis of the constructions of the multitapped meander microstrip and helical delay lines with preset electrical characteristics were worked out. The algorithm of the synthesis implies that the transmission band of the delay line is predicted by its phase-frequency response. The programme enabled us to analyse the properties of the microstrip meander and the helical delay lines.

1 Introduction

The wide band delay lines are applied in radar and navigation systems, in TV and communication systems, and in measuring devices and pulse generators. When a relative transmission band is extremely broad - from direct current till hundreds and thousands of megacycles - only the electrodynamic systems such as meander and helical lines can find application. When the bandwidth of a delay line is over 100-200 MHz and delay time is less than 20-10 ns, the meander microstrip lines are preferable. When delay time is over 20 ns and transmission bandwidth is less than 200-100 MHz, the helical lines are indispensable.

The meander microstrip delay line which consists of the plane meander conductor on one side of the dielectric substrate and bulk shield on the other side (Fig. 1) is fabricated by standard thin or thick film technology.
The helical delay line with inner shields conductive along the helix axis can be fabricated as a four-layered printed board by widespread technology of multilayered printed circuits. The idea of a helical line as a printed board is illustrated in Fig. 2.

![Helical Delay Line Diagram](image)

**Figure 2**: (a) Helix as a printed board. (b) Cross section of a helix delay line with inner longitudinal conductive shields -- a four-layered printed board.

### 2 Mathematical Models

The mathematical models of delay lines connect the electrical characteristics of the lines with their constructional parameters. The main electrical characteristics of delay lines are as follows: phase delay time of the line on low frequencies $t_d$, characteristic impedance of the line on low frequencies $Z_c$, transmission...
band of the line $\Delta f$ and phase delay time of one step of the multitapped delay line on low frequencies $t_{ld}$. Constructional parameters of the meander microstrip line and the helical line with inner longitudinal conductive shields are shown in Figures 1 and 2.

### 2.1 Meander Microstrip Delay Line

The mathematical model of the meander microstrip delay line is based on the method of coupled multiconductor lines. The meander microstrip line is formed when the segments of a multiconductor line are loaded by similar impedances and the currents and the voltages on the ends of the adjacent segments are equalised. The dispersion equation of a simple microstrip meander line was obtained by Weiss. The main problem in analysis of meander microstrip lines is to obtain a relationship between the constructional parameters of the line and its chief electrical characteristics - the relative dielectric constants and wave admittances for in-phase and anti-phase waves, from which the delay factor and phase time-frequency response as well as input impedance-frequency response can be evaluated. These relationships for coupled microstrip lines were derived by Garg & Bahl. More complex cases of various meander microstrip lines were investigated by R. Martavicius and A. Gurskas what is reflected in monographs.

### 2.2 Helical Delay Line

The generalised model of the helical systems, including all possible versions of these systems with bulk or longitudinal conductive shields and an infinite number of various dielectric layers between the helix and the outer or inner shields was proposed and analysed in monographs. It was shown there that helical lines with inner and/or outer bulk or longitudinal conductive shields can be fabricated as four- or six-layered printed boards.

In this paper a simple case of helical line with longitudinal conductive inner shields -- a four-layered printed board -- is analysed. Longitudinal conductive shields increase delay time of the helical lines on low frequencies. When a required transmission band of a delay line is not very broad, such helical lines have a permissible phase-frequency distortion and great delay factor. In case of fairly a broad bandwidth, additional bulk shields are necessary for the correction of phase-frequency response of the helical lines with longitudinal conductive shields - then the helical line becomes a six-layered printed board.

### 3 Algorithm of the synthesis

The problem of the synthesis is finding the values of constructional parameters of delay lines with preset electrical characteristics. The problem can be solved when the quantity of preset electrical characteristics is equal to the quantity of
constructional parameters, varied during the process of synthesis of delay lines. Four preset electrical characteristics of the multitapped delay lines were mentioned above. Microstrip meander and helical delay lines are described with more than four constructional parameters, therefore four of them can be varied during the process of synthesis, and others must be chosen preliminarily.

These constructional parameters of the microstrip meander delay line were varied during the process of synthesis: the width of the meander conductor \( W \), the distance \( S \) between the adjacent strips of the meander, the height of the meander line \( A \), and the length of the line \( L \). The remaining constructional parameters - the thickness of the dielectric substrate \( h \) and its relative dielectric constant \( \varepsilon_r \), and the thickness of the meander conductor \( t \) - must be accepted on the start of the synthesis.

The step of the helix \( p \) ( \( p = W + S \), \( W \) is the width of the helical conductor, \( S \) is the distance between adjacent wires of the helix), the thickness of the helical line \( h \), the height of the meander line \( A \), and the length of the line \( L \) were chosen as varied constructional parameters of the helical line. The remaining parameters - the distance between the helix and the inner shield \( b \) and relative dielectric constant \( \varepsilon_r \) of dielectric in this area were accepted as the primary constructional parameters of the helical line.

There are linear relationships between the varied constructional parameters of the lines and the majority of their electrical characteristics, but one electrical characteristic ought to be discussed more thoroughly. It is a transmission band of the line \( \Delta f \).

Microstrip meander delay lines are used when small delay time and very broad bandwidth are necessary. In this case, when the meander conductor is not very thin, the transmission band of the line is restricted only by its phase-frequency distortion.

Delay time of the helical lines reaches several hundreds of nanoseconds. As a rule, the bandwidth of a line with such a delay time depends on both amplitude-frequency and phase-frequency distortions. But it was mentioned above that a helical line with longitudinal conductive shields has no linear phase-frequency response. Therefore its bandwidth is in most cases restricted by its phase-frequency distortion.

As follows from the above varied constructional parameters of the microstrip meander line, the synthesis of this line is the synthesis of its topology. The first important step in building the algorithm of synthesis is selection of proper pairs of the electrical characteristics and varied constructional parameters of the line. The problem was solved analysing the responses of electrical parameters to values of varied constructional parameters. Such responses are shown in Fig. 3. The pairs were formed by choosing for the electrical characteristic such constructional parameter to which this electrical characteristic is the most sensitive. The selected pairs correspond to thick curves in Fig. 3. The primary values of all constructional parameters of the line are indicated on the Fig. 3.
The algorithm of synthesis of topology of the microstrip meander line with preset electrical characteristics is shown in Fig. 4. It consists four of loops, one enclosed into another. During the cycle of the first loop the algorithm changes the value of constructional parameter \( W \) and calculates the value of characteristic impedance of model of the line \( Z_{cm} \) until it reaches the preset value \( Z_c \).

The first loop is not enclosed into the second and the third loops of the algorithm, because characteristic impedance of the line does not depend on the values of constructional parameters \( A \) and \( L \) (it illustrates dependences in Fig. 3). The second loop of the algorithm is enclosed into the third loop because the value of the length of the line \( L \) affects both the bandwidth and delay time of the line.

During the cycle of the fourth loop the algorithm changes the value of constructional parameter \( S \) and calculates the value of delay time of one step of the line \( t_{1d} \) until it reaches the preset value \( t_{1d} \). The constructional parameter \( S \) changes the values of all electrical parameters of the line therefore the first, the second, and the third loops are enclosed into the fourth loop.
Figure 4. The algorithm of synthesis of topology of the microstrip meander delay line with preset electrical characteristics.
The algorithm ends with the output of the constructional parameters and electrical characteristics of the synthesized microstrip meander line.

![Graph](image)

Figure 5: Dependences of electrical parameters of multitapped helical delay line -- four-layered printed board -- from its varied constructional parameters.

In the same way the algorithm of synthesis of construction of a helical delay line with inner longitudinal conductive shields -- four-layered printed board -- was worked out. In Fig. 5 are shown the dependences of the electrical parameters of the helical line on the values of its variable constructional parameters. According these dependences, the pairs of electrical and constructional parameters of the line were selected - they are marked out in Fig. 5 by thin curves. The algorithm of synthesis of a helical delay line with preset electrical characteristics is similar to the algorithm of synthesis of a microstrip meander delay line in Fig. 4.

4 Conclusion

The programme in PASCAL was written on the base of proposed algorithm for synthesis of constructions of multitapped microstrip meander and helical delay
lines. The programme was worked out on the mathematical models of the meander microstrip lines, meander strip lines, and helical lines with longitudinal conductive shields. The programme synthesizes the constructions of the above mentioned lines with preset electrical characteristics, and calculates electrical characteristics and parameters of the synthesized delay lines. The programme lets to synthesize the meander and helical lines when their primary constructional parameters are changed with determinated step in accepted intervals of their values. It is the first step in optimization of constructions of the meander and helical lines with preset electrical characteristics. The latter is illustrated by 3d mesh in Fig. 6.

Figure 6: The dependence of the area of the substrate of the synthesized meander microstrip lines with \( t_d = 20 \text{ ns} \), \( Z_c = 50 \text{ Ohm} \), \( \Delta f = 0.3 \text{ GHz} \), and \( t_{ld} = 0.1 \text{ ns} \) on the thickness and the relative permittivity of the substrate

Though it is evident that the least area of the substrate corresponds to the minimum of the thickness and to the maximum of the relative permittivity of the substrate, the character and the concrete values of these dependences are quite informative.

The problems will be solved in the future:
1. The synthesis of optimal according to accepted criterion constructions of the meander microstrip and helical delay lines with preset electrical characteristics.
2. The synthesis of the helical delay lines with inner longitudinal conductive and outer bulk shields -- six-layered printed boards.
3. The interface between the synthesis programme and standard packages for CAD of the multilayered printed circuits.

References


