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Metamaterial Development in Millimeter Wave

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Abstract

This paper presents a method in which deterministic electromagnetic simulation tools and statistical modeling methods can be used to optimize RF and microwave metamaterials. During the course of study, the three physical parameters of the structure have been chosen as optimization variables. The results of the hybrid electromagnetic—statistical analysis generated statistical models that could be used to predict the metamaterial performance based on the geometry of the structure.

Key- words: *Optimization, Metamaterials, & Millimeter Wave*

Introduction

Recently material development has received a lot of interest considering the fact that realistic implementation solutions has emerged. Those substances exhibit phase and group velocities of opposite symptoms and a bad refractive index in positive frequency ranges, each traits making them desirable for RF and microwave programs[1-2]. One of the implementation processes begins from the equivalent transmission line model and artificially hundreds of host line with a twin periodical shape of series capacitors and shunt inductors[3-4]. The period of the duration and the price of the capacitors and inductors decide the frequency band. One of the important challenges for the high frequency implementation, wherein the measurement come to be smaller and the system layout regulations become very restrictive is the selection of the inductor and capacitor geometry to gain the specified left-surpassed passband and minimum insertion loss at the favored working frequency. Therefore, the aim of this paper is to layout and optimize, for the primary time, a metamaterial structure for 40 GHz..

Brief Background of Metamaterials :

Metamaterials are artificially loaded media which employ negative permittivity and permeability in finite frequency ranges [1] One of the implementations of such structures are arrays of wires and split-ring resonators [2], [3]. These are complicated 3D systems that arc difficult to apply for RF and microwave circuits. A more practical implementation uses transmission lines periodically loaded with lumped element networks [4, 5]. The starting point is the transmission line model presented in Fig. 1 (a),

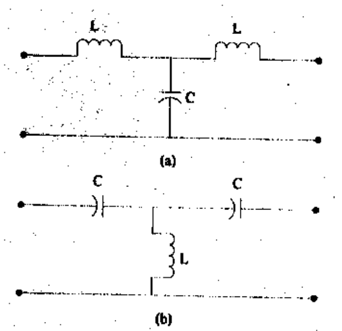

Fig. 1. Transmission line model (a) conventional (b) dual.

The equivalence between the distributed L and C for the transmission line and the permittivity and permeability of the medium is expressed as ε=C, μ =L. By periodically loading this transmission line with its dual in Fig. 1(b), the values of ε and μ change as follows [4]:

$$\varepsilon_{eff} = \varepsilon - \frac{1}{\omega^2 Ld}, \qquad \mu_{eff} = \mu - \frac{1}{\omega^2 Cd} \tag{1}$$

where ε and μ are the distributed inductance and capacitance of the host transmission line. It is obvious that for certain values of L, C and d, the effective permittivity and permeability of the medium becomes negative for some frequency ranges. In these ranges, the refractive index is negative, and the phase and group velocities have opposite signs.

Metamaterial structure analysis and design

The proposed structure is implemented in Low Temperature Cofired Ceramic (LTCC) technology, and the host transmission line is a 75 Ω coplanar waveguide (CPW). The advantage of the CPW is the ease to build shunt lumped elements due to the availability of the ground plane on the same layer as the signal. The series capacitors and shunt inductors are implemented as shown in Fig. 2.

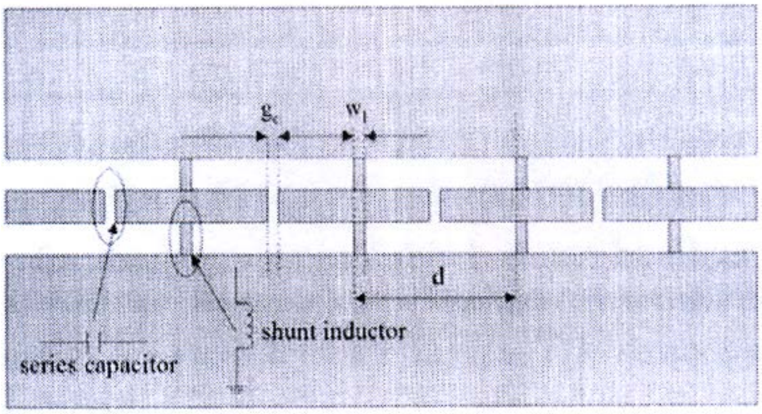

Fig. 2. CPW implementation of metamaterial structure.

The preliminary analysis of the structure dispersion diagram showed that the factors which influence the system performance the most are the values of the series capacitors and shunt inductors, as well as the length of the period. The experiment has been set for a constant characteristic impedance of 75Ω so the width of the signal line and the gap for the CPW are kept constant. Therefore, the three variables are the gap of the capacitor g_c, the width of the inductive line w, and the length of the period d. A full factorial experiment with three factors consists of 2^3=8 treatment combinations. The two levels chosen for each input variable have been controlled by the fabrication process and are presented in Table I.

Variable	**G_c (µm)**	**w_t (µm)**	**d (µm)**
"–" level	100	75	1600
"+" level	200	125	2000

Table 1. Variables for the 2^3 experiment

The output variables are the resonant frequency in the first LH passband f_{res} and the value of the insertion loss at that frequency IL. The eight simulations have been run in Micro Stripes TLM Modeler and the results are presented in Table II.

Run	**G_c**	**W_l**	**D**	**f_{res} GHz**	**IL (dB)**
1	–	–	–	48.1	9.2
2	+	–	–	38.7	5
3	–	+	–	47.7	10
4	+	+	–	39.3	7
5	–	–	+	48.3	12
6	+	–	+	39	7
7	–	+	+	48.4	13.5
8	+	+	+	40.4	9

Table II. 2^3 experiment

Analysis of Variance (ANOVA) statistical analysis has been performed using a user-friendly specialized commercial software. ANOVA reveals the statistical significance of all the input variables and of their interactions and generates regression models of the outputs as a function of the inputs. The first important result we obtained for this case is that the width of tile inductor strip is not statistically significant for any of the output variables and therefore can be eliminated from further analysis. The capacitor gap is only significant for the insertion loss, and it will he included in the regression models. The length of the period is significant for both the outputs. The regression models are given by:

$$f_{res} = 82.26 + 0.0056 \cdot g_c\ (\mu m) - 0.0219 \cdot d\ (\mu m) \qquad (2)$$

$$IL = 23.51 + 0.0256 \cdot g_c\ (\mu m) - 0.0104 \cdot d\ (\mu m)$$

These results are valid only for the intervals in Table I. It can be observed that the design process has been reduced dramatically, first by eliminating a variable from the analysis, then by obtaining explicit equations for the outputs as a function of the inputs. The structure is also optimized with the following goals f_{res} = 40GHz, IL = min.

The optimization is performed using the statistical analysis software and the results are f_{res} = 40GHz and IL = 5.72dB These are obtained for g_c = 100μm and d= 1953.4 μm. The high insertion loss is due to the difficulty to implement the distributed lumped elements at the high frequencies with the limitations given by the design rules of the fabrication process. The next steps include the optimization of the lumped elements, the extension of the statistical analysis to more sophisticated tools and the validation of the optimized structure with test structure fabrication and measurements.

Conclusion:

In conclusion, this paper focuses on the frequency of interest which is 40 GHz and the generation used is multilayer low temperature co-fired ceramic (LTCC). The selected technique for the double terrible metamaterial implementation is a loaded coplanar waveguide (CPW) transmission line. The design dreams are a resonant frequency of40 GHz and minimum insertion loss at that frequency.

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