A Design Method of Composite Right/Left Handed Transmission Lines by Genetic Algorithm

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Abstract

This paper develops right/left handed transmission lines consisting of arbitrarily-shaped conductor elements, which are designed by a genetic algorithm. In the present design method, we choose the dispersion characteristics as a fitness function. A design example is demonstrated, and its effectiveness is proved from comparison of transmission characteristics between the calculated and the measured results.

Keywords : Genetic algorithm, fitness function, left-handed, cell

1. Introduction

In recent years, materials with the left-handed nature have been actively investigated [1, 2]. One type of them is a composed right/left handed transmission line (CRLH-TL) and such a line has been applied to novel devices and components in the microwave and the millimetre-wave regimes [3, 4]. However, a design method for constructing a transmission line with the left-handed nature has not been almost reported so far. So in this paper, we propose a design method based on a genetic algorithm (GA). Our method constructs the CRLH-TL by using arbitrarily-shaped conductor elements on the conductor-backed dielectric substrate, which are yielded under the GA optimization [5, 6] estimating the dispersion curve for a unit cell of the periodic structure. A designed example is demonstrated and usefulness of the present method is verified from the calculated and measured transmission characteristics.

2. Design Method

Figure 1 shows a circuit to derive a unit-cell structure constructing the CRLH-TL, where the unit cell is connected by the input and output microstrip lines. The CRLH-TL is realized by connecting only the unit-cell portion periodically. The unit cell consists of arbitrarily-shaped conductor elements on a dielectric substrate with dielectric constant ε_r and thickness h. It is covered by a shielding box (dimensions $a\times b\times c$). To analyze an arbitrarily-shaped element shown in Fig.1 by the method of moments (MoM), the x-y plane of dimensions $a\times b$ at $z=h$ is divided into equal intervals with $P\times Q$ grids as shown in Fig.2. In the GA, the arbitrarily-shaped unit cell is handled with a binary code. The conductor cells in Fig.2 are 1 and other cells are 0. Since the GA optimization region can be arbitrarily selected, we take a half of the unit-cell geometry as the optimization region to construct a symmetrical unit cell. The fitness function in the GA optimization is defined by difference between the desired dispersion curve and the dispersion curve for the infinite periodic structure with the unit cell yielded by the GA. Considering that the periodic structure is expressed by the cascaded connection of the unit-cell's ABCD matrix shown in Fig. 3, the dispersion curve $\beta(\omega)$ for the infinite periodic cell is obtained from the eigenvalue problem as follows.

$$\beta(\omega) = \frac{1}{l}\cos^{-1}\{\frac{1}{2}(\mathrm{A}+\mathrm{D})\} \tag{1}$$

In this equation, l is the length of the unit cell and the elements of the ABCD matrix are extracted by the TRL calibration technique which is used in measurements, the CRLH-TL structure is determined by minimizing the fitness function.

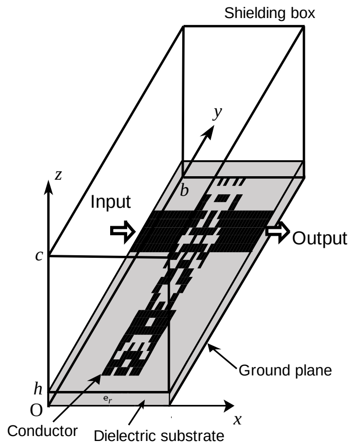


Fig. 1. Unit cell consisting of arbitrarily-shaped conductor elements.

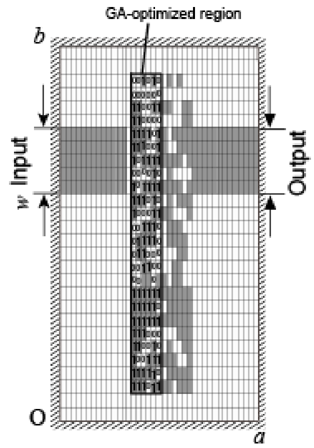


Fig. 2. Unit cell divided into $P\times Q$ grids.

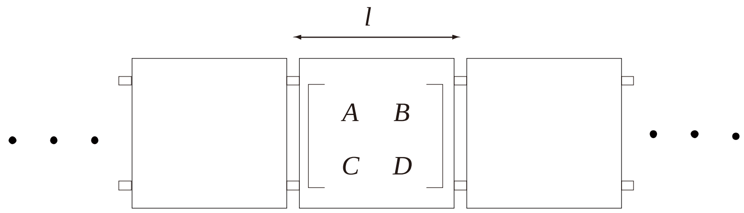


Fig. 3. Periodic structure expressed by cascaded connection of ABCD matrix.

3. Design Example

As an example, we assume that the left-handed nature appears in the frequency range 6-7 GHz and its desired dispersion curve is linear as shown in Fig. 4. The x-y plane of dimensions $a\times b$ at $z = h$ is divided with 39×28 grid and the GA-optimized region is divided into 6×24. The dimensions of the shielding box are a = 7.7 mm, b = 14.7 mm, c = 11.0 mm. The dielectric substrate has the dielectric constant $\varepsilon_r = 2.8$, and the thickness h = 1.0 mm. The number of the sampling frequency points within 6-7 GHz is $N_p = 6$. In the GA procedure, the tournament selection is employed as the selection method and single-point crossover is used. The crossover rate is 0.8 and the mutation rate is 0.02. One generation of population size is 50, the generation number is 200 and the elitist strategy is applied. Figure 4 shows the designed unit cell geometry and the dispersion curve derived from Eq. (1). The dispersion curve for the design unit cell indicated by the black line agrees very well with the desired one indicated by the red line. Therefore it is obvious that the present design method works successfully.

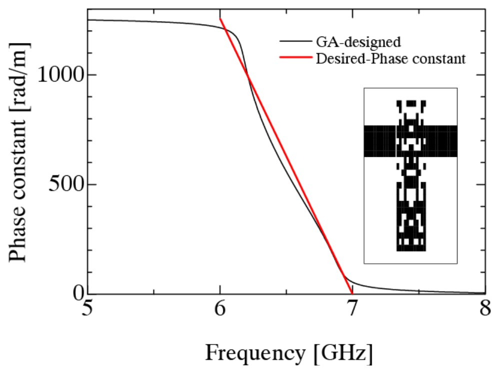
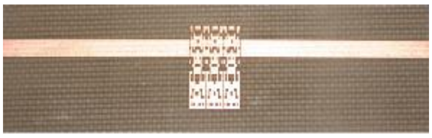


Fig. 4. Geometry of designed unit cell and its dispersion diagram.

4. Experiments

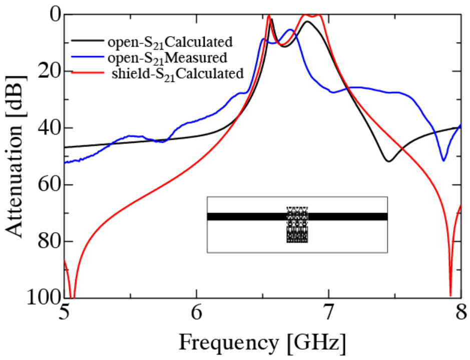
The experimental verification of the GA-optimized CRLH-TL is performed. In this experiment, the CRLH-TLs with various lengths are fabricated by an etching technique in our laboratory, and their transmission characteristics are measured without the shielding box as an open circuit. The photographs of the fabricated lines are shown in Fig. 5. The measured transmission characteristics are shown in Fig. 6 by the blue line. To compare with the theoretical ones, the calculated results for the transmission line with and without the shielding box are given by the red and black solid lines in Fig. 6, respectively. Their calculated results are obtained by the Ansoft HFSS. The measured results agree fairly well with the calculated results. Figure 7 shows the measured and the calculated dispersion curve for the designed CRLH-TL. The measured result which is obtained from the phase-shift measurement for the 10-cell line almost agrees with the calculated result, so that it is verified that the design CPLH-TL exhibits the left-handed nature in 6-7 GHz.


(a)

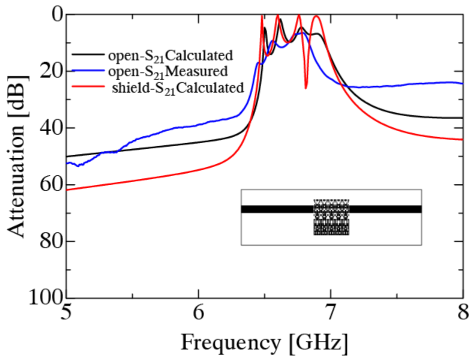

(b)


(c)

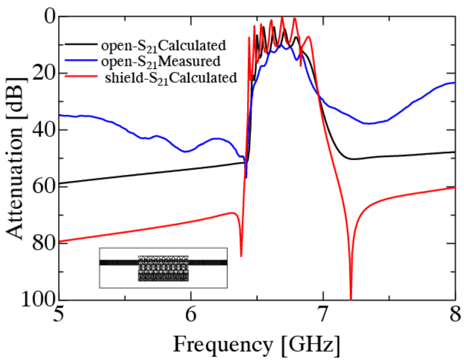
Fig. 5. Photographs of designed CRLH-TLs. (a) 3 cells, (b) 5 cells, and (c) 10 cells.



(a)



(b)



(c)

Fig. 6. Measured and calculated transmission characteristics. (a) 3 cells, (b) 5 cells, and (c) 10 cells.

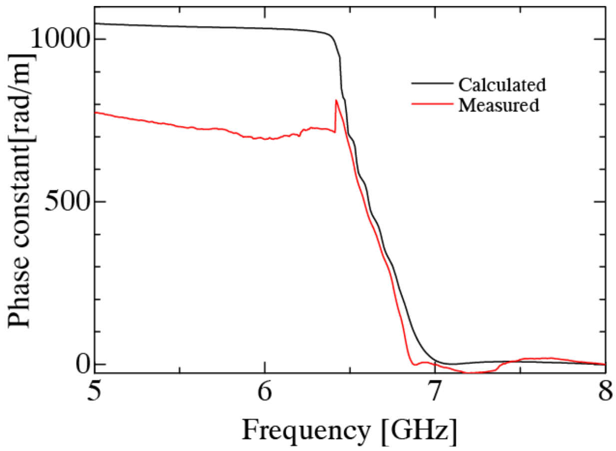


Fig. 7. Measured dispersion diagram obtained from phase shift for the 10 unit cells.

5. Conclusion

This paper has presented the design method for constructing the CRTH-TL by the arbitrarily-shaped conducting elements. The dispersion curve of the infinite periodic structure is employed as a fitness function in the GA optimization. It is demonstrated from the designed example that the conductor elements are successfully generated and the CRLH-TL with specified bandwidth of the left-handed nature is realized. The numerical and experimental results for the designed example have proved usefulness of the proposed design method.

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