Microwave Absorbers Made of Arrays of Square Loops with Lumped Resistors through Optimization with Genetic Algorithm Approach

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Abstract

In this paper, the equivalent circuit model of a microwave absorber is proposed and investigated. The absorber is composed of square metal loops with lumped resistors over the grounded dielectric substrates. The electromagnetic behaviors of these frequency selective surface elements, and the substrate, are studied. A Genetic Algorithm (GA) is employed to optimize the geometrical parameters and the corresponding impedance properties to achieve different design requirements. Finally, two examples are presented and discussed; the results demonstrate the validity and accuracy of the equivalent circuit model.

1. Introduction

Electromagnetic absorbers made of periodic patterns known as frequency selective surfaces (FSSs) have attracted much research interest. As one of the simplest FSS structures, arrays of square loops are widely studied.

In this paper, a simple equivalent circuit model of single square loops with lumped resistors is proposed. The comparison of full-wave simulation on CST and analytical results confirm the validity of the equivalent circuit model. To obtain the optimal design of the absorbers, a genetic algorithm is employed. The combination of equivalent circuit model and Genetic Algorithm (GA) can assist in the fast and efficient design of absorbers.

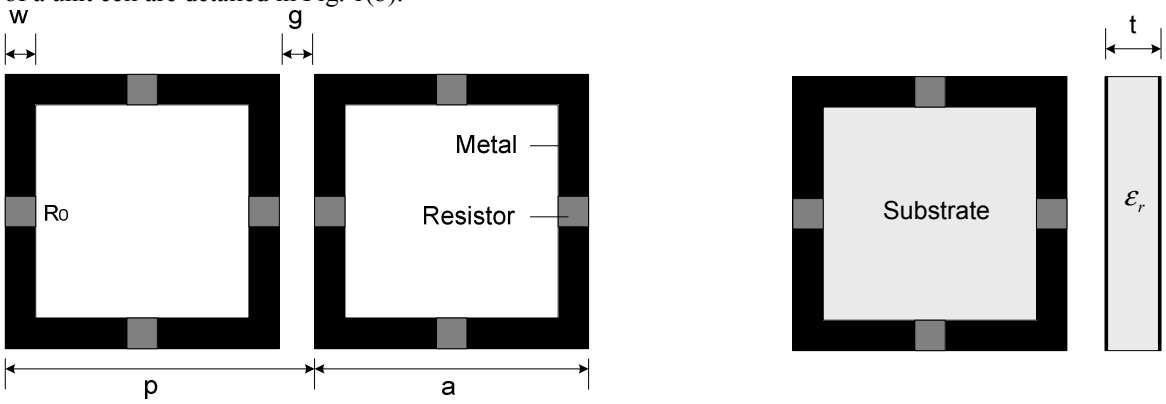
2. Equivalent Circuit Model of Square Loop with Lumped Resistors

The study of equivalent circuit model of the square loops can be derived from [1], which gives the normalized inductances or capacitances of the strip grating by a factor F for both TE and TM incidence. Based on this, the lumped-element equivalent circuit model of single, double or triple square loops are studied in [2-5].

However such FSS structures are considered lossy, and ohmic loss are ignored in the equivalent circuit model, which requires improvements when resistors are introduced in an absorber.

2.1 Proposed Structure and Equivalent Circuit Model

The proposed absorber has three components: a single-layer resistive FSS in the form of single-square loops as an impedance sheet (Fig. 1(a)), a dielectric spacer, and a ground. The absorber is a planar-periodic structure, and the parameters of a unit cell are detailed in Fig. 1(b).



(a) (b)

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Fig. 1 Geometry of the square loops. (a) two-cell square loops (b) the corresponding absorber: front view (left) and side view (right). p **= 16 mm,** g **= 1 mm,** w **= 1.5 mm,** R_0 **= 50 Ω,** t **= 3 mm,** ε_r **= 1.**

The equivalent circuit method (ECM) is useful to predict the frequency response and carry out parametric studies. The qualitative equivalent circuit model for the single square loop array is provided in Fig. 2(a).

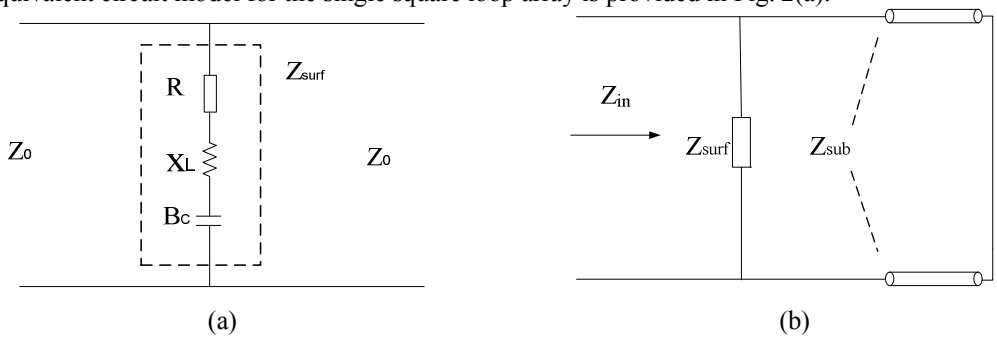


Fig. 2 Corresponding equivalent circuit model of the structures in Fig. 1, (a) square loops (b) absorber.

The three circuit elements given in Fig. 2(a) are calculated as follows:

$$X_L / Z_0 = a / p\sqrt{\varepsilon_r} F(p, 2w, \lambda) \tag{4}$$

$$B_c / Z_0 = 28 * 10^{-6} * a / p\sqrt{\varepsilon_r} F(p, g, \lambda) \tag{5}$$

$$R = 0.7 * R_0 \tag{6}$$

Where the factor F was presented in detail in [1].

For the whole absorber, the input impedance Z_{in} is seen looking toward the ground plane at the plane of the surface, which is equal to the parallel connection between the substrate impedance (Z_{sub}) and the surface impedance (Z_{surf}), which is the impedance of the FSS elements, as shown in Fig. 2(b).

$$Z_{in} = Z_{surf} // Z_{sub} = (Z_{surf} Z_{sub}) / (Z_{surf} + Z_{sub}) \tag{7}$$

The impedance of the lossy surface can be simply represented by:

$$Z_{surf} = R + j * (X_L - 1 / B_c) \tag{8}$$

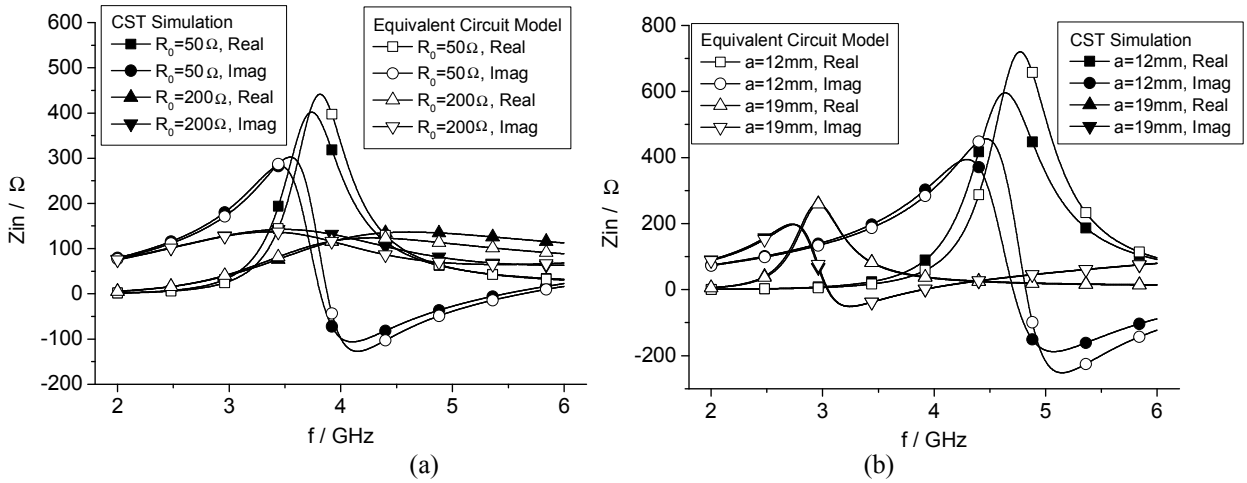
For the grounded dielectric substrate, the equivalent surface impedance can be written as [6]

$$Z_{sub} = j Z_m^{TE,TM} \tan(\beta t) \tag{9}$$

Where $Z_m^{TE} = (\varpi \mu_r \mu_0) / \beta$ and $Z_m^{TM} = \beta / (\varpi \varepsilon_r \varepsilon_0)$ are the characteristic impedances of the substrate for TE and TM polarization, while $\beta = \sqrt{k^2 - k_t^2}$ is the propagation constant along the normal axis of the substrate and $k_t = k_0 \sin(\theta)$ is the transverse wavenumber with θ representing the incidence angle of the incoming wave.

2.2 Property Studies of the Absorber

In order to verify the validity of the circuit model proposed above, the absorbers with different parameters are analyzed by means of full-wave electromagnetic field simulation and equivalent circuit model. Four different cases are analyzed as below. In each case, only one parameter depicted in Fig. 1 is changed. The input impedances of absorbers are shown in Fig. 3.



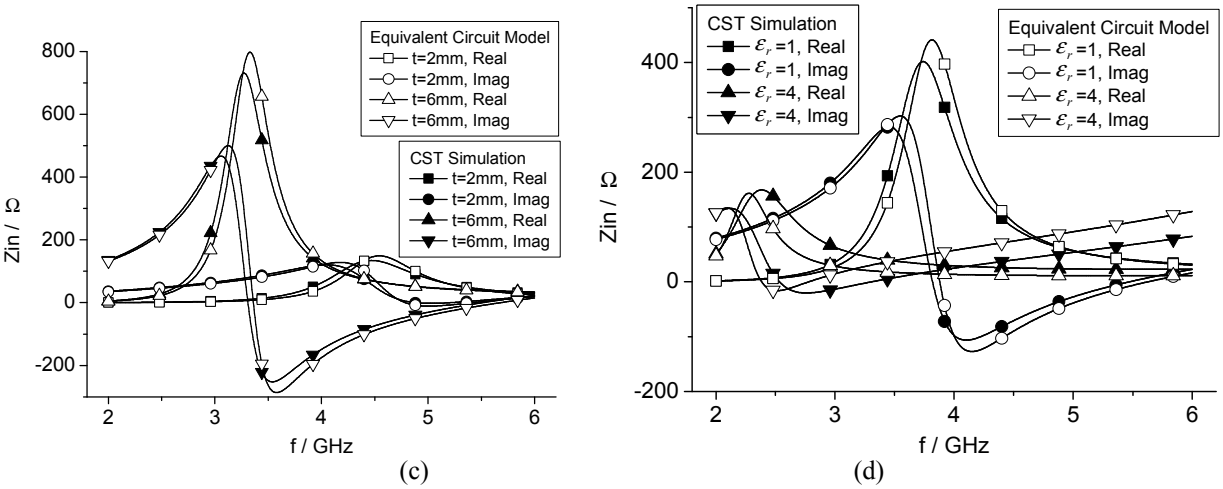


Fig. 3 Input impedance of absorbers with different parameters: R_0 (a), a (b), t (c), ε_r (d).

It is not hard to see, good agreement between the results from CST simulation and the equivalent circuit model is observed over the frequency band 2 – 6 GHz, which also corresponds to λ / p: 3.3-10, considering that the periodic size of the unit cell p is about 15 mm. This defines the application range of the equivalent circuit model we propose. When this model is employed in an absorber design, the operating wavelength should be several times the size of the unit cell to ensure the validity and accuracy of the model.

Obviously, an increasing relative permittivity and decreasing ratio λ / p will both increase the inaccuracy of the model, resulting in the difference between the results from simulation and analytical methods, as observed in Fig. 3(d).

3. Optimization using Genetic algorithm

Genetic algorithms, which imitate the principles of nature evolution, are widely used to search the optimized solutions in complex problems. Here, we use a GA procedure to synthesize microwave absorbers by parameter optimization. The classic GA, applied in this paper, allows for optimization of the unit-cell size, value of resistors and thickness of substrate to fit the design requirements.

A large population of 1000 individual chromosomes is built to avoid reaching a local optimum point. Each chromosome uses 2048-bit binary string to code the parameters. Operations on those chromosomes with three operators: *selection*, *crossover* and *mutation* follow. After approximately 100 generation, the optimized parameters can be obtained.

4. Absorber Design Examples

Two examples of absorbers are presented and discussed in this section. To simplify the optimization process, the permittivity of the substrate ε_r and the distance between two loops g are fixed to be 2.65 and 1 mm, respectively.

The objective in the first case is to design an absorber centered at 4 GHz with strong absorption properties. The fitness function (*Fit*) is defined to be the reflection coefficient of the absorber.

$$\begin{cases} Fit = S_{11} = 20\log[(Z_{in} - Z_0)/(Z_{in} + Z_0)] \quad (@4\ GHz) \\ p \in [10,15]\ mm;\ t \in [0.5,2]\ mm; R_0 \in [10,200]\ \Omega \end{cases} \tag{10}$$

As shown in Fig .4(a), the absorber performs well at the desired operating frequency with one-twenty third of a wavelength thickness.

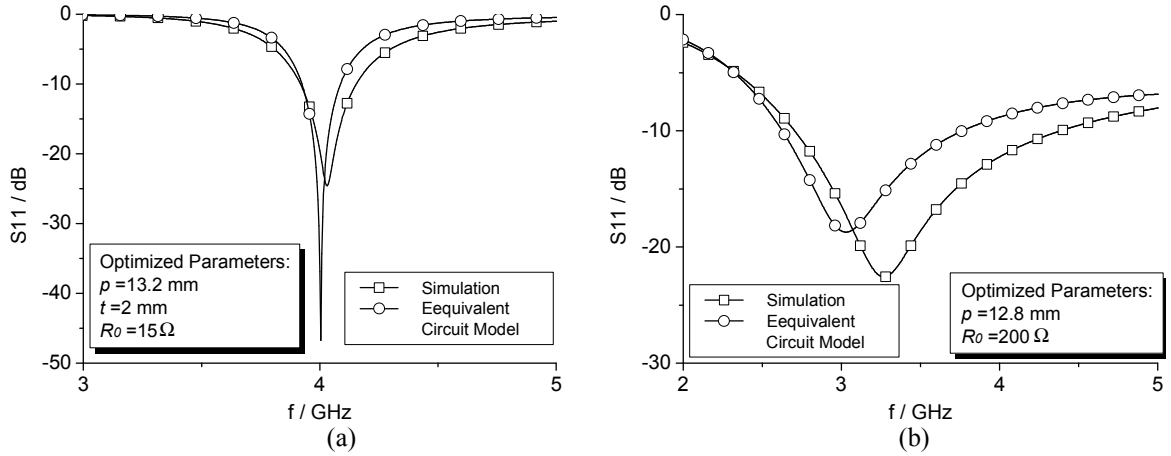


Fig. 4 Reflection coefficients from GA and full-wave simulation: *Case 1* (a), *Case 2* (b)

The objective in the second case is to design an absorber centered at 3 GHz with maximum □10 dB bandwidth. This time, the maximum substrate thickness was fixed at 8 mm, which corresponds to approximately one-eighth of a wavelength at center frequency.

$$\begin{cases} Fit = -BW \quad (@3\ GHz) \\ p \in [10,15]\ mm;\ t = 8\ mm;\ R_0 \in [10,250]\ \Omega \end{cases} \tag{11}$$

As shown in Fig. 4, a reasonable agreement verifies that the combination of equivalent circuit model and GA an efficient way to design absorbers consisting of resistive square loops. However, a 8.5% difference of the center operating frequency in *Case 2* can be observed due to the relative permittivity. This negative effect from the permittivity would be more evident and serious in broadband design, which implies that a more accurate model would be required when substrate with high permittivity is used in design.

5. Conclusion

In this paper, the equivalent circuit model of a microwave absorber consists of resistive single square loop is investigated. An efficient optimization algorithm, say, genetic algorithm (GA) is employed to synthesize and optimize the absorber. The combination of the two methods provides a fast and efficient way for microwave absorber design. Further work using the proposed method in broadband absorber design is in progress.

6. References

1. Marcuvitz, N. *Waveguide Handbook* , McGraw-Hill, New York, 1951, pp.280-285.

2. R. J. Langley and E. A. Parker, “Equivalent-circuit models for arrays of square loops,” *Electron. Lett.,* vol. 18, no. 7, pp. 294–296, 1982.

3. R. J. Langley and E. A. Parker, “Double-square frequency-selective surfaces and their equivalent circuit,” *Electron. Lett.,* vol. 19, no. 17, pp. 675–677, 1983.

4. X. F. Luo, P. T. Teo, A. Qing, and C. K. Lee, “Design of double-square loop frequency-selective surfaces using differential evolution strategy coupled with equivalent-circuit model,” *Microw. Opt. Technol. Lett.,* vol. 44, no. 2, pp. 159–163, 2005.

5. M. Li, S. Xiao, Y.-Y. Bai, and B.-Z. Wang, “An ultrathin and broadband radar absorber using resistive FSS,” *IEEE Antennas Wireless Propag. Lett.,* vol. 11, pp. 748–751, 2012.

6. F. Che Seman, R. Cahill and V. Fusco, “Performance enhancement of Salisbury screen absorber using a resistively loaded high impedance ground plane,” Proceedings of the Fourth European Conference on Antennas and Propagation (EuCAP) , Barcelona, Spain, 2010, pp. 1-5.