Wheeler Cap Measurement for Antennas Using the Genetic Algorithm

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1. INTRODUCTION

Generally, the Wheeler cap method is used to measure the efficiency of small antennas. This method often gives an unreliable efficiency when the antenna has a complicated operating principle. However, if the high-order circuit model which more closely represents the input impedance of the antenna is used in Wheeler cap method, then more accurate efficiency can be achieved. In this paper, we propose a novel method that can build the high-order circuit model using transformer circuits with the genetic algorithm (GA) [1]. To efficiently reduce the searching space in the GA and improve the convergence of the GA process, we suggest a novel scheme that finds appropriate initial values. Finally we verify the proposed method by measuring the efficiency of the microstrip antennas with triple resonances.

2. BUILDING HIGH ORDER CIRCUIT

The high order circuit model using transformers is shown in Fig. 1. The high order circuit consists of one series RLC circuit for input shown in the left side of Fig. 1 and several series RLC circuits that are connected with the input circuit by mutual coupling *M*. The impedance of each RLC circuit is defined as (1) and the total impedance of the high order circuit can be calculated as (2).

$$Z_i = R_i + j\omega L_i + \frac{1}{j\omega C_i},\ (i=1,\ 2,\ \cdots,N) \tag{1}$$

$$Z_{in} = Z_1 + \frac{\omega^2 M_2^2}{Z_2} + \frac{\omega^2 M_3^2}{Z_3} + \cdots + \frac{\omega^2 M_N^2}{Z_N} \tag{2}$$

The gradual slope of the total impedance is determined by the series circuit, Z_1 at the input terminal. Fluctuations in the total impedance at resonance frequencies are determined by mutually connected each RLC circuit. The strength of the fluctuation is determined by the amount of the mutual coupling *M*. Since the number of required transformers can be expected based on the number of resonances in the antenna impedance, the high order circuit using transformers can easily be constructed with a intuition and with a small number of lumped RLC elements.

Now the appropriate values of the lumped elements in the high order circuit are determined using the GA process which usually can find the converged solutions in a short time. However, sometimes

GA can not achieve a good result if the GA works in a large searching space with initial values that are far from the optimum solutions. So for more efficient GA process and to reduce the searching space, we propose a methodology that can determine the proper initial value as follows.

First, the RLC values of lumped elements in the input terminal can be determined using the gradual slope in frequency of the measured data as shown in (3)-(5).

$$R_1 = \left(R_{meas.}(f_1) + R_{meas.}(f_m)\right)/2 \tag{3}$$

$$j\omega(f_1)L_1 + \frac{1}{j\omega(f_1)C_1} = X_{meas.}(f_1) \tag{4}$$

$$j\omega(f_m)L_1 + \frac{1}{j\omega(f_m)C_1} = X_{meas.}(f_m) \tag{5}$$

In these equations, f_1 and f_m are the first and the last frequencies in measured data. So R_1 is determined by averaging the measured resistances at f_1 and f_m. Then L_1 and C_1 can be found by solving (4) and (5).

Next, the lumped element values of the mutually connected series circuit are determined using (6)–(8).

$$M_i = \sqrt{\frac{\left(R_{meas.}(f_i) - R_1\right) \times R_i}{(2\pi f_i)^2}} \tag{6}$$

$$L_i = \frac{M_i^2 (2\pi f_i)}{\left(X_{meas.}(f_i) - X_1(f_i)\right)} \tag{7}$$

$$C_i = \frac{1}{(2\pi f_i)^2 L_i}, \quad (i = 2,\ 3,\ \cdots,\ N) \tag{8}$$

In these equations, f_i is the frequency where the peak value occurs in the fluctuation of the measured input resistance. X_1 is the imaginary value of Z_1 using L_1, C_1, and R_1 from (3)-(5). Then L_i, C_i are lumped values of the mutually connected i-th RLC series circuit and M_i is the strength of mutual coupling between the input terminal and the transformer.

3. EFFICIENCY MEASUREMENT RESULT

After we develop the methodology of finding the appropriate initial values, we build the high order circuit for a microstrip antenna using the GA. The microstrip antenna has a 1.6 mm thick substrate (FR-4, ε_r: 4.2, tanδ: 0.02), a patch size of 60 mm × 50 mm and a feed probe locating at 15 mm and 12.5 mm from each edge, respectively. The high order circuit is built using three transformers since the antenna has triple resonances. Fig. 2 and 3 show the each step of determining the initial values. Fig. 2(a) shows input resistances of each series RLC circuit after M_i is determined to make $R_i(f_i)$ the same as $R_{meas}(f_i)$. Fig. 2(b) also shows resistances after determining L_i using (7). Then C_i is easily found from (8). Fig. 3 shows the total input impedance after determining all the initial values and it clearly shows that the proposed initial-value-find method can produce proper elements values for the high order circuit. Using those initial values in GA process we can find more accurate circuit values and the result is shown in Fig. 4. The measurement and the calculation using the circuit model are represented as dashed and dash-dotted line, respectively. Fig. 4(a) is the impedance of antenna where the antenna is placed in free-space and Fig. 4(b) is the one where the antenna is shielded using the Wheeler cap. The impedance using the circuit model matches fairly well with the measurement. The finalized high order circuit models with and without Wheeler cap are shown in Fig. 5. Parenthetical values are the lumped RLC values with the cap; whereas non-parenthetical values are element values in free-space. In the conventional Wheeler cap, the efficiency is calculated by only comparing the measured resistances (or conductances) [2], [3]. But in the modified method, the resistances in free-space can be exactly separated as the radiating and the loss resistances using high order circuits. Then, the efficiency can be calculated base on the power consumption ratios between the radiating and the loss resistances [4]. A comparison between the measured efficiency using the modified Wheeler cap method and the conventional Wheeler cap method is shown in Fig. 6. The efficiencies using the conventional method are represented by a dash line (comparing resistance) and a dash-dot line (comparing conductance), respectively. The solid-line represents the efficiency of the proposed method and the dotted-line is the efficiency computed using the IE3D EM simulator. The agreement between the efficiency using the proposed method and the simulation is apparent over a wide range of frequency.

4. CONCLUSION

In this paper, we proposed the method to model the input impedance of an antenna using the high order transformer circuit with GA. We also proposed the methodology to determine proper initial values of the high order circuit for GA optimization. The circuit model using the determined initial values and GA was very close to the measured impedance of the antenna under test. Finally, we measured the efficiency of the triple band microstrip antenna using the proposed method and the measured efficiency showed a good agreement with the simulation.

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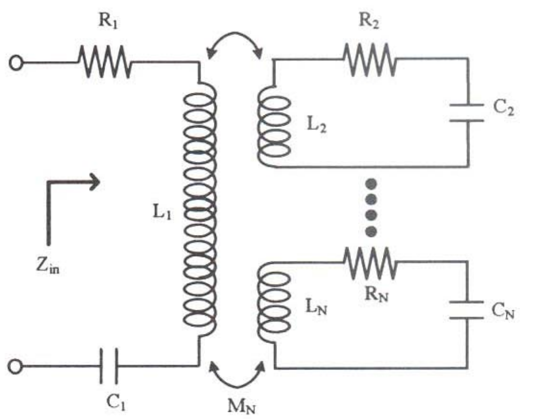

Fig. 1. The high order circuit model using transformer circuit.

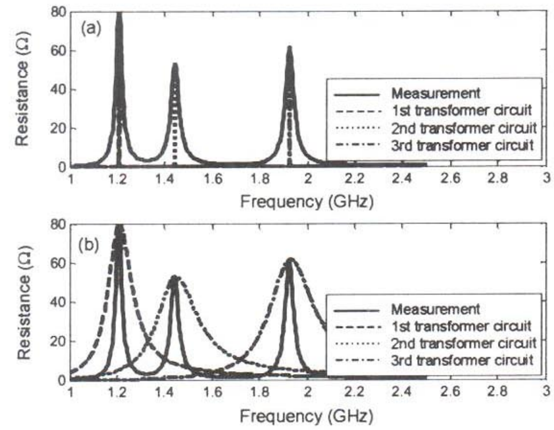

Fig. 2. The resistance of each transformer after determining (a) initial *M* (b) initial *L*

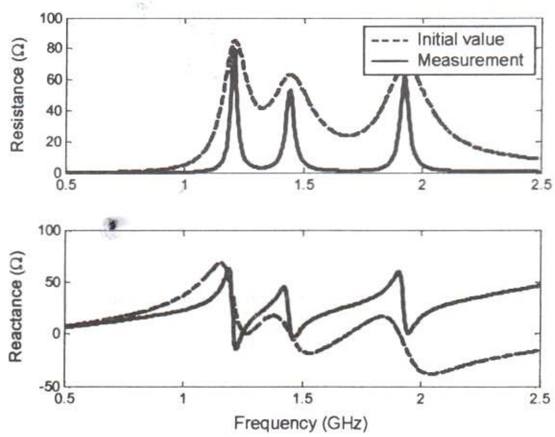

Fig. 3. The total input impedance of after determining initial values..

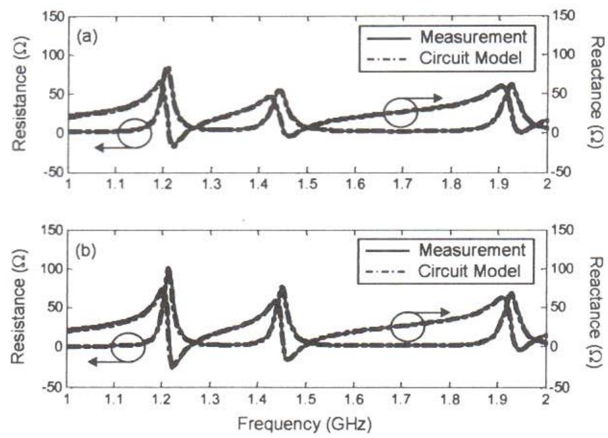

Fig. 4. The impedance of measurement and circuit model where (a) in air (b) on the cap.

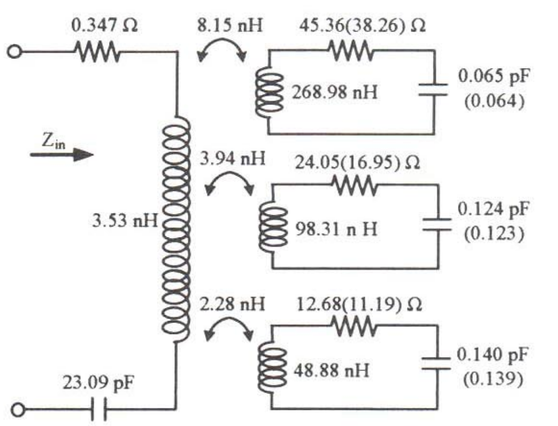

Fig. 5. The high order transformer circuit for triple band microstrip antenna.

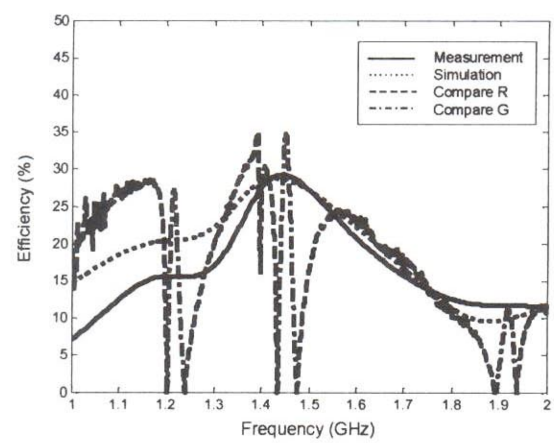

Fig. 6. Efficiency for triple band microstrip antenna.