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GENETIC ALGORITHMS AND METHOD OF MOMENTS FOR THE DESIGN OF PIFAS

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Abstract—This paper presents a novel technique for efficiently combining genetic algorithms (GA's) with method of moments (MOM) for planar inverted-F antennas (PIFAs). MOM is applied to analyze rectangular patches fed by a coaxial probe and shorted with a shorted pin. The impedance matrix of such a mother structure is, then manipulated by a GA optimization procedure in order to detect the optimal patch shape matching the required frequency properties. GA adoption enables optimal shape detection among all possible shapes allowed by the mother structure dimensions. The design example of dual-band antenna is presented, and measurement result is compared to numerical results. Excellent agreement between numerical and measured results is observed.

1. INTRODUCTION

A planar inverted-F antenna (PIFA) [1–3] is in general achieved by short-circuiting its radiation patch or wire to the antenna's ground plane with a shorting pin and can resonate at a much smaller antenna size for a fixed operating frequency. Owing to their compact size the design of PIFAs have attracted much attention, and a variety of dual-band or multi-band PIFAS suitable for applications in mobile phones have been demonstrated recently. PIFA designs usually occupy a compact volume and can be integrated within the mobile phone housing, leading to concealed or internal mobile phone antennas. Because this kind of internal antenna can avoid the damages caused by catching on things and will not break, compared with the conventional protruded whip or rod antennas used for mobile phones, it is now becoming one of the major design considerations for mobile phones. In addition, in comparison to the conventional whip antennas showing omni directional radiation, such PIFAs have the advantages of relatively smaller backward radiation toward the absorption by the user's head can be reduced.

Many novel PIFA designs [4–7], most of them capable of dual-band operation, have been applied in mobile phones in the market. They have been developed though the careful application of engineering judgment and expertise to extend the canonical designs. Either way, the development of new design is often a slow haphazard process that often yields designs that are difficult to manufacture and, therefore, unsuitable for commercial wireless antenna applications. What is needed is a new approach that allows the designer to specify design goals and then generate a candidate optimal structure in a methodical and evolutionary manner. In [8], Johnson and Samii present a novel integration of genetic algorithm and the method of moments for the design of microwave patch antennas. The integration method discussed utilizes direct manipulation of the Z-matrix (DMM) to significantly reduce the computational cost in the optimization process compared to previously reported GA/MOM. In the DMM approach, a mother structure is selected. The GA optimization then searches for an optimal substructure contained thin the mother structure that comes closest to meeting the sign goals.

In this paper antenna analysis is performed by using the electric field integral equation formulation together with a MoM numerical procedure exploiting RWG triangular discretization with a coaxial feed pin. After a convergence test, the implemented numerical code is integrated as an analysis module in a more general code, which allows to design PIFAs matching some specific requirements. MOM module analyses the so-called mother structure and computes the associated impedance matrix. Depending on the patch dimensions and on the discretization scale chosen by the user, it is possible to extract a certain number of sub-structures by metal removal from the mother one. In order to find the optimal patch shape which fully matches the given requirements, the research operation is demanded to a GA module to allow determination of the optimal patch shape without trying all the possible sub-structures and avoid local maximum trapping risks, as may happen when adapting research based on gradient methods.

2. MODELING PIFAS WITH MOM BASED ON RWG BASIS FUNCTION

The Rao-Wilton-Glisson (RWG) basis functions on triangles are used in the present study. The basis function in Fig. 1 includes a pair of adjacent (not necessarily co-planar) triangles and resembles a small spatial dipole with linear current distribution where each triangle is associated with either positive or negative charge.

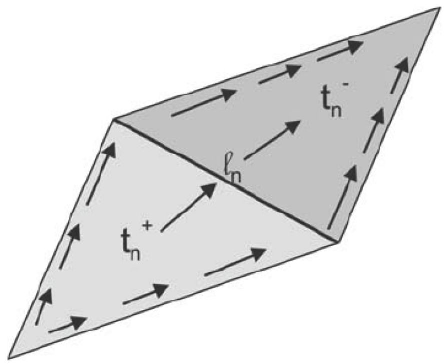


Figure 1. A pair of adjacent triangles used for RWG basis function.

Below, we recall some properties of the most common basis functions. For any two triangular patches, t_n^+ and t_n^-, having areas A_n^+ and A_n^-, and sharing a common edge l_n, the basis function becomes

$$\boldsymbol{f}_n(\mathbf{r}) = \begin{cases} \dfrac{l_n}{2A_n^+}\boldsymbol{\rho}_n^+ & \mathbf{r} \text{ in } t_n^+ \\ \\ \dfrac{l_n}{2A_n^-}\boldsymbol{\rho}_n^- & \mathbf{r} \text{ in } t_n^- \end{cases} \tag{1}$$

and

$$\nabla \cdot \boldsymbol{f}_n^M(\mathbf{r}) = \begin{cases} \dfrac{l_n}{A_n^+} & \mathbf{r} \text{ in } t_n^+ \\ \\ -\dfrac{l_n}{A_n^-} & \mathbf{r} \text{ in } t_n^- \end{cases} \tag{2}$$

where $\boldsymbol{\rho}_n^+ = \mathbf{r} - \mathbf{r}_n^+$ is the vector drawn from the free vertex of triangle t_n^+ to the observation point $\mathbf{r}$; $\boldsymbol{\rho}_n^- = \mathbf{r}_n^- - \mathbf{r}$ is the vector drawn from the observation point to the free vertex of triangle t_n^-. The basis function is zero outside the two adjacent triangles t_n^+ and t_n^-. The RWG vector basis function is linear and has no flux through its boundary.

Scattering or radiation problems are essentially identical- the only difference is that the 'incident' field for the driven antenna is the applied electric field in the feed. The total electric filed is a combination of the incident field and the scattered field,

$$\mathbf{E} = \mathbf{E}^i + \mathbf{E}^s \tag{3}$$

The incident electric field is either the incoming signal or the excitation electric field ion the antenna feed. The scattered electric field $\mathbf{E}^s$ is due to surface currents and free charges on the metal surface S,

$$\mathbf{E} = -j\omega\mathbf{A}(\mathbf{r}) - \nabla\Phi(\mathbf{r}) \quad \mathbf{r} \text{ on } S \tag{4}$$

The magnetic vector potential $\mathbf{A(r)}$ describes surface current radiation whereas the electric potential $\Phi(\mathbf{r})$ describes radiation of surface free charges. In the far field, both the Φ-contribution and the $\mathbf{A}$-contribution are equally important. On the metal surface S, the tangential component of the total electric field vanishes, $\mathbf{E}_{\tan} = 0$, thus giving the electric field integral equations,

$$\mathbf{E}^i_{\tan} = (j\omega\mathbf{A} + \nabla\Phi)_{\tan} \quad \mathbf{r} \in S \tag{5}$$

Assume that the test functions, $\boldsymbol{f}_m$, $m = 1 \dots N$, cover the entire surface S and do not have a component normal to the surface. Multiplication of Eq. (3) by $\boldsymbol{f}_m$ and integration over S gives N equations

$$< \boldsymbol{f}_m, \mathbf{E}^i >= j\omega < \boldsymbol{f}_m, \mathbf{A} > - < \nabla \cdot \boldsymbol{f}_m, \Phi > \tag{6}$$

The surface current density, $\mathbf{J}$ is expanded into the basis functions in the form $\mathbf{J} = \sum\limits_{n=1}^{N} \mathbf{I}_n \boldsymbol{f}_n$, and using $\boldsymbol{f}_m$ $(m = 1, 2, \dots N)$ as a test function, the moment equations are obtained below:

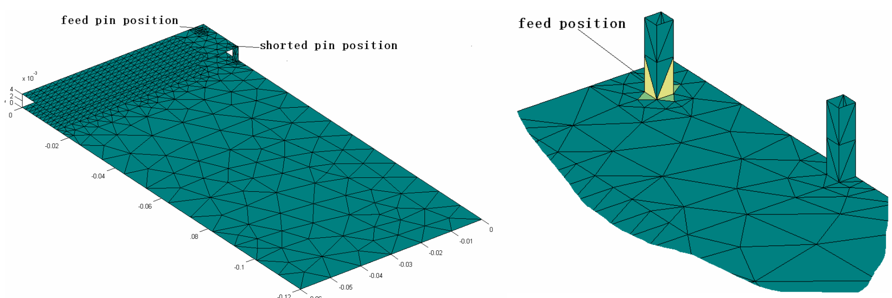
$$ZI = V \tag{7}$$

where $V = \int\limits_S \boldsymbol{f}_m \cdot \mathbf{E}^i ds$.

$$\begin{aligned} Z_{mn} &= \frac{j\omega\mu_0}{4\pi} \int\limits_S \int\limits_S \boldsymbol{f}_m(\mathbf{r}) \cdot \boldsymbol{f}_n(\mathbf{r}') g ds' ds \\ &\quad - \frac{j}{4\pi\omega\varepsilon_0} \int\limits_S \int\limits_S (\nabla \cdot \boldsymbol{f}_m(\mathbf{r}))(\nabla \cdot \boldsymbol{f}_n(\mathbf{r}')) g ds' ds \end{aligned} \tag{8}$$

The square impedance matrix determines electromagnetic interaction between different edge elements. If edge elements m and n are treated as small but finite electric dipoles, the matrix element Z_{mn} describes the contribution of dipole n to the electric current of dipole m, and vice versa.

To design the multifrenquency PIFAs, firstly the mother structure must be carefully molding. The size of top patch size is 60 mm × 15 mm, and the size of ground plane is 60 mm × 120 mm. The opposite position is shown is Fig. 2(a). The mother structure is selected by practical factors such as the dimension of the handsets or the practical feeding points, etc. In the practical PIFA modeling, the feeding area shall be noticed seriously because PIFAs are very sensitive to the feeding area. In this paper, the coaxial probe feed style is used. The modeling of PIFA is present in Fig. 2 as a 'mother' structure. Fig. 2(b) shows the feed model we used in this paper. The feed model is the voltage gap for every feeding edge of a metal column (shown in yellow color in Fig. 2(b)). Here $\varepsilon_r = 1$ according with the practical design requirements of handset antennas. Here Matlab is used to create the antenna structure [9]. Matlab provides several ways of doing so. One way is to use the building-in mesh generator of the Matlab PDE toolbox. This mesh generator creates planar structures of graphical user interface (GUI). To extend the design to a 3D structure, it is usually enough to write a short Matlab script involving the z-coordinate dependency. The model is used by this way.



(a) (b)

Figure 2. The antenna structure modeling built by matlab.

3. GA/MOM INTEGRATION

As discussed previously, the goal here is to develop a method for generation an optimal or near optimal antenna structure. The approach that is adopted in the GA/MOM is to begin with a mother structure through an iterative GA [10–14] search with MoM as a basic analytical method.

To achieve the optimized goals, GA is implemented as an optimizer for the PIFA's patch shapes. The algorithm starts an initial population of shapes that are encoded as chromosomes. After theses chromosomes are evaluated by MoM, a cost function is computed. According to the cost function, the chromosomes are refined into the next generation through a reproduction process that includes crossover and mutation. This series of process are repeated until the cost function is minimized. In this GA process, each patch shape is represented as a binary bitmap. In the resulting chromosome, ones represent the metallized areas and zeros represent the areas without metal, just shown in Fig. 3.

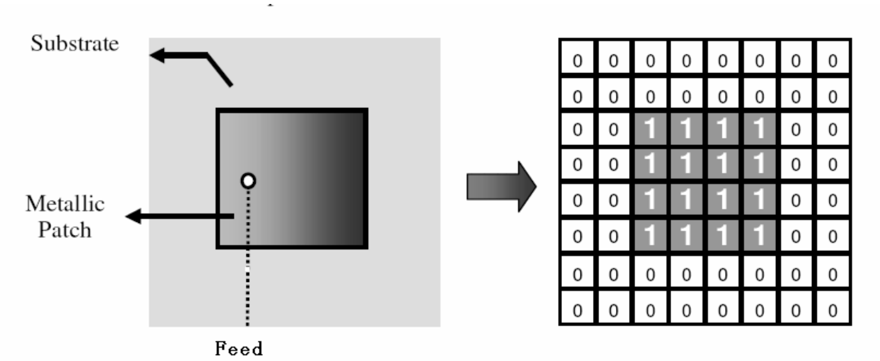


Figure 3. Encoding of patch shapes for antenna shape optimization.

For GA/MoM, let the substructures allowed in the search space be those that can be produced by removing metal of the original structure. Removal of a portion of the metal is equivalent to forcing the current regions to zero, leaving rows and columns in the Z-matrix filled with zeros. In practice, these zero rows and columns in the Z-matrix makes the matrix singular. Since the direct analysis of a given substructure by MoM would simply not include regions without metal, it is quickly realized that the substructure Z-matrix can be produced from the mother Z-matrix by removing the rows and columns associated with the removed metal. The removal of these rows and columns leaves a nonsingular matrix that can be used to find the unknown currents on the substructure. In this method, a mother Z-matrix is constructed that includes the presence of metal everywhere that metal might allowed to be. All possible structures that can be constructed from this mother configuration then become substructures of this mother configuration. The Z-matrices of these subset configurations likewise are realized to be submatrices of the mother Z-matrix. Put simply, the Z-mother structure can be derived from that of the mother structure by simply removing the rows and columns of the matrix corresponding to the pieces of metal that are being removed. The remaining matrix elements are unchanged by this removal of elements. An exception to this rule is that the matrix elements that are formed by junctions between wire segments and metal patches. This exception is easily over come by excluding these 'dependent' rows and columns from the group of removable rows and columns. That means some structures in the model are not changed for ever through the optimal procedure.

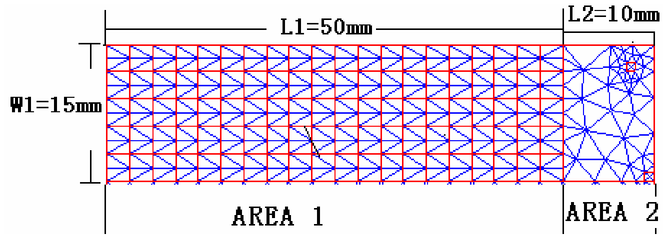


Figure 4. The optimized area and immovable area.

In this paper, the patch area is divided to two parts, shown in below. AREA 1 is to be optimized, and AREA 2 with feed pin and shorted pin junctions is immovable in the whole optimal process. In Fig. 4, the mesh size and mesh shape is very important. Two small rectangles within the patch are created to refine the mesh close to the feed pin and shorted pin respectively.

4. NUMERICAL RESULTS AND MEASUREMENT RESULTS

Before utilizing the optimized procedure to design multi-frequency PIFAs at prescribed frequencies, the MoM numerical convergence has been firstly tested. The top patch with 4 mm height above the ground plan is discretized into 20×10 grid for the chromosome definition.

The next step is using GA/MoM to find the optimal patch shape. In this paper, the following fitness function is adopted,

$$fitness = \max(20 \log_{10}(S_{11})) \tag{9}$$

where S_{11} is the amplitude of the reflection coefficient at the input port and N_f is the number of frequencies required for a multi-frequency operation. In the case of a dual-band design $N_f = 2$. The optimized goal is to find the minimum of fitness.

As an example of the application of the GA/MoM, design methodologies consider the design of a dual-band PIFA antenna. Such dual band antennas would be useful in GSM/DCS dual-mode handsets or PDAs. In the case presented here, the design goal was to produce a

PIFA that have a good match at two frequencies-0.9 GHz and 1.8 GHz. Start with the above PIFA just studied, the GA/MOM optimization was applied with the goal of minimizing the return loss at the two design frequencies. The size of population is selected as 100, and the general optimal step number is set to 100. The crossover ratio in GA is set to 0.8 and mutation ratio is set to 0.05. The best individual from the GA/MoM optimization in terms of patch shape and magnitude S_{11} along with the measured return loss are respectively shown in Fig. 5 and Fig. 6.

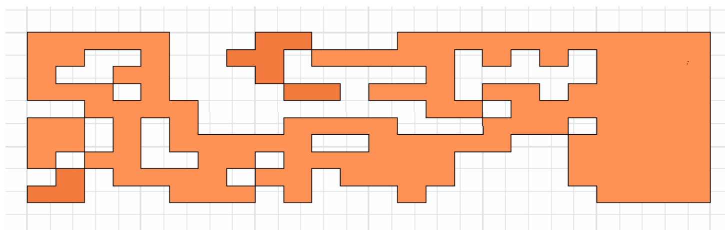


Figure 5. The top patch's shape of PIFA obtained by GA.

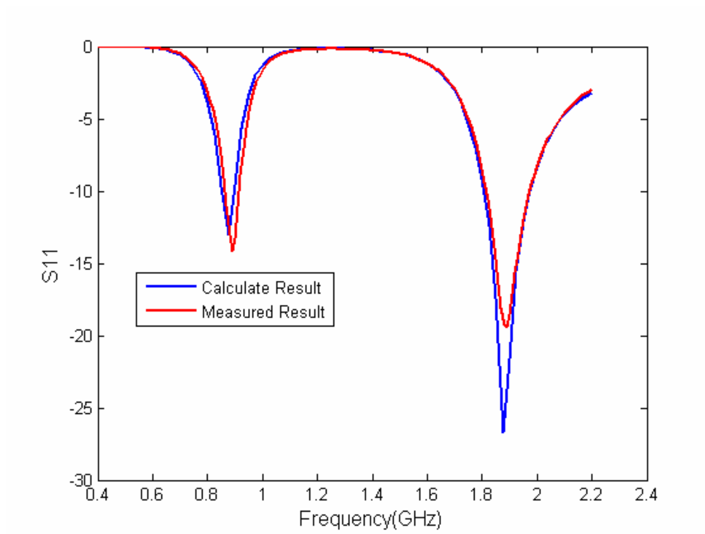


Figure 6. The measured result and calculate result.

5. CONCLUSIONS

A numerical code for multifrequency antenna design has been presented in this paper. This code employs MoM and GA to find the optimal patch shape for PIFAs, starting from a rectangular geometry discretized with a user-chosen detail level. The entire synthesis process is wholly automatic, allowing a user of whatever skill level to carry out satisfactory multifrenquency designs.

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