Multifrequency Metallo-Material Antenna Optimization

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Introduction
Antenna design involves the selection of physical antenna parameters to achieve optimal gain, pattern performance, input impedance and bandwidth requirements subject to specific constraints. Over the past few years, several approaches have been employed to facilitate antenna design by integrating analysis tools with formal optimizers. For the latter, evolutionary optimization algorithms [1], [2] have typically dominated the design sector. However, so far, most design emphasis has been on size and shape optimization rather than material optimization, even though materials provide greater design flexibility. In the few cases that material optimization was pursued, only partial dielectric variations [3] were examined leaving out a large “design space” that would emerge from novel magnetic materials.

A mixture of dielectric and magnetic materials can offer even more advantages by enabling improved antenna impedance matching. To our knowledge, we are not aware of publications that have exploited concurrent material, shape and size optimization. For the first time, this work deals with conformal magneto-dielectric patch antenna designs that concurrently optimize material regions and metallization. This is done by integrating Genetic Algorithms (GA) [4] in conjunction with a rigorous, well verified and fast Finite-Element Boundary-Integral code (FE-BI) [5]. Typically, the GA portion is responsible for changing the geometry including its metallization, magnetic and dielectric materials based on bandwidth, gain and resonant frequency for the cases provided by the FE-BI code. An interface was built to carry out the communication between the optimizer and the solver and extract the intermediate results. We will demonstrate various optimized designs using combinations of dielectric, metallic and magnetic materials. Indeed, we show that certain material combinations provide for truly outstanding performance.

Optimization Algorithm
The optimization procedure used is based on the Genetic Algorithms (GA). GA optimizers are directly connected with the Darwinian concepts of natural selection and evolution. A brief description of the GA key elements is as follows: First, the parameters of each design (called chromosome) are encoded as a string of bits. Typically, the first group of chromosomes (first generation) is created randomly while their fitness is determined by the objective function. Mating of the available chromosomes (which are selected based on their fitness) leads to a new generation. Crossover and mutation are typically used to globally explore the design space and to avoid stagnation. As part of the process, the best chromosome(s) pass unchanged to the next generation (elitism). The process of creating new generations continues till a stop criterion is reached.

Fig. 1, shows the process for a magneto-dielectric optimization. It refers to a printed antenna on a textured substrate (consisting of magnetic and dielectric materials). Thus Fig. 1 shows two different mesh categories. The first (higher) rectangular mesh refers to the
metallization patterning of the antenna and the second (lower) mesh is associated with different material areas. The inclusion of a 3rd category for specifying R-L-C circuits or vertical pins may be another option. We remark that in the top (metallic) mesh there are 3 groups. The black areas represent constant metallic elements whereas the white refer to non metallic regions and colored areas represent surfaces to be optimized. For the lower (material) mesh the colored volume cells represent different dielectric and magnetic material options including air.

Based on this setting, each chromosome contains two parts: one refers to the metallization and the other to the material coding. The metallization chromosome part is a series of single dyadic bits, each bit representing one surface element (the colored part of the higher mesh) and 1 or 0 implying metallic or non metallic area. The material chromosome part is a series of binary bit groups. Each group represents one colored volume of the mesh while the size of each group is determined by the number of different materials being used. For instance, 4 materials need a group of two binary bits for each volume of the mesh.

Once the mesh is created and coded, the solver (see Fig. 1) proceeds to calculate the gain, bandwidth and resonance frequency for a set of material/metal combinations. Each run is then classified according to its resonance frequency and sorted with respect to bandwidth. Gain determines its fitness. Although one single fitness function is used (gain), this is a multi-objective optimization since various criteria are used together (bandwidth and size). The final geometries correspond to multiple best solutions by means of electric size, bandwidth and gain.

Results presentation and handling
Numerous runs were carried out by designing and optimizing various circular and linear polarized metallo-dielectric and metallo-magneto-dielectric designs. Since three parame-

Fig. 1. General optimization scheme for a GA run

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tors (bandwidth, gain and size) are concurrently optimized a major challenge was the presentation of performance parameters and corresponding geometries in a clear and conclusive fashion.

The presentation of the optimized cases was major issue that consumed great effort. We consider an example below to describe the chosen presentation format. It refers to a single layer bow-tie (quad symmetrical) dielectric CP antenna for operation within 1-3GHz (see Fig. 2). Two different material distributions where considered, one with 13 regions (Fig. 2b) and another with 32 (Fig. 2c) regions per quad. The key issue in interpreting the data was finding a clear graphical representation that allowed visualization of the compromises among size, bandwidth and gain. For example one choice (see Fig. 3 leftmost) was to present the cases versus size corresponding to gains above 0 dB. One could then choose to look further into the geometry and bandwidth detail for a given gain value (see Fig. 3 rightmost). Another choice was to provide a 3D representation of the choices among gain, bandwidth and size (see Fig. 3 middle). However, even this chart was found difficult to use and process further since often good data could not be quickly “mined” visually and selected for further review.

After several iterations for best visualization, we found that the 2D colormap in Fig. 4 is most useful. In this chart, we show all collected solutions of the gain versus bandwidth by color “dots”. The key difference in comparison to the 3D plot in Fig. 3 (middle) is that size (thickness) of the antenna is color coded. Thus, one can readily see that the small size antennas are in blue whereas the largest size ones are in red. If the restriction is on a max size, one can then make quick choices on the geometries of interest to be examined further. For example we can manually pick the case with largest bandwidth and smallest thickness that has concurrently exhibited a gain higher than 5dB. This case is identified in Fig. 4 (middle of the graph) with the marking “case of interest”. This case corresponds to a gain of 5.91 dBi, a bandwidth of 8% at 1.25 GHz and is only 0.025λ thick. The geometrical and material details for this design are shown in Fig. 5. Many other optimized designs with impressive performance and sizes 0.1λx0.1λ in aperture (including the finite ground plane) will be presented at the meeting.

![Probe Locations](image1)

**Fig. 2.** PEC (a) and dielectric (b), (c) maps for bowtie CP design using dielectric and metallic optimizations (axes in cm)

![3D chart](image2)

**Fig. 3.** Results of optimizing geometry of Fig. 2 are presented in various ways
**Conclusions**

We presented a novel multi-frequency antenna optimization algorithm to achieve novel metallo-material (magnetic and dielectric) conformal antenna designs. For the first time, combinations of dielectric, magnetic and metallic materials were concurrently modified volumetrically subject to multi-objective optimization criteria. An aggressive optimization scheme using genetic algorithms in conjunction with a fast finite-element boundary-integral code was employed. Interpretation of the multi-objective outputs was found a key issue. The presented color-coded graphs allowed for quick and efficient evaluation of the best/optimized cases. At the meeting, we will demonstrate various optimized designs and show specific designs that exhibit truly outstanding performance.

**References:**


