Synthesizing Broadband Low-loss Artificially Engineered Materials (Aka Metamaterials) for Antenna Applications

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***Abstract*—In this work, we discuss ways to mitigate several problem with Metamaterials (MTMs), and discuss strategies for artificially synthesizing dielectric materials that are broadband and low-loss and, hence, are useful for real-world antenna applications involving low-profile flat lenses and reflectarrays, for example.**

I. INTRODUCTION

Metamaterials (MTMs) were originally introduced as supplements to naturally found dielectric materials, with the promise that they would vastly enlarge the parameter range of natural materials and would thus provide a way to achieve exotic material properties such as double-negativity and zero-index characteristics that are not found in nature. What prompted a precipitous surge of interest in MTMs in the early days was their promise of achieving high-resolution lenses, high-gain antennas with only moderate-size apertures, and even small antennas with wide bandwidths. However, it was soon discovered by researchers in the field that while such properties were indeed achieved by MTMs, it was not without the cost of narrowing the bandwidths–sometimes severely–increasing the losses and lowering the antenna efficiency, also sometimes significantly.

In this work, we discuss ways to mitigate these problems with MTMs, and discuss strategies for artificially synthesizing dielectric materials that are broadband and low–loss and, hence, are useful for real-world antenna applications involving low-profile flat lenses and reflectarrays, for example. The key to circumventing the difficulties with MTM, which we have identified above, is to steer clear of the common practice of using resonant inclusions or “particles” to achieve extreme material properties, such as $\gg 1; \ll 1$; negative index; and, zero index. Our strategy is to develop antenna designs that only call for material parameters that are realistic, so that they can either be acquired off-the-shelf, or by slightly tweaking the available materials by embedding small patches or apertures, often referred to as “particles”, whose dimensions are well removed from the resonance range, thus obviating the problems of dispersion, narrow bandwidths and losses that plague the MTMs, at least those fall in the “exotic” category, e.g., the double–negative or DNG type.

II. DESIGNS

We present here two examples to illustrate how to carry out the synthesis of the artificial dielectrics, both the single-layer and multilayer types-the latter to achieve better control including matching.

It would also include the designs of flat lenses and reflectarrays and a comparison of their performances with those of some of the existing designs.

A. Flat Lens Design

The design parameters chosen for the Ray Optics (RO) lens (see Fig. 1) are: f (center frequency) = 30GHz; h (thickness) = 9mm and F/D = 0.2. As per the gain requirement the diameter D of the lens is chosen to be 63.5mm. The diameter of lens is divided in 10 discrete rings in radial direction with the width of each ring to be 3.175mm (see Fig. 2). The dielectric constants calculated for these rings satisfy the path length condition which is shown in Table I. These dielectric constants were also modified to develop the Zone-Plate version of the lens. We can clearly see that all of these materials may not be commercially available. We have listed some of the most common commercially available dielectric materials in Table II. We employ a unique technique for engineering artificial materials or COTS (commercial off-the-shelf) materials to achieve the dielectric parameters we need for implementing our design, i.e., dial-a-dielectric (DaD). The dial-a-dielectric method is the one in which we tweak the artificial material by placing the square patches on top of dielectric rings as shown in Fig. 3, to achieve the desired dielectric constants. The novelty of this method is that this method does not depend on resonance properties of patches to determine the dielectric constants and hence it does not suffer from the issues of bandwidth and losses as it normally occurs with the other type of methods. The key concept behind the low-loss design is that the patch dimensions are varied very little with combination of artificial material to achieve the transmission phase equal to the actual dielectric layers transmission phase.

TABLE I
MATERIAL PARAMETERS OF RO LENS.

ϵ_{r1}	ϵ_{r2}	ϵ_{r3}	ϵ_{r4}	ϵ_{r5}	ϵ_{r6}	ϵ_{r7}	ϵ_{r8}	ϵ_{r9}	ϵ_{r10}
11.15	11.64	9.8	8.7	7.45	6.15	4.88	3.7	2.64	1.73

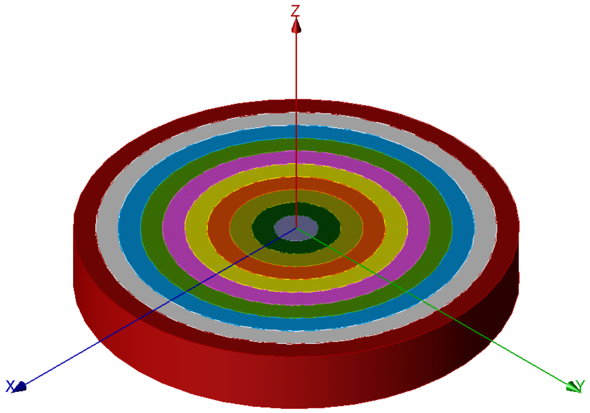

Fig. 1. RO Lens.

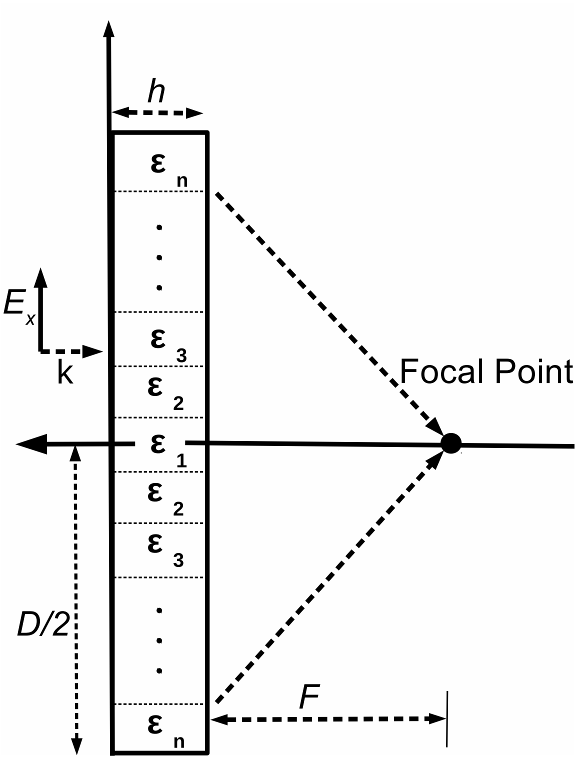

Fig. 2. Design principle.

B. Reflectarray Antenna Design

The reflectarray antenna is designed to work in Ku-band (12–18GHz) with 15GHz as center frequency. Other design parameters (see Fig. 4) chosen are: H (feed height) = 129.79mm; A_x (=A_y) (aperture size) = 210mm and t (dielectric thickness) = 30mm. The proposed design features PEC sheet covered by dielectric blocks . The feed horn illuminates the PEC backed dielectric blocks and sends the radiation in specular direction. Different colors in the figures signify the different values of dielectrics used in the design.

TABLE II
COTS DIELECTRIC MATERIALS USED FOR LENS DESIGN

1.96	2.17	3	4.5	6	9.2	10.2
	2.2	3.02	4.7	6.15	9.8	
	2.33	3.2				
	2.5	3.27				
	2.75	3.55				
	2.94	3.6				
		3.66				

III. RESULTS

Different kinds of lenses were designed using approach mentioned in [2]–[5] and their gains were compared with flat lens design based on Transformation Optics (TO) based approach stated in [1] for which the plots are shown in 5. It is clear from the plot that RO DaD lens (with patches) shows better performance compared to other lenses i.e. gain is comparatively higher than other techniques, specially TO lens.

On the other hand, the offset-fed reflectarray antenna design is also promising. We find (see Fig. 6) that the placement of dielectric blocks on PEC has enhanced the gain in desired direction. The antenna gain is higher throughout the frequency range with dielectrics blocks as compared to without dielectrics (see Fig. 7).

IV. CONCLUSIONS

We have shown here two different kinds of designs one which is ray-optics-based DaD (dial-a-dielectric) lens, and other one as offset fed reflectarray antenna which is made only using dielectric blocks rather than the conventional approach of patch printed on dielectrics for controlling the phase.

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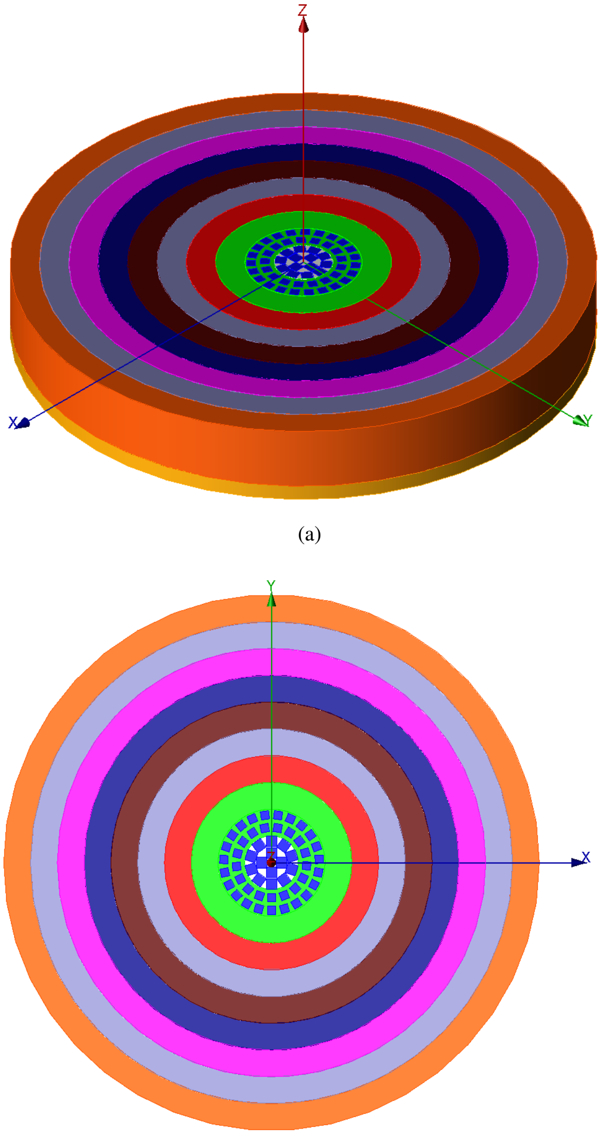
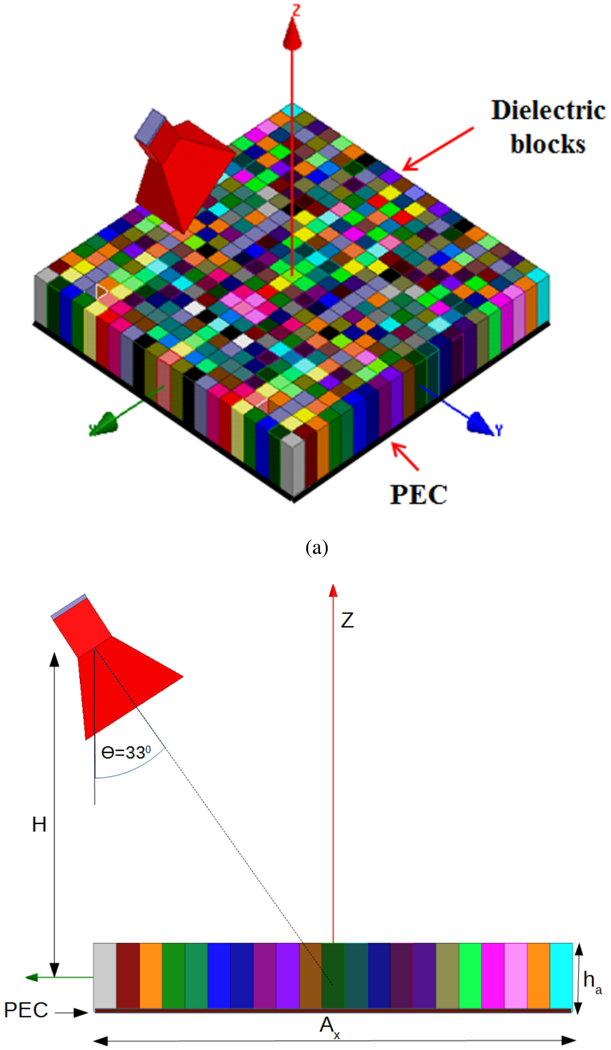


(a)

(b)

Fig. 3. (a) Isometric view (b) Top view of Lens Design



(a)

(b)

Fig. 4. (a) Isometric view (b) Side view of Proposed Reflectarray Design

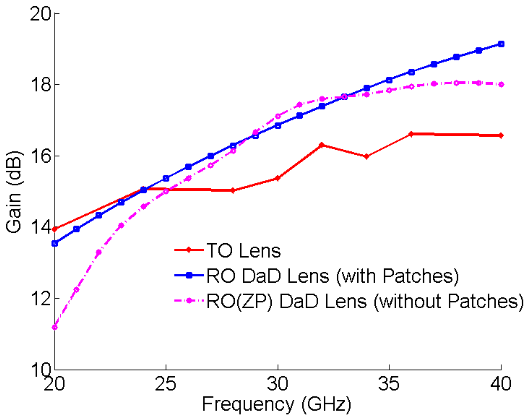


Fig. 5. Gain Comparison of Different Lenses

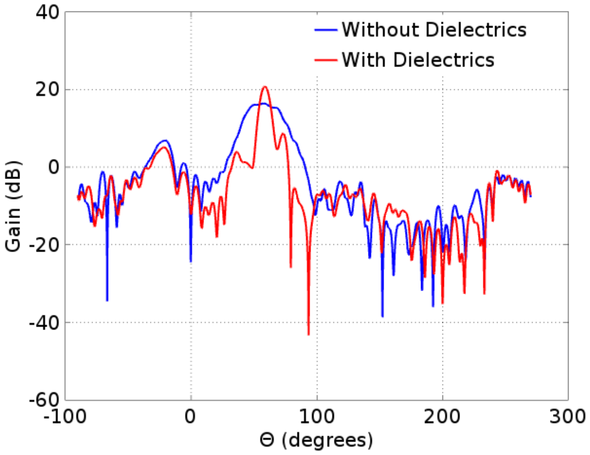


Fig. 6. Reflectarray Radiation Pattern with and without dielectric blocks

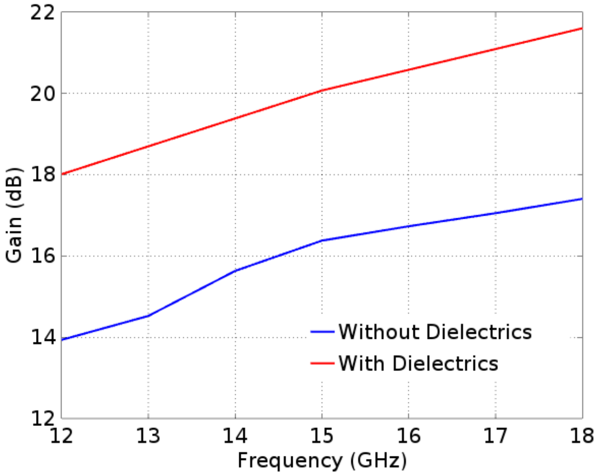


Fig. 7. Reflectarray Gain with and without dielectric blocks