A Novel Shaped Symmetric Wideband Dielectric Resonator Antenna by Binary Material Optimization

Trupti Bellundagi and Binbin Yang

North Carolina Agricultural and Technical State University, North carolina, 27408, USA. byang1@ncat.edu

***Abstract*— This paper presents a novel approach to design Wideband Dielectric Resonator Antennas (DRA) with distinctive shape by leveraging binary material optimization. In this method, a traditional solid bulk DRA structure was partitioned into multiple smaller blocks, each assigned with a unique permittivity variable. This allocation was carefully orchestrated to ensure a symmetrical material distribution within the resonator. A genetic algorithm was employed to optimize the material profile, leading to the creation of a newly shaped DRA. The proposed design yields an impressive 104% fractional bandwidth covering the frequency range from 4.54 to 14.41 GHz at $S_{11} = -10\ dB$ with peak gain of 5.1 dB. This bandwidth represents a significant improvement over the original bulk DRA design, Showcasing the effectiveness and potential of the binary material optimization technique in enhancing antenna performance.**

Keywords—Dielectric Resonator Antenna (DRA), genetic Algorithm, Shape Synthesis

I. INTRODUCTION

Dielectric resonator antennas are compact, high frequency antennas known for their efficient radiation characteristics. They utilize a dielectric resonator, typically ceramic or crystalline, to enhance electromagnetic wave coupling. DRAs are favored for their low profile and excellent impedance matching, making them ideal for various wireless communication applications. Especially wideband DRAs find extensive application in broadband wireless communication systems, radar systems, and satellite communication systems. Additionally, these antennas play a crucial role in electronic warfare systems, enabling jamming and signal interception across a broad spectrum of frequencies. Their unique design properties continue to make DRAs a valuable choice in modern antenna technology.

Numerous techniques have been suggested in the past to enhance the bandwidth of DRAs. These methods include material optimization [1], geometrical optimization [2,3], fractal DRA [4], multi segmented DRA [5] and Stacked DRA [6]. Surprisingly, there has been limited exploration on shape optimization by varying material distribution within DRAs. In this work, we developed a DRA with unique shape, achieved by optimizing its material selection, resulting in wide bandwidth. Additionally, we incorporated fillets to facilitate easy 3D printing.

II DESIGN OF NOVEL SHAPED DRA BY BINARY MATERIAL OPTIMIZATION

In our previous work [1], wideband DRAs with varying material spatial distributions were explored, where materials

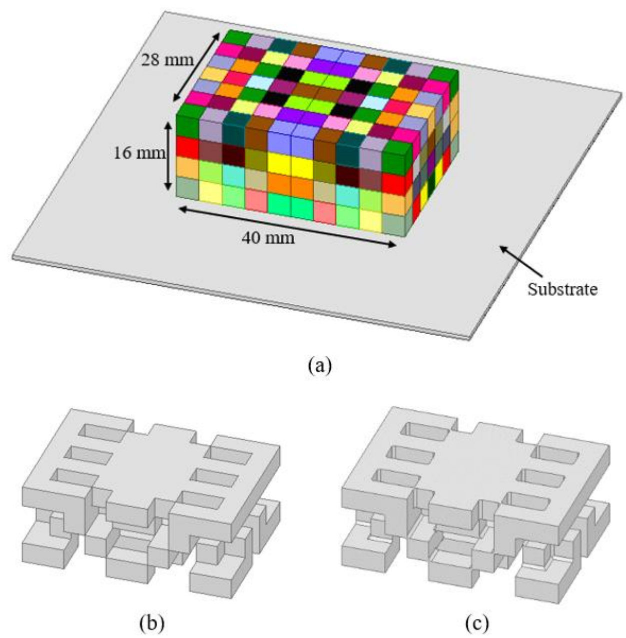
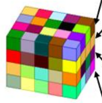


Figure 1 Proposed DRA Model (a) Rectangular DRA divided into sub-blocks (b) Optimized novel DRA (c) optimized DRA with fillets.

in the DRA sub-blocks are allowed to vary continuously. In this work, we extend the design methodology to a binary case, where the material in each sub-block is limited to a binary option. The starting geometry of the antenna is a conventional rectangular dielectric block with the dimension of $40\times28\times16\ mm^3$. By enforcing two planes of symmetry, the antenna is divided into four equal quadrants. Each quadrant was further subdivided into 80 small cubes, each measuring 4 mm in size. Subsequently, we assigned 80 different binary permittivity variables to the cubes in the first quadrant. These same permittivity variables were symmetrically mirrored in the remaining three quadrants, as visually depicted in Figure 1. The material in each small cube takes a binary value of 1 for air or 7.2 for Alumina. The permittivity of 7.2 for Alumina is obtained based on our experimental characterization of a 3D-printed alumina sample after sintering. The DRA is mounted onto a Rogers RO4350 substrate with a thickness of 0.76 mm, and a coaxial probe with a height of 7 mm was used to feed the DRA at its center.

The antenna is then subject to a binrary optimization process using a genetic algorithm, with a population size of 50 and a mutation rate of 0.2. After 700 generations of evolutionary search, an optimal design is arrived at and the corresponding permittivity distributions are listed in table 1,

Table 1. Dielectric constants of each sub-block after optimization

	Fourth Layer	$\varepsilon_{61}=7.2$	$\varepsilon_{62}=7.2$	$\varepsilon_{63}=7.2$	$\varepsilon_{64}=1$	$\varepsilon_{65}=7.2$
		$\varepsilon_{66}=7.2$	$\varepsilon_{67}=7.2$	$\varepsilon_{68}=1$	$\varepsilon_{69}=1$	$\varepsilon_{70}=7.2$
		$\varepsilon_{71}=7.2$	$\varepsilon_{72}=7.2$	$\varepsilon_{73}=7.2$	$\varepsilon_{74}=7.2$	$\varepsilon_{75}=7.2$
		$\varepsilon_{76}=7.2$	$\varepsilon_{77}=7.2$	$\varepsilon_{78}=1$	$\varepsilon_{79}=1$	$\varepsilon_{80}=7.2$
	Third Layer	$\varepsilon_{41}=1$	$\varepsilon_{42}=1$	$\varepsilon_{43}=7.2$	$\varepsilon_{44}=1$	$\varepsilon_{45}=1$
		$\varepsilon_{46}=7.2$	$\varepsilon_{47}=1$	$\varepsilon_{48}=7.2$	$\varepsilon_{49}=1$	$\varepsilon_{50}=1$
 1st Quarter of whole DRA Model		$\varepsilon_{51}=1$	$\varepsilon_{52}=7.2$	$\varepsilon_{53}=1$	$\varepsilon_{54}=1$	$\varepsilon_{55}=1$
		$\varepsilon_{56}=7.2$	$\varepsilon_{57}=1$	$\varepsilon_{58}=7.2$	$\varepsilon_{59}=7.2$	$\varepsilon_{60}=1$
	Second Layer	$\varepsilon_{21}=1$	$\varepsilon_{22}=1$	$\varepsilon_{23}=1$	$\varepsilon_{24}=7.2$	$\varepsilon_{25}=1$
		$\varepsilon_{26}=1$	$\varepsilon_{27}=7.2$	$\varepsilon_{28}=1$	$\varepsilon_{29}=7.2$	$\varepsilon_{30}=1$
		$\varepsilon_{31}=7.2$	$\varepsilon_{32}=1$	$\varepsilon_{33}=1$	$\varepsilon_{34}=1$	$\varepsilon_{35}=1$
		$\varepsilon_{36}=1$	$\varepsilon_{37}=1$	$\varepsilon_{38}=7.2$	$\varepsilon_{39}=7.2$	$\varepsilon_{40}=1$
	First Layer	$\varepsilon_{1}=7.2$	$\varepsilon_{2}=7.2$	$\varepsilon_{3}=1$	$\varepsilon_{4}=1$	$\varepsilon_{5}=7.2$
		$\varepsilon_{6}=1$	$\varepsilon_{7}=1$	$\varepsilon_{8}=1$	$\varepsilon_{9}=7.2$	$\varepsilon_{10}=7.2$
		$\varepsilon_{11}=7.2$	$\varepsilon_{12}=1$	$\varepsilon_{13}=1$	$\varepsilon_{14}=7.2$	$\varepsilon_{15}=7.2$
		$\varepsilon_{16}=7.2$	$\varepsilon_{17}=7.2$	$\varepsilon_{18}=1$	$\varepsilon_{19}=1$	$\varepsilon_{20}=1$

where a permittivity of 1 represents air, and a permittivity of 7.2 indicated an alumina block. By combinations of these permittivity values, we were able to generate a novel, wideband DRA with a distinct shape, as illustrated in Figure 1b.

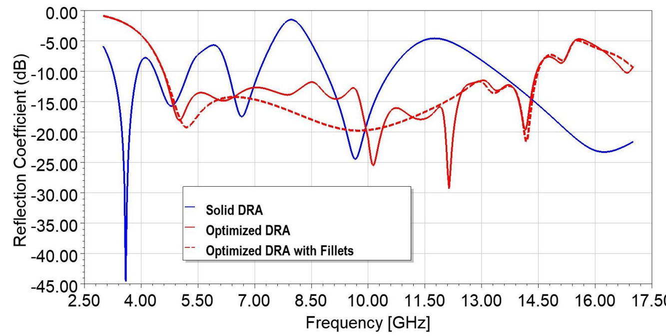
In Figure 1.b, we observe that certain blocks are merely in contact along their edges, while others form right angles with each other. These intricate geometries pose challenges when attempting to achieve high-quality 3D prints with alumina material. To address this issue, we introduced 0.5mm radius fillets at the edges, as depicted in Figure 1.c.

III SIMULATION RESULTS

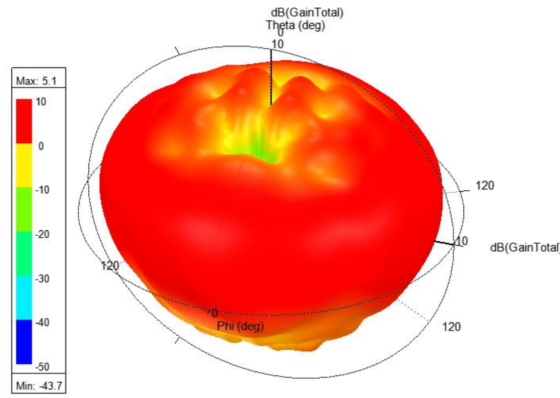
To assess the performance of the optimized DRA, we conducted a full wave simulation and compared the S parameters for all the three models: solid DRA, optimized DRA, and optimized DRA with fillets, as shown in Figure 2 a). The blue curve represents the S parameter of a solid DRA with a permittivity of 7.2. The red curve represents the S parameters for the optimized DRA, which is a hybrid structure comprising both air and alumina. Additionally, the dashed red curve corresponds to the S parameters for the optimized DRA with the inclusion of fillets. From the figure, the solid DRA displays narrow bandwidth and the optimized DRA achieved 104% of fractional impedance bandwidth at S11 = -10 dB, covering the frequency range from 4.54 GHz to 14.41 GHz. The antenna gain pattern is given in Figure 2 b), which is symmetric and resembles closely to the pattern of a monopole antenna.

IV CONCLUSION

we designed a novel-shaped wideband Dielectric Resonator Antenna (DRA) through the application of a genetic algorithm for binary material optimization. Our optimized design resulted in an impressive 104% bandwidth and a symmetric radiation pattern. Additionally, we introduced fillets to enhance the ease of 3D printing for this innovative DRA configuration. This work represents a significant step forward in achieving improved antenna performance while considering practical manufacturing considerations.



(a)



(b)

Figure 2. a) S-parameters of the Solid DRA (blue), the Optimized DRA (red), and the Optimized DRA with fillets (dashed red); b) 3D Gain pattern of the optmized DRA.

AKNOWLADGMENT

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