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Grating Lobes Reduction in an Array Antenna Using Curved Disc Monopoles

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Abstract: This paper shows the study of an array antenna with curved disc monopoles whose average spacing between elements is greater than a wavelength ✦_. The proposed antenna is a linear array, consisting of four equally spaced curved disc monopoles excited by a corporate feed (T-junction power divider). The single element is characterized by a directional radiation pattern in the H plane. Compared to an isotropic monopole antenna array, the proposed array reduces the grating lobes to more than -15dB. As a result, the gain will be increased. The array antenna is fabricated and measured for its impedance and radiation characteristics. The results of the simulation and measurement are in good agreement.

Keywords: Curved disc monopole antenna, Array antenna, Grating lobes, Mutual coupling, Flexible antennas.

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1. INTRODUCTION

Arrays can be considered as a collection of identical radiating elements that are excited to achieve some desired radiating pattern. They can be used to improve the quality of communication links by their capacity for beam shaping, beam steering and high gain, in order to improve the resolution in radar, localization or imaging systems **[1]**. The classical antenna arrays are thoroughly discussed in several antenna books **[2].** In fact, in an array antenna, the inter-element spacing should be less than the wavelength to avoid ambiguity lobes that limits the usefulness of the array.

Several studies have focused on reducing grating lobes in a linear antenna array using different methods. In **[3-4],** the method used is aperiodic placement techniques can effectively suppress grating lobes, even when the elemental antennas are more than several wavelengths in size. In **[5],** other method appliqued on irregular arrangement of subarrays. The authors in **[6]** used the bed of nails structure placed along the E plane of the antenna array. Or using of Fabry-Perot cavity **[7].**

Other works have been carried out on the suppression of the ambiguity lobes, on generate non-uniform spacing between array elements **[8],** or replacing the individual elements in a linear array with a pair of elements called discrete dipole elements (DDEs) **[9]**, or using removable grid cover structures on pyramidal horn **[10]**. Authors in **[11]** have introduced a compensatory waveguide feed layer in metasurface antennas to minimize ambiguity lobes.

To make an array practically usable, the grating lobes must be less than -10 dB and will be the aim of this study.

Consideration of mutual coupling between antenna elements is an important issue in the design of antenna arrays. Several studies have shown that mutual coupling degrades the performance of antenna arrays by changing the directivity and radiation pattern **[12–14].** For narrow-band or single-resonant antenna arrays, the spacing of the elements must be less than a wavelength λ at the resonant frequency to avoid the formation of lattice lobes and to maintain a sufficiently strong mutual coupling between the elements to improve the overall array.

This paper presents the results of study of curved disc monopole array in comparison to an isotropic monopole array. A reduction of grating lobes of more than -15 dB is achieved which improves the maximum gain of the manufactured array with average inter-element spacing greater than a wavelength.

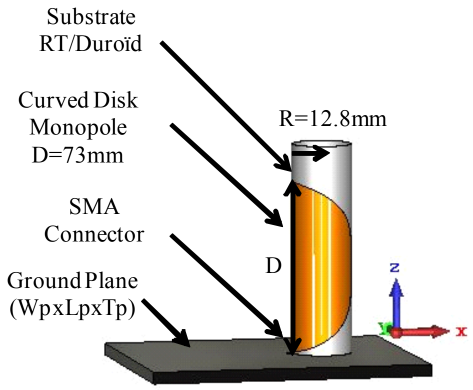
2. ANTENNA DESCRIPTION AND DESIGN GEOMETRY

In this section, the description of the geometry of the array antenna of curved disc monopoles will be presented. In order to do it, the study of the behavior of the single disc monopole antenna and the mutual coupling between two curved disc monopoles is necessary to be able to insert the antenna into an array in an optimal way.

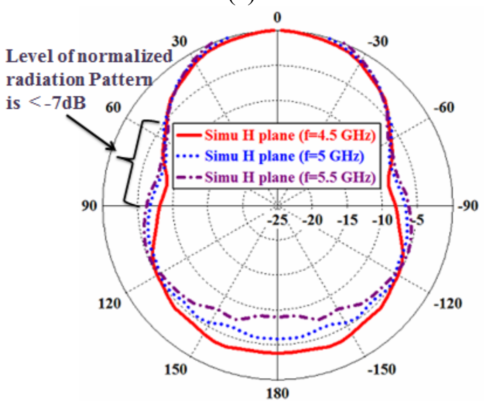
The array antenna studied in this paper consists of antennas monopole disk curved on cylindrical surfaces with radius R=12.8 mm. The structure uses a flexible, low dielectric permittivity substrate with ε_r= 2.2, T_s= 0.254 mm as thickness Tm =18 µm as copper metal thickness mounted over a metallic ground plane.

2.1 A single UWB disc monopole antenna [15]

The figure 1 shows the H plane radiation pattern at the frequencies 4.5, 5 and 5.5 GHz (Studied frequencies for the proposed array antenna); it can be noticed that the radiation is not omnidirectional as in the isotropic antenna. The radiation pattern in H plane shows a drop from field level of 7 dB in the intervals 60° to 90° and -90° to -60° and creates directional forward radiation.
This important characteristic will be benefit to insert in an array antenna.



(a)

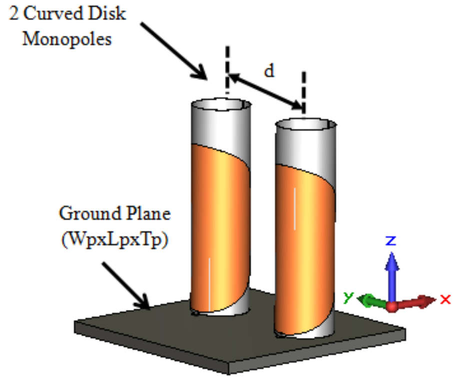


(b)

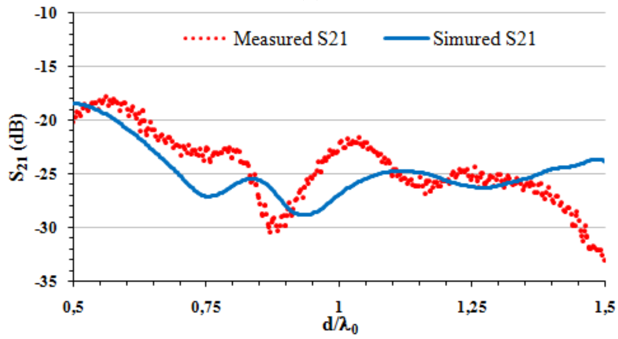
Figure 1. Geometry of a single UWB disc monopole antenna (a), Simulated H-plane (XY) at 4.5, 4.7, 5 and 5.5 GHz frequencies (b)

2.2 Two UWB disc monopole linear antenna array

Before inserting the curved disc monopoles into a linear network, an exhaustive study **[16]** was made of the coupling effect between two elements of these monopoles. Figure 2-b shows the simulated and measured S_{21} of the two curved disc monopoles placed in the same direction and placed at a distance of d (figure 2-a). Is can be noted that from 0.5 d/λ_0 to 1.5 d/λ_0, where λ_0 is wavelength in free space, the coupling is weak (the S_{21} parameters take low values and less than -20 dB). This important feature helps to reduce the level of ambiguity lobes in a multi-element antenna array.



(a)



(b)

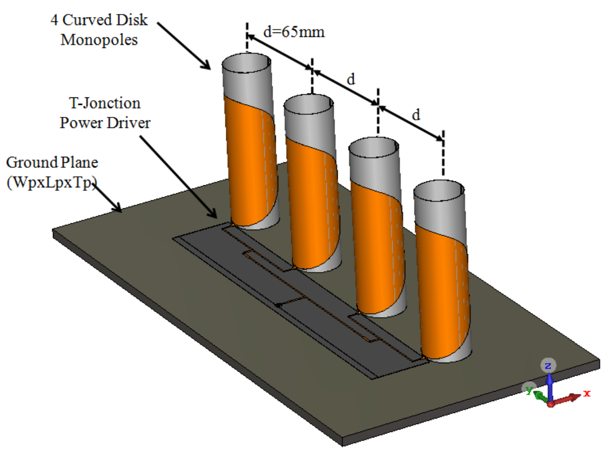
Figure 2. Geometry of two curved disc monopoles antennas (a) Simulated and measured S21 of two curved disc monopoles antennas (b)

2.3 Four curved disc UWB in linear antenna array

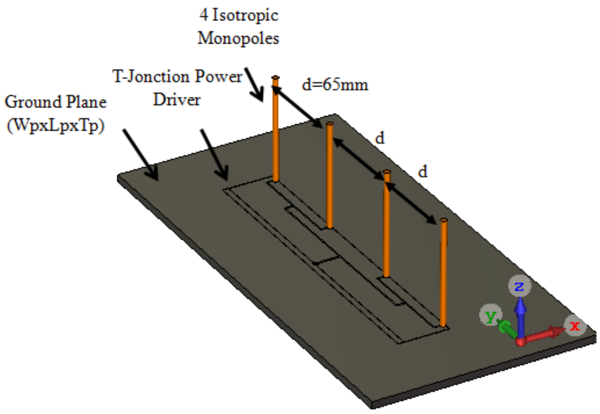
The antenna proposed is a linear array constituted by four equally spaced curved disc monopoles (d=65mm) (Figure 3-a) compared with an isotropic monopoles antenna array spaced with the same distance d (Figure 3-b).

Each curved disc monopole in figure 3-a uses flexible, low dielectric RT/Duroïd 5880 laminates substrate with dielectric permittivity εr=2.2, T_s=0.254 mm as thickness, Tm =18 µm as copper metal thickness, with dissipation factor tanδ=0.001, mounted over a metallic ground plane and excited by a corporate feed (T-junction power divider). Tbe dimensions of the T-junction in the feeding network are also tuned in the simulation environment to avoid impedance mismatching.

The structure in figure 3-b uses a four isotropic monopoles mounted over a metallic ground plane and excited by a corporate feed (T-junction power divider).



(a)



(b)

Figure 3. (a) Geometry of four curved disc monopoles antenna array (b) Geometry of four isotropic monopoles antenna array

3. RETURN LOSS, RADIATION PATTERNS, GAIN AND HALF POWER BEAMWIDTH:

3.1 Return Loss

The comparison between simulation (with CST Microwave Studio® software **[17]**) and measurement (means of an Agilent PNA-X N5242A network analyzer) of return loss of curved disc monopole array antenna shown in Figure 4. It is observed, more resonances and the antenna array still matched for $|S_{11}|$ <-10dB from 3 GHz to 7 GHz. Both simulation and experimental results are in good agreement. The discrepancy observed at high frequency is probably due to the prototype realized (curved discs are not perfectly identical).

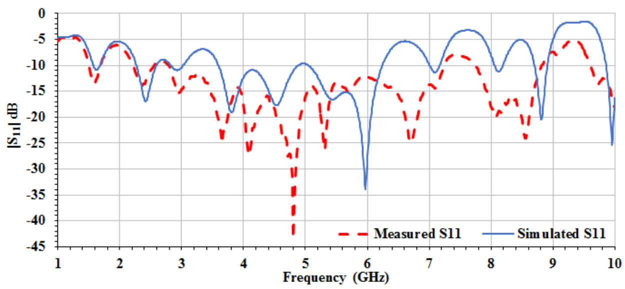
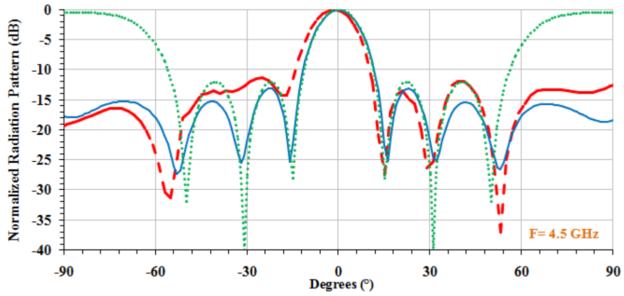


Figure 4. Return Loss of array Antenna of four identical curved disc monopoles

3.2 Radiations Patterns

Figure 5 compares two linear array antennas, simulated and measured H-plane of the linear antenna of four curved disc monopoles and simulated H-plane of the linear antenna of four isotropic antennas. The inter-element spacing for both structures is d=0.975 λ_0 at F=4.5 GHz. It's be noted that the radiations patterns are measured in IETR SATIMO multi-probe near-field measurement system and also by classical calibration and comparison with a known horn antenna.

A reduction in grating lobes level at the angle of ±72° of less than -15 dB is observed in curved disc monopole antennas array in comparison to isotropic one.

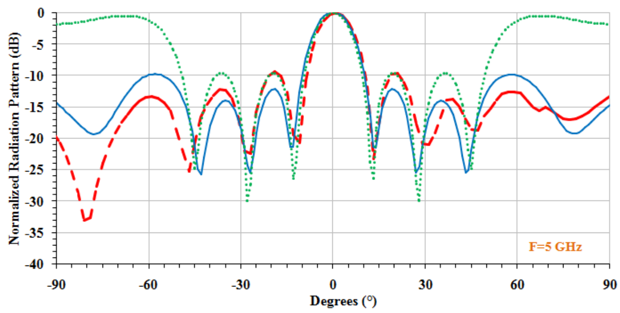


-------- Measured H-plane of curved disc monopoles array
-------- Simulated H-plane of curved disc monopoles array
……. Simulated H-plane of isotropic monopoles array

Figure 5. Comparison of normalized radiation patterns in H-plane of the isotropic monopoles array and curved disc monopoles array at F=4.5 GHz (d=0.975 λ_0)

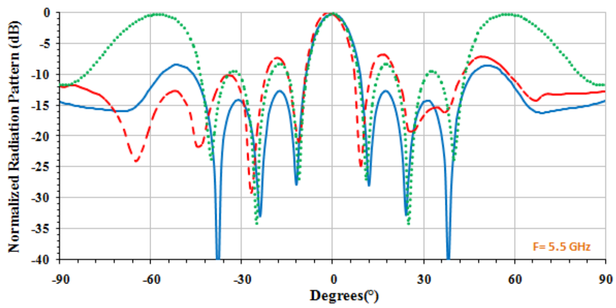
To further prove that the structure of the proposed antenna array gives a reduction of grating lobes level with the inter-element distance more than λ_0, two other inter-element were simulated and tested: d=1.083λ_0 at F=5GHz (Figure 6) and d=1.191 λ_0 at F=5.5GHz (Figure 7). It can be seen that the ambiguity lobes level is lower than -10 dB at frequency F=5 GHz at Θ ±60° (Figure 6) and at frequency F=5.5 GHz at Θ±50° (Figure 7).

It should also be noted that as the frequency increases, the position of the ambiguity lobes approaches the side lobes. A good agreement between simulations and measurements.



------- Measured H-plane of curved disc monopoles array
------- Simulated H-plane of curved disc monopoles array
…… Simulated H-plane of isotropic monopoles array

Figure 6. Comparison of normalized radiation patterns in H-plane of the isotropic monopoles array and curved disc monopoles array at F=5 GHz *(d=1.083λ_0)*



-------- Measured H-plane of curved disc monopoles array
-------- Simulated H-plane of curved disc monopoles array
……. Simulated H-plane of isotropic monopoles array

Figure 7. Comparison of normalized radiation patterns in H-plane of the isotropic monopoles array and curved disc monopoles array at F=5.5 GHz *(d=1.191λ_0)*

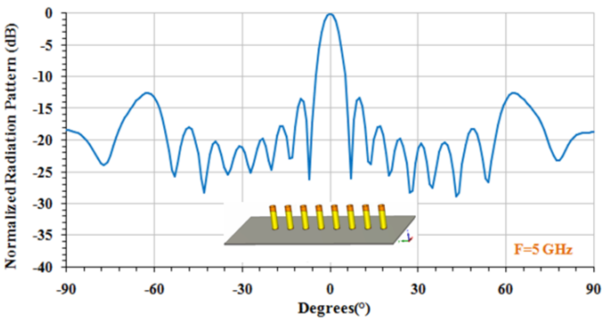
3.3 Gain and half power beamwidth

The following table 1, shows the attractive features obtained with this array consisting of only **4** elements. We note that the gain remains stable at around 14.5 dB for the three frequency points. On the other hand, the half-power beamwidth $\theta_{(-3dB)}$ decreases as the frequency increases.

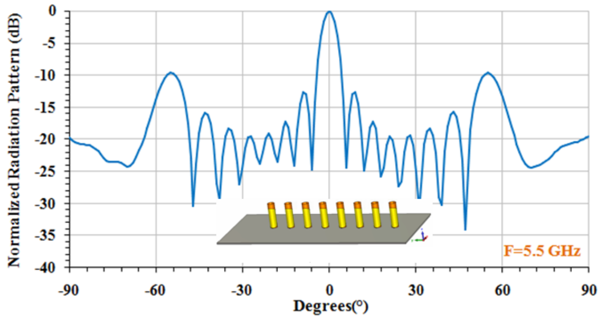
Table 1. Comparison simulation-measurement of gain and half-power beamwidth **θ_{-3dB}** of 4 curved disc monopoles

F (GHz)	d(inter-element)	Simulated θ_{-3dB} (°)	Measured θ_{-3dB} (°)	Simula-ted Gain (dB)	Meas-ured Gain (dB)
4.5	0.975 λ_0	13.9	14.4	15.65	14.69
5	1.08 λ_0	11.7	11.6	14.75	14.60
5.5	1.2 λ_0	10.6	10.0	15.12	14.70

The extension of the simulation for an array of 8 curved disc monopoles at frequencies 5 GHz and 5.5 GHz is shown respectively in the figure 8-a and 8-b. The ambiguity lobes levels appear around 68° and 57° and they are below -8 dB and -10 dB respectively.



(a)



(b)

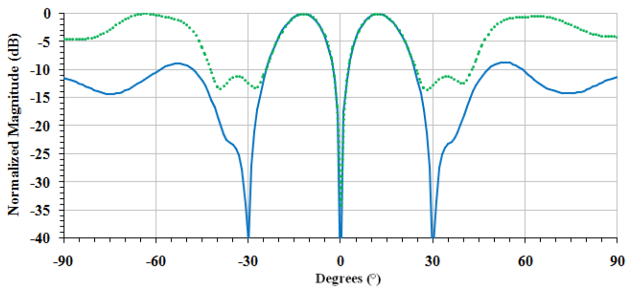
Figure 8: Simulation radiation patterns in H-plane of 8 curved disc monopoles array at (a) F=5 GHz (b) F=5.5 GHz

Attractive results are obtained as described in table 2 and can be validated experimentally.

Table 2. Attractive results of 8 curved disc monopoles

F(GHz)	d (inter-element)	Simulated θ_{-3dB} (°)	Simulated Gain (dB)	Grating lobes level (dB)
5	1.08 λ_0	6	18.43	-12
5.5	1.2 λ_0	5.2	18.17	-10

The reduction of ambiguity lobes was also confirmed for a phased array of 4 curved disc monopoles (figure 9). The weighting applied is as follows: (1dB, 0°)$_{monopole\ 1}$ (1dB, 0°)$_{monopole\ 2}$ (1dB, 180°)$_{monopole\ 3}$ (1dB, 180°)$_{monopole\ 4}$ .The inter-element spacing for both structures is d=0.932 λ_0 at F=4.3 GHz. It can be seen that the ambiguity lobes levels appear around 56° and they are below -8 dB in comparaison to isotropic one.



-------- Simulated H-plane of curved disc monopoles array

…….. Simulated H-plane of isotropic monopoles array

Figure 9. Simulation radiation patterns in H-plane of 4 curved disc monopoles phased array at F=4.3 GHz (d=0.932 λ_0)

4. CONCLUSION

A linear array with four curved disc monopoles for an inter-element spacing is greater than wavelength has been designed, manufactured and measured. The array antenna occupies less space and shows a reduced level of grating lobes against an isotropic monopoles array.

In this antenna, the average inter-element spacing is 0.975λ_0, 1,08λ_0 and 1.2λ_0 respectively, showing a good reduction of the grating lobe lower than −15dB, -10dB and -10dB. A phased array of four curved disc monopoles has been designed and fabricated. In this array, the inter-element spacing is 0.932 λ_0 showing a grating lobe level lower than -8dB. The simulation of the array of eight curved disc monopoles offers an attractive result in gain, half-power beam width **θ_{-3dB}** and at the level of gating lobe.

As a future work, the beam scanning in a wide frequency band of these arrays well be studied and experimentally validated.

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[17] CST: Computer Simulation Technology 3D EM analysis software package for designing, analyzing and optimizing electromagnetic (EM) components and systems.