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# Metamaterial Antenna Array for RADAR Application and its Scan Blindness

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**Abstract**

This paper presents metamaterial-inspired solution to mitigate scan blindness in phased arrays at RADAR frequency taking advantage of less mutual coupling and compactness of metamaterial arrays. This is done by redesigning a metamaterial antenna at RADAR frequency, feeding it with shielded coaxial probe to reduce side lobe level thus making it practical for planar arrays implementation. Input reflection coefficients and mutual coupling is presented varying phase difference among antenna feeds. Results from HFSS confirmed that there is no scan blindness in these newly designed phased metamaterial arrays.

***Keywords:*** RADAR frequency; Phased arrays; Scan blindness

## 1. Introduction

Phased-array antennas have been the backbone of multiple RADAR systems. They are crucial devices in the development of new systems for many military and civil applications. Scan blindness is a well-known artifact present in phased arrays [1]. It lowers efficiency of antenna by limiting range of scanning [2]. It is manifested as a strong mismatch of the active impedance when the scan reaches a certain angle [1]. Many efforts have been devoted to eliminate scan blindness, for example, the sub-array technique is used to suppress scan blindness but at the expense of a larger unit cell size, which causes an increase in power loss to the grating lobes [3]. So, there is a need of such phased-array with small size, no blind points and improved radiation pattern.

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The most straightforward solution to avoid blind spots due to grating lobes is to reduce the coupling between elements. Sometimes, the distance between array elements is a design constraint that cannot be overridden so for these, artificial structures are included to fulfill our requirement. These artificial material arrays are of small size [5], less mutual coupling [6] and have more directive emission [7]. In this work, metamaterial phased arrays with inter-element spacing of $0.4\lambda$ (less than $\lambda$=2) are designed. These arrays have small sizes and mutual coupling is observed. While scanning, blind spots are investigated. These arrays are designed at 5.6 GHz RADAR frequency. Variations in feed are made to get our desired results. Substrate Rogers RT/duroid 5880 (tm) with $\varepsilon_r$ 2.2 is used. This paper is organized as follows: Section 2 explains feed design of antenna [4] and modifications done in it to improve radiation pattern. In Section 3, procedure of antenna redesign at RADAR frequency is explained with result of simulation. In Section 4, linear and planar arrays are simulated and their scan blindness is investigated by varying phase difference among these array elements.

## 2. Feed Design

Metamaterial antenna [4] is taken as a reference. It is fed with rectangular port. To investigate scan blindness, we need to implement linear and planar arrays but planar array is not implementable practically with rectangular port feed. That's why a coaxial feed is used for it with inner radius 1.2 mm and outer radius 4 mm. A shield which is a half ring of via holes is designed and added in coaxial probe feed to reduce side lobes level in radiation pattern of arrays. To observe effect of shield with coaxial feed, two 8-element linear arrays are simulated in HFSS using this antenna [4] with different feeds. One array is fed with coaxial feed and other with shielded coaxial feed as in Fig. 1. Each element of array is fed separately. Both arrays are placed along y-axis with inter-element spacing $\lambda$=2. These arrays are operating at 7.5 GHz. To compare level of side lobes, normalized gain is plotted in Fig. 2, from where it is clear that changing feed from coaxial to shielded coaxial has reduced the side lobe level of array.

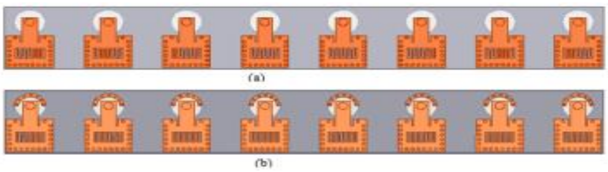


**Figure 1:** Linear arrays with inter-element spacing $0.5\lambda$

*a* Coaxial fed *b* Shielded coaxial fed

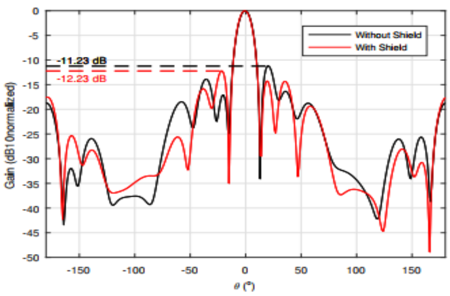


**Figure 2:** Comparison of side lobe level of different feed linear arrays

## 3. Antenna at RADAR Frequency

Antenna [4] was operating at 7.5 GHz. It is redesigned at RADAR frequency of 5.6 GHz to make its application in RADARs. It is done by multiplying all previous antenna dimensions with a factor that is the ratio of antenna current frequency divided by desired antenna frequency. This factor comes out 1.339. With these new dimensions, antenna of length 26.6 mm, width 16 mm and substrate Rogers RT/duroid 5880 (tm) thickness 1.7 mm is simulated as in Fig. 3. Now it is resonating at 5.59 GHz RADAR frequency as from reflection coefficient plot in Fig. 4. This antenna is narrow band antenna.

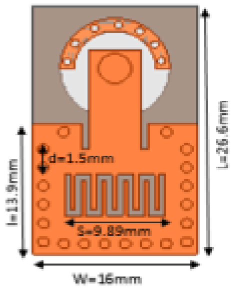


**Figure 3:** Antenna at RADAR frequency

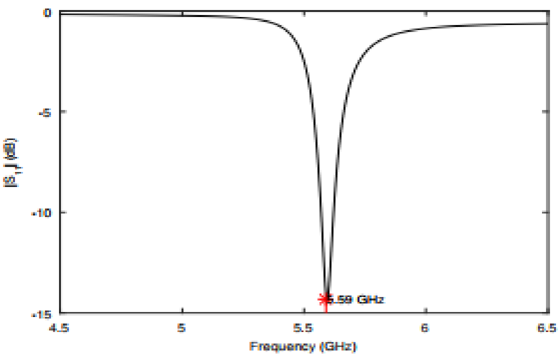


**Figure 4:** Reflection coefficient of antenna resonating at RADAR frequency 5.59 GHz

## 4. Scan Blindness

Scan Blindness occurs in arrays when they are not able to detect incident waves on them from certain angle while scanning. This is due to the reason that antennas in arrays have mutual coupling among them leading to constructive and destructive interference making nulls or blind spots. This decreases array efficiency. To investigate scan blindness in metamaterial antenna arrays at RADAR frequency, a linear array and a planar array is simulated in HFSS using above modified metamaterial antenna. Spacing among elements of array is kept less than $0.5\lambda$ taking advantage of metamaterial antennas small size. Each antenna is fed separately with shielded coaxial feed. For scanning, phase difference $\beta$ among feeds of array is varied from $0^o$ to maximum value $\beta max$ (i.e., $140^o$) with step size of $20^o$. Mutual coupling and reflection coefficients are observed to check blind spots during scanning.

### *4.1. Linear Array*

A linear array of 8 metamaterial antennas is simulated as in Fig. 1(b) with inter-element spacing 0:4$\lambda$. Array is placed along y-axis so gain plot is observed at angle $\varphi$ equals 90*o*. Its width is 27.3 mm and length is 218.7 mm. Central frequency of this array is 5.59 GHz from Fig. 5 and none of the reflection coefficients is 1 as at blind spot it should be one. Mutual coupling among array elements is given in Fig. 6 and it is very low. Scanning is done by changing phase difference among elements $\beta$ as in Fig. 8 and its gain is 13.6 dB. 3D radiation pattern during different beta is shown in Fig. 7 and main beam position is also changing in it. While scanning, it is observed that reflection coefficients for all antennas stays same for all $\beta$ values as in Fig. 5. So, no blind spots are found in this metamaterial antennas array with 0.4$\lambda$ spacing. This is due to very low mutual coupling among array elements. Decrease in gain during scanning is due to reduction in antenna aperture.

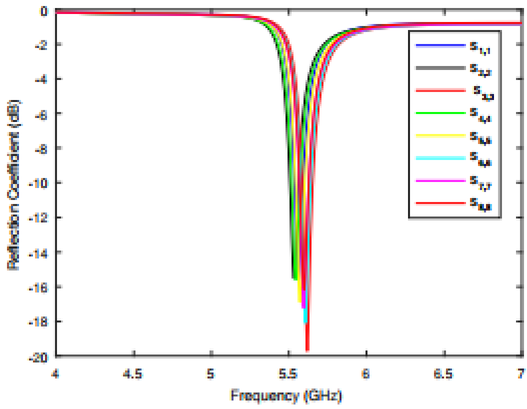


**Figure 5:** Reflection coefficient of linear array at RADAR frequency

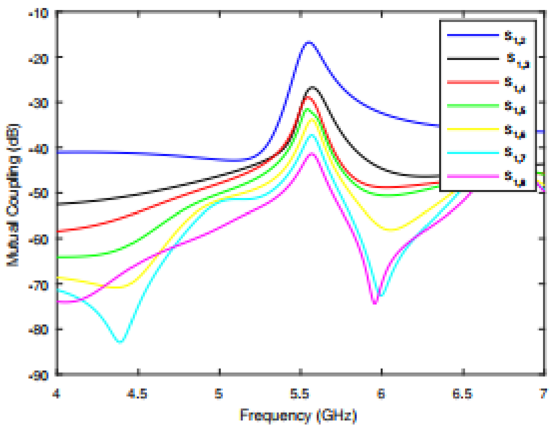


**Figure 6:** Mutual coupling among linear array elements

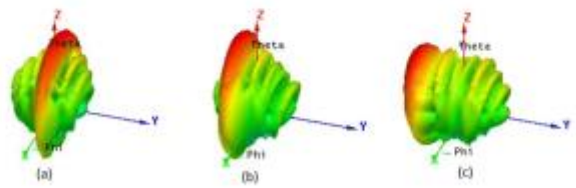


**Figure 7:** 3D radiation pattern of linear array at RADAR frequency *(a)* $\beta = 0^o$ (b) $\beta = 60^o$ (c) $\beta = 140^o$

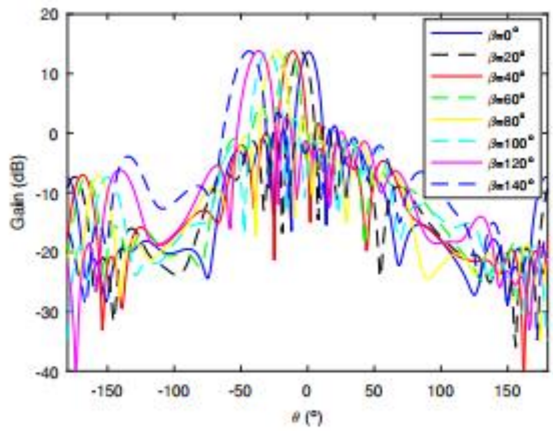


**Figure 8:** Scanning in linear array changing $\beta$ value at phi equals $90^o$

***4.2. Planar Array***

A planar array of 4 x 4 order is simulated at RADAR frequency in xy-plane with inter-element spacing $0.4\lambda$ as shown in Fig. 9. Length of array is 108.8 mm and width is 114.6 mm. It is resonating at 5.6 GHz from Fig. 10. Mutual coupling is very low among elements of planar array as evident from Fig. 11. Its gain is 17.6 dB.

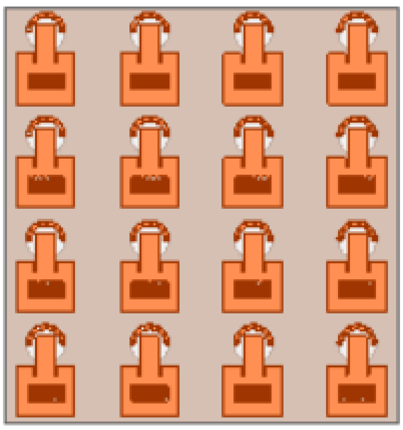

**Figure 9:** 4 x 4 order planar array at RADAR frequency

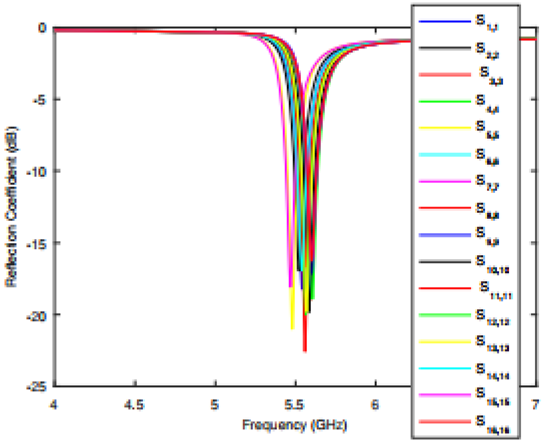


**Figure 10:** Reflection coefficients of planar array

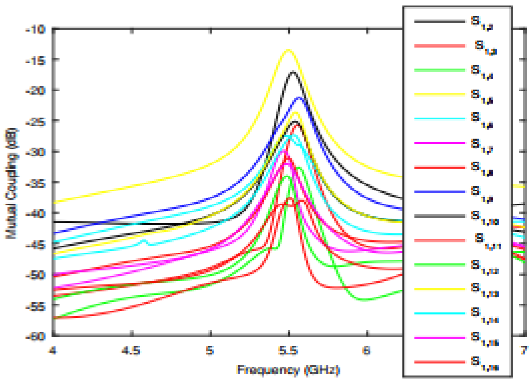


**Figure 11:** Mutual coupling among planar array elements

By varying beta, 3D polar plots are in Fig. 12 and in Fig. 13 depicting change in main beam position along x and y-axis respectively. This array is scanned in two dimensions x and y by first changing $\beta$ along x-axis that is $\beta x$ as in Fig. 14 and then along y-axis $\beta y$ as shown in Fig. 15. Gain is slightly reducing while scanning due to antenna aperture reduction. It is observed while scanning that reflection coefficients are not changing. They stays same as in Fig. 10 and none of them equals one so this array is not blind. This is due to low mutual coupling among elements of planar array leading to no interference and hence no blind spots.

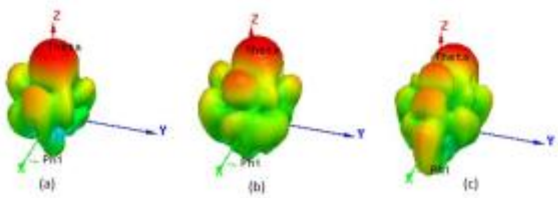


**Figure 12:** 3D radiation pattern of planar array (a) At $\beta x = 0^o$ (b) At $\beta x = 60^o$ (c) At $\beta x = 140^o$

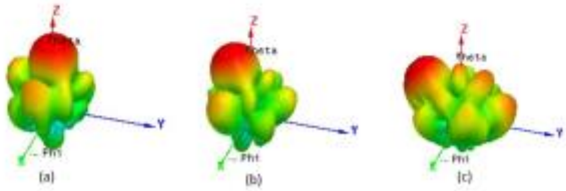


**Figure 13:** 3D radiation pattern of planar array (a) At $\beta y = 0^o$ (b) At $\beta y = 60^o$ (c) At $\beta y = 140^o$

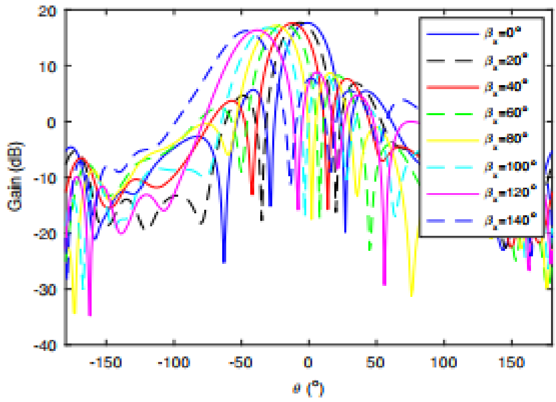


**Figure 14:** Scanning in planar array along x-axis at phi equals $0^o$

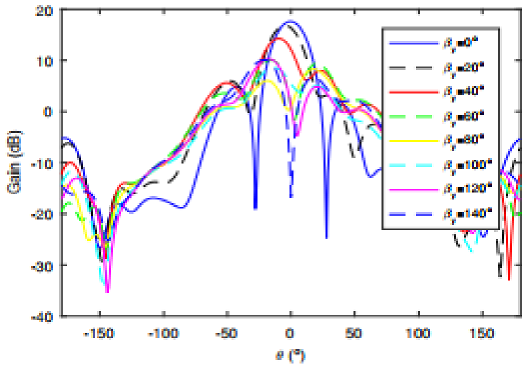


**Figure 15:** Scanning in planar array along y-axis at phi equals $90^o$

## 5. Conclusion

Side lobe level in antenna radiation pattern is reduced by introducing shielded coaxial feed. Operating frequency of metamaterial antenna is changed to RADAR frequency by multiplying a scaling factor of 1.339 with all dimensions of old antenna and simulating a new antenna. This metamaterial antenna now has application in RADARs. Both linear and planar arrays simulated using metamaterial antennas are not blind at any point while scanning from zero to maximum value of phase shift. These arrays can detect all signals or waves coming while scanning giving an additional benefit so no loss of data. This is due to very low mutual coupling among antenna elements even at inter-element spacing of $0.4\lambda$. So a phased metamaterial array with small size, very low mutual coupling, operating at RADAR frequency and with no blind spots is designed in this work. While scanning, gain is reducing due to reduction in antenna aperture. The only drawback is that these arrays are narrow band.

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