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Selection of Antenna Elements of AAS Based on Simulation of RWG Edge Elements

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Abstract

To simulate the distribution of surface current and radiation pattern of single antenna or array antenna system (AAS) the Rao-Wilton-Glisson (RWG) edge elements are widely used in recent literatures. In this paper we consider four different types of antenna element: linear spiral antenna (known as frequency independent antenna), slot antenna, dipole and bowtie antenna for AAS. The rectangular array of different size are simulated to observe the impact of size of array, distribution of surface current, maximum current, radiation pattern (2D and 3D), E-field, H-field, poynting vector, directivity and array gain. The outcome of the paper is: bowtie and spiral array are better than other two in context of rigidity on radian pattern against frequency, intensity of electric and magnetic field and array gain at the expense of design complexity.

Keywords:-Array gain, radiation pattern, current density, incident EM signal and impedance matrix.

Introduction

In array antenna system several element antennas (for example dipole antenna) are arranged in an array of linear, circular, rectangular or some other geometric fashion. Each antenna elements are fed separately with different amplitude and phase of exiting signal. The radiation pattern of antenna elements is combined as if the vector addition EM wave to form the resultant beam of array. The shape, directivity and gain of the radiation pattern of an AAS depend on: the number of antenna elements, geometry of array, weighting factor of feed current of antenna elements. Actually the combination of antenna elements provides a parameter, called array factor which governs the directivity and gain of the AAS. If all the antenna elements in the array are similar then the multiplication of radiation pattern of a single antenna element and array factor provides the radiation pattern of the AAS. Several applications of ASS are discussed in detail in [1], and the algorithms of adaptive beam forming of AAS are discussed by the same author in [2]. In

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4G mobile communication multiple antennas i.e. the AAS is used at both base stations (BS) and mobile station (MS) end where the concept is known as MIMO (multiple input multiple output). In 5G mobile communication the applications of MIMO is more intense than the case of 4G where the term is called 'Massive MIMO'. In [3] slotted patch antenna array is designed for user equipment (UE) of 4G Long-Term Evolution (LTE) and WiMAX where the design and gain characteristics (gain vs. physical angle) are shown explicitly. Similar analysis is found in [4] for full dimension MIMO destined for LTE. In [5] the adaptive filter theory is incorporated with AAS where authors use both LMS and RLS algorithm to achieve desired array factor. The concept of adaptive algorithm with ASS is also found in [6-7]. One of the prominent simulation techniques in evaluation of antenna parameters (impedance matrix, current density, pointing vector, electric and magnetic field vector, 2D and 3D radiation pattern etc.) is rwg elements. The method needs basis function of rwg and MoM equation to evaluate above parameters are discussed in [8-10]. In this paper our aim is to find out the appropriate antenna element of AAS to acquire higher directivity, radiated power, gain and rigidity against frequency.

The entire paper is organized as: second section provides the basic concept of spiral, slot and bowtie antennas; third section deals with concept of rwg elements; fourth section provides results regarding relative performance of different array antenna system and fifth section concludes the entire analysis.

Antenna Basic

This section deals with construction of three basic antennas: linear spiral, slot and bowtie antenna.

Spiral Antenna

Spiral antenna is a frequency independent antenna can be used in wideband communication. The arms of the linear spiral antenna is defined as, $r = a\varphi$; where r is the radius of the antenna and r increases with the angle φ. The design parameters of a spiral antenna are: spacing between the turns, width of arm, inner and outer radius of spiral, flare rate (the rate of growth of spiral with angle) and number of turns. The design procedure of such antenna is discussed in [11-14]. Figure 1(a) shows the basic construction of a linear spiral antenna and the distribution of its rwg edge elements are shown in Figure 1(b).

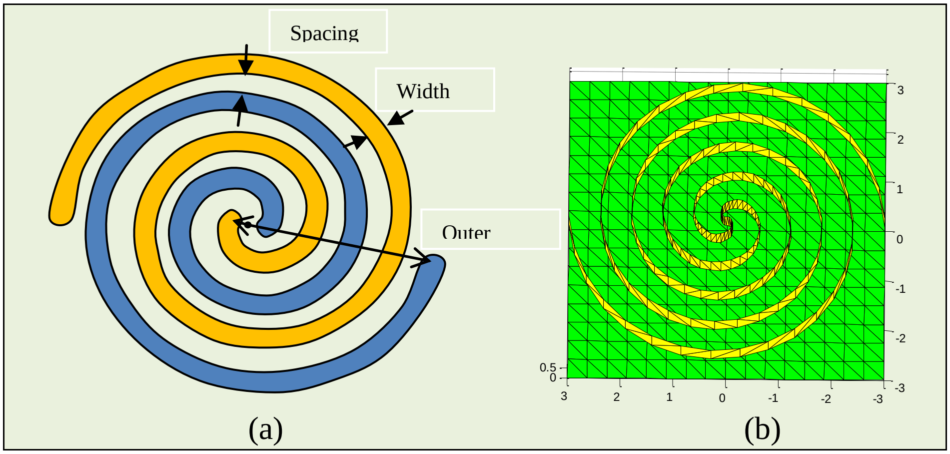


Figure 1: Basic structure of a linear spiral antenna

Slot Antenna

A slot antenna is simply a rectangular cut on a metallic sheet as shown in figure 2(a). The length of the slot is made half the wavelength but the width of the slot is made little smaller. The antenna may be excited by a coaxial line or parallel transmission line and the radiation is found in the direction normal to the sheet. The bidirectional radian pattern of the slot antenna can be made heavily directional by arranging several slot antennas in an array. The distribution of rwg elements on the sheet metal is shown in figure 2(b). The concept of slot antenna with theoretical analysis is found in [15-16].

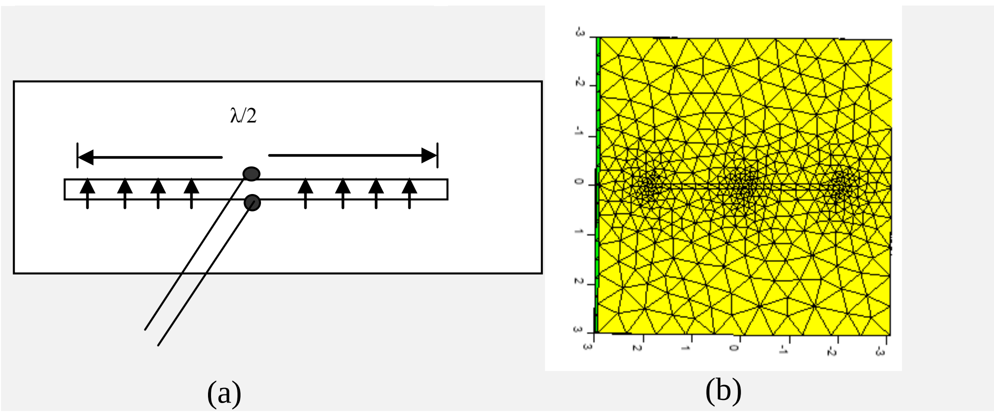


Figure 2: A $\lambda/2$ slot antenna

Bowtie Antenna

The bow-tie is the 2D version of biconical antenna that has wideband characteristics. Although the construction of bow-tie and dipole are almost same but arms of the bow-tie antenna are flared. The radiating area of the bow-tie is larger than that of the dipole hence improvement in gain is expected. The performance of the bowtie antennas depends on several geometric parameters, such as bowtie size, apex angle, and width of gap. Design procedure of such antenna is available in [17-18]. The construction of bow-tie and distribution of rwg elements on the sufferance (bow tie and dipole) are shown in figure 3(a)-(c).

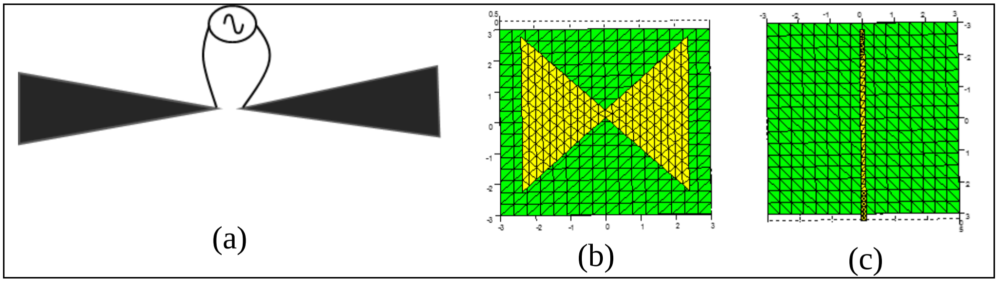


Figure 3: Bowtie and dipole antennas

RWG Elements

At receiving end the EM wave is incident on the surface of the antenna and induces voltage on it according to the Faraday's law hence a potential difference is created between two parts of antenna. This potential varies according the variation of the EM wave i.e. with profile of transmitted signal. The distribution of the potential on the surface of the antenna is analyzed by small dipole element on the surface of the antenna in a continuous fashion where the triangular dipoles are called rwg edge elements. The distribution of *RWG* elements on the surface of a thin dipole antenna is shown in figure 4.

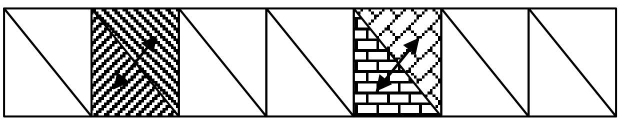
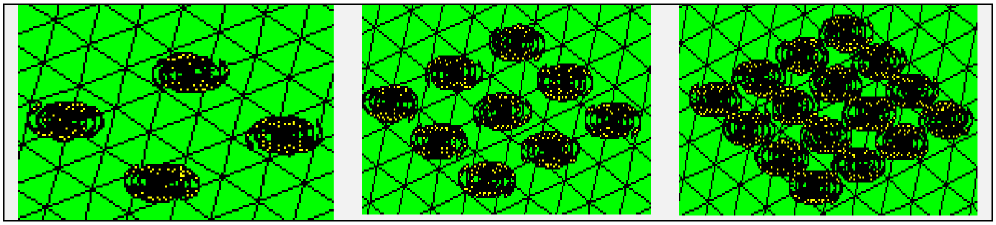


Figure 4: RWG edge elements on a thin dipole antenna

Using the theoretical model of array of rwg elements of [19-22] (where authors use Helmholtz wave equation, vector magnetic potential, scalar potential, impedance matrix, the moment equation and basis function of surface current density) we can determine current density and radiation pattern of array antenna system. The mathematical expressions of antenna parameters and their relations with rwg elements are shown in our previous papers [20-22]. In [20] only the radiation pattern of bow-tie array of rectangular pattern is determined; where as other parameters of AAS are ignored. In [21] a comparison is made between bow-tie and spiral antenna (single antenna) in context of 2D and 3D radiation pattern only. Another comparison of single antenna element is found in [22] where bow-tie and slot antennas are compared using current density and magnetic field. This paper makes comparison of bow-tie and spiral AAS instead of single antenna of [21]-[22]. Here we consider the parameters: maximum current density, *E*-field, *H*-field, pointing vector, total power, gain, directivity, 2D and 3D radiation pattern. Finally dipole and slot antennas are also included in comparison.

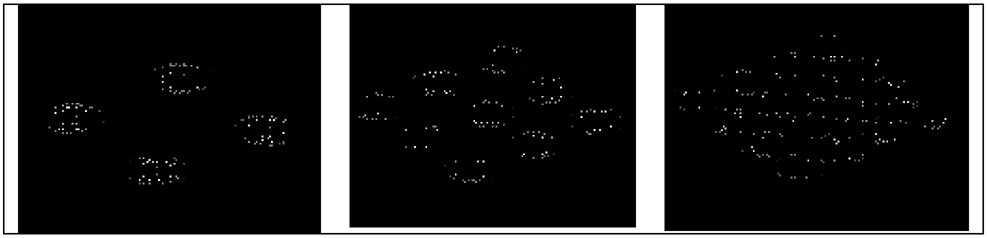
Results

First of all we implement the array of linear spiral antenna based on rwg elements in Matlab taking, operating frequency, f = 75MHz; permittivity, $\varepsilon = 8.854\times10^{-12}$; permeability, $\mu = 1.257\times10^{-6}$. The spiral AAS in closed view is shown in figure 5 for 2×2, 3×3 and 4×4 array. The distribution of current density on the surface of the ASS is shown in figure 6; where the white spot correspond to higher current density. The profile of current density (normalized by incident magnetic field H^{inc}) against distance along x and y (normalized by wavelength) is shown in figure 7 for 2×2, 3×3 and 4×4 array; here the profile reveals the shape of Gaussian filter and the peak current is found higher for larger size of array.



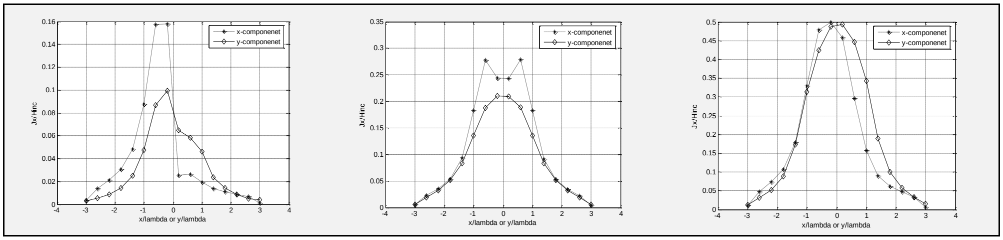
(a) 2×2 array (b) 3×3 array (c) 4×4 array

Figure 5: ASS of linear spiral antenna using rwg elements



(a) 2×2 array (b) 3×3 array (c) 4×4 array

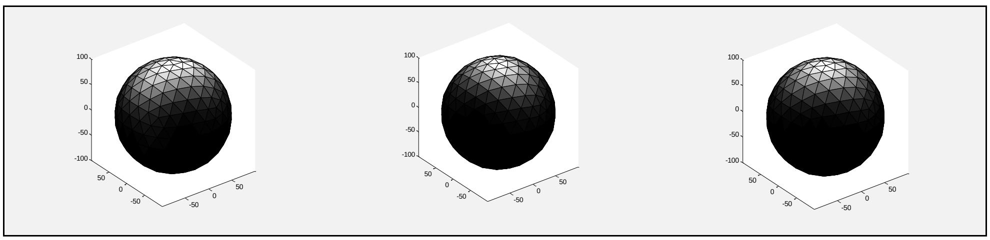
Figure 6: Distribution of intensity of current on AAS



(a) 2×2 array (b) 3×3 array (c) 4×4 array

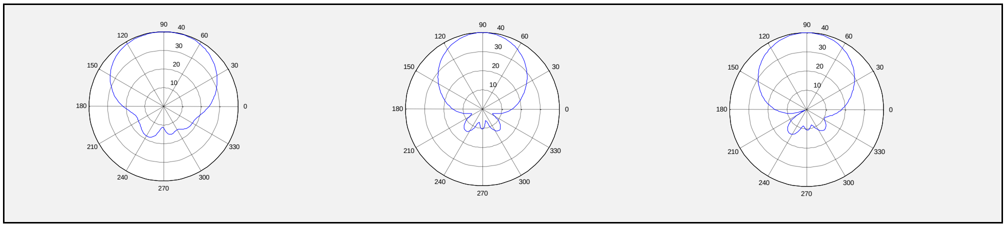
Figure 7: The profile of current density against normalized distance for spiral array.

The 3D and 2D radiation pattern of 2×2, 3×3 and 4×4 array are shown in figure 8 and 9. The reduction in side lobe and enhancement of directivity is found for larger dimension of the array. Maximum current in A/m, electric-field, magnetic field-field, pointing vector, directivity, total received power and logarithmic gain of the AAS for three different dimensions are shown in table 1 where all the parameters mentioned above are found larger with increase in the size of the array.



(a) 2×2 array (b) 3×3 array (c) 4×4 array

Figure 8: The 3D radiation pattern for spiral AAS



(a) 2×2 array (b) 3×3 array (c) 4×4 array

Figure 9: The 2D radiation pattern spiral AAS

Table 1: Comparison of parameters of spiral AAS

Size of the array	MaxCurrent [A/m]	E-field	H-field $\times 10^{-5}$	Poynting $\times 10^{-8}$	W $\times 10^{-9}$	U $\times 10^{-5}$	Total Power $\times 10^{-5}$	Gain Logarithmic
2×2	0.16985	1.0e-003 * [-0.1220 - 0.6868i -0.1208 - 0.6829i -0.0000 + 0.0062i]	0.0321 + 0.1812i -0.0324 - 0.1823i 0.0000 + 0.0016i	0.0000 0.0011 0.1284	1.2840	1.28 40	2.101 8	8.852 4
3×3	0.17259	-0.0005 - 0.0025i -0.0002- 0.0007i 0.0000+ 0.0000i	0.0405 + 0.1943i -0.1307 - 0.6735i -0.0000 - 0.0000i	0.0001 0.0000 0.9610	9.6103	9.61 03	11.38 3	10.15 19
4×4	0.18127	-0.0011 - 0.0040i -0.0010 - 0.0036i 0.0000 + 0.0000i	0.253 + 0.943i -0.299 - 1.062i 0.0000 + 0.003i	- 0.0000 0.012 4.085	40.850	40.8 50	49.89 1	10.02 23

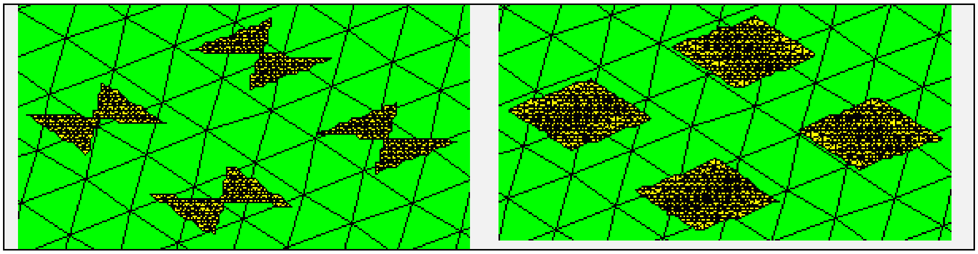
The numerical value of impedance matrix of the spiral AAS is found like below where the impedance of individual element is found larger for larger array.

$Z_{2\times 2}=10^3 \times$[0.6779 - 7.9205i 0.7306 - 8.6384i 0.5090 - 7.0687i 0.4907 - 6.5864i]

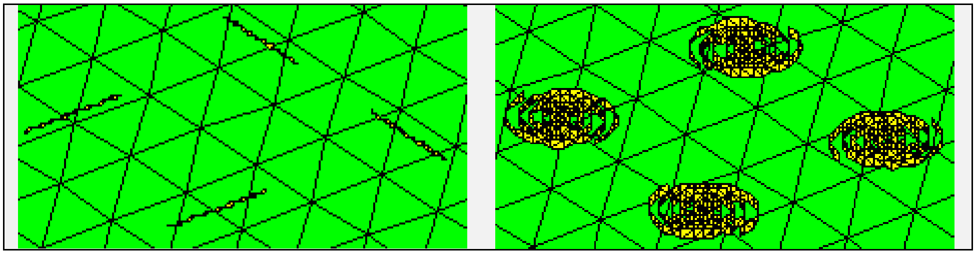
$Z_{3\times 3}=10^3 \times$[1.7210 - 6.8188i 2.8949 - 8.1899i 3.0690 - 8.8700i 0.1354 - 6.2728i
0.0808 - 4.4876i 0.1325 - 6.2789i 3.0765 - 8.9064i 2.9022 - 8.2120i 1.7219 - 6.8217i]

$Z_{4\times4}$= [0.1758 - 0.4631i 0.9147 - 0.6685i 1.2167 - 0.4875i 1.0264 - 0.6346i
0.0416 - 0.3560i 0.0143 - 0.1738i 0.0139 - 0.1725i 0.0347 - 0.3400i
0.6601 - 0.6239i 1.1465 + 0.3353i 1.0206 + 0.4610i 1.0156 - 0.4390i

0.0311 - 0.2671i 0.0117 - 0.1340i 0.0113 - 0.1290i 0.0205 - 0.1935i] $\times 10^4$

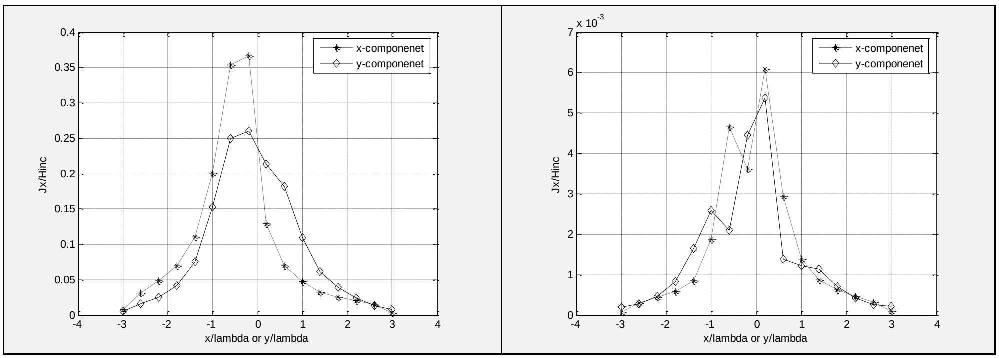


(a) Bowtie array (b) Slot array

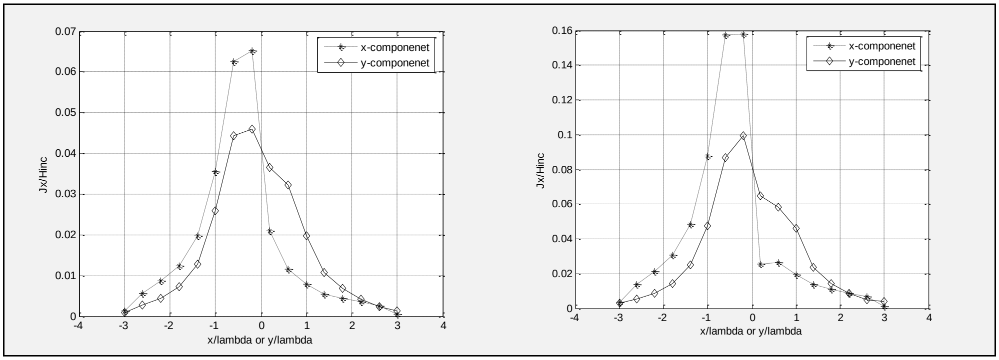


(c) Dipole array (d) Spiral array

Figure 10: The 2×2 array of bowtie, slot, dipole and spiral antenna

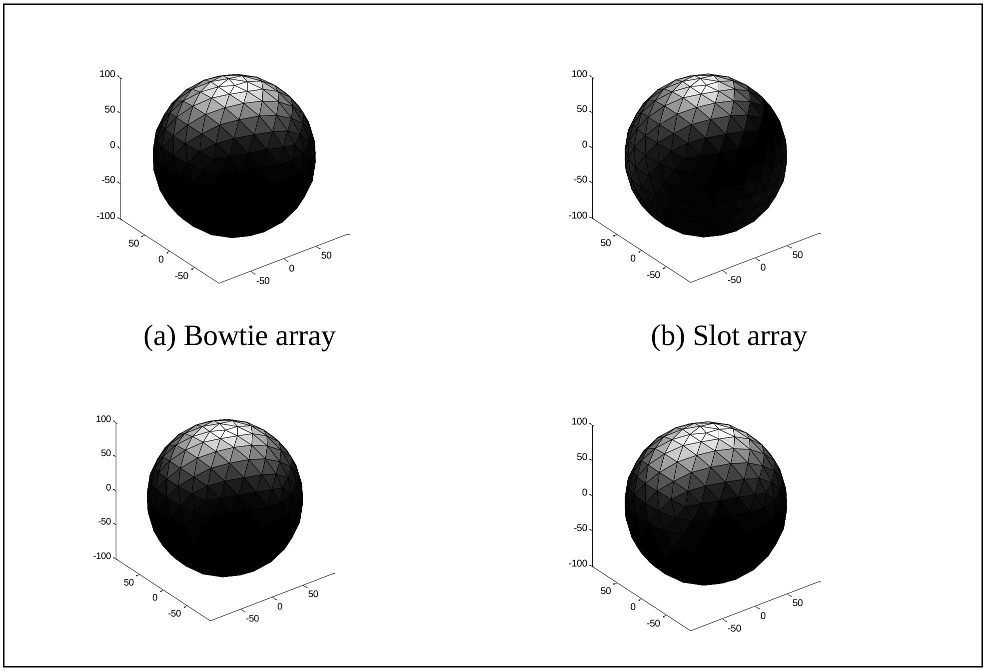


(a) Bowtie array (b) Slot array



(c) Dipole array (d) Spiral Array

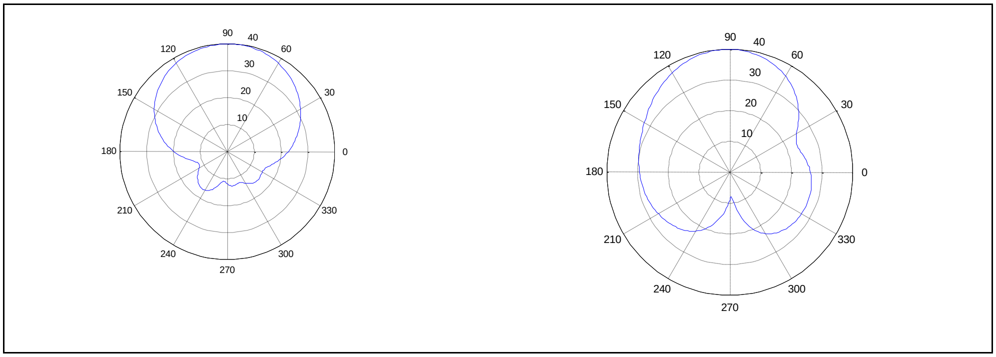
Figure 11: The comparison of current density of 2×2 array of bowtie, slot, dipole and spiral antenna



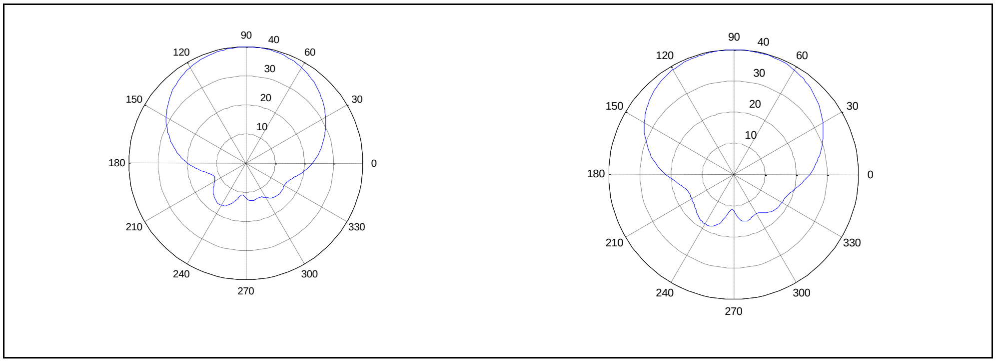
(a) Bowtie array (b) Slot array

(c)Dipole array (d) Spiral Array

Figure 12: The comparison of 3D radiation pattern of 2×2 array of bowtie, slot, dipole and spiral antenna



(a) Bowtie array (b) Slot array



(c) Dipole array (d) Spiral Array

Figure 13: The comparison of 2D radiation pattern of 2×2 array of bowtie, slot, dipole and spiral antenna

The remaining part of the result section will make analysis of four different types of AAS. The distribution of rwg elements on 2×2 array of bowtie, slot, dipole and spiral antenna are shown in figure 10. The normalized current density, 3D and 2D radiation pattern of four types of AAS is shown in figure 11, 12 and 13 respectively. The directivity *U* of four types of AAS is found as: 1.0841×10^{-4}, 1.658×10^{-8}, 3.2689×10^{-6}, and 1.284×10^{-5} respectively. If we compare the four different types of ASS the bowtie array is the best and spiral array is in the second position with respect to all the parameters used in this paper.

Table 2: Comparison of 3D radiation pattern

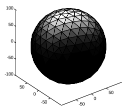
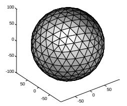
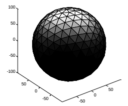
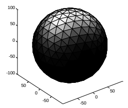
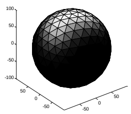
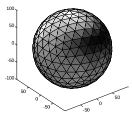
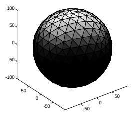
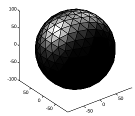
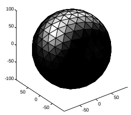
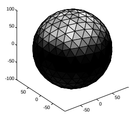
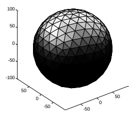
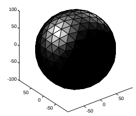
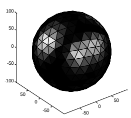
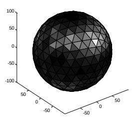
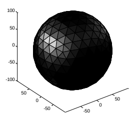
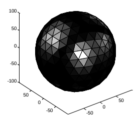
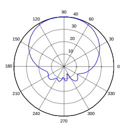
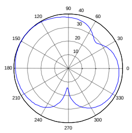
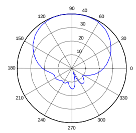
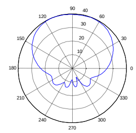
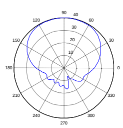
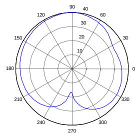
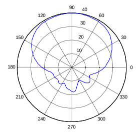
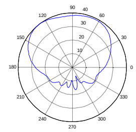
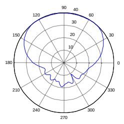
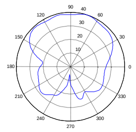
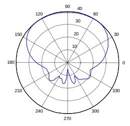
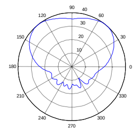
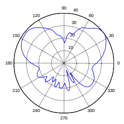
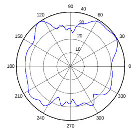
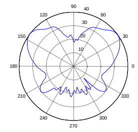
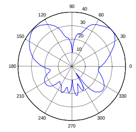
Freq. (MHz)	Dipole	Slot	Bowtie	Spiral
100				
150				
200				
300				

Table 3: Comparison of 2D radiation pattern

Freq. (MHz)	Dipole	Slot	Bowtie	Spiral
100				
150				

Freq. (MHz)	Dipole	Slot	Bowtie	Spiral
200				
300				

The 3D and 2D radiation pattern of dipole, slot, bowtie and spiral array of 2×2 is shown in table 2 and 3 for four different carrier frequencies: 100MHz, 150MHz, 200MHz and 300MHz. The bowtie and spiral array showed the most rigidity in maintaining the radiation pattern independent of frequency.

Table 4: Comparison parameters of 2×2 AAS

Type	**MaxCurrent [A/m]**	**E-field×10^{-4}**	**H-field ×10^{7}**	**Poynting ×10^{-11}**	**W×10^{-12}**	**U×10^{-8}**	**Total Power ×10^{-8}**	**Gain Logarithmic**
Slot	0.16990	-0.0570 - 0.3043i -0.0319 - 0.1677i -0.0000 + 0.0006i	0.0846 + 0.4450i -0.1512 - 0.8075i -0.0025 - 0.0040i	0.0006 -0.0006 0.1658	1.6580	1.6580	2.5930	9.0671
Dipole	0.084406	0.557 + 3.453i 0.561 + 3.476i 0.0000 - 0.020i	-1.490 – 9.225i 1.480 + 9.166i -0.002 - 0.053i	-0.0000 0.18 32.69	326.89	326.89	471.82	9.3416
Spiral	0.16985	-1.220 - 6.868i -1.208 - 6.829i -0.0000 + 0.062i	3.21 + 18.12i -3.24 - 18.23i 0.0000 + 0.16i	0.0000 1.1 128.4	1284.0	1284	2101.8	8.8524

Type	MaxCurrent [A/m]	E-field×10^{-4}	H-field ×10^{7}	Poynting ×10^{-11}	W×10^{-12}	U×10^{-8}	Total Power ×10^{-8}	Gain Logarithmic
Bowtie	0.20571	4.000 + 20.00i 4.000 + 20.00i 0 - 0i	-10.01 - 53.26i 9.77 + 52.17i -0.02 - 0.30i	-0.0000 06 1084	10841	10841	15538	9.3680

Finally all the parameters mentioned previously are compared in table 4 for four types of AAS.

Conclusion

The paper compares four different types of AAS in context of radiation pattern, variation of intensity of current along the dimension of the array, intensity of E-field and H-field, Poynting vector, directivity and array gain. The relative performance of the AAS of the paper will help a designer to choose the best AAS for the AP (Access Point) of a WiFi. Another application of the paper lies in two hop wireless link; where transmitter, relay or receiver can use such array under combining scheme and TAS (transmit antenna selection). In this paper we consider static AAS but the entre wok can be extended for adaptive beamforming to cancel interference of several directions and amplification of gain along the desired direction.

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