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Design and Comparison of Co-axial fed Patch Antenna Arrays at 30GHz

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Abstract— This paper provides a brief comparison of four, eight and sixteen element single substrate patch array antenna at center frequency of 30 GHz. The dimensions of the patches are calculated using mathematical formulae in order to provide optimum level performance at 30GHz with bandwidth 20-40 Ghz. Subsequently characteristics like gain, directivity, S-parameter, 3D far-field and radiation efficiency are found out via the process of simulation. These results are then compared to find the most efficient model at 30 GHz. The structural models make the use of coaxial feeding technique and they have been simulated using Finite Integration Technique (FIT) with add to open boundary condition at -30db accuracy.

Index Terms— micro-strip antenna (MSA), micro-strip patch array antenna (MPA), coaxial coupling, FIT, S-parameters, Directivity, 3D far field plots.

1 Introduction

CURRENT state-of-the-art solid-state-based phased arrays face numerous obstacles such as exuberant cost and technological difficulties in integration [1]. This has led to a rising interest in smaller and low profile antennas such as micro-strip antennas (MSAs) for wireless transmission [2]. An MSA is a narrowband, wide-beam antenna which is fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate, such as a printed circuit board. A continuous metal layer bonded to the other side of the substrate is called ground plane. The microstrip antenna generally has 3 parts: a radiating element (patch), an intermediate dielectric layer or substrate, and a ground plane. The radiating element or patch can be of many shapes like rectangular, square, circular, elliptical, triangular and is usually made of conducting materials such as copper or gold. The functioning and performance of microstrip antenna is dependent on the geometry of the patch, properties of the substrate and feeding techniques. The most common and popular kind of patch is rectangular in shape which we has been used in our model. The dielectric substrate must have properties like low dielectric constant, low loss coefficient and sufficient thickness so as to offer maximum radiation efficiency and bandwidth. But for larger dimensions, low dielectric constant substrates are to be used. It should also be taken into account that although low loss substrates provide good radiation efficiency, they also make the microstrip antenna a high-Q device, resulting in narrow bandwidth. Conversely the use of high dielectric substrates with higher loss provides reduced performance, but greater bandwidth and smaller dimensions.

To get an optimum usage of emerging wireless cellular services like 4G and 5G technologies, it has become important to expand the spectrum of wireless communications. And MSAs are of prime significance in that direction. As pointed out in [3],[4], the propagation characteristics of mm-waves (30 GHz and above) make them a good candidate for future wireless communication systems. As narrow BW of MSAs (typically 1–5%) limits their application, increasing the BW of MSAs has drawn attention as an active research area in this field with a BW up to 70% already in place [5],[6].

2 Feeding technique

The feeding technique used here is called coaxial cable feeding or probe feeding. Coaxial cable consists of an outer conductor and an inner conductor. Microstrip antennas are fed from underneath via a probe as shown in Figure 1. The outer conductor of the coaxial cable is connected to the ground plane, and the center conductor is soldered to the patch antenna. Its major disadvantage is that it provides narrow bandwidth. It is also difficult to construct because a hole has to be drilled in the substrate and the connector protrudes outside the ground plane. The position of the feed can be altered to control the input impedance. The coaxial feed introduces an inductance into the feed that has to be taken into consideration if the height h gets large. Moreover, the probe will also radiate in undesirable directions, which has to be minimized by improving its directivity.

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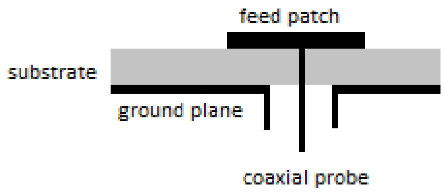

Fig. 1. Side view of antenna structure

3 Design of coaxial probe fed Arrays

Design details:

Patches- PEC, Ground- PEC

Substrate material- Arlon AD 320 (loss free)

The substrate material was chosen to be Arlon due to its excellent dielectric properties which make it suitable to be used as a substrate. The spacing has been taken as λ/2 i.e. 5mm to avoid grating lobes [7]. The array has been designed to have an input impedance of 50 ohm. Waveguide ports have been used to provide excitation to the patches. The design parameters for the arrays are given below in table 1.

TABLE 1
OPTIMIZED DESIGN PARAMETERS

Parameters	Value
Fr	30GHz
ε_r	3.2
h	0.335 mm
Hp	0.05 mm
Wp	3.4503 mm
Lp	2.6216 mm
Wf	3.013 mm
Lf	2.258 mm

where, fr= radiating frequency= 30 GHz

εr1= Dielectric constant of Arlon AD 320(loss free) = 3.2

λair = λ0 = C/fr = 0.01m=10mm

λ=5.58630 at εr1 =3.2

*h= Thickness of substrate= 0.06 * λ at εr = 0.335mm*

hp= Thickness of patch

Wf= width of feed patches

Lf= length of feed patches

4 Structural Visualization

4.1 4 Patch Coaxial Probe fed Antenna

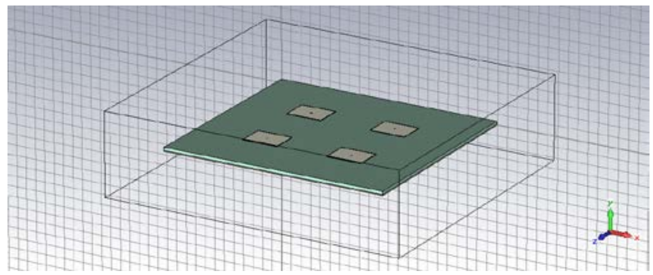

Fig.2. 4-element Antenna

The length of the ground plane (L)is 20.2432mm and its width(w)is 21.9006mm.

4.2 8 Patch Coaxial Probe fed Antenna

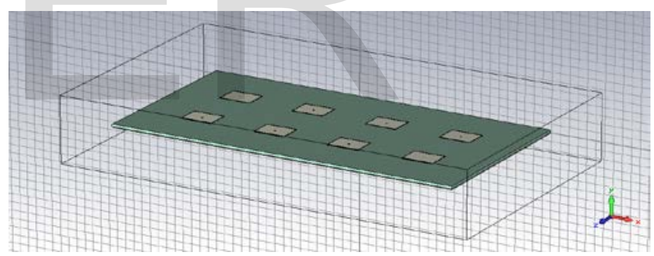

Fig.3. 8-element Antenna

The ground plane has a length (L) of 20.2432mm and width (w) of 38.8012mm.

4.3 16 Patch Coaxial Probe fed Antenna

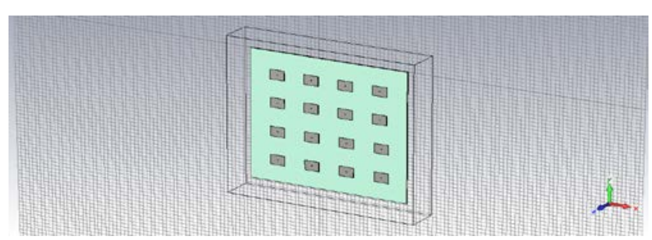

Fig.4. 16-element Antenna

Here the length of the ground plane (L) is 35.4864mm and

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width (w) is 38.8012mm.

5 ANTENNA PERFORMANCE ON THE BASIS OF SIMULATION RESULTS

Using Finite Integration Technique (FIT) as in [7], S-parameters, far-field patterns and the antenna gain are evaluated at 30GHz and the results thus obtained are shown below:

5.1 S-Parameters

S-parameters describes the input-output relationship between ports (or terminals) in an electrical system. For instance, if we have 2 ports (intelligently called Port 1 and Port 2), then S12 represents the power transferred from Port 2 to Port 1. S21 represents the power transferred from Port 1 to Port 2. In general, SNM represents the power transferred from Port M to Port N in a multi-port network. [8]

5.1.1 4-element

It is observed that the S 2(2),1(2) parameter has its lowest peak around -131dB at 24.9GHz.,it shows that matching at the port is quiet good with less return loss. However S3(1),1(2) shows a perfect peak of -124dB at 30Ghz. S3(1),1(2) which shows that there is good isolation between port 3 and 1 for input port modes 1 and 2. The graph also indicates that the coupling between two ports is less. The gross magnified plot of S-parameters is shown in fig 5(a).

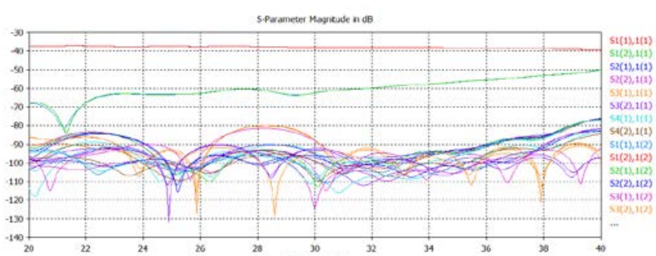


Fig. 5(a) S-Parameters for 4-element micro-strip antenna

5.1.2 8-element

For 8-element array the lowest peak shows approximately -135dB at 29.8 GHz by S7(2),1(1). It is observed that S7,1 is -135 dB at approx 30 GHz, indicating there is less coupling between port 7 to 1 showing good isolation. Magnitude of S1,1 for both input port mode 1 is -112dB at exactly 30Ghz.

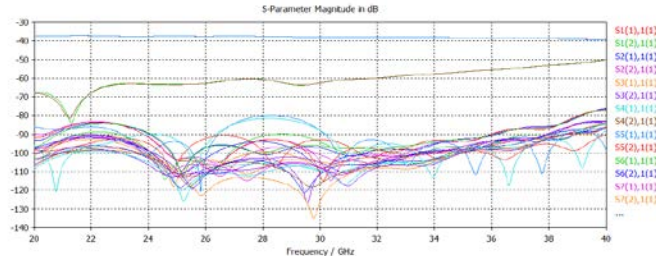
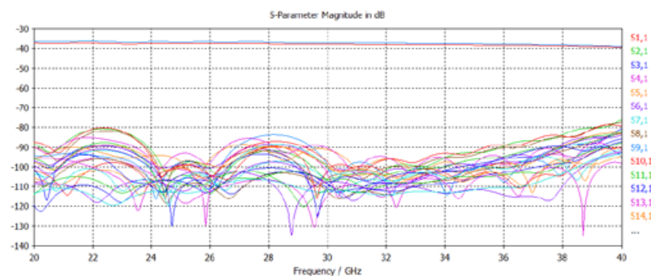


Fig. 5(b) S-Parameters for 8-element micro-strip antenna

5.1.3 16-element

The lowest value of S15,1 parameter is observed at 28.8GHz



with the value of approx. -133 dB, which means port matching is quite good. However S13,1 shows a dip of -130dB at 29.5 Ghz. The plot is shown in the fig 5(c).

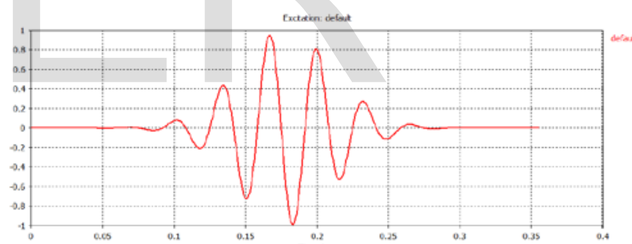


Fig. 5(c). S-Parameters for 16-element micro-strip antenna

5.2 Excitation signal applied for simulation

Fig. 6 Excitation Pulse

5.3 Farfield plots

5.3.1 4-element

Fig. 7.1(a) and (b) show 3D Far field Plot and polar plot respectively. We can see that at 30 GHz polar plot magnitude is 7.6 dBi and directivity 7.672 dBi with side lobe levels -1.4dBi. The side lobe is much smaller compared to main lobe.

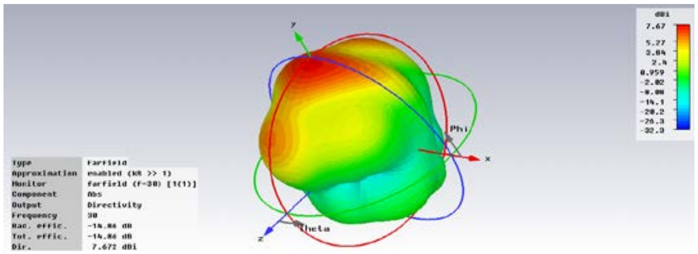
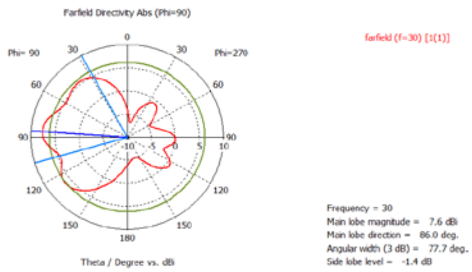


Fig. 7.1(a)

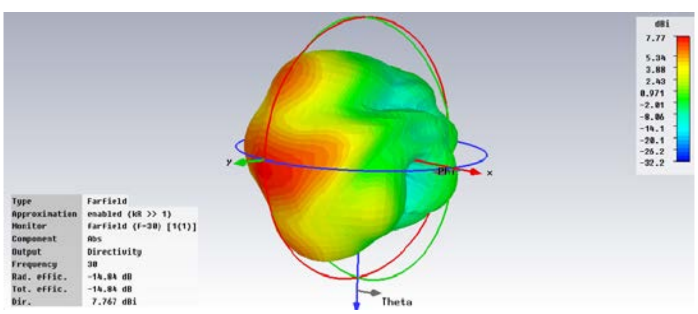


7.1 (b)

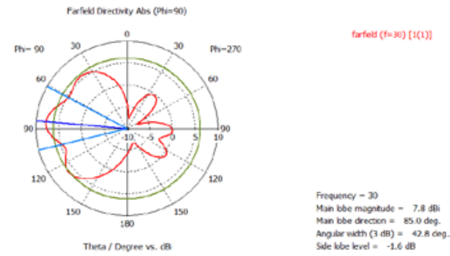
7.1(a) 3-D far field Plots (b) polar plot for 4-element micro-strip antenna

5.3.2 8-element

Fig. 7.2(a) and (b) show 3D Far field Plot and polar plot respectively. Fig 11 displays that, at 30 GHz radiated efficiency and total efficiency are both equal to -14.84 dB with directivity 7.767 dBi whereas in polar plot main lobe magnitude is 7.8 dBi and side lobe level is -1.6dB which is very small compared to main lobe.



7.2(a)

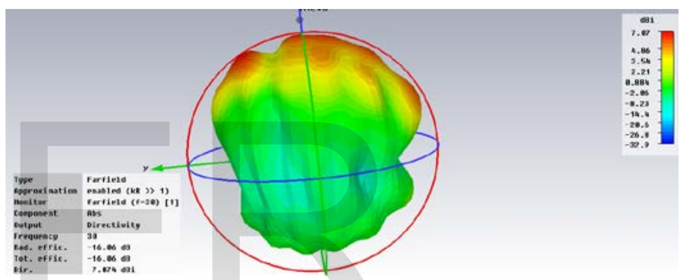


7.2(b)

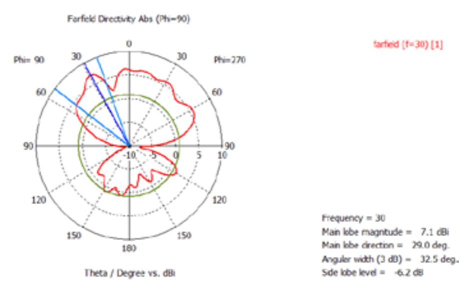
7.2(a) 3-D far field Plots (b) polar plot for 8-element micro-strip antenna

5.3.3 16-element

Fig. 7.3(a) and (b) show 3D Far field Plot and polar plot respectively. For (a), we can see that, at 30 GHz radiated efficiency and total efficiency are both -16.06 dB with directivity 7.074 dBi whereas in polar plot main lobe magnitude is 7.1dBi and side lobe level is –6.2 dB which is quite comparable to main lobe.



7.3(a)



7.3(b)

7.3(a) 3-D far field Plots (b) polar plot for 16-element micro-strip antenna

5.4 Summary of Antenna Results

TABLE 2
OVERVIEW OF RESULTS

Parameter	4-element	8-element	16-element
Directivity (dBi)	7.672	7.767	7.074
Gain (dBi)	7.6	7.8	7.1

Value of S Parameter at 30GHz (dB)	-124	-112	-130
Highest peak of S parameter (dB)	Approx -131dB at 24.9GHz	Approx -135dB at 29.8GHz	Approx -133dB at 28.8GHz
Side lobe level	-1.4	-1.6	-6.2
Radiation Efficiency (dB)	-14.86	-14.84	-16.06
Total Efficiency (dB)	-14.86	-14.84	-16.06

6 Conclusion

The three arrays have been designed and simulated under the same conditions. We have obtained the simulation values of directivity, gain, efficiency, etc for all three cases. Coaxial feed has been given to the patches to enhance the antenna's bandwidth. The directivity of all the three arrays is almost equal with 8-element patch antenna leading the other two with the value of 7.767dBi. Further comparing their gain, here too we observe gain almost in the same range with the highest value at 7.8dBi for 8-element patch antenna. However, the 8-element array has slightly higher side lobe level and a slightly lesser radiation and total efficiency than 4-element array. It can be therefore concluded that amongst the three models designed all of them provide similar specifications. However the 8-element design gives a slightly better performance at 30 GHz in terms of directivity and gain.

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