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Design Optimization of Low Side Lobe Level Microstrip Antenna Array at 28 GHz for 5G Application

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Abstract - *This paper presents 7 element microstrip line feed linear series fed uniform, Binomial, Dolph-chebyshev arrays on a single substrate material of Rogers RT/Duroid 5880 having dielectric constant of* ε_r *= 2.2 with Loss tangent* $\tan\delta$ *= 0.0009 at 28GHz for low side lobe level (SLL) and High Bandwidth. Binomial, Dolph-Chebyshev distribution is achieved using tapered patch width. A 7-element linear Binomial, Dolph-chebyshev array using series feed is designed and compared with Uniform series fed array having identical radiating elements. Uniform series fed array provides gain of 13.5 dB and SLL of -14.92 dB at 28.17 GHz. However, binomial array provides 9.8 dB Gain and no side lobes at 28.2 GHz and Doplh-Chebyshev array provides gain of 12.3 dB and SLL of -20.5 dB at 28.6 GHz. Uniform array has High Gain and High SLL. Whereas binomial array provides Low gain and extremely low SLL and High Bandwidth and Dolph-chebyshevarray has High Gain, Low SLL and High Bandwidth. These series fed microstrip antenna arrays are designed in High Frequency Structure Simulation (HFSS) software version 13. These mm-wave series fed antenna arrays are resonated between 27-29 GHz are used for 5G mobile communication Application.*

***Key Words*: Uniform array, Binomial array, Dolph-Chebyshev array, HFSS, Linear array, Series fed array, Rogers RT/Duroid 5880.**

1. INTRODUCTION

Series fed microstrip antenna (MSA) arrays are used in end to end communication, surveillance radar and microwave sensors. They have potential of low profile, light weight, compact size, easy integration with RF modules and high efficiency over corporate feed arrays due to minimized feed network losses [2]. A synthesis method of series fed array with non-uniform spacing and width is presented using transmission line model and validated on various current distribution techniques to minimize SLL [3].Current amplitude tapering is commonly known technique to reduce SLL [4].

Chebyshev distribution is obtained by tapering the width of feed line or patch to reduce SLL [5]-[7]. Tapered feed line width having inset microstrip feed is used to design 6-element array with SLL of - 18 dB [5]. Both feed line and patch width tapering is used to achieve Chebyshev distribution for SLL of -20 dB [9].A series fed array design is presented by considering patch element and feed line as unit cell using cosine aperture distribution to reduce SLL [8]. Cosine square distribution is achieved by patch width tapering to achieve SLL of -18.6 dB [9]. A proximity-coupled patch array fed by binomial distribution using unequal power divider is presented [10]. It suppresses SLL to -19 dB.

In this paper, series fed linear binomial and Dolph-Chebyshev MSA arrays are designed to achieve extremely low SLL. Binomial and Doplh-chebyshev distribution is achieved by tapering the width of the radiating element. A 7-element linear binomial and Dolph-chebyshevarray with microstrip line feed is designed using series feed to reduce SLL and for High Bandwidth and these are compared with series feed array having identical radiating elements.

2. LINEAR SERIES FED UNIFORM, BINOMIAL, DOLPH-CHEBYSHEV ARRAYS

In this section, series fed linear Uniform, Binomial, Dolph-Chebyshev arrays are designed at 28 GHz on a substrate Rogers RT/Duroid 5880 with dielectric constant ε_r = 2.2, substrate thickness h = 0.508 mm, and loss tangent tan δ = 0.0013. For broadside radiation pattern, all the radiating elements should be excited in same phase. Since MSA provides 180° phase shift along its two radiating edges, the patch to patch connecting feed line of $\lambda/2$ length is used to provide additional 180° phase shift as shown in Fig. 1,2,3.Feed lines are connected in the middle of radiating edges for symmetry of the array with feed point. The array is excited with microstrip line feed.

A 7-element series fed microstrip array with identical radiating elements (Array-1) (see Fig. 1(a)) to compare its performance with binomial array (Fig. 1(b)) and Dolph-Chebyshev array (Fig. 1(c)). Length and width of the radiating elements in Array-1 are taken as L = 3.282 mm, and W = 4.235 mm, respectively. Width and length of the connecting feed lines are taken as 1.565 mm and 2.2 mm corresponding to the characteristic impedance of 50 Ω and $\lambda/2$ line length, respectively. For impedance matching, Initial element is fed with a transmission line of width = 0.5 mm and length = 3.61175 mm.

The patches in the Binomial array have non-uniform amplitudes and the amplitude of the radiating patchess are arranged according to the coefficients of successive term of the following binomial series

$$(a+b)^{n-1} = a^{n-1} + \frac{n-1}{1!}a^{n-2}b + \frac{(n-1)(n-2)}{1!}a^{n-3}b^2 + \cdots$$

Where n = number of patches in the array

The coefficients of a Binomial array were arranged based on Pascal's triangle. Binomial taper coefficients for 7 elements are

Patch 1	Patch 2	Patch 3	Patch 4	Patch 5	Patch 6	Patch 7
1	6	15	20	15	6	1

Dolph-Chebyshev array is an array of non-uniform amplitudes and the amplitude of the radiating sources are arranged according to the coefficients of the chebyshev polynomial. The main advantage of this is to reduce side lobes to certain extent.

The chebyshev polynomial is

$$Tm(x) = \cos(m \cos^{-1} x) \text{ for } |x| < 1 \quad (1)$$

$$T0(x) = 1,\ T1(x) = \cos(\delta) = x$$

Steps involved in calculation of chebyshev coefficients are:

Step1: Calculate r.

Step2: Calculate m and x_0 value.

Step3: Find array polynomial Eteor Eto based on number of Patches.

Step4: Equate array polynomial to Tm (x) and find the Corresponding tapered chebyshev coefficients.

The higher order coefficients of Dolph-Chebyshev array were obtained by using a recursion formula

$$Tm+1(x) = 2xTm(x) - Tm-1(x) \quad (2)$$

Where m = n-1 = degree of the polynomial and n = number of patches

$$x = \frac{1}{2}\{[r + \sqrt{(r2\text{-}1)}]\ 1/m + r - \sqrt{(r2\text{-}1)}]\ 1/m\}$$

$$r = \text{side lobe level ratio} = \frac{\text{main lobe maxima}}{\text{side lobe level}}$$

in dB = 20 log10 (r)

E-field for even sources

$$Ete = \sum_{k=0}^{N-1} ak \cos\left[\frac{2k+1}{2}\right]\varphi\ ;\ N = \frac{ne}{2} \quad (3)$$

E-field for odd sources

$$Eto = 2\sum_{k=0}^{N} ak \cos\frac{2k}{2}\varphi; N = \frac{no\text{-}1}{2} \quad (4)$$

Dolph-Chebyshev taper coefficients for 7 elements are:

Patch 1	Patch 2	Patch 3	Patch 4	Patch 5	Patch 6	Patch 7
1	2.588	4.262	4.981	4.262	2.588	1

3. DESIGN

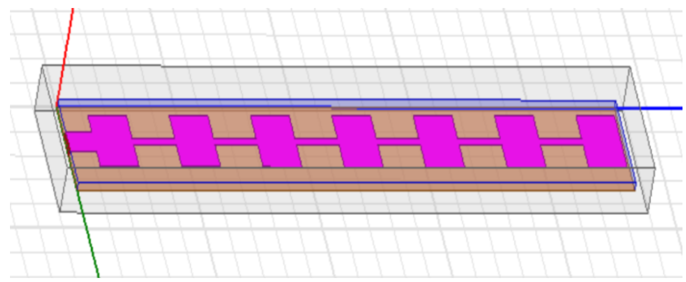

Fig [1.1]: Uniform array

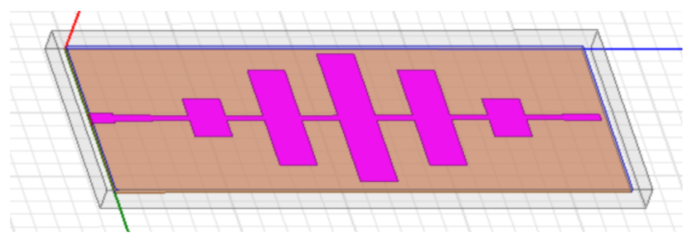

Fig [1.2]: Binomial array

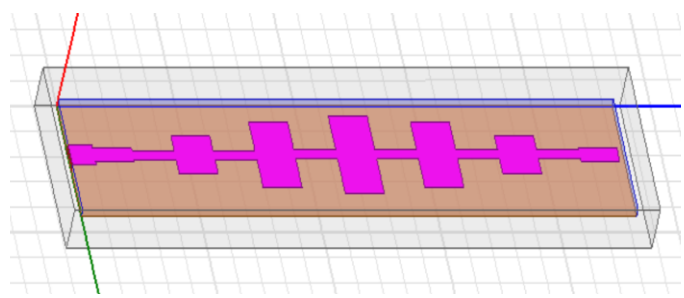

Fig [1.3]: Dolph-Chebyshev array

4. RESULTS

4.1 Reflection Coefficient or Return Loss*:*

Reflection coefficient is also called as return loss and is denoted by S11. The performance of antenna generally depends upon a good reflection coefficient or return loss of at least -10 dB because return loss in antenna is a ratio of incident power to that of reflected power. Consider that the reflection coefficient is 0 dB then nothing has radiated as all the power have reflected from antenna [11].

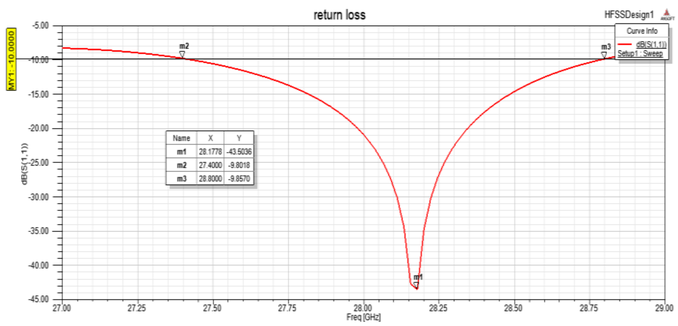

Fig [2.1]: S11 vs frequency plot of Uniform array resonated at 28.1 GHz

As shown in Fig [2.1], it has observed that the Uniform array resonated at 28.1 GHz with return loss -43.51dB and bandwidth of 1.4 GHz.

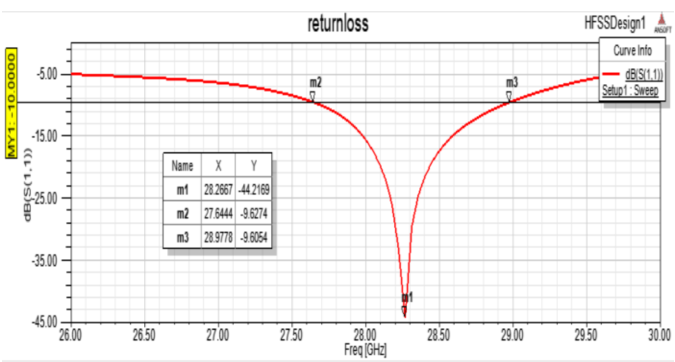

Fig [2.2]: S11 vs frequency plot of Binomial array resonated at 28.26 GHz

As shown in Fig [2.2], it has observed that the Binomial array resonated at 28.26 GHz with return loss -24.83 dB and bandwidth of 1.5 GHz.

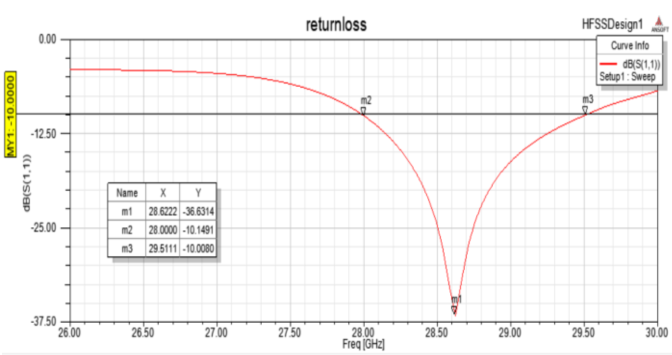

Fig [2.3]: S11 vs frequency plot of Dolph-Chebyshev array resonated at 28.62 GHz

As shown in Fig [2.3], it has observed that the Binomial array resonated at 28.62 GHz with return loss -36.63 dB and bandwidth of 1.52 GHz.

4.2 Voltage Standing Wave Ratio:

The voltage standing wave ratio is a unit less ratio. For microstrip patch antenna design to be used for 5G applications, this ratio should be in the range 1⩽VSWR⩽2 [11]. Higher the value of VSWR greater the mismatch.

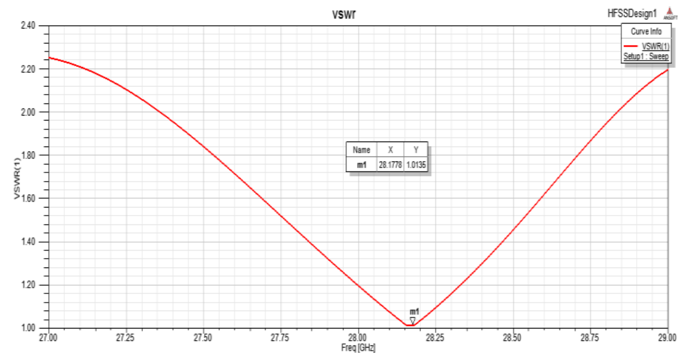

Fig [3.1]: VSWR plot of Uniform array

As shown in Fig [3.1], it has observed that the Uniform array at 28.1 GHz has VSWR 1.01.

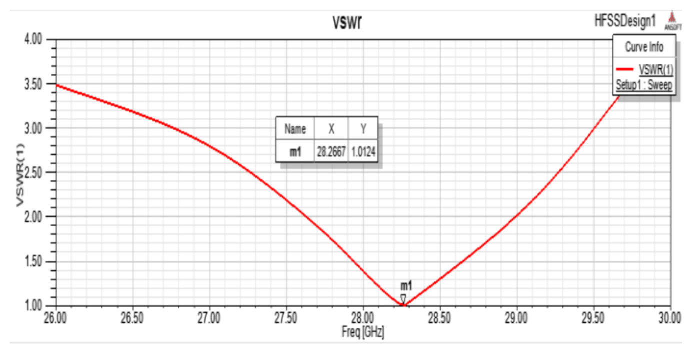

Fig [3.2]: VSWR plot of Binomial array

As shown in Fig [3.2], it has observed that the Binomial array at 28.26 GHz has VSWR 1.01.

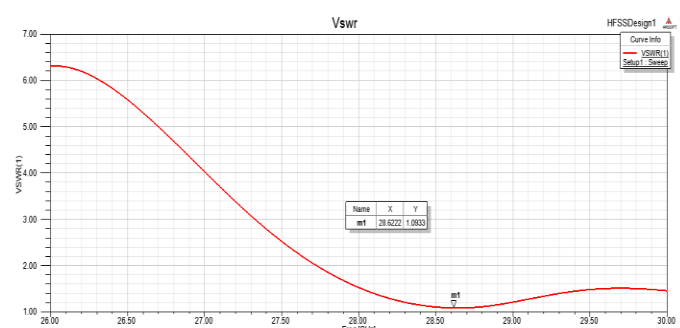

Fig [3.3]: VSWR plot of Dolph-Chebyshev array

As shown in Fig [3.3], it has observed that the Dolph-Chebyshev array at 28.62 GHz has VSWR 1.09.

4.3 Gain:

The Fig.4 shows 3D Gain. The term Gain describes how the antenna transforms its source power into the radio waves at the transmitter side and vice versa at the receiver side. An efficient antenna should consist of minimum 6 dB of gain. High gain is very much required for 5G wireless system because this radiation patterns indicates the quantity of power radiated by antenna.

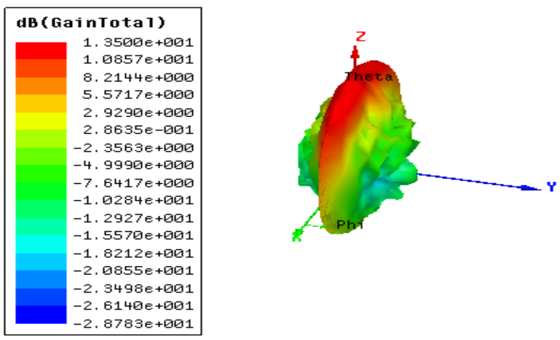

Fig [4.1]: 3D Gain plot of Uniform array

As shown in Fig [4.1], it has observed that the Uniform array at 28.1 GHz has Gain 13.5dB.

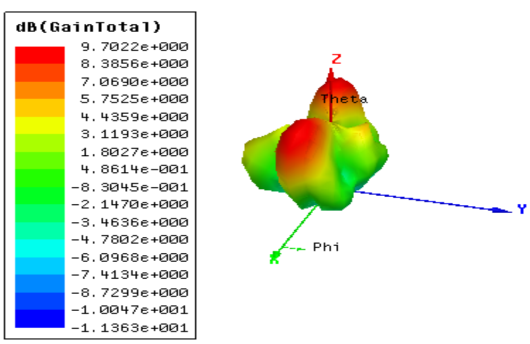

Fig [4.2]: 3D Gain plot of Binomial array

As shown in Fig [4.2], it has observed that the Binomial array at 28.26 GHz has Gain 9.7 dB.

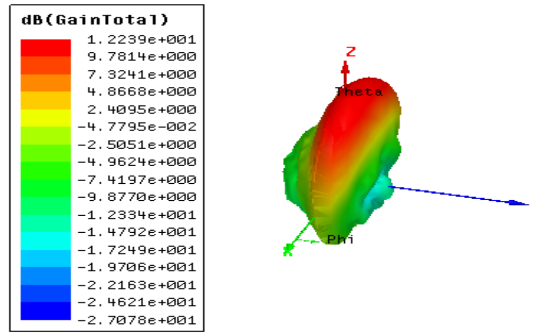

Fig [4.3]: 3D Gain plot of Dolph-Chebyshev array

As shown in Fig [4.3], it has observed that the Dolph-Chebyshev array at 28.62 GHz has Gain 12.23 dB.

4.4 Radiation Pattern:

The Fig.5 shows 2D radiation pattern. Radiation pattern represents the strength of radio waves from an antenna in all directions.

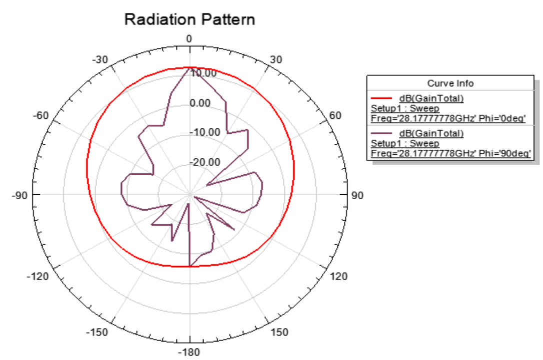

Fig [5.1]: 2D Radiation pattern of Uniform array

As shown in Fig [5.1], it has observed that the radiation pattern must consist of more number of side lobes.

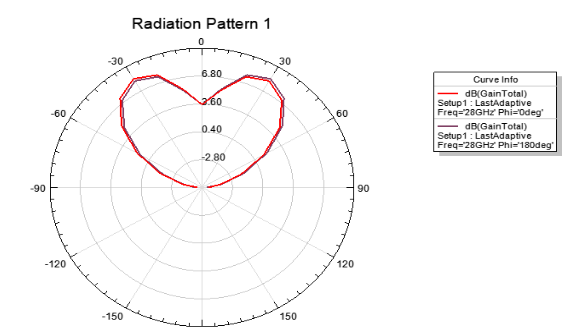

Fig [5.2]: 2D Radiation pattern of Binomial array

As shown in Fig [5.2], it has observed that the Binomial array has no side lobes.

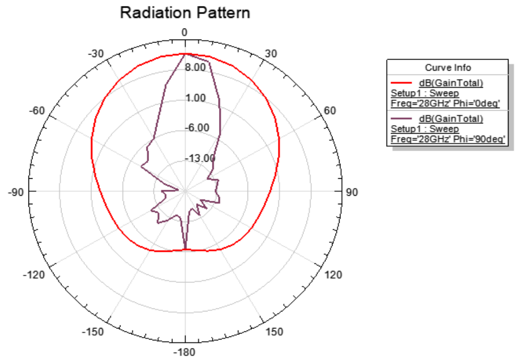

Fig [5.3]: 2D Radiation pattern of Dolph-Chebyshev array

As shown in Fig [5.3], it has observed that the Dolph-Chebyshev array has side lobes in between Uniform and Binomial array.

4.5 Directivity:

Directivity is the measure of the radiation emitted in a particular direction.

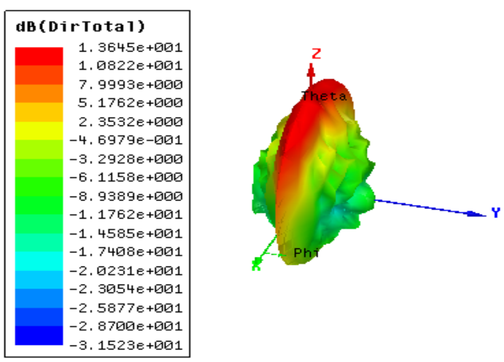

Fig [6.1]: Directivity of Uniform array

As shown in Fig [6.1], it has observed that the Uniform array at 28.1 GHz has directivity13.65dB.

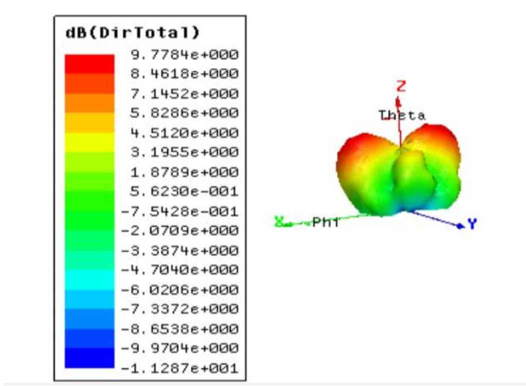

Fig [6.2]: Directivity of Binomial array

As shown in Fig [6.2], it has observed that the Binomial array at 28.26 GHz has directivity 9.77 dB.

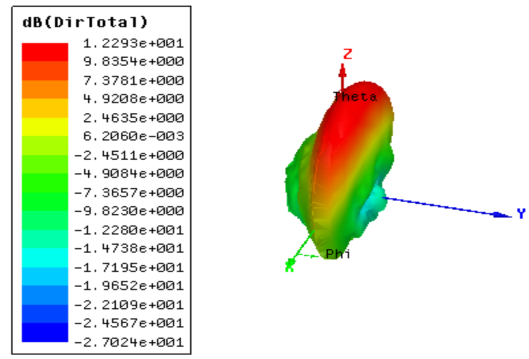

Fig [6.3]: Directivity of Dolph-Chebyshev array

As shown in Fig [6.3], it has observed that the Dolph-chebyshev array at 28.62 GHz has directivity 12.29 dB.

4.6 Impedance Plot:

Fig 7 shows impedance plots.

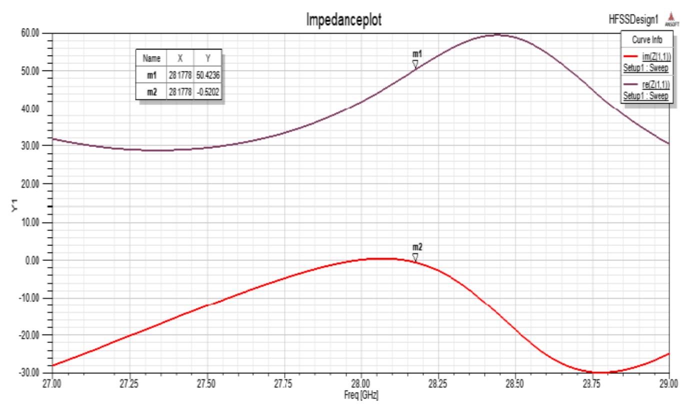

Fig [7.1]: Impedance plot of Uniform array

As shown in Fig [7.1], it has observed that the Uniform array at 28.1 GHz has Impedance matching of 50.42-0.52j.

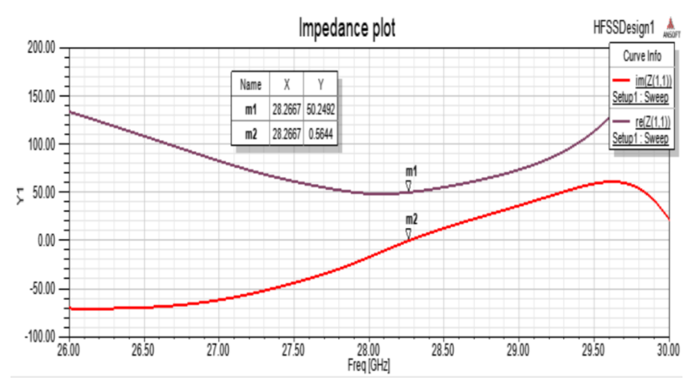

Fig [7.2]: Impedance plot of Binomial array

As shown in Fig [7.2], it has observed that the Binomial array at 28.26 GHz has Impedance matching of 50.24+0.56j.

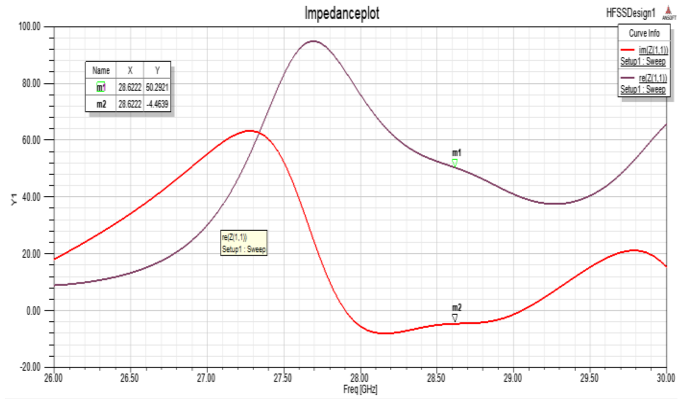

Fig [7.3]: Impedance plot of Dolph-Chebyshev array

As shown in Fig [7.3], it has observed that the Dolph-Chebyshev array at 28.26 GHz has Impedance matching of 50.29-4.46j.

4.7 Gain v/s Theta Plot:

Fig 8 shows the Side lobe level of particular array. Side lobes means unwanted radiation in undesired directions. If side lobe level means side lobes are suppressed up to that level. More SLL is desirable for any type of antenna design.

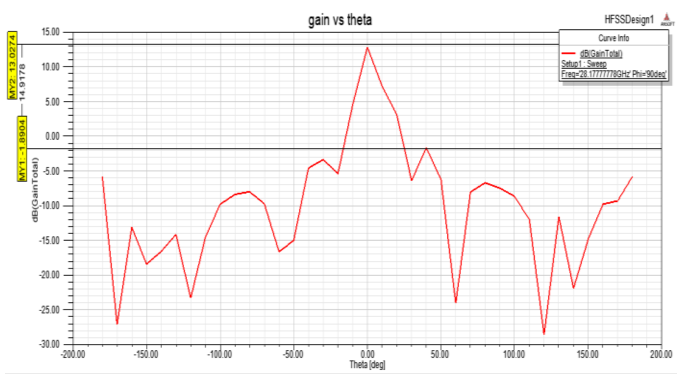

Fig [8.1]: Gain v/s Theta plot of Uniform array

As shown in Fig [8.1], it has observed that the Uniform array at 28.17 GHz has Side Lobe Level (SLL) -14.92 dB. We observed that Uniform array has more number of side lobes. That means side lobes suppression is less in Uniform distribution.

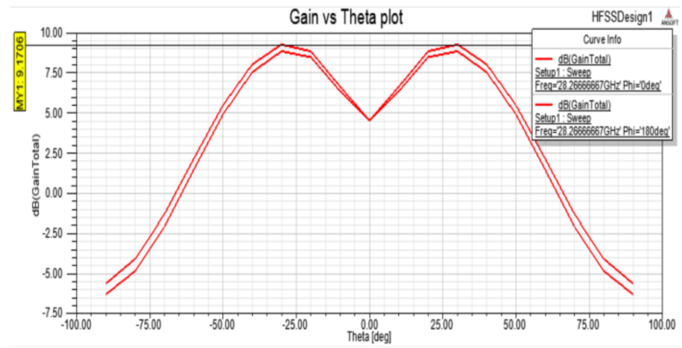

Fig [8.2]: Gain v/s Theta plot of Binomial array

As shown in Fig [8.2], it has observed that the Binomial array at 28.26 GHz has no side lobes then Side Lobe Level (SLL) -∞ dB. We observed that Binomial array has extremely low side lobes.

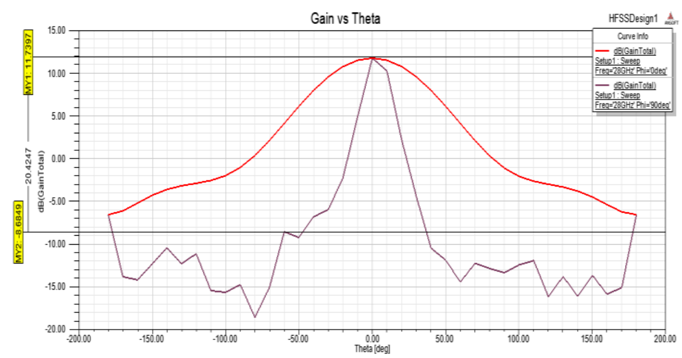

Fig [8.3]: Gain vs Theta plot of Dolph-Chebyshev array

As shown in Fig [8.3], it has observed that the Dolph-Chebyshev array at 28 GHz has Side Lobe Level (SLL) -20.43 dB. We observed that Dolph-Chebyshev array has low side lobes.

4.8 Current Distribution:

Fig 9 shows surface current distribution plots.

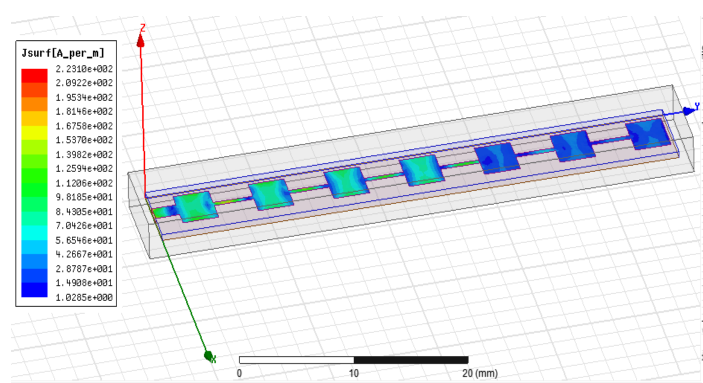

Fig [9.1]: Current distribution plot of Uniform array

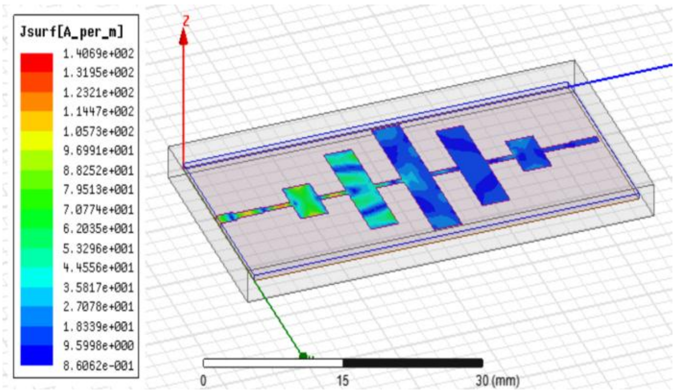

Fig [9.2]: Current distribution plot of Binomial array

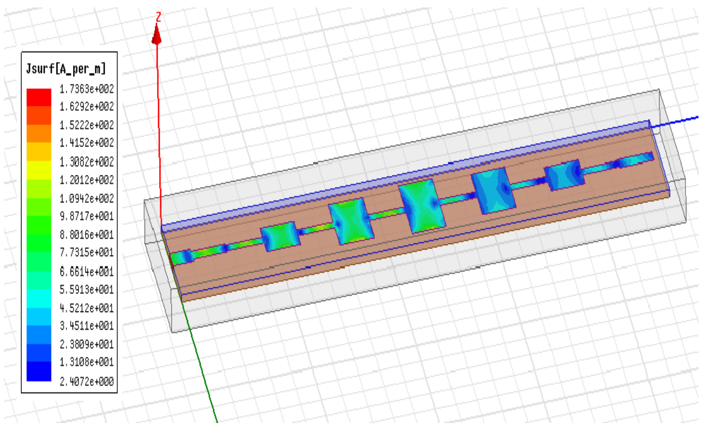

Fig [9.3]: Current distribution plot of Dolph-Chebyshev array

Table 1: Comparison of Linear Series fed Uniform, Binomial, Dolph-Chebyshev Arrays with Previous Series Fed Linear Arrays

Parameters	Existed					Proposed		
	Taylor	Uniform				Uniform	Binomial	Dolph-chebyshev
	[18]	[14]	[15]	[16]	[17]			
No .of elements	8	8	8	8	8	7	7	7
Fo (GHz)	28	28.1	27.85	28	28	28.17	28.26	28.62
Return loss	-31	-35	-13.5	-35	-30.5	-43.5	-44.28	-36.63
Band width (GHz)	1.2	0.5	0.64	1.2	1.4	1.4	1.5	1.52
Gain (dB)	12	13	13	12	12	13.5	9.72	12.24
SLL (dB)	-15.2	-14	-13	-12.5	-15	-14.92	No side lobes	-20.5

5. CONCLUSION

The 1x7 series fed patch antenna arrays designed at 28 GHz are used for 5G mobile communication applications. Series fed Binomial, Dolph-Chebyshev arrays are designed with tapered patch width are compared with uniform series fed array of identical radiating elements. Uniform linear series fed array provides gain of 13.5dB, Bandwidth of 1.4GHz and SLL of -14.92dB. Whereas Binomial and Dolph-Chebyshev arrays provide gain of 9.7dB, 12.4dB, Bandwidth of 1GHz, 1.52GHz and SLL of -26.7 and -20.5dB respectively. The proposed linear series fed Uniform array have high SLL and High Gain, Binomial array have extremely low SLL and low Gain, whereas Doplh-Chebyshev array have low SLL, High Gain and High Bandwidth. Therefore Dolph-chebyshev array provides better results in terms of Gain, SLL, Bandwidth and size compared to Uniform and Binomial array.

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