A High Gain Ultra Wideband Array Antenna For Wireless Communication

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ABSTRACT

This paper focuses on designing a high-gain ultra-wideband antenna by increasing the elements in an antenna array. The basic antenna structure is a windmill shaped structure. The polyethylene substrate with a dielectric constant of 2.25 and a height of 1.6mm is used. The desired antenna parameters are achieved within the ultra-wideband of 4-10 GHz. HFSS (High-Frequency Structural Simulator) is used to validate the design of the antenna. The simulation results show that we could achieve the constant gain of 8 dB in the ultra-wideband frequency range when the number of elements increases beyond 5.

Keywords - *ultra-wideband, antenna, windmill, return loss, gain, directivity, simulation.*

I. INTRODUCTION

Ultra-wideband (UWB) antenna are gaining importance and becoming very attractive in modern and future wireless communication systems, mainly because of increasing demand for the wireless transmission rate by the users and the UWB properties such as high data rate, low power consumption, and low cost, which provides a vast advancement in UWB antennae research and development

As FCC recommended frequency range for UWB antenna is 3.1 GHz to 10 GHz, we consider the same frequency range for wireless communication. The proposed antenna is designed in this frequency range to make it suitable for wireless applications. As we move towards 5G communication, the UWB antenna can play a vital role in it. The data rate and ultra-wide bandwidth obtained are the key parameters that enable mobile communication and short-range communication. Advantages of UWB antenna are high bandwidth, high data rate, compact size, low weight, high fractional bandwidth.

The gain of an antenna plays a vital role in communication applications. As the gain of the antenna increases, the losses are much reduced for effective communication. There are many ways to increase the antenna's gain, such as introducing slots in the structure and implementing an antenna array. When an antenna array is considered, the number of elements in the array and the feeding source plays an important role.

II. RELATED WORK

Azari [3] proposed an octagonal fractal microstrip patch antenna for commercial and military telecommunication applications. The proposed antenna consists of an octagonal fractal patch, and a coaxial feed is used as a feeding technique. The designed antenna covers a frequency range of 10 GHz to 50 GHz. The antenna is designed on Rogers TMM substrate with 6 x 6 cm^2(dielectric constant =4.5, h=1.524 mm). It is shown that the proposed antenna is suitable for telecommunication applications. An array of eight elements is considered in this antenna. According to the octal properties, the interior angle is $135^{o,}$ and the exterior angle is 45^o. Each side of the patch is 2cm. The antenna is simulated in CST software. The experimental analysis shows that the designed antenna exhibits again that is reasonable in the entire bandwidth. The antenna is small in size.

The fractal property used in the design helps in achieving miniaturization and multiband properties. Bai et al. [4] proposed a compact antipodal Vivaldi antenna used in the UWB application. In the proposed antenna low-frequency performance of the Vivaldi antenna is improved. The modification of the traditional Vivaldi structure is carried out by introducing a loading structure like circular -shape-load or slot-load to match termination. The antenna operates at a range of 4 GHz to 50 GHz, and thus it is suitable for UWB communication. The antenna is designed on a 10-mil substrate with a dielectric constant of 2.3. To achieve the antipodal structure, the substrate s flared in the opposite direction to form a tapered slot. The antenna is designed and fabricated on the HFSS platform. The designed antenna's simulation results show high directivity and improved radiation characteristics in the low-frequency range. The antenna exhibits a 2 GHz wider impedance bandwidth, allowing a return loss of -10 dB. The loading structure used here helps to achieve the compact structure, i.e., antenna length and aperture. The beam pattern of the antenna is symmetric in both E and H planes. The gain of the antenna varies around the value of 3 to 12 dBi. The structure makes it satisfying to use in the field of mobile communication. Nair et al. [7] proposed a compact semi-circular directive dipole antenna used for UWB communication and imaging applications and investigated it. The antenna consists of a compact slot line with two symmetrical rectangular pieces and two symmetrical semi-circular patches.

Singhal et al. [12] proposed a tree-shaped fractal antenna for UWB applications. The antenna consists of a third iteration tree-shaped fractal patch, and a coplanar waveguide feeds it. The antenna is designed on the FR4 epoxy substrate with a dielectric constant of 4.4, loss tangent of 0.02, and a thickness of 1.6 mm. The overall dimension of the antenna is 18.5 x 9.2 mm^2. The coplanar structure provides easy integration of the structure in MMICs. The experimental results show that it has an impedance bandwidth of 4.3 to 15.5 GHz. It has an omnidirectional radiation pattern and an acceptable value of gain over the operating bandwidth, radio determination, and satellite applications.

Sun et al. **[15]** presented a planar fan-like antenna used for wide beam applications. The proposed antenna consists of two wideband antipodal tapered slot elements. This element is used to form the fan-like structure and thus achieves wide-angle radiation. The antenna is fabricated on a thick Rogers 4003 PCB substrate. Moosazadeh et al. [14] proposed an ultra-wideband elliptically tapered antipodal Vivaldi antenna used in civil engineering applications. This design is based on a conventional antipodal Vivaldi antenna. Pandey et al. [8] proposed a compact end-fire antipodal Vivaldi antenna for UWB applications such as radar, microwave imaging, and high data rate wireless systems. The proposed antenna covers the frequency range of 2 GHz to 12 GHz. The reflection coefficient of the designed antenna is -10 dB. The obtained fractional bandwidth is more than 166 %. The radiation characteristics are end-fire in its operating band. The radiation efficiency is 60 – 83 %, and the radiation pattern is directional. Good pulse handling capability with a high system fidelity factor makes it suitable for UWB applications.

III. PROPOSED WORK

A. DESIGN OF SINGLE ELEMENT IN ARRAY

Initially, the substrate and ground plane are designed on the axis in HFSS software with the given dimensions. Then the patch is generated here rectangular patch is being used. With the help of the dimensions given microstrip patch is generated. The antenna's bow-tie shape is obtained by cutting the tapered slot in the microstrip patch designed in the previous step. From this point, the antenna is made asymmetric by shifting the patch's right to the left side. An antipodal structure is obtained by achieving this step, which gives the wideband characteristics of the proposed antenna. (180-degree phase shift in the structure helps to achieve wideband characteristics)

Table 1: Dimension of a single element in the array

Dimension	Value	Unit	Description
ε_r	2.25	-	Permittivity
H	1.6	Mm	Thickness
L_{sub}	34	Mm	Length of substrate
W_{sub}	30	Mm	Width of substrate
L_g	7	Mm	Length of the ground plane
W_g	32	Mm	Width of the ground plane
W_s	2.8	Mm	Width of feed
L_s	6.93	Mm	Length of feed

The ground plane shape is changed into a semi-circular ground slot along with a wide rectangular slot. Perfect impedance matching is achieved here at last; two radiators, one at the top and others at the bottom, are added, and thus the final structure, i.e., the windmill structure, is obtained. The windmill structure is used since, compared with other models, it has low return loss.

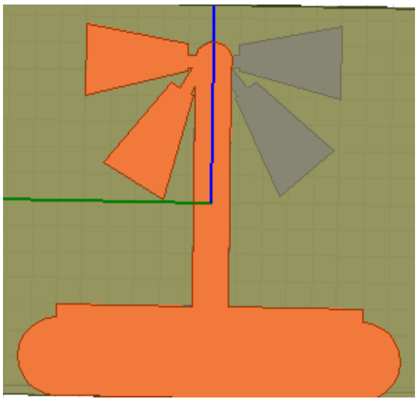

Fig 1: Structure of the proposed antenna

B. DESIGN OF ARRAY ANTENNA

The array antenna is designed by placing each element at a 40 mm distance. Fig 2 shows an example of the 2x2 array.

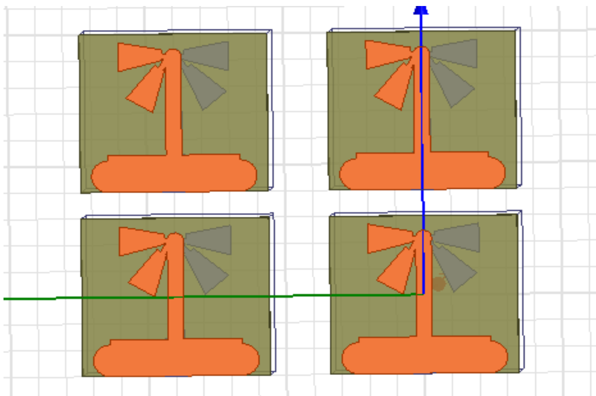

Fig 2: 2x2 array antenna

IV RESULTS AND DISCUSSION

The proposed antenna has a 34 x 30 mm dimension, and the thickness of the substrate is 1.6 mm. An analysis is carried out by increasing the elements in the array. Due to this, the main parameter analyzed is gain. The gain, directivity, radiation pattern, and return loss are discussed as follows.

GAIN

As the main focus of array construction in this work focuses on gain improvement, let's see the impact by increasing the array elements. As in the beginning, the array count was increased gradually as 1x1, 2x2, etc. Due to this, there was a slight increase in gain. When it reached 4x4, the gain level dropped. To increase the elements after 5x5, the gain reached a maximum value of 8 dB and remained constant. Fig 3 shows the comparison of gain.

Table 2: comparison of gain

S.NO	NO OF ELEMENTS IN ARRAY	GAIN
1	1	5.18
2	4	7.38
3	9	8.1
4	16	5.25
5	25	5.85
6	36	8.39
7	49	8.92
8	64	8.85

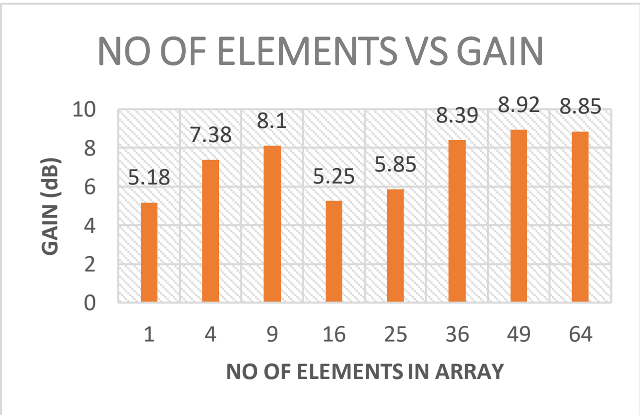

Fig 3: No of element in array versus gain

RADIATION EFFICIENCY

Fig 4 shows the comparison of radiation efficiency. Radiation efficiency shows how the antenna works in all direction and it is an omnidirectional radiating structure.

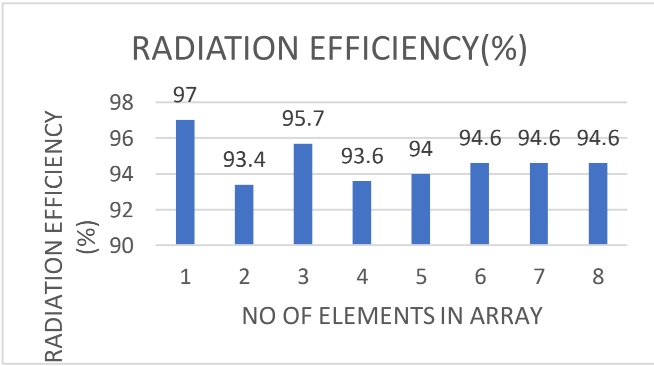

Fig 4: comparison of radiation efficiency

V. CONCLUSION AND FUTURE WORK

The design of the wideband, windmill shape ultra-wideband antenna has been designed for mobile communication. The antenna consists of four radiating arms, with an antipodal structure, which makes the antenna achieve wideband characteristics. The implementation in the array is carried out to improve the gain of the designed antenna. The proposed antenna is designed and validated in HFSS (High-Frequency Structural Stimulator) tool. The simulation results have shown that the antenna operates between 4 GHz to 10 GHz, the recommended FCC band for the UWB antenna. The proposed antenna achieved and maintained a constant value of return loss of -35 dB, a gain of 8 dB, and directivity of 8.27 dB when the elements crossed above 25. The radiation efficiency of the antenna is 97.8 %. The proposed antenna can also be used in short-range communication. The proposed UWB antenna will be fabricated, and the parameters will be tested and compared with the simulated results. The antenna parameters can be optimized in MATLAB coding. The frequency of operation of the antenna can be increased up to 150 GHz, and hence it can be utilized in future technologies. The antenna dielectric substance can be changed to achieve a high-frequency range [16]

APPENDIX

The formulas used for the design of the proposed antenna are given in this section.

$$L_{eff} = \frac{c}{2f\sqrt{\varepsilon_{reff}}} \quad (1)$$

$\varepsilon_{reff}$is calculated as follows,

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[\frac{1}{\sqrt{(1+12\frac{h}{w})}}\right] \quad (2)$$

Where,
the ε_r-The dielectric constant of the substrate
ε_{reff}– Effective dielectric constant.
h – Height of the dielectric substrate
The Width of the patch antenna is given by,

$$W = \frac{c}{2f\sqrt{\frac{(\varepsilon_r+1)}{2}}} \quad (3)$$

Where,

c = velocity of light= 3x10-8 m/s
f = resonance frequency
ε_r= dielectric constant = 4.4

ΔL is calculated as below,

$$\Delta L = 0.412h\frac{(\varepsilon_{reff}+0.3)}{(\varepsilon_{reff}-0.258)}\frac{(\frac{w}{h}+0.264)}{(\frac{w}{h}+0.8)} \quad (4)$$

The effective length (L_{eff}) of the patch is given by,

$$L_{eff}=L+2\Delta L \quad (5)$$

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