Advanced Dual-Polarized Planar Antenna Design for KU Band Millimeter Wave Applications

Sowjanya.B, KLEF Guntur 522302

K saikumar, Koneru Lakshmaiah Education Foundation (KLEF), Vaddeswaram 522302,
Andhra Pradesh, India

Abstract

In our quest for enhanced antenna performance, we turn to the Dolph-Chebyshev distribution to minimize side lobes and increase directivity. This technique effectively curtails unwanted radiation in non-primary directions, thus elevating antenna efficiency. Our simulations and performance evaluations rely on scattering parameter analysis to ensure accuracy and efficiency. This analysis covers a bandwidth centered around 500 MHz, a critical range for Ku band applications and millimeter wave operations. Our study demonstrates the practicality of employing a cross-polarized antenna configuration in Ku band frequencies and millimeter wave applications. We present a clear and concise outline of the antenna's design process, simplifying the antenna array while preserving its essential properties. In conclusion, our research underscores the importance of designing a dual-polarized antenna array that meets the rigorous demands of Ku band applications."

Introduction

In the realm of communication, enhancing the performance of standard communication channels has remained a paramount goal [1]. A promising approach to achieve this enhancement involves leveraging diversity techniques. In this context, the application of two cross polarizations stands out as a viable means to decouple communication channels, thus improving overall channel quality [2]. The integration of two dual-polarized antennas facilitates the realization of these cross polarizations. Furthermore, refining the characterization of polarization information has been explored through various classification methods [3]. To undertake a comprehensive analysis of antennas that exhibit minimal crosstalk between different polarizations, the design of intricate antenna structures becomes essential. Within this domain, micro strip technology emerges as an optimal choice due to its cost-effectiveness and lightweight nature. Nonetheless, the design and development of planar dual-polarized arrays pose significant challenges, notably in achieving a delicate balance between sophisticated compactness, feasibility, and precise parameter control [4]. Many existing designs necessitate increased area for feeding or propose additional signal layers, often combining costly materials with high natural frequencies, inadvertently leading to crosstalk. An innovative solution comes in the form of introducing a second layer with series-fed micro strip antennas to enhance crosstalk suppression. While the dual-polarization can also be achieved through a second-order technique, it does pose fabrication complexities that need to be carefully managed. Ensuring accurate dimensions between the feeding layer and the antenna becomes crucial, and alternative feeding techniques, such as substrate integrated waveguide, present themselves as valuable tools for single radiators [5]. The journey from single to dual polarization can be facilitated through distinct techniques: the first technique primarily addresses single polarization, while the second technique provides insights into surface spacing. The deployment of grid antennas, with the substrate printed on one side and a ground plane on the other, further reinforces the antenna design. An important performance criterion for antenna arrays is the side lobe suppression, requiring values below -13.5 dB to maintain optimal channel quality.

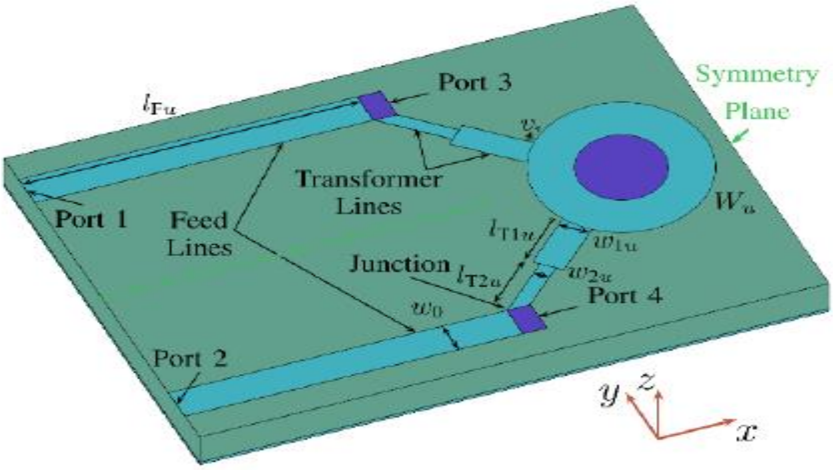


FIG 1: Diagram representation of single element in circular patch.

Design of array column:

In the pursuit of optimizing antenna performance, we introduce preliminary measures for a ten-element antenna array, each meticulously configured with distinct phase and amplitude characteristics. This approach facilitates the comprehensive exploration of antenna behavior, as each individual element contributes synergistically to the array's overall performance. The accompanying figure visually elucidates the intricacies of this antenna array, where each constituent element is uniquely labeled with sequential index numbers, spanning from 1 to N, all aligned along the X direction. This configuration of ten single elements is intentionally crafted to incorporate specific amplitude settings, while concurrently minimizing the presence of undesirable side lobes. Notably, the spatial separation between each element contributes to the reduction in side-lobe magnitudes. At the heart of this design lies the sequential arrangement of the ten elements, which collectively yield a phased array with a distinct main beam and a narrow half-power beam width when the relative phase among the elements is adjusted to ϕ = 0. This configuration ensures a focused and well-defined radiation pattern. Conversely, when the phase relationship between the elements is set to ϕ = 90, a broader radiation pattern emerges, characterized by an expanded half-power beam width. This inherent adaptability in the array's radiation characteristics showcases its versatility and capacity to tailor its performance to different application scenarios. In summary, the introduction of preliminary measures for this ten-element antenna array configuration presents a compelling platform for optimizing performance through fine-tuned phase and amplitude adjustment. The underlying design, visually represented in the accompanying figure, highlights the significance of sequential index labeling along the X direction. The deliberate configuration of single elements with specific amplitudes contributes to the reduction of side lobe effects. Notably, the ability to dynamically transition between focused and broader radiation patterns underscores the adaptability and potential of this antenna array arrangement.

Design of single element array

In the quest to harness optimal resonance frequencies with consistent polarizations, circular patch designs are adopted within a defined coordinate system encompassing the X, Y, and Z axes. The resonance frequency (fr) can be quantified through the equation:

$$(f_r)'_{100} = (f_r)'_{010} = \frac{1}{2L_u\sqrt{\mu\varepsilon}}$$

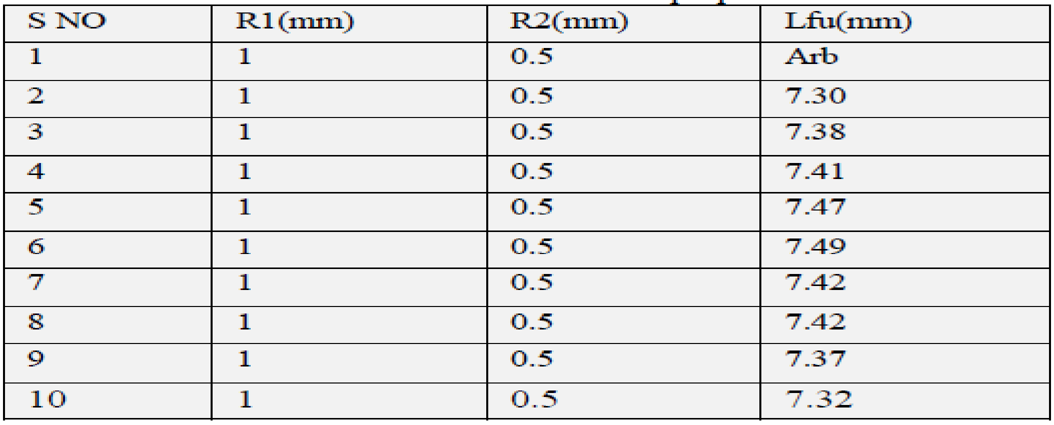
To facilitate the excitation of desired modes and promote polarization uniformity, feeding is executed at two cross-polarized edges. The electric field within the patch and the ground plane manifests a sinusoidal pattern as electromagnetic waves are radiated. Central to the design is a minute aperture located at the patch's center, characterized by sharp edges. The initial feed is localized between specific points. Achieving symmetry across the antenna array's shape is pivotal, with each element oriented at a 45-degree angle, enabling the realization of a planar single-layer configuration utilizing micro strip line feeding techniques. This setup effectively engenders coupling effects between the two cross polarizations. The second polarization's radiation pattern is harnessed through the aid of micro strip feed mechanisms. The substrate's characteristics can be tailored by modifying its shape and dimensions based on the patch's properties. Determining the input impedance necessitates a comprehensive assessment of both the patch and feed techniques. In the pursuit of minimizing crosstalk and enhancing overall performance, Rogers 4350 substrate material is employed, significantly influencing each facet of the feed. Notably, alterations in transformation lines induce the excitation of patch modes. The axial ratio (AR) offers insight into polarization characteristics and is mathematically expressed as:

$$\mathrm{AR} = \frac{\left(E_X{}^2 + E_Y{}^2 + \left(E_X{}^4 + E_Y{}^4 + 2E_X{}^2E_Y{}^2 cos(2\Delta\emptyset)\right)^{1/2}\right)^{1/2}}{\left(E_X{}^2 + E_Y{}^2 + \left(E_X{}^4 + E_Y{}^4 - 2E_X{}^2E_Y{}^2 cos(2\Delta\emptyset)\right)^{1/2}\right)^{1/2}}$$

Here, Ex and Ey represent the magnitudes of the electric field associated with linear polarizations, while Δφ signifies the phase difference between the polarized waves. The polarization ellipse along the y-axis is characterized by the expression:

$$\tau = \frac{\pi}{2} - \frac{1}{2}\tan^{-1}\left[\frac{2E_XE_Y}{E_X{}^2 - E_Y{}^2} cos(\Delta\emptyset)\right]$$

Table 1: Parameters of the proposed antenna.



S NO	R1(mm)	R2(mm)	Lfu(mm)
1	1	0.5	Arb
2	1	0.5	7.30
3	1	0.5	7.38
4	1	0.5	7.41
5	1	0.5	7.47
6	1	0.5	7.49
7	1	0.5	7.42
8	1	0.5	7.42
9	1	0.5	7.37
10	1	0.5	7.32

Geometry parameters:

Here the components are chosen independently. By this group of elements in discrete form tend to form a building like structure. High frequencies with micro strip lines are used here as wave guides. Table 1gives us the clear detail about the proposed antenna array. At each and every patch consists of three ports which are connected to feed line. Here the circuit is connected in positive manner the components are chosen independently. By this group of elements in discrete form tend to form a building like structure. High frequencies with microstrip lines are used here as wave guides. Table 1gives us the clear detail about the proposed antenna array. At each and every patch consists of three ports which are connected to feed line. Here the circuit is connected in positive manner. Line impedance of an transmission line is given by:

$$Z_U = \left\{ \frac{\frac{60}{\sqrt{\varepsilon_e}} ln\left(\frac{8d}{W_u} + \frac{W_u}{d}\right)}{\sqrt{\varepsilon_e}\left[\frac{W_u}{d} + 1.393 + 0.667ln\left(\frac{W_u}{d} + 1.444\right)\right]} \right\}$$

Here the width of an micro strip line can be calculated by measuring thickness, and by knowing the dielectric constant of the substrate. The first element to the last elements are interconnected by maintaining length and width and outer edges cut with fixed width with micro strip lines having 6λ0 and 1λ0 respectively.

Feed Network:

Two micro strip impedance line transformers are connected directly to feed point of the radiating elements. Impedance of the line changes in accordance to the width of micro strip line. We use transformers to obtain broadband behaviour. By using 50 ohms feed lines the characteristic transformer and micro strip patches are connected. Transition of first element feed line is connected from micro strip to coaxial line. The length of the entire micro strip trans-former lines is constant for all the elements, if the size of the patches are equal. If not they result in impedance discontinuities. In order of weak excitation's the first element dimensions are reduced to achieve desired amplitude distribution .At every junction point, power traveling through feed line is decreased by the amount of power that is accepted by a particular element. Coupling of strong feed line and patch corner occurs in first radiating element. The fixed transformer lengths are lT1u = 1.81mm and T2u = 1.72mm, except for the first element which is geometrically small, where its lT21 = 1.90mm. Widths of impedance transformers are carefully adjusted so that each and every element has its amplitude distribution along the array. This variation result in a variable input phase, where feed line lengths (lFu) between the elements are adjusted to obtain desired in-phase excitation of all elements. In HFSS we designed a square patch antenna array having ten elements with dimensions are mentioned in table 1 and inside a circle of radius 1mm.

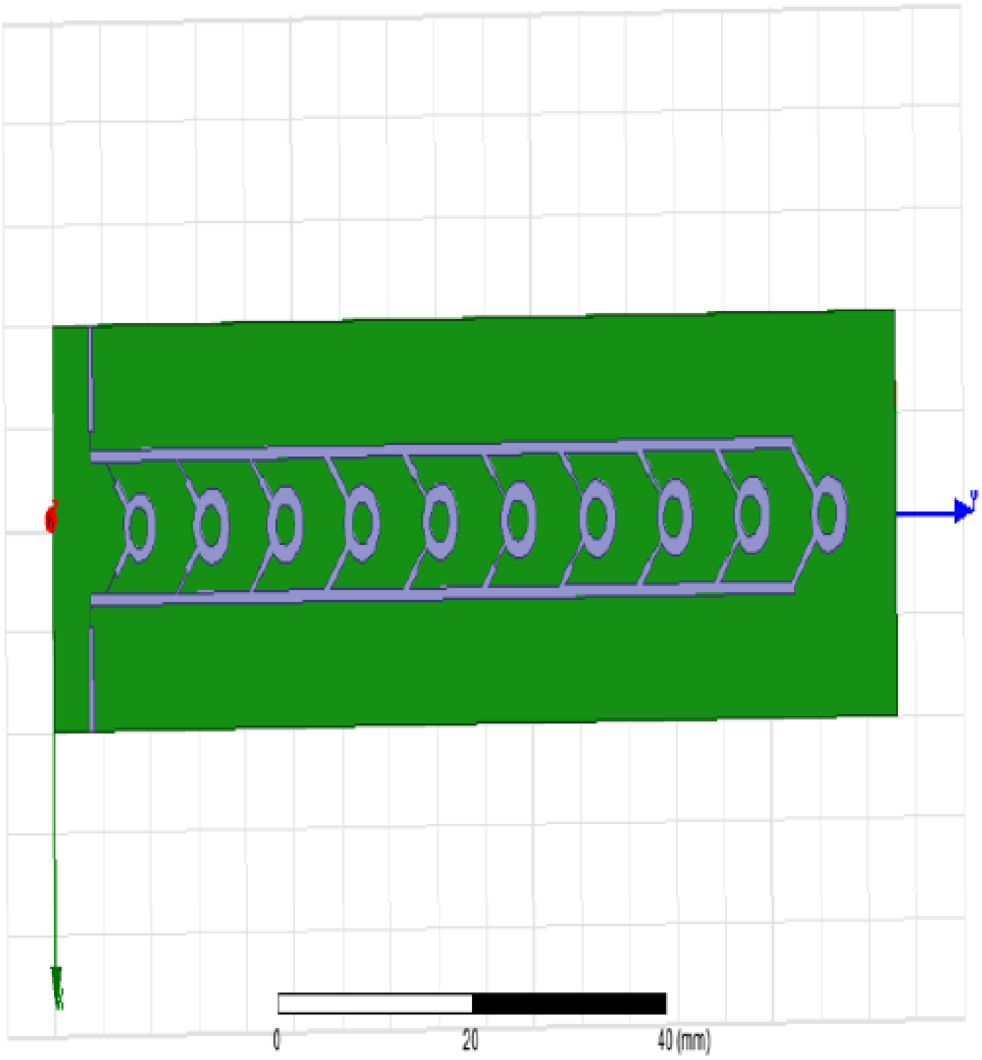


FIG2 : Diagram representation of circular patch array in Hfss.

Analysis of Scattering parameters:

Every element in the array have their own individual scattering parameters are analysed in hfss software. Every element is optimized to get the desired pattern.

$$\mathrm{AF}=\sum_{n=1}^{N} a_n\, e^{j(n-1)\varphi_n}$$

$$\text{Where } \varphi_n = kd_n sin\theta + \beta_n$$

Where Ko denoted the wave number, An is the excitation coefficient, Dn Distance among the radiators, and(β) is the progressive phase shift.

4. Measurement of radiation properties:

S1,1 PARAMETER (RETURN LOSS):

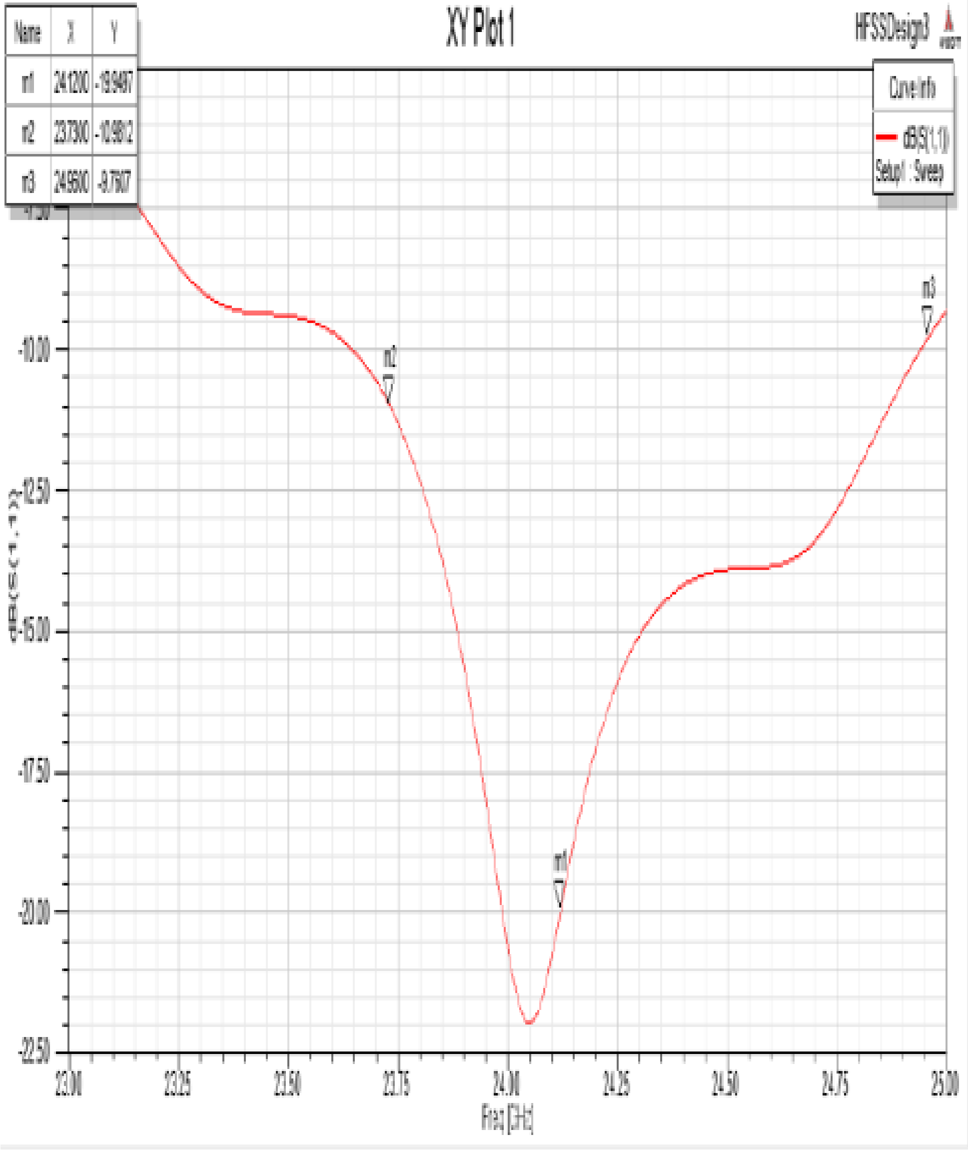


FIG 3: Representation of S11

Radiation Pattern:

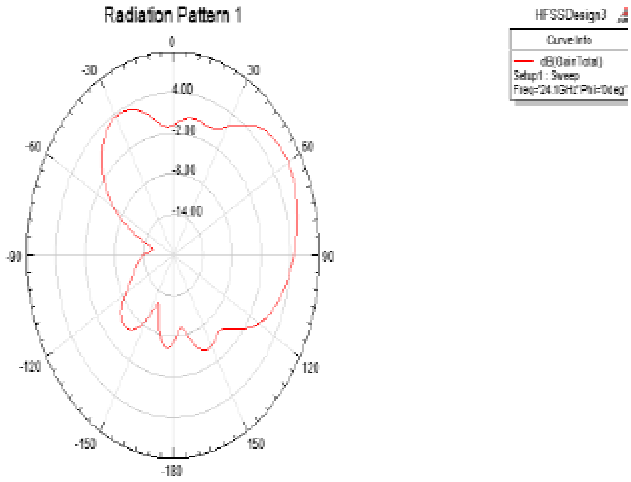


FIG 4: Radiation pattern representation.

Directivity:

FIG 5: Directivity Representation

VSWR:

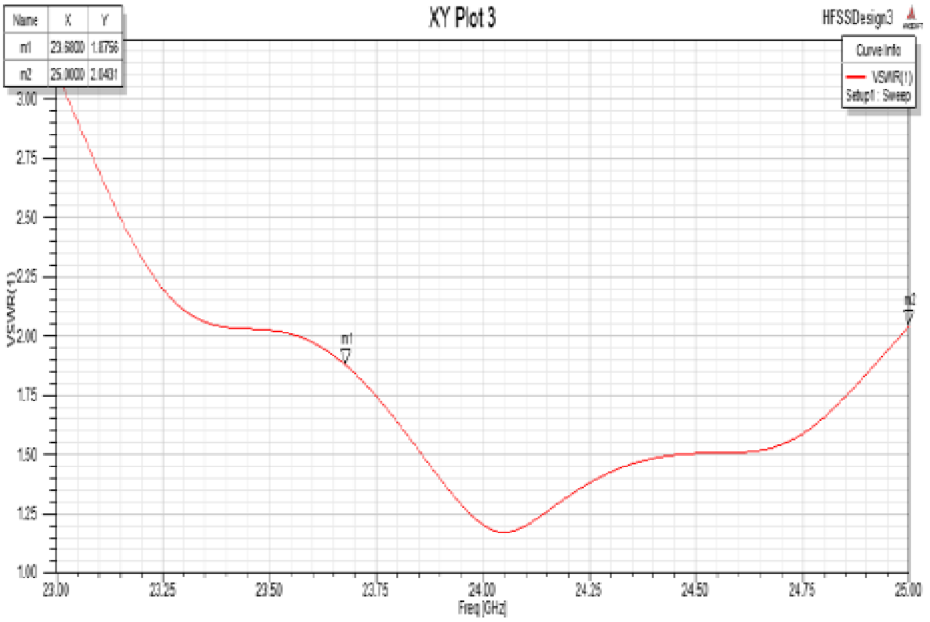
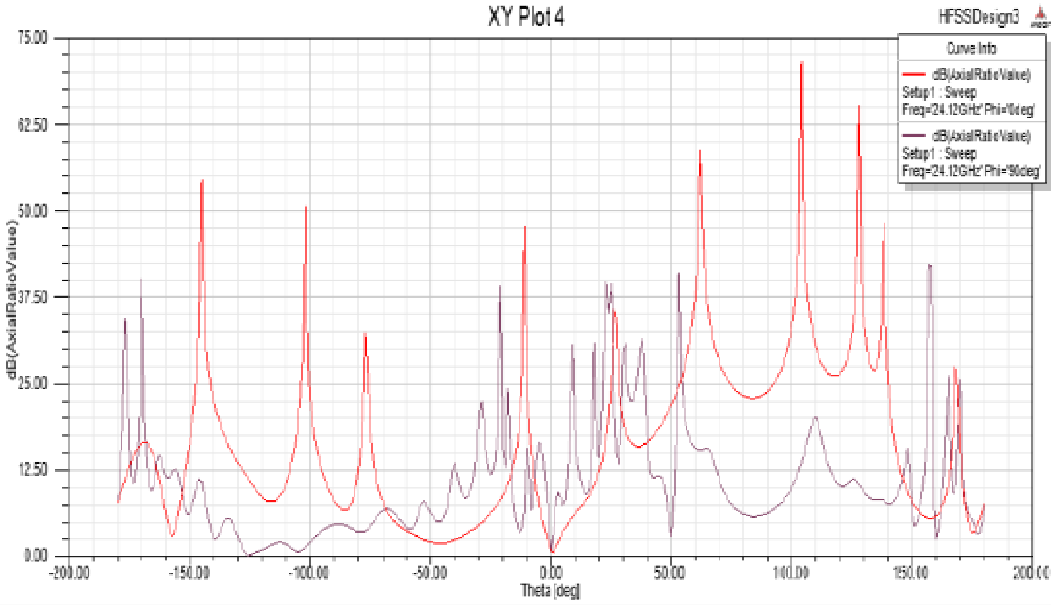


FIG6: VSWRepresentation

Axial ratio



[1

FIG 7:Axial Ratio

Conclusion

"Furthermore, the inherent flexibility of this design paves the way for scalability. The array's antenna elements can be expanded to accommodate a broader spectrum of frequencies and diverse applications. This versatility is further bolstered by the incorporation of various feeding techniques, all contributing to the realization of high-frequency functionalities. In summary, this paper presents a groundbreaking paradigm for millimeter-wave antenna arrays operating in the Ku band frequencies. The adoption of a single-layer structure, utilization of one-dimensional beam forming, and integration of dual-polarization capabilities collectively define this innovation. The implications extend to critical domains such as radar and satellite applications. The potential for future scalability and advanced feeding techniques underscores the enduring significance of this novel antenna array design."

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