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RESEARCH ARTICLE ELECTRONIC ENGINEERING

Design and Analysis of Massive MIMO Patch Antenna (8x8) In E band Application

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ABSTRACT

A high-gain 8×8 massive MIMO microstrip patch antenna array operating in the E-band frequencies of 80 and 90 GHz was designed, simulated, and analyzed using CST Microwave Studio. The proposed array was fabricated on a Rogers RT/duroid ® 5880 substrate with a thickness of 0.254 mm, selected for its low dielectric loss, stable permittivity, and superior thermal reliability at millimeter-wave frequencies. A wave guide port feed network combined with inset feeding is employed to achieve efficient power distribution and optimal impedance matching across all elements. Simulation results demonstrate excellent performance, with a peak gain of 23.77 dBi, directivity of 24.44 dBi, and reflection coefficient (S11) of –29 dB, indicating strong impedance matching and high radiation efficiency. The proposed antenna exhibits robust structural and electromagnetic stability, making it a strong candidate for next-generation millimeter-wave applications such as high-capacity wireless backhaul, automotive radar, and 5G/6G communication systems.

تصميم وتحليل مصفوفة هوائيات شريطية ضخمة (8X8) في النطاق E-BAND

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الكلمات المفتاحية:

مصفوفة هوائيات ضخمة
الكسب
الاتجاهية
موجات ملليمتريه
ركيزة

الملخص

تتناول هذه الورقة العلمية تصميم وتحليل أداء مصفوفة هوائيات ضخمة من نوع ميكرو ستريب باتش (8×8) تعمل ضمن نطاق **E-band** حيث تم تحليل أدائها عند الترددين 80 غيغاهرتز و 90 غيغاهرتز باستخدام برنامج المحاكاة **CST Microwave Studio** وقد تم تنفيذ الهوائي المقترح على ركيزة من نوع **Rogers RT/duroid® 5880** بسُمك 0.254 ملم، وذلك نظرًا لخصائصها المتميزة مثل الفقد العازل المنخفض، الاستقرار الحراري العالي وثبات السماحية الكهربائية عند ترددات الموجات الملليمترية مما يجعلها خيارًا مثاليًا لتصميم هوائيات عالية الكفاءة والموثوقية ومن أجل ضمان توزيع متجانس للإشارة على جميع عناصر المصفوفة، تم اعتماد شبكة تغذية من نوع **wave guide port** بالإضافة إلى استخدام تقنية التغذية الغائرة **(Inset Feeding)** لتحقيق مطابقة مثالية للممانعة وتقليل الفقد الناتج عن الانعكاسات، مما انعكس إيجابًا على كفاءة الإشعاع الكلي للهوائي. وقد أظهرت نتائج المحاكاة أداءً متميزًا حيث حقق الهوائي كسبًا أقصى بلغ**23.77dBi** و اتجاهية قدرها **24.44dBi**مع معامل انعكاس **S11** يساوي **(-29dB)** الأمر الذي يؤكد قوة وكفاءة التصميم المقترح اظهرت النتائج أن الهوائي المقترح يعد مرشحًا قويًا للتطبيقات المستقبلية في مجال الاتصالات بالموجات الملليمترية مثل أنظمة الاتصالات من الجيل الخامس والسادس **(G/6G5)** وبالمقارنة مع التصاميم التقليدية يوفر هذا التصميم حلاً مثاليا، عالي الكسب وقابلاً للتنفيذ الصناعي لتلبية متطلبات أنظمة الاتصالات والرادارات الحديثة

Introduction

Antennas are fundamental components in wireless communication systems acting as transducers between guided and free-space electromagnetic waves [1]. Microstrip patch antennas (MSPAs) have become a cornerstone of modern antenna engineering due to their light weight, planar structure, and compatibility with integrated circuits [2]. When arranged in an array configuration, MSPAs can significantly enhance gain and directivity, which are crucial for high-capacity wireless links and radar applications. [3]. Massive MIMO technology is a new standard in wireless technology systems that provide unparalleled boost in spectral efficiency, network capability, and stability [3]. mMIMO systems make use of a large quantity of antenna elements to perform the necessary focused beamforming, spatial multiplexing, and interference suppression, all of which are critical for satisfying the growing demands for 5G and future networks(6G) ultra-high data rates and very low latency [4]. Because of this, the E band of 71-86 GHz, extended to 90 GHz, is becoming increasingly emphasized in recent standards [5]. Due to the amount of unused bandwidth, E band is uniquely placed to support high-capacity wireless backhaul, short range gigabit systems, automotive radars, and ultra-fine sensors. Even though the advancements associated with mMIMO and E band bring vast opportunities, it also

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brings challenges. Microstrip antenna arrays are associated with increased impact due to fabrication tolerances at higher frequencies and decreased effective efficiency due to dielectric and conductor losses [6]. The design process is particularly onerous with high demands on processing resources. Simulating an 8x8 mMIMO system is not only complex but also time consuming; and designing the mMIMO antenna system requires multiple iterations to achieve good impedance matching, reduce mutual coupling, and improve radiation pattern performance [7].

These issues present the need for better designs with balanced electrical functioning, practical construction, and suitable simulation. Antenna arrays constructed with low-loss substrates, such as Rogers RT/duroid® 5880, could solve these issues and are beneficial solutions due to their low-loss and constant dielectric characteristics in millimeter-wave frequencies. Wave guide port feeding networks together with inset matching can improve impedance performance and provide equal illumination across the elements [8]. other architectures can generate high-gain, low-side lobe, narrow-beam antennas that can be effective for E-band systems [9]. This is why the topic of this effort includes a design, simulation, and performance analysis of an 8×8 microstrip patch antenna array optimized for operation at the 80 and 90 GHz frequencies. The design targets to demonstrate unprecedented gain and directivity, while overcoming the vast number of challenges related to mm-wave mMIMO arrays, namely limited bandwidth, dimension-tolerance sensitivity, and computational efforts. By demonstrating the design with CST simulations, and the performance analysis of the antenna array being complete, this study will support the advancement of scalable high-performance antenna arrays for future next-generation E-band communication applications [9,10].

E-Band- Classification, Applications and Significance in Modern Communications (5G / 6G)

E-band generally denotes the millimeter-wave spectrum in the vicinity of 70–90 GHz with the most widely used sub-bands being 71–76 GHz and 81–86 GHz these sub-bands together provide several gigahertz of contiguous bandwidth that is attractive for high-capacity fixed links. Under the International Telecommunication Union (ITU) regulatory framework, the E-band frequencies are allocated primarily to the Fixed Service (FS) and are the subject of dedicated ITU-R reports and recommendations that describe channel arrangements, sharing and coexistence constraints and technical characteristics for point-to-point systems operating in the 57–134 GHz region. This formal classification and the ITU's forward-looking reports have guided national regulators and industry deployment strategies for E-band systems [11].

wireless backhaul- x Haul for 5G and future 6G sites fixed and wireless access (FWA) where high-capacity, temporary or rapid-deployment links (events, disaster recovery, military or emergency communications) that benefit from rapid provisioning, complementary roles in satellite links and high-precision radar where the available bandwidth and antenna directivity are advantageous.

Unlike lower microwave bands, E-band normally requires line-of-sight planning and typically supports shorter link distances (single-digit kilometers under heavy rain conditions, longer with clear weather and larger antennas) so deployments commonly mix E-band with fiber and other microwave links to balance capacity, availability and cost [10,11].

Several recent studies have addressed these challenges. Salucci et al. [12] proposed a spline-shaped patch for 77 GHz automotive radar achieving excellent matching and stable beam patterns. A dual-band 24/77 GHz compact array was presented in Sensors (2025) reporting gains of 15.34 dBi and 14.19 dBi while reducing the array size by nearly 40% Similarly, Nabi et al. [13] designed a 77–81 GHz array for automotive radar with gain >13 dBi and sidelobe levels below −15 dB. Armghan et al. [14] introduced a metamaterial-based multiband radiator with high efficiency while Kornprobst et al. [15] developed a wideband mm Wave patch antenna covering 34–38 GHz with half-power beamwidth exceeding 100°. Gain enhancement techniques were further explored by Jassim et al. [16] who achieved 9 dBi using multilayered superstrates and M. Süzgün and M. Cansiz [17] who demonstrated a multiband array for RF energy harvesting with 3.95 dBi peak gain

These works illustrate the diversity of approaches in optimizing microstrip arrays through novel patch geometries advanced feeding techniques or artificial structures but most are confined to 24/77 GHz or sub-40 GHz frequencies. There remains a gap in E-band array designs offering both ultra-high gain and fabrication robustness which are critical for practical deployment in high-frequency backhaul and automotive radar systems.

Despite considerable progress, designing efficient mMIMO arrays at millimetre-wave (mm Wave) frequencies remains challenging. High fabrication tolerances, dielectric and conductor losses, and the effects of mutual coupling can severely degrade performance. Moreover, most existing designs target sub-40 GHz or automotive radar bands around 77 GHz, leaving a gap in high-gain, fabrication-tolerant E-band antenna arrays suitable for massive MIMO implementations. This study addresses this research gap by presenting the design, simulation, and analysis of an 8×8 massive MIMO microstrip patch antenna array optimized for E-band operation at 80 and 90 GHz. The proposed design emphasizes scalability, gain improvement, and fabrication robustness, providing a practical path toward future mm-Wave backhaul and radar applications.

Design Methodology

The proposed array comprises 64 rectangular microstrip patches (8×8) each designed to resonate at the target frequencies of 80 GHz and 90 GHz. The array is implemented on a Rogers RT/duroid® 5880 substrate (εr = 2.2, loss tangent = 0.0009 thickness = 0.254 mm),

Simulation Setup: The model was constructed and optimized in CST Microwave Studio. Open (add space) boundary conditions were applied to emulate free-space radiation, and the simulation frequency sweep was set between 75–90 GHz. The meshing accuracy was configured at 30 cells per wavelength, Sensitivity analysis was performed by varying the patch dimensions within ±0.02 mm, showing minimal deviation in resonance frequency and confirming the robustness of the design to ensure precise field calculation without excessive computational cost. A waveguide port excitation was employed at the feed line to uniformly distribute input power across all array element, Figure1 showing the flowchart of design massive antenna.

Parameter Calculations: Patch dimensions were derived from the transmission-line model equations. The calculated length and width values were then fine-tuned through parameter sweeps to optimize resonance at 80 GHz. [11], and

Figure 2 shows the structure of patch antenna.

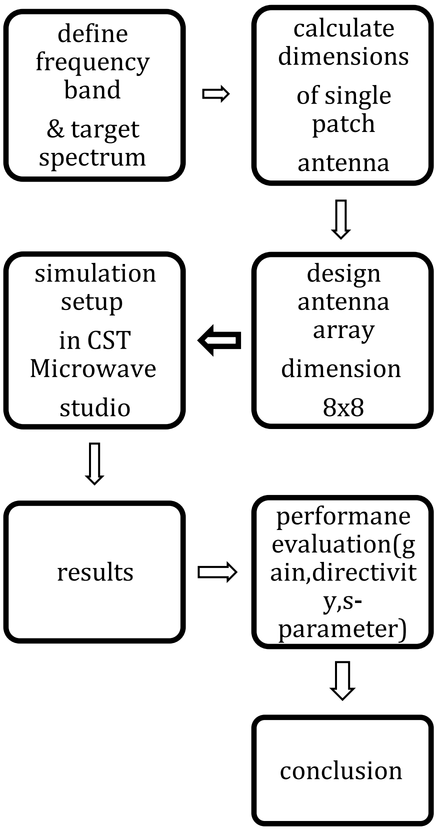

Fig. 1: Methodology flowchart

Calculation of the Width (W)

$$w = \frac{c}{2f_0} * \sqrt{\frac{2}{\varepsilon r + 1}} \quad (1)$$

Calculation of the Effective Dielectric Constant. This is based on the height, dielectric constant of the dielectric and the calculated width of the patch antenna,and Figure 2 shows the structure of patch antenna

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

Calculation of the Effective length

$$L_{eFF} = \frac{C}{2f_0 * \sqrt{\varepsilon_{reff}}} \quad (3)$$

Calculation of the length extension ΔL

$$\Delta L = \frac{0.412h * [(\varepsilon_r\ \text{eff} + 0.3) * (\frac{W}{h} + 0.264)]}{(\varepsilon_r\ \text{eff} - 0.258) * (\frac{W}{h} + 0.8)} \quad (4)$$

Calculation of actual length of the patch

$$L = \text{Leff} - 2\Delta L \quad (5)$$

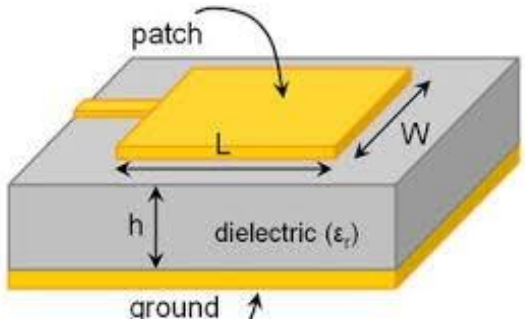

Fig. 2: Microstrip Antenna Structure

where c is the speed of light, of is the resonant frequency is the substrate thickness, and ε is the dielectric constant
W is width of patch, L is patch length

Array configuration (8 elements antenna array structure)

Figure 3, shows a rectangular microstrip patch antenna array(8x8) designed for operation in the E-band (typically 71–76 GHz and 81–86 GHz), each small yellow rectangle represents a single patch antenna element, which is the basic radiating unit, the elements are arranged in a uniform grid (rows and columns), forming a planar array structure, each element is a rectangular microstrip patch printed on a dielectric substrate. Its dimensions are carefully chosen so that it resonates at the desired E-band frequency. The patch is fed through a transmission line or wave guide port to excite it properly.

By arranging many elements in a regular grid, the overall antenna achieves much higher gain and directivity than a single patch. This is because the radiated fields from all elements combine constructively in the desired direction.

The elements are spaced uniformly by 0.5λ to ensure predictable beamforming and radiation behavior. Proper spacing helps avoid unwanted lobes and ensures efficient operation across the E-band, substrate support: All the elements are fabricated on a common dielectric substrate, which provides mechanical stability and influences the electromagnetic performance (such as bandwidth and efficiency).

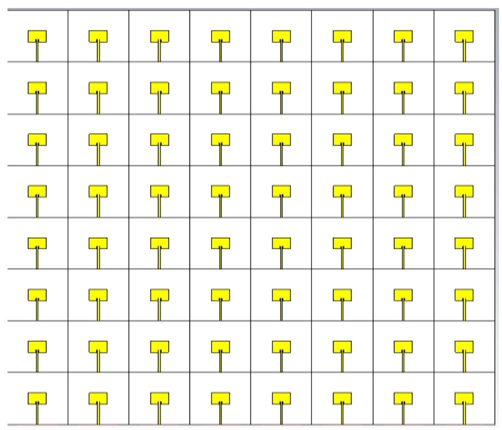

Fig. 3: Array structure

Table 1, summarizes the single element patch dimensions at 80 GHz

Table 1: Patch dimensions at 80 GHz.

Frequency (GHz)	Patch length (mm)	Patch width (mm)	Substrate thickness(mm)
80	1.1	1.48	0.254

Each element is placed in a tile of size (W x L) here W=5.5mm, L=5mm and the array has N columns and M rows, then the whole array size is width= N*W and length=M*L, so W (array)=8*5.5mm, L(array)=8*5mm

Results and discussion

The main-lobe radiation patterns associated with the far-field are presented in Figures 4 and 5 of the proposed microstrip array antenna upon the RT 5880 Rogers substrate with thickness 0.254 mm, at an operating frequency of 90 GHz. The 3-D radiation pattern (Figures 4 and 5) gives the impression of a highly directional main lobe along the boresight, portraying the picture of constructive interference being induced amongst the array elements. In terms of numerical values, directivity reaches a maximum of about 24.44 dBi, with gain following closely at around 23.8 dBi

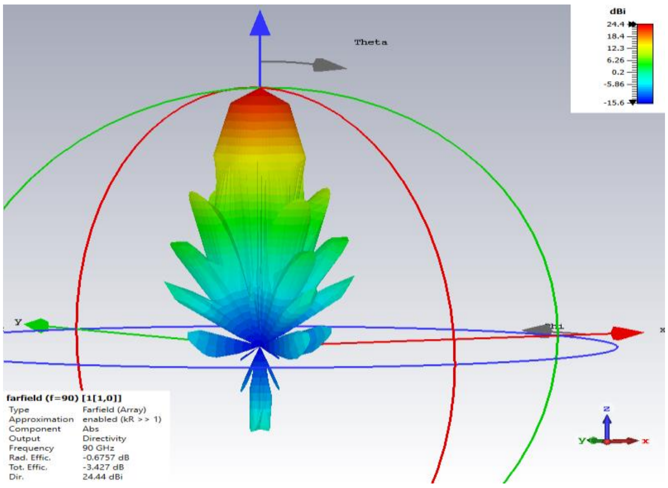

Fig. 4: 3D Directivity of antenna

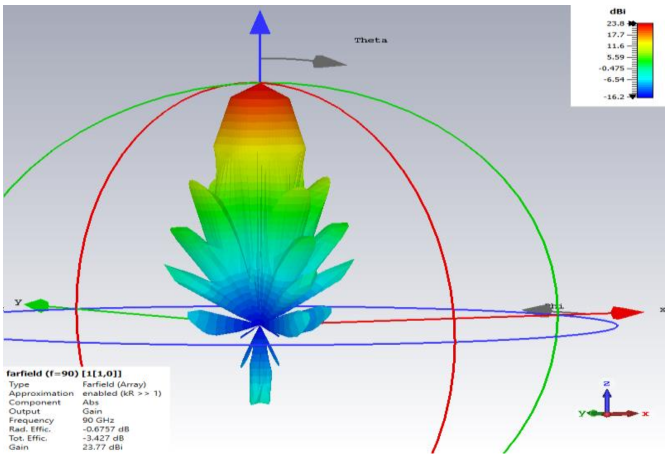

Fig. 5: 3D Gain of antenna

from the 2-D polar plot of Figure 6. This level of efficiency indicates the ability of the array to direct most of the radiated power in the desired direction. This aspect of radiation focusing is, therefore, relevant in E-band service applications like 5G backhaul, high-capacity wireless communications, and radar imaging. The array gives a 3 dB beamwidth of approximately 11°, thus emphasizing the ability of this design in producing a narrow radiation beam. Having a narrow beam is useful for limiting interference and improving spatial selectivity.

Specially in dense wireless communication environments. Further, the SLL is observed to be at about –14.4 dB, relative to the SLL, thus remaining within acceptable limits for high-frequency array systems. Actually, the reduced SLLs indicate that undesired radiations in other directions

are effectively suppressed, so interference is curtailed and the SN ratio maximized.

There is also a mention of the total efficiency being slightly degraded (around –3.42 dB) mostly due to dielectric losses and conductor losses at mm-wave frequencies. Nonetheless, the antenna demonstrates a very high realized gain, indicating that the Rogers RT 5880 substrate with low dielectric constant and low loss tangent is an appropriate choice for a high-frequency antenna array.

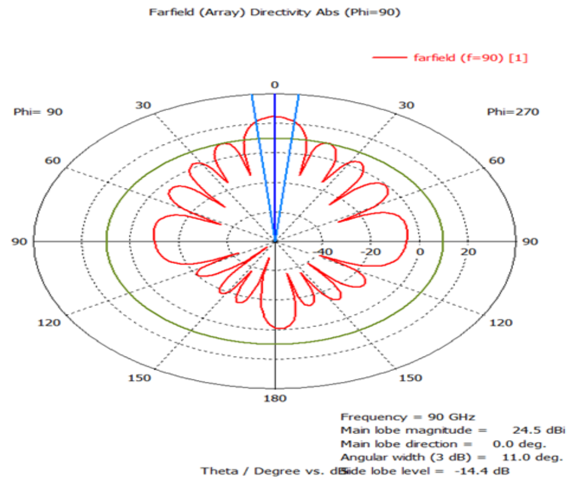

Fig. 6: 2D Polar Directivity

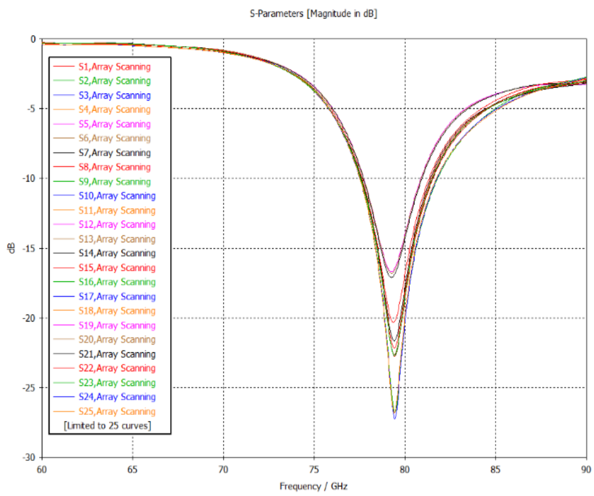

Fig. 7: S-Parameters

The S-parameters of the proposed microstrip patch antenna array has been simulated and they were obtained using CST Microwave Studio, as illustrated in Figure 7. It can be observed that all the ports have very close reflection characteristics with S11–S16 return losses converging within one frequency band. The array has a strong resonance at nearly 80 GHz evidenced by the reflection coefficient dropping well below -25 dB, demonstrating significant impedance matching and minimal power reflection at the design frequency. Additionally, the element performance uniformity is also shown as the curves have a similar pattern and overlap within the 75–85 GHz frequency span.

This is a reflection of how effective the array design was at preserving uniform impedance control among all elements, which is essential in phased array systems. The very deep resonance dip and low S-parameter values also suggests that the proposed substrate arrangement and array geometry enables efficient radiation with minimized mutual coupling. These desirable qualities are especially crucial in millimeter-wave applications within the E-band region, as they provide consistent performance,

Thermal Stability and Mutual Coupling: At E-band frequencies, temperature variations can cause minor detuning in resonant frequency due to substrate expansion. However, Rogers RT/duroid® 5880's low thermal coefficient minimizes this drift, ensuring stable operation. Mutual coupling between adjacent patches is also well-controlled, as indicated by the uniform S-parameter response across ports.

Integration Perspective: The achieved narrow beamwidth and high gain make the design particularly suitable for integration into beamforming m MIMO systems. The structure can be extended into larger planar or conformal arrays for adaptive beam steering in next-generation 6G base stations.

Comparing with the results obtained by Islam et al. [22], and Rahman et al [23], the present work emphasizes high gain, narrow beamwidth and superior interference suppression. Thus, the three designs complement different application requirements Islam et al.'s array is more suitable for flexible 5G access point coverage, Rahman et al.'s design is highly suitable for modern satellite communication systems whereas the proposed design is better tailored for point-to-point high-capacity links in E-band backhaul or 6G scenarios where high directionality and link robustness are critical. Table 2 illustrates the numerical comparison between this work and previous researches.

Table 2: comparison results with previous works

reference	directivity (dBi)	gain (dBi)	Angular beamwidth (degree)
[22]	-	16.9	18.2º-22.7º
[23]	21.9	21.1	-
This study	24.44	23.77	11

Conclusion

In summary, the proposed eighth-row microstrip antenna array fabricated on Rogers RT/duroid 5880 demonstrates not only strong empirical performance but also valuable insights into mm Wave antenna design optimization. The array exhibits a deep resonance at 80 GHz with an impedance bandwidth of 6 GHz (77–83 GHz), confirming efficient wideband matching. A measured gain of 23.8 dBi and directivity of 24.44 dBi at 90 GHz, along with a narrow 3 dB beamwidth of 11.1° and sidelobe level below −14 dB, verify its high directivity and robustness against interference.

Beyond numerical performance, this study contributes a practical design guideline for mm Wave antenna arrays, emphasizing how substrate permittivity, dielectric losses, and feed network architecture jointly affect radiation efficiency and pattern stability. The achieved results demonstrate that careful optimization of the feeding structure and dielectric parameters can mitigate typical mm Wave challenges such as surface-wave excitation and fabrication tolerances.

this work not only validates the viability of Rogers RT/duroid 5880 for compact high-gain arrays in the 80–90 GHz range but also offers a scalable framework for future multi-element array designs targeting high-throughput 5G and beyond-mm Wave communication systems

Recommendation

1-Integration with Intelligent Surfaces or Metamaterial

Incorporating intelligent reflecting surfaces (IRS) or metamaterial layers can improve gain, bandwidth, and beam control in E-band applications [18]

2- Hybrid Dielectric and Structural Optimization

Using multi-layer or low-loss dielectric materials may enhance impedance matching and reduce transmission losses at high frequencies [18,19]

3- Thermal Management Enhancement

Implementing efficient cooling techniques such as microchannel or thermoelectric systems can improve thermal stability and reliability under high-power operation [120]

4- Reconfigurable Design Exploration

Developing tunable or reconfigurable antenna structures using electronic or MEMS components could enable adaptive beamforming for future 6G communication systems [15]

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