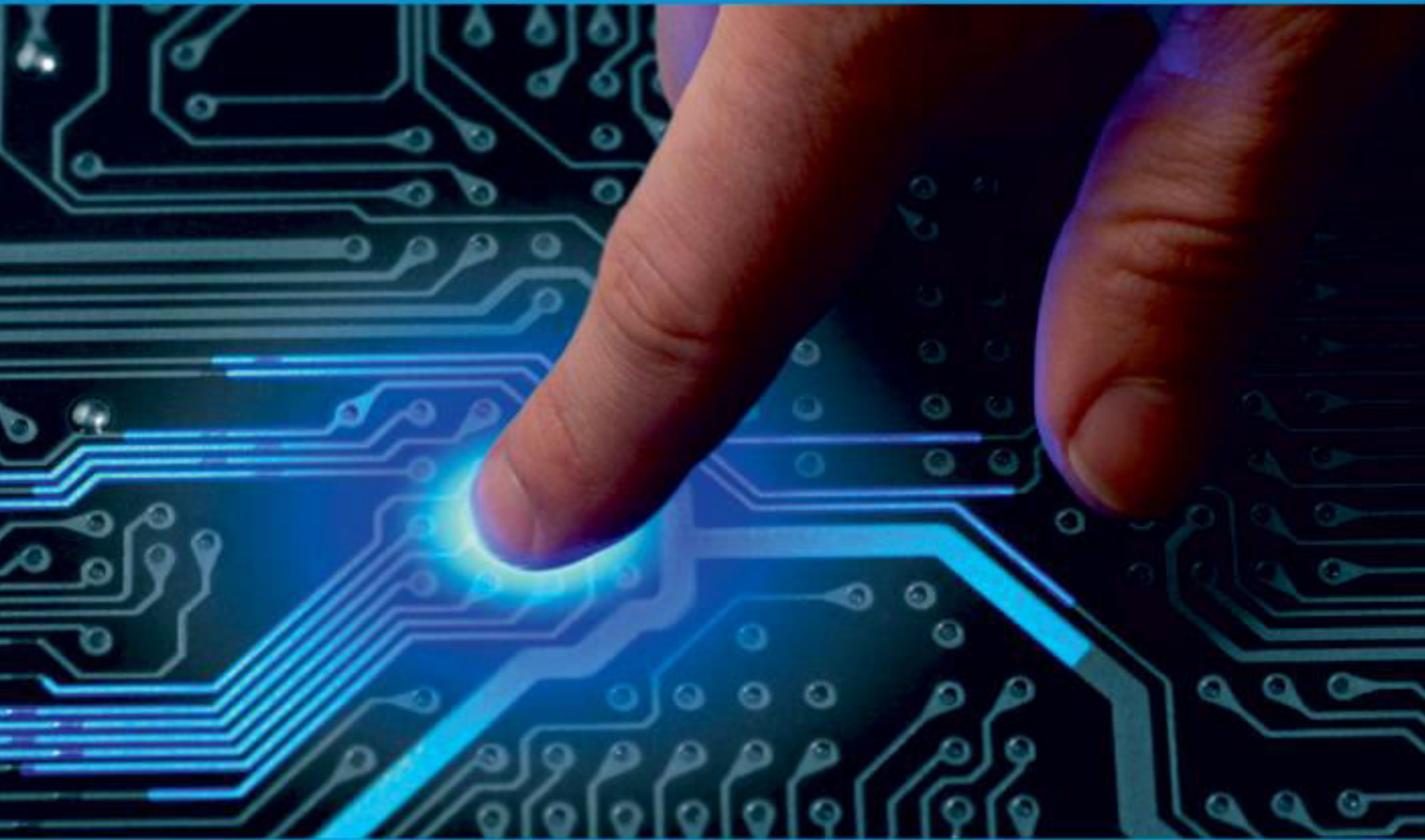
IJIRCCE

e-ISSN: 2320-9801 | p-ISSN: 2320-9798



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN COMPUTER & COMMUNICATION ENGINEERING

Volume 12, Issue 11, November 2024

INTERNATIONAL STANDARD SERIAL NUMBER INDIA

Impact Factor: 8.625

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.625| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

Design of a High-Performance Dual Slot-Patch Antenna for Millimeter-Wave 5G Networks

Sura Aswini, Simma Jahnavi, Yadla Sai Deepthi

Department of ECE, GMRIT, Rajam, A.P., India

Department of ECE, GMRIT, Rajam, A.P., India

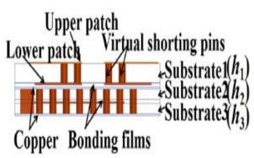
Department of ECE, GMRIT, Rajam, A.P., India

ABSTRACT: This paper presents a compact, dual-mode, slot-patch antenna designed for Ka-band applications, targeting 5G millimeter-wave systems. By combining the slot and patch resonant modes, the design achieves an enhanced bandwidth while utilizing a substrate-integrated coaxial line for feeding. Despite its small size of just $0.05\lambda_0$, the antenna delivers a bandwidth of 27.5% along with stable, unidirectional radiation patterns. Additionally, a 1 × 8 antenna array with an unequal power distribution feed was developed and analyzed. This array achieved an impedance bandwidth of 23%, a peak gain of 15.4 dBi, and sidelobe levels below −18 dB. The antenna's compact design and outstanding performance make it a strong candidate for 5G millimeter-wave applications.

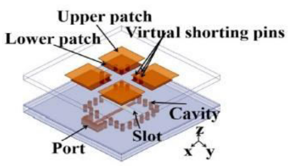
KEYWORDS: Slot-Patch Antenna, Dual-Mode Resonance, Ka-Band Applications,5G Milli Meter -Wave Systems, Substrate-Integrated Coaxial Line (SICL),Compact Design, Impedance Bandwidth, Stable Radiation Patterns, Unidirectional Radiation, Antenna Array, Unequal Power Feed, Peak Gain, Sidelobe Levels, Wideband Performance, Low-Profile Antenna.

I.INTRODUCTION

The demand for low-profile, wideband antennas has grown significantly with the development of compact wireless systems, particularly for 5G applications. While conventional microstrip patch antennas are valued for their unidirectional radiation and simple design, their inherently narrow bandwidth—caused by the high-quality factor of the resonator patch—remains a major drawback. Various methods, such as stacked patches, U-slot and E-shaped patches, and aperture-coupled configurations, have been explored to address this issue. However, these solutions often rely on substrates with specific properties, such as low permittivity and a thickness near $0.1\lambda_0$, which complicates fabrication and integration.This study presents an innovative low-profile slot-patch antenna design that incorporates virtual shorting pins at the internal corners of the patch. These pins enable dual-mode resonance, achieving stable wideband unidirectional radiation while maintaining an ultra-thin structure. Unlike traditional designs that require thicker substrates or more complex configurations, this approach merges two resonant modes into a compact form, greatly enhancing bandwidth without compromising the low-profile nature of the antenna. This makes it well-suited for integration into modern devices.To support the antenna, a compact feed network was created using a meander-topology substrate-integrated coaxial line. This design was further applied to develop a Ka-band linear antenna array with low sidelobes. The integrated system ensures a wide operating bandwidth, symmetric radiation patterns, and consistent gain. Experimental results confirm the strong performance and space efficiency of the slot-patch antenna, establishing it as a promising solution for next-generation 5G millimeter-wave applications, where both compactness and high performance are essential.



(1)



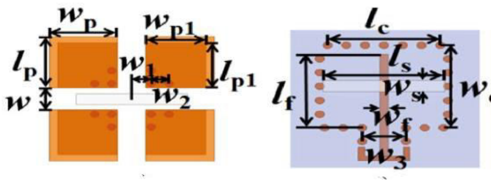
(2)

© 2024 IJIRCCE | Volume 12, Issue 11, November 2024| DOI: 10.15680/IJIRCCE.2024.1211115

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.625| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



(3) (4)

Fig.1 The structure of the proposed slot-patch antenna having : (1)Profile view, (2)viewpoint,(3) plan view of the radiating structure, and (4) top view of the feeding structure.[1].

The proposed slot-patch antenna demonstrates symmetrical radiation patterns, consistent gain, and a wide operating bandwidth, establishing itself as a strong contender for 5G millimeter-wave systems. Experimental validations underscore its suitability for next-generation wireless networks, thanks to its compact design, dependable performance, and ease of integration.

This innovative antenna design effectively bridges the gap between conventional narrowband patch antennas and the wideband compact antennas required for advanced wireless systems. Its low-profile, wideband characteristics, and stable unidirectional radiation highlight its versatility for next-generation communication technologies, enabling high-speed data transmission. These attributes make the antenna particularly well-suited for modern wireless applications where space is limited but high performance is crucial.

II. SLOT-PATCH ANTENNA

2.1 Antenna Structure

The proposed slot-patch antenna includes a central slot within the metallic ground plane, and four rectangular patches mounted on the top surface of Substrate 1, where each patch has dimensions lp × wp. Virtual shorting pins are placed inside the internal corners of the patches to potentially connect to the bottom side of Substrate 1.

This configuration facilitates dual-mode resonance, hence overcoming the challenges of wideband, stable radiation performance in a low-profile design. The antenna is fed by an open-ended substrate-integrated coaxial line (SICL) that extends over Substrates 2 and 3.The SICL outer conductor consists of metallic pins that form a cavity with dimensions lc × wc, which helps to concentrate and stabilize the signal.

The entire structure is fabricated using standard multilayer PCB fabrication techniques. The design uses three substrates (1, 2, and 3) all made from Rogers 4350B laminates with a permittivity of 3.66, which are known for high-frequency stability and low dielectric loss. Rogers 4450 bonding films with a permittivity of 3.54 are used to achieve the multilayer PCB configuration. This combination of material ensures robustness, compactness, and superior performance, hence the antenna is well suited for milli meter-wave applications.

Optimized using Ansoft HFSS, the antenna presents a compact and wideband response tailored for Ka-band applications. Its stable radiation characteristics and low sidelobes make it an excellent candidate for 5G milli meter-wave systems, where compact size and reliable performance are critical. Detailed design dimensions are provided in Table I**.**

Tabel-1: It indicates the values for different parameters I Slot-Patch Antenna.

Parameter	Value	Parameter	Value
w_p	2.4	l_p	2.1
w_{p1}	2.1	l_{p1}	2.1
w	1.0	l_s	3.9
w_1	0.9	l_f	3.2
w_2	0.6	l_c	4.1
w_3	1.4	h_1	0.508
w_c	3.9	h_2	0.254
w_s	0.5	h_3	0.254
w_f	0.27		

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.625| ESTD Year: 2013|

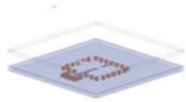
International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

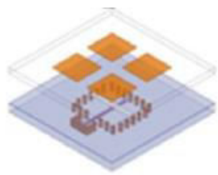
The table outlines the key parameters and their values for designing the slot-patch antenna, with each parameter contributing to the antenna's performance, resonance, impedance matching, and radiation properties. The dimensions **wp** and **lp** correspond to the width and length of the primary rectangular patches on the top surface, which are critical for defining the resonant frequency and radiation characteristics. Similarly, **wp1** and **lp1** represent the dimensions of secondary patches or additional features that fine-tune impedance matching and resonance. The width of the central slot or a significant antenna section, denoted as **w1**, directly influences radiation and coupling properties, while **w2** and **w3** refer to the widths of other components, such as slots or feeding structures, that ensure proper signal distribution and impedance matching.

The slot length, **ls**, plays a vital role in determining the resonance and bandwidth, and **wb** indicates the width of another structural element that affects radiation patterns or coupling. The feeding structure's length, **lf**, is crucial for effective power distribution and impedance matching. Parameters **wc** and **lc** specify the width and length of the substrate-integrated coaxial line (SICL) cavity, which ensures stable radiation and efficient signal routing. Lastly, **h1**, **h2**, and **h3** represent the thicknesses of the substrate layers or bonding films, which influence the antenna's profile, permittivity, and support for resonant modes. Each of these parameters is meticulously optimized to ensure compactness, reliability, and high performance for 5G millimeter-wave applications.

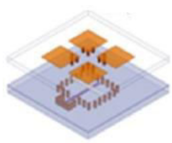
Slot



Adding patches at upper position



Adding shorting pins



Replaced with virtual shorting pins

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.625| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

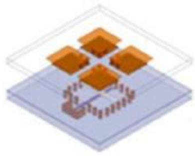


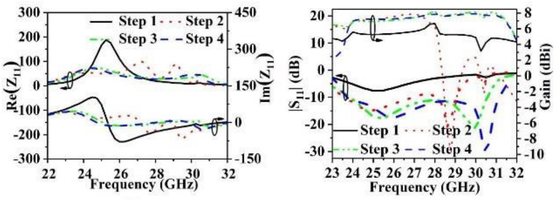
Fig.2 Evaluation of steps in Slot-Patch Antenna [1].

1. Slot creation: This is a slot created on the substrate, which forms the foundation structure of the antenna.

2. Adding Upper Patches: Attach upper patches at the substrate periphery around the slot to create the radiating elements.

3. Install shorting pins for connecting the patches to ground, which further improve performance by offering more pathways to current flow.

4. Replacing with Virtual Shorting Pins: Physic shorting pins with virtual ones for the required mode configuration to be achieved without any connection and hence optimizing the functioning of the antenna for the desired applications.



(1) (2)

Fig.3 (1) Simulated Input Impedance Analysis
(2) Simulated Reflection Coefficient ($|S_{11}|$) and Gain Performance.[1].

It shows how the impedance (Z11), reflection coefficient (|S11|), and gain of a slot-patch antenna change during the design stages. This process improves |S11| and consequently the gain of the proposed antenna, leading to better efficiency at high frequency bands ranging from 22–32 GHz. Overall, the optimization facilitates the antenna's use in 5G millimeter-wave-based applications with guaranteed performance and signal stability.

2.2: Working Principle

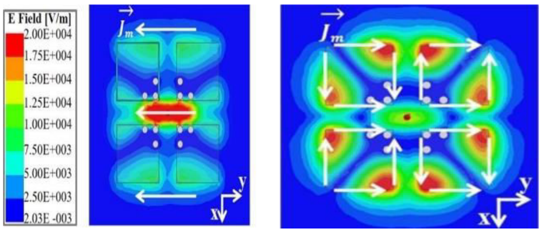
The slot-patch antenna is evolved through four development steps in order to achieve wide operating band along with stable gain. Initially, the SICL cavity-backed slot resonates at an approximate value of 25 GHz, but has poor impedance matching and limited gain. In the second step, adding four patches at the top surface of Substrate 1 introduces new modes of resonance at 27 GHz and 29 GHz along with improved impedance matching. However, the presence of undesired TM01 modes at 29 GHz negatively affects gain. Third Step After connecting shorting pins at each of the internal corners of the patches, slot mode at 24.5 GHz couples with patch mode at 30 GHz. With this dual-mode configuration, the frequency range of operation is extended to 24-31 GHz, and at the same time, stable impedance near 50 Ω is maintained at all these frequencies. The final step is the direct ground connections of the shorting pins are substituted by capacitive coupling-based virtual shorting pins. This step in fabrication reduces the complexity without losing the performance.

The four-step process leads to a powerful slot-patch antenna design with a wideband response from 24 to 31 GHz, stable impedance near 50 Ω, high gain, and suppressed interference from unwanted modes.

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.625| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)



(1) (2)

Fig. 4 Simulated Electric Field Distributions in Substrate 1 of the Proposed Slot-Patch Antenna
(a) At frequency f=24.5f = 24.5 GHz.
(b) At frequency f=30f = 30 GHz.[1].

This compact, low-profile design is tailored for standard PCB manufacturing, ensuring cost-effectiveness for mass production in 5G millimeter-wave systems. By integrating slot and patch resonances, the antenna achieves dual-mode operation while maintaining consistent performance across Ka-band frequencies, making it ideal for the demanding requirements of high-frequency 5G applications.

The simulated electric field distributions reveal that the slot mode dominates at 24.5 GHz, transitioning to the TM_{10} mode at 30 GHz. This transition enables the structure to deliver stable, linearly polarized radiation throughout the entire frequency range.

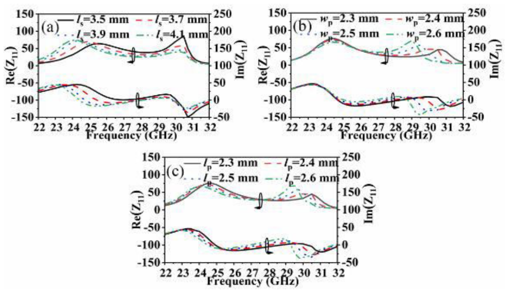
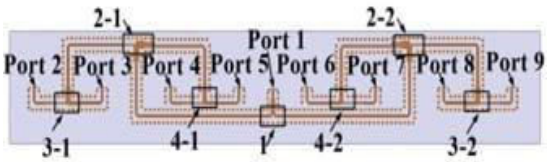


Fig.5 Simulated Input Impedance of the Proposed Slot-Patch Antenna vs. Frequency for Various Geometric Parameters(a) Effect of ls(Slot Length).
(b) Effect of wp (Patch Width).(c) Effect of lp (Patch Length).

The plot illustrates the effect of slot length, ls, and patch width, wp, on the slot-patch antenna's impedance, Z11, across the range of 22–32 GHz. For each plot, both the real and imaginary components of the impedance are shown for various values of parameters and their influence on resonance and the frequency response is made apparent. Optimizing the two parameters allows fine-tuning for high-frequency applications such as for 5G.

2.3: Performance of Antenna

The bandwidth of the proposed slot-patch antenna spans 27.5%, ranging from 23.8 to 31.4 GHz, which covers key portions of the 5G frequency bands, including 24.25–27.5 GHz and 27.5–29.5 GHz. With a height of just $0.05\lambda_0$ at 27 GHz, the antenna achieves a maximum gain of 7.9 dBi, with only a 2.2 dB variation across its operational bandwidth. The use of low capacitive patches is crucial, as they enable virtual shorting to the ground plane, thereby stabilizing the antenna's radiation pattern.



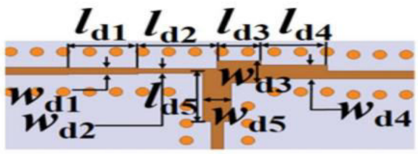
© 2024 IJIRCCE | Volume 12, Issue 11, November 2024| DOI: 10.15680/IJIRCCE.2024.1211115

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.625| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

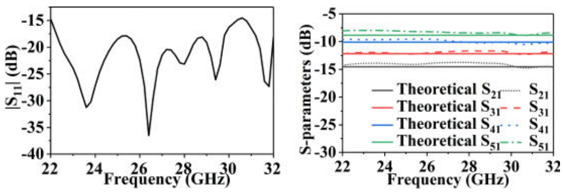
(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

(1)



(2)

Fig.6 Design of the SICL Feeding Architecture
(1) Top view illustrating the 1 × 8 array feed system.
(2) Asymmetric SICL Power Splitter with measurements.[1].



(1) (2)

Fig.7 S-Parameter Simulation of the SICL Feed System(1) Reflection Magnitude ($|S_{11}|$). (2) Transmission Magnitudes ($|S_{21}|$ to $|S_{51}|$).[1].

The S-parameters for the slot-patch antenna are shown above. The simulated radiation patterns demonstrate stable, unidirectional radiation with nearly symmetrical patterns in both the E-plane and H-plane. The cross-polarization is below −40 dB, and the backward radiation is less than −18 dB, ensuring minimal interference and good signal focusing. With its wide bandwidth, stable gain, low profile, and symmetrical radiation patterns, the antenna is well-suited for millimeter-wave 5G applications.

Table-2: Measurement Specifications of SICL Power Dividers (Units: mm)

	PD1	PD2	PD3	PD4
w_{d1}	\	0.23	0.2	0.2
w_{d2}	\	0.15	0.15	0.15
w_{d3}	\	0.76	0.4	0.32
w_{d4}	\	0.475	0.32	0.28
w_{d5}	0.5	0.63	0.53	0.48
l_{d1}	\	1.6	1.6	1.6
l_{d2}	\	1.9	1.6	1.6
l_{d3}	\	1.0	1.6	1.6
l_{d4}	\	1.6	1.6	1.6
l_{d5}	1.735	1.775	1.675	1.675

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.625| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

III. ANTENNA ARRAY

3.1: SICL Feeding Network

The SICL feeding network in the low-sidelobe antenna array utilizes a Taylor distribution with a -20 dB sidelobe level. The design features one equal power divider (PD) and three types of unequal PDs, labeled PD2 to PD4, which are symmetrically placed around the main PD at the input port. These unequal PDs are designed with precise power-division ratios, and their dimensions are provided in Table II. To achieve a compact array design, meander topology is employed, making the array configuration ideal for planar applications.

Simulated results for the SICL network show an $|S_{11}|$ value below -15 dB across the frequency range of 22–32 GHz, indicating strong impedance matching. The output amplitudes align closely with theoretical predictions, and the differential phase between ports is near 0°, ensuring that the signal is coherently distributed across the ports.

3.2: Antenna Configuration Analysis

The configuration of the 1 × 8 slot-patch antenna array is evaluated using a transition from a Substrate Integrated Coaxial Line (SICL) to a standard Ka-band waveguide. The measured $|S_{11}|$ characteristics, obtained with an Agilent Network Analyzer E8363C, reveal an impedance bandwidth of 23% (24.3 to 30.6 GHz). Additionally, radiation performance measurements in a far-field anechoic chamber demonstrate a 22.3% bandwidth (24.7 to 30.9 GHz) for both measured and simulated results. The maximum measured and simulated gains are 15.4 dBi and 15.2 dBi, respectively, with a minimal 3 dB variation across the band.

The radiation patterns exhibit stability and good symmetry, with sidelobe levels below -18 dB, slightly higher than the target due to fabrication tolerances. This design offers a more compact form and higher bandwidth than existing designs, making it suitable for array applications. The results suggest that with further modifications to the feed structure, dual-polarized radiation capabilities could be enhanced in future iterations.

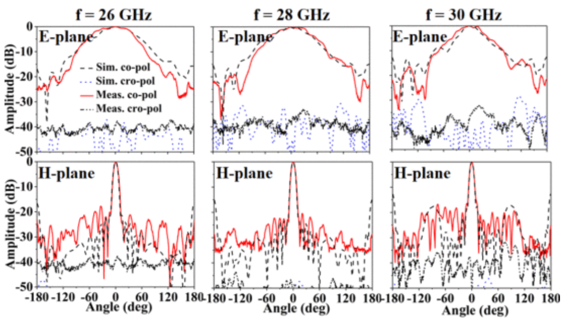


Fig.8 Measuring of a simulated radiation patterns for antenna array.[1].

The radiation patterns of the dual-mode slot-patch antenna at 26 GHz, 28 GHz, and 30 GHz in both the E-plane and H-plane orientations have been depicted through the plots. The co-polarization, which represents the primary signal, exhibits strong, uniform directional behavior at these 5G frequencies, with minimal cross-polarization interference. This indicates that the antenna is capable of providing reliable high-gain, well-focused radiation, making it well-suited for 5G applications.

IV. CONCLUSION

The proposed antenna and array design achieve a wide bandwidth of 27.5% with a slim profile of $0.05\lambda_0$, making it ideal for modern communication systems. The slot and patch resonant modes ensure efficient performance while being compact. A Substrate Integrated Coaxial Line (SICL) feeding network is incorporated to provide precise signal distribution, achieving sidelobe levels below -18 dB and enhancing radiation performance. This compact and efficient design solves space constraints to support seamless integration into next-generation wireless technologies, especially for 5G millimeter-wave applications. It offers practical solutions for advanced communication platforms in terms of high bandwidth, low sidelobe levels, and minimal structural complexity. With SICL technology in innovative integration, it's sure to provide reliable and high-speed performance in space-efficient and industry-ready configuration.

www.ijircce.com | e-ISSN: 2320-9801, p-ISSN: 2320-9798| Impact Factor: 8.625| ESTD Year: 2013|

International Journal of Innovative Research in Computer and Communication Engineering (IJIRCCE)

(A Monthly, Peer Reviewed, Refereed, Scholarly Indexed, Open Access Journal)

REFERENCES

1. J.Xu, W.Hong, Z.H.Jiang, H.Zhang, and K.Wu, "Low-profile wideband vertically collapsed opened circular fix cluster for Ka-band applications," IEEE Trans. Recieving wires Propag., vol. 68, no. 9, pp. 6844–6849, Sep. 2020.
2. Z. Shao, L. Qiu, and Y. P. Zhang, "Design of wideband differentially encouraged multilayer stacked fix recieving wires based on bat algorithm," IEEE Recieving wires Remote Propag. Lett., vol. 19, no. 7, pp. 1172–1176, Jul. 2020.
3. Z. Gan and Z.-H. Tu, "Dual-mode conjoint patch-pair for 5G wideband fix radio wire cluster application," IEEE Radio wires Remote Propag. Lett., vol. 20, no. 2, pp. 244–248, Feb. 2021.
4. Liu, Q. Xue, H. Wong, H. W. Lai, and Y. Long, "Design and examination of a low-profile and broadband microstrip monopolar fix antenna," IEEE Trans. Recieving wires Propag., vol. 61, no. 1, pp. 11–18, Jan. 2013.
5. Z. Gan and Z. -H. Tu, "Dual-mode conjoint patch-pair for 5G wideband fix radio wire cluster application," IEEE Recieving wires Remote Propag. Lett., vol. 20, no. 2, pp. 244–248, Feb. 2021.
6. D. Wang, K. B. Ng, C. H. Chan, and H. Wong, "A novel wideband differentially-fed higher-order mode milli meter-wave fix antenna," IEEE Trans. Radio wires Propag., vol. 63, no. 2, pp. 466–473, Feb. 2015.
7. J. Yin, Q. Wu, C. Yu, H. Wang, and W. Hong, "Broadband symmetrical E-shaped fix recieving wire with multimode reverberation for 5G milli meter wave applications," IEEE Trans. Recieving wires Propag., vol. 67, no. 7, pp. 4474–4483, Jul. 2019.
8. J. Wang et al., "A low-profile vertically polarized magneto-electric monopole radio wire with a 60ndwidth for millimeter-wave applications," IEEE Trans. Recieving wires Propag., vol. 69, no. 1, pp. 3–13, Jan. 2021.
9. K. Fan, Z. Hao, and Q. Yuan, "A low-profile wide band substrate-integrated wave direct cavity-backed E-shaped fix recieving wire for the Q-LINKPAN applications," IEEE Trans. Recieving wires Propag., vol.65, no .11, pp. 5667–5676, Nov. 2017.
10. W. Faded, M. Xue, L. Cao, T. Ye, and Q. Wang, "Low-profile broadband patch-driven meta surface antenna," IEEE Recieving wires Remote Propag. Lett., vol. 19, no. 7, pp. 1251–1255, Jul. 2020.