



OPTIMIZATION-ALGORITHM-BASED FSS-ASSISTED MICROSTRIP AND SIW ANTENNAS FOR 5G MILLIMETER-WAVE APPLICATIONS: COMPARATIVE EVALUATION OF FOUR DESIGNS

Hussein Mahdi Salih¹, Hawraa Riyadh Abed², Ansam R. Raheem³, T abarek Alwan Tuib^{4*}

^{1,2}Education Directorate of Thi-Qar, Ministry of Education, Iraq.

³Department of Cybersecurity, Al Muthanna University College of Artificial Intelligence and Cybersecurity Engineering, Iraq.

⁴College of Engineering, Electronics and Communications Engineering, Al Muthanna University, Muthanna, Iraq.

⁴Al Ayen University, Nasiriyah 64001, Iraq.

¹<https://orcid.org/0009-0005-4411-1591>, ²<https://orcid.org/0009-0004-1247-6732>

³<https://orcid.org/0009-0006-0335-5300>, ⁴<https://orcid.org/0000-0002-1646-0015>

E-mail: hussinmahdi313@gmail.com, hawraa.reid313@gmail.com, ansam.raad@mu.edu.iq, *tabarcka@gmail.com

ARTICLE INFO

Article History

Received: February 03, 2026

Reviewed: March 02, 2026

Accepted: April 10, 2026

Published: June 30, 2026

Keywords:

Siw,
FSS,
5G Application,
Microstrip,
Genetic Algorithm.

ABSTRACT

As the number of users is increasing daily, the generation of network systems has been developed every 10 years to cover all users and smart devices. 5G application is a new generation that came with new applications. 5G works at millimeter wave. However, antennas at millimeter wave have losses. The ring shape of FSS has been introduced depending on Substrate-integrated Waveguide (SIW) technology. SIW has losses at millimeter wave comes from the distance between vias this leads to unwanted radiation with low gain high side lobe, this problem has been solved by controlling the distance between vias to minimize the losses between vias, SIW antenna and microstrip antenna have been designed at higher frequency, furthermore SIW antenna has been with and without slot. The SIW slot antenna has been integrated with the FSS ring, and the proposed design achieved good performance. The parameters of the SIW slot antenna with FSS achieved a high gain of 11.8dBi, a bandwidth of 2.28 GHz, and an efficiency of 94%. According to the results, the design is adequate for 5G applications. In addition, the periodic distance between adjacent FSS unit cells was optimized using a real-coded genetic algorithm to maximize broadside gain while maintaining good impedance matching around the 26–28 GHz 5G band.



Copyright ©2026 by authors and Galileo Institute of Technology and Education of the Amazon (ITEGAM). This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).

I. INTRODUCTION

The need for low-profile, high-gain antennas in millimeter-wave (mm-Wave) applications has increased lately. Improving antenna as well as receiver sensitivity parameters at the user point is the main goal. Yet, there are two important aspects that need to be taken into account: component loss and path loss, both of which have a considerable effect on mm-Wave frequencies [1], [2]. Numerous techniques were investigated by researchers, such as transverse resonance method [3], the method of lines [4], boundary integral-resonant mode expansion (BI-RME) methods [5], finite-difference time-domain (FDTD) techniques [6], and finite-difference frequency domain (FDFD) methods. Numerous antenna configurations were investigated in the body of current literature. Reference [7] introduced modified Vivaldi radiator. The dual V-type linearly tapered slot antenna in the design has 36 GHz center frequency. Furthermore, substrate integrated waveguide (SIW) technology is a good fit for such antenna architecture. As references [8–10] demonstrate, researchers advanced cavity-backed SIW antennas. A single configuration consisting of a coplanar waveguide supporting a slotted SIW cavity is presented in Reference [8]. Furthermore, reference [11] suggested small, single-substrate cavity-backed slot as well as patch oscillator antennas, however the latter does not have comprehensive schematic data. Numerous active antenna approaches were proposed, including varactor tuned antenna, cavity control, oscillation feedback loop, and injection locking [12]. Microstrip patch antennas, or MPAs, are widely used in communications and wireless systems.

Nevertheless, they have drawbacks, like decreased power handling capacity and lesser gain [13]. On the other hand, because of its affordability and compactness, SIW technology has become more popular than conventional microstrips and waveguides [14]. It is crucial to carefully evaluate the parameters in the case when developing SIW cavities. While the waveguide width in substrate integrated waveguide (WSIW) controls the cut-off frequency as well as propagation constant, the spacing (S) and diameter (D) of vias have a major influence on return and radiation losses [15]. Interestingly, the magnetic field produced by the current passing through the probe coincides with the magnetic field within SIW structure [16]. High-gain antennas are necessary for overcoming signal attenuation brought on through oxygen molecule absorption at millimeter-wave frequencies [17]. Using the presently available 5G spectrums in a wave system requires special demands in order to create dual-band radiation [18],[19]. A total of eight Vivaldi elements plus 1-to-8-way SIW power divider make up the antenna design. Yet, it is difficult to achieve wide bandwidth (38.9~45.1 GHz) at such high frequencies [20], [21]. Genetic algorithm (GA)-optimized multiple-input-multiple-output (MIMO) antennas are essential for increasing antenna capacity for 5G and 4G communications. Millimeter waves, or mm-waves, are being investigated by wireless systems more and more for a variety of uses. Wireless networks [22], automotive radars [23], image sensors [24], and biomedical equipment [25] have all recently used the frequency range of 60 to 94 GHz. In order to examine the performance regarding SIW and microstrip antennas at higher frequencies, the presented study introduces them. Slot effecting was studied using SIW antennas at millimeter waves, and the final SIW antenna design incorporates a slot and frequency selective surface (FSS) for improving the antenna's parameters.

II. RELATED WORKS

Several researches have been designs SIW antenna at higher frequency and studied the performance of SIW technology based on main parameters of antenna such as reflection coefficient, gain, bandwidth, directive, efficiency, in addition effecting of slots and vias of SIW antenna have been studied based on parameters [1-9], SIW antenna based on one slots has been designed in [1] with metallic vas at higher frequency, the proposed design achieved good performance at higher frequency, however this design has losses comes from the distance between metallic vias and it has lower gain around 5dBi. [3] SIW antenna has been designed at ka band however this design has big size because the distance between two parallel columns of metallic vias is big based on the standard of waveguide dimension. According to [4] SIW array slot antenna has been designed at 28GHz with air vias, the proposed design achieved lower gain at certain frequency, also there is losses because of mismatching of feedline. [4] Dual array slot antenna has been designed at ka band with metallic vias, the proposed design has big side lobe and the beam of antenna radiated at 50 degrees because of the shape of slot. Several studies have been designed horn shape at higher frequency [6-9]. Based on air and metallic vias. As in [6], [7] have losses at feedline and mismatching, in addition the proposed design has big size, [8], [9] the proposed designs have narrow bandwidth and big size, also the beam of antennas has omnidirectional which is not suitable for 5G base station. Related work of this paper has been summarized in table 1, technique and type of vias has been mentioned for each design.

Table 1: summarizes the related work of this paper.

Ref.	Technology	Vias	Features	Comments
[22]	SIW one slot antenna	Metallic vias filled	- Ka band - S11 is 10dB	- Low gain of 5 dBi - Losses at feed line and vias
[15]	Cavity slot	Vias metallic filled	- ka-band - S11 is 27dB	- Big width of SIW from centre to centre which is 22mm - Radiation pattern has back lobe and not directive
[16]	Array slot	Air filled	28GHz - S11 is -20 dB	- Losses at feed line and vias - Design has back lobe
[17]	Dual array slot antenna	Metal filled	28 GHz - S11 is 15dB	- Big side lobe - Beam of antenna phase at 50 degrees
[18]	Horn slot antenna	Metal filled	15 GHz - S11 is 15dB	- Wide beams - Losses at feed line
[19]	Horn antenna	Air filled	28 GHz - S11 is 17dB	- Wider beam width - Design is big - Losses at feed line
[20]	Horn antenna	Metal filled	2.4 GHz - S11 is 20dB	- Big size - Losses at feed line - Narrow band
[21]	Horn antenna	Metal filled	- Ka- band - S11 is 10dB	- Design has back lobe - Losses at feed line

Source: Authors, (2026).

III. MATERIALS AND METHODS

Figure 1 depicts SIW's overall structure. Its structure includes a substrate at the bottom and top of ground planes, a rectangular waveguide, and two rows of periodic holes [24], [25]. Rogers RT5880 substrate was used in the design of the suggested SIW antennas. The substrate is 0.508 mm thick and has loss tangent of 0.0009 and a dielectric constant of 2.2.

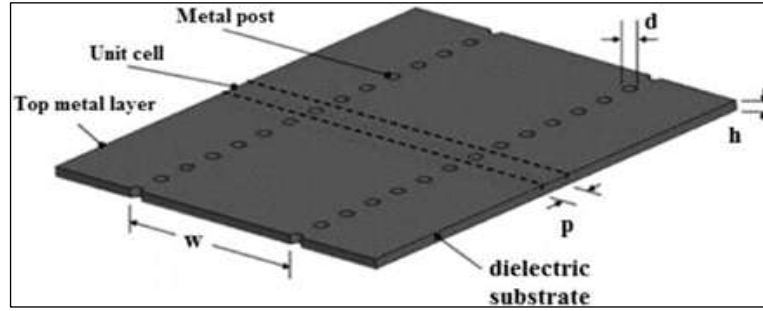


Figure 1: General structure of SIW technology.
Source: Authors, (2026).

Four antennas have been designed based on two technologies which are Microstrip and SIW. At the beginning rectangle patch without slot has been designed and metallic vias inserted at edge of patch to achieve the concept of SIW technology as shown in Figure 2(a). Roger RT 6880 used as substrate with permittivity 2.2 and thickness 0.508mm with full ground plane and losses tangent 0.0009. the second step of this paper cavity slot has been etched on the top of SIW radiation patch antenna to increase the radiation space of antenna in specific direction as shown in Figure 2(b). SIW antenna has been design based on standard waveguide dimension WR34, the patch of SIW antenna has been calculated based on equations below.

$$\frac{s}{d} \leq 2 \quad (1)$$

$$s \leq 2d \quad (2)$$

$$b = \frac{\lambda_0}{\sqrt{2(\epsilon_r + 1)}} \quad (3)$$

$$A_r = A_e + \frac{D^2}{0.95P} \quad (4)$$

$$\lambda_g = \frac{c}{f\sqrt{\epsilon_r}} \quad (5)$$

Designing a rectangular microstrip patch antenna with a cavity slot on top of the radiation patch is the third phase in the presented work, as illustrated in Figure 2(c). The proposed design features a novel slot etched into the radiation patch antenna. This cavity slot comprises three distinct shapes, two triangular slots, one square slot, and two rectangular slots. These elements have been integrated to enhance the antenna's gain and achieve a more compact design. Roger RT5880 used as substrate with thickness 0.508mm, permittivity 2.2 and losses tangent 0.0009. the proposed design has been calculated based the main equations of microstrip technology, the length and width of microstrip antenna have been determined based on the equations (6-9). From Equation (7) and (8) can clearly see the permittivity of substrate is factor to increase or decrease the width of radiation patch, once the permittivity value of substrate is high this leads the width of radiation patch became more compact size. The combination of frequency selective surfaces (FSS) with SIW antennas at millimeter-wave frequencies enables significant improvements in antenna performance, as illustrated in Figure 2(d), the fourth phase of the presented work. Periodic arrays regarding conductive elements, known as FSS structures, are capable of filtering particular frequency bands, giving the antenna's radiation characteristics more control. The final phase in this research is to integrate a SIW slot antenna with FSS, as illustrated in Figures 2(e) and (f). The substrate utilized is Roger RT 5880, which has a permittivity of 2.2 and a thickness of 0.508 mm. The distance between the antenna and FSS is half wavelength, or 5.75 mm. Table 2 refer to all values of antenna dimension such as length, width, and the distance between vias from center to the center. Equation below refers to SIW design such S is the distance between vias, d is diameter of vias A_r is the width of SIW.

Table 2: Dimensions of the antenna.

Symbol	Define	Value (mm)
Ls	Length of substrate	22
Ws	Width of substrate	16
S	Distance between vias	0.8
D	Diameter of vias	0.6
Lp	Length of patch	14.71
Wp	Width of patch	8
Lf	Length of feedline	5.75
Wf	Width of feedline	1.57
Wsiw	Width of SIW	6.5
T1	First slot	0.4
T2	Second slot	0.8
G	Gap antenna and FSS	5.75

Source: Authors, (2026).

IV. GENETIC ALGORITHM OPTIMIZATION OF THE FSS UNIT SPACING

To enhance the FSS-assisted gain improvement, the periodic distance between adjacent unit cells (unit spacing/periodicity) was optimized using a genetic algorithm (GA). In the proposed approach, each candidate solution (chromosome) encodes the FSS unit period p (center-to-center spacing) while keeping the ring topology and substrate parameters fixed. A population of random designs is evaluated through full-wave simulation; the fitness is computed from a weighted objective that favors (i) high realized gain in the broadside direction at the target frequency f_0 and (ii) good impedance matching of the integrated antenna ($|S_{11}| \leq -10$ dB) across the 26–28 GHz band. Selection, crossover, and mutation operators are iteratively applied to evolve the population toward an optimum, while simple geometric constraints (e.g., minimum metal-to-metal spacing for fabrication) are enforced. This GA-driven tuning provides a systematic alternative to manual sweeping and enables the FSS array to be configured such that the reflected field is approximately in-phase with the direct radiation, producing constructive interference and a higher effective aperture.

Table 3: GA Optimization settings, design variable, and equations used to tune the FSS unit spacing.

Item type	Symbol / equation	Meaning	Value / range
Design target	f_0	Optimization center frequency	28 GHz
Design variable	p	FSS unit-cell period (center-to-center spacing)	3.5–6.5 mm (search bounds)
Constraint	$p \geq 2R_{out} + m$	Minimum metal separation margin m for fabrication	$m = 0.2\text{--}0.3$ mm
GA parameter	N_{pop}	Population size	30
GA parameter	N_g	Number of generations	50
GA parameter	P_c	Crossover probability	0.8
GA parameter	P_m	Mutation probability	0.05
GA parameter	N_e	Elitism (best individuals preserved)	2
Equation	(16) $\lambda_0 = c / f_0$	Free-space wavelength at the design frequency	$c = 3 \times 10^8$ m/s
Equation	(17) $g \approx \lambda_0 / 2$	Recommended antenna–FSS spacing for in-phase reflection (initial value)	≈ 5.36 mm at 28 GHz
Equation	(18) $J(p) = w_1 \cdot S_{11}(f_0; p) + w_2 \cdot \phi_{ref}(f_0; p) - 0^\circ /180 + w_3 \cdot (1 - \Gamma_{ref}(f_0; p))$	Normalized multi-objective cost function (minimize) combining matching and FSS reflection-phase behavior	$w_1 + w_2 + w_3 = 1$
Equation	(19) $\text{Fitness}(p) = 1 / (1 + J(p))$	Fitness mapping used by GA (maximize)	—

Source: Authors, (2026).

$$W = \frac{c}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (6)$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{w} \right]^{-1/2}, \quad \frac{w}{h} > 1 \quad (7)$$

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{reff} + 0.3) \left(\frac{w}{h} + 0.258 \right)}{(\epsilon_{reff} - 0.258) \left(\frac{w}{h} + 0.8 \right)} \quad (8)$$

$$L = \frac{c}{2f_r \sqrt{\epsilon_{reff}}} - 2\Delta L \quad (9)$$

V. CAVITY SLOT OF ANTENNA

This antenna uses a slot-loaded microstrip patch method, where the copper inside the patch is selectively removed (etched) to form a composite resonant slot that controls the surface-current distribution and creates additional resonant paths without enlarging the outer patch size. In the shown geometry, the slot is not a simple U-slot or E-slot; it is best classified as a modified polygonal ring-type slot with a nested diamond (rhombus) slot, sometimes described as a composite/nested ring–diamond slot. Electrically, the etched slot forces the RF surface current to flow around the slot edges, increasing the effective current path length (miniaturization effect) and introducing distributed inductive–capacitive loading due to the long slot lengths and narrow gaps, which can shift the resonant frequency, improve impedance matching, and generate an extra coupled mode that supports dual-band/multiband behavior or wider bandwidth depending on the slot dimensions. The outer polygonal ring mainly establishes the dominant current loop and strongly influences resonance and bandwidth, while the internal diamond slot and the small lower slit/notch act as secondary resonators and fine-tuning features that adjust coupling and matching by reshaping current density in the central region of the patch. The guided wavelength λ_g is shorter than the free-space wavelength because waves propagate in an effective dielectric. This λ_g is the reference length for the slot resonator condition (typically half-wavelength) [23], [26].

$$\lambda_g = \frac{c}{f \sqrt{\epsilon_{eff}}} \quad (10)$$

A long-etched slot behaves approximately like a half-wavelength resonator. The effective slot length $L_{\text{slot,eff}}$ is measured along the dominant current path that wraps around the slot edges (not as a straight-line distance). This gives the main slot-created resonance.

$$L_{\text{slot,eff}} \approx \frac{\lambda_g}{2} \Rightarrow f_{\text{slot}} \approx \frac{c}{2L_{\text{slot,eff}}\sqrt{\epsilon_{\text{eff}}}} \quad (11)$$

For composite slots, designers often treat each main loop as a separate resonator. The outer polygonal ring slot can be approximated by its perimeter (sum of side lengths), while the inner diamond introduces another coupled mode. Small corner/fringing effects are captured by a short correction term δ that is later tuned in EM simulation.

$$f_{\text{ring}} \approx \frac{c}{2P_{\text{ring,eff}}\sqrt{\epsilon_{\text{eff}}}} \quad (12)$$

For a polygon, P is just the sum of side lengths

$$P = \sum_{k=1}^N s_k \quad (13)$$

and then apply a small “end correction”:

$$P_{\text{ring,eff}} \approx P + \delta \quad (14)$$

(δ is a small correction that depends on slot width and coupling; in practice you tune this by EM simulation.)

Use its perimeter (or its longest current path) similarly:

$$P_{\text{dia,eff}} \approx \frac{\lambda_g}{2} \Rightarrow f_{\text{dia}} \approx \frac{c}{2P_{\text{dia,eff}}\sqrt{\epsilon_{\text{eff}}}} \quad (15)$$

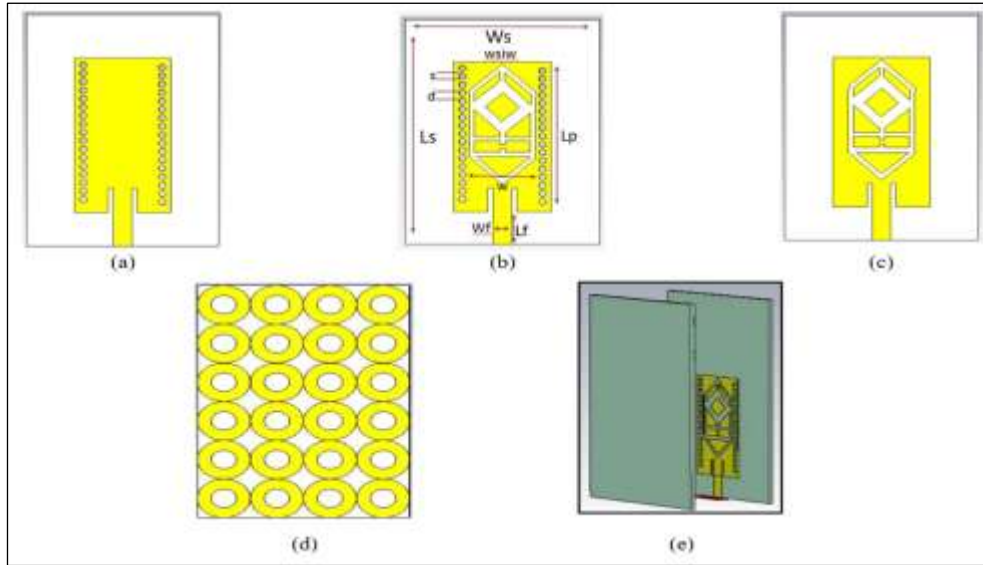


Figure 2: four designs based on two technologies, (a) SIW without slot, (b) SIW with slot, (c) microstrip with slot, (d) design frequency selective surface (FSS), (e) back view of integration of FSS with SIW with slot, (f) front view of integration of FSS with SIW with slot.

Source: Authors, (2026).

VI. WORKING MECHANISM AND DESIGN RATIONALE

SIW cavity-slot antenna: the SIW region supports a TE-like guided mode comparable to the TE₁₀ mode regarding a rectangular waveguide. The via fences as well as top/bottom conductors form low-loss cavity, and radiation is produced by an etched slot on the top conductor. The slot couples the cavity electric field to free space; its length/location primarily set the coupling strength and resonance, while the SIW width and cavity length control the guided wavelength and field confinement. **FSS-assisted enhancement:** the proposed FSS is a periodic surface with a frequency-selective transmission/reflection response. When placed at an optimized spacing above the radiator, the reflected wave from the FSS becomes approximately in-phase with the directly radiated wave in the broadside direction. This constructive interference increases the effective aperture and improves realized gain and front-to-back ratio around the target band (26–28 GHz).

VII. FABRICATION OF THE PROPOSED DESIGN

After the suggested designs were finalized, the design prototype has been constructed and measured. Roger RT board with a thickness of 0.508 mm and a dielectric constant (ϵ_r) of 2.2 was used to manufacture each design. The fabrication procedure was carried out by JAC Engineering, Malaysia. The wet etching PCB fabrication technique was performed for the fabrication of all the components used in this research study. The most challenging aspect is the soldering of the SMA conductor, as good soldering skills are needed in order to obtain good measurement results. Multiple times SMA soldering has been performed on the feed line of different fabricated prototypes. Figure 3 refer to the comparison between four designs of this paper based on same substrate.

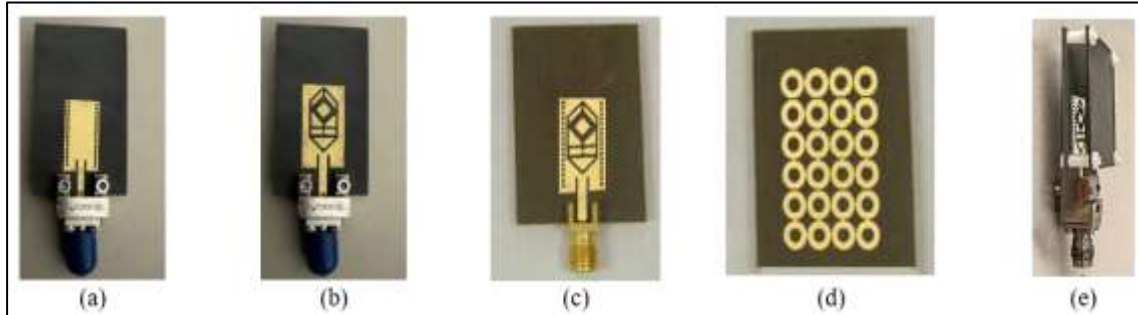


Figure 3: Fabrication of the proposed design, (a) SIW without slot, (b) SIW with slot, (c) microstrip with slot, (d) design frequency selective surface (FSS), (e) integration of FSS with SIW with slot.

Source: Authors, (2026).

VIII. RESULTS AND DISCUSSIONS OF SIMULATION AND FABRICATION

The slot etched into the radiation patch of the SIW antenna serves several critical functions. Primarily, it enhances the antenna's radiation characteristics by providing a path for the electromagnetic waves to radiate efficiently. The slot design helps in achieving better impedance matching, which reduces reflection losses and improves the overall efficiency regarding the antenna. Additionally, the slot influences the current distribution on the patch, which can be tailored to achieve desired radiation patterns and polarization characteristics. The proposed antennas have been designed based on two technologies which are microstrip and SIW at millimeter wave. Roger RT 5880 substrate with thickness 0.508 mm, permittivity 2.2 and loss tangent 0.0009. As simulated results of reflection coefficient for SIW antenna without slot has been resonated at dual frequencies which are 25.7 GHz and 29.2GHz of -13 dB and -11 dB. these two narrow bandwidths come from slot beside feedline and the edge at end of radiation patch as shown in Figure 4(a), The reflection coefficient of SIW antenna with cavity slot resonated at 26 GHz of -19 dB with wider band width around 2 GHz as shown in Figure 4(a), SIW slot antenna achieved wider bandwidth based on cavity slot technique. The reflection coefficient of Microstrip antenna resonated at 27.8 GHz of -12 dB with narrow bandwidth around 0.9 GHz, microstrip technology has losses at higher frequency as shown in figure 4. After designed FSS integrated with SIW cavity slot antenna the reflection coefficient resonated at 28 GHz of -34 dB with wider bandwidth more than 2.2 GHz as shown in Figure 4(a). Figure 4(b) refer to the measurement results of the proposed designs based on reflection coefficient, few losses of each design at certain frequency because of cable loss and connection port.

FSS structure shifted the reflection coefficient of the SIW cavity slot antenna from 26 GHz to 28 GHz with more resonate -34 dB and wider bandwidth. The reflection coefficient of the proposed four designs has been measured by VNA analyzer spectrum as shown in figure 4 (b). microstrip antenna and SIW without slot did not resonate at certain frequency because size of patch not matching with range frequency furthermore there were losses in measurement cable. The reflection coefficient of SIW slot antenna resonate at from (25 – 27) GHz wider bandwidth, after integrated FSS with SIW cavity slot antenna the reflection coefficient shifted to higher frequency and it is resonated from (27 – 29) GHz of -23 dB with wider bandwidth 2 GHz, with perfect fabrication process, clean SMA port and new cable, measurement process shown similar results pf the proposed designs with few losses. 5G application need higher gain of antenna at their frequencies such as 26 GHz, 28 GHz, 38 GHz for base station. SIW antenna without slot achieved gain 8 dB at 26 GHz and 0.4 dB at 28 GHz as shown in Figure 5. SIW cavity slot antenna achieved around 7 dB at the range frequency (26 – 28) GHz as shown in Figure 5(a). Microstrip antenna with cavity slot achieved higher gain at 28 GHz around 10.2 dB because it has wider radiation area than patch of SIW due to the edge of the whole rectangle patch of antenna. After integrated FSS with SIW antenna, the gain of the proposed design increase to 11.8 dB at certain frequency 28 GHz because FSS focus the power on specific direction.

Figure 5(b) refer to the measured gain of the proposed four designs with loss around 1.5dB for each design. Impact of GA-optimized FSS periodicity: the observed improvement after integrating the FSS is strengthened by the genetic-algorithm-selected unit-cell spacing (period p). By optimizing p to maximize boresight gain at 28 GHz while maintaining good matching ($|S_{11}| \leq -10$ dB) across 26-28 GHz, the FSS reflection phase becomes closer to in-phase with the direct radiation from the SIW slot, reducing phase errors and increasing constructive interference. Consequently, the FSS-assisted antenna exhibits deeper impedance matching together with higher realized gain and efficiency than a non-optimized periodic arrangement. The efficiency of the proposed designs has been evaluated based on several technologies such as microstrip and SIW at higher frequency for 5G application base station as shown in Figure 6(a). SIW without slot achieved lower efficiency around 38 % at the range frequency from (26 – 27) GHz. While SIW antenna with cavity slot achieved 70 % at the range frequency from (26 – 32) GHz because the mellitic vias of SIW guide the radiation intensity to specific direction. the proposed design based on microstrip technology achieved efficiency around 89 % at 28 GHz because it the radiation intensity radiated at the whole edge of rectangle patch of antenna. After integrated the FSS with SIW cavity slot antenna the efficiency increases to more than 95 % at the range frequency from (26.5 – 29) GHz. Simulated and measured results of an antenna's radiation pattern in a chamber room provide a comprehensive understanding of its performance.

Simulated results, obtained through computational models, predict the ideal behavior of the antenna under controlled conditions, highlighting the expected directionality and strength of the radiated signal. simulations help in visualizing the main lobe, side lobes, and nulls, offering a theoretical framework for the antenna's performance. In contrast, measured results are gathered in an anechoic chamber, which mimics free-space conditions by absorbing reflections and minimizing external interferences. This controlled environment allows for precise measurement of the antenna's actual behavior, accounting for practical factors such as manufacturing imperfections and material properties. By comparing the simulated and measured results, engineers can validate the design, identify discrepancies, and make necessary adjustments to optimize the antenna's performance, ensuring it meets the desired specifications in practical applications as shown in Figure 6(b). Figure 7 shown simulated and measured radiation pattern of the proposed designs. SIW cavity slot antenna with FSS achieved the highest directive beam according to the simulated and measured results by compare it with rest of designs, H plane of SIW cavity slot antenna with FSS has low side by compare with rest of designs. General simulation and measurement results of radiation pattern were almost similar excepted a bit loss because of cable. The current paper has provided the 3D radiation pattern of the proposed designs to illustrate the maximum power of antenna base in the direction of antenna beam as presented in Figure 8. This paper reflects an in-depth analysis of the performance boosting of the FSS integration, bandwidth, gain, and general efficiency. We have compared the outcomes of SIW antenna and microstrip slot antenna which is a valuable information on the choice of the good antenna types in use in particular high frequency.

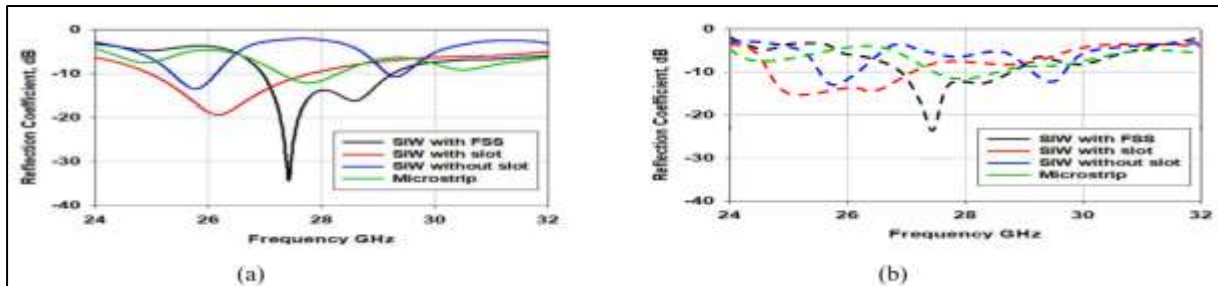


Figure 4: Reflection coefficient of the suggested designs based on Roger substrate, (a) simulated, (b) measured. Source: Authors, (2026).

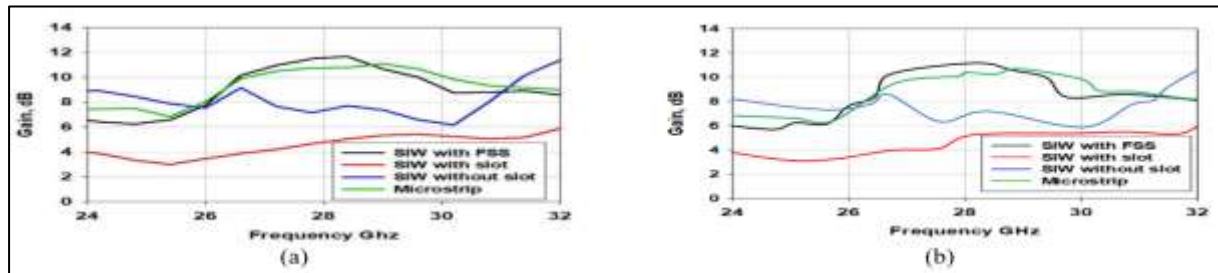


Figure 5: Gain of the suggested four designs based on Roger RT substrate. Source: Authors, (2026).

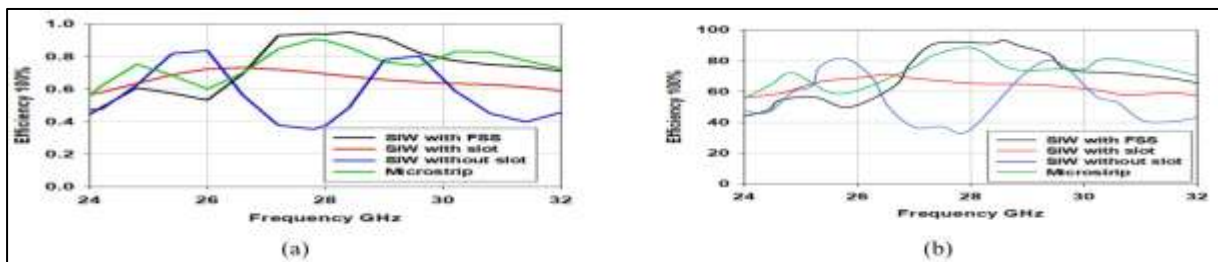


Figure 6: Efficiency of the suggested four designs based on Roger RT substrate. Source: Authors, (2026).

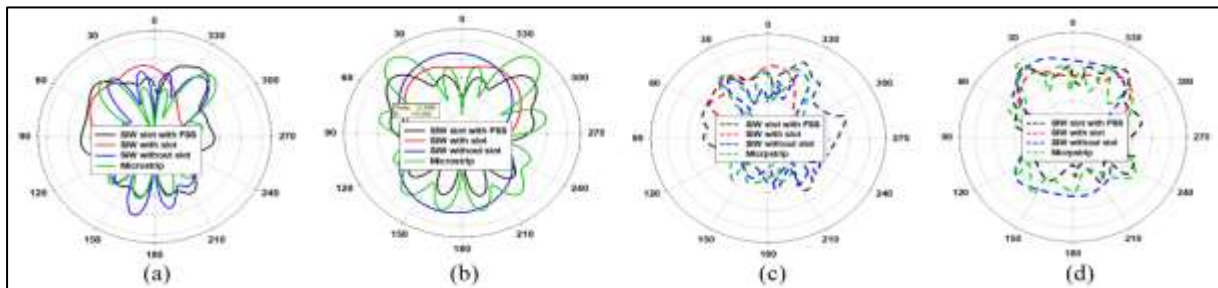


Figure 7: Radiation pattern of the proposed four designs, (a) simulated E plane, (b) simulated H plane, (c) measured E plane, (d) measured H plane. Source: Authors, (2026).

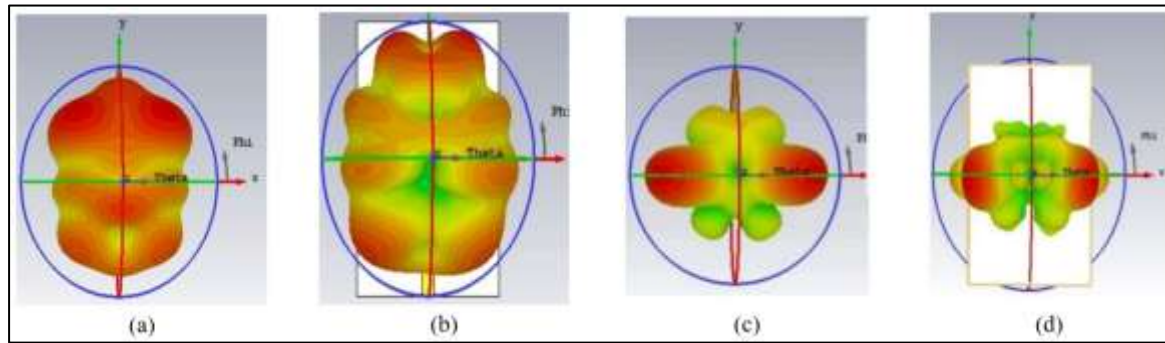


Figure 8: Radiation pattern of the suggested four designs, (a) simulated E plane, (b) simulated H plane, (c) measured E plane, (d) measured H plane.

Source: Authors, (2026).

IX. CONCLUSION

Design 5G antennas (millimeter wave frequency) four-cavity slot antennas. SIW no slot, SIW slot, microstrip antenna, SIW slot antenna in combination with Frequency Selective Surface (FSS). The SIW without slot had low resonance capacity because it was a simple structure. The addition of slot in SIW design led to the improvement of resonance and radiation properties due to the increase in distribution of current. Although the microstrip antenna was small and simple to make, it had an average gain and efficiency. Nonetheless, an integration of FSS and the SIW slot antenna created a great improvement in its performance, which provided better gain, bandwidth, and radiation efficiency. The overall analysis has indicated the possibility of integrating SIW technology with the high-technology approaches such as slotting and FSS integration in order to achieve optimal performance of the antenna in all applications. Finally, the FSS-assisted SIW cavity-slot antenna delivered the best overall performance, achieving about 2 GHz impedance bandwidth around the 26-28 GHz band with a peak realized gain of approximately 11.8 dBi and radiation efficiency above 90% (up to ~95%). Importantly, these improvements are supported by the genetic-algorithm optimization of the FSS unit spacing, which reduces phase mismatch between unit cells and promotes near in-phase reflection toward boresight, thereby increasing constructive interference and effective aperture. Therefore, GA-optimized FSS integration provides a practical route to high-gain, high-efficiency millimeter-wave antennas suitable for 5G applications.

X. AUTHOR'S CONTRIBUTION

Conceptualization: Hussein Mahdi Salih, Hawraa Riyadh Abed, Ansam R. Raheem.

Methodology: Ansam R. Raheem.

Investigation: Hawraa Riyadh Abed.

Discussion of results: Hussein Mahdi Salih, Tabarek Alwan Tuib.

Writing – Original Draft: Hussein Mahdi Salih.

Writing – Review and Editing: Hawraa Riyadh Abed.

Resources: Tabarek Alwan Tuib.

Supervision: Tabarek Alwan Tuib.

Approval of the final text: Tabarek Alwan Tuib.

XI. REFERENCES

- [1] Qamar, F., et al., Interference management issues for the future 5G network: a review. *Telecommunication Systems*, 2019: p. 1-17.
- [2] Anooz, Ruaa Shallal Abbas, and Ban Khalid Ammar. "A Modified Ground for Bandwidth Enhancement of the Microstrip Patch Antenna for 5G Wireless Communications." *SSRG International Journal of Electrical and Electronics Engineering* 11.2 (2024): 19-23.
- [3] Mustafa Mohammed Jawad, Nik Noordini Nik Abd Malik, Noor Asniza Murad, Mona Riza Mohd Esa, Mohd Riduan Ahmad, Anwer Sabah Mekki, Fahad Taha Al-Dhief, Y. M. Hussein, "Implantable slot antenna with substrate integrated waveguide for biomedical applications", DOI: 10.12928/TELKOMNIKA.v19i5.19952, Vol. 19, No. 5, October 2021, pp. 1450~1455
- [4] T. A. Tuib, Y. M. Hussein, R. S. A. Anooz, A. A. Mohammed and F. T. Al-Dhief, "An Array Antenna Based on Substrate Integrated Waveguide Antenna For 5G Application," 2023 Al-Sadiq International Conference on Communication and Information Technology (AICCIT), Al-Muthana, Iraq, 2023, pp. 60-63, doi: 10.1109/AICCIT57614.2023.10218059.
- [5] Y. M. Hussein, M. K. A. Rahim, N. A. Murad and H. O. Hanoosh, "Low Loss Wideband 4×4 Butler Matrix Networks Based on Substrate Integrated Waveguide for 5G Applications," in *IEEE Access*, vol. 12, pp. 7896-7910, 2024, doi: 10.1109/ACCESS.2023.3342713.
- [6] Ayers, J.W., et al., Next generation media monitoring: Global coverage of electronic nicotine delivery systems (electronic cigarettes) on Bing, Google and Twitter, 2013-2018. *PloS one*, 2018. 13(11): p. e0205822.
- [7] Mansoor, Riyadh, et al. "Crosstalk bandwidth of grating-assisted ring resonator add/drop filter." *Optical and quantum electronics* 47 (2015): 1127-1137.
- [8] Al-samman, A.M., M.H. Azmi, and T.A. Rahman. A Survey of Millimeter Wave (mmWave) Communications for 5G: Channel Measurement Below and Above 6 GHz. In *International Conference of Reliable Information and Communication Technology*. 2018. Springer.
- [9] Rost, P., Bernardos, C. J., De Domenico, A., Di Girolamo, M., Lalam, M., Maeder, A., Sabella, D. and Wübben, D. Cloud technologies for flexible 5G radio access networks. *IEEE Communications Magazine* 52(5): 68-76. 2014.

- [10] Li, Q. C., Niu, H., Papathanassiou, A. T. and Wu, G. 5G network capacity:key elements and technologies. IEEE Vehicular Technology Magazine. 9(1):71-78.2014.
- [11] Khandekar, A., Bhushan, N., Tingfang, J. and Vanghi, V. LTE-advanced: Heterogeneous networks. Proceedings of the IEEE European Wireless Conference (EW), 978- 982. 2010
- [12] M. Bozzi, A. Georgiadis, and K. Wu, "Review of substrate-integrated waveguide circuits and antennas," IET Microwaves, Antennas & Propagation, vol. 5, no. 8, p.909, 2011. [Online]. Available: <http://dx.doi.org/10.1049/iet-map.2010.0463>
- [13] H. O. Hanoosh, M. K. A. Rahim, N. A. Murad and Y. M. Hussein, "High Gain Waveguide Tilted Slot Antenna for Millimeter Wave application," 2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), Singapore, Singapore, 2021, pp. 125-126, doi: 10.1109/APS/URSI47566.2021.9703881.
- [14] B. Liu, W. Hong, Y.-Q. Wa, Q.-H. Lai, and K. Wu, "Half mode substrate integrated waveguide (hmsiw) 3-dB coupler," IEEE Microw. Wireless Compon. Lett., vol. 17, no. 1,p.2224,Jan2007.[Online].Available: <http://dx.doi.org/10.1109/LMWC.2006.887244>
- [15] Y. M. Hussein, N. A. Murad, M. K. A. Rahim and H. O. Hanoosh, "Substrate Integrated Waveguide Antenna at Millimeter Wave Frequency," 2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI), Singapore, Singapore, 2021, pp. 577-578, doi: 10.1109/APS/URSI47566.2021.9703727.
- [16] Y. M. Hussein, N. A.. Murad, M. K. A.. Rahim, and H. O.. Hanoosh, "Butler Matrix Components Based on Substrate Integrated Waveguide Fed by Microstrip Separation Feedline for 5G Application", ACES Journal, vol. 39, no. 11, pp. 999–1011, Nov. 2024.
- [17] I. Lima De Paula et al., "Cost-Effective High-Performance Air-Filled SIW Antenna Array for the Global 5G 26 GHz and 28 GHz Bands," IEEE Antennas Wirel. Propag. Lett., vol. 20, no. 2, pp. 194–198, 2021, doi: 10.1109/LAWP.2020.3044114.
- [18] Hatem Oday Hanoosh, M. K. A. Rahim, N. A. Murad, and Y. M. Hussein, "Multi-Beams Waveguide Slot Antennas at X-Band for Wireless Communications Systems ", ACES JOURNAL, Vol. 35, No. 7, July 2020
- [19] Z. Mousavirazi, V. Rafiei, M. M. M. Ali, and T. A. Denidni, "A Wideband CP Cavity-Backed SIW Antenna Fed by Printed-RGW Technology," 2021 IEEE Int. Symp. Antennas Propag. North Am. Radio Sci. Meet. APS/URSI 2021 - Proc., pp. 1531–1532, 2021, doi: 10.1109/APS/URSI47566.2021.9704236.
- [20] L. Sun, B. Sun, J. Yuan, W. Tang, and H. Wu, "Low-Profile, Quasi-Omnidirectional Substrate Integrated Waveguide (SIW) Multihorn Antenna," IEEE Antennas Wirel. Propag. Lett., vol. 15, pp. 818–821, 2016, doi: 10.1109/LAWP.2015.2476346.
- [21] Y. M. Hussein, M. K. A.. Rahim, N. A.. Murad, H. O.. Hanoosh, and N. B. M. Nadzir, "Substrate Integrated Waveguide Antenna at Millimeter Wave for 5G Application", ACES Journal, vol. 37, no. 04, pp. 478–484, Apr. 2022.
- [22] Maria Maqsood, Saima Anwar Lashari, Murtaja Ali Saare, Sari Ali Sari, Y. M. Hussein and Hatem Oday Hatem, "Minimization Response Time Task scheduling Algorithm", DOI 10.1088/1757-899X/705/1/012008, et al 2019 IOP Conf. Ser.: Mater. Sci. Eng. 705 012008
- [23] D. Pozar, Microwave Engineering, 3rd ed. John Wiley & Sons, 2005.
- [24] Ali Abdulateef Abdulbari, Z. Zakaria, Sharul Kamal Abdul Rahim, Y. M. Hussein, Mustafa Mohammed Jawad, Ayad Muslim Hamzah, "Design and development broadband monopole antenna for in-door application",DOI: 10.12928/TELKOMNIKA.v18i1.13171, Vol. 18, No. 1, February 2020, pp. 51~56
- [25] M. B. R. Garg, I. Bahl, Microstrip Lines and Slotlines, 3rd ed. Artech House, 2013.
- [26] E. Hammerstad and Q. Jensen, "Accurate Models for Microstrip Computer-Aided Design," IEEE MTT-S International Microwave Symposium Digest, 1980, pp. 407–409