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Wideband High Gain Antenna Using a Slot Loading and FSS for 5G Application

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In this study, an inset fed rectangular patch antenna is designed for 5G application. The proposed antenna has been designed by utilizing a U-shaped lot loading technique introduced on ground plane for bandwidth improvement. The designed antenna is integrated with parasitic patch as FSS unit cell in order to obtain gain improvement. FR-4 substrate with (ε_r = 4.4 and tanδ = 0.02) is used to design the antenna. The bandwidth and gain parameters are improved by altering the length of the ground plane initially and frequency selective surface (FSS) placed at the back of the substrate to enhance the radiation property of the antenna. Bandwidth improvement of 30 % is obtained for proposed wideband high gain antenna compare to conventional inset feed patch antenna. Maximum gain obtained for proposed wideband high gain antenna is 6 dB at 25 GHz. The obtained return loss is also well below 10 dB range from 24.57 GHz to 27.57 GHz. Bandwidth obtained for the proposed antenna is 3.0 GHz. Slot loading technique with ground optimization is useful for bandwidth improvement without affecting radiation pattern of the antenna. Further FSS integration is an efficient approach to improve the gain of convention antennas. The proposed antenna features good characteristics in terms of return loss, gain and bandwidth which makes it highly suitable for 5G applications in mm-wave band.

Keywords: 5G, Slot loading, Frequency selective surface, Wideband, High gain.

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1. INTRODUCTION

In the development of modern communication era, the critical issues regarding wireless transmission is to provide low latency, stable coverage, and high data rate transmission. To provide all these in 5G technology requires wideband and high gain antenna design (1). It is well known that traditional planar antenna offers narrow bandwidth and low gain [2], Several techniques have been introduced to improve the antenna parameters such as return loss, bandwidth and radiation pattern in a single antenna using split ring resonator (SRR) and ground modification (3-4), Further different slot loading structure and fractal geometry were also suggested for creating the multiple resonances and providing the wideband response by merging the multiple resonances together (5-6). Gain improvement was obtained using array configuration, use of AMC as ground plane and several meta-surface structure over the patch antenna [7-8]. The gain is also enhanced by placing a superstrate over a convention micro strip antenna [9] but bandwidth obtained was quite narrow. Multiple slots loading and U- shaped FSS were also used to enhance the antenna gain while maintaining the bandwidth [10]. A circular cross slot AMC were implemented for gain improvement of monopole antenna using coplanar waveguide feed [11]. Hybrid AMC and FSS were also studied in single structure to improve the antenna parameters [12]. To improve the bandwidth CPW-fed printed monopole with a dual SRR pair exhibiting dual-frequency were investigated and presented [13]. Left-handed metamaterial (LHM) structure with combination of the modified square rectangular Split Ring Resonator and the Capacitance Loaded Strip (CLS) was designed to improve the gain of the patch antenna [14]. Gain is enhanced by shunting inductive loading shorting pins to the broadband symmetrical dual-loop antenna [15]. The suggested technique such as slot loading in radiating element does not provide the stable radiation pattern and makes complex structure. AMC integration and use of meta-surface for gain and bandwidth improvement requires large area. Over the years, different techniques have been incorporated with micro strip patch antennas to improve the bandwidth and gain. These techniques were complex and bulky in size for wireless application. In this work, we have proposed a simple inset feed antenna with wideband coverage and high stable gain using U shape slot loading and FSS incorporation with compact structure. Evaluation stages for return loss and impedance variation is presented to validate the proposed antenna performance. This paper is organized as follows; Section 1 explains the design and analysis of the inset fed antenna and its evaluation stages analysis. Section 2 discusses the effect of FSS incorporation on bandwidth and gain performance. Finally, comparison with reported research work is presented with conclusion.

2. DESIGN AND ANALYSIS OF ANTENNA

The proposed antenna is designed using inset feed and rectangle shaped radiating element. Initially, the resonance frequency selected as 25 GHz which is suitable for 5G application [1]. The length and width of the radiating element was calculated using equations 1 and 2 [5]:

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$$L_{eff} = \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}}\,, \tag{1}$$

were, L_{eff} – Effective length of the radiating patch

$$W = \frac{c_0}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}}\,, \tag{2}$$

where, W – width of the radiating patch, c_0 is the velocity of electromagnetic wave in free space, f_r is the operating frequency and ε_r is the dielectric constant of the substrate. Fig. 1 shows the compact wideband high gain antenna with dimension. The design parameter with its dimension is presented in Table 1.

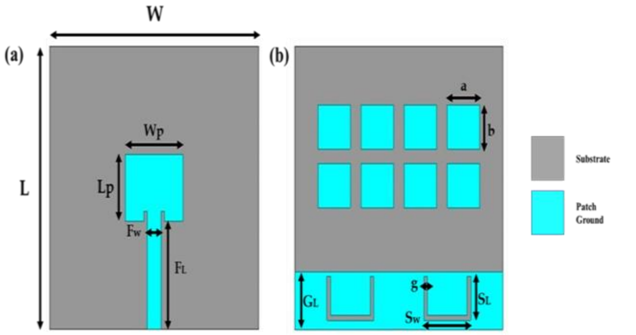

Fig. 1 – Proposed high gain wideband antenna (a) Front side View (b) Back side view

2.1 Evolution Stage of the Proposed Antenna

The inset feed antenna using full ground structure provided the resonance at 24.5 GHz with frequency ranging from 23.4 GHz to 25 GHz. Bandwidth coverage was narrow and desired resonance was also at the upper corner frequency. So, to achieve wideband response stage 2 antenna was designed with quarter ground length and further U shape slot was loaded to the ground plane.

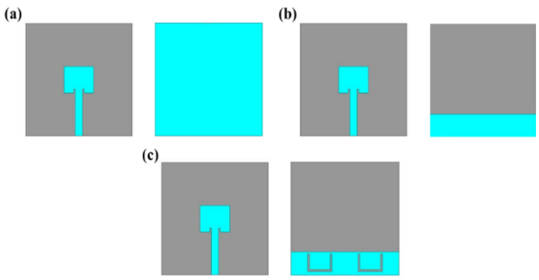

Fig. 2 – Evolution stages of the proposed antenna (a) Stage 1 (b) Stage 2 (c) Stage 3

Slot loading provided lower frequency resonance and in turns improves the return loss near 23.5 GHz. The 10 dB impedance bandwidth coverage is from 24.5 to 27.0 GHz (2.5 GHz) as shown in Fig. 3(a). The impedance variation with frequency is presented in Fig. 3(b) and it is approximately near to 50 Ω for desired band of interest.

It can be observed that slot loading and ground alteration provided wideband response but gain of the antenna was nearly 0.6 dB at 25 GHz. This is very low for 5G application. So, to enhance the gain of the slot loaded antenna FSS unit cell is designed and studied. The detailed analysis is presented in the next section.

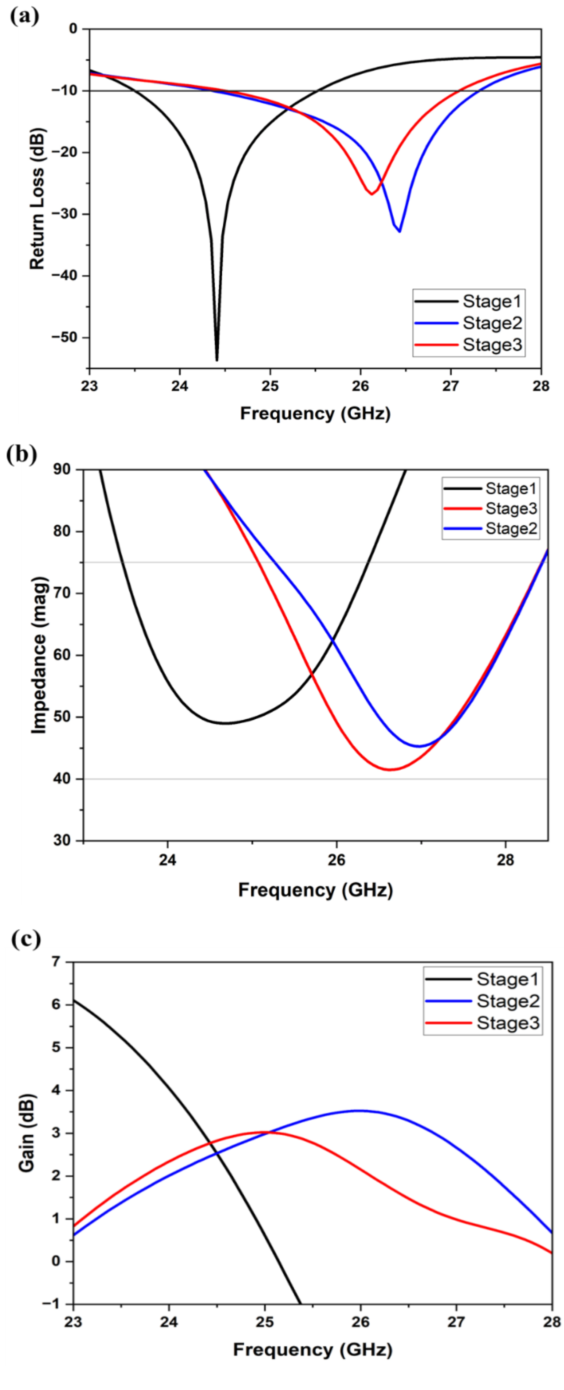

Fig. 3 – (a) Return loss variation (b) Impedance variation with frequency (c) Gain variation with frequency

Table 1 – Design parameter and dimension of the proposed antenna

No	Parameter	Dimension (mm)
1	*L*	14.5
2	*W*	14.5
3	*Lp*	3.4
4	*Wp*	4
5	F_L	5.75
6	*Fw*	1

7	S_L	2.25
8	Sw	3.25
9	G_L	2.95
10	g	0.25
11	a	2.25
12	b	2.25

2.2 Design and Integration of FSS

Frequency Selective Surface (FSS) is a periodic structure which offers properties of resonance depending on length of the radiating structure and it acts as parasitic patch. One can control the reflection phase characteristics and resonance frequency of the FSS by proper selection of substrate material and dimension of the unit cell [7].

These properties of unit cell structures are convenient to manipulate the radiation performance of any planar antennas.

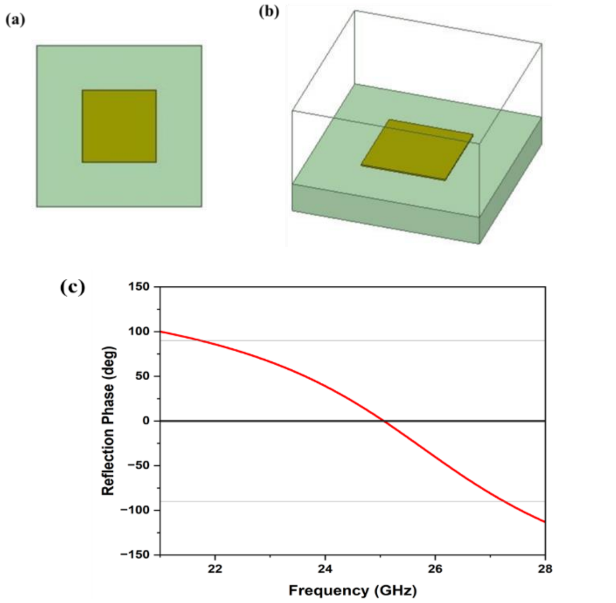

Fig. 4 – Frequency Selective Surface (FSS) unit cell (a) Top view (b) Simulation set up (c) Reflection phase variation of the FSS unit cell

In this work, initially we have designed square shaped unit cell using FR4 substrate (ε_r is 4.4 and tangent of 0.02) to provide the resonance at 25 GHz. It can be observed from the Fig. 5(c) that o degree phase is obtained at 25 GHz as per requirement of the unit cell. The proposed unit-cell structure is shown in Fig. 5(a) and (b).

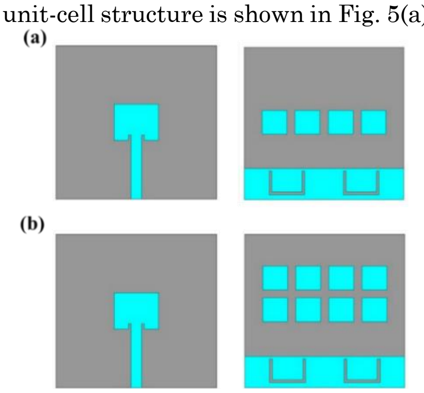

Fig. 5 – Proposed antenna integrated with (a) 4 × 1-unit cell and (b) 4 × 2-unit cell

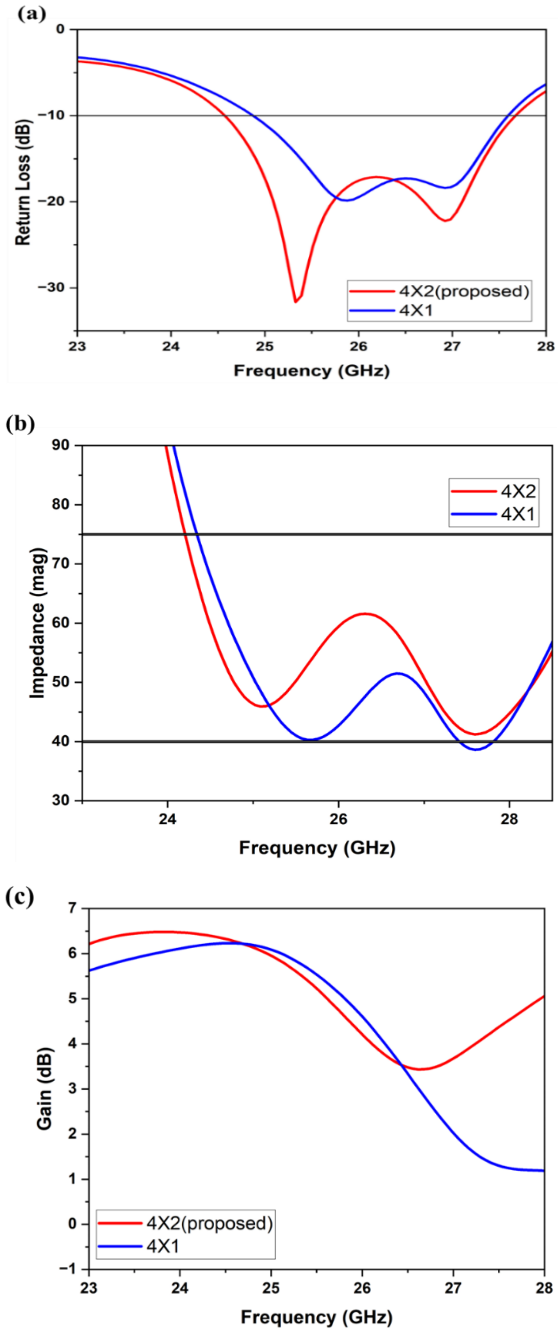

Fig. 6 – (a) Return loss versus frequency variation (b) Impedance versus frequency variation (c) gain versus frequency variation integrated with 4 × 1 and 4 × 2 unit cell of FSS

The square shape radiating element of the unit-cell dimension is (2.25 × 2.25) mm^2 and thickness is 35 μm.

The unit cell was analyzed using periodic boundary condition (PBC) set up to get the resonance frequency and reflection phase characteristics [6] variation with frequency. The reflection phase (S_{11}) response covered the frequency range from 21.7 to 27.25 GHz with ± 90º phase shift as shown in the Fig. 4(c).

The FSS unit cell is integrated with the convention inset feed antenna to enhance the gain. Initially (4 × 1) unit cell was integrated with the antenna as shown in Fig. 4(a) and with (4 × 2) unit cell in Fig. 4(b) respectively. The array of 4 × 1 FSS unit-cell integration at the back of the substrate improved the gain approximately 3 dB compare to convention U-shape slot loaded antenna without FSS integration.

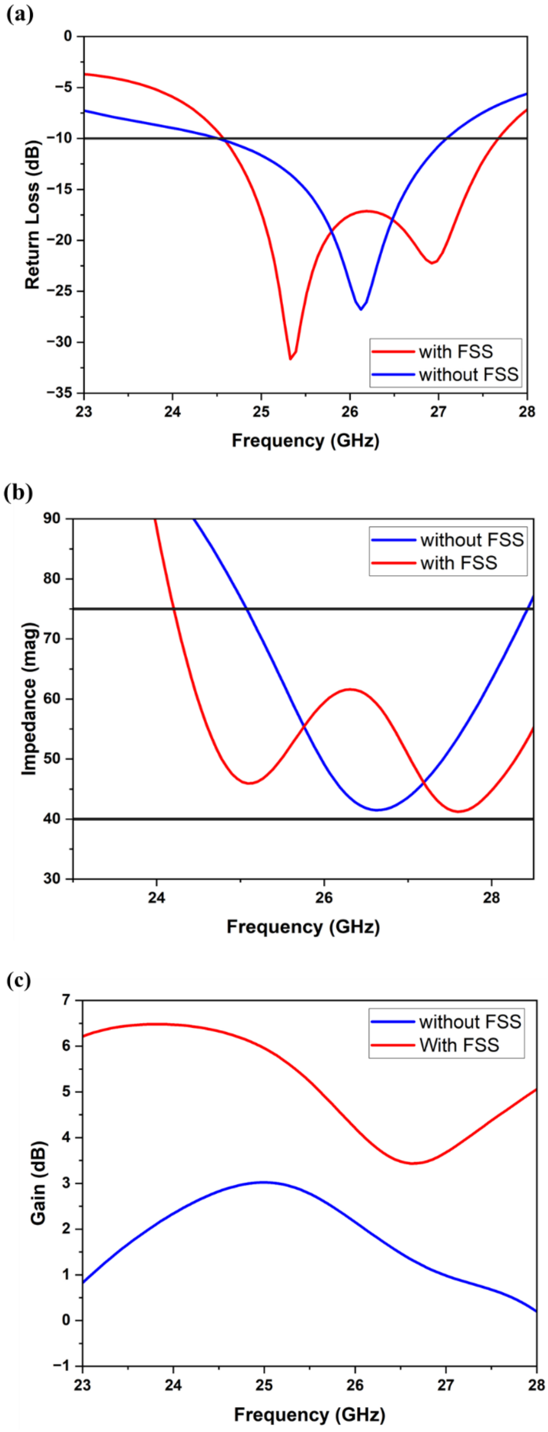

Fig. 7 – (a) Return loss plot (b) Impedance plot and (c) gain plot of the proposed antenna with and without FSS

Further 4 × 2-unit cell array was studied and it was observed that marginal gain improvement obtained near 23 GHz and approximately 2.6 dB gain improvement at 28 GHz. Return loss improvements was more significant for (4 × 2) unit cell at lower frequency. So, we have selected 4 × 2-unit cell integration with conventional antenna. The bandwidth improvement obtained was from 2.5 GHz to 3.1 GHz. It can be seen from the Fig. 6(a) that return loss is well below 10 dB for entire band of interest (24.57 GHz to 27.67 GHz) and Fig. 6(b) depicts the impedance variation for high gain wideband antenna and it is close to 50 Ω for the entire band of interest. The gain versus frequency variation is also presented in Fig. 6(c) for the proposed antenna with integration of FSS unit cell (4 × 1) and (4 × 2).

Fig. 7(a-b) and (c) shows the return loss, impedance and gain variation with respect to frequency for FSS loaded antenna and conventional antenna without FSS loading. It is clearly evident that wideband coverage, better return loss and high gain were obtained for the proposed antenna using FSS and slot loading.

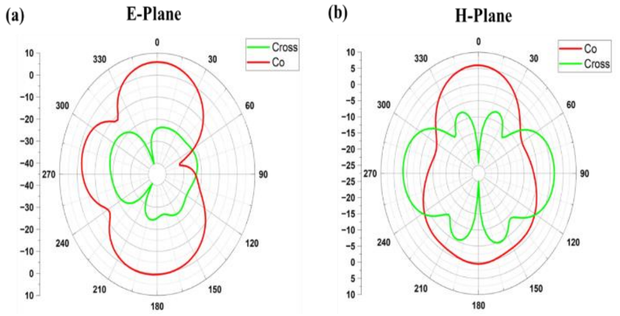

Fig. 8 – Radiation plot of the proposed antenna integrated with FSS at 25 GHz (a) *E*-Plane (b) *H*-plane

The radiation pattern at 25 GHz for *E*-field and *H*-field is plotted and shown in Fig. 8(a) *E*-plane and (b) *H*-Plane. It is observed that a stable radiation pattern is obtained for proposed antenna with bidirectional characteristics.

3. COMPARATIVE ANALYSIS

Table 2 shows the comparison of proposed inset feed high gain antenna with recently reported work for 5G application. It is evident from the gain and bandwidth parameter that proposed high gain wideband antenna offers better bandwidth and stable gain compare to similar work for 5G application.

Table 2 – Comparison table

Ref. No	Size (mm²)	Substrate / (ε_r)	Frequency (GHz)	Band width (GHz)	Gain (dB)
10	14×12	Rogers TC600/6.15	28	~1.1	6.1
12	5×5.26	Rogers Rt/ Duroid 5880/2.2	28	2.1	5.2
13	8.5×8.5	Rogers Rt/ Duroid 5880/2.2	28	1.062	5.4
Proposed Antenna	14.5× 14.5	FR4/4.4	25	3.1	6

4. CONCLUSION

In this work slot loading on ground and FSS as (parasitic patch) incorporated high gain wideband antenna for 5G applications is designed. Ground length reduction to quarter wavelength provided 1.5 GHz bandwidth and creating symmetrical U-shaped slot over the ground further improves the bandwidth to 2.5 GHz. Further gain is improved 3 dB using FSS on ground plane. Low profile, wideband and high gain solution can be provided compare to AMC and meta-surface approach. The bandwidth is improved from 2.5 GHz to 3.1 GHz and the gain improvement of 3dB was obtained using FSS compare to conventional U- shape slot loaded antenna. Proposed antenna covers the band (24.57- 27.67) GHz that is suitable for FR2 5G NR millimeter wave application, defined as n258 band for 5G application.

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Широкосмугова антена з високим коефіцієнтом підсилення, яка використовує завантаження слота та FSS для застосування 5G

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У цьому дослідженні прямокутна патч-антена з вбудованим живленням розроблена для застосування в 5G з використанням U-подібної техніки навантаження на площину землі для покращення смуги пропускання. Розроблена антена інтегрована з паразитним патчем як елементарною коміркою FSS для покращення підсилення. Для розробки антени використовується підкладка FR-4 з (ε_r = 4.4 і tanδ = 0.02). Параметри смуги пропускання та підсилення покращуються шляхом початкової зміни довжини заземленої поверхні та частотно-селективної поверхні (FSS), розміщеної за підкладкою для збільшення випромінювальної здатності антени. Для запропонованої широкосмугової антени з високим коефіцієнтом підсилення досягнуто покращення смуги пропускання на 30 % порівняно зі звичайною вставною фідерною антеною. Максимальне підсилення становить 6 дБ на 25 ГГц. Отримані зворотні втрати також значно нижче 10 дБ в діапазоні від 24,57 до 27,57 ГГц. Отримана смуга пропускання - 3,0 ГГц. Техніка завантаження щілин з оптимізацією землі корисна для покращення смуги пропускання без впливу на діаграму спрямованості антени. Запропонована антена має хороші характеристики щодо зворотних втрат, підсилення та пропускної здатності, що робить її дуже придатною для додатків 5G у мм-діапазоні хвиль.

Ключові слова: 5G, Слотове завантаження, Частотно-селективна поверхня, Широкосмуговий діапазон, Високий коефіцієнт підсилення.