

Design and Performance Enhancement of a Multiband 1×4 Microstrip Array Antenna Using a Slotted Square-Ring Frequency-Selective Surface for Sub-6 GHz 5G Applications

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Abstract- In this work, a wideband 1×4 corporate-fed microstrip array antenna integrated with a slotted square-ring Frequency-Selective Surface (FSS) reflector for sub-6 GHz 5G application is presented. The design was optimized by performing parametric studies of the radiating elements, feed network, FSS reflector, and 1/4 wavelength air gap as shown in the ANSYS HFSS simulation. The antenna functions over the band of 3.5–5.8 GHz and has a high fractional bandwidth of 51.12%. It achieves a peak realized gain of 12.4 dBi with minimal gain variation (~1 dBi) over the band. The FSS reflector has high forward radiation and low back radiation and has the ability to increase the radiation efficiency to 77.5% without increasing the complexity of the feeds. This low cost and high performance design is applicable to 5G base stations, wireless backhaul and broadband directional communication systems.

Keywords - Frequency-Selective Surface (FSS); Microstrip Array Antenna; Radiation Enhancement; Sub-6 GHz.

1. INTRODUCTION

The explosive growth of wireless data, caused by the emergence of multimedia services, cloud computing, IoT, and M2M has fueled the development of 5G networks. Good propagation, wide coverage and non-line-of-sight transmission makes sub-6 GHz the preferred choice for 5G, and is ideal for macro-cellular base stations, wireless backhaul, industrial automation and broadband access networks. The antennas in this band thus need to have a wide bandwidth, high gain, stable radiation pattern, high efficiency, low cost and compact size [1]–[4]. Microstrip patch antennas are much used due to their low-profile, light weight, and ease of fabrication, but with a narrow bandwidth and moderate gain, single elements have limitations. Various enhancement techniques have been considered including slot loaded radiators, corporate fed arrays, DGS, EBG structures, AMC, and FSS, with corporate fed arrays and FSS reflectors showing good performance in terms of gain and radiation efficiency [5]–[12]. Difficulties exist however: For slot loading at least a moderate gain improvement is available; For DGS/EBG techniques the effect on the radiation performance is not very high; Most high gain FSS based designs require complex multi-layer structures and substrates that are expensive, and simultaneous wide bandwidth, stable gain, and high efficiency would be difficult to achieve [13]–[20]. To overcome these drawbacks, in this paper, a 1×4 (one by four) corporate-fed microstrip array antenna with slotted square-ring FSS reflector is designed for sub-6 GHz 5G applications using low-cost FR-4 substrate and simulated in ANSYS HFSS. The design provides a planar structure with simple design and cost savings, and enhances the impedance matching and radiation characteristics by using the corporate-fed array and FSS reflector. Based on the simulation results, the fractional bandwidth of the device is 51.12% (3.5-5.8 GHz), the peak realized gain of the device is 12.4 dBi and the radiation efficiency of the device is ~77.5%, making it suitable for broadband sub-6 GHz wireless applications [21]–[25].

2. LITERATURE REVIEW

The research of microstrip array antennas with a wide impedance bandwidth, high gain and stable radiation pattern has been stimulated by the requirement of high-rate wireless communication. To get high directivity and aperture efficiency, corporate-fed arrays are commonly used and to get better impedance matching, surface wave suppression, and radiation efficiency, various techniques were developed like DGS, EBG, AMC, and FSS

[7]–[12] are used. FSS reflectors are interesting for their frequency-selective properties, which enhance the forward radiation while reducing the back radiation, having a low profile and easy planar implementation when compared to conventional metallic reflectors. Most of the reported FSS-assisted array antennas, however, have a drawback of narrow bandwidth, gain fluctuations, multi-layer structure, or high cost of low-loss substrate [13]–[18] which make the fabrication more complicated. Recent studies on wideband microstrip array antennas [11], [13], [15], [17], [19] and [22]–[24] discuss the trade-offs between bandwidth, gain, structural complexity and profile ever since. Based on these results, this work investigates a corporate-fed 1×4 microstrip array with an optimized slotted square-ring FSS reflector for sub-6 GHz 5G applications. The design combines a joint optimization of the radiating elements, the feed network, the unit cells of the reflector, and the quarter-wavelength air gap, which results in better impedance bandwidth, high gain stability, high radiation efficiency and better directionality, while maintaining a low-cost, FR-4 implementation for practical wireless infrastructure.

3. ANTENNA DESIGN METHODOLOGY

3.1 Design Requirements and Antenna Configuration

The service of 5G wireless communication for sub-6 GHz band is also expected to become reality, which has also increased the demand for antenna systems to achieve a large impedance bandwidth, large realized gain, stable radiation characteristics, high radiation efficiency and a compact and low cost structure. The conventional microstrip patch antenna has low profile, lightweight construction and easy fabrication, but has poor bandwidth and medium gain, which limits the application of the broadband wireless system [21]–[22].

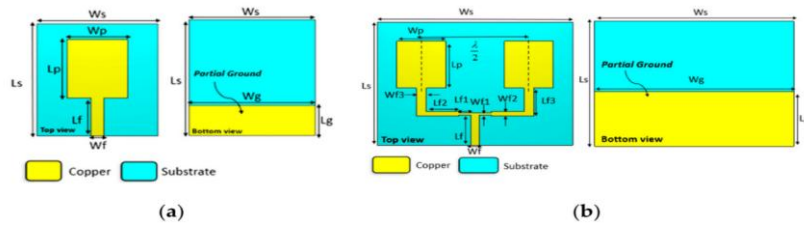


Figure 1. Geometry of the proposed 1×4 corporate-fed microstrip array antenna (a) single element, (b) 1×2 array antenna

The designs of the proposed antenna are shown in Fig. 1. The radiating array is made on a FR-4 substrate and fed in a corporate feed system for equal power distribution between the four radiating elements. An FSS reflector is located under the array with the air gap of about $\lambda/4$ to increase the forward radiation by constructive electromagnetic reflection. The antenna has been designed to cover the frequency range of 3.5 GHz to 5.8 GHz and analyzed using ANSYS HFSS. The proposed antenna in this design comprises of a 1×4 corporate-fed microstrip array that is integrated with a slotted square-ring Frequency-Selective Surface (FSS) reflector as shown in Fig. 2. The first configuration is a single rectangular microstrip patch with the desired resonant property, but has a small radiating aperture and thus low gain [22] and [23]. The antenna is designed as a 1×4 linear arrays for better directivity and the effective gain of the antenna is increased, thus improving the broad side radiation feature. These radiating elements are then fed into a corporate feed network to achieve equal A and B feeding, thus improving the match and power distribution. Then a slotted square-ring FSS reflector is added below the array at a frequency that is about $\lambda/4$ apart. The FSS enhances the forward radiation by positive reflection and attenuates the back radiation, which leads to better realized gain and front-to-back ratio and radiation efficiency with a lower level of antenna complexity [23].

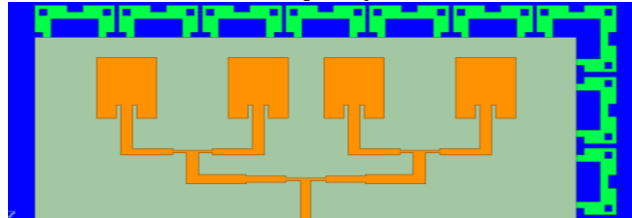


Figure 2. Design of the Proposed 1×4 Array Antenna with FSS Reflectors separated with an Airgap of 16.7 mm.

3.2. Frequency-Selective Surface Design and Performance Enhancement

The geometry of the proposed slotted square-ring FSS is illustrated in Fig. 3. The FSS is composed of a series of unit cells arranged in square rings with a specific periodicity, which gives it frequency selective reflecting properties. These changes to the effective current path allow the reflector to be designed for stable reflection in the operating band of sub-6 GHz [24]–[27].

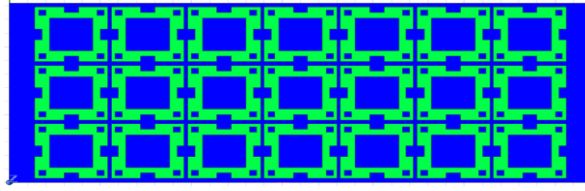


Figure 3. Design of the proposed FSS reflector with 3×7 SSR arrays.

This is done by placing the FSS reflector about $\lambda/4$ below the radiating array so as to create constructive interference between the reflected and radiated electromagnetic waves. This configuration increases forward gain, less back gain and better front-to-back ratio. The air-gap spacing, periodicity and dimensions of the FSS were varied to perform the parametric study in the simulation software, ANSYS HFSS, for achieving stable impedance matching and radiation characteristics within the operating band of 3.5-5.8 GHz [25].

3.5 Geometrical Parameters of the Proposed Antenna

The geometrical parameters of the proposed antenna are given in Table I. The antenna is a corporate fed microstrip array with FR-4 substrate under which a slotted square ring FSS reflector is located that reflects the incident wave. The antenna is designed with a 1×4 corporate fed microstrip array on FR-4 substrate and a slotted square ring FSS reflector is located below the radiating structure. To get constructive electromagnetic reflection, an approximately $\lambda/4$ air gap is kept between the antenna and the reflector.

Table I Geometrical Parameters of the Proposed Antenna.

Parameter	Wg	S	Lf1	Wf1	Wf2	Lf2	Wf3	Lf3
Value(mm)	136	16.88	5	0.79	1.78	10	2.745	15
Parameter	Ls	Ws	h	Lp	Wp	Lf	Wf	Lg
Value(mm)	55	136	1.6	18.25	15	11.84	2.745	29

4. Results and Discussion

4.1 Reflection Coefficient and VSWR

The reflection coefficient of the designed antenna (S_{11}) is shown in Fig. 4. The antenna has a reflection coefficient of less than -10 dB and an impedance bandwidth of 3.5–5.8 GHz, which is 51.12% fractional bandwidth. This better impedance matching is believed to be due to the combination of the corporate-fed array and the slotted square-ring FSS reflector to improve the electromagnetic coupling and minimize the reflection loss [21, 22]. The VSWR response and Measured reflection coefficient plot are shown in Fig. 5 and Fig. 6. The VSWR is maintained low over the band showing good match between the feed network and radiating elements with low mismatch losses. The results confirmed that the proposed antenna is suitable for sub-6 GHz wireless communication broadband application.

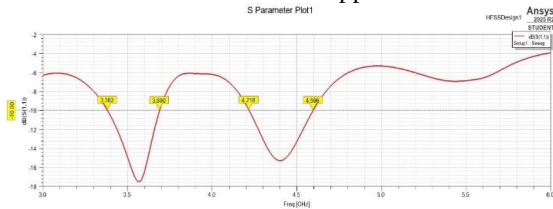


Figure 4. The simulated reflection coefficient plot of the 1×4 array antenna.

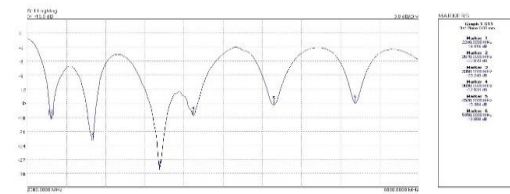


Figure 5. The Measured reflection coefficient plot of the 1×4 array antenna.

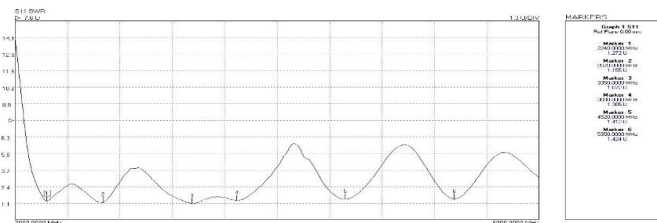


Figure 6. Measured VSWR Characteristics showing the current distribution well below the range.

4.2 Realized Gain and Radiation Efficiency

The simulated realized gain characteristics and fabricated antenna are shown in Fig. 7 and Fig. 8. The realized gain is 12.4 dBi with only slight variation over the operating band and thus shows good radiation stability. In addition to the electromagnetic reflection effect of the slotted square-ring FSS reflector [23], the gain enhancement is obtained from the effective aperture of the 1×4 corporate-fed arrays. The simulated radiation efficiency is about 77.5%, which is a good conversion efficiency of the input power to radiated power. The FR-4

substrate has dielectric losses, but the FSS reflector helps to increase the forward radiation and suppresses unwanted back radiation to compensate for these losses.

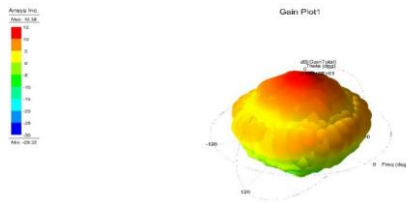


Figure 7. The Gain Analysis plot of proposed antenna.



Figure 8. The Photograph of Fabricated Antenna.

5. CONCLUSION

This work introduces a 1×4 corporate-fed microstrip array antenna that is integrated with a slotted square-ring FSS reflector for sub-6 GHz 5G applications. The antenna has been designed and analyzed using the software, ANSYS HFSS, and it has a wide operating bandwidth of 3.5–5.8 GHz (51.12% fractional bandwidth), a maximum realized gain of +12.4 dBi and a radiation efficiency of $\sim 77.5\%$. The FSS reflector improves the forward radiation, reduces the back radiation and keeps the radiation characteristics stable over the band. The proposed antenna features a broad bandwidth, high gain, and efficient radiation efficiency on a low cost FR-4 substrate, which is suitable for sub-6 GHz 5G base stations, wireless backhaul and broadband wireless systems. The prototype fabrication, experimental validation and usage of different loss of substrates and advanced FSS geometry will be undertaken in future studies to further improve the performance.

6. REFERENCES

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