2 X 2 E Shaped Filter Integrated Antenna for 5G sub 6GHz communication

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Abstract. This work presents a 2×2 E-shaped microstrip patch antenna incorporating an inherent bandpass filtering mechanism for Sub-6 GHz 5G applications. The S-parameter results show two closely spaced resonances at 5.57 GHz and 6.0 GHz, which together form a dual-pole bandpass response. These resonances result from the combined electromagnetic effect of the E-shaped radiating patch and a Jerusalem-cross ground structure that enhances coupling and supports multi- mode operation. Across the composite passband from 5.45 to 6.15 GHz, the antenna achieves a peak gain of 7.2 dBi and radiation efficiency approaching 99%, while maintaining stable radiation characteristics. The integrated dual-resonance behavior eliminates the need for external filter stages, enabling a compact, high-performance bandpass filtenna suitable for next-generation wireless communication.

1 Introduction

Wireless communication technology has undergone remarkable advancement over the past few decades, leading to the enhancement of compact, high-performance, and multifunctional radio-frequency (RF) modules. Among these modules, filters play a vital role in selecting, combining, separating, and rejecting signals according to system requirements. The design of compact, efficient, low- loss, and lightweight filters suitable for modern wireless applications remains a significant research challenge.

In RF front-end systems, antennas are responsible for signal transmission and reception, while bandpass filters (BPFs) ensure spectral selectivity. Integrating these two components into a single structure, known as a filtering antenna or filtenna, has recently emerged as a promising approach to reduce system complexity, physical size, and overall cost. Filtennas simultaneously perform radiation and filtering functions, thereby eliminating the need for separate antenna and filter designs. The embedded filtering characteristics enable the antenna to exhibit bandpass, bandstop, or band-notch responses within the desired frequency range. Various design techniques—such as defected ground structures (DGS), resonator loading, and substrate integrated waveguide (SIW) cavities—have been employed to realize such integrated configurations [1], [2].

Generally, the filter formation approach and the antenna merging approach are the two primary categories of filtenna design methodologies. In the filter synthesis approach, a bandpass filter is designed first, and the antenna element serves as the final resonant stage of the filter. Although this method typically results in a larger overall size, it offers design flexibility and adaptability to different frequency bands. Conversely, the antenna fusion approach directly modifies the radiating element or feed network to introduce parasitic structures that generate radiation nulls near the operating band. This method yields a more compact design but offers limited reconfigurability when the target frequency or performance specifications change [3].

Several recent studies have demonstrated the potential of filtering antenna concepts in enhancing RF system performance. A third-order filtering microstrip antenna array with two radiation nulls adjacent to the passband and a Chebyshev equal-ripple gain response was proposed in [4], where the antenna and feeding network jointly function as a filter without requiring additional circuitry. In [5], a 2×2 inverted-F antenna (IFA) array was designed on a single- layer substrate, featuring radiators and feed structures on opposite sides. The filter's second resonator was replaced with an equivalent slot antenna, achieving sharper gain characteristics and improved suppression of unwanted signals. A broadband filtering antenna array employing a 2×2 patch array with a slotline-based filtering power divider was presented in [6]; the compact feeding network provided excellent stopband rejection, high selectivity, and phase-controlled outputs for fixed-beam applications. Furthermore, a series-fed 2×2 filtering microstrip antenna array (FMAA) was introduced in [7], capable of achieving a second-order filtering response and an additional 3 dB gain enhancement by doubling the number of radiating elements without altering the feeding network. Research study [8] focuses on the development of the fundamental radiating patch, which reflects at 1.8 GHz. Nevertheless, the patch emits two unwanted false modes at 2 and 3 GHz in addition to the fundamental frequency. A broad rejection band filter is created between 2 and 4 GHz utilizing metamaterial driven complementary split ring resonators (CSRRs) to

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eliminate all spurious modes that could reduce system efficiency. In paper [9] for 5G applications, a unique broadband filtenna design is suggested. It is made up of a four-pole lowpass filter design on the feedline and a bow tie gap filled channel antenna. The filtenna uses four resonators, each surrounded by a cylindrical loop-like SRR to accomplish the filtering characteristic. Study [10] demonstrates that this feature can be used to produce very good isolation between channels working over the same or adjoining frequency bands . That work presents a low ratio of frequencies (1.08) common-aperture double band self-diverse double sensing microstrip CP antenna array relying on the consecutive rotation technique. A grooved SIW-based hole is employed to offer the splitting and filtering functions while reducing reverse radiation. Research letter [11] proposes a duplex filtering antenna with two operating bands that have a low profile and consistent inside-band quasi-omnidirectional radiation performance. The isolation is increased and the band-edge filtering roll-off rate can reach 215 dBi/GHz with four transmission zeros (TZs) and four band edge radiation nulls (RNs). For indoor frequency division duplexing wireless systems, the suggested antenna is appropriate. Finally, the use of a filtering distribution network for patch antennas based on even–odd mode theory was proposed in [12] to improve channel isolation in dual-band or closely spaced systems, demonstrating superior phase stability and port isolation compared to conventional designs.

This paper presents the designing of a 2×2 E-shaped filter-integrated antenna, in which slot structures are employed as the intrinsic filtering mechanism, thereby eliminating the need for any external bandpass filter circuitry. The proposed antenna demonstrates effective in- band transmission and out-of-band suppression, achieving selective frequency response by allowing only the desired operating bands to radiate while rejecting unwanted frequencies. The integrated filtering characteristics contribute to improved spectral purity and enhanced system compactness. Furthermore, the antenna exhibits a high gain performance exceeding 7 dBi at both resonant frequencies, confirming its suitability for high-efficiency wireless communication applications.

This paper is organized as follows: Section II describes the method used for design and development process of the filter-integrated antenna; Section III discusses the simulated results; and Section IV concludes the paper with possible future improvements.

2 Design of Filter Integrated Antenna

This section examines the edge-coupled characteristics of the proposed structure, wherein the closely spaced gaps between the feed line and the E-slot arms facilitate strong electric-field coupling. This edge-coupled interaction inherently generates the required filtering behavior, eliminating the need for any external filter components. All simulations and optimizations were carried out using the ANSYS HFSS electromagnetic solver.

2.1 Design of E shaped filter integrated antenna

A coupled-line filter-integrated antenna operating over the 5.5–6 GHz band is proposed. The design incorporates a 2× 2 E-shaped microstrip patch array as shown in Fig.1, excited through a coupled-feed structure, while a Jerusalem- slot embedded in the ground plane is employed to realize an inherent bandpass filtering response. The narrow gaps (g1 and g2) between the central feed strip and the E-shaped arms create an edge-coupled interaction similar to classical parallel-coupled microstrip filter structures. These gaps support strong electric-field coupling, enabling energy transfer between adjacent resonant paths and producing the dual-pole bandpass characteristics observed at 5.5 GHz and 6.2 GHz [13] .

The E-shaped arms function as edge-coupled resonators, and the coupling strength determined by the gap width directly influences the bandwidth and selectivity of the integrated filter response. The surface current plots confirm that strong edge coupling occurs only within the operational band, validating the E-slot geometry as an effective edge- coupled filtering structure. The antenna is implemented on a Rogers 5870 substrate with a dielectric constant of 2.2 and a loss tangent of 0.0009 [14-15]. The vertical slot etched in the ground functions as a single resonator, and when combined with the horizontal slot segments, it forms a dual-resonator structure.

The equivalent Jerusalem-slot circuit, shown in Fig. 2, consists of a cascaded series-resonant branch and a parallel- resonant branch. This combination establishes a bandpass behavior by permitting energy transmission within the desired frequency range while suppressing out-of-band components. The total resonant path length (L3 + L4 + W6 ≈ 27.285 mm) closely corresponds to λg/2 at the design frequency, confirming the formation of the primary resonant mode. The integrated configuration attains a measured peak gain of 5.3 dBi at resonance, demonstrating effective simultaneous filtering and radiation characteristics. Table 1 describes the parametric analysis of the designed filter antenna.

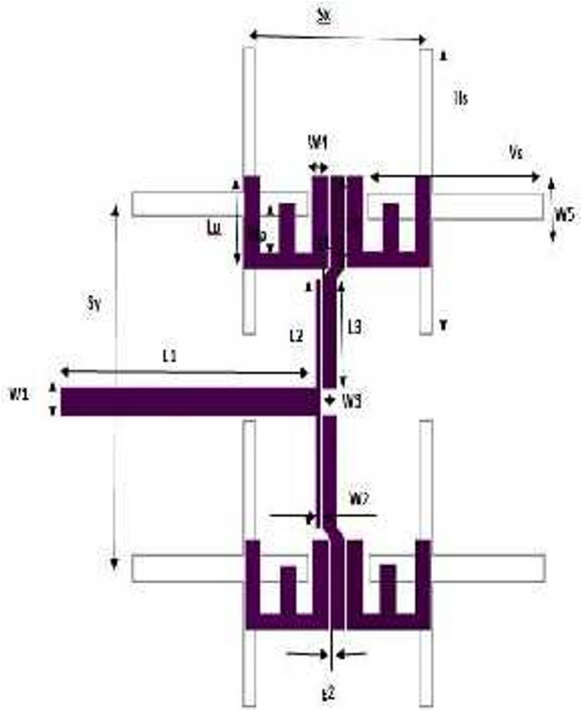

Fig. 1. 2x2 E Shaped Filter Integrated Antenna

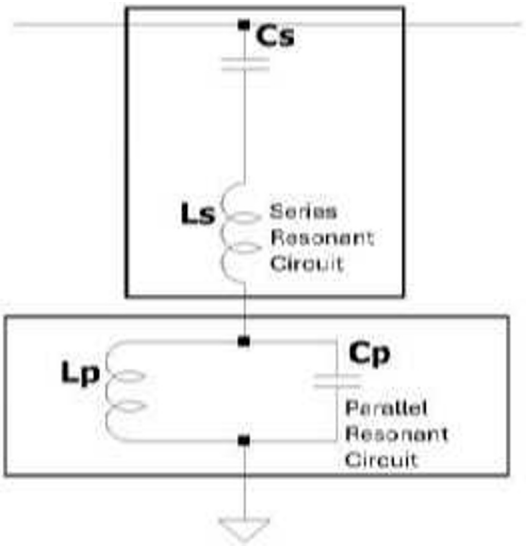

Fig. 2. Circuit model analysis of the Jerusalem cross at the ground plane

Table 1. Parametric Analysis of The Proposed FIA

Antenna description	Parameters	Values(mm)
Width of the rectangular strip taken	W1, W3, W4	2.23
Width of the small rectangular slip	W2	0.5
Horizontal and vertical length of Jerusalem cross	Hs, Vs	23.5, 28
Width of Jerusalem cross	W5	2
Horizontal Distance between two Jerusalem	Sy	27.3
Vertical Distance between two Jerusalem	Sx	26
Lengths of the rectangular strips	L1, L2, L3,L4	41.7, 20, 8.8, 11.07
Length and width of the smaller portion of E	Lp, Mp	7.17, 5
Gaps taken for edge coupling	g1,g2	0.5
Thickness of the substrate	t	0.805
Length and Width of the substrate	L X W	100 x 100

3 Results and discussion of the implemented design

This section discusses the analysis of the implemented filter integrated antenna design and it includes the analyses of various antenna parameters like reflection coefficient, gain, incident and radiated power, radiation efficiency and radiation characteristics. The discussed parameters has been taken for the frequency range of 4-8GHz covering the sub 6GHz band.

3.1 S parameter analysis of Filter Integrated Antenna

The S11 analysis of the developed 2 × 2 E-shaped FIA is depicted in Fig. 3. The S11 curve exhibits two deep and closely spaced impedance minima — one near 5.55 GHz (return loss – 14 dB) and another around 6.2 GHz (return loss – 10 dB) — which correspond to the dual resonant modes generated by the E-slot geometry and the Jerusalem- cross ground structure. These two resonances merge to form a continuous passband covering the 5.5–6.2 GHz region. Outside this range, the reflection coefficient rises significantly above –3 dB, indicating poor impedance matching and suppression of energy at frequencies below 5 GHz and above 6.5 GHz. This selective behavior and strong matching within the desired band and rejection outside it is a good evidence of bandpass filtering.

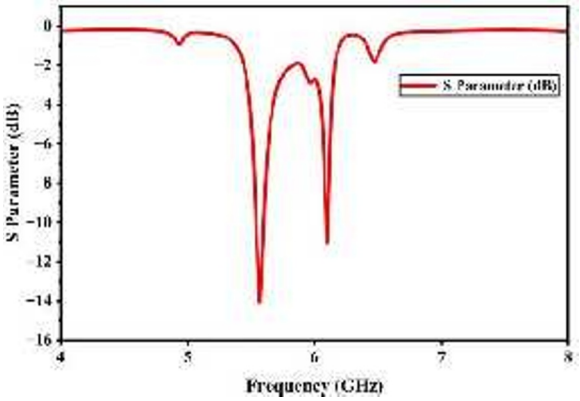

Fig. 3. S parameter analysis for 2X2 FIA

3.2 Gain of Filter Integrated Antenna

The gain response shown in Fig. 4, confirms the bandpass filtering behavior of the proposed 2×2 E-shaped filtenna. A peak gain of approximately 7.2 dB is observed within the 5.5–6 GHz range, which corresponds to dual- resonant passband identified in the S11 plot. Outside this region, the gain drops significantly—below 4 dB for frequencies <5 GHz and below 3 dB beyond 6.7 GHz— indicating strong suppression of out-of-band radiation. This selective enhancement of gain only within the resonant band verifies that the antenna radiates efficiently in the intended passband while rejecting unwanted frequencies, confirming its inherent bandpass filtering capability.

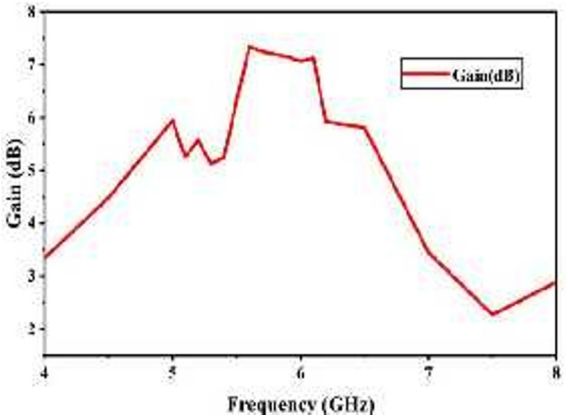

Fig. 4. Gain response of 2X2 FIA

3.3 Power analysis of the proposed design

The radiated–incident power characteristics further verify the bandpass behavior of the proposed 2×2 E-shaped filtenna. While the incident power remains constant at 0 dBW, the radiated power rises sharply within the 5.5–6 GHz region, reaching values close to –2 dBW, indicating efficient power conversion inside the intended passband. Outside this range, the radiated power drops below –10 dBW, demonstrating strong rejection of out-of-band frequencies.This selective radiation behavior aligns with the S11 and gain responses, confirming that the antenna inherently performs bandpass filtering through the combined action of the E-slot resonators and the Jerusalem-cross ground structure.

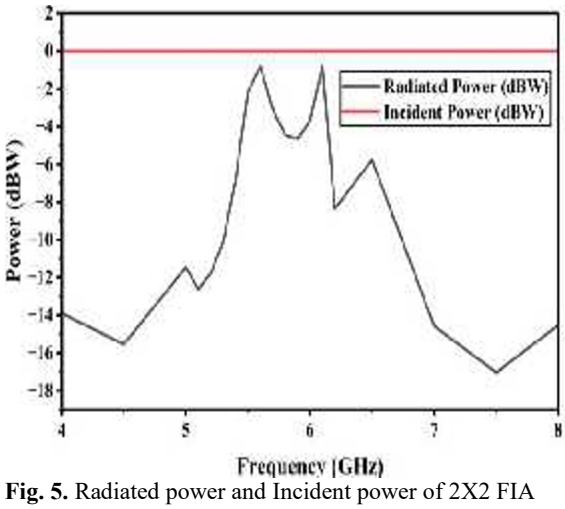

Fig. 5. Radiated power and Incident power of 2X2 FIA

3.4 Surface Current distribution of the Designed FIA

Surface current distribution of the designed 2×2 E-shaped filtenna is in Fig. 6, was analyzed at 4GHz, 5.5GHz, 6.2 GHz, and 8 GHz to validate the filtering mechanism introduced by the E-slot resonators and the Jerusalem-cross ground structure. At the non-resonant frequencies (4 GHz and 8 GHz), the current remains weak and sparsely distributed across the radiating elements, indicating poor excitation of the slot resonators and confirming strong suppression of out-of-band energy. In contrast, at 5.5 GHz and 6.2 GHz, the current becomes highly concentrated along the vertical slot, the central coupling strip, and around the horizontal E-shaped arms, demonstrating strong coupling and the activation of dual resonant modes. These well-defined current paths establish the formation of two closely spaced resonant poles that generate a bandpass response. The transition from weak currents at out-of-band frequencies to strong, localized currents within the 5.5–6.2 GHz region directly confirms that the structure selectively supports radiation only within the intended passband. Thus, the observed current distribution patterns validate the effective integration of filtering behavior into the antenna geometry.

3.5 Radiation pattern of the proposed Filter Integrated Antenna

2D radiation patterns of the proposed 2×2 E-shaped filtenna at the resonant frequencies of 5.6 GHz and 6.2 GHz are presented in Fig. 7. At both frequencies filter integrated antenna shows a stable and well-defined Electric field and Magnetic field patterns that operates predominantly in broadside radiation mode. The presence of a stable broadside main lobe at both resonant frequencies confirms that the integrated filtering mechanism does not adversely affect the primary radiation direction within the passband, while out-of-band frequencies fail to produce a comparable main lobe due to poor resonance excitation

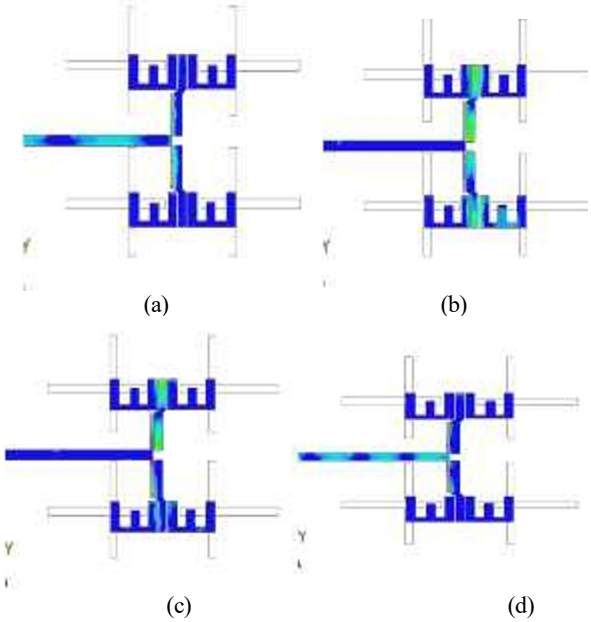

Fig. 6. Current Distribution of Filter Integrated Antenna at 4GHz, 5.6GHz, 6.2GHz, and 8GHz respectively

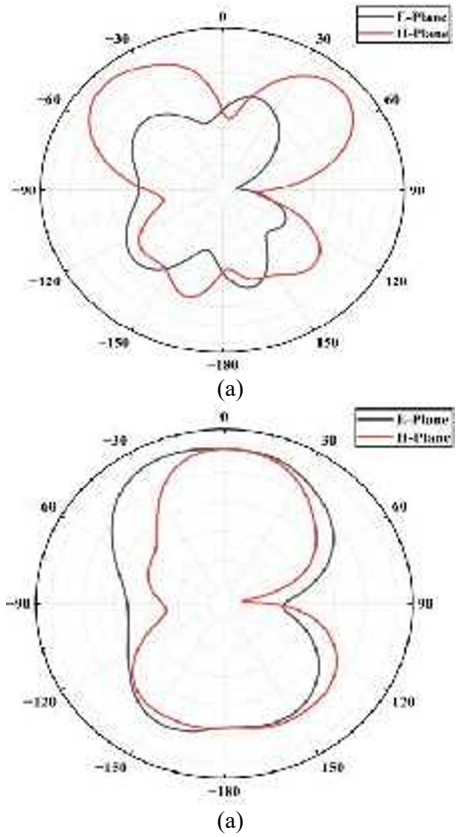

Fig. 7. 2D field patterns for the work at (a) 5.6GHz and (b) 6.2GHz

3.6 Radiation Efficiency of the Designed Filter Integrated Antenna

Radiation efficiency of the designed 2×2 E-shaped filtenna, shown in Fig. 8, provides further evidence of its inherent bandpass filtering behavior. The efficiency rises sharply within the 5.5–6 GHz range, reaching values close to 95–100%. This high efficiency indicates that the antenna effectively converts the delivered power into radiation only within the intended passband. This selective efficiency behaviour reinforces the function of the antenna as a filtenna: only frequencies that excite the dual resonant LC paths exhibit high efficiency, while non-resonant frequencies experience poor radiation due to weak current excitation and mismatched impedance. Thus, the radiation efficiency trend confirms that the proposed design operates as an integrated bandpass filtering antenna for the 5.5–6 GHz band.

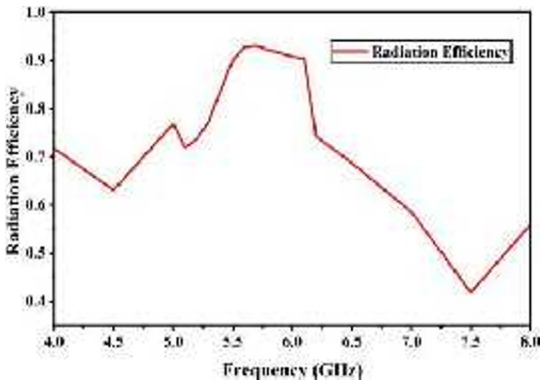

Fig. 8. Radiaiton Efficiency of the designed FIA

4 Conclusion

A 2×2 E-shaped filter-integrated antenna incorporating a Jerusalem-cross ground slot has been designed and validated for Sub-6 GHz communication. The combination of edge-coupled E-slots and the dual-resonant ground structure produces a distinct bandpass response between 5.5–6.0 GHz. The antenna exhibits strong stable broadside radiation, high gain (≈7.2 dB), and radiation efficiency approaching 100% within this passband, while effectively suppressing out-of-band signals. This integrated filtering behavior ensures that only the desired communication band is efficiently radiated, minimizing interference, improving signal purity, and eliminating the need for external filters. Such characteristics make the proposed filtenna highly suitable for Sub-6 GHz applications—particularly WLAN, high-throughput short- range links, and emerging localized 5G allocations around 5.5–6 GHz where selective radiation and rejection of adjacent-band interference are essential.

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