Filtenna for Next-Generation SATCOM

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Abstract. A compact filter-integrated antenna(Filtenna) is presented for millimeter-wave satellite communication systems. The design employs a wine glass slotted bow tie structured antenna with a CSRR graved on the ground plane and a SRR on the top surface near the feed line to introduce filter functionality within the antenna structure. The measured S_{11} response indicates two clear notch bands around 45 GHz and 70 GHz with rejection levels better than −20 dB, effectively suppressing potential interference from neighboring systems. Across the operational band from 40–80 GHz, the antenna maintains good impedance matching and a high gain of 8.5dBi, at the resonant frequencies. A simpler architecture and lower insertion loss result from insertion of the filtering process into the antenna, which removes the need for additional filters. Due to its compatibility, wide bandwidth, and selective rejection characteristics, the proposed Filtenna is a strong candidate for emerging next generation satellite communication.

1 Introduction

Satellite communication (SATCOM) has experienced significant advancements over the past few decades. In pursuit of enhancing the performance of wireless radio-frequency (RF) systems, there has been a focus on creating multifunctional modules. In order to choose, combine, separate, and reject the signals in accordance with the requirements, the filter is crucial. Therefore, For wireless applications, creating compact, efficient, portable, and low-loss filters is a major challenge for researchers. The front end of RF systems features antennas for transmitting and receiving that are combined with bandpass filters (BPFs). These combined components are generally referred to as filtering antennas or filtennas. In recent times, filtering antennas have become a promising option to decrease the complexity, dimensions, and expense of front-end systems. These versatile antennas are designed to facilitate both filtering and radiation functions within a single entity. Additionally, the integrated filters exhibit bandpass, bandstop, and bandnotch properties in the frequency spectrum Innovative filtenna configurations eliminate the necessity to separately design and combine antennas and band pass filters (BPFs), resulting in a more compact structure and ultimately enhancing the performance of the complete front-end network. Among the methods used in the filters used to achieve filtennas are resonators, substrate integrated waveguide (SIW) cavities, and defective ground structure(DGS) [1-2]. Filtering antennas for wireless satellite communication systems have been developed using a variety of techniques, which can be broadly classified into two categories. The first is the filter synthesis approach, in which the antenna radiator serves as the filter's last resonant step after a bandpass filter (BPF) has been built. The second is the antenna fusion strategy, which concentrates on building the antenna itself to produce radiation nulls close to the intended operating band by adding parasitic components to the antenna or feed network. The first method typically produces a larger overall structure, but the design procedure is comparatively simple and flexible to many frequency ranges. The second approach, on the other hand, provides a more compact design because it does not require additional filter circuitry; nevertheless, if the intended frequency band or performance requirements need to be changed, it is difficult to reconfigure or adjust the parasitic components [3].

Research study [4] 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 eliminate all spurious modes that could reduce system efficiency. In paper [5] 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. In research paper[6], the even-odd-mode theory is used to build the filtering network for distribution of a patch antenna for high isolation among two channels with either the same or adjoining operating bands. The structure is more resistant to differential port phase error than conventional designs. Study [7] 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-

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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. 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 [8], where the antenna and feeding network jointly function as a filter without requiring additional circuitry. In [9], 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 [10]; 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 [11], 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 letter [12] 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.

This study presents the design of a double-band bowtie antenna with a frequency bandwidth of (40-80) GHz, covering the Q and V bands in millimeter-wave. In the proposed design, the bowtie antenna is modified by integrating a Split Ring Resonator (SRR) within the feedline structure and a Complementary SRR (CSRR) is craved out in ground plane to realize the filtering characteristics. The antenna is modeled and analyzed using ANSYS HFSS, EM simulation tool, to evaluate its S-parameters, radiation characteristics, and gain performance. The proposed filtenna, designed to operate within the Extremely High Frequency (EHF) range, demonstrates efficient radiation and desirable gain characteristics. Owing to these features, it can serve as a promising candidate for next-generation satellite communication applications, where high data rate transmission and compact antenna integration are essential.

This paper is organized as follows: Section II explains the Filtenna design process; Section III discusses the suggested work outcomes; & Section IV concludes this article.

2 Design Methodology of the Proposed Filtenna

This section discusses about the filtering mechanism of the bow tie antenna by incorporating SRR and CSRR for filtering purpose.

2.1 Bowtie design for the proposed work

A bowtie antenna is designed for the frequency range from 40GHz to 80GHz has a triangle engraved in it that resembles a wine glass. The bowtie structure shown in Figure 1 serves as the primary radiating element, designed with an arm length of 1.5 mm and a flare angle of 60°. The given design formulae in [13] are used to calculate the unslotted bowtie antenna's dimensions for an operating frequency of 45 GHz. The etched slot introduces additional capacitive and inductive effects, creating a new resonant that enhances the impedance.

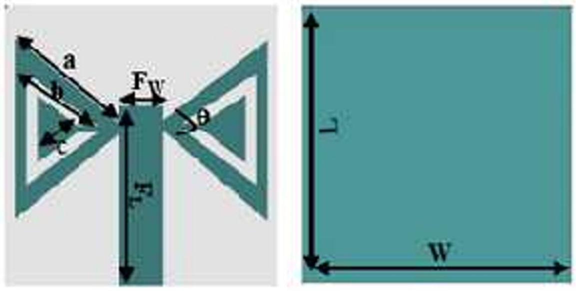

Fig. 1. Bowtie Antenna without Filtering Effect

Change in geometry also improves impedance matching between the radiating element and the feed line, reducing reflection losses (S_{11}). The dimensions of the bow tie antenna are taken as and it is employed on the Rogers 5880 which has a dielectric constant of 2.2 and tangent loss of 0.0009[14-15].

2.2 Filter Integrated Bowtie Using SRR and CSRR

In the proposed antenna configuration, Split Ring Resonators (SRRs) of circular structure are positioned on the upper section of the structure, while Complementary Split Ring Resonators (CSRRs) which also has the same circular structure and size are etched on the lower section of the radiating surface shown in Fig.2. The placement of the SRR and CSRR structure plays a major role in obtaining the filtering mechanism is in Fig.3. Along the feedline, near the intersection of the bowtie arms, is an embedded Split Ring Resonator (SRR). When an SRR is connected in series with the feed, it functions similarly to a resonant series element, allowing the desired band to pass but introducing high impedance outside of its passband. Sharper band edges and tiny reflection peaks next to the main dip are produced as a result. The CSRR in the ground is the complementary resonator, which has a shunt resonance.

Fig. 2. Proposed Geometry of Filter Integrated Bowtie Antenna

Fig. 3. SRR and CSRR in Proposed Geometry

It confirms that the SRR (in feed) and CSRR (in ground) work together as a compact bandpass filter to shape the antenna's spectral response by improving selectivity and noise rejection compared to a bow-tie antenna in Fig.1. The dimensions of the presented Bowtie Filter integrated antenna can be seen in Table 1.

Table 1. Parametric Analysis Table

Description	Parameters	Dimensions(mm)
Bowtie antenna Length	L	5
Bowtie antenna Width	W	5
Feed_Width	F_W	0.8
Feed_Length	F_L	3.2
Flare Angle	ɵ	60°
Arm_1	a	1.5
Arm_2	b	0.7
Arm_3	c	0.55
SRR Gap	G_{SRR}	0.15
Outer Ring Radius	R_{out}	0.7
Inner Ring Radius	R_{in}	0.5
Periodic Spacing	P	0.2

3 Results and Discussion of FIltenna

This section evaluates the proposed work's gain, S_{11}, current distribution and graphical E, H field patterns, among other antenna properties, using the Rogers 5880 Substrate. The proposed antenna's performance was analysed using a constant frequency in HFSS software.

3.1 Reflection Coeffecient

The simulated Bow-Tie antenna without SRR and CSRR's s-parameter is in Fig.4, has a reflection coefficient of |S11|< -10dB, indicating good antenna performance. It resonates for the frequency of 45GHz with the bandwidth of 2GHz and 70GHz with the bandwidth of 4GHz but by integrating bandpass filter in the antenna, the bandwidth is increased to 10GHz in 70GHz resonating frequency and 1GHz in 45GHz is shown in Fig.5. The appearance of additional dips, minor reflection peaks, and sharper variation in the roll off near (43-44GHz) shows the introduction of filtering behavior in the bowtie antenna. These resonating frequencies can be used for High throughput Satellite systems and next generation satellite communication systems.

3.2 Gain

Fig.6 represents the gain of the designed bowtie antenna and Fig.7 depicts the proposed Filtenna's gain for (40-80GHz) frequency sweep. The gain is 6.3dBi for 45GHz and 6dBi for 70GHz for the bowtie antenna, whereas by integrating SRR-CSRR filter prevents off-band energy from reaching the radiator, concentrating the gain in the targeted passband and giving a sharper gain response than a bowtie as seen in Fig.8. Maximum gain obtained after filter integration for 45GHz is 7.5dBi and for 70GHz, it is 8.5dBi.

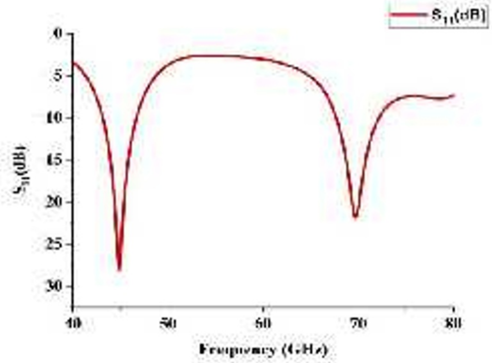

Fig. 4. S Parameter for the designed Bowtie Antenna

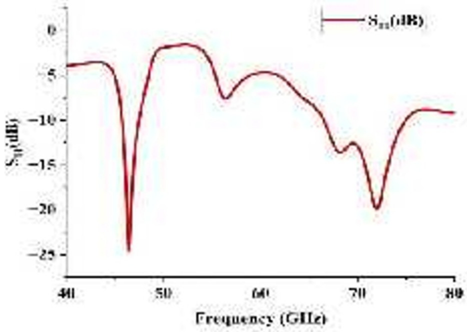

Fig. 5. S Parameter for designed Filter integrated Bowtie Antenna

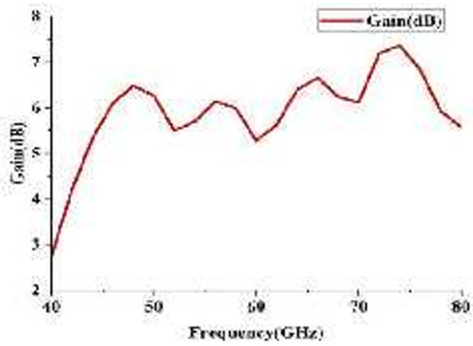

Fig 6. Gain of Bowtie antenna

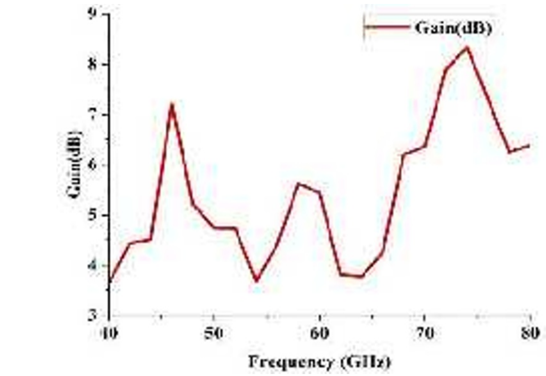

Fig 7. Proposed Filtenna Gain

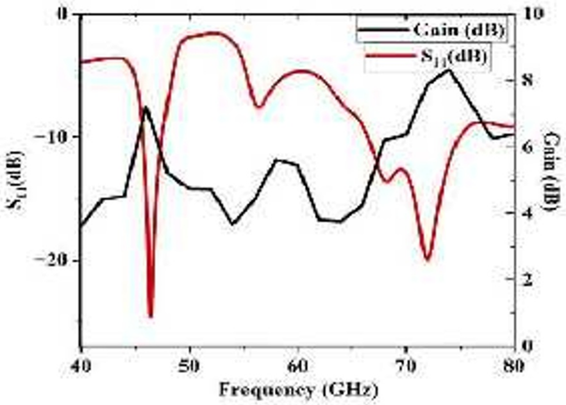

Fig 8. Effect of SRR-CSRR Filter in gain for the proposed Filter

3.3 Axial Ratio (AR)

A low AR implies strong circular polarization (CP), which is required in SATCOM links to reduce polarisation mismatch losses between the transceiver systems in satellite communication. Fig.9 shows the obtained axial ratio for the proposed Filtenna exhibits less than 3 dB for the resonating frequency.

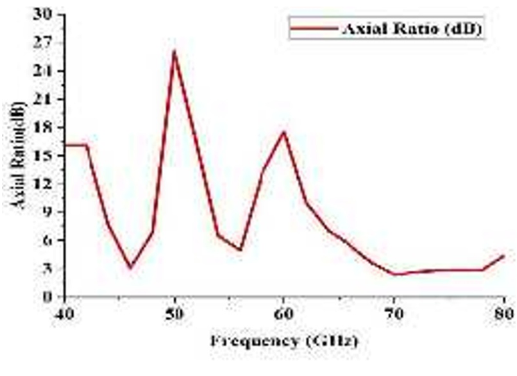

Fig 9. Axial Ratio for the proposed Filtenna

3.4 Current Distribution of Proposed Filtenna

Fig.10. represents the field distribution of the designed filter integrated bowtie antenna. The bow-tie arms have a high concentration of surface currents, especially near the feedline junction and around the triangular portions margins.

The high-intensity regions correspond to places with the high electric field coupling. The circular SRR structures in the antenna's lower half exhibit localized current loops, indicating resonant behavior. The interaction of the bow-tie patch with the SRR/CSRR structures causes perturbations in current flow patterns, which are seen as enhanced current zones around the edges.

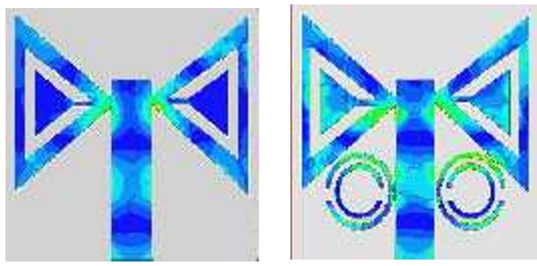

Fig 10. Field Distribution of the designed Filtenna

3.5 2D Radiation Pattern

Radiation pattern for the proposed Filtenna is depicts in Fig. 11 & Fig. 12. Radiation pattern plots shows the co-pol and cross-pol for the proposed work. Bowtie Filtenna is designed in the xy-plane. The electric field is observed in xz-plane, (ϕ=0) while the magnetic field is detected in yz-plane (ϕ=90). High co-polarization and low cross-polarization levels ensure little interference and maximum signal strength.

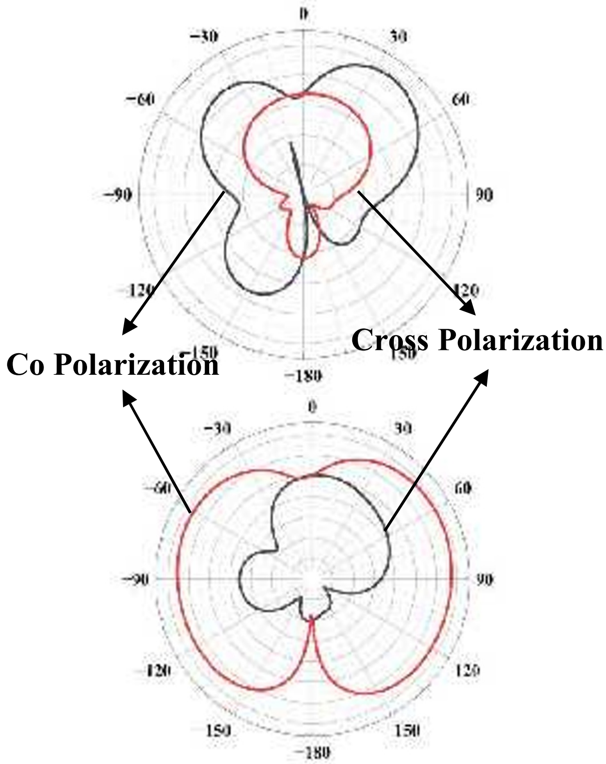

Fig 11. Electric-Field(ϕ=0) and Magnetic-Field(ϕ=90) for 45GHz

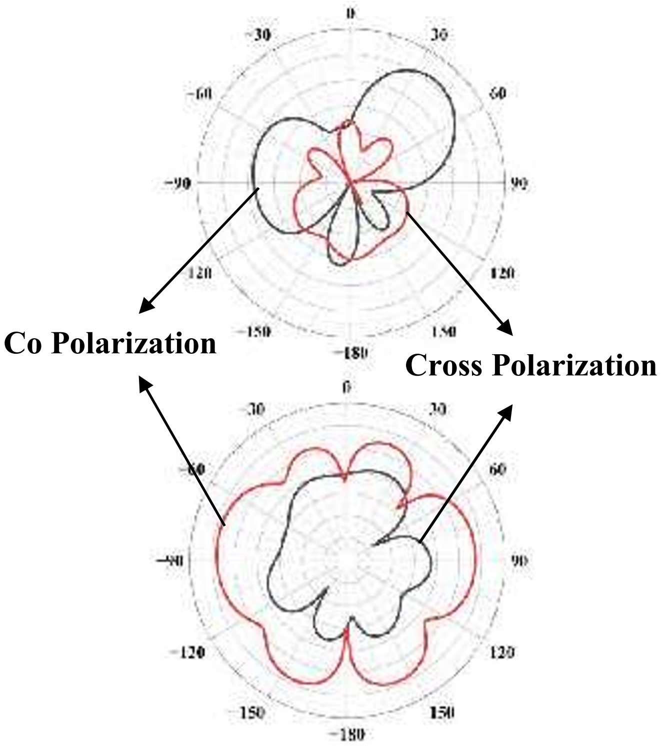

Fig 12. Electric-Field(ϕ=0) and Magnetic-Field(ϕ=90) for 70GHz

4 Conclusion

The bowtie antenna structure which resonates at 45GHz and 70GHz is coupled with SRR-CSRR pair functions as a Filtenna is presented in this work. The proposed Filtenna was simulated and analyzed using HFSS software for Q band and V band in mm-wave. Designed filtenna has a sharp roll off and pointed gain for 45GHz and 70GHz which can eliminates the need for an external bandpass filter, decreasing size, weight, and insertion loss while providing simultaneous filtering and radiation in satellite communication systems. The filter-integrated bowtie antenna with improved frequency selectivity, gain stability, and interference rejection capabilities is analyzed. This Filtenna exhibits low Axial Ratio, good co-polarized radiation, minimum cross polarization. These properties can enhance the link reliability, isolation, and overall system efficiency of next generation Satellite Communication.

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