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# Microstrip Filtenna with T-shaped Stub Feedline for 5G Application

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## Abstract

In this paper, a T-shaped stub-fed microstrip filtenna is proposed. A T-shaped stub-loaded bandpass filter is integrated with a microstrip patch antenna to form the filtenna. The selectivity of the designed filtenna is enhanced compared to the conventional microstrip patch antenna while maintaining the same bandwidth. This makes it a suitable candidate for applications requiring the same bandwidth with improved selectivity. The designs were carried out using CST Microwave Studio and validated through fabrication and measurement in the laboratory. The designed filtenna shows a rejection level improvement of 3 dB and 13 dB at the low and high frequency band edges of 3.4 GHz and 4.3 GHz, respectively. The filtenna operates at 3.6 GHz, making it suitable for 5G applications.

## 1. Introduction

Nowadays, the integration of filters and antennas is gaining increasing research attention [1-3]. This integration of two key components in the RF frontend is often referred to as a filtenna. The filtenna is a multifunctional device as it possesses both radiating and filtering characteristics [4, 5]. It helps reduce the overall size of the RF frontend and tackles interferences occurring between the antenna and filter, as well as losses introduced by the matching circuits [6].

Filtennas have been implemented using various design methods to achieve good radiation and selectivity performance [7-11]. However, filtenna implementation faces several research challenges, including a decrease in in-band peak gain [9, 12], an increase in the feed line length of the conventional patch, slow gain roll-off, difficult synthesis, and an increase in bandwidth [12, 13].

In [9, 14], hairpin resonators are used to implement filtenna designs by replacing the last hairpin resonator with the antenna patch, which acts as the last resonator of the filter. This approach yields enhanced gain performance and increases the operating bandwidth compared to conventional antennas. The limitation of this filtenna is in terms of its size and low rejection levels in the lower frequency band. The filtenna is longer in length compared to the conventional patch antenna. An aperture-coupled hairpin filter is stacked with a microstrip patch antenna to form a filtenna [7]. The filtenna exhibits good performance, such as compact size, improved gain selectivity, and efficiency compared to a weakly coupled antenna and filter on the same plane as in [9]. In [15], a microstrip patch antenna fed by a λ/4 resonator was designed at 4.9 GHz. The feeding suppresses the harmonics and improves the gain performance while the coupling gap controls the bandwidth enhancement level. The filtenna has a low profile and is coupled capacitively by the gap. The filtenna shows good characteristics such as improved bandwidth from 3.1 % to 8.4 %, effective harmonic suppresssion and a low level of cross-polarization.

In [16], a second order bandpass filter with Chebyshev response is synthesized with a U-shaped patch antenna. The λ/2 T-shape resonator acts as the first stage of the filter while the U-shaped patch acts as the second stage resonator. The ripple level is used to determine the mutual coupling coefficient between the T-shaped resonator and U-shaped patch. The filtenna shows good behaviour as the radiation pattern is similar to the conventional inset-fed antenna. The proposed design shows an enhanced bandwidth with good filter rejection levels and a flat passband with a decrease in gain as compared with the conventional patch antenna.

A two pole second order Butterworth filtenna at 2.4 GHz is presented in [17]. The filtenna is designed from a circularly shaped two stage resonator. The second resonator is replaced with a microstrip fan shaped antenna with a circular DGS. The filter synthesis technique is used to properly extract the coupling coefficients to the radiating patch. The filtenna provided good skirt selectivity and flat passband gain with a peak gain of 2.3 dBi. The DGS helps to reduce the size of the filtenna and create further effective capacitance and inductance. The disadvantage of this design is the poor rejection (slow roll-off) in the lower band edge of the gain. A Quasi-Yagi antenna with differential filtering is presented in [18]. The differential filtenna is composed of a driver, director, reflector and double sided parallel strip line filter. The driver acts as the radiator while the reflector is positioned at the centre to serve as ground and facilitate the antenna to radiate forward. The filtenna is designed to operate at 1.8 GHz and peak gain of 5.6 dBi. The gain selectivity is improved as compared with the conventional Yagi antenna. However the roll-off performance of the gain is slow as compared with other designed filtenna with sharp roll-off. In [19, 20], substrates are stacked together to design filtennas. This technique helps address the decrease in peak gain caused by the insertion loss from filter and antenna integration, resulting in high in-band peak gain and good rejection. However, stacking makes the design process complex and the structure high-profile.

T-shaped stub resonators have been used in the design of filtennas [21, 22]. In [21], the T-shaped resonator is used as a dual-mode resonator to design a filtenna with enhanced gain and bandwidth performance. However, the rejection level and gain performance at the lower band edge are poor. In [22], two pairs of T-shaped resonators are integrated through the feedline to a wideband antenna with a Defected Ground Structure (DGS). The filtenna operates at tri-band frequencies with enhanced selectivity, filtering out unwanted frequencies of the wideband.

In this paper, the T-shaped stub resonator is integrated with a microstrip patch antenna to form a filtenna at a frequency of 3.6 GHz. The rejection level is further improved by loading the T-shaped stub compared to [21]. Often in the implementation of filtenna design, the filtenna helps to enhance the bandwidth compared to conventional microstrip patch antennas. However, this design achieves selectivity enhancement while maintaining the same bandwidth. The proposed filtenna functions with a second-order Chebyshev response, exhibiting good radiating and filtering characteristics. Table 1 compares the filtenna review summary.

**Table 1** *Filtenna review summary*

| [REF] | Operating Frequency (GHz) | Peak Gain (dBi) | Low profile | Rejection performance | Method |
|---|---|---|---|---|---|
| [7] | 2.4 | 7 | Yes | Slow roll off | Hairpin filtenna |
| [15] | 4.9 | 7.8 | Yes | Good | T-shaped stub impedance matching |
| [16] | 5 | 4 | Yes | Good | T-shaped stub coupling |
| [17] | 2.4 | 2.3 | Yes | Slow roll off | DGS with fan shaped resonator |
| [18] | 1.8 | 5.6 | No | Slow roll off | Quasi-Yagi |
| [20] | 2.5 | 9.7 | No | Good | Stacked patch |
| [21] | 2 | 7 | Yes | Poor low band rejection | Parallel Coupled Lines |

## 2. Bandpass Filter Design

The basic structure for the bandpass filter used in the design is illustrated in Figure 1. The T-shaped stub consists of a half-wavelength resonator center-tapped by a quarter-wavelength resonator. This center-tapped quarter-wavelength resonator facilitates the creation of a transmission zero. The impedance transformation equation is employed in the design of the bandpass filter, depicting the relationship between the electrical length of the stub, characteristic impedance, and the frequency *(f)* at which the transmission zero occurs, as expressed in Equation (1). In this equation, $Z_0$ represents the characteristic impedance of the stubs on both sides of the feedline, and $\theta_0$ represents the electrical length of the stub at the given transmission zero. Consequently, any alteration in the effective electrical length of the stub results in a corresponding change in the frequency at which the transmission zero occurs.

$$f_0 = \frac{1}{2\pi Z_0 \tan \Theta_0} \tag{1}$$

The bandpass filter utilized in the design features two T-shaped stubs coupled on both sides of the feedline, as depicted in Figure 2. This structure comprises a pair of T-shaped stubs coupled indirectly on both sides of the feedline. The T-Shaped stub is used in this design due to its compact size, low insertion loss and ability to achieve good sharp skirt selectivity. Each T-shaped stub incorporates a vertical resonator positioned at varying distances from the half-wavelength resonator. The vertical resonator situated across the open-ended stub of the T-shaped resonator functions to either limit or extend the effective length of the open-ended stub. Consequently, the placement of the vertical resonator affects the position at which the transmission zero occurs. When the vertical resonator is placed closer to the T-shaped stub, the effective length becomes shorter and shifts to the higher frequency. However when the vertical resonator is placed further away from the T-shaped stub, the effective length becomes longer and shifts to the lower frequency. The stub on the left-hand side has a shorter length (1.3 mm from the half-wavelength resonator), resulting in the transmission zero position at a higher frequency of 4.1 GHz. Conversely, the stub on the right-hand side has a longer length (5 mm from the half-wavelength resonator), thus responsible for the transmission zero position at a lower frequency of 3.4 GHz.

Figure 3a and Figure 3b shows the electric and magnetic field distribution respectively for the loaded T-shaped resonator. The intensity of the electric field is maximal at the open ends of the T-shaped stub. On the other hand, the Magnetic field intensity is maximal at the centre regions of the filter. The coupling that exists in the loaded T-shaped stubs is electromagnetic coupling. This is because the electromagnetic field in each component of the filter causes an electrical charge each other. This therefore transfers electromagnetic field from one filter component to another.

The design parameters are shown in Table 2. The bandpass filter is designed to operate at 3.6 GHz, with the simulated results shown in Figure 4. The bandpass filter exhibits good rejection at both edges of the passband.

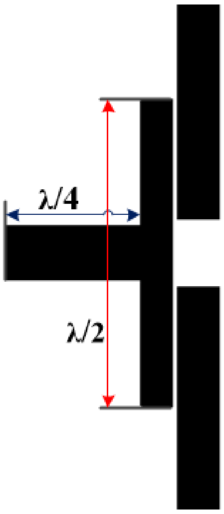
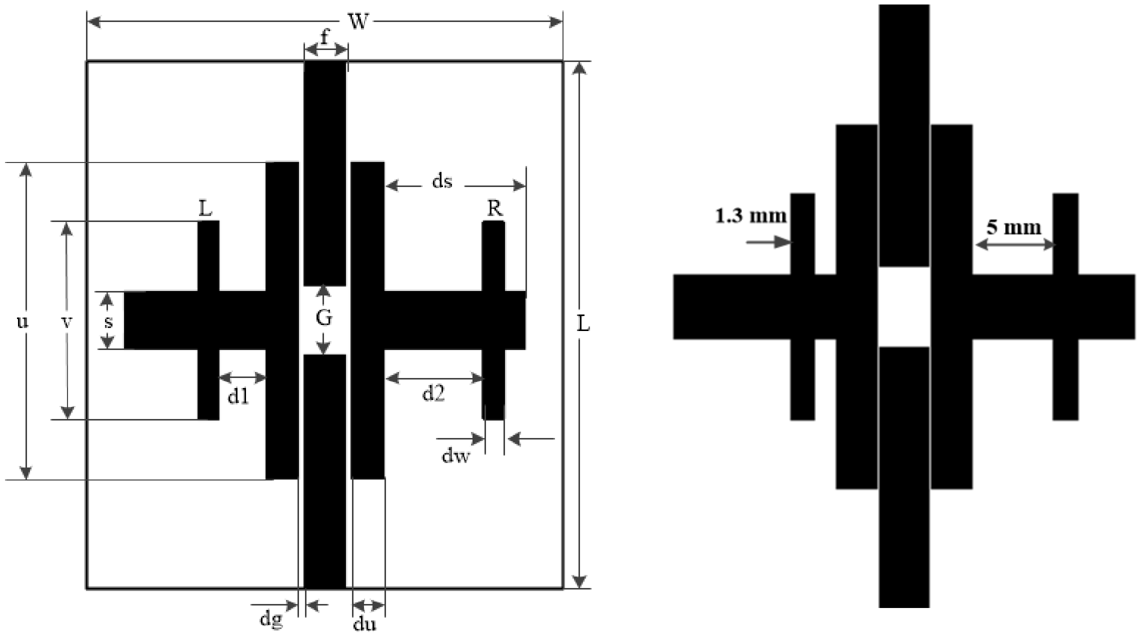
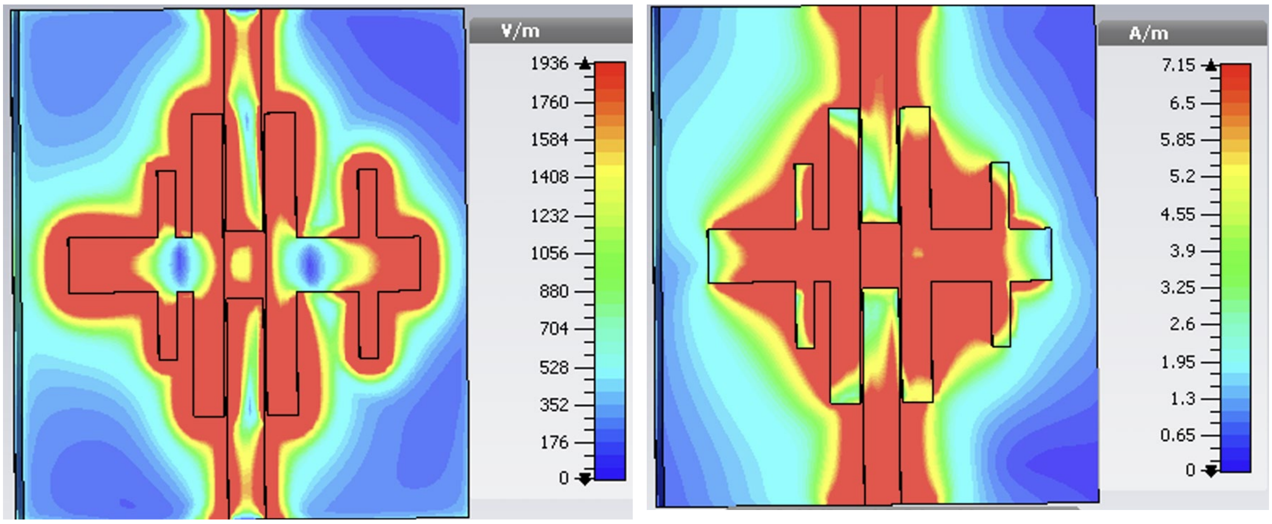


**Fig. 1** *Basic structure for bandpass filter*



**(a)** **(b)**

**Fig. 2** *Proposed bandpass filter (a) Dimension parameters; (b) Placement of vertical resonator*



**(a)** **(b)**

**Fig. 3** *The field distribution of the T-shaped resonator (a) E field; (b) H field*

**Table 2** *Filter dimension*

| Parameter | Value (mm) |
|---|---|
| W | 34 |
| L | 38 |
| u | 22.5 |
| v | 14 |
| s | 4 |
| G | 5 |
| f | 3 |
| d1 | 4.8 |
| d2 | 7 |
| dg | 0.2 |
| du | 1.5 |
| dw | 1.5 |
| ds | 10 |

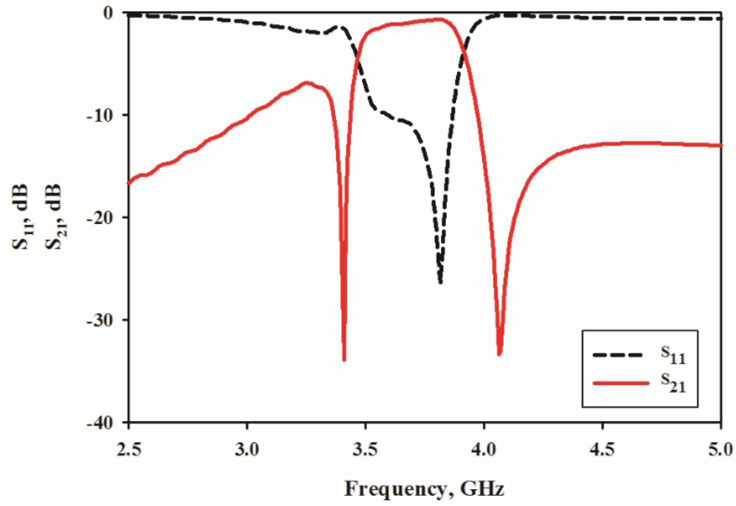
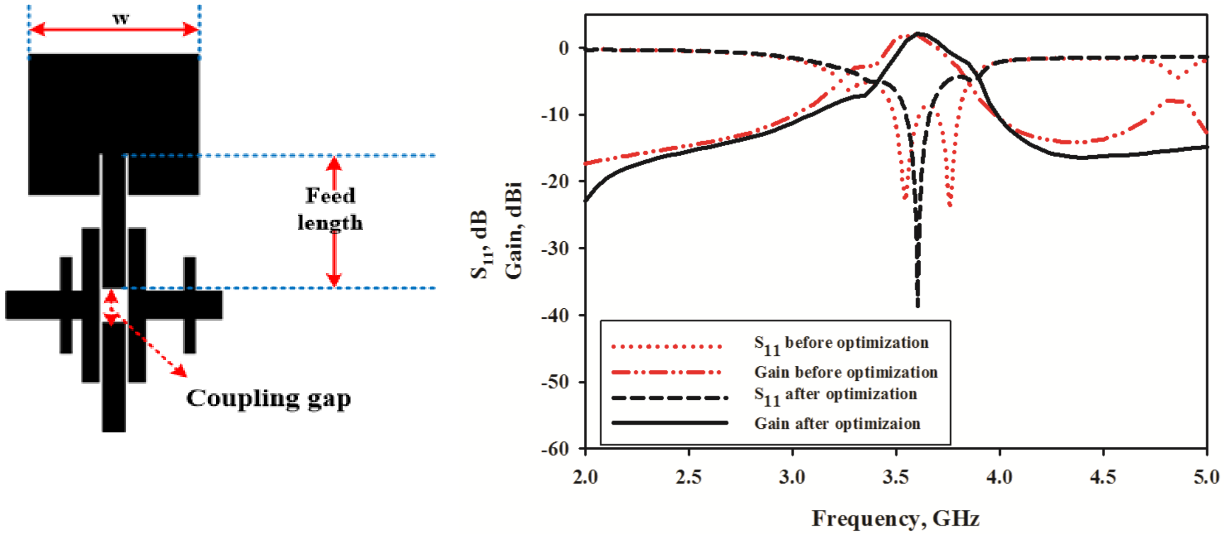


**Fig. 4** *Bandpass filter simulated response*

## 3. Filtenna Design

A conventional patch microstrip antenna is designed to operate at a frequency of 3.6 GHz and is integrated with the designed bandpass filter at the same frequency. The output feedline portion of the bandpass filter is replaced with the patch antenna to enhance the selectivity of the patch antenna. The coupling gap (G) between the input and output feedlines is retained, while the output feedline is substituted with the patch antenna. The conventional patch antenna's feedline length is designed to be a half-wavelength at 26 mm, and the patch width is also designed to be 26 mm. However, there exists a mismatch between the antenna and filter impedance, resulting in poor $S_{11}$ and gain performance of the integrated antenna and filter. Consequently, there is a need to optimize the filtenna design.

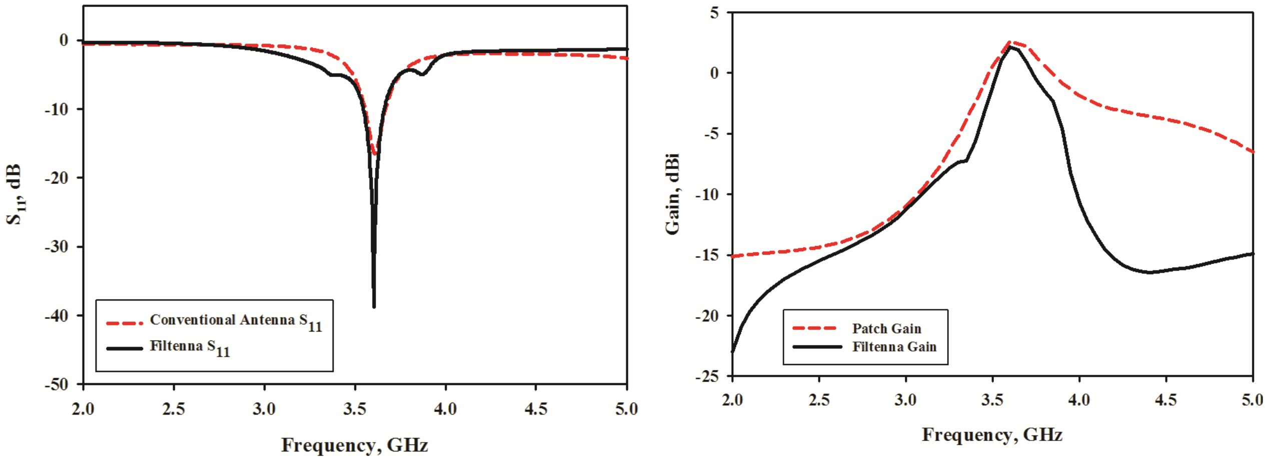
The optimization is carried out by adjusting the feedline and patch widths. The feedline length is optimized by reducing it from 26 mm to 19.5 mm, slightly shorter than half-wavelength. Additionally, the patch width is modified from 26 mm to 22 mm to achieve the best filtenna performance. The comparison results of the filtenna's $S_{11}$ and gain performance before and after optimization are illustrated in Figure 5.



**(a)** **(b)**

**Fig. 5** *Bandpass filter (a) Proposed stuructre; (b) Simulated results (before and after optimization)*

Figure 6 depicts the performance comparison between the designed T-shaped stub-fed microstrip filtenna and a conventional antenna operating at the same frequency. After optimization, it is observed that the designed filtenna exhibits improved out-of-band rejection compared to the conventional patch antenna, as illustrated in Figure 6b. In comparison with the conventional patch antenna, the designed filtenna demonstrates a rejection level improvement of 3 dB and 13 dB at the low and high frequency band edges of 3.4 GHz and 4.3 GHz, respectively. However, the peak gain of the filtenna is 9.7% lower than that of the conventional patch antenna (decreasing from 2.47 dBi to 2.23 dBi). It is noteworthy that the filtenna maintains the same bandwidth performance of the $S_{11}$, as depicted in Figure 6a.



**(a)** **(b)**

**Fig. 6** *Comparison between conventional patch and filtenna (a) $S_{11}$; (b) Gain*

## 4. Results

The simulation of the T-shaped stub-fed filtenna was conducted using CST Microwave Studio. The design was implemented on an FR4 substrate with a height of 1.21 mm and a dielectric constant of 4.0. The simulated results were validated through the fabrication of the prototype, as illustrated in Figure 7. Both the simulated and measured results of the $S_{11}$ and gain are presented in Figure 8. Good agreement is observed in the $S_{11}$ result. However, there are some disparities in the gain performance between the two sets of results. Specifically, the simulated peak gain is 2.5 dBi, whereas the measured peak gain is 4.4 dBi. The gain rejection level for the simulated result is -5 dBi, while that for the measured result is -11 dBi for the lower band edge. For the higher band edge, the gain rejection level is -5 dBi in the simulated result and -9 dBi in the measured result. The disparity between the simulated and measured gain results arises from non-ideal conditions in the measurement setup, such as antenna alignment during gain measurement.

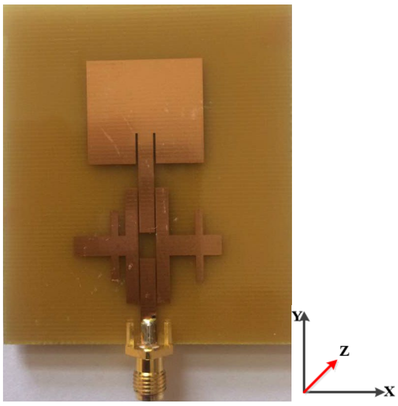
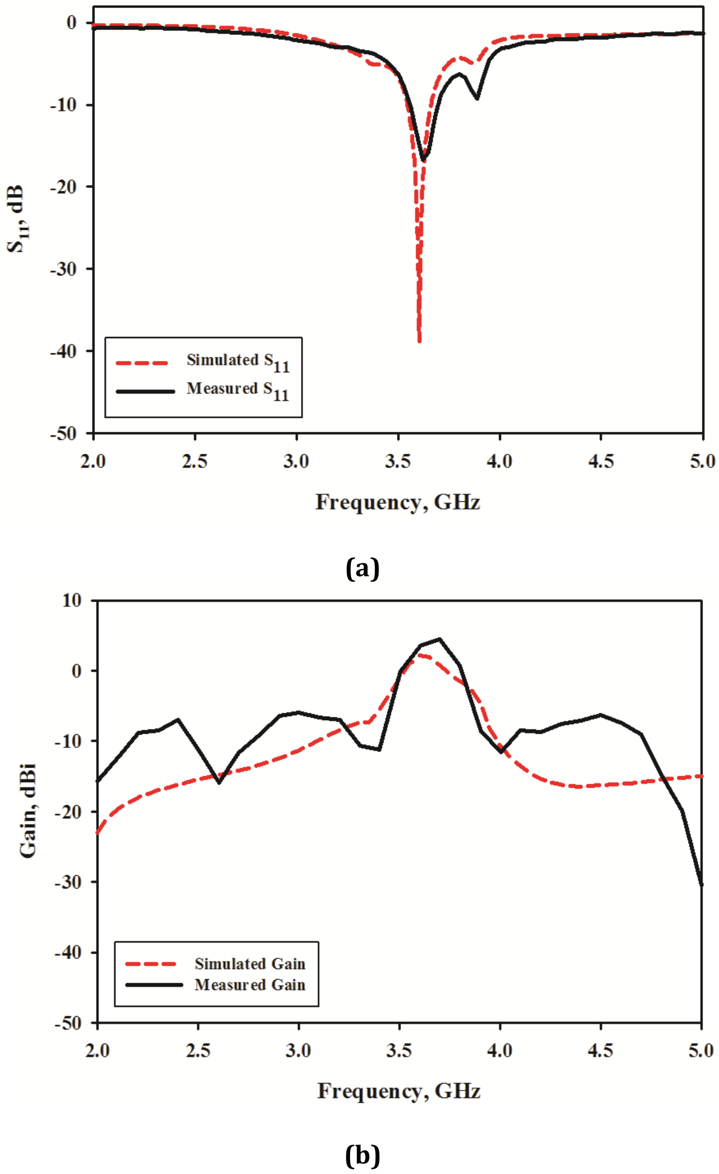


**Fig. 7** *Fabricated prototype*

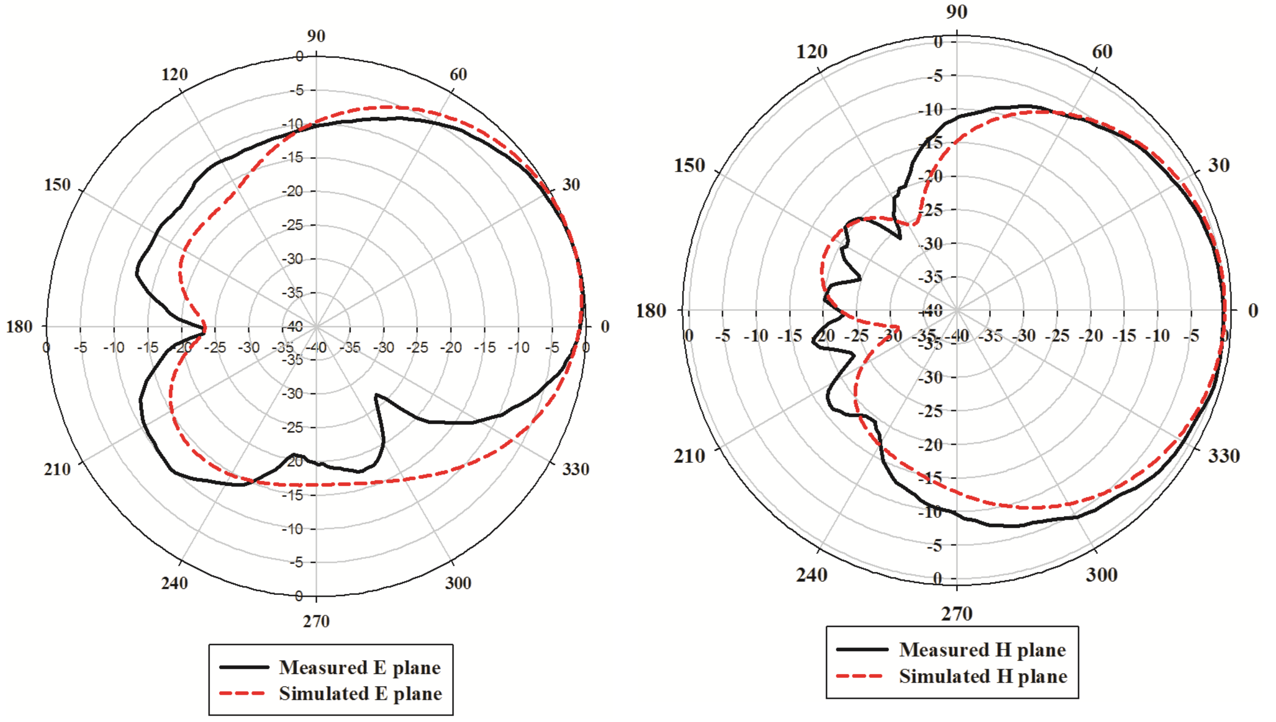


**(a)**

**(b)**

**Fig. 8** *Measured and simulated responses (a) $S_{11}$; (b) Gain*

The radiation pattern was captured in the broadside direction, with the beam tilted towards theta = 15º. The radiation pattern illustrates both the YZ plane and the XZ plane for co-polarization as shown in Figure 9. The main beam shows a tilt, which is attributed to the presence of weak coupling in the feedline. This tilt in the main beam is consistent with findings from previous works, such as [9]. Furthermore, a comparison between the simulated and measured radiation patterns has been conducted, and good agreement has been observed.



**(a)** **(b)**

**Fig. 9** *Radiation patterns (a) YZ-plane; (b) XZ-plane*

## 5. Conclusions

This paper presents a filtenna design utilizing a T-shaped stub feed. The filtenna design involves integrating a patch antenna by replacing the output feedline of a T-shaped bandpass filter. Compared to conventional patch antennas, the filtenna demonstrates enhanced rejection levels. Importantly, it maintains the same bandwidth while improving selectivity, distinguishing it from existing filtenna designs that prioritize bandwidth increase at the expense of selectivity. The results are simulated using CST Microwave Studio and validated through prototype fabrication and laboratory measurements. The designed filter shows promise for 5G applications.

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## Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

## Author Contribution

*The authors are responsible for the study conception, research design, data collection, data analysis, result interpretation and manuscript drafting.*

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