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Design and Analysis of Compact Microstrip Filtenna for Internet of Things Applications

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Abstract- This work presents the design of a compact microstrip filtenna for miniaturized Internet of Things (IoT) devices operating in the Long-Term Evolution (LTE) band. The proposed filtenna integrates a 3rd-order hairpin band-pass filter with a coplanar patch antenna on an FR4 substrate (εr = 4.4, thickness = 0.8 mm), enabling both radiation and interference suppression in a single structure. The filter provides a passband from 2.53 GHz to 2.68 GHz, matching the LTE band with low insertion loss and high transmission. The antenna section achieves good impedance matching and stable radiation performance. Simulation results show a resonant frequency around 2.6 GHz with a return loss better than −27 dB and an omnidirectional radiation pattern suitable for IoT applications. The proposed filtenna offers compact size, reduced circuit complexity, and improved out-of-band interference rejection for reliable LTE-based IoT communication.

Keywords: Internet of Things(IoT), Circular microstrip patch antenna, hairpin band-pass filter, microstrip filtenna.

I. INTRODUCTION

The rapid growth of the Internet of Things (IoT) has increased the demand for compact and efficient wireless communication devices. IoT systems require reliable connectivity, low power consumption, and small device size to support large-scale deployments in smart cities, healthcare, and industrial applications [2]. Many IoT devices use Long-Term Evolution (LTE) communication technology because of its wide coverage, high data rate, and stable connectivity [3].However, modern wireless environments contain many communication signals operating at different frequency bands. This may cause interference and degrade the performance of wireless systems. Therefore, antennas used in IoT devices must provide good selectivity and stable radiation characteristics while maintaining a compact structure [4].

One effective solution to this problem is the use of a filtenna, which integrates a band-pass filter and an antenna into a single structure. The filtenna allows only the desired frequency band to pass while suppressing unwanted signals, reducing interference and improving system performance. In addition, integrating the filter and antenna reduces the overall circuit size and complexity compared to conventional designs where they are implemented separately [5].Microstrip antennas are widely used in wireless communication systems due to their low profile, light weight, low fabrication cost, and ease of integration with microwave circuits [6]. Similarly, hairpin band-pass filters are commonly used in RF and microwave systems because of their compact structure and good filtering characteristics [7]. Recent research has focused on integrating filtering functions directly into the antenna structure to improve system efficiency and reduce the need for additional RF components.

This concept, commonly known as a filtenna, combines the characteristics of a band- pass filter and an antenna into a single device, allowing the antenna to perform both radiation and filtering functions simultaneously [8]. By eliminating separate filtering circuits, filtenna structures reduce system complexity, minimize insertion losses, and improve overall compactness, which is highly desirable for modern wireless and IoT devices. In this work, a compact microstrip filtenna is designed by integrating a third-order hairpin band-pass filter with a coplanar patch antenna on an FR4 substrate. The proposed design operates in the LTE frequency range around 2.6 GHz, which is suitable for IoT communication applications. The objective of this work is to achieve good impedance matching, low return loss, and stable radiation performance while maintaining a compact structure.

A flat gain response within the passband of a filtenna with a fan-shaped radiator and defected ground structure (DGS) is achieved in [11] using a Butterworth band-pass filter. In [12], a high-gain filtenna is reported using a U-slot loaded driven patch and a stacked shorted patch. A compact filtering antenna using a folded open-loop resonator band- pass filter and a varactor-diode-loaded patch is presented in [13]. A low-profile polarization diversity filtenna is reported in [14], where the antenna is fed by a custom- designed coupling probe. A duplex filtenna using substrate integrated waveguide (SIW) technology and two vias is designed in [15] to enhance the selectivity of the passband, achieving an impedance bandwidth of 4.2% at the 9 GHz band. In [16], a dual circularly polarized cavity-backed filtenna using SIW technology is presented, achieving an operating bandwidth of 12% at the 10 GHz band.

A vertically integrated full-duplex filtering antenna with an SIW cavity is reported in [17], which demonstrates a measured realized gain of 4.36 dB and an impedance bandwidth of 3.2% at the 4 GHz band. The filtenna design in [18] uses a circular radiator with coplanar feed, shorting stubs, and a defected ground structure (DGS) to achieve a fractional impedance bandwidth of 20.34% with a peak realized gain of 1.88 dB. In [19], a compact dual-band filtenna is designed using a shorted slot-loaded patch combined with coupled lines and DGS to achieve improved impedance matching and high gain. Several studies have also focused on antenna or filtering antenna designs for Internet of Things (IoT) and LTE applications [20]–[23]. A frequency-reconfigurable filtering antenna using a hairpin filter and a PIN diode switch is presented in [20], operating at 2.47 GHz, 3.42 GHz, 7.18 GHz, 8.4 GHz, and 12.14 GHz for IoT services. In [21], a duplexer-based reconfigurable filtering antenna is designed for 29/20 GHz satellite IoT communication using a microstrip patch antenna, PIN diode switch, and hairpin filter. In [22], an electromagnetic bandgap (EBG) structure is used to design a textile antenna operating at 26 GHz, achieving reduced specific absorption rate (SAR) and a high gain of 8.65 db.

A frequency-reconfigurable filtering antenna for multiple wireless applications, including 4G LTE, is presented in [23], using a slot-loaded quarter-wave monopole and filtering stubs. From the existing literature, it is observed that many reported filtering antennas involve complex structures, and several designs are not compact or coplanar. In many cases, the return loss at out-of-band frequencies is not sufficiently minimized to suppress unwanted interference. Moreover, only a limited number of studies focus on filtenna design for IoT applications operating in the 2.61 GHz LTE band.

In this paper, a compact microstrip filtering antenna integrating a hairpin band-pass filter with a circular microstrip patch antenna is proposed. The proposed filtenna is designed for IoT applications operating over a 2.61 GHz LTE gateway. The antenna structure is simple, compact, and coplanar, making it suitable for integration into small IoT devices and home appliances.

II. DESIGN OF CIRCULAR MICROSTRIP PATCH ANTENNA

A circular microstrip patch antenna is a type of microstrip antenna in which the radiating element is circular in shape. Microstrip patch antennas are widely used in wireless communication systems because of their advantages such as low profile, light weight, compact size, ease of fabrication, and compatibility with printed circuit technology. These antennas are commonly used in applications such as IoT devices, LTE communication, wireless networks, and satellite communication systems. In this work, a circular microstrip patch antenna is designed as the radiating element of the proposed filtenna. The antenna is designed to operate at a resonant frequency of 2.61GHz, which is commonly used in LTE communication systems. The antenna structure consists of a circular radiating patch, dielectric substrate, ground plane, and feed line.

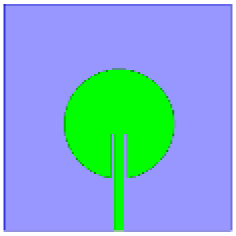

Fig 2.1: (a) Top View

Fig 2.1:(b) Bottom View

The substrate material used for the antenna is FR4 (Flame Retardant 4), which is widely used in printed circuit board (PCB) fabrication due to its low cost, good mechanical strength, and acceptable dielectric properties.The dielectric constant of FR4 substrate is typically around εr = 4.4, and it supports efficient radiation for microwave frequency applications. The overall size of the substrate used in the antenna design is 70 mm × 70 mm, with a substrate thickness of 0.8 mm. The circular radiating patch is placed on the top surface of the substrate, while the ground plane is located on the bottom surface.as shown in fig 2.1 (a)&(b). The radius of the circular patch is chosen as 17 mm to achieve resonance near the desired operating frequency of 2.61 GHz. The antenna is excited using an inset microstrip feed line, which helps in achieving proper impedance matching between the feed line and the radiating patch. The inset feed length is designed as 29.9 mm, which allows the feed point to be located at a position where the input impedance of the antenna is close to 50 Ω, ensuring efficient power transfer and reduced reflection losses.

The performance of the proposed circular microstrip patch antenna is evaluated using the S11 (return loss) parameter. The simulation result shows that the antenna resonates at 2.43 GHz with a return loss of –35.68 dB, indicating good impedance matching and efficient radiation performance.

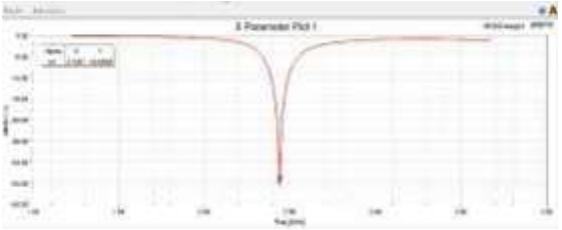

Fig 2.2: S11 Plot of Antenna

The gain of the circular microstrip patch antenna represents the ability of the antenna to radiate power in a specific direction. From the simulation results, the antenna achieves a gain of 4.51 dB at 2.437 GHz, indicating good radiation performance for wireless communication applications.

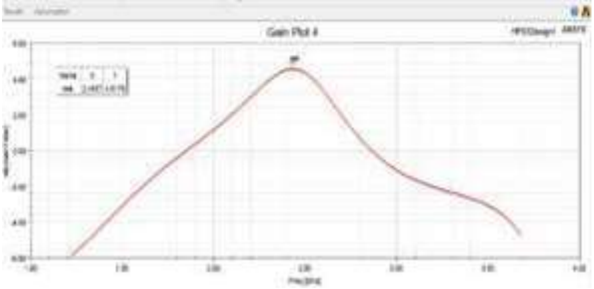

Fig 2.3: Gain Plot of Antenna

The radiation pattern of the proposed circular microstrip patch antenna shows an omnidirectional pattern, which means the antenna radiates electromagnetic waves uniformly in all directions in the horizontal plane. This radiation characteristic makes the antenna suitable for wireless communication applications where signal coverage is required in multiple directions.

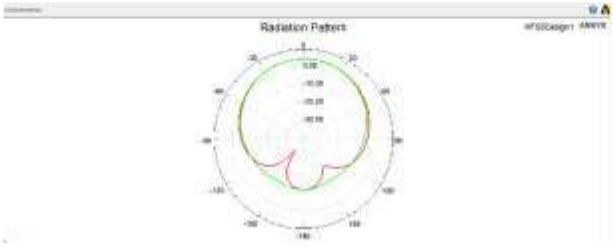

Fig 2.4: Radiation Pattern of Antenna

III. DESIGN 3rd ORDER HAIRPIN BANDPASS FILTER

A hairpin band-pass filter is a compact microstrip filter widely used in RF and microwave communication systems. Hairpin filters are derived from parallel coupled microstrip line filters, where the resonators are folded into a "U" shape to reduce the overall circuit size as shown in figure 3.1 . In this work, a 3rd order hairpin band-pass filter is designed to operate at a center frequency of 2.61 GHz, which is close to the operating frequency of the circular microstrip patch antenna used in the proposed filtenna system. The filter is implemented on an FR4 substrate, which is widely used in microwave circuits due to its low cost and ease of fabrication. The overall size of the filter substrate is 22 mm × 20 mm, with a substrate thickness of 0.8 mm. The hairpin filter consists of three resonator poles, which form the resonant structure of the filter.

These resonators are arranged in a folded configuration to achieve compact size and proper coupling between adjacent resonators. The lengths of the resonator poles are designed to achieve the required resonant behavior at 2.61 GHz. The first and third resonator poles have a length of 15.28 mm, while the second resonator pole has a slightly larger length of 15.35 mm. The slight variation in resonator length helps in controlling the coupling between resonators and improving the overall filter response.

The filter is excited using two inset feed lines, which act as the input and output ports of the filter. The inset feed length is designed as 4 mm, which helps achieve proper impedance matching between the feed line and the resonator structure. These feed lines allow RF signals to enter and exit the filter. The designed filter has two ports, namely Port 1 and Port 2, which are used to analyze the filter performance using S- parameters. The parameter S11 represents the input reflection coefficient, indicating how much power is reflected back at the input port. The parameter S21 represents the transmission coefficient, indicating how much power is transmitted from Port 1 to Port 2 through the filter. A good band-pass filter should exhibit low S11 (good impedance matching) and high S21 within the passband, while suppressing signals outside the desired frequency range.

By assigning these two ports, the S-parameters (S11 and S21) of the filter can be analyzed in HFSS. These parameters help evaluate the performance of the filter in terms of return loss, transmission coefficient, and passband characteristics. The simulation results obtained from HFSS help verify whether the designed 3rd order hairpin band- pass filter meets the required performance at the operating frequency of 2.61 GHz.

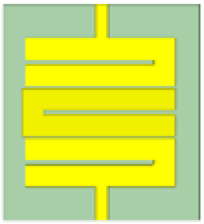

Fig 3.1: 3rd Order Hairpin Bandpass Filter

The S11 parameter represents the input return loss, which indicates how much power is reflected back from the input port of the filter. A lower S11 value means better impedance matching and minimal signal reflection. From the simulation results, the proposed filter shows an S11 value of -45.24 dB at 2.60 GHz, indicating excellent impedance matching and very low reflection at the desired operating frequency.

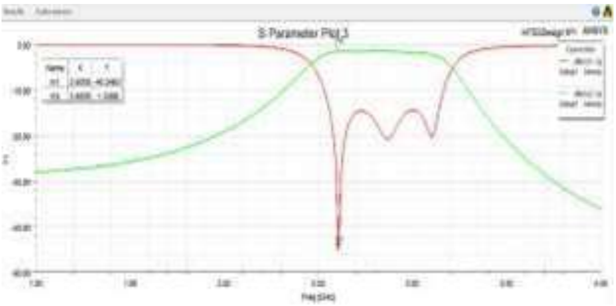

Fig 3.2: S11 & S21 Plot of Filter

The S21 parameter represents the transmission coefficient, which indicates the amount of signal transmitted from the input port to the output port of the filter. From the simulation results, the filter achieves an S21 value of –1.53 dB at 2.60 GHz, which shows that most of the input signal is successfully transmitted through the filter within the passband, confirming good filtering performance.

Initially, the circular microstrip patch antenna was designed with a substrate dimension of 70 mm × 70 mm and a circular patch radius of 17 mm to operate near the 2.61GHz frequency band. Similarly, the 3rd order hairpin band-pass filter was designed separately with a substrate size of 22 mm × 20 mm operating at 2.61 GHz. When these two components are implemented individually, they occupy a larger area in the RF front-end, which increases the overall

device size and reduces compactness. To overcome this limitation, the antenna and filter are integrated into a single compact structure known as a filtenna.
In the proposed design, the filtenna is optimized with a reduced substrate dimension of 40 mm × 40 mm and a circular patch radius of 7 mm, while maintaining an operating frequency of 2.61 GHz. This integration significantly reduces the overall size and improves the compactness of the wireless communication system while maintaining the required filtering and radiation characteristics.

IV. DESIGN OF PROPOSED FILTENNA

The filtenna is designed by integrating the hairpin band-pass filter and the circular microstrip patch antenna into a single compact structure. The main objective of this design is to reduce the overall size of the RF front-end while maintaining both filtering and radiation characteristics. By combining the antenna and filter into a single device, the number of RF components can be minimized, which leads to reduced insertion loss, improved impedance matching, and better system performance.

In the proposed design, the filtenna is implemented on an FR4 substrate with an overall dimension of 40 mm × 40 mm and a substrate thickness of 0.8 mm. The filtenna is designed to operate at a center frequency of 2.61 GHz, which is suitable for wireless communication applications such as LTE and IoT systems. The radiating element of the filtenna is a circular microstrip patch antenna placed on the top layer of the substrate. The radius of the circular patch is optimized to 7 mm, which helps achieve resonance at the desired operating frequency. Compared to the standalone antenna design, the patch radius is reduced to achieve a more compact structure when integrated with the filter.

To incorporate filtering functionality within the antenna structure, three resonator poles are integrated into the design, forming a 3rd order hairpin filter structure. The length of each resonator pole is designed as 16.25 mm, which helps generate the required band-pass filtering response around the 2.61 GHz frequency band. These resonators allow only the desired frequency band to pass while suppressing unwanted signals outside the passband. In addition, a Defected Ground Structure (DGS) is introduced in the ground plane to enhance the filtering characteristics and improve impedance matching. The length of the DGS is designed as 23.6 mm, which modifies the current distribution on the ground plane and helps achieve improved bandwidth and selectivity as shown in figure 4.2 .The filtenna is excited using a microstrip feed line, which provides the RF input signal to the antenna and filter structure. The feed line length is designed as 4 mm, ensuring proper impedance matching between the feed and the radiating element. This feed line allows efficient power transfer from the input port to the antenna. By integrating the circular patch antenna, hairpin resonator filter, and defected ground structure, the proposed filtenna achieves both radiation and filtering functions simultaneously. This integrated approach significantly reduces the overall device size while maintaining good performance in terms of return loss, bandwidth, and transmission characteristics.

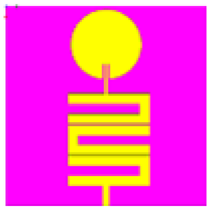

Fig 4.1:Filtenna

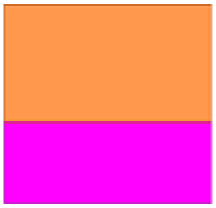

Fig 4.2:Filtenna with DGS

The performance of the proposed filtenna is evaluated using the S11 parameter, which represents the return loss of the antenna system. From the simulation results, the filtenna resonates at 2.63 GHz with a return loss of –33.46 dB, indicating good impedance matching and minimal signal reflection at the operating frequency.

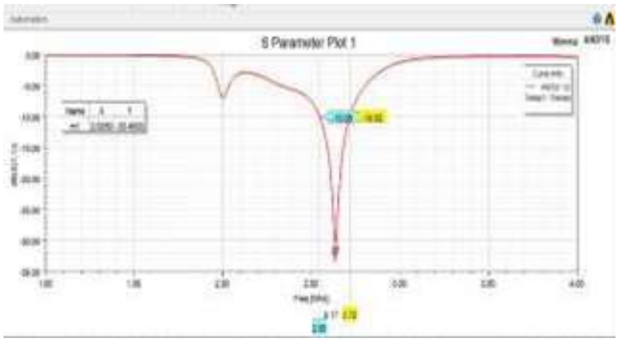

Fig 4.3: S11 plot of Filtenna

The bandwidth of the proposed filtenna is observed to be 170 MHz, which indicates the frequency range over which the antenna operates effectively with return loss less than –10 db. This bandwidth makes the filtenna suitable for wireless communication systems operating around the 2.61 GHz band.

The gain of the proposed filtenna represents its ability to radiate power effectively. From the simulation results, the filtenna achieves a gain of 1.43 dB at 2.63 GHz, which indicates acceptable radiation performance for compact wireless communication applications.

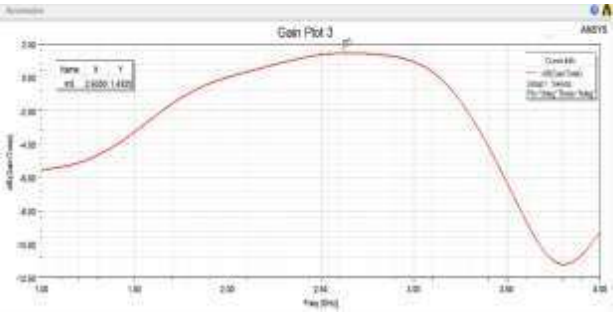

Fig 4.4: Gain Plot of Filtenna

The radiation pattern of the proposed filtenna shows an omnidirectional pattern, meaning the antenna radiates electromagnetic waves uniformly in all directions in the horizontal plane. This radiation characteristic is suitable for wireless communication systems such as IoT and LTE applications, where signal coverage is required in multiple directions.

Fig 4.5: Radiation Pattern Plot of Filtenna

COMPARISON TABLE

Table 1: Comparison Table for Various Parameters of
Proposed Filtenna

Si.No	Dgs	Return Loss	Vswr	Gain	Bandwidth
1	21.4	-15.97db	1.52	-25.5db	125mhz
2	22.3	-17.84db	1.48	-12.6db	114mhz
3	22.9	-21.89db	2.43	-18.9db	132mhz
4	23.4	-25.46db	2.24	0.6db	145mhz
5	23.6	-33.46db	1.04	1.43db	170mhz

V. CONCLUSION

In this project, a compact microstrip filtenna operating at 2.61 GHz has been successfully designed and analyzed for Internet of Things (IoT) applications. The proposed filtenna integrates a band-pass filtering structure with a microstrip antenna, enabling simultaneous frequency selectivity and radiation within a single compact module.The integration of the filter with the antenna effectively suppresses unwanted harmonics and out-of-band signals, ensuring clean spectral radiation and improved electromagnetic compatibility, which are critical requirements for IoT systems. Simulation results demonstrate good impedance matching, low return loss, acceptable bandwidth, and stable radiation characteristics at the desired operating frequency.

By eliminating the need for separate RF filters and interconnecting transmission lines, the proposed filtenna achieves reduced size, lower insertion loss, and enhanced overall efficiency. These features make the design highly suitable for compact, low-power, and cost-effective IoT devices. Hence, the proposed compact microstrip filtenna proves to be an efficient and practical solution for modern wireless IoT communication systems.

REFERENCES

1. Ramesh B., Arindam Deb, and Jibendu Sekhar, "Design of a Compact Microstrip Filtenna for Miniaturized Devices to Access IoT Using LTE," Advanced Electromagnetics (AEM) Journal, vol. 8, no. 1, pp. 86–95, 2023.
2. L. Atzori, A. Iera, and G. Morabito, "The Internet of Things: A Survey," Computer Networks, vol. 54, no. 15, pp. 2787–2805, Oct. 2010.

3. E. Dahlman, S. Parkvall, and J. Skold, 4G: LTE/LTE-Advanced for Mobile Broadband, 2nd ed., Oxford, U.K.: Academic Press, 2014.
4. C. A. Balanis, Antenna Theory: Analysis and Design, 4th ed., Hoboken, NJ, USA: Wiley, 2016.
5. J. S. Hong and M. J. Lancaster, Microstrip Filters for RF/Microwave Applications, 2nd ed., New York, NY, USA: Wiley, 2011.
6. K. L. Wong, Compact and Broadband Microstrip Antennas, New York, NY, USA: Wiley, 2002.
7. S. Sun and L. Zhu, "Compact Microstrip Bandpass Filter Using Hairpin Resonators," IEEE Microwave and Wireless Components Letters, vol. 15, no. 1, pp. 32–34, Jan. 2005.
8. M. A. Antoniades and G. V. Eleftheriades, "A Compact Multiband Antenna Using a Reactive Impedance Surface," IEEE Transactions on Antennas and Propagation, vol. 56, no. 8, pp. 2560–2567, Aug. 2008.
9. S. Chen, Q. Xue, and J. Hu, "Design of filtering antennas with integrated bandpass filter and radiating element," IEEE Transactions on Antennas and Propagation, vol. 65, no. 1, pp. 194–202, Jan. 2017.
10. F. K. Juma'a, "Design and simulation of a compact filtenna for 5G mid-band applications," Iraqi Journal of Electrical and Electronic Engineering, vol. 17, no.2, pp. 53-57, Dec. 2021.
11. A. Kumar and S. Dwari, "Filtering antenna with defected ground structure for improved gain response," IEEE Antennas and Wireless Propagation Letters, vol. 14, pp. 1090–1093, 2015.
12. J. Zhu, S. Gao, and Q. Luo, "High-gain filtering antenna using U-slot loaded patch and stacked shorted patch," IEEE Transactions on Antennas and Propagation, vol. 63, no. 8, pp. 3522–3527, Aug. 2015.
13. X. Chen and K. Huang, "Compact filtering antenna using open-loop resonator filter and varactor-loaded patch," IEEE Microwave and Wireless Components Letters, vol. 26, no. 8, pp. 620–622, Aug. 2016.
14. Y. Li, Z. Zhang, and Z. Feng, "Low-profile polarization diversity filtering antenna with coupling probe feed," IEEE Antennas and Wireless Propagation Letters, vol. 15, pp. 1549–1552, 2016.
15. L. Ge and K. M. Luk, "Duplex filtering antenna based on substrate integrated waveguide technology," IEEE Transactions on Antennas and Propagation, vol. 65, no. 3, pp. 1124–1131, Mar. 2017.
16. H. Chu and Y. X. Guo, "Dual circularly polarized cavity-backed filtering antenna using SIW technology," IEEE Antennas and Wireless Propagation Letters, vol. 17, no. 2, pp. 280–283, Feb. 2018.
17. W. Yang, J. Zhou, and Z. Yu, "Vertically integrated full-duplex filtering antenna using SIW cavity," IEEE Access, vol. 7, pp. 41252–41259, 2019.
18. S. Luo, L. Zhu, and W. Menzel, "Compact coplanar filtering antenna using defected ground structure," IEEE Antennas and Wireless Propagation Letters, vol. 18, no. 3, pp. 452–456, Mar. 2019.
19. Y. Dong and T. Itoh, "Compact dual-band filtering antenna using slot-loaded patch and defected ground structure," IEEE Transactions on Antennas and Propagation, vol. 67, no. 6, pp. 3776–3781, Jun. 2019.
20. A. Singh and R. K. Chaudhary, "Frequency-reconfigurable filtering antenna using hairpin filter and PIN diode switch for IoT applications," IEEE Access, vol. 8, pp. 143210–143218, 2020.
21. M. S. Sharawi, "Duplexer-based reconfigurable filtering antenna for IoT satellite communications," IEEE Antennas and Wireless Propagation Letters, vol. 19, no. 9, pp. 1500–1504, Sept. 2020.
22. N. Chahat, M. Zhadobov, and R. Sauleau, "Millimeter-wave textile antenna using electromagnetic bandgap structure," IEEE Transactions on Antennas and Propagation, vol. 66, no. 5, pp. 2523–2530, May 2018.
23. P. Kumar and G. K. Pandey, "Frequency-reconfigurable filtering antenna using slot-loaded monopole for LTE and wireless applications," IET Microwaves, Antennas & Propagation, vol. 14, no. 10, pp. 1050–1056, 2020.