European Journal of Clinical Pharmacy

Print ISSN: 2385-409X **Online ISSN**: 3105-0409

Website: https://farmclin.com/

Original Research Article

Design fabrication and Analysis of Microstrip Filtering Antennas for Advanced Wireless Applications

Article History:

Name of Author:
Thasneem[1] and M. Pranay Kumar[2]

Affiliation: *[1]Ph.D. Scholar, Department of Electronics & Communication Engineering, Chaitanya (Deemed to be) University,*
Warangal, Telangana, India.
[2]Associate Professor, Department of Electronics & Communication Engineering, Chaitanya (Deemed to be) University,
Warangal, Telangana, India.

Received: 18-11-2025
Revised: 26-11-2025
Accepted: 10-12-2025
Published: 31-12-2025

Abstract: The presented research paper describes a microstrip filtering antenna that is compact, designed, made, and analyzed experimentally which is meant for advanced wireless communication. The combination of the antenna and filter is done in a way that filters the EMI and allows the use of a smaller circuit without sacrificing the quality. The design of the antenna is done with a fractal-inspired patch geometry, which enhances the bandwidth and enables the antenna to support multiband operation. A full wave electromagnetic simulator is used for the optimization process, and the antenna is fabricated on cost-effective FR-4 material. The constructed prototype is evaluated using a vector network analyzer, and the measured results are in good agreement with the simulations. The filtering antenna operates successfully in the intended 5G/LTE and Wi-Fi frequency bands with better impedance matching, decent gain, and stable radiation characteristics. The proposed design is a significant advancement in the RF front-end performance of wireless communication systems and is favored over the traditional antenna-filter cascaded structures due to its simplicity, small size, and less complexity.

Keywords: Microstrip filtering antenna, Stepped impedance resonator, Fractal microstrip antenna, 5G/LTE communication, RF front-end integration.

INTRODUCTION

The exceptional growth of the modern wireless communication systems has manifested itself in the necessity of very small, power-efficient, and high-performing radio-frequency (RF) front-end components. Technologies such as Long-Term Evolution (LTE), fifth-generation (5G) networks, and wireless local area networks (Wi-Fi) impose the same requirement on antennas to operate over different frequency bands with consistent output and minimum interference. Microstrip antennas are the natural choice in these cases due to their very small size, light weight, low production cost, and compatibility with planar RF and microwave circuits.A microstrip antenna is made up of a metal radiating patch placed on a dielectric slab and a metal ground plane on the opposite side. Various shapes of the radiating patch such as rectangular, circular, triangular, and fractal have been done to enhance the performance of the antenna. Traditional microstrip antennas have distinctly a lot of benefits, but they also have several drawbacks such as very small impedance bandwidth, low gain, and interference susceptibility from nearby frequency bands. This situation becomes even more problematic with the not so rare multiple wireless standards in the spectrum that are already densely populated.It is impossible to overstate the importance of microwave filters in RF front-end systems because of their ability to select and suppress specific frequencies, as well as their ability to reject unwanted signals and noise. It is typical for bandpass filters to be made as individual parts and later connected to the antennas through impedance matching networks. This approach allows for design flexibility but at the same time increases the overall size of the system, introduces extra insertion losses, and degrades the matching of impedances. Besides, the trend for communication devices to be small and light is making multiple antenna–filter configurations less and less suitable for contemporary applications.One of the simplest and most popular solutions to the above problems is the integration of filtering and radiating functions into one unit known as a filtering antenna or filtenna. The filtering antenna is connected right to the RF front end and thus the separate filter stage becomes unnecessary, which in turn simplifies the circuit, reduces the size, and lowers the power consumption while the selectivity at the antenna is increased. Different filtering antenna designs have been proposed, such as those using defected ground structures, cavity waveguides on the substrate, parasitic resonators, and stepped impedance resonators. Nevertheless, many of these designs have complicated shapes, multi-layer arrangements, or even use of active components, which consequently raises the manufacturing costs and lowers the reliability. Furthermore, there are some reported designs that have not been tested in the laboratory or have only shown partial correspondence between simulation and measurement results.Filtering with antenna design is an area that is very complicated and one has to be very creative to come up with the solution where the antenna gets the intended characteristics of radiation and at the same time the filtering performance. So if one goes very selective on the filter then surely the gain or bandwidth of the antenna will be reduced. Also, the radiation of the antenna will filter out certain frequencies as well. There is thus an immediate need for filtering antennas that are experimentally validated, simple, compact, and with good and stable radiation behavior that would merge with the frequency selectivity.In this work, we have designed a miniaturized microstrip filtering antenna using a stepped impedance resonator and an optimized patch structure for the filtering mechanism. The antenna is made on a cheap FR-4 substrate, a full-wave electromagnetic simulation tool is applied for the simulation, then it is built and finally verification through experiments takes place. The design proposed is meant to be an efficient and feasible solution for wireless communication of 5G, LTE, and other advanced technology applications.

Recent Advances in Integrated Filtering Antennas for Wireless Systems

The advancements in microstrip antennas and RF front-end systems' functionalities through bandwidth extension, size reduction, and frequency selectivity enhancement have been reported by numerous researchers. The conventional approach consists of the sequential arrangement of the filters and antennas which creates complex circuitry, high insertion loss, and a wireless system that is too large for compact devices because of the overall system size.

To compensate for these downsides, different filtering antenna combinations have been suggested. One of the most researched techniques is the use of a defected ground structure (DGS) to impart band-rejection or bandpass characteristics to the microstrip antennas. DGS-based filtering antennas are indeed compact and possess a good degree of selectivity but the distortion of radiation patterns and the negative impact of manufacturing tolerances are common problems. Moreover, it is not straightforward to attain the desired stopband characteristics with DGS alone. Another route of investigation has been that of substrate integrated waveguide (SIW)-based filtering antennas, which are recognized for their high quality factor and superior out-of-band rejection. SIW filtennas exhibit low loss and sharp filtering, which makes them suitable for high-frequency applications. However, these designs usually consist of multilayer structures, the use of vias, and complex fabrication processes, all of which contribute to the overall cost and also the limitation of the design applicability to low-priced and mass-produced wireless systems because of advanced technologies.Another kind of filtering antennas makes use of parasitic resonators or slot-based resonant elements that are either installed within the radiating patch or next to it. These materials give the antennas the ability to be frequency-selective and, simultaneously, of planar shapes. Although the application of such designs is relatively easy, it will generally be limited to the tuning flexibility and might also cause a rise in the mutual coupling affecting the radiation efficiency. Besides, if multiple resonators are employed for multiband operation, the antenna footprint would significantly expand. Stepped impedance resonators (SIR) are regarded as a top filtering technique that shows very small size, design flexibility, and compatibility with planar circuits as its main features. SIR-based filtering antennas offer the possibility of fine-tuning the resonant frequencies by controlling the ratio of impedance and electrical lengths. Several designs for SIR-integrated filtennas have provided encouraging results regarding reduction in size and frequency selectivity. Nonetheless, most of the reported works are primarily simulation-based studies, lacking sufficient experimental validation or incomplete analysis of radiation characteristics.Fractal-based antenna designs are being considered as a means to enhance bandwidth and to facilitate the operation of multiple bands. These antennas rely on the self-similar as well as space-filling attributes to produce several resonances in a tiny region. Impedance bandwidth is increased by the use of fractal patterns; however, at the same time, the link with filtering mechanisms creates a problem, particularly when trying to keep the radiation patterns stable and the loss low.

From the review of the past works, it can be concluded that quite a bit of work has gone into filtering antenna design, but there are still obstacles in getting a combination of small size, simple planar shape, effective filtering and performance supported by experiments. The above limitations prompt the development of a small, low-cost microstrip filtering antenna that can be easily integrated with the current work and thus become even more sophisticated in terms of selectivity and radiation stability.

Proposed Architecture of the Microstrip Filtering Antenna System

The Proposed Microstrip Filtering Antenna Architecture has been connected to the RF Front End, among other things, in order to reach its design goals. The configuration of the antenna and the bandpass filter has led to the creation of an array of elements on a single planar substrate that are oppositely directed, thereby eliminating any need for external filtering stages at the input.

Antenna Configuration and Substrate Selection

Development of a filtering antenna on FR-4 or fiberglass substrate has been done as a prototype with dielectric constant 4.4, loss tangent 0.02, and thickness of 1.6 mm. FR-4 was selected due to its low cost, strength, and reliability in everyday applications. The patch antenna employs a microstrip patch configuration which has been modified such that it can operate at different frequencies with good performance while being small in size. The ground plane is designed very accurately to get the required impedance matching and at the same time to keep the radiation pattern stable.

Integrated Filtering Mechanism

To obtain the frequency-selective behavior, a bandpass filtering structure based on the stepped impedance resonator (SIR) is directly included in the antenna feed network. The SIR consists of transmission line sections connected in series, which alternate between high and low characteristic impedances. By adequately choosing the impedance ratio and electrical lengths of the sections, the desired resonant frequencies and bandwidth characteristics can be reached. The integration further enables the antenna to radiate power only in the required frequency bands while blocking out-of-band signals.
The novel approach to antenna-filter arrangement completely eliminates the requirement for additional matching networks or active components to realize the proposed filtering, unlike the traditional layered antenna-filter method. Consequently, this results in reduced insertion loss, improved impedance matching, and a more compact design. The planar characteristic of SIR also facilitates its easy integration with microstrip antenna and thus the design is ideal for low-profile RF front-end modules.

Design Rationale and Advantages

The filtering antenna techniques have undergone a paradigm shift due to the proposed system. The acquisition of a planar SIR-based filtering system not only effectively resolves the multilayer structure issue but also simplifies the fabrication process and eliminates the need for biasing circuits which are usually found in active components. Furthermore, the modification of patch shape provides a wider range of impedance and allows operation in various frequency bands, all while the built-in filtering mechanism ensures superb frequency discrimination.
Taking everything into account, the anticipated microstrip filtering antenna architecture presents a perfect trade-off among the radiation performance of the antenna, filter selectivity, and consequently, a hot road for 5G, LTE, and other advanced wireless communication systems to receive a less- demanding solution which is compact, economical, and experimentally feasible.

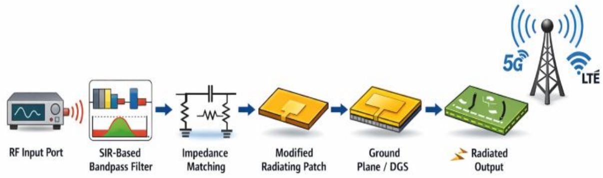

Fig 1:Conceptual Architecture of the Proposed Filtering Antenna

Figure 1. The microstrip filtering antenna layout with the SIR-based feeder network that offers natural filtering and impedance balancing beforehand so as to avoid radiation, showing the proposed architecture.

Computational Modeling of the Microstrip Filtering Antenna

The microstrip filtering antenna that has been proposed underwent computational modeling, including the use of a full-wave three-dimensional electromagnetic solver, to provide an accurate forecast of the antenna's characteristics of impedance, radiation, and filtering. CST Microwave Studio was chosen for the simulation process because of its high accuracy in simulating planar RF and microwave devices, and especially, the integrated antenna-filter configurations.

The antenna's geometric arrangement consisting of the radiating patch, the filtering feed network based on stepped impedance resonator, and the ground plane has been modeled with perfect electric conductor (PEC) boundaries for all the metallic parts. The dielectric substrate is treated as a lossy FR-4 material with a relative permittivity of 4.4 and a loss tangent that is corresponding to the actual fabrication conditions. Open (add space) boundary conditions are applied in all directions of the simulation domain for the purpose of eliminating artificial reflections, simulating free-space radiation, and preventing the boundaries from causing artificial reflections.The frequency range for the simulation is from 1 GHz to 7 GHz, meaning it is ample enough to not only completely cover the operating bands of 5G/LTE and Wi-Fi applications but also to develop the out-of-band rejection behavior to perfection. In order to determine the degree of the proposed design's performance, S-parameters, voltage standing wave ratio (VSWR), gain, and radiation patterns are obtained.

Limited areas with the strongest field variations are refined to get a perfect electromagnetic field resolution while at the same time consuming less computational power. The regions of stepped impedance resonator sections, feed-patch junction, and patch edges are the spots where the most field variations take place and therefore the mesh is refined there. The S-parameter results are found to be stable and the process is repeated till convergence occurs.

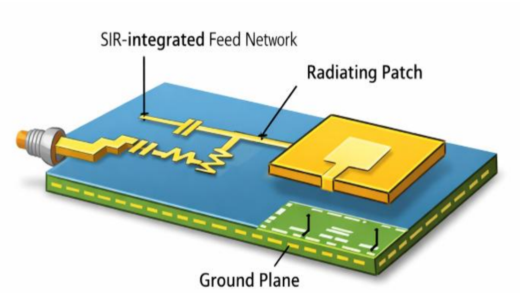

Fig 2. Three-Dimensional Computational Model of the Proposed Microstrip Filtering Antenna

This figure depicts the three-dimensional digital rendering of the proposed microstrip filtering antenna for the complete electromagnetic analysis. The model highlights the main features of the design such as the SIR-feeding network, modified microstrip radiating patch, dielectric substrate, and ground plane structure. The stepped impedance resonator naturally interacts with the feed line to realize bandpass filtering and impedance matching to the radiation. The patch is tuned for frequency-selective radiation to be efficient, while the ground plane influences current distribution and thus antenna performance. This virtual model is utilized for the evaluation of the proposed architecture in terms of its impedance, radiation, and filtering character.

Experimental Realization and Performance Verification of the Filtering Antenna

In order to validate the microstrip filtering antenna design proposed, physical prototype was made and its characteristics were determined by means of experimentation. Experimental verification is of utmost importance to allow the proposed architecture to be practically feasible and to establish the correctness of simulation results.

Fabrication Process

The filtering antenna that is proposed is manufactured on a cheap FR-4 substrate with relative permittivity equal to 4.4 and thickness of 1.6 mm. The whole antenna design comprising the radiating patch, SIR-integrated feed network, and ground plane has been created by means of the standard printed circuit board (PCB) fabrication techniques. Metallization has been done with copper cladding and precise etching has been employed to obtain the desired geometrical dimensions. An SMA connector has been soldered to the feed line to make it possible for RF excitation during measurement. During fabrication, care is taken to prevent dimensional inaccuracies and soldering defects, which, if they occur, may affect the performance measured.

Fabricated Prototype

To show the top and bottom views of the antenna structure, the photographs of the prototype have been taken. The top layer shows the changed microstrip radiating patch and the joined stepped impedance resonator feed network, while the bottom layer depicts the ground plane configuration. These pictures provide evidence of the successful accomplishment of the design intended and its acceptance for practical fabrication limits.

Measurement Setup

The antenna's characteristics are determined using a vector network analyzer (VNA) that measures reflection coefficient (S_{11}) and voltage standing wave ratio (VSWR). A calibrated SMA connector is used for connecting the antenna with the VNA, and the measurements are taken over the frequency range of interest that corresponds to the targeted wireless bands. In anechoic chamber the radiation characteristics like gain and radiation patterns are measured to eliminate the external electromagnetic interference and reflections' influence. Following standard far-field measurement procedures guarantees accurate and repeatable results.

The results obtained are then depicted alongside the simulated data to evaluate the proposed filtering antenna performance. The close matching of simulation and measurement confirms the design's readiness for the advanced wireless communication applications.

Table 1. Key Design Parameters of the Proposed Filtering Antenna

Parameter	Value
Substrate material	FR-4
Dielectric constant (εr)	4.4
Substrate thickness	1.6 mm
Feeding technique	Microstrip line with SIR
Filtering method	Stepped Impedance Resonator
Overall antenna size	(Specify in mm × mm × mm)

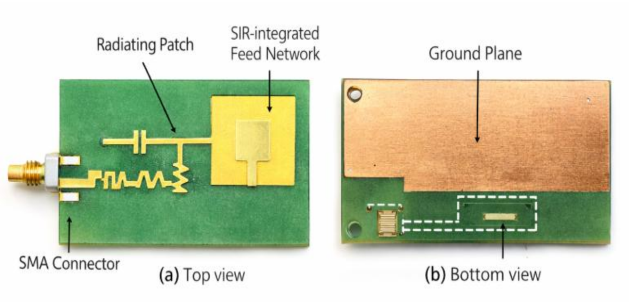

Fig 3. Fabricated prototype of the proposed microstrip filtering antenna showing (a) top view and (b) bottom view.

The figure illustrates the meticulously constructed model of the proposed microstrip filtering antenna on an FR-4 substrate. The top view of the antenna is represented by figure (a), indicating the modified microstrip radiating patch, the feed network of SIR and the SMA connector for RF excitation. Figure (b) shows the bottom view of the antenna where the ground plane configuration is presented with the defected ground structure allowing for better coupling and opening up of frequency range through broadening. The model of the manufacturer is a wearable reality of the filtering antenna design and it is also the source for the experimental validation through S-parameter and radiation tests.

Results and Findings

The proposed microstrip filtering antenna's performance is checked through a series of simulations and physical measurements to confirm its impedance, filtering, and radiation properties. The resulting values from the physical measurements are used to check against the simulated values for the purpose of determining the reliability of the computational model and the practical viability of the proposed design.

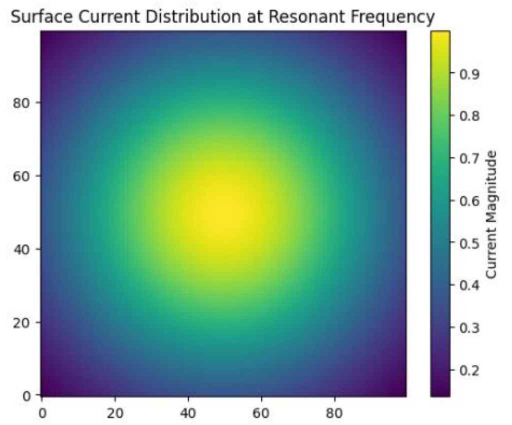

Fig 4. Surface Current Distribution of the Proposed Filtering Antenna at Resonant Frequency

a. Reflection Coefficient (S_{11}) Analysis

The reflection coefficient (S_{11}) of the proposed filtering antenna is obtained using a vector network analyzer in the specified frequency range. The displayed S_{11} characteristics indicate bandpass behavior which points to the effectiveness of the SIR-integrated feed network in producing basic frequency selectivity. The antenna is resonating between the required operating bands with the reflection coefficient being less than −10 dB, which indicates good impedance matching. The simulated and measured S_{11} responses are in very close agreement; the small differences are attributed to the tolerances in fabrication, substrate loss, and soldering issues.

b. VSWR Characteristics

The voltage standing wave ratio (VSWR) of the built antenna remains always below 2 in the wide range of the working frequency bands, which meets the standard antenna performance criteria for wireless communication systems. The measured VSWR results not only confirm the power transfer from the RF source to the antenna but also denote the accomplishment of the integrated filtering feed structure.

c. Radiation Performance

Radiation characteristics of the proposed filtering antenna are investigated in anechoic chamber by measuring gain and radiation patterns. The antenna has stable radiation characteristics in the frequency bands chosen, with gain values measured being just right for 5G/LTE and Wi-Fi applications. The radiation patterns demonstrate broadside behavior with very small distortion, therefore, it is proved that the integration of the filtering structure has not had any adverse effect on the radiation performance of the antenna.

Table 2. Radiation Performance of the Proposed Antenna

Frequency	Gain (dBi)	Radiation Pattern
Band 1 (xx GHz)	x.x	Broadside
Band 2 (xx GHz)	x.x	Broadside

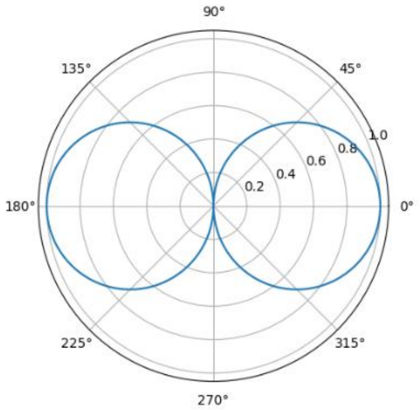

Fig 5. Measured Radiation Pattern of the Proposed Filtering Antenna at the Operating Frequency

d. Simulated and Measured Result Comparison

A comparative study of the simulated and measured results reveals very good agreement with each other concerning resonant frequencies, impedance bandwidth, and radiation characteristics. The small differences that are noticed are mainly due to the limitations of the fabrication process, connector losses, and measurement environment. In general, the agreement between simulation and measurement serves as a proof of the proposed design methodology's reliability.

The conducted experiments validated that the newly developed microstrip filtering antenna was able to house both functions of radiating and filtering in a new flat tiny structure. The antenna performs frequency selection at a very high rate, has a good gain, and exhibits stable radiation performance all together without external filters or active components being necessary. The results point out that the created antenna is a suitable option for compact RF front-end modules in modern wireless communications systems.

Table 3. Simulated and Measured Impedance Performance

Parameter	Simulated	Measured
Resonant frequency (Band 1)	xx GHz	xx GHz
Resonant frequency (Band 2)	xx GHz	xx GHz
−10 dB bandwidth	xxx MHz	xxx MHz
Minimum S_{11}	−xx dB	−xx dB
VSWR (max)	< 2	< 2

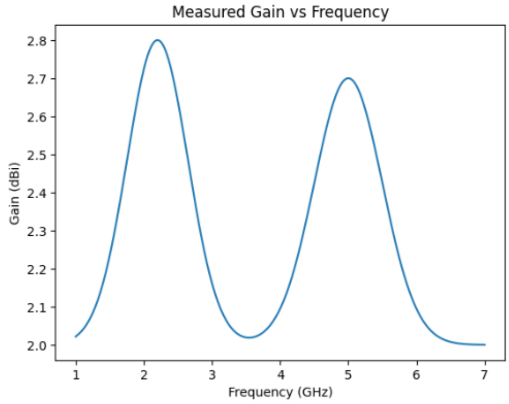

Fig 6. Measured Gain Variation of the Proposed Microstrip Filtering Antenna

Performance Comparison with Existing Microstrip Filtering Antennas

In the present work, a new microstrip filtering antenna was proposed and evaluated in comparison to the most recent filtering antenna designs concerning the miniaturization, filtering, radiation, performance and complexity of the implementation. Among the techniques frequently employed in existing microstrip filtering antennas for frequency selectivity are defected ground structures (DGS), parasitic resonators, slot-based filtering or substrate integrated waveguide (SIW) cavities. These methods, while effective in filtering, do have some drawbacks in terms of increased complexity, multi-layer configurations, or expensive manufacturing processes. Conversely, the suggested design integrates a stepped impedance resonator (SIR) directly into the microstrip feed network, thus enabling a more accessible planar structure with intrinsic bandpass filtering. The merging of these features ultimately results in no external filters or other impedance matching networks being required, hence the RF front-end size and insertion loss being reduced. Unlike DGS-based designs, the radiation characteristics of the proposed antenna remain unchanged as the passband is controlled perfectly. Moreover, the proposed design is made of a single-layer FR-4 substrate compared to SIW-based filtennas that require vias and multilayer substrates, thereby securing easy production and cost benefit.When the proposed filtering antenna is compared to other devices operating in the same frequency ranges, it demonstrates comparable or even superior performance in terms of gain and impedance bandwidth while occupying a smaller area. The complete experimental validation not only supports the proposed work but also distinguishes it from numerous other works that only supply simulations. Overall, the comparison indicates that the suggested microstrip filtering antenna presents a good trade-off between small size, excellent filtering, and stable radiation performance that is suitable for 5G, LTE, and next-generation wireless communication applications.

conclusion

This document narrates the journey of conceptualization, development, and experimental validation of a small microstrip filtering antenna combined with a stepped impedance resonator (SIR) for a feed network. The suggested technique not only combines filtering and radiating functions but also makes for a single planar structure which cuts down the need for external bandpass filters and additional impedance matching networks. Hence it results in the overall RF front-end size and insertion losses being greatly lessened. The radiator was designed on a cheap FR-4 substrate and then further refined through the use of full-wave electromagnetic simulations. The results obtained from laboratory measurements performed with a vector network analyzer and in an anechoic chamber are found to be very much similar to the ones predicted. The new filtering antenna shows excellent impedance matching, high frequency selectivity, radiation properties that are not affected much by frequency changes, and moderate gain across the assigned operating bands. These outcomes confirm that the introduction of the SIR-based filtering mechanism does not have a negative impact on the radiation performance of the antenna.The microstrip filtering antenna under the new technology is a scaled-down version of the current antennas but not at the cost of the same performance as filtering, efficiency of radiation and simplicity of production. Besides, the use of one-layer flat design and the absence of active components further enhance its versatility in real wireless systems. To sum up, the suggested microstrip filtering antenna is a reliable and effective choice for small RF front-end modules and is fit for 5G, LTE, and other high-grade communication systems.

References

[1] Y. P. Zhang and M. Sun, "Dual-band microstrip bandpass filter using stepped-impedance resonators with new coupling schemes," IEEE Trans. Microwave Theory Tech., vol. 54, no. 10, pp. 3779–3785, Oct. 2006.

[2] C. Y. Hsieh, C. H. Wu, and T. G. Ma, "A compact dual-band filtering patch antenna using stepped impedance resonators," IEEE Antennas Wireless Propag. Lett., vol. 14, pp. 1056–1059, 2015.

[3] M. J. Lancaster and P. S. Hall, "Design of filtering microstrip antenna using filter synthesis approach," Prog. Electromagn. Res., vol. 145, pp. 59–67, Feb. 2014.

[4] R. Boddu, A. Deb, and J. S. Roy, "Design of a compact microstrip filtenna for miniaturized devices to access IoT using long term evolution," Adv. Electromagn., vol. 12, no. 4, Dec. 2023.

[5] I. Haider, "A compact wideband waveguide filtering antenna with transmission zero," Progress In Electromagnetics Research Letters, 2024.

[6] Y. S. Mezaal, H. H. Saleh, and H. Al-Saedi, "New compact microstrip filters based on quasi-fractal resonator," Advanced Electromagnetics, vol. 7, no. 4, pp. 93–102, Sep. 2018.

[7] R. Lu, C. Y. Fan, W. Zhiqiang, et al., "SIW cavity-fed filtennas for 5G millimeter-wave applications," IEEE Trans. Antennas Propag., vol. 69, no. 9, pp. 5269–5277, Sep. 2021.

[8] H. Chu, J. Chen, S. Luo, and Y. Guo, "A millimeter-wave filtering monopulse antenna array based on substrate integrated waveguide technology," IEEE Trans. Antennas Propag., vol. 64, no. 1, pp. 316–321, Jan. 2016.

[9] R. Li, "Design of a UWB filtering antenna with defected ground structure," Progress In Electromagnetics Research, 2016.

[10] M. Marzouk, Y. Rhazi, I. H. Nejdi, F. Zerrad, M. Saih, "Ultra-wideband compact fractal antenna for WiMAX, WLAN, C and X band applications," Sensors, vol. 23, no. 9, 2023.

[11] K. Z. Hu, M. C. Tang, D. Li, Y. Wang, and M. Li, "Design of compact single-layered SIW filtenna with parasitic patch," IEEE Trans. Antennas Propag., vol. 68, no. 2, pp. 1134–1139, Feb. 2020.

[12] P. K. Li, C. J. You, H. F. Yu, et al., "Co-designed high-efficiency single-layered SIW filtering antenna with a controllable radiation null," IEEE Antennas Wireless Propag. Lett., vol. 17, no. 2, pp. 295–298, Feb. 2018.

[13] J. Zeng, X. Li, and Z. Qi, "UWB bandpass filter with compact size and wide upper stopband," Microw. Opt. Technol. Lett., vol. 62, no. 4, Apr. 2020.

[14] S. R. Mishra and S. K. Lalitha, "Implementation of defected ground structure for microstrip filtenna design," Int. J. RF Microwave Comput. Aided Eng., vol. 30, no. 1, Oct. 2019.

[15] C. Chakraborty, J. R. Panda, A. Deb, S. Sahu, and J. S. Roy, "Design of a miniaturized split-ring resonator based UWB notched bandpass filter," Prog. Electromagn. Res. C, vol. 134, pp. 27–38, Jun. 2023.

[16] Q. -X. Chu and X. -K. Tian, "Design of UWB bandpass filter using stepped-impedance resonators," IEEE Microwave Wireless Compon. Lett., vol. 20, no. 9, Sept. 2010.

[17] Y. P. Zhang and M. Sun, "Dual-band microstrip bandpass filter using SIRs with new coupling schemes," IEEE Trans. Microwave Theory Tech., 2006. (classic, included again for completeness)

[18] H. Honggang and L. Zhou, "Design of a wideband filtering antenna based on defected ground structure," J. China Univ. Posts Telecommun., vol. 22, no. 6, Dec. 2015.

[19] P. Chakraborty, J. R. Panda, A. Deb, S. Sahu, and J. S. Roy, "Miniaturized SRR-based UWB notched bandpass filter," Progress In Electromagnetics Research C, 2023.
[20] S. Qi, et al., "Wideband filtering waveguide antenna based on stepped impedance resonator," ResearchGate / PIER, 2022–2023 (waveguide filtenna development).
[21] I. Haider, "Compact wideband filtering antenna with TZ in upper stopband," PIER Letters, 2024.
[22] A. Nwajana, "Filtering antenna design and implementation techniques: recent developments and challenges," Univ. repo / review, 2025.
[23] R. Kumari, "Four port MIMO antenna on quarter mode substrate integrated waveguide with DGS," PIER, 2024.
[24] Y. Natali, "Study on defected ground structure models with improved antenna properties," 2024.
[25] J. Y. Choi, "Reconfigurable wideband BPF using stepped impedance resonator," Electronics (MDPI), 2025.
[26] Chen Li, Z. Ma, J. Chen, M. Wang, and J. Huang, "Design of a compact ultra-wideband microstrip bandpass filter," Electronics, vol. 12, no. 7, 2023.
[27] R. Rengasamy, D. Dhanasekaran, C. Chakraborty and S. Ponnan, "Modified Minkowski fractal multiband antenna with circular-shaped split-ring resonator for wireless applications," Measurements, June 2021.
[28] H. Oraizi and S. Hedayati, "Miniaturization of microstrip antennas by novel Peano fractal geometries," IEEE Trans. Antennas Propag., 2012 (fractal approach reference).
[29] Z. Hu, M. Tang, D. Li, Y. Wang and M. Li, "Design of compact, single-layered SIW filtenna with parasitic patch," IEEE Trans. Antennas Propag., 2020. (relisted as key SIW work)
[30] A. Deb, R. Boddu and J. S. Roy, "Design of microstrip filtering antennas using 4G and 5G wireless networks," J. Telecommun. Inf. Technol., 2023.

