

## Review Article

# Filtering Antenna Design and Implementation Techniques: Applications, Recent Developments, Challenges, and Future Opportunities

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Antennas and filters are two key components that make up the configuration of the radio frequency (RF) front end of any wireless communication system. While the antenna is responsible for transmitting and receiving signals in the system, the filter is tasked with selecting signals that fall within the system's operating frequency band, while also rejecting spurious (out-of-band) signals from the system. Following the recent increasing trend toward device simplicity and miniaturization, it is desirable to integrate the antenna and the filter into a single component that achieves both the radiating (i.e., transmitting and receiving) and the filtering functions simultaneously. This integrated component is what is now known as a filtering antenna (or filtenna). The filtenna reduces a system's prefiltering requirements and improves the noise performance of the system. It also finds application in overcoming the insufficiency of stand-alone bandpass filters in suppressing interference in sidebands. This article covers the review of the current state of the art in the design and implementation of filtennas, the practical applications, recent developments, and challenges. Emerging research and future opportunities in filtering antenna design and implementation techniques are also investigated and reported.

**Keywords:** cascade; codesign; filtenna; fusion; hybrid; multilayer; reconfigurable; RF front end; sensor; SIW

## 1. Introduction

The traditional radio frequency (RF) front end of wireless communication systems is normally composed of passive components including antennas [1] and filters [2] that are separately designed and then connected by means of 50-ohm connectors [3]. While the antenna is responsible for transmitting and receiving signals in the wireless communication system, the filter is responsible for selecting signals that fall within the system's operating frequency band, while also rejecting spurious (out-of-band) signals from the system. This conventional design culture certainly gave rise to bulky communication systems with large footprints due to the combined physical sizes of the individual components

that make up a system. The conventional design technique also gave rise to complex circuits, high signal distortions particularly at the band edges, and high losses particularly at the 50-ohm connectors as discussed in [4–9].

Current trends in the state-of-the-art RF front end of wireless communication systems are to integrate the filter and the antenna into a single component known as the filtering antenna (or filtenna) [10–16]. The filtenna can concurrently achieve both radiation (i.e., the transmit and the receive functions of the antenna) and filtration (i.e., the filtering function of the filter). This integration of a filter and an antenna to form a filtenna is a very efficient technique of achieving miniaturization in the modern-day RF front end of wireless communication systems. This state-

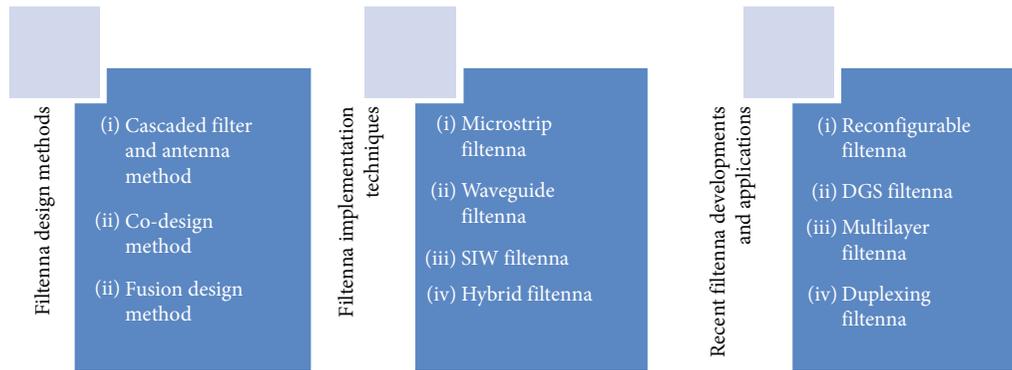


FIGURE 1: Block diagram of the various stages in this article.

of-the-art integrated filtration and radiation technique is capable of significantly improving the wireless communication system's frequency selectivity and bandwidth. It can also lead to improved efficiency due to better stability of the in-band gain and out-of-band rejection on the communication system. Due to the highlighted benefits of integrating an antenna and a filter into a single component, filtennas have recently been receiving an extensive interest from researchers who have been investigating and reporting novel techniques for the design and implementation of filtennas [17–26].

This article looks at the various design and implementation techniques for developing filtennas. It also covers the review of the current state of the art in the design and implementation of filtennas, the practical applications, recent developments, and challenges. Emerging research and future opportunities in filtenna development are also investigated and reported. Most of the literatures that have been reported around filtenna design may be categorized under three standard design techniques. Firstly, the cascaded filter and antenna technique [27–37] is a traditional filtenna design method where a 50-ohm connector or any other type of impedance matching network is used to connect a separately designed filter to a separately designed antenna, forming an integrated filtenna device. Secondly, the codesign technique of filtenna development [38–46] is a synthesis approach of filtenna design that overcomes most of the issues associated with the cascaded technique by utilizing the last resonator of a bandpass filter (BPF) as the radiating element of the code-signed filtenna. Thirdly, the fusion technique [47–53] is a method that eliminates the need for an additional filtering circuit in the filtenna design process. This article also covers a variety of transmission line technologies (both planar and nonplanar) employed in the implementation of filtennas as reported in the literature. The popular and commercially available transmission line technologies that have been reported for the implementation of filtennas include the microstrip technology [54–59], the waveguide technology [60–64], the substrate-integrated waveguide (SIW) technology [65–76], etc. Some researchers have investigated and reported on filtennas that were implemented using hybrid technologies [77–80]. This article also highlights some practical applications of filtennas which include but are not limited to mobile satellite terminals [81], aerospace

communication [82], vehicle communication systems [83–85], RF front-end communication systems [86–88], wireless LAN and Wi-Fi communications [89–92], medical devices and systems [93–95], sensors and sensing systems [96–98], base station communication systems [99–102], etc.

The rest of this article is organized by firstly reviewing the three standard filtenna design methods in Section 2, followed by the various technologies that have been reported for filtenna implementation in Section 3, then an investigation into the recent state-of-the-art developments in filtenna design and applications in Section 4, the challenges and future opportunities associated with filtenna development are researched and reported in Section 5, and the conclusion is then drawn in Section 6. A block diagram illustrating the various stages covered in this article is shown in Figure 1.

## 2. Filtenna Design Methods

This section investigates and reports on the three standard design methods for realizing filtennas. The section starts by firstly looking at the traditional filtenna design method which is the cascaded filter and antenna technique. Secondly, an extensive discussion on the codesign technique (also known as the synthesis method) of filtenna design is covered. Thirdly, the section delves into the final standard filtenna design method known as the fusion technique. The benefits and drawbacks of each method are discussed, and conclusions are drawn by tabulating the extensive comparison among the three design methods.

**2.1. Cascaded Filter and Antenna Method.** The cascaded filter and antenna method is also referred to as the traditional method for filtenna development. In this design method, a 50-ohm transmission line/connector or an alternative impedance matching network is used to connect an independently designed BPF to an independently designed antenna, as shown in Figure 2. The resultant device is an integrated filtenna that combines the radiating functionality of the antenna with the frequency selectivity of the filter [27–37]. Lee et al. [34] applied this technique by introducing a tapered microstrip line transition structure between a quasielliptic BPF and a series-fed array antenna, as shown in Figure 3. There are a few issues with this design method. Firstly, the technique gives rise to a bulky

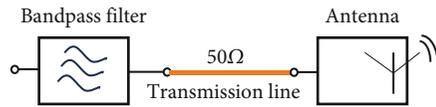


FIGURE 2: Structure of the cascaded filter and antenna design method for filtenna development.

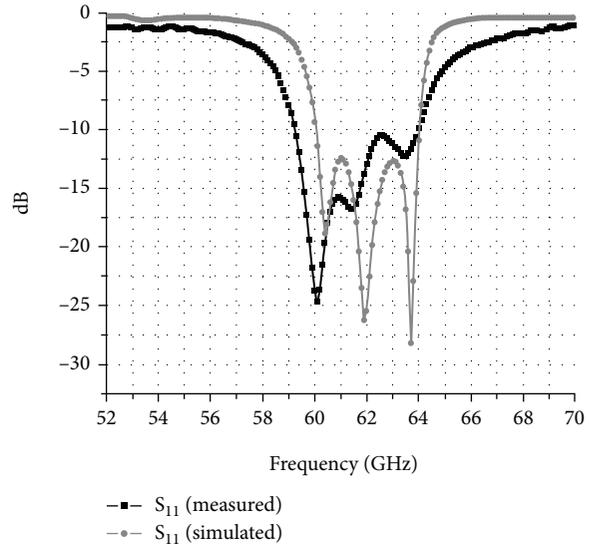
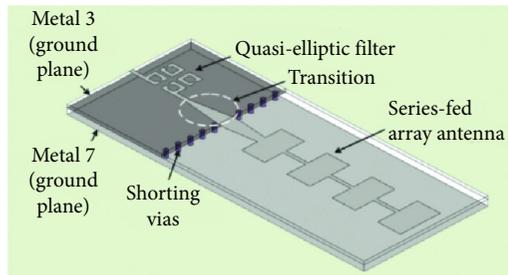
filtenna device. This is because both the component BPF and the antenna are independently designed before being cascaded by means of an extra interface to form a filtenna. Secondly, the connecting interface/matching network or 50-ohm transmission line used in cascading the filter to the antenna introduces additional insertion loss to the RF front-end system. This is due to the imperfections in the link between the BPF and the antenna components. The effect of the linking imperfections is mostly noticeable at the band edges where signal distortion is mostly experienced. Thirdly, this traditional design method needs to be implemented using a wideband antenna. The bandwidth of the antenna should be wider than that of the BPF for the resultant filtenna to function as desired. This is because the BPF normally serves as the foundation in the filtenna development process. Hence, the bandwidth of the component antenna should be wider than that of the BPF to accommodate any mismatch adjustment during the filtenna operation. This is mostly a challenge when employing antennas such as the microstrip patch antenna with a high-quality factor. Fourthly, the cascaded filter and antenna design approach of filtenna development can give rise to design complexity of strong coupling between the BPF and the antenna. This is because an external connecting device (i.e., the 50-ohm connector shown in Figure 2) is needed as an interface between the BPF and the antenna components. Fifthly, it can also result in bandwidth mismatch between the BPF and the antenna components. This is because the BPF and the antenna components are separately designed before being cascaded to form the filtenna. There are no limitations to the structures and topologies that can be used when employing the traditional filtenna design method.

**2.2. Codesign Method.** This is the most popular method of filtenna development. This technique is also referred to as the synthesis approach. The technique overcomes most of the issues associated with the cascaded filter and antenna design approach by utilizing the last resonator of a BPF as the radiating element of the resulting filtenna [38–46]. This technique has been investigated and reported by Wu et al. [44], as shown in the schematic circuit of Figure 4. The third-order BPF network shown in Figure 4a has been modified such that the first resonator has been replaced with a lossy resonator of capacitance,  $C_A$ ; conductance,  $G_A$ ; and inductance,  $L_A$ . The lossy resonator is implemented as a patch antenna forming the radiating component, as shown in Figure 4b. The remaining two resonators of the BPF are implemented as H-shaped  $\lambda/4$  resonators forming the filtering component of the resulting filtenna. The simulation and measurement responses of the sample filtenna are shown in Figure 4c. This technique of achieving radiating and filtering

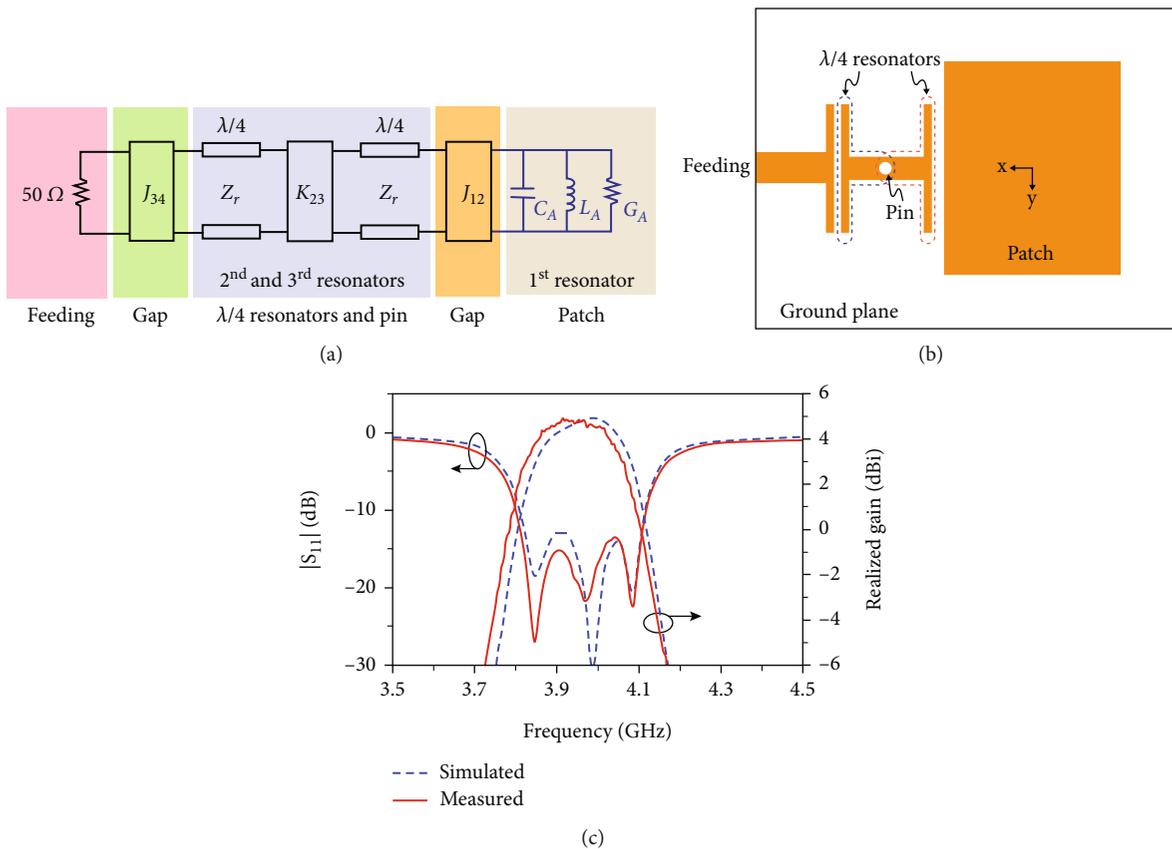
functionalities in a single device by implanting the antenna component as a part of the BPF reduces the cascading losses experienced in the traditional filtenna design method. The reduced losses experienced in the codesign method occur because the BPF and the antenna components are not designed separately. Hence, the losses associated with the 50-ohm connector in the traditional method are absent here. When compared to the cascaded filter and antenna design method, the codesign method has numerous benefits. Firstly, the absence of the connecting interface/matching network or 50-ohm transmission line in the design means less complexity and less footprint for the applicable RF front-end system. This should lead to a noticeable improvement in the efficiency of the system. Secondly, the requirement of a wideband antenna in the traditional method is absent since the filtenna is codesigned as a single device requiring a single bandwidth specification. This makes the codesign method relatively less complex. Thirdly, this method can improve the higher order harmonics suppression in the resulting filtenna as a single integrated device means less harmonics. Fourthly, this technique can significantly improve the bandwidth and frequency selectivity of the filtenna since the radiating and filtering functionalities are both integrated into a single device with no external coupling device (i.e., the 50-ohm transmission line connector in the traditional design method). The drawback associated with the codesign method is that a BPF must first be designed as a foundation to the proposed filtenna. The BPF is then modified by replacing the last resonator with a radiating element as reported in [44].

**2.3. Fusion Method.** This is the state-of-the-art technique of filtenna development which is recently gaining popularity due to its added merit of not establishing an extra filtering circuit in the filtenna design process, as reported in [47–53]. This design approach involves the modeling of filtennas as parallel schematic circuits, as shown in Figure 5. The fusion method combines resonant elements in parallel with an antenna to produce bandstop functionalities at both ends of the passband. This technique normally results in radiation nulls in proximity to the edges of the band. The radiation nulls facilitate the control of the frequency selectivity and the bandwidth of the filtenna. In addition to the merits of the codesign method over the traditional cascaded method, the fusion method achieves a lower insertion loss and higher efficiency since this method does not require a separate BPF before modifications, as is the case with the codesigned method discussed in Section 2.2. Liang et al. [47] applied the fusion method in the development of a microstrip filtenna with gain-filtering response. The filtenna involves an E-shaped radiating element and a U-shaped coupling element slotted into the E-shaped element, as shown in Figure 6. The design is proposed for application in orbital angular momentum filtennas, as investigated and reported in [47].

**2.4. Comparison of Filtenna Design Methods.** The evolution of filtenna design methods from the cascaded filter and antenna technique to the codesign/synthesis technique and currently the fusion technique has been investigated and



(a) (b)  
 FIGURE 3: A cascaded filter and antenna design. (a) Layout. (b) Performance [34].



(a) (b) (c)  
 FIGURE 4: A codesigned filtenna. (a) Schematic circuit. (b) Layout. (c) Performance [44].

reported. The merits and demerits of all three techniques have also been discussed extensively. This subsection is dedicated to the comparison of the three techniques as a way of summarizing the advantages and disadvantages of all three design methods as presented in Table 1.

### 3. Filtenna Implementation Techniques

This section discusses the various technologies that have been employed in the implementation of filtennas. Some of the popular and commercially available technologies

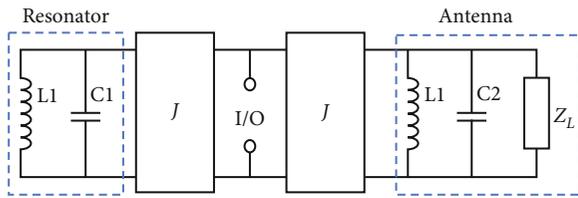


FIGURE 5: Schematic circuit of a filtenna developed by fusion method.

discussed in this section for filtenna implementation include microstrip, waveguide, and SIW. Several researchers have also reported filtennas that are implemented on hybrid technologies and some other technologies including coaxial resonator and 3D metal structures.

**3.1. Microstrip Filtenna.** Microstrip is a planar transmission line technology and perhaps the most established technology employed in the implementation of microwave components including filters [103] and antennas [104]. Its popularity is because it can be fabricated by simple micromilling and photolithographic processes. Microstrip filtennas are cost-effective, simple to design and implement, easy to manufacture/fabricate, and easy to integrate with other planar components in a system. They are also of compact size, leading to profound miniaturization in systems where they are used as subsystems. Despite all the listed benefits of microstrip filtennas, they do suffer from low power handling capability and high radiation loss. Microstrip filtennas are very effective for low-frequency applications but ineffective for millimeter-wave applications. Due to the benefits and wide popularity of the microstrip technology, several researchers have reported filtennas [45, 47, 80, 105–109] implemented with the transmission line. Mansour et al. [45] proposed a microstrip filtenna developed by means of the synthesis design approach discussed in Section 2.2. The design was based on a third-order hairpin resonator Chebyshev BPF operating at a center frequency of 2.0 GHz. To achieve the filtenna response, the last hairpin resonator of the BPF was replaced by a radiating microstrip patch resonator to maintain the third-order feature of the design thereby achieving compactness. The design achieved  $-10$  dB bandwidth of 3.64% and 3.50% for the simulation and measurement results, respectively. In another recently published literature, Liang et al. [47] discussed a microstrip filtenna developed using the fusion method covered in Section 2.3. The design was achieved without the need for an extra circuit which means improved miniaturization. The proposed filtenna which finds application in orbital angular momentum was achieved by combining an E-shaped radiator with a slotted U-shaped coupling structure. The filtenna was developed to operate at a bandwidth of 3.28–3.51 GHz and achieved a peak gain of 6.68–9.04 dBi at the operational band. Tang et al. [80] investigated a compact microstrip patch filtenna array developed on a reusable high-order SIW cavity. The SIW cavity incorporated into the design acted as the first-stage resonator of the component BPF, while also serving as the four-way power divider witnessed in the power mode

allocation. The reported filtenna operated at a center frequency of 13.6 GHz and achieved a peak gain of 13 dBi and 90% peak efficiency. Li et al. [105] reported a single-layer wideband differentially fed dual-polarized filtenna operating at 4.6 GHz, with low cross-polarization. The reported filtenna is composed of four driven and four parasitic microstrip patches and generated two in-band resonances. It also generated three out-of-band radiation nulls and realized a good two-pole bandpass filtering function. The reported bandwidth is 19.5% of the operational center frequency of the filtenna, with a maximum gain of 6.6 dBi. Saleh et al. [106] investigated a compact linearly polarized 5G Vivaldi nonuniform slot filtering antenna operating at 6.55 GHz, with stable radiation patterns and enhanced fractional bandwidth of 2.91%. The filtenna realized a maximum gain of 4.96 dBi. The codesigned filtenna relied on the Vivaldi nonuniform slot antenna profile for its radiation function and achieved its filtering by means of three microstrip hairpin resonators. Wang et al. [107] proposed a wideband self-decoupling dielectric patch filtenna utilizing two lossy microstrip patches designed to resonate at 5.2 GHz, with a fractional bandwidth of 18.46%. The reported filtenna achieved a maximum measured gain of 7.5 dBi, as shown in Figure 7. Li et al. [108] presented a wideband filtering patch antenna loaded with T-shaped strips and relying on a lossy microstrip patch for its radiation function. The patch was designed to resonate at 2.5 GHz with a fractional bandwidth of 16.1%. The proposed filtenna achieved high selectivity, two radiation nulls at 2.23 and 2.81 GHz, and a maximum gain of 9.6 dBi. In [109], Guo et al. proposed a  $2 \times 2$  wideband filtering patch antenna array that exhibited high aperture efficiency and achieved good filtering function. The design employed a lossy patch antenna resonating at 6.65 GHz with a fractional bandwidth of 27.4%. The reported filtenna achieved a maximum gain of 14.2 dBi.

**3.2. Waveguide Filtenna.** Waveguides are one of the earliest transmission line technologies that are still in demand in the 21st century. They are still the best option for high-power and precision test applications. Waveguide filtennas are known for their low insertion loss, high-quality factor, and high-power handling capabilities. The main issue with waveguide filtennas is linked to their bulky size. They are also very expensive and challenging to manufacture when compared to microstrip filtennas. Waveguide filtennas are the best option for high-frequency systems and applications. Numerous researchers have reported filtennas implemented on the waveguide technology [110–114]. Haider et al. [110] applied coupled-resonator theory in developing a wideband filtenna that operates at 9.3 GHz with a fractional bandwidth of 23% and exhibited transmission zero in the upper stop-band. The design proposed a novel frequency-variant coupling network, produced the transmission zero, achieved compactness, and realized higher selectivity. The resulting waveguide filtenna achieved a maximum gain of 3.53 dBi, as shown in Figure 8. In [111], Chen et al. proposed a waveguide slot filtenna array that employed gap waveguide feed network technology. The filtenna component was realized by integrating a high-order gap waveguide cavity and a slot

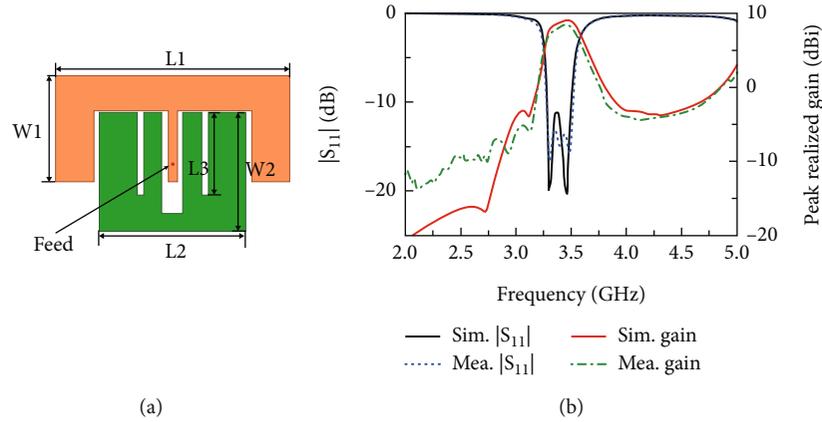


FIGURE 6: Filtenna designed by fusion method. (a) Layout. (b) Performance [47].

TABLE 1: Comparison of the three standard filtenna design methods.

Attribute	Cascaded	Codesign	Fusion
Size	Produces bulky filtenna devices due to the use of independently designed filters and antennas and a matching interface	Produces medium sized filtenna devices due to the absence of a matching interface	Needs no extra filtering element and no matching interface leading to an effective size management
Insertion loss	Higher insertion loss due to the presence of matching interface	Moderate insertion loss due to the absence of a matching interface	Moderate insertion loss due to the absence of matching interface
Complexity	Complex design	Moderately simple design	Simple design
Bandwidth	Requires wideband antenna and may result in bandwidth mismatch between the antenna and BPF components	Better bandwidth matching due to the absence of a matching interface	Best bandwidth matching and the bandwidth may be controlled by the radiation nulls
Efficiency	Poorly efficient	Moderately efficient	Highly efficient
Popularity	Traditional method with declining popularity	Most popular method that is well established	State-of-the-art method with growing popularity

antenna. The proposed design operates at 60 GHz with a fractional bandwidth of 1.87% and achieved a maximum gain of 15.9 dBi. In another research paper [112], Yang et al. presented a highly selective dual-band filtenna that operated at 2 mm-wave center frequencies of 27 and 31 GHz with the respective fractional bandwidths of 5.0% and 6.85%. The design was based on a 3D printed half-mode gap waveguide quadruple-mode resonator and achieved maximum gains of 7.8 and 7.5 dBi at the lower and upper bands, respectively. Qi et al. [113] reported a wideband waveguide filtenna using the stepped impedance resonator (SIR). The waveguide SIR operated at a center frequency of 11 GHz with a fractional bandwidth of 49.6% and achieved three resonance modes, ensuring the filtenna bandwidth is widened from 1.9 to 5.0 GHz. The resulting waveguide filtenna achieved a maximum gain of 10 dBi. In a related research paper [114], Shi-Shan et al. proposed a conical beam filtenna operating at 35 GHz with a fractional bandwidth of 6.29%. The filtenna is composed of a five-way radial filtering power divider and a circular open waveguide. The design was fabricated on metallic waveguides to achieve a maximum gain of 7.83 dBi and a reduced insertion loss at Ka-band.

3.3. *SIW Filtenna*. SIW is a 21st century transmission line technology that combines the benefits of planar technologies (e.g., microstrip) with those of waveguide technologies.

Hence, SIW performs well in both low- and high-frequency applications [115–117]. SIW filtennas are easy to manufacture and can easily be integrated with planar components within a system. The growing popularity of the SIW technology means that several researchers have recently been utilizing it in the implementation of filtennas [118–123]. Guo et al. [118] reported a dual-band SIW filtenna operating at 2.82 and 4.08 GHz for the lower and upper bands, respectively. The impedance fractional bandwidth for both bands is 2.1% and 4.1%, respectively. The designed filtenna utilized the fundamental resonant mode and half-mode SIW architectures in achieving miniaturized circuit and uniform radiation characteristics at the two passbands. The developed SIW filtenna recorded 4.90 and 5.38 dBi maximum gains at the lower and upper passbands, respectively. In [119], Kant et al. proposed a half-mode SIW leaky wave filtenna that operates within 7.7–10.9 GHz, which is a fractional bandwidth of 34.4%. The filtenna realized the bandpass filtering function by means of periodic radiating slot elements on the high-low impedance SIW cavity employed in the design. The proposed filtenna achieved a maximum gain of 14 dBi with a variation of 2 dB in the operating range. In another research paper [120], Wang et al. presented a compact harmonic suppressed SIW filtenna implemented on high-order half-mode SIW cavity. The reported filtenna operates at 5 GHz center frequency with

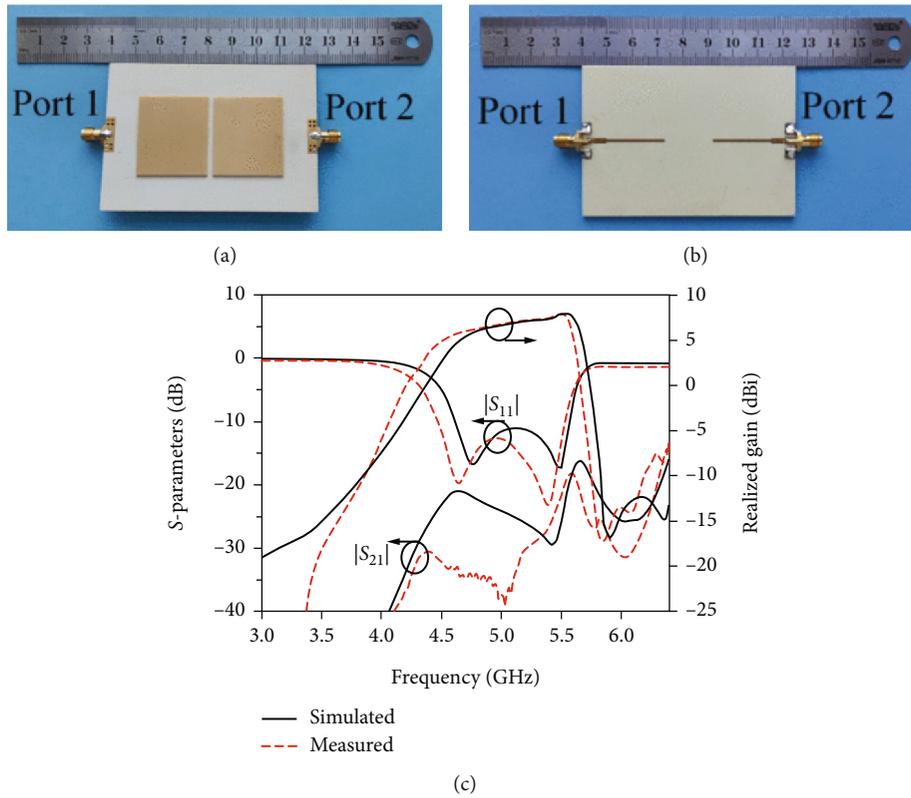


FIGURE 7: Microstrip patch filtenna. (a) Top view. (b) Bottom view. (c) Performance [107].

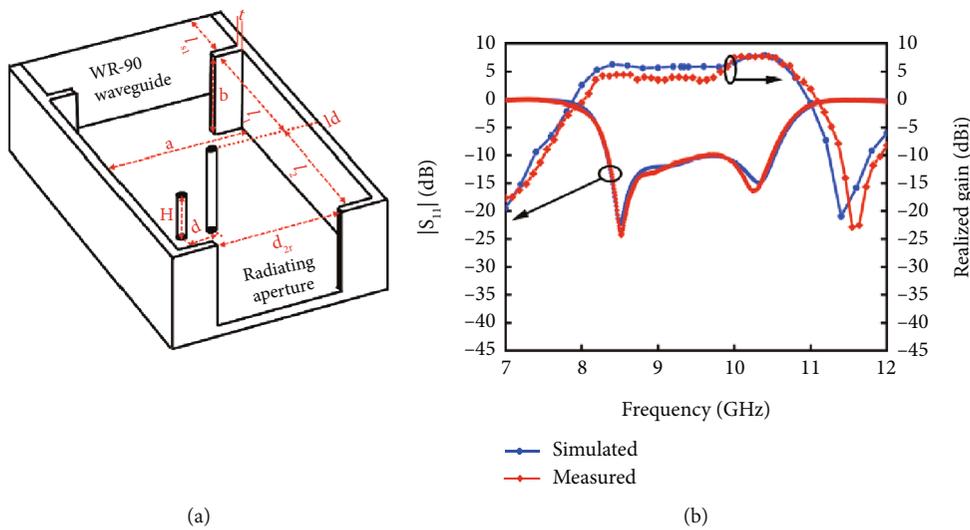


FIGURE 8: Waveguide filtenna. (a) Layout. (b) Performance [110].

an impedance fractional bandwidth of 14.4%. The design achieved a 76.3% device miniaturization and a maximum gain of 7.0 dBi. Huang et al. [121] investigated a millimeter-wave bidirectional SIW filtenna array. The feeding network employed in the design is an SIW filtering power divider operating at a center frequency of 27.5 GHz with a fractional bandwidth of 3.4%. The filtenna is designed for 5G applications and achieved a maximum gain of 5.4 dBi. A compact millimeter-wave wideband filtenna array is

reported in [122]. The circularly polarized  $8 \times 8$  filtenna array utilized a 16-way SIW feeding network operating at 28 GHz with an impedance fractional bandwidth of 14.4%. The design achieved a high gain of 23.9 dBi with high out-of-band rejection, better than 39 dB. Wang et al. [123] reported a single-band SIW filtenna that exhibited two controllable radiation nulls, one in the lower stopband and the other in the upper stopband. The radiation nulls were generated by means of an electric and magnetic mixed coupling

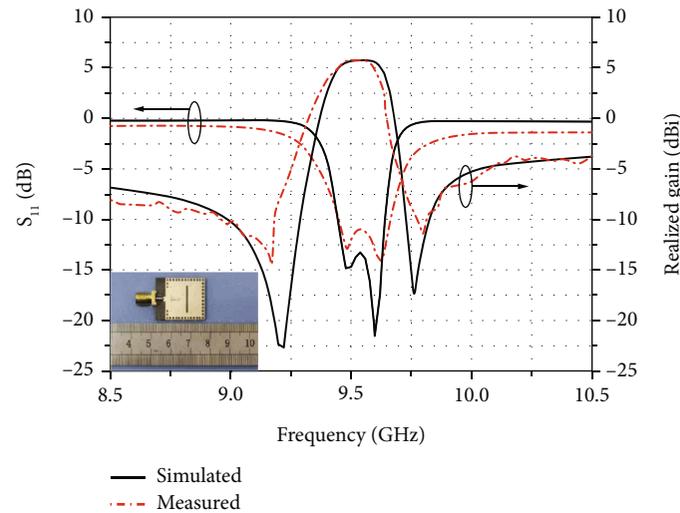


FIGURE 9: Image and performance responses of an SIW filtenna [123].

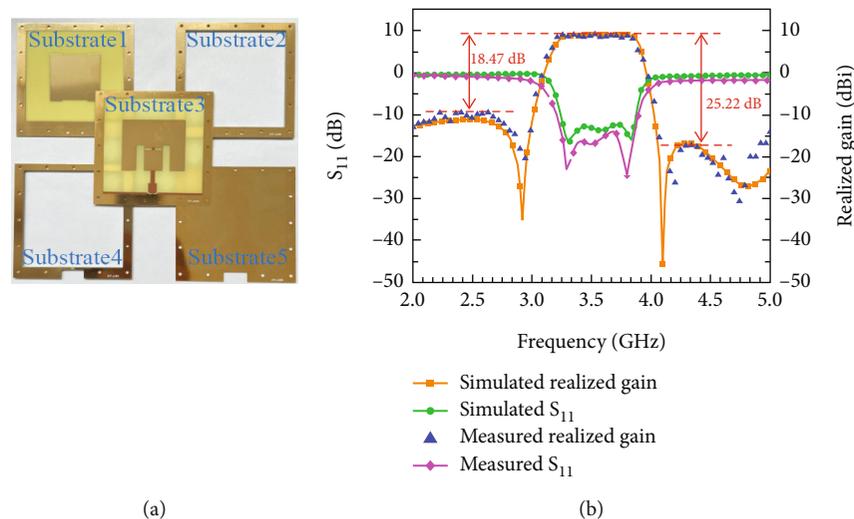


FIGURE 10: Hybrid filtenna. (a) Prototype. (b) Performance [124].

structure, and the fundamental mode enhanced the radiation function of the filtenna. The design was made to operate at a center frequency of 9.6 GHz with an impedance fractional bandwidth of 2.53% and achieved a maximum gain of 5.8 dBi, as shown in Figure 9.

**3.4. Hybrid Filtenna.** Due to the simplicity at which microstrip and SIW components can be integrated to produce a subsystem, several researchers have recently reported hybrid filtennas [124–128] based on the integration of the two conventional transmission lines. Yan et al. [124] proposed a filtenna implemented using stacked microstrip patches and substrate integrated suspended line (SISL). The filtenna operated within the frequency band of 3.20–3.89 GHz resulting in a fractional bandwidth of 19.5%. The design is composed of a rectangular patch, a square stacked patch with grooves, and a segmented feedline. The hybrid filtenna achieved a maximum gain of 9.21 dBi with an out-of-band suppression level better than 18.47 dB, as shown in

Figure 10. Hu et al. [125] reported a single-layer filtenna with controllable radiation nulls, operating at a center frequency of 4.88 GHz and a fractional bandwidth of 9.0%. The filtenna design was differentially fed, implemented using a hybrid of microstrip patches and SIW cavities, and achieved a maximum gain of 7.7 dBi. Li and Deng [126] investigated a single-layer filtenna with two controllable radiation nulls and operated within the frequency band of 3.44–3.62 GHz, a fractional bandwidth of 5.1%, and implemented using a hybrid of SIW and triangular microstrip patch resonators. The design achieved high selectivity and a maximum gain of 7 dBi. In another research paper [127], Yan et al. presented a low sidelobe filtenna array based on higher order mode SIW cavity and microstrip patches. The reported  $1 \times 3$  filtenna array operated at the center frequency of 13.2 GHz with a fractional bandwidth of 3.4%. The simulation and measurement results indicated that a maximum gain of 11.6 dBi and an efficiency of 85% were achieved. The sidelobe levels in the E-plane are both measured to be

lower than  $-19.1$  dB. Zhao et al. [128] employed the microstrip patch resonator and the SIW cavity in the development of a high-gain dual-polarized millimeter-wave filtenna array operating at a center frequency of 28 GHz with a 16.5% impedance bandwidth. Filtering slots were etched around each of the microstrip patches to improve the selectivity of the proposed filtenna array. The design improved on the operating bandwidth and formed a radiation null at the lower band edge by utilizing the SIW feedline. A maximum gain of 20.1 dBi was realized in the design response.

**3.5. Other Filtenna Implementation Techniques.** Some recently published articles have reported filtennas implemented based on coaxial resonators [129–132] and 3D metal [133–135] structures. Filtennas implemented using the coaxial resonator structure promise higher gains, while those implemented on the 3D metal printing technology have recently been attracting a lot of interest due to the numerous interdisciplinary collaborative research efforts going on in the field of 3D printing technology. Zhao and Psychogiou [129, 132] proposed the development of coaxial resonator-based filtennas using the stereolithography apparatus 3D printing technique. The design employs the codesign method and uses a coaxial cavity resonator and an annular slot antenna component that performs the radiating function. The proposed filtennas in [129] operated at the center frequencies of 4.75, 4.80, and 4.60 GHz; the fractional bandwidths of 0.074, 0.083, and 0.076; and achieved peak gains of 5.5, 2.6, and 2.6 dBi, respectively. In another related literature, Mejillones et al. [130] reported a circularly polarized coaxial horn filtenna that finds application in electromagnetic interference mitigation. The design is based on the insertion of radial stubs into a coaxial horn antenna to produce transmission zeros at their resonant frequency, thereby producing a stopband filtering and preserving the polarization. The reported filtenna achieved a measured aperture efficiency of between 41% and 45% in the passband, which is comparable to the standard canonical horn antenna efficiency of between 46% and 50%. In a recent paper published in June 2025, Zhan et al. [131] investigated a state-of-the-art high-gain circularly polarized omnidirectional filtenna based on the coaxial resonator structure. To achieve the filtenna function, four perpendicular slot pairs were used to form the basic omnidirectional circularly polarized radiation element, which is cut into the sleeves and added to the outer conductor of the coaxial resonator cavity. The filtenna achieved a peak gain that is consistently higher than 5.29 dBi across the operational bandwidth. Zhang et al. [133] proposed a full-metal omnidirectional filtenna array based on the 3D metal printing technology. The design is composed of an outer metal shell, a built-in metal post, and three pairs of open circuit branches. The horizontal omnidirectional radiation was achieved by having a circular groove dug on the outer metal shell. The filtenna operated between 2.79 and 2.875 GHz, achieved a peak gain of 6.6 dBi, and a measured out-of-band suppression of 28 dB. Cui and Zhang [134] reported a metallic 3D printed modularized dual-stopband artificial magnetic conductor (AMC)-loaded waveguide slot filtenna. The design operated between

9.25 and 10.6 GHz and achieved a peak gain of 10 dBi across the passband. In a related article, Xu et al. [135] investigated a 3D printed dual-band circularly polarized filtenna with self-diplexing characteristics for millimeter-wave applications. The design is composed of a dual-channel filtering feeding circuitry, a parallelogram-shaped radiator, and a dual-band tapered polarizer. The fabricated filtenna featured overlapped bandwidths of 3.0% and 2.1%, with isolations of greater than 60 and 27 dB in the distinct channel bands.

**3.6. Comparison of Filtenna Implementation Technologies.** Now that the three most popular filtenna implementation techniques have been investigated and reported extensively, this subsection is dedicated to presenting a tabular comparison of the microstrip, the waveguide, and the SIW filtennas as presented in Table 2.

## 4. Recent Filtenna Developments and Applications

This section is dedicated to the state-of-the-art developments in filtenna design. Various researchers have reported novel and interesting advancements in the design and implementation of filtennas. The majority of recently reported filtenna advancements may be grouped into reconfigurable filtennas, defected ground structure (DGS) filtennas, multilayered filtennas, duplexing/multiplexing filtennas, and a host of others not discussed in this article.

**4.1. Reconfigurable Filtenna.** Recent developments of filtennas are based on reconfigurable structures that have become popular in overcoming the limitations associated with congested RF front end and other wireless communication applications. This is because reconfigurable filtennas can vary their operations by simply adjusting their electrical properties/configurations. Hence, this type of filtenna helps reduce the need for different subsystems performing different operations within a system, ensuring the system hardware requirement is compact and simple. In [48], Hu et al. realized reconfigurability in their filtenna design by relying on five varactors for frequency tuning. The design achieved less complexity by supplying only two sets of bias voltages to the frequency adjustment process. The reported filtenna achieved a 19.6% tuning range of 2.53–3.08 GHz. The stopband suppression level within the tuning range exceeded 10 dB. In another research paper, Rodrigues et al. [81] reported a reconfigurable filtenna for mobile satellite application. In the design, a 29 GHz uplink mode microstrip patch is surrounded by a copper structure that resonates at a lower frequency of 20 GHz once connected through a pin diode. Abdelghany et al. [136] proposed a filtenna that finds application in cognitive radio and wireless systems. The design achieved reconfigurability by utilizing four varactor diodes embedded in the BPF component linked to the patch antenna via a feedline, as shown in Figure 11. In [137], Gangwar and Alam reported a filtenna that utilized two switches in a switchable complementary split ring resonator BPF and antenna to achieve reconfigurability. The design finds applications in WLAN and WiMax. Das and Sarkar

TABLE 2: Comparison of the three standard filtenna implementation techniques.

Attribute	Microstrip filtenna	Waveguide filtenna	SIW filtenna
Physical device size	Highly compact	Bulky	Moderately compact
Radiation loss	High	Low	Highly reduced
Manufacturing	Needs demanding production considerations at high frequencies but easy at low frequencies	Challenging to manufacture	Relatively easy to manufacture both at low and high frequencies
Power handling capability	Low	High	Very good
Cost	Not expensive	Very expensive	Cost-effective
Integration with planar devices	Easy	Difficult	Easy
Application	Excellent at low frequency but ineffective at high frequency	Excellent at high frequency but ineffective at low frequency	Excellent at both high and low frequencies

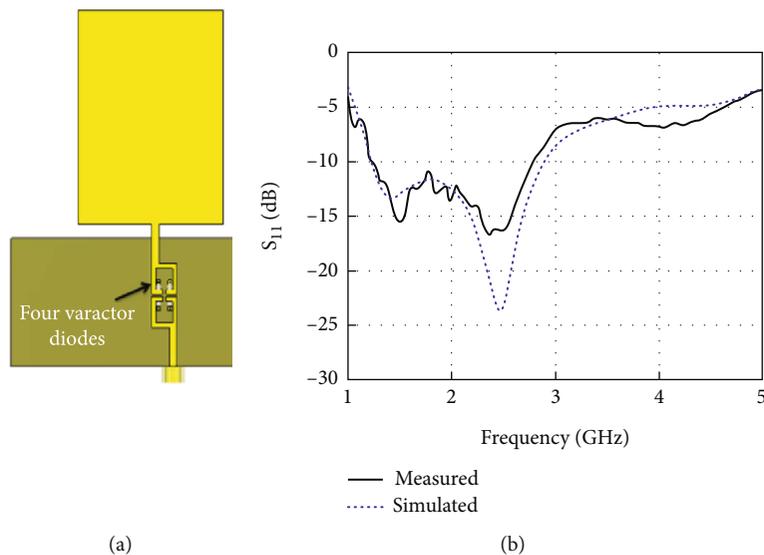


FIGURE 11: Reconfigurable filtenna. (a) Configuration. (b) Performance [136].

[138] proposed another filtenna for WLAN and WiMax applications. In their design, pin diodes were connected to the edges of the innermost resonators to enable switching of operation from dual band to two separate passbands and, hence, achieving reconfigurability.

**4.2. DGS Filtenna.** This section discusses filtennas incorporating DGS in their development. In DGS-based filtennas, the component antenna is integrated into a DGS-based BPF to form a single filtenna subsystem. The defected structure is mostly implanted into the ground plane of the component antenna. The introduction of DGS into a filtenna subsystem contributes to an improved cross-band isolation, as explained in [139–142]. The recent popularity of the DGS in the development of filtennas has encouraged numerous researchers to propose filtennas incorporating DGS-based BPFs. Wang et al. [143] proposed a codesigned filtenna that incorporated a U-shaped patch that acts as the radiator and last stage of the DGS-based filter. The DGS is etched onto the ground plane of the filtenna subsystem and ensures the realization of lower stopband suppression, improved impedance matching, and expanded bandwidth. The proposed filtenna operated at a center frequency of

5.1 GHz and achieved a maximum gain of 3.88 dBi, as shown in Figure 12. Ibrahim et al. [144] investigated a tunable filtenna with DGS-loaded resonators. The proposed filtenna finds application in cognitive radio systems based on software-defined radio transceiver. The design is based on a DGS-based BPF realized by utilizing two coupled DGS resonators and two coupled microstrip transmission lines terminated by two stubs. The filtenna achieved tunability by employing four varactor diodes inserted in the BPF. The filtenna was designed to initially operate within the frequency range of 1.3–3.0 GHz, but the four varactor diodes may be used to tune the filtenna to operate from 2.7 to 2.0 GHz as the capacitance varies from 1.55 to 2.67 pF. In another research paper [145], Tanguturu et al. introduced the DGS in their proposed filtenna to achieve rejection of radiation from unwanted frequencies.

**4.3. Multilayer Filtenna.** Filtennas developed based on multilayered structures have recently been gaining popularity. This is due to their compactness leading to a reduced footprint of the RF front end or other wireless systems where they are applied. Filtennas developed based on multilayered structures are usually made of stacked resonators and a

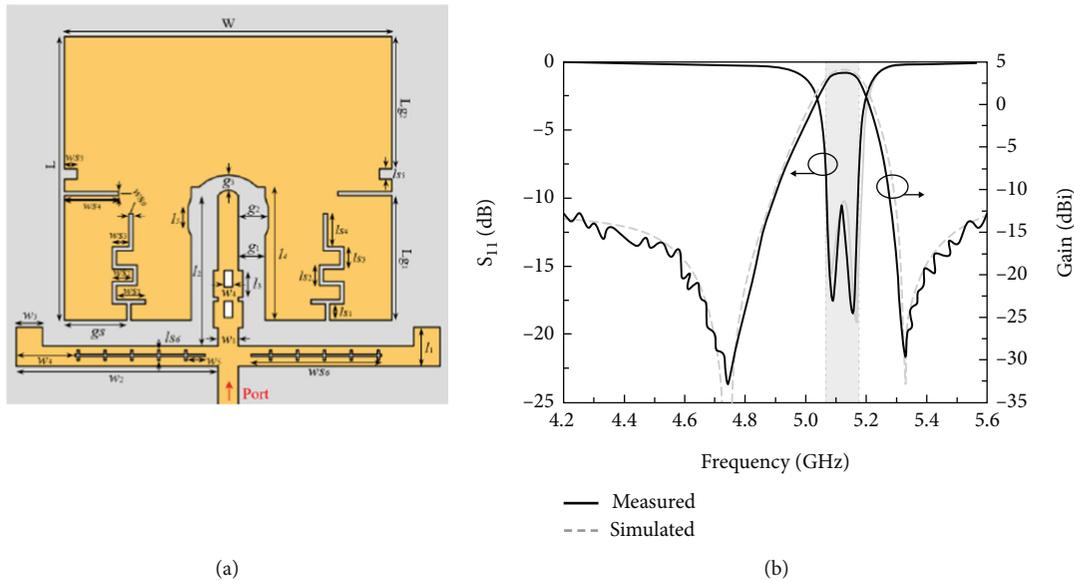


FIGURE 12: DGS filtenna. (a) Configuration. (b) Performance [143].

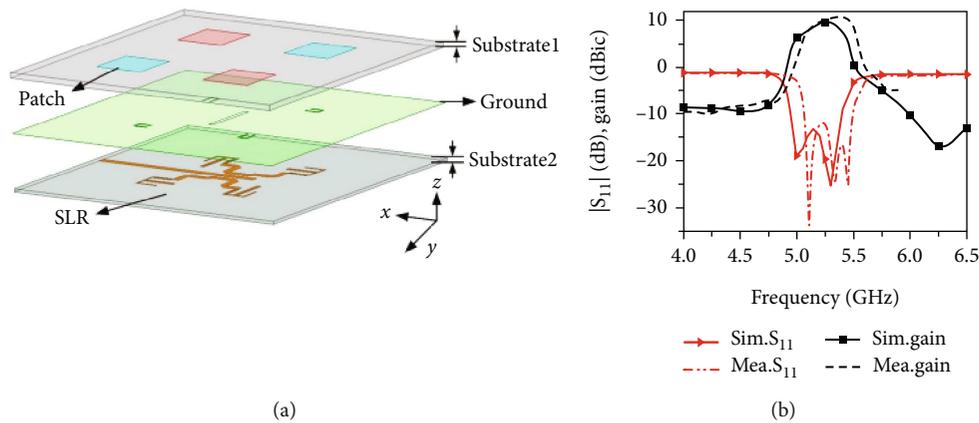


FIGURE 13: Multilayer filtenna. (a) Configuration. (b) Performance [146].

specialized feeding network, as reported in [146–150]. This filtenna development approach normally gives rise to ideal combined filtering and radiating performances while simultaneously achieving subsystem miniaturization. Guo et al. [146] proposed a circularly polarized filtenna array by employing stacked filtering phase shifting theory. The design was based on a slot-coupled feeding network and utilized four sequentially rotated elements with phases of  $0^\circ$ ,  $90^\circ$ ,  $180^\circ$ , and  $270^\circ$ . The proposed filtenna achieved a maximum gain of 10.4 dBi and an impedance bandwidth of 8.1% (i.e., 5.05–5.40 GHz), as shown in Figure 13. In another research paper, Farahani et al. [147] presented a filtenna array based on a distributed coupled-resonator structure. The design was implemented using multilayered SIW cavities and achieved a compact size, low profile, low cost, easy fabrication process, and a high-performance filtenna array. Huang et al. [148] reported a multilayered microstrip patch filtenna that achieved high out-of-band suppression levels. The first layer of the reported design is composed of a parasitic microstrip rectangular patch implanted on Substrate 1, while the sec-

ond layer is a rhombus-shaped patch implanted on Substrate 2. The third layer is a rectangular feeding strip located on Substrate 3. The proposed filtenna achieved a wide bandwidth of 2.4% (i.e., 2.05–2.32 GHz). It also realized high suppression levels of 26.1 and 20.6 dB at low and high out-of-band frequencies, respectively. Cheng et al. [149] investigated a high-gain circularly polarized filtenna based on a stacked patch antenna and a filtering network. The lower stack contains a low radiation patch consisting of a square outer loop and a three-quarter circular inner ring linked to two adjacent edges of the outer loop. The upper stack delivers improved impedance matching and circular polarization within the proposed filtenna passband. The reported filtenna achieved a high gain of 7.0 dBi, an impedance bandwidth of 15.2% (i.e., 1.83–2.13 GHz), and an axial ratio bandwidth of 8.2% (i.e., 1.87–2.03 GHz). Kuosmanen et al. [150] employed the multilayer structure in proposing a dual-polarized wideband filtenna array. The stacked PCB structure is composed of simple two-sided PCBs that are stacked on top of each other and connected by means of vias

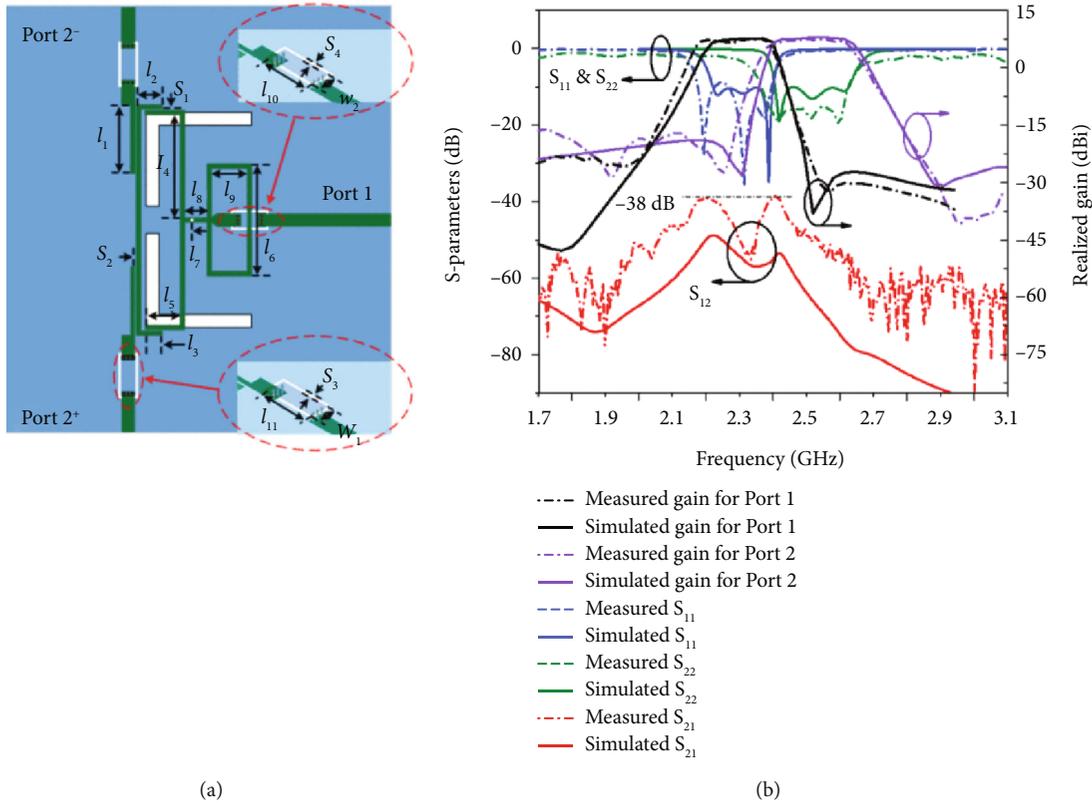


FIGURE 14: Duplexing filtenna. (a) Configuration. (b) Performance [151].

to form a tapered slotline along the surface normal to the PCBs. To achieve the desired filtering effect in the filtenna, the tapered slotlines are corrugated to provide an effective space-saving integration of the filter into a half-wavelength lattice. The design's predicted infinite array performance in the passband is a fractional bandwidth of 102% (i.e., 6.0–18.5 GHz).

**4.4. Duplexing Filtenna.** The need to decongest the RF front end of wireless communication systems is the main motivation for proposing duplexing filtennas in the first place. The reason being that duplexing filtennas not only have filtering and radiating functions like all other filtennas discussed so far in this article but also utilize a single channel in transmitting and receiving signals. This added advantage makes the duplexing filtenna a subsystem of interest which is currently gaining the attention of numerous researchers. Qian et al. [151] proposed a compact dual-polarized duplexing filtenna that achieved high isolation of 34 and 38 dB across the transmit and the receive bands, respectively. The design offers a novel feeding network that is composed of an all-resonator structure and achieves good filtering functions and radiation gains across both bands, as shown in Figure 14. Liu et al. [152] reported a low-profile duplexing filtenna that depicted high roll-off and high isolation in the response curves. The reported duplex filtenna is composed of a ground plane, two feeding networks, and two slot radiation elements. Maithani and Gangwar [153] investigated a compact duplexing filtenna array for application in vehicular communication connectivity. Liang and Chen [154] proposed a

duplexing filtenna employing hanging resonators. The filtenna is composed of seven cavities and achieved high isolations better than 39.4 and 34.5 dB in the lower and higher frequency bands, respectively. Althuwayb and Kumar [155] reported a resonator-based duplexing filtenna implemented on the SIW technology. The proposed design is composed of two feedlines and a common SIW cavity. To achieve half-mode resonator behavior in the SIW cavity, they carved a rectangular slot on the top side of the cavity, along the thin side. The reported duplexing filtenna exhibits an impedance bandwidth of approximately 3.0% (i.e., 8.63–8.88 GHz) in the lower passband and 4.2% (i.e., 9.26–9.66 GHz) in the upper bandwidth. The measured maximum gains are 3.51 and 4.10 dBi in the lower and upper passbands, respectively. In another research paper, Hu et al. [156] investigated a compact vertically integrated duplexing filtenna employing radiating SIW cavities and a common feedline. The proposed duplex filtenna exhibits an impedance bandwidth of approximately 3.2% (i.e., 4.03–4.16 GHz) in the lower passband and 3.9% (i.e., 4.81–5.0 GHz) in the upper bandwidth. The measured maximum gains are 4.36 and 4.83 dBi in the lower and upper passbands, respectively.

## 5. Challenges and Future Opportunities in Filtenna Development

The growing interest in the development of filtennas to meet the current demands of modern-day wireless communication systems, particularly the RF front end of systems, means researchers are continuously investigating novel techniques

to overcome the challenges associated with existing filtenna subsystems. Some of these challenges are intertwined and include reconfigurability, improved efficiency, miniaturization, multifunctionality, and so on. Though reconfigurable filtennas are popular nowadays as they can adjust their properties thereby reducing the number of subsystems needed to perform different operations within a system, their design requires complex configurations to achieve reconfigurability. This challenge has recently been overcome by employing varactor diodes as explained in [48, 81, 136] to achieve the required frequency tuning, thereby largely simplifying the design configuration. The challenge of achieving improved efficiency in filtenna development may be overcome by employing multimode resonators in their design configuration as proposed in [73, 112, 127, 157]. The multimode resonators have been found to be very useful in minimizing the filtenna insertion loss to the tolerable minimum. They also lead to highly miniaturized filtenna subsystems based on the number of modes in operation. A dual-mode resonator, for instance, will reduce the filtenna device footprint by 50%. The challenge of achieving multifunctionality in filtenna subsystems has recently been gaining popularity particularly in the implementation of duplexing filtennas [151–156]. This class of filtennas does not only contribute to the compactness of a system but also has multiple functions including frequency filtering and selectivity, radiation, and the use of a single channel to transmit and receive signals. Millimeter-wave filtennas [158, 159] have been attracting increased interest from researchers due to their ability to reduce the complexity and size of systems while also considerably reducing the cost. Their development process has greatly benefited from the advantages of the SIW transmission line technology discussed in Section 3.3 of this article. Hybrid filtennas [160, 161] have also been implemented to overcome the poor integration challenges associated with waveguide filtennas. This class of filtennas combines the benefits of microstrip technology (including low cost, compact size, and ease of integration) with the advantages of the SIW technology (including low radiation loss and very good power handling capabilities) in a single subsystem. By this, high-frequency operational subsystems can be achieved without the need to worry about the bulky nature of waveguide technology.

The common challenges associated with filtenna development may be summarized in bullet points as follows:

- **Reconfigurability:** The capability of a filtenna to adjust its characteristics including operating frequency, bandwidth, and selectivity to facilitate utilization in various applications. This challenge may be overcome by introducing varactor diodes in the filtenna development process. The varactor diodes are used to switch between the different possible configurations for different applications.
- **Improved efficiency:** The challenge of achieving improved efficiency in filtenna development is directly linked to the utilization of a minimal number of connectors between the subcomponent filters and antennas. The codesign and fusion methods covered in Sections 2.2 and 2.3, respectively, have been successful in achieving minimal insertion loss, thereby improving the efficiency of the resultant filtenna.
- **Miniaturization:** Multimode resonators are known to be useful in overcoming the bulky size of integrated components, and this is true for filtennas. Dual-mode resonators, for example, can reduce the filtenna size by up to 50% when utilized in the development process.
- **Multifunctionality:** The ability to integrate multiple functions into a single filtenna device. Duplexing filtennas are recent designs that have achieved multifunctionality of frequency selectivity, signal radiation, and the use of a single channel to both transmit and receive signals.

There are growing opportunities challenging the current state of the art in filtenna development. Some of these paradigm-changing investigations have been recently proposed in a few research papers. Rao and Ram [162] investigated the techniques for enhancing frequency selectivity in the filtenna development process by utilizing controllable radiation nulls. The effective rejection of out-of-band frequencies in filtennas is greatly linked to the proper utilization of radiation nulls, as explained in the article. Advancements in wideband filtennas [163–165] are also a growing area that needs more exploration by researchers. Dual-polarized [163] and circularly polarized [164] filtennas have been investigated and reported for application in wireless systems requiring wideband operations. A new class of filtennas that is developed based on coaxial resonators [129–132] has recently been proposed. These filtennas promise higher gains and are developed using the codesign method discussed in Section 2.2 of this article. Zhang et al. [133] utilized 3D metal printing technology in the development of a full-metal omnidirectional filtenna array. This is an interesting area of research that is currently attracting a lot of interest from the research community due to the popularity and wide application of the 3D technology in numerous fields of human endeavors. A lot of interdisciplinary collaborative work is currently ongoing that utilizes the 3D technology, and microwave engineers will not want to be left out.

## 6. Conclusions

An extensive review of filtenna design and implementation techniques, applications, recent developments, challenges, and future opportunities has been discussed in this article. The review commenced with an investigation into filtenna design evolution starting from the cascaded filter and antenna approach to the codesign method, and then the fusion method. The different technologies that have been reported for filtenna implementation were also discussed including microstrip, waveguide, and SIW. The advantages and disadvantages of these technologies were extensively reported, and their integration to achieve hybrid filtennas was highlighted. The current state of the art, emerging

research, and future opportunities in filtenna developments have also been covered. This article is a brilliant reference resource for RF and microwave students, engineers, researchers, policymakers, and anyone who may be interested in the development of filtennas.

## Data Availability Statement

No datasets were generated or analyzed during this study.

## Conflicts of Interest

The authors declare no conflicts of interest.

## Author Contributions

**Augustine O. Nwajana:** conceptualization, methodology, data curation, investigation, supervision, writing—original draft; **Stella N. Arinze:** validation, visualization, resources, project administration, software, writing—review and editing; **Solomon H. Ebeonuwa:** formal analysis, funding acquisition, writing—review and editing. All authors have read and agreed to the contents of the manuscript.

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## References

- [1] M. A. Saeed, E. R. Obi, and A. O. Nwajana, "A Compact Linear Microstrip Patch Beamformer Antenna Array for Millimeter-Wave Future Communication," *Sensors* 24, no. 13 (2024): 4068, <https://doi.org/10.3390/s24134068>.
- [2] K. S. K. Yeo and A. O. Nwajana, "A Novel Microstrip Dual-Band Bandpass Filter Using Dual-Mode Square Patch Resonators," *Progress in Electromagnetics Research C* 36 (2013): 233–247, <https://doi.org/10.2528/PIERC12120312>.
- [3] A. O. Nwajana and R. Paul, "Three-Way Equal Filtering Power Divider for Modern Communication Systems," *Engineering Reports* 7, no. 1 (2025): e13036, <https://doi.org/10.1002/eng2.13036>.
- [4] C. X. Mao, Y. Zhang, X. Y. Zhang, P. Xiao, Y. Wang, and S. Gao, "Filtering Antennas: Design Methods and Recent Developments," *IEEE Microwave Magazine* 22, no. 11 (2021): 52–63, <https://doi.org/10.1109/MMM.2021.3102199>.
- [5] S. Liu, Z. Wang, and Y. Dong, "A Compact Coupling-Fed Patch Antenna With Quasi-Elliptic Filtering Response," *IEEE Antennas and Wireless Propagation Letters* 22, no. 12 (2023): 3137–3141, <https://doi.org/10.1109/LAWP.2023.3311989>.
- [6] X. Chen, M. C. Tang, D. Li, and M. Li, "Flexible, Bandwidth-Enhanced, Electrically Small, Electric Near-Field Resonant Parasitic Antenna With Filtering Performance Characteristics," *IEEE Transactions on Antennas and Propagation* 70, no. 6 (2022): 4860–4865, <https://doi.org/10.1109/TAP.2021.3137502>.
- [7] R. Sharma, A. Potnis, and V. Chaurasia, "Modelling of Dielectric Resonator Based Filtenna Covering 2.5/2.6 (B41/n41) Bands Using Machine Learning Algorithms," *Electronics and Communications* 164 (2023): 154642, <https://doi.org/10.1016/j.aeue.2023.154642>.
- [8] Z. Wu, M. C. Tang, and R. W. Ziolkowski, "Electrically Small, Low-Profile, Full-Duplex Huygens Dipole Filtenna," *Microwave and Optical Technology Letters* 64, no. 9 (2022): 1520–1528, <https://doi.org/10.1002/mop.33324>.
- [9] L. I. Daotong, Y. U. Yaqing, M. C. Tang, L. I. Dajiang, M. U. Dongmei, and L. I. Mei, "Active, Compact, Wideband, Receiving Filtenna With Power Adaptation for Space-Limited Wireless Platforms," *Chinese Journal of Aeronautics* 35, no. 8 (2022): 7–11, <https://doi.org/10.1016/j.cja.2021.09.009>.
- [10] Y. Duan, M. C. Tang, Z. Wu, Z. Zhang, D. Yi, and M. Li, "Omnidirectional-Radiating, Vertically Polarized, Wideband, Electrically Small Filtenna," *IEEE Transactions on Circuits and Systems II: Express Briefs* 70, no. 4 (2023): 1380–1384, <https://doi.org/10.1109/TCSII.2022.3224195>.
- [11] H. Gui, Z. Wang, W. Nie, M. Yang, and M. Wang, "Design of a Compact Wideband Filtering Antenna With High Frequency Selectivity," *Progress In Electromagnetics Research M* 131 (2025): 27–35, <https://doi.org/10.2528/PIERM24112503>.
- [12] M. Ribó, M. Cabedo-Fabrés, L. Pradell, S. Blanch, and M. Ferrando-Bataller, "Multimodal Planar Monopole Filtenna for 5G Applications," *AEU-International Journal of Electronics and Communications* 180 (2024): 155338, <https://doi.org/10.1016/j.aeue.2024.155338>.
- [13] C. Ni, B. Wen, W. Wu, and P. Ren, "Wideband Filtering Slot Antenna Design With Stable Gain Using Characteristic Mode Analysis," *Sensors* 22, no. 7 (2022): 2780, <https://doi.org/10.3390/s22072780>.
- [14] L. Jin, H. Tang, J. Shi, L. Lin, and K. Xu, "A Dual-Band, Dual-Polarized Filtering Antenna Based on Cross-Shaped Dielectric Strip Resonator," *Micromachines* 13, no. 12 (2022): 2069, <https://doi.org/10.3390/mi13122069>.
- [15] M. Nouri, A. Jafarieh, H. Behroozi, N. K. Mallat, M. H. Jamaluddin, and S. A. Aghdam, "Compact 5G millimeter-wave Dual-Band Filter With Application in Filtenna," *Microwave and Optical Technology Letters* 63, no. 2 (2021): 620–625, <https://doi.org/10.1002/mop.32637>.
- [16] W. Wang, H. Jin, W. Yu, et al., "Design of a High-Order 2×2 SIW Cavity-Backed Patch Subarray and Its Application in Millimeter-Wave CP Filtenna Array," *IEEE Antennas and Wireless Propagation Letters* 22, no. 4 (2023): 739–743, <https://doi.org/10.1109/LAWP.2022.3223932>.
- [17] S. M. El-Nady, A. S. Abd El-Hameed, E. M. Eldesouki, and S. A. Soliman, "Circularly Polarized MIMO Filtering Dielectric Resonator Antenna for 5G Sub-6 GHz Applications," *AEU-International Journal of Electronics and Communications* 171 (2023): 154882, <https://doi.org/10.1016/j.aeue.2023.154882>.
- [18] P. Ranjan and A. Kumar, "Circularly Polarized Ultra-Wide Band Filtering Antenna With Controllable Band-Notch for Wireless Communication System," *AEU-International Journal of Electronics and Communications* 135 (2021): 153738, <https://doi.org/10.1016/j.aeue.2021.153738>.
- [19] S. Munirathinam and G. Natarajan, "Design, Fabrication, and Performance Analysis of Corporate Feed Filtenna Array Using Complementary Split Ring Resonators," *Microwave and Optical Technology Letters* 63, no. 3 (2021): 924–936, <https://doi.org/10.1002/mop.32690>.
- [20] S. Ahmed, T. Kim Geok, M. Y. Alias, et al., "A UWB Antenna Array Integrated With Multimode Resonator Bandpass Filter," *Electronics* 10, no. 5 (2021): 607, <https://doi.org/10.3390/electronics10050607>.

- [21] J. K. Xiao and X. Q. Liu, "A Self-Packaged Suspended Coplanar Waveguide Leaf-Shaped Wideband Filtenna," *IEEE Antennas and Wireless Propagation Letters* 21, no. 6 (2022): 1148–1152, <https://doi.org/10.1109/LAWP.2022.3159780>.
- [22] P. Mahouti, A. Belen, O. Tari, M. A. Belen, S. Karahan, and S. Koziel, "Data-Driven Surrogate-Assisted Optimization of Metamaterial-Based Filtenna Using Deep Learning," *Electronics* 12, no. 7 (2023): 1584, <https://doi.org/10.3390/electronics12071584>.
- [23] A. Yadav, S. Sharma, D. Sigroha, and A. Sharma, "Metasurface Equipped Circularly Polarized Two-Port Filtering Dielectric Resonator Antenna for 2.5/2.6 GHz Band," *International Journal of Communication Systems* 38, no. 3 (2025): e6122, <https://doi.org/10.1002/dac.6122>.
- [24] M. Patriotis, F. N. Ayoub, Y. Tawk, J. Costantine, and C. G. Christodoulou, "A Compact Active Ka-Band Filtenna for CubeSats," *IEEE Antennas and Wireless Propagation Letters* 20, no. 11 (2021): 2095–2099, <https://doi.org/10.1109/LAWP.2021.3094276>.
- [25] J. Deng, R. Q. Wang, P. Zou, et al., "Design of Compact Differentially-Fed End-Fire Filtenna With High Selectivity," *Microwave and Optical Technology Letters* 67, no. 1 (2025): e70077, <https://doi.org/10.1002/mop.70077>.
- [26] F. K. Juma'a, A. I. Al-Mayoof, A. A. Abdulhameed, F. M. Alnahwi, Y. I. Al-Yasir, and R. A. Abd-Alhameed, "Design and Implementation of a Miniaturized Filtering Antenna for 5G Mid-Band Applications," *Electronics* 11, no. 19 (2022): 2979, <https://doi.org/10.3390/electronics11192979>.
- [27] G. Goussetis and D. Budimir, "Antenna Filter for Modern Wireless Systems," in *2002 32nd European Microwave Conference* (IEEE, 2002), 1–3.
- [28] J. Deng, S. Hou, L. Zhao, and L. Guo, "Wideband-to-Narrowband Tunable Monopole Antenna With Integrated Bandpass Filters for UWB/WLAN Applications," *IEEE Antennas and Wireless Propagation Letters* 16 (2017): 2734–2737, <https://doi.org/10.1109/LAWP.2017.2743258>.
- [29] M. C. Tang, T. Shi, and R. W. Ziolkowski, "Planar Ultrawideband Antennas With Improved Realized Gain Performance," *IEEE Transactions on Antennas and Propagation* 64, no. 1 (2016): 61–69, <https://doi.org/10.1109/TAP.2015.2503732>.
- [30] M. M. Fakharian, P. Rezaei, A. A. Orouji, and M. Soltanpur, "A Wideband and Reconfigurable Filtering Slot Antenna," *IEEE Antennas and Wireless Propagation Letters* 15 (2016): 1610–1613, <https://doi.org/10.1109/LAWP.2016.2518859>.
- [31] A. Balalem, J. Machac, and A. Omar, "Microstrip-CPW Bandpass Filter for Antenna Application," *Microwave and Optical Technology Letters* 50, no. 1 (2008): 51–55, <https://doi.org/10.1002/mop.23001>.
- [32] Y. Chen and Y. Zhou, "Design of a Filter-Antenna Subsystem for UWB Communications," in *2009 3rd IEEE International Symposium on Microwave, Antenna, Propagation and EMC Technologies for Wireless Communications* (IEEE, 2009), 593–595.
- [33] P. Ranjan, S. Raj, G. Upadhyay, S. Tripathi, and V. S. Tripathi, "Circularly Slotted Flower Shaped UWB Filtering Antenna With High Peak Gain Performance," *AEU-International Journal of Electronics and Communications* 81 (2017): 209–217, <https://doi.org/10.1016/j.aeue.2017.08.055>.
- [34] J. H. Lee, N. Kidera, S. Pinel, J. Laskar, and M. M. Tentzeris, "Fully Integrated Passive Front-End Solutions for a V-Band LTCC Wireless System," *IEEE Antennas and Wireless Propagation Letters* 6 (2007): 285–288, <https://doi.org/10.1109/LAWP.2007.891964>.
- [35] C. H. Wu, C. H. Wang, S. Y. Chen, and C. H. Chen, "Balanced-to-Unbalanced Bandpass Filters and the Antenna Application," *IEEE Transactions on Microwave Theory and Techniques* 56, no. 11 (2008): 2474–2482, <https://doi.org/10.1109/TMTT.2008.2005888>.
- [36] W. Cheng and D. Li, "Circularly Polarised Filtering Monopole Antenna Based on Miniaturised Coupled Filter," *Electronics Letters* 53, no. 11 (2017): 700–702, <https://doi.org/10.1049/el.2017.1094>.
- [37] M. Troubat, S. Bila, M. Thevenot, et al., "Mutual Synthesis of Combined Microwave Circuits Applied to the Design of a Filter-Antenna Subsystem," *IEEE Transactions on Microwave Theory and Techniques* 55, no. 6 (2007): 1182–1189, <https://doi.org/10.1109/TMTT.2007.897719>.
- [38] W. Hong, Z. J. Guo, and Z. C. Hao, "Seamless Integration Technology for Filtenna Toward 5G/6G Wireless Communications," *IEEE Open Journal of Antennas and Propagation* 5, no. 1 (2024): 18–36, <https://doi.org/10.1109/OJAP.2023.3342468>.
- [39] M. Oldoni, G. G. Gentili, F. Seyfert, G. Macchiarella, and C. D'Asta, "February. Synthesizability of Filtenna Arrays With Uniform Quality Factor," in *2024 IEEE International Microwave Filter Workshop (IMFW)* (IEEE, 2024), 201–204.
- [40] A. G. Koutinos, G. A. Kyriacou, J. L. Volakis, and M. T. Chryssomallis, "Bandwidth Enhancement of Antennas Designed by Band-Pass Filter Synthesis Due to Frequency Pulling Techniques," *IET Microwaves, Antennas & Propagation* 16, no. 1 (2022): 1–17, <https://doi.org/10.1049/mia2.12206>.
- [41] J. Yun, S. Trinh-Van, J. Y. Park, Y. Yang, K. Y. Lee, and K. C. Hwang, "Cavity-Backed Patch Filtenna for Harmonic Suppression," *IEEE Access* 8 (2020): 221580–221589, <https://doi.org/10.1109/ACCESS.2020.3043320>.
- [42] Z. Wu, A. Zhang, J. Chen, X. Lu, and J. Li, "Co-Design of Low Profile Single-Fed Circularly Polarized Filtering Antenna With High Out-of-Band Rejection," *AEU-International Journal of Electronics and Communications* 102 (2019): 99–104, <https://doi.org/10.1016/j.aeue.2019.01.031>.
- [43] S. C. Lin, P. Y. Chiou, Y. M. Chen, and S. F. Chang, "An Accurate Filtenna Synthesis Approach Based on Load-Resistance Flattening and Impedance-Transforming Tapped-Feed Techniques," *IEEE Access* 6 (2018): 24568–24581, <https://doi.org/10.1109/ACCESS.2018.2829841>.
- [44] Q. Wu, L. Zhu, and X. Zhang, "Filtering Patch Antenna on  $\lambda/4$ -resonator Filtering Topology: Synthesis Design and Implementation," *IET Microwaves, Antennas & Propagation* 11, no. 15 (2017): 2241–2246, <https://doi.org/10.1049/iet-map.2017.0354>.
- [45] G. Mansour, M. J. Lancaster, P. S. Hall, P. Gardner, and E. Nugoolcharoenlap, "Design of Filtering Microstrip Antenna Using Filter Synthesis Approach," *Progress in Electromagnetics Research* 145 (2014): 59–67, <https://doi.org/10.2528/PIER14011405>.
- [46] J. Zuo, X. Chen, G. Han, L. Li, and W. Zhang, "An Integrated Approach to RF Antenna-Filter Co-Design," *IEEE Antennas and Wireless Propagation Letters* 8 (2009): 141–144, <https://doi.org/10.1109/LAWP.2009.2012732>.
- [47] J. Liang, D. Wang, Z. Qi, Y. Gao, and Q. Wei, "Design of a Microstrip Filtering Antenna Without Extra Circuits and Its Application in Orbital Angular Momentum (OAM) Filtering

- Antenna,” *Progress in Electromagnetics Research Letters* 116 (2024): 1–7, <https://doi.org/10.2528/PIERL23103102>.
- [48] K. Z. Hu, J. Yu, D. Li, Z. Chen, X. Chen, and D. Yan, “A Single-Layer Low-Profile Frequency Reconfigurable Filtenna Without Extra Filtering Circuits,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 12 (2024): 4583–4587, <https://doi.org/10.1109/LAWP.2024.3458456>.
- [49] Z. Zheng, D. Li, X. Tan, and Q. Chen, “A Compact Low-Profile Differential Dual-Polarized Filtenna Without an External Filter Circuit for Vehicular Communications,” *IEEE Transactions on Vehicular Technology* 72, no. 5 (2023): 5587–5596, <https://doi.org/10.1109/TVT.2022.3230220>.
- [50] S. Liu, J. Guo, L. Wang, L. Wu, D. Yang, and Y. Chen, “A Low Profile Filtering Antenna Without Extra Circuit,” in *2022 IEEE 10th Asia-Pacific Conference on Antennas and Propagation (APCAP)* (IEEE, 2022), 1–2.
- [51] W. Chen, Z. Yu, X. He, J. Zhou, and W. Hong, “Enhanced-Stopband Dual-Polarized Filtenna Without Extra Circuit for Tile Array Applications,” *IEEE Transactions on Antennas and Propagation* 70, no. 8 (2022): 7193–7198, <https://doi.org/10.1109/TAP.2022.3164205>.
- [52] Y. Q. Sun, Z. J. Zhai, F. Lin, X. Y. Zhang, and H. J. Sun, “High-Gain Low Cross-Polarized Dual-Polarized Filtering Patch Antenna Without Extra Circuits,” *IEEE Antennas and Wireless Propagation Letters* 21, no. 7 (2022): 1368–1372, <https://doi.org/10.1109/LAWP.2022.3168403>.
- [53] X. Ruan and C. H. Chan, “A High-Efficiency Filtering Magnetolectric Dipole Antenna Without Filtering Feed Line,” *IEEE Transactions on Antennas and Propagation* 72, no. 12 (2024): 8947–8957, <https://doi.org/10.1109/TAP.2024.3453417>.
- [54] M. A. Saeed and A. O. Nwajana, “A Review of Beamforming Microstrip Patch Antenna Array for Future 5G/6G Networks,” *Frontiers in Mechanical Engineering* 9 (2024): 1288171, <https://doi.org/10.3389/fmech.2023.1288171>.
- [55] M. A. Saeed and A. Nwajana, “U-Shaped Terahertz Microstrip Patch Antenna for 6G Future Communications,” in *2023 7th International Electromagnetic Compatibility Conference (EMC Turkiye)* (IEEE, 2023), 1–4.
- [56] H. Jin, S. Nie, W. Wang, K. S. Chin, L. Peng, and G. Q. Luo, “A Broadband Single-Fed Circularly Polarized Patch Filtenna With High Suppression Level,” *Microwave and Optical Technology Letters* 64, no. 8 (2022): 1394–1400, <https://doi.org/10.1002/mop.33286>.
- [57] M. A. Saeed and A. O. Nwajana, “Sub-Terahertz Microstrip Antenna Array for Future Communication,” in *2023 International Conference on Electrical, Computer and Energy Technologies (ICECET)* (IEEE, 2023), 1–4.
- [58] A. O. Nwajana and E. R. Obi, “Application of Compact Folded-Arms Square Open-Loop Resonator to Bandpass Filter Design,” *Micromachines* 14, no. 2 (2023): 320, <https://doi.org/10.3390/mi14020320>.
- [59] M. A. Saeed, M. Ahmad, A. Nwajana, M. U. Rehman, M. A. Sohaib, and A. Naseer, “Coaxial Feed Ultra-Wideband Microstrip Antenna for Medical Applications,” in *2022 International Conference on Electrical, Computer and Energy Technologies (ICECET)* (IEEE, 2022), 1–4.
- [60] S. S. Roy, C. Saha, N. K. Mallenahalli, and D. Sarkar, “Circular Split Ring Resonator (C-SRR) Array Integrated Frequency-Notched Horn-Filtenna With Wide and Strong Rejection Band,” *IEEE Access* 9 (2021): 52664–52671, <https://doi.org/10.1109/ACCESS.2021.3069701>.
- [61] R. Lu, C. Yu, and W. Hong, “Millimeter Wave Wide-Angle Scanning Waveguide Slot Filtenna Array for 5G Applications,” in *2021 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (APS/URSI)* (IEEE, 2021), 825–826.
- [62] E. Meyer, T. A. Bressner, A. B. Smolders, and U. Johannsen, “Miniaturized Conical Waveguide Filtenna for 5G Millimeter Wave Base Stations,” in *2021 15th European Conference on Antennas and Propagation (EuCAP)* (IEEE, 2021), 1–5.
- [63] R. H. Mahmud and M. J. Lancaster, “A  $2 \times 2$  Filtering Subarray Element Antennas Using All-Resonator Structures,” *IET Microwaves, Antennas & Propagation* 15, no. 6 (2021): 592–599, <https://doi.org/10.1049/mia2.12080>.
- [64] L. Inclán-Sánchez, “Inverted Microstrip Gap Waveguide Coplanar EBG Filter for Antenna Applications,” *Electronics* 11, no. 18 (2022): 2951, <https://doi.org/10.3390/electronics11182951>.
- [65] M. Hu, Z. Yu, J. Xu, J. Lan, J. Zhou, and W. Hong, “Diverse SRRs Loaded Millimeter-Wave SIW Antipodal Linearly Tapered Slot Filtenna With Improved Stopband,” *IEEE Transactions on Antennas and Propagation* 69, no. 12 (2021): 8902–8907, <https://doi.org/10.1109/TAP.2021.3090854>.
- [66] H. Y. Wang, G. Zhao, R. Y. Li, and Y. C. Jiao, “A Low-Profile Half-Mode Substrate Integrated Waveguide Filtering Antenna With High Frequency Selectivity,” *Progress in Electromagnetics Research Letters* 99 (2021): 35–43, <https://doi.org/10.2528/PIERL21051206>.
- [67] A. O. Nwajana, K. S. Yeo, and A. Dainkeh, “Low Cost SIW Chebyshev Bandpass Filter With New Input/Output Connection,” in *2016 16th Mediterranean Microwave Symposium (MMS)* (IEEE, 2016), 1–4.
- [68] A. M. Maruti and B. S. N. Kishore, “Dual-Band SIW Slot Array Filtering Antenna for X and Ku Band Applications,” *Progress in Electromagnetics Research Letters* 103 (2022): 109–117, <https://doi.org/10.2528/PIERL22020306>.
- [69] K. Z. Hu, M. C. Tang, D. Li, Y. Wang, and M. Li, “Design of Compact, Single-Layered Substrate Integrated Waveguide Filtenna With Parasitic Patch,” *IEEE Transactions on Antennas and Propagation* 68, no. 2 (2020): 1134–1139, <https://doi.org/10.1109/TAP.2019.2938574>.
- [70] A. Chandekar, A. Kumar, P. Jadhav, A. A. Althwayb, and K. Aliqab, “Semi Circular SIW Cavity Coupled Patch Filtenna,” *IEEE Access* 13 (2025): 37865–37871, <https://doi.org/10.1109/ACCESS.2025.3543629>.
- [71] W. Wang, H. Jin, W. Yu, et al., “A Single-Layer Dual-Circularly Polarized SIW-Cavity-Backed Patch Filtenna With Wide Axial-Ratio Bandwidth,” *IEEE Antennas and Wireless Propagation Letters* 20, no. 6 (2021): 908–912, <https://doi.org/10.1109/LAWP.2021.3066616>.
- [72] A. O. Nwajana and K. S. K. Yeo, eds., “Practical Approach to Substrate Integrated Waveguide (SIW) Diplexer: Emerging Research and Opportunities,” in *Advances in Mechatronics and Mechanical Engineering (AMME)* (Hershey, PA, USA: IGI Global, 2020), <https://doi.org/10.4018/978-1-7998-2084-0>.
- [73] J. Li, L. Xiang, Y. Shi, X. Y. Wu, and W. Hong, “Single-Layer Millimeter-Wave Filtenna With Quasi-Elliptic Gain Response Under Dual-Mode Resonance,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 9 (2024): 2797–2801, <https://doi.org/10.1109/LAWP.2024.3408044>.
- [74] R. Lu, C. Yu, F. Wu, et al., “SIW Cavity-Fed Filtennas for 5G Millimeter-Wave Applications,” *IEEE Transactions on*

- Antennas and Propagation* 69, no. 9 (2021): 5269–5277, <https://doi.org/10.1109/TAP.2021.3061110>.
- [75] Y. X. Huang, Y. X. Yan, S. C. Tang, W. Yu, and J. X. Chen, “Substrate-Integrated-Waveguide-Fed Slotted Patch Filtering Antenna and Array With Enhanced Selectivity,” *AEU-International Journal of Electronics and Communications* 172 (2023): 154936, <https://doi.org/10.1016/j.aeue.2023.154936>.
- [76] A. O. Nwajana, A. Dainkeh, and K. S. K. Yeo, “Substrate Integrated Waveguide (SIW) Diplexer With Novel Input/Output Coupling and No Separate Junction,” *Progress in Electromagnetics Research M* 67 (2018): 75–84, <https://doi.org/10.2528/PIERM18021603>.
- [77] Y. Qian and S. Xie, “Wideband Circularly Polarized Filtering Hybrid Antenna,” *Applied Sciences* 12, no. 21 (2022): 11018, <https://doi.org/10.3390/app122111018>.
- [78] H. S. Farahani, B. Rezaee, and W. Bösch, “Ka-Band Coupled-Resonator Filtering Magneto-Electric Dipole Antenna,” in *2020 50th European Microwave Conference (EuMC)* (IEEE, 2021), 722–725.
- [79] W. Chen, Z. Yu, and J. Zhou, “A Hybrid Beamforming System Based on Active Antenna Array With Stacked Patch Filtenna,” in *2022 IEEE MTT-S International Wireless Symposium (IWS)* 1, IEEE, 2022), 1–3.
- [80] S. C. Tang, X. Y. Wang, W. Yu, W. W. Yang, and J. X. Chen, “Compact Microstrip Patch Filtenna Array Based on Reusable High-Order SIW Cavity,” *IEEE Antennas and Wireless Propagation Letters* 22, no. 2 (2023): 268–272, <https://doi.org/10.1109/LAWP.2022.3208861>.
- [81] L. Rodrigues, T. Varum, and J. N. Matos, “The Application of Reconfigurable Filtennas in Mobile Satellite Terminals,” *IEEE Access* 8 (2020): 77179–77187, <https://doi.org/10.1109/ACCESS.2020.2989529>.
- [82] J. Li, Y. Shi, and L. Xiang, “Compact Wide Upper Stopband Suppression Filtering Antenna for Aerospace Applications,” *IEEE Journal on Miniaturization for Air and Space Systems* 5, no. 4 (2024): 211–220, <https://doi.org/10.1109/JMASS.2024.3445257>.
- [83] D. Pang, H. F. Su, X. P. Li, H. L. Xu, and X. Y. Zhang, “Compact Broadband Dual-Band Filtenna With High Selectivity for Vehicle Application,” *IEEE Transactions on Vehicular Technology* 73, no. 1 (2024): 45–52, <https://doi.org/10.1109/TVT.2023.3303531>.
- [84] D. Pang, Z. X. Xia, H. F. Su, Y. M. Xue, L. H. Ye, and X. Y. Zhang, “Compact High-Gain and Wide-Azimuth-Beam Filtenna for V2X Communication,” *IEEE Transactions on Antennas and Propagation* 71, no. 11 (2023): 9066–9071, <https://doi.org/10.1109/TAP.2023.3305036>.
- [85] D. Pang, H. F. Su, C. X. Mao, H. L. Xu, and X. Y. Zhang, “Compact Dual-Band Filtenna With Controllable Radiation Nulls for Vehicle Application,” *IEEE Transactions on Vehicular Technology* 72, no. 3 (2023): 3430–3439, <https://doi.org/10.1109/TVT.2022.3217885>.
- [86] D. Li, M. C. Tang, Y. Wang, K. Z. Hu, and R. W. Ziolkowski, “Compact Differential Diplex Filtenna With Common-Mode Suppression for Highly Integrated Radio Frequency Front-Ends,” *IEEE Transactions on Antennas and Propagation* 69, no. 11 (2021): 7935–7940, <https://doi.org/10.1109/TAP.2021.3083797>.
- [87] P. P. Shome, T. Khan, S. K. Koul, and Y. M. Antar, “Filtenna Designs for Radio-Frequency Front-End Systems: A Structural-Oriented Review,” *IEEE Antennas and Propagation Magazine* 63, no. 5 (2021): 72–84, <https://doi.org/10.1109/MAP.2020.2988518>.
- [88] Z. A. A. Nasser, Z. Zakaria, N. A. Shairi, S. N. Zabri, and A. M. Zobilah, “Design of Compact Filtenna Based on Capacitor Loaded Square Ring Resonator for Wireless Applications,” *Progress in Electromagnetics Research M* 96 (2020): 21–31, <https://doi.org/10.2528/PIERM20063008>.
- [89] S. Saxena, R. Sharma, M. D. Upadhayay, A. Shrivastava, and P. K. Mishra, “Novel Filtenna for Wireless Applications,” *Materials Today: Proceedings* 47 (2021): 6953–6959, <https://doi.org/10.1016/j.matpr.2021.05.213>.
- [90] M. M. Hosain, S. Kumari, and A. K. Tiwary, “Sunflower Shaped Fractal Filtenna for WLAN and ARN Application,” *Microwave and Optical Technology Letters* 62, no. 1 (2020): 346–354, <https://doi.org/10.1002/mop.32013>.
- [91] H. Su, Y. Zhang, L. L. Wu, J. H. Ou, and X. Y. Zhang, “Modeling and Design of Nonresonant-Node-Based Filtenna for Tri-band Wi-Fi Application,” *IEEE Transactions on Microwave Theory and Techniques* 71, no. 11 (2023): 4982–4995, <https://doi.org/10.1109/TMTT.2023.3266507>.
- [92] P. Pal, R. Sinha, and S. K. Mahto, “A Compact Wideband Circularly Polarized Planar Filtenna Using Synthesis Technique for 5 GHz WLAN Application,” *AEU-International Journal of Electronics and Communications* 148 (2022): 154180, <https://doi.org/10.1016/j.aeue.2022.154180>.
- [93] A. Haider, M. Rahman, M. Naghshvarianjahromi, and H. S. Kim, “Time-Domain Investigation of Switchable Filter Wide-Band Antenna for Microwave Breast Imaging,” *Sensors* 20, no. 15 (2020): 4302, <https://doi.org/10.3390/s20154302>.
- [94] M. Hussain, A. Abbas, W. A. Awan, and S. I. Naqvi, “Miniaturized Arrow-Shaped Flexible Filter-Embedded Antenna for Industrial and Medical Applications,” *Applied Sciences* 14, no. 23 (2024): 11004–13417, <https://doi.org/10.3390/app142311004>.
- [95] F. Benassi, G. Paolini, D. Masotti, and A. Costanzo, “A Wearable Flexible Energy-Autonomous Filtenna for Ethanol Detection at 2.45 GHz,” *IEEE Transactions on Microwave Theory and Techniques* 69, no. 9 (2021): 4093–4106, <https://doi.org/10.1109/TMTT.2021.3074155>.
- [96] M. Esfandiyari, A. Lalbakhsh, S. Jarchi, M. Ghaffari-Miab, H. N. Mahtaj, and R. B. Simorangkir, “Tunable Terahertz Filter/Antenna-Sensor Using Graphene-Based Metamaterials,” *Materials & Design* 220 (2022): 110855, <https://doi.org/10.1016/j.matdes.2022.110855>.
- [97] M. Adhikary, A. Sarkar, A. Sharma, A. Biswas, and M. J. Akhtar, “Miniaturized SIW Filter Antenna With Loadable Sensor for Various Microwave Sensing Applications,” in *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting* (IEEE, 2017), 2505–2506.
- [98] J. Cui, A. Zhang, and S. Yan, “Microfluidic Filtering Antenna for Sensor Application,” in *2020 13th UK-Europe-China Workshop on Millimetre-Waves and Terahertz Technologies (UCMMT)* (IEEE, 2020), 1–2.
- [99] R. Wu, G. H. Wen, Y. Liu, and F. C. Chen, “A Broadband Filtering Antenna Array for Sub-6 GHz Base Station Applications,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 1 (2024): 394–398, <https://doi.org/10.1109/LAWP.2023.3325621>.
- [100] J. W. Wang, S. Sun, R. Ma, and X. Y. Zhang, “Compact Dual-Polarized Filtenna With Steep Roll-off Rate for Base Stations,” *IEEE Antennas and Wireless Propagation Letters* 21,

- no. 8 (2022): 1698–1702, <https://doi.org/10.1109/LAWP.2022.3177937>.
- [101] Y. Wang, H. Su, R. C. Dai, L. T. Chen, L. H. Ye, and X. Y. Zhang, “A Systematic Approach to Design Spatial Filtenna for Aperture-Shared Base-Station Array,” *IEEE Transactions on Antennas and Propagation* 71, no. 10 (2023): 7792–7803, <https://doi.org/10.1109/TAP.2023.3299409>.
- [102] J. W. Wang, R. Ma, S. F. Bo, H. Huang, and X. Y. Zhang, “Multipath-Coupling-Based Filtenna for Base-Station Applications,” *IEEE Transactions on Antennas and Propagation* 71, no. 11 (2023): 8473–8482, <https://doi.org/10.1109/TAP.2023.3306466>.
- [103] A. O. Nwajana, “Circuit Modelling of Bandpass/Channel Filter With Microstrip Implementation,” *Indonesian Journal of Electrical Engineering, and Informatics* 8, no. 4 (2020): 696–705, <https://doi.org/10.52549/ijeei.v8i4.2466>.
- [104] M. A. Saeed and A. O. Nwajana, “Design of a Rectangular Linear Microstrip Patch Antenna Array for 5G Communication,” in *2024 IEEE International Symposium on Phased Array Systems and Technology (ARRAY)* (IEEE, 2024), 1–4.
- [105] D. Li, X. Huang, F. Yang, et al., “A Single-Layer Wideband Differentially-Fed Dual-Polarized Filtenna With Low Cross-Polarization,” *Microwave and Optical Technology Letters* 67, no. 1 (2025): e70074, <https://doi.org/10.1002/mop.70074>.
- [106] S. Saleh, N. Timmons, J. Morrison, and W. Ismail, “Compact Linearly Polarized 5G Vivaldi Non-Uniform Slot Filtering Antenna,” *Ain Shams Engineering Journal* 15, no. 2 (2024): 102364, <https://doi.org/10.1016/j.asej.2023.102364>.
- [107] X. F. Wang, L. L. Yang, X. Y. Wang, and J. X. Chen, “Wideband Self-Decoupling Dielectric Patch Filtennas With Stable Filtering Response,” *IEEE Access* 10 (2022): 126561–126568, <https://doi.org/10.1109/ACCESS.2022.3225877>.
- [108] L. Li, H. D. Xiong, W. Y. Wu, A. B. Fu, and J. Y. Han, “A T-Shaped Strips Loaded Wideband Filtering Patch Antenna With High Selectivity,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 1 (2024): 89–93, <https://doi.org/10.1109/LAWP.2023.3318223>.
- [109] J. Guo, Y. Chen, D. Yang, K. Sun, J. Pan, and S. Liu, “Design of Wideband Filtering Patch Antenna Array With High Aperture Efficiency and Good Filtering Performance,” *IEEE Transactions on Antennas and Propagation* 72, no. 1 (2024): 974–979, <https://doi.org/10.1109/TAP.2023.3331253>.
- [110] I. Haider, A. Basu, and S. K. Koul, “A Compact Wideband Waveguide Filtering Antenna With Transmission Zero,” *Progress in Electromagnetics Research Letters* 119 (2024): 59–65, <https://doi.org/10.2528/PIERL24030403>.
- [111] C. Chen, J. Chen, P. Yan, L. Wen, and W. Hong, “Design of a 60 GHz Slot Filtenna Array Using Gap Waveguide Feed Network,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 2 (2024): 668–672, <https://doi.org/10.1109/LAWP.2023.3331845>.
- [112] X. Yang, G. Zhang, W. Zhang, et al., “Design of Dual-Band Filtering Antenna Based on 3-D Printed Half-Mode Gap Waveguide Quadruple-Mode Resonator,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 2 (2024): 468–472, <https://doi.org/10.1109/LAWP.2023.3323474>.
- [113] S. S. Qi, Y. Guo, and W. Wen, “Wideband Filtering Waveguide Antenna Based on the Stepped Impedance Resonator,” *IET Microwaves, Antennas & Propagation* 17, no. 3 (2023): 183–189, <https://doi.org/10.1049/mia2.12307>.
- [114] Q. Shi-Shan, Z. Keren, and W. Wu, “Compact Ka-Band Conical Beam Filtenna,” *IET Microwaves, Antennas & Propagation* 17, no. 3 (2023): 208–215, <https://doi.org/10.1049/mia2.12326>.
- [115] A. O. Nwajana and E. R. Obi, “A Review on SIW and Its Applications to Microwave Components,” *Electronics* 11, no. 7 (2022): 1160, <https://doi.org/10.3390/electronics11071160>.
- [116] X. P. Chen and K. Wu, “Substrate Integrated Waveguide Filter: Basic Design Rules and Fundamental Structure Features,” *IEEE Microwave Magazine* 15, no. 5 (2014): 108–116, <https://doi.org/10.1109/MMM.2014.2321263>.
- [117] S. Wang, H. C. Li, L. Yang, G. Zhang, and R. Gómez-García, “SIW-Based Input-Reflectionless Filter/Filtenna Using Complementary-Diplexer Architectures,” *IEEE Transactions on Microwave Theory and Techniques* 73, no. 4 (2025): 2206–2216, <https://doi.org/10.1109/TMTT.2025.3532037>.
- [118] B. C. Guo, K. Z. Hu, D. Yan, S. Y. Pan, M. C. Tang, and P. Wang, “Design of Compact Dual-Band Substrate Integrated Waveguide Filtenna,” *Microwave and Optical Technology Letters* 64, no. 6 (2022): 1070–1076, <https://doi.org/10.1002/mop.33224>.
- [119] R. Kant, C. S. Prasad, S. K. Sahoo, A. Biswas, and M. J. Akhtar, “Half-Mode Substrate Integrated Waveguide-Based Filtering Leaky-Wave Antenna,” *AEU-International Journal of Electronics and Communications* 171 (2023): 154886, <https://doi.org/10.1016/j.aeue.2023.154886>.
- [120] W. Wang, H. Jin, W. Yu, L. Liu, K. S. Chin, and G. Q. Luo, “A Compact Harmonic-Suppressed Filtenna Based on Miniaturized High-Order Half-Mode SIW Cavity,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 12 (2024): 4728–4732, <https://doi.org/10.1109/LAWP.2024.3467280>.
- [121] Y. X. Huang, Y. X. Yan, W. Yu, W. Qin, and J. X. Chen, “Integration Design of Millimeter-Wave Bidirectional Endfire Filtenna Array Fed by SIW Filtering Power Divider,” *IEEE Antennas and Wireless Propagation Letters* 21, no. 7 (2022): 1457–1461, <https://doi.org/10.1109/LAWP.2022.3171526>.
- [122] W. Wang, H. Jin, W. Yu, L. Liu, K. S. Chin, and G. Q. Luo, “Millimeter-Wave Compact Wideband High-Gain 8 × 8 CP Filtenna Array With Densified 16-Way SIW Feeding Network,” *IEEE Transactions on Antennas and Propagation* 72, no. 6 (2024): 5283–5288, <https://doi.org/10.1109/TAP.2023.3340021>.
- [123] C. Wang, X. Wang, H. Liu, Z. Chen, and Z. Han, “Substrate Integrated Waveguide Filtenna With Two Controllable Radiation Nulls,” *IEEE Access* 8 (2020): 120019–120024, <https://doi.org/10.1109/ACCESS.2020.3005948>.
- [124] N. Yan, H. Zhou, and K. Ma, “A Filtering Antenna With Slots and Stacked Patch Based on SISL for 5G Communications,” *Electronics* 12, no. 6 (2023): 1331, <https://doi.org/10.3390/electronics12061331>.
- [125] K. Z. Hu, K. H. Yuan, D. Li, M. C. Tang, Z. Chen, and D. Yan, “A Single Layer Differentially Fed Filtenna With Controllable Radiation Nulls Using Hybrid SIW Cavity and Patches,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 8 (2024): 2286–2290, <https://doi.org/10.1109/LAWP.2024.3387731>.
- [126] D. Li and C. Deng, “A Single-Layer Filtering Antenna With Two Controllable Radiation Nulls Based on the Multimodes of Patch and SIW Resonators,” *IEEE Antennas and Wireless Propagation Letters* 22, no. 3 (2023): 551–555, <https://doi.org/10.1109/LAWP.2022.3218135>.
- [127] Y. X. Yan, Y. X. Huang, S. C. Tang, and J. X. Chen, “Low-Sidelobe Microstrip Patch Filtenna Array Fed by Higher Order Mode SIW Cavity,” *IEEE Antennas and Wireless*

- Propagation Letters* 22, no. 8 (2023): 1873–1877, <https://doi.org/10.1109/LAWP.2023.3268172>.
- [128] W. Zhao, H. Jin, W. Wang, W. Yu, K. S. Chin, and G. Q. Luo, “High-Gain Dual-Polarized Millimeter-Wave Patch Filtenna Array,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 4 (2024): 1361–1365, <https://doi.org/10.1109/LAWP.2024.3355898>.
- [129] K. Zhao and D. Psychogiou, “Monolithically Integrated Coaxial Resonator-Based Filtennas Using SLA Three-Dimensional Printing,” *IEEE Antennas and Wireless Propagation Letters* 22, no. 1 (2023): 189–193, <https://doi.org/10.1109/LAWP.2022.3206757>.
- [130] S. C. Mejillones, M. Oldoni, S. Moscato, M. D’Amico, and G. G. Gentili, “Circularly Polarized Coaxial Horn Filtenna for Electromagnetic Interference Mitigation,” *IEEE Transactions on Antennas and Propagation* 71, no. 12 (2023): 9487–9496, <https://doi.org/10.1109/TAP.2023.3321422>.
- [131] D. Zhan, K. Zhu, and S. Qi, “A Novel High-Gain Circularly Polarized Omnidirectional Filtenna Based on Coaxial Structure,” *Radioengineering* 34, no. 3 (2025): 423.
- [132] K. Zhao and D. Psychogiou, “Additively-Manufactured Coaxial Resonator-Based Filtennas,” in *2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI)* (IEEE, 2022), 1590–1591.
- [133] S. Q. Zhang, S. W. Wong, Z. Zhang, and Y. He, “Full-Metal Omnidirectional Filtenna Array Using 3D Metal Printing Technology,” *IEEE Transactions on Antennas and Propagation* 72, no. 5 (2024): 4095–4106, <https://doi.org/10.1109/TAP.2024.3385914>.
- [134] X. Cui and B. Zhang, “A Metallic 3D Printed Modularized Dual-Stopband AMC-Loaded Waveguide Slot Filtering Antenna,” *Progress in Electromagnetics Research B* 100 (2023): 19–38, <https://doi.org/10.2528/PIERB23020601>.
- [135] H. Xu, H. Liu, T. Huang, and T. Y. Liu, “3-D Printed Dual-Band Circularly Polarized Filtering Antenna With Self-Diplexing Property for Millimeter-Wave Applications,” *IEEE Transactions on Antennas and Propagation* 72, no. 4 (2024): 3807–3812, <https://doi.org/10.1109/TAP.2024.3370300>.
- [136] M. A. Abdelghany, W. A. Ali, H. A. Mohamed, and A. A. Ibrahim, “Filtenna With Frequency Reconfigurable Operation for Cognitive Radio and Wireless Applications,” *Micro-machines* 14, no. 1 (2023): 160, <https://doi.org/10.3390/mi14010160>.
- [137] A. K. Gangwar and M. S. Alam, “Frequency Reconfigurable Dual-Band Filtenna,” *AEU-International Journal of Electronics and Communications* 124 (2020): 153239, <https://doi.org/10.1016/j.aeue.2020.153239>.
- [138] S. Das and P. Sarkar, “A Dual-Band Reconfigurable Filtering Antenna using PIN diodes for WiMAX and WLAN applications,” *International Journal of RF and Microwave Computer-Aided Engineering* 32, no. 12 (2022): e23439, <https://doi.org/10.1002/mmce.23439>.
- [139] S. R. Mishra and S. K. Lalitha, “Implementation of Defected Ground Structure for Microstrip Filtenna Design,” *International Journal of RF and Microwave Computer-Aided Engineering* 30, no. 1 (2020): e21998, <https://doi.org/10.1002/mmce.21998>.
- [140] R. C. Dai, S. Sun, H. Su, and X. Y. Zhang, “Analysis and Design of Dual-Modal Filtenna for Dismountable Aperture-Shared Array,” *IEEE Transactions on Antennas and Propagation* 72, no. 6 (2024): 4806–4817, <https://doi.org/10.1109/TAP.2024.3391901>.
- [141] D. Li, M. C. Tang, Y. Wang, K. Z. Hu, and R. W. Ziolkowski, “Dual-Band, Differentially-Fed Filtenna With Wide Bandwidth, High Selectivity, and Low Cross-Polarization,” *IEEE Transactions on Antennas and Propagation* 70, no. 6 (2022): 4872–4877, <https://doi.org/10.1109/TAP.2021.3138505>.
- [142] G. M. Elashry, H. A. Mohamed, A. A. Abd-El-Hadi, and E. A. Abdallah, “Cloverleaf Filtenna With Reconfigurable Quintuple Rejection Bands Using Defected Microstrip Structure,” *AEU-International Journal of Electronics and Communications* 168 (2023): 154708, <https://doi.org/10.1016/j.aeue.2023.154708>.
- [143] H. Chang, M. Liu, D. Lin, and J. Wang, “A Compact Single Layer Filtering Antenna With DGS for 5.1 GHz Application,” *Progress in Electromagnetics Research Letters* 107 (2022): 1–7, <https://doi.org/10.2528/PIERL22072703>.
- [144] A. A. Ibrahim, H. A. Mohamed, A. R. D. Rizo, R. Parra-Michel, and H. Aboushady, “Tunable Filtenna With DGS Loaded Resonators for a Cognitive Radio System Based on an SDR Transceiver,” *IEEE Access* 10 (2022): 32123–32131, <https://doi.org/10.1109/ACCESS.2022.3160467>.
- [145] S. H. Tanguturu, G. Soundarya, R. Kiruthika, and N. Gunavathi, “Filtenna With Defected Ground Structure for 5G Application,” in *2023 International Conference on Computer Communication and Informatics (ICCCI)* (IEEE, 2023), 1–5.
- [146] X. Guo, M. Du, W. Wu, Z. Feng, and Z. Wan, “Circularly Polarized Antenna Array Using Filtering Phase Shifting Theory,” *Progress in Electromagnetics Research Letters* 116 (2024): 9–16, <https://doi.org/10.2528/PIERL23101101>.
- [147] H. S. Farahani, B. Rezaee, and W. Bösch, “A Ka-Band Multi-layer Filtering Array Antenna With Distributed Coupled-Resonator Topology,” in *2022 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting (AP-S/URSI)* (IEEE, 2022), 796–797.
- [148] H. S. Huang, D. L. Wu, Z. H. Rong, L. H. Ye, and F. Jiang, “A Patch Filtenna With High Out-of-Band Suppression Levels,” *Microwave and Optical Technology Letters* 67, no. 3 (2025): e70175, <https://doi.org/10.1002/mop.70175>.
- [149] G. Cheng, B. Huang, Z. Huang, and L. Yang, “A High-Gain Circularly Polarized Filtering Stacked Patch Antenna,” *IEEE Antennas and Wireless Propagation Letters* 22, no. 5 (2023): 995–999, <https://doi.org/10.1109/LAWP.2022.3229951>.
- [150] M. Kuosmanen, S. E. Gunnarsson, J. Malmström, J. Ala-Laurinaho, J. Holopainen, and V. Viikari, “Dual-Polarized Wideband Filtering Antenna Array Based on Stacked-PCB Structure,” *IEEE Open Journal of Antennas and Propagation* 6, no. 1 (2025): 38–50, <https://doi.org/10.1109/OJAP.2024.3466234>.
- [151] J. Qian, S. Gao, B. S. Izquierdo, H. Wang, H. Zhou, and H. Xu, “Compact Dual-Polarized/Duplex Filtering Antenna With High Isolation,” *IEEE Open Journal of Antennas and Propagation* 4 (2023): 677–685, <https://doi.org/10.1109/OJAP.2023.3292862>.
- [152] T. T. Liu, J. F. Li, L. H. Ye, X. X. Tian, and C. X. Mao, “Low-Profile Duplex Filtering Antenna With High Isolation and High Roll-off Filtering Response,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 11 (2024): 3907–3911, <https://doi.org/10.1109/LAWP.2024.3418817>.
- [153] S. The Maithani and R. K. Gangwar, “A Compact, Dual-Band, Full-Duplex Conformal Filtering Antenna Array for

- Seamless Vehicular Connectivity,” *IEEE Transactions on Vehicular Technology* 73, no. 7 (2024): 10617–10626, <https://doi.org/10.1109/TVT.2024.3372193>.
- [154] G. Z. Liang and F. C. Chen, “A Duplexing Filtering Antenna With Small Frequency Ratio and High Isolation Using Hanging Resonators,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 11 (2024): 3897–3901, <https://doi.org/10.1109/LAWP.2024.3401220>.
- [155] A. Kumar and A. A. Althuwayb, “SIW Resonator-Based Duplex Filtenna,” *IEEE Antennas and Wireless Propagation Letters* 20, no. 12 (2021): 2544–2548, <https://doi.org/10.1109/LAWP.2021.3118566>.
- [156] K. Z. Hu, M. C. Tang, Y. Wang, D. Li, and M. Li, “Compact, Vertically Integrated Duplex Filtenna With Common Feeding and Radiating SIW Cavities,” *IEEE Transactions on Antennas and Propagation* 69, no. 1 (2021): 502–507, <https://doi.org/10.1109/TAP.2020.2999381>.
- [157] D. Li, X. Huang, K. Z. Hu, Z. Chen, and D. Yan, “A Planar Single-Layer Differentially-Fed Dual-Band Dual-Polarized Filtenna Based on Multimode Resonant Structure,” *IEEE Transactions on Antennas and Propagation* 72, no. 12 (2024): 9468–9473, <https://doi.org/10.1109/TAP.2024.3454466>.
- [158] Y. Wang, J. Xu, L. Xiang, K. Chen, and W. Hong, “Low-Cost Wideband Millimeter-Wave Filtenna and Its Arrays for Miniaturized IoT Devices,” *IEEE Internet of Things Journal* 11, no. 16 (2024): 27073–27084, <https://doi.org/10.1109/JIOT.2024.3398606>.
- [159] S. F. Yao, S. Xu, Y. M. Xue, et al., “Miniaturized Dual-Wideband Millimeter-Wave Filtenna in Package for 5G Applications,” *IEEE Antennas and Wireless Propagation Letters* 22, no. 7 (2023): 1726–1730, <https://doi.org/10.1109/LAWP.2023.3262561>.
- [160] M. Xiang, Z. H. Bian, D. Y. Xiong, et al., “A Simple Single-Layer Wideband Filtenna With Multiple Controllable Radiation Nulls,” *Microwave and Optical Technology Letters* 67, no. 1 (2025): e70075, <https://doi.org/10.1002/mop.70075>.
- [161] K. Z. Hu, X. F. Wu, H. Y. Huang, D. Li, Z. Chen, and D. Yan, “A Low-Profile Single-Layer Differentially Fed Circularly Polarized Filtenna With Intrinsic Common-Mode Rejection,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 10 (2024): 3028–3032, <https://doi.org/10.1109/LAWP.2024.3420113>.
- [162] A. V. Rao and G. Ram, “Means of Employing Radiation Nulls in Filtennas—A Review,” *IEEE Access* 12 (2024): 79468–79480, <https://doi.org/10.1109/ACCESS.2024.3408460>.
- [163] K. Huang, Y. Zhang, J. Y. Zhou, and Q. H. Liu, “Dual-Polarized Wideband Dipole Filtenna Using a CMRC Radiator Structure,” *IEEE Antennas and Wireless Propagation Letters* 24, no. 1 (2025): 162–166, <https://doi.org/10.1109/LAWP.2024.3487210>.
- [164] N. Ullah, Y. Liu, S. U. Rahman, S. Khan, and F. Wang, “Design of a Compact Filter Integrated Wideband and Circularly Polarized Antenna Array for K-Band Application,” *Measurement* 225 (2024): 113978, <https://doi.org/10.1016/j.measurement.2023.113978>.
- [165] J. Li, H. Ma, K. Zhang, S. Li, H. Zhao, and X. Yin, “Wideband Reflectionless Antipodal Tapered Slot Filtenna With High Out-of-Band Absorption Ratio,” *IEEE Antennas and Wireless Propagation Letters* 23, no. 1 (2024): 309–313, <https://doi.org/10.1109/LAWP.2023.3323553>.