



Design of a Compact Microstrip Filtering Antenna for Wireless Communication Systems

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ABSTRACT

Wireless communication systems have grown more in demand for compact and high-performance systems and that means that RF components are beginning to be integrated together. In this article, a small size of microstrip filtering antenna (filtenna) has been designed which integrates both the filtering and radiating features into a single antenna structure. The proposed structure consists of a rectangular microstrip patch antenna integrated with a microstrip bandpass filter operating at a center frequency of 1.9 GHz. The performance of the proposed design is evaluated using full-wave electromagnetic simulation. The simulation results show that the filtenna achieves a bandwidth of 77 MHz, a return-loss of about -10 dB, and a gain equal to 6.57 dBi. The integration of the filter and antenna reduces the overall circuit size while maintaining good electrical performance, making the proposed design suitable for modern wireless communication systems. The design offers a simple solution for compact wireless devices.

Keywords: Filtering antenna, Microstrip antenna, Hairpin resonator, Bandpass filter, Filter synthesis, Wireless communication systems.

INTRODUCTION

Wireless communication systems need smaller and lower-cost RF front-end components while still providing good performance. In a conventional RF system, the antenna and bandpass filter are usually designed as two separate parts and connected by transmission lines. This arrangement is useful, but it increases the size of the circuit and adds some insertion loss. It also makes the design more difficult when a small wireless device is required [1]–[3].

A filtering antenna, also known as a filtenna, is one possible way to reduce these problems. In a filtenna, the antenna and filter functions are combined in one structure. This can reduce the size of the RF front-end and make the overall structure simpler. It can also help to control unwanted signals outside the operating band. For these reasons, filtering antennas have been studied for different wireless communication applications [4]–[6].

Several methods have been used to design filtering antennas. One method is to combine a microstrip patch antenna with resonators to obtain the required filtering response. Mansour et al. [7] used a filter synthesis method to combine two hairpin resonators with a rectangular patch antenna and obtained a third-order Chebyshev bandpass filtering antenna. Other works have used different resonator structures, such as slotted resonators and T-shaped structures, for different wireless applications [8]–[12]. These studies show that the filter and antenna can be combined in one structure while keeping a good filtering and radiation performance.

A filtenna can be designed using different types of structures. Waveguide and cavity structures can provide a high quality factor and low loss, but they normally have a larger size and require more difficult fabrication. Microstrip

structures, on the other hand, are planar and can be fabricated using a simple process with relatively low cost. They also provide a compact structure. For this reason, microstrip technology is a suitable choice for small wireless communication systems [13-16].

Hairpin resonators are often used in microstrip bandpass filters. Their folded shape helps to make the resonator more compact, while the distance between the resonators can be used to control the coupling. The spacing between the parallel arms also affects the coupling and the unloaded quality factor. When the spacing is small, the coupling between the arms becomes stronger, while a larger spacing can increase the radiation loss. Therefore, the resonator dimensions and spacing need to be selected according to the required filter response. In this work, hairpin resonators are used to form the third-order bandpass filter before its integration with the rectangular patch antenna [7,17].

Hairpin filters are also a compact type of microstrip bandpass filter. The resonators are folded into a U-shaped form, which reduces the required physical size. The filter performance depends mainly on the resonator dimensions and the coupling between neighboring resonators. The coupling can be changed by changing the spacing between the resonators, which helps to obtain the required center frequency and bandwidth. Due to their simple structure and small size, hairpin filters are useful in RF and microwave circuits [17].

The rectangular microstrip antenna is one of the commonly used types of microstrip antennas because of its simple structure and easy fabrication. It consists of a rectangular metal patch printed on a dielectric substrate with a ground plane on the other side. The resonant frequency of the antenna depends mainly on the patch dimensions and the properties of the substrate. The patch can also be coupled with other structures to modify its frequency response. In this work, a rectangular microstrip patch is used as the radiating element and is integrated with the hairpin resonators to form the proposed filtering antenna [9,10].

This paper presents a microstrip filtering antenna operating at 1.9 GHz. The design uses a rectangular microstrip patch and two hairpin resonators based on the filter synthesis method. The filter antenna was designed and simulated using CST Microwave Studio. The final design provides a bandwidth of about 77MHz, a return-loss better than -10dB, and a gain of 6.57 dBi. The proposed filtering antenna provides a simple and low-cost solution for wireless communication systems.

The 1.9 GHz frequency range is used in several wireless communication systems. One example is Digital Enhanced Cordless Telecommunications (DECT), which operates around this frequency range in many regions. Therefore, the 1.9 GHz band is of interest for compact wireless communication devices [2].

The remainder of this paper is organized as follows. Section II describes the design procedure of the bandpass filter and the proposed filtering antenna. Section III presents the simulation results and discusses the performance of the proposed design. Finally, Section IV concludes the paper.

FILTER-ANTENNA DESIGN

This section explains the design of the microstrip filtering antenna. The structure is made of a microstrip feed line, two hairpin resonators, and a rectangular patch antenna. It operates as a third-order bandpass filter with a center frequency of 1.9GHz and a bandwidth of 50MHz. The simulation results indicate good out-of-band suppression and a suitable radiation pattern for wireless communication applications.

A- Third Order Microstrip Filter Subtractor

The filter is designed using hairpin microstrip resonators with a center frequency of 1.9 GHz using a third-order Chebyshev low-pass prototype with a passband ripple of 0.0432 dB. The normalized prototype values are $g_0 = g_4 = 1.0$, $g_1 = g_3 = 0.8516$, and $g_2 = 1.1032$ for a normalized cutoff frequency of $\Omega_c = 1$. The calculated fractional bandwidth (FBW) is 0.026, while the coupling coefficients between adjacent resonators are $M_{12} = M_{23} = 0.027$, and the quality factors of the external input/output ports are $Q_{e1} = Q_{e2} = 32$.

The filter is applied on a commercial FR4 substrate has a dielectric constant (ϵ_r) of 4.3 and a substrate thickness of 1.5 mm. A 50 Ω coupled microstrip line is used at both the input and output ports to provide impedance matching. Figure 1 shows the proposed three-order hairpin microstrip filter. The filter consists of three hairpin resonators connected between the input and output ports. Figure 1(a) shows the 3D model of the filter, while Figure 1(b) shows the front view with the main dimensions. The overall size of the filter is 80 mm $\times$ 85 mm. The dimensions of the resonators and the spacing between them are selected according to the required filter response. The filter response was calculated from the coupling matrix and plotted in MATLAB [17], as shown in Figure 2. Three resonant poles appear inside the passband. The first and third poles are located at 1.885 GHz and 1.915 GHz, while the second pole is located at 1.9 GHz.

Figure 3 shows the resonator model used in the filter. The resonator is modeled with two weak coupling port to

obtain the resonance frequency at 1.9 GHz as shown in Figure 3, the strip line width is 1mm, length is 18 mm and the resonator width is 11 mm. At resonance, the field of electrical charges are concentrated near the ends of resonator arms, and the magnetic-field is strongest near the center of the resonator. The coupling between adjacent resonators is produced by the interaction of these electric and magnetic fields.

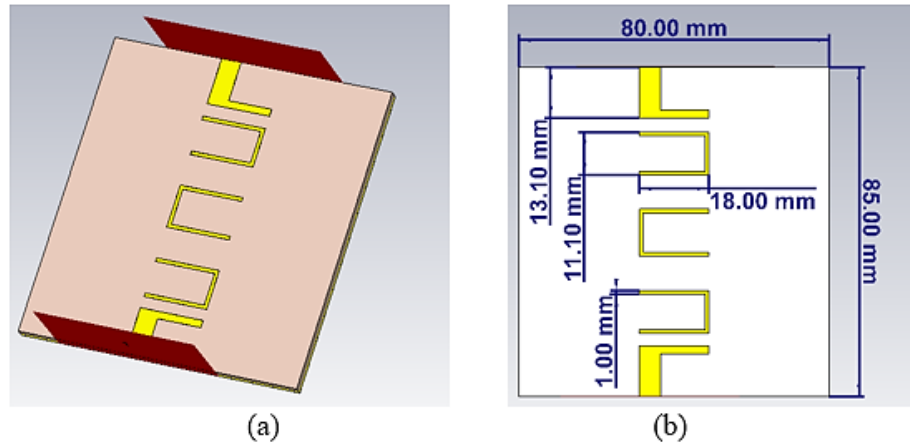


Figure 1. Three-order hairpin microstrip filter model and dimensions. (a) 3D view of the proposed filter; (b) front view with the main dimensions. The overall filter size is 80 mm $\times$ 85 mm. The resonator length arm is 18 mm, the resonator width 11mm, and the arms width 1 mm.

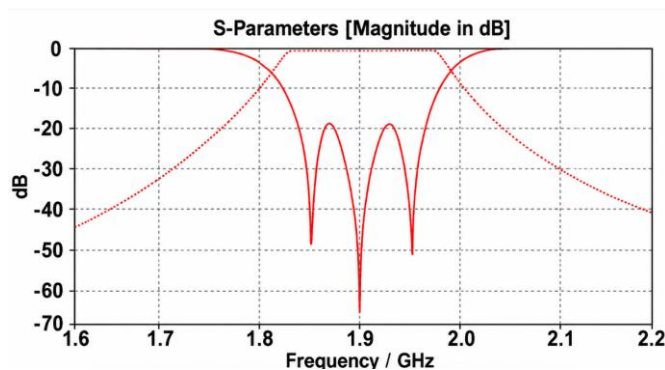


Figure 2. Responses of the proposed third-order bandpass filter calculated from the matrix of coupling.

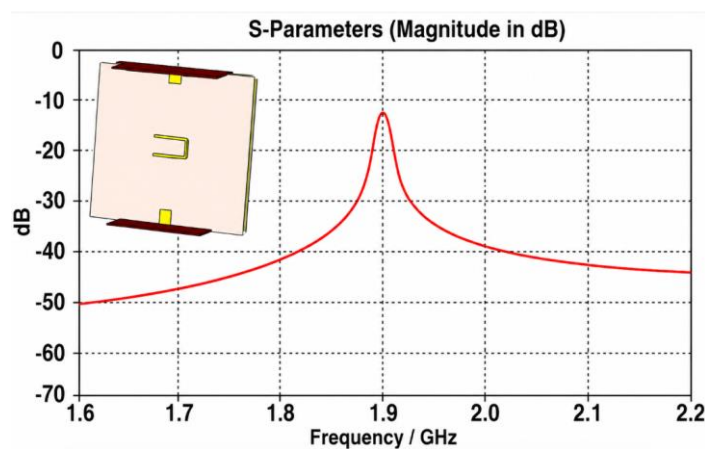


Figure 3. Response of the signal hairpin resonator

When the parallel arms of the hairpin resonator are placed close to each other, the currents flowing through them have nearly the same magnitude but opposite directions. This current distribution reduces radiation loss because

part of the radiated fields cancels each other, resulting in a higher unloaded quality factor (Q). However, reducing the spacing too much increases the coupling between the parallel lines. On the other hand, increasing the spacing weakens the coupling and allows more radiation loss. Therefore, the spacing between the resonator arms should be selected carefully to achieve a suitable balance between a high unloaded quality factor and the required coupling [17].

B- Coupling between resonators

The coupling value between two neighboring resonators is calculated by the method in [17]. Figure 4(a) shows the CST model used for this purpose. The coupling changes with the spacing (S) between the two resonators. The simulated S_{21} response for a spacing of 2 mm is presented in Figure 4(b). The coupling coefficient (M) is then obtained from the equation given in [17]. The relationship between M and the resonator spacing is presented in Figure 5. It can be seen that increasing the spacing reduces the coupling between the hairpin resonators. During the variation of the distance S between the resonators, the resonator length was changed to maintain the same filter center frequency.

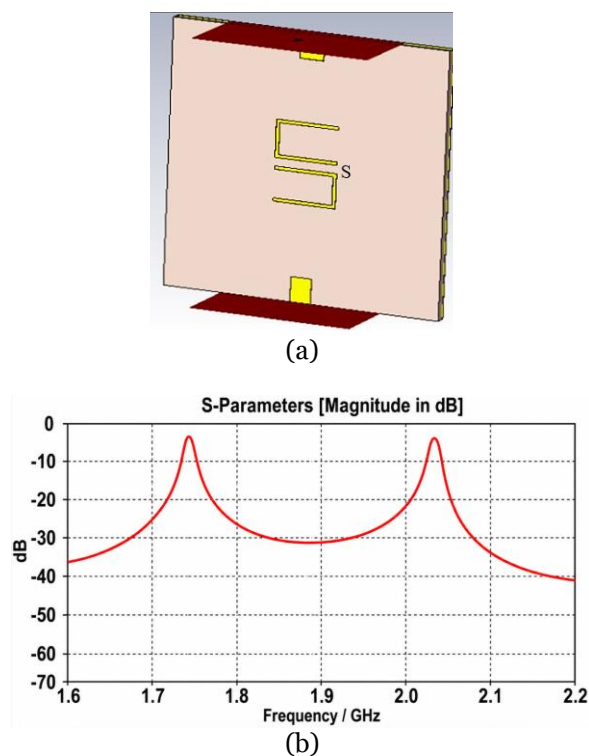


Figure 6. Coupling coefficient (M_{12}): (a) CST model; (b) Simulated S_{21} response.

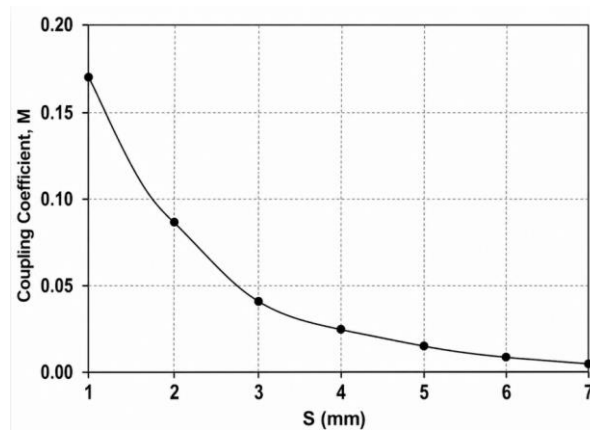


Figure 5. of coupling coefficient M vs distance between two resonators

C- External Coupling (Q_e)

The external coupling between the first port and the first resonator is obtained using the structure shown in Figure 6(a). The first port is strongly coupled to the first resonator, while the second port is placed away from the resonator to achieve weak coupling, so $Q_{e2} = \infty$. This model gives the simulated S_{21} response shown in Figure 6(b). The Q_{e1} is calculated using the f_0 and -3 dB bandwidth of the model's S_{21} response, using the equation given in [17]. Figure 7 shows Q_{e1} as a function of gap g between the feeding line and the resonator; when the gap g is increased, the source coupling is weakened and hence the external Q_{e1} value increases.

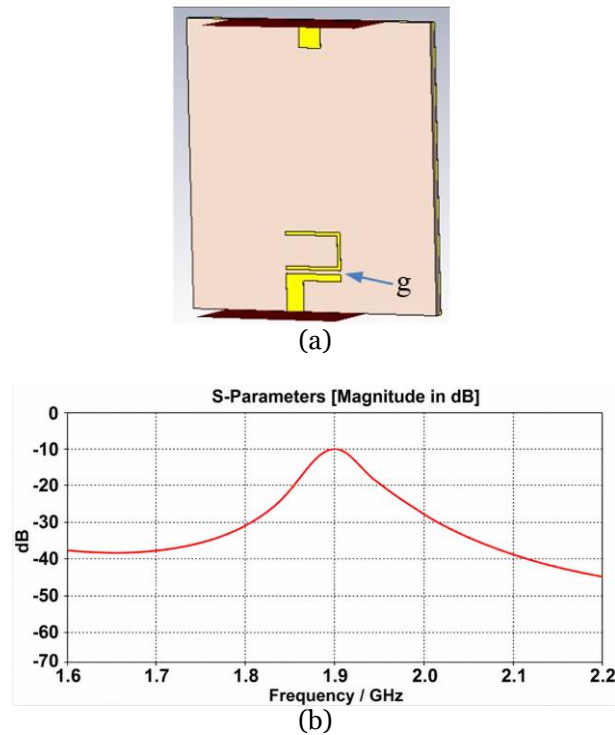


Figure 6. External quality factor (Q_e): (a) CST model; (b) S_{21} response.

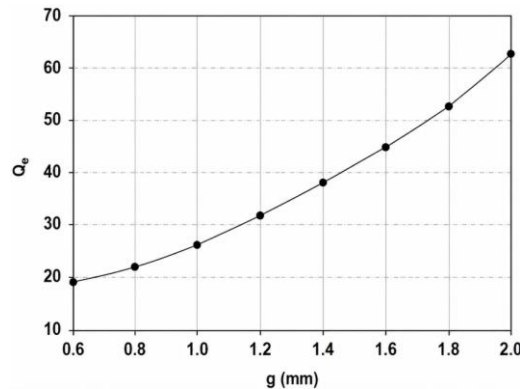


Figure 7. External quality factor vs distance between probe and resonator

D- The Filter Simulated Response

The proposed filter structure was simulated using CST Microwave Studio, a commercial three-dimensional electromagnetic solver. The simulated frequency response is shown in Figure 8. The filter operates at a center frequency of approximately 1.887 GHz. The simulated insertion loss at the center frequency is about 0.77 dB, while the return loss is better than -12 dB over the filter passband. The simulated -10 dB bandwidth is 48 MHz. These results indicate that the proposed filter provides good passband performance with acceptable insertion and return losses.

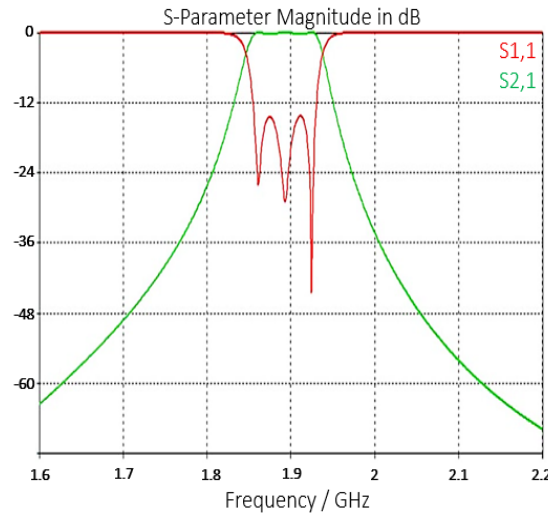


Figure 8. Simulated response of the filter model

E- Filtenna Sutstructure

The filtering antenna is developed from the bandpass filter presented in the previous section. The third hairpin resonator and Port 2 are substituted with a rectangular antenna, as shown in Figure 9. The patch radiation quality factor (Q_r) is chosen to match the external-quality factor (Q_{e1}). All filter dimensions remain unchanged except for the distance between the middle resonator and the rectangular patch, which is adjusted to obtain the required coupling coefficient, $M_{23} = 0.027$.

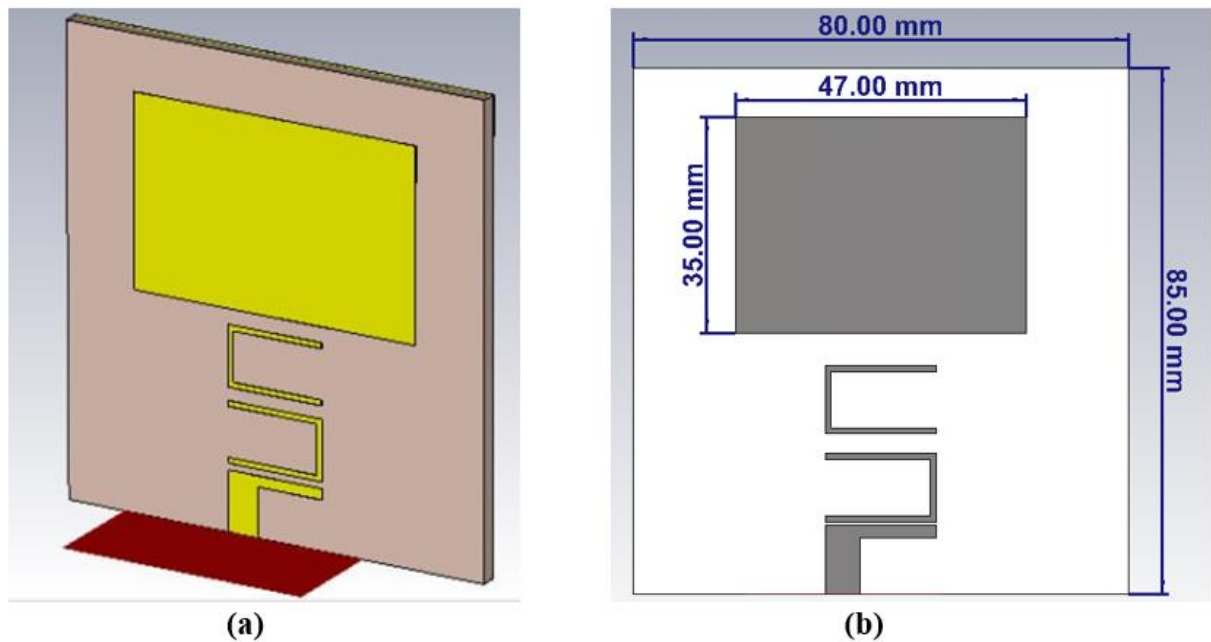


Figure 9. Geometry and dimensions of the proposed filtenna: (a) 3D view; (b) front view with dimensions.

Figure 10(a) shows the CST model used to extract the radiation quality factor (Q_r) of the rectangular patch. The simulated S_{21} response is shown in Figure 10(b), where S_{21} is the transmission coefficient between two weakly coupled ports. The value of Q_r is obtained from the resonant frequency and the -3dB BW using the method described in [17]. The calculated value is about 32, which is identical to the required external coupling value (Q_{e1}).

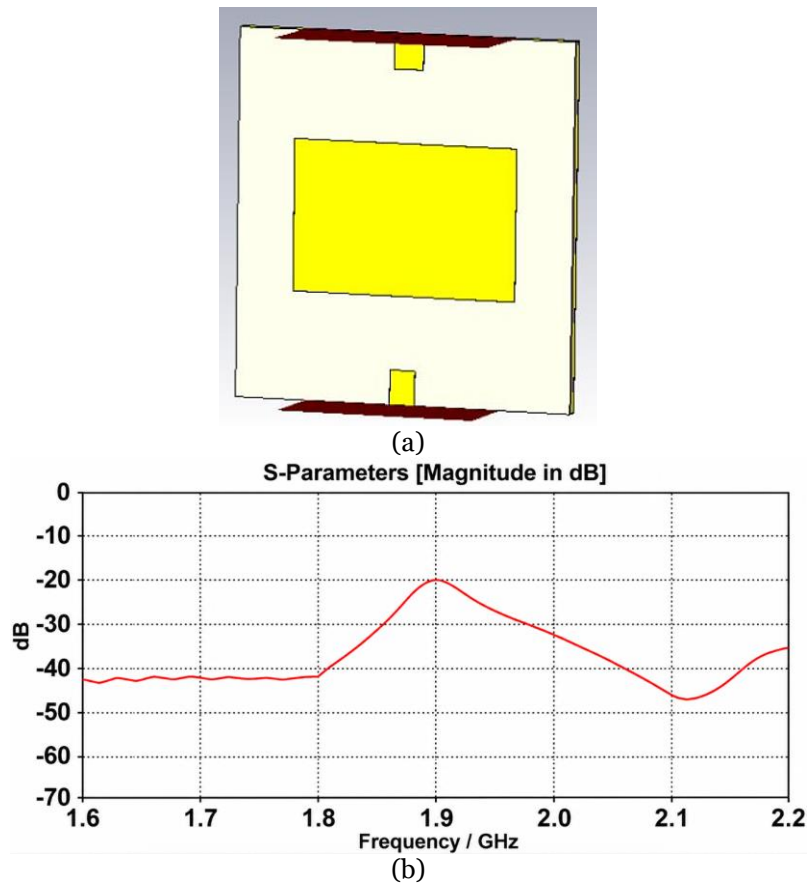


Figure 10. (a) Rectangular patch geometry; (b) S₂₁ response.

Figure 11(a) shows the CST model used to calculate the coupling between the middle resonator and the rectangular antenna. The coupling is controlled by changing the spacing (S_2) between them. Two weakly coupled ports are used to excite the structure. Figure 11(b) shows the simulated S₂₁ response, where two resonant peaks at f_1 and f_2 can be seen. The coupling strength between the 2nd resonator and the rectangular antenna is calculated using the equation given in [17]. Figure 12 shows the relationship between the coupling coefficient (M_{23}) and the spacing (S_2). The required spacing for $M_{23} = 0.027$ is about 2.7 mm.

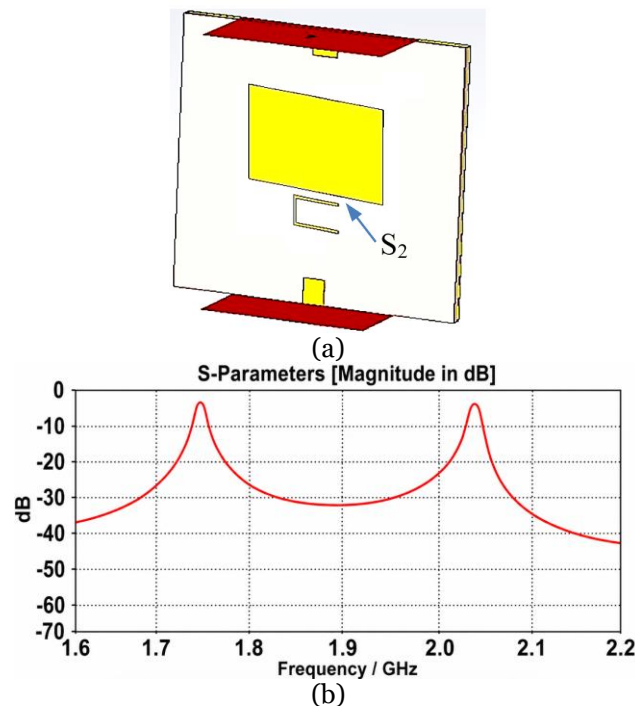
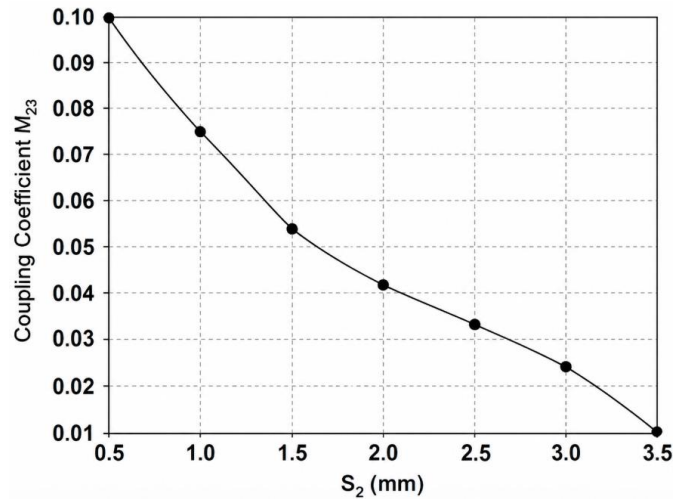
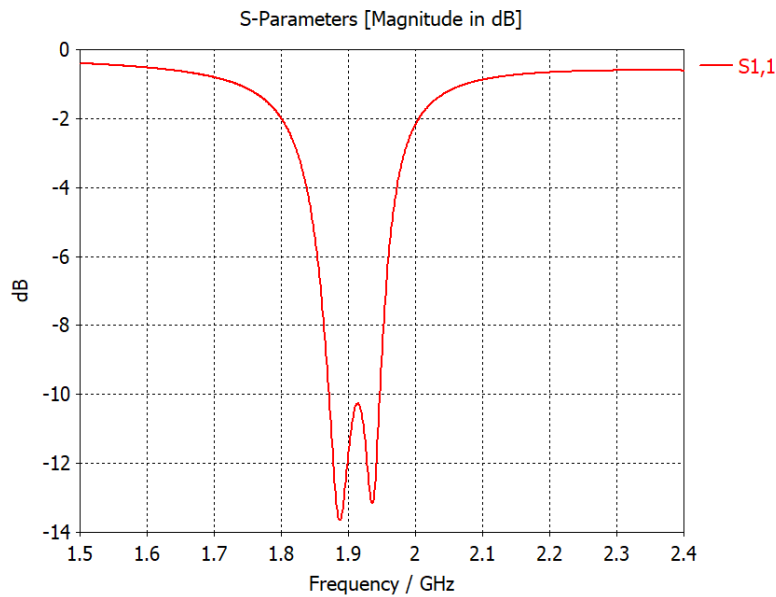


Figure 11. (a) Structure used for extracting the coupling coefficient M_{23} ; (b) Simulated transmission response (S₂₁).

Figure 12. Variation of M_{23} with the spacing S_2

FILTENNA SIMULATION RESULTS

The filtering antenna was designed and analyzed using CST Microwave Studio. Figure 13 shows the simulated S_{11} response. Two resonant minima can be seen within the operating band, showing the filtering behavior of the proposed structure. The operating frequency is 1.92 GHz, and the simulated -10 dB bandwidth is about 77 MHz. Figure 14 shows the simulated 3D radiation pattern of the proposed filtering antenna at 1.92 GHz. The radiation pattern shows that the antenna radiates mainly in one direction. The simulated gain is about 6.57 dBi. The change in center frequency and bandwidth is caused by the integration of the rectangular patch with the filter. The patch changes the coupling and resonance of the structure, resulting in a small frequency shift and a different bandwidth. Further adjustment of the structure requires electromagnetic optimization, which can take a long simulation time.

Figure 13. Simulated S_{11} response of the filtering antenna.

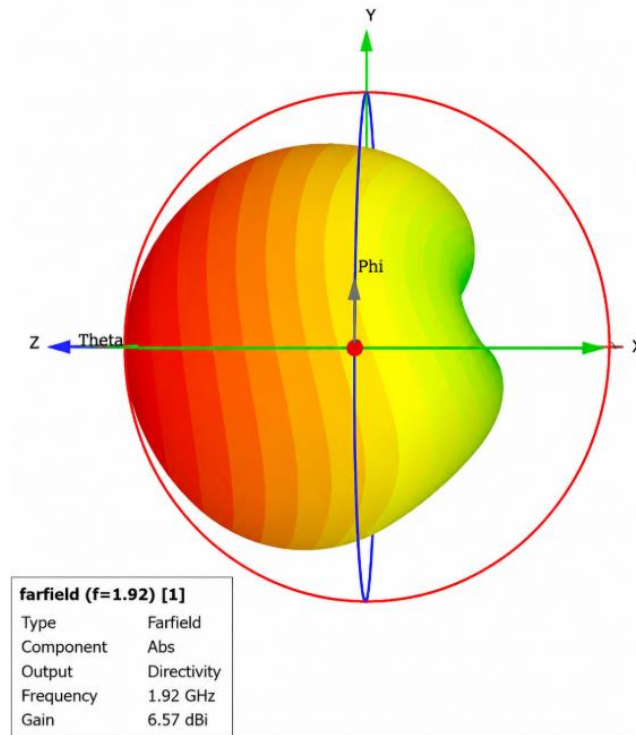


Figure 14. Simulated 3D radiation pattern of the proposed filtering antenna at 1.92 GHz.

CONCLUSION

This paper presented the design of a compact microstrip filtering antenna operating at 1.9 GHz. The proposed structure combines a rectangular microstrip patch with two hairpin resonators to perform both filtering and radiation in a single device. The filter synthesis method was used to design the filtering antenna, and the final design was simulated in CST Microwave Studio. The antenna operates at about 1.92 GHz with a bandwidth of 77 MHz and a gain of 6.57 dBi. The S₁₁ response indicates that the filtering behavior is preserved after replacing the third hairpin resonator with the rectangular patch. The proposed design provides a compact and simple solution that can be used in wireless communication systems.

ETHICAL DECLARATION

Conflict of interest: No declaration required. **Financing:** No reporting required. **Peer review:** Double anonymous peer review.

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