# Wideband Microstrip Bandpass Filter Using Fr4 Substrate for Wlan Applications

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***Abstract*—An interdigital resonator-based bandpass structure is implemented on an FR4 substrate and analyzed using ANSYS HFSS to enhance signal selectivity in wireless communication systems. The filter is designed and simulated to allow the desired frequency band to pass while attenuating unwanted out-of-band signals. The rapid expansion of Wi-Fi, Bluetooth, and IoT devices within this spectrum has increased congestion, making efficient band selection essential for stable performance. The simulated S-parameter results demonstrate low insertion loss within the passband along with satisfactory impedance matching. The interdigital configuration strengthens capacitive coupling between adjacent fingers, enabling controlled resonance and stable frequency response. Owing to its compact planar structure and flexible design characteristics, the filter is suitable for integration into WLAN and IoT RF front-end applications. The proposed design focuses on achieving stable passband transmission with reliable selectivity while maintaining a simple geometry suitable for practical implementation.**

***Index Terms*—Interdigital Filter, Microstrip Bandpass Filter, 2.4 GHz ISM Band, WLAN Interference Suppression, RF Filter Design, ANSYS HFSS, S-Parameters, FR4 Substrate, Resonator Coupling, Wireless Communication Systems**

## I. INTRODUCTION

The 2.4 GHz industrial, scientific, and medical band, where technologies such as Wi-Fi, Bluetooth, Zigbee, and various Internet of Things devices operate simultaneously, has become highly significant due to the rapid expansion of wireless communication systems. As multiple devices share the same frequency spectrum, the possibility of electromagnetic interference increases, which can degrade signal quality, reduce data transmission efficiency, and affect overall system reliability. To ensure stable operation, the front-end stages of wireless systems incorporate radio frequency filtering techniques to select the desired operating band while suppressing out-of-band noise and interference. When a specific frequency range must be transmitted efficiently while attenuating frequencies outside that range, bandpass filters provide an effective solution. Owing to its compact structure, low fabrication cost, and easy integration with printed circuit boards, microstrip technology is widely adopted in modern RF circuit design. The interdigital resonator configuration, characterized by closely spaced metallic fingers producing distributed capacitive and inductive effects, offers a practical approach for achieving compact bandpass characteristics at the intended frequency. The center frequency and bandwidth can be accurately controlled by adjusting geometric parameters such as finger length, width, spacing, and the number of resonators. ANSYS HFSS is employed to design and simulate a 2.4 GHz interdigital microstrip bandpass filter suitable for WLAN and IoT applications, ensuring efficient signal transmission within the desired band while maintaining stable impedance characteristics.

## II. INTERDIGITAL FILTER

A compact planar resonant structure known as an interdigital microstrip bandpass filter is used to allow a specific frequency band to propagate while attenuating signals outside that band. In this configuration, a microstrip transmission line is loaded with multiple parallel metallic fingers arranged in an interdigital pattern on a dielectric substrate. The operation of this structure is based on the formation of distributed inductance and capacitance. Fabricated on a substrate such as FR4, it consists of several closely spaced transmission line resonators positioned in an alternating arrangement, where one end of each resonator is short-circuited to ground through a via while the opposite end remains open. The narrow gaps between adjacent fingers create strong capacitive coupling, while the length of each metallic strip determines the effective inductive behavior. Together, these distributed elements form a resonant LC structure that establishes a low-impedance transmission path at the desired center frequency. At resonance, signal energy is efficiently transferred from input to output, resulting in a clear passband in the transmission response with minimal insertion loss.

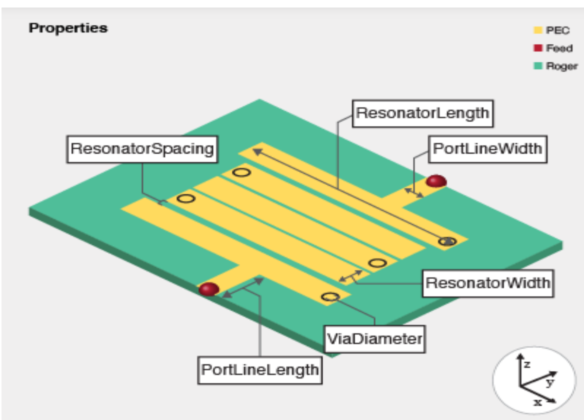


Fig. 1. Geometrical layout of the proposed interdigital bandpass filter.

The operating frequency of the proposed interdigital bandpass filter is governed by the interaction between distributed inductive and capacitive elements formed within the structure. The metallic fingers behave as inductive sections, while the narrow separations between adjacent fingers create capacitive coupling. Together, these elements establish a resonant response that defines the center frequency of the passband. The amount of coupling is strongly influenced by the spacing between the fingers as well as the dielectric properties of the substrate material. The effective dielectric constant, determined by the substrate characteristics and microstrip geometry, affects the propagation of electromagnetic waves and defines the guided wavelength inside the structure. The bandwidth and passband sharpness are related to the quality factor, which indicates how efficiently energy is transmitted around the center frequency. By modifying parameters such as finger dimensions, number of resonators, spacing, and substrate features, the filter's frequency response can be accurately tailored. The compact interdigital arrangement makes it highly suitable for WLAN and IoT bandpass filtering applications.

## III. DESIGN METHODOLOGY

The proposed interdigital microstrip bandpass filter is designed to achieve a passband centered at 2.4 GHz for WLAN applications. The center frequency $f_0$is first selected according to the required wireless communication standard. For practical fabrication and low-cost implementation, an FR4 substrate with a relative dielectric constant $\varepsilon_r = 4.4$and thickness $h = 1.6$mm is chosen. To determine the wave propagation characteristics within the substrate, the effective dielectric constant of the microstrip line is calculated using

$$\varepsilon_{eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(\frac{1}{\sqrt{1 + 12h/W}}\right)$$

where $W$represents the width of the microstrip line. Using this value, the guided wavelength inside the substrate is obtained from

$$\lambda_g = \frac{c}{f_0\sqrt{\varepsilon_{eff}}}$$

where $c$is the velocity of light in free space. For bandpass operation around 2.4 GHz, each resonator length is initially approximated to be close to $\lambda_g/2$, since half-wavelength resonators are typically employed in bandpass filter configurations. The exact dimensions are later fine-tuned using electromagnetic simulation tools. The interdigital bandpass structure consists of multiple parallel microstrip fingers arranged alternately and coupled to each other. In this configuration, each finger behaves as a resonator, while the gaps between adjacent fingers introduce capacitive coupling. The physical length of the fingers contributes mainly to inductive energy storage, whereas the spacing between them controls the coupling strength between resonators. The center frequency of each resonator can be approximately described by the LC resonance relation

$$f_0 = \frac{1}{2\pi\sqrt{L_{eq}C_{eq}}}$$

where $L_{eq}$ and $C_{eq}$ denote the equivalent inductance and capacitance of the resonator section. Increasing the resonator length effectively increases the inductive component, which shifts the passband toward lower frequencies. Similarly, decreasing the spacing between fingers enhances capacitive coupling, resulting in wider bandwidth and stronger energy transfer between resonators. By carefully adjusting parameters such as finger length, width, spacing, and the number of resonators, the passband frequency, bandwidth, and insertion loss characteristics can be precisely controlled. After finalizing the initial geometrical parameters, the complete bandpass filter structure is modeled using ANSYS HFSS. A frequency sweep is performed typically from 1 GHz to 4 GHz to evaluate the S-parameters. The design is iteratively optimized until a well-defined passband centered near 2.4 GHz with low insertion loss and good impedance matching is achieved, ensuring effective signal transmission within the WLAN frequency band while suppressing unwanted frequencies outside the passband.

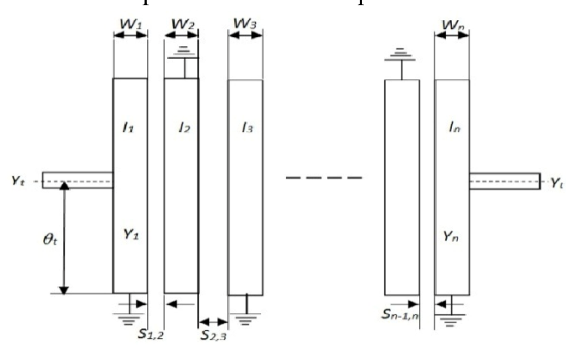

Fig. 1. Layout of the proposed interdigital bandstop filter showing geometrical dimensions.

The second stage of the design process involves defining the detailed geometric configuration of the interdigital structure. During this stage, multiple metallic fingers are arranged in parallel and alternately connected to opposite sides of the transmission line to establish strong capacitive coupling between adjacent resonators. The key structural parameters include finger length, finger width, spacing between fingers, and the overall substrate dimensions. The interaction between the inductive effect produced by the strip length and the capacitive effect introduced by the narrow gaps forms an equivalent LC resonant network. This resonant mechanism determines the center frequency of the passband. By carefully adjusting the finger length and the spacing between adjacent fingers, the center frequency and bandwidth can be accurately tuned to the desired operating band. Proper dimensional optimization at this stage ensures controlled passband characteristics, efficient signal transmission, and a compact physical structure suitable for practical wireless communication applications. In addition, the strength of electromagnetic coupling between adjacent resonators directly influences the selectivity and sharpness of the passband response. Careful balancing of inductive and capacitive effects improves transmission efficiency within the desired frequency range. This systematic geometric refinement ultimately enhances overall filter stability and performance in real-world RF front-end systems.

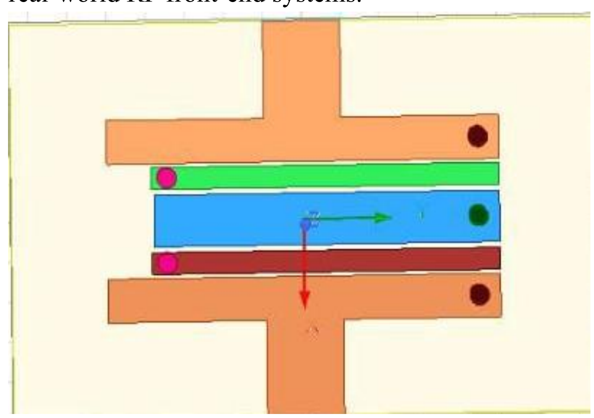

Fig. 2. Three-dimensional electromagnetic structure of the proposed filter in ANSYS HFSS.

The final stage of the design process involves implementing the optimized layout in ANSYS HFSS for full-wave electromagnetic simulation. The complete three-dimensional model includes the ground plane, metallic conductors, excitation ports, and dielectric substrate. Radiation boundary conditions are applied to emulate open-space behavior, and the scattering parameters are evaluated over a broad frequency range to analyze the filter's transmission and reflection characteristics. Adaptive meshing is employed to enhance computational accuracy and ensure reliable simulation results. The simulated response confirms the presence of a well-defined passband around the desired operating frequency, demonstrating efficient signal transmission with low insertion loss. The impedance characteristics within the passband indicate stable matching performance. Through iterative refinement of finger dimensions and spacing, the filter achieves controlled bandwidth, compact geometry, and practical suitability for PCB fabrication in WLAN and IoT wireless communication systems.

Table 1-Design Parameters of Microstrip Interdigital Bandstop Filter

| S.NO | PARAMETER | SYMBOL | VALUE | UNIT |
|---|---|---|---|---|
| 1 | Substrate | - | FR4 Epoxy | - |
| 2 | Relative Permittivity | $\epsilon_r$ | 4.4 | - |
| 3 | Substrate Thickness | h | 1.6 | mm |
| 4 | Conductor Material | - | copper | - |
| 5 | Conductor Thickness | t | 0.035 | mm |
| 6 | Characteristic Impedance | $Z_0$ | 50 | Ω |
| 7 | Substrate Length | Lsub | 40 | mm |
| 8 | Substrate Width | Wsub | 30 | mm |
| 9 | Finger Length | Lf | 12 | mm |
| 10 | Finger width | Wf | 1.0 | mm |
| 11 | Gap Between Fingers | G | 0.5 | mm |
| 12 | Number of Fingers | N | 5 | - |
| 13 | Target Notch Frequency | Fo | 2.4 | GHz |

## IV. RESULTS AND DISCUSSION

The performance of the proposed wideband microstrip bandpass filter is analyzed using electromagnetic simulation in ANSYS HFSS. The objective of this analysis is to verify the practical behavior of the filter in terms of signal transmission, reflection, and frequency selectivity within the intended WLAN operating band. The simulation is carried out over a wide frequency range to observe the complete response of the filter, including both passband and stopband characteristics. The obtained results provide a clear understanding of how the designed structure performs under realistic conditions.

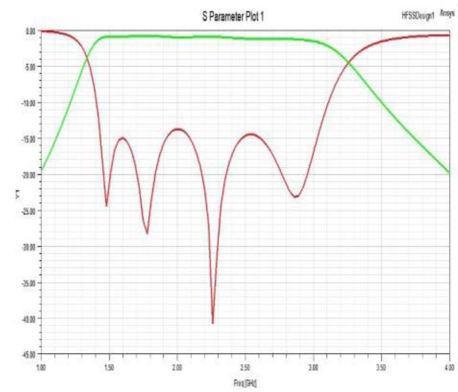


Fig. 1. Simulation and Performance Analysis of and S-Parameters for a High-Order Wideband S-Band Filter.

The simulated HFSS model of the proposed wideband microstrip bandpass filter on an FR4 substrate. The structure consists of multiple interdigital metallic fingers arranged to create strong capacitive coupling between adjacent resonators. The complete model includes the substrate, ground plane, and excitation ports, representing a practical implementation of the design. The geometry and layout confirm that the structure is compact and suitable for integration in WLAN communication systems.

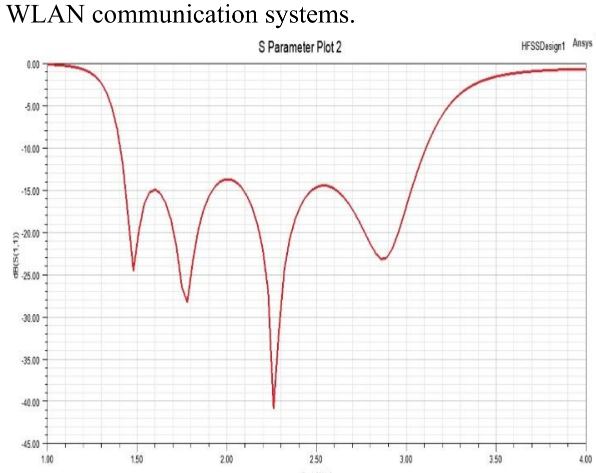


Fig. 2. Simulated S11 and S21 response of the proposed wideband microstrip bandpass filter.

The simulated S-parameter response of the proposed filter is presented in Fig. 4, which illustrates the transmission (S21) and reflection (S11) characteristics across the frequency range. A clear passband is observed around the 2.4 GHz region, confirming that the filter allows the desired frequency components to pass effectively. Within this band, the S21 parameter remains close to 0 dB, indicating low insertion loss and efficient signal transmission. Simultaneously, the S11 parameter exhibits values below -10 dB and reaches approximately up to -40 dB at certain frequencies, demonstrating strong impedance matching and minimal signal reflection. The presence of multiple resonance dips in the response indicates effective coupling between the interdigital resonator elements, which contributes to the wideband behavior and improved selectivity of the filter. Outside the passband, the transmission decreases significantly, ensuring that unwanted frequency components are effectively suppressed. This sharp transition between passband and stopband confirms good filtering performance. The overall response observed from the simulation reflects stable and efficient operation under practical conditions, validating the suitability of the proposed design for WLAN applications in the 2.4 GHz frequency range.

## V. CONLUSION

In this study, a compact interdigital microstrip bandpass filter operating around 2.4 GHz has been designed and analyzed for WLAN applications using an FR4 substrate with optimized geometrical dimensions. The proposed structure utilizes closely spaced metallic fingers to generate strong capacitive coupling along with inductive effects, forming an equivalent LC resonant mechanism that produces a well-defined passband response. Simulation results across a wide frequency range confirm efficient signal transmission near the desired center frequency while providing effective attenuation outside the operating band. The S-parameter analysis demonstrates low insertion loss within the passband and satisfactory impedance matching, validating the effectiveness of the design methodology. Surface current distribution further confirms the resonant behavior, showing concentrated energy flow along the interdigital fingers at the operating frequency. The compact planar configuration, combined with ease of fabrication using standard PCB techniques and cost-effective substrate material, makes the proposed filter highly suitable for practical WLAN and IoT RF front-end applications requiring stable and efficient band selection in the ISM band.

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