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(RESEARCH ARTICLE)

Simulation of Microstrip LBPF with Sharp Roll-off and Wide Stop-Band Suppression

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Abstract

The design analysis of a lightweight micro-strip LPF with an ultra-wide rejection band is presented in this work. To accomplish steep roll-off and ultra-wide stop-band rejection, the suggested filter makes use of sophisticated resonator topologies, such as modified stepped impedance structures or tiny micro-strip resonant cells. Excellent harmonic noise suppression, reduced insertion loss in the pass-band, and a compact and small size make this structure ideal for contemporary microwave and radio frequency applications. Full-wave simulations and practical data are used to evaluate the filter design, demonstrating its outstanding sensitivity and scalability.

Keywords: Advance Design System; Microstrip; Open Circuit Stubs; Selectivity; S-Parameter

1. Introduction

In wireless communication systems and applications such as blocking unwanted signals and lowering spurious harmonics, radio frequency based or microwave based LBPFs are crucial passive parts. Low cost, compact size, minimal insertion loss, and wide stopband performance characteristics make low-band pass filters (LBPFs) highly favourable in modern designs [1]. Among the various types, microstrip lowpass filters are widely used due to their compatibility with planar fabrication and integration with printed circuit board (PCB) technology [2].

Compact, effective, and high-performance filtering components that can function well across a wide frequency range are increasingly necessary as modern wireless communication systems evolve. In RF and microwave circuits, LPFs play a critical role in eliminating unwanted high-frequency signals, reducing electromagnetic interference (EMI), and enhancing overall signal integrity. A low-loss, without vertical holes design with sharp roll-off behaviour and enhanced stopband suppression is offered by a compact planar low-pass filter that uses folded stepped-impedance resonators on FR-4 substrates [3]. Lowpass filter employing a broadside-coupled configuration for ultrawideband harmonic attenuation [4]. Their planar structure, ease of manufacture, and suitability for PCB integration make microstrip LPFs ideal for compact and cost-sensitive applications [5]. The filter exhibits a quasi-elliptic function response, providing transmission zeros near the passband edge. These transmission zeros result in a steep slope and sharp transition between passband and stopband [6].

Despite these advantages, conventional LPF designs often suffer from poor suppression of spurious harmonics and narrow stopband bandwidth, leading to signal distortion and degraded performance at higher frequencies [7]. A new photonic bandgap configuration can be designed for a low-pass filter with an extensive stopband [8]. As the demand for higher data rates, greater bandwidth efficiency, and multiband operation increases, it becomes essential to design LPFs that exhibit ultra-wide rejection bands and steep roll-off characteristics while maintaining a compact footprint [9]. To enhance stopband characteristics while preserving low-profile integration, recent research has explored advanced resonator structures such as compact microstrip resonant cells (CMRCs), defected ground structures (DGS), and

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stepped-impedance resonators (SIRs) [10, 11]. These structures allow for better control of the filter's electrical response, such as insertion loss, passband flatness, and out-of-band attenuation [12, 13].

To verify the proposed design, simulations were carried out using Advanced Design System (ADS) which is a efficient electronics Graphical User Interface automation program for fast speed electronic, microwave, and radio frequency applications. ADS provide accurate simulation tools such as S-parameter analysis, harmonic balance, and layout optimization, which enable precise modelling of the microstrip structure [14]. S-parameter analysis is used in RF and microwave engineering to characterize linear electrical networks, especially at high frequencies where voltage and current measurements are difficult. Stepped-impedance hairpin resonators are used in compact low-pass filters to achieve elliptic-function responses, which allow for improved stopband suppression and sharp transition bands in a smaller footprint [15].Compact designs with better selectivity can be obtained by employing rat-race directional couplers in microstrip lowpass filters to produce longer stopband performance with increased harmonic suppression [16].The design approach for lowpass filters presented in this study uses finite-frequency transmission zeros, which increase the filter's selectivity by producing abrupt attenuation poles at target frequencies. This improves the stopband performance and roll-off steepness [17]. Using ADS, the filter's electrical performance was thoroughly evaluated and optimized before fabrication. Its graphical interface and integration of layout and schematic views significantly streamline the design and verification process, making it an indispensable tool in the development of modern microwave filters.

In this proposed work, a small sized micro-strip LPF with a wide stop-band is considered. The filter consists of unit elements along with shunt stepped-impedance lines, based on a transmission line topology using open-circuited stubs. Open-circuited stub is a transmission line segment that has an open ending. Depending on OC stub's length and frequency, it introduces reactive impedance when linked at a point in a circuit. Compact low pass filters employing multimode resonators can achieve ultra-wide stop-bands with strong harmonic suppression, making them suitable for applications requiring compact size and wide rejection bands [18]. To enhance the stopband and improve selectivity, conventional stubs are substituted with stepped-impedance OC (open-circuited) stubs, which introduce transmission zeros within the rejection band. By establishing a cross-coupling connection between the filter feed lines, the stub-line filter's stopband can be expanded [19]. This leads to wider rejection bandwidth and improves overall filter performance [20, 21].

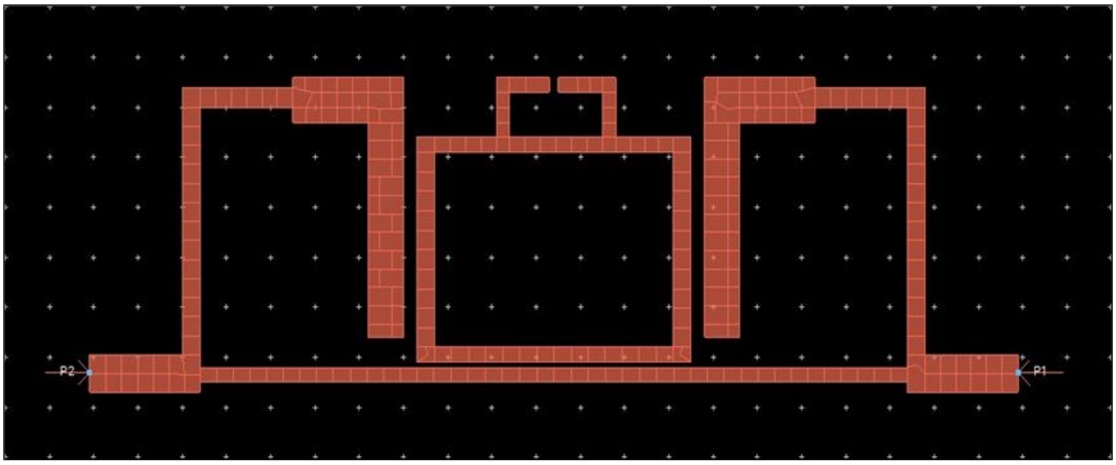

Figure 1 2-D view of the Low Bandpass Filter in ADS

The proposed filter is designed using microstrip technology, simulated, and its performance is validated using ADS. Microstrip is a piece of conducting strip which is printed on a dielectric substrate with a ground plane on the bottom. Simulation and measurement results confirm the filter's effectiveness in achieving ultra-wide stopband, sharp roll-off, and compact size, meeting the stringent requirements of modern wireless systems [22, 23].

2. Design methodology

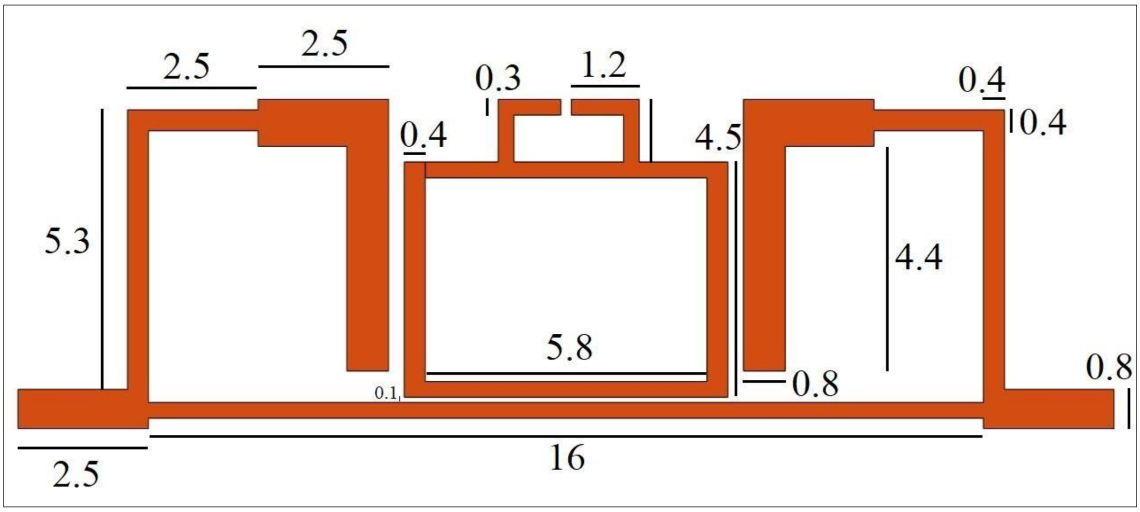

Figure 2 Dimensional layout of LBP filter in mm

The Figure 2 shows a proposed design of the suggested micro-strip configuration filter. The corresponding transmission line circuit model for the suggested structure is provided. This figure illustrates that the layout of the filter is divided by two symmetric-unit elements into two symmetrical cross-sectionalareas consisting of open circuited stubs and one shunt OC stub. While Z_2 donates the characteristic impedance of the shunt open circuited stub, Z_1 and Z_{11} define the characteristic impedances of the two-section OC stubs. Furthermore, Z_{12} defines the Z_0, i.e., characteristic impedance of the unit elements. Each circuit model element's electrical length is determined by θ.

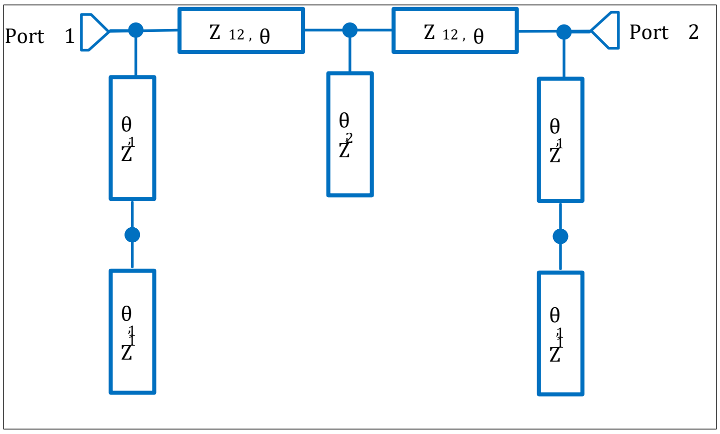

Figure 3 Impedance model of the proposed micro-strip LBPF

The filter's lowpass performance is intended to have a very wide rejection band, a cut-off frequency of 2.38 GHz, and a sharp rate of attenuation. Advance Design software (ADS) is used to optimize the filter's circuit model and specify the ideal circuit parameter values. According to the results, the optimum values are Z_1 = 101.7Ω, Z_{11} = 47.5Ω, Z_{12} = 159Ω, and Z_2 = 12.1Ω. The filter is designed to produce three symmetric attenuation poles within the stopband to achieve a large rejection band and extremely high selectivity, as shown in Figure 3. Consequently, at the mid-stopband frequency (f_0) of 9.0 GHz, the electrical length (θ) of the circuit parameters is selected to be a quarter wavelength. Consequently, one transmission zero is produced at f_0 by the one-section open-circuited stub (Z_2). Both stepped stubs produce two transmission zeros, f_{z1} and f_{z2}, because the entire length of each two-section open-circuited stub at f_0 is roughly half wavelength (2θ). For example, $f_0 – f_{z1} = f_{z2} - f_0$. These two transmission zeros are symmetric to f_0. As a result, the filter exhibits three attenuation poles in the stopband. The two symmetric transmission zeros (f_{z1} and f_{z2}) for $Z_1 = Z_{11}$ occur at $f_0 – f_{z1} = f_{z2} - f_0$, respectively.

Meanwhile, by altering the values of Z_1 and Z_{11}, the positions of these two transmission zeros as well as the attenuation level can be changed. The filter performance with various values of Z_1 and Z_{11} is displayed in Figure 3. It should be mentioned that shifting the initial transmission zero close to the filter's cut-off frequency might increase the filter's selectivity and lengthen its stopband. Nevertheless, the bandwidth, the insertion loss attenuation level at the stopband, and the selectivity are all traded off. The steepness of the passband-to-stopband transition is known as selectivity. It shows the rate at which frequencies outside the desired band are attenuated by the filter. For instance, the attenuation level of the insertion loss is reduced, and the stopband width increases as the parameter selectivity is increased.

3. Results and discussion

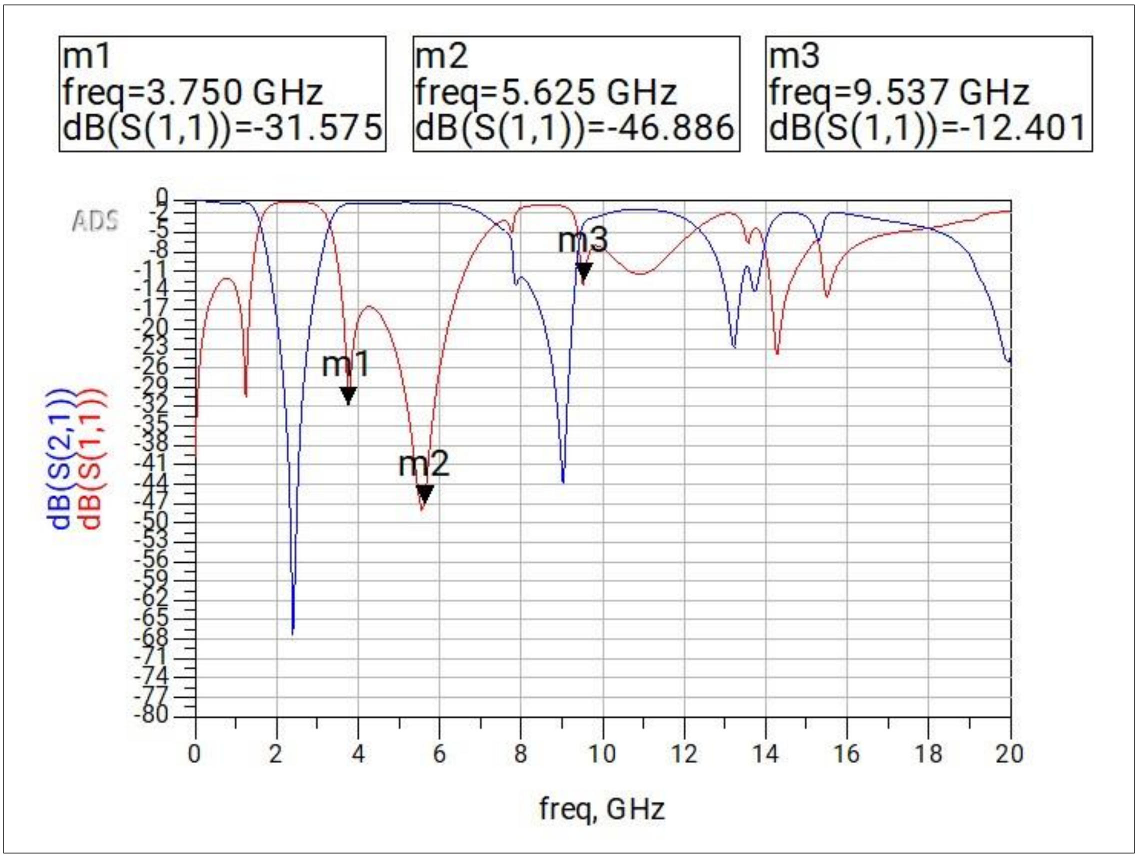

Figure 4 S-parameter Analysis of attenuation poles within 3GHz to 10GHz

A lowpass filter of compact size has been designed to achieve a cut-off frequency at 2.38 GHz, offering a return loss of 30 dB and featuring three ripples within the pass-band, which is indicative of a Chebyshev low band pass filter. The filter's structure is engineered in a specific way such that it produces three-transmission zeros, also known as attenuation poles and they are at 3.75 GHz, 5.625 GHz, and 9.537 GHz, providing strong rejection in the stopband with a maximum insertion loss of 46.88 dB. To realize this response, the characteristic impedances (Z_0) of the transmission line sections are selected as Z_1 = 101.7Ω, Z_{11} = 47.5Ω, Z_{12} = 159Ω and Z_2 = 12.1Ω and $\theta=90°$ at 9.5 GHz.

The design utilizes FR-4 substrate characterized by a dielectric constant ε_r = 4.6 and thickness of 0.254 mm. To reduce the filter's physical size, the open-ended stubs are folded perpendicularly. The filter layout is modelled and analysed using the ADS full-wave electromagnetic simulator [24]. The micro-strip layout of the filter is simulated and the result thus achieved is depicted as in Figure 4. The simulated results of the proposed filter show equivalent ripples in both the stop-band as well as in the pass-band. Using a high precision printed-circuit board technology, the layout of the designed model can be easily fabricated.

4. Conclusion

This work has created and demonstrated a unique low-pass filter construction with an extended wideband stopband. Together with unit elements, the filter uses a configuration of shunt stepped-impedanceopen circuited stubs. Setting the open-circuited stubs' electrical length to double that of the unit elements at the mid-stopband frequency is a crucial design technique. By producing more transmission zeros at the cut off frequency and inside the rejection zone, this method greatly improves the filter's frequency-selective behaviour. Finite-frequency transmission zeros boost the filter's selectivity by creating abrupt attenuation poles at target frequencies, are used in the lowpass filter design methodology described in this work. As a result, the roll-off steepness and stopband performance are enhanced [25]. Because of its extremely high selectivity and equal-ripple performance in the pass-band, the filter is a good fit for contemporary communication systems that require little in-band distortion and a rapid roll-off. Using experimental prototyping and full-wave electromagnetic (EM) simulations, the suggested design has undergone thorough validation. The precision and resilience of the design process are validated by the high degree of agreement between the measured, simulated, and analytically calculated findings. All things considered, the shown filter design offers a small, powerful solution for applications needing accurate frequency control and effective out-of-band signal suppression. Future research might examine integrating this design method into bigger RF front-end systems and extending it to band-pass or multiband filter designs.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest to be disclosed.

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