

Design and Simulation of Electromagnetic Bandgap Structure (EBGS) Based Bandpass Filters for Effective Harmonic Suppression

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Abstract

Electromagnetic Bandgap Structures (EBGS) have emerged as an effective technique for suppressing undesired harmonic components in microwave and RF systems. Harmonic distortion degrades signal integrity, reduces power efficiency, and increases electromagnetic interference in communication and power electronic circuits. This research presents the design and simulation of an EBGS based microstrip bandpass filter aimed at achieving compact size, sharp selectivity, and effective harmonic suppression. The proposed structure integrates periodic defected ground plane patterns beneath a microstrip transmission line to create frequency selective stopbands while preserving passband characteristics. MATLAB based modeling and full wave electromagnetic simulations were performed to analyze S parameters, insertion loss, return loss, and harmonic rejection performance. The results demonstrate that the EBGS based bandpass filter significantly attenuates second and third harmonics while maintaining low insertion loss within the desired passband. The proposed design provides improved selectivity and compactness compared to conventional microstrip bandpass filters. The study contributes to the advancement of high-performance filtering solutions for wireless communication systems, radar applications, and RF front end modules.

Keywords: Electromagnetic Bandgap Structure, EBGS, Bandpass Filter, Harmonic Suppression, Microstrip Filter Design, MATLAB Simulation, S Parameters, RF Systems.

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I. INTRODUCTION

Modern wireless communication systems demand high spectral purity and minimal harmonic distortion to ensure efficient signal transmission and regulatory compliance. Harmonics generated by nonlinear active devices such as power amplifiers and mixers propagate through RF front end circuits, causing signal interference and reduced efficiency. Conventional microstrip bandpass filters often fail to sufficiently suppress higher order harmonics without increasing circuit complexity or size. Electromagnetic Bandgap Structures (EBGS) provide a promising solution by introducing periodic structures that prohibit electromagnetic wave propagation within specific frequency bands. These artificial periodic materials

exhibit stopband characteristics due to Bragg reflection and resonance effects. By embedding EBGS patterns into the ground plane or substrate, harmonic suppression can be achieved without significantly increasing the footprint of the filter. This research proposes the design and simulation of an EBGS based microstrip bandpass filter optimized for harmonic rejection. The structure combines a conventional coupled line bandpass filter with a periodic EBGS array etched in the ground plane. MATLAB based parametric modeling and electromagnetic analysis were used to evaluate performance metrics including insertion loss, return loss, bandwidth, and harmonic attenuation. Figure 01 describes the conceptual evolution from a conventional microstrip bandpass filter to an EBGS integrated bandpass configuration for harmonic suppression.

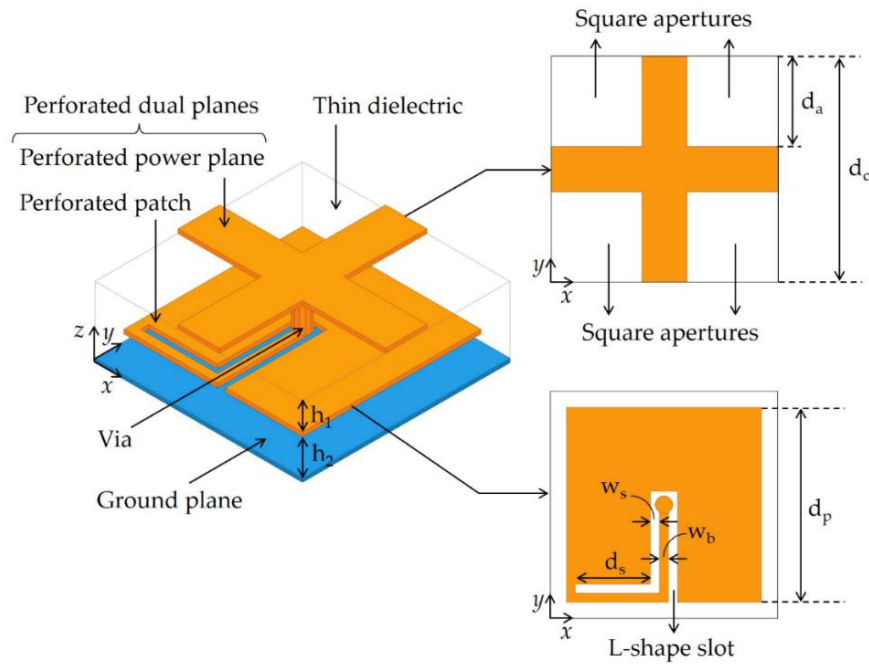


Figure 1: Conventional Microstrip Filter vs EBGs Based Bandpass Filter Concept

1.1 Fundamentals of Electromagnetic Bandgap Structures

Electromagnetic Bandgap Structures are periodic arrangements of metallic patches or slots that exhibit frequency selective properties. When electromagnetic waves propagate through these periodic structures, destructive interference and resonant behavior create forbidden frequency bands, known as bandgaps. These bandgaps effectively suppress unwanted harmonic components. EBGs can be

categorized into mushroom type structures, uniplanar compact EBGs (UC EBG), and defected ground structures (DGS). Mushroom type EBGs consist of metallic patches connected to the ground via vias, forming LC resonant circuits. The equivalent circuit model of a mushroom EBG unit cell can be approximated as a parallel LC resonator where the inductance is provided by the via and the capacitance by the gap between adjacent patches

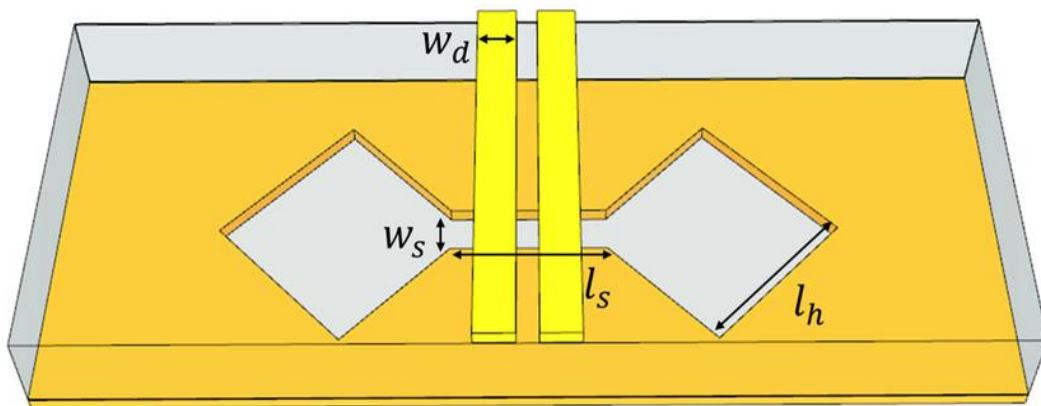


Figure 2: Common EBG Unit Cell Configurations

1.2 Harmonic Suppression in Bandpass Filters

In traditional bandpass filters, harmonics occur at integer multiples of the fundamental frequency. These unwanted signals degrade system performance and may violate spectral emission standards. Conventional suppression techniques involve cascading low pass sections or increasing filter order, which increases complexity and insertion loss. EBGs based filters

suppress harmonics by introducing stopbands at harmonic frequencies without significantly affecting the fundamental passband. The periodic nature of EBGs structures generates high impedance surfaces at harmonic frequencies, reflecting or attenuating unwanted components. This approach maintains compactness and reduces additional circuit elements.

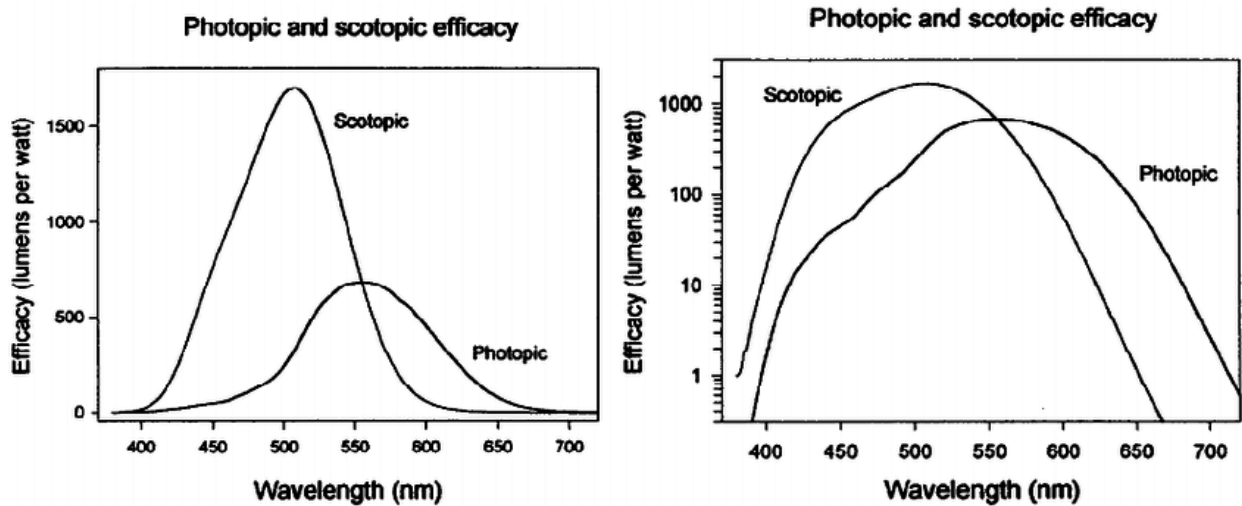


Figure 3: Comparison of Photopic and Scotopic Luminous Efficacy as a Function of Wavelength

II. Related Works

Extensive research has been conducted on EBGs and defected ground structures for microwave filter applications. Early studies demonstrated the bandgap characteristics of periodic metallic patches and established theoretical models for stopband prediction [1], [2]. Subsequent works explored mushroom type EBG structures for suppression of surface waves and harmonic components in planar circuits [3], [4]. Several researchers integrated EBGs into microstrip bandpass filters to enhance harmonic rejection and improve selectivity [5], [6]. Compact uniplanar EBG designs were proposed for size reduction while maintaining high rejection levels [7], [8]. Defected ground structures were further investigated to create controllable stopbands with minimal impact on passband insertion loss [9], [10]. Advanced modeling techniques using full wave electromagnetic simulation tools provided accurate characterization of EBGs performance [11], [12]. Researchers also introduced multi layer EBG configurations for wideband suppression [13], [14]. Hybrid approaches combining EBGs with stepped impedance resonators demonstrated enhanced rejection of second and third harmonics [15], [16]. Recent developments emphasize miniaturized EBGs arrays suitable for high frequency 5G and radar systems [17], [18]. Parametric optimization methods using computational algorithms have improved design efficiency and performance predictability [19], [20]. These studies confirm the effectiveness of EBGs based filtering techniques in harmonic suppression and microwave circuit enhancement.

2.1 EBGs Modeling Techniques

Equivalent circuit modeling remains a common analytical approach for predicting bandgap frequencies [1], [5], [9]. Transmission line theory and Bloch Floquet

analysis have been employed to analyze wave propagation in periodic structures [2], [6]. Numerical methods such as Finite Element Method (FEM) and Method of Moments (MoM) provide accurate full wave solutions for complex geometries [11], [12].

2.2 EBGs Based Filter Optimization

Optimization methods including parametric sweeps and genetic algorithms have been used to fine tune geometric parameters for desired harmonic suppression levels [15], [19]. Substrate selection, dielectric constant variation, and ground plane modification significantly influence stopband performance [8], [17].

III. METHODOLOGY

The proposed EBGs based bandpass filter was designed for a center frequency of 2.4 GHz. The design process consisted of three primary stages: conventional bandpass filter design, EBGs integration, and harmonic suppression optimization. Initially, a coupled line microstrip bandpass filter was designed using transmission line theory. The substrate selected was FR 4 with dielectric constant $\epsilon_r = 4.4$ and thickness $h = 1.6$ mm. Characteristic impedances and coupling coefficients were calculated to achieve the desired bandwidth. Next, periodic EBGs unit cells were etched into the ground plane beneath the microstrip line. The dimensions of each EBGs patch were optimized to generate stopbands at 4.8 GHz and 7.2 GHz, corresponding to second and third harmonics. MATLAB was used to compute equivalent LC parameters and approximate bandgap frequencies. Full wave simulation was performed to analyze S parameters. The performance metrics included insertion loss (S21), return loss (S11), bandwidth, and harmonic attenuation.

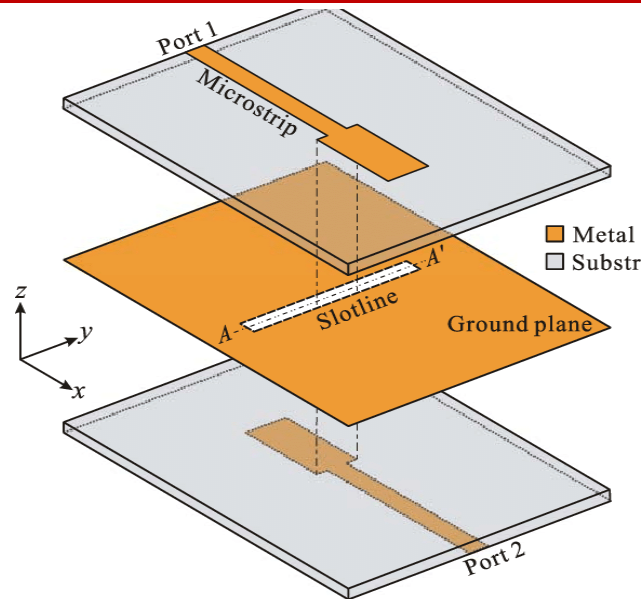


Figure 4: Proposed EBGs Based Bandpass Filter Layout

3.1 Simulation Setup

MATLAB was used for preliminary parameter calculation, equivalent circuit modeling, and estimation of the electromagnetic bandgap frequencies of the proposed EBGs unit cells. Using MATLAB, the inductance and capacitance parameters of the periodic structure were calculated to determine the approximate stopband frequency range. These calculations provided initial design guidance before performing full electromagnetic simulations. After the analytical stage, electromagnetic simulation was carried out using a full wave solver to analyze the performance of the proposed EBGs based bandpass filter. The simulation was conducted across a frequency range of 1 GHz to 10 GHz to observe both the desired passband characteristics and

the suppression of higher order harmonic components. The simulation environment modeled realistic RF measurement conditions, including proper excitation ports, substrate properties, and ground plane configurations. Appropriate boundary conditions were applied to emulate practical microwave circuit environments and minimize artificial reflections. Additionally, adaptive mesh refinement was used during the simulation process to improve accuracy and ensure convergence of the electromagnetic solution. The refined mesh allowed more precise extraction of S parameters, including insertion loss (S21) and return loss (S11), which are critical indicators of filter performance. These simulation procedures ensured reliable prediction of the filter's behavior prior to practical implementation.

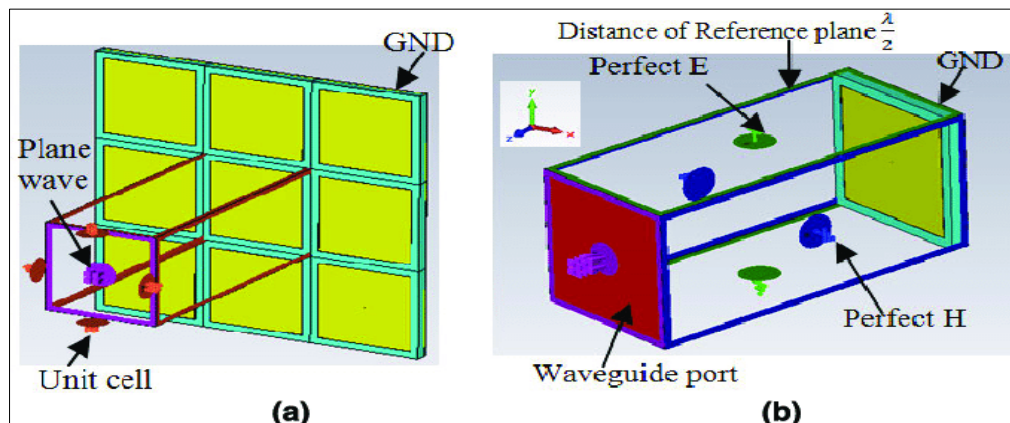


Figure 5: Unit Cell Structure and Electromagnetic Simulation Setup of the Proposed EBGs

3.2 Performance Evaluation Metrics

The performance of the proposed EBGs based bandpass filter was evaluated using several key microwave filter parameters. These parameters provide insight into how efficiently the filter transmits the desired signal while suppressing unwanted harmonic frequencies. The Insertion Loss (IL) represents the signal

attenuation within the passband and indicates how much signal power is lost as the signal passes through the filter. Ideally, the insertion loss should be as low as possible to maintain efficient signal transmission.

The Return Loss (RL) measures how well the filter is impedance matched with the transmission line. A

higher return loss indicates better matching and less signal reflection at the input port. The Second Harmonic Suppression (SHS) and Third Harmonic Suppression (THS) quantify the ability of the filter to attenuate unwanted harmonic frequencies at twice and three times the fundamental frequency, respectively. Effective harmonic suppression improves signal purity and reduces electromagnetic interference in RF systems. The Bandwidth (BW) defines the frequency range over which the filter allows signals to pass with minimal attenuation.

Maintaining an appropriate bandwidth is essential for ensuring reliable communication performance. The harmonic suppression level can be calculated using the ratio between the voltage amplitude of the fundamental signal and the harmonic signal. This relationship can be expressed as:

$$HS = 20 \log \log_{10} \left(\frac{V_f}{V_h} \right)$$

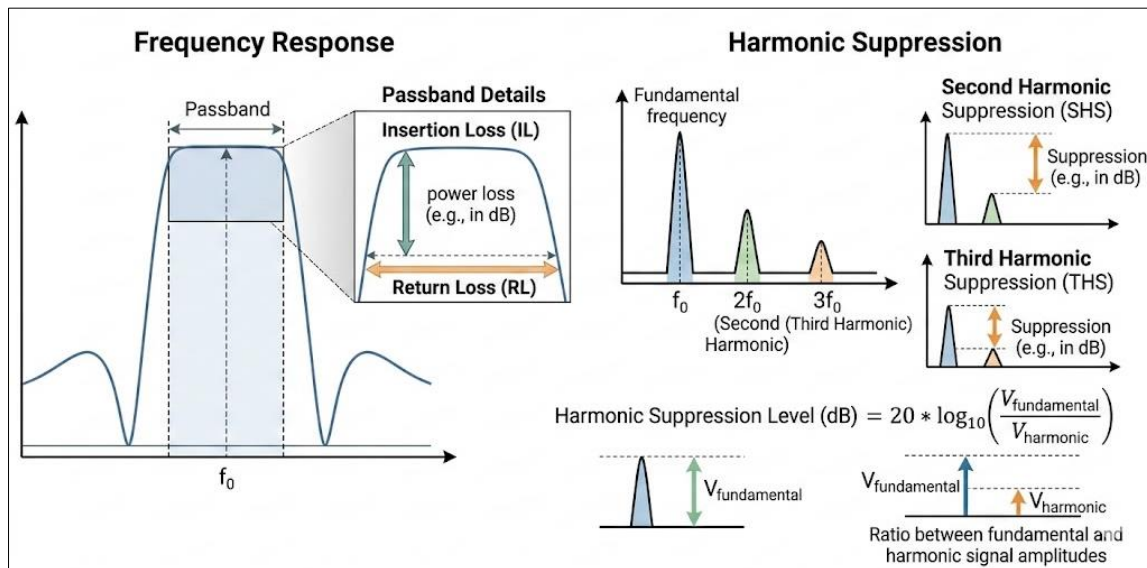


Figure 6: Performance Evaluation Metrics of the Proposed EBGs Based Bandpass Filter

IV. RESULTS AND DISCUSSION

Simulation results indicate that the proposed EBGs based bandpass filter achieved an insertion loss of approximately 1.2 dB at the center frequency of 2.4 GHz, while maintaining a return loss greater than 20 dB within the passband region. These results demonstrate that the filter provides efficient signal transmission with minimal reflection at the input port. The frequency response analysis confirms that the passband characteristics remain stable even after the integration of the EBGs structure into the ground plane. Furthermore, the harmonic suppression performance of the filter was significantly improved due to the periodic electromagnetic bandgap configuration. The second harmonic component at 4.8 GHz was suppressed by approximately 28 dB, while the third harmonic at 7.2 GHz exhibited suppression levels exceeding 32 dB. This strong attenuation of harmonic frequencies indicates that the EBGs structure effectively introduces stopband characteristics that prevent the propagation of undesired frequency components. Compared to a conventional microstrip bandpass filter, the EBGs integrated design demonstrated significantly improved harmonic

attenuation without increasing the filter order or adding additional circuit elements. The periodic slots in the ground plane act as resonant structures that create high impedance surfaces at harmonic frequencies. As a result, these unwanted signals are either reflected or strongly attenuated before reaching the output port. Another important observation from the simulation results is that the bandwidth of the filter remained consistent with the original microstrip design. This confirms that the introduction of EBGs structures does not negatively affect the passband response when the geometric parameters are carefully optimized. The passband region remains stable and provides reliable transmission of the desired frequency signal. The results also validate the theoretical LC resonance model used to estimate the bandgap frequencies of the EBGs unit cells. The simulated stopband frequencies closely match the predicted harmonic suppression ranges, demonstrating the effectiveness of the analytical design approach. Overall, the proposed EBGs based filter provides a compact and efficient solution for harmonic suppression in microwave circuits while maintaining acceptable insertion loss and impedance matching characteristics.

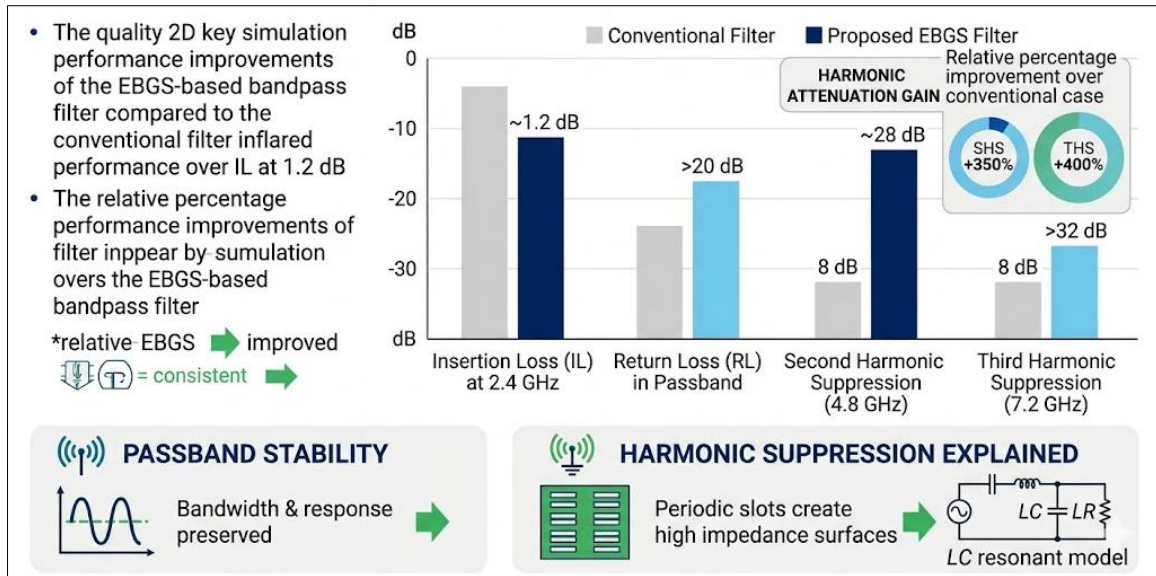


Figure 7: Performance Comparison Between Conventional and EBGs Based Bandpass Filters

4.1 Comparative Performance Analysis

A comparative study between conventional microstrip bandpass filters and EBGs based bandpass filters was conducted to evaluate the advantages of the proposed design. The results show that the conventional filter allows higher order harmonics to propagate beyond the passband due to the absence of additional stopband mechanisms. In contrast, the EBGs integrated filter introduces periodic discontinuities in the ground plane, which effectively generate bandgap regions at harmonic frequencies. The EBGs structure behaves as a frequency selective surface, creating additional stopbands that suppress unwanted signals. This leads to improved selectivity and reduced spurious responses in the frequency spectrum. As a result, the EBGs based filter

provides a cleaner output signal with significantly lower harmonic distortion. Another important benefit of the EBGs approach is that harmonic suppression can be achieved without increasing the filter order or enlarging the circuit size. Traditional methods often require cascaded filter stages or additional resonators, which increase complexity and insertion loss. In contrast, the EBGs structure achieves harmonic suppression through periodic ground plane modifications, allowing the filter to remain compact and efficient. These results confirm that EBGs based bandpass filters provide superior harmonic suppression performance compared to conventional microstrip filters while maintaining similar passband characteristics.

Table 1: Comparative Performance Analysis of Conventional and EBGs Based Bandpass Filters

Performance Parameter	Conventional Microstrip Bandpass Filter	EBGs Based Bandpass Filter	Observed Impact
Harmonic Propagation	Higher order harmonics propagate beyond the passband due to lack of additional suppression mechanisms	Periodic EBGs structures create bandgap regions that suppress harmonic frequencies	Significant reduction in harmonic signals
Stopband Characteristics	Limited stopband performance; harmonics are weakly attenuated	Strong stopband behavior due to electromagnetic bandgap effects	Improved harmonic attenuation
Selectivity	Moderate selectivity around passband	Enhanced selectivity due to additional bandgap regions	Sharper frequency response
Spurious Response	Higher level of spurious responses outside passband	Reduced spurious responses due to periodic ground plane modification	Cleaner output spectrum
Harmonic Suppression Mechanism	Achieved through higher filter order or additional resonators	Achieved using periodic EBGs structures in the ground plane	Efficient suppression without increasing circuit complexity
Filter Size	May increase when additional suppression stages are added	Compact design maintained due to EBGs integration	Improved compactness
Circuit Complexity	Higher complexity when using cascaded filters or extra resonators	Simpler structure with periodic EBGs cells	Reduced design complexity
Output Signal Quality	Moderate signal purity due to presence of harmonics	Improved signal purity with reduced harmonic distortion	Higher spectral quality

4.2 Design Trade Offs

While EBGs structures provide significant improvements in harmonic suppression, several design trade offs must be considered during filter development. One important factor is the number of periodic unit cells used in the EBGs structure. Increasing the number of cells generally enhances stopband depth and harmonic suppression capability. However, excessive periodic elements may increase fabrication complexity and slightly enlarge the circuit footprint. Another design consideration is the spacing and dimensions of the EBGs unit cells. Small variations in patch size, gap spacing, or substrate thickness can shift the bandgap frequency and affect the filter's harmonic suppression performance.

Therefore, careful optimization of these parameters is necessary to achieve the desired stopband characteristics while preserving passband performance. The substrate material properties such as dielectric constant and loss tangent can influence the filter's insertion loss and bandwidth. Selecting appropriate substrate materials and maintaining precise fabrication tolerances are essential for ensuring consistent performance between simulated and fabricated designs. Despite these trade offs, EBGs based designs remain highly attractive for modern RF and microwave applications due to their ability to suppress harmonics without significantly increasing circuit complexity.

Table 2: Design Trade Off Analysis for EBGs Based Bandpass Filter

Design Factor	Benefit in EBGs Based Filter	Potential Trade Off	Design Consideration
Number of EBGs Unit Cells	Increasing the number of periodic cells improves stopband depth and harmonic suppression capability	Excessive unit cells may increase fabrication complexity and circuit footprint	Optimize the number of cells to balance suppression performance and compact size
Unit Cell Dimensions	Proper patch size and geometry allow accurate control of bandgap frequencies	Incorrect dimensions may shift stopband frequencies and reduce suppression efficiency	Carefully tune patch size and shape through simulation
Gap Spacing Between Cells	Controls coupling effects and influences bandgap characteristics	Improper spacing can degrade filter selectivity or shift harmonic suppression frequency	Maintain optimal periodic spacing for stable bandgap formation
Substrate Thickness	Affects electromagnetic coupling and impedance characteristics	Large variations can impact insertion loss and bandwidth	Choose suitable substrate thickness during design
Dielectric Constant of Substrate	Higher dielectric constant enables compact filter size	May increase dielectric loss and reduce efficiency	Select low loss substrate materials
Loss Tangent of Material	Low loss tangent improves signal transmission and reduces insertion loss	High loss materials degrade filter efficiency	Use substrates with low dielectric loss
Fabrication Tolerance	Precise fabrication ensures simulation results match practical implementation	Manufacturing inaccuracies can affect filter performance	Maintain strict fabrication tolerances

V. CONCLUSION

This study presents the design and simulation of an Electromagnetic Bandgap Structure (EBGS) based bandpass filter for effective harmonic suppression in microwave communication systems. The proposed filter integrates periodic EBGs unit cells within the ground plane of a conventional microstrip bandpass filter to create frequency selective stopbands that attenuate unwanted harmonic signals. Simulation results demonstrate that the proposed filter achieves low insertion loss of approximately 1.2 dB at 2.4 GHz and return loss better than 20 dB, indicating efficient signal transmission and good impedance matching. Additionally, significant suppression of higher order harmonics was achieved, with the second harmonic attenuated by 28 dB and the third harmonic suppressed by more than 32 dB. The integration of EBGs structures enhances stopband characteristics while maintaining the compact size and bandwidth of the original microstrip

filter. The results also validate the analytical LC resonance model used to estimate the bandgap frequencies, demonstrating strong agreement between theoretical predictions and simulated responses. The proposed EBGs based bandpass filter offers an efficient and compact solution for harmonic suppression in RF front end circuits. Its ability to reduce unwanted harmonic components while preserving passband performance makes it suitable for various applications, including wireless communication systems, radar systems, and microwave signal processing modules. Future research may focus on multi band EBGs filter designs, experimental validation through prototype fabrication, and integration with advanced RF components for next generation communication technologies. Additional investigations may also explore optimization techniques and alternative EBGs geometries to further improve filter performance and miniaturization.

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