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REGULAR ARTICLE

Compact SIW Based Band Pass Filter for sub 6 GHz Band Application

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In recent years, with the increasing demand for wireless communication systems operating in the sub 6 GHz frequency band, there has been a growing need for compact and efficient band pass filters. Substrate Integrated Waveguide (SIW) is a promising technology that offers advantages such as miniaturization, low insertion loss, and high selectivity. In this paper, we propose a compact SIW-based band pass filter for sub 6 GHz band applications. The proposed filter is designed using a stepped impedance resonator (SIR) and a modified E shape coupling structure to achieve the desired band pass response. The filter is fabricated on a low-cost and commercially available substrate to make it suitable for mass production. Simulation and measurement results show that the proposed filter exhibits good performance in terms of insertion loss, return loss, and selectivity. The compact size and high performance make the proposed SIW-based band pass filter ideal for various wireless communication systems operating in the sub 6GHz frequency band. The optimization process is performed using Ansoft HFSS software, where the design parameters of the filter are adjusted to achieve the desired frequency response characteristics and is going to be proposed with the requirements of Frequency Coverage of (– 3 dB) i.e.., – 3300 to 3700 MHz, Insertion Loss less than 1 dB, Stop bandwidth – 32 dB and Lower and upper band relaxation of 30 MHz.

Keywords: Sub-6GHz, Band pass Filter, Substrate Integrated Waveguide (SIW), Stepped Impedance Resonator (SIR), Miniaturization.

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1. INTRODUCTION

The design and implementation of small-sized, high-performing filtering components have attracted a lot of attention in the field of microwave engineering, particularly in view of the upcoming uses for 5G wireless communication systems. Compared to previous wireless technologies, sub-6 GHz 5G offers significantly faster data transfer speeds, lower latency, and greater capacity. These improvements are made possible by the use of advanced technologies such as massive MIMO (multiple-input, multiple-output) and beamforming, which allow for more efficient use of spectrum and better coverage.

One of the key benefits of sub-6 GHz 5G is its ability to provide broader coverage than the higher-frequency mm Wave (millimeter wave) 5G technology. Sub-6 GHz 5G signals can travel further and penetrate obstacles more easily, making it well-suited for providing wide-area coverage in urban and suburban environments. Extensive research efforts worldwide have been prompted by the need for effective filtering systems that can handle the increasingly crowded RF spectrum while preserving low loss and good selectivity. Because of its favorable qualities, such as low loss, high quality factor, and simplicity of integration with planar processing techniques, Substrate Integrated Waveguide (SIW) has emerged as a promising solution among the different technologies investigated [1].

Recent advancements in SIW technology have led to the development of innovative filtering structures that combine the benefits of SIW with metamaterial-based resonators, such as Complementary Split Ring Resonators (CSRR) and Fractal Open Complementary Split-Ring Resonators (FOCSRR). These resonators introduce unique electromagnetic properties, enabling the realization of compact and high-performance filtering components with improved selectivity and wideband characteristics [2].

Researchers have experimented with a variety of design approaches and configurations in an effort to achieve better performance and miniaturization. SIW filters that use split circular rings and rectangular stubs, and quasi-elliptic. SIW filters that use microstrip-line cross-coupled and slot-coupled structures [3]. In order to accomplish wideband operation and wide stopband features, the integration of metamaterial elements such as FOCSRRs and T-shaped transmission lines has also been studied [4].

In [5], the waveguide integrated substrate and the metamaterials, using S-shaped resonators for the two selected frequency bands (8.7, 13.4) GHz and (9.5, 15) GHz. In [6], rectangular split ring resonator (RSRR) utilized for microwave band stop filter design 1 to 4 GHz frequency band. Microstrip-line structures are the most frequently utilized for filter design due to their ease of manufacture, circuit diversity, and low cost [7]. DMS are periodic structures with specific dimensions and spacing that are introduced into the resonators of the filter to modify their electrical properties, such as resonant frequency, bandwidth, and harmonic suppression, to achieve the desired filter

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performance [8]. The 5G NR bands n77 (3300 – 4200 MHz), n78 (3300 – 3800 MHz) and n79 (4400 – 5000 MHz) have been planned for the 5G network [9].

2. PROPOSED FILTER DESIGN

The design and analysis of a small SIW-based bandpass filter are discussed in this paper. The compact SIW based bandpass filter for sub 6GHz applications were proposed. Using Ansys software, a compact SIW based bandpass filter for sub 6GHz application is designed. The substrate used for this filter is FR4. Substrate Integrated Waveguide (SIW) is used in the proposed filter in order to provide low insertion loss, high selectivity, and excellent out-of-band rejection. It consists of a resonator that is coupled to input and output ports.

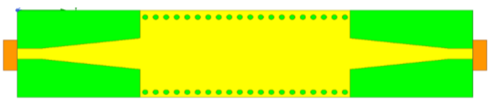
The filter structure comprises of a rectangular SIW cavity with an array of via holes to realize the side walls of the wave guide [10]. The resonating structure consists of resonators which are etched on the top layer of SIW. Here modified E shape slots on the top layer which is responsible for wideband response at low band frequency. The following design procedure is adopted for the proposed filter. This resonator when integrated with SIW, generates passband well below the characteristic SIW cutoff frequency. Hence

$$fc(TE_{10}) = \frac{C}{2W_{eff}\sqrt{\varepsilon_r}} \quad (1)$$

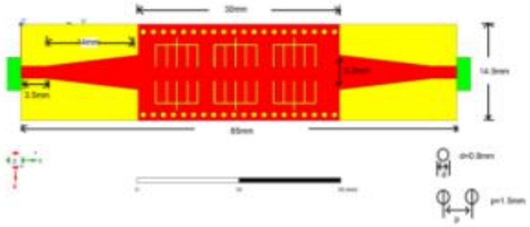
$$W_{eff} = w_s - \frac{d^2}{0.95s} \quad (2)$$

Here W_s and W_{eff} denotes the width and effective width of the waveguide. The speed of the light is represented by C and dielectric constant of the substrate is represented by ε_r, where (ε_r = 4.4). The diameter d and the patch s of via holes are placed accordingly with d/λ_g = 0.8 mm and d/s = 1.5 mm. So that it satisfies the constraint of minimum leakage loss. At last, the parameters of the resonators are fine-tuned using full wave simulator to obtain the filter with desired resonant characteristics.

(a)



(b)



(c)

Fig. 1 – Design iteration of band pass filter

The construction of the proposed filter system was carried out into three discrete steps. At first the symmetrical shaped filter was designed and the dimensions of the filter design is 65 mm × 14.5 mm as shown in the Fig. 1. The filter was printed over the FR4 substrate. Implemented to meet the technical requirements for high quality performance in the frequency range of 3.3 to 3.7 GHz a dielectric constant of 4.33 was used for the fabrication of this filter.

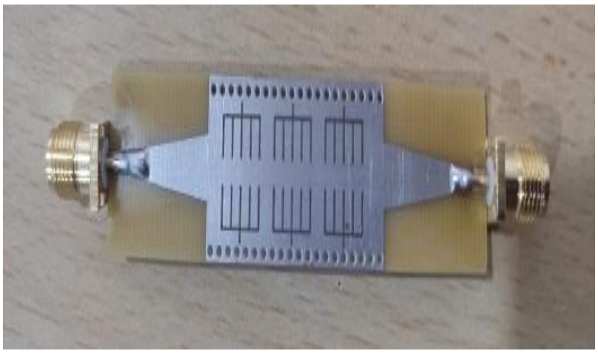
Where

- Width (WSIW) = 13 mm
- Dielectric Substrate Length (L) = 30 mm
- Taper Section Length (L_t) = 14 mm
- Width of Taper Section (W_t) = 5.2 mm
- Diameter (d) = 0.8 mm
- pitch (p) = 1.5 mm

A pair of slots are loaded onto the top surface of the suggested filter to achieve a wide passband and a wide lower and upper band of rejection. For the purpose of validating the analysis, the suggested SIW filter has been simulated, made, and tested.

3. RESULT AND DISCUSSION

The proposed SIW filter prototypes are fabricated using 0.8 mm thick FR4 substrate having a permittivity of 4.4 and dielectric loss tangent of 0.030 and shown in Fig. 2. The proposed compact SIW filters occupy compact size of 65mm and 14.5 mm respectively.



(a)

(b)

Fig. 2 – Fabricated BPF model: (a) front view, (b) back view

The simulated frequency response of the proposed filter results reveal that the proposed compact SIW filter operates from 3.2 GHz to 4.3 GHz with a minimum insertion loss less than 0 to – 2 dB.

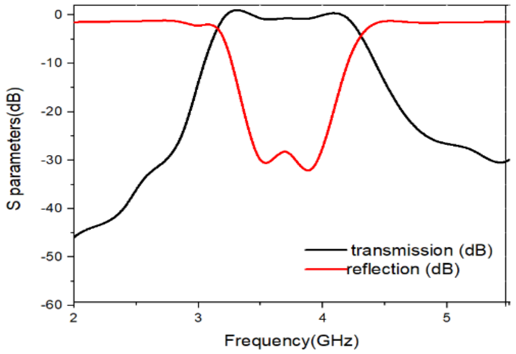


Fig. 3 – Frequency response of proposed BPF

Because waveguides naturally have low insertion loss, they can produce very sharp filters with very high Q_s when combined with a waveguide built at resonant length. These filters are frequently used in duplexers for radar applications because they operate at high frequencies, provide the requisite frequency selectivity, and can withstand high transmit powers to hundreds of dB.

In Table 1 comparison analysis of existing filters was discussed. From the analysis, the observed results agree with those predicted by simulation. Centre frequency of 3.5 GHz within a 3 dB fractional bandwidth of 62%, stop bandwidth of – 30 dB, lower and upper band relaxations of 30 MHz Insertion loss as measured is less than 1 dB. The filter's size is extremely small and suited for use in applications operating sub 6 GHz.

Table 1 – Performance comparison of state of the art.

Ref.	S_{21} (dB)	S_{11} (dB)	Size(mm²)	Frequency GHz)
[10]	< 1.5	> 17.6	15.5 × 9	9.17 to 20.31
[11]	1.07	> 20	7.5 × 12.5	6.11
[11]	0.60	> 15 dB	$0.12\lambda_g \times 0.22\lambda_g$	2.55 to 3.95 GHz
[12]	– 0.4 to – 0.2 dB	> – 30	65 × 14.5	6.10 to 15.06 GHz
[13]	– 3.5 dB	> – 10	13.5 × 38.6	3.4 GHz to 3.8 GHz
[prop work]	0 to – 2 dB	> – 32	65 × 14.5	3.2 to 4.3 GHz

4. CONCLUSIONS

The modified E slot based wise band SIW band pass filter proposed in this paper. This structure wide band response in lower frequency band. The proposed filter structure is simulated, fabricated. With low cost FR 4 substrate, planar filter easily integrated on any device. From the 3 dB bandwidth, insertion loss and return loss suitable for 5 G applications.

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Компактний фільтр на основі SIW для додатка Sub 6GHZ діапазону

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Останніми роками, зростає попит на системи бездротового зв'язку, які працюють у діапазоні частот Sub 6GHZ, зростає потреба у компактних та ефективних пропускних елементах. Інтегрований хвилевод підкладки (SIW) – це перспективна технологія, яка пропонує такі переваги, як мініатюризація, низька втрата вставки та висока селективність. У даній статті запропоновано компактний пропускний фільтр на базі SIW для додатків Sub 6GHZ діапазонів. Запропонований фільтр розроблений за допомогою ступінчастого резонатора імпедансу (SIR) та модифікованої структури зчеплення E форми для досягнення потрібної реакції проходу смуги. Фільтр виготовляється на недорогій підкладці, щоб зробити його придатним для масового виробництва. Результати моделювання та вимірювання показують, що запропонований фільтр демонструє хороші показники з точки зору втрати вставки, втрати повернення та селективності. Компактний розмір і висока продуктивність роблять запропонований фільтр на основі SIW ідеальним для різних систем бездротового зв'язку, що працюють у діапазоні частот Sub 6GHZ. Процес оптимізації виконується за допомогою програмного забезпечення ANSoft HFSS, де проектні параметри фільтра регулюються для досягнення бажаних характеристик частотної відповіді та будуть запропоновані з вимогами частотного покриття (– 3db), тобто – 3300 до 3700 МГц, втрата вставки менше 1 дБ, зупинка пропускної здатності – 32 дБ і нижня та верхня смуга розслаблення 30 МГц.

Ключові слова: Sub 6GHZ, Фільтр проходу діапазону, Інтегрований хвилевод підкладки (SIW), Ступінчастий резонатор імпедансу (SIR), Мініатюризація.