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REGULAR ARTICLE

Analysis of A Low-Profile Circular Slotted BPF For 5G New Radio Applications

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A low profile microstrip circular slotted bandpass filter is designed on RT duroid 5880 substrate with ε_r of 2.2, δ of 0.0009. Wide bandwidth and out of band suppression are the two major factors that has to be considered while designing an RF bandpass filter. An-soft HFSS v13 which is based on FEM, is used to numerically design and simulate a circular slotted BPF. Circular slot-ted BPF is designed and simulated on a 0.254 mm thick substrate having an area of 12 × 34 mm². A 50 Ω microstrip transmission line is utilized to attach the circular slotted microwave bandpass filter. Circular slotted BPF offers reflection coefficient of – 32.1 dB and – 41.1 dB at 3.2 GHz and 6.1 GHz respectively. Transmission co-efficient of about 0.2 dB has been observed at 3.2 GHz and 6.1 GHz. 3 dB bandwidth of about 0.4 GHz and 1.4 GHz covering the frequency ranges from 3 GHz-3.4 GHz and 5.3 GHz-6.7 GHz. Group delay of 0.32 nS and 0.67 nS has been observed at 3.2 GHz and 6.1 GHz. Fractional bandwidths of 12.5 % and 22.9 % have been observed. These results make the circular slotted bandpass filter suitable for 5G new radio applications.

Keywords: Microstrip, Band pass filter, 5G new radio applications, Reflection coefficient

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1. INTRODUCTION

RF & Microwave filters are implemented by using waveguides, distributed elements, lumped elements, cavities and transmission lines. In the process of shifting to the upper frequency bands the circuits need to be replaced with distributed elements made up to microstrip transmission lines. The length of these microstrip lines is chosen with a length of either $\lambda/4$ (or) $\lambda/2$ which are termed as quarter wave transmission lines and half wave transmission lines respectively. Earlier the research on high frequency BPF was confined in designing various UWB bandpass filters, multi-band, tunable, harmonic suppression, balanced ports etc. [1-3]. In the recent years, negative group delay microwave circuits have gained more attraction due to its numerous practical applications [4-7]. Along with this coupling matrix calculation also plays a key role in attaining reconfigurability [8]. The negative group delay circuit is employed to broaden the bandwidth of analog feedback power amplifier [9]. Microstrip filters are utilized in many microwave systems such as radars, measurement and test systems and in satellite communications. The advantage of choosing these microstrip filters is low cost, light weight and easy to fabricate. Usually, resonators employ periodic structures in their design which also helps in facilitating the design of microstrip filter [10-12]. As the lower frequency band is already congested almost all the communication channels has shifted to higher frequency bands. It is required to develop the circuits that process the signals at higher frequency bands [13].

In this paper a circular slotted band pass filter is designed by using coupled microstrip transmission lines. A circular slotted bandpass filter is designed and analyzed for 5G new radio applications. A 50 Ω impedance transmission line is attached to the microstrip rectangle measuring 3 × 9.8 mm². This approach has allowed us to more thoroughly analyze the EM characteristics of the BPF. Remaining article is structured as follows. Part 2 presents the design and analysis of the research article and part 3 presents the iterative process of the circular slotted BPF. Part 4 presents the results and discussions for circular slotted BPF and there by concluding the article with part 5.

2. ANALYSIS OF CIRCULAR SLOTTED BPF

The circular slotted BPFs equivalent circuit can be expressed in terms of equivalent capacitance and inductance. The circuit's equivalent capacitance and inductance can be changed by varying the resonant

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frequency. Compared to traditional bandpass filters, microstrip rectangular BPFs exhibit exceptional performance. Fig. 1 represents the circular slotted bandpass filter. It is designed by attaching a 50 Ω microstrip transmission line to the microstrip rectangle. The electrical properties of the bandpass filters in microstrip planar technology are enhanced by careful substrate selection. The choice of substrate is typically influenced by two elements, such as losses and absorption coefficients. Because it is lightweight, and easy to fabricate Rogers/RT duroid 5880 has been selected as the substrate material. The most accessible material is Rogers/RT duroid 5880 which has the following physical characteristics: a thickness of 0.254 mm, a *tan δ* of 0.0009 and a ε_r of 2.2. HFSS calculator, which is based on the FEM, is used to numerically design the electrical dimensions of the microstrip circular slotted BPFs. The following lists the mathematical formulas used to design the circular slotted bandpass filter. Table 1 displays the dimensions used in the design of the circular slotted bandpass filter. The equivalent circuit for the circular slotted bandpass filter is shown in Fig. 2.

$$L = \frac{\lambda_g}{4} \tag{1}$$

$$\lambda_g = \frac{\lambda_0}{4F_r\sqrt{\varepsilon_{r_{eff}}}} \tag{2}$$

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+\left[\frac{12h}{w}\right]\right]^{-1/2} \tag{3}$$

$$\frac{w}{h} = \frac{2}{\pi}\left\{(B-1) - \ln(2B-1)\frac{\varepsilon_r-1}{2\varepsilon_r}\left[\ln(B-1) + 0.39 - \left(\frac{0.61}{2\varepsilon_r}\right)\right]\right\} \tag{4}$$

Where

$$B = \frac{60\pi^2}{Z_C\sqrt{\varepsilon_r}}$$

Where 'h', 'Z_C', 'B' and ε_{reff} represents the thickness of the substrate, characteristic impedance broader dimension of the feed lines and substrate effective relative permittivity respectively.

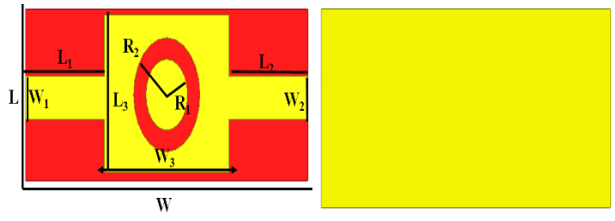


Fig. 1 – Circular slotted BPF

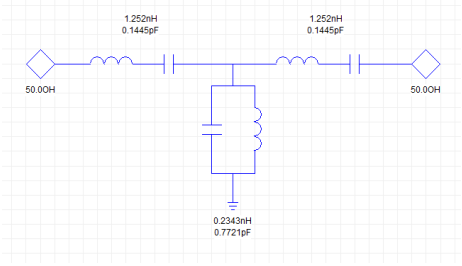


Fig. 2 – Equivalent Circuit of Circular slotted BPF

Table 1 – Geometric parameters of the Circular slotted BPF

Parameter	Values (mm)
L	12
W	34
L_1	9.8
L_2	9.8
W_1	3
W_2	3
L_3	11
W_3	15
R_1	2.5
R_2	4

3. EVOLUTION PROCESS

Initially, a microstrip transmission line was used to attach a microstrip rectangle measuring 11 mm × 15 mm. Step 2 involves subtracting a circle with a radius of 4 mm from the filter design in step 1. Our suggested circular slotted BPF is the third iteration. Step 3 involves by subtracting a circle measuring a radius of 2.5 mm. Fig. 3 illustrates the circular slotted bandpass filter's iterative design. The circular slotted BPFs resonance is determined by its dimensions; the largest resonance is found in smaller dimensions and vice versa. Two rectangles measuring 3×9.8 mm^2 are used to feed a circular slotted BPF utilizing microstrip technology. The circular slotted bandpass filter's reflection coefficient at various iterations is shown in Fig. 4. The first iteration filter provides S_{11} values of – 38 dB and resonates at 4.5 GHz. The second iteration filter provides S_{11} values of – 31 dB and – 40 dB resonates at 3.2 GHz and 6.1 GHz respectively. The third iteration filter is the last one and provides reflection coefficients of – 32.1 dB and – 41.1 dB at 3.2 GHz and 6.1 GHz respectively. These results make the circular slotted BPF suitable for 5G new radio applications.

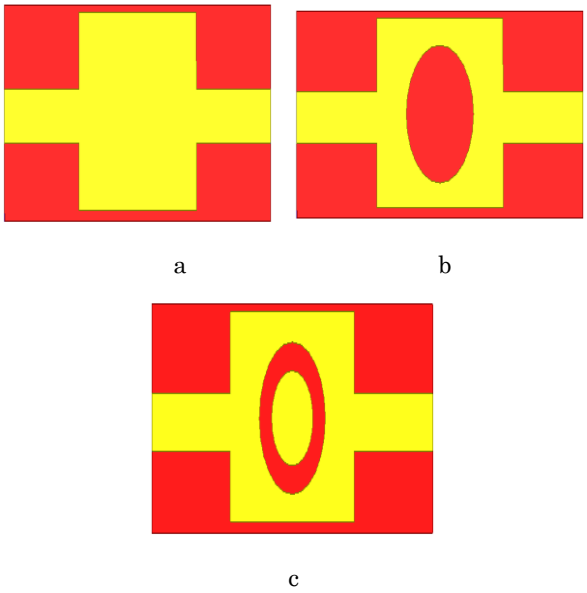


Fig. 3 – Evolution of Circular slotted BPF

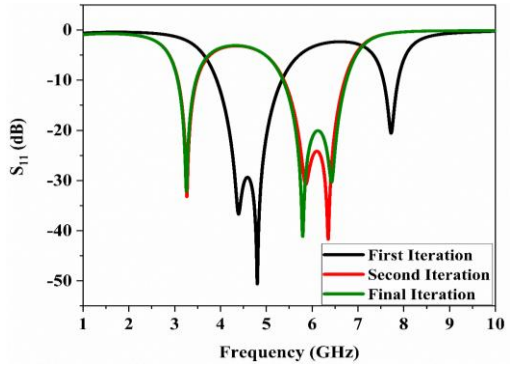


Fig. 4 – Reflection Co-efficient of the Circular slotted BPF

4. RESULTS AND DISCUSSION

Fig. 5 displays the frequency response of S_{11} and S_{21}. Circular slotted BPF offers reflection coefficients of – 32.1 dB and – 41.1 dB at 3.2 GHz and 6.1 GHz respectively. A transmission coefficient of 0.2 dB has been observed at 3.2 GHz and 6.1 GHz. 3 dB bandwidth of about 0.4 GHz and 1.4 GHz covering the frequency ranges from 3 GHz-3.4 GHz and 5.3 GHz-6.7 GHz. Fractional bandwidths of 12.5 % and 22.9 % have been observed. The circular slotted bandpass filter's phase delay and group delay are shown in Fig. 6. Time delay that the frequency component experiences while passing through the filters is known as the phase delay of each filter. The average time delay experienced by the composite signal is known as the group delay. Group delay of 0.32 nS and 0.67 nS has been observed at 3.2 GHz and 6.1 GHz. Surface current distribution at 3.2 GHz and 6.1 GHz is shown in Fig. 7. A maximum

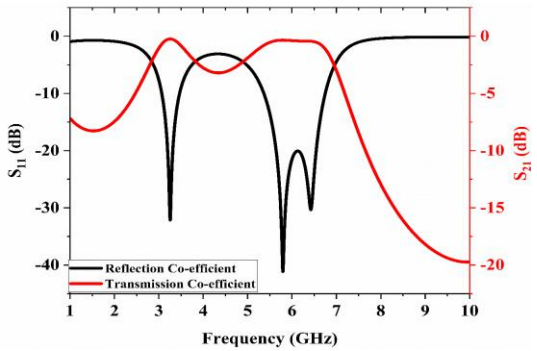


Fig. 5 – *S*-Parameters of the Circular slotted BPF

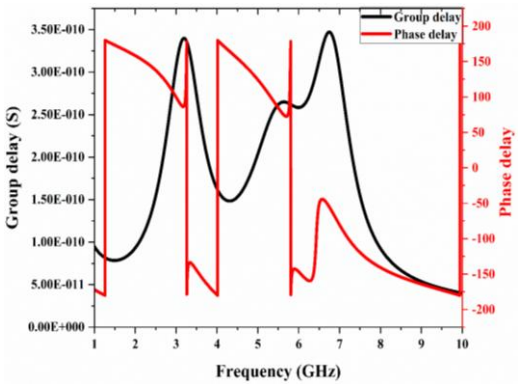
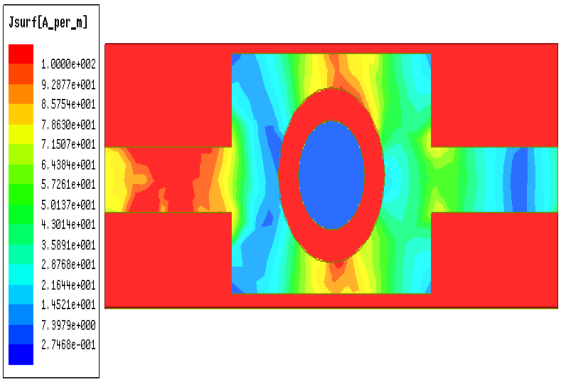
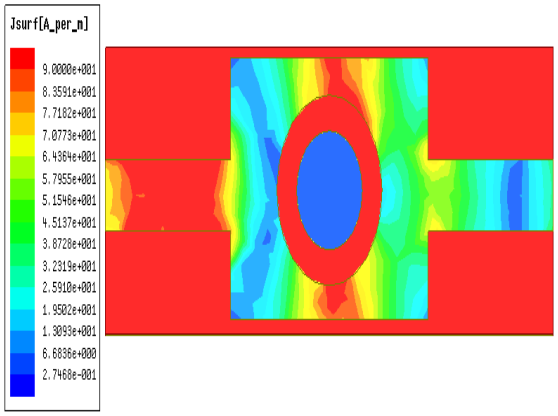


Fig. 6 – Circular slotted BPFs Group delay and Phase delay



a



b

Fig. 7 – Surface Current distribution (a) 3.2 GHz (b) 6.1 GHz

value of 100 Am^{-1} and 90 Am^{-1} has been observed at 3.2 GHz and 6.1 GHz and maximum amount of distribution is observed at the feed lines and on the circular ring. These results make the circular slotted BPF suitable for 5G new radio applications.

5. CONCLUSION

This article concludes the analysis of a compact, low loss microwave bandpass filter for 5G new radio applications. The dimensions of the microstrip circular slotted bandpass filter are 12×34 mm^2. Circular slotted BPF offers reflection coefficient of – 32.1 dB and – 41.1 dB at 3.2 GHz and 6.1 GHz respectively. Transmission coefficient of about 0.2 dB has been observed at 3.2 GHz and 6.1 GHz. 3 dB bandwidth of about 0.4 GHz and 1.4 GHz covering the frequency ranges from 3 GHz-3.4 GHz and 5.3 GHz-6.7 GHz. Group delay of 0.32 nS and 0.67 nS has been observed at 3.2 GHz and 6.1 GHz. Fractional bandwidths of 12.5 % and 22.9 % have been observed. These results make the circular slotted bandpass filter suitable for 5G new radio applications.

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Аналіз низькопрофільного смугового фільтра з кільцевими щілинами для застосувань у мережах 5G

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Смуговий фільтр низького профілю на основі мікросмужкової лінії з кільцевими щілинами розроблено на підкладці RT duroid 5880 з діелектричною проникністю $\varepsilon_r = 2{,}2$ та тангенсом кута діелектричних втрат $\delta = 0{,}0009$. Широка смуга пропускання та ефективне придушення сигналів поза цією смугою є двома ключовими факторами, які необхідно враховувати при проектуванні радіочастотних смугових фільтрів. Для чисельного проектування та моделювання такого фільтра використано програмне забезпечення Ansoft HFSS v13, що базується на методі скінченних елементів (FEM). Фільтр спроектовано та змодельовано на підкладці товщиною 0,254 мм із розмірами 12 × 34 мм². Для підключення фільтра використовується мікросмужкова лінія передачі з хвильовим опором 50 Ом. Коефіцієнт відбиття фільтра становить – 32,1 дБ на частоті 3,2 ГГц та – 41,1 дБ на частоті 6,1 ГГц. Коефіцієнт передачі на цих частотах (3,2 ГГц та 6,1 ГГц) становить приблизно 0,2 дБ. Смуга пропускання за рівнем – 3 дБ становить близько 0,4 ГГц (у діапазоні 3-3,4 ГГц) та 1,4 ГГц (у діапазоні 5,3-6,7 ГГц). Групова затримка на частотах 3,2 ГГц та 6,1 ГГц становить 0,32 нс і 0,67 нс відповідно. Відносні смуги пропускання становлять 12,5 % та 22,9 %. Отримані результати свідчать про придатність розробленого смугового фільтра з кільцевими щілинами для застосування в системах зв'язку 5G (5G New Radio).

Ключові слова: Мікросмужковий, Смуговий фільтр, Застосування в системах 5G New Radio, Коефіцієнт відбиття.