The effect of tuning screws of the S-parameters of a 5G bandpass Filter

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Abstract. In this paper, the design and simulation of a symmetrical waveguide filter are presented based on the insertion loss method. The designed WR-34 waveguide filter is operating at 28 GHz, where its dimensions are a=4.32mm and b=8.64mm, a fractional bandwidth of 2.15% a return loss level better than 16 dB, a frequency range from 22Ghz to 33 GHz. The structure is a 5th-order bandpass filter with five resonators and six symmetrical circular inductive irises. In order to optimize the frequency response, five tuning screws were added to the center of each resonator, while two other screws were positioned before the first iris and the last iris from the wave ports. The simulation model of the filter is developed in two different simulators ANSYS high-frequency Structure Simulator (HFSS) and CST Studio Suite so as to validate the obtained results and to depict the effects of tuning screws on the S-parameters of the filter while generating scenarios depending on the depth of penetration of each screw**.**

1 Introduction

The development of wireless communication has led to the emergence of two major trends, especially in microwave applications[1]. The first trend could be described as the increase in operational frequencies since microwave applications are on a rapid rise, therefore more bandwidths are available. While the second trend depicts the huge increase in bandwidth and data rate, where the bandwidth of new wireless devices doubles every 18 months, conforming to Edholm's law[2]. Otherwise, this increasing demand in wireless technology has commanded the saturation and limitation of the frequency spectrum Therefore, developing filtering devices has become an essential issue to avoid channel interferences and take advantage of the spectrum frequency's range.

In this context, microwave filters are one of the most significant devices in all wireless transmissions, since they can split between the desired and none desired frequencies. Especially mobile communications which are based on the transfer of millimeter waves ranging from 3 to 300Ghz [3]. As already known, the quantity of insertion loss in the passband is usually inversely proportional to the bandwidth of the filter[4], which causes a problem in the case of designing a narrow bandpass filter. To remedy this, an excessively high Q resonator factor should be used to design the filter so that it could respond to the required narrow bandwidth and the low insertion loss quantity[5]. For this reason, waveguide filter technology is considered to be the most qualified for this purpose[6] as it offers low passband insertion loss, extremely high rejection in the stopband, and a high Q factor[7].

For many years, this domain was facing challenges concerning the cost, size, and time of developing such efficient devices, especially when the response of a given filter after fabrication does not meet the required specifications. This mismatch is generally due to the manufacturing tolerances and the type of material adopted in production. In order to remedy this, a tuning procedure after fabrication has become an overriding issue, this process could be done either manually or automatically[8–10].

Unfortunately, the regulation has been limited to the level of technologists and experts in the microwave domain, since there is no direct or unique relationship between the depth of the screws inside the filter and the S-parameters. At this point, it should be mentioned that screws play a major role in adapting the filter response such as the other discontinuities: irises and posts that could take the symmetrical aspect or an asymmetrical one[11].

This paper presents the design of a bandpass filter dedicated to 5G applications with the insertion loss method, where we will vary the depth of penetration of screws to see their impact on the frequency response of the concerned paper. This work will be organized as follows. A discussion about the adopted design method is elaborated in section2, the synthesis and simulation process are presented in section 3. While section 4 presents a discussion about the obtained results in the four scenarios after varying the depth of penetration of the screws to prove the effect of their depth of penetration on the frequency response of the filter. Finally, the conclusions and some short terms perspectives are drawn in section 5.

2 Insertion loss Method

Generally, two famous methods are used to design microwave filter. The first method was helpful in the case of low frequency filters in radio, telephony, Called image parameter method. While, the modern recent procedure, named insertion loss method uses networks synthesis techniques to design an effectively specific response[12]. It allows high degree of control over the passband and stopband amplitude. This method takes as a first step a low-pass filter prototype, normalized in impedance and frequency. The design process is illustrated in Fig.1

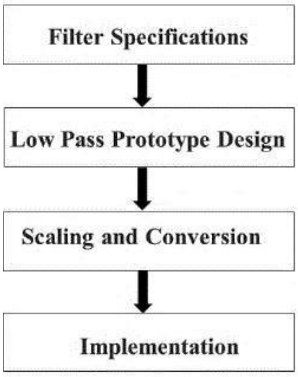

Fig 1: Process of filter design by insertion loss method

The detailed steps of this method are elaborated in the references[13–15].

3 Synthesis and simulation process

To deepen the theory presented in the previous section, we have chosen a bandpass filter with inductive irises of fifth-order designed in waveguide technology. This filter operates in the extremely high-frequency band (EHF), ranging from 22 GHz to 33 GHz, with a resonance frequency of 28 GHz, a relative bandwidth of 2.13%, and a return loss quantity around 15 dB. The illustration in Fig.2 depicts the geometrical structure of the filter, which is characterized by six inductive circular irises separating between five cavities, within a screw in the center of each cavity with two other screws positioned before the first iris and the last iris from the wave ports, which make them seven in total. It should mention that the screws were added with the aim of tuning the frequency response or the S-parameters of the waveguide filter whose internal dimensions are a = 8.64 mm, b = 4.32 mm.

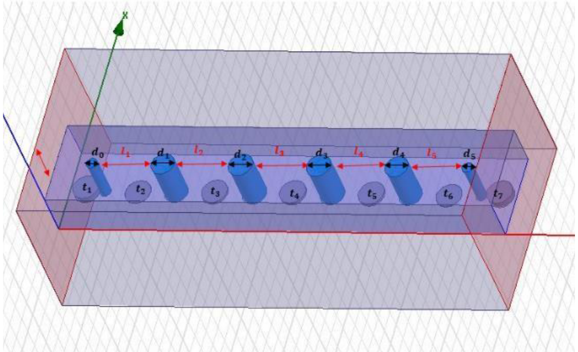

Fig 2: Interior topology of the waveguide filter structure

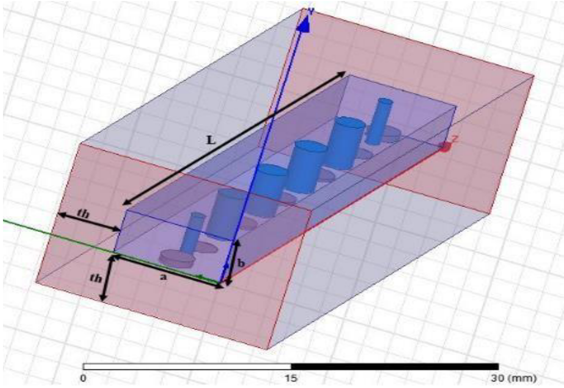

Fig 3: Exterior topology of the waveguide filter structure

In order to calculate the irises dimensions and the lengths of the five resonators, a Matlab code was used, and Table 1 illustrates the numerical values in mm of the parameters of these irises, where d_i is the diameter of each iris and b is their common height. Whereas, Table 2 presents the lengths l_i of each resonator.

d_0	d_1	d_2	d_3	d_4	d_5
1.096	2.315	2.436	2.436	2.315	1.096
b =4.32					

Table 1: The parameters of the five irises in mm

l_1	l_2	l_3	l_4	l_5
5.557	5.616	5.572	5.616	5.557

Table 2: Lengths of the resonators in mm

Knowing that the tuning screws were added such as discontinuities in the form of inductive circular insertions, they allow adjusting the S-parameters, in this purpose Table.3 summarizes the numerical values of their dimensions, where t_i is the height and D is the common diameter of all the tuning screws.

t_1	t_2	t_3	t_4	t_5	t_6	t_7
0.658	0.015	0.262	0.332	0.262	0.015	0.658
D = 2.571						

Table 3: The dimensions of the tuning screws in mm

Other dimensions worthen to be noted are the length of the waveguide L = 45.72 mm, the thickness of the waveguide was chosen to be th =5 mm and R = 3.054 mm referring to the distance between the wave ports and the first and last posts, these previous dimensions are depicted in Fig.3.

4 Results and discussion

4.1 Parametric study on the screw's properties

A parametric study was carried out, to determine the optimal value of D the diameter of the screws where Fig.4 shows the geometry of the considered structure. The range of the parametrisation goes from 2.5mm to 3mm. This step was effectuated under the CST environment.

After running the simulation, the obtained graph depicts that the optimal value of the diameter of the five screws is D= 2.72mm this value presents a good quantity of return loss and insertion loss around the resonance frequency. The Fig.5 and Fig.6 show clearly this aspect.

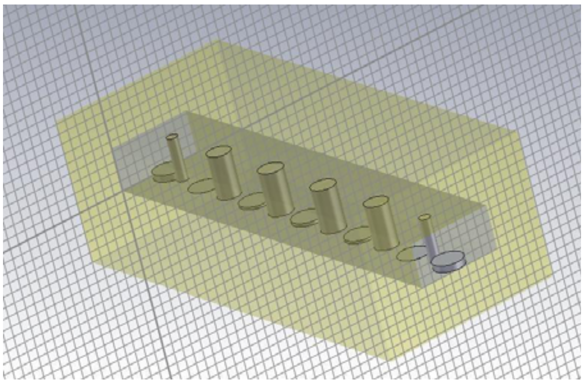

Fig 4: Geometry of the structure under CST

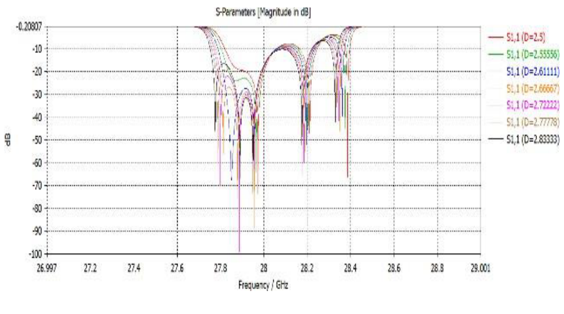

Fig 5: The plot of S_{11} after the parametric study on D

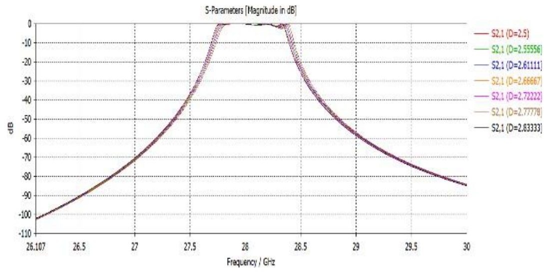

Fig 6: The plot of S21 after the parametric study on D

4.2 The variation of the depth of screws

The wavelength is around 10 mm at the frequency of 29Ghz, in this case, the performances of our filter may be affected by the variation of the depth of penetration of each one of the screws. With this aim, we structured the experiment to analyse how this mechanical penetration affects the S-parameters of our filter. After the creating the structure geometry, we will take into consideration four scenarios, to see if the depth of penetration of these discontinuities do influence in a way or another the response of the filter. For this Table.4 summarizes the depth of the screws in the four cases.

Scenario	t_1	t_2	t_3	t_4
1	0.658	0.04	0.262	0.332
2	0.326	0.015	0.262	0.166
3	0.658	0.015	0.3	0.332
4	0.658	0.015	0.262	0.332

Table 4: Corresponding screw depth combinations for the four scenarios

Taking into consideration that the structure geometry of the filter is symmetrical compared to the central screw (4th screw), where $t_1 = t_7$, $t_2 = t_6$, and $t_3 = t_5$. Only four geometrical variables will be varied, that are as follows: t_1, t_2, t_3, and t_4.

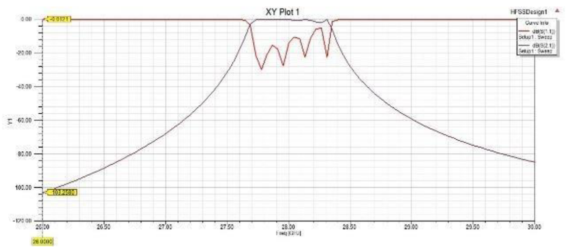

Fig 7: First scenario

As could be seen, the Fig.7 presents the S-parameters of our structure, based on the combination 1 of the depth of the screws. From the illustration, the bandwidth and center frequency had nearly met the specifications. We can also see that the amount of the return loss is around 9dB. Besides, an appearance of four zero poles, and a lower and upper stopband insertion loss quantities of 103.25 dB and 84dB. While, the illustrations of both Fig.8 and Fig.9 depicting the second and third scenarios does not show a good response for both S_{11} or S_{21} since there is a ripple in S_{21} in the bandwidth. A disappearing of the zero poles in the bandwidth, and the performance of the insertion loss had decreased in both cases.

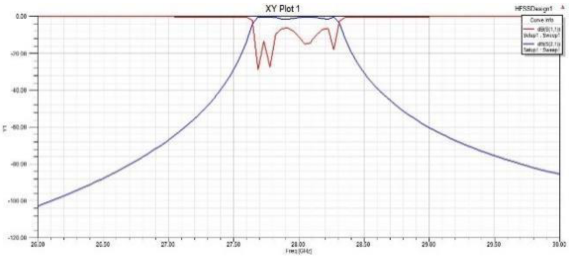

Fig 8: Second scenario

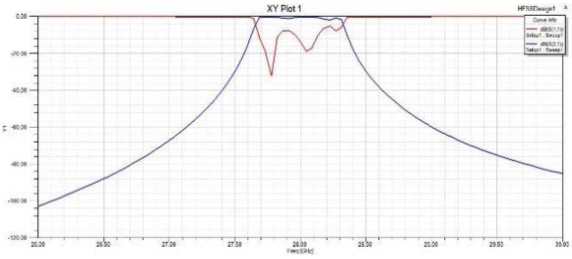

Fig 9: Third scenario

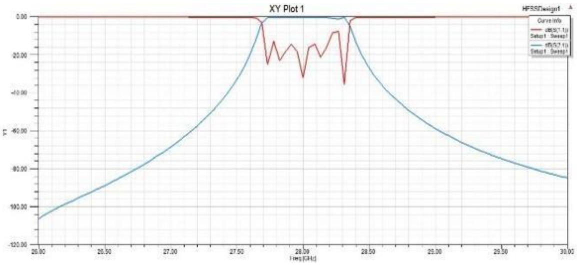

Fig 10: Fourth scenario

The 4th and last scenario have shown good agreement in terms of the fractional bandwidth, the center frequency which is 28GHz. The return loss quantity is around 10dB, and we can clearly see that the number of zero poles has increased to five in the bandpass. Considering the lower and upper stopband insertion loss measurements we can extracts the quantity of 106 dB at 26GHz and 85 dB at 30GHz.This scenario had showed better performances in view of all the properties of our filter, as could be seen in Fig.10.

The results of the paper [5] presented the aspect of the same specifications of our geometry, and we can clearly see that the results are similar. They used HFSS to elaborate the results compared to the mathematical model obtained from Matlab, while we used both simulators HFSS and CST.

Reference	***[9]***	***[5]***	***Proposed design***
Return Loss(dB)	17dB	15dB	16dB
Resonance frequency (GHz)	3 GHz	28 GHz	28 GHz
Number of screws	5	5	5
Screws Diameters(mm)	3	2.68	2.72

5 Conclusion

In this work, the design and simulation of a bandpass waveguide filter, with inductive discontinuities in the form of symmetrical circular irises, along with the effect of the depth of penetration of the seven screws to improve the frequency response of our filter. It was clear that the S-parameters are sensitive to the depth of our discontinuities, since the operating wavelength is around 10mm in the range of frequencies going from 26GHz to 29Ghz. The obtained results have showed a good agreement with the previously fixed specification. Where these results depict a low passband insertion loss and a good return loss level for the entire passband. Therefore, the main addition of this work is that this type of design is a reliable filtering device structure especially of millimeter-wave band, that presents a large bandwidth and a fast data transfer rate to overcome with the limitations of the spectrum range of frequency.

A short-term prospect was settled, which is developing an automated tuning process to control the response of the filter based on an intelligent controller such as FLC, which duplicates the human reasoning. This control will be effectuated on the depth of screws, to overcome the obligation of using only experts in the domain.

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