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Design of a 28 GHz Bandpass Filter for 5G Applications

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Abstract

One of the essential passive devices is the Bandpass Filter. Since the frequencies used for this technology are diverse and each frequency has different characteristics that can affect signal quality, the Bandpass Filter is employed to filter the signals received by the antenna, ensuring that only the desired frequency signals are processed. Within the mm Wave range, 26 GHz and 28 GHz emerge as the two most relevant bands. Therefore, this paper presents the design of a schematic for a Bandpass Filter operating at mm-wave frequency (28 GHz) using Lumped-Distributed Parameters. The schematic is created using system design software, employing a standard normalized 5-pole/5th order prototyped Lowpass Chebyshev combined with a standard formalized 3-pole/3rd order prototyped Lowpass Chebyshev to control the desired bandwidth according to the design parameters. The designed Bandpass Filter at 28 GHz exhibits a Return Loss value of -281.579 dB, an Insertion Loss of -1.929E-15 dB, and a desired Bandwidth of 1 GHz.

Keywords: Bandpass filter, mmWave, Lumped-Distributed Parameters

Abstrak

Salah satu perangkat pasif yang sangat penting adalah Bandpass Filter. Karena frekuensi yang digunakan untuk teknologi ini sangat beragam dan masing-masing frekuensi memiliki karakteristik yang berbeda yang dapat mempengaruhi kualitas sinyal. Bandpass Filter digunakan untuk memfilter sinyal yang diterima oleh antena yang dapat memastikan hanya sinyal yang sesuai dengan frekuensi yang diinginkan untuk diproses. Dalam kisaran mmWave, 26 GHz dan 28 GHz muncul sebagai dua pita yang paling relevan. Maka dalam paper ini, dirancang sebuah rangkaian skematik Band Pass Filter yang bekerja pada frekuensi mm-Wave (28 GHz) menggunakan Lumped-Distributed Parameters. Rangkaian skematik ini dibuat menggunakan perangkat lunak perancangan sistem. Dengan menggunakan standard normalized 5-pole/5th order prototipe Lowpass Chebyshev yang dipadukan dengan menggunakan standard normalized 3-pole/3th order prototipe Lowpass Chebyshev sebagai pengatur bandwidth yang diinginkan sesuai parameter perancangan. Hasil perancangan Bandpass Filter 28 GHz memiliki nilai Return Loss -281.579 dB, Insertion Loss -1.929E-15 dB dan Bandwidth yang diinginkan sebesar 1 GHz.

Kata-kata kunci: *Bandpass filter; mmWave; Lumped-Distributed Parameters*

1. Introduction

The 5G network technology, mainly operating in the mm-wave frequency spectrum, has attracted widespread attention. This frequency spectrum distinguishes it from previous generations of cellular networks, ranging from 2G to 4G [1] [2] [3]. Filters, consisting of electronic circuits, pass signals within a specific frequency range while attenuating or rejecting calls outside that range, aiming to reduce interference or unwanted signals [4]. Due to the crucial role of a filter device in eliminating or weakening distortions in the original signal, the applied filter specifications must be excellent and optimal, capable of performing with high efficiency. Therefore, designing or selecting a filter requires meticulous and accurate technical calculations [5].

A combination of passive and active devices will be of great importance. One essential passive device is the Band Pass Filter (BPF). As the frequencies used in this technology are diverse and varied, with each frequency having distinct characteristics affecting signal quality, bandpass filters filter signals received by the antenna, ensuring that only the desired frequency signals are processed. This is essential to ensure high signal quality in 5G networks [6].

In the mmWave range, 26 GHz and 28 GHz emerge as the two most relevant bands. The latter (27.5-29.5 GHz) is not included in Agenda Item 1.13 WRC-19, but the global market drives the need for an additional 5G spectrum. Countries like the US, South Korea, Japan, and Canada highly support this band for 5G services. The 28 GHz band has also seen its first commercial launch, with Verizon utilizing this frequency for Fixed Wireless Access (FWA). Meanwhile, the 26 GHz (24.25-27.5 GHz) is one of the most widely supported 5G candidate bands being discussed in WRC-19 and has been harmonized within the EU, which means that European countries must ultimately leverage it effectively [7] [8] [9] [10] [11]. The potential 5G Band and Other Uses Are Between 20-30 Ghz is presented on Figure 1.

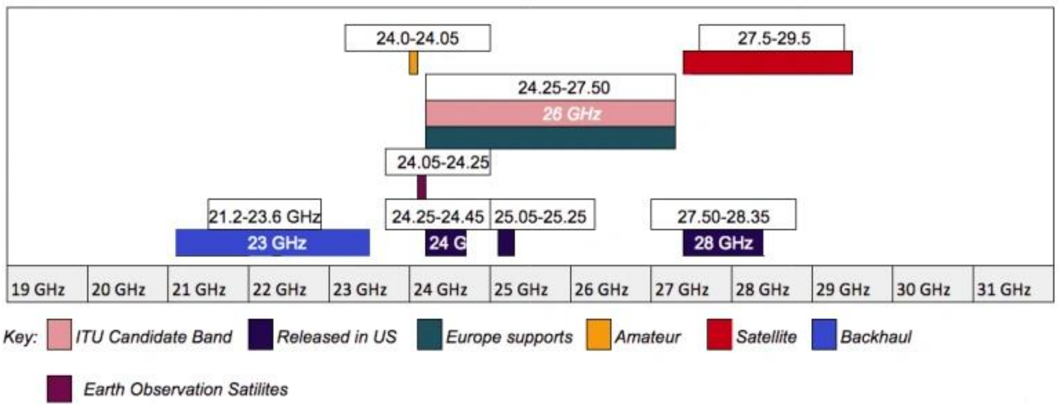

Figure 1. The Potential 5G Band and Other Uses Are Between 20-30 Ghz

In the design of filters, many aspects need to be considered, especially concerning the parameters of Return Loss, Insertion Loss, and Bandwidth required. Return Loss depicts how a component or transmission system reflects or does not transmit power. It significantly affects the overall performance of the filter. Insertion Loss is the power loss that occurs when a signal passes through a Bandpass Filter. This is the result of attenuation or losses that happen within the filter itself. Meanwhile, bandwidth has a significant impact on the Bandpass Filter. Bandwidth refers to the frequency range in which the Bandpass Filter passes signals with sufficiently high gain.

Designing a Bandpass Filter must consider the desired bandwidth according to the application's needs. A narrower Bandwidth provides better selectivity and higher attenuation in the stopband, but it may limit the gain at the desired center frequency. On the other hand, a wider Bandwidth allows higher gain at the center frequency, but selectivity and stopband attenuation may be reduced.

In previous research, most filter designs at mm-wave frequencies were created using Monolithic Microwave Integrated Circuit (MMIC) technology and exhibited high Insertion Loss, exceeding 2 dB **[12] [13] [14] [15]**. Research **[12]** employed the concept of a D-CRLH (Composite Right-/Left-Handed) Resonator integrated with MMIC. Study **[13]** utilized Dual-Behavior Resonators with GaAs technology. Research **[14]** focused on designing a BPF (Bandpass Filter) using mutual coupling techniques, while Research **[15]** explored miniaturized Resonances using silicon technology. Meanwhile, Lumped Element Bandpass Filters have several advantages that make them popular in various applications. Some key benefits of Lumped Element Bandpass Filters include their compact size, low cost, and adjustable bandwidth **[16] [17]**.

In this paper, we conducted simulations of a 28 GHz Bandpass Filter using a Lumped Element circuit with system design software. Bandpass filter characteristic is presented on **Figure 2.**

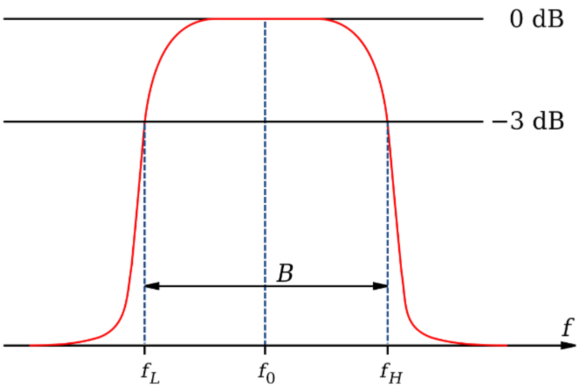

Figure 2. Bandpass Filter Characteristic

2. Method

The circuit model used in the 28 GHz Bandpass Filter design is the standard normalized 5-pole/5th order prototype *Lowpass Chebyshev*, which transforms **Figure 3** to **Figure 4**. This transformation is by equations (1) – (4), where the impedance value Z = 50 ohms.

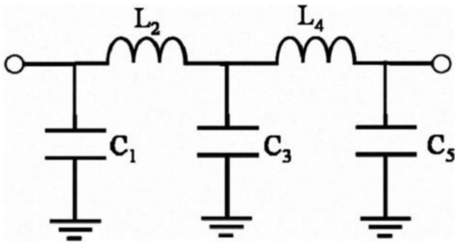

Figure 3. Standard Normalized 5-Pole/5th Order Prototype Lowpass Chebyshev

$$L_{shunt_n} = \frac{g_n Z_0}{(2\pi)^2 BW f_c} \quad (1)$$

$$L_{series_n} = \frac{BW f_c Z_0}{g_n (2\pi f_c)^2} \quad (2)$$

$$C_{shunt_n} = \frac{BW}{g_n Z_0 (2\pi(\quad FC))^2} \quad (3)$$

$$C_{series_n} = \frac{g_n}{2\pi BW Z_0} \quad (4)$$

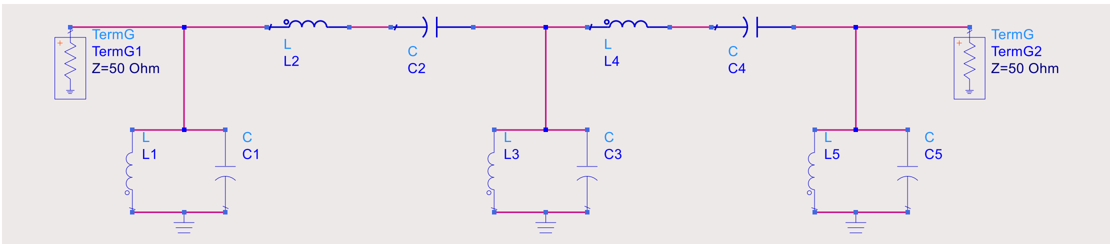

Figure 4. The Series and Parallel Bandpass Filter Circuits With LC Resonator Of 5th Order.

Based on the calculations using equations (1) - (4), the results are tabulated in Table 1. The values of L1 and L5 are 4.56312 nH, L2 and L4 are 0.01480 nH, and L3 is 7.85839 nH. As for the importance of C1 and C5 are 0.00708 pF, C2 and C4 are 2.18235 pF, and the importance of C3 is 0.00411 pF. The Values of L and C for the 5th order 28 GHz Bandpass Filter is presented on **Table 1**.

Table 1. The Values of L and C for the 5th order 28 GHz Bandpass Filter

The Importance of L and C for the 5th order 28 GHz Bandpass Filter.				
L1 (nH)	L2 (nH)	L3 (nH)	L4 (nH)	L5 (nH)
4.56312	0.01480	7.85839	0.01480	4.56312
C1 (pF)	C2 (pF)	C3 (pF)	C4 (pF)	C5 (pF)
0.00708	2.18235	0.00411	2.18235	0.00708

3. Results and Discussion

Several challenges arise in designing an RF Bandpass Filter (BPF) operating at mm-wave frequency, precisely at 28 GHz with a 1 GHz Bandwidth. These challenges include achieving better signal isolation, increasing selectivity, and handling higher power levels. When designing the Bandpass Filter, it is essential to determine the specifications such as Return Loss, Insertion Loss, and Bandwidth parameters as specified in **Table 2 [18] [19]**.

Tabel 2. Parameters or Initial Design Targets

No	Parameter yang diinginkan	Nilai	Satuan
1	*Frequency Center* (Fc)	28	GHz
2	*Bandwidth*	> 2	GHz
3	*Return Loss*	< -10	dB
4	*Insertion Loss*	< 2	dB

The 28 GHz Bandpass Filter Circuit, 5th Order Chebyshev with LC Resonator is presented on **Figure 5**.

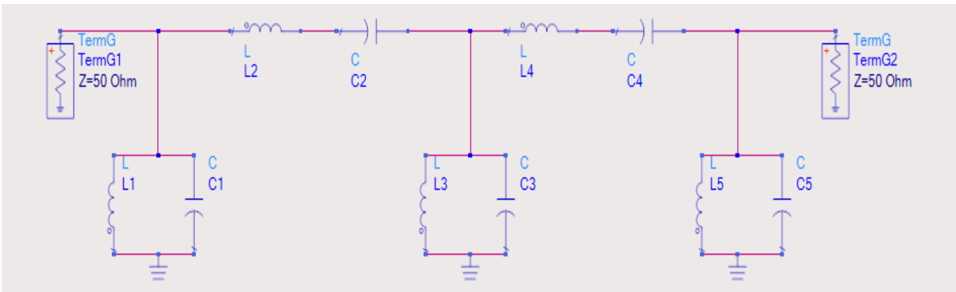

Figure 5. The 28 GHz Bandpass Filter Circuit, 5th Order Chebyshev with LC Resonator

The Simulation Results Of The 5th-Order Chebyshev Bandpass Filter Circuit With Lc Resonator At 28 Ghz is presents on **Figure 6**.

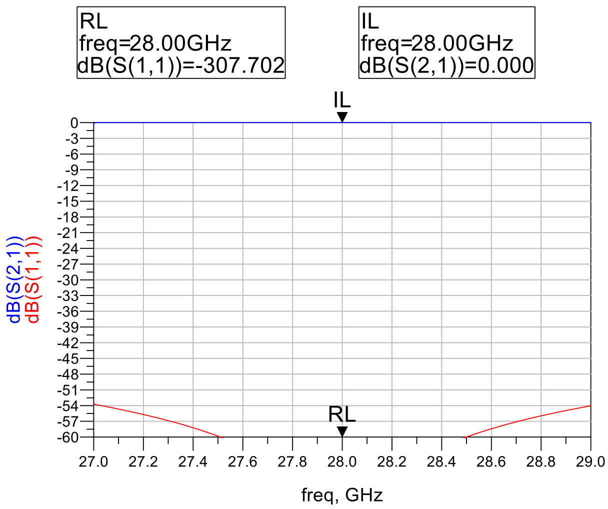

Figure 6. The Simulation Results Of The 5th-Order Chebyshev Bandpass Filter Circuit With Lc Resonator At 28 Ghz

Based on the design shown in Figure 5 and the simulation results in Figure 6, RL represents the Return Loss, and IL represents the Insertion Loss. The simulation results indicate that the Return Loss for this design is -307.702 dB, and the Insertion Loss is 0 dB. From the results in Figure 5, an ideal Bandpass filter is achieved, where the Return Loss is -307.702 dB and the Insertion Loss is 0 dB. However, this perfect filter design could be more attainable, considering the resulting bandwidth appears infinite. Therefore, an alternative circuit is required to obtain the desired bandwidth.

3.1 The process of Bandwidth Adjustment

The next stage of the mm-wave BPF design is to modify Experiment 1 from the previous simulation. The modifications made are:

It adds a standard normalized 3-pole/3rd order prototype lowpass Chebyshev circuit as a controller for the desired bandwidth. The addition on the upper left and upper right sides of the basic standard normalized 5-pole/5th order prototype lowpass Chebyshev circuit is to adjust the desired bandwidth, resulting in a more precise bandwidth value with the presence of the standard normalized 3-pole/3rd order prototype lowpass Chebyshev circuit cut at its midpoint. To create the middle normalized 3-pole/3rd order prototype lowpass circuit cut at its core, equations (1) - (4) are utilized.

By using equations (1) – (4), the calculation results of the standard normalized 3-pole/3rd order Chebyshev Lowpass prototype circuit are tabulated in **Table 3**.

Table 3. The values of L and C for a 28 GHz Bandpass Filter of 3rd order.

Table of L and C values for 3rd order 28 GHz BPF.			
L6 (nH)	L7(nH)	L8(nH)	L9(nH)
0.01968	4.56536	4.56536	0.01968
C6 (pF)	C7 (pF)	C8 (pF)	C9 (pF)
1.64182	0.00708	0.00708	1.64182

The 28 ghz bandpass filter (bpf) circuit is a combination of a 5th-order chebyshev with a 3rd-order chebyshev and an lc resonator is presented on **Figure 7**.

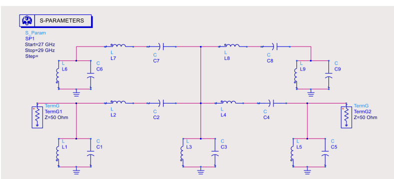

Figure 7. The 28 GHz Bandpass Filter (BPF) Circuit is A Combination Of A 5th-Order Chebyshev With A 3rd-Order Chebyshev and an LC Resonator

The design of the Bandpass Filter for 28 GHz in 5G applications involves combining the standard normalized 5-pole/5th order prototyped Lowpass Chebyshev to control the desired bandwidth more precisely. This is achieved by incorporating the bar normalized 3-pole/3rd-order prototyped lowpass, which is truncated at its centre, as shown in **Figure 7**. The values of L and C are in **Table 1** and **Table 2**. The simulation results of the 5th order chebyshev bandpass filter circuit with lc resonator is presented on **Figure 8**.

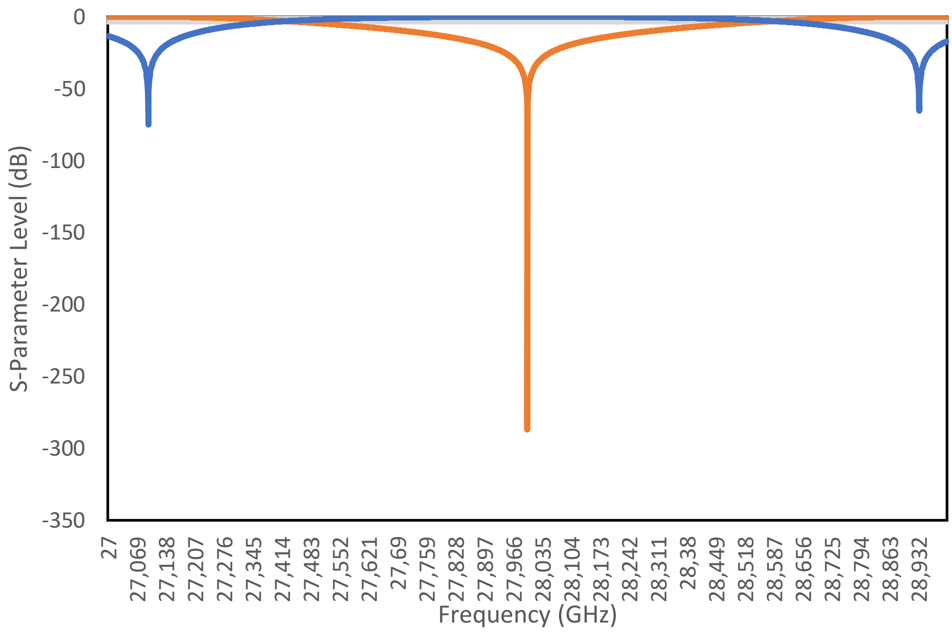

Figure 8. The Simulation Results of the 5th Order Chebyshev Bandpass Filter Circuit with LC Resonator

From the simulation results, by adding a standard normalized 3-pole/3rd order prototype Lowpass Chebyshev circuit as the desired bandwidth controller, **Table 4** was The Simulation Results Table for the Design of 28 GHz BPF with 5th Order and 3rd Order Chebyshev Circuit.

Table 4. The Simulation Results Table for the Design of 28 GHz BPF with 5th Order and 3rd Order Chebyshev Circuit.

No	Target Parameters	Value	Unit
1	Frekuensi Center (Fc)	28.00	GHz
2	*Bandwidth*	1	GHz
3	*Return Loss*	-286.911	dB
4	*Insertion Loss*	-2.893E-15	dB

From Figure 8, it can be observed that the Return Loss value in this design is -281.579 dB, the Insertion Loss value is -1.929E-15 dB and the desired Bandwidth of 1 GHz within the range of (27.59 - 28.59 GHz) can be achieved by adding components on the upper left and upper right sides of the basic standard normalized 5-pole/5th order prototype Lowpass Chebyshev circuit.

This addition controls the desired bandwidth more precisely by including a bar-normalized 3-pole/3rd order prototype Lowpass Chebyshev truncated in the middle section.

4. Conclusion

The design of a 28 GHz Bandpass Filter for 5G applications utilizes a combination of standard normalized 5-pole/5th order Lowpass Chebyshev prototype and standard normalized 3-pole/3rd order Lowpass Chebyshev prototype to control the desired bandwidth according to the design parameters. The designed Bandpass Filter at 28 GHz yields the following results: Return Loss of -281.579 dB, Insertion Loss of -1.929E-15 dB, and the desired bandwidth of 1 GHz.

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