

The Research on the Bandpass Filter for 5G N79 Band

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Abstract. With the continuous development of communication technology, 5G technology has gradually replaced the original 4G network and has been applied to all walks of life with its advantages of faster connection speed, lower delay, and larger capacity. The RF front-end market has also benefited from the prosperity of 5G, and filters are the most significant business segment in the RF front-end market. Filters are widely used in the 5G network technology hardware because it can significantly ensure the signal's integrity. The shield stripline bandpass filter and the high-resistance silicon-based bandpass filter using, which use Integrated passive devices (IPD) technology, are two ordinary filters on the market. This article will briefly outline the structure and performance of the two filters and use the comparison method to compare the advantages and disadvantages of the two filters. Finally, some reasonable solutions are proposed for improvement, such as adding a defective ground structure to the strip linear filter to reduce the insertion loss, replacing the material of the IPD filter with glass, and using active components instead of IPD to make the filter.

Keywords: Bandpass filter, 5G, Stripline, Silicon, N79 band.

1. Introduction

5G is the 5th generation mobile network. Compared with the 4G network, 5G is being accepted and used by more and more people with its faster connection speed, lower latency, and larger capacity. According to the GSM Association, 5G networks are expected to have more than 1.7 billion users worldwide by 2025 [1]. The rapid development of 5G has also driven the development of the RF front-end market. According to the global RF front-end market report issued by IMARC in 2021, the global market size in 2021 will reach as high as 174 US dollars, and it is predicted that its annual growth rate will reach 14.7% by 2027 and develop to a global market of 38.6 billion US dollars in 2027. market size. Among them, the proportion of filters is as high as 54%, which is more than half of the overall market [2]. Filters are essential for developing 5G networks, which can separate signal bands to prevent noise and external signal interference to ensure signal integrity. Among them, filters with miniaturization, high performance, and low cost are essential for the application of 5G networks [3]. This paper introduces two band-pass filters for the 5G N79 frequency band, using stripling technology with a shielded structure and IPD technology based on high-resistance silicon. They are two different techniques, but both are used to improve the performance of bandpass filters. The bandpass filter part will introduce the structure and performance of the two filters, and the third section compares, finds out the problem, and proposes a relative solution. Finally, the whole content is summarized in the summary section.

2. Bandpass filter

2.1. The shield stripline bandpass filter for 5G N79 band

The stripline bandpass filter is used to avoid the bad behaviors of discrete components at high frequencies, which use the cavities, PCB stripline, and so on to achieve this goal.

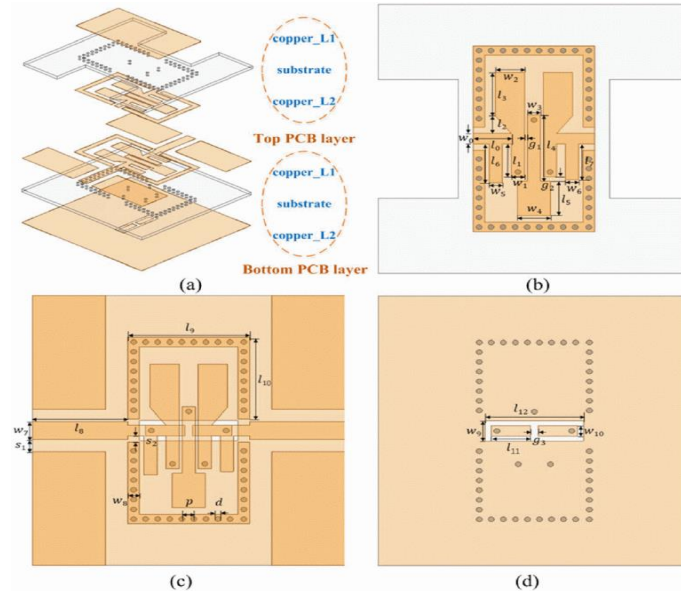


Figure 1. Overall schematic of the filter. (a) 3D view. (b) Top view. (c) Bottom view [4].

Figure 1 presents the overall structure of a shielded stripline bandpass filter from a 3D view, top view, and bottom view. The filter comprises two single-layer PCBs and six metal screws tightened around the filter's edges. On this basis, a stripline filter consists of two copper layers, L1 and L4, with a group of shielding vias which are one stepped impedance resonator (SIR) and two gradient impedance resonators (GIR) are added to make the cavity more compact to improve sealing and reduce radiation loss [4].

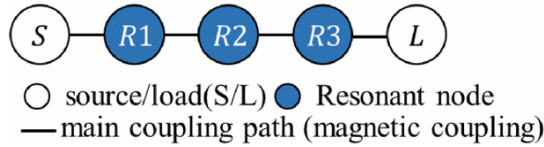


Figure 2. Filter's coupling scheme [4].

$$\begin{bmatrix} M_{11} & M_{12} & M_{13} \\ M_{21} & M_{22} & M_{23} \\ M_{31} & M_{32} & M_{33} \end{bmatrix} = \begin{bmatrix} 0 & 1.22 & 0 \\ 1.22 & 0 & 1.22 \\ 0 & 1.22 & 0 \end{bmatrix} \quad (1)$$

The coupling scheme and matrix of the stripline filter are shown in Figure 2 and (1), respectively. Resonant node R2 represents the SIR resonator, and R1 and R3 represent the GIR resonator. And these three resonators have the same coupling coefficient; in this case, it can help to convert the first high-order resonant frequency to a harmonic higher than the triple frequency to obtain better stop-band performance [4].

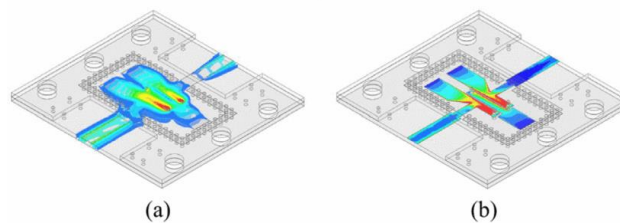


Figure 3. Magnetic field distributions. (a) in substrates, (b) on shielded stripline [4].

The effect of cavity sealing is shown in Figure 3. Figure 3(a) shows the magnetic field is confined into the shielding cavity with no leakage. Figure 3 (b) shows the magnetic field is coupled between three resonators. Both filters' designs help reduce the radiation loss, resulting in the reduction of insertion loss.

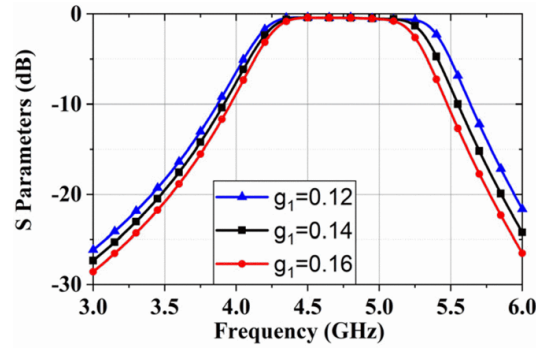


Figure 4. Comparison of S-parameters between filter's bandwidth and gap width [4].

Figure 4 shows the relationship between the filter's bandwidth and the gap width between the resonators. From the graph, the bandpass filter's bandwidth decreases as the gap width increases. When the bandwidth is reduced, the magnitude of the coupling coefficient is also reduced. In that case, the required filter's bandwidth can be tuned by changing the gap width value.

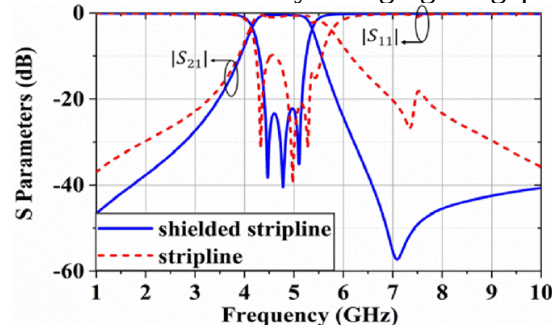


Figure 5. Comparison of S-parameters of traditional stripline filter and shield stripline filter under the same topology [4].

Figure 5 shows a performance comparison of a conventional stripline filter and a shielded stripline filter under the same test conditions. The results show that the shielded stripline filter has a better factor Q. The reason is that this filter has relatively higher selectivity because its suppression effect at the outer band frequency is better than that of the traditional strip linear filter. Insertion loss is also lower than conventional stripline filters at its operating frequency.

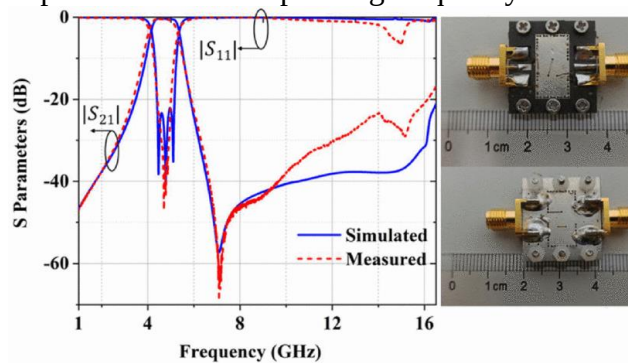


Figure 6. Simulated and measured S-parameters [4].

Tests will be performed on a Rogers 5880 substrate to demonstrate its ability to remove interfering noise rejection of out-of-band. The test results are shown in Figure 6. The filter size is only $8.16 \times 15.45 \text{ mm}^2$ and has a good rejection below -20dB in the test range from 1 to 16.2GHz. Its center frequency is 4.62GHz, 3-dB bandwidth of 1.22 GHz. The insertion loss is approximately 0.5 dB [4].

In conclusion, this filter has the advantage of low insertion loss, wide stopband, and small sizes and is widely used in the 5G N79 band's application.

2.2. The IPD technology bandpass filter for the 5G N79 band

This part introduces a band-pass filter designed by high-resistance silicon-based IPD technology for the N79 frequency band of 5G communication [5]. Traditional passive devices often use distributed design in wireless communication; each design area is responsible for one parameter. However, such a design will cause passive components to occupy most of the circuit board area during use, resulting in the problem of low overall hardware integration. Integrated passive devices (IPD) have benefits such as better performance, device miniaturization, and low assembly cost [6]. These advantages perfectly meet the requirements and expectations of 5G communication systems for radio frequency devices. It is also worth mentioning that IPD made of high-resistance silicon has larger resistivity up to 2000 $\Omega\cdot\text{cm}$ and lower inductance and wiring losses compared with other materials, such as gallium arsenide and aluminum oxide, and are used to fabricate and achieve higher-performance passive devices.

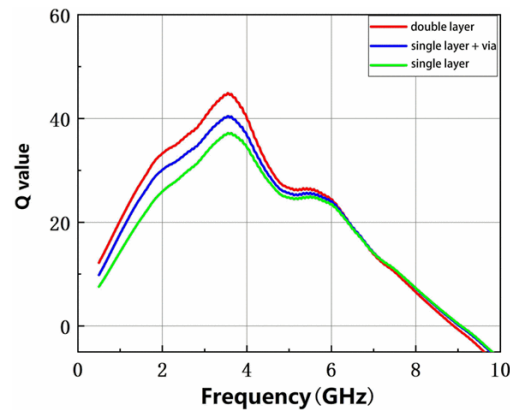


Figure 7. The measurement result of factor Q with inductors component design [5].

The design of the inductive components in the IPD. Inductors are critical components in IPDs. Ideally, their role is to store and transport energy without generating energy. But in reality, there are three main ways of inductor energy loss: radiation loss, conductor loss, and substrate loss. In this case, reducing the inductance loss is an effective way to improve the IPD performance. Figure 7 shows the two main methods of reducing inductance losses and the results in comparison. The green curve represents the results of the most basic single-layer inductor design, and this curve serves as a control for the other two effects. Blue represents a single-layer inductor design with through-hole inductors. The principle is to increase the line spacing or line width to avoid the generation of the proximity effect and increase the effective contact area of the metal. Still, it eventually leads to an increase in the inductance area. The red curve adopts the design of the double-layer structure. Compared with the other two structures, the Q value obtained by the double-layer structure design is the best among the three forms [5].

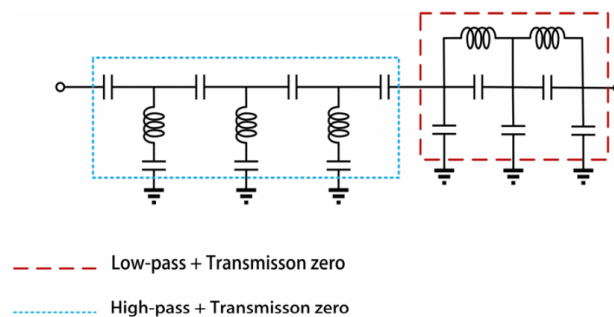


Figure 8. The topology design of the bandpass filter [5].

Figure 8 shows the topology of this filter. In the high-pass and low-pass parts, we use the transmission zero-up coupling design and the transmission zero-coupling design, respectively, and set up multiple outer-band transmission zero positions that can be controlled by capacitance and inductance to realize the movement of the transmission zero point. In addition, because this design

uses only five inductive components, its structure also reduces the use of inductive components and the core area of the device and improves the integration of the system.

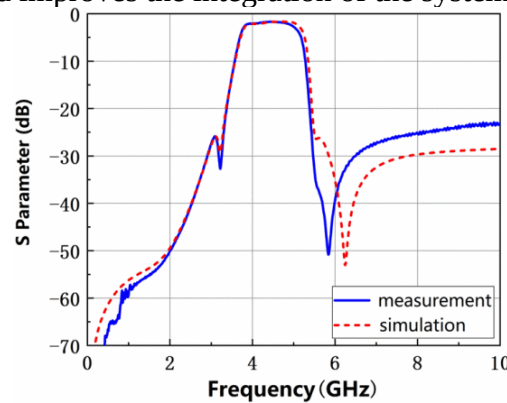


Figure 9. The comparison between the simulation and measurement [5].

The performance test of the filter will be carried out on a test pad with a size of 2mm*1.5mm. The test uses the GSG probe with a spacing of 150um and the SLOT method to calibrate the filter. The test results can refer to in Figure 9; from the passband from 3.8 to 5.5 GHz, the insertion loss is less than 2.5dB. The filter's suppression effect is the best before 2.5GHz, which can be as high as 70dB and the average suppression effect is more significant than 40dB. The filter also has a good suppression effect after 5.5GHz, generally higher than 20dB.

3. Data comparison and analyze the problem

Table 1 summarizes the data from the previous two filters' result graphs Figure 7 and Figure 10. In Table 1, the shielded stripline filter has lower insertion loss compared to the high-resistance silicon-based IPD filter at the operating frequency range from 4.5 to 5GHz, which are 0.5 dB and 2dB, respectively. Using more design areas and complex circuit components may be one of the reasons why stripline filters have lower insertion loss than IPD filters. In comparison, the size of the stripline filter is $8.16 \times 15.45 \text{ mm}^2$ and the IPD filter's design area is $2 \text{ mm} \times 1.5 \text{ mm}$, which is 40 times larger. The stripline filter builds a two-layer filter structure to reduce the insertion loss and the suppression effect on the outer band. In comparison, the IPD filter only uses a multi-layer inductance structure and a high-low-pass cascade topology composed of a small number of components. The bottom four rows of data columns represent the average suppression effect of the out-bands of the two filters. The recorded out bands are the four intervals of 0-2GHz, 2-4.5 GHz, 5-7GHz, and 7-10GHz. In the out-band of 0-2GHz and 2-4.5GHz, which are lower than the operating frequency range, the IPD filter has a better suppression effect. However, the stripline filter has a better suppression effect in the out-band of 5-7GHz and 7-10GHz above the operating frequency range. The performances of the two filters introduced in Section 2 are excellent, but there are still ways to improve their performance.

Table 1. The Data summary for the previous two filters [4,5].

Parameters	Stripline filter	IPD filter
Size	$8.16 \times 15.45 \text{ mm}^2$	$2 \text{ mm} \times 1.5 \text{ mm}$
Insertion loss (4.5 to 5GHz)	0.5 dB	2 dB
Materials used	Copper layer with two PCB	high-resistance silicon
Attenuation (0 to 2GHz)	38.6 dB	62.3 dB
Attenuation (2 to 4.5GHz)	16.2 dB	28.8 dB
Attenuation (5 to 7GHz)	36.2 dB	41.2 dB
Attenuation (7 to 10GHz)	42.3 dB	25.7 dB

Table 2. Added DGS and before and after quarter wavelength stubs [4].

Parameters	Filter before improvement	Filter after improvement
Size	$8.16 \times 15.45 \text{ mm}^2$	$8.16 \times 15.45 \text{ mm}^2$
Working frequency	4.62 GHz	4.38 GHz
3-dB bandwidth	1.22 GHz	1.93 GHz
Insertion loss	0.46 dB	0.25 dB
Suppression on out-band	-20 dB on 16.17 GHz	-20 dB on 12.80GHz

The shield stripline filters' structure is based on the primary filter built by two PCBs and adding multiple copper layers around the filter with shielding vias to form a closed cavity to reduce radiation loss. A way to improve this filter is to add a defective ground structure (DGS) and quarter wavelength stubs. The DGS is an etched-out pattern defect created on the ground plane of a printed microstrip board, which can help expand the filter's bandwidth, improve the stripline filter's parameters and compact the circuit size [7]. The quarter wavelength stubs can be made for a notch filter [8] which can attenuate specific frequencies and form the lowpass filtering response, improving the filter's performance in the out-band frequency band. In Table 2, the improved filter still works on the N79 band of 5G. But its 3-dB bandwidth has been increased from 1.22GHz to 1.93GHz. Happily, the insertion loss was reduced from 0.46dB before the retrofit to 0.25dB. The modified filter also has a more decisive rejection of the outer band than before, mainly due to adding the extra quarter wavelength stubs.

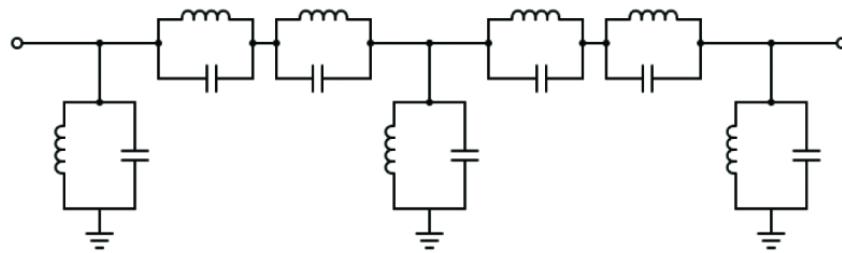


Figure 10. Bandpass filter design topology [9].

Table 3. Data comparison of LTCC and glass IPD [9].

Parameters		LTCC	IPD
XY dimension		$2.0 \times 1.25 \text{ mm}$	$2.0 \times 1.25 \text{ mm}$
Z height		0.65 mm	0.3 mm
Insertion loss	4.4-5.0 GHz	2.09 dB	1.97 dB
Attenuation	0.6-2.7 GHz	50.9 dB	35.0 dB
Attenuation	5.49-5.67 GHz	31.2 dB	17.7 dB
Attenuation	5.67-5.95 GHz	35.0 dB	28.5 dB
Attenuation	6.2-15.0 GHz	33.0 dB	26.3 dB

For the IPD filter, although its performance and the data presented are outstanding, there are still two ways to improve its performance.

The first is to change to glass material and structure. The IPD's substrate can use glass with high resistivity and good RF capability. A series of materials, such as AlCu, and DK, are used to form capacitors. A specific photolithography process and thick copper RDL for protection are used to create the main inductance layer. And multiple RDL stacking can not only protect the main inductor layer but also improve the inductor Q factor and the RF performance of the filter so that the inductor Q factor can be as high as 100. However, the use of multiple RDLs will increase the overall thickness and increase the usable area. On this basis, using a spiral inductor design can help reduce the working area while keeping the inductance factor Q at a relatively high level. Figure 10 shows the 5th-order

ellipse topology we used in the filter design to improve the rejection of the passband accessory. To demonstrate the superiority of its design and materials, the article also tested the low-temperature co-fired ceramic (LTCC) technology to draw corresponding data and conclusions. Both experiments were performed with filter design and simulation in the 3D electromagnetic simulation tool Ansys HFSS [9]. Table 3 shows the comparison between glass IPD and LTCC. IPD has lower insertion loss and design volume and has a lower attenuation effect on the out-band frequency range. In addition, glass IPDs have lower insertion loss and design area than the high-resistivity silicon IPDs mentioned in Section II, showing better performance.

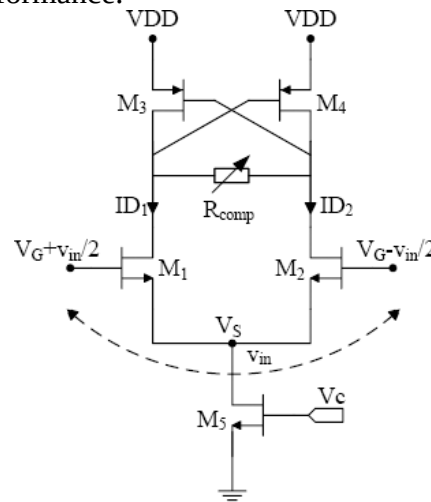


Figure 11. The OTA used for the active filter [10].

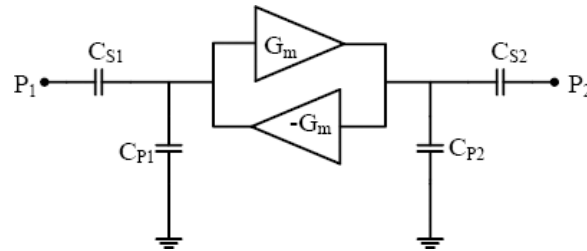


Figure 12. Gyrator-Based Active Resonator [10].

Table 4. Data comparison of passive and active filters [4,10].

Parameters	IPD bandpass filter	Active bandpass filter
Size	2mm*1.5mm	1.4mm*0.12mm
Insertion loss	0.46 dB	0.1 dB
bandwidth	1.22 GHz (3dB)	1.35GHz to 2.35GHz(1dB)
Out-band attenuation	More than 30 dB (<4.5 GHz, >5GHz)	More than 40dB (< 1.06GHz, >2.89GHz)

The second way is to use an active device to make the bandpass filter, for example, a gyrator resonator. Figure 11 shows the transconductor. This OTA is designed as a single-stage common source topology to avoid the internal poles that may happen on the cascode transconductor. The NOMS transistors M_1 and M_2 control the current source, which is supplied to transconductance. Two PMOS transistors M_3 and M_4 in cross-coupled way to load the output of the differential transconductor. The transistor M_5 has three functions. The first function controls the total current. The second function is to control the common-mode current [10]. Its working principle is to control the voltages of transistors M_1 , M_2 , and M_5 to balance the common-mode current. The third function is to help improve the OTA's common mode rejection performance. Figure 12 shows the gyrator-based resonator, which creates much more power on specific frequencies to resonate. Table 4 is a data comparison between active and passive filters. In this table, the active bandpass filter has

a lower size and less insertion loss, which are $1.4\text{mm} \times 0.12\text{mm}$ and 0.1 dB, respectively. The active bandpass filter also performs better on the suppression in the out-band frequency range.

4. Conclusion

This paper mainly introduces two band-pass filters applied to the 5G N79 band, which are band linear filters and filters using IPD technology. A detailed introduction of the structures and data summary of the two filters are presented. In the comparison section, a DGS structure and a quarter-wave stub can be added to the stripline filter to improve bandwidth, out-band rejection, and decrease its insertion loss. For high-resistivity silicon-based IPD filters, use glass which has higher resistivity and higher RF capacity to replace silicon or replace the passive device with active components, both solutions can help to increase bandpass filter's bandwidth and reduce its insertion loss. The filters mentioned in this article all have low insertion loss, wide stopband, and good performance and are the good choice for 5G communication.

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