TSV-Based Hairpin Bandpass Filter for 6G Mobile Communication Applications

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LETTER

TSV-Based Hairpin Bandpass Filter for 6G Mobile Communication Applications

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Abstract Aimed at sixth-generation (6G) mobile communication applications, three fifth-order novel ultra-compact hairpin bandpass filter is proposed. Through-Silicon Via (TSV), a three-dimensional integration technology, is used to implement the arms of hairpin units, and some hairpin units consist of four arms. In this letter, the design method of the three proposed filters is introduced, and the filtering characteristics are verified by HFSS, an industry-grade simulator based on finite element method. The results reveal that the three proposed filter has the center frequency of 0.405 THz, 0.3915 THz, and 0.3955 THz with bandwidth of 0.1 THz, 0.077 THz, and 0.063 THz and exhibits an insertion loss of 2.0 dB and return loss over 12.4 dB, 13.4 dB, and 14 dB. The size of the three proposed filters is both 0.284 × 0.0325 mm^2 (1.29 × 0.148 λ_g^2).

key words: Sixth-generation (6G) mobile communication; terahertz (THz) frequency band; hairpin bandpass filter; Through-silicon via (TSV)

Classification: Electron devices, circuits and modules (Silicon)

1. Introduction

With the high demands in wireless communications, sixth-generation (6G) mobile communication can provide efficient communication, unprecedented pace, and ubiquitous connectivity [1-2]. Terahertz (THz) range can meet the increased bandwidth, improved efficiency, and high-reliability of 6G wireless communication [3]. Microstrip bandpass filters with compact size and lightweight need to be redesigned for high-performance functional in the channels of communication systems [4]. Microstrip hairpin filter with simple structure, and high integration [5-8] has widely been utilized in microstrip bandpass filter at below 100 GHz. However, after entering the THz frequency band, the transmission loss of the microstrip line increases sharply, which no longer meets the performance requirements of the filter.

Fortunately, Through-Silicon Via (TSV) can achieve very good signal transmission function in the THz frequency band. TSV provides vertical electrical connections with low loss and, therefore, has been extensively investigated and developed [9-29]. Therefore, a TSV-based hairpin bandpass filter at THz band is meaningful for 6G mobile communication.

The proposed filter is designed using odd-even mode analysis and coupling coefficient theory as described in Section 2. The results of the S-parameters and a performance comparison of relative THz bandpass filters are presented in Section 3. Finally, some conclusions are drawn in Section 4.

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2. Design of TSV-based hairpin bandpass filter

In this section, the design method of the TSV-based four-arm hairpin filter is described. The TSV-based hairpin bandpass filter is consistent in the electronic circuit model given in Fig. 1 and topology structure given in Fig. 2. In this work, the substrate material in the TSV-based hairpin unit is assumed to be high-resistivity silicon. The high-resistivity silicon exhibits three important features, which are the dielectric constant of 11.9, dielectric tangent of 0.005 and resistivity of 1000 Ω•cm. The four types of hairpin unit is modeled in High Frequency Structure Simulator (HFSS) software [30], which are shown in Fig. 3. As depicted in Fig. 4, the three main structures of the fifth-order hairpin bandpass filter combines the input/output and internal coupling units.

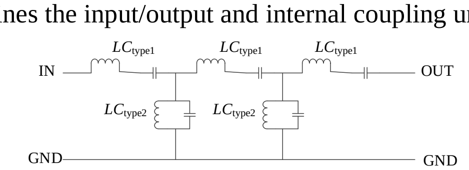

Fig. 1 The circuit model.

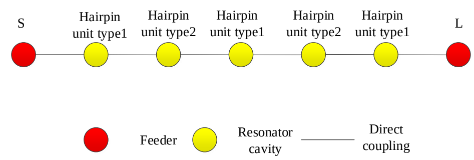

Fig. 2 The topology of structure.

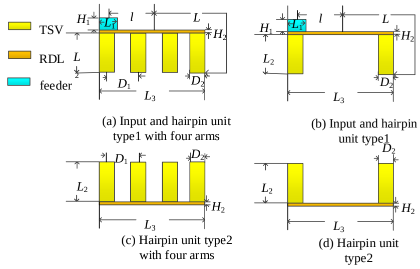

Fig. 3 The hairpin unit of HFSS model.

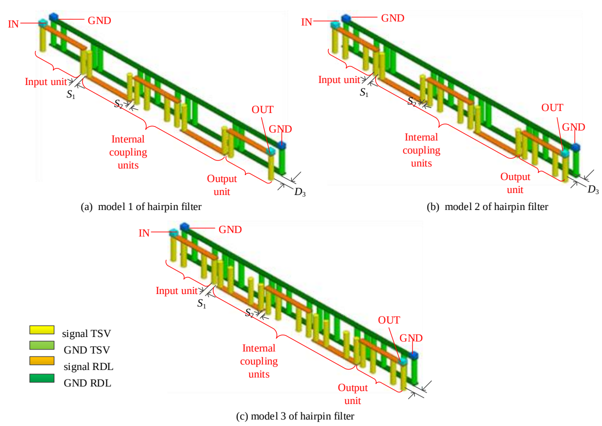

Fig. 4 Three HFSS models of hairpin filter.

3. Simulation Results and comparison

The parameters of the proposed filters are listed in Table I. And the *S*-parameters are shown in Fig. 5. As the hairpin unit with four arms increase, the in-band return loss will increase. But the band width of the proposed filter will decrease.

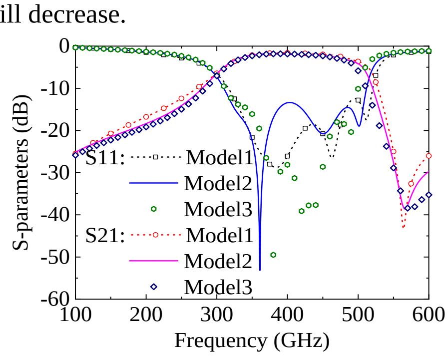

Fig. 5 The comparison between S-parameter of three HFSS models.

A related THz hairpin filter and three related THz SIW filters are compared with the three proposed hairpin filters in Table II. With higher bandwidth, the filters in this work provides higher channel capacity for microwave signal transmission. Moreover, the size of the proposed hairpin filter is considerably smaller than the other hairpin filters, which shows that the structure of the proposed filters is more compact.

Table I. Structure parameters of proposed hairpin filter

	Structure parameter	Symbol	Value (μm)
Feeder	Length	L_1	5.8
	Width	W	5.1
	Height	H_1	4
TSV	Diameter	D_2	5.1
	Length	L_2	26.5
RDL	Length	L_3	54.3
	Width	W	5.1
	Height	H_2	1
Distance	Adjacent TSV	D_1	12.3
	Signal RDL to GND RDL	D_3	8
	Type 1 hairpin unit to Type 2	S_1	2.5
	Type 2 hairpin unit to Type 1	S_2	3.6

Table II. Comparison with different THz filters

Filters	Type	CF (THz)	BW (THz)	IL (dB)	RL (dB)	Size (mm^2)	Size λ_g^2
[26]	Hairpin	0.12	0.02	6.9	10	0.3×0.05	0.41×0.069
[27]	SIW	0.16	0.02	1.5	10	0.9×0.325	2.25×0.81
[28]	SIW	0.14	0.023	2.4	11	1.8×0.79	2.90×1.27
[29]	SIW	0.331	0.051	1.5	15	0.68×0.21	2.59×0.80
Model 1	Hairpin	0.405	0.1	2.0	12.4	0.284×0.0325	1.29×0.148
Model 2		0.3915	0.077	2.0	13.4	0.284×0.0325	1.29×0.148
Model 3		0.3955	0.063	2.0	14	0.284×0.0325	1.29×0.148

4. Conclusion

In this paper, based on TSV technology, a hairpin bandpass filter is first proposed for 6G mobile communications. The novel structure enhances the coupling effect and improves the returns the return loss characteristic in the hairpin bandpass filter.

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