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MICROWAVE AND OPTICAL TECHNOLOGY LETTERS provides quick publication (three- to six-month turnaround) of the most recent findings and achievements in high frequency technology, from RF to optical spectrum. The journal publishes original short papers and letters on theoretical, applied, and system results in the following areas:

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MICROWAVE AND OPTICAL TECHNOLOGY LETTERS



VOLUME 63 / NUMBER 3

MARCH 2021

RESEARCH ARTICLES

A highly independent and controllable dual-band bandpass filter based on source-load coupling with stub-block isolation structure 729

Yus Rama Denny and Teguh Firmansyah

A 35-GHz high image rejection resistive mixer using a tunable resonator and a narrowband bandpass filter 736

Jihoon Kim

A compact LTCC semi-lumped highpass filter with vialess structure 742

Kewei Qian and Miao Tian

A 30-GHz low-power CMOS LNA for 5G communication systems 746

Jiye Liu, Liang Wu, Zhangming Zhu, and Shubin Liu

Determination of unique and stable complex permittivity of granular materials from transmission and reflection measurements 753

Chuang Yang

Experimentally investigating the degradations of the GaN PA indexes under different temperature conditions 758

Shaohua Zhou

Compact wideband microstrip-slotline bandpass filter with sharp selectivity and suppressed spurious harmonic 764

Yongqiang Chai, Chonghu Cheng, Yanfeng Shi, Chanchan Qin, and Shengbo Hu

A 3-D artificial anisotropy one-step leapfrog weakly conditionally stable finite-difference time-domain algorithm with improved accuracy 770

Pingjuan Zhang

3-D printed waveguide attenuators operating at ka-band (26.5-40 GHz) 775

Yi Wang, Cheng Guo, Xiaobang Shang, and Wen Wu

Tone injection-based cancellation technique for nonlinear distortion reduction of modulated signals in BAW resonators 781

Marta González-Rodríguez, Carlos Collado, José M. González-Arbesú, Jordi Mateu, Gabriel Montoro, and Pere Lluís Gilabert

Selectivity-enhancement technique for parallel-coupled SIR based dual-band bandpass filter 787

Daotong Li, Ju-An Wang, Ying Liu, Zhen Chen, and Lisheng Yang

Directional passive intermodulation effect by distributed nonlinearities in two-port network 793

Xiong Chen, Ling Wang, and Ming Yu

Design of wide stopband lowpass filter using transformed radial stub based on substrate integrated suspended line technology 798

Huan Zhang, Kaixue Ma, Haipeng Fu, and Ningning Yan

3D printed coaxial microwave resonator sensor for dielectric measurements of liquid 805

Ali Musa Mohammed, Yi Wang, and Michael J. Lancaster

Novel dielectric waveguide filter using isosceles right-angled triangular resonators 811

Zhengwei Huang, Yong Cheng, and Yuanjian Liu

A graphene-metamaterial hybrid structure for the design of reconfigurable low pass terahertz filters 817

Wei Xu, Tao Lv, Haiyang Guo, Jiayi Yang, Yaqi Bi, Qian Zhang, Di Feng, Tao Deng, and Xiuhua Li

- Design of tunable power detector towards 5G applications** 823
Issa Alaji, Walid Aouimeur, Haitham Ghanem, Etienne Okada, Sylvie Lépilliet, Daniel Gloria, Guillaume Ducournau, and Christophe Gaquière
- Design of high-efficiency continuous resistive-reactive class-J power amplifier** 829
Guohua Liu, Zhong Zhao, Zhiqun Cheng, and Sudong Li
- A novel two-dimensional crest factor reduction method based on concurrent output capacity of power amplifiers** 835
Ke Tang, Hang Huang, Cuiping Yu, Yongle Wu, Qiuyan Jin, Jinchun Gao, and Yuanan Liu
- SPICE modeling for RF kink effect in body contacted PD-SOI nMOSFETs** 840
Kiahn Lee and Seonghearn Lee
- Investigation and design of enhanced decoupled UWB MIMO antenna for wearable applications** 845
Amit Baran Dey, Soumya Sundar Pattanayak, Debasis Mitra, and Wasim Arif
- A CPW-fed compact square slot antenna with wideband circularly polarized for C-band application** 862
Nader Felegari, Sajad Zafari, Narges Malekpour, and Hamid Reza Hassani
- High gain compact ultra-wideband “antenna-frequency selective surface” and its performance evaluation in proximity of soil surface** 869
Surajit Kundu
- Pattern and polarization reconfigurable circularly polarized antenna based on two pairs of planar complementary dipoles** 876
Yang-Dong Yan, Yong-Chang Jiao, and Chi Zhang
- A 16-element array fed with a switchable power divider** 883
Tsair-Rong Chen, Ting-Yan Liu, Hao-Yuan Cheng, and Jeen-Sheen Row
- Frequency agile multiple-input-multiple-output antenna design for 5G dynamic spectrum sharing in cognitive radio networks** 889
Rifaqat Hussain, Muhammad U. Khan, Naveed Iqbal, Eqab AlMajali, Saqer S. Alja'afreh, Umar Johar, Atif Shamim, and Mohammad S. Sharawi
- A compact flexible fractal ultra-wideband antenna with band notch characteristic** 895
Qiang Zou and Shiyu Jiang
- A high-gain cavity-backed slot antenna using a perfect magnetic conductor ground plane and multilayered superstrates** 902
Majid Kialashaki, Ali Khaleghi, and Mahboubeh Taraji
- In-silico and in-vitro testing of an implantable superstrate loaded biocompatible antenna for MICS band applications** 910
Gurprince Singh and Jaswinder Kaur
- A low-profile wideband planar phased array of cavity-backed slot microstrip elements for two-dimensional beam scanning applications** 917
Ya-Bing Yang, Fu-Shun Zhang, Jiao-Cheng Zhao, Yuan Liao, and Ning Li
- Design, fabrication, and performance analysis of corporate feed filtenna array using complementary split ring resonators** 924
Sathish Munirathinam and Gunasekaran Natarajan
- A single-layer filtering patch antenna array with simple differential feeding network** 937
Na Nie and Zhi-Hong Tu
- A novel planar wide-angle scanning phased array under operation of TM_{10} and TM_{20} modes** 944
Lian-Xu Guan, You-Feng Cheng, Ju Feng, and Cheng Liao
- Low radar cross-section, broadband circularly polarized antenna using quaternary artificial magnetic conductor** 952
Meng Guo, Wei Wang, Jing Wang, and Linshu Gong
- Extremely low-profile wideband array antenna using TCDA with polarization convertor** 959
Seongjung Kim and Sangwook Nam
- A wideband low-profile antenna using hybrid metasurface structure** 965
Dongxu Chen, Wan Chen Yang, Quan Xue, and Wenquan Che
- Optimizing the efficiency of gallium nitride-based light-emitting diodes from contact area of current spreading to electrode** 970
Adam Shaari, Faris Azim Ahmad Fajri, Ahmad Fakhurrrazi Ahmad Noorden, Muhammad Zamzuri Abdul Kadir, and Suzairi Daud
- Magnetic field detection using fiber bundle and magnetic fluid as sensors** 975
Samian, Andi H. Zaidan, Akbar S. Arifianto, Pujiyanto, and Ahmad Taufiq

- Dual parameter in-line fiber Mach-Zehnder interferometer based on few-mode fiber** 980
Jin Wang, Bo Liu, Yongfeng Wu, Yaya Mao, Lilong Zhao, Tingting Sun, Tong Nan, and Yang Han
- Experimental studies on the effects of fog and haze on free-space optical link at 405 nm** 987
Sree Madhuri Aovuthu, Govardhani Immadi, and Venkata Narayana Madhavareddy
- Comparison between GaN and InN quantum-dot semiconductor optical amplifiers** 993
Ali Gehad Al-Shatravi, Muaffak Abdullah, and Amin Habbeb Al-Khursan



MARCH 2021

[Previous Issue](#) | [Next Issue](#)

[GO TO SECTION](#)

[Export Citation\(s\)](#)

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Pages: 725-728 | First Published: 03 February 2021

[First Page](#) | [PDF](#) | [Request permissions](#)

RESEARCH ARTICLES

[A highly independent and controllable dual-band bandpass filter based on source-load coupling with stub-block isolation structure](#)

Yus Rama Denny, Teguh Firmansyah

Pages: 729-735 | First Published: 22 October 2020

[Abstract](#) | [Full text](#) | [PDF](#) | [References](#) | [Request permissions](#)

[A 35-GHz high image rejection resistive mixer using a tunable resonator and a narrowband bandpass filter](#)

Jihoon Kim

Pages: 736-741 | First Published: 19 September 2020

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RESEARCH ARTICLE

A highly independent and controllable dual-band bandpass filter based on source-load coupling with stub-block isolation structure

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Abstract

The main problem of dual-band bandpass filter (BPF) structures is to control each passband performance individually, separately, and independently. This Letter is proposed a dual-band BPF based on a source-load coupling structure with stub-block isolation to overcome the problem. The lower band resonator structure is placed on the top side, while the upper band resonator is placed at the bottom side, with the source-load (SL) coupling structure in the middle. An additional stub-block isolation structure is added to the center of the SL coupling structure. As a result, we have successfully designed an independent dual-band bandpass filter with highly controllable working frequency/frequency center (f_c), bandwidth (BW), reflection coefficient (S_{11}), and isolation (ISO) between the passbands. The proposed dual-band BPF was fabricated on an RT/Duroid 5880 substrate. Furthermore, this dual-band BPF achieved an insertion loss/fractional bandwidth of 0.48 dB/7.71% and 0.35 dB/12.37% at 1.82 and 2.58 GHz, respectively. The

good agreement between the simulated and measured results validates the proposed method.

KEYWORDS

controllable dual-band BPF, source-load coupling, stub-block isolation

1 | INTRODUCTION

A highly flexible RF device must be supported by a high-performance bandpass filter (BPF) that can be controlled. This requirement has motivated many researchers to produce BPFs with controllable performance.¹ Several methods have been proposed to control the frequency passband, such as the stepped impedance ring resonator (SIRR) with shorted stubs,² defected and irregular stepped-impedance resonators (DI-SIRs),³ multilayer resonator,⁴ loop resonator,⁵ cross resonator,⁶ substrate-integrated waveguide (SIW) cavities,⁷ and half-mode substrate integrated waveguide (HMSIW).⁸ Furthermore, to increase the isolation, some researchers have proposed a circular resonator⁹ and a ring resonator. Moreover, a quasi-elliptical waveguide resonator was proposed by Reference 10 to control the frequency and bandwidth. However, none of the proposed methods has a controllable performance frequency, bandwidth, reflection coefficient, and isolation simultaneously.

In this Letter, a dual-band BPF based on a source-load coupling structure is proposed, as shown in Figure 1A. It is clearly distinct from the microstrip structure used in References 1-11. The topology of the coupling structure is given in Figure 1B. Furthermore, M_{MN} denotes the coupling matrix values between two resonators for ($M = S, I, 2, L$ and $N = S, I, 2, L$), can be derived as follows:

$$M_{MN} = \begin{pmatrix} 0 & 0.307 & 0 & -0.389 & 0 & 1.000 \\ 0.307 & 0.819 & 0.080 & 0 & 0 & 0 \\ 0 & 0.080 & -0.579 & 0 & 0 & 0.008 \\ -0.389 & 0 & 0 & -25.95 & -66.122 & 0 \\ 0 & 0 & 0 & -66.122 & -169.205 & -0.116 \\ 1.000 & 0 & 0.008 & 0 & -0.116 & 0 \end{pmatrix}$$

The coefficients of the coupling matrix are taken from the optimization process. By using this structure, the frequency, bandwidth, reflection coefficient, and isolation in each passband can be adjusted individually with

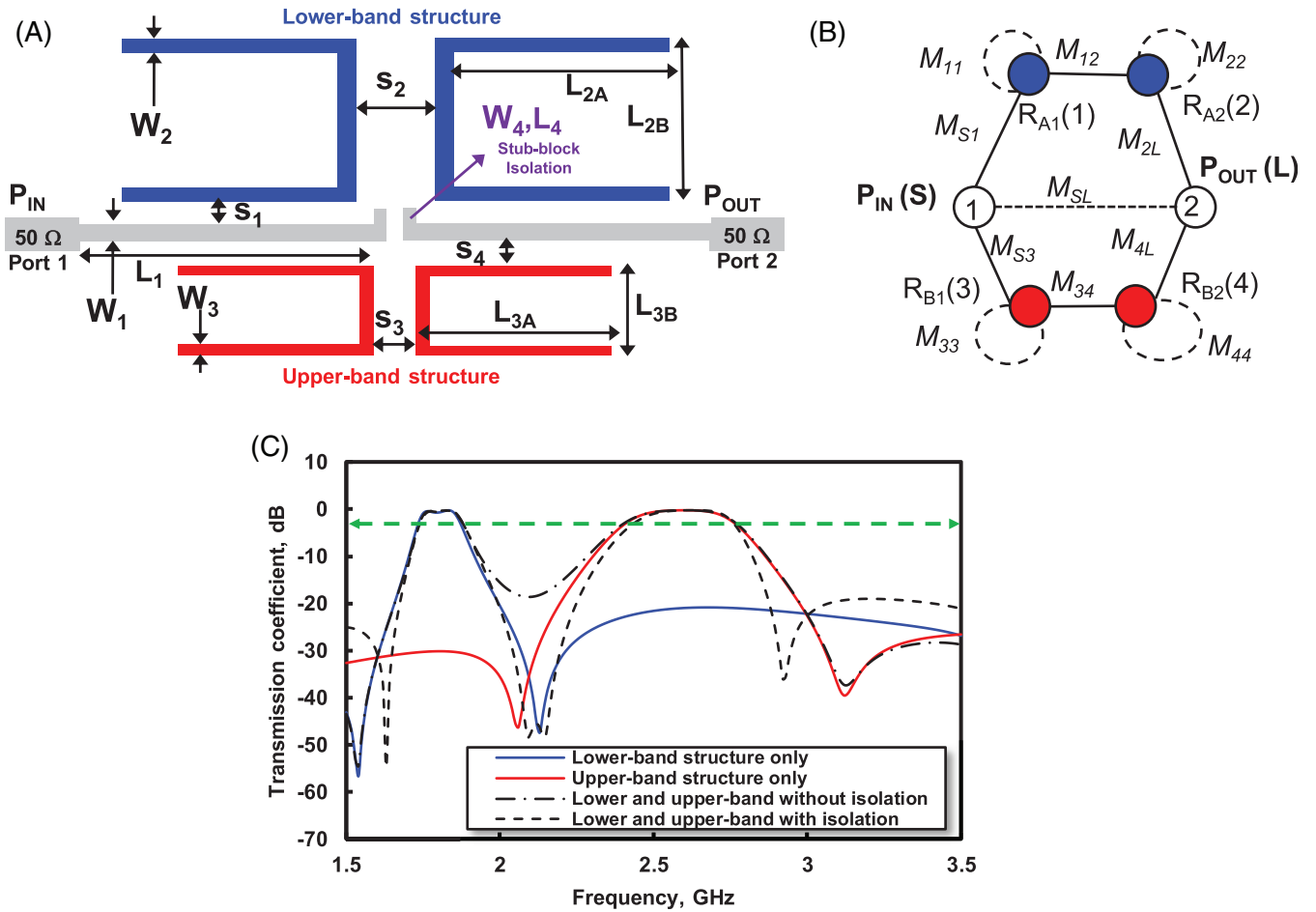


FIGURE 1 A, proposed dualband BPF with a source-load coupling structure and stub-block isolation; B, topology of the coupling structure; and C, the dualband BPF response strategy [Color figure can be viewed at wileyonlinelibrary.com]

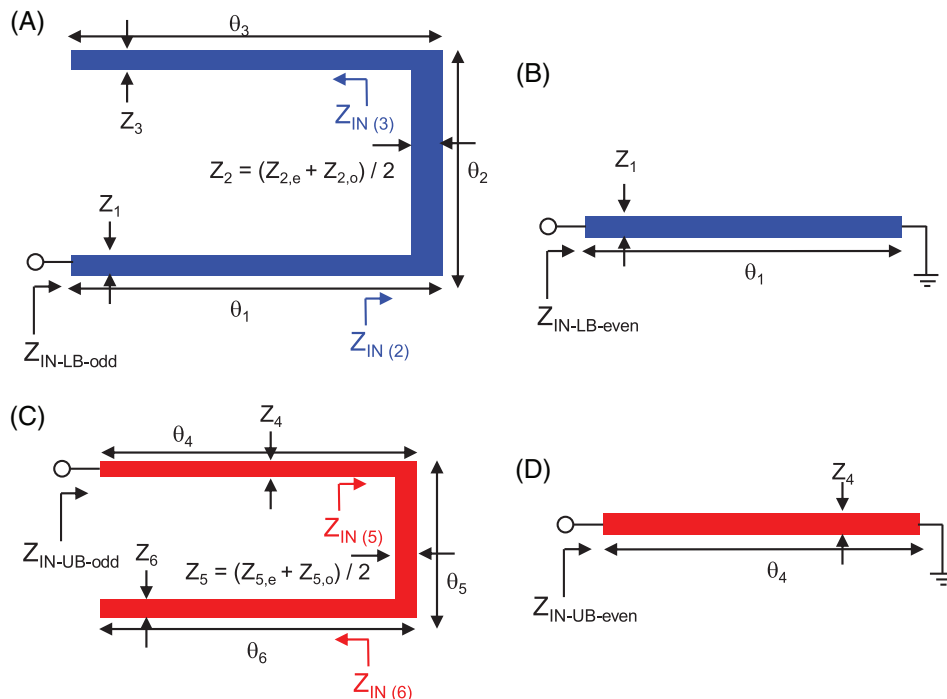


FIGURE 2 A, Odd-mode structure lower band; B, even-mode structure lower band; C, Odd-mode structure upper band; and D, even-mode structure upper band [Color figure can be viewed at wileyonlinelibrary.com]

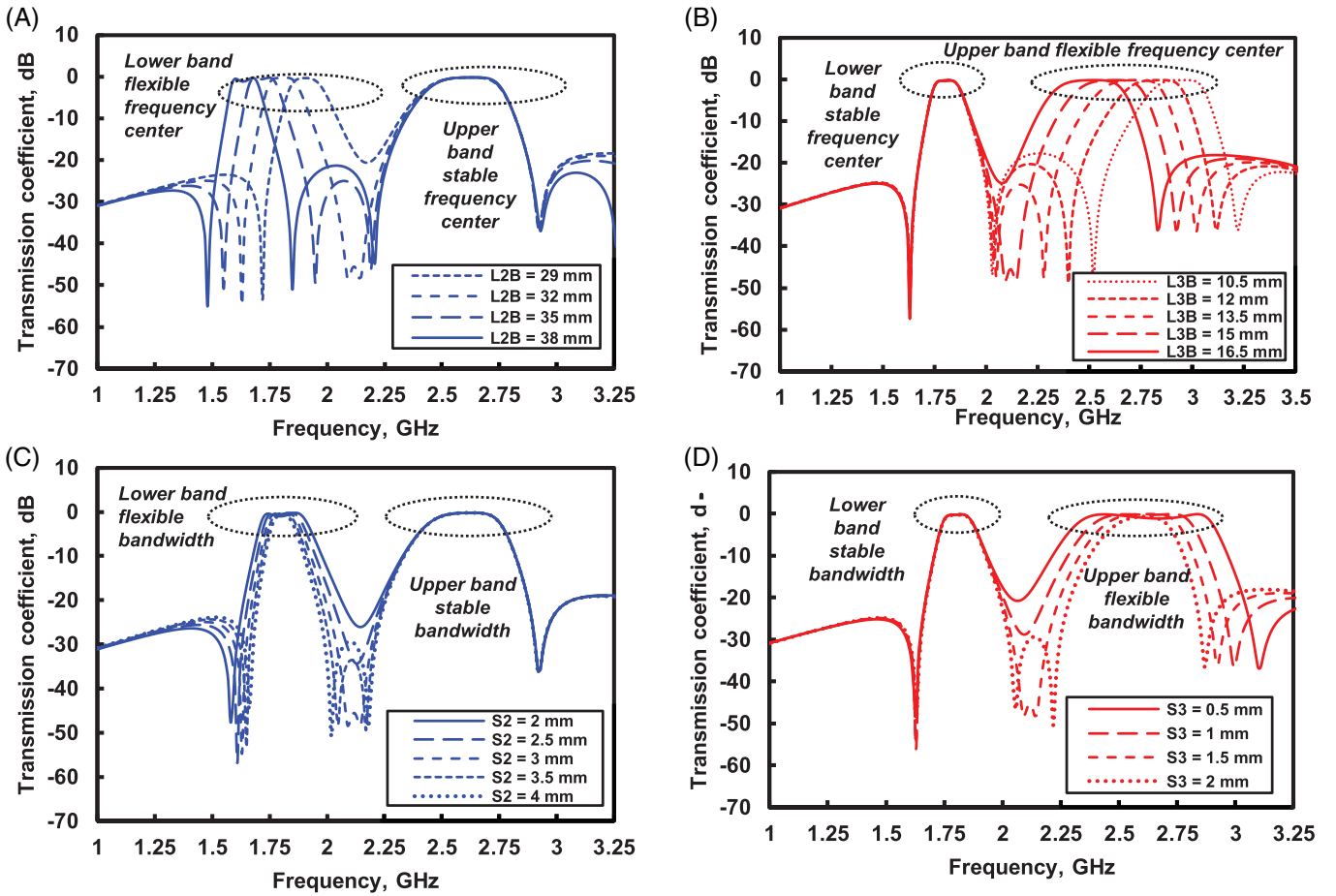


FIGURE 3 A, Band pass frequency of the lower band for various lengths L_{2B} ; B, band pass frequency of the upper band for various lengths L_{3B} ; C, bandwidth characteristics of the lower band for various gaps S_2 ; and D, bandwidth characteristics of the upper band for various gaps S_3 [Color figure can be viewed at wileyonlinelibrary.com]

convenience and robustness. The proposed method is validated by the good agreement between the simulated and measured results.

2 | DUAL-BAND BPF BASED ON SOURCE-LOAD COUPLING WITH STUB-BLOCK ISOLATION

The proposed dual-band BPF is constructed by using four important segments, that is, a source-load coupling structure, a lower band resonator, an upper band resonator, and an additional isolation structure. The source-load (P_{IN} and P_{OUT}) coupling structure is positioned in the middle, where (W_1, L_1) represent the width and length, respectively. Furthermore, the lower band resonators are placed at the top, constructed by a coupled-resonator (R_{A1} and R_{A2}) with the back-to-back position, where (W_2, L_{2A}, L_{2B}) represent the widths and lengths of the lower band resonator. Moreover, the upper band resonators are arranged at the bottom. They are composed of a coupled-resonator (R_{B1} and R_{B2}) with a back-to-back position, where (W_3, L_{3A}, L_{3B}) represent the widths and lengths of the upper band resonator. The additional isolation is added at the center, with (W_4, L_4)

representing the width and length isolation structures, respectively. Furthermore, (S_1, S_2, S_3, S_4) represent the gaps between the source/load and lower band, intercoupled lower band, intercoupled upper band, and source/load and upper band, respectively.

Figure 1C shows the dual-band BPF response. If the lower band or upper band structures are applied separately, the transmission coefficient will respond separately. However, if they are combined, the interference between two passbands will increase. To reduce interference, the isolation structure should be added at the center. Furthermore, the odd-mode structure of lower band, even-mode structure of lower band, odd-mode structure of upper band, and even-mode structure of upper band are shown in Figure 2A-D, respectively. The value input impedance of odd-mode at lower band $Z_{IN-LB-odd}$ can be derived:

$$Z_{IN(3)} = -jZ_3 \cot \theta_3 \quad (1)$$

$$Z_{IN(2)} = Z_2 \frac{Z_{IN(3)} + jZ_2 \tan \theta_2}{Z_2 + jZ_{IN(3)} \tan \theta_2} \quad (2)$$

$$Z_{IN-LB-odd} = Z_1 \frac{Z_{IN(2)} + jZ_1 \tan \theta_1}{Z_1 + jZ_{IN(2)} \tan \theta_1} \quad (3)$$

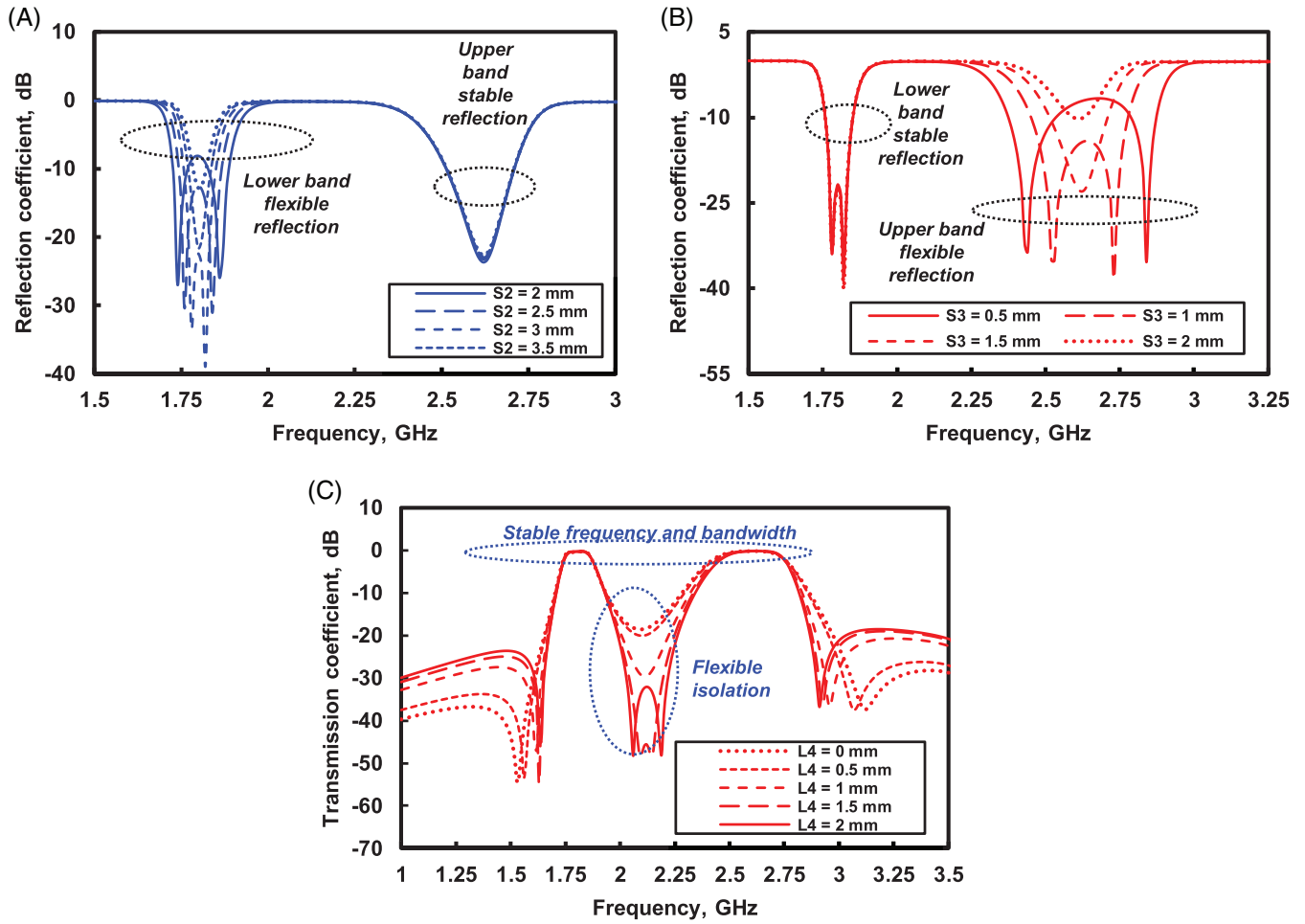


FIGURE 4 A, Reflection coef. Characteristics of the lower band for various gaps S_2 ; B, reflection coef. Characteristics of the upper band for various gaps S_3 ; and C, isolation characteristics for various lengths L_4 [Color figure can be viewed at wileyonlinelibrary.com]

Moreover, Equation (3) can also be expressed as:

$$Z_{IN-LB-even} = jZ_1 \tan \theta_1 \quad (7)$$

$$Z_{IN-LB-odd} =$$

$$Z_1 \frac{Z_2(-jZ_1 \cot \theta_1 + jZ_2 \tan \theta_2) + jZ_3 \tan \theta_3 (Z_2 + Z_1 \cot \theta_1 \tan \theta_2)}{Z_3 Z_2 + Z_3 Z_1 \cot \theta_1 \tan \theta_2 + Z_2 Z_1 \cot \theta_1 \tan \theta_1 - Z_2^2 \tan \theta_2 \tan \theta_3} \quad (4)$$

with

$$Z_2 = \frac{Z_{2,e} + Z_{2,o}}{2} \quad (5)$$

The resonant can be derived from admittance condition $Y_{IN-LB-odd} = 0$ or impedance condition $Z_{IN-LB-odd} = \infty$,¹ or it has a denominator equal with zero.

$$\begin{aligned} & Z_3 \left(\frac{Z_{2,e} + Z_{2,o}}{2} \right) + Z_3 Z_1 \cot \theta_1 \tan \theta_2 \\ & + Z_1 \left(\frac{Z_{2,e} + Z_{2,o}}{2} \right) \cot \theta_1 \tan \theta_1 \\ & - \left(\frac{Z_{2,e} + Z_{2,o}}{2} \right)^2 \tan \theta_2 \tan \theta_3 = 0 \end{aligned} \quad (6)$$

Furthermore, the value input impedance of even-mode at lower band $Z_{IN-LB-even}$ can be derived:

Moreover, the value input impedance of odd-mode at upper band $Z_{IN-UB-odd}$ can be derived:

$$Z_{IN(6)} = -jZ_6 \cot \theta_6 \quad (8)$$

$$Z_{IN(5)} = Z_5 \frac{Z_{IN(6)} + jZ_5 \tan \theta_5}{Z_5 + jZ_{IN(6)} \tan \theta_5} \quad (9)$$

$$Z_{IN-UB-odd} = Z_4 \frac{Z_{IN(5)} + jZ_4 \tan \theta_4}{Z_4 + jZ_{IN(5)} \tan \theta_4} \quad (10)$$

Equation (10) can also be derived as:

$$\begin{aligned} & Z_{IN-UB-odd} = \\ & Z_4 \frac{Z_5(-jZ_4 \cot \theta_4 + jZ_5 \tan \theta_5) + jZ_6 \tan \theta_6 (Z_5 + Z_4 \cot \theta_4 \tan \theta_5)}{Z_6 Z_5 + Z_6 Z_4 \cot \theta_4 \tan \theta_5 + Z_5 Z_4 \cot \theta_4 \tan \theta_4 - Z_5^2 \tan \theta_5 \tan \theta_6} \end{aligned} \quad (11)$$

with

$$Z_5 = \frac{Z_{5,e} + Z_{5,o}}{2} \quad (16)$$

The resonant can be derived from admittance condition $Y_{IN-UB-odd} = 0$ or impedance condition $Z_{IN-UB-odd} = \infty$,¹ or it has a denominator equal with zero.

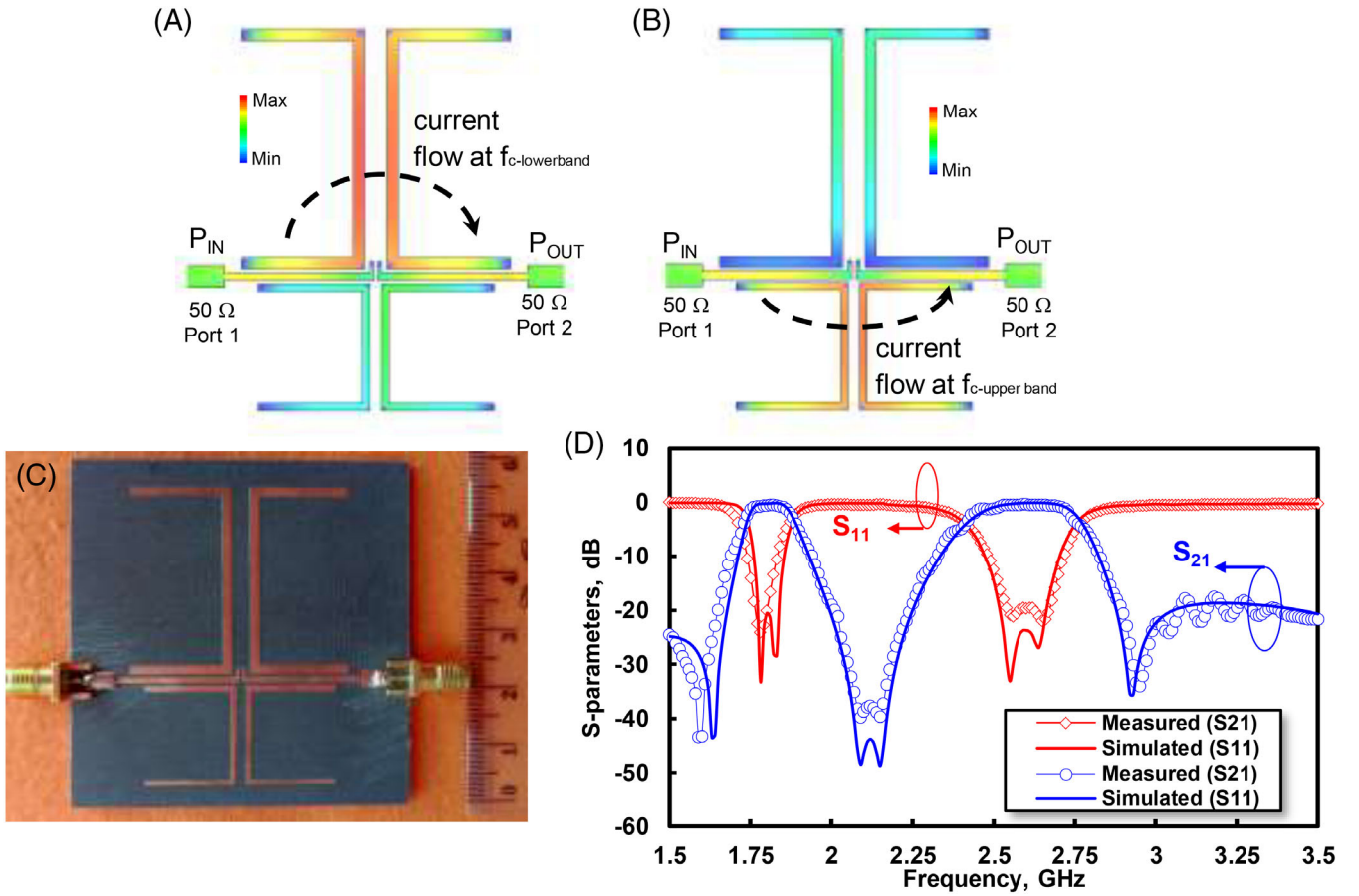


FIGURE 5 Current surface at A, lower band of $f_c = 1.82$ GHz; B, upper band of $f_c = 2.58$ GHz; and C, photograph of the proposed method; and D, comparison of simulated and measured result [Color figure can be viewed at wileyonlinelibrary.com]

$$\begin{aligned}
 & Z_5 \left(\frac{Z_{5,e} + Z_{5,o}}{2} \right) + Z_6 Z_4 \cot \theta_4 \tan \theta_5 \\
 & + Z_4 \left(\frac{Z_{5,e} + Z_{5,o}}{2} \right) \cot \theta_4 \tan \theta_4 \\
 & - \left(\frac{Z_{5,e} + Z_{5,o}}{2} \right)^2 \tan \theta_5 \tan \theta_6 = 0
 \end{aligned} \quad (17)$$

Furthermore, the value input impedance of even-mode at upper band $Z_{IN-UB-even}$ can be derived:

$$Z_{IN-UB-even} = jZ_4 \tan \theta_1 \quad (18)$$

with the impedance (Z_N) and electric length (θ_N).

3 | RESULTS AND DISCUSSION

Figure 3A,B show the relationship between the bandpass frequency/frequency center of the lower band response under various lengths L_{2B} and the bandpass frequency/frequency center of the upper band response under various lengths L_{3B} , respectively. The figures show that by increasing the dimension of L_{2B} , the bandpass frequency of the lower band will gradually shift to a lower frequency, while the upper band will remain stable. Moreover, the bandpass frequency of the

upper band will be shifted by various lengths L_{3B} , while the lower band will remain stable.

Moreover, Figure 3C, D show the relationship the bandwidth characteristics of the lower band for various gaps S_2 , and the bandwidth characteristics of the upper band for various gaps S_3 , respectively. Moreover, the bandwidth of each passband can be controlled individually and separately by varying the gaps S_2 and S_3 . It can be seen that by increasing the gap S_2 , the bandwidth of the lower band will become narrower and can be adjusted separately. Furthermore, by decreasing gap S_3 , the bandwidth of the upper band only will increase.

Figure 4A-C show the reflection coefficient characteristics of the lower band for various gaps S_2 , the reflection coefficient characteristics of the upper band for various gaps S_3 , and the isolation characteristics for various lengths L_4 , respectively. The reflection coefficient value of the lower band can be controlled separately by varying gap S_2 without any impact on the upper band. Moreover, the reflection coefficient value of the upper band can be adjusted individually by varying gap S_3 . Furthermore, the isolation characteristics can be changed by varying the length L_4 without affecting the frequency passband or bandwidth of the lower band and

TABLE 1 Comparison with some previous dualband BPFs

Refs.	Freq (GHz)	Insertion loss (dB)	−3 dB FBW (%)	Independent and controllable			
				Freq	BW	Ref. coef	ISO
2	1.39/1.82	2.48/3.60	9.30/6.60	Yes	–	–	–
3	2.45/5.20	1.30/2.80	6.93/4.03	Yes	–	–	–
5	5.01/8.25	0.81/0.83	6.59/6.10	Yes	–	–	–
6	1.14/2.31	0.22/1.87	94.19/33.52	Yes	–	–	–
7	3.61/6.40	1.30/1.20	8.20/6.70	Yes	–	–	–
9	2.43/3.73	2.50/1.30	4.50/6.10	–	–	–	Yes
10	2.40/5.20	1.40/3.00	9.20/9.50	–	–	–	Yes
11	3.78/4.82	1.38/1.82	11.3/10.7	Yes	–	–	–
12	0.69/2.67	0.70/1.76	23.5/30.0	–	Yes	–	–
13	1.57/2.38	1.21/1.95	9.90/6.50	–	–	–	Yes
14	2.52/3.54	0.62/0.55	5.90/5.10	Yes	–	–	–
15	8.13/11.13	0.88/1.28	3.90/3.60	Yes	–	–	–
16	2.40/3.20	1.47/1.65	15.4/10.9	Yes	Yes	–	–
17	9.42/9.99	2.20/2.30	3.00/3.30	–	Yes	–	–
18	1.59/1.92	1.49/1.44	6.90/9.40	Yes	–	–	–
19	5.50/12.5	0.50/2.91	92.0/17.0	–	Yes	–	–
This study	1.82/2.58	0.48/0.35	7.71/12.37	Yes	Yes	Yes	Yes

Abbreviations: BW, bandwidth; FBW, fractional bandwidth; ISO, isolation.

upper band. Moreover, Figure 5A,B show the current surface at lower-band of $f_c = 1.82$ GHz and upper band of $f_c = 2.58$ GHz, respectively. It can be seen that at the lower band, the surface current flows at upper part of BPF. Meanwhile, the surface current flows at lower part of BPF at the upper band.

The proposed dual-band BPF was fabricated on an RT/Duroid 5880 substrate with a permittivity of 2.2 and a thickness of 1.575 mm. A momentum simulation produced by the Advanced Design System (ADS) was used to optimize the structure. Furthermore, the R&S ZVA67 VNA was used to measure the BPF performance. The dimensions were as follows (all in millimeters): $W_1 = 1.0$, $W_2 = 1.5$, $W_3 = 1.0$, $W_4 = 0.5$, $L_1 = 10$, $L_{2A} = 15$, $L_{2B} = 32$, $L_{3A} = 15$, $L_{3B} = 15$, $S_1 = 0.5$, $S_2 = 3.0$, $S_2 = 1.5$, and $S_4 = 0.5$. The dual-band BPF insertion loss/fractional bandwidth was 0.48 dB/7.71% and 0.35 dB/12.37% at 1.82 and 2.58 GHz, respectively. Figure 5C,D show photographs of the fabricated dual-band BPF and comparisons of the simulated and measured results, respectively. Moreover, Table 1 shows comparison with some previous dual-band BPFs such as References 11–19.

The proposed method is validated by the good agreement between the simulated and measured results. Furthermore, Table 1 gives the performance comparison of the dual-band BPF with some previous works, from which it can be deduced that the proposed BPF structure can enable adjustment of the frequency, bandwidth, reflection coefficient, and

isolation of each passband individually with convenience and robustness.

4 | CONCLUSIONS

We have successfully designed an independent dual-band bandpass filter with a highly controllable working frequency/frequency center, bandwidth, reflection coefficient, and isolation between the passbands. This performance can be obtained by applying the source-load coupling with a stub-block isolation structure. The proposed dual-band BPF was fabricated on an RT/Duroid 5880 substrate. Furthermore, this dual-band BPF achieved an insertion loss/fractional bandwidth of 0.48 dB/7.71% and 0.35 dB/12.37% at 1.82 and 2.58 GHz, respectively. The good agreement between the simulated and measured results validates the proposed method.

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