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Design of Dual-Band Bandpass Filters for Cognitive Radio Application of TVWS Band

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Abstract

This paper presents a novel design for dual-band bandpass filters. The proposed filters are applicable to the carrier aggregation of the TV white space (TVWS) band and long-term evolution (LTE) band for cognitive radio applications. The lower passband is the TVWS band (470–698 MHz) whose fractional bandwidth is 40 %, while the higher passband is the LTE band (824–894 MHz) with 8 % fractional bandwidth. Since the two passbands are located very close to each other, a transmission zero is inserted to enhance the rejection level between the two passbands. The TVWS band filter is designed using magnetic coupling to obtain a wide bandwidth, and the LTE band filter is designed using dielectric resonators to achieve good insertion loss characteristics. In addition, in the proposed design, a transmission zero is placed with cross-coupling. The proposed dual-band bandpass filter is designed as a two-port filter (one input/one output) as well as a three-port filter (one common input/two outputs). The measured performances show good agreement with the simulated performances.

Key Words: Cognitive Radio, Cross Coupling, Dual-Band BPF, TV White Space.

I. INTRODUCTION

Wireless communication systems require larger frequency bandwidth because multimedia transmissions have become commonplace. Through frequency aggregation, wider bandwidth can be accommodated; thus, high-speed data can be transmitted via the combined wider bandwidth. Recently, for spectrum sharing, the TV white space (TVWS) band has been open for wireless communication applications. Therefore, this band must be aggregated with a conventional mobile frequency band. Such mobile communication systems require bandpass filters that cover more than two frequency bands in order to aggregate two separate frequency bands. These multiband bandpass filters have been studied by many researchers [1–5]. Most design methods focus on two or more narrow communication bands; however, in this new design, a TVWS band with a large bandwidth is combined with conventional narrow communication bands. In this paper, a design method for a dual bandpass filter (BPF), in which the two passbands include a wide TVWS band and a narrow long-term evolution (LTE) band, is proposed. To acquire sufficient coupling for the wide bandwidths, the method proposed in [6] is used. The proposed filter has two bands whose lower passband covers 470–698 MHz bandwidth, while the higher passband occupies 824–894 MHz.

II. DESIGN PROCEDURES

A dual-band BPF is designed based on the procedures for standard Chebyshev BPFs [7]. The filter consists of two

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BPFs at the center frequencies of 584 MHz and 859 MHz, respectively. The two BPFs are designed, and then two filters are combined. The conventional BPF design for the TVWS band is shown in Fig. 1, where air coils (0806SQ; Coilcraft Inc., Cary, IL, USA) are used to reduce the insertion loss. Since the two passbands are located very close to each other, in order to obtain sufficient isolation between the two passbands, transmission zeros are introduced in the stopband. In the proposed design, cross couplings are included as shown in Fig. 2(a) [8, 9]. The influence of the cross-coupling capacitor is shown in Fig. 2(b). The larger the coupling capacitances, the nearer they become to the passband, as shown in Fig. 2(b). Too large cross-coupling can cause deterioration of passband characteristics.

The designed BPF for the TVWS band is shown in Fig. 3. The frequency responses of the designed BPF together with

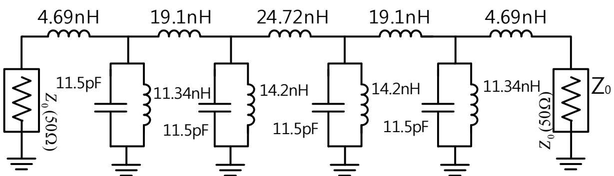


Fig. 1. Conventional bandpass filter configuration for the TV white space (TVWS) band.

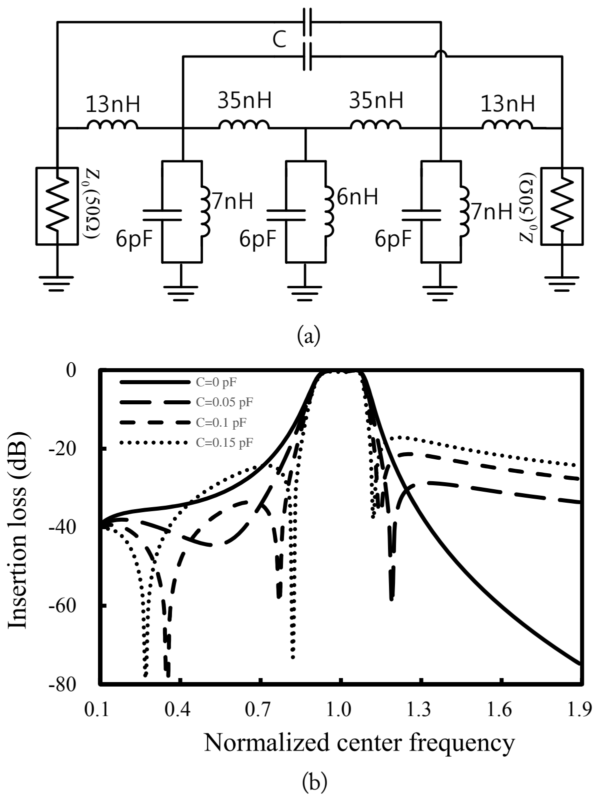


Fig. 2. Bandpass filter with cross couplings between nonadjacent resonators: (a) designed circuit and (b) simulated results.

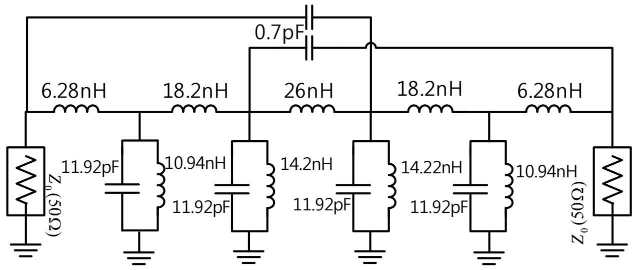


Fig. 3. Designed bandpass filter for the TV white space (TVWS) band with cross couplings.

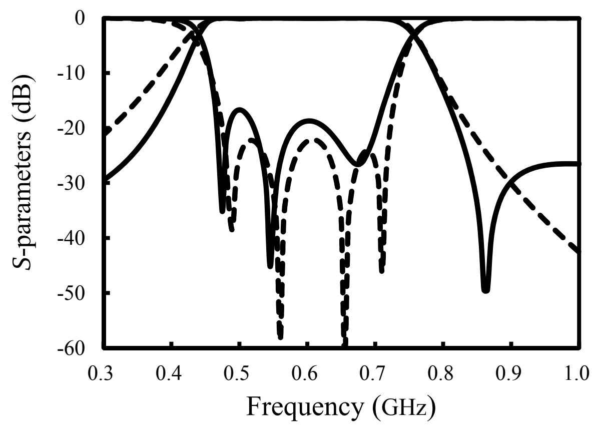


Fig. 4. Frequency responses of two bandpass filters for the TV white space (TVWS) band (solid=with cross couplings, dotted=without cross couplings).

the conventional BPF (Fig. 1) [10] are compared in Fig. 4, where the isolation by transmission zeros is pronounced. In a similar manner, the BPF for the LTE band is designed. In this band, the bandwidth is narrow, and dielectric resonators (DRs) are used to reduce the insertion loss. The conventional three-pole BPF is shown in Fig. 5(a), where resonators made of lumped elements are replaced with DRs [11, 12].

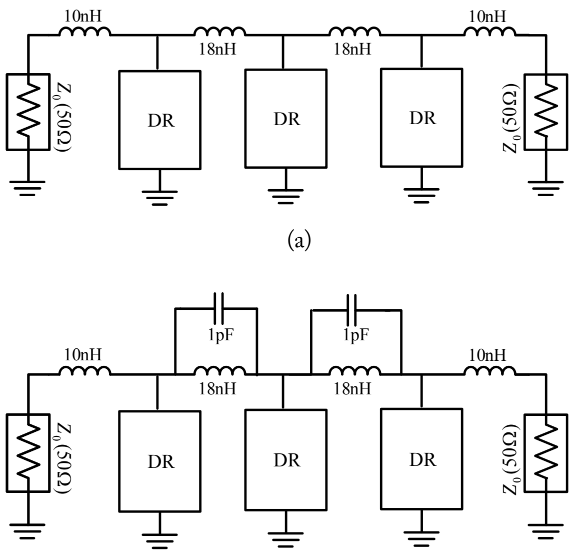
To increase the isolation characteristics, transmission zeros are also introduced in this design as shown in a modified circuit in Fig. 5(b). As the passband is narrow, the series coupling inductors are replaced with parallel LC resonant circuits; the transmission zeros are located at the stopband between the two passbands. A comparison of the simulated performances is shown in Fig. 6, where the solid line represents the responses with transmission zeros.

Next, the two designs are combined in two ways. The resulting filter network has a common input port and a common output port, as shown in Fig. 7, while in the other design a common input port together with two output ports, the TVWS band output and the LTE band output, are separated as a diplexer (Fig. 8).

Figs. 7 and 8 show two different types of filter networks. Since the two designed BPFs have very good isolation characteristics, optimization using ADS software was performed without much difficulty combining the two filters. The element values of the two networks are presented in Tables 1 and 2.

III. MEASURED RESULTS

The proposed dual-band BPF was fabricated on a 0.8-mm-thick FR-4 (relative dielectric constant of 4) substrate. Fig. 9 shows the simulated and measured S-parameters of the two-port design. The insertion loss (S_{21}) of the TVWS and LTE bands was measured as 1.9 dB and 2.1 dB, respectively. The return loss characteristics (S_{11}) were measured at lower than –10 dB within both passbands. The isolation levels between two bands were obtained below –30 dB. Fig. 10 shows the S-parameter of the three-port design. The insertion loss was measured at less than 1.3 dB within both passbands, and the return loss was lower than –10 dB together with about 30 dB of isolation characteristics. Table 3 summarizes the measured return loss, insertion loss, and



(b)

Fig. 5. Designed LTE-band bandpass filter: (a) conventional circuit and (b) circuit with transmission zeros.

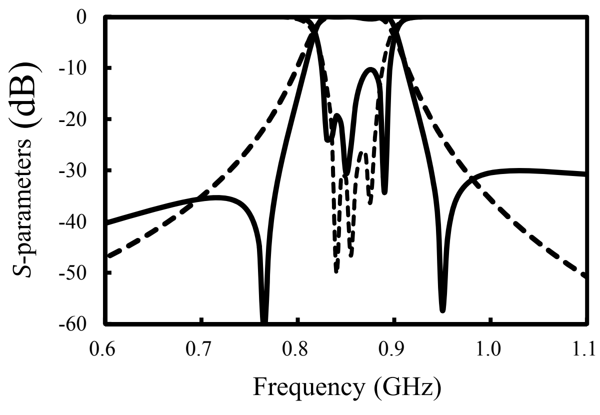


Fig. 6. Simulated frequency performances of Fig. 5(a) and (b).

Table 1. Parameter for two-port dual-band bandpass filter

L_1	L_2	L_3	L_4	L_5	L_{p1}	L_{p2}	Cp_1
14	27	30	12	23	16	13	8
Cp_2	Cc_1	Cc_2	DR	ε_r	D_i	D_o	L
8	0.5	1	DR	38.5	2	6	14.5

Unit: Ln (nH), Cn (pF), Di, Do, L (mm)

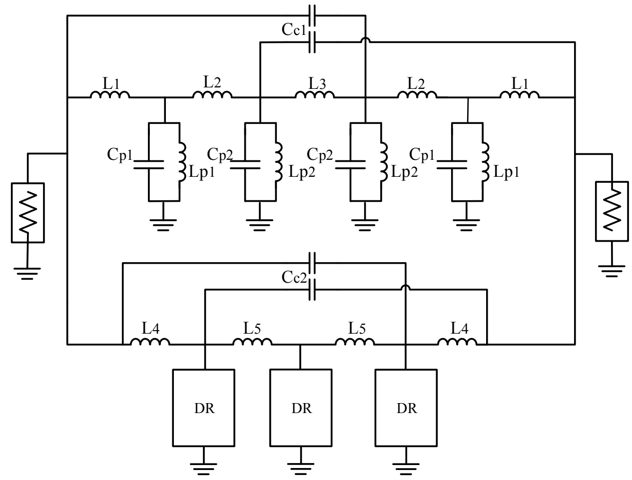


Fig. 7. Designed dual-band bandpass filter (two ports).

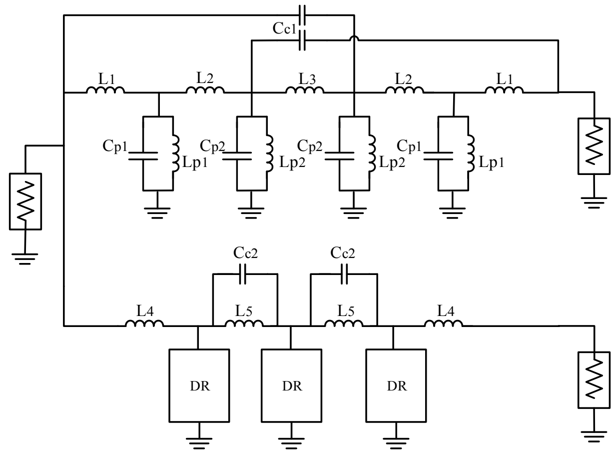


Fig. 8. Designed dual-band bandpass filter with a common input port and two output ports (three ports).

Table 2. Parameter for three-port dual-band bandpass filter

L_1	L_2	L_3	L_4	L_5	L_{p1}	L_{p2}	C_{p1}
13	21	29	10	18	19	13	8
C_{p2}	C_{c1}	C_{c2}	DR	ε_r	D_i	D_o	L
8	0.5	1	DR	38.5	2	6	14.5

Unit: Ln (nH), Cn (pF), Di, Do, L (mm)

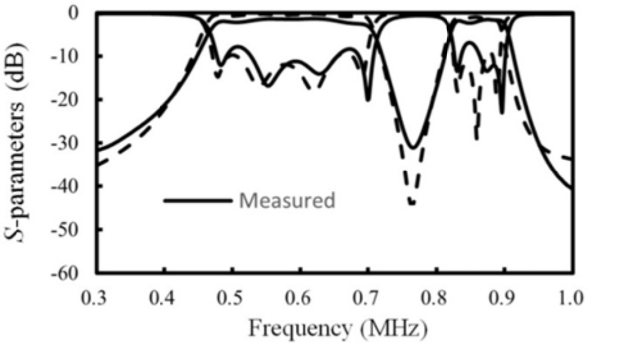


Fig. 9. Simulated and measured *S*-parameters of proposed two-port dual-band bandpass filter.

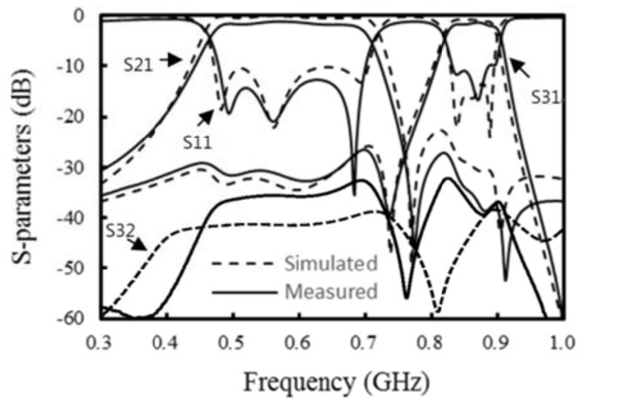


Fig. 10. Simulated and measured *S*-parameters of proposed three-port bandpass filter.

Table 3. Performance summaries of the dual-band bandpass filter

Filter design	Freq.	Return loss	Insertion loss	Isolation
2-port	TVWS	−11	1.9	−31
	LTE	−9	2.1	
3-port	TVWS	−15	1.3	−29
	LTE	−10	1.2	

YVWS= TV white space, LTE= long-term evolution.

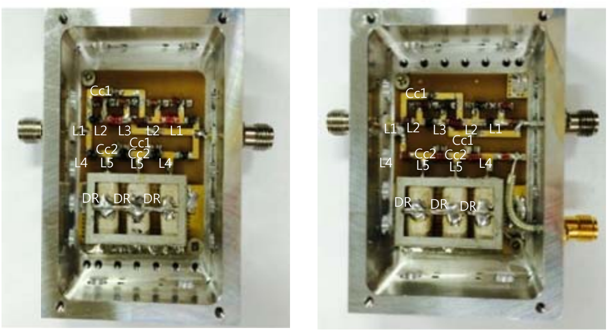


Fig. 11. Photograph of the proposed designs: (a) two-port (3.1 cm × 4.2 cm) and (b) three-port (diplexer; 3.1 cm × 4.2 cm).

isolation characteristics. In Fig. 11, photographs of the proposed dual-band BPF and the diplexer are presented.

IV. CONCLUSIONS

In this paper, a dual-band BPF that can cover the whole TVWS band as well as the LTE band 5, is proposed. To isolate the two closely located bands, a transmission zero is inserted using a cross-coupling scheme as well as a modified inverter scheme. The proposed dual-band filter has 40% and 8% fractional bandwidth for each bandwidth, which is unusual in a dual-band filter design. Therefore, the proposed dual-band BPF can be applied to cognitive radio applications in the TVWS band.

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