Tri-notched Ultra-wideband Bandpass Filter Design Using FMMR, CSRR, DGS and inter-digital couples

Ji-Chyun Liu[a], Jing-Chung Xu[a], Meng-Xi Wu[a], Ching-Ping Kuei[b]
[a]*Dept. of Electrical Eng., Chien Hsin University of Science & Technoloy*
[b]*Dept. of Electronics Eng., Chien Hsin University of Science & Technoloy*
229, Chien-Hsin Rd.,Jung-Li,Taiwan,R.O.C
jichyun@uch.edu.tw

Abstract **—A folded multiple-mode resonator (FMMR) with complementary split ring resonator (CSRR), defected ground structures (DGS) and inter-digital couple is introduced for ultra-wideband bandpass filter design in this paper. The wider bandwidth (3.1 to 9.8 GHz) with FBW = 126 %, lower insertion loss (0.26 dB), and higher rejection level (-44 dB) of UWB band at central frequency f_0 = 5.6 GHz are presented. By using the CSRR and inter-digital couple, three notch responses can exist in the UWB passband for blocking the interference signals. Adjusting the size factor of CSRR and inter-digital couple, the wide tuning ranges of notch frequencies included the desired frequencies of 5.18/6.10/8.08 GHz are achieved. The wide tuning ranges of two notch frequencies cover from 5.0 GHz to 8.4 GHz. It is a simple way to control the notch response.**

I. INTRODUCTION

The increasing demand for short-range and high-speed wireless communications has required a wideband (3.1-10.6 GHz) bandpass filter (BPF) to support ultra-wideband (UWB) operations [1]. Various UWB BPFs with the multiple mode resonators (MMR) have been developed. In recent, the compact wide-band BPF using FMMR and the C-shaped slot has been introduced [2]. The resonators fold two wings of the conventional single SIR for compact size and wide bandwidth. Since the structure and design method of the FMMR is very simple and comprehensive. The compact wideband microstrip filter with two close-to-band transmission zeros has been presented. It is an interested research topic to design a UWB filter with the FMMR.

The allocated spectrum for the wireless local-area network (WLAN) 2.4GHz (2.4–2.484 GHz) and 5.2/5.8 GHz (5.15–5.35 GHz/5.725–5.825 GHz) bands are applied in wireless systems recently. Since the operating bands of 5.2/5.8 GHz to block WLAN signals that may interfere with the UWB systems, a desirable notch response in this 5.2/5.8 GHz band will be necessary for a practical UWB BPF. Various multi band-notched UWB BPFs with the multiple mode resonators (MMR) have been developed [3-10].

For dual-notched bands, a novel asymmetric coupling trip was presented, and two notched bands centered at 4.3 and 8 GHz have -10dB rejection fractional bandwidths of about 4.2% and 3.8% [3]. Based on a simplified composite right/left-handed (SCRLH) resonator, dual notched bands at 5.85 (3 dB bandwidths are 7.9%) and 8.05 GHz (3 dB bandwidths are 6.4% and the attenuation was more than 15 dB [4]. By CPW detached-mode resonator (DMR) and broadside-coupled microstrip/CPW transition, first-notched band was at 5.23 GHz with 21.9 dB insertion loss and -10dB notched FBW of 1.91%, and second-notched band was located at 5.81 GHz with a rejection level of 23.97 dB and a -10dB bandwidth of 2.07% [5]. Using HPF and realizing defected stepped impedance resonator, dual-notched bands at 5.75 and 8.05 GHz was presented [6].

For tri-notched bands, a nonuniform periodical slotted ground structure was used [7]. The first notch band is presented at 5.4 GHz with a rejection level of 23.99 dB and a 10-dB FBW of 1.11%. The second notch band is located at 5.98 GHz with a rejection level of 23.97 dB and a 10-dB FBW of 1.34%. The third notch band is obtained at 6.76 GHz with a rejection level of 32.78 dB and a 10-dB FBW of 2.95% [7]. Using triple-mode stepped impedance resonator, the notched bands have high selectivity (3 dB FBW are 3.6%, 3.6% and 4.1%, respectively) and the attenuation is more than 12 dB at the center frequencies of 5.2, 5.85 and 8.0 GHz [8]. Based on stub loaded resonator, the notched bands have high selectivity, the center frequencies at 3.6, 5.9 and 8.0 GHz and 3 dB FWB are 2.9, 3.7, and 2.3 % respectively, and the attenuation is more than 10 dB at the centre frequencies [9]. Based on parallel integration of gap-coupled microstrip resonators (GCMR) and two tri-section stepped-impedance resonators (TSSIR) to generate multiple notches [10], the first notch band is presented at 5.63 GHz with a rejection level of 20 dB and a 3-dB FBW of 6.2%, the second notch band is located at 6.47 GHz with a rejection level of 24.3 dB and a 3-dB FBW of 7.26%, and the third notch band is obtained at 8.93 GHz with a rejection level of 11 dB and a 3-dB FBW of 14.1%.

Based on the FMMR and the C-shaped slot [2], an improved slot embedded in the folded multiple-mode resonator, designated as FMMR based bandpass filter with CSRR, is introduced in this paper. To obtain low insertion loss, high out-of-band rejection level and wider band are presented. By using CSRR in FMMR and inter-digital couple, two notch responses can exist in the UWB passband for blocking the WLAN signals. Adjusting the size factor of CSRR and inter-digital couple, the wide tuning ranges of notch frequencies included the desired frequencies of 5.2/5.8 GHz can be achieved. Frequency responses and current

Corresponding author:jichyun@uch.edu.tw
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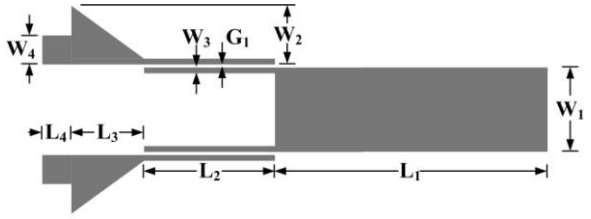
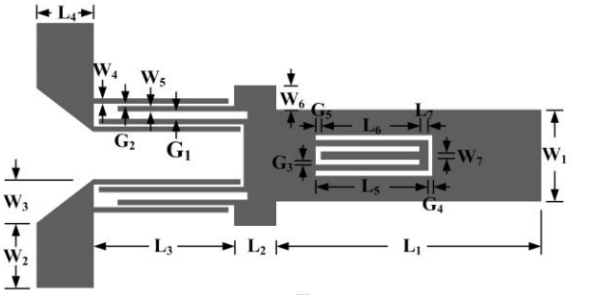
distributions are presented and discussed.

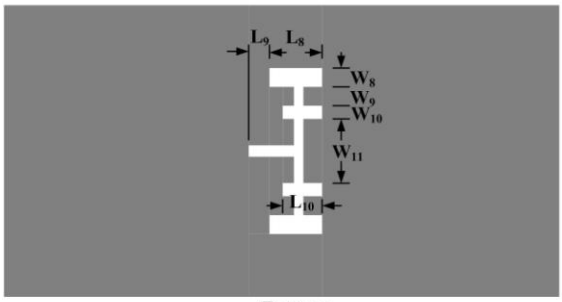
II. FMMR FILTER CONFIGURATION

The FMMR configurations are shown in Fig.1. The typical FMMR is presented in Fig.1 (a) [2]. Modified the MFRR with CSRR in MMR and the inter-digital couple, the inter-digital coupled CSRR FMMR is designed in Fig.1 (b). The detail dimensions are listed: L_1=14.1 mm, L_2=2.2 mm, L_3=7.51 mm, L_4=3 mm, L_5=6 mm, L_6=5.25 mm, L_7=0.45 mm, L_8=2.8 mm, L_9=1.1 mm, L_{10}=2.1 mm, W_1=4.84 mm, W_2=3.44 mm, W_3=2.31 mm, W_4=0.25 mm, W_5=0.25 mm, W_6=1.3 mm, W_7=0.4 mm, G_1=0.44 mm, G_2=0.21 mm, G_3=0.3 mm, G_4=0.25 mm, and G_5=0.3 mm.



(a)





(b)

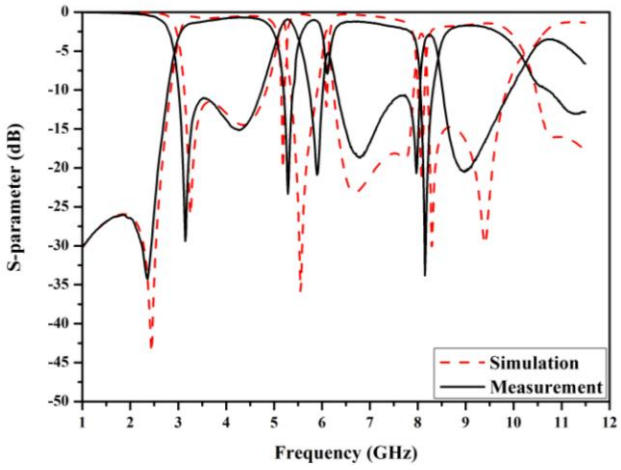
Fig.1 FMMR configurations
(a) Typical FMMR, (b) Inter-digital coupled DGS CSRR FMMR

III. SIMULATION & RESULTS

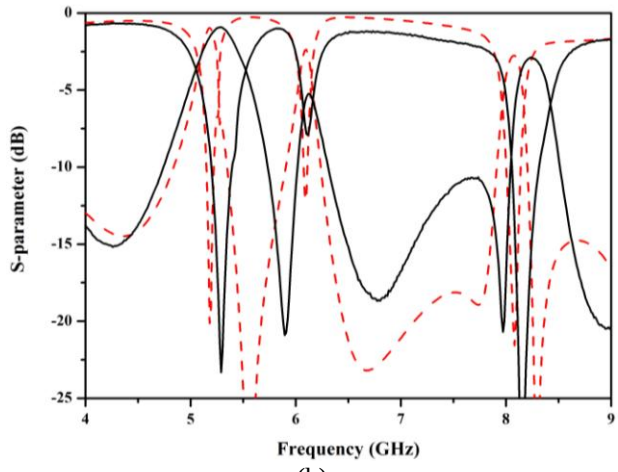
The simulations for FMMR filters are achieved with the aid of IE3D CAD [11]. The Duriod-3003 substrate with dielectric constant ε_r= 3, δ=0.0013, thickness h = 1.57mm is used for experiments. For the requirement of 50Ω impedance, the width of strip is 2.0 mm, length of feed-line is 9.0mm, effective dielectric constant ε_{eff} = 2.39 and guided wavelength λ_g = 43 mm at frequency f_o = 4.51 GHz.

A. S-parameters frequency responses

The inter-digital coupled CSRR FMMR is simulated and measured in Fig. 2 and listed in Table I. Both simulated and measured results are with agreement. It is evident that the multiple resonances occur within a wideband responses. The three passbands of the UWB BPF centered at 3.91, 5.63, 6.98 and 9.07 GHz have 3 dB fractional bandwidths of 2.049 GHz (3.021–5.07 GHz), 0.743 GHz (5.276–6.019 GHz), 1.76 GHz (6.156–7.916 GHz), and 1.76 GHz (8.232–9.992 GHz) and measured minimum insertion losses of 0.58, 0.26, 0.27 and 1.437 dB, shown in Fig.2 (a) respectively. Three passband return losses are better than -12 dB. The three notched bands centered at 5.18, 6.10 ,and 8.08 GHz have -10dB rejection fractional bandwidths of about 1.35 , 0.58% and 1.7% shown in Fig.2 (b). It can be seen that three extremely narrow notched bands have been achieved, which can reject the undesired narrow band radio signals. The Photograph of CSRR FMMR is shown in Fig. 3. For comparison, four previous works of tri-notched UWB resonator and the proposed filters are listed in Table II. It is evident that the compact size, wider bandwidth and tri-notched responses of these five filters are obtained and available for applications.



(a)

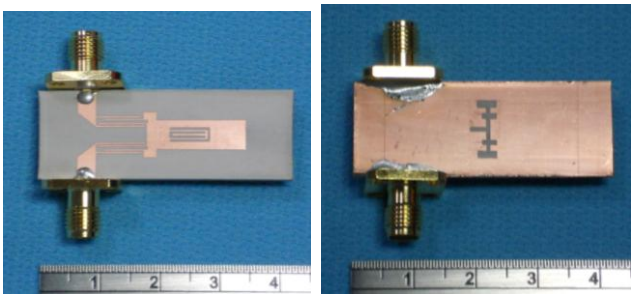


(b)

Fig.2 S_{21} and S_{11} frequency responses of inter-digital coupled DGS CSRR FMMR. (a) Full band, (b) Notched band

TABLE I
Frequency response

Simulation		Inter-digital coupled FMMR
fo (GHz)		5.6
-3dB BW (MHz)		6971
FWB (%)		126
Min insertion loss(dB)		-0.26
Rejection Level(dB)	Lower zero	-44
	Upper zero	-
Notch 1	Frequency(GHz)	5.18
	Attenuation (dB)	-20
	-10dB BW (MHz)	70
Notch 2	Frequency(GHz)	6.10
	Attenuation (dB)	-12
	-10dB BW (MHz)	35.6
Notch 3	Frequency(GHz)	8.08
	Attenuation (dB)	-21.5
	-10dB BW (MHz)	140



(b) (b)

Fig.3 Photograph of inter-digital coupled DGS CSRR FMMR (a) Top, (b) Bottom

B. Surface current distributions

Figs. 4 present the surface current distributions. The inter-digital coupled DGs CSRR FMMS exhibit the identical surface current distributions according to multiple resonances. The transmission zero GHz) are represented with attenuation (blue) in output port. Two notch resonances (5.20, 6.10 and 8.08 GHz) are observed, the inter-digital couple is excited at the frequency of 5.20 and 8.08 GHz, and the CSRR is acted at the frequency of 6.10 GHz.

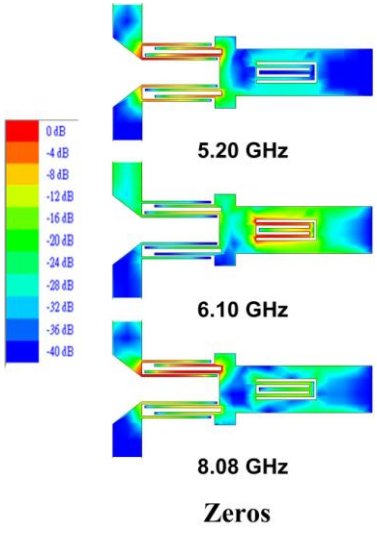


Fig. 4 Current distributions for inter-digital coupled CSRR FMMR

TABLE II
Comparison of five tri-notched UWB filters

Simulation		This work	Ref [30]	Ref [31]	Ref [32]	Ref [33]
Size (mm)		43 × 14	23.4 × 17.34	30.6 × 20	31 × 20	8.2 × 37.6
Notch 1	Frequency (GHz)	5.18	5.4	5.2	3.6	5.63
	Attenuation (dB)	20	24	20	16	20
	-10dB BW (MHz)	70	60	100	100	200
	-10dB FBW%	1.35	1.11	1.9	2.9	3.55
Notch 2	Frequency (GHz)	6.10	5.98	5.8	5.9	6.47
	Attenuation (dB)	12	24	26	16.5	24.3
	-10dB BW (MHz)	35.6	80	100	220	200
	-10dB FBW%	0.58	1.34	1.72	3.7	3.0
Notch 3	Frequency (GHz)	8.08	6.76	8.0	8.0	8.93
	Attenuation (dB)	21.5	33	29	10	11
	-10dB BW (MHz)	140	200	180	184	600
	-10dB FBW%	1.7	2.95	2.25	2.3	6.71

C. Notch responses

By tuning the CSRR in FMMR and the inter-digital couples, three notch responses can exist in the UWB passband for blocking the WLAN signals. The varied size factors q_1 of the inter-digital couple (L_3) in FMMR are presented in Fig.5 with the size factors q_2 = 1.0 of CSRR. The notched resonances are varied from 4.8 ~ 6.4 GHz and 7.5 ~ 8.4 GHz. Then the varied size factors q_2 of the CSRR (L_5) are presented in Fig.6 with the size factors q_1 = 1.0 of inter-digital couple. The notched resonances are varied from 5.6 ~ 6.4 GHz. The wide tuning ranges of two notch frequencies

cover from 4.8 GHz to 8.4 GHz. It is a simple way to control the notch response.

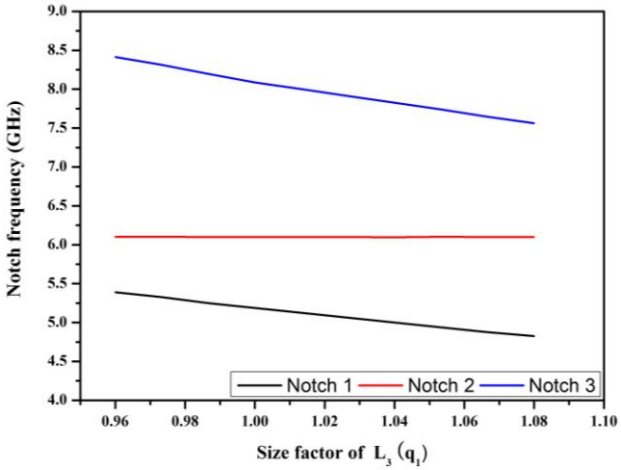


Fig.5 Notch frequencies of varied inter-digital couple

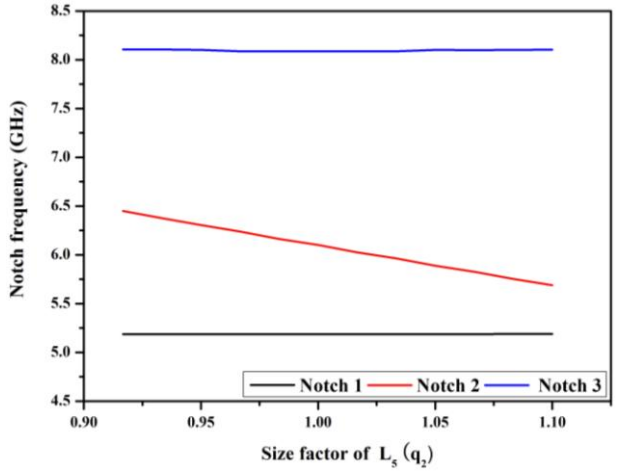


Fig.6 Notch frequencies of varied CSRR

IV. Conclusion

Applications of folded multiple-mode resonator with DGS, CSRR structure and inter-digital couple for wide band-pass filter design are presented in this paper. The structure and design method of the FMMR is very simple and comprehensive. The novel configurations of FMMR with DGS, CSRR and inter-digital couple are constructed to improve the performance of the conventional FMMR. Using the CSRR in FMMR and the inter-digital couple are a useful method to obtain the notch in UWB response for blocking the interference signals. Adjusting the size factor of the CSRR, the wide tuning ranges of notch frequencies included the desired frequency of 5.18/6.10/8.08 GHz are achieved. The wide tuning ranges of three notch frequencies cover from 5.0 GHz to 8.4 GHz.

Based on inter-digital couple DGS CSRR FMMR to generate triple notches, the first notch band is presented at 5.18 GHz with a rejection level of 20 dB and a 10-dB FBW of 1.35%, the second notch band is located at 6.10 GHz with a rejection level of 12 dB and a 10-dB FBW of 0.58%, and the third notch band is obtained at 8.08 GHz with a rejection level of 21.5 dB and a 10-dB FBW of 1.7%. The notch responses are controllable by tuning the size factors. It can be applied to the microwave UWB systems with the ability of blocking the interference signals.

Acknowledgments

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