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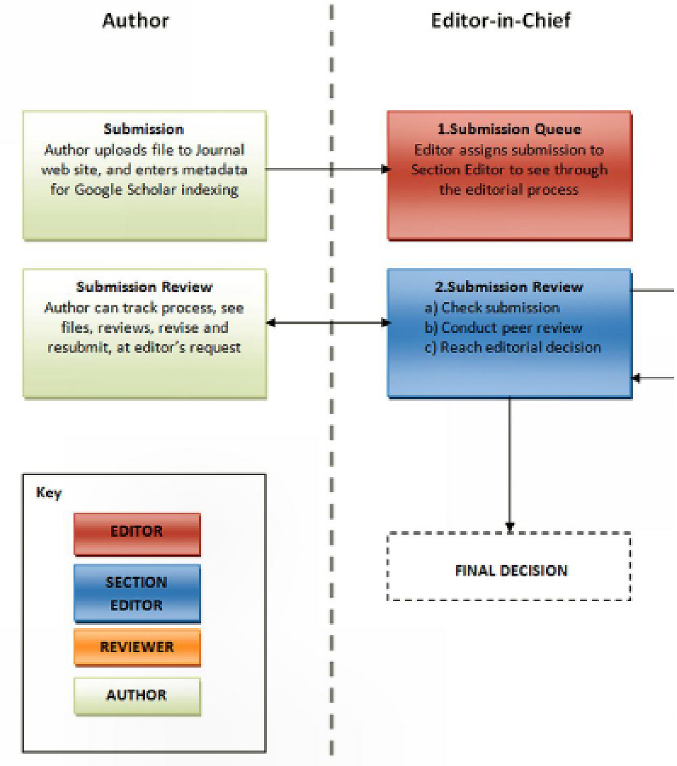

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Multi-Wideband Bandpass Filter Using Meandered Stub-Stepped Impedance Resonators for Multiband Application

Teguh Firmansyah[1], Herudin[1], Cindy Chairunissa[2], Mudrik Alaydrus[3], Gunawan Wibisono[4]

Abstract – *This paper proposes a multi-wideband bandpass filter (MW-BPF) using meandered stub-stepped impedance resonators (MS-SIR). This research shows that MS-SIR resonator can not only generate five-pass bands, but it also yields wide-fractional bandwidth, good transmission coefficients, and ease of fabrication. A transmission line analysis was used to design and to investigate the filter structure. Furthermore, this filter was fabricated on a FR4 substrate having a size of 0.08 λ_G × 0.14 λ_G, with λ_G as the wavelength at the first resonant frequency. The MW-BPF achieves the following transmission coefficients/ fractional bandwidth: -0.84 dB / 42.5 %, -1.36 dB / 21.49 %, -1.85 dB / 14.95 %, -2.12 dB / 10.69 %, and -2.11 dB / 6.02%, at 0.44 GHz, 0.88 GHz, 1.30 GHz, 1.77 GHz, and 2.15 GHz, respectively. This filter can be applied to DVB-T400, GSM800/GSM900, GPS1200, WCDMA1800, and LTE2100. The validity of the proposed design has been shown by the good agreement between the simulation and measurement results.*
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***Keywords**: Bandpass Filter, Meandered, Stepped Impedance Resonators, Wideband*

Nomenclature

θ_N	Electrical length (°) with N= 1, 2, 3,…
ε_r	Permittivity ($C^2N^{-1}m^{-2}$)
λ_G	Wavelength at the first resonant frequency
j	Imaginary number
BW	Bandwidth (GHz)
FBW	Fractional bandwidth (%)
f_c	Center frequency (GHz) with N= 1, 2, 3,…
f_N	Frequency (GHz) with N= 1, 2, 3,…
GDs	Group delays (ns)
h	Substrate thickness (mm)
K	Impedance ratio
L_N	Microstrip length (mm) with N= 1, 2, 3,…
S_{11}	Reflection coefficients (dB)
S_{21}	Transmission coefficients (dB)
tan δ	Loss tangent/ dielectric loss
W_N	Microstrip width (mm) with N= 1, 2, 3,…
Y_{IN}	Input admittance (Ω^{-1})
Z_{IN}	Input impedance (Ω)
Z_0	Characteristic impedance (Ω)
Z_N	Impedance (Ω) with N= 1, 2, 3,…
ADS	Advanced Design System
BPF	Bandpass filter
CSRR	Complement split ring resonator
DGS	Defected ground structure
DLS	Double layered structure
DVB-T	Digital Video Broadcasting-Terrestrial
FR4	Epoxy laminate material
GPS	Global Positioning System
GSM	Global System for Mobile communications
HTS	High temperature superconducting
I/O port	Input/output port
K	Impedance ration
LTCC	Low temperature co-fired ceramic
LTE	Long Term Evolution
MEMC	Mixed electric and magnetic coupling
MMR	Multi mode resonator
MS-SIR	Meandered stub-stepped impedance resonators
MSLRR	Multiple stubs loaded ring resonator
MLS	Multi layered structure
MW-BPF	Multi-wideband bandpass filter
NLC	Nematic liquid crystal
PCB	Printed circuit board
PMR	Penta mode resonator
SIR	Stepped impedance resonator
SLR	Stub loaded resonator
SSIR	Stub stepped impedance resonator
TPF	Transversal planar filter
VNA	Vector Networks Analyzer
WCDMA	Wideband Code Division Multiple Access
YBCO	Yttrium barium copper oxide

I. Introduction

A bandpass filter (BPF) is an important component in modern wireless communication systems not only to suppress harmonics but also to reduce the noise and to decrease signal interferences [1]-[2]. Planar BPFs are especially well-known filter structures that can be fabricated easily by using a printed circuit board (PCB) technology [3]-[4]. They are also suitable for commercial applications due to their low-cost integration and

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compact size [4]-[5]. In recent years, designing multiband BPFs with multiband frequencies has become a trend to support the development of numerous types of wireless communication standards. There are some attractive design methods to produce a multiband BPF such as the transversal planar filter (TPF) [6]. In this method, two transmission-line segments were arranged in parallel structure and sharp-rejection multi-passbands filtering were generated by exploiting feedforward-interference principles. However, this filter size is too large. [7] and [8] have proposed a low temperature co-fired ceramic (LTCC) technology to obtain a compact filter size. However, LTCC suffers from some major drawbacks such as ceramic shrinks after firing, requiring heat removal, and difficulty to be manufactured. In addition, the unwanted coupling, parasitic effect, and the values of lumped elements cannot be predicted and controlled accurately. Furthermore, BPF based on slot complement split ring resonator (CSRR) was proposed by [9], here the slot CSRR as perturbation was used to excite the space-orthogonal degenerate mode. This method was applied for dual-mode filter. A good insertion loss has been achieved, but the BPF has a complex structure. Moreover, high temperature superconducting (HTS) BPF was proposed by [10]. This filter was fabricated on double-sided YBCO thin films with a 2-inch-diameter 0.5-mm-thick MgO wafer substrate. Further, reconfigurable and tunable BPFs were proposed by [11] and [12] by using Varactor /PIN diodes and nematic liquid crystal (NLC), respectively. These methods produce the tuning capability of bandwidth and center frequency, but they suffers from some drawbacks such as requiring active components, power supply, and a complex structure. To generate a multiband BPF, multi-mode resonator (MMR) and λ/4 resonators with mixed electric and magnetic coupling (MEMC) have been presented by [13]. This proposed method requires external coupling paths and fewer resonator numbers. In order to control the resonant modes independently, a multiple stubs loaded ring resonator (MSLRR) with MEMC was proposed by [14]. However, this filter has still a complex structure. In another study, to miniature BPF size, a double layered structure (DLS) was presented by [15]. Furthermore, a multi-layered structure (MLS) was proposed by [16], and Ref. [17] demonstrated that with a defected ground structure (DGS) it would be possible to generate a good stopband rejection with high passband selectivity. High complex configuration of filter structures is still a major problem of DLS and MLS methods. DGS method in the ground plane will bring disadvantages such as package problems and fabrication difficulties.

The most popular method to generate multiband BPF is the stepped impedance resonators (SIR), firstly introduced by Makimoto and Yamashita in the 1980s [18]. The SIRs have shown advantageous performances in designing microstrip BPF such as a good stopband, a simple structure, a miniature size, and a low insertion loss [19]. The resonant frequencies of SIR can be tuned by adjusting the impedance ratio.

Furthermore, [20] proposed an inverted SIR to produce dual-pass band. Moreover, SIR combined with DGS was investigated by [21], and SIR combined with interdigital capacitors was proposed by [22] in order to control the harmonic frequencies. Another multiband BPF design method is based on stub loaded resonators (SLR). This method was investigated by [23]-[24].

Furthermore, the SLR method was combined with SIR method to achieve a simple design and good passband selectivity [25]-[30], this method was called stub-stepped impedance resonator (SSIR).

To achieve significant size reduction, there are some methods such as stub loaded U-shape [31], ring resonator [32], stub loaded transversal [33], and multi stub loaded [34]-[35]. Furthermore, a tunable stub loaded filter was proposed by [36]; this filter has a compact size and it is reconfigurable. The resonators are composed by a pair of varactor-loaded square split rings, an open stub and a one-end shorted closed-loop ring. These resonator employs the Skyworks varactor diodes SMV1405-074LF to adjust the center frequency and the bandwidth of second pass-band.

However, they suffers from some drawbacks such as requiring power supply, active components and a complicated structure. As a novelty, this research proposed a multi-wideband bandpass filter (MW-BPF) with meandered stub-stepped impedance resonators (MS-SIR).

In order to realize the five-band bandpass filter, this research proposed to replace the conventional half-wavelength open-circuited stub single-frequency resonators with meandered stub-stepped impedance resonators (MS-SIR). Compared with conventional half-wavelength open-circuited stub single-frequency resonators, the MS-SIR resonator could generate not only the five pass-bands, but also better transmission coefficients, higher fractional bandwidth, and compact size. To the best of knowledge, it is the first design of five-passband BPF with wide fractional bandwidth using MS-SIR, which can significantly improve the fractional bandwidth.

Furthermore, a meander method was proposed in this research to obtain a significant size reduction. A meander method could reduce a filter size as reported by [37]. Other methods to reduce filter size are rectangular dual spiral resonator [38], λ/2 stub [39], cascaded resonators [40], asymmetric SIR [41], and single penta mode resonator [42]. However, they have still a complex structure. This filter was fabricated on a FR4 substrate with ε_r=4.4, h=1.6 mm, and tan δ=0.0265.

The proposed MW-BPF was simulated by Advanced Design System (ADS). The design methodology will be detailed in the following sections. Section 2 describes the design of multi-band BPF by folded MS-SIR. The transmission line analysis has been used to investigate the filter structure. The simulation and measurement results of the MW-BPF are described in Section 3. Finally, Section 4 concludes this research.

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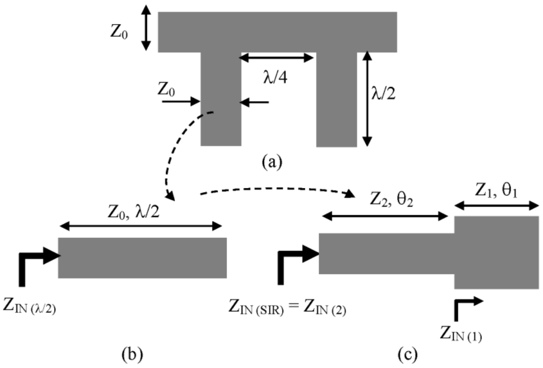
II. Stub-Stepped Impedance Resonators Structure Analysis

A conventional single-band microstrip bandpass filter is shown in Fig. 1(a). The structure of single-BPF consists of a quarter-wavelength (λ/4) and an open-circuit stub resonator (λ/2) [20]. The bandwidth of a single-band microstrip BPF is in principle determined by the characteristic impedances of open-circuit stub resonator as shown in Fig. 1(b).

Further, the filter structures are commonly optimized for the microstrip realization. In this work, to realize the five-band operation, each open-circuit stub resonator (λ/2) is converted to open-circuit stub-stepped impedance resonators as shown in Fig. 1(c).



Figs. 1. (a) A single band BPF based on conventional half-wavelength open stub resonator, (b) A half-wavelength open stub resonator, (c) A stub-stepped impedance resonator

Moreover, the filter structure of MW-BPF using stub-stepped impedance resonators structure is shown in Fig. 2(a), with the Z_N (N=1,2,3) and θ_N (N=1,2,3) stand for the characteristic impedance and electrical length, respectively. Furthermore, Fig. 2(b) shows the even-excitation characteristic impedance of stub-stepped impedance resonators and Fig. 2(c) shows the odd-excitation characteristic impedance of stub-stepped impedance resonators. By investigating the input impedance Z_{IN} of the stub-stepped impedance resonators at the even- excitation condition as shown in Fig. 2(b), the following equations can be derived:

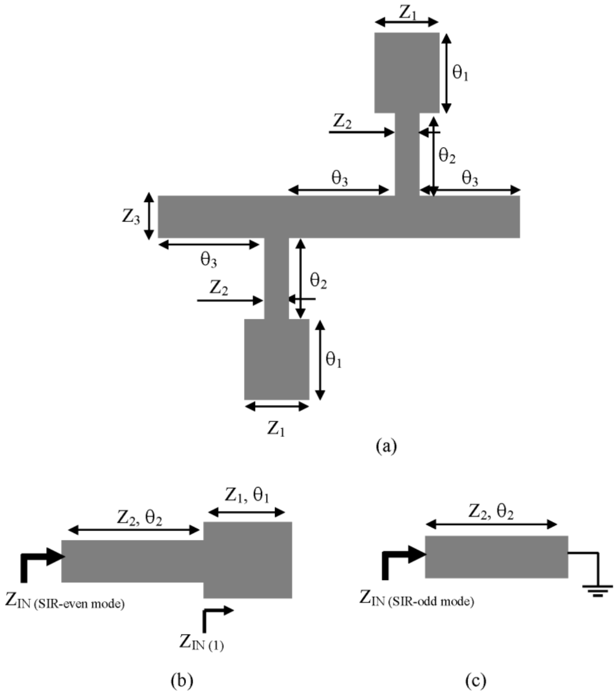
$$Z_{IN\,(1)} = -jZ_1 \cot\theta_1 \tag{1}$$

and:

$$\begin{aligned} Z_{IN\,(SIR-even\ excitation)} &= Z_2 \frac{Z_{IN(1)} + jZ_2 \tan\theta_2}{Z_2 + jZ_{IN(1)} \tan\theta_2} \\ &= Z_2 \frac{-jZ_1 \cot\theta_1 + jZ_2 \tan\theta_2}{Z_2 + j(-jZ_1 \cot\theta_1)\tan\theta_2} \end{aligned} \tag{2}$$

Therefore, the input admittance is given by:

$$Y_{IN\,(SIR-even\ excitation)} = \frac{1}{Z_2} \frac{Z_2 + Z_1 \cot\theta_1 \tan\theta_2}{-jZ_1 \cot\theta_1 + jZ_2 \tan\theta_2} \tag{3}$$



Figs. 2. (a) The multi-wideband BPF with stub-stepped impedance resonators structure, (b) even- excitation stub-stepped impedance resonators structure, (c) odd- excitation stub-stepped impedance resonators structure

The resonant frequencies can be extracted from the admittance condition $Y_{in} = 0$ or the impedance condition $Z_{in} = \infty$ [23], [43]-[45].

Therefore, the resonance condition of the structure is found as follows:

$$Z_2 + Z_1 \cot\theta_1 \tan\theta_2 = 0 \tag{4}$$

This can be obtained when:

$$\tan\theta_2 = -\frac{Z_2}{Z_1}\tan\theta_1 \tag{5}$$

or:

$$\theta_2 = \pi - \tan^{-1}(K \tan\theta_1) \tag{6}$$

With the impedance ratio $K = Z_2/Z_1$, electrical length θ_N (N=1,2), and $\pi = 180°$. For electrical length $\theta_1 = \lambda/4$, and without any frequency dispersion, the relation between resonant frequency (f_N) and fundamental resonant frequency (f_1) can be derived [25],[43]-[45]:

$$\frac{f_N}{f_1} = \frac{\theta_N}{\theta_1} \tag{7}$$

$$f_N = \frac{2\theta_N}{\pi} f_1 \tag{8}$$

Therefore, the even- excitation of the proposed stub-SIR obtains three resonant frequencies, which can be extracted by:

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$$f_{even\ excitation-1} = f_1 \tag{9}$$

$$f_{even\ excitation-2} = \frac{2f_1}{\pi}(\pi - \tan^{-1}(K \tan \theta_1)) \tag{10}$$

$$f_{even\ excitation-3} = \frac{2f_1}{\pi}(2\pi - \tan^{-1}(K \tan \theta_1)) \tag{11}$$

By investigating the input impedance Z_{IN} at the odd-excitation condition as shown in Fig. 2(c), the following equation can be derived:

$$Z_{IN\ (SIR-odd\ excitation)} = jZ_2 \tan \theta_2 \tag{12}$$

The resonant frequencies can be extracted from the impedance condition $Z_{in} = \infty$ [25], [43]-[45].

Meanwhile, the resonance condition of the structure is found as follows:

$$\tan \theta_2 = \infty$$

$$\theta_2 = \frac{(2n-1)}{2}\pi \tag{13}$$

By Equation (8), the odd- excitation obtains four resonant frequencies, extracted by:

$$f_{odd\ excitation-1,2,} = (2n-1)f_1 \quad ; n = 1, 2 \tag{14}$$

It is notable that the total of resonant frequencies in even- excitation and odd- excitation has provided the five pass-bands frequency. Figs. 3(a) to (c) show a design curve of θ_2 (degrees) for different values of impedance ratio (K) and θ_1 (degrees).

In this research, the following filter structure was chosen: $Z_1 = 30\Omega$, $\theta_1 = 10°$, and $Z_2 = 50\Omega$, hence $K = 1.66$ and $\theta_2 = 163°$ as shown in Fig. 3(a). FR4 substrate was used and it has $\varepsilon_r = 4.4$ [45].

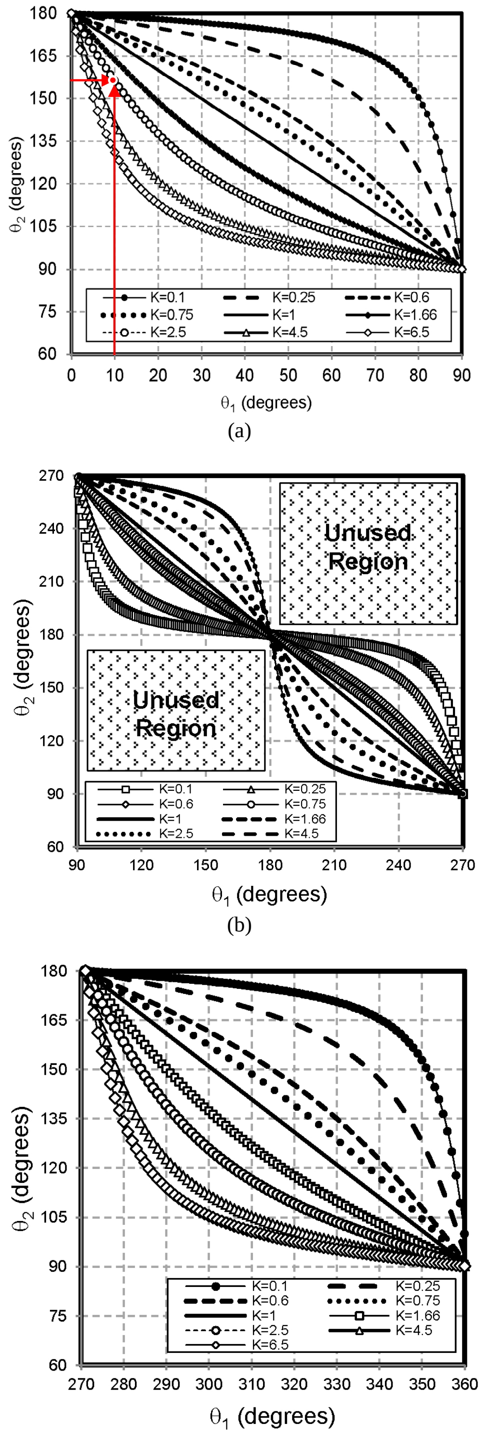
The unused-region is shown in Fig. 3(b); it is also noted that $K = 1$ stands for uniform resonator/ without step impedance resonator.

Moreover, Fig. 4(a) illustrates the change of the second pass-band by the impedance ratio (K) and Fig. 4(b) shows the effect of frequency ratio by the impedance ratio (K), demonstrating that the impedance ratio (K) has no effect on the frequency ratio.

III. Multi-Wideband Bandpass Filter with Meandered Stub SIR

To validate the practical usefulness of the multi-wideband bandpass filter with meandered stub SIR, the prototype has been designed, built, and tested. The design guidelines of this BPF process were expounded in Section II.

In this paper, the characteristic impedance $Z_0 = 50\ \Omega$ has been used, this Z_0 value was equal with the terminated port (I/O port).



Figs. 3. The curve of θ_2 (degrees) for different values of impedance ratio (K) and θ_1 (degrees). (a) with 0 <θ_1< 90 (degrees), (b) with 90 <θ_1< 270 (degrees), (b) with 270 <θ_1< 360 (degrees)

Furthermore, in order to produce a compact size, the following filter structure has been chosen: $Z_1 = 30\Omega$, $\theta_1 = 10°$, and $Z_2 = 50\Omega$. So the value of impedance ratio becomes $K = Z_1/Z_2 = 1.66$. Based on Fig. 3(a), with $\theta_1 = 10°$ and $K = 1.66$, the value of θ_2 becomes $\theta_2 = 163°$.This initial physical dimensions of MW-BPF have been simulated by Advanced Design System

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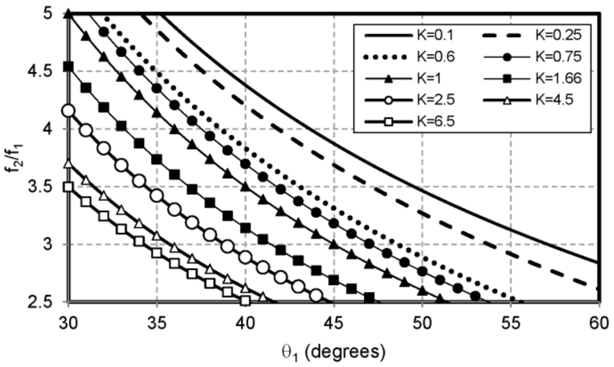
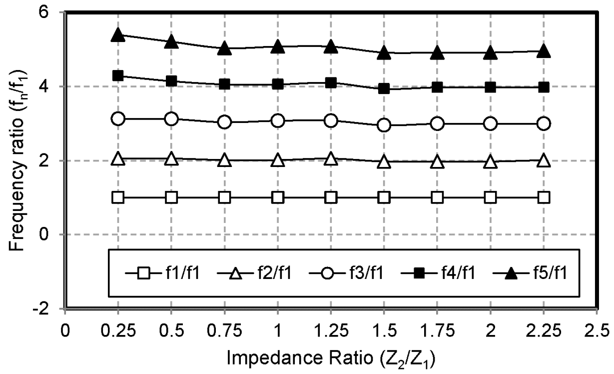
(ADS). This filter structure must be optimized to consider the impact of bends, open ends, shorted ends, and impedance discontinuities. After the optimization, the filter structure becomes Z_1 = 36.3Ω, θ_1 = 10.9°, Z_2 = 50.47Ω, θ_2 = 160.4°. The size is slightly changed compared to the original filter structure.



(a)



(b)

Figs 4. (a) The change of the second frequency-band by the impedance ratio (K) and length θ_1 (degrees), (b) the effect of frequency ratio by impedance ratio (K)

This filter has been fabricated on FR4 substrate with ε_r= 4.4, h=1.6 mm, and tan δ= 0.0265. In order to reduce filter size, a meander method is also proposed. Fig. 5(a) shows the layout of multi-wideband bandpass filter with meandered stub SIR (MS-SIR). The dimensions are given as follows (all in millimeters):

$$W_1 = 5.0, W_2 = 3.0, W_3 = 3.0$$

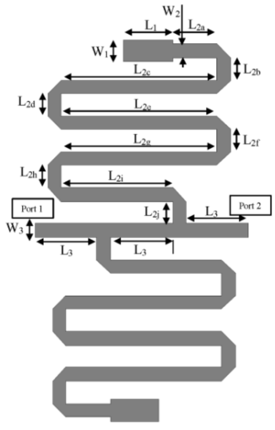
and:

$$L_1 = 11, L_{2a} = 10,\ L_{2b} = 5, L_{2c} = 35,\ L_{2d} = 5, L_{2e} = 35,\ L_{2f} = 5,\ L_{2g} = 35,\ L_{2h} = 5,\ L_{2i} = 25,\ L_{2j} = 5,$$

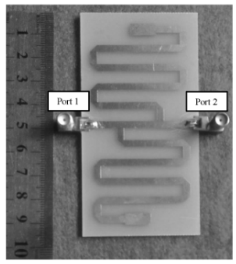
and $L_3 = 14$, with L total:

$$\left(L_1, L_{2a}, L_{2b}, L_{2c}, L_{2d}, L_{2e}, L_{2f}, L_{2g}, L_{2h}, L_{2i}, L_{2j}\right) = L_{2stub} = 165.$$

Moreover, Fig. 5(b) shows the photograph of multi-wideband bandpass filter with meandered stub SIR (MS-SIR).



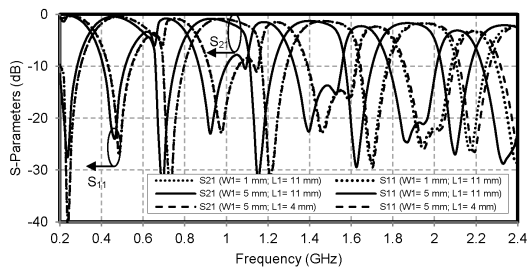
(a)



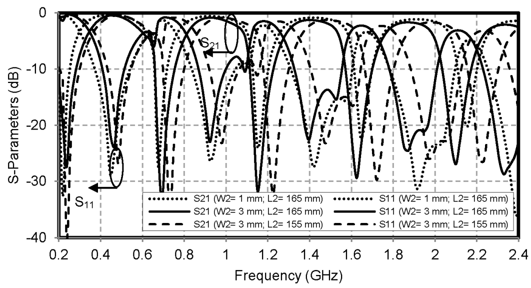
(b)

Figs. 5. (a) The layout of multi-wideband bandpass filter with meandered stub SIR (MS-SIR), (b) The photograph of multi-wideband bandpass filter with meandered stub SIR (MS-SIR)

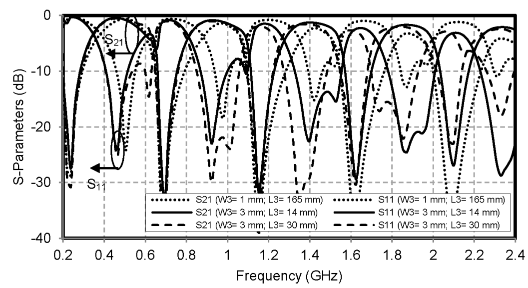
Fig. 6(a) shows the extracted reflection coefficients (S_{11}) and the transmission coefficients (S_{21}) with different W_1 and L_1. It can be seen that the reflection coefficients (S_{11}) of frequency f_1, f_2, and f_3 are more stable than f_4, and f_5, by different W_1 and L_1.



(a)



(b)



(c)

Figs. 6. Reflection coefficients (S_{11}) and transmission coefficients (S_{21}) (a) Response with varied W_1 and L_1. (b) Response with varied W_2 and L_2. (c) Response with varied W_3 and L_3

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However, the transmission coefficients (S_{21}) at all frequencies are still stable.

Besides that, Fig. 6(b) shows the extracted reflection coefficients (S_{11}) and transmission coefficients (S_{21}) with varied W_2 and L_2. The chart shows that both the reflection coefficients (S_{11}) and transmission coefficients (S_{21}) are still fairly constant at f_1, f_2, and f_3. Otherwise, at the f_4, and f_5, the reflection coefficients (S_{11}) and transmission coefficients (S_{21}) vary moderately, also affecting the frequency shift. Furthermore, Fig. 6(c) shows the extracted reflection coefficients (S_{11}) and transmission coefficients (S_{21}) with varied W_3 and L_3. It can be seen that the reflection coefficients (S_{11}) decrease dramatically without resulting in frequency shift.

Furthermore, Fig. 7 shows the extracted transmission coefficients (S_{21}) and fractional bandwidth (FBW) response with different W_1. The figure shows that by increasing W_1, the fractional bandwidth will be stable and the transmission coefficients (S_{21}) will increase slightly. Therefore, the transmission coefficients (S_{21}) value are still higher than -3 dB.

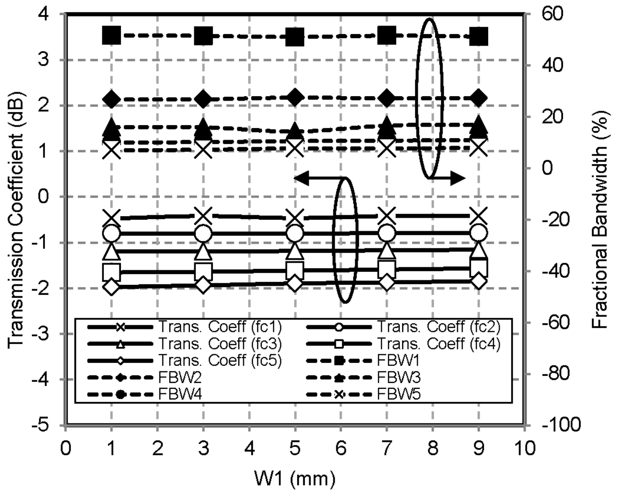
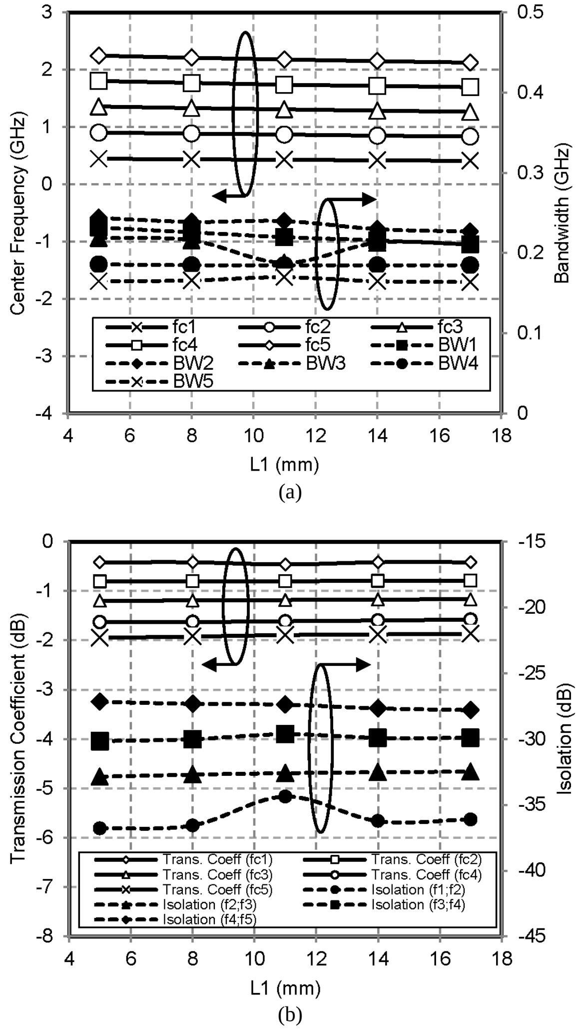


Fig. 7. Transmission coefficients (S_{21}) and fractional bandwidth (FBW) response with varied W_1 (mm)

Fig. 8(a) shows center frequency (f_c) and bandwidth (BW) response with varied L_1 (mm). The figure demonstrates that both of center frequency and bandwidth are stable for L_1 between 4-18 mm. Moreover, Fig. 8(b) illustrates transmission coefficients (S_{21}) and isolation response with varied L_1 (mm). Isolations value are better than -25 dB, Consequently, that is no interferences signal between pass-band. And then Fig. 8(b) shows that the transmission coefficients (S_{21}) value are higher than -3 dB.

Fig. 9(a) shows the center frequency and the bandwidth response with different L_{2a} (mm), and Fig. 9(b) reports the transmission coefficients (S_{21}) and isolation response with different L_{2a} (mm). The figures indicate that both the center frequency and transmission coefficients (S_{21}) are stable. However, bandwidth and isolation are increased while L2a is decreased.



Figs. 8. (a) Center frequency and bandwidth response with varied L_1 (mm), (b) Transmission coefficients (S_{21}) and isolation response with varied L_1 (mm)

Figs. 10(a)-10(e) show the surface current distribution on multi-wideband bandpass filter with meandered stub SIR. The surface current distribution at the first frequency band (f_1=0.44 GHz) was flowed at the center area and slightly at the upper resonator area as shown in Fig. 10(a). At the second frequency band (f_2=0.88 GHz), the surface current distribution was flowed only at the upper resonator, as shown in Fig. 10(b). Furthermore, at the third frequency band (f_3=1.30 GHz), the surface current distribution was flowed at the upper resonator, with a slight distribution at the lower resonator, as shown in Fig. 10(c).

Moreover, both the fourth frequency band (f_4=1.77 GHz) and the fifth frequency band (f_4=3.03 GHz) show that the surface current mostly flows in the lower resonator, with a little surface current in the upper resonator as shown in Fig. 10(d) and Fig. 10(e), respectively. The surface current distribution of MW-BPF has been simulated by Momentum-ADS. Plotting the surface current distribution on BPF provides important information for the RF signal flows.

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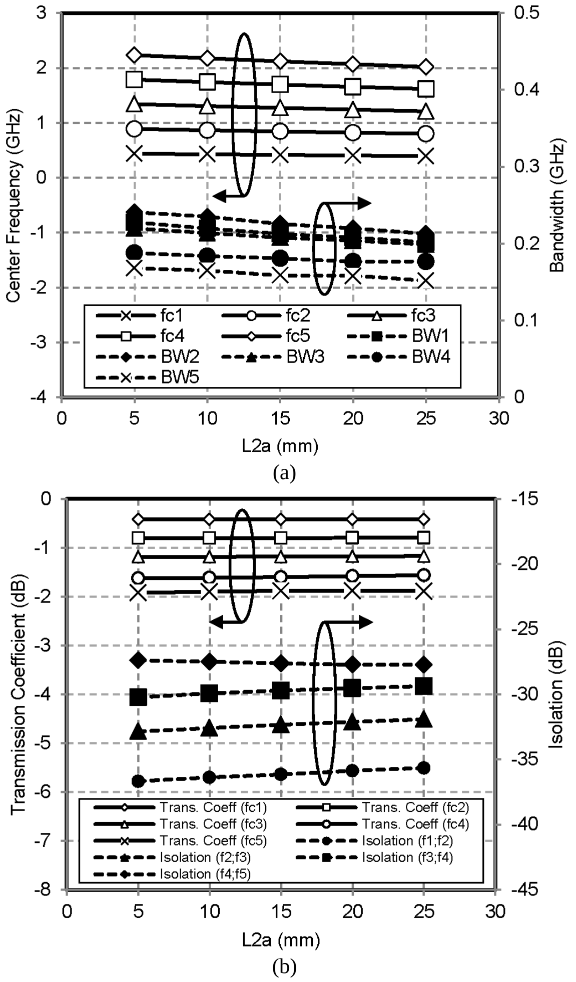
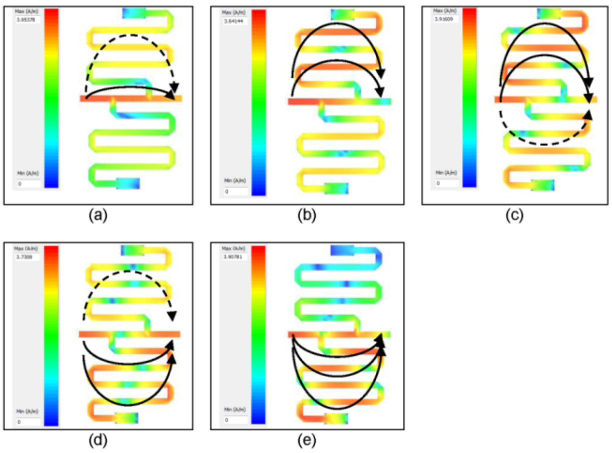


Figs. 9. (a) Center frequency and bandwidth response with varied L_{2a} (mm), (b) Transmission coefficients (S_{21}) and isolation response with varied L_{2a} (mm)



Figs. 10. Surface current distribution on multi-wideband bandpass filter with meandered stub SIR, (a) 0.44 GHz, (b) 0.88 GHz, (c) 1.30 GHz, (d) 1.77 GHz, and (e) 2.15 GHz

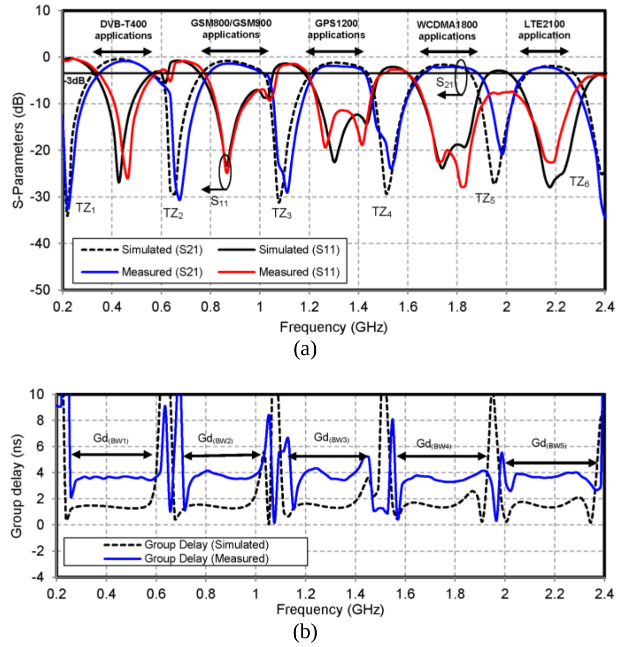
Fig. 11(a) shows the comparison between simulation and measurement results achieved by the MW-BPF. A VNA Rohde Schwarz ZVA67 was used to test the fabricated prototype the MW-BPF.

Both simulated and measured results of the multi-wideband bandpass filter with meandered stub SIR have accomplished the five passbands' requirements.

The MW-BPF achieves the following transmission coefficients/fractional bandwidth: of -0.84 dB / 42.5 %, -1.36 dB / 21.49 %, -1.85 dB / 14.95 %, -2.12 dB / 10.69 %, and -2.11 dB / 6.02%, at 0.44 GHz, 0.88 GHz, 1.30 GHz, 1.77 GHz, and 2.15 GHz, respectively.

Moreover, both simulated and measured group delays (GDs) of all the pass-bands below 6 ns are depicted in Fig. 11(b).

Table I summarizes the comparison of the proposed MW-BPF.



Figs. 11. (a) Simulation and measurement results of the proposed MW-BPF, (b) Simulated and measured results of group delay of the proposed MW-BPF

TABLE I
SUMMARY OF THE PROPOSED BPF COMPARISON

Ref	Method	Band	Center Freq (GHz)	Trans. coef (dB)	-3dB FBW (%)
[13]	Mixed electric and magnetic coupling (MEMC)	5	2.10 / 3.00 / 4.00 / 4.70 / 7.20	-0.98 / -1.76 /-1.22 / -1.77 / -2.39	13.70 / 5.60 / 10.50 / 5.10 / 2.90
[15]	Double-layered structure	5	1.50 / 2.50 / 3.50 / 4.50 / 5.80	-1.50 /-1.80 / -0.90 /-1.20 / -2.50	4.50 / 4.50 / 3.60 / 4.50 / 2.70
[26]	Trimode stub-loaded stepped impedance resonators	5	0.60 / 0.90 / 1.20 / 1.50 / 1.80	-2.80 / -2.90 / -2.90 /-2.60 / -2.30	5.80 / 5.20 / 5.80 / 8.20 / 8.00
[42]	Penta mode resonator (PMR)	5	0.63 / 1.2 / 1.8 / 2.49 / 3.46	-0.43 / -0.86 / -1.10 / -1.98 / 2.55	28.50 / 10.00 / 13.60 / 4.80 / 4.20
This Work **Multi-wideband**	Meandered Stub-SIR (MS-SIR)	5	0.44 / 0.88/ 1.30 / 1.77 / 2.15	-0.84 / -1.36 / -1.85 / -2.12 / -2.11	**42.5 / 21.49 / 14.59 / 10.69 / 6.02**

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This filter can be applied to DVB-T400, GSM800, GPS1200, WCDMA1800, and LTE2100. This filter has a compact size of 0.08 $\lambda_G \times 0.14\ \lambda_G$, with λ_G is wavelength at the first frequency. Furthermore, the MW-BPF achieves transmission zeros of -32.1 dB, -30.7 dB, -29.0 dB, -23.9 dB, -20.8 dB, and -34.2 dB, at 0.22 GHz, 0.68 GHz, 1.11 GHz, 1.53 GHz, 1.99 GHz, and 2.40 GHz, respectively. Finally, the validity of the proposed design was shown by the good agreement between simulation and measurement results.

IV. Conclusion

The MS-SIR resonator could generate not only the five pass-bands, but also high fractional bandwidth.. This MW-BPF has a compact size of 0.08 $\lambda_G \times 0.14\ \lambda_G$, with λ_G is wavelength at the first frequency. This filter can be applied to DVB-T400, GSM800/GSM900, GPS1200, WCDMA1800, and LTE2100. Both the simulation and measurement results of the multi-wideband bandpass filter with meandered stub SIR have accomplished the five passbands with wide fractional bandwidth. A good agreement can be observed between the simulated and measured results which demonstrates the validity of the design.

Acknowledgements

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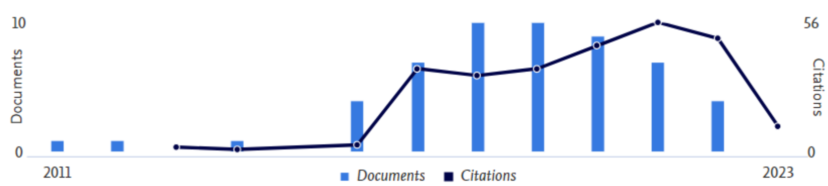

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