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Band-pass Filter with Harmonics Suppression Capability

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Article Info	ABSTRACT
	This paper presents a Band-pass Filter (BPF) with a very wide suppressions band. The filter design is based on a modified U-shaped slot. Two pair of U-shaped slots is used to ensure that the filter can suppress the unwanted frequencies up to 4th harmonics. In order to achieve sharp skirt, two transmission zeroes are created near the passband area. Additional transmission zeroes are introduced to deepen the stopband area. Therefore, the passband range starts from 1.3 to 3.3 GHz and the stopband range from 3.3 GHz up to 9 GHz are achieved. The filter performances are verified through simulated and measured results.

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1. INTRODUCTION

Many modern communication systems demand multifunctional RF front-end. Multifunctional antenna such as reconfigurable and filtering antennas have the advantage because it can reduce the overall size and complexity in the systems [1]. However, this antenna also exposed to unwanted harmonic frequencies which can cause interference in the communication system. Therefore, filter can be used to remove unwanted frequency by means of being completely eliminated or partially suppressed them.

There are many types of filter can be used as the filtering purposes in the RF front-end. Various filter structures are presented [2]-[13] such as parallel coupled line technique, stepped impedance resonator and multimode resonator.

Filter presented in [2], [3] have dual-band band-pass filter. Filter in [2] consists of symmetrical Y-shaped central-loaded stepped-impedance, overlapped with the hexagon ring resonator. It has a center frequency at 1.9 GHz and 3.4 GHz, with the minimum insertion loss results of 0.9 dB and 1.0 dB, respectively. The simple structure is based on parallel coupled line technique of filter in [3], it has an insertion loss at 2.4 GHz for -0.6 dB while at 5 GHz for -2.1 dB. Filters with more than a quad-band are also been reported in [4]-[5]. By using multimode resonator (MMR), λ/4 resonator with mixed electric and magnetic coupling (MEMC), filter in [4] has a quint-band bandpass. Center frequencies are achieved at 2.1 GHz, 3.0 GHz, 4.0 GHz, 4.7 GHz and 7.2 GHz with the insertion loss of 0.98 dB, 1.78 dB, 1.22 dB,

1.77 dB and 2.39 dB, respectively. However, the more bands the filter has, the more complex structure or design of filters will become.

Ultra-wideband bandpass filter is reported in [6], achieved from 3.1 GHz to 10.6 GHz with minimum insertion loss of 1 dB. The filter consists of λ/2 stepped impedance resonator (SIR) with a short stub and two open-circuited stubs loaded. Another filter covers from 1.72 GHz to 3.99 GHz is presented in [7] with the insertion loss of 0.81 dB. The filter is composed of square-loop resonator, three-coupled line load and interdigital feed lines. UWB bandpass filter ranging from 0.5 GHz to 1.9 GHz is achieved in [8]. The filter also has seven transmission zeros which are located from 2.04 GHz to 5.9 GHz with insertion loss greater than 20 dB. A compact bandpass filter with source-load coupling cover from 3.08 GHz to 4.34 GHz [13]. It consists of triple-mode stub-loaded resonator which can generate one odd mode and two even modes. However, this filter has a complex design in order to achieve a wide range of passband and stopband simutanoeusly.

This paper presents a Band-pass Filter (BPF) with a very wide suppressions band. The analysis of the filter which consists of two pairs of modified U-shaped slot is presented. With this structure, the proposed structure is able to have a band-pass from 1.3 GHz to 3.3 GHz and supressed the other unwanted frequencies up to 4th harmonics. To verify the performance, the filter is fabricated and measured. Both of the simulated and measured results are agreed reasonably well, demonstrating that the filter has a good band-pass bandwidth and broadband harmonic suppression.

2. PARAMETRIC STUDIES FOR FILTER DESIGN

Harmonic frequencies can somehow contribute to an error and a problem to the wireless communication systems. By integrating a filter to an antenna structure, the harmonic frequencies can be eliminated. There are many designs or shapes of filter introduced from the previous research works. For example; ring-shape, bowtie-shape, square/rectangle-shape and U/L/Γ/π-shape are introduced to filtering an antenna frequency. In this paper, a modified U-shaped slot filter with a CPW-fed has been designed.

2.1. Single-, dual-, triple- and quad-line (s) rectangle-shape of filter

The forming of modified U-shaped slot is based from rectangle slot. Figure 1 shows a single rectangle-shape slot and was given a name as configuration A. The substrate dimension is 150 x 100 mm^2 (length, l x width, w). The single slot denoted as a stub1 has a dimension of length=$l1$ and width=$w1$, placed in the middle of CPW feedline with f=3 mm and g=0.5 mm. The slot length, $l1$ is approximately a quarter wavelength at the operating frequency. Thus creating a stop-band function.
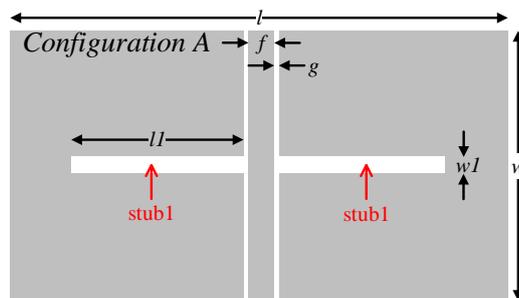
Figure 1. Configuration A – single-line, rectangle slot

Figure 2(a) shows insertion loss (S_{21}) results of Configuration A by varying $l1$ when $w1$ of stub 1 is fixed at 1 mm. When $l1$=9 mm, the -10 dB stopband bandwidth is 4.76 GHz to 6.12 GHz, with the center frequency, fc=5.4 GHz. When $l1$=10 mm, the bandwidth is covered from 4.21 GHz to 5.65 GHz, with fc=4.8 GHz. Bandwidth is ranging from 3.87 GHz to 5 GHz when $l1$=11 mm, with fc=4.3 GHz.

Meanwhile, Figure 2(b) shows S_{21} results when $l1$ is fixed at 10 mm and the value of $w1$ is varied from 1 mm to 5 mm. Bandwidth percentage is increasing from 14.6% ($w1$=1 mm) to 20.8% ($w1$=3 mm) and 24.1% ($w1$=5 mm). From both of the figures, we can notice that if the length of the stub is shorter, the center frequency (fc) is higher as shown in Equation (1). Meanwhile, when the width of the slot is wider, the quality factor becomes lower and thus the bandwidth is increased.

$$l \propto 1 / f \tag{1}$$

(a)   (b)
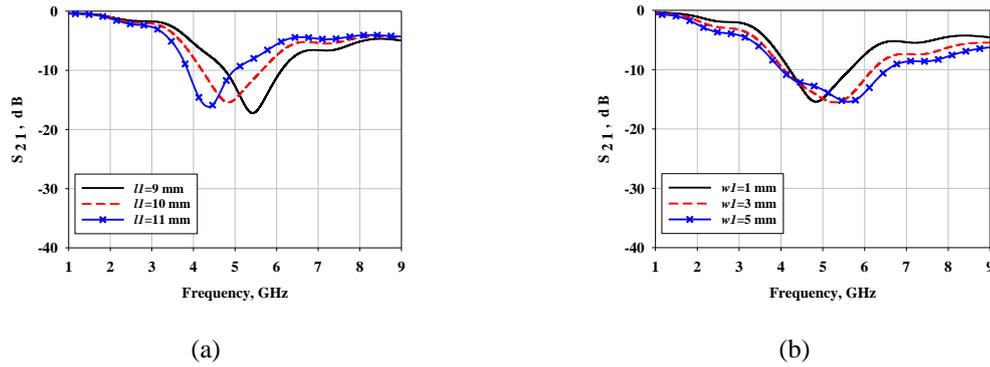
Figure 2. S_{21} Results of configuration A when (a) Vary *l1*, *w1*=1 (b) Vary *w1*, *l1*=10

Other rectangle slot shape such as dual-lines, triple-lines and quad-lines are shown in Figure 3, Figure 4 and Figure 5. Dual-lines, rectangle slot as shown in Figure 3(a) consists of two slots known as stub1 and stub2. The structure is given a name as Configuration B. Stub1 has a dimension of *l1* x *w1* while stub2 has a dimension of *l2* x *w2*. The distance between stub1 and stub2 is 1 mm. Figure 3(b) shows the insertion loss results of Configuration B when *l1*=9 mm and *l2*=7 mm. Value of *w1* and *w2* is fixed at 1 mm. The low-pass response is achieved from 2 GHz to 5 GHz. By adding an additional slot, the stop band frequency range is wider compared to having only one slot. For example, the band-stop is achieved from 4.8 GHz to 6.1 GHz using Configuration A (*l1*=9 mm). Meanwhile, by using Configuration B (*l1*=9 mm, *l2*=7 mm), the band-stop covers from 4.9 GHz to 8.0 GHz. The introduction of stub2 has helped to create a stopband at higher frequency.

(a)   (b)   (c)
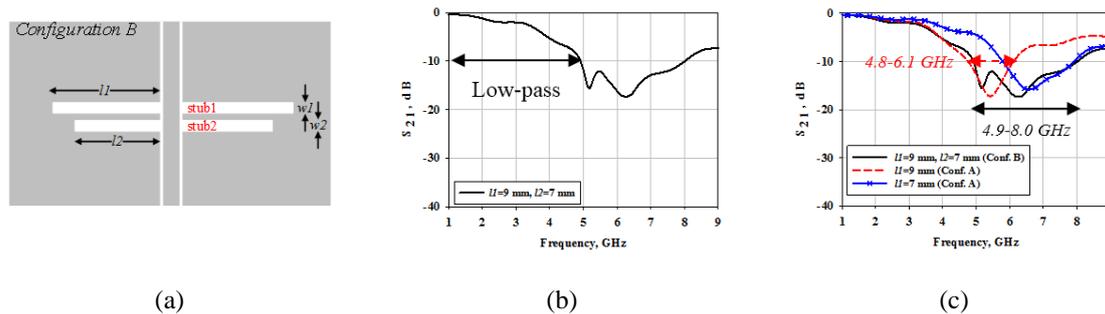
Figure 3. (a) Configuration B - dual-lines, rectangle slot (b) S_{21} result when *l1*=9, *l2*=7 (b) S_{21} result; configuration B vs configuration A

Figure 4(a) has three stubs where the size of stub1 is *l1* x *w1*, stub2 is *l2* x *w2* and stub3 is *l3* x *w3*. The structure is denoted as Configuration C. The distance between each stub is 1 mm. Figure 4(b) shows the insertion loss result of Configuration C when *l1*=12 mm, *l2*=9 mm, *l3*=7 mm. Value of *w1*, *w2* and *w3* is fixed at 1 mm. With this configuration, the band-stop is now wider which covers from 3.7 GHz to 7.8 GHz.

Quad-lines, the rectangle shape shown in Figure 5(a) has one additional stub compared to the triple stub known as stub4. This structure is known as Configuration D. The size of stub 4 is *l4* x *w4*. The rest of the stubs are the same as previous Configuration C. The Band-stop from 3.7 GHz to 9.0 GHz is now achieved when *l1*=12 mm, *l2*=9 mm, *l3*=7 mm, *l4*=6 mm as shown in Figure 5(b). Value of *w1*, *w2*, *w3* and *w4* is fixed at 1 mm. The distance between each stub is 1 mm. Therefore, it can be concluded that when an additional rectangular shape slot is added to the filter structure, multiple stopbands are achieved and the combination of these stopbands make the bandwidth of the band-stop become wider.

(a)   (b)

Figure 4. (a) Configuration C - triple-lines, rectangle slot (b) S_{21} result;
configuration C vs configuration B

(a)   (b)

Figure 5. (a) Configuration D - quad-lines, rectangle slot (b) S21 result;
configuration D vs configuration C

2.2. Combined dual-, triple- and quad-lines rectangle-shape of filter

Figure 6(a), Figure 6(b) and Figure 6(c) show the combination of dual-, triple- and quad-lines into one unit of the resonator namely Configurations E, F and G respectively. There are two connecting boxes known as boxt and boxr. The dimension of the boxt is lt x wt while the boxr is lr x wr as shown in Figure 6(d) and Figure 6(e) respectively. In this paper, the size of the boxt is fixed at 1 mm x 1 mm while the size of the boxr is fixed at 2 mm x 1 mm, unless it is mentioned otherwise.

Figure 7(a) show the S_{21} result of Configuration E when the length of $l1$=9 mm and $l2$=7 mm while $w1$=$w2$=1 mm. The result is compared to Configuration B with the same length of $l1$, $l2$, $w1$ and $w2$. By having connecting part, the filter result of Configuration E is different, even though the length is same as Configuration B. Therefore, to analyze the result obtained in Figure 7(a), both of the rectangular slot length in Configuration B are added by 1 mm. As a result, Configuration E with $l1$=9 mm and $l2$=7 mm produced quite same bandwidth size with the filter of Configuration B; $l1$=10 mm and $l2$=8 mm. When boxt and boxr is added to the antenna structure, the insertion loss of the filter will produce a slight notch (blue circle) as shown in Figure 7. The notch occurs depending on the distance between each stub (e.g. wr and wy). The wider the width between the stubs (e.g. distance between stub1 and stub2 or between stub2 and stub3), the smaller the bandwidth of the notch will be produced as shown in Figure 7(c).

The insertion loss result of Configurations F and G are shown in Figure 8. Both of the results are being compared with the same length of stubs but different in configurations. Configuration F is compared with C while Configuration G is compared with D. As expected from Figure 7, results in Figure 8 also have a slight notch coming from the distance between each slot (e.g. wr and wy). This will prevent the filter to have wide bandwidth for the band-stop. Therefore, Configuration D is the best results so far in term of bandwidth performance. However, the filter requires four pairs of switch to turn on and off the filter later on.

(a)   (b)   (c)

(d)   (e)
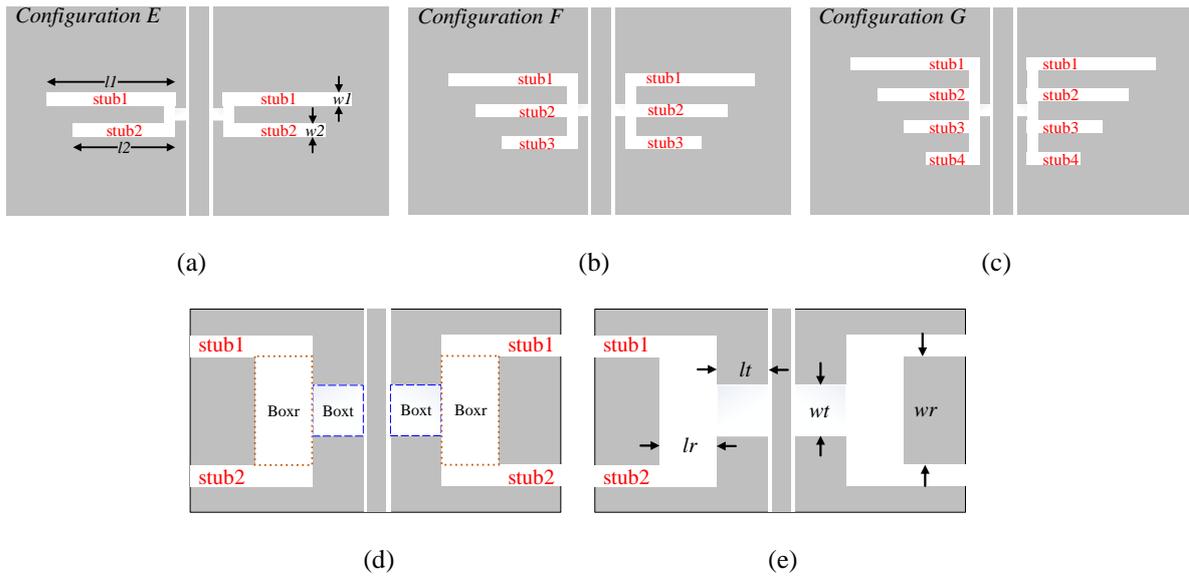
Figure 6. Combined rectangle slots' shapes (a) Dual-lines (b) Triple-lines (c) Quad-lines (d) Zoom-in boxt and boxr (e) Dimension of boxt and boxr

(a)   (b)   (c)
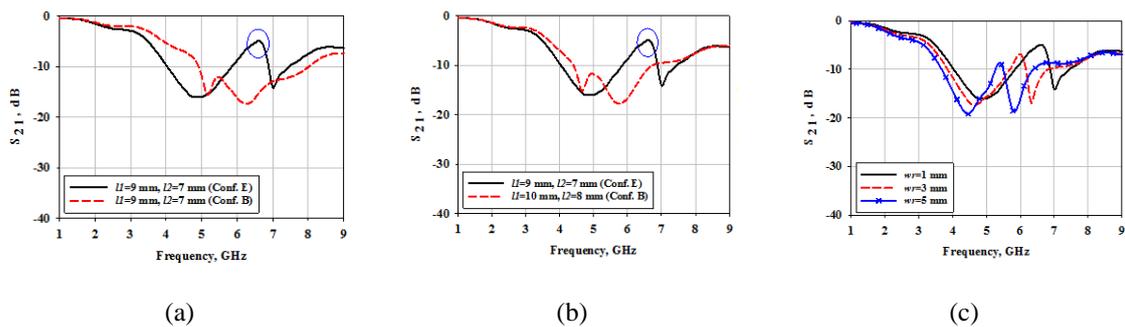
Figure 7. S_{21} results of (a) Configuration E vs configuration B – same length (b) Configuration E vs configuration B – different length (c) Configuration E ($l1$=9 mm and $l2$=7 mm), vary wr

(a)   (b)
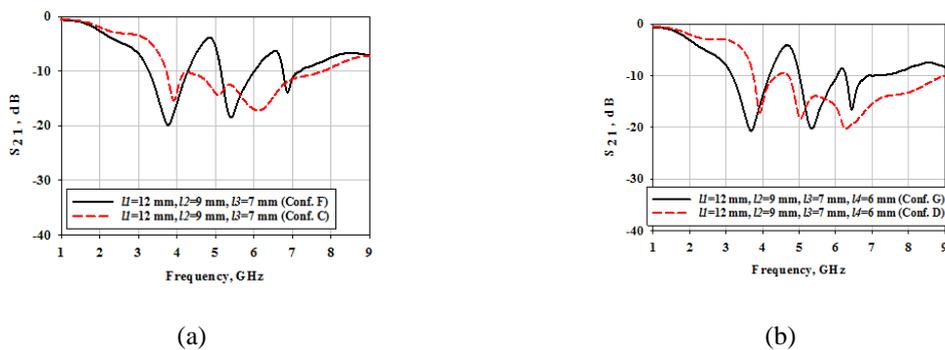
Figure 8. S_{21} results of (a) Configuration F vs configuration C (b) Configuration G vs configuration D

2.3. Other configuration of filter

In this paper, another possibility of configuration is investigated to achieve a better result in term of the insertion loss, S_{21}. For example, a combination of one Configuration E and one Configuration A will produce the Configuration J as shown in Figure 9(a). Other configuration as shown in Figure 9(b) is a

combination of one Configuration E and two Configuraions A will produce Configuration K. Lastly, Figure 9(c) is a combination of two units of Configuration E to become a Configuration L. Because of Configuration L have two units of connecting part, the upper unit of connecting part is known as boxt and boxr while the lower unit is known as boxv and boxy.

(a)   (b)   (c)
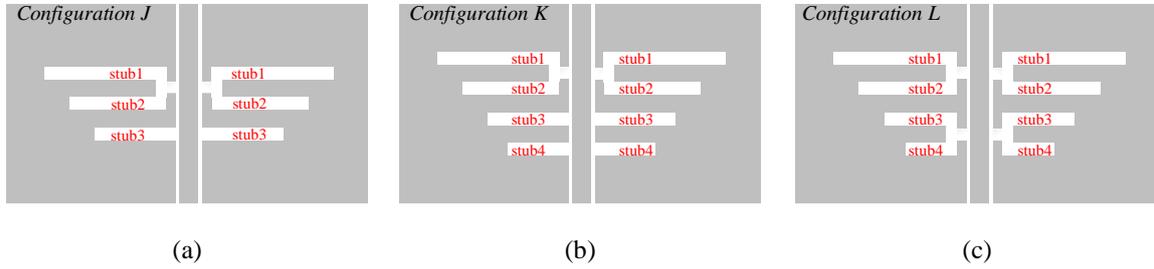
Figure 9. Rectangle slot shape (a) Combine dual and single-line (b) Combine dual and two single-line
(c) Two units of combine dual-lines

        Based on Figure 10, we noticed that the Configuration L provide better performance in terms of bandwidth compared to Configuration K. Configuration J, with the size of *l1*=12 mm, *l2*=9 mm and *l3*=7 mm have the stopband results from 3.39 GHz to 4.10 GHz and 5.12 GHz to 7.67 GHz as shown in Figure 10(a). The maximum ratio for Configuration J is 1.5:1.
        Configuration K, with the size of *l1*=12 mm, *l2*=9 mm, *l3*=7 mm and *l4*=6 mm has a stopband ranging from 3.44 GHz to 9 GHz with the ratio of 2.62:1 as shown in Figure 10(b). Figure 10(c) shows the stopband result from 3.41 GHz to 9 GHz for Configuration L with the ratio of 2.64:1. Configuration L has the same length as Configuration K but different in shape. Therefore, Configuration L is chosen because it can provide wider bandwidth and less switch is used compared to Configuration D. The bandwidth of band-stop can be improved by selecting the right length of the rectangular slot shape and the width of the distance between each slot.

(a)   (b)   (c)
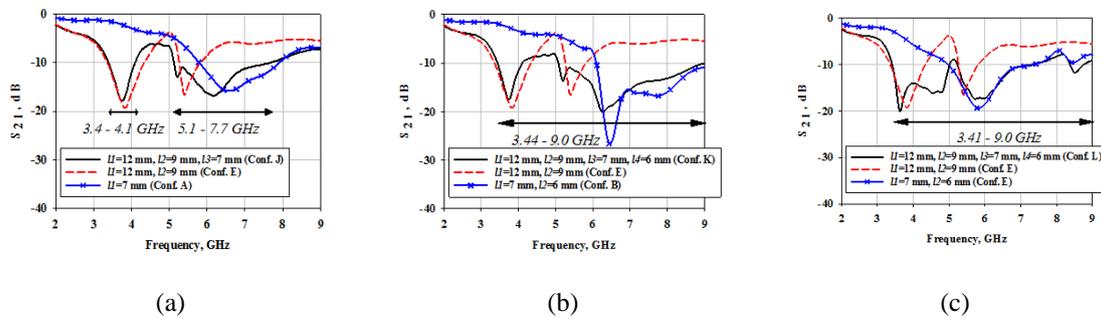
Figure 10. S_{21} results of (a) Configuration J vs configuration E and configuration A (b) Configuration K vs
configuration E and configuration B (c) Configuration L vs configuration E

3.   FINAL DESIGN OF PROPOSED FILTER
        Figure 11(a) shows the final design of the proposed filters. Zoom-in views of the upper and lower connecting part are shown in Figure 11(b) and Figure 11(c). The dimensions of the filter are listed in Table 1. In this design, the filter should have a band-pass result from 1.5 GHz to 3.0 GHz. This is because, the higher order modes will be eliminated when the filter is applied to an antenna structure. Figure 11(d) shows the photograph of the fabricated filter using FR4 substrate with a thickness of 1.6 mm.

(a) (b)

(c) (d)
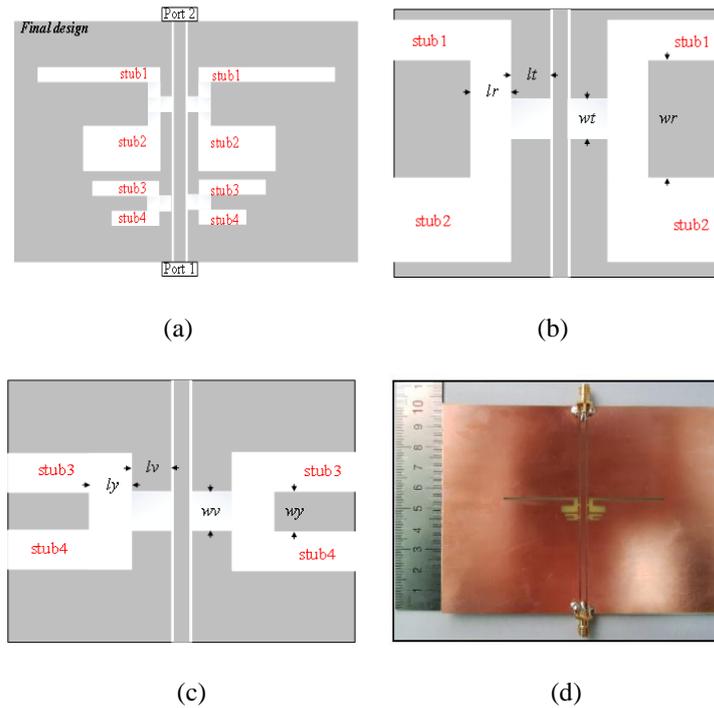
Figure 11. (a) Final design of the proposed filter (b) Zoom-in view of the upper connecting part (c) Zoom-in view of the lower connecting part (d) Photo of the fabricated filter

Table 1. Dimensions of the Final Design

Parameter	Size (mm)	Parameter	Size (mm)	Parameter	Size (mm)	Parameter	Size (mm)
l	150	w	100	f	3	g	0.5
l1	40	l2	9	l3	7	l4	6
w1	1	w2	3	w3	1	w4	1
lt	1	lr	2	lv	1	ly	2
wt	1	wr	3	wv	1	wy	1

Figure 12 shows the simulated and measured results of the final design of the proposed filter as shown in Figure 11(d). The results show good agreements between simulation and measurement. The insertion loss in Figure 12 shows that the band-pass is measured from 1.35 GHz to 3.31 GHz against that of the simulated result ranging from 1.38 GHz to 3.29 GHz. Two transmission zeroes are created near the passband. The 10 dB rejection band therefore is extended to 9 GHz, for both simulated and measured results.
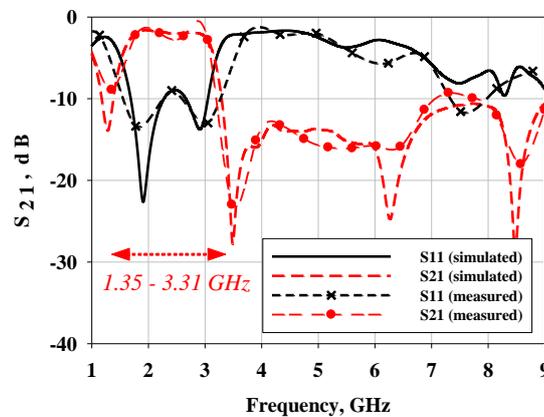
Figure 12. Simulated and measured S_{11} and S_{21} results of the proposed filter

4.   CONCLUSION

A new design of band-pass filter with harmonic suppression is presented. The proposed filter is achieved based on connecting two shape of the rectangular-slot into one unit of filter known as a U-shaped slot. By having two pairs of U-shaped slots, the filter has a wider rejection band from 3.33 GHz to 9 GHz. The proposed filter shows that it can eliminate the harmonic frequencies effectively.

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