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RESEARCH ARTICLE

Design of microstrip hairpin bandpass filter for 2.9 GHz – 3.1 GHz S-band radar with defected ground structure

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Abstract

Radar has been widely used in many fields, such as telecommunication, military applications, and navigation. The filter is one of the most important parts of a radar system, in which it selects the necessary frequency and blocks others. This paper presents a novel yet simple filter design for S-band radar in the frequency range of 2.9 to 3.1 GHz. The center frequency of the filter was designed at 3 GHz with a bandwidth of 200 MHz, insertion loss larger than -3 dB and return loss less than -20 dB. Fifth order microstrip hairpin bandpass filter (BPF) was designed and implemented on Rogers 4350B substrate which has a dielectric relative constant value of (ε_r)= 3.48 and substrate thickness of (h) =1.524 mm. One element of the square groove was added as Defected Ground Structure (DGS) which can decrease the filter size, reduce harmonization, and increase return loss. Two scenarios were used in the measurement, i.e. with and without enclosed aluminum casing. Results showed that BPF without casing obtained the insertion loss of -1.748 dB at 2.785 GHz and return loss of -21.257 dB in the frequency range between 2.785 to 2.932 GHz. On the other hand, BPF with casing shows a better performance, in which it obtained the insertion loss of -1.643 dB at 2.921 GHz and return loss of -19.529 in the frequency range between 2.820 to 3.021 GHz. Although there is small displacement of frequency and response value between the simulation and implementation, our BPF has the ability to work on S-band radar with a frequency range of 2 to 4 GHz.

Keywords: Microstrip bandpass filter, fifth-order hairpin, square groove DGS, return loss, S-band radar

INTRODUCTION

Communication technology such as wireless and radar system requires a high-performance bandpass filter (BPF) at the microwave frequency spectrum. The BPF performance should have a low insertion loss and a wide stopband characteristic (Srisathit, Tangjit, & Surakampontorn, 2010; Wong & Lum, 2012). BPF microstrip structure plays an important role in microwave communication system due to its ability to work at high frequency. Microstrip filter has various advantages, such as small and light size, a neat structure, affordable price, and easy to be integrated with other components (Singh *et al.*, 2012). The BPF is implemented in a hairpin form because of its neatly arranged structure so that it can be easily designed and implemented (Wong & Lum, 2012). The hairpin form is modified from parallel-coupled lines, in which a half-wavelength resonator is bent to make a "U" shape and make it more compact (Hong, J. S. & Lancaster, 2001; Wong & Lum, 2012; Zakriti *et al*., 2013).

Various researches have been conducted on the development of microstrip BPF with good performance, compact size, and affordable price. There are several prominent technologies available, such as Low-Temperature Co-fire Ceramic (LTCC), Low-Temperature Co-fire Ferrite (LTCF), as well as some new structure to further improve the quality like the Photonic Band Gap (PBG), Defected Ground Structure (DGS), and Substrate Integrate Wave-guide (SIW) (Khandelwal *et al.,* 2017) (Shaman *et al*., 2016) (Weng *et al*., 2008). Specifically, DGS has been much studied and developed as one of the promising technique in Electromagnetic Bandgap (EBG). Therefore, in this paper, 1-element square groove DGS was implemented on BPF microstrip hairpin in the frequency range of 2.9 to 3.1 GHz. The frequency range is suitable for S-band radar and is normally used in communication, maritime weather, and navigation. Firstly, the design specification was simulated and optimized. Secondly, the proposed filter is then implemented on the Rogers 4350B substrate. Finally, enclosed aluminium casing was added to further reduce the signal and noise interference, and subsequently improve the filter performance.

LITERATURE REVIEW

Radar

The concept of radar is relatively simple, in which it operates by transmitting the electromagnetic energy and subsequently detecting the echo resulting from the object reflection. If the object moves, the radar will follow its track and predict the location of the object. Radar is an active equipment which uses its own transmitter, unlike many other optical sensor and infrared. Radar can detect the relatively small object whether from afar or a close distance in any possible weather conditions

(Skolnik, 1990). At first, radar was developed to fulfil the military needs to monitor and control the weapons. Radar technology is being developed from time to time. Today, the main usage of radar is for travelling safety such as planes, ships, and spaceships, also for long-distance sensing such as for detecting the weather condition (Skolnik, 1990).

The radar transmits pulse which is layered to a Radio Frequency (RF) carrier and then receive a reflection from the scatterer both the wanted and unwanted ones. The appropriate and expected target scatterers can include space, air, sea, or surface based vehicle(Griffiths *et al.*, 2015). Recently, radar application is used widely in various fields. Table 1 shows the wide range use of radar application depends on its operating frequency range (Bruder, Carlo, Gurney, & Gorman, 2003).

Table 1 Radar frequency band and its typical usage.

IEEE Band Designation	Frequency Range	Typical Usage and Characteristics
HF	3-30 MHz	Over the horizon surveillance; *low range and low resolution*
VHF	50-330 MHz	Long range (Line of Sight) surveillance, Foliage penetration (FOPEN), counter-stealth, ground penetrating; *low/medium resolution*
UHF	300-1000 MHz	Long range surveillance, FOPEN; *low/medium resolution*
L	1-2 GHz	Long range surveillance, Long-range air traffic control; *medium resolution and small weather effects*
S	2-4 GHz	Moderate-range surveillance, terminal air traffic control, long-range weather observation, airborne early warning (AEW); *moderate weather effect in heavy precipitation*
C	4-8 GHz	Long-range tracking, weather observation, weapon location; *increased weather effect in light/medium rain*
X	8-12 GHz	Short-range tracking, missile guidance, mapping marine radar, airbone intercept, battlefield surveillance, weapon location; *reduce to short range operation in rain*
Ku	12-18 GHz	High-resolution mapping, satellite altimetry, man-portable/unmanned air vehicle (UAV) radar; *short range due to water vapor absorption*
K	18-27 GHz	Police radar; *very limited use due to high water vapor absorption*
Ka	27-40 GHz	Short-range very high-resolution mapping, airport surveillance; *short range due to water vapor absorption*
V	40-75 GHz	Scientific remote sensing; *high water vapor absorption*
W	75-110 GHz	Automobile cruise control (77 GHz), missile seekers, very high-resolution imaging (94 GHz); *high water vapor absorption elsewhere in the band*
Mm	110-300 GHz	Experimental; *limited to short range due to high water vapor absorption*

Table 1 shows that in order to fulfil the surveillance needs, characterize the long-term weather, air-bone early warning (EAW), and air traffic control terminal, it all needs a radar that works at the S-band frequency within the range of 2 – 4 GHz (Bruder *et al.*, 2003).

Filter

The filter is an arrangement used to filter or strain certain frequency and let the necessary frequency to pass through while eliminating the unnecessary ones. The filter is also an electric network that changes the characteristic of amplitude and/or signals phase in form of frequency(Pozar, 1998).

The filter is used to controlling the frequency response of a Radio Frequency (RF) system or microwave by letting the shipping at the frequency of the passband and the damping inside the bandstop. In every filter group created, they will be influenced by the filter parameters which are work frequency, input/output impedance, cut-off frequency, steepness, bandwidth and ripple (Hong, J. S. G. & Lancaster, 2004; Rhea, 1995; Thede, 2004).

In the actual work, the perfect filter response is impossible to achieve because of the physical characteristic of its components. There is no perfect component so that there will be no perfect filter. But the arrangement of the filter can be designed close to perfect with a perfect way (Bowick, 1982).

Filter Response

The filter can be categorized, based on the passband response characteristic, as Butterworth, Chebyshev, Bessel, Gaussian and others (Kinayman & Aksun, 2005). In this research, the approach used is the Chebyshev response, because it has a better selectivity compared to the Butterworth response. Chebyshev response has a constant ripple in the passband's area while Butterworth response does not have any ripple in the passband's response. Moreover, the Chebyshev response produces a high level of steepness from its passband to the stopband (Bowick, 1982; Hong, J. S. G. & Lancaster, 2004).

Filter Parameter

Some of the parameters used to evaluate the performance of any filter are the S-parameter, return loss, insertion loss, and VSWR (Voltage Standing Wave Ratio) parameters. The S parameter is a very important concept in microwave design because it is easy to measure and can work well under high frequency (Bowick, 1982; Pozar, 1998). Return loss is a loss of the quantity of power which is reflected back to the source due to transmission barrier or an unmatching combination. Insertion loss is a loss of some power which transferred to load due to its component combination. Return loss and insertion loss can be put as dB. VSWR is a comparison between the maximum voltage amplitude towards standing wave minimum voltage amplitude (Kinayman & Aksun, 2005). Bandwidth is a difference between upper and lower frequency on a combination when the amplitude response is 3 dB under bandpass response (Bowick, 1982). The Illustration of bandwidth can be seen in Fig 1.

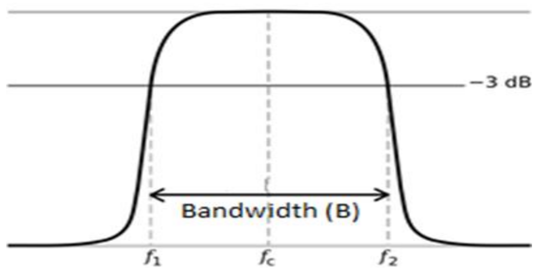

Fig. 1 Bandwidth calculating method.

The lower frequency (f_1) is the initial value of frequency from the working frequency while the upper frequency (f_2) is the final score from the working frequency.

Microstrip Line

Them microstrip line is a transmission media which is used in the RF circuit and microwave. When the microstrip measurement is subtracted, so that the dimension becomes smaller than the wavelength, therefore the microstrip can be used as the lumped element. The important parameter in designing the transmission line is the impedance characteristic (Gotsis & Kortezi), dielectric effective constant (ϵ_{re}), attenuation ($\propto$), discontinuity reactance, disperse frequency, expected wave at the surface, and radiation. Microstrip is a transmission line which consists of a conductor strip and a ground plane separated by the dielectric. The microstrip is generally used because it is easier in manufacturing and the losses emerged is relatively lower than the lumped combination (Pozar, 1998).

Hairpin-Line Bandpass Filters

Hairpin-Line bandpass filters are the filter which has a neatly arranged structure. This filter has a concept achieved by using the resonator folds from parallel-coupled, half-wavelength resonator filters, and have the "U" shape. The consequence is that the design looks similar to the one for a parallel-coupled and half-wavelength resonator. As for the resonator folds, it is important to estimate the reduction from the length of a coupled-line which can reduce the coupling between the resonators. Similarly, if both of the Hairpin resonator's arm are counted carefully, they function as a set of a coupled line which has a good influence in a coupling. Fig. 2 shows the configuration of Hairpin BPF (Hong, J. S. & Lancaster, 2001; Kinayman & Aksun, 2005).

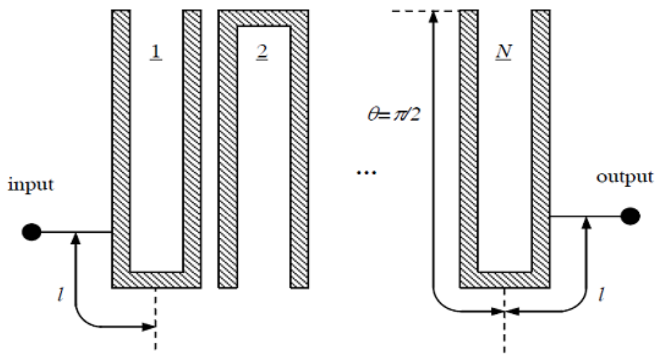

Fig. 2 Hairpin BPF configuration.

The microstrip hairpin BPF has been implemented many times, with various techniques and goals. Each development cycle will try to improve the performance parameters. Wong, C.Y. *et al.* (2012) produced BPF using a hairpin resonator arranged on two separate layers with the same substrate FR-4. The arrangement of 2 layers is intended to control the effect of vertical and horizontal coupling (Wong & Lum, 2012). On the other hand, Eugene A. O. *et al*, (2015) implemented BPF through a combination of hairpin form with patch resonator. The patch addition technique causes the increasing of capability in frequency selectivity through an independently controllable transmission zero. As a result, there is no significant difference between the simulation results and the realization results (Ogbodo *et al*., 2015). Another technique to maximize the performance of the BPF hairpin filter is to select a good substrate material. Abhay Purohit, et al, (2015) undertook BPF development research using two substrate materials for S-Band radar applications. In its development, it uses a Chebyshev response with a ripple of 0.5dB. The use of a different substrate proved to give different performance results (Purohit & Toshniwal, 2015). Another technique to improve the performance of hairpin BPF is to adjust the filter dimension, the distance between the resonator and the addition of the square groove technique (Srisathit, K. & Tangjit, J. 2010).

Defected Ground Structure (DGS)

DGS is a pattern sketched on the ground plane. The structure of DGS usually used at the filter combination in a microstrip line which will reject a particular frequency or bandgap. The DGS method is done to change the nature of wave by making one or more pattern at the ground plane. DGS is one of the EBG (Electromagnetic Bandgap) ways to suppress the surface wave which often used at the microstrip antenna. The DGS structure has been used at the microstrip line which rejects particular frequency (Khandelwal *et al.*, 2017; Zulkifi *et al.,* 2010). DGS will suppress the surface wave by omitting (Petchsawang & Duchon, 2009) some part of the ground plane (Weng *et al.*, 2008; Zulkifi *et al.*, 2010). The purpose of designing BPF by adding DGS can minimize the filter size and omit the harmonics as well as increase return loss value from the filter (Breed, 2008).

DGS form is modified from a simple slot to a much complex one. A lot of patterns/forms can be cast at the ground plane which later can be used as the DGS unit. The casted pattern will distract the distribution flow and change the antenna impedance. This kind of distraction can change the characteristic of microstrip transmission because the DGS unit can be represented by using the equivalent circuit of capacitance and inductance (LC) (Khandelwal *et al.*, 2017). Today, there are many experimented DGS forms such as the *slot, meander lines, slot variat*ions, spiral head, arrowhead-slot, "H" shape slots, inter-digital DGS, and various dumbbell shapes (Breed, 2008; Weng *et al.*, 2008). The addition of DGS to the BPF hairpin aims to achieve the tight bandwidth value and suppress the high harmonic distortion value (Boutejdar *et al.,* 2007; Vidya, K. & Jayanthy, T., 2011). The square groove technique is one of an example of the DGS form. The development of square groove technique aims to reduce the spurious and harmonic distortion value. The size of the square groove can be controlled in order to get the best result. The length of the square groove can be adjusted so that it minimalizes the resonance frequency. Other DGS structure such as dumbbell can also suppress the harmonic distortion, in which it is able to suppress the harmonic distortion at the second and third order at the five pole hairpin microstrip (Vidya, K. & Jayanthy, T., 2011).

Methodology/Materials

Designing the hairpin microstrip BPF is done by adding the DGS which operates at the center frequency of 3 GHz. DGS is one of the developing technique from EBG to suppress the surface wave which often used at the microstrip antenna. Resonator model used in this filter is the 1 element square groove. The square groove form of DGS technique produces a smaller filter dimension and can omit the harmonic distortion and increase the value of return loss(Breed, 2008). The research stages refer to Fig. 3.

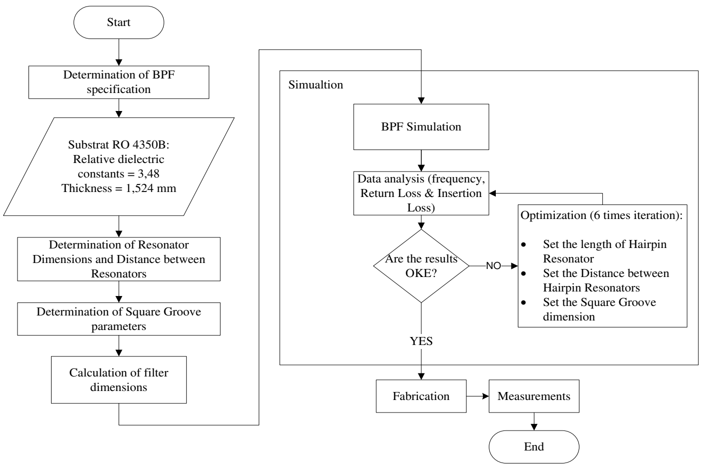

Fig. 3 Research methodology.

Filter specification

Filter specification used in designing the BPF is shown in Table 2.

Table 2 Filter specification.

BPF Parameters	Value
Frequency *start* (*f_1*)	2.9 GHz
Frequency *stop* (*f_2*)	3.1 GHz
Frequency *center* (*fc*)	3 GHz
Bandwidth	200 MHz
Return loss	≤ -20 dB
Insertion loss	≥ -3 dB
VSWR	1.22
Filter Order	5
Frequency Response	*Chebyshev*

The hairpin BPF design is embodied by the microstrip line. Substrate Rogers 4350B is used for the microstrip line with the specification shown in Table 3.

Table 3 Substrate specification used.

Substrate	*Rogers* 4350B
Dielectric effective constant (ε_r)	3.48
thickness (*h*)	1.524 *mm*
Loss tangent dielectric (δ)	0.004

Filter order is set according to the Chebyshev approach. In this research, it is set in the 5th order. Using the Chebyshev table for ripple 0.1 dB, the value of the prototype element is obtained as follow:

$g_0 = g_6 = 1$
$g_1 = g_5 = 1.1468$
$g_2 = g_4 = 1.3712$
$g_3 = 1.9750$

Furthermore, designing the hairpin microstrip BPF with DGS method is started by deciding the filter dimension by counting the parameters already set such as the width, the length, and the distance between resonator, and sliding factor, so that the result can be achieved from the manual calculation with the existed formulas.

Resonator ˩idth

The value of W (the width of the resonator line) is achieved by using the following calculations. For $W/h \leq 2$, then

$$u = \frac{W}{h} = \frac{8exp(A)}{exp(2A)-2}, \tag{1}$$

where

$$A = \frac{Z_c}{60}\left\{\frac{\varepsilon_r+1}{2}\right\}^{0.5} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\,0{,}23 + \frac{0{,}11}{\varepsilon_r}, \tag{2}$$

and Z is the impedance characteristic and ε_r is the constant for the relative dielectric.

For $W/h \geq 2$, then

$$u = \frac{W}{h} = \frac{2}{\pi}\left\{(B-1) - ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r}\left[ln(B-1) + 0{,}39 - \frac{0{,}61}{\varepsilon_r}\right]\right\}, \tag{3}$$

where

$$B = \frac{60\pi^2}{Z_c\sqrt{\varepsilon_r}}, \tag{4}$$

Therefore the width of the resonator (W),

$$W = u \times h \tag{5}$$

where W is the estimation of a width of the microstrip line which is intended in accordance with Z_c, and h is the thickness of dielectric which depends on the type of substrate.

Effective Dielectric Constant (ε_{eff})

Effective dielectric constant ε_{eff} at the microstrip line can be decided using Eq.(6)-(8).

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1 + \frac{10}{u}\right)^{-ab} \tag{6}$$

where

$$a = 1 + \frac{1}{49} ln\left[\frac{u^4 + \left(\frac{u}{52}\right)^2}{u^4 + 0{,}432}\right] + \frac{1}{18{,}7} ln\left[1 + \left(\frac{u}{18{,}1}\right)^3\right], \tag{7}$$

$$b = 0{,}564\left(\frac{\varepsilon_r - 0{,}9}{\varepsilon_r + 3}\right)^{0{,}053}. \tag{8}$$

The length of Microstrip Lambda

Deciding the length of microstrip lambda can use Eq. (9) and (10),

$$\lambda_{air} = \frac{c}{f} \tag{9}$$

$$\lambda_{microstrip} = \frac{\lambda_{air}}{\sqrt{\varepsilon_{eff}}} \tag{10}$$

Sliding Factor

The value of sliding factor cannot be decided in a fixed value. But, it can be predicted by taking the best result using the Eq. (11) and (12),

$$\mathrm{b} = \frac{\theta^0}{360^0}\ \mathrm{x}\ \lambda_{\mathrm{microstrip}}, \tag{11}$$

and

$$\mathrm{S_r} = 2\ \mathrm{x}\ \mathrm{b} \tag{12}$$

The ength of Resonator

The length of the resonator is the length of the line used in the hairpin filter. Eq. (13) can be used to obtain the length of the resonator,

$$L = \frac{(90-\theta^\circ)}{360}\ x\ \lambda_{microstrip}. \tag{13}$$

The ₩ngth of 《ap

According to the shielding theory, the distance between the line to the side of shielding has to be more than 5 times the thickness of the dielectric substance. Eq. (14) is used to obtain the length of Tap.

$$The\ Length\ of\ Tap = 5\ x\ h \tag{14}$$

Distance between ✗esonator

To get the coupling coefficient, use Eq. (15),

$$Mi, i+1 = \frac{FBW}{\sqrt{gi.gi+1}} \tag{15}$$

Where M is the value of coupling coefficient and FWB is the bandwidth frequency and gi is the Chebyshev element at the i-th order.

Square Groove

The form of square groove dimension is half the width of its resonator. To get the value of square groove value, use Eq. (16),

$$W_r = \frac{1}{2}\,W. \tag{16}$$

Every stage of the research is done in a good and proper manner in order to get the best filter result. The design of BPF hairpin produced is shown in Fig. 4.

Referring to the calculation using existing specifications and equations, the BPF hairpin dimensions obtained are listed in Table 4.

The length of resonator L at 13.303 mm is acquired from L1+W+L2+1/2Sr on one side and L3+Wr+L4+1/2Sr on the other side. This result becomes the input for the simulation stage. The result of this design is evaluated and simulated by using the ADS 2011 software.

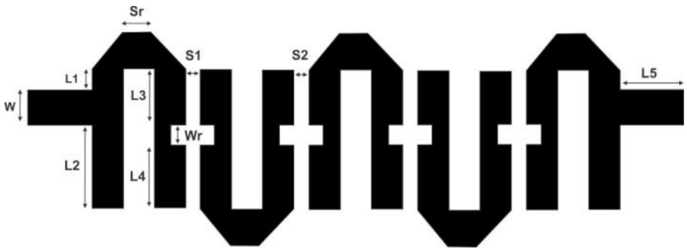

Fig. 4 hairpin layout.

Table 4 Calculated BPF parameter.

W(mm)	L1(mm)	L2(mm)	L3(mm)	L4(mm)	L5(mm)	S_r(mm)	W_r(mm)	S_1(mm)	S_2(mm)
4.312	1.5	5.828	4.742	4.742	7.26	3.326	2.156	0.159	0.121

RESULTS AND FINDINGS

Simulation

According to the result acquired from the parameter calculation, the next stage is a simulation which will be using the Advanced Design System (ADS) with the result shown in Fig. 5.

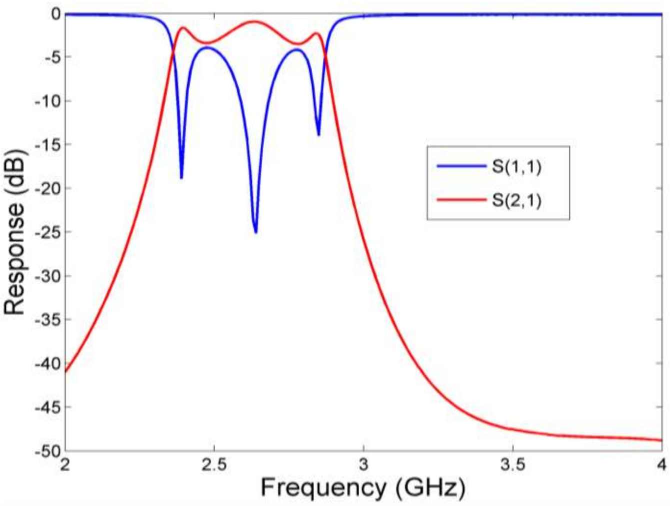

Fig. 4 Insertion loss and return loss of the first simulation results

Based on the above simulation, the frequency at the peak point is 2.78 GHz and the bandwidth is 120 MHz.

According to the simulation with the input from the calculation before, it can be seen that the acquired parameters are not yet in line with the designed specification. For instance, the decided specification is the value of insertion loss ≥ -3 dB, whereas the simulation result shows the value of insertion loss at -15.94 dB. Therefore, the simulation is further optimized in order to get the appropriate filter parameters in accordance with the specification.

Table 5 Insertion loss and return loss: Simulation of the first stage.

Response (dB)	f_1(2.9 GHz)	f_c(3 GHz)	f_2(3.1 GHz)
Insertion Loss (S2,1)	-7.11	-15.94	-31.58
Return Loss (S1,1)	-2.46	-1.17	-0.43

Optimizing Simulation

Optimizing simulation is conducted to obtain the appointed specification value by changing the resonator parameter. To meet the decided specification value, the optimization is run 6 times with the data of filter shown in Table 6. After the sixth optimization, the targeted specification has already been achieved.

The result of the 6th resonator optimization can be seen in Fig. 6. The result shows a suitability with the designed specification. The peak frequency is at 3 GHz with the insertion loss of -0.07 dB, return loss of -29.9 dB, and the bandwidth of 200 MHz. VSWR acquired is 1.07, better than the designed specification.

Table 6 Parameters value after optimalization.

Optimization to-	W (mm)	L1 (mm)	L2 (mm)	L3 (mm)	L4 (mm)	L5 (mm)	Sr (mm)	Wr (mm)	S1 (mm)	S2 (mm)
1	1	1	9	5	5.5	9	3.35	0.5	1	0.8
2	1	1.5	11.5	5.5	7	7	3.35	0.5	1.5	0.8
3	1	1.5	9	5.5	7	7	4.9	0.5	2	3.1
4	1	1.5	9	5.5	7	7	4.9	0.5	0.6	1.9
5	1	2	9	5.5	7	7	4.9	0.5	0.6	2
6	1	2.7	9	5.5	7	7	4.9	0.5	0.6	2

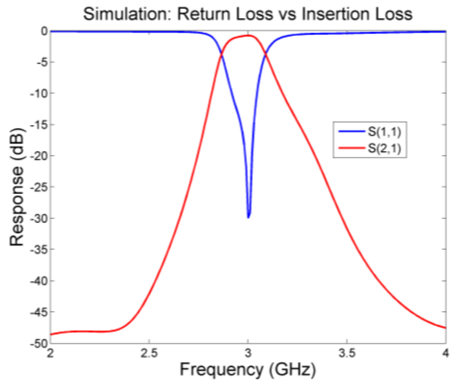

Fig. 5 Insertion loss and return loss of the 6th resonator optimization.

Table 7 shows the complete result of the 6th optimization.

Table 7 Insertion loss and return loss from the 6th optimization.

Response (dB)	f_1(2.9 GHz)	f_c(3 GHz)	f_2(3.1 GHz)
Insertion Loss	-1.76	-0.76	-4.62
Return Loss (dB)	-7.92	-29.98	-2.96

Realization

Filter realization/fabrication used Rogers 4350B substrate with the thickness of 1.524 mm and the dielectric constant of 3.48. The connector used in this filter realization is an SMA type because its characteristic is suitable for a small filter construction. Based on the optimization, the layout of hairpin BPF can be seen in Fig. 7.

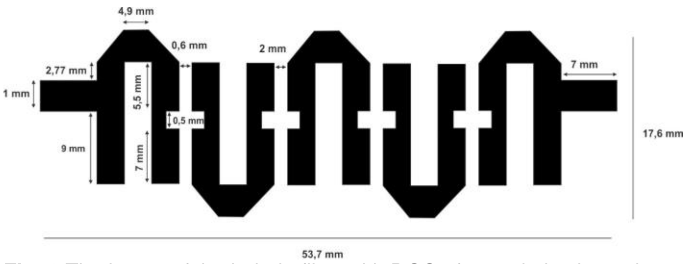

Fig. 6 The layout of the hairpin filter with DGS after optimization to be implemented.

The actual result of BPF hairpin printed with substrate roger 4350B is shown in Fig. 8.

Fig. 7 Actual result of BPF hairpin printed with substrate roger 4350B.

The filter performance parameters are measured on both conditions without and with aluminium casing.

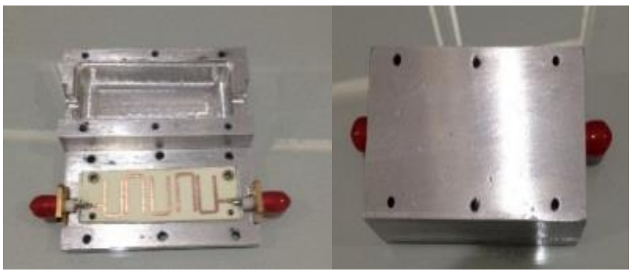

Fig. 8. Hairpin filter with DGS using aluminium casing.

Measurement Results

Measurement of BPF hairpin by DGS method was done by using ADVANTEST R3370 Vector Network Analyzer with the range of 3 kHz - 20 GHz. The measurement is performed to find out whether the filter specification matches with the appointed specification or not. The performance of BPF can be found out and analyzed based on the result of the measurement. The parameters used are insertion loss, return loss and VSWR. Before the filter is enclosed in an aluminium casing, the measurement of the return loss and insertion loss filter indicates a deviation from the simulation result. Fig. 10 shows the graph of return loss and insertion loss between the simulation results with the realization results without casing.

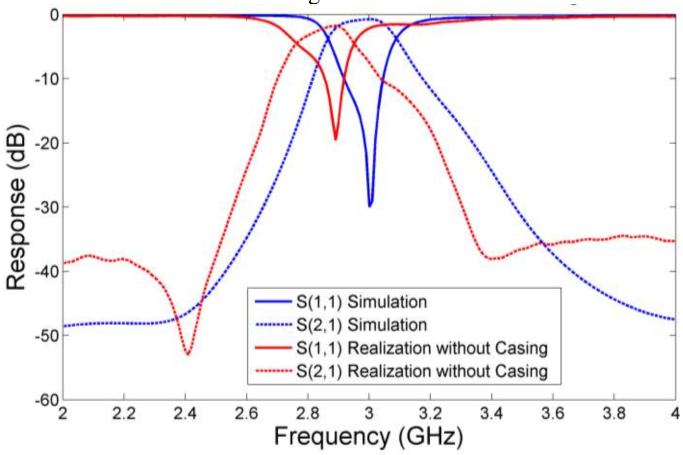

Fig. 9 Comparison of return loss and insertion loss between simulation result and realization result without casing.

Based on Fig. 10, it appears that the return loss value is still below the set value, which is equal to -21.257 dB at 2.883 GHz frequency and bandwidth of 147 MHz. The center frequency also shifts by 117 MHz, from 3 GHz to 2.883 GHz. Meanwhile, the insertion loss value of the filter without casing meets the specification with a value of -1.748 dB. After the addition of the casing, the acquired values of return loss and insertion loss is shown in Fig. 11.

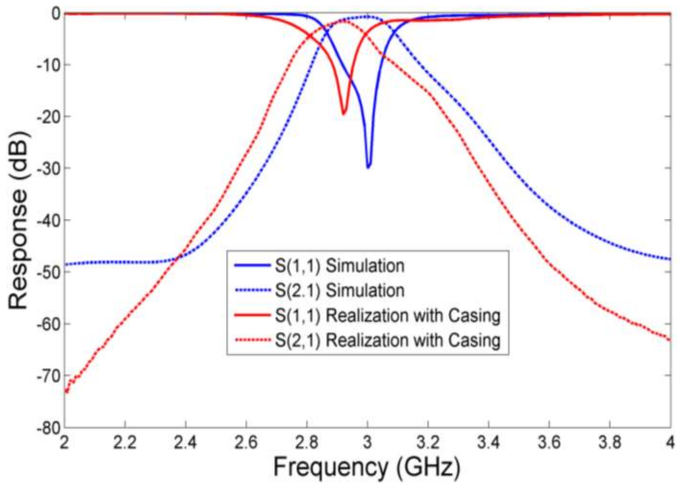

Fig. 10 Comparison of return loss and insertion loss between simulation result and realization result with the casing.

The figure shows the comparison of the value of return loss and insertion loss from the result of filter measurement with casing, and the result of the simulation. If compared, the value of return loss and insertion loss between the filter with the casing and without casing, it can be seen that the addition of the casing affects the return loss and insertion loss as shown in Fig. 12.

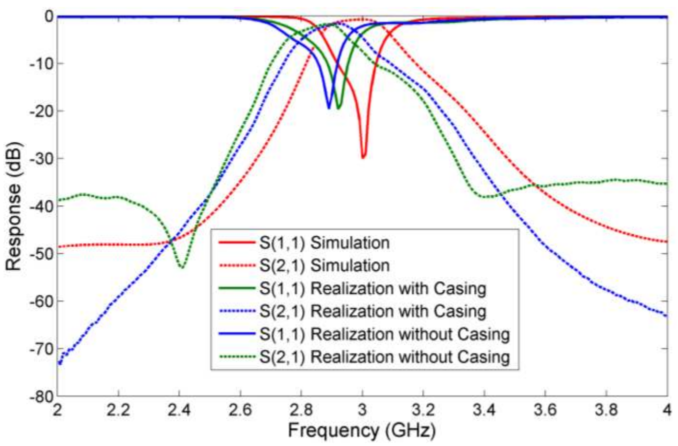

Fig. 11 Comparison of return loss and insertion loss between simulation, realization without casing and realization with the casing.

The measurement of filter bandwidth is done by looking at the range of insertion loss. Fig. 13 shows the result of measurement without casing, where the start frequency (f_1) is at 2.785 GHz and the stop frequency (f_2) is at 2.932 GHz. Therefore, the bandwidth acquired is 147 MHz as can be seen in Fig. 13.

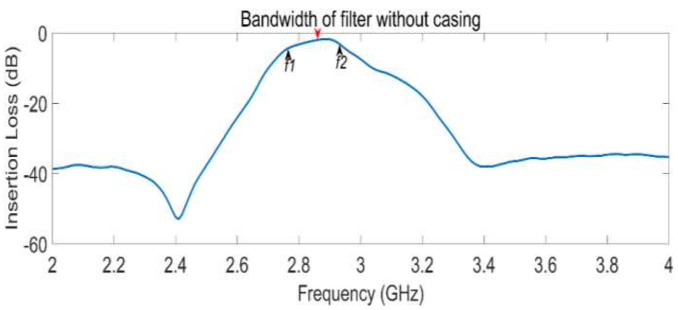

Fig. 12. The bandwidth of filter without casing.

After going through the fabrication process, it is found that the BPF parameter deviates from the appointed specification. Thus the aluminium casing is added in order to get the parameter value suitable with the specification already set. Bandwidth measurement with casing shows the start frequency (f1) is at 2.820 GHz and stop frequency (f2) is at 3.021 GHz. Thus the bandwidth acquired is 201 MHz as shown in Fig. 14. It is proved that from the bandwidth side, an addition of casing influenced for the betterment and improvement of bandwidth.

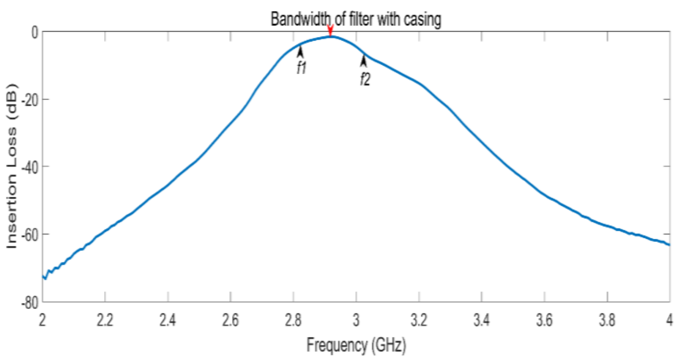

Fig. 13. The bandwidth of the filter with the casing.

The measurement of VSWR is done by looking at the graphic of return loss response. Fig. 15 shows the value of VSWR for filter without casing is at 1.189. This value can be seen at the top right in the figure.

Fig. 14. VSWR of the filter without casing.

Fig. 16 shows that the value of VSWR for a filter with casing is at 1.237. This value can be seen at the top right in the figure. The Fig. shows the influence of adding the casing towards hairpin BPF parameters.

Fig. 15. VSWR of the filter with a casing.

Table 8 shows the parameters data as the result of a simulation, the result of realization with and without the casing.

Table 8 Comparison of simulation and measurement result of hairpin BPF with DGS.

Parameter	Simulation Result	Without Casing Measurement	With Casing Measurement
Center frequency (f_c)	3 GHz	2.883 GHz	2.921 GHz
Frequency band	2.9 – 3.1 GHz	2.785 - 2.932 GHz	2.820-3.021 GHz
Bandwidth (f_2 - f_1)	(3.1 – 2.9) GHz BW= 200 MHz	(2.932 – 2.785) GHz BW= 147 MHz	(3.021-2.820) GHz BW=201 MHz
Return Loss	-29.98 dB	-21.257 dB	-19.529 dB
Insertion Loss	-0.76 dB	-1.748 dB	-1.643 dB
VSWR	1.07	1.189	1.237

CONCLUSIONS

The simulation, measurement, and analysis of the designed filter show that the addition of an enclosed aluminium casing can improve the characteristics of the designed filter. The addition of an enclosed aluminium casing causes the bandwidth to increase from 147 MHz to 201 MHz, the insertion loss changed from -1.748 dB to -1.643 dB, while the return loss changed from -21.257 dB to -19.529 dB. The simulation results show that BPF can operate in the range 2.9 - 3.1 GHz, in accordance with the appointed specification, but the measurement of BPF with the casing shows a slight shift of the frequency range to be 2.820 – 3.021 GHz.

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