Band-Pass Filter Microstrip at 3 GHz Frequency Using Square Open-Loop Resonator for S-Band Radar Applications

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Abstract

In telecommunication, filters are often used to pass the desired frequency. One of them is the Band-Pass Filter (BPF) which is passing signals between the upper cut-off frequency and the lower cut-off frequency. This research aims to make a band-pass filter that can pass 3 GHz frequency with a bandwidth of 200 MHz. This filter is designed with a square open-loop resonator simulated using Advanced Design System (ADS) software. The filter is made using FR 4-epoxy substrates with a dielectric constant (ε_r) of 4.6 and substrate thickness (h) of 1.6 mm. Based on the simulation results obtained in the form of a comparison graph between the response of magnitude to frequency, it shows that the value of the return loss (S_{11}) parameter of -23.549 dB, insertion loss (S_{21}) parameter value of -1.397 dB, and a slightly shifted middle frequency of 2.890 GHz. Then for the measurement results obtained a parameter value return loss (S_{11}) of -16.364 dB, parameter value insertion loss (S_{21}) of -3.561 dB with a center frequency of 3.185 GHz.

Keywords: bandpass filter, filter, microstrip, square open-loop resonator

I. INTRODUCTION

In a radio communication system, any device which employs radio wave for its propagation purpose needs a filter to opt the signal waves it uses. One type of filter that is often used in telecommunications equipment is a bandpass filter which is a filter that passes a signal within a certain range and will reject the frequency signal outside the specified range [1]. The bandpass filter itself is grouped into two parts, namely wide-band band-pass filter and narrow-band band-pass filter.

There are several researches on this area which have been done before. The first study was conducted to realize the bandpass filter with a hairpin method that works at a frequency of 3 GHz [2]. The second study was conducted to realize a microstrip bandpass filter with an octagonal hairpin shape that works at a frequency of 2.9 – 3.1 GHz with a resonant frequency of 3 GHz [3]. Then the third study was carried out by modifying the shape of the hairpin line with the addition of the Defected Ground Structure to have a value of 0 at the center frequency of 1.27 GHz [4]. The fourth study was carried out to design a tight microstrip bandpass filter on a U-shaped resonator [5]. The fifth study is the Compact Microstrip Dual-Band bandpass filter on the step resonator impedance for C-band applications [6].

The purpose of this research is to be able to design and realize a microstrip bandpass filter using an open-loop square resonator at a frequency of 3 GHz with a bandwidth of 200 MHz so that it can work at a frequency of 2900 MHz to 3100 MHz which can be applied to S-band radar and can produce desired values of return loss and insertion loss.

II. DESIGN OF THE FILTER

One important thing in making filters with microstrip media is determining the shape of the resonator to be used. In general, a resonator is a media that connects a source port with a load port.

A. Flowchart

In the process, the bandpass filter that is made has several stages as shown in Figure 1. The first step is determining the filter specification which includes filter frequency, filter bandwidth, filter resonator shape, the dimensions of the filter, and the substrate that will be used in the filter manufacturing.

The next one is the process of designing a square open-loop resonator made in the Advanced Design System (ADS) software along with the simulation of the design until the resonator design produces an output value of return loss and insertion loss as needed. However, when the results are not suitable, re-design, or re-modification of the design should be carried out until the results are obtained according to the needs. After the results are correct, the design will be brought to the

process of making a prototype of the square open-loop bandpass filter microstrip.

After that is the process of measuring the prototype filter that has been realized. Later, analyzing the results of the simulation and measurement of the filter to obtain a return loss and insertion loss value from the simulation results and the measurement results.

B. Square Open-Loop Resonator

A resonator will resonate at a certain frequency, then with the existence of that resonance, an RF wave will be channeled. In general, a resonator circuit can be made using inductors (L) and capacitors (C) and the magnitude of the resonant frequency between the circuit L and C is equal to $\frac{1}{\omega}\sqrt{LC}$ [7]. There are various kinds of materials and manufacturing technologies for making filters, one of which is the LC filter, which is a lumped element filter, then a planar filter, a coaxial filter, and a dielectric filter. LC filters are the simplest and have the smallest filter sizes, but the quality factor is so low that their performance will be poor. Planar filters are filters that are quite simple and easy to make [8].
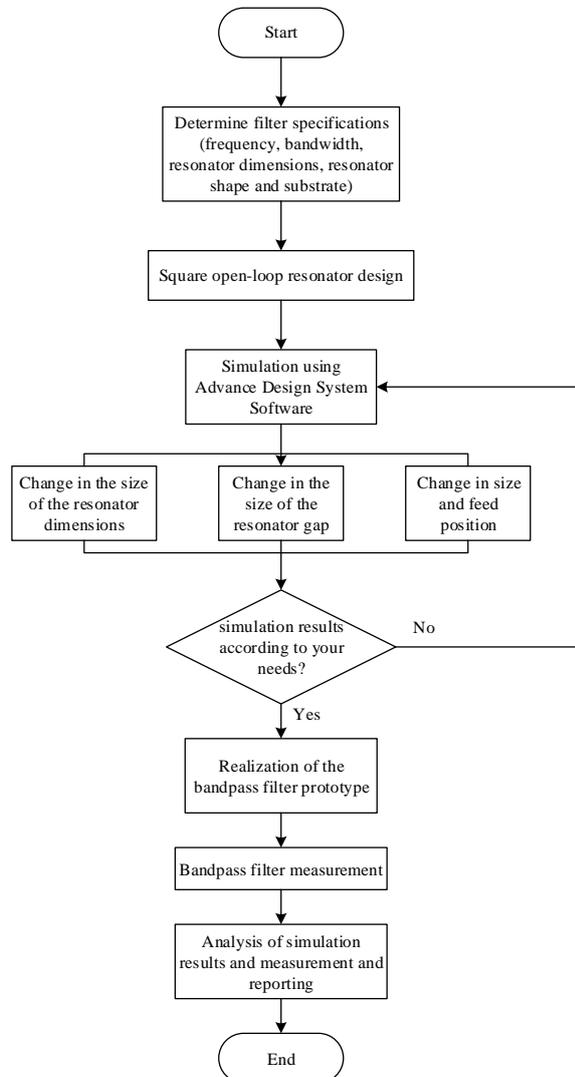
Figure 1. Flowchart

C. Microstrip Structure

In the design with microstrip media, the components L and C are realized using the form of a square open-loop resonator by bending a single straight resonator into a square, as shown in Figure 2. By bending it 90° will form a gap between the two ends of the resonator. So that the two of the ends of the resonator will form a capacitor that can store capacitance energy. Theoretically, for a resonator to resonate at the desired frequency, the length of a resonator must be ½ the wavelength [9].

The general structure of the microstrip is illustrated in Figure 3. The transmission line in the microstrip consists of a conductor strip of width *W* and thickness *t* and a ground-plane conductor at the bottom separated by a dielectric substrate having a dielectric constant of ε_r and thickness *h* [10].

D. FR 4-epoxy Substrate

FR 4-*epoxy* substrate has several material arrangements, at the very top there is a layer of air as the outer portion of the substrate, then the yellow layer at the top of the substrate is a copper conductor material that functions as a resonator path with a thickness (*t*) 0.035 mm, in the next section, the FR 4 layer with a dielectric constant (ε_r) is used, which is 4.6 with a thickness (*h*) of 1.6 mm, and the bottom part is the ground plane which is a conductor made of copper.

In this design, the FR 4 substrate is used as the material for making the band-pass filter. FR 4-epoxy substrate is most often used as an electrical insulator which has considerable mechanical strength because it has a non-zero air absorption rate. This FR 4 or Flame Resistant 4 substrate is also a fiberglass matting that serves with epoxy resin. FR 4 has low water absorption, good insulation property, and can withstand heat temperatures up to 140 degrees Celsius.
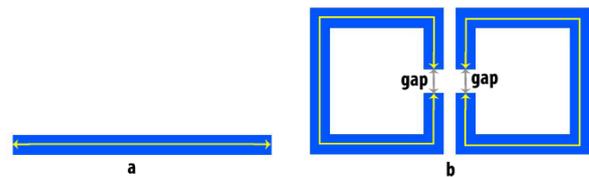
Figure 2. ½ λ_g Square Open-loop Resonator Design : (a) Single Straight Resonator, (b) Single Straight Double Resonators Bent 90° Facing Each Other.
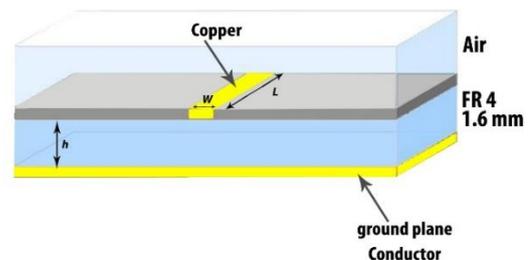
Figure 3. Substrate FR 4

E. Wavelength Calculation

In resonator design, to determine a frequency, the length of the resonator is made with a length of ½λ_g. This calculation uses the exact formula of Hammerstad and Jensen [11] as in (1).

$$\lambda_g = \frac{300}{f(GHz)\sqrt{\varepsilon_{reff}}} \; mm \qquad (1)$$

From (1), λ_g is the wavelength or length of the resonator transmission line, which later the results of these calculations are used in the design of the resonator shape as the reference length of the square open-loop resonator where the frequency is gigahertz and the effective dielectric constant is calculated as in (2).

F. Effective Dielectric Constant Calculation

The relative dielectric constant of the dielectric constant can be considered as a homogeneous medium and substrate replacement air medium. In (2), ε_{reff} is the effective dielectric constant of the type of substrate used, namely FR 4, with the variable ε_r as the substrate dielectric constant, and the variables a and b in (2) are in (3) and (4).

$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left(1+\frac{10}{u}\right)^{-a.b} \qquad (2)$$

$$a = 1 + \frac{1}{49}ln\left[\frac{u^4+\left(\frac{u}{52}\right)^2}{u^4+0.432}\right] + \frac{1}{18.7}ln\left[1+\left(\frac{u}{18.1}\right)^3\right] \qquad (3)$$

$$b = 0.564\left(\frac{\varepsilon_r-0.9}{\varepsilon_r+0.3}\right)^{0.053} \qquad (4)$$

III. FABRICATION, MEASUREMENT, AND DISCUSSION

Calculation of the input channel width of the FR4-*epoxy* material with $\varepsilon_r = 4.6$ and $Z_0 = 50\Omega$, where the equation approach for *W/h* is *W* for microstrip width and *h* for microstrip dielectric medium thickness. For the feed line width at the resonator, (5) is used as the initial design reference. To determine a frequency, the length of the resonator is made with a length of ½ λ_g using (1) with the effective dielectric constant using (2).

For parameter *u* in (2) and (3) is the data from the result of (5) with two conditions, namely when *u = W/h* ≤ 2 and *u = W/h* > 2. These results will later be used as an initial determinant of the design length and width in making the band-pass filter resonator in ADS software. It can be seen that there are two parameters for each dimension whose values are different. Because the size of the resonator to be made is desired to have a small size, the value of the *W/h* ≤ 2 is taken which can be seen in Table 1.

TABLE 1
RESONATOR SIZE BASED ON THE CALCULATION

Parameter	Transmission line dimensions (mm)	
	Length (L)	Width (W)
W/h ≤ 2	53.89	2.97
W/h > 2	51.91	4.69

A. Resonator Width Calculation

The calculation of the input channel width of the FR 4-epoxy material with $\varepsilon_r= 4.6$ and $Z_0 = 50\ \Omega$, A is the variable that needs to be calculated first to complete (5) where the equation approach for W/h, namely W for the microstrip width and h for the microstrip dielectric medium, is obtained from Wheeler [12] and Hammerstad [13] as in (6).

$$\frac{W}{h} = \frac{8e^A}{e^{2A}-2} \qquad (5)$$

$$A = \frac{Z_0}{60}\left[\frac{\varepsilon_r+1}{2}\right]^{0.5} + \frac{\varepsilon_r-1}{\varepsilon_r+1}\left[0.23 + \frac{0.11}{\varepsilon_r}\right] \qquad (6)$$

B. Design Specifications

As in Table 2, the bandpass filter work at a frequency between 2.90 GHz – 3.10 GHz with a center frequency of 3.00 GHz, a bandwidth of 200 MHz using microstrip technology with a resonator form, namely square open-loop. In determining the specifications for this bandpass filter, it is found that by having a resonant frequency of 3 GHz and a BW of 200 MHz, the filter that will be produced is a narrow-band bandpass filter.

The minimum return loss value is -13.979 dB based on the conversion of return loss versus voltage standing wave ratio (VSWR) where when the VSWR is at a value of 1.50 [14] because when the VSWR value has exceeded 1.50, it causes half of the power loss and the results of the response will be unfavorable. Therefore, according to Table 2, the value of the return loss (S$_{11)}$ parameter that must be generated is at least -10 dB to get bigger results, so that at the time of transmission, the power is reflected as little as possible, this will affect the output.

C. Resonator Design Layout for Simulation

The resonators in Figure 4 are made facing each other which is separated by a gap between the two ends of the resonator as in Figure 2 which shows a gap with a predetermined distance so that the parameter values that will be generated can reach a good state. The band-pass filter prototype realized in Figure 5 is the upper layer of the substrate, namely the conductor strip that has gone through a design fabrication process with etching sizes as shown in Table 3. Whereas Figure 6 is a part of the ground plane substrate with an additional 2 cm distance up and down from the conductor etching strip.

TABLE 2
BAND-PASS FILTER SPECIFICATIONS

Parameters	Value
Carrier Frequency (*f_c*)	3 GHz
Range Frequency	2.9 GHz – 3.1 GHz
Bandwidth	200 MHz
Return Loss (RL)	Minimum -10 dB
Insertion Loss (IL)	Maximum -3 dB
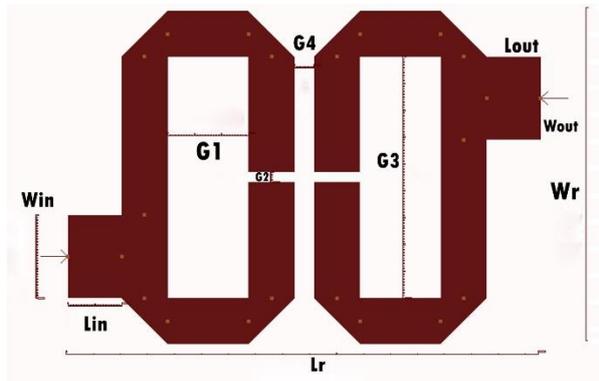
Figure 4. Layout Design of a 3 GHz Bandpass Square Open-loop Resonator Design.
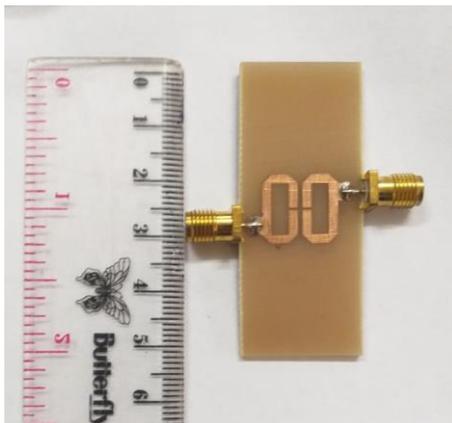
Figure 5. Conductor Strip 3 GHz Bandpass Filter Prototype.

Figure 6. Conductor Strip 3 GHz Bandpass Filter Prototype.

By bending it by 90 degrees as shown in Figure 4, and having a gap between the two ends of the resonator, this method can store capacitance like a capacitor properly. The modification process during simulation is very easy to do by only paying attention to the distance or gap between resonators, the change in the results at the time of modification can be seen clearly making it easier to observe changes in parameter values that are part of the changes that have been made. Then, a slight 45-degree crop at the corner end of the square open-loop resonator provides the advantage of suppressing signal attenuation when the transmission is as small as possible.

TABLE 3
SIZE MICROSTRIP FOR SIMULATION

Parameters	Sizes (mm)
W_f	1.7
L_f	23.625
W_r	12.4
L_r	17.521
W_{in}	3.1
W_{out}	3.1
L_{in}	2
L_{out}	2
G_1	3
G_2	0.37
G_3	9.1
G_4	0.721

TABLE 4
CHANGE IN SIZE DURING SIMULATION

Simulation	Dimensions (mm)				Connector (mm)			
	Gap				In		Out	
	1	2	3	4	L	W	L	W
I	3	0.1	8.1	0.234	2	2.6	2	2.6
II	3	0.4	8.1	0.580	2	3.1	2	3.1
III	3	0.37	9.1	0.721	2	3.1	2	3.1

Table 3 shows the size of the microstrip in Figure 4 to obtain the simulation result parameter values that were simulated using the Advance Design System 2011 software. The bandpass filter has been designed in the form of a square open-loop resonator with the size as in Table 3. The gap information in Table 4 is data from the distance measurement on the resonator, for G_1 is the distance from the inside width of the resonator from left to right, while G_3 is the inner distance from the square shape from top to bottom.

In Table 4 there are change sizes for parameters L_{in}, L_{out}, W_{in}, and W_{out}. L_{in}/L_{out} here is the measure for the length of the input/output connector, then for W_{in}/W_{out} is the size for the width of the feed. In Table 4, changes to L_{in} and W_{in} were made to see changes in the results of the return loss and insertion loss, as well as for L_{out} and W_{out} with the final positions determined as in Figure 4, where this is the best position to produce insertion loss and return loss parameter value.

The parameter G_2 is the distance between the two ends of the resonator which affects the result of the delivery, while the G_4 parameter is the two square open-loop resonators facing each other and have an effect on the resulting value of the reflection during transmission so that the transmission can be received properly without losing more than a half of its power. And parameter W_f is a measure for the width of the square open-loop resonator feed line while L_f is the length of one part of the square open-loop resonator. Whereas W_r is the width and L_r is the length of the overall size of the resonator as shown in Figure 4.

The simulation process is carried out with three parameters of modification, namely modification of the resonator dimensions such as the width and length of the resonator, then the modification of the distance (gap) in the resonator and, changes in size and position in the

input and output feed. Before getting the results of the design size in Figure 4, changes were made several times during the optimization of the design with the best experimental results taken can be seen in Table 4.

The parameters in Table 3 that have gone through the modification process get results that can be seen as in Figure 4, one of the parameters of change is the change in feed size. It can be seen in Table 4 that is the experiment I the results of the response graph are not close to the desired specifications, so changes are made to the L_{in} input feed width and the L_{out} output feed width. From these changes, the results of the response graph change for the better, namely, the reduced ripple at the peak and the values of S_{11} and S_{21} are better. However, because the desired frequency is 3 GHz, the result of these changes has not reached the specifications so that it needs to be modified again by changing other parameters. These changes were made to the resonator gap size, namely, at G_1, G_2, G_3, and G_4 changes in these parameters have an effect on the resulting response, it can be seen in Table 4 that several changes to the resonator gap have been made to achieve better results.

From Figure 7, 8, and 9 can be concluded that the best response is looked in Figure 9, then from this response, a re-simulation is performed by raising the mesh higher, resulting in a response as shown in Figure 10. The effect of this increase in mesh occurs to changes in response form, especially changes in the form of the S_{11} response, where the center frequency shifts around 0.030 GHz from 2.990 GHz to 3.020 GHz. Before achieving these results, several effects of parameter changes that resulted in differences in response results have been re-simulated. Changes in the G_2 parameter in experiment II have an effect on changes in the length of the resonator feed, it can be seen in Table 4 that the gap is changed to be more spaced at a value of 0.4 mm, this results in the middle frequency shifting closer to 3 GHz, then the S_{21} response looks getting better with the shape of the S_{21} curve seen the more curved upward so that the S_{21} parameter value changes to be better than before, but the bandwidth in the response looks still quite wide. Then in the S_{11} response, there is a change in ripple caused by a change in the distance in G_4, where G_4 is made not too close to the two resonators, at 0.580 mm this makes the ripple on S_{11} decrease, but it is still seen that the middle frequency is divided into two parts at 3.110 GHz and 3.270 GHz so it needs to be modified again to get rid of the ripple.

In experiment III, changes were made to the G_2 parameter which was the cause of the change in the response of the graph on S_{21}, with this change, the value of S_{21} became even better, which is almost close to zero but the bandwidth here looks even wider. With this change in the G_2 parameter, the center frequency has approached 3 GHz. Because the previous results still have ripple, a change is made again to the G_4 parameter where after this change the ripple has disappeared with the S_{11} value getting better at -40.845 dB and the bandwidth looks even narrower. Changes in G_2 are the same as changes in parameters G_1 and G_3, where if the parameters G_1 and G_3 are carried out then this changes the size of the resonator feed which results in changes in

the shift in the middle frequency which refers to (1). In addition to affecting the middle frequency, changes in the parameters of G_1 and G_3 also affect the transmission result, where the bending on the inside of the resonator refers to the theory of the Square Open-Loop Resonator which is able to store capacitance energy because the capacitance is directly proportional to the surface area of the conductor plate, and is inversely proportional with the separation between the plates in the parallel capacitor plate, this affects the process of transmitting radio waves as a channel of information. Experiments I, II, and III use mesh 25 so from experiment III it is re-simulated using a larger mesh, which is 260 with an improved insertion loss of -1.397 dB and a return loss of -23.406 dB. From these data, experiment III with a larger mesh is taken to be realized.

The bandpass filter is realized with the size and shape in Figure 4 with the sizes shown in Table 3 which are simulated using ADS software with simulation result as in Figure 10, the insertion loss value is -1.397 dB and the return loss is -23.406 dB with a center frequency of 3.020 GHz with a bandwidth of 200 MHz which is then realized with the FR 4-epoxy substrate by etching technique and using two 50 ohm SMA connectors at the input and output.
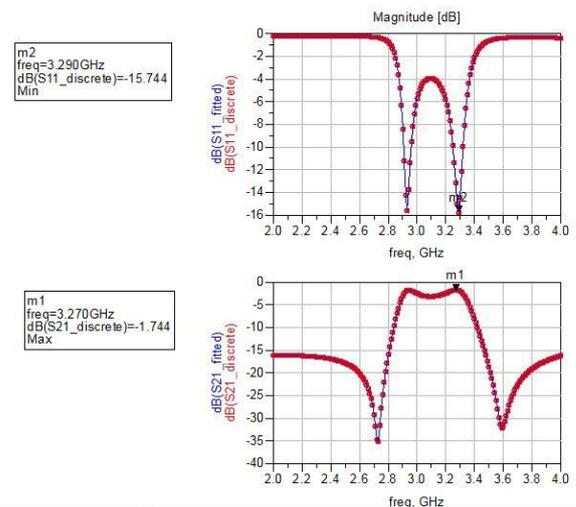
Figure 7. Response Simulation I for S_{11} & S_{21}
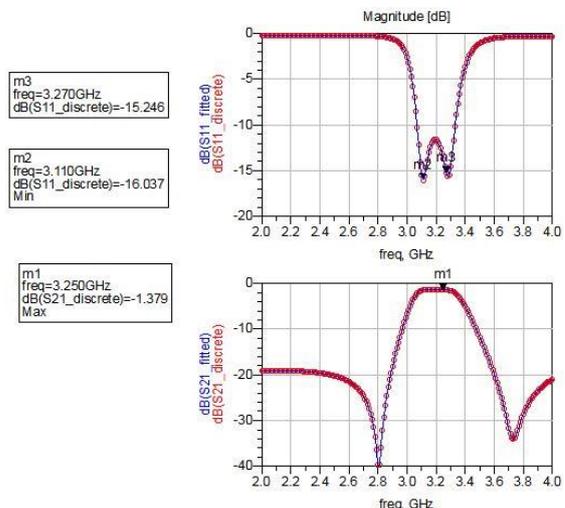
Figure 8. Response Simulation II for S_{11} & S_{21}
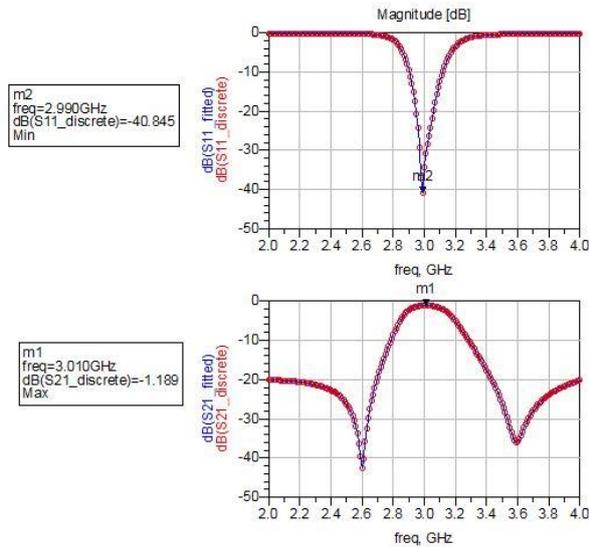
Figure 9. Response Simulation III for S_{11} & S_{21}
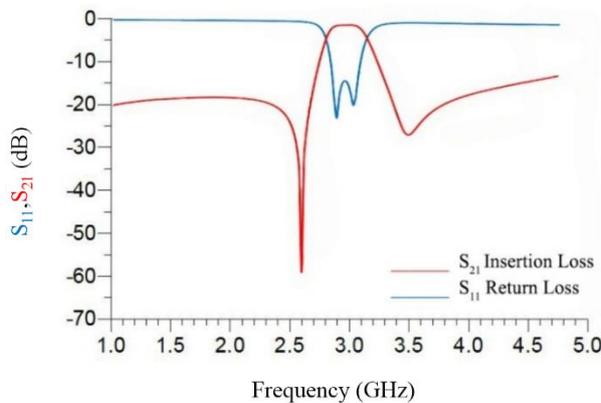
Figure 10. Response S_{11} and S_{21} with mesh 260.

The result of hardware measurement can be seen in Figure 11, where the measurement results are compared with the simulation results. The result of the measurement for the insertion loss value is shown by a dashed red line with a value of -3.561 dB, while the data obtained from the simulation for insertion loss is shown with a red line with a value of -1.397 dB. From the two results between measurement and simulation there is a difference of 2.164 dB. The return loss value at the time of measurement is -16.364 dB which can be seen on the dotted blue line, while the return loss value during the simulation is -23.406 dB which is shown by the blue curve line so that there is a difference of 7.185 dB. The results of the simulation are better when compared to the measurement results. Comparative data between simulation and realization can be seen in Table 5.

TABLE 5
SIMULATION AND THE REALIZATION

Parameters	Simulation Result	Realization Result
f_c	3.020 GHz	3.185 GHz
Range Frequency	2.920 – 3.120 GHz	2.985 – 3.285 GHz
Bandwidth	200 MHz	200 MHz
Return Loss	-23.406 dB	-16.364 dB
Insertion Loss	-1.397 dB	-3.561 dB
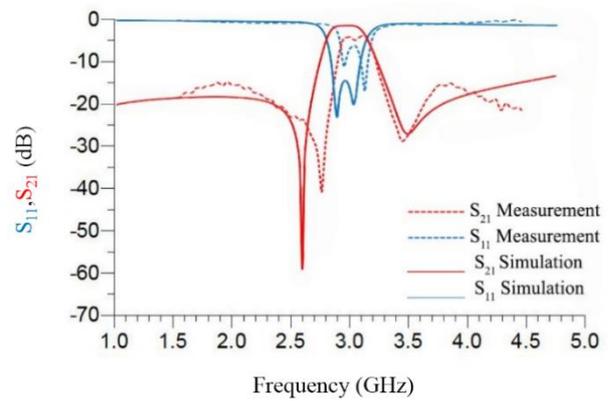
Figure 11. Response S_{11} and S_{21} Measurement & Simulation.

From several previous papers, there are some methods used that are deemed inadequate to produce good values of insertion loss and return loss. There are some of the results of the paper look good, but there are some that show a very significant difference between simulation, and realization. So, the results can be considered to be not optimal.

Whereas in this design the results of the simulation have reached the specifications, as well as in the measurement, although there is a shift but the differences of the simulation and measurement look good. For the size of the resonator that is realized it has a small size so that it fits the microstrip filter method using a square open-loop resonator.

The difference in the results for the parameters S_{11} and S_{21} is due to changes in material conditions, dielectric loss, and reliability during simulation and realization. During the simulation, the material used is ideal. This is because the ADS software is arranged in such a way that the materials used are in accordance with the specifications. Such as the thickness of the material, the permittivity of the material that has been treated, and the adjustments with the measuring instrument.

Because the quality of materials sold in the market may differ from those simulated and in fact on the market the quality and reliability of the materials provided have decreased, it can cause differences in results during realization and simulation. In addition, the etching and soldering processes also affect the realization results.

CONCLUSION

The 3 GHz microstrip bandpass filter has been successfully realized with a square open-loop resonator using a FR 4-epoxy substrate capable of working at a frequency 3.085 GHz – 3.285 GHz with a bandwidth of 200 MHz for the parameter (S_{11}) return loss of -16.364 dB, (S_{21}) insertion loss -3.561 dB and a center frequency of 3.185 dB. From the simulation results and measurement of the band-pass filter, a difference of 7.185 dB is obtained for the return loss parameter (S_{11}) and a difference of 2.154 dB for the insertion loss parameter (S_{21}) with the simulation results of the band-pass filter for the return loss parameter (S_{11}) of -23.549 dB and the value of insertion loss (S_{21}) -1.397 dB with a center frequency of 3.020 dB. Changes in G_1, G_2, and G_3 are the cause where the resonator dimensions change,

which also affect the shift in the center frequency. Because the longer the resonator, the smaller the frequency, while the shorter the resonator, the greater the frequency. Changes in parameters G_1 and G_3 also affect the transmission results. Whereas changes in G_4 result in changes in the response results of S_{11} and S_{21}, the change in distance affects the transmission process from the transceiver to the receiver to a minimum so as not to lose a lot of power and a little power that is reflected.

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