International Journal of Engineering & Technology, 7 (2.29) (2018) 711-715

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Design of 2.75-2.85 Ghz Frequency Microstrip Band Pass Filter with Square Open-Loop Resonator in Radar Method

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Abstract

Radar is an important component for people. A number of functions could be taken into account on a various aspect in term of quantifying the distance of a specific object, developing a map, and/ or forecasting climate. Generally, one of the main instruments within a radar is a filter. The aim of this study is to design a simple Band Pass Filter which able to be effectively worked on frequency 2.75–2.85 GHz. The filter is designed at the mid frequency of 2.8 GHz with ≤ -20 dB of Return Loss Range, ≥ -3 dB for Insertion Loss, and 100 MHz for Bandwidth, then it is manufactured into a Square Open-Loop Resonator microstrip. The filter uses Rogers R04035B for its substrate with 3.48 of Dielectric Constant Values (ε_r) and 1.524 mm of Substrate Thickness (h). The radar's filter is simulated by a software of Computer System Technology (CST) suite 2015. The simulation results -31.608995 dB for Return Loss Range, -2.0529871 dB, and 100 MHz for Insertion Loss and Bandwidth respectively. By the end of this process, this instrument is applied and a Network Analyzer is then utilized to get a comparable output. It produces a quite different ranges of -23.519 dB for Return Loss, -2,183 dB for Insertion Loss and 90 MHz for Bandwidth. The study results a design of radar's simple band pass filter which work effectively on frequency 2.75–2.85 GHz.

Keywords: *Band Pass Filter; CST; Microstrip; Square Open-Loop Resonator*

1. Introduction

Information and technology is an important thing in supporting contemporary human activities(1-3). The increasing of communication and information needs urge the development in telecommunication technology field, especially in wireless communication system. Along the time, the technology of telecommunication has the role in helping human's life not only in direct communication among people but also it can be used for detecting unknown situation around people. One of technology which is developing today is Radar (Ratio Detection and Ranging)(4).

In radar technology, the filter has the important role in accepting and dispatching the information(5). In daily life, the filter can be seen from the word 'filter' itself that means shift. There are various kinds of filter, such as air filter that is used for filtering the dirty air to be cleaner, coffee of tea filter for filtering the dregs of coffee and tea, etcetera. The filter can also found in telecommunication, but it is the frequency filter. As its name, this filter has a function of filtering the incoming frequencies, so that the users can get the wanted frequencies. It can be reinforced in Band Pass Filter (BPF) that can be found in radar. Nonetheless, radar is developed by microstrip BPF to make a radar to be more efficient and simpler. The expected BPF sharp and design is the BPF that has the good efficiency value, small return loss value, wider bandwidth, light load, and has a cheap cost.

2. Methodology/ Materials

Systematic design of BPF to gain filter appropriate with the wanted specifications applies the following main steps:

a. Determining the desired filter characteristics and PCB material (substrate) to be used.
b. Performing the calculation of resonator dimensions that suits the frequency of work, positioning power supply, and determining the distance between the resonators to get the size of the wanted bandwidth filter.
c. The radar's filter is simulated by a software of Computer Systems Technology (CST) suite 2015
d. Fabricating filter with a substrate Rogers R04350B.
e. Measuring filter with a Vector Network Analyzer

3. Result and Discussion

3.1. Basic Formulation

3.1.1. Band Pass Filter

BPF is a filter that passes the signals which take the frequency from the consisted frequentation tape or the other band pass. The frequency from the above or below signal cannot be passed or fainted by band pass filter arrangement(6). Figure 1 shows the graphic of respond frequency in BPF.

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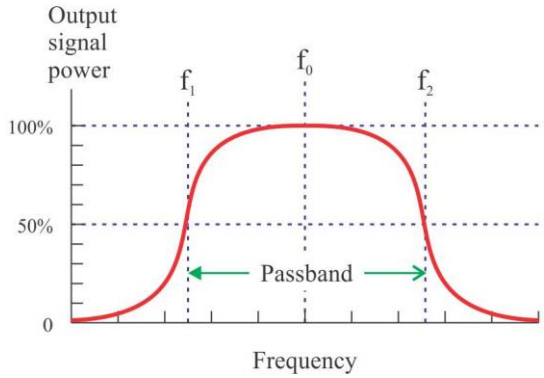


Fig. 1: Graphic of respond frequency from BPF (6)

3.1.2. Return Loss

Return loss is a comparison between the amplitude of the reflected wave toward the amplitude from the sent wave(7). Amplitude happens because there is the discontinuity between the transmission line and the impedance of the input load (antenna) [3]. The return loss has many variations huge. It depends on the frequency and it is a reflection parameter value which is stated in decibel with -∞ to 0 (dB) as its value [3]. The equation that is needed to look for the value of return loss is:

ReturnLoss (dB) = 20 log |Γ| (1)

3.1.3. Insertion Loss

Insertion loss (IL) is the loss of energy that produced because there is the sets insertion between the source and the load(8). The energy that is sent from the source and the load has once reflected the source, and also there is part of it that transformed to the load, nonetheless the energy which is sent to the load will be loose because there is a component in its arrangement. It what is called as insertion loss(9). If it in dB, the value of insertion loss must be near with 1 or 0, therefore the energy that is received by the load is appropriate with the energy which is sent to the load. In the filter, insertion loss is not a wanted part, but practically it is impossible to get the insertion loss in 0 dB. Insertion is stated as follow:

$$Insertion = 10log_{10}\frac{p_T}{p_R} = -20\ log_{10}|S_{21}|\ dB \quad (2)$$

3.1.4. Voltage Standing Wave Ratio

Voltage Standing Wave Ratio (VSWR) is a ratio of the maximum comparative voltage amplitude toward the minimum voltage standing wave amplitude(7, 8). Maximum voltage (V) and minimum voltage (V) happen because there is a superposition between the incoming wave and bounce wave. If both of these waves have the same phase, then the maximum voltage will happen, and if the phase is different, then the minimum voltage will happen. The good VSWR value is the value which near with 1. The value of return loss relates with the VSWR in which the good return loss is under -9,54dB. This value is gotten for the value of VSWR 2. Therefore, it can be said that the value of the reflected wave is not too big.

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{|V^+|+|V^-|}{|V^+|-|V^-|} = \frac{1+|\Gamma|}{1-|\Gamma|} \quad (3)$$

Which the value of bounce coefficient is:

$$\Gamma = |\frac{V_{reftected}}{V_{input}}|$$

3.1.5. Microstrip Program

The process of microstrip program is determining the value of W (width of resonator line) uses the equation (2) to (7). In order to find u = w/h < 2, it uses the equation of (4) to (5).

$$\frac{w}{h} = \frac{8e^a}{e^{2A}-2}\left(for\ \frac{w}{h} < 2\right) \quad (4)$$

$$A = \frac{Z_0}{60}\left\{\frac{\varepsilon_r+1}{2}\right\}0.5+\frac{\varepsilon_r-1}{\varepsilon_r+1}\left\{0,23+\frac{0,11}{\varepsilon_r}\right\} \quad (5)$$

To find u = w/h > 2, it uses the equation of (6) and (7)

$$\frac{w}{h} = \frac{2}{\pi}\left\{(B-1)-ln(2B-1)+\frac{\varepsilon_r-1}{2\varepsilon_r}\left[ln(B-1)+0,39-\frac{0,61}{2\varepsilon_r}\right]\right\} \quad (6)$$

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} \quad (7)$$

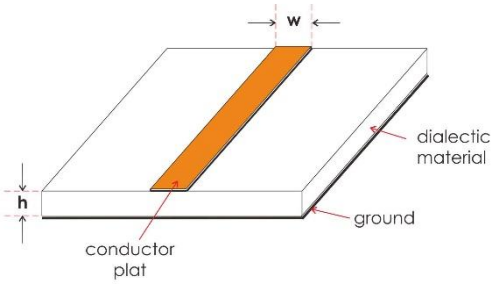


Fig. 2: Type of physical microstrip(10)

According to shielding theory, there is a determination of the length of input and output tapping line in which the gap between the line and the side part of shielding must be more than five folds of the dialectic material thickness or subtract thickness.

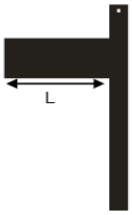


Fig. 3: Length of tape

Input/ output line length

(L) = 5 x h (8)

3.1.6. Impedance Wave

The type of wave which propagates in *ikrostri* line is a hybrid wave. The wave which has the electrical field and magnet in axial component (longitudinal) is can be seen in Figure 4.

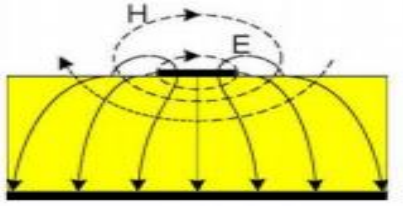


Fig. 4: Electrical and magnet field in micro strip

The wave impedance can be calculated in two kinds of formulas as follow: u = w/h ≤ 1

$$\varepsilon_{r,eff} = \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left[\left(1+\frac{12}{u}\right)^{-0,5}+0,04(1-u)^2\right] \quad (9)$$

$$Z_0 = \frac{n}{2\pi\sqrt{\varepsilon_{r,eff}}}In\left(\frac{8}{u}+0,25u\right) \quad (10)$$

which: n= 120 π ohm, while for u=w/h ≥ 1

$$\varepsilon_{r,eff} = \frac{\varepsilon_{r,eff}+1}{2}+\frac{\varepsilon_{r,eff}-1}{2}\left(1+\frac{12}{u}\right)^{-0,5} \quad (11)$$

$$Z_0 = \frac{n}{\sqrt{\varepsilon_{r,eff}}}[u+i,393+0,677.In(u+1,444)]^{-1} \quad (12)$$

Hammersted and Jensen give the formula which is more appropriate(11).

$$\varepsilon_{r,eff}\ \frac{\varepsilon_r+1}{2}+\frac{\varepsilon_r-1}{2}\left(1+\frac{10}{u}\right)^{-a,b} \quad (13)$$

which:

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

$$b = 0{,}564\left(\frac{\varepsilon_r - 0{,}9}{\varepsilon_r + 3}\right)^{0{,}053} \quad \ldots \quad (14)$$

3.1.7. Wave Length

In order to determine the length of the wave or the length of the microstrip pan can be determined with the equation(7):

$$\lambda_g = \frac{c}{f_{c\sqrt{\varepsilon_{r,eff}}}} \quad (15)$$

3.1.8. Square Open-Loop Resonator

The working principle of the resonator is using resonation principal, then it can be said that resonator will work (resonate) in one frequency. Therefore, the resonation will supply the radio frequency (RF) wave. Commonly, the arrangement of resonator can be made by using the L (inductor) component, C (capacitor), and the calculation of $1/\sqrt[\omega]{LC}$ [12] as the frequency of resonation between the L and C arrangement. In sharping the micro strip filter, the L and C components are realized with square open loop resonator by bending the straight resonator to be a square. The bending of 90º will sharp a gap (open tip) between both of resonators tip, so that it will sharp the capacitor which able to keep capacity energy. Theoretically, resonator can resonate in every wanted frequency. Therefore, the length of resonator must be made with a halp (1/2) of wave length as its length(12).

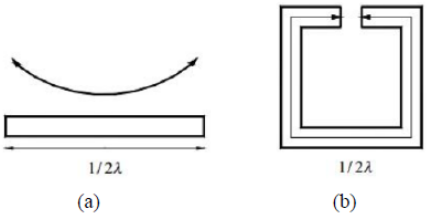


Fig. 5: Straight square open loop and resonator (10, 12)

3.2. Filter Design

3.2.1. Filter Specification

Table 1: Filter Specification

No	Parameter	Specification
1	Bottom frequency	2,75 GHz
2	Center frequency	2,8 GHz
3	Top frequency	2,85 GHz
4	*Bandwidth*	100 MHz
5	*Return Loss*	≤ -20 dB
6	VSWR	< 2 dB
7	*Insertion Loss*	≥ -3 dB
8	*Impedance*	50 Ohm

Table 2: Rogers R04350B Specification

Type of subtracting	Rogers R04350B
Dialectic Constanta	3,48
Subtract Thickness (h)	1,524 mm
Losstan/ Dissipation factor	0, 0037
Conductor plate thickness	0,035 mm

The width of input/ output line with Rogers R04350B

$$B = \frac{60\pi^2}{Z_0\sqrt{\varepsilon_r}} = 6.348795955$$

Therefore:

$$u = \frac{w}{h}$$

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

$$= 2{,}288298127 > 2$$

Therefore:

W= h x 2.2882988127 = 3.487 mm

Based on these calculations, obtained transition channel width (w) for input and output resonator filter with a design using the material R04350B Rogers is 3,487 mm. Based on these calculations, obtained transition channel width (w) for input and output resonator filter with a design using the material R04350B Rogers is 3,487 mm.

Calculation of input length output

L= 5 x h = 5 x 1,524 mm = 7,6 mm

Size Calculation Resonator

u = w/h = 2,288298127

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

$$a = 0{,}999790356$$

$$b = 0{,}564\left(\frac{\varepsilon_r - 0{,}9}{\varepsilon_r + 3}\right)^{0{,}053} = 0{,}537132552$$

$$\varepsilon_{r,eff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left(1 + \frac{10}{u}\right)^{-ab} = 2{,}742815122$$

This filter program wants the filter to works in the 2,8 GHz middle frequency so that the wavelength of a microstrip can be calculated.

$$\lambda_g = \frac{c}{f_{c\sqrt{\varepsilon_{reff}}}} = 65\ mm$$

Therefore the resonator length can be calculated as $½\lambda_g$ in which (1/2 x 6.5mm)= 32.5 mm

$$a = \frac{½\lambda g + gap}{4} + w$$

Which (a) is side resonator length and gap or the width of the gap and (W) is the resonator width. There is no formal rule to calculate the gap and (W) itself, and then the resonator length which can be gotten is:

$$a = \frac{½\lambda g + gap}{4} + w = 10.375 \text{ mm}$$

The distance between the resonators is very influenced the wanted performance. The writer here is emphasizing the simulation to get the good result for the filter program through change the distance of the resonator S11 (S), change the resonator length (a), and change the input/ output line which is symbolized with (t).

3.2.2. Filter Square Open Loop Resonator Design

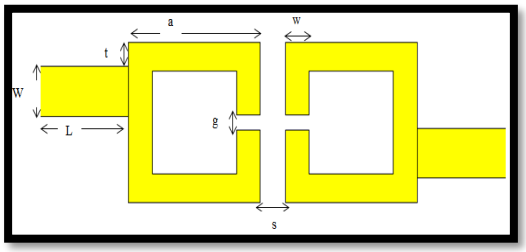


Fig. 6: Filter design

Table 3: Samples of Optimization Data

Opt	t (mm)	a (mm)	w (mm)	g (mm)	W (mm)	L (mm)	s (mm)
1	1.00	10.60	2	1	3.487	7.6	2.10
2	1.20	10.80	2	1	3.487	7.6	2.10
3	1.40	11.00	2	1	3.487	7.6	2.15
4	1.60	11.20	2	1	3.487	7.6	2.15
5	1.75	11.106	2	1	3.487	7.6	2.18
6	1.80	11.20	2	1	3.487	7.6	2.20
7	1.80	11.125	2	1	3.487	7.6	2.25

Table 4: Optimization Result Data

Opt	Frequency (GHz)	Return Loss (dB)	Insertion Loss (dB)	Bandwidth (MHz)
1	2.9735	-11.101113	-1.9592096	103.7
2	2.9020	-13.383379	-1.8189142	104.6
3	2.8318	-15.336794	-1.8706126	100.9
4	2.7710	-19.635592	-1.8587371	100.1
5	2.8000	-31.608995	-2.0529871	100.0
6	2.7690	-30.351155	-2.1740299	94.1
7	2.7568	-25.019613	-2.4076681	89.7

From the optimization result in Table 4, it can be seen that the filter design which appropriates with the specification is in the fifth optimization with 2.8 GHz as its frequency value, -31.608995 dB as the return loss, -2.0529871 dB as insertion loss and 100 MHz bandwidth. Therefore, the filter design which is chosen is in the fifth optimization.

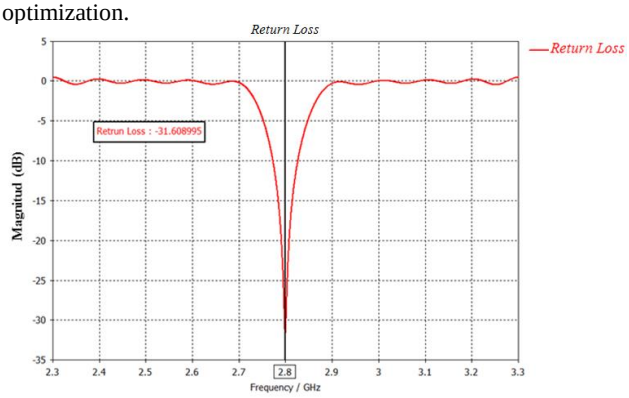


Fig. 7: Return Loss Respond

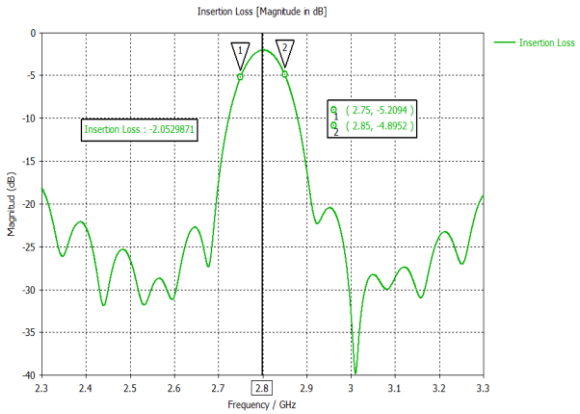


Fig. 8: Insertion Loss Respond

3.2.3. Filter Realization of Square Open-Loop Resonator

After the optimization design which uses the simulator produces the program which appropriates with the specification, then filter realization is worked, through measuring to get the respond value from the return loss and insertion loss. This picture below is the picture of realization of band pass filter square open-loop resonator.

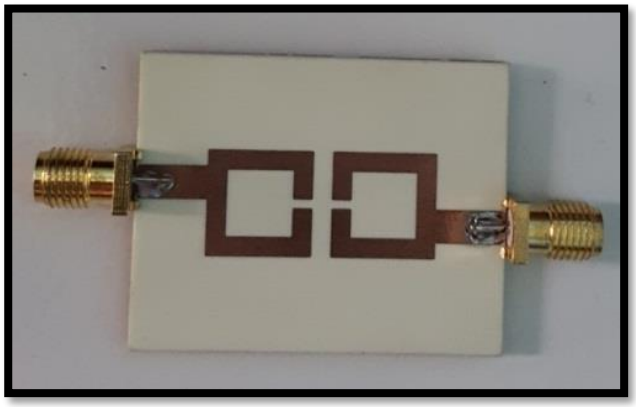


Fig. 9: Realization of filter square open loop

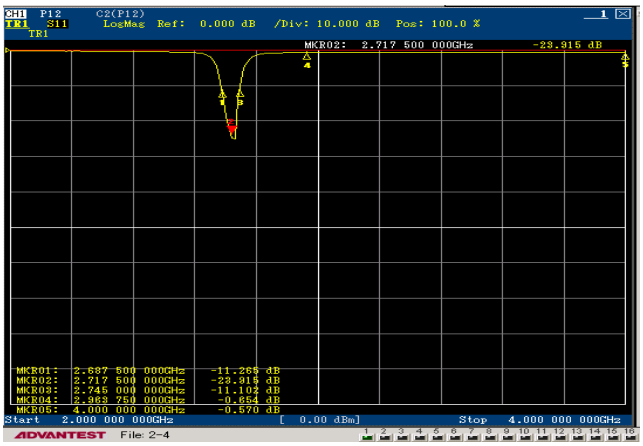


Fig. 10: Measurement or return loss

From this measurement, it can be gotten the value of return loss in -23,519 dB with 2,217 GHz as its frequency. This result has 83 MHz as the shift of frequency. This picture below is the result from the filter measurement to find the insertion loss respond.

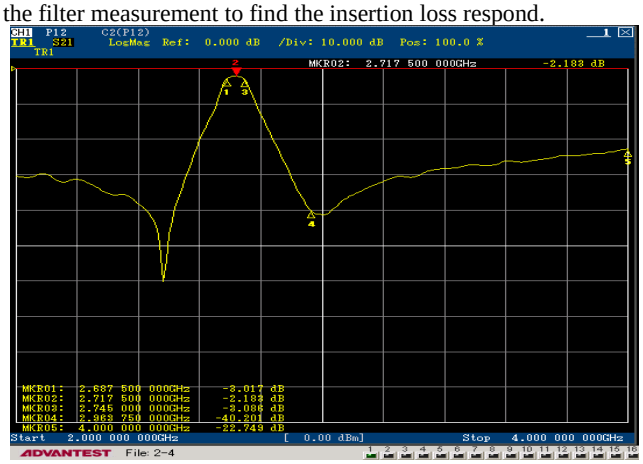


Fig. 11: Insertion loss measurement

This measurement gets -2.183 dB as the insertion loss value with the frequency in -2.717 GHz. Table 5. shown comparative between measurement and simulation result.

Table 5: Comparative simulation, measurement, and specification

Parameter	Specification	Simulation	Measurement result
Center frequency	-2.8 GHz	-2.8 GHz	-2717 GHz
Frequency range	2.75-2.85 GHz	2.75-2.85 GHz	2.67-2.76 GHz
Return loss	≤ -20 dB	-31.608995 dB	-23.519 dB
Insertion loss	≥ -3 dB	-2.0529871 dB	-2.183 dB
VSWR	≤ 2	1.053696	1.138
Bandwidth	100 MHz	100 MHz	90 MHz

From the comparative result in Table 5, it can be seen that the frequency has a shifting until 83 MHz so that it becomes 2.717 GHz, but this shifting is still in radar S-band's working frequency. The return loss measurement also gets a shifting, but it is still appropriate with the wanted specification. Besides it, the insertion loss also gets the shifting, but it is also still appropriate with the wanted specification.

4. Conclusion

From this final assignment research, conclusions about BPF square open-loop resonator as follows:

a. Filter with the square open-loop resonator is realized successfully.

b. The result of filter respond simulation is appropriate with the wanted specification in which the middle frequency is 2.8 GHz, <-

20 dB as the return loss, > -3 dB as insertion loss, 100 MHz bandwidth, and <2 VSWR.

c. Based on the fabrication result, the frequency shifts from 83 Ghz into 2,717 GHz. Besides that, the bandwidth presses into 10 MHz. The return and insertion loss also change from the simulation, but it is still appropriate with the wanted filter specification.

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