Design and realization bandpass filter with square groove defected at 3 GHz

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Abstract. In this paper, microstrip structure is developed to realized a bandpass filter at 3 GHz of the center frequency with 200 MHz bandwidth. The filter based on the hairpin method with used square groove technique at the resonators. It has compact in the size and also have good responses for insertion loss, return loss and bandwidth. The design methodology is present with design, fabrication and measurement the prototype used VNA. The filter designed for simulation and realization with substrate Roger 4350B with permittivity 3.48, loss tangent 0.0038, and thickness 1.524 mm using five poles resonators. The simulation and optimization is done using ADS 2011. Responses Insertion Loss at 3 GHz -0.7 dB and the Return Loss at -29.9 dB.

1. Introduction

In the recent progresses at the wireless communication and radar system demand the good performance from the specification devices [1]. One of the devices for this requirement is bandpass filter. Investigation about bandpass filter to be continue in the world. Microwave bandpass filter is very important module for the communication system. In this paper, description about bandpass filter for the S band radar with range frequency 2.9 – 3.1 GHz, and the 200 MHz bandwidth used the hairpin and square groove defect method. Modern microwave communication system requires microstrip bandpass filters with improved performance for insertion loss, return loss responses, reduced size, high rejection are always needed to reduce cost and enhance the system performance [2]. There has been much researcher conducted design on the microstrip filter. For the realize this, miniaturization filter hairpin can be used. Design and realization for bandpass filter used the microstrip structure. The propagation wave microstrip at the printed circuit board with two media, air and the electric, so this structure is inhomogeneous [5]. Conventional design filter used the microstrip line, introduced by Crystal and Frankel. Since resonators are the basic components of a planar filter, It is necessary to select proper resonator types used in filter design. A conventional half-wavelength open-line resonator is always too large. The obtain the better spurious performance, combination of open stub, spurring and complementary split ring resonator etching at the ground plane, may apply at the input or output port of the BPF. A bandpass filter is an electronic device or circuit that allows signals between two specific frequencies to pass, but that discriminates against signals at other frequencies. So, the bandpass filter has two frequency cut off, in the lower frequency and the higher frequency. Some bandpass filters require an external source of power and employ active components such as transistors.
and integrated circuits; these are known as active bandpass filters. Other bandpass filters use no external source of power and consist only of passive components such as capacitors and inductors; these are called passive bandpass filters. In this paper, Bandpas filter with hairpin the square groove at line will be simulation and fabrication.

2. Structure and Theory
The general structure of the microstrip can be illustrated at the figure 1. Conducting microstrip width \( w \) and the thickness \( t \), is on the top of the dielectric substrate that has a relative dielectric constant and the thickness, and the bottom substrate is ground plane. Wave traveling in microstrip line not only travel in the dielectric medium they also travel in the air media above the microstrip line. Thus they don’t support pure TEM waves. Transverse electromagnetic (TEM) is a mode of propagation where the electric and magnetic field lines are all restricted to directions normal (transverse) to the direction of propagation the Transverse Electric and Magnetic (TEM) mode, both the electric field and the magnetic field (which are always perpendicular to one another in free space) are transverse to the direction of travel. If you wonder how this is possible, bear in mind that it is happening in three-dimensional space. In pure TEM transmission, the waves have only transverse component and the propagation velocity only depends on the permittivity and the permeability of the substrate. But in the case of microstrip line the magnetic and electric field also contain a longitudinal component, and their propagation velocity is dependent on the physical dimensions of the Microstrip as well. A microstrip resonator is any structure that is able to contain at least one oscillating electromagnetic field. There are numerous forms of microstrip resonator. In general, microstrip resonators for filter designs may be classified as lumped-element or quasilumped-element resonators and distributed-line resonators or patch resonators [5].

3. Hairpin Filter
Hairpin resonators filter are compact structures and the topology. The hairpin line filter, like the half wave parallel coupled line filter, is one of the preferred configuration in stripline or microstrip because ground connection are not required. Basically, hairpin filter can be thought of as a. Folded version of a half wave parallel coupled line filter [4]. The filter have resonators structure for half wavelength with the concept be obtained folding resonator is U shape. It can make design more simple and smaller than the parallel couple. Each resonator of the hairpin filter is 180 degrees so that the length from the center to either end of the resonator is 90 degrees [3]. The proposed filter is simply derived from the conventional hairpin method. At the conventional hairpin method, the line of the transmission or the resonator throughout flawless. If the two arms of each resonator are closely spaced, they function as a pair of coupled lines themselves, which has an effect on the coupling as well. Conventional filters employ coupled line input. Tapped line input has a space saving advantage over coupled line input.
Further while designing sometime the coupling dimensions required for the input and output coupled line is very small and practically not achievable which hinders the reliability of the design. Thus tapped line input is preferred over coupled line input. But, this paper proposed, the hairpin filter with the defected at the resonators. Defected the resonators have the form is square. The edge of the resonator for the design bandpass filter can be show at the figure 2.

The advantage of hairpin filter over end coupled and parallel coupled microstrip realizations, is the optimal space utilization. This space utilization is achieved by folding of the half wavelength long resonators. Also the absence of any via to ground plane or any lumped element makes the design simpler. The following figure shows a typical hairpin structure.

![Figure 2. Hairpin Square Groove Microstrip](image)

4. Square Groove Microstrip
Modification of hairpin with square groove microstrip bandpass filter show at the figure 3. Defected square groove is the defected at the line microstrip with the square shape. Defected square groove at the design had dimension 0.5 from the width of the line resonator, and position at the middle of the length from every resonators. Design of the bandpass filter used five poles resonators microstrip hairpin with defected at the middle of the each resonators. The effective dielectric constant in terms of \( w \) (width of the Microstrip), \( h \) (height of the substrate) and \( \varepsilon_r \) (relative dielectric constant) given by Hammerstad and Jensen [5]. For the design bandpass filter hairpin with the defected groove, we can used many groove at the resonator. But, this paper just used one groove at every resonators. The effect of the groove on the designed single stage bandpass filter was then investigated. Design and simulation of this bandpass filter hairpin with defected square groove used the Advanced Design System 2011.

![Figure 3. Hairpin with Defected Square Groove](image)
Electromagnetic wave with the microstrip line be effected by air and the substrate of Roger 4350B, so the structure is not homogeneous, it would require constant relative dielectric \(\varepsilon_{reff}\) as a replacement. Constant dielectric \(\varepsilon_{reff}\) can be regarded as constant dielectric medium homogeneous.

\[
\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left(1 + \frac{10}{u}\right)^{-2b}
\]

\[u = \frac{w}{k}\]

\[a = 1 + \frac{1}{40} \ln \left[\frac{(\frac{\varepsilon_r - 1}{\varepsilon_r + 1})^2}{u^2 + 0.425^2}\right] + \frac{1}{15} \ln \left[1 + \left(\frac{u}{0.35}\right)^2\right]\]

\[b = 0.564 \left(\frac{\varepsilon_r - 1}{\varepsilon_r + 1}\right)^{0.551}\]

At the design of microstrip hairpin with this method, sliding factor can not be determined with certainty, so used the assumption \(\theta = 10^\circ\).

\[b = \frac{\theta^\circ}{360^\circ} \times \lambda_{microstrip}\]

For determine the length \(L\) of the resonators, can used formula:

\[L = \frac{(90 - \theta^\circ)}{360^\circ} \times \lambda_{microstrip}\]

The guided wavelength can be calculated using equation:

\[\lambda_g = \frac{c}{f \sqrt{\varepsilon_{reff}}}\]

Constant \(c\) at the formula is speed of light at the vacuum and the \(\lambda\) is wavelength.

5. Design and simulation
To verify the performance of the filter, the five-order BPF is designed at the centered frequency of 3 GHz with a fractional bandwidth of 15 percentages. To verify the numerical characterization, the hardware realization is carried out by fabricating both designed hairpin BPF on Rogers RO4350 dielectric substrates with the thickness of 1.524 mm, with the line of microstrip used the copper thickness 0.035 mm and fully grounding copper at the bottom line of the substrate. Conventional hairpin bandpass filter composed with U shape. This design for the miniature size and making compact of the bandpass filter but have good response. Defected of the hairpin microstrip design will be has small bandwidth. Design the bandpass filter used the Advanced Design System 2011. The figure design bandpass filter for simulation showed in figure 3. The filter design doing optimization for to get the small dimension at the simulation. For experimental characterization purpose, 2 SMA connectors types are soldered at the input/output ports of each filter, Realization of bandpass filter with square groove hairpin method show at the figure 6. The design of the filter generate from the layout at the software. At the realization, the filter used the SMA connector (Sub Miniature version A) is connector design for radio frequency, with impedance 50 Ohm. SMA is designed for use from DC to 18 GHz, but is most commonly encountered with WiFi antenna systems and USB Software Define Radio. A standard-
polarity SMA male connector has a center pin surrounded by barrel with inside threads, and the standard SMA female connector has a center sleeve surrounded by a barrel with outside threads.

![Figure 4. Response IL and RL Simulation](image)

**Figure 4.** Response IL and RL Simulation

**Figure 5.** Comparison Response Simulation and Realization

Realization of bandpass filter use casing aluminum with width 2 mm and the space. Dimension bandpass filter hairpin with defected square groove result of realization is 5.3 x 1.6 cm².

At figure 4 show the response of simulation from Advanced Design System with the response return loss at -29.9 dB and the response Insertion Loss is -0.7 dB at the center frequency 3 GHz, for the -2.9 GHz the response return loss is -7.92 dB, while insertion loss is 1.76 dB. And for the 3.1 GHz have response Return Loss -2.96, while Response Insertion -4.62 dB. At the figure 5, comparison of the return loss from the simulation and the realization. The simulation (green line) peak response return loss is -29.9 dB at the 3 GHz and the peak realization return loss at 2.9 GHz is -19.53 dB. There are differences result simulation and realization for frequency 100 MHz at the peak of response return loss, and the shift value of the response insertion loss and return loss.

The measurement of the realization bandpass filter use the vector network Analyzer.

![Figure 6. Realization Bandpass Filter](image)

**Figure 6.** Realization Bandpass Filter

Table I depicts result from the simulation and the realization. The maximum frequency for insertion loss and the return loss of the simulation is 3 GHz, while the realization at 2.921 GHz. Bandwidth of the simulation and the realization is 200 MHz, but the return loss for simulation is 29.98 dB and insertion loss is 0.76 dB. For the realization module bandpass filter has response return loss is 19.529 dB and the insertion loss is 1.643 dB.
Table 1. Result Simulation and Realization

| Parameter                | Simulation | Realization |
|--------------------------|------------|-------------|
| Frequency center (GHz)   | 3          | 2.921       |
| Bandwidth (GHz)          | 0.2        | 0.2         |
| Return Loss (dB)         | -29.98 dB  | -19.529 dB  |

6. Conclusion

We have proposed and analyzed a band pass filter using hairpin planar structures for S-band radar applications with the square groove at the middle of resonators. The proposed device was designed for 3 GHz operational frequency. The return loss and insertion loss of the designed device were analyzed using ADS. Based on the calculation results, the designed device has an operational bandwidth of 200 MHz from 2.9 GHz to 3.0 GHz. The maximum return loss from the ADS simulation at 2.99 GHz with S11 has been obtained -29.9 and for the insertion loss is -0.76 dB. And for the realization bandpass filter, the maximum S11 is -19.5 dB at the 2.9 GHz, and for the S21 is -1.6 dB. The narrow bandpass filter based on the hairpin square groove with five resonators has been simulation and realization. From the figure 5, there is different response between simulation and realization about frequency center and the response of S11,S21. The dimension of filter realization is 5.3 x 1.6 cm².

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