Designing, Simulation and Fabrication of Hairpin Band Pass Filter Using 5.8GHz

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Abstract— Hairpin Filter is one of the most popular microwave frequency filters because of it is compact and does not require grounding. The filter is designed at center frequency of 5.8 GHz with a fractional bandwidth of 3.45%. This frequency is presenting for wireless LAN application and operates in the ISM band (Industrial, Scientific and Medical) application. There are several step to design this filter that including by determine filter specification, order of filter, low pass filter prototype elements, low pass to band pass transformation, physical dimension (width, spacing, length) and wavelength guide. The simulation of the filter will be done using IE3D and fabricate on FR4 substrate by using etching process. Improvement technique will be introduced to get better response for scattering parameter.

Key words: Band pass filter, cross-coupling, microstrip filter, hairpin resonator

I. INTRODUCTION

Microwave communication network and relay station are used commercially for routine multichannel communication transmission , both long distance and local. Air and sea navigation is more reliable new that microwave technology has been applied and on a consumer level, microwave ovens are becoming more common. These are some example of the everyday uses of microwave. The field is relatively now are, but it is very progressive and fast growing. Microwave filters are vital components in a huge variety of electronic systems, including mobile radio, Satellite Communication Receivers and Radar. Due to the advancement in the field of mobile and wireless communications, fully integrated analogue filters for high-frequency applications are now receiving great interest worldwide. In modern wireless communication systems wider bandwidth, multiband and low profile filter are in great demand for both commercial and military applications. Wireless operations, such as long range communications, are impossible or impractical to implement with the use of wires. The term is commonly used in the telecommunications industry to refer to telecommunications systems (e.g., radio transmitters and receivers, remote controls, computer networks, network terminals, etc.) which use some form of energy (e.g. Radio frequency (RF), infrared light, laser light, visible light, acoustic energy, etc.) to transfer information without the use of wires. Information is transferred in this manner over both short and long distances. Applications may involve point-to-point communication, point-to-multipoint communication, broadcasting, cellular networks and other wireless networks.

Wireless communication, emphasizing on wireless local area networking in this project, is growing rapidly. Increasing number of users requires more bandwidth and thus higher frequency. The 5.8 GHz band is nothing new but it brings new problems for implementation on laminated substrates. It is therefore of interest to study how a circuit using distributed components behaves at 5.8 GHz. This project deals with the designing and fabrication of different types of microstrip bandpass filters. The designing is done using IE3D simulation program developed by Applied Wave Research USA. In the design of a Microwave filter using microstrips two types of design approaches are taken. First, transforming the lumped element design to equivalent planar structure. Second, using micro strip resonators and the concepts of immitance inverter. For the bandpass design the second approach is used.

II. CROSS-COUPLED FILTER

Fig. 1 shows two typical microstrip cross-coupled bandpass filters comprised of coupled hairpin resonators. The dielectrics substrate with a ground plane is not shown in the diagram. The filter of may be catalogued to the canonical filter with a general coupling structure as depicted, where each node represents a resonator, the full lines indicate the main path couplings, and the broken lines denote the cross couplings. The eight pole filter may belong to another type of cross-coupled filter –namely, the so called cascaded quadruplet (CQ) filter. This is not the case for other realization such as canonical structure. Where each cross coupling affects all the transmission zeros, making the filter more difficult to tune.

Although only two types of cross-coupled hairpin-resonator filter have been described, the filter with more poles are easily built up and the building up of the filter with other configuration may also be possible. It would seem that pratical method to design this class of filter is to derive a coupling matrix from the transfer function and realize the coupling matrix in terms of inter-resonator coupling. Obviously, this design method requires the knowledge of mutal-coupling between coupled microstrip hairpin resonator. In general, four basics structure may be counted in the cross couple hairpin-resonator filters.

The hairpin filter is one of the most popular low microwave frequency filters because of it is compact and does not require grounding. It has been widely used in telecommunication to reduce the unwanted frequency. It is also open circuit ends .Its form is derived from the edge-coupled resonator filter by folding back the ends of the resonators into a **"U"** shape. This reduces the length and improves the aspect ratio of the microstrip significantly as compared to that of the edge-coupled configuration. There are many substrates with various dielectric constants that are used in wireless applications. Those with high dielectric constants are more suitable for lower frequency applications in order to help minimize the size. Its design on FR4 laminates is very difficult to do because of the relatively poor performance of the laminate at the microwave region. The laminate properties of the FR4 become nonlinear unlike more expensive microwave laminates. The motivation to use FR4 in the low microwave frequencies is its cost.

The interdigital and comb line filters required ground connections, which to achieve when using microstrip line on ceramics substrates. When stripline and microstrip is used, the hairpin filter is one of the preferred configurations. This is particularly useful when one is interested in MIC or MMIC circuits. The hairpin-line filter can be considered basically to be folded version of a half-wave parallel couple line filter. It is much more compact, though and gives approximately the same performance. As the frequency increase, the length-to-width ratio is smaller for a given substrate thickness, so that folding the resonator becomes impractical. Hence this type of resonator is more suitable at lower frequency. In general, the hairpin filter is larger than the combline and interdigital filter. But because no grounding is required, it is amenable to mass production as a larger number of filters can be simultaneously printed on a single substrate, thereby lowering production cost.

The hairpin filter configuration is derived from the edge-coupled filter. To improve the aspect ratio, the resonators are folded into a **"U"** shape (see Figure 2). 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. From 90 degrees, **0** degrees are "slid" out of the coupled section into the uncoupled segment of the resonator (fold of the resonator). This reduces the coupled line lengths and, in effect reduces the coupling between resonators.

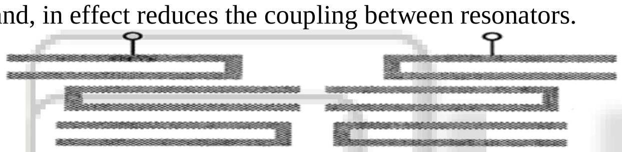

Fig. 1: six-pole canonical filter with coupling diagram

III. HARPIN FILTER

A. *Tapped Line Input:*

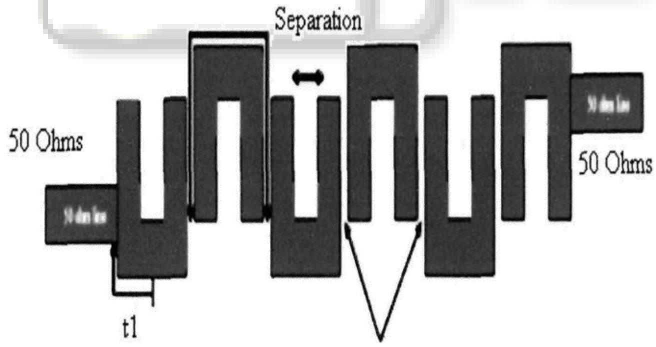

Fig. 2: Hairpin Filter

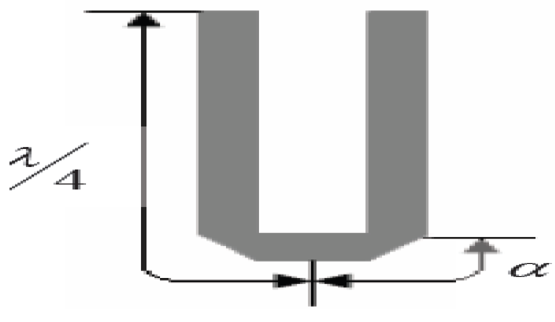

Fig. 3: Tapped Hairpin Resonator

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.

$$t = \frac{2l}{\pi}\sin^{-1}\left(\sqrt{\frac{\pi\frac{Z_o}{Z_r}}{2Q_e}}\right)$$

α is called the slide angle. If the slide angle is small it might lead to coupling between the arms of individual resonator. The voltage at the end of hairpin arms is ant phase, and thus causes the arm to arm capacitance to have seemingly disproportionate effect. The added capacitance lowers the resonant frequency requiring a shortening of the hairpin to compensate. To avoid this, slide angle is kept as large as possible. But by increasing the slide angle the coupling length between two resonators reduces, so as to attain the required coupling.

1) *Condition 1:*

$A \supset 1.52$

$$\frac{w}{h} = \frac{8e^{A}}{e^{2A} - 2}$$

2) *Condition 2:*

$A \leq 1.52$

$$\frac{w}{h} = \frac{2}{\pi}\left[B - 1 - \log_e(2B-1) + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left[\log_e(B-1) + 0.39 - \frac{.61}{\epsilon_r}\right]\right]$$

$Z_0 = 50\Omega$

f =5.8 GH_Z

h = 1.27 m

$\epsilon_r = 6.08$

A = 1.7459

W = 1.8875 mm

λ = 12.2mm

L=$\frac{\lambda}{4}$ =3.05

For an efficient radiator a pratical width that leads to good radiation efficiencies.

W = 32.67 mm

ϵ_{reff} = 9.72mm

Actual length = 36.008

Finally effective length = 18.004

IV. NUMERICAL AND EXPERIMENTAL RESULTS

In this chapter a presentation of the microwave hairpin filter geometry is made. The integral equation in 3D dimension (Zealand IE3D) version 14.0 is used for simulation. Zealand IE3D is specialized tool for the fast and accurate 3D simulation of filter at higher frequencies. Filter design starts with specifying the material used in designing, with their thickness, relative dielectric constant , loss tangent etc.

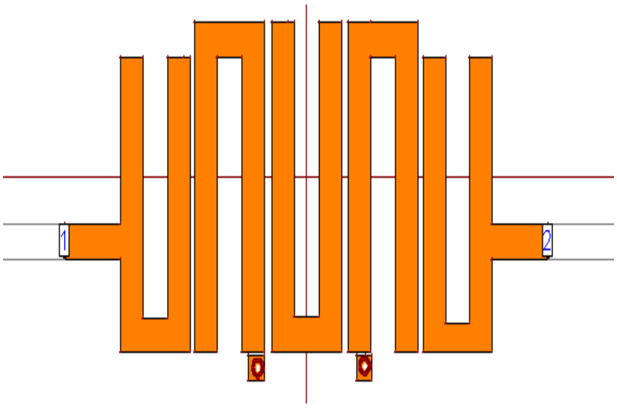

Fig. 4: Microwave hairpin filter with ground holes in iterated base

In case we are adding ground holes having 1.33mm in width and 13mm for better impedance matching by which we are getting maximum amount of matching at frequency f=5.8 GHz having value of return loss (RL) = -52.8607 dB, at this frequency will transmit its maximum amount of energy for the communication, at frequency f= 5.8 GHz we are getting value of return loss (RL) = -18.3514 dB which is higher than -24.8607 dB, means at this frequency will receive some return waves having which decreases radiation efficiency of filter.

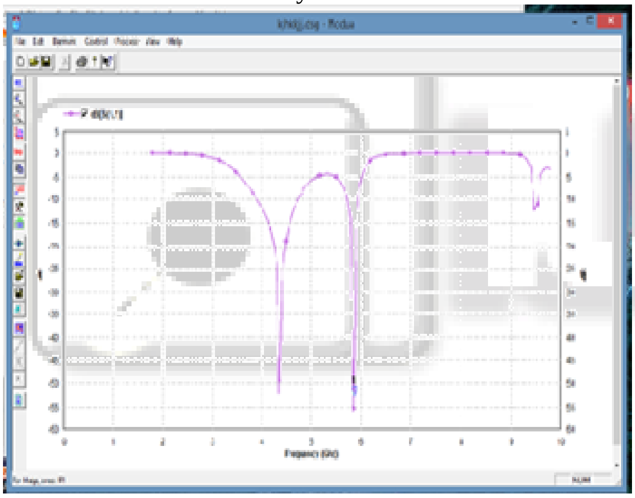

Fig. 5: Return loss vs. frequency graph for Microwave hairpin band pass filter with ground holes in iterated base

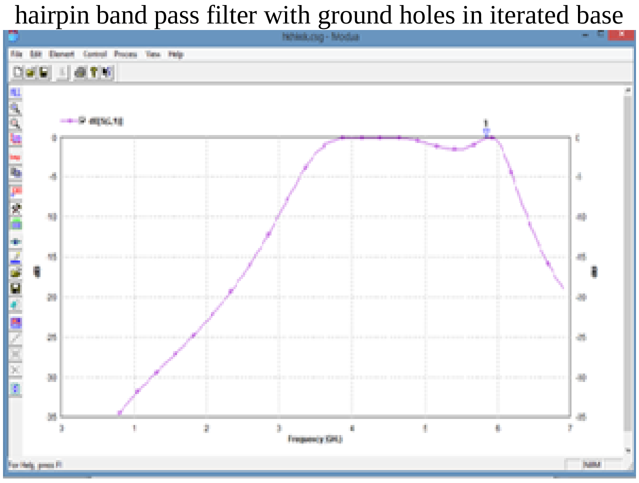

Fig. 6: Insertion loss vs. frequency graph for Microwave hairpin bandpass filter with ground holes in iterated base

A. In Tabular Form:

Frequency(GHz)	4.2	5.8
Return Loss(dB)	-39	-52
Insertion Loss(dB)	-0.1	-0.01

Table 1: Return loss, insertion loss and frequencies of Microwave hairpin bandpass filter with ground holes in iterated base

B. Facilities Required For The Proposed Work:

(1) IE3D software
(2) Calculate lumped element parameter using ie3d
(3) Machine

C. Advantages:

(1) The absence of any via to ground plane or any lumped element makes the design simpler.
(2) Optimal space utilization.

D. Application:

(1) Wi Fi
(2) Mobile communication
(3) Receiver system

V. CONCLUSION

In this paper we have presented a microstrip hairpin bandpass filter incorporating use of via ground holes. This design approach uses $\lambda/8$ resonators and thus reducing the size by 35% as compared to the conventional design. Effect of tap point height and microstrip width on filter performance measuring parameters is studied. A detailed sensitivity analysis is carried out to develop relationships. It has been shown that the effect of microstrip width is much more pronounced as compared to tap point height on FBW, IL and RL. Desired center frequency can be easily tuned by adjusting resonator lengths. Less than 2% FBW is achieved at 5.8 GHz without increasing the gap between adjacent resonators. IL in passband is less than 0.003 dB and RL is greater than 55 dB with good out of band rejection. There is no spurious response till $3f_0$. In this design methodology high Q_e can be achieved with greater flexibility in tap point location. This flexibility can be used for improving the impedance matching and thereby improving the RL. The design approach is validated by designing and fabricating a filter on FR4 substrate. S-parameter measurements were quite accurate with reference to simulated results.

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