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# A High Selectivity and Small Sized Double Fold Microstrip Hairpin Line Bandpass Filter for L-Band RF/Wireless Communication Systems

**Jagdish Shivhare, B. V. R. Reddy**

***Abstract:*** ***This technical paper presents a new type of double folded hairpin line microstrip bandpass filter with high selectivity, low cost and 40-50% reduction in size compared to a conventional hairpin line bandpass filter. The filters are not only compact size due to the slow-wave effect, but also have a wider upper stopband resulting from the dispersion effect. These attractive features make the resonator filters hold promise for RF/wireless, mobile communications and other ground and space applications. The design topology has the advantage of desirable narrowband, high selectivity, reasonable return loss, small sized and low cost microstrip filters, make the design more simpler for wider applications in the modern wireless radio communication systems. The expected frequency responses have been simulated by using the Agilent-make ADS and IE3D-Zealand softwares. The measured and simulated results show good agreement.***

***Keywords—Folded-hairpin line resonator, microstrip filters, slow wave, cross couplings, dielectric constant.***

## I. INTRODUCTION

Planar structured double-folded microstrip hairpin line bandpass filters are easy to design and develop by using low cost printed circuit technology. A double-fold hairpin line bandpass filter has been developed on the RT-Duroid-Alumina substrate of dielectric constant 10.2 and thickness of 1.27 mm. The peripheral of each resonator is made a square, the width of the microstrip is determined for 50 ohms, the gap between coupled lines is kept minimum[1-2]. With the help of imperical equations, graphs and simulated results, we have worked out the total size of a fourth-order conventional hairpin line filter at a center frequency of 1.325 GHz, that is 25 mm x 25 mm (A=625 $mm^2$). At the same center frequency the size of a double fold hairpin resonator filter will be 18 mm x 18 mm (324 $mm^2$) i.e. 52 % of A i.e. reduction in size is 48 % compared to the size of the conventional hairpin resonator filter in the same frequency range.

## II. ITHE CONCEPT OF THE FOUR-FOLD HAIRPIN LINE RESONATOR

The length of filter with parallel coupled resonator of length ($\lambda/2$) increases with the order of the filter. To solve this problem, $\lambda/2$ resonator is folded in U-shaped structures to get a conventional hairpin line resonator of $\lambda/4$ length with respect to the center of the U-shaped resonator (fig-1a).

Further reduction in size is made by folding again the two arms of the open ends of the hairpin line resonator to form a pair of closely coupled lines to enhance the capacitive nature of open end arms(fig.1-b). This structure is known as single-fold resonator (fig-1c). Even more reduction in size could become possible by again folding the single fold structure into the double fold structure (fig.1-d). The single fold structure of resonators may reduce the size of the filter by 35-45% while the double fold will bring down the size upto 45-55% of the conventional hairpin line bandpass filter at the same center frequency of the filter. Norrnally this kind of filters are realized using dielectric resonators.The design technique uses an approximation polynomial and a lowpass filter prototype.The loaded quality factor and the coupling coefficient between the different resonators could be calculated.To make the design easy and simple, the peripheral of each resonator is made a square, length of the U-shaped coupled lines is extended to its maximum, the width of lines is made large and the space between coupled lines is kept minimum possible.The filters consisting the double folded resonators are of narrow band, moderate quality factor, high stop band attenuation and reasonable return loss in passband [3-4].

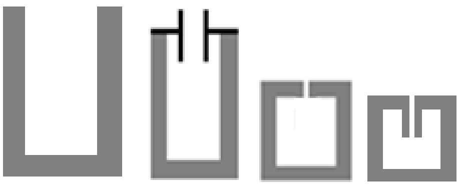


**Fig. 1. Conventional, capacitor loaded, single-fold and double-fold hairpin line resonators**

## III. DESIGN PROCEDURE OF A DOUBLE-FOLD HAIRPIN RESONATOR FILTER AT 1.325 GHz

**Design specifications of the filter:**

| | | |
|---|---|---|
| Centre Frequency (CF) | : 1.325 GHz | |
| Insertion loss | : < 3 dB | |
| Passband (3 dB) Bandwidth | : ± 0.025 GHz | w. r. t. c. f. |
| Stopband (30 dB) Bandwidth | : ± 0.050 GHz | w. r. t. c. f. |
| Return Loss in passband | : >15 dB | |
| Input/output Impedance | : 50 Ohms | |

* (Size of conventional hairpin resonator filter at Center frequency 1325 MHz : 25 mm x 25 mm: 625 $mm^2$ i.e A, where $\lambda/4=3x\ 10^{11}/ [4 \times 1325 \times 10^6 \times (10.2)^{1/2}]$.

A resonator of the proposed double-fold hairpin resonator filter is shown in fig. 2.

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**Jagdish Shivhare**, Department of Electrical Electronics and Communication Engineering, ITM University, Sector-23A, Gurgaon-122 017, India.

**B. V. R. Reddy**, University School of Engineering & Technology, Guru Govind Singh Indraprashth University, Sector -16C, Dwarka, Delh, India.

This filter is a fourth-order cross-coupled structure and the couplings exist between adjacent and non-adjacent resonators as shown Fig 3.

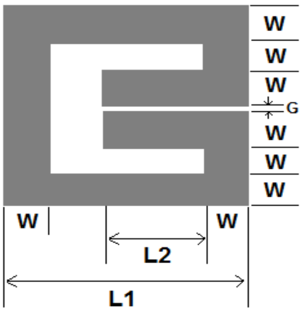


**Fig. 2. Structure of double fold resonator**

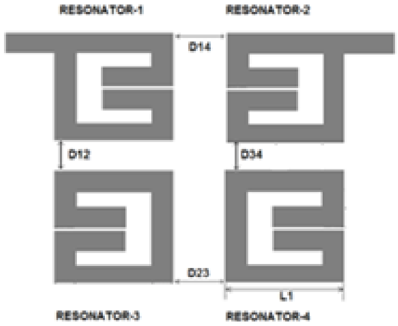


**Fig. 3.A fourth-order double fold hairpin resonator filter**

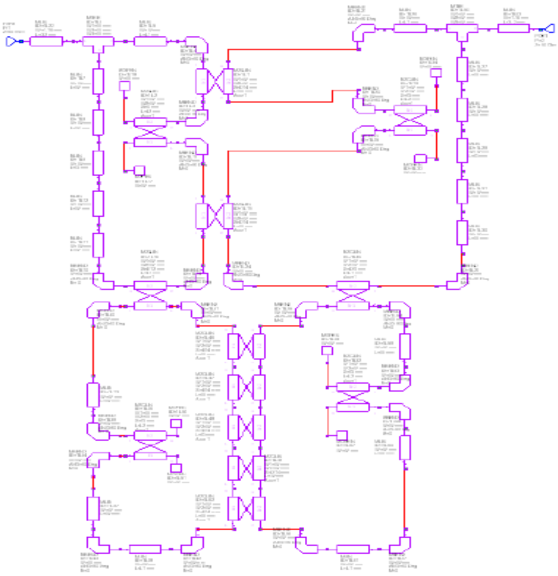

**Fig. 4. Schematic diagram**

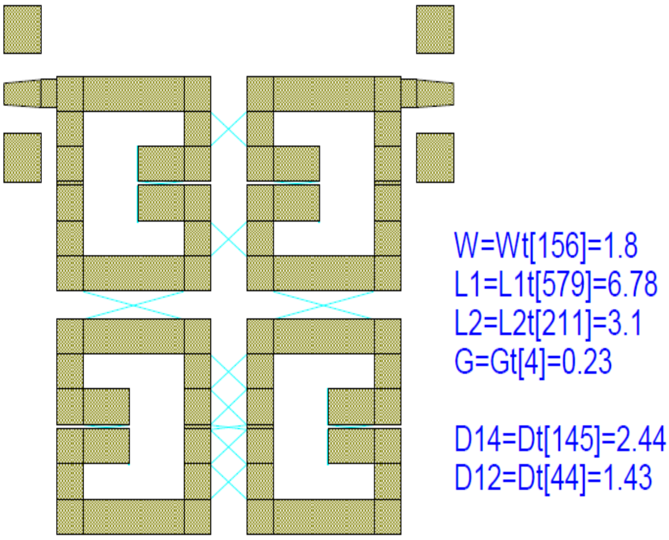


**Fig. 5. Layout and dimensons**

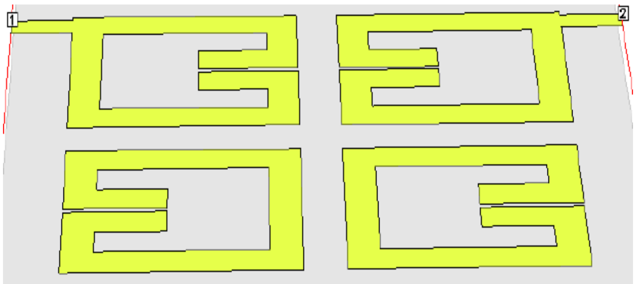

**Fig. 6. Optimized Layout**

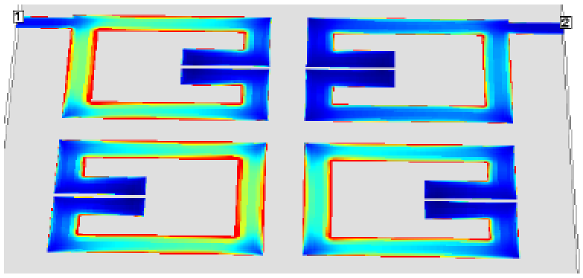

**Fig. 7. Current distribution**

Dimensions of hairpin resonators of the filter are $L_1$ : 6.78 mm, $L_2$ : 3.1, W: 1.8 mm, G : 0.23 mm $D_{12}$= $D_{34}$ :1.43 mm and $D_{14}$=$D_{23}$ :2.44 mm

*Size of the filter:18 mm x 18 mm (324 $mm^2$ i.e. 52 % of A: 625 $mm^2$) i.e reduction in size is 48 % of A

The design calculations and simulation/optimization of the fourth-order, double fold hairpin line filter have been done by using existing design methodology and supporting softwares in the following steps [7-11].

1.Finding the element values of LPF prototype by using the approximate synthesis method.The relations between the bandpass design parameters and the lowpass elements are

$Q_{ei} = Q_{eo} = C_1/\Delta\omega$

$$k_{n,n-1} = k_{N-n,N-n+1} = \frac{\Delta\omega}{\sqrt{C_n C_{n+1}}}, \text{ for } n=1 \text{ to } N/2$$

$$k_{m,m+1} = \frac{\Delta\omega J_m}{C_m}, \text{ for } m=N/2,$$

$$k_{m-1,m+2} = \frac{\Delta\omega J_{m-1}}{C_{m-1}}, \text{ for } m=N/2,$$

where

$\Delta\omega$ : fractional bandwidth of the bandpass filter,

C : Capacitance of the lumped capacitor
J : Characteristric admittance of the inverter,
N : degree of the filter

2. To calculate the resonator parameters: The length of the coupled lines can be calculated by:

$$\cot g\theta_p = \frac{-R + \sqrt{R^2 + 4Z_c^2 \sin^2\theta_s}}{2Z_c \sin\theta_s}$$

$$\text{and } R = (Z_{pe} + Z_{po})\cos\theta_s - (Z_{pe} - Z_{po}).$$

where $\theta_s$ : Electric length of the resonator
$Z_c$ : Characteristic impedance
$Z_{pe}$ :Even mode impedance
$Z_{po}$ : Odd mode impedance

3. Calculations for the coupling parameters,

4. Input/output tapped length,

5. Geometric parameters,

6. Gptimization of filter parameers by varying the geometric dimensions:

7. The values of coefficient of coupling between resonators can be calculated against the distances between the resonators.

8. The design technique uses an approximation polynomial and a low filter prototype.

9. The loaded Q factor and the mixed coupling coefficients between different resonators can be calculated by using the equations, graphs and commercial softwares.

$$Q_e = \frac{g_0 g_1}{\text{FBW}}$$

$$M_{12} = M_{45} = \frac{\text{FBW}}{\sqrt{g_1 g_2}}$$

$$M_{23} = M_{34} = \frac{\text{FBW}}{\sqrt{g_2 g_3}}$$

$$M_{ij} = \frac{f_{p2}^2 - f_{p1}^2}{f_{p2}^2 + f_{p1}^2}$$

Where $f_{p1}$ and $f_{p2}$ are the lower and higher split resonant frequencies of a pair of coupled resonators. We have used EM simulator to model the coupling coefficient and external Q.The hairpin transmission lines and bends are realized by using the MBEND90x and MLIN elements. [12-14].

$$\theta_t \approx arctg\sqrt{\frac{G_a}{bQ_{ei}}}$$

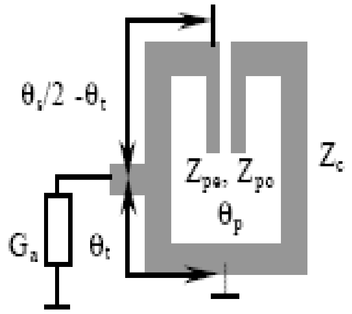


**Fig. 8. Input/output tapped electrical length.**

## IV. RESULTS AND DISCUSSIONS

We have simulated a fourth-order double fold hairpin line microstrip bandpass filter at center frequency 1.325 GHz and insertion loss of 3.322 dB, lower and upper 3dB bandwidths are 1300 MHz and 1350 MHz and more than 30dBc attenuation at 1275 MHz and 1375 MHz as shown in fig.9. Due to the inaccuracies in fabrication, improper input-output connections, grounding etc. the measured center frequency is shifted to lower side by 0.015 GHz and occurred at 1.310 GHz having insertion loss of 3.178 dB and return loss of 10 dB(min) in passband, as shown in fig 10.The measured results show that more than 30 dBc stopband attenuation is achieved in ± 0.050 GHz bandwidth i.e rate of slope in stopband is 0.7 dB/MHz, which meets the requirements of out of band attenuation to supress the unwanted harmonics and spurious as shown in figs. 11 to 15 . It is cleared from fig 14, that the second passband repeats at 2935 MHz with loss more than 6 dB and the out of band attenuation better than 25 dBc. The developed filter shows that the measured and simulated results are in good agreement as shown in fig.16. The filter is presented in photograph, fig.17.

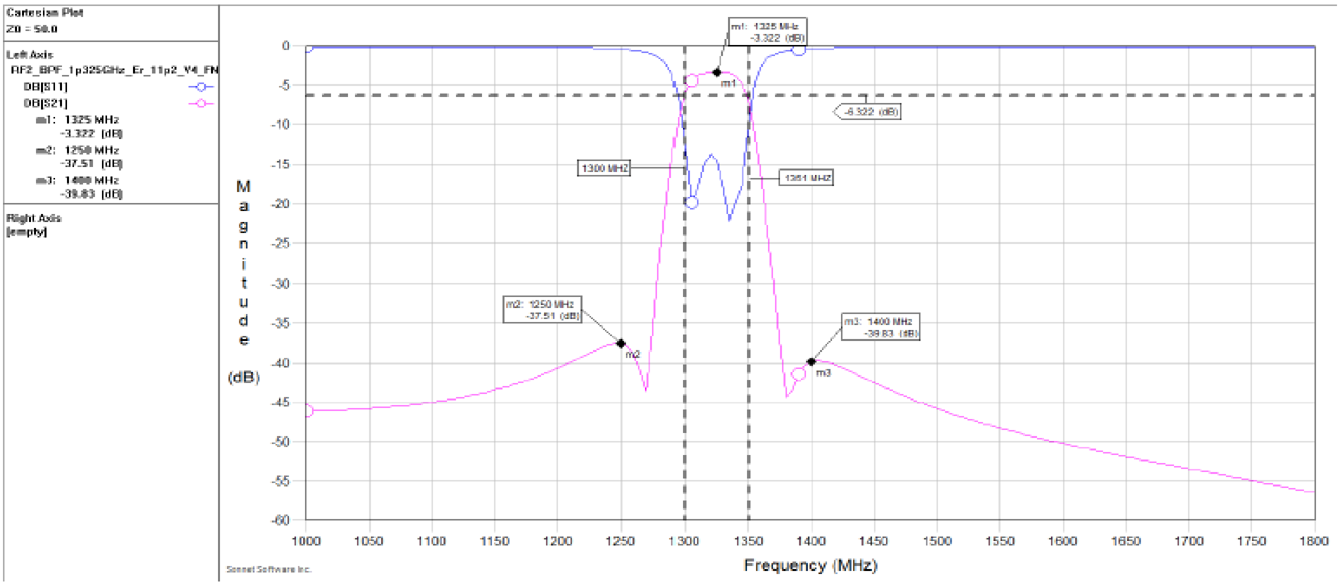


Fig. 9. Simulated response

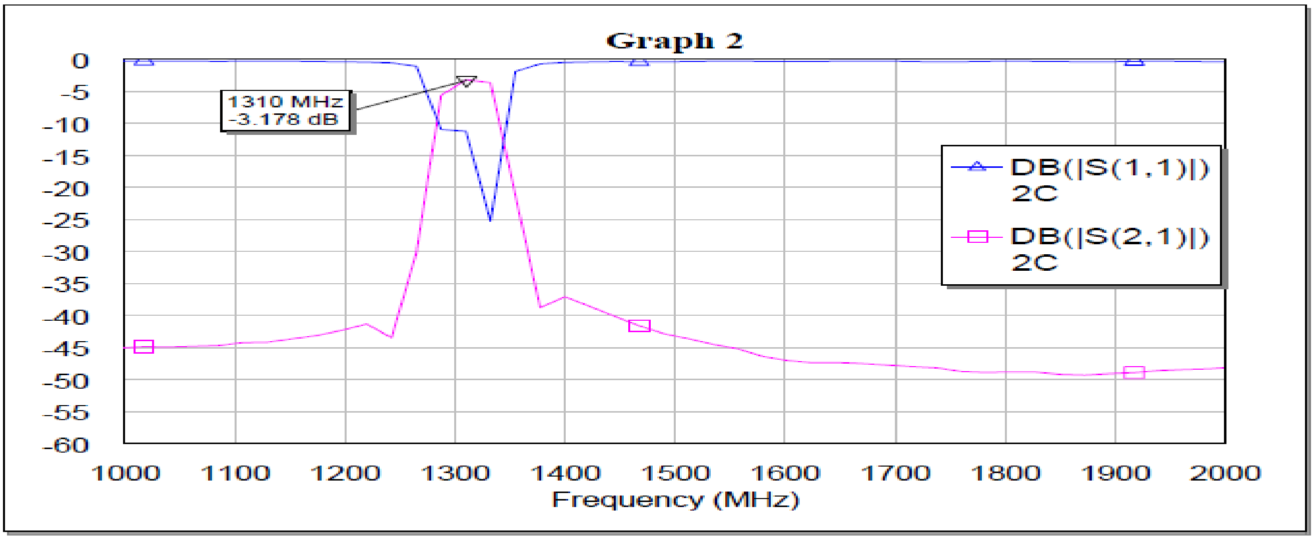


Fig. 10. Measured results of the filter

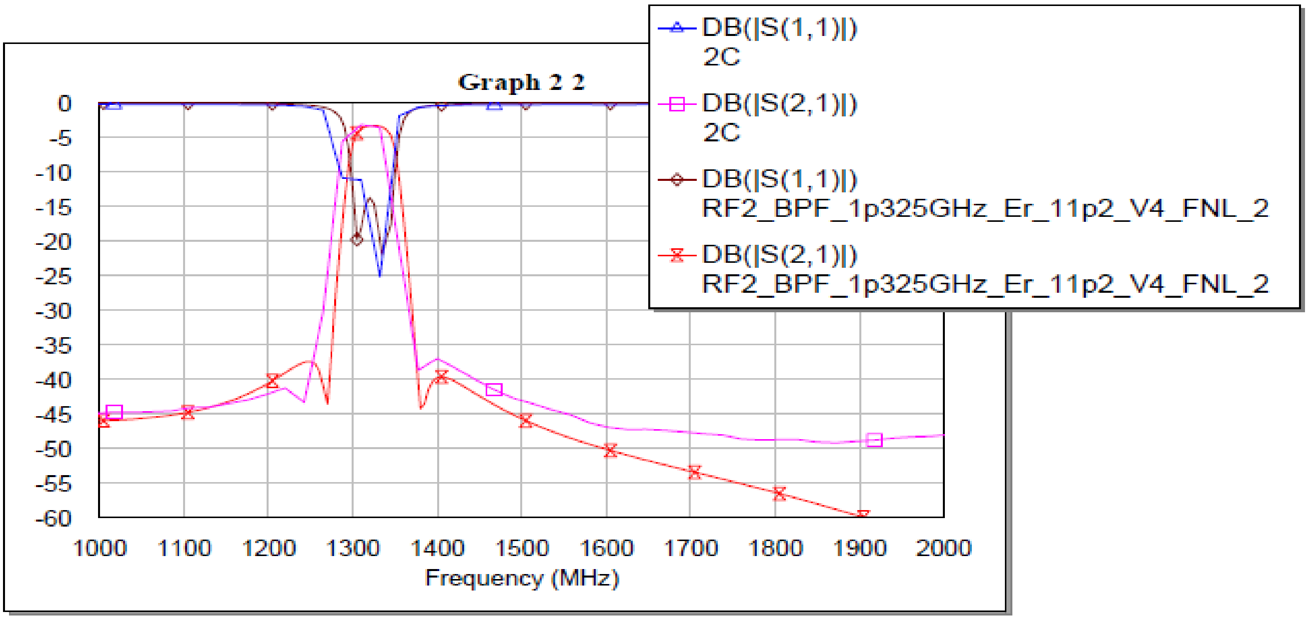


Fig. 11. Comparision of simulated and measured results

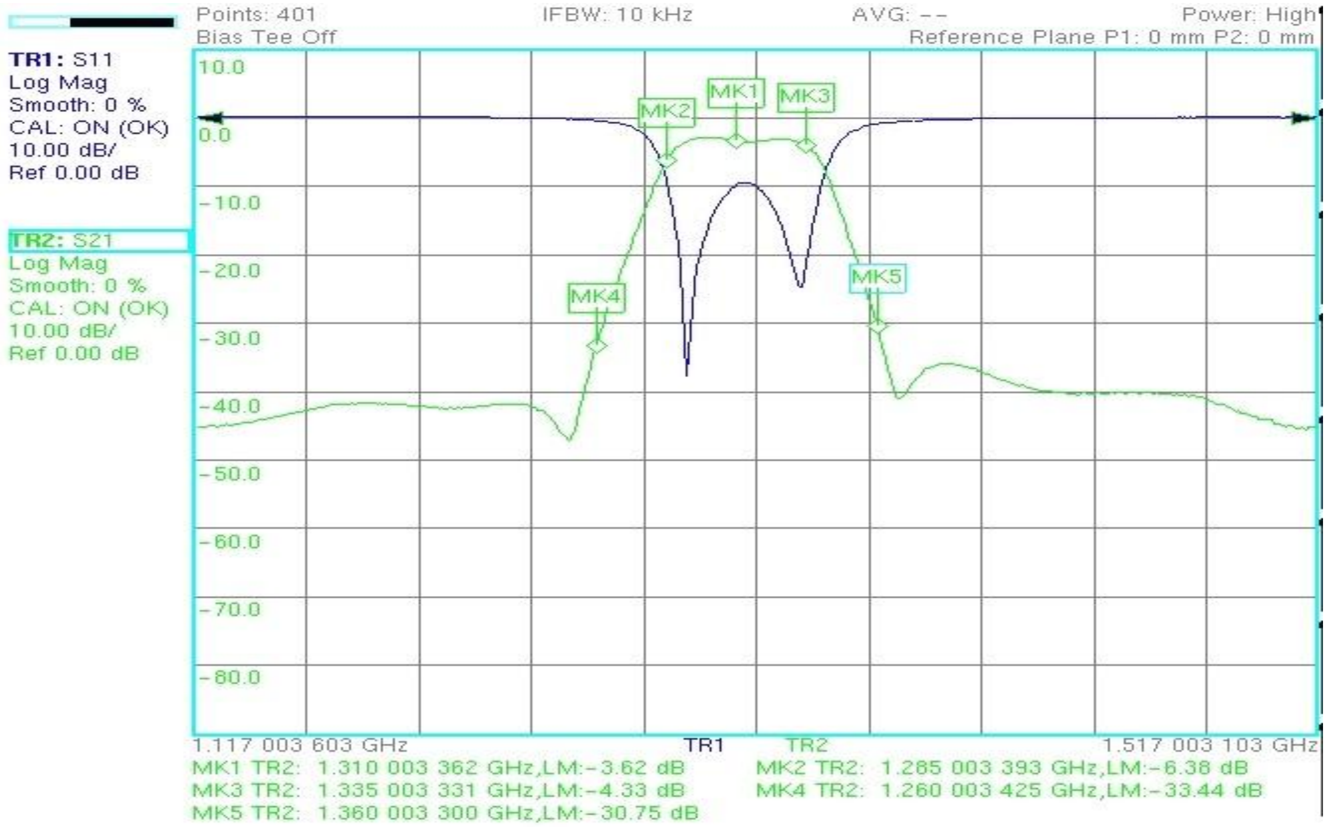


**Fig. 12. Measurement of performance in in 0.4 GHz span**

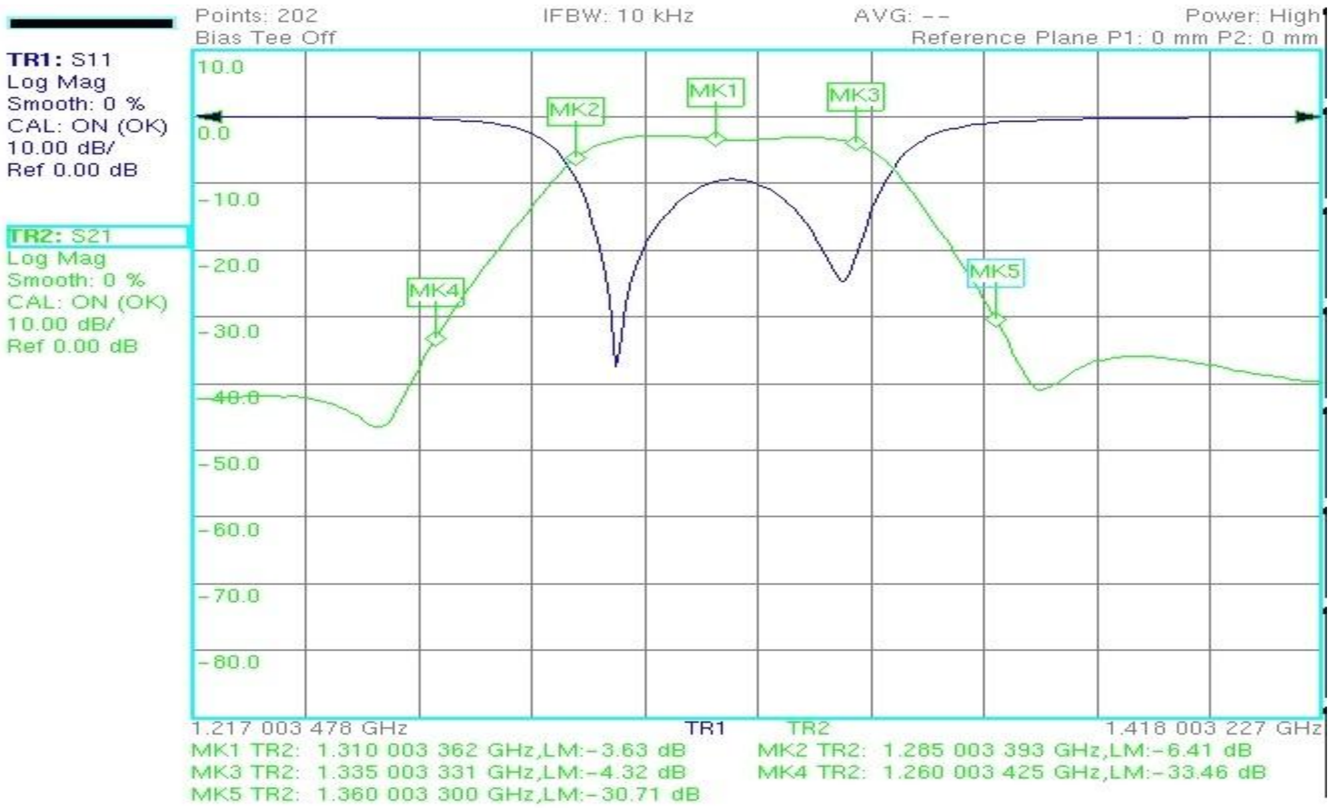


**Fig. 13. Measurement of performance in in 0.2 GHz span**

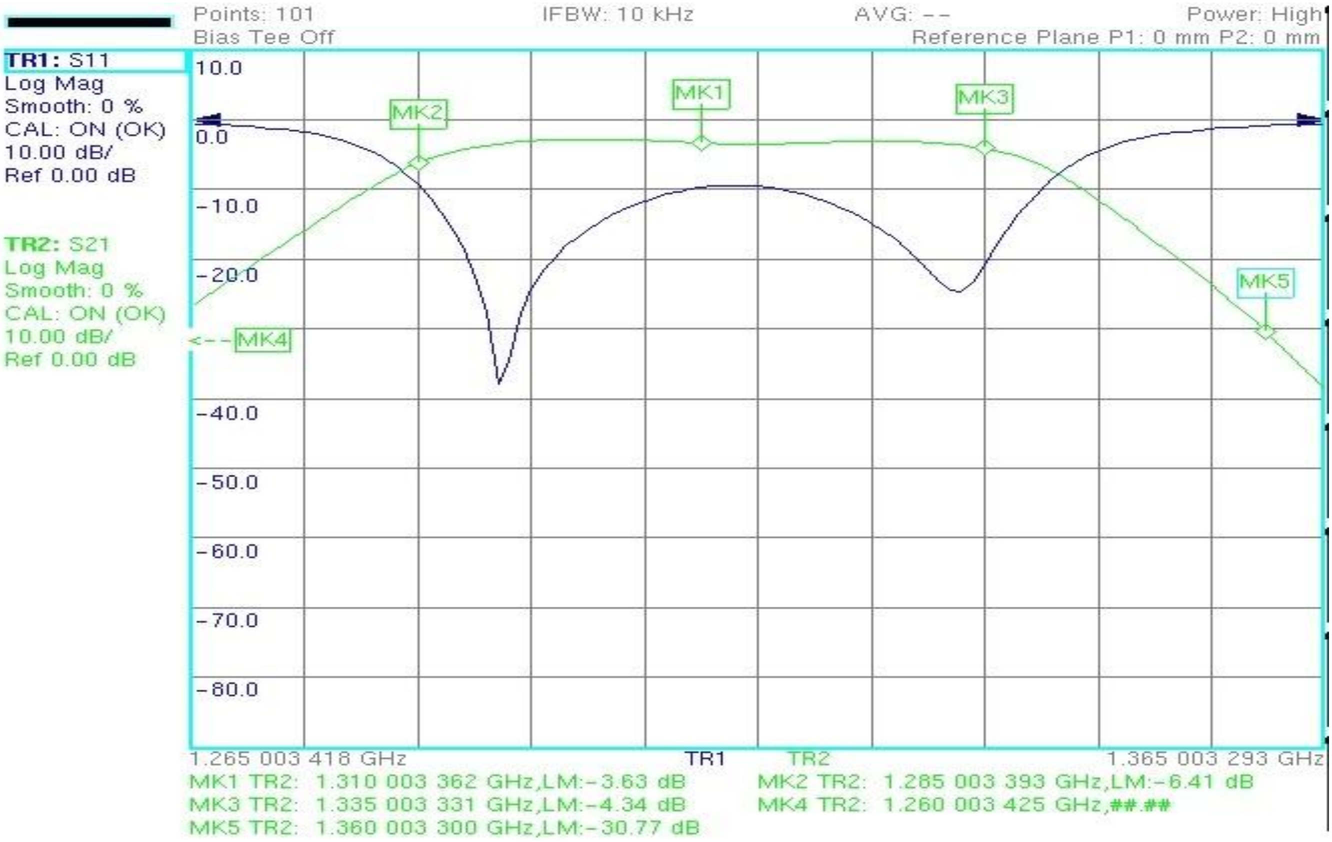


**Fig. 14. Measurement of performance in in 0.1 GHz span**

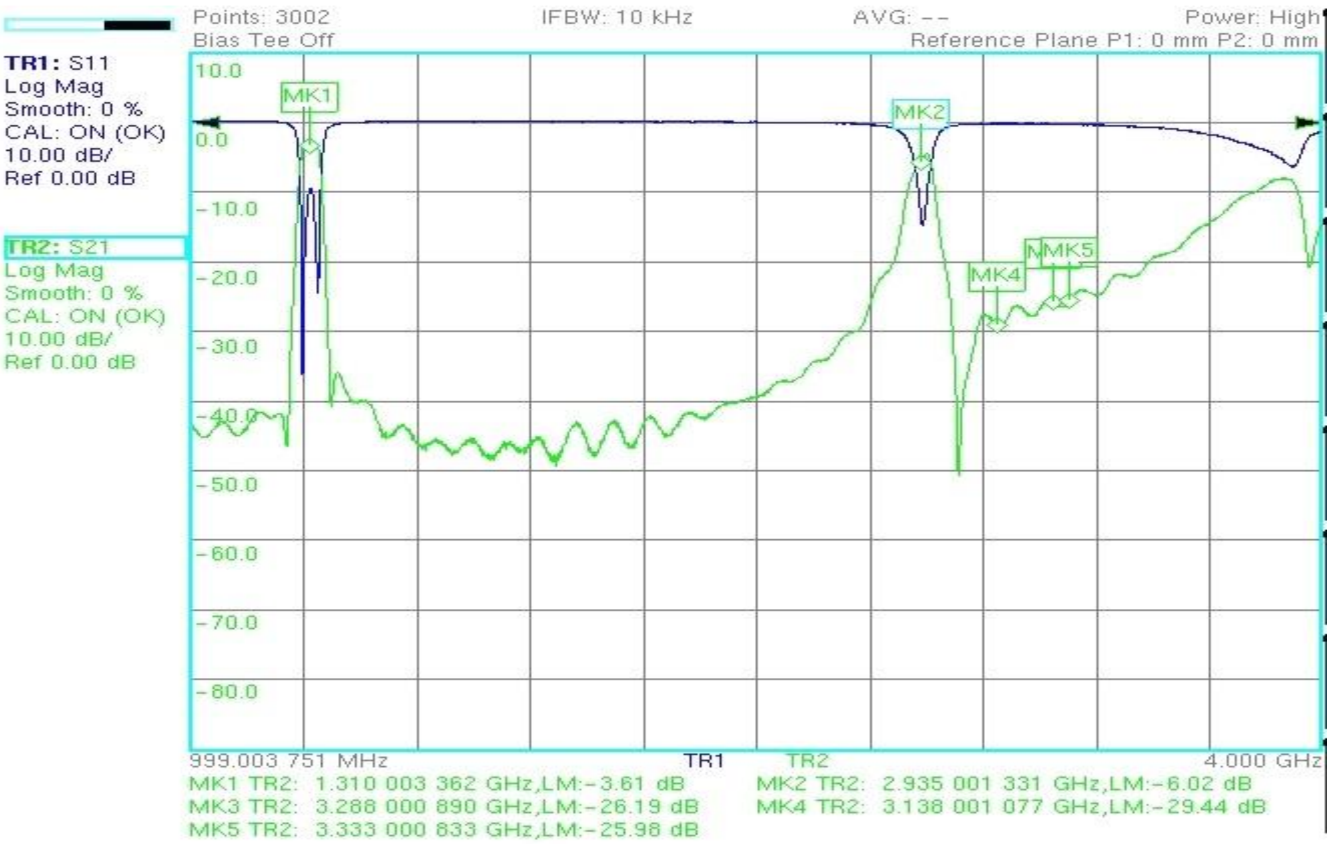


**Fig. 15. Measurement of performance in 1-4 GHz range**

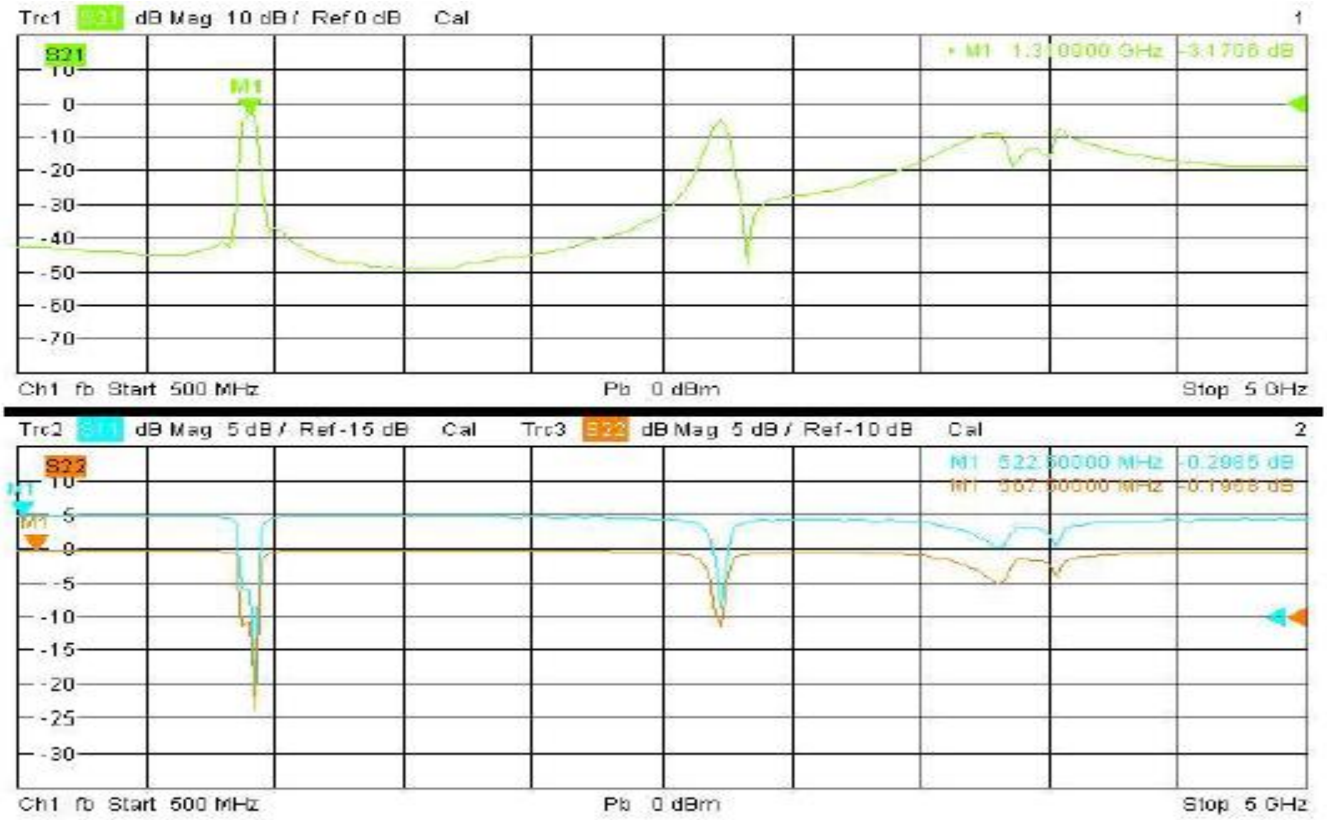


**Fig. 16. Measured results in 5 GHz span**

**1. TABLE: COMPARISION OF SIMULATED AND MEASURED RESULTS OF THE FILTER**

**Optimized dimension of a conventional hairpin line bandpass filter:25 mm x 25 mm : (A=625 mm$^2$)**

| S. No. | **Parameters** | **Unit** | **Design Specs(D.S .)** | **Double-fold Simulated** | **Double-fold Measured( M)** | **Variation (%)*** | **Remarks** |
|---|---|---|---|---|---|---|---|
| 1 | Center frequency | MHz | 1325 | 1325 | 1310 | -1.13 | Acceptable |
| 2 | Insertion loss in band | dB | ≤ 3 | 3.332 | 3.178 | 5.93 | Acceptable |
| 3 | 3dB BW Lower side | MHz w.r.t.c.f . | 1300 | 1300 | 1285 | -1.15 | Acceptable |
| 4 | 3dB BW Upper side | MHz w.r.t.c.f . | 1350 | 1350 | 1350 | 0.0 | Acceptable |
| 5 | 30 dBc B W Lower side | MHz w.r.t.c.f . | 1275 | 1275 | 1260 | - 1.176 | Acceptable |
| 6 | 30 dBc B W Upper side | MHz w.r.t.c.f | 1375 | 1375 | 1375 | 0.0 | Acceptable |
| 7 | Return loss in passband | dB | >15 | 14 (min) | 10 (min) | --------- | Acceptable |
| 8 | Size of filter /(Reduction in size) | mm$^2$ /% | Minimum possible | 18 mm x 18 mm=324 mm$^2$ | **52% of A/ Reduction (48 % of A)** | ------------- | Acceptable |

***Variation (%) with respect to the measured value : [100-(Measured data/Designed Specs.data) x 100]**

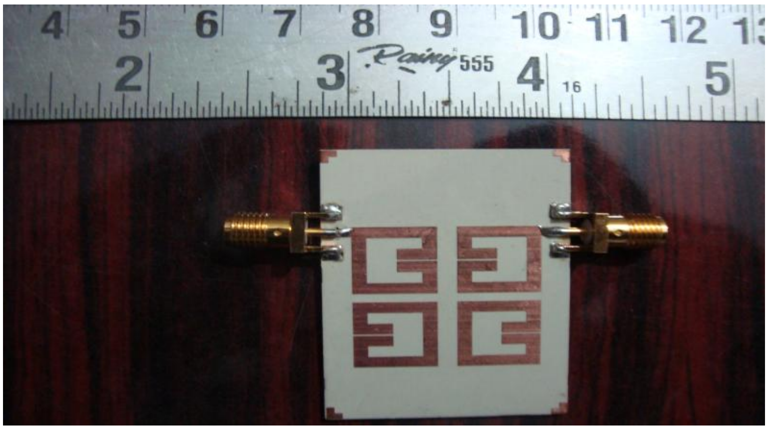

**Fig. 17. Photographs of double fold resonator filter at 1.325 GHz**

## V. FUTURE SCOPE: FOUR FOLD HAIRPIN LINE FILTER AT 1.325 GHZ

We have designed and simulated the frequency responses of single, double and four fold hairpin line filters at the same center frequency of 1.325 GHz, to study their comparative performances and reduction in size compare to the size of a conventional hairpin resonator filter (A :25 mm x 25 mm=625 mm$^2$) for future R & D work.

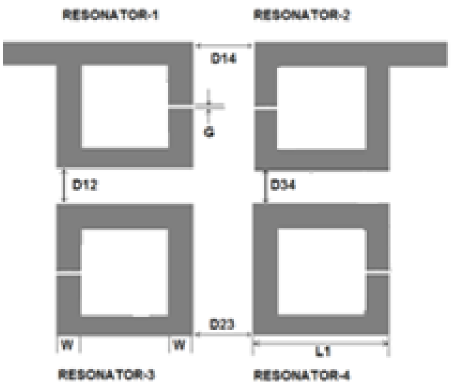


**Fig. 18. Single fold filter 400 mm$^2$ i.e. (64% of A) reduction in size (36 % of A)**

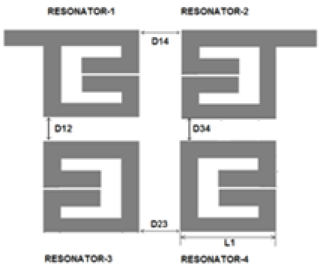


**Fig. 19. Double fold filter 324 mm$^2$ i.e.(52% of A) reduction in size (48 %ofA)**

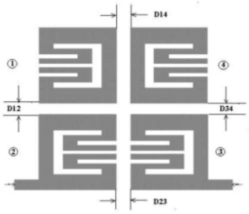


**Fig. 20. Four fold filter 250 mm$^2$ i.e (36% of A) reduction in size (64% of A)**

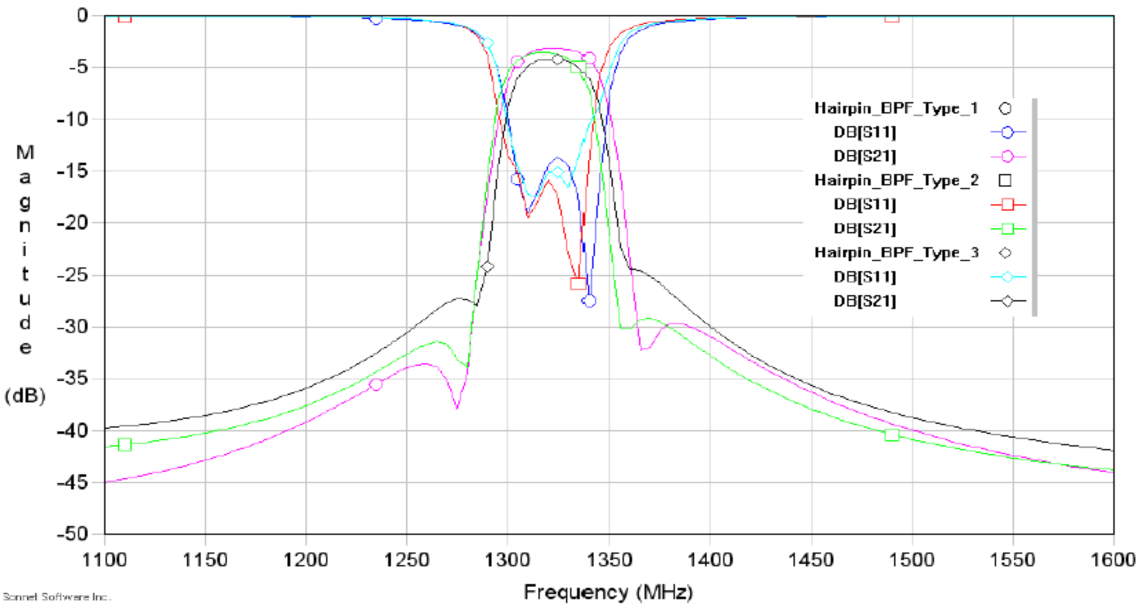


**Fig. 21. Comparision of simulated responses of single, double and four fold filters at 1.325 GHz.**

## VI. CONCLUSION

This paper presents the design and development of a fourth-order, double-fold microstrip hairpin line bandpass filter at 1.325 GHz for RF/Wireless/mobile communications. The reduction in size of filter is 48 % of the optimized size (A=625 $mm^2$) of the conventional hairpin line bandpass filter at the same centre frequency. The measured results are close to the simulated results. There are limitations of the design in terms of inaccuracy of sharp folding and coupling between the adjacent and non-adjacent (cross-coupled) folded hairpin line resonators in the filters. The developed filter can be used for RF/wireless applications.

## REFERENCES

1. Ilia G. Iliev and Marin V Nedelchev "CAD of Cross Coupled Miniaturized Hairpin Bandpass Filters" Microwave Review, December 2002, pp.49-52
2. S. Jovanovic, A Nesic "Microstrip bandpass filters with new type of capacitive coupled resonators, Electronics Letters 41,(1), 2005, page 19-21
3. Hong, J. S. and M. J. Lancaster, "Coupling Microstrip Square Open-Loop Resonators for Cross-Coupled Planar Microstrip Filters" IEEE Trans.Microw.Theory Tech. Vol. No. 5, October 2006. .
4. S Zhang,Y Li, S.-W. Ma, J.-K. and S. Xiao "Compact microstrip band pass filters" Journal of Electromagnetic Waves & Applications,Vol.21, No.3, 2007, 329-339.
5. M D Pozar, *Microwave Engineering* , Third Edition, Wiley2005, pp. 416-438
6. Deng,P.H., Y. S. Lin, C. H Wang, C. H. Chen "Compact Microstrip bandpass filters with good stopband rejection" IEEE Transactions on Microwave Theory and Techniques,Vol.54, No.2, Feb 2007, 533-539
7. Jen-Tasi Kuoet, Ming-Jyh Maa and Ping-han Lu, "Microstrip filter with Compact miniaturized hairpin line resonators" IEEE Microwave Theory and Guided Letters,Vol. 10,No.3, March 2005, pp 94-95
8. Tsai,C.-M.,S.-Y. Lee,and H.–M. Lee), "Transmission line filters with capacitively Coupled lines" IEEE Trans.Microw.Theory and Tech.Vol.51,No.15, 2003, page 1517-1524.
9. Zhu, Y.Z, Y.J. Xie and Y. Feng "Novel microstrip bandpass filters" Progerss in Electronics Research PIER, 2007, pp. 29-41.
10. Xiao, J.K., S W Maa, S Zhang and Y. Li "Novel compact band pass filters "Journal of Electromagnetic Waves and Applications, Vol.21, No.10, 2007, page 1341-1351
11. Moon-Seok Chung, I-Soo Kim, and Sang-Won Yun,"Hairpin Line bandpass filter with an attenuation pole" presented at APMC 2005 Volume 4, Dec. 2005, pp 4-7.
12. ADS Agilent-make Softwares for Design and Simulation, 2013 by M/S Agilent Technology Ltd.
13. Ansoft-HFSS-3D software for Electromagetnic modeling, 2013 by M/S Ansoft Software Corporation
14. Zealand Software IE3D for Simulation and Optimization, 2014 by M/s Zealand Software Corporation.