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A High Performance and Small Sized Four-Fold Microstrip Hairpin Line Bandpass Filter at 2.250 GHz for Communication Systems

Jagdish Shivhare, B. V. R. Reddy

Abstract: ***The contents of this technical paper is presented a new class of multi-folded hairpin line microstrip bandpass filter with improved performance, low cost and great reduction (60-65%) in size compared to a conventional hairpin line bandpass filter.The expected frequency responses have been simulated/optimized by using The Agilent-make ADS/IE3D-Zealand softwares. The measured results are very close to the simulated/optimized results.***

Keywords—Substrate, folded-hairpin line resonator, miniaturized microstrip filters, narrow band, selectivity, slow wave, ADS/IE3D softwares.

I. INTRODUCTION

Planar structured multi-folded hairpin line microstrip bandpass are easy to filters are easy to fabricate by using low cost printed circuit technology. The folded-hairpin line topology has the advantage of desirable narrowband, moderate return loss, compact structure and low cost microstrip filters make the design more meaningful for further development and applications in the modern mobile radio communication systems. A multi-fold hairpin line bandpass filter has been designed on the RT-Duroid-Alumina substrate of dielectric constant 10.2 and thickness of 1.27 mm. The width of the microstrip is determined for 50 ohms and is made large, the peripheral of each resonator is made a square, length of the U-shaped coupled lines is extended to its maximum and the gap between coupled lines is made as small as possible[1]. By using the imperical equations. Graphs and simulation/optimization, we have obtained the total size of a fourth-order conventional hairpin line filter at 2.250 GHz is 35 mm x 20 mm (A=700 mm^2). At the same center frequency the size of a multifold hairpin line bandpass filter will be 18 mm x 15 mm (270 mm^2) i.e. 38.6 % of A or reduction in size is approx. 61% compared to the size of the conventional hairpin line bandpass filter at the center frequency 2.250 GHz.

II. THE CONCEPT OF THE FOUR-FOLDED HAIRPIN LINE RESONATOR

The length of parallel coupled filter is too long and the size increases with the order of filter. To solve this problem, hairpin line filter, using folded λ/2 resonator(U-shaped) structures were developed.

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Further reduction in size is made by folding again the two arms of the conventional hairpin line resonator(single-fold) to form a pair of closely coupled lines to enhance the capacitive nature of open end arms. This structure helps to reduce the size of the filter upto 35-40% of the size of the conventional hairpin line bandpass filter. Even more reduction in size i.e 45-50% and 60-65% is employed by further folding the two arms of the single-folded hairpin line resonators i.e. double-folded and multi-folded hairpin line resonators[2-4].The filters consisting the folded resonators are of moderate quality factor and high stop band attenuation compare to the filters with conventional hairpin line resonators.

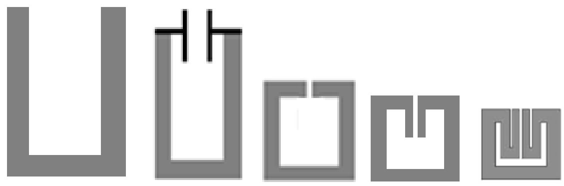

Fig. 1. Actual, capacitor loaded, single-fold, double-fold and four-fold resonators

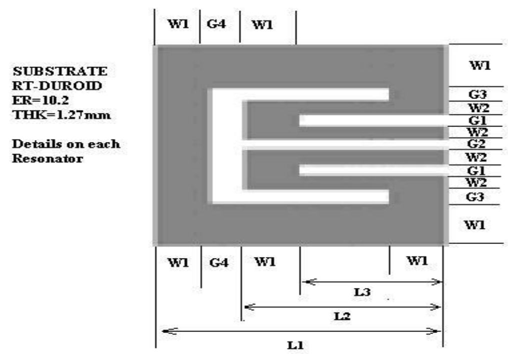

Fig. 2. Structure of a four-fold resonator

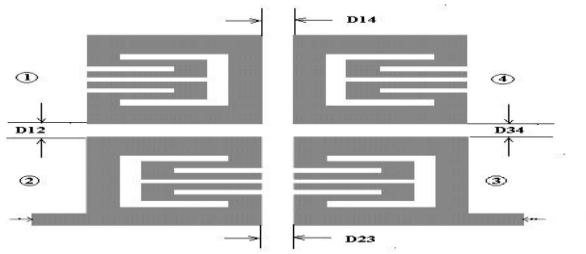

Fig. 3. A fourth-order filter consisting of resonator

III. DESIGN PROCEDURE OF FOUR-FOLD HAIRPIN LINE RESONATOR FILTERS

Desired specifications of the filter:

Centre Frequency (CF) : 2.25 GHz
Insertion loss : < 4 dB
Passband (3 dB) Bandwidth : ± 0.025 GHz w. r. t. c. f.
Stopband (30 dB) Bandwidth : ± 0.075 GHz w. r. t. c. f.
Return Loss in passband : >15 dB
Input/output Impedance : 50 Ohms

The design methodology and supporting softwares are available to design, simulate/optimize the multi-folded hairpin line filters[5-6]. Design calculations of four-fold hairpin line microstrip filters can be done 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 : Characteristic 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 θ_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.

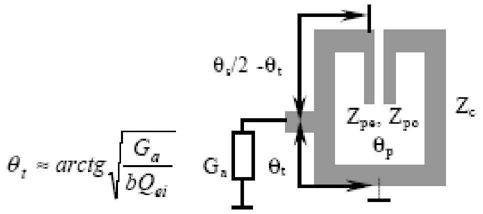

Fig. 4 Input/output tapped electrical length.

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. [12-13].

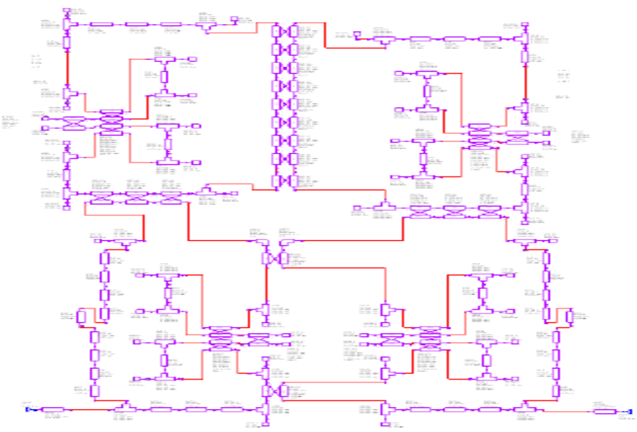

Fig. 5 Schematic diagram

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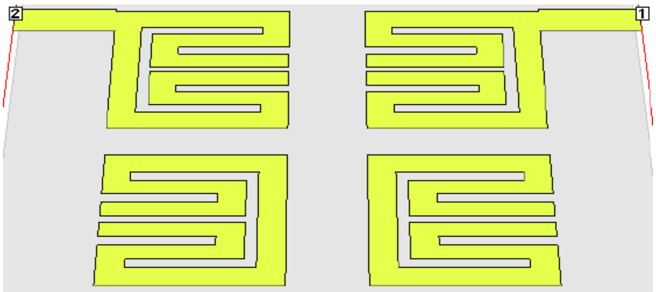

Fig.6 Optimized Layout of the filter at 2.250 GHz

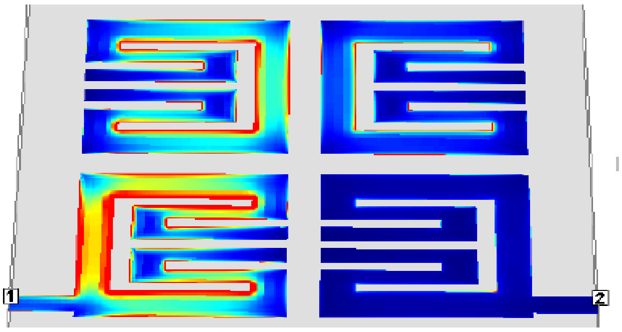

Fig. 7 Current density

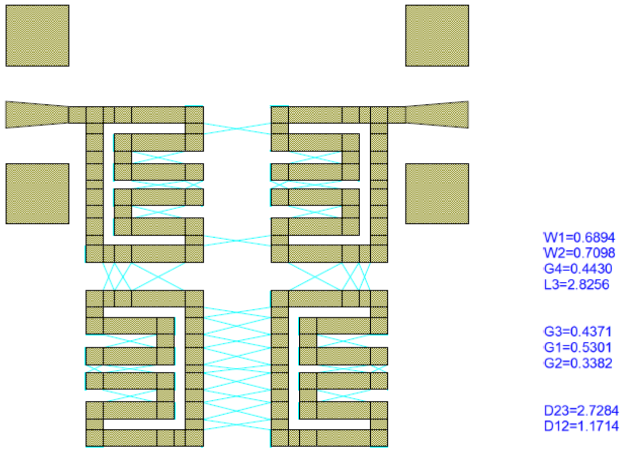

Fig. 8 Optimized dimensions of filter

Optimized Dimensions of resonators of the filter
L_1 : 2.86 mm, L_2 : 3.53 mm, L_3: 4.87 mm , W_1 : 0.67 mm W_2 : 0.70 mm , G_1: 0.53 mm
G_2 : 0.33 mm G_3 : 0.43 mm, G_4: 0.82 mm, D_{12}=D_{34} 1.54 mm, D_{23}=D_{14}: 2.73 mm
* Size of the filter:18 mm x 15 mm(270 mm$^{2)}$ i.e 38.6 % of 700 mm^2 (35 mm x 20 mm of conventional hairpin line filter).

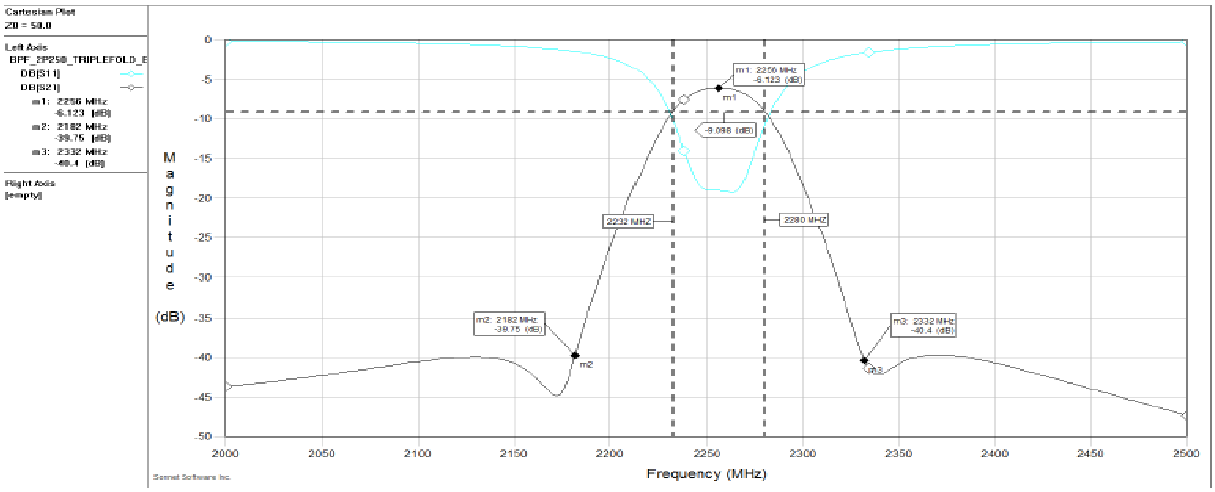

Fig. 9 Simulated response and measured results of the developed filter

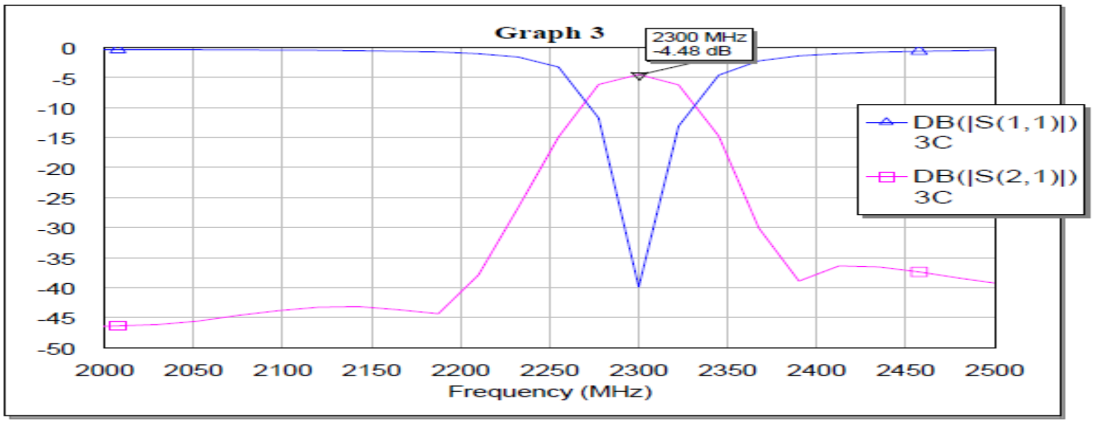

Fig. 10 Measured results of the developed filter

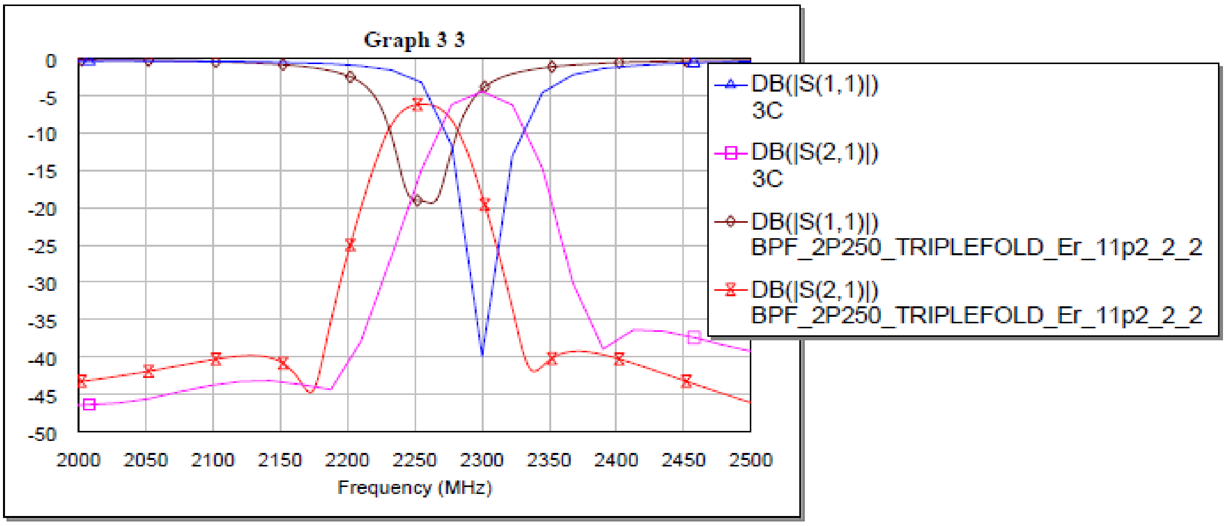

Fig. 11 Comparison of simulated and measured results of the filter

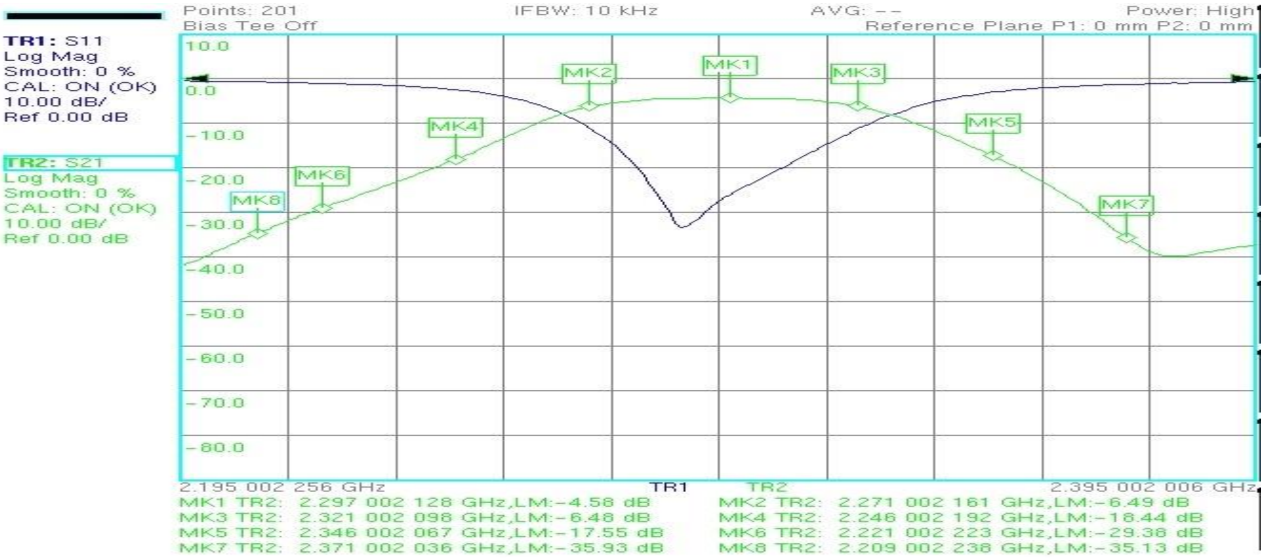

Fig. 12 Measured results in 0.2 GHz span

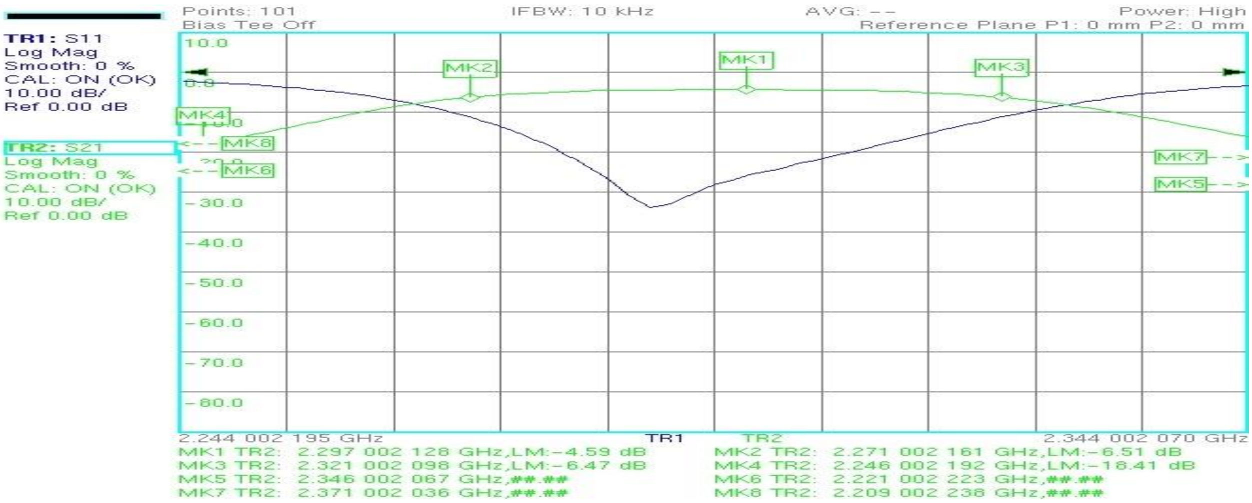

Fig. 13 Measured results in 0.1 GHz span

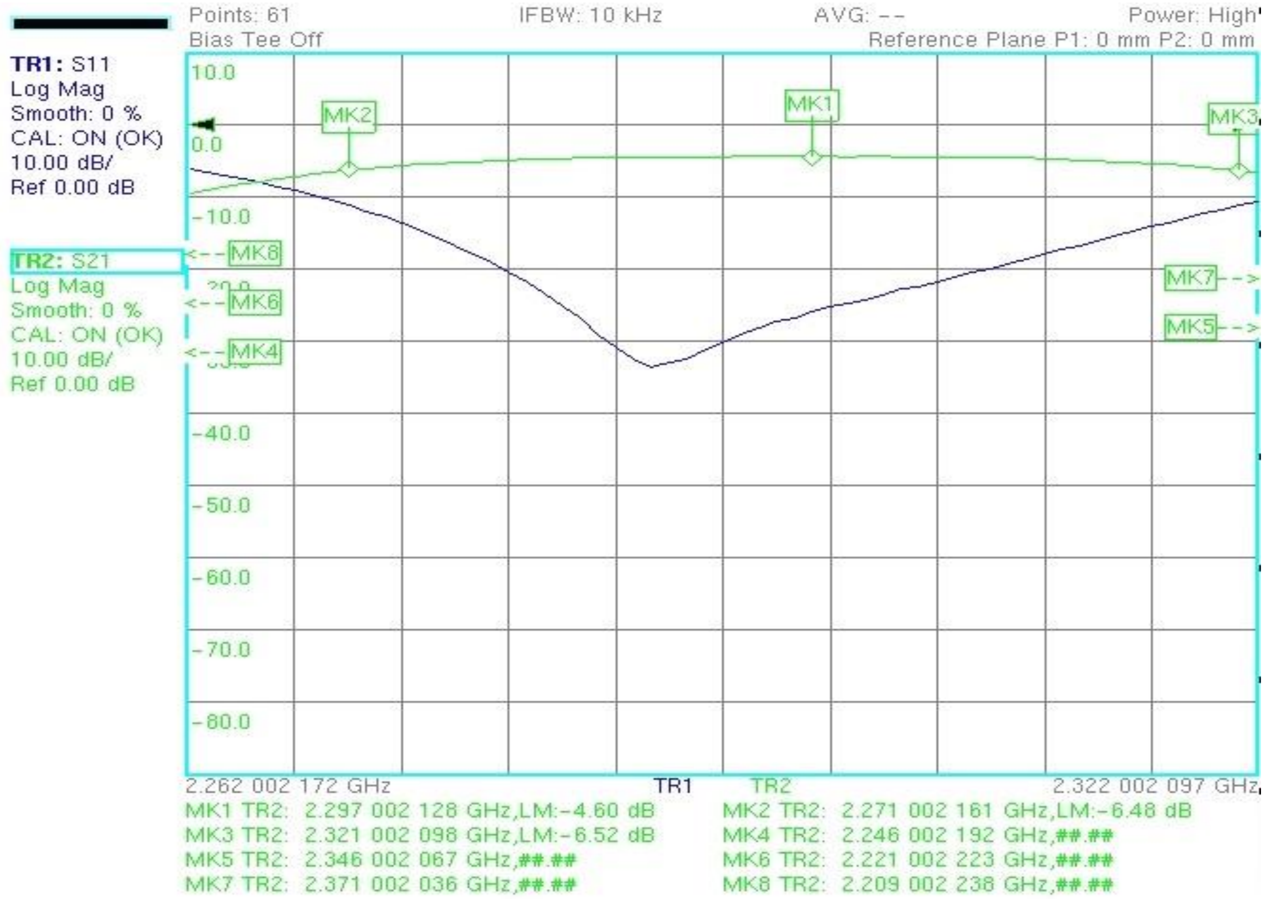

Fig. 14 Measured results in 0.062 GHz span

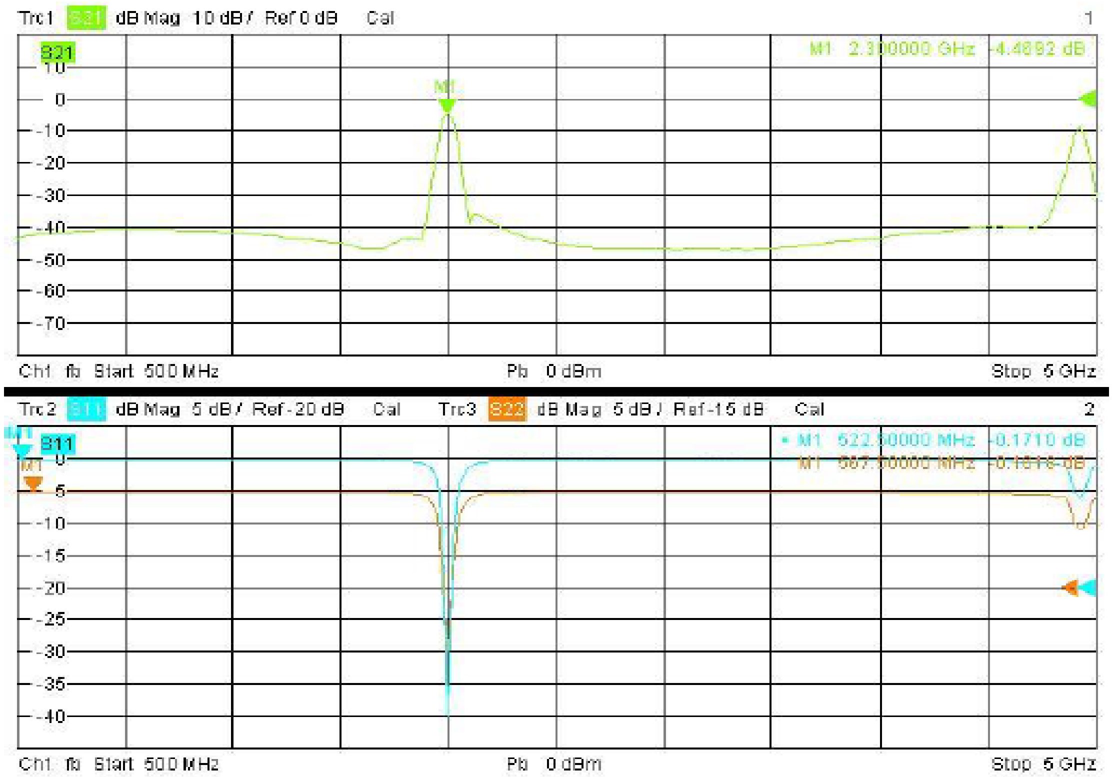

Fig. 15 Measured results in 5 GHz span

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

Optimized dimension of a conventional hairpin line bandpass filter:35 mm x 20 mm : (A=700 mm^2

S. No.	**Parameters**	**Unit**	**Design Specs.**	**Four-fold Simulated**	**Four-fold Measured**	**Remarks**
1	Center frequency	GHz	2.250	2.256	2.300	Acceptable
2	Insertion loss in band	dB	< 5	6.12	4.48	Acceptable
3	Passband 3dB-band width (Lower side)	GHz w.r.t.c.f.	±0.025	±0.025	±0.026	Acceptable
4	Passband 3dB-band width (Upper side)	GHz w.r.t.c.f.	±0.025	±0.025	±0.024	Acceptable
5	Stopband 30 dB-bandwidth (Lower side)	GHz w.r.t.c.f.	±0.080	±0.080	±0.088	Acceptable
6	Stopband 30 dB-bandwidth (Upper side)	GHz w.r.t.c.f.	±0.080	±0.080	±0.074	Acceptable
7	Return loss in passband	dB	>15	>10	>10	Acceptable
8	Size of filter /(Reduction in size)	mm^2 /%	Minimum	18 mm x 15 mm=270 mm^2	**38.6 % of A=700** mm^2 **Reduction (61.4 % of A)**	Acceptable

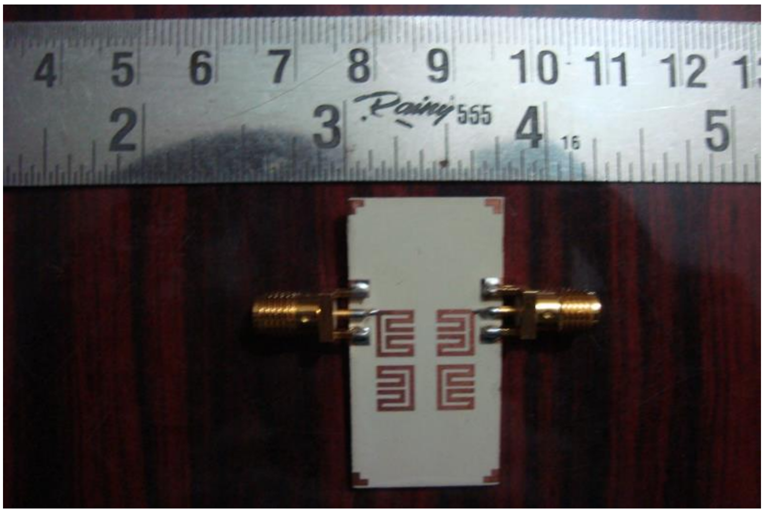

Fig.16 Photographs of the developed fourth-order hairpin line filter

V. RESULTS AND DISCUSSIONS

The desired center frequency is 2.250 GHz, but the best simulated/optimized center frequency is 2.256 GHz to obtain the other parameters as per given specifications. The measured center frequency 2.297 GHz i.e shifted by 0.041 GHz to the upper side of the center frequency due to inaccuracy in fabrication/input-otput connections, improper grounding etc. The deviations in passband, stopband and return loss are also due to inaccuracies in fabrication but are acceptable.

VI. CONCLUSION

This paper presents a four-fold microstrip hairpin line bandpass filter design techniques.The reduction in size of the fourth-order filter are 61% of the optimized size (A) of the conventional hairpin line bandpass filter at 2.297 GHz centre frequency. The measured results are close to the simulated/optimized results. There are limitations of the design in terms of inaccuracy of sharp folding and coupling between the adjacent and cross-coupled folded hairpin line resonators in the filters. The developed filter can be used for RF/wireless communication systems.

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