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Microstrip Parallel Coupled Bandpass Filter Design for Applications at 2.4 GHz

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ABSTRACT
Designing Microstrip filter is the prime requirement for optimum and efficient performance of next generation communication systems. This research article presents design, and mathematical and numerical analysis of a parallel coupled microstrip band pass filter, its electrical responses obtained through iterative numerical electromagnetic simulations, and discussions on the results measured and tested after fabrication using FR4 substrate. Comparing this filter with international industry standards for its operational frequency applications at 2.4 GHz using Ansoft Designer Software we found satisfactory parameters such as insertion loss above -5.00 dB, reflection loss below -20 dB, negligible energy loss and frequency bandwidth of 6.25%. Volumetric miniaturization and sustainable compatibility we researched are pivotal in RF and microwave communication spectrum resulting into minimum cost to production and a step towards green earth saving the material extraction from the earth's crust.

General Terms
Reflection loss, Insertion loss

Keywords
Microstrip Parallel Coupled Filter, Scattering Parameters, Ansoft Designer

1. INTRODUCTION
Since the time unknown and immemorial, the importance and applications of Communication system existed for exchanging the information between transmitting source/s and receiving end/s. In present era of technology revolution of the wireless-mobile-satellite-digital optical communication, the researchers and end users use developed systems for the error free, precise, and accurate exchange of data and information. These communication systems used different active and passive devices and components integrated in the circuits to perform various operations in far better way at desired operational frequency from the allocated frequency spectrum. Filters are one of these components of the circuit at specified frequency for the desired communication. Bandpass filters are used to get the particular band of frequencies from the cluster of frequencies. Microstrip filters are selected for their ease of design, analysis, fabrication, low loss, small size and less weight. Filters can be realized in various structures like waveguide, coaxial lines, microstrip lines etc. Various technologies are known for the design of filters and nowadays different types of CAD tools are available and preferred for the design, analysis and simulation of filters required as per electrical and mechanical specification. This research work was carried out using Ansoft designer software for the design, modeling, numerical analysis and simulation. Based on the requirement and desired design specification, we chose operational frequency of 2.4 GHz for this microstrip bandpass filter where lumped or distributive elements are utilized.

Section II describes design, mathematical modeling and analysis of microstrip filter for 2.4 GHz at length for designated specifications. 3-D numerical solution through iterative simulation of filter-model and electrical parameters obtained as results are reproduced in section III. Section IV discusses these simulation results for the microstrip parallel coupled band pass filter designed using FR4 substrate. Section V concludes the satisfactory achievement of improved performance parameters after completion of all the simulation and analysis, fabrication, test and measurements. Also, significant discussions on the limitations, constraints, technological contributions for future and assumptions made for this research are done.

2. MATHEMATICAL MODELLING AND NUMERICAL ANALYSIS
The distributive elements are used at microwave frequencies to design the filter using insertion loss method instead of conventional image parameter method for the obvious technical reasons. The centre frequency of 2.4 GHz is selected to achieve the bandwidth of 300 MHz, the minimum attenuation less than -20 dB and 0.01 dB pass-band ripple. The 4^{th} order Chebyshev filer is designed using standard dielectric material FR4 having frequency independent dielectric constant of 4.4 for the operating conditions considered for this research. The standard steps generally been adopted while designing, and analyzing this kind of filters are followed to avoid unwanted procedural errors [1], [2], [3].

Design specifications considered for this filter are as boxed follows:

- *Edge / parallel coupled topology*
- *Bandpass with an approximate bandwidth of 7% of 4^{th} order with 0.01 dB pass band ripple at 2.4 GHz central frequency.*
- *Source and Load resistance of 50.0 Ohms each*

Filter synthesis for realizing the transfer functions, usually results in so called law pass prototype filters. Low pass prototype filter is defined as the low pass filter whose element values are normalized to make the source resistance or conductance equal to one, denoted by g_0 = 1, and the cutoff angular frequency to be unity, denoted by Ω_c = 1(rad/s).

The fourth order low pass filter is designed using filter prototype element values g_0=1, g_1=0.4489, g_2=0.4078 and g_3=1.1008 [4]. The designed prototype is transformed to band pass filter of the said specifications. With use of prototype element values, the admittance parameters are calculated, and the odd and even mode impedances are further calculated and solved with help of calculated admittance parameters. The BPF circuit is simulated with Ansoft designer software in order to predict the performance of the filter. In order to improve the response of the filter, optimization process has been introduced along the simulation procedure focusing on the filter dimension [4].

Filter transformation from prototypes to bandpass filter is required for getting bandpass characteristics. The component L is converted to series combination of L_s and C_s as expressed mathematically in (3) and (4), whereas the component C becomes parallel combination of L_p and C_p as expressed in (5) and (6). Fractional bandwidth (FBW) in (2) can be calculated using ω_0 is the center frequency, $\omega_1 and\ \omega_2$ the band edge frequencies chosen for the purpose of designing the band pass filter expressed in (1).

$$\omega_0 = \sqrt{\omega_1 \omega_2} \quad (1)$$

$$FBW = \frac{\omega_2 - \omega_1}{\omega_0} \quad (2)$$

$$L_s = \left(\frac{1}{FBW\ \omega_0}\right) Z_0\, g \quad (3)$$

$$C_s = \left(\frac{FBW}{\omega_0}\right) \frac{1}{Z_0\, g} \quad (4)$$

$$L_p = \left(\frac{FBW}{\omega_0}\right) \frac{Z_0}{g} \quad (5)$$

$$C_p = \left(\frac{1}{FBW\ \omega_0}\right) \frac{g}{Z_0} \quad (6)$$

These given equations and expressions are used to design the parallel coupled Microstrip bandpass filter for desired specifications.

$$\frac{J_{01}}{Y_0} = \sqrt{\frac{\pi}{2} \times \frac{FBW}{g_0 - g_1}} \quad (7)$$

$$\frac{J_{01}+1}{Y_0} = \frac{\pi FBW}{2} \times \frac{\pi 1}{g_0 g_1} \text{ for j = 1 to n-1} \quad (8)$$

$$\frac{J_{yj1}+1}{Y_0} = \sqrt{\frac{\pi}{2} \times \frac{FBW}{g_0 g_1 + 1}} \quad (9)$$

Where g_0, $g_{1,\dots,}$ g_n are the elements of a ladder – type low pass prototype with a normal cut off $\omega_0 = 1$, and FBW is the fractional bandwidth of band pass filter. The $J_{i,\ i+1}$ are the characteristic admittances of j inverters and Z_0 is the characteristic impedance of the terminating line. The even_ and the odd_ mode characteristic impedances of the coupled strip line bandpass filter are determined by (10) and (11) [5], [6].

$$(Z_{oo})_{j,j+} = \frac{1}{Y_0}\left[1 + \frac{J_{j,j+1}}{Y_0} + \left(1 + \frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad (10)$$

$$(Z_{oe})_{j,j+} = \frac{1}{Y_0}\left[1 - \frac{J_{j,j+1}}{Y_0} + \left(1 + \frac{J_{j,j+1}}{Y_0}\right)^2\right] \quad (11)$$

The calculated values of Z_{oo}, Z_{oe}, length, width and line spacing for each coupled line was calculated and mentioned in the Table I. The substrate used is a standard FR4 substrate with dielectric constant ($\mathcal{E}_r$) = 4.4, Height (h) = 1.56 mm, Thickness (t) = 0.035 mm and Loss tangent (Tan δ) = 0.025. The calculated values of width, length and space are rounded off for the ease of fabrication of this parallel coupled microstrip filter for the specified applications [7], [8].

Table 1: Calculation of Z_{oo}, Z_{oe}, W, L and S

N	$Z_{oo}(\Omega)$	$Z_{oe}(\Omega)$	W (mm)	L (mm)	S (mm)
1	108.10	57.32	1.029	17.85	0.6213
2	85.75	65.12	1.341	17.56	1.762
3	82.69	66.98	1.369	17.52	2.23
4	85.75	65.12	1.341	17.56	1.762
5	108.10	57.32	1.029	17.85	0.6213

Table I shows the values of odd impedance and even impedance calculated using equations described. These impedances are required for finding different parameters of parallel coupled band pass filter such as Length (L), Width (W) and Space(S). The odd mode characteristics impedance (Z_{oo}) is calculated by equation (13) and the calculated output is 108.10 Ω. The even mode characteristics impedance (Z_{oe}) is calculated by equation (14) and the calculated output is 57.32 Ω. The width, length and space are calculated and results are1.029mm, 17.85 mm and 0.6213 mm for section 1. Same way, $Z_{oo,}$ Z_{oe} are calculated for section 2 which are 85.75 Ω, 65.12 Ω.

The width, length and spacing are calculated and the results are 1.341 mm, 17.56 mm and 1.762 mm respectively. The $Z_{oo,}$ Z_{oe} are calculated for section 3 which are 82.69 Ω, 66.98 Ω. The width, length and spacing are calculated and the results are 1.369 mm, 17.52 mm and 2.23 mm.

3. REALIZATION OF MICROSTRIP BAND PASS FILTER USING ANSOFT DESIGNER SOFTWARE

The designed parallel (edge) coupled band pass filter layout is depicted in fig.1. This parallel coupled microstrip bandpass filter is operated at frequency of 2.4 GHz. The length, width and space specified in the fig.1 are calculated and lengths of filter for subsections are given by L_1, L_2, etc. Same way, widths and spaces are specified by W_1, W_2, etc. and S_1, S_2, etc. respectively. The source signal is propagated through port signal and it will propagate in different sections of the filter. Port 1 and Port 2 are designed to apply the source signal while do the analysis and simulation of parallel coupled band pass filter.

Fig.1 gives the layout of the parallel coupled bandpass filter designed in the computer simulation software. As depicted in fig.1 designed filter has two ports and coupling sections. Fig.1 shows the physical structure of parallel coupled microstrip filter. This filter is simulated using Ansoft designer software and the substrate used for this filter was FR4 substrate which has dielectric constant of 4.4 throughout the frequency range. The dimension of this simulated filter was 166 mm ×50 mm as shown in fig.1

The width, length and space are calculated and results are1.029mm, 17.85 mm and 0.6213 mm for section 1. Same way, $Z_{oo,}$ Z_{oe} are calculated for section 2 which are 85.75 Ω,

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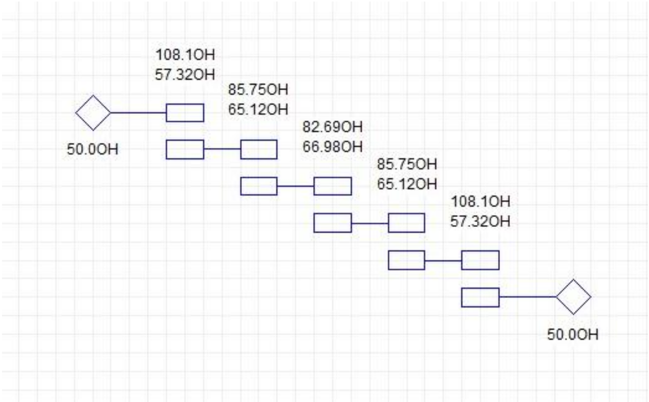

Fig 1: Basic layout of designed parallel coupled band pass filter with odd and even impedance

The Z_{oo}, Z_{oe} are calculated for section 3 which are 82.69 Ω, 66.98 Ω. The width, length and spacing are calculated and the results are 1.369 mm, 17.52 mm and 2.23 mm [9].

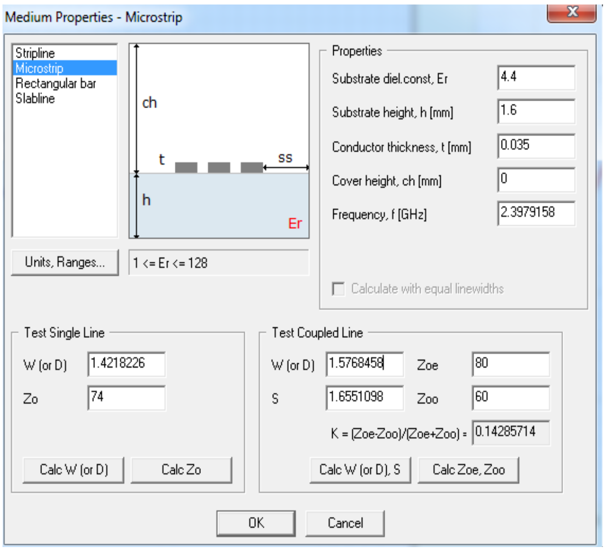

Fig 2: Medium properties of the designed filter

As depicted in fig.2, the microstrip filter is used for the filter design and dielectric constant of the material is 4.4. The substrate height is 1.6 mm and conductor thickness is 0.035 mm and the operational frequency is considered 2.4 GHz.

4. RESULT DISCUSSION

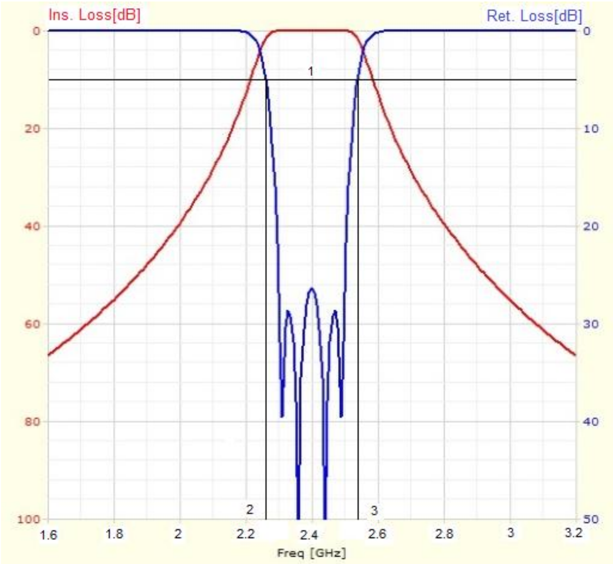

Fig 3: Insertion loss and reflection loss of simulated microstrip band pass filter

The simulation result for parallel coupled filter operated at 2.4 GHz is shown in fig.3. The fig.3 shows different scattering parameter of the designed filter. As seen from the notation 1, the simulated output values of S_{11} and S_{12} were below -20 dB and above -5dB respectively. With consideration of -10dB value, the bandwidth achieved is about 300 MHz as indicated by notations 2 and 3. The frequencies are Lower PB (f_{p1}) at 2.24 GHz and Upper PB (f_{p2}) at 2.56 GHz for bandwidth of 6.67% as shown fig.3.

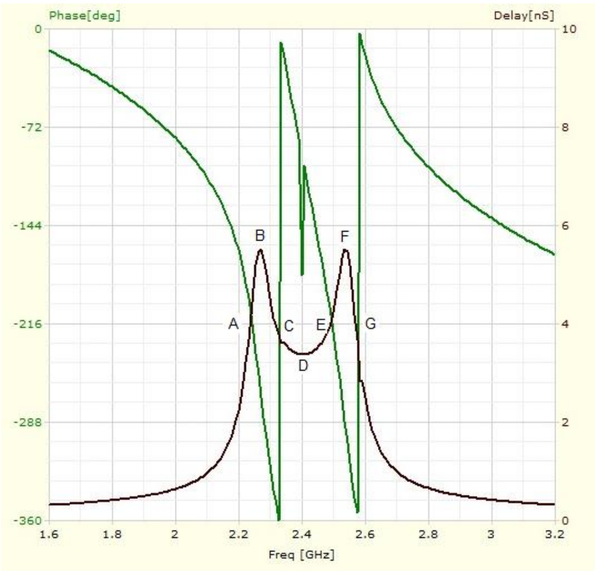

Fig 4: Phase delay and group delay analysis of microstrip filter at 2.4 GHz

No significant phase delay observed and so filtered signal would be in-phase with the input signal with no loss in energy and information contents. Similarly the group delay too is infinitesimally un-noticeable. The phase delay and group delay of the parallel coupled band pass filter operated at 2.4 GHz is shown in fig.4. As marked points A, B, C, D, E, F, G; the average rate of phase delay for AB is 0.2 µrad/Hz, 0.2

µrad/Hz for BC, 0.04 µrad/Hz for CD, 0.04 µrad/Hz for DE, 0.15 µrad/Hz for EF, 0.3 µrad/Hz for FG. Therefore overall average rate of phase delay for the bandwidth of 300 MHz is 0.15 µrad/Hz. This justifies the negligibly small change in the phase at the output port of the filter produced here.

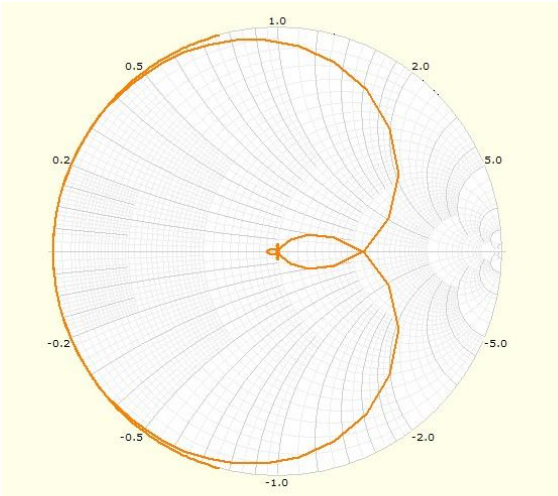

Fig 5: Smith Chart of microstrip bandpass filter operated at 2.4 GHz

The smith chart of the parallel coupled microstrip band pass filter operated at 2.4 GHz is shown in fig.5. As no nulls in the specified band seen here shows a great response of this filter. Resonating at 2.4 GHz in the range of 2.24 GHz – 2.56 GHz with no nulls reflects maximum power transfer and a good impedance match for the ports justifying the S-parameters' values.

5. CONCLUSION

Simulation results of the designed parallel coupled microstrip band pass filter are verified and proven acceptable while measuring during standard test set-ups in the laboratory. Insertion loss and return loss of the filter are above -5 dB and below -20 dB respectively. These results are internationally acceptable for the RF and microwave communication applications. This paper will be useful to the researchers in the field of RF and microwave communication for the design, numerical and mathematical analysis and for the understanding of simulation process.

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