DESIGN AND SIMULATION OF PARALLEL COUPLED MICROSTRIP BAND PASS FILTER AT 2.45GHZ

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ABSTRACT: Filter is one of the key component of microwave communication system. Filter ensures the propagation of signal in required frequency band and attenuates the signals out of the band range. Microwave filters can be realized by using coaxial, waveguide, stripline and microstrip structure. Microstrip filter is preferable due to of its compact size and low weight. Stub line, end edge, parallel coupled, interdigit, combline type of microstrip filters are in use for the time. Parallel coupled microstrip filter has advantageous in to the terms of simple design structure techniques, easy to fabricate and integrate with other RF component/ devices. Design and simulation of parallel coupled microstrip band pass filter is presented in this paper. The proposed filter is designed for 2.45GHz using HFSS ANSYS simulation software. Roger3003 dielectric substrate of height 1.5mm is used as substrate. Defected ground structure approach incorporated to enhance bandwidth. 28.57% fractional bandwidth (2.0720-2.7720GHz) is achieved with 0.2dB insertion loss in pass band and 30 dB attenuation at 2.2 GHz. Return loss is greater than -27dB in pass band of having maximum return loss of -43.12 dB at 2.6290 GHz. Simulation results exhibit good performance of proposed filter. This filter can be used for ISM band application (2.4-2.5GHz) and 2.6GHz band (2.5-2.69GHz) for terrestrial mobile communication system.

KEYWORDS: Microwave Filter, Microstrip parallel coupled line, parallel coupled Band Pass Filter (PCBPF), Fractional Bandwidth (FBW), Defected ground structure (DGS)

I. INTRODUCTION

Controlling of frequency response at a particular frequency is done by two port network called filter. Filter passes the signal in desired band (pass band) range and attenuates the signal out of the band (stop band) range. Conventional frequency responses are well defined as low pass, high pass, band pass and band reject characteristics [1]. Research on the microwave filter started in 1930's. A research paper on microwave filter is published in 1937 by Mason and Sykes. The work done by the many scientists; such as H. A. Bethe (Noble prize winner), N. Marcuvitz, E. M. Purcell and J. Schwinger (Noble prize winner) etc. in early advancement time of microwave filter is still mark bench for today's time specially in the area of field theory [2].

Microwave filters were realized using waveguide, coaxial line in earlier. Planar technology brings tremendous advancement in realizing compact microstrip filters. George Matthaei presented his work on practical realization of interdigit filters and combline filters. Interdigit filters are basically folded coupled parallel transmission line provide open circuit at one end and short circuit at another [3].

Matthaei, Young and Jons book (often called bible of the filter world) [3] on Microwave filter is the milestone in the field of basic design approach of microwave filters**.** Microstrip filters are very attractive and widely used for the RF designer due to of its low profile, light weight and compactness but with making compromise for bandwidth. Up to 20% Fractional bandwidth (FBW) is obtainable for microstrip filter [3]. Microstrip band pass filters can be realized as End-Coupled half-wavelength resonator, Parallel-Coupled half-wavelength resonator, Hairpin-line Band Pass flters, Interdigital Band Pass filters, Combline filters, and half or quarter wavelength stub filter [4].

When two or more than two parallel transmission line are placed in a close proximity to each other, they become electromagnetically coupled via their electric and magnetic field. This coupling is desirable in realization of microwave filter for selection/suppression of frequency in pass band/stopband frequency. Line dimension and spacing should be calculated according to desired coupling factor and even and odd mode impedance of coupled line section [5]. Parallel line coupling is advantageous in terms of compactness and easiness with integration with other devices. High data rate wireless system require more than that of 20 % FBW. Achieving wide bandwidth for microwave filter is a challenge for researcher from last few decades. Number of techniques/designs have been proposed and investigated such as using ring resonator, quasi lumped element, multi-mode resonators, fractal design structure, defected ground structure, split ring resonators, metamaterial and more others [6-10]. A tri coupled transmission line with radial stub was exhibited by Yechou Laheen. Author enhanced bandwidth up to 71.53% bandwidth by applying radial structure [11]. Defected ground structure is widely adopted to improve the bandwidth. In DGS a pattern is etched out in the ground plane which results in disturbing shield current distribution. This change may cause significant variation in equivalent capacitance and inductance of transmission line. The Dumbbell shaped DGS are in use which consist two wide defected similar pattern (In general square, triangle, circular etc.) connected by narrow width slot.

The position of pattern should be under the top conducting layer and aligned to get pronounced coupling [12].

II. MICROSTRIP TRANSMISSION LINE

Advancement in transmission lines from bulky waveguide to planar transmission line has pend new attractive design techniques for microwave engineers. Waveguide and coaxial lines were mostly in use in earlier time. In present scenario stripline, microstripline, slotlineetc are the key component of microwave communication system. Waveguide exhibit high power handling capability with low transmission loss but having limitation factor in terms of bulky size and high cost value. Coaxial line faces complexity in fabrication with some microwave components. Coaxial line considered a good choice when high bandwidth needed. With compare to waveguide and coaxial line, microstrip and other planar transmission line have compact size, low profile weight, economic and having nice pacing with other active or passive microwave devices/component [13]. A typical microstrip line structure is shown in fig1.

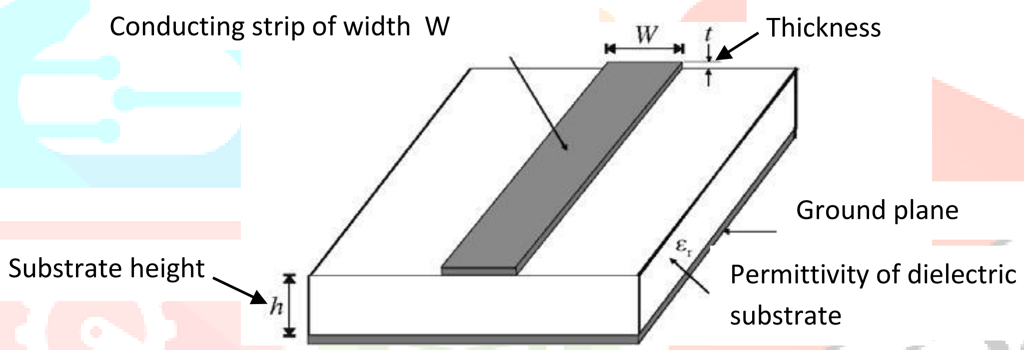

Figure1: General structure of Microstrip Transmission line

It consist a conducting trace of width W, separated by ground plane using dielectric substrate of permittivityϵ_r.Microstrip line support quasi TEM fields instead of pure TEM field due to of different phase velocity of TEM field in air region (c) and dielectric region($c/\sqrt{\epsilon_r}$). Equations (1-4) are used to calculate effective dielectric constant, characteristics impedance of microstripline forgiven permittivity and height of substrate [4].

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left\{\frac{1}{\sqrt{1 + \frac{12h}{w}}} + 0.04\left(1 - \left(\frac{w}{h}\right)^2\right)\right\} \quad \text{for} \frac{w}{h} \leq 1 \qquad (1)$$

$$\epsilon_e = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\frac{1}{\sqrt{1 + \frac{12h}{w}}} \quad \text{for} \frac{w}{h} \geq 1 \qquad (2)$$

$$Z_0 = \begin{cases} \frac{60}{\sqrt{\epsilon}} In\left(\frac{8h}{W} + \frac{W}{4h}\right) & \text{for w/h} \leq 1 \quad (3) \\ \frac{120\pi}{\sqrt{\epsilon_e}\,[W/h + 1.393 + 0.667\, In(W/h + 1.444)]} & \text{for w/h} \geq 1 \quad (4) \end{cases}$$

III. PARALLEL COUPLED MICROSTRIP BAND PASS FILTER(PCBPF)

For design microstrip filters, coupled microstrip transmission line are extensively used due to of its very simple design structure and easy integration suitable for modern planner technology. Half-wavelength line resonators are placed in such manner that adjacent coupled resonator is parallel to each other as shown in Fig2. [5].

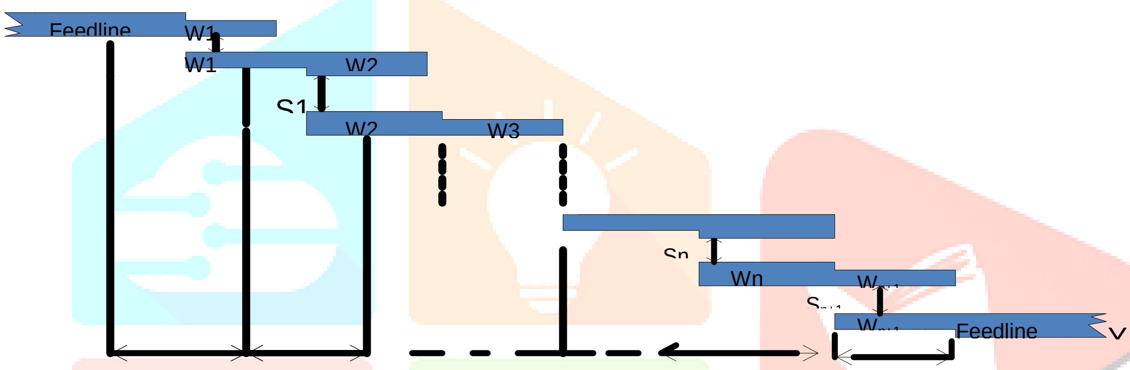

Figure2: Structure of Parallel Coupled Microstrip Transmission Line (W_1,W2…..W_{n+1} are width of the transmission Line and S_1,S_2……S_{n+1} spacing between the pair of coupled Lines)

The coupled configuration supports two quasi TEM mode; Even and Odd mode. Both even and odd mode excited simultaneously but having different phase velocity. Parallel coupled structure provided greater coupling for specified spacing s between two coupled lines. For N^{th} order filter N+1 cascaded coupled line required as indicated in the fig 2. Even and odd mode impedances can be calculated for each coupled section by following equation (5-9) [5].

$$J_{01} = \frac{1}{Z_0}\sqrt{\frac{\pi\Delta}{2g_0g_1}} \quad (5)$$

$$J_{i,i+1} = \frac{1}{Z_0}\frac{\pi\Delta}{2\sqrt{g_{i+1}g_i}};\ \text{i} = 1 \text{ to n} - 1 \quad (6)$$

$$J_{n,n+1} = \frac{1}{Z_0}\sqrt{\frac{\pi\Delta}{2g_ng_{n+1}}} \quad (7)$$

Here n is the number of coupled section, $g_0, g_i, \ldots, g_{n+1}$ are low pass prototype elements and Δ is fractional bandwidth(FBW) defined as

$$\Delta = \frac{\omega_2 - \omega_1}{\omega_0}$$

ω_1 and ω_2 are the lower and upper frequency of passband respectively wheras ω_0 is centre frequency ;generally given by $\omega_0 = \sqrt{\omega_1 \omega_2}$.

$$Z_{0e} = Z_0[1 + Z_0 J_i + (Z_0 J_i)^2] \qquad (8)$$

$$Z_{00} = Z_0[1 + Z_0 J_i + (Z_0 J_i)^2] \qquad (9)$$

Z_{0e} and Z_{0O} are the even and odd mode impedances of pair of coupled line calculated by knowledge of impedance Inverter J. Impedance inverter is used to transform a filter circuit in to an equivalent form suitable for implementing microwave structure[14].

IV. DESIGN STEPS AND SIMULATION RESULTS:

Step I: Centre pass band frequency, fractional bandwidth, filter response characteristics, and desired stop band attenuation should specify. Maximally flat, equal ripple, Elliptic function and linear phase are some practical filter responses.
Step2: On the basis of step 1, order of filter has to be find out by using attenuation versus normalized frequency graphs given in [3].
Step3: Even and odd mode impedance value for each coupled section can be calculated using equations (8-9) discussed in earlier section.
Step 4: Calculation for width of transmission line(TL), length of TL and spacing between coupled line.
PCBPF design strongly depends on proper selection of width, length and spacing given substrate height. Equation (10) can be used to calculate width w of coupled line for dielectric material of height h [5].

$$\frac{W}{h} = \begin{cases} \dfrac{8e^A}{e^{2A} - 2} & \text{for } w/h \le 2 \\ \dfrac{2}{\pi}\left[B - 1 - In(2B-1) + \dfrac{\epsilon_r - 1}{2\,\epsilon_r}\left\{In(B-1) + 0.39 - \dfrac{0.61}{\epsilon_r}\right]\right. & \text{for } w/h \ge 2 \end{cases} \qquad (10)$$

Where $A = \frac{Z_0}{60}\sqrt{\frac{\epsilon_r+1}{2}} + \frac{\epsilon_r - 1}{\epsilon_r + 1}\left(0.23 + \frac{0.11}{\epsilon_r}\right)$ and $B = \frac{277\pi}{2Z_0\sqrt{\epsilon_r}}$

Z_0 is the 50Ω characterstic impedance of line.

An approximate synthesis technique is described in [15] to determine w/h and s/h from knowledge of Z_{0e} and Z_{0o}. A simplified expression is given in equation(11) to calculate s/h ratio[15]

$$\frac{s}{h}=\frac{2}{\pi}\cosh^{-1}\left\{\frac{\cosh[(\pi/2)(w/h_{se}]+\cosh[(\pi/2)(w/h)_{so}]-2}{\cosh[(\pi/2)(w/h)_{so}]-\cosh[(\pi/2)(w/h)_{se}]}\right\} \qquad (11)$$

Where

$$\left(\frac{W}{h}\right)_{se}=\frac{2}{\pi}\cosh^{-1}\left(\frac{2d-g+1}{g+1}\right)$$

$$\left(\frac{W}{h}\right)_{so}=\frac{2\leq}{\pi}\cosh^{-1}\left(\frac{2d-g-1}{g+1}\right)+\frac{4}{\pi(1+\epsilon_r/2)}\cosh^{-1}\left(1+2\frac{w/h}{s/h}\right),\epsilon\leq 6$$

$$\left(\frac{w}{h}\right)_{so}=\frac{2}{\pi}\cosh^{-1}\left(\frac{2d-g-1}{g-1}\right)+\frac{1}{\pi}\cosh^{-1}\left(1+2\frac{w/h}{s/h}\right),\epsilon\geq 6$$

g and d are defined as

$$g=coah\left(\frac{\pi s}{2h}\right),d=\cosh\left(\pi\frac{w}{h}+\frac{\pi s}{2h}\right)$$

Calculation is somewhat complicated and lengthy. Many authors reported MATLAB program to estimate w/h and s/h ratio. They also verified their results by using simulation software also [16-18]. M. AlperUslu and LeventSevgi developed a MATLAB based filter design software code (MWFilter designer) to design filter automatically and plot filter characteristics when filter specifications are participated. Filter type, dielectric material along with its permittivity and height is initial value to run the program. All other dimension is automatically calculated by program [17]. K.N.Shamanna et al. presented three graph to determine w/h;s/h;l/λ ratio for desired bandwidth parameter for dielectric substrate of having permittivity less than 10[18].

Filter Specifications for proposed PCBPF:

Centre frequency of passband: 2.45 GHz; FBW: 15%; Passband ripple :0.1 dB; Stopband attenuation: -25dB; Source/ load impedance: 50 ohm
Based on required filter specification and design steps discussed; order of filter is3. Low pass prototype element values for equal ripple 0.1 dB are $g_o=1$; $g_1=1.0315$; $g_2=1.1474$; $g_3=1.0315$;
$g_4=1$ [3]. Even and Odd mode impedance value is calculated and given in table 1

Table1: Even and Odd impedance value of coupled section

Coupled section	Z_{0e}	Z_{0o}
1,4	63.4729	41.3994
2,3	52.4178	47.7975

Roger3003 (Permittivity = 3, loss tangent = .0013) of height 1.5mm is chosen as dielectric substrate. w/h and s/h are determined using given equations discussed in previous section and graph [18]. Further optimization function of HFSS is used to get the final dimension of coupled line section.

Table 2: Final parameters of coupled line section

Coupled line section	Width of coupled line(mm)	Spacing between coupled line(mm)	Length of coupled line(mm)
1,4	1.896	0.20	18.8
2,3	2.76	0.98	18.8

50 ohm characteristics impedance is realized by using microstrip line of width 3.01mm with length 19.5 mm. Proposed filter has designed and simulated. S-parameter are shown in fig (3). Return loss of -30 dB is obtained at 2.4GHz

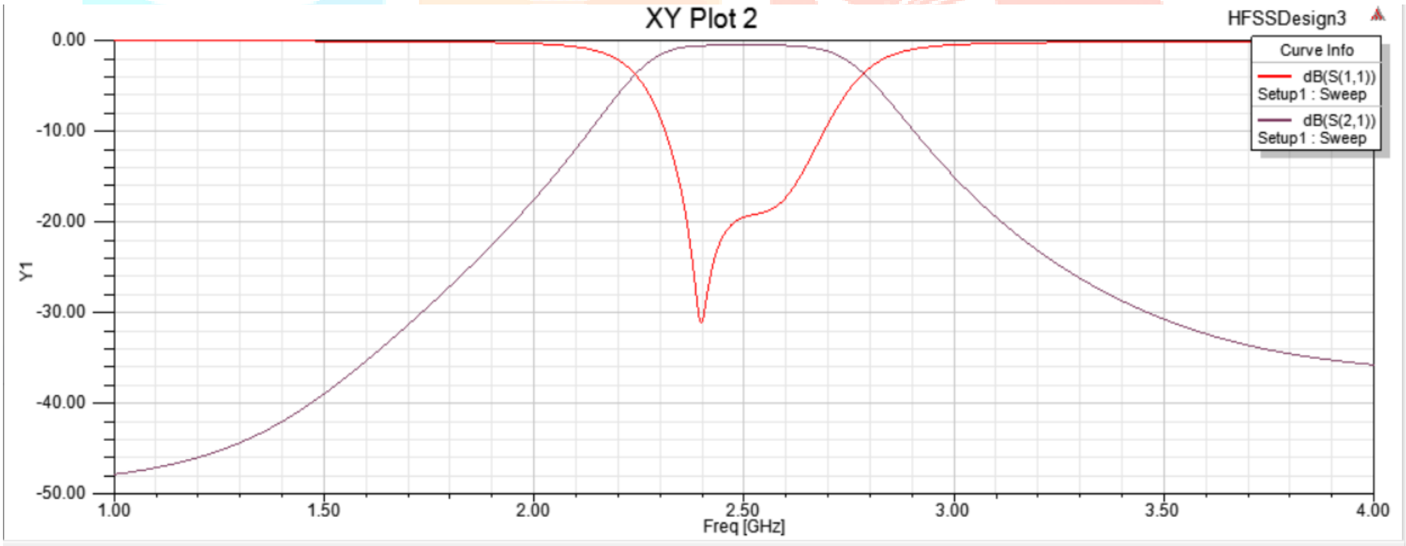

Fig3. Simulation Result S_{11} and S_{21} for PCBPF

Modification in ground plane is beneficial to improve performance of microstrip devices. Modification can be done in many ways such as making variation in dimension, cutting peculiar shape in ground plane etc. DGS is also applied for proposed design. A combination of four vertical thin bar and one aligned horizontal thin bar are etched out underneath each transmission coupled line pair. Fig (4) shows the proposed filter structure with DGS in HFSS environment.

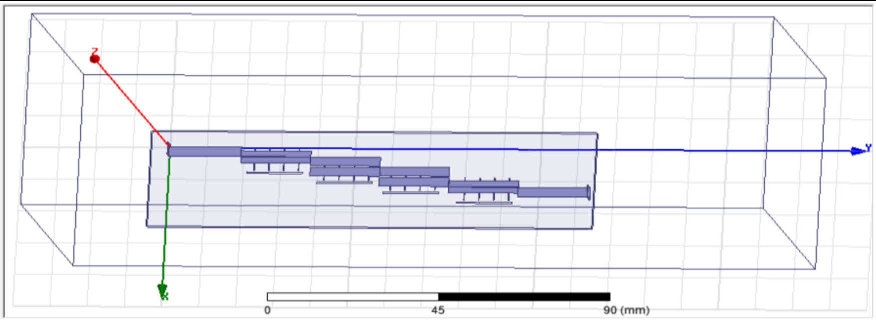

Fig4:Simulation model of the proposed filter with DGS

Defected ground structure provides better performance compare to the without DGS as indicated by fig (5). 3dB bandwidth of approximately 700 MHz (28% FBW) is obtained with -20dB attenuation at 1.78 GHz,3.29 GHz. Return loss of -27.81, -34.81 and -43.12 dB is observed at 2.152GHz, 2.461GHz and 2.629 GHz respectively.

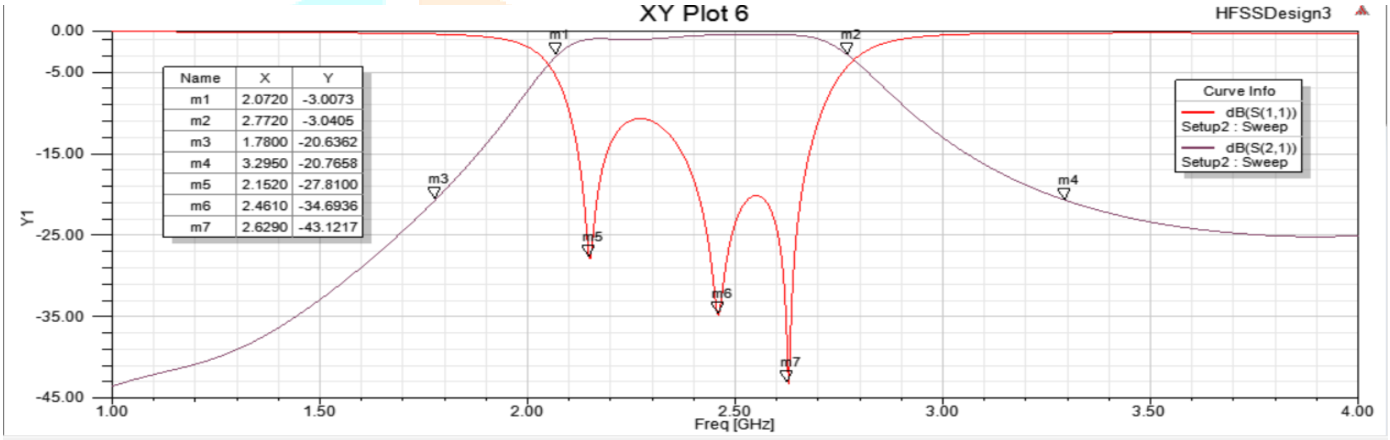

Fig5: Insertion loss and Return loss graph of proposed filter with DGS

V. CONCLUSION

Parallel coupled microstrip band pass filter is in extensive use because of its very simple structure, easy fabrication and its integration possibility with other microwave components. The paper briefly discusses the basic fundamental theory, equations and steps to design a PCBPF. Roger 3003 (permittivity =3, losstangebt=.0013) dielectric substrate of height 1.5 mm is used to implement the proposed design. Filter is simulated using simulation software HFSS. 700 MHz bandwidth (2.0720 -2.7720GHz) is obtained with 28% FBW. The filter response includes 2.4-2.5 GHz ISM band and 2.5-2.6 GHz band for terrestrial mobile communication services. The simulated result show return is greater than -25 dB in pass band range. Return loss of -27.8dB, -34.69dB, -43.12dB are observed at 2.15GHz,2.46GHz,2.62GHzrespectively. -20dB attenuation shown at out band frequency 1.7GHz and 3.2GHz.

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