Design of Microstrip Coupled Line Bandpass Filter Using Synthesis Technique

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***Abstract*—In this Paper, aim is to achieve a narrow bandwidth filter. For that coupled line filter is good choice.**

Coupled-line filter is designed on microstrip for its compactness. Microstrip dimension are calculated using synthesis technique formula. A Coupled-Line Microstrip Filter is designed for centre frequency 2.4GHz and it is made up of FR-4 material having permittivity *Єr=4.4. Coupled* line filter demonstrate the fourth order of the Chebyshev elements and its response corresponds to bandpass filter. The geometry is analysed by using Computer Stimulation Techniques (CST) software.

***Index Terms*— Coupled lines, directional couplers, microstrip, microwave, synthesis, bandpass filter, narrow, bandwidth, CST.**

I. INTRODUCTION

The key component of the microwave communication system is filter and there are various types of filter that used in microwave communication systems. They are classified as low-pass filter, high-pass filter, band-pass filter, and band-stop filter. The Microwave band pass filter is the fundamental component that contributes to the overall performance of a wireless communication systems it maybe in receiving or transmitting devices, to filter out unwanted frequency. The wireless communication systems have increased the demand of bandpass filters with higher accuracy. In the modern communication system, the demand for the precised, narrow bandwidth and low loss had led to the innovative design of a band-pass filter. While designing a band-pass filter, the parameters such as center frequency, bandwidth, low pass frequency, high frequency etc. should be considered. As communication devices are getting smaller day by day, due to its rough use, robustness. The compact size of the filter is another important design consideration.

Coupled-line filter is a good choice for the design of microstrip bandpass filter [1]. A basic coupled line filter using high quality material, can achieve the desired specification.

The low cost, ease of design and good performance will provide a helpful example of modern RF filter design. Coupled-line microstrip bandpass filters is easy to design for narrow bands and for relatively large band, it becomes complex, as more parameters are need to be considered. For GHz frequency range the coupled-line microstrip bandpass filter is a general choice. The physical dimensions of the coupled transmission lines can be derived with published formula or minimal simulation software capability. The PCB fabricated coupled-line microstrip bandpass filter usually consists of narrow bandwidth. The main disadvantage of coupled-line microstrip bandpass filter is the presence of spurious passbands at the harmonics of the bandpass filters operational frequency [1], [5].

Inductively Compensated Parallel Coupled Microstrip Lines for center frequency of 1.8GHz with 10% bandwidth was designed. The methodology was based on the lumped compensation technique approach. The Applications of the inductively compensated coupled-line structure for a parallel coupled microstrip bandpass filter was discussed [2].

The Complete Design of Microstrip Directional Couplers Using the Synthesis Technique was presented. The design approach was based on symmetrical two-line microstrip directional couplers that include the physical length at the desired operational frequency with center frequency of 300MHz [3].

This paper presents the design of a parallel-coupled microstrip bandpass. The design is based on the Synthesis Technique and it makes use of quarter wave long resonators and admittance inverters. The filter designed to centre frequencies of 2.4GHz, the bandwidth (BW) is about 10%, the minimum attenuation amounts to -30 dB and the pass-band ripple is obtained equal to 0.5 dB. The design technique, parameter analysis and results of a 4th order coupled line bandpass filter at simulation frequency of 2.4GHz is presented in this paper.

A. *Coupled line filter*

The coupled lines of Fig 1, or other symmetric three-wire lines, can be represented by the structure and equivalent circuit shown in Fig 3. If TEM propagation is assumed, then the electrical characteristics of the coupled lines can be completely determined from the effective capacitances between the lines and the velocity of propagation on the line. The Fig 3, C_{12} represents the capacitance between the two strip conductors, and C_{11} and C_{22} represent the capacitance between one strip conductor and ground. Because the strip conductors are identical in size and location relative to the ground conductor, (i.e) $C_{11} = C_{22}$. Now consider two special types of excitations for the coupled line: the even mode, where the currents in the strip conductors are equal in amplitude and in the same direction, and the odd mode, where the currents in the strip conductors are equal in amplitude but in opposite directions.

At the point which two unshielded transmission lines are in close proximity, power can be coupled from one line to the other due to the interaction of the electromagnetic fields. Such lines are referred to as *coupled transmission lines*, and they typically consist of three conductors in close proximity, although more conductors can be used. Fig 1 shows basic examples of coupled transmission lines. Coupled transmission lines are assumed to operate in the TEM mode, which is rigorously valid for coaxial line and stripline structures, but only approximately valid for microstrip line, coplanar waveguide, or slot line structures. Coupled transmission lines can support two distinct propagating modes. This feature can be used to implement a variety of practical directional couplers, hybrids, and filters. The coupled lines shown in Fig 1 are symmetric, that means the two conducting strips have the same width and position relative to ground. This simplifies the analysis of their operation. The design of coupled stripline and coupled microstrip line are calculated by Wheeler microstrip equation and synthesis technique [1],[5].

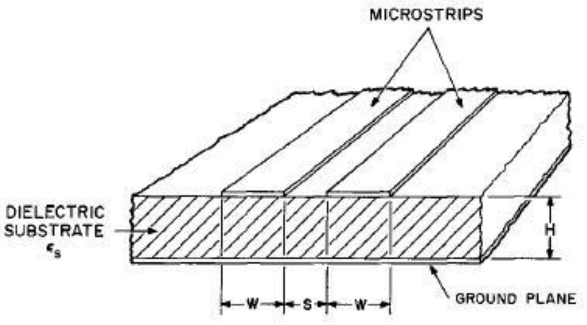

Fig 1: General structure of parallel (edge)-coupled microstrip bandpass filter.

B. *Parallel coupled filter*

The general layout of a parallel coupled microstrip bandpass is shown in Fig 2. The parallel coupled line filter structure consists of open circuited coupled microstrip lines. These coupled lines are quarter wavelength, (λ/4) long and are equivalent to shunt resonant circuits. The coupling gaps correspond to the admittance inverters in the low-pass prototype circuit. Even- and odd- mode characteristic impedances of parallel-coupled half-wave resonators are computed using admittance inverters [2].

These even and odd mode impedances are then used to compute physical dimension measurement of the filter. Now consider a bandpass filter composed of a cascade of $N + 1$ coupled line sections, as shown in Fig 2. The sections are numbered from left to right, with the load on the right, but the filter can be reversed without affecting the response, since each coupled line section has an equivalent circuit of the form. The equivalent circuit of the cascade is as shown in Fig 2.

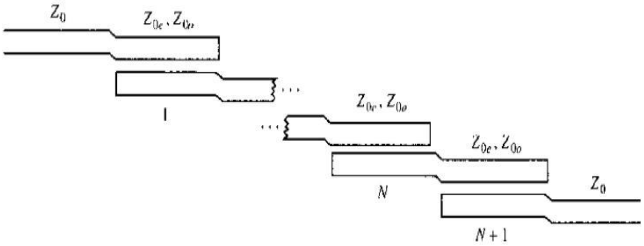

Fig 2: General structure of parallel (edge)-coupled microstrip bandpass filter.

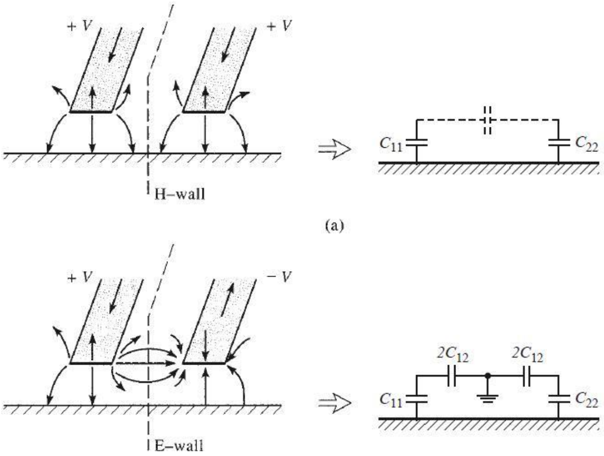

Fig 3: Even- and odd-mode excitations for a coupled line, and the resulting equivalent capacitance networks. (a) Even-mode excitation. (b) Odd-mode excitation.

C. *Image Impedance*

A parallel coupled line filter section is shown in Fig 3a, with port voltage and current definitions and then derive the open-circuit impedance matrix for this four-port network by considering the superposition of even- and odd-mode excitations, which is shown in Fig- 3b. The current sources i_1 and i_3 drive the line in the even mode, while i_2 and i_4 drive the line in the odd mode. By superposition, the total port currents, I_i , can be expressed in terms of the even- and odd-mode currents This result yields good the open-circuit impedance matrix $[Z]$ that describes the coupled line section. For symmetric condition, all other matrix elements can be found, once the first row is known. A two-port network can be formed from a coupled line section by terminating two of the four ports with either open or short circuits, or by connecting two ends; there are 10 possible combinations. These combinations are used to analyse the filter characteristics of this circuit by calculating the image impedance (which is the same at ports 1 and 3), and the propagation constant. The image impedance in terms of the impedance parameters and When the coupled line section is $\lambda/4$ long ($\theta = \pi/2$), the image impedance reduces to

$$Z_i = \tfrac{1}{2}(Z_{0e} - Z_{0o})$$

D. Nomenclature.

- ☐ Z_{0e}, Z_{0o} =Even- mode and odd-mode characteristic impedance of the coupled microstrip lines.
- ☐ Z_0 =Characteristic impedance of the equivalent single microstrip line.
- ☐ ( ) , ( ) = Shape ratio (width-to-substrate thickness and gap between lines to substrate thickness) for the coupled microstrip lines.
- ☐ (—) ,(—) , (—) = Shape ratio for the equivalent single line general case, corresponding to even-mode geometry, corresponding to odd-mode geometry.
- ☐ ε_r= Substrate relative permittivity

II. DESIGN METHODOLOGY

General structure of parallel-coupled microstrip bandpass filters that use quarter wavelength line resonators. They are positioned such that adjacent resonators are parallel to each other along half of their length [1], [4], [5], [6].

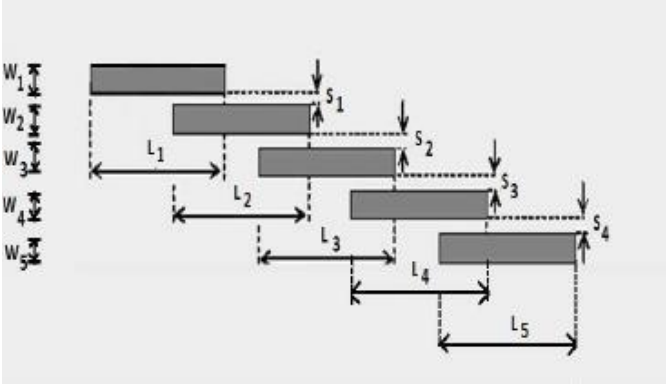

Fig 4: Structure of proposed parallel (edge)-coupled microstrip bandpass filter design.

A. Filter Elements Calculation

1.The filter design procedure started with a four-post (n=4) step write low pass model (i.e., with Chebyshev reaction) with component estimations of the low pass model are taken from normalized values of gi i.e. g 1, g 2, g 3. The component estimations of the low pass model are g1 =1.6703 g4 = 0.8419, g2 =1.1926 g3 =2.3661, g5 = 1.0000.

2. The normalized element values of the low pass prototype filters is then transformed to the L-C elements for the desired middle frequency f_0 and desired source impedance, which is normally 50 ohms for micro strip filters.

3. The next main step in the design of microstrip bandpass filter is to find an appropriate microstrip realization that approximates the lumped element filter. The filter is fabricated on a FR-4 substrate having dielectric constant ε_r=4.4 and of thickness h=1.57mm.

4. The design equations for parallel coupled bandpass filter given in terms of its admittance [1], [5].

$$\tfrac{1}{2}(Z_{0e} - Z_{0o}) = JZ_0^2$$

$$Z_0J_1 = \sqrt{2\ 1}$$

$$Z_0J_n = 2\sqrt{\ -1*} \quad \text{for } n= 2, 3, \ldots, N.$$

$$Z_0J_{N+1} = \sqrt{2\ *\ +1}$$

Where g_0, g_1…….g_n is the element of a ladder-type lowpass prototype with a normalized cutoff frequency, and FBW is the fractional bandwidth of bandpass filter is based on characteristic admittances of J inverters and Y_0 is the characteristic admittance of the terminating lines.

5. The next step of the filter design is to find the dimensions of coupled microstrip lines based on desired even- and odd-mode impedances. Firstly, determine equivalent single microstrip shape ratios (w/h). Then it can relate to coupled line ratios to single line ratios. For a single microstrip line [3],[6].

$$Z_{0se} = \frac{}{2^0}$$

$$Z_{0se} = \frac{}{2^0}$$

( ) = ( ) | =

( ) = ( ) | =

6. Now using single line equations to find ( ) and ( ) from Z_{0se} and Z_{0so} calculation given in Table- 1.

$$\frac{w}{h} = \frac{8\ \sqrt{[\ (\ \ \sqrt{(\epsilon+1))-1]}\ \frac{7+(4/\epsilon)}{11} + \frac{1+(1/\epsilon)}{0.81}}}{[\ (\ 42.4\ \sqrt{\epsilon+1)-1]}}$$

( ) and ( ) by applying Z_{0se} and Z_{0so} (as Z_0) to the single line microstrip equations.

( )′ = 0.78( ) + 0.1( )

7. Using width of single line microstrip, Calculate the odd and even spacing of stripline and its spacing ratio. Which is given in Table- 2.

$$= \frac{2}{h}{}^{-1}\left[\frac{h[\ 2\ (\ )\ ]+h[\ 2\ (\ )\ ]-2}{\cosh[\ 2\ (\ )\ ]-h[\ 2\ (\ )\ ]}\right]$$

8. After finding the spacing ratio *s/h* for the coupled lines, now to find *w/h* for the coupled lines,

$$(\ ) = {}^{1}\ h^{-1}(d) - {}^{1}{}_{2}\ (\ )$$

Where,

$$g = \cosh\ [{}^{1}{}_{2}\ (\ )]$$

$$d = \frac{\cosh[\ (\ )\ ](\ +1)+\ -1}{2}$$

9. The shape for the coupled lines is found Thus, the length of the required resonator is

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

N	gn	Z0	Z0Jn	Z0O(Ω)	Z0e(Ω)
1	1.6703	52.62	0.3066	39.3690	70.350
2	1.1926	50.311	0.1112	45.058	56.178
3	2.3661	50.219	0.0935	45.7621	55.112
4	0.8419	50.373	0.12153	44.6619	56.8149
5	1.9841	50.222	0.0940	45.7418	55.1418

Table 1: Tabulation of Even and Odd mode characteristic impedance and Inverter admittance.

III. DESIGN AND SIMULATION

This filter consists of a ground, substrate and striplines. The ground and striplines structure are made up of PEC. The software generates physical layout dimensions which can then be transformed to a PCB layout. The physical dimension of the filter is 50*40*1.57mm and each section dimension is given in Table 2. The resulting layout specifications are width (W), length(L) and inter-trace separation (S) for the coupled line structure. These parameters are entered into a layout specification such as CST layout which can generate Gerber files required by PCB fabrication facilities. The resulting filter design was nearly identical to that produced by published formula. After designing layout in software, the prototype can be fabricated and tested on the bench. The design was created in CST-MWS design environment, implementing the equations using its wide parameterization capabilities.

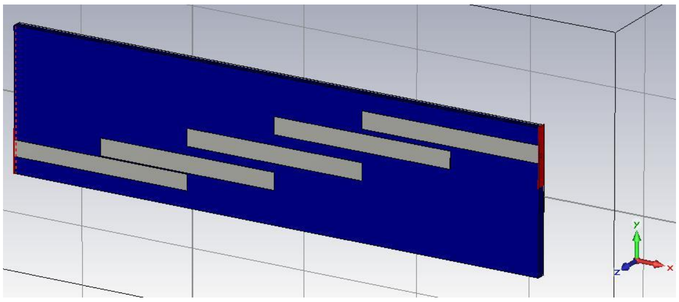

Fig 6: Structure of a fourth order coupled line micro strip band-pass filter designed using CST (Front View).

N	W/H	S/H
1	1.243	0.114
2	1.824	0.923
3	1.874	1.136
4	1.793	0.497
5	1.873	1.807

Table 2: Filter physical dimension- width and space

IV. RESULTS AND DISCUSSION

The simulated filter structure and response is shown in Fig 6 and Fig 7. In the response graph S-Parameter (dB) is plotted on the y axis and frequency (GHz) on the X axis. It is clear that the simulated center frequency is found to be 2. 4GHz.The band edge frequencies are 2.40GHz and 2. 47GHz.The value of insertion loss (S_{21}) and return loss(S_{11}) at 2.43GHz are -0.6336 dB and -21.4 dB respectively.

The results obtained after running transient solver are shown in the plot in Fig 6**.** From the plot it is clear that the insertion loss is - 1.17 dB, Here the input port was numbered port 1, isolated port was port 3, output port was port 2, and coupled port was port 4. A simulation study was performed to verify the validity of the above dimensions in millimeter. For the simulation purpose we have used CST. Simulated structure of the desired band stop filter is shown in Fig 6 and Fig 7 indicates the response of the filter using CST solver Transient solver.

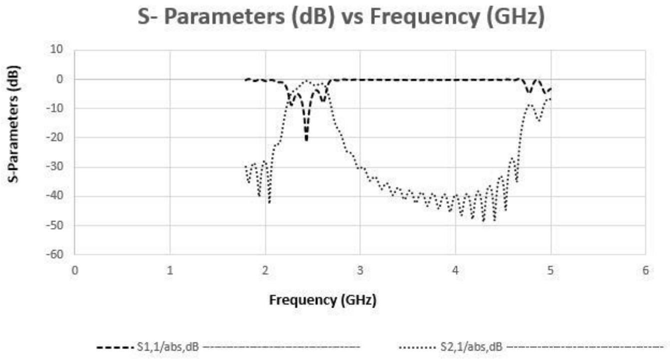

Fig 7: Simulated Performance of four-pole coupled line micro band-pass filter

A. *Return loss S_{11}*

Return loss is the loss of signal power resulting from the reflection caused at a discontinuity in a transmission line. This discontinuity can be a mismatch with the terminating load or with a device inserted in the line. It is usually expressed as a ratio in decibels (dB)

$$RL\left(dB\right) = 10\log_{10}\frac{P_i}{P_r}$$

Where RL(dB) is the return loss in dB, P_i is the incident power and P_r is the reflected power. Return loss is related to both standing wave ratio (SWR) and reflection coefficient (Γ). Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines are matched. A match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss.

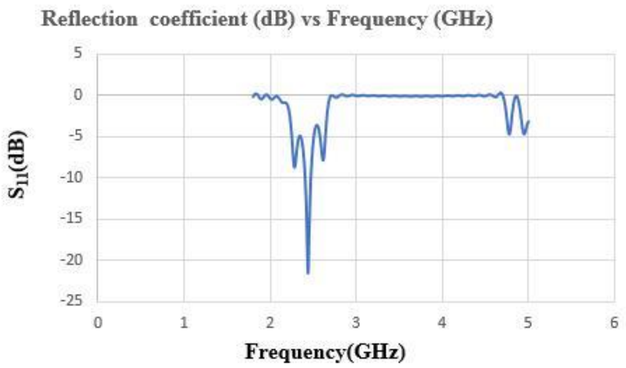

Fig 8: Measured Return loss (S11) of four-pole coupled line microstrip band-pass filter using CST.

B. *Insertion Loss S_{21}*

The attenuation, or loss in signal power, resulting from the insertion of a component, such as a connector or splice, in a circuit. Insertion loss is measured as a comparison of signal power at the point the incident energy strikes the component and the signal power at the point it exits the component. Insertion loss typically is measured in decibels (dB), although it also may be expressed as a coefficient or a fraction. A negative loss is a gain.

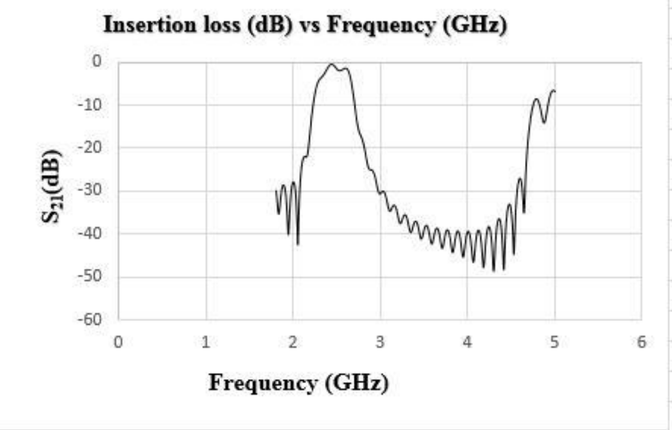

Fig 9: Measured Insertion loss (S21) of fourth order coupled line microstrip band-pass filter using CST

V. CONCLUSION

A coupled line bandpass filter was successfully designed by synthesis technique and simulated by using a CST design tool. Both designs were nearly identical in their physical dimensions and in simulated frequency responses. These frequency responses were well within specified range of 2.4GHz and narrow bandwidth response is achieved.

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