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Two Step Coupled Gap Resonator and Its Application as Bandpass Filter

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ABSTRACT

In this paper, a two step gap coupled resonator is modelled for designing a bandpass filter. The proposed structure is viewed simultaneously as edge coupled section and parallel coupled section. A detailed nodal analysis of the proposed coupled gap sections using different current and voltage equations are described, which is further derived to obtain different admittance parameter equations. Finally comparing those equations with normal two port network, even and odd mode impedance difference (Z_{0o}-Z_{0e}) equations are obtained in terms of parallel coupled admittance inverter (J_{g1}) and shunt susceptance (B_{g1}) at the edge coupled section. This equation is further used for designing the resonator with bandaccepted characteristics. A three pole wideband bandpass filter is demonstrated by series arrangement of four such coupled resonator unit. The proposed bandpass filter exhibits FBW of 53.5%. All the results are well verified by numerical simulation and validated through experiments.

Index Terms—Bandpass Filter, Edge coupled, Open ended stub, Parallel coupled, Stepped type coupled gap resonator.

I.INTRODUCTION

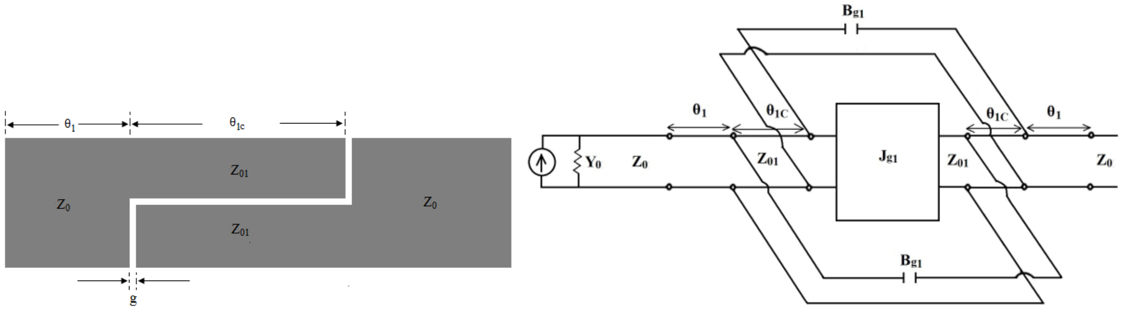
Bandpass filter(BPF) is always one of the prime component for designing any trans-receiver system. It is a component which allows certain frequency band and rejects out of band one. Several bandpass filters were designed in planar forms on stripline, microstrip and Coplanar waveguide (CPW)[1-2]. Edge coupled bandpass filter was the primary invention in the era of bandpass filter design techniques. Later, Parallel-Coupled Wideband Bandpass filters were made of Image Parameter Method [3]. Several bandpass filters have been proposed by the use of transformation techniques also [1]. The major concerns for designing any bandpass filter include bandwidth, insertion loss and selectivity. In [4], the parallel coupled bandpass filters were designed and improvements of the design were also introduced. Moreover, in [5], a modified microstrip bandpass filter using resonating properties of the half wavelength coupled resonators was introduced, which reduced the size of a parallel coupled filterand improved the performance compared to the conventional

one in terms of bandwidth and compactness. A planarbandpass filter was also realized earlier by CPW technology
with open ended stub discontinuity [6]. Many research articles showed the design mechanism of compact and high selective bandpass filter using a combination of series open ended stub and shunt short ended stub to design CPW bandpass filter [7-8]. Stepped-impedance resonators were synthesized with higher fractional bandwidth but lower insertion loss [9-10]. Band-pass filters based on ring resonators described in [11] have a high-Q factor and compact size. Several multimode resonator filters were developed for wide pass-band, good in-band and out-of-band performances [12-13]. Wideband ring resonators with loading of open circuited stubs [14] as well as a wideband band-pass filter using transversal resonator and quadruple mode ring resonator [15] were proposed. A high selective bandpass filter with adequate isolation diplexer is proposed recently by mixed electromagnetic coupling [16].

In this paper, modelling of a two step coupled gap resonator is realized and used to design a bandpass filter. Basically, the proposed resonator is a combination of edge coupled and parallel coupled sections. Detailed analysis of the proposed resonator are derived to get different admittance parameter equations. These equations are then compared with normal two port network equations to synthesize the even and odd mode impedance difference (Z_{0o}-Z_{0e}) at the edge coupled section. These equations are very effective for designing bandpass filter. The operating frequency depends on the length of the resonator. Due to larger coupling area than the individual end coupled or parallel coupled resonating section, the proposed resonator resonates at a lower frequency. A three pole wideband bandpass filter is also demonstrated by series connection of four such proposed coupled resonator. This synthesis technique may be found very effective to analyze and design of different circuits.

II. DESIGN EQUATIONS

The proposed two step coupled gap resonator filter is treated as a combination of both edge coupled and parallel coupled sections as shown in Fig. 1(a). The resonating stubs are positioned such that adjacent resonators are in parallel to each other along the full of their length. To analyse such resonator, nodal analysis method or KCL is used. Thus, different current and voltage equations are obtained, which are further simplified and different admittance parameter equations are generated. Comparing those equations with normal two port network even and odd mode impedance difference (Z_{0o}-Z_{0e}) equation is obtained which is fruitful in designing of any bandpass filter having both the edge and parallel coupling.



(a) (b)

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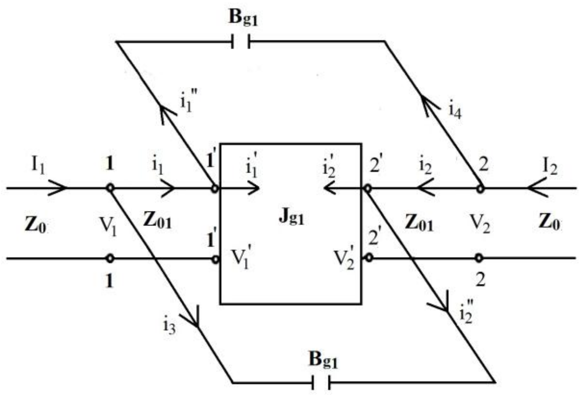


(c)

Fig. 1: (a) Schematic of proposed two step type gap coupled resonator (b) Simplified circuit model and (c) circuit model including current and voltage.

Fig. 1(b) and 1(c) shows the circuit modelingof the unit cell of the proposed resonator.The ABCD matrix of the coupled section of the proposed resonator can be represented as-

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} 0 & +\dfrac{1}{jJg_1} \\ -jJg_1 & 0 \end{bmatrix} \qquad (1)$$

Where, 'J_{g1}' is the admittance parameter of J-inverter and 'B_{g1}' is the shunt susceptance. Now, from equivalent ABCD matrix of transmission line we get,

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \begin{bmatrix} Cos\theta_C & jZ_{01}Sin\theta_C \\ j\dfrac{Sin\theta_C}{Z_{01}} & Cos\theta_C \end{bmatrix} \qquad (2)$$

Applying KCL at node 1 and node 2 and by solving enormous equations the admittance parameter values are obtained as-

$$Y_{11} = \left[\frac{\left(\frac{B^2}{B_{g1}} - \frac{AB}{B_{g1}} - BjJ_{g1}\right)\left(DjJ_{g1} - \frac{1}{B_{g1}}\right) + \left(A - \frac{B}{B_{g1}} + \frac{B^2 jJ_{g1}}{B_{g1}}\right)\left(C - \frac{D}{B_{g1}}\right)}{\left(A - \frac{B}{B_{g1}}\right)^2 - \left(BjJ_{g1}\right)^2} + \frac{1}{B_{g1}} \right] \qquad (3)$$

and

$$Y_{12} = \left[\frac{\left(\frac{-B}{B_{g1}} + A + \frac{B^2 jJ_{g1}}{B_{g1}}\right)\left(DjJ_{g1} - \frac{1}{B_{g1}}\right) + \left(\frac{B^2}{B_{g1}} - \frac{AB}{B_{g1}} - BjJ_{g1}\right)\left(C - \frac{D}{B_{g1}}\right)}{\left(A - \frac{B}{B_{g1}}\right)^2 - \left(BjJ_{g1}\right)^2} + \frac{D}{B_{g1}} \right] \qquad (4)$$

Considering half wavelength resonator section($\theta = 90^0$), equation (3) may be simplified as-

$$\therefore Y_{11} = \frac{(J_{g1}B_{g1}Z_0 + B_{g1} + Z_0^2 - jJ_{g1}B_{g1}Z_0^2)}{-Z_0^2 - J_{g1}^2 B_{g1}^2 Z_0^2} + \frac{1}{B_{g1}} \quad (5)$$

Similarly, Considering θ=90^0 in equation (4) may be simplified as-

$$\therefore Y_{12} = -\frac{j(Z_0 + J_{g1}Z_0^2 - B_{g1}Z_0 + J_{g1}B_{g1}^2)}{Z_0^2(1 + J_{g1}^2 B_{g1}^2)} \quad (6)$$

The Y-matrix may also be represented as-

$$\begin{bmatrix} I_1 \\ I_2 \end{bmatrix} = \begin{bmatrix} V_1 \\ V_2 \end{bmatrix} \begin{bmatrix} 0 & -\frac{j(Z_0 + J_{g1}Z_0^2 - B_{g1}Z_0 + J_{g1}B_{g1}^2)}{Z_0^2(1 + J_{g1}^2 B_{g1}^2)} \\ -\frac{j(Z_0 + J_{g1}Z_0^2 - B_{g1}Z_0 + J_{g1}B_{g1}^2)}{Z_0^2(1 + J_{g1}^2 B_{g1}^2)} & 0 \end{bmatrix} \quad (7)$$

Comparing the equations (5) and (6), even and odd mode impedance difference is obtained as-

$$(Z_{0e} - Z_{0o}) = \frac{Z_0^2(1 + J_{g1}^2 B_{g1}^2)}{(Z_0 + J_{g1}Z_0^2 - B_{g1}Z_0 + J_{g1}B_{g1}^2)} \quad (8)$$

Using the equation (8), the different dimensions of coupled lines and gaps are calculated. Fig.2 represents the three dimensional mesh view of even and odd mode impedance difference with respect to admittance of J-inverter (J_{g1}) and shunt susceptance (B_{g1}).

III. DESIGN OF A TWO STEPCOUPLED GAP RESONATOR

The design is implemented by two slots originating from the edge of the central strip on both sides such that the slots are connected to each other as shown in Fig 3(a). The resonator discontinuity formed is that of two quarter wavelength (λg/4) series open ended stubs. The discontinuity further transforms a short circuit at the starting terminal which forms a band acceptance response.

The proposed band accepted filter is designed by considering a Chebyshev lowpass prototype with 0.1 dB passband ripple. From (8) the even and odd mode impedance is obtained. Arlon AD320 material of permittivity of 3.2, thickness of 1.58 mm and loss tangent of 0.003 are considered for the proposed design. The widthof 3.8mm is chosen to match 50 ohm transmission line. J_{g1} values are calculated from normal parallel coupled bandpass filter design equation [1] and simultaneous differences of even and odd mode impedances are obtained from equation (8) for different FBW and tabulated in Table I. Bg1 values are calculated from existing coupled mode forlmulas[1].

From equation (8),

$$(Z_{0e} - Z_{0o}) = \frac{Z_0^2(1 + J_{g1}^2 B_{g1}^2)}{(Z_0 + J_{g1}Z_0^2 - B_{g1}Z_0 + J_{g1}B_{g1}^2)}$$

$$= \frac{50^2[1 + (-j1190)^2 \times (0.0351)^2}{[50 + 50^2 \times 0.02 - 50 \times (-j1190) + (-j1190)^2 \times 0.0351]} = 35.6628 + j44.93$$

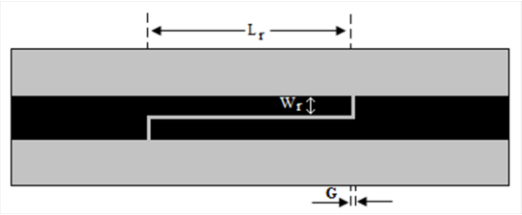
$$\left|(Z_{0e} - Z_{0o})\right| = 57.4173 \cong 57.4\Omega$$

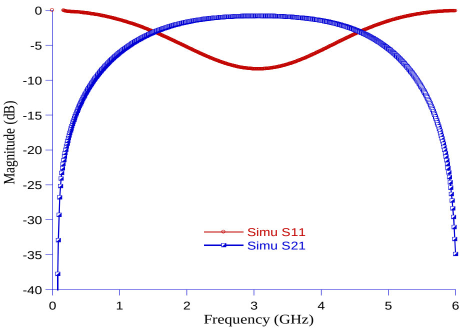
TABLE I

DESIGN PARAMETERS DUE TO CHANGE OF FBW

FBW(%)	Admittance "j_{g1}"	Shunt Susceptance "B_{g1}"	(Z_{oe}-Z_{oo})
20	0.0203	-j1190	22.4021
30	0.0249	-j1190	32.2905
40	0.0287	-j1190	41.2402
50	0.0321	-j1190	49.6941
60	0.0351	-j1190	57.4173
70	0.0380	-j1190	65.0603
80	0.0406	-j1190	72.0244
90	0.0430	-j1190	78.5232
100	0.0454	-j1190	85.1023

The designed filter have a fractional bandwidth of (FBW) = 60% at the center frequency f0 = 3 GHz. From Table-I, J_{g1}=0.0351 considering the FBW and the elemental values. Simply by solving the equation (51), the difference between even and odd mode characteristics equation is found to be 57.4ohm which is depicted in table I. If the gap (g) becomes small, the even mode impedance goes high and lowers the odd mode impedance. In order to achieve the desired value of impedance difference, width of coupled line section or stub considered as W_r = 1.8 mm, gap, g = 0.2 mm and the length of the resonator required is L_r =15 mm with a complete length of the coupled section is 18.4 mm[1,3].





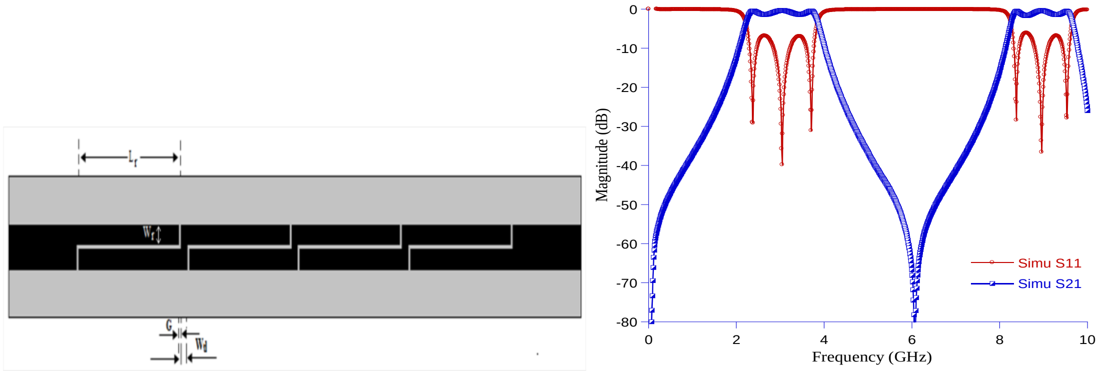
(a) (b)

Fig. 3: (a) Schematic of unit cell of proposed step type coupled gap resonator (b) Simulated S-parameter Responses

The length of the resonator is chosen to have center frequency near to 3GHz and the gaps have been optimized to have a good response. This schematic diagram is then simulated using HFSS EM Simulator software and simulation result shows a band accepted response at centre frequency 3.1GHz.

IV. THREE POLE BANDPASS FILTER DESIGN USING SERIES ARRANGEMENT OF PROPOSED RESONATORS

Four such proposed two step gap coupled resonators are placed in series such that the discontinuities in the central transmission line is kept closer to each other which provide higher field confinement. Hence, a good possible compactness is obtained with adequate higher bandwidth. Numbers of pole increases as the number of discontinuities are increased in the design.



(a) (b)

Fig. 4: (a) Schematic of proposed three pole series resonatorbased bandpass filter (b) Simulated S-parameter responses

The filter has designed with a fractional bandwidth FBW = 60% at the center frequency f_0 = 3 GHz. Same substrate considered for the design. Assuming gap between two consecutive resonators W_d = 1mm, a three pole bandpass filter has been obtained. The layout design of the filter is portrayed in Fig. 4(a). The simulated result in Fig. 4(b) shows 3dB bandwidth from 2.23 GHz to 3.86 GHz with a center frequency of 3.045 GHz and maximum insertion loss of -1.27dB, thus covering the entire S-Band. Also, the selectivity of 37.77dB/GHz at the rising edge and 36.97dB/GHz at the falling edge are observed which is quite high.

V. CONCLUSION

Design of bandpass filter using two step coupled gap resonator is demonstrated. Detailed circuit analysis of the proposed resonator has been done. This equation forms are found very effective in designing such coupled circuits. Combination of four resonators in series provides a wideband bandpass filter with low insertion loss. Close arrangements of such resonators give rise to field confinement, which further improves the bandwidth of the filter around 53.5% (FBW), which is quite high. This methodology of designing BPF might be an appealing candidate for compact and wideband systems.

VI. ACKNOWLEDGEMENT

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