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Spiral Inductor and Interndigital Capacitor Based Coupled Resonator Bandpass Filter

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***Abstract* - 5G Wireless Communication systems are gradually becoming compact and more advanced. As a part of future wireless transceiver, the bandpass filter has been designed using coupled spiral inductor and interdigital capacitor using Microstrip technology.Their quasi-lumped dimensions make the proposed filter compact and its high frequency equivalent circuit prove them as RLC resonator. The proposed resonator filter is analyzed and optimized using High frequency Structure Simulator on GaAs substrate using High Frequency Structure Simulator (HFSS). The results are compared with the existing Bandpass filter and it shows better performance.**

Keywords—Bandpass Filter, Inter-digital Capacitor, Coupling, Compact, Filter Resonator, Spiral Inductor

I. INTRODUCTION

5G connects practically everyone and everything, including computers, objects and devices, to be linked together.Ultra-high-speed 5G mobile networks are accelerating in research to meet this.Because of their advantageous properties, including wave propagation and usable bandwidth, lower 5G bands (3.3GHz-4.2 GHz and 4.4 GHz-4.99GHz) are suitable for early implementation.Ultra wideband filterhas been developed and simulated in order to meet this challenge and to meet the current demands [1].

For the design of radio frequency RF/Microwave filters, coupled resonator circuits are of importance, particularly the narrow-band bandpass filters (BPFs) that play a significant role in many applications[1].Various techniques such asdesign of waveguide filter, dielectric resonator filter,ceramic combline filter, microstrip filter, superconducting filters and micro-machined filters are discussed in [4] to extend the bandwidth of bandpass filter. Another way of constructing broadband filters is cascading high pass and low pass filters.In order to achieve an optimal bandpass response, no systematic way to measure the ideal response of the low- and high-pass sections is known[2]. At high frequency active components are also playing vital role to design the RF components [5-8].

The proposed bandpass filter presents the design of bandpass filter which is beyond the narrowband approximation. It consists of two lumped elements (spiral inductor and Interdigital capacitor) in shunt form to design coupled resonator based filter. The designed bandpass filter covers the pass band range of 1.6 GHz-10 GHz frequency.The filter designed on GaAs substrate having the height of 0.8 mm. The filter shows insertion loss of 0.1 dB and return loss of 58 dB, fractional bandwidth of 145% and dimensions are 4mm×8mm.

II. METHODS

(A) COUPLED RESONATOR FILTER

For representing a broad range of coupled-resonator filter topologies, the general coupling matrix is of interest as shown in Fig.1.Inductance, capacitance, and resistance, respectively, are denoted by L, C, and R. The network representation is presented in Fig.2.

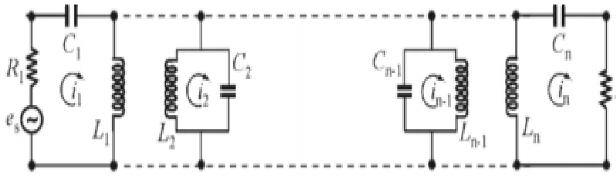

Figure.1Equivalent circuit of n-coupled resonators [4].

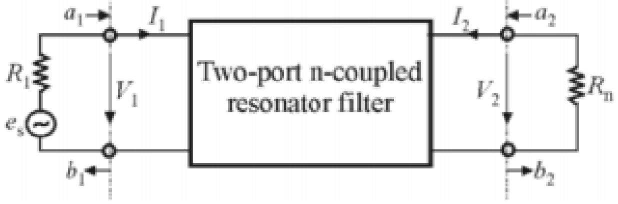

Figure.2Network representation of Fig 1.[4]

Qualumped monolithic components- Inter-digital capacitorand Rectangular Spiral Inductor are used to design wideband filter.The electrical circuit proves to behave like a resonator.

(B) INTER DIGITAL CAPACITOR

Interdigital capacitor is one type of monolithic or integrated capacitor. It is a periodic system with several fingers, as seen in Fig.3.

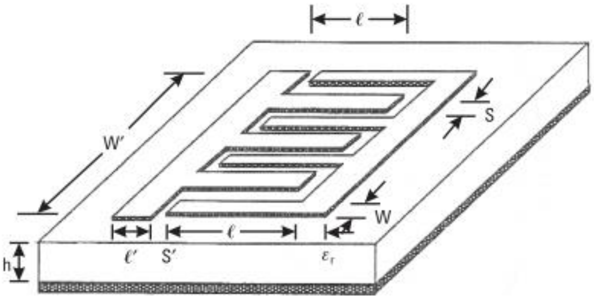

Figure3. An Inter-digital configuration capacitor[9]

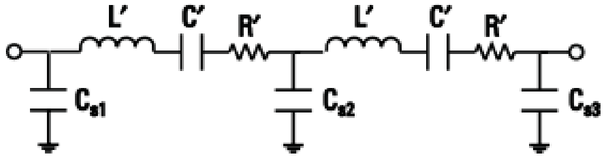

Figure4. Equivalent Circuit of Inter-digital Capacitor[9]

Fig 4. Shows the lumped element electric circuit model of Fig.3. The equivalent electric parameters totally depend on the physical dimensions as illustrated in Fig.3.

For interdigital capacitance, an approximate expression is given by [5]

$$C = \frac{\varepsilon_r+1}{W'}\, l\,[(N-3)A_1 + A_2] \qquad \text{(i)}$$

C is the capacitance along W', A_1 and A_2 are the capacitances per unit length of the fingers, N is the number of fingers.

(C) RECTANGULAR SPIRAL INDUCTOR

In the coupled-line method, using multi-conductor coupled microstrip lines, an inductor is analyzed.This method forecasts the efficiency of the spiral inductor reasonably well for upto N = 2 and frequency upto 18 GHz [9]. Fig.5 depicts the Rectangular spiral inductor and Fig.6 shows its Electric Circuit (EC) model.

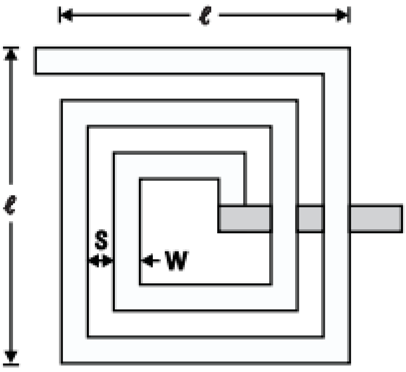

Figure 5. Rectangular Spiral Inductor [9]

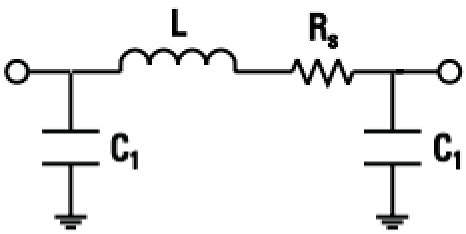

Figure. 6 Equivalent Circuit of Spiral Inductor [9]

$$L(nH) = 2 \times 10^{-4} l \left[ln\left(\frac{l}{W+t}\right) + 1.193 + \frac{W+t}{3l}\right].K_g \quad \text{(ii)}$$

$$K_g = 0.57 - 0.145\ln\frac{W}{h}, \frac{W}{h} > 0.05$$

The expression Kg represents the existence of a ground plane and decreases as the plane on the ground is brought closer. The terms W, t, h and Rsh are the line width, line thickness, substrate thickness, length of the section, and sheet resistance per square of the conductor, respectively.

(D) COUPLING COEFFICIENT

Resonator coupling coefficients are commonly used in the design of resonators.They provide a reasonably precise method for the direct synthesis of narrow-band filters and provide initial estimation parameters of the structure for wide-band filter optimization synthesis[10].

A dimensionless physical quantity representing the coupling coefficient is the coupling between two lumped components. The value of coupling coefficient defines how well the lumped components are coupled to each other [11]. Their Electric Coupling (k_E), Magnetic Coupling (k_M) and mixed coupling (k_X) are defined as Eq(s) (iii), (iv) and (v), respectively.

$$k_E = \frac{f_m^2 - f_e^2}{f_m^2 + f_e^2} = \frac{C_m}{C} \text{ (iii)}$$

C and C_m represent the self-capacitance and mutual capacitance respectively.

$$k_M = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2} = \frac{L_m}{C} \text{(iv)}$$

L and L represent the self-capacitance and mutual inductance respectively.

$$k_x = \frac{f_e^2 - f_m^2}{f_e^2 + f_m^2} = \frac{CL'_m + LC'_m}{LC + L'_m C'_m} \text{ (v)}$$

Where, C, L, C'_m and L'_m are self-capacitance, the self – inductance, the mutual capacitance and the mutual inductance of an associated equivalent lumped element circuit. Resonance frequency and quality factor are listed as Eq. (vi) and (vii), respectively. Where, Q_o is the unloaded quality factor and Q_e is the external quality factor of the resonator.

$$\text{Resonance frequency } f_0 = \frac{1}{2\pi\sqrt{LC}} \text{ (vi)}$$

$$\frac{1}{Q} = \frac{1}{Q_o} + \frac{1}{Q_e} \text{(vii)}$$

III.RESULTS AND DISCUSSION

Fig 7 shows the proposed band pass filter configuration. Rectangular spiral inductor and Interdigital capacitor are connected to form parallel LC tank circuit. Fig.8 presents implementation on the band pass filter on microstrip technology. Fig 9 depicts its physical dimensions. The quasi-lumped dimensions$\left(\frac{\lambda_g}{8}\right)$are taken with reference to the guided waveguide at cut off frequency of 8GHz.

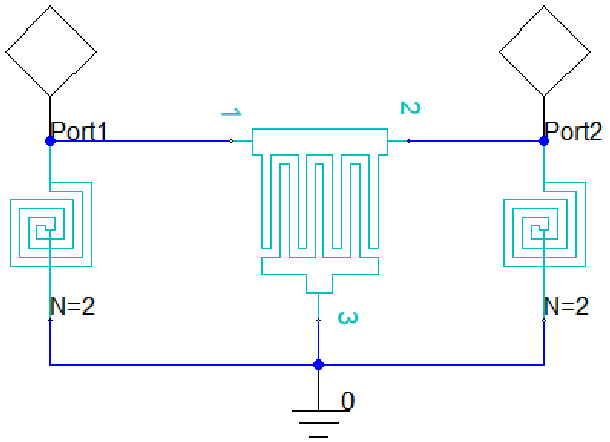

Figure. 7 Spiral Inductor and Inter-digital Capacitor based LC tank Circuit

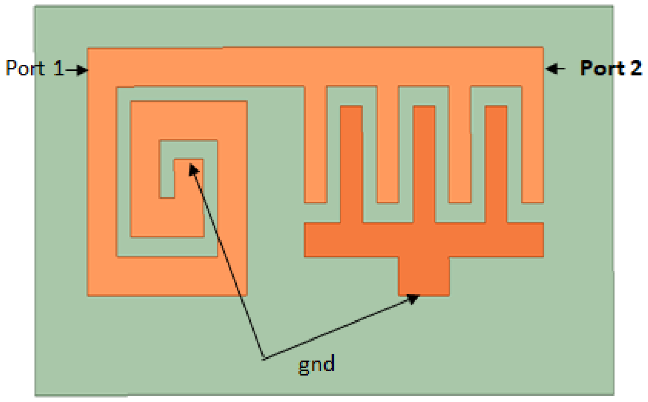

Figure8. Micro strip design of Figure.7

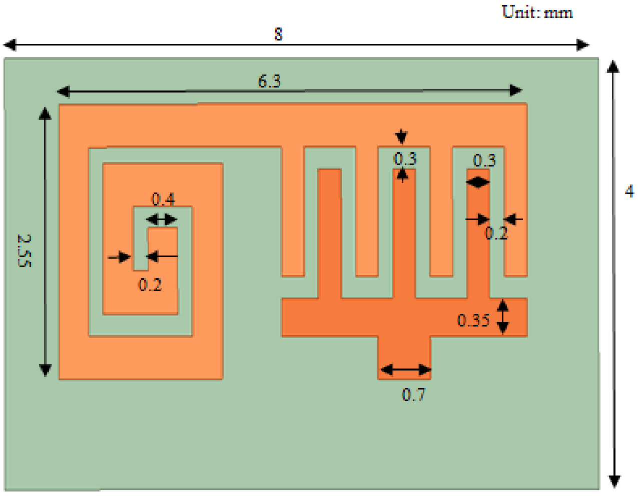

Figure 9. Dimensions of Proposed Resonator Filter

By considering the GaAs substrate dielectric constant 12.9 and height of 0.8mm the bandpass filter is simulated. The input and output port are of 50 ohm resistance. Fig. 10 illustrates its S-parameter response that shows the return loss of 58 dB and insertion loss of 0.1 dB.

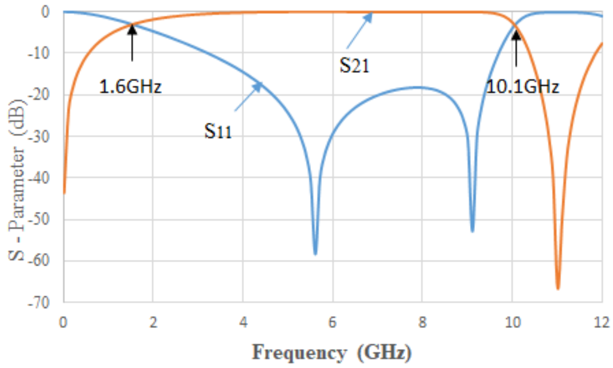

Figure10. Insertion Loss and Return Loss

Table 1. Comparison with existing research work.

Sr.No.	**Passband range (GHz)**	**Fractral Bandwidth (%)**	**Insertion loss (dB)**	**Dimension (mm^2)**
Ref.12	2.8 - 10.6	116	0.4	34.6 × 14.6
This work	1.6 – 10.1	145	0.1	4 × 8

IV: CONCLUSION

Table 1. Compares the latest UWB bandpass filter and proposed filter. The presented design offers the better response in terms of fractral bandwidth, Insertin loss and miniaturization. For compact wireless communication transceivers, the proposed bandpass filter demonstrates its improved application.

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