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Novel design of spiral inductor structure for optimized inductance and Q factor and its comparative analysis

Shakshi Mishra*, Govind Kumar and Manish Kumar Gupta*****

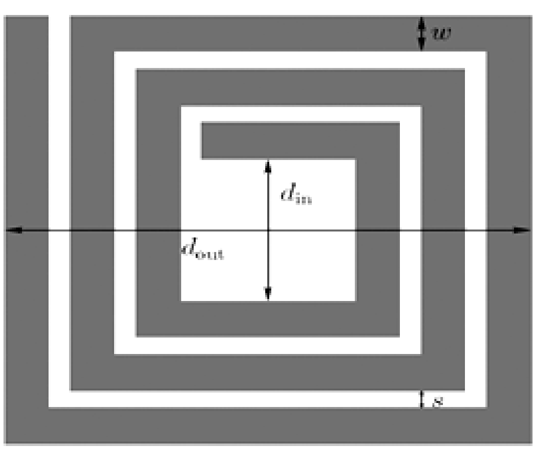
ABSTRACT

On chip spiral inductors are widely used monolithic interconnect devices in RF circuit designs. Various approaches for spiral inductors modeling on silicon are reported in past years. These models are developed using numerical method techniques, curve fitting techniques, or by using empirical formulae. Therefore these technical reports are either with relative errors or not applicable over a wide range of layout's dimensional variations (i.e. length, width, thickness of thickness and spacing of spiral conductor, height of the substrate, etc.). we propose analysis of the inductance of existing spiral inductor (both square inductor and circular inductor) based on current sheet approximation and comparison of the result with the Agilent ADS. propose analysis, design and fabrication of some novel designs of RF inductor(s) which can be functional upto 50GHz and designed in the same dimension in comparison with the previously mentioned RF inductors. The purpose of this research is to introduce new architecture(s) of spiral inductors with improved and optimized quality factor and inductance. It will lead to decrease power loss in RF devices.

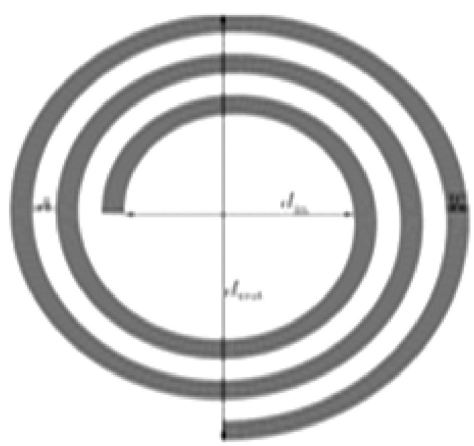
Index Terms: spiral inductor, inductance, Q factor, multi GHz frequency range.

1. INTRODUCTION

Two types of spiral inductor namely square inductor and circular inductor have been introduced in this evolution. Designs of these inductors are shown in figure below.



(a)



(b)

Figure 1: (a) Square spiral inductor. b) Circular spiral inductor.

*,** Yagyavalkya Institute of Technology, Jaipur, *Emails: Shakshi26@gmail.com, govind.yit@gmail.com*
*** Vivekananda Global University, Jaipur, *Emails: mkg.met@gmail.com*

There is a trade off in the performance of these two inductors. Circular spiral inductors better performance in terms of Q factor but the inductance parameter is not good in comparison to square spiral inductors [1].

Fabrication facilities limit the shape of inductors .In square shape spiral inductor the angles are generally 90^0.Structural parameters like inductor width, spacing between turns ,overall dimension of inductor substrate property are key factors that affect the inductance and Q factor of inductor [2].

2. INDUCTANCE AND Q FACTOR OF SPIRAL INDUCTOR

A spiral inductor optimization problem may be formulated as Q is Q factor, L is inductance, N no of turns, W width of spiral, S spacing between the turns, D diameter of design

2.1. Inductance of spiral inductor is

$$L\text{ total} = L\text{ self} + M_+ + M_-$$

L total =total mutual inductance

L self = self inductance

M_+ mutual inductance in same direction

M_- mutual inductance in opposite direction

$$Lself = 0.02l\left[\ln\frac{2l}{W+t} + .50049 + \frac{W+t}{3l}\right]$$

Where l is the length of the segment, W is the width of the conductor, and t is the thickness of the conductor.

The mutual inductance between two parallel conductors of equal length

$$M = 2lH$$

Spiral inductor occupies a large area which in turn increases cost. The goal of proposed design is to provides linear inductance and high Q factor for a larger range of frequencies (1 GHz to 200 GHz) for a given described area [3] [4].

2.2. Calculation of Figure of Merits

Quality factor is the most important figure of merit of the inductor. For an inductor Q is proportional to the energy stored which is equal to the difference between the peak magnetic energy and electric energy [5].

$$Q = 2\pi\frac{\textit{peak megnatic energy - peak electric energy}}{\textit{energy loss in one ocsillation cycle}}$$

$$Q = \frac{\omega L_s}{R_s}.\frac{R_p}{R_p + \left[\left(\frac{\omega L_s}{R_s}\right)^2 + 1\right]R_S}$$

$$\times\left[1 - \frac{R_s^2\left(C_s + C_p\right)}{L_s} - \omega^2 L_s\left(C_s + C_p\right)\right]$$

$$Q = \frac{\omega L_s}{R_s} . substrate\ loss\ factor.\ self\ \ resonance\ factor$$

3. PROPOSED DESIGN OF SPIRAL INDUCTOR

Fig. 2 shows the top view of the proposed structure which consists of a ground substrate over which spiral inductor made of polysilicon is designed. This structure is designed such as for a large range [1 to 200 GHz] of frequencies inductance could be linear and more RF devices can be operated using this linear inductance.

Table 1
Parameter values of the proposed design.

	Values
Width (W)	4μm
Spacing between turns (S)	4μm
Curve	2 √2 μm
length (CL)	4 μm
Curve width Angle	90^0
Frequency range	1 to 200 GHz

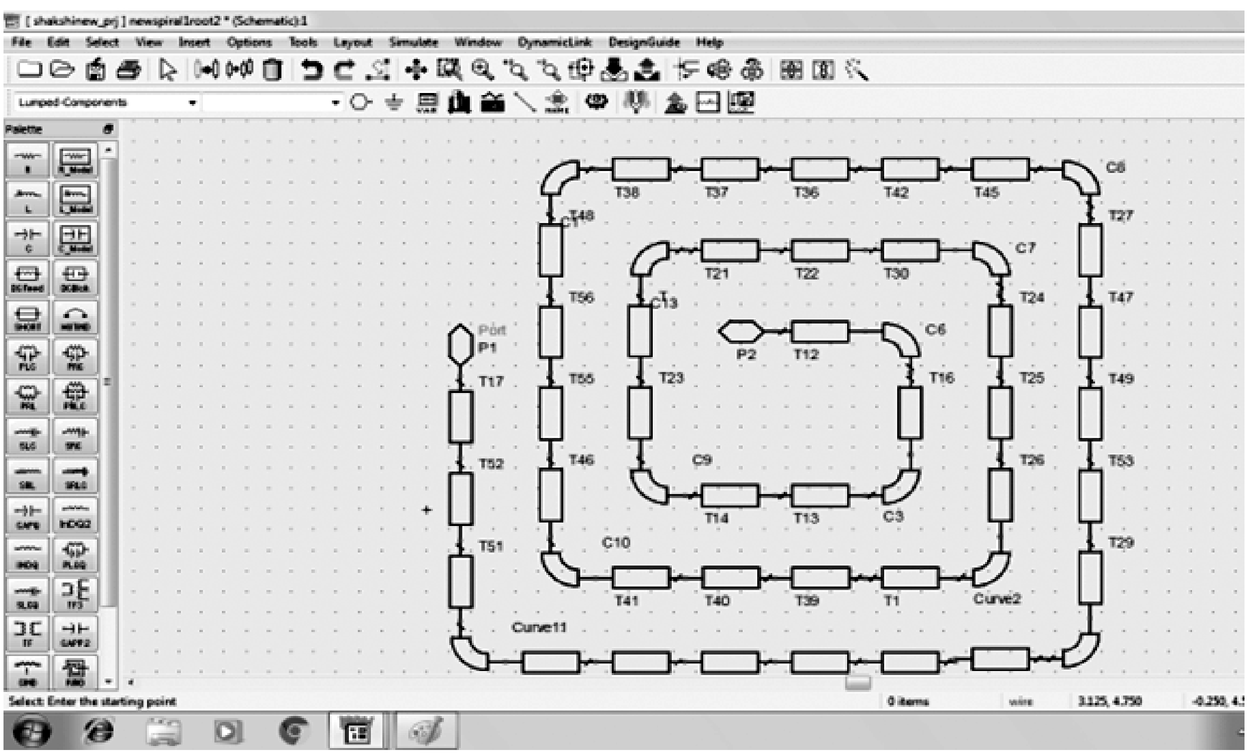
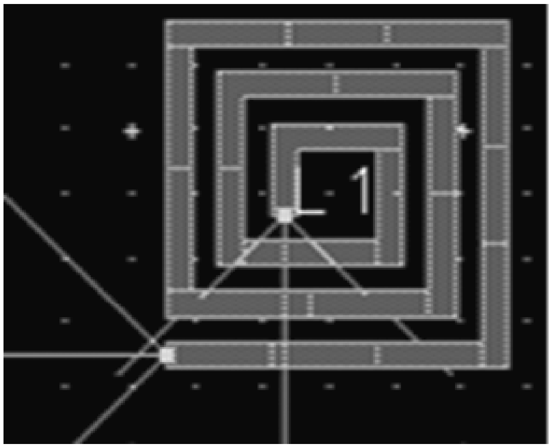


Figure 2: Schematic view of spiral inductor with w = 4μm and CL = 2.828 μm

4. CURVE LENGTH PHENOMENON IN PROPOSED STRUCTURE

The curve length phenomenon is introduced in this proposed design. The design can be varied according to the curve length which makes this design an appropriate combination of square and circular spiral inductors. In this paper, we have taken curve length as 2.828 μm. Results produced by square, circular and proposed designs are compared for inductance and Q factor parameters.



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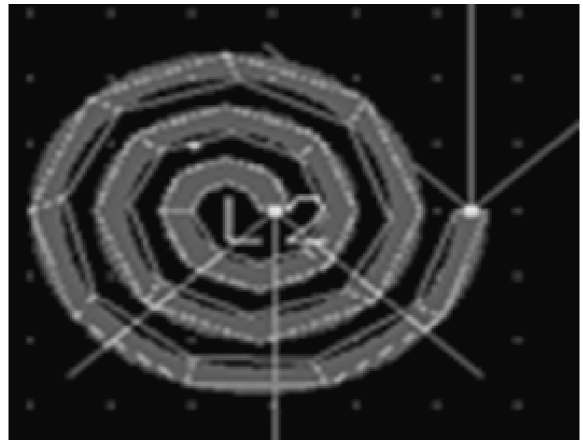

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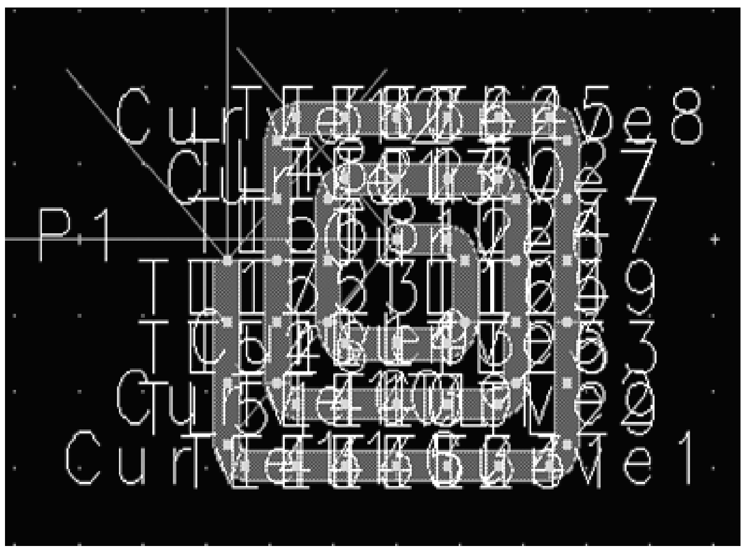

(c)

Figure 3: Layouts designed in ADS for (a) square inductor (b) circular inductor and (c) proposed inductor

5. SIMULATION RESULTS OF PROPOSED STRUCTURE

The The results proposed in this paper are generated from simulation of proposed structure. The figures shown below depict inductance and Q factor variation with frequency.

5.1. Inductance

Proposed designed are simulated for RF frequency range using Agilent ADS tool. Optimized linearity of inductance over large range of frequency is found in simulation, as shown in Fig. 1.4. This is very important result as this inductor design do not compromise with inductance value for better Q-Factor.

5.2. Q factor

Variation in Q – factor with frequency is shown in Fig. 1.5. It is clear that the proposed inductor design shows better frequency range for quality factor in comparison to square inductor while its Q factor value is also admirable.

Design parameters of spiral inductors and simulated values of inductance and Q-factor are shown in following tables.

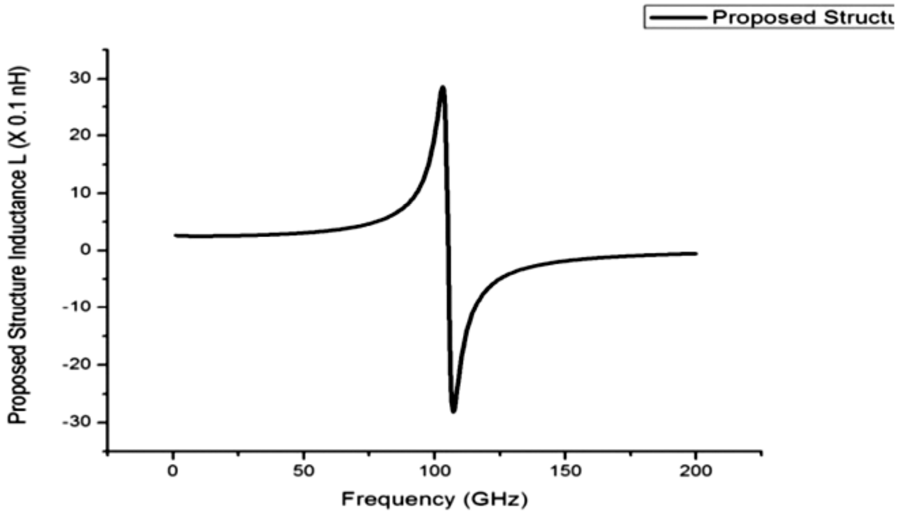

Figure 4: Graph for effective inductance

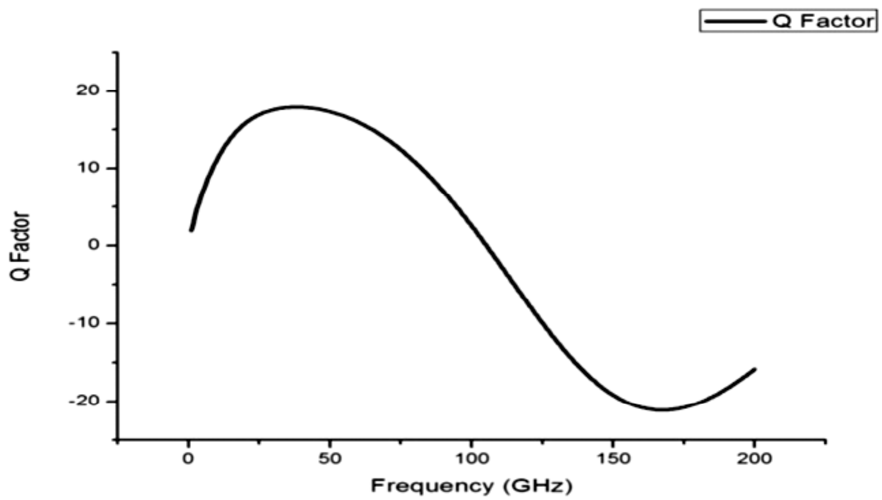

Figure 5: Graph for Q factor

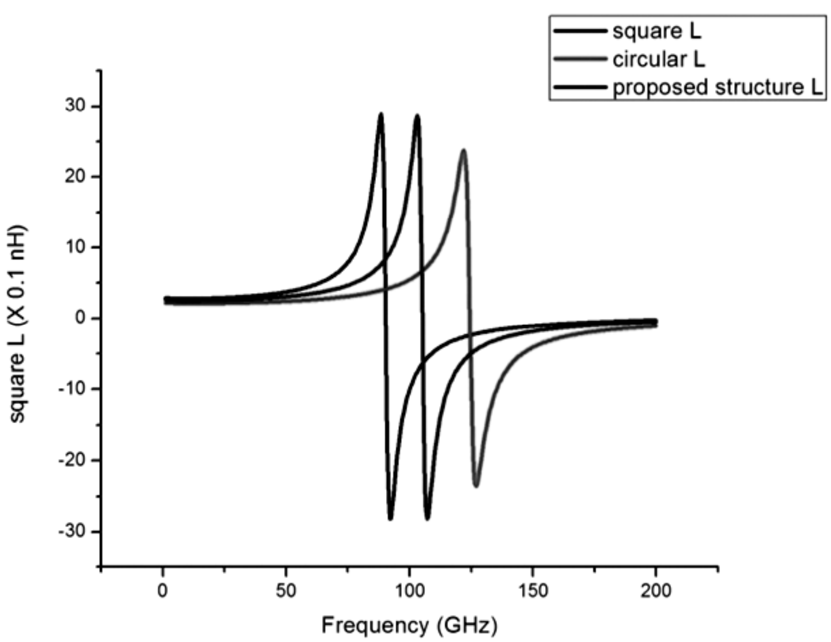

Figure 6: Inductance vs. Frequency curve for spiral proposed inductors for 1 to 200 GHz.

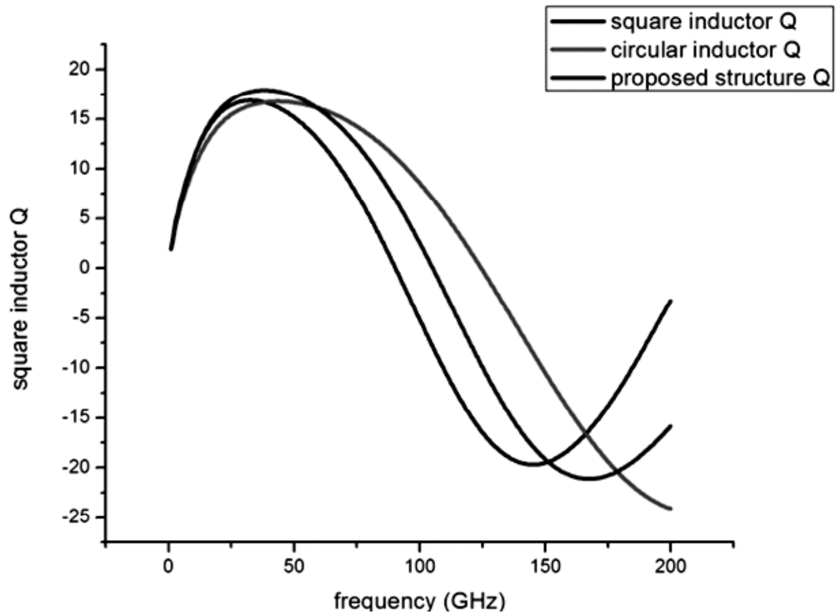

Figure 7: Q Factor vs. Frequency curve for spiral proposed inductors for 1 to 200 GHz.

The outer diameter of structure is 55×50 μm^2.

Table 2
Inductance and Q factor results for different types of spiral inductor

Types of inductor	*Inductance*		*Q- Factor*		*L at Q_{max} (nH)*
	L (nH)	*FrequencyRange (GHz)*	*Q_{max}*	*Frequency (GHz)*	
Spiral inductor	0.329	40	16.861	33.5	0.309
Circular inductor	0.271	63	16.749	44	0.233
Proposed structure of inductor	0.312	51	17.911	38.5	0.280

6. CONCLUSION

Proposed new spiral inductor structure is analysed for inductance and Q factor. It is clear from results that the inductance is linear up to frequency 90 GHz with curve length =2.828 μm which also has Q_{max} = 17.911 at frequency = 38.5 This proposed design is optimum solution for better inductance and Q-factor and removes trade off of these parameters as it appears in circular and square inductor designs. It can be used over multi GHz frequency range with microwave and communication devices.

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