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Differential Transformer based Design of Bandpass Filter for 1.8 GHz

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Abstract

This paper represents Bandpass filter using FR4 substrate based on differential transformer. The transformer is full differential & symmetric made by two intertwined spiral inductor. This design is located at 1.8 GHz center frequency. It passes frequency from 1.68 GHz to 1.85 GHz frequency and rejects the other frequencies. The overall area of the PCB is 73.59mm x 73.59mm. For getting expected results we varied the turns of inductor, value of capacitor & size of each component. Variation in size of component (scaling effect) gives the effect on inductance, self resonant frequency & quality factor.

Keywords: Bandpass Filter; Differential Transformer; spiral inductor.

INTRODUCTION

Filters have important roles in many RF/microwave applications. The electromagnetic spectrum is limited and has to be shared; filters are used to select or confine the RF/microwave signals within assigned spectral limits. [7] Depending on the requirements and specifications, RF/microwave filters may be designed as lumped element or distributed element circuits; they may be realized in various transmission line structures.[6] In [1] transformer based design of BPF using the integrated passive device is given which introduce about IPD fabrication process and gives idea about LC tank circuitry. The term microwaves may be used to describe electromagnetic (EM) waves with frequencies ranging from 300 MHz to 300 GHz, which correspond to wavelengths (in free space) from 1 m to 1 mm. Therefore, by extension, the RF/microwave applications can be referred to as communications, radar, navigation radio astronomy, sensing, medical instrumentation, and others [3] The BPF includes the design of transformer which composed of two inductors. Structural parameters such as the outer dimension, number of turns, the distance between the centers of lines (or pitch), and substrate property are all important factors in determining the performance of on-chip inductors. [2] The dynamic growth in RF electronics has demanded and vitalized the need of high-performance on-chip passive components. One of these components, the on-chip spiral inductor. The spiral pattern and geometry can also be optimized to enhance the quality factor, but these alternatives often come with trade-offs or compromises. [4] The generation and processing of signal at microwave frequencies(from below 0.1Ghz to 30 GHz) are typically achieved in microstrip circuits using element constructed from microstrip transmission lines and combined with semiconductor component.[5]

DESIGN AND ANALYSIS

The basic configuration of full differential bandpass filter is illustrated in Fig[1]. The BPF is composed of one transformer and two capacitors. The transformer structure is composed of two intertwined spiral inductor and it follows eight air-bridged structures. Two capacitors are inserted between GND terminal and PORT terminal which forms two LC tank circuits. Hence it is two pole Bandpass filter. The GND terminal is nothing but termination provided to circuit.

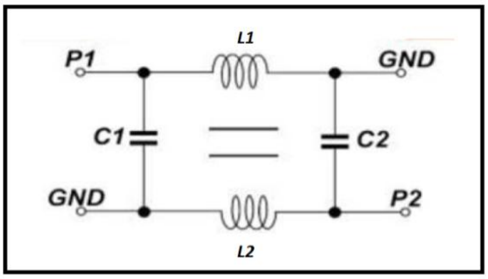

Fig.1. Equivalent diagram of BPF

Basic component of the proposed design is a Inductor. Basically there are three types of on-chip inductors. The most widely used type is the planar spiral inductor, and a square shaped spiral inductor. Although a circular shaped inductor may be more efficient and yield better performance, the shape of inductor is often limited to the availability of fabrication processes. [4].This Bandpass Filter configuration forms two synchronously tuned coupled resonators which posses magnetic coupling between them. Fig.[3] shows simulation result of BPF which indicates S-parameter response. The characteristics of second order BPF having two poles (fp1 & fp2) and these transmission pole are depend on inductive coupling of transformer. Furthermore the value of S-parameter can be controlled by changing value of capacitor. This significantly affects the FBW's. The GND's used in this design are PTH GND's. Capacitors are SMD capacitor which are having standard values & standard sizes. This configuration is built on FR4 substrate. It is flame resistant, with good thermal and mechanical properties for rigid laminates.

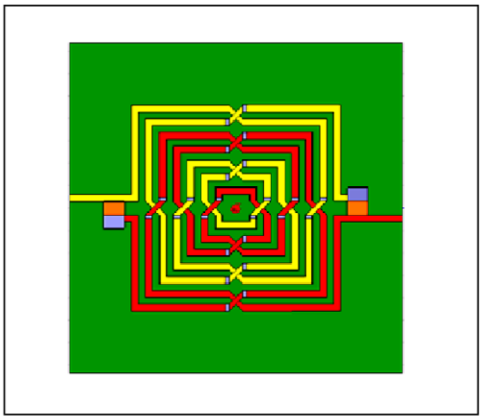

Fig.2. Differential Transformer based BPF

MATHEMATICAL MODELLING

In order to design a differential transformer BPF, important parameters are taken into consideration. The substrate height of FR4 substrate is taken to be 1.6 mm. By assuming the no of turns of inductor the value of inductor was calculated with the following equation [1] where $D_0 \, and \, D_1$ are the inner and outer diameters of inductors respectively.

The inductance can be calculated as

$$L = \frac{(0.03937 \times a^2 \times n^2)k}{(8a + 11c)} \quad (1)$$

Where $a = \frac{(D_0+D_1)}{4}$; $c = \frac{(D_0-D_1)}{4}$

Coupling Coefficient is given as,

$$k = \frac{(\omega_+^2 \; - \omega_-^2)}{(\omega_+^2 + \omega_-^2)} \quad (2)$$

Mutual Inductance is given as,

$$M = \left\{k \times 6.025 \times 10^{-7} \, (R_i \, + R_o)n^{\frac{5}{3}} \times \ln\,[4(1 + \frac{2R_i}{(R_o \, - R_i\,)}]\right\} \quad (3)$$

Taking the center frequency at 1.8 GHz, the value of capacitor can be calculated from below equation [4],

$$f = \frac{1}{\sqrt{(2\pi LC)}} \tag{4}$$

As we have used the SMD capacitor of standard value in our design so we have not further analyzed the other parameters of capacitor.

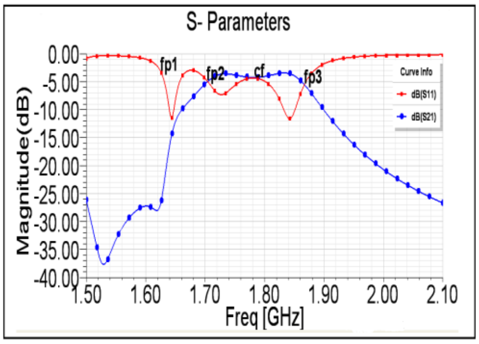

Fig.3. Variation of S-parameter with Frequency [GHz] (initial design)

We obtained this result given in Fig. [3] with the help of above design formulae. As we can observe from this result there are three transmission poles but according to our expected result there must be only two transmission poles. At 1.8 GHz the graph of insertion loss (S_{21}) and return loss (S_{11}) are at same point.

RESULTS AND DISCUSSION

The overall design was simulated on HFSSv11 software. The graph of S_{21} and S_{11} should be opposite. So we scaled down (reduction in area) the initial design to obtain the expected result. We observed the characteristics of S_{21} and S_{11} given in Fig. [3]. We observed that in the modified design the return loss decreased as required and the value of insertion loss has a maximum peak at center frequency (cf) i.e. 1.8 GHz.

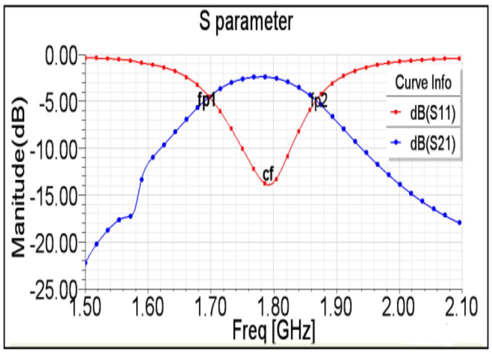

Fig.4. Variation of S-parameter with Frequency [GHz] (modified design)

Table 1: Calculated and measured values of spurious resonance frequencies

Name	Freq (GHz)	Magnitude(dB)
fp1	1.6800	-5.5920
fp2	1.8576	-5.9181
cf	1.7943	-13.8437

The observed values of S_{21} and S_{11} are-2.5db and 13.84db respectively. We also calculated the value of VSWR. Ideally the value of VSWR should be between 0 and 1. We verified the result of VSWR.

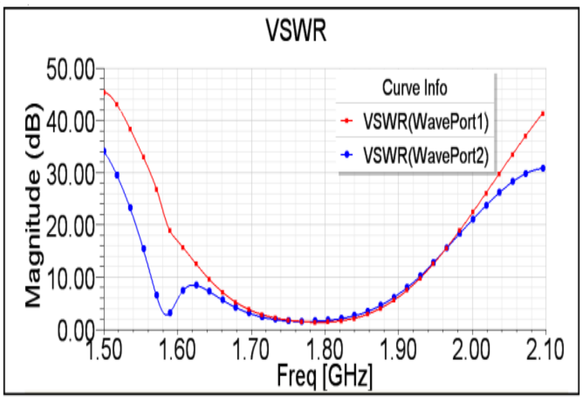

Fig.5. Variation of VSWR with Frequency [GHz]

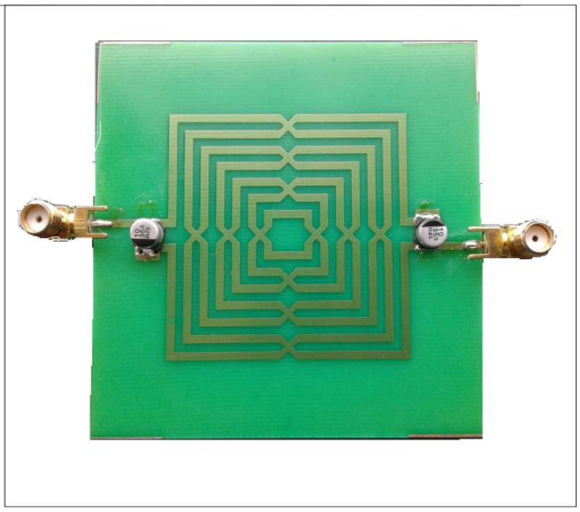

Fig.6. Image of fabricated BPF

CONCLUSION

In this paper differential transformer based band pass filter at 1.8 GHz is introduced. By decreasing size of overall design (scaling down) the characteristics of modified design is improved as compared to our initial design. As our design is at 1.8 GHz, it can be used for GSM based applications. This can also be designed at 2.4 GHz, 3.8 GHz and 5.8 GHz by changing the design parameters. Depending on the above frequencies it can be used for various applications such as ISM and LTE.

REFERENCES

[1] Yang Li, Cong Wang, and Nam-Young Kim "Design of Very Compact Bandpass Filters Based on Differential Transformers" *IEEE Microwave and Wireless Components Letters, Vol. 25, no. 7, July 2015,* pp. 439-441

[2] Saurabh Mehta and Manish Mehta "A Novel Approach: Square Spiral Inductor for RF Telemetry Application" *International Journal of Computer Applications (0975 – 8887) Recent Trends in Electronics and Communication (RTEC 2013),* pp. 23-25

[3] Jia-Sheng Hong and M. J. Lancaster "Microstrip Filters For Rf/Microwave Applications" A Wiley-Interscience Publication John Wiley & Sons, Inc., pp. 121-142

[4] JI CHEN "On-Chip Spiral Inductor/Transformer Design and Modelling for Rf Applications" B.S. Fudan University, 2006, pp. 72-81

[5] Jianjun J. Zhou and David J. Allstot, "Monolithic Transformers and Their Application in a Differential CMOS RF Low-Noise Amplifier" *IEEE Journal Of Solid-State Circuits, Vol. 33, No. 12, December 1998*

[6] Dr. E.H.Fooks and Dr, R.A. Zakarevicius,"Microwave Engineering using Microstrip circuits", Prentice Hall of Australia Pty Ltd, 1990, pp. 214-221

[7] IIT Delhi, Advanced Microstrip trainer kit

[8] D.M.Pozar, Microwave Engineering, 4th Ed. New York: Wiley, 2005, pp.414-416

[9] Z. Zhang and X. Liao, "Micromachined passive bandpass filters based on GaAs monolithic-microwave-integrated-circuit technology," *IEEE Trans. Electron Devices*, vol. 60, no. 1, pp. 221–228, Jan. 2013.

[10] L. Darcel, P. Duême, R. Funck, G. Alquié "A new Methodology for achieving MMIC Bandpass Active Filters at High Frequencies"*12th GAAS Symposium-Amersterdam, 2004,* pp. 87-90

[11] Ali M. Niknejad "Analysis, Design, And Optimization of Spiral Inductors and Transformers for Si RF Ics" Electronics Research Laboratory College of Engineering University Of California, Berkeley, pp.76-81