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Very compact differential transformer-type bandpass filter with mixed coupled topology using integrated passive device technology

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ABSTRACT

This paper presents a very compact differential transformer-type bandpass filter based on mixed coupled resonators that are developed using integrated passive device technology on a GaAs substrate. The center frequency of the proposed BPF is 900 MHz with a 3-dB fractional bandwidth of 85%, which is applicable to the long-term evolution application frequency range for band 8; the overall size of the filter is notably small compared with other studies and is only $7.5 \times 10^{-3}\,\lambda_0 \times 7.5 \times 10^{-3}\,\lambda_0$. The implemented differential type transformer offers a high coupling effect to ensure that the final device has excellent RF performance. Moreover, the proposed structure greatly reduces the size and introduces two transmission zeros near the passband edge in the stopband, which results in a high level of selectivity and harmonic suppression. Meanwhile, it is possible to control the rejection level by adjusting the capacitor electrode sizes, which provides greater design flexibility. Finally, experimental verification demonstrates very good agreement between the modeled and measured results, thereby validating the correctness of the proposed filter design based on the integrated passive device process.

1. Introduction

Recently, a growing demand for wireless and mobile communication systems with low cost, compact size and high performance has been heavily investigated. Several conventional technologies, such as printed circuit boards and low-temperature co-fired ceramic technology, cannot meet the requirements for this continuing trend [1,2]. Along with the advent of integrated passive device (IPD) technology, the above-mentioned issues were skillfully conquered, and IPD technology offered compatibility with active devices to make an essential system in both a package and a system on chip [3–6]. Furthermore, the bandpass filter (BPF) is an essential device in wireless and mobile communication systems. BPFs exist in the RF front end of both the receiver and transmitter circuits to reject noise that may interfere with sensing transmission; therefore, the demand for BPFs is highly desired. In the past several years, many studies have presented and proposed various topologies and design methods in which two primary methods are typically applied. One of the methods uses the transmission-line structure to realize the filter design [7–10], and the other standard method uses lumped LC-type structures [11–16]. Using the transmission-line structure avoids a complicated fabrication process, which reduces the cost of the entire chip. However, filters based on this transmission-line structure have encountered difficulty in reducing chip size. With regard to the LC-type BPF, although it overcomes the issue of large chip size, it does not meet the desired prototype responses due to the parasitic effect. Therefore, design freedom is seriously limited. In addition, the LC-type BPF has a trade-off between high RF performance and compact size because too many elements are required for realizing a high RF performance BPF. Hence, several challenges still remain for the implementation of high RF performance, extensive design freedom and compact size.

In this paper, a very compact differential transformer-type BPF is presented based on a mixed coupled resonator topological structure using IPD technology on a GaAs substrate, which overcomes the above-mentioned issues. The center frequency of the proposed design is located at 900 MHz, which is desired for long-term evolution (LTE) applications. To date, most studies have focused on the frequency of filter research over the L band, and there are almost no reports on low frequency (<1 GHz). Obviously, this untapped research area is in urgent of study. Fortunately, the proposed work provides great and valuable research and application in this field. In this work, the realization of a differential type transformer offers a high magnetic coupling effect, which ensures that the final device has an excellent insertion loss. In addition, the proposed design introduced two transmission zeros to ensure sharp passband skirt performance and good harmonic suppression in the

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stopband. The floating capacitor electrode provides more design freedom to achieve a high rejection level in the stopband. The principal IPD fabrication process, the detailed design theory of the BPF and the experimental results are discussed. Finally, a comparison with other recently published research studies shows that the proposed work has excellent characteristics along with low fabrication cost, high RF performance, and very compact occupied size.

2. Fabrication process and filter design

The IPD technology adopted here uses a highly resistive GaAs substrate, a low loss SiN_x dielectric material, and high conductivity copper/gold layers to realize these passive components for excellent performance. Fig. 1 shows the cross-sectional view of the IPD process and the actual implemented capacitor and inductor. Both the bottom metal and top metal are 5-μm thick with 0.1 μm of Au and 4.9 μm of Cu. The first passivation layer is composed of SiN_x and is deposited on a GaAs substrate with a thickness of 0.2 μm to attain an even surface. The second 0.2-μm thick SiN_x layer is deposited on the bottom metal layer to define the dielectric for the metal–insulator–metal (MIM)-type capacitor. Finally, all components are passivated with a thickness of 0.3-μm SiN_x to protect the components from oxidization and moisture. The relative dielectric constant of the substrate is 12.85, and the GaAs substrate is 200-μm thick.

The basic configuration of the proposed differential transformer-type BPF is illustrated in Fig. 2. The proposed pattern is composed of two inductors and two capacitors. The two inductors are intertwined and overlapped using six air-bridge structures, which form the differential transformer through magnetic coupling. The two capacitors are in series on the transformer termination on the inner surface. To form the resonance circuit, the two ports for impedance terminations are defined as ground. An embedded structure is skillfully introduced to minimize the dimensions of the overall circuit. For the detailed parameters of the proposed pattern, the two inductive metal lines are 15 μm in width, and the spacing of the metal line is 15 μm. The other optimal parameter values are as follows: $Lc=245$ μm, $Wc=65$ μm, $R_{in}=258$ μm, $R_{out}=363$ μm, and $P_a=158$ μm. For the spiral inductor, by not considering the resistive loss and the capacitive effect of the rounded corners of the spiral inductor, the inductance of the spiral inductor can be expressed as [17]

$$L = 6.025\times10^{-7}(R_{in}+R_{out})n^{5/3}\ \ln\left[4\left(1+\frac{2R_{in}}{R_{out}-R_{in}}\right)\right] \quad (1)$$

where n is the number of turns, R_{in} is the inner radius of the transformer, and R_{out} is the outer radius of the transformer. Additionally

$$R_{\text{out}} = R_{\text{in}} + 2nW + 2(n-1)S \quad (2)$$

where S is the gap between the inductor lines and W is the trace width of the spiral inductor. In addition, the Q-factor of the inductor is a measure of the ratio of stored versus lost energy per unit time,

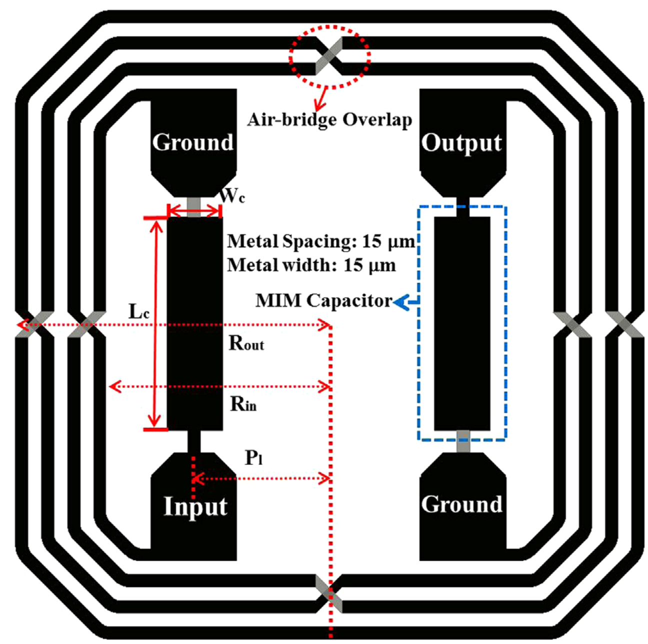

Fig. 2. Configuration of the proposed BPF constructed by a differential transformer.

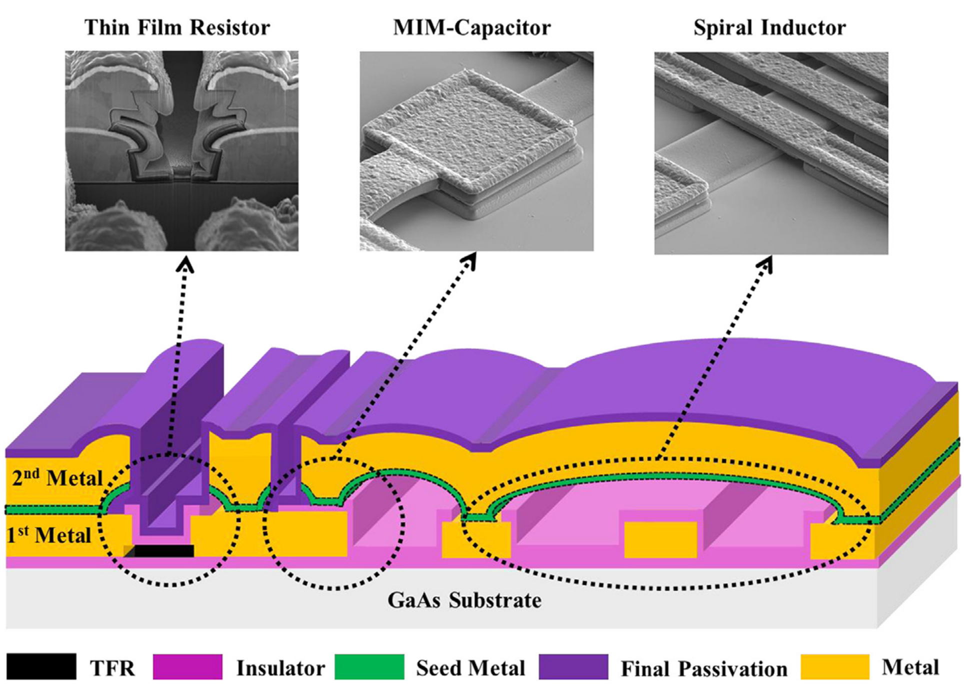

Fig. 1. Cross-sectional view of the IPD process on a GaAs substrate.