Compact Microstrip and CPW Duplexers Using Complementary and Conventional Logarithmic Spiral Resonators

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Introduction

Duplexers are one of the key components in wireless communications systems operating in full-duplex mode. In such systems, the duplexer enables the transmitter and the receiver to share one common antenna but operate on different frequency bands simultaneously. Duplexer designs involve T-junctions and bandstop/bandpass filters which prevent the crosstalk of the two channels. In resent years, electromagnetic bandgap (EBG) structures have received great attention and have been applied to various electromagnetic problems. One particular application is antenna duplexers [1],[2]. However, the stopband property in conventional EBG structures is due to the periodic arrangement of many EBG elements which makes the structure bulky.

Recently, we proposed a super compact metamaterial particle called logarithmic spiral resonators (LSRs) and used them in microwave filter applications [3],[4]. The stopband property in LSRs is due to the resonant behavior of individual elements and not due to the periodicity. Therefore LSR can generate a stopband even with one element. In this paper we study the applications of complementary and conventional LSRs in microstrip and coplanar waveguide (CPW) duplexer designs, respectively. Being the dual counterpart of complementary LSRs (CLSRs), the conventional LSRs are investigated here for the first time.

Microstrip Duplexer Design

The microstrip duplexer is formed by a microstrip T-junction and two monofilar CLSRs etched underneath the two microstrip arms as shown in Figure 1. In this combination, the microstrip technology provides the dominant excitation condition of time-varying electric field applied along the spiral axis. The two spirals have different resonance frequencies i.e., they reflect the waves falling in their own stopbands. However, we noted additional reflection bands in the transmission spectrum in certain cases. These additional stopbands are due to multiple reflections between the T-junction and the resonators, and reveal themselves when the resonators are not properly placed relative to the T-junction [2]. This phenomenon was studied by removing one of the spirals and placing the other one in different locations. In this study, we used Zeland IE3D v.11.2. The substrate has a dielectric constant of 4.4 and a thickness of 0.78 mm; the microstrip lines have equal widths of 1.5 mm. The spiral on arm #2 has the following parameters: $A = 0.1$, $n = 0.8$, $\phi = 6\pi$ rad, and a track width of 0.4 mm (see [3] for spiral design and parameter definitions). The resonance frequency of this spiral is 2.18 GHz. The spiral on arm #3 is a scaled ver-

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sion of spiral #2 where the scale factor is ×1.1. Therefore, the resonance frequency of spiral #3 is expected to be 1.98 GHz (= 2.18 GHz/1.1).

For certain values of a, which determines a certain phase delay, and after multiple reflections from spiral #2 at close proximity of its resonance frequency, the total amplitude of the waves going to port #3 likely to cancel the amplitude of the waves directly transmitted from port #1 to #3, and therefore causes a stopband in $|S_{31}|$ (see [2] for details). Figure 2 demonstrates the undesired stopband in $|S_{31}|$ at 2.18 GHz when spiral #3 is removed and spiral #2 is located at $a = 34.5$ mm. The same phenomenon occurs for the other spiral when it is located at $b = 37.5$ mm.

In order to eliminate the unwanted stopbands from the duplexer transmission spectrum, the distances between the center of T-junction and spiral centers are chosen as $a = 9$ mm and $b = 22$ mm. Figure 3 shows the theoretical S-parameters of the resulting microstrip duplexer. The duplexer operates on two bands centered at 1.97 GHz and 2.18 GHz. The isolation between the two channels in each arm is higher than 50 dB while the insertion loss in each channel is 0.38 dB and 1.48 dB, respectively. At resonance frequency, the feature size of each spiral is very small, about $0.09\,\lambda_g$.

CPW Duplexer Design

Coplanar waveguides (CPWs) have several advantages, such as the ease of shunt and series connections, low radiation, and low dispersion [5]. In nonsymmetric CPW circuits, such as T-junctions (shown in Figure 4), air-bridges are used to equate the potentials of the ground planes which then eliminate coupled (odd) slot-line mode causing the CPW to radiate [5]. Here we used three air bridges with the same height of 0.5 mm, width of 2 mm, length of 8 mm and located them 6 mm away from the center of the T-junction. The central strips and slots are 6.6 mm and 0.4 mm in width, respectively, and the substrate is the same as before.

The CPW duplexer is a CPW T-junction with two conventional monofilar LSRs printed underneath the slots on each arm as shown in Figure 4. In the CPW design, the spirals are metal and excited by time-varying *magnetic field* applied along the spiral axis, whereas in the previous microstrip design, the spirals were apertures and excited by the time-varying *electric field* applied along the spiral axis.

The spiral pair on arm #2 has the following parameters: $A = 0.1$, $n = 0.9$, $\phi = 7\pi$ rad with a track width of 0.4 mm. The resonance frequency of these spirals is 2.33 GHz. The dimensions of the spirals on arm #3 are 5% smaller (i.e. the scale factor is ×0.95). Thus, the resonance frequency of these spirals is expected to be 2.45 GHz (= 2.33 GHz/0.95). In order to eliminate the additional stopbands discussed above, the distances between the center of T-junction and spiral centers are chosen as $a = 35$ mm and $b = 34$ mm. Figure 5 shows the simulation results for the CPW duplexer. It operates on two narrow bands centered at 2.33 GHz and 2.46 GHz. The isolation between the two channels in each arm is 29.16 dB and 22.54 dB, respectively, and the insertion loss in each channel is less than 1.35 dB. Although LSRs have narrow bandwidth, the use of a few stages can improve the bandwidth and isolation performance without requiring too much area since the feature size of each spiral is very small, about $0.06\,\lambda_g$ at resonance frequency.

Conclusion

Two duplexer designs for microstrip and CPW technology have been presented using super compact LSRs as bandstop filters. In microstrip duplexer one complementary monofilar LSR with a feature size of $0.09\,\lambda_g$ at resonance frequency has been used on each arm. The isolation levels higher than 50 dB have been predicted between two channels with low insertion losses. In CPW duplexer a pair of conventional monofilar LSRs with an individual feature size of $0.06\,\lambda_g$ at resonance frequency has been used on each arm. The predicted moderate isolation levels can easily be improved by cascading a few stages. The additional stopbands due to multiple reflections have been demonstrated. These undesired stopbands are eliminated by proper placement of the spirals relative to the T-junction.

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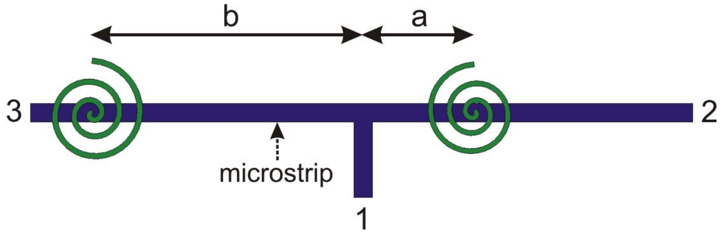

Figure 1: Layout of the microstrip T-junction with monofilar CLSRs etched in the ground plane.

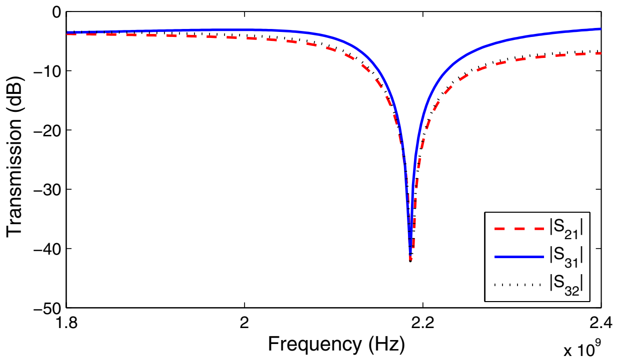

Figure 2: Theoretical transmission characteristics of the microstrip T-junction when the spiral on arm #3 is removed and the spiral on arm #2 is placed at $a = 34.5\,\mathrm{mm}$.

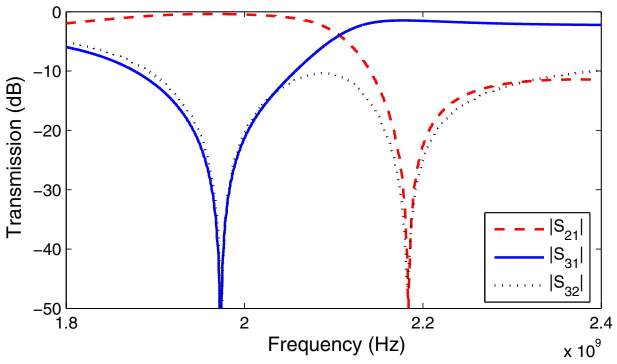

Figure 3: Theoretical transmission characteristics of the microstrip duplexer in Figure 1 where $a = 9\,\mathrm{mm}$ and $b = 22\,\mathrm{mm}$.

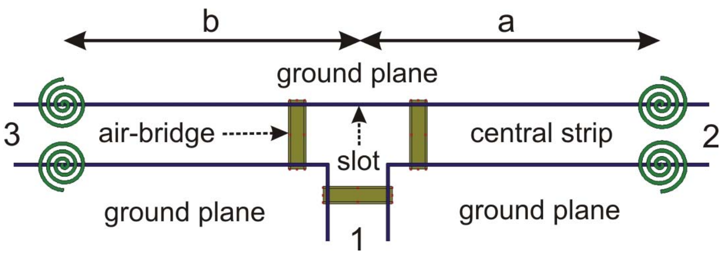

Figure 4: Layout of the CPW T-junction with monofilar LSRs printed in the back substrate side.

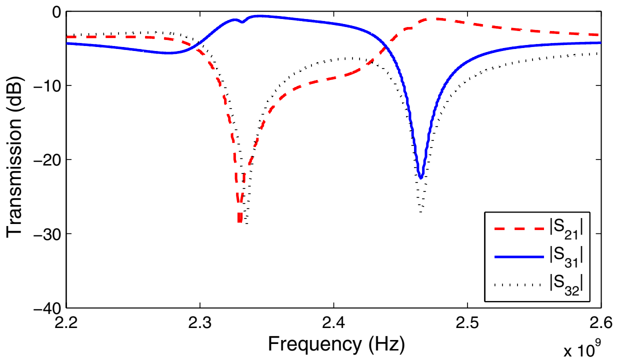

Figure 5: Theoretical transmission characteristics of CPW in Figure 4 where $a = 35\,\mathrm{mm}$ and $b = 34\,\mathrm{mm}$.