Differential transmission lines loaded with split ring resonators (SRRs) and complementary split ring resonators (CSRRs)

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Abstract

In this paper, it is demonstrated that complementary split ring resonators (CSRRs) and split ring resonators (SRRs) can be used to control the propagation in differential transmission lines. Specifically, it is shown that by etching CSRRs in the ground plane of a microstrip differential pair, the common (even) mode can be efficiently suppressed, this being of interest for common mode noise rejection. It is also demonstrated that the differential (odd) mode can be suppressed by merely etching SRRs in the upper substrate side, between the pair of transmission lines. These results are of interest in applications where differential lines are used, for instance, high speed digital circuits.

1. Introduction

Transmission lines loaded with split ring resonators (SRRs) [1] or complementary split ring resonators (CSRRs) [2] can be considered to be one-dimensional metamaterials exhibiting negative effective permeability and permittivity, respectively, in a certain frequency band in the vicinity of resonance. Thus, signal transmission is precluded in that band, whereas these artificial lines are transparent media below and above. The rejection characteristics of these SRR- and CSRR-loaded lines have been applied to the design of stop band filters or band pass filters with improved stop bands [3,4]. In the present paper, SRRs and CSRRs are applied to control the transmission characteristics (even mode and odd mode) in differential transmission lines. Thanks to the symmetric topology of these particles, we can either inhibit the propagation of the even or odd mode in these differential lines. The suppression of the even mode is of particular interest for common mode noise rejection in circuits based on differential lines, such as high speed digital circuits.

2. Selective rejection of the even or the odd mode in differential transmission lines

A differential transmission line in microstrip consists on a pair of identical coupled lines, as depicted in Fig. 1(a). These lines can support two basic modes: the even (or common) mode, which is normally undesired, and the odd (or differential) mode, which is the fundamental mode of these lines. Among the properties of these lines, they exhibit high immunity to electromagnetic interference (EMI), noise and crosstalk, and they are therefore very interesting in applications where these properties are essential, such as high speed digital circuits. Since the common mode is undesired, the presence of such mode in the lines is considered to be a kind of noise, and the suppression of this common mode noise is a subject of interest.

To suppress the common mode, several strategies have been recently pointed out [5-6]. In this paper, the common mode is rejected by etching CSRRs in the ground plane, as shown in Fig. 1(b). The equivalent circuit model of the structure is depicted in Fig. 2(a). As reported in [7], L models the inductance of the line, C accounts for the electric coupling between the lines and the CSRR, and the

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CSRR is modelled by the parallel resonant tank, L_c-C_c. Finally, C_m and L_m model the mutual capacitance and inductance between the coupled lines.

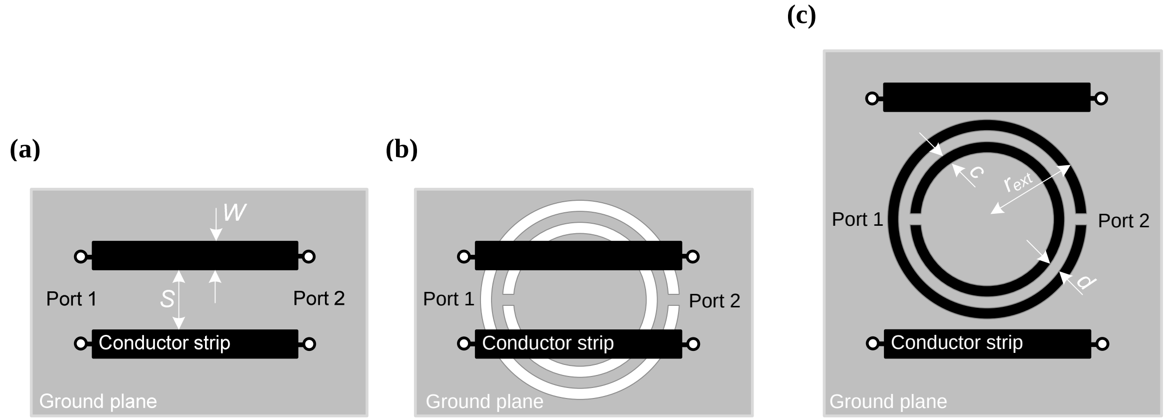

Fig. 1: Typical topology of a microstrip differential line (a), a microstrip differential line with a CSRR etched in the ground plane for common mode rejection (b) and a microstrip differential line with a SRR etched in between both lines for differential mode rejection (c).

The equivalent circuit model of the structure of Fig. 1(b) under common mode excitation is depicted in Fig. 2(b), whereas for the odd mode is depicted in Fig. 2(c). For the odd mode, the resonator is short circuited to ground, and the resulting model is that of a conventional transmission line. For the even mode, we obtain the same circuit as that of a CSRR-loaded line, but with modified parameters. Thus, we do expect similar stop band behaviour for the common-mode.

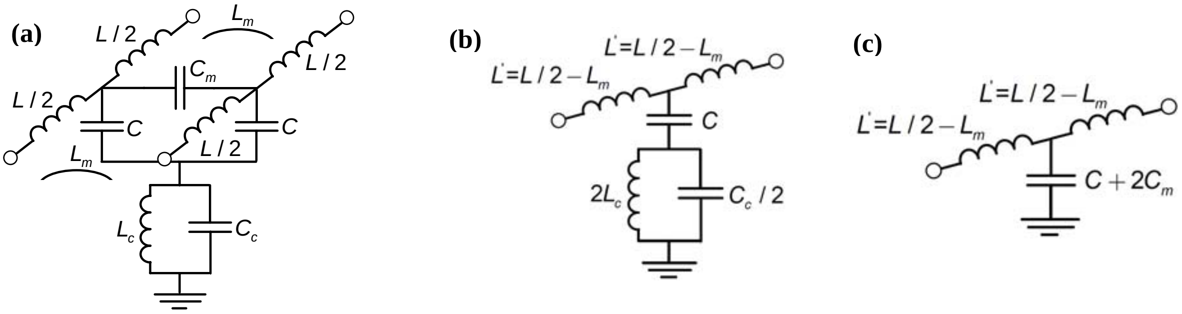

Fig. 2: Circuit model of the differential microstrip line loaded with a CSRR (a), equivalent circuit model for the common mode (b) and equivalent circuit model of the differential mode (c).

Notice that the slits of the CSRR are perfectly aligned with the symmetry plane of the structure. This is necessary to apply the symmetry properties of the structure that lead us to obtain the equivalent circuits of Figs. 2(b) and 2(c), after considering that the symmetry plane is a magnetic or an electric wall, respectively. From the point of view of field distributions, for the common mode, there is a strong density of electric field lines in the same direction below both lines. This causes CSRR excitation and hence a stop band. For the odd mode, the direction of the electric field lines is opposite in both strips of the differential line. If the structure is symmetric, the opposite electric field vectors in both lines exactly cancel and the CSRR is not activated.

In some applications, however, it may be of interest to reject the differential signals, while keeping the common mode unaltered. To this end, the strategy is to etch a SRR between both lines, as depicted in Fig. 2 (c). Similar symmetry arguments lead us to this conclusion, that is, for the common mode, there is not a net magnetic field flow in the SRRs and the structure is transparent to this mode. However, the SRR is excited under odd excitation, and a stop band for this mode appears.

3. Results

The predictions of the previous section are validated through the electromagnetic simulation of a CSRR- and a SRR-loaded differential pair. The simulated structures, as well as the common mode and differential mode insertion loss are depicted in Fig. 3. The results confirm that we can selectively suppress either the common mode or the differential mode, by keeping the other mode unaltered. Obviously, the stopband bandwidth can be enhanced by etching additional resonators to the line.

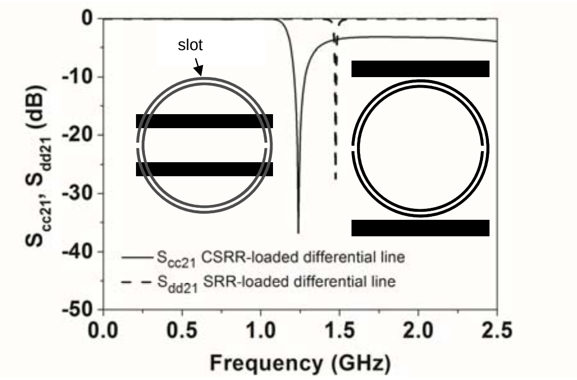

Fig. 3. Simulated common-mode $|S_{cc21}|$ and differential $|S_{dd21}|$ insertion loss for the structures shown in the insets. For the CSRR-loaded differential line, dimensions are c=0.2mm, d=0.2mm, r_{ext}=5mm, W=1mm, S=2.5mm; for the SRR-loaded differential line, dimensions are c=0.2mm, d=0.2mm, r_{ext}=5mm, W=1.143mm, S=10.4mm. The considered substrate has a thickness of h=1.27mm and a dielectric constant of ε_r=10.2.

4. Conclusion

In summary, it has been demonstrated that SRRs and CSRRs can be used to selectively suppress the even or odd mode in differential transmission lines. The results of this work are of interest in many applications involving the use of differential lines, such as high speed digital circuits.

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