Slow-wave Rail Coplanar Strip (R-CPS) Line with Low Impedance Capability

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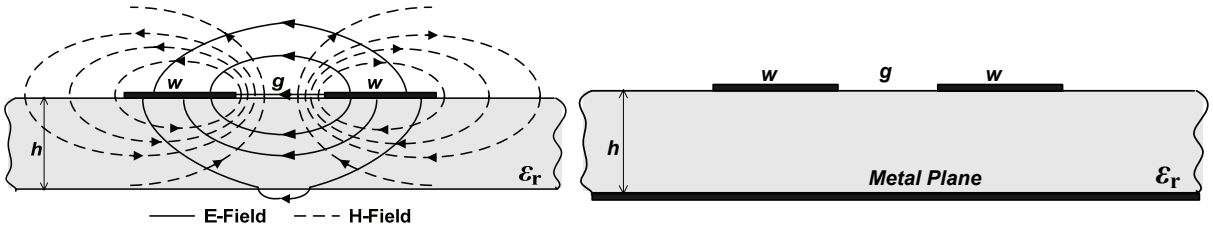
Abstract

The coplanar stripline (CPS) offers the same advantage of uniplanarity as the coplanar waveguide, while exhibiting a differential configuration, which is required in many applications. However, the CPS suffers from the drawback of relatively high impedance, which makes it impractical for several components and even for a simple 50 Ω line when the substrate is very thin. This paper proposes a novel CPS geometry with a "rail" configuration, the rail CPS (R-CPS) line, incorporating periodic strip loads over the back plane, to solve this problem. At the same time, this structure exhibits a slow-wave property, which can dramatically reduce the circuit size. Complex characteristic impedance and phase constant of the R-CPS transmission line are characterized.

1. Introduction

Coplanar transmission lines (CPW and CPS) have their trace and ground conductors printed on the same layer and can therefore easily integrate series and shunt passive and active components. Moreover, in contrast to microstrip lines, they retain the benefit of moderate resistive loss on thin and high-ε substrates (e.g. in MMIC silicon technology [1-2]) since their traces may be kept relatively wide in 50-Ω environment. In particular, the CPS exhibits a differential configuration (Fig. 1a), which is required in many microwave systems, such as balanced amplifiers and integrated antennas. However, the CPS structure tends to suffer of excessively large characteristic impedance due to the relatively weak shunt capacitance between the traces. This fact prevents the design of several components, such as low-pass stepped impedance filters. The problem becomes particularly severe with very thin substrates, where the shunt capacitance may be so small that even a simple 50 Ω transmission line may become unrealizable.

In the case of a CPW, the problem of high impedance with thin substrates is easily solved. First, the equivalent per-unit-length shunt capacitance of a CPW is almost twice that of a CPS, since the center conductor of a CPW is parallel-coupled to two ground conductors at its two edges, which almost doubles the capacitance. Second, in most circuit designs, a conductor-backed CPWs (CBCPW) are used, leading to strongly increased shunt capacitance allowing arbitrarily low impedance values, while the possible excitation of parasitic parallel-plate modes are prevented (?????) by the existence of groundings. In a CPS, a back conductor may also be introduced, as shown in Fig. 1b. However, no direct mechanism for suppression of the parasitic common mode is available due to the inexistence of a physical ground on the trace level, and any accidental (fabrication tolerance) dissymmetry, even small, may alter the response [3].



(a) (b)

Fig. 1. (a) Field distribution in the CPS. (b) Conductor-backed CPS.

In this paper, we propose an R-CPS as a solution to this problem. An array of periodic transverse strips is printed at the back of the substrate beneath the two CPS lines, so as to form a kind of "railroad" structure. These strips increase the per-unit-length capacitance of the line, thereby increasing the shunt capacitance and decreasing the characteristic impedance of the structure. The width of the strips is made wide enough for minimal resistance loss, while their length is made short enough to avoid resonance. Since the strips are galvanically isolated (not forming a connective conductor), the common mode is completely prevented from propagating. At the same time, the proposed R-CPS line is a slow-wave structure due to the reactive loading of the strips, and the circuit size can therefore be reduced.

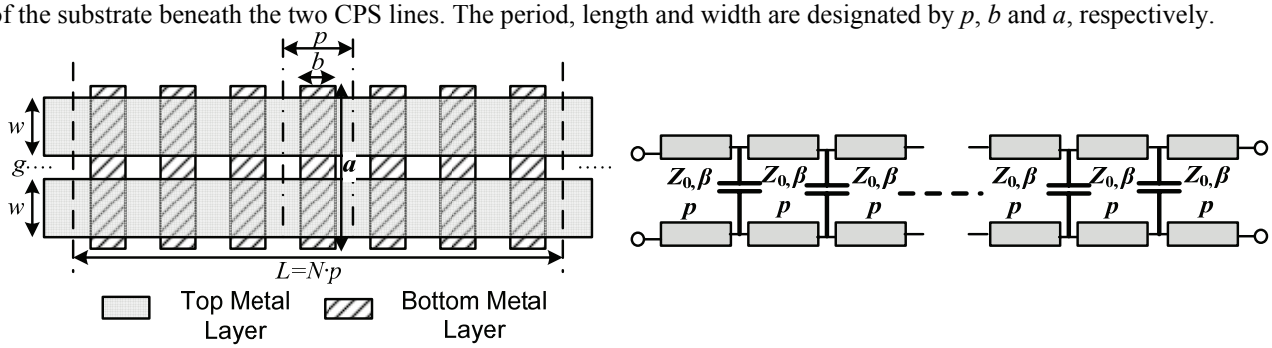
2. Description of the R-CPS Transmission Line

In the absence of any loading, the characteristic impedance of a uniform CPS (with infinite substrate) reads [4]

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_r}} \frac{K(k)}{K'(k)}, \tag{1}$$

where $k=g/(g+2w)$. From this expression, it appears that the impedance decreases as the gap with g is decreased, and decreases as the dielectric constant increases. However, the gap cannot be unlimitedly reduced in practice for a given ε_r, and this sometimes makes 50Ω impedance design very difficult or impossible. This is particularly problematic with practical finite and small height substrates.

Fig.2(a) shows the proposed R-CPS line structure. It consists of transverse strips periodically printed at the back of the substrate beneath the two CPS lines. The period, length and width are designated by p, b and a, respectively.



(a) (b)

Fig. 2. (a) Structure of the R-CPS line. (b) Approximate equivalent circuit model.

3. Modeling and Parameter Extraction

The approximate circuit model of the R-CPS line of Fig.2(a) is shown in Fig.2(b). Once the shunt capacitance value is known, the transmission parameters of the line can be computed using the periodic conditions of Floquet theorem. This circuit model provides an intuitive understanding of the fundamental property the structure, namely the increased shunt capacitance providing decreased characteristic impedance. However, it is too simplistic to model the exact operation of the R-CPS line structure, where the strips are typically coupled to each other. In practice, one can simply compute the overall transmission parameters of the periodic structure from the full-wave simulated or measured ABCD matrix of one unit cell. In this paper, these parameters are extracted by identifying the periodically loaded line with an effective transmission line exhibiting complex characteristic impedance and propagation constant (Fig.3). The ports of the periodic structure are first calibrated to calculate the ABCD matrices. For a section of transmission line ($L=N\cdot p$) with complex characteristic impedance Z_0 [$Z_0=Re(Z_0)+Im(Z_0)$] and propagation constant γ ($\gamma=\beta+j\alpha$), the ABCD matrix of the two port network is expressed as:

$$\begin{bmatrix} A_L & B_L \\ C_L & D_L \end{bmatrix} = \begin{bmatrix} \cosh\beta L & jZ_0 \sinh\beta L \\ j\sinh\beta L / Z_0 & \cosh\beta L \end{bmatrix} \tag{2}$$

The characteristic (Bloch) impedance is then obtained from the available ABCD matrix as:

$$Z_0 = \sqrt{\frac{B_L}{C_L}} \tag{3}$$

$$\cosh(\gamma L) = \frac{A_L + D_L}{2} \tag{4}$$

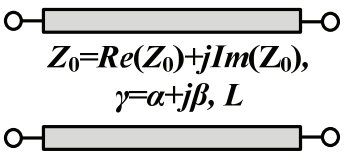
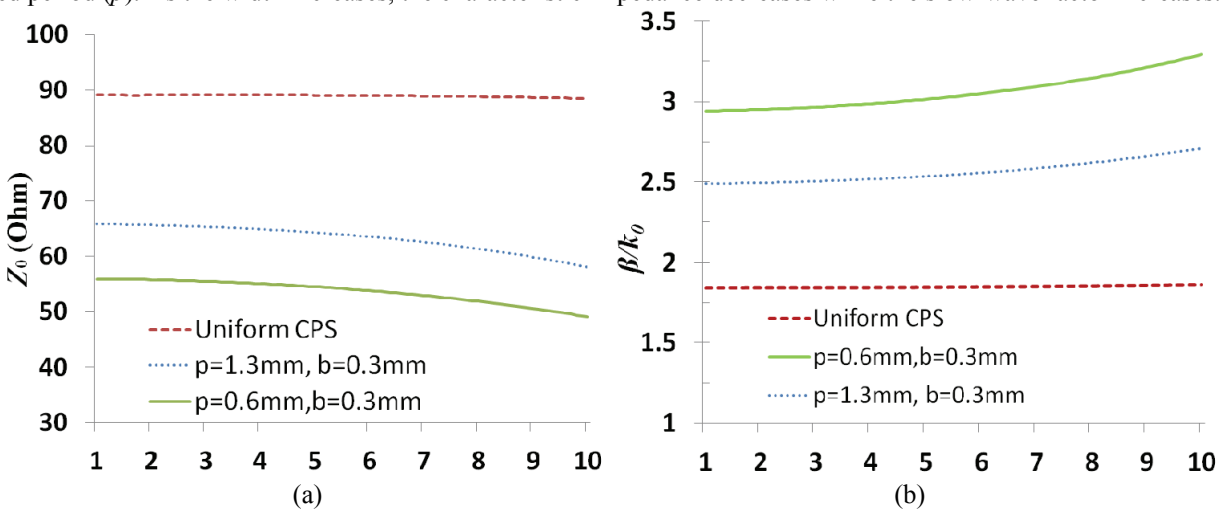


Fig. 3. Equivalent effective transmission line.

4. Results and Discussion

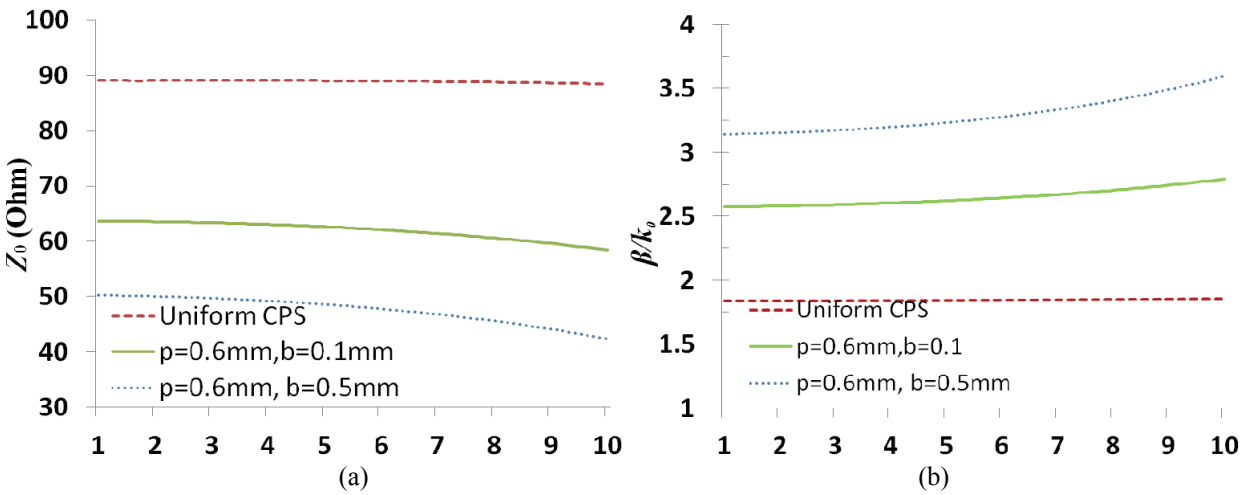
The R-CPS line transmission parameters are now investigated based on the method presented above. Fig.4(a) shows the characteristic impedance of uniform CPS line and R-CPS line for different values of period p from 1.3 mm to 0.6 mm with a fixed width b of the strip. The substrate used for simulation has a dielectric constant of ε_r=10.2 and a height of h=20 mil. The width of the CPS strips is w=38 mil and the gap between the strips is g=6 mil, which is around the minimum tolerance of typical PCB fabrication processes. For the uniform CPS without any loading, the characteristic impedance is 88 Ω. With the periodic loading strips of the R-CPS, the characteristic impedance is decreased significantly and may reach an arbitrarily low value. Fig.4(b) shows the normalized propagation constant of the R-CPS line compared with that of the uniform CPS. The curves show that the R-CPS line is a slow-wave structure, meaning that the size of the circuits can be reduced. Due to its periodic nature, it has stop-bands [5] and may thereby suppress spurious harmonics. As the distance between the strips (p) is reduced, the characteristic impedance reduces, while the slow-wave factor increases.

Fig.5(a)-(b) show the same transmission line parameters for different values of width (b) of the strips with a fixed period (p). As the width increases, the characteristic impedance decreases while the slow-wave factor increases.



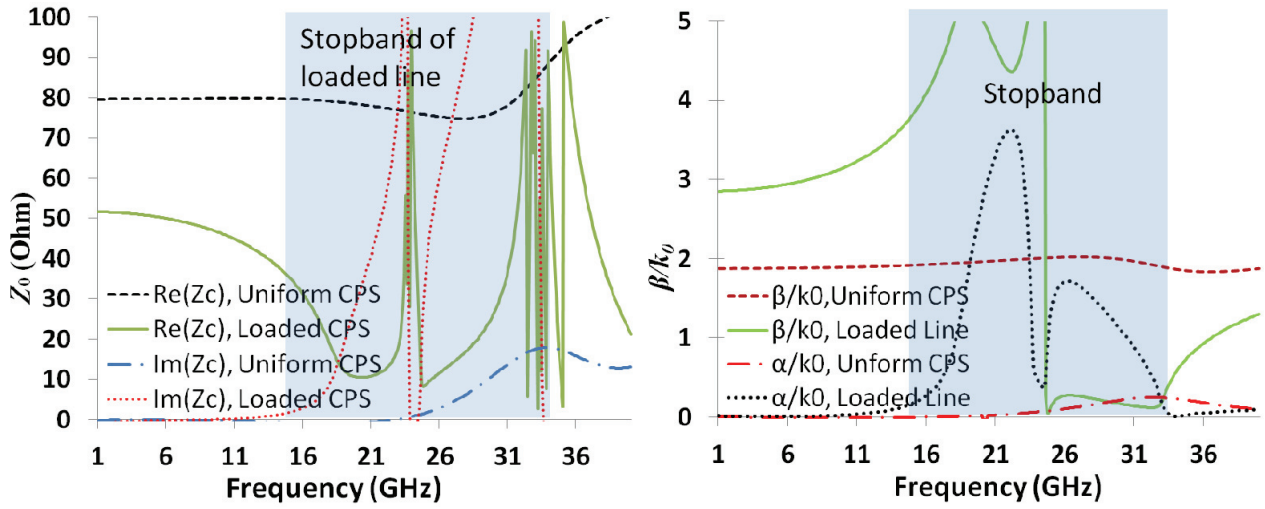
(a) (b)

Fig.4. R-CPS transmission line parameters for different values of the period (p) of the strips.
(a) Characterisitc impedance. (b) Propagation constant.



(a) (b)

Fig.5. R-CPS transmission line parameters for different values of the width (b) of the strips.
(a) Characterisitc impedance. (b) Propagation constant.



(a) (b)

Fig.6. Wide frequency band comparison of the uniform CPS and R-CPS (p=0.6mm, b=0.3mm) transmission lines. (a) Characteristic impedance. (b) Dispersion relation.

To investigate the characteristics of the R-CPS line over a wide frequency band, Fig.6(a) shows its real and imaginary parts of the characteritic impedance compared with those of the uniform unloaded CPS, while Fig.6(b) shows the complex propagation constants. At low frequencies, the impedance (Z_c) and propagation constant (β) of the R-CPS line are purely real since the periodic structure is in its pass-band. This is the frequency band of operation of R-CPS line. As frequency increases, Re(Z_c) decreases while β increases. Then these parameters become imaginary (Im(Z_c) and α), which indicates the appearance of a stopband. In some applications, the stopband may help to remove the parasitic harmonic response.

5. Conclusion

This paper has proposed an R-CPS transmission line, which incorporates periodic loading strips at the back of the substrate to overcome the shortcoming of excessively high impedance of the conventional uniform CPS structure. The R-CPS structure retains the uniplanar and differential benefits of the CPS structure, while allowing arbitrarily low characteristic impedance, controllable by choosing strip parameters, and thereby extending the range of applications of CPS technology. Moreover, due to its slow-wave nature, the R-CPS circuits are more compact and may suppress parasitic harmonics. Though backed with metallization, the R-CPS does not support a common mode since these metallization trips do not form a connective area. Due to its unique characteristics, the proposed R-CPS may find applications in various circuits and components.

6. Acknowledgments

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7. References

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