Balanced Composite Right/Left-Handed Metamaterial CPW Transmission Line with Improved Bandwidth

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Abstract

We present a balanced metamaterial-inspired coplanar waveguide transmission line with enhanced bandwidth. The coplanar waveguide line is composed of a basic cell with two split-ring resonators, two series capacitances (interdigital capacitors), two wide shunt inductances (metallic strips), and four shunt capacitances (implemented through open-ended stubs). The configuration exhibits a wide bandpass response as a result of a balance between advance and delay phase characteristics. The interpretation is based on an equivalent circuit model, full-wave electromagnetic analysis, and measured responses of a prototype designed for microwave (C-band) frequency operation.

1. Introduction

In the last years the interest in the so-called metamaterials has noticeably increase because of their unusual properties, and a great deal of research activity has been done. In all cases, the underlying idea for improvement is the achievement of both negative permittivity and permeability in a given frequency range by an appropriate engineering of the dispersion characteristics [1]-[4]. Based on this concept, the authors present a balanced composite right/left-handed (CRLH) transmission line made with a coplanar waveguide (CPW) line and split ring resonators (SRRs). Besides, distributed loading elements are employed in order to provide an improved control of the transmission line response. In particular, the cell consists of a CPW line loaded with two SRRs, two series capacitances (interdigital capacitors), two shunt inductances (metallic strips), and four shunt capacitances (open-ended stubs), see Fig. 1. These components are electrically small compared to the propagating wavelength and are located on the resonators symmetry axis. Bond wires were added in order to avoid the excitation of high-order propagating modes.

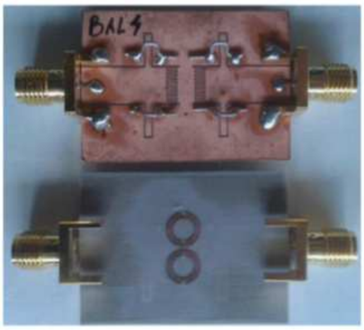

Fig. 1: Fabricated prototype of the Balanced CPW line.

2. Equivalent circuit model

The equivalent circuit of the cell is used in order to understand the operation of the circuit, as shown in Fig. 2. Due to the symmetry conditions, a magnetic wall has been placed along the center of the transmission line. Thus, Fig. 2 actually depicts half of a unit cell.

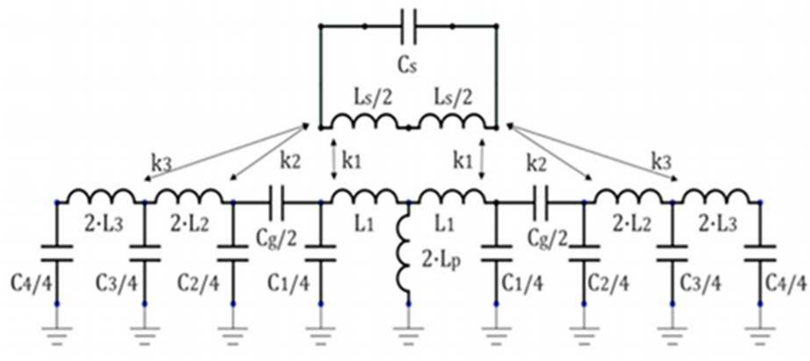

Fig. 2: Equivalent circuit of the proposed balanced cell.

A simple LC circuit is used to model the different portions of the CPW transmission line. Thus, the equivalent components L_1, C_1 are the per-section inductance and capacitance of the portion lines placed between both interdigital capacitors, L_2, C_2 between interdigital capacitors and the stubs, and L_3, C_4 are the per-section inductance and capacitance at the input/output access ports.
The series inductances and the shunt capacitances mentioned above are defined from the geometry of the CPW transmission line. The open-ended stubs are modeled by the shunted capacitance C_3, whereas the series element C_g models the interdigital capacitor. L_p models the interconnection to the lateral ground planes by means of wide shunt strips. Equally, the resonant circuit $L_s - C_s$ represents the SRR. Finally, the coupling coefficients k_1, k_2 and k_3 account for the interaction between the resonators and the host transmission line. k_1 is determined from the mutual inductance, according to the fractional theory, described in [1], k_2 and $k_3$were adjusted using a curve-fitting procedure. The equivalent components and coupling coefficient values are defined in Table I.

TABLE I
Equivalent circuit element values for the proposed balanced cell

TABLE I					
C_s (pF)	**L_s (nH)**	**C_g (pF)**	**L_p (nH)**	**L_1 (nH)**	**L_2 (nH)**
0.53	1.25	0.66	5	0.46	0.96
L_3 (nH)	**C_1 (pF)**	**C_2 (pF)**	**C_3 (pF)**	**C_4 (pF)**	
0.13	0.56	0.43	2.1	0.12	
k_1	**k_2**	**k_3**			
0.55	0.14	0.05			

ISBN 978-952-67611-2-1

3. Results

The configuration exhibits a wide bandpass response as a result of this balance between advance and delay phase offsets, as shown in Fig. 3. Specifically, a fractional bandwidth (FBW) of around 33% can be achieved with an acceptable tradeoff between the insertions loss and selectivity. The interpretation is based on an equivalent circuit model, full-wave electromagnetic analysis, and measured responses of a prototype designed for microwave (C-band) frequency operation. Due to the small dimensions of the resonators employed, the resulting line is very compact. Potential use of these transmission lines can be foreseen in many applications concerning planar microwave devices with severe size restrictions and wide frequency bandpass responses.

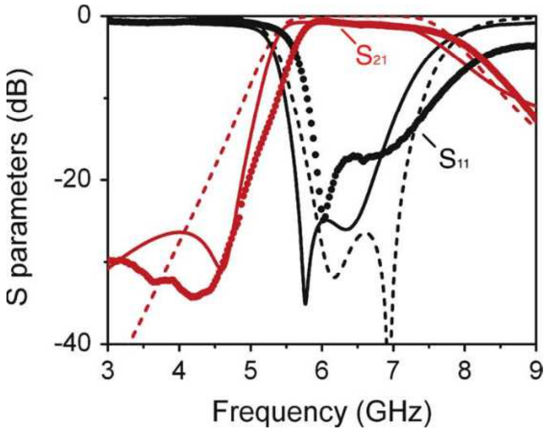

Fig 3. Simulated (solid line), equivalent circuit (dashed line), and measured (solid symbol) reflection S11 (black) and transmission S21 (light) coefficients for the proposed line

4. Conclusions

This paper presents a balanced coplanar waveguide transmission line loaded with split-ring resonators, series interdigital capacitors, wide shunt metallic strips, and shunt open-ended stubs. The configuration exhibits a wide bandpass response because left and righted modes of propagation are obtained at the same frequency. Therefore is demonstrated a technique for achieving a considerable increase in the bandwidth of these highly dispersive transmission lines. Specifically, an FBW of around 33% can be achieved with an acceptable tradeoff between the insertions loss and selectivity. Finally, a confirmation of the balanced behavior has been obtained by studying the dispersion characteristics of the basic unit cell. Potential use of these transmission lines can be foreseen in many applications concerning planar microwave devices with severe size restrictions and wide frequency bandpass responses.

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