Composite Right/Left-Handed Transmission Line With Wire Bonded Interdigital Capacitor

Francisco P. Casares-Miranda, *Student Member, IEEE*, Enrique Márquez-Segura, *Senior Member, IEEE*, Pablo Otero, *Member, IEEE*, and Carlos Camacho-Peñalosa, *Member, IEEE*

***Abstract*—An enhanced composite right/left-handed (CRLH) transmission line (TL) is presented in this letter. This TL, designed in microstrip technology, is implemented by means of a new improved interdigital capacitor (IDC), the so-called wire bonded IDC (WBIDC). The use of the WBIDC broadens the frequency band where the CRLH TL can be considered as a TL. A conventional 70-Ω CRLH TL (using IDCs) has been compared, by full-wave simulation and measurements, with its enhanced counterpart (using WBIDCs). In addition, this enhanced CRLH TL has been used to design a CRLH diplexer which presents several advantages over standard CRLH coupled lines (using IDCs). The diplexer response has been verified by means of a full-wave electromagnetic solver.**

***Index Terms*—Composite right/left-handed (CRLH) metamaterials, microwave passive circuits, wire bonded interdigital capacitor (WBIDC).**

I. Introduction

In recent years, the interest in artificial materials has reappeared among the scientific community, in particular materials showing simultaneously negative permittivity and permeability [1], [2]. Some results have been achieved in the synthesis of materials that show those properties in one or two propagation directions [3], [4]. It is now possible to design devices with equivalent circuits that are dual to an infinitesimal length of transmission line (TL). The phase velocity in such devices points opposite to the Poynting vector, which means that the device performs as a transmission line using double-negative metamaterials. In microstrip technology, the interdigital capacitor (IDC) and short-circuited parallel stub are the most used circuits when a composite right/left-handed (CRLH) TL is designed [3]. Fig. 1(a) shows a novel microstrip unit cell where the IDC has been replaced by the recently proposed wire bonded IDC (WBIDC) [5], [6]. Fig. 1(b) shows its equivalent circuit [7]. When several unit cells are cascaded, the resulting enhanced CRLH TL has a broader frequency range than its conventional counterpart. This enhancement is due to the elimination of the resonances appearing in the IDCs [8].

II. IDC/WBIDC Based CRLH TL

Although the IDC can be easily built in microstrip technology, it has a major drawback. In order to obtain high capacitance values, many long, thin fingers are needed, along with thin slots between them. Therefore, the IDC is a multiconductor structure and the resonances of the different modes appearing in the structure arise when more than three fingers are used. When the IDC is used in a CRLH TL, those resonances occur and prevent the line from propagating any signal at these frequencies. The so-called WBIDC overcomes this drawback by interconnecting the ends of the fingers on the same side of the IDC. This is done by means of bonding wires, which prevent all the modes of the multiconductor structure from appearing, with the exception of the fundamental one. In consequence, the operational frequency range of the CRLH TL is significantly increased as will be shown in this letter.

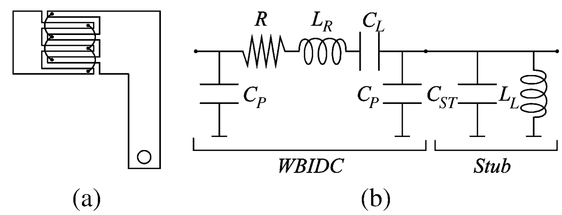

Fig. 1. (a) Microstrip WBIDC/stub CRLH unit cell. (b) Equivalent circuit of the WBIDC/stub CRLH unit cell [7].

Fig. 2(a.1) and (b.1) show two different CRLH TLs (IDC and WBIDC based, respectively) that have been fabricated to demonstrate the above mentioned improvement. Both CRLH TLs have a characteristic impedance of 70 Ω and consist of seven cells as the one shown in Fig. 1(a), printed on Rogers Ultralam 2000 substrate with $\varepsilon_r = 2.4$ and $h = 1.52$ mm. Fig. 2(a.2) and (b.2) show the magnitude of simulated S parameters of the prototypes. In the same way, Fig. 2(a.3) and (b.3) show the measured S parameters. Good agreement can be observed between simulation and measurement results. Fig. 2(a.4) and (b.4) show the normalized attenuation and phase constants [7]. All of Fig. 2(a) (IDC based), show the undesired resonances above 4 GHz. In contrast, Fig. 2(b), based on a WBIDC CRLH TL, show how the new line can be used in a wider frequency band.

The asymmetric configuration of the CRLH TL has been chosen $(C_L - L_L - C_L - L_L - \cdots - C_L - L_L)$, instead of the symmetric one $(2C_L - L_L - C_L - L_L \cdots C_L - L_L - 2C_L)$. Note that the symmetric topology would need capacitors of value $2C_L$ at both ends of the TL, increasing the number and length of the fingers and, therefore, decreasing the resonant frequencies and practical bandwidth.

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The authors are with the Departamento Ingeniería de Comunicaciones, E.T.S. Ingeniería de Telecomunicación, Universidad de Málaga, Málaga 29071, Spain (e-mail: casares@ic.uma.es).

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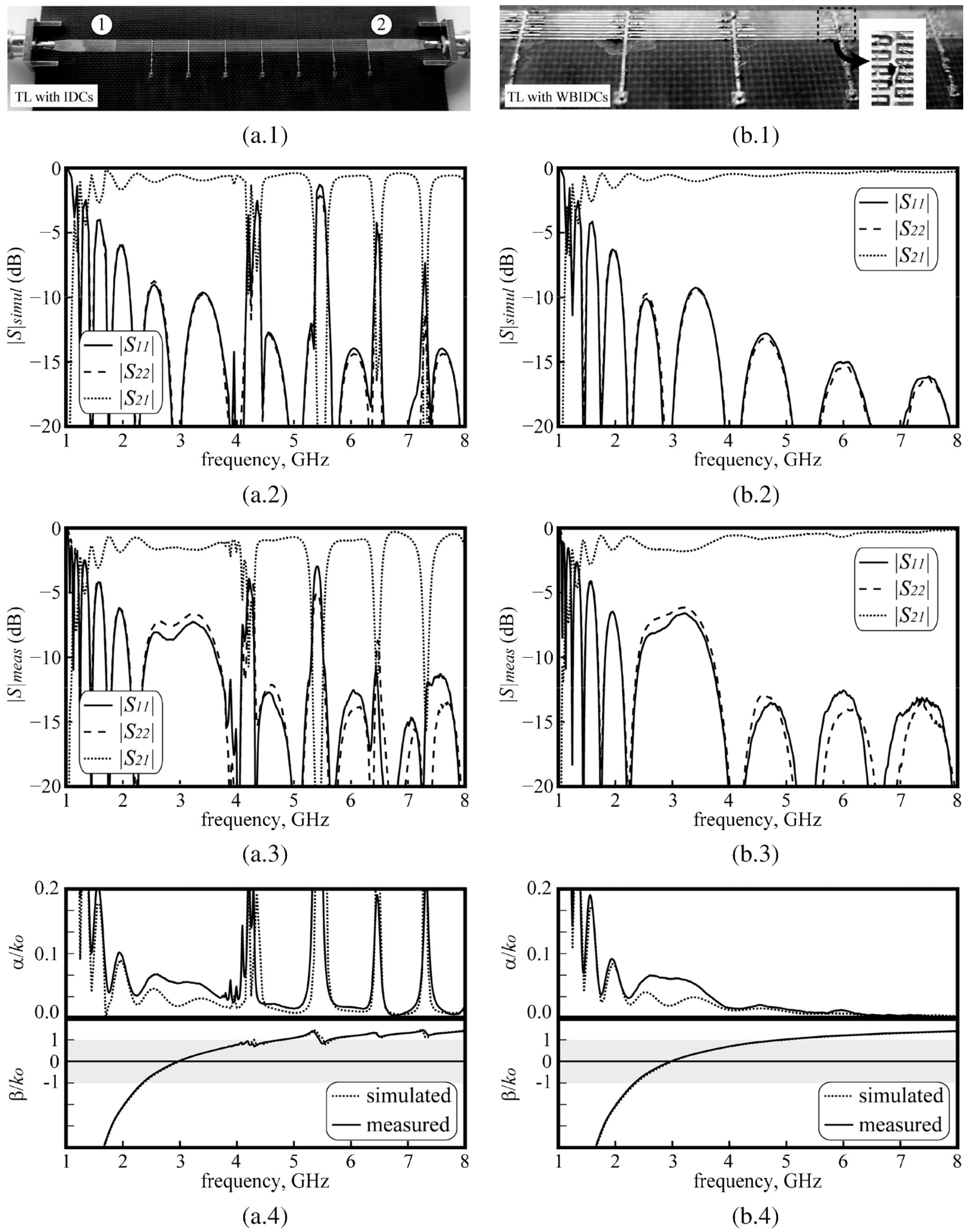

Fig. 2. Comparison of two different CRLH TLs based on IDC and WBIDC circuits, respectively (IDC/WBIDC: ten fingers with length = 7.13 mm, width = 0.15 mm, gap = 0.13 mm; STUB: length = 5 mm, width = 0.2 mm). (a.1) IDC based CRLH TL prototype. (a.2) Simulated (Ansoft Ensemble—MoM) S parameters of the IDC based prototype. (a.3) Measured S parameters of the IDC based prototype. (a.4) Simulated (Ansoft Ensemble—MoM) and measured normalized propagation constant of the IDC based prototype. (b.1)–(b.4) the same, but a WBIDC based prototype.

III. Diplexer Application

Directional couplers have been shown as one of the main applications of the CRLH TL theory. These couplers were first introduced by Prof. Itoh's group [9]. To demonstrate the utility of the proposed technique and the improvement obtained in applications demanding distributed components, two coupled-line diplexers (with the lines of Fig. 2, where the IDC and WBIDC have the same dimensions) have been analyzed. Two CRLH TLs are placed parallel one each other to result in a four port device, as shown in Fig. 3. In both cases the gap between lines is $d = 0.13$ mm. Fig. 4(a) and (b) show the simulated S parameters

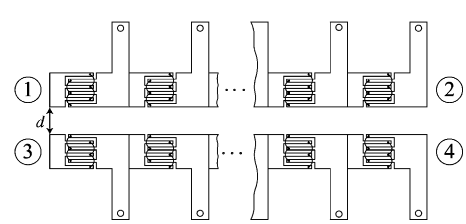

Fig. 3. Novel CRLH coupled lines using the WBIDC CRLH TL.

of both diplexers, with IDCs and with WBIDCs, respectively. Again, the improvement in the frequency response of the

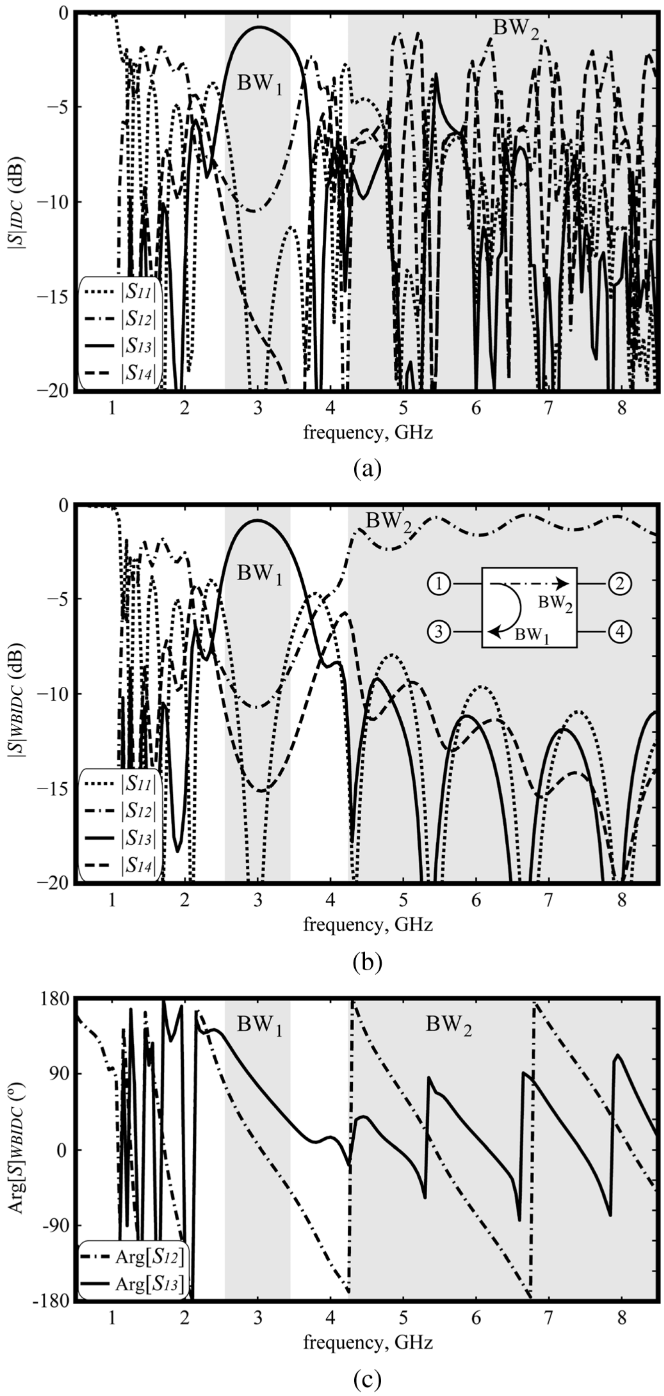

Fig. 4. Simulated (Ansoft Ensemble—MoM) S parameters of a diplexer based on IDC and WBIDC CRLH TLs. (a) Diplexer based on IDCs. (b) Diplexer based on WBIDCs. (c) Phase response of the WBIDC diplexer.

circuit is evident. When the WBIDC replaces the IDC, the frequency band named BW$_2$ in Fig. 4 can be also used. The inset of Fig. 4(b) shows a schematic diagram of a diplexer consisting of two WBIDC coupled lines, which envisages the possibility of using this circuit as, i.e., a diplexer or a combiner. Fig. 4(c) shows the phase response of the WBIDC diplexer of Fig. 4(b).

IV. Conclusion

In this letter, the remarkable improvement in frequency response of the CRLH TL when WBIDCs are used instead of IDCs, has been demonstrated. The undesired resonances of the IDC, due to the multiconductor structure, are removed when the bonding wires of the WBIDC are connected, extending significantly the frequency range of the CRLH TL in the higher frequencies. To further demonstrate future applications of this novel CRLH TL, a coupled-line diplexer using WBIDCs has been designed. This device also extends the frequency range of operation, which suggests new applications of circuits including this novel CRLH TL.

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