Wire Bonded Interdigital Capacitor

Francisco P. Casares-Miranda, Pablo Otero, *Member, IEEE*, E. Márquez-Segura, *Member, IEEE*, and C. Camacho-Peñalosa, *Member, IEEE*

***Abstract*—Interdigital capacitors (IDCs) are convenient capacitance devices in microstrip circuits, even if only low capacitance values can be achieved. Nevertheless, undesired resonances degrade their performance when frequency increases. Short circuits across the end of alternate fingers of the IDC improve its high frequency response by eliminating that drawback. Simulated and measured results are presented.**

***Index Terms*—Interdigital capacitor (IDC), microwave passive circuits, wire bonded interdigital capacitor (WBIDC), wire bonding.**

I. Introduction

RECENT advances in metamaterial transmission lines and microwave devices have renewed the need and interest in the availability of broadband planar capacitors of high nominal capacitance [1], [2]. Fig. 1(a) shows a microstrip interdigital capacitor (IDC), which is a widely used component to build a few picofarads capacitance in microstrip technology [3], [4]. The equivalent circuit usually employed to model this component is shown in Fig. 1(b). This circuit adequately models the IDC at low frequencies and predicts the series resonance at f_s, as shown in Fig. 1(c). When analyzed with a full-wave EM solver, however, additional resonances at frequencies f_i can be observed as well. If the series capacitance C_0 is small enough, then f_1 approaches f_s. Otherwise, when a larger value of C_0 is needed, the number, or the length, or both, of the fingers of the IDC have to be increased. The length of the fingers can not grow indefinitely, it has to be shorter than a quarter guided wavelength [5]. On the other hand, the increment in the number of fingers results in lower frequencies of the undesired resonances. Even if there are only a few fingers, some of the resonant frequencies will be lower than the frequency of the series resonance, that is, $f_i < f_s$. In that case, the IDC performance is degraded because its usable frequency band is shortened, as shown in Fig. 1(c).

The IDC is a multiconductor structure, which presents pass- and stop-bands [3], [6]. This work shows how the short circuits across alternate fingers of the IDC improve the high frequency response, because the number of stop-bands is reduced. This improvement is obtained without any diminution in capacitance value. The improvement is demonstrated by numerical analysis and verified with experiments. From now on, the resulting device will be called wire bonded interdigital capacitor (WBIDC).

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The authors are with the Dpto. 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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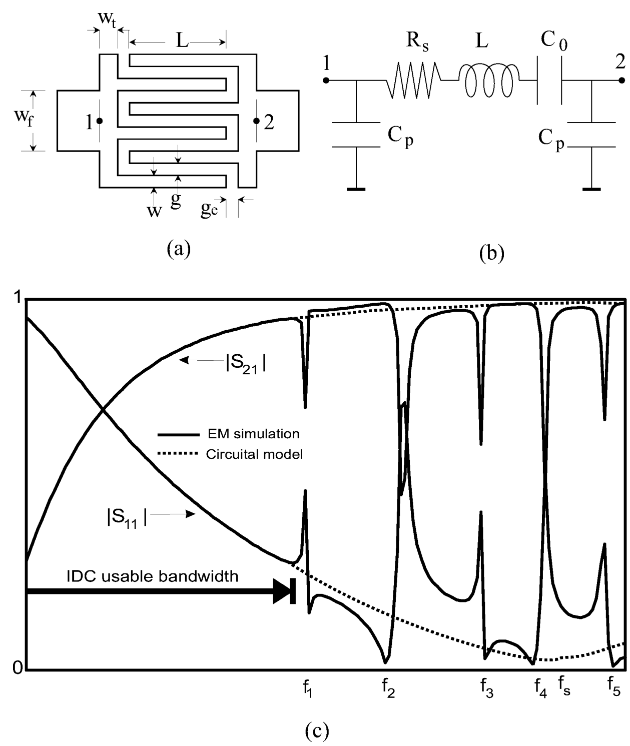

Fig. 1. (a) Microstrip interdigital capacitor (IDC). (b) Equivalent circuital model of the IDC. (c) Typical S parameters of a series IDC.

II. Circuital Models and Frequency Response

Fig. 1(c) shows typical S-parameters of a series IDC. Spurious spikes in $|S_{11}|$ and $|S_{21}|$ can be observed at frequencies f_i, which prevent the IDC to be used beyond the lowest frequency, f_1, where the IDC could still show a capacitive behavior. All IDCs show that problem when designed and built. If the series IDC was considered to be a single series capacitance, the value of that capacitance, C_{eff}, could be obtained from the S_{11} parameter of the series IDC by means of

$$C_{\text{eff}} = \frac{-1}{Z_0 2\pi f \operatorname{Im}\left[\frac{(1+S_{11})}{(1-S_{11})}\right]} \tag{1}$$

where Z_0 is the reference impedance and f is the frequency.

Fig. 2(a) and (b) show circuital models of the IDC presented in Fig. 1(a) and of the proposed WBIDC. Considering that it is a short transmission line, a finger can be represented by a series inductance and a shunt capacitance. For the sake of clarity, shunt capacitances are not shown in Fig. 2. Capacitive coupling is modeled by the capacitances C_{ij}, where i and j are the finger numbers. Inductive coupling can be neglected in a first approximation [7]. Bonding wires short circuit alternate fingers, that is, fingers on the same port of the IDC, leading to the simplified equivalent circuit shown in Fig. 2(b).

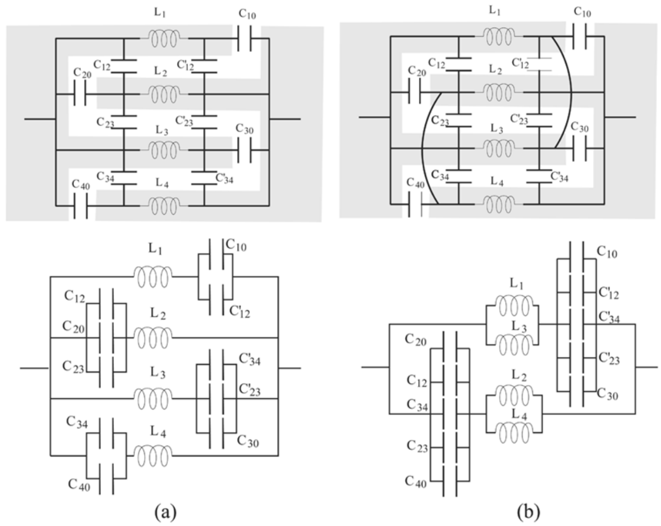

Fig. 2. (a) Circuital model of the IDC. (b) Circuital model of the WBIDC.

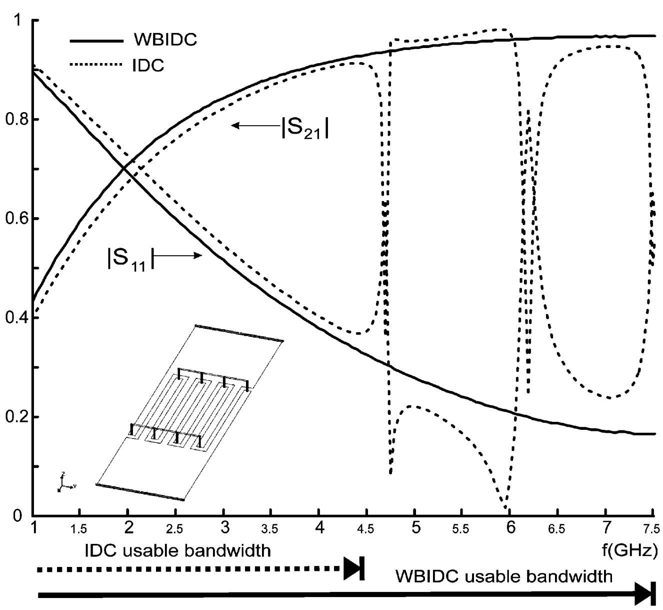

Fig. 3. Simulated S parameters of the IDC and the WBIDC (eight fingers; $W_f = 4.89$ mm; $W_t = 0.1$ mm; $L = 6.2$ mm; $W = 0.41$ mm; $g = 0.23$ mm; $g_e = 0.3$ mm).

Fig. 2(b) shows how the multiconductor structure is modified when the bonding wires are connected, no matter the number of fingers. The structure can be seen as overlapping strips. Therefore, the spurious spikes in the frequency response are eliminated and, with them, the main shortcoming of the IDC. Fig. 2(a) and (b) explain why the capacitance values of the IDC and the WBIDC are very similar (identical in the ideal case) at very low frequencies.

III. Prototype Simulations and Measurements Results

A number of prototypes of IDC and WBIDC have been analyzed and built to demonstrate the technique. Rogers Ultralam substrate ($\varepsilon_r = 2.4$; $h = 1.57$ mm) has been used in prototypes. The WBIDC prototypes were built using a 100-μm gauge wire. The numerical analysis has been carried out with the help of Ansoft Ensemble. As sketched inside Fig. 3, the bonding wires of the WBIDC have been simulated by means of vias from the IDC layer, through an air layer, to a new metal layer where strips connect the vias. Fig. 3 shows the computed S-parameters of the IDC and the WBIDC circuits. The frequency of the series resonance, f_s, is about 7.5 GHz. The undesired resonances below f_s that can be observed in the IDC parameters are not present in the corresponding parameters of the WBIDC.

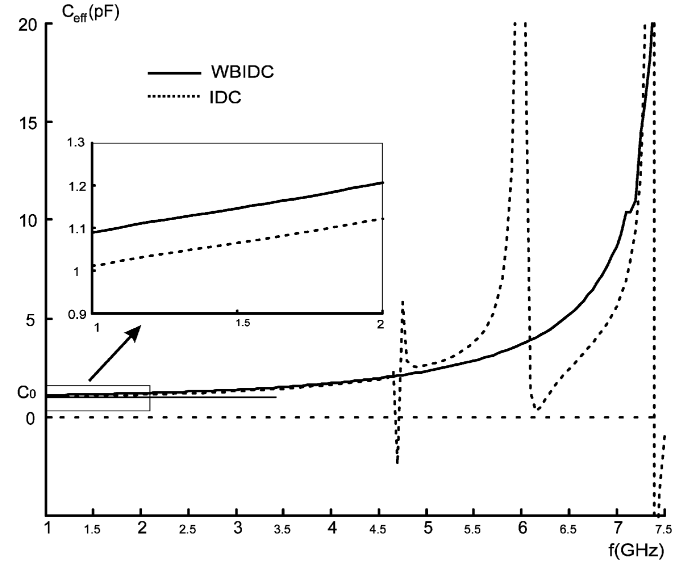

Fig. 4. Simulated value of $C_{\rm eff}$ of the IDC and the WBIDC.

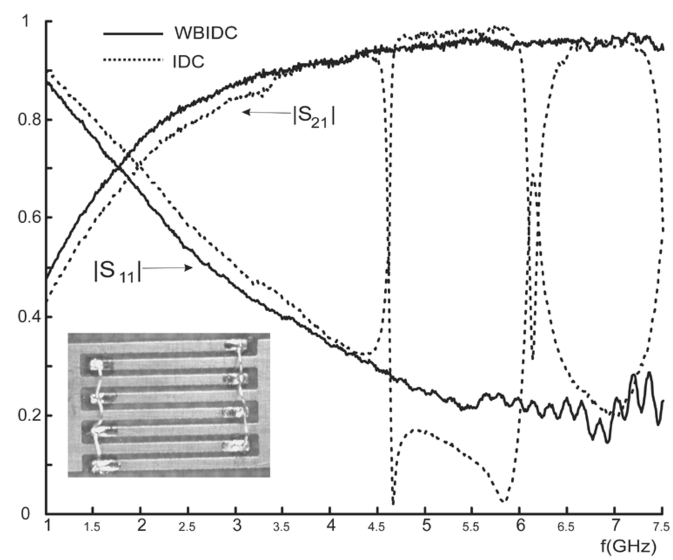

Fig. 5. Measured S parameters of the IDC and the WBIDC.

The values of $C_{\rm eff}$ versus frequency of these IDC and WBIDC, computed with the help of (1), are shown in Fig. 4, where it can be seen that the capacitive response of the WBIDC does not present the spurious spikes of the IDC. It can be seen, as well, that the operating band is extended from 4.5 GHz up to 7.5 GHz. The inner frame in Fig. 4 shows in detail the value of $C_{\rm eff}$ of the IDC and the WBIDC at lower frequencies.

Fig. 5 shows the measured S-parameters of the same circuits of Fig. 3. The very good agreement between Figs. 3 and 5 demonstrates the benefit of using the WBIDC.

IV. Conclusion

In this letter, a method to overcome the main limitation of IDCs has been presented. All IDCs show this problem when designed and built, a problem that is eliminated by the connection of bonding wires across alternate fingers of the IDC. Numerical electromagnetic analysis shows a notable improvement in the frequency response of the IDC. Numerical results have been verified with experimental work.

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