Progress In Electromagnetics Research Letters, Vol. 71, 1–5, 2017

Wideband Interdigital Capacitor with Spurious Spikes Suppression

Bo Zhou*, Qipeng Wang, Yue Lu, and Chong-Hu Cheng

Abstract—A wideband interdigital capacitor (WIDC) is proposed and verified. By short interconnecting the open ends of interval fingers with microstrip lines etched on PCB bottom layer, the spurious spikes that limit the bandwidth of conventional interdigital capacitor (IDC) are eliminated. The bandwidth and capacitance of IDC increase more than 2800% and 100%, respectively.

1. INTRODUCTION

Interdigital capacitor (IDC) is usually used to build lumped filters or couplers because of its large capacitance, high Q-value and easy fabrication [1–5]. The structure of conventional IDC is shown in Fig. 1(a). Normally, higher capacitance is required for the application at lower frequency. Capacitance increment of IDC can be reached if the size or the number of fingers is increased. However, increasing the size of fingers is in conflict with size reduction. And increasing the number of fingers results in unwanted resonances at frequencies f_1, f_2, f_3 and f_4, which limits its working band, shown in Fig. 1(b). Because IDC is a multi-finger structure, it presents the characteristic of multiple passbands and stopbands in its equivalent circuit. All IDCs have this problem when being designed and built. Bond wire was proposed to eliminate the spikes of IDC in [6, 7], but the bond wire is equivalent to an inductor and results in unexpected effect, and wire bonding is not good for mass assembly and production as the consistency of bond wire circuits is not good. Via interconnections which interconnect the interval open ends of interval fingers were proposed in [8].

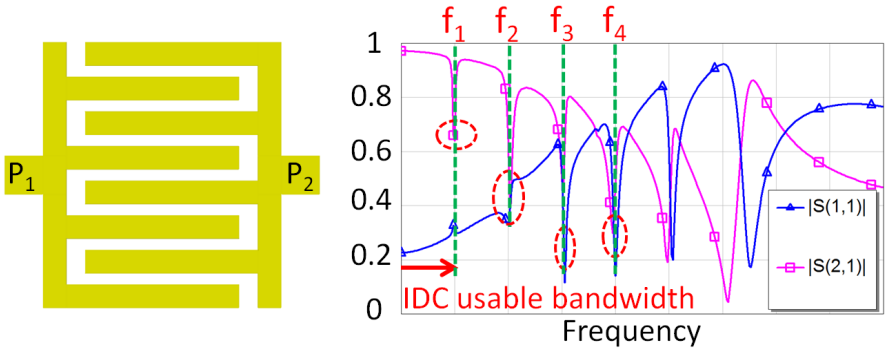

Figure 1. Conventional IDC with 8 fingers, (a) structure and (b) its corresponding S-parameters.

In this paper, a wideband interdigital-capacitor (WIDC) is proposed on a Rogers 4003C substrate. With short interconnecting the open ends of interval fingers using via and microstrip interconnections,

Received 28 August 2017, Accepted 29 September 2017, Scheduled 4 October 2017
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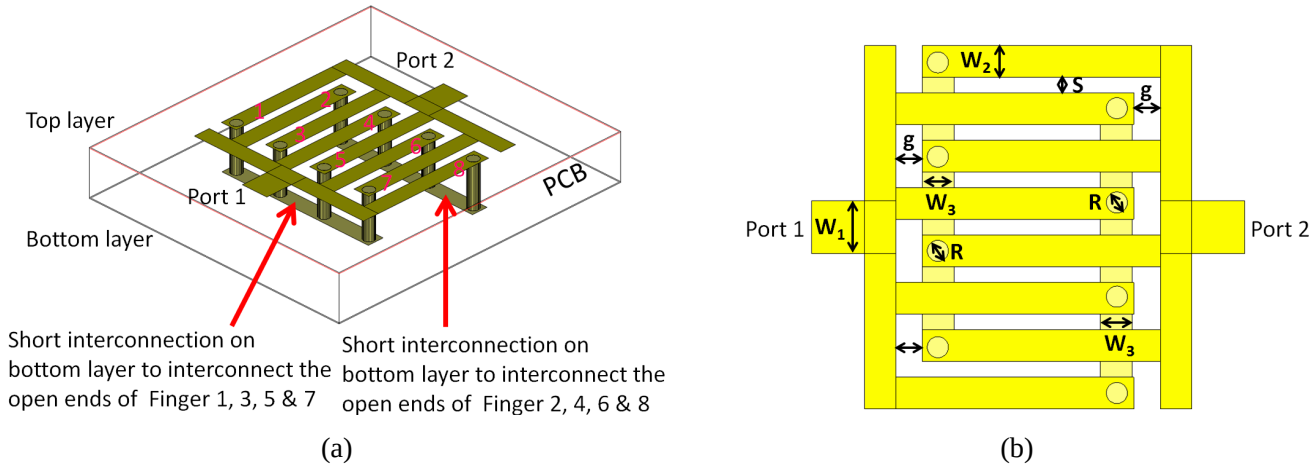

Figure 2. The proposed WIDC, (a) structure and (b) dimension parameter definitions.

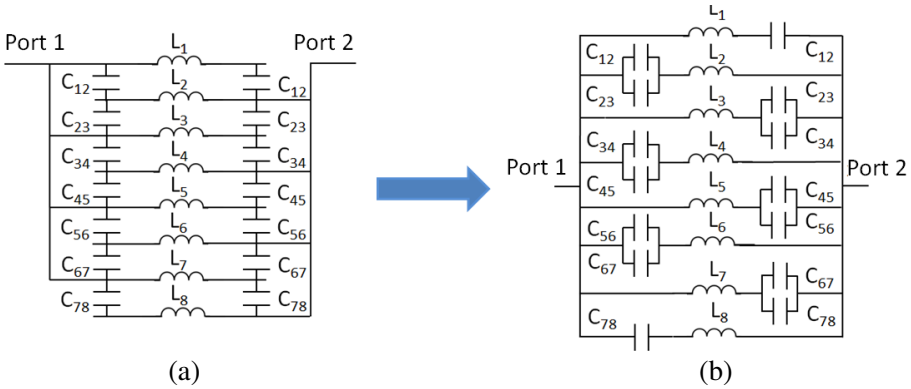

Figure 3. (a) Equivalent circuit and (b) transformational circuit of conventional IDC.

and spurious spikes suppression and capacitance increment are both achieved. The bandwidth and capacitance of IDC are increased more than 2800% and 100%, respectively.

2. CIRCUIT DESIGN

The structure of the proposed WIDC with eight fingers is shown in Fig. 2(a), and the planar view with dimension parameters' definitions are shown in Fig. 2(b). The equivalent circuit conventional IDC is shown in Fig. 3(a), and Fig. 3(b) is its transformation form. As we can see in Fig. 3(b), the scattering capacitors and inductors result in the unwanted resonances at frequencies f_1, f_2, f_3 and f_4. The open ends of interval fingers are interconnected using via transitions and bottom layer etched microstrip lines. Fingers 1, 3, 5 and 7 are short interconnected, and Fingers 2, 4, 6 and 8 are short interconnected as well. In Fig. 4(a), a finger is equivalent to a series inductance, and capacitive coupling between adjacent fingers is marked by the capacitances C_{ij}, where i and j are the finger numbers. Fig. 4(b) shows how the equivalent circuit is changed when the short interconnections are installed. Therefore, the unwanted spikes in the frequency response are removed as the number of stopbands is decreased. Fig. 4 also illustrates capacitance increment with regrouping the equivalent inductances and capacitances.

3. SIMULATION AND MEASURED RESULTS

The proposed IDC is fabricated on an RO4003C substrate with a dielectric constant of 3.38 and thickness of 0.508 mm. Input and output ports of the proposed WIDC are both 50 Ω with a microstrip width of

1.14 mm. The EM-simulation uses AXIEM, which is a full-wave electromagnetic (EM) simulator. The final optimal parameters are: $W_1 = 1.14\,\text{mm}$, $W_2 = 0.7\,\text{mm}$, $W_3 = 0.7\,\text{mm}$, $g = 0.5\,\text{mm}$, $S = 0.2\,\text{mm}$, $L = 6.2\,\text{mm}$ and $R = 0.4\,\text{mm}$, where the parameters are defined in Fig. 2(b). The top and bottom side photographs of the proposed WIDC are shown in Figs. 5(a) and (b), respectively. Fig. 6 shows the simulated S-parameters of WIDC and IDC. The spurious spikes at 3.2, 4.6, 6.6, 7, 8 and 8.8 GHz are

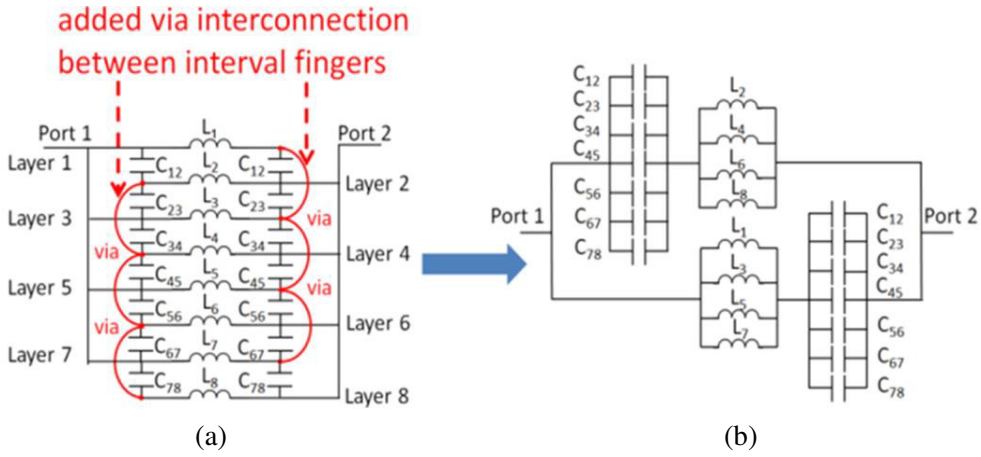

Figure 4. (a) Equivalent circuit and (b) transformational circuit of WIDC.

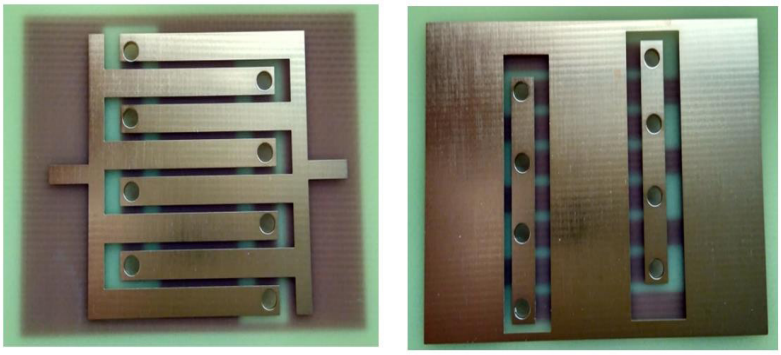

Figure 5. Photograph of the proposed WIDC, (a) top and (b) bottom.

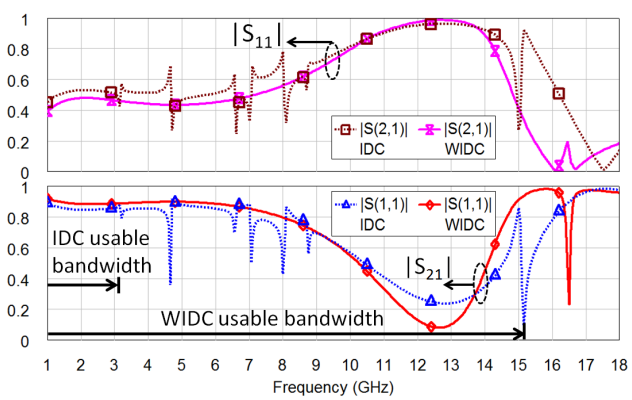

Figure 6. Simulated S-parameters of WIDC and IDC.

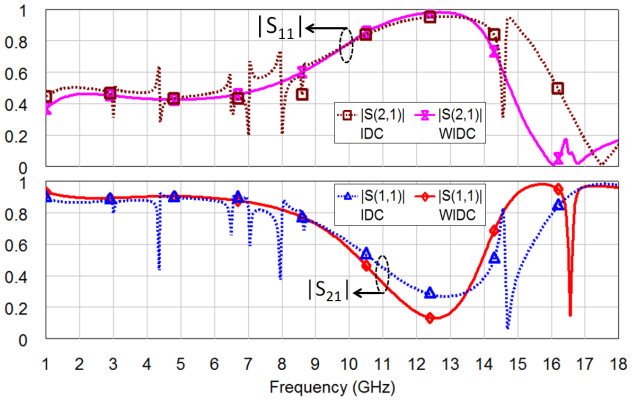

Figure 7. Measured S-parameters of WIDC and IDC.

removed, as the distribution of current is altered when interval fingers are interconnected. It can be seen in Fig. 6 that the operating band is extended from 3.2 GHz to 15.2 GHz, which is more than 2800% bandwidth increment. Fig. 7 shows the measured S-parameters of WIDC and IDC. The measurements agree well with the simulated results. The capacitance of the WIDC and IDC can be obtained from the measured S_{11} parameters by means of

$$C = \frac{-1}{Z_0 2\pi f \mathrm{Im}\left(\frac{1+S_{11}}{1-S_{11}}\right)} \tag{1}$$

where Z_0 is the reference impedance and f the frequency. The inner frame in Fig. 8 shows, in detail, the capacitance of WIDC and IDC extracted from the measured S_{11} parameters of WIDC and IDC. As we can see, the capacitances of WIDC and IDC at 2 GHz are 5.1 pF and 2.5 pF, respectively. The capacitance of WIDC is increased about 100% compared with that of IDC from 1 to 3 GHz.

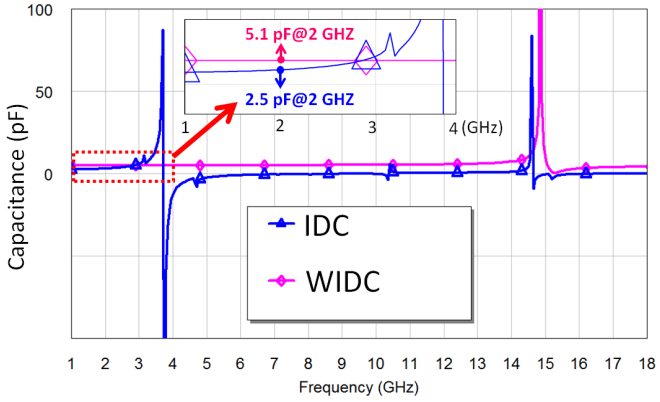

Figure 8. Capacitance extracted from the measured S_{11} parameters using formula [1].

4. CONCLUSION

A wideband IDC is proposed and fabricated on a Rogers 4003C substrate. The open ends of interval fingers are short interconnected with via transitions and PCB bottom etched microstrip interconnections to suppress the spurious spikes. The bandwidth is increased more than 2800%. And more than 100% capacitance increment is also achieved, which is good for building compact lumped components with the proposed WIDC.

ACKNOWLEDGMENT

This work was supported by the National Natural Science Foundation of China (Grant No. 61601239), Natural Science Foundation of Jiangsu Province of China (Grant No. BK20160906), China Postdoctoral Science Foundation (Grant No. 2016M601858), Postdoctoral Science Foundation of Jiangsu Province of China (Grant No. 1601030B).

REFERENCES

1. Cao, K. and C. Cheng, "Stacked plate capacitor design technique for filters constructed on multilayer substrates," *Electron. Lett.*, Vol. 52, No. 20, 1695–1697, 2016.
2. Zhou, B., W. Sheng, and Y. Zheng, "Miniaturized and wideband lumped LTCC branch-line coupler for dozens of megahertz applications," *Microwave and Optical Technology Letters*, Vol. 56, No. 9, 2001–2005, 2014.

3. Brzezina, G., L. Roy, and L. M. Eachern, "Design enhancement of miniature lumped-element LTCC bandpass filters," *IEEE Trans. Microw. Theory Tech.*, Vol. 57, No. 4, 815–823, 2009.
4. Hoft, M. and T. Shimamura, "Design of symmetric trisection filters for compact low-temperature co-fired ceramic realization," *IEEE Trans. Microw. Theory Tech.*, Vol. 58, No. 1, 165–175, 2010.
5. Brzezina, G. and L. Roy, "Miniaturized 180 circ hybrid coupler in LTCC for L-band applications," *IEEE Microwave and Wireless Components Letters*, Vol. 24, No. 5, 336–338, 2014.
6. Casares-Miranda, F. P., P. Otero, E. Marquez-Segura, and C. Camacho-Penalosa, "Wire bonded interdigital capacitor," *IEEE Microwave and Wireless Components Letters*, Vol. 15, No. 10, 700–702, 2005.
7. Page, J. E., E. Marquez-Segura, F. P. Casares-Miranda, J. Esteban, P. Otero, and C. Camacho-Penalosa, "Exact analysis of the wire-bonded multiconductor transmission line," *IEEE Trans. Microw. Theory Tech.*, Vol. 55, No. 8, 1585–1592, 2007.
8. Zhou, B., K. Liu, J. Cheng, and Y. Ji, "Capacitor structure and capacitor using the same U.S. patent application," US 2016/0381797, 2016.