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Multilayer thick-film technology as applied to design of microwave devices

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Abstract

Possibilities of the sandwich multilayer technology to design microwave integrated circuits are discussed. Original designs of various passive microwave devices realized as multilayer sandwich structures are presented. Experimental results confirmed a good potential of the sandwich technology to design high-performance multilayer microwave integrated circuits.

Keywords: Microwave integrated circuits (MICs)

1. Introduction

The low temperature co-fired ceramics (LTCC) technology is generally used to fabricate multilayer microwave integrated circuits (MICs).[1–4] Allocation of passive components within several layers makes it possible to design highly integrated MICs of a small size. The low-cost LTCC technology using the screen-printing technique suits well for a mass production of microwave devices with improved price/performance.

The thick-film sandwich technology was shown to be an alternative to the LTCC one regarding a design of microwave devices as multilayer MICs.[5]

Microwave devices using transmission line sections are of a large size at low microwave frequencies and exhibit a spurious response. At the same time, the both multilayer technologies allow designing very compact and free of spurious response microwave devices based on quasi-lumped components.

The goal of this paper is to demonstrate a good potential of the sandwich technology for the design of multilayer MICs. Miniature quasi-lumped-element bandpass filter, 3 and 10-dB directional couplers, and a balun for wireless applications were designed as multilayer sandwich structures, fabricated and experimentally investigated.

2. The sandwich multilayer technology

Though the sandwich multilayer technology is quite similar to the LTCC one, there are some principal differences between them. The LTCC technology uses the screen-printing technique for metallization patterning over thin dielectric sheets (~100 μm). Patterned sheets are stacked up, laminated and fired under the temperature of about 850 °C. One can say that metallization patterning in the LTCC technology is fabricated "in parallel". In turn, a thick ceramic substrate is used as the core of multilayer structure in the sandwich technology. Conductive and dielectric pastes are, respectively, applied for metallization patterning and fabrication of additional thin dielectric layers on the both sides of the thick ceramic substrate. A typical layer thickness is 15 μm for the conductive layers and 60 μm for the dielectric ones. The layers are deposited "in series" manner with a consecutive co-firing of each layer. The co-firing temperature is approximately the same as for the LTCC structures—up to 900 °C.

The sandwich multilayer technology have the following advantages for MICs realization with respect to the LTCC process: (i) smaller thickness of dielectric layers with respect to LTCC materials allows decreasing the area occupied by parallel-plate capacitors; (ii) parasitic grounded capacitances are sufficiently eliminated due to using of the thick substrate.

The sandwich process is compatible with planar thin-film technology. The ceramic substrate employed in the sandwich

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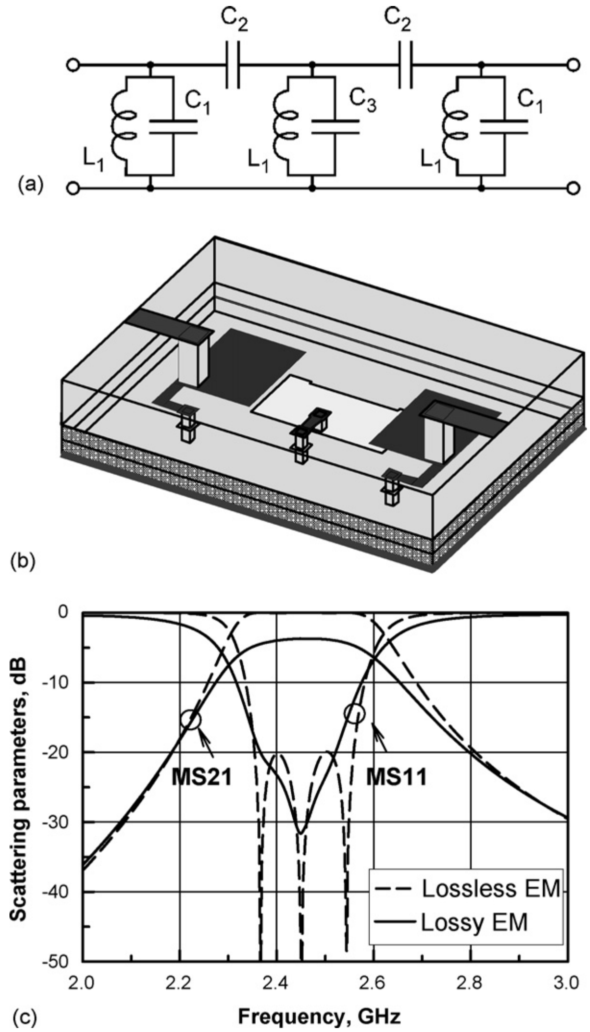

Fig. 1. Equivalent circuit (a), multilayer implementation (b) and characteristics (c) of the three-pole bandpass filter.

structures could play the role of PCB, onto which a front-end module would assembled.

3. Passive microwave devices realized as sandwich multilayer structures

The three-pole Chebyshev bandpass filter for Bluetooth and WLAN applications (2400–2500 MHz) was designed as a sandwich multilayer structure based on quasi-lumped-elements. The equivalent circuit of the filter is shown in Fig. 1a. The filter structure (Fig. 1b) uses two 60-μm thick dielectric layers with the dielectric constant $\varepsilon_r = 10.2$ and the loss tangent $\tan\delta = 0.002$, which are situated underneath the 1-mm thick alumina substrate. Grounded capacitances were realized as parallel-plate capacitors. Serial coupling capacitances were produced by overlaying electrodes of the capacitors situated in different layers. Inductors were designed as transmission line sections of corresponding length. The microstrip feed lines placed on the top surface of the substrate are connected to the filter by via holes. The silver paste with $R_{dc} = 0.02\ \Omega$/square was used for 15-μm thick metallization pattern. The size of the sandwich filter structure is

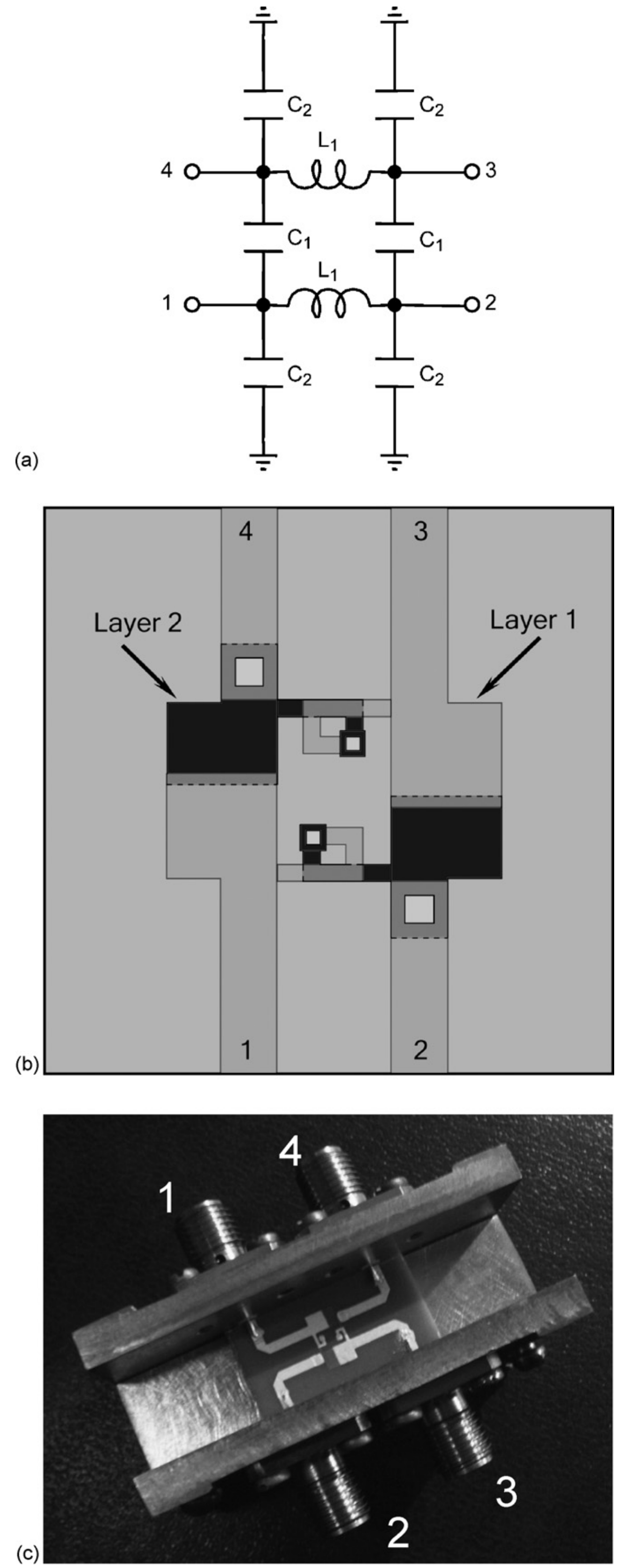

Fig. 2. Equivalent circuit (a), layout (b) and photograph (c) of a directional coupler accomplished by the sandwich multilayer technology.

8.7 mm × 4.5 mm. Characteristics obtained by the electromagnetic simulation of the lossless and lossy filter structures are presented in Fig. 1c. The in-band insertion loss does not exceed 4 dB and the return loss is better than 20 dB.

Two quasi-lumped-element directional couplers with the coupling value of 3 and 10 dB were implemented using the sandwich multilayer technology. The equivalent circuit shown in Fig. 2a was obtained by replacing the quarter-wavelength transmission line sections of a conventional branch-line directional coupler by lumped-element Π-networks. The 50 Ω transmission line sections were replaced by the Π-networks consisting of serial inductance and parallel capacitances, whereas the 35 Ω transmission line sections were replaced by the capacitive Π-networks representing an impedance inverter. Fig. 2b shows the layout of the directional coupler containing parallel-plate capacitors and two-turn stacked inductors, which are situated within two conductive layers on 1-mm thick alumina substrate. The size of the 3 and 10-dB directional couplers is 5.9 mm × 5.2 mm and 7.2 mm × 6.5 mm, correspondingly. The photograph of the 3-dB directional coupler is shown in Fig. 2c. Measured characteristics of the devices are presented in Fig. 3. In general, the experimental data are in a good agreement with the simulation results. For the both directional couplers in the operating frequency band (2400–2500 MHz), the measured return loss and the isolation are better than 20 dB. Measured insertion loss is about 0.5 dB. The amplitude unbalance is better than ±0.5 dB, and the phase error is less than ±1.5°.

The rat-race ring is often used as a matched balun. However, a large size limits its application at low microwave frequencies. Replacing the 270° transmission line section in the rat-race ring by a lumped-element impedance inverter as a capacitive Π-network may solve the problem. Other three 90° transmission line sections of the rat-race ring can be replaced by lumped-element Π-networks consisting of serial inductance and parallel capacitances. The equivalent circuit is illustrated by Fig. 4a. The sandwich implementation of the balun is shown in Fig. 4b. The device uses 1-mm thick alumina substrate with one additional dielectric layer and three conductive layers. Using the thick ceramic substrate allows eliminating an influence of parasitic capacitance to the ground. The size of the matched balun designed for the frequency 2.45 GHz is 13 mm × 12 mm. The photograph of the matched balun is shown in Fig. 4c. Results of electromagnetic simulation of the lossy balun structure are presented in Fig. 5, in a comparison with measured characteristics. According to the simulation results, the device provides in the frequency range 2.2–2.7 GHz the equal power splitting with the amplitude unbalance ±1 dB. The return loss is better than 25 dB and the isolation is not worse than 20 dB. The insertion loss is about 0.2 dB. The phase difference is 180 ± 5°. The measured data are in a good coincidence with the simulated

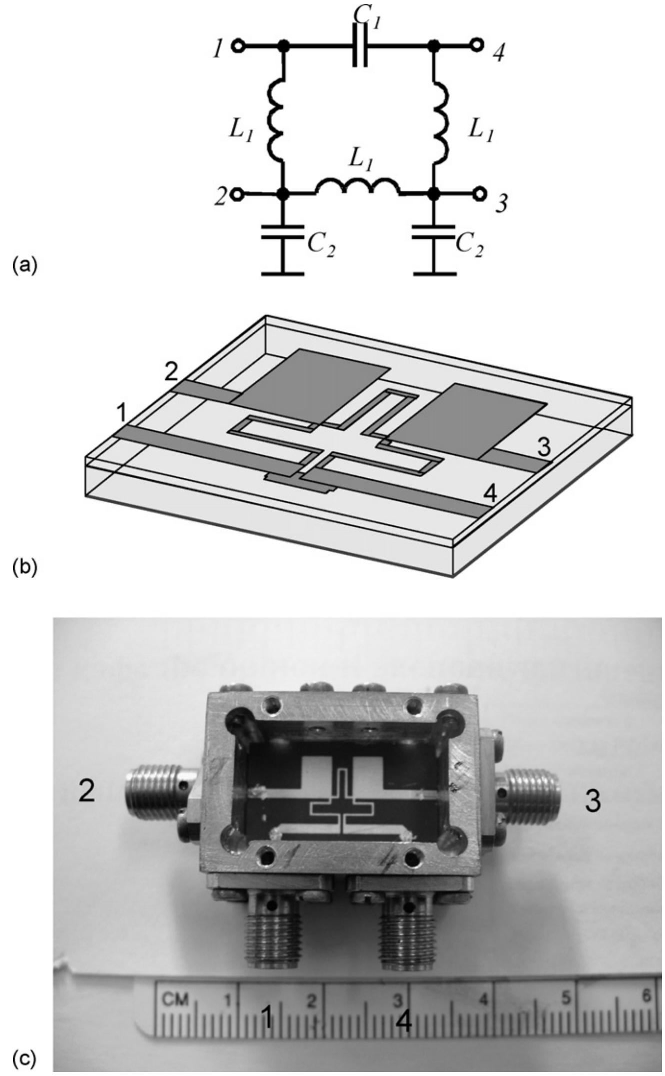

Fig. 4. Equivalent circuit (a), layout of multilayer MIC (b) and photograph (c) of the balun.

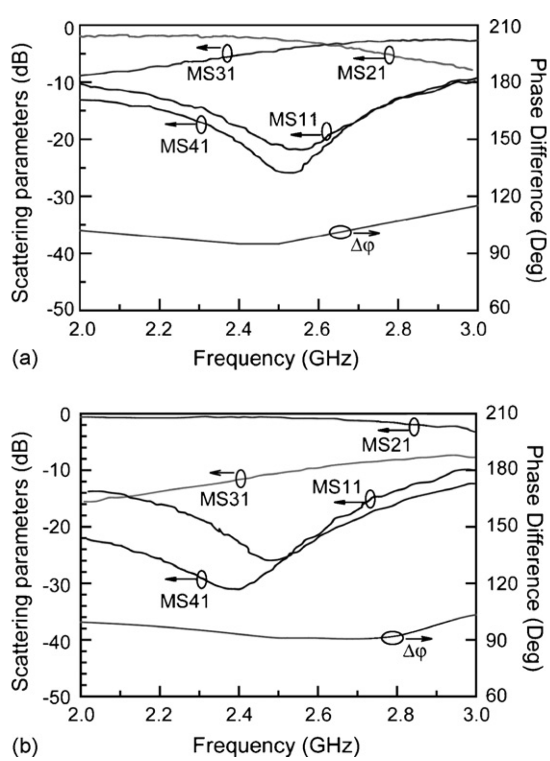

Fig. 3. Measured characteristics of the directional couplers with the 3-dB (a) and 10-dB (b) coupling.

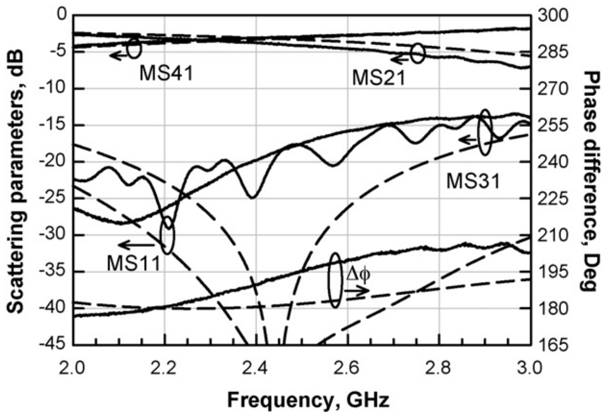

Fig. 5. Characteristics of the balun (simulated results, dashed lines; measured data, solid lines).

ones, excepting a slight shift of the characteristics to the lower frequency.

4. Conclusion

The original design of the miniature quasi-lumped-element bandpass filter, two directional couplers and the matched balun realized as multilayer MICs using the sandwich technology were presented. A good coincidence between the simulated and measured characteristics was observed for all the devices under investigation. The insertion loss of the microwave devices manufactured by the sandwich technology could be reduced by using conductive pastes with as lower surface impedance as in the LTCC technology.

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