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A Compact Broadband Balun on Multilayer Organic Substrate

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***Abstract*— We present the design and development of a compact, broadband balun based on a quasi-lumped LC transformer. The balun is constructed on a multilayer Liquid Crystal Polymer (LCP) substrate. The balun has a wide range of operating frequency from 0.9 GHz to 3.6 GHz. Within this operating band, the balun achieves a measured insertion loss of less than 1 dB, a measured return loss of better than 10dB, a measured amplitude imbalance of less than 1 dB and a measured phase imbalance less than 7 degrees. This balun has an extremely compact size of 2 mm x 2.5 mm.**

Key terms: Balun, Multilayer, Defected ground structure

I. INTRODUCTION

Balun is an important component in advanced communication circuits. They are widely used in RF/microwave circuits to convert single ended signals into differential ended signals. To achieve broadband performance, the Marchand topologies are used to design the balun as in [1]-[3]. This type of baluns is based on quarter-wavelength transmission lines and becomes large at low frequencies. Several techniques have been reported to miniaturize the Marchand baluns [4]-[6]. Transitions between distinct transmission line media such as coplanar-waveguide to slotline or coplanar-waveguide to coplanar-stripline (CPW-to-CPS) can be used to achieve compact broadband baluns as reported in [7], [8].

In this paper, we present the design and development of a novel, compact, planar wide-bandwidth balun on a multilayer organic substrate. This balun is based on a quasi-lumped LC transformer which rejects common mode signals and transforms the impedance of the differential mode signal. This quasi-lumped LC transformer is realized by metal-insulator-metal (MIM) capacitors and meandered inductors on a multilayer organic substrate. It does not require any quarter-wavelength transmission line section and can be realized with very small size while having wideband performance. Based on this technique, a balun that has a 4:1 bandwidth ratio from 0.9 GHz to 3.6 GHz and an extremely small size of 2.5 mm x 2 mm x 0.36 mm is demonstrated. Even- and odd-mode half circuits are used to analyze the balun. The performance of the balun is verified by a 3-dimensional (3-D) electromagnetic (EM) simulator and on-wafer S-parameter measurements.

II. BALUN DESIGN

A balun can be considered as a differential-mode transformer that rejects common-mode signals and allows differential-mode signals. In this proposed balun, the differential-mode transformer is realized by a novel, compact quasi-lumped LC structure. Fig. 1a shows the 3-dimentional depiction of the balun, and Fig. 1b shows the multilayer cross section. The balun is built on a multilayer Liquid Crystal Polymer (LCP) substrate which has three metal layers and two dielectric layers. The LCP has dielectric constant of 2.9 and loss tangent of ~0.002. The substrate thicknesses are H1=2 mil and H2 = 12 mil. Coplanar waveguide probe pads are added for probe measurements. Through vias are used to ground the probe pads. Port 1 of the balun is excited between a MIM capacitor C which is realized on the top and middle layers of the substrate. This capacitor is connected to two meandered line inductors L. The other ends of these inductors are connected to the second MIM capacitor C which has identical dimensions as the previously described capacitor. The top metal pad for this capacitor is port 2 of the balun. The bottom metal pad for this capacitor is routed to the top metal layer by a via and becomes the signal trace for port 3 of the balun. All ports are matched to 50-ohm.

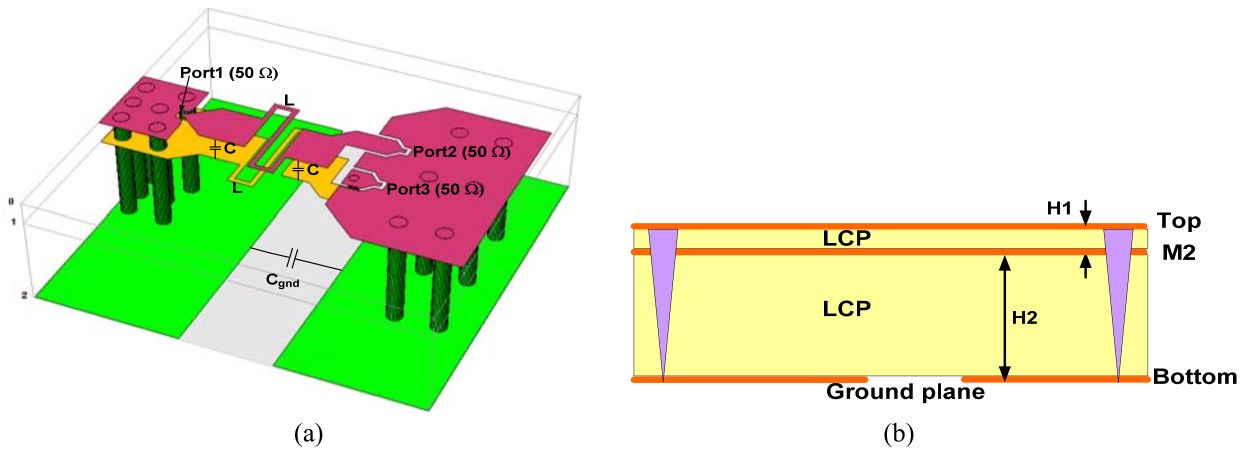
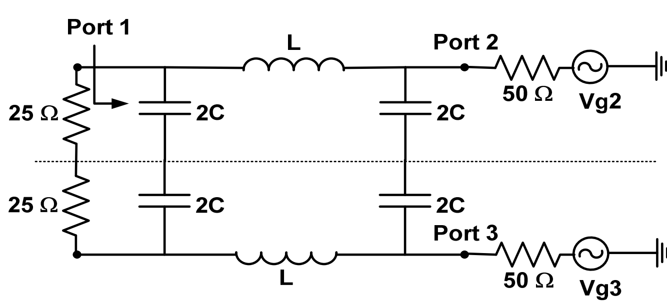
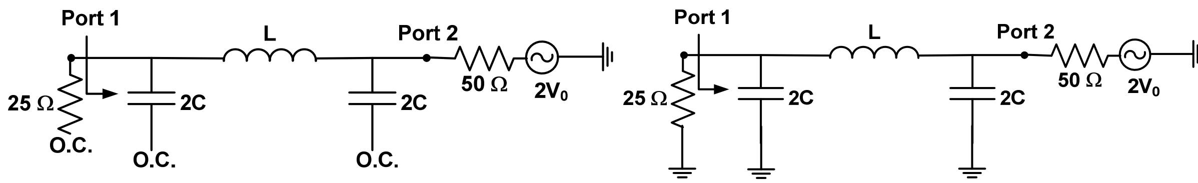


Fig.1. (a) 3-dimentional view and (b) cross section of the balun

The equivalent circuit for the balun in a symmetrical form is shown in Fig. 2a. The capacitors Cs are realized by metal-insulator-metal (MIM) capacitors on top and middle metal layer of the substrate. The inductors Ls are realized by small meandered lines on top and middle metal layers of the substrate. The ground is defected and creates a small capacitor C_{gnd} which can be neglected.



(a)



(b) (c)

Fig.2. (a) Equivalent circuit of the balun (b) even-mode half circuit and (c) odd-mode half circuit

The balun can be analyzed by decomposing the equivalent circuit into a superposition of even-mode and odd-mode half circuits. For the even-mode, due to the symmetry of the circuit, the center of the equivalent circuit becomes an open circuit as illustrated in Fig. 2b. Since there is an open circuit, there is no current flowing and the common mode signal is rejected. On the other hand, considering the odd-mode half circuit, the center of the circuit effectively becomes a short circuit resulting in Fig. 2c. The LC network can be designed to match 50-ohm to 25-ohm. For example, to match 50-ohm to 25-ohm with VSWR less than 1.5 at center frequency of 2.8 GHz and 600 MHz bandwidth, the values of L and C are C=1.1 pF and L=1.8 nH. So, by properly choosing the values of L and C, this balun can be designed to operate at a desired frequency band. For experimental purposes, the values of C, C_{gnd} and L are determined so that the balun covers a bandwidth from 0.9 GHz to 3.6 GHz with an input return loss S11 of better than 10 dB. The values of C, C_{gnd} and L are shown in table I. The comparison of the simulated S-parameters between the circuit model and EM simulation of the balun is shown in Fig. 3. As can be seen, the simulated S-parameters of the circuit model and EM simulation of the balun correspond very well. The fabricated prototype is shown in Fig. 4. The size of the balun is 2.5 mm x 2 mm without the probe pads.

TABLE I

SUMMARY VALUES OF C, C_{gnd} AND L

C (pF)	C_{gnd} (pF)	L (nH)
0.5	0.08	2.1

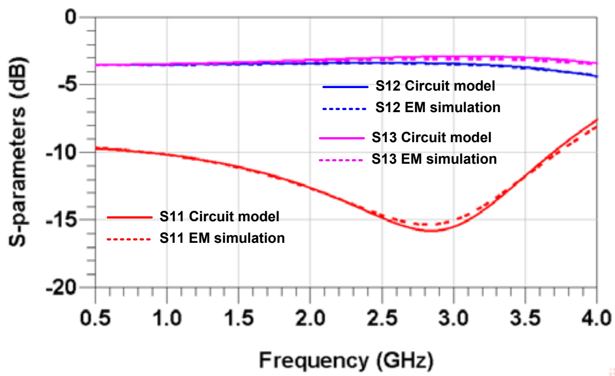


Fig. 3. Comparison of simulated S-parameters between circuit model and EM simulation of the balun

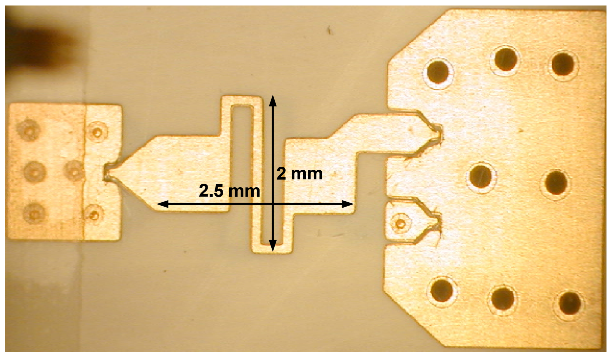


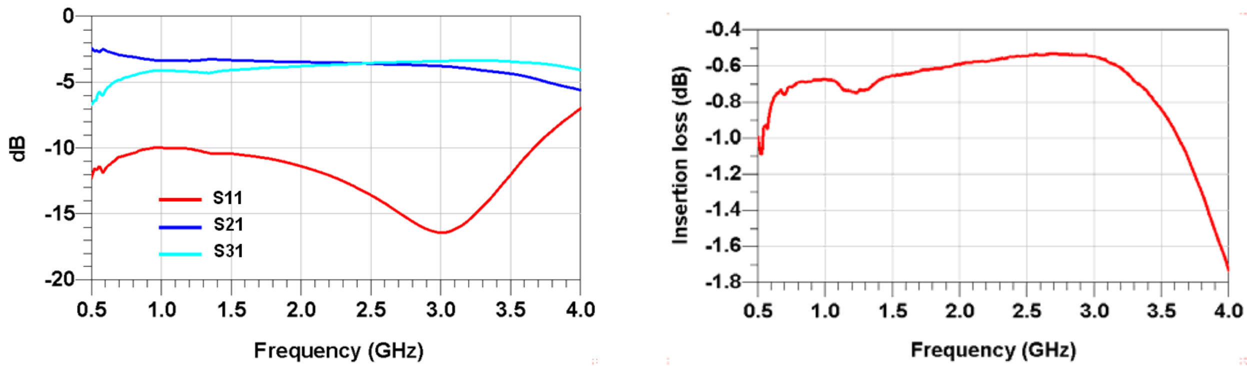
Fig. 4. Balun fabricated prototype

III. EXPERIMENTAL RESULTS

The balun is simulated using the High Frequency Structure Simulator (HFSS) [9]. The electrical performance of the balun was measured on a Cascade Microtech RF probe station with an Agilent E8364 2-port network analyzer. The probes were calibrated using standard TRL calibration on Picoprobe CS-9 substrate [10].

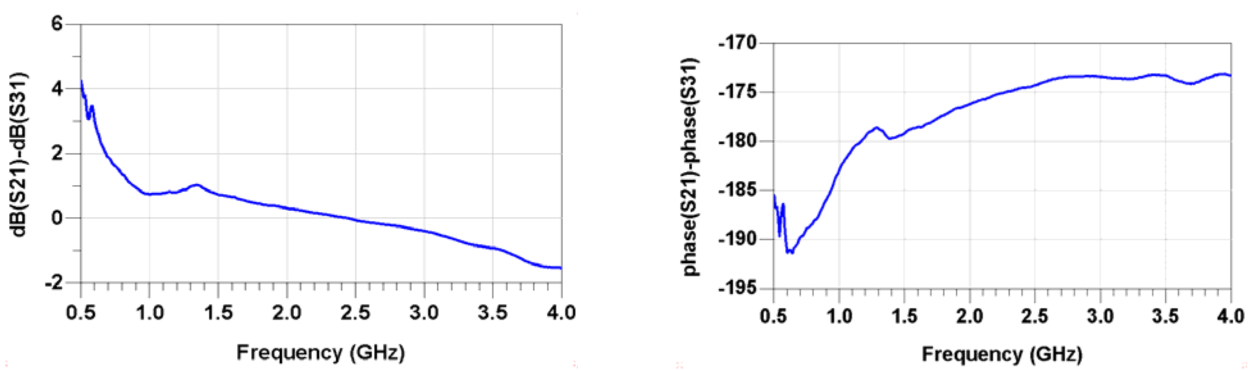
The measured S11, S12, S13 and insertion loss of the balun are shown in Fig. 5. As can be seen in Fig. 5a, the balun has a measured input return loss of better than 10 dB from 0.9 GHz to 3.6 GHz. From the measured S12 and S13, the insertion loss can be calculated as $IL = 10\log_{10}\left(|S12|^2 + |S13|^2\right)$ (dB). The measured insertion loss is shown in Fig. 5b. As can be seen, the measured insertion loss of the balun is better than 1 dB in the operating band from 0.9 GHz to

3.6 GHz. The measured amplitude imbalance and phase imbalances are shown in Fig. 6. As can be seen, in the operating band of 0.9 GHz to 3.6 GHz, the balun has a measured amplitude imbalance of better than 1 dB, a phase imbalance of better than 7 degrees. Table II shows the comparisons of this design with published planar broadband compact baluns in terms of bandwidth, phase imbalances, amplitude imbalances and size. In this table, λ_g is the guided wavelength at the center frequency of the baluns. As can be seen, this proposed balun achieves the smallest size and comparable performances as compared to other published planar baluns.



(a) (b)

Fig. 5. (a) Measured S-parameters (a) and insertion loss (b) of the balun



(a) (b)

Fig.6. Measured amplitude imbalance (a) and phase imbalance (b)

TABLE II

COMPARISON OF BALUN DESIGNS

Baluns	Bandwidth (GHz)	Amplitude Imbalance (dB)	Phase Imbalance (Degree)	Size
[7]	1.4 – 2.6	±0.5	±1.5	0.22 λ_g x 0.04 λ_g
[8]	1.9 – 3.0	± 0.4	± 10	0.22 λ_g x 0.17 λ_g
[9]	3.1 – 8.0	± 0.7	± 5	0.14 λ_g x 0.11 λ_g
[10]	0.2 – 2.0	± 0.3	± 6	0.13 λ_g x 0.09 λ_g
This work	**0.9 – 3.6**	**± 1**	**± 7**	**0.03 λ_g x 0.02 λ_g**

IV. CONCLUSIONS

A compact, novel, wideband balun is designed and fabricated on multilayer LCP substrate. The balun is based on a quasi LC transformer network which rejects common mode signals and allows differential mode signals to pass to the output. The experiment results show that the balun has an operating frequency band from 0.9 GHz to 3.6 GHz. Within this operating band, the input return loss is better than 10 dB, the insertion loss is better than 1 dB, the amplitude imbalance is better than 1 dB and the phase imbalance is better than 7 degrees. The total size of the balun is 2.5 mm x 2 mm x 0.36 mm.

ACKNOWLEDGMENT

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