A Novel Structure for Ultra Broadband Broadside-Coupled Impedance Transformer

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***Abstract* — This paper presents a novel structure for ultra broadband 4:1 broadside-coupled PCB impedance transformer. Analysis, simulations and measurements of the developed transformer are given and discussed. Three prototypes of the proposed structure are implemented (Trafo I, Trafo II and Trafo III) at resonant frequencies 2.3, 1.3 and 0.85 GHz, respectively with fractional bandwidth (FBW) of greater than 400 %. The implemented transformers show an ultra broadband performance with a transmission loss of less than – 1 dB and return loss of at least – 10 dB in the desired bandwidth. In a comparison, simulations and measurements are found very close to each other. To the knowledge of the authors, the achieved performance of the designed transformers has been never obtained in the literature.**

***Index Terms* — Broadband, impedance transformer, PCB, broadside-coupled.**

I. INTRODUCTION

Broadband impedance transformer (BIT) plays an important role in microwave circuits design for many applications such as broadband power amplifier design, load-pull characterization and antennas [1- 4]. Most of RF power transistors need such transformer because of their low input impedances (less than 5 Ohm) and also their low output impedances (5 – 15 Ohm depends on the used technology). In broadband design, BIT may be considered the suitable section which transforms the input/output impedances to 50 Ohm and vice versa resulting in an ease matching and size reduction.

In the past decades, traditional transformers such as lumped elements transformers and ferrite based transformers are considered [6] but their performances are quite band limited. Now, unconventional transmission line transformers on multilayers such as printed circuit board (PCB) [2], low temperature cofired ceramic (LTCC) [7], high temperature cofired ceramic (HTCC) and monolithic Si/ GaAs ICs [1], [3], [5] introduce the best solution in broadband design. Such kind of transformers requires EM simulation which is more accurate and realistic compared to other simulators.

In this paper, we introduce a novel structure for ultra broadband impedance transformers based on PCB as a part of broadband PA design in the frequency band. Sec. II presents the analysis and design for the proposed structure. Simulations and measurements of three implemented BITs at different resonant frequencies are compared and discussed in Sec. III. Finally, Sec. IV summarizes and concludes the work.

II. ANALYSIS AND DESIGN

A two layers 4:1 impedance transformer implemented on PCB is described. Fig. 1 shows two half sections of the proposed structure separated by a small gap and located on the upper layer. The bottom layer is a mirrored copy of the upper structure and both are connected together through via hole. The side ports on the bottom layer should be connected to ground which results in 4:1 transformer as symbolized in Fig. 2.

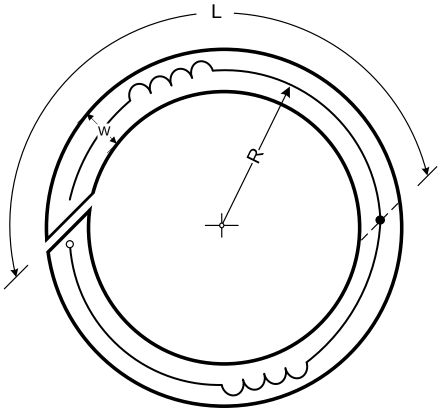

Fig. 1. Upper layer of the proposed structure.

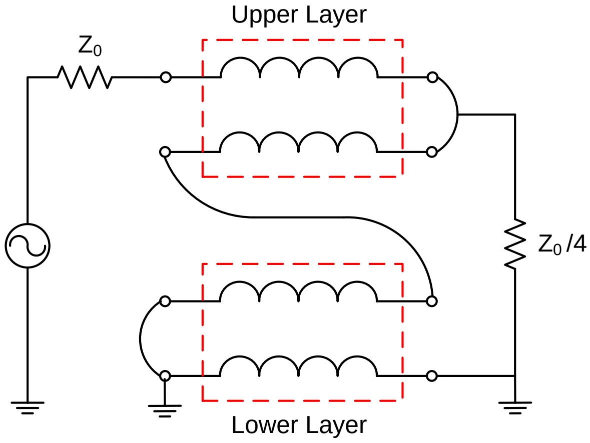

Fig. 2. 4:1 impedance transformer.

At a certain frequency f_0, the radius R can be deduced by the relation:

$$R = \lambda/8\pi \qquad (1)$$

while *w*, the conductor width depends on the characteristic impedance Z_0, dielectric constant ε_r and dielectric thickness *h*. towards design phase for 4:1 BIT, Z_0 is suggested to be 50 Ohm for all implemented prototypes. A Rogers substrate RO4003 with $\varepsilon_r = 3.38$ and $h = 0.51$ mm is used, resulting in a conductor width of 3 mm (25 Ohm).

III. SIMULATIONS AND EXPERIMENTAL RESULTS

All simulations were done for the implemented transformers based on High Frequency Structural Simulator (HFSS v.11) from Ansoft 50 to 12.5 Ohm whereas measurements are done 50 to 50 Ohm. Then the measured S-parameters can be converted to 50 to 12.5 Ohm and compared to the simulated results using Advanced Design System (ADS) from Agilent.

In order to compare the performance of the implemented transformers with the state-of-the-art, a measure of broadband performance FBW which is the fractional bandwidth given by [1] is used for this purpose together with the small signal performance and the used technology:

$$FBW = \Delta f / f_0 \,, \tag{2}$$

$$\Delta f = f_H - f_L \,,\; f_0 = \sqrt{f_L f_H} \tag{3}$$

Figs. 3, 4 show both simulations and measurements for the first implemented impedance transformer (Trafo I) at $f_0 = 2.3$ GHz. The PCB prototype and the input return loss S_{11} are presented in Fig. 3 while Fig. 4 shows the output return loss S_{22} and the transmission loss S_{21} in dB. It is obvious that both diagrams show very good agreements between simulations and measurements up to 12 GHz. Regarding with the small signal performance, a very low loss $S_{21} < -1$ dB, input/ output return losses of < -10 dB over a fractional bandwidth of 447 % can be achieved.

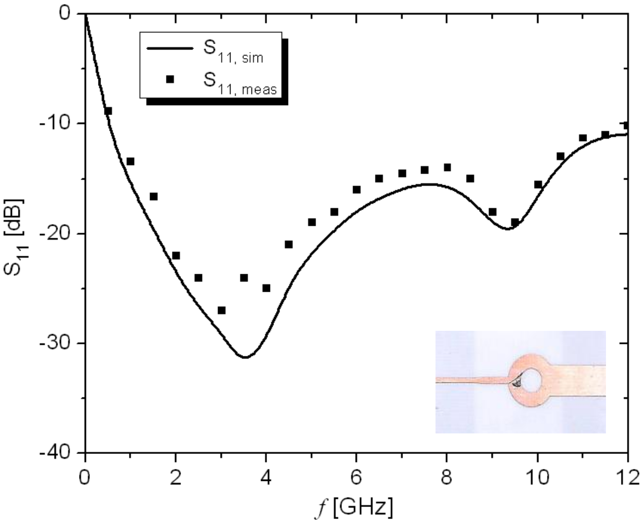

Fig. 3. Simulated and measured input return loss (S_{11}) of Trafo I, $Z_0 = 50$ Ohm.

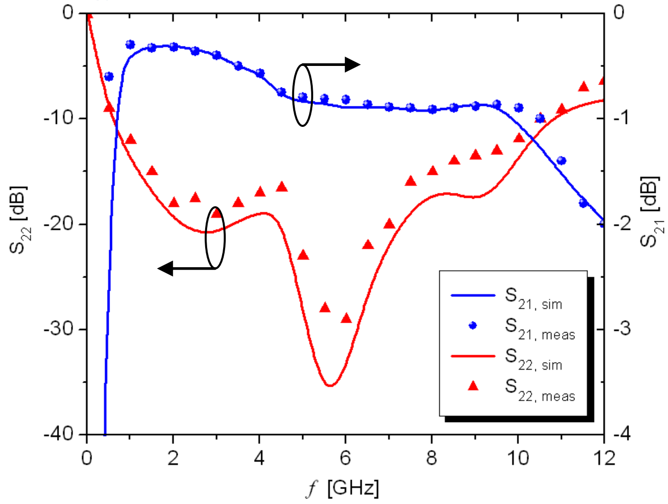

Fig. 4. Simulated and measured input return loss (S_{11}), transmission loss (S_{21}) of Trafo I, $Z_0 = 50$ Ohm.

The simulated and experimental results of the second transformer (Trafo II) that was designed at $f_0 = 1.3$ GHz are presented in Figs. 5, 6. Fig. 5 shows a PCB prototype for the implemented transformer together with its input return loss in the frequency band (20 kHz – 12 GHz). From the diagram, an input loss of < -10 dB over a fractional bandwidth of 630 % can be observed. However, an output return loss of < -10 dB and transmission loss S_{21} of -1 dB can be also achieved as depicted in Fig. 6. Both figures show us an excellent agreement between simulations and measurements.

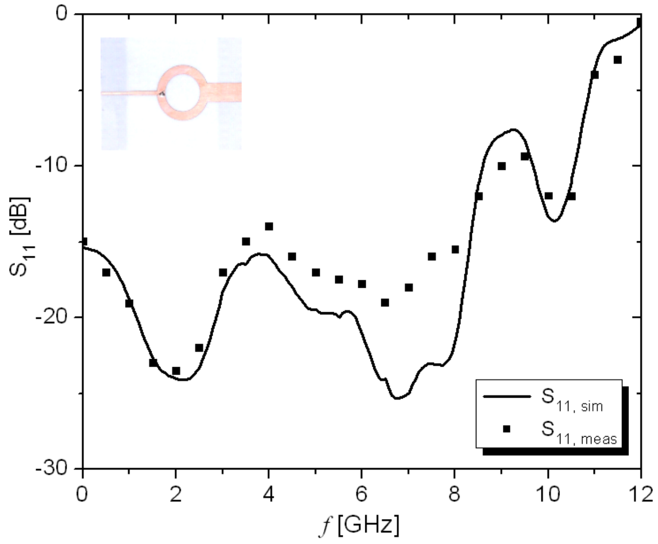

Fig. 5. Simulated and measured input return loss (S_{11}) of Trafo II, $Z_0 = 50$ Ohm.

Finally, the performance of the third implemented 4:1 transformer (Trafo III) at $f_0 = 850$ MHz. is given in Figs. 7, 8. It is clear that both simulations and measurements are very close to each others as shown in the figures. Also, as expected from the simulations, the measured performances show us high input/ output return loss of < -10 dB and very low transmission loss in order of – 1 dB over a fractional bandwidth of approx. 800 %. Table I summarizes the achieved results of this work and give a comparison to the state-of-the-art regarding f_0 and FBW.

IV. CONCLUSION

In this paper, an ultra broadband structure for impedance transformer on PCB has been introduced. Three implemented transformers at 2.3, 1.3 and 0.85 GHz show an excellent performance compared with the state-of-the-art. Simulations and measurements of the designed transformers were demonstrated and good agreements could be achieved. A low loss of – 1 dB, input / output return loss of – 10 dB could be obtained. All of all, the achieved performance based the proposed structure has been never given in the literature.

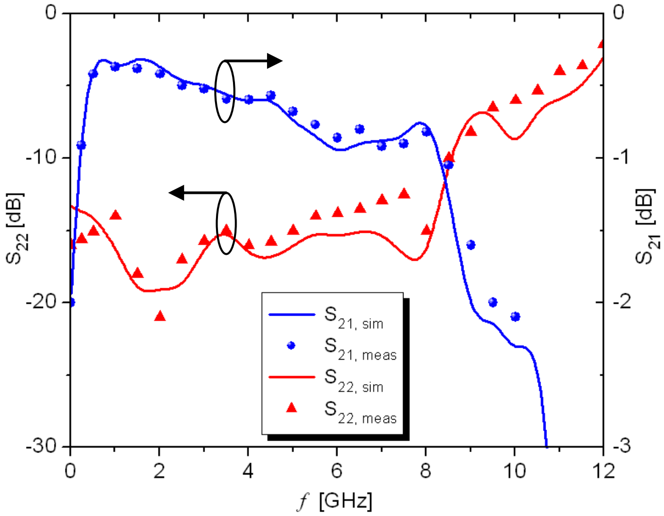

Fig. 6. Simulated and measured input return loss (S_{11}), transmission loss (S_{21}) of Trafo II, Z_0 = 50 Ohm.

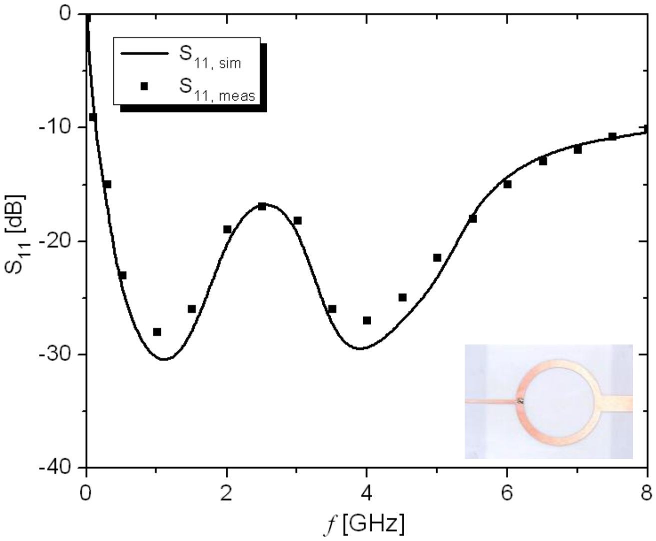

Fig. 7. Simulated and measured input return loss (S_{11}) of Trafo III, Z_0 = 50 Ohm.

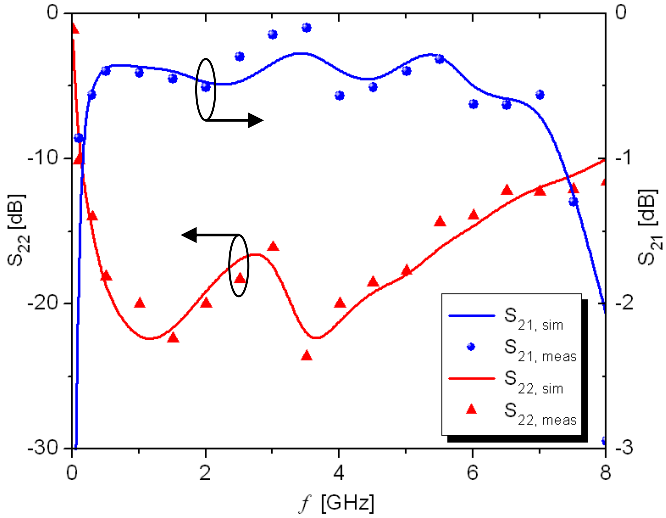

Fig. 8. Simulated and measured input return loss (S_{11}), transmission loss (S_{21}) of Trafo III, Z_0 = 50 Ohm.

TABLE I

SUMMARY OF BIT PERFORMANCE

Ref.	f_0 [GHz]	f_H - f_L [GHz]	FBW [%]	S_{21} [dB]
[1]	8.6	10	130	-1
[2]	0.95	1	120	-
[3]	5.1	11	215	-1.2
Trafo I	2.3	10.3	447	-0.95
Trafo II	1.3	8.3	638	-1
Trafo	0.85	7.1	835	-1

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