An Integrated Transformer Balun for 60 GHz Silicon RF IC Design

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***Abstract* — A broadband monolithic transformer balun has been designed and fabricated at millimeter-wave frequencies. The balun is implemented on 0.13 um CMOS process and integrated with the 60 GHz mixer circuit. A measured amplitude and phase balance less than 3dB and 5 degrees respectively over the 50-65 GHz frequency band was achieved. The designed device has advantages of small size, simple layout and wide operational frequency range.**

***Index Terns* —** Passive balun, RF IC design, CMOS.

I. INTRODUCTION

In mm-wave IC circuits passive baluns are incorporated into circuits such as balanced mixers, phase shifters, power amplifiers and antennas. Typical implementations of passive baluns are either coupled transmission lines, (e.g. the Marchand balun and the ring-hybrid) or transformer baluns. Transmission line baluns comprise quarter wavelength sections and occupy much large area compared to transformer baluns. Consequently, they are commonly used in lower frequency applications up to 4 GHz [1], [4]. In the higher frequency range conventional transformer and Marchand-type transformer are used in [3] for balanced mixers operating in the 15-40 GHz frequency range. For frequencies above 40 GHz stacked transformer structures are used to achieve higher coupling between the transformer windings and to reduce chip area [5].

In this paper, we report a broadband monolithic transformer balun which operates at frequencies from 55 GHz to 65 GHz. The balun is integrated with the double-balanced 60GHz down conversion mixer. It was designed by using basic transformer equations and electromagnetic (EM) solver.

This paper is organized as follows. In the first part of the paper we describe a simplified design procedure to obtain the optimal geometry for a given frequency band. The second part of the paper shows the measurement and simulation results (phase and amplitude balance). The paper finishes with the summary of the results.

II. DESIGN PROCEDURE

Figure 1 show the balun which operates in the 55-65 GHz frequency range providing the balanced input to the Gilbert cell mixer. It is designed as a vertically stacked 1:1 conventional transformer implemented in adjacent metal layers for tighter coupling. Additional capacitors are added in shunt at the ports to tune the balun to 60 GHz frequency and reduce the losses.

The first step of the design procedure is the estimation of transformer winding self inductance based on the compact electrical model of a transformer in the pass band frequency range [1]

$$f_c = \frac{R}{2\pi L_p \sqrt{1 - k_m^2}} \qquad (1)$$

where f_c is a given centre frequency, L_p is the self inductance of the primary winding, k_m is the coupling coefficient between the transformer windings and R is total resistance including loading of the source.

The next step is to estimate physical dimensions from the winding self inductance for the centre frequency of 60GHz by using planar microelectronic inductor formulae derived in [6].

In order to match the ports and minimize the transmission loss additional tuning capacitors are added in parallel at each port. The value of tuning capacitance is estimated from the equation for the -3dB bandwidth of a resonant RLC circuit

$$BW = \frac{1}{(2\pi RC)} \qquad (2)$$

where BW is the bandwidth, R total resistance and C is the total capacitance shunting the circuit including the parasitic capacitance. The final dimensions, the length of the winding, conductor width and spacing are then optimized with the finite element method (FEM) electromagnetic solver [7].

III. RESULTS AND DISCUSSION

The balun was fabricated on IBM CMOS8SF technology on the top RF metal layers. The technology is 130 nm CMOS with 8 metal layers, 3 thin, 2 thick and 3 RF layers. The die photograph of the balun is shown in Fig 1. The balun including the probe pads measures 0.33 mm x 0.4 mm. In a typical balanced mixer configuration, the area occupied by this balun is 0.1 mm x 0.5 mm. The 3-port S-parameters of the balun were measured using Suss-Microtech Probe Station with 110 GHz probes and 110 GHz Anritsu Network Analyser.

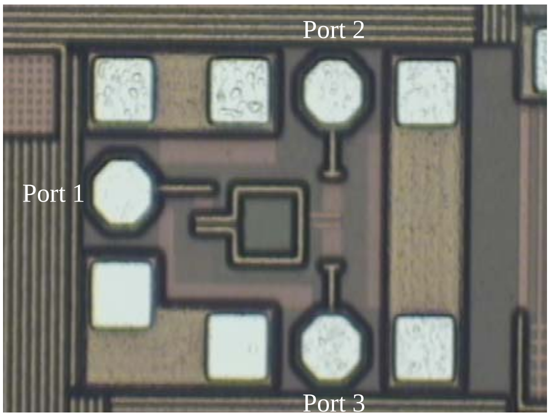

Fig. 1 Photograph of the fabricated transformer balun (0.33 mm x 0.4 mms).

To characterize the 3-port transformer balun, we first measured the 3- port S-parameters and then evaluated phase and amplitude balance (difference) by

$$\psi = \text{ang}\left(\frac{S_{31}}{S_{21}}\right) \tag{3}$$

$$A = 20Log_{10}\left|\frac{S_{31}}{S_{21}}\right| \tag{4}$$

Fig. 2 and Fig. 3 show the amplitude and phase balance between the two ports. The amplitude balance is better than 3dB for the frequencies from 50 to 65 GHz. From Fig. 3 it can be seen that the phase balance is about 5° from the 180° phase difference between the two ports.

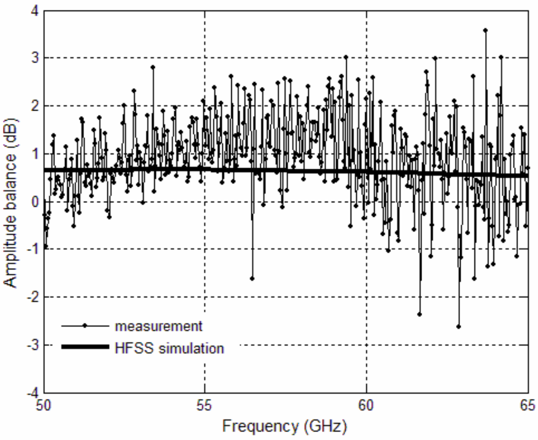

Fig. 2 Measured and simulated amplitude difference.

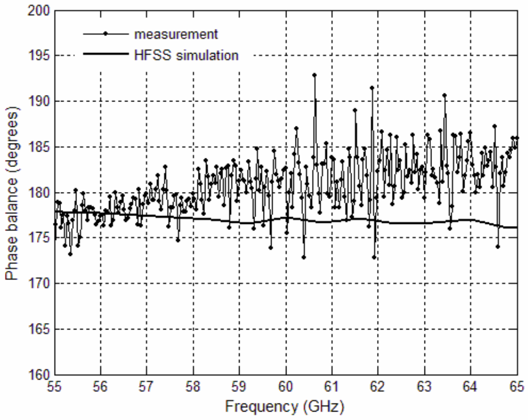

Fig. 3 Measured and simulated phase difference.

The measured transmission loss (S_{21} and S_{31}) including -3dB power splitting is about 6 dB for the frequency range from 55 to 65 GHz. The inaccuracy between the measured and simulated results can be attributed to the simulation set up used and the thermal noise in the receiver present during measurements.

IV. CONCLUSION

This paper presents a compact on-chip stacked transformer balun with integrated tuning capacitors. The designed device has advantages of small size, simple single turn layout and wide operational frequency range. It is shown that the balun provides good phase and amplitude balance for the frequency range from 50 to 65 GHz. The new balun is currently integrated with Gilbert cell mixer and could be also easily integrated with other parts of any RF circuit at around 60 GHz.

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