Miniaturized SiGe V-Band Active Transmit Balun

Jian Zhang, Guochi Huang, and Vincent Fusco

The Institute of Electronics, Communications and Information Technology (ECIT)
Queen's University of Belfast, Belfast, United Kingdom

Jian.zhang@qub.ac.uk

Abstract—A miniaturized V-band active transmit balun suitable for direct attachment to an integrated on-chip dipole antenna is proposed in this work. The circuit is constructed using a 0.35 μm SiGe HBT bipolar process (Infineon fT / fmax=170/250 GHz) operating at 55-65 GHz is fabricated and measured. The circuit exhibits a more than 11 dB conversion gain with magnitude imbalance less than 1 dB and phase error less than 5 degrees from 55 GHz to 65 GHz. The chip area is 0.6x0.7 mm2 including all pads.

I. Introduction

The millimeter-wave band, especially the unlicensed spectrum at the 60 GHz carrier frequency allows capability to support Giga-bit/sec data rate wireless communication applications [1]-[2]. The available bandwidth at 60 GHz is plentiful (frequencies of 57–64 GHz are available in North America and Korea, 59–66 GHz in Europe and Japan). However 60 GHz systems exhibit several challenges that have made them difficult to deploy for general consumer use. A major system constraint is high path loss since these systems deliberately occupy the oxygen absorption band to facilitate spectral reuse as well as to limit transmission range. This implies a need for high-gain beam-forming antennas. In order to resolve these problem, different types of on-chip antennas, such as dipole, patch, and slot have been presented [3]-[5]. Among these, the dipole is finding roles in developing on-chip realization mainly because of its simple geometry, its potential for beam steering as well as its resistance to proximity effects when mounted as compared to unbalanced radiating elements. For proper dipole antenna operation a balanced feeding network is needed.

In this paper we present an active transmit balun to feed the dipole antenna. Compared with a traditional passive balun, such as the transformer or Marchand balun, the active balun presented here uses the concept of LCR feedback to adjust gain and phase unbalance separately. Unlike traditional passive balun designs the active balun presented here shows positive conversion gain and occupies a small physical footprint.

II. ACTIVE BALUN DESIGN

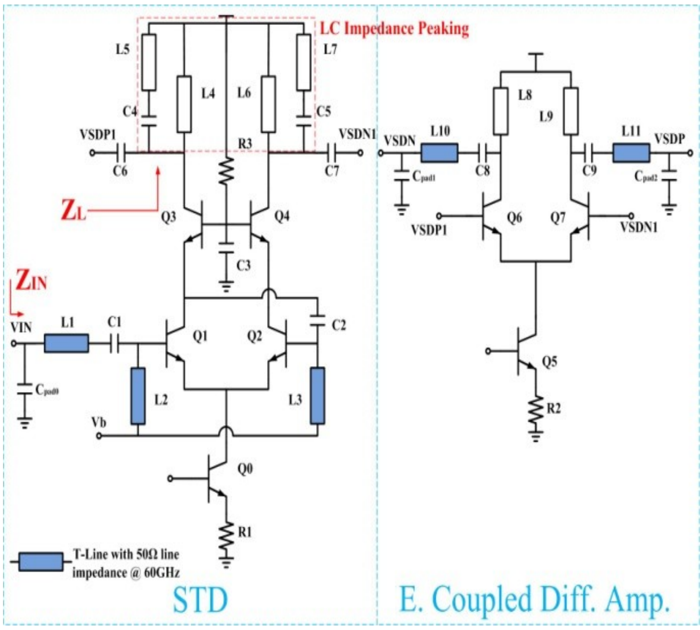

Fig. 1 Schematic of the active balun

Fig. 1 shows the designed V-band active balun which is composed of one single-ended to differential converter and one emitter coupled differential amplifier [6-7]. An LC impedance peaking network is adopted for the load of the STD circuit. If we ignore the series resistance of the transmission line inductors, the impedance ZL seen into the network from the collector node of Q3 or Q4 can be expressed as:

where L4, L5 are the inductance of transmission lines TL4 and TL5, respectively. Thus by properly choosing the value for L4, L5 and C4, ZL can be made very large in the desired frequency

band in order to force the output current to flow into the following stage. However, in practice the series resistance in the transmission line inductor will limit the impedance peaking effect. In our design transmission line inductors, L1 to L3 as shown in Fig. 1, with 50 Ω characteristic impedance at the desired frequencies are introduced at the input stage for the purpose of impedance matching. Note that, at millimeter-wave frequencies, e.g. 60GHz, the base impedance of a bipolar transistor is relatively small compared with a 50 Ω transmission line. Therefore, the input impedance can be simplified as:

where C1 and Cpad0 are the capacitance of the AC coupling capacitor C1 and bonding pad, respectively. ZB is the impedance of the transistor Q1 looking into base node and is much less than ZL1. ZL1 is the characteristic impedance of the transmission line L1, which is around 50 Ω at 60GHz. As can be seen from (2), if C1 is much larger than Cpad0, then the second term in the denominator and Cpad0 in the first term can be ignored. Thus, the input impedance will be dominated by the characteristic impedance of the transmission line L1. In the design, C1 is set to 1pF and the bond pad capacitance Cpad0 is less than 40fF. As a result, a good 50 Ω impedance matching can be achieved over a wide frequency band.

For the active part, a part of output signal at collector node of Q1 is coupled to the base of Q2 through capacitor C2, which helps alleviate the unbalanced distribution of the input signal between Q1 and Q2 due to the fact that the output impedance of the tail current source is not sufficiently high. Thus the differential mode current flowing into the output node VSDN1 is increased. Transistors, Q3 and Q4, are introduced to alleviate the Miller effect so as to enhance the bandwidth. Then, an emitter coupled differential amplifier, Q6 and Q7, with high common mode rejection are connected in the follow and used to amplify the desired signal and reduce the phase and amplitude imbalance of the differential signal through further compress the common mode signal generated by the first stage. The output matching network is designed with a series CLC network to get 50 Ohm impedance for the purpose of testing.

III. MEASUREMENTS

The presented active balun was fabricated using Infineon 0.35µm SiGe technology. The microphotograph of the circuit is shown in Fig. 2. The circuit was measured on wafer using GSG probes. An Agilent E8361A network analyzer was used to measure the S-parameters.

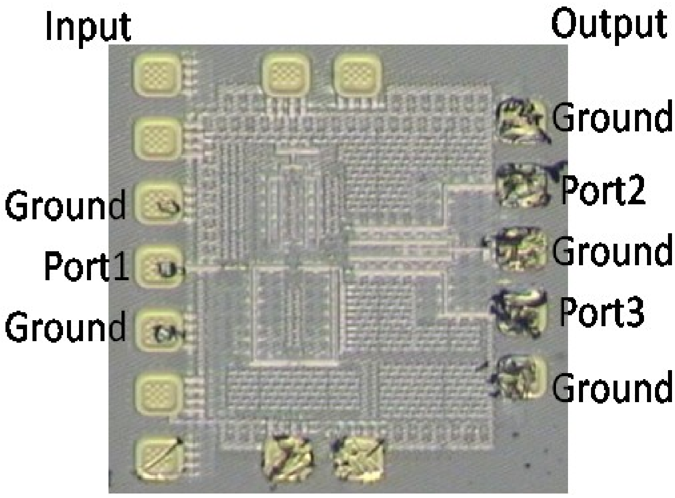

Fig. 2 Micrograph of the proposed active balun

The circuit worked under 3.3V dc@17.5mA. bias. The measured S-parameters of the circuit are shown in the Fig. 3. It depicts that around 10dB conversion gain and better than -10dB return loss in the frequency of the interest. Fig. 4 shows the magnitude balance and phase error of the active balun. Here the measurements exhibit a magnitude imbalance around ±1.5 dB@ 60GHz. The measured phase error is less than 5 degrees over the frequency range 55 GHz to 65 GHz.

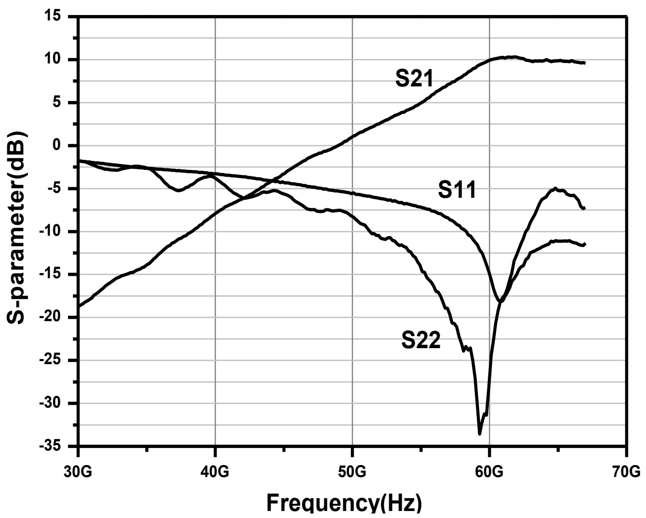

Fig. 3 The measured conversion gain and return loss

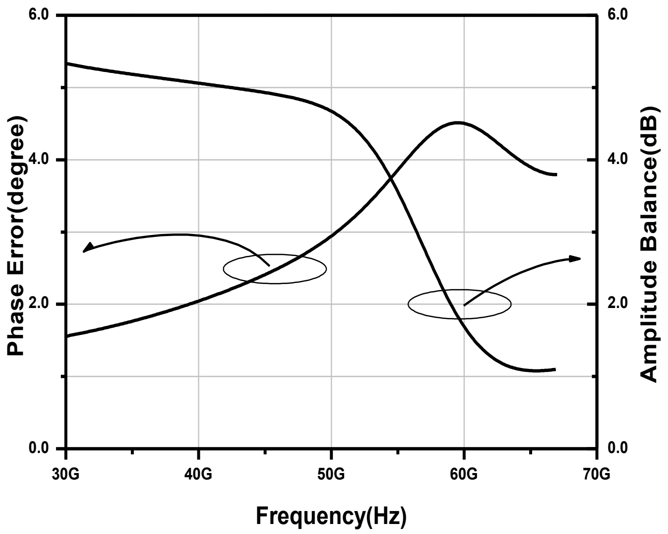

Fig. 4 The measured magnitude balance and phase error

In order to verify its availability, the measured amplitude and phase characteristics of the presented balun circuit are substituted into a linear 1×2 phased array with 1/2λ antenna spacing for array factor calculation [8]. Fig. 5 shows the calculated radiation patterns for practical magnitude and phase characteristic. Curve A depicts the ideal case with magnitude balance and zero phase error; Curve C represents the measured case with magnitude unbalance of 1.6 dB and phase error of 5 degree; Curve B shows the case with magnitude balance and phase error of 5 degree; Curve D describes the one with magnitude unbalance of ±1.6 dB and zero phase error. We can clearly find that a ±1.6dB magnitude unbalance and 5 degree phase error results in a reduction of dipole gain along bore sight of only 0.7dB relative to the results obtained if a perfect balun was used. These results indicate that the presented active balun can be used in transmitter circuits despite the magnitude imbalance at its outputs.

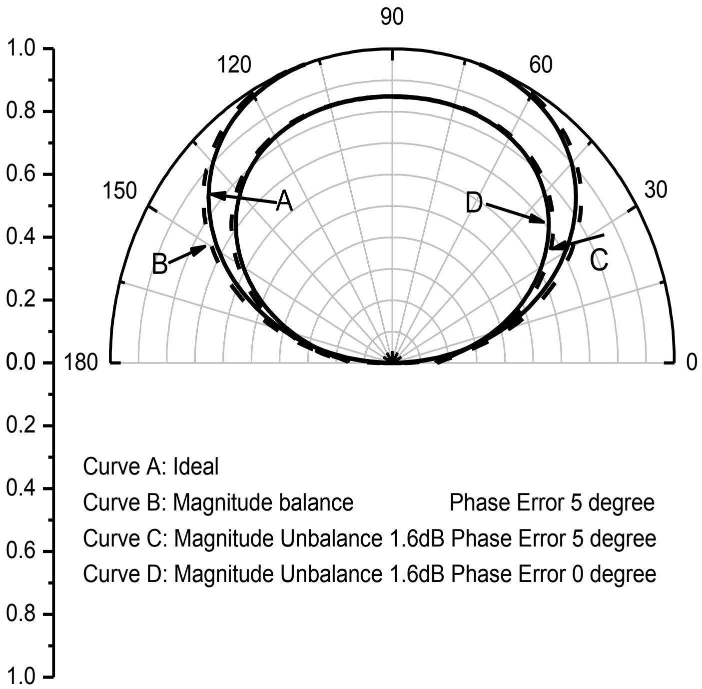

Fig. 5 Calculated array pattern obtained using the measured transmit balun magnitude and phase characteristic data at 60GHz.

The presented active balun was designed for transmit application, thus its power handling capability and linearity are important. Fig. 6 shows the input and output P1dB is around -8dBm and 2dBm respectively. Fig. 7 gives simulated noise performance, a noise figure less than 8 dB was obtained.

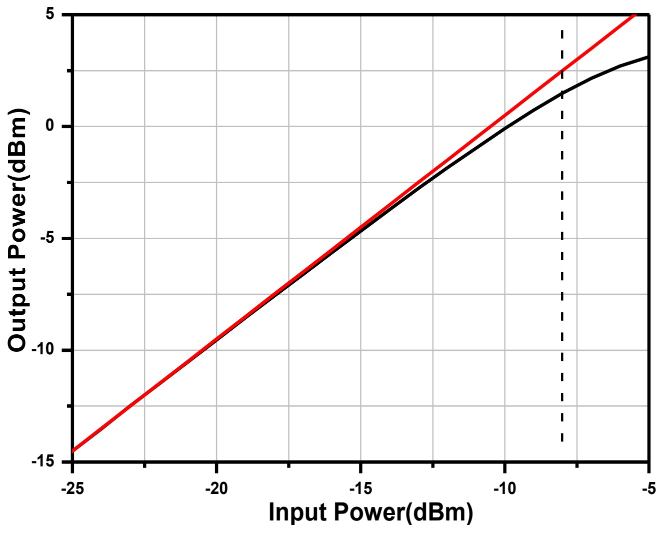

Fig. 6 The measured 1dB compression point

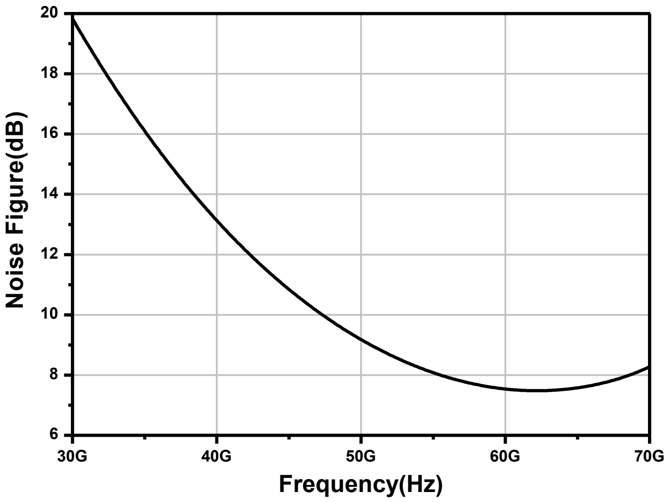

Fig. 7 Simulated noise figure of the active balun

IV. Conclusion

A miniaturized 55-65 GHz active balun using 0.35μm SiGe HBT bipolar process (Infineon fT / fmax=170/250 GHz) technology is presented in this work. It is used as an active compact matching network for V-band balanced antennas. Explicit design equations are also provided. The circuit was designed, fabricated, and measured. The balun due to its compact size can be easily integrated with on-chip dipole antenna structures.

Acknowledgment

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