Ka/Q-Band Doubly Balanced MMIC Mixers with Low LO Power

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***Abstract*—An InP-based broadband double-balanced mixer was developed having interchangeable RF/LO-ports and covering frequencies from 30 to 45 GHz, with a conversion loss of 12 ± 2 dB at the low LO power of 4 dBm. This broadband characteristic was achieved through the use of side-coupled baluns for both the RF and LO ports. The ring quad-diodes used state-of-the-art super-lattice layers, which provided good control of turn-on voltage and were monolithically integrable with in-house HEMT's and HBT's. The diodes exhibited a very low turn-on voltage of 0.15 V at 1 mA, low series resistance, and high cutoff frequencies.**

***Index Terms*—Balun, doubly balanced mixer, InP-based Schottky diodes, MMIC, quad-ring mixer.**

I. Introduction

THE recent technological advances of systems and components operating at Ka-band and above make it of great importance for the deployment of satellite communication links [1], [2]. The increasing demand for higher frequencies and the continuous requests for additional capacity necessitate the allocation of wider bandwidths to support the growing amount of data passing through the satellite payload. The trend of this rapid growth of high data rate service is bringing closer the commercial exploitation of EHF band for satellite communication [3], which, in turn, will provide an increasing demand for Ka-to-Q band circuits and functional modules for the systems. Among the many circuits, the mixers need to provide both the down-conversion for the receiver and up-conversion for the transmitter of the payload. It is cost-effective if a broadband MMIC mixer can facilitate dual band coverage with low power requirements within the bandwidth.

Accordingly, this paper describes the development of a broadband doubly balanced MMIC mixer covering from 30 to 45 GHz using side-coupled baluns [4] for RF and LO drives. The mixing elements used graded Schottky diodes for low turn-on voltage. The mixer achieved conversion loss of 12 dB at low LO power of 4 dBm.

II. Diode Quad

Most commercial Si-based Schottky diodes have low turn-on voltage ranges from 0.25 V to $\sim$ 0.7 V at 1 mA; however,

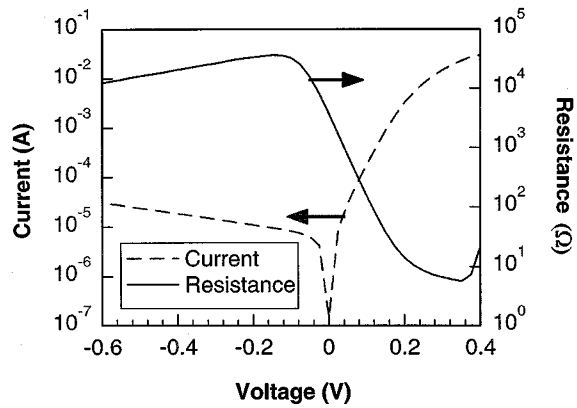

Fig. 1. Schottky diode dc characteristics.

they suffer from relatively high series resistance and poor frequency response. For a typical InP-based Schottky diode (with an AlInAs barrier layer), the turn-on voltage is about 0.7 V. The quad-ring diodes used in this MMIC mixer design are InP-based Schottky-barrier devices, which use the state-of-the-art design of chirped super-lattice layers consisting of alternating InAlAs and InGaAs [5]. These, in turn, provide the ease of control of turn-on voltage and barrier height. The turn-on voltage of the diodes increases as the number of periods in the super-lattice is increased. The diode used in this design has 3 periods of super-lattice, and turn-on voltage of 0.15 V at 1 mA with junction area of 6×6 μm^2. The diode-model parameters were extracted using broadband S-parameter measurements as well as dc characterization. The series resistance R_S and the intrinsic diode resistance were determined by the I–V curve and the diode dc resistance measurements as shown in Fig. 1. The diode's parasitic and bias-dependent intrinsic parameters were then obtained by fitting the equivalent circuit to the measured S parameters from 1 GHz to 60 GHz. The series resistance R_S for these diodes is about 4 Ω, and the zero-voltage junction capacitance is about 0.05 pF. The cutoff frequency of the diodes is about 0.8 THz.

III. Mixer Design

In this work we attempted to design a planar mixer with wide, overlapping RF-and LO-bands, very low LO drive, spurious-response rejection, and monolithic integration with other technologies. Planar side-coupled RF and LO baluns were designed [2] to meet these requirements. The balun consisted of an open circuit impedance section about one-half wavelength; the standing wave formed a short-circuited node near the center of the section. At this center, the current was at its maximum. Two short-circuited impedance sections,

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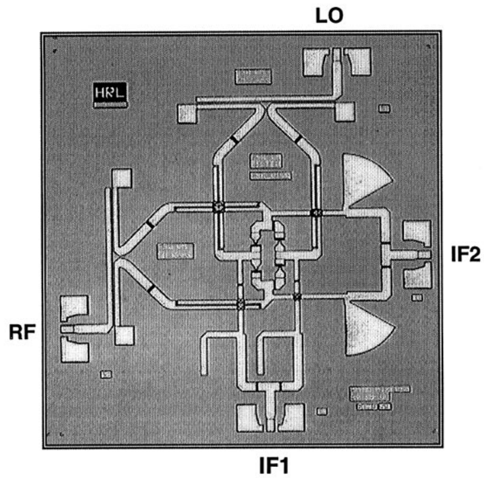
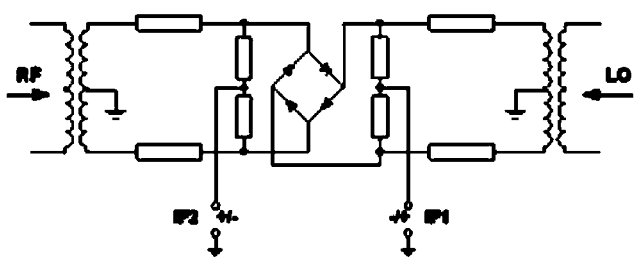


(a)



(b)

Fig. 2. (a) Photograph of a Ka/Q band double-balanced mixer. (b) Equivalent circuit of the mixer.

each having quarter-wavelengths, were coupled to the open circuit transmission line at the first half and the second half, respectively. The signals induced at the output ports of the short- circuited lines were of equal amplitudes and opposite phases. These baluns and the quad-ring diodes were connected to form a complete double-balanced mixer. The IF signals were extracted by simply shorting the ends of each two-wire pair carrying the RF and LO signals at approximately one-quarter wavelength of the highest operating frequency of 45 GHz. Consequently, the resulting impedance seen at the diode was high, but the IF signal was unaffected. In accord with potential applications in some communication systems, instead of grounding one of the IF ports gaining extra 3 dB, both IF ports were connected to 50-Ω loads. Thus, the two IF outputs had the same magnitudes and opposite phases. The mixer was then fabricated on a 3$''$ semi-insulating 100 μm-thick InP substrate. Fig. 2(a) shows the photograph of this mixer, which has an area of 2×2 mm^2, and its equivalent circuit is shown in Fig. 2(b).

IV. Performance

The wideband balun was evaluated using two-port on-wafer measurements with one of the output ports terminated with 50-Ω loads. Fig. 3 shows a plot of the measured insertion loss of the baluns and the amplitude and the phase balances between the two output ports. Disregarding inherent split loss of 3 dB, the insertion loss was less than 2 dB from 30 GHz to 60 GHz; the amplitude imbalance was less than 1 dB and the phase imbalance was less than 4° from the 180° phase difference between the two output ports. It should be pointed out that the performance of the balun, based on the analysis, is also valid above 60 GHz, however, due to the bandwidth limitation of our analyzer; the results could only be measured up to 60 GHz.

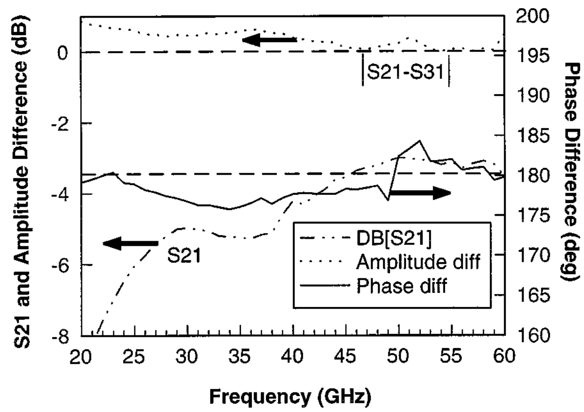
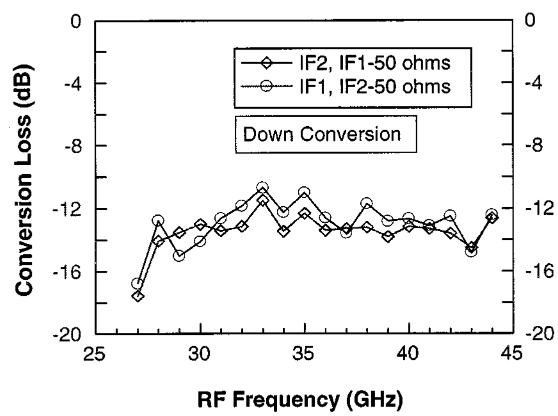
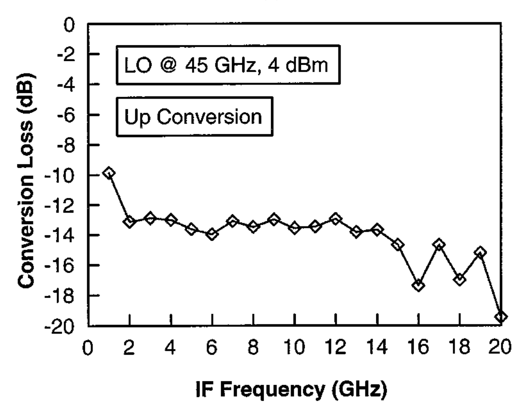


Fig. 3. Measured performance of the wideband balun.



(a)



(b)

Fig. 4. Conversion loss of the double-balanced mixer at fixed LO power of 4 dBm and frequency of 45 GHz for (a) up conversion and (b) down conversion.

While one of the ports was terminated with a 50-Ω load, the conversion loss of the mixer was measured separately at output ports IF1 or IF2 (as labeled in Fig. 2) as a function of the RF frequency sweeping from 27 GHz to 44 GHz. The LO drive was 4 dBm and fixed at 45 GHz. As shown in Fig. 4(a), the obtained conversion loss was 12 ± 2 dB within a RF bandwidth from 30 to 45 GHz. The 1 dB compression point of 1.4 dBm was measured.

It is worth noticing that an additional 3 dB conversion loss improvement can be obtained if one of the IF ports was grounded. A similar conversion loss measurement for the up conversion was taken on the same mixer. The RF signal sweeping from 1 GHz to 20 GHz was inserted at one of the ports IF1 with the other port IF2 terminated at 50-Ω; then the output signal was taken at the RF port as labeled in Fig. 2. The measured up conversion loss [shown in Fig. 4(b)] was about 13 dB from 1 GHz to 14 GHz with the aforementioned LO operating conditions.

V. Conclusion

In this letter, we have presented the design of a wide band double-balanced mixer with very low LO drive requirement. The InP-based quad-ring diodes, the central part of the mixer, were fabricated by using state-of-the-art super-lattice layers, which provided ease of control of turn-on voltage and an integrated solution with the HEMT and HBT technologies. The diodes exhibited a low turn-on voltage of 0.15 V at 1 mA. A conversion loss of 12 ± 2 dB in the 30–45 GHz band at the very low LO power of 4 dBm was measured at two IF ports. Additional 3 dB improvement could be achieved if one of the IF ports was terminated with ground.

Acknowledgment

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