A Ultra Low-Power Highly-Linear HITD Based Down-Converter for K-band Applications

I.Magrini, M.Camprini, A.Cidronali, G.Collodi, G.Manes

Dept. of Electronics and Telecommunications, University of Florence, V.S. Marta, 3 I-50139 Firenze - ITALY

Abstract - **In this paper a single balanced mixer, suitable for K band applications, is described. The prototype is realized using an InP process and it is based on Heterojunction Interband Tunnel Diodes (HITDs). The circuit, consisting of a pair of HITDs connected to a coplanar Lange coupler, is optimized by a proper diode scaling in the 19-26 GHz band, providing an IF ranging from zero up to 7GHz. Measurements highlight a conversion loss ranging from 6dB to 10dB and an IIP3 of 8dB in the desired band. Due to the diodes characteristic no DC supply is needed and the functionality is achieved with a LO power of -2dBm. The results also show a good agreement between the experimental data and simulations.**

I. INTRODUCTION

Over the last ten years, the trend in RF consumer applications has lead to the need for higher data rate and wider bands. The push for that comes from the increasing use of high data rate applications combined with the high performances achieved by wired connections, which force wireless applications to have improved performances as well.

In the case of RF systems the need for wider bandwidth means higher operating frequencies.

The availability of reliable technologies for such frequencies opens the door to wireless broadband applications like, for instance, the Local Multipoint Distribution System (LMDS) and the Wireless Metropolitan Area Networks (WMAN). Last but not least, the Ultra Wide Band (UWB) reserves an amount of the K band for automotive applications. A higher operating frequency obviously implies that parasitic elements become relevant and lay-out elements, which could have been ignored so far, are not negligible anymore, thus influencing the circuit performance. Therefore an accurate modeling of these ever smaller layout elements becomes very important and an accurate electromagnetic (EM) modeling of RF on-chip structures, like coils and interconnections, is needed. A further consequence of high operating frequencies is the effort to obtain good performances with a reasonable LO power.

In this paper a passive mixer operating in the 19-26 GHz band is presented. The circuit, based on a couple of HITD and a coplanar Lange coupler [1], has been realized using an InP process. The use of HITD devices as a mixing element must not surprise [2] since, due to their inherent quasi-square I/V device characteristic around zero-bias, it is possible to achieve a reasonable low conversion loss with a low LO power and a high linearity. The circuit has been designed by using an equivalent circuit model in conjunction with EM simulations. This paper briefly introduces the HITD technology features, the circuit description along with the design strategy. Finally a number of experimental results is reported to validate the design approach. The demonstrated mixer capability as a linear wide-band down-converter, reports a 8dBm IIP3 and demanding for a low LO level namely, -2dBm.

II. QUANTUM MICROWAVE MONOLITHIC INTEGRATED CIRCUIT TECHNOLOGY AND MODELING

The device technology adopted in this paper has been developed for low-power microwave applications [3], whose description is beyond the aim of this paper. It is based on the Heterojunction Interband Tunneling Diode (HITD), a two terminal device that exhibits a DC characteristic as reported in Fig. 1. The HITD has an almost quadratic I/V characteristic that permits the design of mixers with particularly high linearity. Moreover, being the current transport regulated by a PN heterojunction, the low frequency noise is considerably lower then FET based solutions. It is also demonstrated that the parasitic capacitance is considerably low and fairly voltage independent. All the above characteristics make the HITD a candidate for K band applications.

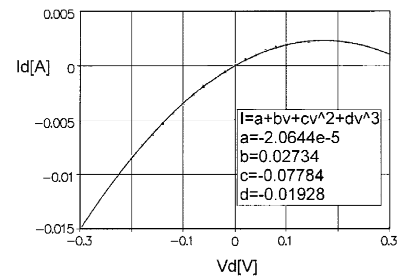

Fig. 1. Approximation by a third degree polynomial of the I/V HITD characteristic around zero voltage. Symbols: measured data; continuous curve: fitting.

The HITD equivalent circuit model is reported in Fig. 2, whose parameter identification procedure is based on the time-domain technique reported in [4].

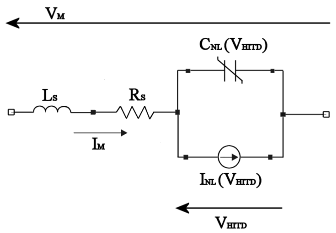

Fig. 2. HITD's Equivalent circuit
(V_M; I_M are the voltage and current measured pair).

Fig. 3 reports the comparison between modelled and measured data in the I\V plane at a frequency considerably lower, 5GHz, due to the present limitation of the equipment, namely the Large Signal Network Analyzer (LSNA), [4]. By the way this limitation didn't affect strongly the model capability in the design procedure as it will be demonstrated below.

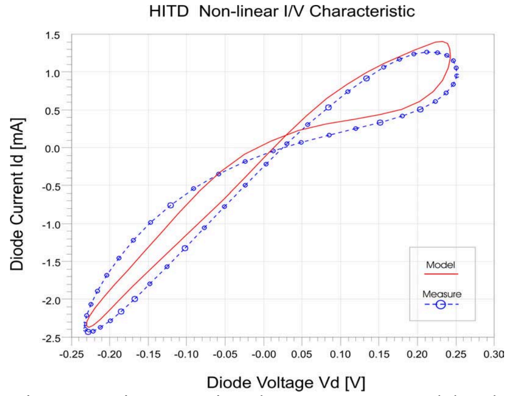

Fig.3: Time-Domain comparison between HITD model and LSNA measurements (V_{DC}= 0 V, F_{RF} = 4.8 GHz, P_{RF} =-2 dBm).

III. The K Band Mixer Topology and Design

The mixer topology is a single balanced structure based on a 90th degree hybrid as it is reported in Fig 4. In order to achieve the largest band, a Lange structure for the directional coupler has been chosen.

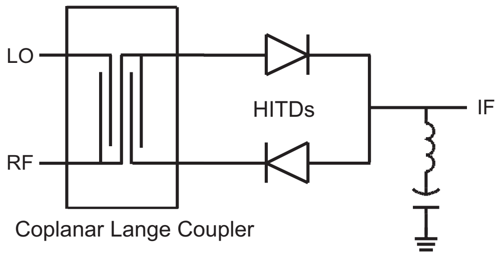

Fig. 4. Mixer topology.

The monolithic integration of the directional coupler with the HITDs on an InP substrate with a 600 um thickness requires coplanar waveguide technology. The whole design has been carried out using Agilent's ADS Momentum tool.

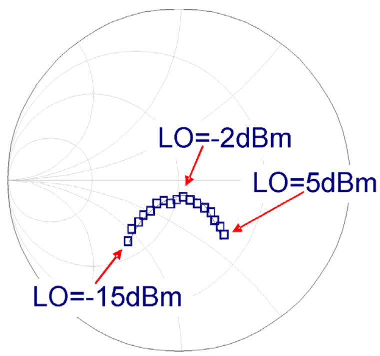

Fig. 5. RF optimum RF termination for a 2.5x2.5um HITD, as a function of the LO level.

Conventionally the mixer optimization, in terms of conversion loss and linearity, consists in the search for the optimum diodes termination. In this case we adopted a different approach, that is, to select the diode size and the LO level ensuring that 50 Ohms is the optimum termination for the best trade-off between Conversion Loss and IIP3 linearity.

Figure 5 reports the final analysis of the optimum diode termination as a function of the LO level at 19 GHz. The diode cross section is square and the size is 2.5 um, from the figure it can be seen that near -2dBm the value is close to 50Ω. These will be the LO level and the diode size adopted in the remaining design phase.

According to fig. 4 it is shown that the LO and RF signals are shorted at the IF port by means of a resonant LC circuit, composed by a lumped capacitor and a distributed inductor. The solution is necessary to allow a proper LO and RF current flowing through the diode and to improve the isolation.

Finally the prototype of the K band Down Converter, shown in Fig 6, occupies an area around 1.4 mm^2.

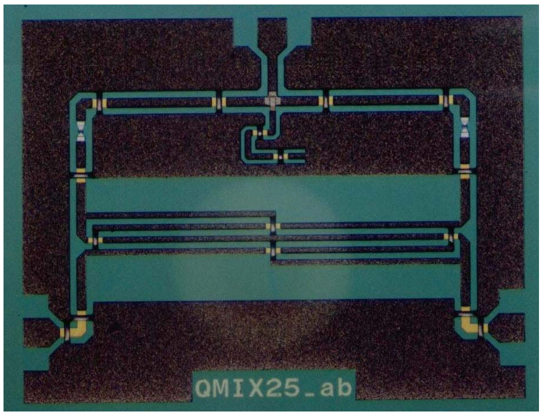

Fig. 6. The MMIC prototype photograph; dimensions: 1mmx1.4mm.

IV. Experimental Results

Mixer features have been tested by applying a 19 GHz, -2 dBm LO signal and sweeping the RF signal between 19.5 GHz and 26GHz. The conversion loss is reported in Fig. 7, in terms of simulated and measured data.

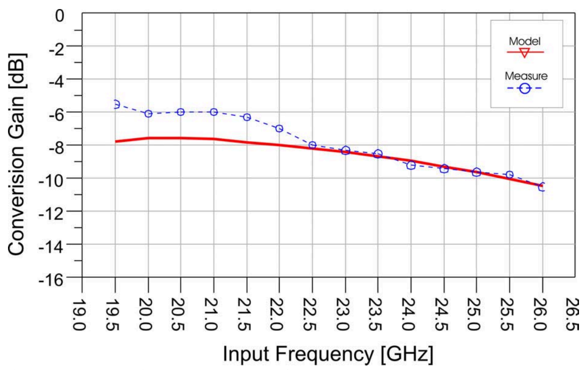

Fig. 7. Conversion Loss Vs IF frequency, F_{LO}= 19 GHz, P_{LO} =-2 dBm, P_{RF}=-20 dBm

The curves show a maximum conversion loss of 10 dB for a RF frequency of about 26 GHz, with 4dB maximum ripple in the band of interest for the applications.

A two tones test has permitted to evaluate the compression, the second and third order intermodulation products: the frequency settings were LO=19GHz, RF1=25.5GHz, RF2=25.51 GHz. The result of the test is shown in Fig. 8. A 1dB compression point of about –3dBm, an IIP2=18dBm and an IIP3 of 8dBm have been obtained.

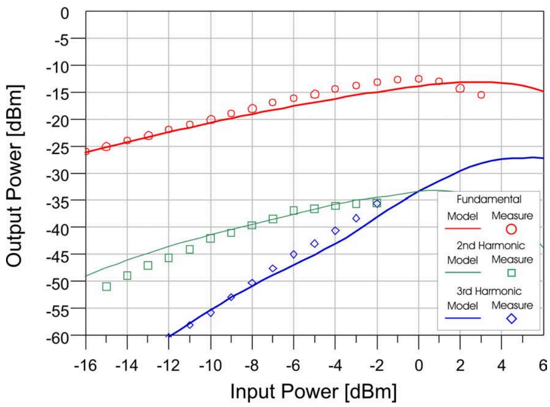

Fig. 8. Conversion Loss Vs IF power, F_{LO}= 19GHz, P_{LO} =-2 dBm, RF1=25.5 GHz, RF2=25.51 GHz.

The agreement between measured and simulated performances points out the reliability and accuracy of the design approach and the quality of the modelling procedures.

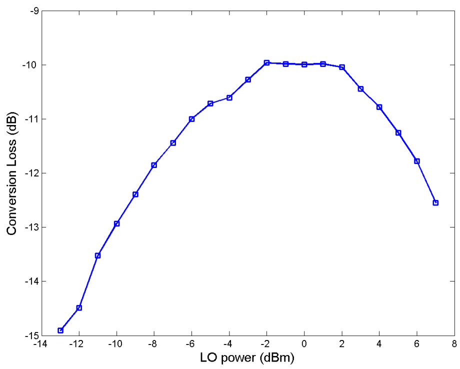

Fig. 9. Output IF power Vs LO power; LO=19GHz, RF=25.5GHz.

It is worth nothing that the value of the 1dB compression is reached for an input power which is close to the LO level. This is due to the particular I\V diode characteristic which, having a negligible third order nonlinearity permits the compression level close to the LO level.

This effect is not observed for the conventional Schottky diode based mixer. The conversion loss as a function of the LO power is reported in Fig. 9. As it is depicted, a flat maximum level is in the range -2dBm to +2dBm.

Moving to the mixer spurious response, a set up close to the maximum mixer band has been chosen. The output spectrum for an LO of 19.8 GHz and an RF signal of 25.5 GHz is shown in Figure 10.

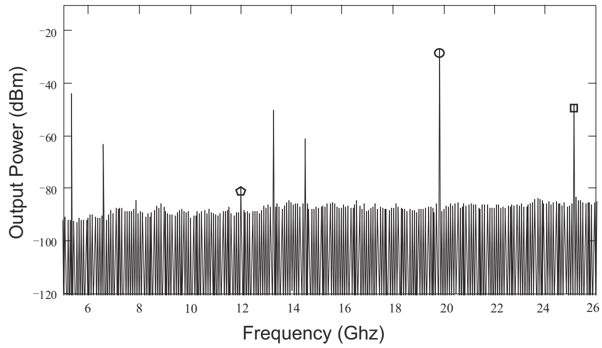

Fig.10. Output spectrum, F_{LO}= 19.8 GHz, P_{LO} =-2 dBm, RF=25.

Due to the Lange coupler signal de-phasing (90 degree) the mixer reject properties, differently from the 180 degree balanced mixer, are related only to the even harmonics of one signal (RF or LO) mixing with the even harmonic of the other. In addiction, when the sigma port is used as the LO port, the 180° hybrid mixer suppresses all the mixing products involving the even harmonic of the LO as well [5].

Looking at the output spectrum, the magnitude of the 2RF-2LO signal, located around 12 GHz (diamond), is around –80 dBm. This result highlights the good suppression of the spurious signals. The output filter effectiveness can be evaluated from the same graph, by looking at the LO and RF leakages. Taking into account an input power level for the LO and RF signals around -2 dBm and –45 dBm respectively, an isolation of 26 dB for the LO-IF port and 20 dB for the RF-IF port is obtained.

Finally, the LO isolation to the RF and IF ports as a function of the LO power is shown in Figure 11.

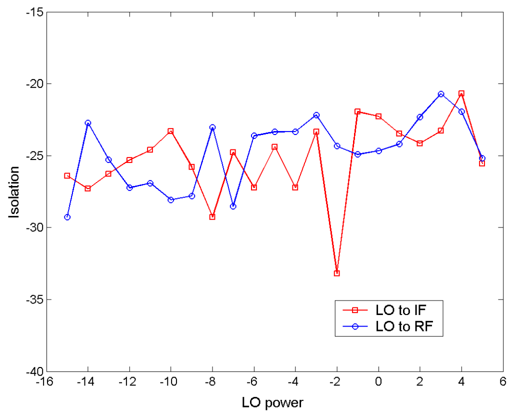

Fig.11. LO isolation to IF and RF ports. LO=19GHz, RF=25.5.

CONCLUSIONS

This paper presents a passive single balanced down converter for K band applications. The prototype is based on a coplanar waveguide Lange coupler and a pair of HITDs. The latter allows a tight control of the RF impedance permitting the optimization of the conversion properties using a low LO level (-2dBm), which in turn results an interesting feature for the system-level optimization. The experimental results show a conversion loss ranging from 6dB to 10dB, an IIP2 of 18dBm and an IIP3 of 8dB in the desired band.

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