# A Highly Linear Single Balanced Mixer Based on Heterojunction Interband Tunneling Diode

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Abstract - **In this paper a compact and highly linear MMIC single balanced mixer based on Heterojunction Interband Tunnel Diode (HITD) technology working at 1.8GHz, is described. The prototype consisted of a pair of HITDs biased at zero volts and a lumped element directional coupler with arbitrary impedance terminations. The salient feature of the mixer is the linearity due to the quasi square law DC characteristics exhibited by the device around zero voltage. The design techniques along with a detailed experimental validation are provided. The prototype exhibited an IIP3 power level of 17 dBm and a 1dB compression point of 7.5 dBm.**

## I. Introduction

The increasing interest in personal communication (PC), especially in the field of DCS-1800 MHz and the ISM band (2.45 GHz and 5.8 GHz) applications, has stimulated research on low power consumption, compact and integrated multifunctional components. In order to achieve these target the original approach and a new solution have to be taken into account. Low power consumption in particular becomes an important topic for wireless applications in order to conserve battery power, and to improve the talk-time. Zero biased nonlinear elements are of particular importance in low power circuit development.

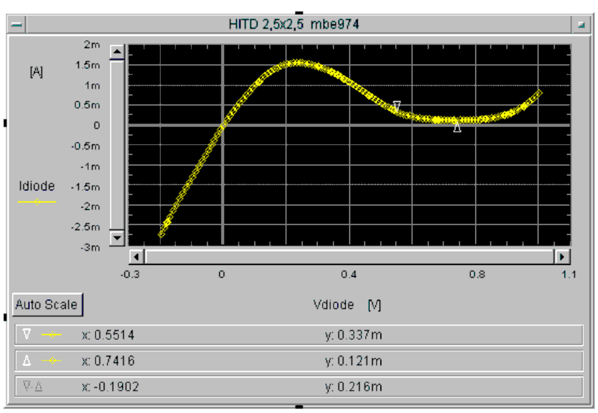


Fig.1: HITD Diode I/V characteristic

The availability of a novel technology such as Heterojunction Interband Tunneling Diodes (HITDs) enables the implementation of this nonlinear element into new MMICs. High compactness is another important objective in PC systems. Functional blocks, commonly used in transceiver RF sections [1], such as amplifiers, mixers, modulators and phase shifters, make use of sub-circuits (power combiners, filters, matching networks and directional couplers) designed by adopting a standard distributed elements approach. The monolithic implementation of such sub-circuits often results in large die area, owing to the dimension of the transmission lines. High integration levels and compactness of these sub-circuits may be achieved by considering new circuit configurations based on a lumped-element approach [2]. Furthermore, implementations of these circuits using passive elements would improve the power handling capability and phase noise characteristics of the communications system. Active configurations are generally very compact, and allow wide band operations but these implementations tend to increase the power consumption of circuits.

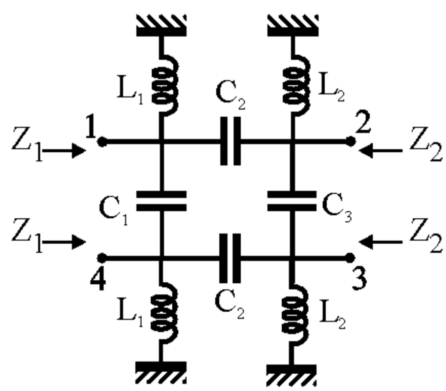


Fig.2: The lumped element directional coupler (LEDC) topology

This paper presents a novel highly linear single balanced mixer based on a 90 degree Lumped Element Directional Couplers (LEDC) [3] and a pair of HITDs biased at zero volt. The square-law behavior of the I/V characteristic of HITDs at V=0V, (as seen in Fig.1) enables the design of efficient single balanced mixer. It is well known [4] that a nonlinearity of the n-th degree generates n-th order mixing products. Consequently, the use of electron devices showing an approximately 2-nd degree

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nonlinearity in the mixer design, allows an inherently good performance in terms of third order intermodulation products. In a mixer operating at microwave frequencies, at which the unbiased junction impedance becomes a dominant factor, HITDs appear to be more flexible devices than the Schottky devices in this respect, [5]. Primarily, it is the fact that the barriers of a HITDs can be tailored during device designing in such a way that nonlinearities associated with the devices can be taken under control to match the microwave signal pump requirements. It is also possible in principle, to choose different layer structures for a device of the same diameter to obtain optimum resistive nonlinearities. These are the main motivations for the investigation of the single balanced where the nonlinear element are tunnel diodes biased in V=0V.

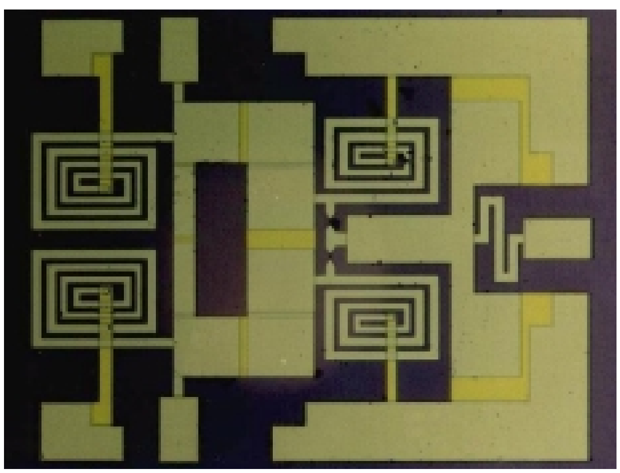

Fig. 3: chip photo of the single balanced mixer prototype implemented by LEDC and HITD.

## II. Design Technique

The LEDC circuit is designed considering as characteristic impedance for two out of the four ports, the same value as the non-linear elements connected to them, while the other ports maintain the 50 Ω characteristic impedance of the system. This technique allows tailoring the circuit to the specific impedance requirement of the terminating elements. The LEDC topology is based on a two coupled π-LC cells topology [3] as shown in fig.2, where $Z_1$ and $Z_2$ are the characteristic impedances at ports 1 and 4, and at ports 2 and 3 respectively. Introducing the parameters:

$$n = \frac{Z_1}{Z_2} \tag{1}$$

representing the ratio between the system impedance, $Z_1$, and the impedance associated to the termination, $Z_2$, and the mean value:

$$Z = \sqrt{Z_1 \cdot Z_2} \tag{2}$$

The LEDC design formulae can be expressed in the following form, [6]:

$$C_1 = \frac{1}{\sqrt{n}\cdot\omega_0\cdot Z} \quad C_2 = \frac{\sqrt{2}}{\omega_0\cdot Z} \quad C_3 = \frac{\sqrt{n}}{\omega_0\cdot Z}$$
$$L_1 = \frac{Z}{\omega_0\cdot\left(\sqrt{2}+\frac{1}{\sqrt{n}}\right)} \quad L_2 = \frac{Z}{\omega_0\cdot\left(\sqrt{2}+\sqrt{n}\right)} \tag{3}$$

The matching problem between the LEDC and the nonlinear elements is solved considering that the $Z_2$ consists in the impedance of the diode biased at V=0V.

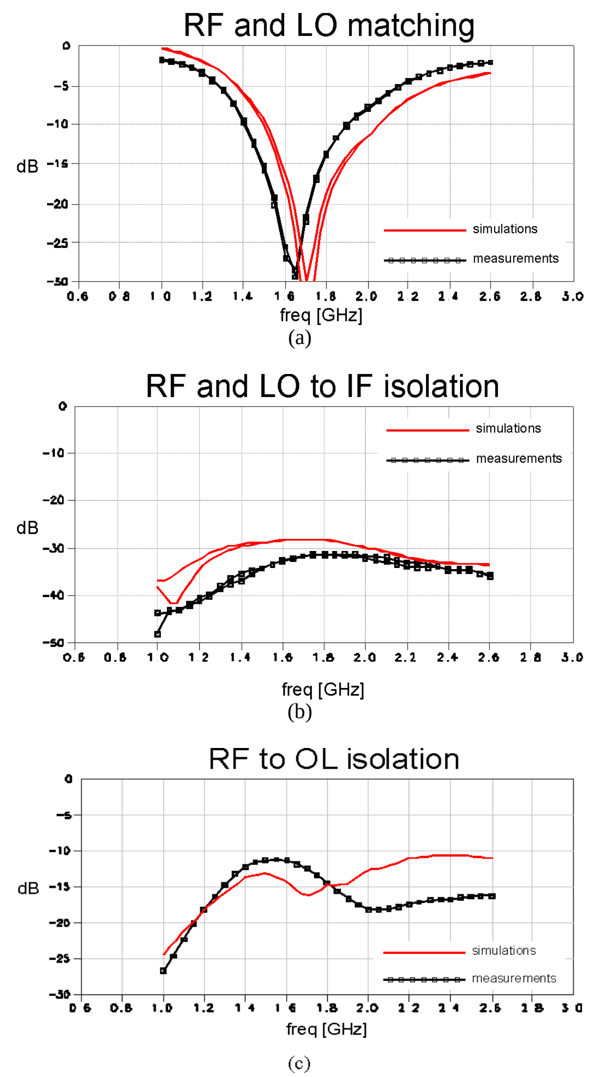


Fig.4: Small signal mixer characteristics: a) Matching, b) RF and LO to IF isolation, c) RF to LO isolation

At the operation frequency of 1.8GHz and in this bias condition the diode - which is a 2.5x2.5μm$^2$ square mesa -

exhibits an impedance value around 35Ω and a negligible reactive part. Therefore, the values of the LEDC circuit element have been calculated using $Z_1$=50Ω and $Z_2$=35Ω. Moreover it has to be pointed out that the diodes used in the circuit have shown very high current densities (50-60KA/cm$^2$) and peak to valley ratios between 10 and 15, [7].
The prototype, implemented on an InP substrate, is represented in Fig. 3, and is realized in coplanar technology. The entire design has been carried out using the Momentum tool within the Agilent ADS package. This approach allows careful design of the dimensions of any element, and enables the consideration of any E.M. coupling between different parts of the circuit, giving a further compact arrangement, [6]. An output low-pass LC filter was also introduced on-chip, as it is easily identifiable in Fig. 3.

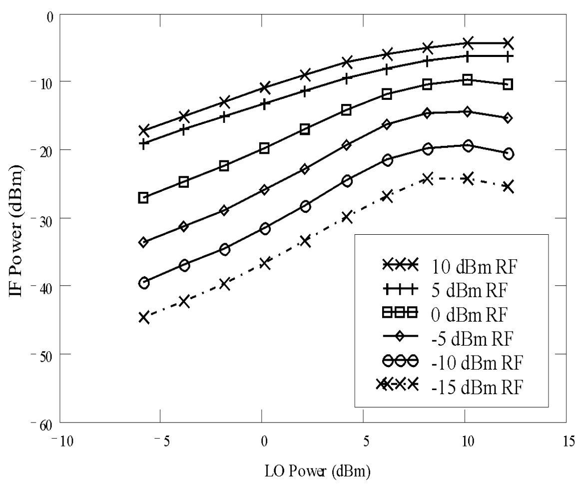


Fig.5: IF power as a function of LO power at different RF power levels

### III. EXPERIMENTAL RESULTS

The small signal mixer performance in terms of impedance matching, isolation between the RF and LO to IF and the isolation between RF and LO are reported in Fig. 4. In the same graph the simulated performance are also reported for the sake of comparison. Concerning the RF and LO ports matching (Fig.4a), a slight frequency shift is observed in graph, it is mainly due to an incorrect guess of the HITD reactive behavior. The RF and LO to IF isolation (Fig.4b) is obtained because of the output IF filter, otherwise this feature would be unachievable. The LO to RF ports isolation (Fig.4c) is around –15dB at the design frequency, it is a common value for mixers implemented using 90 deg coupler. In any case this performance can be improved implementing 180 deg coupler.

The large signal performance of the prototype has been tested using a LO frequency of 1.8GHz and a RF frequency of 1.83GHz with different levels of LO and RF power. Fig.5 shows the mixer performance in terms of IF output power with respect to the LO level depending upon different RF power. From the graphs is possible to observe that a value of 5dBm is a acceptable trade off between IF power and linearity.

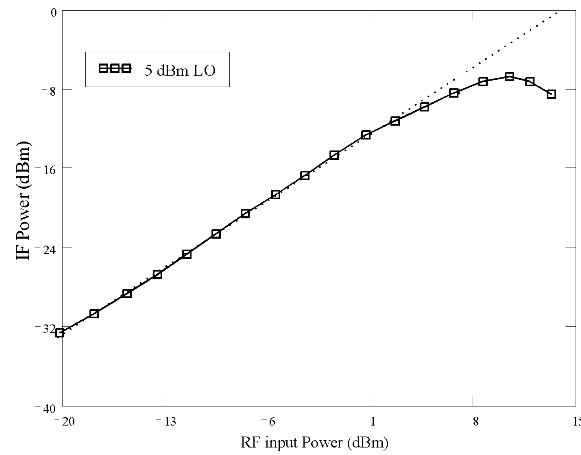


Fig. 6: Output IF power, for an input RF frequency of 1.83GHz and LO=1.8GHz and 5dBm

The main characteristic of the proposed mixer is the linear response, which results in a high value for both the 1dB compression point and the input third-order product (IIP3) parameters. Fig. 6 reports the IF level as a function of the RF power for 5dBm LO; the graph permits to evaluate a 1dB input power compression point of 7.5dBm.

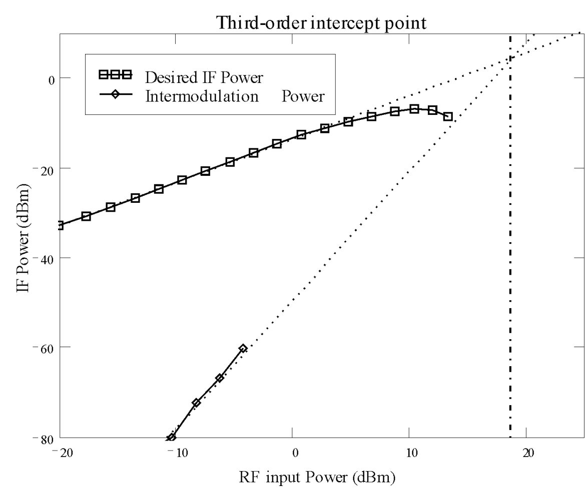


Fig.7: IF and IM3 output power for RF1=1.82GHz, RF2=1.84GHz, LO=1.8GHz, 5 dBm. The calculated IIP3 is 18.5dBm

The linearity of the mixer has been tested using two RF signals respectively at 1.82GHz and 1.84GHz. Fig. 7 plots the IF and the IM3 versus the RF input power. The IIP3 is measured and determined as 18.5dBm under the LO level of 5dBm. It is worth to observe that usually this performance is obtained in double balanced diode mixers.
In Fig. 8, the rejection behavior concerning the spurious responses, 2*RF-2*LO, for RF=1.83GHz and LO=1.8GHz, is reported for different LO level. In particular they appear to be more than 17dB below the IF output level, at the same conditions for the LO and RF input powers. The other spurious responses like the (2,1) and the (1,2) are rejected by the IF filter; their values (not reported here) stand below the –40dB level.

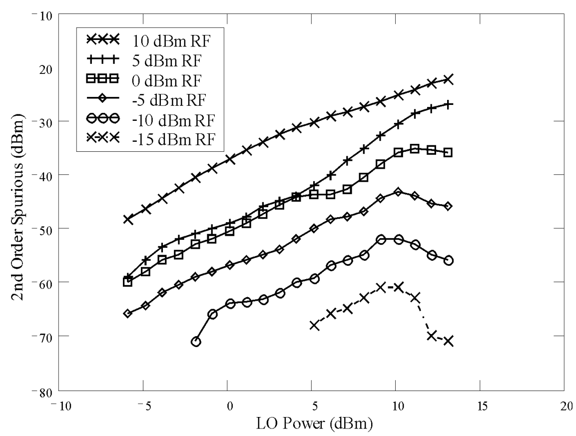


Fig. 8: spurious response (2,2 ) as a function of LO power at different RF power levels; RF=1.83GHz, LO=1.8GHz.

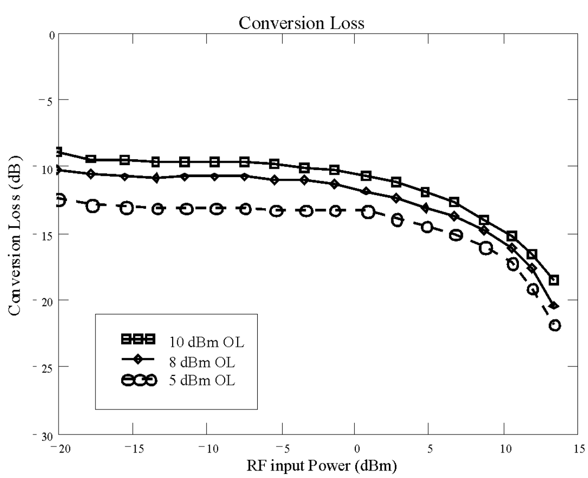


Fig.9: Conversion Loss as a function of different LO power

Finally the mixer conversion loss, shown in Fig. 8, is around 10dB in the linear behavior range. This performance, which is higher than the conversion loss of typical Scottky diode mixer, constitutes the main drawback of the proposed mixer and is due to the low degree on nonlineariy presented by the HITDs. However as discussed in [5] this feature is strongly related to the peak voltage and current presented by the diode. In that sense further experimental results for the conversion loss obtained changing the diode structure and consequently the HITD I\V characteristic will be provided in the final paper.

## IV. CONCLUSION

A compact single balanced mixer for ISM application, consisting of a tunnel diode biased at 0V, has been described. Showing the diode a quasi 2-nd order nonlinearity, they appear interesting for the linear mixer development. The prototype working in the 1.8 GHz band has been realized on InP substrate. Isolation between the input\output ports and matching are reported. Large signal measures describe the linear response in terms of both the 1dB compression point and the 3rd order intercept point (IIP3). This work is part of a project on the applications of quantum functional devices to MMICs.

## REFERENCES


[1] H. Suwaky, T. Nakagawa, T.Ohira "An MMIC local oscillator for 16-QAM digital microwave radio systems", IEEE Tran. Microwave Theory and Tech., vol.43, no.6, June 1995 pp.1230,1235

[2] K. Ali, A. Podell " A wide band GaAs monolithic spiral quadrature hybrid and its circuit application " IEEE - JSSC Vol. 26 nr.10 Oct. 1991.

[3] G. Avitabile, A. Cidronali, C. Salvador, M. Speciale "A Compact MMIC 90° Coupler for ISM Applications ", IEEE - MTT-S Denver CO June 1997.

[4] S. A. Maas, 'Nonlinear Microwave Circuit', Artech House

[5] Y. Liu, D P. D.Steenson,'Investigation of subharmonic mixer based on a quantum barrier device', IEEE Tran. Microwave Theory and Tech., vol.48, no.4, April 2000 pp.787-763

[6] A. Cidronali, G. Collodi, M. Desphande, N. El-Zein, H. Goronkin, G.Manes, V. Nair, C. Toccafondi,' A MMIC lumped element directional coupler with arbitrary characteristic impedance and its application' 30th European Microwave Conference, Paris, France, 2-6 October 2000

[7] N. El-Zein, M. Deshpande, G. Kramer, J. Lewis, V. Nair, M. Kyler, S. Allen, and H. Goronkin, 'DC and RF Characterization of Different Heterojunction Interband Tunneling Diodes', International Conference on Indium Phosphide and Related Materials, May 2000, pp. 146-149