A Highly Linear Mixer For Zero-IF Bluetooth Receiver

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In this paper a compact and highly linear monolithic integrated circuit (MMIC) suitable for zero-IF Bluetooth receiver is described. The prototype is designed in order to overcome the drawbacks that homodyne receivers present, like flicker noise, LO leakage and sensitivity to the 2-nd, 3-rd order intermodulation products. For these tasks a passive sub-harmonic topology has been utilized. The fabricated prototype exhibites a 3-rd order intercept point of +30dBm, 2-nd order intercept point of +98dBm, conversion loss of 8dB, 1-dB compression point of +4 dBm and better than 50dB small signal isolation RF and LO ports.

INTRODUCTION

Short-range microwave links using the newly introduced Bluetooth standard are expected to be key elements for the next generation of wireless systems. To reach this ambitious goal the Bluetooth enabling technologies have to meet rigorous requirements in terms of size, low cost and low DC power consumption in the implementation of the fundamental functional blocks. This trend go through the removal of expensive external components, such as surface acoustic wave (SAW) filters and inductors, reducing the need for external RF tuning elements, thus making the IC simple to develop and to implement in high volume, low cost applications. The low-power\low-cost conscious system design approach takes carefully into account the process technology, the design method as well as the definition of the optimum system architecture, see Abidi et al (1). Among the others, zero-IF receivers may play an important rule in the design of wireless systems provided that some issues were carefully understood and corresponding solutions provided. The zero-IF architecture permits high-level of integration and eliminates the requirement for image filter, the drawbacks consist in the presence of DC offset onto the desired low pass band-base signal, high sensitivity to flicker noise and high requirement for rejection of local oscillator feed-through. These are the main design challenges for the designers that make zero-IF yet a relative complex architecture to implement. Specifications for the Bluetooth standard for the receiver sensitivity, adjacent channel interference, co-channel interference and intermodulation distortion are defined on the basis of system simulations obtained considering conventional superheterodyne or low-IF receiver architectures. If compared with the above mentioned architectures, the zero-IF one is considered more sensitive to high level in-band co-channel interference and with low adjacent channel protection. This is the typical situation for systems that are interference limited rather than range limited, see Haartsen and Mattison (2). To this end is clear that the use of zero-IF receiver in wireless product can be exploited if highly linear mixers, in terms of 3-rd and 2-nd order intermodulation products, are developed in low-cost technological process.

In the down-converter proposed in this paper, all the issues introduced above have been approached resulting in an quadrature highly linear mixer MMIC prototype described in the next session. The performance of such a system has been also tested implementing the Bluetooth receiver in the HP-Agilent system simulator and performing the appropriated test, see application note 1333 (3).

CIRCUIT DESIGN

The schematic Bluetooth zero-IF receiver considered here is represented in Fig.1, in which the key component is the in-phase (I) and quadrature (Q) demodulator topology based on even harmonic mixer.

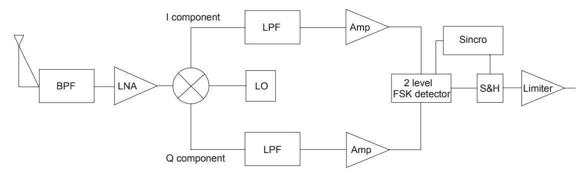

Fig.1. Zero-IF Bluetooth receiver architecture

The subject of this paper is the design and the test of a mixer prototype compliant whit this architecture. The topology of the mixer, as shown in Fig.2, consist in a 90° Lumped Element Directional Coupler (LEDC) and a double pair of antiparallel diodes, which act as single ended mixer, see Cohn et al (4) and Mantipour et al (6). The diode configuration is the responsible for the reduction of the 2-nd degree nonlinearity and hence for the strong reduction of the 2-nd order intermodulation product. This feature along with a high IIP3 are the key parameters for the reduction of the DC offset and in-band co-channel interference.

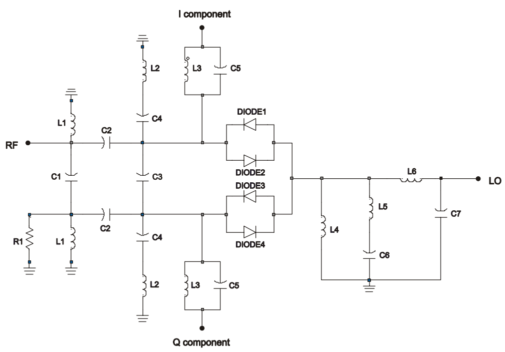

Fig. 2. I Q mixer schematic

The LEDC has the functions of power divider, phase shifter and matching network for RF signal, moreover it offers an idler for the LO. The LEDC design and topology are based on the formulas introduced in Cidronali et al (7). Differently by the topology presented in (7) the inductors in parallel to the I and Q ports has been replaced by a L-C series. This simple solution shows a double behavior: it realizes the required termination for the LO and the equivalently act as the required inductance value, L2 for the RF signal; two resonant cells complete the output network for the I and Q ports. They present an open circuit at RF and a short circuit for base-band signal. As shown in Fig. 2 the I/Q outputs of LEDC are directly connected to the diodes.

The LEDC circuit is designed considering as characteristic impedance for the two coupled ports, a value that arises from the trade-off between the IM2, IM3 levels, the conversion loss and the RF\LO isolation; Z2 in (7). In the particular case of the diodes pair, the device impedance at zero bias is of the order of a hundred ohms under the effect of the LO signal. It depends on the parasitic resistance, the reactive component and the I/V characteristic around zero. The other ports, the RF and the isolated port, maintain the 50Ω characteristic impedance of the system. This technique allows tailoring the circuit to the specific impedance requirements of the terminating elements and optimises the linearity of the mixer as deeply discussed in Cidronali et al (8), allowing the circuit to reach very high values for IP2 and IP3.

The use of a subharmonic mixer implemented by a couple of diodes biased in Vd=0V, gives the advantage of an inherently absence of flicker noise. Additionally, the lack of active components in both the RF and in the LO branches maintains the intermodulation performance and avoids a possible performance degradation in terms of flicker noise contribution.

An important requirement in zero-IF receiver consists in the high LO to RF port isolation. This prevents the various forms of time-variant DC off-set, which is a major reason of receiver sensitivity decreasing. In the topology introduced here, this requirement is met by the inherent band pass selectivity of the LEDC in conjunction with the mixer even harmonic pumping. Finally, the LO matching network provides the required match for the LO source and the proper short termination for RF signal. .

EXPERIMENTAL RESULTS

An MMIC prototype has been manufactured by the OMMIC foundry GaAs-ED02AH process, the choice for this kind of technology must not surprise, the possibility to integrate in the same chip the LNA, the direct modulated VCO transmitter along with high Q passive components are factors which determines high performance, low power consumption and possibly a favourable overall cost budget. The chip size is $1x1.5mm^2$, a description of the performance is provided in the following.

The prototype performance characterization is divided in small signal test and intermodultation\convertion loss test. In the first group the most significant parameters consists in the phase and amplitude balance between the I and Q channel. The imbalance arises by the difference between the nominal and the actual element parameters that compose the LEDC, the electromagnetic interaction between those elements increase the imbalance.

Momentum tool within the ADS HP-Agilent product has been a significant phase of the design. The experimental results around the 2.4GHz ISM band are provided in Fig.3a\b.

From Fig.3a is possible to evaluate a phase mismatch at 2.4GHz of 4.5 degree while from Fig.3b an amplitude mismatch of 1dB, which are value normally achieved whit similar configuration. As discussed in the previous section a second important parameter consists on the LO to RF isolation, it is reported in Fig. 4 and its value spans in the range of –50,-60 dB. Moving on the large signal characterization, the Fig. 5 reports the Conversion Loss (CL) for a LO signal at 1220MHz and an RF at 2440GHz, due to the impossibility to tune the two test signal exactly on the desired frequency a IF=250Hz has been observed instead of a DC level.

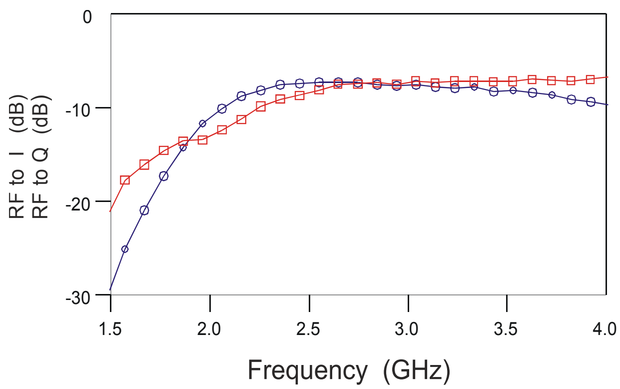

Fig. 3a Measured small signal amplitude for RF to I (circle) and RF to Q (square) components

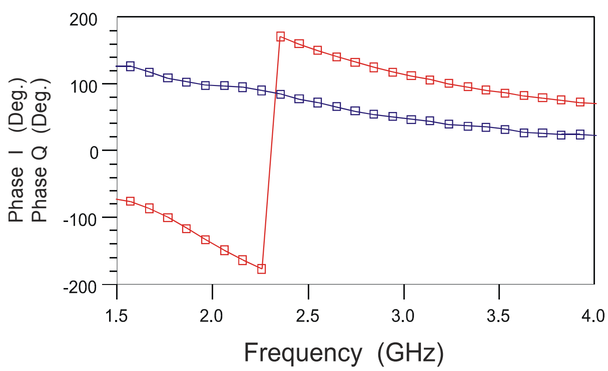

Fig. 3b Measured small signal phase for RF to I (circle) and RF to Q (square) components

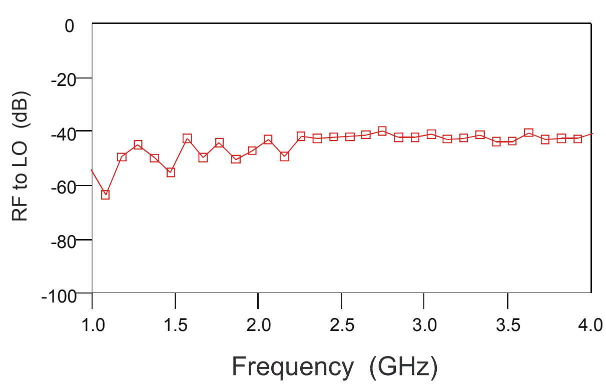

Fig. 4 : Measured small signal isolation between LO and RF ports

The level of this low frequency signal has been reported in the figure allowing the calculation of a minimum CL of 8dB (loss referred to the single I\Q component) with a LO power of 13dBm.

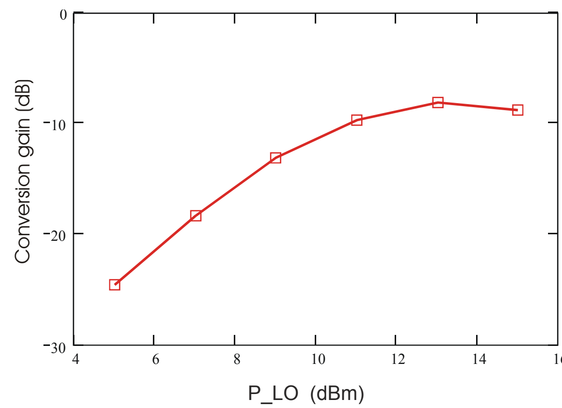

Fig..5 Measured conversion gain for a LO of 1220MHz and RF=2440 MHz, -10dBm

The intermodulation products are the most interesting feature of the prototype. Naturally this topology is only virtually free of 2-nd order nonlinearity, in reality is easily demonstrable that the resistive loss in series with a two-terminal nonlinearity give rise to a even nonlinearity which are responsible for the IM2. These terms become more relevant as the LO level increases. As it is shown, Fig.6 reports the IM2 as a function of RF level for different the LO levels, namely from 11dBm to 15dBm which are level that guaranty the same CL, see Fig. 5. The other relevant drawback of direct conversion receiver is the presence of DC offset deriving from local oscillator selfmixing.

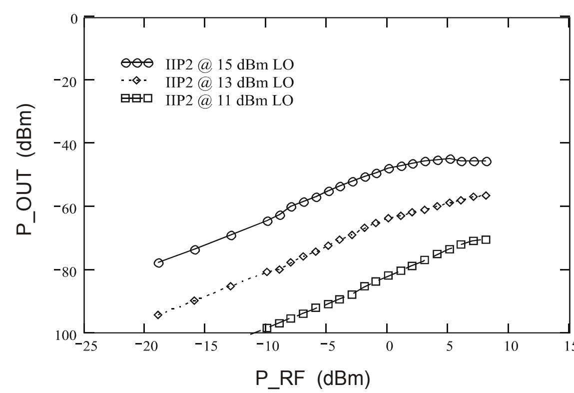

Fig.7 Measured 2-nd intermodulation product for a LO of 1220 MHz RF1=2441.5 MHz and RF2=2442.5 MHz

The graph in Fig.7 show the growth of DC offset related to different LO power. The DC level is also strictly related to the LO power. The best performance is obtained for not advanced power of 12 dBm. For this response the optimum LO level has been fixed at 11dBm.

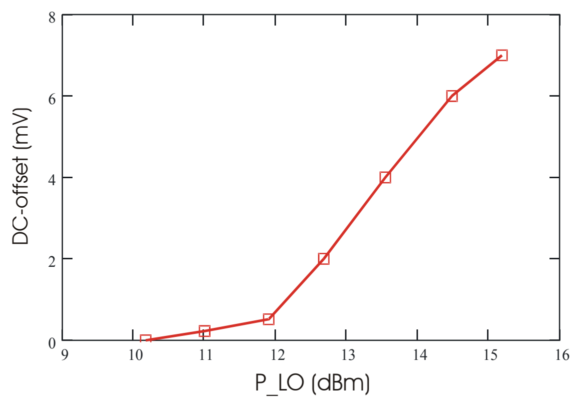

Fig.7 Measured DC offset for different LO power

This LO power furnish the highest possible IM2 and IM3 for the mixer: whith an LO of 1220MHz and 11dBm level, and two RF signals, respectively RF1=2441.5MHz and RF2=2442.5MHz exhibits an IIP3= 30dBm and an IIP2 of 98dBm (Fig.8). These values can be considered excellent if compared with the available literature (5),(6),(8) and in Nimmagadda et al (9).

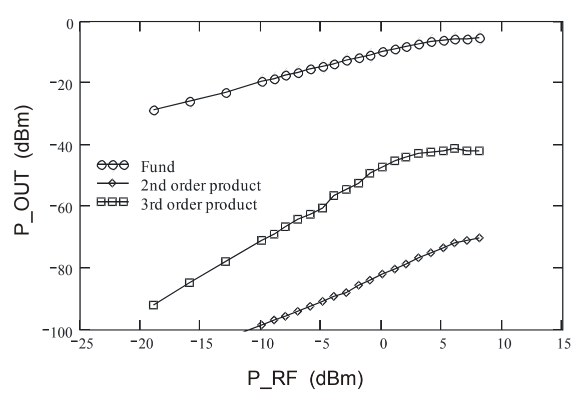

Fig.8 Measured insertion loss, 2-nd and 3-rd intermodulation product for a LO of 1220 MHz and 11dBm level, and RF1=2441.5 MHz, RF2=2442.5 MHz

CONCLUSIONS

This paper presents a passive harmonic mixer suitable for ISM band (Industrial Scientific Medical) direct conversion receivers. The tests on the prototypes (15 samples) have shown excellent values of IP2 and IP3, conditions that guarantee an elevate suppression of in-band co-channel interference.

Moreover the downconversion carried out through passive zero bias devices can limit the introduction of the flicker noise in order to avoid the signal to noise ratio corruption.

REFERENCES

(1) A. A. Abidi, G. Pottie, W. J. Kaiser, ”Power-conscious design of wireless circuits and systems”, Proceeding of the IEEE, Vol.88, no. 10, Oct. 2000, pp. 1528-1545.

(2) J. C. Haartsen, S. Mattisson, “Bluetooth, a new low power radio interface providing short range connectivity”, IEEE Proceedigs of the IEEE, Ottobre 2000.

(3) Agilent Technologies, ‘Performing Bluetooth RF measurement today’ application note 1333

(4) M. Cohn, I. E. Degenford, and B. A. Newman, "Harmonic mixing with an antiparallel diode pair," IEEE Trans. Microwave Technology Tech., VoI.23, 1975.

(5) B. Matinpour, C. Chun, S. Han, C. H. Lee, J. Laskar,’A compact monolithic C-band receiver direct conversion receiver’, IEEE Microwave and Guided Wave letters, Vol.10, no. 2 Feb. 2000, pp.67-70

(6) M. Shimozawa, K. Kawakami, H. Ikematsu, K. Itoh, N. Kasai, Y. Isota, O. Isota, "A monolithic integrated even harmonic quadrature mixer using a balance type 90 degree phase shifter for direct conversion receivers," 1998 IEEE Radio frequency IC Sym. Digest, pp.209-212.

(7) 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 Microwawe Conference, Paris, France, 2-6 Ottobre 2000.

(8) A. Cidronali, G. Collodi, M. Deshpande, N. El-Zein, V. Nair, G. Manes, H. “A Highly Linear Single Balanced Mixer Based on Heterojunction Interband Tunneling Diode”, IEEE Trans. on Microwawe Theory and Techniques, Vol. 49. 12, Dec. 2001.

(9) K. Nimmagadda, Gabriel M. Rebeiz, “A 1.9 GHz Double-balanced subharmonic mixer for direct conversion receiver“, Radio Frequency Integrated Circuits (RFIC) Symposium, 2000. Digest of Papers. 2001 IEEE , 2001