Using HBT BiCMOS Differential Structures at Microwaves in SiGe Technologies

H. Bazzi, S. Bosse, L. Delage, B. Barelaud, L. Billonnet, B. Jarry

I.R.C.O.M.- UMR CNRS n°6615 – 87060 LIMOGES Cedex, France – *gary@ircom.unilim.fr*

This paper discusses the use of differential structures for active functions at microwaves. Starting from the example of a single-ended LNA structure, we show the advantages of using a differential approach with the design examples of a LNA, a floating negative resistance and a differential compensated LC filter structure

INTRODUCTION

During the last three decades, the use of Silicon technology was restricted to low frequency digital and analogue applications. Due to great advances of Silicon, and Silicon-Germanium technologies particularly during the last decade, Silicon-based ICs have found an increasing importance for RF applications (1). Recently, the number of articles reporting the use of SiGe technology for RFIC design has increased significantly.

In comparison to GaAs, Si/SiGe technology is obviously advantageous, according to its capability to achieve more compact and cost effective circuits. Anyway, in spite of these advantages, the designer has to be aware of some new constraints at microwaves.

The first major problem is encountered for CAD tools. Because of the classical use of silicon technology for digital and analogue applications at low frequencies, most part of the component libraries are naturally developed for CAD software using the same approach. The design philosophy of these circuits is very far from that used for classical microwave analogue circuits. As a result, some components like inductors are not available, because they are not classically used at low frequencies. In some processes, it is also the case for varactor diodes. Some component models are at now still not parameterised, thus making any optimisation a hard task.

For technological reasons, the ground plane of a circuit on silicon is located on the top of the substrate. It is then not possible to strictly consider microstrip lines, even if recent works have shown the feasibility of transmission lines in polymers such as BCB, allowing performances close to those obtained with GaAs (1).

From the design point of view, another problem comes from the specific conductivity of the doped Silicon

(SiGe) substrate and its bad isolation (some tenths of ohms.cm compared to 10^5 ohm.cm for pure silicon).

This leads to a considerable increase in the number of parasitic capacitances. These capacitances are non-negligible regarding the other capacitances of the circuits.

A particular attention should also be paid to the leakage currents due to the specific conductivity of the substrate. To solve this problem, many manufacturers use guard rings. These rings are buried layers, surrounding partially or totally the component to be protected by acting as PN junction biased in inverse. A positive point is that, all these protection processes clearly allow a more compact implementation in comparison to GaAs.

Note that another important point also resides in the fact that in circuits using bipolar transistors, the designer must be familiar with particular biasing methods and topologies which clearly complicates the design procedure.

Among all the Si/SiGe processes, the SiGe BiCMOS HBT is a promising solution for active function design at microwaves. BiCMOS HBT is the name given to heterojunction bipolar transistor, for which the base is doped with Germanium. Using this reliable and stable process, the designed chips work much faster. Besides, this technology takes advantage of the integration capability of CMOS process that again leads to more compactness.

CLASSICAL SINGLE-ENDED LNA STRUCTURES

We present here a classical topology of a single-ended Low Noise Amplifier using a BiCMOS HBT SiGe process. Such realisation do not focuses on performances but just emphasises the ability to design classical microwave functions such as low noise amplifiers using BiCMOS HBT SiGe process. Layout of the LNA using AMS BYR 0,8 µm process is given in figure 1. Circuits dimensions are 660x720 µm².

Simulations show that this LNA presents at 1,64 GHz a gain of 12 dB associated with a noise figure of 4,6 dB.

Compression point has been simulated for an input power of -3,6 dBm with a IP3 third-order interception point of 18,6 dBm. This circuit is at the foundry. Measurements will be available at the conference.

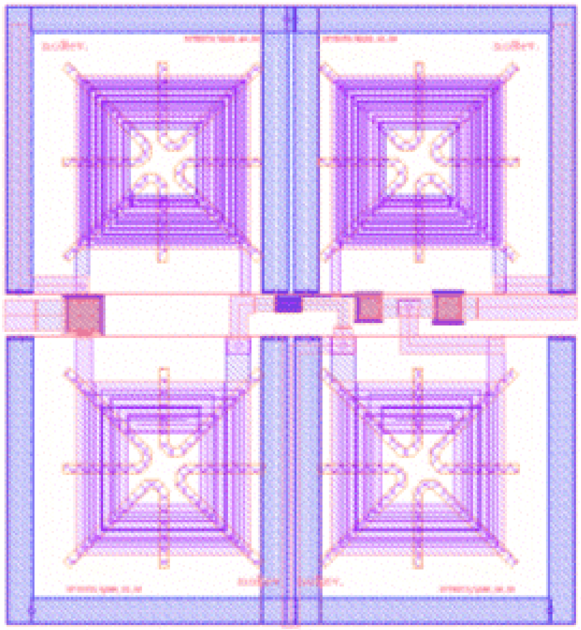

Figure 1 : Layout of the single-ended LNA

DIFFERENTIAL MICROWAVE LNA STRUCTURES

Since many years ago, the differential structure was limited to the low frequency applications. Differential structures have the following advantages compared to single-ended topologies :

- They are insensitive to noise and interference coupled through supply lines and substrate.

- Many linearisation method used for transconductance stages can also be used for low noise amplifiers and filters using this approach.

- They have smaller even-order distortion.

Figure 2 shows a differential LNA architecture. It consists of an input transistor Q_A and a cascode transistor Q_B which provide high isolation between input and output. A parallel RC circuit is added in series between the two transistors of the cascode stage to produce Miller's effect in order to reduce the high input impedance due to the input high current gain of the transistor. Input impedance value can be reached through the appropriate choices of R and C, without affecting the optimum noise figure of the circuit. The circuit die is about 200x200 μm^2.

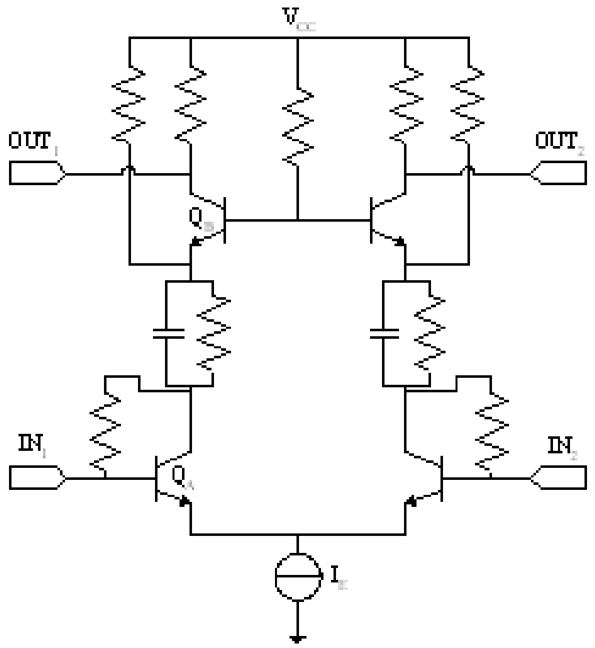

Figure 2 : Schematic of the differential LNA

The S-parameters are shown in figure 3. The LNA has a gain of 8.5 dB at 2GHz. At this frequency, the noise figure is about 1.5 dB.

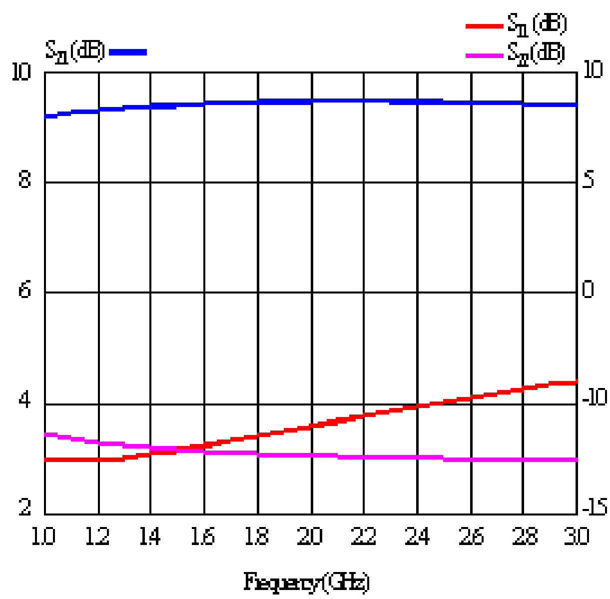

Figure 3 : S-Parameters of the differential LNA

Figure 4 shows the Noise factor of the differential LNA is about 1.7 dB at 2 GHz.

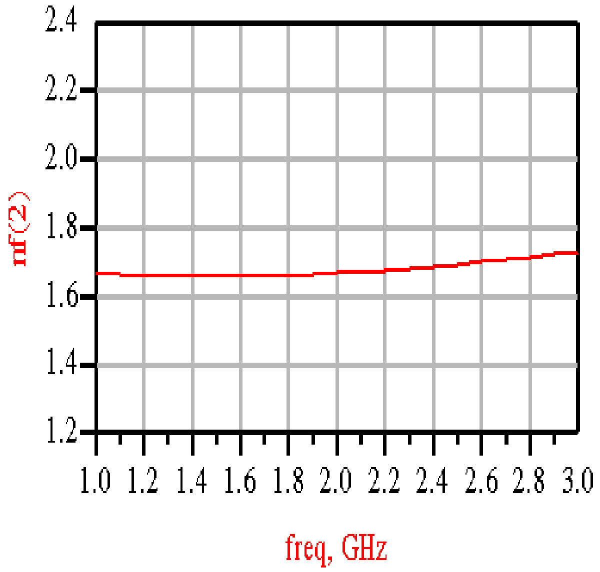

Figure 4 : Noise Figure of the differential LNA

OTHER DIFFERENTIAL MICROWAVE STRUCTURES

Differential Negative Resistances

The described circuit uses a BiCMOS SiGe HBT technology. Such differential topologies generally present a real part of the impedance not strongly frequency-dependent and are recommended for wideband applications (2). Layout of the circuit is presented in figure 5. Three spiral inductors are used to bias and stabilise the transistors. A current source sets the emitter current. Symmetric performances are obtained between the two ports. The associated imaginary part can be considered as a negative capacitance.

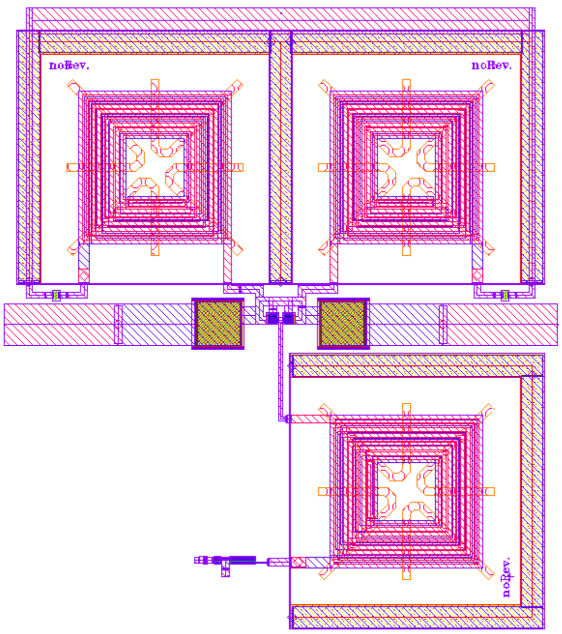

Figure 5 : Differential negative resistance

Circuit dimensions are 690x800 µm². The negative resistance performed is about -10 Ω at 1,8 GHz. The imaginary part is equivalent to a -2,4 pF negative capacitance that can also be used to design a gyrator (2). Power consumption is about 46 mW.

Differential Compensated LC Active Filters

A simple balanced circuit based on a topology proposed in (3) for active LC filter is now briefly presented. The previous differential negative resistance is used to compensate for insertion losses introduced by the inductors of the resonator. Two transconductances are also used to tune the central frequency and the gain of the filter. Schematic of this circuit is presented in figure 6. A bandpass response is obtained with a quality factor of about 125 at 2 GHz. The S-parameters are presented in figure 7. The noise figure (figure 8) is about 4,5 dB at 2 GHz. All these results clearly show the interest of such techniques for selective active filter responses at microwaves.

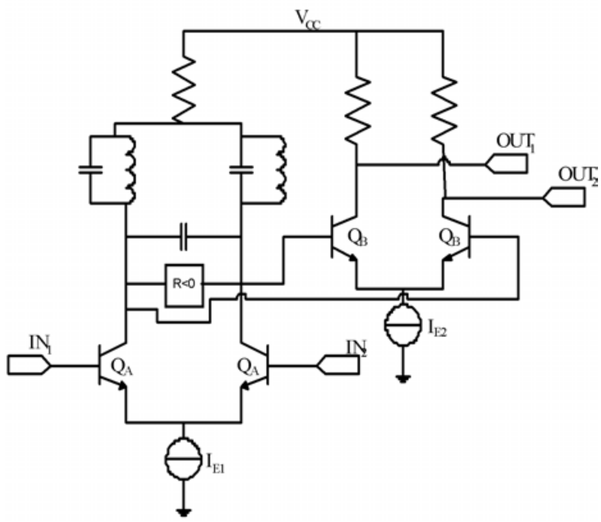

Figure 6 : Schematic of differential filter

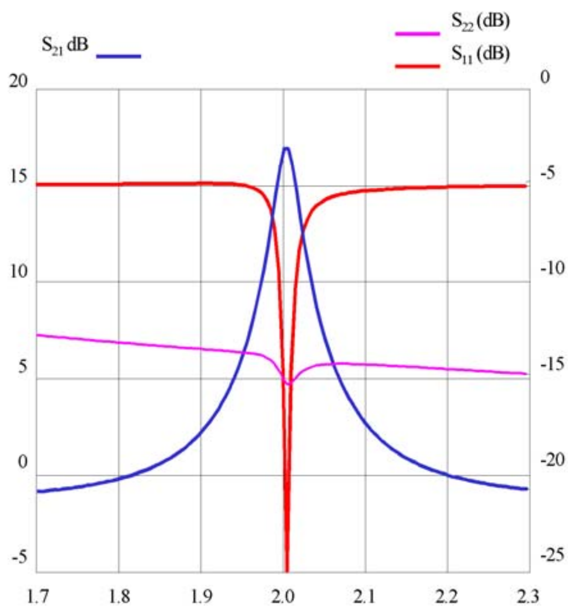

Figure 7 : S-Parameters of the differential filter

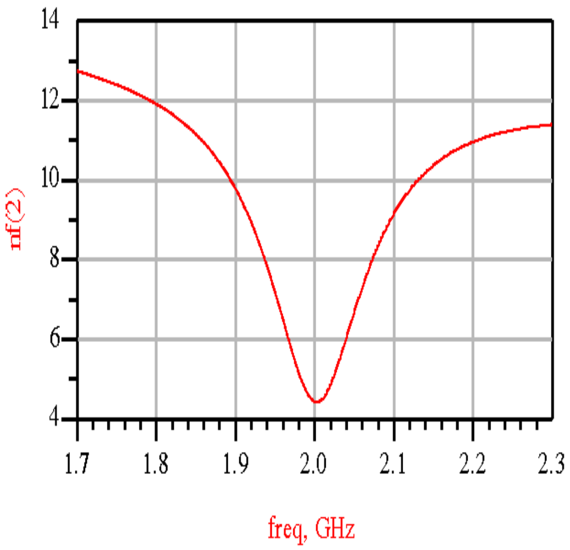

Figure 8 : Noise figure of the differential filter

REFERENCES

(1) J.D. Cressler, "A new contender for Si-based RF and microwave circuit applications", *IEEE Trans. on MTT*, Invited Paper, vol. 46, no.5, pp. 572-589, May 1998.

(2) D. Li, Y.Tsividis, "Active LC filters on silicon", *IEE Proc.-Circuits Devices Syst.*, vol. 147, no. 1, February 2000.

(3) W.B. Khun, "Design of integrated, low power, radio receivers in BiCMOS technology", *Dissertation presented to the faculty of the Virginia Polytechnic Institute and State University,* 1995.