Design of Differential Low Noise Amplifiers for UWB Antennas in the Low Band of the SKA Project

Oscar A. Garcia-Perez[1,3], *Vicente Gonzalez-Posadas*[2], *Jose L. Jimenez-Martin*[2], *Jose M. Serna-Puente*[3], *Enrique Garcia-Muñoz*[1], *Daniel Segovia-Vargas*[1]

[1] TSC-UC3M, Avda. de la Universidad 30, 28911 Leganes Madrid (Spain). {ogarpe, legarcia, dani}@tsc.uc3m.es

[2] DIAC-UPM, Ctra. Valencia km. 7, 28031 Madrid (Spain). {vgonzalz, jljimene}@diac.upm.es

[3] OAN, Cerro de la Palera s/n 19141 Yebes Guadalajara (Spain). jm.serna@oan.es

Abstract

Differential amplifiers can be an appropriate solution in the implementation of radio astronomy receivers, due to their efficient interference and harmonic isolation. In this paper, two different topologies are presented. The first one consists of two single ended amplifiers in a balanced topology. The second one is formed by cascading two simple differential stages. Both circuits operate in the 300MHz to 1GHz bandwidth. Firstly, gain and noise characterizations of each amplifier have been done. Lastly, noise analysis of the whole reception system, formed by the antenna and the differential amplifiers, is presented.

1. Introduction

The SKA (Square Kilometer Array) project is an international effort to investigate and develop the technologies needed to build a new radio telescope with a square kilometer area [1]. This instrument will be much more sensitive than current telescopes, and it will operate in the 100MHz to 25GHz bandwidth.

Various related activities are being pursued around the globe. The process of making a low noise amplifier for the 100MHz to 1GHz frequency range is one of these tasks. The main problem of radio-astronomy systems operating at this frequency band their the high level of atmospheric noise received by broadband antennas with not much directivity.

Using differential devices in electronics is very common at low frequencies. However, differential technology has been rarely used at microwave frequencies. For the case of low noise amplifiers, using a differential topology would substantially reduce the amount of noise coupled in the common mode (i.e. noise produced by the bias sources). On the other hand, there are inherent design problems coming from working with differential S-parameters instead of classical ones.

2. Microwave Differential Amplifiers

Low frequency applications have been using balanced circuits for many years for reducing noise interferences and eliminating the signal return path. There are many advantages by using differential circuits instead of single-ended devices. These properties have not gone unnoticed for researchers, what has led to a great increase in their use for high-frequency and microwave applications. Main benefits are:

- Interference isolation
- Higher dynamic range
- Reduced even-order harmonic distortion

On the other hand, there are some inherent disadvantages in the use of these differential circuits in microwave systems, such as:

- Double the number of components
- Increase the size
- More power consumption
- More difficult to design and characterize

By using the mixed-mode scattering parameters [2], which extend the standard two-port scattering parameters to a four-port differential device, the last disadvantage can be strongly mitigated. Furthermore, the development of the so called *PMVNA's* (Pure-Mode Vector Network Analyzers) [3], which allow measuring directly these mixed-mode scattering parameters, can be crucial to facilitate the design of such devices. Thus, differential devices can become a very practical solution in many microwave systems.

Two typical microwave differential amplifier topologies are shown in *Fig. 1*. The first one consists in two independent single-ended amplifiers, with differential input and output ports (balanced amplifier). The second one uses two amplifying devices with a common bias current source (differential amplifier). The main difference introduced by the second circuit is its common-mode rejection. Balanced device may get this property including an extra differential amplifier stage (not necessary low noise) at its output. Both types of scheme have been designed and will be presented in next sections.

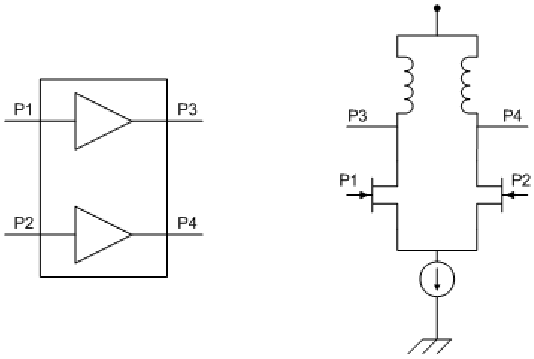

Fig. 1: Typical differential amplifier topologies.

3. Differential Low Noise Amplifier Design

The design of a balanced low noise amplifier (board view and schematic) is shown in *Fig. 2*. It has been designed in microstrip technology (*εr=3.4*, *H=1mm*), and consists of two independent and identical single-ended amplifiers. Each amplifier is formed by cascading three common-source stages. The power supply of each stage is done by using a self-polarized bipolar transistor. Shock inductors have been formed by several inductors (with several values) in series, to ensure a good isolation between the polarization network and the AC circuit over all the bandwidth. Similarly, several shunt grounded capacitors have been placed to avoid voltage peaks in the circuit. FET transistors are low noise MESFETs (*Agilent ATF-34143*).

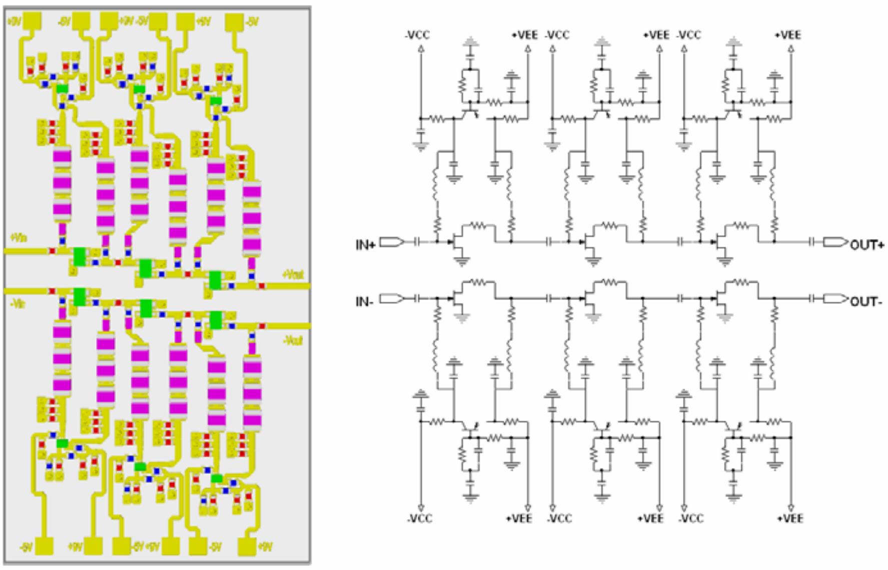

Fig. 2: Top view of the circuit board (35.62mmx64.81mm) and schematic.

The differential low noise amplifier with common bias source is represented in *Fig. 3*. Microstrip substrate parameters are *εr=2.7* and *H=1mm*. The circuit schematic has been formed by cascading two simple differential stages. Similarly to the previous design, multiple series shock inductors and shunt capacitors have been added in the polarization network to ensure a correct performance over all the frequency range.

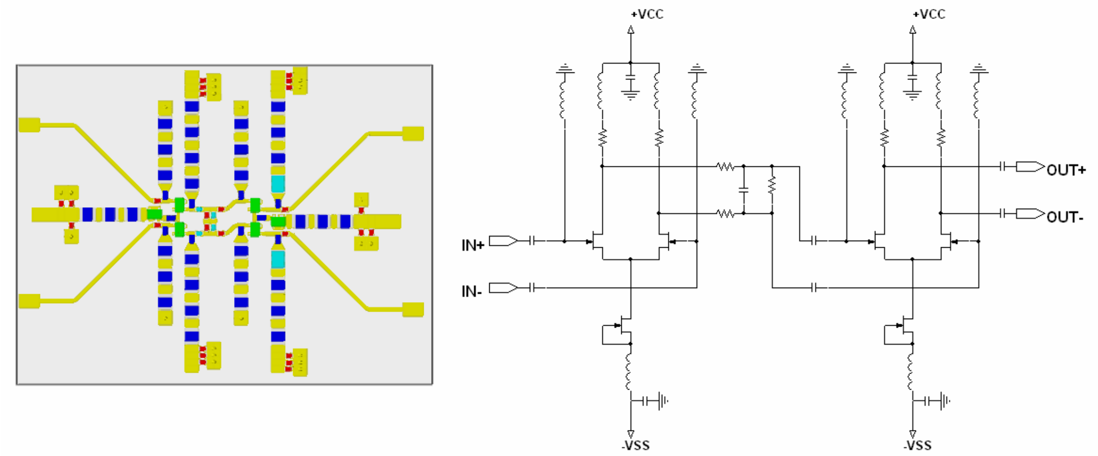

Fig. 3: Top view of the circuit board (62.4mmx48.1mm) and schematic.

The simulated results of the previous amplifiers are shown in *Fig. 4*. These results have been obtained by placing ideal baluns at both input and output ports, transforming the 4-port device to a 2-port circuit. In the operating bandwidth (from *300MHz* to *1GHz*), the gain is larger than *45dB* for the first design case and larger than *27dB* for the second one. The maximum noise factor values for the balanced and differential amplifier are *0.45dB* and *1.5dB* respectively in the operating bandwidth.

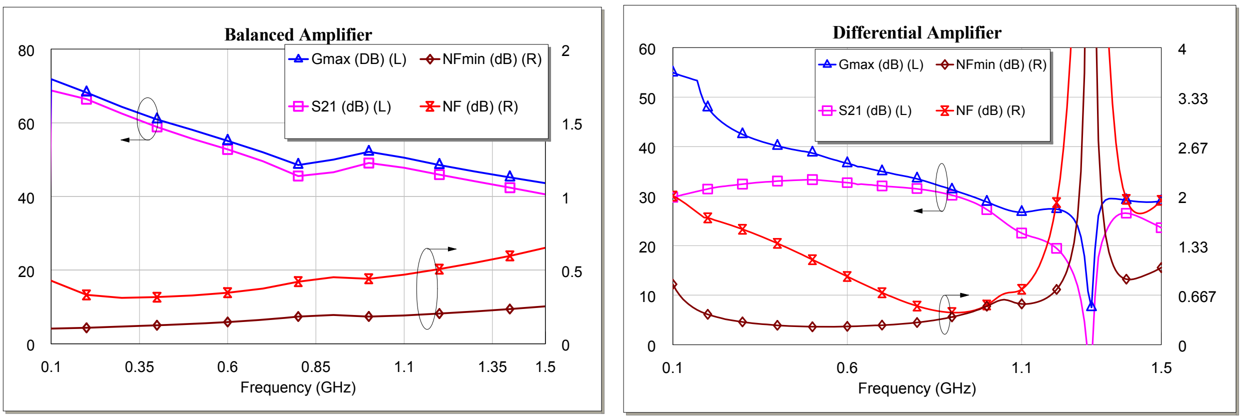

Fig. 4: Simulated gain and noise parameters for the balanced (left) and differential (right) amplifiers.

4. Receiver Noise Characterization

Once the gain and noise characteristics of the differential amplifiers have been presented, the next step is to evaluate the overall receiving, including the antenna. This scheme is presented in *Fig. 5*:

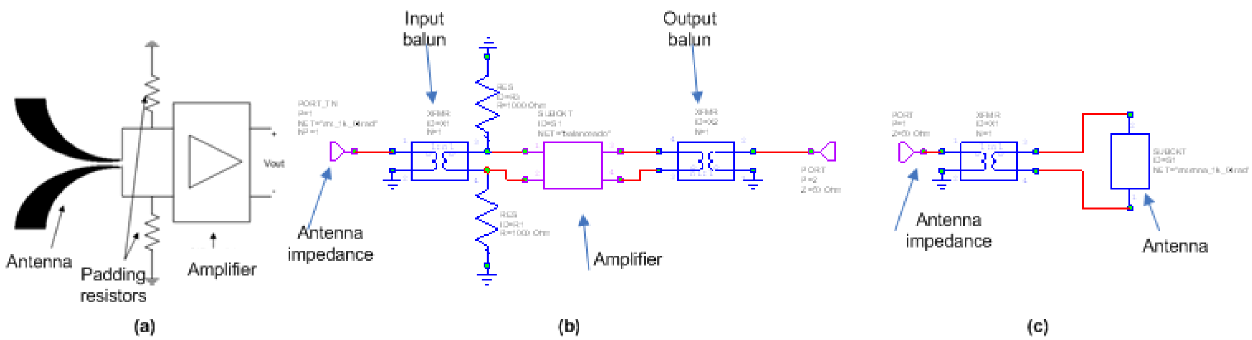

Fig. 5: Receiver system (a), receiver measurement circuit (b) and antenna impedance measurement circuit (c).

The radiating element is a bunny-ear antenna, with two ports, whose impedance has been measured for different scanning angles. In each port there is a grounded shunt resistor. At this stage, the amplifier input ports are also connected. The purpose in this section is to characterize the noise performance of the entire receiver, using different antenna impedances (due to several scanning angles). The need of a two-port circuit to compute the noise simulations requires the use of ideal baluns as shown in *Fig. 5 (b)*. Antenna impedance is also calculated by using a balun, to transform the two-port antenna to a single-port device (*Fig. 5 (c)*).

The noise characterization has been done using the equivalent input noise temperature T_e. This parameter can be computed as (1), where T_0 is the standard temperature in *K* (*290K*), and *NF* is the noise factor. This measurement uses the port termination values for the source impedance when computing the noise factor.

$$T_e = T_0 \cdot (NF - 1) \tag{1}$$

Noise temperature graphs for the two amplifier topologies at several scanning angles (*0rad*, *0.4rad* and *0.8rad*) are presented in *Fig. 6*. Noise temperature values lower than *88K* have been achieved in both cases. The optimum padding resistor values have been searched to get minimum noise temperature. These optimum values are *3kΩ*, for the balanced amplifier, and *1kΩ* for the differential amplifier.

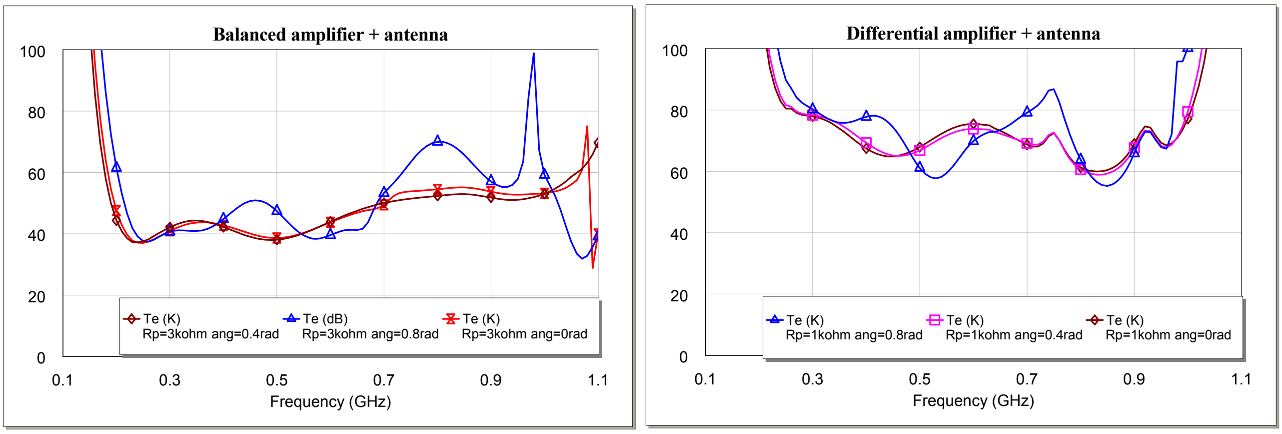

Fig. 6: Equivalent input noise temperature for the balanced (left) and differential (right) amplifiers.

5. Conclusion

Differential amplifiers have been presented as a very efficient solution in the development of broadband receiving systems with low noise requirements. Particularly, two possible differential schemes have been presented in this paper. Good results are expected in the real implementation due to the right characterization obtained by simulation.

6. Acknowledgments

This work has been supported by the Fundación General de la Universidad de Alcalá – Instituto Geográfico Nacional (FGUA-IGN) for the SKADS Project.

7. References

1. http://www.skatelescope.org/

2. D. E. Bockelman, and W. R. Eisenstadt, “Combined Differential and common-Mode Scattering Parameters: Theory and Simulation,” *IEEE Trans. on Microw. Theo. and Tech.*, vol. 43, no 7, pp. 1530-1539, Jul. 1995.

3. D. E. Bockelman, and W. R. Eisenstadt, “Pure-Mode Network Analyzer for On-Wafer Measurements of Mixed-Mode S-Parameters of Differential Circuits,” *IEEE Trans. on Microw. Theo. and Tech.*, vol. 45, no 7, pp. 1071-1077, Jul. 1997.