SDR based radio-frequency noise measurements

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***Abstract*—Self-testing solution are very useful not only for make sure that devices are operating in the correct way, but also to realize system auto-calibration: auto-calibration is based on the experimentally extraction of proper parameters and it is usually realized by adopting radio frequency noise injection subsystems. In these cases, the systems use power acquisition devices, based on diode detectors, to perform the measurements; this solution denotes poor reconfigurability, unless a very complicated system architecture is adopted. In this paper we prove that the measurements needed for the over mentioned purpose, can be performed avoiding the application of complex architectures, by using software-defined radios with high level of potential reconfigurability and flexibility.**

***Index Terms*—Noise Measurements, Software-Defined Radio, RF-chain calibration, RF-chain self-test**

I. Introduction

Nowadays, self-testing devices have found wide use in many areas, most of all because knowing the state of operation of the system under test, becomes an information that cannot be neglect in real time test analysis [1]. To implement this functionality, it is possible to add a particular subsystem called BIST (Built-In Self Test devices). The BIST ensures the injection of a known signal into the RF-chain under test in order to verify the system functionalities [1]. In many cases, it is preferred to use noise source injection system instead of a deterministic signal since, in this way, it is possible not only to test the correct operation of the system, but also to perform a calibration of the system itself [2] [3]. In order to measure the RF-chain output signal and determine the desired information, it is necessary to use a proper measurement system. One of the methods adopted for power signal acquisition, is the use of a square-law detector, by which the diode's incident power can be transformed into a DC voltage signal [3]. Such systems fail to provide high reconfigurability unless a more complicated architecture is achieved. Another way to acquire information from a signal that is injected into a system is through the use of architectures based on Analog-to-Digital Converter (ADC) devices, as shown in [3]. Among the numerous solutions able to implement these architectures, we can find the use of Software Defined Radios (SDRs). These architectures provide In-phase and Quadrature components (I/Q components) for all the signals involved. From this set of data it is possible to extract a great amount of information regarding the main characteristics of the received signal. In this paper we demonstrate first, the use of a commercial SDR to perform noise measurements [4], and second how it is possible to derive system calibration state. After briefly describing in Chapter II the adopted methodology and materials, we present the major results in Chapter III.

II. Materials and Methods

To carry out the measurements, the SDR Adalm Pluto provided by Analog Devices was used. Its operation is based on the Zinq Z-7010 FPGA from Xilinx, while the AD9363 transceiver, also from Analog Devices, is used for the radio frequency interface (see Fig. 1).

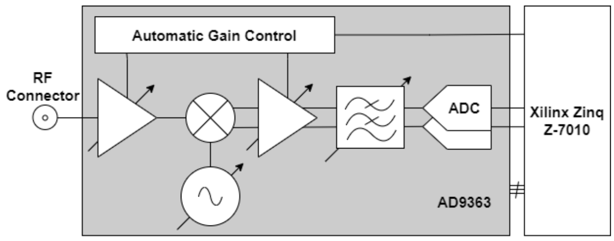

Fig. 1. Simplified receiver block diagram of the SDR Adalm Pluto board. As visible from the picture the entire RF interface is included in the AD9363 transceiver, in which a homodyne receiver architecture was implemented.

The resulting system makes it possible to receive, via the homodyne receiver's I/Q outputs, a signal that can range from 325 MHz up to 3.8 GHz. The 12-bit ADCs used to read the signals can provide data at a sample rate ranging from 65.2 kSPS to 61.44 MSPS, while connection with a personal computer is provided by a USB type 2.0. The lower limit of the system noise figure (NF) is 3.5 dB, and its value is determined by the chain gain, which can be made variable through an

Automatic Gain Control (AGC) algorithm. Gnu Radio software was used to write the code, as it provides an easy radio development platform. A dedicated program was designed to perform Double Side Band (DSB) power measurements. The developed algorithm allows for the calculation of the spectral power density value over the system's bandwidth, fixed by the SDR. The acquired I/Q samples are then used for the squared magnitude calculation, in order to retrieve the input signal power (see Fig.2). This calculated power was smoothed by a moving average function and converted into dBm, finally we remove the SDR contribution on the measures. For the spectral power density, it is sufficient to divide the power calculated in the previous step by the system's bandwidth.

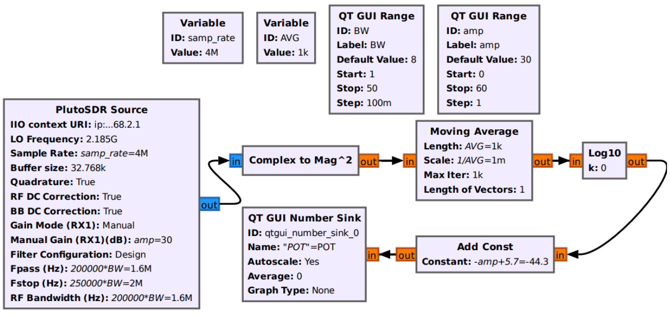

Fig. 2. GNU Radio block diagram used for the implementation of the SDR Adalm Pluto board's algorithm. The I/Q samples collected by the SDR were squared and added together to calculate the detected signal power. These data are smoothed by a moving average and conditioned to retrieve the power value in dBm and the power spectral density.

To test the developed algorithm, it was decided to use as a Device Under Test (DUT) the Cubesats satellite receiver system operating in Ku-band presented in [5] [6]. In fact the knowledge on the proper operation and calibration of these systems is a key factor in satellite communications and measurement systems [3]. Compared with the architectures presented in [5] [6], the RF-chain is slightly modified (see Fig. 3): the attenuator has been moved after the mixer, as the intent is to maximize the impact of the attenuation factor on the system's noise figure, while the other changes were actuated to avoid electrical issues. To calculate the DUT's noise figure (F_{SYS}) and its gain, with the setup shown in Fig.4, the Y-factor method will be used (1), the output power measurements is taken from the DUT with the noise source switched on (P_{HOT}) and off (P_{COLD}). The Y-factor calculation is performed by three different setup: the first one is composed of a noise figure meter (HP8970S) in order to calculate automatically the Y-factor value; the second setup consist of a spectrum analyzer (FSVA3000) with noise marker function to calculate the Y-factor; the last setup is made through an Adalm Pluto SDR by using it through the previously described algorithm.

$$F_{\mathrm{SYS}} = \frac{ENR}{Y-1}, \quad Y = \frac{N_{\mathrm{HOT}}}{N_{\mathrm{COLD}}} \tag{1}$$

To calculate the gain from the noise power density measurements equation (2) is used: G_{TOT} is the total Gain of the system under test, N_{HOT} and N_{COLD} is the power spectral

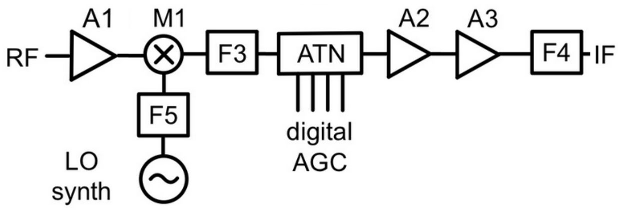

Fig. 3. Modified Ku-band receiver block scheme for Cubesats satellites. The receiver is set to downconvert a 14 GHz signal to an IF frequency set at 2.185 GHz, while the attenuator is set for changing the characteristics of the radio frequency system.

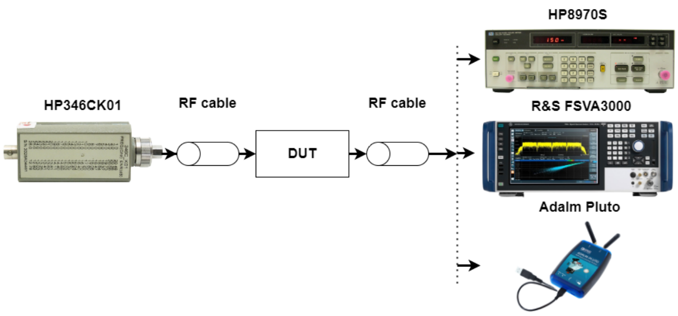

Fig. 4. Experimental setup used for comparative measurements, it denotes how the noise injection part and the device under test remain the same for all measurements, while only the measurement part changes.

density in hot and cold state, *ENR* is the noise source Excess Noise Ratio, T_0 is the environment temperature and k_{B} is the Boltzmann constant.

$$G_{\mathrm{TOT}} = \frac{N_{\mathrm{HOT}} - N_{\mathrm{COLD}}}{ENR \cdot T_0 \cdot k_{\mathrm{B}}} \tag{2}$$

As we want to test the algorithm under different conditions and prove one of the possible aspects of reconfigurability level, measurements with the SDR will be performed in two observation bands of 2MHz and 4MHz respectively, while the receiver attenuation factor will be changed in order to increase the receiver's noise figure and decrease its gain.

III. Results

As a first step, receiver and SDR calibration measurements were implemented through continuous wave measurements. The receiver already mentioned in previous section has a maximum gain of 50 dB, showing a good accordance whit the results obtained in [5]. Since the SDR is constituted by an RF chain having an adjustable gain (see Fig. 2), its value must be set to avoid compression of the last stages and, at the same time, it must be high enough to allow a correct reading by the ADC. The gain was set to be 30 dB. Since the gain set in the SDR affects the power measurements, it was decided to compensate this value by subtracting it from the calculated power value. Moreover, a power offset of 5.7 dB is also compensated, which was derived through the SDR calibration. Through the various setups, the noise power at the receiver output was measured, and then the Y-factor was calculated. Then the system's noise figures of the different setups were calculated and compared to evaluate the measurements results (see Fig.5). The graph denotes how, through all the setup configurations, it was possible to derive a similar value of NF of the system. Compared to the value reported in article [5], the value is slightly different because the RF chain was modified and because the input cable contribution was not compensated, in fact the goal was not to derive the receiver's NF but to compare the noise measurements with different measurement setups. From the noise measurements, system gains were then derived and compared to receiver calibration in order to validate the developed algorithm (see Fig.6).

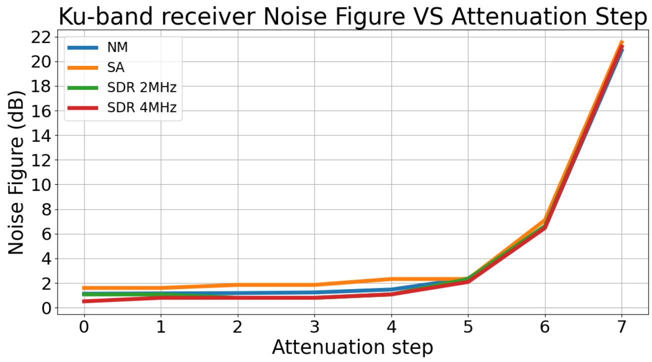

Fig. 5. System's noise figure calculated with Noise Meter (NM), Spectrum Analyzer (SA) and SDR with two different bandwidth (SDR 2MHz & 4MHz). In order to compare the results in different scenarios, the attenuator factor was changed with an exponential characteristic.

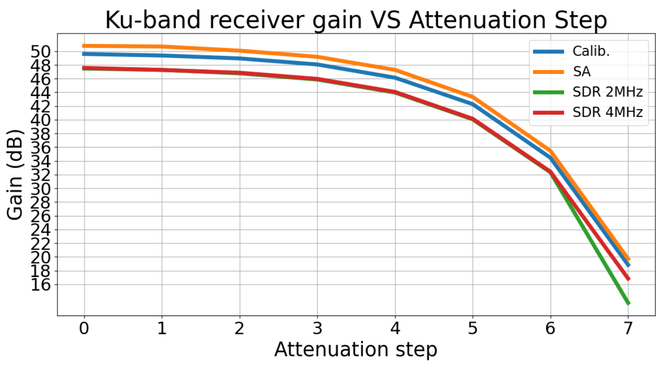

Fig. 6. System's Gain comparison between calibration results (Calib.), performed with a continuous wave characterization, and the noise measurements performed with Sectrum Analizer (SA) and the SDR with two bandwidth (SDR 2MHz & 4MHz).

As we can see from Fig.6, it was possible to calculate the system gain with good accuracy, as the value was close to the one reported in article [5]. As it can be seen in Fig.6, there are discrepancies between different gain measurements. In fact, while the noise figure measurements using the Y-factor are used to be less sensitive to the many sources of uncertainty in the measurements, this does not happen for gain measurements.

IV. Conclusions

This paper demonstrates for the first time how it is possible, under certain slight restrictive conditions, to perform noise measurements by using SDR. Measurements made using a noise source and a Ku-band receiver showed how it is possible to derive the noise figure and gain of the overall system with results similar to those obtained using complex measurement instruments. Following this original approach, it will be feasible to realize innovative systems and, thanks to the high reconfigurability level provided by the SDR, it will be also possible to solve issues related to self-testing procedures. The discrepancies between the measurements and the reference values can be attributed to the SDR characterization uncertainties.

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