A methodology to reproduce slow operative temperature transitions and to measure their induced effects on receivers for radio astronomical applications

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Abstract-A methodology to reproduce slow variations of operative temperature of electronic devices, and to measure the induced effects on them, is presented. That method has been conceived in order to test and characterise the new receivers developed for the Italian SKA (Square Kilometre Array) demonstrator, based on the re-instrumentation of part of the Northern Cross radio telescope, located in Medicina (Italy). All the instruments of the measurement system are controlled by a PC (i.e. initialization, calibration and data acquisition). This way has been possible to obtain a new thermal characterization method of electronic devices, complementary to the most common one, where the devices are measured at different, but steady, operative temperatures.

I. Introduction

In conventional radio telescopes, the receivers are located in well protected and controlled environments. In particular their operative temperature is kept constant from the LNA, which often works at cryogenic temperatures, to the back end. Moreover it is always possible, even during an observation, to perform their calibration by means of injections of well know amounts of noise, typically just after the antenna output and, in any case, before the low noise amplifier. Such way is not viable when the receivers are arranged in array configuration with a large number of elements and/or they are distributed over a wide area (i.e. not in the focus of a dish). This is the typical situation of the Aperture Array technology (AA), which is probably the most promising and versatile one, and, over all, the only that can fully satisfy the strong astronomers' requirements in the SKA low frequency (i.e. less than 1GHz) band.

A. The SKA project

The future of radio astronomy, in the 0.1 to 25GHz frequency band, will be the Square Kilometre Array. A large amount of small antenna sensors will be combined together in order to synthesise an overall collective area in the order of a million square meters, spread over an area more than 3000Km wide [1]. The collective area will be subdivided in a big central core and many smaller remote stations, up to 100, to provide the necessary baselines. To synthesise the entire collective area, the signals of each antenna have to be amplified, conditioned, digitized and finally processed. So a massive use of low cost, both analogue and digital, electronics will be necessary, pushing the instrument in the direction of a "software telescope". The overall SKA budget is in a range from 1 to 1.5 billion euros. The array construction will be completed in 2020, but just during the next decade, part of the array will be ready to give science at high level (SKA Phase 1).

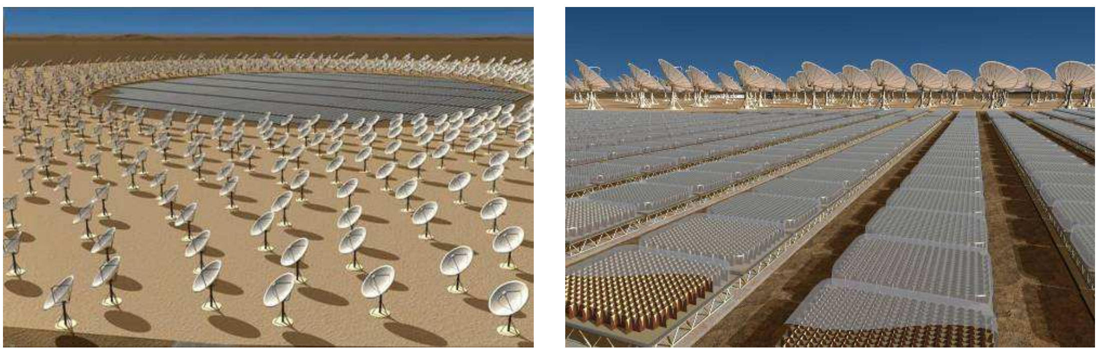

Figure 1. An artist impression of the SKA core (left) and a particular of the aperture array (right).

Different antenna sensors and receiver architectures are today under study or in a construction phase as prototypes, called demonstrators. The European radio astronomical community is currently contributing to this world wide project by means of the SKADS (SKA Design Study) project: a 4 years research programme co-funded by the EC [2, 3]. SKADS focuses on the AA technology because this kind of antenna sensor is the only one that can provide all the following features at the same time: high sensitivity, large Field Of View (FOV) and multi beam capability.

Figure 2. Aerial view of the Northern Cross radio telescope.

B. The Italian SKA demonstrator

One of the three SKADS demonstrators is the Italian BEST (Basic Element for SKA Training) project. It is based on the re-instrumentation of part of the Northern Cross radio telescope, one of the largest low frequency (408MHz) arrays in the northern hemisphere, located at Medicina, nearby Bologna [4].
In order to reduce the risks the re-instrumentation is faced in three successive steps with increasing size, both as collective area and number of receivers. At the end of the re-instrumentation phase, the BEST total collective area will be about 8000m^2, which is comparable with the effective collecting area of a future proposed SKA station (about 10000m^2). The principal goals of BEST are: to produce low cost, high performance, easily replicable technology, to investigate beamforming algorithms for Radio Frequency Interference (RFI) rejection and multi beams techniques, to give the possibility to test concepts, algorithms and technologies on a large demonstrator where, at the same time, are present both high sensitivity and high RFI level, to give the possibility to do science with a 1% SKA demonstrator and finally, but not the least, to transfer quickly all of those things to EMBRACE and 2-PAD, the other two SKADS demonstrators.

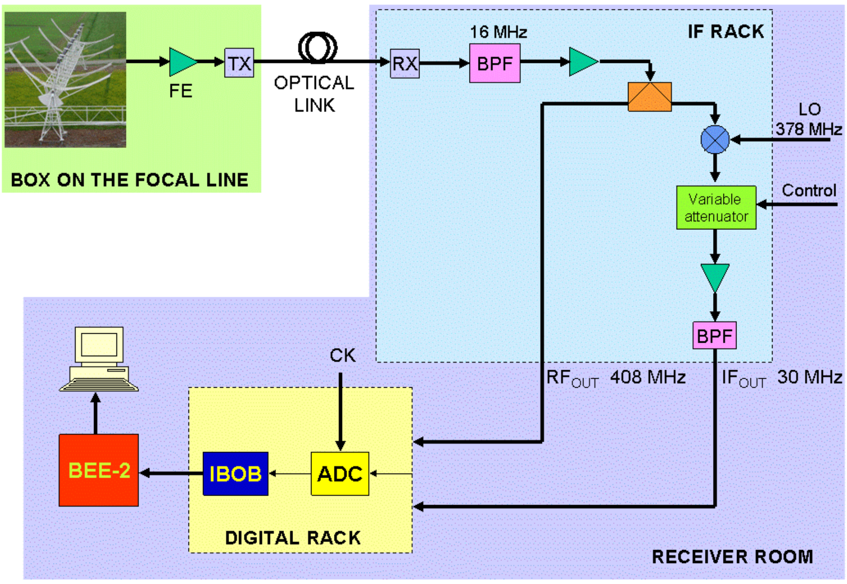

Figure 3. BEST receiver chain. The antenna shown is a N/S elements.

BEST receivers are located inside waterproof boxes and are composed by a three stages low noise front end and an optical transmitter, in order to transport the RF signals (16MHz centred at 408MHz) directly in a central protected and shielded receiver room, located inside the main building. This way the system reliability and maintainability are considerably improved [5]. There, signals are down converted, digitised and finally processed by a powerful, FPGA based, digital back end.
To lower costs and in order to gain a significant experience on the AA viability for the SKA, we are investigating if it is possible to avoid any active temperature control system and any hardware calibration system. In other words, with BEST system, we would like to understand if it possible to compensate gain and phase variations of receivers, induced by external temperature variations (i.e. day night, sunny to cloudy and/or rainy), only at back end stage (i.e. with periodic observations of strong well known radio sources called "calibrators").

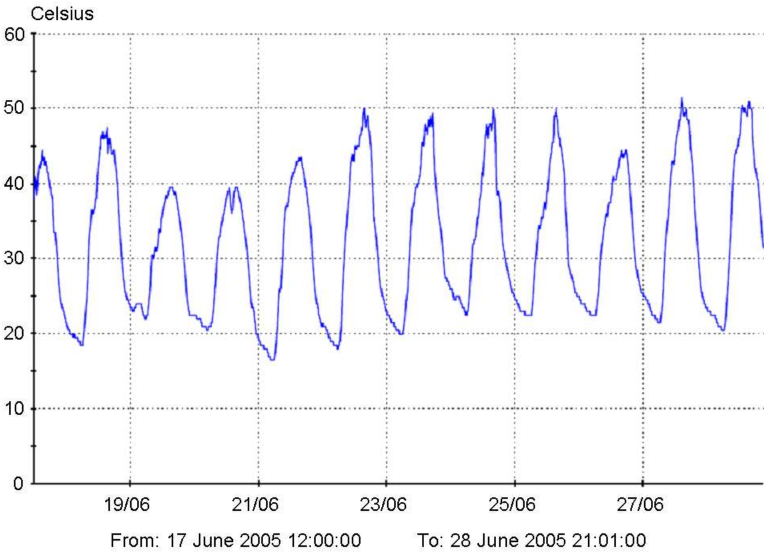

Figure 4. Typical temperature variation of the receiver boxes in summer time.

We monitored the temperature inside the boxes installed on the focal lines of the Northern Cross radio telescope, both in summer and winter time. Typical thermal excursions are from +50°C to +20°C, in about 12 hours, from day to night (and vice versa from +20°C to +50°C from night to day) during summer or from 10°C to –5°C in winter. In the receiver design phase, a deep thermal characterization has been carried out, measuring the gain variations both of front end and optical transmitter, at different, but steady, operative temperatures in those range [6].

Figure 5. BEST-1: one of the four receiver boxes installed on the antenna.

II. The measurements system

In late 2004, the first 4 prototype receivers where installed on the focal line of one North/South cylinder (BEST-1). They were composed by, see Figure 5 in clockwise from bottom, a double stage LNA, a low pass filter, a RF driver and the optical transmitter. The antenna was pointed towards Cassiopeia-A, one of the strongest radio sources in the sky, for several weeks. This way, even only a quarter of BEST-1 (i.e. a single receiver) was able to receive the sky signal. Figure 4 reports a typical recorded trace of a single receiver, in total power mode. As is it possible to recognize, a ripple is superimposed on the sky detected power, in some parts of the trace (see the red circle in Figure 4). We concluded that a more deep thermal characterization of the receivers was necessary in order to understand the origin of that unexpected trace.

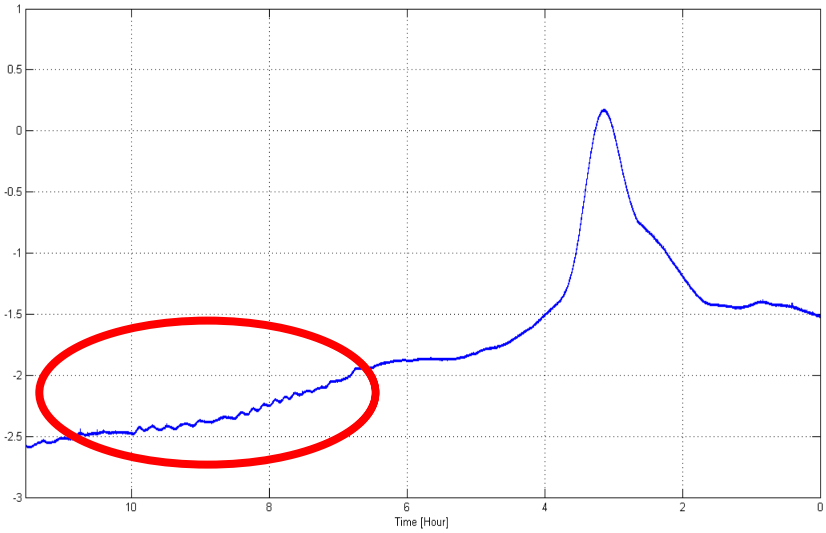

Figure 6. Detected power of a transit of the radio source CAS-A.

In order to perform such thermal characterization, we set up an automatic measurement systems capable to acquire various parameters (like gain, phase, temperature, voltage and current) of a DUT inside a temperature chamber. The measurement system was composed by a vector network analyser (HP8751A) and a data acquisition unit (Agilent 34970A) connected to a PC through IEEE-488 bus interface. In order to reproduce the slow temperature variations which we needed to perform the tests, we made use of the non perfect isolation of the chamber (Model BK-1104 by Associated Testing Laboratories). When we wanted to reproduce a slow cooling (heating) of the electronics, we set the chamber temperature at +50° (-10°C) and, after a steady state we switched off the heater (cooler), but not the fan inside the chamber (otherwise the temperature inside the chamber could be no longer uniform). This way the temperature inside the chamber, thanks to the non ideal thermal isolation of the chamber, slowly decreased (increased). Typically the laboratory is at +20°C and, under this condition, the temperature variations last at least 6-8 hours.
The control software has been developed with National Instruments LabVIEW 7.1 7]. Through the control panel is it possible to switch between configuration and acquisition mode. In the first one, for the data logger, is it possible to set each parameters of all the temperature sensors (up to three) and to configure other channels in order to acquire voltages and currents, if the devices under test have any test point. For the VNA, the operator can choose to recall an instrument state and/or calibration or not. Other parameters which can be set are the acquisition rate (expressed in sample per minute) and the overall measurement duration (expressed in hh:mm:ss). The software can acquire from the VNA the active markers on each trace, which the user has to set from the VNA front panel, and/or the whole channels traces. Then the program generates three files. In the first one are collected all the data of the data acquisition unit and the active markers of the VNA. The other two files collect all the traces of each VNA channel (one row for any trace). All the acquired data are associated to their own acquisition date and time.
In order to identify which device (or devices) was responsible of the ripple generation, the measurement system acquired the data of two different chains under the same temperature transitions. In particular, one was composed of RF devices only (Front end, low pass filter and RF Driver), and the other one was composed only of optical devices (optical transmitter and optical connectors). The

measurements have been performed in a frequency band from 350 to 450MHz, with an averaging factor of 16, in order to reduce the traces noise. The VNA channels are calibrated with simple RESPONSE calibration. A full 2-port calibration was not possible since we wanted to measure the gain of two different chains at the same time. Since the RF chain has a gain of about 60dB whereas the optical link an insertion loss of about 30dB, some RF attenuators have been inserted in order to compensate such difference and to avoid the saturation of the VNA receiver on the RF chain. A 3dB optical attenuator, which corresponds to 6dB of RF attenuation, has been introduced in the optical link in order to avoid the saturation of the photodiode of the optical RX. In order to perform the calibration of both channel (RF and optical) with the same RF power level, we considered the attenuators part of the DUTs. Since all the attenuators were out of the chamber, their values did not change during the measurements, so they have been considered as constant offsets in the VNA measurements, and compensated in post processing phase.

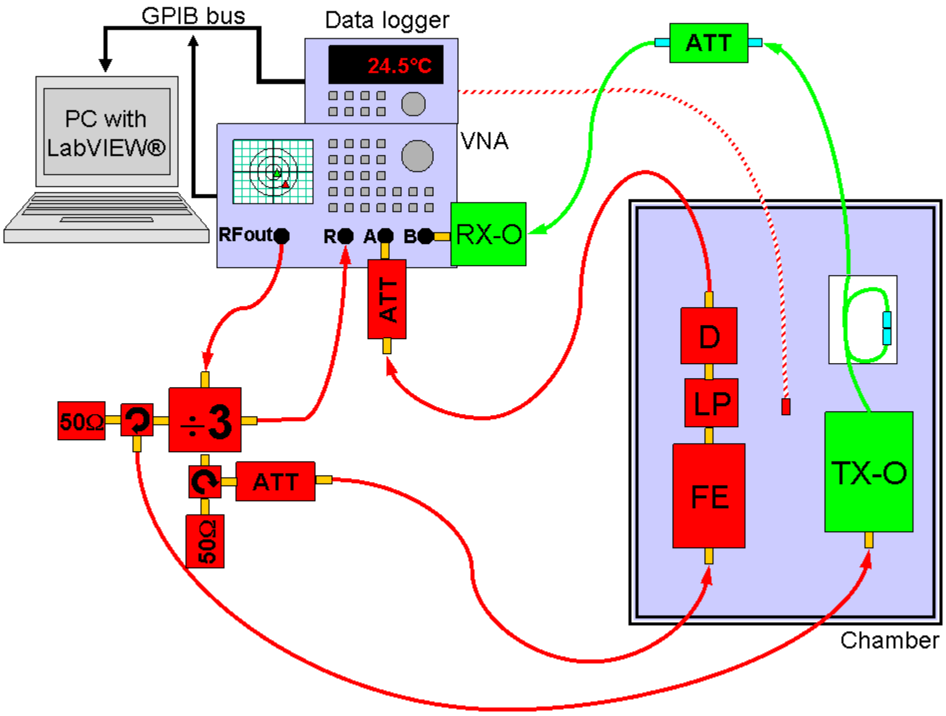

Figure 7. Block diagram of the measurement system.

Several cooling and heating tests have been performed and in each one the optical link shown a ripple on its gain trace, whereas the front end not (see Figure 8).

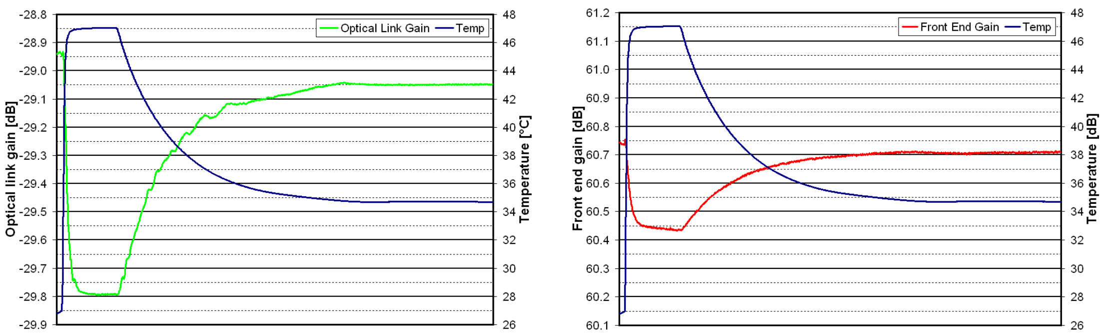

Figure 8. Example of measured optical link and front end gain variations versus temperature.

Moreover, analysing the collected data, we estimated the value of the ripple amplitude in ±0.02dB (see Figure 9), with a variable period in the range from 10 to 15 minutes (see Figure 10). These values are very similar to the ones we measured on the traces of the detected power of the transit of the radio source CAS-A.

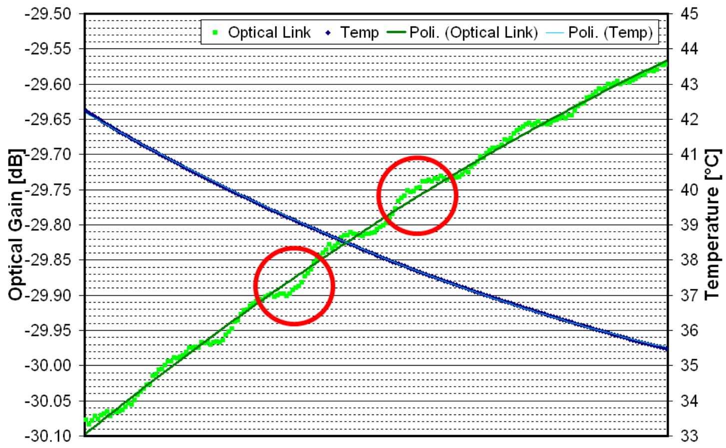

Figure 9. Ripple on optical link trace: amplitude estimation.

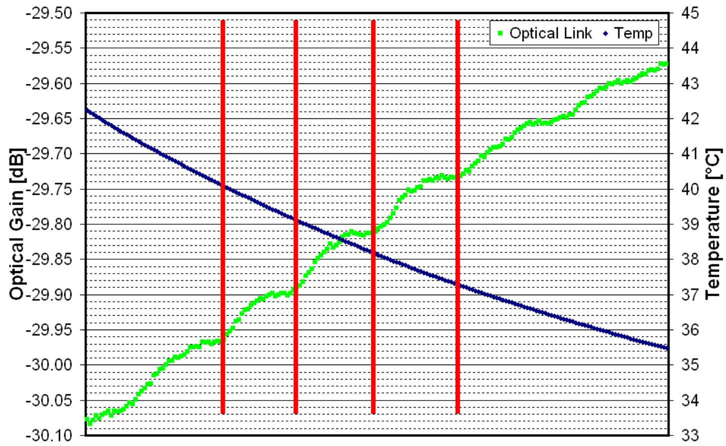

Figure 10. Ripple on optical link trace: period estimation.

III Conclusion

A method to measure the induced effects of slow variations of the operative temperature of radio astronomical receivers has been presented. This method is complementary to the well established thermal characterization carried out at different, but constant, temperature steps. Thanks to this measurement system, we identified the origin of a very small gain ripple in our radio telescope receivers' gain. Moreover we have been able to measure its amplitude and period, which are in agreement with the values that it is possible to recognise in the detected traces obtained when the receivers are installed on the antenna.

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