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Reliability tests and experimental analysis on radioreceiver chains

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I. INTRODUCTION

The current work is developed in collaboration with the *Istituto di Radioastronomia*, *Istituto Nazionale di Astrofisica* (IRA-INAF) located at Medicina (Bologna), in the context of the BEST (Basic Element for SKA Training) project. BEST has been conceived inside the SKADS (Square Kilometer Array Design Study) supported by UE FP6. SKA is the name given to a new generation radio-telescope that will have one km^2 of effective collecting area.
The ISSC (International SKA Steering Committee) coordinates SKA and expects to start the instrument construction from 2010.
SKA will be the most sensitive radio-telescope ever built that allows a deeper knowledge of the universe.
Its features will be:

- frequency range: 0.10 GHz to 25 GHz;
- 1 km^2 collecting area that will guarantee very high sensitivity;
- distribution of the collecting area on several stations distribute over 3000 km in order to obtain high resolution;
- high reduction of interferences thanks to powerful algorithms of adaptive beamforming.

It will offer many simultaneous Fields Of View (FOV), each exploiting several independent beams, therefore many users will be able to observe simultaneously different parts of the sky at different frequencies.
This work considers two solutions for the radioastronomical signal receiver chains, one conveys the analog signal through coaxial cable, the other one uses optical fibre.
A reliability analysis to estimate the MTBF of the two approaches has been implemented in order to suggest how to improve it through proper solutions.
Since the reliability prediction indicated the front-end, installed on the focal line of the antenna, as the more stressed block by environmental and climatic factors, we recommended to perform the reliability tests on it. The whole tests plan has been characterized and some preliminary results are reported in the paper.

II. SYSTEM DESCRIPTION

Two solutions of receiver chains have been taken into consideration. Both these chains send an analog signal to the receiver room. The first solution does it through coaxial cable (used now in the Northern Cross receiver chain), while the other uses an optical link.
Comparing the two solution above mentioned, the main advantages in using the optical analogue links are: wider band, lower signal attenuation, lower weight and dimensions, more strength and flexibility, better electric insulation and interferences immunity.
In describing these different solutions (coaxial cable or optical fibre), in order to simplify the schematisation, only 8 cylindrical reflectors of the N-S arm are considered. First solution, reported in Figure 1, shows the path of the signal transmission and control. In this case the astronomical signals, coming from the four receivers (for each cylindrical reflector) placed on the focal line of the antenna, are sent to the reference cabin through a coaxial cable of about 70m lenght. Here the signal is converted to the base band, digitised and then converted and formatted to be transported by an optical digital link. This signal is sent into the main receiver room through a 700m optical link and then reconverted back to the electrical domain, ready to be processed and analyzed.

Local oscillator (LO) at 378 MHz, digital clock (frequency sampling at 80MHz) control and synchronization (PPS) signals are sent from the processing room to the outdoor cabin. Power supply is sent to the cabins and to the antenna focal lines (front ends) through the coaxial cable (feed through).
Details about current configuration are shown in figure 2.

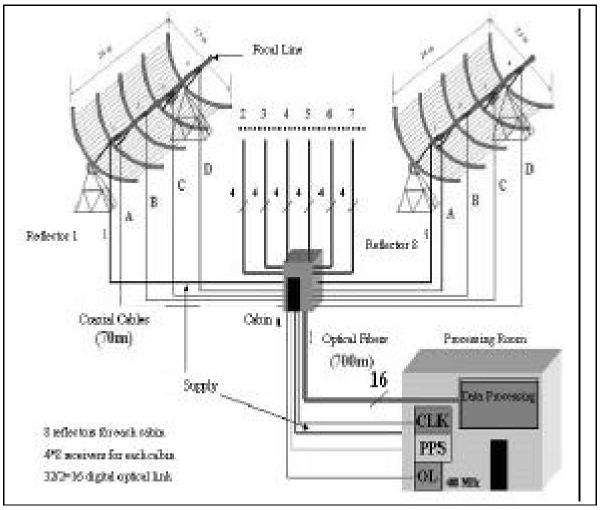

Figure 1: Representation of main transmission and control signals of N-S arm

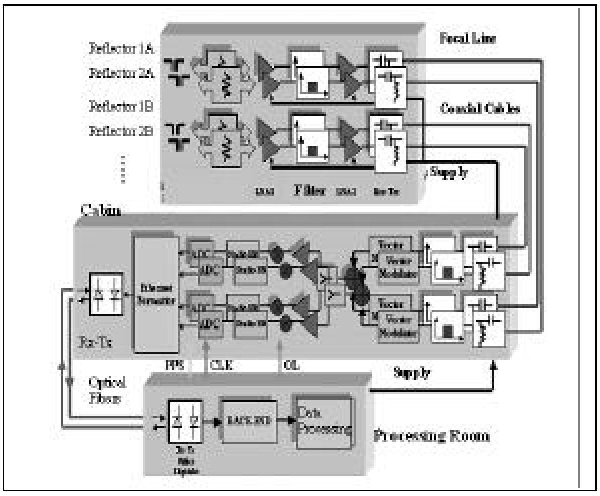

Figure 2: Analog coaxial cable link: schematic block

The astronomical signal is received by an array of dipoles and sent to a front-end stage, composed by an LNA, a pass-band filter (16MHz bandwidth around 408MHz) and an additional amplifier stage. Signal filtering is absolutely required to remove unwanted interference, while the low noise amplifier is necessary to minimize the total noise figure of the whole receiver system.
From the focal line, the signal is sent through a coaxial cable to the outdoor cabin, located at the base of the antennas, where the signal is filtered again and then handled by a vector modulator, required to form the beam. The signal is then converted down to the base band, filtered (low pass) and digitalized.
An Ethernet Formatter processes the digitalized signal before being transferred through optical transceivers (standard Gb-Ethernet) via an optical mono-modal fibre link to the processing room, where the optical signal is re-converted to an electrical signal, available for further elaborations.

The second solution is based on the idea to transport the analog signals via an optical link directly from the front-ends (installed on the focal lines) to the processing room. This solution increases the reliability and makes easier maintenance activities, the major part of the processing hardware being indoor (in a temperature controlled and humidity sheltered room). This assures a complete protection from atmospheric agents, temperature variations, electrical discharge, etc. In addition this solution offers a direct accessibility to the equipment to simplify maintenance operations, with logistic and economical advantages. Moreover it would allow to obtain a simplified control, synchronism and LO signals distribution. Figure 3 shows the main transmission and control signals for a cabin of Northern Cross N-S arm. In this figure it is possible to observe that the external links are composed by only mono-modal optical fibre for signal transmission and coaxial cables for power supply. Figure 4 shows a block diagram of this architecture. The use of an analog fibre link needs to install an optical transmitter (laser) on the antenna focal lines after the first stage, including one LNA and two amplifiers with two pass-band filters between them. To remove the high noise figure introduced by the laser, an additional amplifier stage is needed to increase the gain before optical link.
This optical signal reaches the processing room where the optical receiver reconverts it back to an electrical signal. Here the chain architecture is exactly the same of that one described in the first solution. The main advantage of this approach is that the LO and the synchronism signals are distributed only in the main processing room, where is installed the whole digital receiver. So we have the advantage of an easier maintenance and cheaper electronic devices can be used because they are in a sheltering room and then isolated from atmospheric discharges.

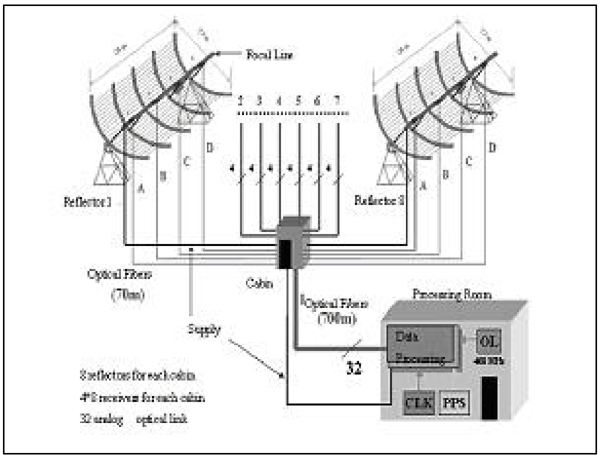

Figure 3: Representation of main transmission and control signals of N-S arm

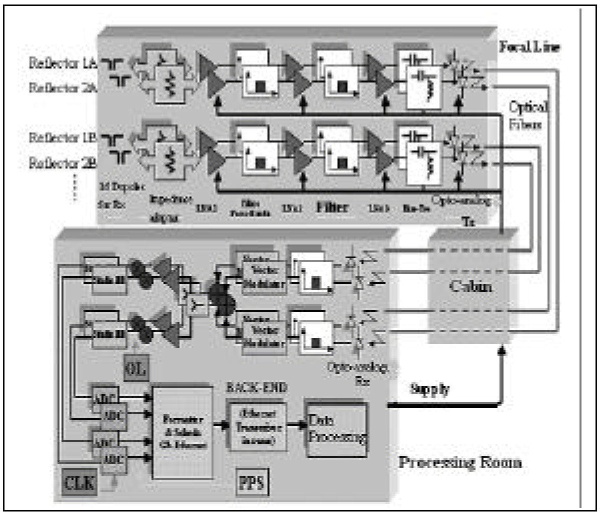

Figure 4: Analog optical fibre link: schematic block

III. RELIABILTY RECEIVER CHAINS

The first solution (fig. 2) (coaxial cable) is composed by three stages with three different operative environments, while the radio on fibre solution (fig.4) has two stages because electronics in outdoor cabin are removed. In both cases a reliability analysis was performed from the front-end to the back-end[1] input.

Reliability analysis has been made according to the data-base MIL-HDBK-217-FN2 (Mode I case 3). As hypothesis we assumed: series functional configuration for the whole system, operative temperature of 30° C and a 100% Duty Cycle (24/24 hours), independent faults and constant failure rate. In addition we considered different operative environments. In this the GM (Ground Mobile) for the antenna, GF (Ground Fixed Uncontrolled) for the cabin and GB (Ground Benign Controlled) for the processing room have been used.

Information about the failure rate in the GB environment is obtained by the manufacturers of the optical transceivers. Environmental multiplicative factors (π_E) able to change GB failure rates in GF or GM ones, depending from the position where the transmitters/receivers are located, have been supplied by the manufactures.

From the reliability analysis we focused that the radio on coaxial chain has a failure rate of $\lambda=94.126*10^{-6}h^{-1}$ which corresponds to an MTBF of about 10624 h, (about 1.2 years considering the system working 24/24 hours and without any maintenance). On the same hypothesis, for the radio on fibre chain configuration we obtain $\lambda=26.891*10^{-6}h^{-1}$ and MTBF=37187 h, that correspond to about 4.2 years of life.

Figures 5 shows the all system MTBF trend of the two possible solutions Vs temperature.

From a climatic-environmental point of view, the most critical devices of the two chains are those placed on the focal line, i.e. the front-end with two stages for the coaxial case and with three stages plus the optical transmitter in the other case.

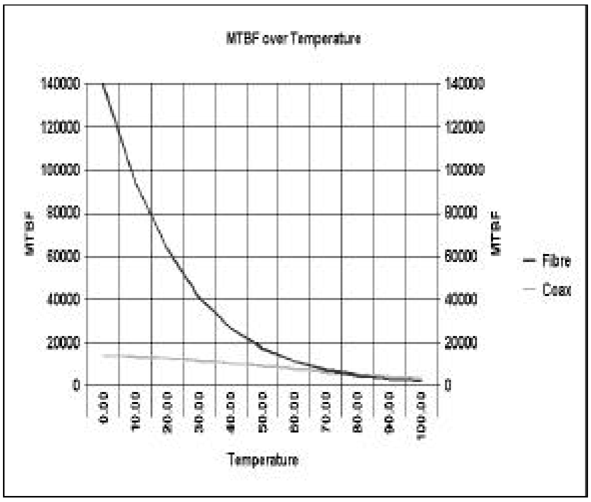

Figure 5: MTBF of the two possible solutions Vs temperature

IV. RELIABILITY TESTS AND RESULTS

Basing on both the architectural advantages and reliability prediction results, we decided to continue the investigation on the solution with analog optical fibre chain. Since the reliability analysis of the front-

[1] "Beck-end": Stage that elaborates data, computers cluster.

end shows that it is the most critical block, we have stressed these blocks with mechanical and thermal cycles in reliability tests laboratory.

With reference to IEC 60068 standards, the planned tests for the front-end have included: Water (Rb), Shock (Ea), Random Vibrations (Fh), Composite temperature and humidity cycles (Z/AD).

In this work we explain, in detailed way, the severity and the results of composite temperature and humidity cycles (Z/AD) applied to a LNA. From results important information to improve the project design are obtained.

Z/AD test is planned to detect defects in device caused by "breathing" as distinct from absorption of moisture. This test differs from other damp heat cycles for a greater severity; in fact, there are a higher number of temperature variations in a given time; a greater cyclic temperature range; a higher cyclic rate of change of temperature and a number of excursions to sub-zero temperatures.

For composite temperature and humidity cyclic test, 10 temperature/humidity cycles of 24 hours for each are applied to the device (switched off). The temperature range is (65 ± 2) °C to (-10 ± 2)°C with (93 ± 3)% of relatively humidity. The device has been cooled in the first five of nine cycles while in the remaining no cooling have been apply. In the final cycle, following the accomplishment of the temperature and humidity sub-cycle, the chamber is maintained at a temperature of (25 ± 2) °C and (93 ± 3)% of relatively humidity for a period of 3,5 hours; after test, samples is removed from the chamber and is kept under standard atmospheric conditions for a period of 24 hours before the specified final measurements are made [7].

Before the composite temperature and humidity cyclic test, we have defined the device fuctional parameter under measurement. This allows to determine the failure condition comparing the same parameters before and after the test. The parameters, we have chosen, are the S-parameters; these are interesting because they totally carachterize a circuit and then can be considered markes of a possible failure. The S_{21} parameter measures the device gain then its excessive reduction do not allow us to detect the weak radioastronomical signals.

The measure of S-parameters are performed with a vector network analyzer, the survey of values is made up by 801 points with 16 as avaraging factor, in a frequency range of 300-500 MHz. After the composite temperature and humidity cyclic test, we have measured again the device S-parameters and no change on the values have been found; the electrical characteristics of the front end seemd to be very stable Vs the temperature variation.

In figure 6 and 7 the measure of S_{21} module and phase before and after test are shown (frequency range: 300-500 MHz, in our case the operative radio band is centered at 408 MHz).

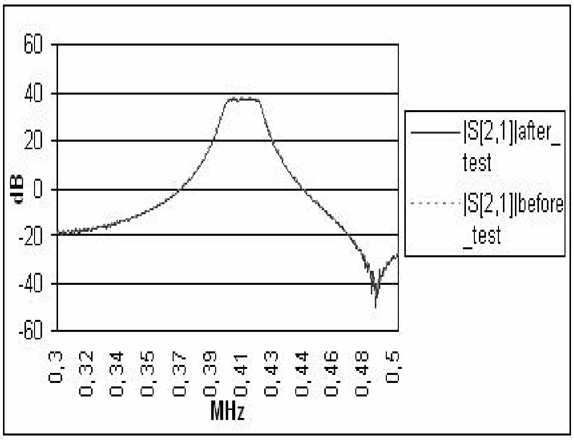

Figure 6: Device S21 module before and after test

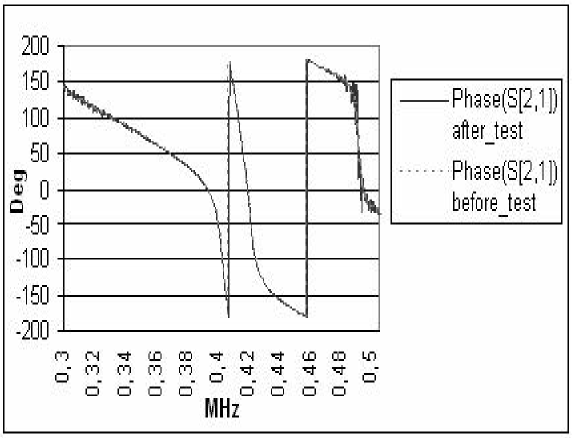

Figure 7: Device S21 phase before and after test

After the tests a visual inspection on the LNA and its housing box has allowed us to underline the following results:

- the lid gasket of the case didn't behave properly at the high temperature.
- the front-end case shows oxidation effects on its surface.

V. CONCLUSIONS

In conclusion the reliability analysis of the analog optical links approach, shows a less faults probability (lower maintainance costs). The front-ends tested, have survived from Composite temperature and humidity cyclic test (Z/AD), while clear alarm signs come from the behaviour of the cases containing the front-ends.

These results are very important for the re-engineering of the Northern Cross antenna as a SKA test bed, but they will be very valuable also in the design of the new generation radiotelescope (SKA). Since it will be extremely large (1 square kilometre) the maintainance costs, related to the reliability, becomes very important.

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