

Northern Cross radioreceiver chains: the environmental test on the critical subsystem

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Abstract –This research 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. SKA is the name given to a new generation radio-telescope that will have 1 km² of effective collecting area. SKA will be the most sensitive radio-telescope ever built that allows a deeper knowledge of the universe. After a reliability analysis we estimated the MTBF of the two approaches so we suggested the most reliable solution to implement. This work considers the most reliable solution for the radio astronomical signal receiver chains, the solution that conveys the analog signal through optical fibre. 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 environmental tests on it. The whole tests plan has been characterized and some preliminary results are reported in the paper [1].

I. Introduction

Two solutions of receiver chains have been taken into consideration. Their description is detailed in the [1].

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.

The main advantages in using the optical analogue links, comparing the two solution above mentioned, are: wider band, lower signal attenuation, lower weight and dimensions, more strength and flexibility, better electric insulation and interferences immunity; this technological solution showed an higher level of reliability prediction.

After a reliability evaluation [1], the optical link configuration was chosen for the implementation of the re-engineering of the Northern Cross Radiotelescope, it 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. 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. The important aspect 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.

II. Environmental tests and results on the critical subsystem

A. Random vibration test implementation

Reliability prediction 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 and GB (Ground Benign Controlled) for the processing room have been used.[1]

From the reliability evaluation we focused that the radio on coaxial chain has a failure rate lower than the failure rate of radio on fibre chain configuration. The fibre chain configuration has a failure rate $\lambda=26.891*10^{-6}h^{-1}$ and MTBF=37187 h, that correspond to about 4.2 years of life.

From the reliability evaluation point of view, the most critical devices of the radioreceiver chains are those placed on the focal line, i.e. the front-end and the optical transmitter. So we decide to do some development tests, with reference to IEC 60068 standards, on the front-end prototypes. From results, after the composite temperature and humidity cycles (Z/AD) important information to improve the project design are obtained [1].

Other important test we planned and implemented on the front-end prototypes: the Random Vibrations test [6]. We defined the device functional parameter under measurement, so this allows to determine the failure condition comparing the same parameters before and after the test. The parameters, we choose, are the S-parameters; these are interesting because they totally characterize a circuit and then can be considered marks of a possible failure. The S_{21} parameter measures the device gain then its excessive reduction does 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 averaging factor, in a frequency range of 300-500 MHz.

In figure 1 and 2 the measure of S_{21} module and phase before test are shown only the frequency range of interest: 400-416 MHz, in our case the operative radio band is centered at 408 MHz; the three front-ends, number 8, 9 and 10, were tested with random vibrations.

The random vibration test was implemented by executing vibrations on the system on three axis in a frequency range 1Hz – 5kHz. The test was performed with the spectral density of acceleration in the frequency range of 10 (m/s²)²/Hz, the trapeze as profile of spectral density of acceleration, the duration of the test long every axis of 100±5% min and a preliminary excitation not longer than the 10% of the entire test. At the end of the test the measures of the control parameters were carried out.

From the handbook of the HP8510B [10] we estimated the instrumental uncertainty on the S_{21} parameter in amplitude of 0.08dB and phase of 0.6 deg for a measure of reference till -50dB; such values of uncertainty are worth for a frequency between 0.045-2 GHz.

From the comparison with the data measured after and before the random vibration test, the values of the amplitude of S_{21} turn out substantially unchanged, in fact we observe a variation between -0.06 dB and +0.04 dB, while the variation of the phase is greater of a factor two regarding the uncertainty introduced from the instrument and we can see an increase between 0.9 Deg and 1.9 Deg in each device, as we can see in figure 3 and 4, where the difference from measurements of S_{21} module and phase after and before vibration tests are shown, in the frequency range of interest (400-416 MHz).

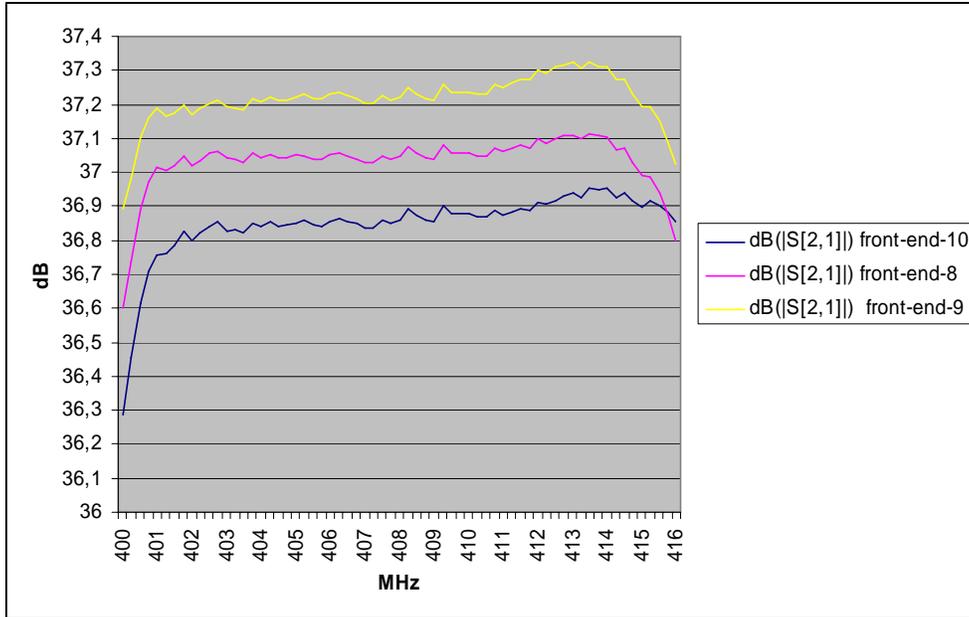


Figure 1: Parameter S_{21} : measurement of module for the devices before stress test

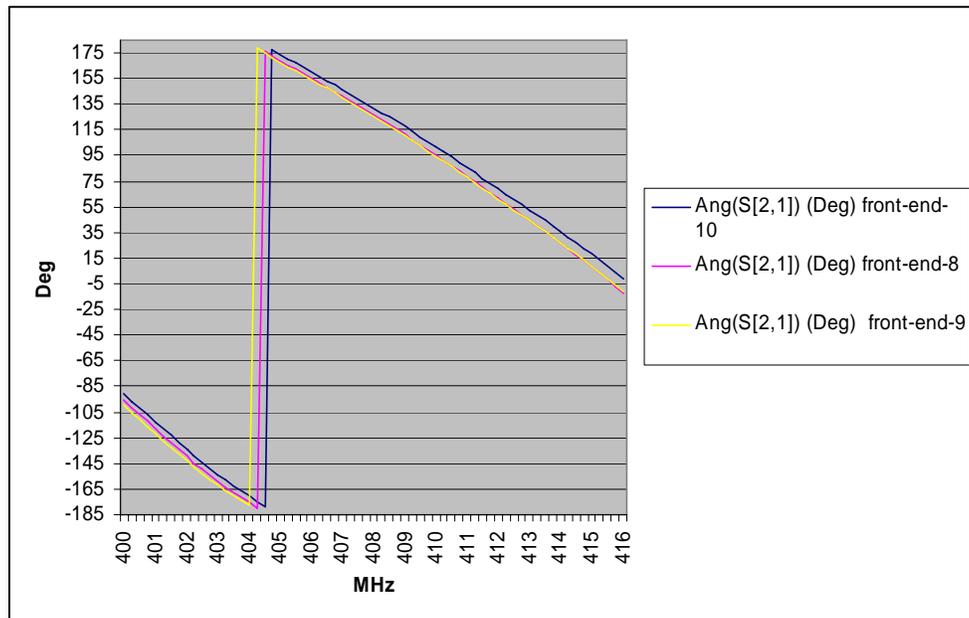


Figure 2: Parameter S_{21} : measurement of phase for the devices before stress test

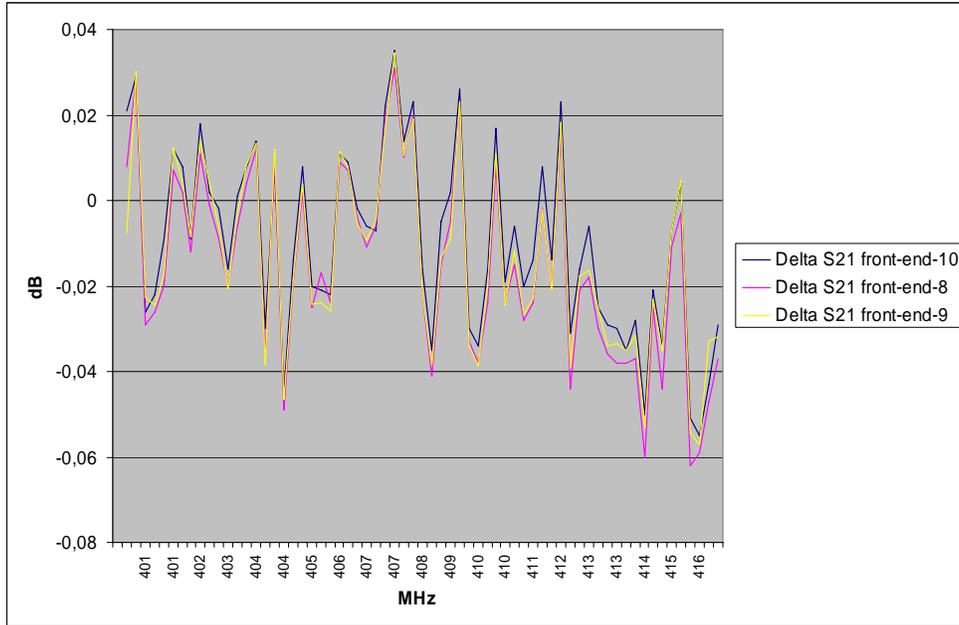


Figure 3: Parameter S21: difference between measurement of module after and before random vibration test

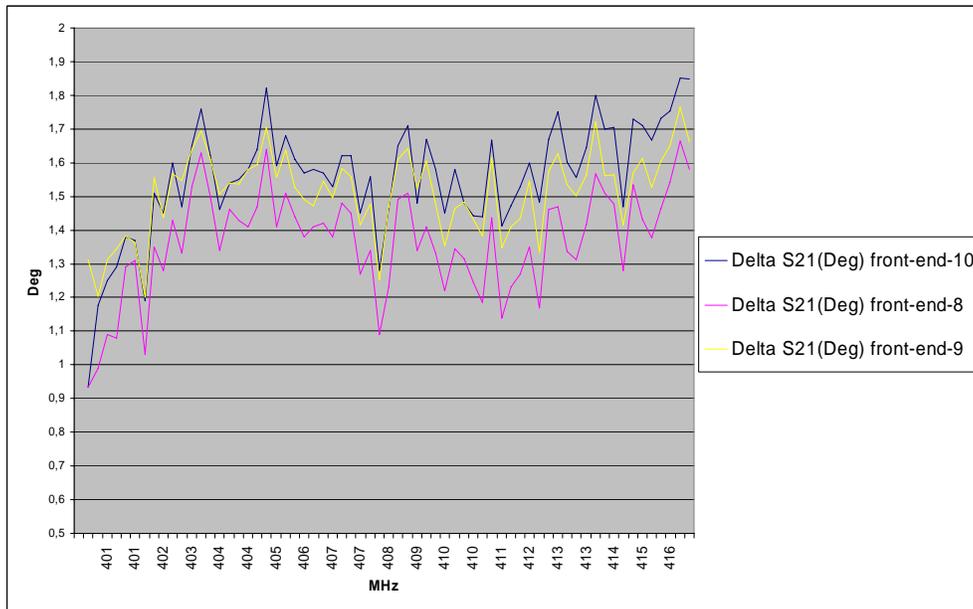


Figure 4: Parameter S21: difference between measurement of phase after and before random vibration test

B. Water and Shock Test Planning

Referring to IEC 60068 standards, we planned tests for the front-end that include Water (Rb) [7], Shock (Ea) [8] solicitations.

The primary purpose of water test is to verify the ability of enclosures, covers and seals to maintain components and equipment in good working order after and, when necessary, under a standardized drop field or immersion in water. Test R includes an artificial rain test based upon natural conditions but not taking into account high wind speeds generally associated with natural rain.

The test that we decided to carry out is Rb 1, than is applied when the impact with the water is due to rainstorms or to strong and continues rain, due also to watering systems; in such test the object is fixed to an apt support and

subordinate to the impact with the water generated from a semicircular tube, the kind of the tube is chosen according to the dimension and form of the device under test.

The severity chosen for the test execution is:

- Angle of the nebulizer nozzles: $\pm 60^\circ$
- Water capacity for hole: $0,6 \pm 0,03$ l/min
- Oscillation angle of the tube: 180°
- Duration: 2 times x 5 minutes

Moreover it is previewed that the tube must oscillate along an angle 360° , 180° for every side of the vertical axis; the time for a complete oscillation, from $+180^\circ$ to -180° to $+180^\circ$ must be 12 seconds

At the end of the test, the object, completely externally dried, will examine at sight and control dimensionally and functionally.

The purpose of the test Shock (Ea) is to determine the attitude of the device under test to survive to specific severity of shock in order to demonstrate the design quality of its intrinsic mechanical robustness; and to use the results, regarding mechanical weaknesses and degradation of specified performances, in order to decide the acceptability of the device. It essentially consists in subjecting a sample to not repeated shock of standardized form with a specific peak and a duration of acceleration. The test 'Ea' is directed to not packed samples, inserted in their guard of transport or of use.

If it is possible, the severity of the test and the pulse shape applied to the sample would have to be such to reproduce the effects of real transport or conditions of exercise to which the device will be subordinate. Given the purpose of this test, the sample champion during the treatment will be always bound to the structure of assembly or the table of test.

On the device under test must be applied three successive shocks for every axis side, that is a total of 18 shocks.

For our device we propose a test with a semisinusoidal shock form, that it is used in order to reproduce the effects of hits deriving from impacts with or from linear systems, as for example hits involving an elastic structure.

Considering that the device will install permanently on the focal line of the antenna, that the possible combinations and that the answer spectrum of transport or employment conditions is not known, we choose to apply an acceleration of 150 m/s^2 with a impulse duration of 11ms.

An important factor, in order to obtain the form and the severity of demanded shock, is the answer in frequency of the entire system of measure, included the accelerometer; this one could introduce some effects of resonances in high frequency, so to reduce such effects we would introduce a filter pass-low.

To better assure the reproducibility of the test, we advise to specify the speed variation and its tolerance, so to obtain an impulse equivalent to the nominal one. This speed variation can be determined by the integration of the acceleration/time curve.

The effective speed variation must be within 15% of the nominal impulse value. The application of this method can be difficult and to demand the use of sophisticated equipment.

This test is important because generally in the systems the inner parts are complex (an example connected in series, with many degrees of freedom and with damping), so it permit to show damages due to effects of resonances couple.

III. Conclusions

In conclusion the reliability analysis of the analog optical links approach, shows a less faults probability (lower maintenance 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 [1], while front ends subordinate to random vibrations test unchanged their characteristics under investigation.

Referring to IEC 60068 standards [8], we planned other important tests for the front-end as Water (Rb) and Shock (Ea), that will give us important information for the optimization of the product design.

These results will be 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 kilometer), the maintenance costs, related to the reliability, becomes very important.

After the test and to have verified the compliance of the prototypes to the detailed lists, we propose to carry out the compliance and reliability tests on front-end taken from the effective process of production.

References

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