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ENVIRONMENTAL TESTING: BEHAVIOR OF A RADIO RECEIVER CHAIN FRONT-END

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Abstract

The proposed approach has been conceived in order to test and characterize 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). SKA represents a new-generation radio-telescope that will have 1 km^2 of effective collecting area. It can be considered as the most sensitive radio-telescope ever built that allows a deeper knowledge of the universe. In order to guarantee the implementation of a reliable radio-receiver chain, we proposed to test the front-end that will be installed in the focal line of the antenna. The front-end has turned out as the most critical subsystem of the radio-receiver chain from a preliminary reliability analysis reported in [1]. For this reason, in the paper some results are obtained by vibration tests as well as shock and water tests are presented in order to prove the performance of the circuit under test (CUT) in particular environmental conditions.

1. Introduction

The future of radio-astronomy, in the 0.1 to 25GHz frequency band, will be the Square Kilometre Array. (SKA) A large amount of small antenna sensors will be combined together in order to synthesize an overall collective area in the order of a million square meters, spread over an area more than 3000km wide [2]. 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 then processed. So, massive use of low-cost analogue and digital electronics will be necessary, pushing the instrument in the direction of a “software telescope”. Planning the array construction to be completed in the year 2020, different antenna sensors and receiver architectures are today under study or in a construction phase as prototypes, called SKA demonstrators. One of these is represented by 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, Italy. In order to reduce the risks the re-instrumentation is faced in three successive steps with increasing size, both in collective area and number of receivers. At the end of the re-instrumentation phase, the BEST total collective area will be about 8000 m^2, which is comparable with the effective collecting area of a future proposed SKA station (about 10000 m^2). The principal goals of BEST are low cost, high performance, easily replicable technology, investigation of beamforming algorithms for Radio Frequency Interference (RFI) rejection and multi beam techniques, the possibility to test concepts, algorithms and technologies on a large demonstrator.

In conventional radio-telescopes, the receivers are located in well-protected and controlled environments. In particular their operating temperature is kept constant from the Low Noise Amplifier (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 feature of the Aperture Array technology (AA), which is probably the most promising and versatile one and, over all, the only one that can fully satisfy the strong astronomers' requirements in the SKA low frequency band (*i.e.* less than 1GHz).

After a reliability evaluation [1], the optical link configuration was chosen for the implementation of the re-engineering of the Northern Cross Radio-telescope; it is based on the idea to transmist the analog signals via an optical link directly from the front-ends (installed on the focal lines) to the processing room (Fig. 1). This solution increases reliability and makes maintenance activities easier, the major part of the processing hardware being indoor (in a temperature controlled and humidity sheltered room). This assures complete protection from atmospheric conditions, temperature variations, electrical discharge, *etc*. In addition, this solution offers direct access to the equipment to simplify maintenance operations, with logistic and economical advantages. Moreover it would allow to obtain simplified control, synchronism and LO signals distribution. The use of an analog fibre link needs to install on the antenna focal lines a front-end are composed by a three-stages low-noise front-end and an optical transmitter, in order to transmit the RF signals (16MHz centred at 408MHz) directly to a central protected and shielded receiver room, located inside the main building.

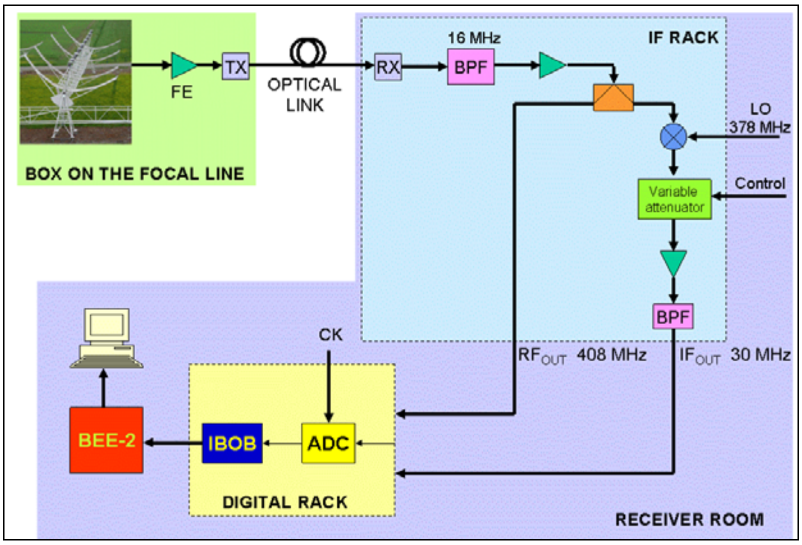

Fig. 1. BEST receiver chain; the antenna shown is a N/S element.

2. Tests and results

2.1. Planning and implementation of random vibration test

From the reliability evaluation point of view, the most critical devices of the radio-receiver chains are those placed in the focal line, i.e. the front-end and the optical transmitter. We decide to make some tests, with reference to IEC 60068 standards [3], on the front-end prototypes, in order to evaluate the behavior of the front-end. From results, after the composite temperature and humidity cycles (denoted as Z/AD) important information to improve the project design are obtained [1].

In addition we implemented a random vibration test on the front-end prototypes according to the IEC 60068-2-64 international Standard [4]. To this aim we defined the device functional parameters under measurement, in order to determine the failure condition and compare each parameter before and after the test. In particular, we choose the S-parameters able to characterize the CUT and to induce a potentially faulty condition. In particular, the S_{21} parameter measures the device gain and S_{11} measures the input reflection coefficient, so their excessive variation does not allow us to receive the weak radio-astronomical signals.

The measurement of S-parameters is performed by means of a vector network analyzer, with survey of values made up by 801 points with 16 as averaging factor, in a frequency range of 300-500 MHz.

Three front-ends, denoted as 8, 9 and 10, were tested with random vibrations. The test was implemented by executing vibrations on the system on three axes in a frequency range of 1Hz–5kHz. In this frequency range the test was performed with the acceleration spectral density equal to 10 $(m/s^2)^2/Hz$, the trapezium as profile of acceleration spectral density, the duration of the test along every axis of 100±5% min and a preliminary excitation not longer than 10% of the entire test. At the end of the test the measures of the S-parameters were carried out. Referring to the S_{11} and S_{21} parameters, the plots of both module and phase before the stress test are shown in Figs 2÷5. The frequency range of interest is 400-416 MHz, considering that the operating radio-band of the Northern Cross Radio-telescope is centered at 408 MHz.

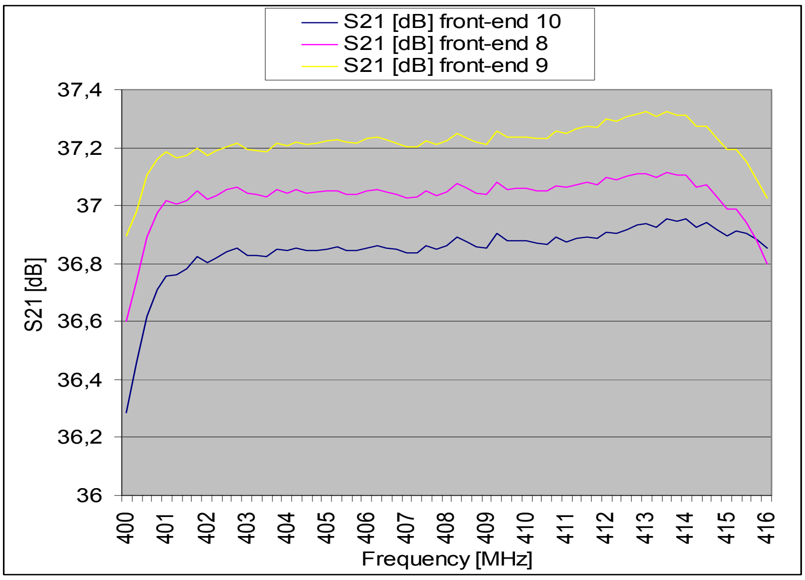

Fig. 2. Parameter S_{21}: measurement of module for the devices before stress test.

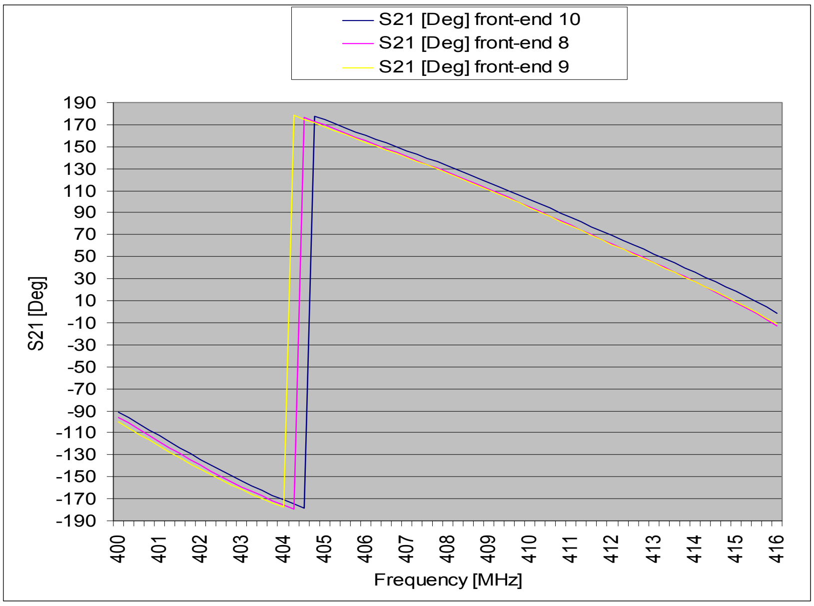

Fig. 3. Parameter S_{21}: measurement of phase for the devices before stress test.

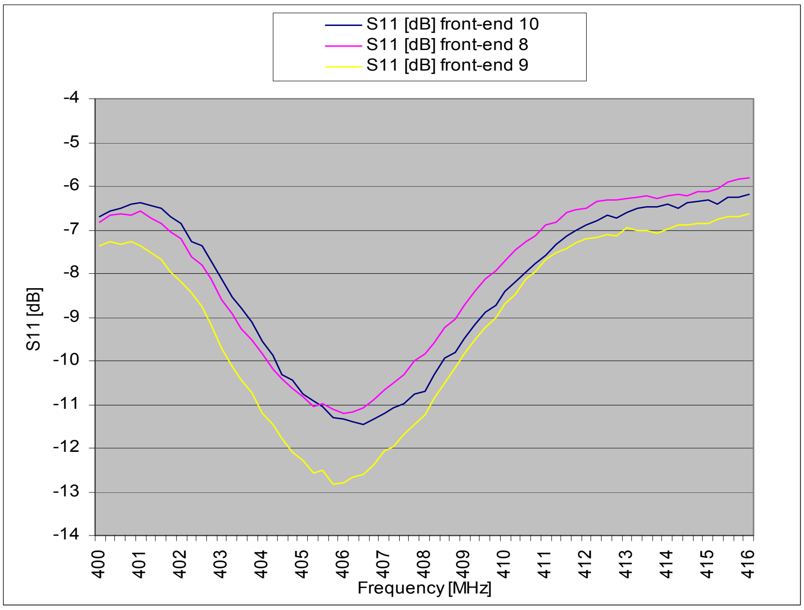

Fig. 4. Parameter S_{11}: measurement of module for the devices before stress test.

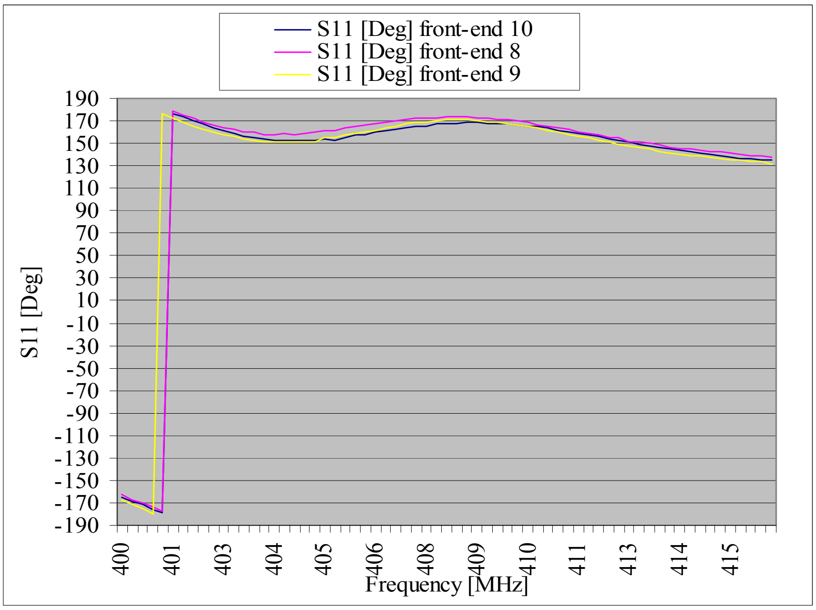

Fig. 5. Parameter S_{11}: measurement of phase for the devices before stress test.

We estimated the instrumental uncertainty on the S parameter on level of 0.08dB and phase of 0.6 deg for a measure of reference till -50dB; such values of uncertainty are valid for a frequency between 0.045-2 GHz.

From the comparison with the data measured after and before the random vibration test in the frequency range of interest (400-416 MHz), the values of the amplitude of S_{21} turn out substantially unchanged. In fact, in Fig 6, we can observe a variation between -0.06 dB and +0.04 dB, while, as shown in Fig. 7, the variation of the phase is greater by a factor of two regarding the uncertainty introduced from the instrument. We can also observe an increase between 0.9 Deg and 1.9 Deg for each device. However the variation trends of S_{21} module and phase for all devices are comparable; instead the variation trends of S_{11} module and phase of the three devices are different. The values of the amplitude and phase of S_{11} turn out changed, then the variation range amplitude is between -0.15 dB and +0.3 dB and the variation range in phase is -1.55 Deg and 2.55 Deg, as we can observe in Figs 8 and 9 respectively. In such two ranges of variation so wide, the variation average of S_{11} amplitude is 0.10±0.08dB for the front-end number 10, 0.06±0.08 dB for the receiver 8 and 0.05±0.08 dB for the receiver 9. Referring to the phase, instead, the variation average of S_{11} is equal to 0.42±0.63 Deg for the front-end 10, 0.52±0.54 Deg for number 8 and 0.71±0.66 Deg for the device 9.

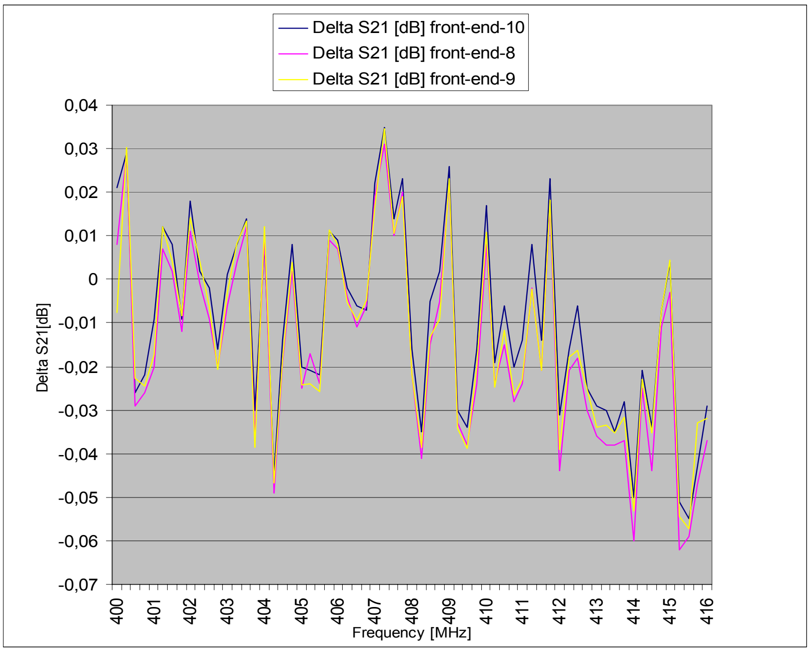

Fig. 6. Parameter S_{21}: difference between measurement of module after and before random vibration test.

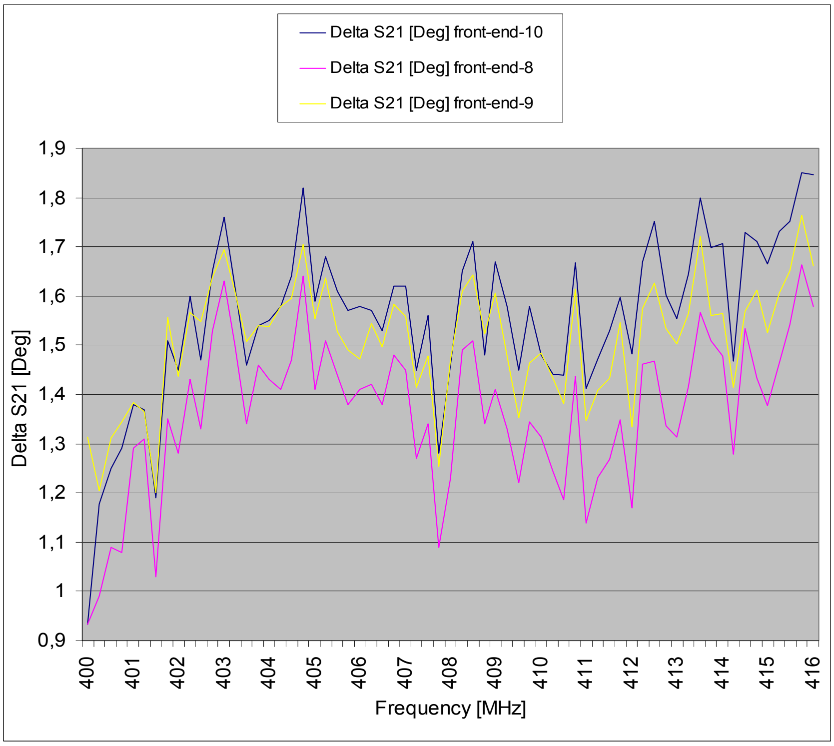

Fig. 7. Parameter S_{21}: difference between measurement of phase after and before random vibration test.

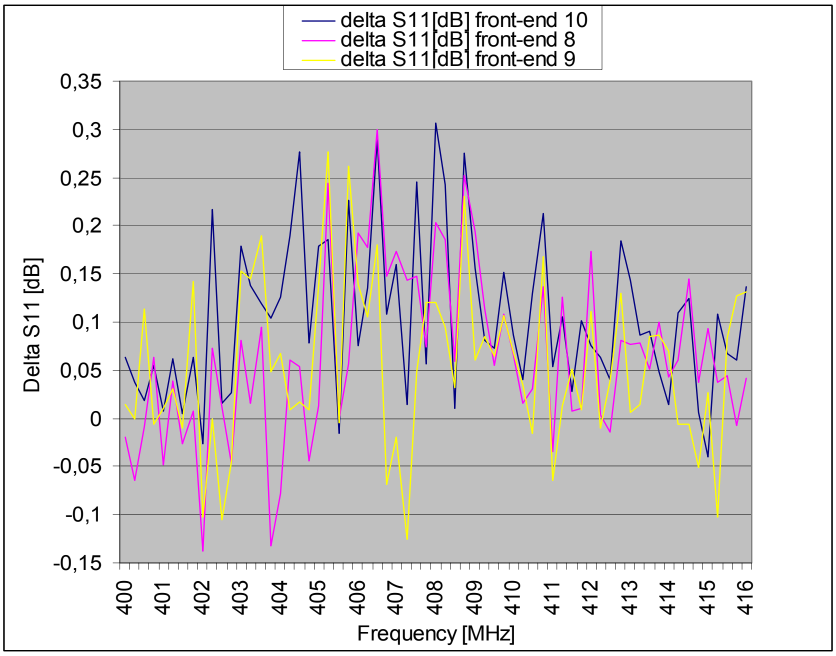

Fig. 8. Parameter S_{11}: difference between measurement of module after and before random vibration test.

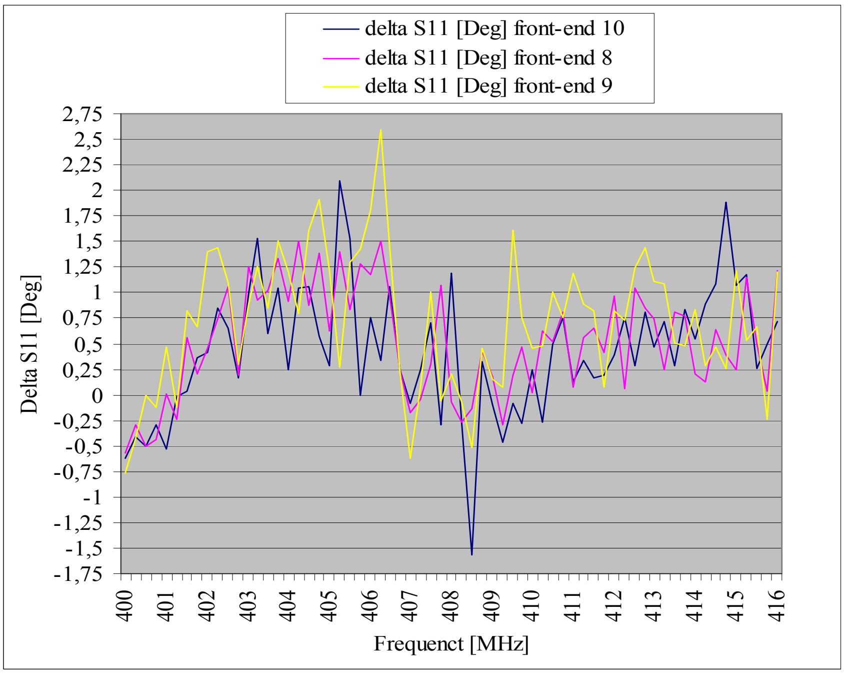

Fig. 9. Parameter S_{11}: difference between measurement of phase after and before random vibration test.

2.2. Planning of other tests

The typical environmental location of the new radio-telescope will be in a desert. It represents a particular environmental condition characterized by different and strong environmental stresses; so it is fundamental to analyze the behavior in different condition of all devices placed in the focal line of the antenna. To this aim, in addition to vibration tests other two significant tests are planned according to the IEC 60068 Standard: Water (Rb) [5] and Shock (Ea) [6].

The primary purpose of the 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; however it does not take into account high wind speeds, a typical condition generally associated with natural rain.

In this work we proposed to carry out the "Rb1" test in order to simulate a particular condition where the impact with water is due to rainstorms or to strong and continued rain, due also to watering systems; in such test the CUT is fixed to an apt support and subordinate to the impact of water generated from a semicircular tube whose characteristics are chosen according to both the dimension and form of the device under test.

The severity chosen for the test implementation is:

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

Moreover it is planned 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° to - 180° to +180° must be 12 seconds, according to the Standards. At the end of the test, the object, completely externally dried, will be examined at visually and controlled dimensionally and functionally.

The purpose of the test Shock (Ea), instead, is to determine the attitude of the device under test to survive a specific severity of shock; the "Ea" test allows 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 upon the acceptance of the device. It essentially consists in subjecting a sample to singel shock of standardized form with a specific peak and a duration of acceleration. The "Ea" test is directed unpacked 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 subjected.

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

In this work we propose a test with a semi-sinusoidal 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 in the final condition the receiver will be permanently installed in the focal line of the antenna, the possible combinations and that the spectrum response of transport or employment conditions are unknown, so we choose to apply an acceleration of 150 m/s^2 with an impulse duration of 11ms.

In order to obtain the form and the severity of the demanded shock, an important factor is represented by the frequency response of the entire system of measure, included the accelerometer; this one could introduce some effects of resonances at high frequency, whose contribution can be reduced with a pass-low filter.

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. The 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 require the use of sophisticated equipment.

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

3. Conclusions

The front-ends, the weakest block of the entire radio-receiver chain, have been stressed by environmental and climatic factors, samples of front-ends with a composite temperature and humidity cyclic test (Z/AD) and other with a random vibration test (Fh). From the results: a front-end has survived the composite temperature and humidity cyclic test (Z/AD)[1] and three front-ends subordinate to the random vibration test showed a good behavior of their characteristics under investigation, in particular for S_{21} parameter.

Referring to IEC 60068 Standards [3], 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.

The design for reliability of the analog optical links shows a probability of fewer faults and then lower maintainance costs. These results will be very important for the re-engineering of the Northern Cross Radio-telescope and they will be very valuable also in the design of the new generation radio-telescope (SKA). Since it will be extremely large (1 square kilometer), the maintenance costs, related to the reliability, become very important.

After the test on the prototypes, we propose to carry out the compliance and reliability tests on the front-end taken from the effective production process, in order to verify the permanence of the characteristics trends.

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