Test and measurements of reliability performance
on radioreceiver chains for
the Northern Cross Radio Telescope
(Bologna, Italy)

M. Catelani, Valeria L. Scarano

University of Florence, Italy
Department of Electronics and Telecommunications
marcantonio.catelani@unifi.it - valeria.scarano@unifi.it
Tel/Fax: +39.055.4796393, Via S. Marta, 3 - 50139 Florence, Italy

S. Montebugnoli, G. Bianchi, F. Perini

I.N.A.F. - I.R.A., Italy
National Institute for AstroPhysics - Institute of RadioAstronomy
s.montebugnoli@ira.inaf.it, g.bianchi@ira.inaf.it, f.perini@ira.inaf.it
Tel:+39.051.6965823, via Fiorentina 3508/B - 40060 Medicina (Bo), Italy
LabME: MEASUREMENTS, RELIABILITY AND QUALITY LAB

LabME belongs to the Electronics and Telecommunications Department of the University of Florence

Our research activities are focused on:

• Electrical and Electronic Measurements
• Reliability, Availability and Maintainability
• Automatic Diagnosis and Measurement Systems
• Fault Analysis and Diagnosis
• Device Stress Testing and Qualification
• Risk and Safety Analysis (FTA, FMEA, FMECA)
BEST: NORTHERN CROSS UPGRADING

Basic Element for SKADS Training (BEST): this is a project by IRA -INAF which gradually will upgrade part of the 30000 m² area of the Croce del Nord (Northern Cross).

TARGET: to test and try new technologies and instrumentation systems to use on the SKA radiotelescope.

Prototypes and algorithms developed in the BEST project:
- Antennas (focal lines)
- Front-end
- Optical fibre links
- Receivers
- Beamforming algorithms
- Post-processing algorithms
- Calibration techniques
**SKA radiotelescope**, as the final system will be:

- expensive (about 1.5 billions of dollars)
- complex (about thousands/millions of antennas/receivers).

A Reliability Analysis, both at device and system level, should be performed in order to evaluate design options and reduce the Frequency of Failures and, consequently, the Maintenance Costs.

In the **BEST** project a reliability experimental analysis was performed in order to

- choose between two different kinds of receiver chain (Digital or Analogue optical link solutions);
- identify the most reliability critical items in the receiver chain.
Digital optical link solution

Base band and A/D conversion

Digital sampling clock and local oscillator signals
Digital optical link solution block diagram
Analogue optical link solution

Base band and A/D conversion
Analogue optical link solution block diagram
Receiver chain performances based on *Analogue optical link* are better:

- potential wider bandwidth for further upgrading (up to 2.5 GHz)
- electrical insulation
- immunity to electromagnetic interferences

Even concerning reliability and maintainability matters, the *Analogue optical link* solution seems to be better because:

- more devices in an easily reachable area ⇒ easier maintenance
- more devices in a sheltered environment ⇒ lower environmental stress levels
This analysis has been performed according to the following tools and hypothesis:

- MIL-HDBK-217-FN2 data base
- Series reliability functional configuration
- 100% duty cycle
- Operating temperature: 30°C
- Environments:
  - GM (Ground Mobile) for antenna equipment
  - GF (Ground Fixed Uncontrolled) for cabin equipment
  - GB (Ground Benign Controlled) for processing room equipment
Above 80°C of operating temperature the MTBF values of the different solutions are quite the same.

**Coaxial cable solution:**
- **Digital optical link solution**
  - MTBF: 10624 h → ~1.2 years

**Optical fibre solution:**
- **Analogue optical link solution**
  - MTBF: 37187 h → ~4.2 years
RELIABILITY PREDICTION and COSTS

Sub-system Reliability prediction report

Coaxial cable configuration with digital optical link

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Failure Rate [failure*10^3 h^-1]</th>
<th>MTBF [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical TX</td>
<td>40</td>
<td>25,000</td>
</tr>
<tr>
<td>Optical RX</td>
<td>20</td>
<td>50,000</td>
</tr>
<tr>
<td>Analogue Receiver</td>
<td>1,645633</td>
<td>607,669</td>
</tr>
<tr>
<td>Digital Receiver</td>
<td>16,63268</td>
<td>60,268</td>
</tr>
<tr>
<td>Front-end</td>
<td>10,262285</td>
<td>97,444</td>
</tr>
<tr>
<td>Ethernet</td>
<td>5,625384</td>
<td>177,766</td>
</tr>
<tr>
<td><strong>System</strong></td>
<td>94,125982</td>
<td>10,624</td>
</tr>
</tbody>
</table>

Optical link configuration with analogue optical link

<table>
<thead>
<tr>
<th>ITEM</th>
<th>Failure Rate [failure*10^3 h^-1]</th>
<th>MTBF [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Optical TX</td>
<td>11,145606</td>
<td>89,721</td>
</tr>
<tr>
<td>Optical RX</td>
<td>1,939433</td>
<td>515,615</td>
</tr>
<tr>
<td>Analogue Receiver</td>
<td>0,427974</td>
<td>2,338,591</td>
</tr>
<tr>
<td>Digital Receiver</td>
<td>2,102192</td>
<td>475,694</td>
</tr>
<tr>
<td>Front-end</td>
<td>11,275112</td>
<td>88,683</td>
</tr>
<tr>
<td>3rd stage</td>
<td>1,013827</td>
<td>986,362</td>
</tr>
<tr>
<td><strong>System</strong></td>
<td>26,891316</td>
<td>37,187</td>
</tr>
</tbody>
</table>

COSTS of the complete Northern Cross antenna re-instrumentation (352 receivers)

<table>
<thead>
<tr>
<th></th>
<th>Digital links option</th>
<th>Analogue links option</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total costs</strong></td>
<td>€ 2.640.501,72</td>
<td>€ 2.204.237,90</td>
</tr>
</tbody>
</table>

Total costs do not consider the cost of the analogue optical transmitter and receiver, which can be obtained:

$$\frac{2.640.501,72E - 2.204.237,90E}{352} \approx 1240 \text{€}$$
RELIABILITY CRITICAL DEVICES

The most reliability critical devices, in the case of the Analogue Optical Link solution, are those which are installed on the focal line of the antenna, i.e. the three stages front-end and the optical analogue transmitter.

In the whole Croce del Nord 352 devices of each type are needed.

A failure of one of these devices calls for the removal and change of the failed device with a new one, with a cost of at least 500€ (about 420$), the most of which due to labour, and with a system down time of more than 4 hours.

On the critical devices some reliability tests could be planned and implemented.
ENVIRONMENTAL TESTS ON CRITICAL DEVICES

Possible Quality Tests:
• Pre-compliance/ Compliance Test
• Reliability Test: Life test, Accelerated/High Accelerated Life Test
• Environmental Stress Screening

The Compliance Tests allow:
• To stress components or devices, in semifinal or final configuration, with environmental and electrical severities level comparable with the nominal ones.
• To compare, by a quantitative point of view, devices implemented in different technologies or carried out from different production processes.

Example: Planned and Implemented Tests on INAF MEDICINA Front-End:
• Random Vibrations Test
• Cycling Humidity and Temperature Test

The parameters chosen in order to verify the devices fault are the S-parameters.
The failure rate function for electronic components and systems

\[ \lambda(t) = \lim_{\Delta t \to 0} \frac{\text{Prob} \{ t < t \leq t + \Delta t \}}{\Delta t} = \frac{1}{\text{Prob} \{ t > t \}} \lim_{\Delta t \to 0} \frac{\text{Prob} \{ t < t \leq t + \Delta t \}}{\Delta t} \]

- **latent defect**: defect that it exists but that has not been still recognized
- **failure**: the attitude of an entity (component, device, etc.) cease to execute the demanded function
- **failure mechanism**: the chemical, physical process or of other nature, that generates the breakdown
POSSIBLE FUTURE RESEARCH ACTIVITIES:

RELIABILITY TESTS

**Life Tests** have the aim to verify or evaluate the component or device life in specific environmental conditions, which simulate the operating conditions.

**Accelerated Reliability Tests** are Life Tests in which the environmental severities levels are higher than the operating conditions in order to decrease the test time.

In order to extend the validity of the results test to real operating life the application of some chemical and physical models are necessary.

<table>
<thead>
<tr>
<th>STRESS FACTORS</th>
<th>CHEMICAL AND PHYSICAL MODELS</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEMPERATURE</td>
<td>ARRHENIUS</td>
</tr>
<tr>
<td>TEMPERATURE+BIAS</td>
<td>EYRING</td>
</tr>
<tr>
<td>TEMPERATURE CYCLES</td>
<td>COFFIN –MENSON</td>
</tr>
<tr>
<td>POWER CYCLES</td>
<td>COFFIN – MENSON</td>
</tr>
<tr>
<td>TEMPERATURE AND HUMIDITY</td>
<td>REICH HAKIM EYRING PECK</td>
</tr>
<tr>
<td>VOLTAGE AND CURRENT</td>
<td>EYRING</td>
</tr>
</tbody>
</table>
POSSIBLE FUTURE RESEARCH ACTIVITIES:
ENVIRONMENTAL STRESS SCREENING

Application of environmental and/or electrical stresses to electronic components/devices (DUT) with the scope to transform the latent defects in premature failures. [MIL-HDBK 344 A]

Why the ESS?
- Variability of the characteristics of the production processes, also in electronics
- Necessity to evidence the intrinsically weak population in short times and with low costs
- The necessity to satisfy the lack of reference data that concur to correlate the effectiveness of solicitation types and levels with occurring of the failures

What is necessary for the definition of the test plan?
- To choose in opportune way the type (environmental, electrical, etc); and the severities (profile test) of stress, the application of the solicitation does not have to induce undesired failure mechanisms in the device under test.
CONCLUSIONS

• Optical fibre receiving chain was chosen because of better performances and higher reliability ⇒ lower maintenance costs;
• The devices installed on top of the focal lines are identified as the most reliability critical ⇒ a test plan was planned and implemented with good results.


FUTURE RESEARCH ACTIVITIES FOR THE RADIORECEIVER CHAINS

The dimension and the cost of the SKA radiotelescope suggested to deep the reliability of the instruments and devices that will be implemented.

Reliability analysis should be performed in terms both of Reliability Prediction and Environmental Tests as:

• Pre-compliance/ Compliance Test
• Environmental Stress Screening
• Reliability Test: Life test, Accelerated/High Accelerated Life Test
Test and measurements of reliability performance on radioreceiver chains for the Northern Cross Radio Telescope (Bologna, Italy)

Thank you for your attention!

M. Catelani, Valeria L. Scarano

University of Florence, Italy
marcantonio.catelani@unifi.it - valeria.scarano@unifi.it
Tel/Fax: +39.055.4796393, Via S. Marta, 3 - 50139 Florence, Italy

S. Montebugnoli, G. Bianchi, F. Perini

INAF, Italy
s.montebugnoli@ira.inaf.it, g.bianchi@ira.inaf.it, f.perini@ira.inaf.it
Tel:+39.051.6965823, via Fiorentina 3508/B - 40060 Medicina (Bo), Italy