Design of High Temperature Electronics for Well Logging Applications

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1 Introduction

Well logging represents the most developed applied industry currently using high temperature electronics technology. The penetration of high temperature electronics in this market exceeds that of other application sectors like automotive or aerospace.

Well logging has been the primary driving force and leading financial sponsor for the development of high temperature electronics in the last 25 years. The use of high temperature components within the petroleum exploration and geothermal industry is characterised by:

- Low volume /100 tools per year.
- High level of specialisation / many different sensors used.
- High accuracy, high performance up to 22 bits of resolution.
- High reliability level/5 years at 150°C

High temperature electronics and the interaction with the design, implementation, production and testing are presented in Figure 1.

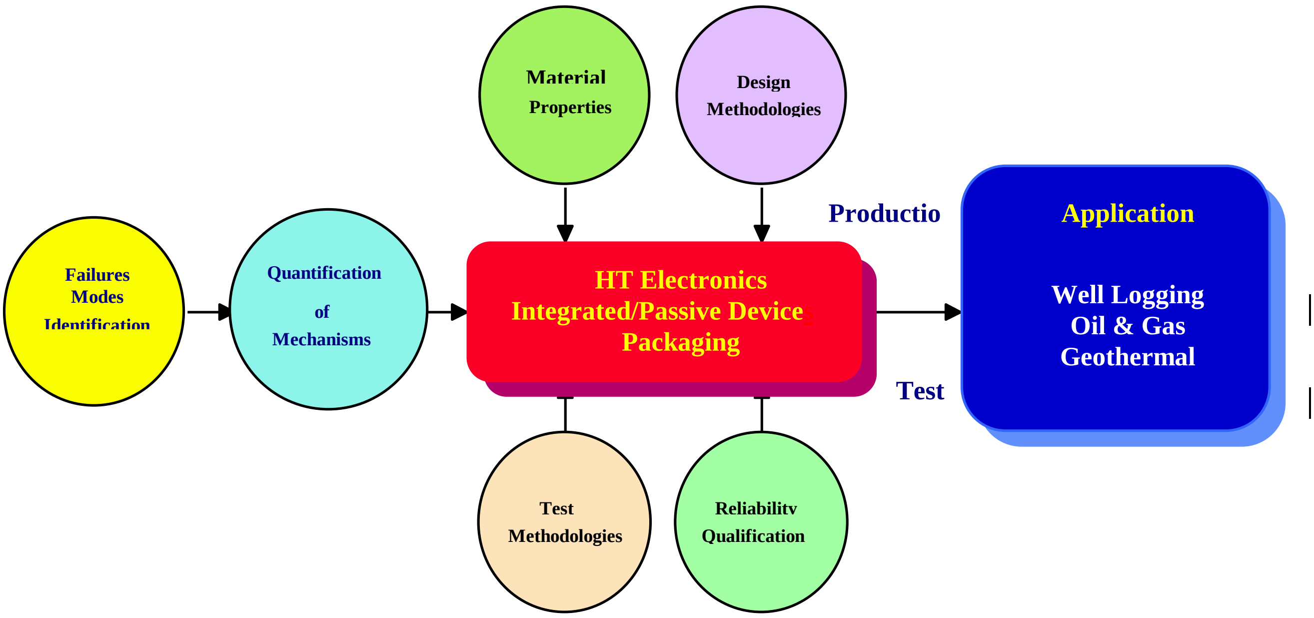

Figure 1. High temperature electronics design and implementation

This paper describes a number of issues related to the design of high temperature electronics for well logging applications.

The paper is organised as follows: In Section 2 the characteristics and the temperature requirements for electronics components used in well logging are presented. In Section 3, the applications are described. Design issues in high temperature electronics for well logging applications are presented in Section 4. Section 5 discusses the trends and future developments in the industry.

2 Characteristics and Temperature Requirements for Electronic Components in Well Logging Applications

Within the field of oil and gas well logging, the use of integrated instrumentation systems that withstand high temperatures aims at increasing the recovery of oil while at the same time reducing costs, emissions and safety hazards.

The development in technology for the high cost, low volume well applications can be extended to cover general process monitoring thereby impacting the competitiveness of a large range of industries.

Operating conditions in oil wells are just outside the operating range of standard sensors and electronics in terms of requirements on size, operating temperature or pressure.

Putting together a well logging system is a major undertaking since there are few standard components available, and the demands on reliability are strong. As a consequence, well logging projects have been large, and been forced to address many issues, from sensing through communication to data management, within the same project. Even though a large number of innovative solutions have been developed, the full potential of new technologies has not been exploited.

The main operating conditions and time requirements for typical applications are presented bellow:

Well Depths:

- Oil and gas: 3-6 km.
- Geothermal: 10 km.

Temperature Range

- Majority of oil wells are under 125°C with 80% <150°C
- 95% of oil wells are under 175°C
- Only 2% or 3% are 200°C range or higher
- Geothermal wells: 25°C to 400°C with most wells being covered by 325°C

Environmental Conditions:

- Vibrations 10g at 10-60Hz, 1g at 240Hz
- Mechanical shocks 500g/5ms
- Pressure 150 bars
- Substances: oil, mud, humidity; corrosive chemicals

Typical Applications and Operation Time Requirements

- Traditional wire line logging (2 to 6 hours)
- Measurement while drilling (from 100 hours to 500 hours)
- Permanent gauges, intelligent completions (>40,000 hours)

2.1 Design Approaches

The tools for logging applications, with the exception of those for very high temperature and short logging time using thermal insulation, are build using commercial materials and components, selected and qualified for the operating temperature. The rules for selecting and using the materials and components are summarized as follows:

- Stringent selection and testing procedures for standard commercial grade components and materials.
- The use of ASICs for specific functions.
- The use of MCMs (Multi Chip Modules) when size is critical.

- No use of organic materials when long-term reliability is mandatory.

There are various packaging options available for today's high temperature electronics. These solutions are specific to the application with a customed assembly process, which in generally comes at a cost premium.

3 Well Logging Applications

Well logging and data analysis technologies enhance the ability to image between wells and provide information with increased resolution into the reservoir model. Optimal well placements are achieved by identifying the best producing locations, considering azimuthal anisotropy, and focusing on mechanical rock strengths in order to achieve high performance drilling while preserving wellbore integrity.

Wireline logging determines which formations intersected by the wellbore may contain hydrocarbons (typically less than 1 percent of the well), and takes measurements to provide descriptive and quantitative evaluations of the rock penetrated, and the type and amount of fluid contained therein.

Although logging while drilling (LWD) has been available for more than 15 years, for much of that time the tool suite was too limited for the technology to contribute fully to formation evaluation. In the past few years, this situation has changed. Now LWD does offer a useful range of downhole measurements for petro-physical purposes.

In logging the well, four main types of equipment are used:

- Downhole instruments that measure data from different sensors,
- Computerised surface data acquisition systems that analyse and store data,
- Cable/wireline that is used for data communication with the downhole instruments and mechanical support
- Hoisting equipment to raise and lower instruments.

4 High Temperature Design Issues in Well Logging Applications

In this section the main high temperature design issues in well logging applications are presented and discussed.

High temperature electronic systems for well logging applications require electronic circuits that preserve their properties, functions, and reliabilities up to the desired operation temperature and interconnection/packaging technology on a substrate to form an electronic circuit with long term reliable operation capability

The main design issues for high temperature electronics for well logging applications are:

- Proper understanding of field operating conditions / mission profile
- Selection process of components that can meet high temperature performances
- Design methodologies that can accommodate the drift of performances of parts
- Design of integrated devices (ICs, ASICs, integrated instrumentation systems) that meet industrial requirements and increase reliability and testability
- Passive component development for high temperature operation
- High temperature materials
- Interconnections
- Packaging for high temperature reliable operation
- Electrical and mechanical assembly
- Testing and reliability data (performance specification and lifetime at high temperatures)
- Electronic system integration that meets the requirements of well logging applications

This is illustrated on Figure 2.

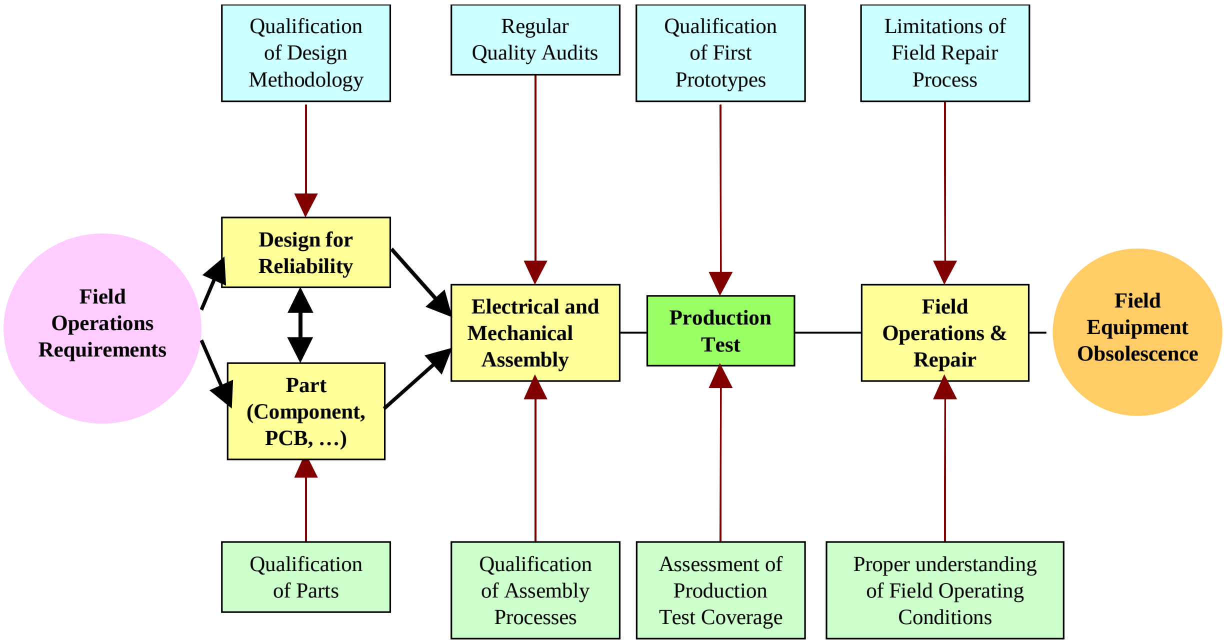

Figure 2. Main design issues for high temperature electronics for well logging applications

The high temperature designer has to understand each and every part of the design and assembly process of the equipment and its specific failure mechanisms and their sensitivity to environmental conditions.

The reliability of the overall system is limited by its weakest element. When replacing the first part in the failure chain, it is critical to know what is coming next, and so on until the latest failure mechanism is reached. Figure 3 illustrates this cascade of failures over the operating time of a tool under given operation conditions.

Nevertheless, the best approach is to use technologies completely qualified to fulfil the overall lifetime of the tool. Cost and associated risks due to the failure or due to the repair process push technology departments to select the right solution.

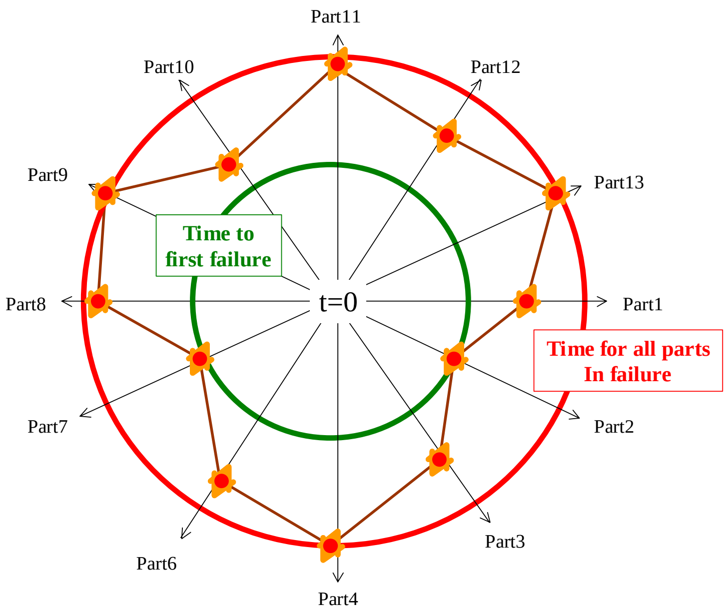

Figure 3. Cascade of failures over the operating time of a tool under given operation conditions

Figure 4 represents the failure probability as a function of time for a sub-assembly that is part of a high temperature electronics system. Infant mortality is eliminated using burn in methods and screening tests.

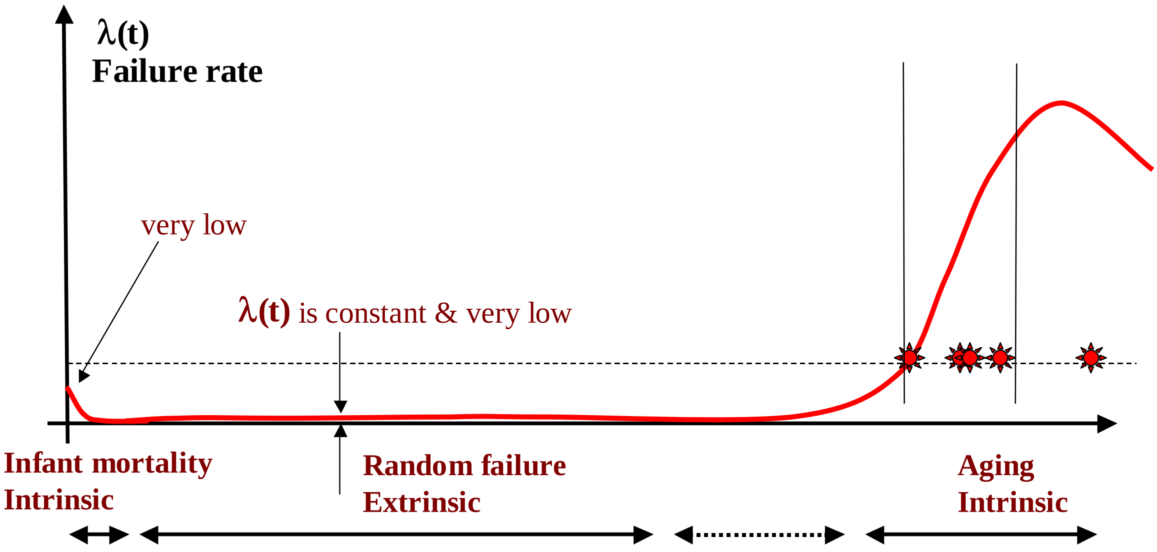

Figure 4. Sub-assembly failure probability as a function of time

4.1 Design Steps Over the Complete Lifetime Cycle of Oilfield Equipment

In the design phase is important to review the specificities of each design step over the complete life cycle of oilfield equipment. The following elements are extremely important for the design of high temperature electronics equipment.

4.1.1 Understanding Field Requirements

Considering that there is a diversity of oil fields from different market segments, it is important to understand what the customer really wants so the high temperature equipment is designed optimal (no over-design or under-design). Mission profile includes normal and non-normal exploitation and defines the application domain of the equipment.

4.1.2 Design for Reliability

Derating factors, fault tree analysis and "no single fault failure", FMECA, heavy mixed domain simulations (electrical – thermal – mechanical – hydraulical) have to be considered early in the design phase. Design should also focus on manufacturability, and design upgrade for obsolescence management

4.1.3 Selection of Parts and Materials

In this phase the library of failure modes and qualified parts are collected, proper qualification plans are made and market intelligence is gather taking into account the obsolescence issues including the evaluation of standard components versus ASICs and MCMs.

Physics of failure methodology or qualification by knowledge of the technology allow for selection of the best solution, decrease risk, and focuses the analysis on real issues. Physical and chemical properties of materials, metallurgy interfaces should be identified and quantified.

4.1.4 Electrical and Mechanical Assembly

High temperature electronics quality requires industrial processes, well monitored but still compatible with low production volume.

Delaminations, contamination and bad solder joints, are major reliability concerns and should be addressed in the early phase of the design. Process definition, monitoring and non-destructive analyses are key solutions to avoid problems during equipment qualification.

4.1.5 Production Test

Testing is one of the most important phases for qualifying the functionality of the equipment for high temperature operation. The assessment of test coverage determines the balance between the time necessary for test (cost) and the coverage of the blocks and modes of operation that are tested.

Based on qualification tests of first prototypes, the production test specification and the necessary tests and screen tests are defined. Screening tests should get rid of early failures without taking too much of the equipment remaining life at constant failure rate.

4.1.6 Field Operations and Repair

Proper training of Field Engineers to understand the equipment limitations and strengths. The field repair process has to be understood and limited in scope to meet equipment assembly process quality. The ultimate goal is to meet customer expectations, as specified during Field Requirement Analysis phase.

5 Trends and Future Developments in High Temperature Electronics in Well Logging Industry

The well logging industry provides low volume, highly specialised high temperature electronics technology and has a strategic significance for the developments in high temperature electronics.

ASIC on bulk silicon or on SOI, Multi chip packaging, thermo-mechanical simulations are major axis for future high temperature developments.

6 References

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