Testing Electronic Components for Low Temperatures Wireless Communication Link - LTCL

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ABSTRACT

Smooth operation of superconducting magnets requires efficient and convenient connection from the inside sensors to the outside monitoring and diagnostic systems. This paper proposes a wireless link between inside and outside the vessel in comparison to the traditional complex wired infrastructure. Some commercial-off-the-shelf (COTS) key electronic components for this wireless link are tested inside liquid nitrogen (LN2), presenting their operation outside the vendor specifications. Moreover, tests are planned for liquid helium (LHe) and setup is being made to investigate a complete 60~GHz wireless link from inside a LHe cryostat to the outside by using radiation hard components, specifically for particle accelerators at CERN.

Keywords: low temperature; communication link; wireless diagnostics; electronics testing

1. INTRODUCTION

Immense research is being carried out on superconductors for different applications including quantum computing, space exploration, particle accelerators and superconducting colliders [1]–[3]. These applications require sophisticated monitoring, diagnostic and control systems with the help of sensors inside the superconducting magnets. These sensors are connected to the diagnostic systems placed at room temperatures with the help of special wires that go through different temperatures layers and complex mechanical interfaces thus limiting the number of instrumentations. This work is carried out to show the feasibility of wireless communication through low temperature vessel with the help of microwave windows. This will eliminate the need for complex inserts for instrumentation thus reducing the complexity and production cost. Moreover, it will make possible to have more measurement points as no additional wires will be needed from inside to outside the vessel. The concept is shown schematically in Fig. 1 where both power and data communication is being made wirelessly.

Different microcontrollers and a field programmable gate array device (FPGA) were successfully tested in this experiment when immersed inside liquid nitrogen (LN2). For the use in particle accelerator applications at CERN, in several special cases, it is necessary to employ radiation hard components. So a radiation hard microcontroller ATSAM4E16E and a Smartfusion2 SoC FPGA were selected for testing whose hardness have been reported in [4]–[6]. Moreover, these components are planned to be tested in liquid helium (LHe) through wired as well as 60 GHz wireless links in near future.

2. LN2 MEASUREMENT SETUP AND RESULTS

To measure the components inside LN2, a well was carved inside a piece of foam, with a size little bigger than the chip, as shown in Fig. 2. The carved foam was then attached on top of the board with the help of Silicon glue. During the measurements, the well was refilled continuously to keep the chip immersed in LN2.

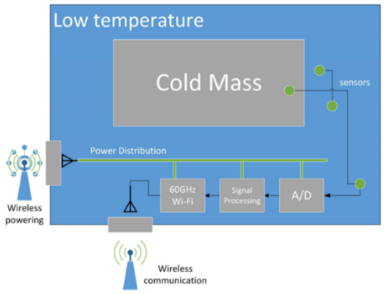


Fig. 1. Wireless communication and power distribution through microwave windows

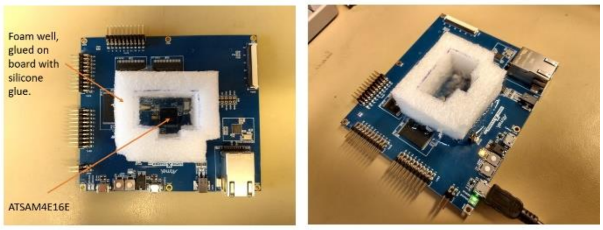


Fig. 2. A carved foam well, glued on ATSAM4E XPRO to isolate the microcontroller chip (ATSAM4E16E) from other board components. The well was filled with LN2 for the low temperature tests.

2.1. Testing Microcontrollers

An 8-bit microcontroller, ATmega16 was tested by mounting it on a small breadboard and dipping it inside LN2 thermos. The tests were run using different external oscillators (crystal and ceramic) as well as internal RC oscillator. Results shown that the microcontroller remained operational. In addition, was even possible to re-program the unit while inside LN2. This microcontroller however has not been reported as radiation hard. Keeping the radiation hardness factor in view, a commercial-off-the-shelf (COTS) microcontroller ATSAM4E16E was selected for testing in LN2. Its commercial datasheet [7] mentions that its lower operational limit is -40°C. The microcontroller was tested with the help of ATSAM4E Xplained PRO (XPRO) evaluation board [8] which provides an on-board debugger, a reset button, a user push button, a user LED and a 12 MHz Quartz crystal along with lot more other features. Atmel studio 7.0 was employed to program the micro-controller and a USB interface was used to communicate with a laptop computer driving the tests. The following tests were run using micro-controller's internal 8 MHz RC oscillator as well as an external 12 MHz crystal oscillator.

- *LED Flash:* The on-board user LED was used as simple visual signal indicating that the microcontroller continues to run while immersed in LN2.

- *Analog to digital converter (ADC):* This test was carried out by varying voltage with the help of a potentiometer and logging the internal ADC reads obtained while the microcontroller run in LN2.

- *Universal Asynchronous Receiver/Transmitter (UART) using external crystal oscillator:* The internal UART communication worked fine when microcontroller used the external crystal oscillator.

- *UART using internal 8 MHz oscillator:* The internal UART communication stopped working after some time inside LN2 when the microcontroller was using its internal 8 MHz internal RC oscillator.

- *Internal temperature sensor:* The internal temperature sensor of the microcontroller continued to operate in LN2 and measured a minimum of -186°C (LN2 temperature is -196°C).

- *Digital to analogue converter (DAC):* The 12-bit internal DAC was used to generate a sinusoidal signal presented on an oscilloscope. The waveforms were continuous and correct, indicating the internal DAC was performing fine in LN2.

- *Programming inside LN2:* The microcontroller was re-programmed successfully while in LN2.

2.2. Testing Smartfusion2 SoC

The tested SmartFusion2 M2S010 System-on-chip (SoC) FPGA indicates in its datasheet a recommended lower operation temperature of -40°C. This FPGA was evaluated with the help of a M2S010-MKR-KIT [9], shown in Fig. 3, which adds a USB port and 8 user LEDs among other features. Libero SoC v12.3 software was used to program the FPGA via the USB interface. The following tests were run to confirm the chip performance inside LN2:

- *LED Flash:* The 8 on-board user LEDs were used as a simple visual signal driven by a set of logic cells. The LED flashing worked fine while the chip was in LN2.
- *UART:* The UART communication implemented worked normally while the chip was in LN2.
- *Re-programming:* The chip was re-programmed while in LN2.

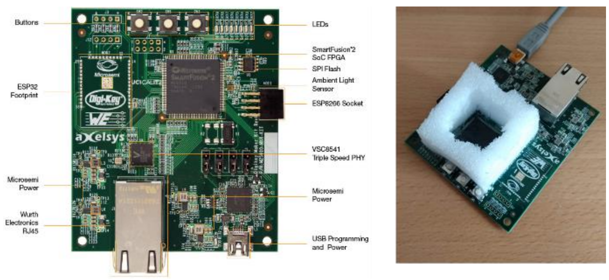


Fig. 3. M2S010-maker-kit (left) components marked on the board (right) carved foam well, glued to isolate the Smartfusion2 SoC FPGA chip

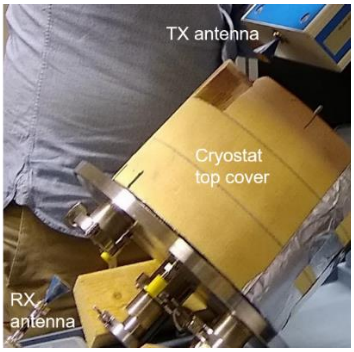
3. FUTURE STEPS: LIQUID HELIUM MEASUREMENT SETUP

After the successful tests of a radiation hard microcontroller and a SoC FPGA inside LN2, the measurement setup is being made for testing the components inside LHe. A custom board with ATSAM4E16E is being produced which can be dipped inside LHe. For this purpose, a small cryostat is planned to be used with different inlets for the cables. In the first phase, wired testing of the microcontroller will be made, whereas the communication will be made wirelessly through 60 GHz links in the second phase. ST60A2G0 [10] 60 GHz transceiver (TRX) chip will be used for this communication which has also proven itself to be feasible for radiation hard environments [11][12]. As shown in Fig. 4, two test PCBs with TRX chips and required drive electronics have been prepared for chip characterisation. The PCB has been provided with transmitter and receiver ports, as well as differential digital data ports.

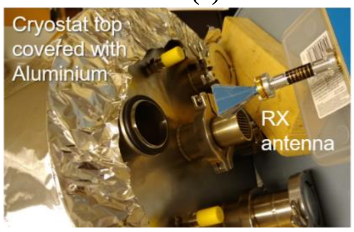
Fig. 4. 60 GHz RF boards (blue) mounted on the evaluations kits (green) for link testing

3.1 Construction of Low Temperature Communication Link

A 60 GHz wireless test will be done to check if the communication can be established through the cryostat top cover via an inlet hole on the lid. Fig. 5 (a) shows TX and RX horn antennas separated by the cryostat cover where antennas are 50 cm apart. As the lid of cryostat is metallic, the RX antenna is placed just in front of an inlet hole which makes the antennas communicate through the thermal insulation material. Yellow curve in Fig. 6 (a) shows the power received by the RX antenna when both antennas are communicating through free-space and for this case S21 values lie between -20 and -30 dB for 50-75 GHz band. Fig. 6 (b) shows S21 for the Fig. 5 (a) setup for which values lie between -15 and -22 dB with some fluctuations. In this setup, the thermal insulation material acts as a waveguide which results in higher receive levels compared to free-space. In reality, the cryostat cover will be surrounded by the metallic wall, which is tested by wrapping the cryostat cover with an Aluminium sheet as shown in Fig. 5 (b). Yellow curve in Fig. 6 (c) corresponds to S21 for this setup which shows more reflections especially at high frequencies. However, the response looks better than the free space for frequencies up to ~ 65 GHz.

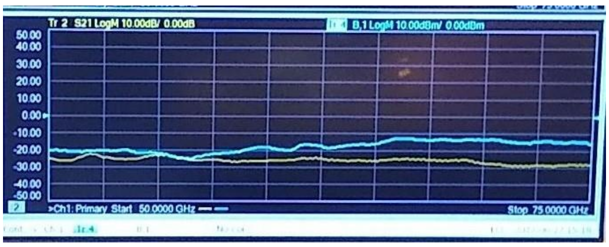


(a)

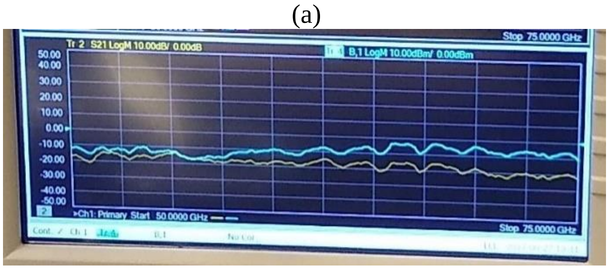


(b)

Fig. 5. 50 cm horn to horn wireless link through cryostat top cover (a) without Aluminium wrapping (b) with Aluminium wrapped around the cover



(a)



(b)

(c)

Fig. 6. Yellow curve showing the S21 for 50 cm long 60 GHz communication link. TX and RX antennas are communicating

through (a) free space (b) cryostat cover without Aluminium wrapping (c) cryostat cover with Aluminium wrapping

4. CONCLUSIONS

The limited tests done shows very promising results, the first selected COTS already remain functional at the temperature of interest (outside the commercial specifications). Besides, tests are planned for more COTS and for operation even lower temperatures, inside liquid helium (LHe). A complete setup is being mounted to investigate a complete wireless link from inside a LHe cryostat to the outside.

5. ACKNOWLEDGEMENT

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