Operation of FPGAs at Extremely Low Temperatures

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Abstract

This paper describes the operation of FPGAs at very low temperatures eg -160°C. Both Actel and Xilinx parts are tested. It was found that low temperature operation is not a problem with the parts tested, but there is a problem with powering on an FPGA at cold temperatures.

1 Introduction

The mil-grade versions of FPGAs are typically rated at -55°C to +85°C. Since this range satisfies most of the customer requirements, there is no incentive for the manufacturer to qualify FPGAs outside of this range. There are some terrestrial applications for high temperature applications, such as in oil well monitoring, but no need for very low temperature applications.

The environment in other planets have wide temperature variations compared to earth. For example, the surface temperature on Mars can vary from -120°C to +20°C. In order to use qualified parts on a Mars Rover such as MER, it is necessary to enclose them in a protective box, known as a 'warm-box', where the temperature is controlled by resistive heating elements.

Unfortunately this approach results in complex wiring, since all peripherals such as motors and cameras, need to be wired individually to the warm-box. The wiring could be simplified, if a bus system is used to send commands to control the peripherals. However, this then requires electronic components to be outside of the warm-box, and subject to ambient temperatures.

An on-going project at JPL is testing components at low temperature, to determine whether components can withstand the cold temperature. In particular, Xilinx and Actel FPGAs have been tested at low temperature. There are several criteria for successful operation at low temperature:

- Can the FPGA operate normally?
- Can the FPGA be powered up?
- Does the FPGA performance degrade over time?

So far we have some results for the first two, and the long-term tests are underway.

1 Devices tested

At this point we have tested one Actel FPGA (A54SX32A) , one Xilinx Virtex FPGA (XCVR600) and one Xilinx Virtex Pro FPGA (XC2VP20-FF1152). The Actel FPGA is fuse programmable and the Xilinx FPGAs are RAM programmable. The Virtex Pro FPGA contains two embedded PowerPc processors.

2 Test Circuit-1

The Actel and Virtex parts are mounted on a custom test board (fig 1).

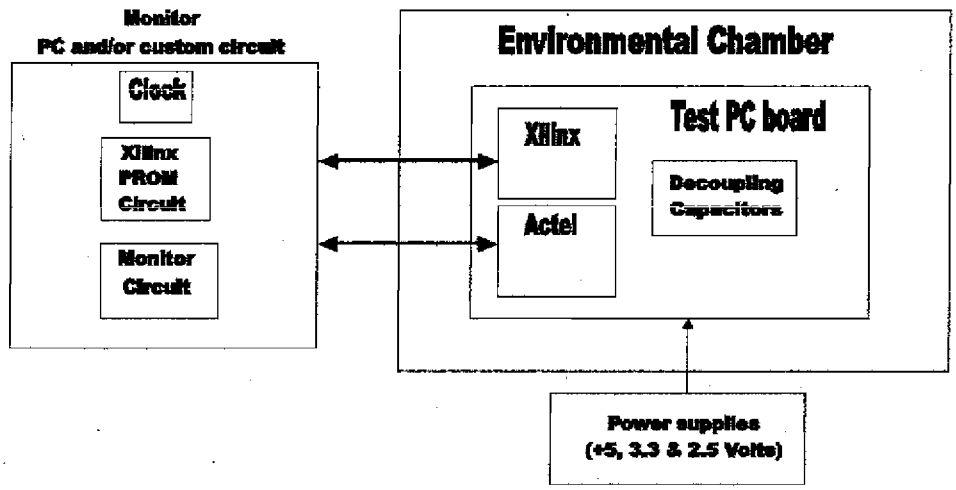

Fig 1 : Test circuit 1

A minimum number of components are on the test board; other support components are on a support board at the end of a cable.
In order to check whether the part is working at low temperatures, a self-checking test circuit is programmed into the FPGA (Actel) or configured using the serial configuration ROM (Xilinx Virtex). The test circuit consists of two identical counters. A comparator compares the most significant 8 bits of the counters every clock, and sets a flag if they disagree.
Other circuits including memory and delay chains are configured but not used in this test.

4 Test circuit 2

For the Virtex Pro test a standard circuit board was used (fig 2)
The board was modified for the temperature test by

- bypassing all voltage convertors and providing power externally
- wiring reset and configuration switches so they can be operated outside the chamber

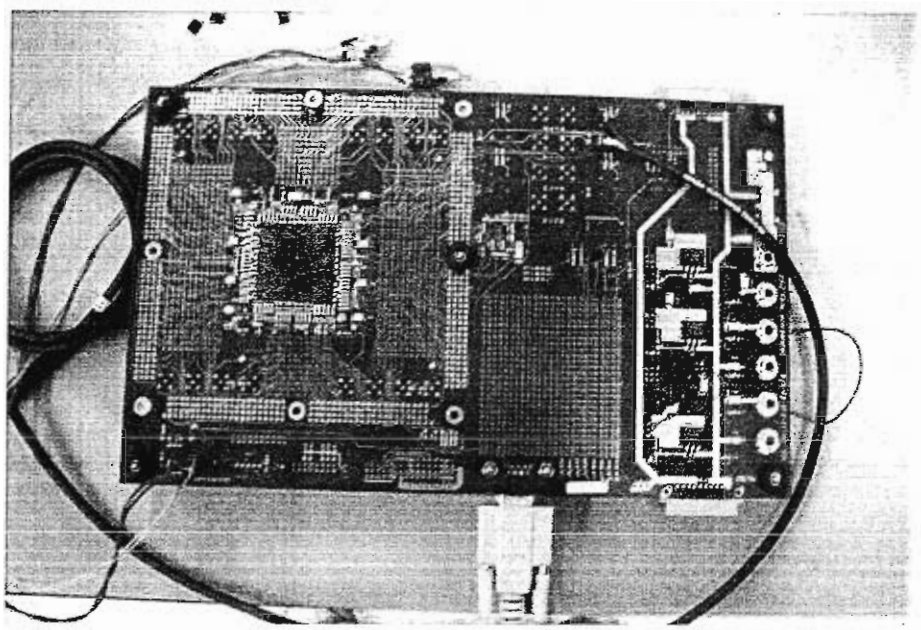

Figure 2: Virtex Pro test Board

The circuit used for the test has identical firmware running on both embedded PowerPc processors. One processor outputs to memories, and a serial data bus, the other reads the memories but does not write. A comparator circuit checks the Processors outputs at every clock. The firmware is designed to indicate failures over a serial line, which is monitored on a PC.

4 Test Procedure

The FPGAs were tested by placing the test board in a chamber cooled with liquid nitrogen; gradually lowering the temperature from 20°C down to -120°C.
The FPGAs were also tested for correct operation after powering up at various temperatures. As well as monitoring the temperature, the current was recorded using meters and a current probe.

5 Results

The Xilinx Virtex FPGA and the Actel FPGA were functional from 25°C down to –165°C. The Xilinx Virtex pro FPGA was functional down to -120°C, which was the limit of testing.
The operating current in all cases did not vary significantly. However the Xilinx Virtex FPGA exhibited an unexpectedly large startup surge current in its core supply at cold temperature. It was found that if this large current was not supplied, the FPGA would not start up at cold temperature.
Figure 4 shows the scope screen shots of startup surge current at various temperatures. The bottom curve is the current and the top curve is the voltage level.

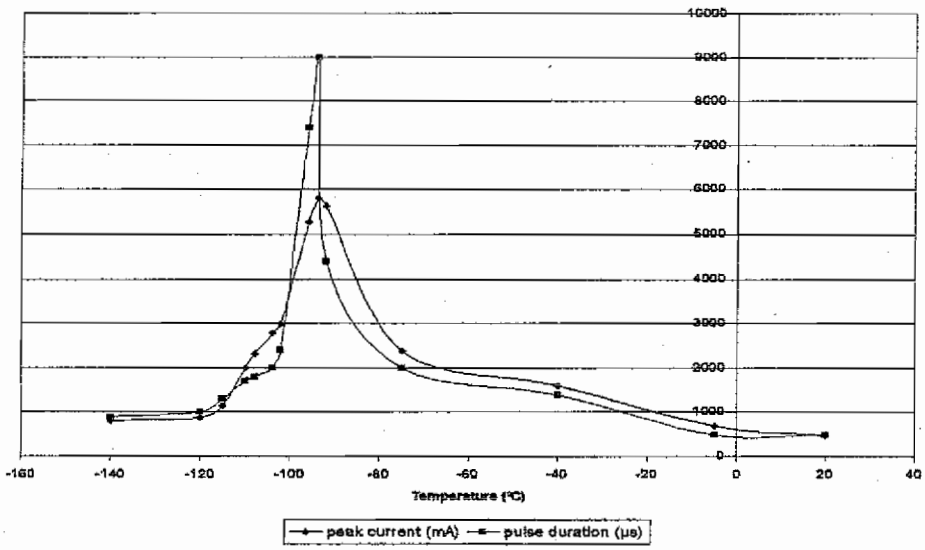

Fig 3: Startup current vs temperature

Measurements were performed at many temperatures and the results summarized in Figure 3; which is a plot of the peak current of the surge against temperature. This plot also shows the duration of the current surge. The startup peak current increases with cold temperature to a peak of 5.6A, at -90°C and then the current decreases with lower temperature. At room temperature the peak startup current is 463mA. At -140°C the peak startup current is down to 812mA.

6 Summary

The Actel FPGA and the Xilinx FPGAs tested were functional down to low temperature. Power cycling was not a problem on the Actel FPGAs, but a problem was observed on the Xilinx Virtex FPGA. In this case, excessive start-up current surge prevents the FPGA from configuring unless sufficient current is available. The magnitude and duration of the start-up surge current is temperature dependant; it peaks at 5.6 Amps at -90°C.

7 Acknowledgments

The work described in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration

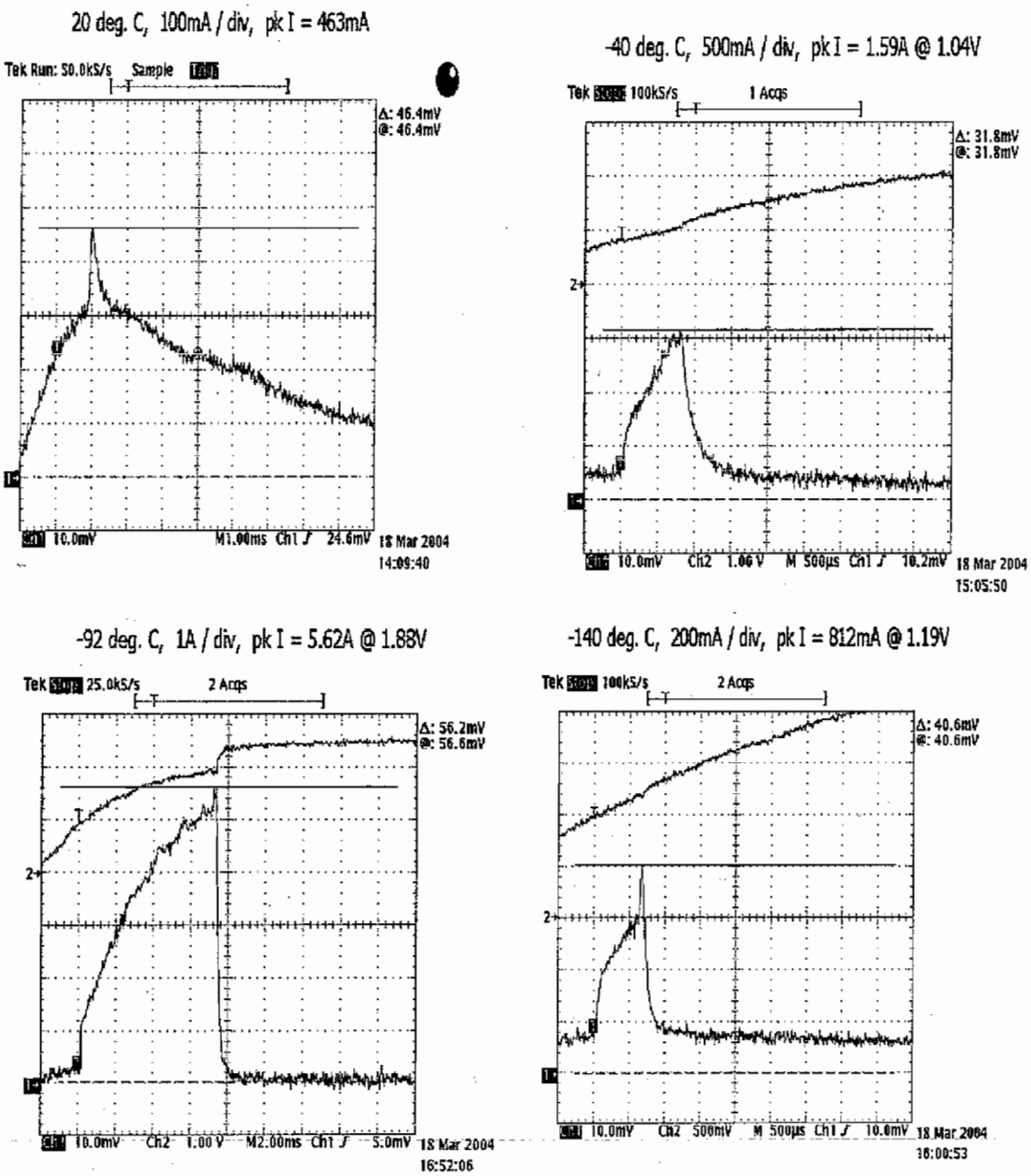

Fig 4 Scope shots of startup current at various temperatures for Virtex FPGA