Photon radiation testing of commercially available off-the-shelf microcontroller devices

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Abstract: The results of photon radiation testing of various microcontroller devices are described. This testing was useful to select the microcontroller in a 6DOF MEMS-based INS. This system is being developed for the in-vivo monitoring of tumour position during clinical radiotherapy treatments. This application requires a radiation-tolerant processor in order to perform appropriately in a radiotherapy environment. A phantom has been built to replicate the working conditions that the microcontroller devices are required to endure. Each time, a number of identical microcontrollers have been exposed, in turn, to X-ray doses in excess of 50 Gy from a clinical radiotherapy LINAC.

Keywords: respiratory phantom, mechatronic system, microcontroller chip, radiation tolerance, radiotherapy

Classification: Electron devices, circuits, and systems

References


1 Introduction

When designing electronic devices for use in a radiotherapy facility, it is often desirable to determine whether the electronics will be affected by the radiation and to determine what can be done to minimize or resolve this issue. It is well known that rad-hard technologies offer an immediate solution to this issue. Nevertheless, rad-hard devices can be expensive to design and fabricate and rarely offer the same functionality as commercial-off-the-shelf (COTS) devices. In a previous work [1], it is mentioned that applications in which rad-hard devices have been used traditionally, such as aerospace and defence, are now increasingly moving towards COTS solutions where possible because of the cost and functionality benefits of these alternatives. In the abovementioned work, a sensing device was proposed to be employed in radiotherapy facilities. This MEMS-based sensor is an implantable device capable of tracking internal organ motion with six degrees of freedom (6DOF) and without the need for complicated external instrumentation. Such a device was conceived because of the need by physicians to know the exact position of tumour targets in radiation oncology [2]. In this paper, we report the results of a series of tests carried out with only the microcontroller part of the design. Further testing will be carried out with the entire sensor embodiment once the sensor miniaturization phase is reached. In this work, various PIC and dsPIC Microchip microcontroller devices were tested.

Photon radiation test reports on dsPIC devices are nonexistent in the literature; though a brief report on proton and heavy ion radiation tests of Microchip PIC devices is available [3]. At the time such a report was written, Microchip had not introduced devices with Flash technology. The devices subjected to radiation tests performed well after having received proton and heavy ion radiation. Nevertheless, a few errors in memory operations were reported as part of an evaluation of the PIC devices for general space suitability.

Another report [4], where X-ray radiation tests were carried out on devices with similar technology to Microchip PIC’s, suggests the possibility of using X-ray radiation to erase information from the internal memory of the devices. The parts were irradiated positioned 5 cm from the X-ray generator with a dose rate of 7.6 Gy per minute. It was discovered experimentally that 16 K CMOS EPROMs are entirely erased after irradiation with a dose of 380 Gy. Finally, it is widely known that PCB manufacturers often perform X-ray inspections in order to detect faulty soldering. An industry source establishes the recommended exposure of COTS devices to X-rays while performing solder testing [5]. This document reports that an X-ray dose threshold of 50–150 Gy yields to a total dose damage in flash memory devices. Similarly,
permanent damage may occur to DRAM and microprocessor devices with dose thresholds of 150–700 Gy.

2 Tested devices

Only Microchip devices were subject to radiation testing. An element of each product family provided by the aforementioned manufacturer was selected. It is assumed that every device from a given family is made by the same fabrication process. The chosen families were the PIC16F MCU, PIC18F MCU, PIC24F MCU and dsPIC DSC, which should cover most of the Microchip devices available in the market [6, 7]. The chosen controllers from each family were the PIC16F887, PIC18F4550, PIC24FJ64GA004 and dsPIC30F2011.

Table I. Memory specifications of the tested devices.

<table>
<thead>
<tr>
<th>Device</th>
<th>Flash Memory (KB)</th>
<th>RAM (Bytes)</th>
<th>EEPROM (Bytes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIC16F887</td>
<td>14</td>
<td>368</td>
<td>256</td>
</tr>
<tr>
<td>PIC18F4550</td>
<td>32</td>
<td>2048</td>
<td>256</td>
</tr>
<tr>
<td>PIC24FJ64GA004</td>
<td>64</td>
<td>8192</td>
<td>0</td>
</tr>
<tr>
<td>dsPIC30F2011</td>
<td>12</td>
<td>1024</td>
<td>0</td>
</tr>
</tbody>
</table>

These devices are highly-integrated single-chip microprocessors that combine a powerful RISC architecture and a superscalar machine organization. The main functional elements of these controllers are fixed point and floating point, flexible addressing modes and a C compiler optimized instruction set architecture. Furthermore, the dsPIC30F2011 has DSP capabilities and all the DSP instructions are single cycle. These devices’ die is approximately 1.5 mm x 1.5 mm and is hermetically-sealed in ceramic quad flat packages. The devices require a voltage of 2.5 V to 5.5 V and dissipate less than 0.02 W at full speed.

3 Test preparation

Five printed circuit boards with QFN versions of each selected device were fabricated to carry out radiation tests in the Royal Preston Hospital, Department of Nuclear Medicine, Preston, UK. These 3.5 cm x 4 cm printed circuit boards are interfaced to a PC via a standard UART interface. The five controllers from each lot were programmed with the same code, which contained the program to work alongside the monitoring PC. The programmed code is capable of performing logic and arithmetic operations, storing results in RAM and sending these data in real time to the UART port. The monitoring PC is able to read the RAM and the program code that communicates the microcontroller to the PC. By doing so, the PC will know if either a RAM or program memory location is perturbed during the radiation tests. The UART control registers are also located in the RAM memory map, thus if the RAM is perturbed by the radiation field the communication may crash.

A 30 cm x 30 cm x 3 cm polyethylene phantom was fabricated to test the electronic boards. Fig. 1 (a) shows that the phantom has 2 hollow spaces,
one space for placing the board and cabling and the other space for placing a 0.56 cm$^3$ graphite Farmer ionization chamber model 327/1289 (Saint-Gobain Cristals & Detectors$^TM$). The sensitive element of the chamber was mounted at the same depth as the microcontroller board. In order to mimic human tissue density, the phantom was placed in between four solid-water slabs. Fig. 1 (b) illustrates this basic setup. The linear accelerator (LINAC) used was an Elekta Precise Treatment System$^TM$. The field size during irradiation was 10 cm x 10 cm at 100 cm from the source. The beam potential was 6 MV and the equivalent cumulative dose is 0.938 Gy per 100 monitor units ($mu$). The dose rate is approximately 600 $mu$ per minute but it is not constant. This fluctuation is normal for treatment machines. The treatment room temperature was 19.5$°C$ during the tests and the atmospheric pressure was 1020 mbar.

![Diagram of setup](image)

**Fig. 1.** (a) Both the Farmer chamber and the microcontroller board were placed between four solid-water slabs. (b) The polyethylene phantom and its arrangement in the LINAC room (not to scale).

The five boards were exposed to a total dose of approximately 60 Gy. The energy spectrum of photons from the LINAC is shown in Fig. 2 (a). Fig. 2 (b) shows how the dose was delivered in 14 fractions as follows: 1 fraction of 100 $mu$ (0.938 Gy), 2 fractions of 200 $mu$ (1.876 Gy) and 12 fractions of 500 $mu$ (4.69 Gy).

4 Test results

The previously mentioned 6DOF sensor is designed for use in ordinary clinical radiotherapy sessions. Therefore the dose was fractioned as if in course of a similar treatment. This is valid although the dose fractions were administered to the boards one by one throughout the same day as opposed to daily intervals as per a treatment. This technique is also known as hyper fractioning. Fig. 2 (c) shows how the dose was administered.

All the boards were tested prior to receiving radiation and a first set of data were collected. A second set of data from the radiation tests were gathered. Here, it is important to mention that a series of glitches were observed during the irradiation process. There seemed to be an occasional
short delay that appeared to be a reset event. It was concluded that these events might have occurred due to the fluctuation of the machine dose rate. After the tests, more readings were taken and then this third set of data was compared against the first and the second sets. The three sets of data were compounded by readings of the 12K program locations as well as the results from approximately 10,000 logic and arithmetic operations per board.

Fig. 2. (a) Energy spectrum used in this work. (b) Dose delivered per fraction. (c) Accumulated dose delivered to the microcontroller boards.
The comparison was made using a combination of two applications: a Visual Basic text file program and an algorithm implemented in MatLab. In every case, the three sets matched perfectly, meaning that the radiation did not affect any of the memory locations in the microcontrollers.

5 Conclusion

All the selected devices survived the radiation test. No testing with a different energy spectrum was carried out since the purpose of this study was to determine whether any of the chosen controllers could be used as part of an implantable device. Higher energies might result in a different response, however such energies may not be usable for human treatments. It has been mentioned before that the dose rate of the LINAC used in this work is not constant. Although the dose rate fluctuates during treatment, the total dose is controlled to account for fluctuations. We do not know whether the system (both the microcontroller and the PC) responded to this. It is assumed that a falling dose rate could not affect the performance of the microcontroller, but a rising dose rate might have produced a reset at some point. We know that the entire system did not re-start in the middle of the process nor was the communication link lost. Even though a reset had occurred, the reading of the entire RAM and program memory location was unperturbed because a single memory reading is an independent event within the monitoring process and not even a reset can break the communication course. It is thought that the system did not fail during the process and no effects were observed because semiconductor ICs only suffer irreversible damage from charging effects caused by higher energies than the one used in this work. While radiation effects do not always result in a hard failure, users often have no way to recover devices from the effects of the exposure. The system described within this paper certainly demonstrates that no hard failure occurred. Therefore, it is believed that Microchip’s technology and the way the communication protocol was handled would be a good choice as part of the 6DOF design or any in-beam clinical radiotherapy application.

6 Acknowledgments

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