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14. ABSTRACT

This paper presents results of target location specific direct injection on a 8051-based microcontroller in a development board versus a custom test board. Three target locations showed no failure in both environments. Using the custom board, an effect was found in a target location which was not observed using the development board.

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Direct Power Injection of Microcontrollers in PCB Environments

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***Abstract* – This paper presents results of target location specific direct injection on a 8051-based microcontroller in a development board versus a custom test board. Three target locations showed no failure in both environments. Using the custom board, an effect was found in a target location which was not observed using the development board.**

1 INTRODUCTION

Prediction techniques have become important because electromagnetic radiation can damage and/or alter the peformance of electronic circuits [1]. While it has been shown that high power can damage electronic systems, upsets may be more likely to occur, and are important to understand. Upsets or intermittent problems to a microcomputer can lead to invalid instructions and change the system's function. Digital systems tend to recover on their own but the delay in time is an issue. While most digital circuits are immune to noise, electromagnetic pulses can lead to timing issues for clocked digital circuits.

This paper studies the susceptibility of 8051-based microcontrollers mounted on a standard development board and a custom board designed specifically for direct power injection testing. Development boards are made to be versatile by supporting numerous package pinouts, easy programming, multiple displays, and different system configurations. As a result, routing on this type of board is dense and can impact the amount of energy injected on the signal of interest. In addition, coupling to other components becomes an issue in this test configuration. Custom board design allows for better control of the power injected on the microcontroller but places the system in isolation. Digital electronics will inevitably reside within a larger system and while effects tests for an individual microcontroller are important, modeling effects in an environment similar to final placement is important. This study will be used to model how test board type, injected power, pulse width, and frequency affect the instruction set of an 8051-type microcontroller.

2 EXPERIMENT

The MikroElectronika development board shown in Fig. 1 is 267 mm by 216 mm and is a fully contained system used for programming Atmel 8051 microcontrollers [2]. It is attached to the microcontroller using a mount configured for a 20 pin dual in-line package (DIP). RF power is injected into the IC using a coaxial cable that has been modified to function as a probe [3].

Figure 1: MikroElektronika Easy 8051v6 board.

The custom board shown in Fig. 2 is 76.2 mm by 76.2 mm and uses a 50Ω feed that connects directly to the clock pin. The design is based on the IEC 62132-4 documentation [4]. The board material is 0.787 mm-thick FR4 with relative permittivity of 4.2 and loss tangent of 0.02.

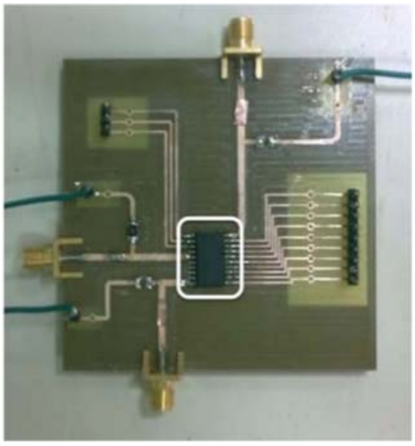

Figure 2: Custom board.

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Similar to [5], a 8051 microcontroller has been subjected to time-controlled RF pulses where a set of instructions have been implemented. The upset can be tied to an assembly language instruction for more fundamental understanding and model development. The Atmel AT89LP2052, 8-bit microcontroller has been programmed to complete a binary count from 2^0 to 2^8. A 20 pin SOIC has been assembled on the custom board with dedicated RF feeds to the clock, VCC and ground. Fig. 3 shows a block diagram of the experimental set up for direct injection. Assuming no performance changes, the microcontroller is either mounted for test using the development board (DIP) or soldered onto the custom board (SOIC). LabVIEW has been used to control the power level and timing of the RF source (MXG), and data acquisition using the oscilloscope. An external amplifier is not used as this study is to understand upset or timing shifts and not failure to the LP2052.

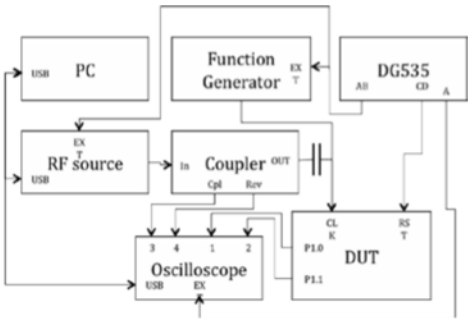

Figure 3: Test set up for direct injection.

The RF pulse has been injected onto the microcontroller based on a complete 1µs clock cycle (target location 1) during a no operation (NOP) instruction. Shorter clock cycles have been divided into 0.24 µs segments and are described in Table 1. Pulse widths shorter than 0.24 µs could not be achieved using the MXG. A 20 dB bi-directional coupler is used to monitor power input to the microcontroller.

Table 1: Target location description and time.

Target Location	Pulse width (µs)	ID
Complete clock cycle	1	TL1
Logic high	0.48	TL3
1st ½ logic high	0.24	TL4
2nd ½ logic high	0.24	TL5
Logic low	0.48	TL7
1st ½ logic low	0.24	TL8
2nd ½ logic low	0.24	TL9

An initial experiment was conducted where frequency was varied between 50 and 100 MHz and MXG ower was swept from 5 to 17 dBm, using both boards (Table 2). For each power level and frequency, 100 shots were injected at the 7 target locations. Using LabVIEW the data collection takes up to 6 hours for 14000 shots. An additional program is used to process and analyze the data, taking up to 2 hours.

Table 2: Initial RF injection test on both boards.

Board	Demo	Custom
f (MHz), in 5 MHz steps	50-100	50-90
# of shots	100	
Power level (dBm), in 0.12 dB steps	5 - 17	
Target locations	1, 3, 4, 5, 7, 8, 9	
Total # of RF injections	7700	6300
Data collection	5-6 hours	

An upset is equivalent to a change in the P1.1 output pin of the microcontroller. In the counter algorithm, this is the 2nd least significant bit. The data is collected using an oscilloscope and converted to binary. It is then compared with a previously stored reference waveform. Each bit in a 90 µs observation window is compared and if different, adds to an error counter. An upset is achieved when the counter reaches a predefined number associated with the window. The DG535 resets the microcontroller after each experiment. Fig. 4 shows a photograph of the test.

In both boards, the shortest pulse widths (0.24 µs) did not produce upsets, namely TLs 5, 8 and 9. However, TL 4 did experience an upset and corresponds to the 1st half of the clock cycle. Focused experiments were conducted on TL 1, 3, 4 and 7 as shown in Table 3, where the power range was modified to 10 – 17 dBm and the number of shots was increased to 200.

Table 3: Focused RF injection test on both boards.

Board	Demo	Custom
f (MHz), in 5 MHz steps	50-100	
# of shots	200	
Power level (dBm)	10 - 17	
Target locations	1, 3, 4, 7	
Total # of RF injections	6600	8800

Figure 4: Photograph of experiment.

3 RESULTS

The focused experiment results have been processed to compare how the board impacts upsets. TL 1 experienced an upset throughout the entire frequency range studied. It encompasses a complete clock cycle and has the greatest vulnerability. Fig. 5 shows the coupled port voltage where the first upset occurs for TL 1. The custom board requires 0.02 V less to realize an upset compared to the development board with mount. The actual input voltage to the microcontroller is an order of magnitude greater than what is plotted due to the 20 dB coupled port.

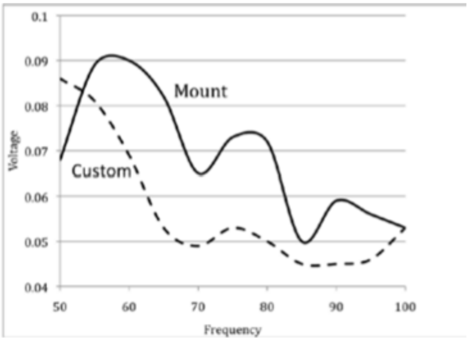

Figure 5: TL 1 output power for both boards.

At 50 MHz, the custom board requires more voltage to generate an upset and this is observed for TL 1, 3 and 7. Beyond 60 MHz, TL 4 did not have an upset on the development board whereas it did on the custom board. This indicates that the custom board can be sensitive to narrow width pulses.

Fig. 6 shows a plot of the input impedance up to 250 MHz for both boards. A 8.5 GHz Agilent VNA has been connected to the directional coupler and the clock pin of the microcontroller (clock not in operation). This gives an idea of the input impedance the MXG source sees to determine how much voltage is being reflected at the injection pin. The calibrated one-port reflection coefficient (shown as return loss (RL) indicates that most of the power input to the clock pin on the custom board will be rejected except at 54 MHz. Similarly the mount shows two frequencies where RL is better than 15 dB, at 83 and 148 MHz. At 227 MHz both boards have a reflection dip indicating a match to the system and therefore an ability to inject voltage with little reflection.

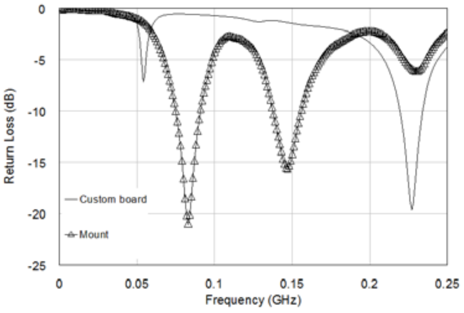

Figure 6: Clock pin RL (dB) for both boards.

4 CONCLUSIONS

A 8051-type microcontroller has been tested in two environments, one on a versatile development board and the other on a custom designed RF injection board. The input impedance of both boards differ which may imply that more power is needed to generate upsets in order to overcome the impedance mismatch. Within the 60 to 100 MHz range, the custom board requires less voltage to generate an upset, while at 50 MHz, the mount requires less voltage. This data is useful to understand how board design can be used in modeling microcontroller upset as a function of controlled pulse widths.

Acknowledgments

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