Influence of Operation- and Program-States on the Breakdown Effects of Electronics by Impact of EMP and UWB

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Abstract: This paper deals with the influence of different operation- and program-states on the breakdown effects of electronics by impact of EMP and UWB pulses. Different electronic devices like shift registers, microcontrollers and personal computers were exposed to high amplitude transient pulses.

Keywords: EMP, UWB, susceptibility, electronics

Introduction

The goal of this investigation is to measure the susceptibility of electronic devices to a transient electromagnetic field threat. Modern electronics are of vital importance for the function of traffic systems, security systems and modern communication. A malfunction in one of these areas may cause casualties and economic disasters. Nowadays HPM and UWB equipment can be bought by everyone. Fast rise time pulses have a very broad spectrum and, compared to a HPM pulse, a very small energy content. Taken the aspect of electromagnetic terrorism into account an UWB system could be a very dangerous weapon. Therefore, the susceptibility of electronics to pulsed electromagnetic fields like EMP and UWB pulses is of great interest. The intention of this work is to analyze the influence of different operation- and program-states on the breakdown effects. On that account different electronic devices built in different technologies have been tested.

General Measurement Setup

The applied pulseshape is in general double exponential as shown in Figure 1 with the pulse parameters rise time (t_r) and full width half max value (t_{fwhm}) as a describing value for the pulse length.

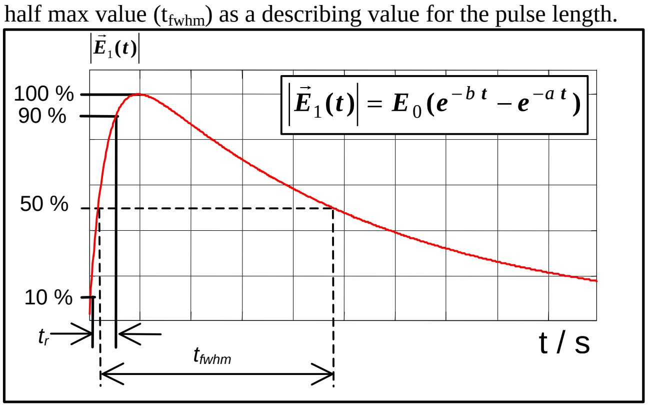

Figure 1. Pulseshape and definitions

The measurements were carried out with two different TEM waveguides. Waveguide 1 is an open area test simulator with a maximum height of about 23 m described in [1]. Waveguide 2 [2] is an open waveguide inside a shielded room enclosed by absorber walls. The measurements of the electromagnetic properties were done by electric and magnetic groundplane and free field probes as described in [3].

Definitions

Failure Rates

To describe the different failure effects two quantities have been defined [4]. The Breakdown Failure Rate (BFR) has been defined as the number of breakdowns of a system, divided by the number of pulses applied to it. A breakdown means no physical damage is done to the system. After a reset (self-, external- or power reset) the system is going back into function.
The Destruction Failure Rate (DFR) of the device under test has been defined as the number of destructions divided by the number of pulses applied to the system. Destruction is defined as a physical damage of the system so that the system will not recover without a hardware repair.

Principle Behavior of BFR and DFR

The BFR and DFR behaves in principle as shown in Figure 2. As important parameters for the description of the susceptibility of a system four quantities have been defined [5]. The Breakdown Threshold (BT) specifies the value of the electrical field strength, at which the BFR reaches 5% of the maximum value. The Breakdown Bandwidth (BB) has been defined as the span of the electrical field strength, in which the BFR changes from 5% to 95% of the maximum. Equivalent definitions can be done for the destruction failure rate DFR (compare Figure 2).

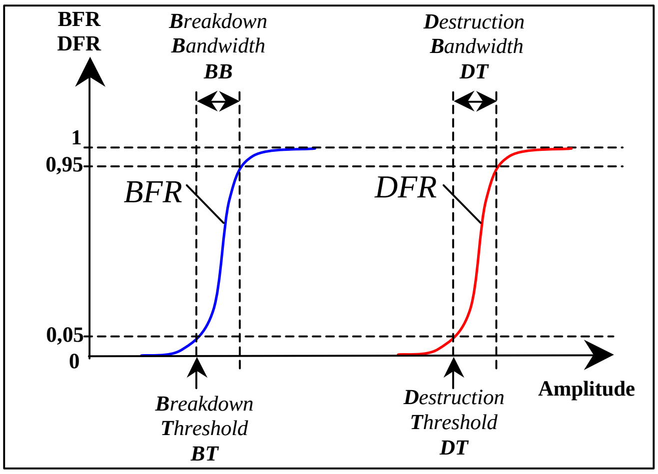

Figure 2. BFR, DFR - principle behavior and definitions

Difference in static and dynamic operation states

To observe the influence of the operation states on the breakdown effects of electronics, shift registers and microcontrollers were chosen. The devices were exposed to the pulses in a dynamic operation state with different clock rates, and in a static operation state without any clock signal.

Test Setup

To apply the different pulses to the EUT a modular setup has been realized (Figure 2) [6]. For the test of shift registers ten separate channels were built with a combination of different printed circuit boards. The circuit boards have been connected with ribbon cables to realize different coupling lengths at the input and output pins of the devices under test. In Fig.3 a shift register test setup with 20 cm ribbon cable length at the input pins and ≈ 0 cm ribbon cable length at the output pins of the test devices is shown. The power supply, shown at the top, has been realized with ten separate accumulators. LEDs and resistors have been used as loads to observe the operating states of the devices. Shift registers in four different technologies were tested (Std.-TTL, LS-TTL, HC-CMOS, HCT-CMOS)

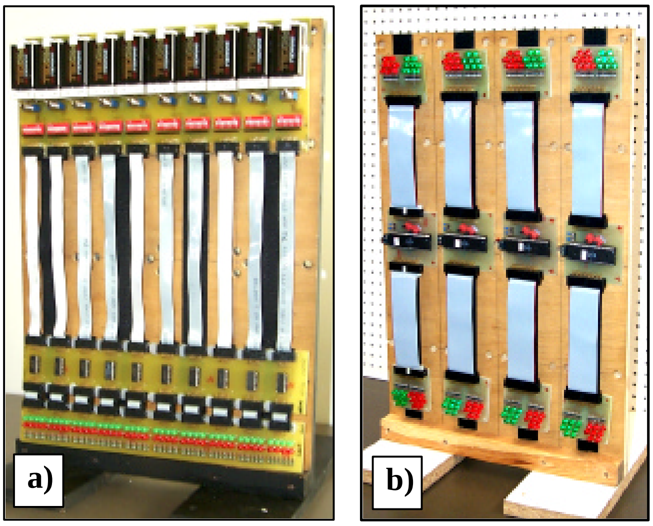

Figure 3. Test Setup: a) Shift registers, b) Microcontrollers

Furthermore, three different types of microcontroller circuits have been tested. Four microcontrollers of the same type have been tested simultaneously to observe any difference. The micro-controller circuits have been placed vertically on a wooden wall (Fig. 3b) which has been placed in the waveguides as well as the shift registers. The different states of the I/O-ports have been monitored via different coulored LEDs. A variation of the data-, quartz-, reset- and power supply-line length was done with ribbon cables.

During the test a program was running on the microcontrollers which can get into two different states. In status 1 two ports are high and two ports are low to observe this state. After a switch the program moves to the second state in which the microcontrollers were exposed to the pulses. The intention was to observe a self reset of the system by changing from status 2 back to status 1. Without the implementation of two states a self reset cannot be observed due to the fast reset action. In status 2 the I/O-Ports are changing from low to high to investigate the influence of two very different operation states on the susceptibility.

Measurement Results

As a first result it can be noticed, that almost all tested devices are much more susceptable in a dynamic operation state than in an static operation state. Fig. 4 and 5 are showing the breakdown thresholds of shift registers built in four different technologies determined in dynamic and static operation state.

Shift registers built in CMOS technology are much more susceptable in a dynamic operation state than in a static operation state. If the input line length is increased the breakdown threshold BT is decreased as expected, because more energy couples to the system. In a static operation state with an input line length of about 0 cm, up to 25 kV/m (maximum possible fieldstrength for the testpulse in the used laboratory) no breakdown was observed.

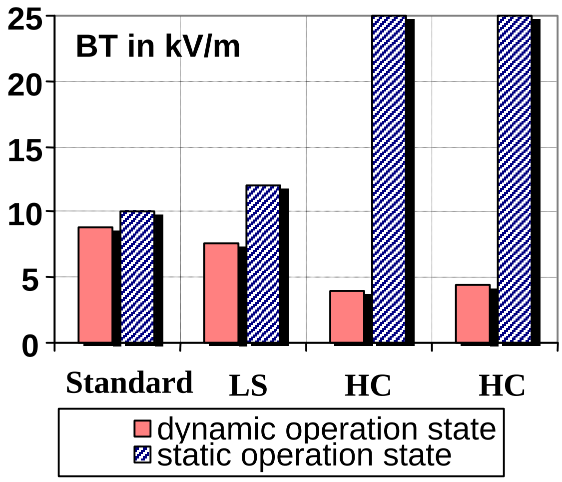

Figure 4. Breakdown Threshold BT of shift registers built in four different technologies in dynamic and static operation state, input line length » 0 cm

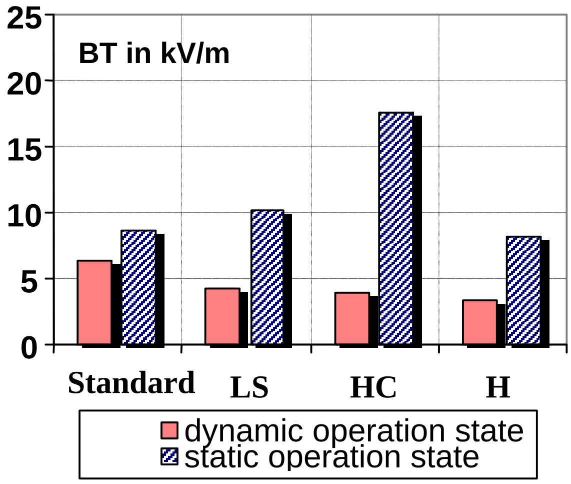

Figure 5. Breakdown Threshold BT of shift registers built in four different technologies in dynamic and static operation state, input line length » 20 cm

Shift registers built in TTL technology are also more susceptable in a dynamic operation state than in a static operation state but not as much as shift registers in CMOS technology.

Furthermore, the comparison of TTL- and CMOS-shift registers showed that TTL devices are more susceptable in a dynamic operation state and CMOS devices are more susceptible in a static operation state.

The same behavior has been observed during the investigation of three different microcontroller circuits. The features of the microcontrollers are:

- -RISC Architecture
- -High-speed CMOS Process Technology
- -32 x 8 General Purpose Working Registers
- -Flash on Board
- -EEPROM on Board

The devices were tested in five different test setups and the pulses were applied in dynamic and static operation states. In the dynamic operation states the clock rates were varied from 1 MHz up to 8 MHz (8 MHz is the maximum permissible clock rate for the tested microcontrollers). In the static operation states up to 25 kV/m no breakdown has been observed at each test setup. In the dynamic operation state, the breakdown thresholds vary from 1 up to 6 kV/m electrical field strength depending on the test setup.

Influence of Different Program States

To observe the influence of program states on the breakdown effects of electronics, microcontrollers and personal computer were chosen. The devices were exposed to the pulses in different program states.

Microcontroller

Fig. 6 shows the flow chart of the microcontroller test program as mentioned above. The pulses were applied in the program states A (all I/O-ports = LOW) and B (all I/O-ports = HIGH) were maximal resp. minimal current is flowing through the microcontrollers as a result of maximal resp. minimal current at all I/O ports. Fig.7 shows the breakdown thresholds BT of three different microcontroller systems (clock rate = 1 MHz) for an UWB testpulse with a rise time of t_r = 100 ps and a pulse length of t_{fwhm} = 2,5 ns. The results are shown for five different test setups of the microcontroller systems. At each setup and microcontroller system

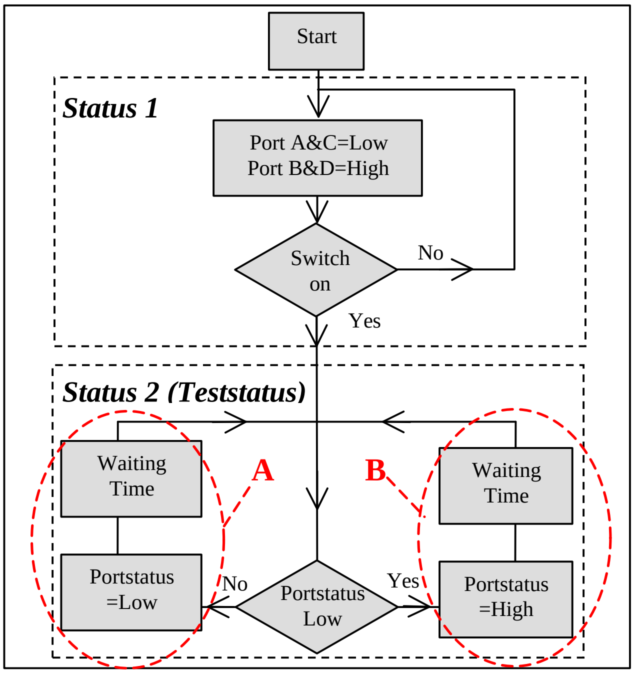

Figure 6. Microcontroller test program with teststates A (portstates = LOW) and B (portstates = HIGH)

a higher susceptibility in portstate HIGH was observed. However the difference of the breakdown thresholds in portstate LOW and HIGH are very small in comparison with the absolut values of the breakdown thresholds. On account of this, the statement, that the influence of the program states is negligible, is valid. Furthermore, the test has been carried out with the microcontroller systems working at eight different clock rates. At each clock rate the same effects have been observed and in general the influence of the program state was very low.

Personal Computer

During the investigation the tested personal computers were operated in a minimal configuration which consists of mainboard, processor, random access memory and accumulator power supply . For monitoring the function of the systems, an ISA-bus monitor card has been developed which allows to monitor data lines, address lines and internal system states separately. The minimal configurations were placed in the waveguides in such a way, that coupling into the monitor card is minimal. A simple DOS version has been chosen as the operating system, to avoid breakdowns as a result of a higher level operation system. The operation system as well as the test programs were loaded directly before the test from a floppy disk drive, so that no hard disk drive was necessary.

To observe the influence of different program states concerning the susceptibility of personal computers, a test program with separate subroutines has been implemented in the investigated pc systems. Different hardware elements (Direct Memory Access controller (DMA) and Programmable Interval Timer Module (PIT)) on the mainboards were activated. The DMA-main-routine as well as the PIT-main-routine is separated into three subroutines with different functions inside the DMA-controller resp. the PIT-module. During each subroutine, the pulses have been applied to the systems. After each subroutine a CPU test has been performed to make sure that the complete system was working properly.

Fig.8 shows the breakdown thresholds BT of three personal computer systems for an UWB testpulse with a rise time of t_r = 100 ps and a pulse length of t_{fwhm} = 2,5 ns.

Different personal computer systems showed a very low influence on the breakdown thresholds BT of the test program status, in comparison with the absolute values of the breakdown thresholds. Neither in the main routines nor in the sub routines a significant change of the breakdown thresholds BT has been observed. The breakdown thresholds vary from about 1.5 kV/m up to 3 kV/m electrical field strength. Similar results have been observed if pulses with other rise times and pulse lengths were applied.

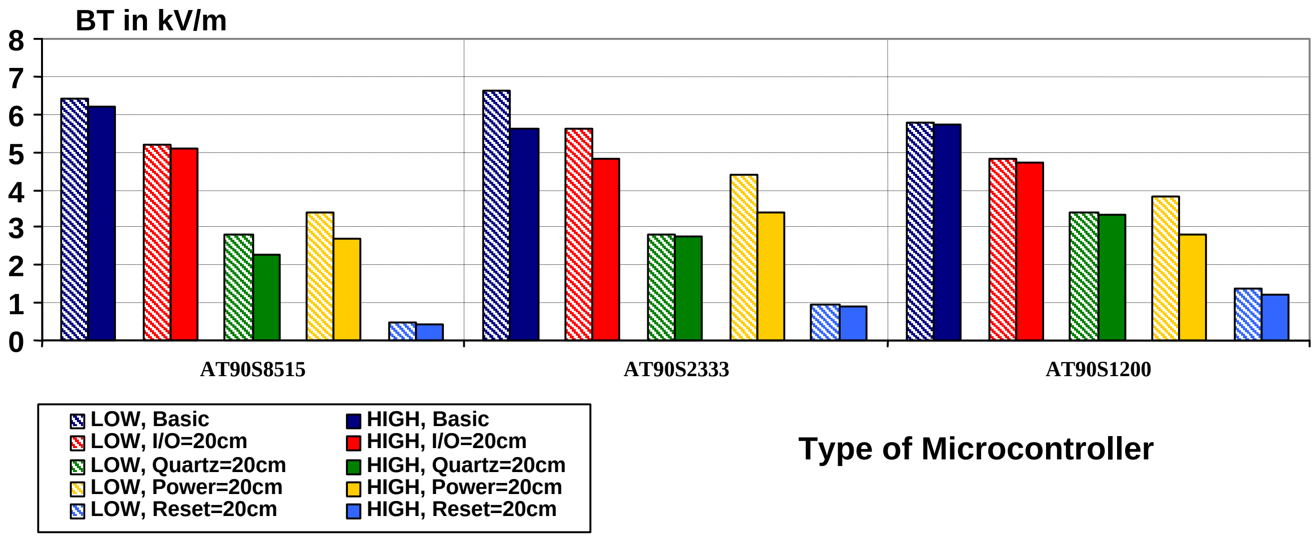

Figure 7. Breakdown Threshold BT of three microcontroller systems in portstate LOW and HIGH measured in five different test setups (clock rate = 1 MHz)

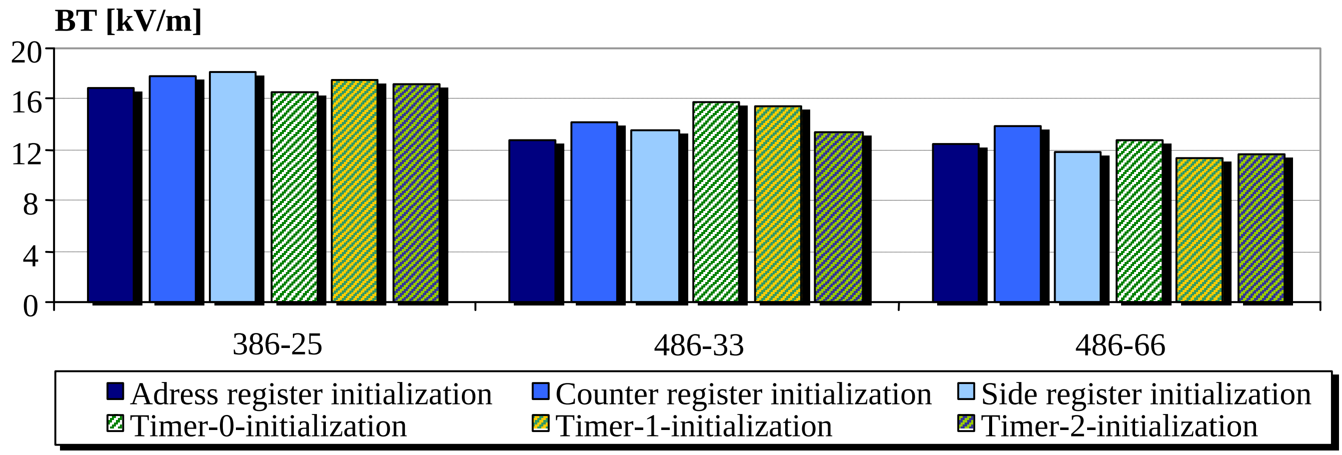

Figure 8. Breakdown Threshold BT of three personal computer systems in six different program states

Conclusion

As a first result it can be noticed, that the susceptibility of electronic devices to EMP and UWB pulses is much higher in a dynamic operation than in static operation. This behavior was observed at differnt devices (shift registers and microcontroller circuits) and different technologies (Std.-TTL, LS-TTL, HC-CMOS, HCT-CMOS).

The investigation of TTL- and CMOS-shift registers has shown, that devices built in CMOS technology are much more susceptable in a dynamic operation state than in a static operation state and shift registers built in TTL technology also are more susceptable in a dynamic operation state than in a static operation state but not as much as shift registers in CMOS technology. Furthermore the comparison of TTL- and CMOS-shift registers among each other has shown, that TTL devices are more susceptable in a dynamic operation and CMOS devices are more susceptible in a static operation (concerning the absolute values of BT in comparison with TTL-devices). The same behavior was observed during the investigation of three different microcontroller circuits. The devices were tested in five different test setups and with eight different clock rates (in dynamic operation state). Generally the susceptibility was much higher in the dynamic operation states than in the static operation states.

The investigation concerning the influence of different program states on the breakdown effects of electronic devices has shown, that this factor is always very low. Three different microcontroller systems tested in five different test setups and with eight different clock rates have shown an negligible influence of the program states. The same results have been observed during the investigation of personal computer systems in a minimal configuration. Different personal computer systems showed a very low influence on the breakdown thresholds BT of the test program status, in comparison with the absolute values of the breakdown thresholds.

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Biographical notes

Michael Camp received the Dipl.-Ing. degree in electrical engineering from the University of Hanover (Germany) in 1999. He is currently pursuing the Ph.D. degree at the Institute for Electrical Engineering and Measurement Science at the University of Hanover. His research areas covered high frequency measurement techniques and the susceptibility of electronics to fast transient pulses (UWB)

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