UWB and EMP Susceptibility of Modern Electronics

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Abstract: The susceptibility of different types of single microcontrollers and complex micro-processorboards to unipolar fast rise time pulses is determined. Rise times down to 100 ps and field amplitudes up to 50 kV/m have been applied to the devices.

I. INTRODUCTION

The goal of this investigation is to measure the susceptibility of microelectronic systems to transient electromagnetic field threat. Modern micro-processors are of vital importance for the function of traffic systems (airplanes, traffic guidance), security systems and modern communication. 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, because it can be built in a very small volume due to the low energy content of the pulse. Therefore the susceptibility of microcontrollers and micro-processorboards to pulsed electromagnetic fields like EMP and UWB pulses is of great interest. The intention of this work is to study the different damaging quantities like energy, amplitude and rise time of the electromagnetic pulse as well as the different parameters of the electronic circuits separately.

II. GENERAL MEASUREMENT SETUP

The measurements were carried out with an open waveguide [1] shown in Fig. 1, inside a shielded room. The absorbers were placed on interchangeable wooden walls. The position of the septum can be adjusted via nylonthreads. The measurements of the electromagnetic properties were done by a **T**ime **D**omain **R**eflectometer (TDR) and electric and magnetic groundplane and free field probes as described in [2].

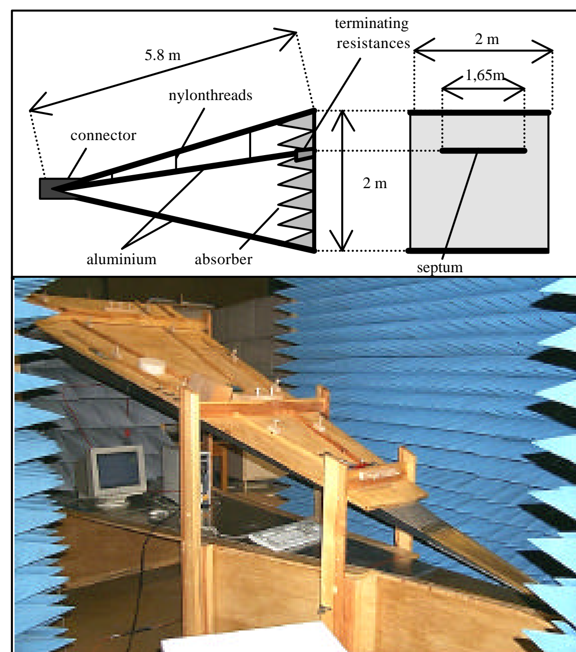

Figure 1: Waveguide

The field probes have been calibrated up to 8 GHz. The measured equivalent area $A(\omega)$ for three different electric groundplane probes (conical monopoles) is shown in Figure 2.

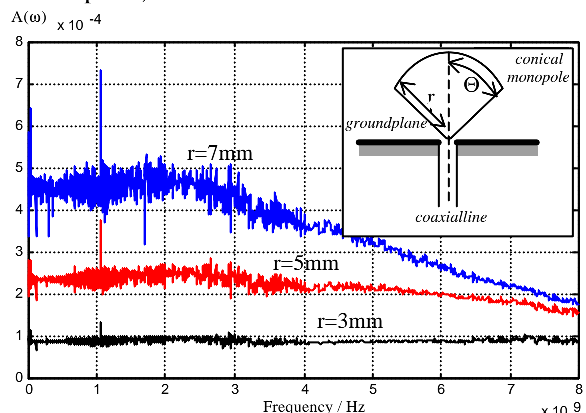

Figure 2: Equivalent area of three groundplane probes with different radii r

The applied pulseshape is generally double exponential as shown in Figure 3.

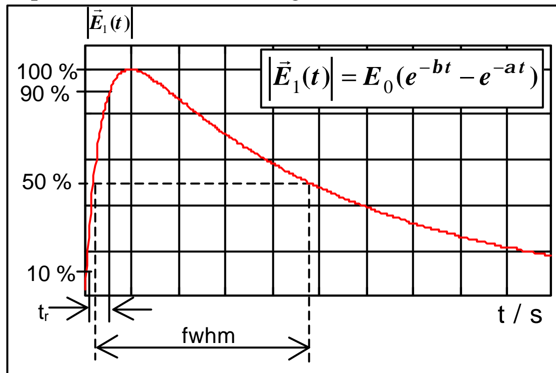

Figure 3: Pulseshape and definitions

Four different pulse generating devices are available. Table 1 shows the rise time (t_r) and the full width half max value (fwhm) of the different pulses.

Table 1. Pulse Data

Pulse	Rise time t_r	fwhm
UWB	100 ps	2.5 ns
EMP (fast)	1.5 ns	80 ns
EMP (med.)	5 ns	300 ns
EMP (slow)	10 ns	500 ns

III. DEFINITIONS

To describe the different failure effects two quantities have been defined. The **B**reakdown **F**ailure **R**ate (**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.

Table 2. Failure Rates

Breakdown	**D**estruction
Delay Time Pulse Self-, External-, Power-Reset	Pulse
Breakdown **F**ailure **R**ate	**D**estruction **F**ailure **R**ate
$BFR = \frac{No.of\ Breakdowns}{No.of\ Pulses}$	$DFR = \frac{No.of\ Destructions}{No.of\ Pulses}$

The **D**estruction **F**ailure **R**ate (**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. The main topic of this paper will be the determination of the **BFR**.

IV. SUSCEPTIBILITY OF MICRO-CONTROLLERS

IV.1 Test Setup

Three different microcontrollers with a different number of I/O-ports, as shown in Fig. 4, have been investigated. The microcontrollers were exposed to the UWB pulse shown in Table 1.

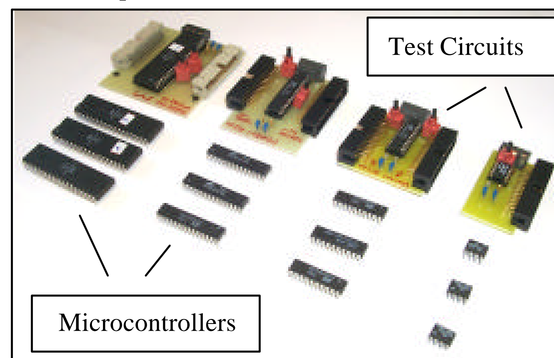

Figure 4: Microcontrollers and test circuits

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 influence of different data-, quartz- and power supply-line lengths has been tested as well as a variation of the clock rate. Figure 5 shows the basic elements of a microcontroller circuit and the modified parameters.

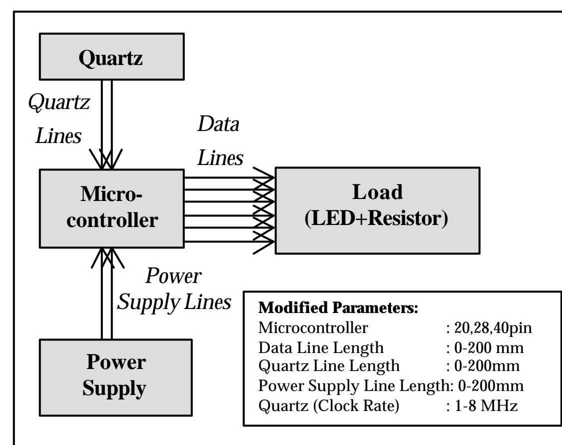

Figure 5: Basic microcontroller circuit and modified parameters

Four microcontrollers of the same type have been tested simultaneously to observe any difference. The microcontroller circuits were placed vertically on a wooden wall (Figure 6) which has been placed in the waveguide. The different states of the I/O-ports are monitored via different coulored led´s. The variation of the data-, quartz- and power supply-line length was done with ribbon cables (Figure 6).

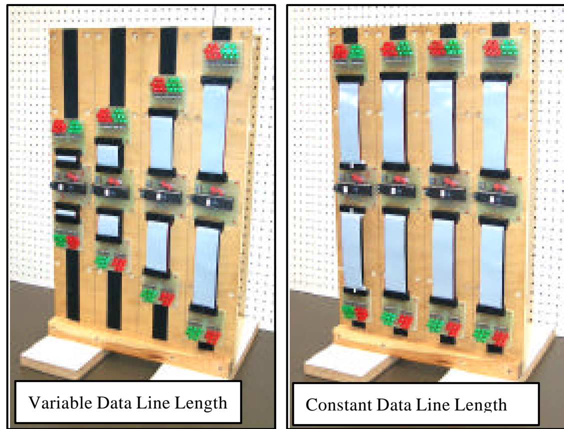

Figure 6: Microcontroller test setup

During the test a program was running on the microcontrollers which can get into two different states (Figure 7). 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 is 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 the portstatus on the susceptibility.

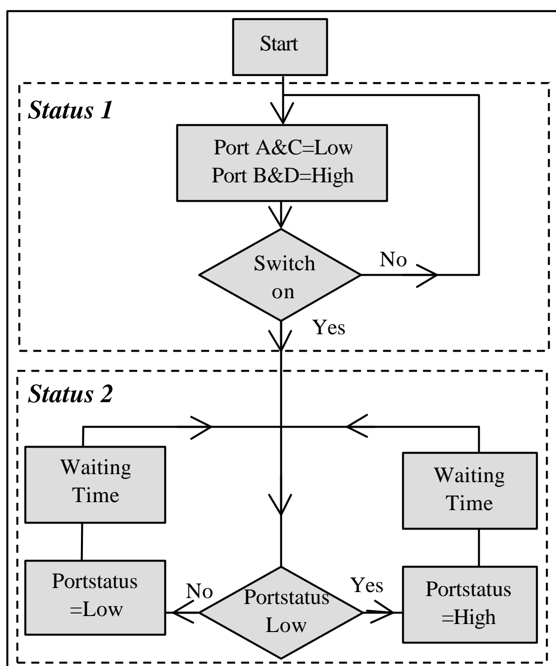

Figure 7: Microcontroller test program

IV.2 Measurement Results

IV.2.1 Principle Behavior of BFR

As a first result it can be noticed, that a breakdown of a system occurs at much lower field amplitudes than a destruction. The **BFR** behaves in principle as shown in Figure 8. As important parameters for the description of the susceptibility of a system two quantities were defined. The **B**reakdown **T**hreshold (**BT**) specifies the value of the electrical field strength, at which first breakdown effects occur. The **B**reakdown **B**andwidth (**BB**) is defined as the span of the electrical field strength, in which the **BFR** changes from zero to one (Figure 8).

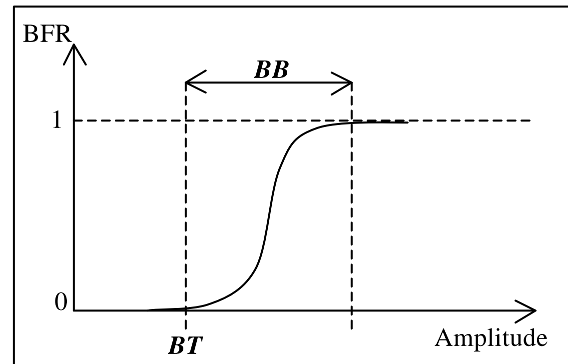

Figure 8: BFR - principle behavior and definitions

IV.2.2 Effect of I/O-Portstate

A second result of this investigation is, that the susceptibility of microcontrollers depends on the states of the I/O-ports. The amount of influence depends on the different parameters (Figure 5) and the type of microcontroller (Figure 4). Therefore in the following results the BFR is shown for low as well as for high I/O-port status.

IV.2.3 Results for Basic Setup

As the basic setup a state with quartz-, data- and power supply lines at minimal length and a clock rate at 1 MHz was defined. Figure 9a to 9c shows the results for three different microcontrollertypes.

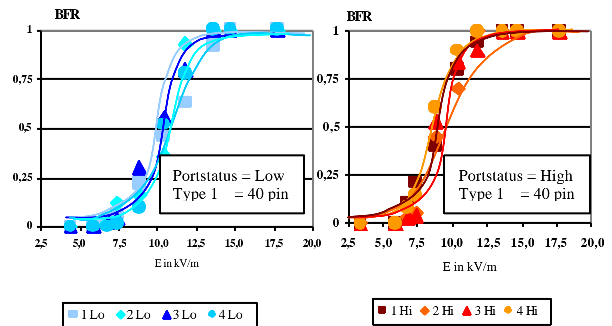

Figure 9a: **B**reakdown **F**ailure **R**ate for microcontroller type 1 (40 pin) at basic setup

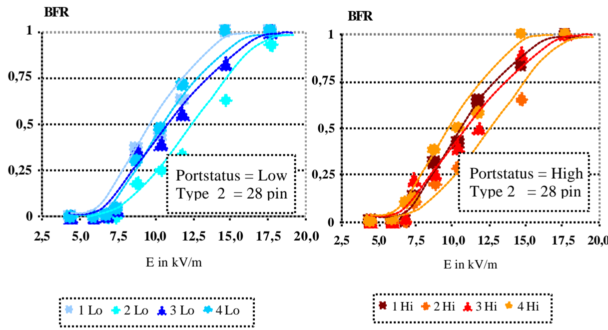

Figure 9b: **B**reakdown **F**ailure **R**ate for microcontroller type 2 (28 pin) at basic setup

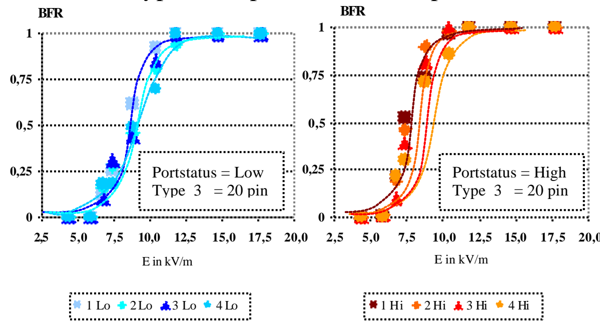

Figure 9c: **B**reakdown **F**ailure **R**ate for microcontroller type 3 (20 pin) at basic setup

The breakdown parameters **BT** and **BB** of the microcontroller circuits do not much vary by different devices of the same type of microcontroller as shown in Fig. 9a to 9c, but well influenced by the microcontrollertype. In the following analysis the breakdown parameters **BT** and **BB** have been determined as the average of four microcontrollers of the same type.

IV.2.4 Effect of the Data Line Length

Figure 10ab shows the behaviour of the **BT** and the **BB** for three different microcontrollertypes at different data line lengths for I/O-portstatus low and high.

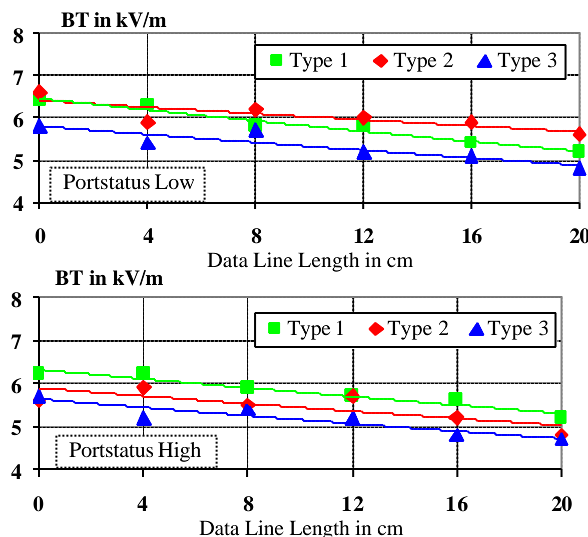

Figure 10a: BT for three different microcontrollers at different data line lengths

The **B**reakdown **T**hreshhold (**BT**) is weakly influenced, the **B**reakdown **B**andwidth (**BB**) approximately not influenced by the data line length. The amount of the **BT** is decreasing by about 1kV/m from minimal data line length to 20 cm data line length as shown in Figure 10a. The effect on the **BB** is of minor character (Figure 10b).

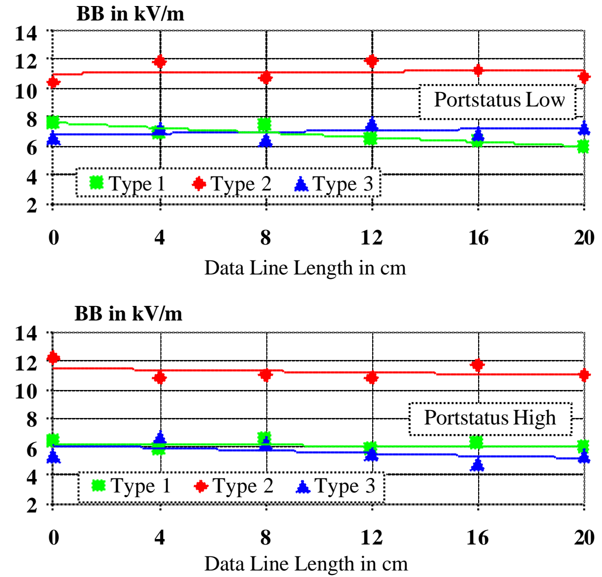

Figure 10b: **B**reakdown **B**andwidth **BB** for three microcontrollers at different data line lengths

IV.2.5 Effect of the Quartz Line Length

The effect of the quartz line length on the **BT** is much higher than the effect of the data line length. The amount of the **BT** is decreasing by about 3 kV/m from minimal quartz line length up to 20 cm quartz line length as shown in Fig.11. Further there is a influence on the **BB** by the quarz line length. The amount of the **BB** is decreasing by about 1.5 kV/m from minimal quartz line length up to 20 cm quartz line length.

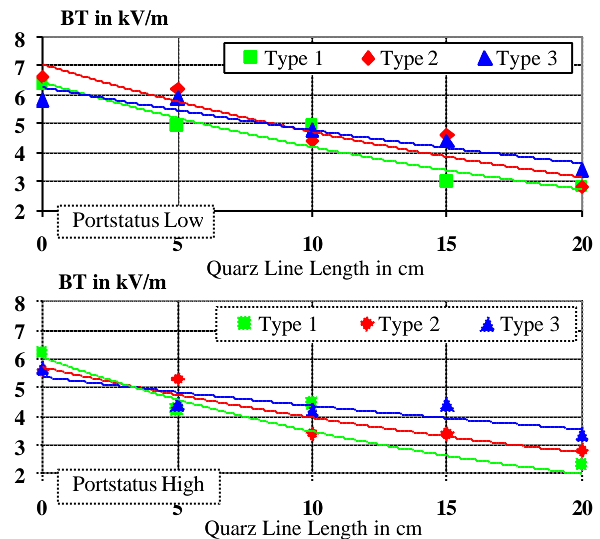

Figure 11: BT for three different microcontrollers at different quarz line lengths

IV.2.6 Effect of the Power Supply Line Length

The **B**reakdown **T**hreshhold **BT** also strongly depends on the power supply line length as shown in Figure 12. The value of **BT** is decreasing by about 3 kV/m from minimal up to 20 cm power supply line length. The value of **BB** is decreasing by about 2 kV/m from minimal up to 20 cm power supply line length.

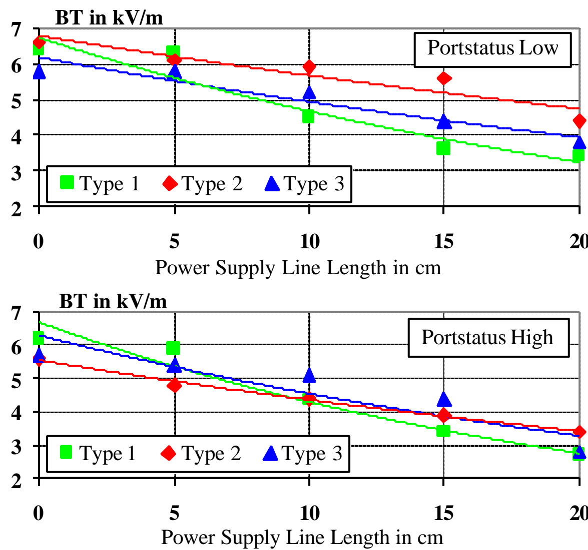

Figure 12: BT for three different microcontrollers at different power supply line lengths

IV.2.7 Effect of the Clock Rate

The **BT** as well as the **BB** are not influenced by a variation of the clock rate up to 8 MHz.

IV.2.8 Results

The **BT** of the tested microcontrollers was generally much influenced by the clock- and power supply line length as shown in Fig. 11 and Fig. 12, little influenced by the data line length as shown in Fig. 10a, not influenced by the clock rate and low influenced by the microcontrollertype. The **BT** is approximately linear decreasing by a variation of the operating lines, while the line length is not longer than 20 cm.

Table 3: Influence on BT and BB

	Data Line Length	Quarz Line Length	Power Supply Line Length	Clock Rate	Type of Controller
BT	Low	High	High	None	Low
BB	None	Low	Medium	None	High

The **BB** is generally little influenced by the quartz line length, medium influenced by the power supply line length, not influenced by the data line length and clock rate and strongly influenced by the microcontrollertype (Fig. 9a-c).

V. SUSCEPTIBILITY OF MODERN MICROPROCESSOR BOARDS

V.1 Measurement Setup

The susceptibility measurements were done by a computer which controls both measurement equipment and generator/amplifier as shown in Fig. 16. The data lines of the equipment under test (EUT) and of the different field probes are fiber optical links so there is no coupling to the lines. The communication between the controlling computer, generator/amplifier and measurement equipment is done with the General Purpose Interface Bus (GPIB).

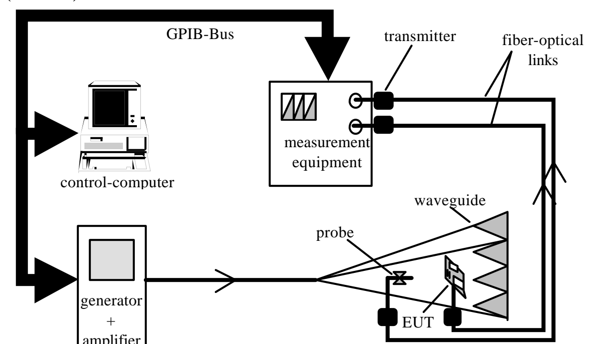

Figure 13: Measurement setup

Different microprocessor boards as shown in Fig. 16 were tested. During the test a program was running on the board which provides a rectangular signal at a selected pin of the parallel port. This signal was monitored to make sure that the mainfunctions of the board (processor, RAM, etc.) are still in function.

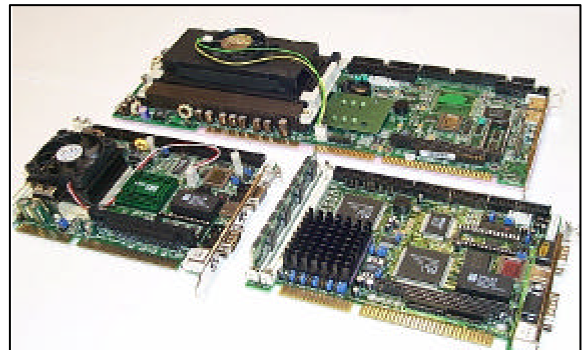

Figure 14: Different microprocessor boards

After a breakdown of the board, an external reset has been carried out with a fiber optical link, to get the board back to function. The boards were exposed to the pulses described in chapter III. Approximately five thousand pulses were applied to the boards.

V.2 Results

As a first result it can be noticed, that the **BT** strictly depends on the rise time and therefore on the energy distribution of the pulse spectrum. Fig. 15 shows the results for a rise time of 100 ps (UWB) and 1.5 ns (EMP). Using the UWB pulse the **BT** starts at

approximately 12 kV/m and for the EMP pulse at approximately 30 kV/m. The ratio between these two field strengths is 2.5, which is in a good agreement with the calculated σ_E=2.4 and σ_V=2.5 in [4] between a UWB pulse with a rise time of 100 ps and an EMP with a rise time of 1.5 ns (Table I).
A second result of this investigation is, that there is only a narrow **BB** (≈1kV/m) if a UWB pulse generator is used, but a broad **BB** (≈20 kV/m) of the electrical field strength if a EMP pulse generator is used.

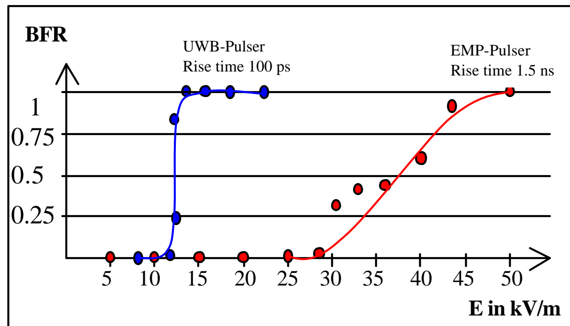

Figure 15: BFR of a Rocky-518 HV board with a Pentium MMX CPU 233 MHz at different rise times

In a second test the behaviour of two different boards with approximately the same physical dimensions has been examined. Therefore the size of the coupling structures on the board is comparable. It was observed that the **BT`s** of the boards are different (Fig. 16).

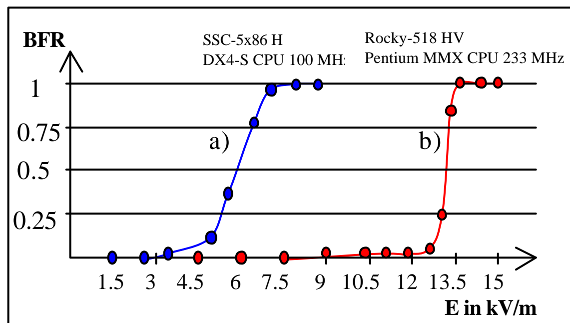

Figure 16: BFR due to an irradiation with the UWB a) SSC-5x86 H board b) Rocky-518 HV

For a Rocky-518 HV board with a Pentium MMX^{tm} CPU at 233 MHz irradiated with the UWB pulse the **BT** is approximately at 12 kV/m. For a SSC-5x86 H board with a DX4-S CPU at 100 MHz the **BT** is at approximately 4 kV/m. The different behavior of the boards is based on the different susceptibility of the on board devices and the different layouts of the boards.
In [3] the HPM susceptibility of the SSC-5x86H board was determined. The susceptibility threshold depended on the frequency and was located between 200 V/m and 2 kV/m. In comparison to our results, the necessary HPM field strength was only by a factor of 2 to 20 lower although the energy density of the UWB pulse is much lower (approximately by a factor of 1000) than the single shot energy density of the HPM burst signal, used in [3], so that the energy efficiency of the UWB pulse is much higher.
Further two boards of the same type have been tested to observe any difference in the behaviour. Figure 17 shows that there is only a small difference in the **BFR** for the Rocky-518 HV board as well as for the SSC-5x86 H board.

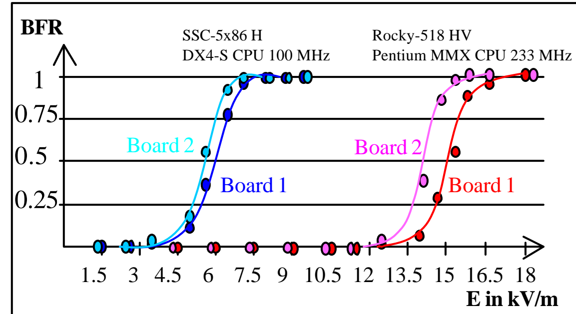

Figure 17: Difference in the **BFR** at boards of the same type

VI. Summary

The susceptibility of different types of single microcontrollers and complex microprocessorboards to unipolar fast rise time pulses has been determined. The susceptibility of the tested microcontrollers was in general much influenced by clock- and power supply line length, little influenced by data line length and approximately not influenced by the clock rate.
Further the susceptibility field strength levels of different microprocessor boards were determined. The different boards failed at 4 kV/m or 12 kV/m fieldstrength of the applied UWB pulse. The susceptibility vs pulses with slower rise times was higher (about 30 kV/m vs a fast NEMP). This can be explained with the relative energy and voltage efficiency shown in [4]. The investigation of two different boards with nearly the same dimensions showed that the devices on the board are of vital importance for the breakdown effects.

REFERENCES

[1] **C.Braun**, *„Aufbau eines breitbandigen Wellenleiters für NEMP Modell Simulationen“*, INT Bericht 6/84, Okt. 84

[2] **C.Braun, P.Guidi, H.Schmidt**, *„Elektrisch kurze Antennen zur Feldmessung“*, INT Bericht 1/96, März 96

[3] **C.Braun, W.Graf, P.Guidi, H.Schmidt**, *„HPM Störfestigkeitsuntersuchungen an modernen Hochleistungsprozessor-platinen“*, INT Bericht 3/96, Mai 99

[4] **D.Nitsch, M.Camp,** *"UWB and EMP Susceptibility of Modern Microprocessor-boards",* EMC Europe, Brugge, Sept. 2000