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Susceptibility of personal computer systems to electromagnetic pulses with double exponential character

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Abstract. In this paper the susceptibility of personal computer systems to fast transient electromagnetic pulses with double exponential pulse shapes (EMP, UWB) is determined. The influence of the computer generation, RAM-values, different program states and the pulse shape, as well as the destruction thresholds of single PC-components (CPU, RAM, BIOS, Mainboard) have been investigated.

1 Introduction

Risks as a result of upset effects of personal computer systems are ranging from harmless breakdown effects of household computers to perilous failure effects. Taken the aspect of electromagnetic terrorism into account, pulses with fast rise times and pulse lengths (EMP, UWB) are posing a dangerous threat, because new developed pulse generating devices can be built in a very small volume due to the low energy content of the pulse.

In this paper the susceptibility of different personal computer systems to fast transient electromagnetic pulses with double exponential pulse shapes (Fig. 1) have been determined. It is shown that the susceptibility strongly depends on the computer generation and the pulse shape, but is less influenced by different program states or RAM-values. In addition the destruction thresholds of single PC-components have been investigated

2 General Measurement Setup

The applied pulse shape is in general double exponential as shown in Fig. 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. Five different pulse generating devices are available. Table 1 shows the rise time (t_r) and the full width half max value (t_{fwhm}) of the different pulses. The measurements were carried out with two different TEM waveguides.

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Table 1. Pulse Data.

Pulse	Rise time t_r	Pulse length t_{fwhm}
UWB	100 ps	2.5 ns
EMP (fast)	1.5 ns	80 ns
EMP (med.)	5 ns	300 ns
UWB – slow EMP	500 ps – 10 ns	2.5 ns - 1600 ns

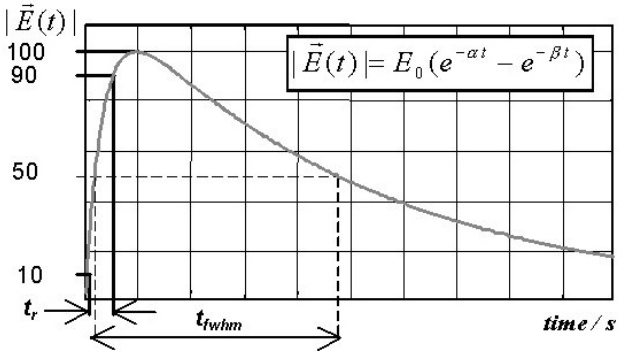

Fig. 1. Double Exponential Pulse Shape.

3 Definitions

3.1 Failure Rates

To describe the different failure effects two quantities have been defined (Fig. 2). 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

Table 2. Tested Personal Computer Systems.

Processor (Intel)	Clock rate (MHz)	Minimum structure size (μm)	Number of transistors (CPU)
8088	5	> 1.5	28 000
80 286	10	1.5	130 000
80386DX20	20	1.5	275 000
80486SX25	25	1.0	1.2e6
80486DX33	33	1.0	1.2e6
P80486DX266	66	0.6	1.2e6
P I	75	0.6	3.3e6
P I	100	0.6	3.3e6
P I MMX	200	0.35	4.5e6
P II	266	0.28	7.5e6
P III	450	0.25	9.5e6
P III	500	0.18	28.1e6

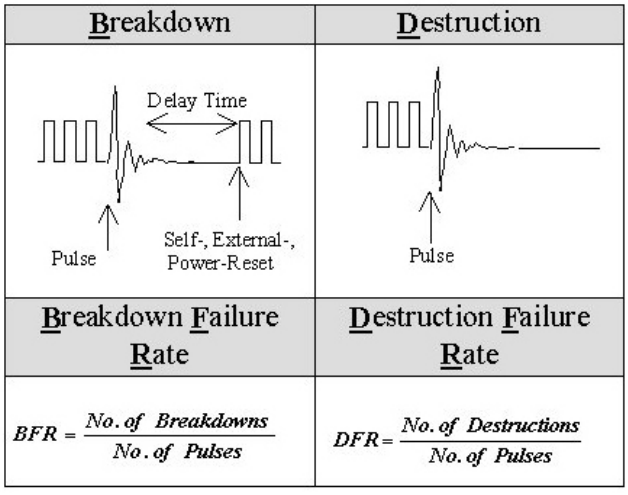

Fig. 2. Failure Rates.

defined as a physical damage of the system so that the system will not recover without a hardware repair.

3.2 Principle Behavior of the BFR and DFR

The BFR and DFR behaves in principle as shown in Fig. 3. As important parameters for the description of the susceptibility of a system four quantities have been defined [2]. 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 (see, Fig. 3).

4 Personal Computer Test Setup

Different personal computer systems have been choosen for the measurements. Table 2 shows the different systems starting from an 8088 processor based system up to Pentium III system with a clock rate of 500 MHz.During the investigation the tested personal computers were operated without any external shielding or wiring in a minimum configuration which consists of mainboard, processor, random access memory and accumulator power supply (see, Fig. 4).

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 via different colored LEDs. The minimal configurations were placed in the waveguides in such a way, that coupling into the monitor card is minimal (see, Fig. 7). Figure 5 shows for example two of the tested systems with the ISA-bus monitor card implemented.

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

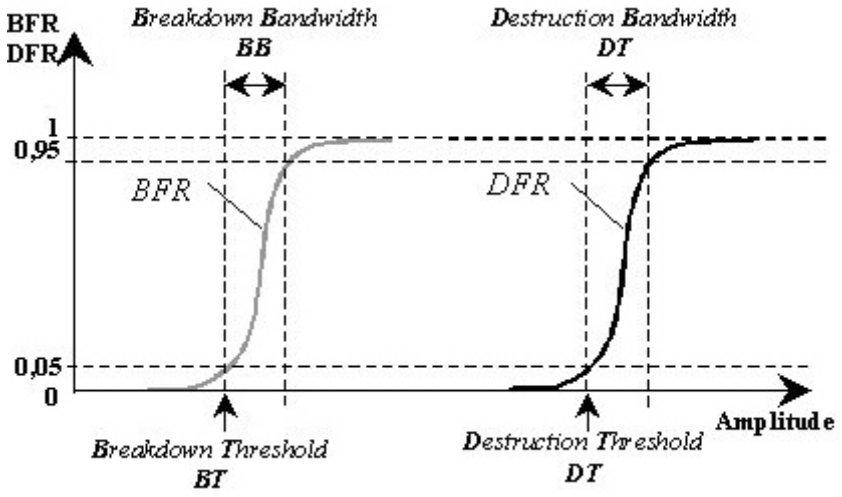

Fig. 3. BFR, DFR – principle behavior and definitions.

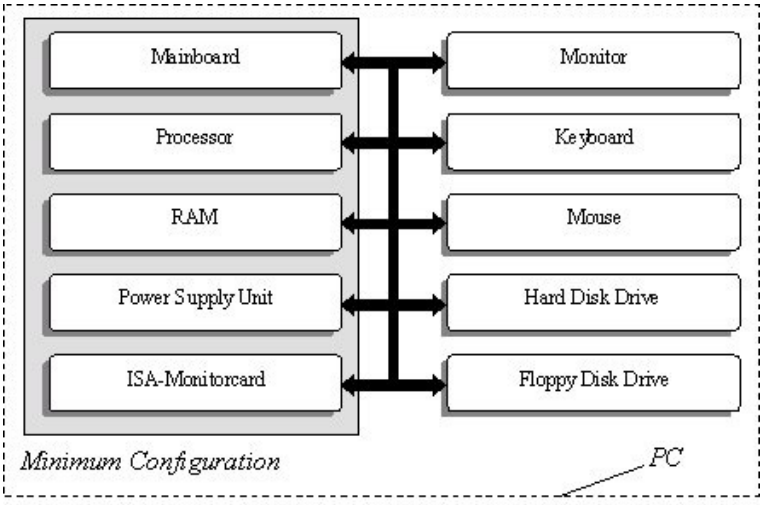

Fig. 4. Personal computer system and minimum configuration for the susceptibility tests.

each subroutine a CPU test has been performed to make sure that the complete system was working properly. Figure 6 shows the flow chart of the personal computer test program.

Figure 7 shows the general test setup used in this investigation. The EUT is placed in the waveguide so that coupling into the ISA-bus monitor card is minimal. The accumulator power supply unit is located behind the EUT. The Floppy disk drive as well as the recharger for the power supply unit have been removed before the test have been started.

5 Measurement Results

5.1 Increase of the Susceptibility with Progress of the Computer Generation

Figure 8 shows the Breakdown Failure Rates (BFR) of the tested personal computer systems separated into AT (a) and ATX (b) systems. The Breakdown Failure Rates behaves in principle as shown in Fig. 3. Below a certain field strength no failure of the systems has been observed (BFR=0). Above a certain field strength each single pulse applied to the systems is leading to an upset of the system (BFR=1). Between these values the Breakdown Failure Rate is strictly monotonic increasing.

Figures 9 and 10 show the Breakdown Thresholds BT and the Breakdown Bandwidths BB (see, Fig. 3) of the tested personal computer systems. The Breakdown Thresholds are decreasing very much with the progress of the computer generation. Responsible for this behavior are three different factors. The clock rate as well as the number of elements (transistors, ...) is increasing with the progress of the computer generation. Furthermore the minimum structure size is decreasing very much.

The Breakdown Bandwidth shows a trend similar to the Breakdown Thresholds. With Progress of the computer generation the Breakdown Bandwidth values are also decreasing

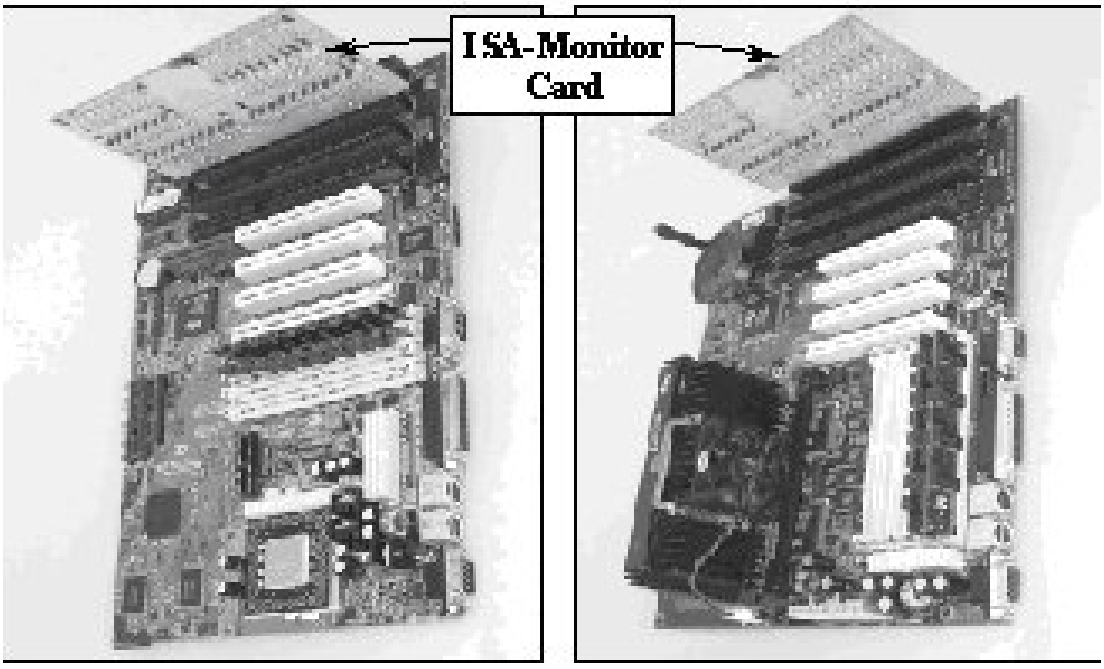

Fig. 5. Personal computers in minimal configuration with ISA monitor card.

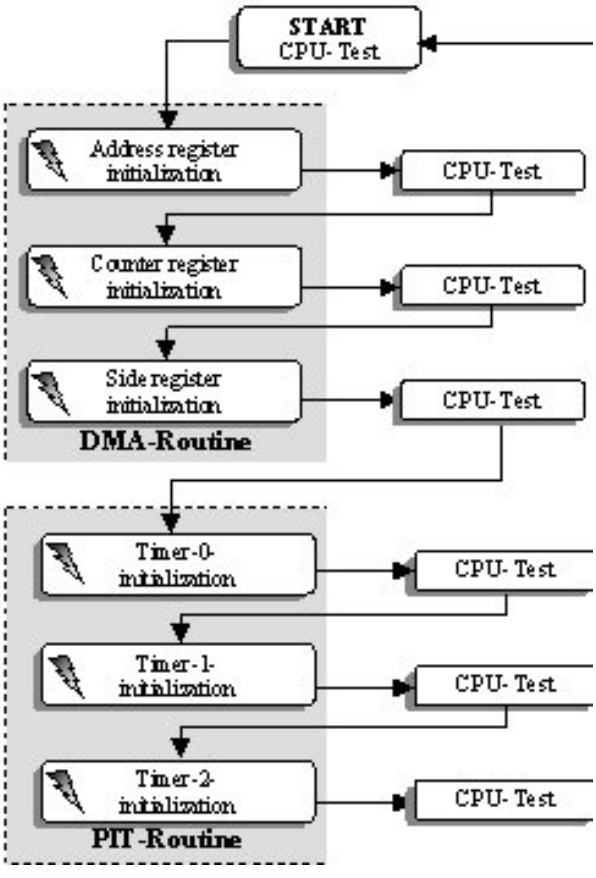

Fig. 6. Personal computer test program.

very much. Between AT- and ATX-systems is a factor, which decreases the Breakdown Bandwidth values at AT-systems in comparison with ATX-systems.

5.2 Influence of different Program States

Figure 11 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.

5.3 Influence of different RAM Values

Several personal computer systems were equipped with five different RAM values to determine the influence on the failure effects. Figure 12 shows the Breakdown Thresholds BT of two 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. The influence on BT and BB is negligible.

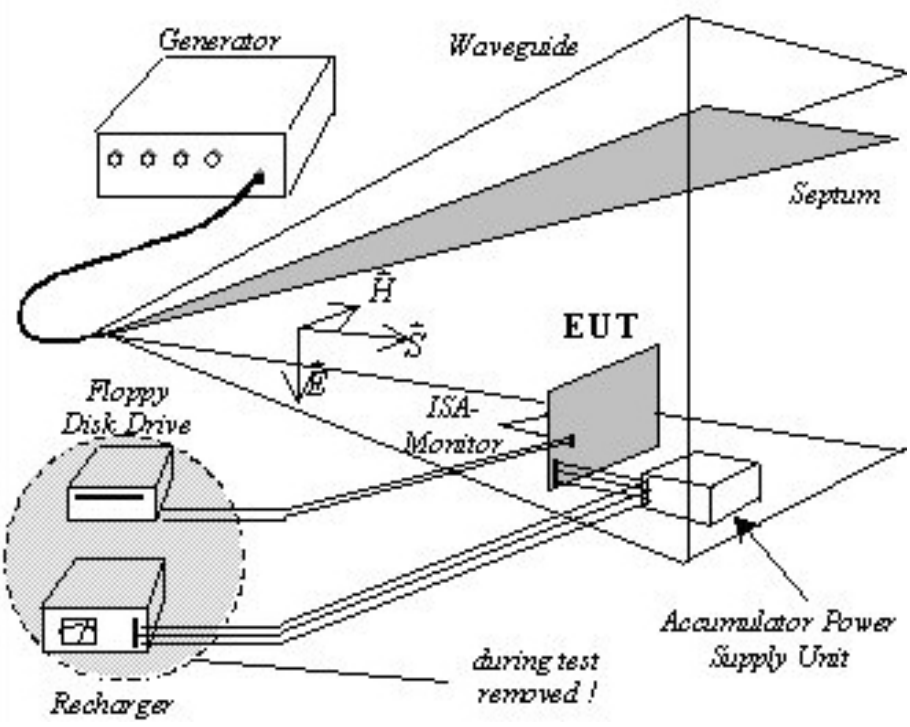

Fig. 7. General Test Setup.

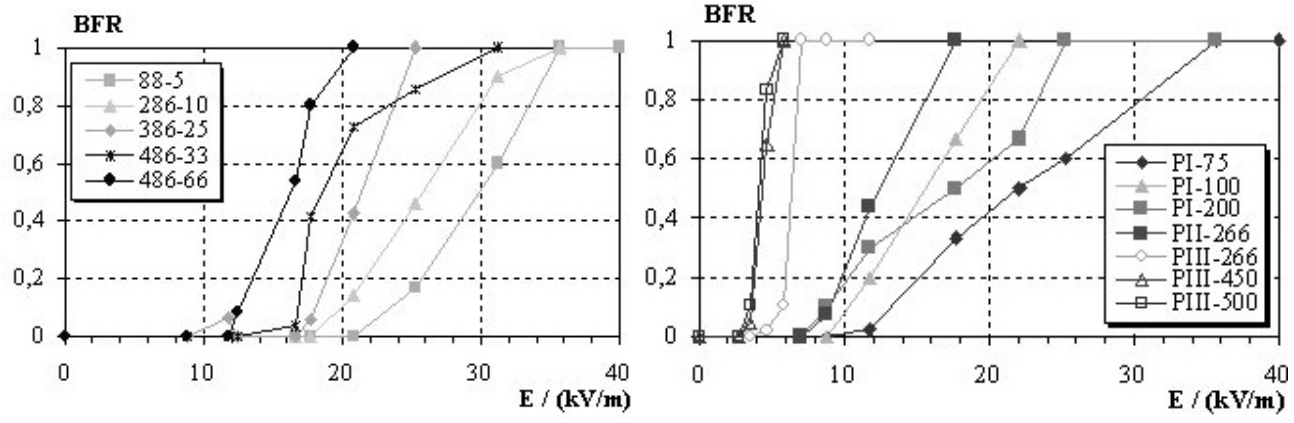

Fig. 8. Breakdown Failure Rates of the tested personal computer systems separated into AT and ATX systems (pulse parameters: $t_r = 100$ ps, $t_{\mathrm{fwhm}} = 2.5$ ns.

5.4 Destruction Thresholds of PC-Components

To determine the destruction thresholds of single pc components like CPU or RAM devices, different personal computer systems were exposed to high amplitude pulses. Upon destructions have occured each component have been changed and tested with an identical control system whether the device is working properly or not. Figure 13 shows the Destruction Thresholds DT of Mainboard, CPU, BIOS and RAM devices of two personal computer systems for an EMP testpulse with a rise time of $t_r = 7.5$ ns and a pulse length of $t_{\mathrm{fwhm}} = 180$ ns. The mainboards tested in this investigation are much more susceptable than the CPU, BIOS or RAM devices, although the CPU has the largest scale integration. There is a factor of about 20 between the Destruction Thresholds of mainboards on the one side and CPU, BIOS and RAM devices on the other side.

6 Conclusion

The investigation of the susceptibility of different personal computer systems to EMP and UWB pulses has shown, that the susceptibility is increasing very much with progress of

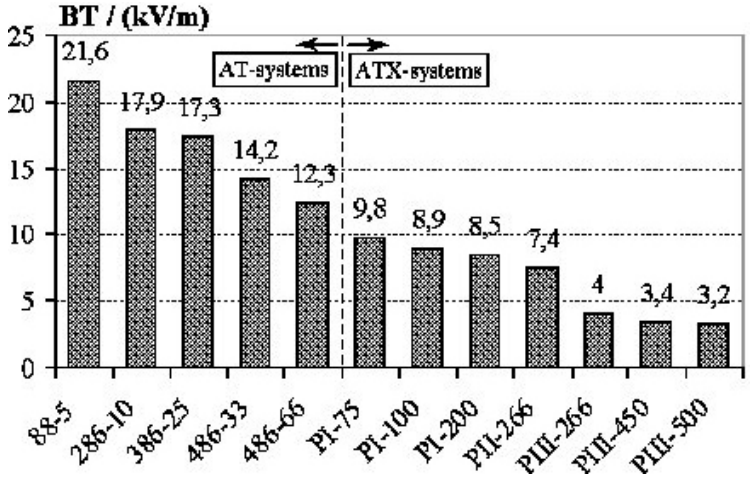

Fig. 9. Breakdown Thresholds BT of the tested personal computer systems (pulse parameters: $t_r = 100$ ps, $t_{fwhm} = 2.5$ ns).

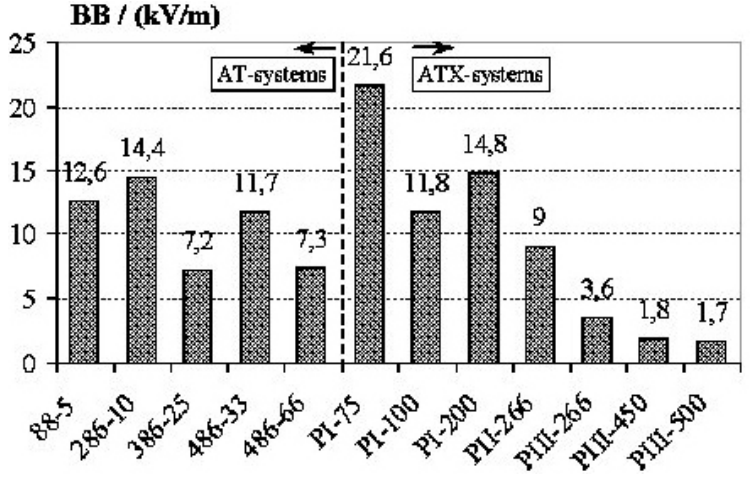

Fig. 10. Breakdown Bandwidth BB of the tested personal computer systems (pulse parameters: $t_r = 100$ ps, $t_{fwhm} = 2.5$ ns).

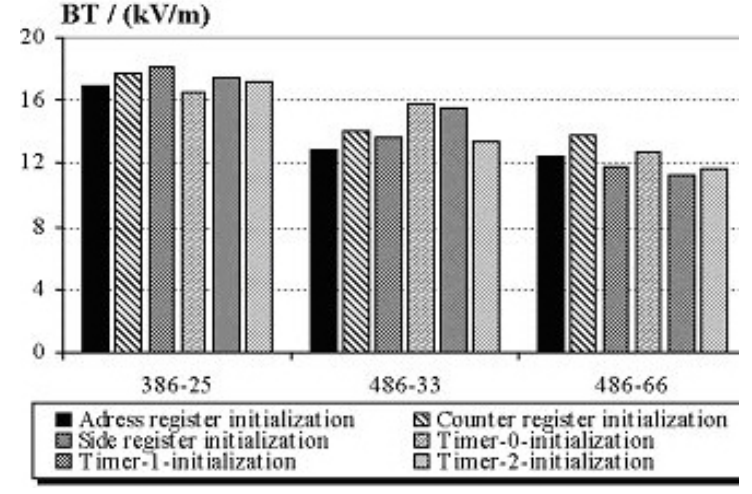

Fig. 11. Breakdown Thresholds of three different personal computer systems in six different program states (pulse parameters: $t_r = 100$ ps, $t_{fwhm} = 2.5$ ns).

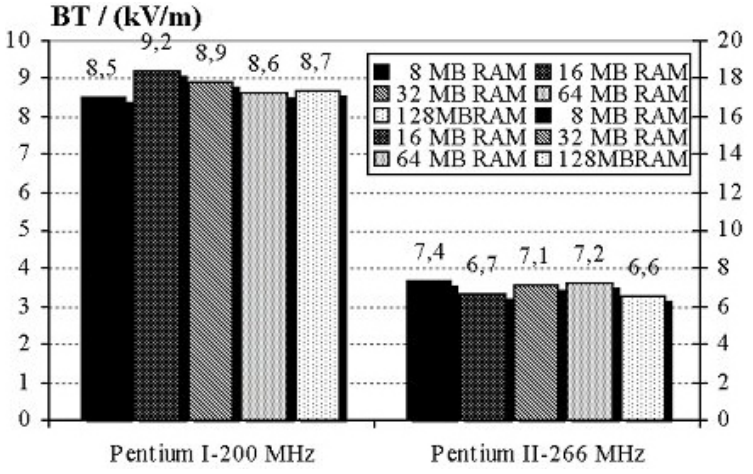

Fig. 12. Breakdown Thresholds of two different personal computer systems with five differnet RAM values (pulse parameters: $t_r = 100$ ps, $t_{\mathrm{fwhm}} = 2.5$ ns).

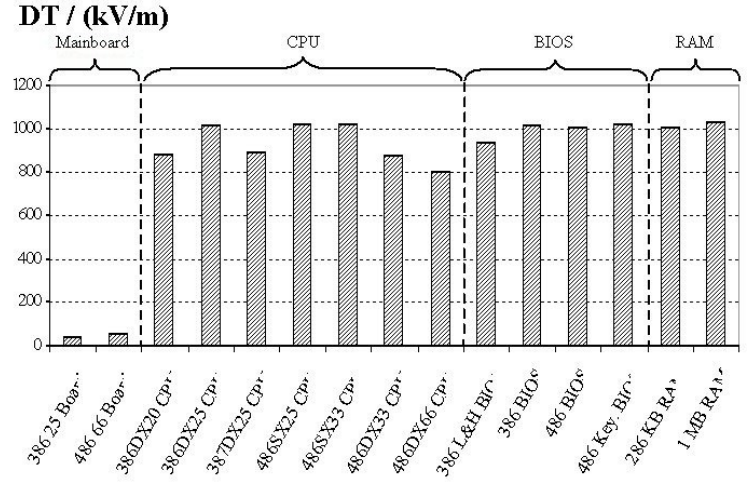

Fig. 13. Destruction Thresholds of different PC components.

the computer generation. In contrast, program and operation states, as well as the implemented RAM values, are of minor character concerning the failure behavior.

Regarding the destruction effects, the tested mainboards are much more susceptible than the CPU, RAM or BIOS devices, although the CPU has the largest scale integration.

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