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Comparison of the HPM and UWB Susceptibility of Modern Microprocessor Boards

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ABSTRACT

The large importance of modern microelectronics for our society makes the investigation of their susceptibility to electromagnetic threats like High Power Microwaves (HPM) and ultra wide band pulses (UWB) a very important topic. Particularly the susceptibility of microprocessor boards to those electromagnetic threats was thoroughly examined in different test facilities. The understanding of the basic common and different effects of these two classes of electromagnetic threat pulses is of large interest.

In this paper the advantages and the disadvantages of HPM and UWB pulses are examined based on susceptibility tests of two different microprocessor boards in five different test facilities. The measured data is presented and discussed by using time- and frequency domain quantities, the average spectral amplitude and the energy- and amplitude efficiency [1].

INTRODUCTION

Microprocessors and other electronic components are essential parts of modern technical equipment. An upset or malfunction in one of these components could cause huge financial losses (e.g. downtime of bank computers) or even the loss of life (e.g. malfunction in airport security systems). It is well known that electromagnetic pulses with fast risetimes of a few ns or less and high amplitudes (UWB pulses), as well as High Power Microwave (HPM) pulses can cause an upset or the destruction of electronic components. Therefore the determination of the susceptibility of electronic devices to these two classes of electromagnetic threats is of great importance.

As targets two microprocessor boards (MB) of different operating frequencies and capabilities were chosen, because microprocessor boards are nowadays used in nearly all modern electronic systems. Examined were MB with Pentium and AMD 486 class chips. To determine the general coupling behavior of boards of this size, a generic board was built and its system transfer function was measured. With those system transfer functions an estimation of the transfer functions of the real MB was done.

At the HPM test site of the INT, Euskirchen and the mode stirred chamber of the University of Magdeburg the susceptibility levels of the MB to cw and HPM signals were measured with respect to the parameters necessary field strength, frequency and pulse duration. At the UWB test site of the WIS, Munster and with the UWB pulse generator of Rheinmetall, Unterlüß the susceptibility levels of the MB to EMP and UWB signals were measured with respect to rise time, amplitude and pulse repetition frequency. The most work was put into an expanded evaluation of the gathered data and the comparison of the behavior of the MB to an irradiation with HPM and UWB pulses. The expanded evaluation was based on energy and amplitude efficiencies and the average spectral amplitudes as well as common time- and frequency domain quantities like amplitude and energy density.

Following a short introduction of the used test facilities which are capable of generating the different threats the general measurement setup of the MB for determining their susceptibility levels is presented. Based on the data which was gathered in the five test facilities, the results of the expanded evaluation will be shown. These results and their impact on the HPM and UWB efficiencies are discussed.

TEST FACILITIES

For the determination of the susceptibility levels of the chosen MB five different test facilities were used. The HPM test site of the INT, Euskirchen (see Figure 1a) is based on a TEM waveguide in which HPM pulses can be generated with several microwave generators. In the mode stirred chamber of the University of Magdeburg (see Figure 1b) cw- and HPM signals of large field strengths can be generated with the help of the resonant behavior of the resonance chamber. The TEM waveguide of the WIS, Munster (see Figure 1c) is similar to the INT waveguide. With a large number of impulse generators EMP and UWB pulses with a generally double exponential pulse shape and a large bandwidth of rise times, amplitudes and repetition rates can be generated in this waveguide. The UWB simulation facility of the WIS, Munster is based on a Half-IRA system (see Figure 1d) and is capable of generating bipolar free field UWB pulses with variable field strengths and rise times. The UWB simulation facility of Rheinmetall, Unterlüß (see Figure 1e) generates a bipolar free field UWB pulse with a high field strength and a short rise time. The characterizing data of these test facilities are shown in tables Ia and Ib.

Table Ia: HPM Facilities

Facility	Pulse shape	Frequency range	Amplitude	PRF[1]
TEM waveguide of the INT	HPM	150 MHz to 3,4 GHz	max. 4 kV/m	1 Hz to 10 kHz
Mode stirred chamber University of Magdeburg	cw, HPM	80 MHz to 1000 MHz	max. 1000 V/m	cw to 10 kHz

Table Ib: UWB Facilities

Facility	Pulse shape	Rise time	FWHM[2]	Amplitude	PRF
TEM waveguide of the WIS	Double exponential	100 ps to 100 ns	2,5 ns to 400 ns	up to 50 kV/m	up to 200 Hz
UWB Simulator of the WIS	Bipolar	100 ps to 400 ps	300 ps to 1 ns	up to 25 kV/m	up to 200 Hz
UWB Simulator of Rheinmetall	Bipolar	-	-	-	-

[1] PRF pulse repetition frequency
[2] FWHM full width half max value

MEASUREMENT SETUP

Examined were two different MB:

1. SSC 5x86 AMD 133 MHz
2. Rocky-518HV Pentium/MMX 233 MHz

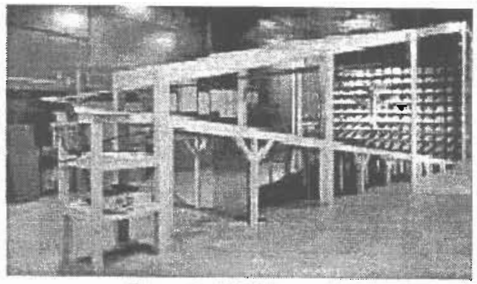


Figure 1a: INT Wave guide

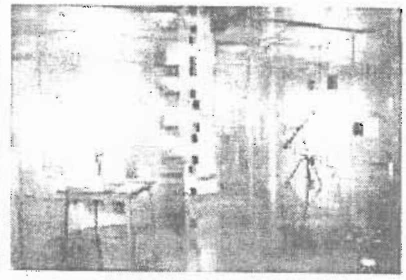


Figure 2b: Mode stirred chamber of the University of Magdeburg

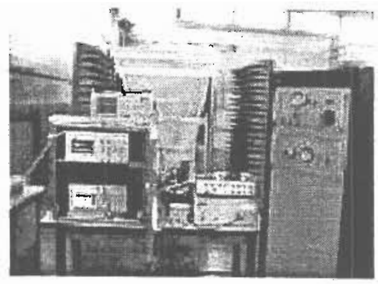


Figure 1c: WIS Wave guide

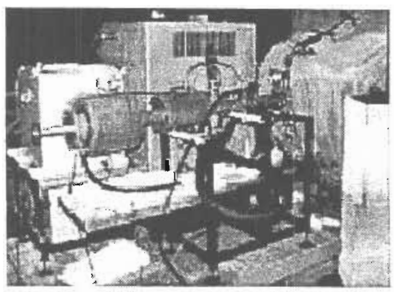


Figure 1d: Rheinmetall UWB Simulator

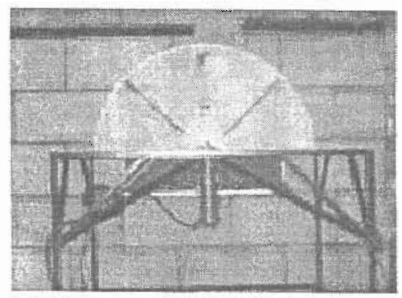


Figure 1e: WIS UWB Simulator

These MB have the functionality of a PC on a single board which does not have any external power supply, cables or shielding structures. Therefore only the direct coupling to the MB has to be taken into account. That is why, the reproducibility of the experiments in different test facilities is very high. The MB were programmed such that they permanently send a rectangular pulse on a pin of their parallel ports. This signal was monitored with an oscilloscope (see figure 2). As soon as the MB stopped sending this signal a malfunction was recorded. The MB was connected to the measurement equipment via fiber optical links to avoid coupling into the measurement lines. The perpendicular axis of the MB was oriented parallel to the electrical field and vertical to the magnetic field in all test facilities. The basic measurement setup which was kept the same in all trials is shown in figure 2.

SUSCEPTIBILITY LEVELS

In this chapter the results of the determination of the susceptibility levels in the different test facilities are presented. To compress the large number of results to a manageable number, for HPM and cw signals the highest (HL) medium (ML) and smallest (SL) susceptibility level over the frequency was determined. An example of this evaluation is shown in figure 3.

For pulsed signals another quantitiy is of importance: the breakdown bandwidth (BB) [1,2]. The lower border of the BB represents the susceptibility level of the MB to pulses with a high PRF (HPRF), the upper border represents the the susceptibility level of the MB to pulses with a low PRF (LPRF). This behavior is shown in figure 4. The compressed results of the susceptibility levels of the MB are shown in figure 5a and 5b for HPM and cw signals and in figure 6a and 6b for EMP and UWB pulses.

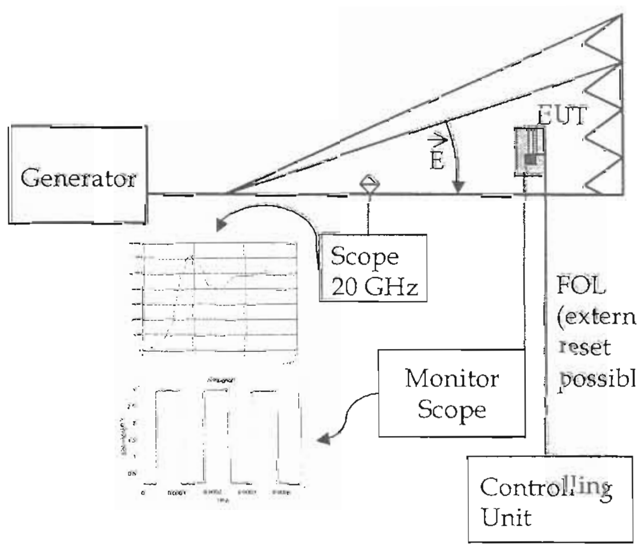


Figure 2: Basic measurement setup

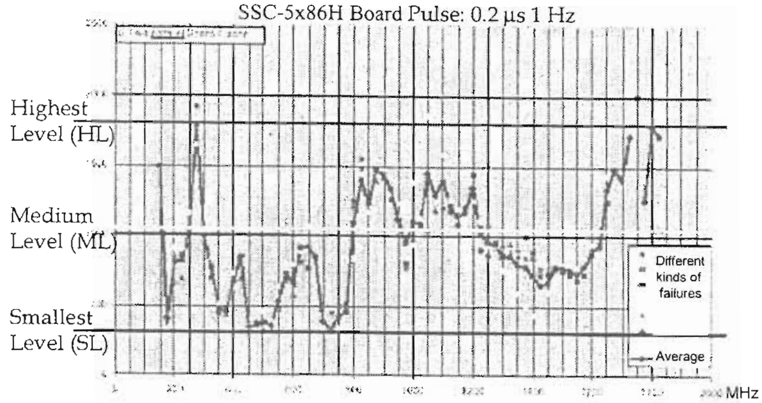


Figure 3: Compression of the measurement data (HPM, cw)

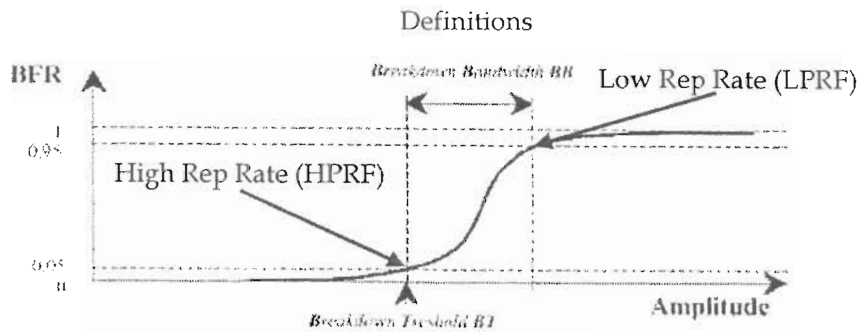


Figure 4: Compression of the measurement data (EMP, UWB)

A first look at those susceptibility levels leads to the following results:
The difference between the susceptibility levels of long HPM pulses and cw signals are small. The duration of HPM pulses (above a certain minimal duration) has nearly no influence on the susceptibility levels of the MB. The effect of the repetition rate of the HPM pulses on the susceptibility levels of the MB is only of minor significance. The SL value for both MB is about a few 100 V/m, the HL value of both MB is located between 1 kV/m and 2 kV/m. The effect of the rising of the PRF for EMP and UWB pulses is significantly lowering the susceptibility levels. The susceptibility levels are extremely dependent on the pulse shape (in the case of the used pulse shapes the maximal difference in the susceptibility levels was a factor of 25 in necessary field strength). The lowest susceptibility levels for EMP and UWB pulses are a few kV/m.

EVALUATION BASICS

For a more detailed evaluation of the results with regard to the susceptibility levels and the pulse characteristics one has to take some more complex time- and frequency domain quantities into account which have to be determined and discussed. In the following quantities which were selected for the detailed evaluation are introduced. In the time domain the maximal amplitude $\hat{A}(t)$ (HL and SL for HPM and cw signals and HPRF

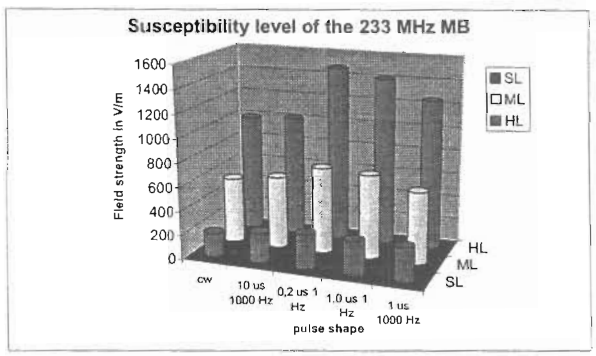


Figure 5a: Susceptibility levels of the 233 MHz MB to HPM and cw signals

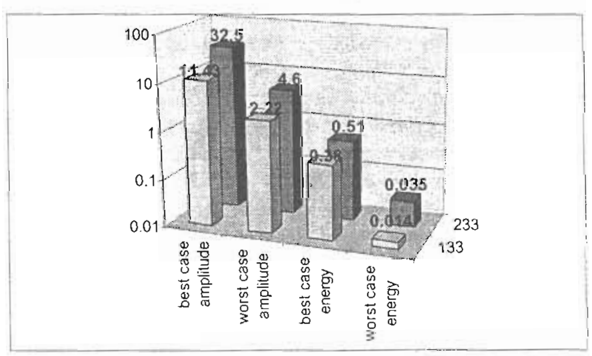


Figure 5b: Susceptibility levels of the 133 MHz MB to HPM and cw signals

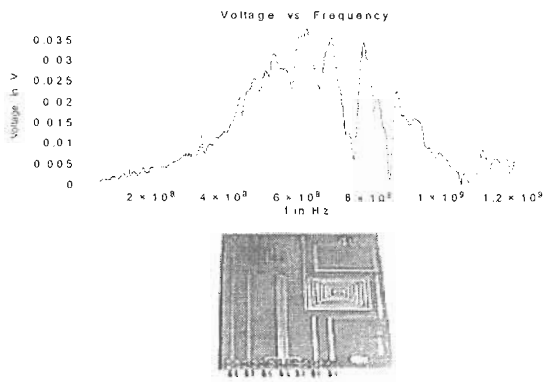


Figure 6a: Susceptibility levels of the 233 MHz MB to EMP and UWB pulses

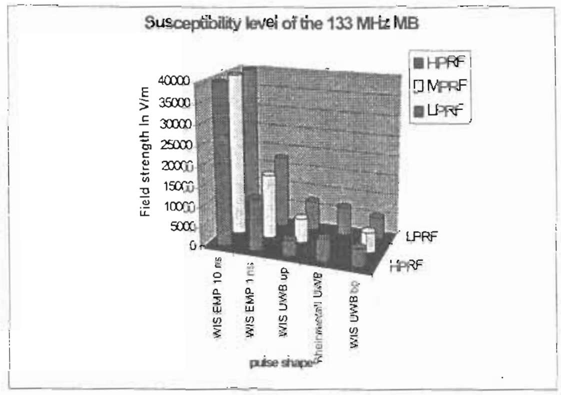


Figure 6b: Susceptibility levels of the 133 MHz MB to EMP and UWB pulses

and LPRF for EMP and UWB pulses), the overall energy density of the field signal $\hat{E}(t)$, the PRF efficiency $\eta_{PRF} = \frac{LPRF}{HPRF}$ and the frequency efficiency $\eta_{Freq} = \frac{SL}{HL}$ were selected. In the frequency domain the maximal spectral amplitude $\hat{A}(f)$, the average spectral amplitude and energy density $\rho_A = \|A(f)\|_1^{100MHz,3GHz}$ and $\rho_E = \|A(f)\|_2^{100MHz,3GHz}$ and the amplitude- and energy efficiency $\eta_A = \frac{\|A(f)\|_1^{100MHz,3GHz}}{\|A(f)\|_\infty}$ and $\eta_E = \frac{\|A(f)\|_2^{100MHz,3GHz}}{\|A(f)\|_2}$ were selected. The norms used in the prior equations are based on C. Baum´s introduction of norms for describing pulse characteristics [4].

EVALUATION RESULTS

One of the most important quantities for the evaluation of HPM pulses is η_{Freq} because it is a measure for the effectiveness of a HPM pulse in the case that the system transfer function, the orientation of the system and the actual layout of the cable bundles of the target system are not known. In figure 7 η_{Freq} is shown for the different pulse shapes and both MB. The average is about 0.2 which leads to the assumption that the quality of the coupling resonances is very low (near 5). A similarly important quantity is η_{PRF} for EMP and UWB pulses because it determines whether it makes sense to use repetitive pulses for disrupting a given system or not. Figure 8 shows η_{PRF} for both MB and all used EMP and UWB pulse shapes.

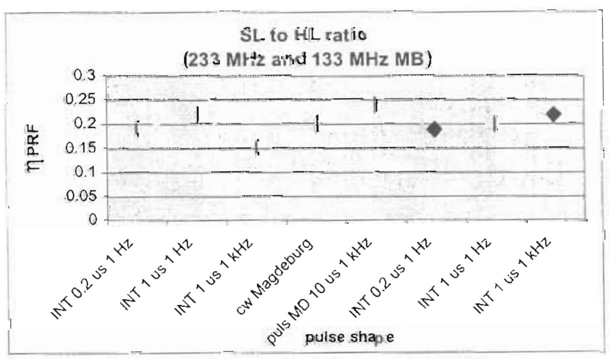


Figure 7: Frequency efficiency of both MB

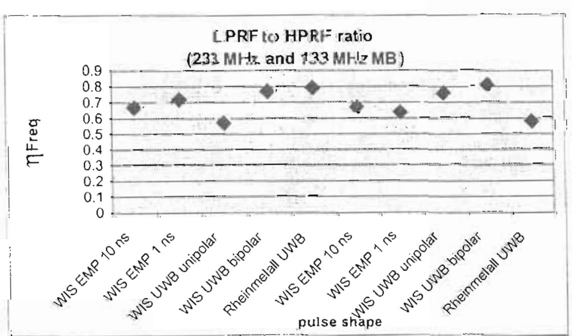


Figure 8: PRF Effizienz für beide Platinen

The average value of the PRF efficiency is 0.7 which means that the usage of a repetitive system would lower the susceptibility level by approximately 30% compared to a single shot system. The energy density which is necessary for a disruption of the MB is of large importance for the selection of the source and the power supply and determines their weight and size. This energy density is shown in figure 9 for two cases: best case (blue): the SL value for HPM and cw signals and the HPRF level for EMP and UWB pulses) and worst case (red) the HL value for HPM and cw signals and the LPRF level for EMP and UWB. Depending on the pulse shape some pulses need a million times the energy other pulses need for a disruption of the MB functionality. Noticeable is that the most effective HPM pulse in the best case scenario (SL) needs only 2 or 3 times the energy a UWB pulse needs to disrupt the MB. In the worst case scenario the most effective HPM pulse needs 60 to 70 times the energy of the UWB pulse.

The large differences in the susceptibility levels for different EMP and UWB pulses are demonstrating that an evaluation of the pulse efficiencies only in the time domain is not sufficient. The determination of the energy- and amplitude efficiencies (see figure 10) are making clear why those susceptibility levels differ that much. The pulses which do not have distributed their power and energy in the for MB relevant spectral range [3] have a very bad energy- and amplitude efficiency which does analytically explain the measured values. Even the highest measured difference in the for a disruption necessary energy of the different pulses (10^6) and the maximal difference of the energy efficiency is the same (factor of 10^6 between WIS EMP 10 ns and WIS UWB bipolar).

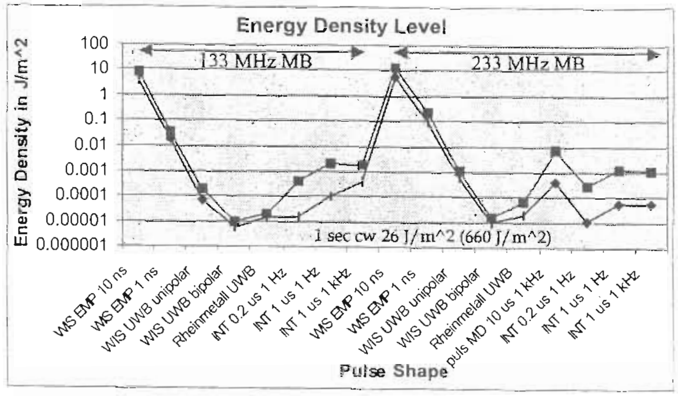


Figure 9: Energy density of the pulses for both MB

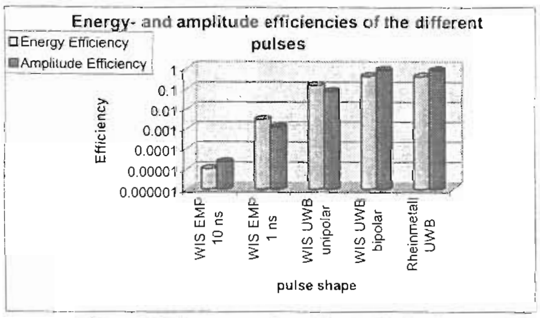


Figure 10: Energy- and amplitude efficiencies

The average spectral amplitude or of the pulses determines the amount of coupled voltage or current in the system. Figure 11a shows this quantity for all EMP and UWB pulses normalized on a 10 kV/ field strength The significant differences in the coupled amplitudes are explaining the differences in the for a disruption of the MB necessary field strengths. Figure 11b shows the average spectral amplitude at the for the disruption of the MB necessary field strengths. It is very interesting how well the mathematical concept of the average spectral amplitudes in the certain frequency range describes the necessary field strengths for disrupting the MB for the different pulse classes. For UWB pulses an average spectral amplitude of 10^{-5} V/m/Hz is sufficient for disrupting the MB.

Figure 12 shows the ratio of the necessary energy density and

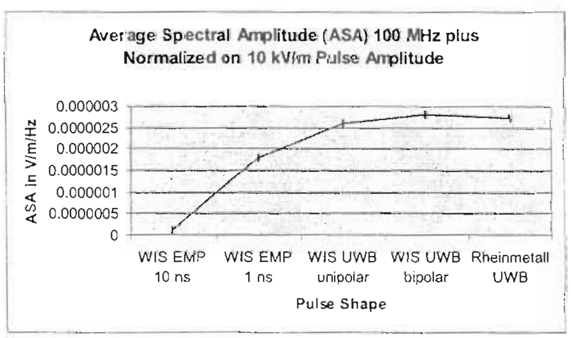


Figure 11a: Average spectral amplitudes of the pulses (10 kV/m amplitude)

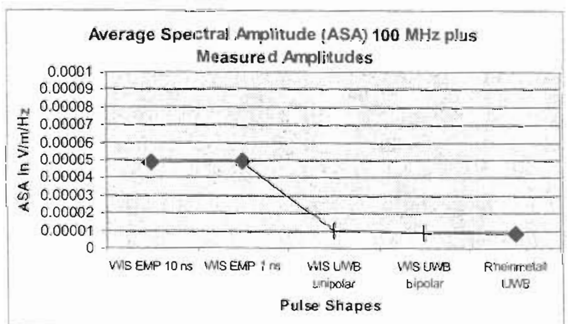


Figure 11b: Average spectral amplitudes of the pulses (threat level)

field strengths of the most effective HPM/cw signals and the most effective EMP/UWB pulses. Because all HPM signals had a high PRF the HPRF values for the EMP/UWB pulses were chosen for this comparison. For the HPM signals two cases were calculated: best case (SL values) and worst case (HL values). A HPM signal needs between 2 and 71 times the energy a UWB pulse needs to disrupt the MB Signal but only a factor of 0,03 to 0,45 of the field strength.

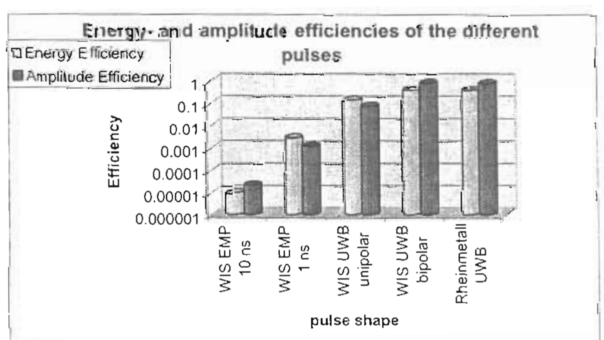
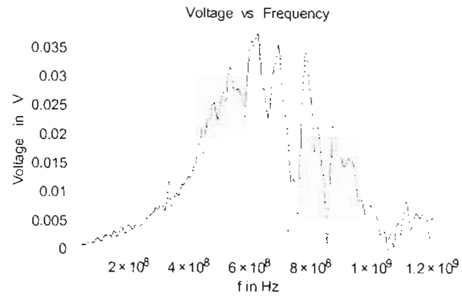


Figure 12: Comparison of the HPM and UWB pulses: Energy und Amplitude

COUPLING TO MORE COMPLEX STRUCTURES

For the comparison of the effectiveness of HPM and UWB pulses the SL to HL ratio of the HPM signals is of large importance. This ratio is based on the quality of the system transfer function peaks. To determine this quality for MB a generic MB was built at the WIS and the system transfer function of this system was measured at 10 different micro strip line outputs. . Figure 13 shows a picture and the system transfer function of the generic MB.
The quality Q of the system transfer function peaks compared to the lowest level of coupling is about 5 which very nicely describes the coupling behavior and η_{Freq} of the real MB ($\eta_{Freq} \approx \frac{1}{Q} = 0.2$). A quality this low is very rare in a metal enclosure like a PC. Figure 14 shows the system transfer function of a generic PC which was built at the WIS. Obviously it is much more difficult to match the HPM frequency to the peaks of the transfer function and the quality of the peaks is much higher than in the case of the MB so that η_{Freq} for systems with metal enclosures is going to be very low.



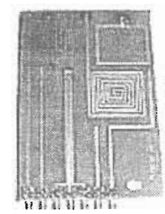


Figure 13: system transfer function and picture of the generic MB

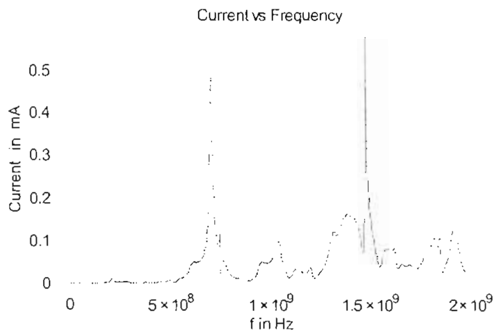


Figure 14: system transfer function of the generic PC

SUMMARY

In this paper the susceptibility levels of two MB were determined in five different test facilities. The susceptibility levels of the MB are in the range of some 100 V/m field strength (HPM) and a few kV/m (UWB). The coupling behavior and the disruption effectiveness of the EMP and UWB pulses was very well described via the energy- and amplitude efficiencies and the average spectral amplitudes. HPM signals need to have between 2 and 71 times the energy than an UWB pulse needs to disrupt the functionality of the MB but only a factor of 0,03 to 0,45 of the field strength.

[1] D. Nitsch, H. Friedhoff, J. Maack, F. Sabath, M. Camp, H. Garbe, *UWB and EMP Susceptibility of modern Microprocessor Boards*, EMC Europe 2000, Brügge (Belgium), September 11. – 15., 2000, pages 345 – 350

[2] M.Camp, H.Garbe, D.Nitsch, *UWB and EMP Susceptibility of Modern Electronics,* IEEE EMC, Montreal, August 13.-17., 2001, ISBN: 0-7803-6569-0, pages 1015-1020

[3] D. Nitsch, H. Friedhoff, J. Maack, F. Sabath, M. Camp, J.L. ter Haseborg, *UWB and EMP Susceptibility of modern Electronics*, EUROEM 2000, Edinbourgh (Schottland), Juni 2000, page 25

[4] C. E. Baum, *Norms of Time Domain Functions and Convolution Operators*, Mathematics Notes 86, Albuquerque, NM, USA, 1985