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Detection of transient disturbing signals on PC boards

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Abstract. This paper shows a possibility to visualize signal propagation in electronic circuits. Instead of using various galvanic measurement points all over the circuit, a test method is shown which measures the radiated field of the printed circuit board. By use of a 2-dimensional positionable field probe it is possible to get an overview over the signals running on the different parts of the PCB. In order to measure transient disturbing signals and distinguish them from normal device operation, problems of probe design and triggering need to be discussed.

1 Introduction

Against the background of Intentional EMI (IEMI) and the task to develop protecting strategies it is essential to know how a coupled-in signal is propagating on modern electronic systems. After years of research, protection technology for electronic circuits is developed in form of retrofittable electronic devices (Krzikalla and ter Haseborg, 2004). The devices are able to protect the electronics even against fast Ultra Wide Band (UWB) pulses.

As previous investigations show, the coupling paths of electromagnetic disturbances in an electronic system are all kinds of conductive structures in the system (Nitsch, 2005). The typical coupling frequencies of real electronic systems are located between several 10 MHz (f_1) and a few Gigahertz (f_2) (Camp, 2004). Under worst case conditions, a generic electronic device is penetrable on all its coupling dimensions as long as the disturbing signal has significant spectral density in the corresponding frequency range. Tracks leading signals, whose amplitude is high enough to disturb the device under test (DUT), are hard to predict. The only solution would be to implement wide band protecting devices at all pins of all chips. Under economic considerations this would be the worst solution and the retrofitting of existing boards is nearly impossible.

Fortunately, many real electronic circuits are embedded in a metal case. This case serves, if implemented properly, as a wideband electromagnetic shield against electromagnetic interferences. If we assume the case as a good shield in the given frequency domain, the protection solution can be limited to the ports of the device as shown in Fig. 1.

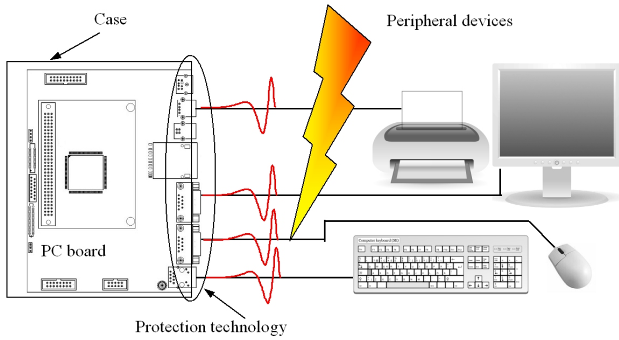

Fig. 1. Electronic system under IEMI threat.

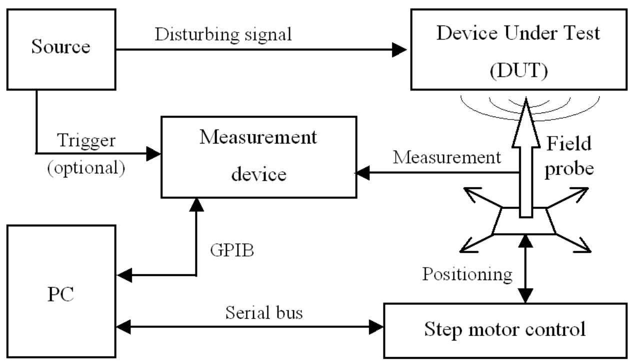

Fig. 2. Near field scan measurement system.

In order to perform an intelligent protection different aspects have to be taken into account:

– Which ports are susceptible to IEMI?

– Are there ports which are not susceptible to IEMI?

– How far gets the disturbing signal on the board?

– Are there unintended but useful filter effects on the system which hinder the disturbing signals to propagate?

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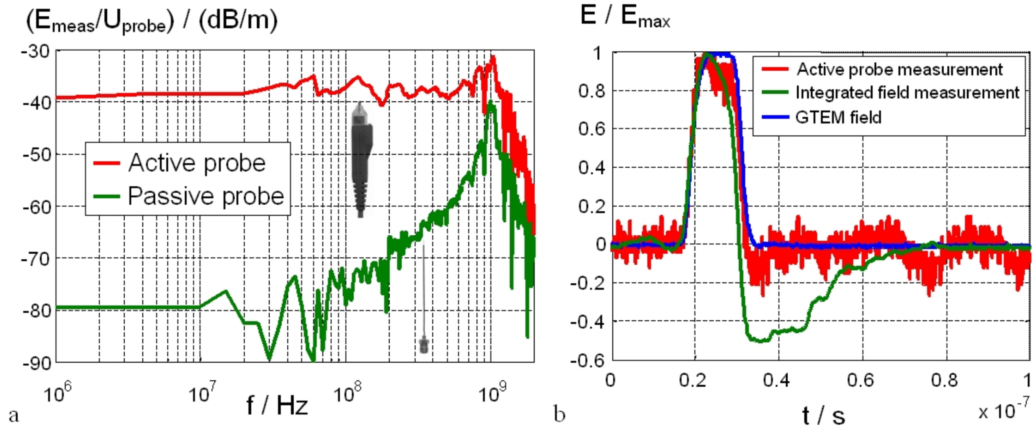

Fig. 3. Field probes: **(a)** transfer characteristics, **(b)** Philips PM5712 pulse measurements.

The classical approach to answer these questions would be the galvanic probe measurement at several points of the PCB. This would be sufficient for small board but for a normal PC board tens or hundreds of measurement points are needed. As a result, costs and efforts rise. Problems of galvanic probing at high frequencies like transfer resistance and signal loading by the probes input impedance appear. In order to perform cost-effective PCB measurements with minimum effort the idea was born to measure the inevitably radiated fields of the signals running on the board instead of direct galvanic probing. A suitable measurement system is presented in the next section.

2 Measurement system

A primary design goal of the presented measurement system was its ability to perform measurements of PCB boards without user interaction. Based on the fact that a complete PC board scan takes hours of measurement time it should work autonomously after definition of the scan area and discretization. Furthermore, the gained measurement results should be in an appropriate data format to perform comprehensive postprocessing when needed.

In order to meet these requirements, the test system presented in Fig. 2 was implemented. It consists of a signal source which is exposing the device under test with a repetitive disturbing signal. The radiated near field of the DUT is measured by an electric field probe at each discretization step. Probe design and test are discussed later. The field probe is positioned by a 2-dimensional manipulator beneath the DUT. With the step motor control the setup has a positioning accuracy of about 50 μm. The step motor communicates via serial bus with a PC. The field probe is connected to a measurement device whose memory is read out by the PC via GPIB bus. Time domain as well as frequency domain measurement devices could be implemented in the system. For the measurement of transients, a scope was used. In order to get time consistent data, the scope is triggered directly by the source. This procedure gives the possibility to determine propagation delays on the board. The PC provides a measurement software written in Matlab which performs all the communication and data acquisition. As requested, the user has to specify only the scan area and discretization and the system accomplishes all the measurements automatically. As the data format is Matlab raw data several additional postprocessing tools where implemented to visualize the measurements in graphs or even animated videos.

2.1 Field probes

Suitable field probes for the described measurement application can be either active or passive. Both types have been considered for the test system. The requirements for any suitable field probe are:

- Cut-off frequency is high enough for disturbance signal
- Probe dimensions are small enough to be positionable
- Probe head is as small as possible to get high discretization

As the source of the disturbing signal a Philips PM5712 is used. It generates a rectangular pulse with a risetime of t_r=4 ns. The pulse length is variable between 10 ns and 10 μs. The highest frequencies are generated at about 700 MHz.

The two investigated probes and their transfer characteristics, measured in a GTEM cell, are shown in Fig. 3a.

2.1.1 Passive probe

The passive probe is a semirigid cable with bared inner conductor. The implementation of these simple monopole probes is sufficiently described in (Baudry and Mazari, 2006)

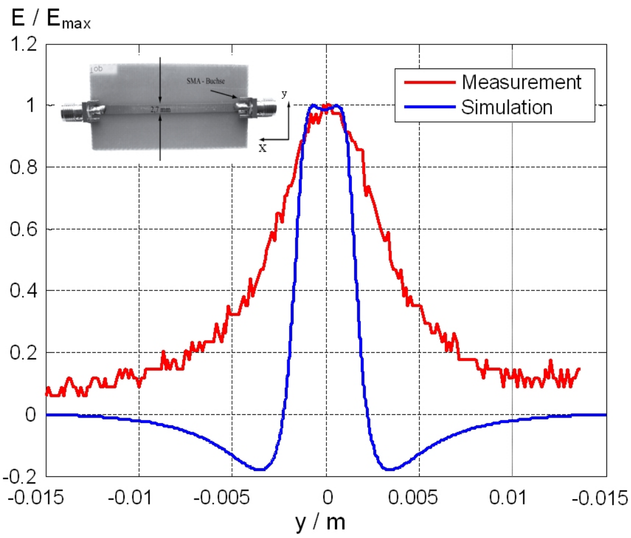

Fig. 4. Microstrip line measurement and simulation.

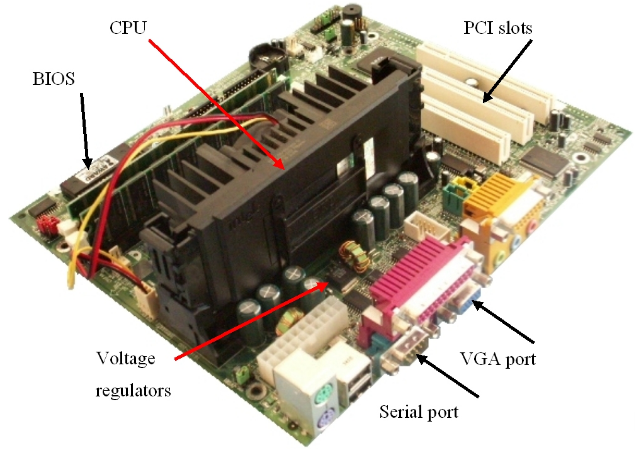

Fig. 5. Pentium III PC board 1.

and (Gao, 1998). As one can see it has directly under cutoff a nearly linear rise with increasing frequency. The transfer characterristic can here be assumed as nearly differential.

For the requested measurement in time domain a post-processing of the measurement data would be necessary. The first theoretical approach would be to perform a Fourier Transform of the data, divide it by the probes transfer characteristic and accomplish an Inverse Fourier Transform to get the field form without probe influence. In praxis, this procedure leads to no satisfying results. Due to the high damping coefficient at lower frequencies and the lack of the transfer characteristic beneath the lowest measured frequency, mathematical instabilities occur. A better solution is the direct mathematical integration in time domain by adding up the multiplication of signal and sampling time for each time step. Figure 3b shows that the gained results are nevertheless unsatisfactory compared to the direct measurement.

2.1.2 Active probe

The active probe is a Tektronix P6245, a high input impedance device which is normally used for contact measurements up to 1 GHz. As the devices transfer characteristic is nearly constant in the interesting frequency domain, the electric field amplitude can be calculated by simple multiplication with a proportional factor. Figure 3b shows that this probe is far more suitable for the given measurement problem.

Overall, the active probe has proven to be an adequate solution for the near field scan system. Besides the proportional transfer characteristic in the interesting frequency domain, it features also a higher gain as can be derived from Fig. 3a. Furthermore, the numerical effort is far less, a fact that should not be disregarded against the background that a complete PC board scan consists of up to 20 000 single measurements in time domain (ATX board, discretization 2 mm).

2.2 Probe calibration and discretization

After the choice of a proportional probe, the proportionality factor A has to be determined. There are three general possibilities:

- measurement in a known electromagnetic field
  => $A = E_{\text{meas}}/U_{\text{probe}}$
- comparison between the simulated and measured field of a well defined structure
  => $A = E_{\text{sim}}/U_{\text{probe}}$
- calculation of the field of a simple structure (e.g. an unscreened conductor)
  => $A = E_{\text{calc}}/U_{\text{probe}}$

For the calibration of the active probe described above, the first two possibilities where considered. The antenna factor A can be directly derived from Fig. 3a to A=-38 dB. A simulation of an implemented test board with a 50 Ohms microstrip line by the use of FEM showed the same result.

After being able to measure the field of a PCB correctly in the given frequency domain, it is essential to know how exact the system can distinguish between several PCB lines. Figure 4 compares the FEM simulation with the field probe measurement orthogonal to the stripline at a distance of 1 mm. The measurement doesn't map the exact field shape across the microstrip line. The negative peaks cannot be determined and the field profile is broader due to the integration of the probe over its surface. The maximum field strengths match exactly as expected from calibration. At a distance of 2 mm from the middle of the stripline the measured amplitude is fallen to 80% of E_{max}. This can be assumed as the maximum applicable discretization. With a further discetization increase adjacent lines couldn't be distinguished any more.

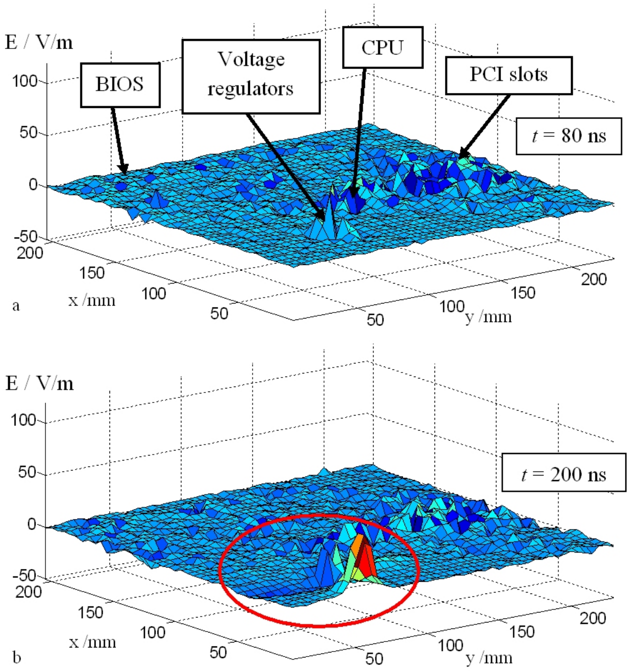

Fig. 6. PC board scan (discretization 5 mm).

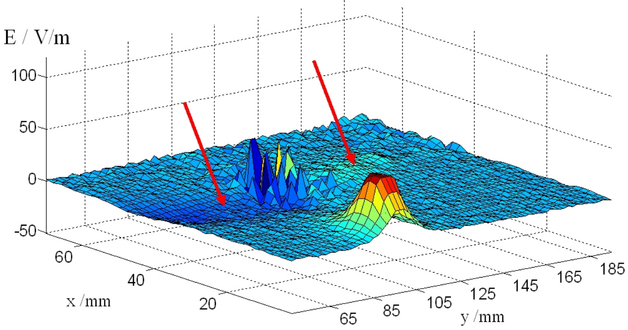

Fig. 7. Details from Fig. 6b (discretization 2mm).

2.3 Triggering

In order to perform measurements in the time domain, a trigger signal for the scope is necessary. As the measurement task is to visualize a transient signal propagation on the board, a trigger event should be derived from the pulse itself. Three scenarios are possible:

– second field probe at transient input of DUT

– galvanic probing at transient input of DUT

– direct signal from feeding source

The first two solutions could detect a superposition of the disturbances with the PCBs operational signals which leads to trigger instabilities. Consequently, the trigger signal is directly derived from the feeding source. Apart from that, the use of a galvanic probe directly on the PCB is a possibility to determine the operational signals and their distribution on the board. Thus, the system can also be used for signal integrity measurements and failure detection on electronic circuits.

3 Measurement results

With the presented measurement system the transient propagation on two PC motherboards was tested. One of these Pentium III boards is shown in Fig. 5. With the serial and the VGA port one bi-directional and one output port where chosen as to be disturbed. The device is exposed during normal operation in the BIOS setup. Only the power supply and the disturbance signal where connected. During serial port exposure, a TFT was additionally installed on the VGA port.

3.1 EMI Noise Floor

Figure 6 shows two measurements at different time steps during serial bus exposure. Under normal operating conditions without disturbance, the board radiates its EMI fields as can be seen in Fig. 6a. The CPU and the PCI slots can be made out easily. The worst EMI source is the region between the ports and the CPU slot (compare to Fig. 5) where are located the voltage regulators. As these devices are switching permanently, the radiated field is very high. Other board devices and structures show comparably low radiation. If an animated video is created during post-processing, one can see that the EMI fields are uncorrelated with the trigger events derived from the disturbing signal.

3.2 Transient measurement

If the pulse from Fig. 3b is applied to the serial port of the PCB, the radiation pattern of Fig. 6b can be measured at the time of maximum pulse amplitude. An increase of the PCBs near field can be measured in the vicinity of the port. A further look on the interesting region with a highly discretized measurement (Fig. 7) shows left- and right-handed to the voltage regulators a field decrease (left) and increase (right). These effects are directly correlated to the disturbance. Any uncorrelated signal would have been averaged over the measurement points to a noise floor comparable to the EMI fields in Fig. 6a.

A measurement of the exposure of the VGA port has also been accomplished but lead to no results. The measurement showed only the EMI noise floor of Fig. 6a. This port is far less susceptible to the transient disturbance signal. The conclusion that bi-directional ports are more susceptible than output-only ports matches with former investigations (Camp, 2004).

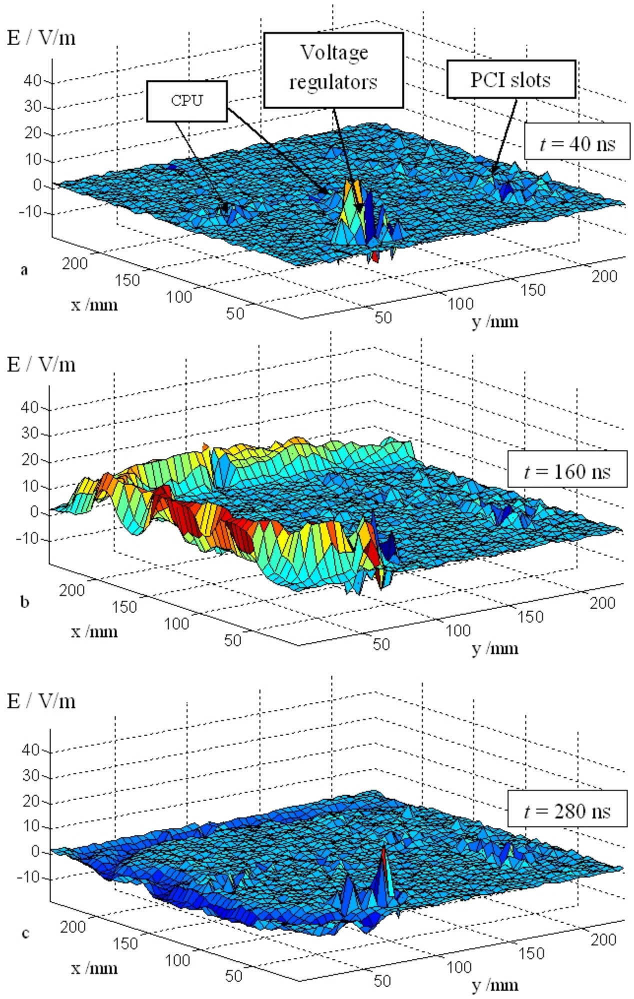

Fig. 8. Transient signal propagation and resonances.

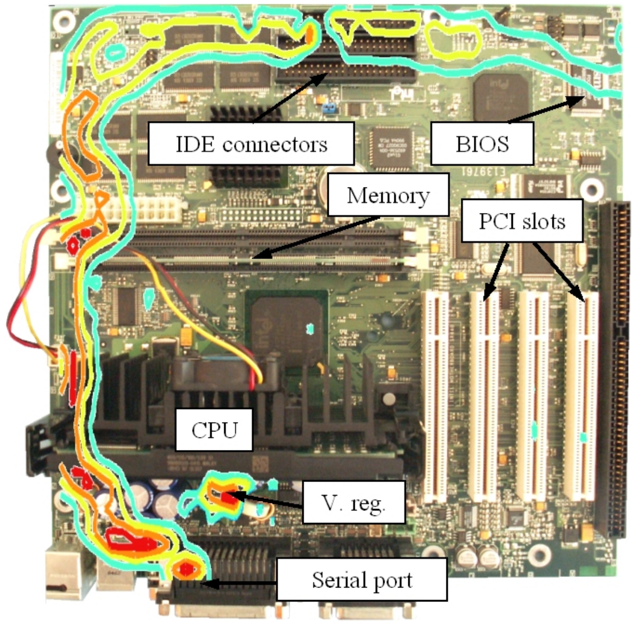

Fig. 9. Endangered parts of a PC motherboard.

3.3 Transient signal propagation and resonances

Because the measurements presented above showed only slight effects in the near vicinity of the exposed port, another PC board with the same processor was investigated. Selected near field radiation patterns are presented in Fig. 8.

Due to the fact that the construction of the two boards is very similar, the EMI noise floor (Fig. 8a) is nearly the same. Again, EMI sources like CPU, PCI slots and voltage regulators could be estimated. Also on this board, the voltage regulators radiate the highest EMI fields.

The serial port exposure shows in contrast a complete different behavior (see Fig. 8b and Fig. 8c). At the timestep of the highest pulse amplitude (Fig. 8b), the distribution of the transient is not limited to the vicinity of the port. It runs in a wide arc over essential parts on the edge of the board. Several timesteps later a decrease of the field strength is detectable on the same parts of the motherboard. The pulse was reflected on the far side of the PCB (Fig. 8c).

For the estimation of the disturbing potential of this effect it is essential to know which parts and integrated devices are affected by the propagated disturbance. In order to obtain this knowledge, Fig. 8b was converted into a contour plot. Figure 9 shows its superposition with the boards picture. This method visualizes that the pulse is running from the serial port via the edge of the CPU and memory slots to the BIOS. On its way, the IDE ports are also affected by the disturbance. A further propagation to the connected hard disks is probable.

An exposure of the VGA port has also been carried out. The results are similar to those presented above. The VGA port is again very less susceptible.

4 Conclusions

It is shown that the use of a 2-dimensional near field scanner is a good possibility to visualize the propagation of an arbitrary signal on a printed circuit board. Instead of extended galvanic probing, it is suitable to measure the radiated field of the PCB lines.

For the design of the measurement system the spectral distribution of the signal has to be taken into account. For the probe design, the probes dimensions have to be considered in order to get a high discretization. The use of non-proportional probes is not recommended due to the high numerical expense for thousands of measurement points.

Intelligent triggering gives the opportunity to accomplish several different measurement tasks. Dependent on the trigger source it is possible to realize transient signal propagation measurements as well as EMI or noise detection. Even failure measurements on PCBs can be carried out.

The accomplished measurements show that the propagation of a transient disturbance on a PC motherboard, coupled via the ports and connectors only, depends on the design of the board itself. While on one of the boards the disturbing signal is damped near the input ports, the other shows a propagation over wide parts of the PCB. As a consequence, basic functional parts (CPU, memory, etc.) of a modern PC board can be affected by the disturbance without direct coupling into the board itself. Even other devices (e.g. hard disks), which are connected to the board, could be disturbed.

The presented setup and the measurements are part of the study “Protection of Electronic Systems against Electromagnetic Sources”, commissioned by the Armed Forces Scientific Institute for Protection Technologies – NBC-Protection (Munster, Germany).

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