Design and Setup of an UWB Simulator for Susceptibility Investigations

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ABSTRACT

For an investigation of the effects short pulses have on modern electronic systems the generation of a fast transient field with high magnitude is necessary. In many cases the design of the simulator is checked in an intermediate field pre test. In this paper a fast transient simulator is presented and the results of intermediate field scans are compared with values of an antenna scan under far field conditions. We will show, that due to near field effects for a design check under intermediate field conditions the pulse duration is a more appropriate measure for the main beam direction than the maximum peak electric field.

INTRODUCTION

Electronic components and subsystems (e.g. microprocessor boards) are essential parts of modern civilian and military systems like airplanes, communications, traffic management or safety systems. A setup or failure in these systems could cause a major accident or economic disaster. Therefore the susceptibility of modern electronic systems to fast transient fields like EMP and UWB pulses is of great interest. For the investigation of the effects of short pulses on modern electronic systems the generation of a fast transient field with high magnitude is a necessary part. An UWB simulator should be able to illuminate the whole cross section of the target system with a electromagnetic field pulse with an amplitude of more than 5 kV/m and a rise time of less than 500 ps. Because ordinary wide band antennas are not able to radiate high magnitude pulses with an extreme short width due to their dispersion, short pulse systems are in need of special pulse radiating antennas. There are several antenna designs (e. g. reflector IRA or TEM horn antennas) available for pulse radiating applications.

In this paper the setup of a short pulse simulator system for susceptibility investigations is presented. The system consists of a reflector type IRA driven by a high voltage pulser with a rise time of less than 500 ps and an output voltage higher than 100 kV. To achieve the required pulse shape we have used a dielectric lens to transform the plane wave inside the coaxial system into a spherical wave launched at the feed. The objective of the paper is to compare the results of a transient intermediate field scan with values of a field scan performed under far field conditions. We will be shown, that due to near field effects an intermediate field scan of the pulse parameters results in a significant failure. Particularly in the intermediate field the direction of the maximum pulse amplitude differs from the estimated main beam direction. In contrast the direction of the shortest pulse duration agrees quite good with the estimated main beam direction. Under far field conditions both the shortest pulse duration and the maximum peak value identify the main beam. But due to near field effects we found that for a design check under intermediate field conditions the pulse duration is a much better measure for the main beam direction than the maximum peak electric field.

CONSTRUCTION DETAILS

In order to generate high voltage pulses with voltage amplitudes of several 100 kV`s two major technologies are known: Marx Generators, and Tesla Transformers. We began our investigations with a 6 stage Marx Generator with an output voltage of 150 kV and changed to the Tesla Transformer technology for the following reasons: compact size, low input voltage on primary side, low energy requirements of the pulser, capability to operate better on higher repetition rates. Especially the low energy requirements for the generation of UWB pulses with rise times < 500 ps and pulse widths < 1 ns are giving the Tesla Transformer an advantage over the Marx Generator. Our source system generates an output voltage well above 100 kV out of an input voltage of less than 5 kV.

The generation of pulse rise times of less than 500 ps at pulse amplitudes above 100 kV via gas or oil discharge is usually done by fast overcharging of a spark gap. Because of the fact, that a fast overcharging leads to a much higher voltage across the gap than a slow charging, there is a higher electrical field strength inside the gaps. By using several gaps in series, the leading edge of the pulse can be sharpened. We designed a pulse forming system consisting of three sections, a charging line, a pulse line, and a load line for basic investigations (Fig 1). Each line is separated from the other by a discharge gap. At the last gap the electrical field strength between the electrodes can be higher than 1 MV/cm before the spark is ignited. Each line is designed as a 50 Ω pulse line of a certain length. In each line a capacitive voltage probe is placed to measure the voltage. The system is designed to operate at pressures up to 20 bar.

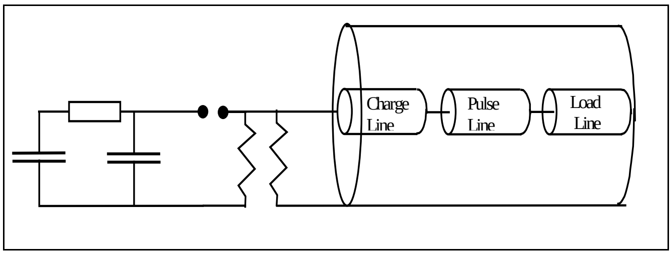

Fig. 1: Tesla Transformer and pulse forming system

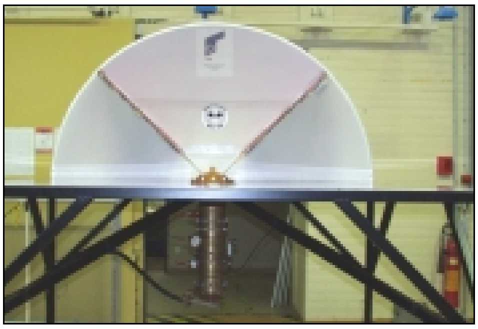

Fig. 2: Half IRA with the compact gas switch UWB pulser

For our simulator we used a reflector type IRA design consisting of a parabolic reflector with a diameter of D = 1.8 m and a focus length of F = 0.755 m. In order to minimize the disturbance of the radiated field by the large pulser system, the antenna was built as a half IRA [3]. The half IRA design operates with one half of the antenna and we used a metal plate, at the horizontal symmetry plane, as a mirror for the electromagnetic field and for the electromagnetic decoupling of the space below and above the metal plate. The antenna is fed by a 50 Ω TEM feed consisting of two triangular metallic plates.

The most complicated part of the antenna design is the adaptation between the coaxial source system and the feed of the antenna. Usually, one would want to keep this region electrically small, but the high voltage denies this possibility. In order to solve the problem we inserted a feed point lens at the connection between the source and the beginning of the feed arms. The effect of the lens is that it's converts the plane wave inside the coaxial source system to a spherical wave launched onto the feed arms. The focus of the spherical wave is on the ground plane, matching the focus of the parabolic reflector. The dielectric constant $\varepsilon_r = 3.18$ of the plastic used in the source system requires a minimum dielectric constant of $\varepsilon_r = 5.5$ for the lens material. With respect to a low budget realization we made the lens out of deionized water, covered by a plastic cap.

RESULTS

Before the UWB Simulator can be used for susceptibility investigations the qualification of the design an the set up is an important task. Referring to the availability of open area test sites or large anechoic chambers the design of field simulators is often checked with a pre field scan under near or intermediate field conditions. The main objectives of the pre test are the identification of the main beam direction and the measurement of the beam width. These measurements are based on the assumption that only the behaviour of the field strength is influenced by unwanted near field effects. In order to stress the advantages and the applicability of the intermediate field results as a basis to predict the far field performance we consider antenna scans of the presented UWB simulator under both intermediate and far field conditions.

We start the investigations on the performance of the UWB simulator with intermediate field measurements at a observing distance of R = 11 m. In order to divide near field effects from measurement problems we calculate the electric field using a TEM-based analytical model. The calculated and measured peak electric field values in the vertical plane are plotted in Fig. 3 as a function of the direction angle. Measurement points below the level of the metallic plate are indicated by negative direction angles $\varphi_v < 0°$. Due to the blockage effect of the metallic plate a step of the curve can be observed at $\varphi_v = 0°$. The comparison of both curves demonstrates a good agreement of the maximal radiation but one can observe a shift of 5° of the related direction angle. In a superficial interpretation one could identify the angles of the maximal radiated field as the direction of the main beam and therefore the shift as a unwanted design failure. But in the far field the main beam is indicated by both the maximum pulse amplitude and the minimal pulse width. If we consider the pulse duration (Fig. 4) there is just a small deviation between the calculated and the measured values. The deviation will be acceptable, if we take into consideration that the bandwidth of the measurement set up influences pulses with an pulse width shorter than 0.8 ns and results to a lower limit of the measured pulse width of 0.44 ns. It can be noticed that there are only a 1° difference between the calculated and the measured direction of the shortest pulse width. We found that the reason for this small deviation are reflections on the finite metallic plane which are not taken into consideration by the used model.

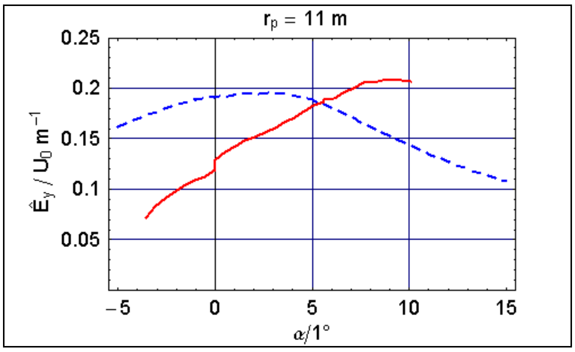

Fig. 3: Peak electric field in the vertical plan (solid: measured, dashed: predicted)

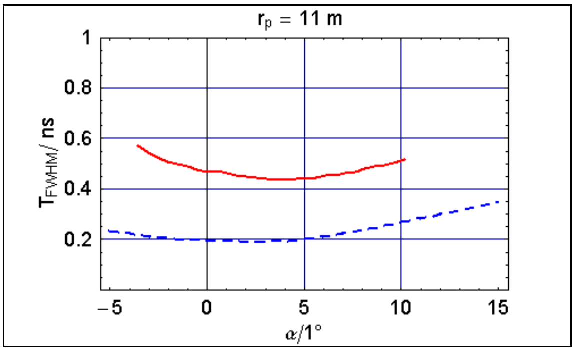

Fig. 4: Pulse width as a function of the direction angle in the vertical plane (solid: measured, dashed: predicted)

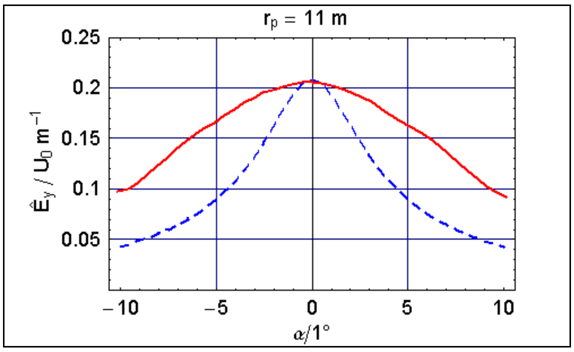

Fig. 5: Peak electric field in the horizontal plan (solid: measured, dashed: predicted)

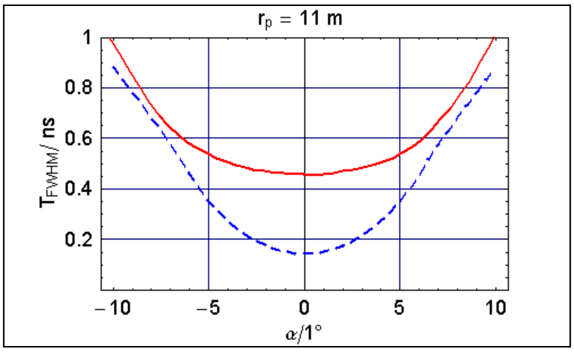

Fig. 6: Pulse width as a function of the direction angle in the horizontal plane (solid: measured, dashed: predicted)

The values of the scan in the horizontal plane are shown in Figure 5 (peak electric field) and Figure 6 (pulse duration). Due to the symmetry of the antenna design the horizontal scans giving symmetric values with respect to $\varphi_h = 0°$. As calculated the maximum peak electric field strength and the shortest pulse duration are occurring at $\varphi_h = 0°$. The deviation of the peak values of the electric field are caused by scattering of the field at the relatively large feed arms of the UWB simulator.

Following the intermediate field considerations we investigated the far field radiation pattern of the UWB simulator. We achieved an excellent agreement between the calculated and measured values of the vertical and horizontal antenna scans in a distance of 50 m. As an example the calculated vertical antenna scan is shown in Fig. 7 (pulse amplitude) and Fig. 8 (pulse width). The main beam lobe angle defined by both the shortest pulse and the strongest field is at 0.6°. The beam width in both directions is similar to the beam width of the intermediate scans. Due to the near field dispersion described in [5] the pulse width decreases to the rise time of the feeding voltage signal of 0.15 ns as expected. The far field radiation factor can be determined to $r_p \bullet E_{max} / U_0 = 3$.

The characteristic parameters of the UWB simulator (measured and calculated) are given in Tab. 1. With the exception of the highest peak field direction there are good agreements between the antenna scans under intermediate and far field conditions. Particularly the beam width and the direction of the shortest pulse of the intermediate field considerations are appropriate values for the prediction of the far field radiation behavior.

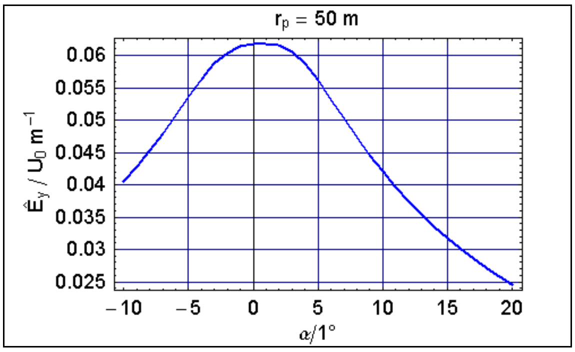

Fig. 7: Computed pulse amplitude at r_p =50 m (far field)

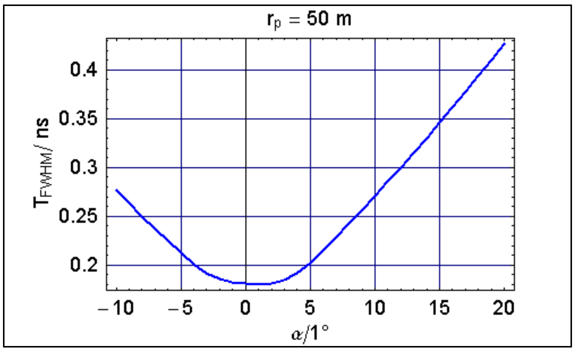

Fig. 8: Computed Pulse width at r_p =50 m (far field)

Table 1: Performance of the UWB Simulator

	Vertical			Horizontal		
	Measured r_p = 11 m	Calculated r_p = 11m	Calculated r_p = 50 m	Measured r_p = 11 m	Calculated r_p = 11m	Calculated r_p = 50 m
Direction of max. peak field	8°	3°	0.6°	0°	0°	0°
Spot size (50 % voltage)	±9°	±9°	±11°	±10°	±4°	±4°
Transfer factor (E_{max} / $U_0\, m^{-1}$)	0.22	0.20	0.06	0.21	0.21	0.06
Direction of min. T_{FWHM}	4°	3°	0,6°	0°	0°	0°
min. T_{FWHM}	0.45 ns	0.19 ns	0.15 ns	0.45 ns	0.19 ns	0.15 ns

CONCLUSION

In this paper we have considered the impact of near field effects on antenna scans in both the vertical and the horizontal plane of a half IRA. The comparison of measured and calculated antenna scans under both intermediate and far field conditions shows that the pulse amplitude based field scan fails in the intermediate field. Particularly the direction of the highest amplitude differs from the main beam direction due to underestimated near field effects. In contrast to the pulse magnitude other pulse parameters like the rise time or the pulse width are less influenced by the near field effects. Summarizing one can notice that a design qualification under near or intermediate field conditions should use the pulse width only.

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