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Linear and nonlinear filters under high power microwave conditions

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Abstract. The development of protection circuits against a variety of electromagnetic disturbances is important to assure the immunity of an electronic system. In this paper the behavior of linear and nonlinear filters is measured and simulated with high power microwave (HPM) signals to achieve a comprehensive protection against different high power electromagnetic (HPEM) threats.

1 Introduction

For the guarantee of the reliable functionality of electronic systems also under difficult electromagnetic conditions new adapted protection concepts are necessary. The disturbance or even destruction of electronic systems in civil or military applications by man-made intentional electromagnetic interferences (IEMI) can lead to high costs or endanger human life in the worst case. The investigation of the behavior of different protective circuits against different high power electromagnetic- (HPEM-) signals (e.g. ultra wideband- (UWB-) and high power microwave- (HPM-) pulses) is of special interest. Due to the high amplitudes and interference spectra with frequencies within the GHz range, these interferences represent a large threat. For the protection against line-bounded UWB pulses the behavior of different linear and nonlinear filters and protection elements has been tested and simulated in preceding contributions (Weber et al., 2004; Weber, 2004). Very fast suppressor diodes with extremely small parasitic capacities and linear bandpass filters in micro strip technique have shown promising results. Nonlinear protection elements have not shown any or only small effect against high frequency line-bounded CW-signals contrariwise, since the response times of the elements are still too large (Brauer et al., 2008).

For the development of a comprehensive protection concept against HPEM disturbances the behavior of the described linear and nonlinear filters is to be tested and evaluated also against HPM pulses within this investigation. The discussion and evaluation of the measurement results consider the energy reduction of the line-bounded coupled pulse, as well as the maximum peak pulse power of the used protection circuits.

The validation of simulation models under HPM conditions is also taken into account. Nonlinear protection elements are simulated in SPICE and linear filters are simulated in Agilent's Advanced Design System (ADS) up to several GHz. As it is challenging to take all parasitic effects of the protection elements into account, the models and simulations are verified by improved measurements in time and frequency domain.

2 Protection concepts and simulation models

In previous contributions different linear and nonlinear filters have been examined under UWB conditions. For HPEM hardening these elements have to be investigated also with HPM-signals. In this case it is difficult to predict the behavior of the protection devices, because of the large radiated power in the RF-region. Linear filters may show nonlinear effects, while nonlinear elements, like fast suppressor diodes, can reach the upper limit of the load capacity.

In this work a highpass filter and a bandpass filter in microstrip technique as well as a varistor and a suppressor diode in SMD casing are taken into account. The test boards with the mounted filters and the technical specifications are shown in Fig. 1.

During the development and the evaluation of protection concepts, the prediction of the behavior with the help of simulations plays a decisive role. The development of linear filters in microstrip technique can be done with the design tool Advanced Design System (ADS). An optimization as well as a simulation in frequency and time domain is possible. Figure 2 shows the simulated and measured insertion loss of the highpass and the bandpass in the frequency domain.

In the case of nonlinear elements analog behavior models (ABM) in SPICE are used. These models are based

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Varistor	
Identification	VC06LC18X500
Clamping voltage	50 V
Suppressor diode	
Identification	GBLC05C
Clamping voltage	9.8 V
Highpass	
Corner frequency	f_G = 920 MHz
Attenuation	20 dB max.
Bandpass	
Center frequency	f_0 = 2.45 GHz
Bandwidth	Δf = 200 MHz

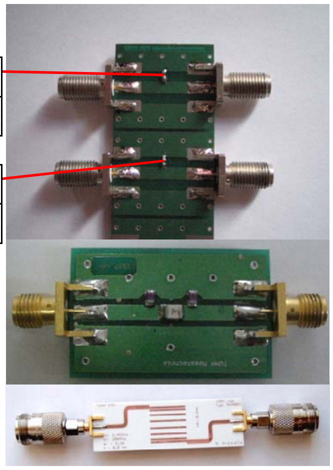

Fig. 1. Investigated protection elements with technical specifications.

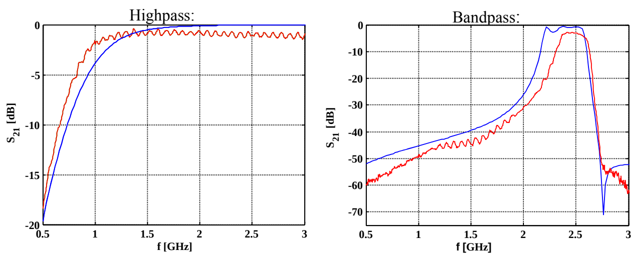

Fig. 2. Simulated (blue) and measured (red) insertion loss of the linear filters.

on measurements and more accurate than the models of the manufacturer in most cases. The limitation to frequencies smaller 1 GHz is a huge drawback. Apart from that ABM models have shown promising results under UWB conditions (Brauer and ter Haseborg, 2008).

3 Protection devices under real HPM-conditions

The described elements are investigated under real HPM conditions, i.e. that the devices are stressed by an interference signal coming from a HPM source coupled into a line. The results are compared and evaluated with simulated signals in SPICE.

3.1 Measurement and simulation setup

The only national HPM test facility is located at the Armed Forces Research Institute For Protective Technologies in Munster Germany. The following measurements have been accomplished inside this facility. The schematic measurement setup is shown in Fig. 3. A PCB board with coplanar microstrip lines with different lengths and terminations is used as coupling structure inside the anechoic chamber. The

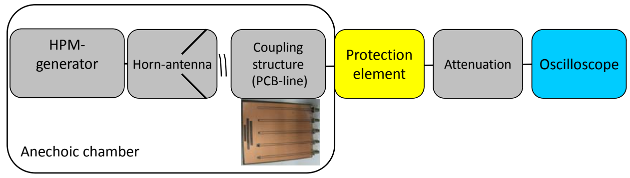

Fig. 3. Schematic setup for the generation of coupled HPM signals.

HPM source has a radiated pulse power of some 100 MW, whereas the center frequency has been chosen to the range of 650–800 MHz. With a peak field strength of approx. 23 kV/m and under worst case conditions (12.5-cm-PCB lines in parallel to the E-field) a voltage of approx. 250 V at a typical IC input/output (resistor and capacitance in parallel) can be measured. The protection test boards are connected to the test lines outside the test facility and the resulting signal is measured with an oscilloscope.

The SPICE setup contains a source, attenuation and the protection element. The source can be directly loaded by the data files from the measured coupling signal inside the anechoic chamber without any protection in the setup. The attenuation can be adjusted to any value, which is needed to emulate the damping factor of the cables in the measurement setup. The ABM model is a single part, which represents the whole behavior of the protection element, which is terminated by a 50-Ω-load.

3.2 Evaluation of the results

Figure 4 shows the simulated and measured signal with and without the nonlinear protection elements. The measured HPM pulse is not predictable and reproducible, determined by the pulse generator. The delivered pulse is damped with approx. 17 dB for both elements. For different amplitudes the varistor shows the same damping behavior, as the suppressor diode only attenuates for voltage level over 10 V approx., which has also been assessed in Brauer and ter Haseborg (2008). The simulation and measurements are not corresponding, which leads to a constraint of the ABM models.

Figure 5 shows the results for the linear filters. The typical damping ratio can be observed as well as the difference between measurement and simulation, as observed in the determination of the insertion loss in Fig. 2.

All filters have also been placed inside the anechoic chamber. A completely different performance has been determined, as the pulse couples also into the filter structure. Nonlinear effects cannot be excluded in this case, although none of the filters have been destructed.

4 Emulated HPM signals in the laboratory

The emulation of coupled and line-bounded HPM-signals in a laboratory is simplifying the further investigations of

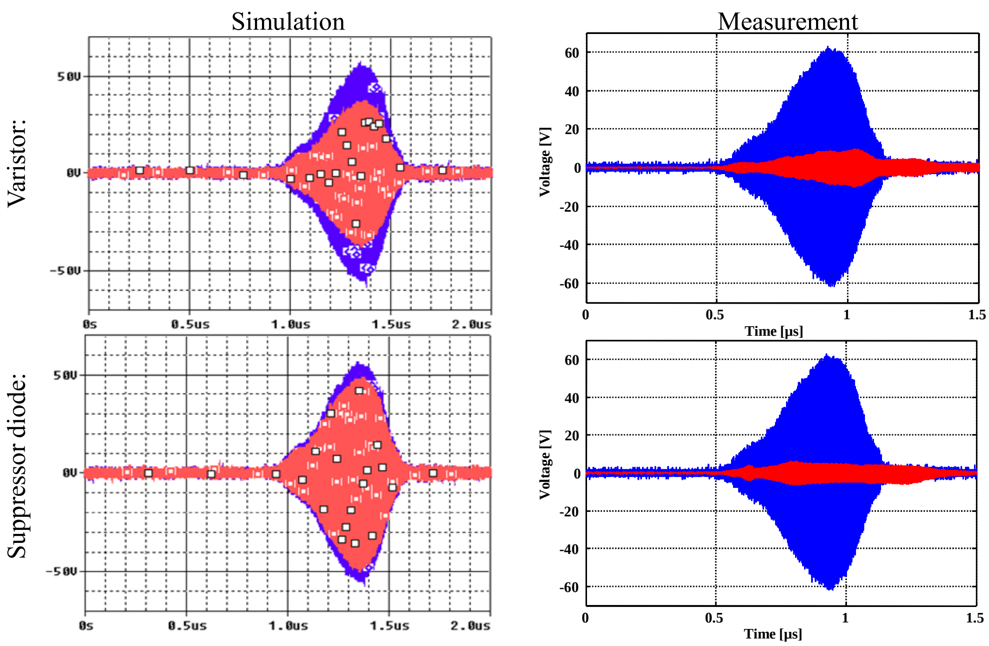

Fig. 4. Simulation and measurement results without (blue) and with nonlinear filters (red) with coupled 715-MHz-HPM signals.

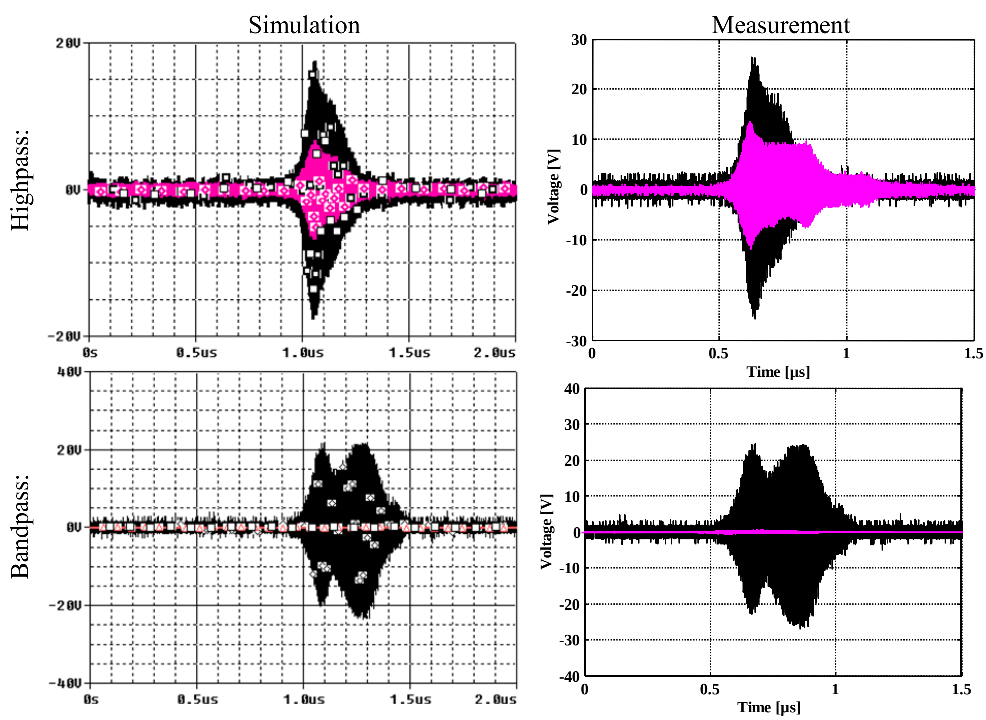

Fig. 5. Simulation and measurement results without (black) and with linear filters (magenta) with coupled 715-MHz-HPM signals.

different protection elements. The setup which is used for this purpose is shown in Fig. 6. A RF-switch is used to modulate the RF-signal delivered from a signal generator. The switch is controlled by an arbitrary function generator, where the pulse rise time and duration can be adjusted. The different protection circuits are stressed by the obtained signal after a maximum amplification of approx. 53 dB.

In case of the simulation in SPICE and ADS the HPM source is now built up in a similar way. A sinusoidal source with specific frequency and amplitude is modulated by a

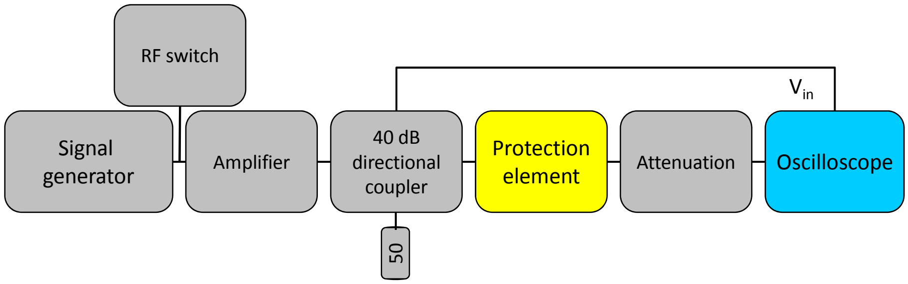

Fig. 6. Schematic setup for the generation of emulated HPM signals.

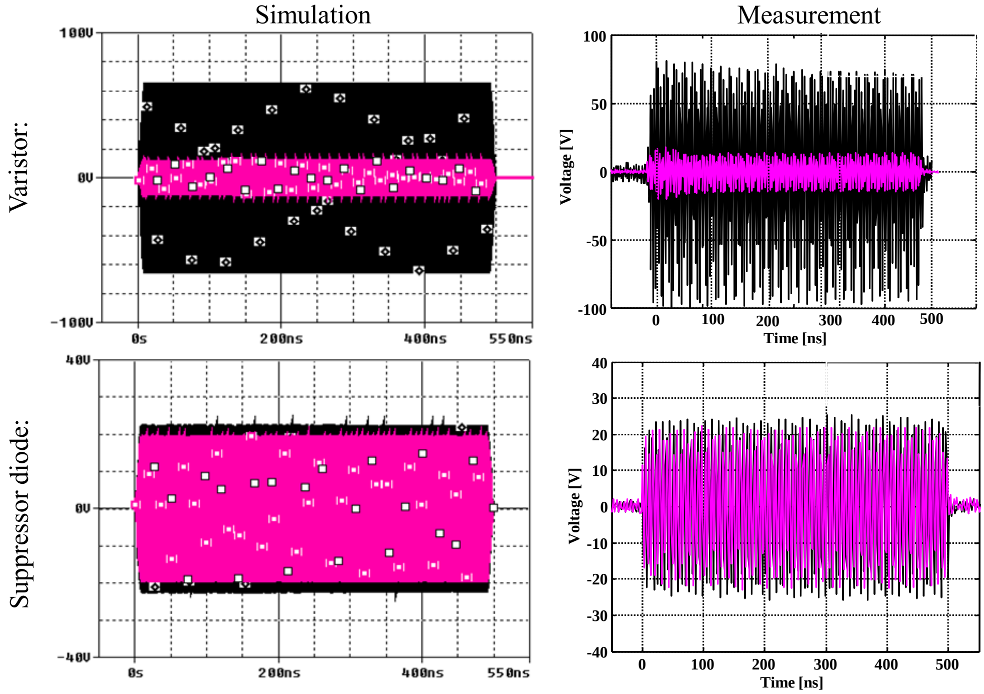

Fig. 7. Simulation and measurement results without (black) and with nonlinear filters (magenta) with emulated 715-MHz-HPM signals.

second source with specific rise time and pulse duration. Figure 7 shows the measurement and simulation results. The varistor shows the same attenuation as under real HPM conditions. The suppressor diode shows merely no attenuation for smaller signals, which corresponds to the nonlinear behavior of the element. On the other hand it can be seen, that the correspondence between the simulation and measurement results is much better than in the case of real HPM signals.

With the help of the described setups the parameters of the HPM disturbance signal can be adjusted to any required value only restricted by the measurement equipment. Especially the amplitude of the pulse is limited by the amplifier and does not reach the required amplitudes. A linear coupling behavior in case of radiated HPM signals is an important assumption to apply this method.

The setup is also useful to determine the maximum peak pulse power of the elements. At a maximum pulse power of 47 dBm and pulse duration of 500 ns none of the filters have been damaged. With CW signals the upper limit of input power for the suppressor diode is approx. 26 dBm, during the varistor and the highpass are destructed at 34 dBm. The bandpass show no sensibility up to 47 dBm.

5 Conclusions

In this contribution different protection elements have been tested and evaluated under HPM conditions. Up to 800 MHz a nonlinear behavior for fast suppressor diodes and a sufficient damping of nonlinear and linear elements can be seen. For higher amplitudes and at higher frequencies the protection capability is not sufficient. Also the ABM models in

SPICE do not reflect the specific behavior of the nonlinear elements. This leads to a need for new protection concepts against HPM pulses and simulation models in the GHz-range.

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