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Validation of the D-dot probe for HPEM pulsed electromagnetic field measurements

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Abstract

The article concerns the problems of high-energy electromagnetic environment. The article characterizes the high-power electromagnetic pulse and discusses the position for generating such impulses and the station for their measurements. The main attention was devoted to the D-dot measuring probes for measuring the pulsed electromagnetic field. Additionally, this article presents a method for validation of D-dot probe using HPM pulses.

1. Introduction

In recent years, we have seen increased interest in the High Power Electromagnetic Environment (HPEM), especially the production of high power impulse electromagnetic fields and their impact on electronics. In an environment of high power electromagnetic microwave source is a relatively new kind of risks, both for military systems, and civilian systems. Operation using this type of source is generally referred to as intentional electromagnetic disturbance. HPEM (High Power Electromagnetic) radiated environment, which is naturally harmful, can also occur at frequencies up to several tens megahertz. Technological developments within the area of high-power microwaves have made it possible to produce more powerful microwave sources for illuminating large operational installations. At the same time, it is possible to generate relatively strong fields with compact systems that can be contained, for example, in a briefcase [1, 2].
The potential threat from HPM has increased. If an HPM system is fielded by a North Atlantic Treaty Organization (NATO) country, there may be a need to harden co-located friendly systems against the fields produced. However, the actual threat that may exist from friendly or hostile sources in any particular scenario has not yet been fully defined by any NATO nation. The information provided below is therefore general and unclassified. National Authorities should be consulted to determine if an HPM environment needs to be specified for any particular system or equipment [3].
While the effects of other high power electromagnetics environment like LEMP (lightning electromagnetic pulse) and NEMP (nuclear electromagnetic pulse) have been tested and measurement in the past and characteristics are readily available, HPM is a comparatively new research area [3].

The power of radiated HPM sources ranges from kilowatts to gigawatts (peak). In general, the frequency ranges from tens of MHz up to several GHz. Figure 1 represents a frequency relation between LEMP, NEMP and HPM sources adapted from IEC 61000-2-13 [3].

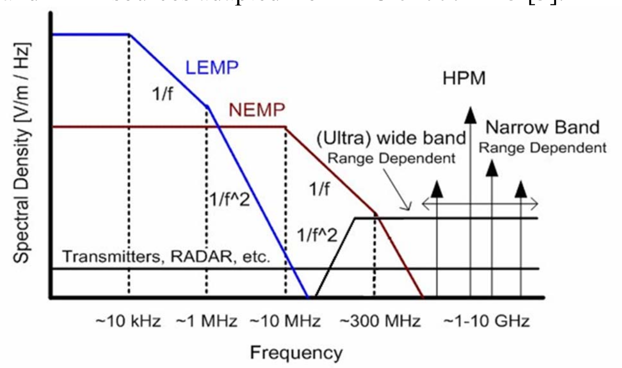

Figure 1. Comparison of Typical High Power Electromagnetic Environments (HPEM) [3]

2. High power electromagnetic pulse source

High power microwave pulse called HPM is a very short duration pulse (the duration time is a few of nanoseconds) and high power (a few of gigawatts in pulse).
An example of an HPM generator is the DS110F generator. It is a small compact high-power RF source, suitable for interfering with critical infrastructure devices. The basic specification of the HPM DS110F generator is shown in Table 1. Components of the generator are high-voltage power supply, 300 kV Marx generator and a resonant antenna. High voltage power supply system supplies the Marx generator by 50 kV voltage (symmetrical voltage ± 25 kV), he is charged until the threshold set by the switch that sets pressure gas N_2 in the generator. When changing the position of the switch, antenna is fed a 300 kV voltage, the sparker contained in the air is isolated by the pressure gas N_2 [4].

Table 1. DS110F specifications [4]

Parameter	Value
Size	500 x 410 x 200 mm
Weight	24 kg
Peak radiated power	160 MW
Radiation pattern	Dipole
Pulse duration	4 ns
Repetition rate	> 5 Hz (10 Hz typ)
Centre frequency	350 MHz
3 dB bandwidth	100 MHz
Operating time (without reflector)	> 1 hours

3. The laboratory stand for measuring the HPM pulse

Figure 2 presents a block diagram of the laboratory stand for generation and measurement of HPM pulses. The main elements: the generator and the detection system, were placed in the anechoic chamber so that the probability of damage to other electronic devices in the vicinity is very small. In addition, they were placed on a metal floor lined with ferrites, thanks to which a common reference mass was ensured. The laboratory stand elements located in the anechoic chamber are arranged in accordance with the block diagram shown in Fig. 2. In this case, a reflector has been attached to the generator, providing a larger radiation focus in the given direction (this is an optional element) [1, 5].

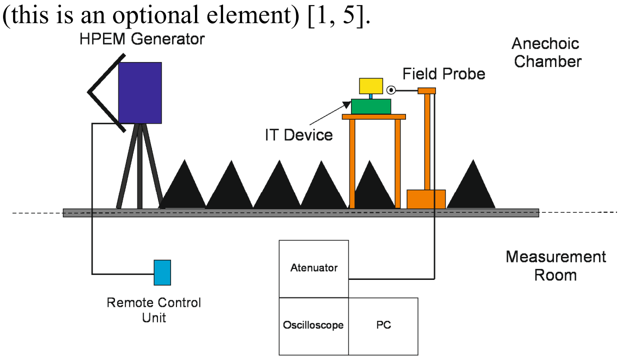

Figure 2. Block diagram of the laboratory stand for HPM pulse measurement

Before measuring HPM pulse parameters, it is necessary to check and assess whether a particular high frequency detection system can be used for this purpose. The analyzed detection systems consist of two elements - a balun and a proper antenna.
The balun is used to transform a symmetrical line into an asymmetrical line. This element is an electronic device, so it is characterized by such parameters as transmittance and impulse response time.
The HPM pulse amplitude measurement systems should have a large dynamic range, which means that HPM pulses must be measured with very high and very small amplitudes. Therefore, in order to meet the above condition, it is first of all necessary to ensure that the balun transmittance introduces excessive attenuation of the measurement signal.
The main task of the proper antenna (Probe) is to register changes taking place in an electric or magnetic field. An example of such a probe can be a dipole antenna. The probe, like any other electronic component, has its resistance and conductance. This makes it able to store changes in electric or magnetic field. Then these changes are transformed into voltage and fed to the next device located in the laboratory stand. There are two types of measuring probes: D-dot and B-dot.
The antenna proper is a key element in the study HPM pulses. The proper antenna has to be adapted to test impulses of short duration as well as have a short rise time. From the receiving side, a measuring probe (D-dot or B-dot) should be connected to the oscilloscope, the function of which is to test the measurement environment. The D-dot probe (B-dot) is a detector of electrical (magnetic) induction of a received signal sent to the oscilloscope after passing through the matching circuit (balun). Due to its properties, the probe is used as a receiving antenna converting the electromagnetic pulse into an electrical signal. Additional placement of the probe on the plastic base reduces the impact of the external environment on the measurements to a minimum. The exact parameters of the sample Prodyn D-dot probes are presented in Table 2.
The probe should be mounted on a plastic stand to reduce the impact on the measurements to a minimum. The sensor located on the probe is a passive device and therefore does not require external power supply. The D-dot probe is a detector of electrical induction of the received signal, sent to the oscilloscope after passing through the matching system.

Table 2. Parameters of Prodyn D-dot probes [4]

Parameter	Value				
	AD-40	**AD-55**	**AD-70**	**AD-80**	**AD-20**
Effective area	$1x10^{-2}m^2$	$3x10^{-3}m^2$	$1x10^{-3}m^2$	$3x10^{-4}m^2$	$1x10^{-4}m^2$
Frequency of response (3 dB)	> 1 GHz	> 2 GHz	> 3.5 GHz	> 5.5 GHz	> 10 GHz
Rise Time (10% do 90%)	< 0,29 ns	< 0,17 ns	< 0,11 ns	< 0,064 ns	< 0,029 ns
Capacity	$1,43x10^{-12}$ F	$7,80x10^{-13}$ F	$4,49x10^{-13}$ F	$2,91x10^{-13}$ F	$1,40x10^{-13}$ F
Max. Output	± 4kV	± 1,5kV	± 1kV	± 1kV	± 150V
Connector output	SMA	SMA	SMA	SMA	SMA

4. Validation of the D-dot probe

This chapter presents the results of measurements that were used to validate the D-dot probe for HPM pulse measurements. For this purpose, three research experiments were carried out according to various scenarios. All tests were carried out according to the schemes shown in Figure 3.
In order to validate the D-dot probe for measurement of HPM impulses, three test scenarios were prepared, according to which measurements were made.

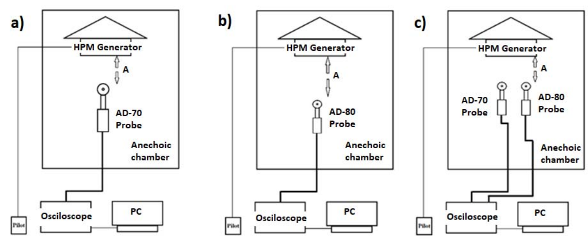

Figure 3. Measurement diagrams used to validate the D-dot probe for measuring HPM pulses

4.1 Scenario No. 1 - Comparison of measurement results using a reference probe for channel 1

In the discussed scenario, measurements should be performed in two stages. In the first stage, the calibrated reference probe AD-70 should be connected to the measuring system (discussed in chapter 3) via Channel No. 1 in the oscilloscope, and then to measure the HPM pulse. For this purpose, use the measurement diagram from Fig. 3a). In the second stage of the scenario, the tested (validated) AD-80 measuring probe should be connected to the measurement system via Channel No. 1 in the oscilloscope, and then perform the HPM pulse measurement. For this purpose, use the measurement diagram from Fig. 3b). A very important task in this scenario is the location of the measurement probes during measurements in the same place in the anechoic chamber. The recorded measurement results should be subjected to statistical and comparative analysis, thanks to which it will be possible to determine the correctness of the indications of the tested D-dot probe.

4.2 Scenario No. 1 - Comparison of measurement results using a reference probe for channel 2

In the discussed scenario, measurements should be performed in two stages. In the first stage, the calibrated reference probe AD-70 should be connected to the measuring system (discussed in chapter 3) via Channel No. 2 in the oscilloscope, and then to measure the HPM pulse. For this purpose, use the measurement diagram from Fig. 3a). In the second stage of the scenario, the tested (validated) AD-80 measuring probe should be connected to the measurement system via Channel No. 2 in the oscilloscope, and then perform the HPM pulse measurement. For this purpose, use the measurement diagram from Fig. 3b). A very important task in this scenario is the location of the measurement probes during measurements in the same place in the anechoic chamber. The recorded measurement results should be subjected to statistical and comparative analysis, thanks to which it will be possible to determine the correctness of the indications of the tested D-dot probe.

4.3 Scenario No. 3 - Comparison of measurement results using a reference probe and a test probe

In this scenario, the measurements should be made once. For this purpose, use the measurement diagram from Fig. 3c). The AD-70 measuring probe should be connected to the measurement system via Channel No. 1 in the oscilloscope, the AD-80 measuring probe should be connected to the measurement system via Channel No. 2 in the oscilloscope and then measure the HPM pulse. During the measurement HPM pulse oscilloscope trigger select the channel 1. Thus recorded measurement results to be analyzed and statistical comparison so that it will be possible to determine the accuracy of the indications of the test probe D-dot.

5. Mesurement results

As part of the measurements according to the scenario No. 1, the results of measurements from the calibrated reference probe AD-70 were obtained (red color in the presented graphs) and the test results from measurements using the tested (validated) AD-80 measuring probe (blue color on graphs). Figure 4 shows the measured time courses and the calculated density spectral of HPM pulses using both measuring probes. These waveforms represent the average value of 10 measured HPM pulse. As can be seen from the presented time waveforms, the difference between two values of the electric field intensity is 4 kV/m. In relation to the maximum measured value of the electric field intensity of 175 kV/m, this gives a percentage value of 2,3% difference between the waveforms. The differences visible on the spectral density waveforms are not significant and will be the greater the greater the differences in time waveforms. From the presented measurement results for this scenario, it should be stated that the tested AD-80 measuring probe fulfills its task with accuracy of +/- 4 kV/m (2,3%).

a) b)

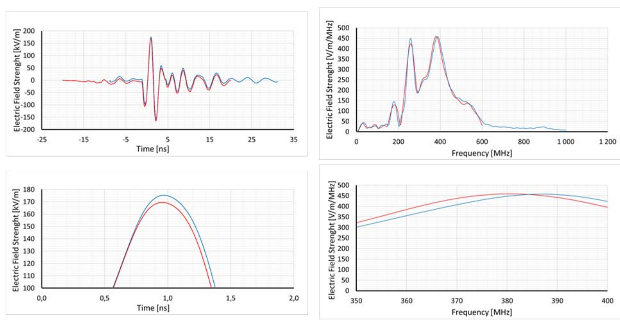

Figure 4. Measured electric field strength values using the calibrated AD-70 reference probe (red color) and the tested (validated) AD-80 measuring probe (blue): a) time waveform, b) spectral density

a) b)

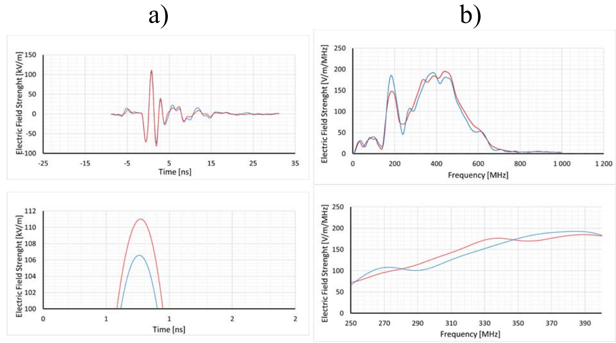

Figure 5. Measured electric field strength values using the calibrated AD-70 reference probe (red color) and the tested (validated) AD-80 measuring probe (blue): a) time waveform, b) spectral density

As part of the measurements in scenario No. 2, the results of measurements from the calibrated AD-70 reference probe were obtained (red color in the presented graphs) and the test results from measurements using the tested (validated) AD-80 measuring probe (blue color on graphs). Figure 5 shows the measured time courses and the calculated density spectral of HPM pulses using both measuring probes. These waveforms represent the average value of 10 measured HPM pulse. As can be seen from the presented time waveforms, the difference between two values of the electric field intensity is 4 kV/m. In relation to the maximum measured value of the electric field intensity of 100 kV/m, this gives a percentage value of 4,0% difference between the waveforms. The differences visible on the spectral density waveforms are not significant and will be the greater the greater the differences in time waveforms. From the presented measurement results for this scenario, it should be stated that the tested AD-80 measuring probe fulfills its task with accuracy of +/- 4 kV/m (4,0%).

a) b)

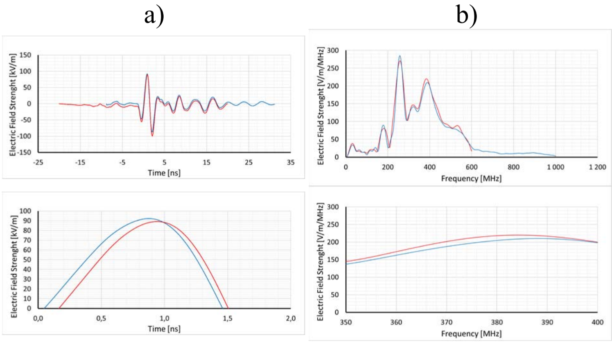

Figure 6. Measured electric field strength values using the calibrated AD-70 reference probe (red color) and the tested (validated) AD-80 measuring probe (blue): a) time waveform, b) spectral density

As part of measurements in scenario 3, the results of measurements from the calibrated reference probe AD-70 were obtained (the red color in the presented graphs) and the test results from measurements using the tested (validated) AD-80 measuring probe (the blue color in the presented graphs) connected simultaneously to the measurement system. Figure 6 shows the measured time courses and the calculated spectral density of HPM pulses using both measuring probes (AD-70 and AD-80). These waveforms represent the average value of 10 measured pulse HPM.

As can be seen from the presented time waveforms, the difference between two values of the electric field intensity is 4 kV/m. In relation to the maximum measured value of the electric field intensity of 100 kV/m, this gives a percentage value of 4,0% difference between the waveforms. The differences visible on the spectral density waveforms are not significant and will be the greater the greater the differences in time waveforms. From the presented measurement results for this scenario, it should be stated that the tested AD-80 measuring probe fulfills its task with accuracy of +/- 4 kV/m (4,0%).

Based on the measurements (according to three scenarios) it can be concluded that the validated AD-80 measuring probe in relation to the calibrated AD-70 measuring probe shows values with different accuracy for different measured pulses. Therefore, the probe should be validated as a function of the amplitude of HPM pulses and the corrective coefficients for this D-dot probe should be determined.

5. Conclusions

The main purpose of this article is to present validation of the D-dot measuring probe for measurements of extremely high-energy HPM pulses consisting in the measurements of validation of a selected measuring probe used in the HPM pulse measurement system.

The calibration probe AD-70 and the AD-80 probe were used for the measurements, which was validated. The implementation of measurements and analyzes allows to conclude that the obtained measurement results using probes AD-70 and AD-80 are comparable. Due to the high similarity of the results obtained, it can be concluded that the AD-70 probe can be replaced with the AD-80 probe in the system for measuring the intensity of the electromagnetic field generated by the HPM pulse generator.

The second most important conclusion from the conducted analyzes is confirmation of correctness of the measurement probe indications in the HPM pulse measurement system. Based on the measurements, it can be concluded that the validated AD-80 measuring probe in relation to the calibrated AD-70 measuring probe shows values with different accuracy for different measured pulses. Therefore, the probe should be validated as a function of the amplitude of HPM pulses and the corrective coefficients for this D-dot probe should be determined.

6. Literature

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