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High-Power, Pulsed Electromagnetic Field Training-Range Meter, Pm-Hpm1

Wysokiej mocy, pulsujący miernik pola elektromagnetycznego w zakresie treningu, Pm-Hpm1

Abstract. *This research paper reviews a broadband, PM-HPM1 meter for pulsed electromagnetic fields over a very wide range of dynamic measurements. The device is intended to conduct laboratory and field measurements over a frequency range of 10 MHz – 12 GHz, and with durations ranging from several nanoseconds to several hundred microseconds. Measured EM field strengths ranges from 5 V/m to 500 kV/m.*

Streszczenie. *W artykule przedstawiono szerokopasmowy miernik PM-HPM1, impulsowych pól elektromagnetycznych o bardzo dużym zakresie dynamicznym pomiarów. Urządzenie przeznaczone jest do wykonywania pomiarów laboratoryjnych oraz polowych w zakresie częstotliwości 10 MHz – 12 GHz, oraz o czasach trwania od kilku nanosekund do kilkuset mikrosekund. Zakres mierzonych natężeń pól EM obejmuje przedział od 5 V/m do 500 kV/m.*

Keywords: measurement method, pulse field, measuring tools.
Słowa kluczowe: metoda pomiaru, pole impulsowe, narzędzia pomiarowe.

Introduction

The meter, with its working name PM-HPM1, is an autonomous, electronic device for taking laboratory and field measurements of high-power pulsed electromagnetic field strengths (HPM).

It is a broadband device measuring pulsed electromagnetic radiation over a frequency range of 0.01 GHz to 12 GHz. The PM-HPM1 meter is equipped with a D-dot probe, which measures the electric component (E) of the field and enables measuring the parameters of electromagnetic field strength over up to 4 hours, with the battery fully charged.

The intensity of the measured field can be expressed in units electric intensity [V/m] or power density [W/m^2].

It measures both the electromagnetic field intensity parameters, as well as pulse time parameters, and spectral parameters for signals with frequencies below 1 GHz.

The software of the meter allows to save the final results of the measurements on a computer hard drive, as well as to copy them to other media and to load them.

Fig. 1. Photo of the PM-HPM1 meter

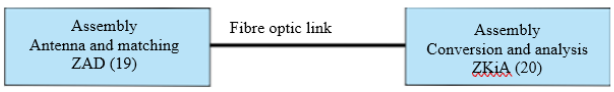

Fig. 2. Meter assemblies

Overall structure of the PM-HPM1 meter

Fig. 2 illustrates the overall structure of the meter. The design consists of two clearly separated assemblies, namely, an antenna and matching assembly (ZAD) (19) and a programmable conversion and analysis assembly (ZKiA) (20), wherein the measurements are controlled and where the measured values are quantified using specialized computer software. The ZAD (19) is located at the measuring point, where the electromagnetic field strength can be very high and cause damage to electronic systems not protected by a highly tight electromagnetic shield. The ZKiA (20) can be located at a large distance from the measuring point, where the electromagnetic field strength is not high and it is not required to place it in an electromagnetically tight casing. Both assemblies are linked via a broadband fibre-optic connection.

Antenna and matching assembly (ZAD)

The task of the ZAD is to receive an electromagnetic wave and reduce the received signals to a level measurable at the ZKiA. The change in the range of measured signal amplitudes is obtained by modifying measurement chain attenuation values.

Under impact of the electromagnetic field strength, two symmetrical analogue electric signals are induced in the D-dot antenna (1), which are then converted in the balun (2) into a single, asymmetrical analogue signal.

The ZAD includes the following elements:

- The D-dot antenna (1) is comprised on two dipole elements with a small effective area. Antenna components are separated by reference ground. Two analogue, symmetrical electrical signals proportional to the change in the electromagnetic field component over time in one plane (first derivative) are present on antenna outputs.

- The desymmetrizer (balun) (2) connected via its inputs to two D-dot antenna symmetrical outputs (1) and at its coaxial cable output. The desymmetrizer changes two symmetrical analogue electrical signals from the antenna into a single asymmetrical signal.
- The coaxial cable (3) joins the desymmetrizer output with a set of attenuators (4).
- A set of microwave attenuators (4) with total attenuation depending on the measured signal range, used to reduce signal voltage to a value measurable at the ZKiA. The attenuators are hooked-up at the coaxial cable output (3), not to deteriorate the signal/(noise+interference) ratio within the coaxial cable.

The elements referred to above are located outside the shielding casing, since, due to their design and intended purpose (antenna), they do not require additional electromagnetic shielding.

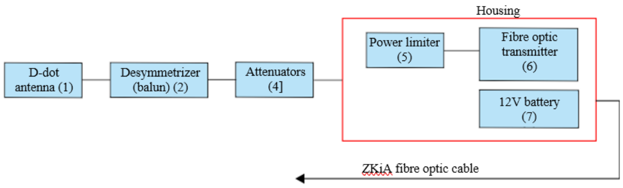

Fig. 3. Antenna and matching assembly

Other ZAD components (19) are placed inside an electromagnetically tight casing with an input microwave connector and output fibre-optic connector.

The following ZAD components are placed in the casing:

- Power limiter (5) that limits the maximum signal level at the input of the HF analogue signal fibre-optic transmitter (6), which prevents its damage.
- HF analogue signal broadband fibre-optic transmitter (6).

An electric signal from the limiter output (5) is applied at the fibre-optic signal transmitter input. Inside the analogue transmitter (6) the electrical signal modulates the light signal of the laser diode, which is sent via the optical fibre (9) to the ZKiA assembly (20). The transmitter is characterized by high linear dynamics for the entire transmitted signal microwave band.

- Power supply (7) in the ZAD (19) is required only for the fibre-optic transmitter (6) and consists of a battery and a short-circuit, overload and over-discharge protection system.

In the event of a need to simultaneously measure an electromagnetic field electric component in two planes (e.g., for signals with circular polarisation), there are two ZAD systems with D-dot antenna dipole elements (1) offset by 90° relative to each other within the meter.

ZAD signals (19) are then transmitted via the fibre-optic link (9) with a very wide bandwidth, resistant to electromagnetic wave interference, to the ZKiA (20) located in a safe zone.

Conversion and analysis assembly (ZKiA)

The ZKiA, depending on the frequency band of measured signals, is of the structure illustrated in Fig. 4 or 5.

The lower frequency band of measured signals are frequencies falling within the programmable digitizer (14) analogue input band, and are at least half its sampling frequency (14). The upper frequency band of measured signals are frequencies above the lower band.

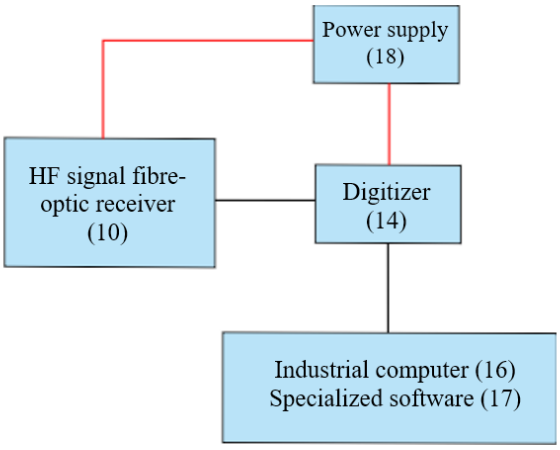

Fig. 4. ZKiA structure for the lower frequency band of measured signals

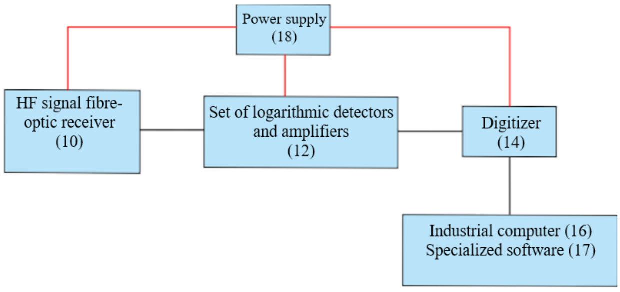

Fig. 5. ZKiA structure for the upper frequency band of measured signals

The ZKiA (20) comprises the following components:

- Fibre-optic signal receiver (10) that converts a light signal into an electric signal using a PIN photodiode. Receiver (10) is characterized by a very wide bandwidth and high linearity of optical-to-electric signal conversion. The conversion coefficients of the fibre-optic signal transmitter (6) and fibre-optic signal receiver (10) are matched so that the receiver output signal amplitude is equal to the transmitter input signal amplitude.
- Programmable digitizer (14), which is a high-speed analogue-to-digital converter that quantises the analogue signal after it exceeds the preset amplitude threshold. Quantised, digital signal values are sent via a digital link, e.g., USB, to a computer (16). In the case of lower frequency band of measured signals, the fibre-optic receiver output (10) is connected directly with the analogue digitizer input (14). In the case of the upper frequency band of measured signals, the digitizer analogue input (14) is connected to the output of the logarithmic detector and amplifier set (12) that convert the fibre-optic receiver output signal.
- Broadband set of logarithmic detectors and amplifiers with a wide dynamic range (12) (only for the upper frequency band of measured signals) is made of detectors and amplifiers that convert HF radio signals into proportional direct current voltage (pulse envelope). The output voltage of the set (12) is proportional to the input voltage decimal logarithm, which ensures a very high dynamic range of processed input voltages.

- Computer (16) with specialized computer software (17), the task of which is to implement the following functionalities:
  - configure operating parameters and modes of the programmable digitizer,
  - control the process of signal acquisition by the programmable digitizer,
  - effectively register pulsed signals routed to the digitizer input, taking into account potentially high values of their processing period relative to their duration and processing period variables,
  - reconstruct the primary shape of the antenna input signal (1) for the lower frequency band based on a digitizer-recorded signal and analogue chain spectral transmittance using equivalent digital filter transmittance; based on the recorded response and known transmittance form, the computer software employs reverse filtration to determine excitation, which is the temporal form of the electric field,
  - calculating electric field strength based on quantised values of the digitizer signal and calibration coefficients entered during the certification process,
  - implement the Fourier transform for electric field signals in the lower frequency band
  - visualize signals recorded and electric field signals, as well as their Fourier transforms obtained through processing,
  - measurement and tabular screen presentation of the parameters of signals recorded and electric field signals obtained through processing,
  - measurement results archiving.

Due to the distance from the source of strong electromagnetic fields and the additional shielding of the building or field objects, the ZKiA (20) does not have to be fitted with a special electromagnetically tight casing, while simultaneously enabling continuous measurements and immediate access to measurement results for operators.

Tests

The calibration tests were conducted at the Laboratory of Electromagnetic Field Calibration and Metrology of the Wrocław University of Technology, Fig. 6, Fig. 7.

Numerous laboratory and environmental tests were also conducted using the PM-HPM1 meter, which confirmed its advantages, such as resistance to variable weather conditions, serial measurement recording from individual to several thousand recordings, very wide dynamic range of measured fields:

- (0.2÷500) kV/m for the (10÷100) MHz frequency range,
- (0.05÷500) kV/m for the (0.1÷1) GHz frequency range
- 5 V/m÷400 kV/m for the (1÷12) GHz frequency range,

very wide range of temporal parameters for measured pulses 2 ns ÷ 300 ms, measuring spectral parameters of the pulses over a 10 MHz – 2.5 GHz frequency range.

Measurement examples shown in Fig. 8, 9, 10 and 11.

Conclusions

There are currently no portable high-power pulsed electromagnetic field meters available in the Polish market that can operate under adverse and demanding weather conditions.

Wider application of this measuring equipment type entails numerous benefits, such as:

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CALIBRATION RESULTS **PM-HPM1 meter**

Meter name: **PM-HPM1**
Response type: **frequency**
Range: **from 100 MHz to 900 MHz**
Signal type: **CW**
Measurement conditions: **TEM 5 cm chamber**
Reference field RMS value: **E_0 = 200 V/m**
Reference field frequency: **f_0**
Operation without envelope detector, attenuation **0 dB**

f_0	reference field strength (RMS value)	meter indication E_m (RMS value)	Cf	uncertainty
[MHz]	[V/m]	[V/m]	[V/m]	[%]
100	200	175	1.14	15
300	200	185	1.08	15
600	200	181	1.10	15
900	200	199	1.01	15

Response type: **amplitude**
Range: **from 50 V/m to 1300 V/m**
Signal type: **CW**
Measurement conditions: **TEM 5 cm chamber**
Reference field RMS value: **E_0**
Reference field frequency: **f_0 = 300 MHz**
Operation without envelope detector, attenuation **0 dB**

reference field strength E_0 (RMS value]	meter indication E_m (RMS value)	$Cd=E_0/E_m$	uncertainty
[V/m]	[V/m]		%
50	46.0	1.09	12
100	90.6	1.10	12
200	181.0	1.10	12
300	272.0	1.10	12
400	364.0	1.10	12
500	454.0	1.10	12
600	542.0	1.11	12
800	724.0	1.10	12
1000	902.3	1.11	12
1200	1078	1.11	12
1300	1162	1.12	12

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Fig. 6. Calibration report, lower frequency range

- measuring electromagnetic field radiation emitted by directed-energy devices (E-bombs) under laboratory and training ground conditions,
- possible correlation of HPM pulse impact on electronic devices and entire vehicles with the level of electric field pulse strength level,
- possible performance tests involving absorbers and absorber-covered electronic devices under training ground conditions,
- possibility to correlate the level of the high-power electromagnetic field strength falling on biological tissues and entire organisms.
- environmental measurements of high-power pulsed field induced by radars.

The source literature contains proposed solutions for HPM meters within narrow frequency bands. However, no ready solutions ensuring measurements over a broad frequency range were encountered, starting with small field

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CALIBRATION RESULTS **PM-HPM1 meter**

Response type: **amplitude**
Range: **from 20 V/m to 1000 V/m**
Signal type: **1 µs pulses, 1 ms repetition rate**
Measurement conditions: **TEM 5 cm chamber**
Reference field RMS value: **E_0=20 V/m**
Reference field frequency: **f_0 = 1 GHz**
Operation with envelope detector **version 3**, attenuation **0 dB**

reference field strength E_0 (RMS value)	meter indication E_m (RMS value)	$Cd=E_0/E_m$	uncertainty
[V/m]	[V/m]		%
20	20.2	0.99	12
50	49.6	1.01	12
100	98.4	1.02	12
200	198.4	1.01	12
500	495.2	1.01	12
1000	995.4	1.00	12

Response type: **frequency**
Range: **from 1 GHz to 13 GHz**
Signal type: **5 µs pulses, 1 ms repetition rate**
Measurement conditions: **free space**
Reference field RMS value: **E_0 = 20 V/m**
Operation with envelope detector **version 3**, attenuation **0 dB**

f_0	reference field strength (RMS value)	meter indication E_m (RMS value)	Cf	uncertainty
[GHZ]	[V/m]	[V/m]	[V/m]	[%]
1	20	20.6	0.97	15
2	20	18.7	1.07	15
3	20	21.1	0.95	15
4	20	22.2	0.90	15
5	20	21.4	0.93	20
6	20	21.2	0.94	20
7	20	20.2	0.99	20
8	20	22.8	0.88	20
9	20	23.2	0.86	20
10	20	24.2	0.83	20
11	20	20.3	0.99	20
12	20	19.4	1.03	20
13	20	18.6	1.08	20

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Fig. 7. Calibration report, upper frequency range

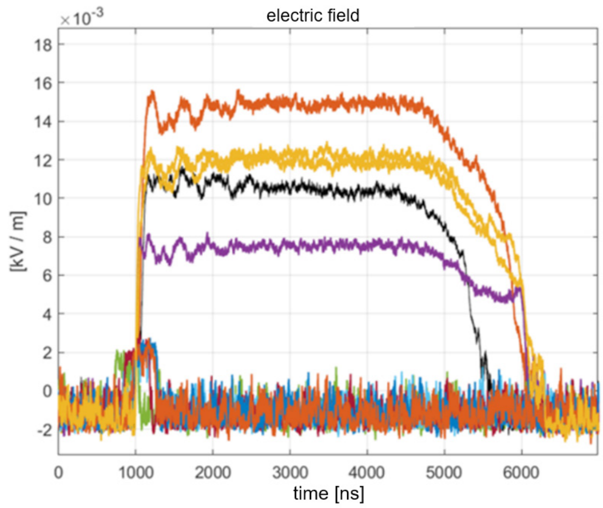

Fig. 9. Maritime training ground, recording HPM generator signals under pulsed operation with a 5 Hz repetition rate

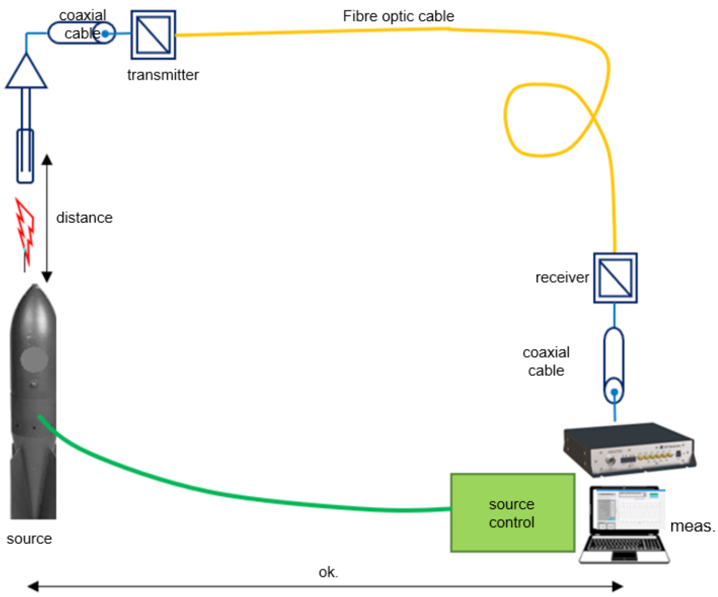

Fig. 10. Land training ground, schematic diagram of the measurement system employed within the tests (*d* distance marked in the diagram was adjusted)

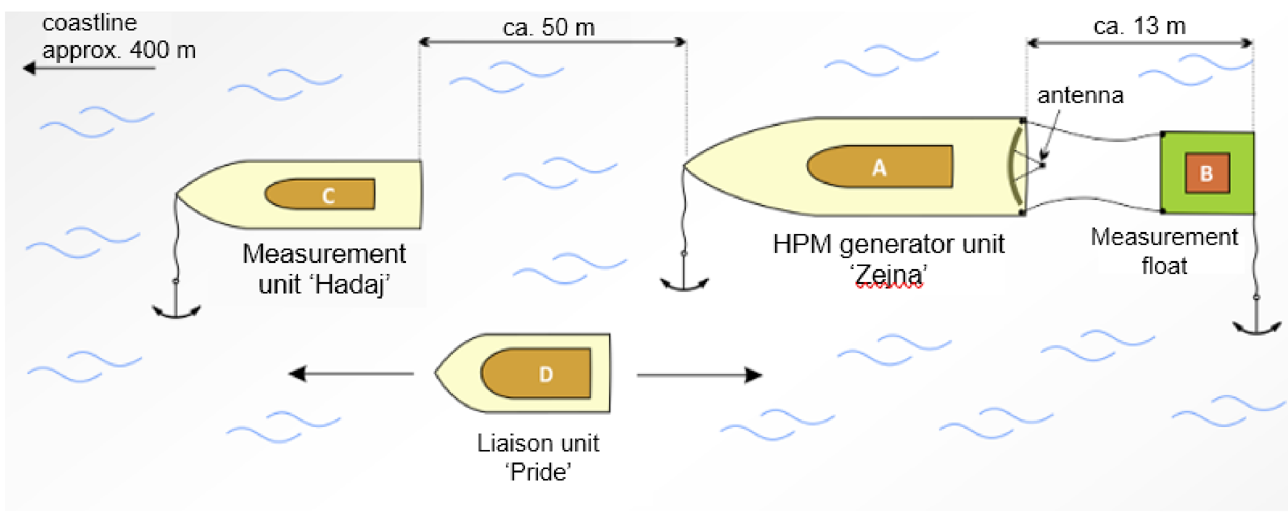

Fig. 8. Maritime training ground, research experiment vessel deployment

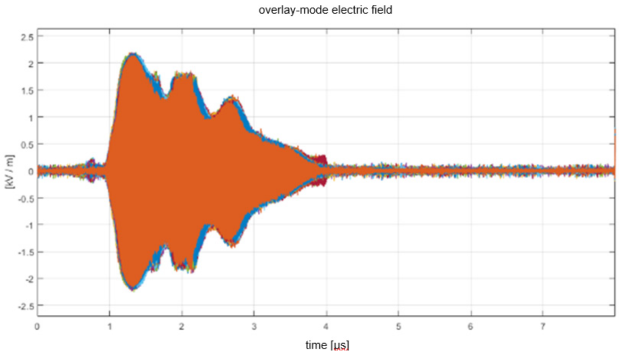

Fig. 11. Land training ground, recording HPM generator signals, 100 pulses generated, 10 ms repetition rate

strengths to high field strengths, operating under field conditions and with an additional certificate that specifies measurement accuracy, issued by an accredited laboratory.

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REFERENCES

[1] Reports covering the implementation of task PSOB/16–062/2014/WAT/P, DOB-1–3/PS/2014 Project, Warsaw 2021.