

METHODS FOR FREE-SPACE ULTRA-SHORT SOLITARY EMP MEASUREMENT

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Summary There are some suitable methods for ultra-short solitary electromagnetic pulses (EMP) measurement. The EMPs are generated by high power microwave generators. The characteristic of EMPs is high power level ($P_{max} = 250$ MW) and very short time duration ($t_p \in <1, 60>$ ns). Special requirements for measurement methods are placed because of the specific EMPs properties. Two suitable methods for this application are presented in the paper. The first – calorimetric method, utilizes the thermal impacts of microwave absorption. The second method presented – magneto-optic method, use the Faraday’s magneto-optic effect as a sensor principle. It was realized combined calorimetric sensor and there were made some experimental EMP measurements with good results. The sensor utilizing magneto-optic method is in development.

1. INTRODUCTION

In connection with the events of the last few years and with the increased number of terrorist activities, the problem of identification and measurement of electromagnetic weapons or other systems impact occurred. Among these are also microwave sources, which can reach extensive peak power of up to $P_{max} = 250$ MW. Solitary, in some cases several times repeated, impulses lasting from $t_p \in <1, 60>$ ns, cause the destruction of semiconductor junctions. The analysis of the possible measuring methods, convenient for the identification and measurement of the ultra-short solitary electromagnetic (EM) pulses is presented in this paper; some of the methods were chosen and used for practical measurement.

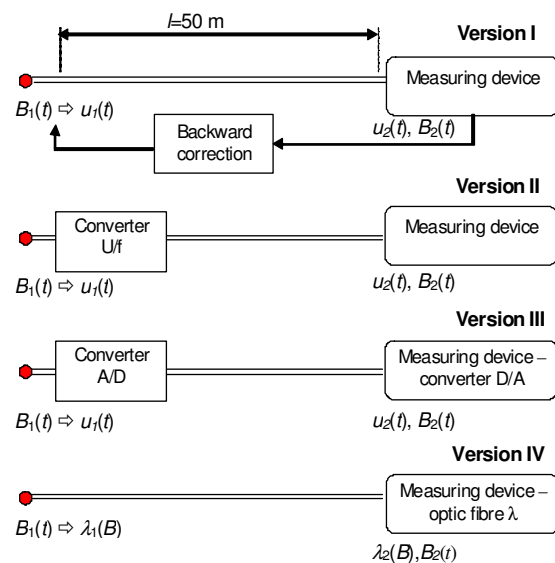


Fig. 1. Principles of the methods based on Faraday’s induction law and magneto-optic effect

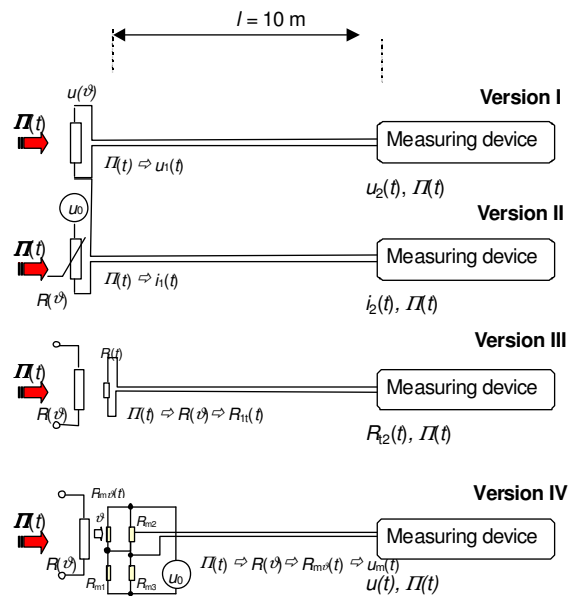


Fig. 2 Calorimetric measurement of the solitary impulse power

2. METHODS

2.1 Method based on Faraday’s induction law

One group of methods is based on the Faraday’s induction law application, where the impulse is located by sensor (coil with $N_s = 1 \div 50$ turns). Signal induced in the coil is led to the recording device, generally an oscilloscope. Due to safety requirements, the distance between the sensor and the oscilloscope is $l = 50$ m. This parameter introduces a quality decrease of the recorded information in the way of the signal amplitude reduction, change of the signal phase and the impulse prolongation.

Elimination of this limitation is in Version I, depicted in Fig. 1., made by backward correction exploiting the Laplace transform. Impulses up to

limit pulse length $T_{\max} = 1$ ns were measured by this method and magnetic flux ϕ was evaluated [5].

Version II exploits the possibility of principal elimination of the influence of the transmitting line between the sensor and the measuring device by an analogue U/f. converter. Available measuring devices can achieve measured impulses with the limit length $T_{\max} = 5$ ns.

The solution in Version III is similar to Version II, the difference is in the digital converter applied. By an available measuring devices application and fulfilled sampling theorem we can measure impulses with the limit length $T_{\max} = 20$ ns.

2.2 Method based on Faraday's magneto-optic effect

Version IV in Fig. 1. is based on Faraday's magneto-optic effect [5]. Connection between the sensor and the measuring device is implemented in the optical wavelength.

The possible active sensors are of three basic types. The first type is garnet with high Verdet constant, the second is optic fibre, and the third is based on magneto-optic properties of ferromagnetic mono/multi thin film. Next types of the Version IV sensors are based on the magneto-optic Kerr's effects (MOKE), or surface MOKE (SMOKE) effect. By an available measuring devices application we can measure impulses with the limit length $T_{\max} = 0.1$ ns.

The named methods indicate electromagnetic parts of the wave – electric or magnetic. They don't express the power conditions of the electromagnetic wave. For some of the measurement it is essential to evaluate power flow through the defined area.

2.3 Calorimetric method

Into next type of converters belongs the group of calorimetric methods. We can measure power supplied by impulse (Poynting's vector) when we use the calorimetric converter. The sensor is connected to the measuring device (oscilloscope) by an optic fiber of $l = 50$ m length. Fig. 2. depicts four versions of the method utilizing calorimetric measurement.

Version I discussed in [6,7] has sensor in the form of an ideal resistor and enables measurement of the maximum value of microwave power P_{\max} . The analyzed peak voltage corresponds to peak value of power P_{\max} . For available measuring devices we can measure impulses with the limit length $T_{\max} = 50$ ps. Version II scans change of resistance of the sensor, created by an evaporated thin layer, in dependence on the impulse energy. For available measuring devices we can reach accuracy 30 % up to impulse limit length $T_{\max} = 0.1$ ns.

Version III is based on the measurement of the temperature change of the thermistor, placed in contact with the layer. Under the same conditions as for previous version we can reach the accuracy improvement of an order of magnitude.

Version IV is the bridge connection of version III. Several thermistors are attached in series to the evaporated layer; next three resistors create a DC bridge of Weston type with the thermistors. The change of the resistance in the thermistor arm is evaluated. The voltage in measuring bridge diagonal is consequently integrated. So the value of the impulse energy is obtained which the measuring device records. For available measuring devices we can measure impulses with the limit length $T_{\max} = 0.03$ ns with accuracy to 10 %.

3. METHODS APPLICATION

Calorimetric method and magneto-optic method were chosen as perspective for EM pulse measurement. The advantage of calorimetric method is the capability of physically correct high power measurement. However, it doesn't give the information about pulse waveform. Magneto-optic method allows ultrashort pulses waveform measurement because of its high bandwidth.

3.1 Realization of calorimetric method

The calorimetric sensor was of the disc design. The carbon with changed crystal lattice was used as one of the thin layer types. For microwave vircator with output power of $P_{\max} = 250$ MW, length of pulse $t_p \in <10, 60>$ ns combined calorimetric sensors were designed as is shown in Fig. 3. – version IV. The concept was designed after consultation [8] for supposed power and the impulse length with room for absorption and damping of the possible back EMG wave.



Fig.3. Realization of optimized combined calorimetric sensor

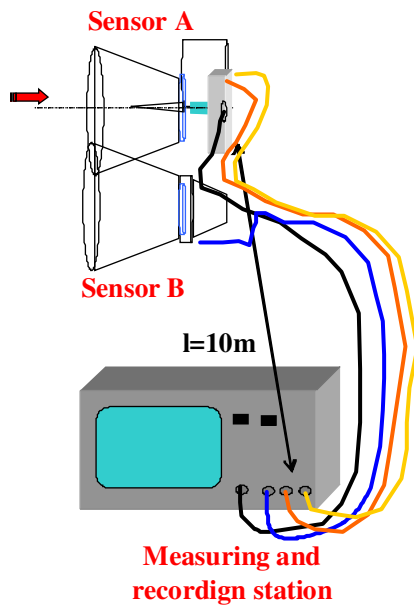


Fig.4. Calorimetric measurement setup

The length of connection between sensor and measuring device was $l_{\min} = 10$ m due to the safety requirements, as shown in Fig.4. When the vircator is in function, the hard RTG emission is generated beside the microwave emission. The energy of electron beam is $W_b = 1$ MeV. The sensor was calibrated with hf generator in absorption room.

Described sensor was used for vircator energy measurement. Vircator is pulse high-energy source of microwave energy based on the virtual cathode effect – experimental construction is shown on Fig. 5.

The waveform of measured small microwave power is in Fig.6. Fig.7. shows the waveform of vircator's anode current by initiation. The sensor was calibrated with RF generator in absorption room, Fig. 8.



Fig. 5 Experimental construction of vircator,
 $P_{\max} = 250$ MW

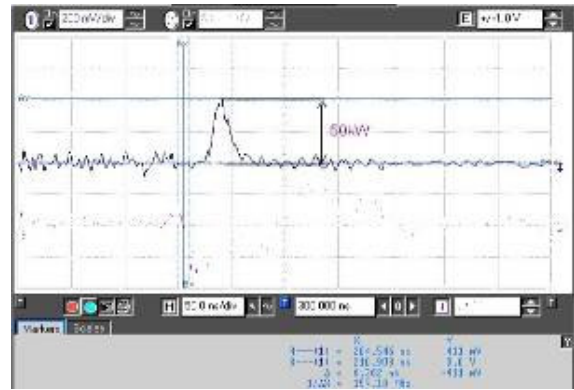


Fig.6. Measured waveform of small microwave power

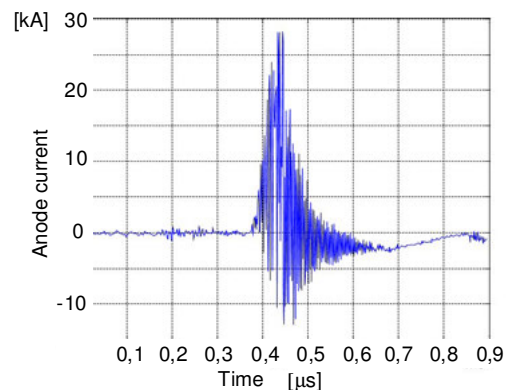


Fig.7. Waveform of vircator's anode current



Fig.8. Calibration of calorimetric sensor

3.2 Design of magneto-optic method

Magneto-optic (MO) method is proposed for next experiments. The polarization rotation of light passing MO sensor is affected by magnetic part of EM pulse. The rotation is due to the magnetic field and properties of the sensor material (Verdet constant). For free space measurement can be used MO garnet, glass or thin film. Sensor based on optic fibre is suitable for magnetic curl field measurement.

The absolute measurement method utilizing MO glass element (Fig. 9.) has been experimentally realized with low frequency magnetic field. Laser beam with linear polarization passes MO glass placed in Helmholtz coil – Fig. 10. Laser beam



Fig. 9. Detail of MO element – glass FR-5

is fed through analyzer subsequently and the polarization rotation is converted to intensity modulation. The intensity of light is sensed by photodiode.

Next, the differential method has been realized. Differential method utilizes Wollaston prism and offers better sensitivity.

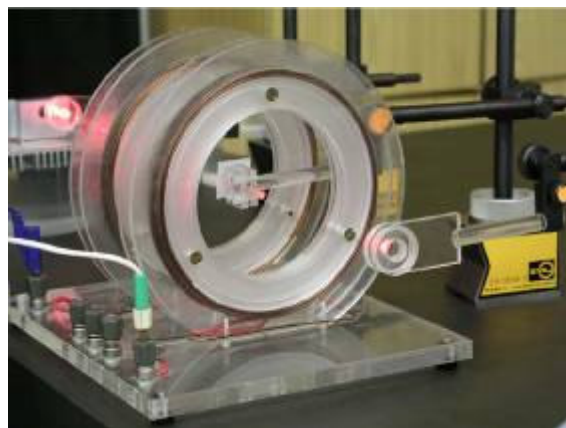


Fig. 10. MO element in Helmholtz coil

The sensitivity of the sensor and its bandwidth are contradictory properties. Because of the high power level of EM pulse, the sensitivity of the sensor is not critical requirement. The bandwidth of the sensor has to be appropriate to measured signal characteristic – it has to be able to detect transients with duration 1 ns. The corresponding bandwidth for this requirement reaches value of 350 MHz.

4. CONCLUSION

The overview of several methods suitable for measurement of the short solitary impulses with high power level was given. The characteristics of the designed method were discussed. Some methods were experimentally tested and evaluated.

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