ABSTRACTS

Electromagnetic emissions at LMJ-PETAL facility: understanding, mitigation and measurement.

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Abstract

The LMJ-PETAL is a large-scale facility that combines high energy nanosecond laser beams (300 kJ/3 ns in 2022) and high-power picosecond beam (400 J/0.6 ps in 2021). A combination of these beams is able to generate MV/m electromagnetic pulses (EMP) in GHz domain in the interaction chamber that may produce equipment failures, diagnostic damages, and spurious signals in detectors. The main mechanism of EMP generation is the return current through the target holder, induced by the electron ejection from the laser-irradiated target [1]. However, other processes may also strongly contribute to the electromagnetic emissions [2].

The upgrade of PETAL up to energy of 1 kJ cannot be achieved without an efficient EMP mitigation strategy. By performing in-situ measurements on smaller-scale laser facilities and multiphysics, multiscale large scale numerical simulations, we further improved the understanding EMP generation processes and developed an efficient mitigation device [3]. We present in this paper a new resistive and magnetic target holder designed to reduce the current discharge. It was tested and validated in experiments showing the robustness and efficiency of this device at kJ energies.

Moreover, we present two recent advances in the understanding of EMP generation and detection. First, a THz emission makes a significant contribution to the signal when the main EMP source is efficiently mitigated. Second, the discharge current at a few cm from the target can be measured with a good precision 4 m away from the target in the experiment chamber. This observation, validated by PIC simulations and near field measurements, may lead to a new efficient hot electron diagnostic.

References

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2 F. Consoli *et al.*, High Power Laser Sci. Eng. **8**, e22 (2020)
3 M. Bardon *et al.*, Phys. Rev. Res. **2**, 033502 (2020)

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EMP emission from laser interactions with gas jets

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Abstract

Electromagnetic pulses (EMP) are generated in a variety of high power laser experiments when hot electrons are expelled from the laser-target and oscillating currents are excited in the target mount and surrounding chamber [1]. Previous work has focused on laser interactions with solid targets [2], where the EMP amplitude is known to be highest. However the few measurements available for under-dense and near-critical density plasmas [3,4] suggest that the EMP is significant and likely to grow with the new generation of ultra-intense, high repetition rate laser systems [5].

To date there has been no theoretical framework proposed for the emission of EMP from gas jets, which makes it difficult to estimate the severity of its impact on new laser systems. We therefore present a model of EMP emission based on an expanding laser-plasma channel in a gas. The plasma channel ionises the gas as it expands and triggers a discharge to ground when the plasma makes contact with the gas jet nozzle. Model estimates for Vulcan Petawatt and Vega-style interactions suggest the EMP amplitude can reach ~10μT or ~10 kV/m in the far field of the target - higher than the electromagnetic susceptibility of electronics [6]. We also present preliminary results from an experiment on the Vega 3 laser, which show good agreement with the predicted B-field spatial profile and accumulated target charge.

Using our model, we show that damage to gas jet nozzles is probably caused by the impact of plasma ions rather than Ohmic heating of the nozzle surface. Other physical mechanisms that could contribute to EMP emission from gas jets, such as a spark gap discharge, are discussed. The impact of this work is broad, allowing scientists to optimise their experiments by reducing damage to expensive gas jet nozzles and minimizing the electrical disruption of diagnostics. It likewise represents a rich seam of more fundamental research, connecting the physics of laser-target charging, ion acceleration, high-voltage breakdown and antenna emission.

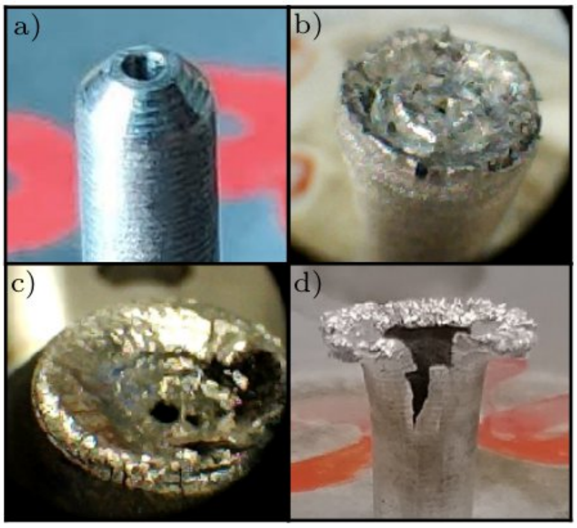

Figure 1. Gas jet nozzle damage observed on the Vulcan Petawatt laser by G. Hicks *et al.* [7]. (a) Nozzle prior to shot (b-d) Nozzles after a single full-power shot, with the laser focused 400 µm above the nozzle tip. Extensive melting and cracking is observed.

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Simulations and measurements of microwave pulses associated with high-power short-pulse laser interactions with solid targets and the possible mitigation methods

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Abstract

The high-power short-pulse laser interactions with matter are accompanied by the emission of strong electromagnetic pulses (EMP's) with substantial contribution in the MHz to multi-GHz frequency range [1], which is a cause of well-known complications in the execution of experiments at large laser facilities. The issue of predicting the frequency spectra and the amplitudes of microwave pulses for the planned experimental conditions is of prime importance, as well as the investigation of mitigation methods for such pulses. The mechanisms leading to these pulses had been enumerated, but a quantitative prediction of the EMP spectra and amplitudes is a major challenge [2]. This is due to a large span in spatial and temporal scales involved and to the fact that both the kinetic aspects of fast charged particle propagation and the electromagnetic aspects of interaction of such particles with conductive elements inside the interaction chamber need to be taken into account. In this contribution we explore a simplified approach to EMP simulation, based on restricting the spatial simulation domain to a small vicinity of the target and performing the simulation in a short time interval following the laser-target interaction. The signal obtained in this way together with the subsequent reverberations inside the interaction chamber is likely to constitute a major part of the EMP effect, and certainly it is useful in guiding EMP mitigation approaches based on modifications in vicinity of the target and the target support. We make educated guesses about the characteristics of the fast electrons escaping from the target and use this as an input into a commercial simulation package capable of handling the charged particle kinetics in the presence of realistic conducting elements. We compute electromagnetic fields in the vicinity of the target and the target holder under conditions corresponding to a real life experiment performed at the 10 TW fs laser in IPPLM, as well as in other setups involving higher laser pulse energies. We also perform simulations for arrangements aimed at mitigation of EMP emission, such as the ”birdhouse" target concept [3]. Our simulations show that EMP generated off metal foils contains substantial contribution from microwave frequencies higher than 6 GHz, which is a bandwidth of probes and oscilloscopes used in many EMP studies. Our results indicate that in the case of solid targets it is useful to measure EMP in correlation with the laser-accelerated proton energies [4].

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EMP WORKSHOP
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EMP from fs Laser Plasma at ELI-MAIA

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Abstract

An Electro-Magnetic-Pulse driven by the PW HAPLS laser in the ELI MAIA[1] (ELI Multidisciplinary Applications of laser Ion Acceleration) beamline was investigated. Extensive 3DT simulations and initial results from an ELI MAIA commissioning at 10 J / 30 fs laser pulses in the most dangerous GHz range will be presented.

The EMP inside and outside an interaction chamber was successfully simulated using the ANSYS HFSS software with a transient solver. Simulations predict a moderate EMP decay time due to multiple reverberations in an interaction chamber confirmed by D-dot and B-dot probe measurements. Broader-frequency microwave tests show distinctive features of a very fast initial pulse onset and a slower buildup of lower frequencies with a protracted decay time. An interaction spot and a conductive large-size target tower excited by a return current seem responsible for differences.

An application of a rigorous EMP rules for suppression, protection and mitigation techniques[2] enabled a low-noise, a high-dynamic range measurements and a reliable performance of an ELI MAIA diagnostic and control systems.

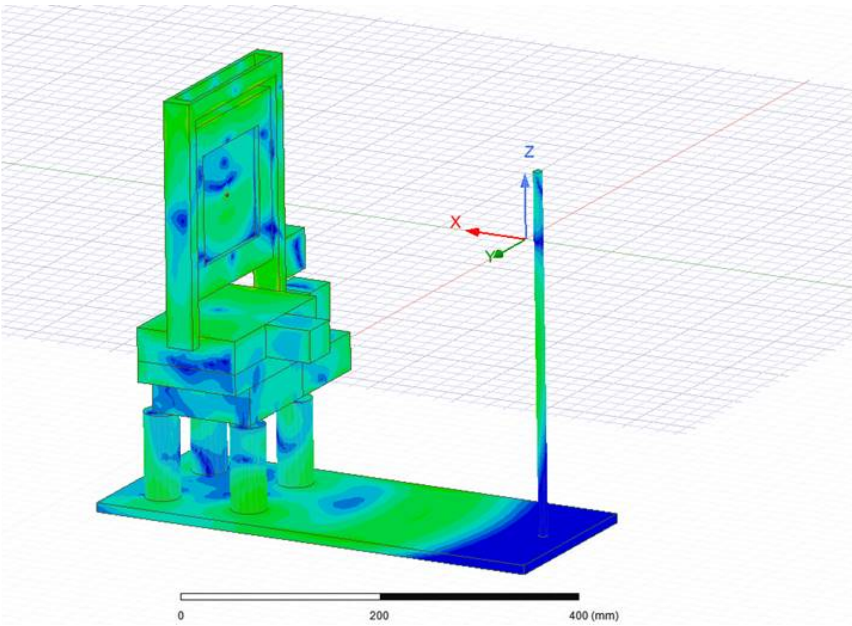

Figure 1. ELI MAIA target tower surface return current in 1.65 ns.

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EMP and electron energy correlations in laser particle acceleration from metallic targets

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Abstract

High Power laser is more and more considered as an alternative option for particle acceleration because of the more compact size of the system and, in some cases, because of the accelerated beam parameters or economical costs. The short laser pulse in its interaction with the target initially transfer the energy to the electrons and further, indirectly, to the atomic ions, producing the aceleration of the particles up to hundreds of MeV and even higher. For using such an acelerated particle beam to different applications, a rigurous characterisation of its parameters is necessary. Techniques for such a beam characterization are not trivial since the operation of the measuring instruments might actually affect the particle beam, making the beam characterisation difficult and sometimes imposible to characterize in real time, while using the beam for some particular applications. On the other hand, a drawback of the laser-based particle acceleration method consists in generation of strong **E**lectro**M**agnetic **P**ulses (EMP), known to produce issues to the experimental devices and electronics.

While EMP generation could hardly be avoided or even attenuated, the aim of this work is to use such signals to determine the accelerated particles parameters. Thus, we carried experiments in order to demonstrate correlation between the generated EMP signals with accelerated particle parameters from thin metalic targets. The experimental correlation between the maximal recorded accelerated electron energy and generated EMP signal energy for different materials with different thicknesses is presented in Fig. 1

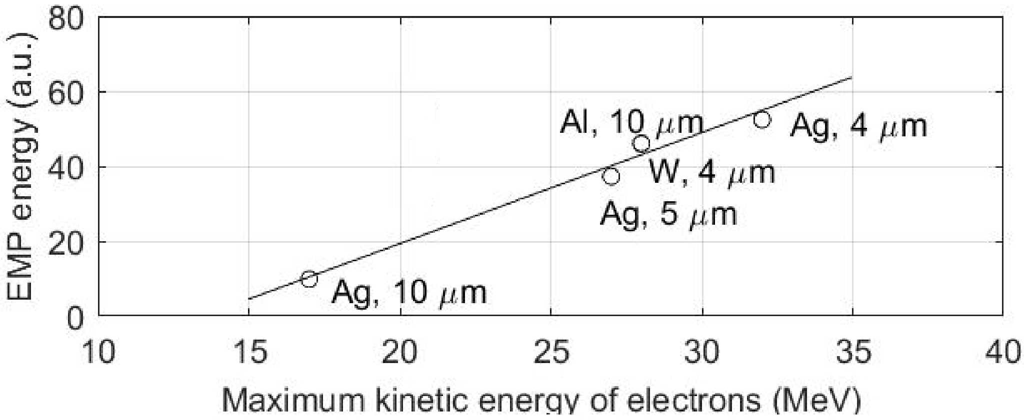

Figure 1. Electron maximal (recorded) energy from different material and thicknesses and produced EMP correlation

A further step in understanding the obtained experimental correlation was to model the emission process considering the charged particle accelerated movement as a source of the EMP generation. By taking into consideration the experimentally measured electron maximal energies, as well as their extraction energy and attenuation while moving through different materials, simulation of the theoretically emitted signal were performed. In Fig. 2, a comparison between experimentally recorded EMP (Fig. 2a) signals and simulation of the EMP generated signals (Fig. 2b) from Ag targets with different thicknesses is presented.

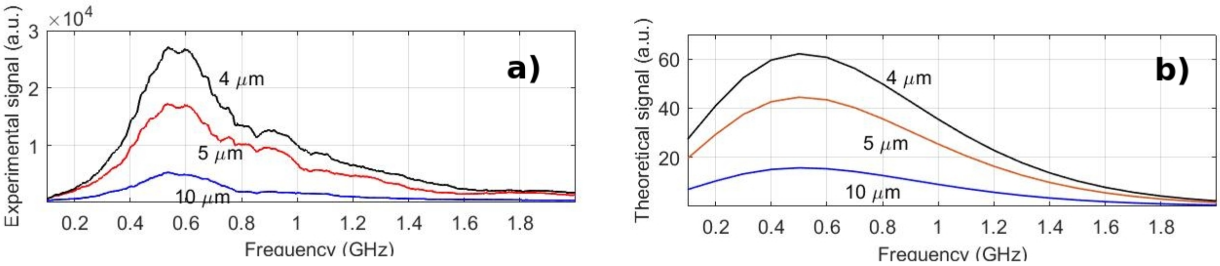

Figure 2. EMP generation in electron acceleration from Ag targets with different thicknesses a) experimental and b) theoretical simulation

Similar simulations for different target materials and film thicknesses were performed and compared with the experimentally recorded signals. The good agreement between the obtained simulation and the recorded signals in all our experimental cases suggest that used mathematical model is reasonably modeling the main EMP generation process and, consequently, based on the EMP real-time in-situ measurements, a reasonable particle beam characterization could be achieved.

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Laser-matter interaction as an innovative source of intense radiofrequency-microwave fields

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Abstract

The interaction of high energy and high intensity laser pulses with matter produces a wide band of electromagnetic and particle radiation of remarkable intensity, easily overcoming several hundreds of megawatt. In particular, the electromagnetic content includes radiofrequency, microwave, infrared, visible, UV, X and γ components. The low frequency part of this emission constitutes the well-known "Electromagnetic Pulses" (EMPs), omnipresent effect of laser-matter interactions in all the regimes. It was experimentally found that they scale with the energy and especially with the intensity of the incoming laser pulses [1]. Planned new laser facilities with enhanced features are thus expected to show very high levels of EMPs. Their intensity can be in several cases so high – MV/m order - to make them a serious issue for every electronic device placed within and nearby the experimental chamber. This is the reason why they are a very hot research topic for both Inertial Confinement Fusion and Laser-Plasma Acceleration studies.

Although the main push has been devoted to mitigation techniques for these EMP fields, there is a number of interesting and promising studies aiming at exploiting the mechanisms at the base of their generation. They include the generation of kilotesla transient magnetic fields [2] and of traveling waves for particle acceleration and focusing [3].

A new application has been recently proposed in ENEA – Centro Ricerche Frascati [4] for creating large-intensity (MV/m and beyond) transient electric fields, with specific spatial distributions and existing in big volumes of space, for a large number of applications such as: medicine, biology, electromagnetic compatibility, material science, aerospace, electronics, sensors. Fields can have spatial distributions that can be tailored to the specific application: quasi-uniform, quasi-linear gradients, …

We will describe here the methodology proposed, the associated numerical modeling and then the experiments performed with ENEA-ABC nanosecond laser facility (30 J, 3 ns) that proved the effectiveness of the proposed setup.

The methodology resolves in an original way the classical problem of generating quasi-uniform electric fields over large volumes and with very fast transients. This has the great potential to enable present and future laser plants to be innovative sources of tailored radiofrequency-microwave transient fields for a wide number of important applications.

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EMP WORKSHOP
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Towards laser driven Electromagnetic Radiation sources for Electromagnetic Compatibility testing

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Abstract

Recent advances on laser technology have enabled the development of ultrashort (fs) high peak-power (PW) laser systems, which are becoming available at large-scale laser facilities such as the Extreme Light Infrastructure (ELI). During the interaction of such extreme pulses with a target, a high amplitude electromagnetic pulse (EMP) is generated, which can severely compromise the good outcome of an experimental campaign. The strength and shape of this pulse strongly depends on the laser parameters and target configuration.

The understanding of the physical generating mechanism and ability to control the strength and shape of the EMP will not only prevent disruption of electronic devices during an experiment but also enable one for the development of a laser induces EMP (LIEMP) source as a new generation of radio-frequency source for Electromagnetic Compatibility testing.

The unique properties of LIEMP may serve interests in the communities of inertial confinement fusion, high-field physics, avionics and astrophysics. In this presentation, we will show, based on theoretical and experimental results, how the shape and strength of the EMP can be tailored either with the aim to prevent electronic disruption or as a new generation of radio-frequency source.

Frascati, 26 September 2022

Broadband THz-Time Domain Spectroscopy of Water

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Abstract: **Measurements of absorption coefficient and refractive index of water in a broadband THz frequency range (0.5-12 THz) as a function of temperature are reported. They were obtained by a THz-Time Domain Spectroscopy (TDS) setup using THz pulse generation by two colors laser-induced air-plasma and heterodyne detection based on THz air biased coherent detection. We make the measurements in transmission configuration on a water sample of a thickness of only 27 μm. The data have been compared with the literature ones and with the measurements obtained by another THz-TDS setup in attenuated total reflection configuration with traditional THz pulse generation and detection by two antennas. The quality of the data showed excellent. This opens the possibility to study the THz optical properties even in liquids presenting strong THz absorption, like, for example, biological systems.**

THz spectroscopy in water or liquid, showing strong absorption at these frequencies, is typically performed using the attenuated total reflection (ATR) configuration or on very thin samples. Moreover, a high intensity THz field is required to have high signal/noise ratio and a large frequency bandwidth to characterize the complete molecular dynamics of water and water mixtures.. THz generated by focusing on air high intensity femtosecond laser pulses (THz pulses emission from plasma), owns these above-mentioned peculiarities. In particular, two-colors laser-induced air plasma THz generation [1,2] together with THz Air Biased Coherent Detection (ABCD) [3] enable to setup THz-TDS experiments able to collect data characterized by high signal/noise ratio and by a broadband frequency range, from some hundreds of GHz up to tens of THz. Here we report measurements of absorption coefficient and refractive index of water as a function of temperature in a THz frequency range 0.5-12 THz in transmission and in ATR configuration by two THz-TDS setups: one with THz plasma generation and ABCD detection and another setup using two photocon-ductive antennas (PCA) for THz generation and detection.

The two color laser-induced air-plasma THz-TDS system employs high energy femtosecond pulses produced by a Ti:Sapphire Chirped-Pulse-Amplification (CPA) laser. The sketch of our setup is shown in Fig. 1. An 800 nm femtosecond laser pulse and its second harmonic are together collinearly focused on air to produce an air plasma filamentation of some mm length. High power THz pulse is produced by different nonlinear phenomena [4,5] and finally get a THz spectral bandwidth equivalent to the optical bandwidth. THz pulse is then guided into the sample and in the detection area by a traditional four parabolic mirrors THz-TDS configuration [6]. The measurement of the THz field is based on the ABCD technique. Optical probe and terahertz beams are collinearly focused on air on a same spot to induce a second harmonic pulse (400 nm) by third order nonlinear response of the air. A pair of electrodes with a 1 mm gap, high voltage biased at 500 Hz, synchronized with the 1 KHz laser repetition rate, is placed across this spot. This electric field together with the optical probe field produce a second harmonic signal, which constitutes a local field for the heterodyne detection. Second harmonic radiation, filtered by a 400 nm bandpass filter, is sent into a photomultiplier tube, whose signal is measured by a lock-in amplifier referenced to the 500 Hz bias modulation frequency.

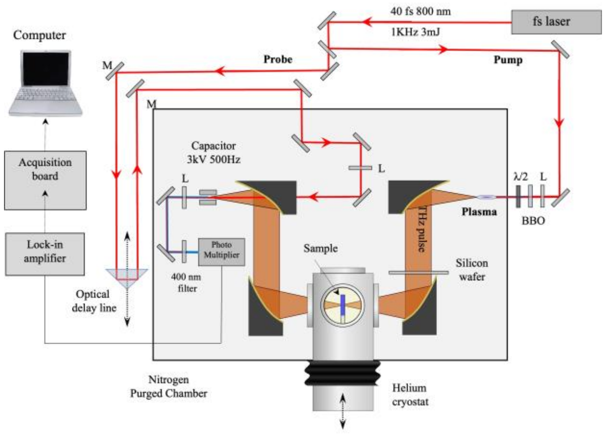

Figure 1. Broadband THz-TDS setup with THz pulse generation by two colors laser-induced air-plasma and ABCD technique.

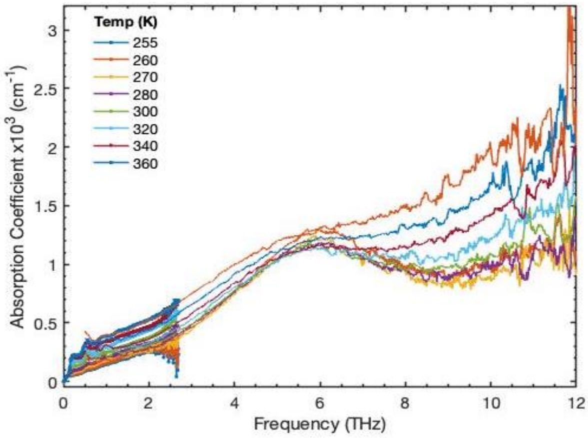

Figure 2. Water absorption coefficient as a function of temperature measured by broadband THz-TDS setup (continuous lines) and PCS THz-TDS setup (close circles).

The transmission measurements have been realized using a homemade cell build with two circular diamond windows, 1 mm thick, and a 27 μm thick brass spacer washer. Two copper rings with six through screws closed and held the cell together. The cell was temperature controlled by a close cycle helium cryostat with a temperature stability of ± 0.1 °C. The cell is filled with double distilled water.

To extract the optical parameter of water from the acquired transmission THz data, we performed a complex analysis of the transfer function of the whole window-water-window system alike that reported on [6] for two-layer samples. This analysis relies on an accurate knowledge of the optical parameters and thickness of the diamond windows, which have been, therefore, previously measured performing the THz-TDS experiment on the diamond windows alone.

Measurements on water in ATR configuration were carried out using a standard silicon prism cell with both the THz-TDS setups. The agreement between the two sets of data is very good.

In Fig. 2, we show the frequency behavior of absorption coefficient of water as a function of temperature (which extends down to the supercooled regime, 255-360 K) measured with broadband THz-TDS setup in transmission configuration and with the PCA THz-TDS setup in ATR configuration. The quality of the extracted values showed excellent. The agreement between the data obtained with the two different THz-TDS setups is very good extending the probed spectral range from almost 0 to 12 THz. Our finding confirms the possibility to study the THz optical properties in liquids presenting strong THz absorption, like, for example, water-mixture biological systems, even with more complex pump-probe nonlinear spectroscopic techniques, which potentially require the transmission configuration.

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Experimental estimation of the EMP spectral microwave energy generated by a LOLLIPOP target

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Abstract

The LOLLIPOP target is an object specifically designed for the EMP studies [1]. The purpose of this target is to have experimentally a direct access to the discharge current which is a consequence of electron expulsion by the laser from the target. This discharge current is a major contributor to the EMP in microwave range. Indeed, by blocking this current circulation thanks to a cage around the target, the EMP is almost cancelled [2]. In addition to this current measurement, the magnetic field was systematically measured by a RB230 Prodyn probe inside the experimental chamber.
If the major part of the physics involved in laser induced EMP is now understood (Cf. [3]), some discrepancies between the models and the experimental results still remain. The question is to known if theses discrepancies come from the measures or from the models.
The only way to check the measurement is to compare a common quantity from these measures. A direct comparison from the discharge current and the magnetic field makes obviously no sense. However, the microwave energy emission from the target could be obtained from the discharge current. The same quantity could be also got from the magnetic field. The two diagnostics provide a consistent estimation of the microwave energy emission from the target, which gives fair evidence that the discrepancies are not experimentally related.

Keywords:
Laser, electromagnetic pulse.

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Electro-optical sensing of intense electromagnetic pulses in a multi-hundred joule laser facility

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Abstract

Electromagnetic pulses (EMPs) generated by the interaction between energetic laser pulses and matter represent a hazard for the safe operation of laser-plasma experiments at high-power facilities and, at the same time, they promise interesting applications where intense (up to the MV/m) pulsed fields (with durations in the order of ns) are required. Therefore, their characterization and absolute measurement is a topic of high interest. In the last years, numerous measuring techniques and devices have been implemented for detecting EMPs, in terms of both electric and magnetic component of the generated wave, among which conductive probes and electro-optical sensors have been used.
The latter have the potential advantage (over the more commonly used conductive probes) of being less subject to the interaction with plasma particles and radiation and electromagnetically couple less efficiently with surrounding metal objects, due to the absence of conductive components. These features make them very useful for EMP measurements close to the interaction point, but they were only tested in facilities with tens of Joules energy, nanosecond long laser pulses. When higher energies are involved, even electro-optical methods for EMP detection might be affected by the large amount of produced ionizing radiation.
Here we present experimental data obtained at the PALS laser facility (~600 J pulses in 350 ps) where electro-optical detectors have been successfully implemented at short distance from target (<0.5 m). We addressed the delicate issue of high ionizing radiation produced, and we characterized the EMP emission in terms of intensity and spectral components with these probes. We compared the results with those from a conductive probe placed close to the electro-optical ones. The electro-optical probes, here used for the first time on a multi-hundred Joule facility, provided results consistent with the ones of the conductive antenna and proved therefore to be a suitable alternative of high performance for EMP measurements.

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EMP WORKSHOP
Frascati, 26 September 2022

Measurement of target current using inductive probe

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Abstract

It is generally considered that for the generation of laser-driven EMP various mechanisms are responsible. One of the most important sources of EMP is a pulse of target current that compensates a charge of the target created by escaped electrons. This conference contribution is aimed at the measurement of this target current using an inductive current probe. Our inductive current probe operates analogously to a B-dot probe, except that it is designed to be sensitive only to the component of the magnetic field driven by the target current. This method is beneficial since the current is not affected by an additional resistance of a shunt resistor and its parasitic parameters. In experiments on the PALS iodine laser system (1315 nm, 700 J, 300 ps, 10^{16} W/cm^2) the target current reaches the order of kA and the carried charge could exceed 10 μC depending on the target configuration and beam parameters. In this contribution, we present results from experiments with various arrangements using different designs of the current probe. We also discuss methods to calibrate and test the reliability of the target probe using a 200 ps electric pulse generator ("simulator of the target current") and a femtosecond laser.

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EMP WORKSHOP
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EMP measurements at VEGA: status and prospects

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Abstract

We present and compare experimental studies of electromagnetic pulses (EMP) produced at the high-power 30 fs lasers VEGA-2 with 200 TW and VEGA-3 with 1 PW. The seed space charge fields are triggered by the interaction of the laser pulses focused to relativistic intensities onto solid density and gas targets, at intensities ranging from several 10^{19} W/cm^2 to several 10^{20} W/cm^2. The detection of EMP is achieved by passive calibrated B-field and E-field antennas with large bandwidth from 9 kHz to 400 MHz and 300 MHz to 8 GHz respectively.

Outstanding features are the excited cavity modes, clearly detected by the compact antenna system, that can be tailored by modification of the experimental geometry. The detected magnetic fields inside the interaction chamber show amplitudes ranging from tens to hundreds of µT, which is up to ten times stronger than earth's magnetic field. Electric fields in the vicinity of the interaction chamber show amplitudes of hundreds of V/m, which is of the order of fields encountered in cm distance to GSM mobile phones. In the experimental hall, amplitudes hint at a dipole-like radiation field that bears the order of one ten-thousandth of the laser pulse energy.

Building upon the study, we present prospects for a target geometry mitigating EMP and perspectives to make use of systematic quantitative evaluation of EMP.

EMP WORKSHOP
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On the EMP Issues at ELI-NP

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Abstract

ELI-NP is a user facility in Romania, available for experiments of unprecedented performance in the field of plasma and nuclear physics [1], [2]. Its High-Power Laser System was recently commissioned and is the most powerful in the world, being able to provide 2 x 10 PW with 1 shot per minute repetition rate, 2 x 1 PW at 1 Hz and 2 x 100 TW at 10 Hz pulses.

When a high-power laser beam is focused onto a small target, a broad range of types of radiation, from electromagnetic fields of tens or hundreds of kV/m to ionizing radiation, such as X – rays, γ-rays, high-energy electrons, ions and neutrons, flood the target chamber. The Electromagnetic Pulse (EMP) is generated mainly by the impulse of charged particles which excites the chamber and equipment within it [3]. This causes the chamber and equipment to ring at their natural frequencies, which can extend from MHz up to THz. The EMP is emitted from the chamber through ports and wiring into the surrounding room, where it is modified by reflection and absorption from equipment and the walls of the room. The EMP is also propagated down the beam tube to the laser components. Semiconductor devices in equipment within the target chamber and surrounding rooms are susceptible to damage and malfunction by EMP-induced voltages. These need to be protected by shielding or moved away from the source of EMP. Signals from target diagnostics are degraded by EMP pick-up. There is also a need to ensure that the level of EMP in occupied areas, outside the target area, is safe for personnel. Likewise, designing a proper EMP shielding for diagnostics is a high priority at high-power laser facilities. These lasers operate at a high repetition rate and the solution of using passive diagnostics in experiments, immune at EMP, is not viable. The issues mentioned above raise significant engineering difficulties for the teams involved in the development of the instrumentation for experiments. A good understanding of the magnitude and frequency range of the EMP helps in the development of models, strict control of the unwanted conducted and radiated EMP emissions and designing the efficient EMP shielding system.

In this challenging context, a significant effort for implementing an EMP measurement installation in the laser experiments has been made by the scientists from ELI-NP. The instrument presented in Figure 1 was developed for the commissioning experiments for the particle acceleration with the 1 PW laser. This is fully operational and it turned out already to be a useful tool to verify the effectiveness of the EMP shielding around the chambers and experimental areas, study the generation mechanisms of EMP and find optimal solutions to reduce or mitigate its effects [4]. The main features of the EMP measuring instrument and preliminary results achieved with it are reported here. The shielding strategy applied at ELI-NP with the current status of the implementation of the EMP shielding within the building is presented too. The important aspects considered in the design of experimental instruments to obtain and maintain the overall integrity of the electromagnetic shield are pointed out.

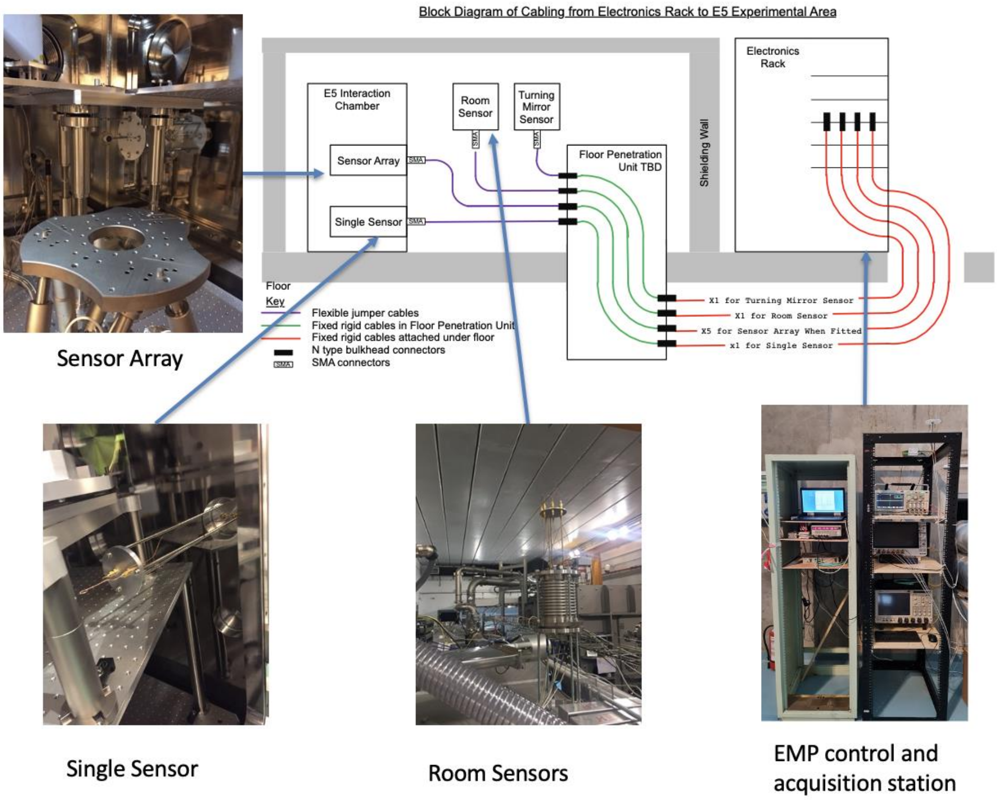

Figure 1. Overview of EMP measurement system used in the commissioning experiments for particle acceleration with the 1 PW laser.

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