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# Laser-based control of Spark Gap Switches: Topologies and Considerations for HPEM Applications

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Modern high power electromagnetic radiators require high amplitude, high speed, low jitter switches for synchronization, command, and control when combining multiple sources. Spark gap switches, highly used in HPEM applications, are an old, but nevertheless, reliable technology that can be used for this purpose. The topology consists of two electrodes placed in a pressurized enclosure containing an insulating gas (e.g. nitrogen, SF6, hydrogen), subject to a potential difference and a triggering source. Three basic triggering techniques can initiate the closing of the arc between the electrodes, namely, self breakdown, electric triggering, and laser triggering, which can be summarized as follows:

- In self-breaking spark gaps, the discharge is triggered by the ionization of the gas between the electrodes, caused by an increasing electric field produced by the applied voltage [1]. This mechanism is the simplest one, but the jitter can be in the 10's of nanoseconds range for the 20-30 MV/m breakdown electric field [2].
- In electrically triggered spark gaps, an external electrical signal pre-ionizes the gas, easing the discharge process by the background electric field. This second mechanism offers jitter times in the range of the 100's of picoseconds for breakdown fields in the range of 100-200 MV/m [3].
- In laser triggered spark gaps, which represents the approach of interest in this paper, the pre-ionization is produced by a laser pulse focused between the two electrodes. The discharge can initiate at an electric field between 10 and 20 % lower than the self-breakdown electric field for the same gas pressure. This process is linked to the ionization density induced by the laser in the gas. This triggering mechanism was investigated for the first time in 1965 [4]. According to the laser peak power, two ionization regimes are involved and are quantified using Keldysh parameter $\gamma$ [8]: either multi-photon ionization when $\gamma \geq 1$ resulting in the generation of a plasma condensed in the focal region, or electron-tunneling when $\gamma \leq 1$ resulting in a plasma channel few times longer than the Rayleigh length. The first regime ($\gamma \geq 1$) is favored by the use of industrial-grade lasers with nanosecond pulses and energy levels ranging from mJ [5] to J [6], resulting in nanosecond and 100's of picoseconds time jitters, respectively. The second regime ($\gamma \leq 1$) favored by the use of scientific-grade ultrafast lasers delivering femtosecond pulses with lower energy levels ranging from µJ to 10's of mJ, produces lower jitters down to 15 ps [7].

This paper presents a quantitative assessment on the synchronization of 50-kV HPEM sources using laser triggered spark gaps with jitter in the order of 10 ps and breakdown electric fields in the 5 MV/m range. The analysis is based on the consideration of the Keldysh parameter, plasma modeling in the time and space domains, and electromagnetic field simulations for different laser parameters and topologies (electrodes geometry, gas type, and pressure, laser pulse width, and energy). The design of an experimental setup will be presented. It includes a gas-filled laser spark gap, laser seeding optical system, the high voltage source and the measurement system. This setup will allow us to fully characterize the laser-induced plasma in time and space domains and measure the resulting jitter in the pulse.

## References

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