TIME JITTER OF GAS DISCHARGE CLOSING SWITCHES – A REVIEW –

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Outline

- **Background**
- **Survey Summary**
- **Concluding Remarks**

Background – Objective and Method

- **Objective: To identify switches with low time jitter.**
  - » **Hold-off voltage in the range 10-500 kV**
  - » **Pulse-repetition rate up to 1 kHz**
- **Method: Searching the following databases**
  - » **Engineering Village 2**
  - » **IEEE Xplore**
  - » **References within references**
- **Limitations:**
  - » **Only gas discharge switches**

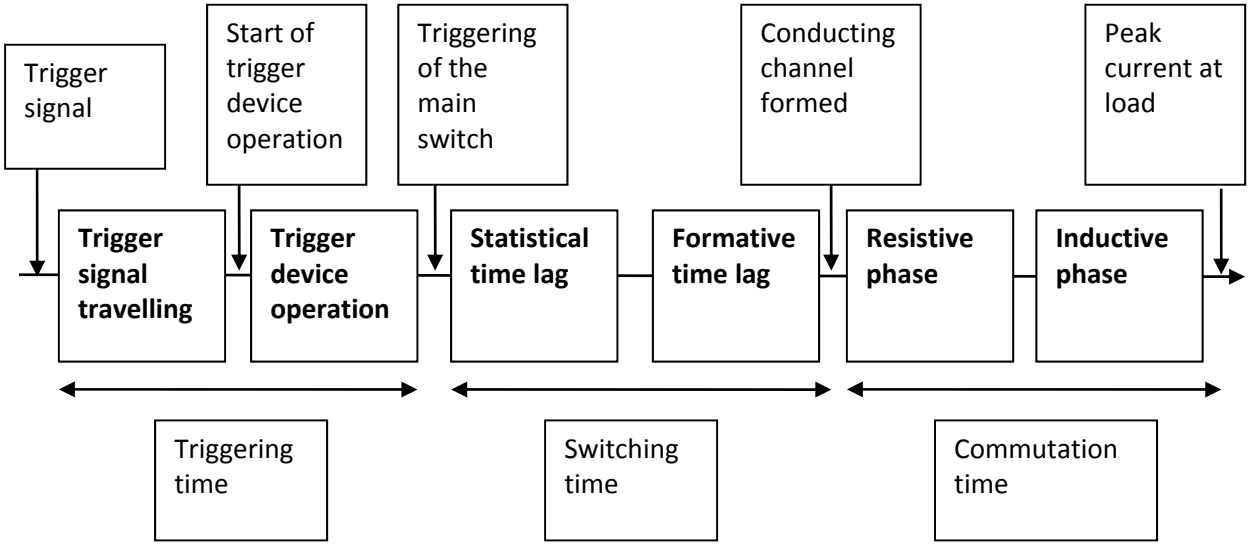
Background – Requirements of a Switch

1. Hold-off voltage
2. Peak current
3. Average current
4. Coulombs per shot
5. Impedance (in system)
6. Voltage drop
7. Delay time
8. Recovery time
9. Repetition rate
10. Duty cycle
11. Jitter
12. Pre-fire
13. Triggering requirements
14. Thermal dissipation
15. Cooling requirements
16. Lifetime
17. Reliability
18. Maintainability
19. Fault modes
20. Weight
21. Volume
22. Cost
23. Ease of installation and removal
24. Orientation
25. Configuration, coaxial, stripline, etc.
26. Shielding requirements, RF, etc.
27. Operating environment, e.g.,
    Pressure (altitude)
    Temperature
    Radiation (uv, neutrons, gammas, etc.)
    Stress (Acceleration, magnetic pressure)
28. Others
29. The one we forgot
30. The one that does you in
31. Etc.
32. ?

B. Novac and I. Smith, "Pulsed Power and Applications - Short Course in Pulsed Power", *presented at the* Power Modulator Conference, San Francisco, USA, 2004

Background – Jitter in Pulsed-Power Systems

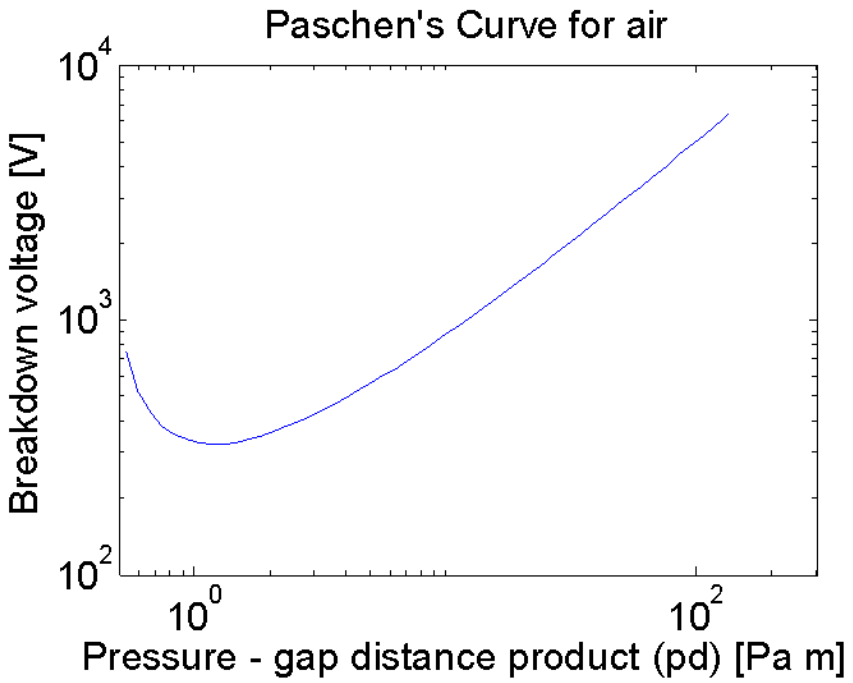
- **The sequence of events from trigger command to closure of switch**



In this survey, only the time jitter in the switching delay time is considered.

Survey of Gas-Discharge Closing Switch Techniques

- **Low-Pressure Switches (1-100 Pa)**
  - » **Vacuum Tubes**
  - » **Metal Vapour Switch**
  - » **Thyratron**
  - » **Cold-Cathode Thyratrons**
    (Pseudospark Switch and Backlighted Thyratron)
  - » **Cross-Field Devices**
- **High-Pressure Switches (0.1-10 MPa)**
  - » **Spark-Gap Switches**
  - » **Surface-Discharge Switches**
  - » **Corona-Stabilised Discharge Switches**



Survey of Gas-Discharge Closing Switch Techniques

- **Spark-Gap Switches**
  - » **Self-Triggered**
  - » **Over-Voltage Triggered**
  - » **Trigger Electrode (Trigatron)**
  - » **Field-Distorted Three-Electrode Gaps**
  - » **Electron-Beam-Triggered**
  - » **Laser-Triggered**

Summary of Survey

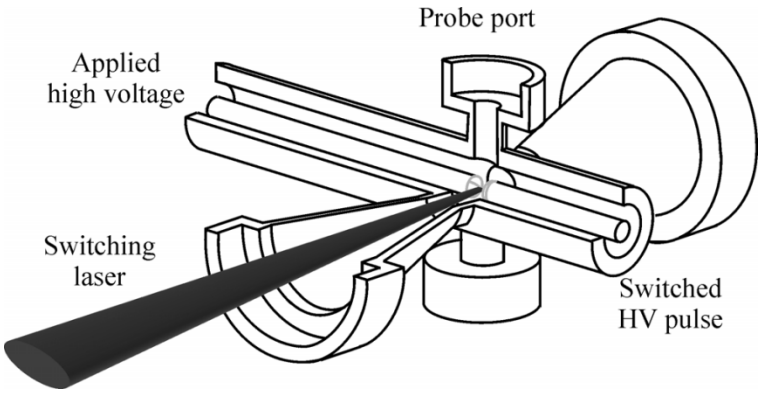
Switch type	Sub-ns-jitter reported?	Hold-off voltage of 100 (500) kV reported?	Pulse-repetition frequency of 100 Hz (1 kHz) reported?
Vacuum Tube	No	No	No
Metal vapour switch	No	Yes (No)	No
Thyratron	No	Yes (No)	Yes
Cold-cathode thyratron	Yes	Yes (No)	Yes
Crossed-field device	No	Yes (No)	Yes
Surface-discharge switch	Yes	No	No
Corona-stabilised discharge switch	Yes	Yes (No)	Yes
Spark-gap switch			
- Self-triggered	Yes	Yes (Yes)	Yes (Yes)
- Trigatron	Yes	Yes (Yes)	Yes (No)
- Field-distorted three-electrode gap	Yes	Yes (No)	Yes (No)
- Laser-triggered	Yes	Yes (Yes)	No

Identified switches

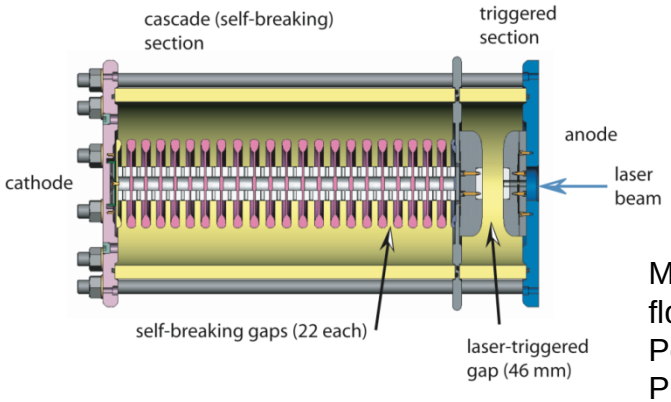
- **Laser-triggered spark-gap switch**
  - » **Lowest time jitter**
  - » **Fibre-delivery of laser pulse promising**
- **Field-distortion three-electrode switch**
  - » **Most mature**
- **Corona-stabilised discharge switch**
  - » **Least developed**
  - » **Great potential for high repetition rate**
- **Pseudospark switch**
  - » **Uncertain voltage scalability**
  - » **Great potential for high repetition rate**

Survey – Spark Gap, Laser-Triggered

- **Laser beam focused in the spark gap to create free electrons**
  - » **Spot focus on cathode**
  - » **Spot focus mid-gap**
  - » **Line focus along spark-gap axis**
- **Used in cascade or single gap**
  - » **5 MV / - / 4 ns**
  - » **4.5 kV / - / < 15 ps**



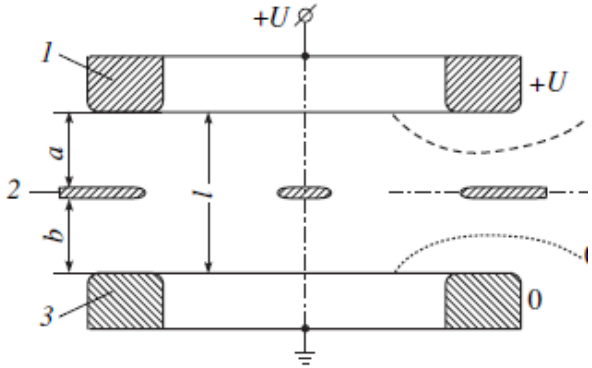
G. J. H. Brussaard and J. Hendriks, "Photoconductive operation of a laser triggered spark gap", IEEE Transactions on Dielectrics and Electrical Insulation, vol. 14, pp. 976-979, 2007

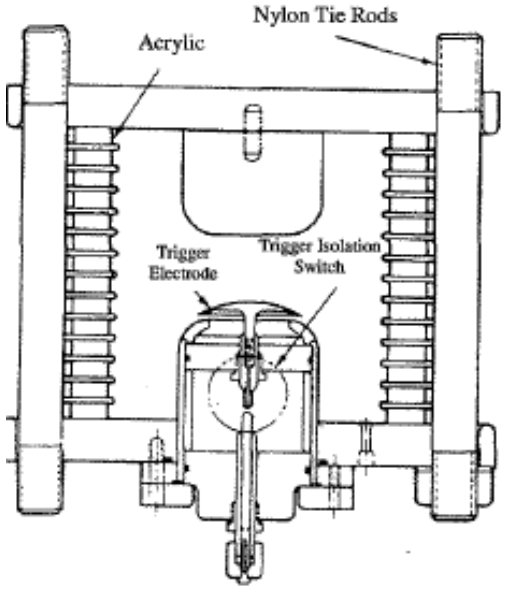


M. E. Savage, et al., "An overview of pulse compression and power flow in the upgraded Z pulsed power driver", in 2007 IEEE Pulsed Power Plasma Science Conference, 17-22 June 2007, Piscataway, USA, 2007

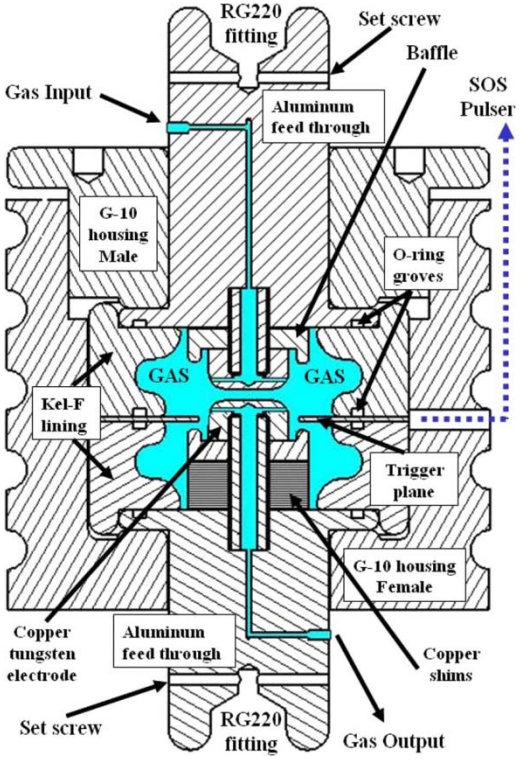
Survey – Spark Gap, Field-Distortion

- **Third electrode between the main electrodes**
- **Does not significantly disturb field distribution in open state**
  - » **50 kV / 100 Hz / < 1 ns**
  - » **300 kV / - / 30 ps**
- **Two types**
  - » **Mid-plane**
  - » **V/n switch**





V. Carboni, et al.
Switching Note 32, 2002

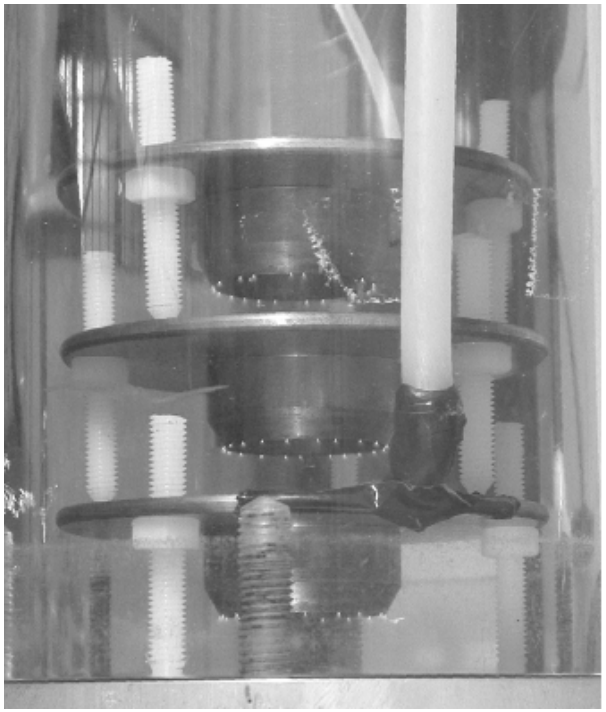


Y. Chen, et al., "Low-jitter triggered spark gap with high-pressure gas mixtures“, IEEE Transactions on Plasma Science, vol. 36, pp. 2546-53, 2008

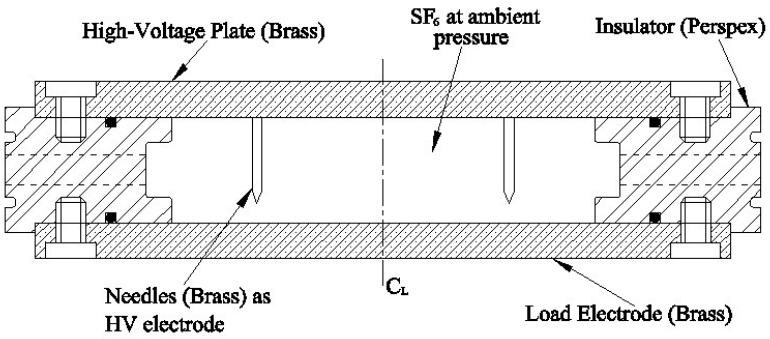
A. I. Gerasimov, "Multichannel spark gaps with control bar electrodes: their development and application (a review)," Instruments and Experimental Techniques, vol. 47, pp. 1-31, 2004.

Survey – Corona-Stabilised Discharge

- **At open state, corona discharge in the spark gap**
- **The space charge makes the field more uniform**
- **Increase the recovery time of the switch**
  - » **100 kV / 1 kHz / -**
  - » **100 kV / - / < 2 ns**



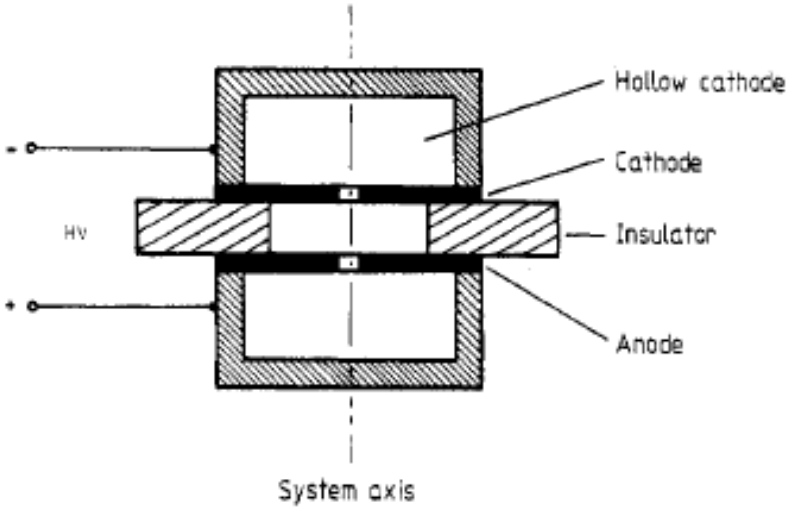
J. R. Beveridge, et al., "A corona-stabilised plasma closing switch", IEEE Transactions on Dielectrics and Electrical Insulation, vol. 16, pp. 948-955, 2009



P. Sarkar, et al., "A high-repetition rate closing switch for EMP applications", IEEE Pulsed Power Plasma Science Conference, Piscataway, USA, 2007

Survey – Cold-Cathode Thyratron

- **Low-pressure switch**
- **Hollow cathode with opening facing anode**
- **In open state: low-current, high-voltage steady-state discharge**
- **Injecting electrons into hollow cathode triggers breakdown**
- **Pseudospark switch**
  - » **Electrically triggered**
  - » **32 kV / 1 kHz / 5 ns**
- **Backlighted thyratron**
  - » **Optically triggered**
  - » **10 kV / 10 Hz / sub-ns**



G. Mechtersheimer, et al., "High repetition rate, fast current rise, pseudo-spark switch“, Journal of Physics E (Scientific Instruments), vol. 19, pp. 466-70, 1986.

Concluding Remarks

- **Four switch types identified:**
  - **Laser-triggered spark-gap switch**
  - **Field-distortion three-electrode switch**
  - **Corona-stabilised discharge switch**
  - **Pseudospark switch**
- **Only a few of the requirements of a switch were considered.**

Thank you!