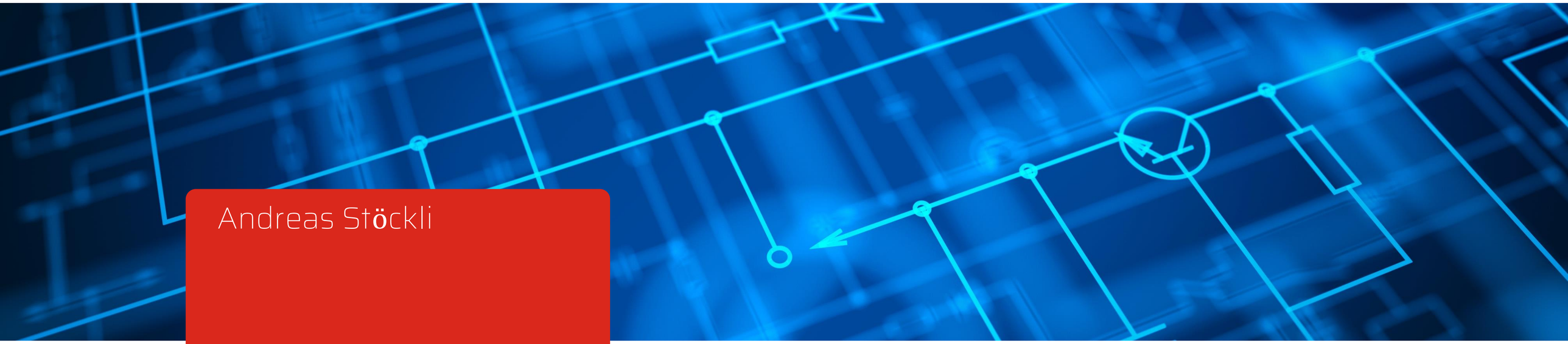
Solid state power switches for pulsed power applications



Andreas Stöckli

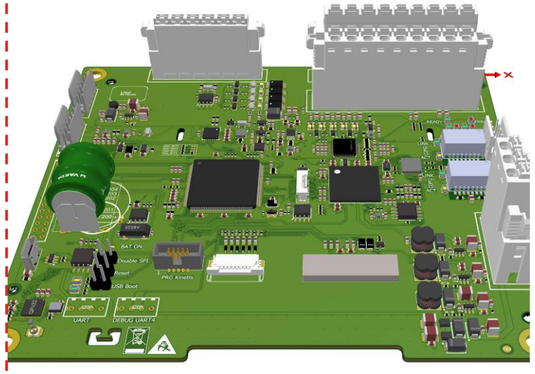
May 28, 2024

From designer of custom-build electronics to technology leader in pulsed power switches and solid-state circuit breakers

Content

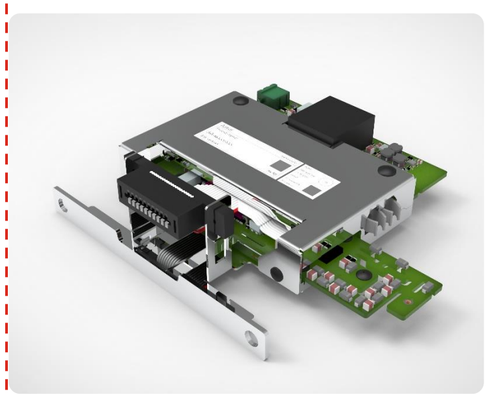
Timeline

1996 2001 2006 2010 2011 2016 2020 2025



Customized Electric Solutions

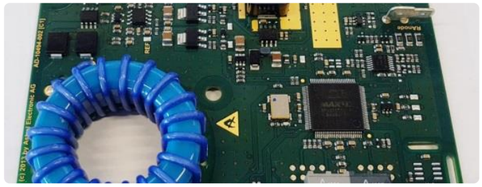
Astrol established in Baden, Switzerland.

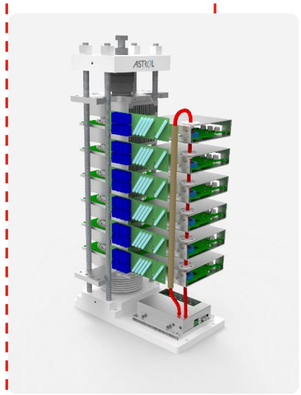


Gate Drive Units & Power Supplies

Start cooperation with ABB.

Trigger Controllers & Optical Interfaces





Power Switches

Astrol officially continues ABB's pulsed power assembly business.

Design of own stack assemblies, gate drive units and integrated pulsed power solutions.

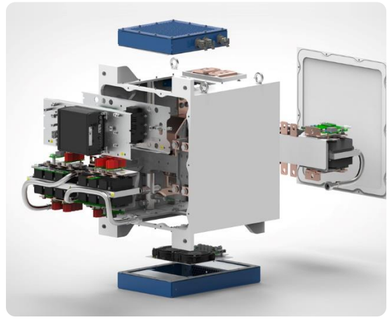
Solid-state AC & DC breakers

Design of new solid-state breaker technology from scratch.

Technology leader in the field of high di/dt solid-state power switching.

ASTROL

Astrol owned products & trading business



Solid-state Circuit Breakers

Marine DC grids

- **Platform A**: 1.5 kV, up to 3 kA, DNV and CCS certified. 3 kV version upon request
- **Platform B**: 1.5 kV up to 5 kA

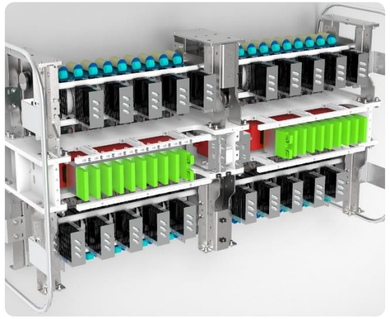
Smart-grid DC & AC

- 3-phase MV platform: up to 11 kV, up to 3 kA per phase

Customized SSCB

- Upon request

Our breakers are based on IGBT technology, IGCT-based breakers and hybrid breakers available upon request



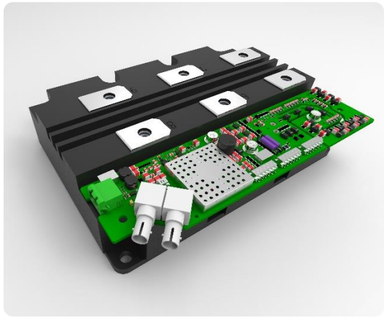
Solid-state Power Switches

Power Switch Assemblies
With the following subcategories:

- AC switches
- Integrated switching systems
- High di/dt switch assemblies
- Standard thyristor assemblies
- Diode assemblies
- IGBT assemblies
- Crowbar assemblies
- MOV and BOV assemblies

Current and voltage ratings
Up to 100 kV, 200 kA*
High di/dt up to 30 kA/µs

* (higher ratings) upon request



Gate Drive units & Isolated Power Supplies

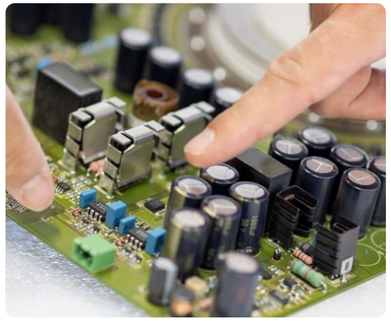
Gate Drive Units for:

- IGBT
- BIGT
- SiC
- IGCTs
- Thyristors

Fully programmable to optimize switching behaviour

Programmable monitoring functions

Inductive power supply solutions up to 100 kV



Customized Electronics

Electronics design and manufacturing

- HW and SW design
- Prototype
- Industrialization
- Series production

Trading Business (Benelux)

astrolkwx
power electronics solutions

- Jiashan Sine Busbars
- Hitachi Energy Semiconductors
- Littelfuse Rectifiers
- IXYS Semiconductors
- Meccal Heatsinks
- Danotherm Resistors
- Electronicon Capacitors
- Eaton Fuses
- Petercem Sensors
- Powerex

What is pulsed power?

And what are the main applications

- One or more very short high energy pulse(s) or bursts of several high energy pulses.
- Applications with current rise rates (di/dt) above the standard product range.
- Applications which must handle high current and high voltage for a defined short time.

Fields of application

What is pulsed power used for?

Generate heat: Sintering

Electromagnetic Radiation

- Radar
- Medical Equipment
- Microwave

Change materials

- DeSox-DeNox
- Hemp treatment
- Rock blasting

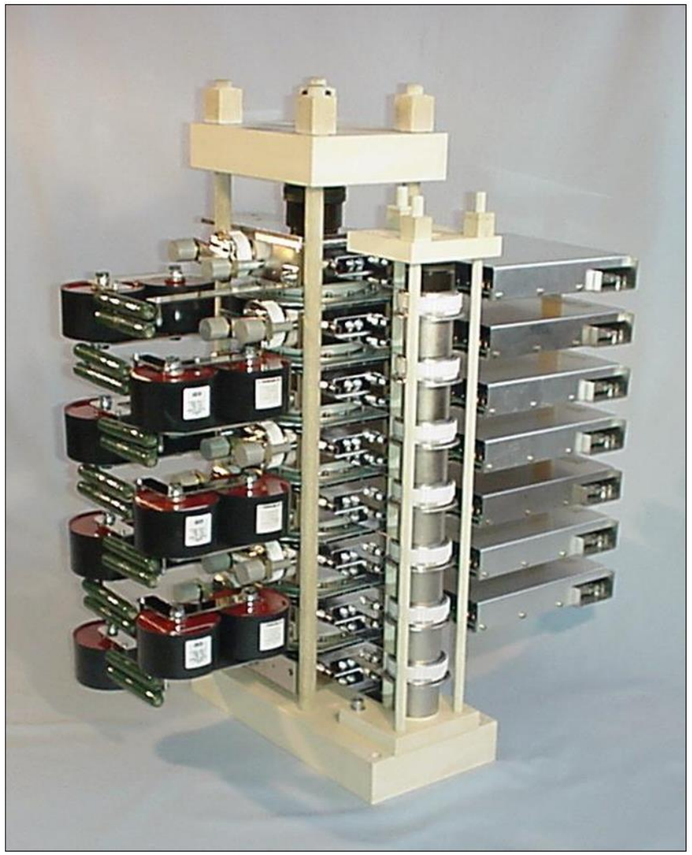
Magnetic Acceleration & Forming

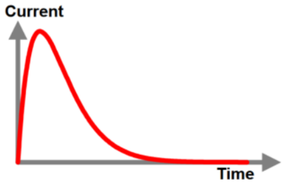
- Fusion Power
- Railgun
- Satellite launching
- Magnetic forming

Energy dump

- Crowbar switch
- Impedance measurement

Pulsed power introduction





Pulsed power is electric energy in the form of high current single pulses or burst of several pulses.

Standard or special semiconductor elements, connected in series and parallel.

- Pulse voltage up to **100‘000 Volts**
- Pulse current over **1 million Ampère** possible
- The pulse length is typically in the range of microseconds to milliseconds

Different types of Semiconductors

- Single Shot (low repetition) Discharge Switches

Crowbar / Electro-magnetic Launching / Magnetic Forming / Rock Blasting

→ Thyristors

- Repetitive Discharge Switches

Medical Equipment / Radars / Repetitive Electromagnetic Launching / Impedance Measurement / DeSox-DeNox

→ GCT

- Turn On-Off Switches

Fusion Power / Fish Barriers / Klystron Modulators

→ HiPak IGBT, StakPak IGBT, IGCT

Semiconductor devices for pulsed power

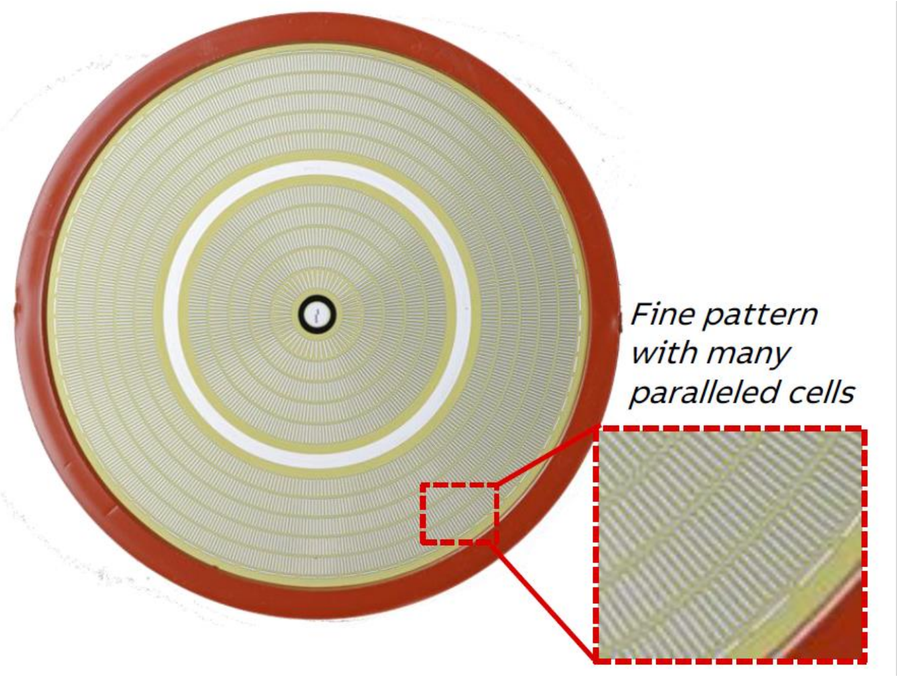
And what are the main applications

- Structure high di/dt devices

- Structure low di/dt devices

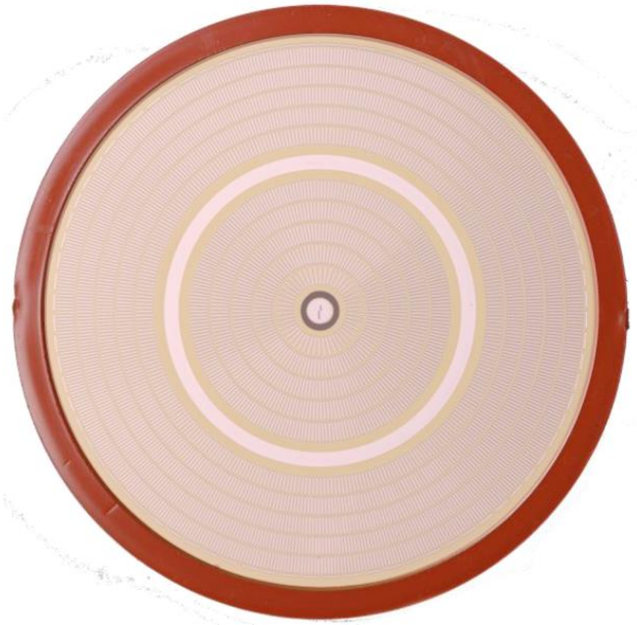
Brief comparison Thyristor - GCT

One big single cell



Conductive area immediately after firing

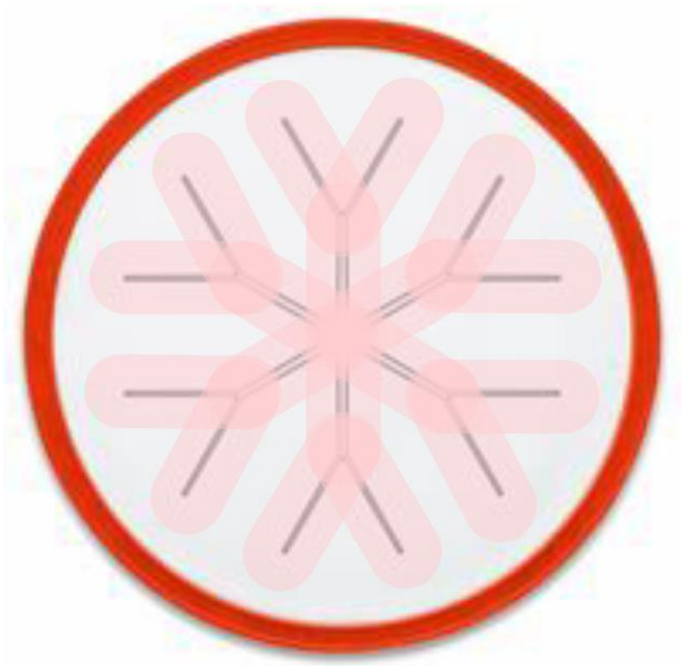
When the device turned on, the switch takes time to become conductive. The so called «plasma-spreading» can be observed on the figures below.

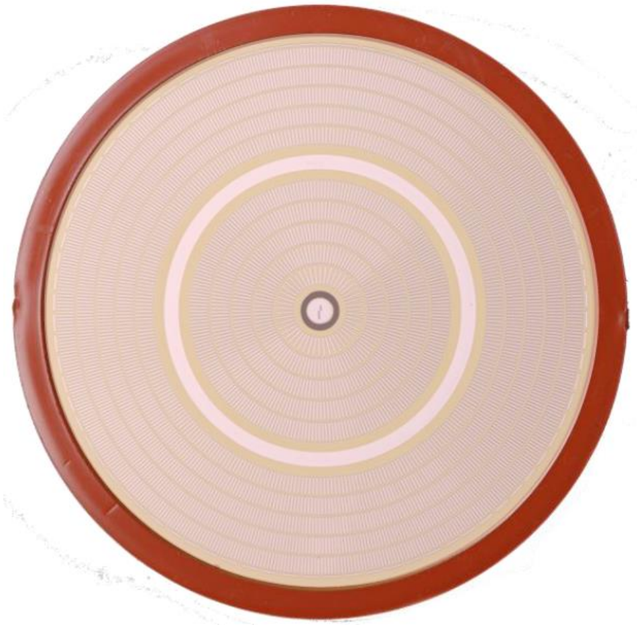


Conductive Area

Conductive area after 10-50us (fast application)

As you can see, only a small area is conductive. This means that hotspots can occur on the silicon at higher di/dt, which leads to a reduction in operating life and even complete destruction.

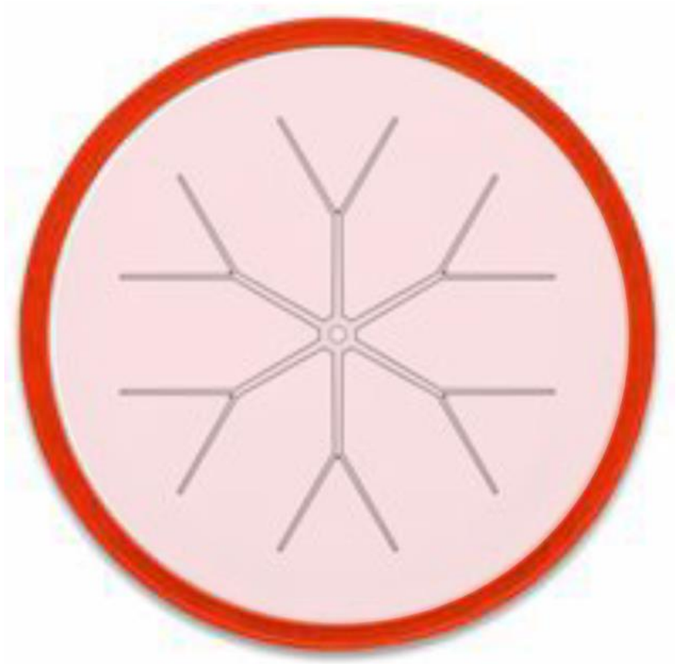




Conductive Area

Conductive area after >1ms (slow application)

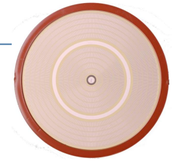
For standard application where current is not rising very much a PCT can be used.



Conductive Area

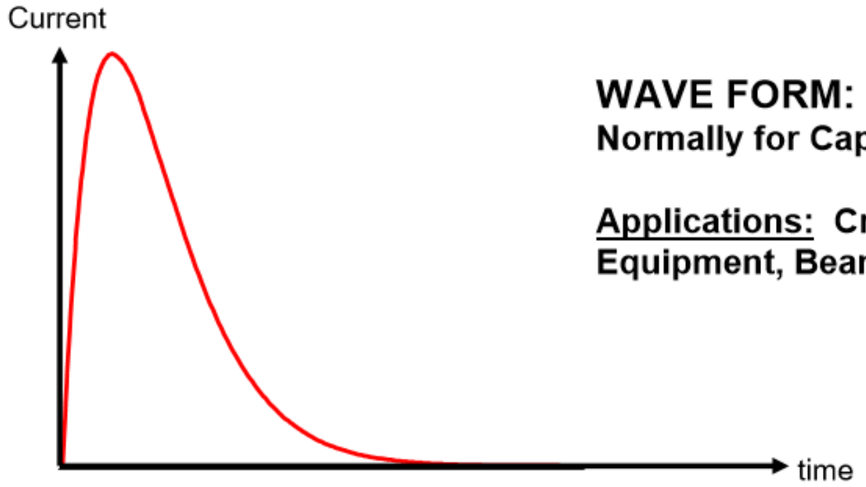
Typical pulsed power wave forms (discharge)

- 1 big cell
- Takes time till this cell is fully conductive.
- Temperature gradient goes from conductive to non-conductive area.
- Temperature gradient can create higher (than expected) temperature differences and therefore create additional thermo-mechanical stress.
- With a high number of pulses this can cause earlier end-of-life indications for the same amount of fired pulses (PCT compared to GCTs).



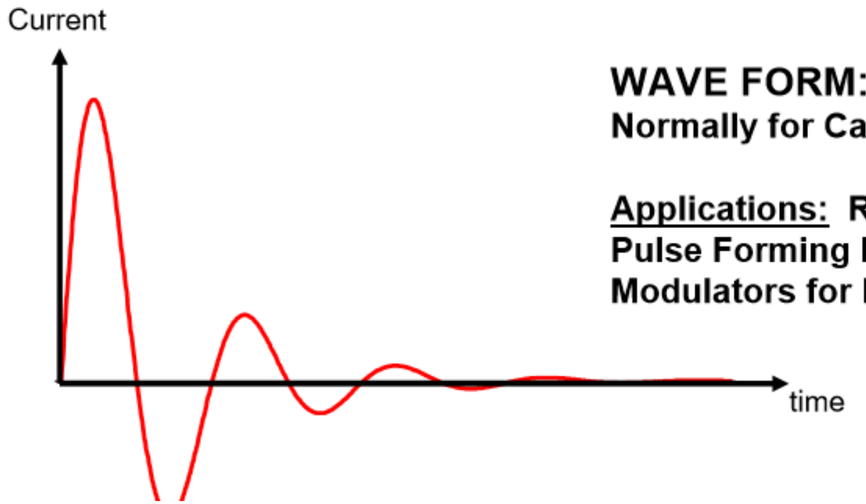
- >1000 cells switched in parallel
- After the firing signal, the cells homogeneously become conductive within microseconds.
- The current distribution is equal over the whole surface within short time after the firing pulse
- The equal current distribution allows optimum loading over the whole wafer and result therefore in highest robustness and high lifetime expectancy.
- Additionally, a more uniform current density over the whole contact surface can be reached.

Typical pulsed power wave forms (discharge)



WAVE FORM: EXPONENTIAL DECAY
Normally for Capacitor Discharge into a resistive load.

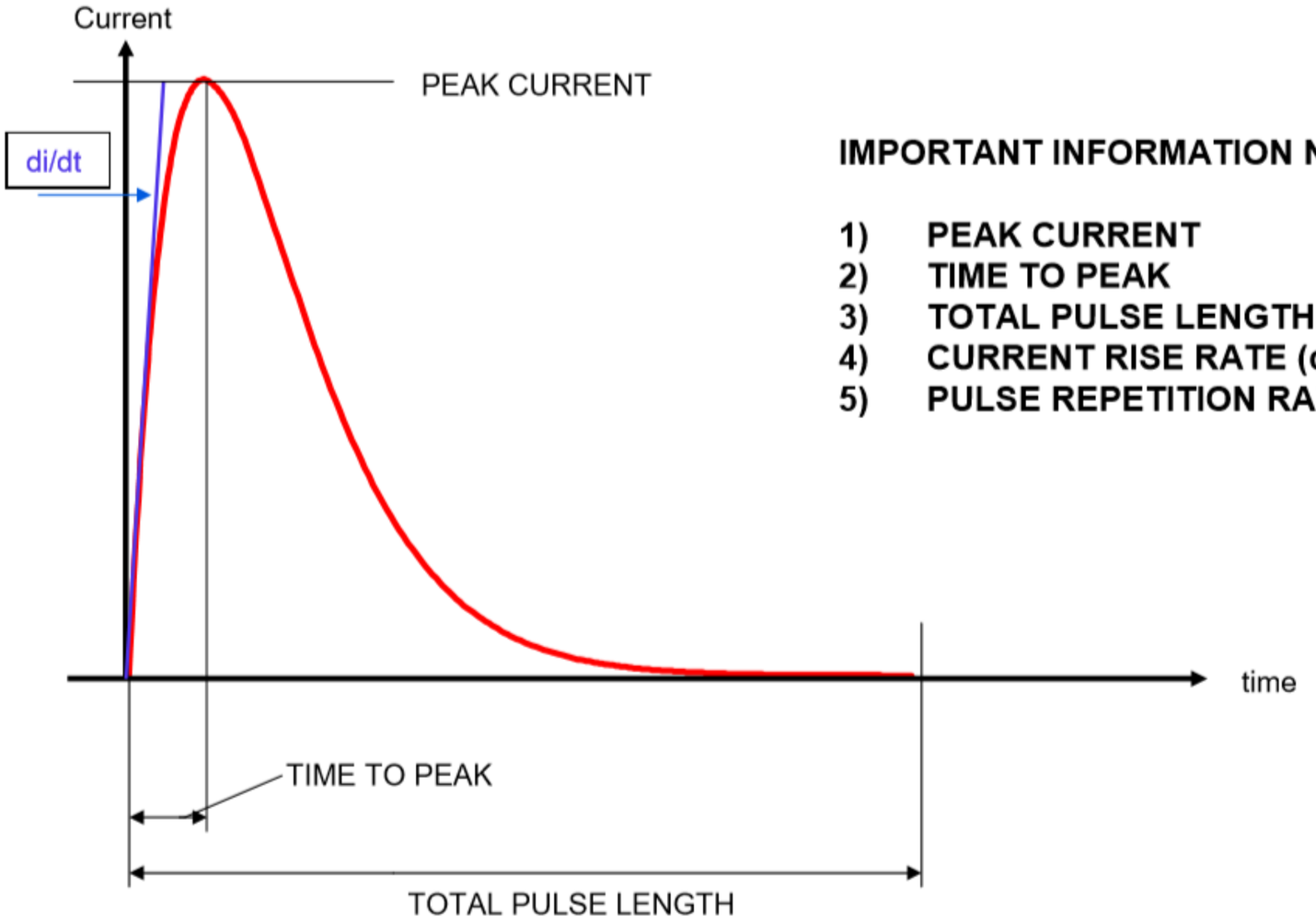
Applications: Crowbars, Railguns, Launchers, Test-Equipment, Beam Dump



WAVE FORM: DAMPED SINE WAVE
Normally for Capacitor Discharge into an inductive load

Applications: Railguns, Magnetic Forming, Pulsed Corona, Pulse Forming Networks, Pulsed Power Supplies, Pulse-Modulators for Particle Accelerators

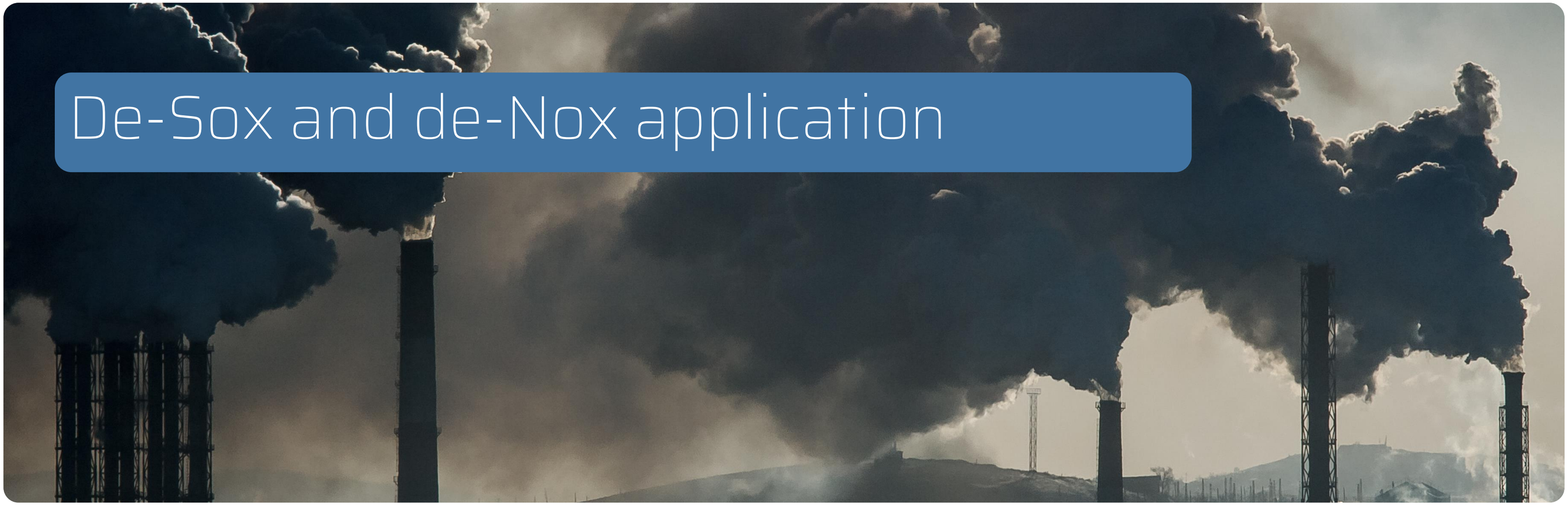
Diverse selection criteria



IMPORTANT INFORMATION NEEDED:

1) **PEAK CURRENT**
2) **TIME TO PEAK**
3) **TOTAL PULSE LENGTH**
4) **CURRENT RISE RATE (di/dt)**
5) **PULSE REPETITION RATE**

Customized pulsed power systems

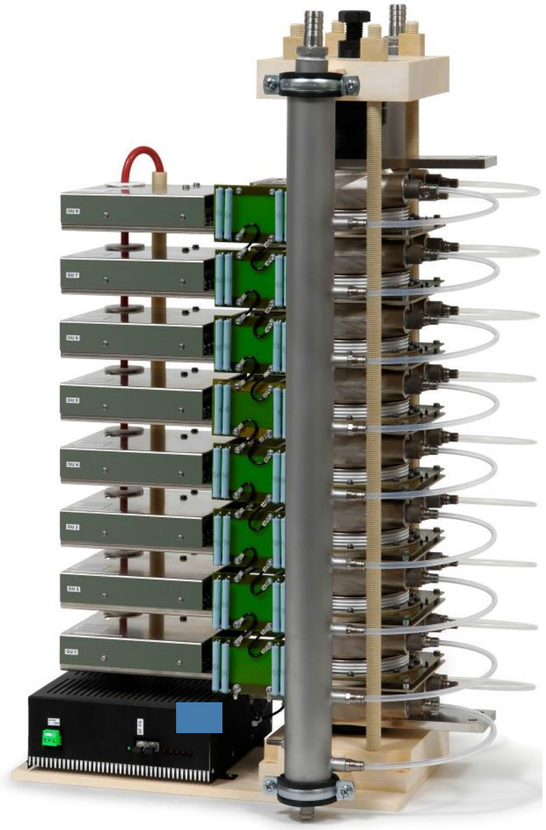


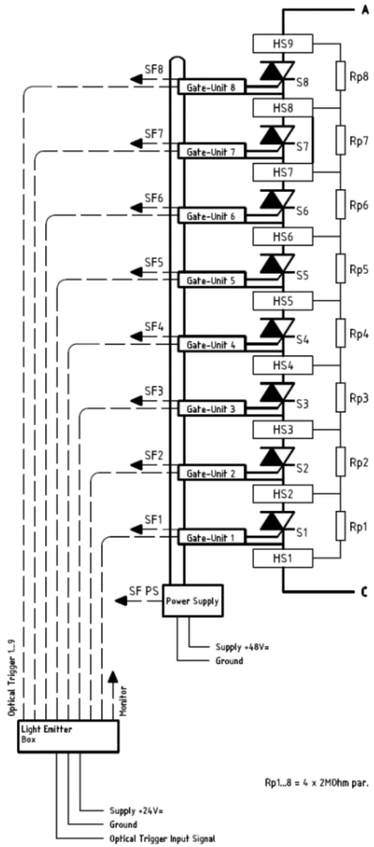
De-Sox and de-Nox application

20kVdc / 12.6kA / 300Hz High di/dt Discharge Switch

Pulsed discharge system used for carbonization of large stel manufacturing plant.

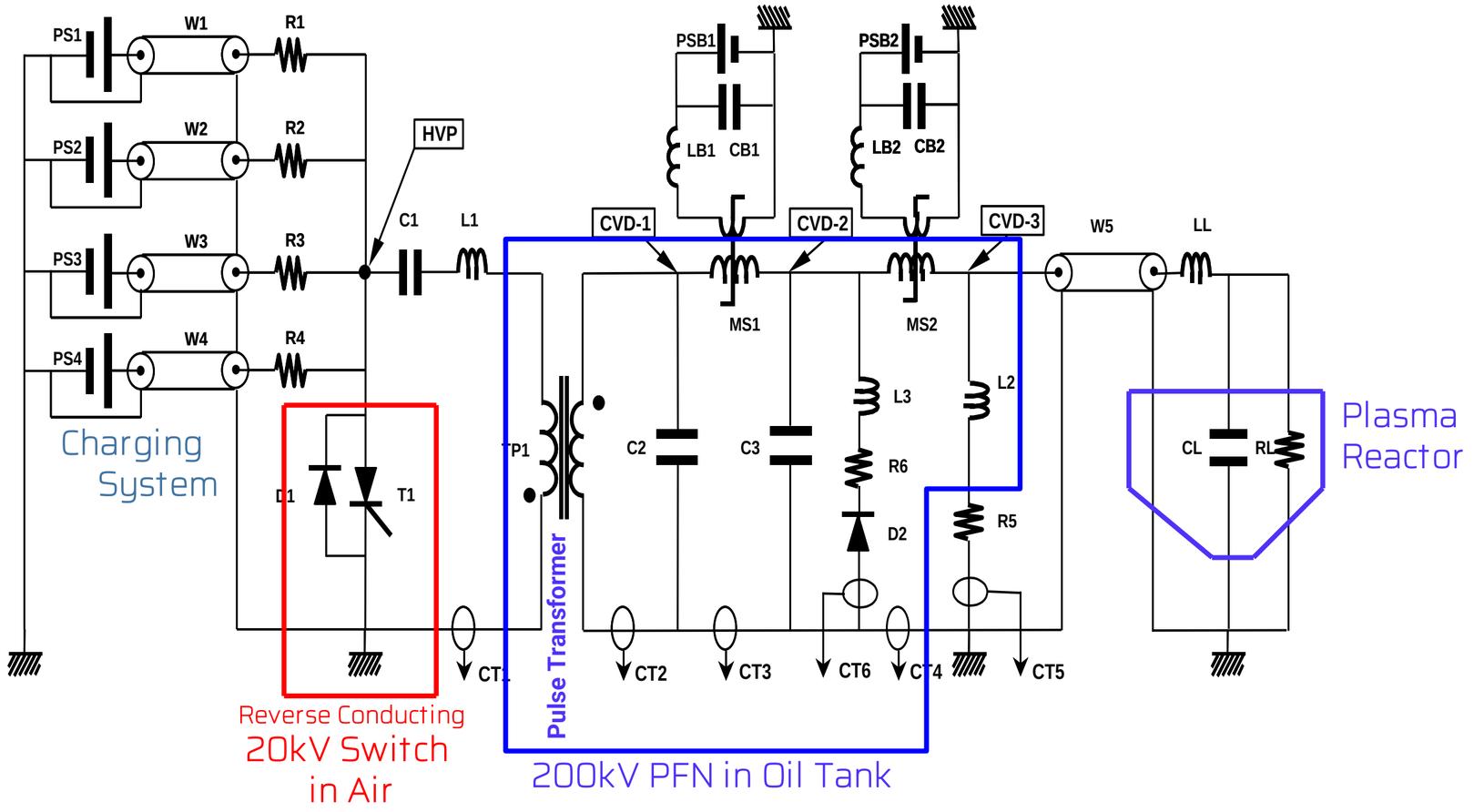
20kVdc / 12.6kA / 300Hz High di/dt Discharge Switch



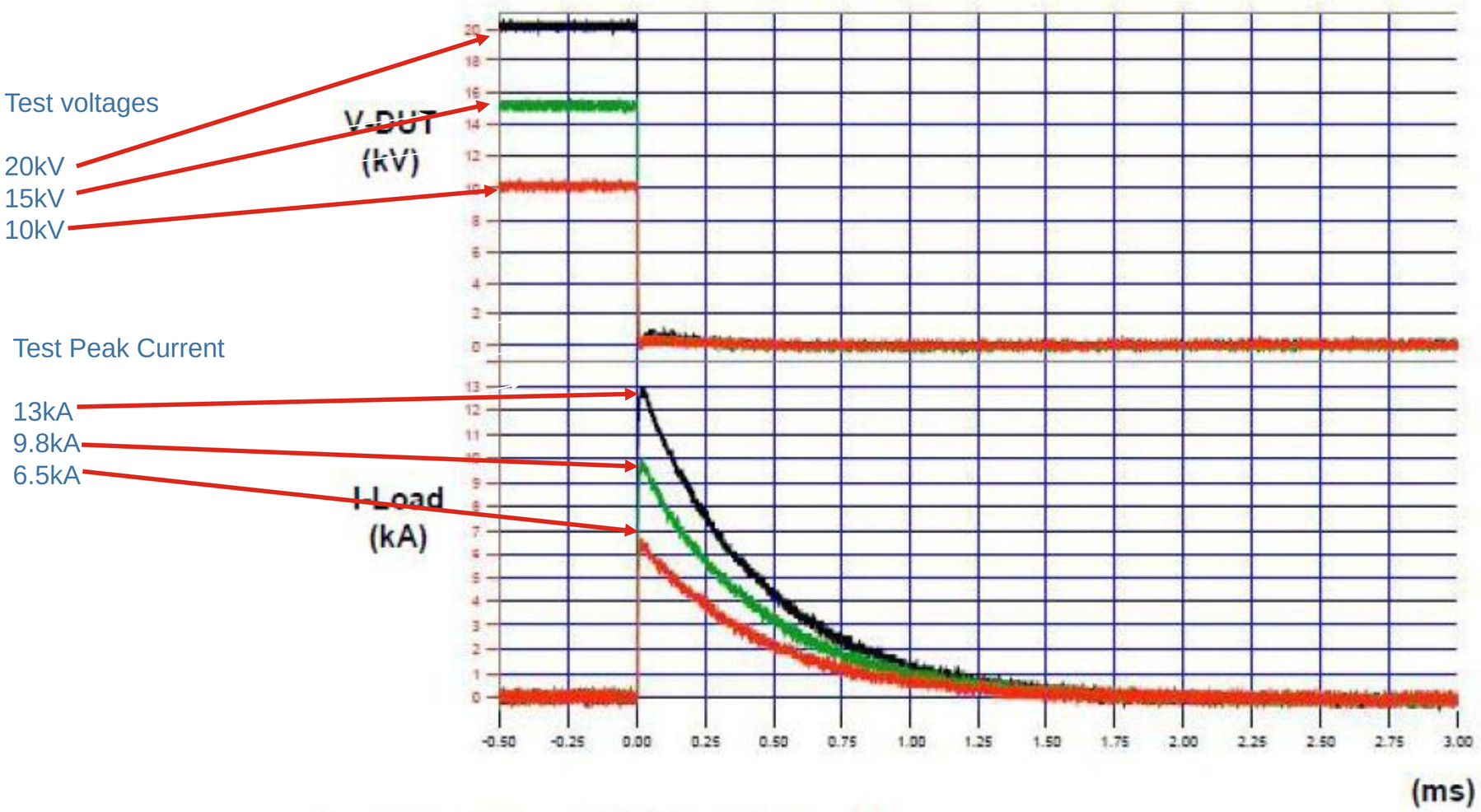


Charge Voltage:	20 kVdc
Pulse Current:	12.6 kA
Current Rise Rate:	10 kA/µs
Pulse Duration:	10 µs
Pulse Duration Arcing:	250 µs
Pulse Shape Normal:	Exponential Decay
Pulse Shape Arcing:	Damped Sine
Pulse Repetion Rate:	300 Hz
Cooling:	Transformer Oil
Semiconductors (8):	ABB 5SPR 26L4508
Power Supply:	Astrol 200W
Light Distribution Box:	Astrol 9x optical
Clamping System:	40 kN

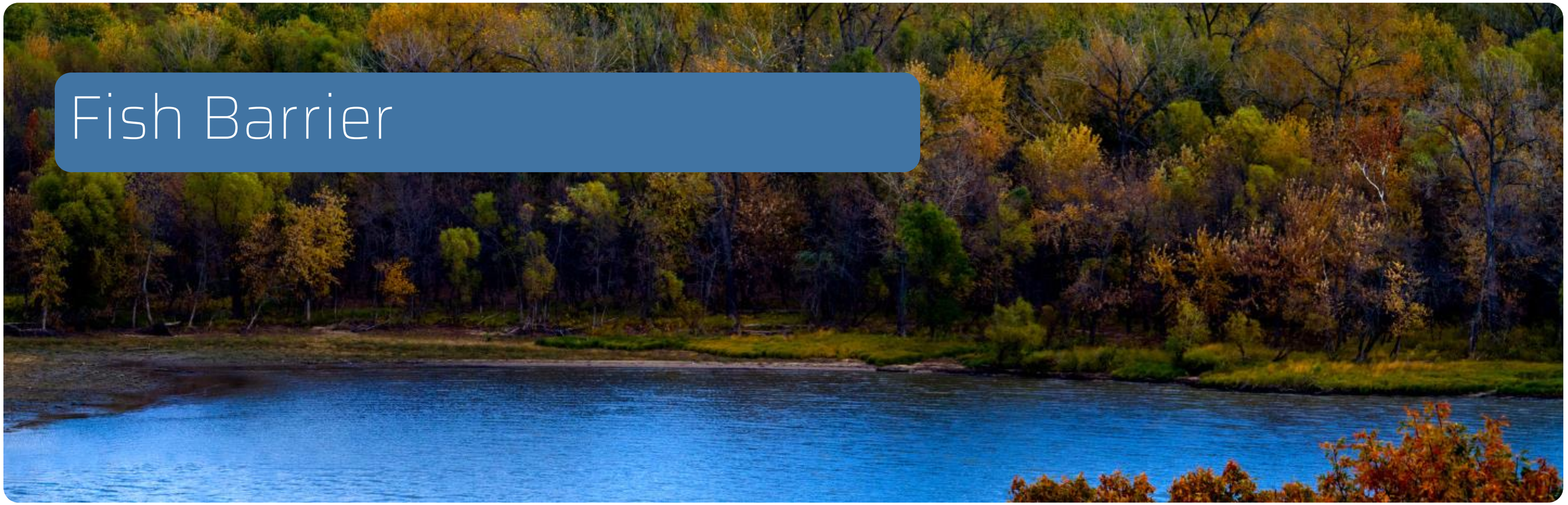
Diagram of the Pulsed Discharge System



Pulseform at different voltages



Test Peak Current at 6.5kA – 9.8kA – 13kA

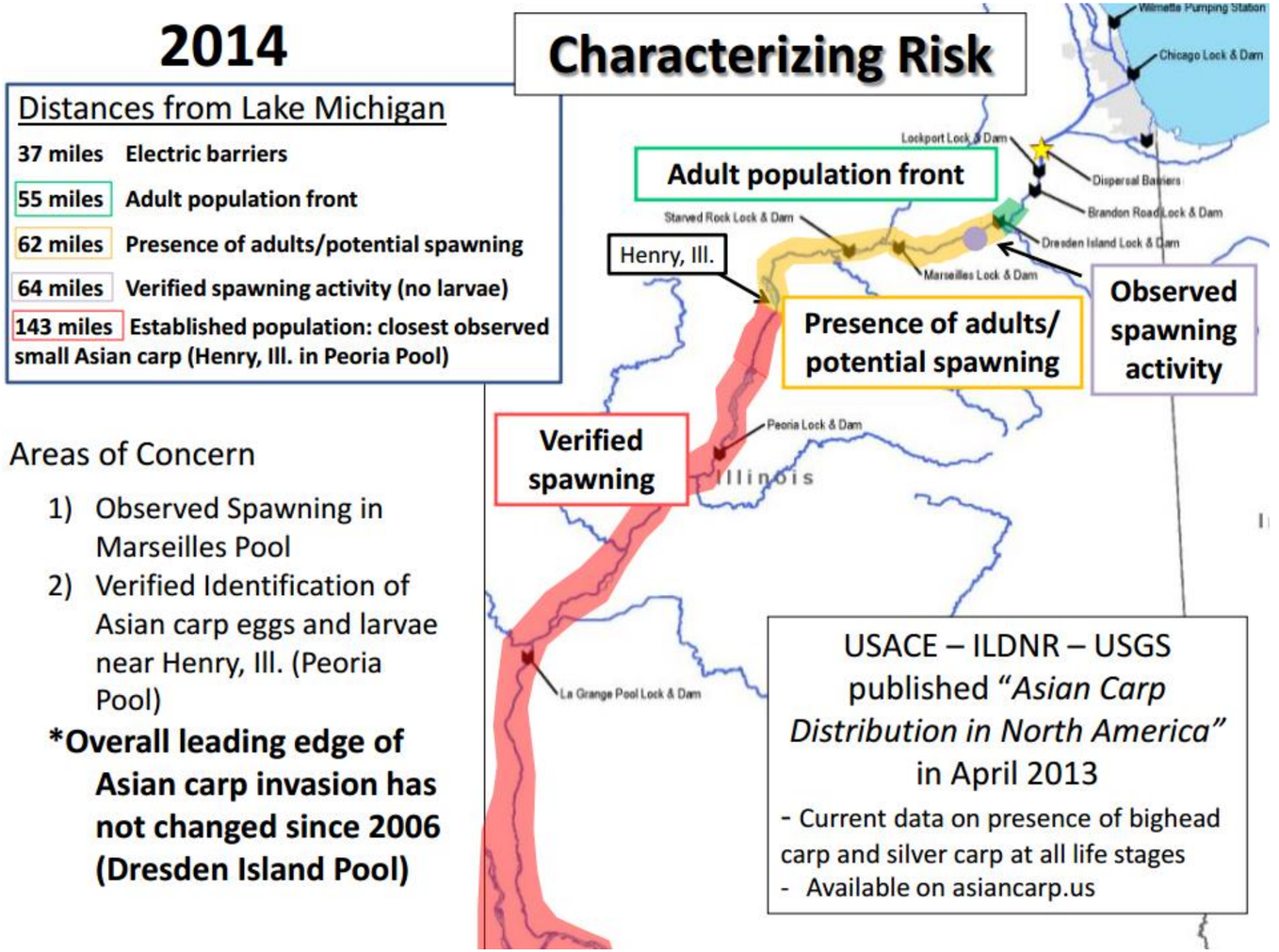


Fish Barrier

Environmetal Protection

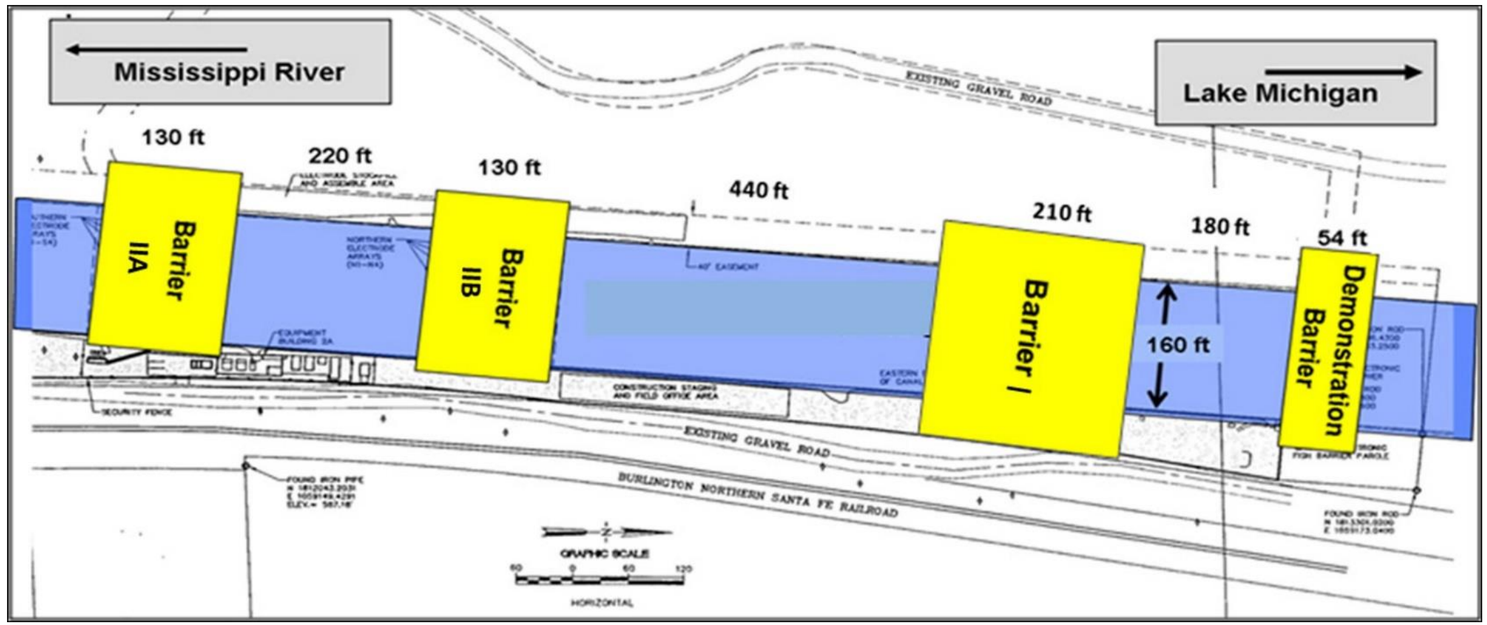
Two 3.4kV/30kA and one 2kV/10kA switch to ensure environmental protection from invasive species.

Characterizing of risks



Location of the barrier

The card below shows the place where the barrier is installed. There are at the moment three barriers in a row. Each barrier has two 3.4kV/30kA and one 2kV/10kA switch working together. Always one of the big switches are in the off mode and can be instantently enabled if one of the others breaks.



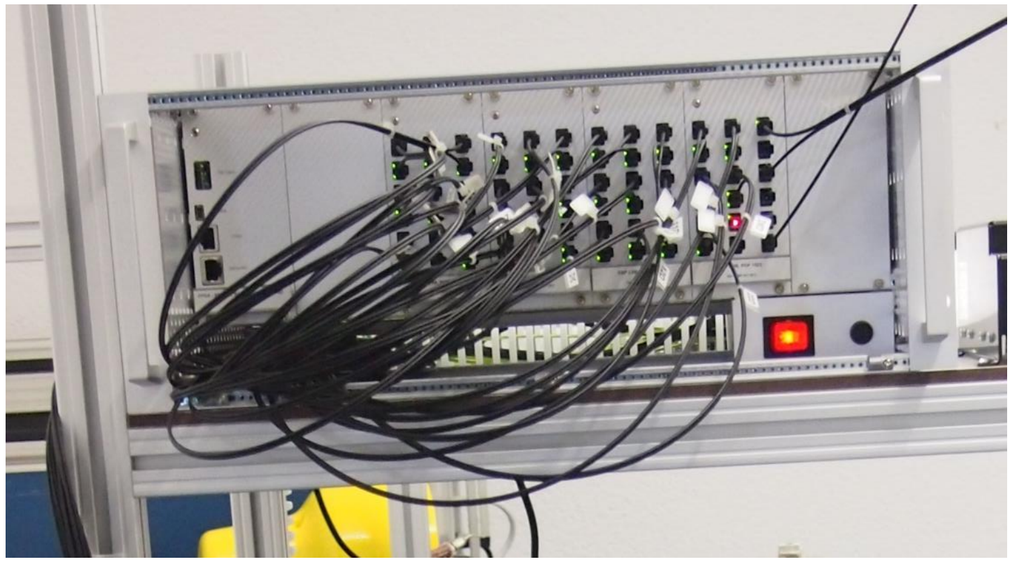
For more information see also :
http://www.lrc.usace.army.mil/Missions/CivilWorksProjects/ANSPortal/Barrier.aspx

Specification for 3.4 kV / 30 kA IGBT <big switch>

Charge Voltage:	3.4kVDC (max)
Peak Current:	30kA
Pulse Length:	1ms - 7ms typically
Maximum power:	1MW (maximum power depends on water)
Pulse Shape:	LR shaped rectangular pulse form
Current Rise Rate:	Depends on inductance and resistance of water
Pulse Rep. Rate:	100Hz (max)
Switching Components:	IGBT Vces = 32 x 6.5kV in parallel connection
Cooling:	Deionized water
Auxiliary Supply:	120VAC
Environmental:	Indoor in cabinet
Production Status:	Qualified series production

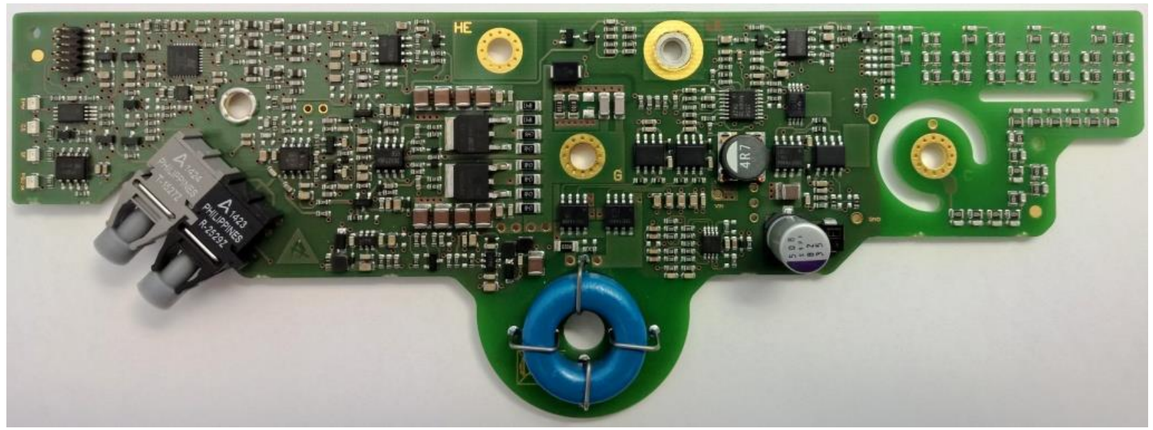
Trigger generator

The pulsed power switch (big switch) has 32 IGBT devices in parallel connection.
The gate units are all triggered at the same time.
The trigger generator has 32 individual optical transmitter and receiver pairs.
Each transmitter output has a controlled light output level as well as a defined transmit and receive delay time.

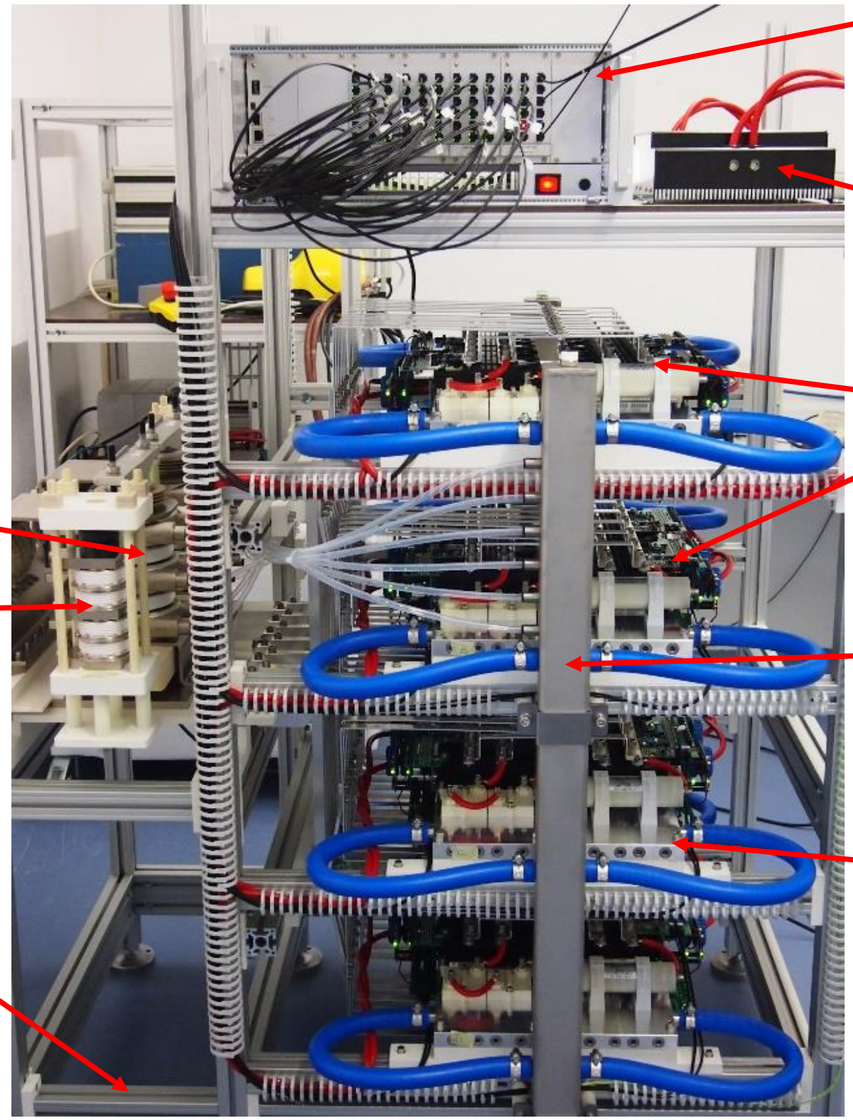


Gate unit

- Fits on every standard High voltage IGBT (4.5kV & 6.5kV)
- Collector voltage sense (dv/dt control, active clamp)
- Glass- or plastic optical fiber
- Current loop power supply for easy powering
- Programmable Vgeon/Vgeoff voltage
- Programmable rise of rate of gate voltage
- Programmable error behaviour



Complete switch



Summary

- The presented 3.4kV / 30kA chopper was successfully produced and tested at Astrol, as well as in the field.
- Astrol has worked close together with the customer for several years to realize this product.
- After several years of experiments, the systems are qualified and ready to be installed in other rivers and canals.
- High reliability and long life-time was a key argument for this application.

Questionnaire for Pulsed Power Applications

Working in an area where new system designs and experimental systems are invented, we know how difficult it is for the designer and the supplier of components to select the right parts for the application. Because the selection of components is often not based on datasheet figures, Astrol Electronic AG is offering a service to support customers with the selection of the right switch assembly.

Please answer the questions below as detailed as possible

Company / Organisation

Address

City

Contact Person

Phone / E-mail

Application Description

Project Status ☐ Research ☐ Prototype ☐ Development ☐ Series Production

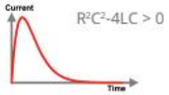
Questions for selecting the semiconductor components or switch assembly

Used Power Source ☐ Capacitor ☐ Other:

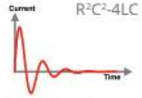
Charge Voltage V

Peak Pulse Current Level A

Peak Pulse Current Waveform ☐ Over damped sine wave ☐ Under damped sine wave



$R^2C^2-4LC > 0$



$R^2C^2-4LC < 0$

☐ Other: Please attach sketch / circuit of the pulse form

Pulse Duration tp = µsec to peak µs total

Expected Initial di/dt Value di/dt = kA/µs

Pulse Repetition Rate f = Hz

Used Load Type

Reverse voltage from the load? ☐ Yes % of Charge Voltage or V ☐ No

Should the component or switch block full voltage direct after the pulse? ☐ Yes ☐ No

Must the component or switch be in the position to switch "off" the current? ☐ Yes ☐ No

How would you like to trigger the switch? ☐ Optical ☐ Electrical

How long will the system be in use per day? Hours per day

How many days per year? Days per year

Life-time expectation of the system: Years, or: Pulses

Ambient temperature range: °C

Operating temperature range: °C

Preferred method of cooling (in case required): ☐ Convection Air ☐ Forced Air ☐ De-Ionized Water ☐ Oil

What is the isolation medium? ☐ Clean Air (indoor cabinet) ☐ Outdoor (humid air) ☐ Air Conditioned Area ☐ Oil immersion ☐ SF-6 Inert Gas

What is your time schedule?

Any further information which can be important (please add a circuit diagram):

Please return the completed questionnaire to:

Astrol Electronic AG
Andy Stöckli
ast@astrol.ch

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CH-5504 Othmarsingen

Thank You

Visit us at booth 19

Presentation by Astrol