ABB Switzerland Ltd, Semiconductors
Fabrikstrasse 3
CH-5600 Lenzburg / Switzerland
www.abb.com/semiconductors

High Power Reverse Conducting Solid State Switch for Environmental Applications

(De-NOx / De-SOx Modulator)

Adriaan Welleman

Manager Pulsed Power & Assemblies

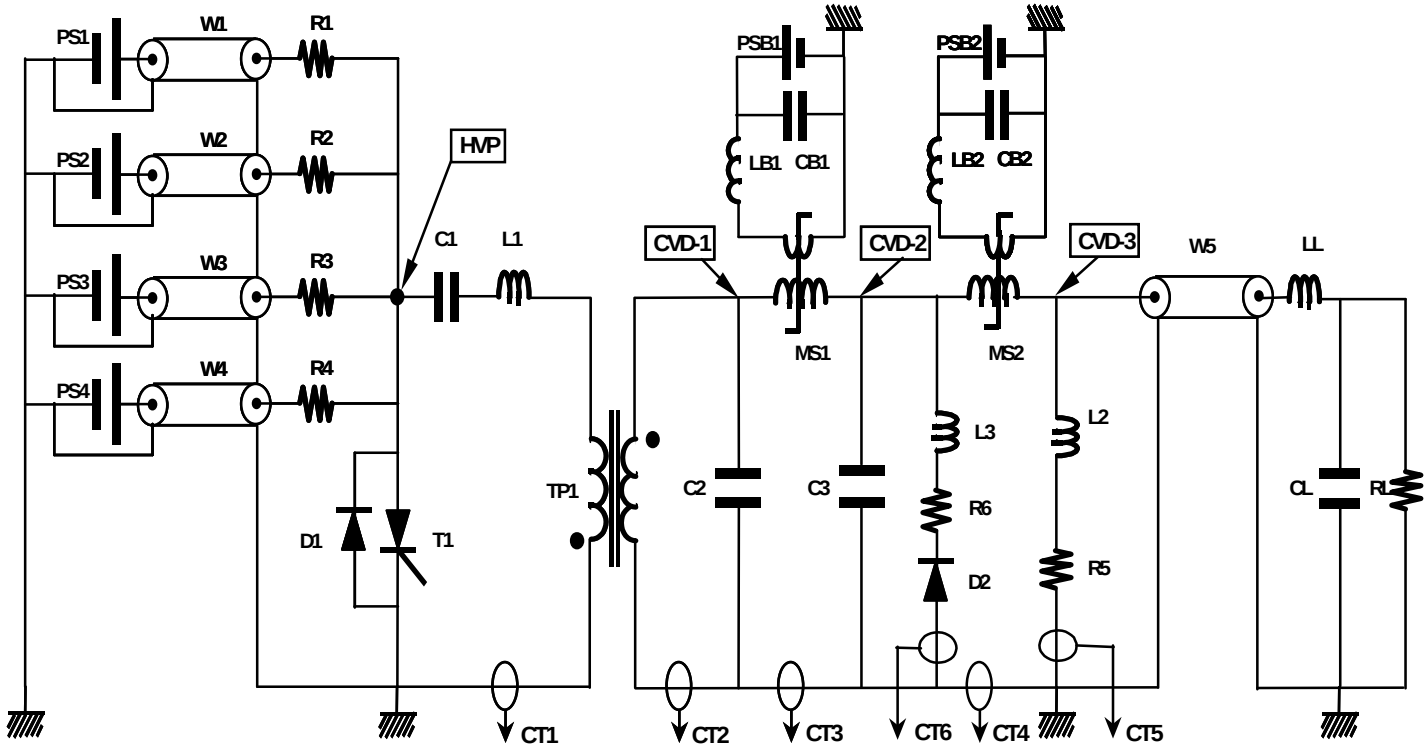
ABB Switzerland Ltd, Semiconductors

adriaan.welleman@ch.abb.com

Introduction

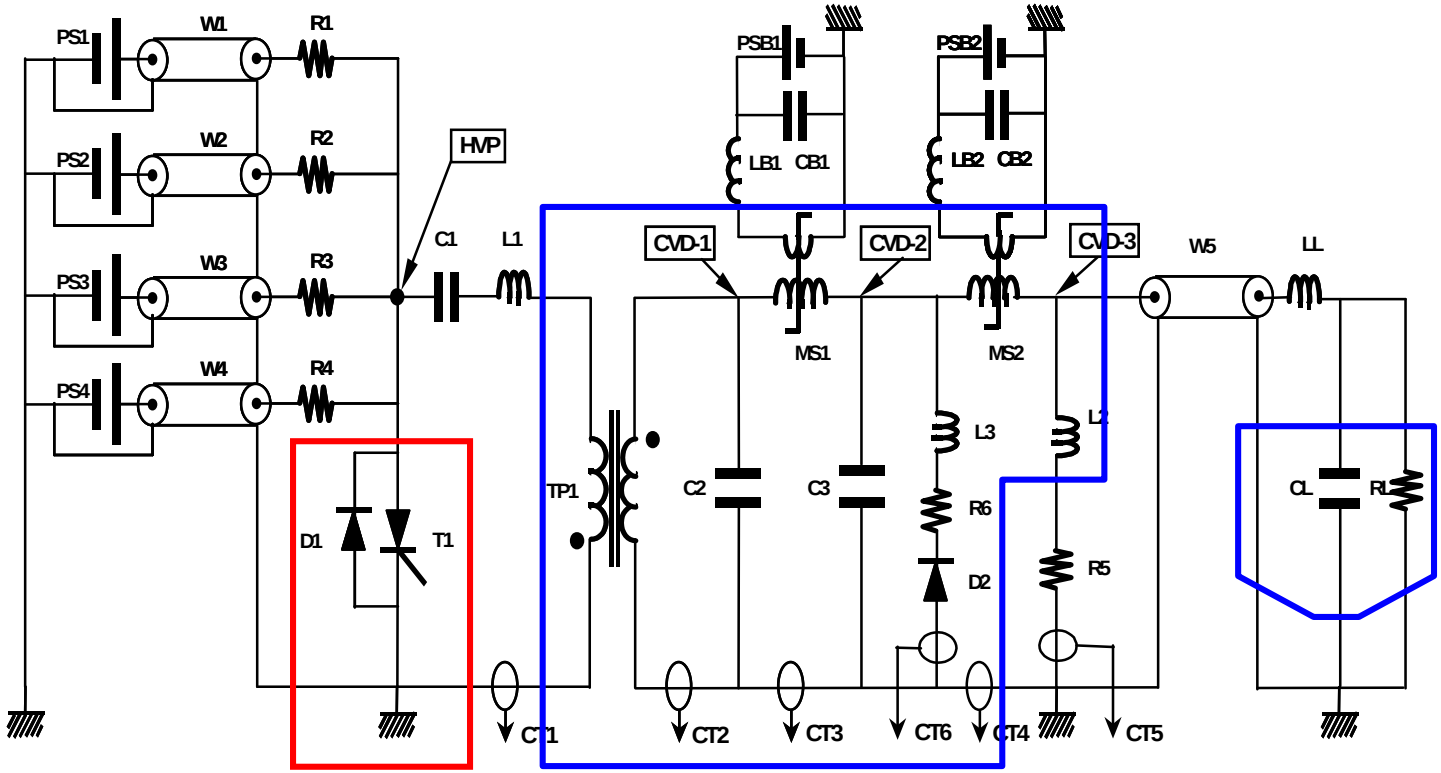
- Application
- Specification
- Component Selection
- Solid State Switch Design
- Switch Construction and Cooling
- Test Results
- Reliability
- Summary

Application



Plasma Reactor

Application



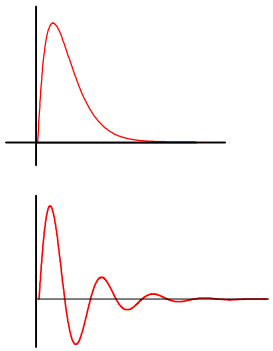
Plasma Reactor

20 kV primary switch in Air

200 kV system in Oil Tank

Specification of Discharge Switch

Charge Voltage	**20 kVdc**
Pulse Current	**12.6 kA**
Current Rise Rate	**10 kA/µs**
Pulse Repetition Rate	**300 Hz**
Pulse Form (normal)	**Exponential decay**
Pulse Width (normal)	**12 µs**
Pulse Form (during arcing)	**Damped Sine**
Pulse Width (during arcing)	**250 µs**
Cooling	**Transformer Oil**



Two prototypes with the same specification, supplied by ABB in year 2002 worked well during a five years period.

One failed in 2007 because of condensation caused by water cooling issues, not by devices.

Component selection

Following parameters are important and also give a technical edge to the semiconductor devices:

- **High DC Voltage (20 kVDC cont.)**
- **High Peak Current (12.6 kA – 12 µs nominal)**
- **High Current Rise Rate (di/dt=10 kA/µs)**
- **High Pulse Repetition Rate (300 Hz)**
- **Low Inductance**
- **Life-Time more than 12 years (24 h/day)**

Component selection

Following parameters are important and also give a technical edge to the semiconductor devices:

- **High DC Voltage → Need series connection**
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Component selection

Following parameters are important and also give a technical edge to the semiconductor devices:

- **High DC Voltage → Need series connection**
- **High Peak Current → Need large wafer area**
- **High Current Rise Rate (di/dt=10 kA/µs)**
- **High Pulse Repetition Rate (300 Hz)**
- **Low Inductance**
- **Life-Time more than 12 years (24 h/day)**

Component selection

Following parameters are important and also give a technical edge to the semiconductor devices:

- **High DC Voltage → Need series connection**
- **High Peak Current → Need large wafer area**
- **High Current Rise Rate → Need fine gate structure**
- **High Pulse Repetition Rate (300 Hz)**
- **Low Inductance**
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Component selection

Following parameters are important and also give a technical edge to the semiconductor devices:

- **High DC Voltage → Need series connection**
- **High Peak Current → Need large wafer area**
- **High Current Rise Rate → Need fine gate structure**
- **High Pulse Repetition Rate → Need adequate cooling**
- **Low Inductance**
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Component selection

Following parameters are important and also give a technical edge to the semiconductor devices:

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- **High Pulse Repetition Rate → Need adequate cooling**
- **Low Inductance → Need Gate-Unit and FW Diode near**
- **Life-Time more than 12 years (24 h/day)**

Component selection

Following parameters are important and also give a technical edge to the semiconductor devices:

- **High DC Voltage → Need series connection**
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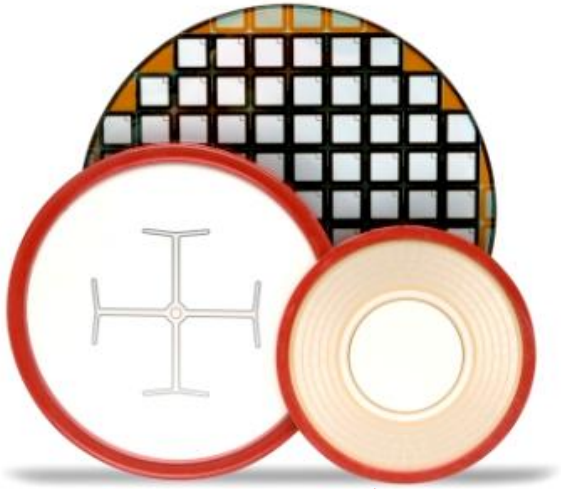
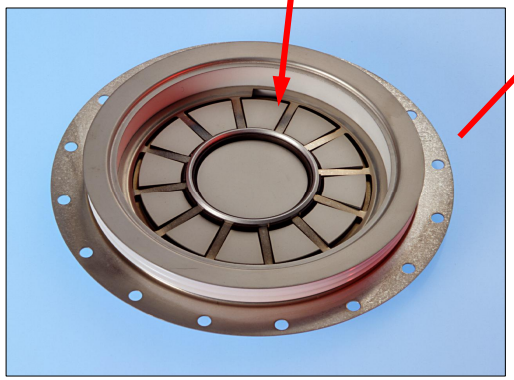
- **High Current Rise Rate → Need fine gate structure**
- **High Pulse Repetition Rate → Need adequate cooling**
- **Low Inductance → Need Gate-Unit and FW Diode near**
- **Life-Time more than 12 years → Dedicated design with reliable devices from Mass production**

Component selection

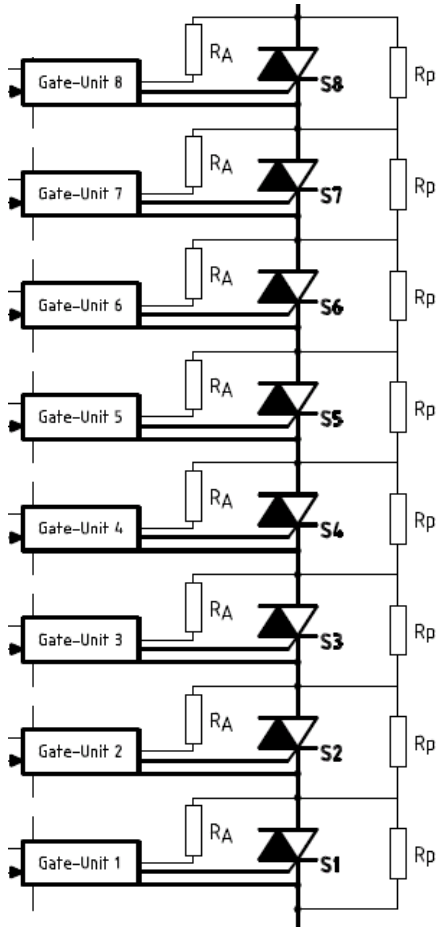




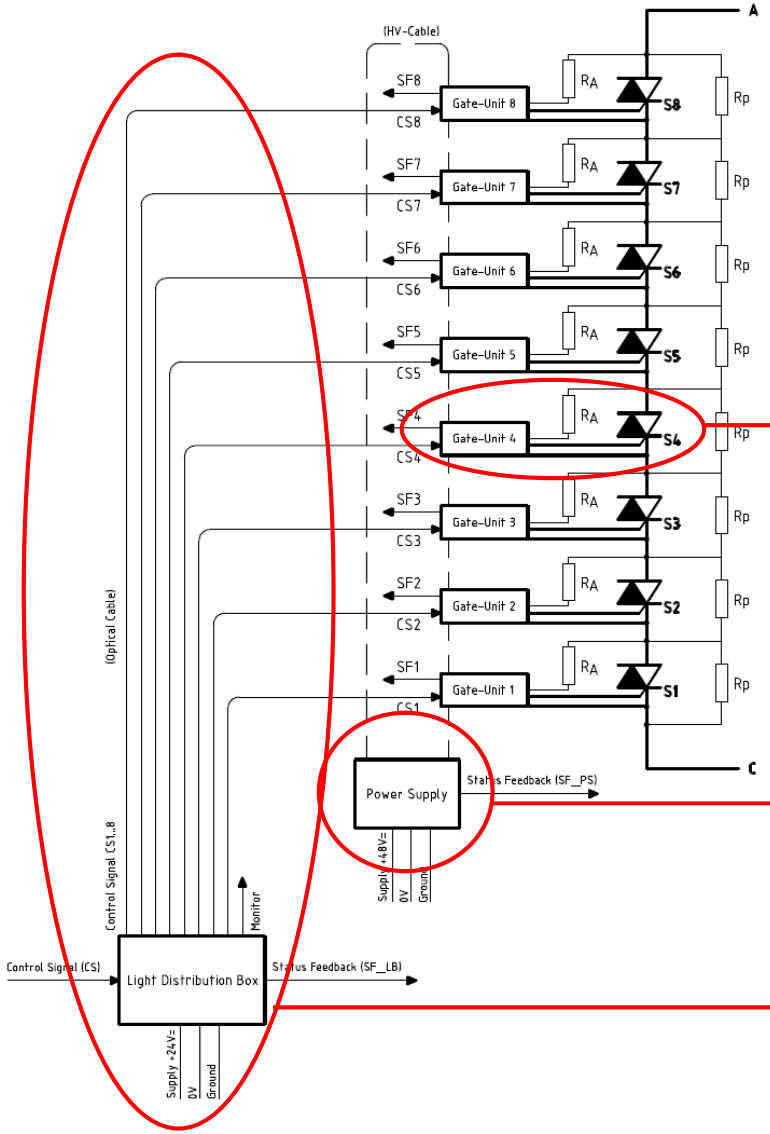
Reverse Conducting Discharge Device
P/N: 5SPR 36L4506
Driver Unit integrated
Vdrm=4500V, Vrrm=0V (Integrated Diode)
Wafer diameter 91 mm
I-pulse up to 80 kA (10µs)
Di/dt capability ≤ 30 kA/µs
Designed for series connection

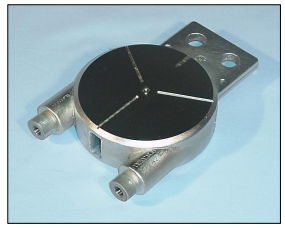
Solid State Switch Design

- For 20kVdc series connection of devices is needed
- Each device has 4.5kV blocking voltage capability
- Because of cosmic ray withstandability (reliability) the devices should be only charged to max. 2.8 kVdc
- This will mean 7 devices for 20 kVdc, but because of redundancy it was decided to use 8 devices in series



Solid State Switch Design





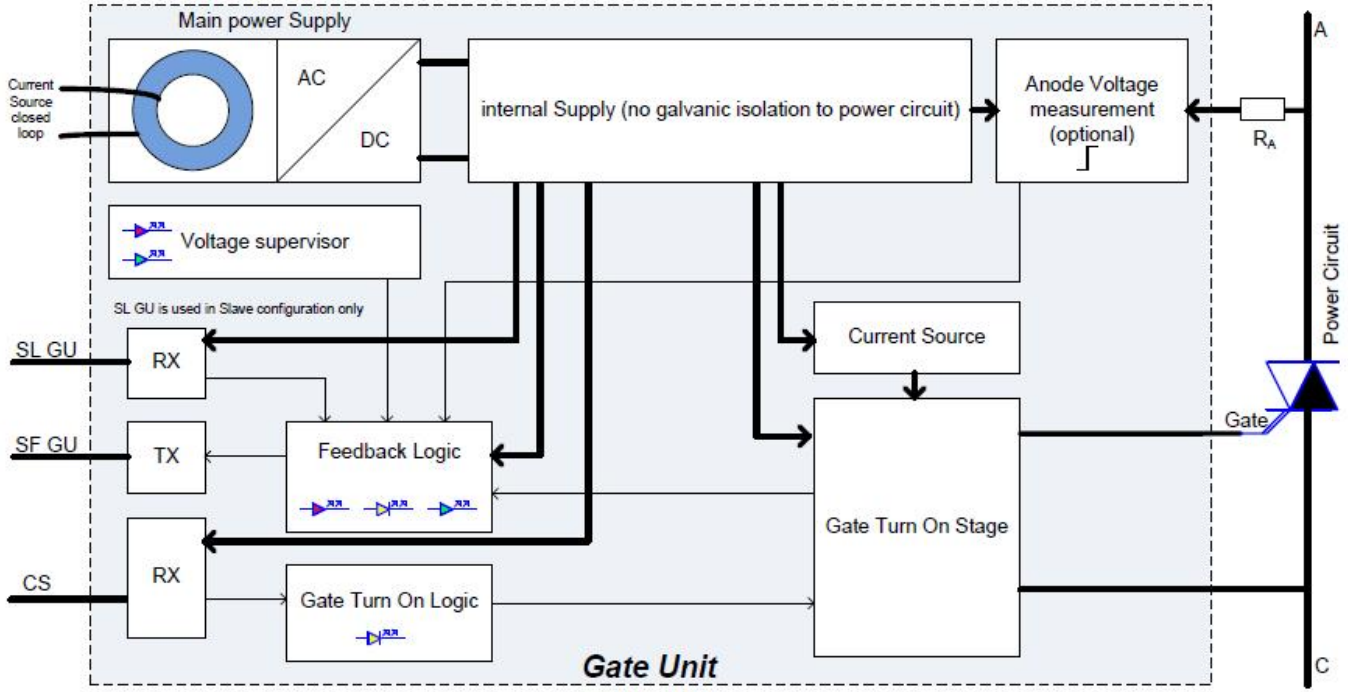
Heatsinks between devices

Switching Devices

Current Source Power Supply

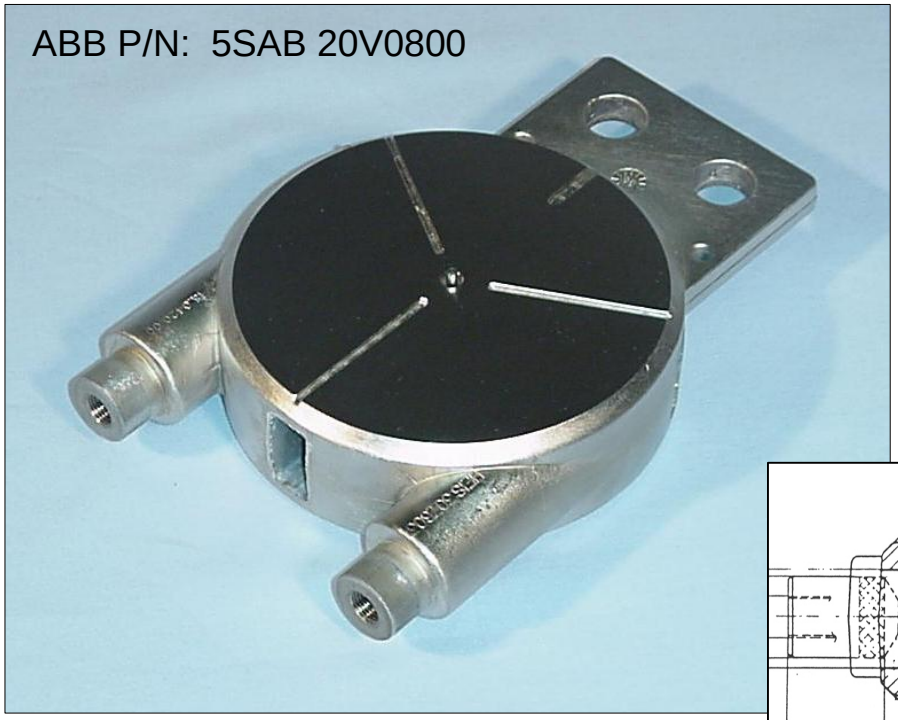
Trigger box (and optical cables)

Gate Driver Unit

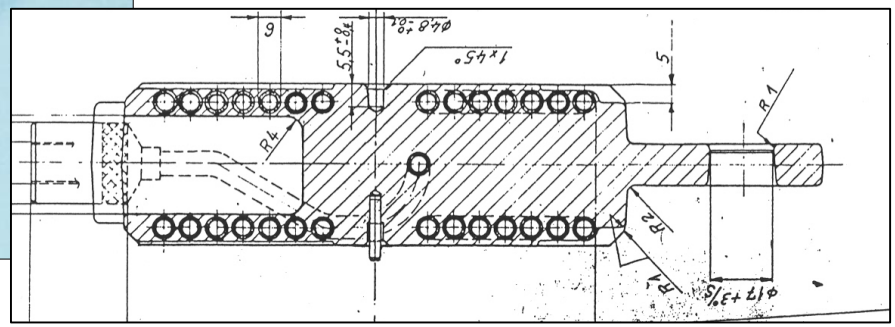


Cooling

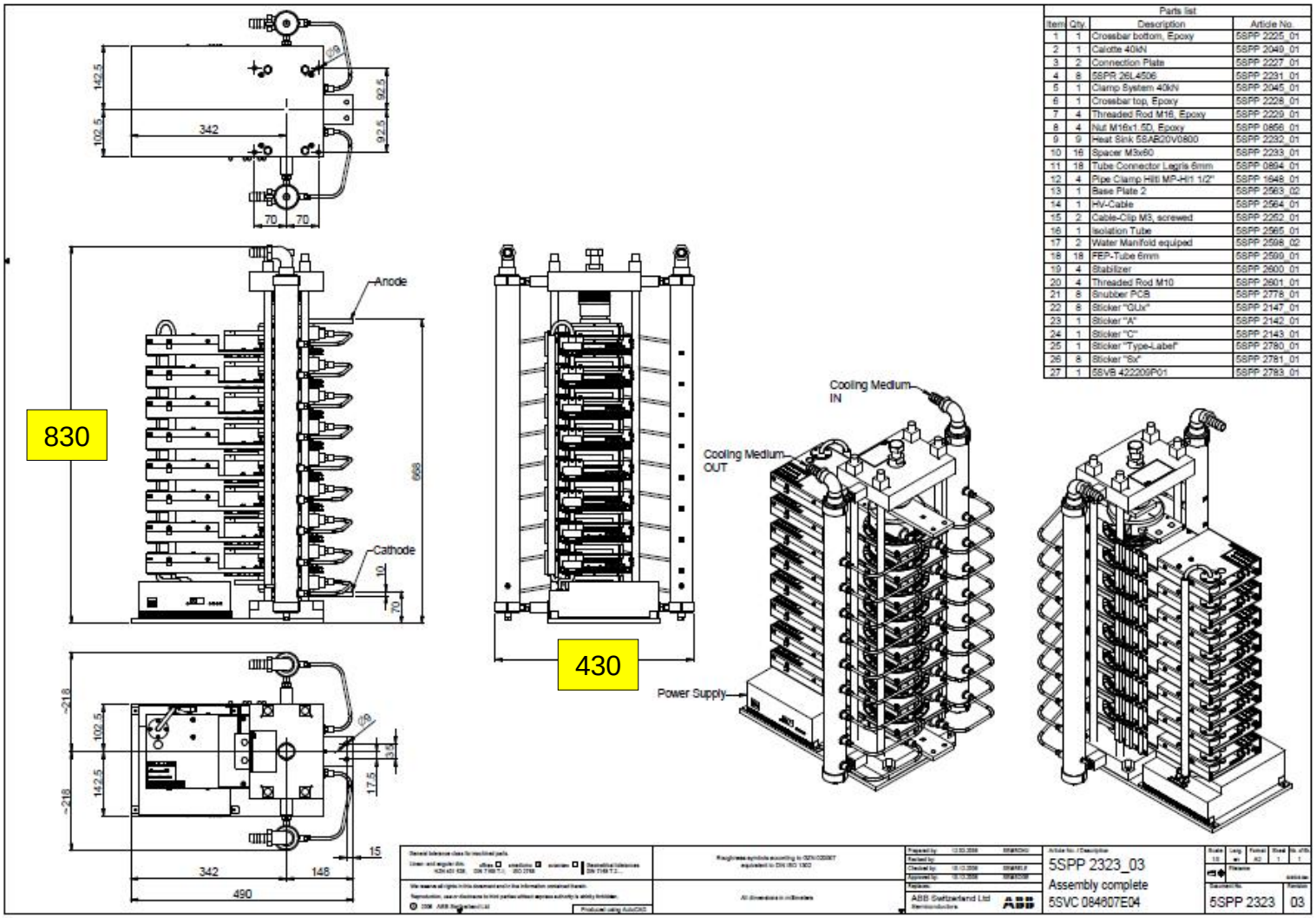
For 300 Hz operation and compact, low induction design, the switch is equiped with heatsinks cooled with transformer oil which is available in the oil tank of the main system



Cross section of heatsink 5SAB 20V0800



Assembly Construction



Switch Assembly Complete

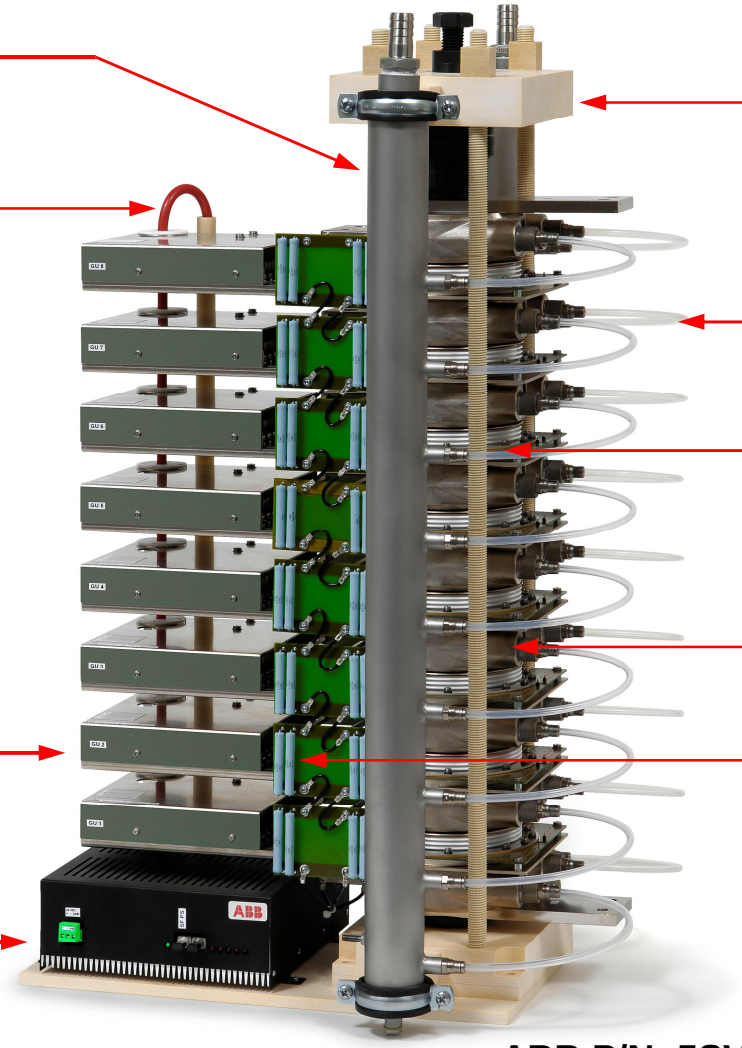
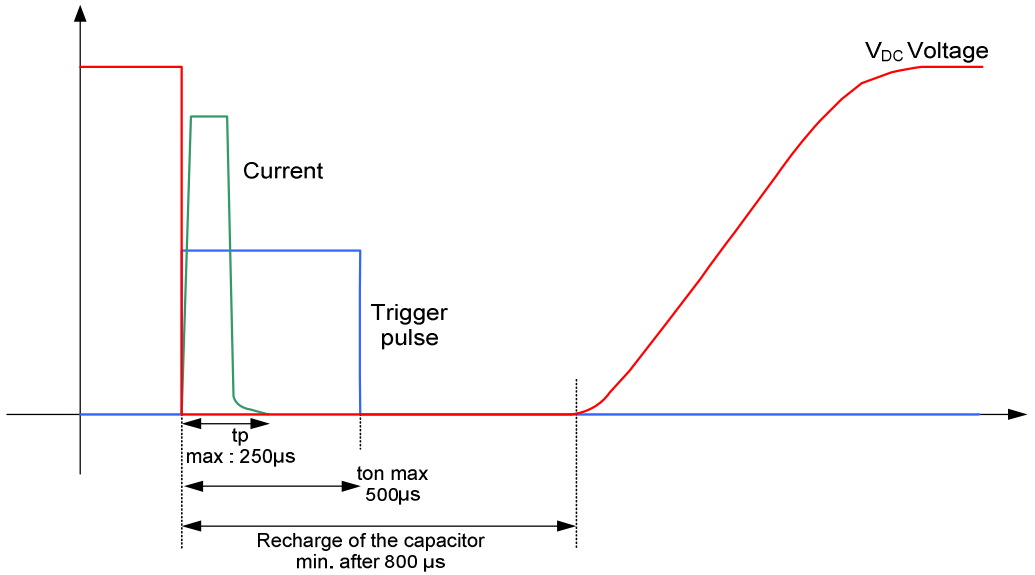


ABB P/N: 5SVC 083607E03

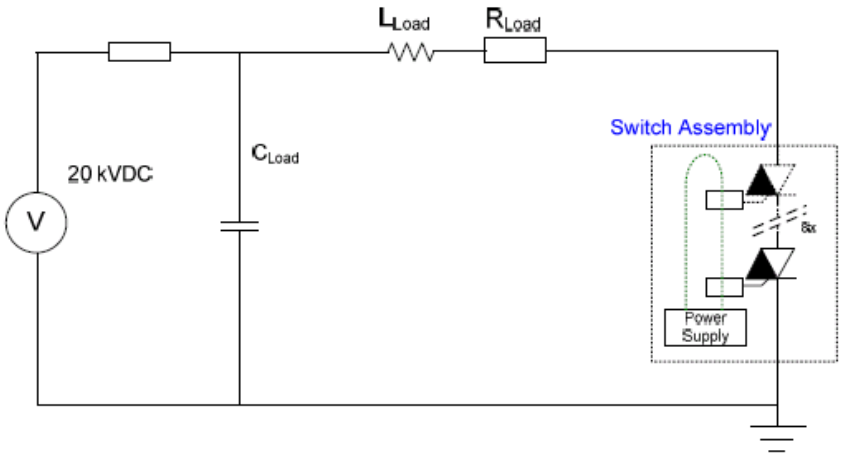
Triggering

The driver units are individually triggered by an optical control signal which is given by the light distribution box.

The trigger pulse has to be longer as the pulse of the main current because discharge devices are not able to switch-off current.



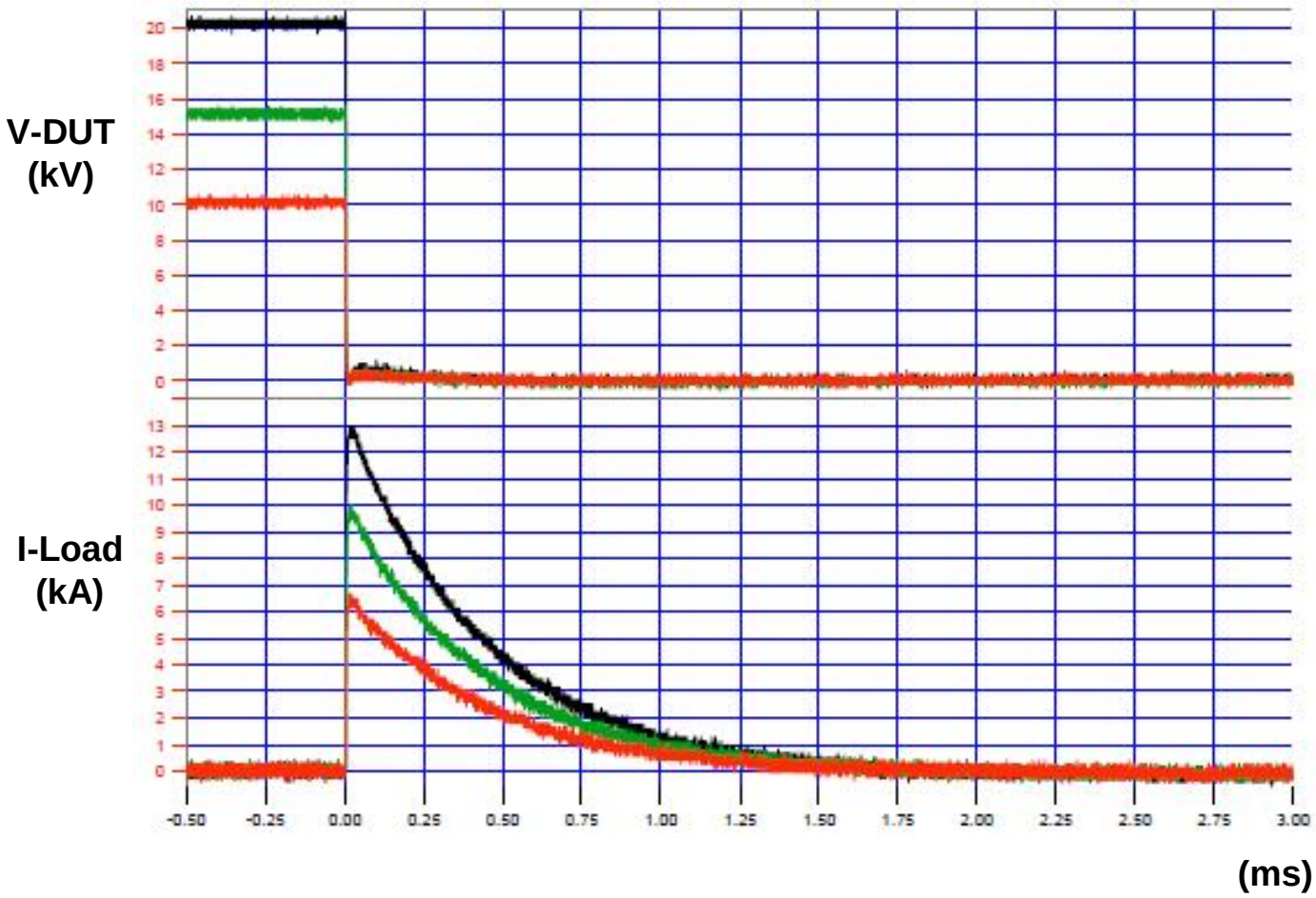
Tests



Nr.	Test	Conditions	Limits
1)	Blocking voltage test on device level	V_{DR} = 4.0 kV, sinus halve wave, 50 Hz Without parallel resistors Tj = 25°C	I_{DR} < 10 mA
2)	Voltage sharing	V_{dc_Switch} = 20 kV DC Tj = 25°C	Maximum difference V_{AK_S1}...V_{AK_S8} = 400V
3)	Difference of gate voltage delay of the 8 semiconductors	Turn on V_{GK} = 5 V Tj = 25°C	Maximum difference of gate voltage delay = 50 ns
4)	Functional pulse test	R-L-C circuit Single pulse $V_{\_Switch}$ = 20 kV $I_{\_Switch}$ > 12.6 kA R = 1.5 Ω L = 2 µH C = 290 µF Ta = 25°C	Go / No go
5)	Isolation test (Between Anode, Cathode and the 48 VDC input of the inductive power supply)	Viso = 40 kV DC / 1 min. Ta = 25°C	I_{iso} < 1 mA

Test (Application Oriented)

Test with Charge Voltage Vdc = 10kV - 15kV - 20kV



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

Test Results

	Device number								1 Leakage current forward @ VDR = 4.0kV (without Rp)							
	Dv No S01	Dv No S02	Dv No S03	Dv No S04	Dv No S05	Dv No S06	Dv No S07	Dv No S08	IDR S01	IDR S02	IDR S03	IDR S04	IDR S05	IDR S06	IDR S07	IDR S08
	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[mA]	[mA]	[mA]	[mA]	[mA]	[mA]	[mA]	[mA]
Lower limit																
Upper limit									10	10	10	10	10	10	10	10
SNo:																
392-061-08_017	PP24.08	PP24.30	PP24.25	PP24.27	PP24.42	PP24.49	PP24.01	PP24.04	0.3	0.1	0.2	0.1	5.9	5.1	5.0	0.1
392-061-08_018	PP24.07	PP24.09	PP24.14	PP24.15	PP24.17	PP24.24	PP24.26	PP24.43	0.1	1.1	0.2	0.1	1.6	0.2	0.1	0.1
392-061-08_019	PP24.46	PP24.47	PP24.50	PP23.38	PP23.42	PP23.46	PP24.11	PP24.36	0.5	2.0	3.8	0.1	1.2	2.0	0.4	1.4
392-061-08_020	PP24.37	PP24.39	PP24.41	PP24.32	PP23.23	PP24.35	PP23.17	PP23.37	0.1	1.8	1.8	6.4	0.1	5.4	1.1	2.9
392-061-08_021	PP23.43	PP23.45	PP24.10	PP24.23	PP23.22	PP23.41	PP24.18	PP24.38	5.3	0.1	0.1	0.1	6.8	0.5	0.4	0.1
392-061-08_022	PP23.08	PP24.34	PP23.16	PP23.20	PP23.31	PP23.30	PP24.19	PP24.20	0.1	0.2	1.2	0.1	3.0	0.4	0.2	0.1

	2 Voltage sharing forward (DC voltage) @ VDC = 20 kV									3 Gate delay with the light distribution Box and the Assembly Monitor to VGK of Sxx @VGK = 5V								
	VAK S01	VAK S02	VAK S03	VAK S04	VAK S05	VAK S06	VAK S07	VAK S08	Max. diff. VAK S01... VAK S08	tdelay S01	tdelay S02	tdelay S03	tdelay S04	tdelay S05	tdelay S06	tdelay S07	tdelay S08	tdelay S01..S08
	[V]	[V]	[V]	[V]	[V]	[V]	[V]	[V]	[V]	[ns]	[ns]	[ns]	[ns]	[ns]	[ns]	[ns]	[ns]	[ns]
Lower limit																		
Upper limit									400	+/-25	+/-25	+/-25	+/-25	+/-25	+/-25	+/-25	Ref.	50.0
SNo:																		
392-061-08_017	2510	2500	2550	2540	2510	2540	2500	2530	50	3.0	-8.0	-2.0	-4.0	2.0	4.0	-2.0	0.0	12.0
392-061-08_018	2530	2540	2560	2510	2530	2500	2510	2510	60	-3.0	-1.0	-4.0	3.0	-6.0	-2.0	6.0	0.0	12.0
392-061-08_019	2490	2510	2540	2510	2530	2530	2510	2500	50	-5.0	-6.0	-10.0	-15.0	-4.0	-9.0	-8.0	0.0	15.0
392-061-08_020	2530	2540	2550	2480	2510	2470	2530	2520	80	1.0	8.0	10.0	1.0	6.0	4.0	3.0	0.0	10.0
392-061-08_021	2540	2510	2490	2520	2510	2540	2510	2520	50	3.0	-4.0	1.0	-5.0	-5.0	-6.0	-7.0	0.0	10.0
392-061-08_022	2510	2520	2520	2490	2470	2500	2550	2550	60	-4.0	-6.0	-2.0	3.0	-6.0	-5.0	-4.0	0.0	9.0

	4 Pulse Test	5 Iso. Test	6 Water leakage test	6 GU Protocol OK							
	20kV / 12.6kA	I Iso 40 kVDC / t=1min.	no leakage	S01	S02	S03	S04	S05	S06	S07	S08
	[go / no go] (Mno)	[mA]	[go / no go]	[go / no go]	[go / no go]	[go / no go]	[go / no go]	[go / no go]	[go / no go]	[go / no go]	[go / no go]
Lower limit											
Upper limit		1									
SNo:											
392-061-08_017	OK (62)	< 0.1 mA	OK	OK	OK	OK	OK	OK	OK	OK	OK
392-061-08_018	OK (060)	< 0.1 mA	OK	OK	OK	OK	OK	OK	OK	OK	OK
392-061-08_019	OK (099)	< 0.1 mA	OK	OK	OK	OK	OK	OK	OK	OK	OK
392-061-08_020	OK (100)	< 0.1 mA	OK	OK	OK	OK	OK	OK	OK	OK	OK
392-061-08_021	OK (033)	< 0.1 mA	OK	OK	OK	OK	OK	OK	OK	OK	OK
392-061-08_022	OK (023)	< 0.1 mA	OK	OK	OK	OK	OK	OK	OK	OK	OK

Reliability

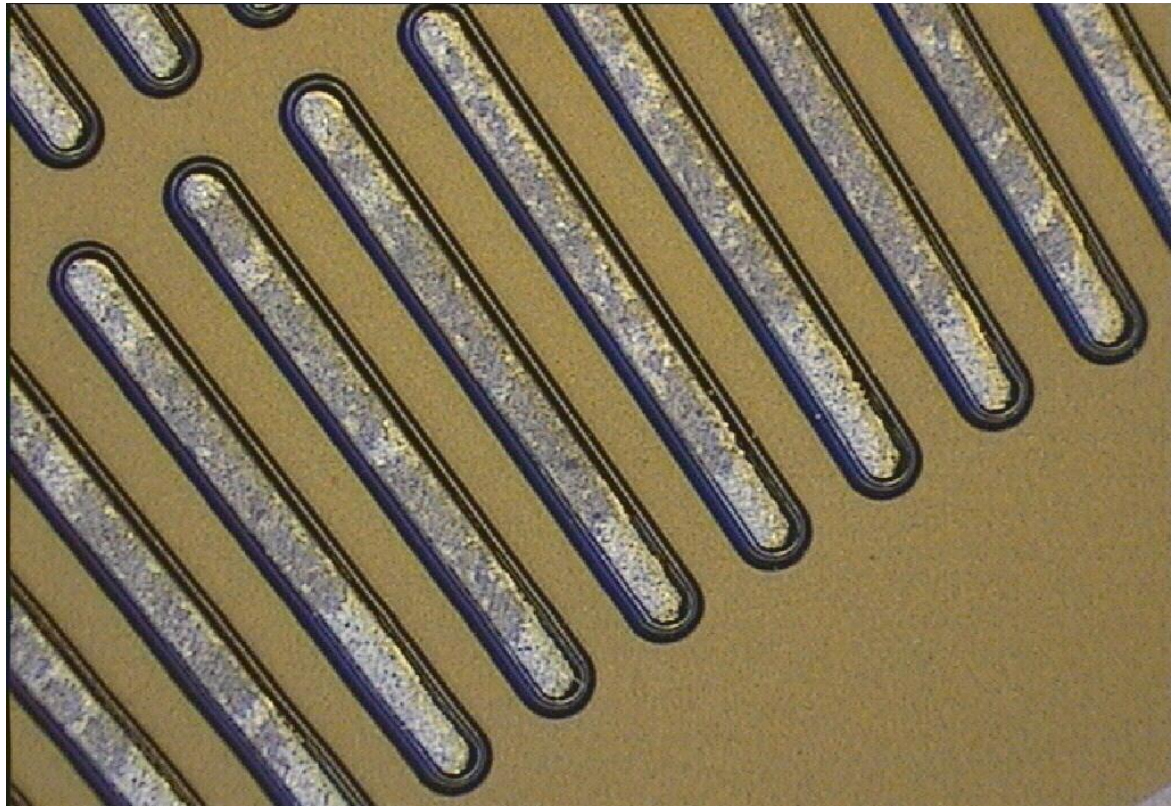
The used devices are based on one wafer technology instead of smaller chips in parallel connection.

In case of device failure the switch will continue to operate as the device has a short circuit failure mode and remaining series devices are still functioning. (Redundancy) Failures are monitored by the driver unit.

Device tests were performed with 31 kA @ 100 µs for 1 Mio pulses and no real degradation of the wafer was detected. The devices in the switch have 400x lower stress.

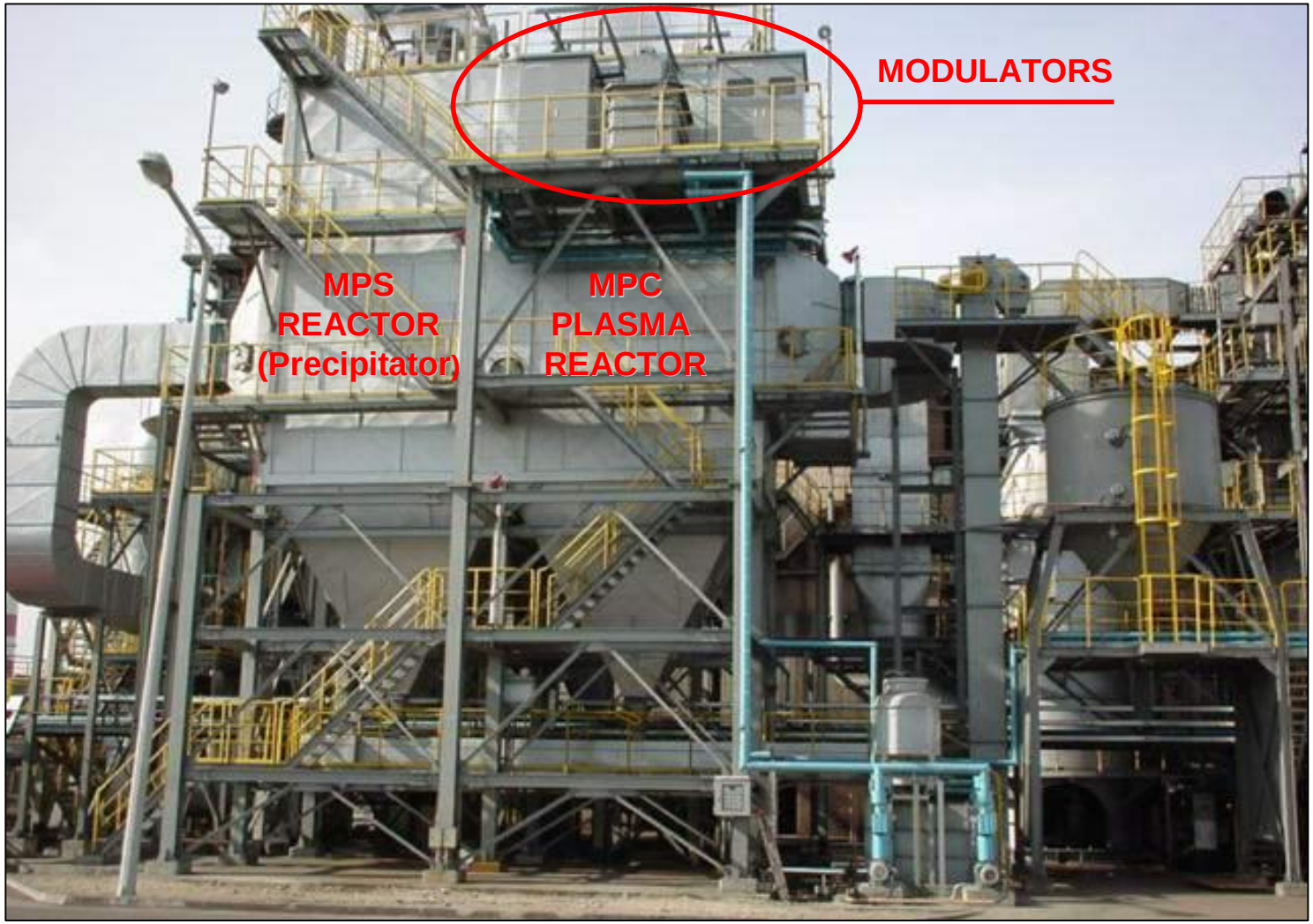
By analysing the devices which were used in the prototype from 2002 till 2007 it was confirmed that the wafers had not reached half of the expected lifetime.

Reliability



Contact Fingers on wafer from prototype switch after 4 years operation

Korean Steel Sintering Plant



Total 36 modulator switches were built for this application in 2009

Summary

It has been shown that proper designed high power solid state switches are now becoming also succesfull in Industrial and Environmental applications.

Experience with field applications and several tests have proven that reliability is at a very high level.

System cost is almost comparable to tube driven designs, but operation cost for the solid state version is clearly less.

ABB has successfully supplied more than 400 switch assemblies for high power pulse modulators during the last 4 years and gained very large experience in Military as well as Industrial applications.

Thank you for your attention

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