Paper # 113
Power Conditioning & Switching

Solid State Discharge Switches for Single Pulse and Repetitive Pulse Applications

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Abstract

Solid state switches for capacitor discharge applications are described. The presentation will show some examples of high current switches which can be used for different pulsed power applications. Two different designs are described.

1) Single shot switches for pulse current in the range of 50 to 200kA, used for Railguns, Active Armour, Crowbar Systems and Industrial Applications like magnetic forming or Ignitron replacement.
2) Repetitive pulse switches in the range of up to some tenths of kA, used for radar-, or laser power supplies, and medical modulators.

   The repetitive designs are solid state alternatives or replacements for thyratrons.

Both designs are built up as a modular system using semiconductor components with blocking voltages of 4.5 kV up to 13.5 kV per device level which can be used in series connection to reach higher voltages. The switch assemblies are ready-to-use and come as complete power

part with driver boards, trigger control box and if required with water cooled heat sinks, forced air cooling, or air convection cooling.

Introduction

Based on long term experience, collected mainly with military applications like Rail Guns and Active Armour, a range of optimized semiconductor devices for pulsed applications was developed by ABB Switzerland Ltd, Semiconductors and described in this presentation. The presented devices are optimized for pulsed discharge, and fit very well for switching the short but high power demand used in this field. Devices are available in different versions with silicon wafer diameters up to 120 mm and blocking voltages of over 6500V. Because of the different application requirements a differentiation is made in device technology. Depending on the discharge circuit, devices with low, medium or high di/dt can be selected. Thyristor structures can go commercially as high as 8500V with 120 mm silicon wafers and GTO-like structures are available up to 4500V with silicon wafer diameters from 51 to 91 mm. If required, the GTO-like designs can be also supplied as reverse conducting version with a monolithic integrated diode. For higher voltages or higher currents as one device can handle, a combination of devices in series and/or parallel connection can be used. The switches described are custom specific designed and are delivered as ready-to-use units. The solid state switch solutions shown in the presentation, are based on a standard platform of components existing already several years.

Non Repetitive Switches

Non repetitive switching devices or switch assemblies are designed in such a way that these are optimized for this type of application, therefore it can be often possible to use the same type of device in another configuration for higher pulse repetition rates. The non repetitive designs have normally no active cooling or cooling possibility and the devices need time to dissipate the heat after every shot. Depending on device, pulse energy, mass, mechanical- & electrical design and ambient temperature, this can be in the range of some seconds till up to several 10 minutes. For example are Crowbar Switches and Beam Dump Switches typical single shot switches as these normally operate only once a day or even less. Electric guns or large magnetic forming applications, are normally non-repetitive switches with up to one pulse per 10 seconds.

Reverse Conducting Discharge Switch 70 kA / 21 kVdc / 100 µs

ABB has designed and produced some discharge switches for non repetitive applications which had to fulfil the specification showed in table 1.

Parameter	Normal Condition	Short Circuit Condition
Breakdown Voltage Stack	36 kV	36 kV
Max. Charge Voltage	21 kVdc	21 kVdc
Peak Pulse Current Forward	70 kA	140 kA
Peak Pulse Current Reverse	30 kA	50 kA
Current Rise Rate (di/dt)	3 kA/µs	9 kA/µs
Pulse Duration	100 µs	50 µs
Pulse Form	Damped Sine Wave	Damped Sine Wave
Pulse Rep. Rate	1 Shot / Min.	1 Shot / 10 mins.
Lifetime	20.000 Shots	1.000 Shots

Table 1. *Specification for Reverse Conducting 70 kA / 21 kV switch assembly.*

For the specification showed in the table 1, the reverse conducting 91 mm discharge device, 5SPR 26L4506, with integrated driver unit [1] was selected. To withstand the 21 kVdc charge voltage 8 components with Vdrm=4500V / Vdc=2800V per device have to be used in series connection. The single devices can handle the required nominal forward current of 70kA and reverse 30kA. Also the short circuit condition can be fulfilled without parallel connection of devices. Because of the di/dt of 3 kA/µs (9 kA/µs short circuit condition) a GTO-like wafer structure was used. In Fig. 1, the wafer structure of the device is shown together with the complete component.

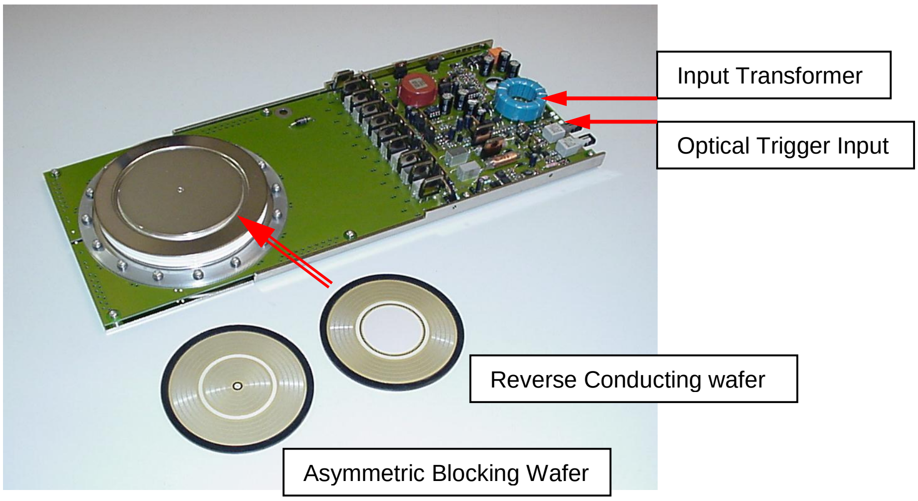
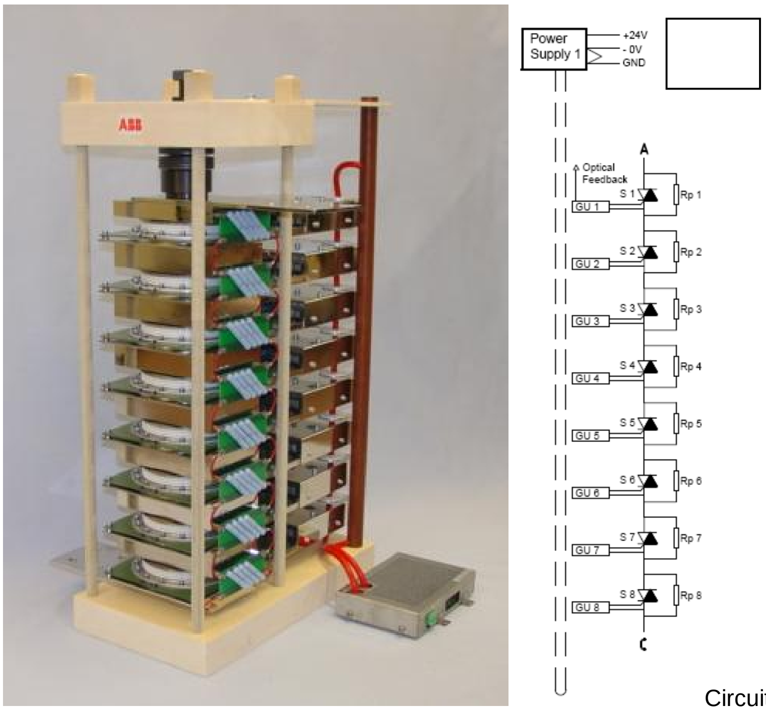


Fig.1: 5SPR 26L4506, Reverse Conducting Integrated Discharge Switching Device 4500V

Because of the reverse conducting component, there is no need for a separate freewheeling diode. The switch assembly consists of 8 devices in series connection with large Nickel plated aluminum blocks of 150 x 150 x 40 mm for spacing between the driver-units and to enable heat dissipation. The isolated clamping is done by glass fiber epoxy base plate and crossbar with glass fiber epoxy threaded rods M-20. The clamping force of 40 kN is created by a Bellville spring pressure pack. To energize the driver units, a separate current source power supply is used. The power supply output is 25kHz / 4A which is flowing in a HV closed loop cable sloped through the input transformers of all 8 driver units. The isolation voltage of the closed loop cable must be at least 2x the max. charge voltage of the switch. A light distribution box with 8 optical outputs will simultaneous fire all the driver units trough optical cables. The trigger input of the light distribution box can be an electrical or optical trigger signal. Fig 2 shows the switch assembly with closed loop power supply. The light distribution box is not shown.



Circuit diagram

Fig. 2: *Switch assembly complete with current source power supply*

Because reverse conducting devices are used, there is no need of a snubber circuit, only voltage sharing resistors of 500 kΩ are used over each device level. Fig. 3 and 4 shows

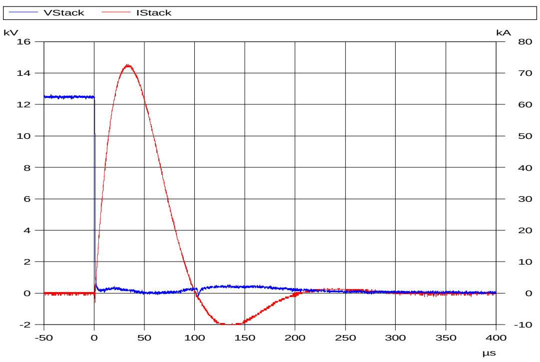


Fig. 3: *Single Pulse test with 75kA / 12.5 kVdc*

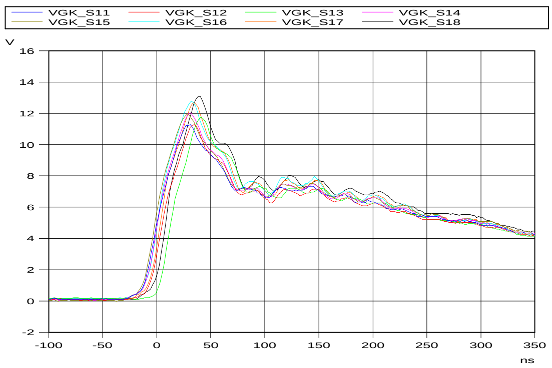


Fig. 4: *Gate signal delay at Turn-On (Tj=25°C)*

a part of the test results. The switch assembly is one of three units which are in use for magnetic forming, but can be used for several other applications. By using water cooled heat sinks between the devices it is possible to increase the pulse repetition rate to about one shot per 5 seconds.

High di/dt Single Device Switch 13.5 kV / 120 kA

ABB has developed together with the Institute de Recherche de Saint-Louis (ISL) in France a very compact single pulse switch [2] which is based on the same wafers as described before. To miniaturize a high voltage, high di/dt and high current switch for single pulse capacitor discharge a series connection of 3 switching wafers, each blocking 4.5 kV and one diode wafer 4.5 kV was used. The result is a reduction in weight and size by about 55% compared to the original discrete device solution. This reduction is specially important if the device is used in mobile applications like active armour or tank guns but also useful for dump switches and crowbars. The construction of the device was first made as prototype and extensive tested at ISL.

Target Specification	
Forward Blocking Voltage	13.5 kV
Reverse Blocking Voltage	4.5 kV
DC Charge Voltage	10.0 kV
Peak Pulse Current	120 kA @ 100 µs
Current Rise Rate	10 kA/µs
Overall Dimensions	Ø 120 mm x H ≤ 55 mm
Weight	< 3.0 kg

Table 2. *Target specification multichip discharge device*

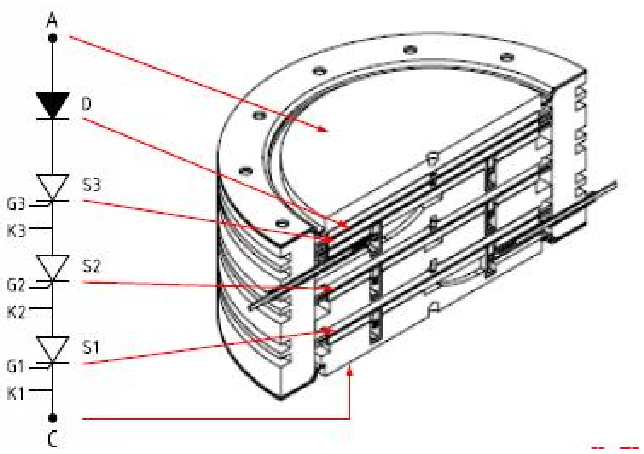


Fig. 5: *Electrical diagram and device construction O.D. = 120 mm, Height = 54 mm*

Fig. 6: *ABB p/n 5SPB 36Z1350 prototype with Diode and switching wafers*

The housings of the prototypes are made of a special machined glass fiber epoxy, and the pole pieces are screwed into this epoxy housing. Due to this the device is not hermetically sealed, but acceptable for the prototypes and collecting test results. The final version will be hermetically sealed and made with a glazed ceramic housing and plasma welded flanges. Because of the multichip construction the device is purely single shot as the wafers in the middle of the device can be hardly cooled. For higher pulse rates, a severe derating of the device is required.

I-pulse (kA)	**di/dt (kA/µs)**	**t-pulse (µs)**	**Shots n**
110	2.2	125	200
80	12.5	25	20
10.5	24	50	2

Table 3: *Measured results on one of the prototype devices*

This device is described in more detail in 13th EML Berlin 2006 paper # 151. [3]

Low di/dt, Long Pulse, Discharge Thyristor Switch for 260 kA / 15 kVdc

A design was made to discharge a 3 MJ capacitor bank using a series connection of Ns=5 and parallel connection of Np=3 thyristors with 120 mm wafer size. The devices are rated for Vdrm=5200V / Vdc=3300V. The requirement in the application is for 260 kA / 15 kVdc / 3 ms pulse / 165 A/µs / 113 MA^{2}s action. Because of voltage reversal the thyristors needed a protection circuit which was designed with Rs / Cs / Rp and MOV. The triggering is done with a simple driver unit per device level which is inductive coupled with a trigger generator. The isolation between the driver units is guaranteed by a HV isolated closed loop cable which current will trigger all 15 thyristors simultaneously. The trigger generator is fired by an optical signal. The thyristors are assembled with 135 kN clamps on a glass fiber epoxy base which has a thickness of 100 mm. The trigger generator is located under the base plate

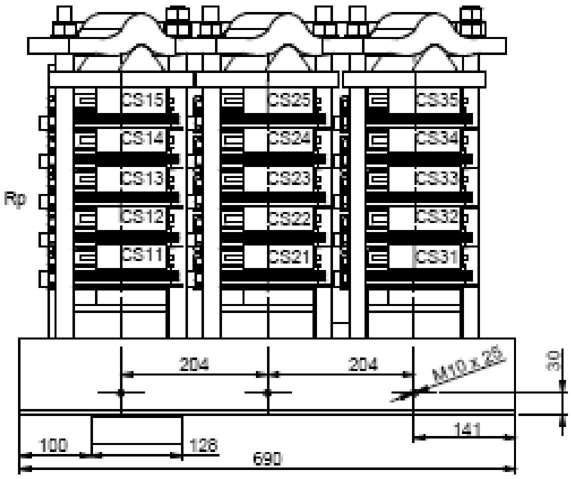


Fig. 8: Mechanical construction Thyristor switch

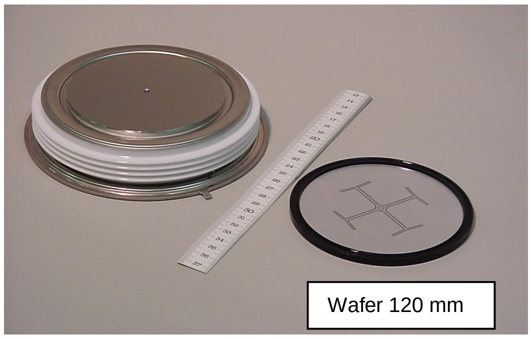


Fig. 9: ABB device p/n 5STP 5252U000x

Fig.10: Trigger Generator

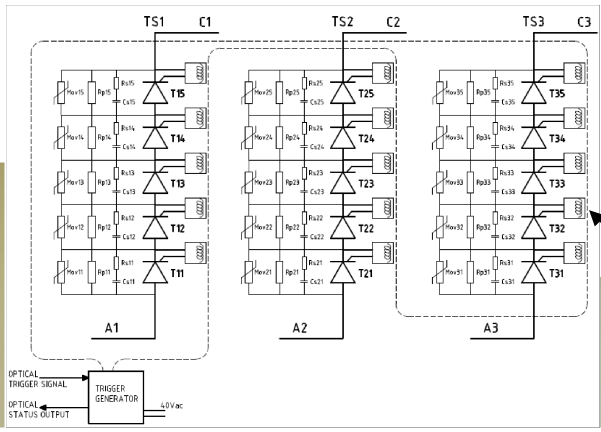


Fig. 11: Circuit Diagram

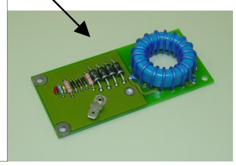


Fig. 12: Inductive Coupling

The temperature increase of the thyristor wafer after the shot is about 110°C. Because the assembly is used at low rep rates of some shots per minute, the large aluminium blocks between the devices will dissipate the heat as air convection cooling. For higher pulse repetition rates active cooling or more devices with lower blocking voltage have to be used.

Repetitive Switches

For higher pulse repetition rates switch assemblies are designed, using the same technology as described but are using active cooling with water or air. These switches are mainly in use as alternatives to Thyratrons or thyratron replacements. Since the last years solid state switches have shown that reliability and maintenance are compensating the higher initial costs compared with a tube solution in low and medium frequency systems. ABB is supplying increasing volume to companies producing Radar Power Supplies, Medical Accelerators and Pulsed Corona Discharge systems. The switch assembly presented is a typical example for a medium power system using a PFN. The device selected has a 51 mm 4500V GTO-like wafer with a monolithic integrated diode and the driver unit is mounted around the device.

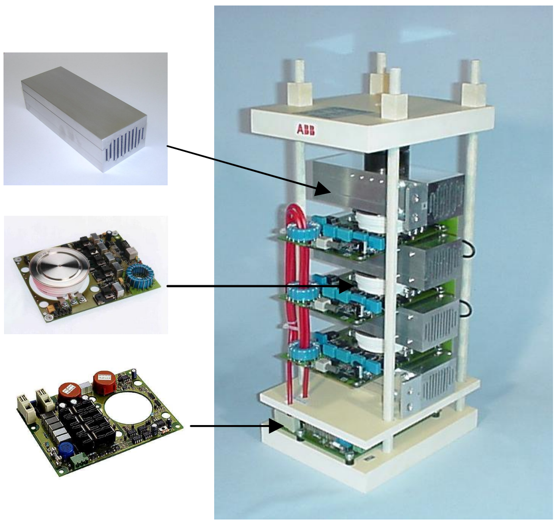


Fig. 13: *Switch Assembly for forced air cooling with detail of heat sink, integrated device and power supply*

Pulse Rep. Freq.	V - Stack	I - Stack	E/Pulse per Stack	Power loss per Device	Tj
[Hz]	[V]	[A]	[mW]	Device [W]	[°C]
1300	4210	890	350	152	67
1300	6340	1350	900	390	125
1000	6250	1340	740	247	91
1000	7340	1580	1050	350	116
800	7350	1600	900	240	89
T 800	8420	1840	1275	340	114

Table 4: *Tested values at different frequencies*

The switch is specified for pulse repetition rates of up to 1300Hz. Table 4 shows a list with different current values vs. frequency and voltage. The measurement was done with 35°C ambient temperature and an air pressure drop over heat sinks of total 300 pa. The measurement shows also that the temperature increase in the switch is with 1300Hz near to the limit. The same switch assembly with wider heat sinks was designed for areas where ambient temperatures above 35°C can occur. The GTO-like devices have the driver unit surrounded to enable fast switching of the device with a very low inductive gate-path. The driver unit and the device are designed and optimized for very fast switch-on and allow high di/dt switching. The energy for the driver units is supplied by a closed loop current source 25kHz / 4A, the isolation between the driver levels is given by the isolation voltage of the closed loop current source cable.

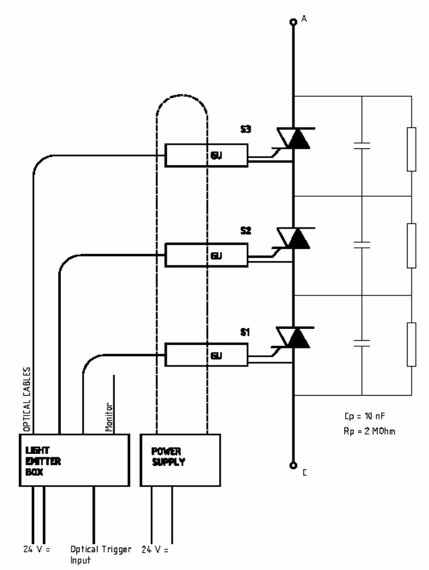


Fig. 14: *Circuit Diagram of Switch Assembly*

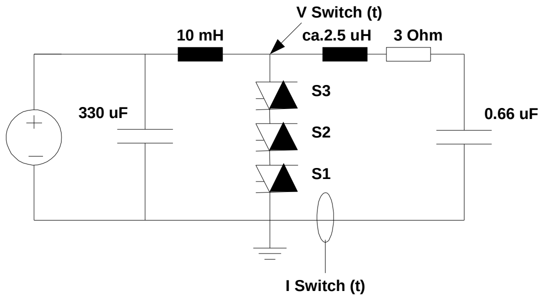


Fig.15: *Test Circuit*

The switch can be operated till up to 1300Hz, above 1300 Hz the losses, especially in the driver unit, will increase. In Fig 16 the pulse curve is shown for a current of 1200A @ 1200Hz. The switches were verified under application conditions from -25°C till up to +50C ambient temperature and full current of 1300A / 1300Hz / about 6µs pulses.

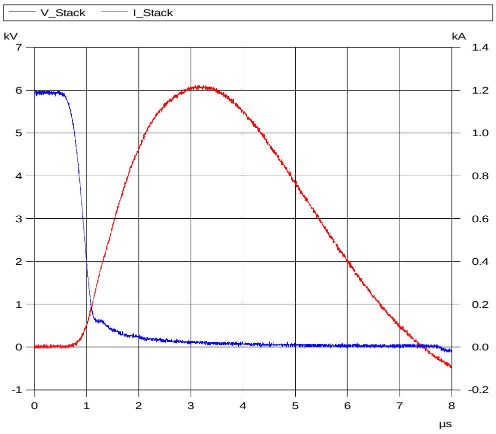


Fig. 15: *Measurement at Ta=25°C*

Fig. 15 shows one of the measurements which were done for qualification.

Conclusions

It has been shown that solid state switches are state of the art today. ABB is producing in volume a wide range of reliable semiconductor devices and switches which are optimized for pulsed power applications. Solid state switches are successfully replacing tubes and other technologies in many applications. Due to deliveries in all kind of applications a large field experience has been built-up. The initial higher cost of a semiconductor switch is compensated by the higher reliability and almost no maintenance.

References

[1] A. Welleman, W. Fleischmann, J. Waldmeyer,
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[2] E. Spahn, G. Buderer, V. Brommer, K. Sterzelmeier,
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[3] A. Welleman, E. Spahn, G. Buderer,
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