DEVELOPMENT OF A PULSED POWER SUPPLY UTILIZING 13 KV CLASS SIC-MOSFET

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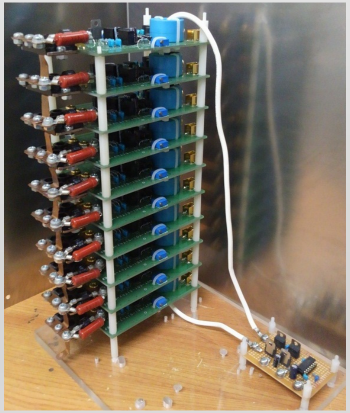
Motivation

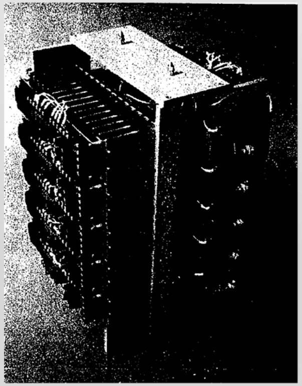
Various kinds of pulsed power supplies are used in an accelerator, such as kicker magnet supplies. Thyratron are widely used for those power supplies.

However, a thyratron has a drawback in life-time and reliability.

Therefore, replacing a thyratron by semiconductor switch has been energetically tried using a variety of devices, such as Thyristor, IGBT, SI-Thyristor....



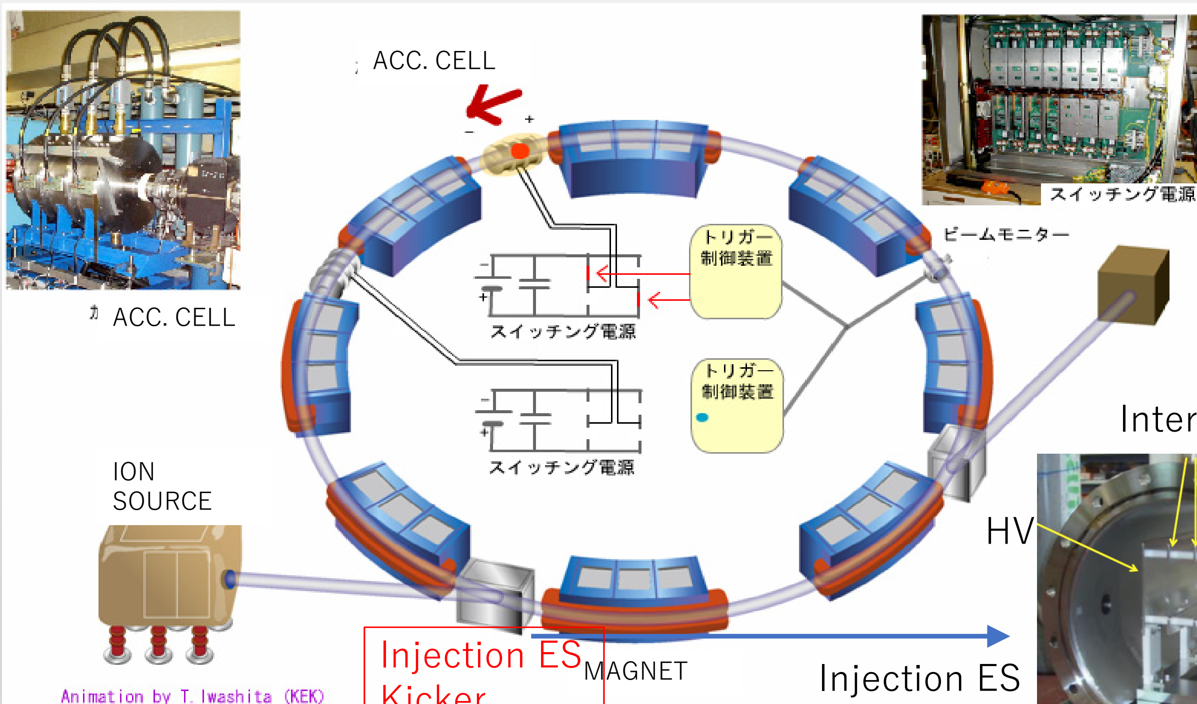
H. Kobayashi et al., “Electrostatic Injection Kicker for KEK Digital Accelerator Driven by SI-Thyristor Matrix Array Power System”, in Proc. 5th EAPPC, Kumamoto, Japan (2014).

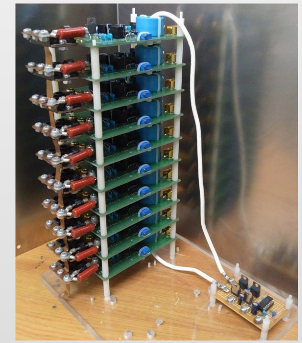


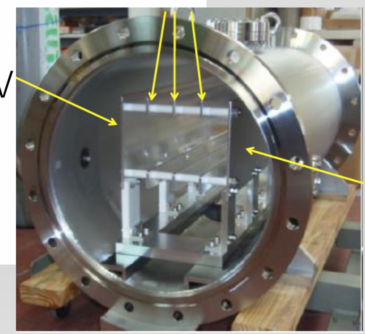
K. Okamura et al., “High Speed, High Power Switching of Semiconductor Switches”, in Proc. 9th Pulsed Power Conference, Monterey, California, USA (1989).

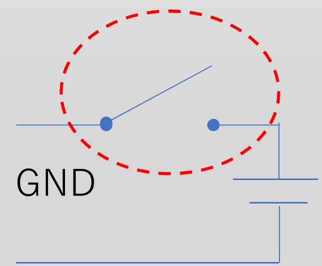
But a number of devices must be connected in series because of the limited withstand voltage of a conventional Si semiconductor device.

Application of this Switch









Injection ES Kicker

KEK Digital Accelerator

T. Iwashita et al., "KEK Digital Accelerator", Phys. Rev. ST-AB, vol. 14, 071301 (2011).

H. Kobayashi et al., "Electrostatic Injection Kicker for KEK Digital Accelerator Driven by SI-Thyristor Matrix Array Power System", in Proc. 5th EAPPC, Kumamoto, Japan (2014).

Advantages of SiC

Comparison of Material Property

（ Eg: Band Gap、μn:Electron Mobility、 Ec:Breakdown Field Strength、vsat:Saturated Drift Velocity、λ:Thermal Conductivity

Material	Eg (eV)	μn (cm2/Vs)	Ec (MV/cm)	Vsat (10^7 cm/s)	λ (W/cmK)
Si	1.12	1350	0.3	1.0	1.5
4H-SiC	3.26	1000	2.8	2.2	4.9

●High Withstand Electric Field x10
●High Drift Velocity x2
●High Thermal Conductivity x3

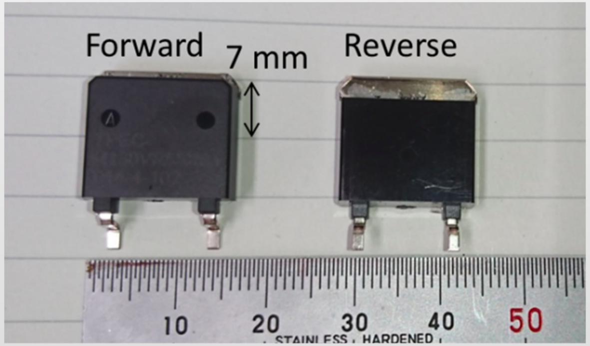
⇨ SiC has a potential of fabricating a high voltage, high speed, and high durability switching device.

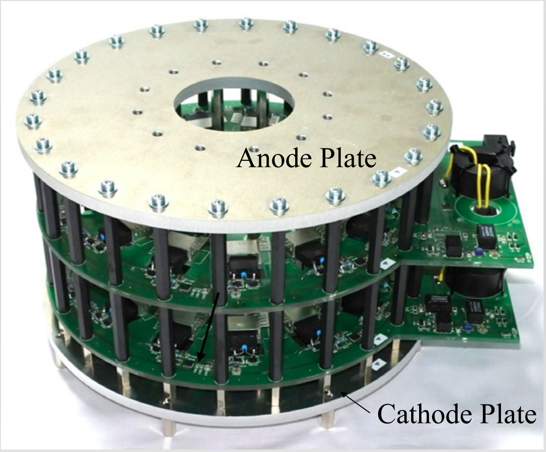
In this Study

In this study, we treat a 13 kV class SiC-MOSFET developed by TPEC, which denotes Tsukuba Power Electronics Constellation.

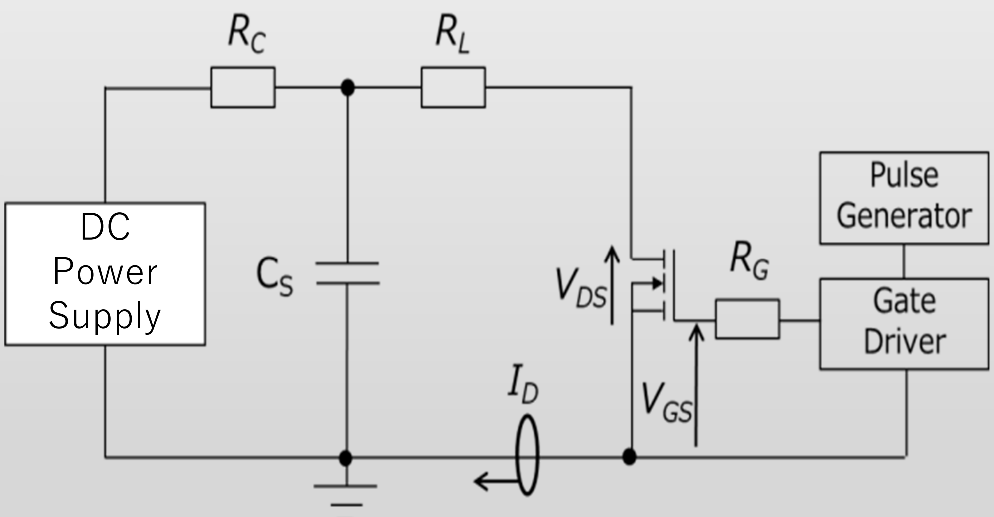
First, I will show you basic switching properties of a single device.

Then, I will show you the design and experimental results of the high voltage switch.

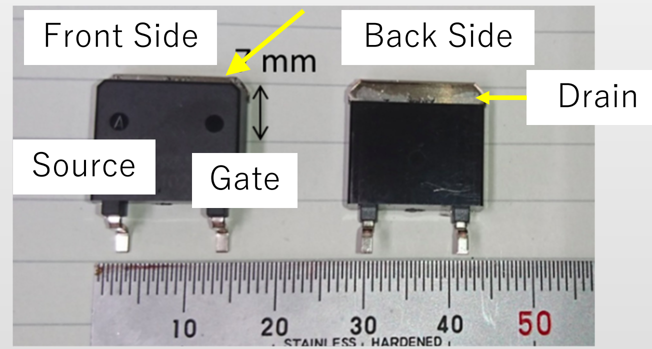


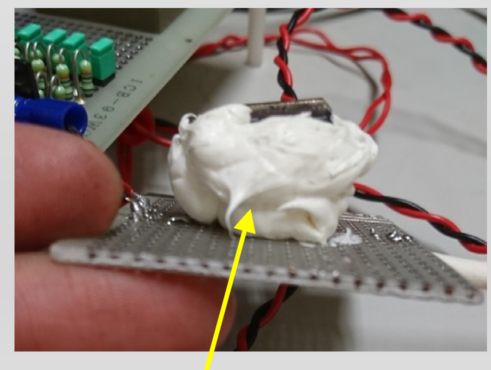


Device Evaluation Test



Standard TO-268-2L package

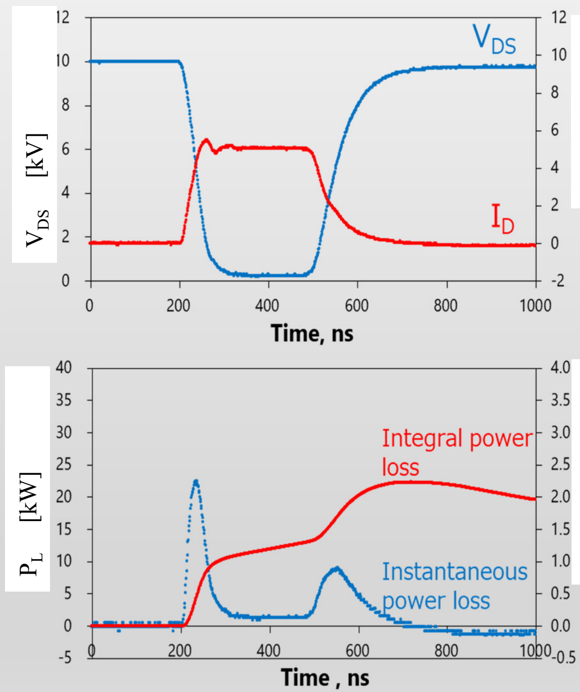




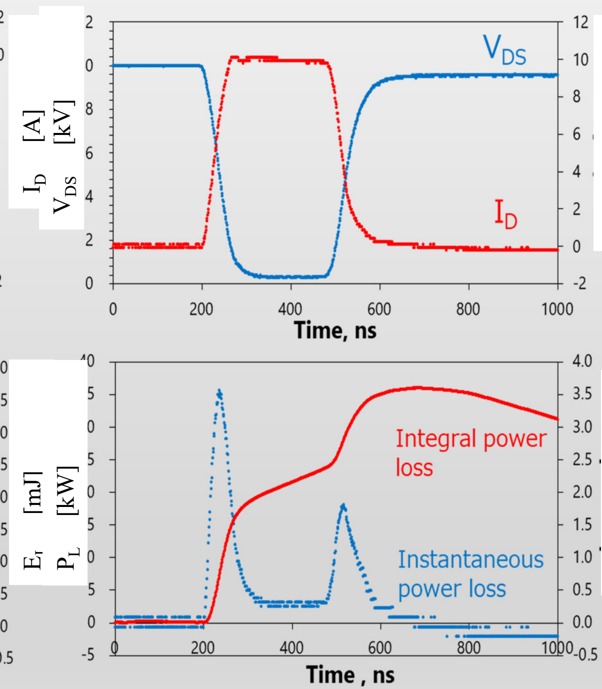
The device surface was covered with silicone rubber.

Test Result

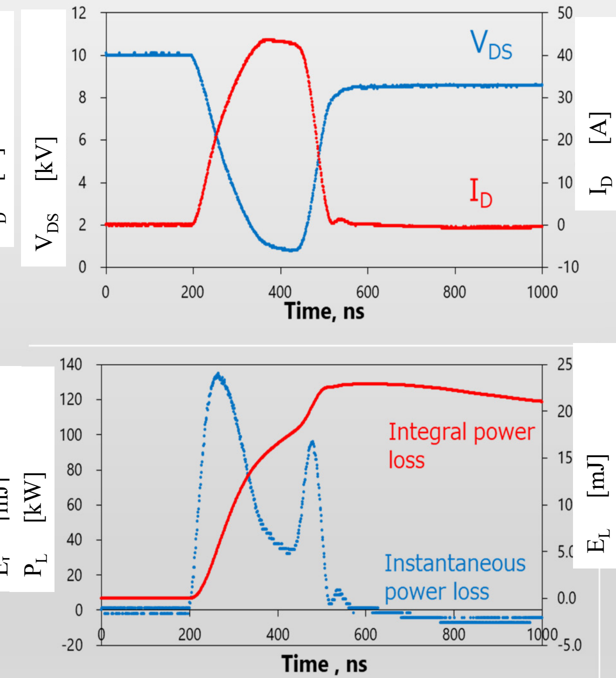
R_L=2 kΩ



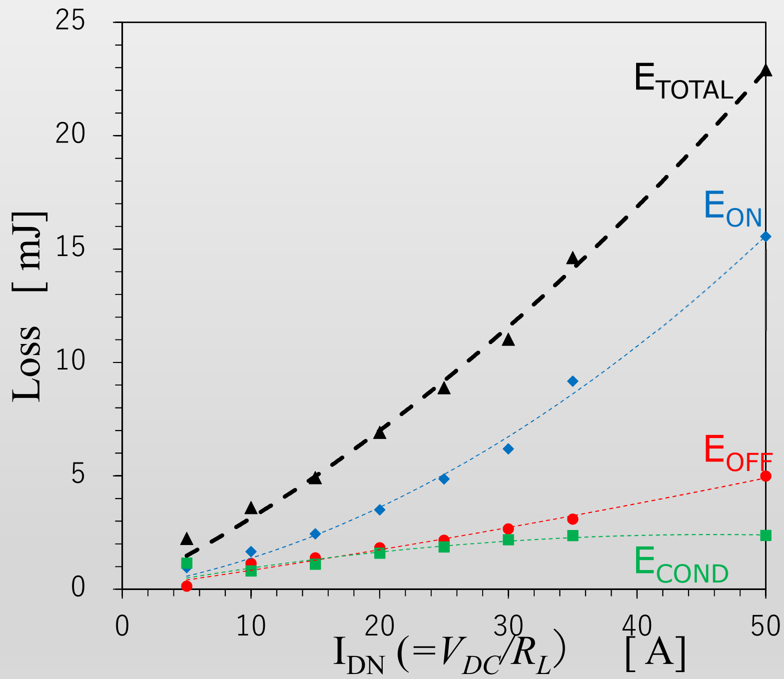
R_L=1 kΩ



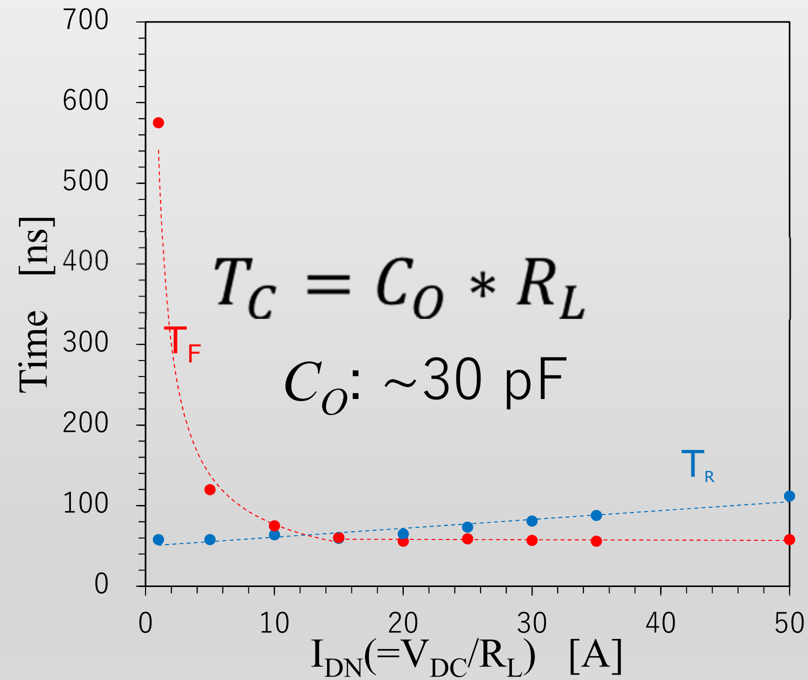
R_L=200 Ω



Test Result

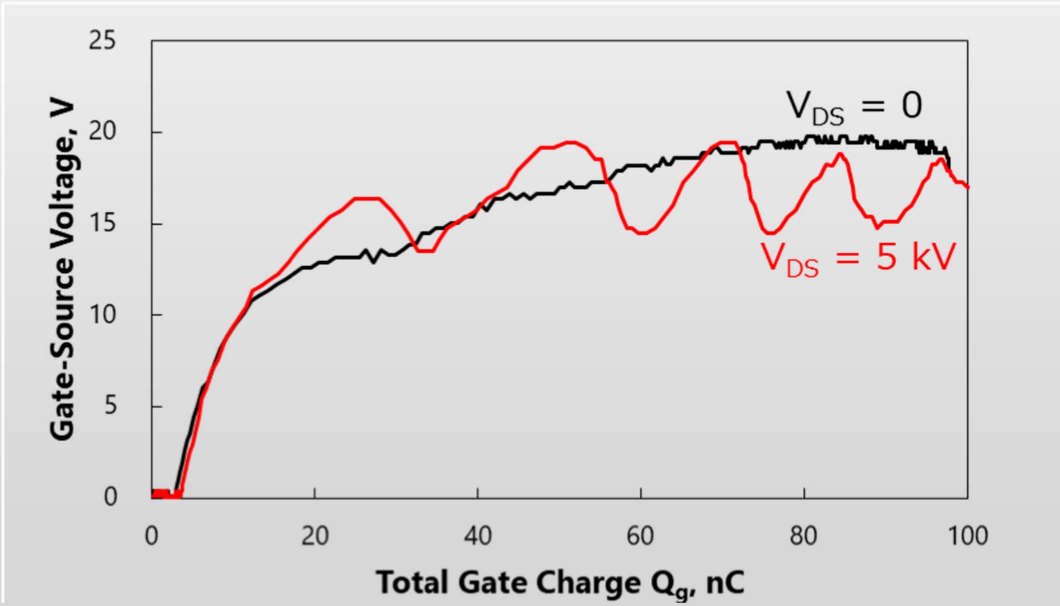


Loss [mJ]
E_{TOTAL}
E_{ON}
E_{OFF}
E_{COND}
I_{DN} ($=V_{DC}/R_L$) [A]



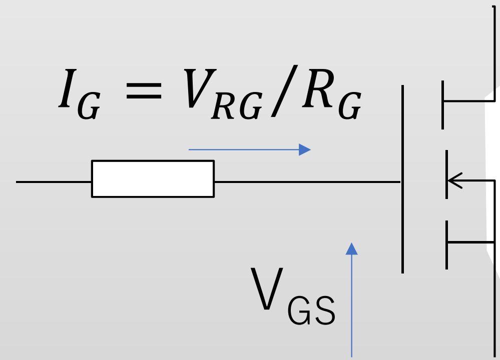
Time [ns]
$T_C = C_O * R_L$
C_O: ~30 pF
T_F
T_R
I_{DN}($=V_{DC}/R_L$) [A]

Gate Charge Characteristics



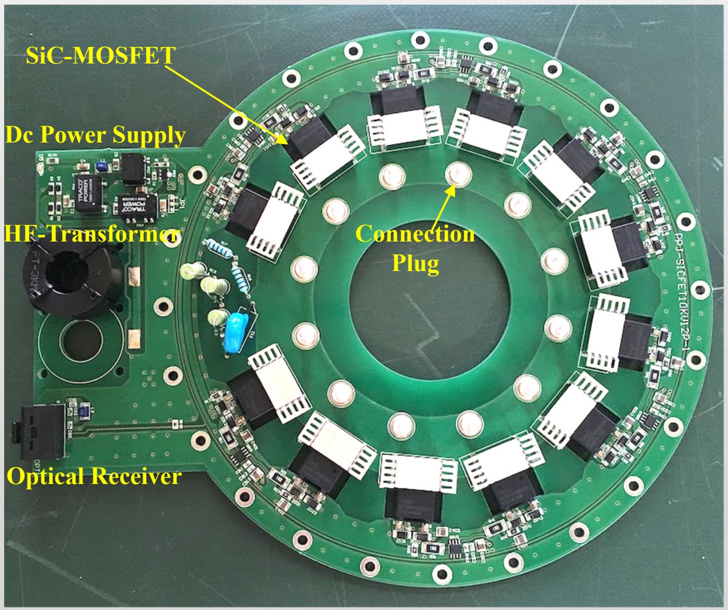
Required gate charge is ~80 nC.

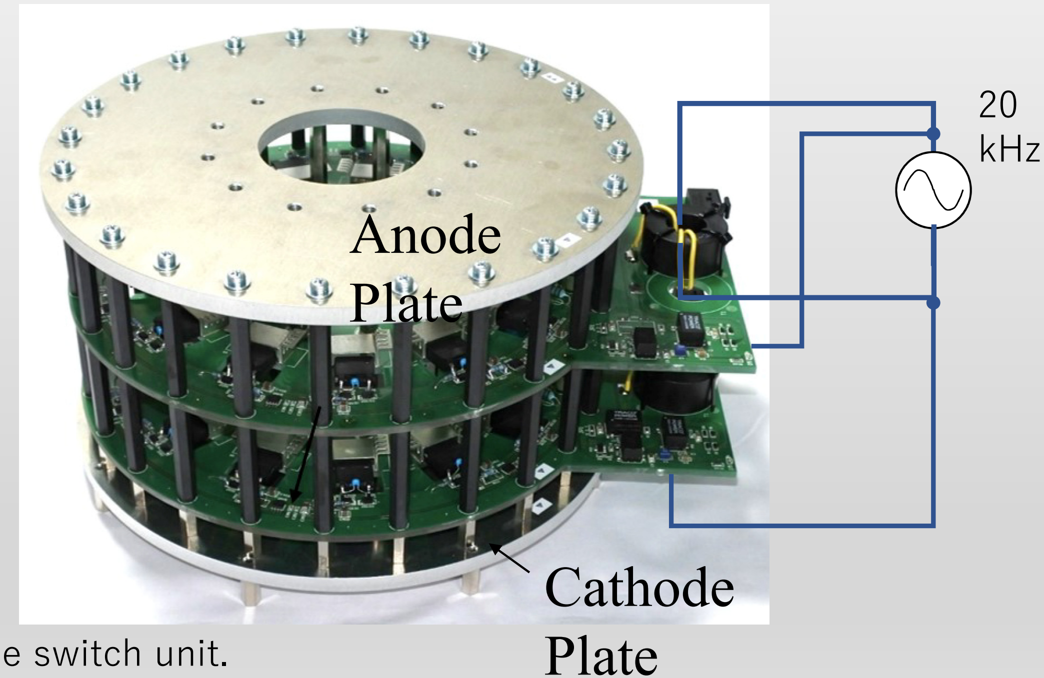
$$I_G = V_{RG}/R_G$$



$$Q = \int I_G \, dt$$

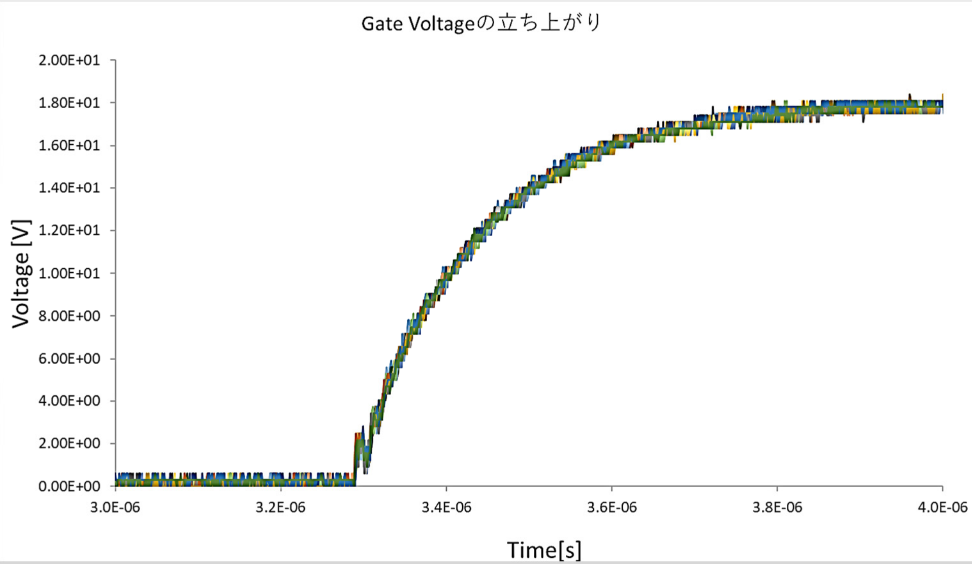
High Voltage Switch Unit

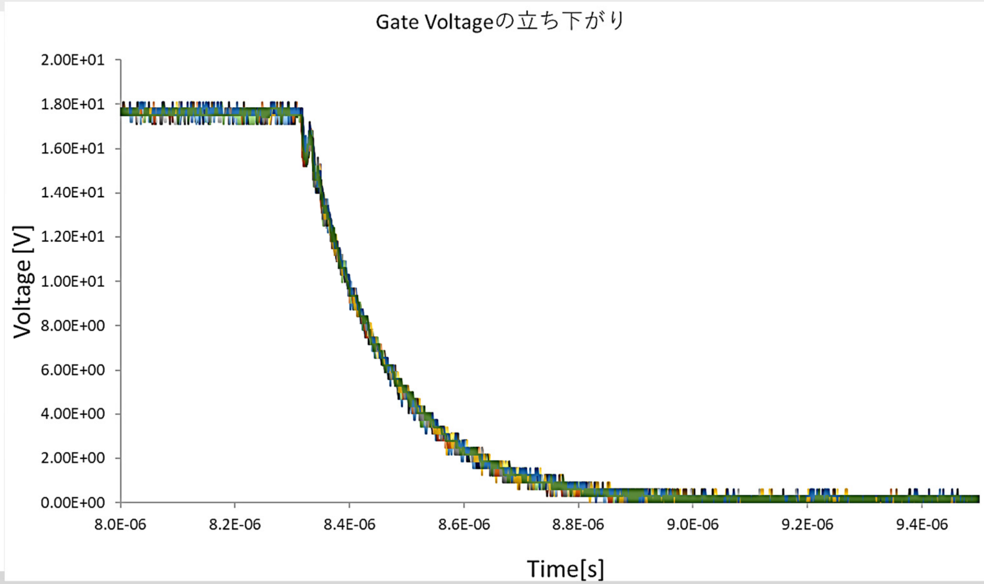




Two boards are stacked in the switch unit.

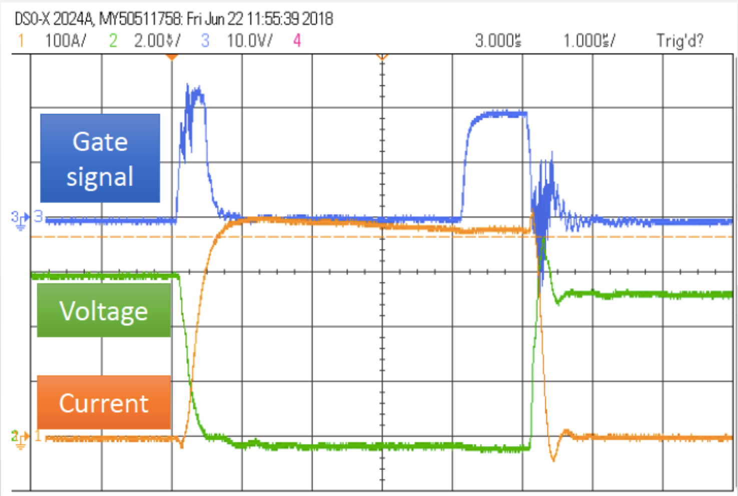
Gate-Source Voltage Waveforms

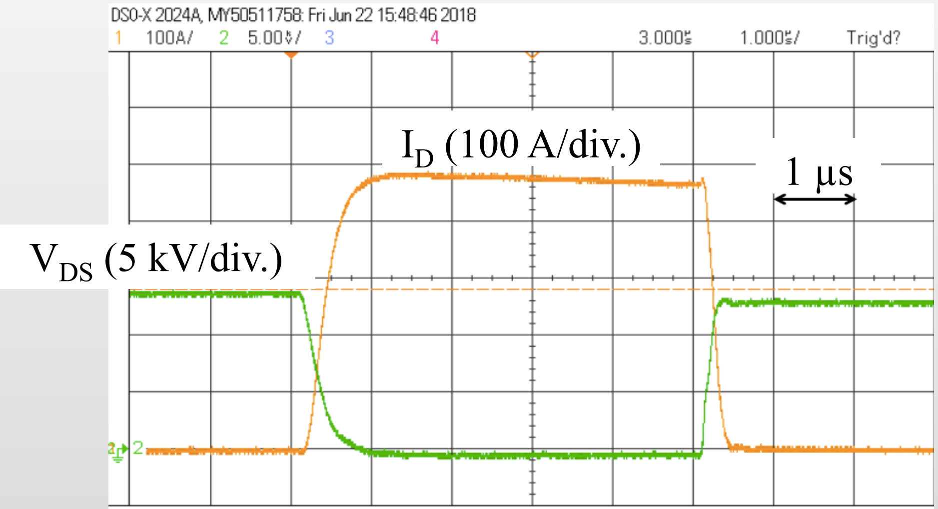




All the gate waveforms are completely overlapped.

Long Pulse Mode Test





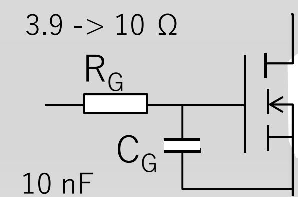
At first, we set the gate circuit same as that of the single device test.

However, we observed the unstable operation as shown in the left figure. And we found one FET was broken after the experiment.

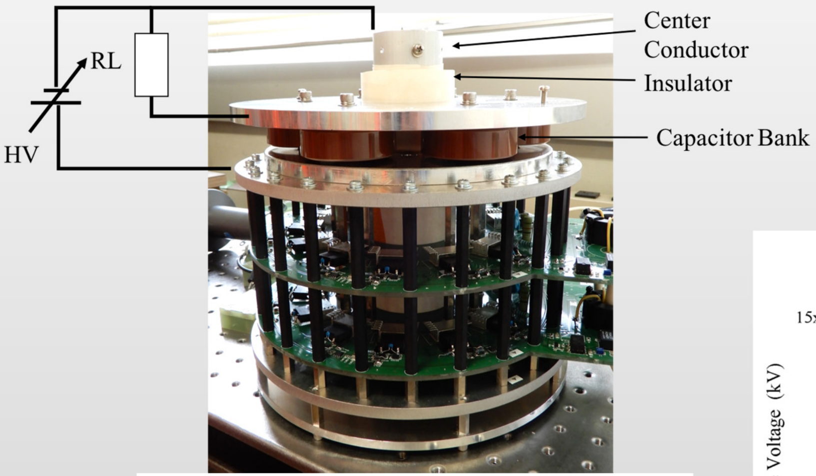
We considered that high speed switching of the SiC-MOSFET induced the unexpected voltage at the gate terminal.

So, we increased the gate resistance and insert the shunt capacitance as shown here.

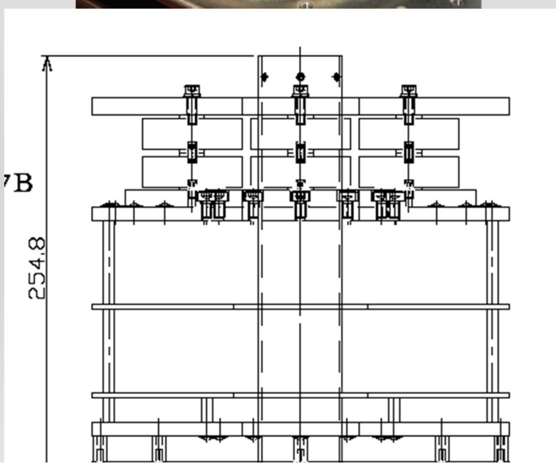
As a result, successful operation of 14 kV-490 A was confirmed. But the switching time was increased to 430 ns.

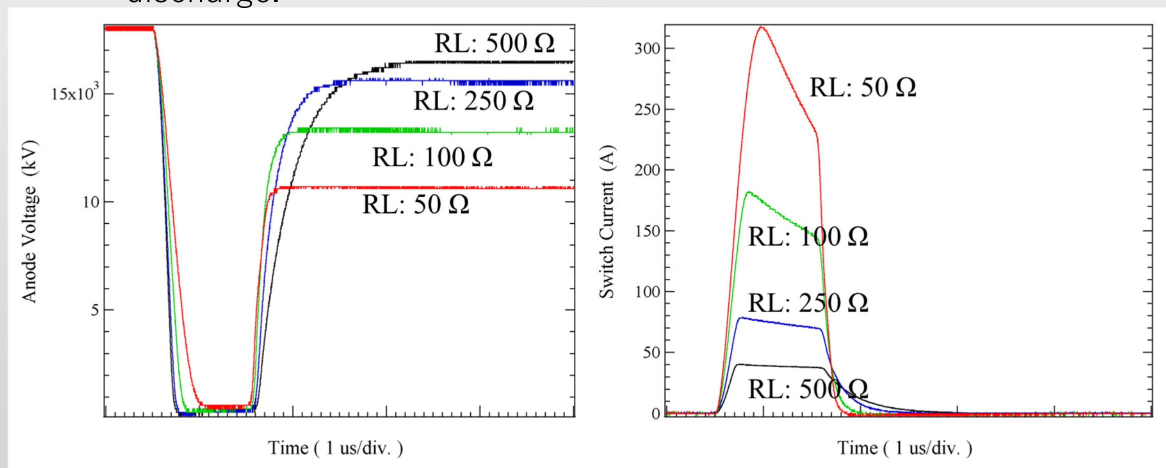


Short Pulse Mode Test



Short pulse test was conducted with a coaxial construction by assembling an inner cylindrical return conductor and a capacitor bank with the body of the switch unit. Also, insulation cylinders made of Nomex® paper are inserted between the body of the switch unit and the center conductor to prevent an electrical discharge.





With the load resistance of 50 Ω, 18 kV-318 A-1 us rise time of 289 ns pulse operation was successfully confirmed!

SUMMARY and FUTURE PLAN

- Device evaluation test of a 13 kV class SiC-MOSFET has been executed.
  - 10 kV-43.5 A switching was confirmed.
  - Gate charge required to drive the MOSFET is ~80 nC.
- Encouraged by a successful result of a single device evaluation, we designed a high voltage switch unit.
  - In long pulse mode operation, 14 kV-490 A-5 us operation was confirmed.
  - In short pulse mode operation, 18 kV-318 A-1 us operation was confirmed.
- This switch will be installed in the KEK Digital-Accelerator as the turn-off switch of the injection ES kicker.
- We are planning to evaluate the next-generation SiC-MOSFET, which has twice device area and multiple source terminal.

THANK YOU FOR YOUR ATTENTION!