Future Power Delivery System

Profs. Alex Huang & Mesut Baran
Semiconductor Power Electronics Center (SPEC)
NC State University
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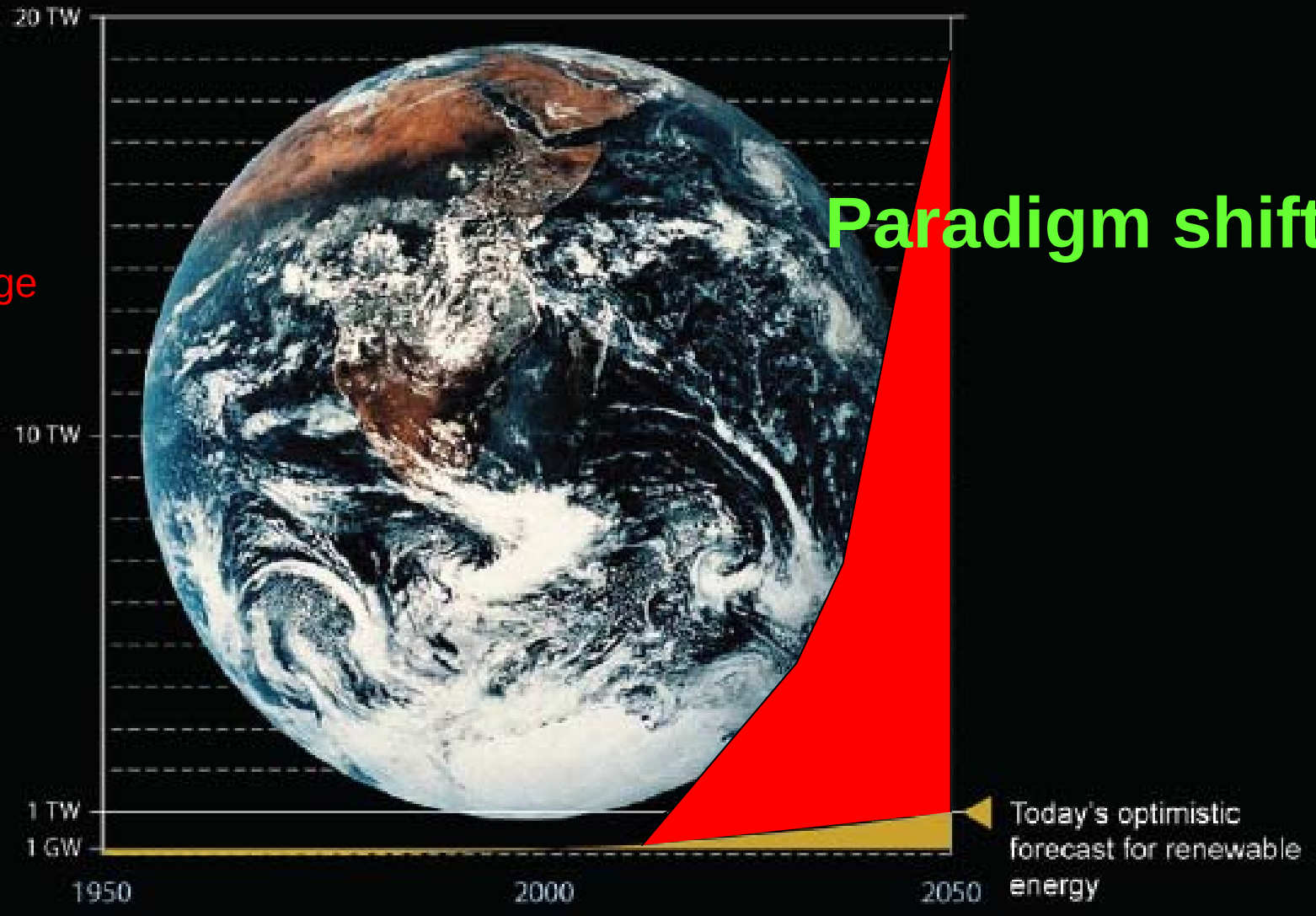
Magnitude of Challenge Requires Global Action and a Change in Trajectory

Energy Crisis
- Security
- Sustainability
- Climate Change

Green and renewable energy



Curtsey NREL.gov

A Paradigm Shift like the Computer Industry

Pre-1980s

Centralized Mainframes

Paradigm Shift

Distributed Computing

- **Shipping 250M pcs/yr.**
- **Ubiquitous ownership**
- **Ubiquitous use**
- **Ubiquitous sharing**

Paradigm Shift for the Power Industry

Today

Centralized Generation
100+ year old technology

Paradigm Shift

Future Power System

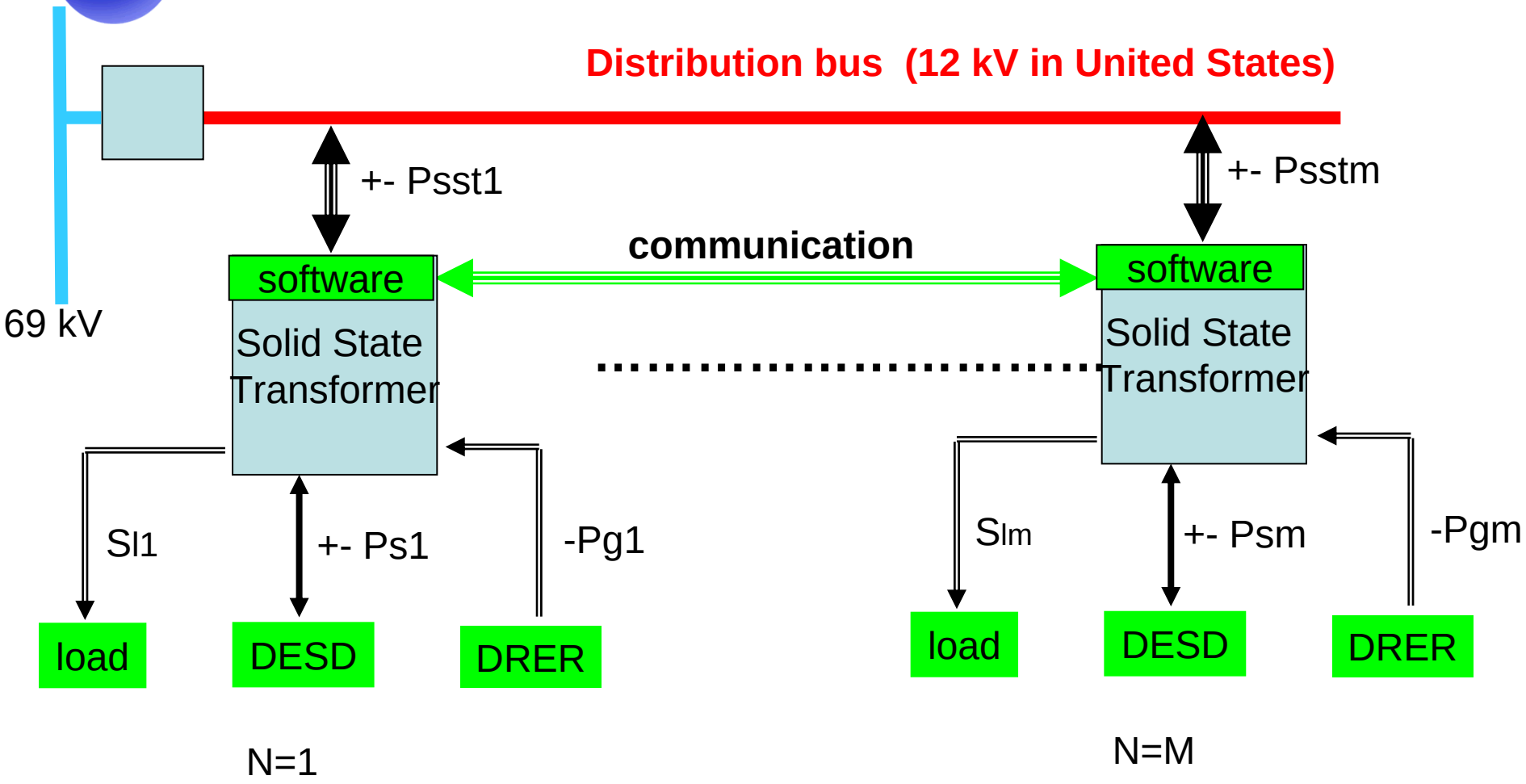
Distributed Renewable Energy Resources (DRER)

- **Ubiquitous sales**
- **Ubiquitous ownership**
- **Ubiquitous use**
- **Ubiquitous sharing**

Future Delivery System

- A new delivery system to allow:
  - Plug-and-play of any Distributed Renewable Energy Resource (DRER) anywhere and anytime.
  - Plug-and-play of any Distributed Energy Storage Device (DESD) anywhere and anytime.
- A new management system for DRER, DESD and load
  - Control is distributed
  - everything is connected by communication

Future Distribution System



- **Need to isolate low voltage side plug & play action from the bus**
- **Low voltage side voltage = 120V, 480 V etc**
- **SST rating: 10 kVA, 100 kVA and 1000 kVA**

SST Capability

- Allows plug & play
  - System immediately recognize the load, storage and generation (*real time Sl, Ps, Pg*)
- Power factor correction
  - Unity power factor on the distribution bus ($Q_{bus}=0$)
- Instant Demand side management
  - Adjust load bus voltage (*Vl adjustable*)
- Limit fault current
  - SST limits current at 2 p.u.
- IEC16850 Standard on Grid Side
- IEEE 1547 on the load/DRER/DESD side
- Real time information of the system
  - Serve as advanced metering
- Optimal operation by distributed software
  - Electric constraints
  - Economic constraints
  - Social constraints

Control Objectives

At any given $t=t_k$,

Ptotal (tk)=sum (Psst1(tk), …..Psstm(tk))

Under constraints *A(tk), B(tk), C(tk)*

Objective: maximize Pg1….m

or

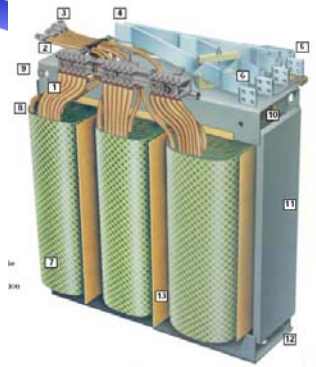
Objective: Minimize Ptotal

or

Objective: keep Ptotal = constant

……..

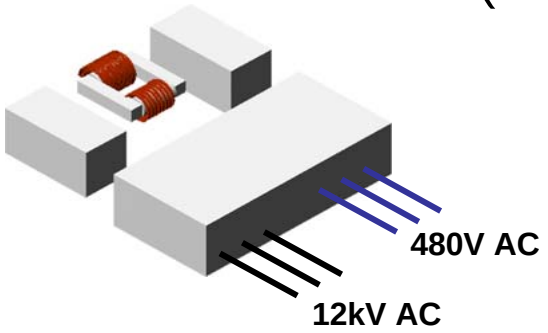
Enabling Technology



Conventional Transformer

size reduction
weight reduction

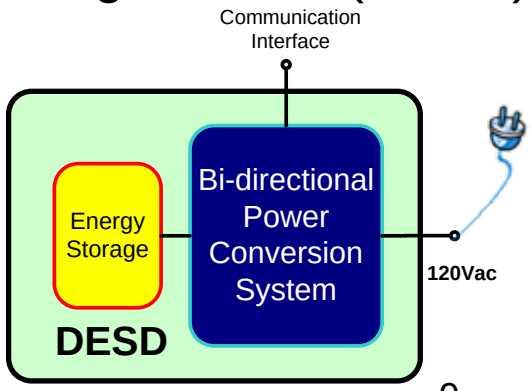
Solid State Transformer (SST)



Today's High Power
Li-ion battery

reduction in size, cost, weight

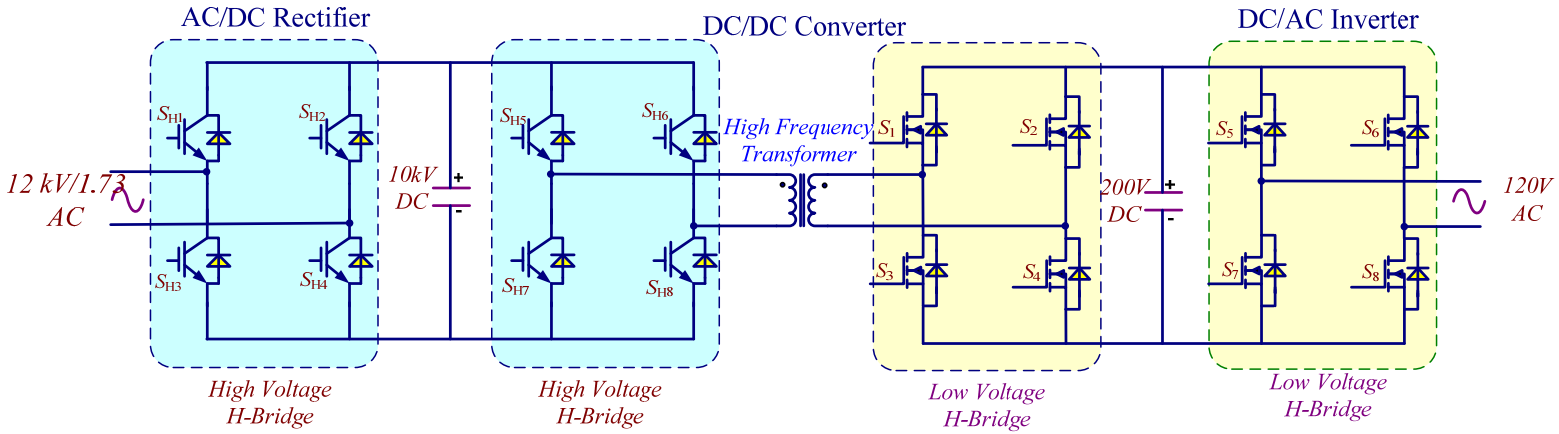
Distributed Energy
Storage Device (DESD)



Example 10 kVA SST

for single-phase residential applications

Input side: 15kV, 2A SiC IGBTs
Output side: 300V, 100A GaN FETs
High voltage DC bus: 10kV, low voltage DC bus: 200V.



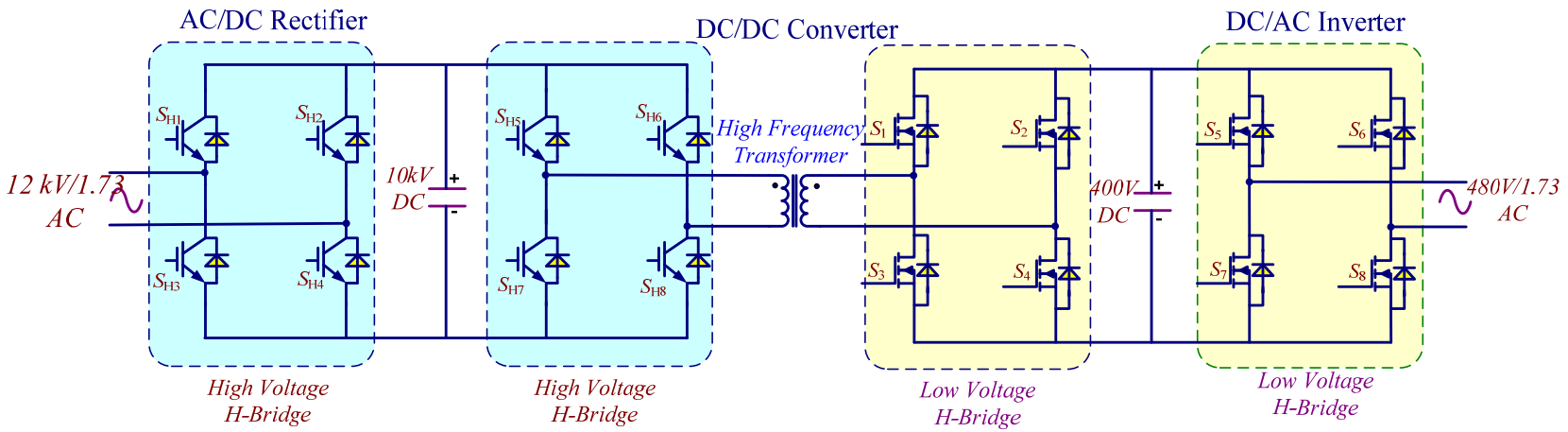
Major issues:

- Control power self-generation
- Insulation
- Thermal management
- Control
- Communication Interface
- Interface to load, DESD and DRER

Example 100 kVA SST

for 3-phase industrial applications

Input side: 15kV, 5 A SiC IGBT
Output side: 600V, 120A GaN devices
High voltage DC bus: 10kV, low voltage DC bus: 400V



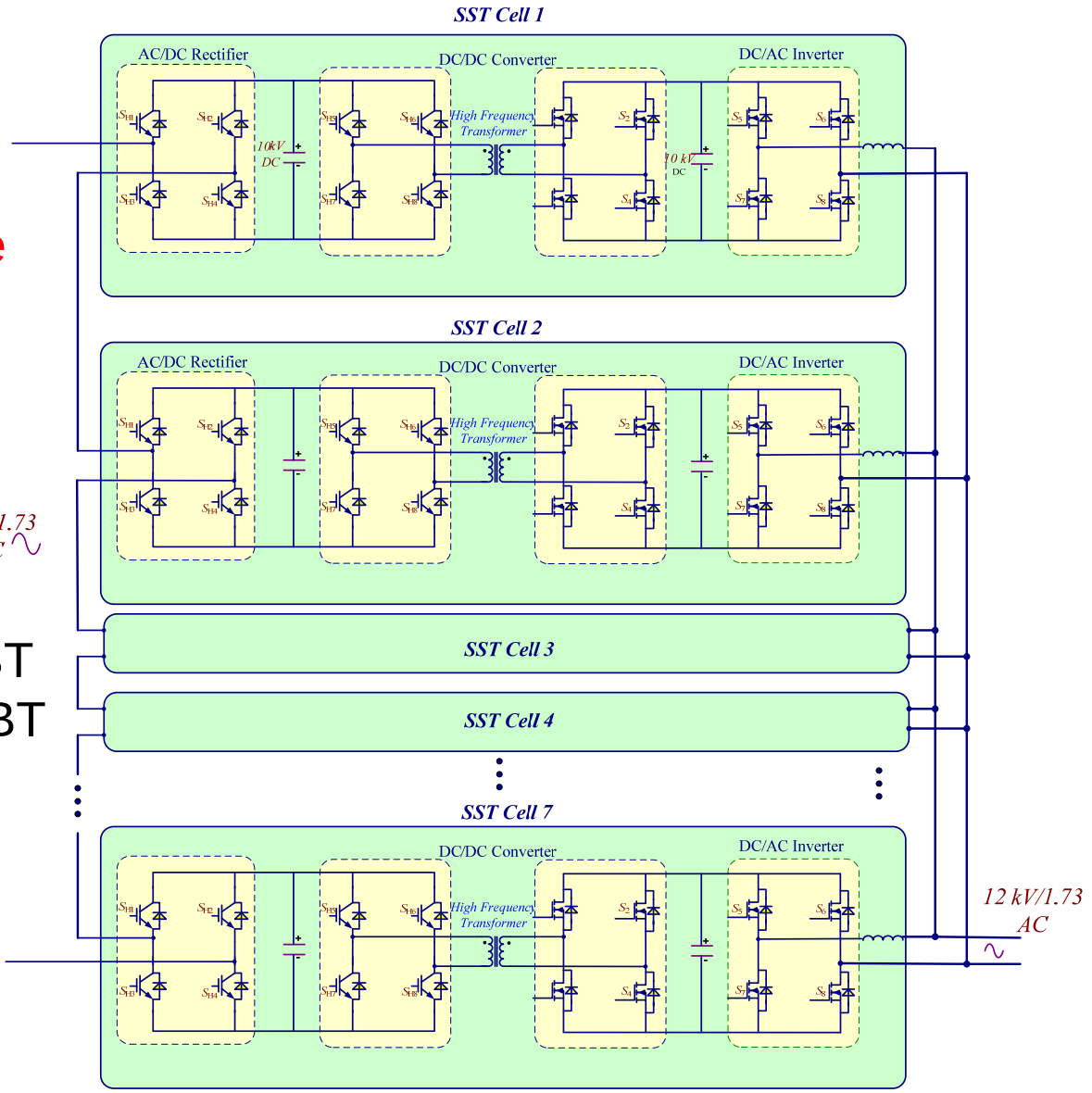
(1 phase shown)

Example High Voltage SST

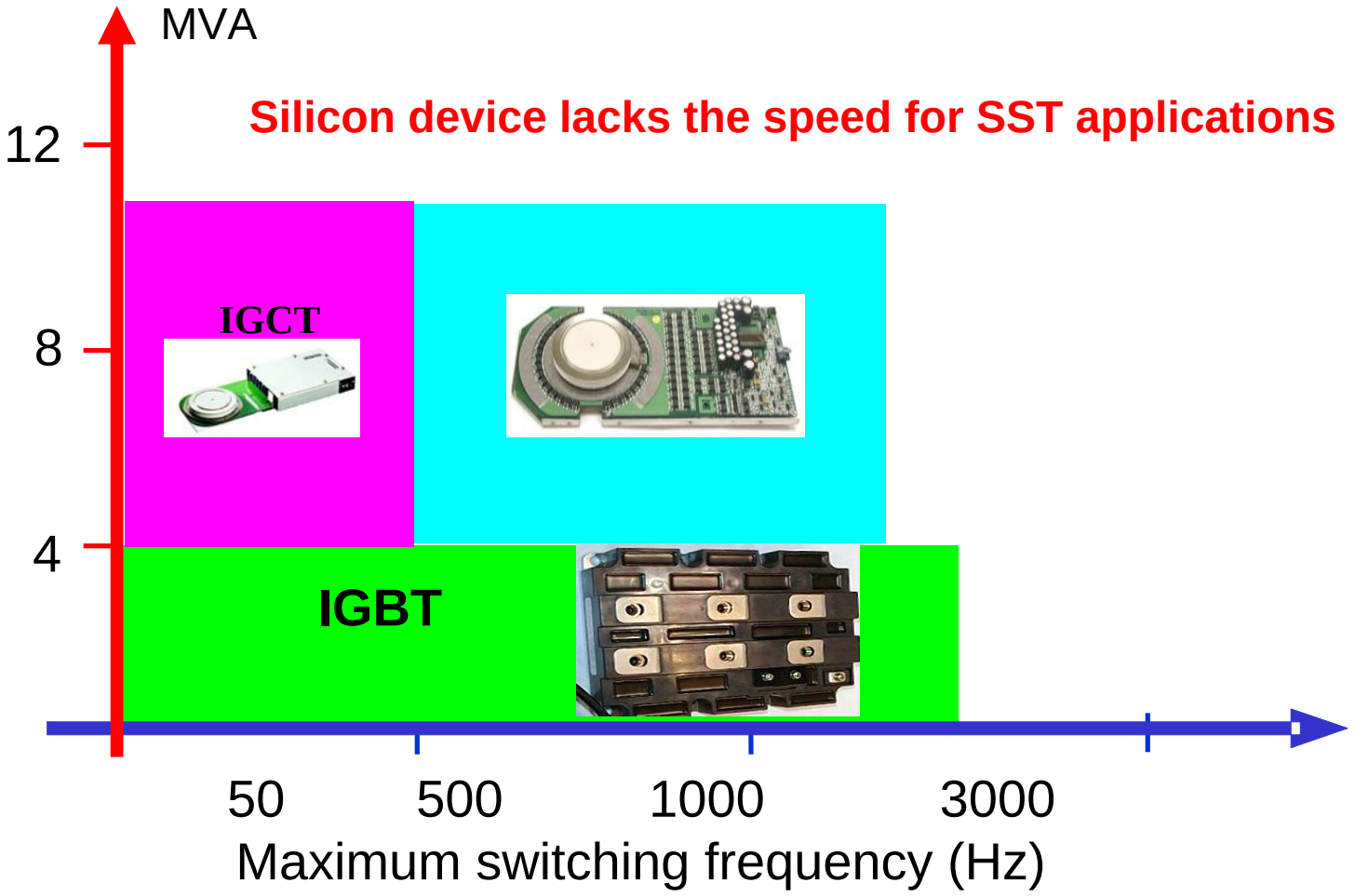
SST Topology

Modular Converter Structure
(one phase shown)
Input: 69 kV
Output: 12 kV
Rating: 700 kVA

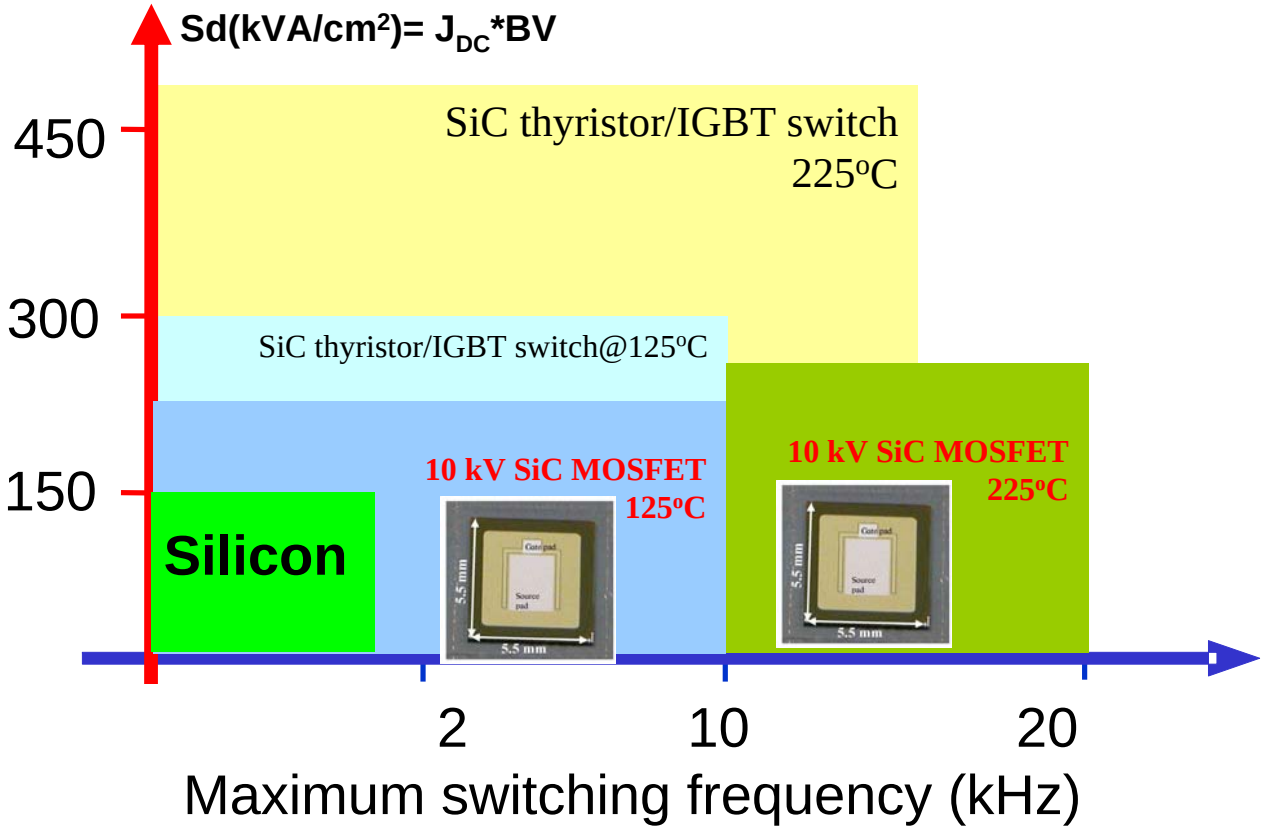
Devices:
Input side: 15 kV/5 A SiC IGBT
Output side: 15 kV/5A SiC IGBT



State-of-the-art silicon power device



Silicon Carbide Power Device

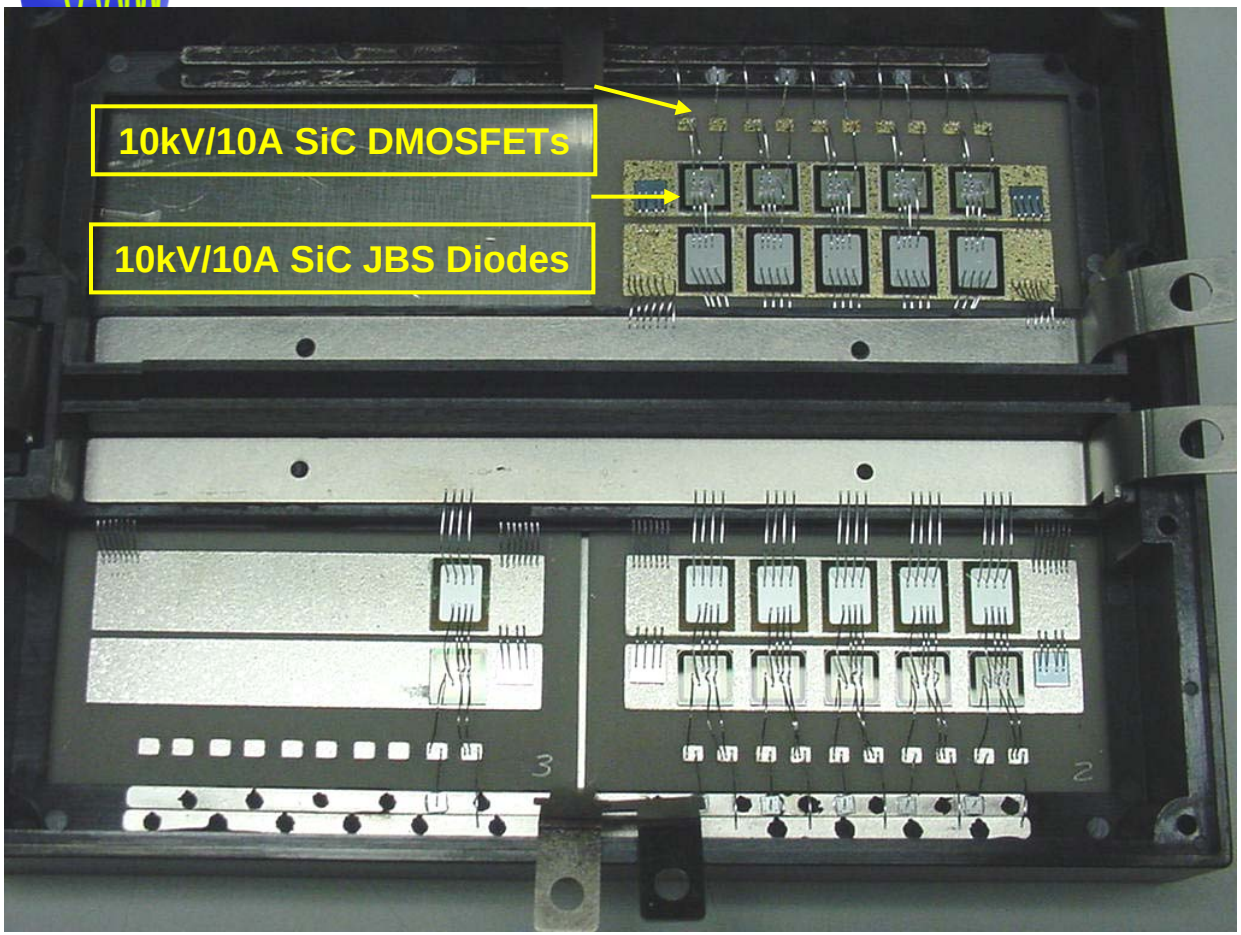


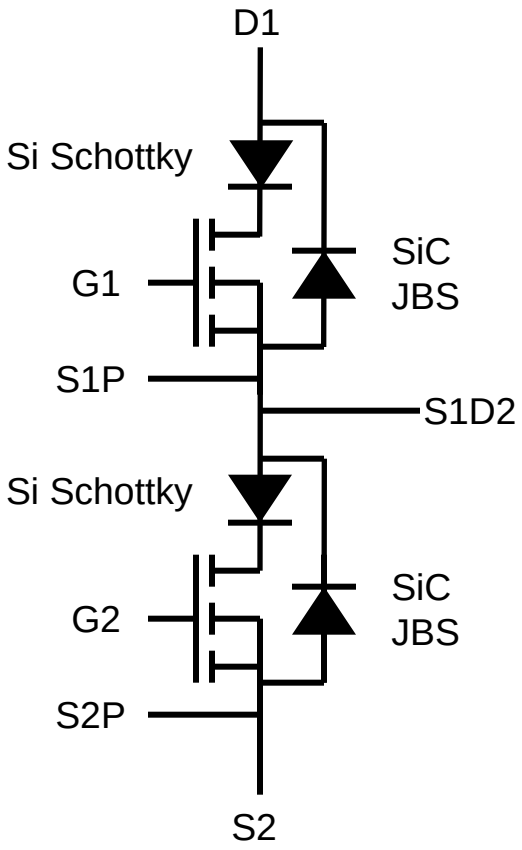
- SiC material can potentially improve the frequency-power rating trade off by 15 times

  lower losses and higher operating temperature

  allows the increase of P and f

DARPA HPE-II 10kV/50A Half H-Bridge Module

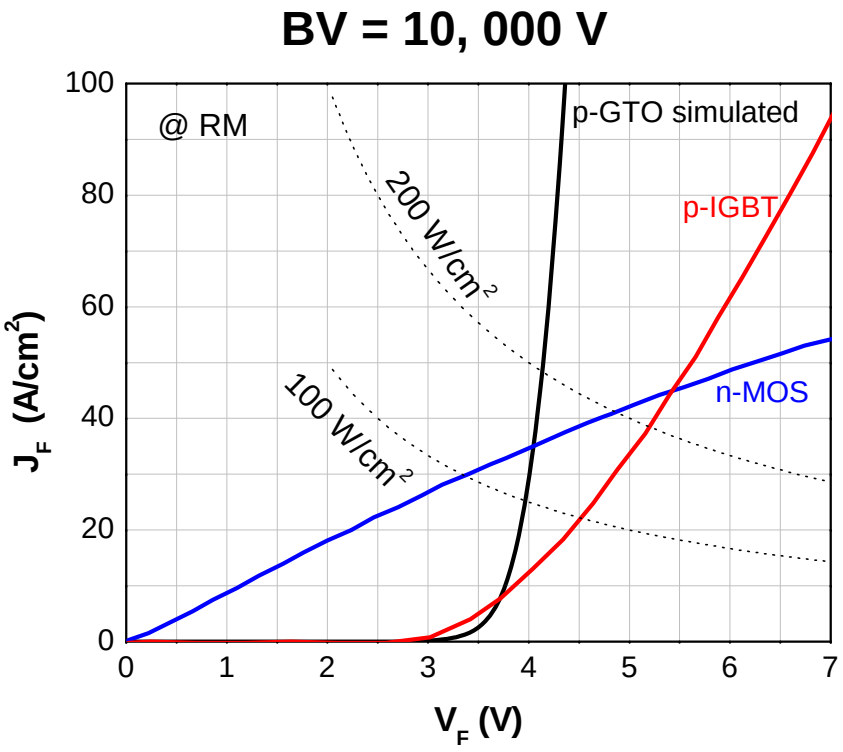


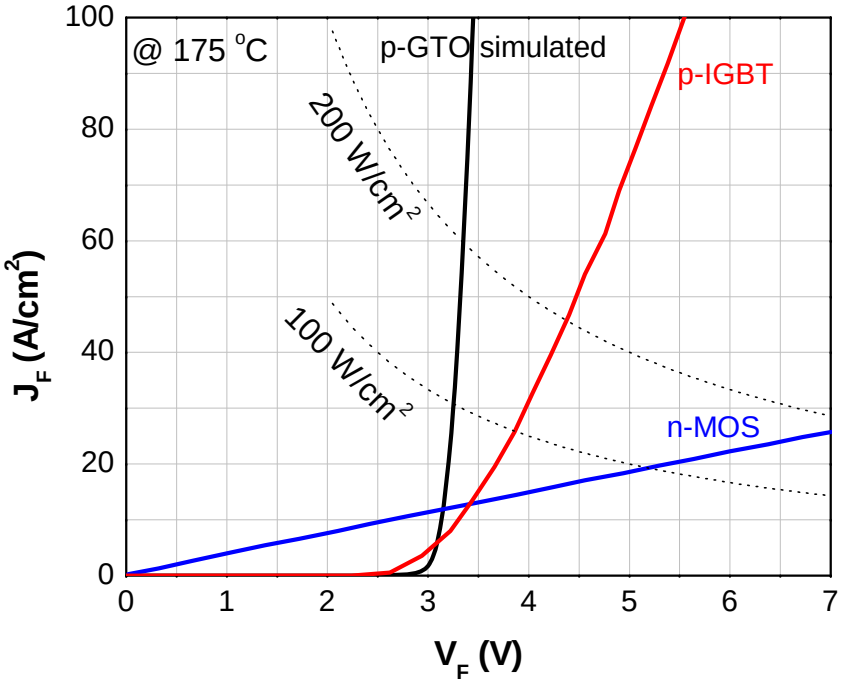


- **High current requires multiple chips in parallel, a challenge for SiC**
- **Lower current application such as 10 kVA SST makes sense for initial insertion**

Questions?

SiC Bipolar Devices

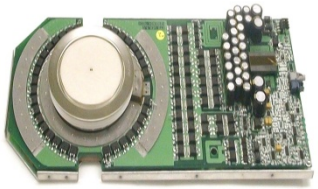




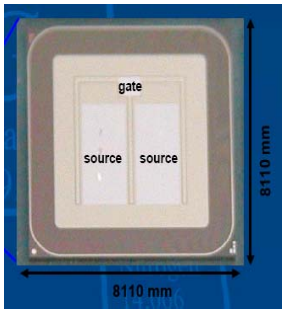
Fundamental Science

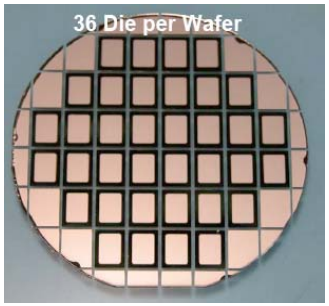
15 kV, 200°C, 350 kW/cm²
Silicon Carbide IGBT Technology
and 600V, 100A GaN Technology

4.5 kV, 125°C, 150 kW/cm²
Silicon Bipolar Technology



15 X improvement in speed*power

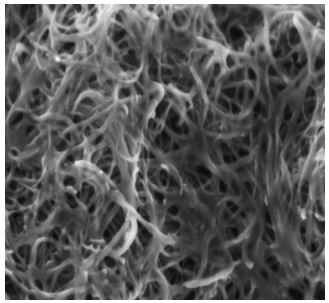




Nanofiber Li-ion Cell
(250WH/kg, 3.5 kW/kg, 20000 cycle)

Today's Advanced
Li-ion Cell

3 X improvement
in Li-ion power density



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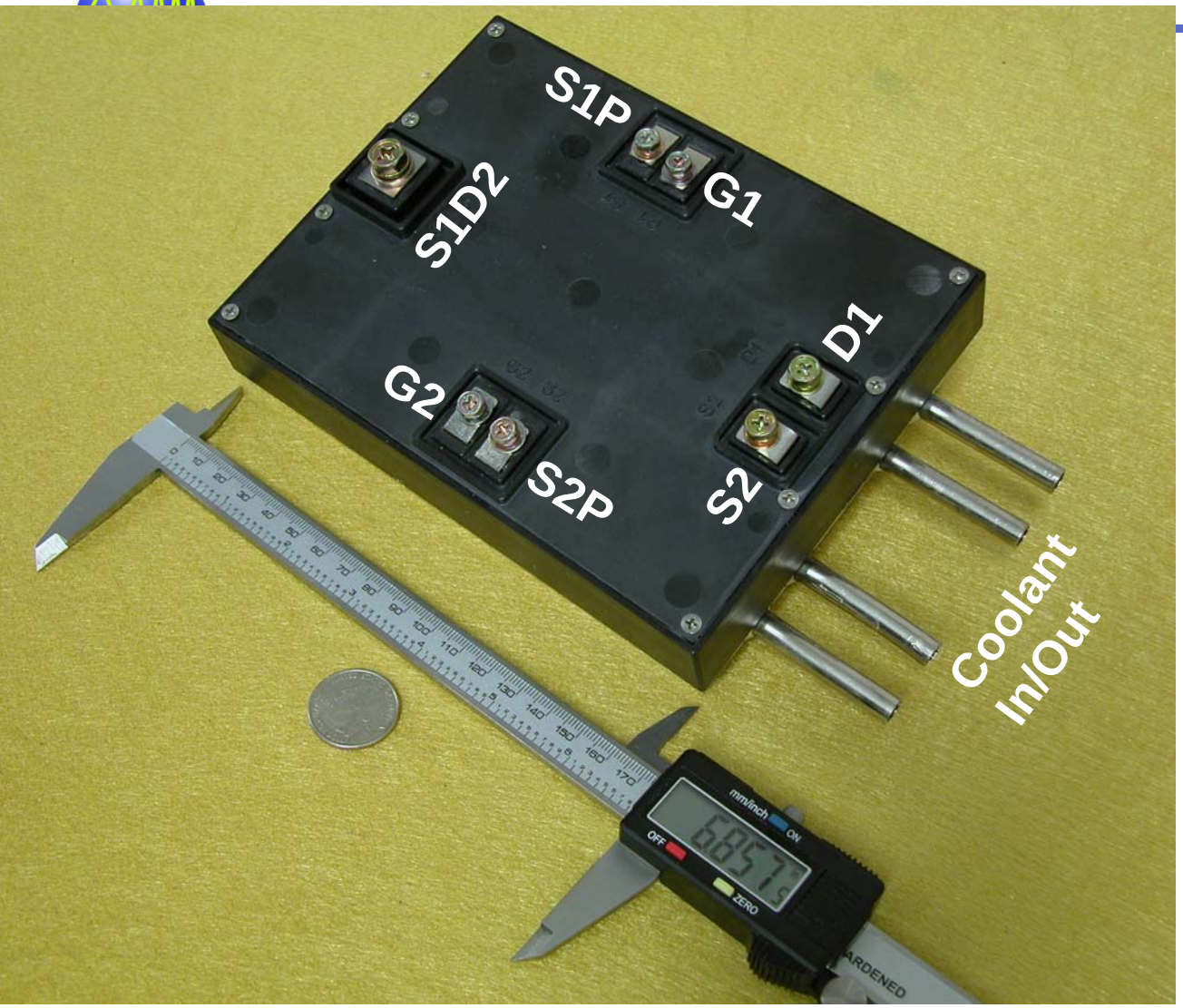

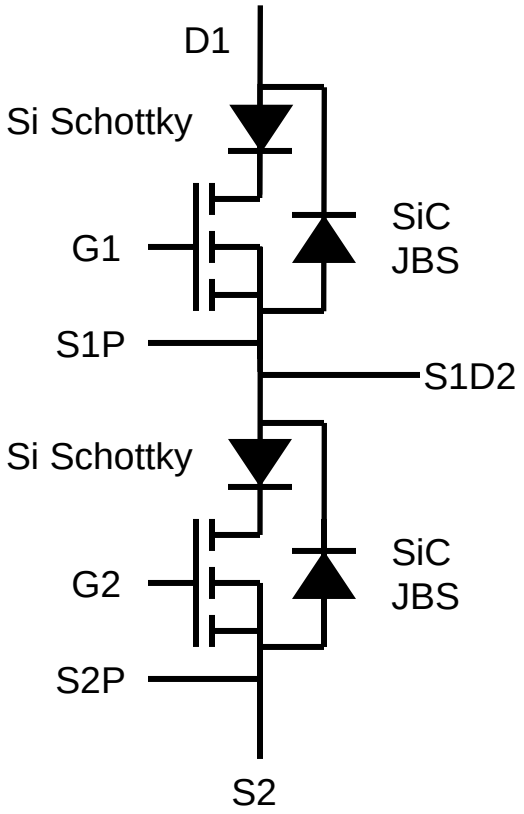

Dimensions ~ 7 x 5 inches