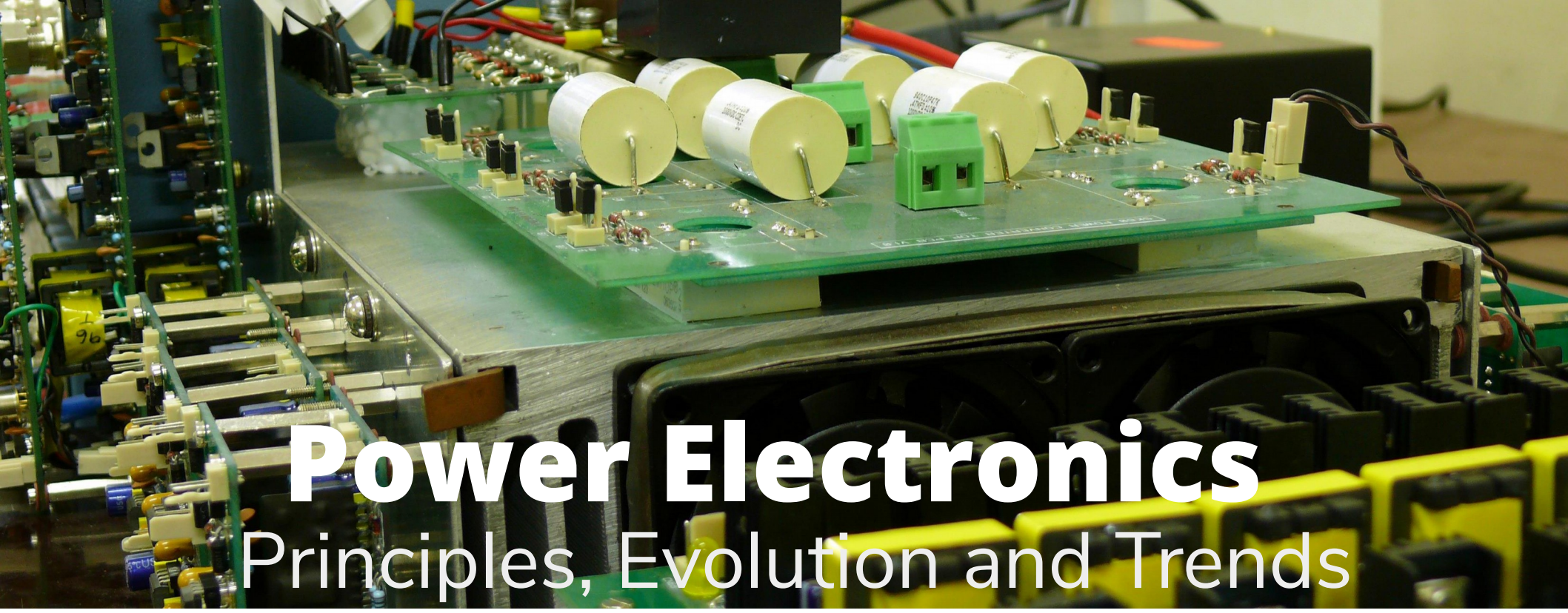


Power Electronics

Principles, Evolution and Trends

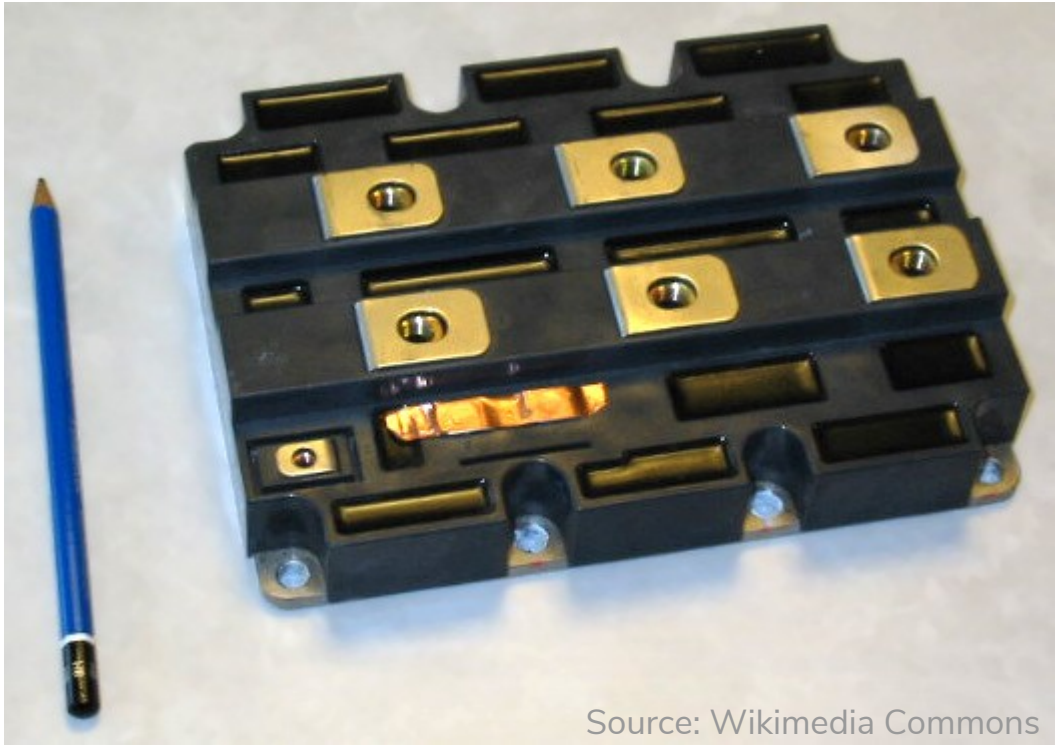
Dinesh Gopinath
College of Engineering Trivandrum

Part – I
Principles

What is Power Electronics?

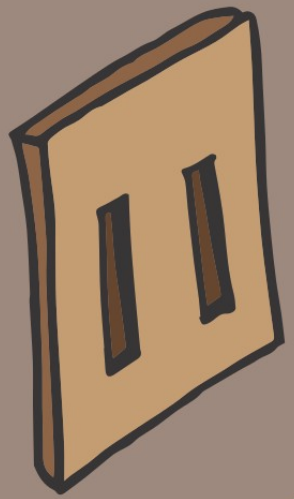
Efficient Conversion, Conditioning & Control of Electrical Power

Using Power Semiconductor Devices



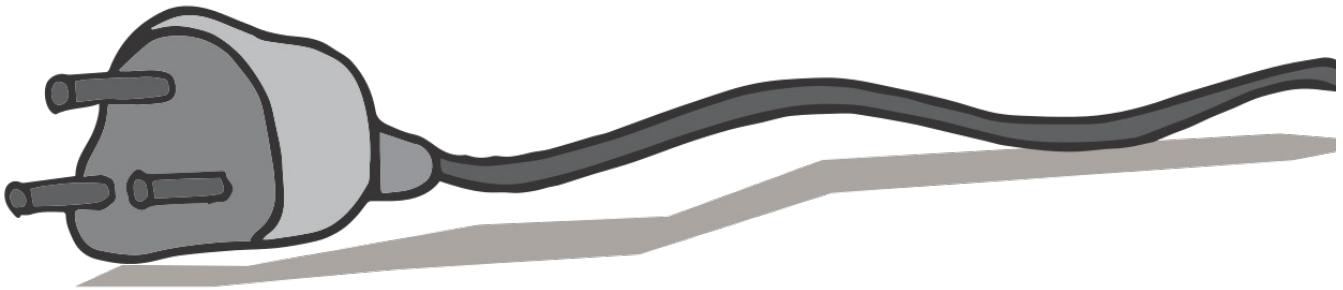
Source: Wikimedia Commons

Why Power Conversion?



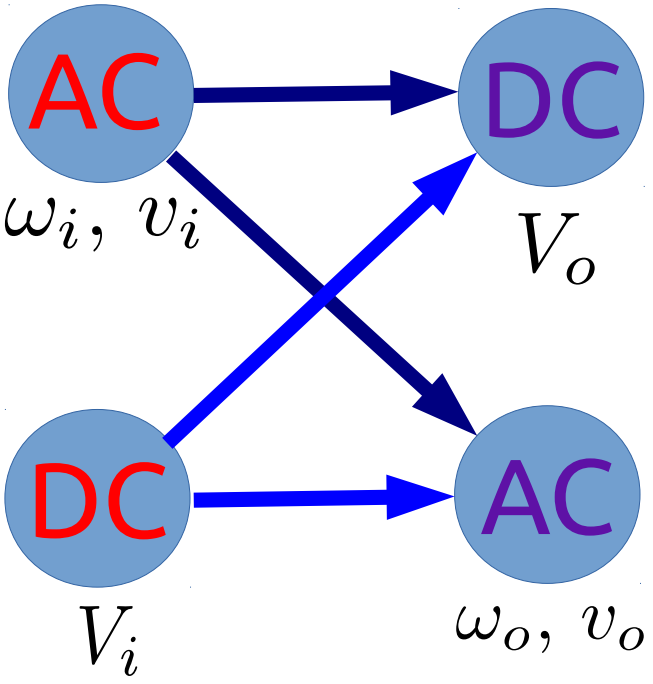
Incompatible

Source and Sink

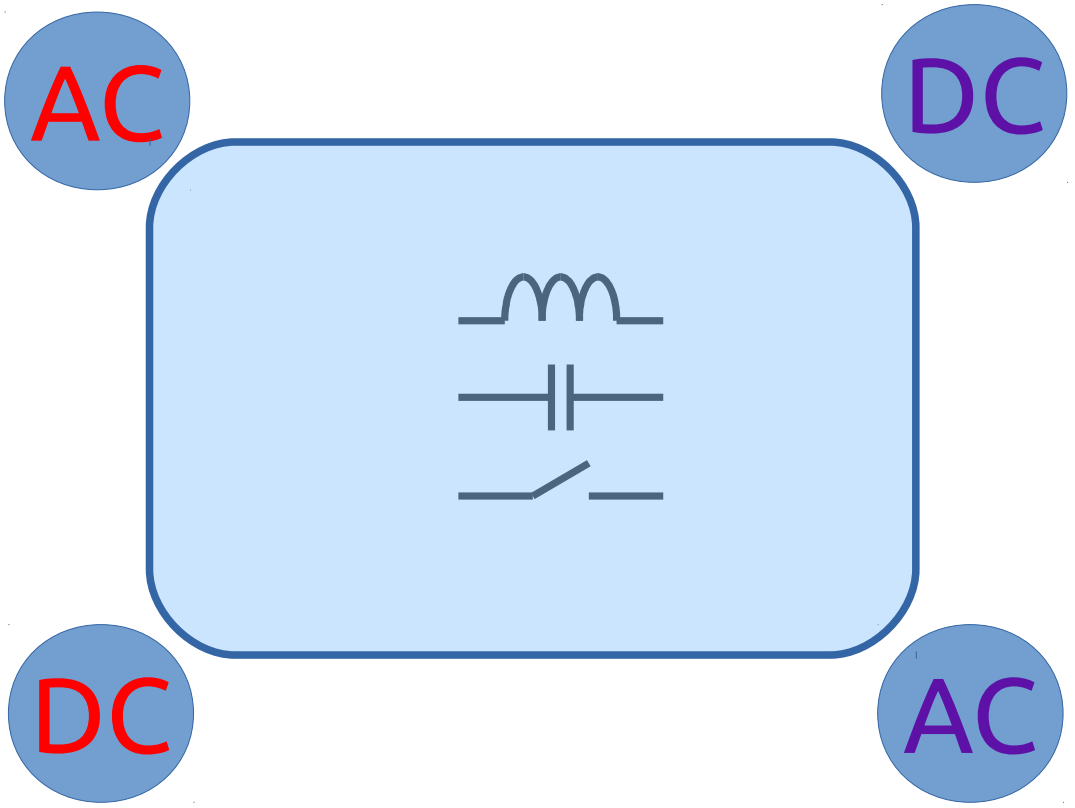


Source: www.pixabay.com

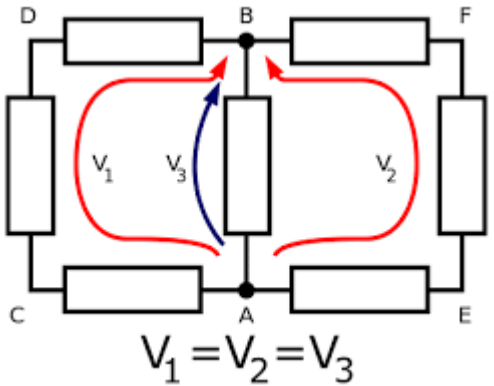
Conversion Functions



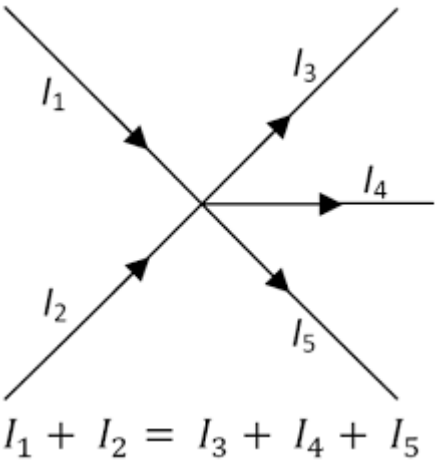
The Switch Matrix



Restrictions



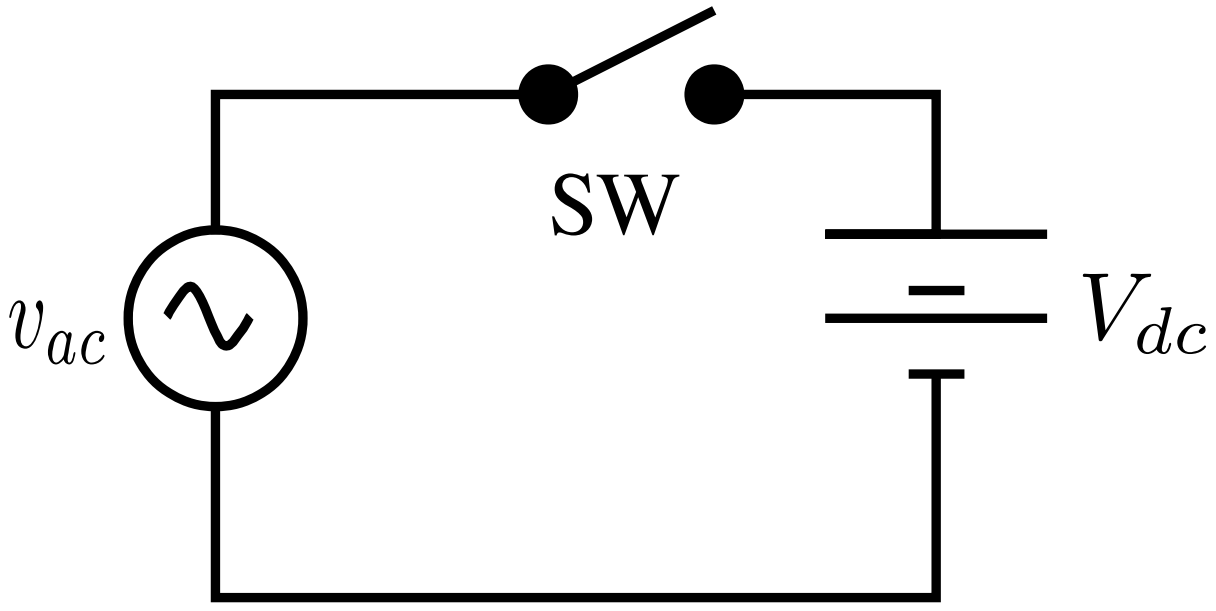
KVL



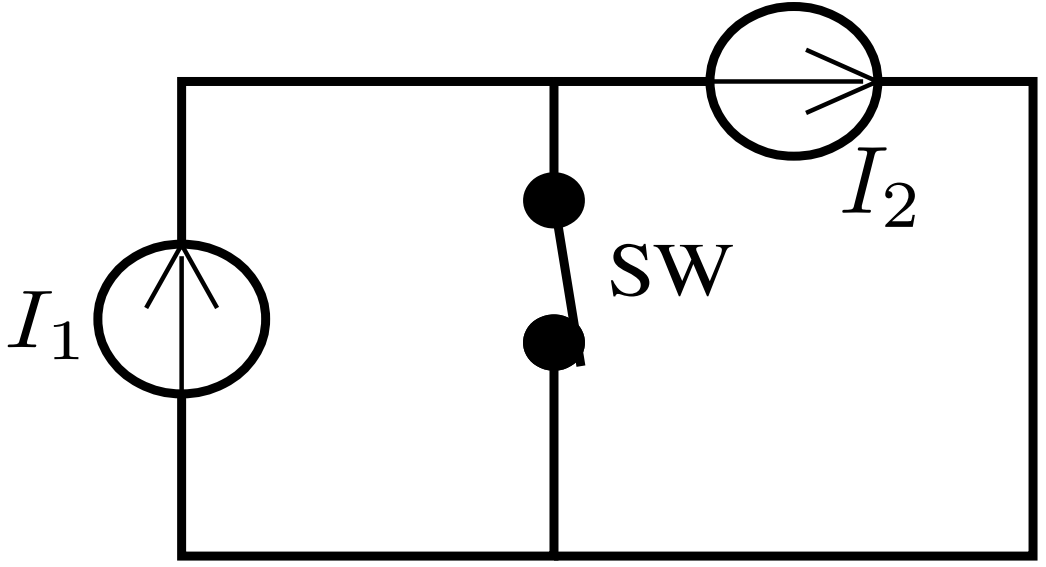
KCL

Source: Wikimedia Commons

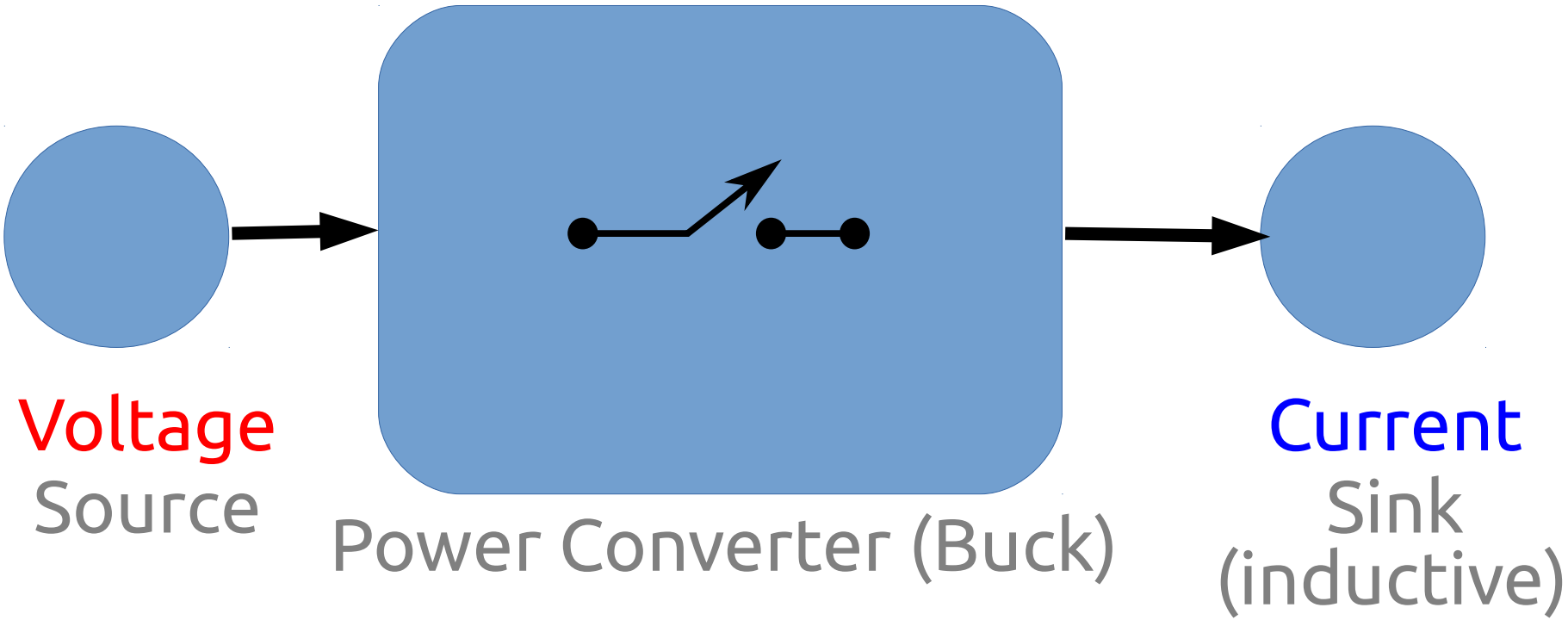
Switch Can't be Closed!



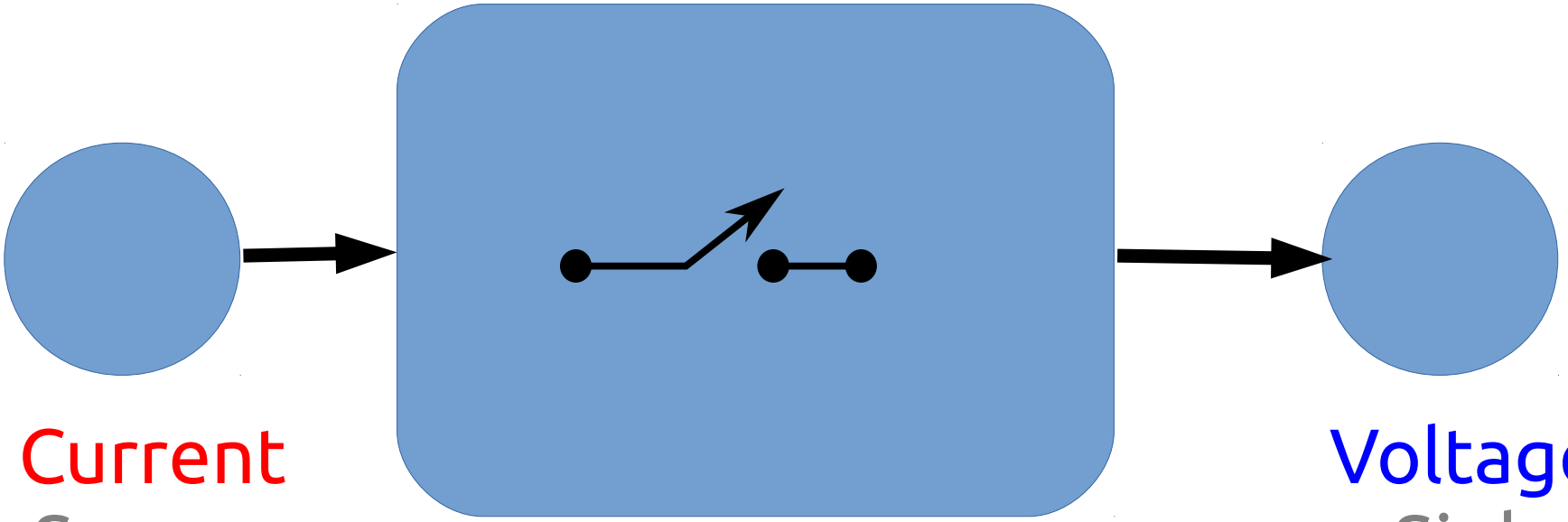
Switch Can’t be Opened!



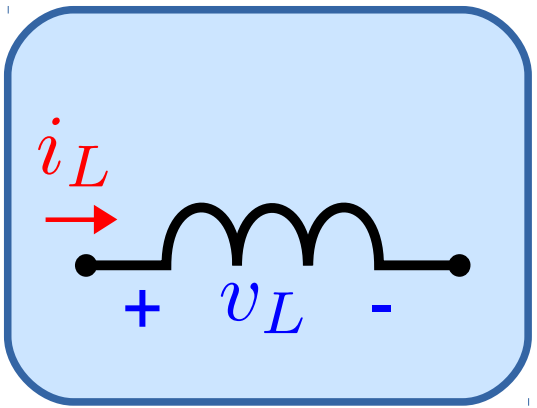
Source Must Be Dual To Sink



Source Must Be Dual To Sink



Passive Elements

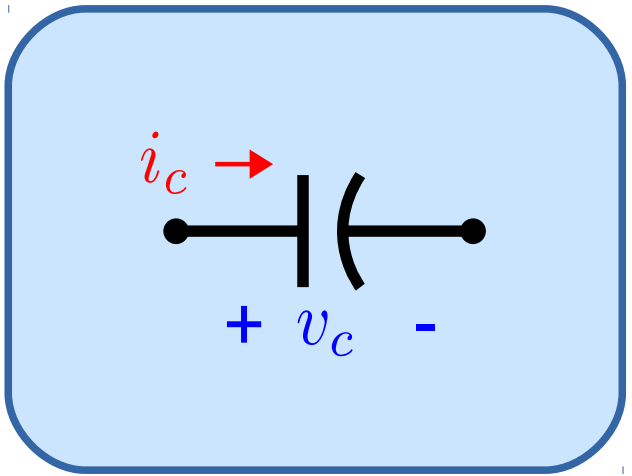


L: Current-Stiff Element

Can interface two voltage sources

Source: Wikimedia Commons

Passive Elements



Source: Wikimedia Commons

C: Voltage-Stiff Element

Can interface two current sources

Power Switching Devices

Source: Wikimedia Commons

MOSFETs

IGBTs

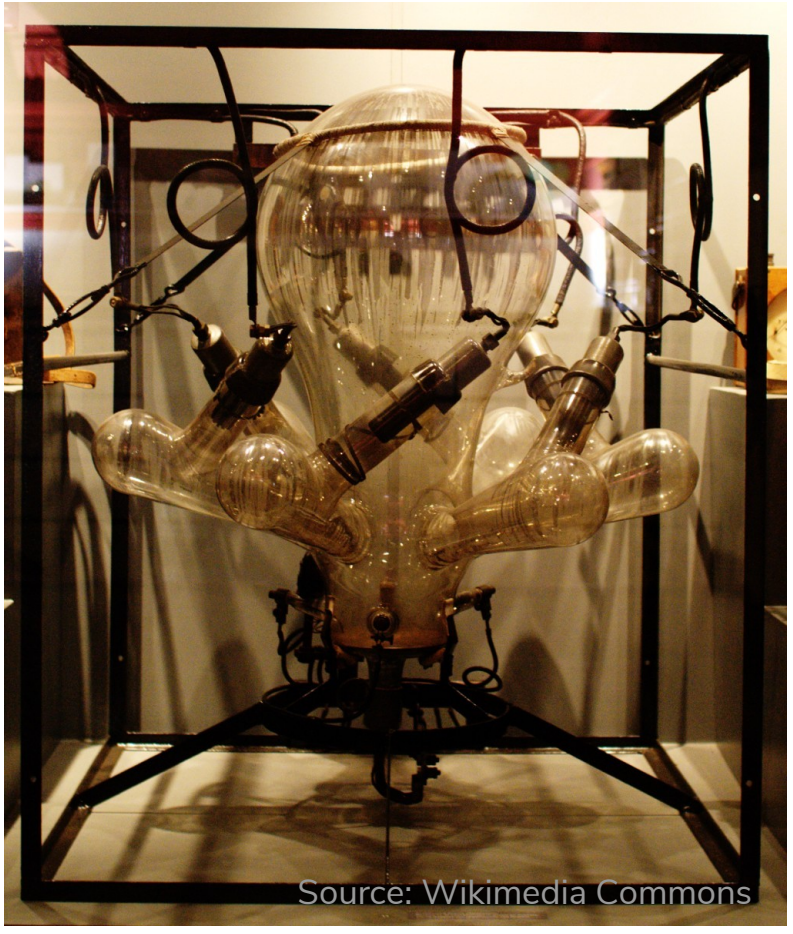
SCRs

GTOs

IGCTs....

Part – II
The Evolution

History



1902-1920

Mercury Arc Rectifiers

Thermionic Vacuum Tubes

Triodes/Diodes as variable resistors (gate control)/current Control

History

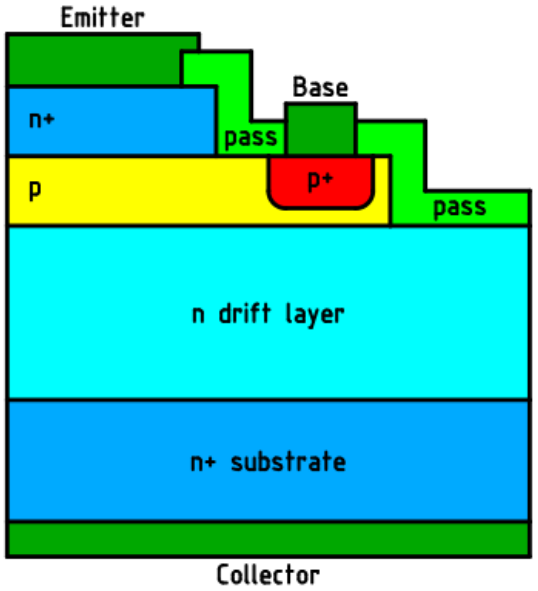
Source: Wikimedia Commons

1925-28:

The First “Inverter” using triodes as switches

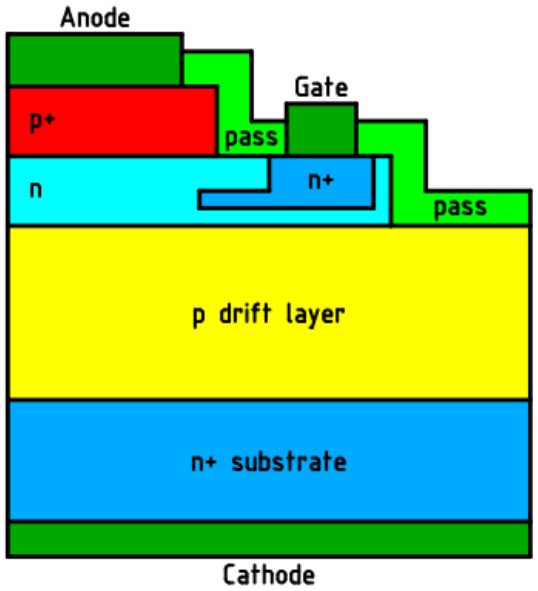
(D. C. Prince, GE)

Semiconductor Devices



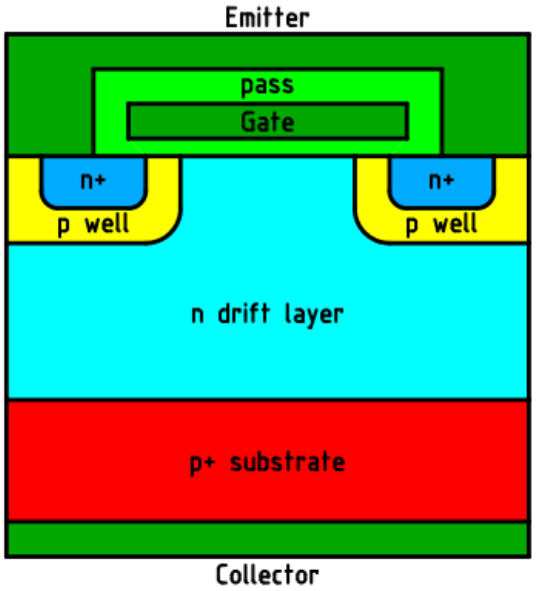
BJT

1970s



Thyristor

1956



IGBT

1983

Source: Wikimedia Commons

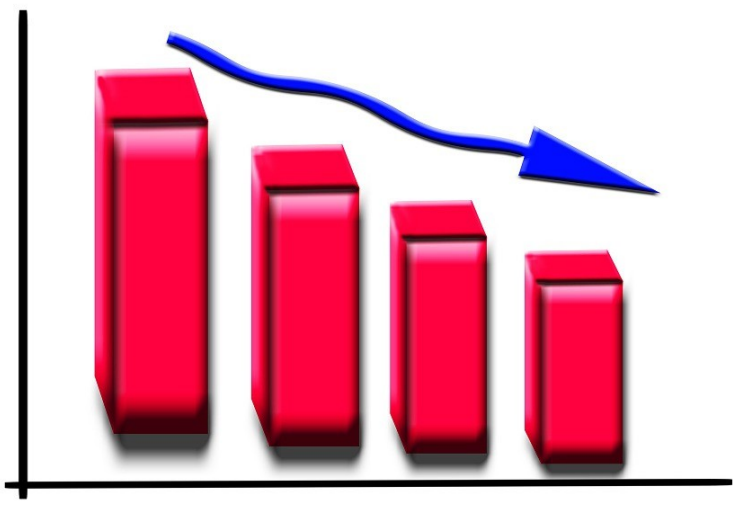
Modern Power Devices

Ruggedness

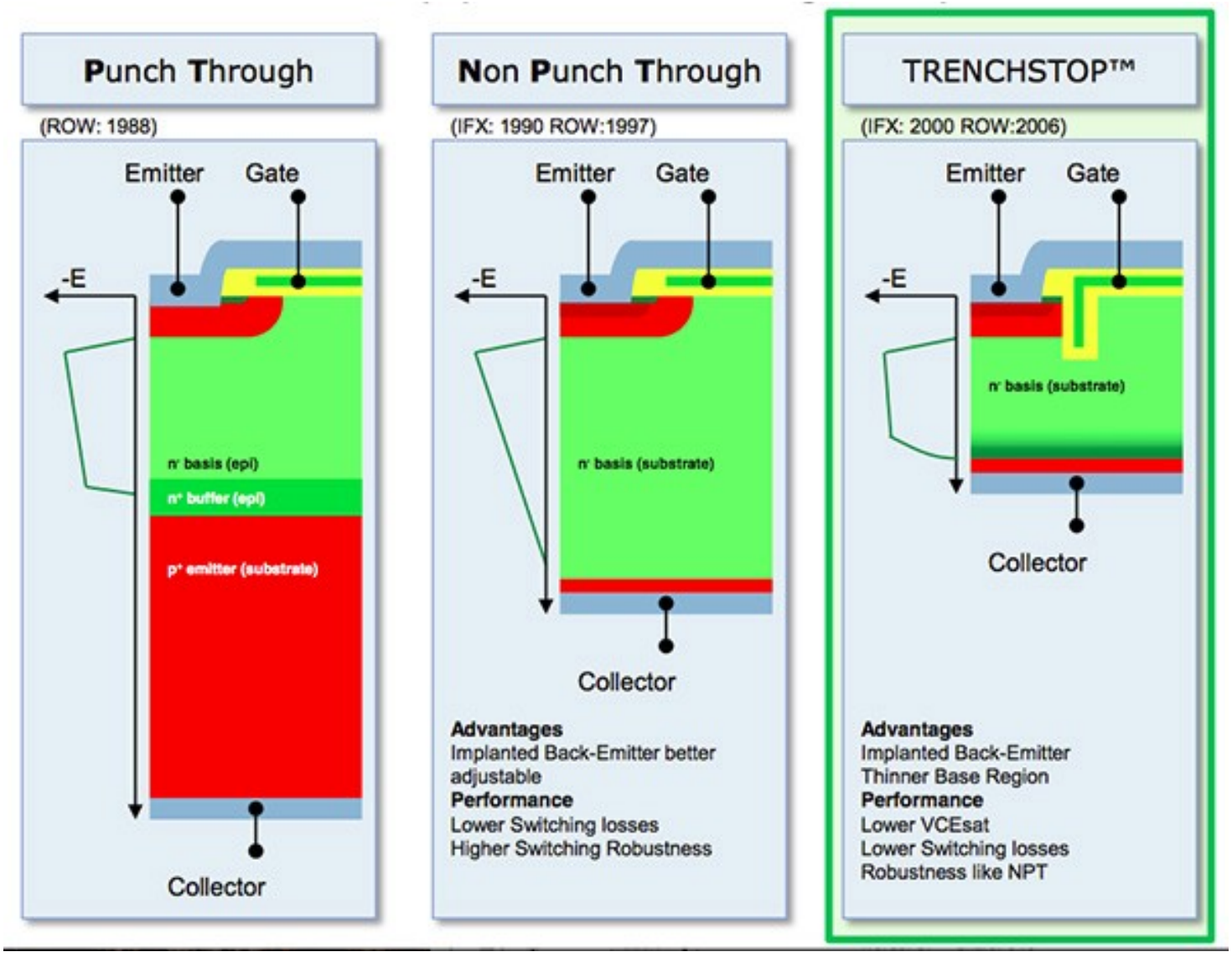
Controllability

Modern Power Devices

Switching Time Losses

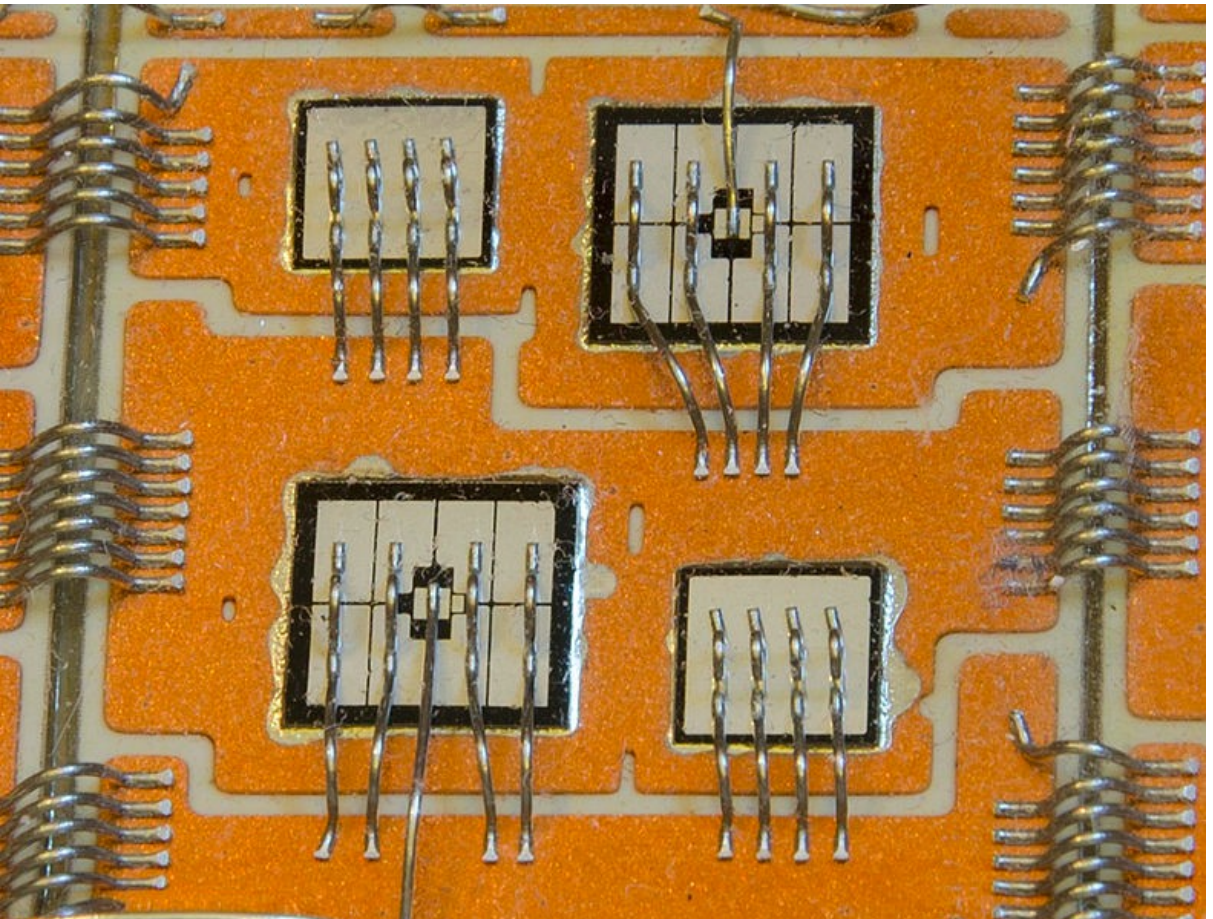


IGBTs



Source: Digikey/Infineon

Modern IGBTs



60%

Reduction in V_{CE}

Trench FieldStop

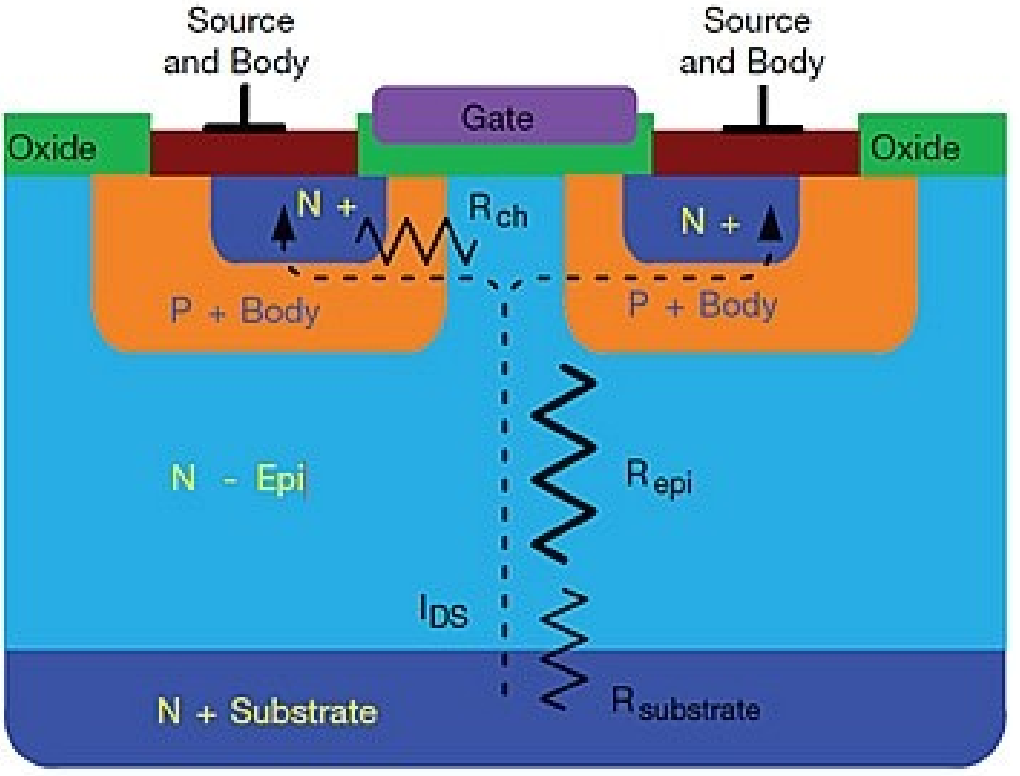
Infineon Module

Source: Wikimedia Commons

MOSFETs

Planar MOSFETs

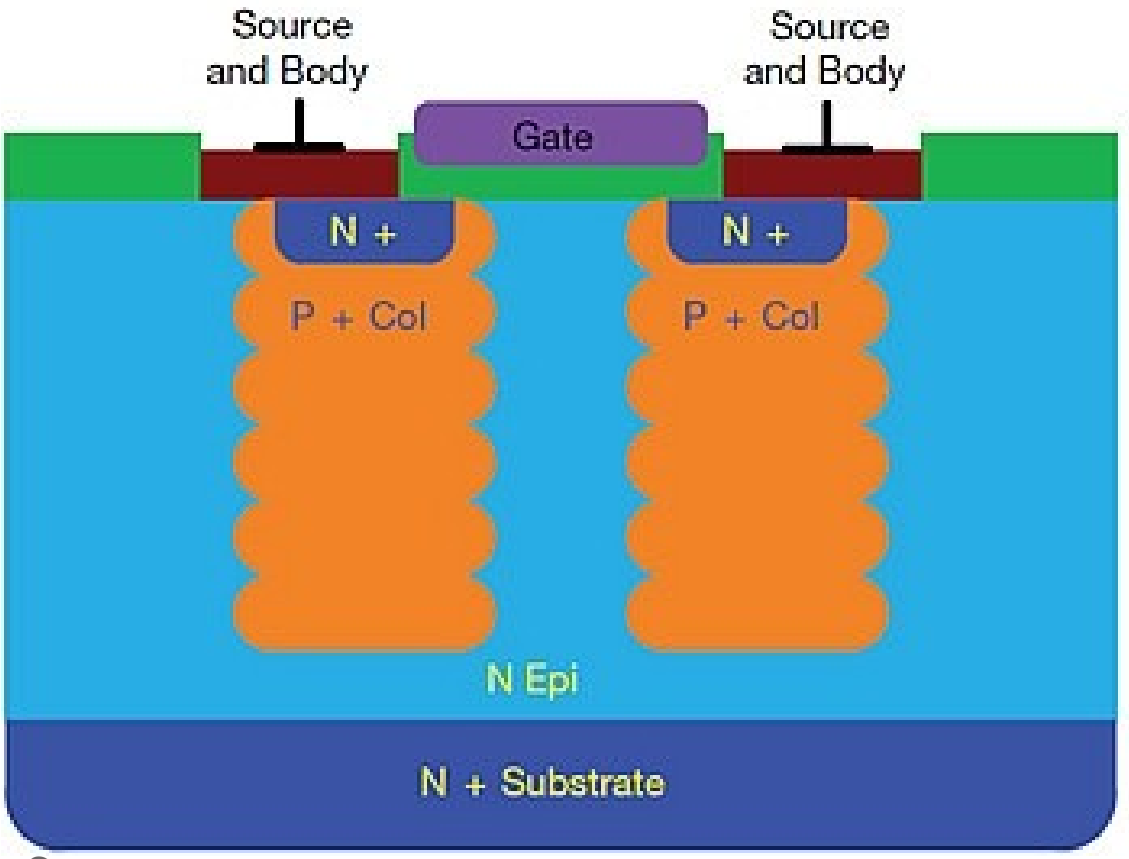
(Conventional)



Source: www.eenewspower.com

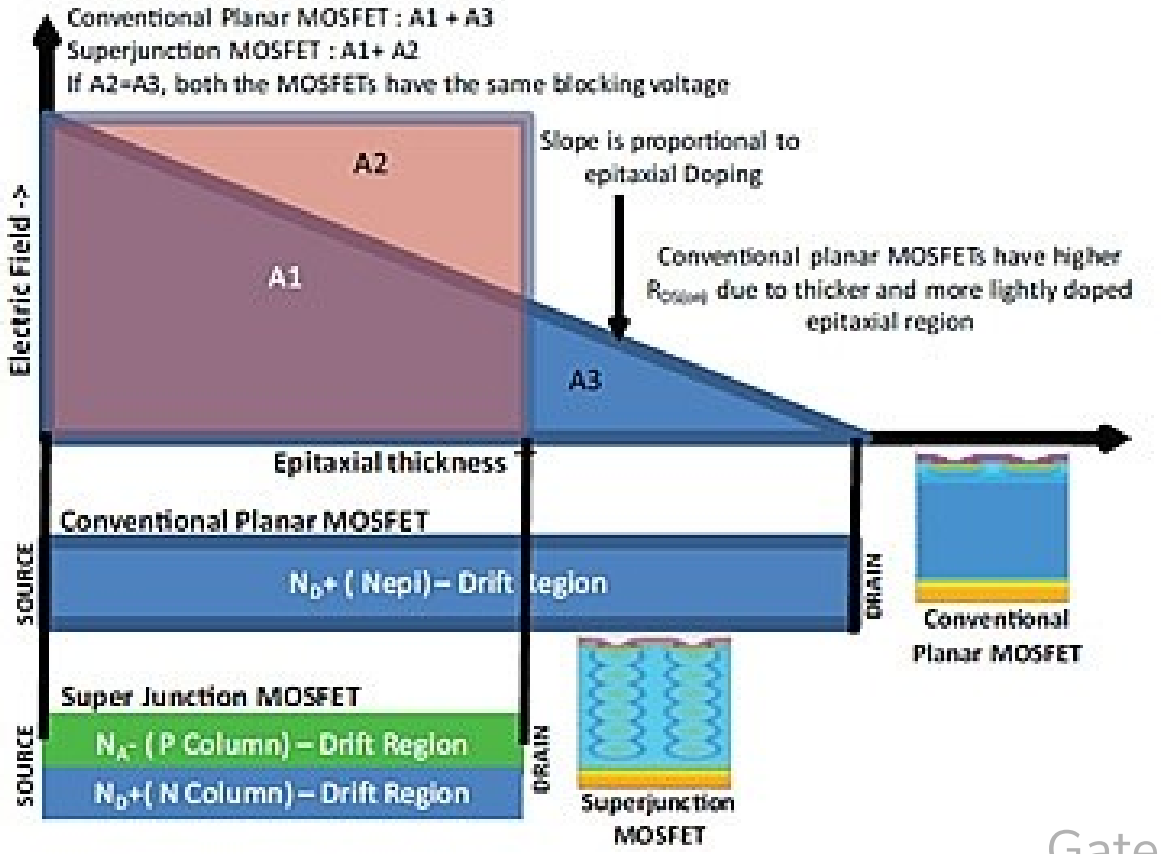
Modern MOSFETs

SuperJunction MOSFETs



Source: www.eenewspower.com

Modern MOSFETs



Source: www.eenewspower.com

Up to

50%

Reduction in $R_{DS(ON)}$

Gate Cap, Output Charge, Die Size

Challenges

- Packaging
  - Wafer Handling
  - Low R_{th}
  - Low L_s

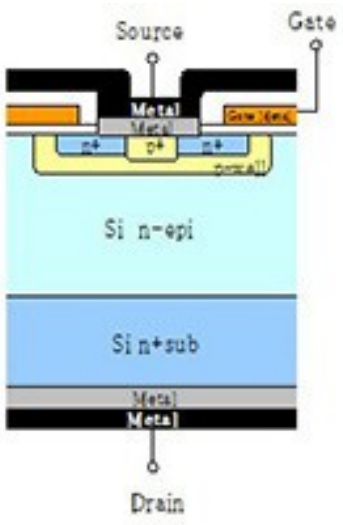
Wide Bandgap Devices

SiC

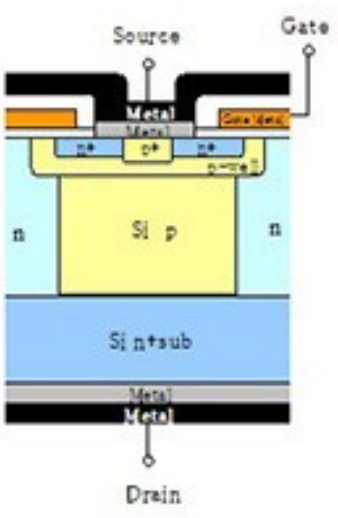
GaN

Property	Si	SiC
Band gap energy (eV)	1.12	3.26
Breakdown electric field (V/cm)	2×10^5	2.2×10^6
Thermal conductivity (W/cmK)	1.5	4.56
Maximum junction temperature (°C)	200	600

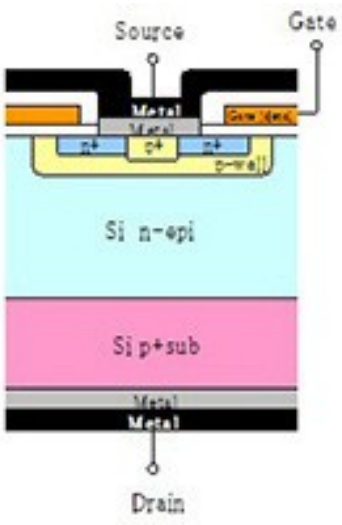
Source: Nagarajan Sridhar, “Power Electronics in Automotive Applications,” White Paper, Texas Instruments, 2013



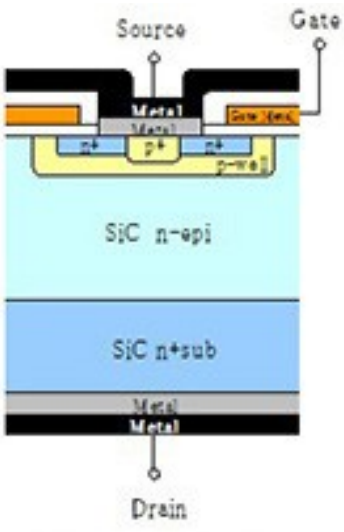
Si-DMOS



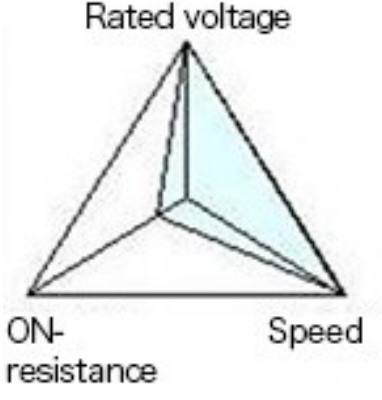
Si Super Junction MOS

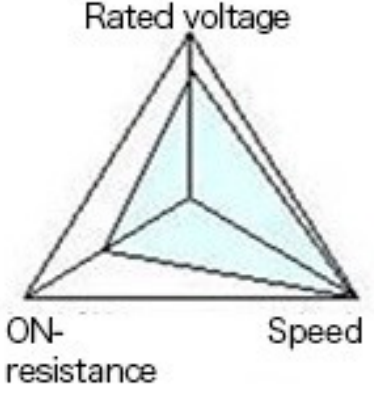


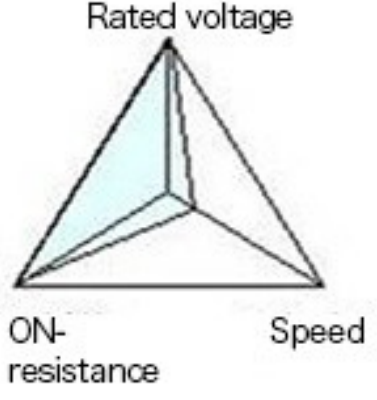
Si-IGBT

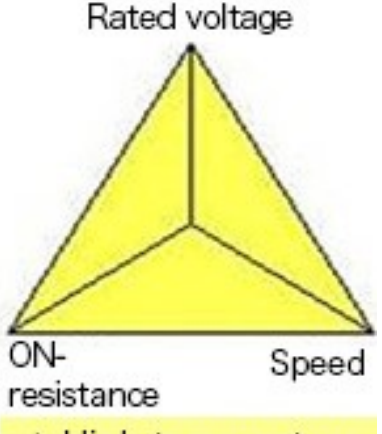


SiC-DMOS



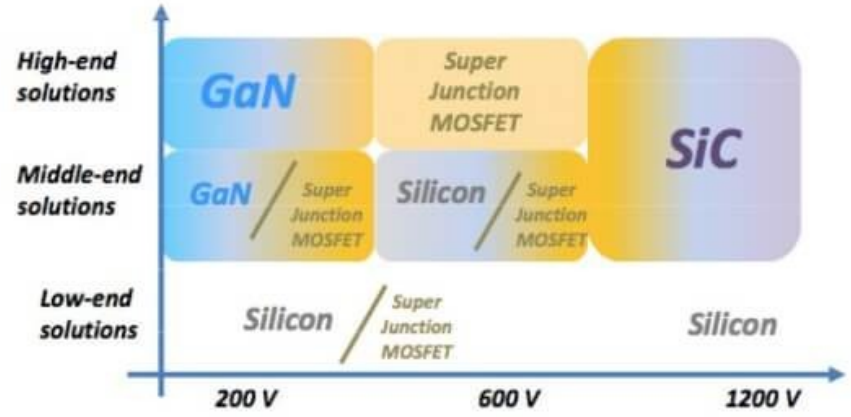




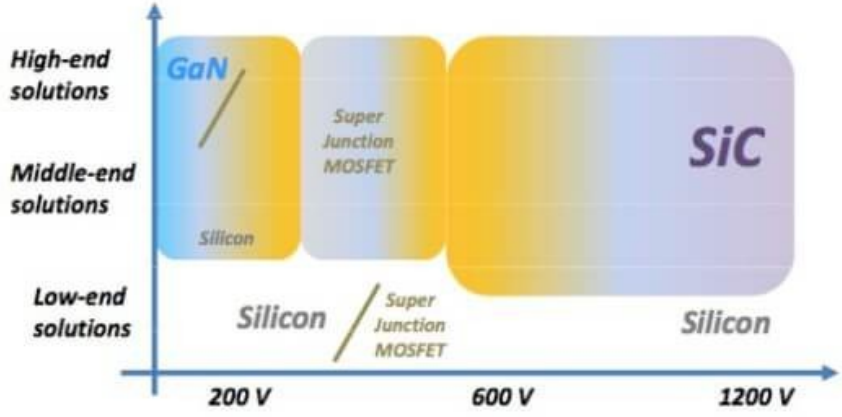


SiC FETs

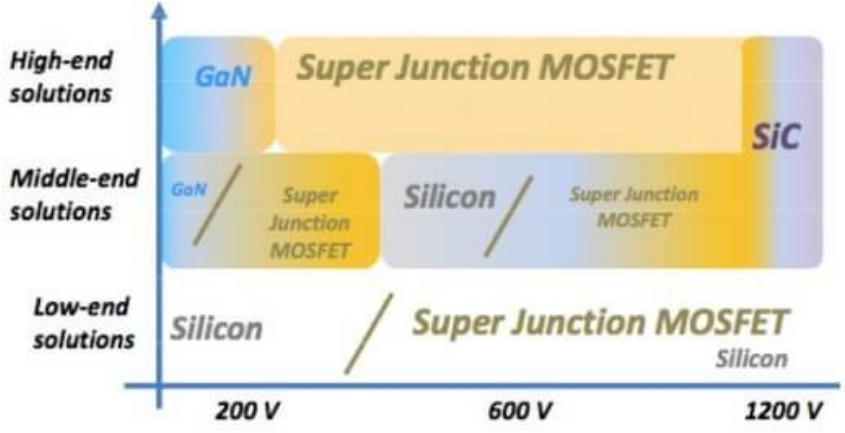
Source: micro.rohm.com



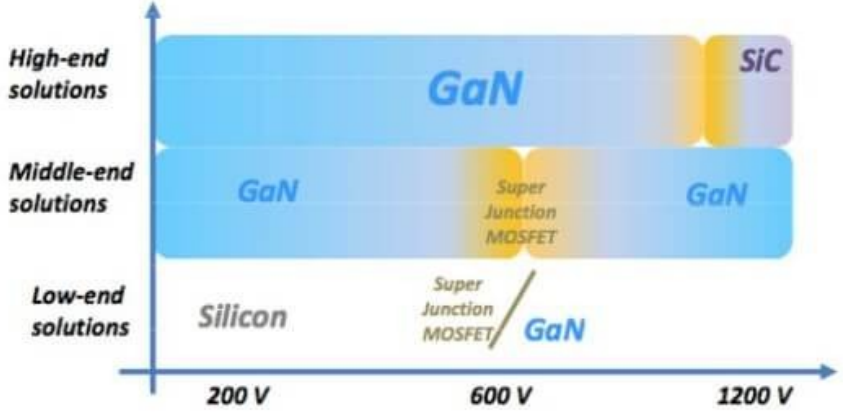
What Yole Developement showed in 2011 as future view



A SiC supplier's view of future



A Super Junction supplier's view of future



Now that 600V GaN-on-Si is qualified, a GaN solution supplier's view for future

Source: www.pntpower.com

The Old Question

MOSFETs Or IGBT?

Voltage Rating >1700V, <400V

Switching Frequency kHz, MHz?

The New Question

SiC Or GaN?

MOSFETs or IGBTs?

Control/Modulation

Mature

- PWM

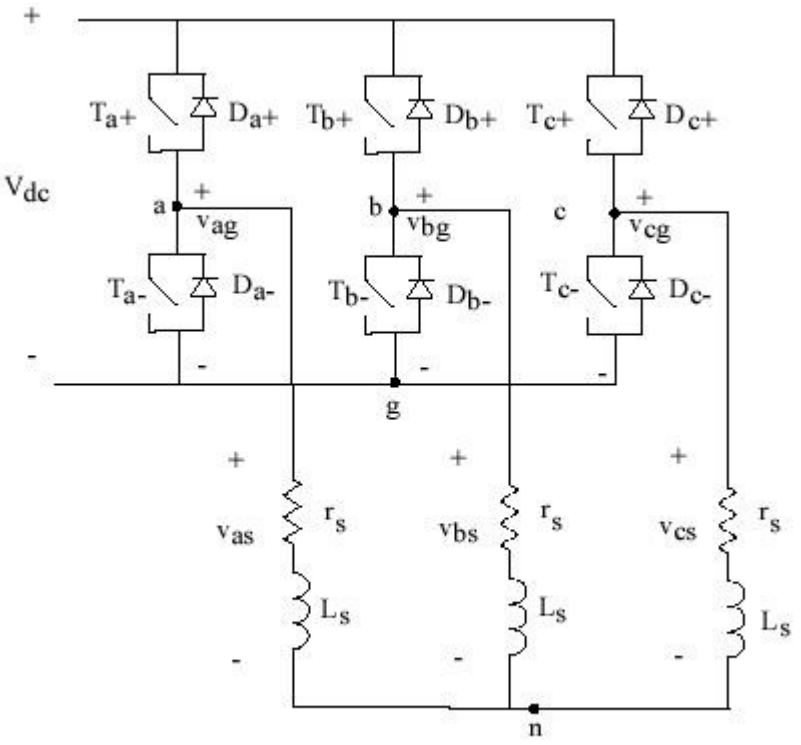
Some Future Directions

- Predictive
- Heuristics based
- Model Based Control

Future Trends

What remains the same?

Topologies



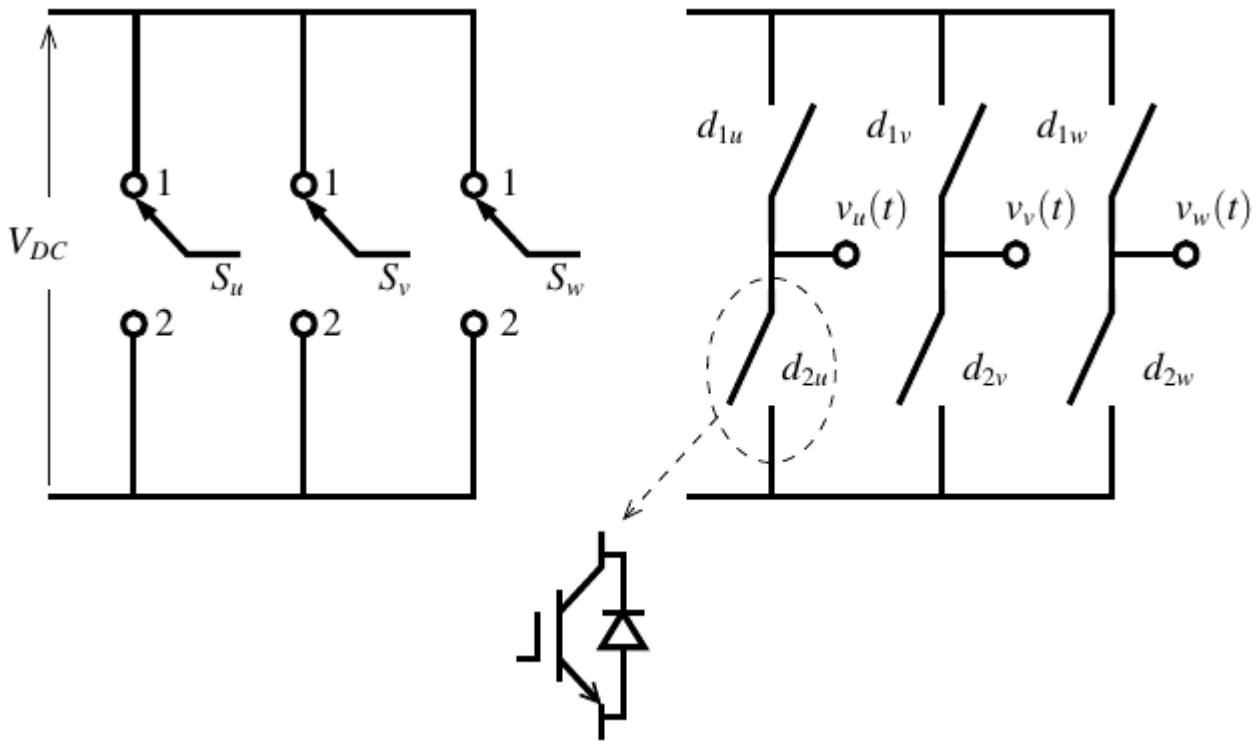
Source: Wikimedia Commons

Major Topologies

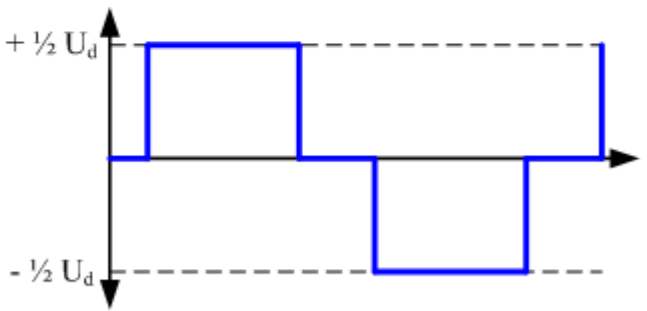
- Bridge (2-Level, 3-Level)
- Interleaved Topologies
- Soft-switching (ZVT - LLC)
- Isolated Low Power Topologies
- Dual-Active Bridge (DAB)
- Current-Fed Dual Topologies

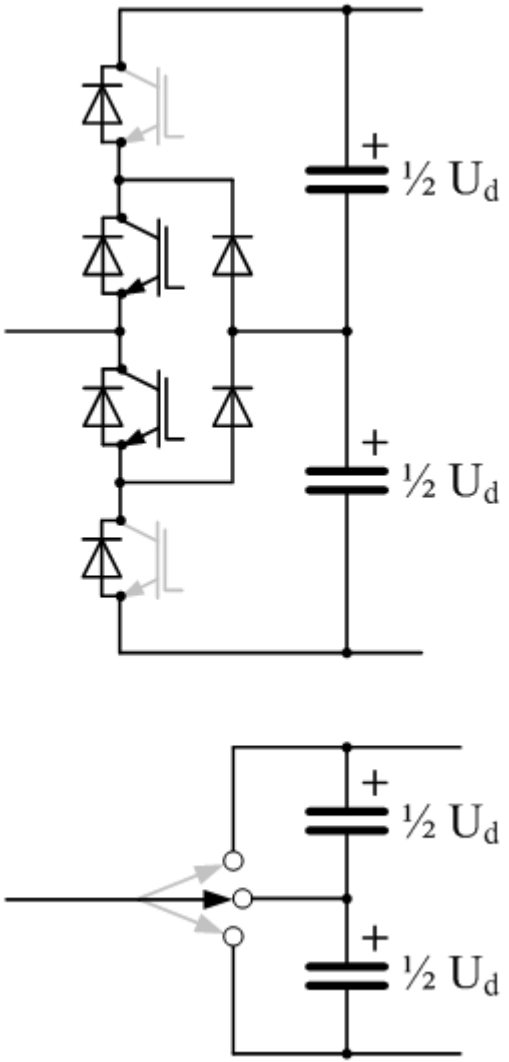
Architectures!

Bridge



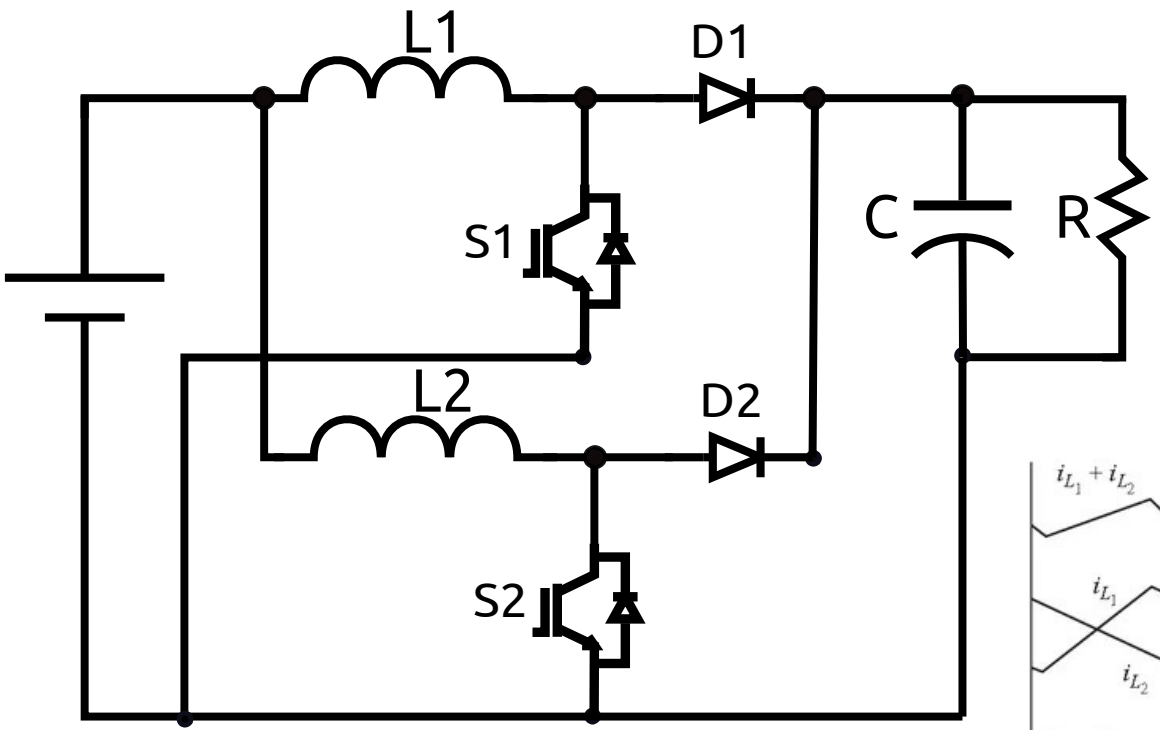
3-Level

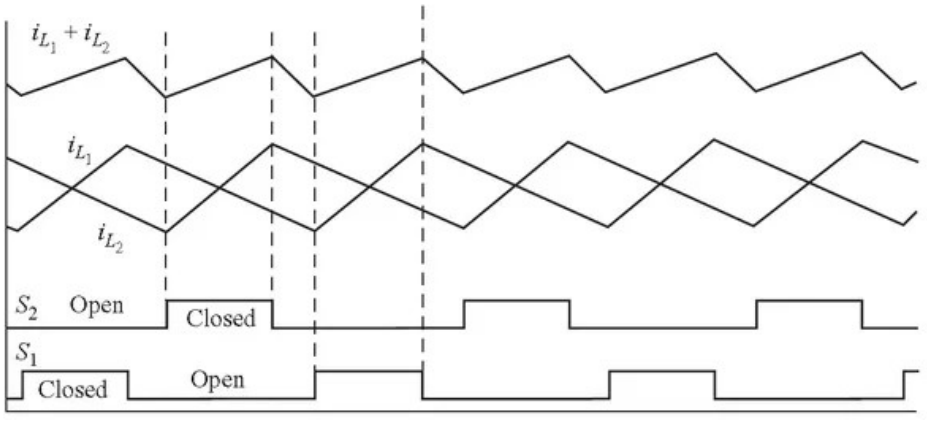




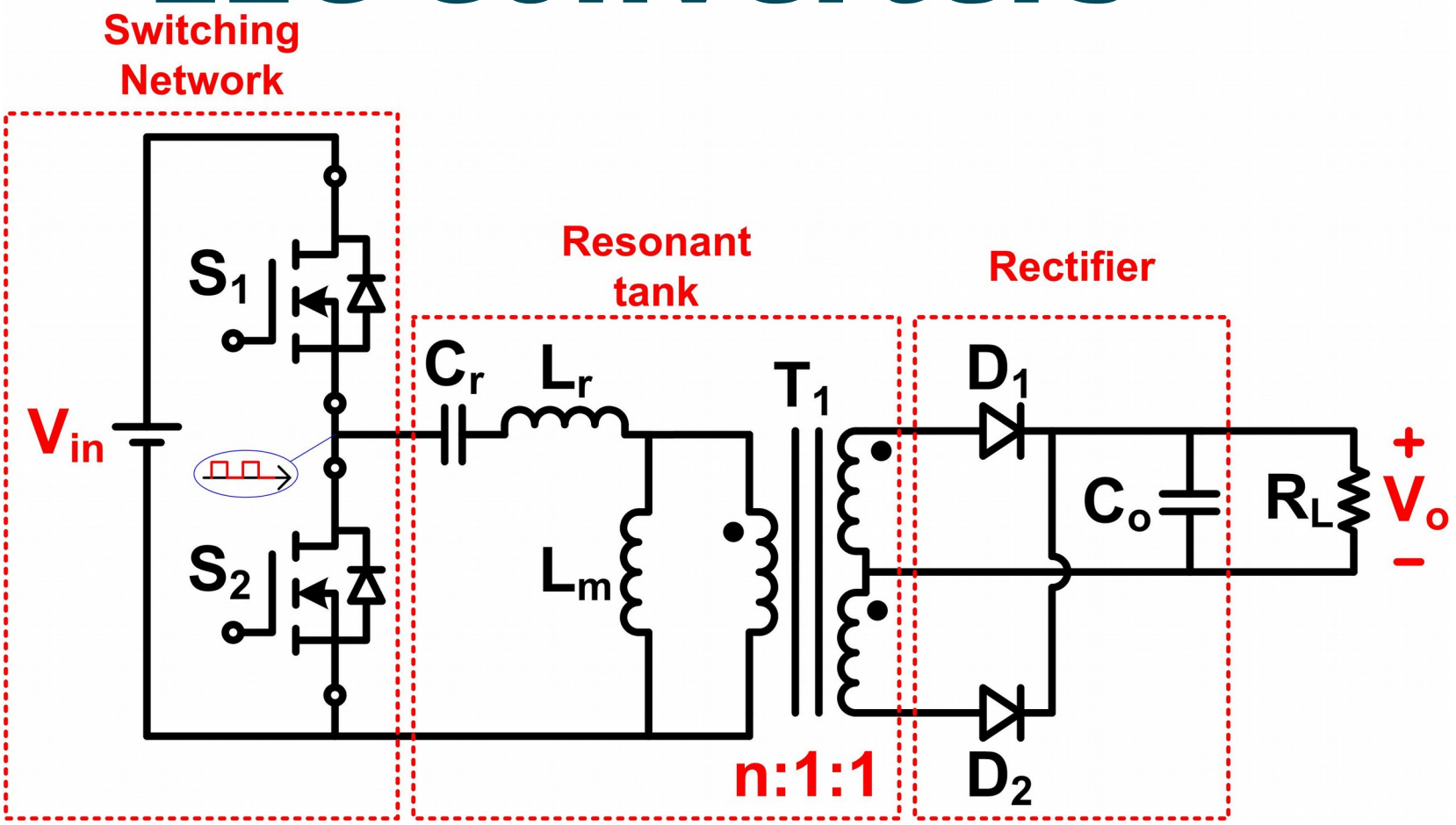
Source: Wikimedia Commons

Interleaved Boost

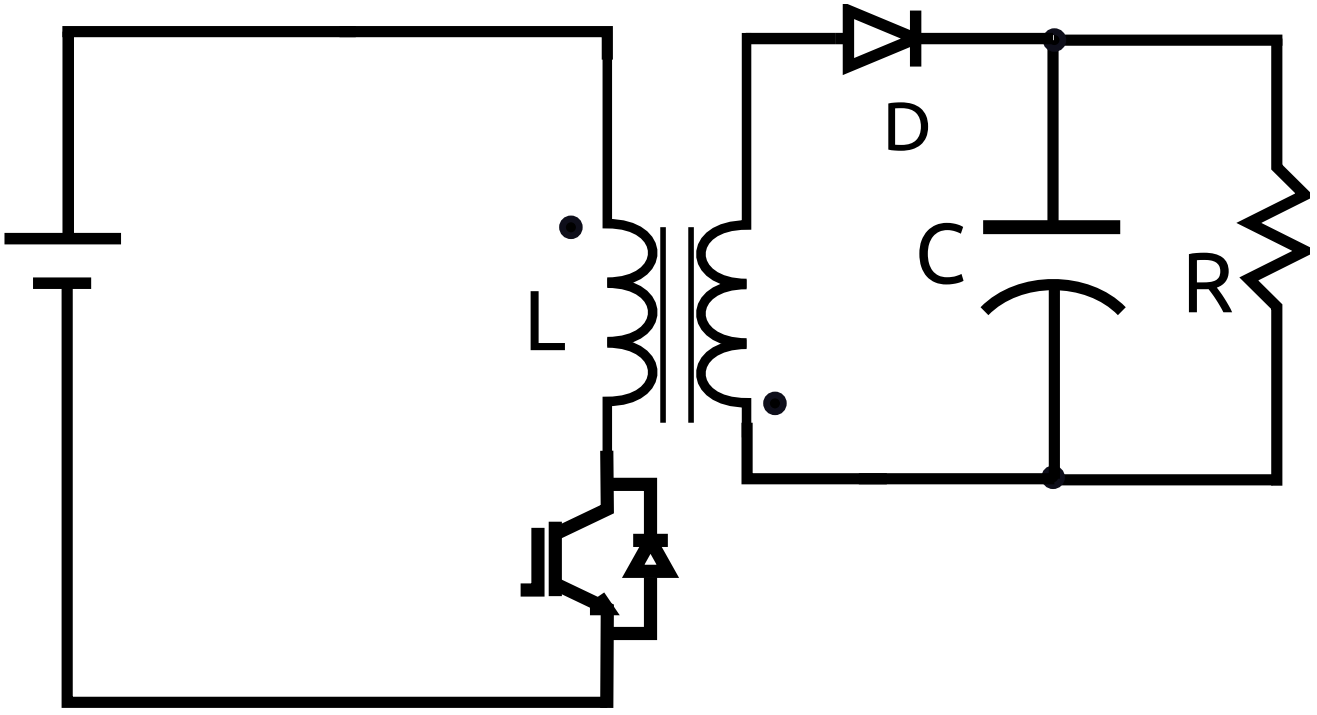




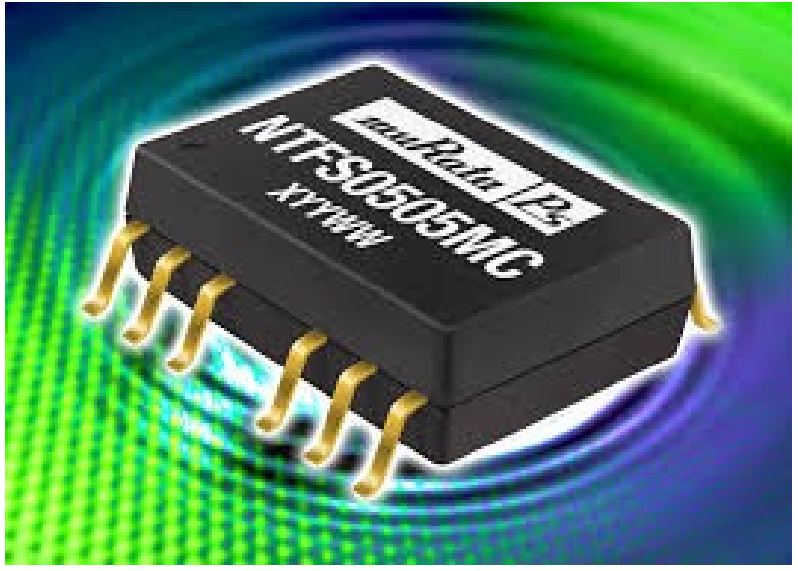
LLC Converters



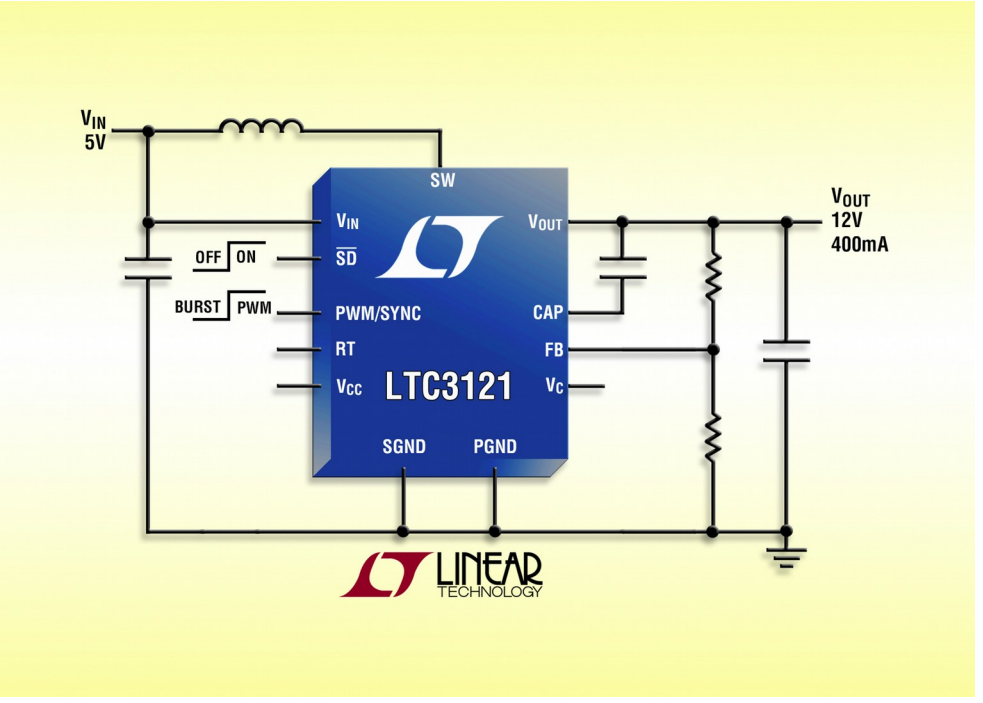
Isolated Low Power Converters



Integrated Low-Power DC-DC Converters

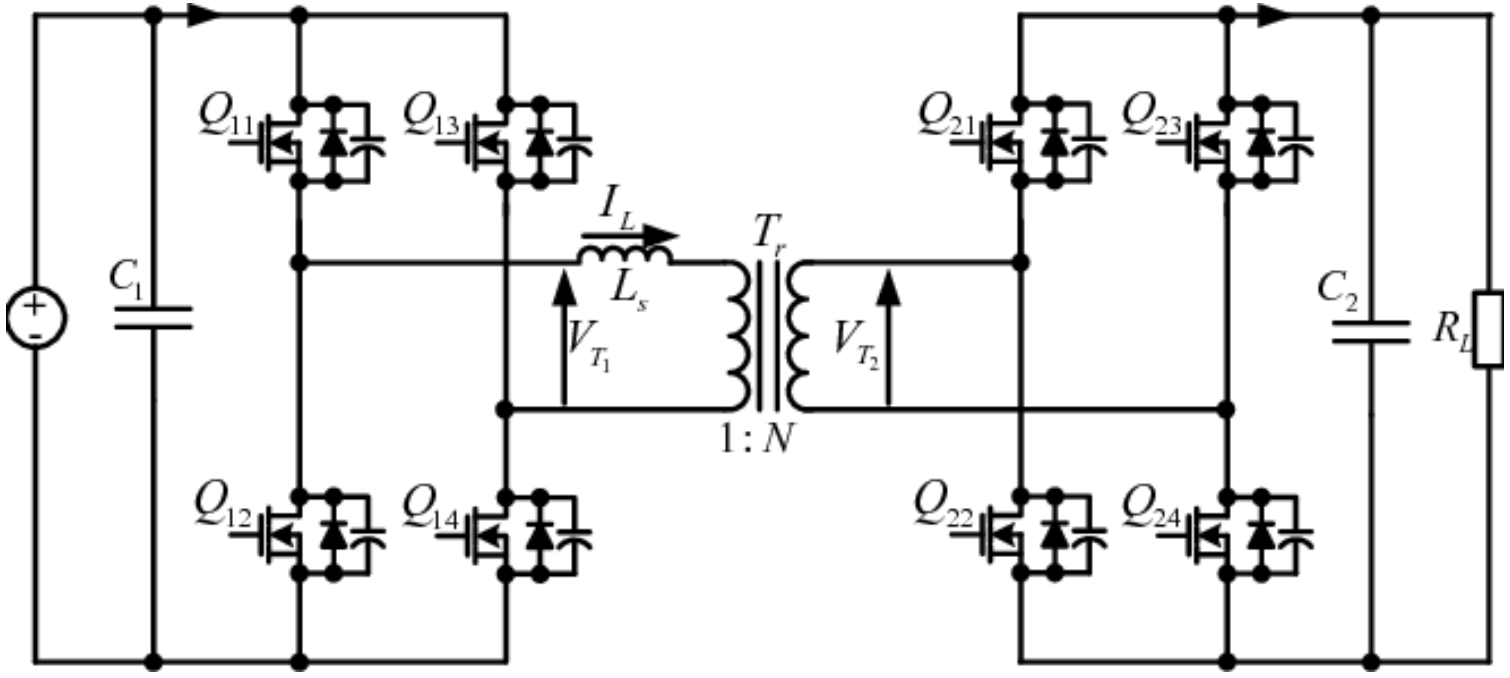


Source: Murata Power Solutions



Source: Linear Technology (Now Analog Corp)

Isolated High Power Converters



Source: researchgate.net

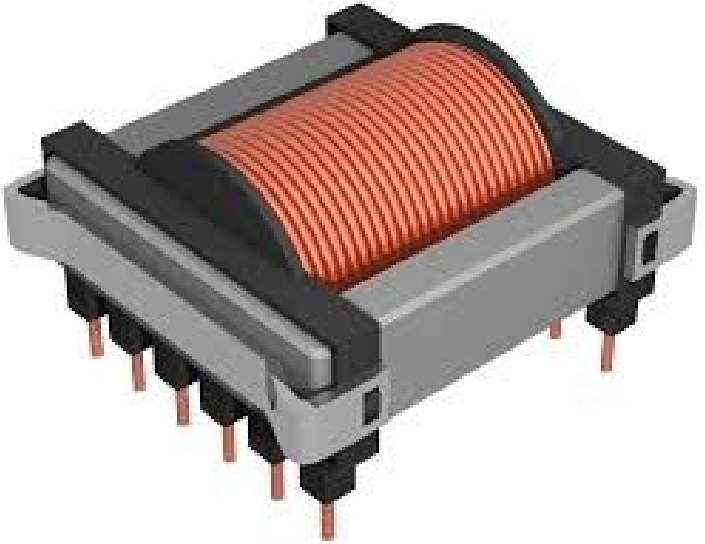
Dual Active Bridge

What remains the same?

Magnetics

Materials

Limitations

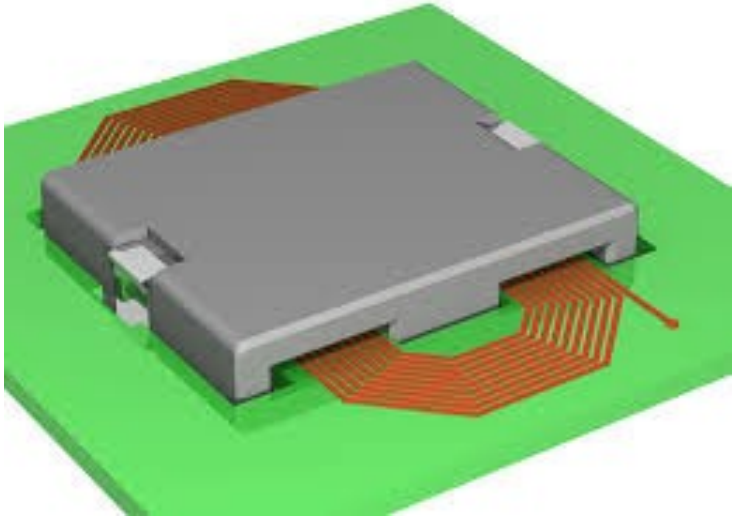


Source: Wikimedia Commons

Some Modern Trends

Geometry:

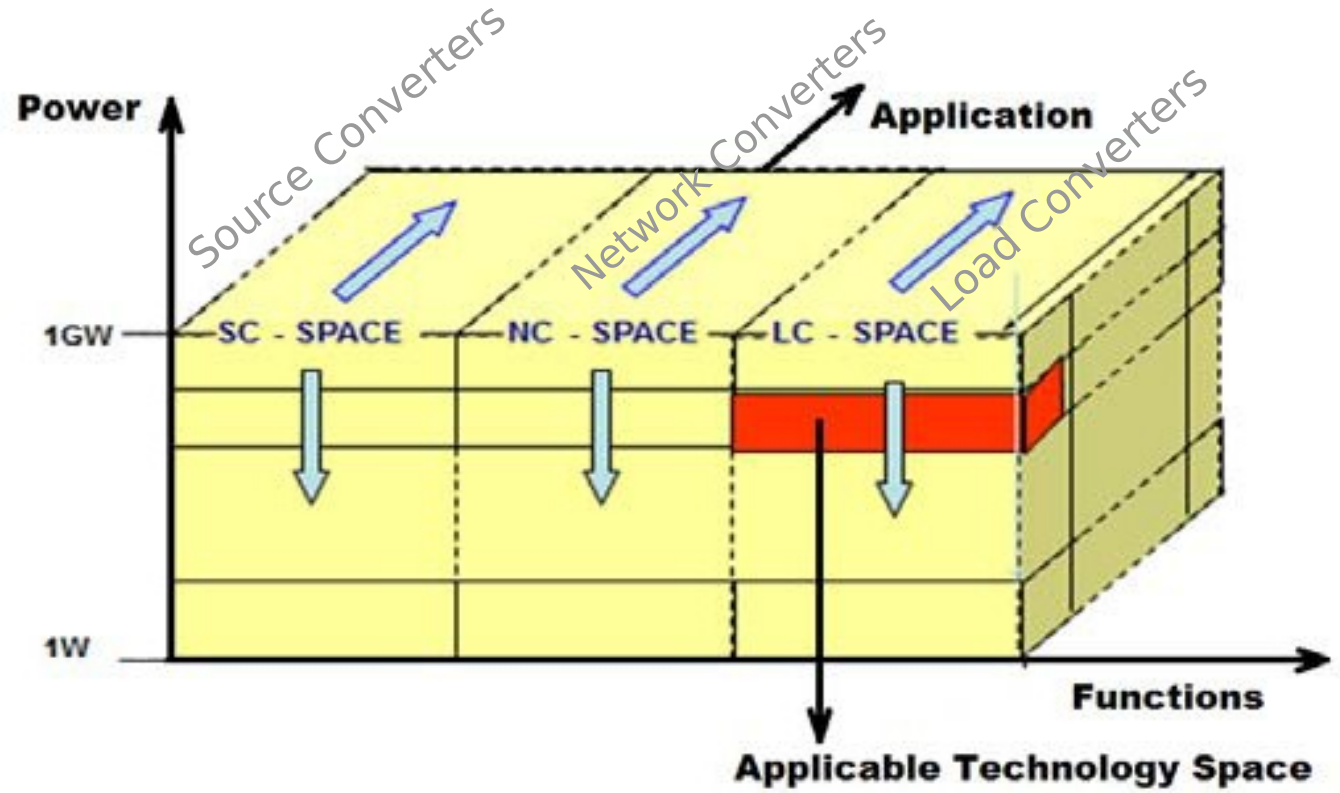
Planar, PCB



Source: Wikimedia Commons

Application Areas

“Technology Space” in PE



Source: J. D. van Wyk & F. C. Lee, “On a Future for Power Electronics”, IEEE Journal of Emerging and Selected Topics in PE, Vol. 1, No. 2, June 2013

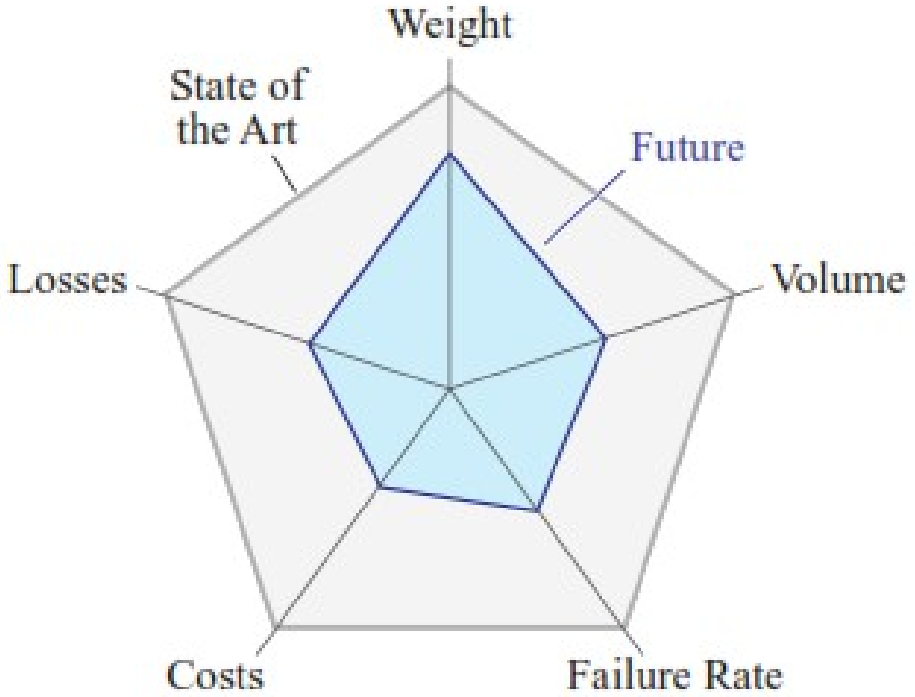
New Areas

- Smart Grid: Evolution of Power Grid
- Distrbuted Power Systems
- Transportation: EVs, HEVs, More Electric Aircrafts, Ships.

Electric Vehicles

- Regenerative braking (AC/DC)
- On-board charger (AC/DC)
- Dual-battery system (DC/DC)
- Battery management for Lithium-Ion (Li-Ion) batteries
- 48V-12V bi-directional power supply
- 400V Battery Systems
- Bi-directional 400V-12V power supply (DC/DC)
- Traction motor (DC/AC)

New Targets



Source: J. W. Kolar *et. al*, “Performance Trends and Limitations of Power Electronic Systems”

New Targets

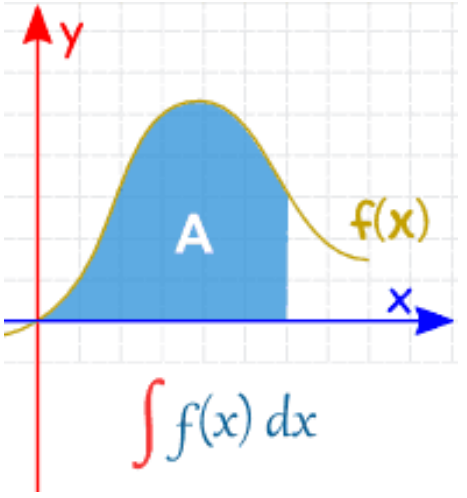
Source: www.infineon.com/power

New Targets

- Power Density
- Efficiency
- Costs

New Paradigms

- Power Conversion -> Energy Management
- Converters -> “Systems”
- Life Cycle Costs



Source: mathisfun.com

Summary

- Trends in a mature field influenced by external factors
- More emphasis on system level design and optimization

References

1. Jose I. Leon, *et. al.,* “The Essential Role and the Continuous Evolution of Modulation Techniques for Voltage-Source Inverters in the Past, Present, and Future Power Electronics,” IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 63, NO. 5, MAY 2016
2. KAWANO Masashi, HIROSE Jun And AIHARA Takashi, **“**Power Electronics Technology: Current Status and Future Outlook,” Fuji Electric
3. Hubert Kerstin, Björn Rentemeister, Thomas Risse, “Where is the Journey Headed? : The Future of High-Power Semiconductors,” Bodo's Power Systems, November 2014, [Obtained from www.infineon.com/power]

References

4. J. W. Kolar, J. Biela, S. Waffler, T. Friedli, and U. Badstuebner, “Performance trends and limitations in power electronics,” in Proc. 6th Int. CIPS, Mar. 2010, pp. 17–36.
5. J. D. van Wyk & F. C. Lee, “On a Future for Power Electronics”, IEEE Journal of Emerging and Selected Topics in PE, Vol. 1, No. 2, June 2013
6. S. S. Williamson, A. K. Rathore and F. Musavi, "Industrial Electronics for Electric Transportation: Current State-of-the-Art and Future Challenges," in IEEE Transactions on Industrial Electronics, vol. 62, no. 5, pp. 3021-3032, May 2015. doi: 10.1109/TIE.2015.2409052

References

7. www.eenewspower.com

8. Industry Sources: Web sites of Infineon, Onsemi, Rhom, Mitusbishi Electric, IRF, Toshiba, etc.

Thank You