A Technology’s Journey – 40 Years of APEC

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Why APEC?

- PowerCon served industry
- PESC served academics and industrial researchers.
- 1985 was last PowerCon.
- Need for IEEE to better serve industry.
- Small group in Boston decided to act.
    - Difficulty getting IEEE HQ to agree to timing.

APEC 1986

- New Orleans
- Conference committee of 8 people.
- 34 papers
- 5 Education Seminars:
  - Feedback theory (Jonathan Wood)
  - Resonant converters (Marty Schlecht)
  - Power devices (Phil Hower)
  - High frequency design (Rudy Severns)
  - Magnetics (Alex Kusko and Ed Bloom)

Talk Organization

- Look at ‘86 technology by extracting a few papers from Conference Record.
- Compare with today’s technology.
- Look a bit into the future.

Where Were We in 1986?

Mag Amps still around:

- “Inherent Benefits of a 1 MHz High Precision Mag Amp Regulated Off-Line Switching Power Supply” by C. Finger, Tracor Aerospace.

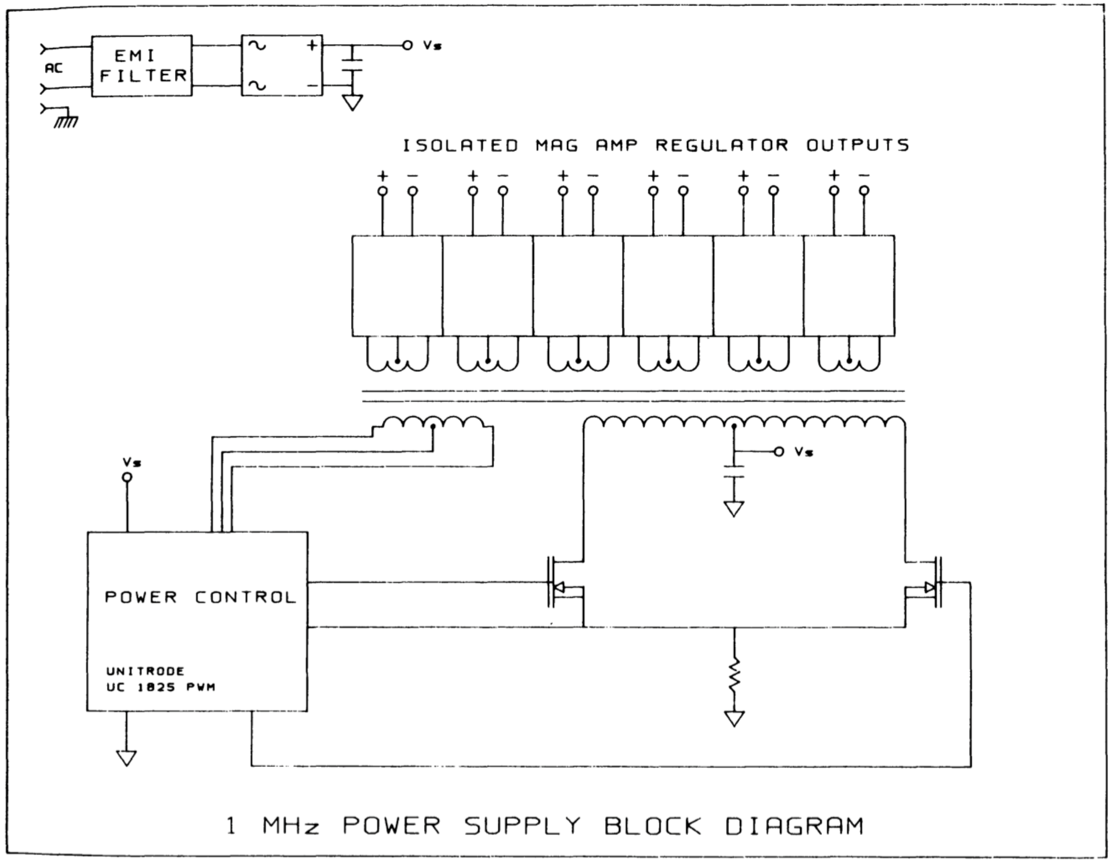
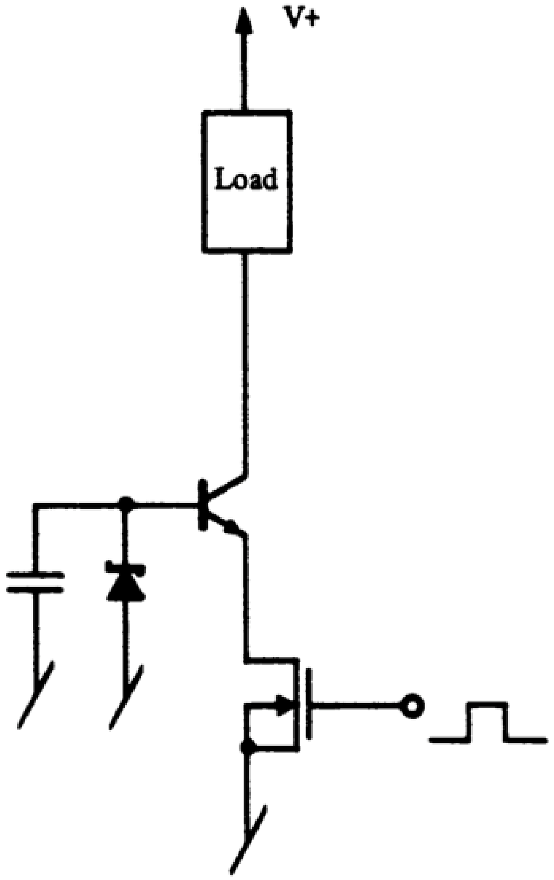


FIGURE 1

Where Were We in 1986 (cont'd)

- BJTs and MOSFETs equally represented
  - "A High Efficiency Power MOSFET Used as the Control Element in an 800 Volt Switch" by Severns, Cogan, and Fortier (Siliconix) (emitter switching of a BJT)

  - Commercial MOSFETs (e.g., IRF150) used a 5 mask set. Today's discrete FETs use ~15, and incorporate the Superjunction.



Where Were We in 1986 (cont'd)

- Increasing interest in high frequency switching
  - "Secondary Side Resonance for High Frequency Power Conversion" by K.-H. Liu and F.C. Lee
    - 800 kHz

  - The terms *quasi-resonant*, *ZVS*, and *ZCS* are being added to our vocabulary.

Where Were We in 1986? (cont'd)

- Digital control ICs introduced:
  - “Applications of Digital PWM Integrated Circuits,” Hirsch et al., IXYS Corp. (IXDP100)

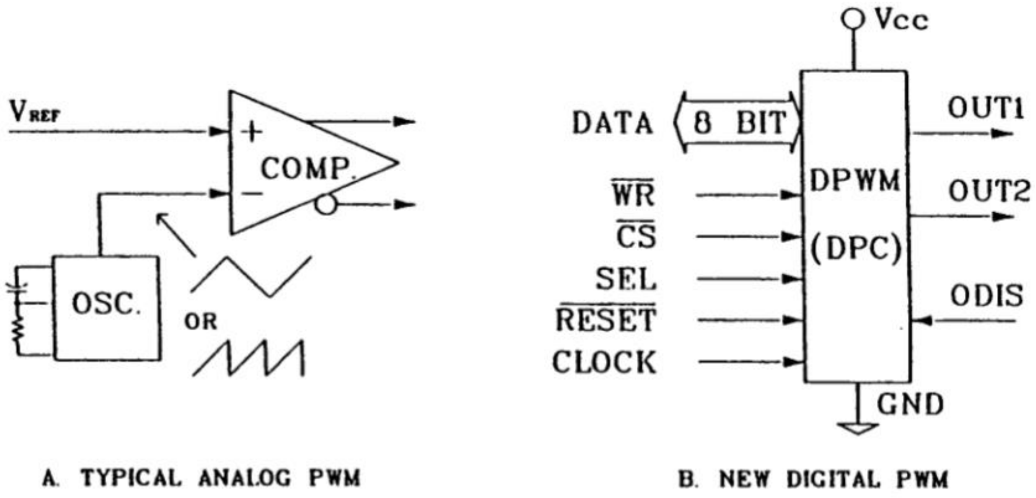


FIG. 1 : TRADITIONAL ANALOG AND NEW DIGITAL PWM

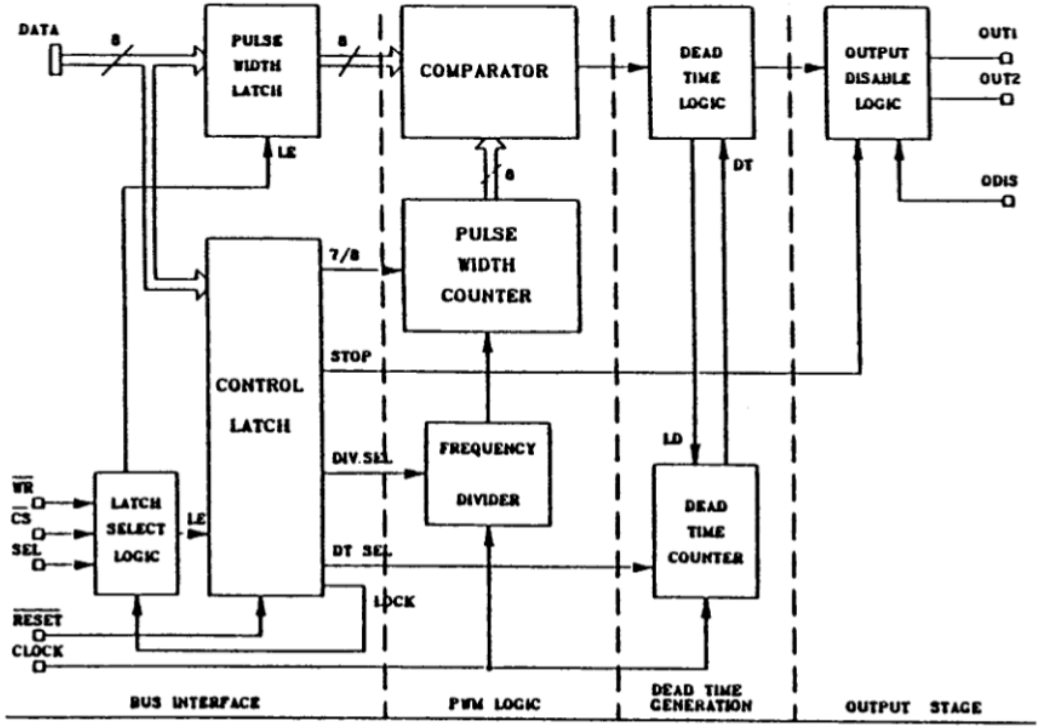
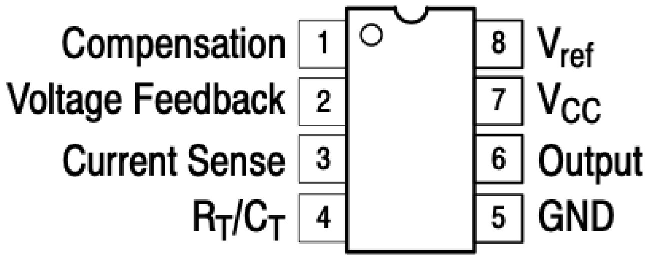


FIG. 3 : Digital PWM block diagram

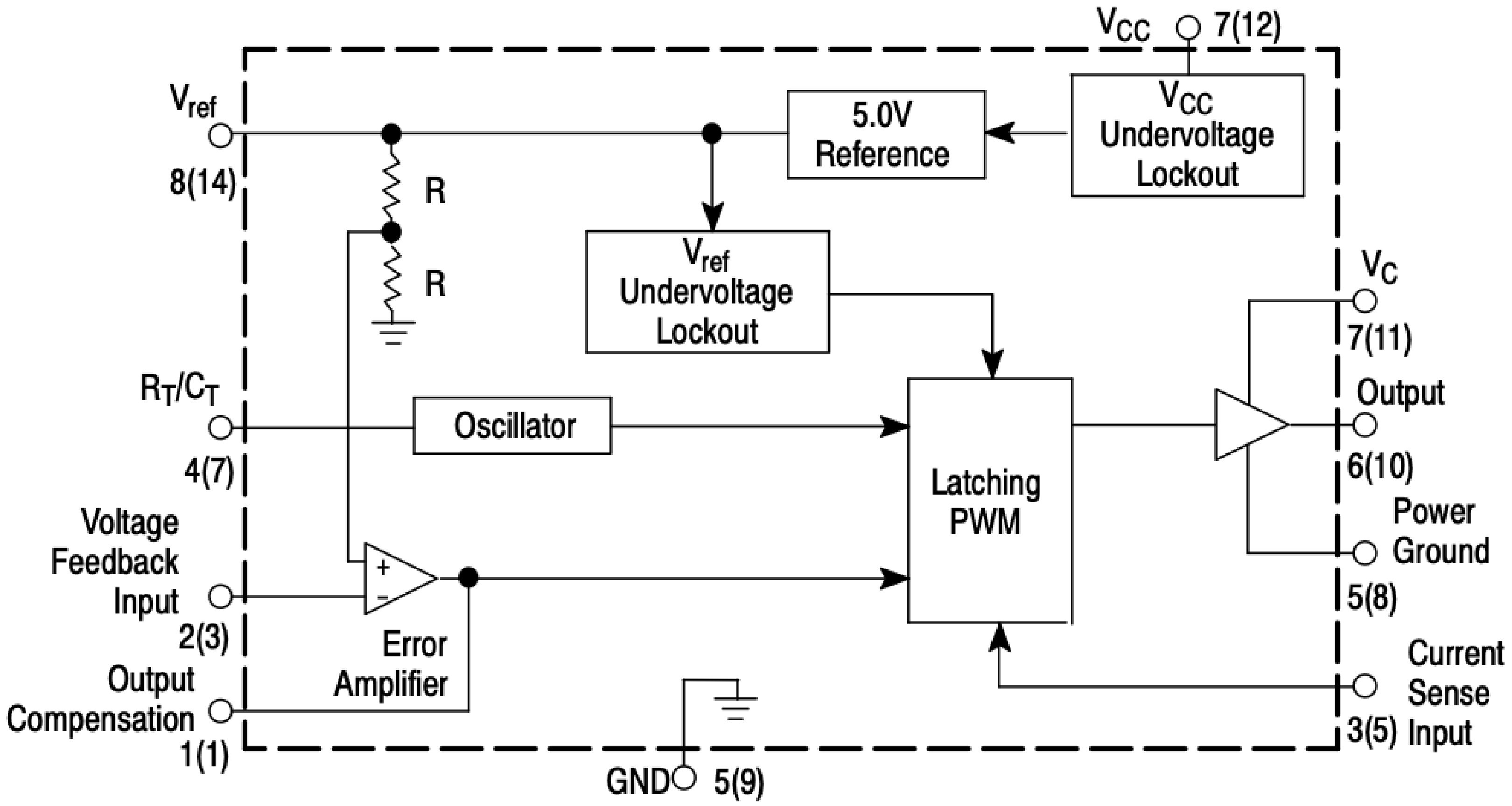
Unitrode 3842 Current Mode Controller

c. 1982

PIN CONNECTIONS



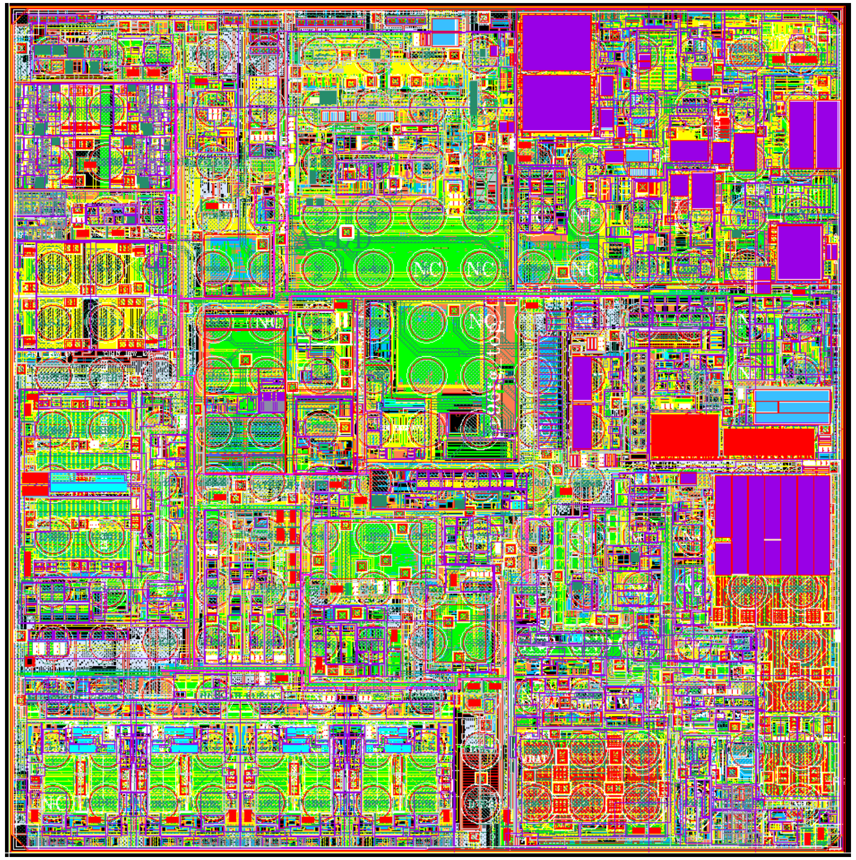
(Top View)



Pin numbers in parenthesis are for the D suffix SOIC−14 package.

Figure 1. Simplified Block Diagram

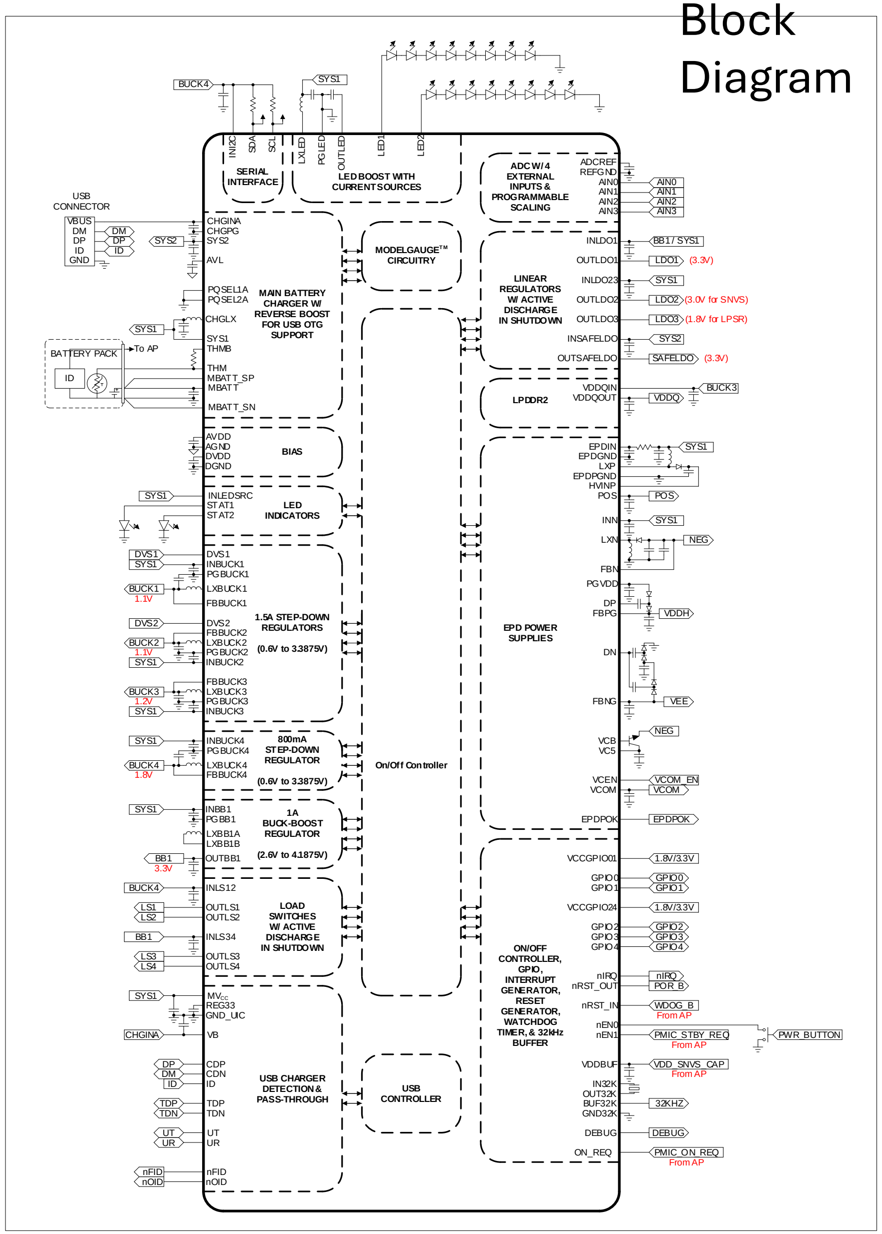
MAXIM MAX77796 PMIC



- Bi-Directional DC-DC Charger
- 4 DC-DC Buck Converters
- 1 DC-DC H-bridge Converter
- 2 DC-DC Boost Converters
- 1 DC-DC Inverting Converter
- 2 WLED Current Sink Drivers
- 2 Charge Pumps
- 4 Linear Regulators
- 2 High Current Op-Amps
- Full Run-Time Configurability

Courtesy Dr. Brett Miwa, MAXIM

Block Diagram



Where Were We in 1986? (cont'd)

- Advent of the *COMFET* (RCA) (aka the *IGT* (GE)*)*
  - "Application of COMFETs (IGT) to 40 kHz Off-Line Switcher" by AT&T Bell Labs and RCA Solid State Division.
  - "… dynamic latching at turn-off was the major problem … a strong function of the dv/dt of the drain-source voltage."
  - One of the first papers characterizing the switching behavior of the COMFET/IGT.

Device Technology 2024 and Beyond

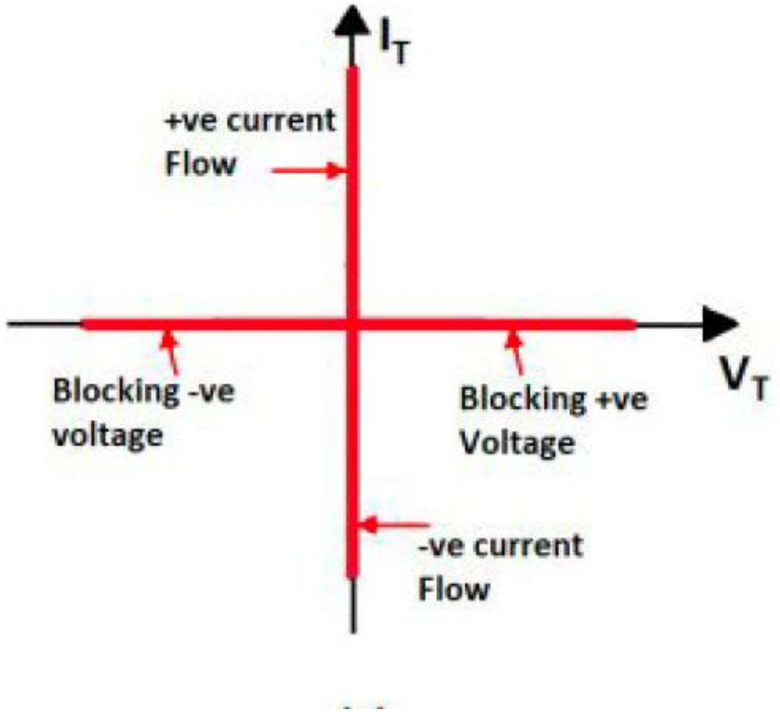
- Now in the middle of an evolution based on new semiconductor materials.
- SiC and GaN becoming more common.
  - High temperature and high frequency applications.
- Even diamond is being discussed.

Evolution of Traction Systems in Tokaido Shinkansen Trains

Type	 Series 0	 Series 100	 Series 300	 Series700	 Series N700 N700A	 **N700S**
Year	1964	**1985**	**1992**	**1999**	**2007**	2020 (2018)
Speed	210km/h	220km/h	270km/h	270km/h (Sanyo Section: 285km/h)	285km/h (Sanyo Section: 300km/h)	285km/h (Sanyo Section: 300km/h)
Semiconductor device	Diode	**Thyristor**	**GTO thyristor**	**IGBT**	**Low-loss IGBT**	**SiC IGBT & Schottky**
Control system	Tap changer control	**Thyristor phase control**	**PWM Conversion System**			
Cooling system	**Forced ventilation cooling system**				**Blower-less cooling system**	
Traction motor	**DC motor**		**3-phase induction motor** **4-pole**			**6-pole**
Electric breaking	**Rheostatic braking**		**Regenerative breaking**			

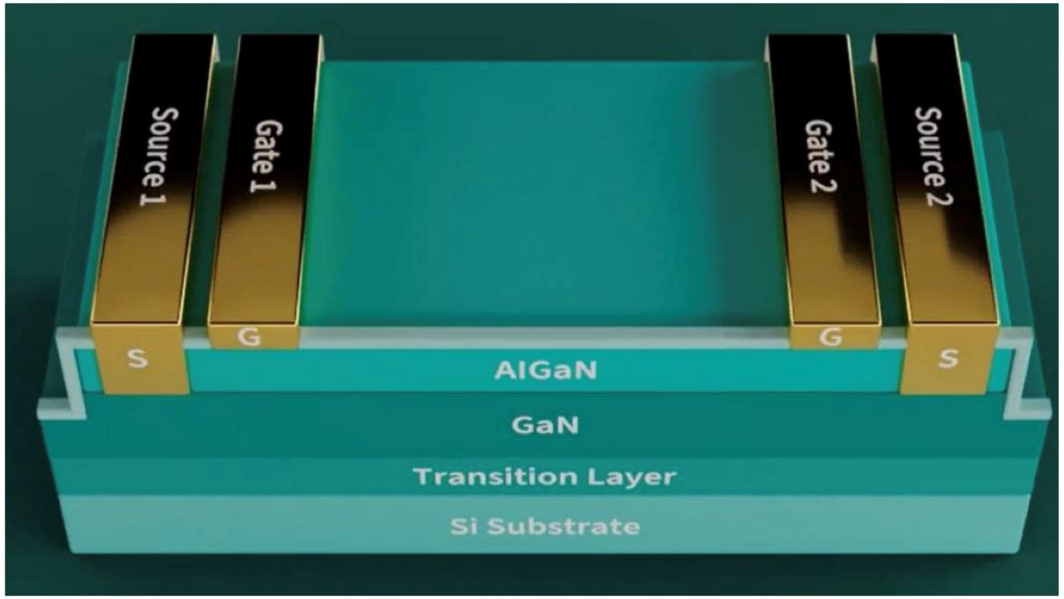
Device Technology 2024 and Beyond (cont'd)

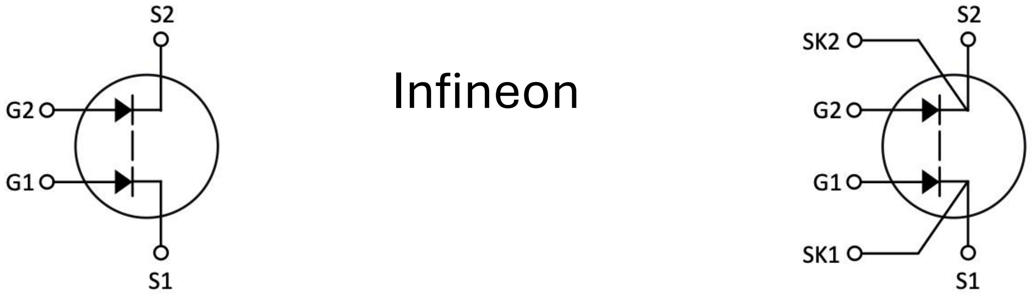
- Four quadrant switching devices
  - BDS (Infineon), B-TRAN (Ideal Power), BiDFET, FQS ("Four Quadrant Switch," Transphorm)



Monolithic BDS device

- Dual gate design
- Shared drain access region (common-drain)





Infineon

Power Electronics in Transportation

- Advanced devices, batteries and motors enabling increased electrification of transportation.
- Power density of motors competitive with jet engines (excluding fuel and batteries.) due to new steels, designs, and integrated electronics.
- Class 8 trucks.
- Aircraft.

Eviation Signs Deal with Cape Air for 75 All-Electric Alice Commuter Aircraft (PR Newswire 4/15/22)

• Range	540 NM
• Speed	240 Kt
• MTOW	6,350 kg
• Battery	920 kWh (NMC)
• Battery wt.	3,600 kg (60% MTOW)

Emerging Challenges and Opportunities

- Rapid advances in power electronics has created a Christmas list of opportunities. Mention 4 here:
  - Converters on the grid.
  - Piezoelectric energy storage.
  - A potential revolution in MRI power supplies.
  - Artificial Intelligence and power electronics.

Inverter Based Grid Resources (cont'd)

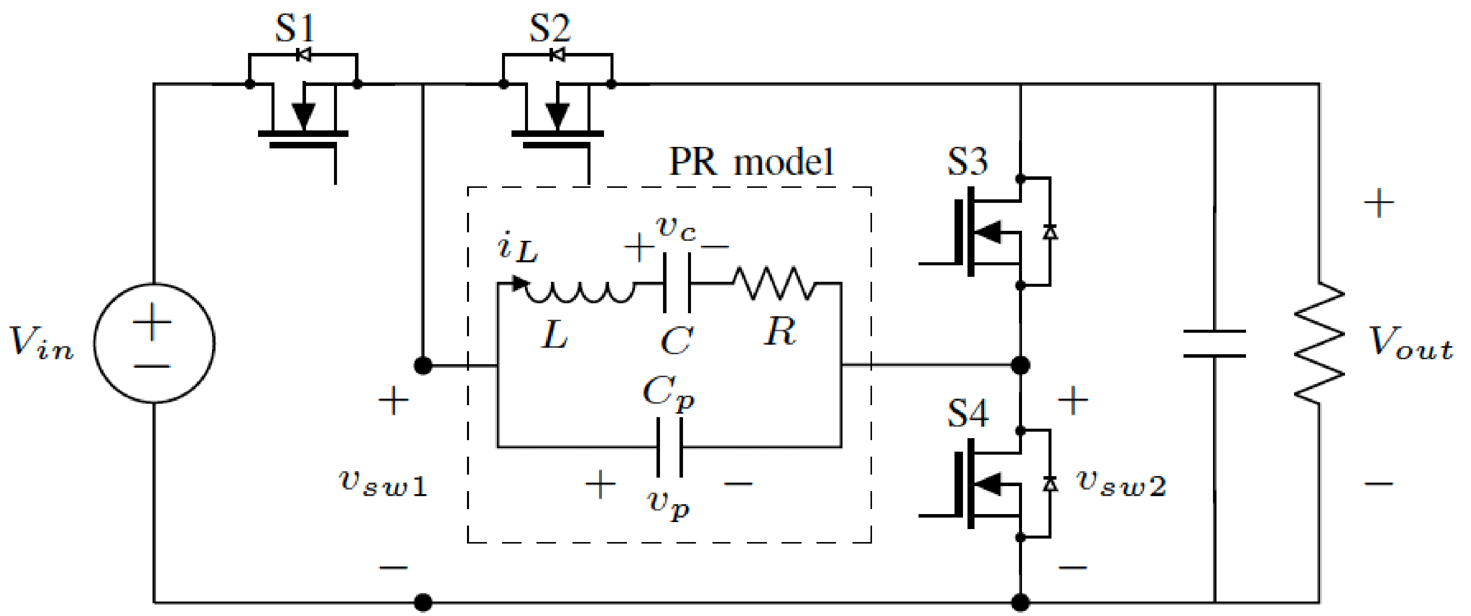
- Solar, Wind, Storage, Fuel Cells, etc. interface through inverters.
- Inverter products of different manufacturers may have very different responses to the same grid event.
- UNIFI – "Universal Interoperability of Grid-Forming Inverters" consortium co-led by ENREL, EPRI and U. T. Austin.
- Requires predictable behavior.

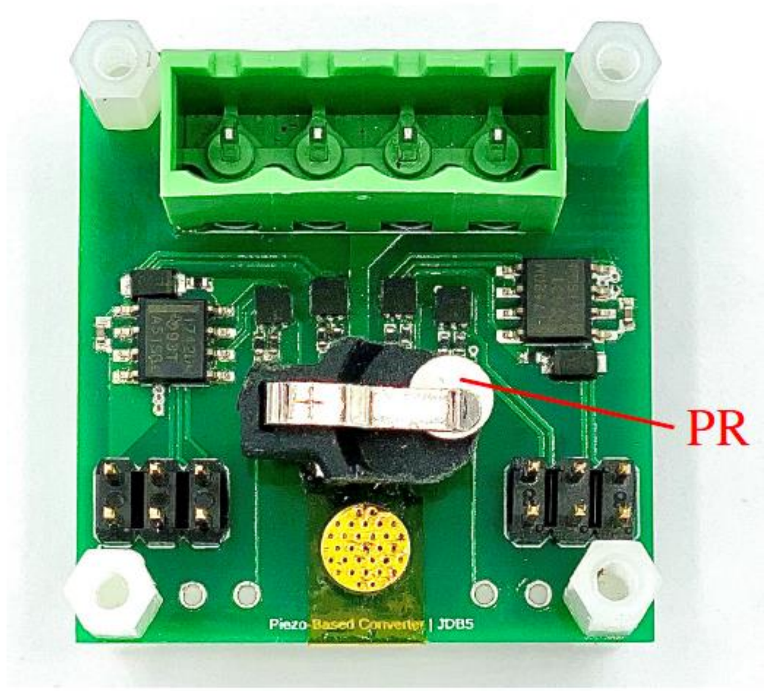
Piezoelectric Based Converters

- Ceramics of various compositions.
- Experience mechanical strain when E-field applied.
- Results in stored mechanical energy. Released as electrical energy when strain relieved.
- Model as electro-mechanical resonant tank circuit.
- Very high power density, ~ 6 kW/cm^3.
- Eliminates magnetics.
- Not plug-and-play. Circuits need redesign.

Piezoelectric Resonators Eliminate Passives

1 kW/cm^3 Resonator power density @ 493 kHz

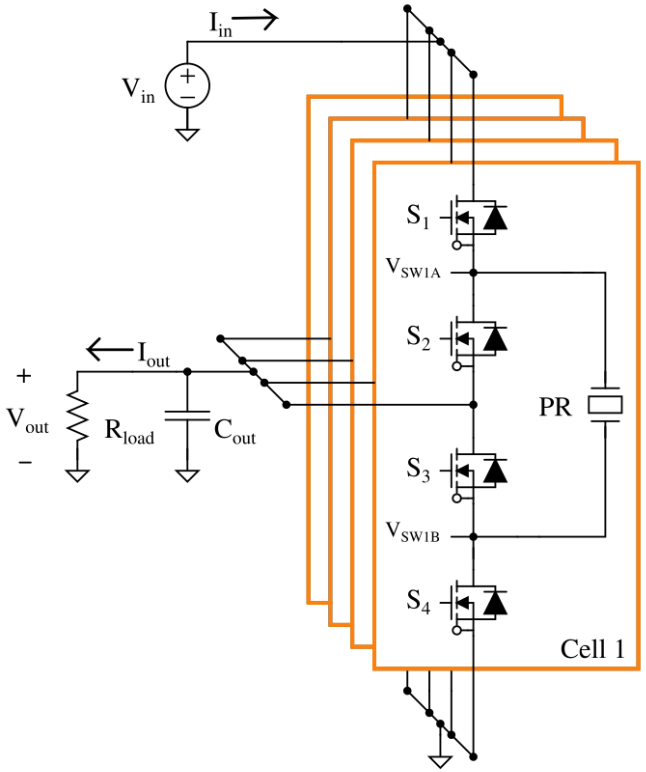


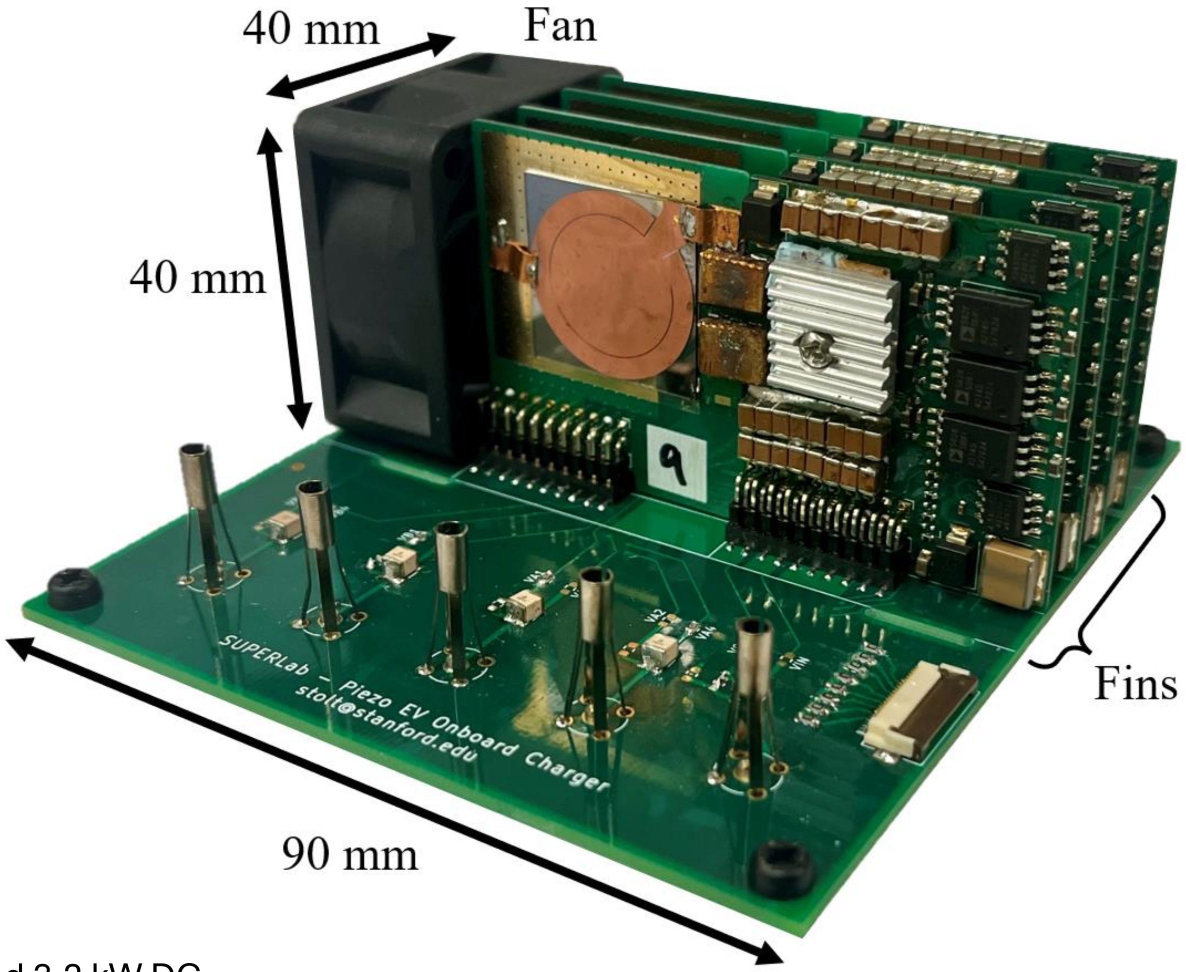


J.D. Boles et al., "A Piezoelectric-Resonator-Based Dc-DC Converter Demonstrating 1 kW/cm^3 Resonator Power Density", TPEL 2023

Piezoelectric Resonators Eliminate Passives

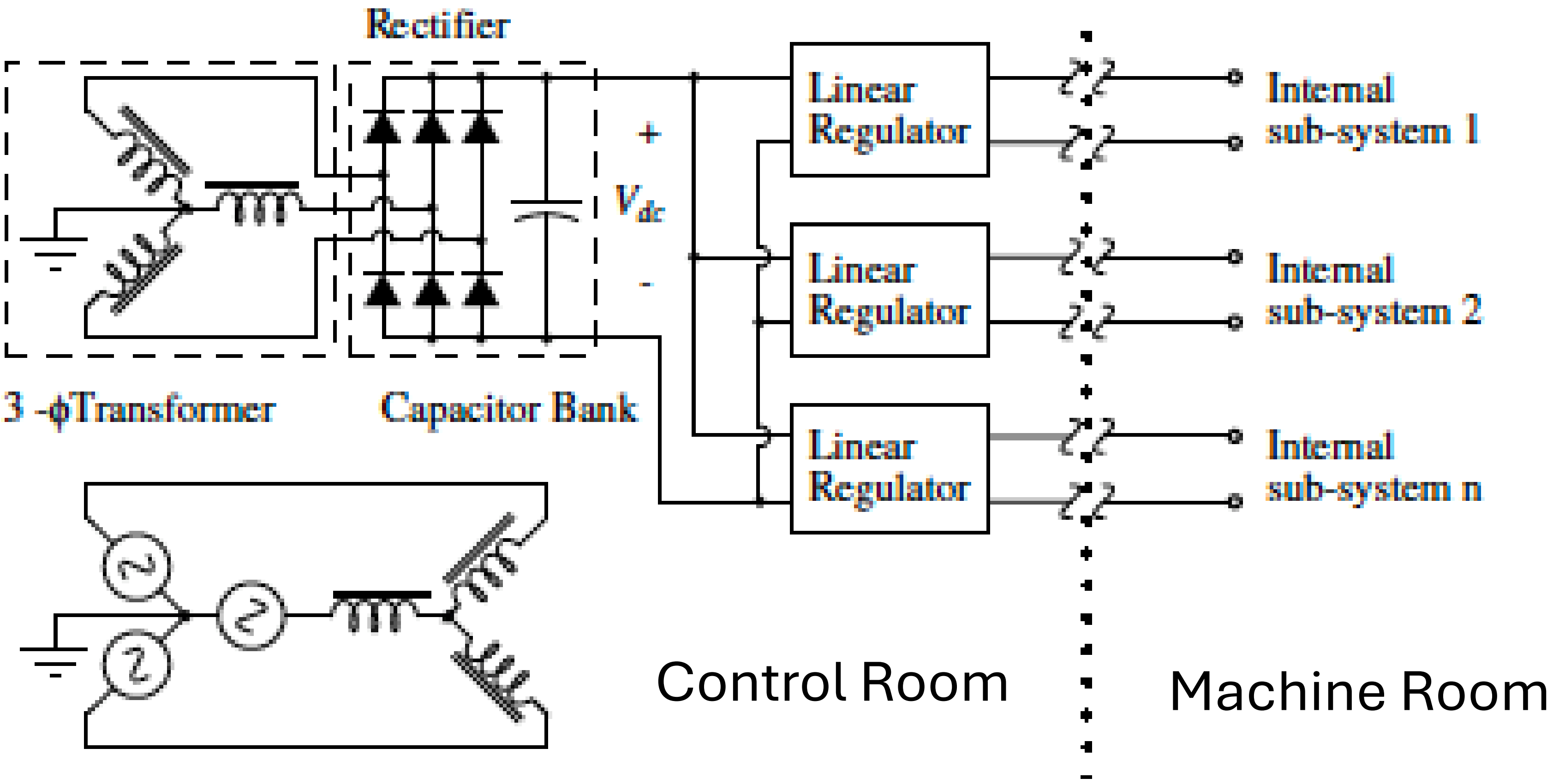
3.2 KW, 6.2 MHz, 5.7 kW/cm³





E. Stolt, et al., "A Spurious-Free Piezoelectric Resonator Based 3.2 kW DC-DC Converter for EV On-Board Chargers", TPEL, Feb. 2024

MRI RF Receiver Power Supply and Physical Architecture



Courtesy Juan Rivas

AI for Power Electronics?

- Is AI an enabler for more efficient design/manufacturing/failure analysis processes?
- Maybe, Maybe not, but a great market for power electronics.
- Newest NVIDIA AI GPU dissipates 2.7 kW!

Conclusion

- Power Electronics has come a long way since 1986.
- Progress driven by new devices, materials and applications.
- Continuing challenge is cost.
- An exciting future with continued evolution of technology and applications.

Acknowledgements

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THANK YOU

See you at APEC's 50th!

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