

# 6.622 Power Electronics

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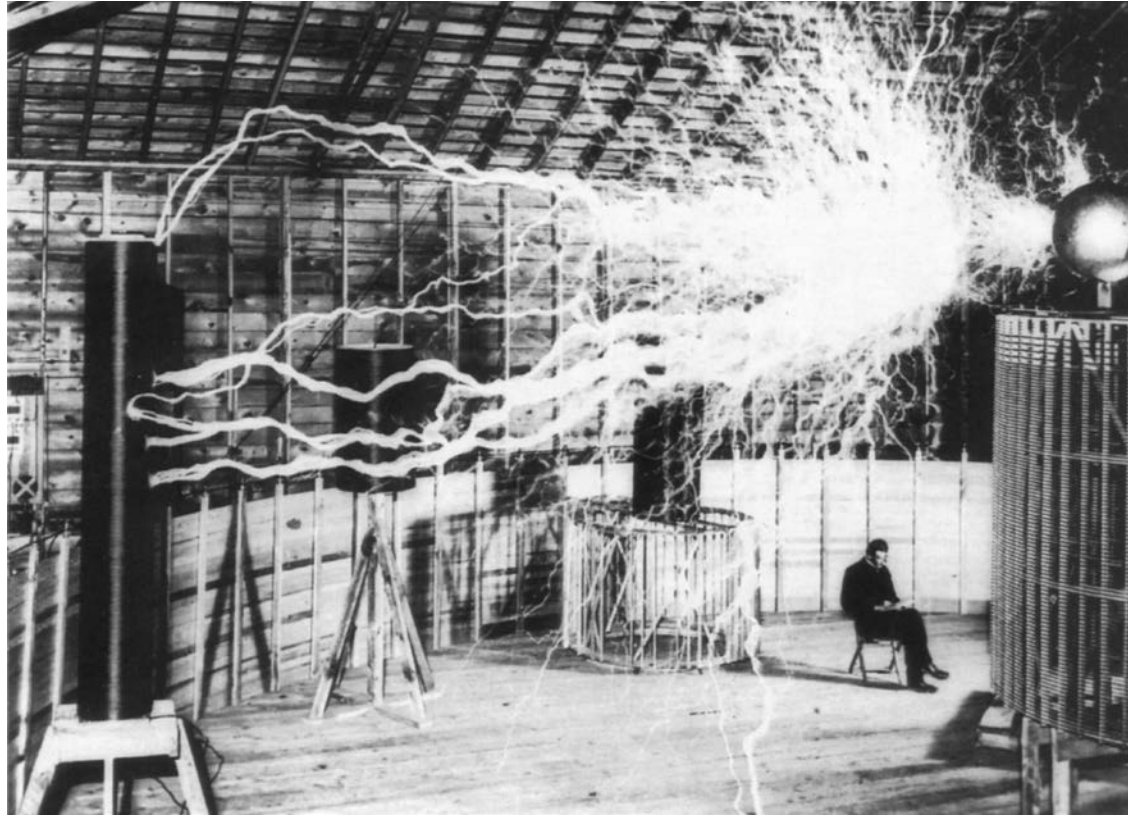


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***“If we could produce electrical effects of the required quality, this whole planet and the conditions of existence on it could be transformed.”***

**- NIKOLA TESLA**

# 6.334 Power Electronics

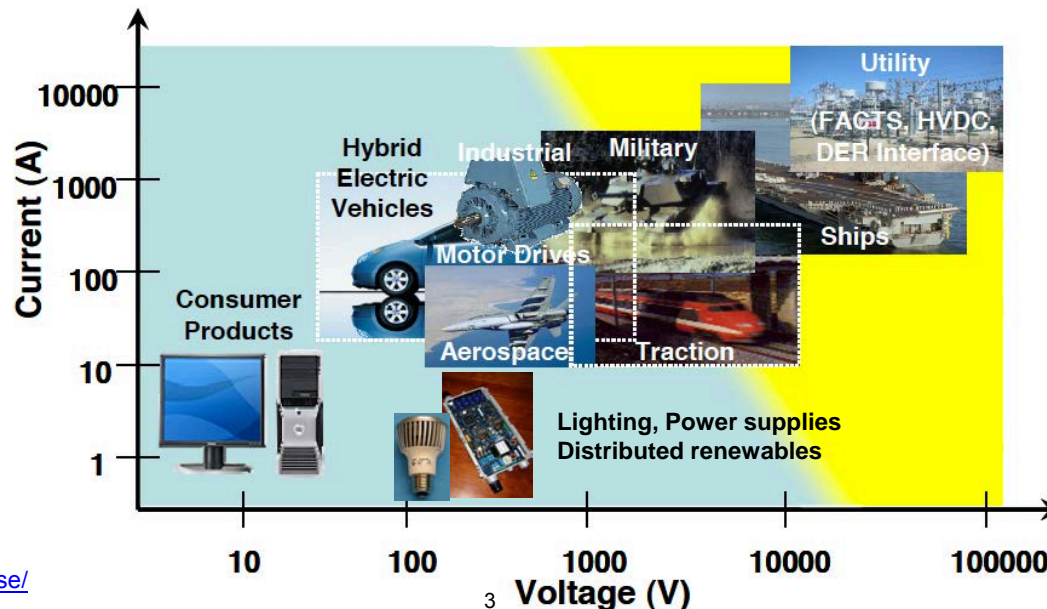
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“This technology encompasses the use of electronic components, the application of circuit theory and design techniques, and the development of analytical tools toward efficient electronic conversion, control, and conditioning of electric power”

- IEEE Power Electronics Society Definition

# Power Electronics

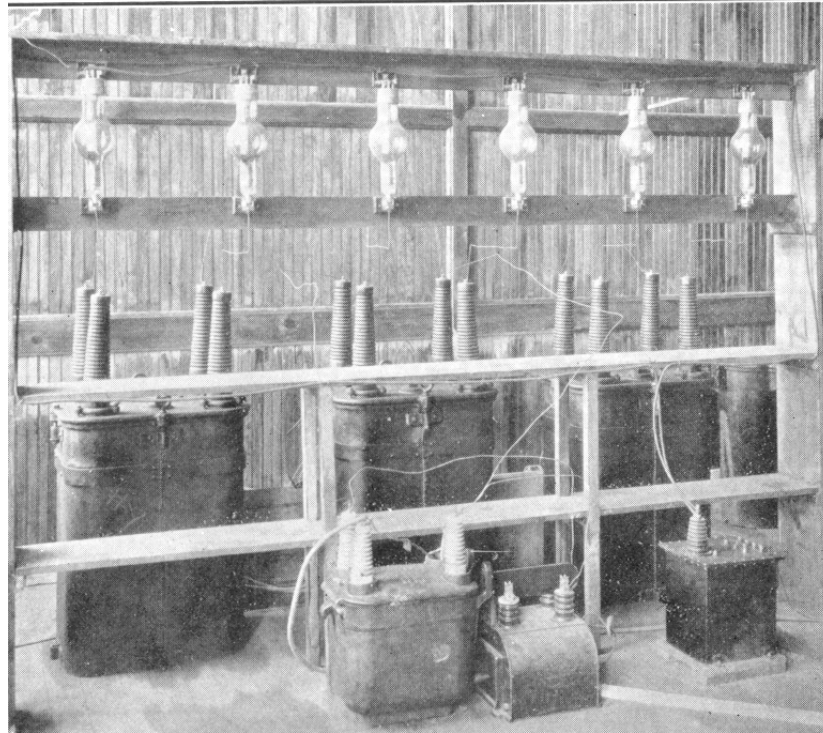
- The primary function of power electronic circuits is the processing and control of electrical energy
  - It is a core technology in our electrical infrastructure
  - The majority of electrical energy used passes through one or more power electronic converters
    - Continuously increasing
- In many applications, the power electronic circuitry is a major factor determining system size, functionality, and performance



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# Power Electronics circa 1927

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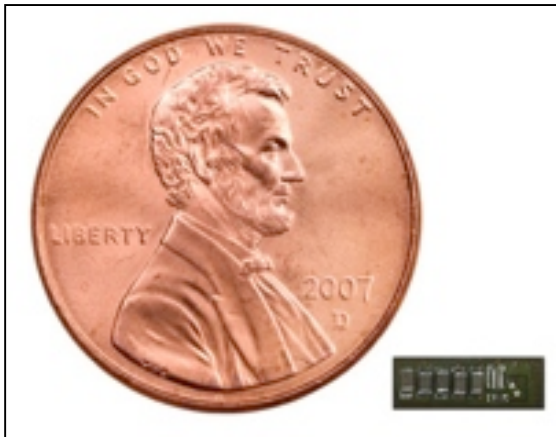


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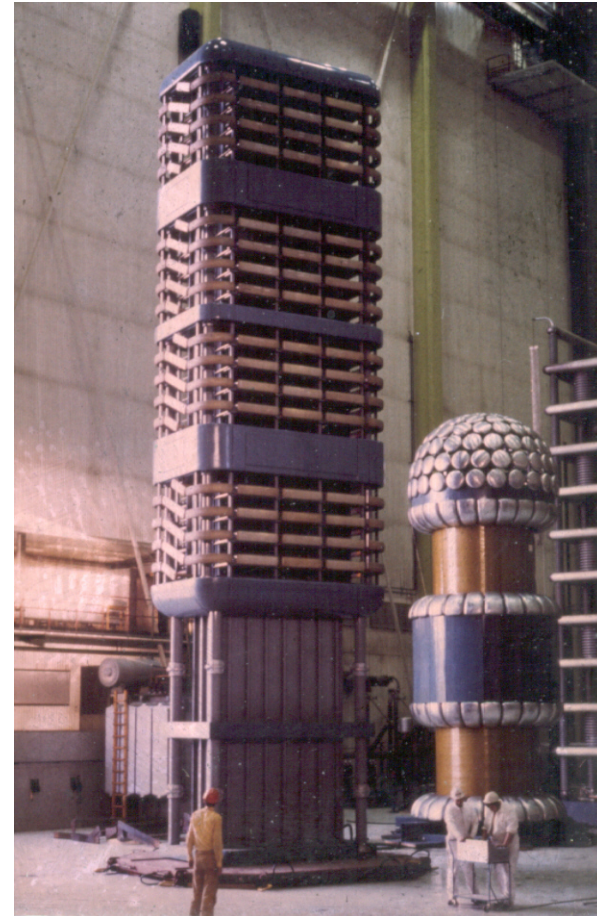
**20 kW Kenotron Rectifier Set**  
(From Principles of Rectifier Circuits, Prince and Vogdes, McGraw Hill 1927)

# Power Electronics Today

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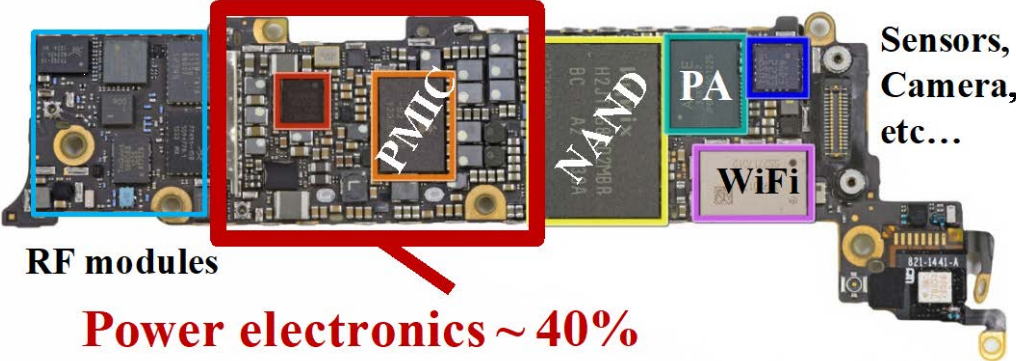
**From milliWatts to gigaWatts...**



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# Portable Electronics

## Example: iPhone 5 Motherboard



**Power electronics ~ 40%**

- WiFi – 3.3V
- Flash – 3.0V
- MEMS sensors – 2.4V~3.6V
- RF modules – 2.5V~5.5V
- CPU, Display, Camera, etc...

Photo credit: [www.ifixit.com](http://www.ifixit.com).  
Courtesy of iFixit. Used under CC BY-NC-SA.

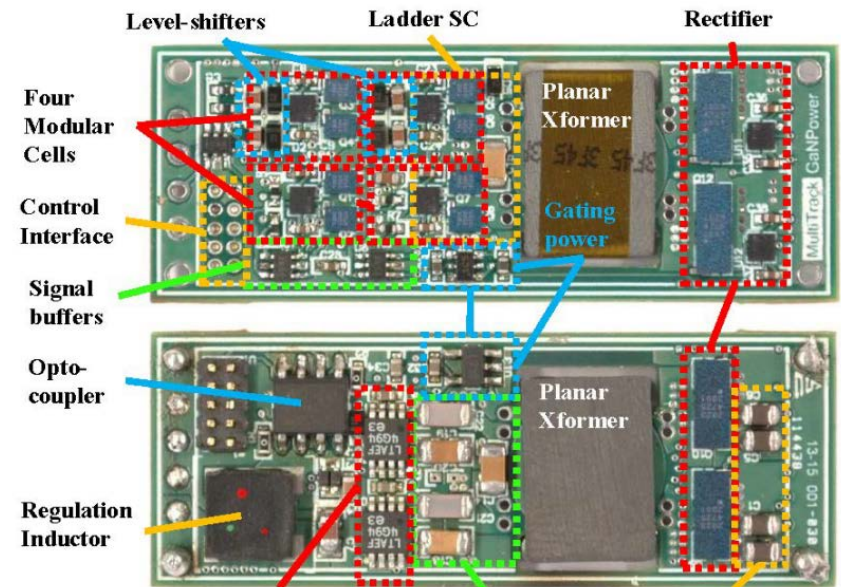
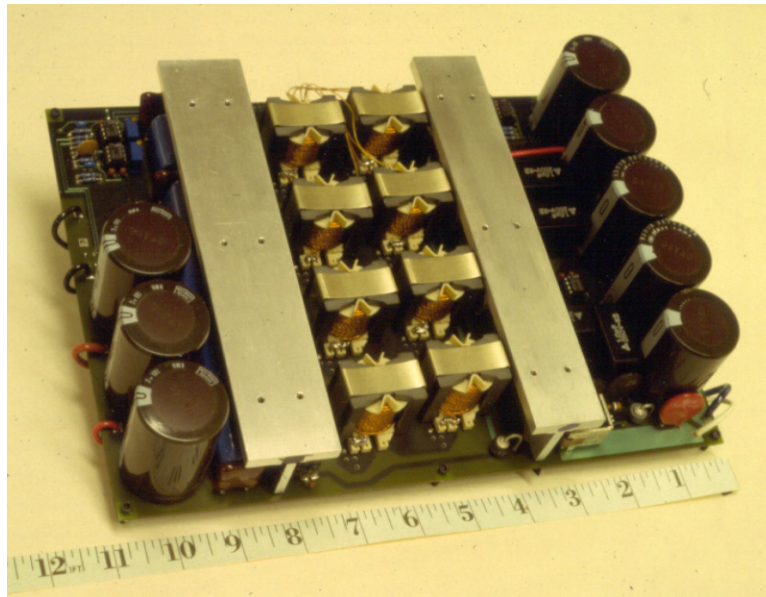


[Apple iPad Adapter]

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## Power converters for portable electronics

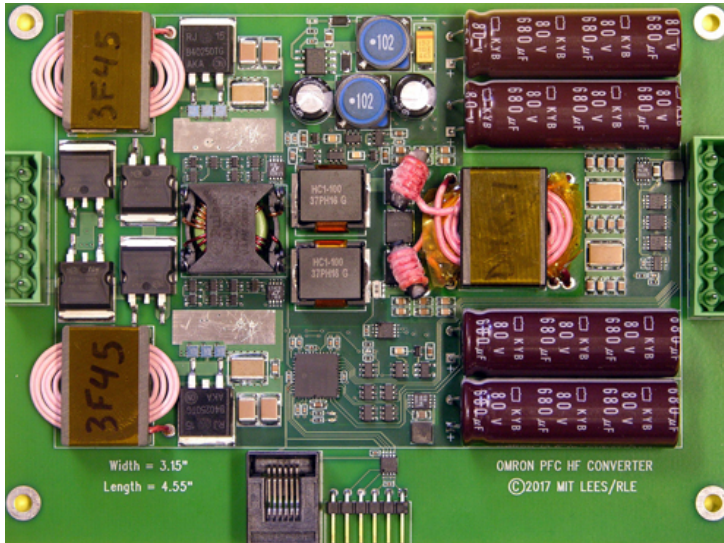
# Computers and Telecommunications



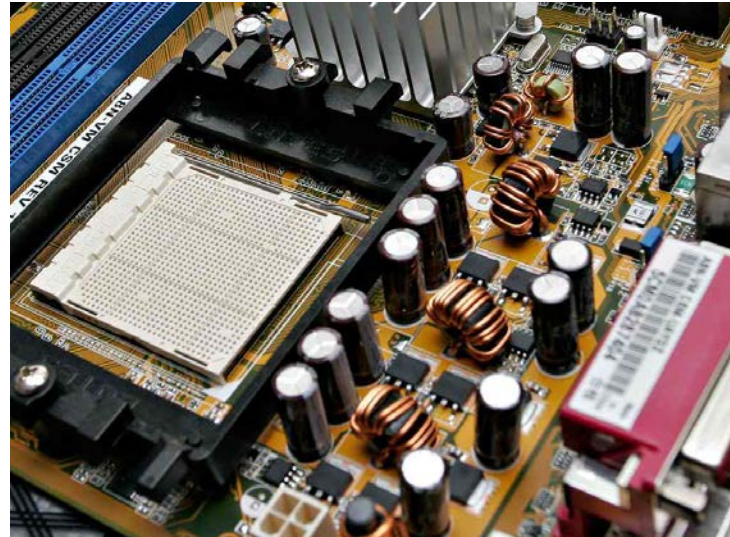
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**Front-end and distributed power converters for server systems**

# Computers and Telecommunications



PFC Power Supply, Circa 2017  
(Juan Santiago-Gonzalez, MIT)



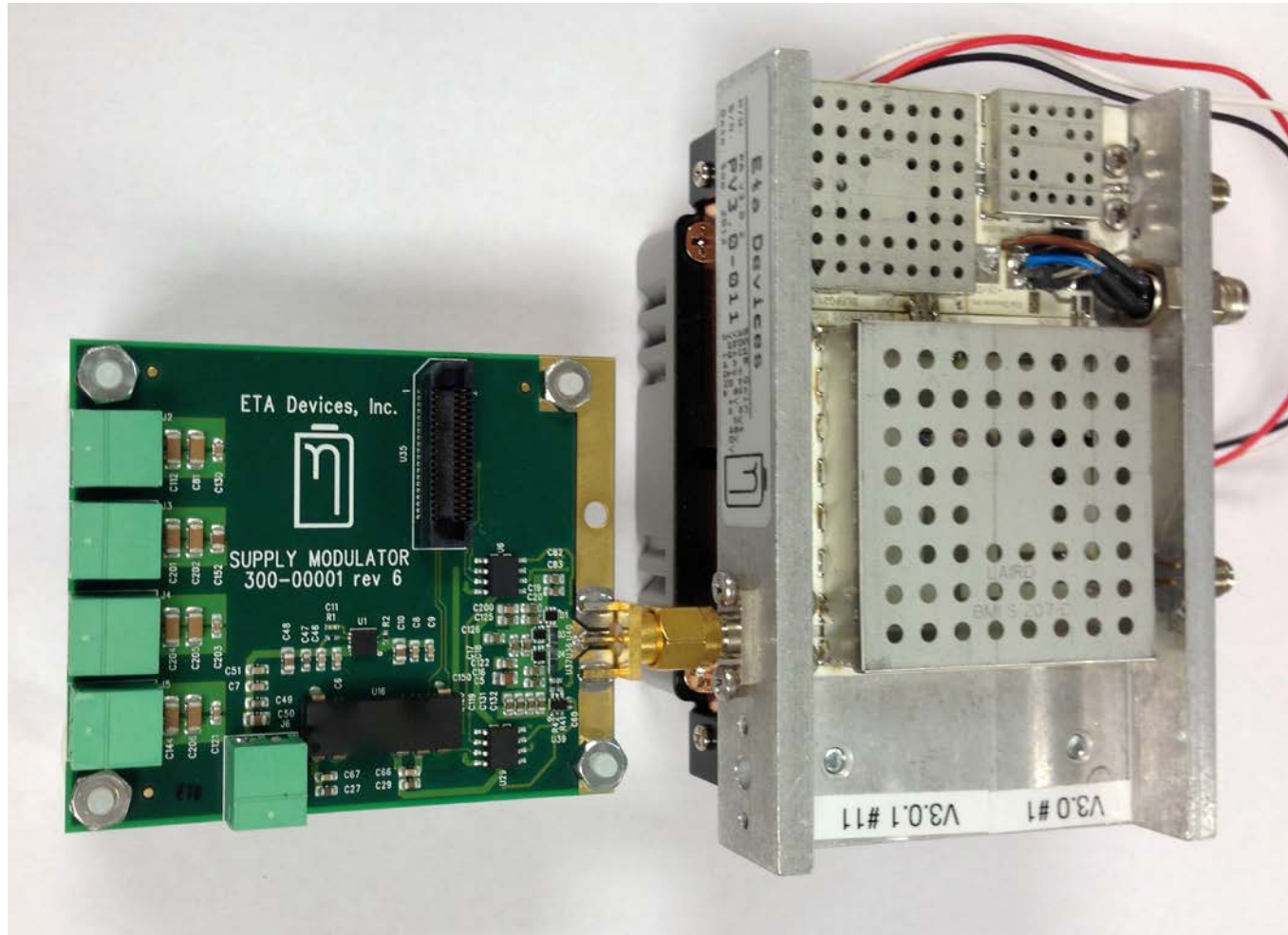
Adapted from <http://www.directron.com/psu.html>

## Power Supplies for Servers and Desktop Computer Systems

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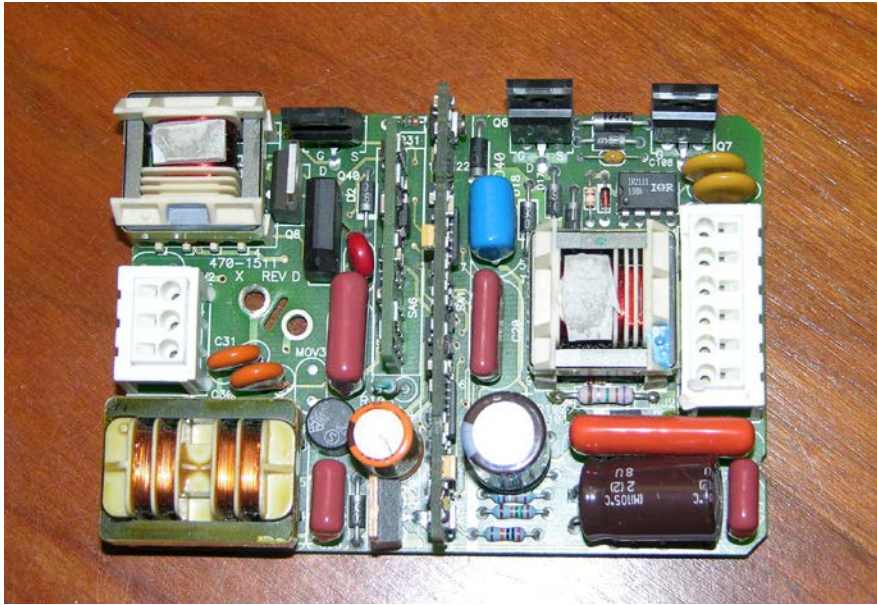
# Communications and RF



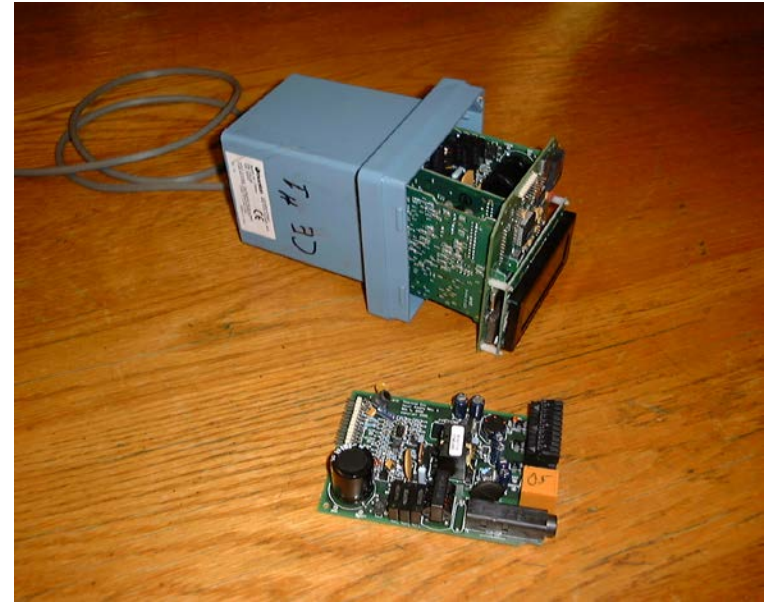
## Power supply modulator and rf amplifier for communications

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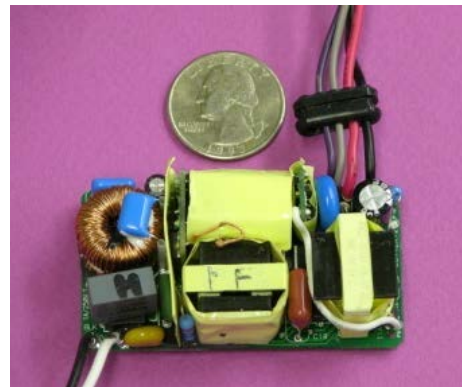
# Commercial Applications



**Dimmable Ballast (Lutron)  
Florescent lighting**



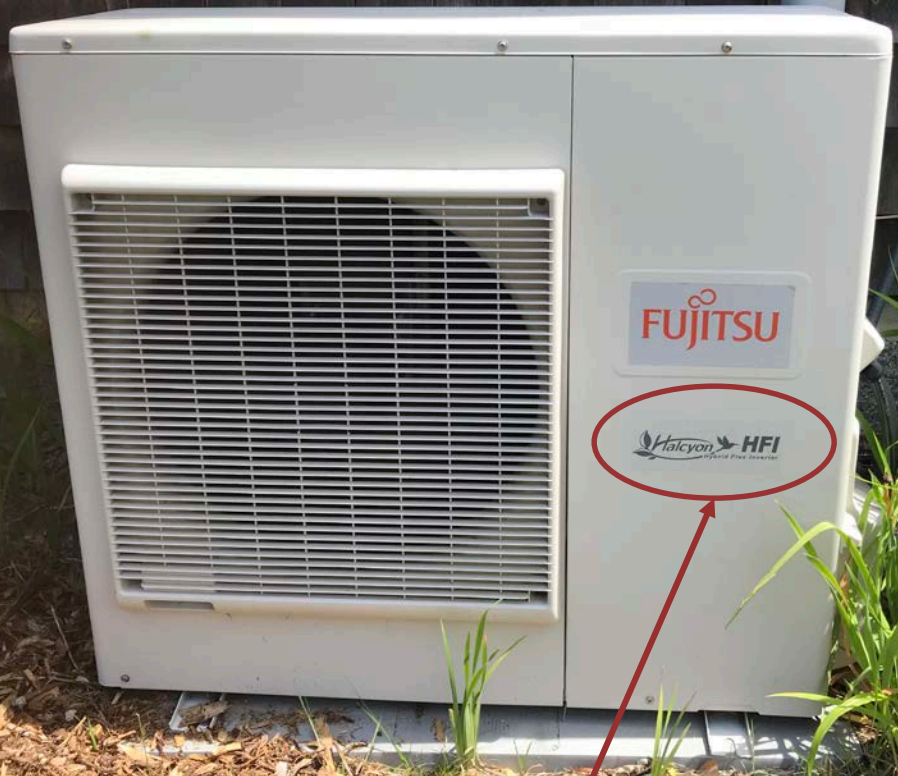
**20 W Dual-Output Off-Line Converter**



**LED driver  
(Cooper, ~20 W)**

# Appliances

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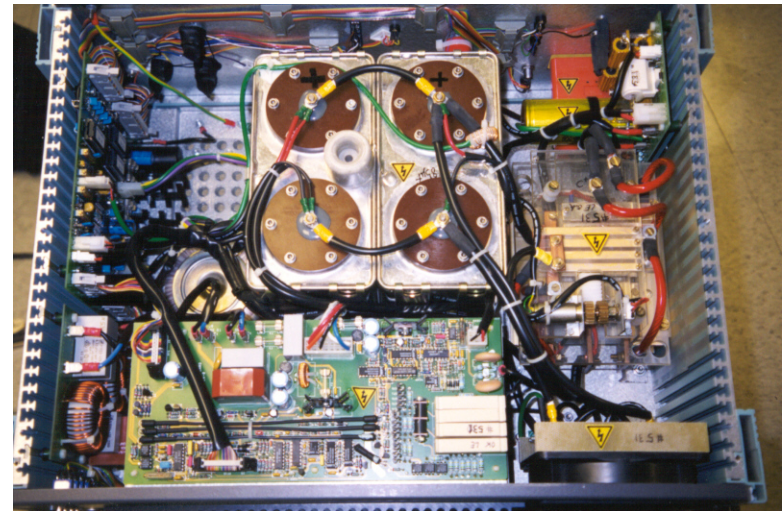


**Ultra-Quiet Air Conditioning Unit  
with “Hybrid Flex Inverter”**

**Ultra-Quiet Dishwasher  
with “Inverter Direct Drive”**



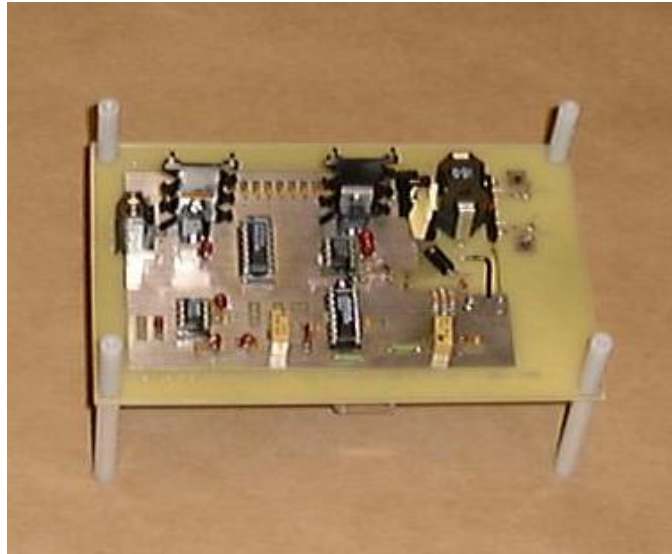
# Medical Applications



**A magnetic stimulator for medical applications  
(generates 5000 A pulse trains in a transducer coil)**

# Scientific Applications

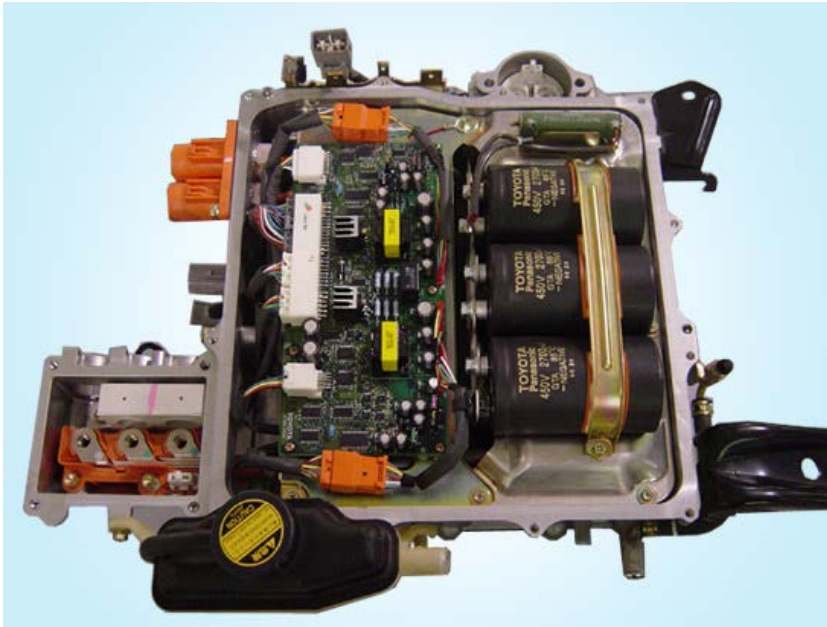
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**A 2 MHz 1.4 kV pulse generator  
for a portable Drift Spectroscope**

# Transportation

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Adapted from [www.cleangreencar.co.nz/prius-technical-info.html](http://www.cleangreencar.co.nz/prius-technical-info.html)

**Toyota  
Inverter for Toyota Prius**



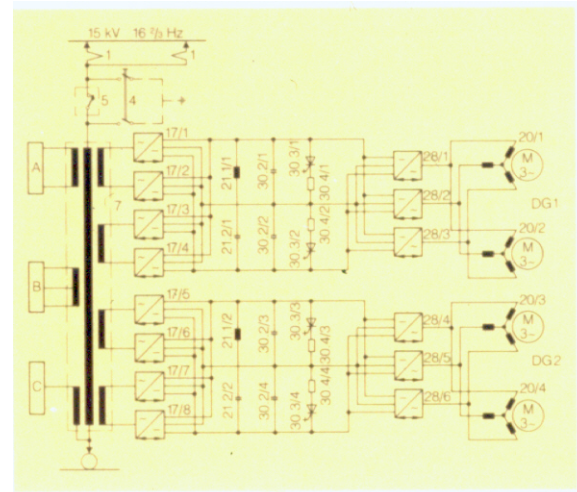
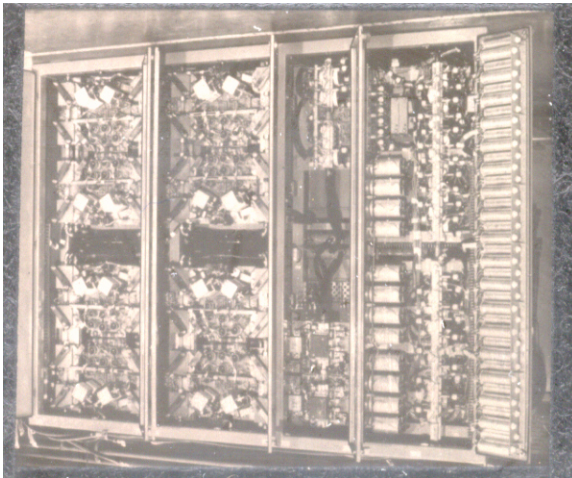
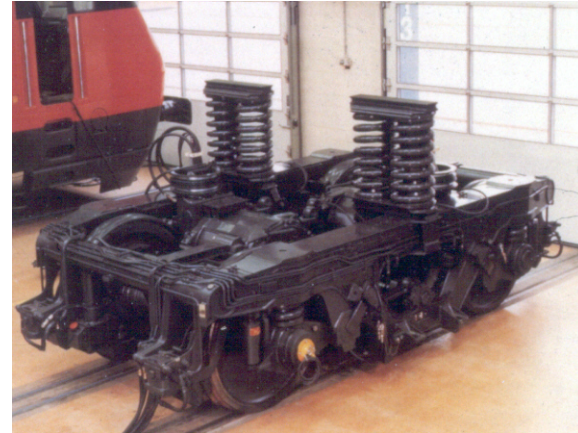
Adapted from [www.hap.com/products/Motors/EMI/index.html](http://www.hap.com/products/Motors/EMI/index.html)

**Hitachi Automotive Products  
Inverter and motor for small EV**

Not only are power electronics central to hybrid and electric vehicles, but *improvements* to power electronics can be important. A recent 2016 redesign of the power electronics (using SiC devices) improved the fuel economy<sup>14</sup> of a Prius by 5%.

# Transportation

Re 4/4 460 Locomotive, motor bogie, and power electronics (4x1.7 MW drive plus 3x100 kW aux power)



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# Transportation

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## Japanese Maglev train and wayside power electronics

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# Transportation (Aerospace)

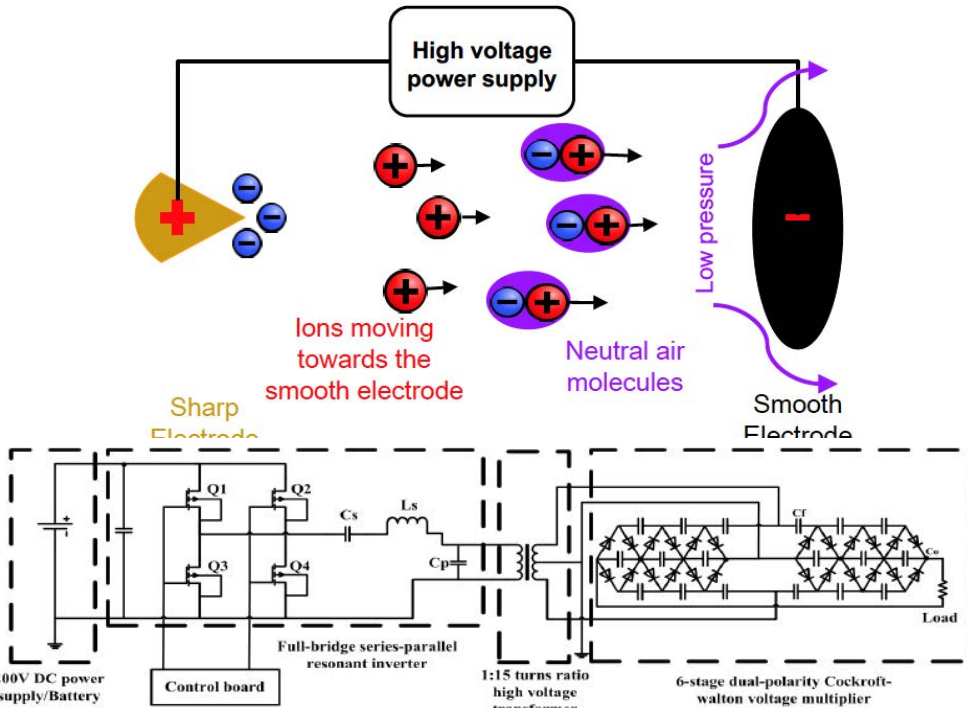
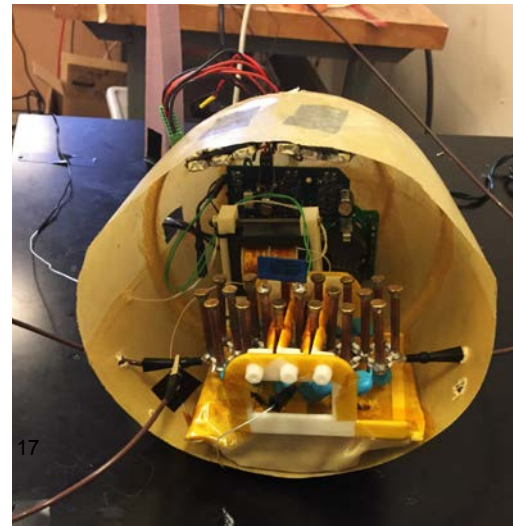
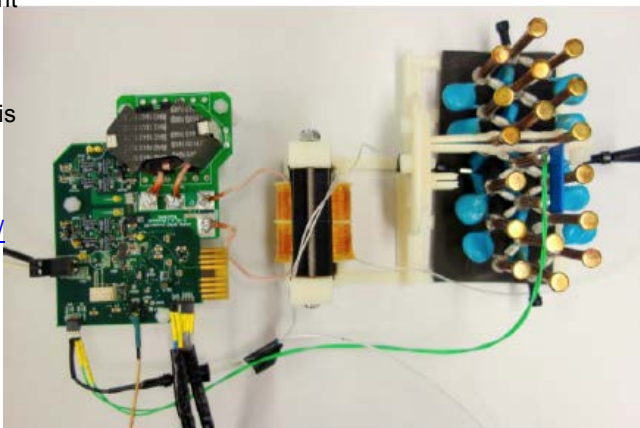
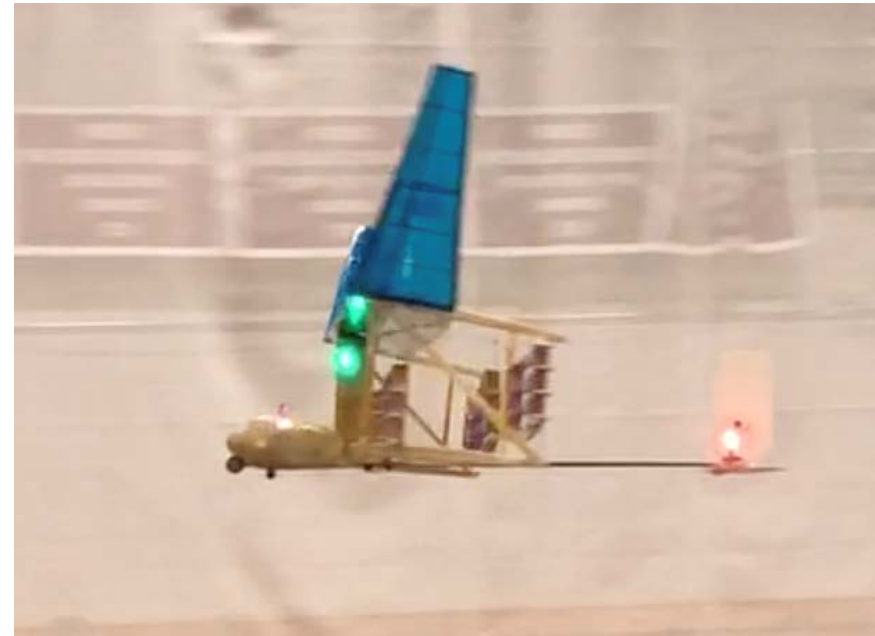


Fig. 3 Topology of a 40 kV 750 W dc-dc converter



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40 kV power supply EAD Propulsion

# Power Generation and Transmission



Microinverter for Photovoltaics  
Enphase Energy, 2008



Custom "Boost Converter" MPPT tracker  
Developed by Robert Pilawa,  
MIT Solar Electric Vehicle Team



Inverter for Residential PV System  
Courtesy Prof. Pat Chapman, UIUC



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# Power Generation

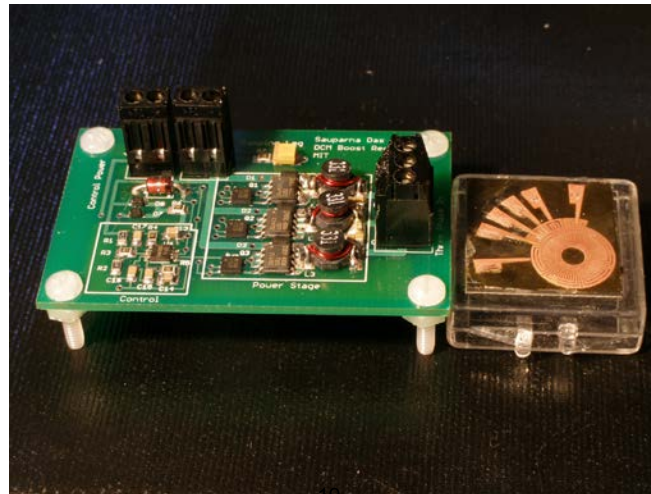
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**Alternator with Integrated Switched-Mode Rectifier  
MIT / LEES 2007**



**Foil field alternator with rotating power electronics  
MIT / LEES 2005**

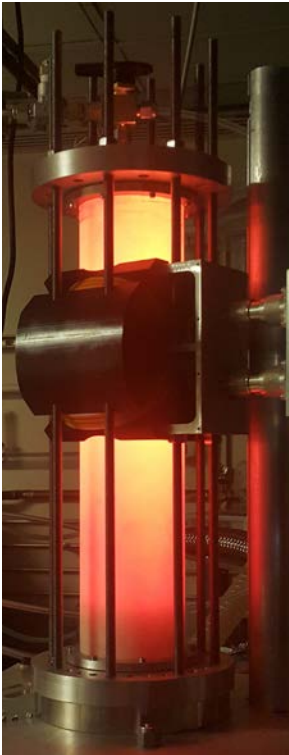


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**MIT/GaTech Microfabricated Generator and Switched-Mode Rectifier  
(Photos courtesy of Mr. Sauparna Das, MIT Laboratory for Electromagnetic and Electronic Systems, 2005)**

# HF & VHF Power

- Many applications require power at HF (3 – 30 MHz) or VHF (30 MHz – 300 MHz) frequencies
  - plasma generation, induction heating, wireless power, MRI, ...
  - Often narrow-band (e.g., ISM band 6.78 MHz, 13.56 MHz, 27.12 MHz)



**Plasma Chamber with SF<sub>6</sub>  
driven at 13.56 MHz  
(Anas Al Bastami, MIT)**

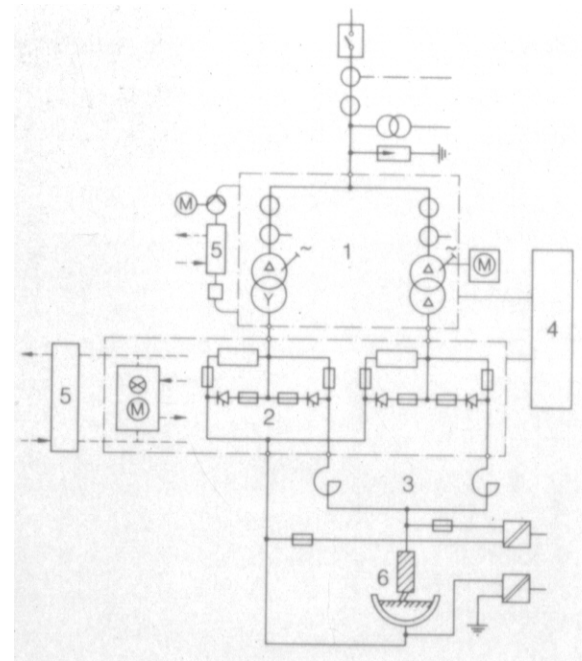
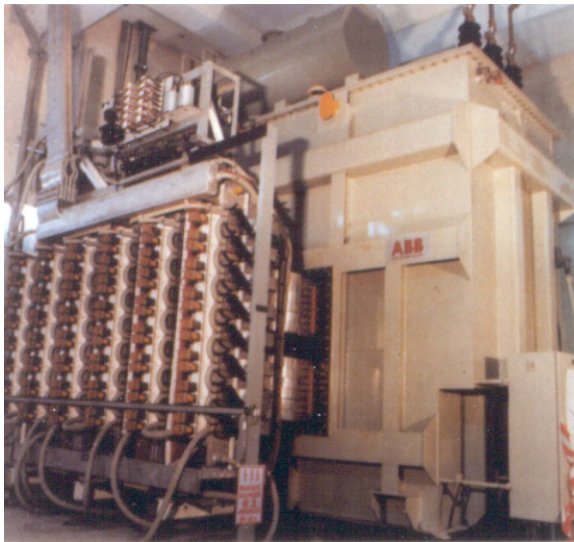


**3 x 30kW 27.12MHz RF generators  
(GHP300KE, Sairem) and their water cooling  
circuit in an induction heating application**



**10.5T2000M  
(Communication Power  
Corp.) 16-channel 40-450  
MHz 32 kW power  
amplifier for MRI**

# Industrial Applications

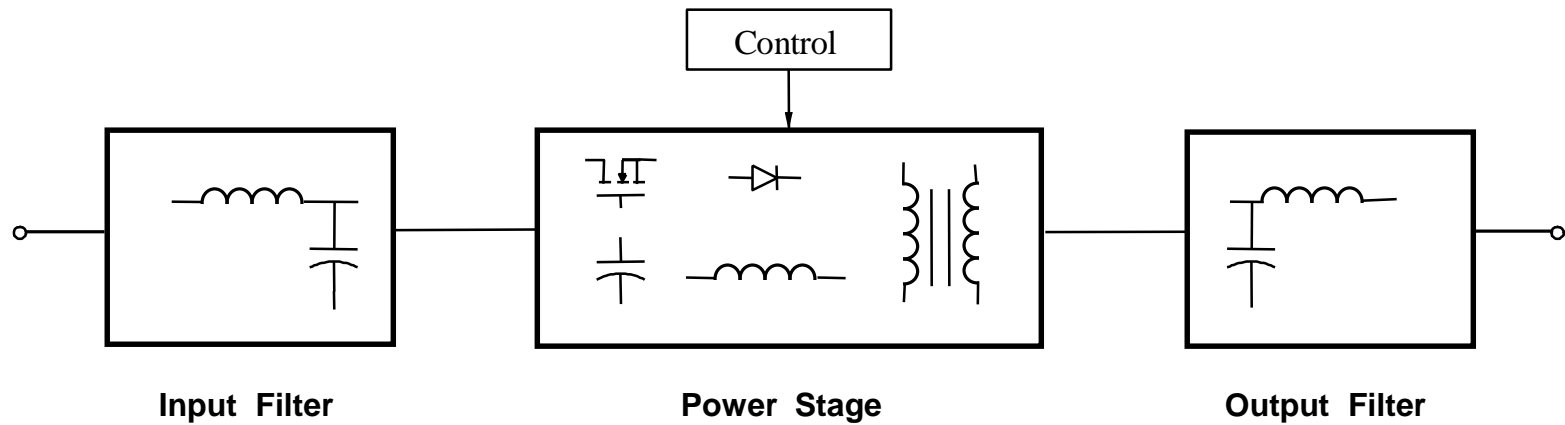


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## 12-pulse thyristor converter and transformer for a dc arc furnace

# Structure of Power Electronic Systems

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# Evolution of Power Electronics

- Evolution leverages advances in all of
  - Circuit design
  - Semiconductor devices
  - Passive components and materials
  - Packaging and cooling
  - Controls



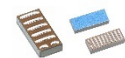
**Thyristor 1950s**



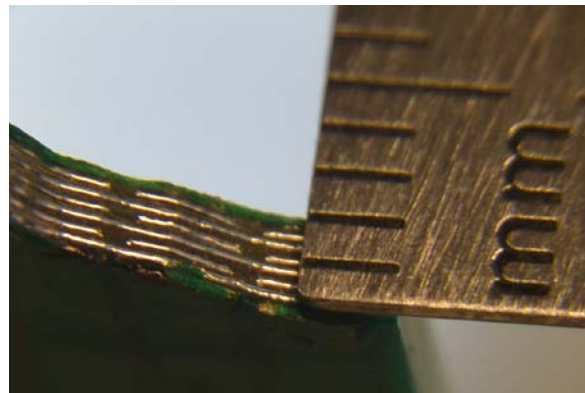
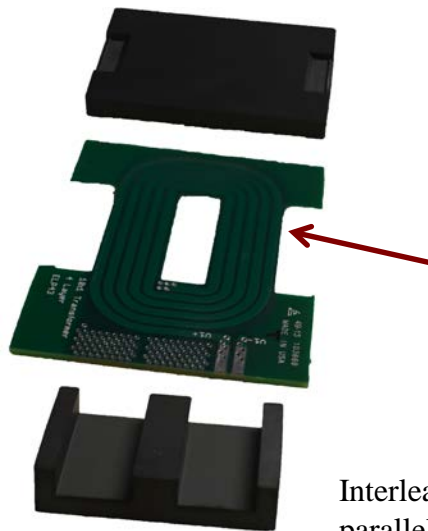
**BJT  
1960s**



**Power MOSFET  
1980s**

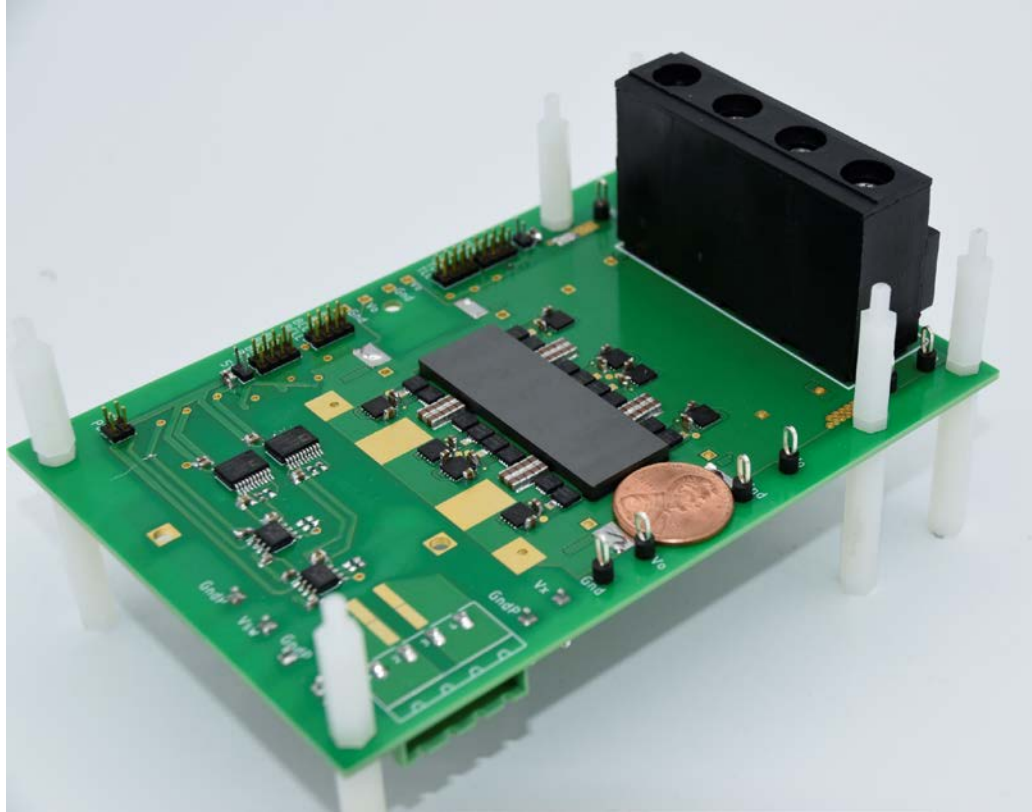


**GaN FET  
2010s**



Interleaved 10:1 PCB Transformer with high layer count and paralleled secondaries for high current

# Example Power Converter



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**1 kW, 1 MHz, 380-12 V  
Server Power Supply, Circa 2021  
(Mike Ranjram, MIT)**

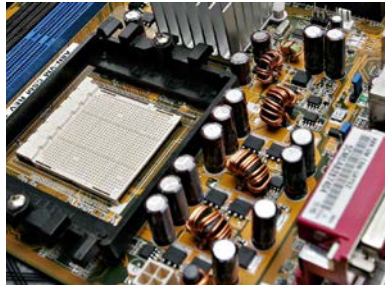


# Power Electronics Needs & Goals

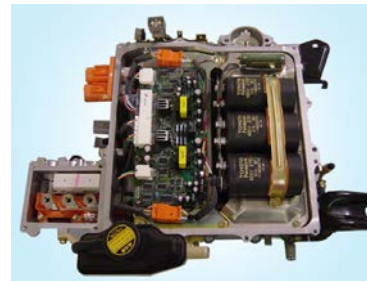
- All kinds of systems are limited by energy and how it is controlled and processed



Efficient Lighting  
(LED driver)



Computers  
(Power Supply)



Transportation  
(Inverter for Prius)



Renewable Energy  
(Microinverter)

- Needs / Goals

- Miniaturization (smaller, lighter)
- Higher efficiency (converters *and* systems)
- Higher performance (better systems)
  - Bandwidth, operating range,...
- Applications (create entirely new *system* opportunities)



Mobile Devices  
(Power management)

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6.622 Power Electronics

Spring 2023

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