Power Electronics and the Next Electrical Energy Revolution

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The 21st Century Energy Revolution

- Throughout history (and before), there has been a sequence of energy revolutions.
- The use of draft animals and water power.
- Steam power and combustion engines.
- Hydrocarbon fuels for transportation.
- Electrification.
- Each of these has *completely changed* the way people live and work.

The 21st Century Energy Revolution

- Today, we are in early stages of a new energy revolution.
- We see it in personal computers, cell phones, portable devices, industry . . .
- We see it in hybrid cars now on the road.

www.familycar.com

The 21st Century Energy Revolution

- Modern electrical demands are much different from the
  - Incandescent lights
  - Electric stoves
  - Motors

  that represent the 20th century electrical energy revolution still sweeping the world.

The *Solar Two* thermal solar power plant.
from www.nrel.gov

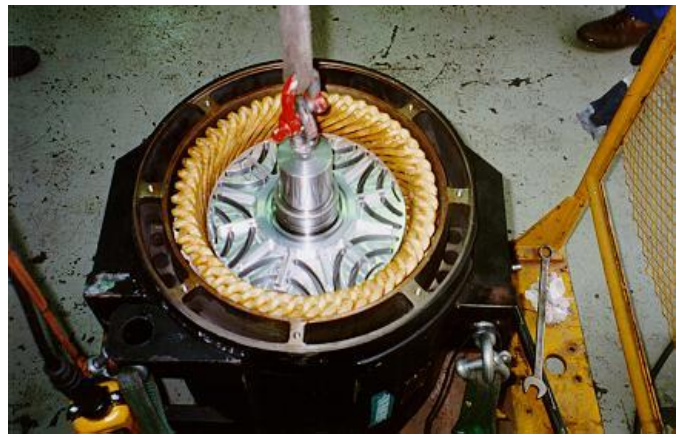
The 21st Century Energy Revolution

Generation and use are changing quickly.

research.ee.sun.ac.za

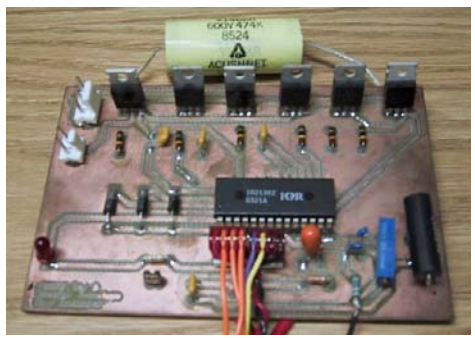
www.microturbine.com

www.
nrel.gov



www.edmunds.com

www.osesemi.com

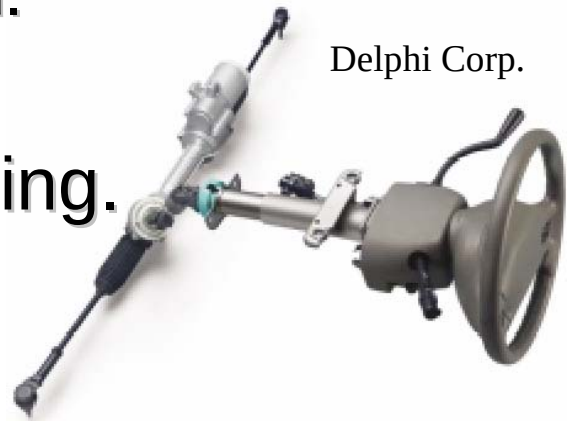


Signs of Revolution

- Jetliners are moving to all-electric
- Car electrical systems are retooling.
  - Electric air conditioning, power steering, suspension, control, pumps are better.
  - The 12 V system is being superseded.
- Formerly mature rechargeable battery markets are exploding.

www.mpcproducts.com

Delphi Corp.



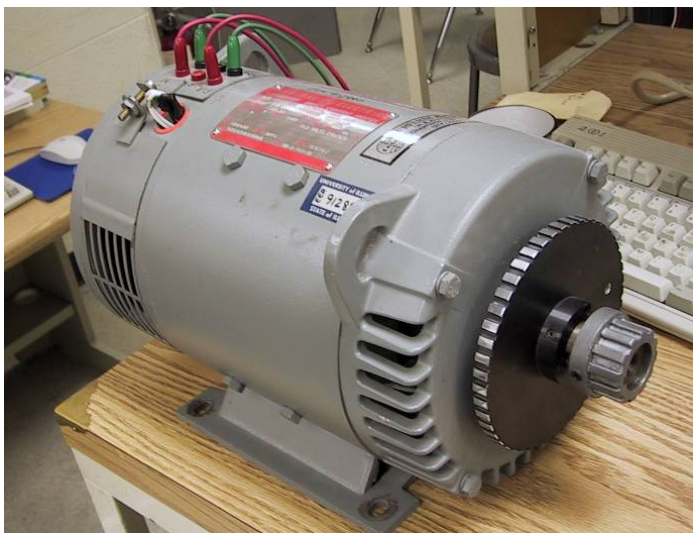
- Wind power has crossed the economic threshold.

Signs of Revolution

Long-anticipated energy growth in east Asia and south Asia is occurring.

The Three Gorges dam

www.tourroundchina.com



Industrial dc motor

Whole classes of formerly high-tech equipment are disappearing.

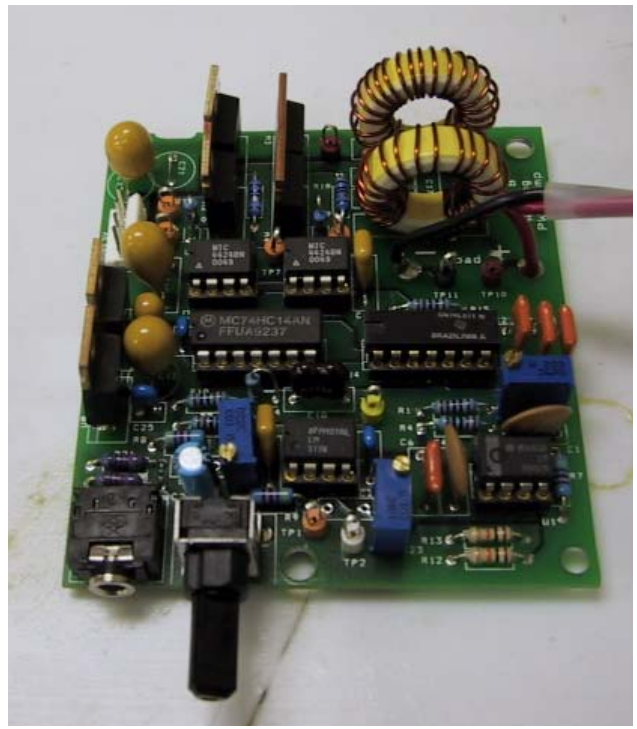
Signs of Revolution

- Electricity continues to grow as a fraction of all energy use.
- Electrification is now considered a key element of economic development.
- Much of the world has little energy access.
- Many countries may skip wired grids.

www.ccm.co.nz

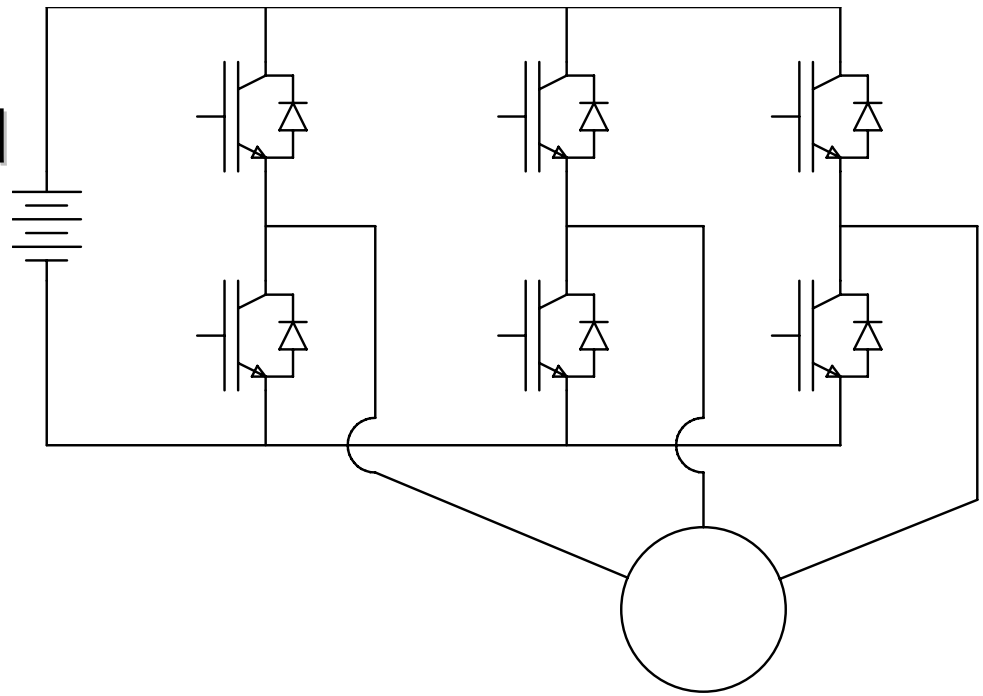
Why a Revolution?

- Much of the revolution is based on using electronic circuits to process *energy*.
- **Power electronics** is the application of electronic circuits to the control and conversion of *electrical energy*.
- This is fundamental to any electrical product.
- It cannot be done with linear circuits.



Principles

- Power electronic circuits use switches.
- A switch controls energy flow without any loss.
- We must find good ways to operate and control switches to convert energy in a desired way.

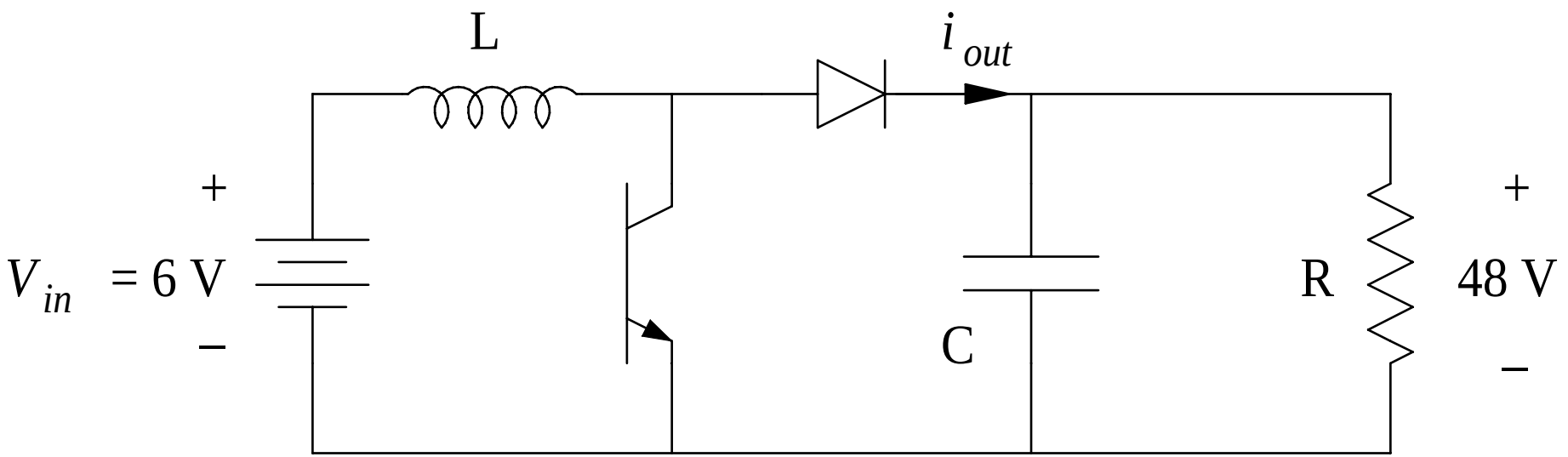


Example

- Many seasoned engineers will tell you the function below is impossible. How can you put in a dc voltage and get a higher one out without power loss?

Example

- The circuit to do this is deceptively simple, but is challenging to analyze and control.
- The semiconductors are used as switches.



R = 38.4Ω

Example

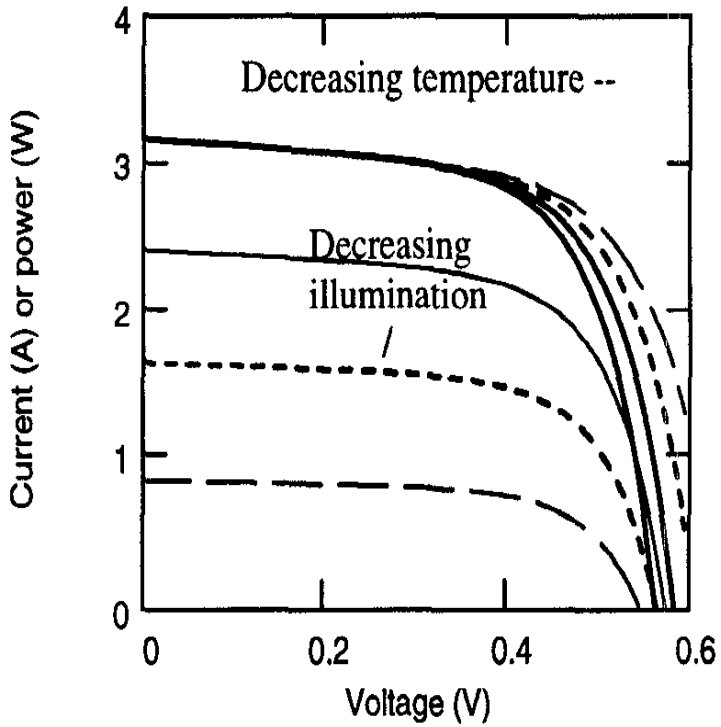
- Good analysis methods for this circuit appeared in the late 1970s, but they were justified only in the 1990s.
- Good controls for it remain a research topic.
- There are still circuits for which good design techniques have not been fully developed.

Space station: the design is dominated by power.

www.nasa.gov

Example

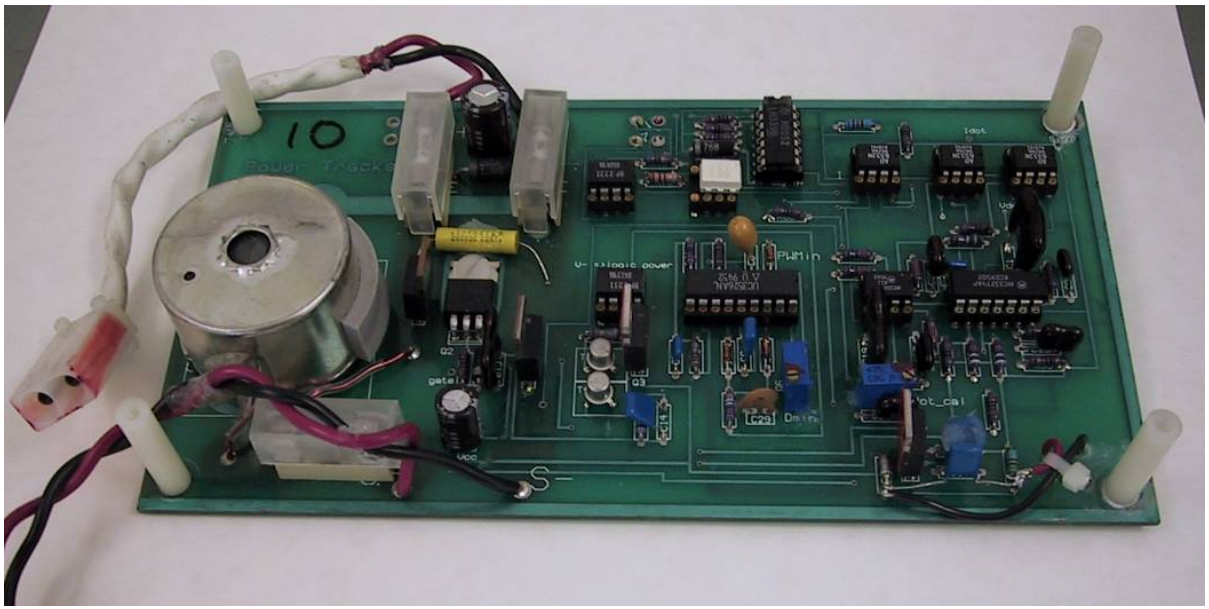
- Deliver maximum energy from a solar panel.
- Track this “maximum power point” as it changes with illumination and temperature.



www.usgaspower.com

Example

- A 100 W converter to draw maximum energy from a solar panel and deliver it to a battery, with control of the battery charge process:



Grand Challenges

- The current energy revolution has power electronics at its heart.
- Within twenty years, nearly *all* electrical energy will be processed through power electronics.
- Power electronics is a critical enabler to deliver electricity from renewable and alternative energy resources.

Grand Challenges

- *Transportation electrification.* It is well established that more electric transportation produces multiple advantages:
  - Fuel flexibility
  - Emissions reduction
  - Efficiency enhancement
  - Performance improvements
- Energy storage remains the key problem: how to store adequate energy on a mobile platform?

Sample Challenges

- Develop “universal power interfaces” that deliver energy from a variety of sources.
- Process power from wind, waves, and the sun.
- Implement fuel cells.
- Enhance the operation and capacity of electricity grids.
- Support fast-changing power needs in the electronics industry.
- Implement hybrid and electric cars.

Source: www.theautochannel.com

Other Challenges

- Make it possible to do just about anything with electrical energy
  - Better lighting
  - More efficient appliances
  - More reliable electronics
  - Miniature consumer products
- Enhance electrical energy safety and reliability

www.energystar.gov

Challenges -- Digital Power

- A sample design challenge:
  - Digital designs are moving to lower voltages to "reduce power" and squeeze dimensions.
  - Near-term example: 1 V power (at 70 W) for microprocessor
  - Longer-term: 0.5 V power, still at 70 W
- How do you deliver 140 A to a chip without burning something up?
- If a conversion circuit includes a diode (they always do) with a 0.7 V drop, then providing 0.5 V power yields at best ~40% efficiency.

Challenges – Digital Power

- It gets worse.
- Whenever an electrical connection is made to something, there is wire involved – and wires have inductance.
- A typical value of inductance is about 5 nH/cm.
- Does that matter?
- Yes, fast changes can induce hundreds of volts, even along just a centimeter of wire.
- Almost impossible to deliver high-performance power at low voltages.

Challenges – Vehicles

- Power electronics is an essential enabler for electric and hybrid cars.
- The electric motor, batteries, extra equipment, and major operating components such as brakes all use power electronics.

Hybrid Electric Vehicles

- A hybrid car combines electric and fuel-driven operation.
- Energy storage in the form of liquid fuel supports long range.
- Batteries are also used.
- Electric drive supports better efficiency and performance.
- Good designs yield about double the fuel economy. The best could triple it.

HEV Emissions

An HEV has at least five characteristics that reduce emissions:

1. The engine is smaller since the electric motor does some of the work, especially during peaks.
2. The engine can shut off when the car stops.
3. We can choose to operate the engine only at its highest efficiency.
4. The electrical system can be used to prepare emission controls for cold starts.
5. Braking energy can be recovered and stored in the batteries.

Challenges – Vehicles

- The designs are recent and immature.
- The target power level for a car is at least 100 kW for the drive. This is equivalent to roughly 200 HP.

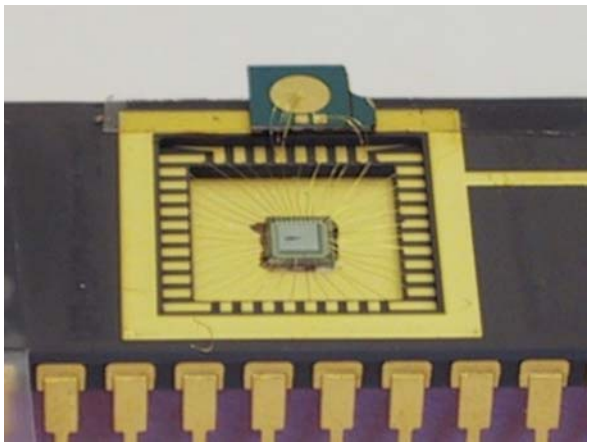
Illinois plug-in hybrid prototype

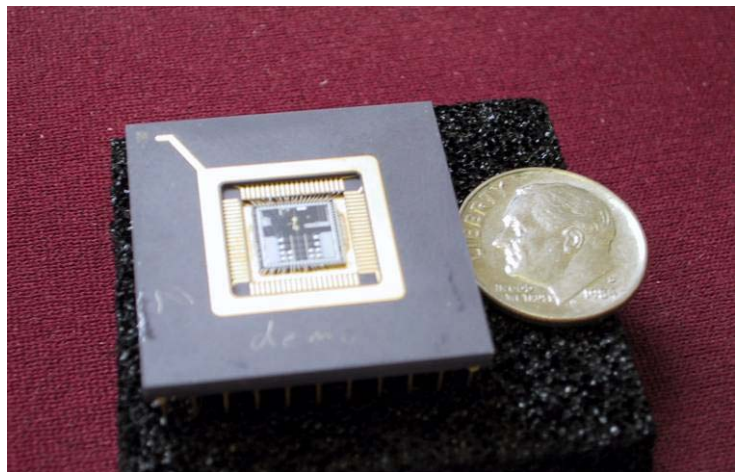
Challenges – Vehicles

- In more conventional cars, power needs are increasing. Current cars use about 1 kW.
- Near-term designs will need up to 5 kW.
- The move may be to a standardized 42 V system, or could jump to much higher levels.
- Why 42 V? The highest voltage below safety limits.

Challenges – Miniature Power

- A sample design challenge:
  - Efficient miniature power for communications and for network nodes.
- Supply just a few milliwatts, with very high efficiency.
- Example: power on a chip.





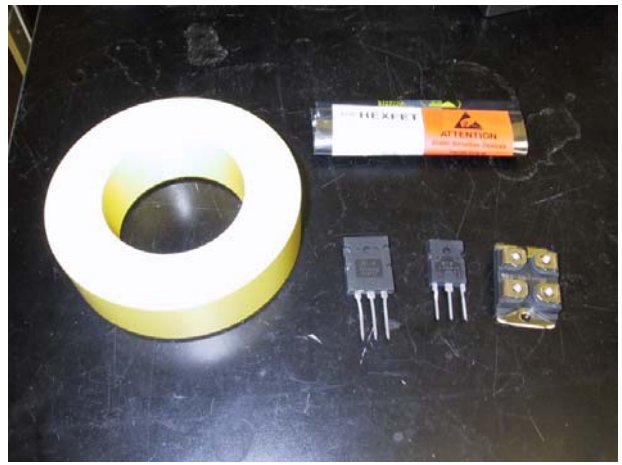
Challenges – Power Supplies

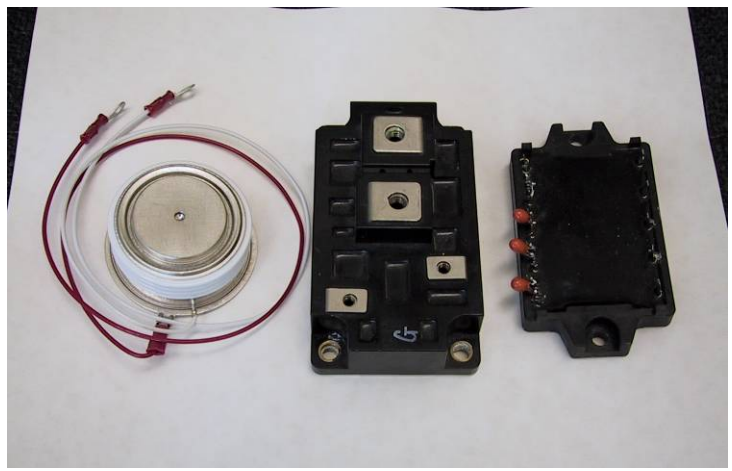
- Reduce the size, weight, and cost.
- Increase the efficiency, reliability, and performance.

- “Power in the plug.”
- Universal power conversion.

Broader Challenges

- Challenges in control, and tools for design.
- There is much basic science yet to be done to unify the field and expand its methodology.
- Challenges in devices:
  - Full-wafer single devices
  - New types of devices intended for energy conversion
  - Compound semiconductors for power switching



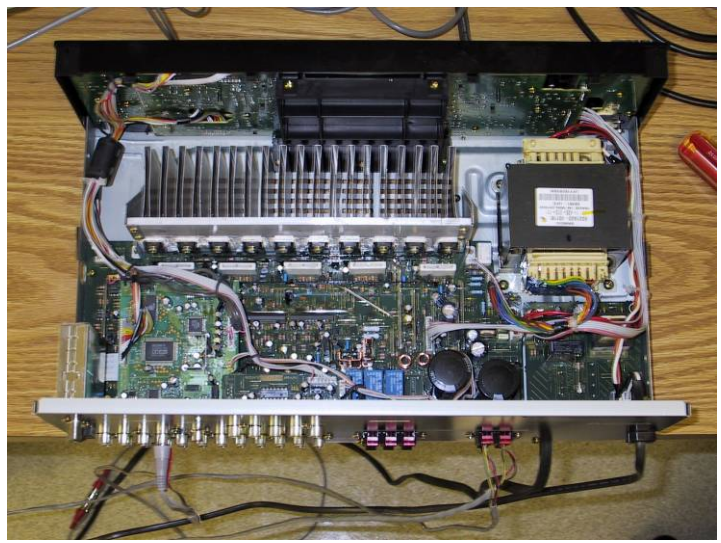


Unusual Devices

- Several widely-sold devices are unique to power electronics.
- About *half* of the discrete semiconductor market.
- Example: the IGBT (insulated gate bipolar transistor).
  - A special voltage-controlled transistor.
  - Optimized for switch applications.
  - Small devices can manage a few kilowatts of power. Large ones reach 100 kW and above.

Advanced Applications

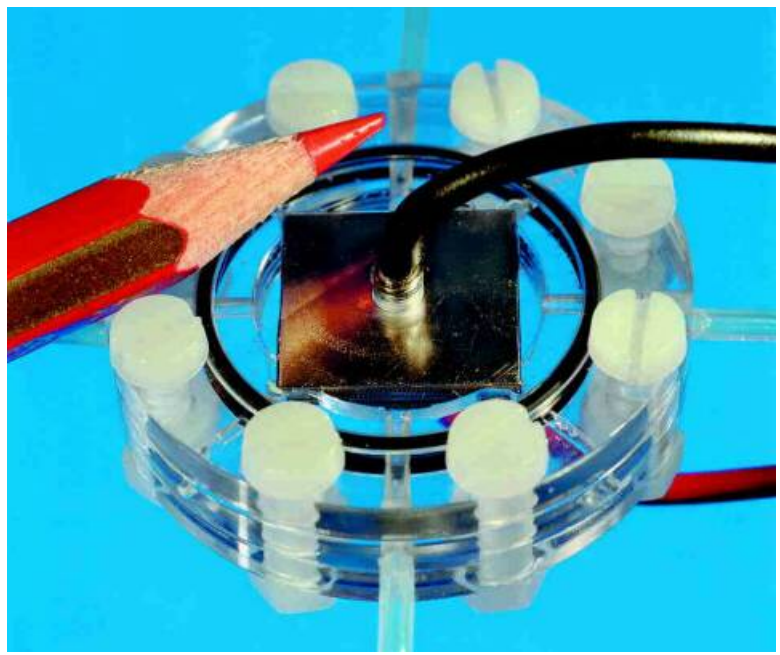
- Switching audio amplification – full fidelity output from a digital music source.
- Direct energy processing to the loudspeaker.
- Efficiency of about 90%.
- Compare to clunky old-fashioned class AB unit.



Fuel Cell Conversion

- Fuel cells have voltage limits, current limits, and rate limits.
- If highest efficiency is paramount, it can take a minute or more to adjust the fuel flow for best operation.
- Electrically, this requires an *energy buffer* so quick electrical loads can be served while waiting for the fuel cell to catch up.

www.fuelcells.org



Conclusion

- An accelerating 21st century revolution is underway.
- The ways we use energy, the ways we produce it, and the ways we process it are changing.

- Energy alternatives and sustainability are the expected outcomes.
- Power electronics is the innovation that drives this revolution.
- The challenges are vast and the issues are growing.