Power Engineering Depth and Integrated Power Electronics Research

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Presented at
ECE Faculty Interview, Oct. 2020

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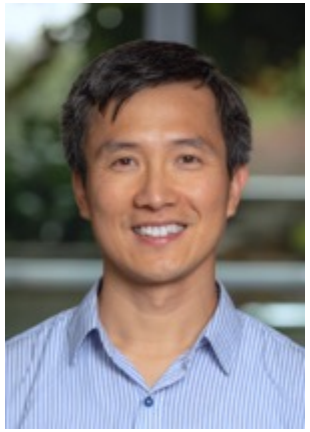


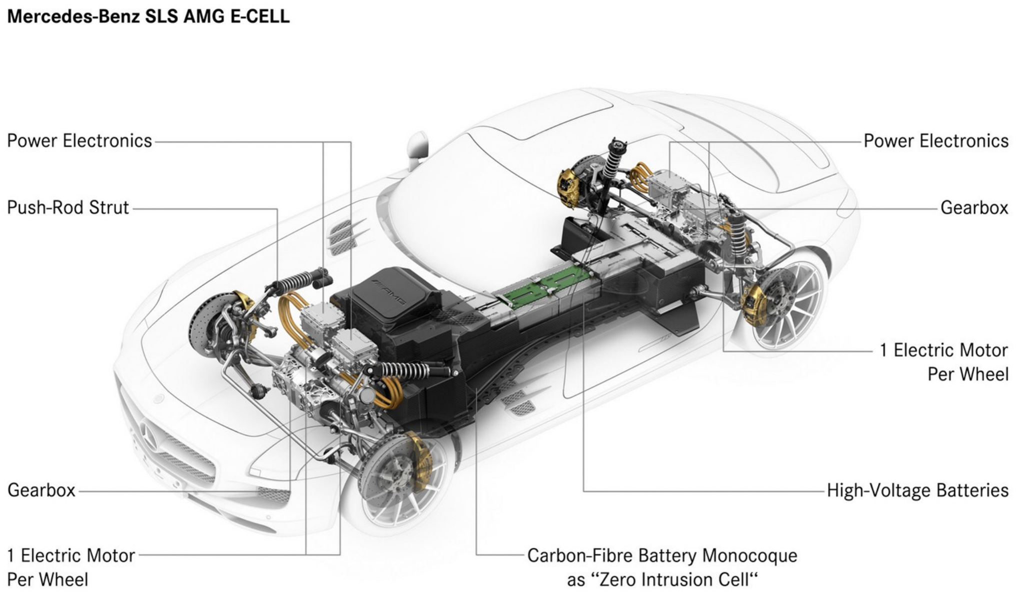
- **Ph.D.** **UC Berkeley, USA** **2013**
- **M.S.** **KAIST, Korea** **2006**
- **B.S.** **HUST, Hanoi, Vietnam** **2003**

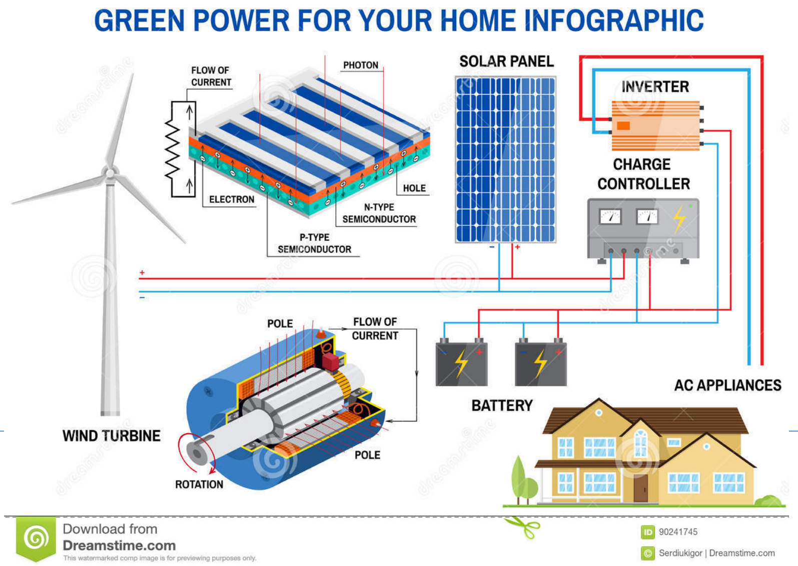
- **Prior experience:**
  - University of Colorado Boulder 2016 – 2019
  - Lion Semi., San Francisco, CA 2012 – 2015
  - Rambus, Sunnyvale, CA 2012
  - Intel, Beaverton, OR 2009
  - Oracle, Santa Clara, CA 2008
  - JDA Tech., Korea 2004 – 2007
  - VAST, Vietnam 2002 – 2004

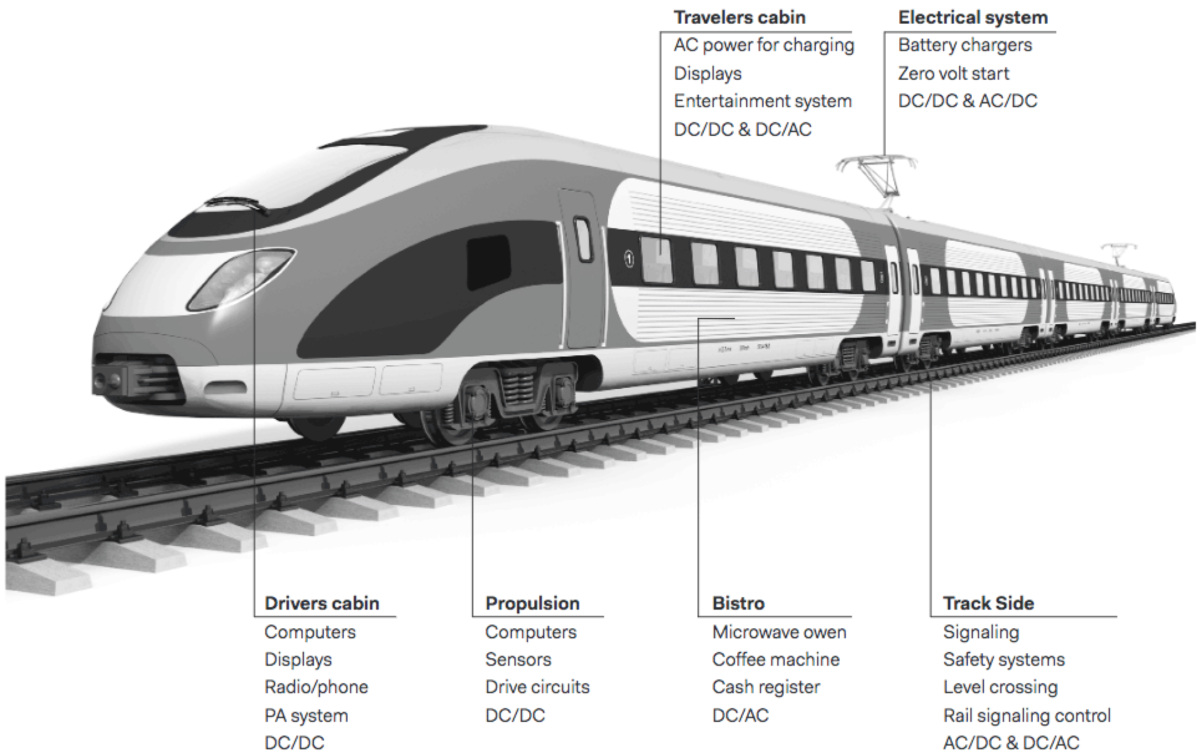
The Need for Power Electronics and Engineering

- Power Electronics and engineering are needed in all electronic devices.

Power Engineering Application

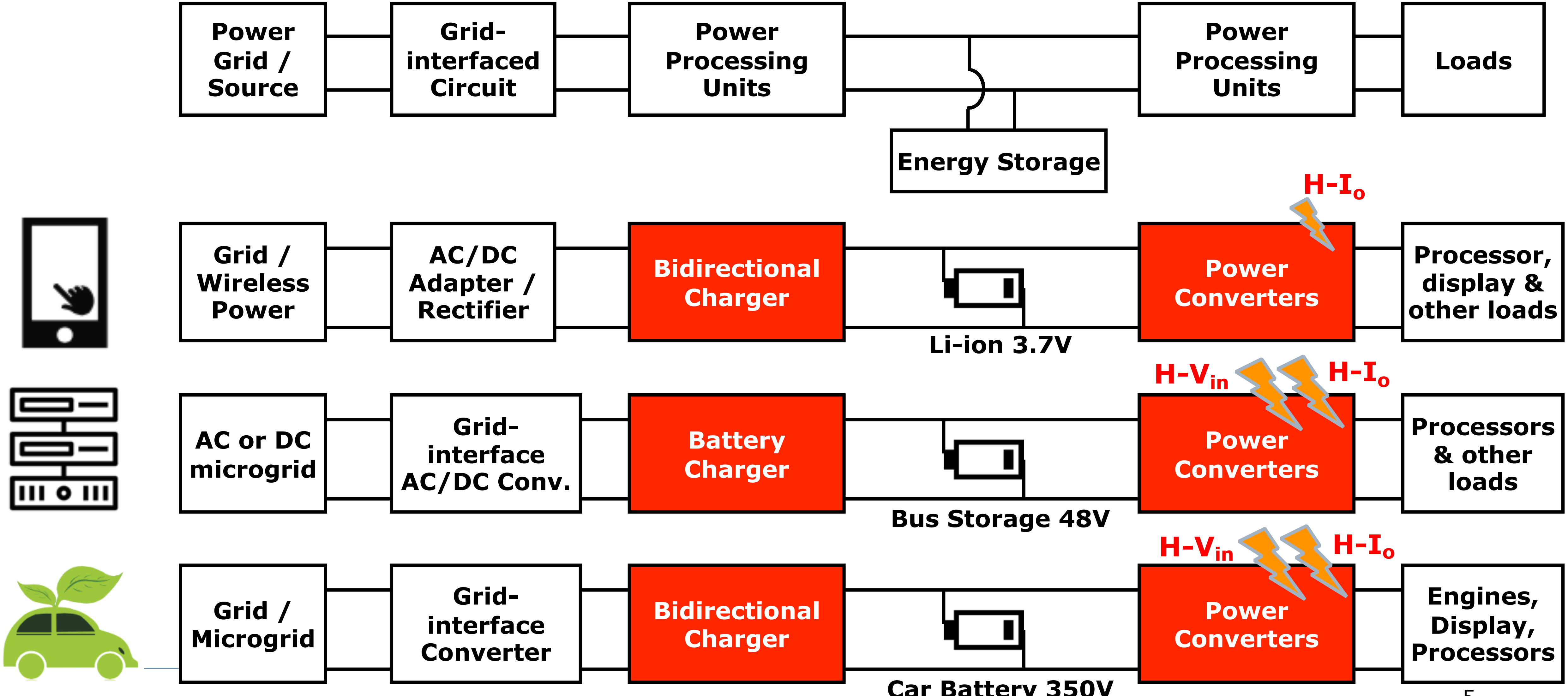




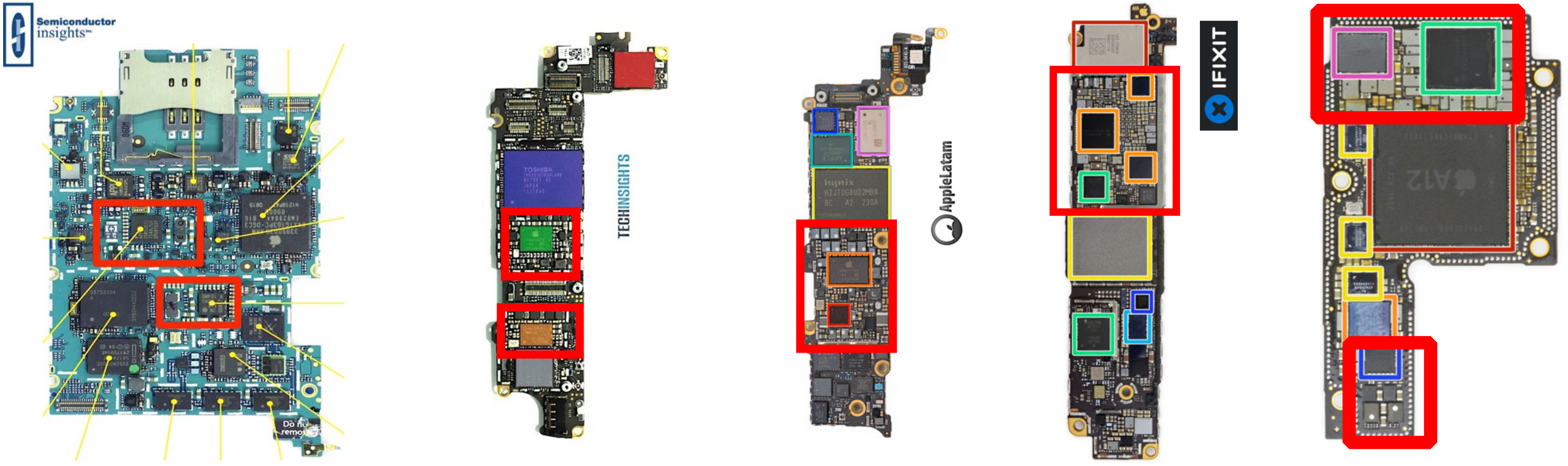


- **No design fits all needs**
  - Power, voltages, currents,
  - Transient response
  - …

Challenge: Increase Voltage for Larger Power



Challenge: Complex Power Management



iPhone 3GS: ~10%

iPhone 4S: 15%

iPhone 5: ~18%

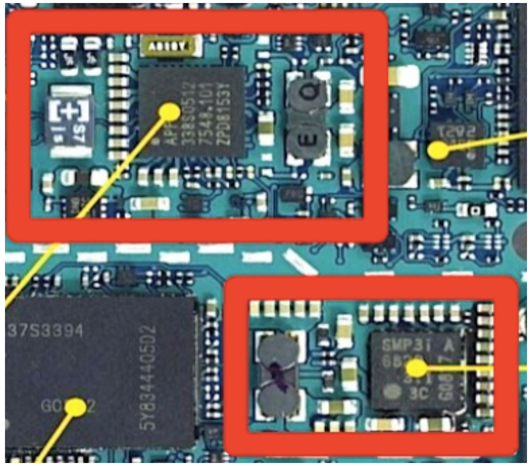
iPhone 8: ~20%

iPhone XS: ~30%

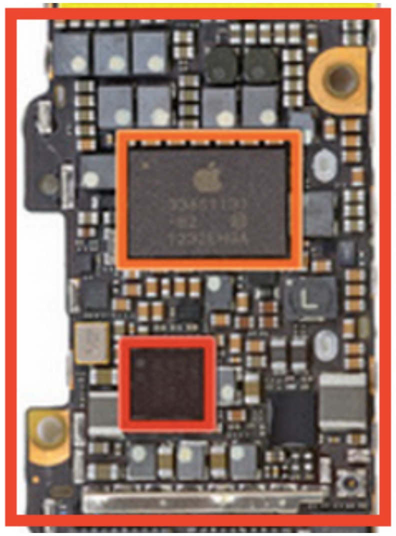
- ☐ **Space for power management keeps increasing!!!**

Discrete Passives Dominate Space

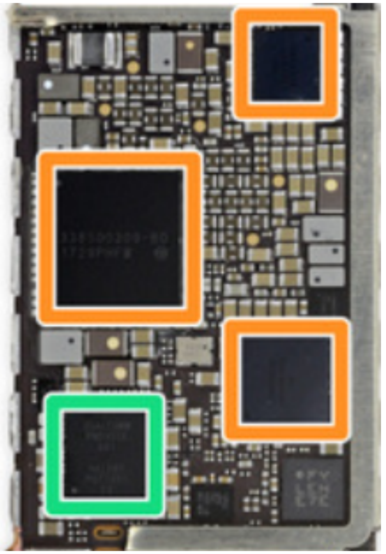
>40 power rails on a smartphone



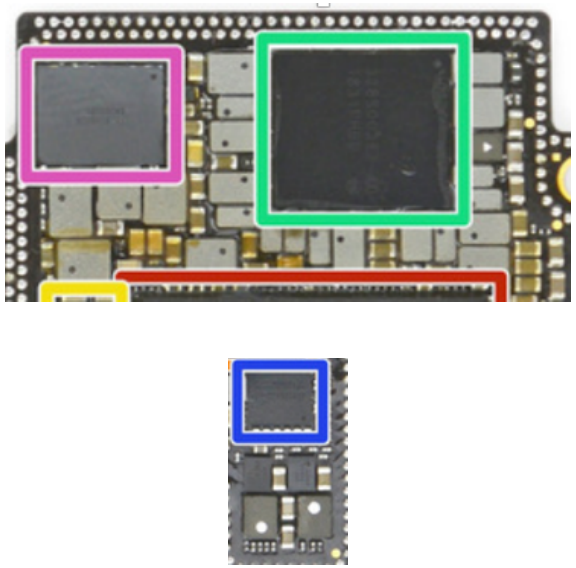
iPhone 3GS:
~10%



iPhone 5:
~18%



iPhone 8:
~20%

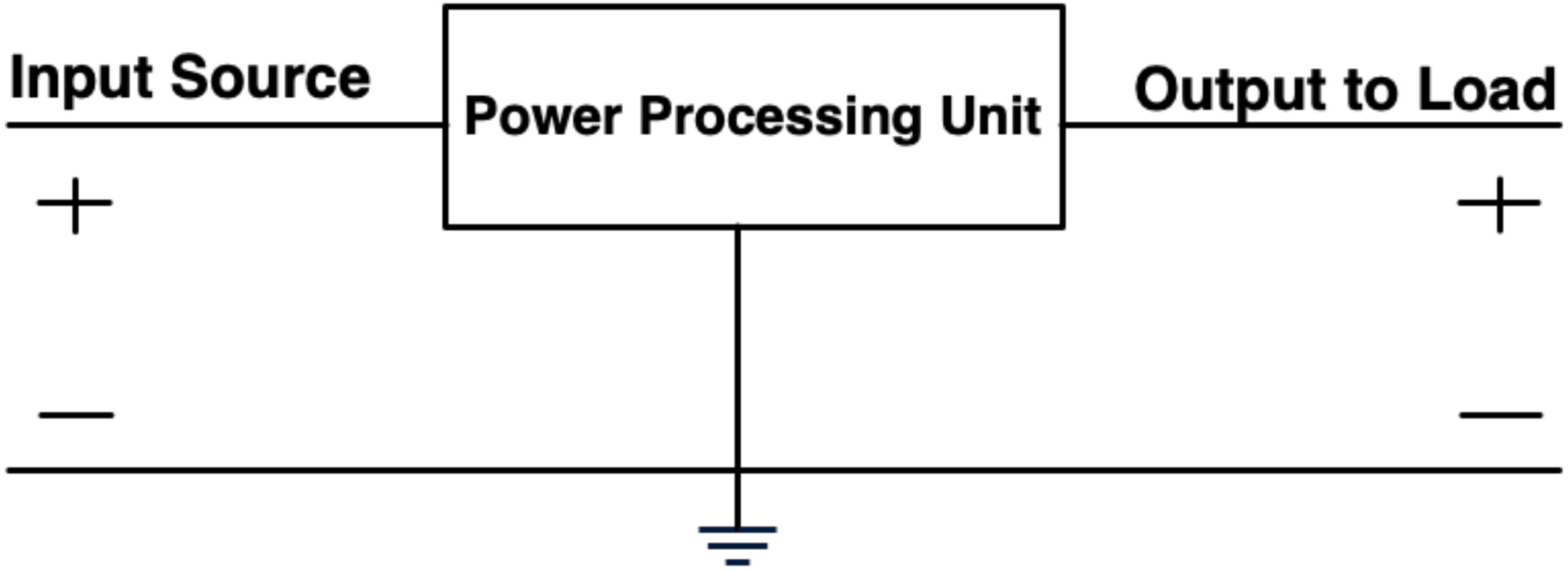


iPhone XS:
~30%

- **No Moore's Law here to help!**
- **This is a common problem in many electronic systems!**

Power Management/Processing Unit

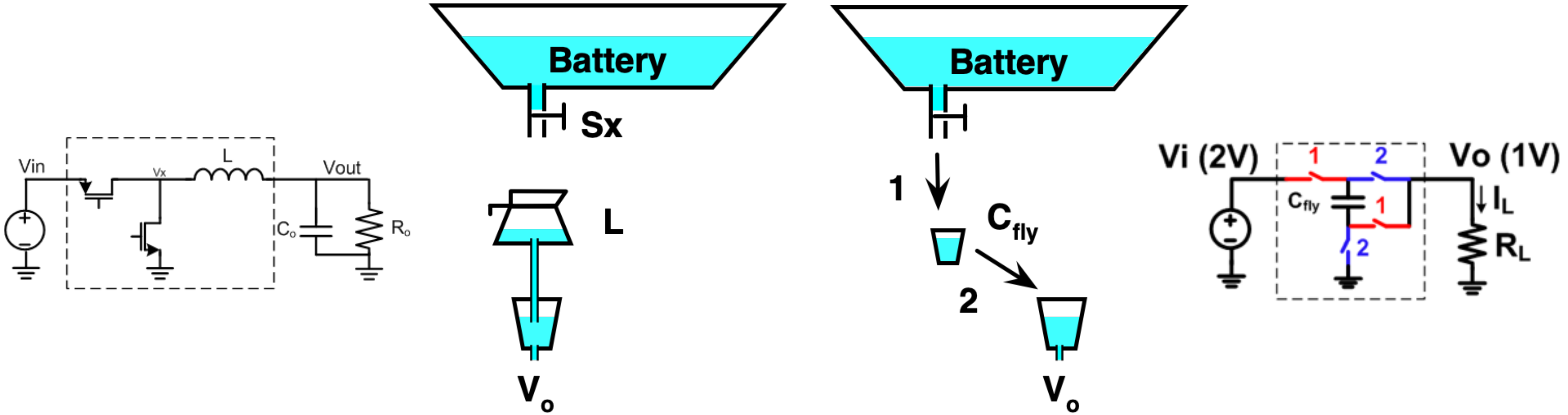
- Battery
- Power adapters
- Etc.



- Display
- Processors
- Sensors
- Etc.

- Provide and manage output voltages and currents

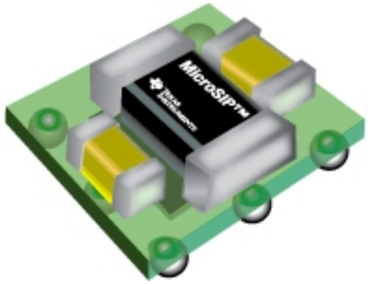
Converter Magic – Switched-Mode Power Supply



- **Switched Inductor (Buck, Boost)**
  - Transfer charge in form of ind. current
- **Switched-Capacitor (SC)**
  - Transfer charge in form of cap. volt. ripple

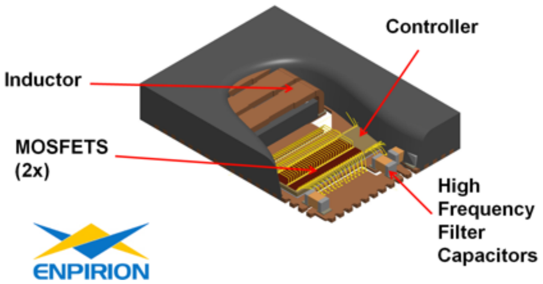
- **While providing more output power, the converter needs to**
  - Minimize operation losses: switching and conduction
  - Minimize discrete components

Switched-Inductor Regulator Products

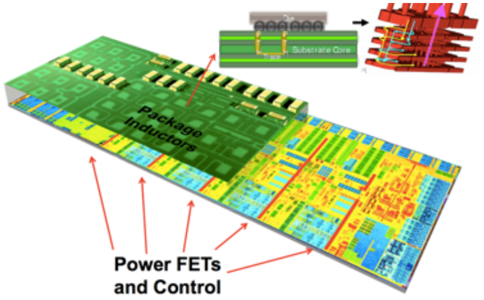


TI uSiP, 2013
2.3x2.9x1mm, 0.09A/mm^2

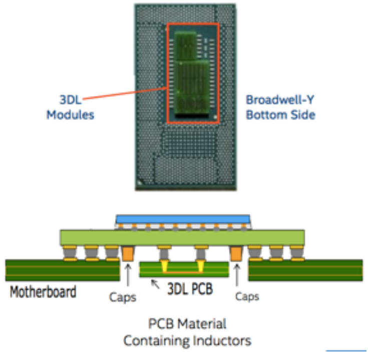
Micrel, 2014
2.5x3x1mm,
0.13A/mm^2



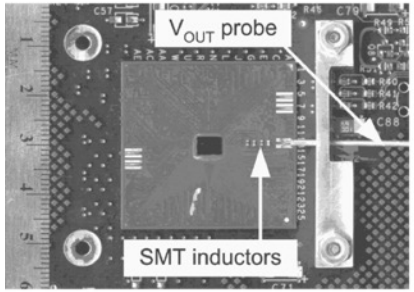
Enpirion, 2014 8x11x3mm,
0.09A/mm^2



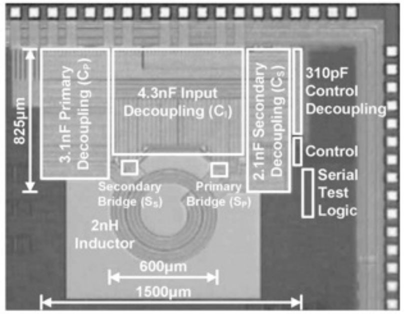
Intel Haswell, 2013
- Co-int. switches
- Package inductors



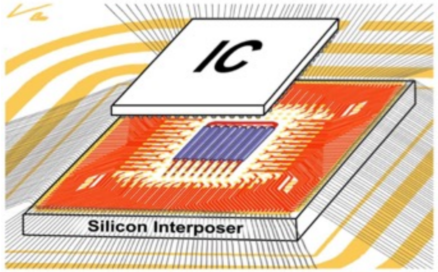
Intel Broadwell, 2014
- Inductors on 3DL PCB



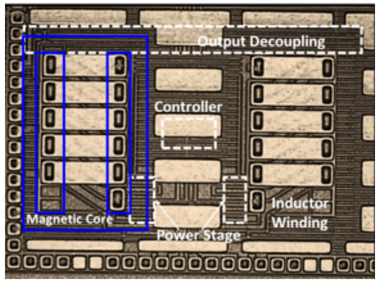
Intel, 2005
0.33A/mm^2, 83.2%,
233MHz



U. Minnesota, 2008
0.2A/mm^2, <80%,
170MHz

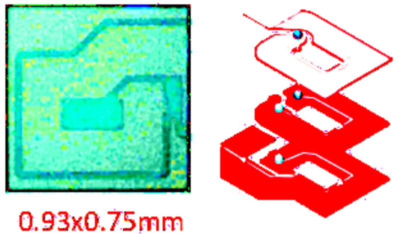


U. Columbia, 2013
3.21A/mm^2, low 70s%
125-200MHz



Intel, 2017
- 1.5nH, 100MHz
- On-die, solenoid, planar inductor

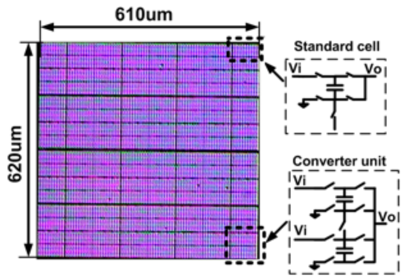
3D model



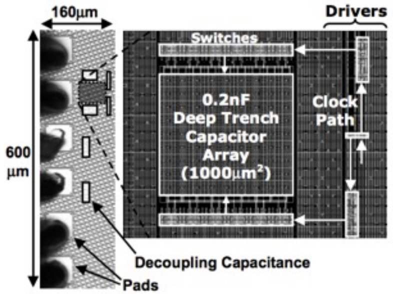
0.93x0.75mm

Intel, 2019
- Air-core, in-package
- 100MHz

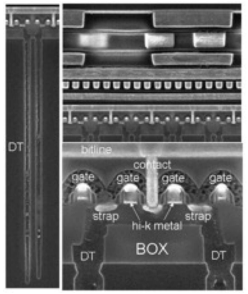
Switched-Capacitor Converter Products



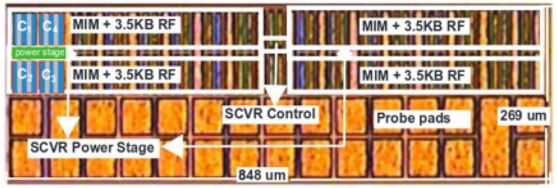
UC Berkeley, 2010
0.9A/mm², ~81%,
MOS, 32nm



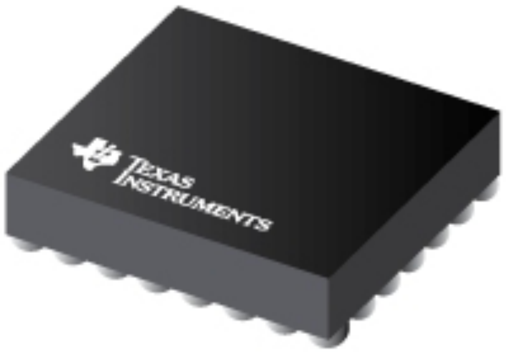
IBM, 2010
2.3A/mm², ~88%,
deep trench, 45nm



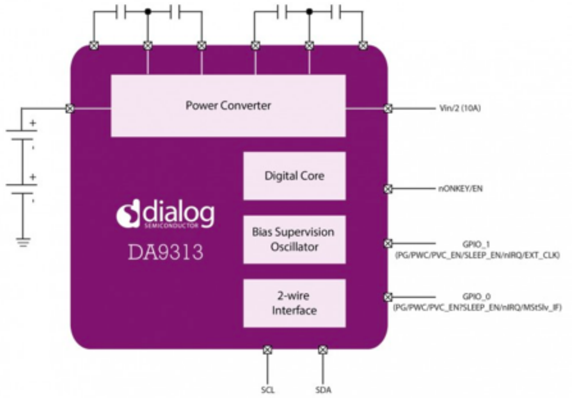
ETHZ, 2012, 2014
~4.6A/mm², 86%,
deep trench, 45nm



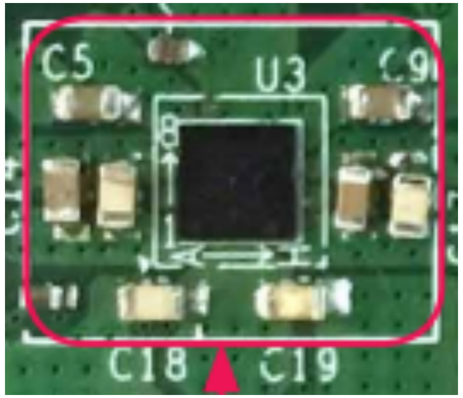
Intel, 2013
0.88A/mm², ~84%,
MIM, 22nm



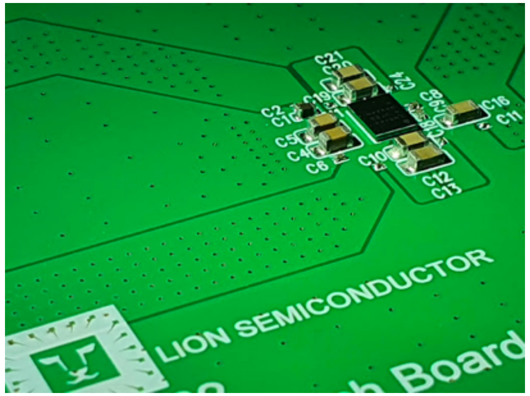
TI, BQ25971
8A 2-1 SC Battery Charger



Dialog, DA9313
10A 2-1 SC Battery Charger

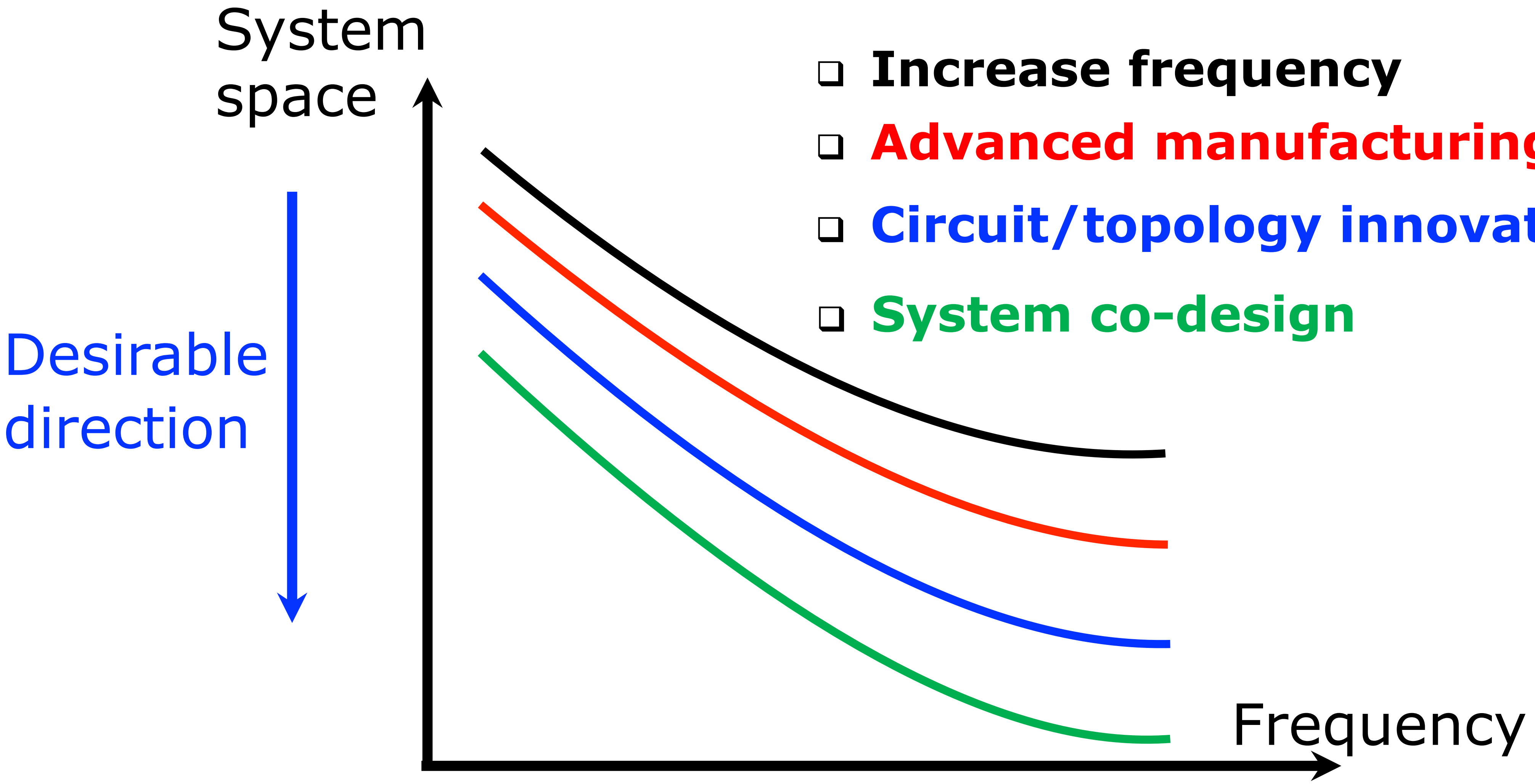


NXP, PCA9468
2-1 SC Charger, ~98%



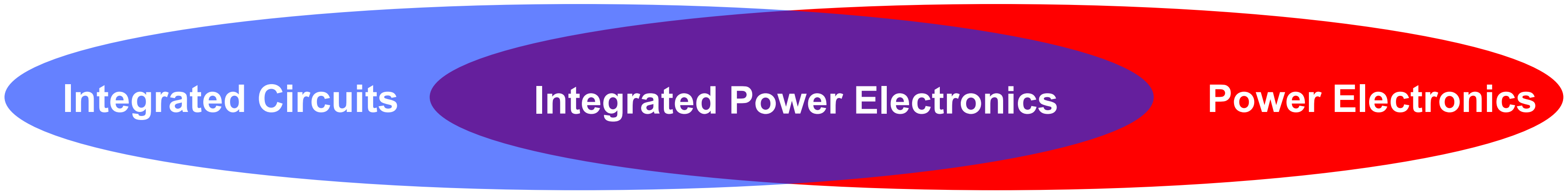
LionSemi, LN8282
2-1 SC Charger, >98%

Miniaturization with iPower



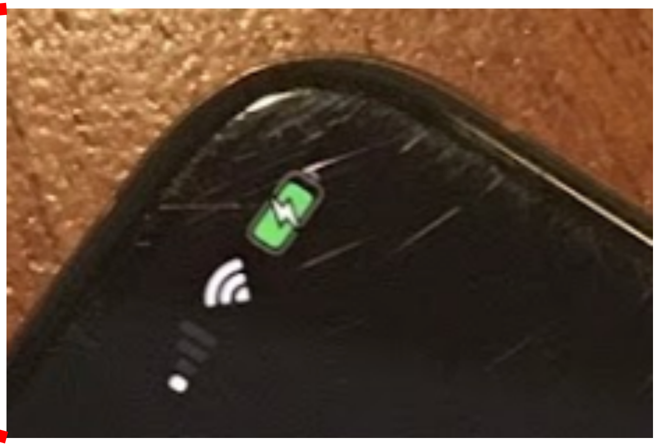
- Increase frequency
- Advanced manufacturing
- Circuit/topology innovations
- System co-design

Problems to Work On



- **Better integrated converter topologies and technologies**
- **Efficient operations while transferring and managing power**
- **Wide-bandgap transistors (Gallium Nitride, GaN)**
- **Hard problems to work on today:**
  - High conversion ratio
  - High current density
  - Fast transient response

SC Converter For Wireless Battery Charger



- **Apple iPhone 11 being wirelessly charged by Mi9 Pro 5G**
  - Enabled by Lion Semiconductor's SC converter technology

UCSD ECE

Power Engineering Depth

Current Courses on Power Engineering

- ECE 121A: Power Systems Analysis and Fundamentals (ECE 35)
- ECE 121B: Power Systems Analysis and Fundamentals (ECE 121A)
- ECE 124: Motor Drives (ECE121B, ECE125A)
- ECE 125A: Introduction to Power Electronics I (ECE 121A)
- ECE 125B: Introduction to Power Electronics I (ECE 125A)
- ECE 128A: Real World Power Grid Operation
- ECE 128B: Power Grid Modernization (ECE 35 and ECE 128A)
- ECE 128C: Power Grid Resiliency to Adverse Effects (ECE 128B)
- ECE 129: Renewable and Energy Storage Resources (ECE 35)

Power Engineering Courses

Graduates with a desire to work in fields of renewable energy including solar and wind, electric and hybrid electric vehicles, electric trains, hybrid and electric airplane and submarines!, power supplies and UPS systems, pulsed power, and power systems need to have a good understanding of power converters and electric machines as well as strategies suitable for controlling them. Currently there is a very high demand for the power electronics engineers and is expected to grow very quickly in the near future. Just check companies like Tesla, Apple, General Motors, General Atomics, Raytheon, and Boeing …

Power electronics and motor drives depth covers five courses, power system analysis (ECE121A), energy conversion (ECE121B), power electronics I&II (ECE125A&B), and introduction to motor drives (ECE124). Also ECE171A-Linear Control System Theory, is strongly recommend to be taken by students interested in power depth. All the power depth courses come with Lab and projects to be simulated with advanced power electronics software! Finally, power engineer means an electrical engineer who can actually get something to work! To make the bridge between knowing and doing!

ECE121A-Power System Analysis

This course introduces concepts of large-scale power system analysis: balanced three-phase systems, single-phase and three-phase transformers, per unit system and single line diagram, transmission line modeling, and power flow study. It provides the fundamentals for advanced courses and engineering practice on electric power systems, power electronics, electric machinery, smart grid, and electricity economics.

ECE121B-Energy Conversion

AC and DC machines are widely used in many modern energy conversion applications, including propulsion for hybrid-electric vehicles, power system grid, distribution system, industrial companies, electric vehicles, wind energy generation, and flywheel energy storage systems. Because of flexibility of controls offered by modern power electronic circuits, interest in electric machines is steadily increasing. Principles of electro-mechanical energy conversion, fundamental concepts of magnetic circuits, and the steady-state performance of direct current, induction, and synchronous machines will be discussed in this course.

Power Engineering Courses

ECE125A-Power Electronics I

Power electronic circuits provide the means for efficient control and conversion of electric power through the use of solid-state switches. Applications of power electronics include switch mode power supplies, DC/DC and DC/AC converters, electric and hybrid electric drives, high voltage DC networks (HVDC), and renewable and hybrid generating systems among many others. This course provides a conceptual foundation for the analysis and design of power electronic circuits, covering principals of operation of AC/DC and DC/DC converters. Also, thermal design and protection of the power converters will be covered in this course.

ECE125B-Power Electronics II

Design and control of dc-dc converters, PWM rectifiers, single-phase and three-phase inverters, power management, and power electronics applications in renewable energy systems, motion control, and lighting will be presented. The intent of this course is to provide an adequate education for senior and graduate students on high-frequency power converters. Synthesis and analysis techniques will be developed through the study. Applications and advances of the high-frequency switching power converter in renewable energy and electric vehicles will be presented.

ECE124-Introduction to Motor Drives

Control of AC and DC motors has been a work in progress for the past century. Recent rapid advances in power electronics control and power switches has made it much easier to control the motors with much higher quality at much lower cost. Traditional industrial motor drives, EVs, HEVs, and wind energy are a few applications of the variable motor drives. Motor drive course provides control technique such as vector control and direct torque control (DTC) of the induction machines. Moreover, this course introduces different control method for direct current motors using different type of power converters, such as DC-DC and AC-DC converters.

ECE 121A – Power Systems Analysis and Fundamentals

Topics Covered

- Introduction to power system and energy conversion
- 3-phase AC circuit analysis
- Single-phase transformers
- Three-phase transformers
- Design and modeling of transmission lines
- Power system modeling and single-line diagram
- DC & AC power flow control

Lab Outline

- Lab 1: Pre-Lab simulation software
- Lab 2: Y-Δ Connections, 3-phase source, 3-phase inductive and capacitive loads
- Lab 3: Power factor correction in three-phase system
- Lab 4: Measurement of single-phase transformer parameters and its equivalent circuit
- Lab 5: Voltage regulation and transformer characteristic under load condition

ECE 121B – Energy Conversion

Topics Covered

- Introduction to energy conversion
- Basic of magnetic circuits
- Modeling and operation of DC motors and Generators
- Steady-state analysis of three-phase induction motors
- Steady-state analysis of synchronous machines

Lab Outline

- Lab 1: Pre-Lab simulation software
- Lab 2: Characteristic of DC generators
- Lab 3: Characteristic of DC motors
- Lab 4: Rotor locked and no load test of induction motors and its equivalent circuit
- Lab 5: Torque characteristic and speed control
- Lab 6: Measurement of synchronous machine circuit parameters

ECE 125A – Power Electronics I

- **Topics Covered**
  - Overview of power semiconductor devices and characteristics
  - Diode (Uncontrolled) rectifiers
  - Controlled AC-DC rectifiers
  - Non-Isolated DC-DC converters
  - Isolated DC-DC converters
  - Power loss calculation and thermal considerations
  - Snubber circuits
- **Lab Outline**
  - Lab 1: Pre-Lab simulation software
  - Lab 2: Half-wave single-phase diode rectifiers with R, RL, and LC Loads
  - Lab 3: Full-wave single-phase diode rectifiers with R, RL, and LC Loads
  - Lab 4: Full-wave three phase diode rectifiers with R, RL, and LC Loads
  - Lab 5: Buck converter CCM and DCM operations
  - Lab 6: Boost converter CCM and DCM operations
  - Lab 7: Buck-Boost converter CCM and DCM operations

ECE 125B – Power Electronics II

- **Topics Covered**
  - State-space modeling of DC/DC converters
  - Single-phase and three-phase inverters
  - PWM switching techniques for DC/AC inverters
  - Closed loop control of power converters
  - Grid interface and control of solar panels
  - Applications of power electronics in power & energy
  - Soft switching and resonant converters
- **Lab Outline**
  - Lab 1 & 2: Closed loop modeling of DC-DC Converters
  - Project 1: Modeling of 6-step 3-phase inverter under inductive, unity power factor, and capacitive conditions
  - Project 2: Implement Sine-PWM & SVM switching patterns under Inductive, Resistive, and capacitive conditions
  - Project 3: Design and modeling Closed-Loop control system for grid-tied operation
  - Project 4: Implement MPPT for Solar panels connected to grid through 3-Phase inverter
  - Presentation: Each group will present all the projects combined in one presentation at the end of quarter

ECE 124 – Introduction to Motor Drives

- **Topics Covered**
  - Describe the operation of DC motor drives to satisfy four-quadrant operation to meet mechanical load requirements.
  - Design torque, speed and position controller of DC motor drives.
  - Describe the operation of induction machines in steady state that allows them to be controlled in induction-motor drives.
  - Learn speed control of induction motor drives in an energy efficient manner using power electronics.

- **Lab Outline**
  - Project 1: Modeling of H-Bridge Converter with RLE load and design current and voltage loops using different control techniques
  - Project 2: Control design and modeling of speed and torque control of separately excited DC motors
  - Project 3: Design and modeling of full-bridge controlled rectifier and implement field weakening control of DC motor above base speed
  - Project 4: Open-loop and closed-loop control of induction motors using 3-Phase PWM converters and constant V/f control method
  - Presentation: Each group will present all the projects combined in one presentation at the end of quarter

ECE 128A – Real World Power Grid Operation

Description

This course provides practical insights into the operation of the power grid. It will cover the same subjects, and depth, that actual power system operators' certification course covers. It systematically describes the vital grid operator's functions, the processes required to operate the system, and the enabling technology solutions deployed to facilitate the processes. The course uses actual case histories, and real examples of best in-class approaches from across the nation and the globe. It presents the problems encountered by operators and the enabling solutions to remedy them. Industry tools will be provided to the students.

Opportunities for the Students

ECE graduates with aspirations of working in the power systems field will find this course extremely beneficial as it tackles real operational situations and solutions that cannot be found elsewhere. The demand for engineering graduates, at utility companies and companies that cater to them, such as consulting firms, equipment suppliers and system integrators, has increased by many folds over the last few years. Students who take this course, with its real-life examples and solutions in the operational aspects of the power grid, will have a clear advantage in seeking these new job opportunities.

Course Purpose

The aim of this course is to increase the understanding of the dynamic phenomena in the power systems by providing practical insights into the operation of the power grid and the vital grid operator's functions and actions. The core materials are supplemented by real-world examples. It will also include details of power outages that affected millions of people in which the instructor acted as the principal investigator. The core materials of this course have been approved for system operator's education and certification. It includes a review of power system fundamentals, followed by chapters on active and reactive power flow, frequency and voltage stability.

Course Coverage

- Introduction of power systems operations and fundamentals
- Utility and independent system operators (ISO's) control rooms
- Power system equipment in generation, transmission, distribution and substations
- Real power and reactive power deficits ion the grid
- Grid frequency control
- Voltage and angle issues and remedies
- Grid oscillations
- Major disturbances and blackouts
- Geomagnetic disturbances
- Case studies on all the above
- Governing Standards

ECE 128B – Power Grid Modernization

Description

This course provides an in-depth coverage of the future power grids spanning form: power generation through the power delivery systems down to the end-user. It covers the practical aspects of the technologies, their design and system implementation. Topics include: the changing nature of transmission and distribution systems with renewable resources; intelligent grid applications; smart meters; phasor measurement units; advanced metering infrastructure; microgrids distributed energy resources and the information and communications infrastructures needed. It uses actual examples along lessons learned and best practices. Industry tools will be provided to the students.

Opportunities for the Students

All electrical utilities are modernizing their grids, albeit at different stages in this process, and are looking for graduate engineers with background in smart grid applications. Our graduates, who take this course and its sister course, Renewable and Energy Storage Resources Course, and the other power courses that ECE is offering, will be very desirable to hire in power systems jobs at utility companies, smart equipment vendors and consulting firms. Students who took this course have landed very exciting jobs in the power field.

Course Purpose

This objective of this course is to detail the areas that different utilities (large and small) are pursuing to modernize their grids and how they integrating these with their information/communications systems. It will give the student a commanding knowledge of intelligent new devices and systems that are being installed into the different parts of the grid (generation, transmission and distribution systems) as well as on the customer side. The course materials will be reinforced with unique and powerful tools and projects to enhance the hands-on experience of the student in this field.

Course Coverage

- Conventional and emerging transmission and distribution systems
- Flexible AC transmission systems (FACTS) and High Voltage Direct Current Systems (HVDC) and their use in the new transmission systems
- Phasor measurement units (PMU)
- Distribution Automation
- Fault Location Isolation and Restoration Service (FLISR) and voltage control
- Microgrids
- Smart meters
- Advanced Metering Infrastructure (AMI) and its supporting systems
- Examples from real applications
- Governing Standards

ECE 128C – Power Grid Resiliency to Adverse Effects

Description

This course offers unique insight and practical answers, through actual examples, of how power systems are affected by extreme weather and wildfires, and the countermeasures to mitigate them to make the system more resilient. It presents lessons learned from previous extreme events. It covers topics not found in any references, textbooks, courses or technical papers. This course will expose the student to many proven practices for successful restoration of the power grid, increased system resiliency, and ride-through after extreme weather, providing examples from around the globe. The students will be provided with tools for assessing the vulnerability and resilience of the grid.

Opportunities for the Students

System resiliency is the number one concern for electrical utilities according as the vast majority of all customer electric outages are triggered by natural events. The students of this course will learn how to make the power grid more resilient to the effect of extreme events. They will learn best practices that utilities are taking or should be implementing to achieve higher levels of resiliency. As this course is the only course given on the subject nationwide, our graduates will have a unique advantage over students from other universities in this very important aspect for the utilities and system operators.

Course Purpose

The objectives of this course is to provide expert knowledge into how current equipment designs are being increasingly challenged by natural conditions and events. The course not only captures the operational impacts of extreme conditions, such as power failures, but also examines longer-term effects on the electrical equipment and systems, including accelerated aging of equipment. It gives a rich set of ideas for improving power system resilience, backed by sound engineering, science and historical lessons.

Course Coverage

- Effects of heat waves on thermo-electric generators, electric loads, etc.
- Effects of droughts on power generation, transmission systems and distribution equipment
- Failure of distribution transformers and underground cables due to heat waves and droughts
- Effect of heavy precipitation on equipment withstand
- Effect of high winds on power towers and poles
- Structural hardening
- Grid resilience
- Case histories from around the globe
- Countermeasures and remedies
- Governing Standards

ECE 129 – Renewable and Energy Storage Resources

Description

This course will provide students with the theoretical and practical knowledge of renewable energy resources and energy storage systems. It provides a solid foundation on hydroelectric, solar (both photovoltaic and concentrating solar, wind, geothermal, wave and tidal sources. It covers energy storage systems of all kinds, present and emerging. The course will present lessons learned from actual systems and results of detailed studies on the applications (technical and economic viability) of renewable energy resources and energy storage systems. The students will also be provided with a number of industry tools to assess renewable energy sources and energy storage systems.

Opportunities for the Students

As all electrical utilities (and increasingly number of their customers) are now progressively using more renewable energies and energy storage, they are constantly looking for new hires with solid backgrounds in these fields. Our students, who take this course, as well its sister course, Grid Modernization Course, and the other power courses that ECE is offering, will have a clear edge over graduates from other universities. This has been proven by our recent graduates who landed great jobs within the power industry. Jobs that would have been out of reach to our students before.

Course Purpose

The purpose of this course is to provide students with the needed solid theoretical background and practical knowledge for mastering the different aspects of renewable energy sources and energy storage systems . The approach of the course is designed around real applications of these systems on the power transmission/distribution systems as well as within the customer premises. All that is reinforced with tools to enhance the hands-on experience of the student in this field.

Course Coverage

- Introduction to Renewable Energy And Energy Storage On The Grid – And Review Of Fundamentals
- Hydroelectric Power (large, medium, small, micro and pico hydroelectric plants)
- Wind Energy
- Solar – Photovoltaics (PV) Power
- Solar – Concentrating Solar Power Plants (CSP)
- Wave and Tidal Power
- Geothermal Energy
- Biomass Energy
- Energy Storage: Types, Applications As Enablers For More Renewables Resources
- Integration distributed energy resources and energy storage into the grid (benefits and concerns)
- Standards