Title

Power Electronics to Reinvent the LED Lighting System

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Power Electronics to Reinvent the LED Lighting System

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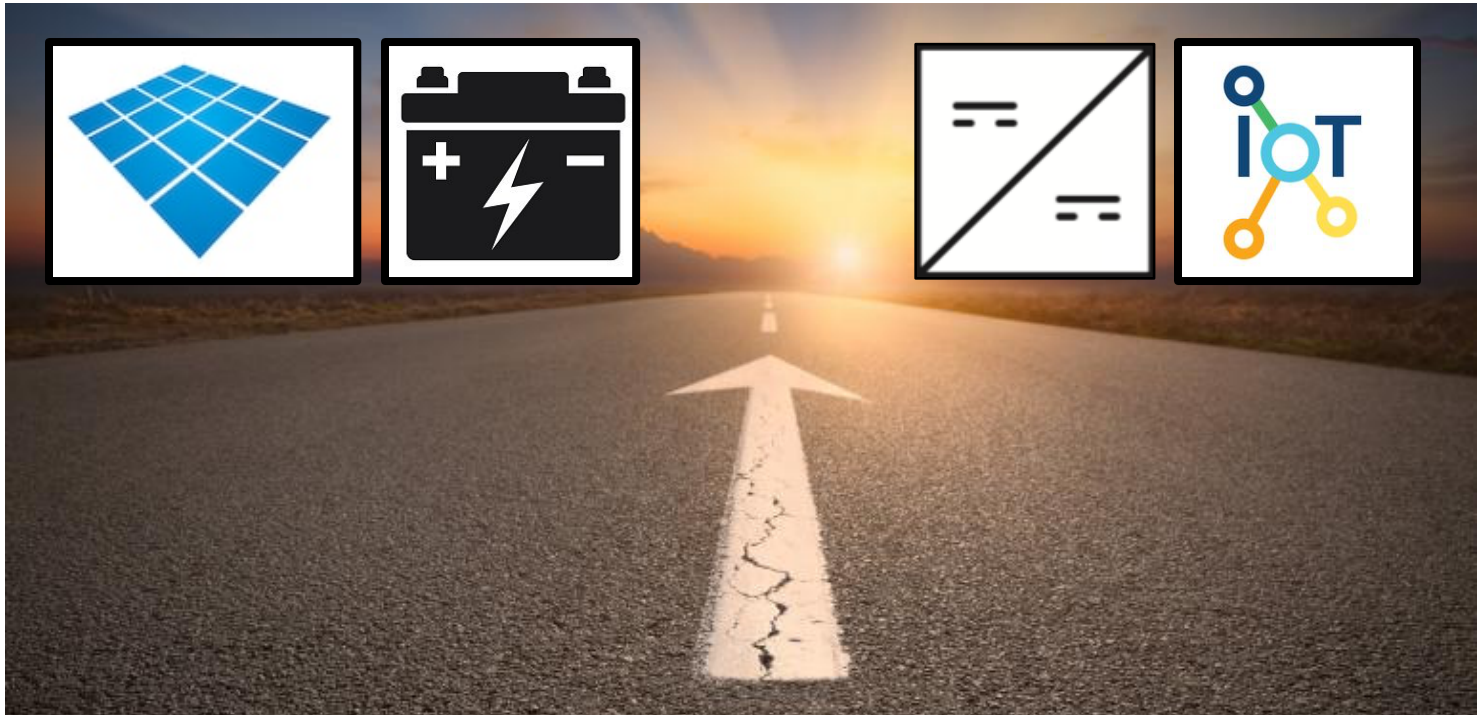
The Building Electricity Revolution

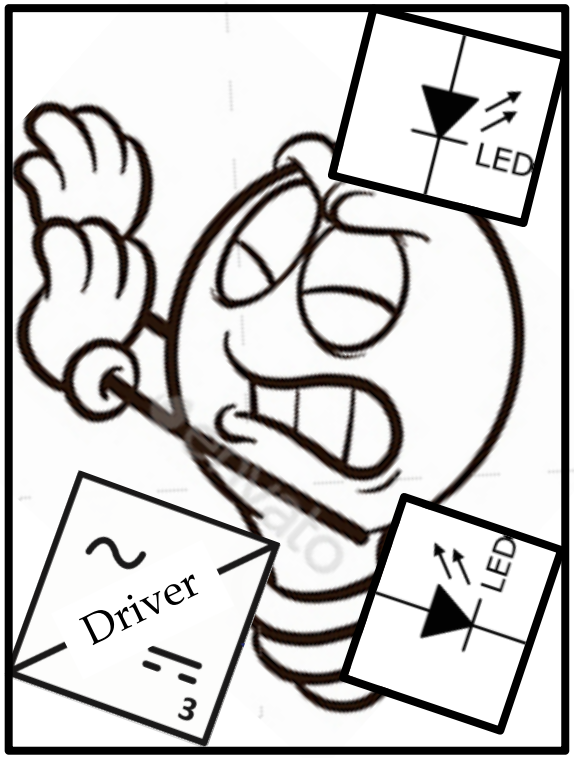


- New building technology on the horizon: Solar, storage, DC power, IOT
- Building power distribution is set to undergo one of the most drastic transformations since the dawn of electricity

Problems in the Lighting Industry

- Not very concerned with what may be profitable in 10 years
- Too focused on incremental device-level improvements
- Doesn't think outside the "integration" box

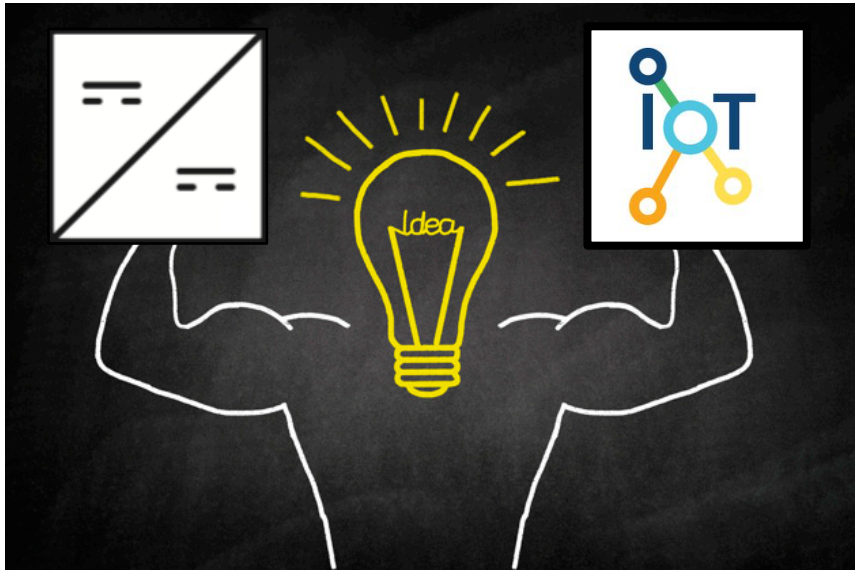
- Role of the lab: guide industry and influence standards
- Scientific question: How can we improve lighting systems to adapt and benefit from new building technology?



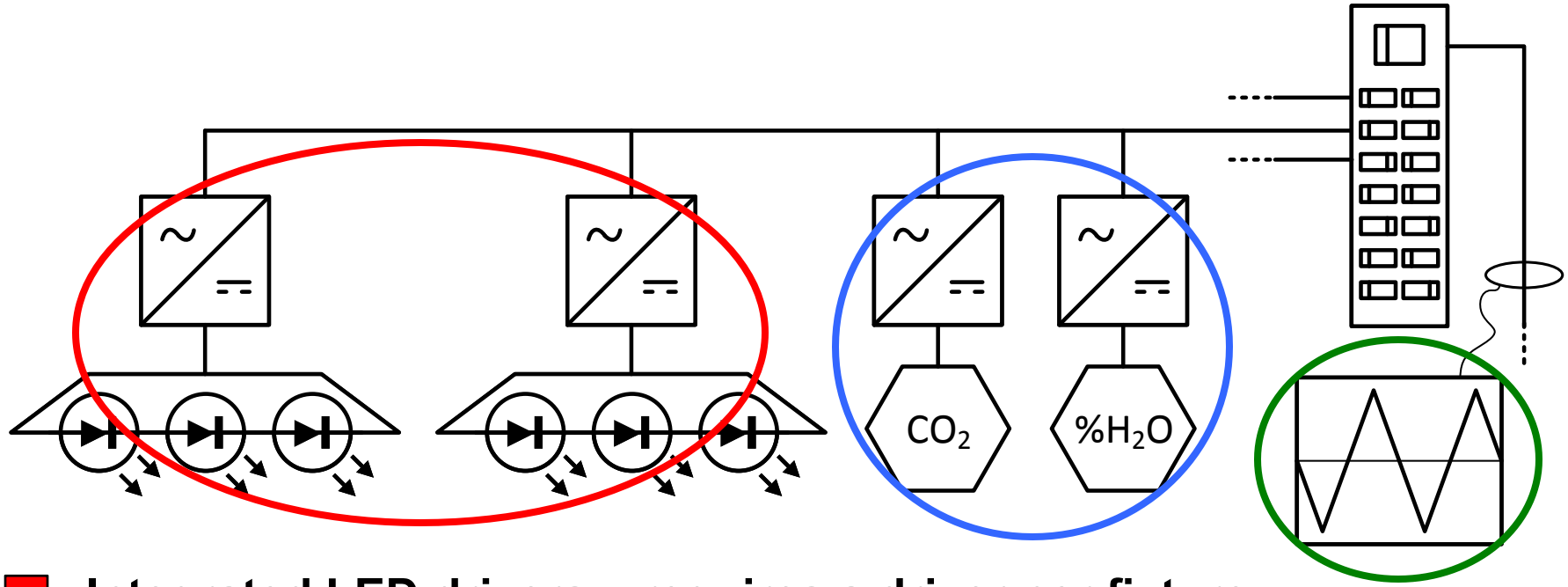
The Integration Box

Proposal

- We propose a new lighting system architecture that improves performance and enables the adoption of new technology (IOT, DC)
- Hypothesis: These design ideas will allow HUGE improvements on **efficiency**, **cost**, and **reliability**
- Experiment: Develop prototypes! Also collaborate with industry

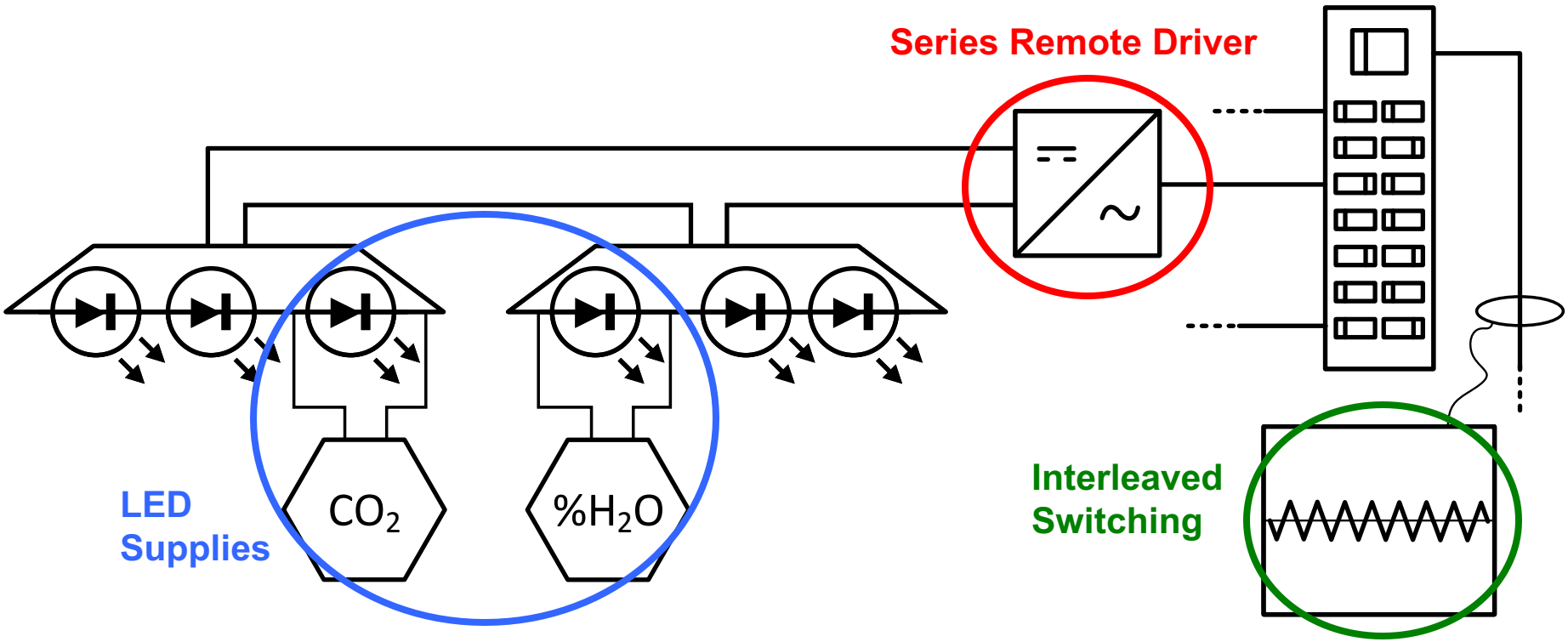


Lighting and IOT Systems Today



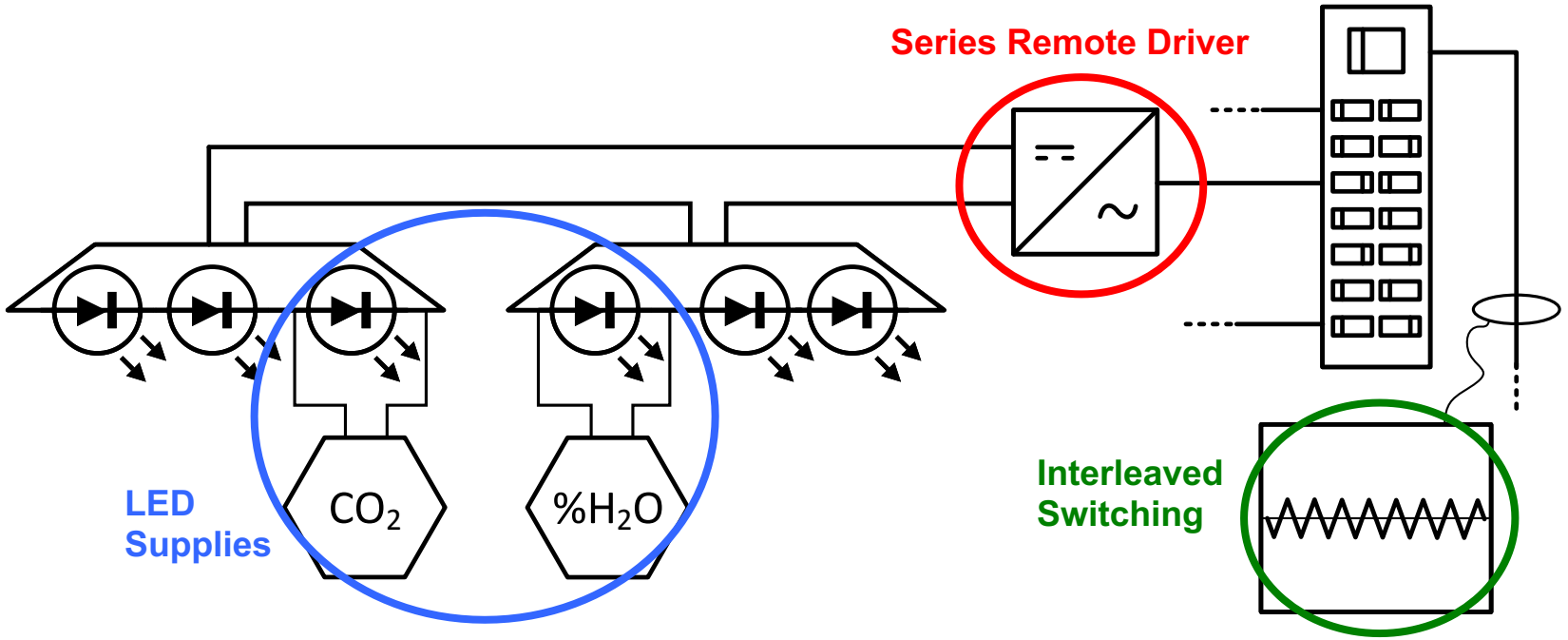
- Integrated LED drivers – requires a driver per fixture, converts from 120 V AC to LED voltage
- Harmonic injection – converter switching injects harmonics that degrade power quality, requires bulky filter capacitors
- IOT supplies – each device requires an inefficient and costly low-power wall adapter

Proposed Solutions



- Remote LED drivers with fixtures wired in series
- Controller that interleaves switching of neighboring converters
- LEDs as a power supply for IOT devices

Impact



- Lighting System Power Consumption **-5%** [3]
- Lighting System Cost ***(0.8^(N-1))** [1,3] ***0.8** [1,2] ***0.7** [6] (N = # fixtures)
- Lighting System Cost ***0.7** [1,2] ***0.7** [6]
- IOT Device Power Consumption **-15%** [4]
- IOT Device Cost ***0.5** [5]

1. "DOE Manufacturing Roadmap Solid-State Lighting Research and Development 2014"
2. W. Chen, S.Y.R. Hui, "Elimination of an electrolytic capacitor in AC/DC light-emitting diode (LED) driver with high input power factor and constant output current"
3. D. Gerber, R. Liou, R. Brown, "Energy-Saving Opportunities of Direct-DC Loads in Buildings"
4. CUI Inc, "Efficiency standards for external power supplies."
5. Digikey estimate for humidity sensor and required electronics
6. RSMeans labor estimate

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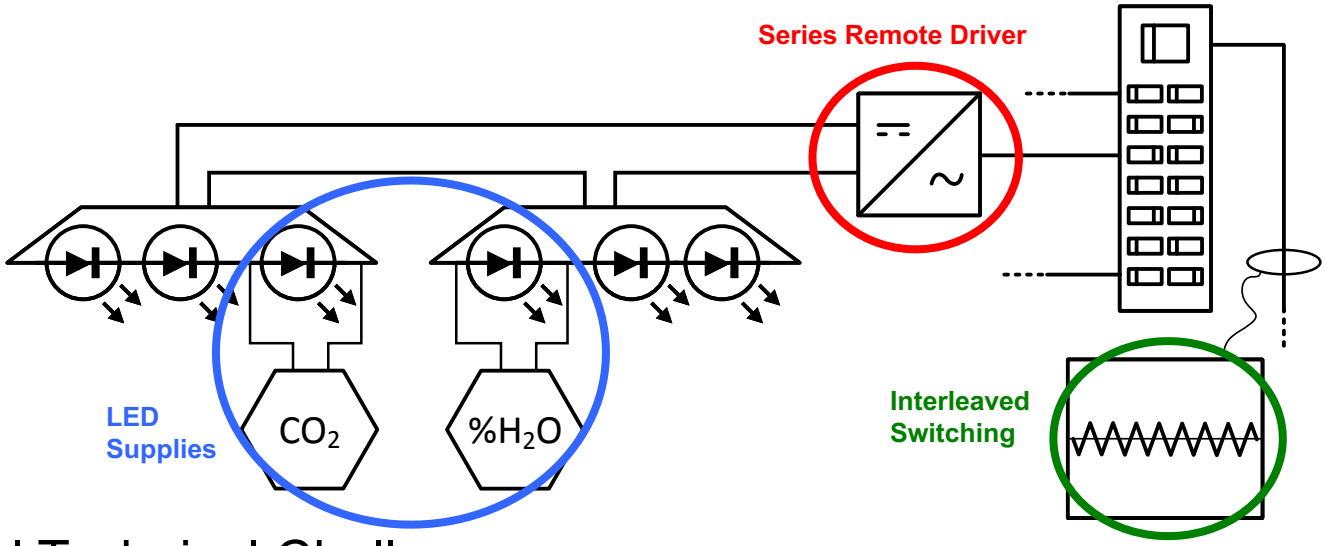
Challenges and Risks



- Several Technical Challenges
  - Developing a bypass circuit if an LED fixture blows
  - Decentralizing the interleaved switching algorithm
  - Powering the IOT devices while lights are off
- Risks
  - It doesn't work
  - It violates some obscure electrical code in buildings
  - Electricians are too lazy

Proposed Research

Series Remote Driver

Staff: me, intern

- **Y1: Test prototype with buck-boost, modern LEDs, wire runs, and protection**
- **Y2: Identify how to overcome barriers to market**

Interleaved Switching

Staff: postdoc Jason Poon

- **Y1: Make decentralized and robust to duty cycle and wire impedance**
- **Y2: Prototype in LED drivers**
- **Y2: Identify how to overcome barriers to market**

LED supplies for IOT

Staff: me, intern

- **Y1: Build prototype with several IOT devices**
- **Y2: Allow low dimming robustness**
- **Y2: Design controls to modulate power to devices while lights off**

Potential Partners

- **Industry: Phillips, Lumencache, Bosch, Delta, EMerge Alliance**
- **UCB: Seth Sanders**
- **WSU: Fariborz Musavi**
- **CSU: Jim Cale**
- **NREL: Barry Mather**

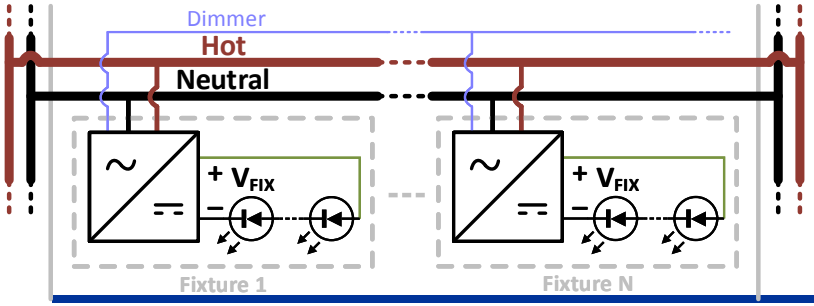
Impact and Outcome

- **Impact**
  - Save energy and reduce e-waste for millions of devices
  - Lowers cost, which facilitates market entry for new building technologies such as DC and IOT
- **Outcome**
  - Publications and inventions for the lab
  - Propose changes to lighting/electrical code
  - Disseminate technology within industry
- **Looking Forward**
  - Future funding from DOE solid state lighting program, ARPA-E, CEC, ESTCP
  - Power electronics research initiative
    - Develop capability at the lab
    - This project can be a stepping stone for larger costlier projects in other lab initiatives such as electric transportation

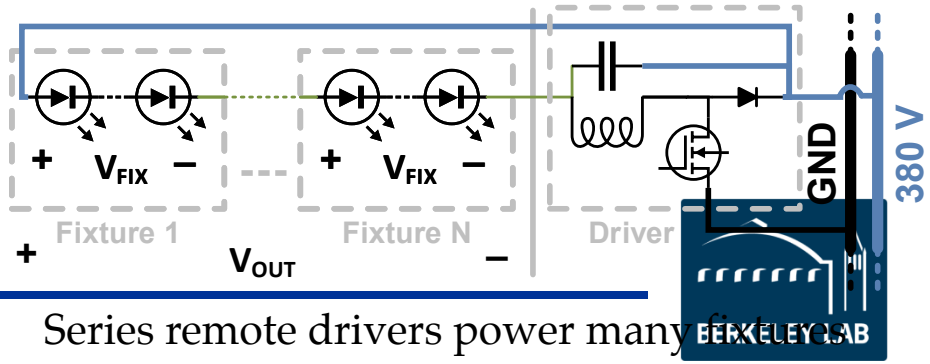
Backup

Concept 1: Series Remote Drivers

- LED retrofit bulbs have internal drivers, and are designed to plug into existing incandescent or fluorescent AC fixtures
- Remote drivers are physically separate from the lamp's LEDs. Existing remote LED drivers use a parallel fixture design
- We further propose to wire fixtures in series for remote drivers
- Applications: zone and/or high-bay lighting



Traditional systems require a driver per fixture

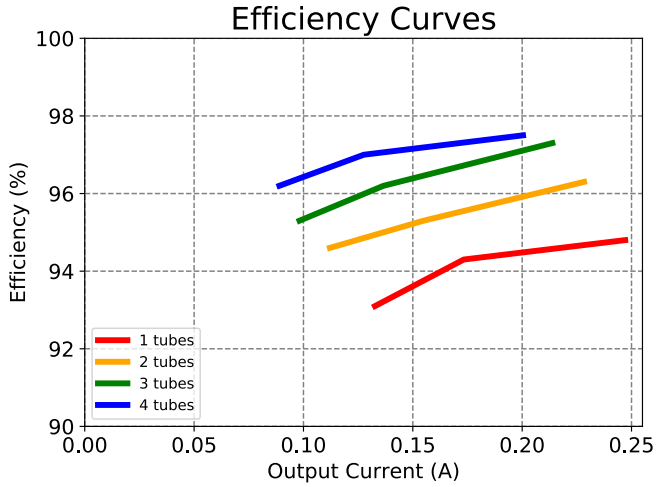


Series remote drivers power many fixtures

Concept 1: Series Remote Drivers

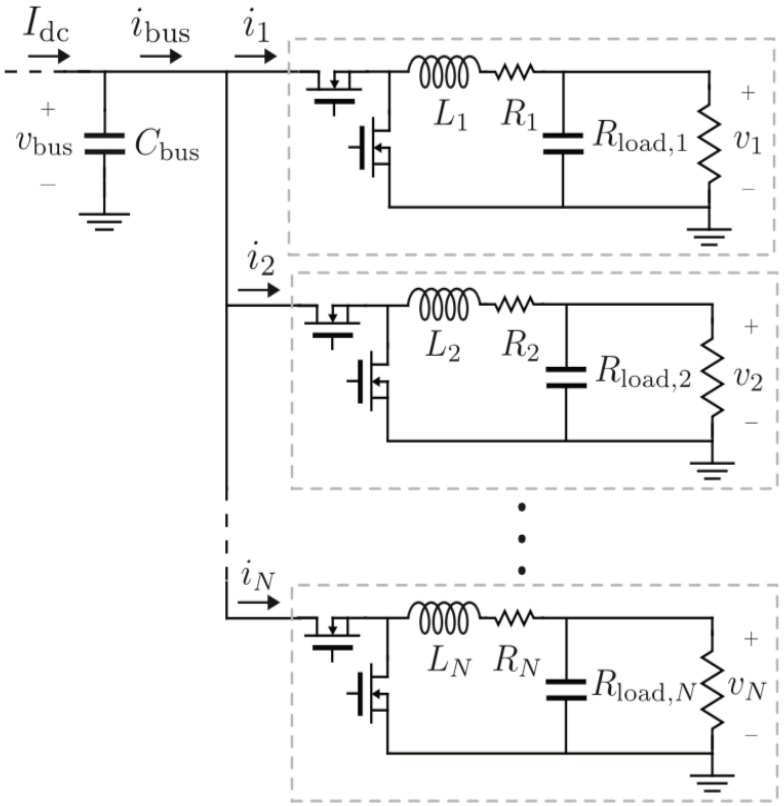
- **Advantages**
  - Reduces driver **cost/size** by factor of N: a single driver powers N fixtures
  - **Efficiency** increases with more series fixtures
  - Reduces maintenance **cost**: driver can be easy to access, not mounted in luminaire
  - Easy to add dimming controls and battery backup to a single driver
- **Staff: me**
- **Milestones**
  - Y1: Test a prototype with buck-boost, modern LEDs, realistic wire runs, and required circuit protection
  - Y2: Identify how to overcome barriers to market entry

Tube LED prototype



Concept 2: Interleaved Switching

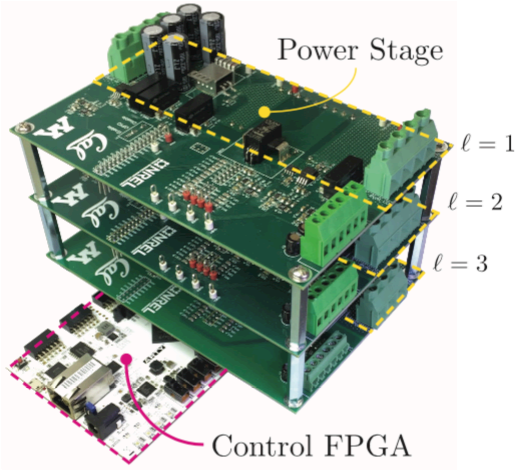
- LED drivers are switching converters. They inject current harmonics onto the AC line that degrade power quality
- Requires large input filter capacitors, which are often bulky, costly, and prone to failure
- *Minimum distortion point tracking* (MDPT) is a novel decentralized control algorithm that interleaves switching among multiple converters
- Causes the harmonics to destructively interfere at the feeder



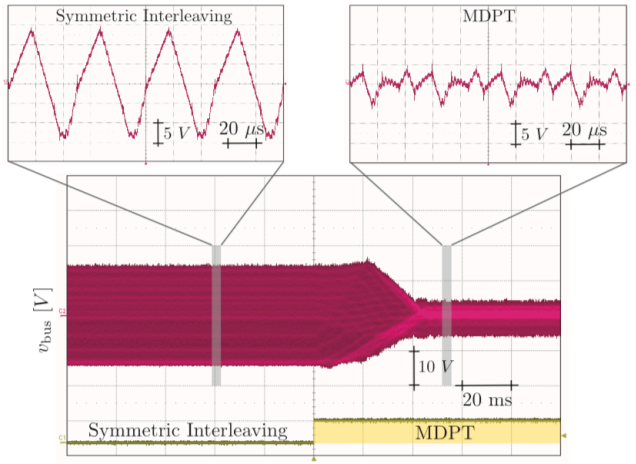
Several converters with interleaved switching algorithms whose harmonics destructively interfere at the feeder

Concept 2: Interleaved Switching

- **Advantages**
  - Improves **power quality** beyond the feeder
  - OR allows a reduction in the **size/cost** of the driver's input filter capacitors by 3.5x or more
  - Can eliminate electrolytic components, improving **reliability**
- **Staff: postdoc Jason Poon**
- **Milestones**
  - Y1: Analyze effect of duty cycle and wire impedance on harmonic reduction
  - Y2: Design and prototype LED drivers with MDPT
  - Y2: Research practical and code roadblocks for implementing MDPT in buildings



A prototype for testing algorithms

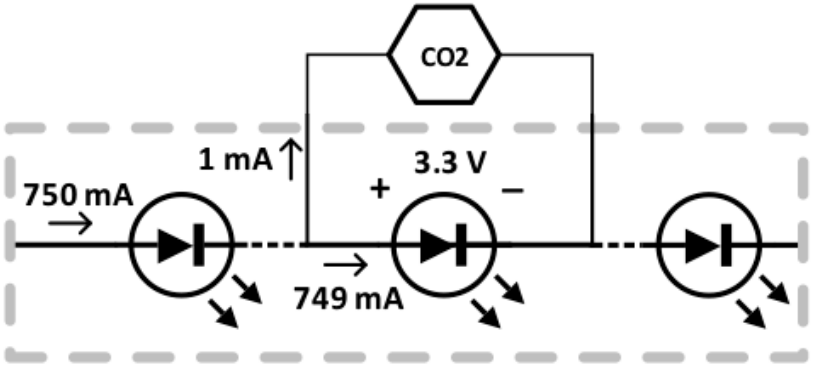


Sample line current ripple

Concept 3: LEDs as IOT Power Supplies

- Internet of Things (IOT) devices often require low voltage (3.3 to 5 V) and low power to operate
- Low-power converters with high step-down conversions are usually inefficient
- We propose a novel LED fixture design that can efficiently provide low-voltage supplies for IOT sensors
- The technique leverages the LED as a constant voltage supply

The CO2 sensor uses the LED as a supply. Since it draws substantially less current, the LED's brightness is largely unaffected



Concept 3: LEDs as IOT Power Supplies

- **Advantage – eliminating the IOT device's supply can have substantial savings in cost (~2x) and efficiency (~15%) over millions of devices**
- **Applications – any ceiling grid IOT devices**
  - Occupancy sensors
  - Air quality and humidity sensors
  - Daylight sensors
- **Staff: me + summer intern**
- **Proposed Work**
  - Y1: Prototype LED supplies for several IOT devices
  - Y2: Investigate functionality at low dimming
  - Y2: Design controls for modulating power to devices while the LEDs are off