modBulb: A modular Light Bulb for Visible Light Communication

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Embedded Visible Light Communication

- VLC has been mainly researched as an alternative to WiFi
  - High bitrates in the orders of GBit/s
- Embedded Visible Light Communication
  - Not all applications require high bitrates
  - Internet connectivity is only one application
- Embedded VLC applications
  - Localization
  - Gesture Recognition
  - Camera Flash Synchronization
Motivation

- Light transmitter is a key component in VLC
  - Decides light intensity, data rate, etc
- Lack of truly open source hardware
  - Repeatability of experiments
- Existing solutions: OpenVLC [HotWireless 2015], Linux Light Bulbs[VLCS 2015]
  - Limited bandwidth
  - Not very flexible (eg: multiple LEDs, LEDs with different wavelengths)
- Can we design an open VLC hardware to enable a wide spectrum of applications?
Contributions: modBulb

- Flexible baseband generator
  - MCU, FPGA or a hybrid architecture
- Wireless connectivity
  - Over-the-air updates for MCU and FPGA through WiFi
- Exchangeable light source
  - Efficient LED driving, flexibility to change LEDs
- Open hardware & software
Modular Design

- Baseband Generator
  - Modulated signal is digital
- LED Driver - Constant current driving
  - Non-linear IV characteristics
- LED(s)
  - Multiple LEDs
  - LEDs with different wavelengths
Baseband Generators: MCU & FPGA

**MCU baseband generator**
- CC3200 - ARM Cortex-M4 Core at 80 MHz
- Over-the-air updates through Wi-Fi
- Dedicated WiFi network processor
- Constrained by clock frequency
- Easy to program

**FPGA baseband generator**
- Microsemi AGLN060 at 20 MHz (∼200 MHz)
- Over-the-air updates through MCU
- Parallel processing
- Precise control over the timing
- Complex to program
The modulation affects on the ability of performing additional processing.
The FPGA based baseband generator allows higher throughput at the expense of ease of use.
LED Drivers: Linear Regulator & Switching Regulator

**Linear regulator based driver**
- Controls the current linearly
- High heat dissipation, inefficient
- Simple to prototype
- Bulky due to the attached heat sink

**Switching regulator based driver**
- Controls the current by switching
- Very low heat dissipation, efficient
- Switching noise can appear in modulated light
- Widely used in commercial lighting

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Noise comparison

The switching regulator introduces noise at the benefit of power efficiency.
Efficiency of the Driver Circuits

<table>
<thead>
<tr>
<th>LED driver</th>
<th>LED current (A)</th>
<th>Input power (W)</th>
<th>Output power (W)</th>
<th>Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear</td>
<td>0.566</td>
<td>6.79</td>
<td>3.47</td>
<td>51.10</td>
</tr>
<tr>
<td>Switching</td>
<td>0.508</td>
<td>3.48</td>
<td>3.04</td>
<td>87.36</td>
</tr>
</tbody>
</table>

The linear regulator based driver is less efficient than the switching regulator based driver circuit.
Multiple LEDs

Since modBulb controls current, multiple LEDs can be added to increase the light intensity.
OOK modulation at 1 MBit/s

BFSK modulation at 500 KBit/s

modBulb achieves a superior datarate than existing open embedded VLC hardware.
FPGA & MCU baseband generators, Switching LED driver
Conclusions & Future work

- modBulb is an open tool to be used with embedded VLC
- Can be used beyond prototyping applications
- Future work
  - modBulb as a VLC receiver
  - Analog modulations such as OFDM
- modBulb will be truly open source
  - Schematics & PCBs
  - Other design files
- Visit our demo to see modBulb in action
Thank You

Q & A