

modBulb: A modular Light Bulb for Visible Light Communication

Kasun Hewage ¹, Ambuj Varshney ¹, Abdalah Hilmia ¹,
Thiemo Voigt ^{1,2}

¹Uppsala University, Sweden ²SICS Swedish ICT, Sweden

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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

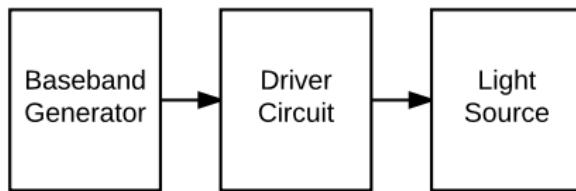
Motivation

- 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

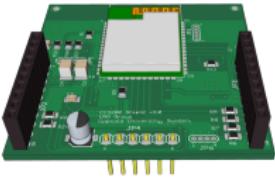
- Flexible baseband generator
 - MCU, FPGA or a hybrid architecture
- Wireless connectivity
 - Over-the-air updates for MCU and FPGA through WiFi
- Exchangeable light source
 - Efficient LED driving, flexibility to change LEDs
- Open hardware & software

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

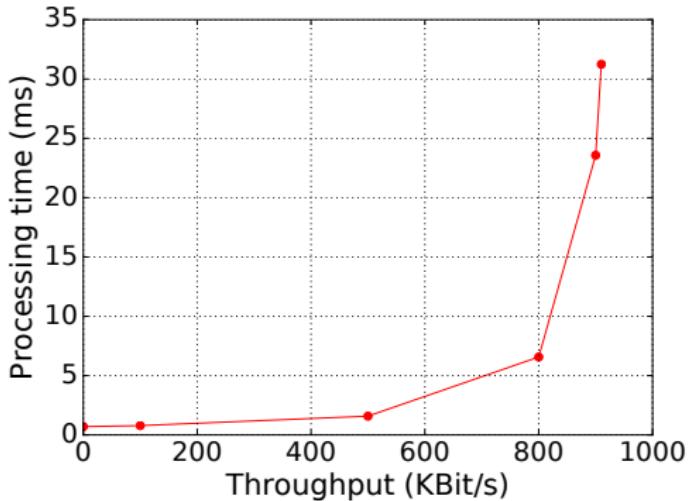


FPGA baseband generator

- 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

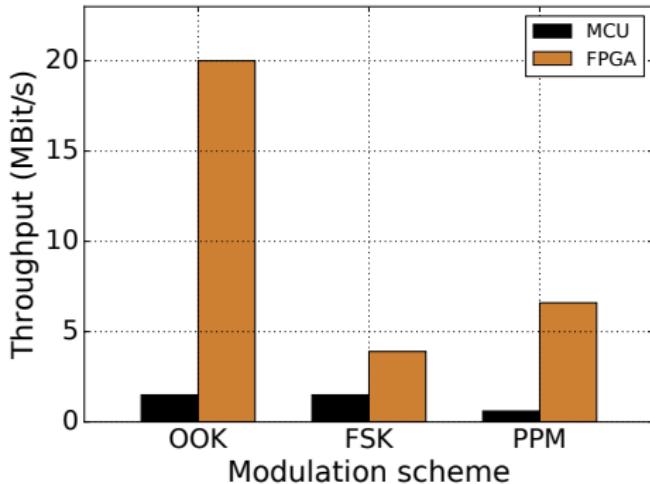
- Microsemi AGLN060 at 20 MHz (~200 MHz)
- Over-the-air updates through MCU
- Parallel processing
- Precise control over the timing
- Complex to program

Modulation overhead



The modulation affects on the ability of performing additional processing.

Achievable Throughput



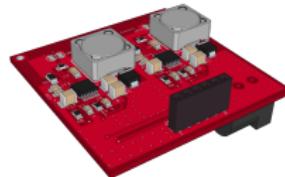
The FPGA based baseband generator allows higher throughput at the expense of ease of use.

LED Drivers: Linear Regulator & Switching Regulator



Linear regulator based driver

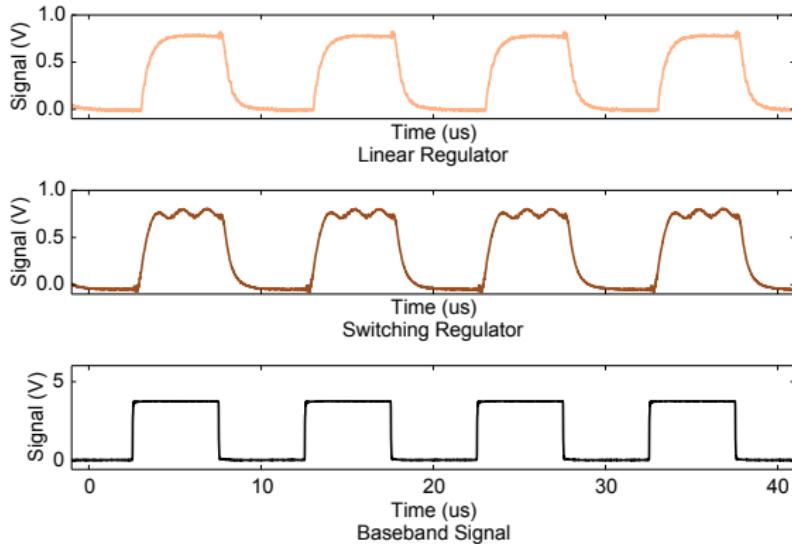
- Controls the current linearly
- High heat dissipation, inefficient
- Simple to prototype
- Bulky due to the attached heat sink



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

Noise comparison



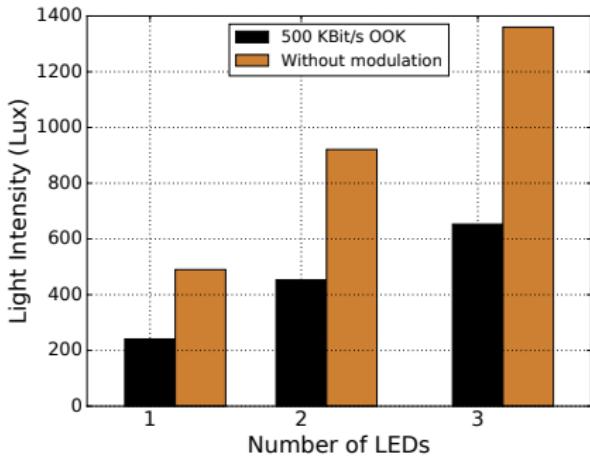
The switching regulator introduces noise at the benefit of power efficiency.

Efficiency of the Driver Circuits

LED driver	LED current (A)	Input power (W)	Output power (W)	Efficiency (%)
Linear	0.566	6.79	3.47	51.10
Switching	0.508	3.48	3.04	87.36

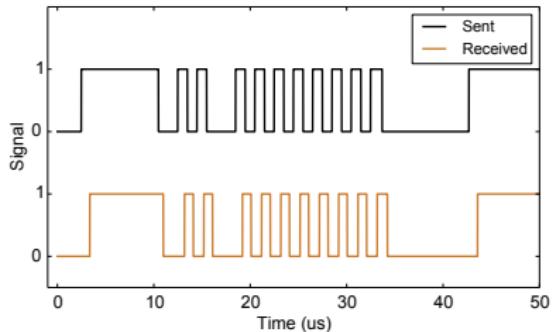
The linear regulator based driver is less efficient than the switching regulator based driver circuit.

Multiple LEDs

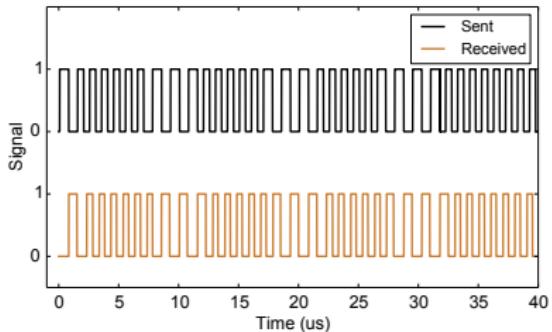


Since modBulb controls current, multiple LEDs can be added to increase the light intensity.

Sent & Received Waveforms



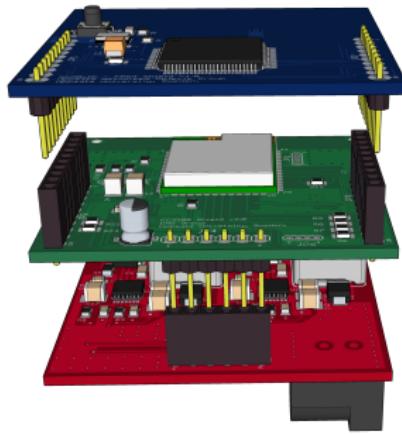
OOK modulation at 1 MBit/s



BFSK modulation at 500 KBit/s

modBulb achieves a superior datarate than existing open embedded VLC hardware.

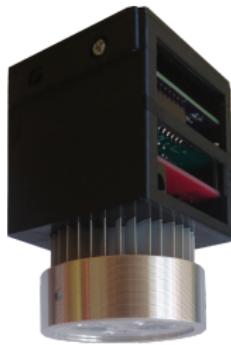
All Together



FPGA & MCU baseband generators, Switching LED driver

Conclusions & Future work

- modBulb is an open tool to be used with embeded 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

Thank You
Q & A