Software Defined Visible Light Communication

Wireless Innovation Forum Conference on Wireless Communications Technologies and Software Defined Radio

March 11-13, 2014

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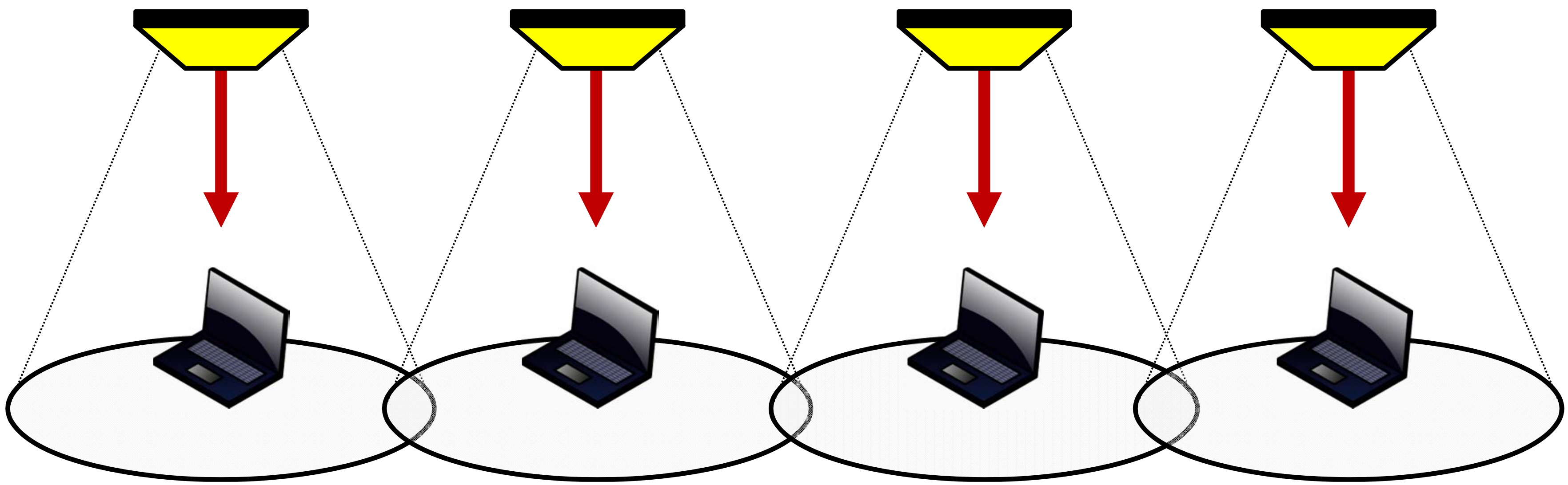
Motivation

- Consider how the wireless communications industry has changed over the past decade, and will change in the coming decade…

Continuing to Meet the Demand

- What changes are needed to meet growth in demand?
  - Increased spectrum
  - Adaptive networks
  - Smaller cells

We look to provide wireless data from every luminaire!



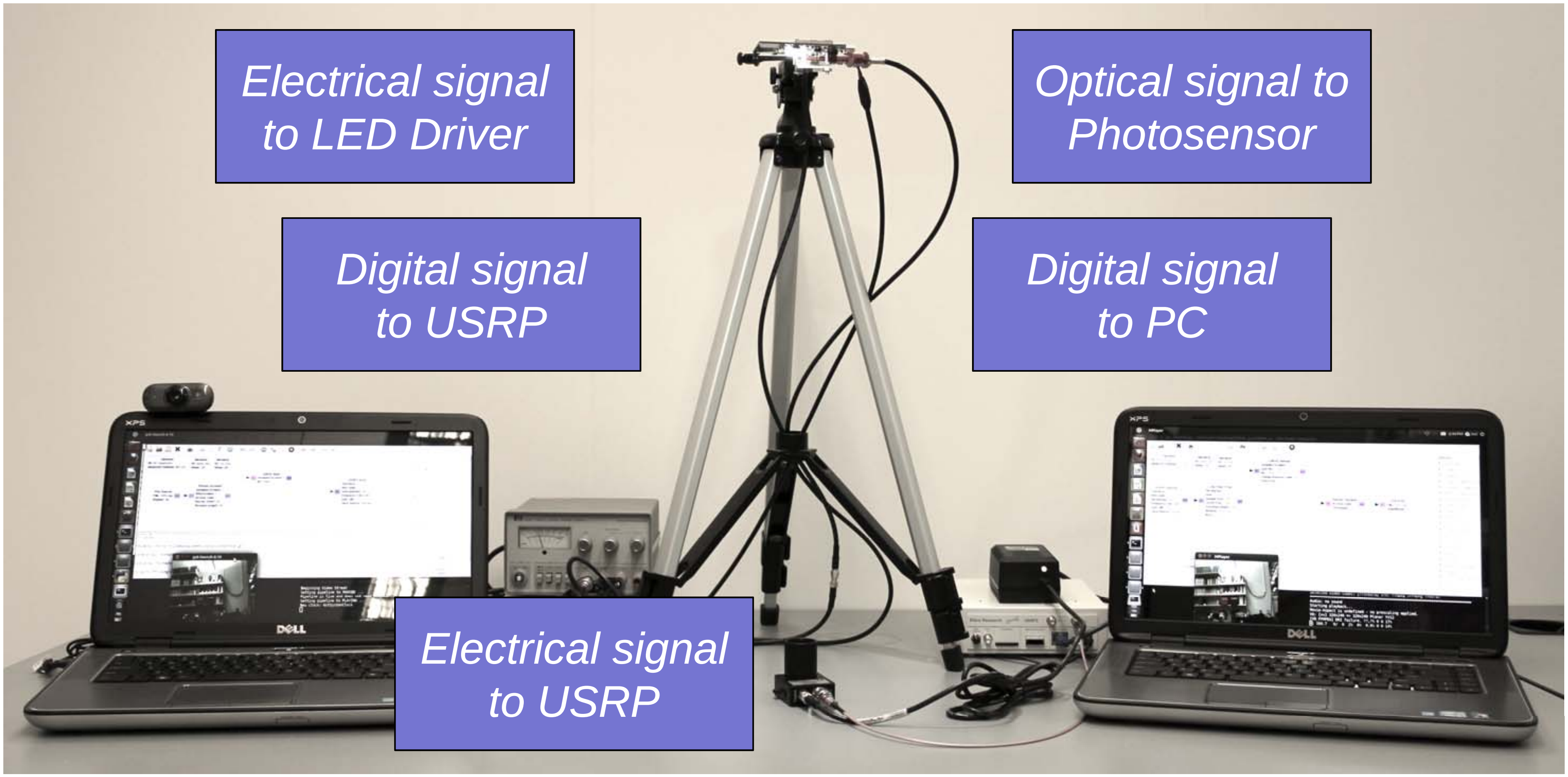
Visible Light Communication

- Applications
  - Underwater communication
  - Wireless in RF restricted areas
  - Indoor Positioning
  - Near-field communication
  - Secure data transfer
  - Dual-use luminaires
- Comparison to RF (or SDRs)
  - Intensity Modulation w/ Direct Detection
  - Baseband / Low frequency modulation
  - Strictly Positive signal
  - Nonlinear electro-optic conversion
- VLC Techniques and Research Areas

A system combining these techniques has a high degree of complexity.

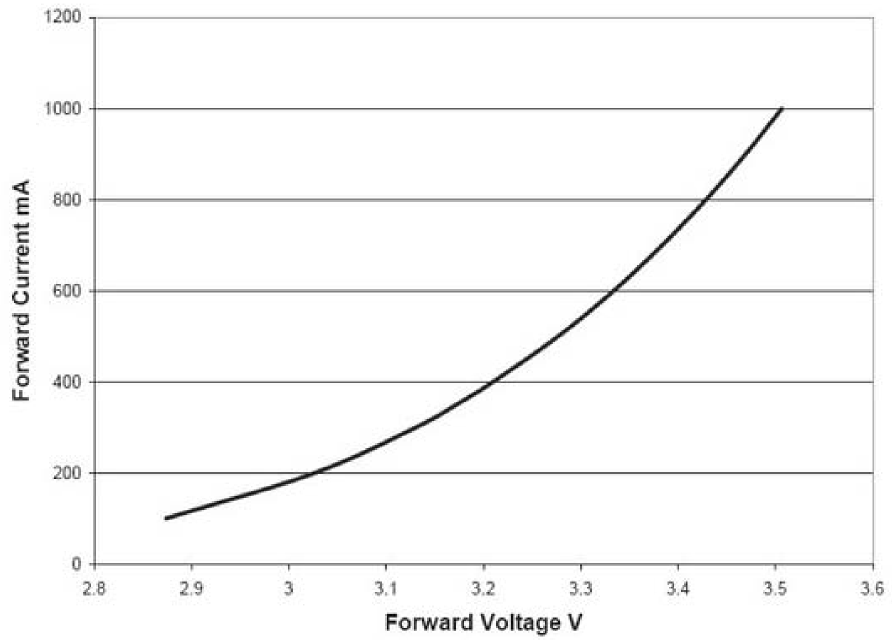
This motivates a Software Defined VLC system allowing flexible integration of hardware prototypes with novel signal processing techniques.

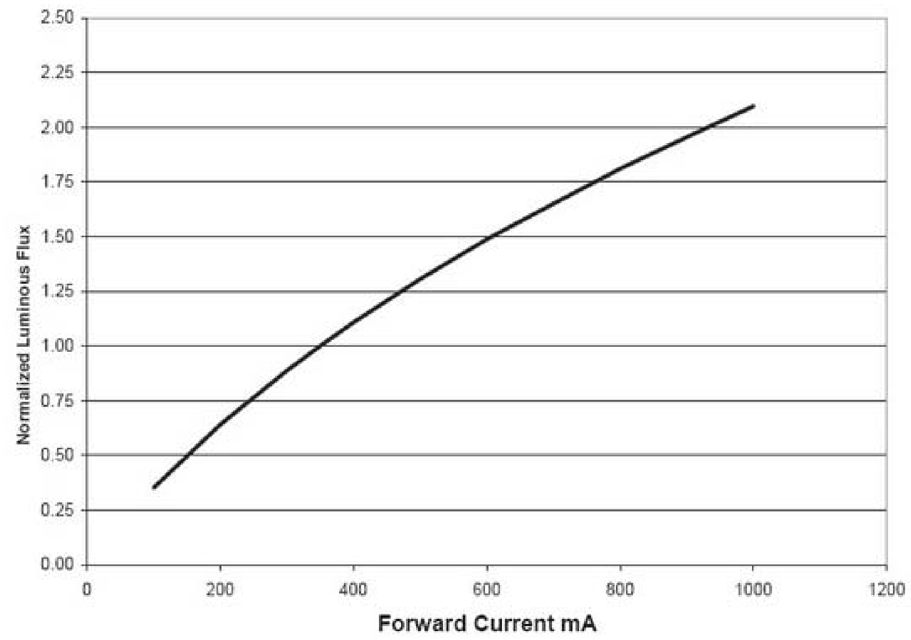
Software Defined VLC (SDVLC)



Optical Wireless Channel

- Electro-Optic Conversion

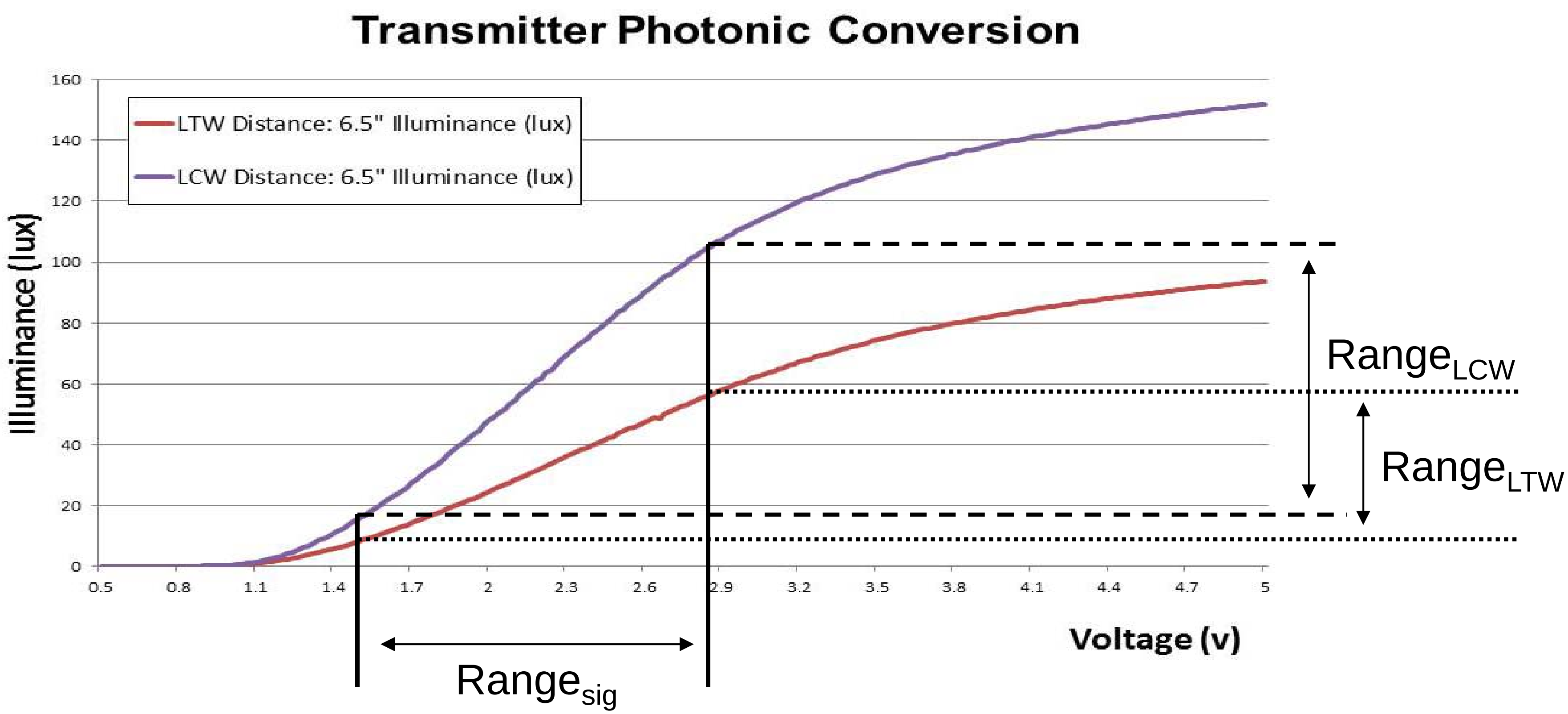




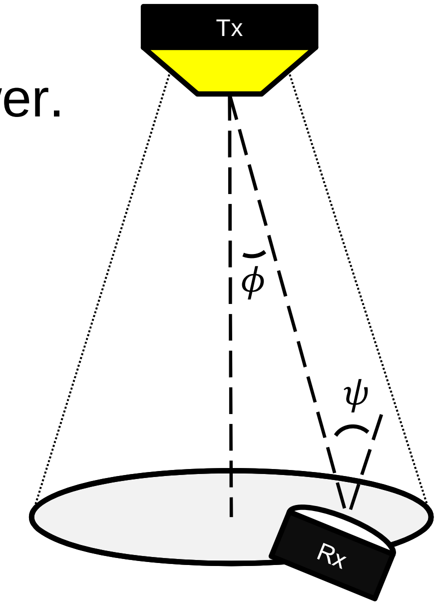
Source: Philips Lumileds – Luxeon Rebel

Optical Wireless Channel

- Electro-Optic Conversion
  - Ideally, conversion is linearized OR linear region is used



Optical Wireless Channel



- Define $x(t)$ as the instantaneous optical signal power.
  - $\min\big(x(t)\big) = 0$
  - $x(t) \geq 0$ for all t
- Average optical signal power:
  - $P_t = \lim_{T \to \infty} \frac{1}{2T} \int_{-\infty}^{\infty} x(t)dt$
- Instantaneous received signal current:
  - $y(t) = R\big(x(t) * h(t)\big) + n(t)$
  - Given dominant LOS path, $h(t) \approx H\delta(t)$
- DC Channel Gain
  - Dependent on the angle of emission, ϕ, and angle of arrival, ψ.
  - $H = \begin{cases} \frac{A}{d^2} R_o(\phi) g(\psi) \cos(\psi), & 0 \leq \psi \leq \Psi_c \\ 0, & \psi > \Psi_c \end{cases}$

$$R_o(\phi) = \frac{m+1}{2\pi} \cos^m(\phi) \qquad m = -\ln 2 / \ln\big(\cos \Phi_{1/2}\big) \qquad g(\psi) = n^2 / \sin^2(\Psi_c)$$

Constraints in Dual-Use VLC

- Bandwidth
  - Illumination LEDs are commonly phosphor coated blue LEDs.
  - Slow decay of phosphor limits 3dB bandwidth to 2-5MHz.
  - Bare LEDs have bandwidth in the range of 10-20MHz.
  - Alternatives: Laser Diodes and Micro-LEDs (Not common for illumination)
- Power Requirements
  - OW links constrain average *optical* power.
  - Typical lighting requirement is 400 lux at the working surface.
  - Signal to Noise Ration in an OW link is defined as

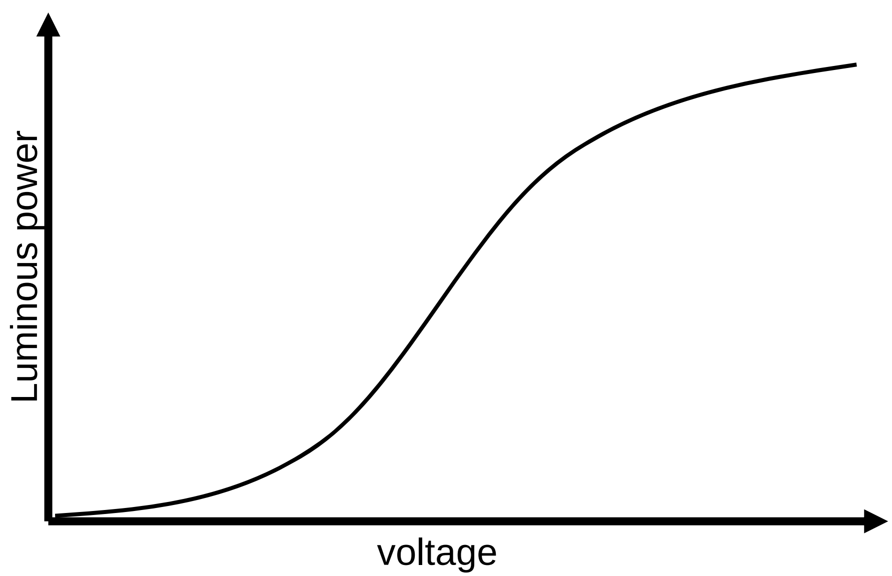
$$SNR = \frac{(RHP_t)^2}{\sigma^2}$$

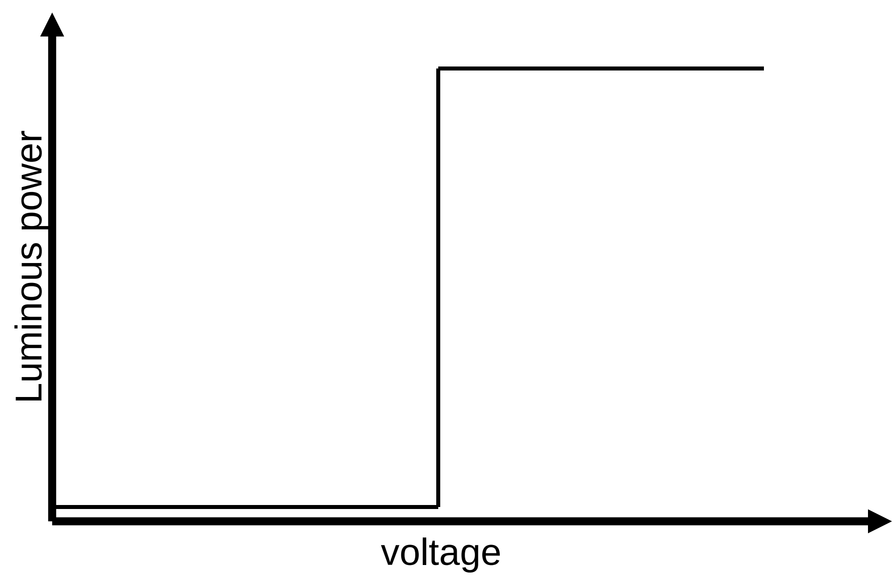
- Dynamic Range
  - DC bias affects range as it approaches 0 or peak instantaneous power.
  - Received signal power can vary greatly due to receiver rotation.
  - Transmitter non-linearity also affects dynamic range.

SDVLC Hardware Architecture

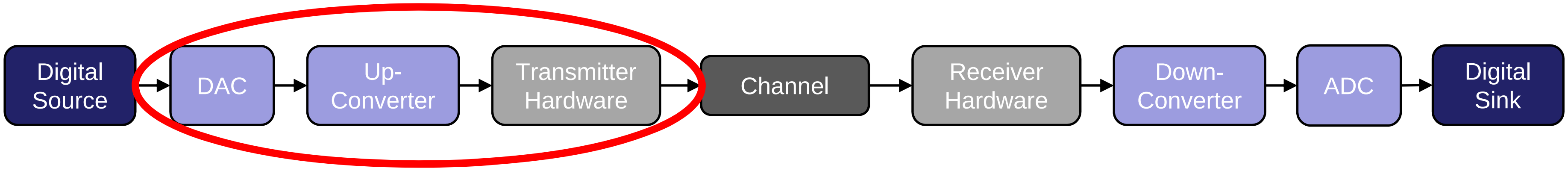
High-level Software Defined Communication signal chain

- **Transmitter Architecture: Conversion**
  - Analog vs Discrete level optical conversion

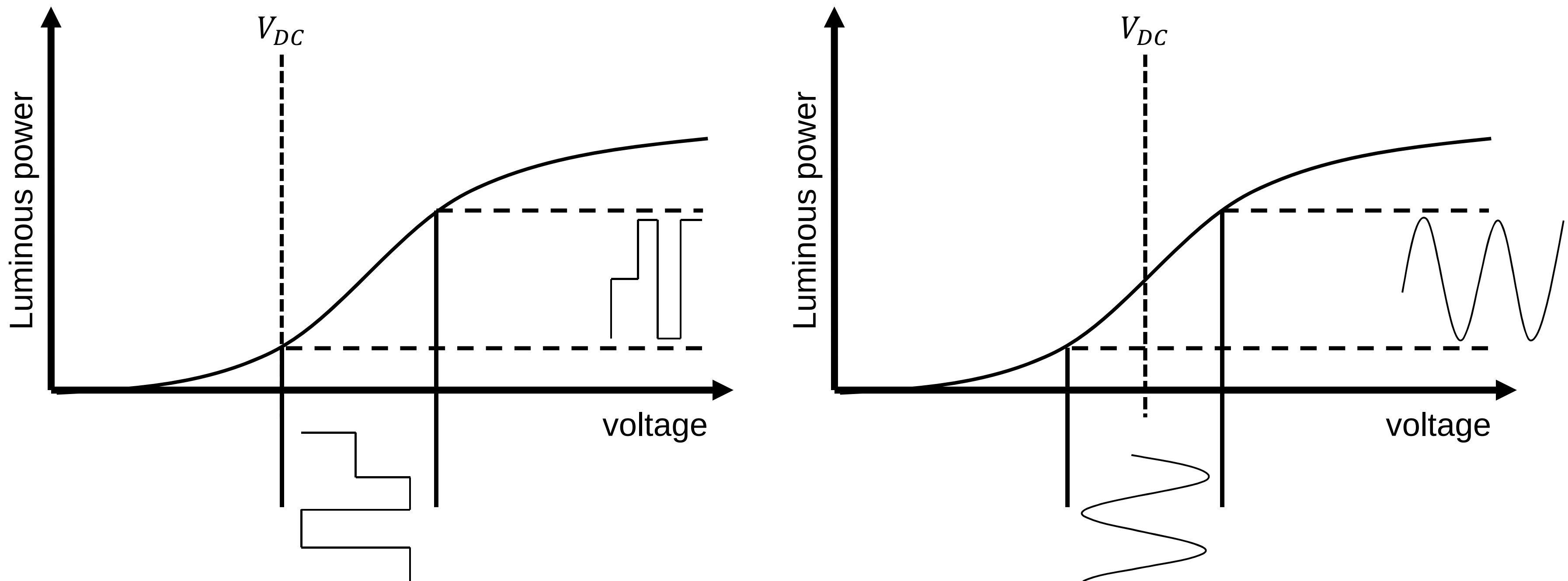




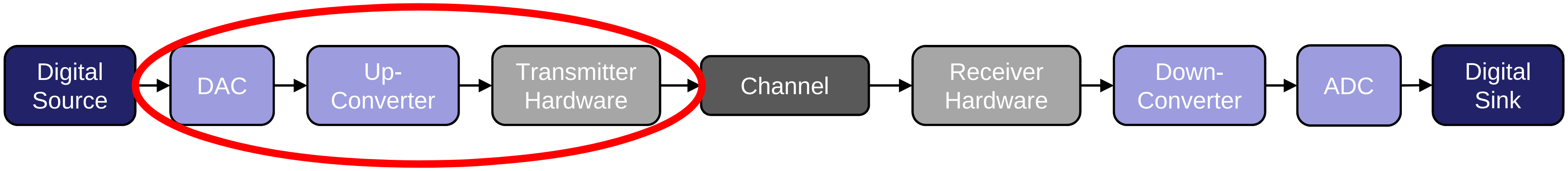
SDVLC Hardware Architecture



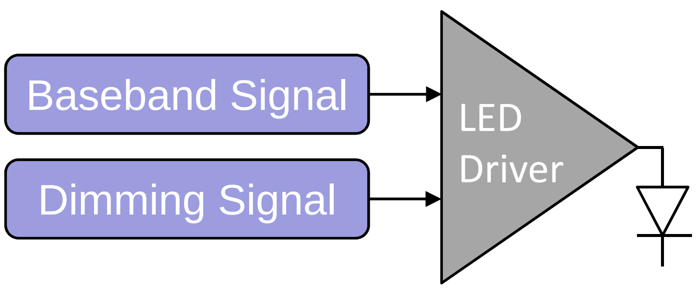
- **Transmitter Architecture: Biasing**
  - DC Bias to start of linear range and limit *electrical* signal to $0 \le \mathrm{signal} \le \mathrm{range}$
  - DC Bias to center of linear range and limit *electrical* signal to $\pm\, \mathrm{range}/2$

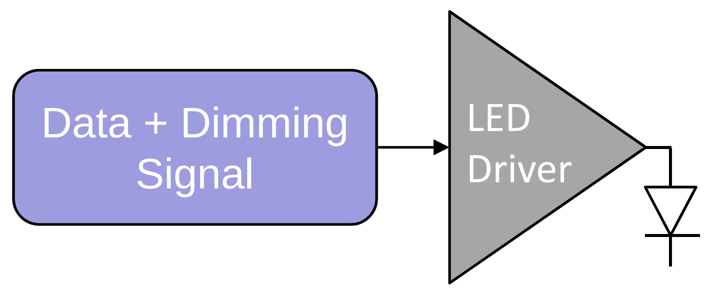


SDVLC Hardware Architecture



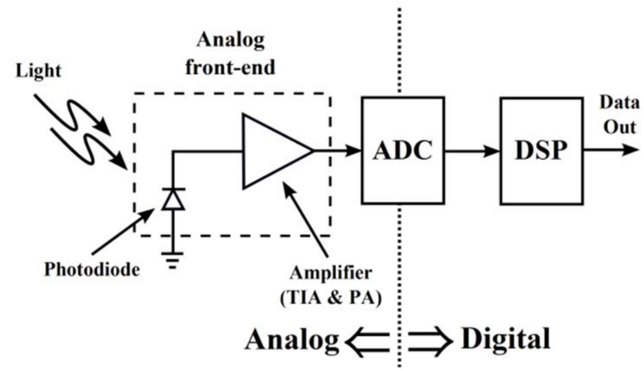
- **Transmitter Architecture: Dimming**
  - Dimming can either be a separate input to the driver (e.g. DC bias) or incorporated into the drive signal.
  - IEEE 802.15.7 specifies Variable PPM (VPPM)- a two level modulation scheme with pulse width control for dimming and PPM for data transmission.

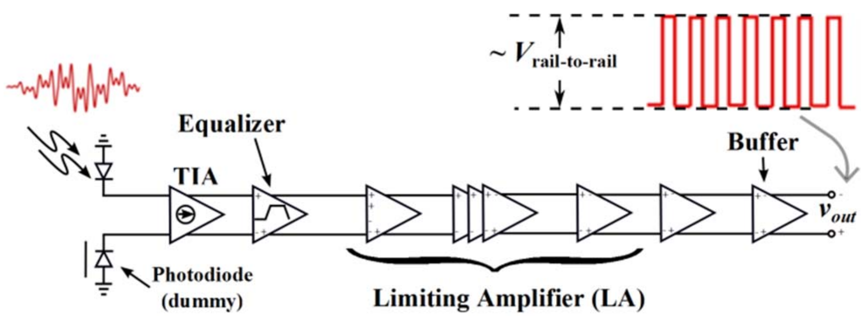


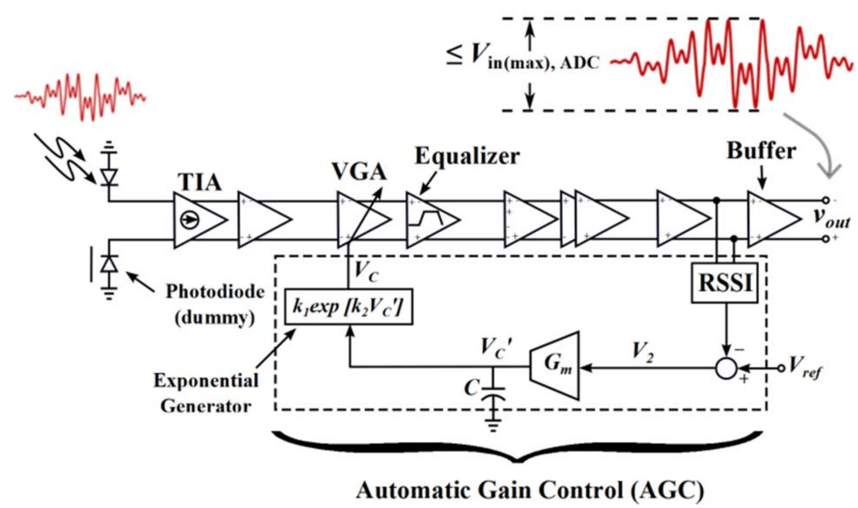


SDVLC Hardware Architecture

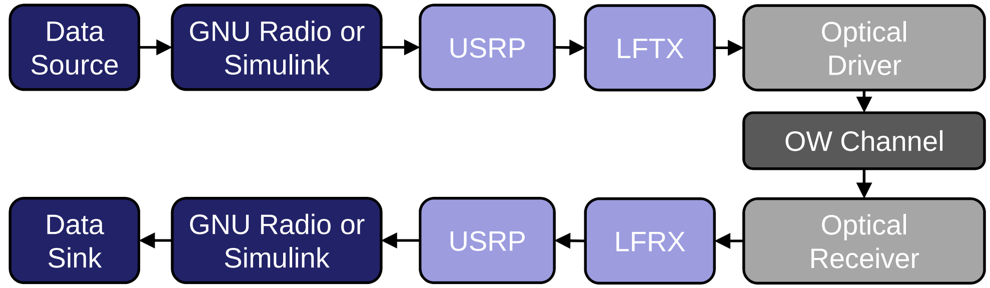
- **Receiver Architecture: Conversion**
  - Photo source generates an electrical current, which is amplified and converted to a voltage signal.
  - This signal can also be implemented as discrete level or analog.



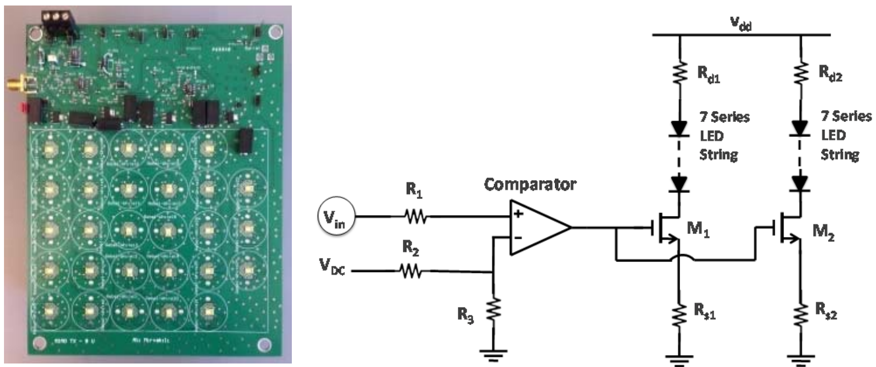




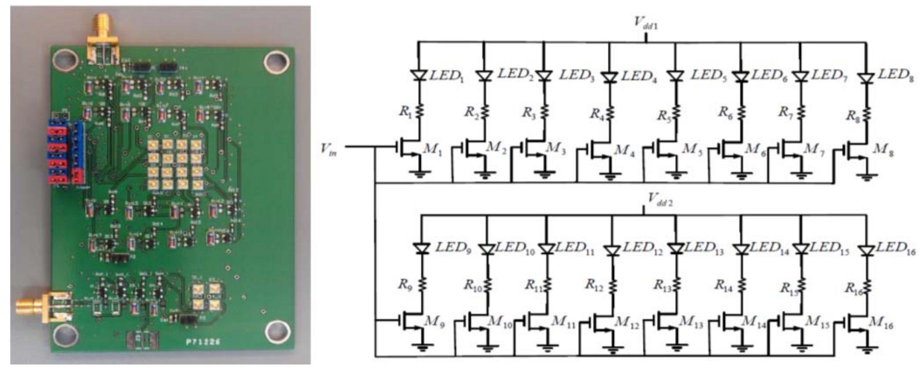
SDVLC Platform



- **Transmitters**



Two-Level Driver

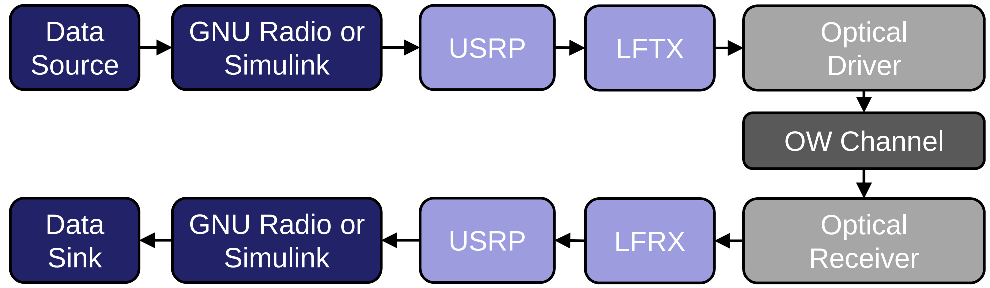


Analog Driver

- Max Luminous Output: ~2500 lm
- Limited to testing pulsed modulation
- Drive signal passes through DC-DC adder circuit to reach turn on voltage.

- Max Luminous Output: ~800 lm
- Flexible for various modulation schemes.
- Drive signal passes through Bias T for passband or DC-DC adder for baseband.

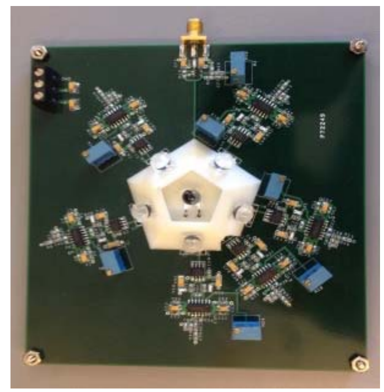
SDVLC Platform

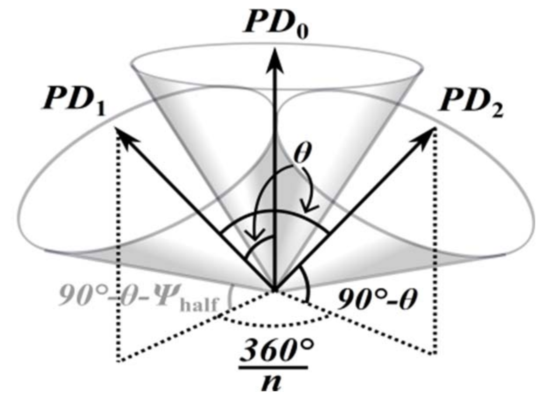


- **Receivers**

Thorlabs PDA36A Transimpedance Amplifier

- Optical Concentrator
- Single photodiode
- Variable gain amplifier



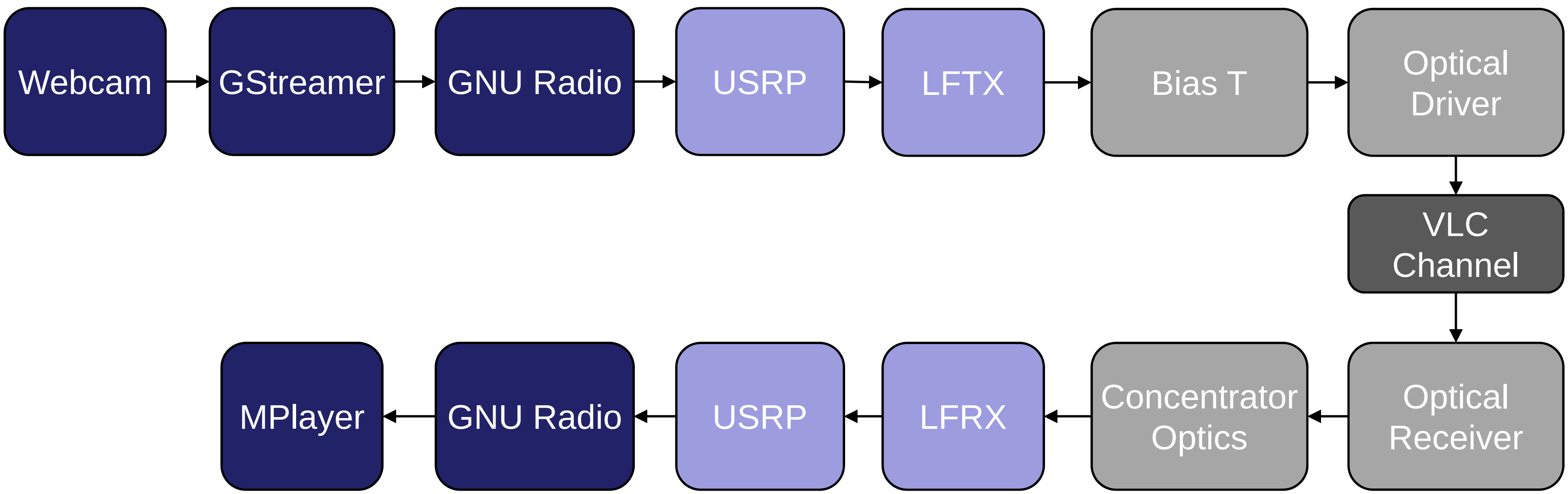


Diversity Receiver

- Larger photodiodes, no additional optics
- Six photodiodes, diverse layout
- Variable gain, combined signal

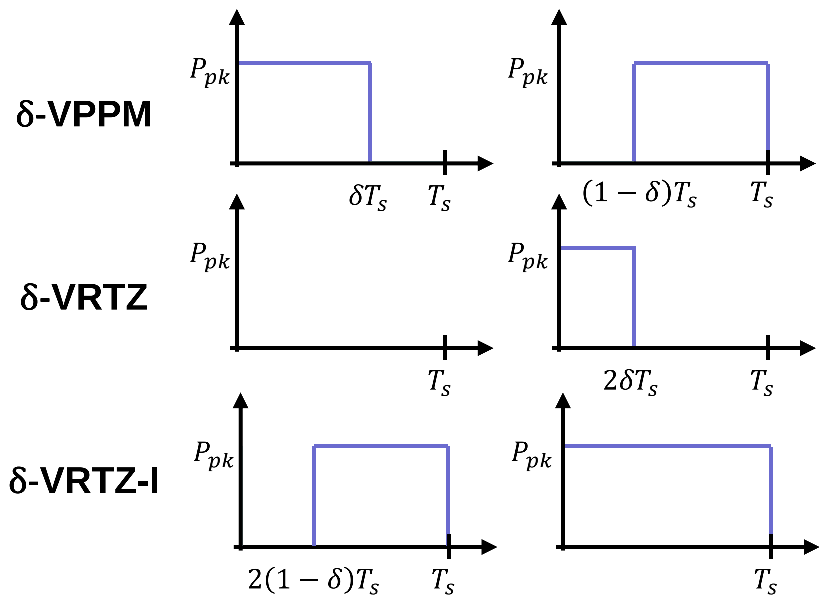
SDVLC for Demonstration

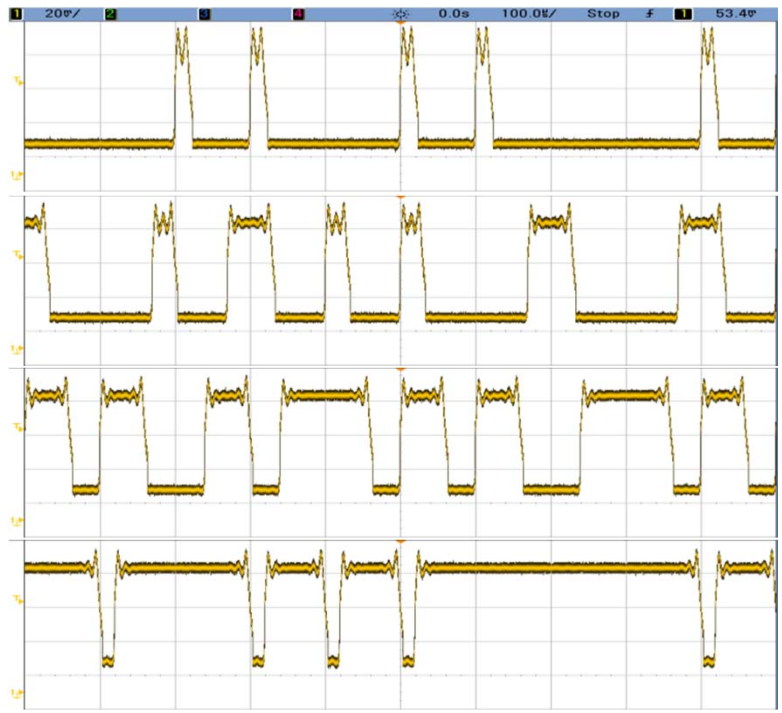
- We utilize Gstreamer to encode a webcam video stream in real time and transmit the video over the VLC link.
- Live streaming over a VLC channel allows us to demonstrate the concept in a tangible manner.



SDVLC for Adaptive modulation

- Adapting modulation for dimming is essential in dual-use VLC.
- VPPM is the technique proposed in IEEE 802.15.7.
- We incorporate Variable RTZ OOK and RTZ-I OOK in order to increase the minimum pulse period and extend dimming range.





0.1 VRTZ

0.3 VPPM

0.7 VPPM

0.9 VRTZ-I

Additional Applications

- Adaptive modulation for maximum throughput
  - Higher order modulation for close proximity LOS
  - Lower order modulation for diffuse (multipath) scenario
- Dynamic channel selection with optical diversity receiver
  - User device rotation leads to drastic changes in received signal
  - Use selective subsets of photosensors in diverse alignment
- Implementation of Software Defined Heterogeneous Network
  - Incorporate VLC as a supplemental downlink channel
- Educational outreach
  - Ease of implementation for teaching the basics of optical wireless networks

Summary & Conclusions

- We provide an overview of VLC and a discussion of the challenges relating to adaptation of SDR to the visible light medium.
- We detail an instance of an SDVLC implementation.
- We discuss challenges in implementing a dual-purpose illumination & communication platform and provide proof-of-concept results of a dynamic scheme that adapts to illumination.
- We provide additional examples of potential applications of a functional SDVLC system.

Current research in SDR is leading the way to next gen RF systems…

SDVLC expands the "Software Defined" concept beyond the RF domain and into the broader classification of Software Defined Communication!

Thanks for your attention!

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This work was supported primarily by the ERC Program of the National Science Foundation under NSF Cooperative Agreement No. EEC-0812056.