Visible Light Communication and Applications in SMART Grids

Sihua Shao

Assistant Professor

Department of Electrical Engineering

New Mexico Tech

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Outline

- Smart grids need new wireless access technologies
- VLC offloads data traffic from radio access
- VLC secures wireless communication
- Retro-VLC could be a better solution
- Retro-VLC also supports real-time tracking

What are Smart Microgrids Supposed to Do?

- As a subset of smart grids, smart microgrids operate in grid-connected mode and offer the benefits of distributed computing and communications to deliver **real-time** information and enable **instantaneous balancing** of electrical supply and demand at the level required for **each discrete device**.

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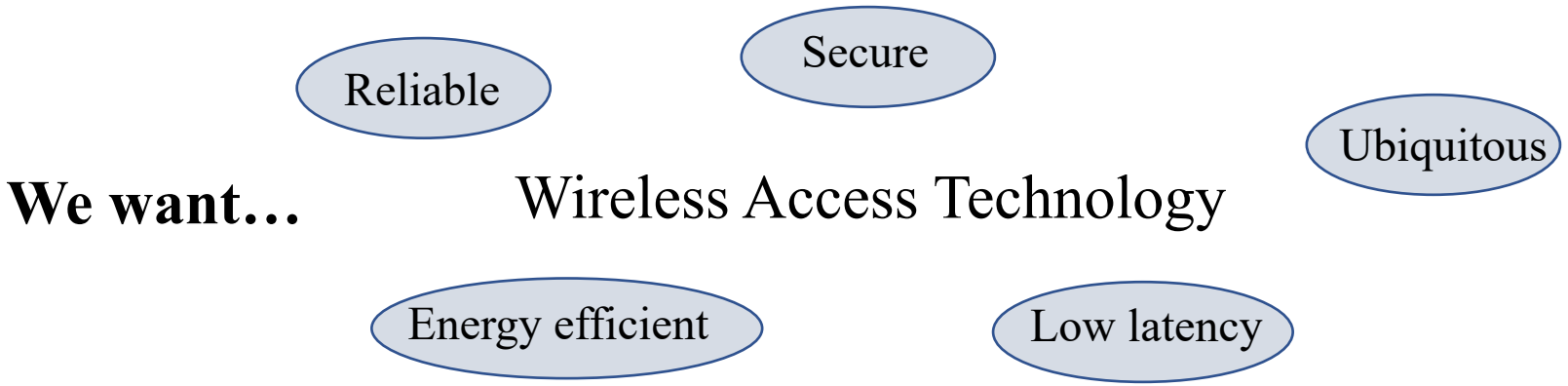
In a Home Area Network (HAN)…

- Smart grid delivers electricity to loads on a **targeted, as needed** basis.
- Microgrid operations perform multi-tier custom diagnostics and schedule **load shedding** and **level demand** in real time.
- Smart appliances, IoT sensors, and other electric devices **adjust their run schedule** to reduce electricity demand on the grid at critical times and lower consumers' energy bills.



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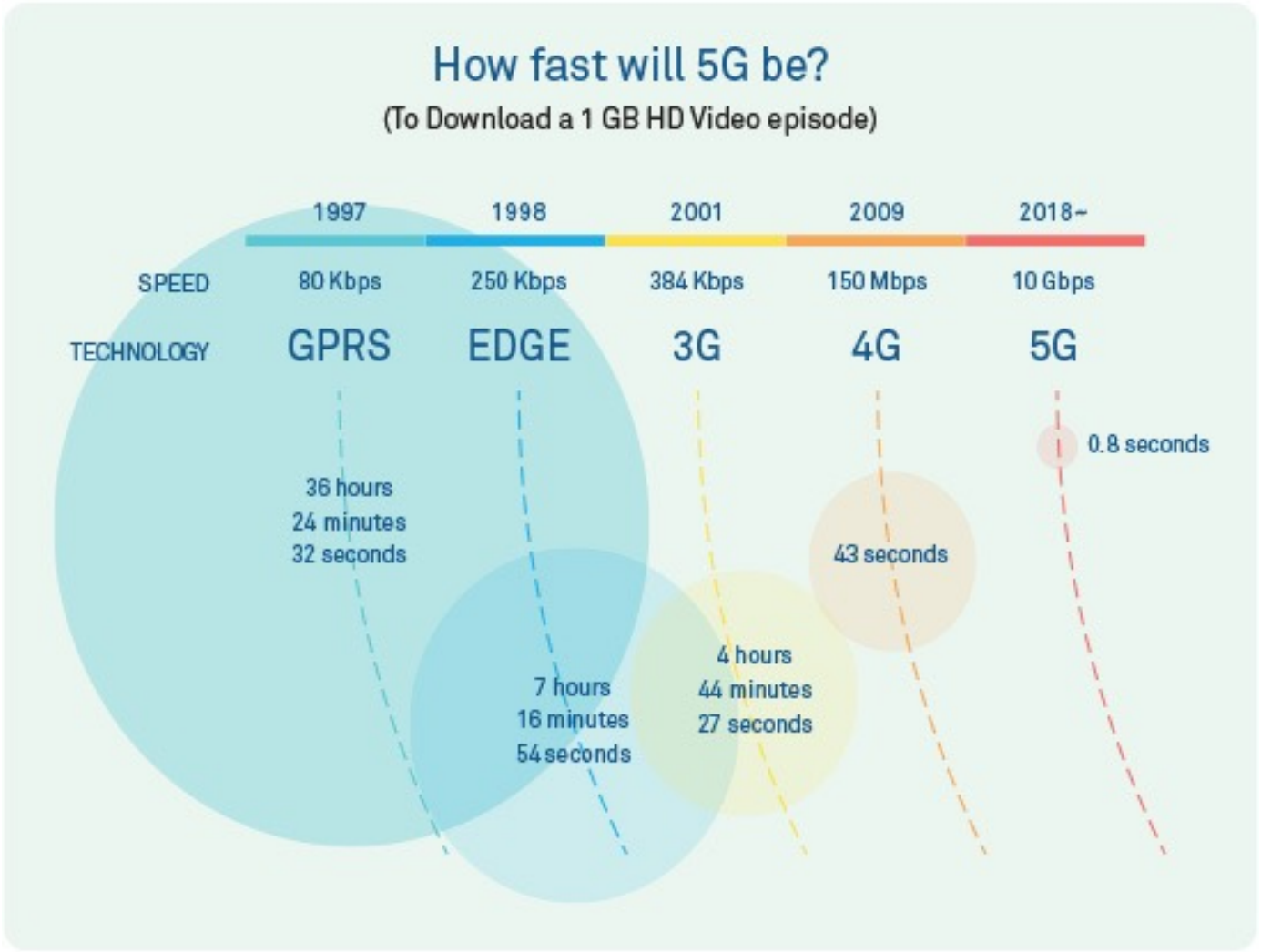
Wireless Technology Evolution

Basic Phone Call

Short Message Service

Multimedia Message Service



Massive Connections

Ultra-low Latency

Ultra-high Speed

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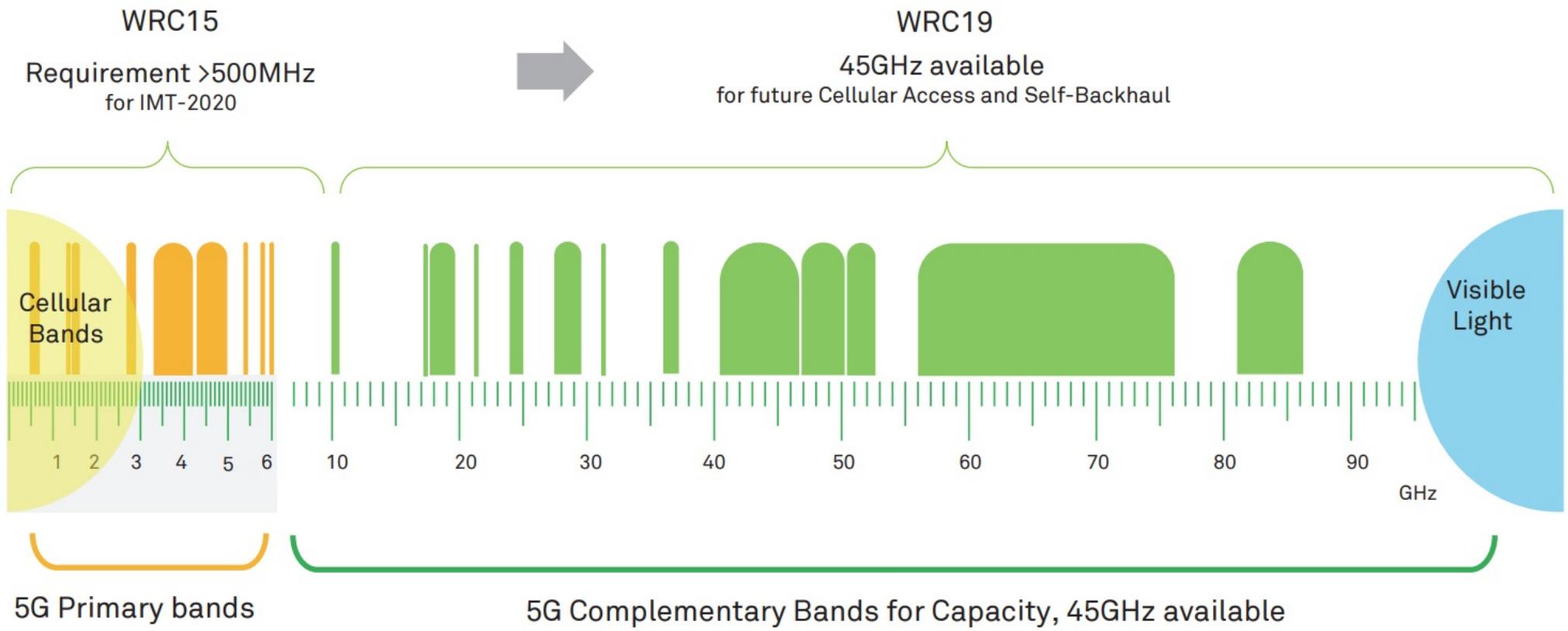
5G Spectrum Exploitation



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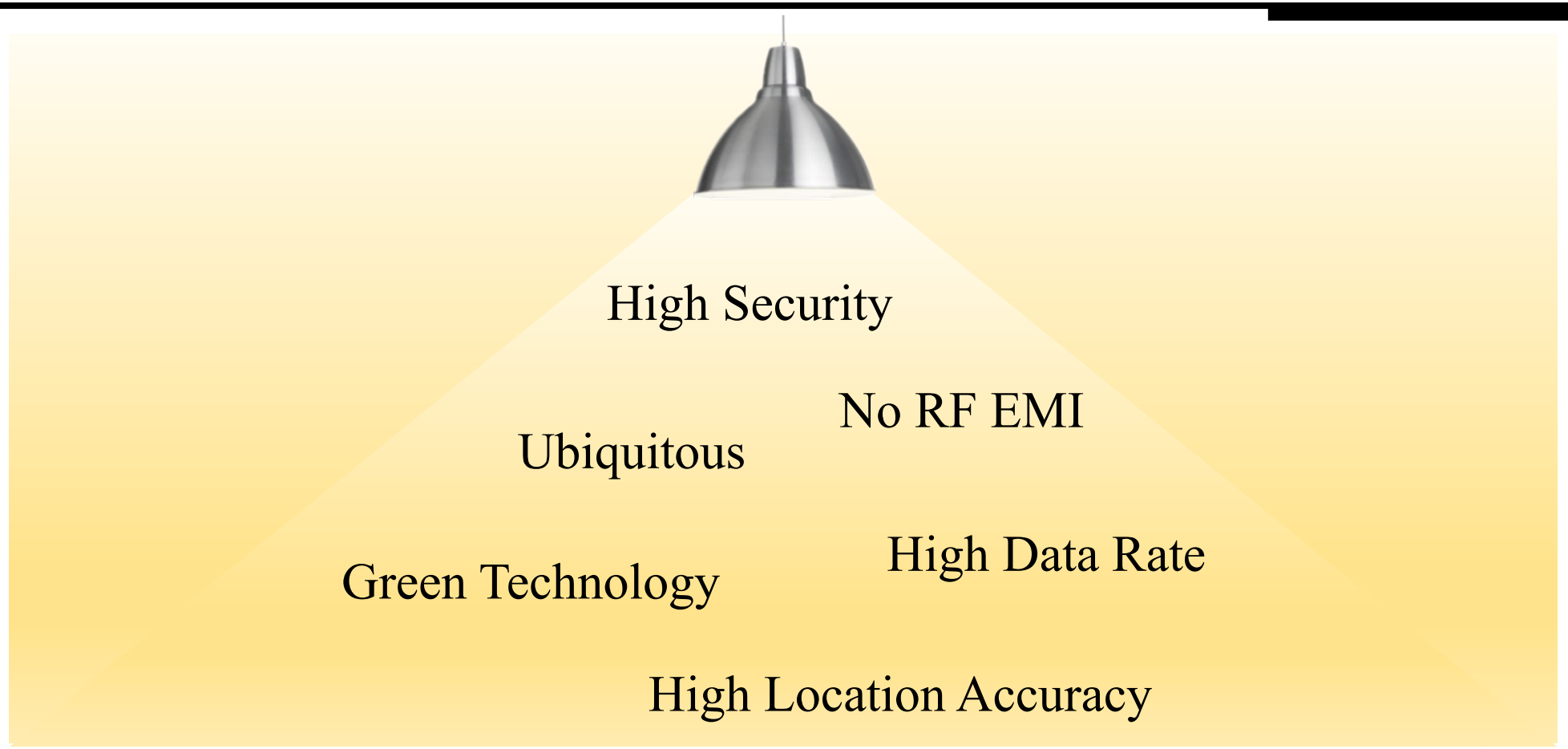
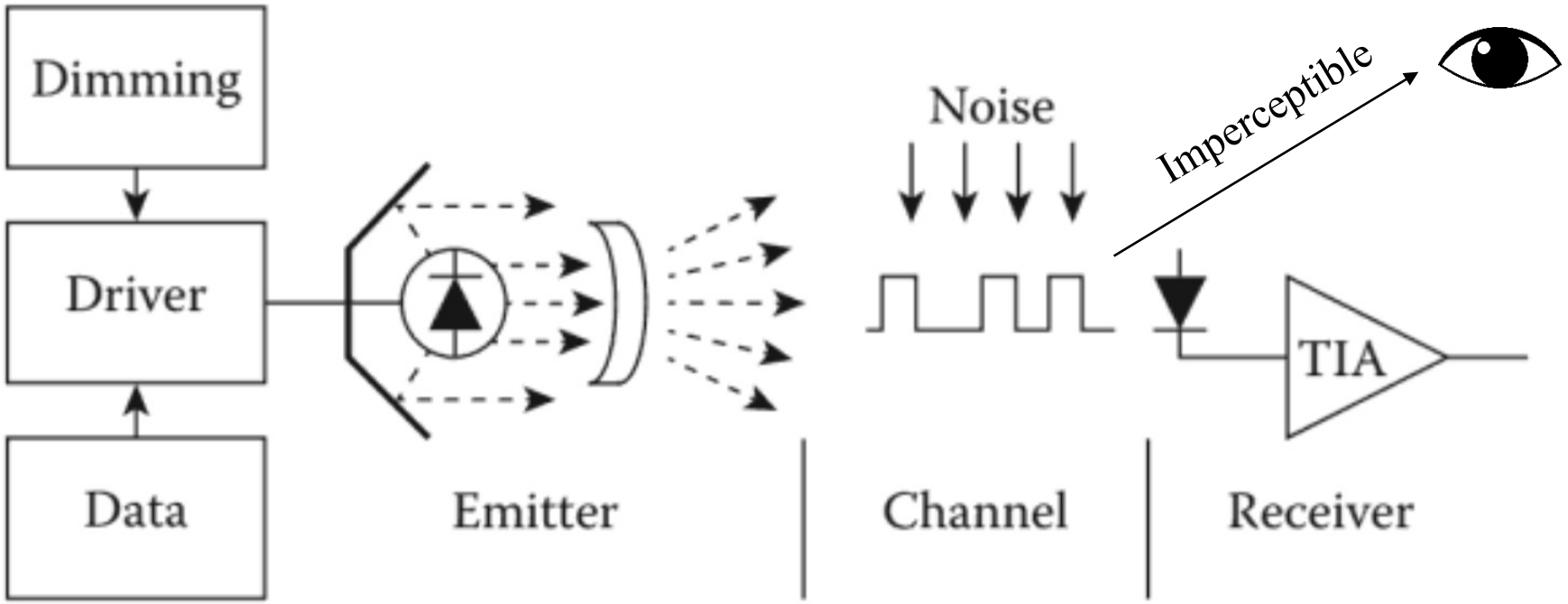
How about VLC?



Combining Lighting with Communication

- A typical VLC schematic diagram with LED transmitter and PD receiver



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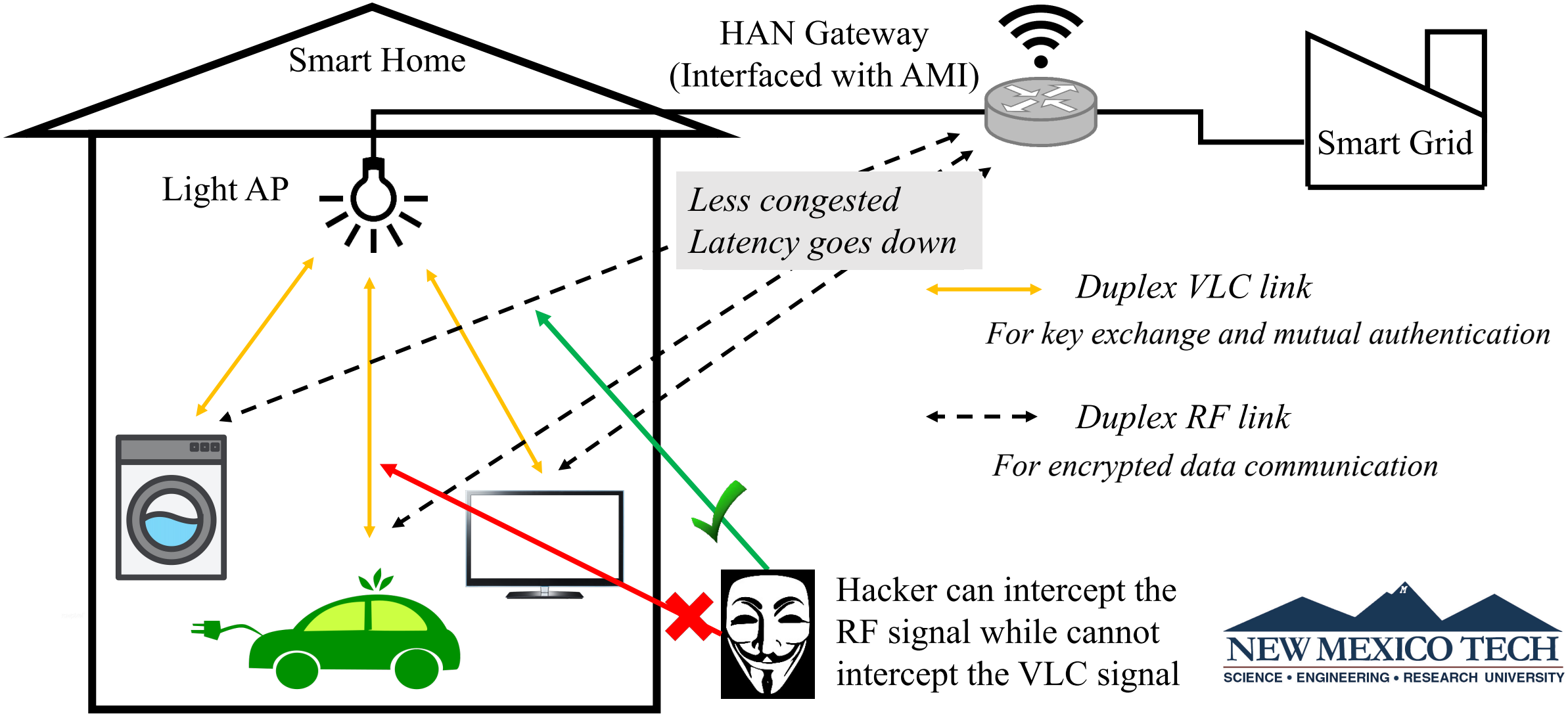
Benefits are Two-fold



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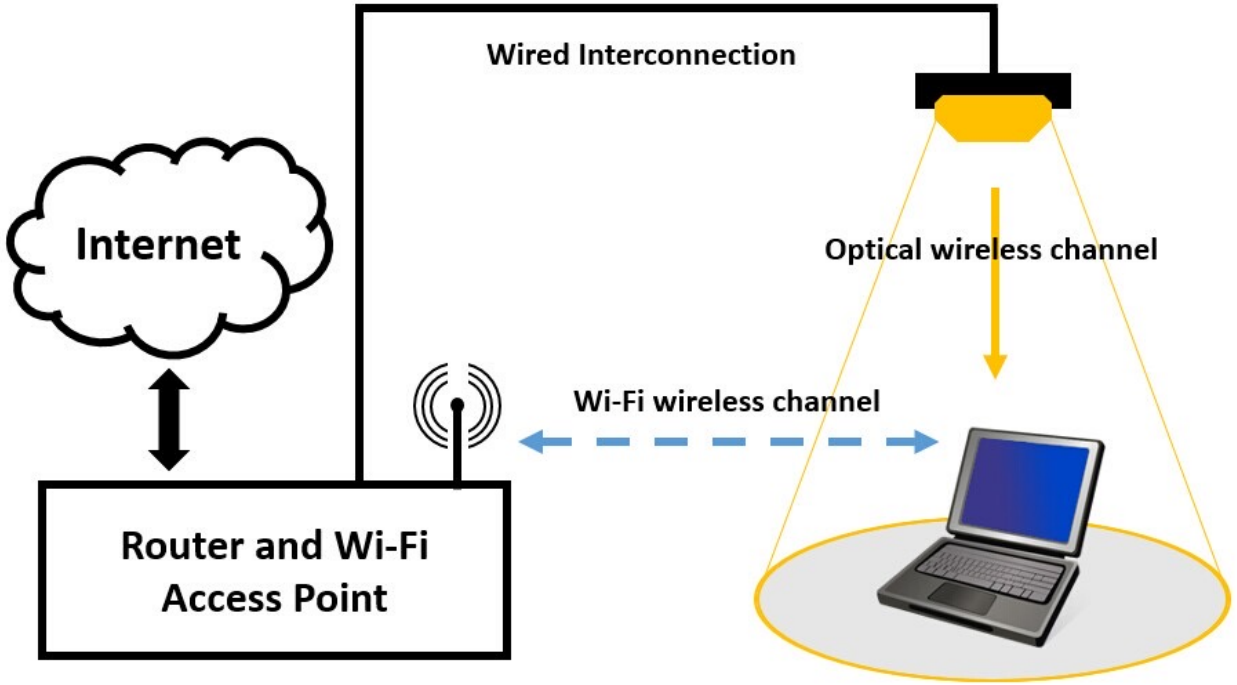
VLC Connect to the Internet - Uplink?

- Uplink of VLC is a challenge.
- Incorporate RF uplink could be a solution.



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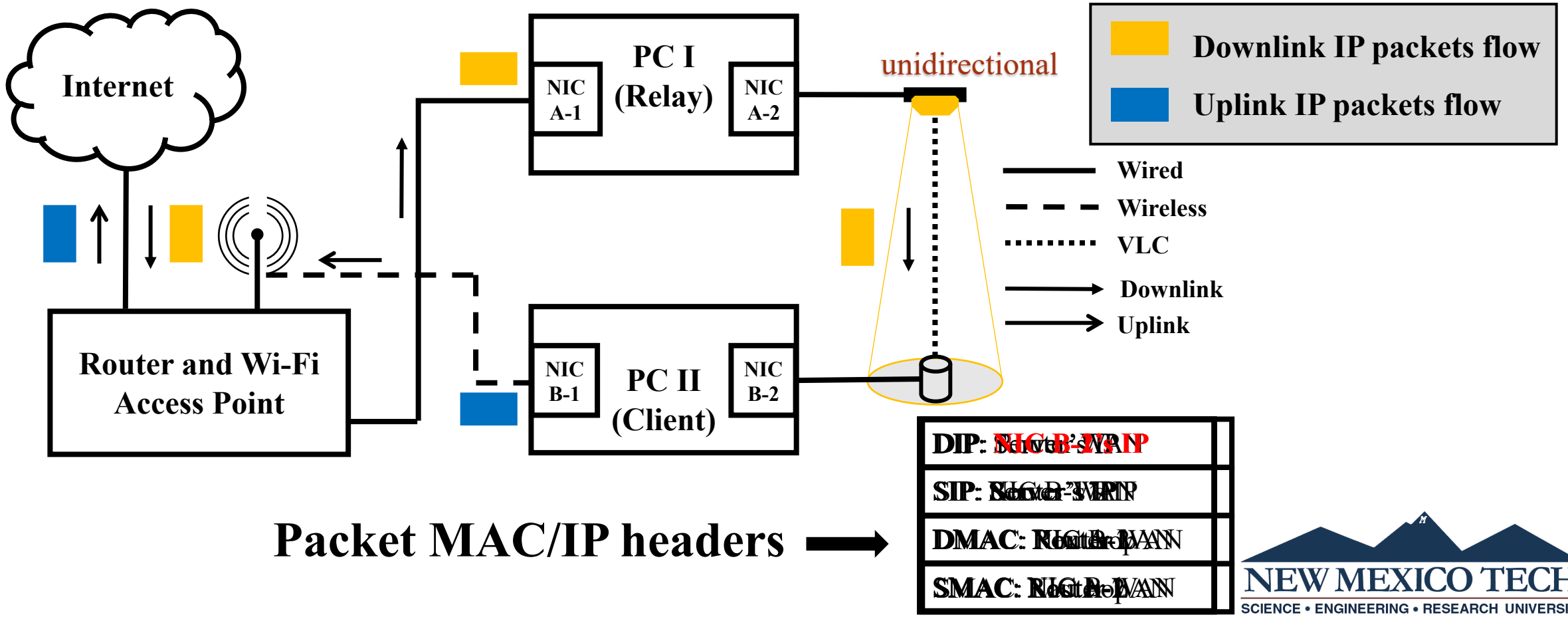
VLC Connect to the Internet - Uplink?

- **Asymmetric Li+WiFi System Architecture and Traffic Flow Demo**



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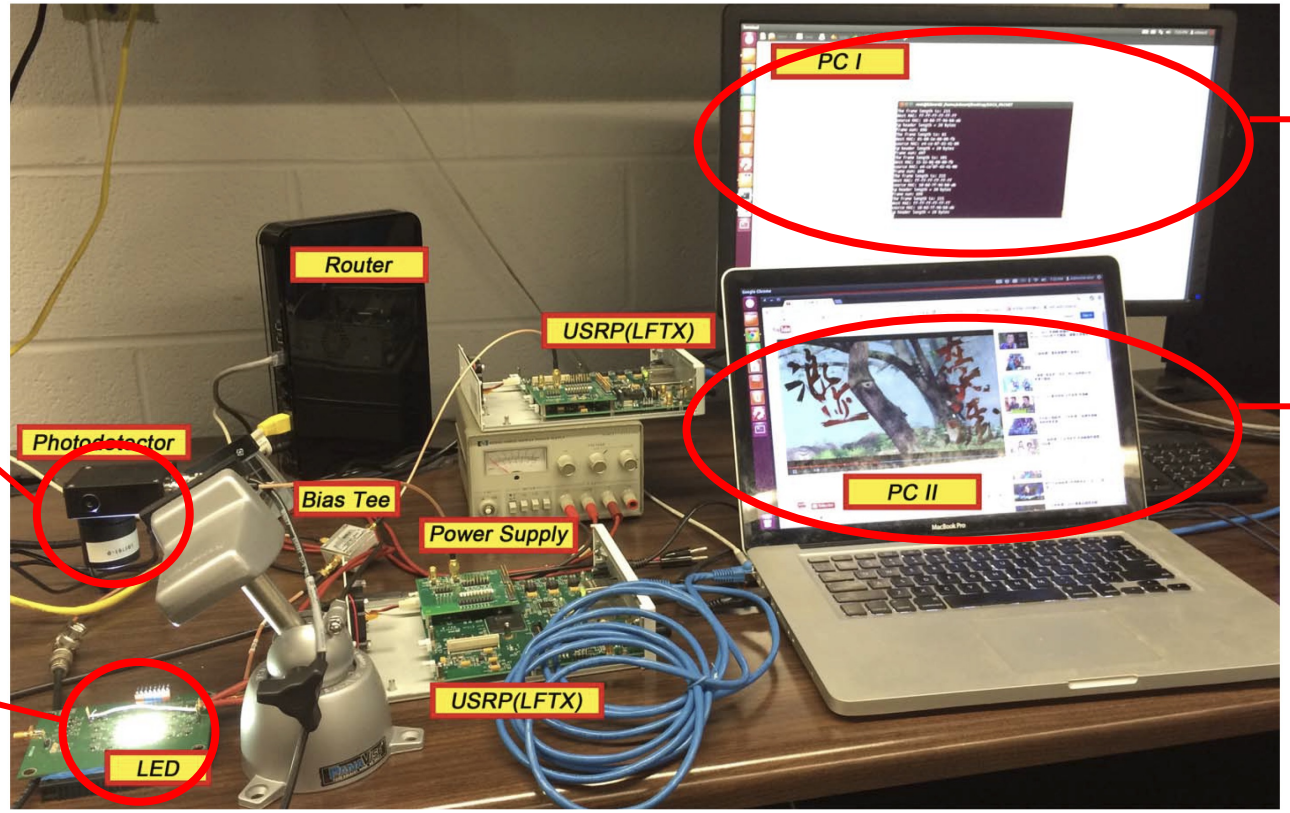
VLC Connect to the Internet - Testbed

- In the following video, we show a testbed using visible light communication (VLC) to connect to the Internet.



The client that is connected to the Internet

The receiver

The controller for software-defined VLC

The light source

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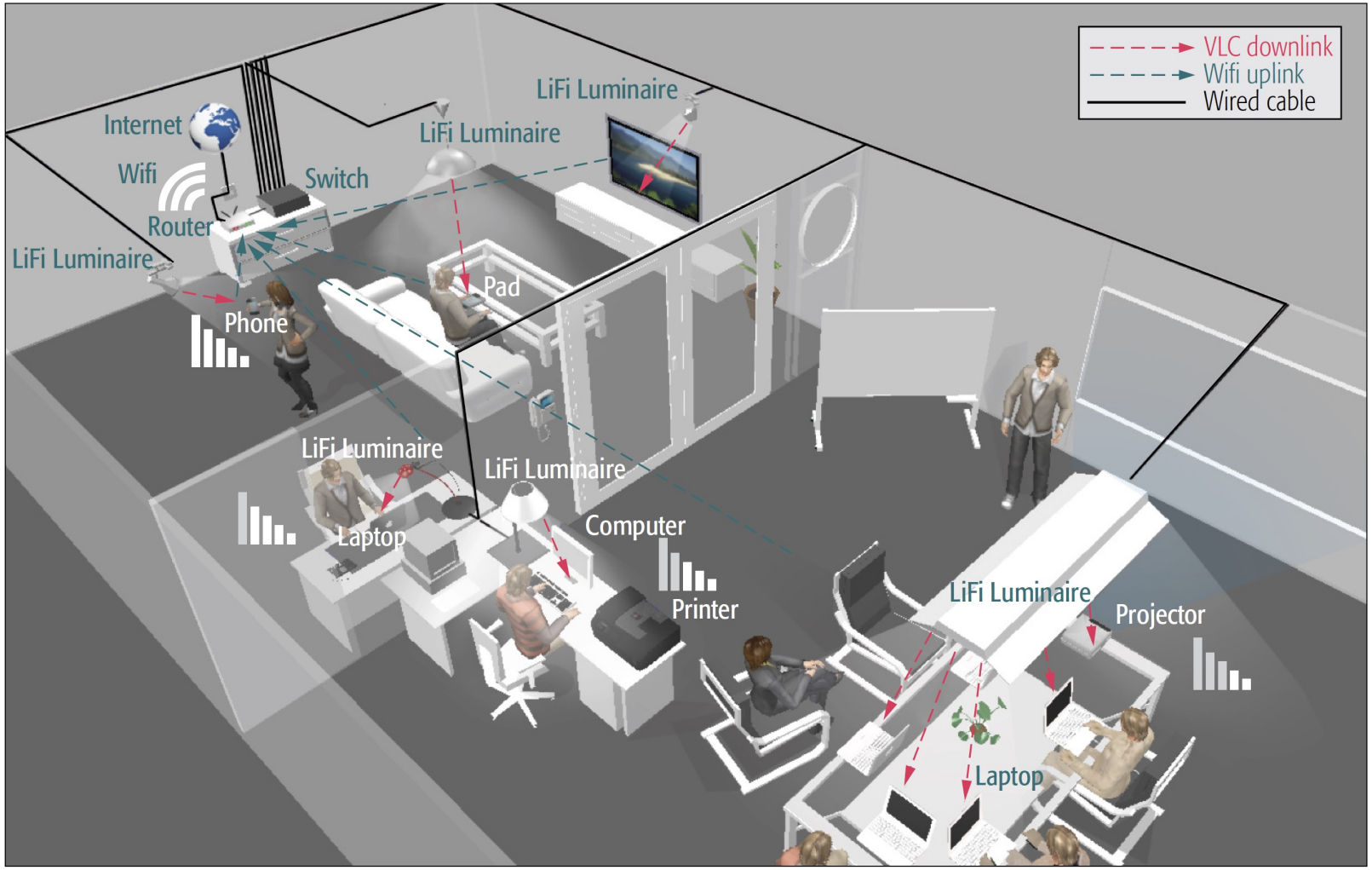
VLC Connect to the Internet

An Indoor Li+WiFi HetNet



The coexistence of LiFi and WiFi leverage ubiquitous LiFi luminaire to alleviate the wireless radio channel congestion and provide better quality of experience to the end users.

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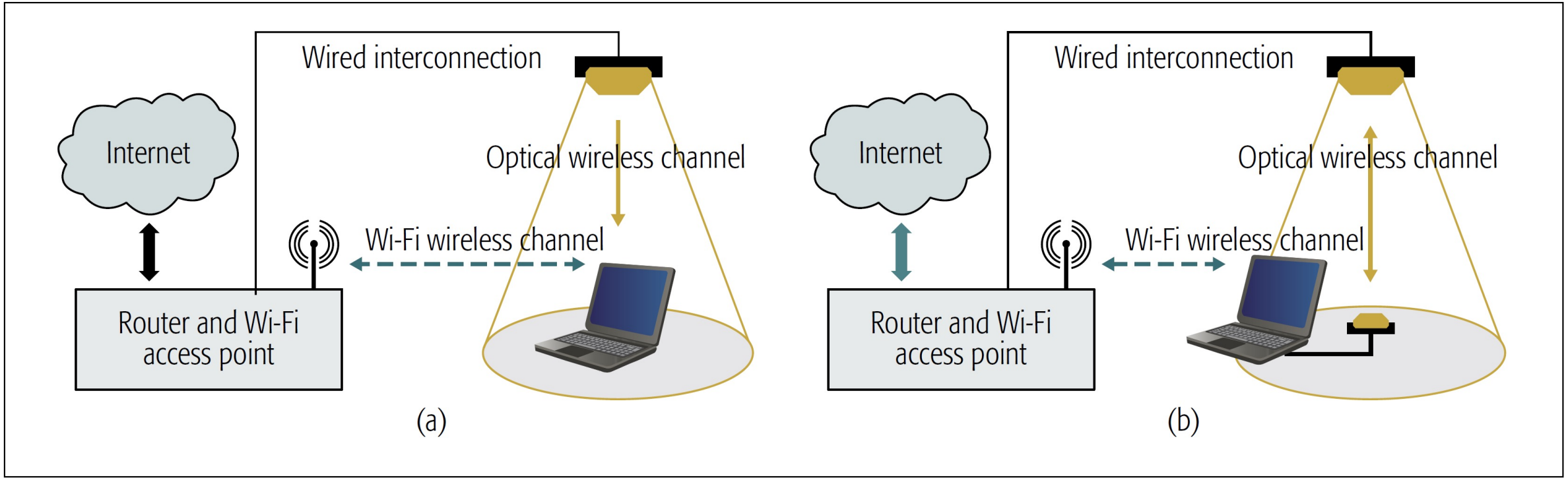
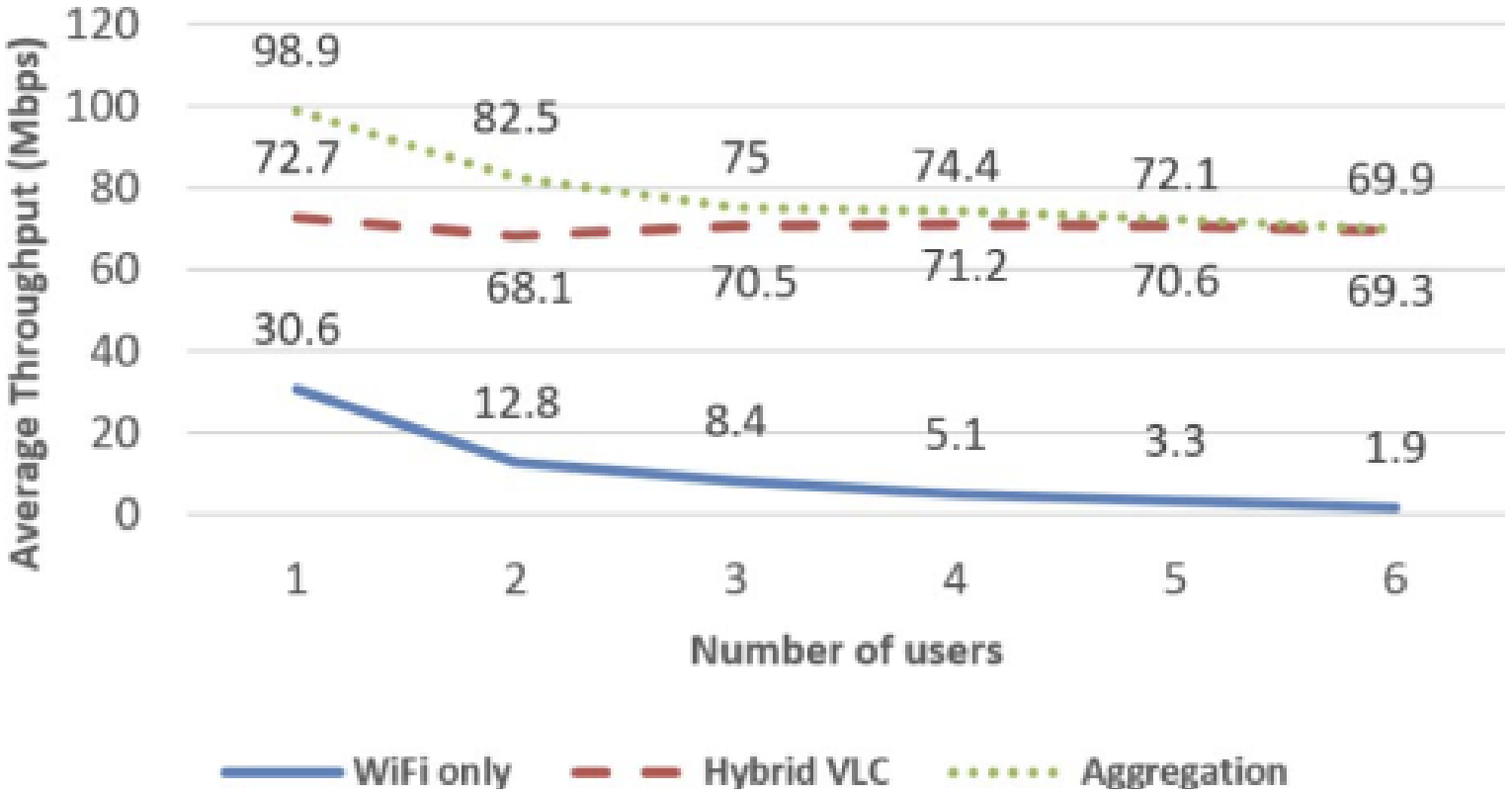
Configurations – Hybrid and Aggregated



Configurations of the a) hybrid system, and b) the aggregated system.

Experimental Results

- Throughput vs. Number of users



Keynotes:

- WiFi performs badly for more access devices.
- VLC performance is stable.
- Aggregation boosts data rate.

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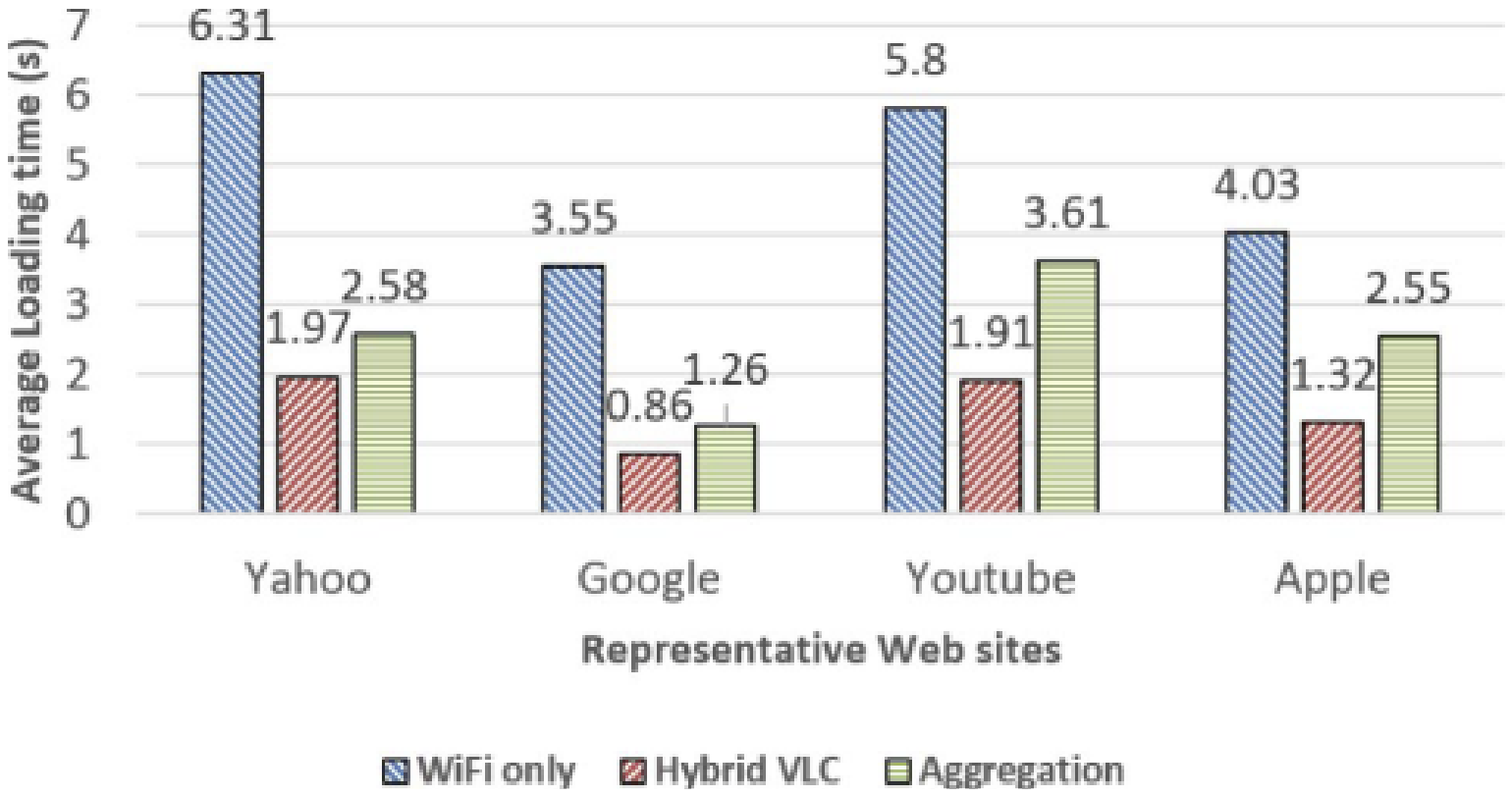
Experimental Results

- Loading time in web browsing



Keynotes:

- WiFi performs the worst.
- VLC performs the best.
- Aggregation system is held back by high WiFi latency.

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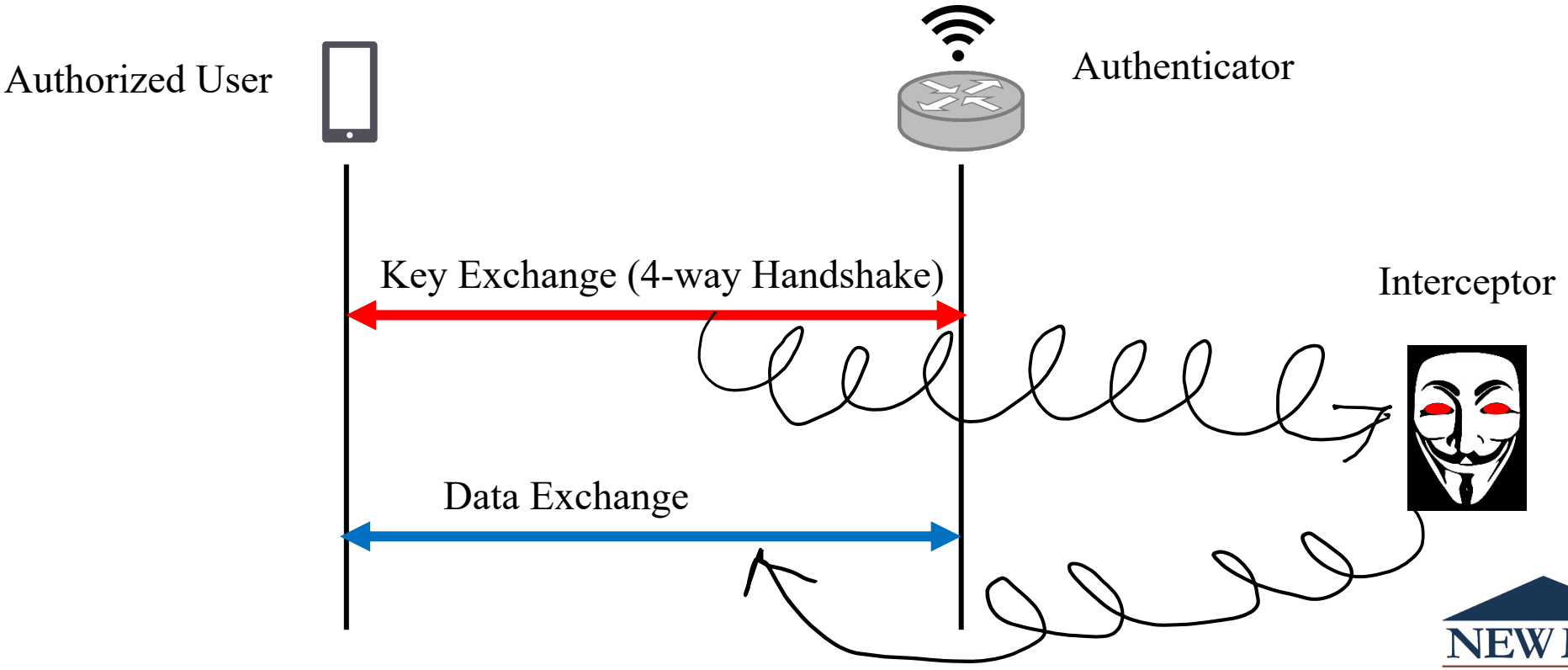
Data Privacy is Another Concern

- WLAN Vulnerability – WPA2 Personal



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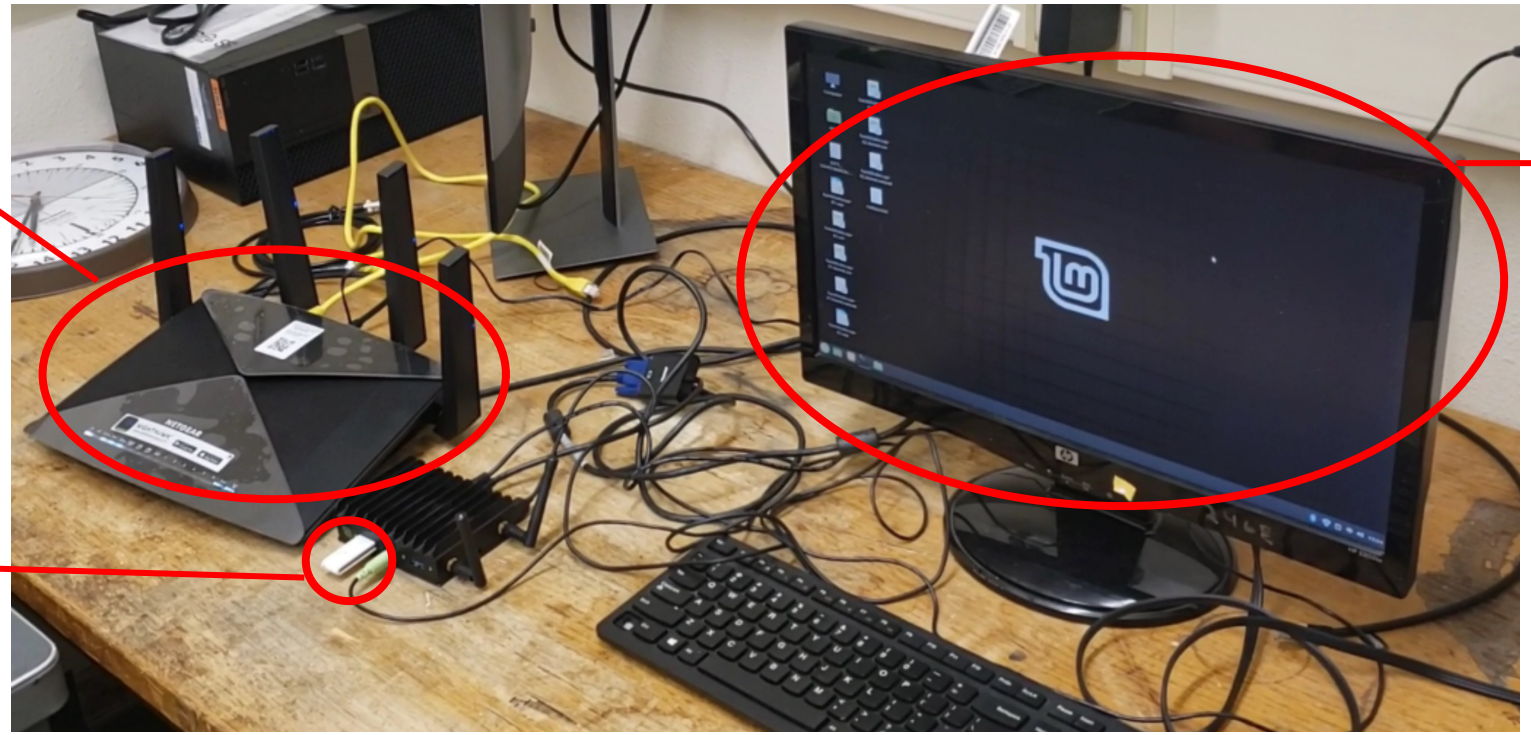
WLAN Vulnerability – WPA2 Personal

- In the following video, we show how the WiFi login password can be stolen by a passive interceptor.



WiFi Router

Wireless Adapter (Passive Interceptor)

Intercepted packets and decrypted WiFi password will be shown on this screen

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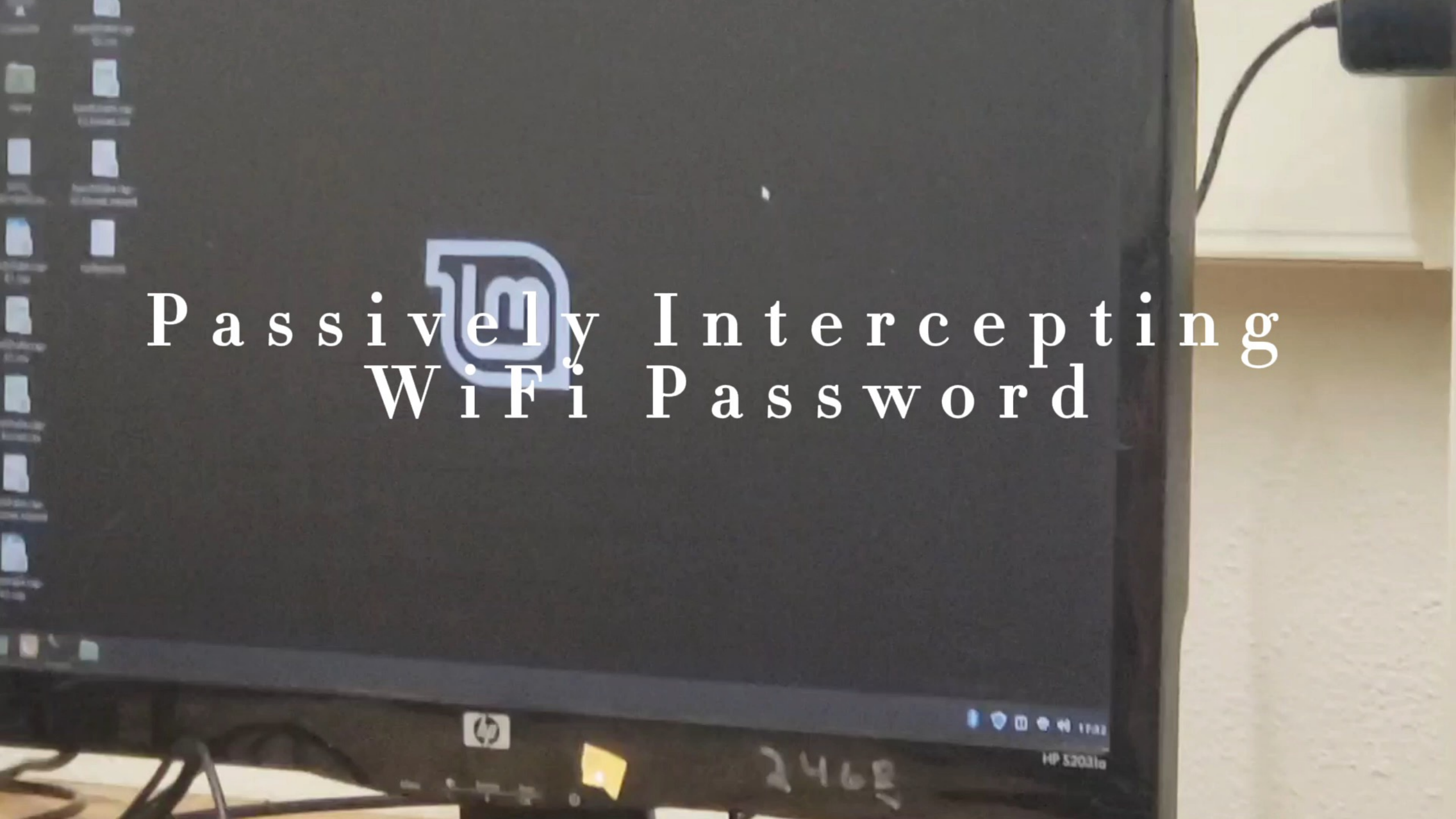
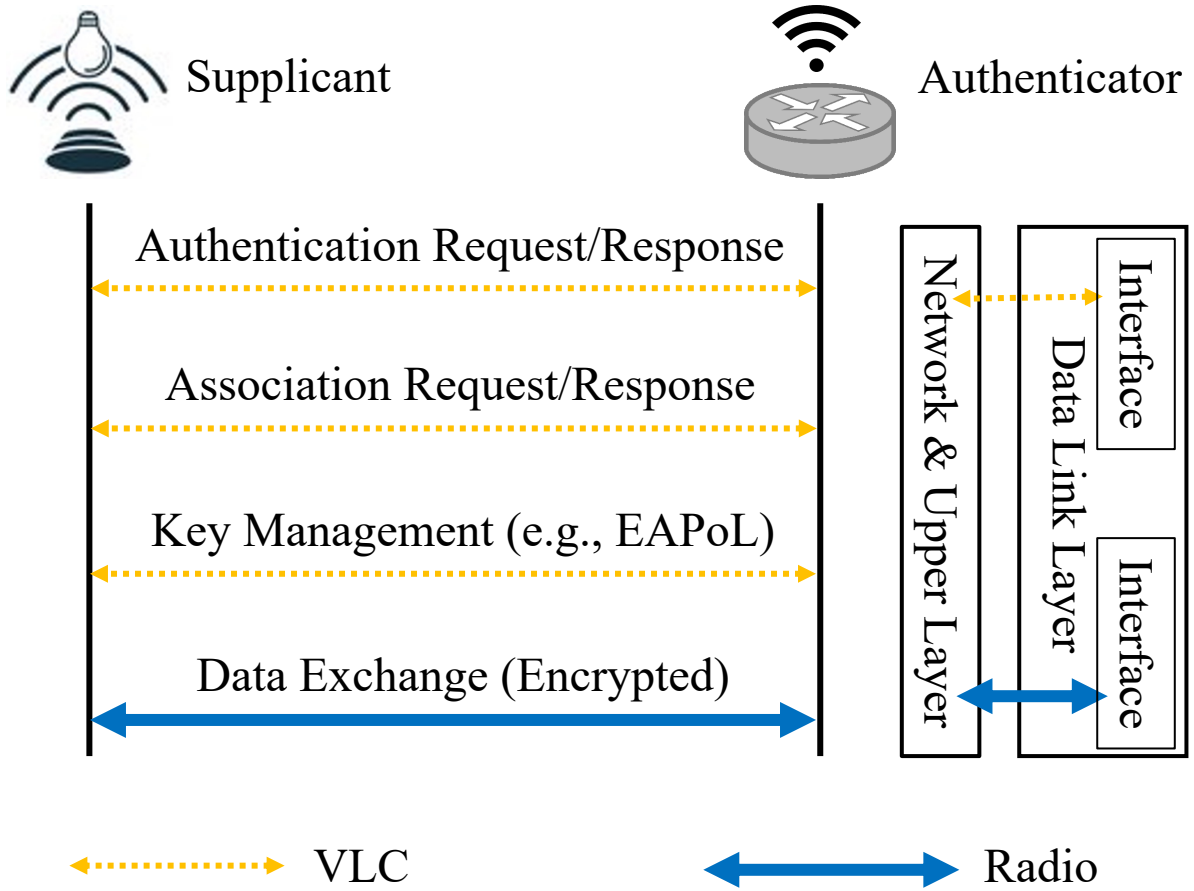

Passively Intercepting
WiFi Password

VLC Could be A Solution

- Sensitive data is exchanged on the VLC link.



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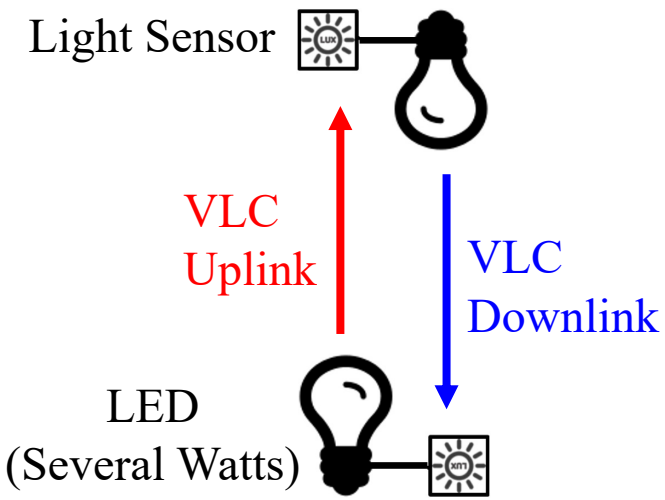
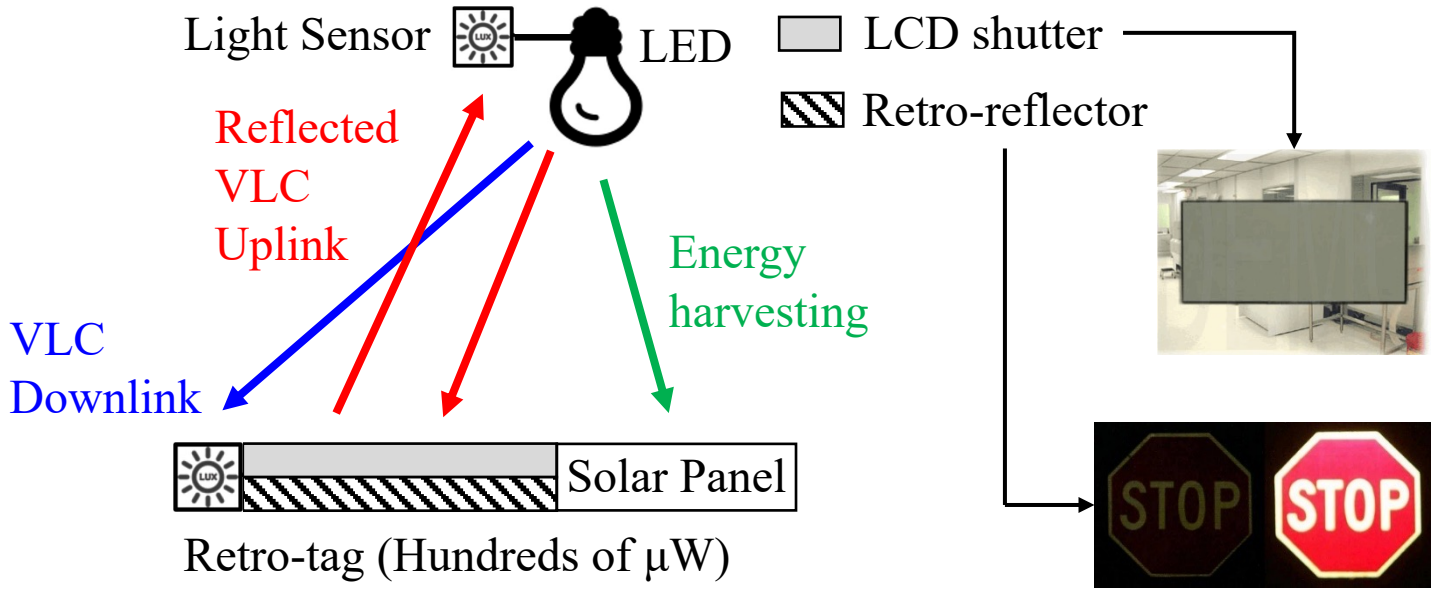
Maybe Retro-VLC is Better?

Conventional Symmetric VLC



- High power
- Miss uplink alignment
- Potential uplink glaring
- Bulky size

Ultra-low-power Asymmetric Retro-VLC



- Ultra-low-power uplink transmission
- Uplink alignment ensured by retro-reflectivity
- No diffused uplink glaring light
- Small size and light weight

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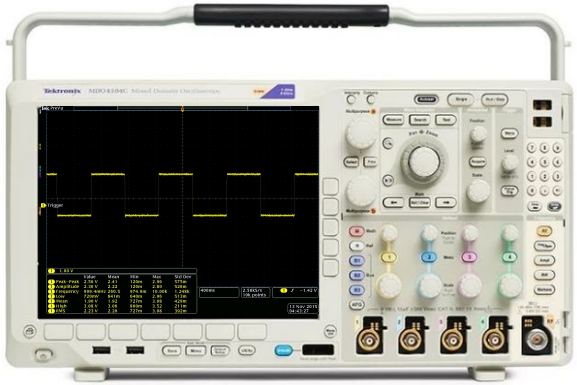
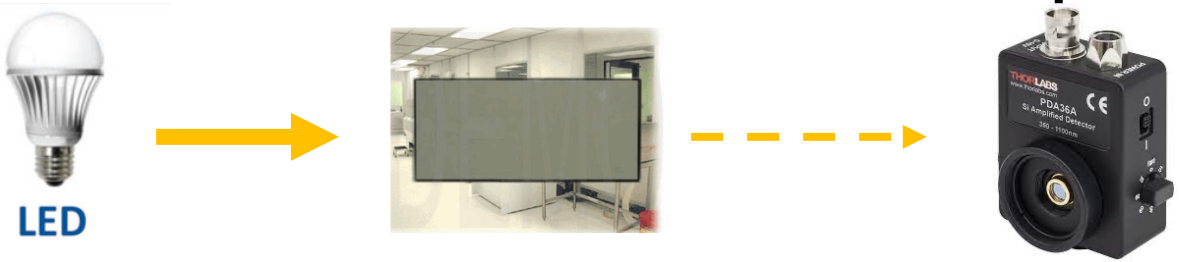
The Bandwidth is Limited

- Twisted Nematic shutter:
  - Low voltage (~ 3.3 V)
  - Low frequency (~ 200 Hz)
- Pi-cell shutter:
  - High voltage (> 10 V)
  - High frequency (up to 5 kHz)

Let's do some experiments:





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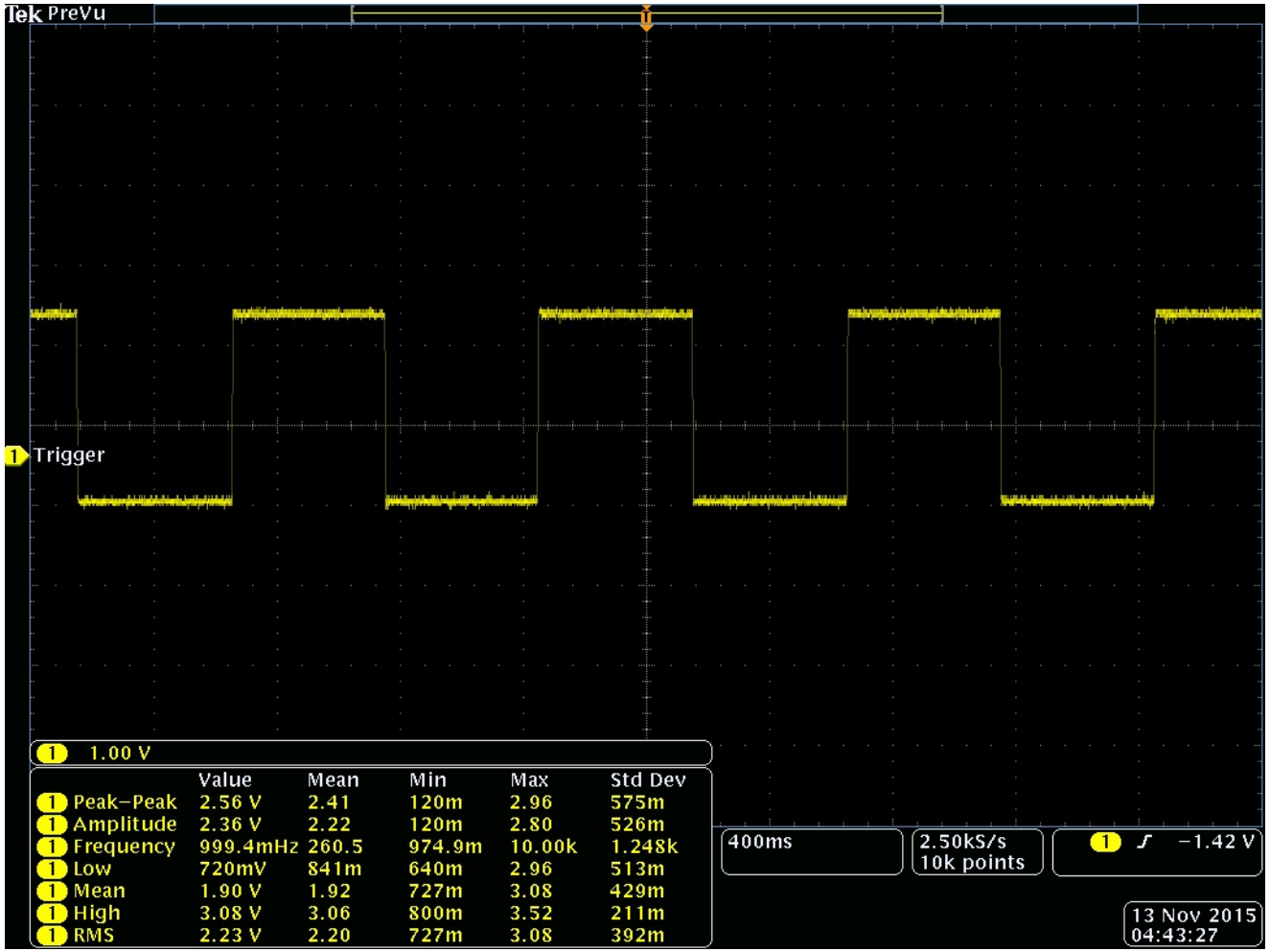
Bottleneck of LCD shutters



Modulation Frequency

2 Hz

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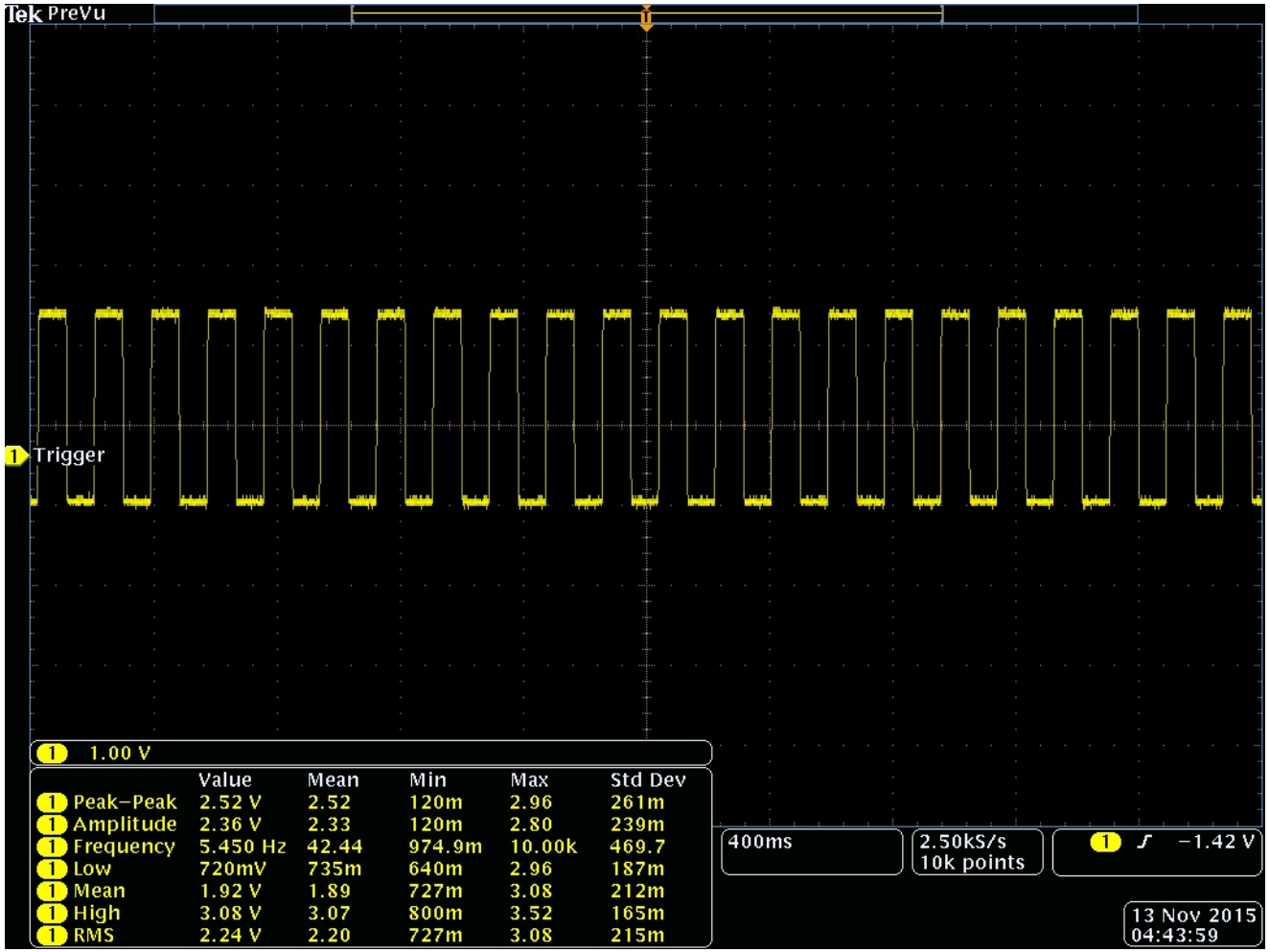
Bottleneck of LCD shutters



Modulation Frequency

10 Hz

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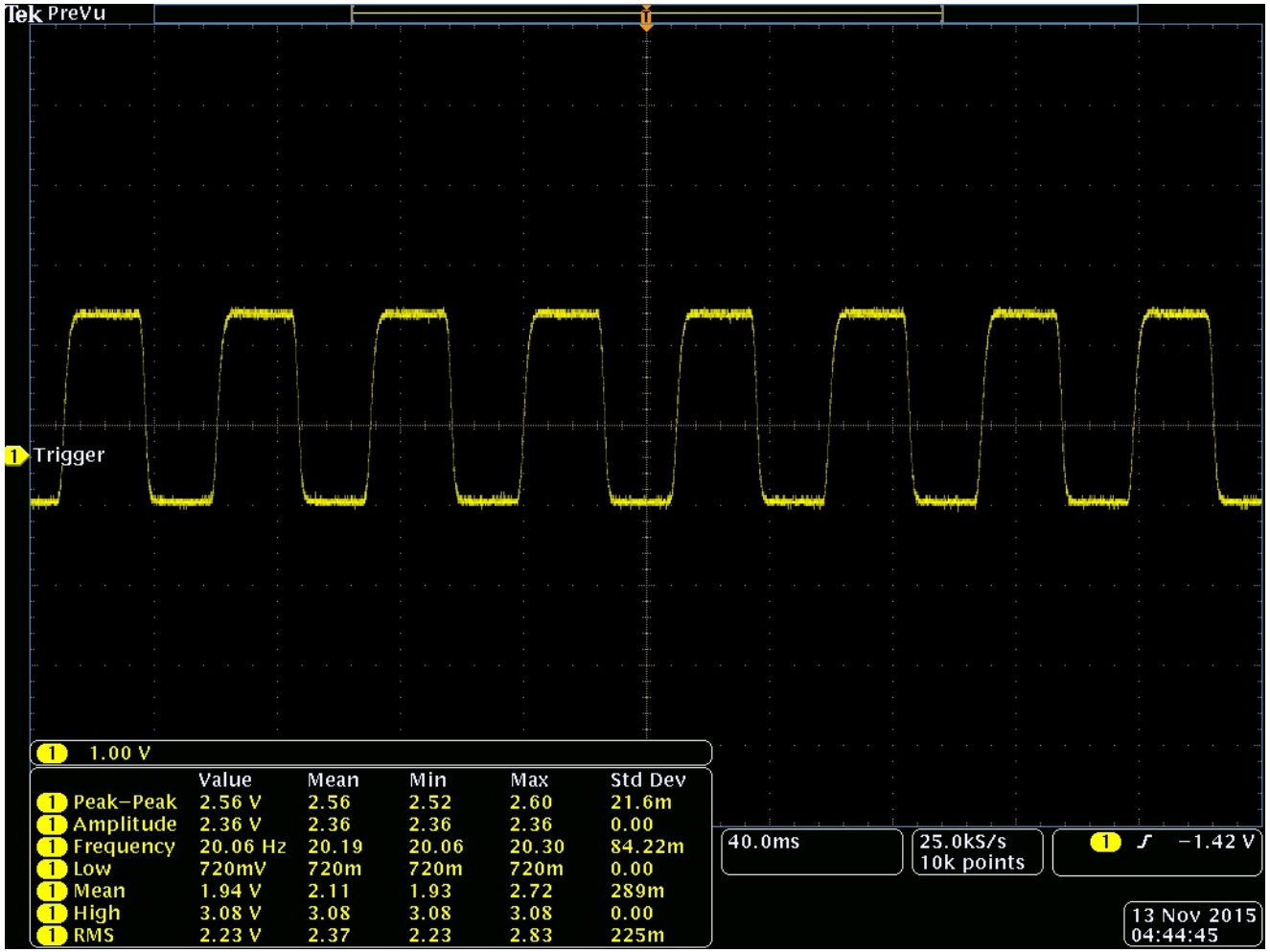
Bottleneck of LCD shutters



Modulation Frequency

40 Hz

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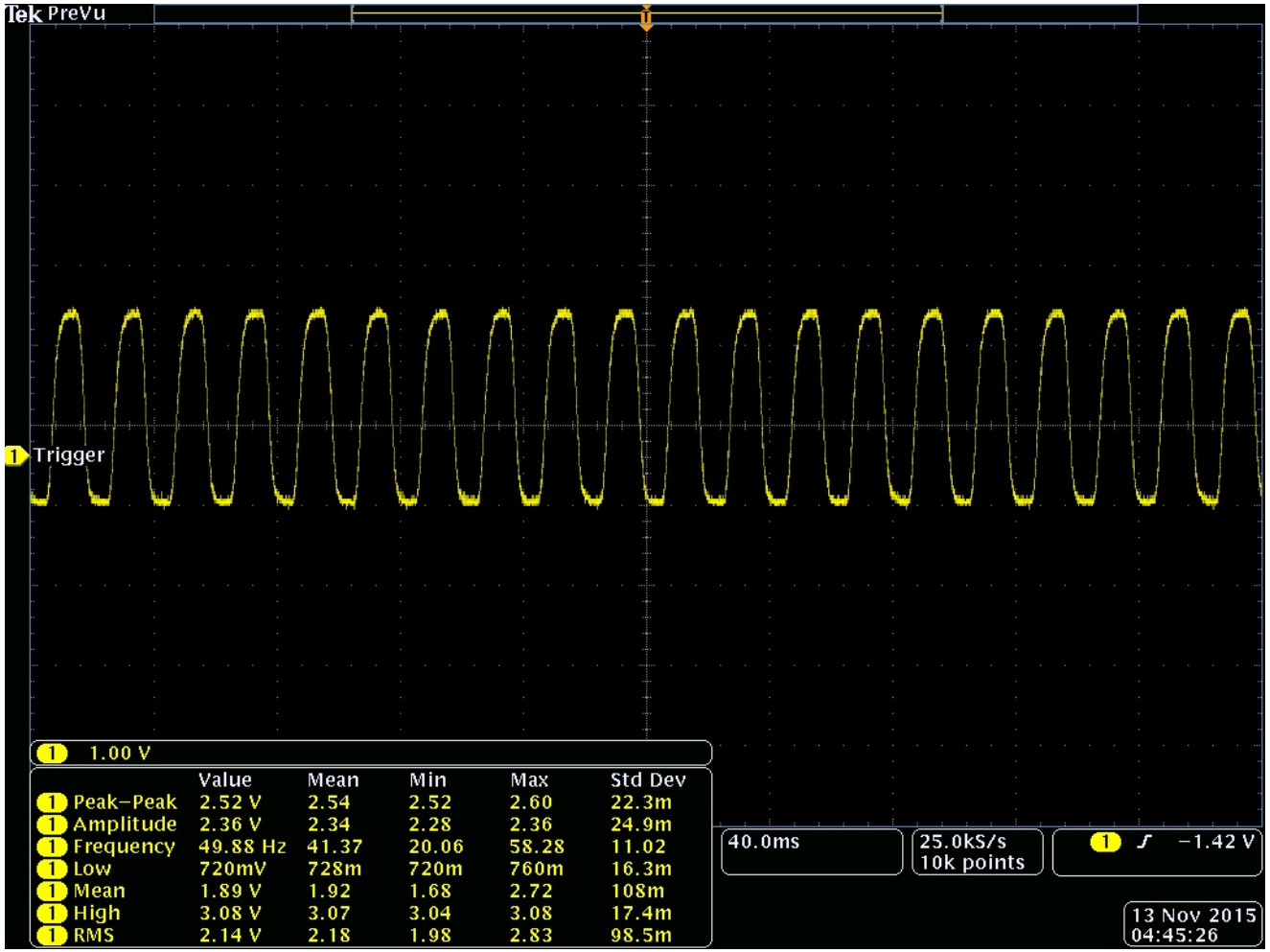

Modulation Frequency

100 Hz

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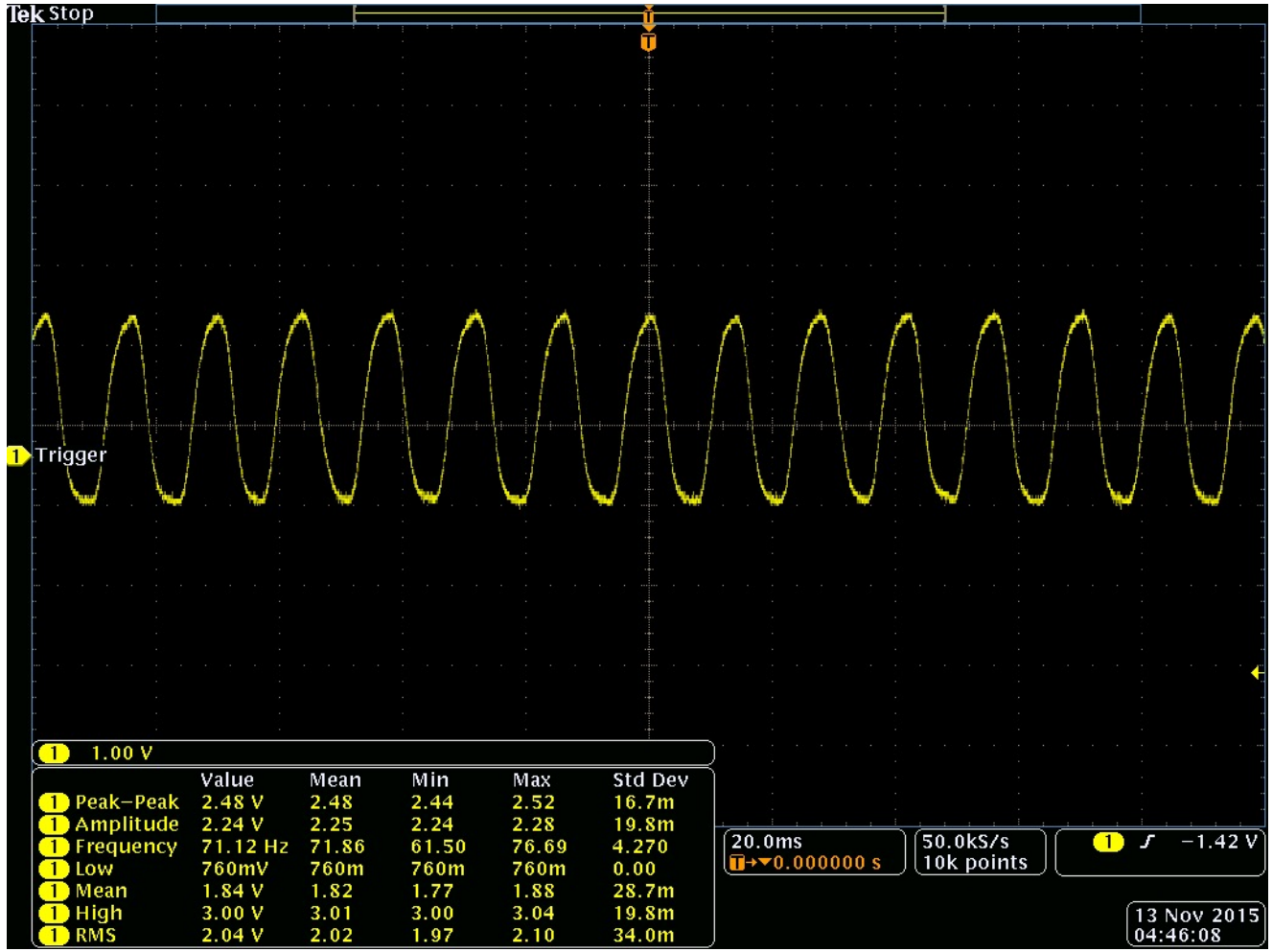
Bottleneck of LCD shutters



Modulation Frequency

140 Hz

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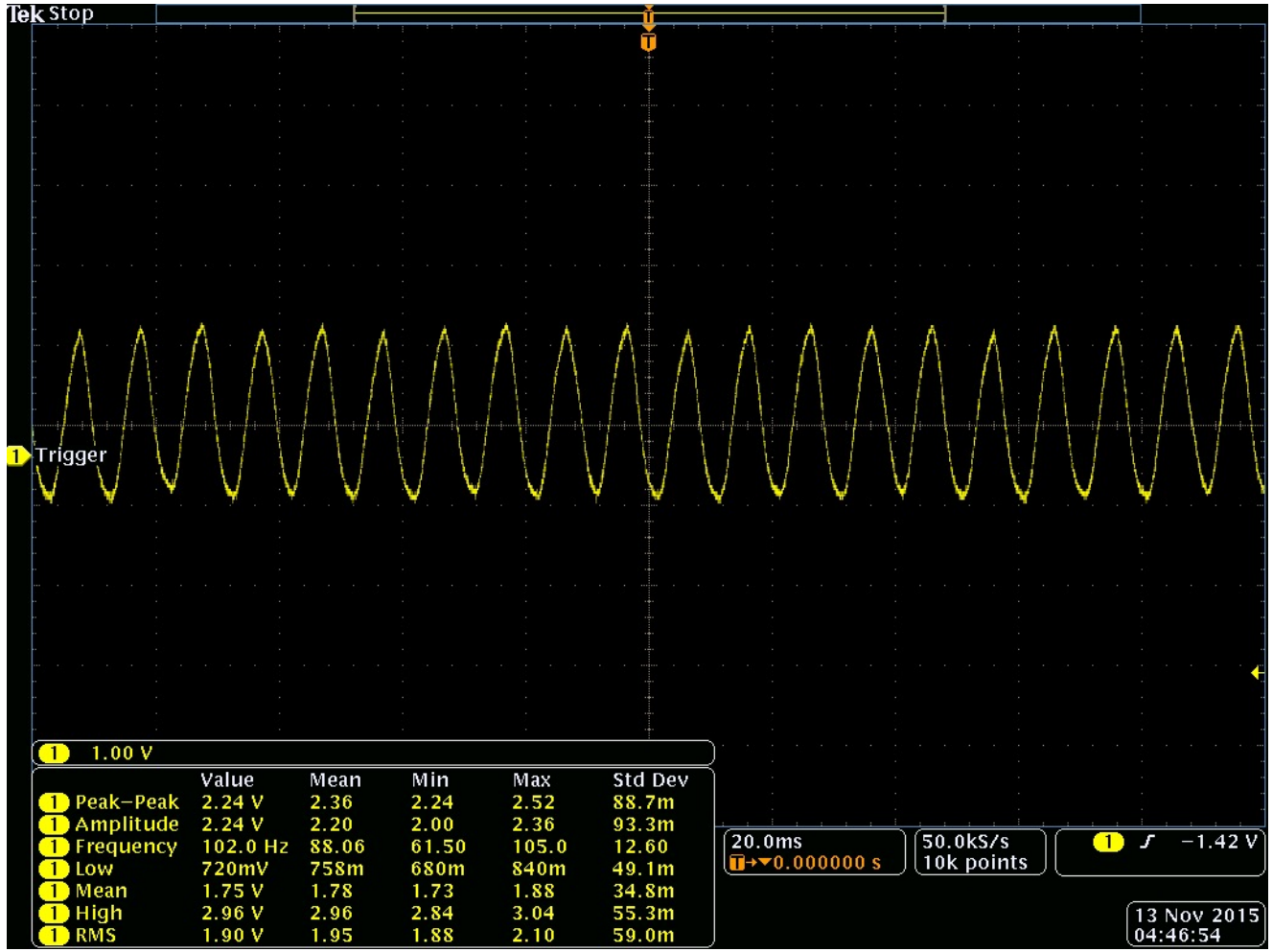
Bottleneck of LCD shutters



Modulation Frequency

200 Hz

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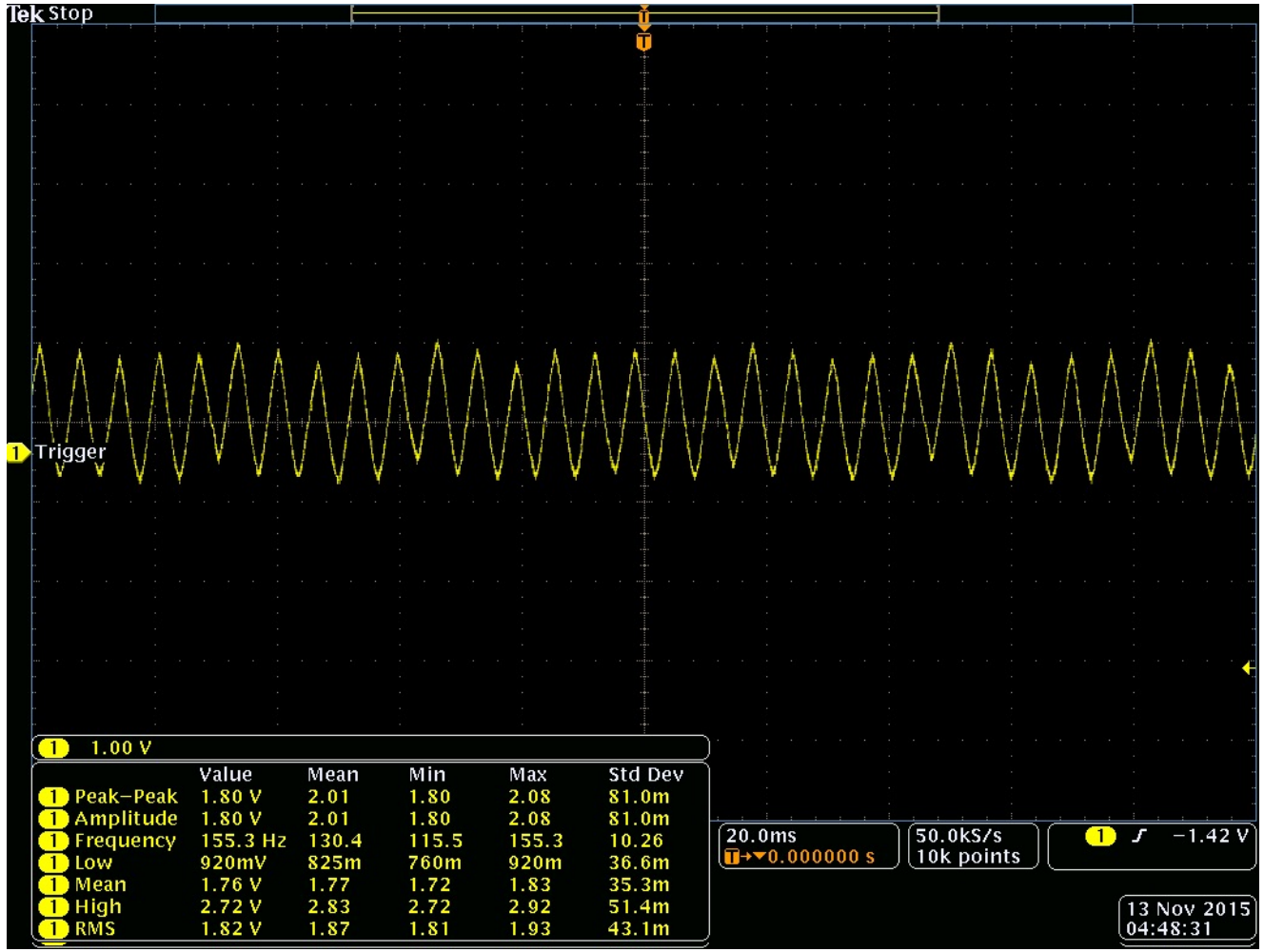
Bottleneck of LCD shutters



Modulation Frequency

300 Hz

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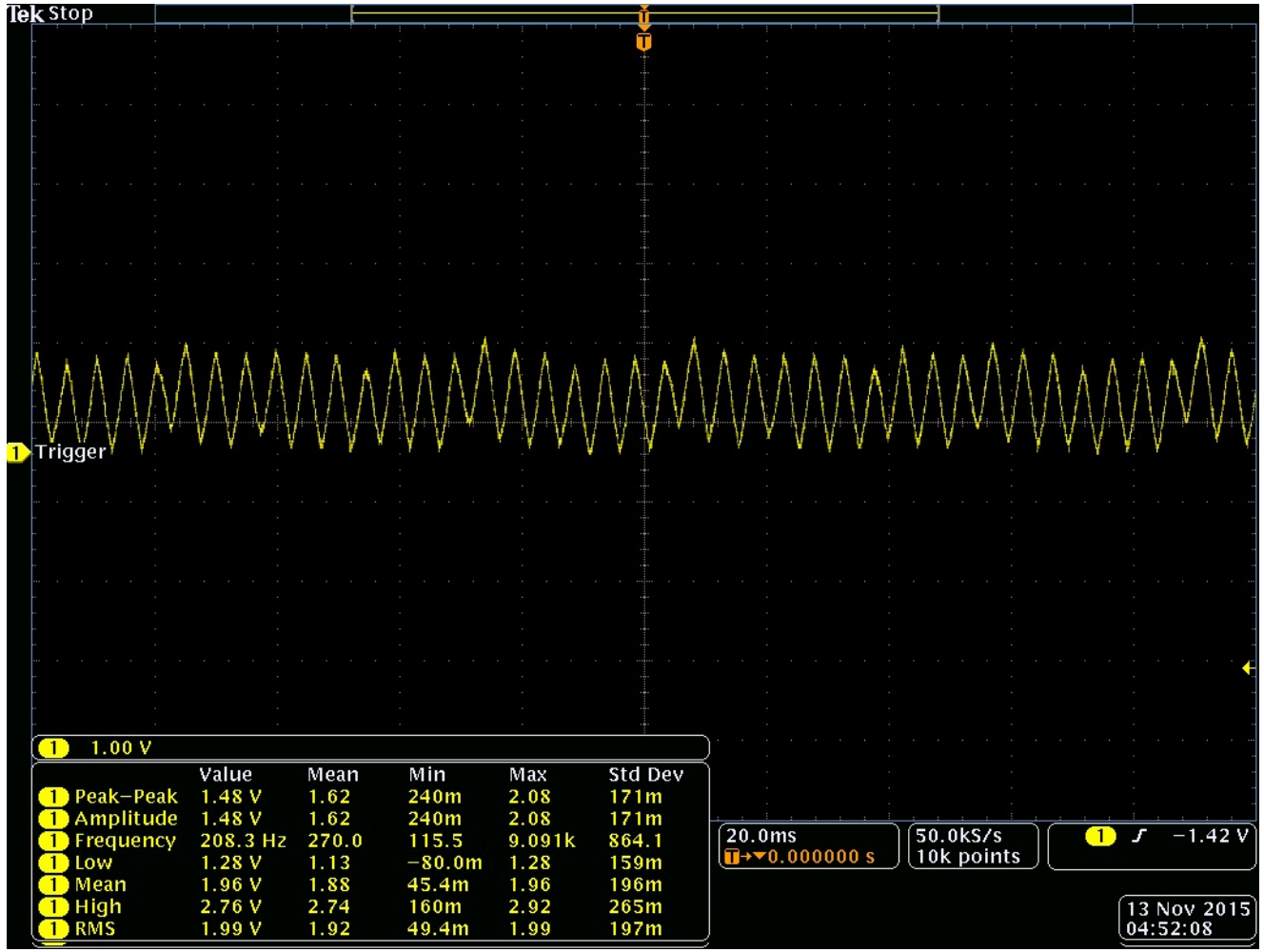
Bottleneck of LCD shutters



Modulation Frequency

400 Hz

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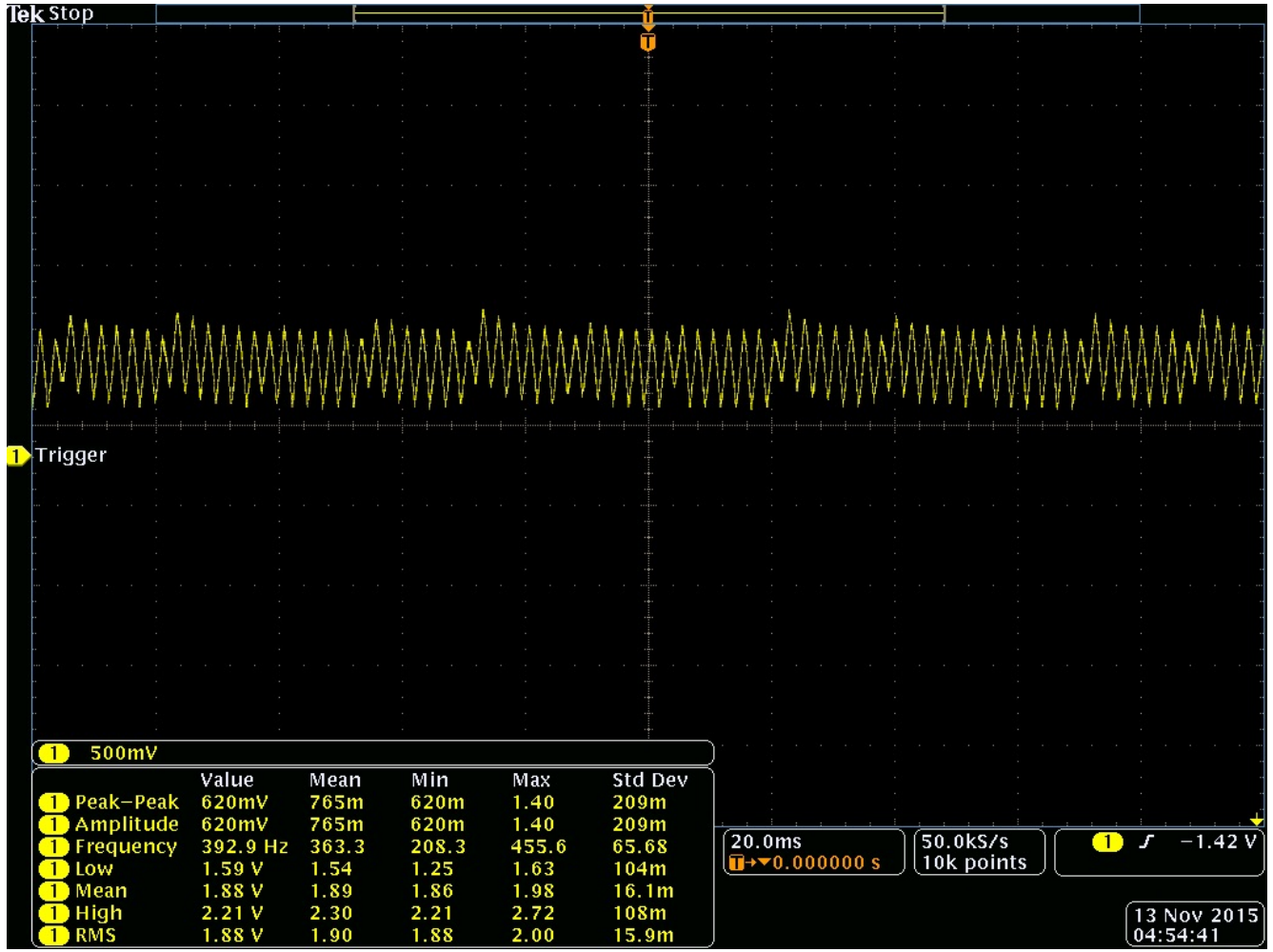
Bottleneck of LCD shutters



Modulation Frequency

800 Hz

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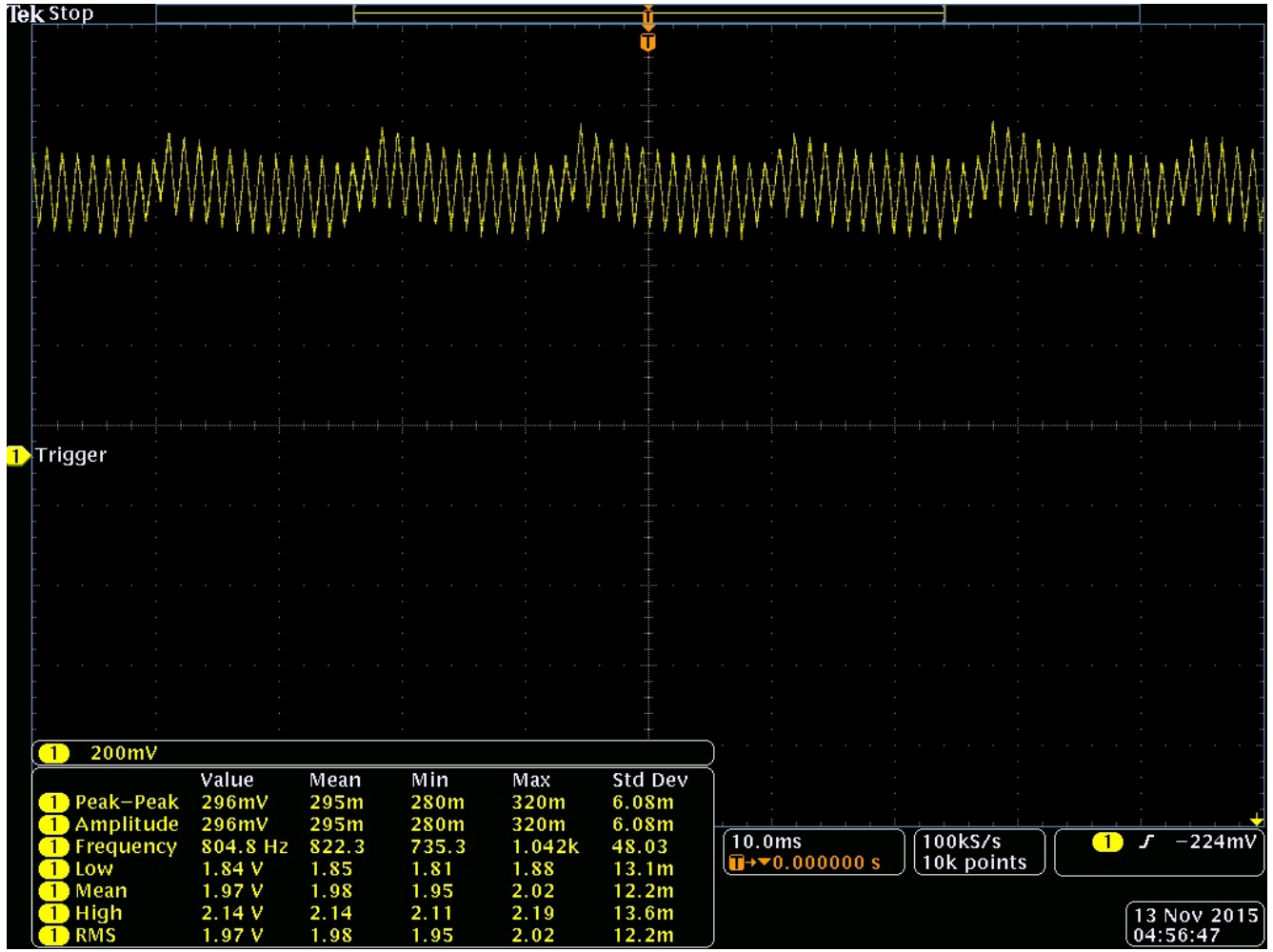
Bottleneck of LCD shutters



Modulation Frequency

1600 Hz

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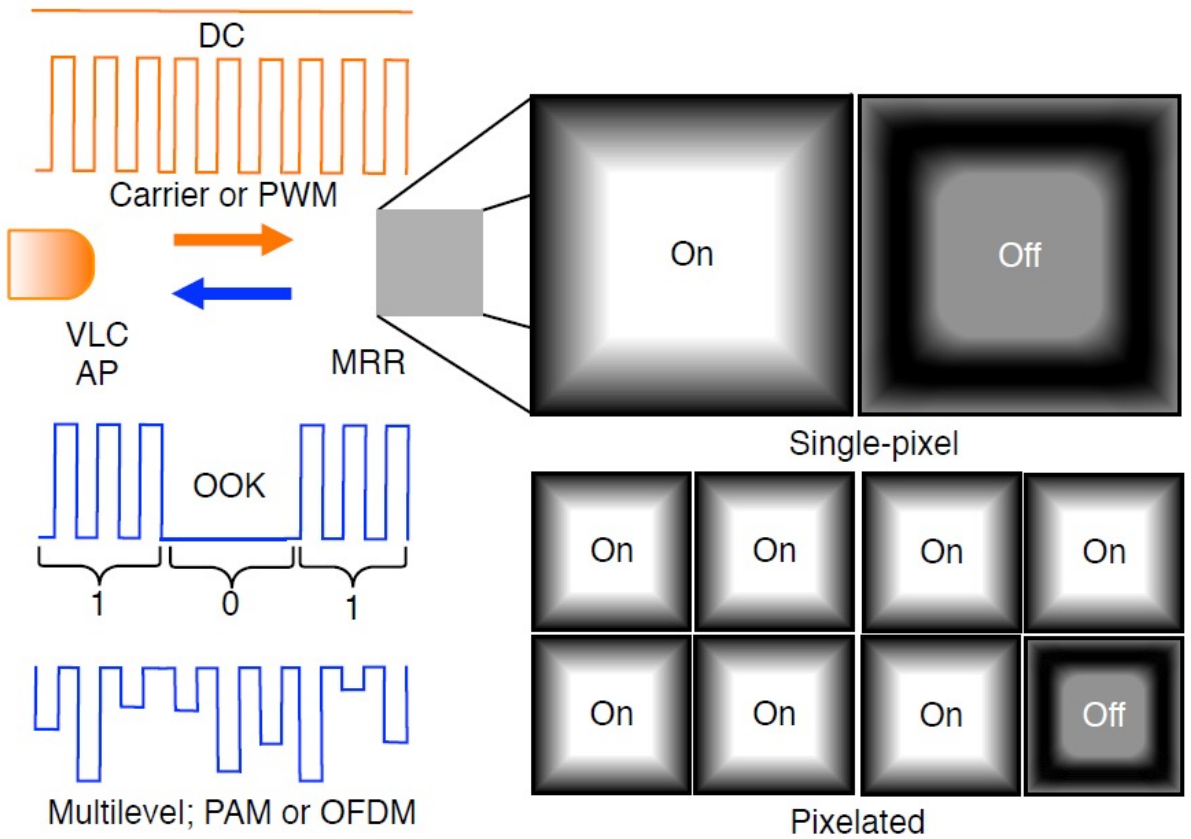
A Novel Pixelated Retro-VLC Tag

- Instead of using one shutter, multiple smaller shutters form the pixelated Retro-VLC tag.
- Smaller LCD shutters has faster switching speed.
- Multi-level optical signals are enabled.
- PAM, OFDM modulation schemes are possible.



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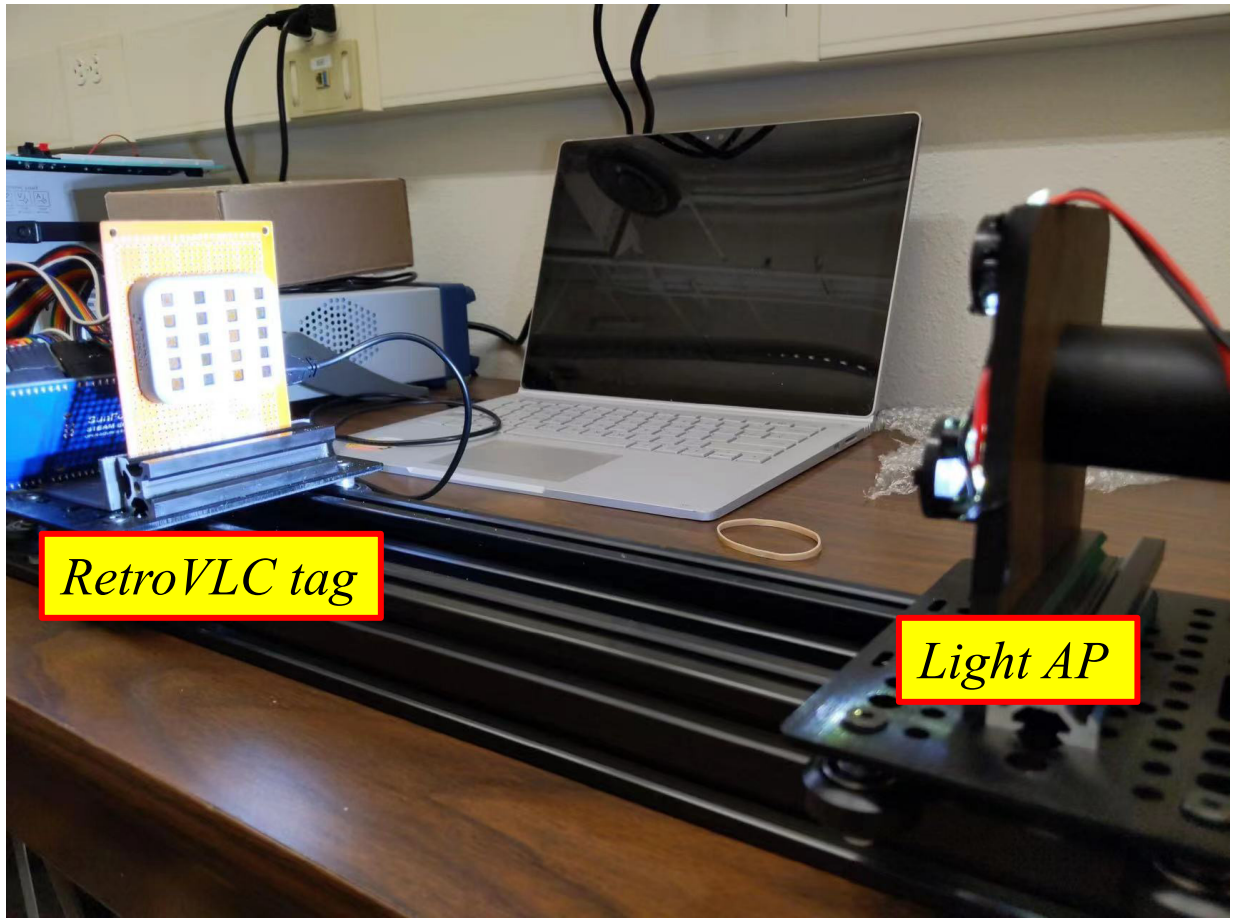
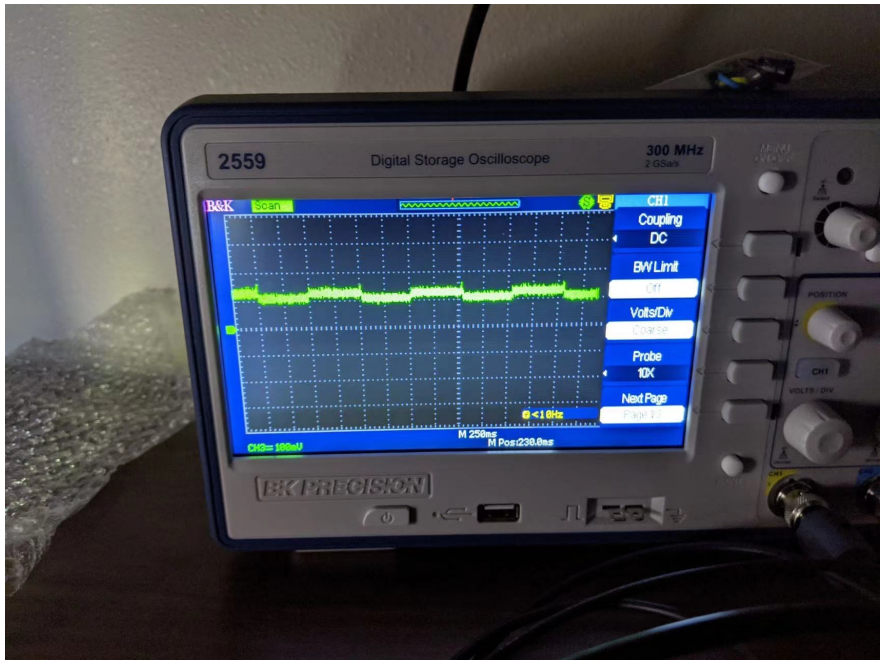
A RetroVLC Array Testbed from NMT





A square wave signal from RetroVLC tag

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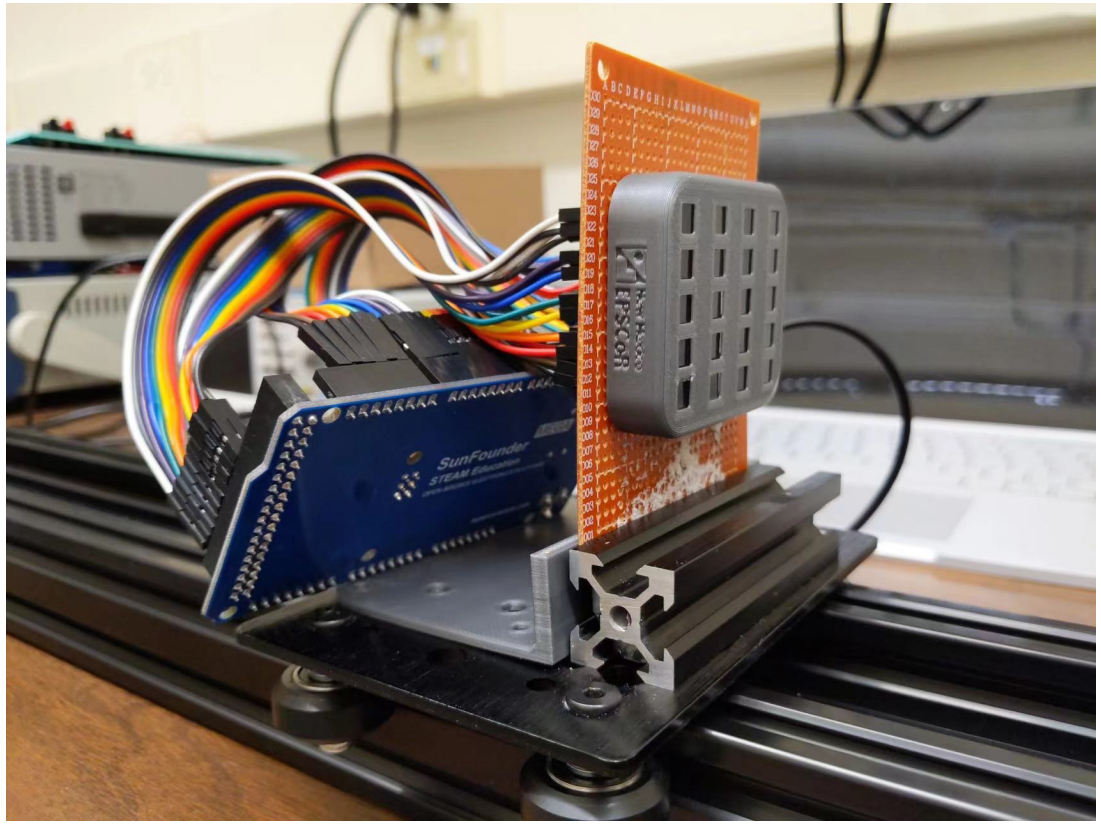
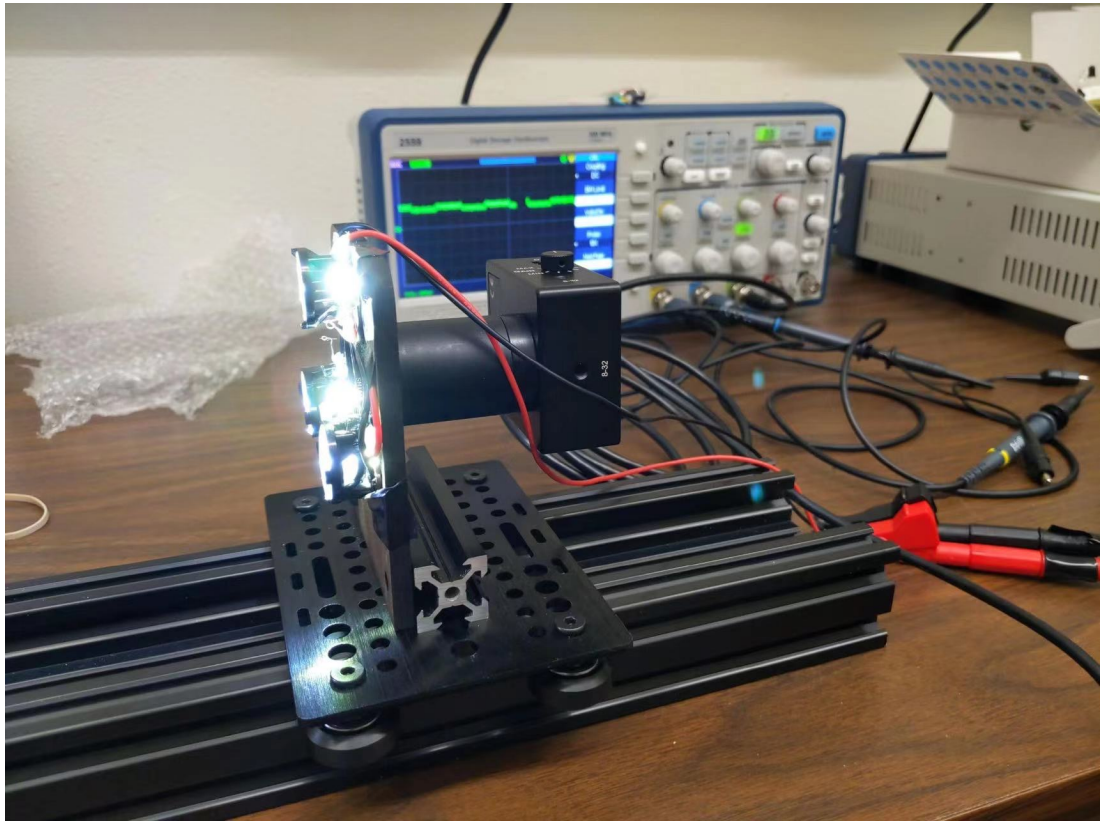
A RetroVLC Array Testbed from NMT



MCU controlled pixelated RetroVLC



Light Source + Avalanche PD

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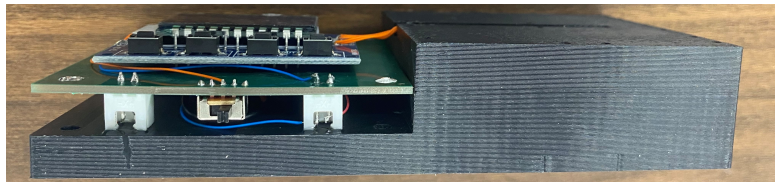
A RetroVLC Prototype from NJIT

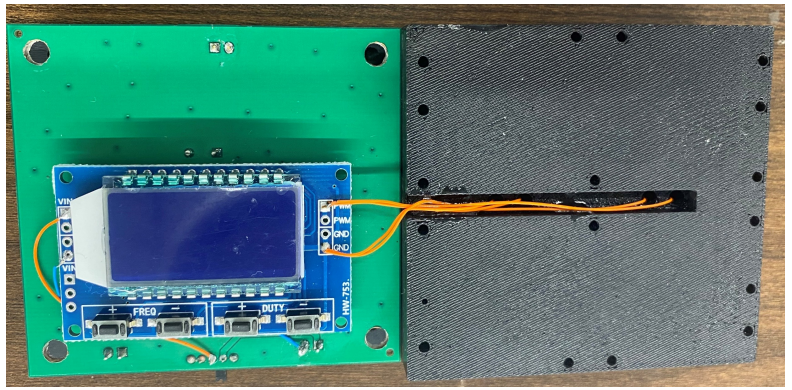
- This device is developed by my collaborator Dr. Abdallah Khreishah from New Jersey Institute of Technology.

Corner Cube Retroreflector

Solar Cell



Driver Circuit



NJIT New Jersey Institute of Technology

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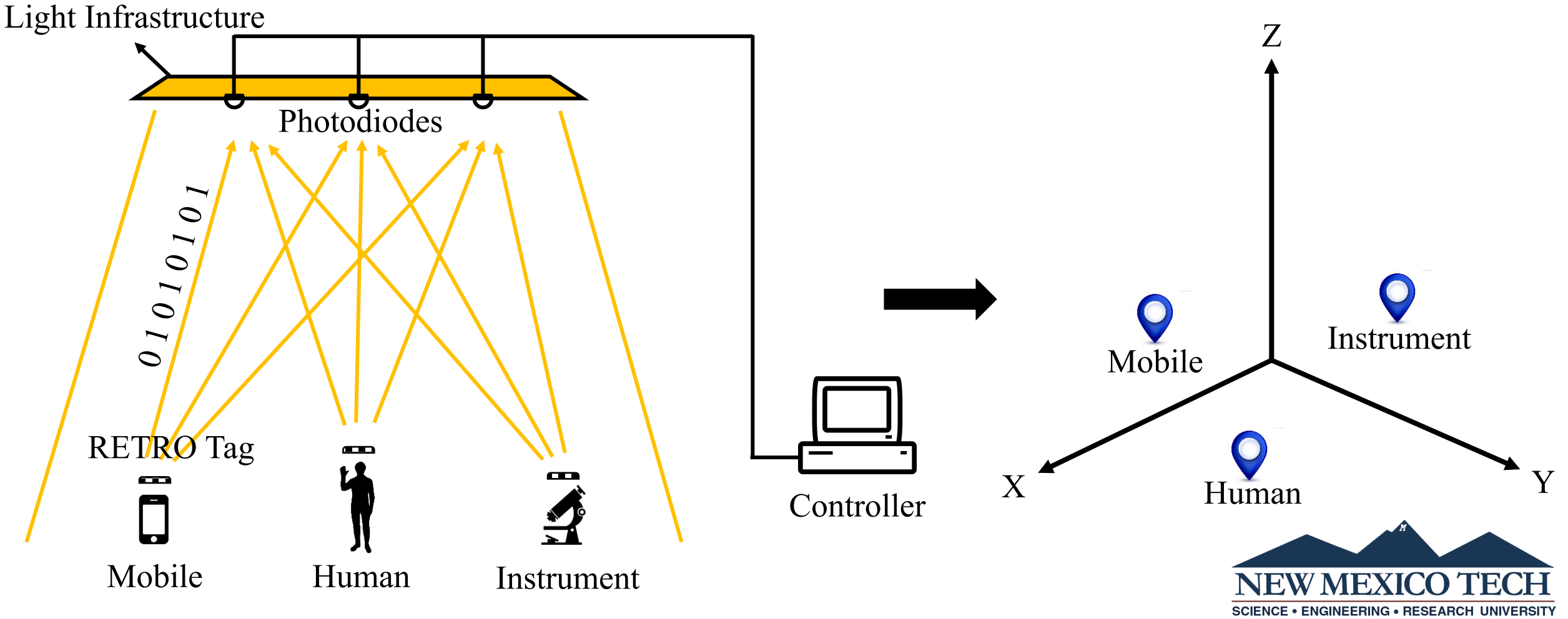
Retro-VLCP: Real-time Tracking



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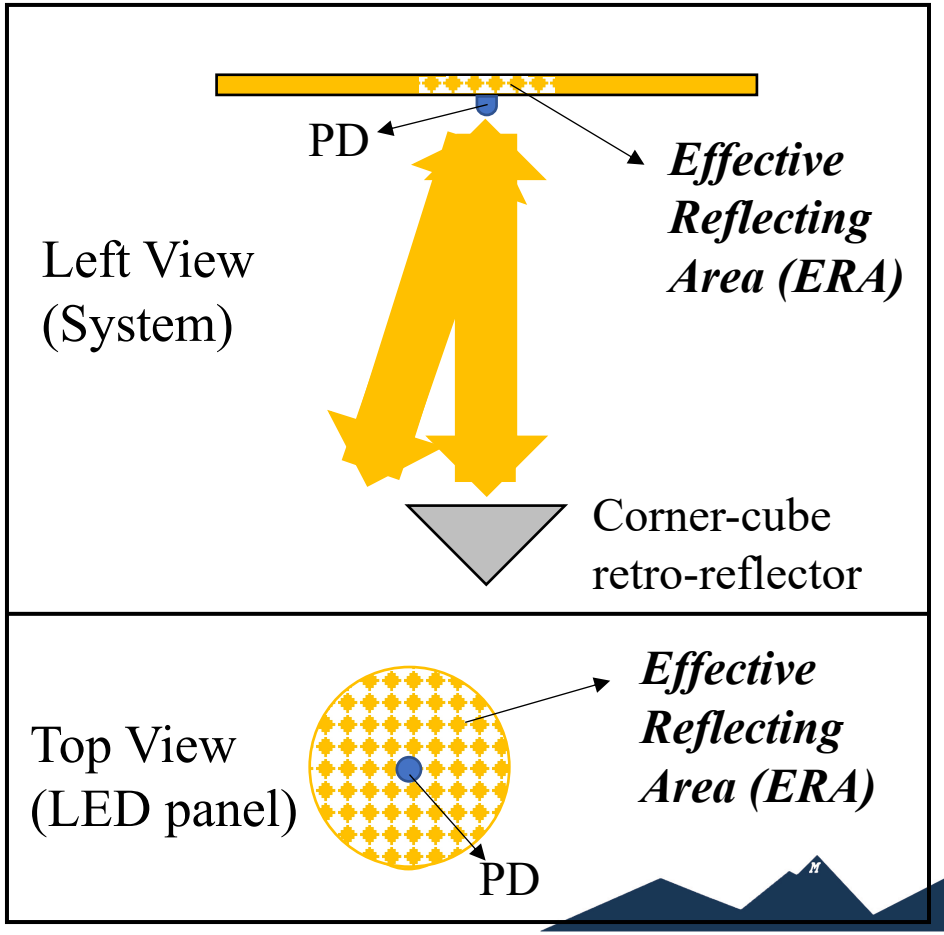
Retro-VLCP: Challenge

- **RSSI and Trilateration based Localization**
  - Key Feature: When retro-reflector changes its location and orientation, the received optical power on each PD will change.

*Correlate the **effective reflecting area** with the **location** of retroreflector?*



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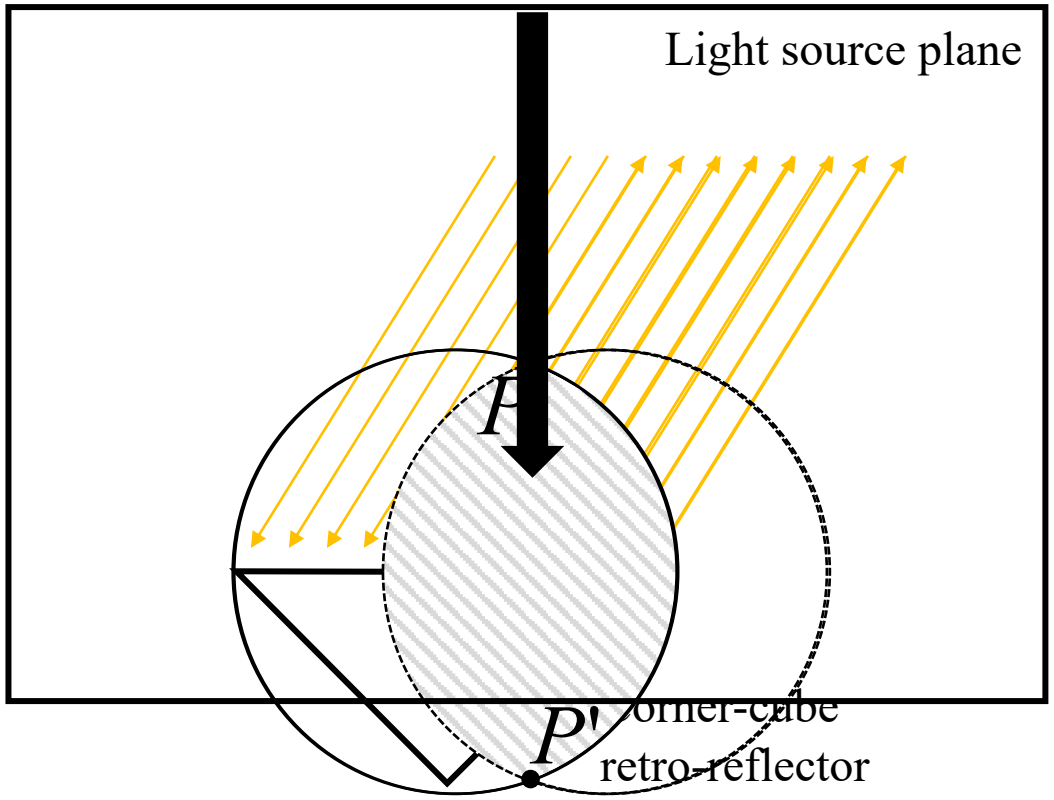
Retro-VLCP: Key Idea

❑ **Derive Effective Reflecting Area (ERA)**

Light rays hit into this region will be retro-reflected.



Step 1: Map the overlapped region to the light source plane.
$P \rightarrow$ photodiode
$P' \rightarrow$ symmetric point

Step 2: Rotate the overlap region around P.

Step 3: Trajectory of P' bounds ERA.

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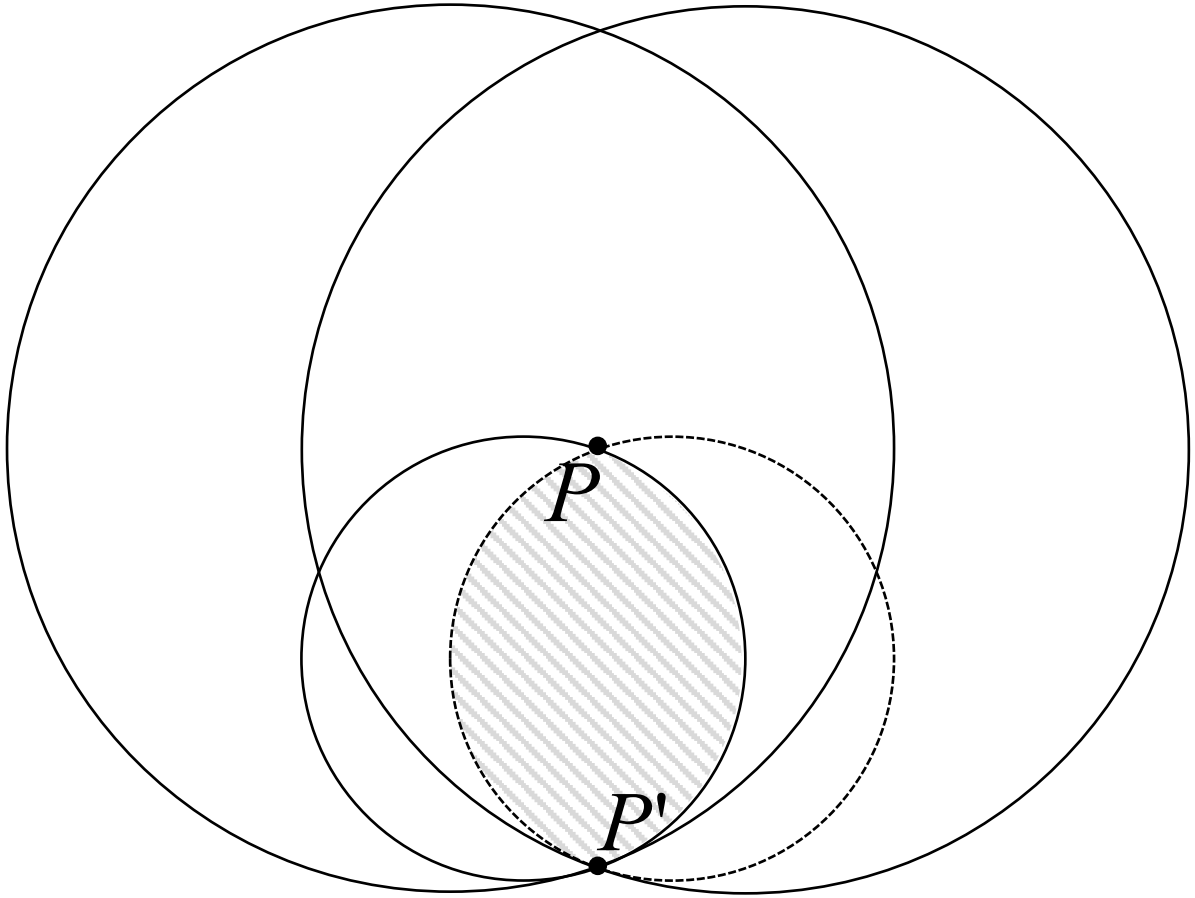
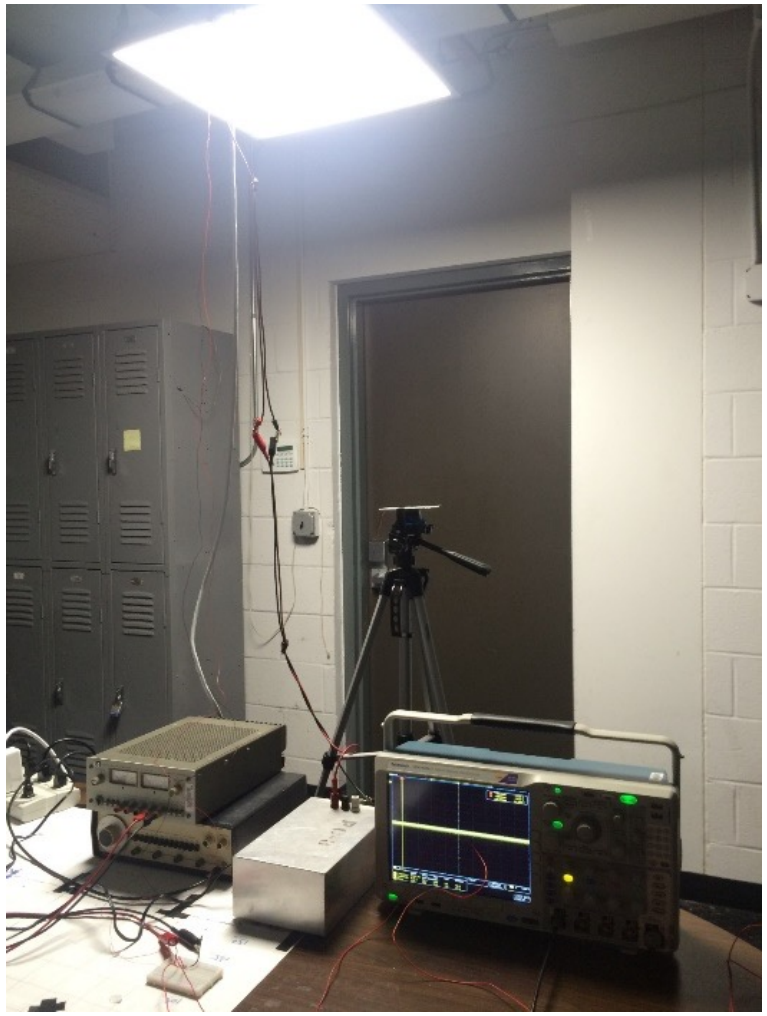
Retro-VLCP: Key Idea

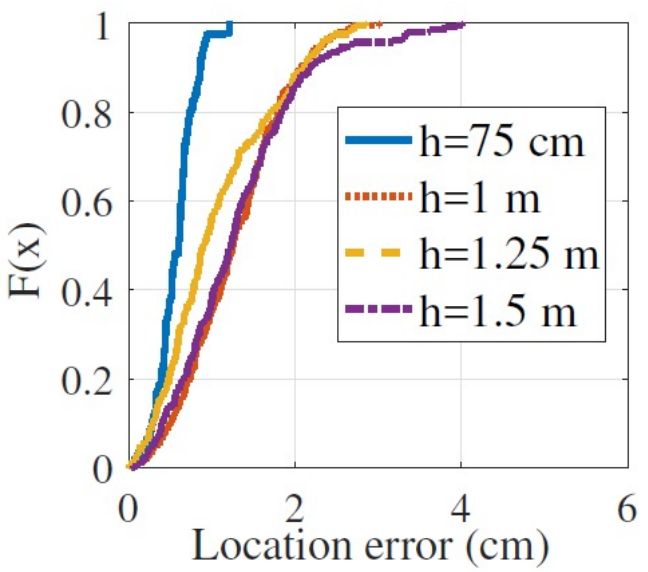
- Derive Effective Reflecting Area (ERA)

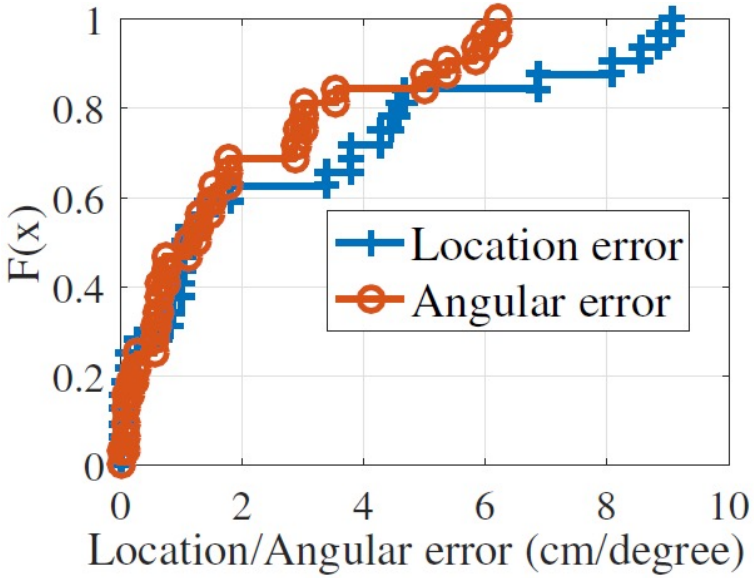


Retro-VLCP: Experiment Evaluation



Centimeter-level location accuracy





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