Describing and Sampling the LED Flicker Signal

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Talk Outline

1.   Describe the imaging model and define the Flicker Signal.

2.   Describe the manifestations of this signal and metrics of interest.

    • Wave function with both temporal and spatial components, unified by this model.

3.   Describe how to measure this from a common test lab setup.

    • Testing with this model in mind helps reduce the likelihood of missing an unexpected temporal or spatial effect.

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Flicker Background

- Artifact of *temporal aliasing* of sensor integration window and pulse-width modulated (PWM) light sources which have a period on the same time scale (order of magnitude) or longer.
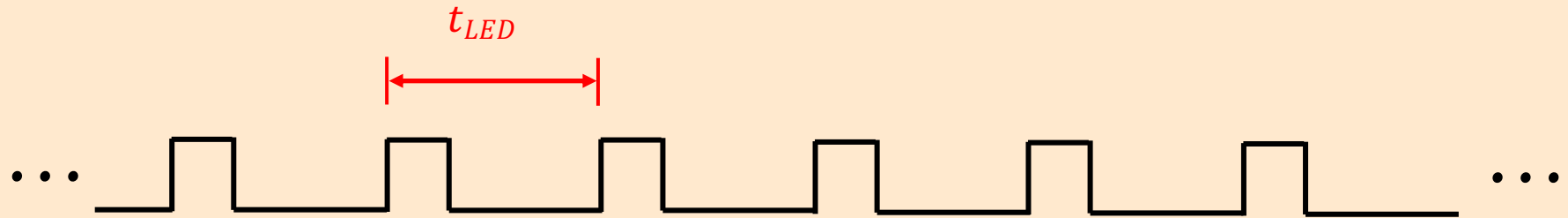
(Emergency lights should be flashing. Brake and tail lights should be constant)

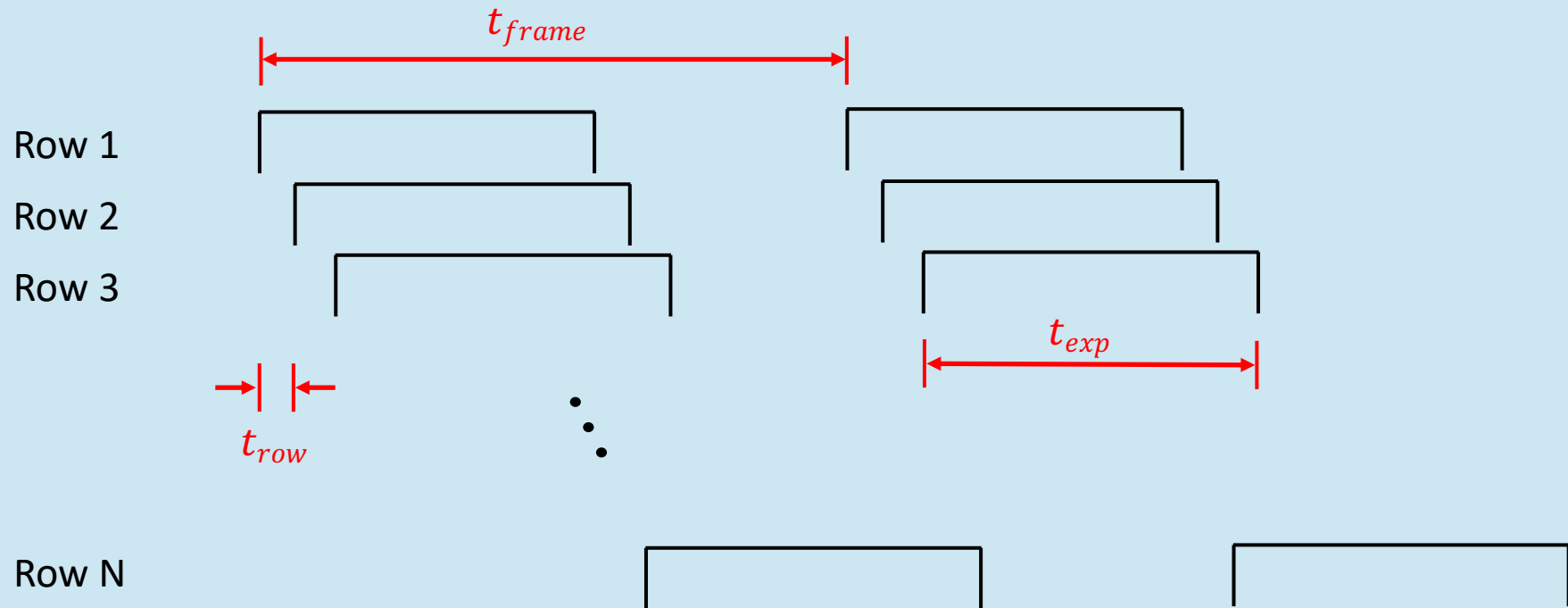- IEEE P2020 Sub-group 1 is looking this effect in automotive imaging.

Timing Diagram

Imaging Model Assumptions

Assumptions

- LED and frame capture timing is regular (no jitter, no varying rate)

- The exposure scheme is the same over all frames (temporally non-varying scheme)

**Notable Non-Assumption**

Don't care how a pixel makes its digital value based on the light it is exposed to.

- Generally from here on out we call this the **scheme**

- Includes both capture and rendering (tone-mapping)

"long exposure"

"med exposure"

"short exposure"

t_{exp}

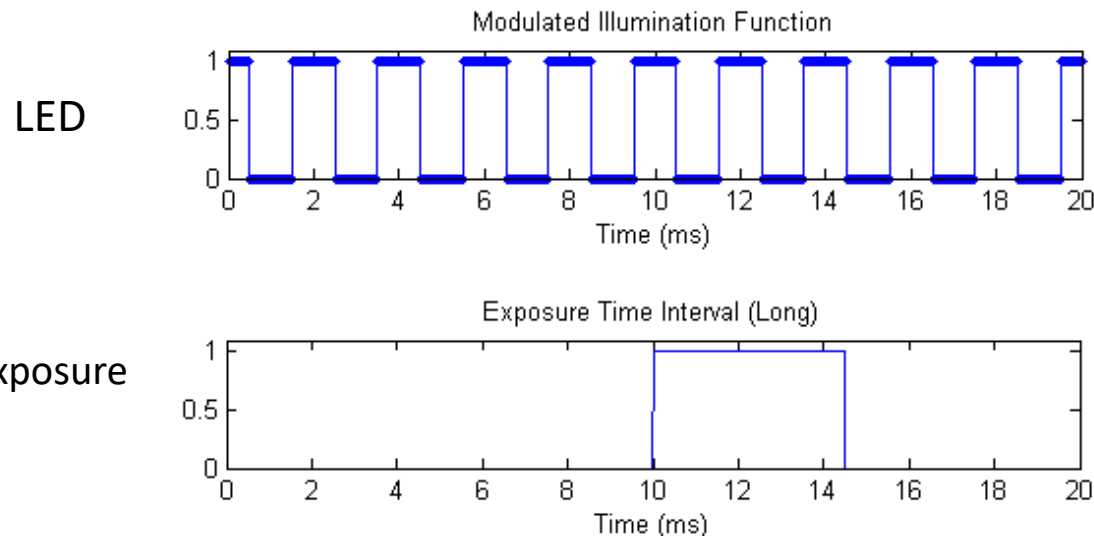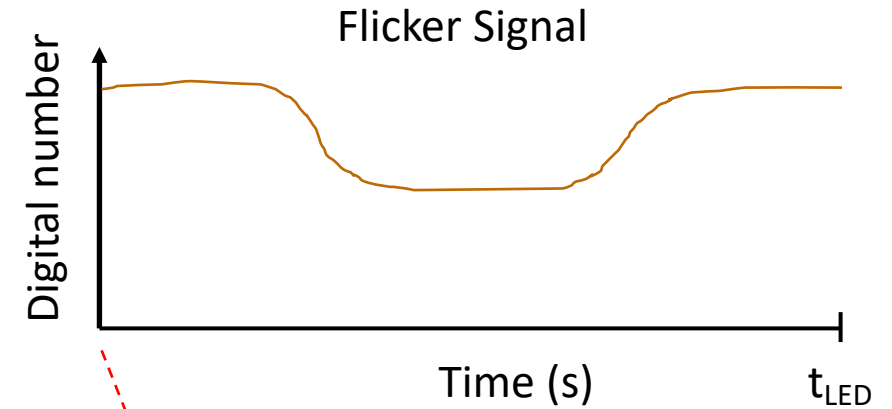imatest ®
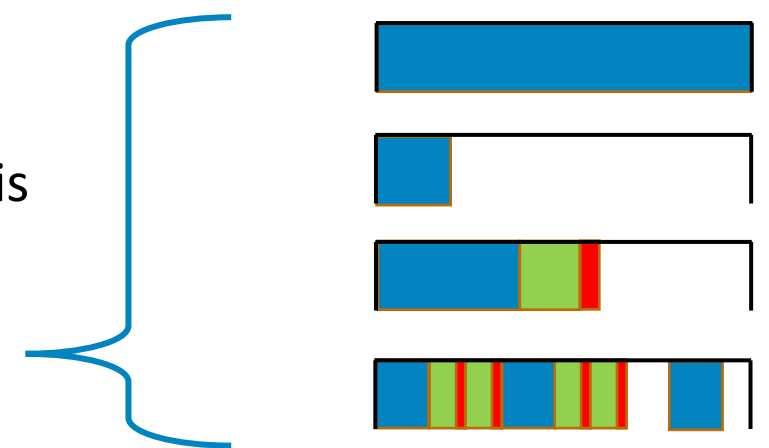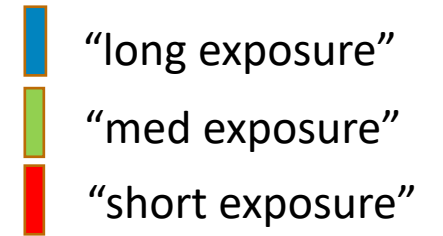
Canonical Flicker Period

The pattern of light a pixel is exposed to is fully characterized by the exposure window start relative to the LED signal's start.
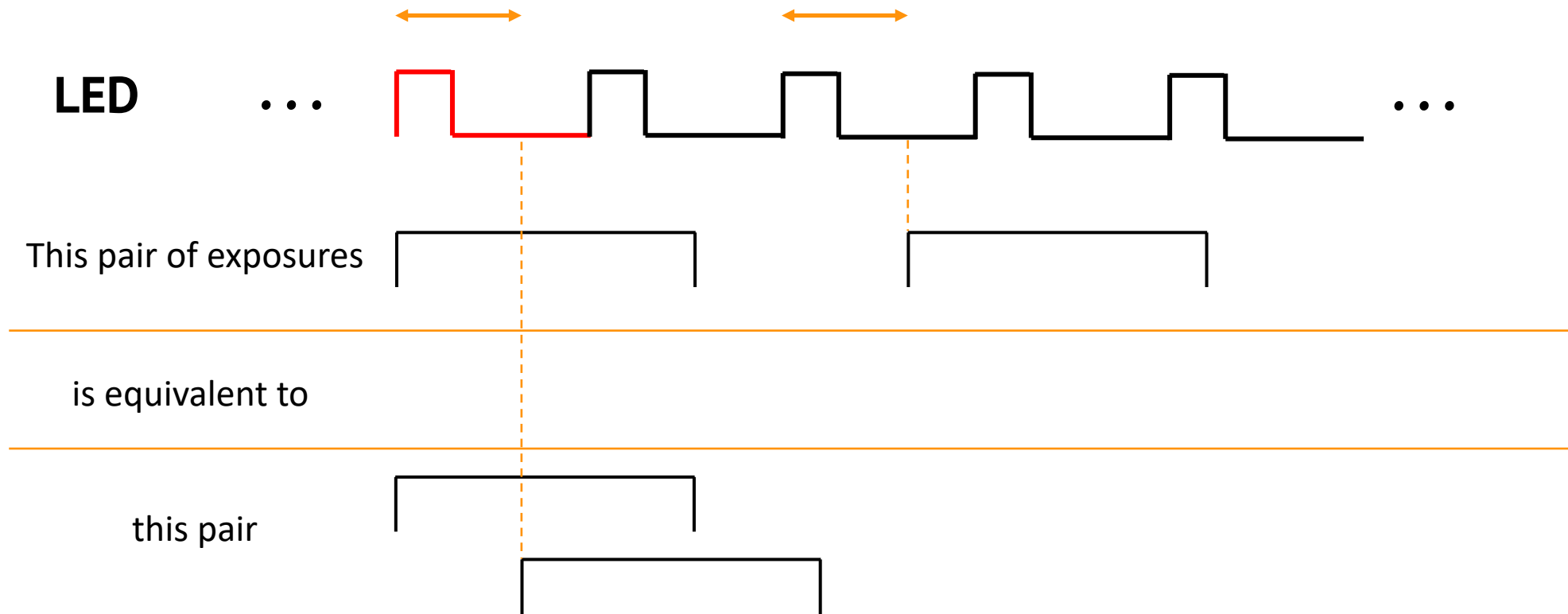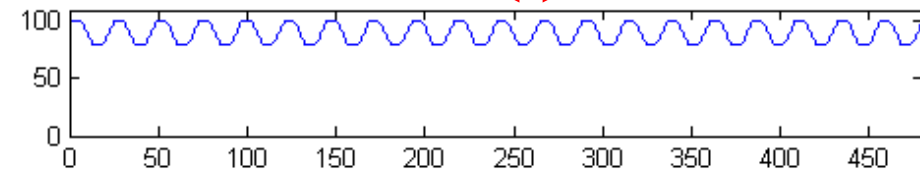

The **Flicker Signal** is defined as the pixel's digital response over the **canonical flicker period**, which is a continuous temporal interval containing all possible offsets between the LED signal and exposure window.

Flicker Signal Anatomy

- Continuous, defined in length by the smaller of either the frame and LED light period.

- Can be measured at any point in the signal chain, from any "channel" of image data

- If linear data and simple exposure model, this is **one period** of the convolution of the exposure window with the LED signal
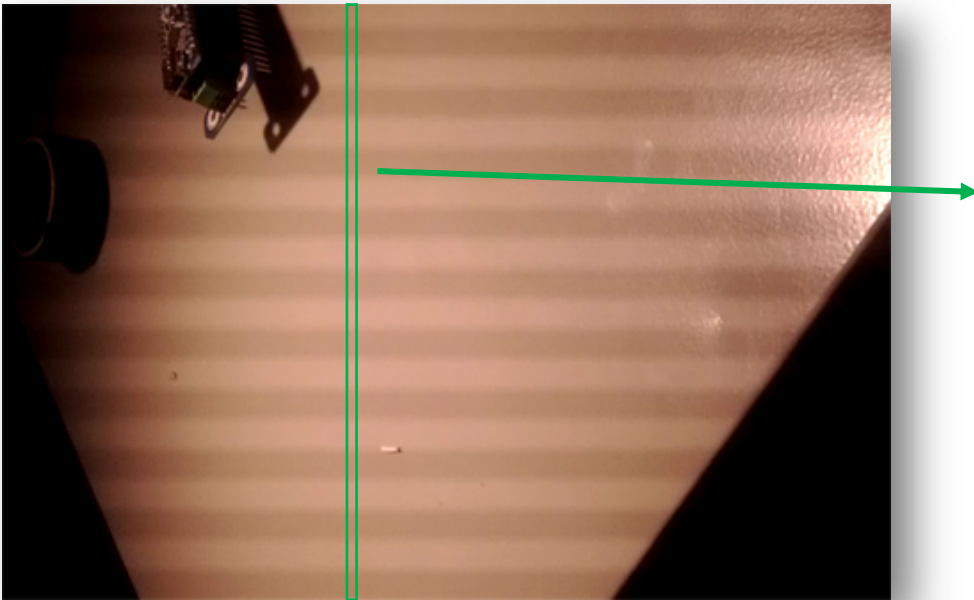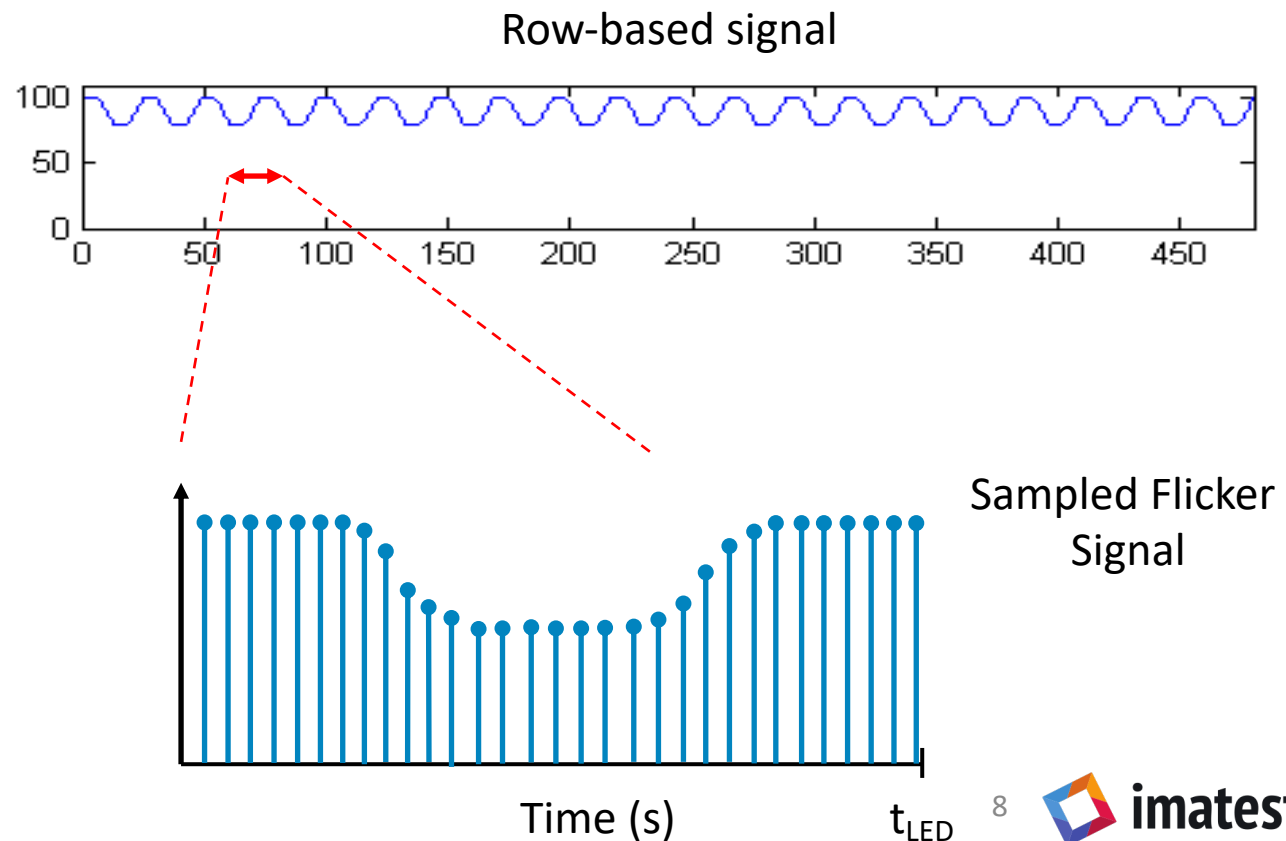

Flicker Signal

Digital number

Time (s) t_{LED}

One period

LED

Modulated Illumination Function

Exposure

Exposure Time Interval (Long)

conv()

Periodic convolution

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Manifestation: Illumination Banding

"Marching Bands" in areas illuminated by flickering lights caused by each row having slightly different exposure window than its neighbor, leading to periodic spatial effect which often very obviously has structure of the Flicker Signal.


Row-based signal

Sampled Flicker Signal

Every row gives a sample of the signal offset by t_{row}.

Time (s)

t_{LED}

8

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Manifestation: Flickering Point Source.

"Point sources" such as automotive lights or signage often appear to "flicker on and off" **temporally** rather than exhibit spatial banding.

Each point on this sign is just sampling at a different phase in the Flicker Signal.

Frame   1   2   3   4   5   6

Flicker Signal

t_{LED}

Image courtesy of P2020 SG1.
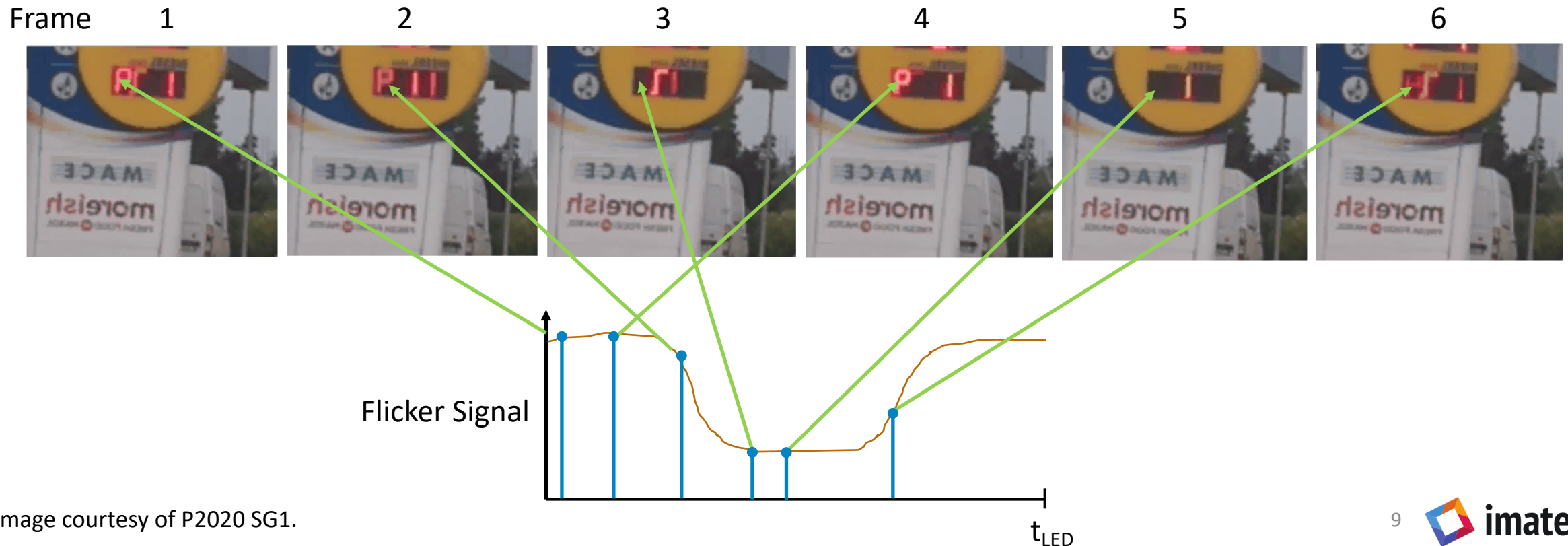
Metrics Derived Solely from Flicker Signal

- Contrast metrics from peak to peak (e.g., Weber, Michelson)
- "Band edge width" metric: how many rows a transition would encompass
- Proportion of bands which are light/dark
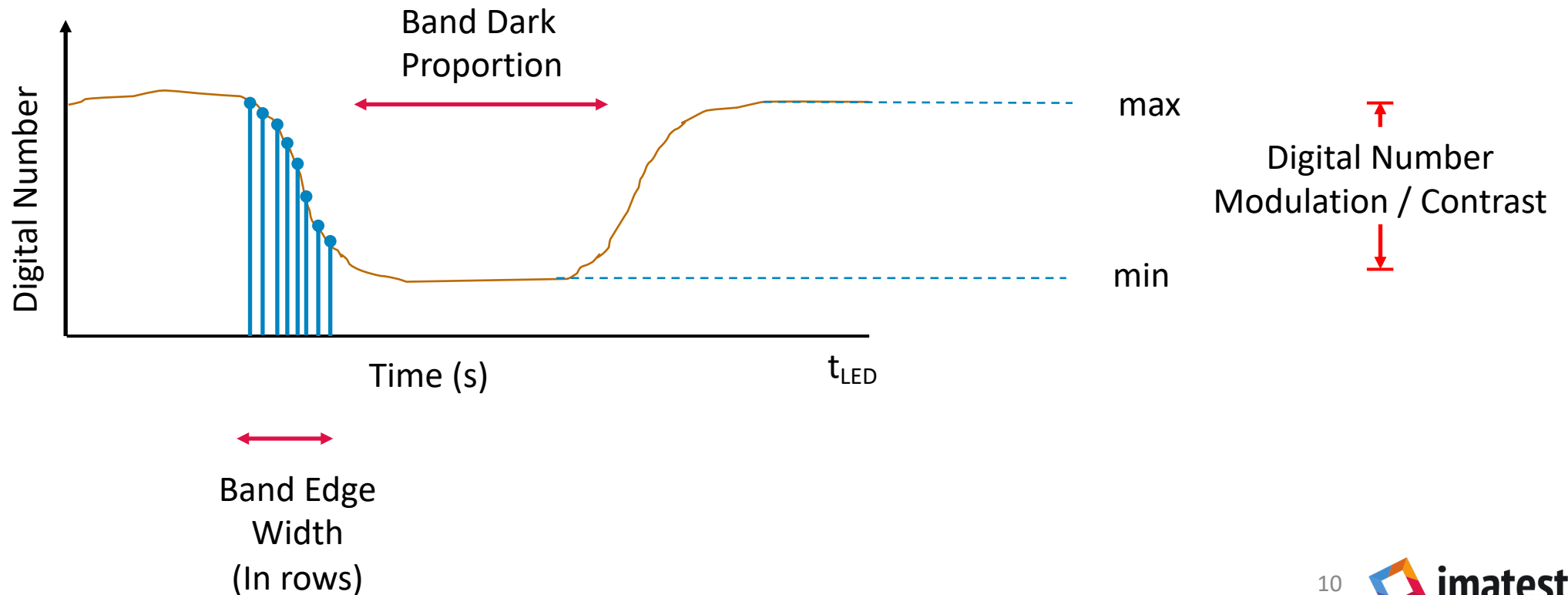
Metrics Derived Against On/Off/True Reference

- Percentage of time the light is not seen at all
  - *i.e.,* matches "true off" pixel level

- Total area of difference from what the true level for that light power and duty cycle "should be"
  - *e.g.*, as determined by running a DC light that matches the perceived brightness of the PWM source
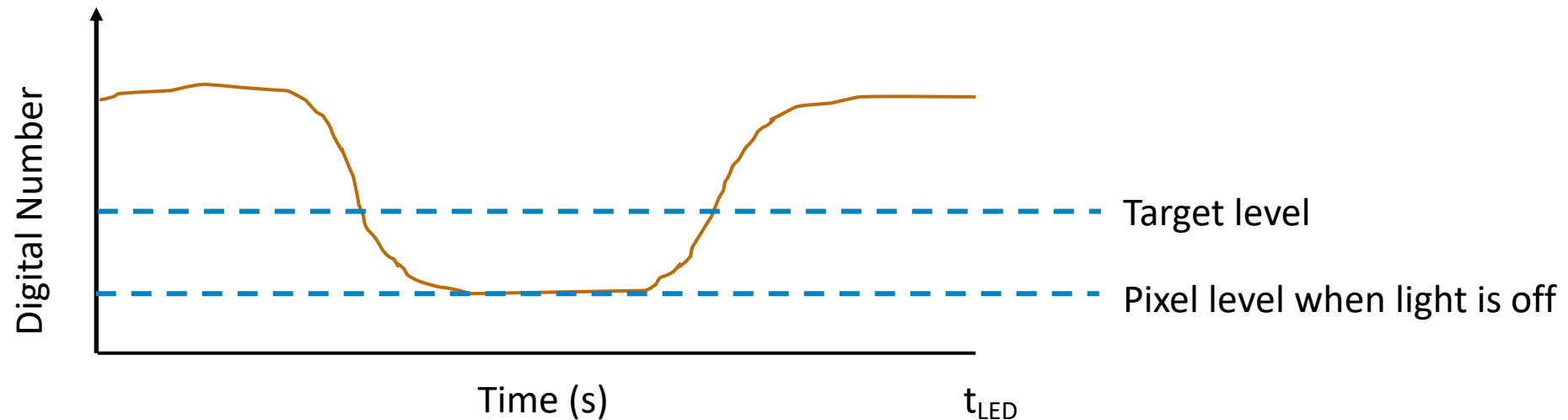
Additional Dimensions of the Flicker Signal

- **Light Source properties**
  - Brightness of source
    - Different brightnesses will be handled, compressed different ways
  - Frequency
  - Duty cycle, pulse shape

- **Camera properties (operating point)**
  - Exposure "scheme" (generalization of exposure time) for given light condition
  - Tone mapping, HDR combination scheme
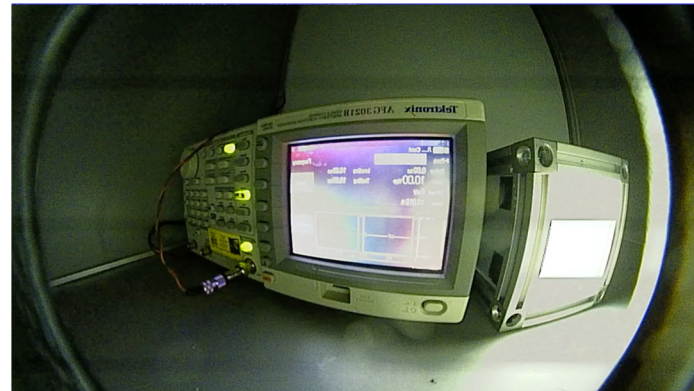
Brightness
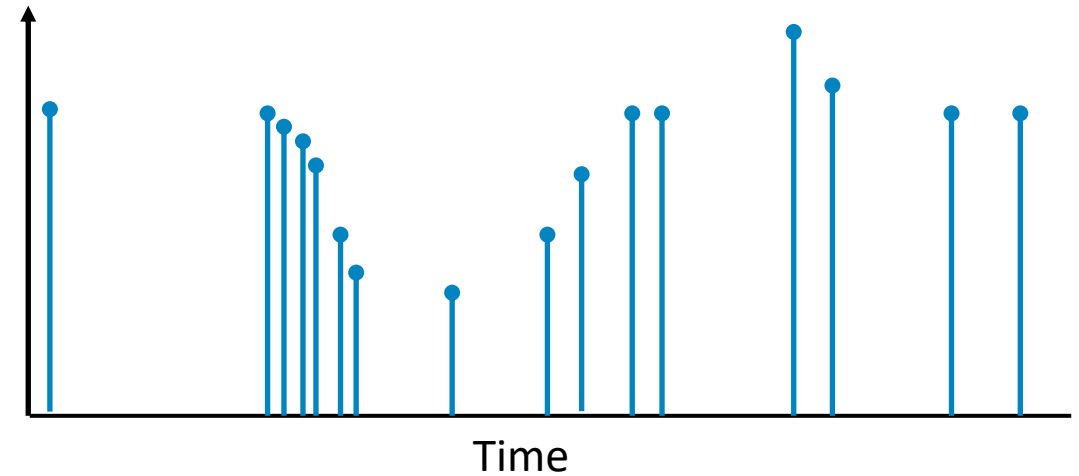
LED Freq.

Capture Scheme

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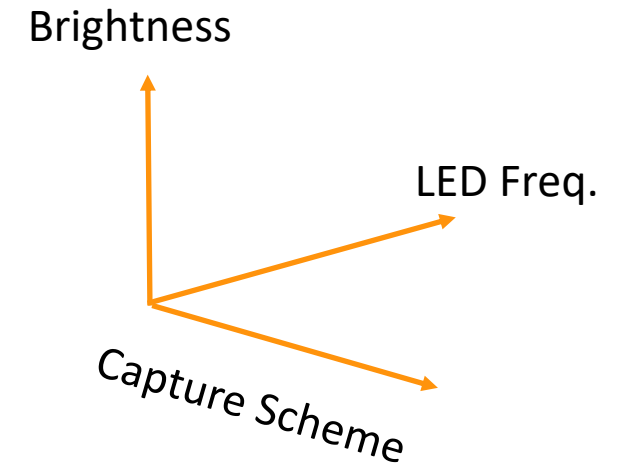
Test Coverage of the Flicker Signal

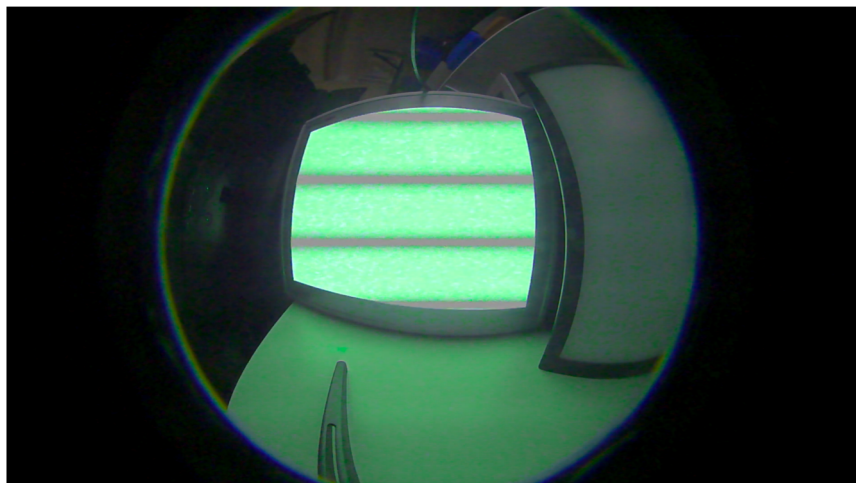How densely do you need to sample to measure your metric?

How do you ensure coverage?

1. "Phase bank" of light sources
   - Triggered captures and light
   - Could ensure minimal sampling across the domain

2. "Tonal Patch" target
   - Make use of video duration
   - Make use of spatial sampling
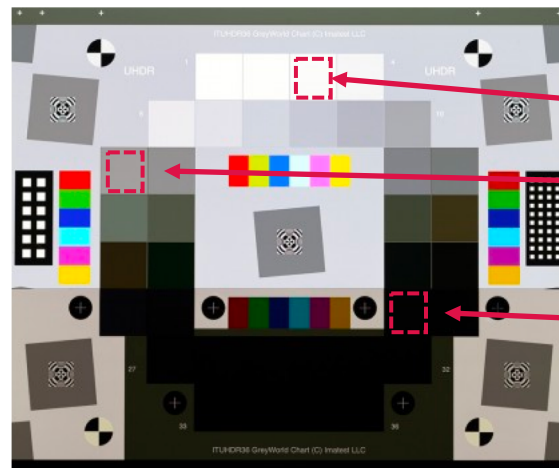   - - Region of Interest (ROI) size

Time

~90Hz flicker, 30fps video

Measurement from Patch-Target Video

PWM lightbox

Transmissive HDR target (150dB, 36 samples)

Brightness

LED Freq.

Capture Scheme

What spread of phase samplings of the Flicker Signal can
we get with an ROI of R rows over F frames?

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Measurement Model Assumptions

- Uniform lighting within ROI

- Exposure scheme and tone-mapping is the same for all pixels in a test ROI (spatially non-varying scheme)

- Rows that have different exposures are all offset by a fixed interval

- All pixels in a row are exposed the same way (row-based exposures)

Total Set of Phase Samplings from Video ROI

$S(t)$, the sampling function of phases of the Flicker Signal on the domain [0, t$_{LED}$]:

$$S(t) = \sum_{f=0}^{F-1} \sum_{r=0}^{R-1} \delta\big(t - \big(f \cdot t_{frame} + r \cdot t_{row}\big) \bmod t_{LED}\big)$$

F : Number of frames
R : Number of rows in ROI
δ(t) : discrete delta function

- For a given LED frequency and sensor frame rate, row time.

- Can convert to phase in normalized units or degrees to compare more directly across different LED frequencies.
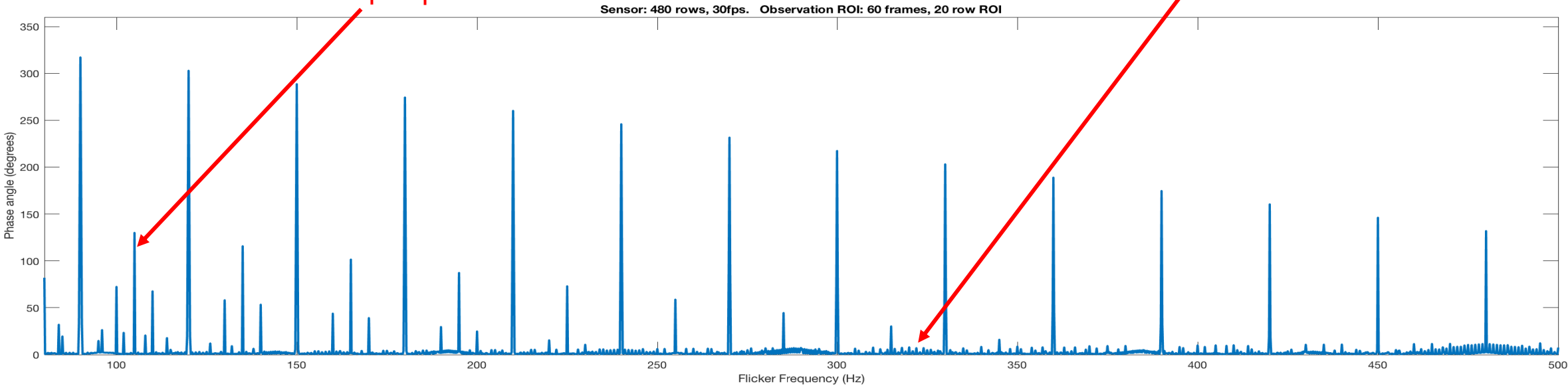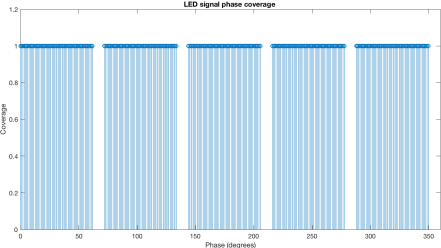
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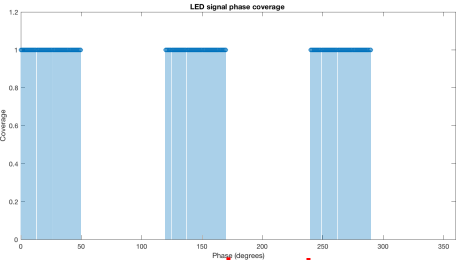# Maximum Phase Gap

Flicker Signal sampling coverage from video ROI

- Adding more rows to this ROI adds "comb-like" structure.

- Adding more frames adds more copies of these combs
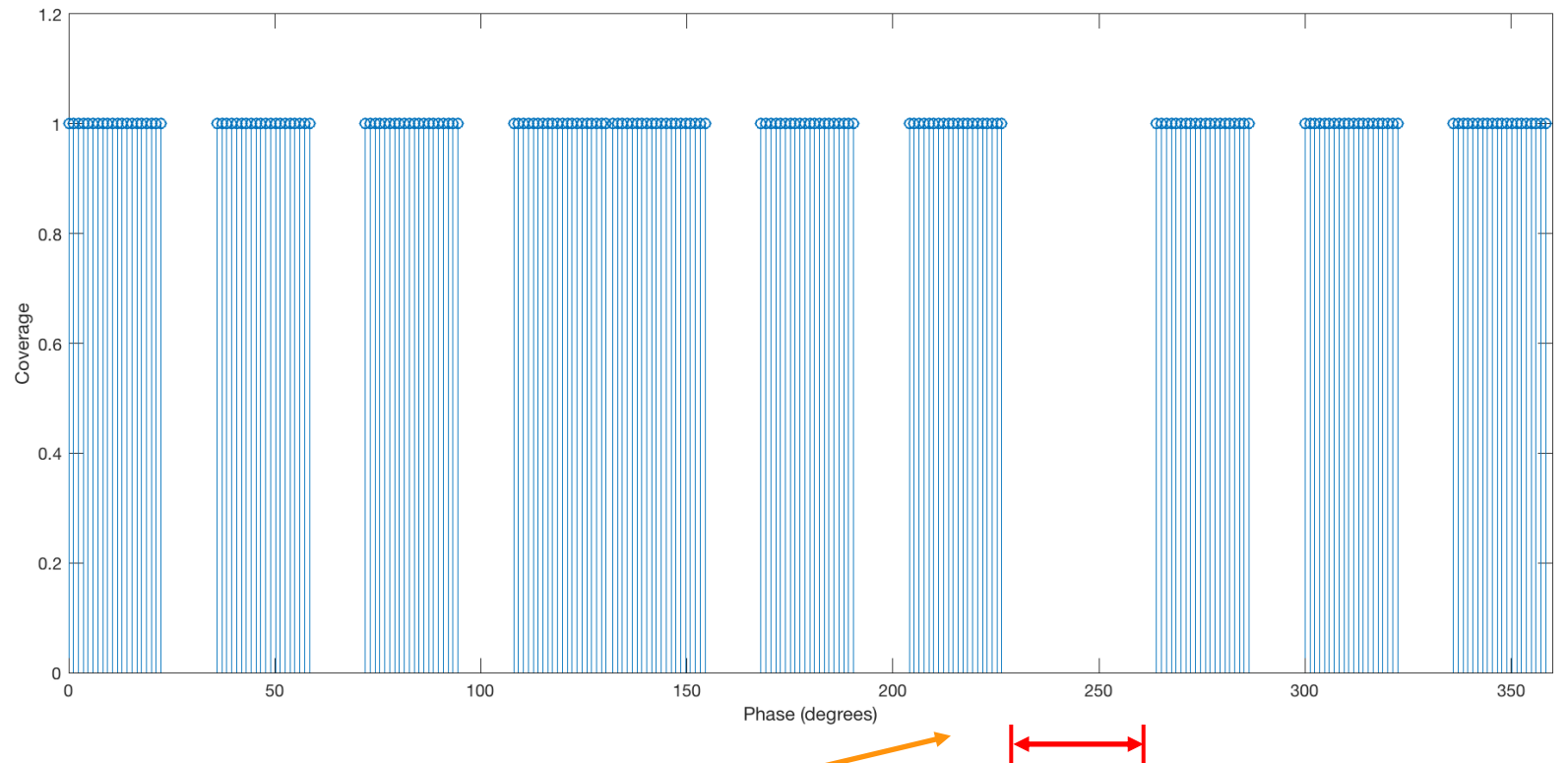
Can look at maximum phase gap for a set of parameters.

Maximum Phase Gap Coverage

General trend: A reasonably-sized ROI (20rows) for a reasonable test video duration
(<10s) can produce enough coverage for at all but a few degenerate frequencies.

Conclusions

- Proposed definition of Flicker Signal is a unified description of the spatial and temporal effects of LED flicker

- "Flicker KPIs" should be derived from data keeping in mind this signal and its concepts of sampling coverage

- This signal can be measured from test lab measurements with reasonable amounts of data (for most LED frequencies of interest)

- Realistic test plans may need to test against many different light levels, camera operating points, and frequencies of concern.

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Thank you for your attention.

Please direct questions to the author at rob@imatest.com.

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