A Visible Light Vehicle-to-Vehicle Communication System Using Modulated Taillights

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Presenter – Michael Plattner

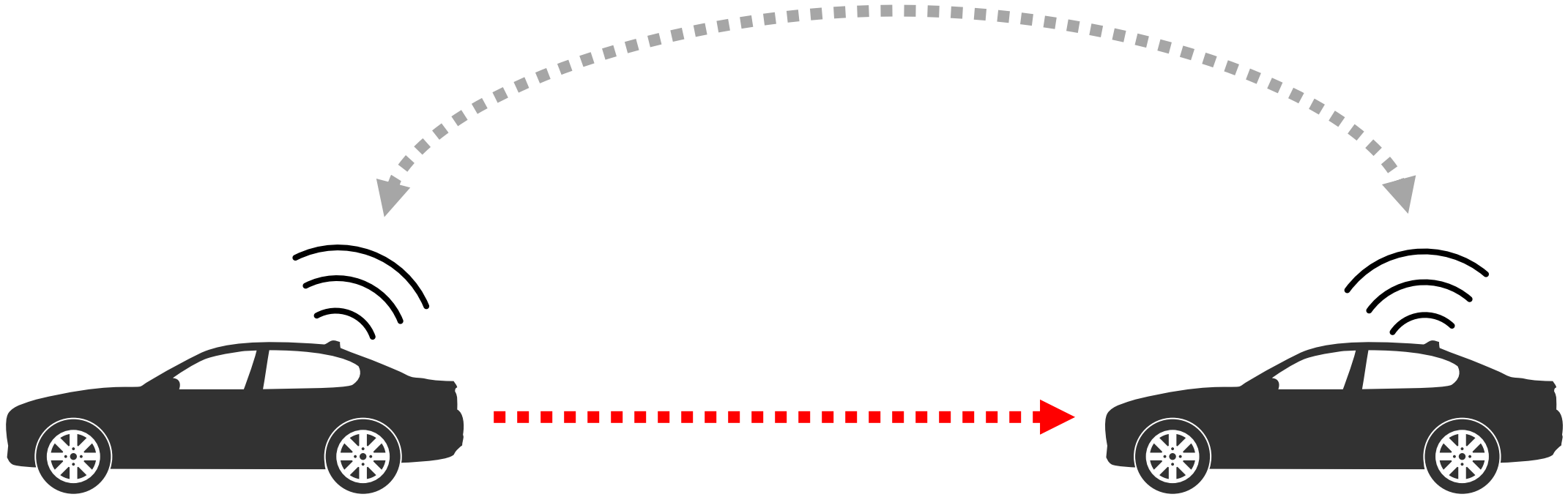
- Michael Plattner, BSc MSc
- Age: 27
- born in Innsbruck, Austria
- Assistant Professor for Mobile Systems
  at University of Applied Sciences Upper Austria
- PhD student
  at Johannes Kepler University Linz

Research Topics

- Mobile Communication Systems
- Intelligent Transportation Systems
- Simulation and Modelling
- Connected Vehicles

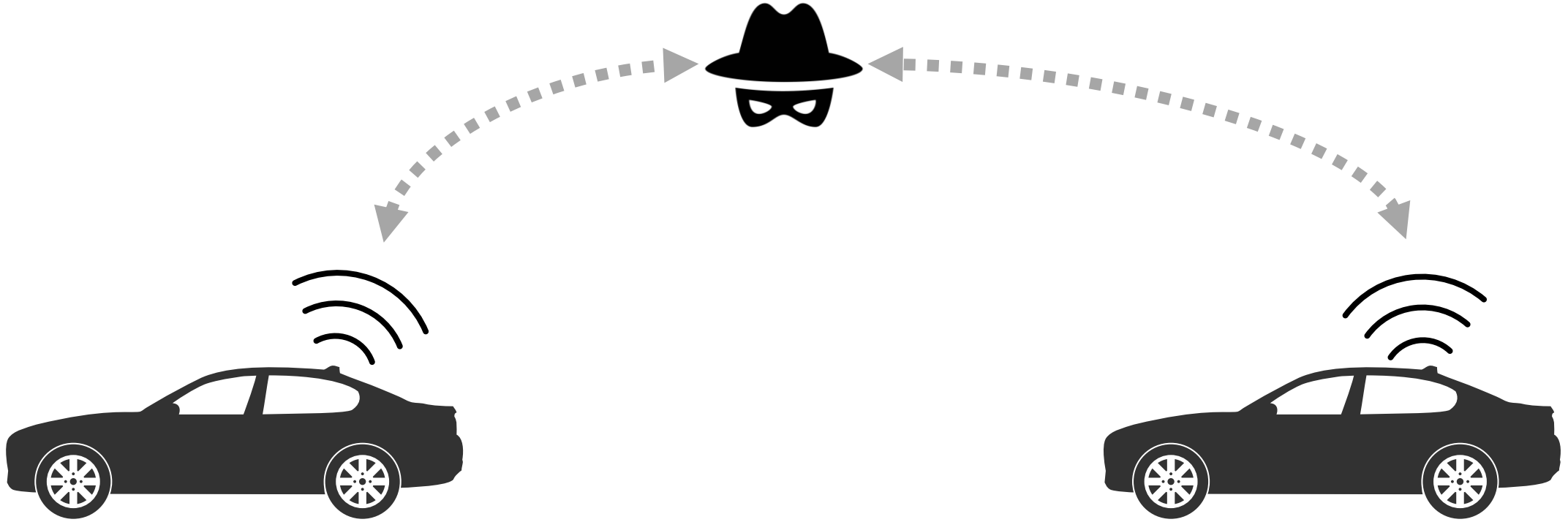
Idea

Out-of-band channel using modulated taillights for V2V communication



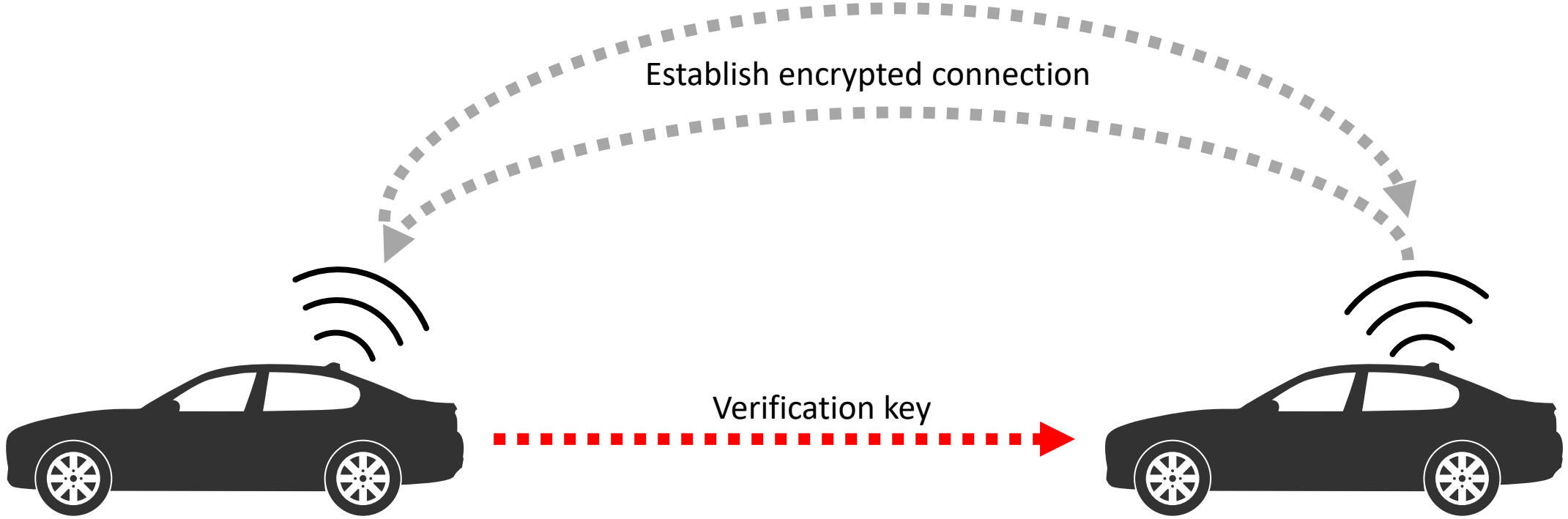
Idea

V2V communication might be attacked by a man-in-the-middle



Idea

Identity of sender can be veryfied using out-of-band channel.



Requirements

- Use state-of-the-art LED taillights
- Camera used as receiver
- Visible light spectrum
- Not perceivable for the human eye

UDPSOOK - Modulation

- Undersampled Differential Phase Shift On-Off Keying
- Modulation frequency multiple of cameras FPS

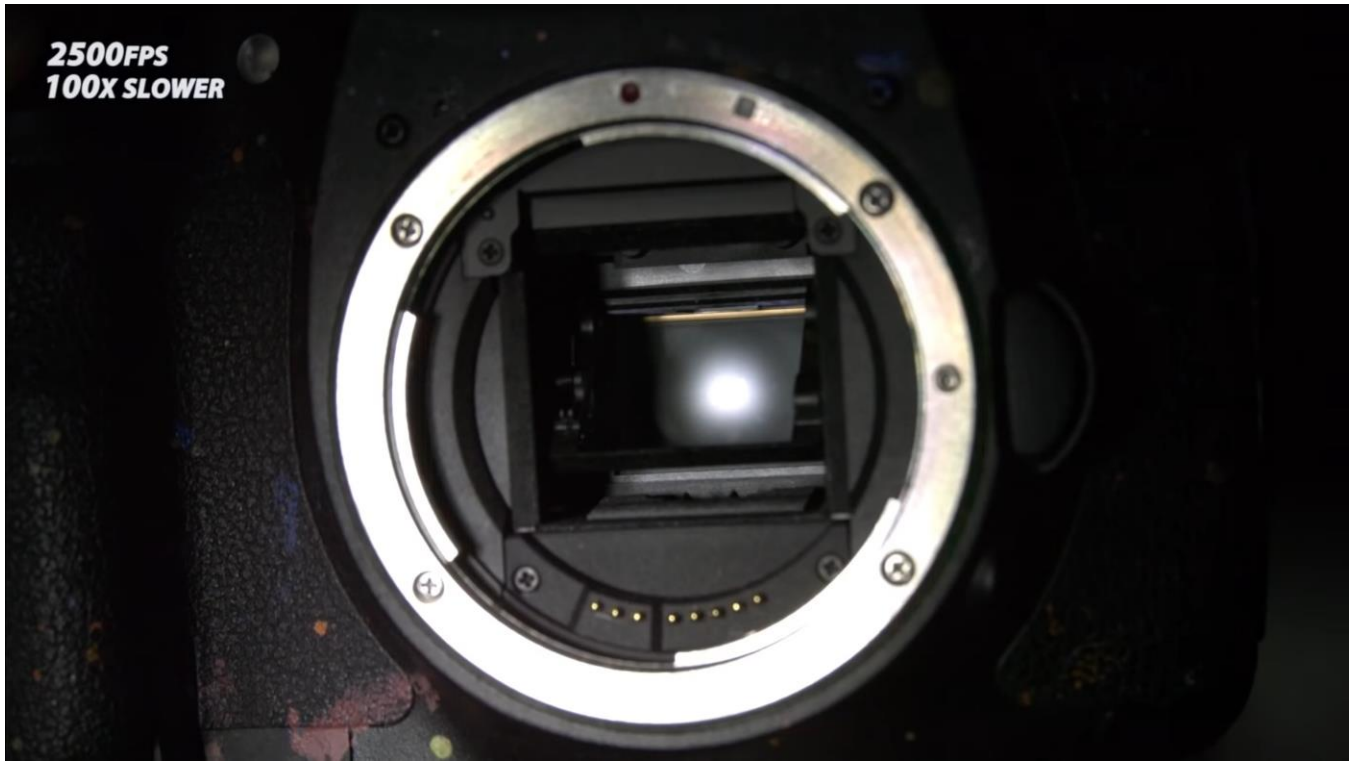
$$e.g. \qquad f_S = 30Hz \qquad\qquad f_{mod} = 120Hz$$

- Utilizes rolling shutter effect of cameras
- Information encoded in the phase shift between frames

N. Liu, J. Cheng, and J. F. Holzman, “Undersampled differential phase shift on-off keying for optical camera communications,” Journal of Communications and Information Networks, vol. 2, no. 4, 2017, pp. 47–56.

UDPSOOK

- Rolling shutter of DSLR camera
  - Exposure time: 1/30 s
  - Recorded with a high-speed camera



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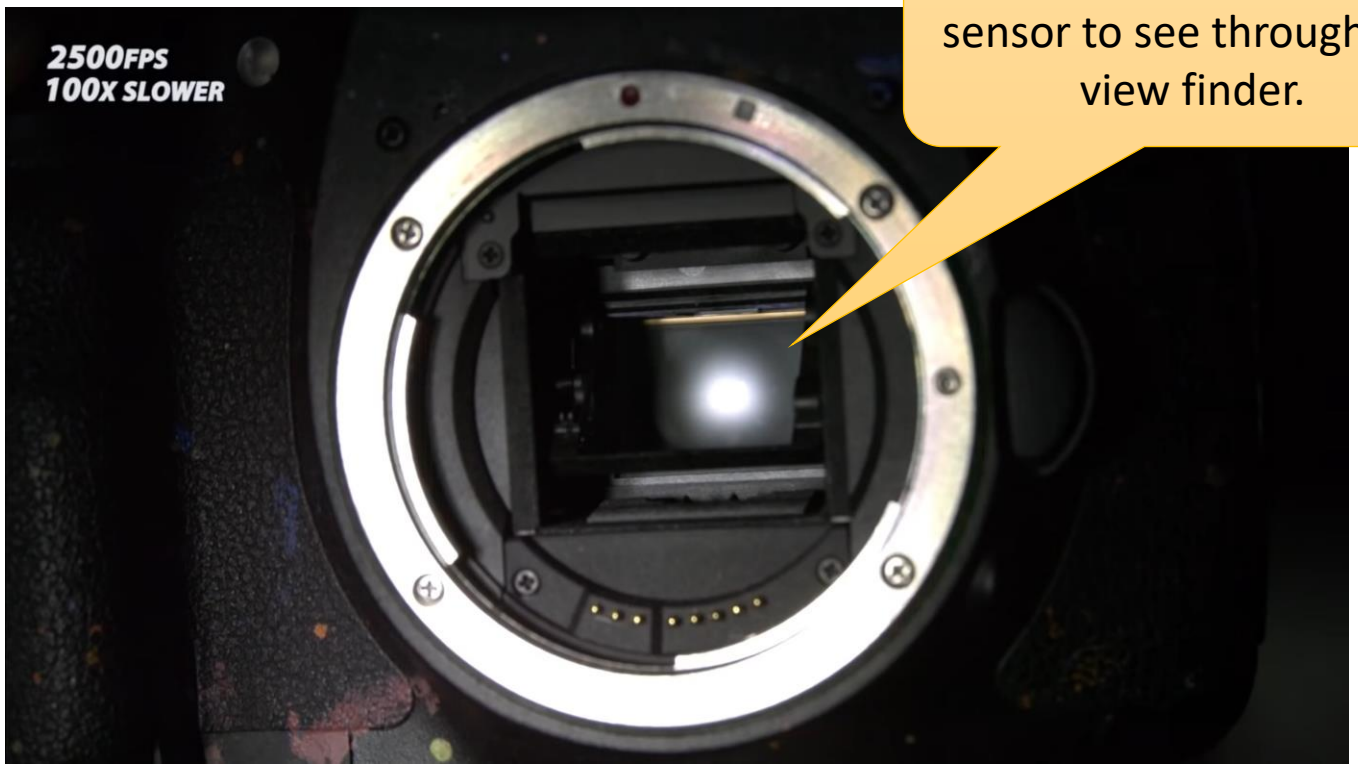

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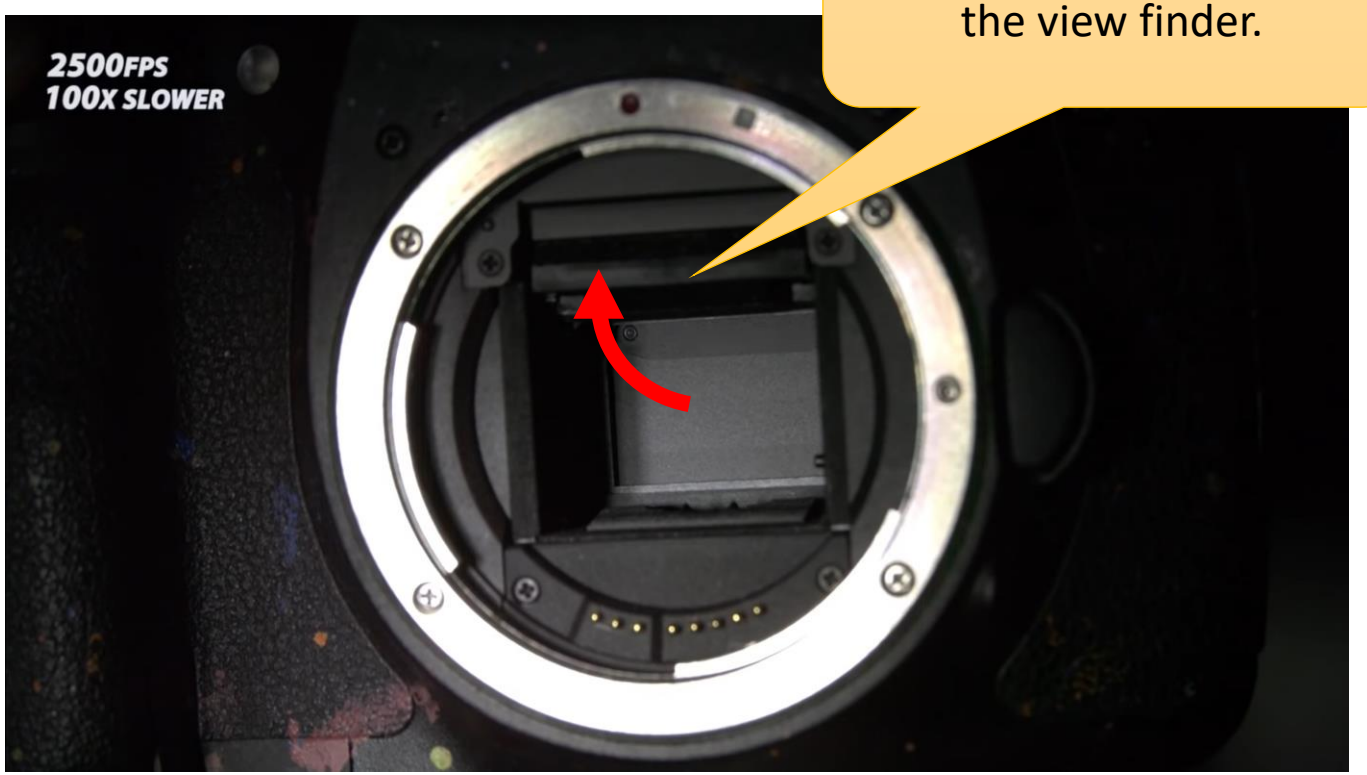

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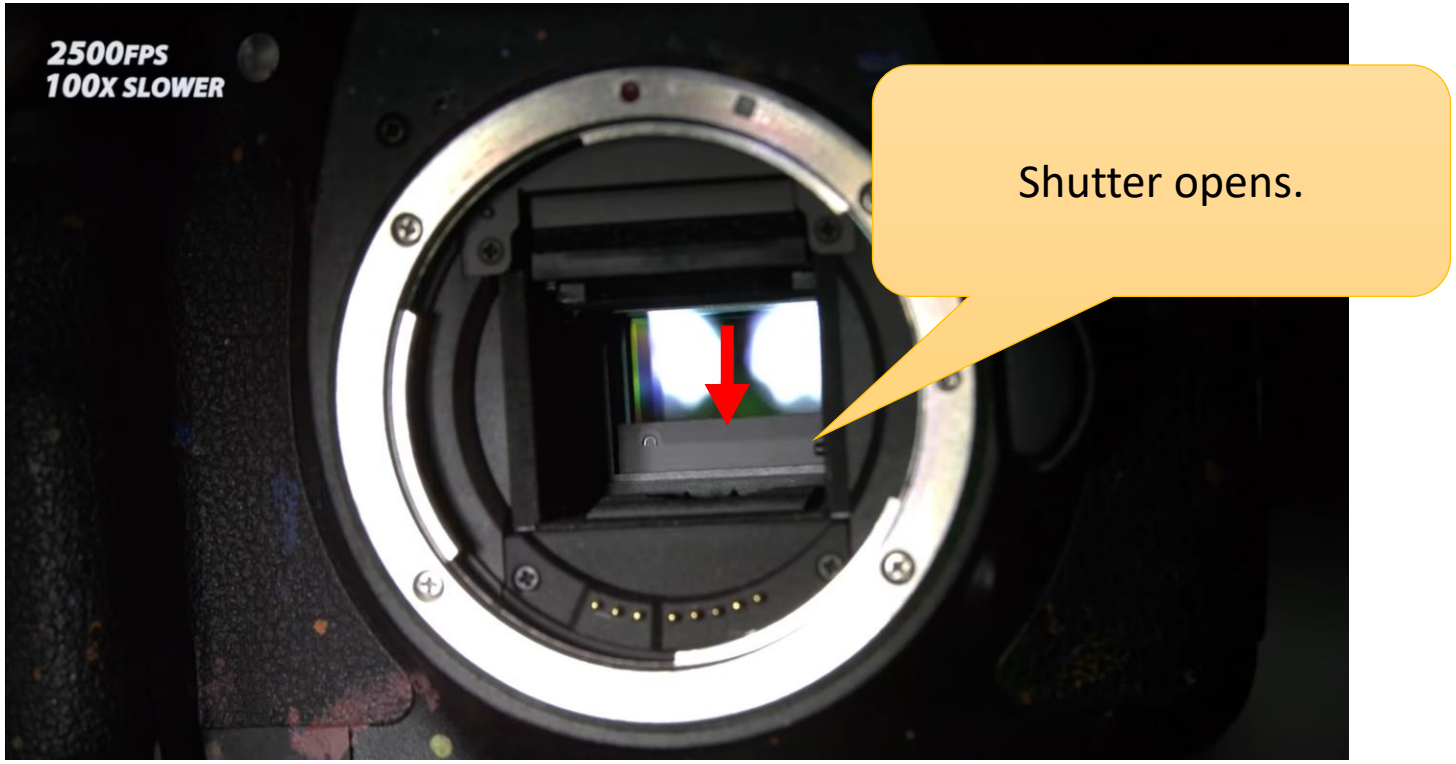

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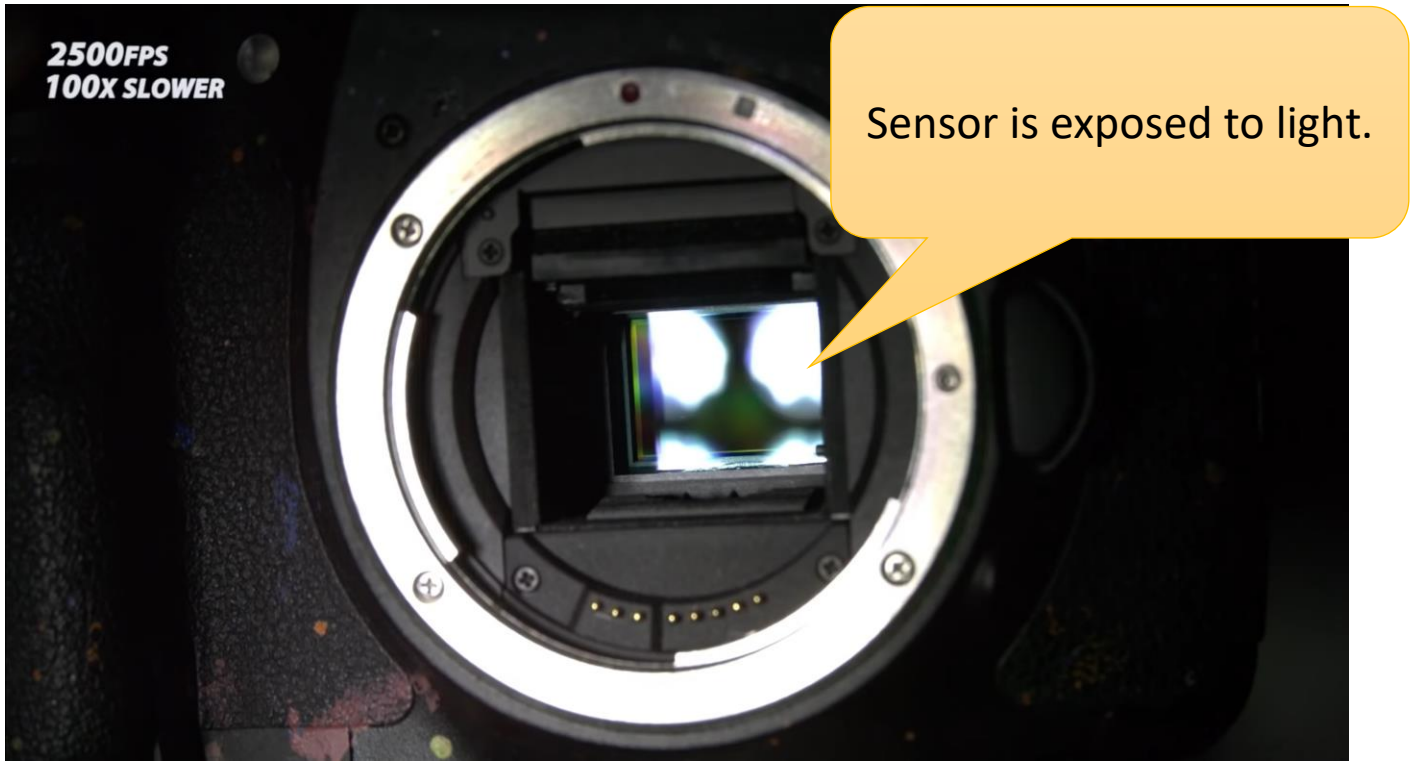

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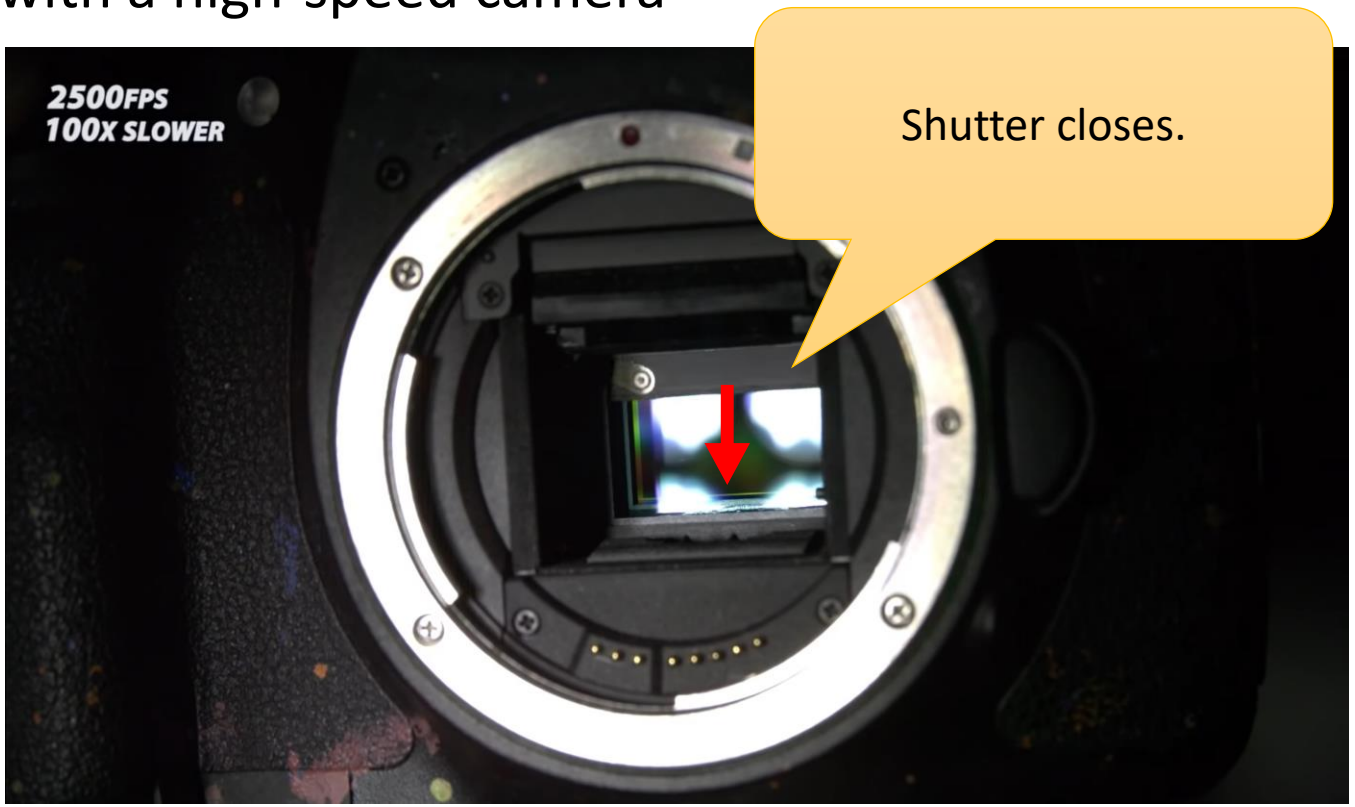

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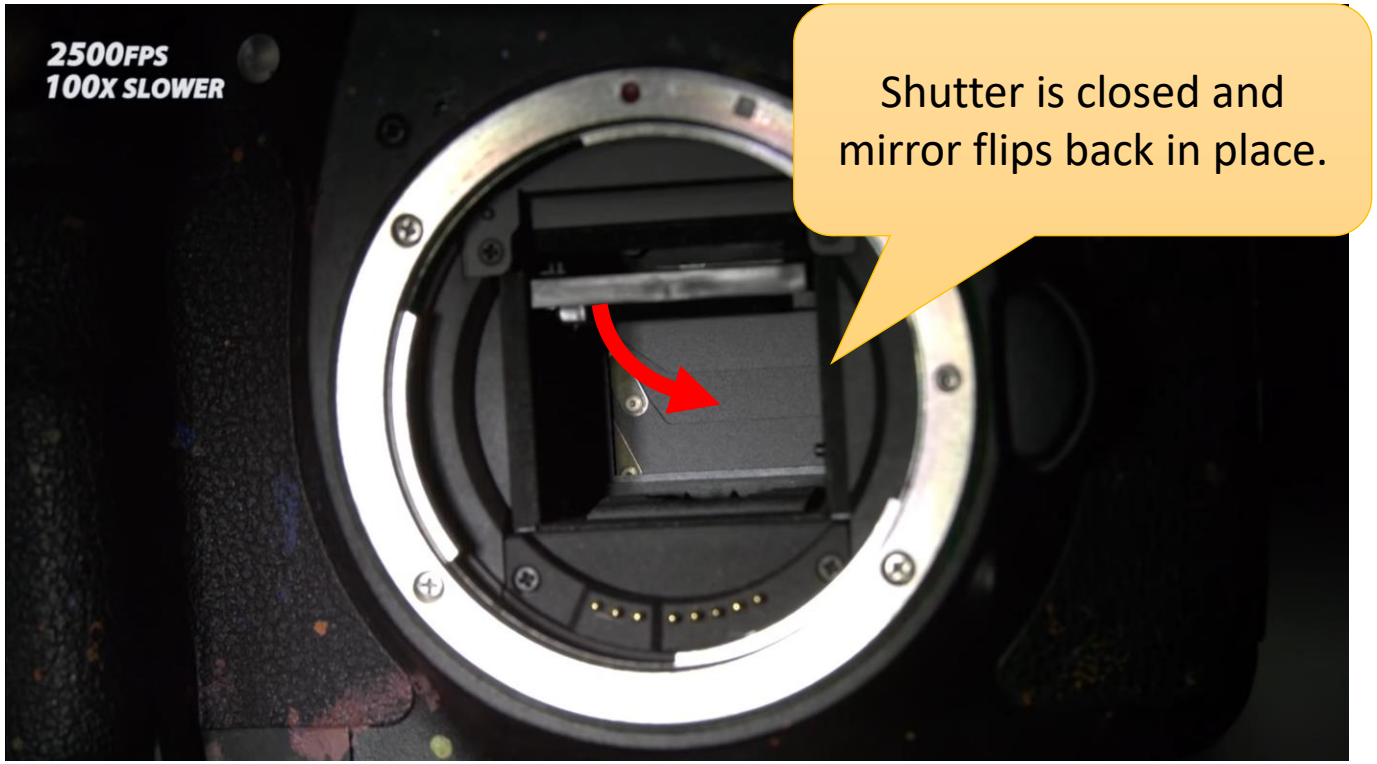

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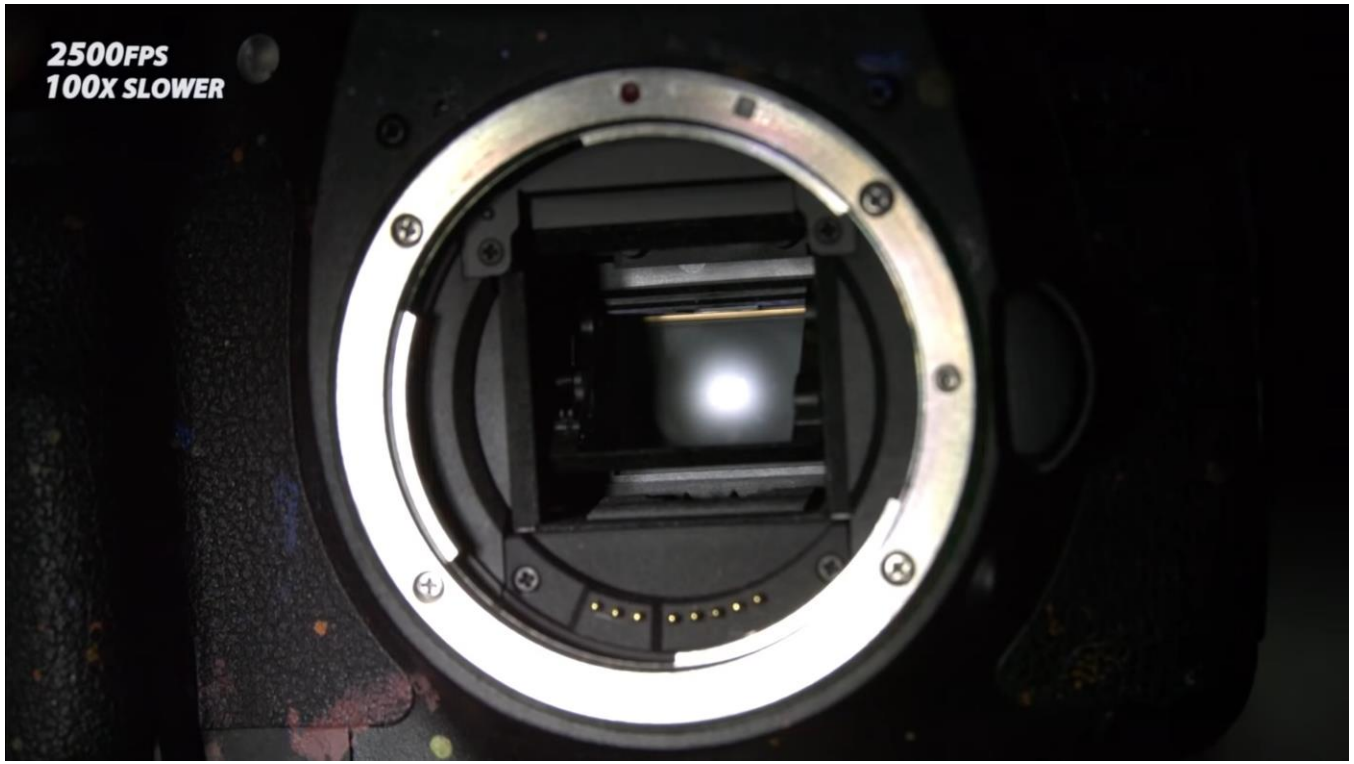

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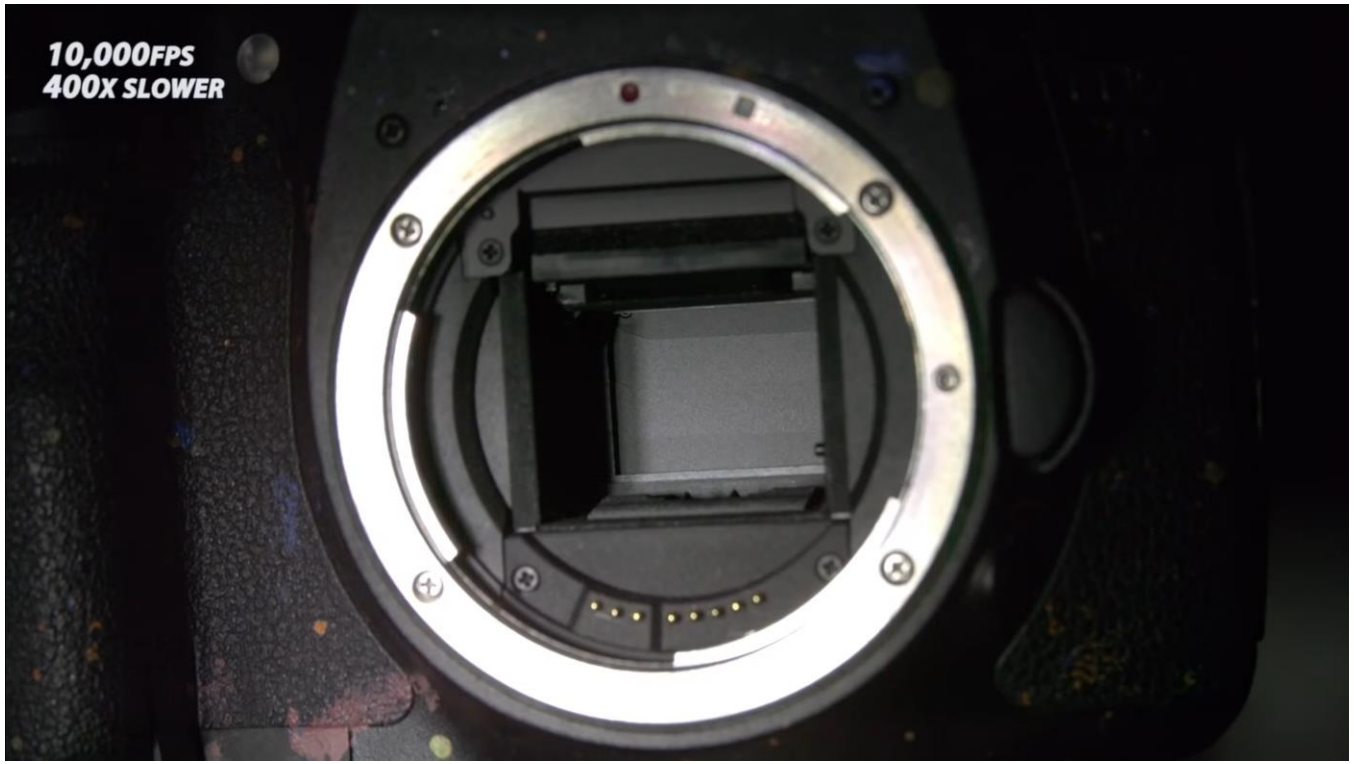

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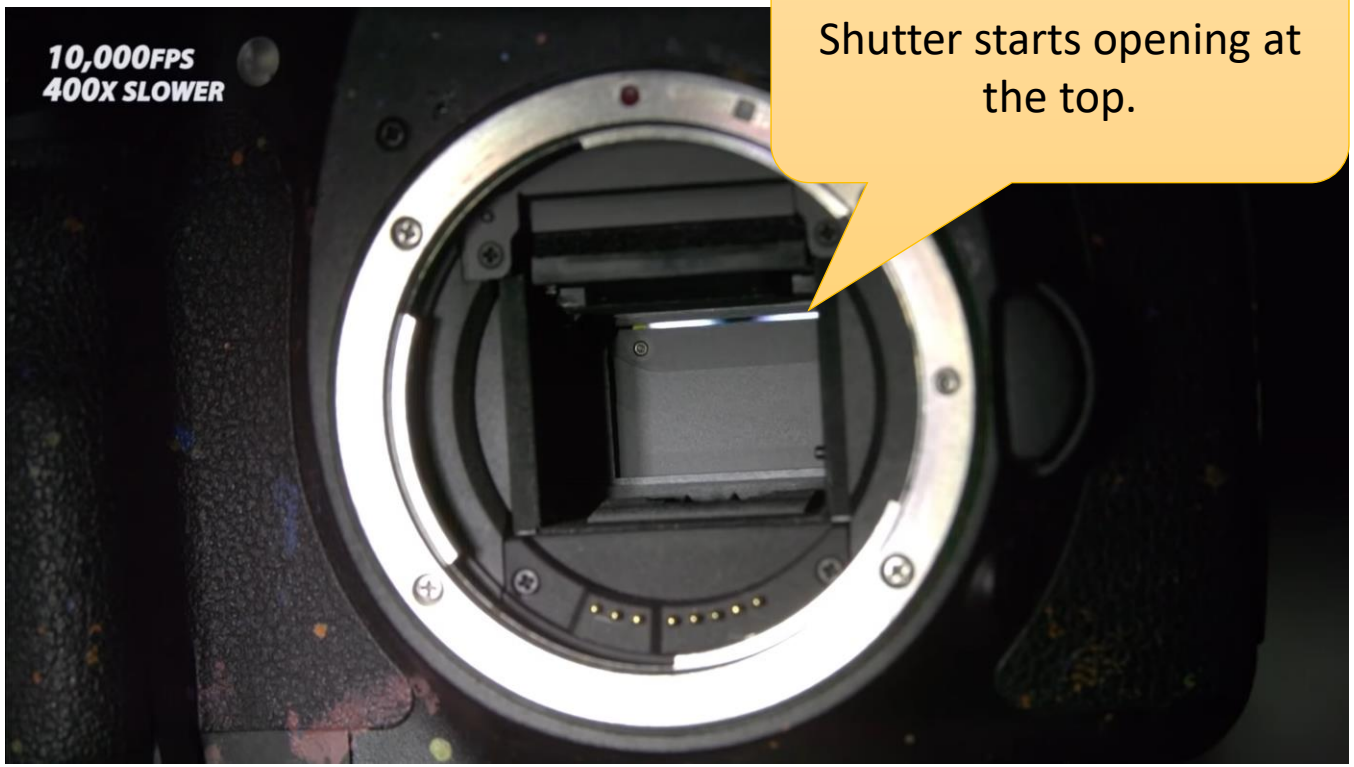

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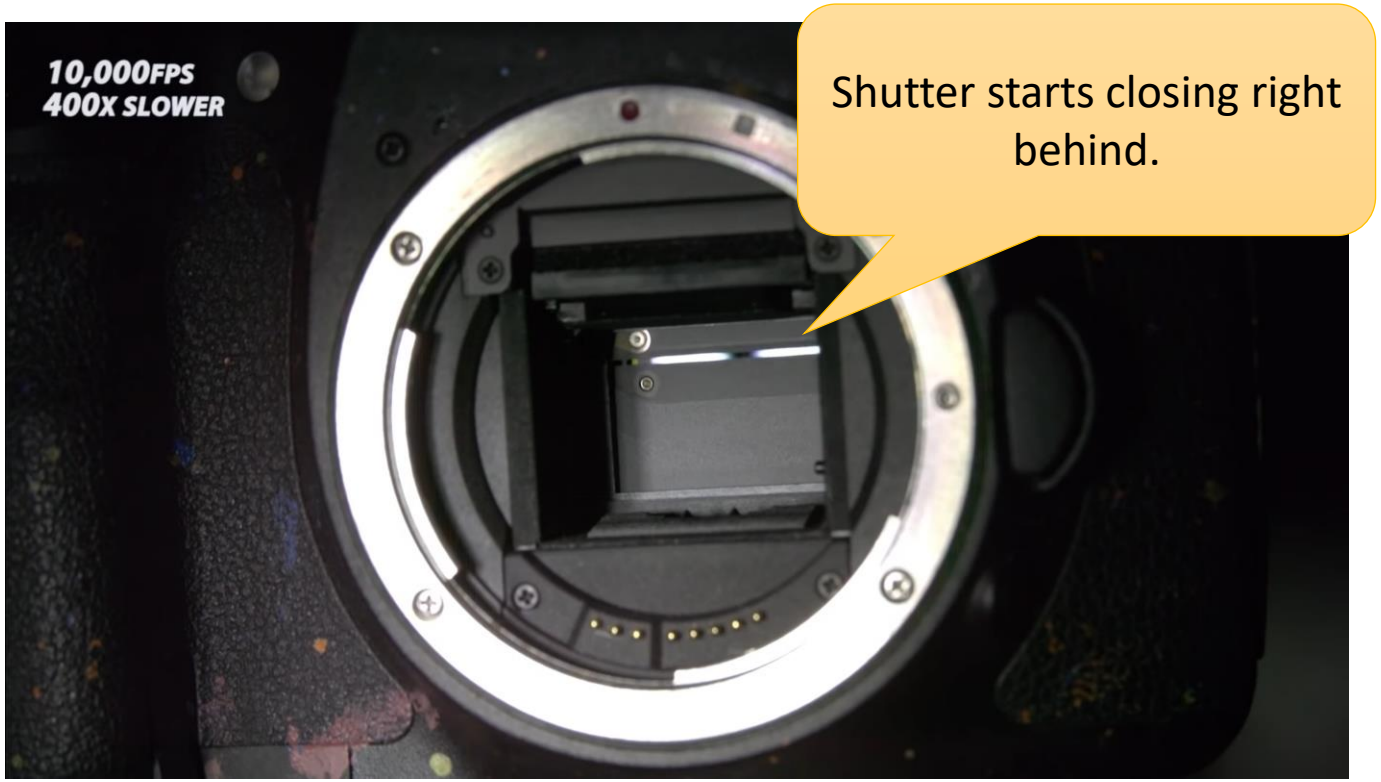

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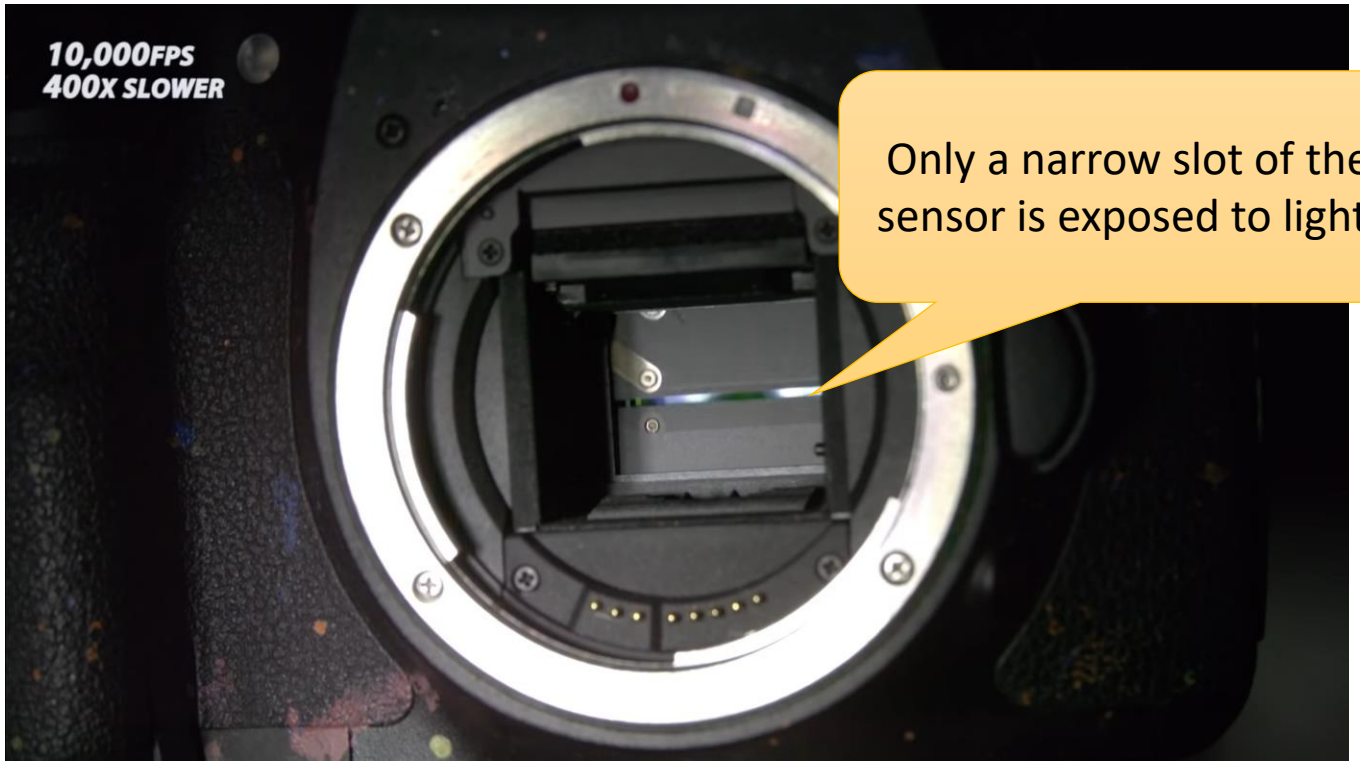

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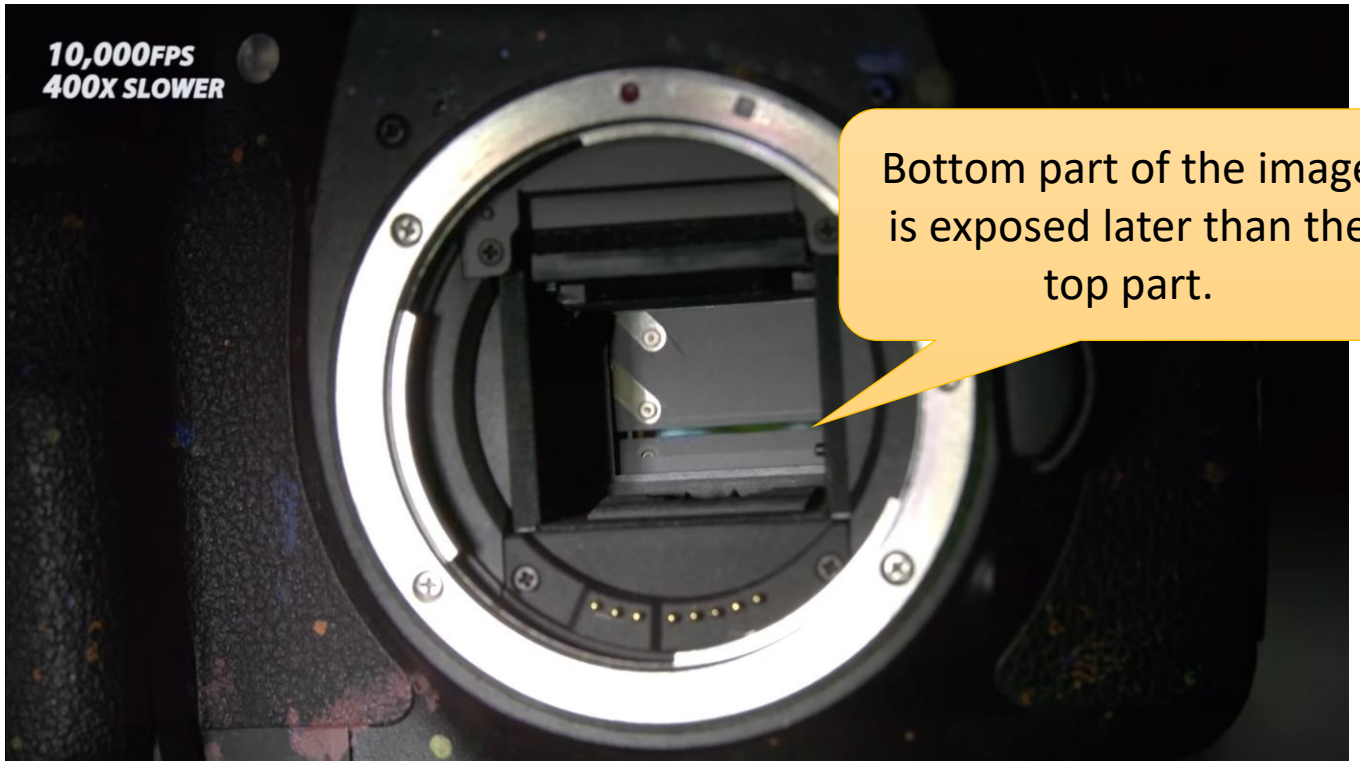

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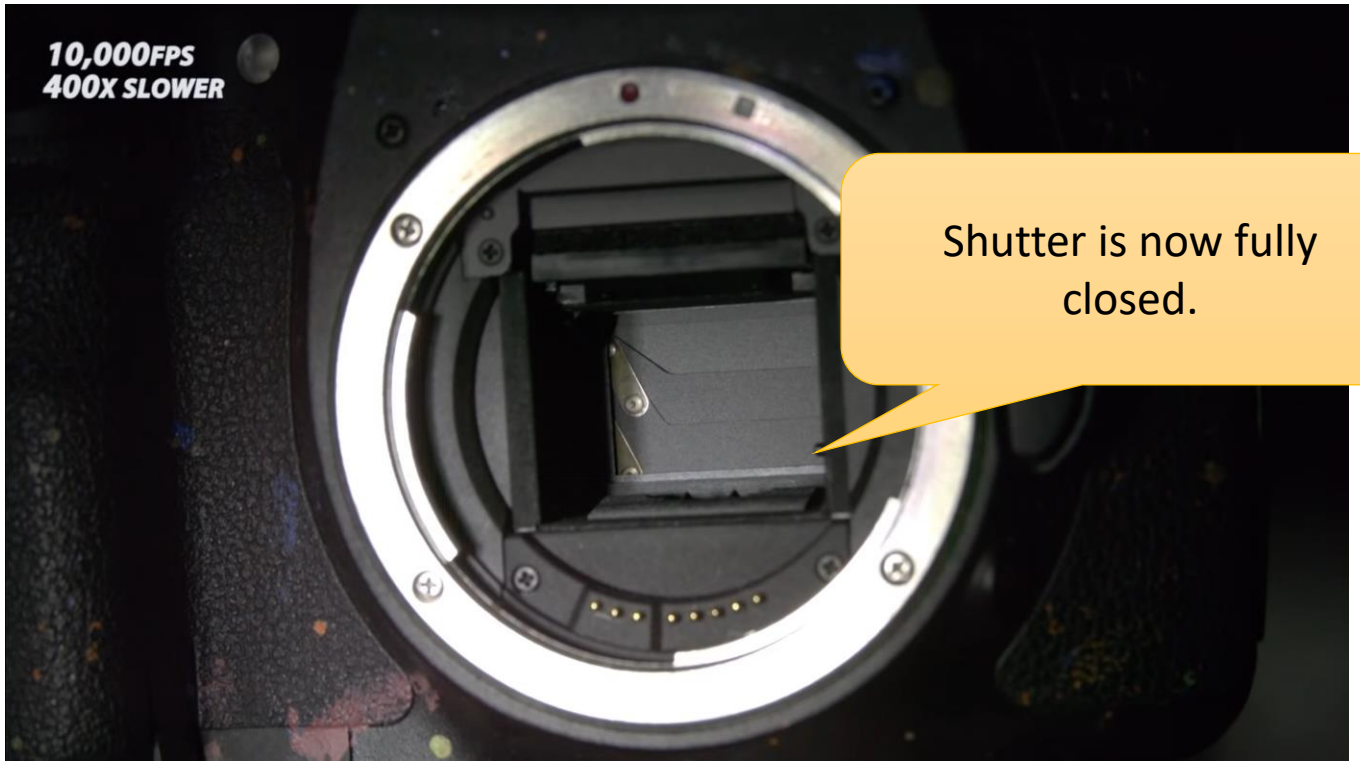

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- Rolling shutter effect
  - Image captured line by line
  - Fast moving objects get skewed

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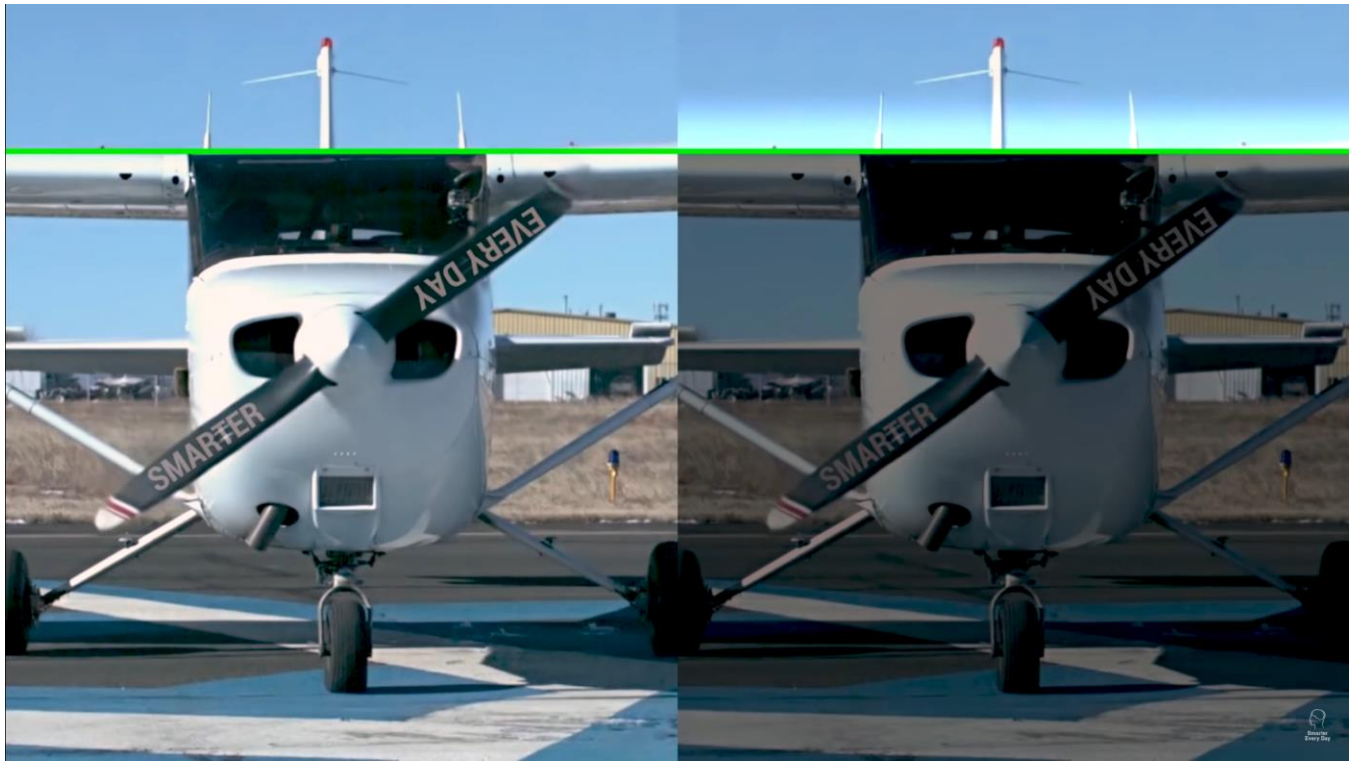

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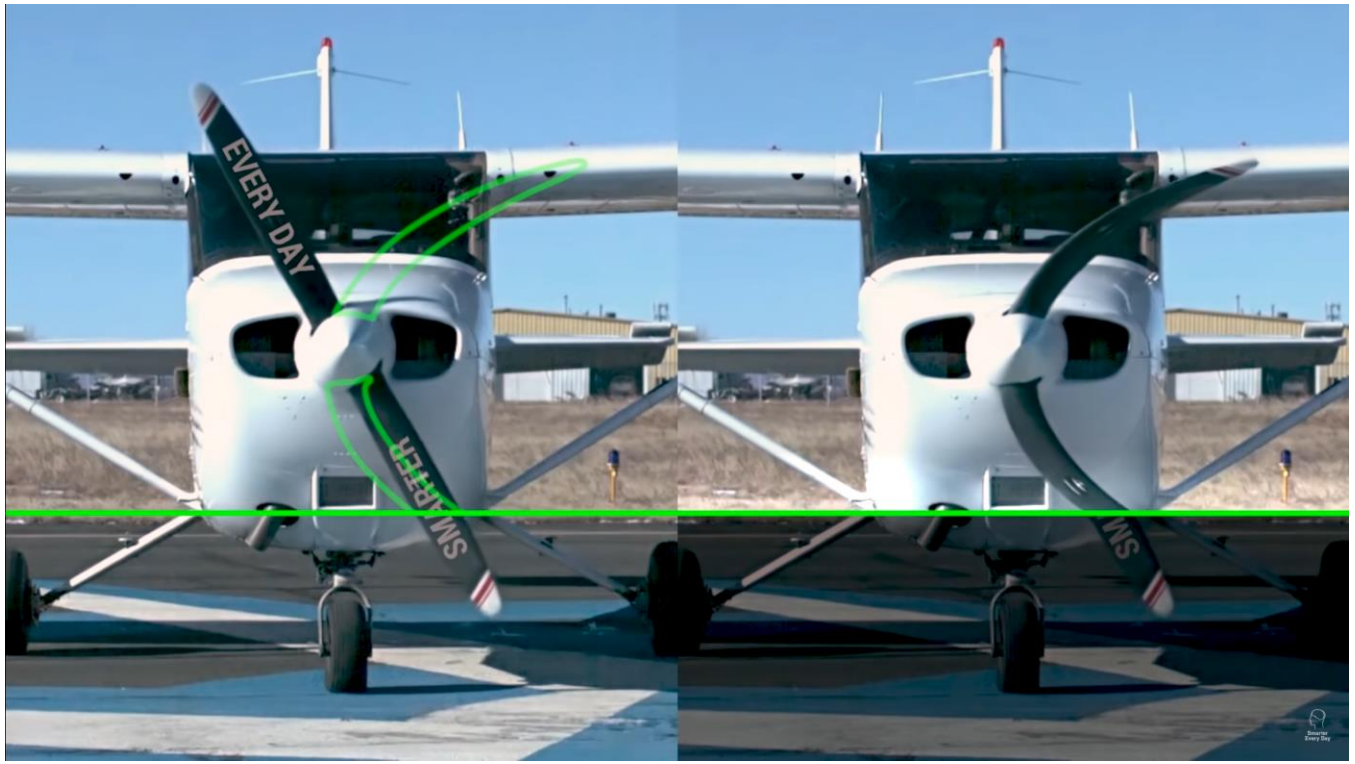

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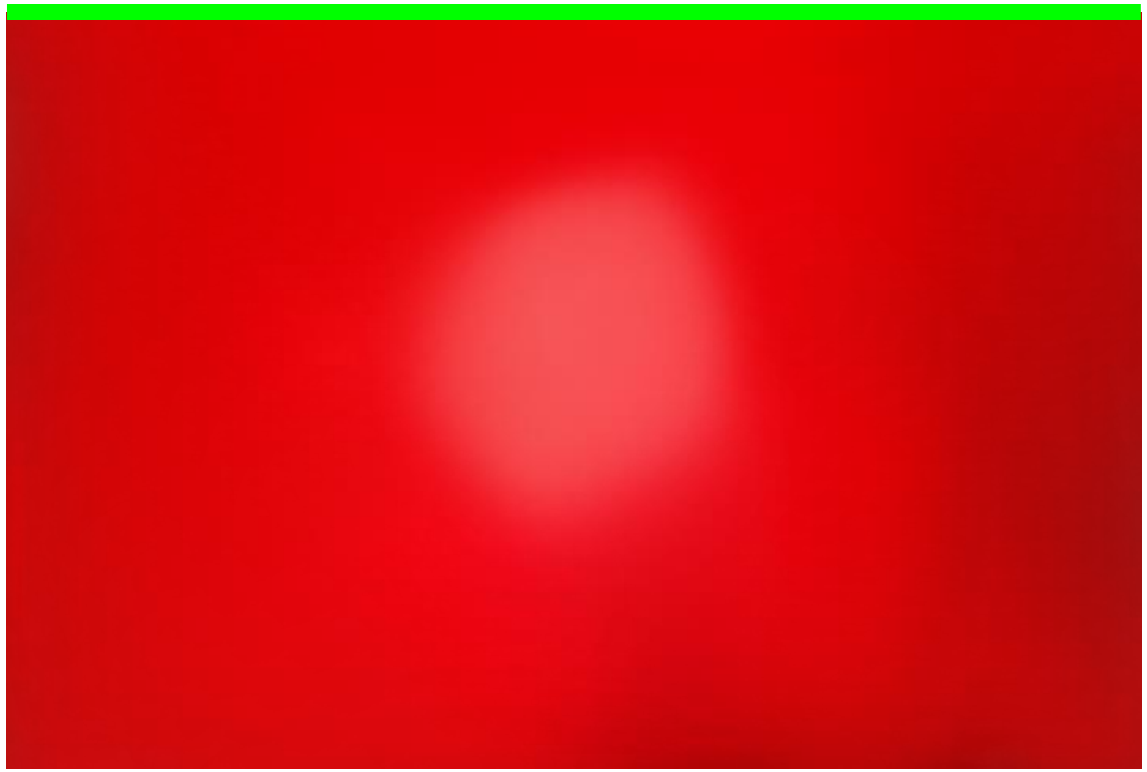

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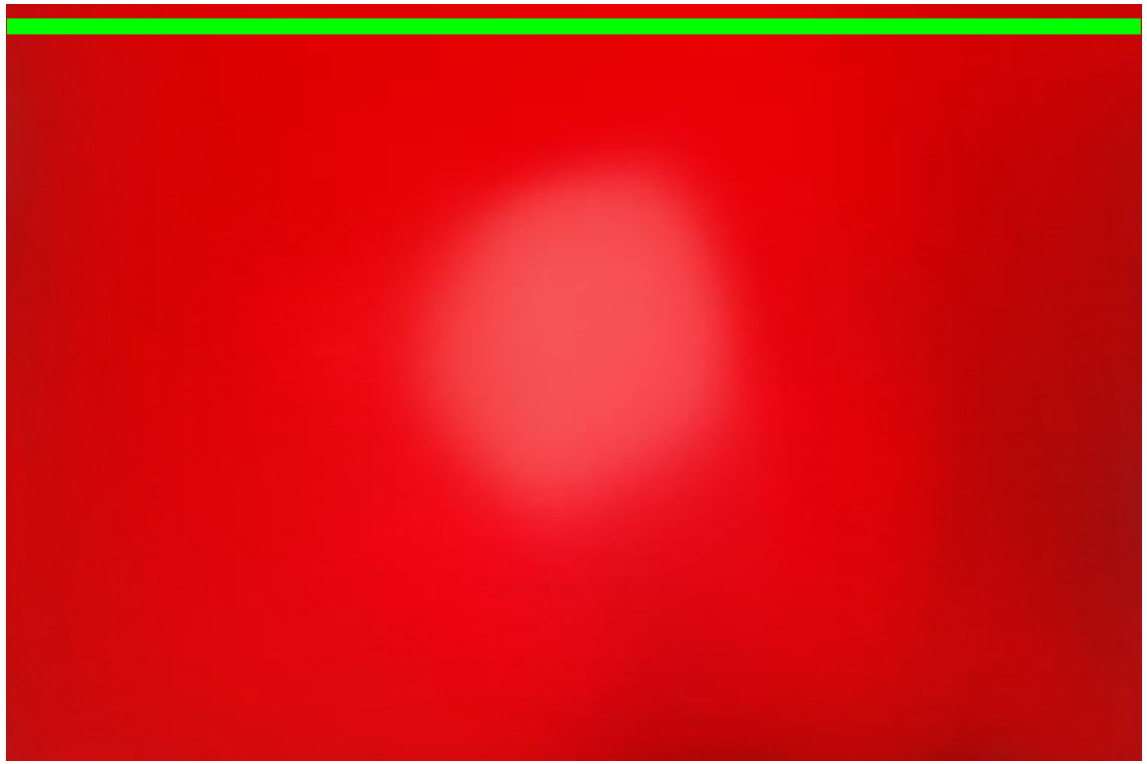

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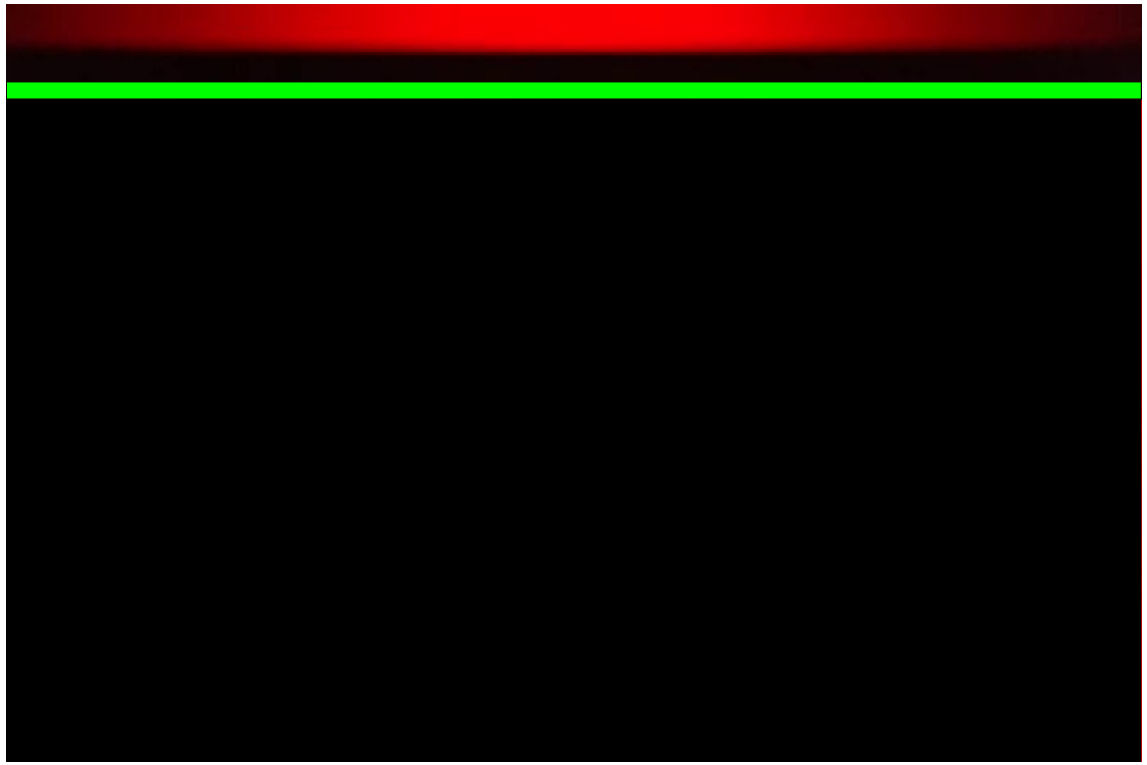

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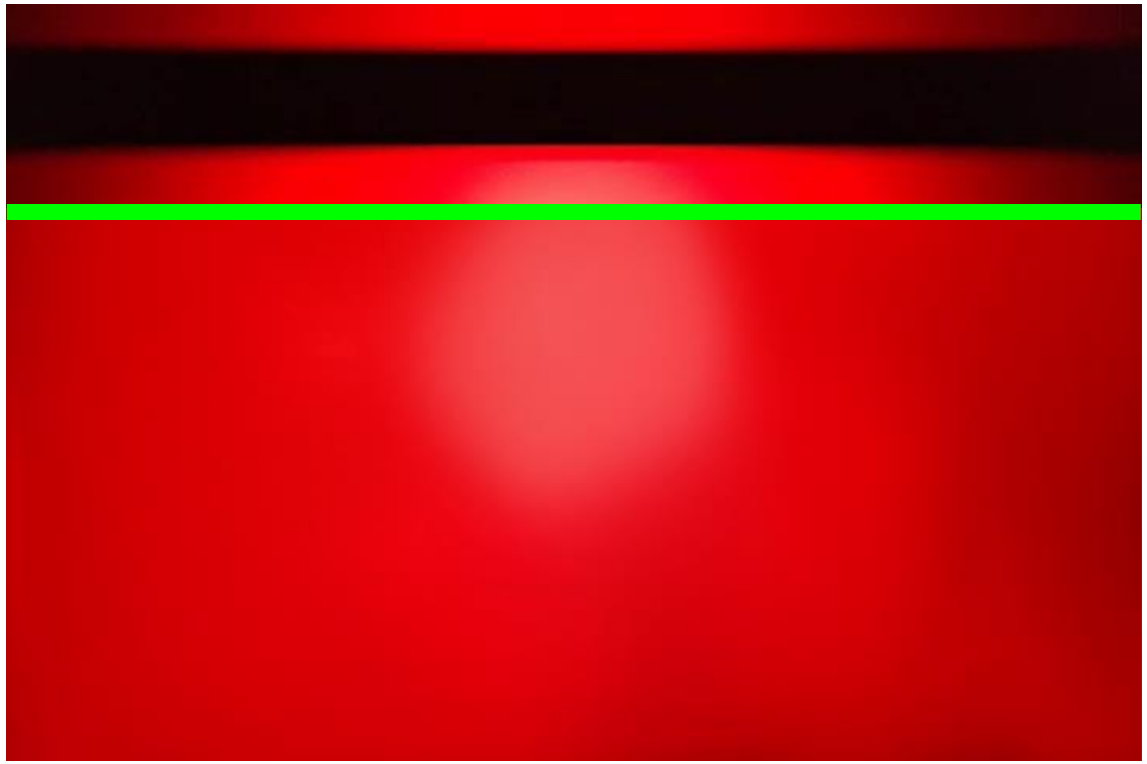

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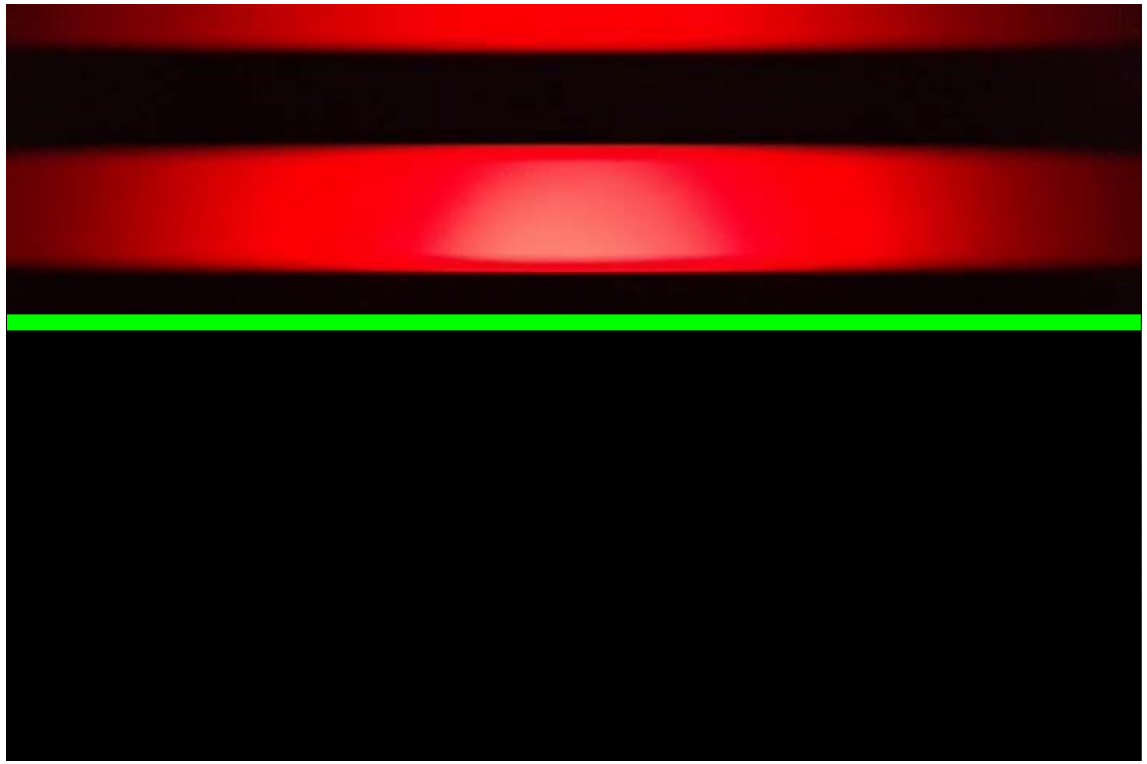

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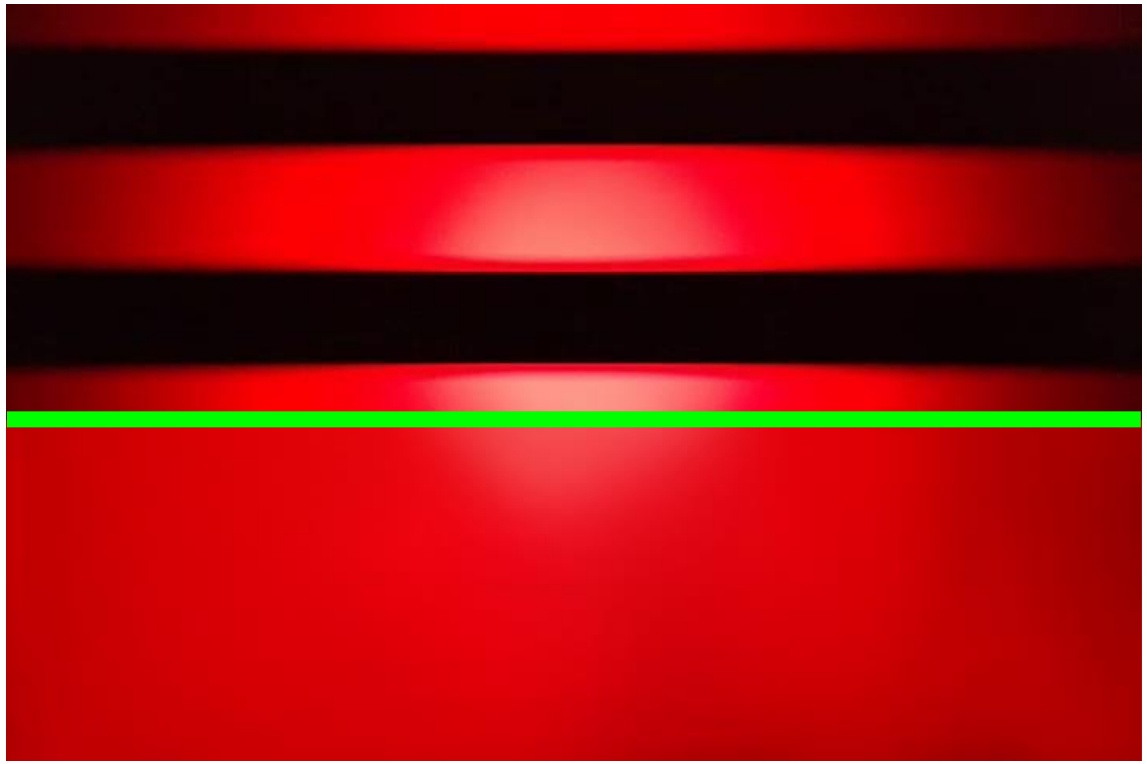

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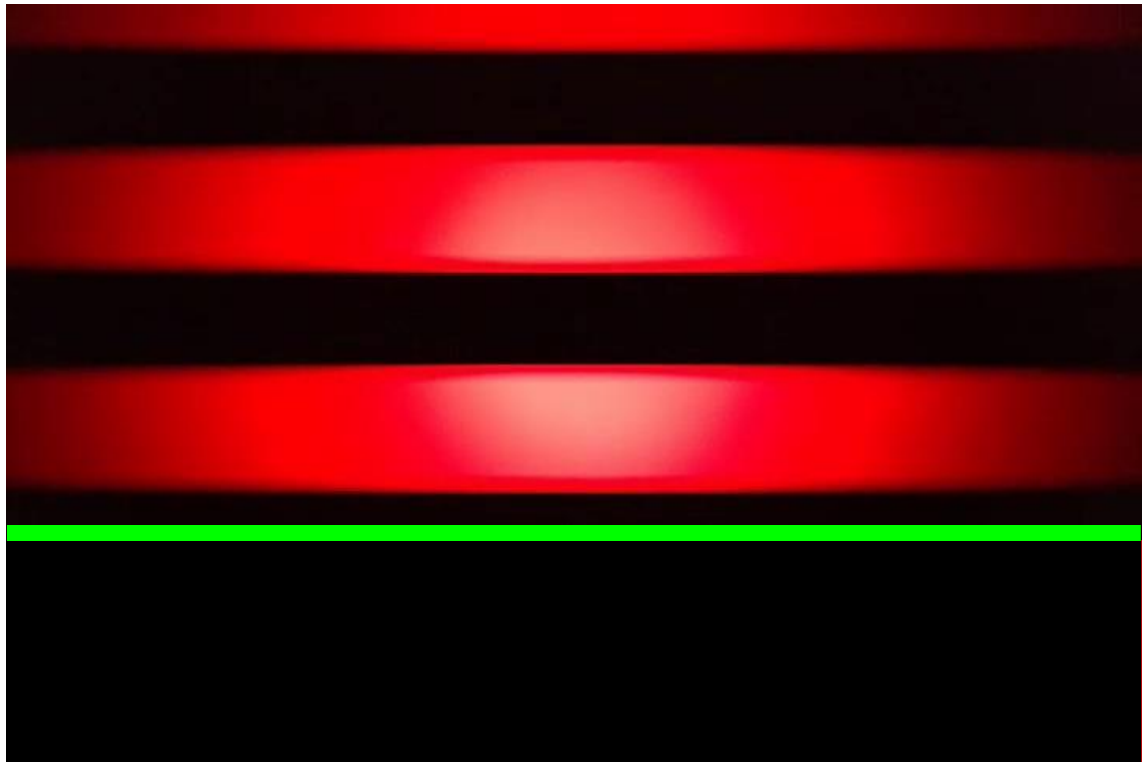

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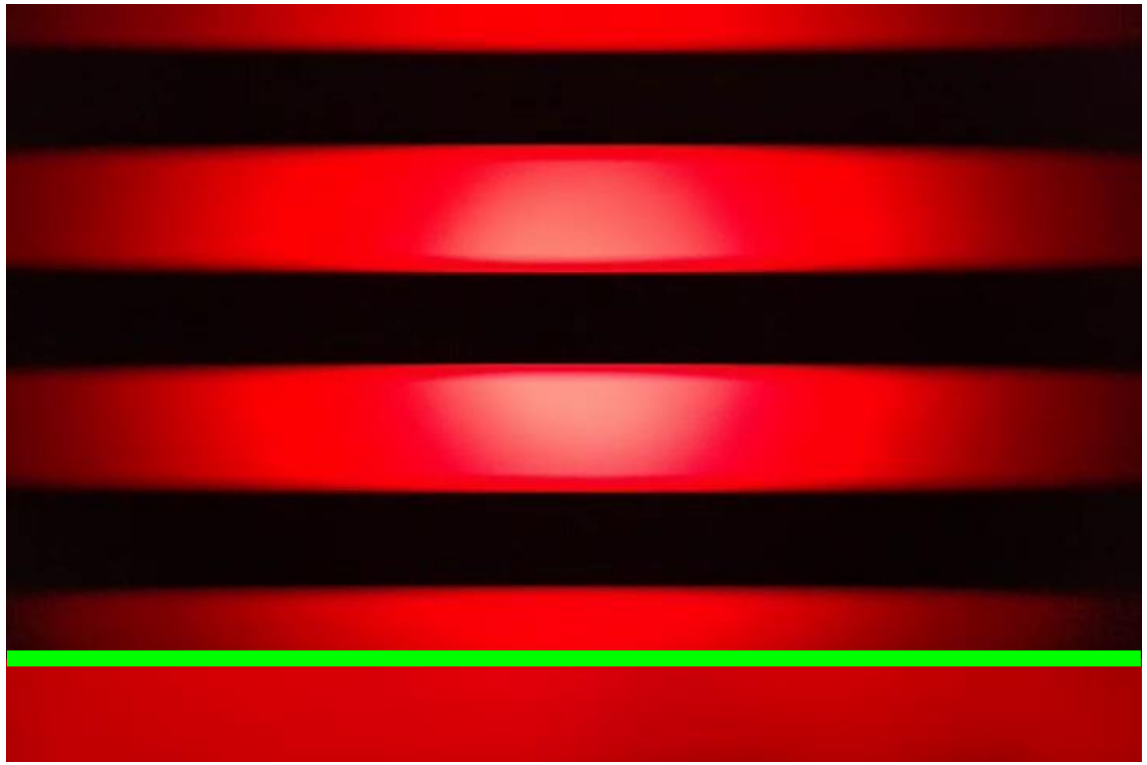

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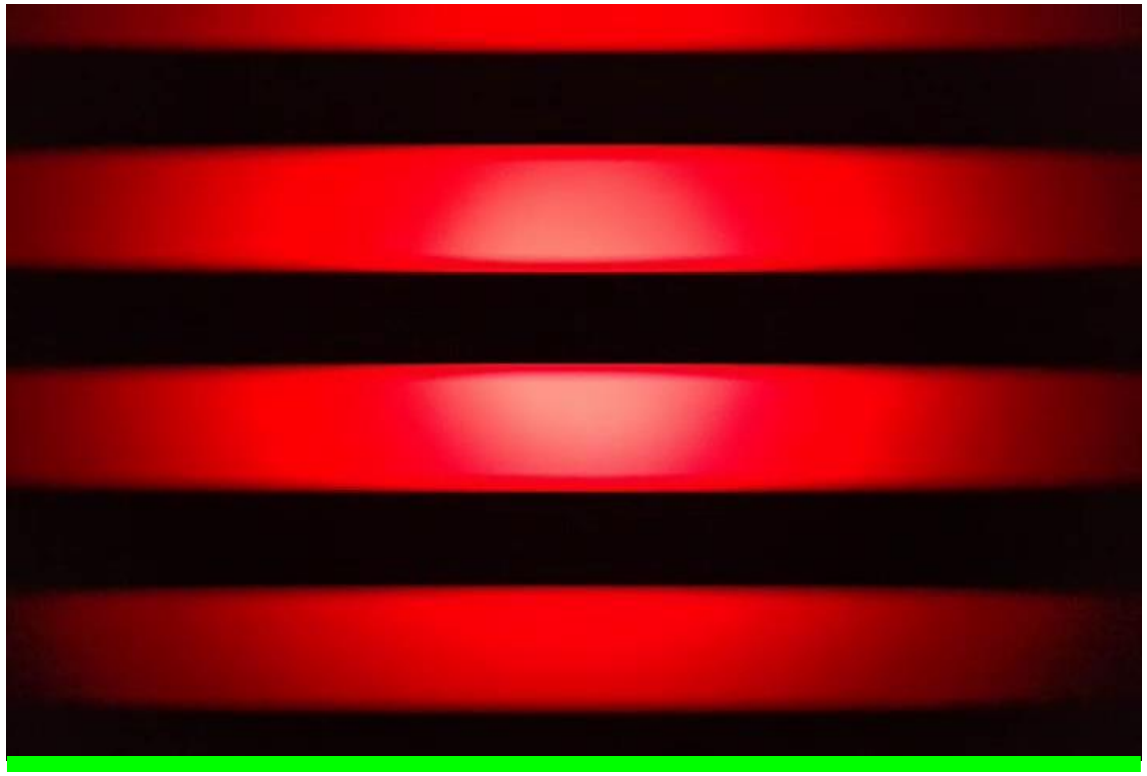
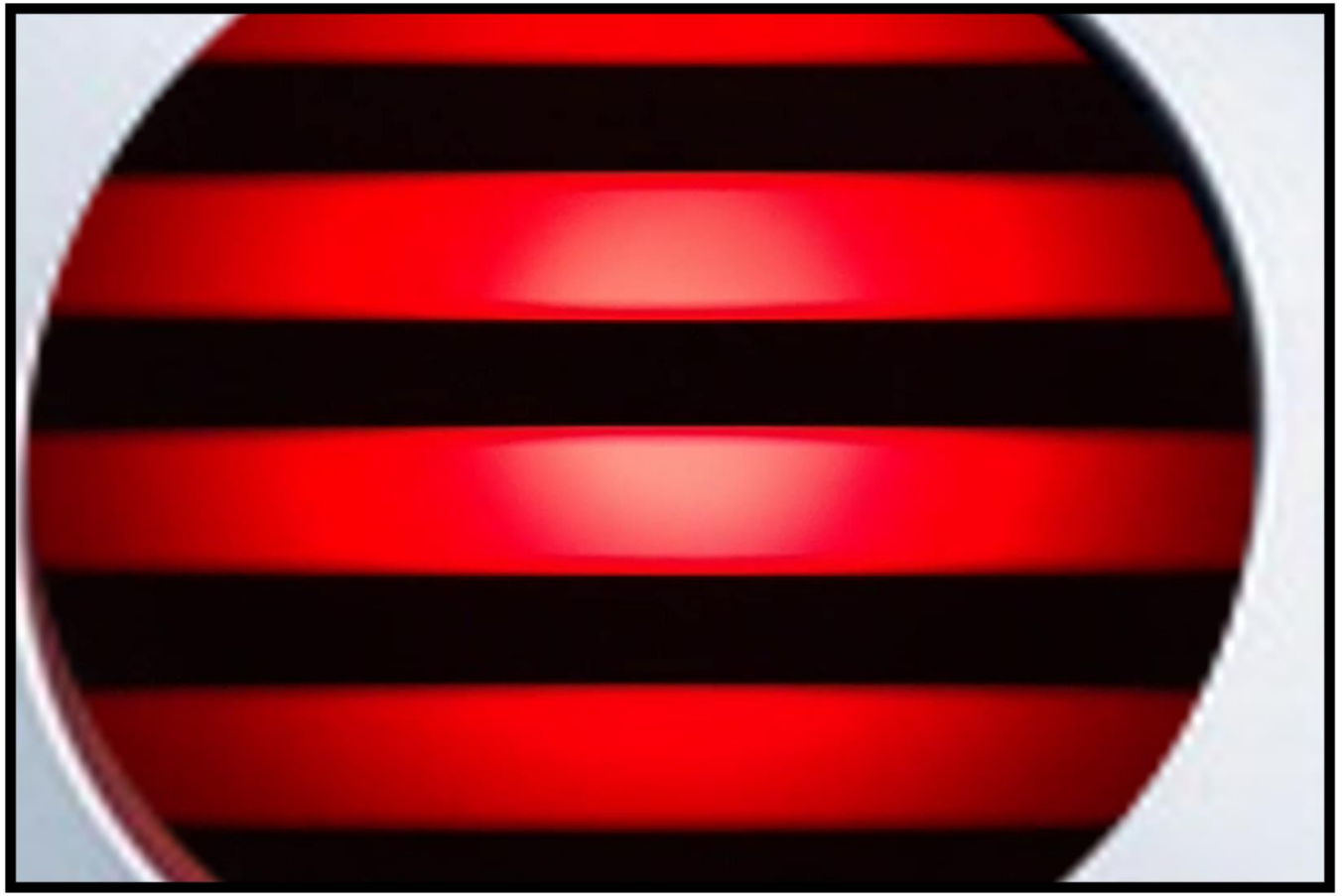


UDPSOOK

- Only a small portion of the stripe pattern is visible.
- The state depends on the position of the light source.



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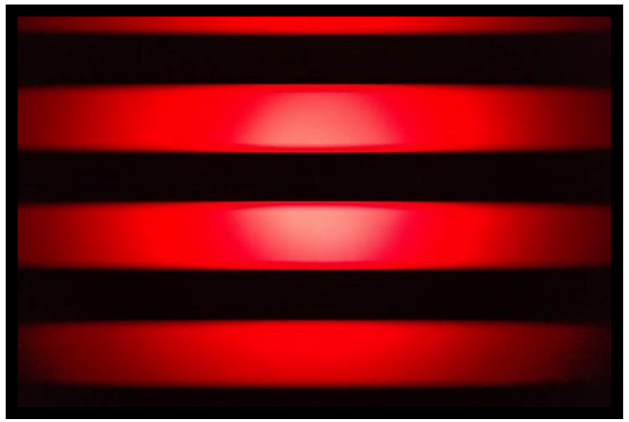

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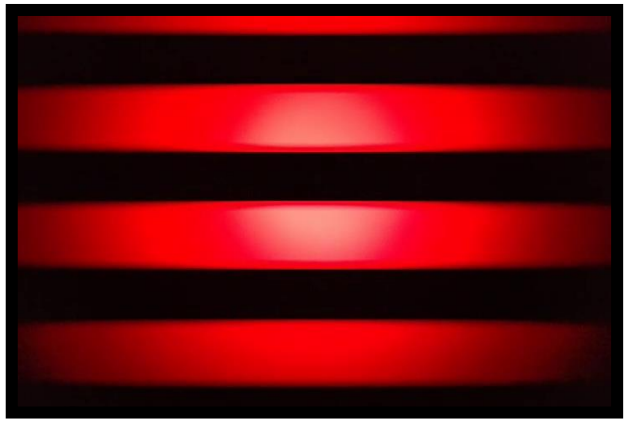

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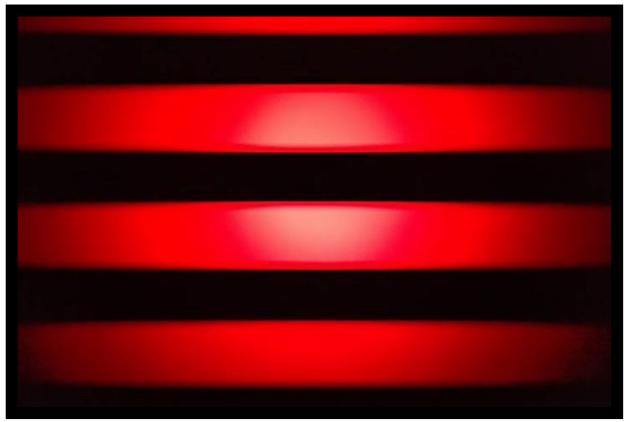

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UDPSOOK

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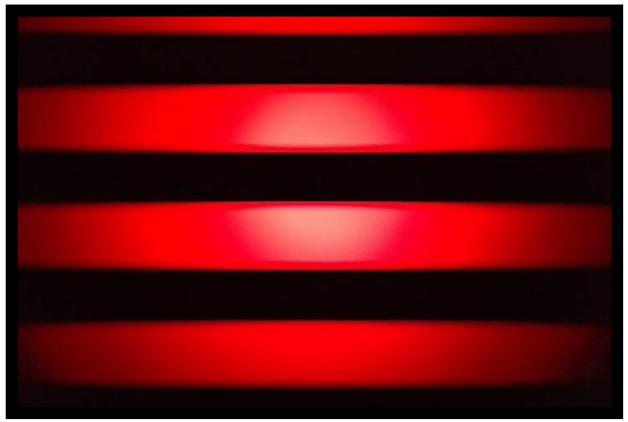

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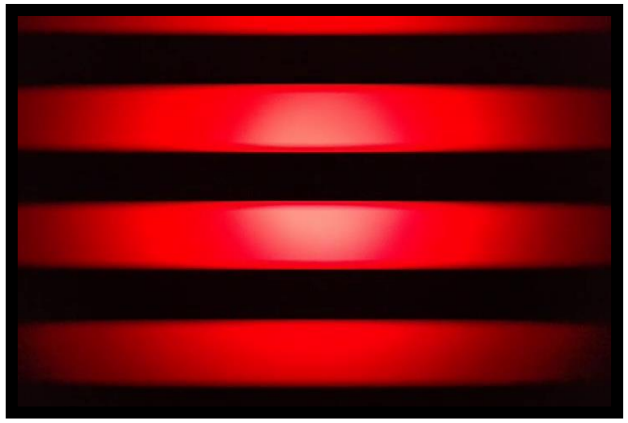

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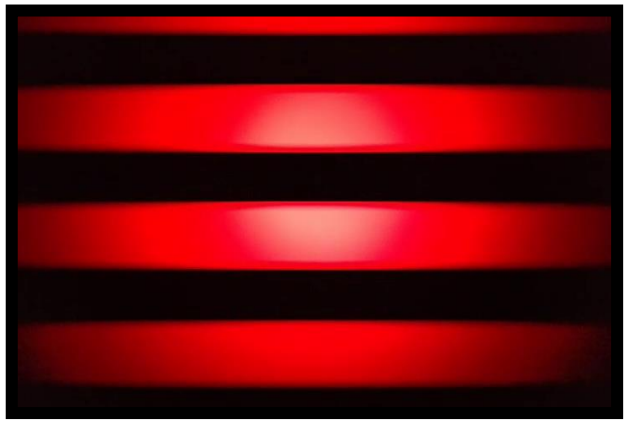

With phase shifts:

UDPSOOK – In practice

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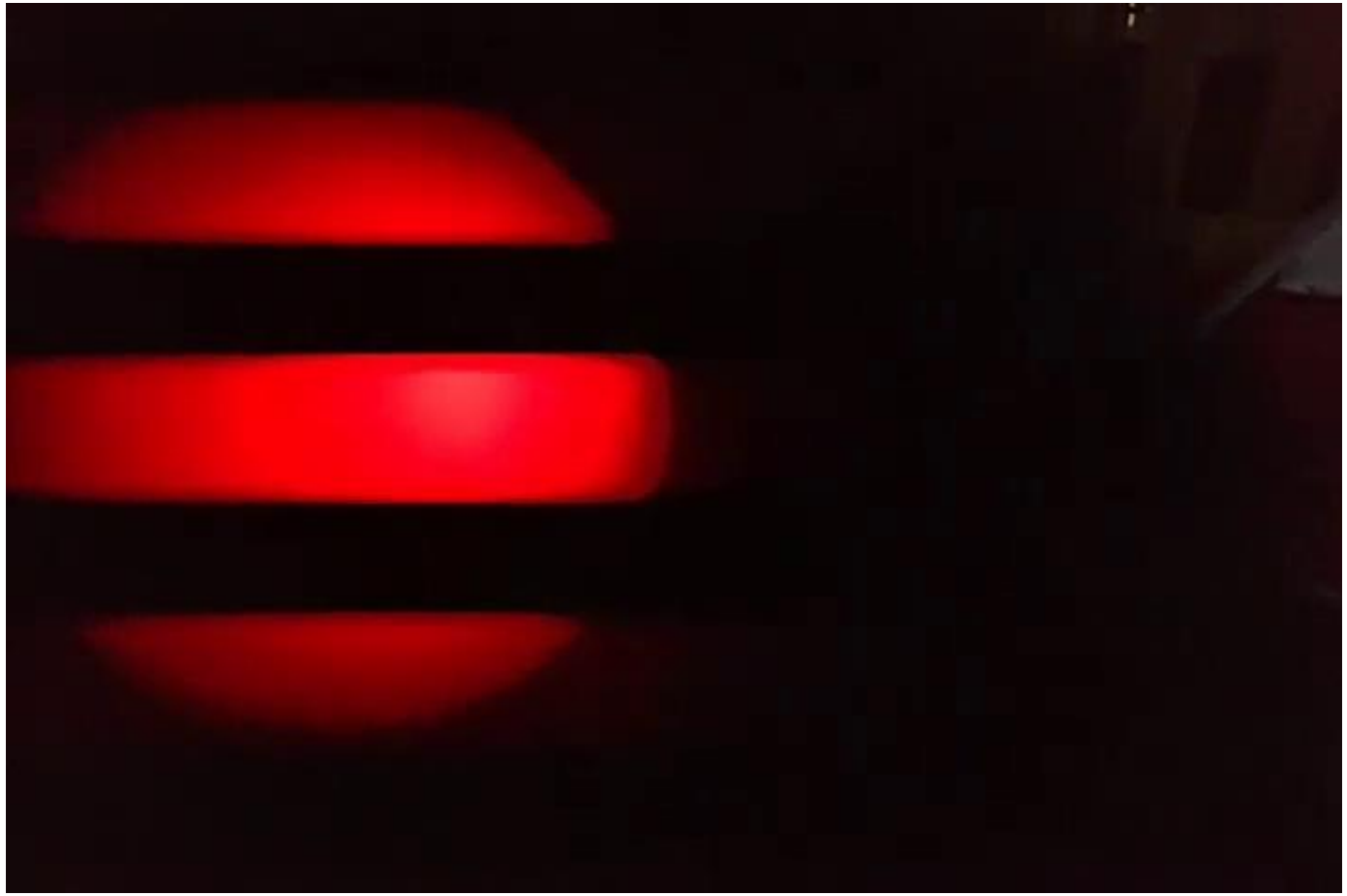

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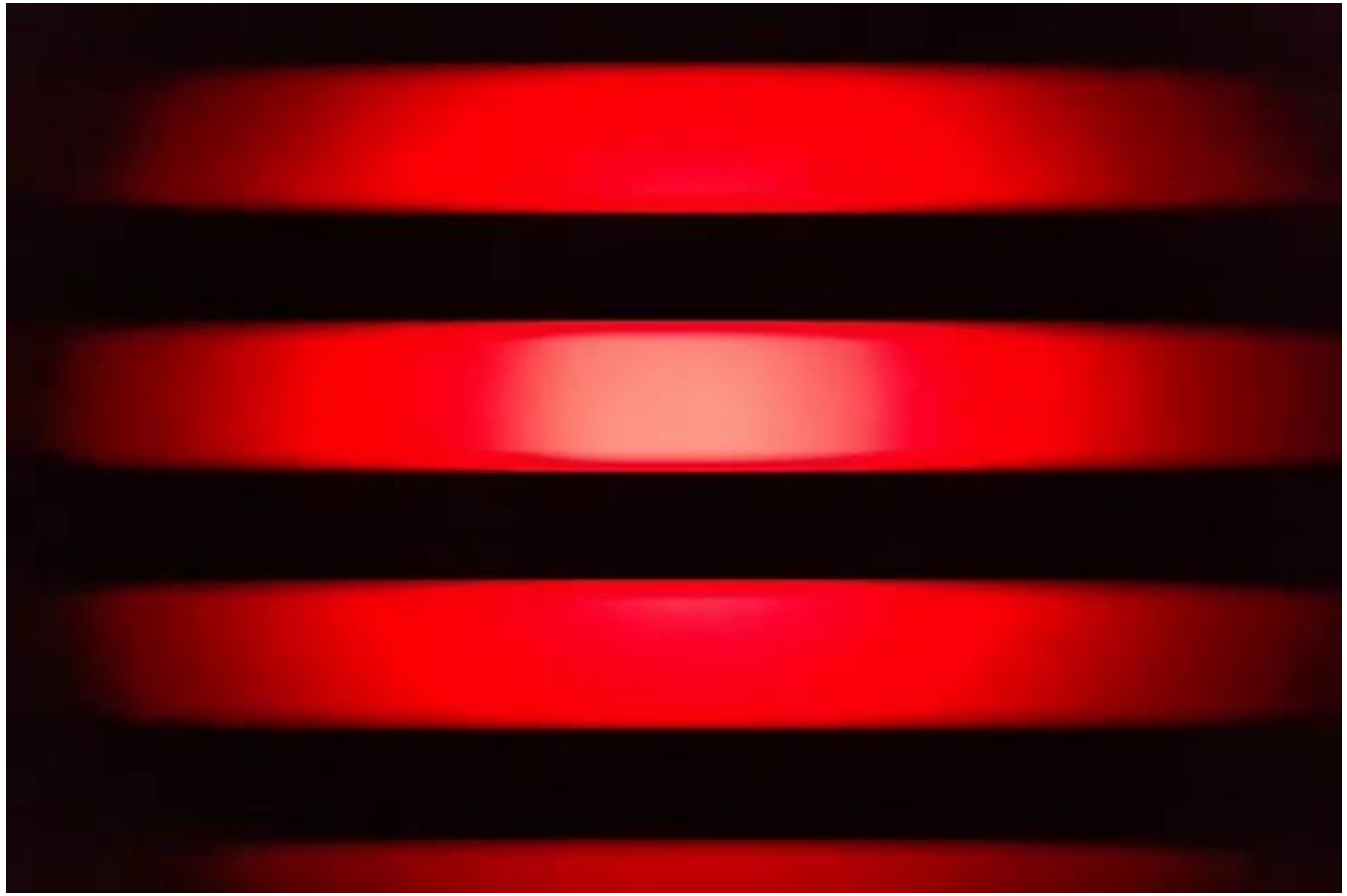

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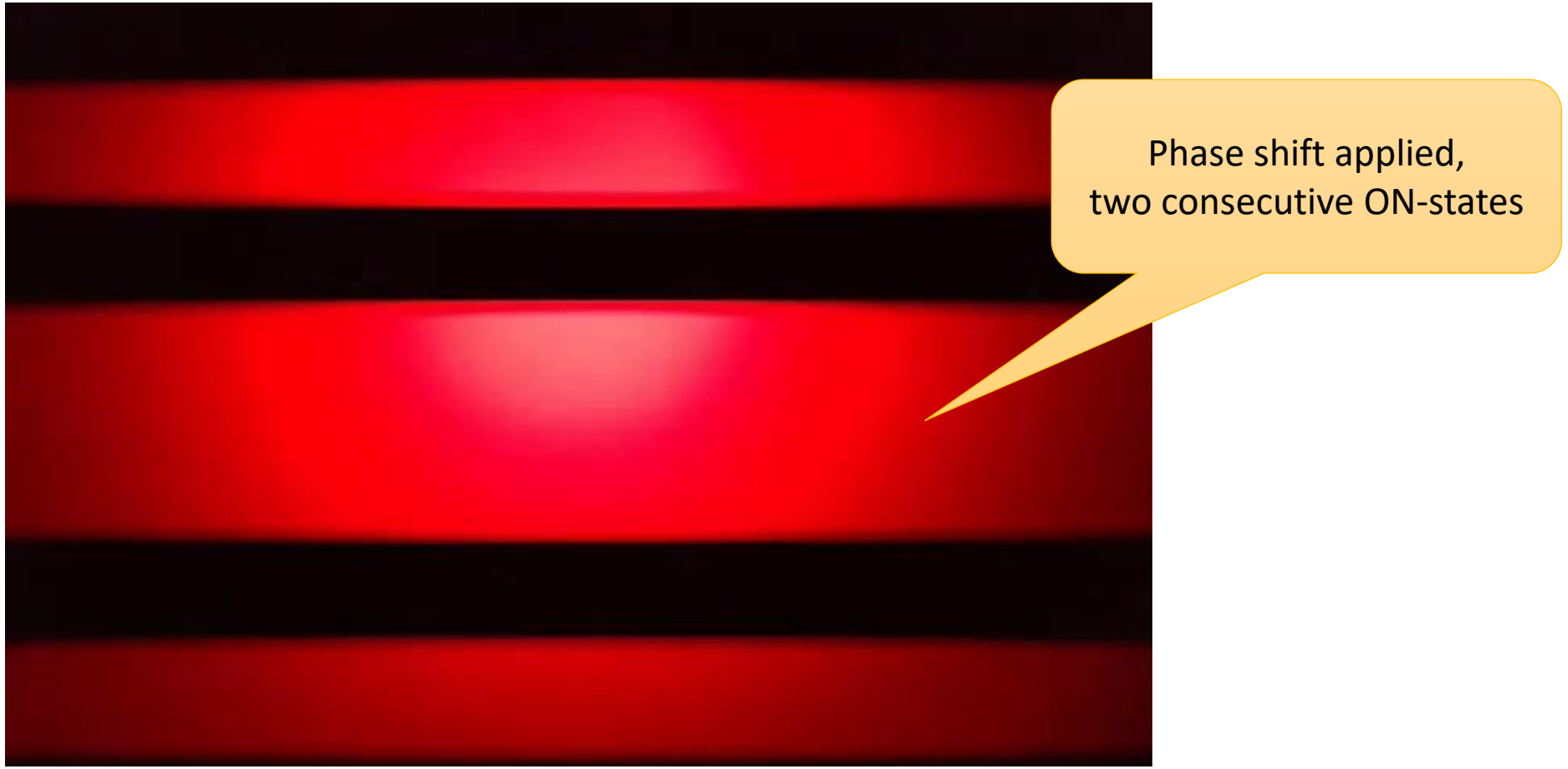

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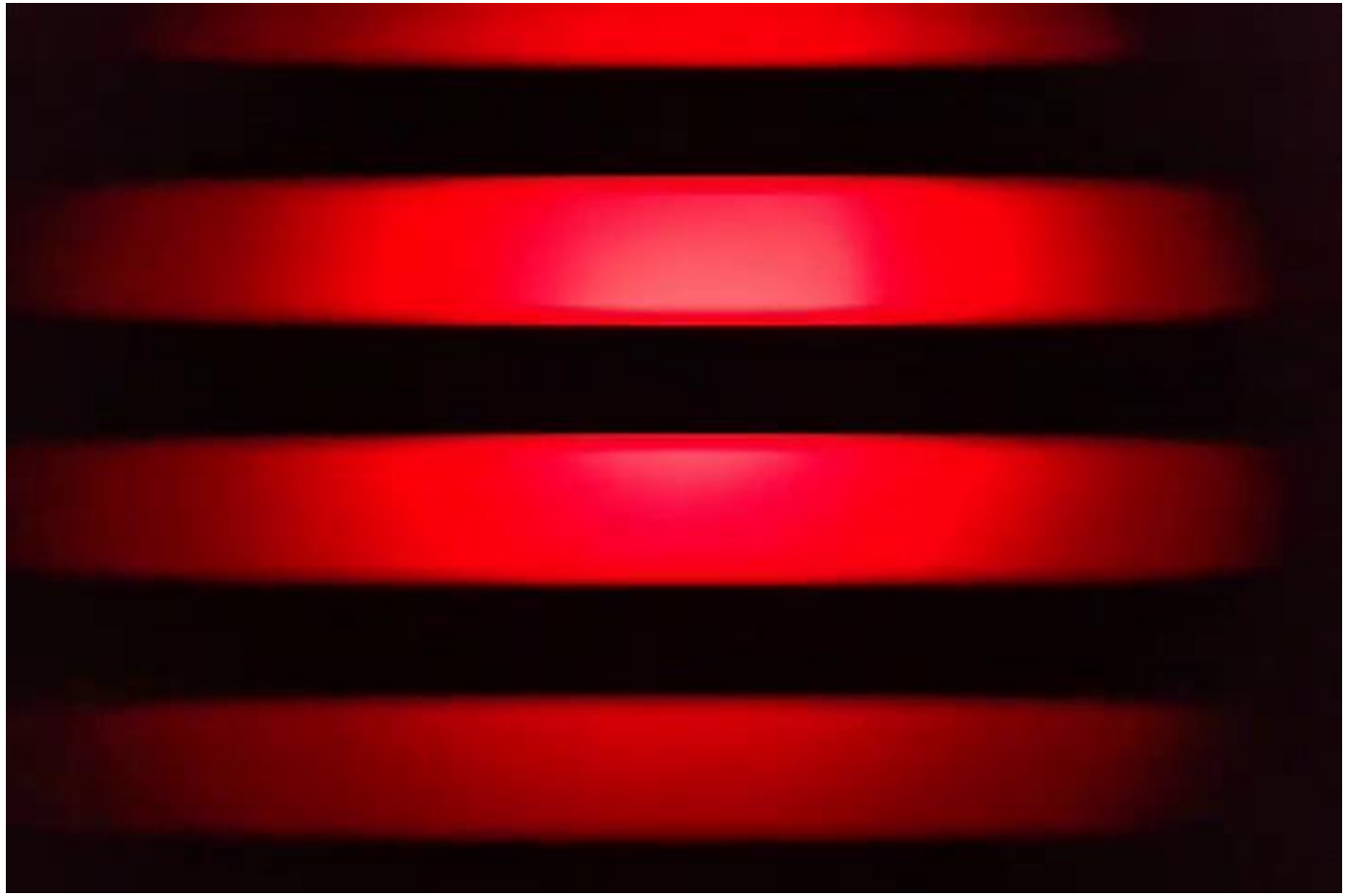
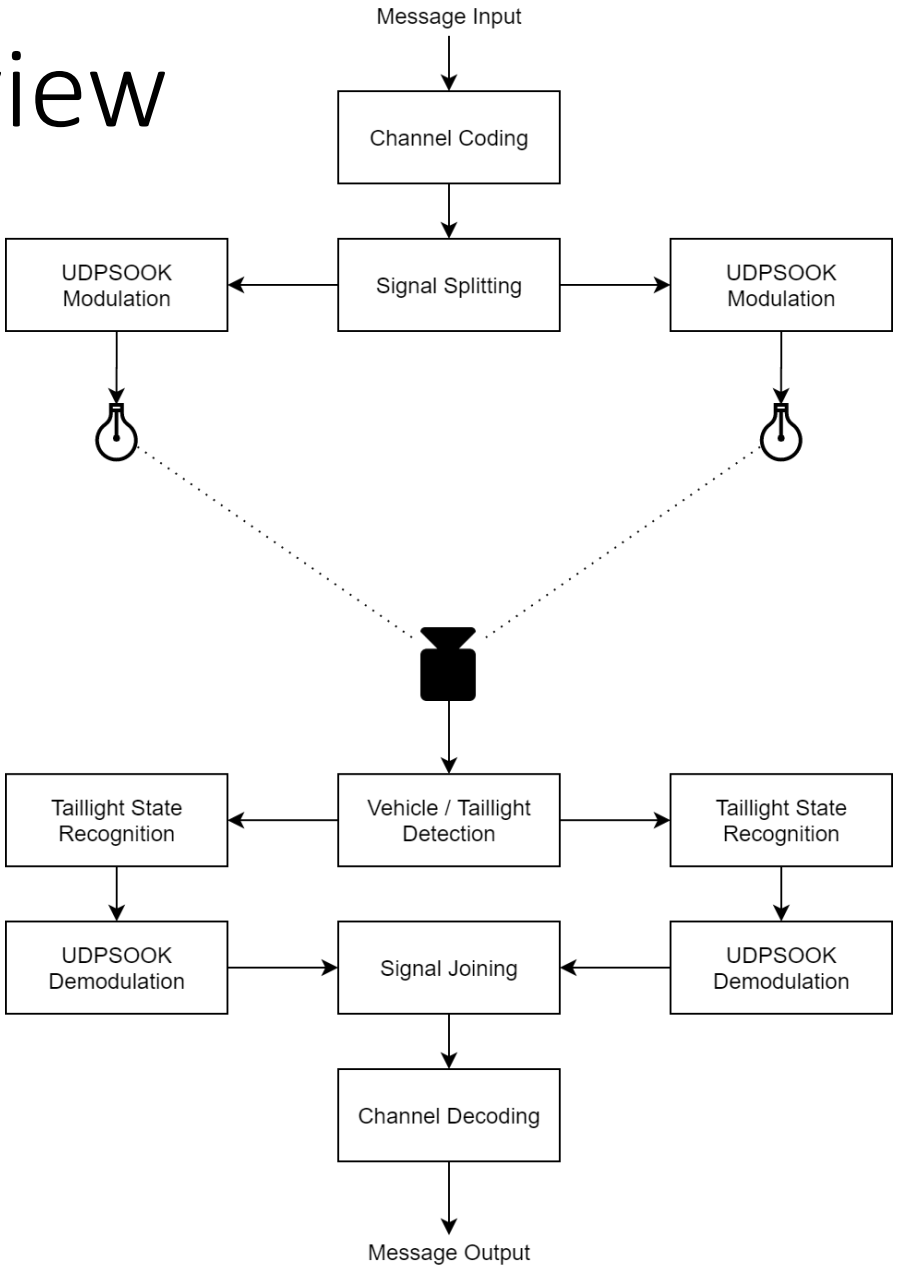
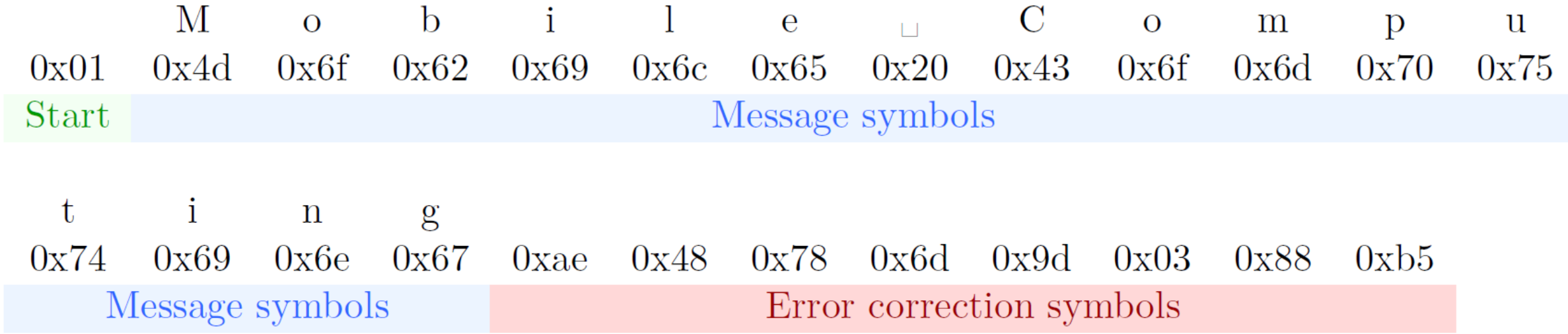


System Overview



Channel Coding

- Message contains 128-bit verification key
- Reed-Solomon channel coding
  - RS(24/16) with 8-bit symbols
  - Additional start symbol
  - Code word length: 200 bit

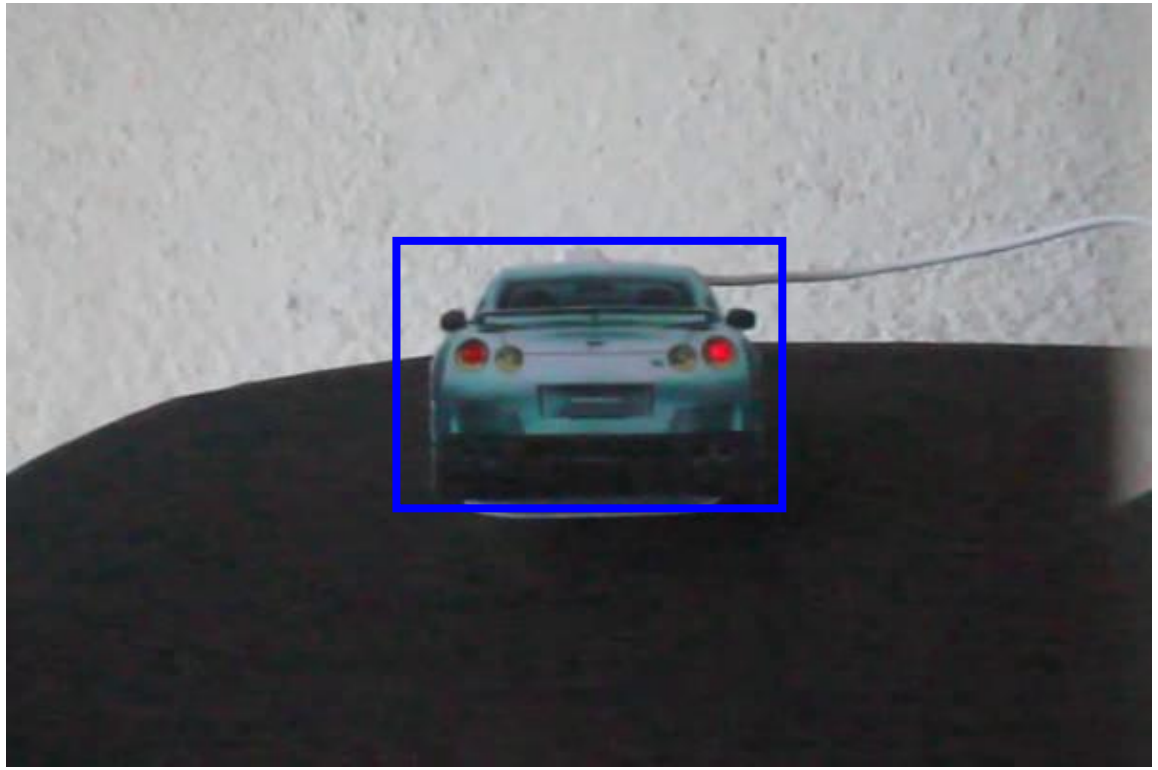


Receiver - Camera

- Frame Rate: 30 FPS
- Exposure Time: 1/2000 seconds

Receiver - Camera

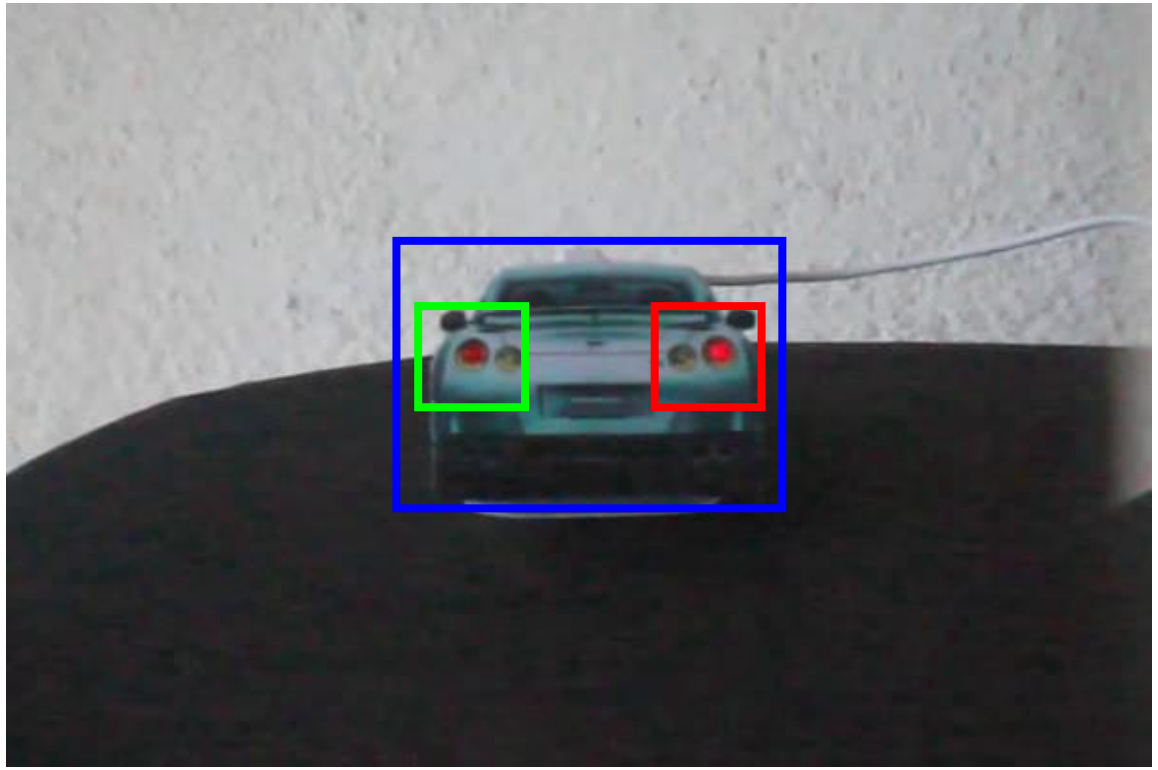
- Vehicle Detection with YOLO framework
  - Every 20th frame for real-time performance



J. Redmon, S. Divvala, R. Girshick, and A. Farhadi, “You only look once: Unified, real-time object detection,” arXiv, 2015.

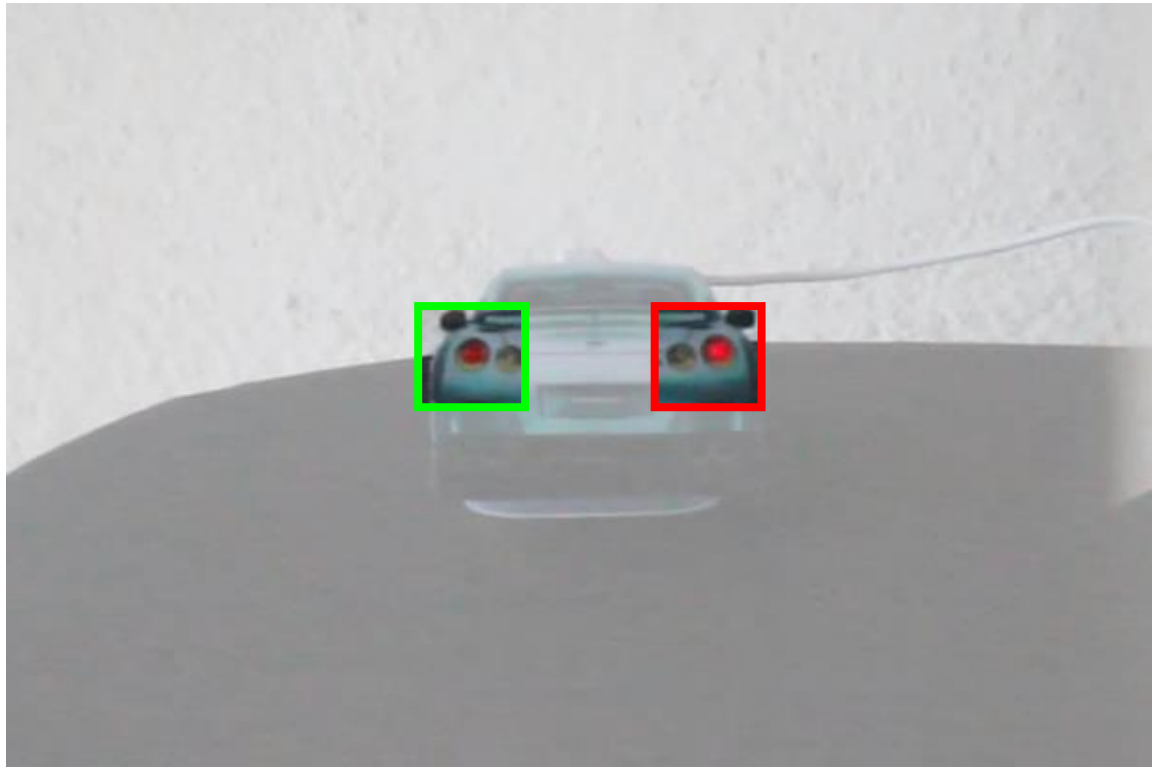
Receiver - Camera

- Static estimation of taillight ROI‘s



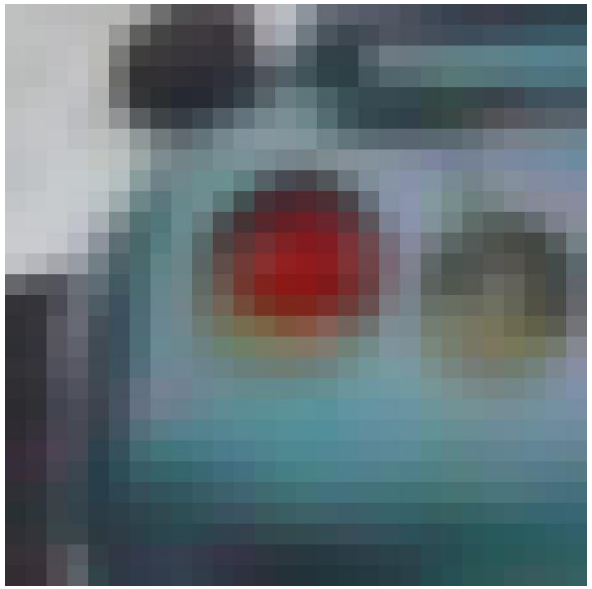
Receiver - Camera

- Crop ROI‘s and scale to 28x28 pixels

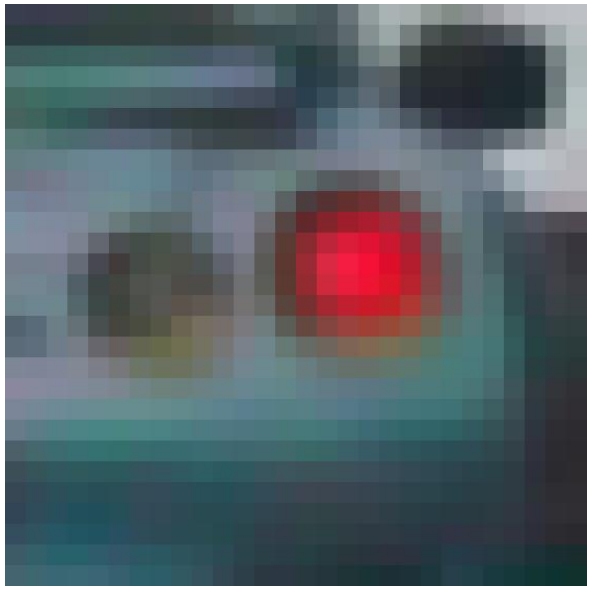


Receiver - Camera

- Classify states of taillights using neural network
  - Same state as before => Bit 0
  - State changed => Bit 1



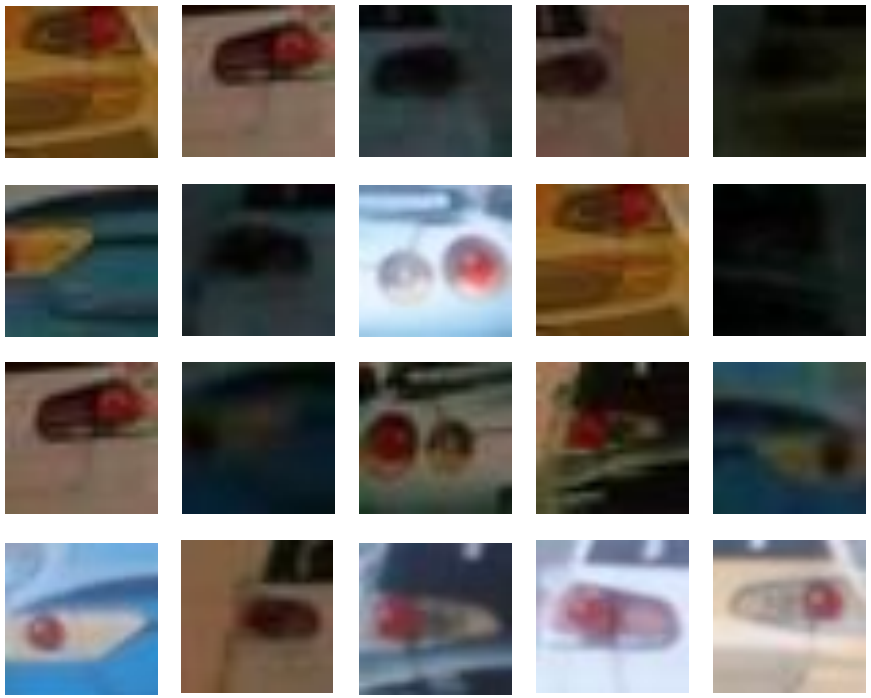
OFF

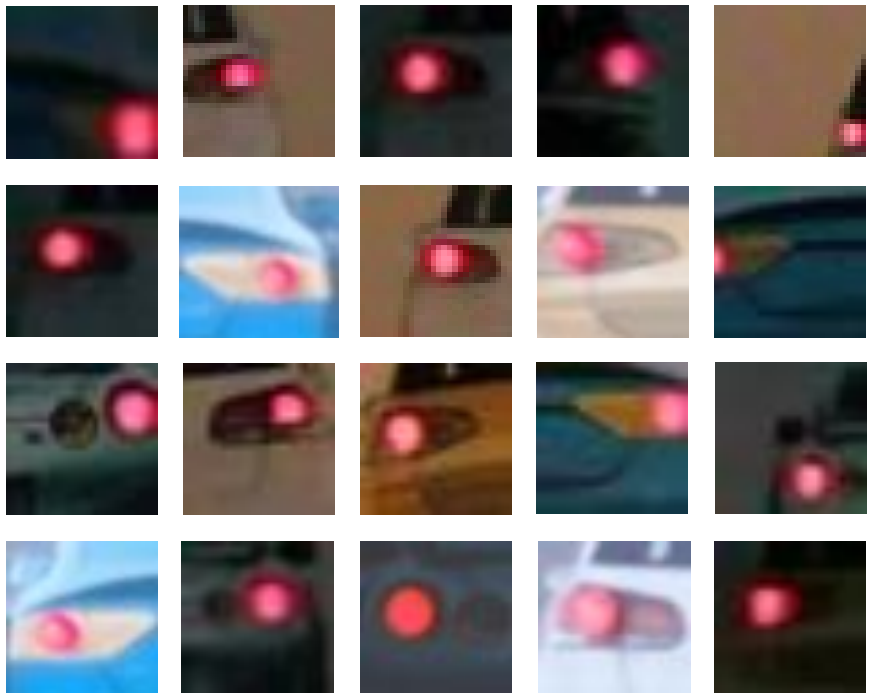


ON

Receiver – Taillight State Recognition

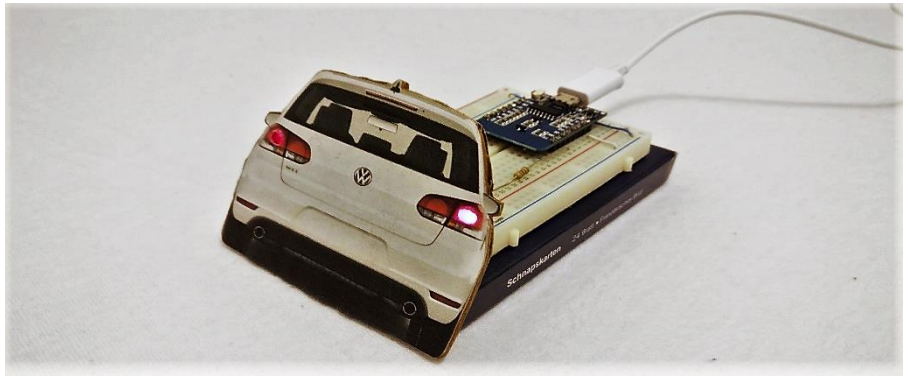
- Convolutional Neural Network
  - Trained with >4000 images of taillights
  - Various car models, environments, etc. to adapt to multiple scenarios.





Evaluation

- Transmitter
  - 1:24 car models
  - Microcontroller ESP8266
  - LED taillights with UDPSOOK modulation

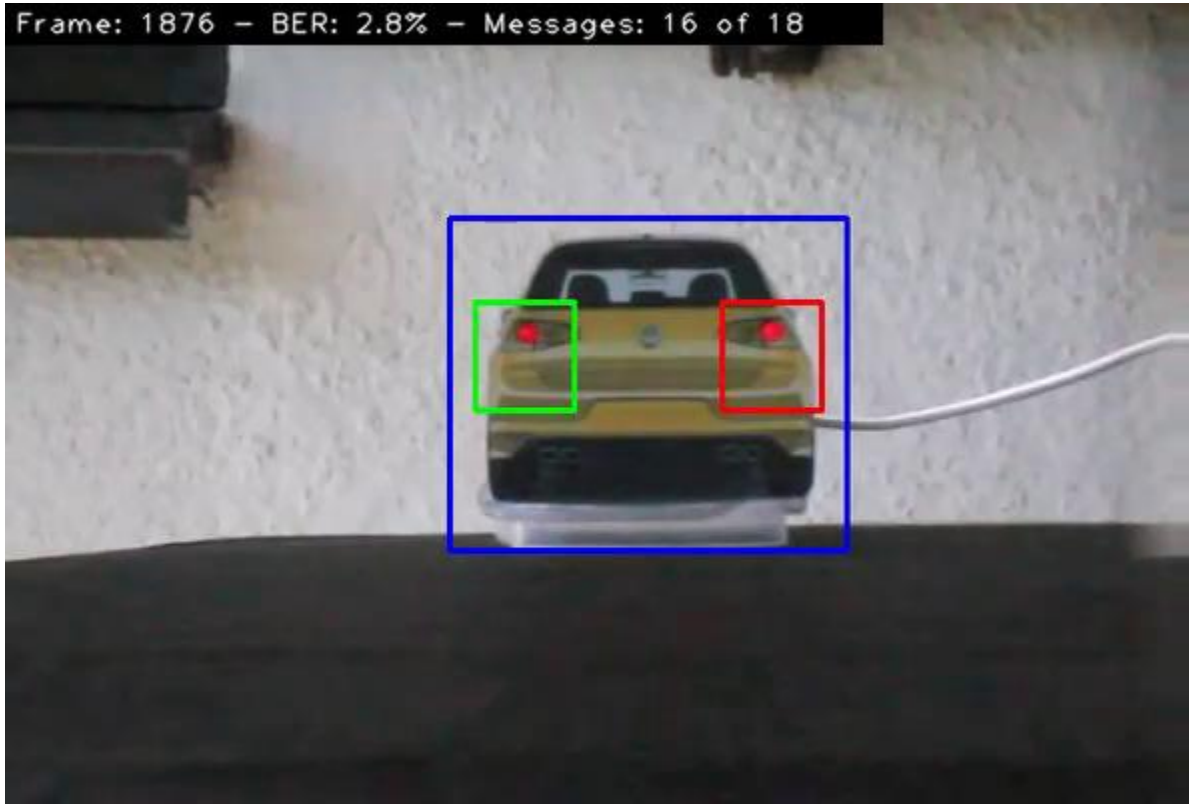


- Receiver
  - Canon EOS 1100D DSLR camera
  - Videos recorded with 30 FPS
  - Exposure time set to 1/2000 s

Evaluation – Single Example Video

Result: Bit error rate = 2.6%

18 of 20 Messages (128 bit) received correctly



Bold rectangle…ON

Thin rectangle…OFF

Evaluation – Single Example Video

Result: Bit error rate = 2.6%

18 of 20 Messages (128 bit) received correctly

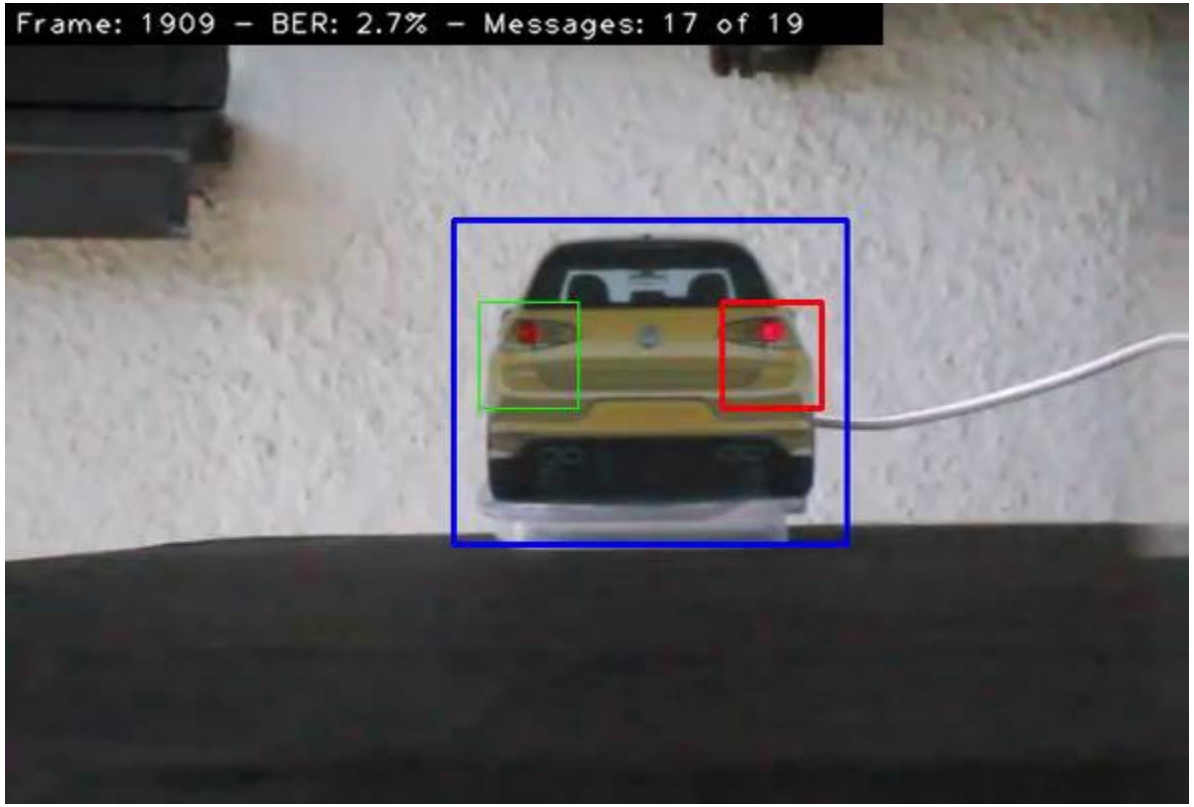
Bold rectangle…ON

Thin rectangle…OFF

Evaluation – Single Example Video

Result: Bit error rate = 2.6%

18 of 20 Messages (128 bit) received correctly



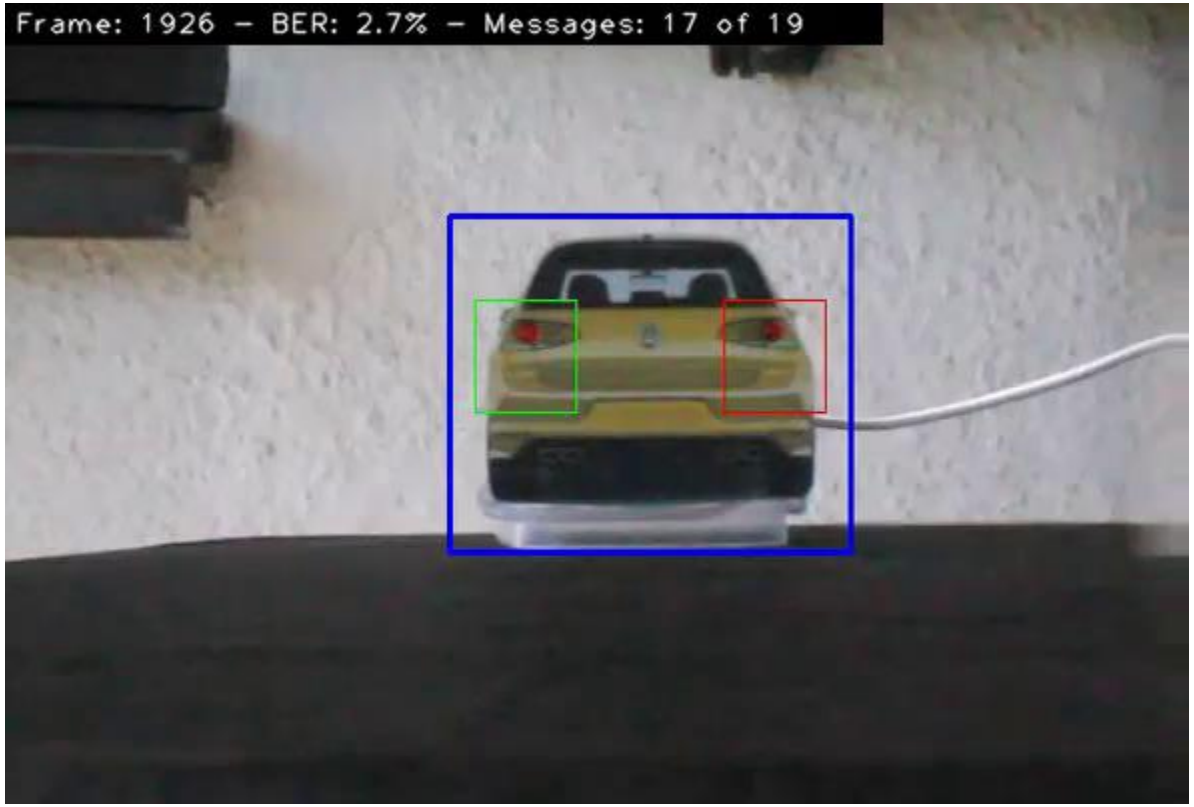
Bold rectangle…ON

Thin rectangle…OFF

Evaluation – Single Example Video

Result: Bit error rate = 2.6%

18 of 20 Messages (128 bit) received correctly



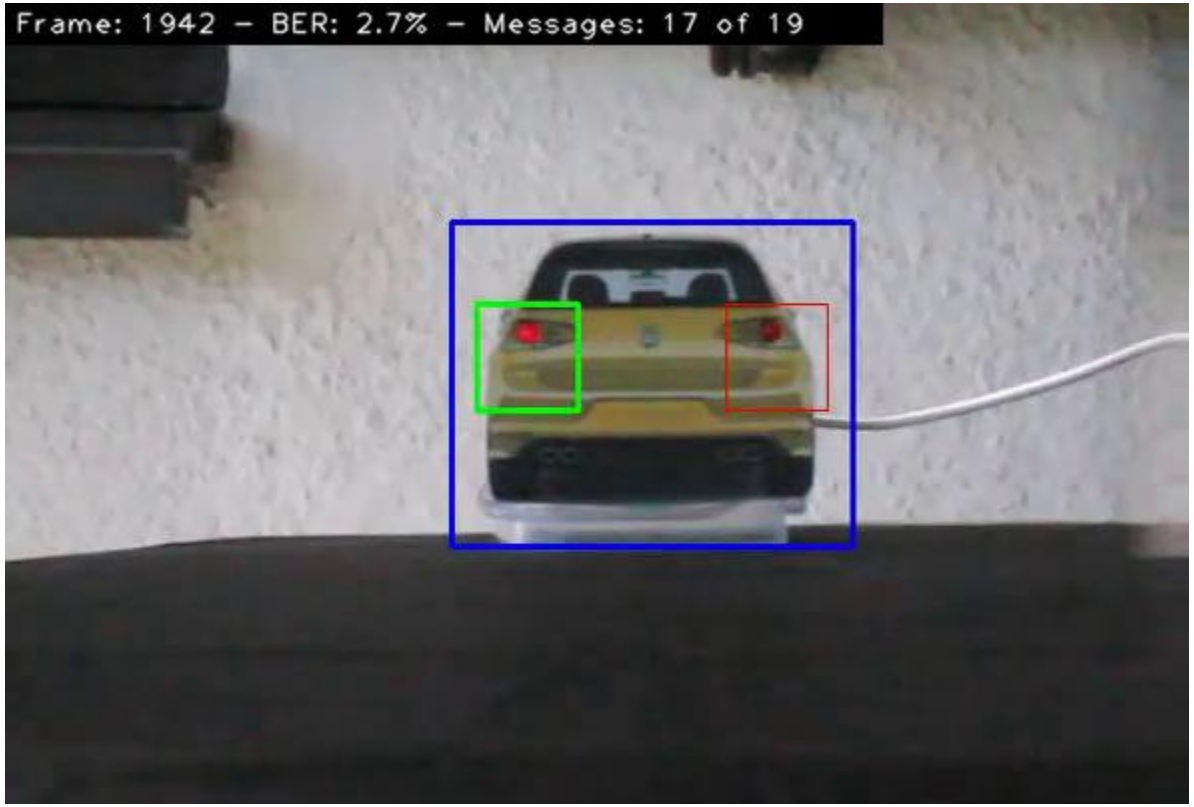
Bold rectangle…ON

Thin rectangle…OFF

Evaluation – Single Example Video

Result: Bit error rate = 2.6%

18 of 20 Messages (128 bit) received correctly



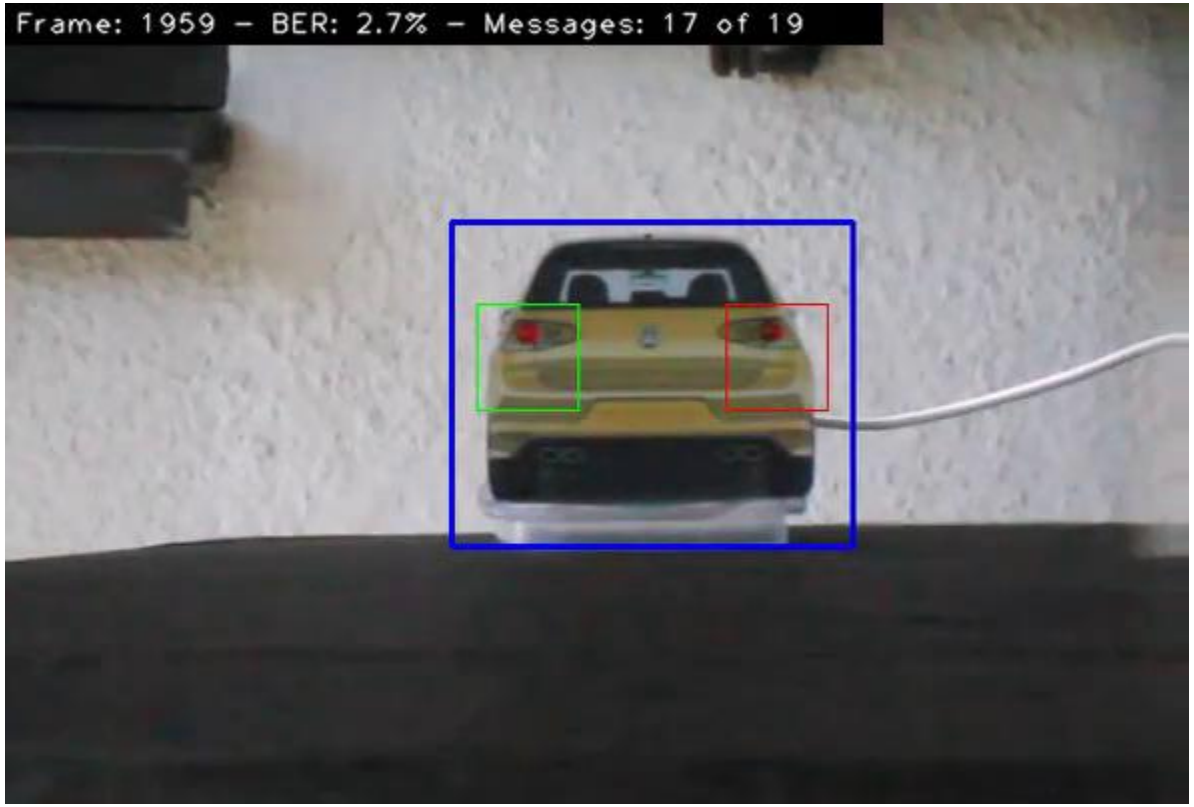
Bold rectangle…ON

Thin rectangle…OFF

Evaluation – Single Example Video

Result: Bit error rate = 2.6%

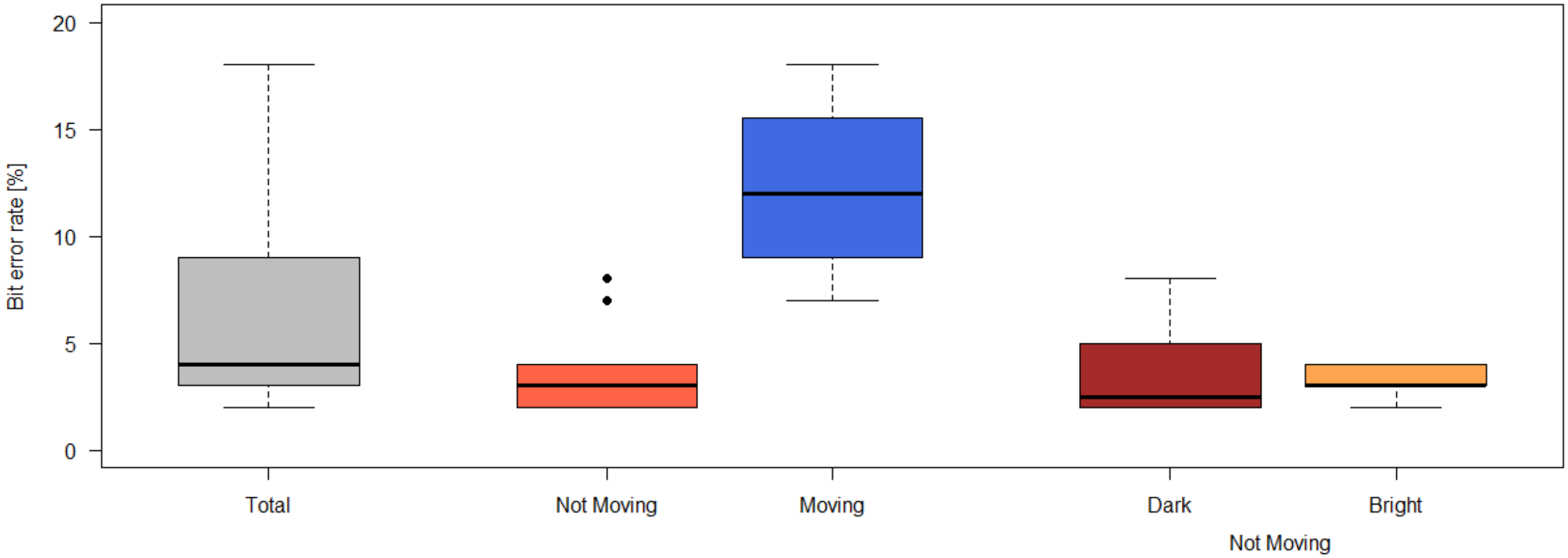
18 of 20 Messages (128 bit) received correctly



Bold rectangle…ON

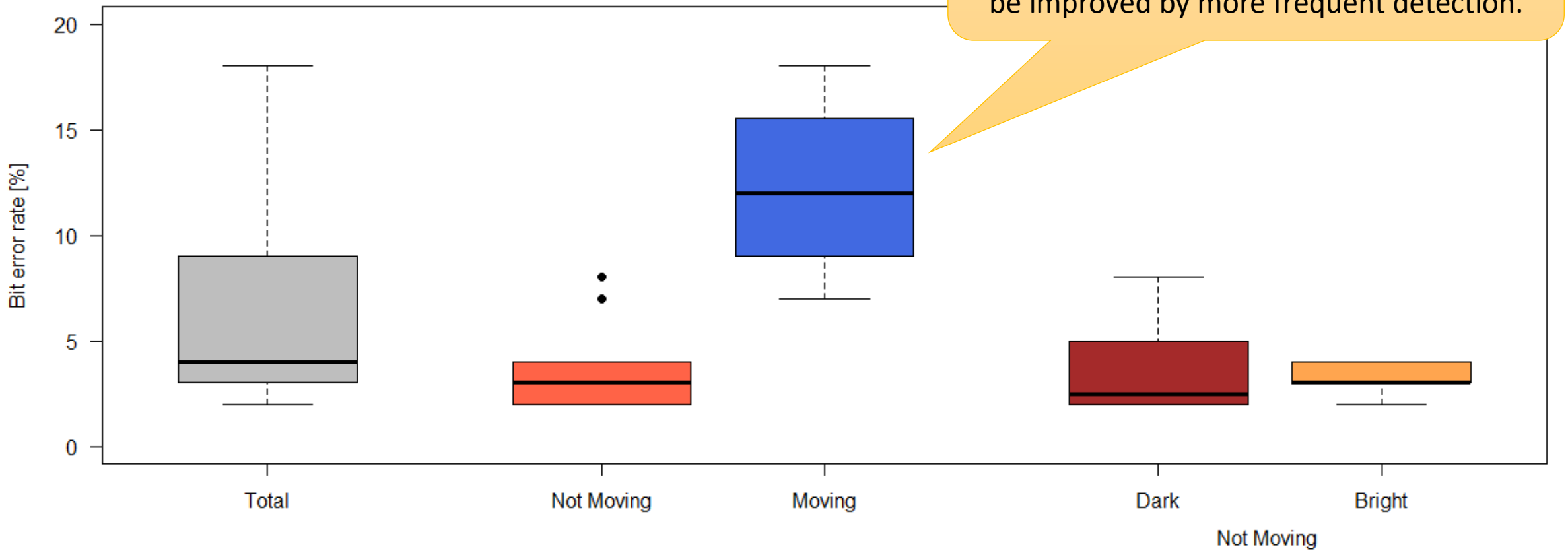
Thin rectangle…OFF

Evaluation – Bit error rate

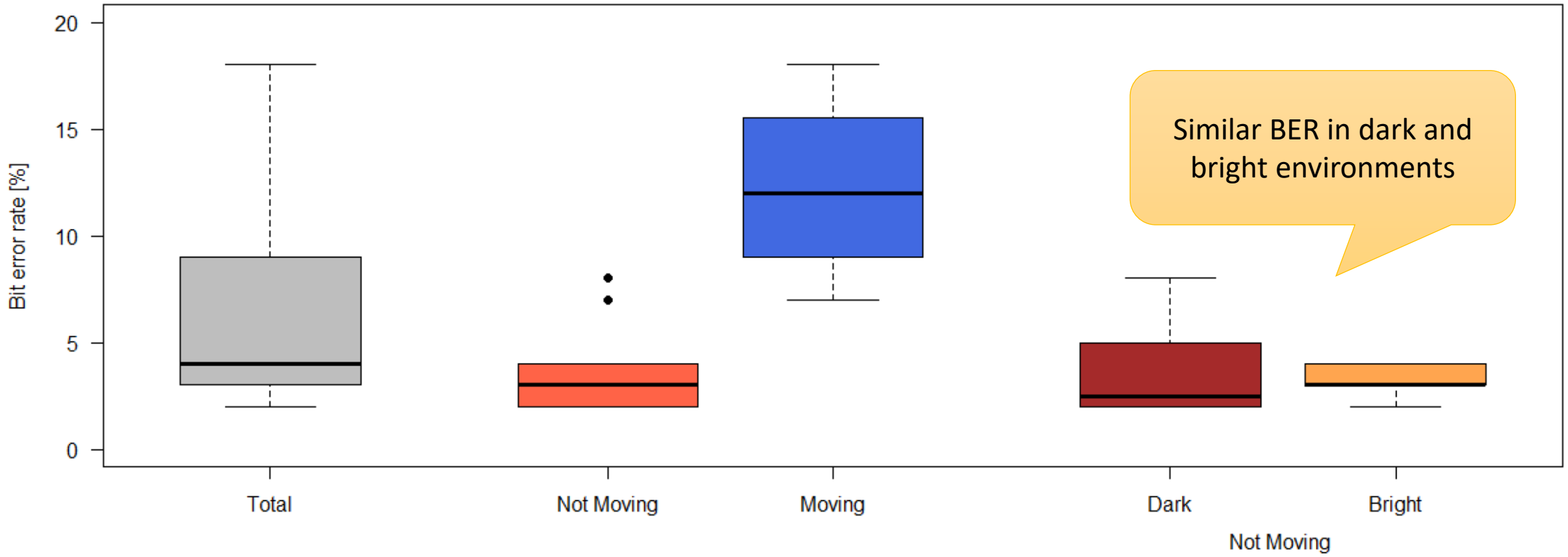


Evaluation – Bit error rate

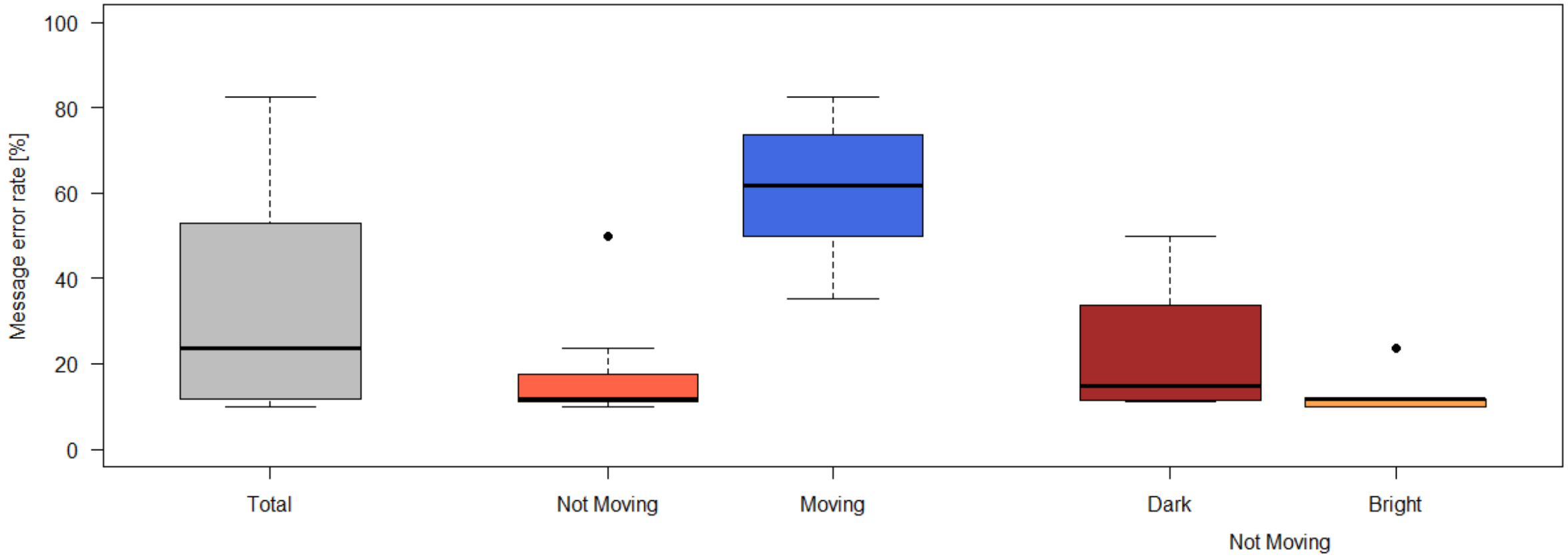
Poor BER with moving transmitter is caused by vehicle detection every 20th frame. Can be improved by more frequent detection.



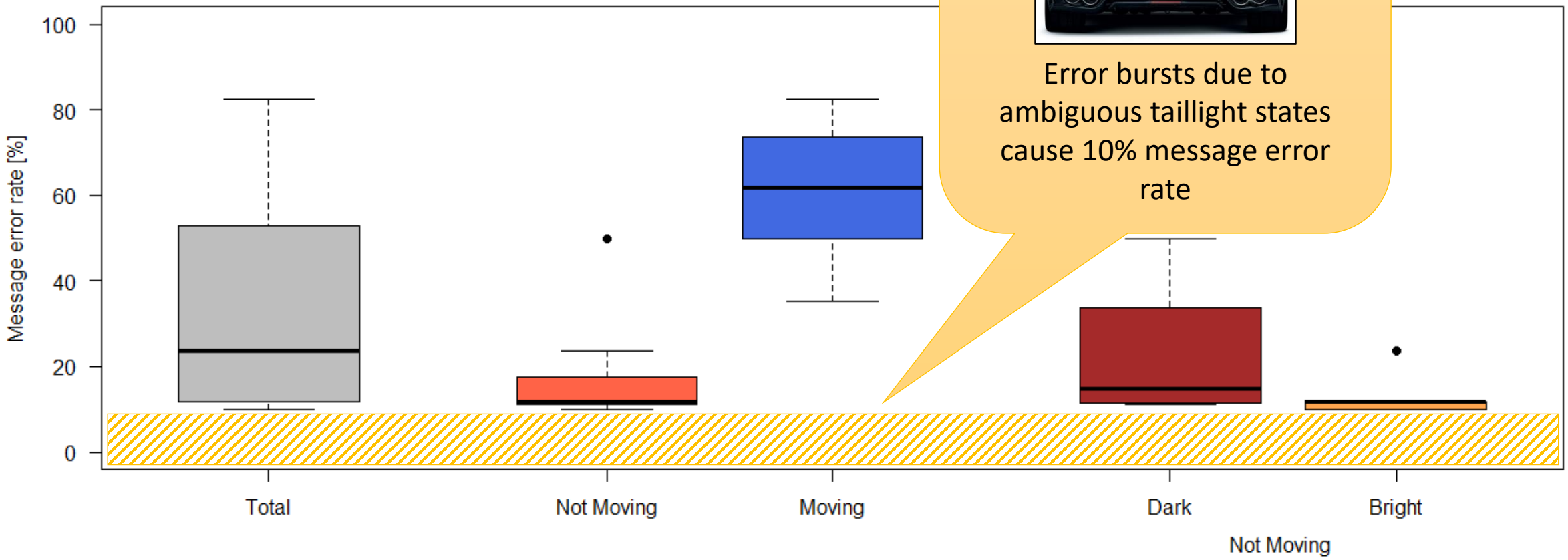
Evaluation – Bit error rate



Evaluation – Message error rate

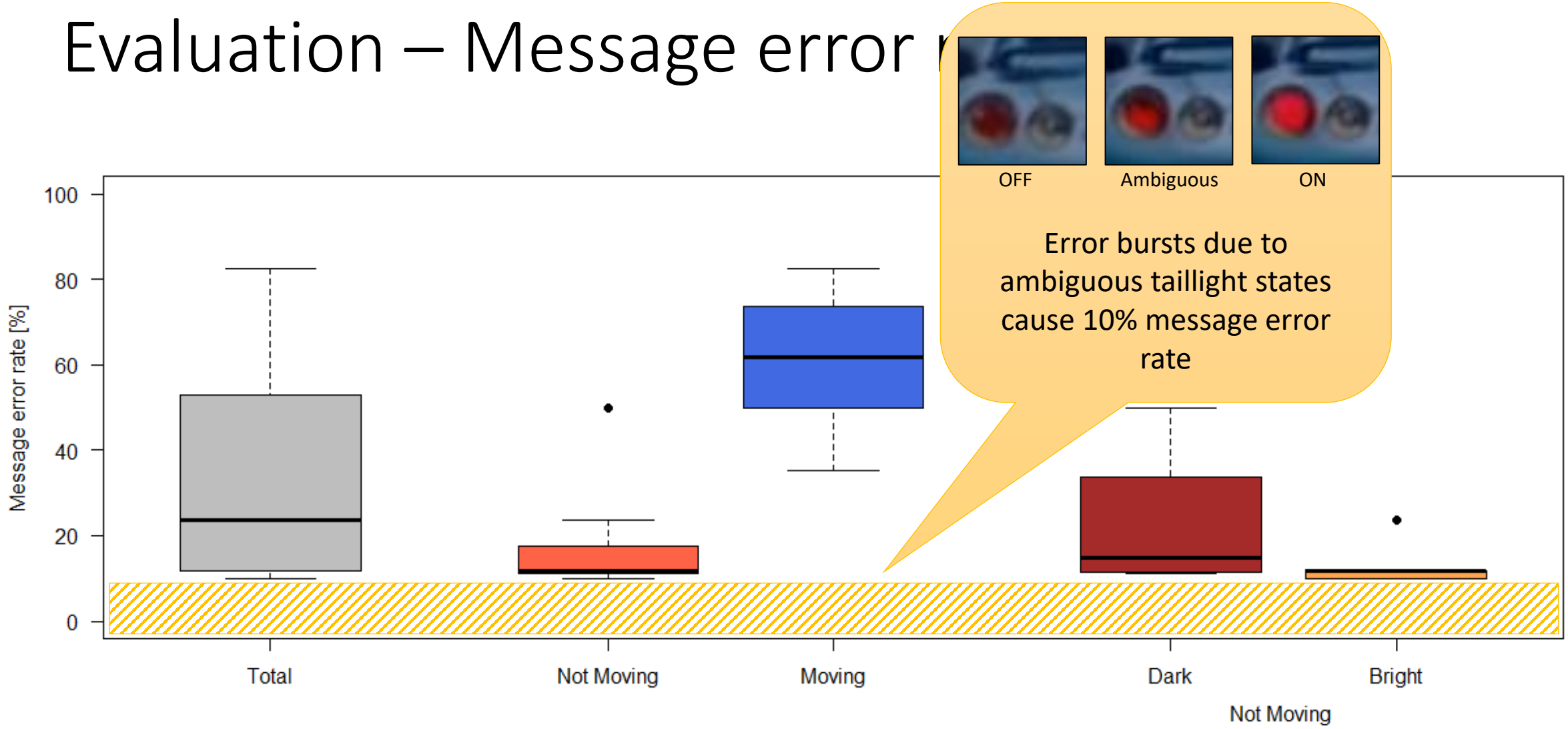


Evaluation – Message error r

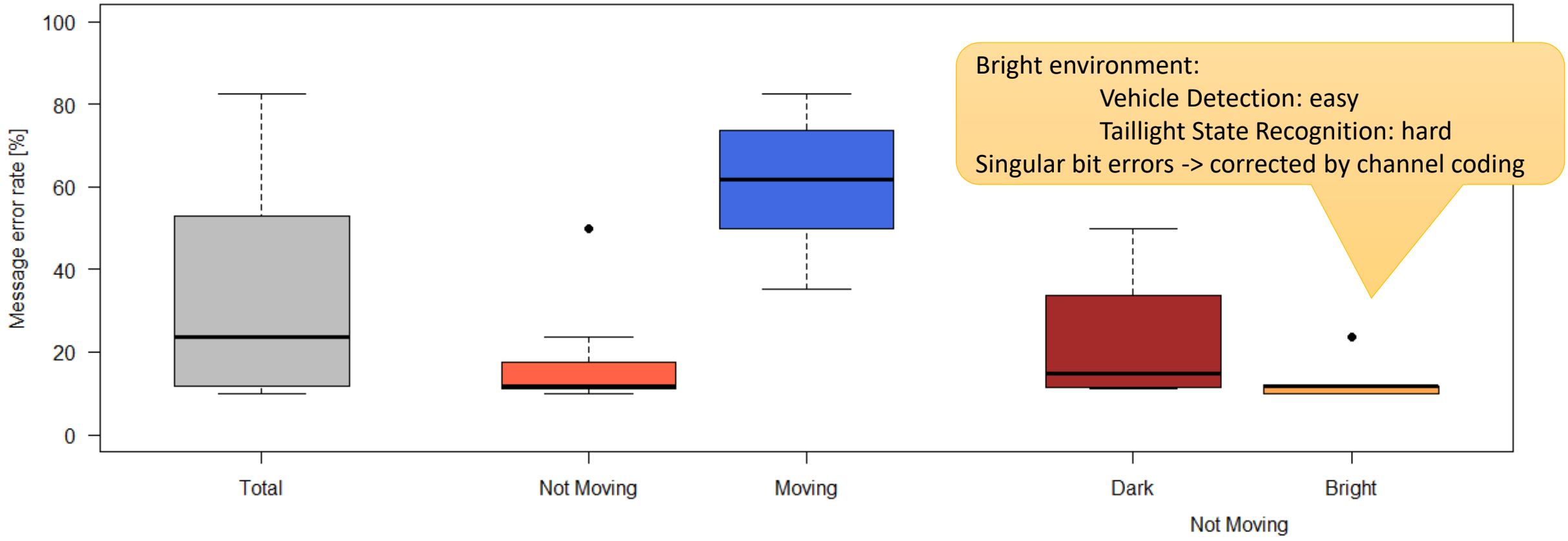


Error bursts due to ambiguous taillight states cause 10% message error rate

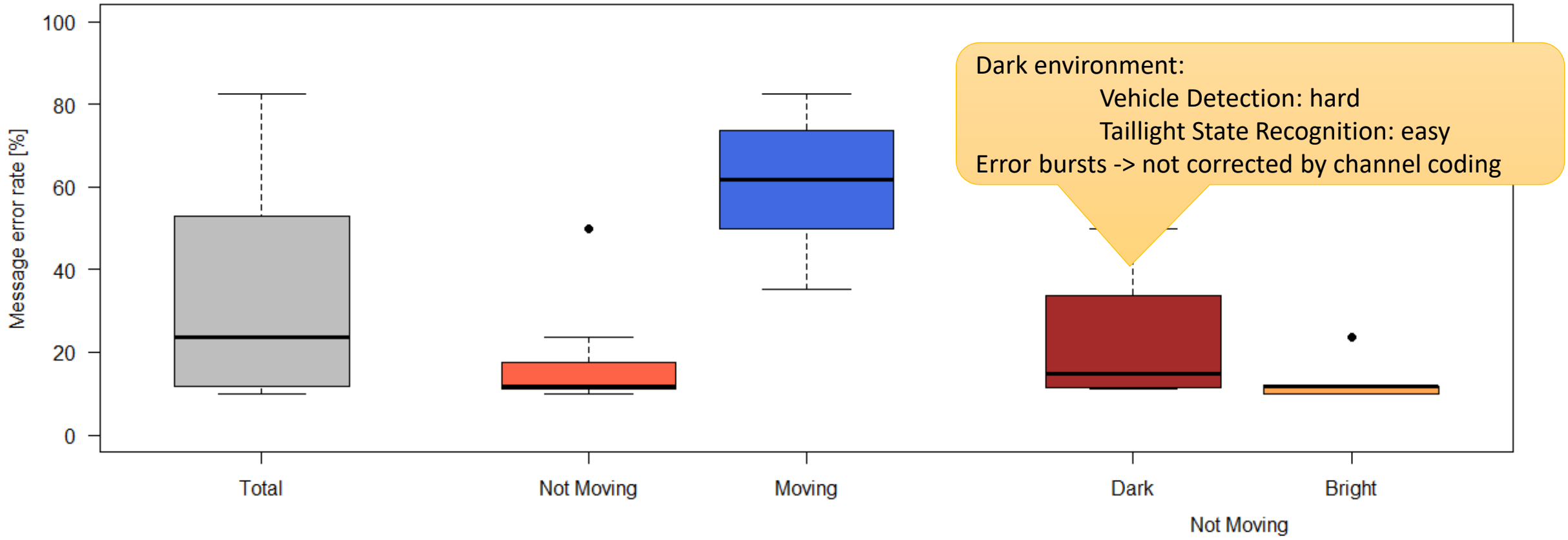
Evaluation – Message error r



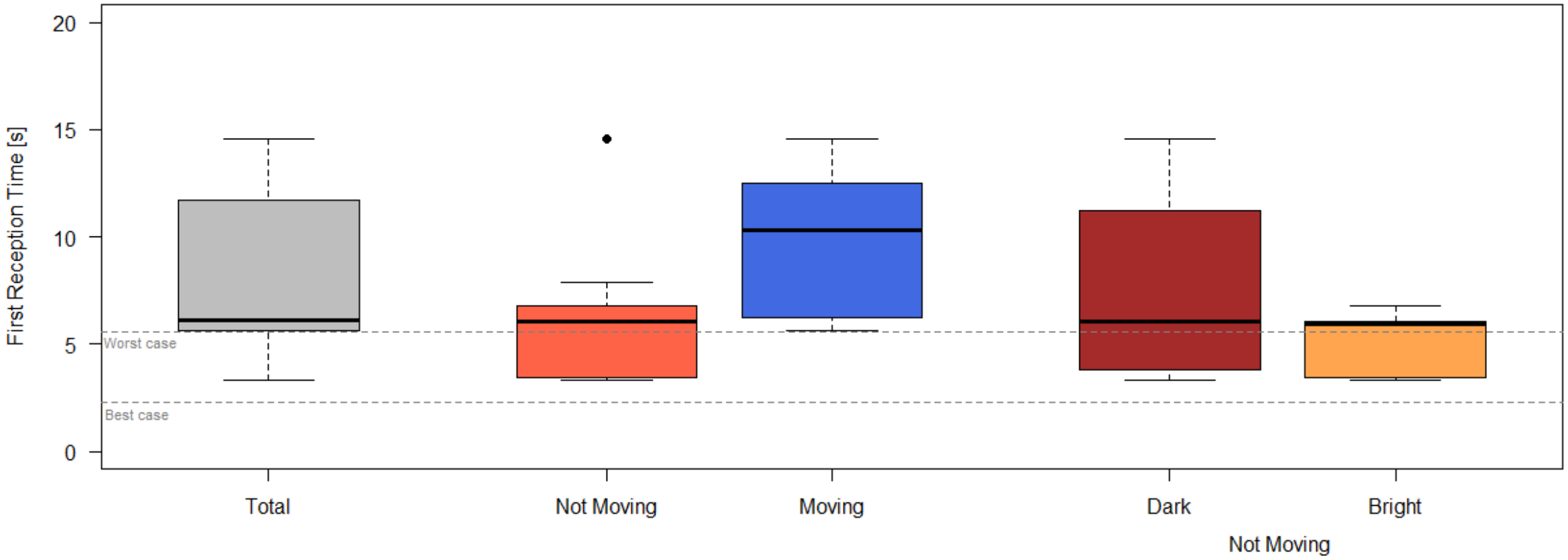
Evaluation – Message error rate



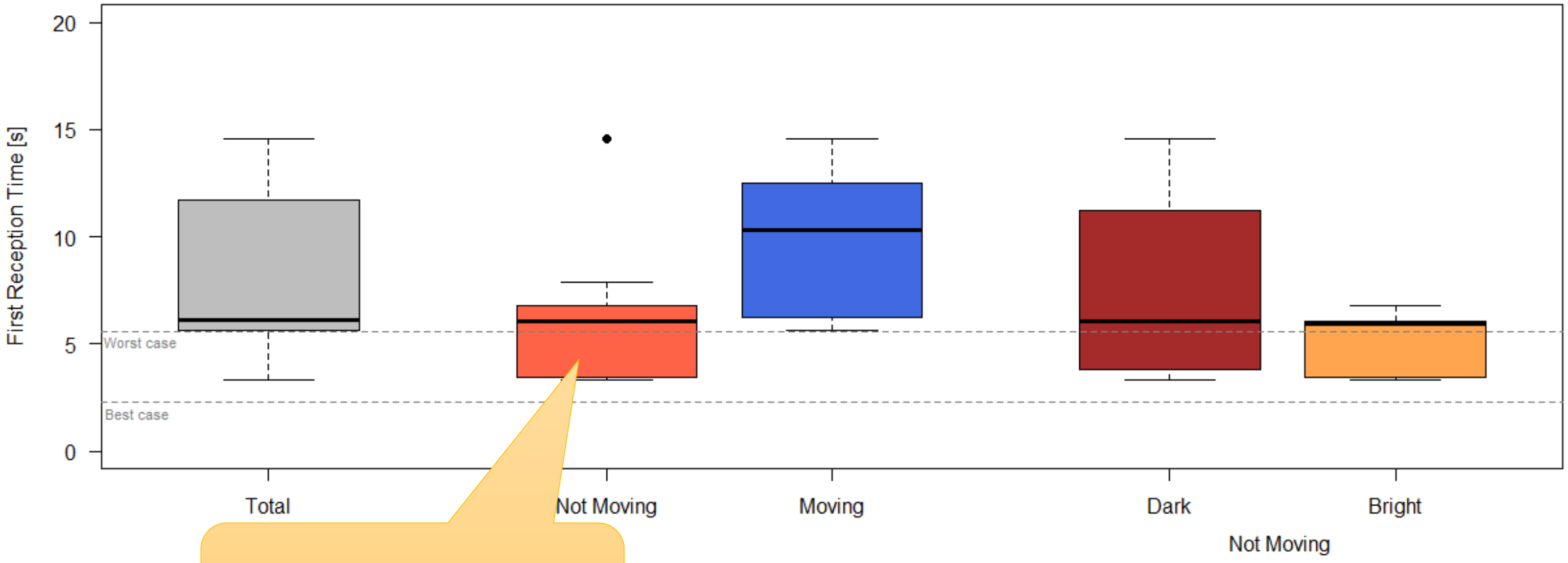
Evaluation – Message error rate



Evaluation – First reception time



Evaluation – First reception time



Approx. 5 seconds to transmit a 128-bit message

Conclusion

- Optical Out-of-Band Channel for Vehicle-to-Vehicle Communication
- Prototypes of car models in scale 1:24
- Camera with rolling shutter very short exposure time is needed.
- Results:
  - BER of 3.64% on average (1.94% standard deviation)
  - Approx. 5 seconds to receive the first correct message
- Can be used for identity verification in platooning

Thanks for reading!

For questions, please contact Michael.Plattner@fh-hagenberg.at

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