

A Multi-Functional Imager for TOF and High Performance Video Applications Using a Global Shuttered 5µm Cmos Pixel.

**Peter Centen¹, Juul v.d Heijkant¹, Jeroen Rotte¹, Klaas Jan Damstra¹,
Assaf Lahav², Adi Birman², Steffen Lehr³, Sabine Roth³, Ruud van Ree¹**

- 1) Peter.centen@grassvalley.com, Breda, the Netherlands**
- 2) TowerJazz, Haifa, Israel**
- 3) Viimagic, Villingen, Germany**

Acknowledgement

- The development of TOF was part of 2020 3D Media, A European Funded Project.
- <http://www.20203dmedia.eu/>

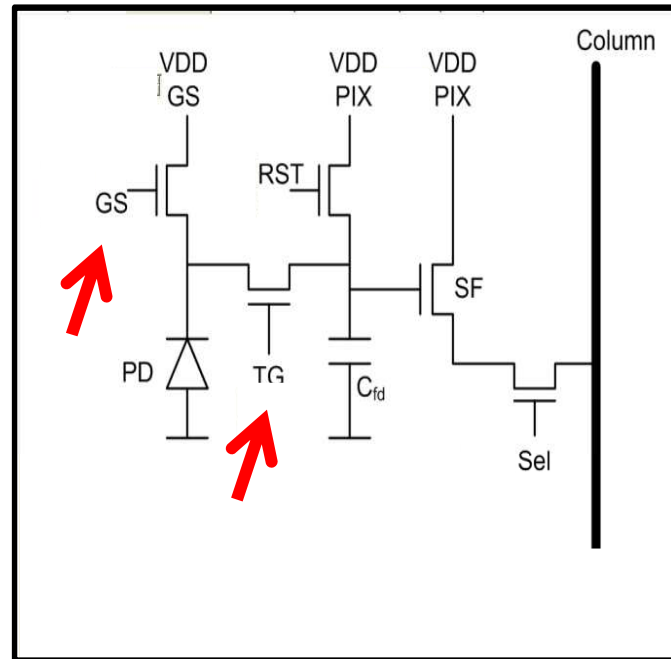
Agenda

- **Introduction**
- **A Simple Test**
- **TOF Shading**
- **Some Results**
- **Conclusion**

Introduction

- **Long ago:** synchronous detection with CCD's, together with Dalsa
 - Cost one metal-mask
 - Sensitivity down with 1/6-th, aperture = 16%
- **Recent:** wouldn't it be nice if one could do TOF with the same CMOS imager one generates video with
 - A 5T-global shutter'd pixel has already two functions
 - Light sensitivity under control of the GS
 - A Storage node under control of TG and RG
 - The cost was a different pulse pattern and different TG, GS voltage settings

Introduction

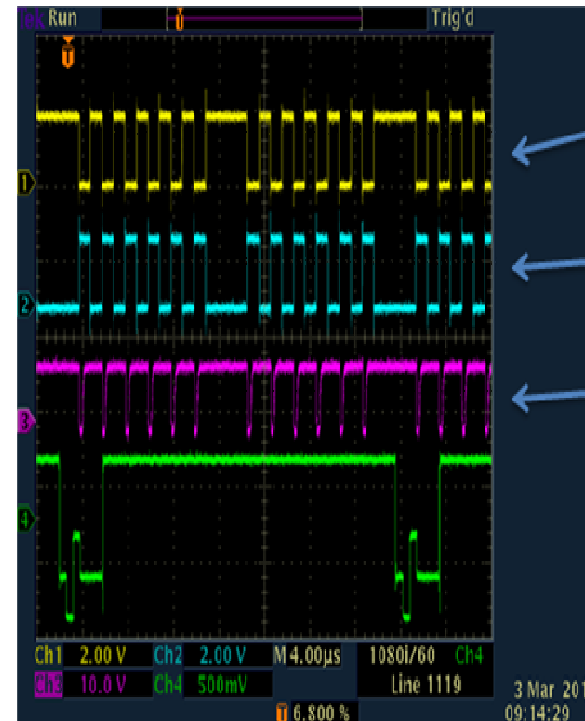
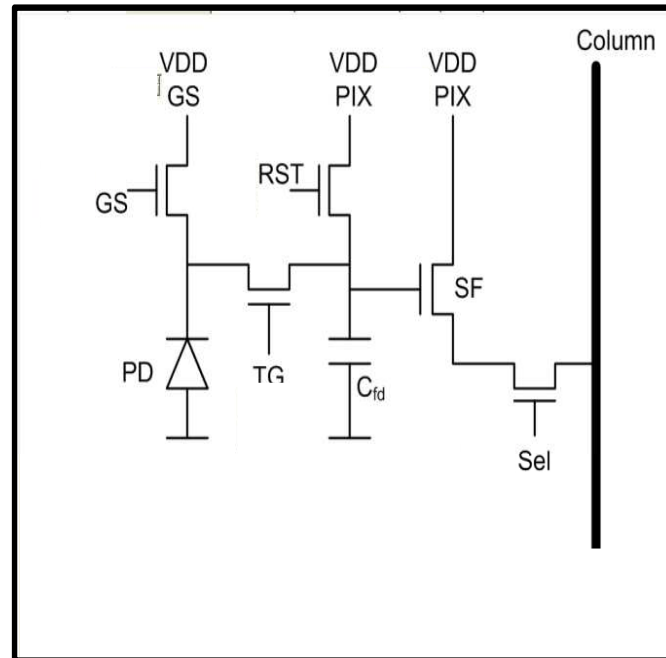


**Synchronous detection with GS and TG
And storage at the FD**

Introduction

- **It was not straightforward**
 - The first approach was a short TG and GS in the order of the Lightpulse duration
 - That didn't work: switching is fast, transport is slow
- **What did work was**
 - a relatively long duration of TG,
 - GS inverse of TG and
 - small duration of the Lightpulse
- **All measurements**
 - with a 5*5um pixel and an array of 594(H)x960(V)
 - At 60 frames/sec
 - 850 nm LED illumination

Introduction



Global shutter (GS)

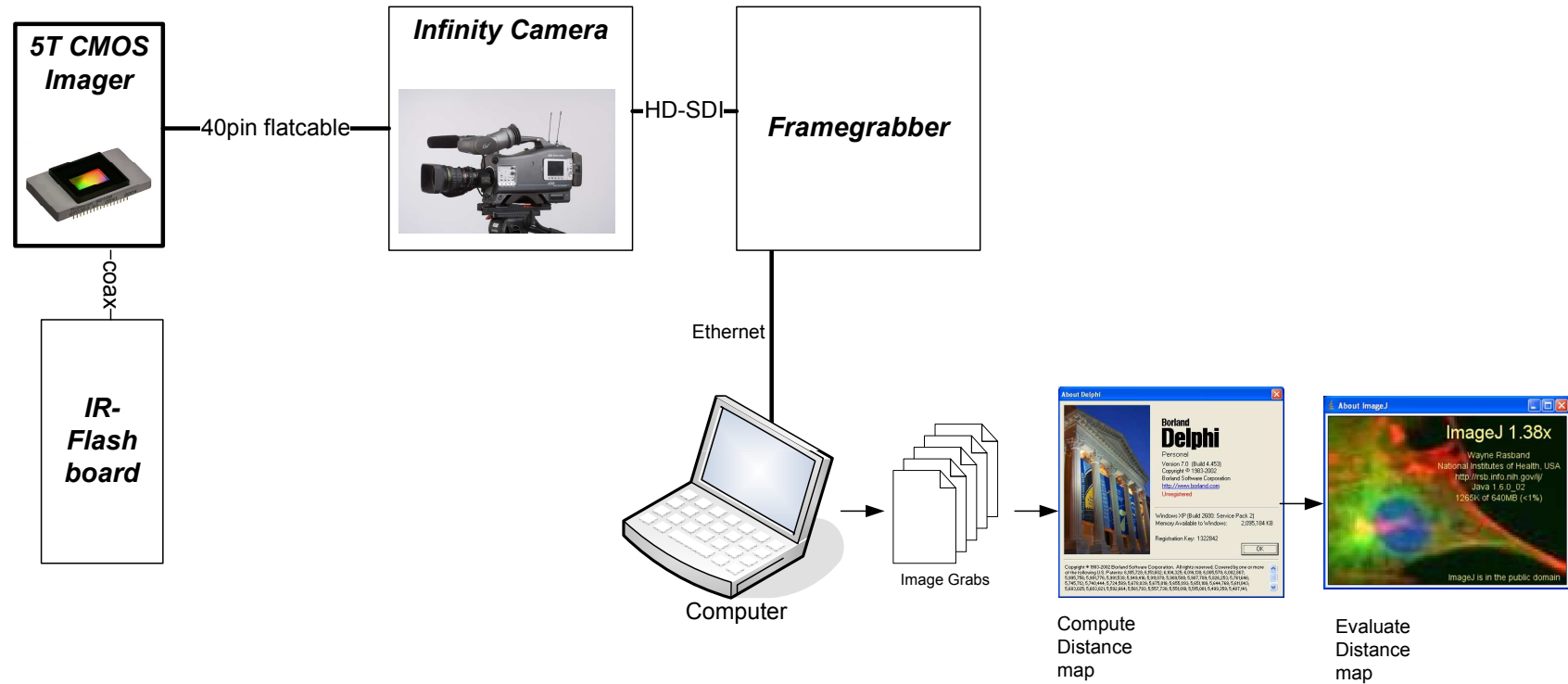
Transfer gate (TG)

LED Pulse

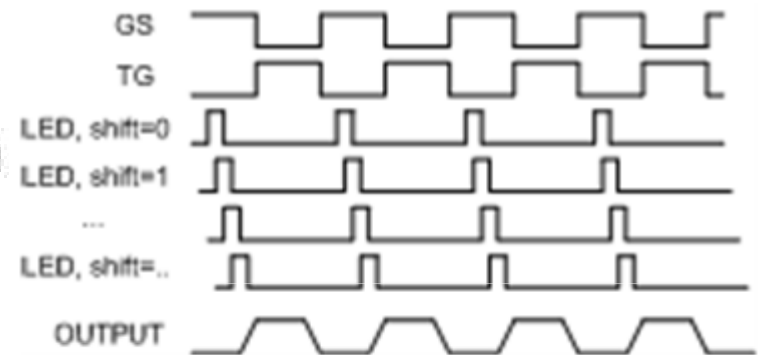
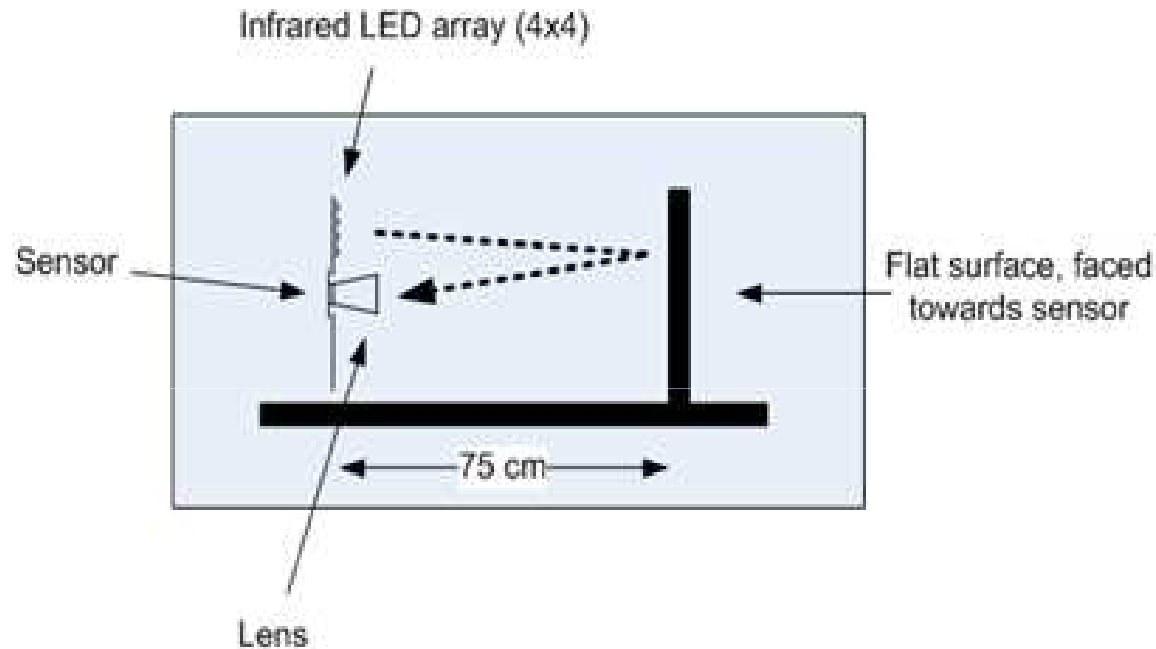
-GS is the inverse of TG

-LED pulse is much smaller in duration than TG

Test-setup



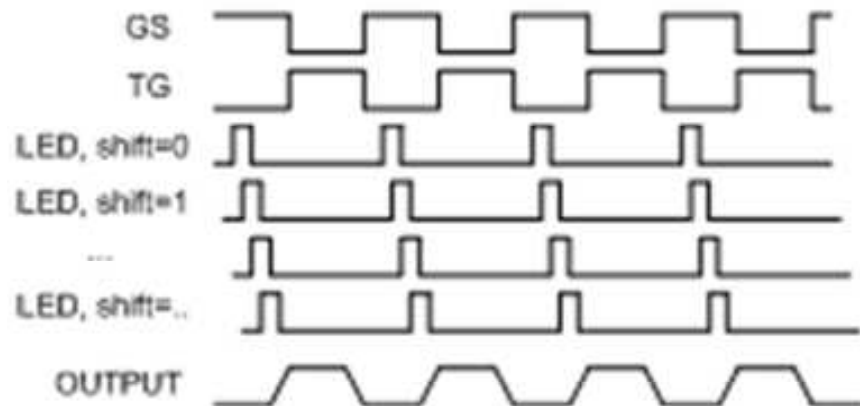
A Simple Test: Shift LED-pulse timing



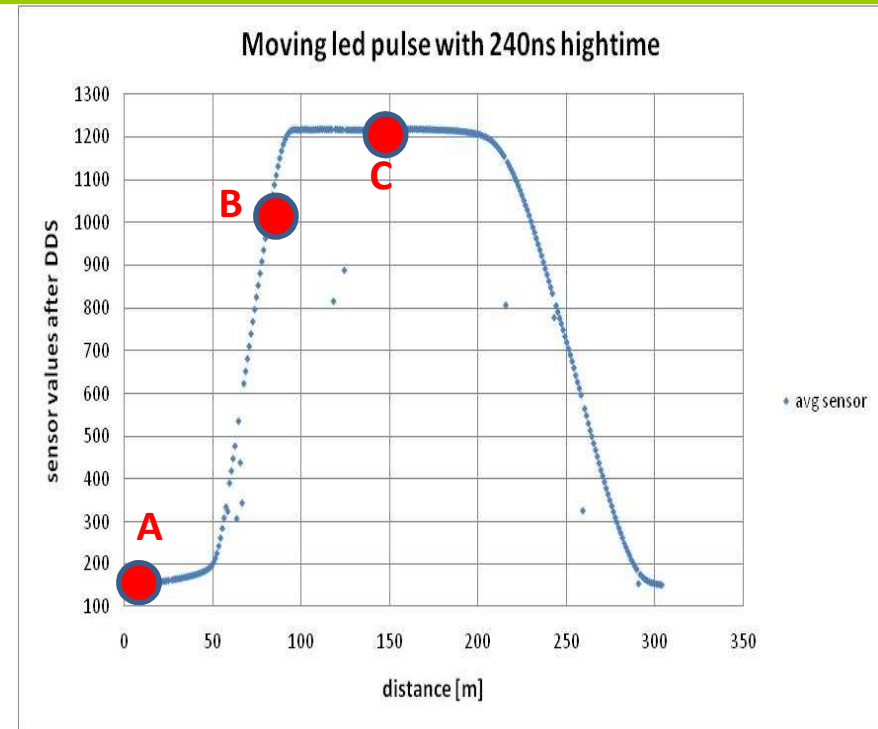
**Shift: 0,1,2,.....LED-pulse shift
a multiple of the masterclock**

- duration TG: **high= 1us**, low=1us; GS=not.TG
- duration LED pulse: **240ns** → 36m equivalent

Light Pulse Shift in TG Window



Shift: 0,1,2,.....LEDpulse shift
a multiple of the masterclock



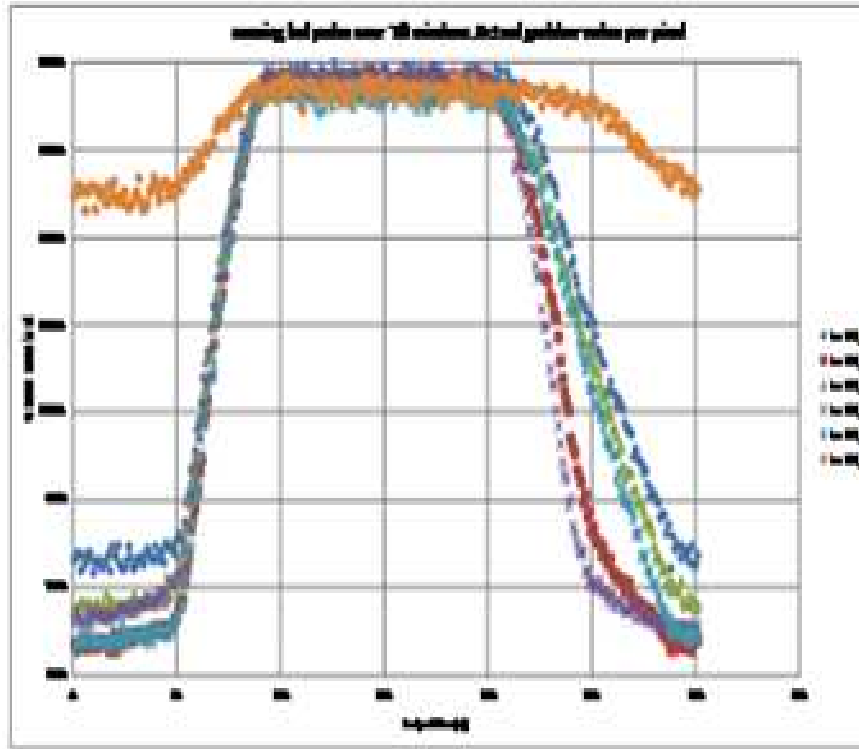
A: Background

B: Proportional with Distance+Background

C: Total reflected+Background

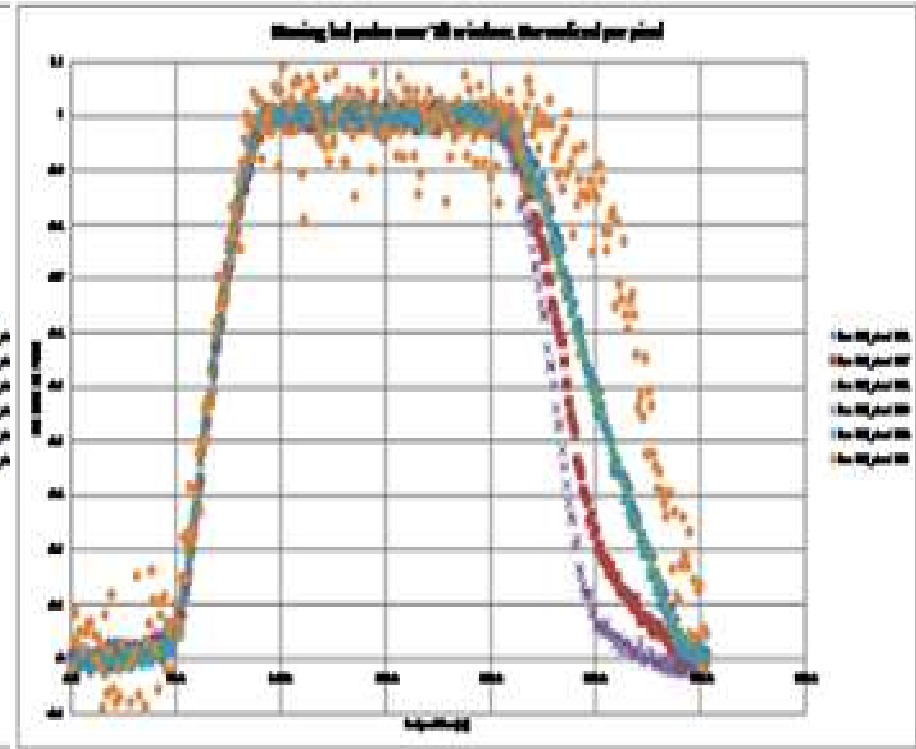
$$\text{Depth} = D_{\max} * (\mathbf{B} - \mathbf{A}) / (\mathbf{C} - \mathbf{A}) + D_{\text{offset}} \quad \text{with} \quad D_{\max} \approx 36 \text{ meter}$$

A Diversity of Pixel Responses



Absolute Pixel Value

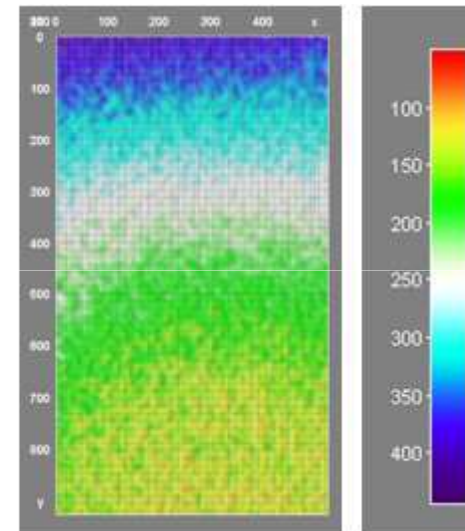
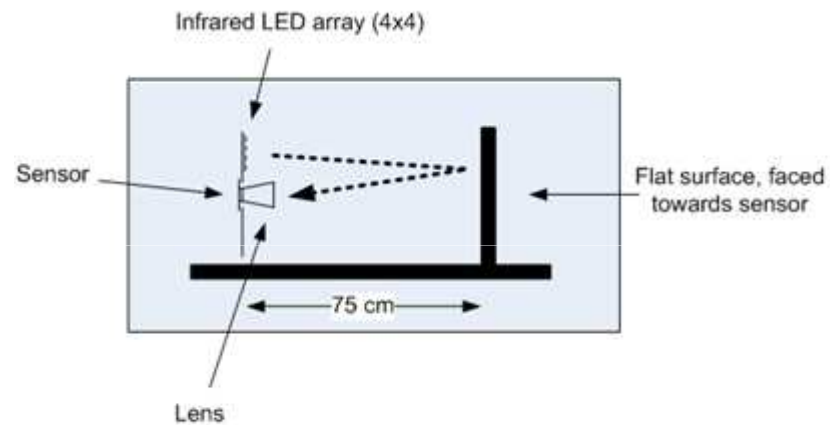
LED pulse and Rising edge TG
Is linear and coincide



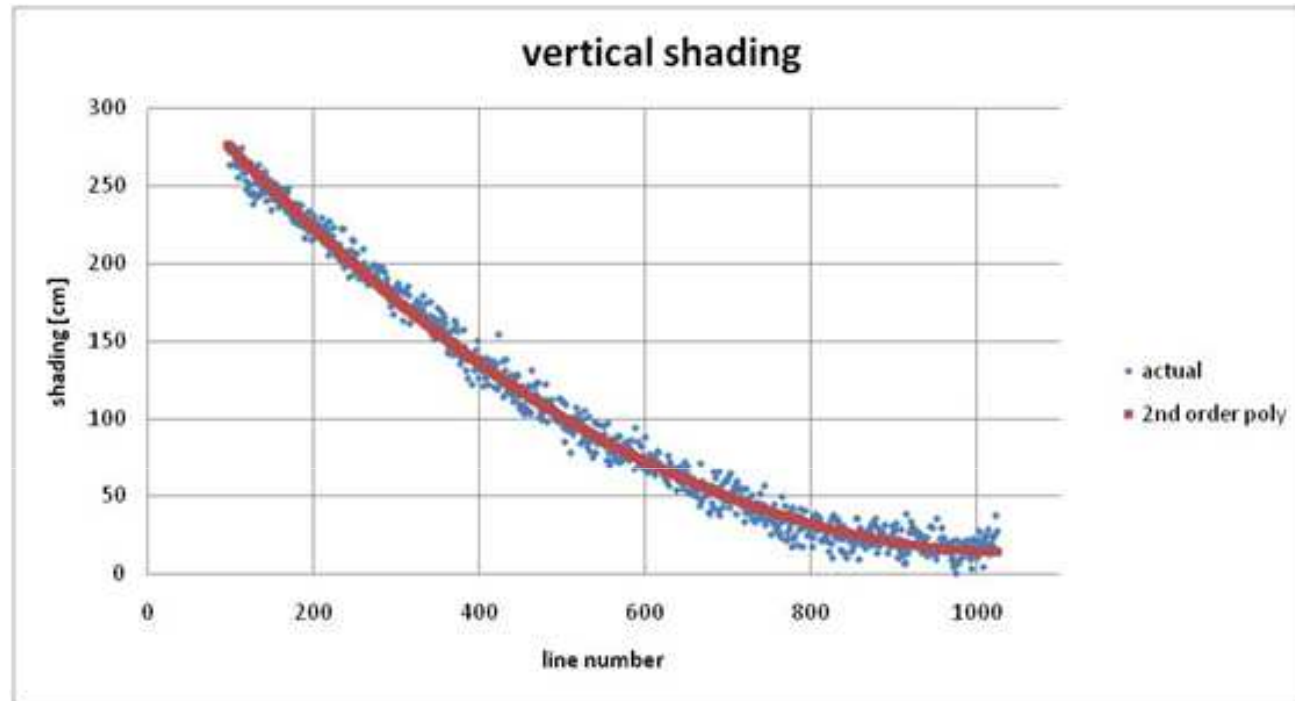
Normalized Pixel Value

$$0 < (\text{B-A}) / (\text{C-A}) < 1$$

TOF: Shading



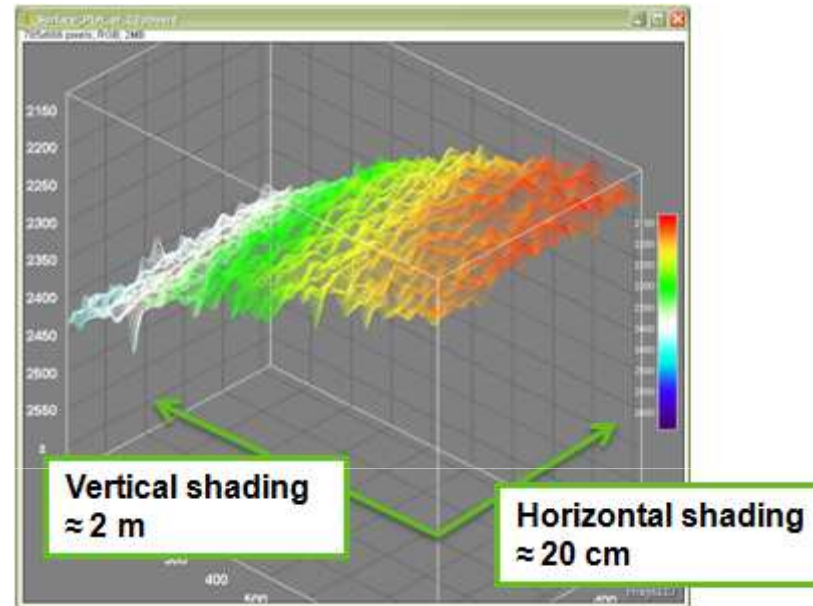
TOF: Shading 1D



**Vertical shading about 250 cm equivalent or
some 17ns delay between first line last line**

.....and mirrored first pixel/first line out

TOF Shading 2D

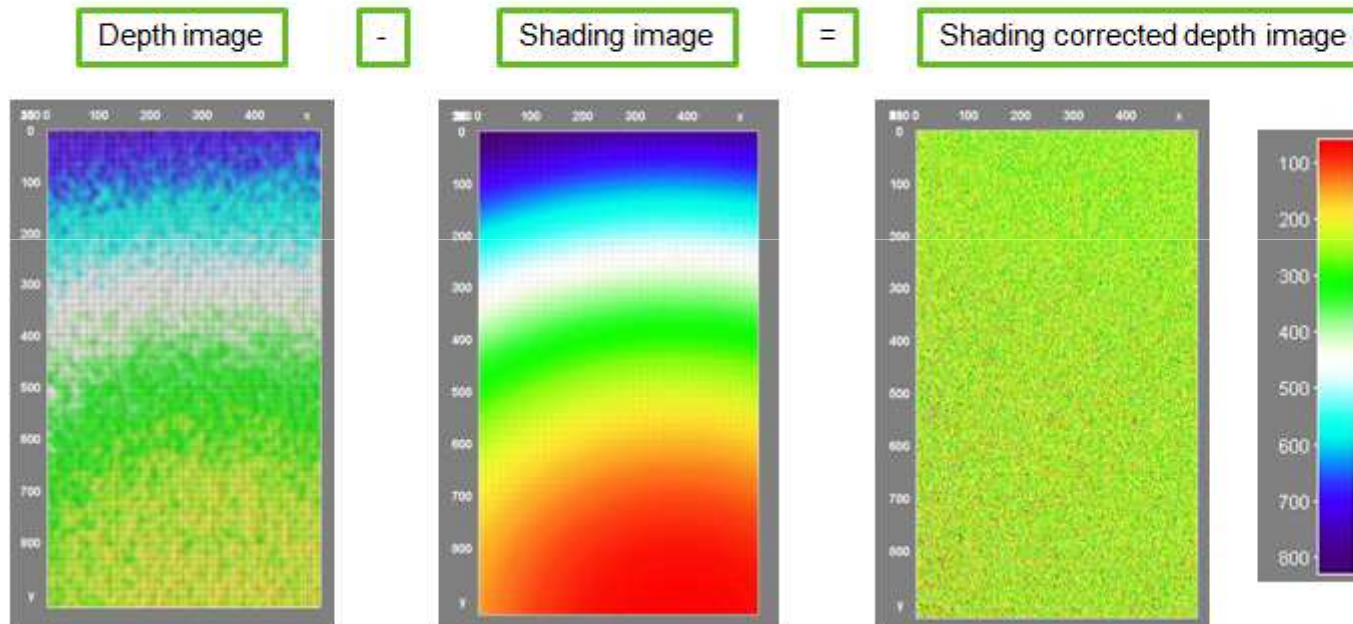


**Spin-off: get ns information about the H,V timing of the imager
-17 ns vertical and 2.0 ns horizontally**

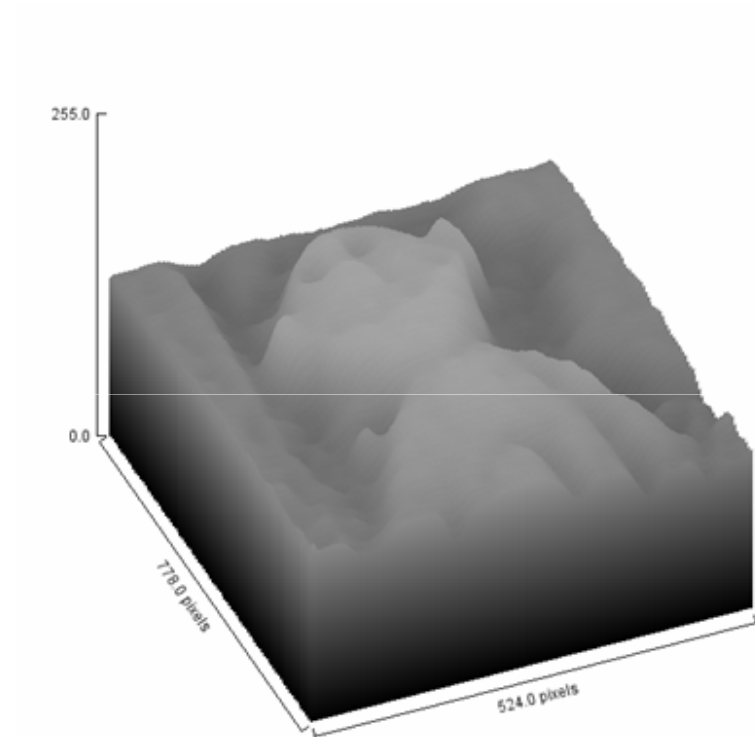
TOF: Shading 2D

2nd-order polynomial
In x and y

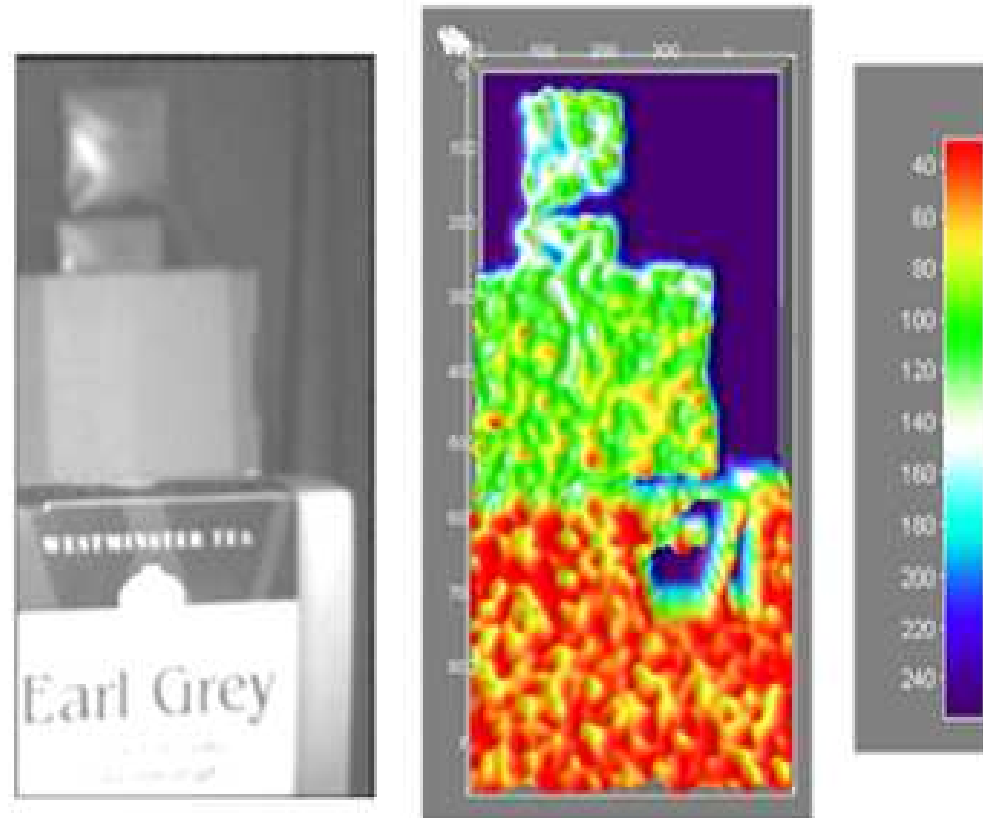
256 averaged frames



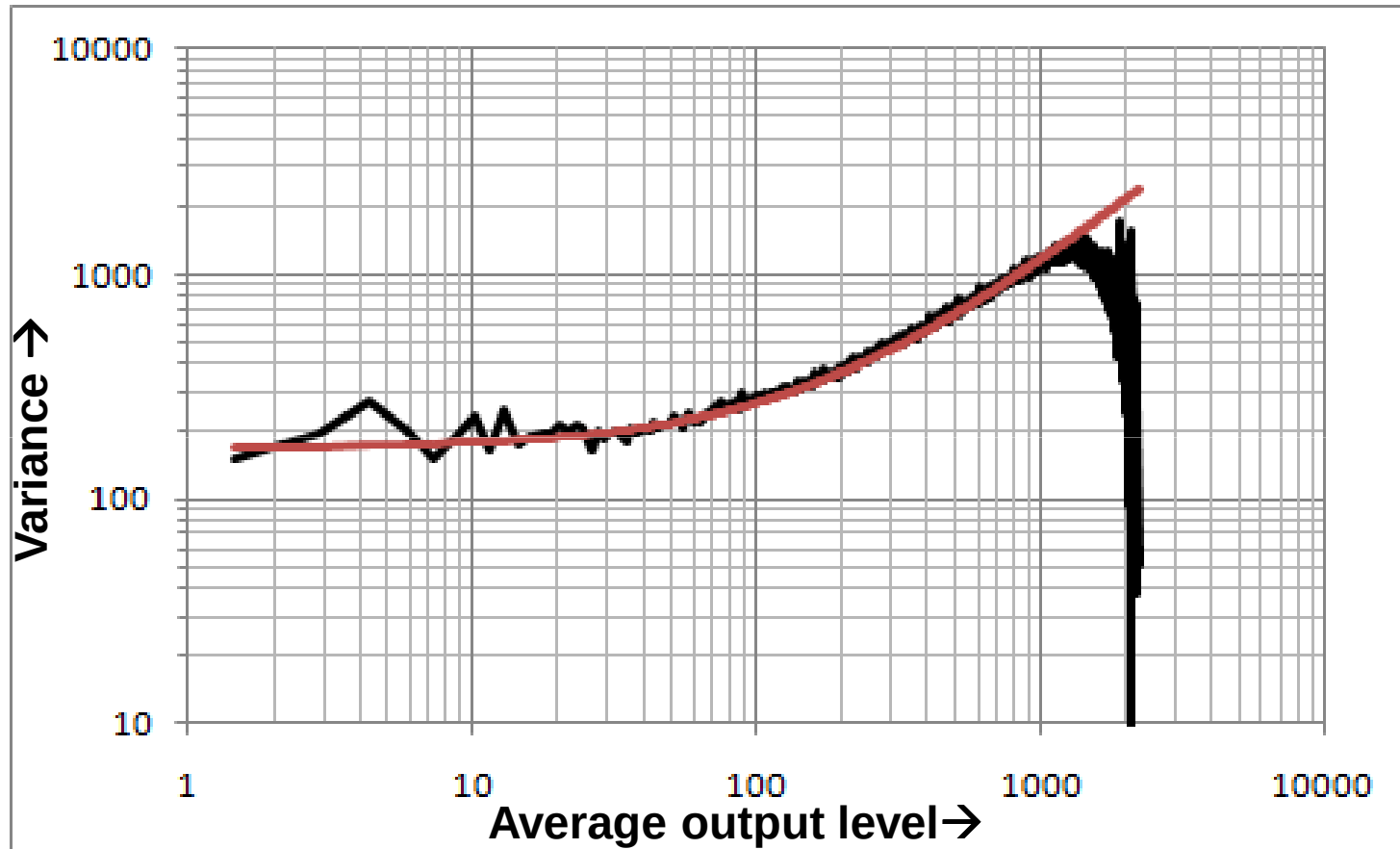
Some results: Depth map



Some results: Depth map



Some results: Shotnoise in TOF mode



Qmax is limited to 2kel and linear to about 1.4kel

Some results: Noisy

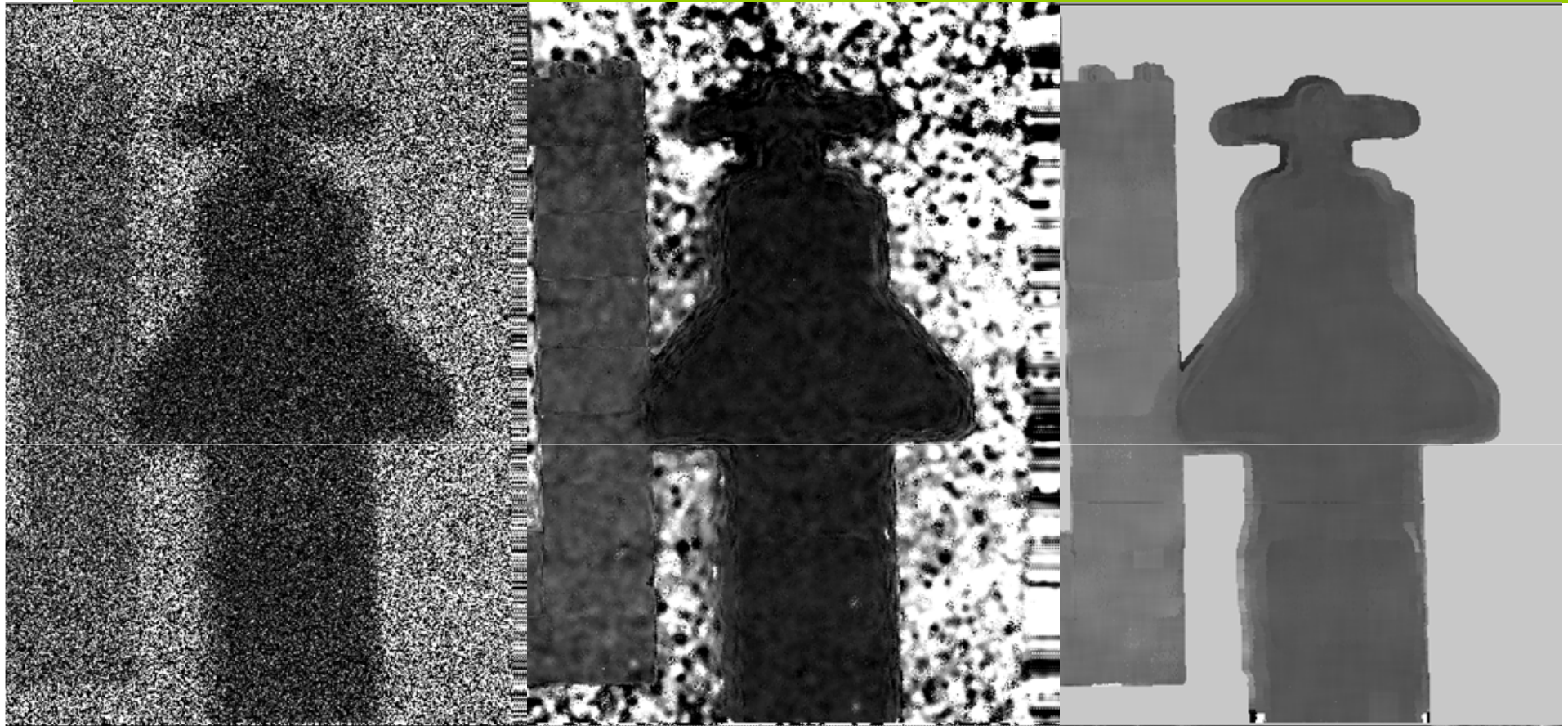
	D+ND - shading	
	measured	
area	avg (cm)	stdev (cm)
1	38.2	114.3
2	65	98
3	47	76.7
4	56.2	99.3

Rough estimation for the variance without background

$$\text{Stdev} \approx D_{\max} \sqrt{2/N_{\max}}$$

with $N_{\max}=1000$ e and $D_{\max}=1600$ cm then $\text{Stdev} \Rightarrow 72\text{cm}$

Noise and signal processing



Original depth map

$$\text{TOF} = (\mathbf{B} - \mathbf{A}) / (\mathbf{C} - \mathbf{A})$$
$$(\text{Depth} = D_{\max} * \text{TOF})$$

Bilateral filter

Non local

TOF

Literature	Pixel size [$\mu\text{m} \times \mu\text{m}$]		Technology	0.18 μm 4m1p
Buttgen, SPIE, 2004	50x50		Chip Size	5mm (H) x 10mm (V)
Yoshimura, ISSCC 2001	46.4x54		Pixels	574 (H) x 960 (V)
Nieuwenhove, IEEE Sensors, 2007	30x30		Pixel size	5x5 μm
Kawahito, IEEE Sensors, 2007	15x15		Clock frequency	74MHz
Tubert, IISW2009	11.2x11.2		Read Noise	6e
This paper	5x5		Sensitivity in Green	55 kel/luxsec
			Qmax	15kel

Conclusion

- **Use is made of a plain pinned photodiode**
 - Adapted levels of TG and GS and RG and duration of TG 1us high and 1us low
 - Duration of TG and GS(= inv TG) much longer than lightpulse
 - The $Q_{\max}$ during video usage is 15kel, during TOF it reduces to 2kel
 - Only the rising edge of TG wrst LED pulse timing is usable
- **Future work**
 - Need for reducing the noise
 - Bilateral filtering, longer integration times
 - Increase the $Q_{\max}$ during TOF usage
 - Reduce duration LED pulse ($=D_{\max}$)
 - Depth and total reflected image in one frame
 - applying different timing for odd and even lines (TG and GS) to get the depth image and the total reflected image in one frame. And the background in a second frame.
 - Applying modulo 3 timing to the vertical lines (TG and GS) to obtain background, depth, total reflected from the same time instand at the cost of reduced spatial resolution

Questions

