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The SKED: Speckle Knife Edge Detector

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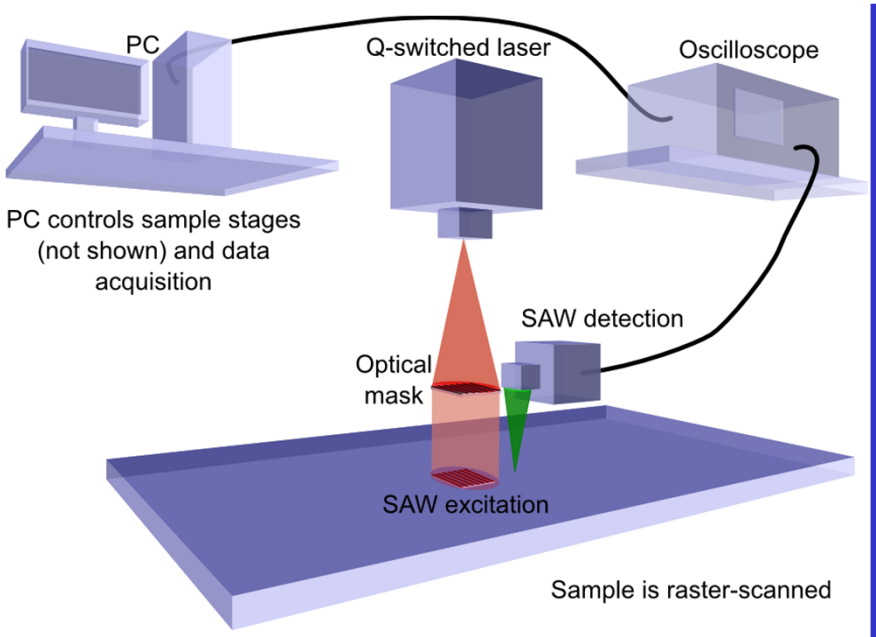
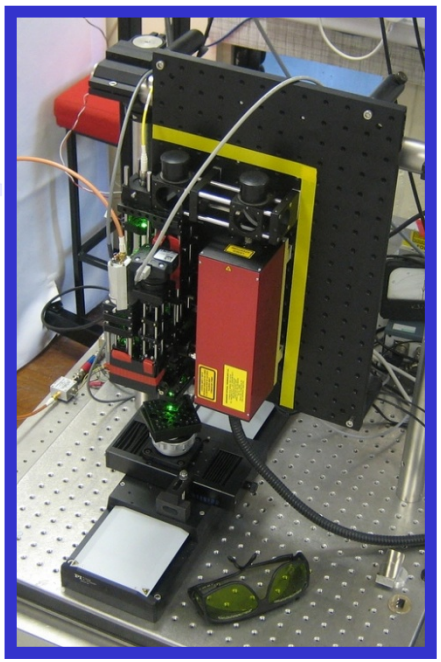
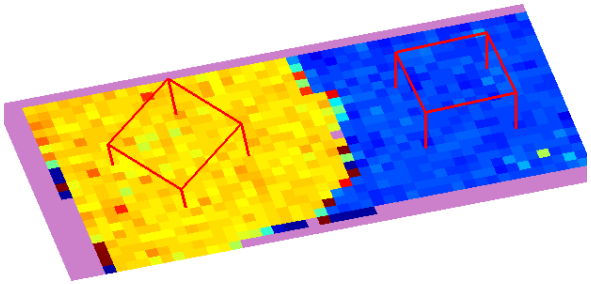
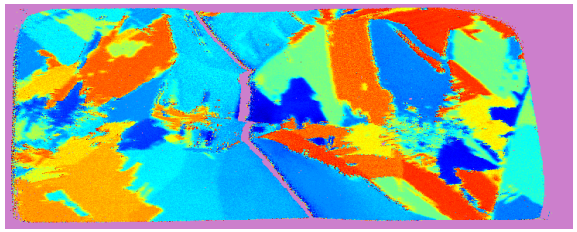
LU Background

- Generation laser, coupled with optical detector to detect the acoustic waves
- Often together in one box
- Often needs smooth surface





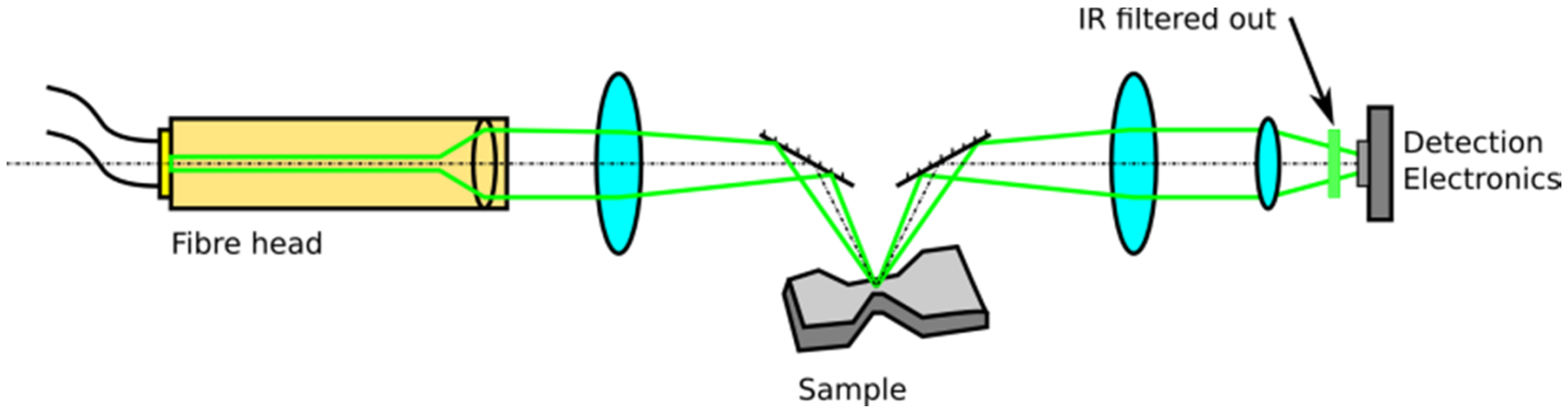




Background

How is sound detected with light?

- Interferometry (change in surface height)
- Doppler effect (change in surface velocity)
- Optical beam deflection (change in surface angle)
- We generally use optical beam deflection, using a split detector instead of a knife edge: needs a good surface finish

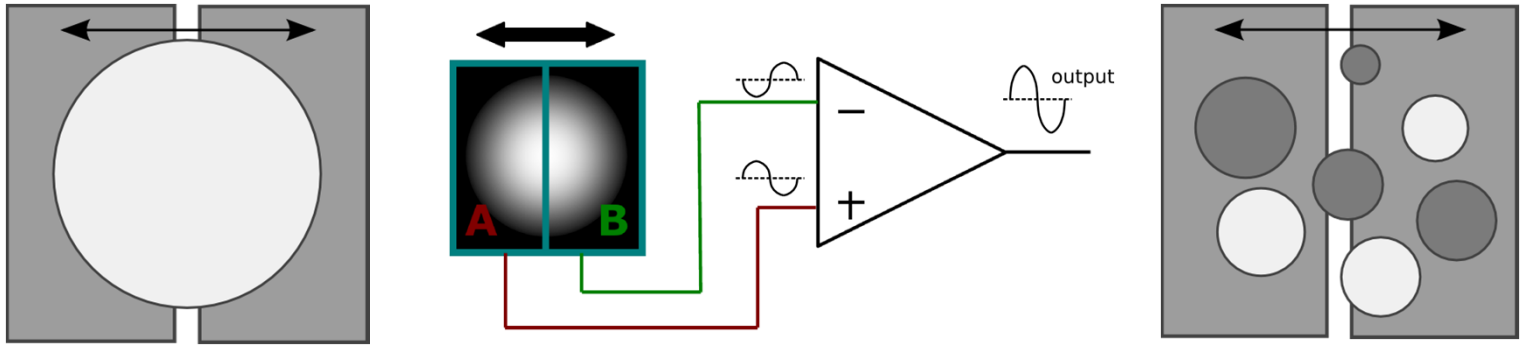


Background

Effect of optical speckle on KED

System works only with optically smooth surface: if the surface is rough, the spot on the detector becomes speckled

As the beam is deflected by the passing ultrasound, both dark and light speckles may pass over the KED (or split photodiode), attenuating the desired signal

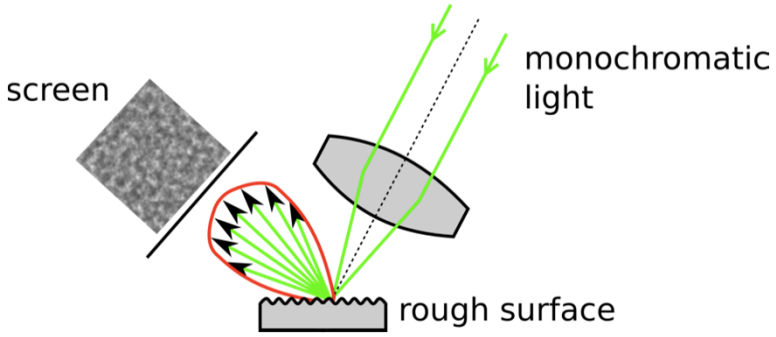


Background

Optical detection of ultrasound on rough surfaces

Difficult to detect ultrasound waves on rough surfaces because light is scattered as it is reflected – Speckle

Solutions can be costly (>£80k), big (>50x50x30cm) and/or difficult to make/setup

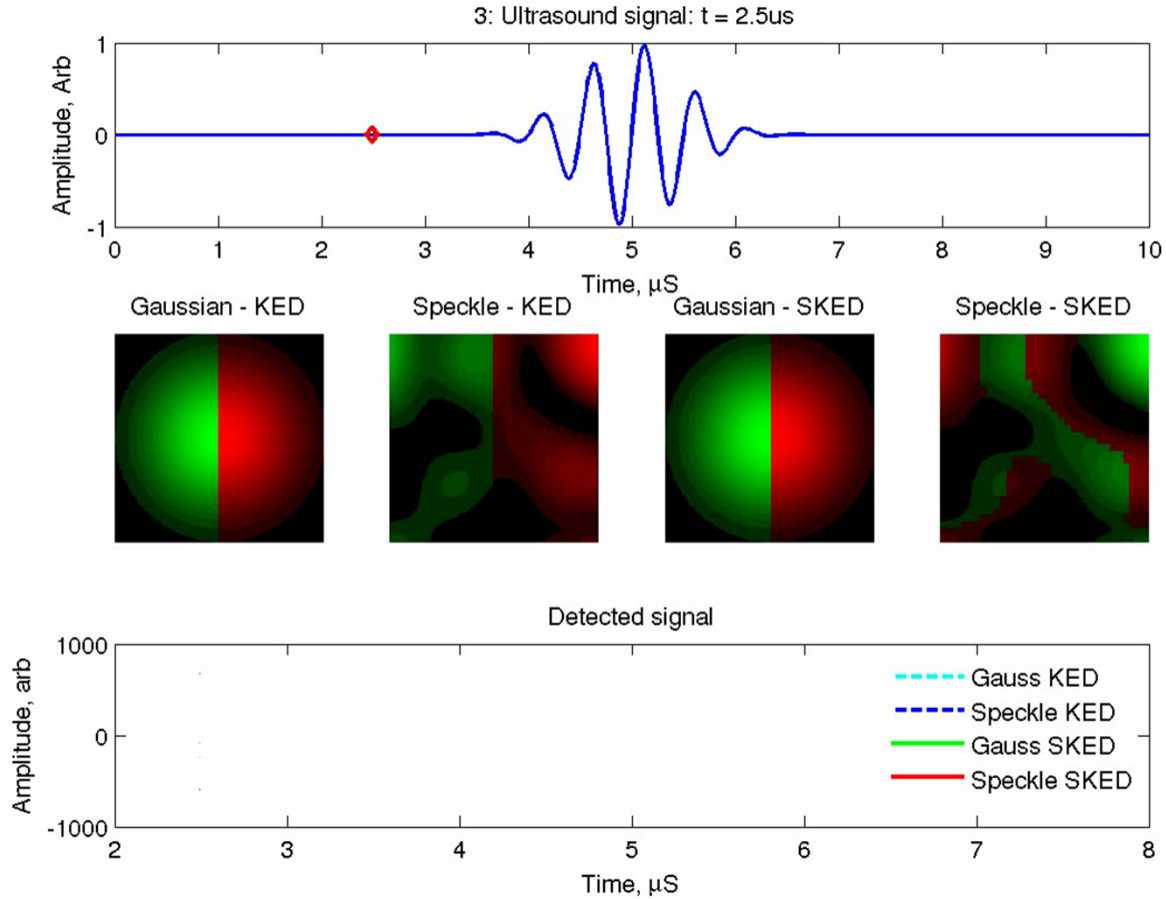


Inspection needs addressed

- Improve reliability of detection methods for non-contact non-destructive testing and evaluation.
- Reduction of cost and physical size of instrumentation
- Improved performance and SNR for defect detection on machined and un-machined surfaces, including detection of subsurface defects
- Access to new parameters: major impact in determining new crack/damage precursors
- Systems usable in hostile environments, e.g. steel mills

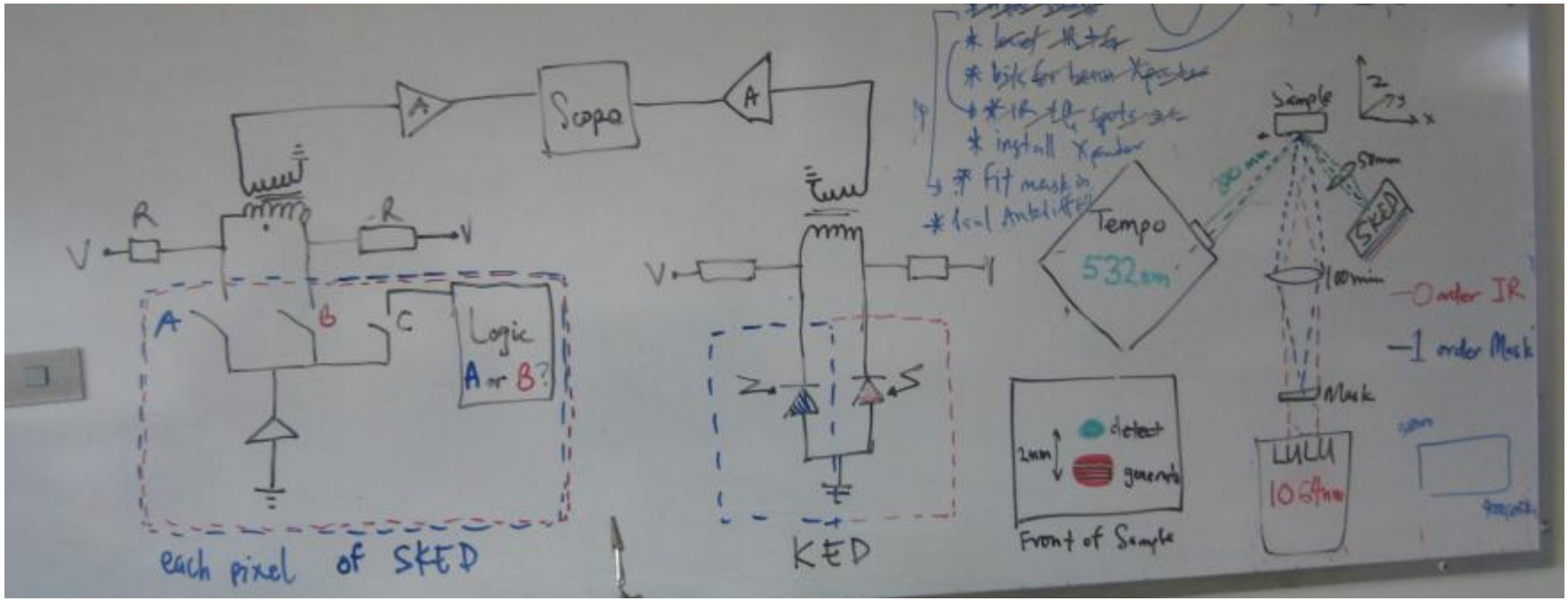
SKED: Principle of operation (v)

Compare light distribution over the photosensitive array and split each bright domain into its own KED



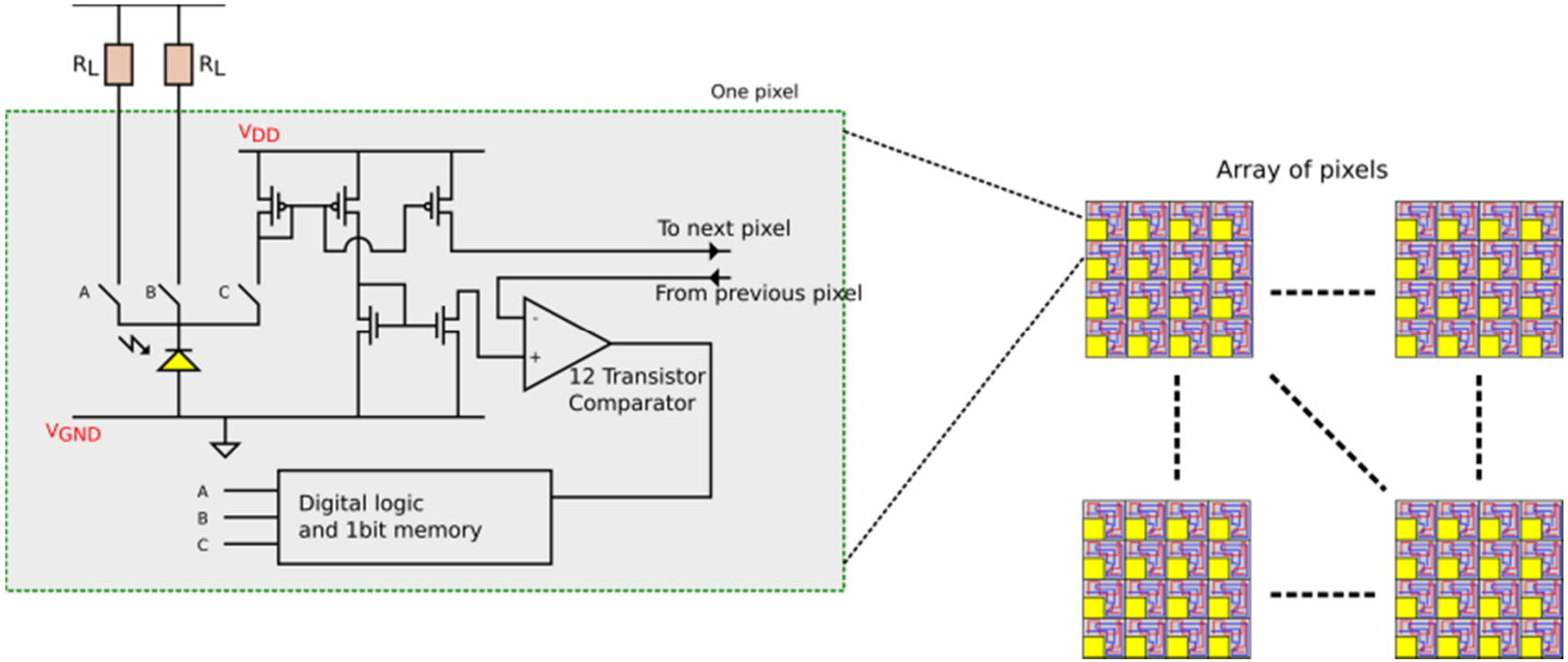
SKED - Schematic

SKED vs KED



SKED - Schematic

Pixel internals

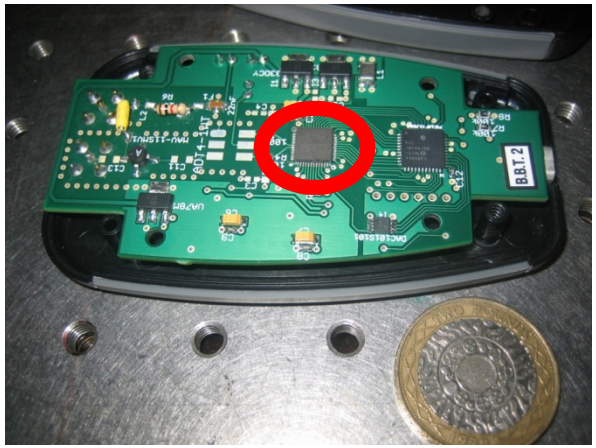


SKED Prototype

Packaging and electronics

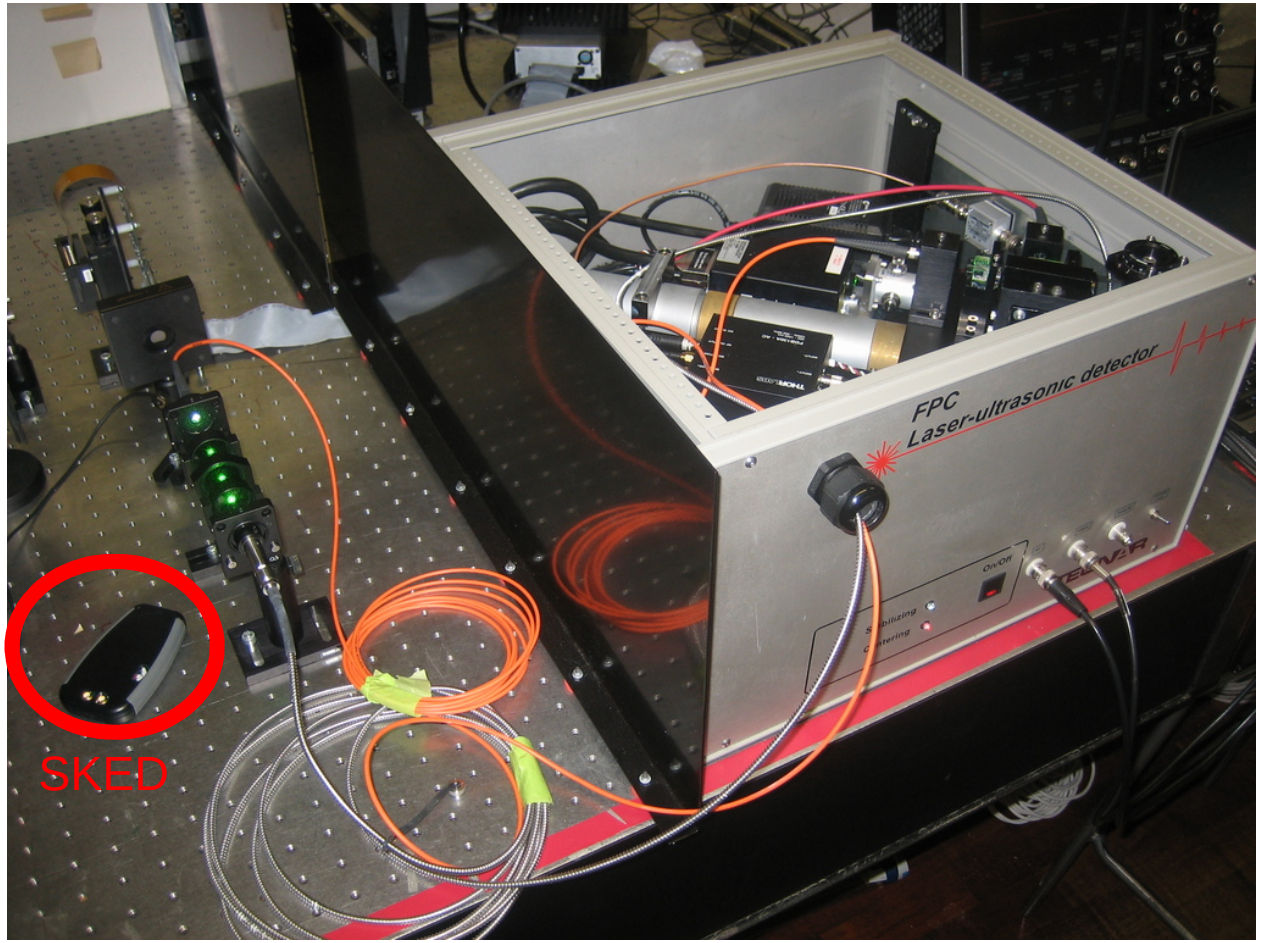
The device itself takes up <10mm^2 of silicon, and requires nothing more than a few RF components to amplify the analogue signal, and (optionally) a £2 PIC chip to read off or apply configuration information via USB.

You also need a laser to provide the light source – this could be fibre-coupled – and a couple of lenses.



SKED Prototype

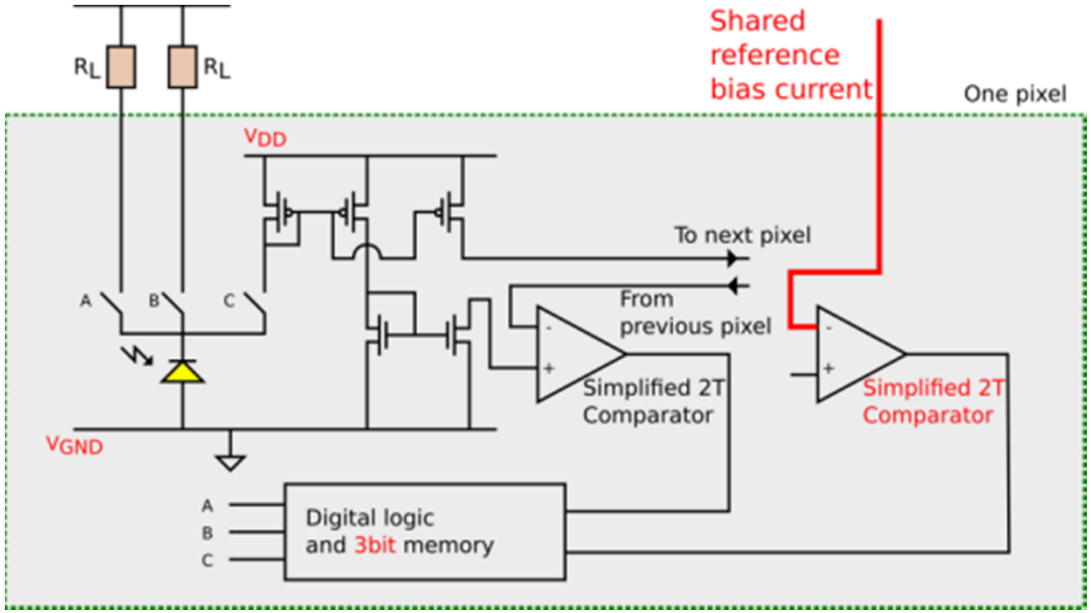
Speckle knife edge detector, next to Fabry Perot (£80k)



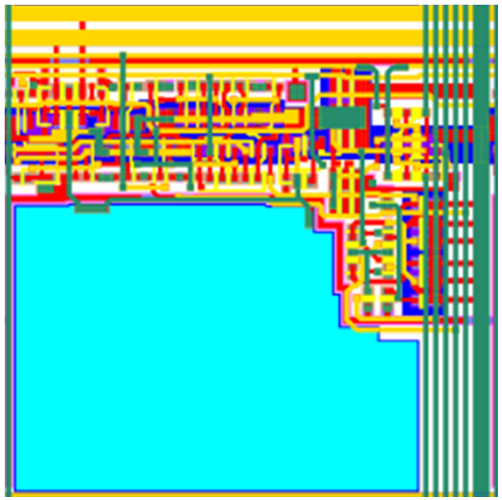
Design parameters

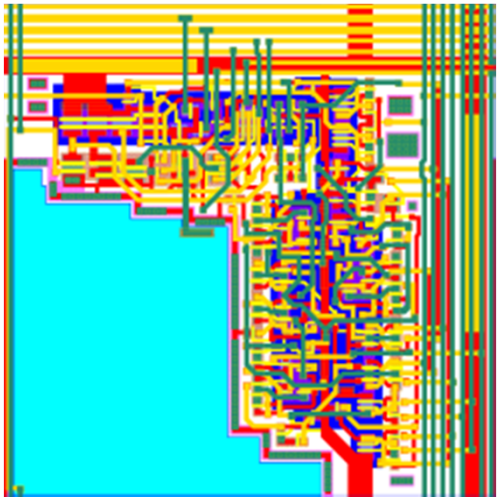
- Light power
- Speckle size
- Fill factor and pixel size
- Number of pixels required
- Sensitivity
- Bandwidth
- Adaption speed
- CMOS process – smaller pixels?

SKED2 Schematic



SKED1

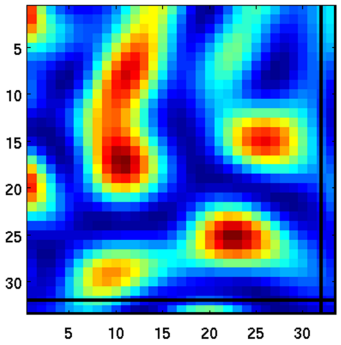


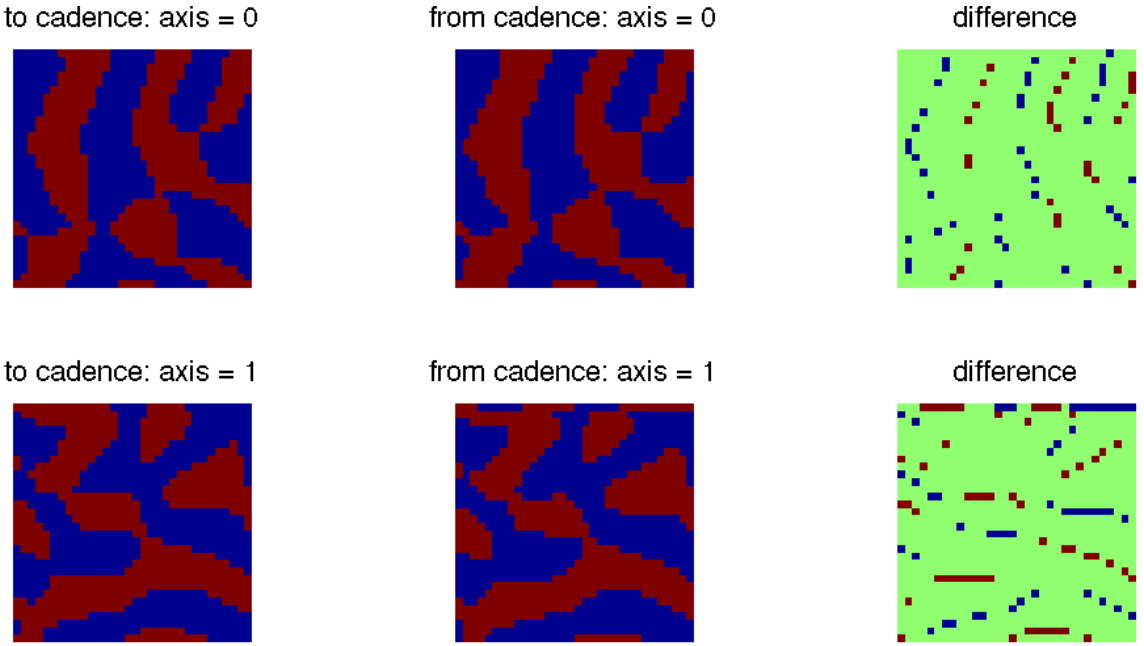


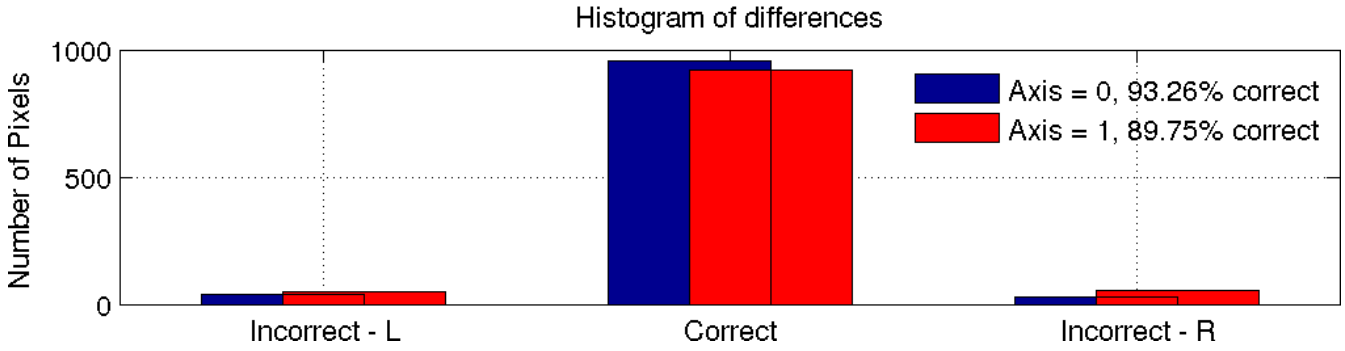
SKED2

SKED2 configuration accuracy

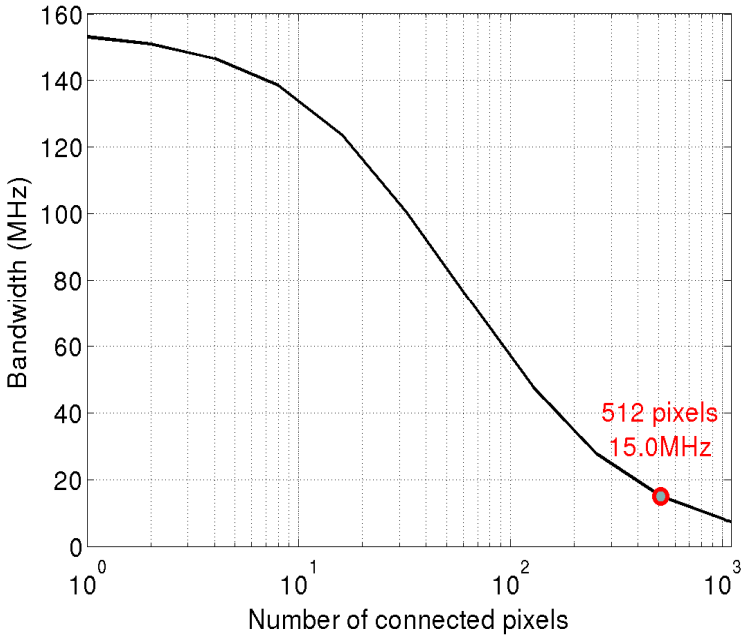
Speckle data

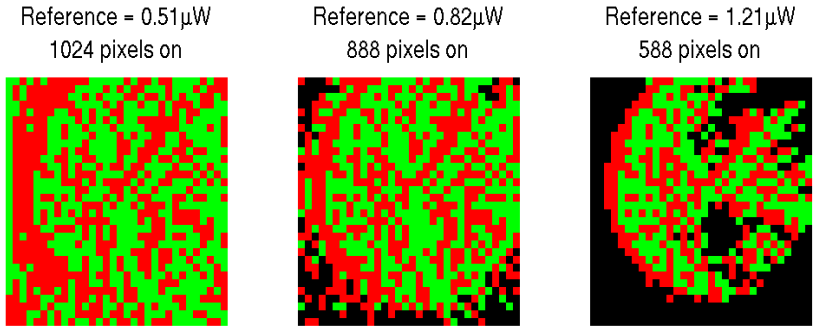


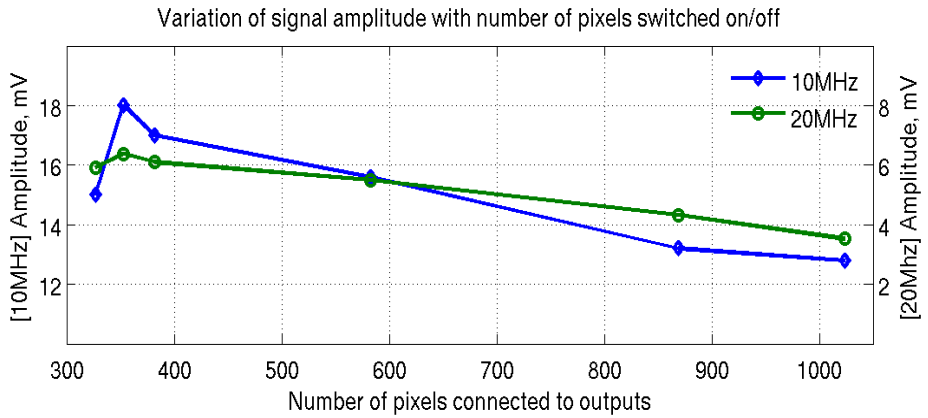




SKED2 - results

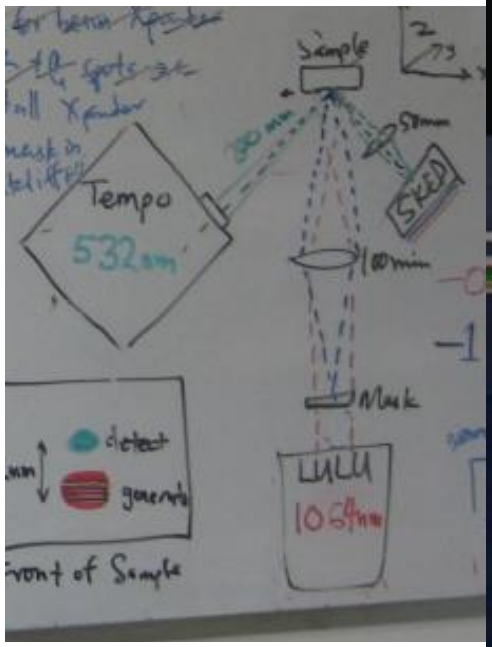


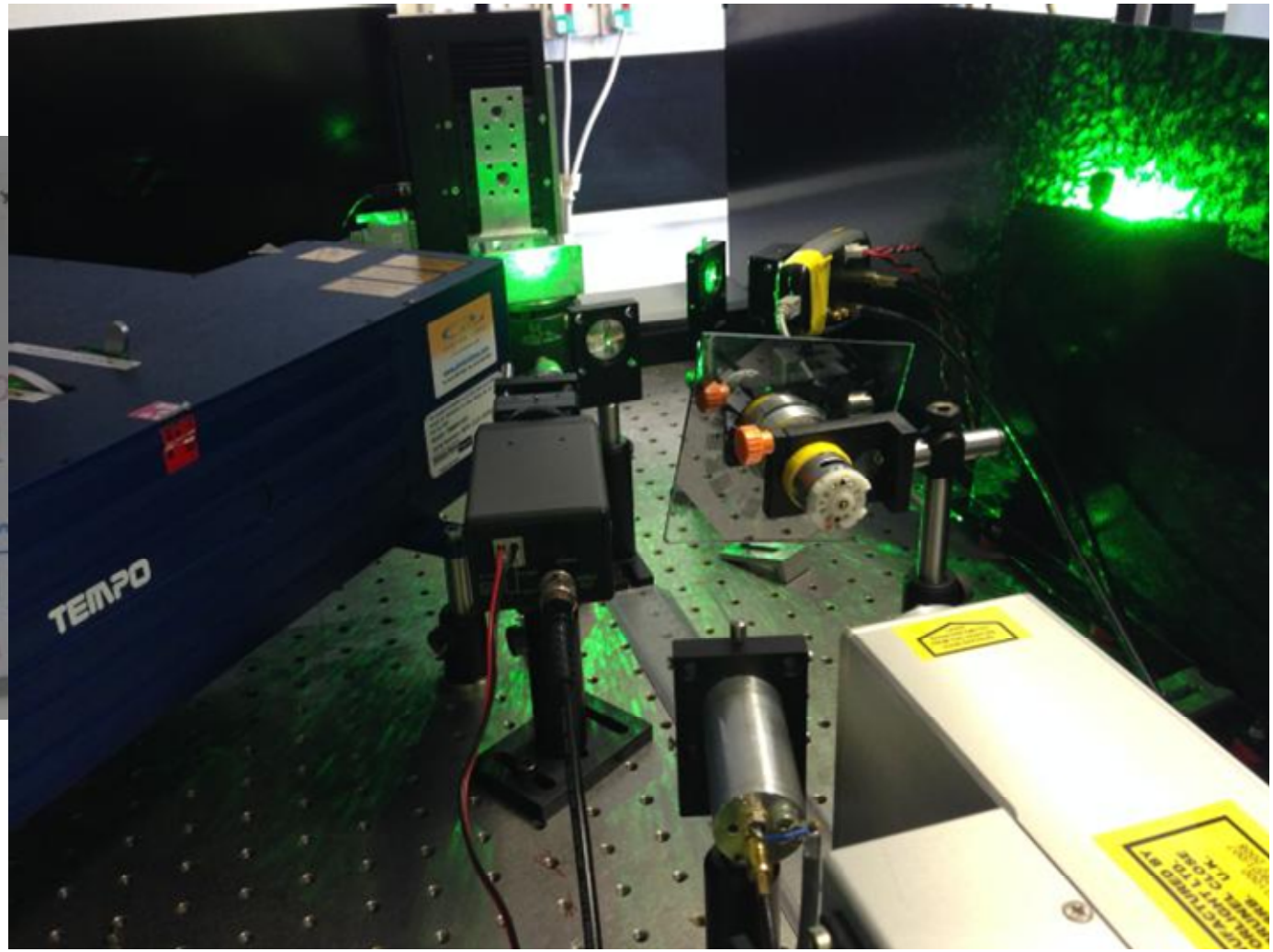




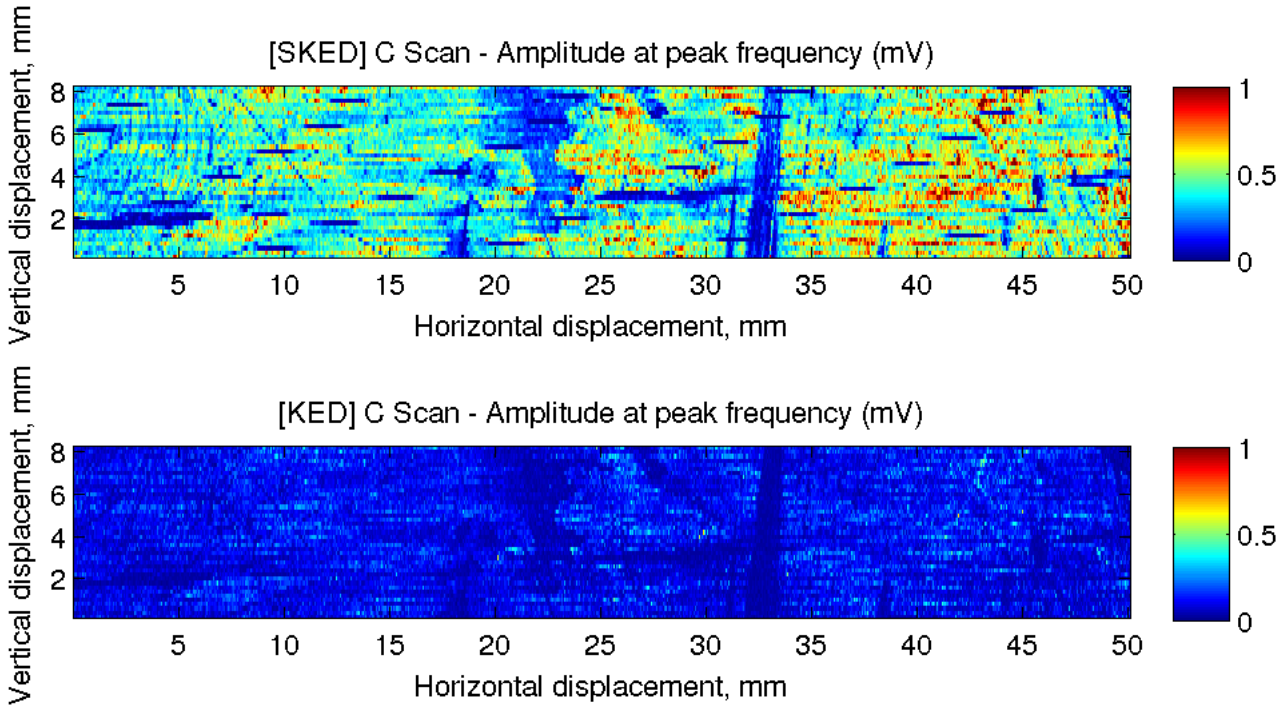
SKED1: Fixed number of pixels attached to output, bandwidth limited
SKED2: Can disconnect or connect pixels as required, bandwidth variable – improved signal

SKED2 – experimental setup

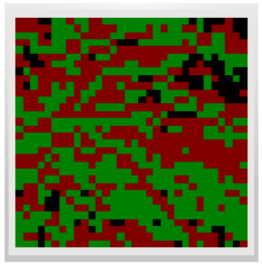




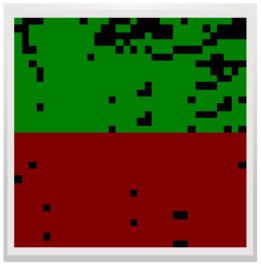
SKED2 - results



SKED configuration

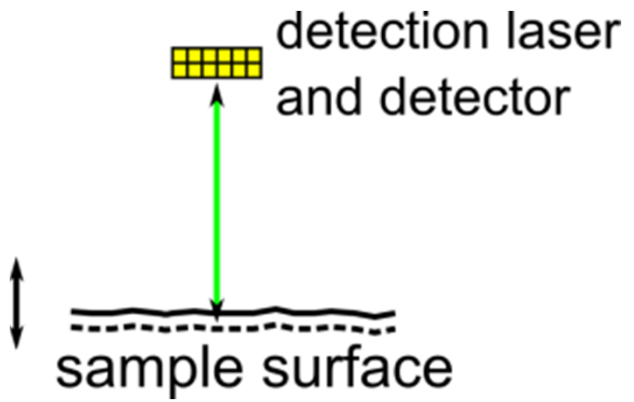


KED configuration

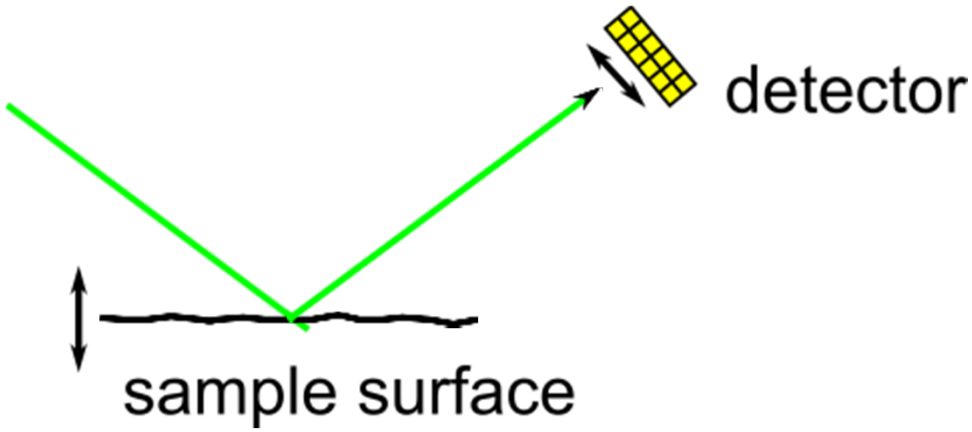


SKED2 – Bulk wave detection (v)

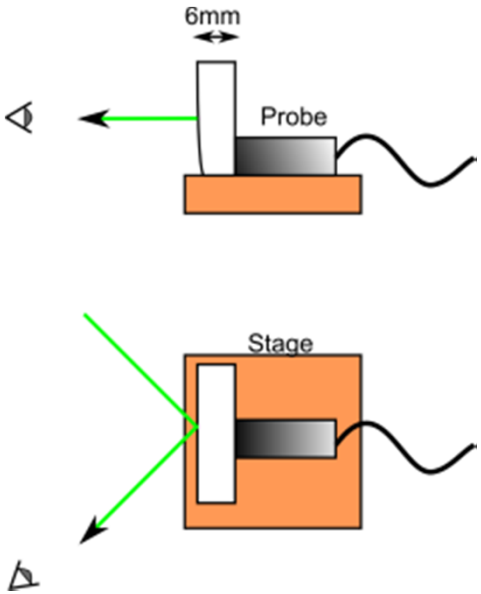
Normal detection will fail
to detect out of plane motion

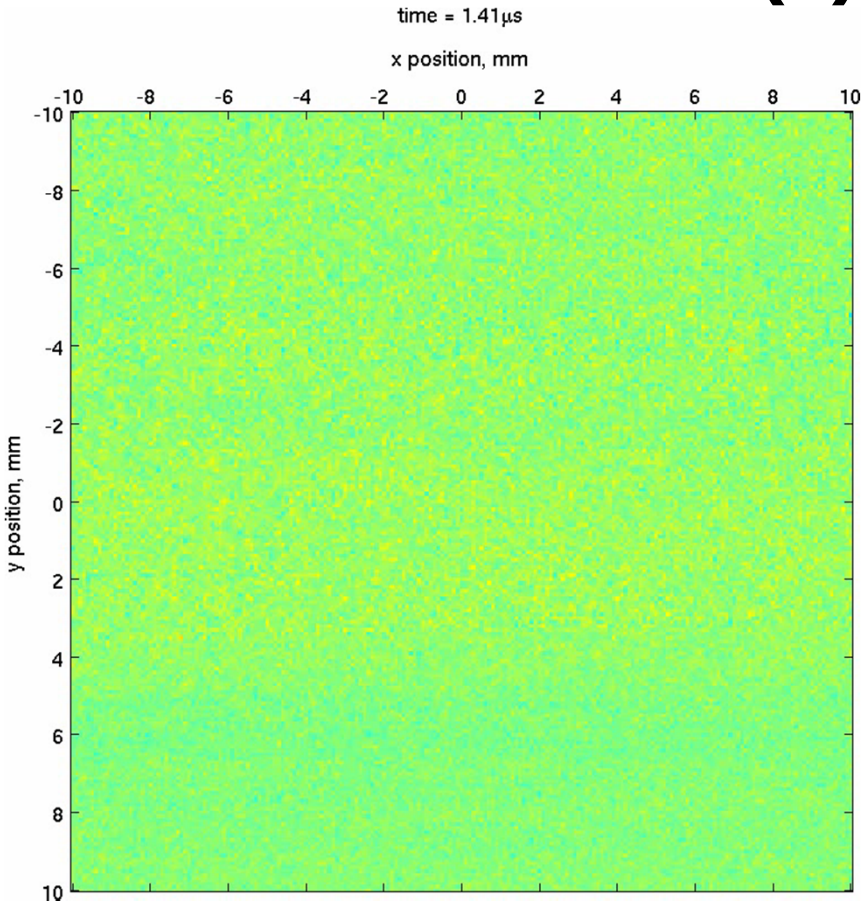


Detect at an angle



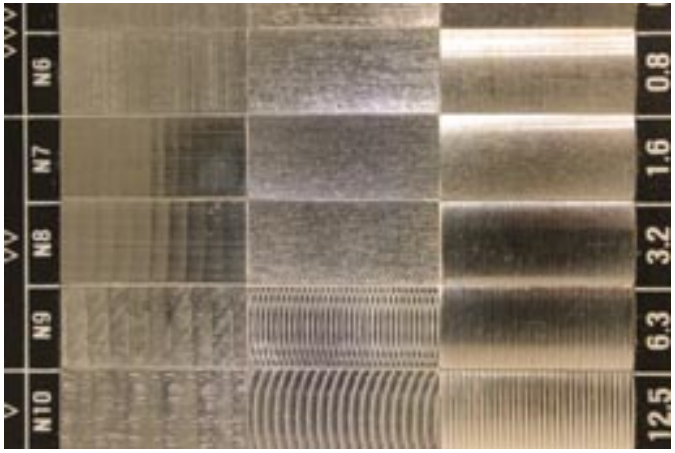
SKED2 – Bulk wave detection (v)



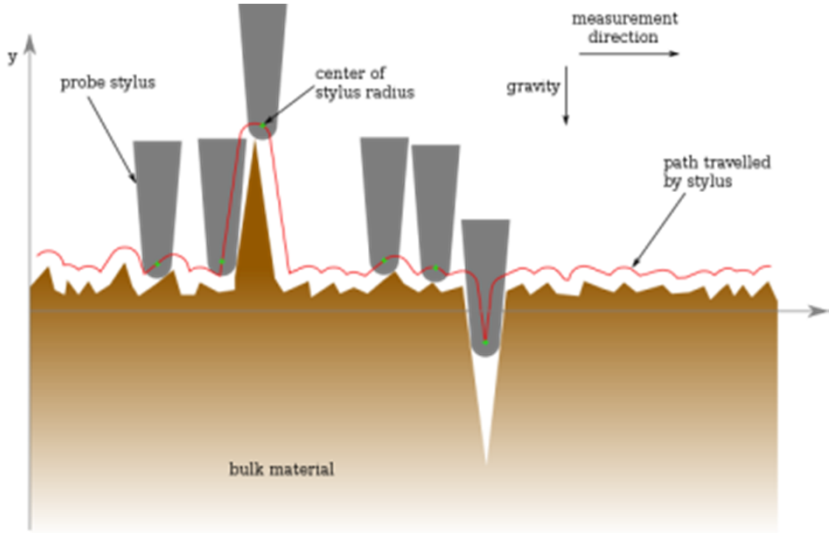


2 x 2cm^2 Aluminium Block, 10MHz probe.

How rough is rough?



Rubert Comparison Specimens
ISO 5436



$$R_a = \frac{1}{n}\sum_{i=1}^{n}|y_i|$$

Arithmetic average of absolute surface features

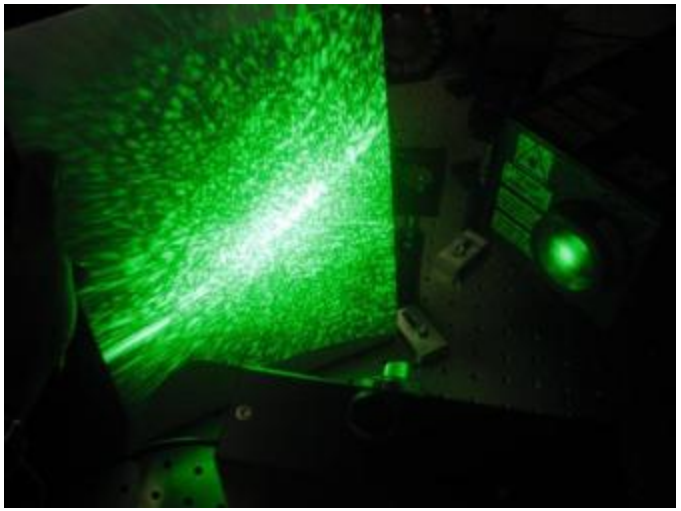
$$\Delta h < \lambda/8$$

Rayleigh Criterion summarised

Graded roughness samples

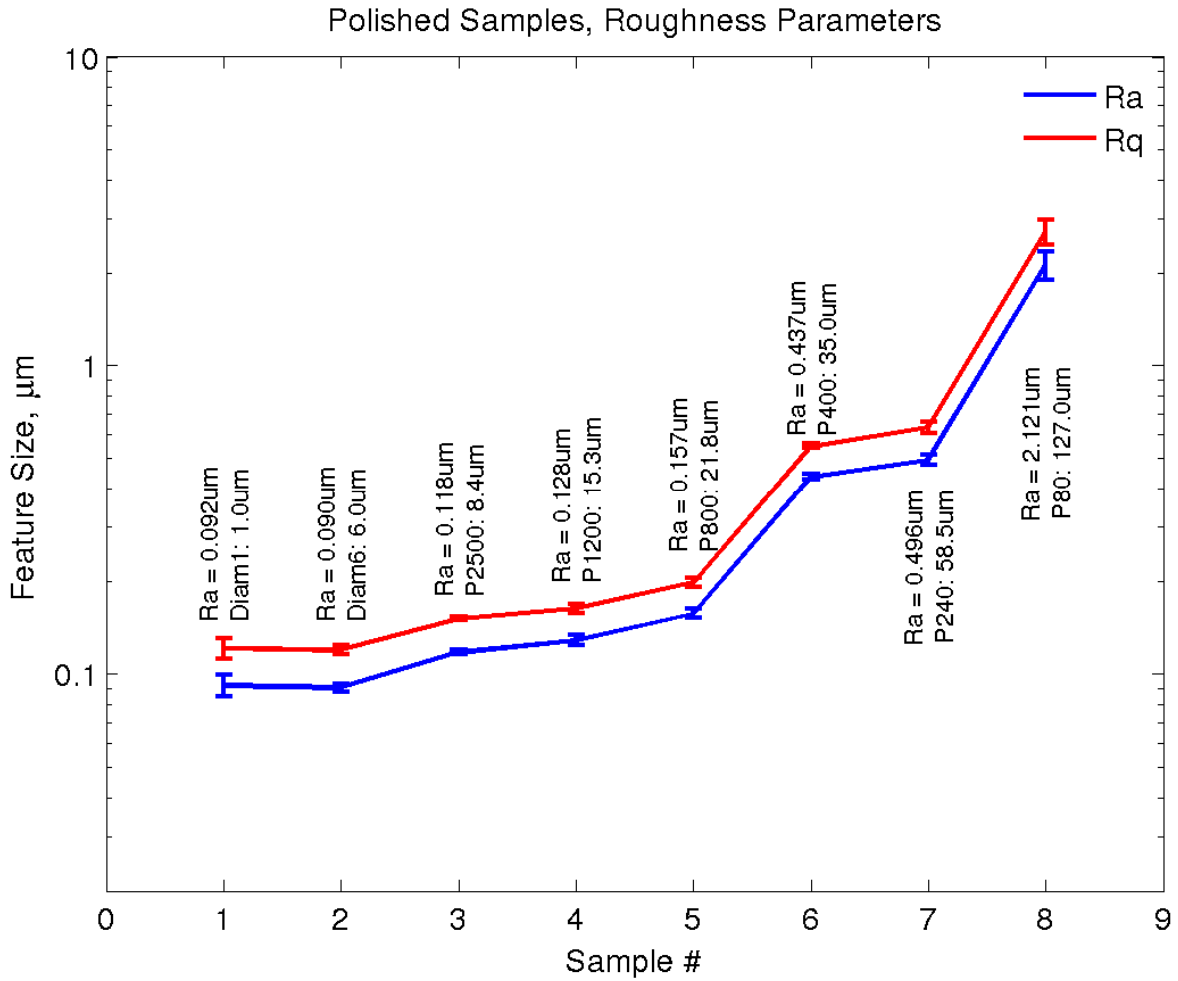
Scrap aluminium block

- Sawn into eight ~1cm^3 blocks
- **Polished to 8 different grades of finish**
- Black is just a resin base, good for handling

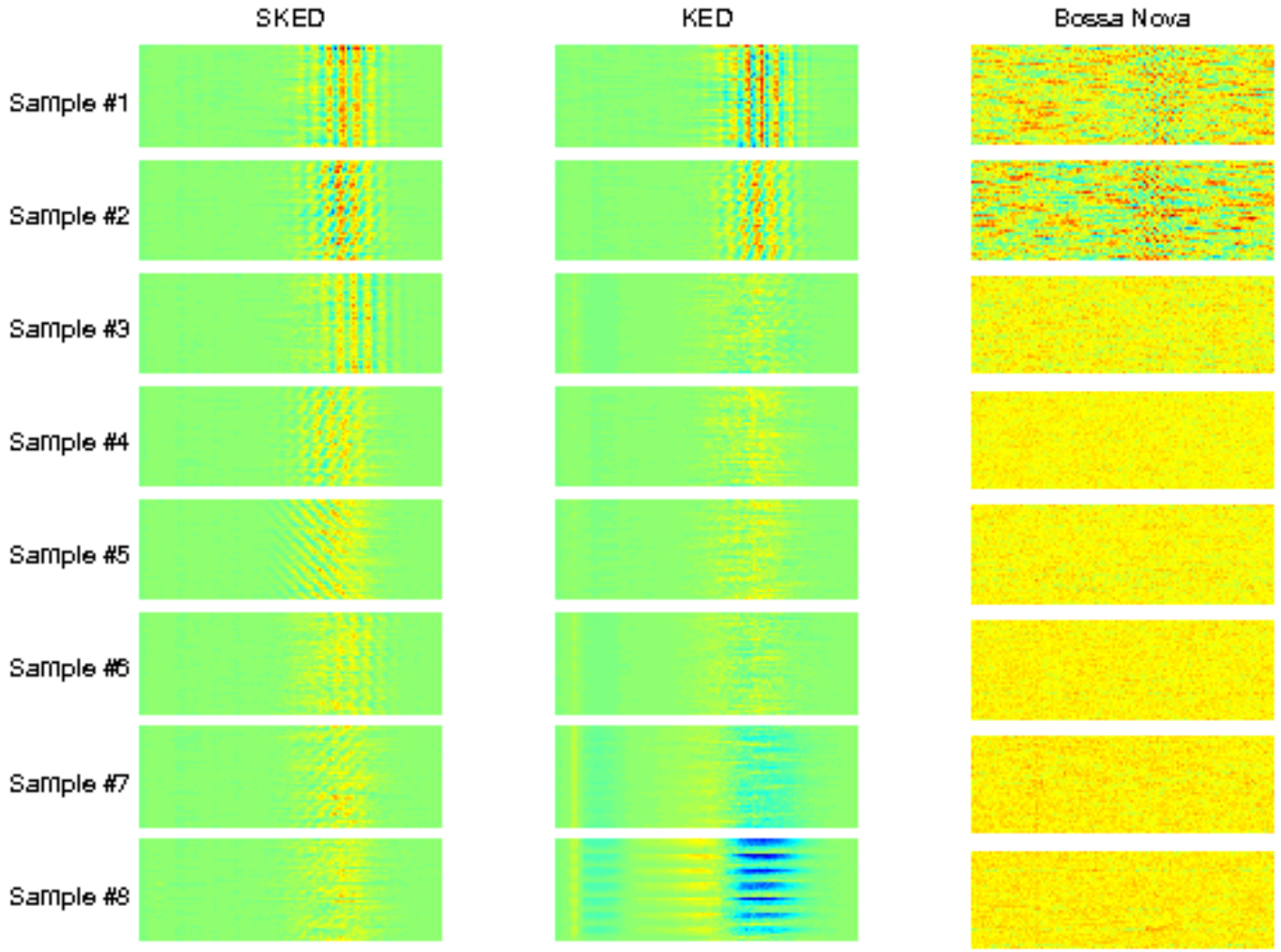


Speckle from Sample 4 shown on an A4 sized sheet of paper – big lens needed to collect more light

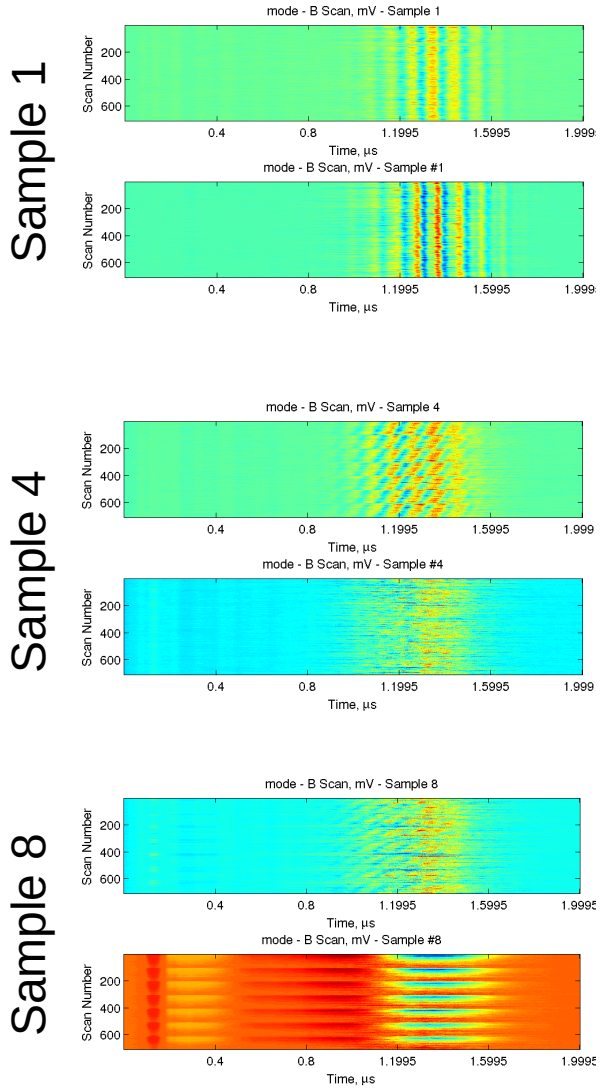
Graded roughness samples – (Ra)

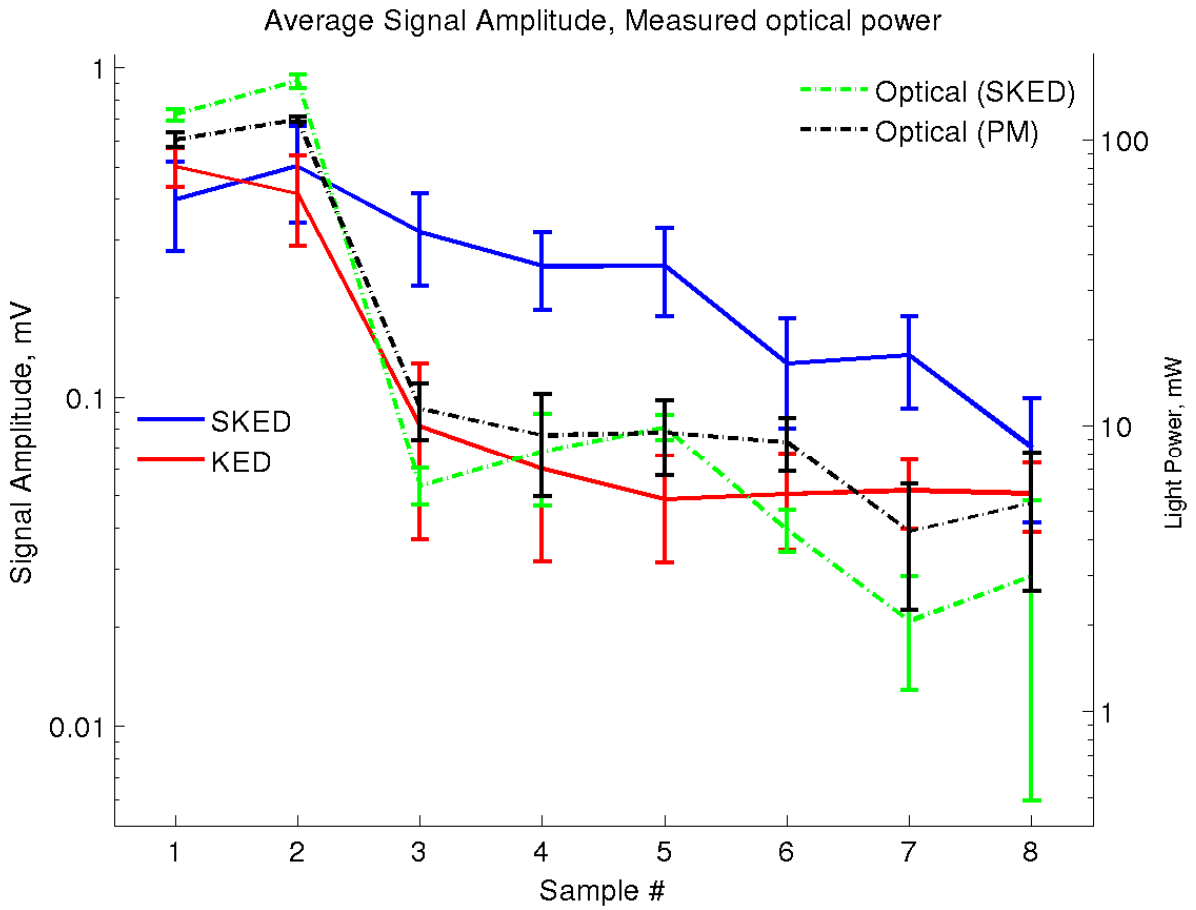


Graded roughness samples – results (1)

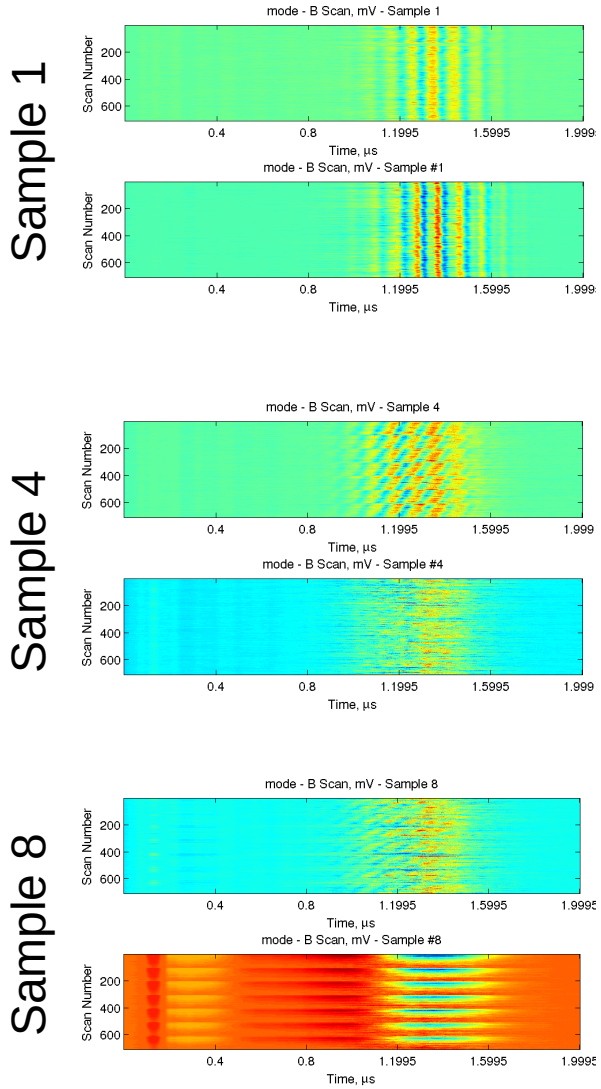


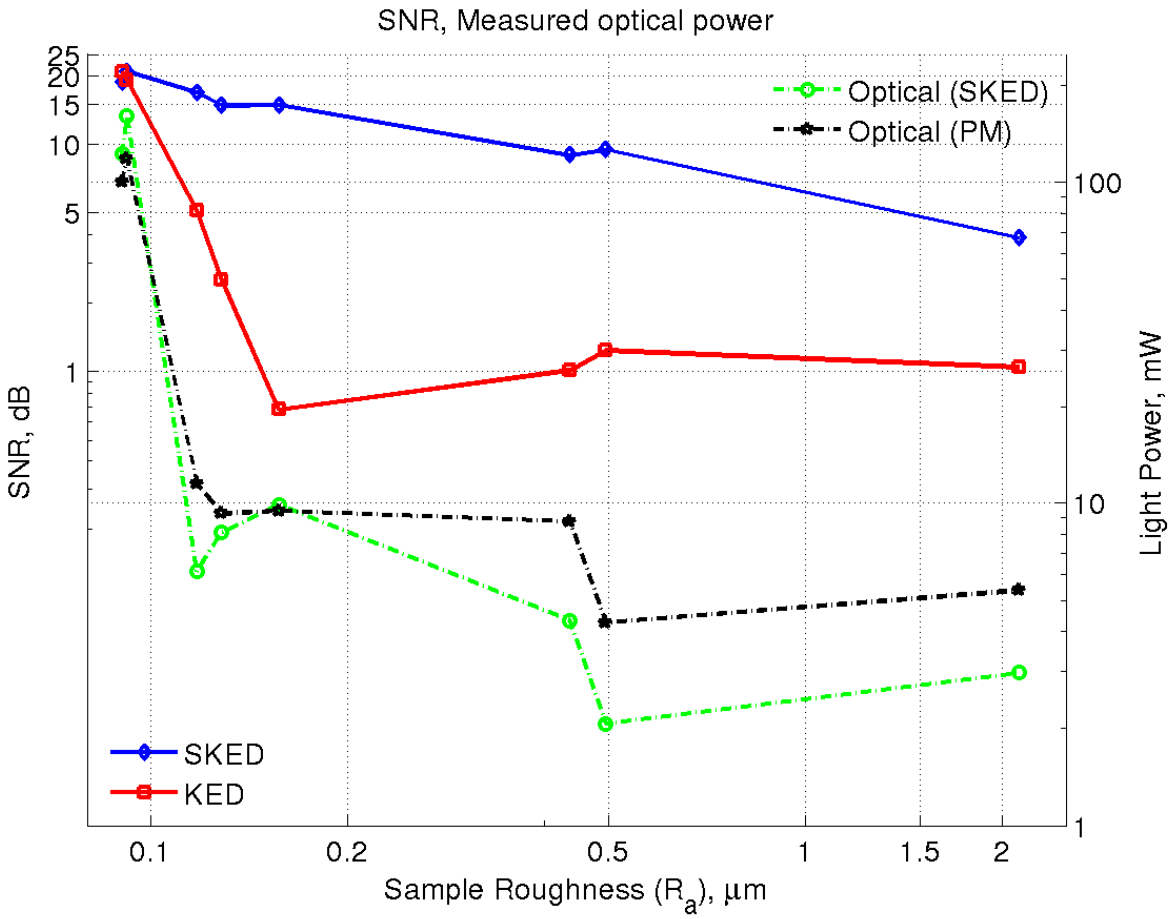
Graded roughness samples – results

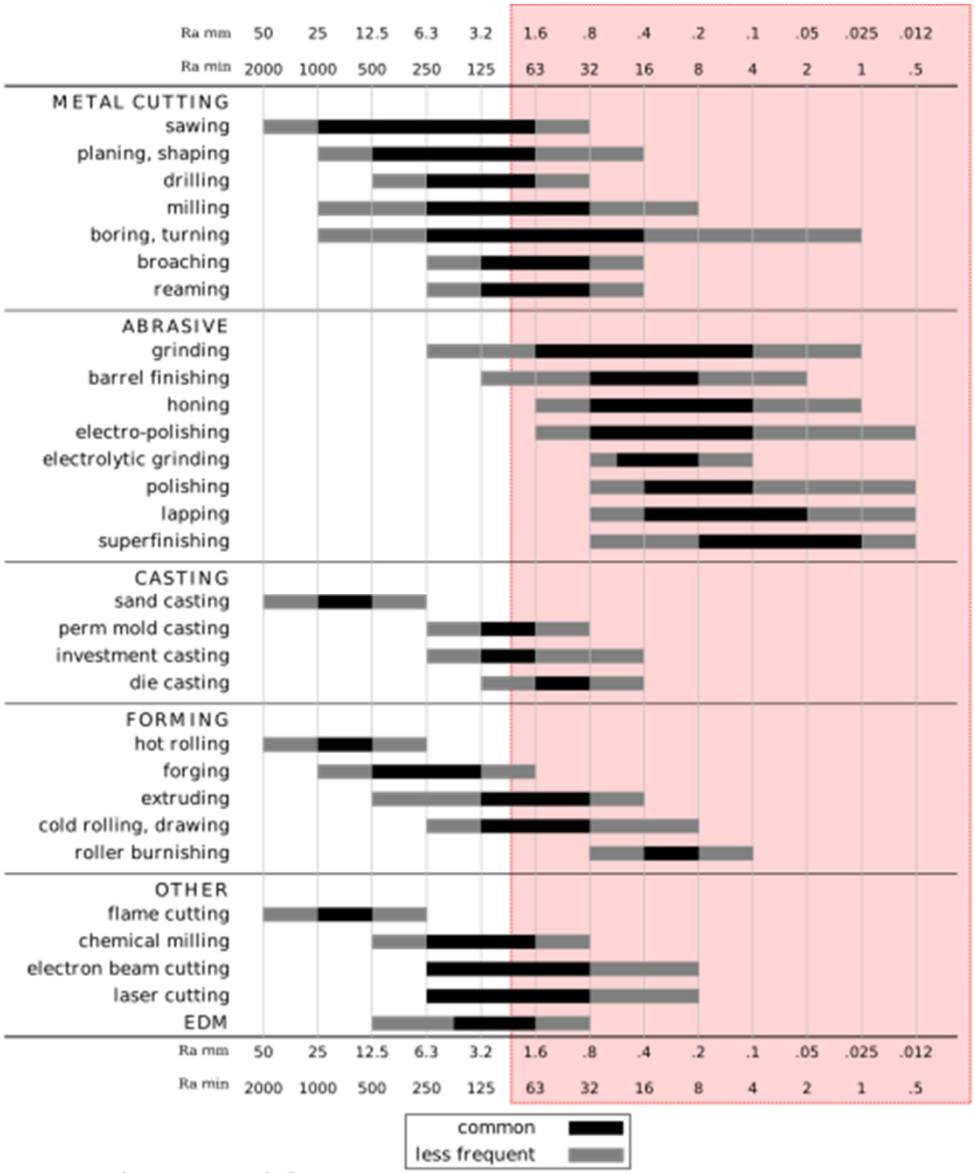


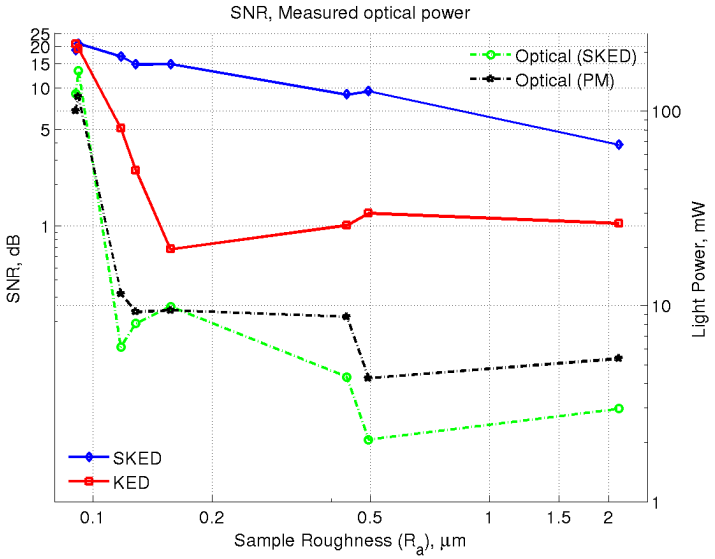


Graded roughness samples – results (2)





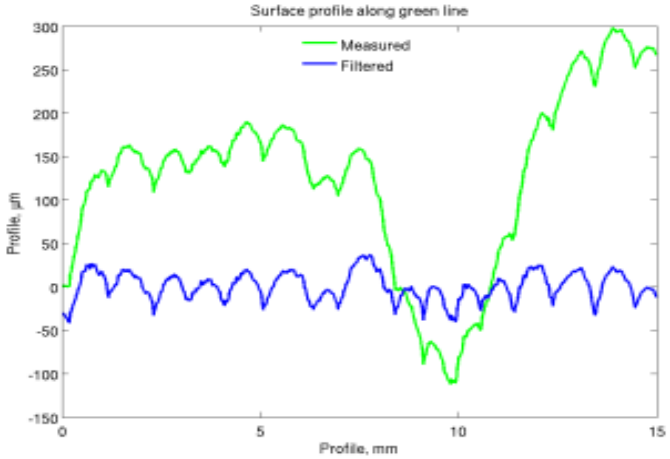


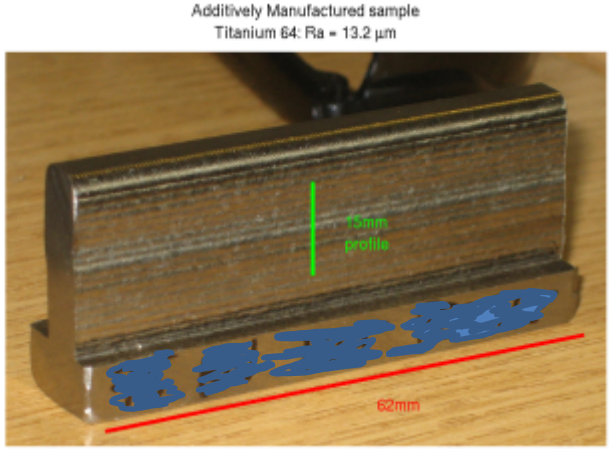


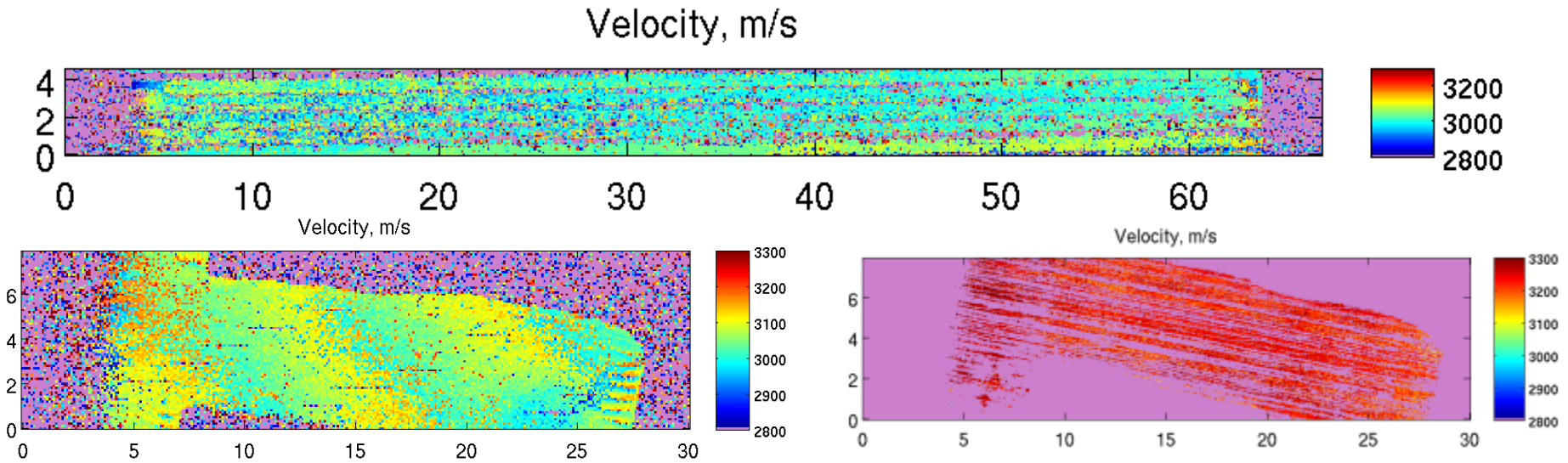
Can determine the required detection laser light budget given a finish and a required SNR

Aluminium Macbook
Ra = 1.83µm

Beyond roughness – coping with topology







Can track big deviations in light beam due to uneven surface topology because we use a large area detector array (2mm*2mm)

Headline specifications

- Acquisition speed: Can grab up to 0.5 Msamples/second
- Bandwidth: 15MHz (full array) to 60MHz (10x10 pixels)
- Sensitivity: minimum displacement that can be detected for a given about of light/bandwidth

  SKED: 1.2×10^{-6} nm$(W/Hz)^{½}$ **[Preliminary]**

  Bossanova Tempo: 2×10^{-7} nm$(W/Hz)^{½}$
- Sensor area: 2x2mm: Results presented use a 25mm diameter lens with focal length = 50mm
- Tested successfully with surfaces with roughness beyond 2µm scanned, waviness up to 13µm

Conclusion

- Introduced laser ultrasound generation and detection
- Introduced an fast adapting knife edge detector - SKED
- Presented some results comparing SKED with existing technology
- Presented SKED2 results. Fewer is better?
- Characterized for roughness

Thank you very much

Questions/Suggestions?