Parallel Ultrafast Ultrasonics

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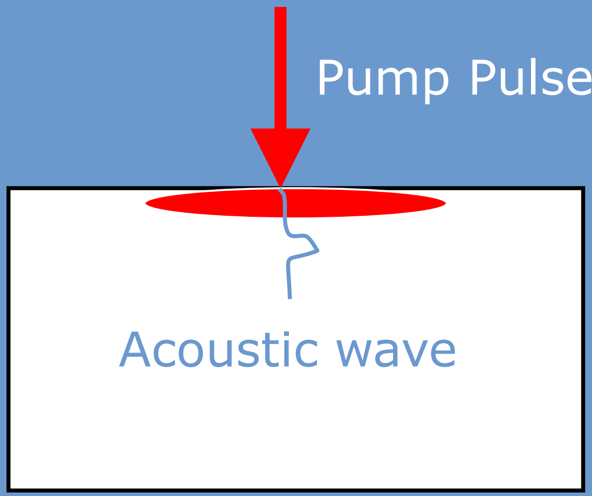
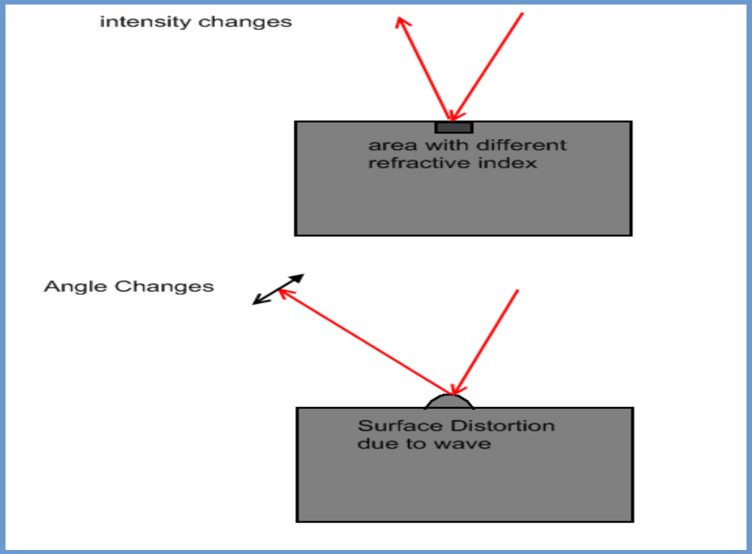
Talk Outline

- Introduction
- Typical experiment setup
- Moving to parallel detection
- Our approach
- Commercial Detector
- Custom Detector
- Conclusions

Introduction – Laser generation and detection of ultrasound

- Laser pulse absorbed
- Rapid local heating
- Heating causes expansion
- Expansion generates sound wave

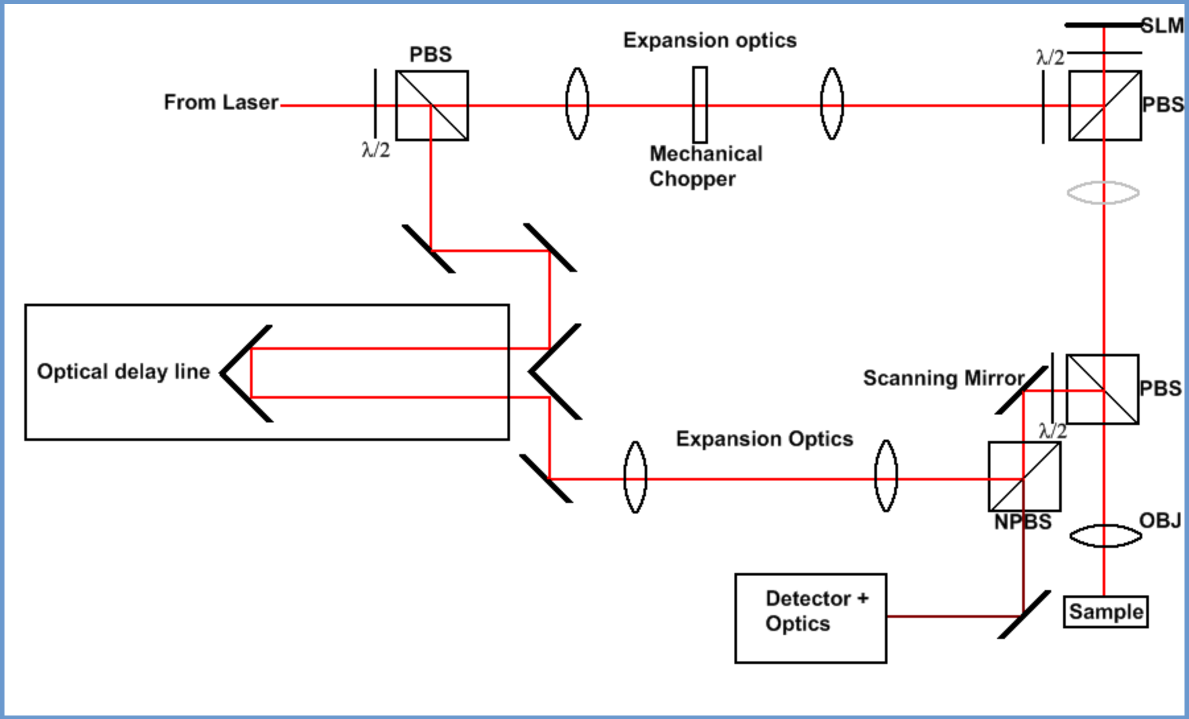




- Different mechanisms for detection
- Reflectivity
- Surface changes
- Very large background with small signal of interest

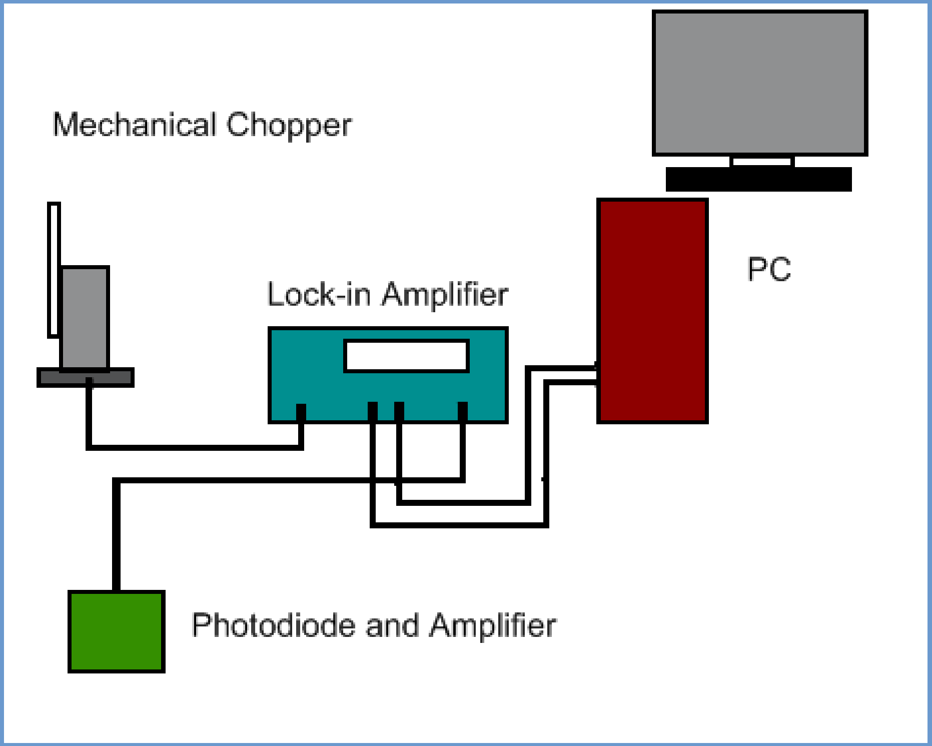
Experiment Setup

- Detection and generation laser the same
- Time delay imposed by mechanical scan of delay line
- Path lengths important for system layout
- Keep pump losses to minimum
- Pump and probe beams separated by polarisation optics



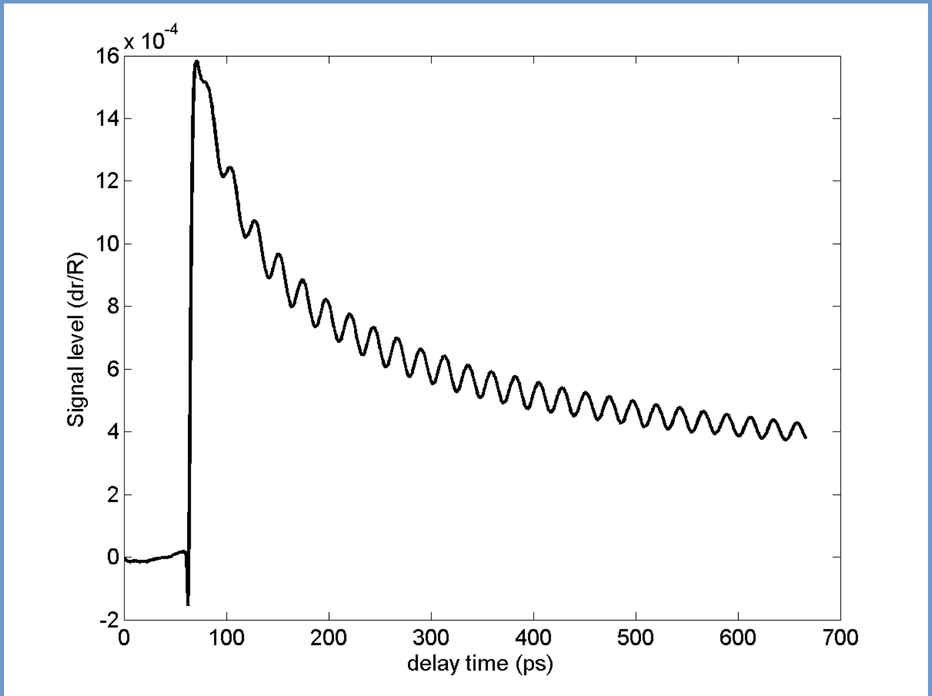
Single Channel Detection

- Single photodiode detector
- Lock-in amplifier with reference from pump arm chopper
- Sample GaAs as gives large signal
- Sample forms an interferometer



Single Channel Result

- 3 main components to signals
- Coincidence peak
- Thermal relaxation
- Brillouin oscillations
- Signal of interest 10^{-4} →10^{-6} times smaller than DC light level



Moving to multiple channels

- Need another way to demodulate the signal as multiple lock-ins become impractical
- Need to capture many photons for required SNR
- Our Approach is to use an integrating detector and a suitable algorithm

- Phase stepping used to demodulate signal
- N steps per chopping cycle
- Usually only 3 or 4 steps required
- However we have square wave modulation
- This introduces errors due to the presence of harmonics

$$\Delta\alpha = \frac{2\pi}{N}$$

$$S_1 = \sum_{m=0}^{N-1} I_m \cos\alpha_m$$

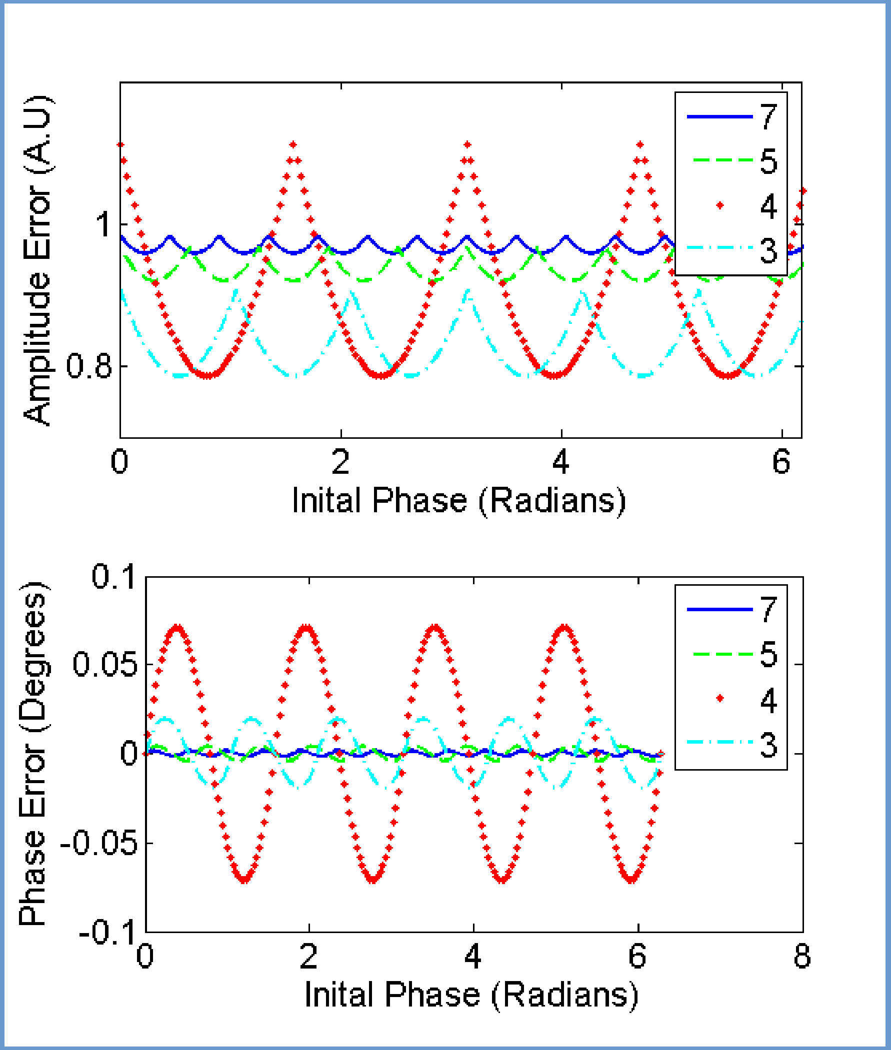
$$Amplitude = \sqrt{S_1^{\,2} + S_2^{\,2}}$$

$$S_2 = \sum_{m=0}^{N-1} I_m \sin\alpha_m$$

$$Phase = \tan^{-1}\left(\frac{S_2}{S_1}\right)$$

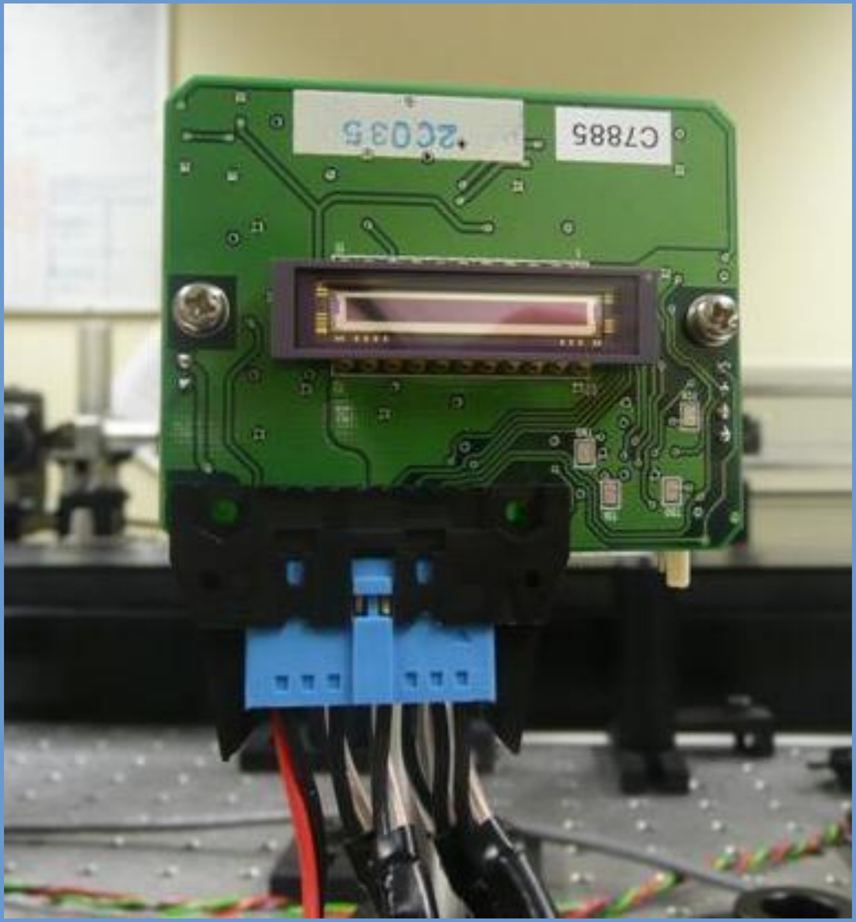
Impact of harmonics on phase stepping

- Harmonics cause amplitude-phase cross talk
- For low number of steps this has a huge effect
- Choose a number of steps where the errors are acceptable for the application



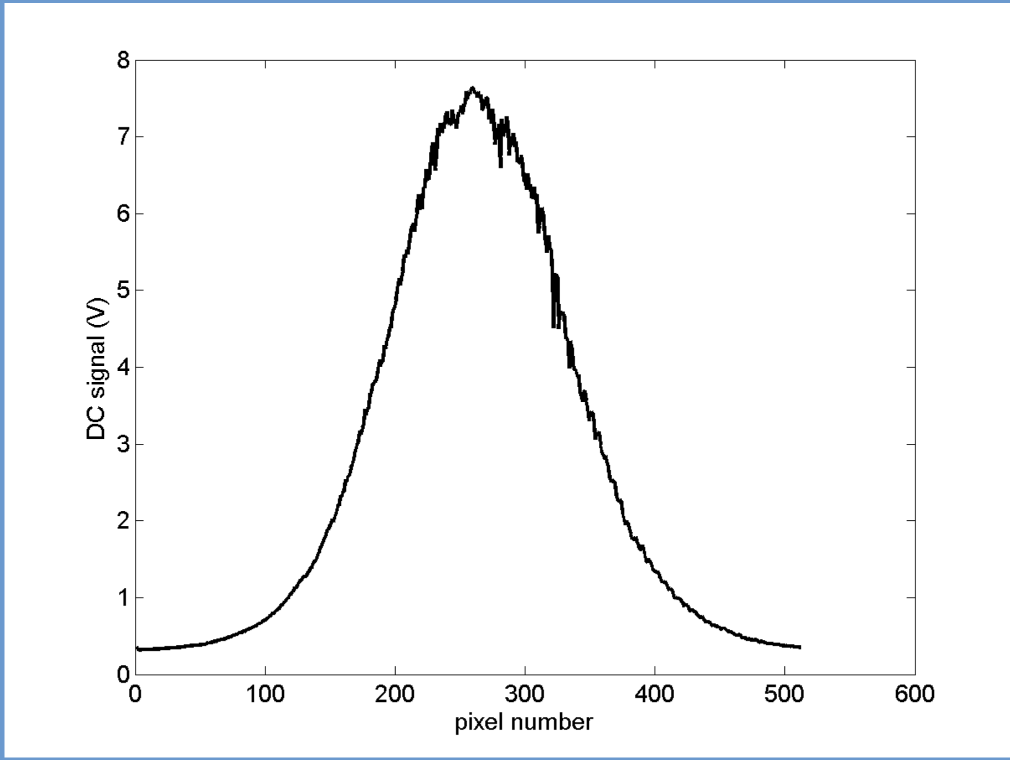
Linear Array detector

- Hamamatsu 512 pixels
- Pixels read rate 500KHz
- Rolling shutter
- Pixels size 50μm x 2500μm
- Can capture 3.25×10^{8} photons before saturating
- Custom timing board to generate clocks and chopper sync signal
- Sample and hold circuit required to reduce requirements on ADC



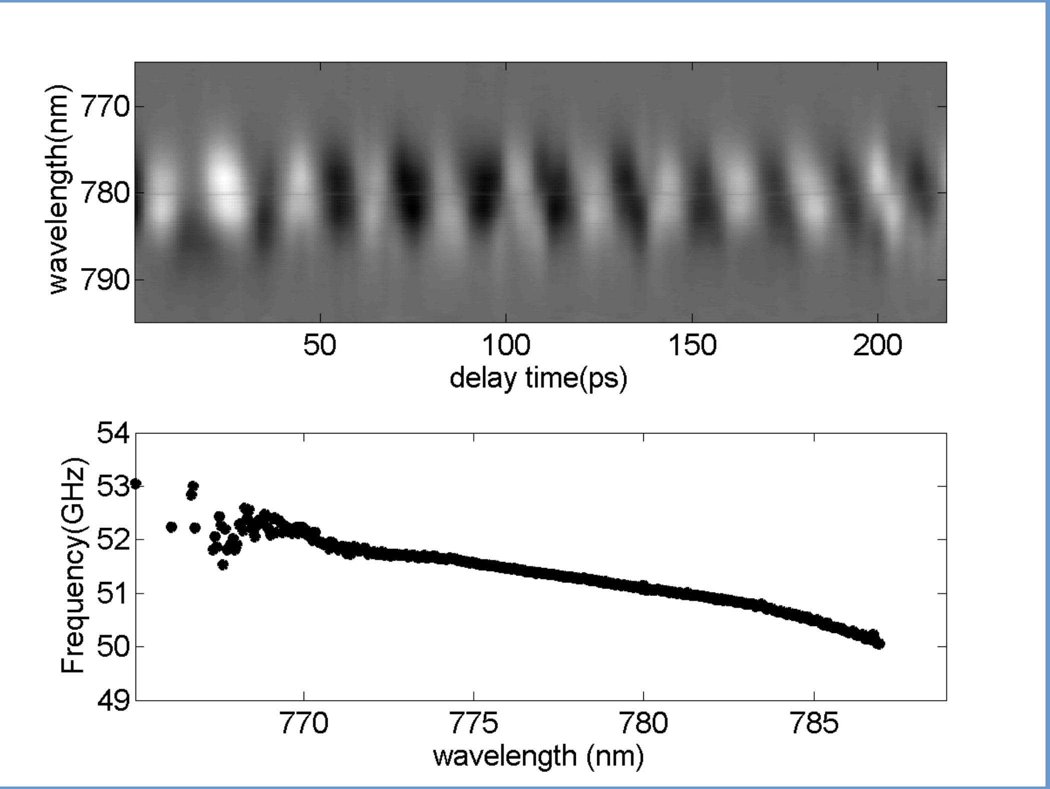
Commercial Array Experiment

- Each pixel corresponds to a different probe wavelength
- 800 averages used in this case
- Experiment time approx. 40mins
- SNR very good comparable to photodiode lock-in case
- Amplitude distribution verses wavelength
- As move away from centre SNR will get worse due to less light at that wavelength
- Approximately 220 pixels of usable signal



Commercial Array Experiment

- Frequency changes verses wavelength as expected
- End regions noisier than central region
- Graph slopes off as amplitude reduces due to influence of signal processing and nearby noise spikes
- For comparable SNR to photodiode lock-in case need approx 400 averages (taking 22 mins)
- Lock-in and photodiode takes approximately 3.5 hours (4 second per scan x 6 averages x 512 channels)
- Experiment with linear array is approximately 10 times faster



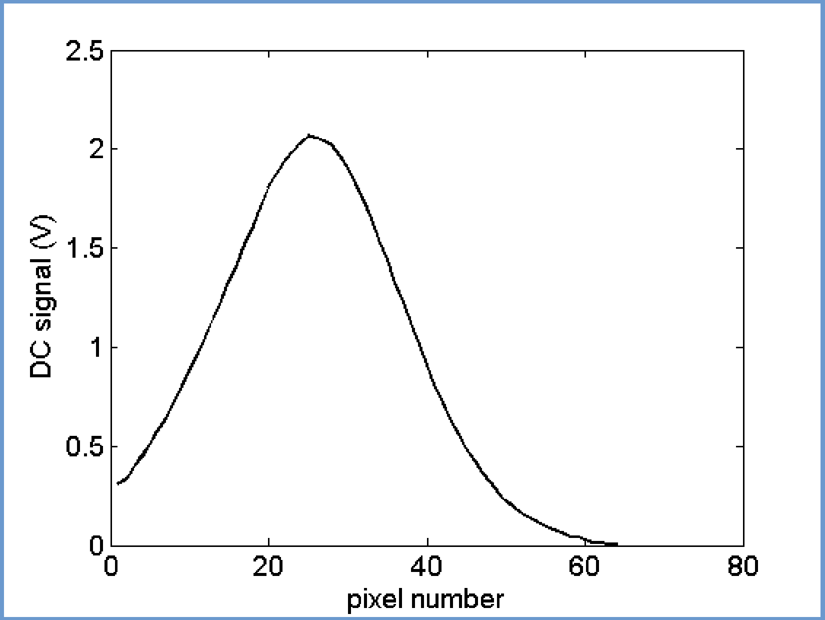
- Performing experiment in parallel also reduces impact of environmental changes as all data is affected in the same way

Custom detector

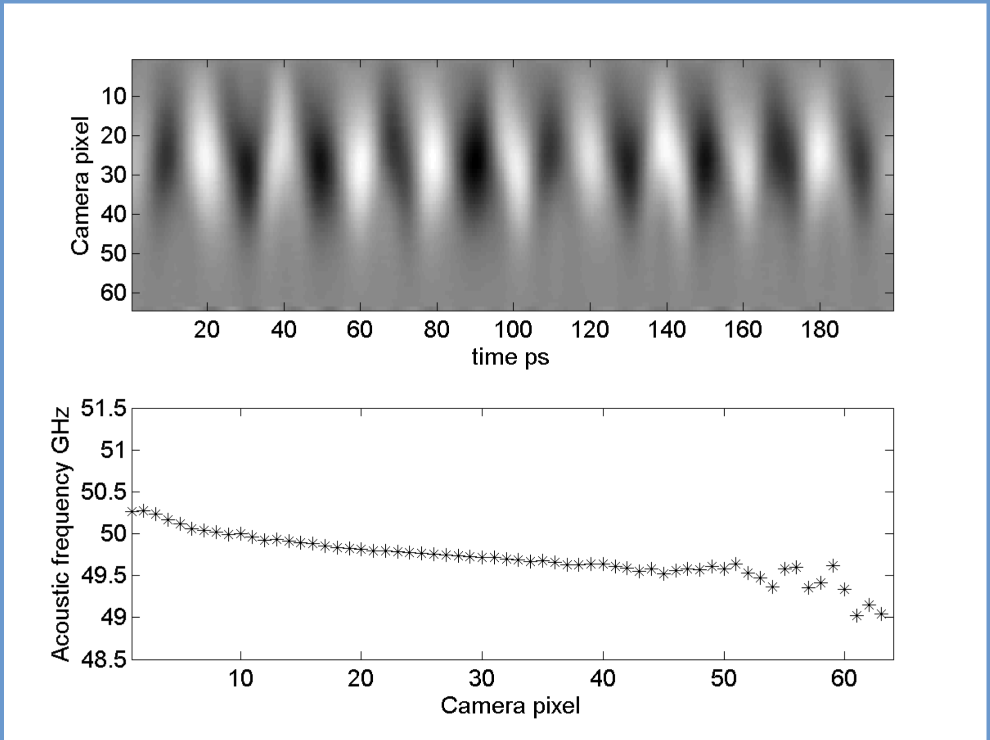
- 64x1 linear array detector
- Pixels built on active sensor principle with 4 large independently switchable capacitors to increase well depth
- 4 phase mode of operation : reset, integration, idle and readout
- Global shutter removes the phase shift between pixels caused by the rolling shutter in commercial detector
- Pixels are randomly addressable
- Faster readout (frame rate of 160KHz /10MHz pixel rate)

Custom detector result

- 200 averages taken on GaAs111

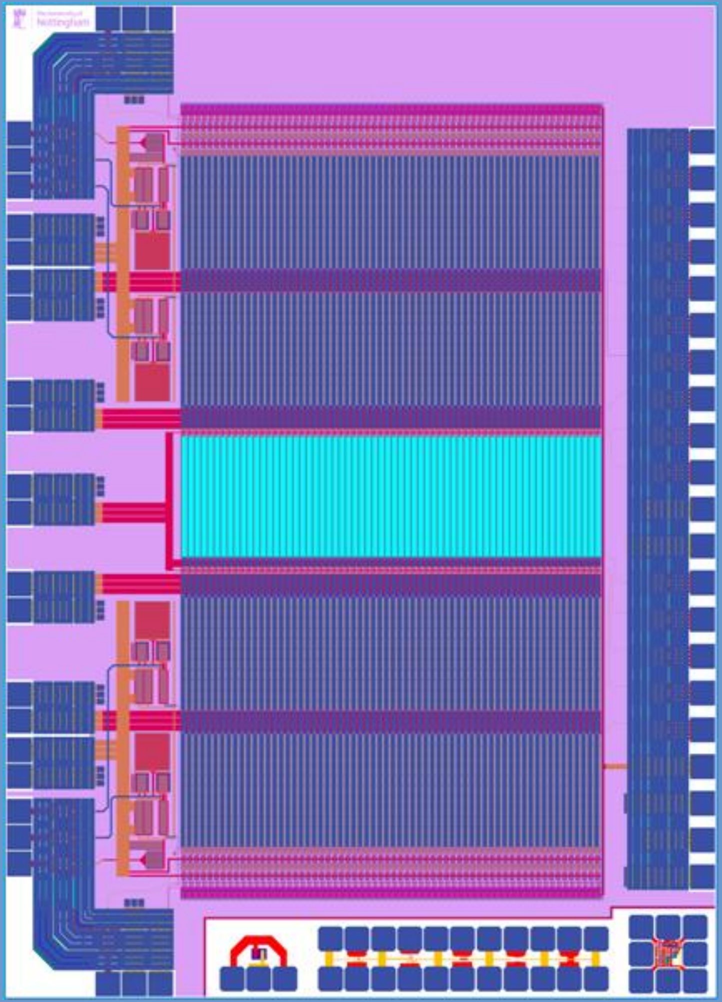


- Centre wavelength is 800nm (approximately pixel 26)



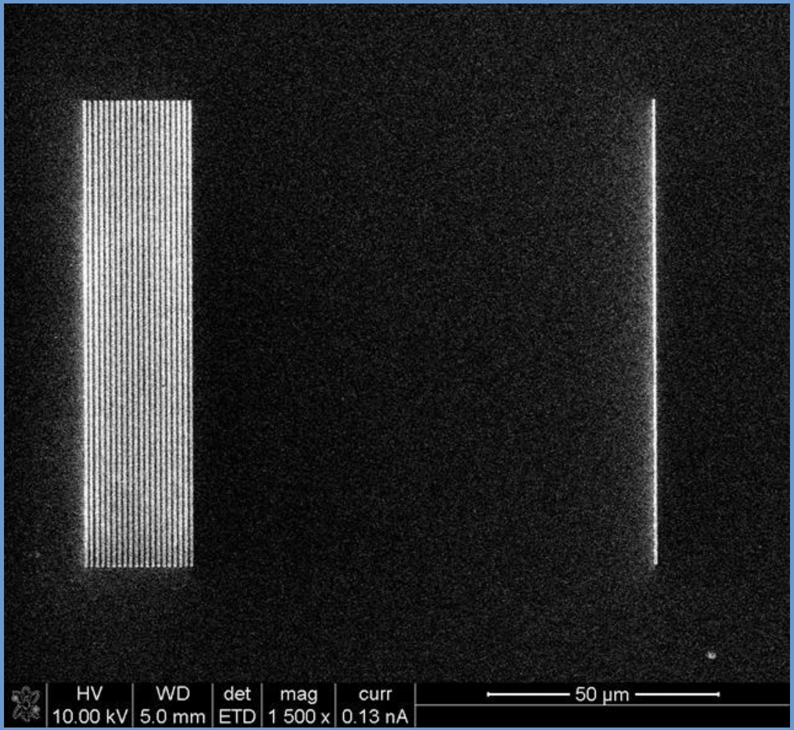
Custom detector continued

- The number of pixels easily be increased in future revisions of the detector.
- Even expanding to 512 to match Hamamatsu the chip size will still be considerably smaller due to the design employed.
- Noise levels look promising from the data taken so far but needs to be investigated further.
- Taking data with the custom array is currently only 2x faster than the Hamamatsu detector.
- This is due to a lack of multiplexer on the detector outputs. Which will be included in the 2nd revision of the driver board.
- Currently the ADC card is the limiting factor in the data acquisition speed



Future work

- Perform more experiments with custom detector. Investigated its noise performance, limitations and consider improvements for future designs.
- Generation and detection of high frequency surface waves (100s MHz- low GHz) using spatial light modulator
- Generation and detection of very high frequency surface waves with acoustic wavelengths below the optical wavelength (1GHz to 10GHz) using surface structures



Conclusions

- Measure very small modulation depths (10^{-6}) across multiple channels (512) with commercial detector
- Performance approaching single photodiode & lock-in can be obtained
- Custom array achieves better performance in terms of both data acquisition speed and number of photons captured compared to commercial detector
- Parallel approach reduces experiment time by order of magnitude or more.
- Parallel approach will become increasingly useful when looking at surface waves.

- Any Questions?