Acoustics '08 : June 29th – July 4th Paris

Parallel detection for picosecond ultrasonics

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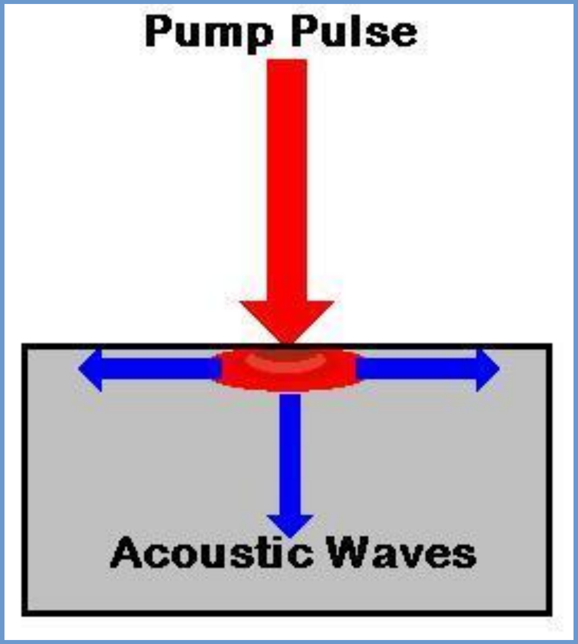
Talk Outline

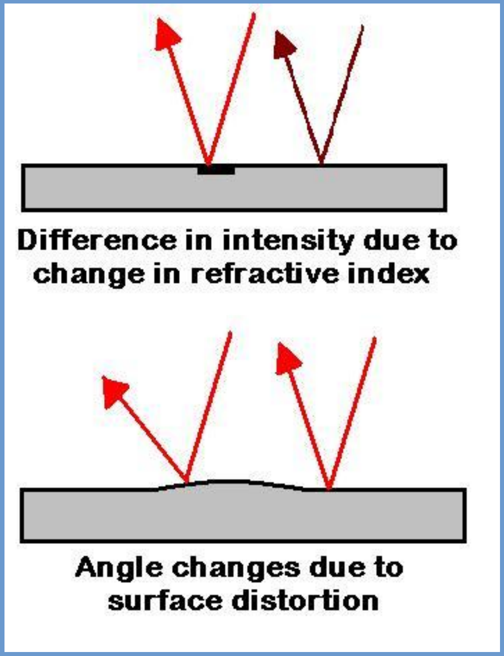
- Introduction
- Typical experiment setup
- Moving to parallel detection
- Commercial detector
- Custom detector
- Future work
- Conclusions

Introduction – Laser generation and detection of ultrasound

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

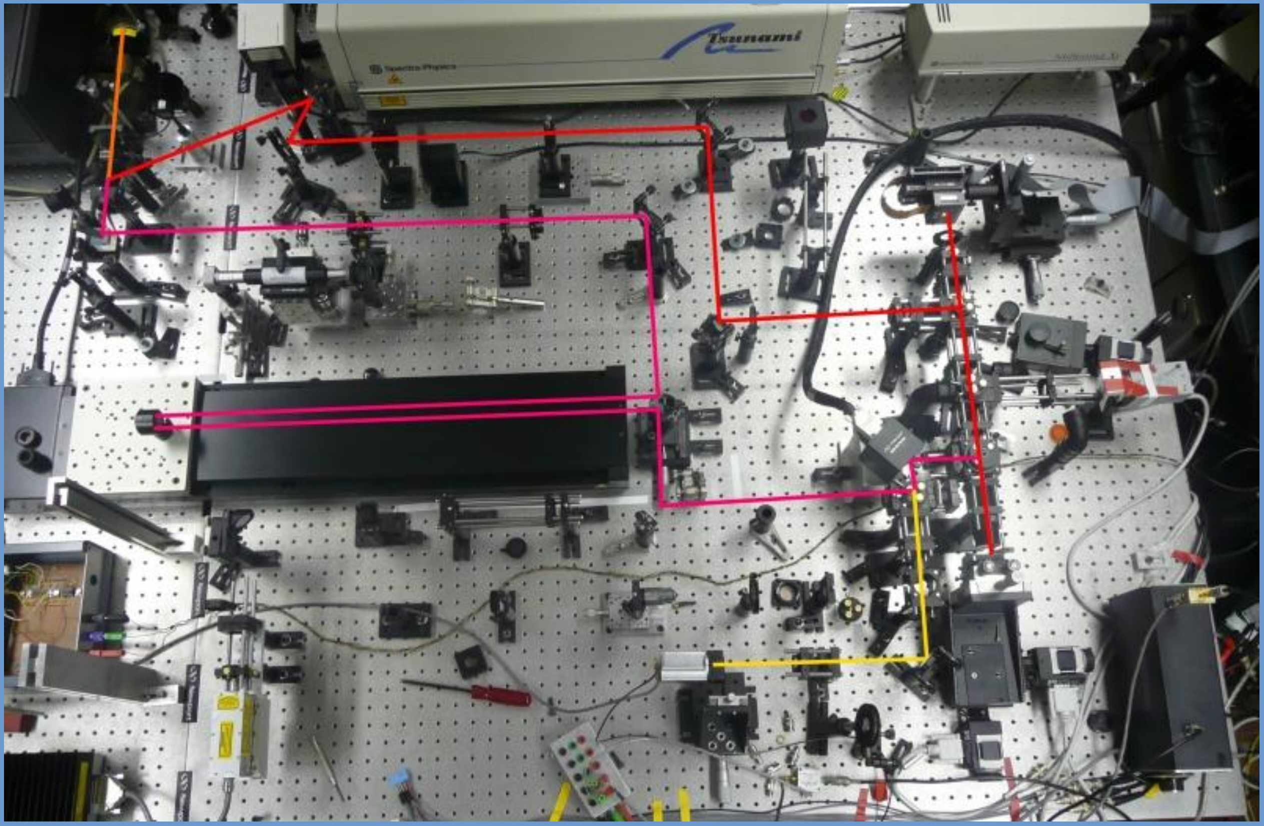


- Different mechanisms for detection
- Reflectivity
- Surface changes
- Very large background with small signal of interest



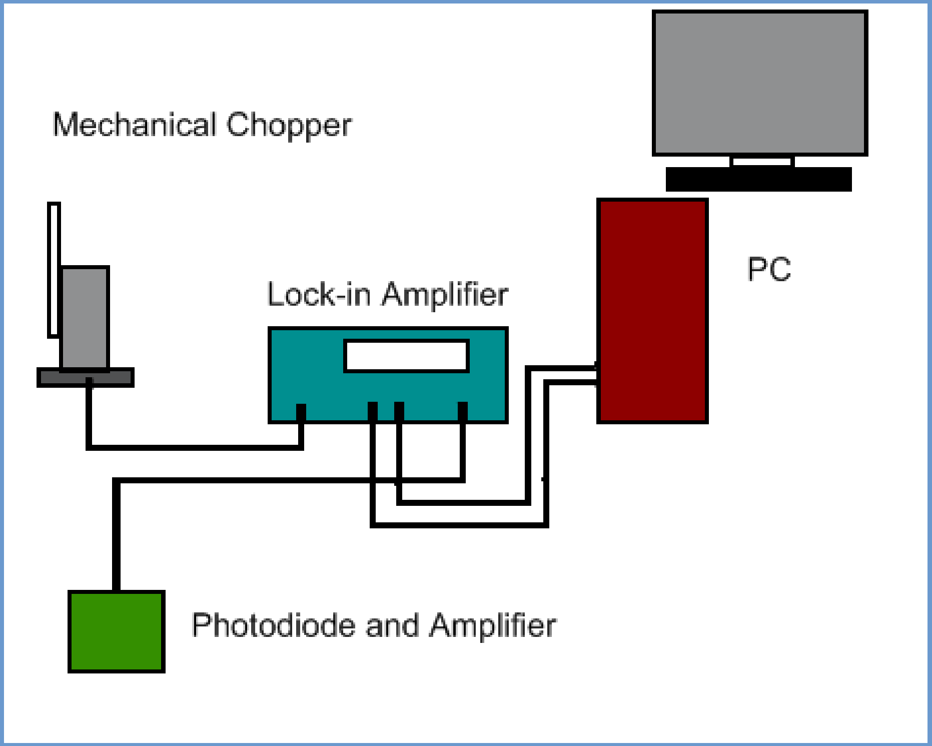
Experiment Setup

- Typical pump/probe setup
- Time delay between pump and probe imposed by mechanical scan of delay line mirror
- Pump beam modulated by mechanical chopper
- Pump and probe beams separated by polarisation optics



Single Channel Detection

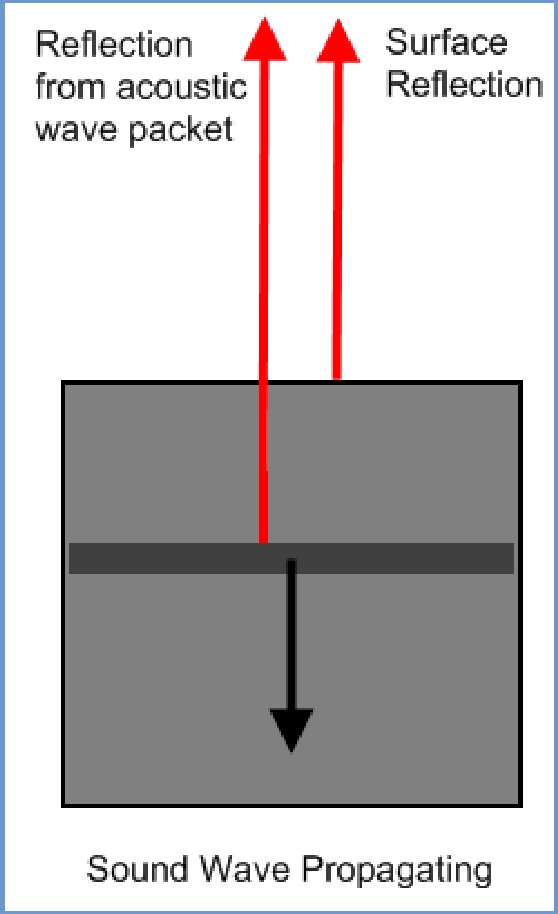
- Single photodiode detector
- Lock-in amplifier with reference from pump arm chopper
- Sample GaAs as gives large signal
- Sample forms an interferometer



Brillouin Oscillations

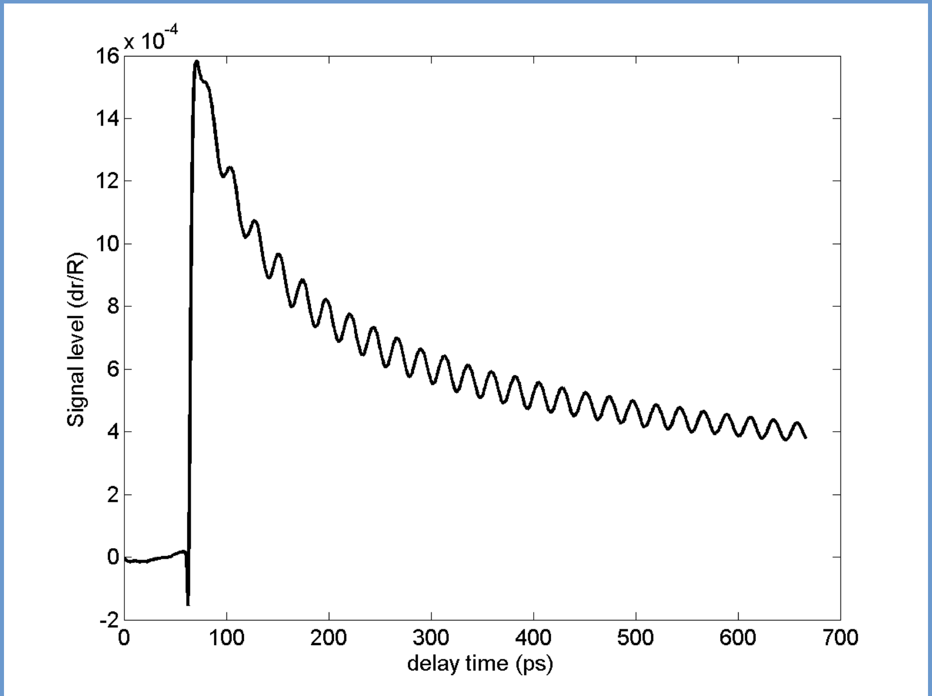
- GaAs semi transparent at 800nm
- Reflection from surface
- Reflection from travelling acoustic wave
- Interfere to produce oscillatory signal

$$F_b = \frac{2v_a n}{\lambda}$$



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 are required for reconstruction of amplitude and phase
- However, we have square wave modulation and this can introduce errors due to the presence of harmonics

α= angle

$\Delta\alpha$ = change in α between steps

S1 = real part of signal

S2 = imaginary part of signal

N = number of steps

m=current step

I = measured intensity

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

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

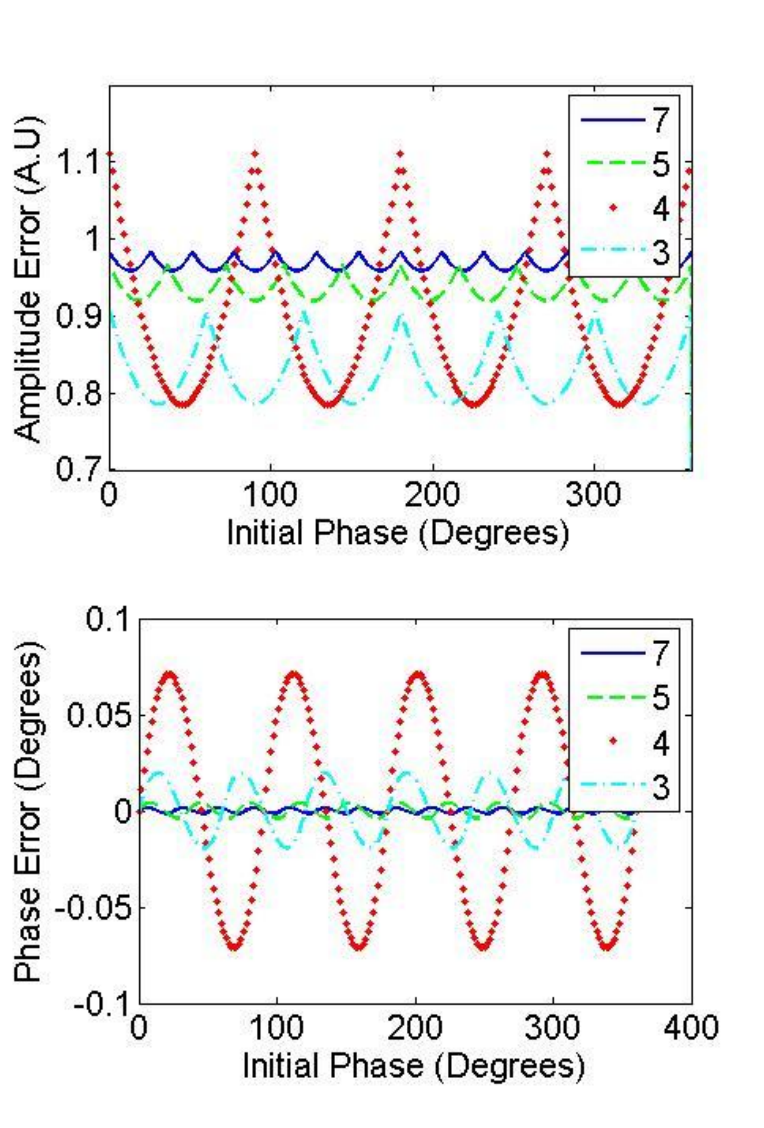
$$S_2 = \sum_{m=0}^{N-1} I_m \sin\alpha_m$$

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

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

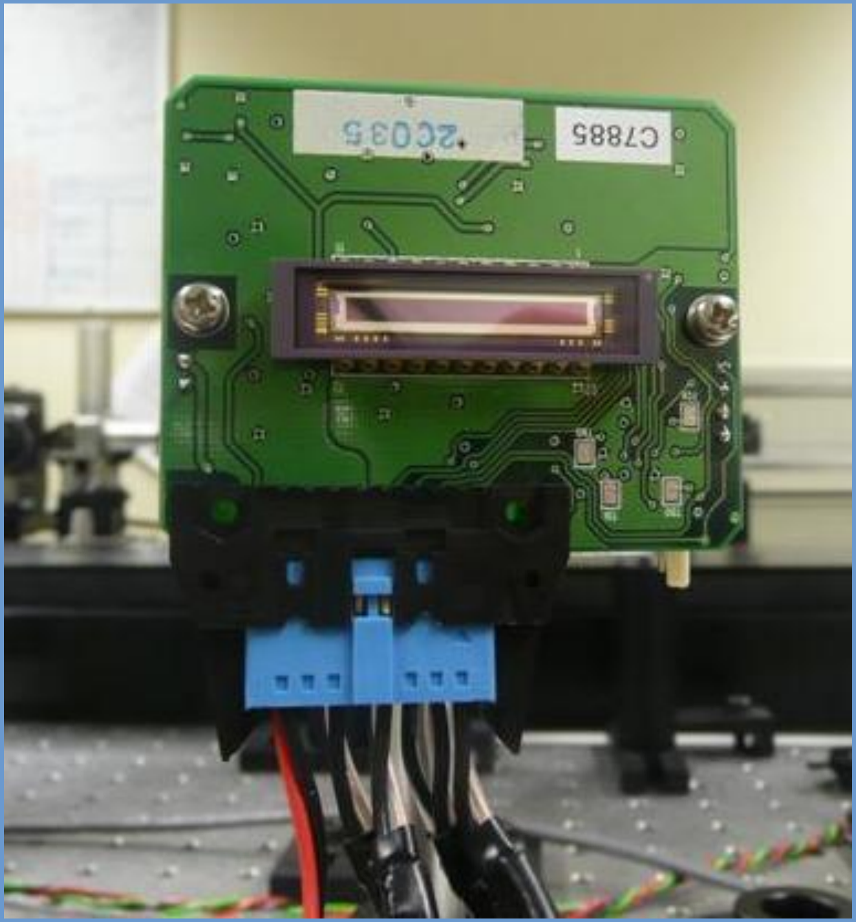
Impact of harmonics on phase stepping

- Harmonics cause amplitude-phase cross talk
- This is a serious problem if the phase of the signal is changing
- For a low number of steps this has a huge effect
- A typical 4 step algorithm has >30% variation in amplitude with changes in initial phase of signal
- Error decreases with number of steps and algorithms with an odd number of steps are better
- Choose a number of steps where the errors are acceptable for the application



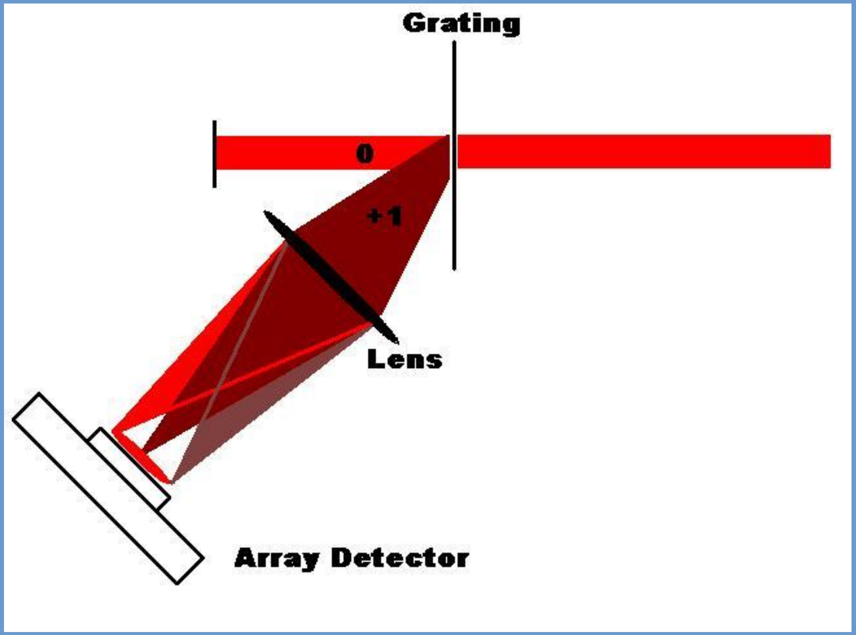
Linear Array detector

- Hamamatsu 512 pixels
- Pixels read rate 500KHz
- Rolling shutter – therefore the phase for each pixel is different
- Pixels size 50μm x 2500μm
- Can capture $3.25\text{x}10^{8}$ photons before saturating
- Custom timing board to generate clocks and chopper sync signal
- Sample and hold circuit required to reduce requirements on ADC



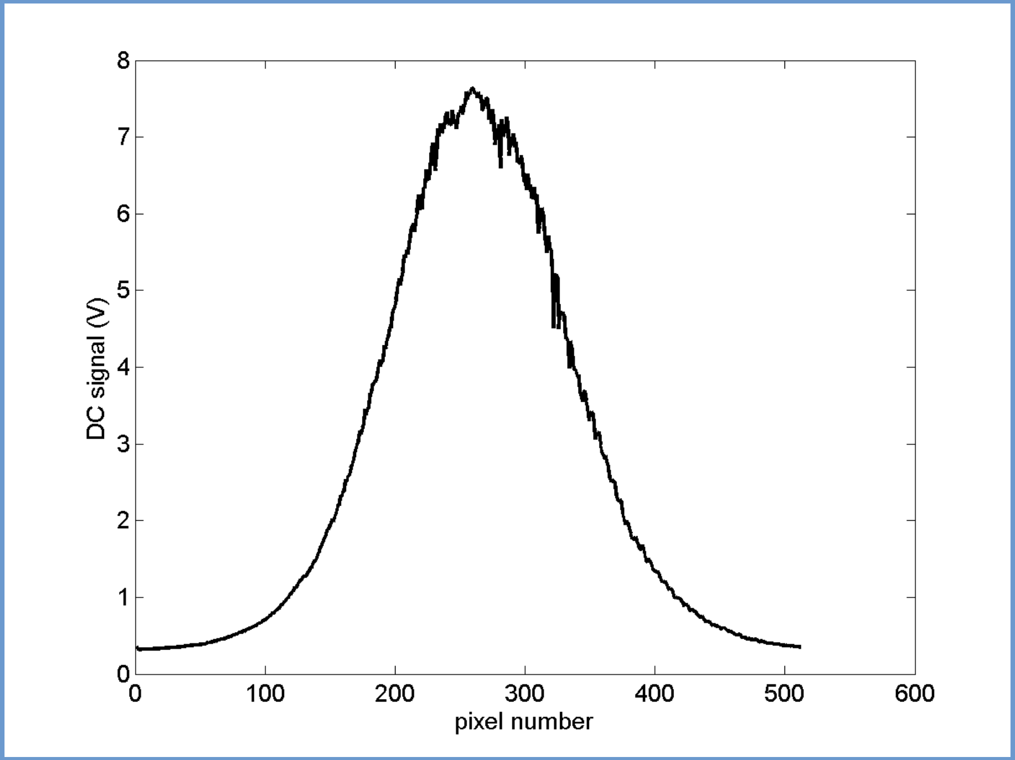
Array Experiment

- Same experiment as for single channel except using multiple wavelengths
- Laser has spread of wavelengths due to very short pulses
- Wavelengths are spread across the array by using a diffraction grating
- Frequency detected will vary with wavelength measured on each pixel



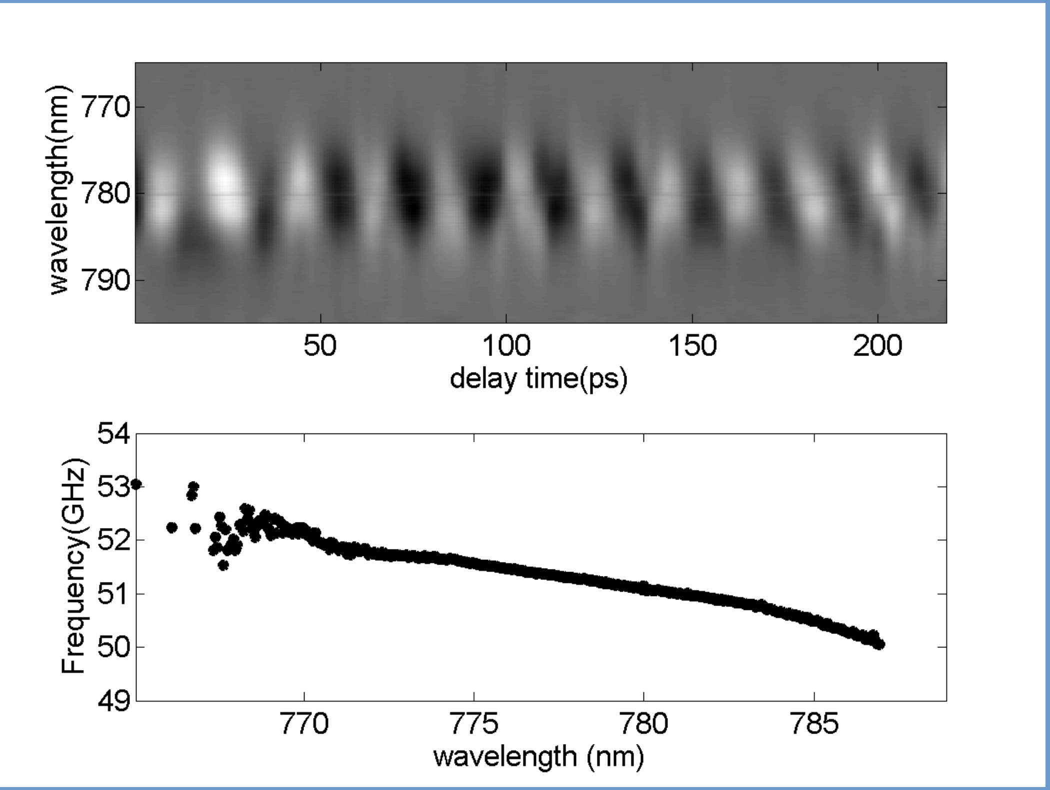
Commercial Array Experiment

- Each pixel corresponds to a different probe wavelength
- 400 averages used in this case
- Experiment time approx. 22mins
- SNR very good comparable to photodiode lock-in case
- DC light distribution verses wavelength
- As move away from centre SNR will get worse due to there being less light on the pixels
- Approximately 220 pixels of usable signal



Commercial Array Experiment

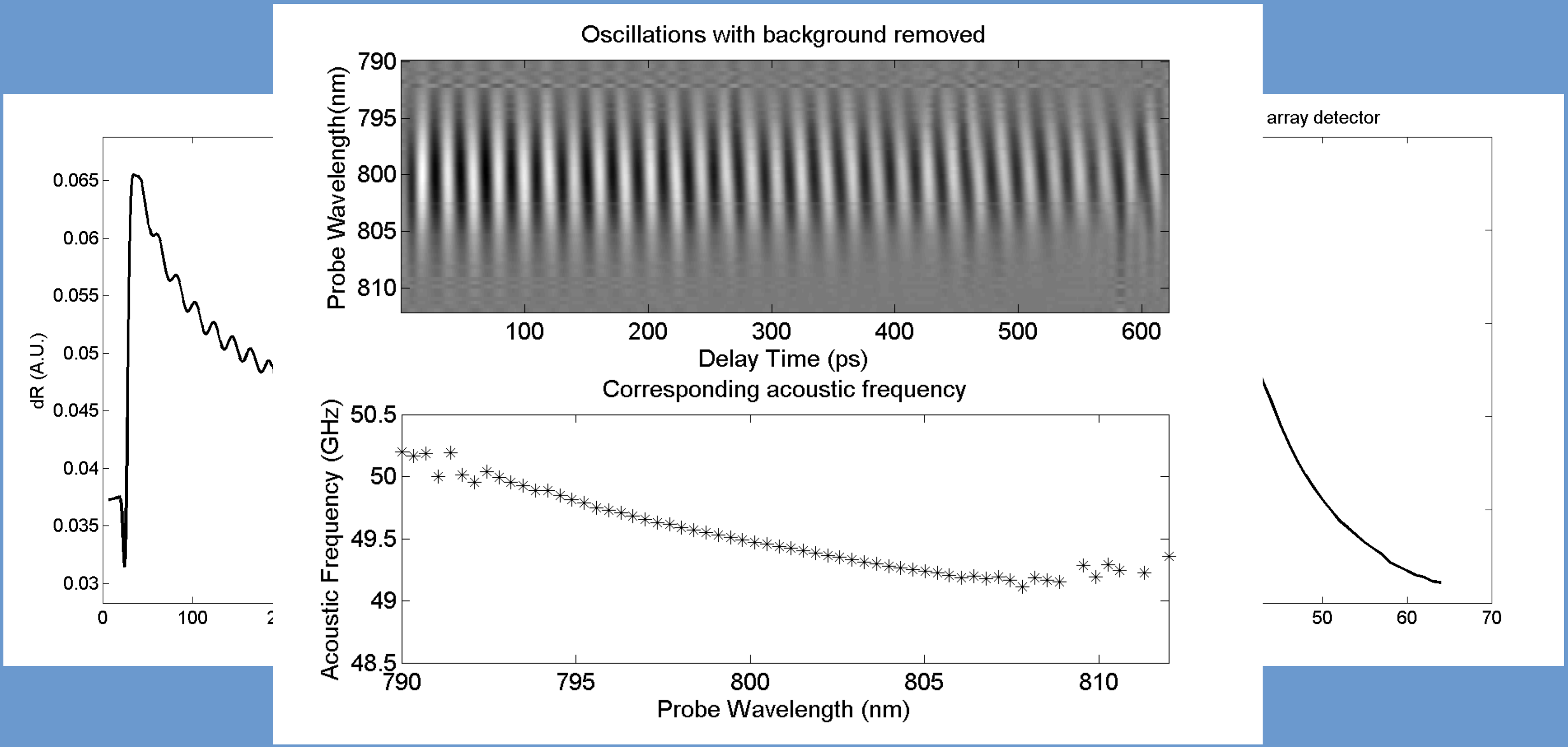
- Frequency changes verses wavelength as expected
- End regions noisier than central region
- Graph slopes off as amplitude reduces due to influence of signal processing and nearby noise spikes
- For comparable SNR to photodiode lock-in case need approx 400 averages (taking 22 mins)
- Array uses much less light than the photodiode case
- 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)

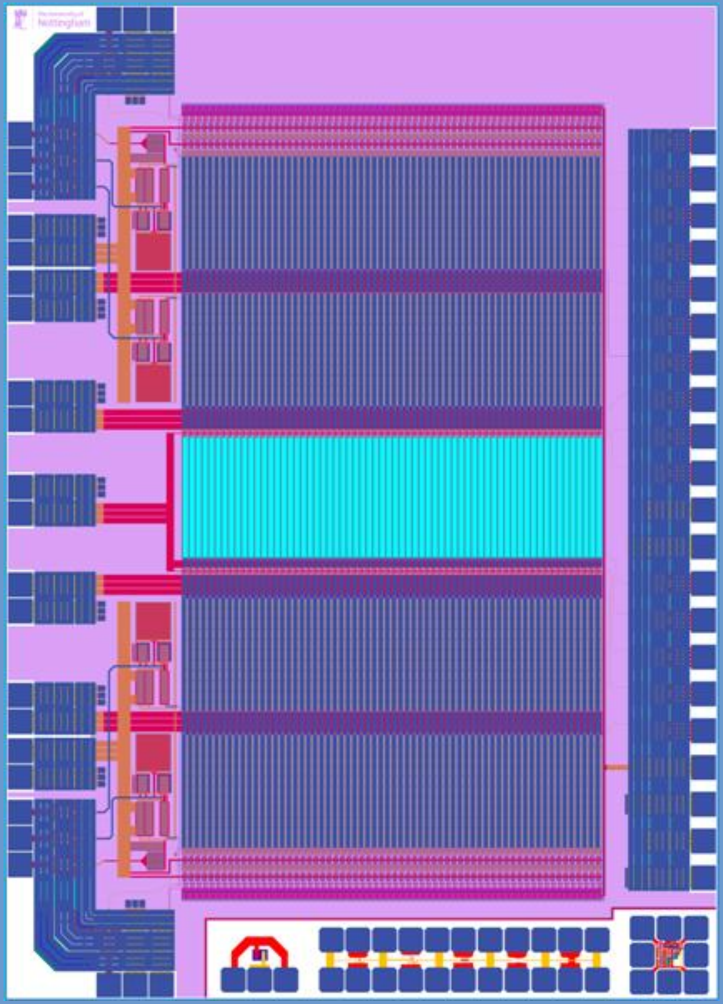
Custom detector result



- 50 Averages
- Sample GaAs 111 substrate
- Centre wavelength is 801nm (approximately pixel 30)
- Experiment time ~7minutes

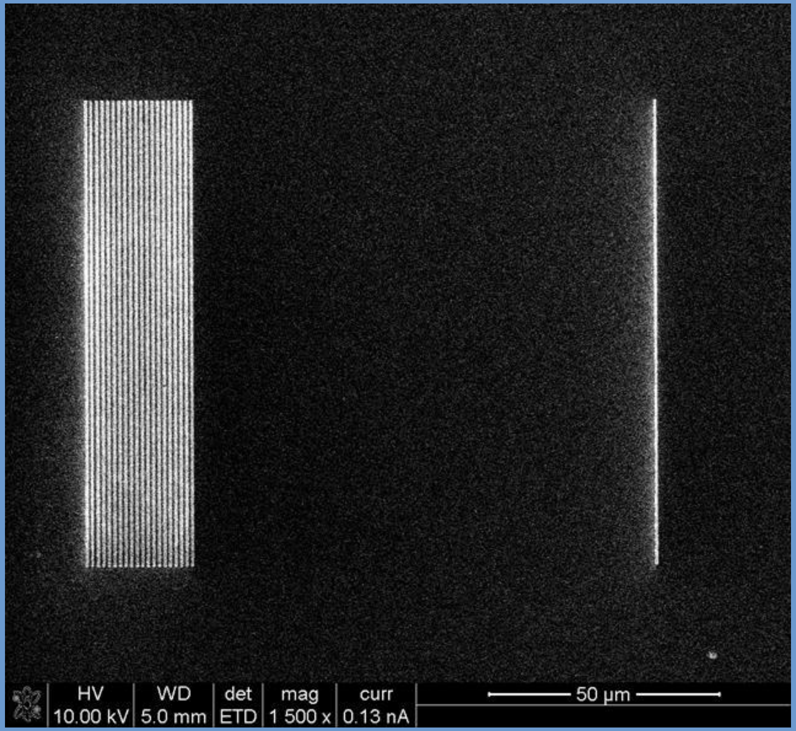
Custom detector continued

- The number of pixels can easily be increased in future revisions of the detector.
- Expanding to 512 pixels to match the Hamamatsu detector the overall 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 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



Time Comparison

	Measurements required for comparable SNR	Total Time	WRT to commercial device
Single photodiode \ lock-in amplifier	1 channel 6 averages 2000 data points	24 seconds	210 minutes
Commercial Array	512 channels 400 data points 400 Averages	22 minutes	22 minutes
Custom Array	64 channels 2000 data points 50 Averages	7 minutes	11 minutes

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?

Acknowledgements:

We wish to thank the EPSRC for funding this work