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Full-field imaging and microscopy with modulated light cameras

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Overview of talk

- Modulated light cameras
- Possible architectures and design considerations
- Compact, low power circuits
- Early prototypes
- Preliminary results
- Conclusions, work in progress and future work

Detection of modulated light

- Intensity modulation and synchronous (lock-in) detection can be a powerful combination
- SNR is improved by the narrow detection bandwidth
- Can provide immunity to large levels of background radiation
- Applications include many pump/probe techniques, heterodyne interferometry, radiology, range finding, optical coherence tomography and machine vision

Modulated light cameras

- Several examples exist in the literature
  - Ohta J, Yamamoto K, Hirai T et al. IEEE T ELECTRON DEV 50 (1): p166 (2003)
  - Ando S, Kimachi, IEEE T ELECTRON DEV 50 (10): p2059 (2003)
  - Mitic J, Anhut T, Meier M, et al. OPT LETT 28 (9): p698 (2003)
- Most use integrating CCD or CMOS ‘active pixel sensors’, or are not phase sensitive (ac envelope detectors)
- For our work at Nottingham, we required phase sensitivity and the ability to work with a large dc background

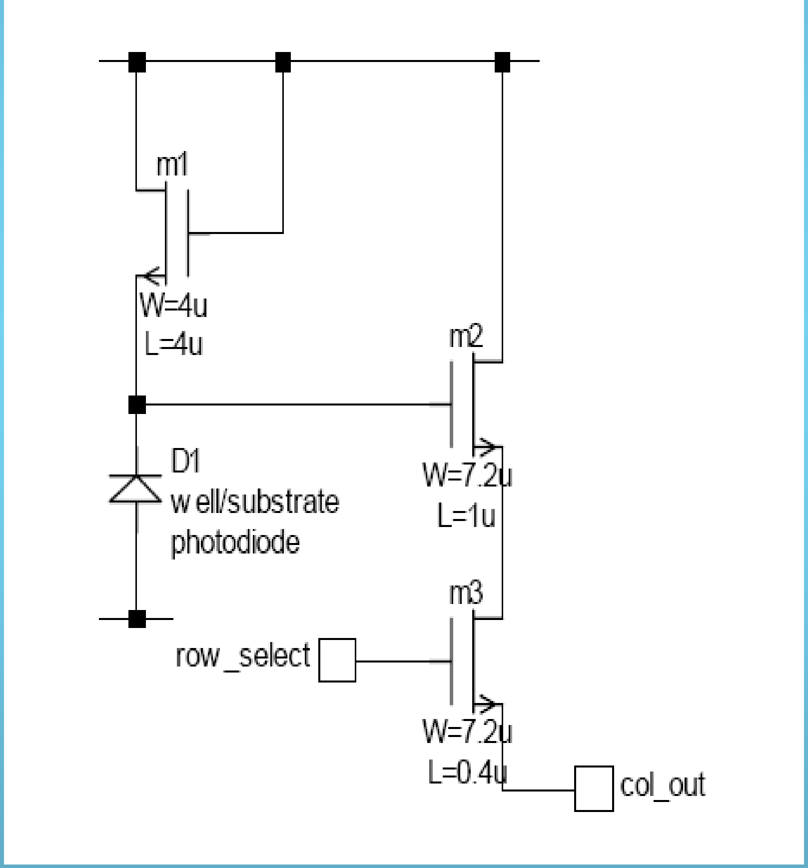
Design considerations

- Typical phase sensitive point measurement system uses
  - High quality photodiode
  - Commercial lock-in amplifier
  - Several kg, several hundred watts
  - Single channel
- Modulated light camera in standard CMOS process
  - Parasitic photodiodes
  - 10 mm^2 of silicon
  - 500 mW
  - Many channels
- Clearly, some compromises are necessary

Possible architectures

- Pixel parallel
  - Each camera pixel has a lock-in amplifier
  - Difficult to control size and power
- Column parallel
  - Each column of pixels share demodulation circuitry
  - Images are acquired row by row
- Chip parallel
  - Only one channel of demodulation circuitry
  - Very inefficient, but no moving parts

Basic photodiode circuit – log pixel



- Unlike the active pixel sensor, this circuit has a continuous output
- High transimpedance, but relatively large time constant limits speed
- Circuit frequency response is light dependent
- Logarithmic response at low light levels

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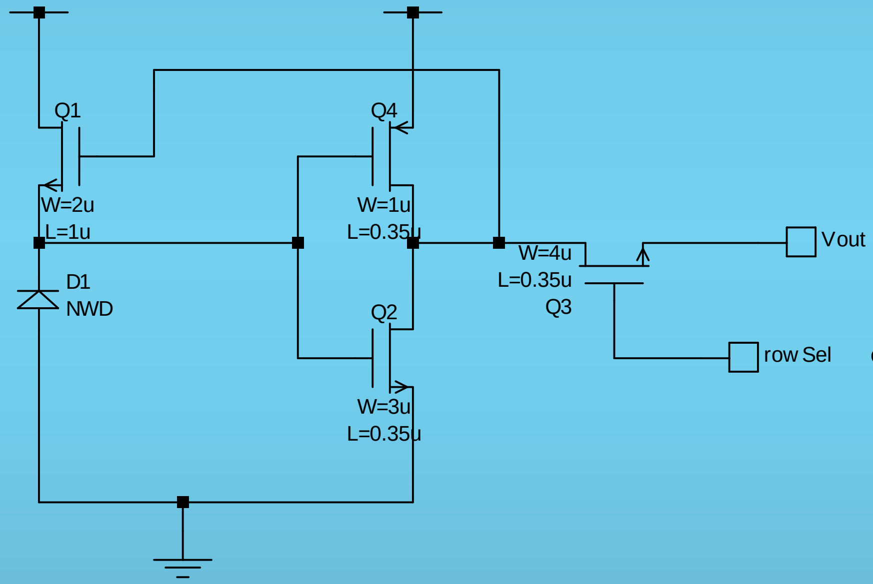
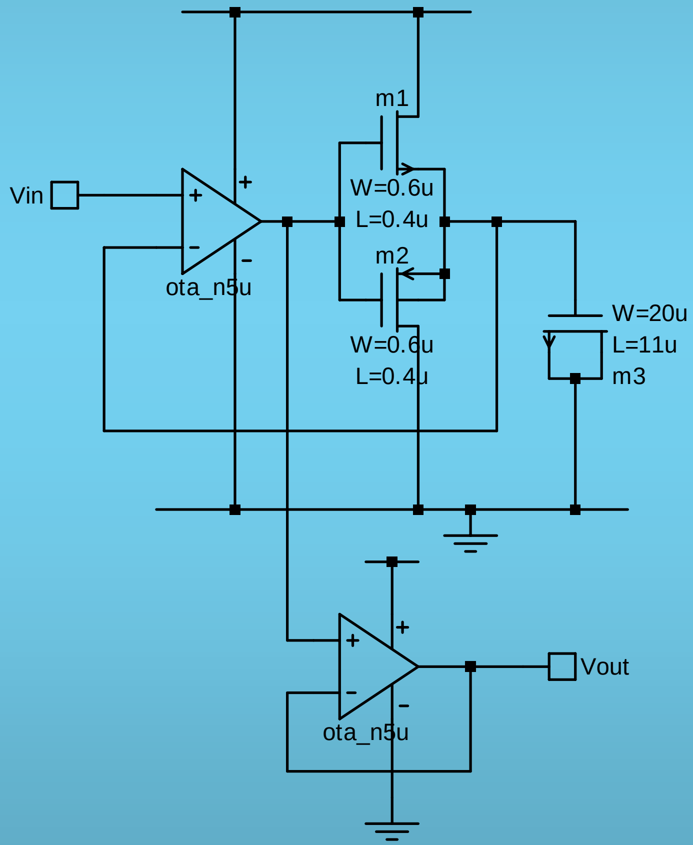
Feedback buffered photodiode circuit



- This circuit uses feedback buffering to suppress the effect of the photodiode capacitance
- Frequency response is still light dependent, but many times faster than simple circuit

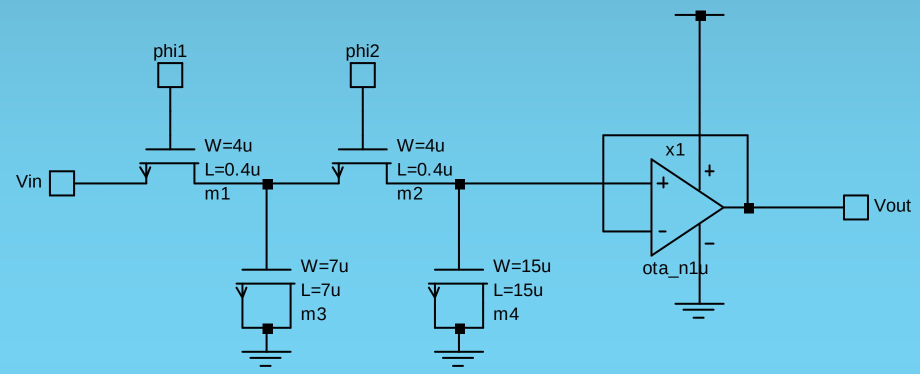
Compact, low power bandpass amplifier

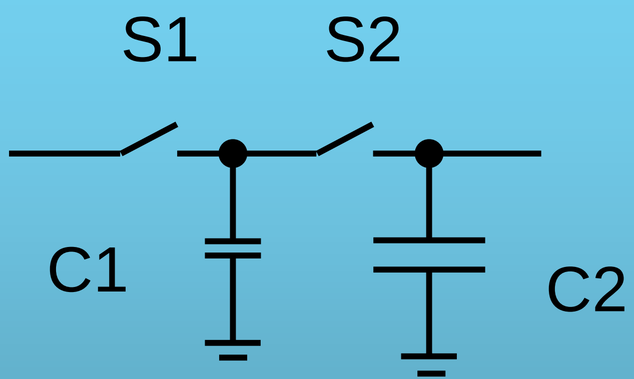


- Designed by C. Mead
- Hysteretic differentiator (HD)
- A gain stage with low pass feedback
- For dc, the gain is unity
- For signal frequencies, the amplifier is effectively open loop
- Robust, low power amplifier

Compact correlator circuit

- Switched capacitor circuit using just 4 transistors
- S1 and C1 perform track and hold
- S2 and C2 allow averaging of the sampled voltage
- C1 << C2
- S1 and S2 are never closed simultaneously
- Compact, but inefficient





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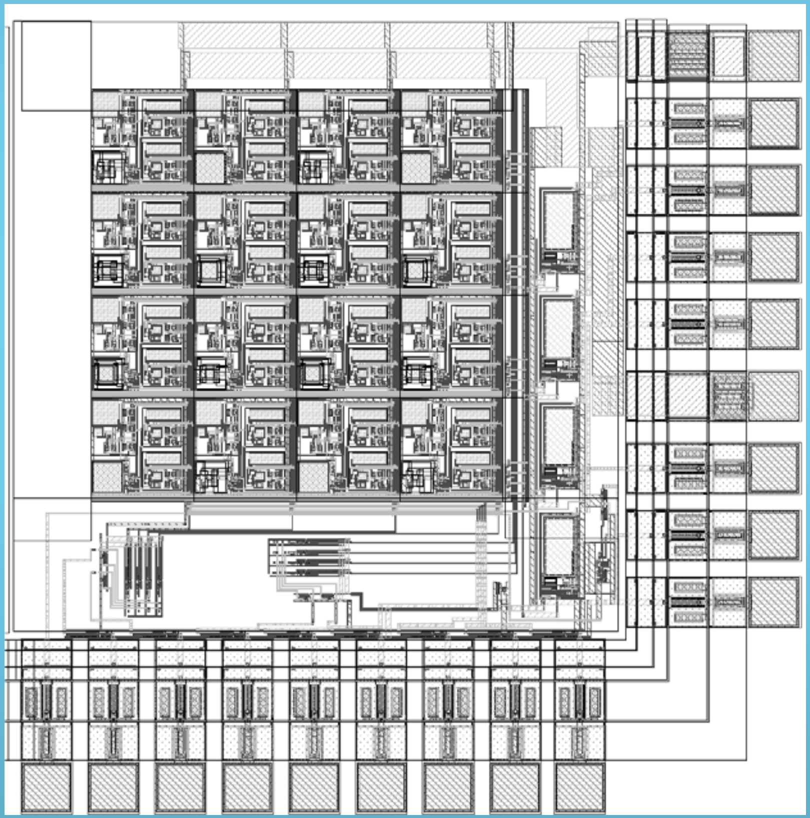
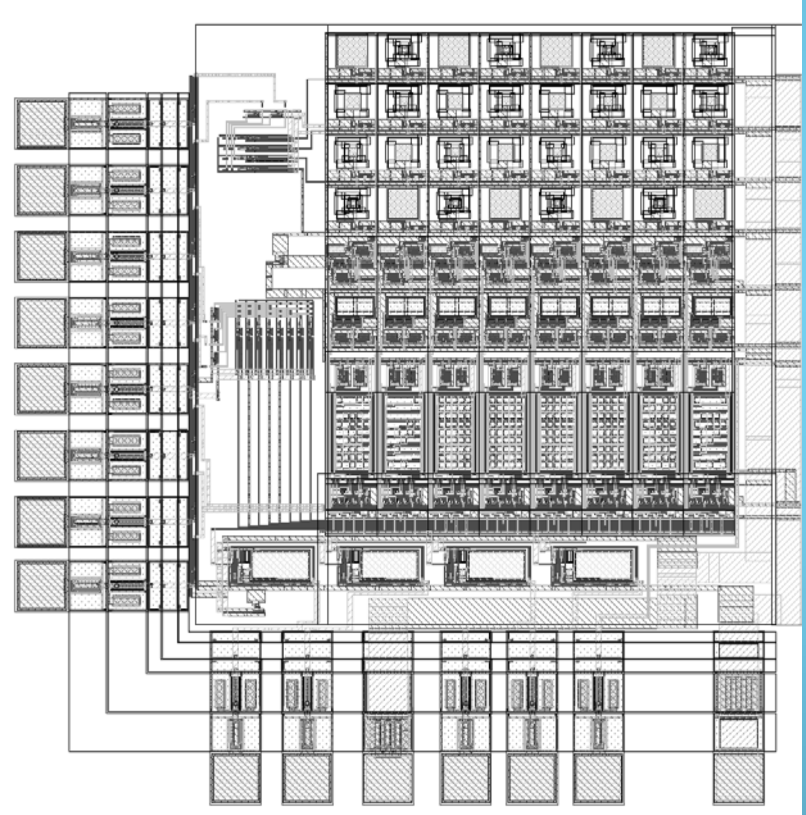
Pixel-parallel prototype

- 4 x 4 ‘camera’
- Fully parallel (pixel parallel)
- Each pixel contains photodiode and load, HD and switched capacitor correlator
- Pitter MC, Goh JYL, Somekh MG, et al. ELECTRON LETT 39: p1339 (2003)



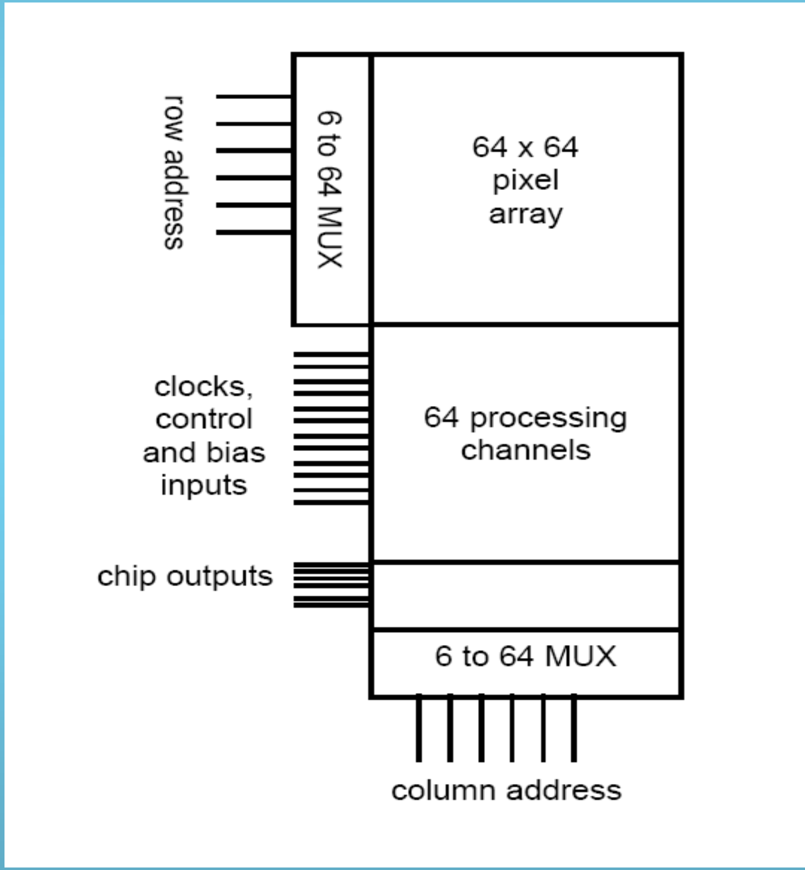
Column-parallel prototype



- 8 x 4 pixel array with 8 channels of demodulation circuitry
- Each demodulation circuit contains HPF, HD and switched capacitor mixer

64 x 64 column-parallel camera

- Randomly addressable 64 x 64 pixel array with dc ouput
- 64 channels of demodulation circuitry consisting of HPFs, HD amplifiers and switched capacitor correlators
- Each channel has 2 correlators allowing simulataneous measurement of ac amplitude and phase (IQ demodulation)



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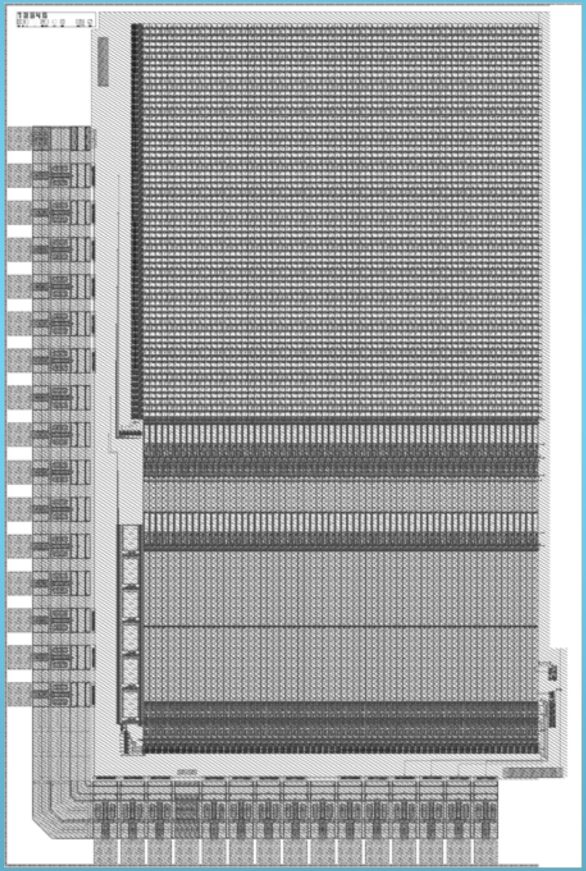
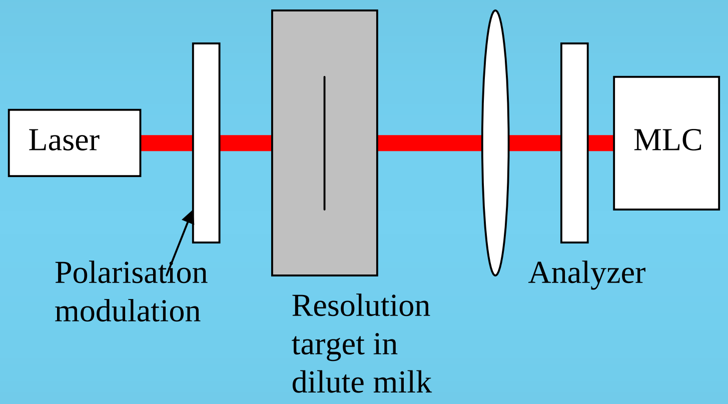
64 x 64 column-parallel camera



- Designed for low contrast modulated signals (< 5% modulation depth)
- Modulation frequencies from around 200 Hz up to 200 kHz
- Standard CMOS process, less than 10 mm^2
- Cost around £5k for 20 prototypes

Polarisation modulation imaging



- Ramachandran H, Narayanan A, OPT COMMUN 154: p255 (1998)
- The technique uses polarisation to partially separate unscattered and multiply scattered illumination
- Multiply scattered light carries no useful image information
- It will depolarise and not contribute to the modulated signal
- If using an integrating sensor (APS or CCD) this depolarised background will eventually saturate the sensor

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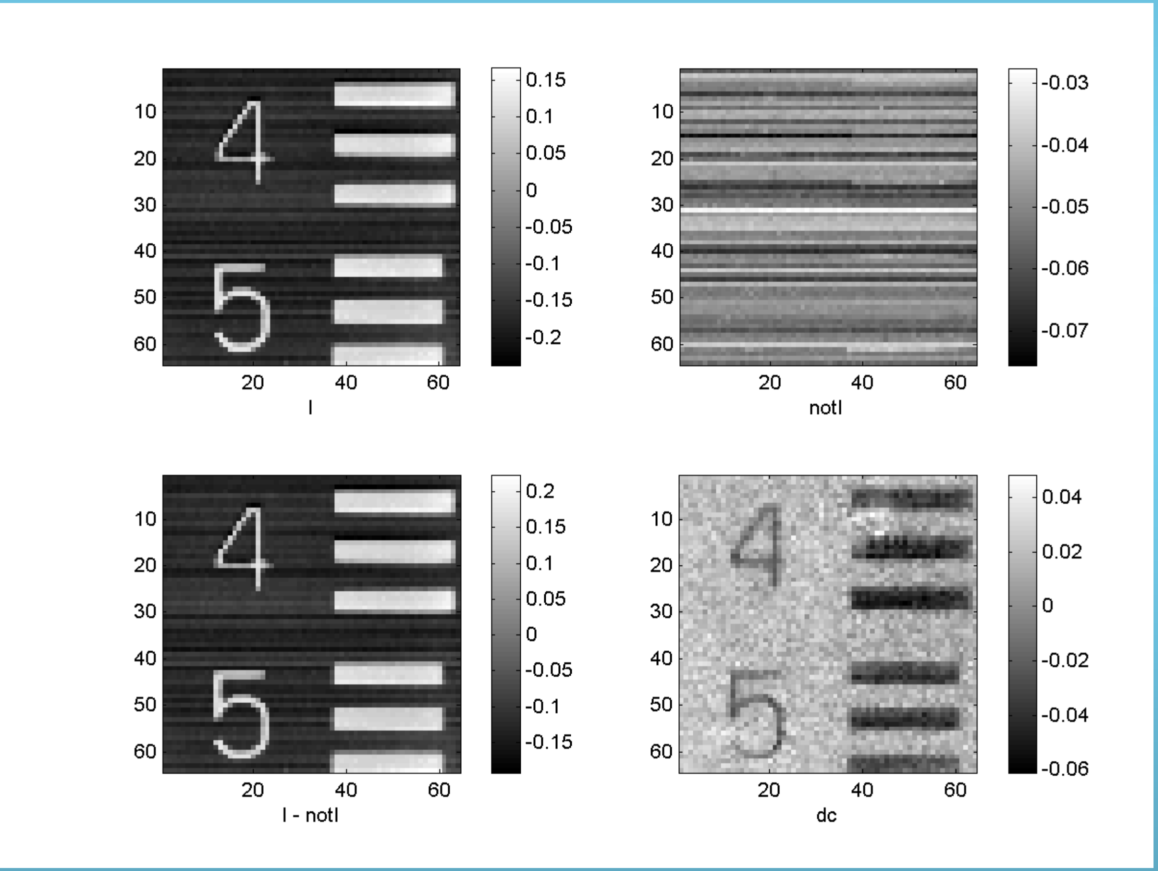
2% milk



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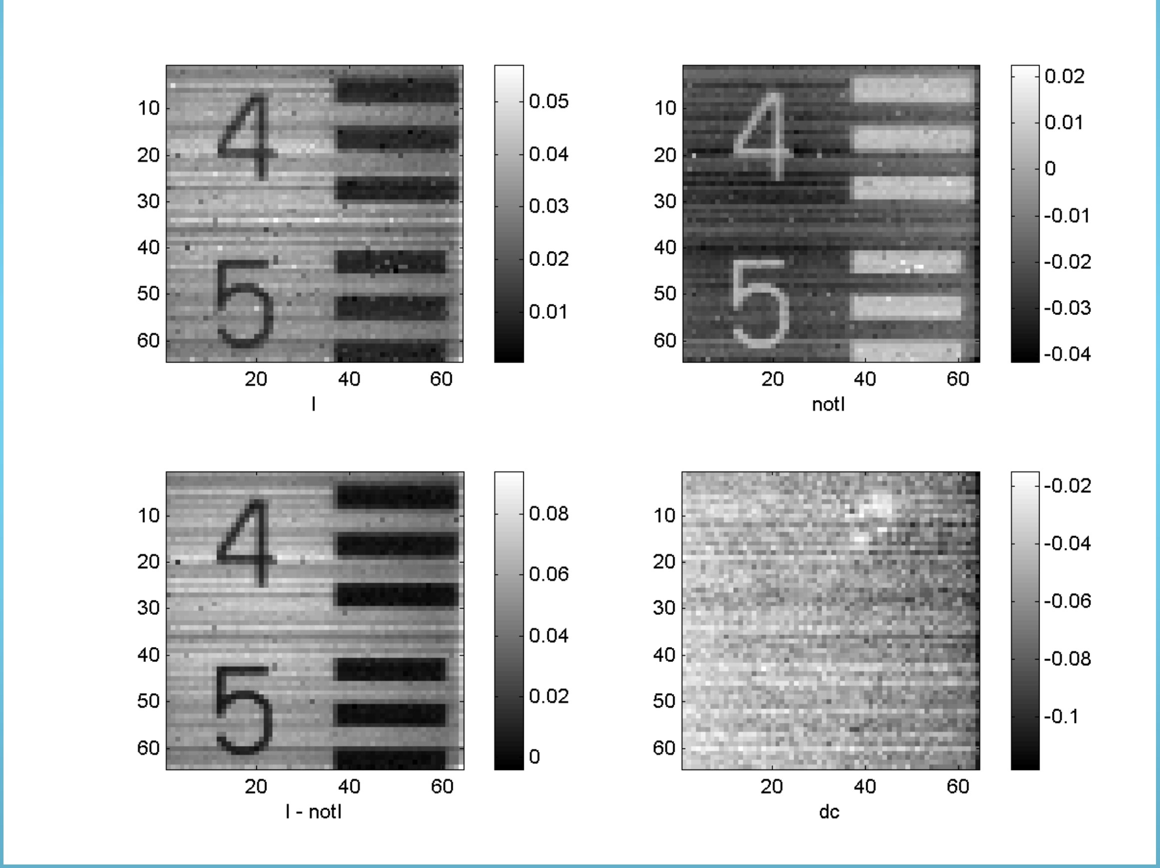
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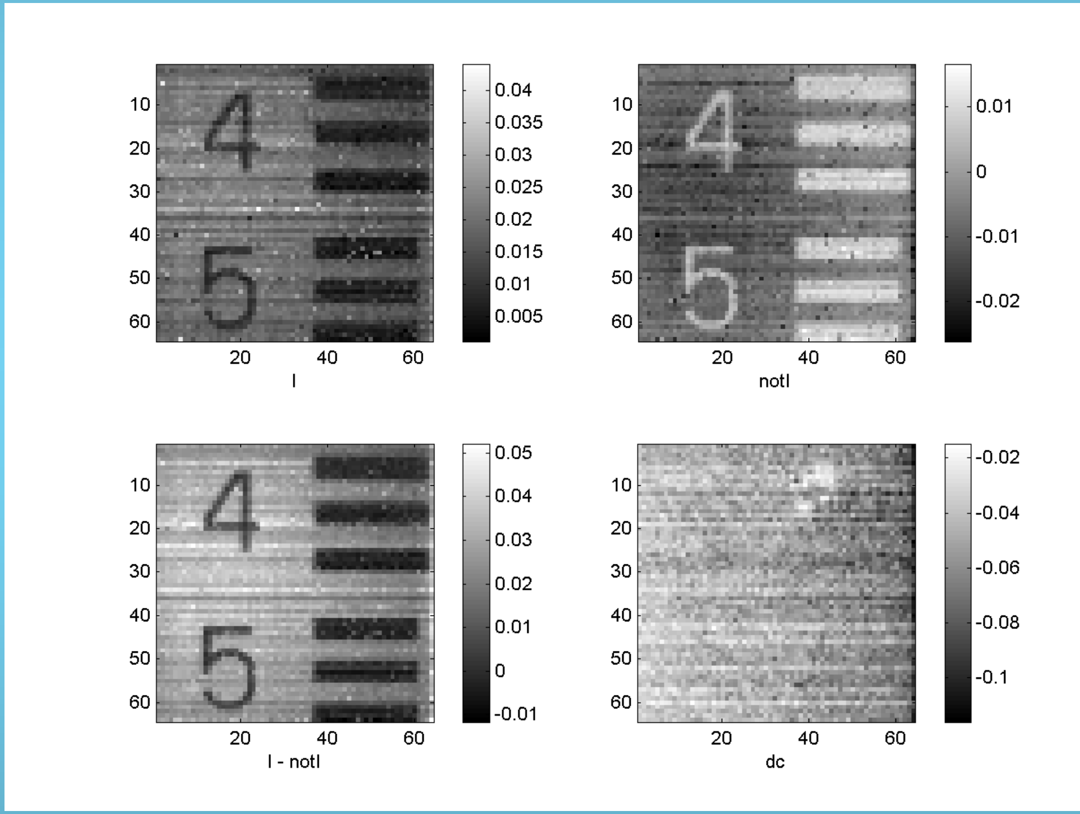

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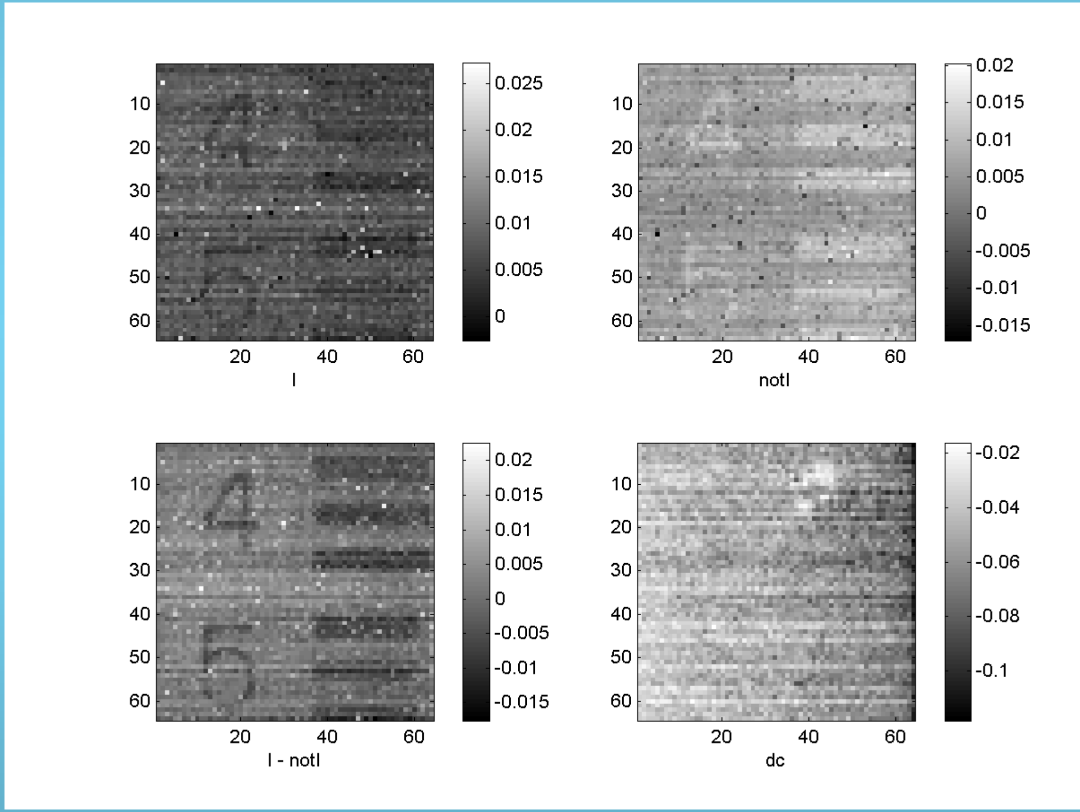

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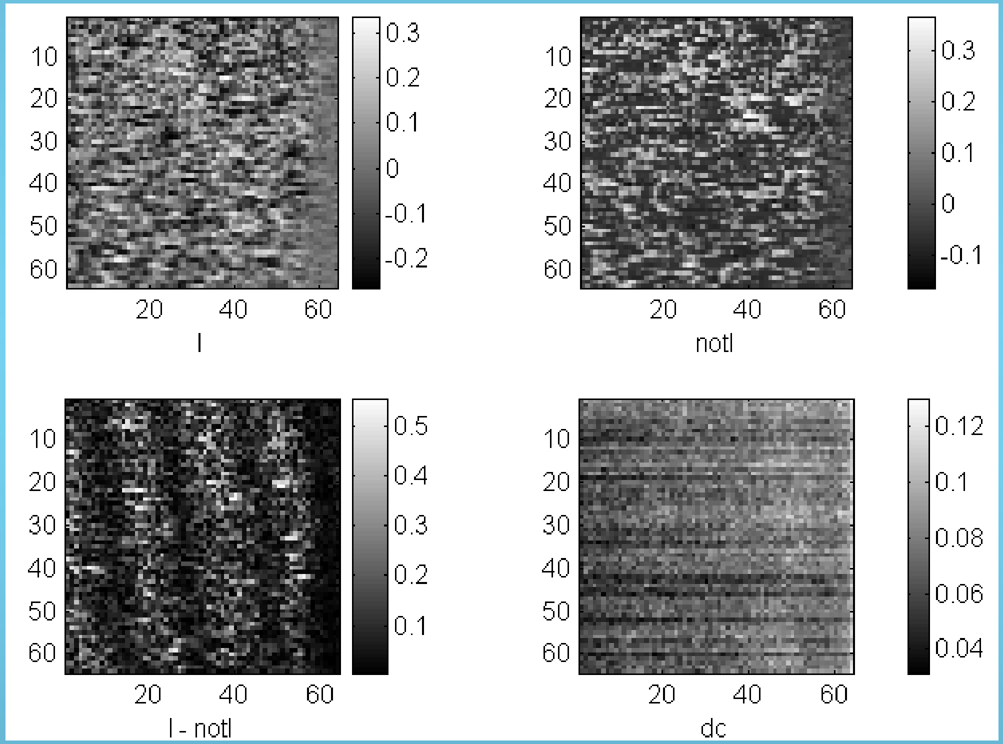
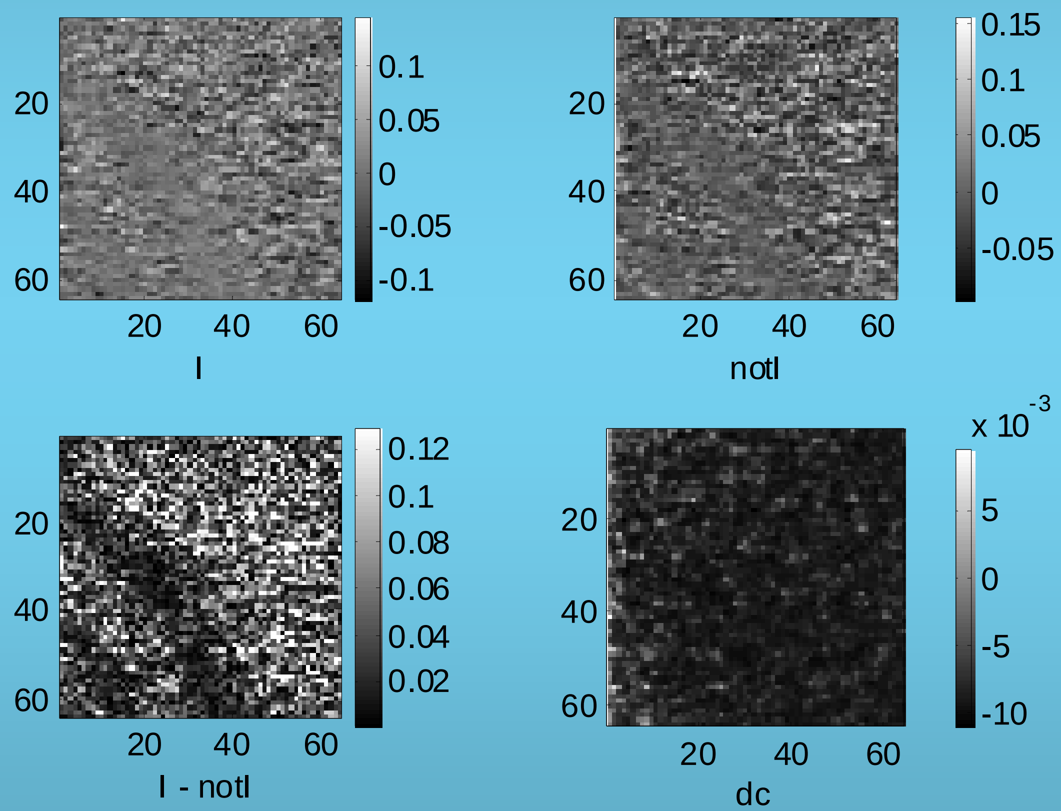
ESPI vibration analysis with MLC



- With a CCD, ESPI on vibrating objects is limited to time-averaged techniques
- These produce low contrast Bessel fringes
- Using MLC allows for subtraction and so produces $\sin^2$ fringes of higher contrast and greater order

ESPI vibration analysis with MLC



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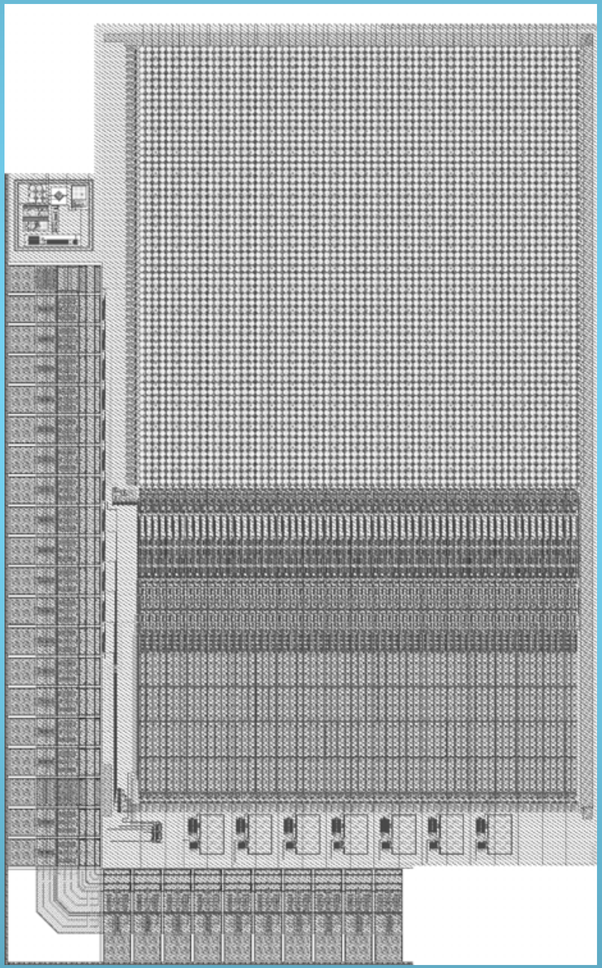
WIP and future work

- 64 x 64 pixels
- IQ demodulation
- Modulation frequencies from 20 kHz up to around 4 MHz
- "proper" mixers
- "proper" integrators
- Future work will concentrate on high frequency designs



Acknowledgements

- We thank the EPSRC for funding this work

ps: reference for heterodyne microscope mentioned in presentation abstract:

Pitter MC, See CW, Somekh MG, "Full-field heterodyne interference microscope with spatially incoherent illumination," OPT LETT 29 (11): p1200 (2004)