Adaptive acoustics: correcting for aberration in materials with microstructure

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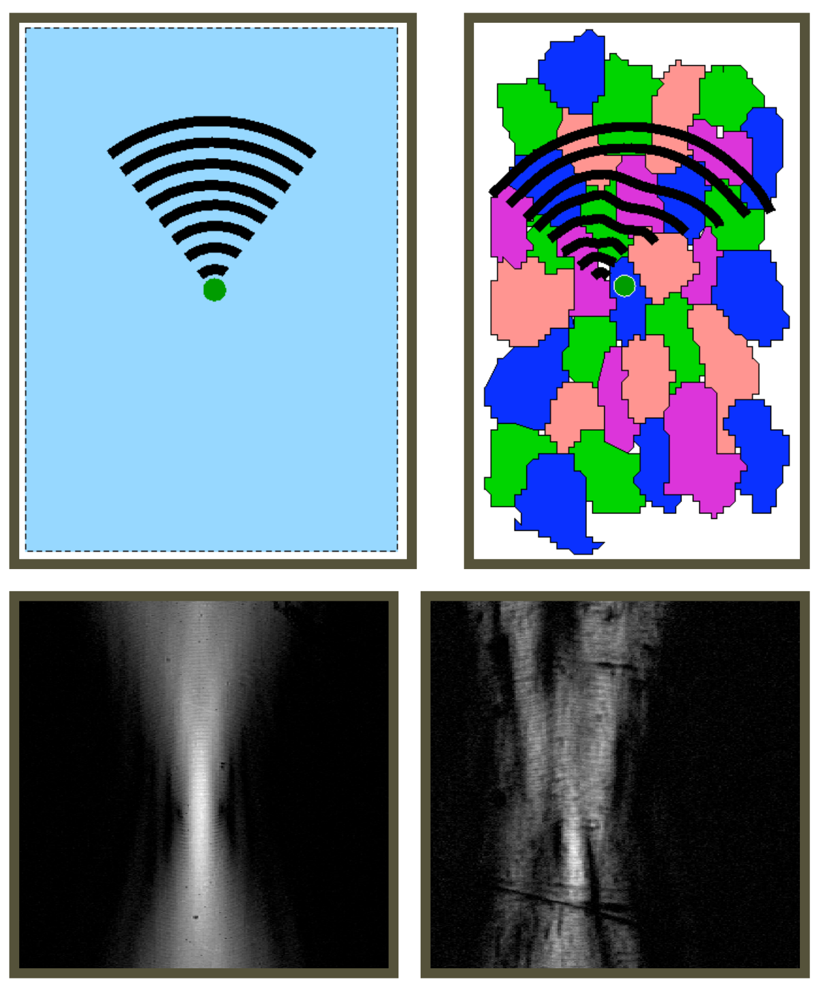
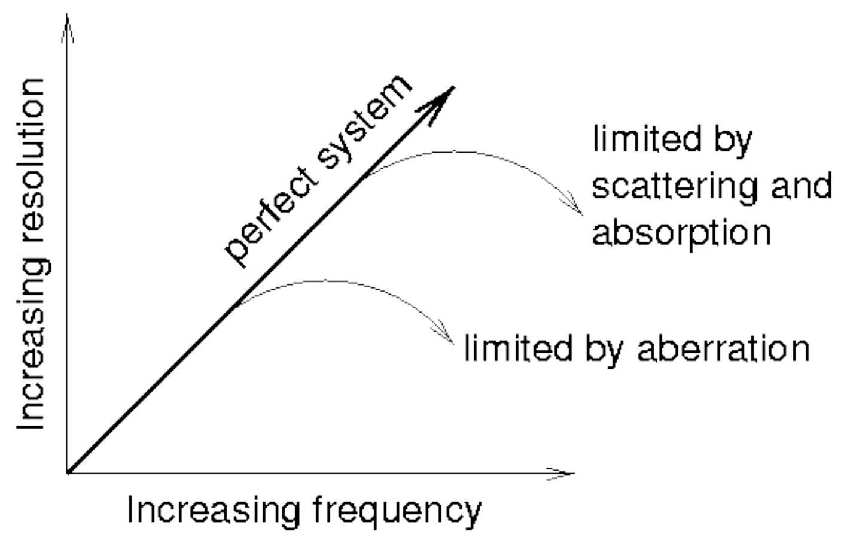
Introduction

Acoustic waves are sensitive to the properties of the medium through which they travel... this is what makes ultrasound so useful for NDT applications, where we may be trying to find faults (cracks, delamination) or evaluate parameters (residual stress, nonlinear response). Unfortunately, the waves may be sensitive to properties that ruin the measurements.



For example, the orientation of grains in metals affects the velocity of waves passing through them. This has a deleterious effect on the acoustic wavefront. If one tries to focus acoustic waves through this microstructure, the wavefront will tend to be aberrated, and no longer be focused at a diffraction-limited region. This will have an effect on the detected ultrasonic signal, and has implications for the probability of detection (PoD) of faults, and ultimately the resolution of the measurement system.

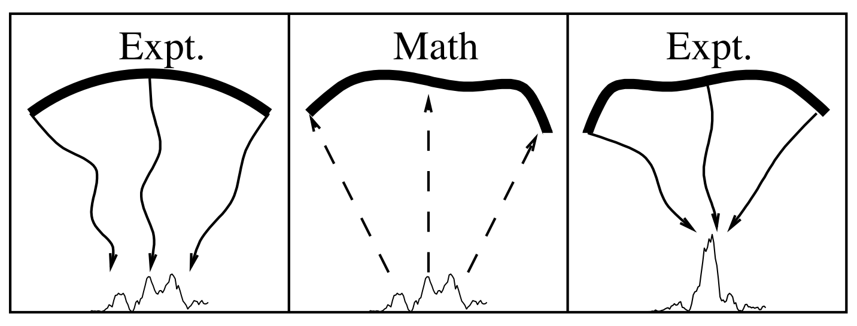


The greyscale images above illustrate the effects of aberration on focused surface acoustic waves (SAWS), which we can image using our optical scanning acoustic microscope (O-SAM). On the left the waves propagate on an isotropic material and a diffraction-limited focus is achieved. On the right, the SAWs are propagating through several grains, randomly oriented. Although very little acoustic energy is absorbed, an acoustic detector at the geometric focus of the arcs would detect only a low signal. In a "normal" system this would be interpreted as a fault with the material (for example a crack) - a "false positive." If your signal is constantly dropping out due to the effects of aberration, it can make your results very difficult to interpret.

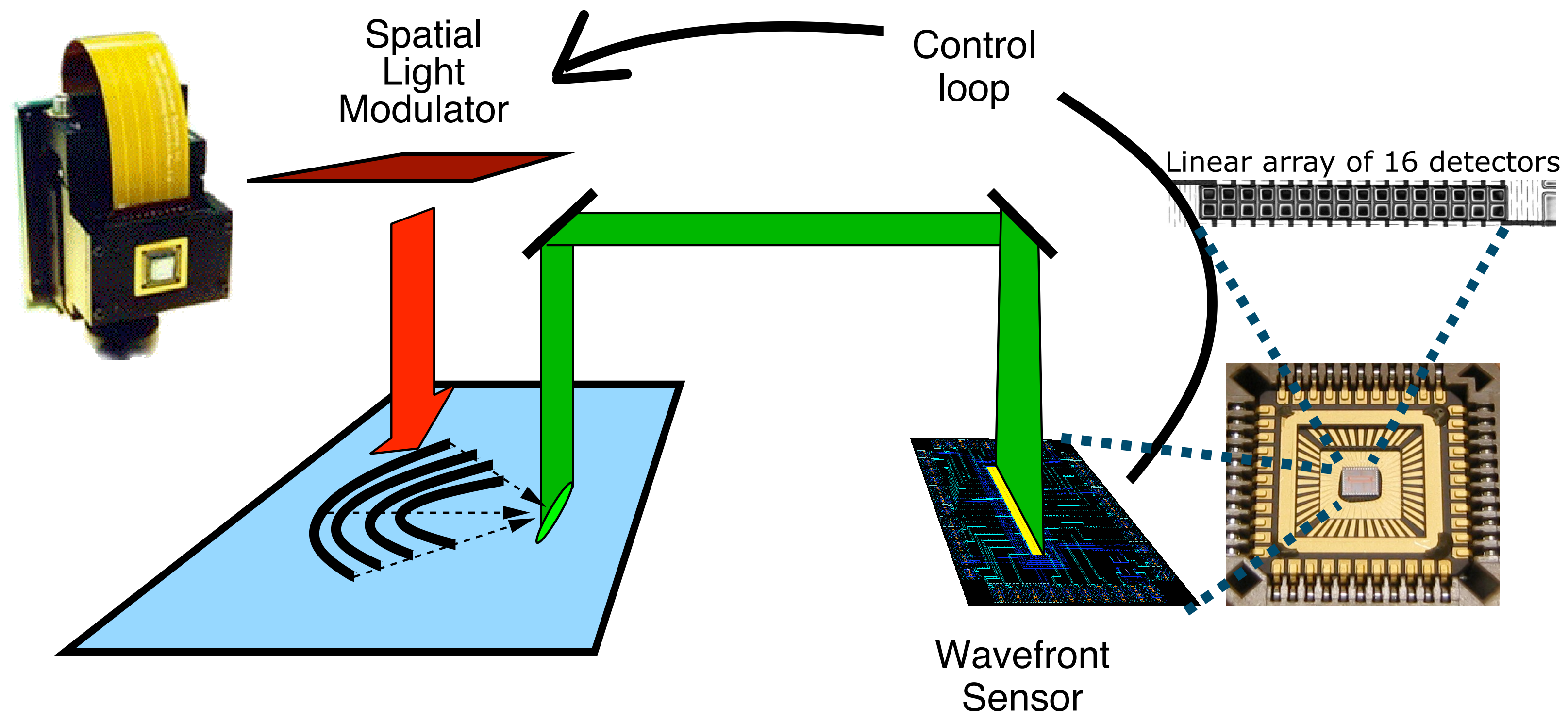
Aberration correction in theory

We use an analogous technique to adaptive optics, used in Earth-bound astronomy:

- Instead of a "guide star" (a reference by which we can measure the aberration) we use a set of geometric arcs as the ultrasonic excitation source
- Instead of an optical wavefront sensor (e.g. Shack-Hartmann) we use an acoustic wavefront sensor across the intended focal plane



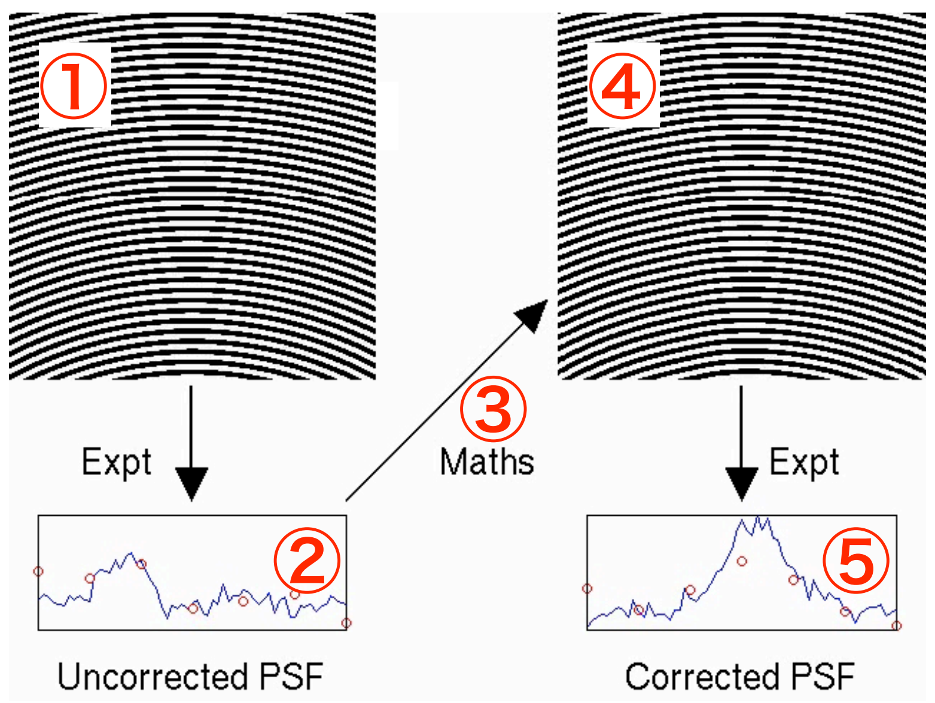
- Instead of a deformable mirror to correct for the effects of aberration, we adjust the acoustic source
- Instead of aberration changing with time, aberration changes with sample position



Aberration correction in practice

We study the effects of acoustic aberration using our O-SAM instrument, which uses lasers to excite and detect SAWs. The key aspects of the system for aberration correction are the *spatial light modulator* (SLM) and the *acoustic wavefront sensor* (AWFS).

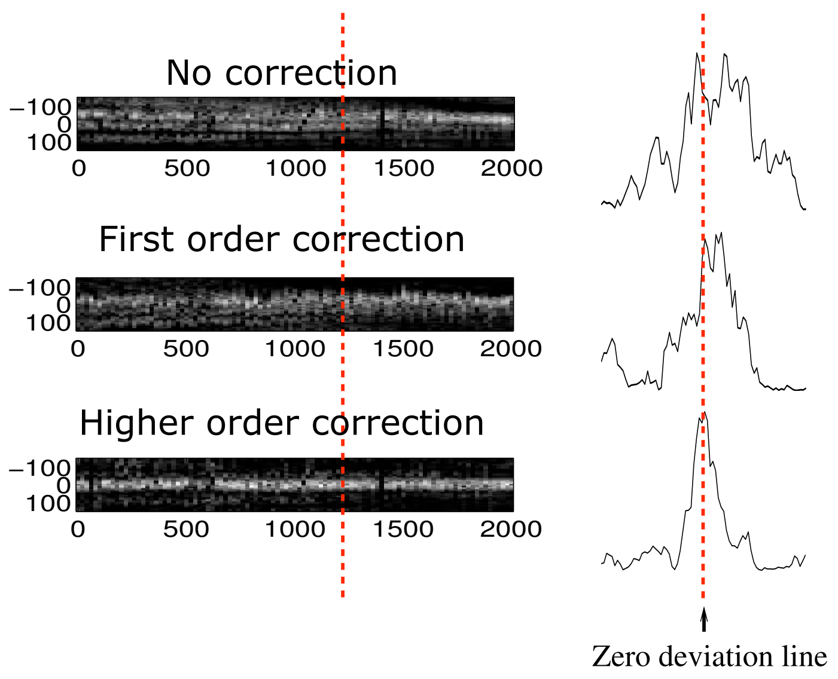
Each time the sample is moved relative to the acoustic source and detector, aberration correction is performed:



1. Pattern of geometric arcs applied to SLM
2. Point spread function (PSF) measured by AWFS in focal plane
3. Angular spectrum propagation technique is used to calculate what the source of the measured PSF would be if the waves were propagating in free space. This is effectively subtracted from the geometric source that was actually used to propagate the waves through the aberrating medium
4. This new pattern is applied to the SLM
5. The corrected PSF is measured by the AWFS

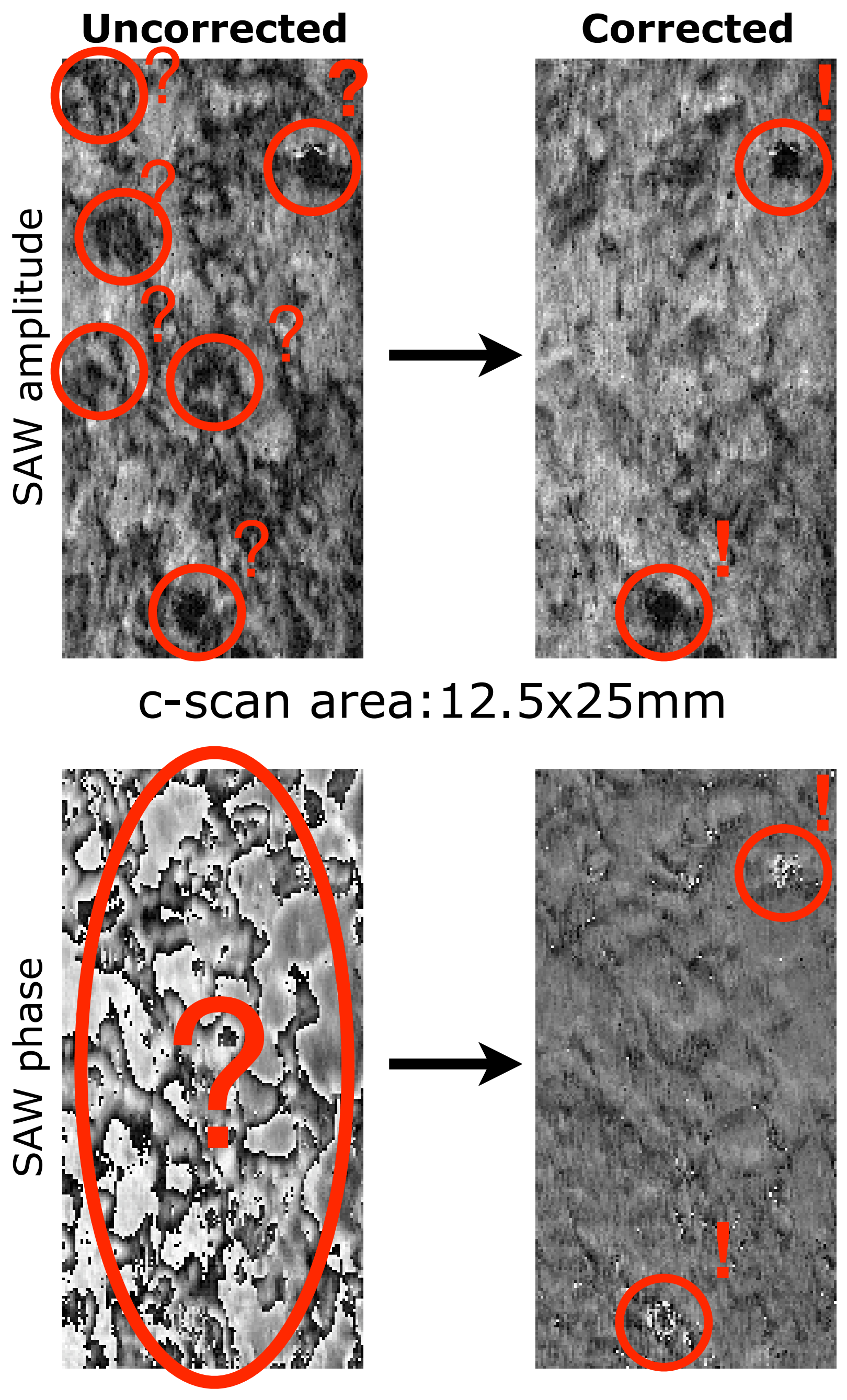
Results

- 3 line scans on same sample (x-axis is sample position, y-axis is AWFS data)



- no correction
- first order (tilt) correction
- higher order correction

- Higher order correction not only re-centres the PSF, it also reduces the width and increases height

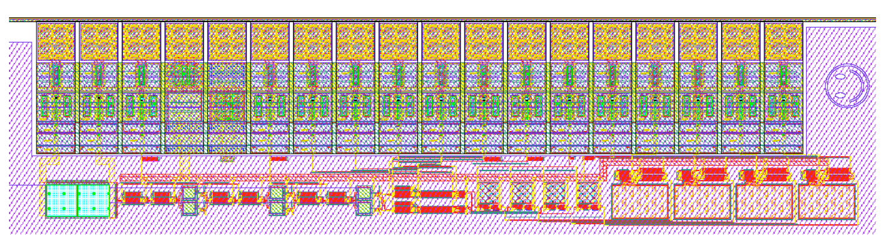


c-scan area:12.5x25mm

- C-scan images of a Ti alloy
- For perfect sample, both amplitude and phase images would be uniform in tone
- 2 "real" defects - Vickers indentations - ideally these would be easy to spot (reduced SAW amplitude, change in phase)
- Uncorrected amplitude image suffers from severe signal drop-out: several areas *could* be defects
- Uncorrected phase image particularly tricky to interpret
- After aberration correction has been performed (on the right) the images are much easier to interpret, and the defects clearly identifiable

The future

- Bigger detection laser (on order) will help SNR on AWFS
- Integrate all the AWFS electronics onto one integrated optical sensor chip (1 channel shown)



- Work on correction algorithms (recursion/predictive etc)