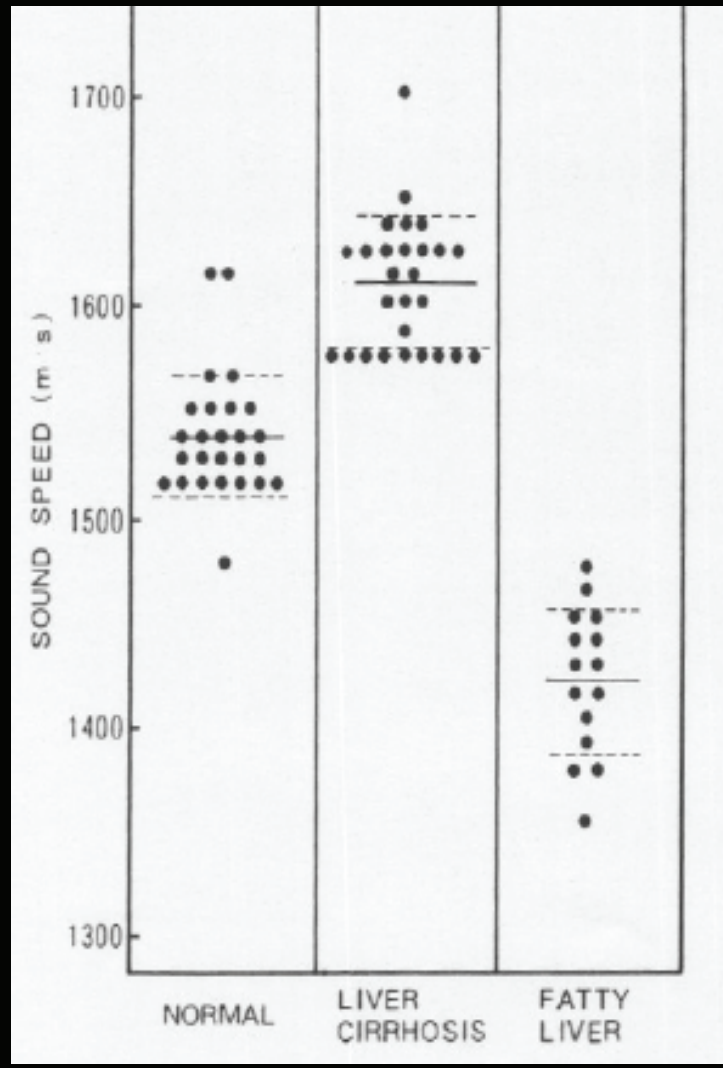
Brightness-based methods for correcting beam-former Speed of Sound (SOS)

Jihad H Al-Sadah, James A Zagzebski
University of Wisconsin – Madison
Medical Physics

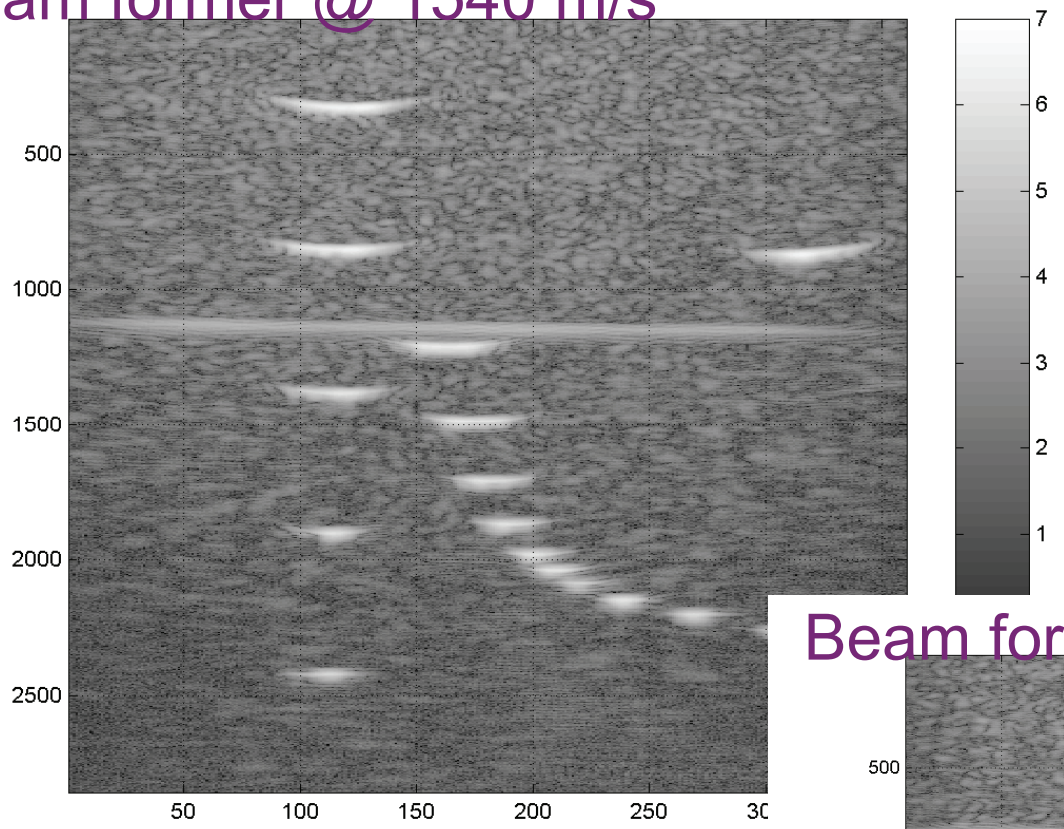
Justification of the study

- Clinical Significance
  - Indication of disease
    - Fatty liver, cirrhosis
- Image quality
  - Zeroth order correction,
    - Low computational cost
  - Good impact on image quality



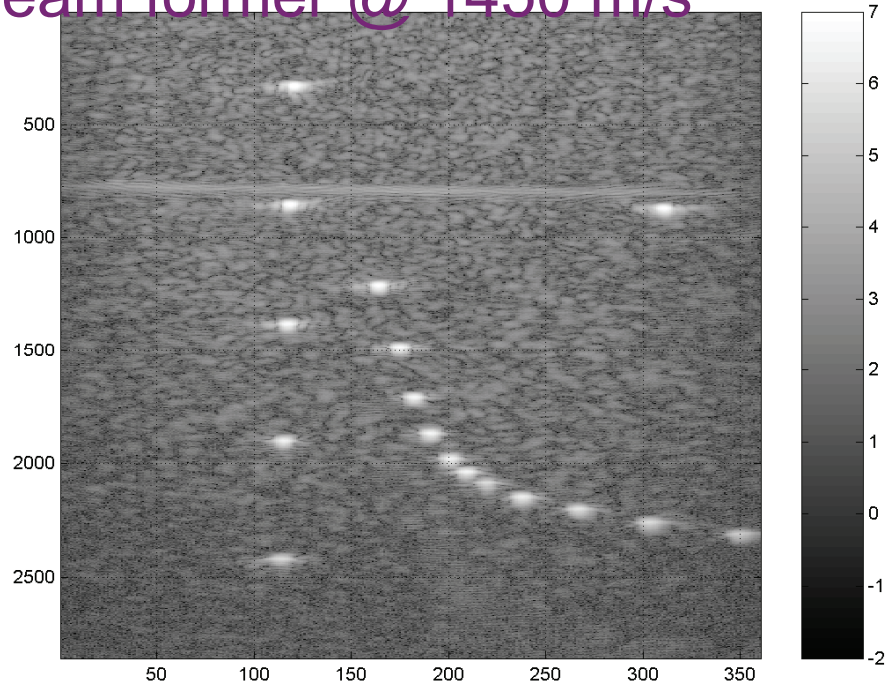
Hayashi1988_ A New Method of Measuring In Vivo Sound Speed in the Reflection Mode

Beam former @ 1540 m/s



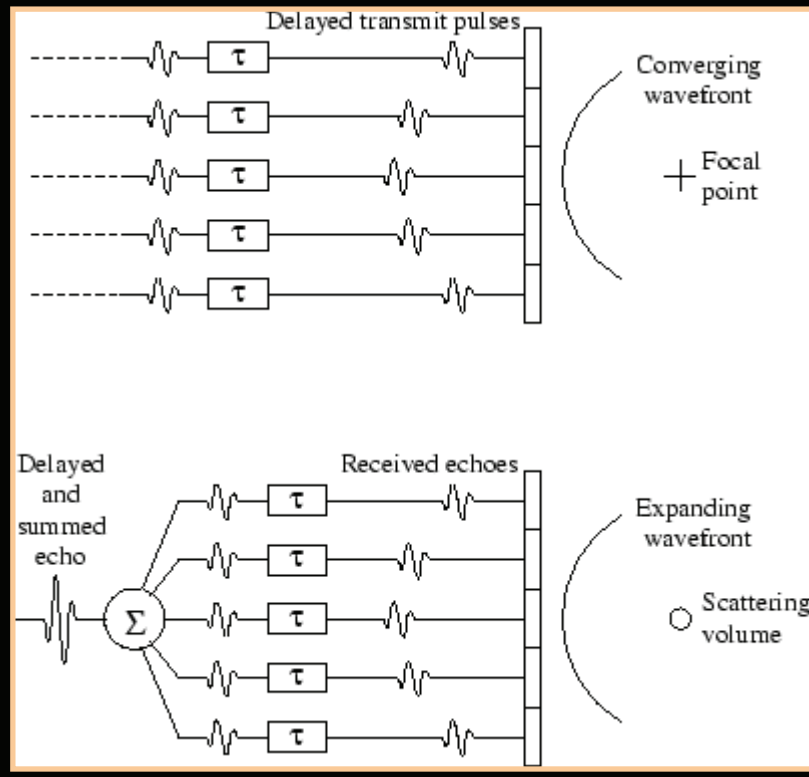
ATS 539
Rubber@1460m/s

Beam former @ 1450 m/s



Experimental: Beam former / Siemens

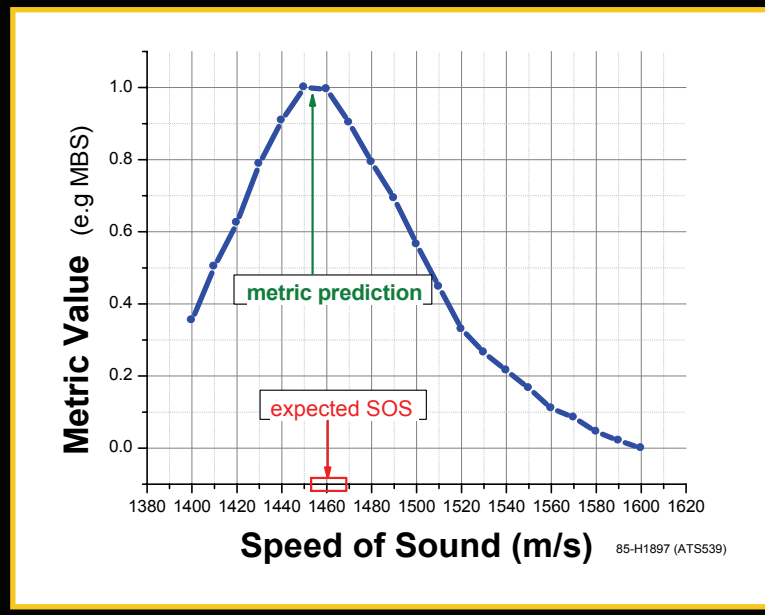
- SOS is important in Tx and Rx
- Siemens /Antares Research interface allows control over:
  - SOS-Tx: bfpropagationve
  - SOS-Rx: propagationvelc
- Phantoms used:
  - RMI403: ≈gel of 1540m/s
  - ATS539: ≈rubber of 1460m/s



dukemil.egr.duke.edu/Ultrasound/k-space/img26.png

Objectives of the study

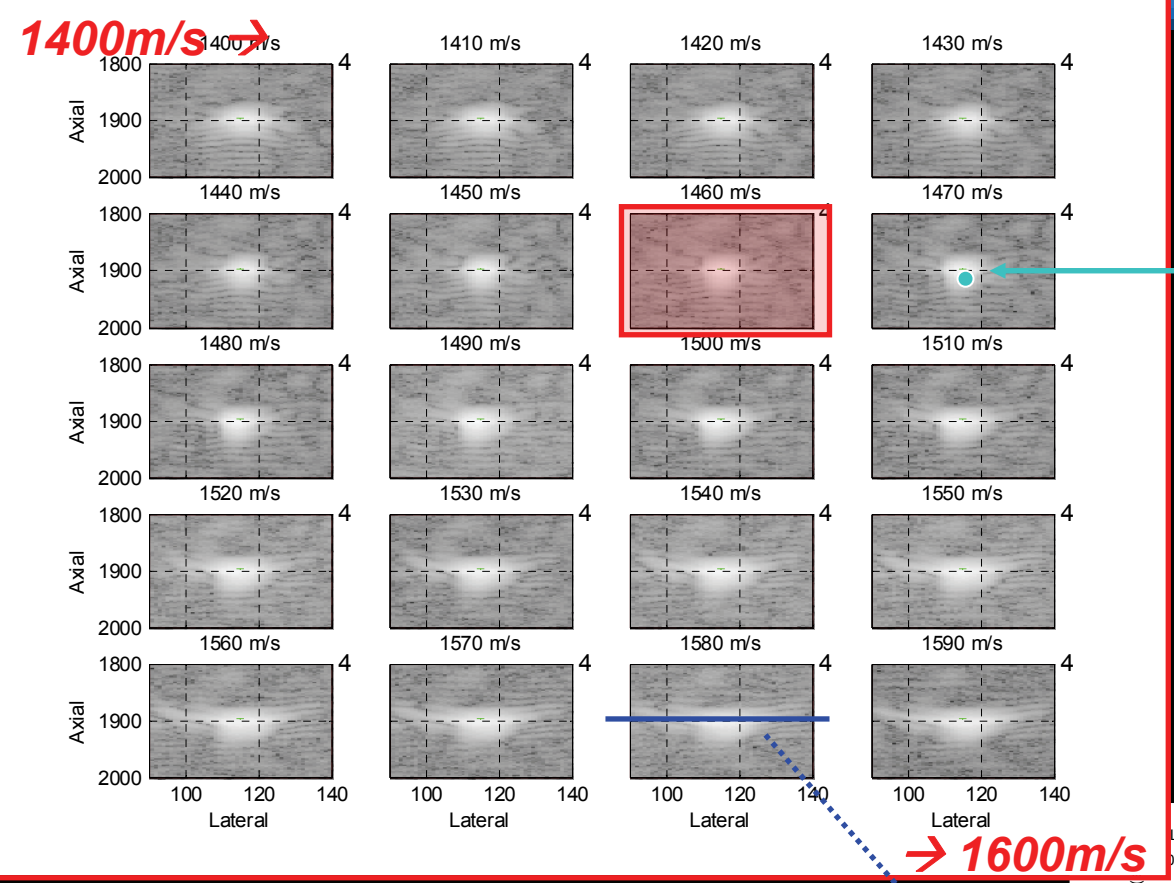
- Development of Metrics
  - Point feature
  - Brightness over area
  - Correlation metrics
- Physical basis investigation
  - Defocusing effects



- Experimental Observation
  - *distance to probe surface affect SOS estimate*

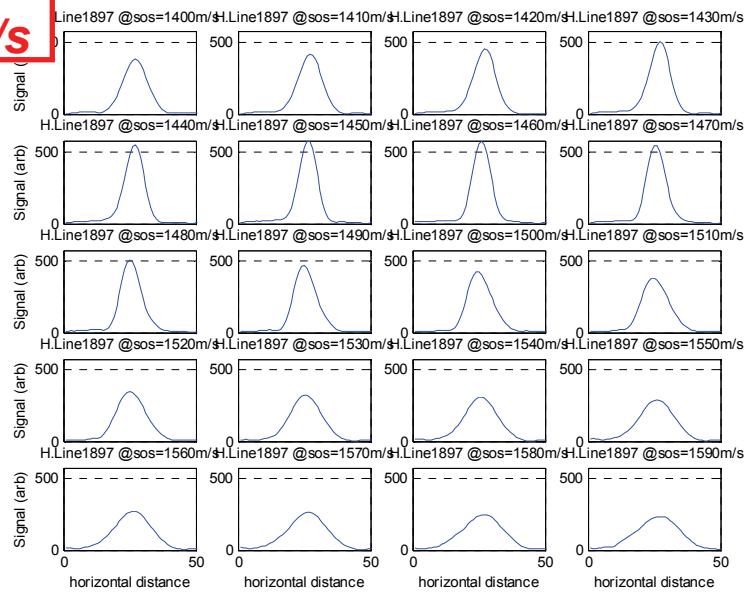
Outline: POINT FEATURE METRICS

1. **Metrics of "defocusing" of *point* features**
   - **Lateral profiles, Axial profiles**
   - **Focusing enhance reverberation**
2. *Correlation* Loss Metrics
3. *Brightness* Variation Metrics
   - Defocusing basis
4. Analysis
   - Axial depth effect on SOS
   - General Spatial variation of SOS
5. Conclusions

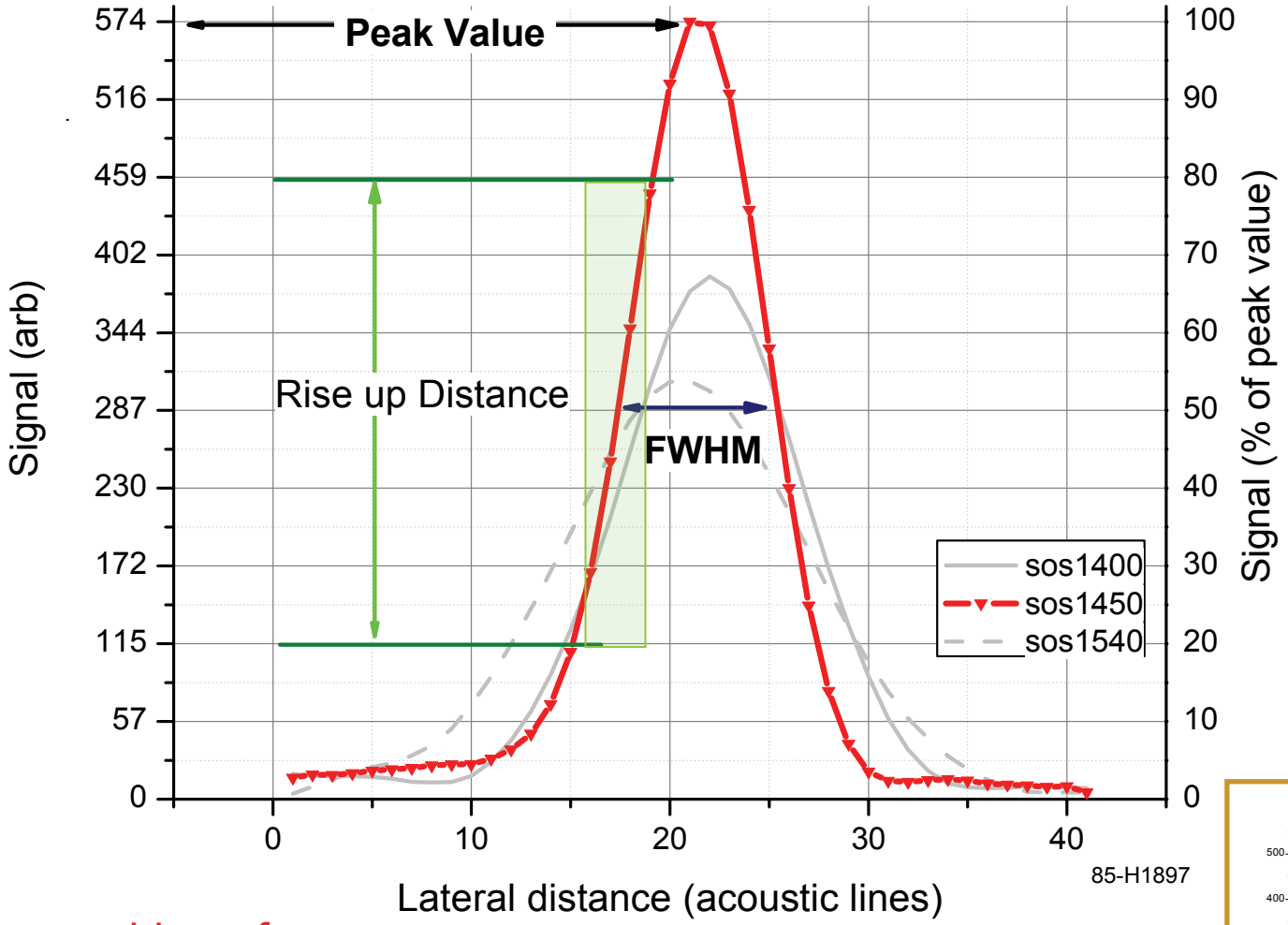


1. Select a region
2. Find the center
   - Max(image (x,y, sos))
3. Apply metrics to envelop detected RF-data curves passing through the center

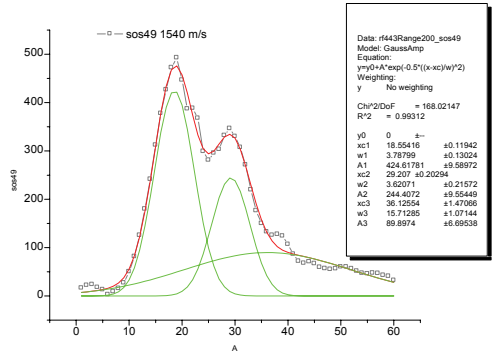
≈rubber of 1460m/s



Simple Metrics of a curve (not based on fitting)



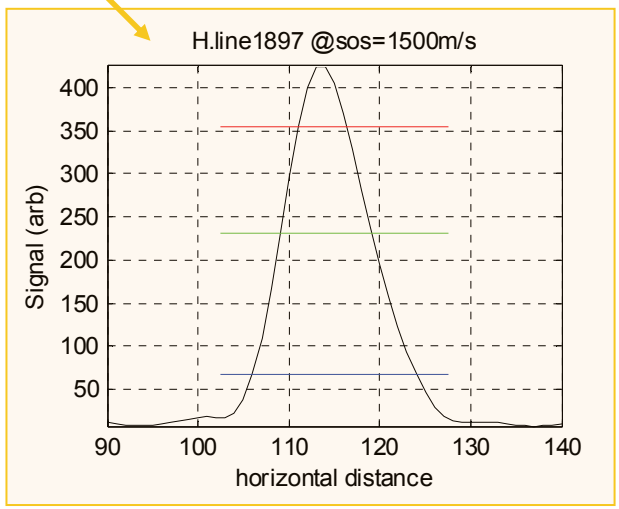
≈rubber of 1460m/s



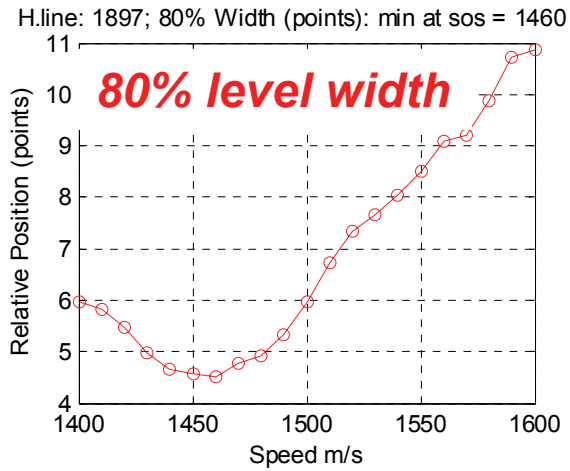
Fitting is costly; and not simple in the axial direction →

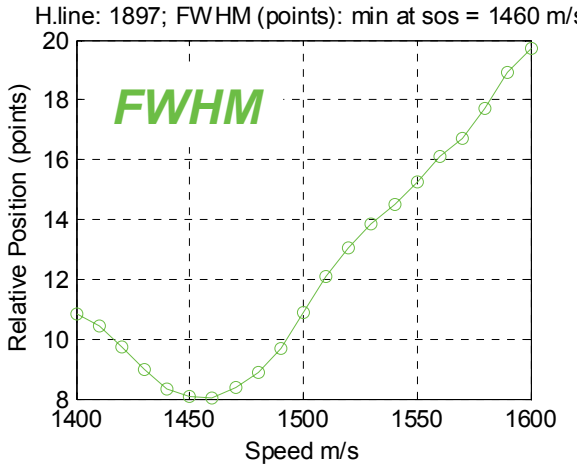
Width characterization of a point's: Lateral profile

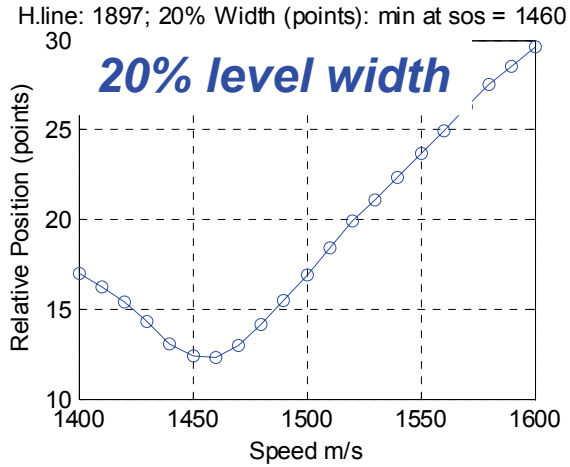
- 50% or lower are *stable* metrics
- 80% width had occasional failures



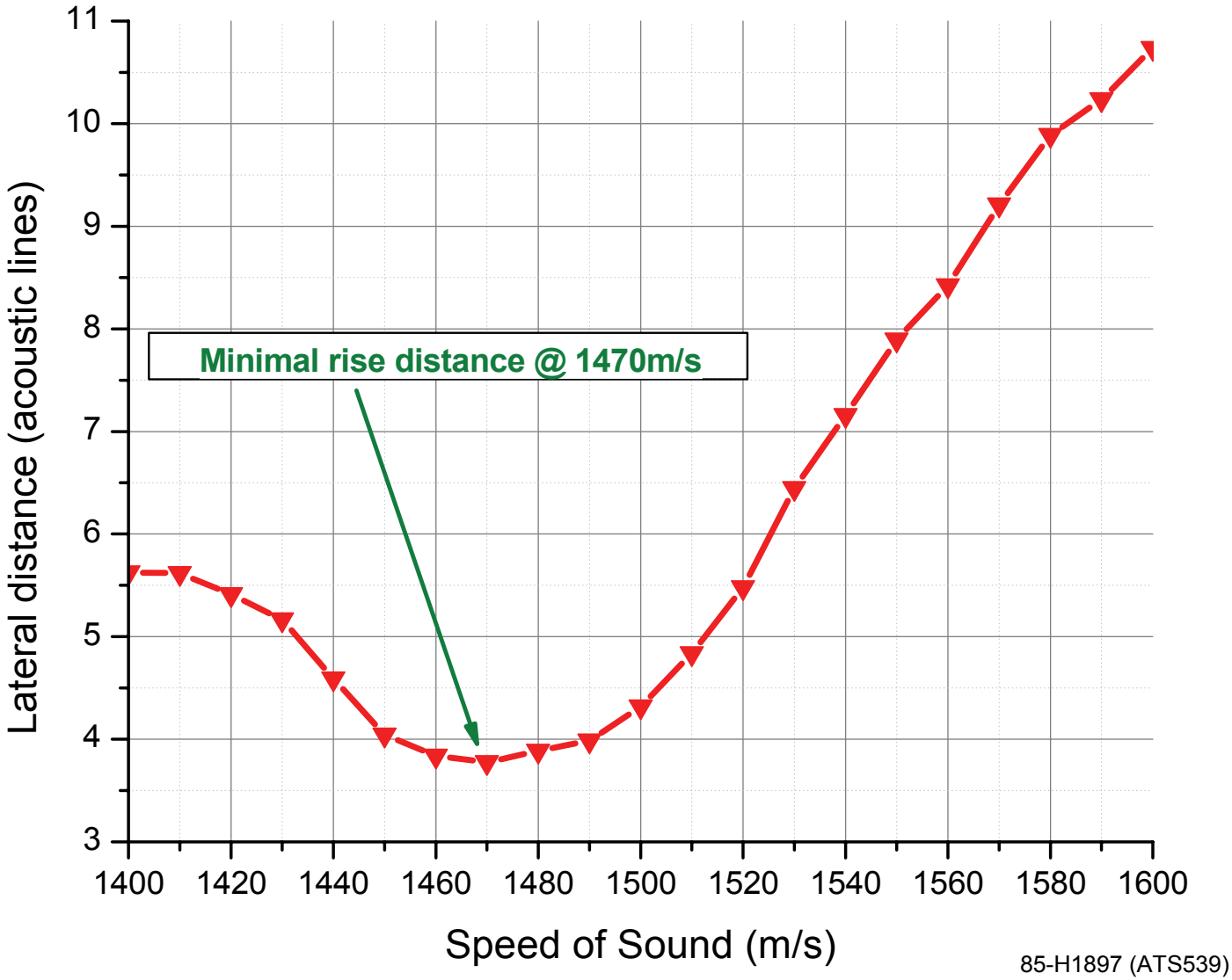
≈rubber of 1460m/s





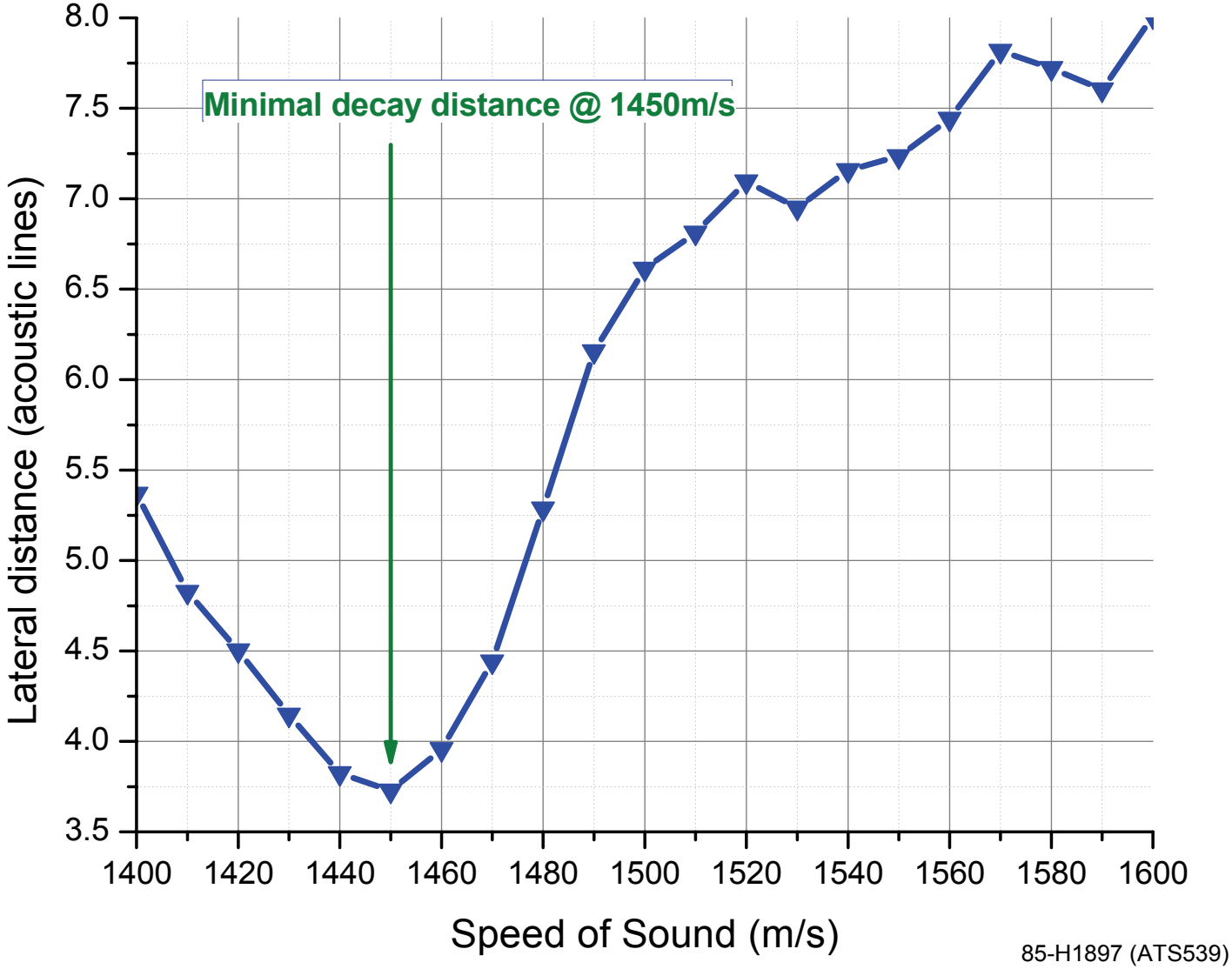


Lateral Rise up distance of a point feature 's peak curve



85-H1897 (ATS539)

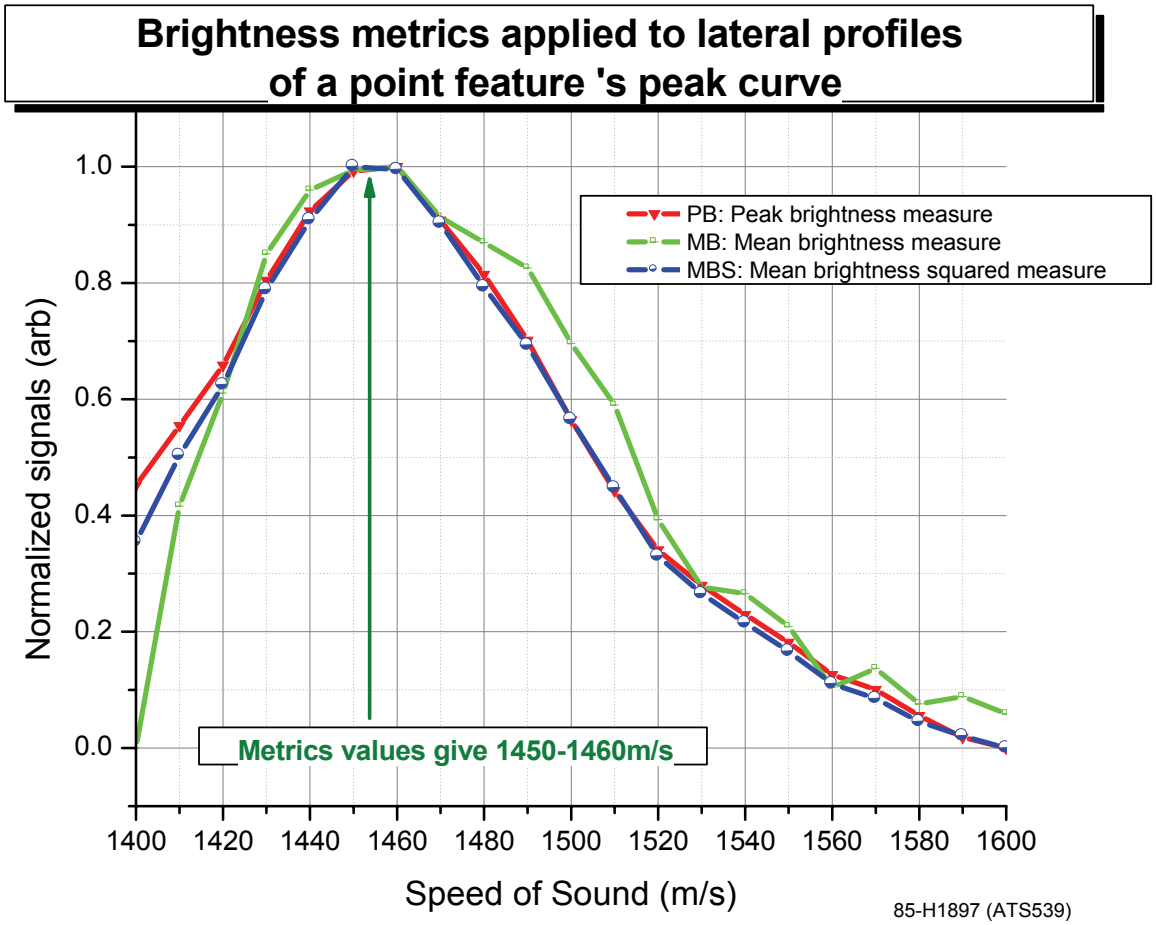
Lateral decay distance of a point feature's peak curve



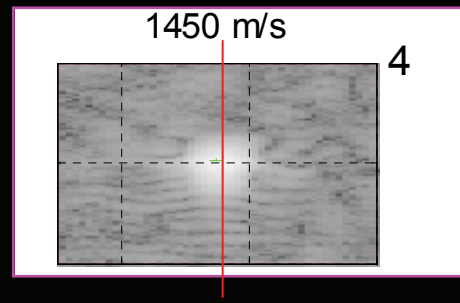
85-H1897 (ATS539)

Brightness approach on lateral profiles

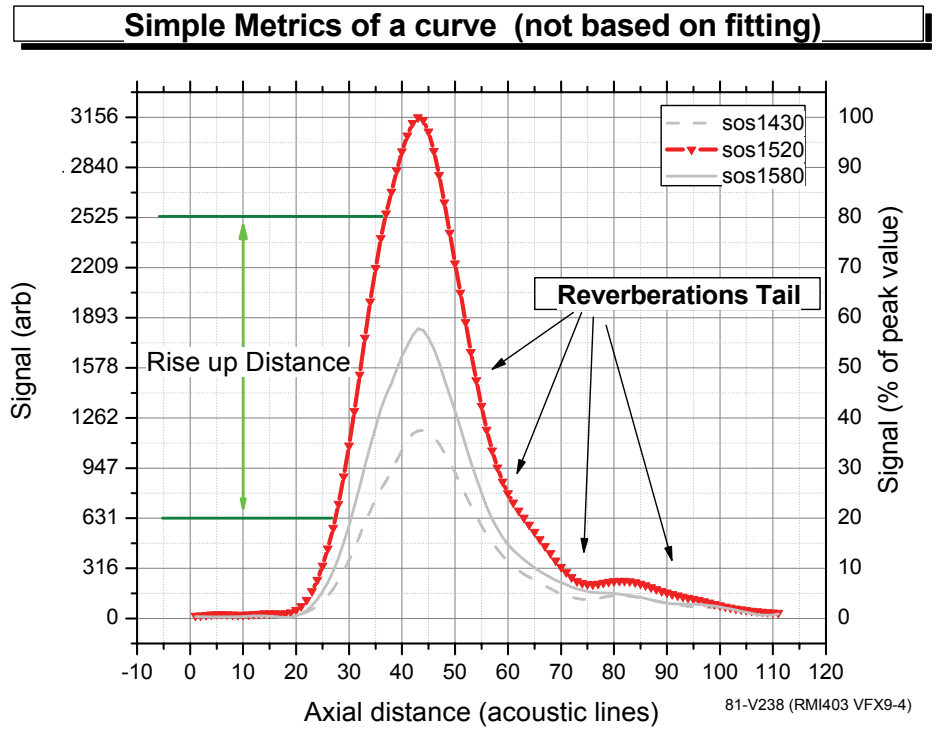
- MBS is more stable than MB
- Generally not as reliable as width metrics
- Sensitive to point position and distance from the surface of the probe



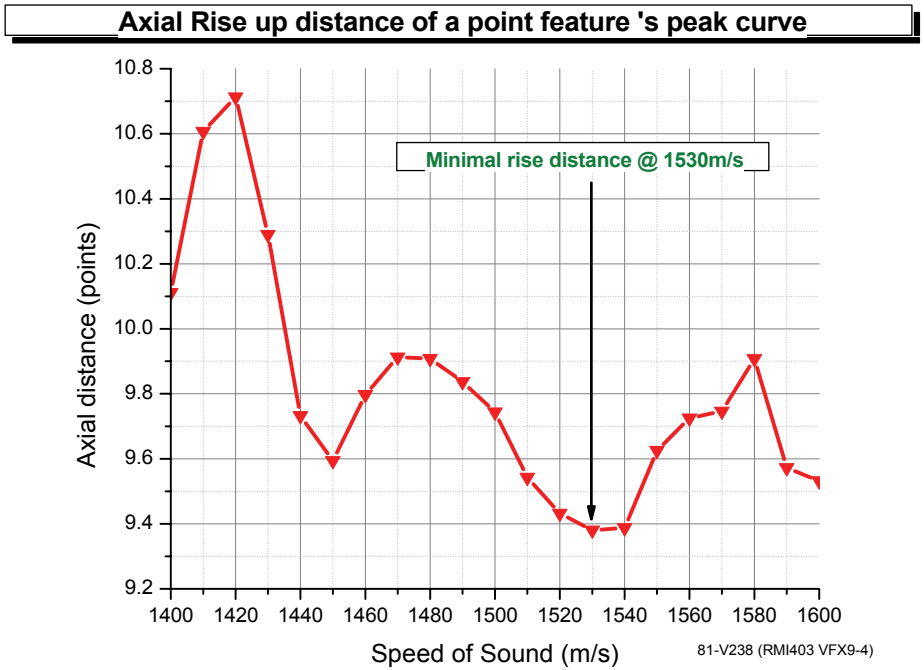
Axial *profiles: competing effects*

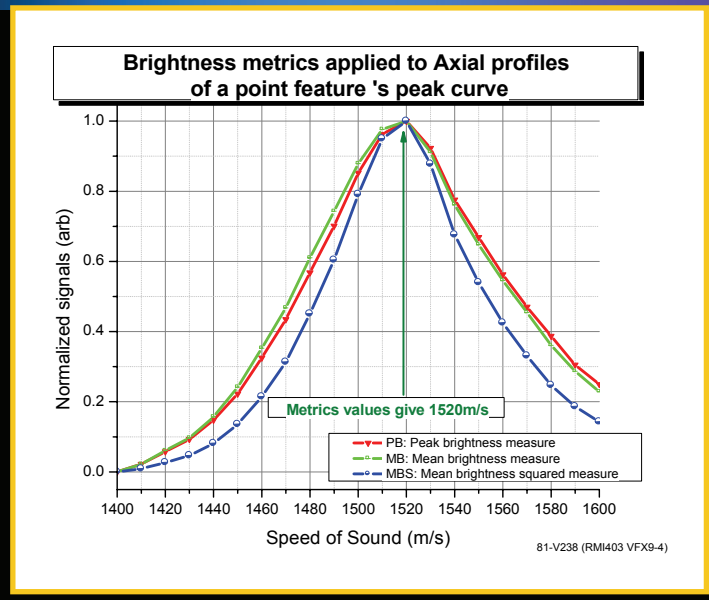


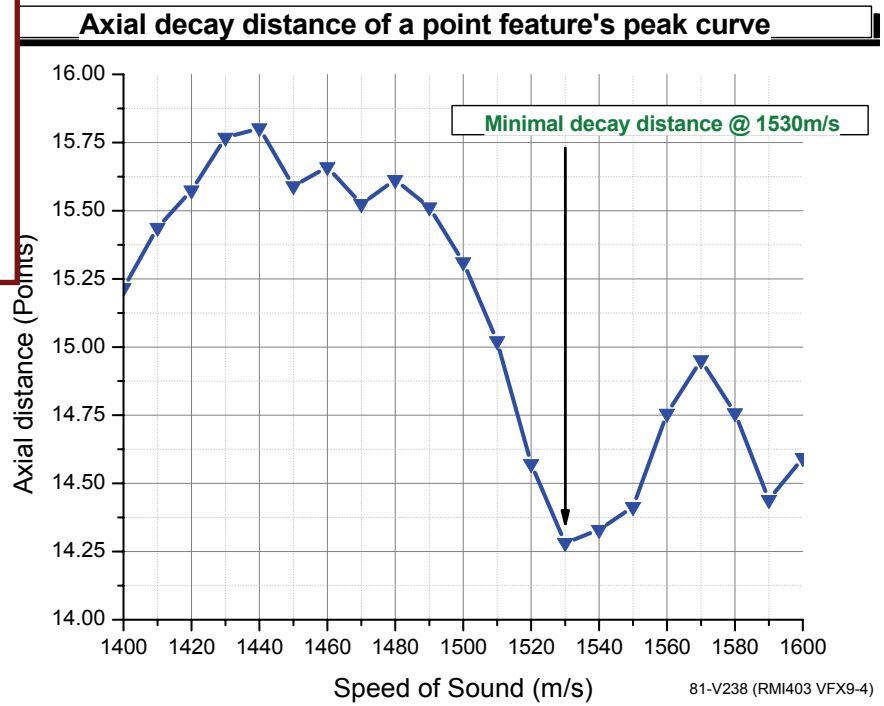
- Better Rx resolution
  - Shorter decay/ rise up distance
- "*Elongated damping*" due to a well focused Tx
  - Wider peaks!



Axial profile metrics:

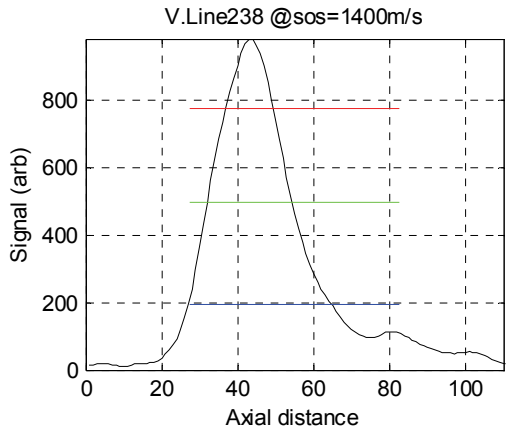


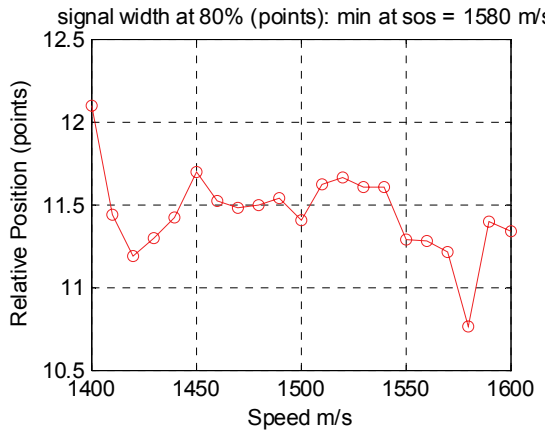


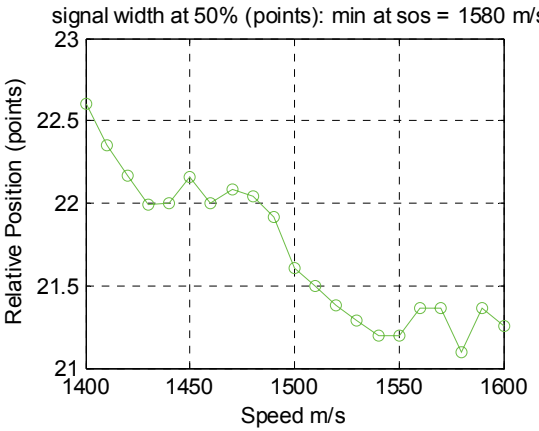


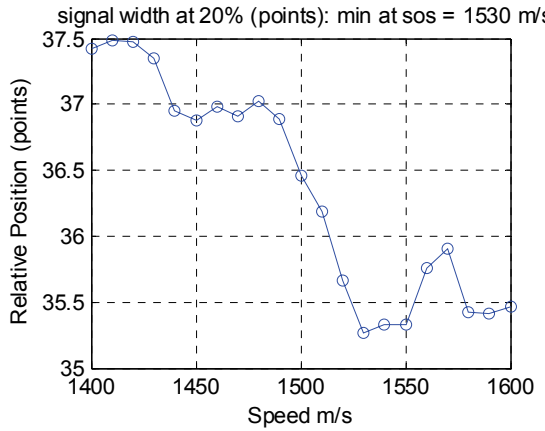
Axial Peak width metrics

- Notice effect of *"elongated damping"* on the failure of axial width metrics





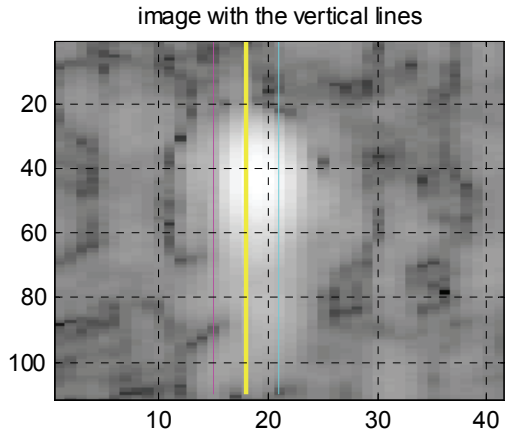


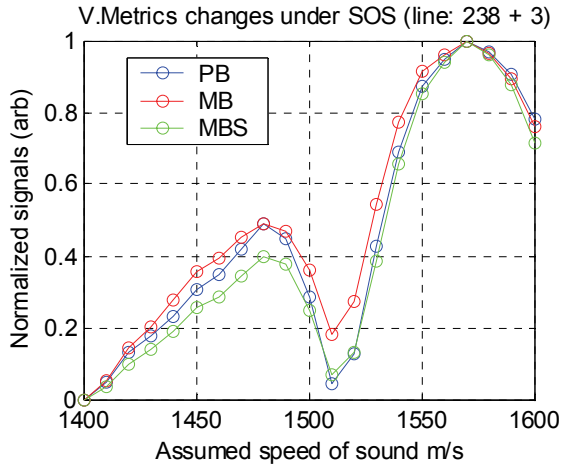


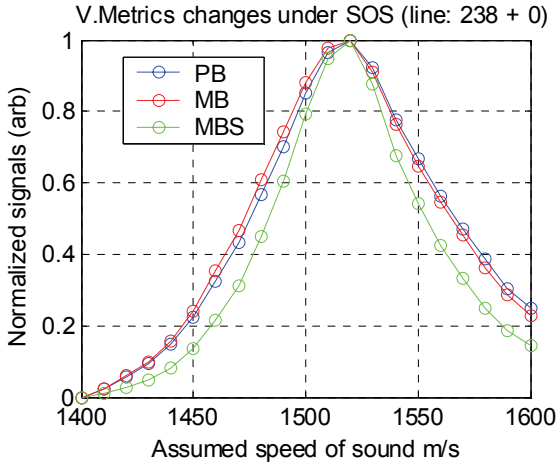
Brightness based Axial metrics:

- Flipping over lateral position → sensitivity to lateral position
- Intermediate lines show intermediate SOS estimates

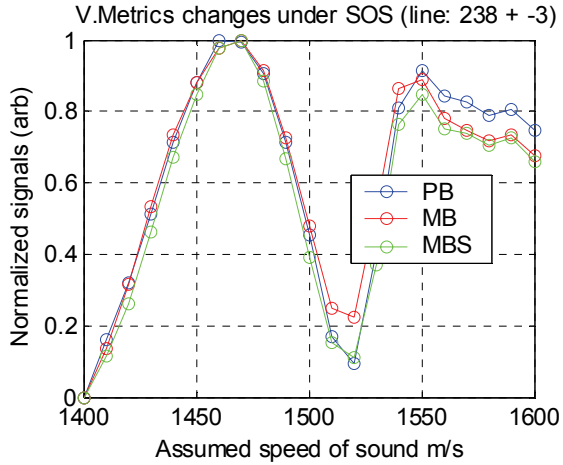
- Extended interfaces should resolve such difficulty
  - e.g. organ boundary like fatty region interfacing liver
- Work in progress







On center → correct



Off center → failure

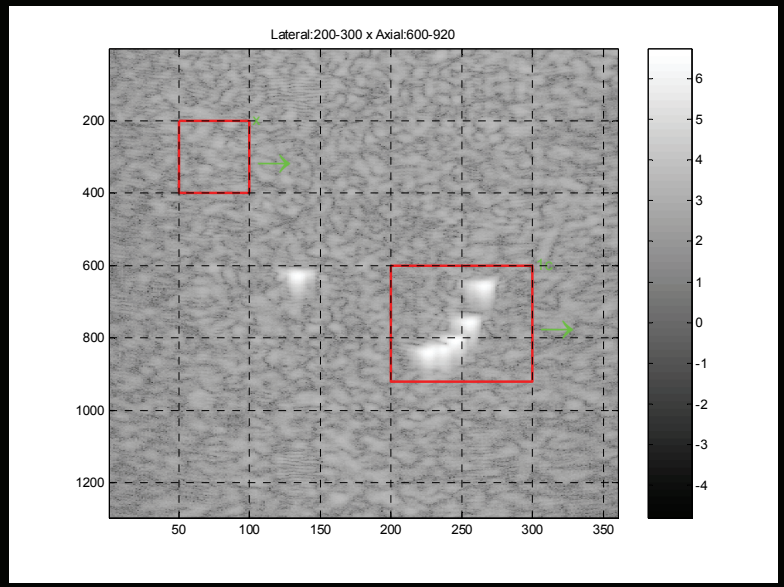
Outline : **Correlation *Loss Metrics***

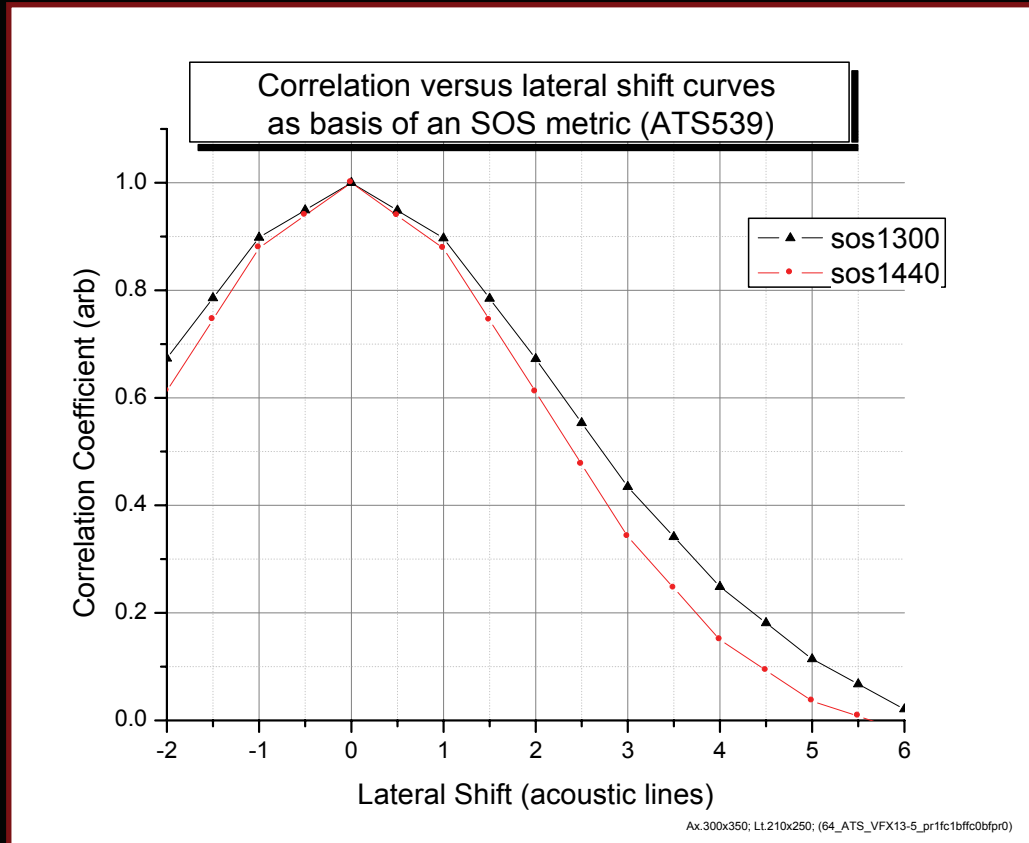
1. Metrics of “defocusing” of *point* features
   - Lateral profiles, Axial profiles
   - Focusing enhance reverberation
2. ***Correlation*** **Loss Metrics**
3. *Brightness* Variation Metrics
   - Defocusing basis
4. Analysis
   - Axial depth effect on SOS
   - General Spatial variation of SOS
5. Conclusions

Correlation Metrics

$$correlation`(sos, shift) = \sum_{p=p_i}^{p_f} \sum_{l=l_i}^{l_f} rfMaster(sos, p, l).T_{shift}\left[rfMaster(sos, p, l)\right]$$

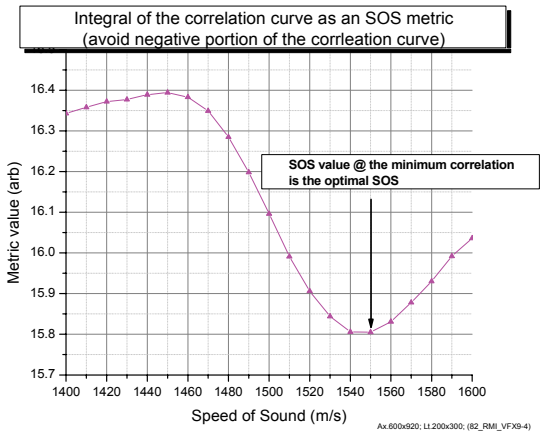
$$T_{shift}\left[rfMaster(sos, p, l)\right] =$$
$$rfMaster(sos, p, l + floor(shift)) + (shift - floor(shift)) * rfMaster(sos, p, l + ceil(shift))$$

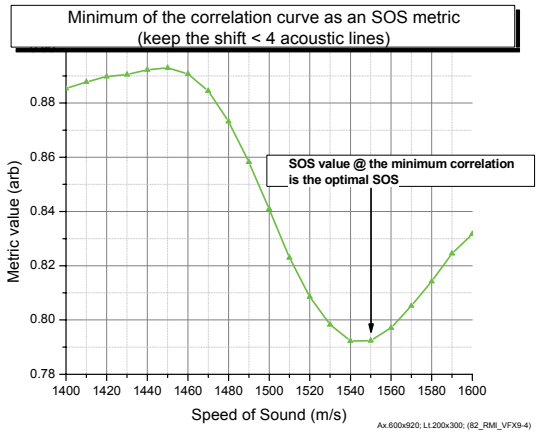


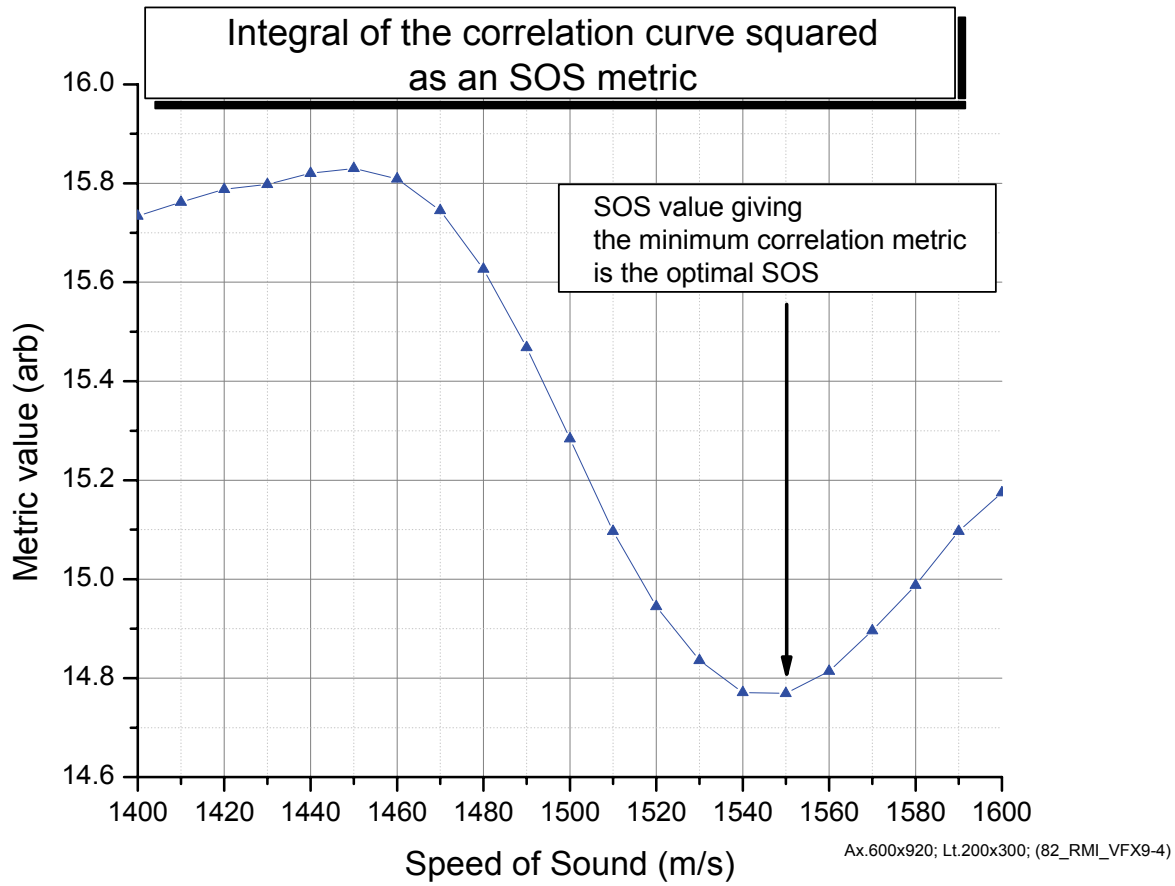


Valid Correlation Metrics

- Based on correlation loss curve
  - Sum of Squares: most robust
  - Sum: avoid negative portion
  - Min: keep lateral shift <4

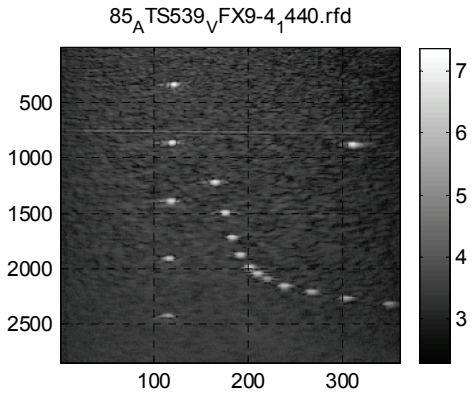


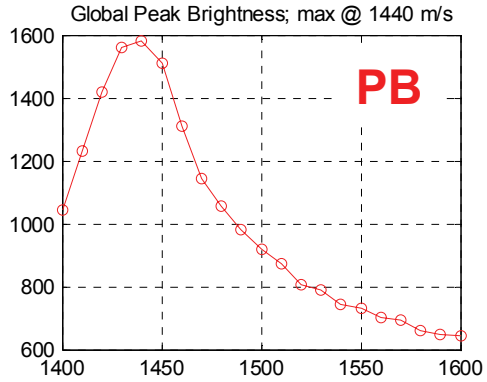




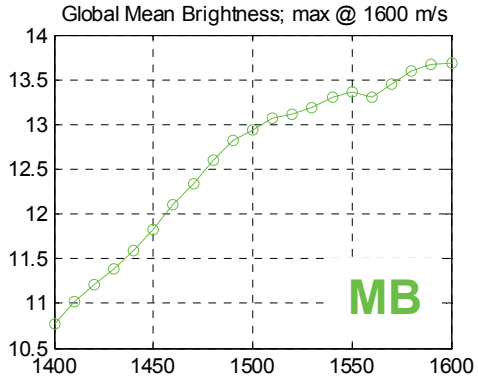
Outline: **Brightness**

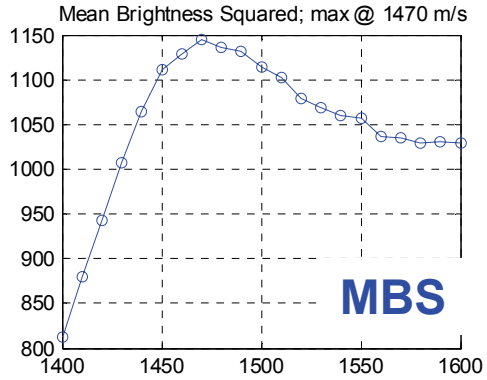
1. Metrics of “defocusing” of *point* features
   - Lateral profiles, Axial profiles
   - Focusing enhance reverberation
2. *Correlation* Loss Metrics
3. ***Brightness*** **Variation Metrics**
   - **Defocusing basis**
4. Analysis
   - Axial depth effect on SOS
5. Conclusions

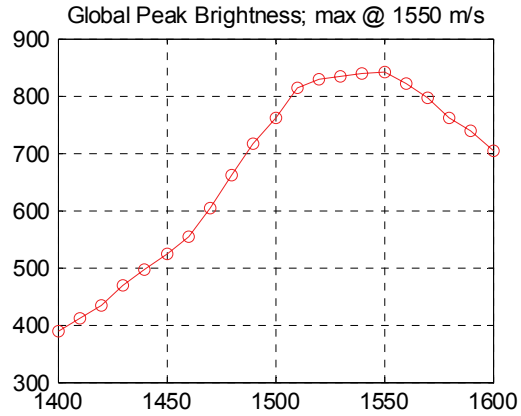




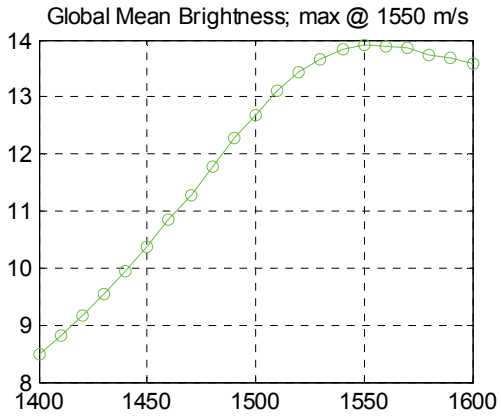
- ATS-539
  - Expect≈1460m/s
  - result≈1450m/s

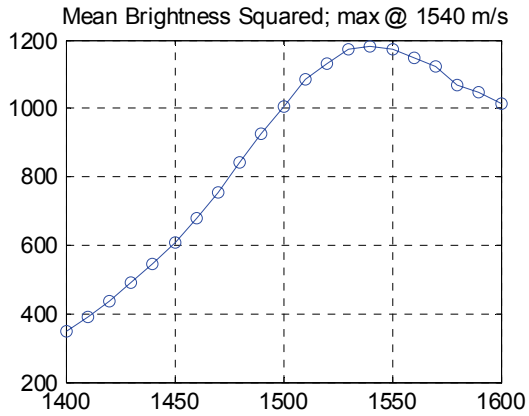






- RMI-403
  - Expect≈1540m/s
  - result≈1550m/s



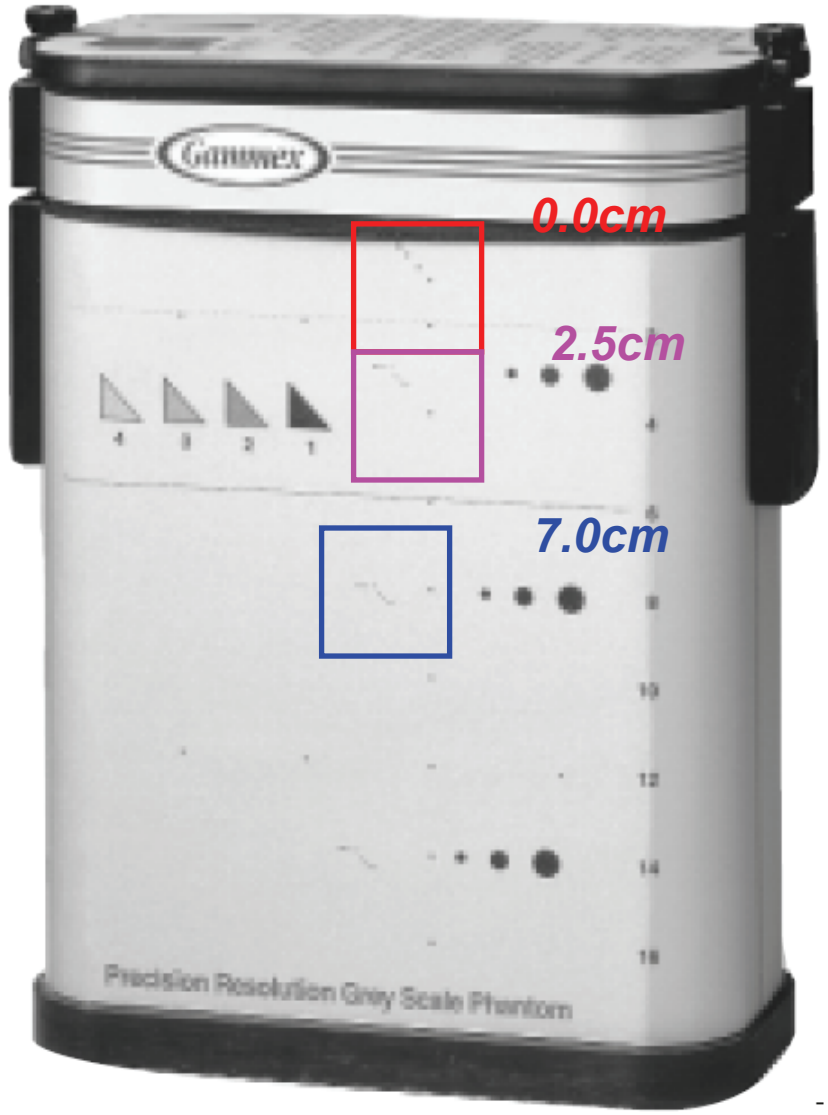


Comments

- Mean brightness squared is:
  - robust metric (less failures than Peak /mean)
  - Still as simple and computationally light
  - Does not need/avoid point features
- Peak and mean brightness occasionally fails
- Spatial stability of the metric applied to small regions is under investigation
  - There is a slight depth variation

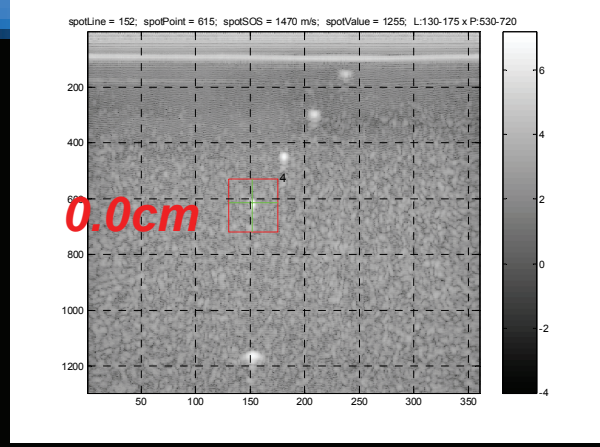
Observation: optimal SOS varies with Depth

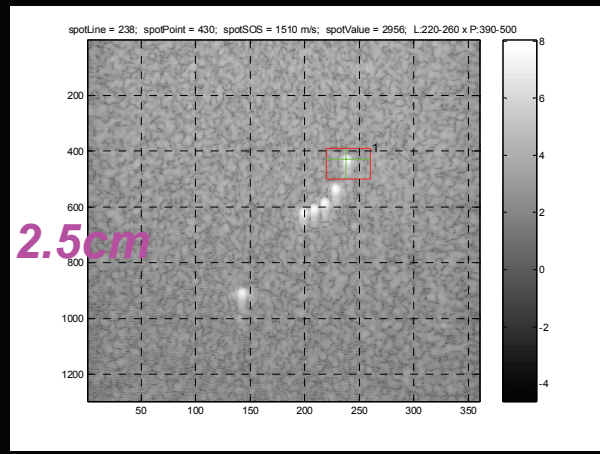
- Estimates vary with distance from the surface of the transducer
- Avoid first few cm's
  - estimates are lower than expected
- 3 - 5cm away from surface seems reasonable

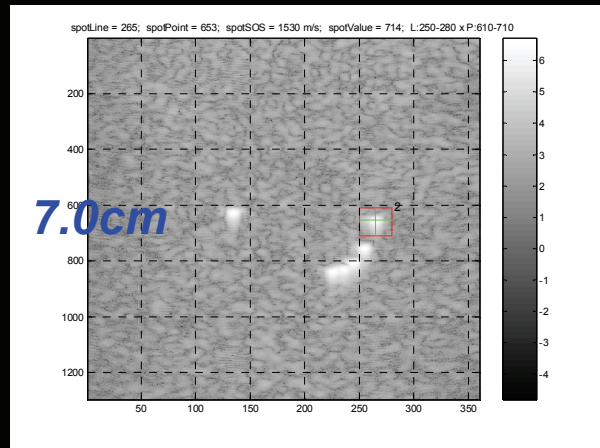


Low Depth lowers SOS Estimate

	0.0cm	2.5 cm	7.0 cm
Visual	1470	1510	1530
Brightness Sq	1490	1530	1540
Lateral Width	1470	1510	1520
Ax. Rise/decay	1460	1530	1550
Correlation	1450	1500	1540







Summary

Metric	Speedy	Accurate	Robust	Clinic. site	**Score**
Axial Rise up	√√√	√√√	√√	√√	√√√
Lateral Width	√√	√√√	√√√	√	√
Mean Sq Brightness	√√	√√√	√√	√√√	√√
Correlation Mean square	√	√√√	√√√	√√√	√√

Conclusions

- There appears to be *several stable* metrics for SOS
  - Correlation
  - Axial edge dulling
  - Mean brightness square
- *Low* separation from surface *lowers* SOS estimates
  - Keep 3-5cm at least
  - physical basis? elevational focus?
  - There is room for phase aberration correction on the basis of SOS

Thank you