Department of Electrical and Computer Engineering

Aberration Correction With the Overdetermined, Fan-Filtering Algorithm (OFF)

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1 Screen-model aberration correction

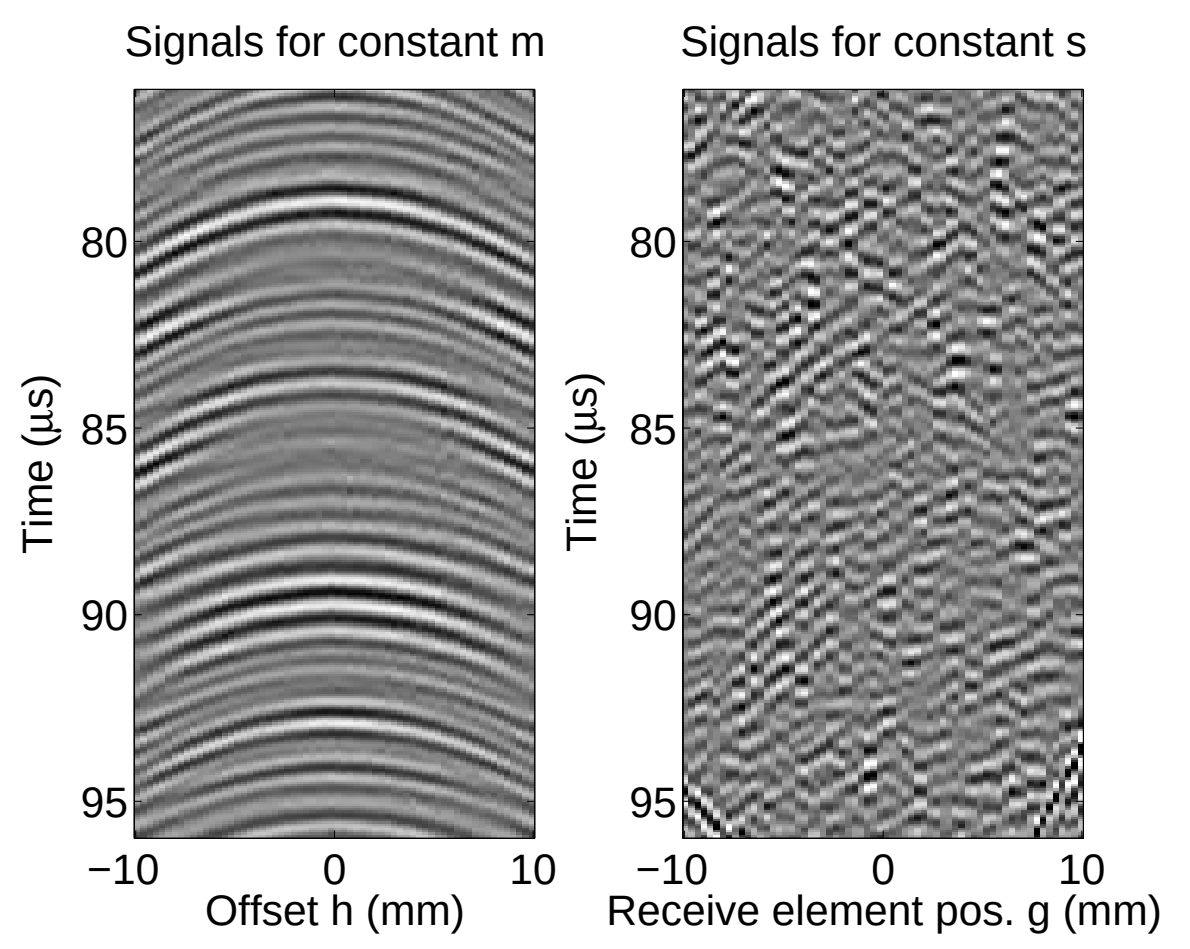
Three representative forms:

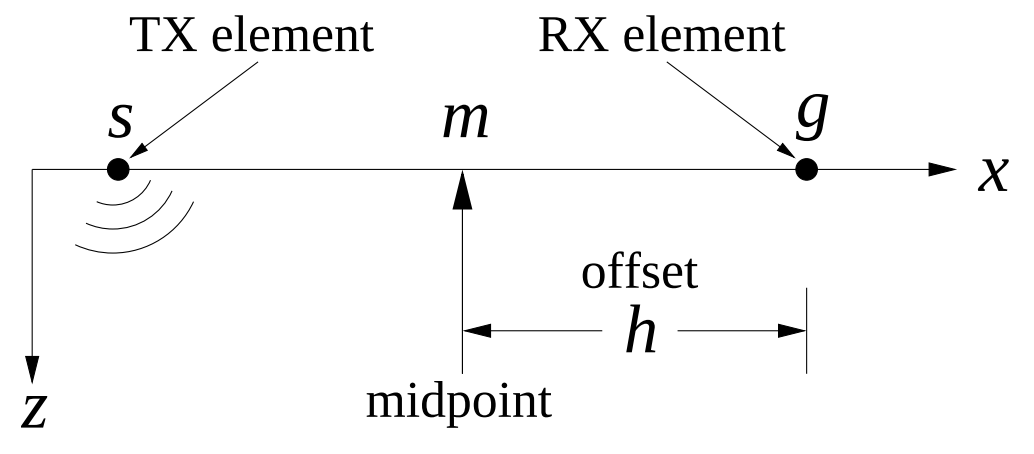
- Iterative transmit focus (NNCC [1])
- Image quality metric (speckle brightness [2])
- Common-midpoint signal analysis with "complete" data (NFSR [3])

↑

Promising—why?

- Don't assume we know correct focusing operator
  (Focusing may discard useful information!)
- Common-midpoint signals (left, below) are highly correlated





$$m = \frac{g+s}{2} \quad \text{(midpoint)}$$
$$h = \frac{g-s}{2} \quad \text{(offset)}$$

Time shifts between common-midpoint signals are caused by

1. Aberration ← Good
2. *Moveout*—delay vs. offset, due to geometry ← Problematic

Must correct the moveout to avoid bias in aberration estimates.
At azimuth angle θ, use change of variables $t \to t'$: [3]

$$t' = \sqrt{\left(\frac{t}{2}\right)^2 + \frac{h^2}{c^2} - t\frac{h}{c}\sin\theta_c} + \sqrt{\left(\frac{t}{2}\right)^2 + \frac{h^2}{c^2} + t\frac{h}{c}\sin\theta_c} \qquad (1)$$

Problem: Echoes come back from many θ simultaneously!
$\Rightarrow$ Have bias from scatterers at $\theta \neq \theta_c$.

2 Angle preselection with fan filters

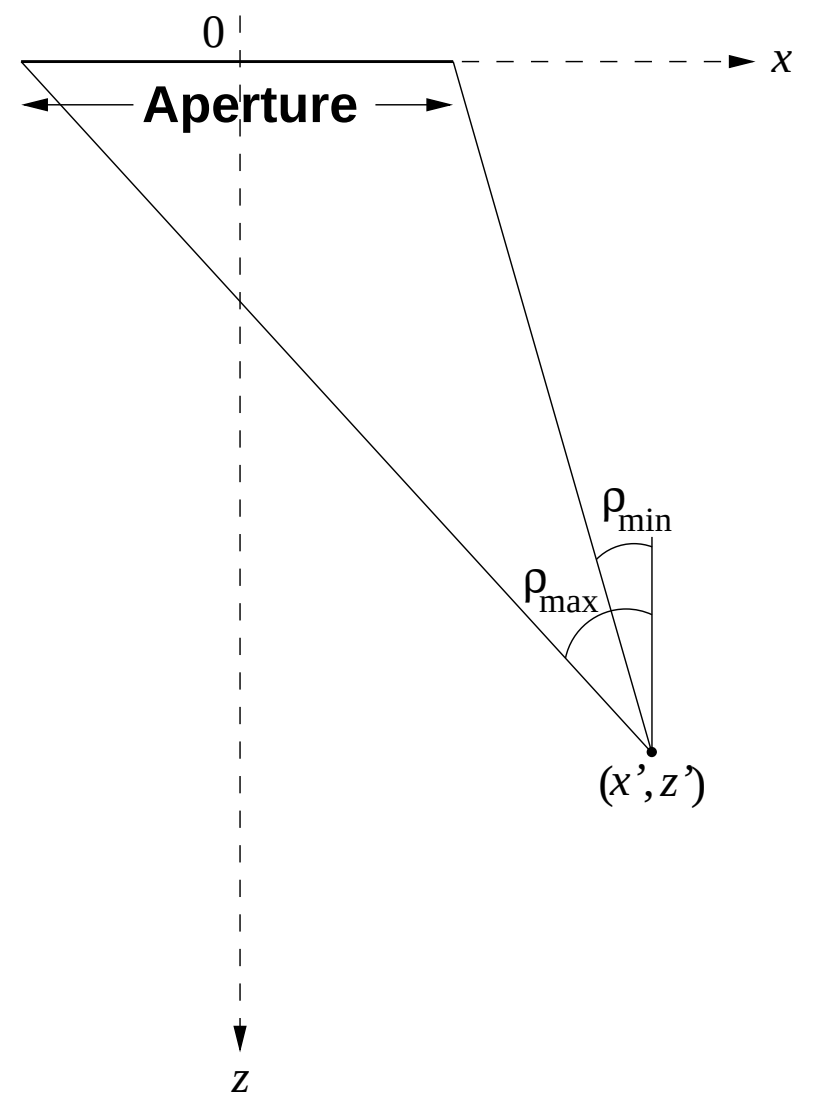
Model signals along aperture from point source at (x', z') as

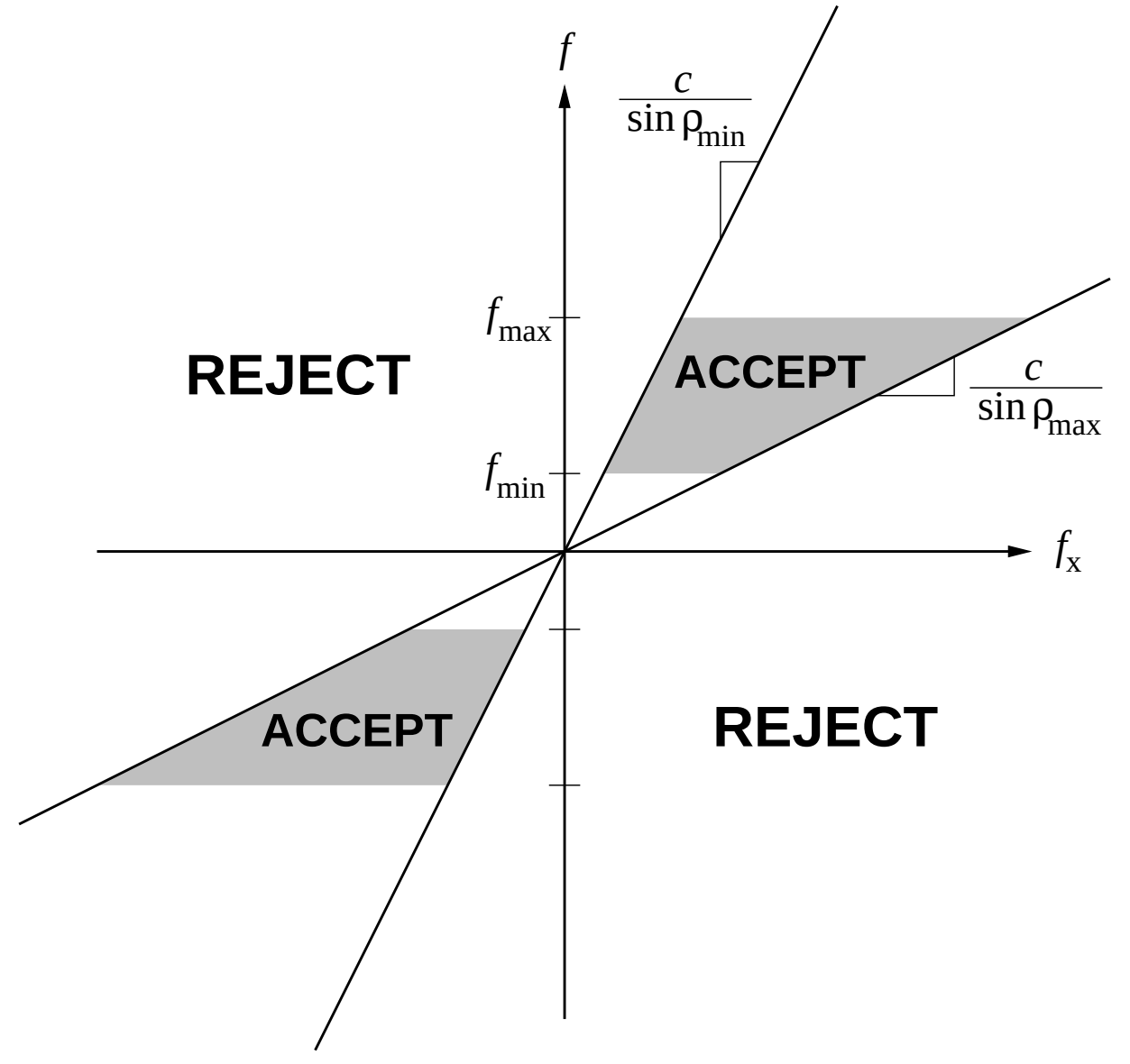
$$\tilde{d}(x,t) = p\left[t - \frac{1}{c}\left((x-x')^2 + z'^2\right)^{1/2} - \tau(x)\right], \qquad (2)$$

where $p(t)$ is xmit pulse and $\tau(x)$ is aberration profile.
If no aberration, can show

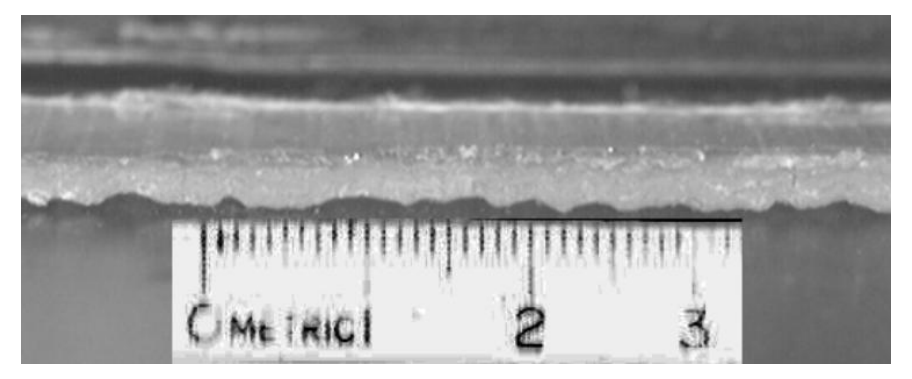
$$F_x = -\frac{F}{c}\frac{x-x'}{\left((x-x')^2+z'^2\right)^{1/2}} = \frac{F}{c}\sin\rho. \qquad (3)$$

That is, the 2-D spectrum occupies a fan-shaped region.

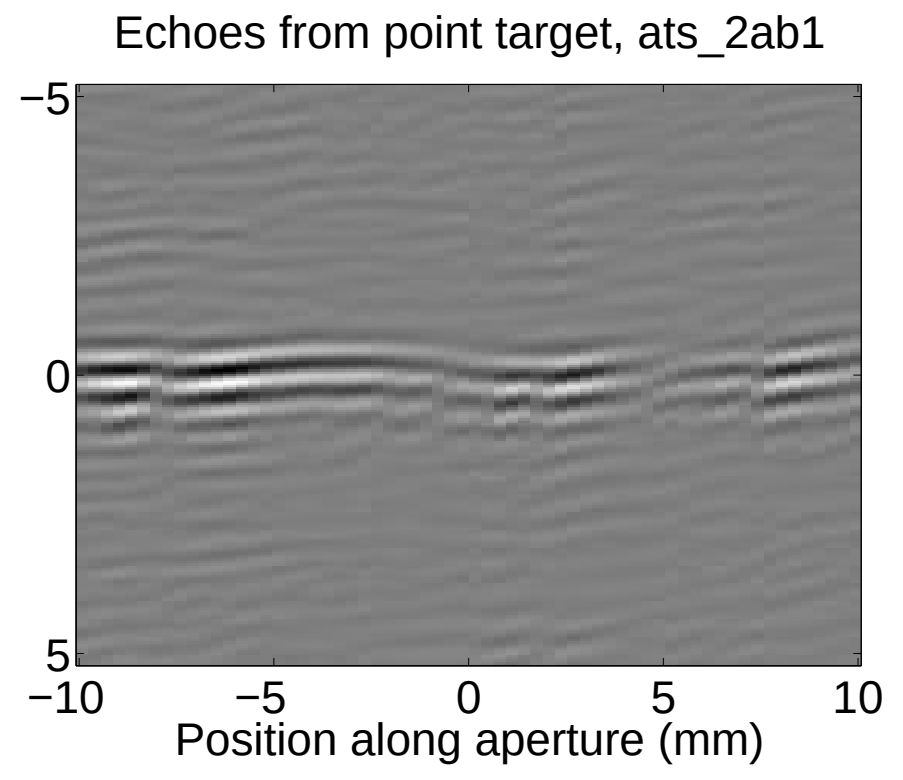




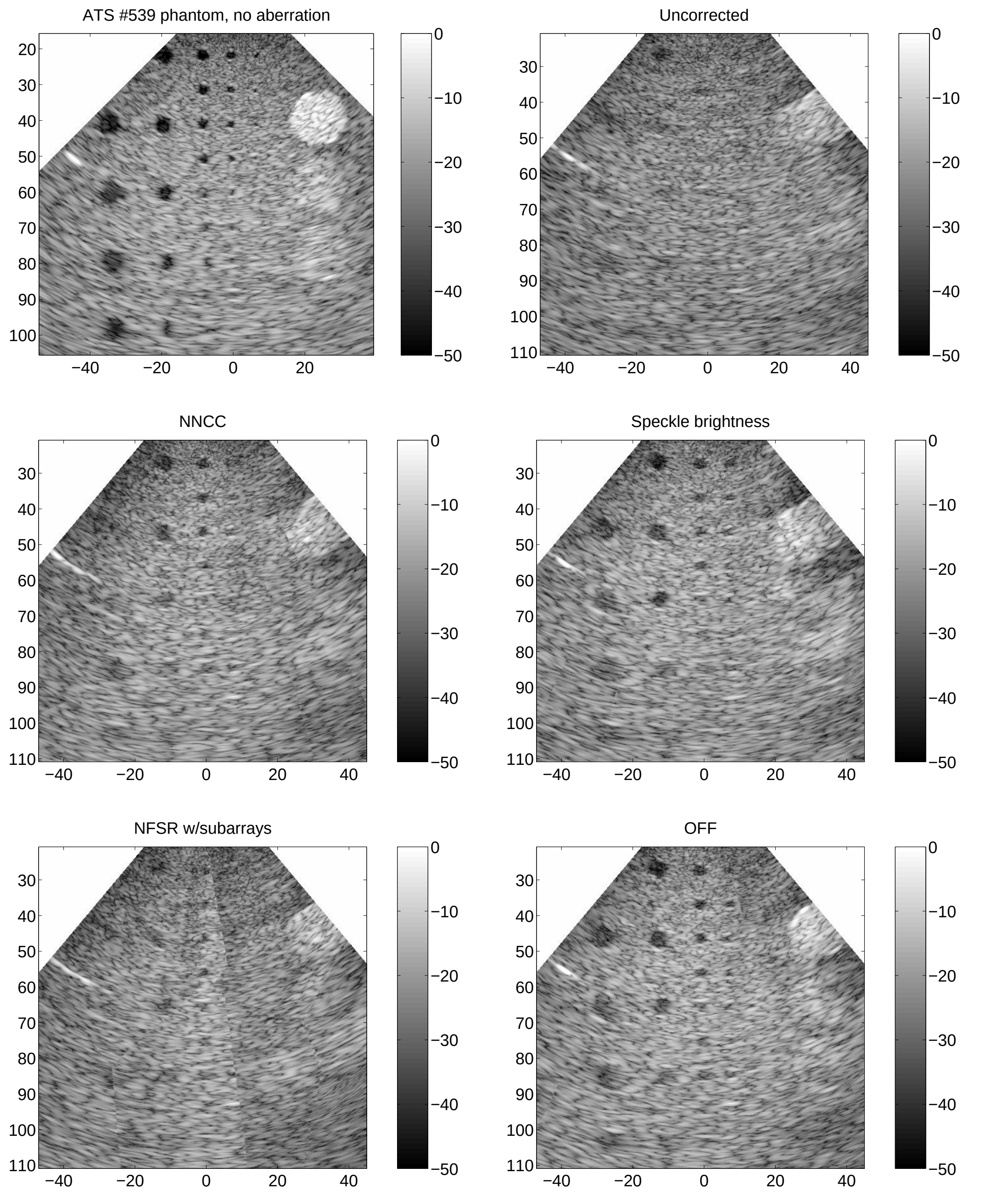
Idea: Pre-filter data to select θ-ranges of interest.
(Still viable even under moderate aberration)



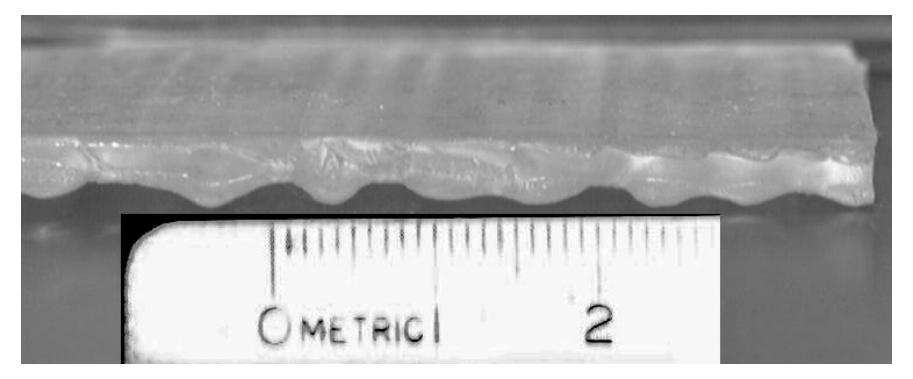
"Thin" aberrator: 3-mm-thick GE RTV615, 6 mm from transducer.



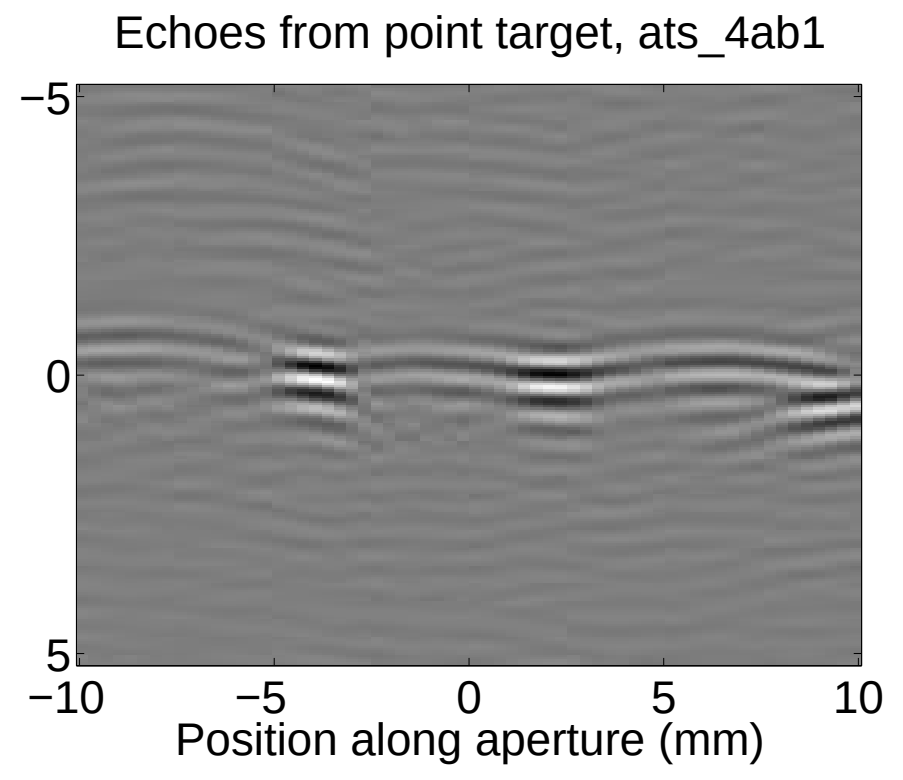
The wavefield from a point reflector: Note the amplitude fluctuations and discontinuities caused by diffraction.



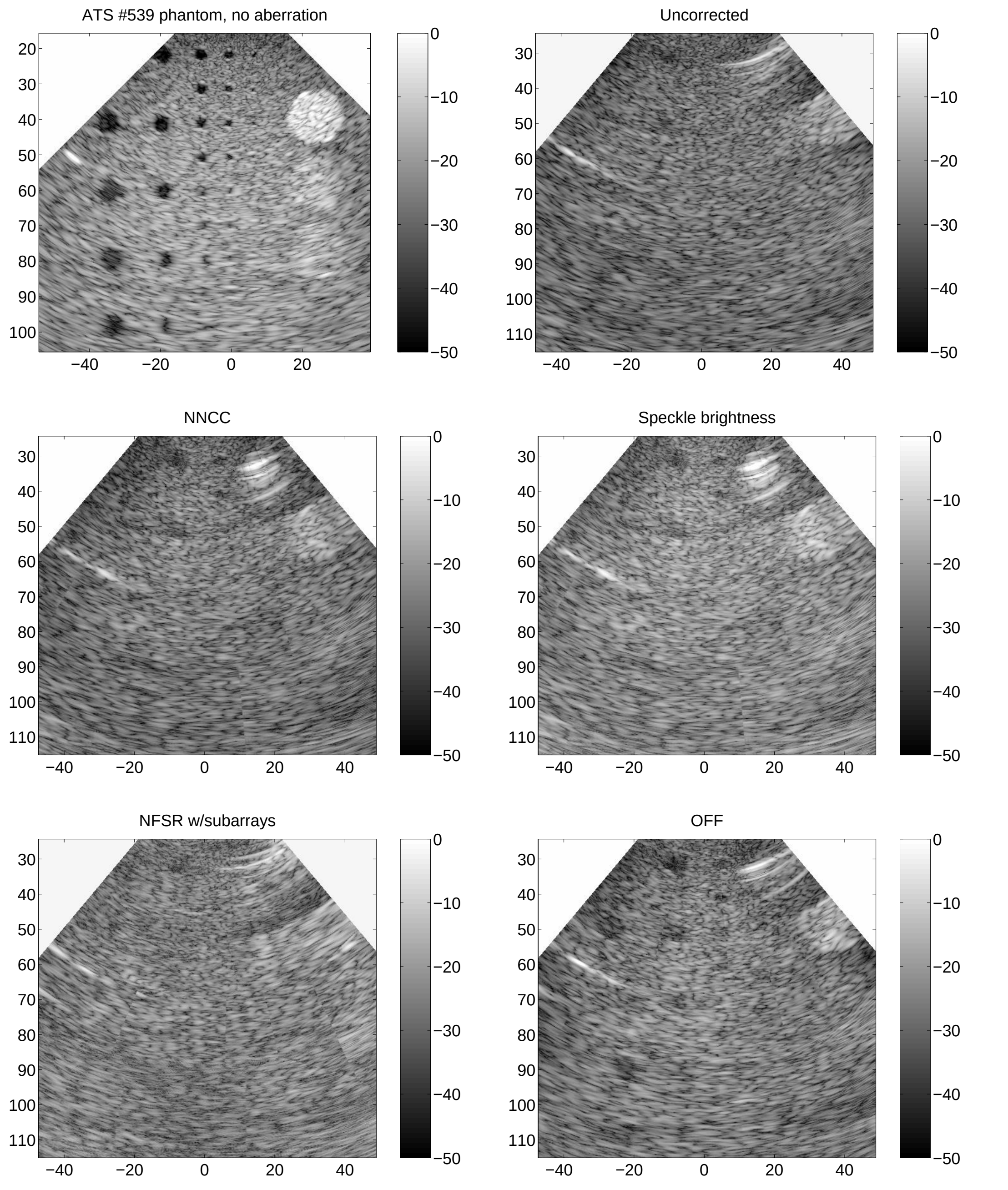
Images from data acquired through "thin" aberrator: Control (no aberration), uncorrected, and corrected with aberration profiles supplied by four different algorithms. (Axis labels in millimeters.)



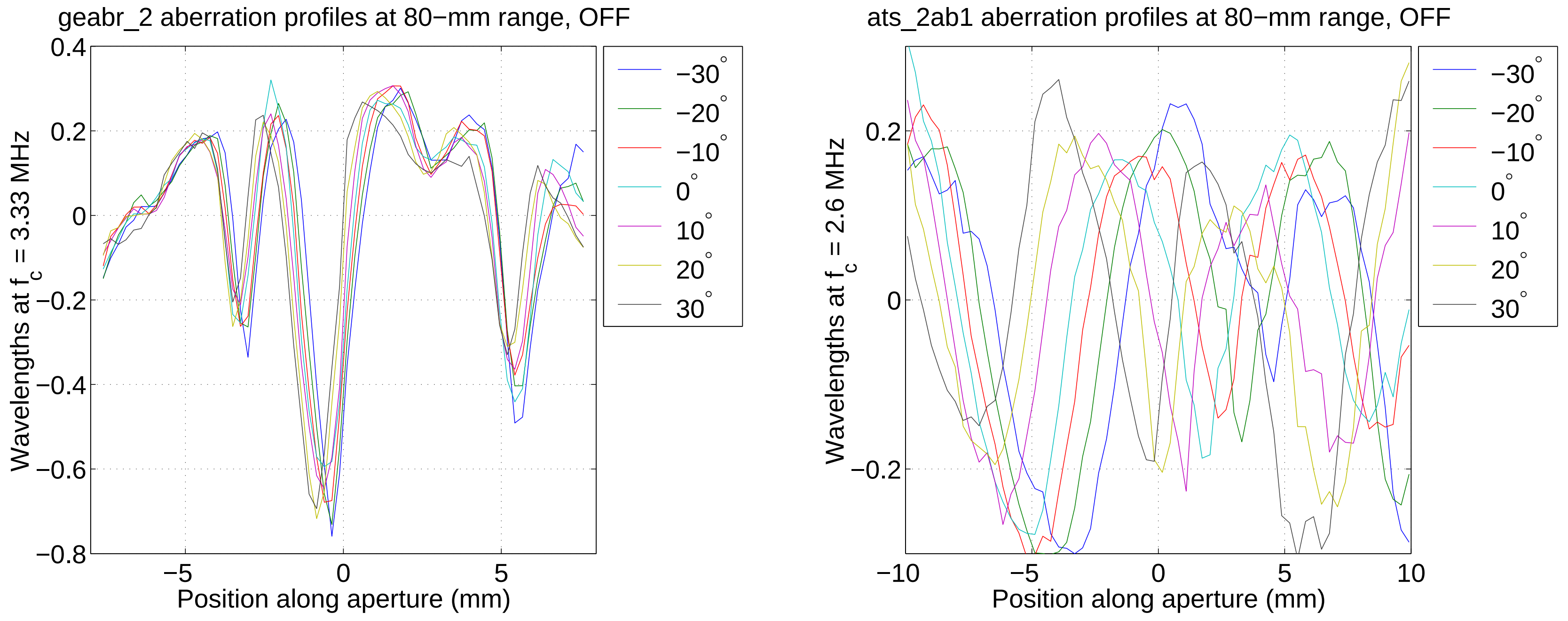
"Thick" aberrator: 4-mm-thick GE RTV615, 9 mm from transducer.



The wavefield from a point reflector: Note the extreme amplitude fluctuations and severe diffraction artifacts.



Images from data acquired through "thick" aberrator: Control (no aberration), uncorrected, and corrected with aberration profiles supplied by four different algorithms. (Axis labels in millimeters.)



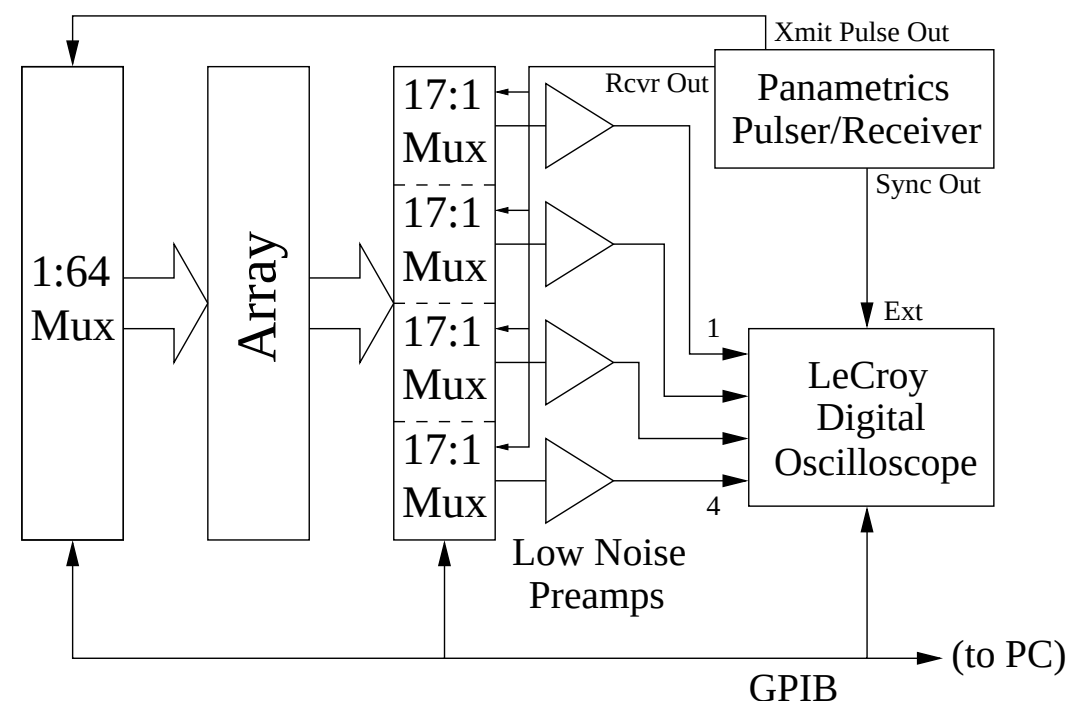
OFF-estimated aberration profiles for two data sets illustrate the algorithm's ability to find accurate profiles over a wide steering range. Left: Near-field aberration from "2X" aberrator in [4]; Right: Aberration from "thin" aberrator, above.

3 Overdetermined, Fan-Filtering Algorithm (OFF)

Given a complete data set from an N-element, 1-D transducer,

1. Split the data into N wavefields, one for each single-element firing.
2. Apply fan filters to these N wavefields, preserving echoes from the region of interest.
3. Correct common-midpoint signals for moveout using (1).
4. Cross-correlate to find pairwise time-shifts between common-midpoint signals.
5. Form overdetermined linear system, regularize, and solve for aberration profile using SVD.
6. Repeat process for each region of interest.

4 Experimental Results



Complete data were collected using a 1-D, 2.6-MHz array transducer and a custom data acquisition system which was able to select single elements for transmit and receive. Aberration profiles were estimated for up to 28 regions of interest distributed in azimuth and range. These estimated profiles were used to form the images in the center panel.

5 Conclusions and Future Work

- OFF resulted in the best images for the data sets tested.
- Still hope for even better screen-model algorithms.
- Note: Problem very similar to seismic "statics correction." [5]
  Main difference is addition of fan filtering.

Still to do:

- Obtain complete data from clinical settings (use pulse compression?).
- Extend to multirow transducers (costly but straightforward).
- Consider iteration.

References

[1] S. W. Flax and M. O'Donnell, "Phase-aberration correction using signals from point reflectors and diffuse scatterers: Basic principles," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 35, no. 6, pp. 758–767, November 1988.

[2] L. Nock, G. E. Trahey, and S. W. Smith, "Phase aberration correction in medical ultrasound using speckle brightness as a quality factor," *Journal of the Acoustical Society of America*, vol. 85, no. 5, pp. 1819–1833, May 1989.

[3] Y. Li, "Phase aberration correction using near-field signal redundancy—Part I: Principles," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 44, no. 2, pp. 355–371, March 1997.

[4] M. O'Donnell and S. W. Flax, "Phase-aberration correction using signals from point reflectors and diffuse scatterers: Measurements," *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control*, vol. 35, no. 6, pp. 768–774, November 1988.

[5] M. T. Taner, F. Koehler, and K. A. Alhilali, "Estimation and correction of near-surface time anomalies," *Geophysics*, vol. 39, no. 4, pp. 441–463, August 1974.