

LA-UR-12-26653

Approved for public release; distribution is unlimited.

Title: Acoustic Imaging of Delaminations and Cracks Using Time Reversal and Nonlinear Spectroscopy Techniques

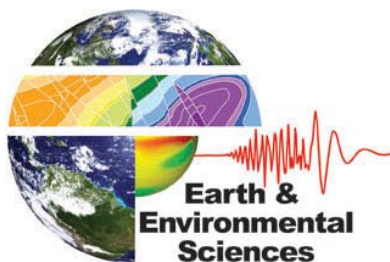
Author(s): Anderson, Brian E.
Ten Cate, James A.
Ulrich, Timothy J. II
Le Bas, Pierre-Yves

Intended for: Fall TCG-I Meeting, 2012-11-27/2012-11-29 (Los Alamos, New Mexico, United States)



Disclaimer:

Los Alamos National Laboratory, an affirmative action/equal opportunity employer, is operated by the Los Alamos National Security, LLC for the National Nuclear Security Administration of the U.S. Department of Energy under contract DE-AC52-06NA25396. By approving this article, the publisher recognizes that the U.S. Government retains nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes. Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy. Los Alamos National Laboratory strongly supports academic freedom and a researcher's right to publish; as an institution, however, the Laboratory does not endorse the viewpoint of a publication or guarantee its technical correctness.



Acoustic Imaging of Delaminations and Cracks Using Time Reversal and Nonlinear Spectroscopy Techniques

LANL EES-17 Acoustics Team:

Brian E. Anderson

James A. Ten Cate

Timothy J. Ulrich

Pierre-Yves Le Bas

Motivation for Our Work

- China Lake rocket motors (solid fuel) - delaminations between fuel and outer casing.
- Mock propellant manufactured delamination sample.
- We inspect samples at low vibration levels (doesn't further damage the samples).
- We look for delaminations and cracks.
- We're developing a noncontact source to use with our noncontact sensor for inspection of samples.



Slide 2

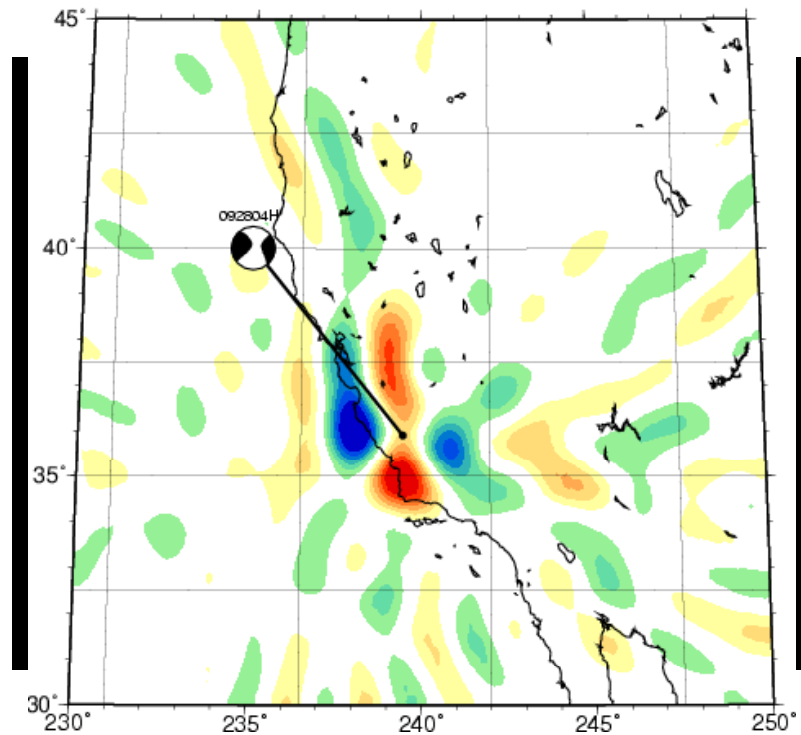
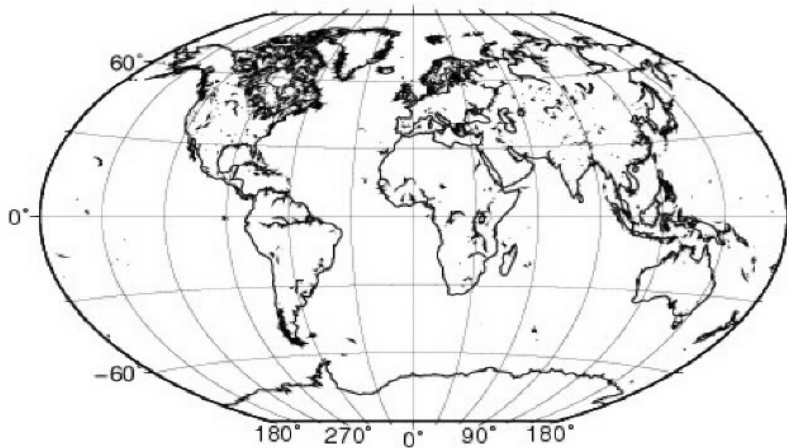
Imagine Reversing the Ripples in a Pond



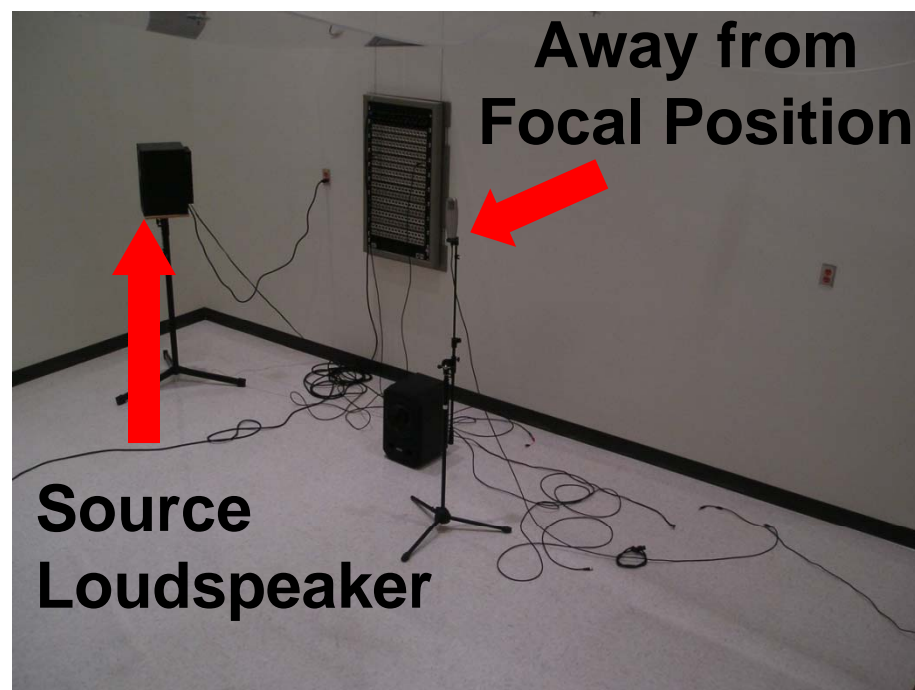
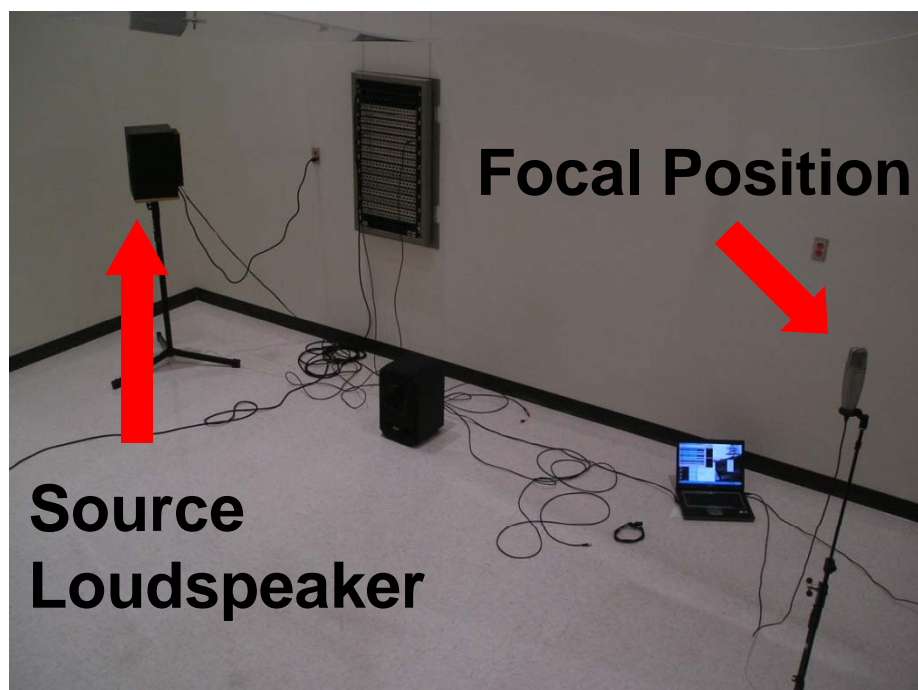
Larmat *et al.*, Geophys. Res. Lett., (2009).
Anderson *et al.*, Acoust. Today, (2008).

Time Reversal of Earthquakes

Time : 4914 s



Audio Demonstration for Speech Privacy



Clap



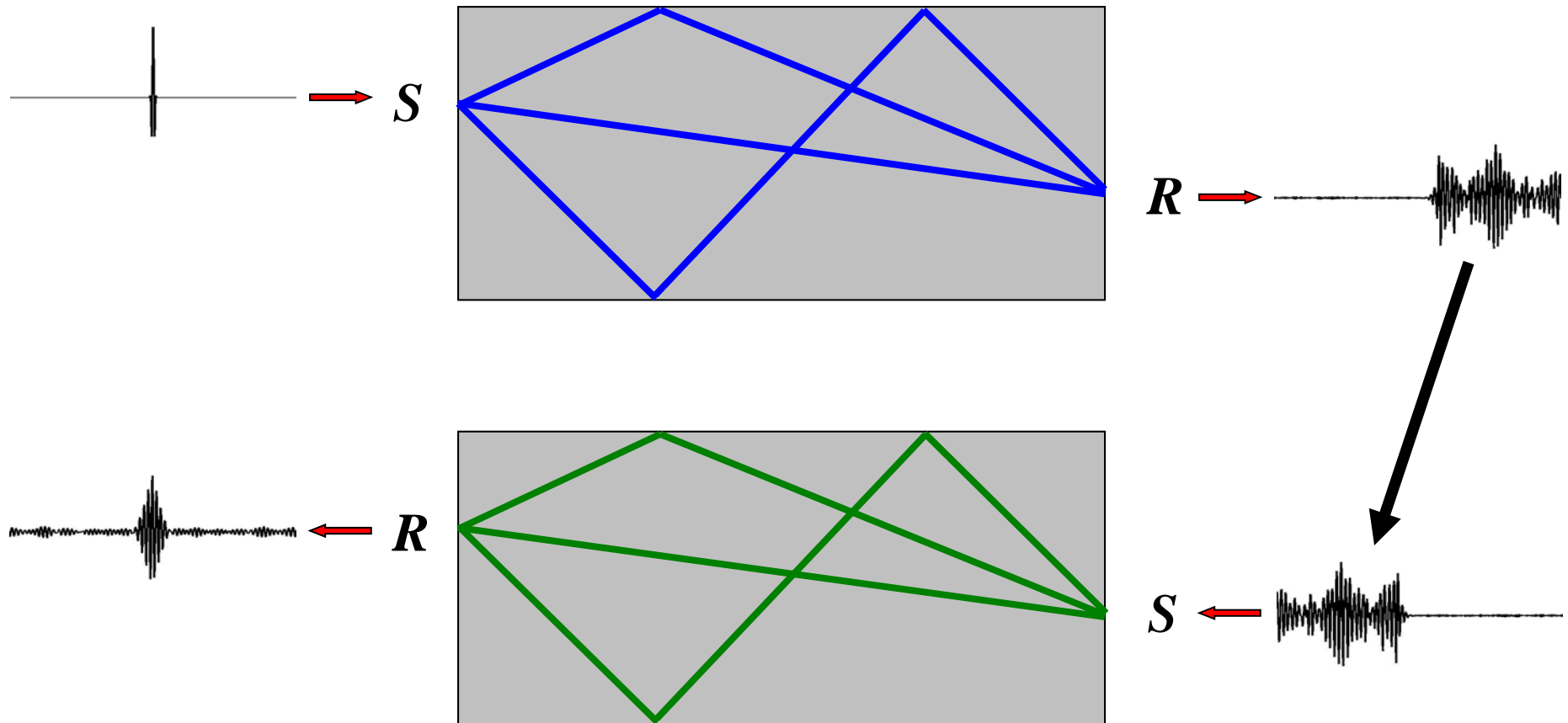
Away



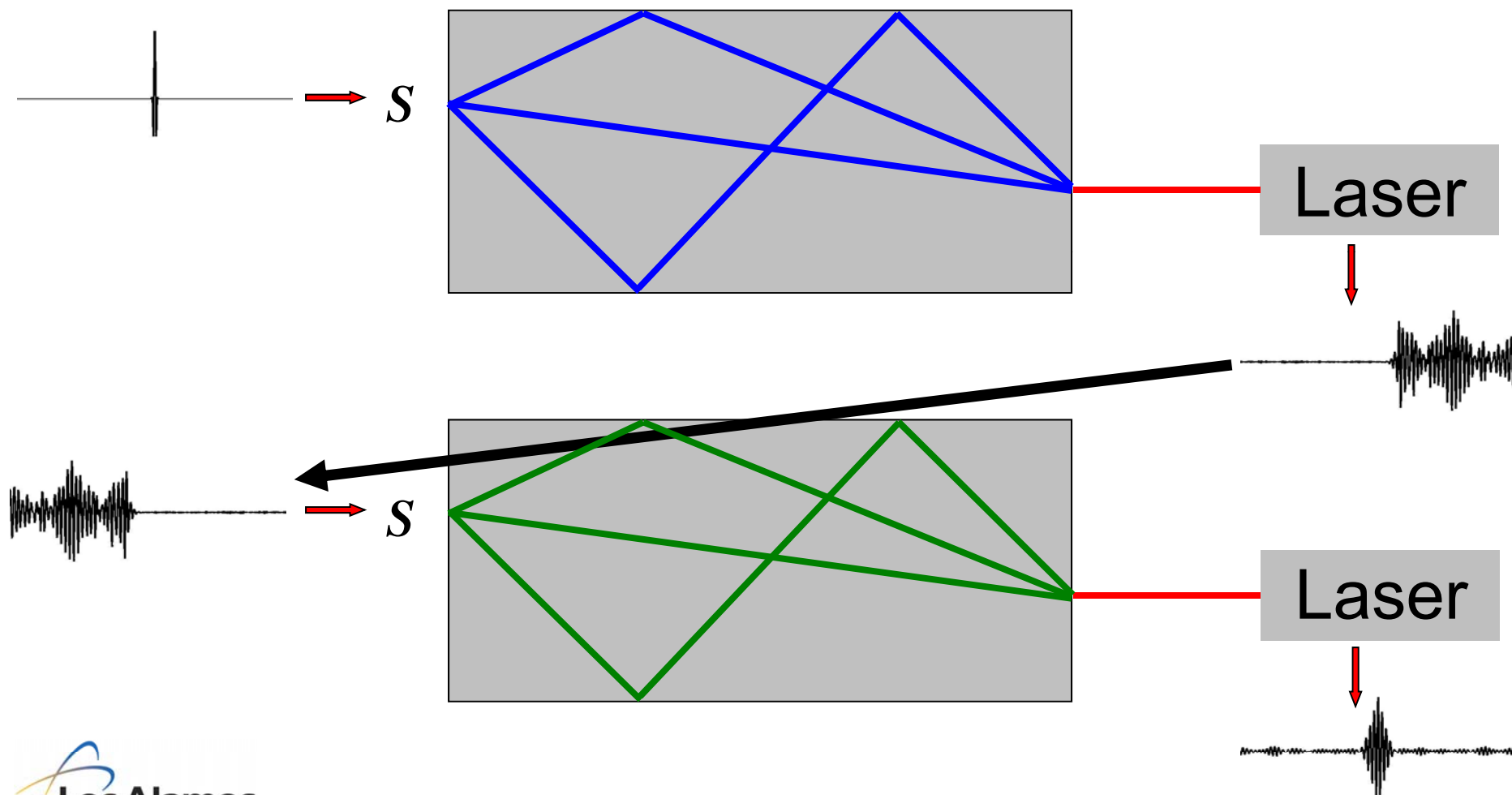
Focus



Standard Time Reversal (Source Reconstruction)

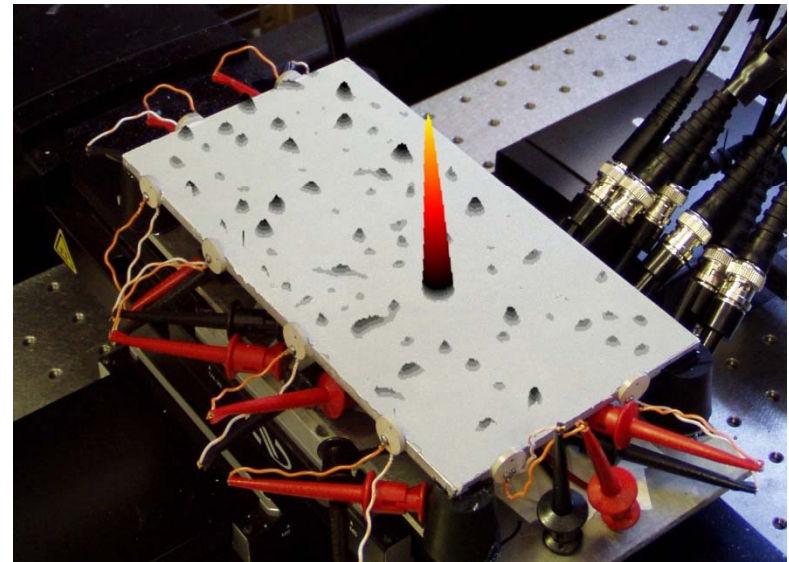
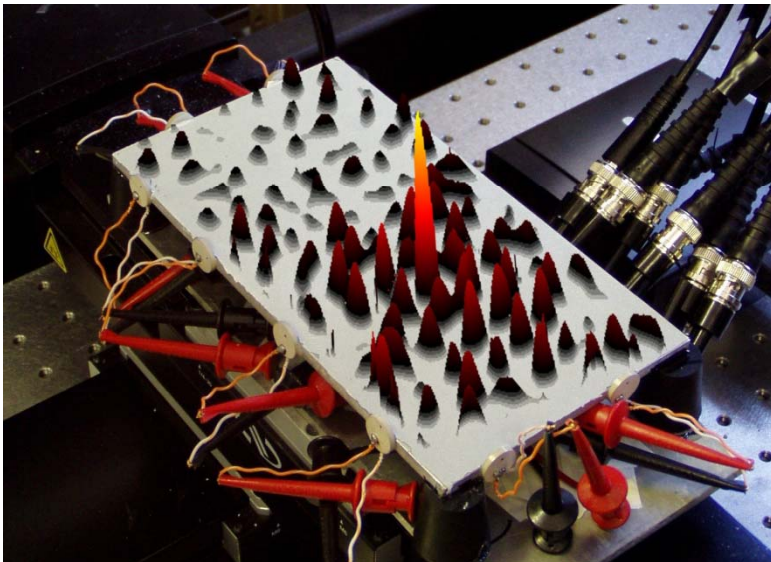
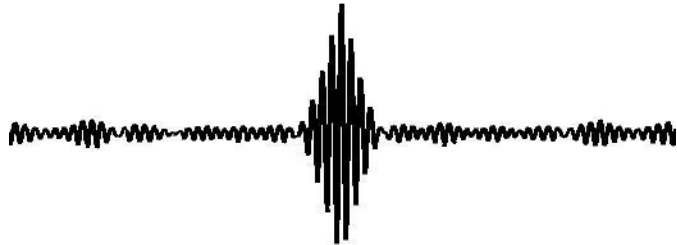


Reciprocal Time Reversal (High Amplitude Focusing)

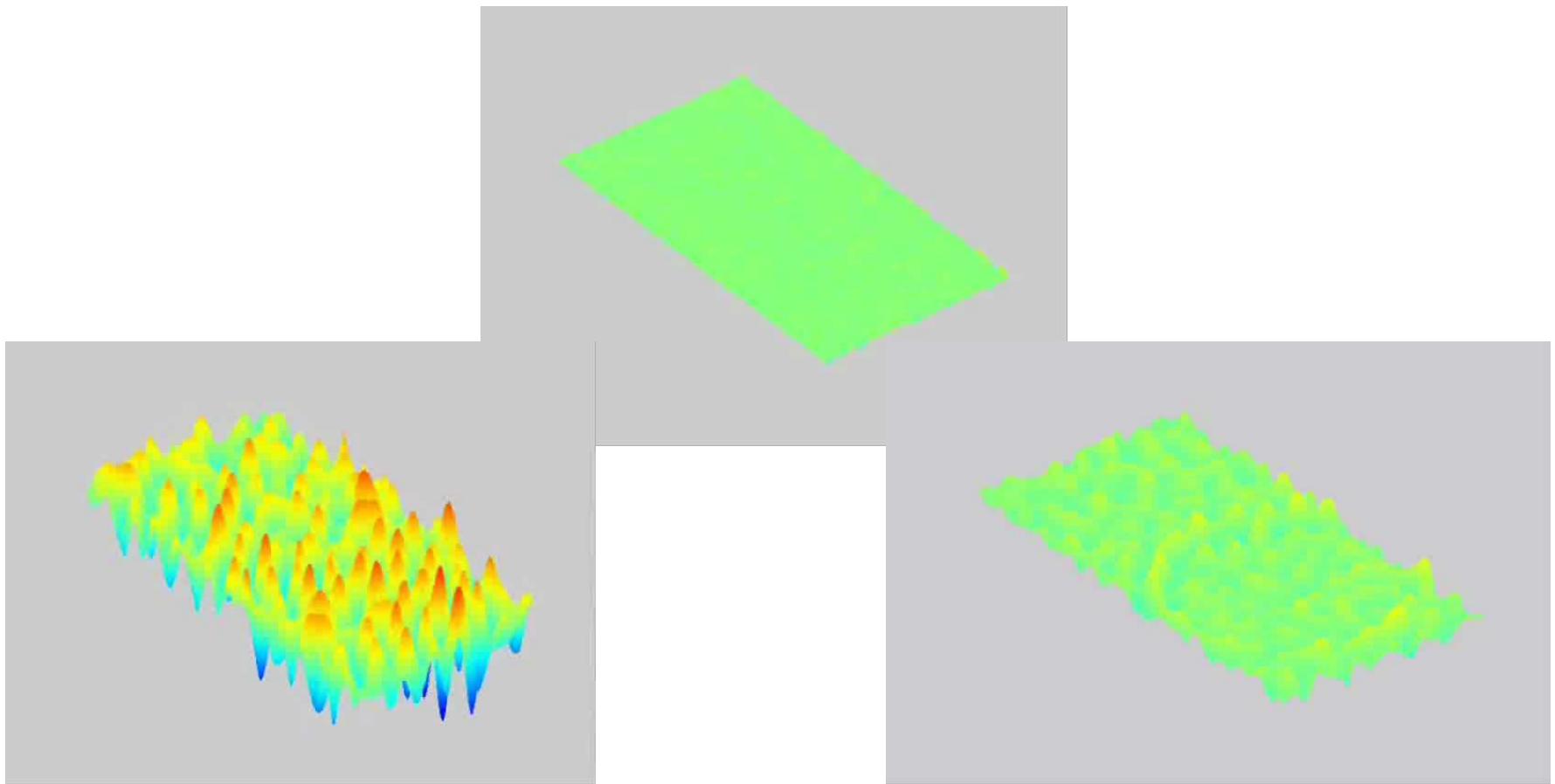


Anderson *et al.*, Acoust. Today, (2008).
Ulrich *et al.*, J. Acoust. Soc. Am., under review.

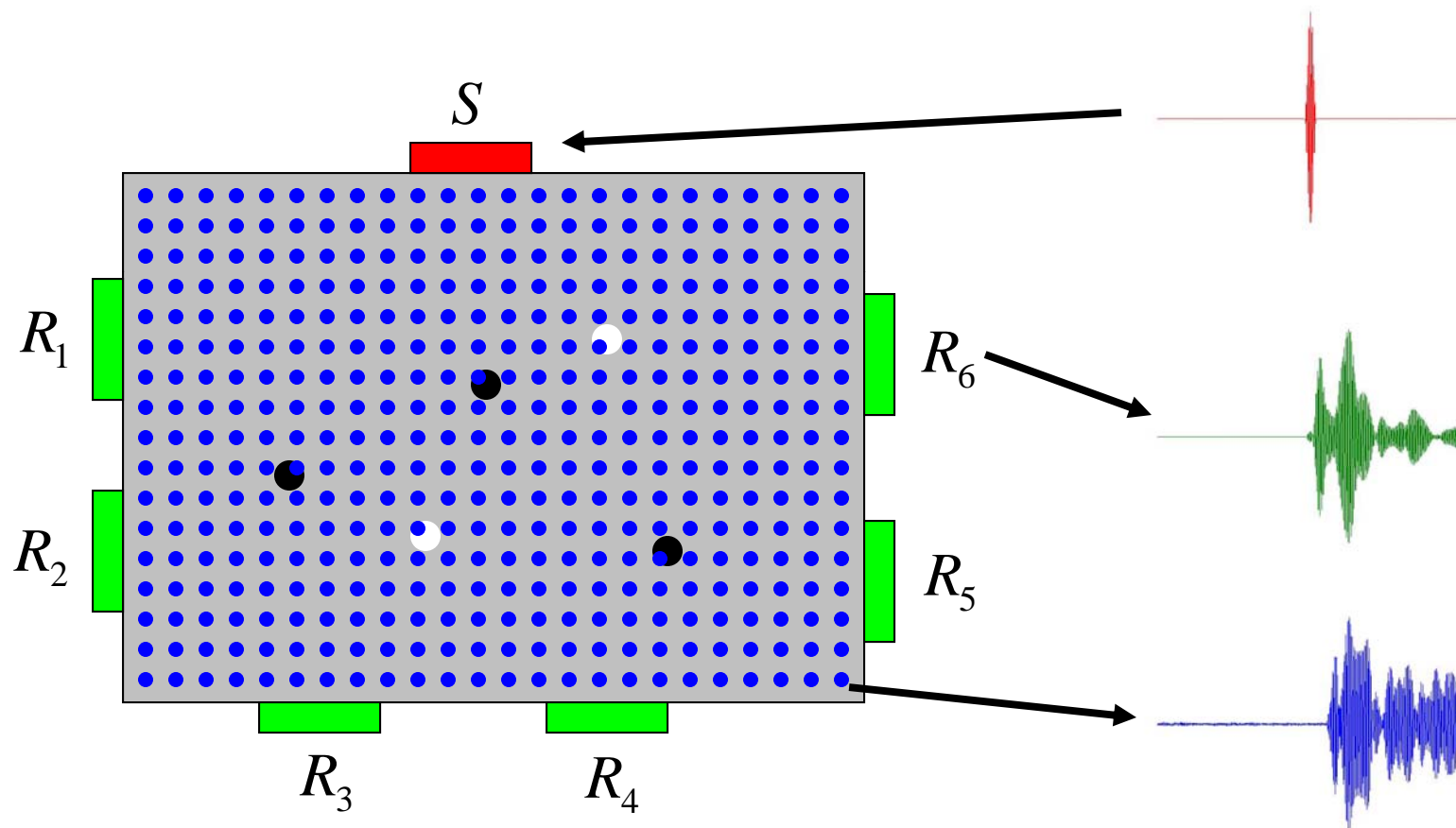
Comparison of Time Reversal w/ and w/o Deconvolution



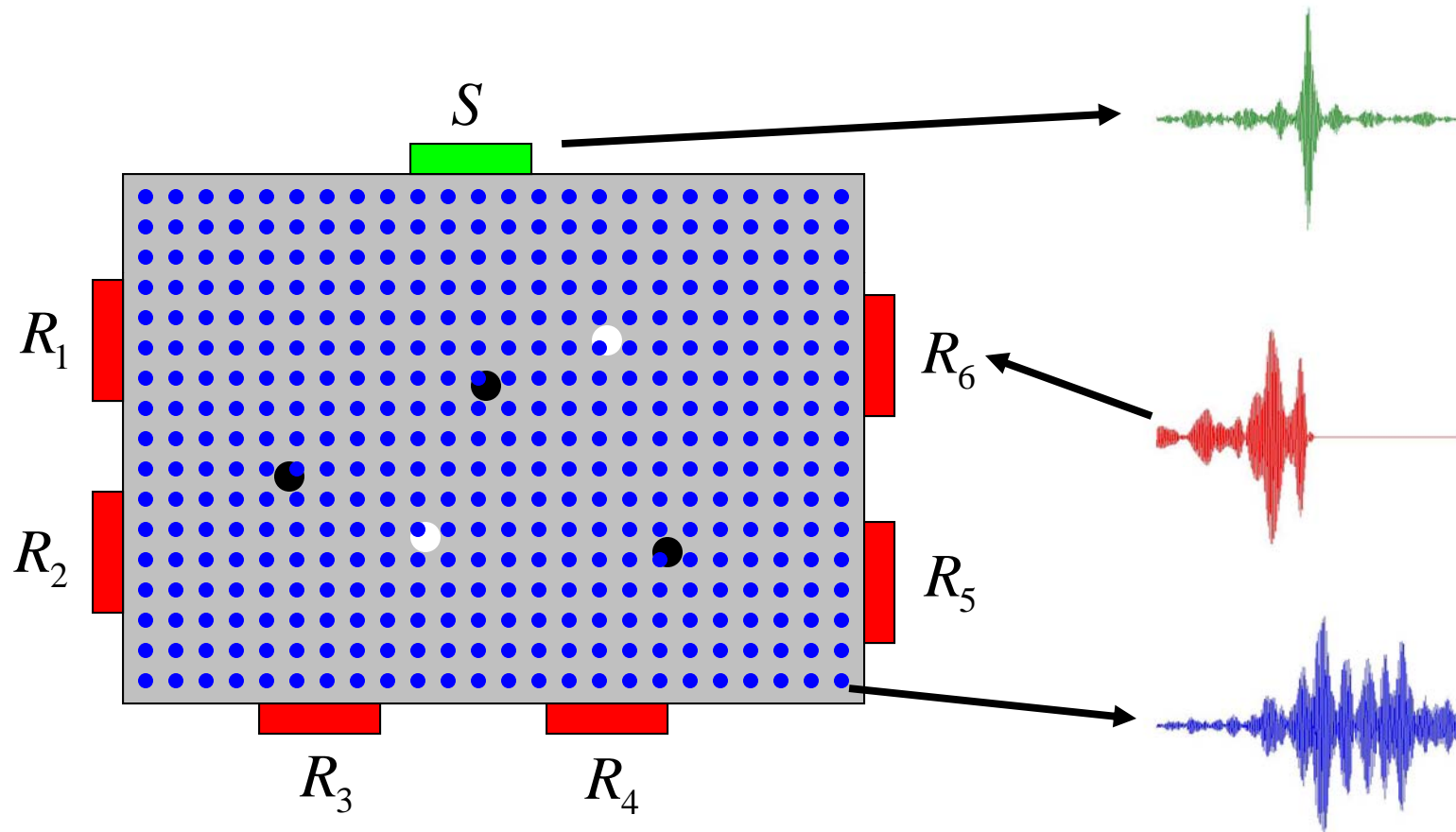
Time Reversal – Wave Propagation Movies



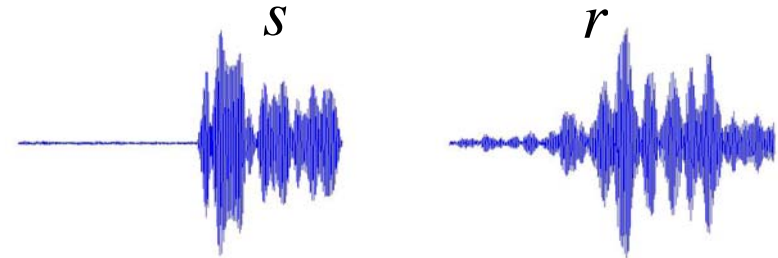
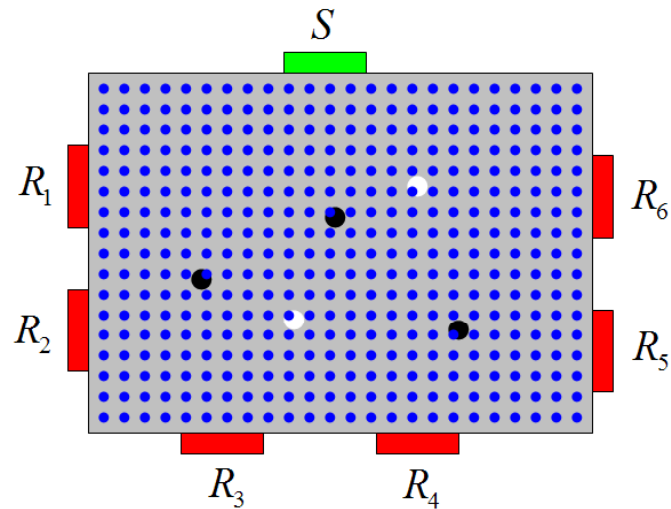
Reverse Time Migration to Image Delaminations



Reverse Time Migration to Image Delaminations



Reverse Time Migration to Image Delaminations



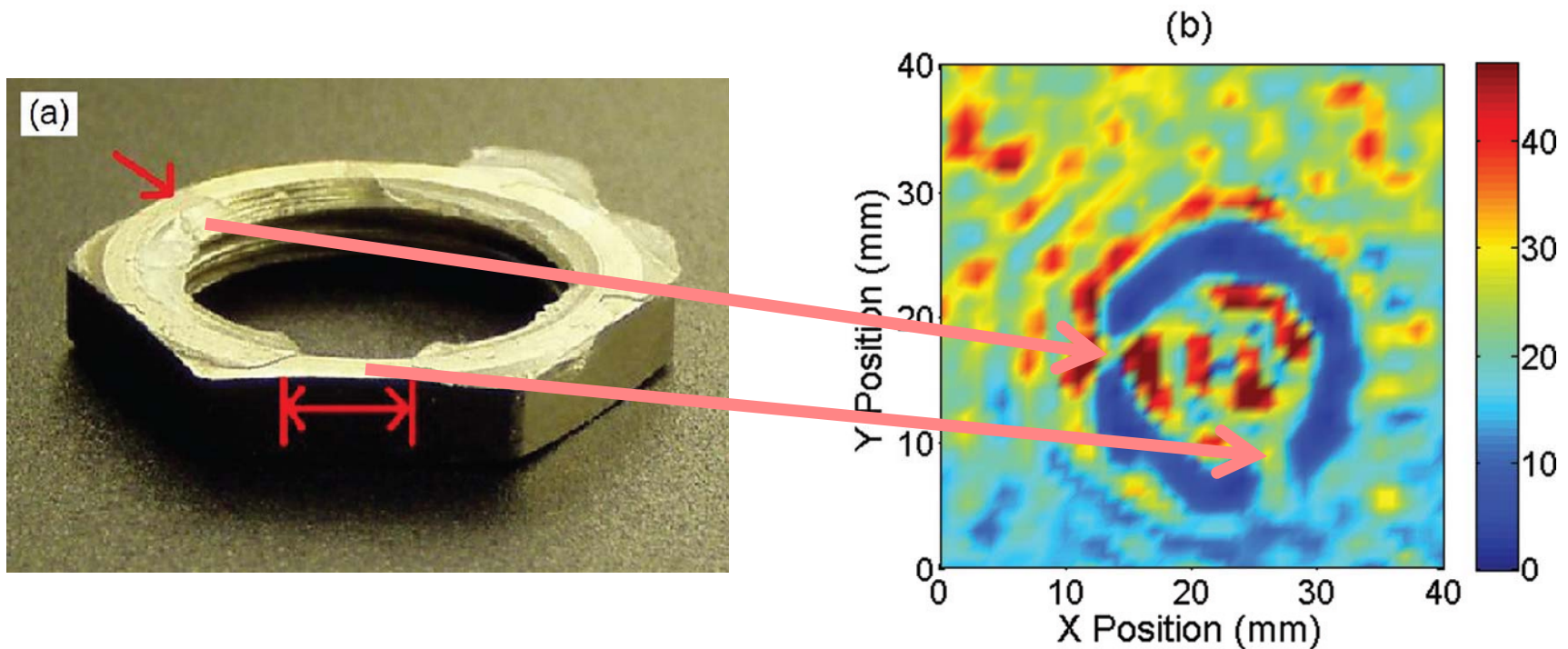
$$IC = \{s(x_s, y_s, t) \otimes r(x_s, y_s, t)\}_{t=0}$$

$$IC = \sum_{i=f_L}^{f_H} |S(x, y, \omega_i) \cdot R(x, y, \omega_i)|$$

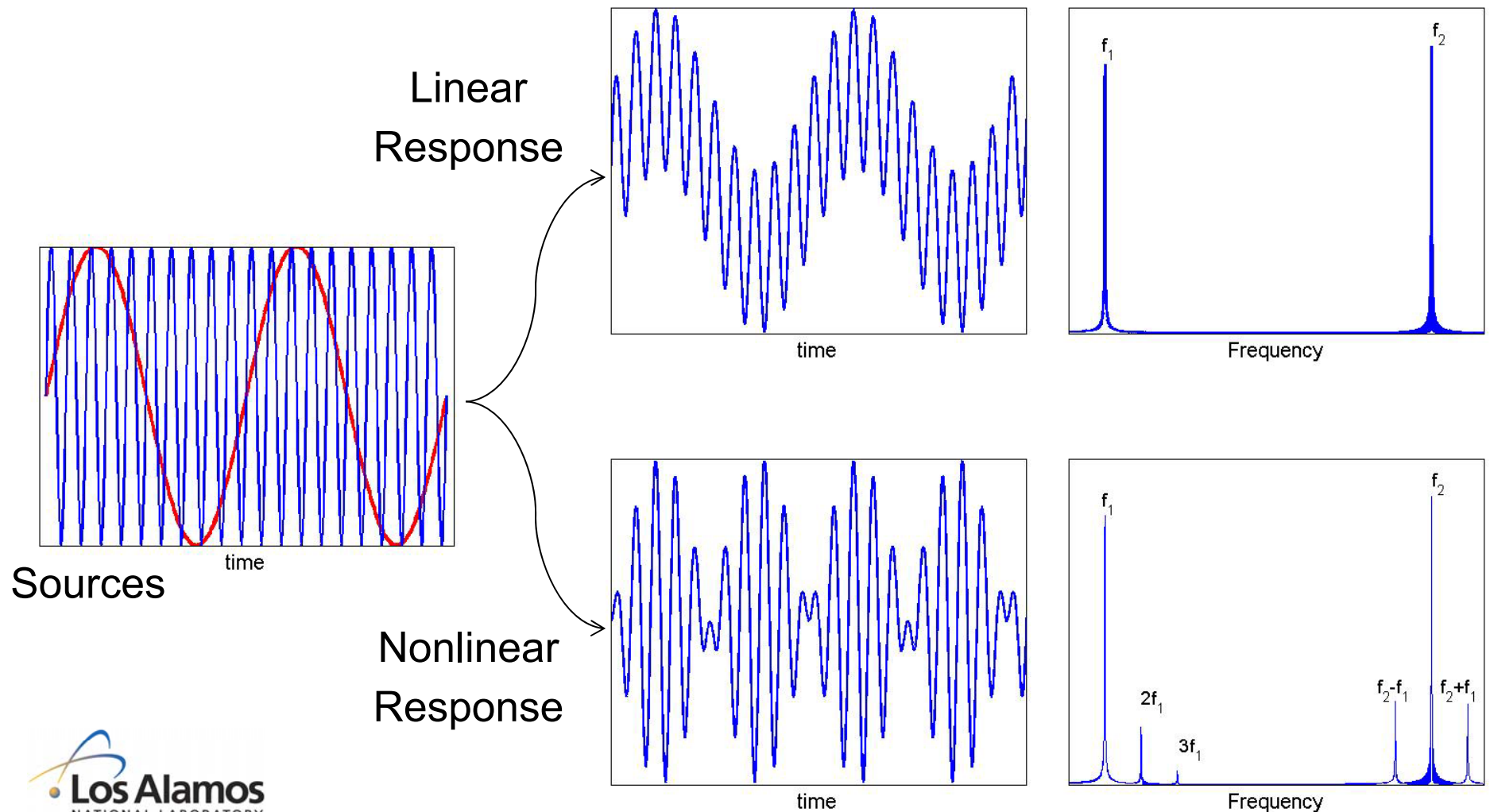
High Impedance Scatterers \rightarrow Minima

Low Impedance Scatterers \rightarrow Maxima

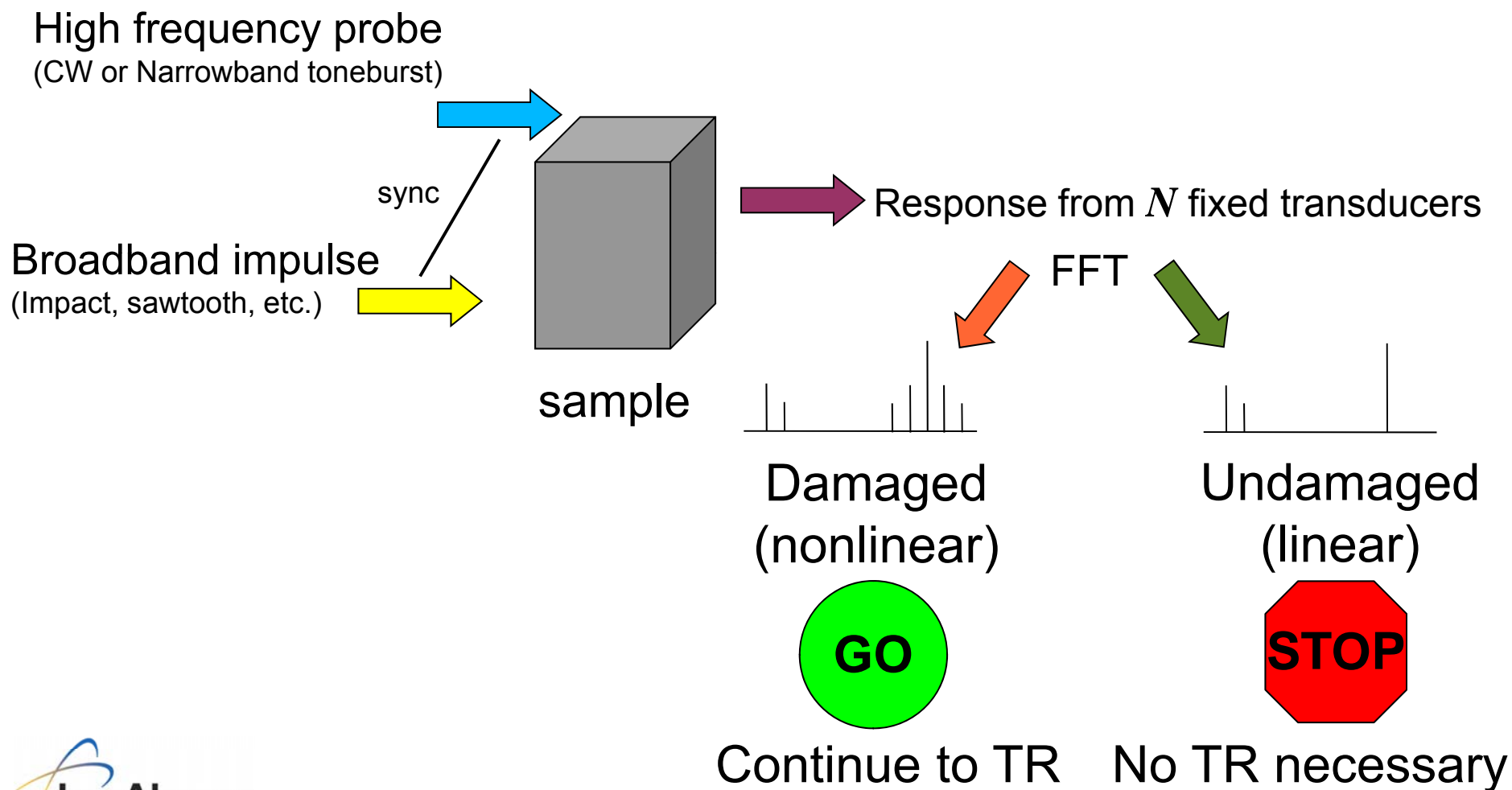
Reverse Time Migration to Image Delaminations



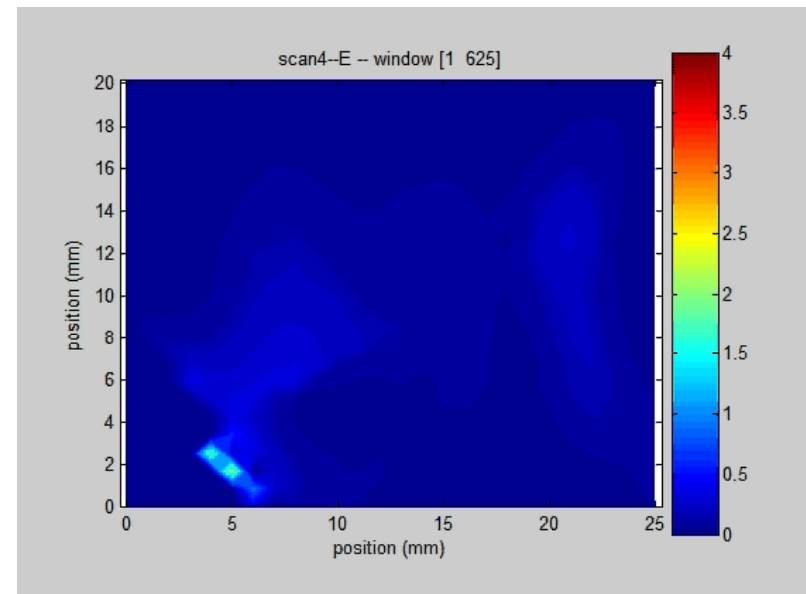
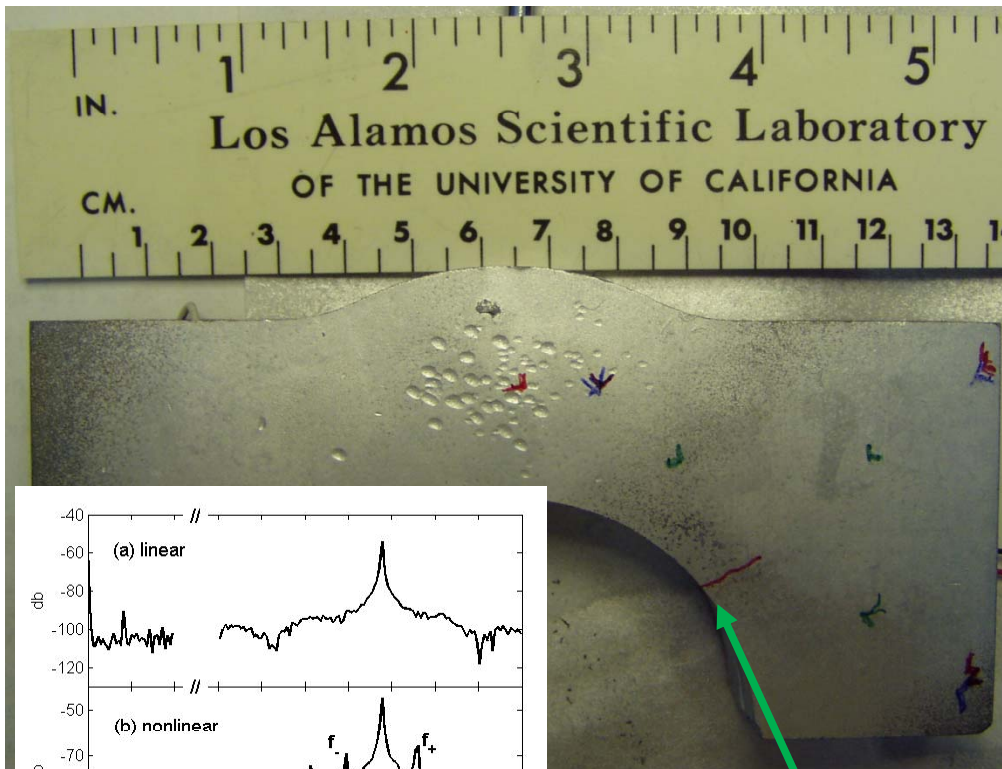
Nonlinear Wave Modulation & Harmonic Generation



Damage Diagnosis through Nondestructive Evaluation (Nonlinear Techniques)



Imaging of a Crack Using Time Reversal

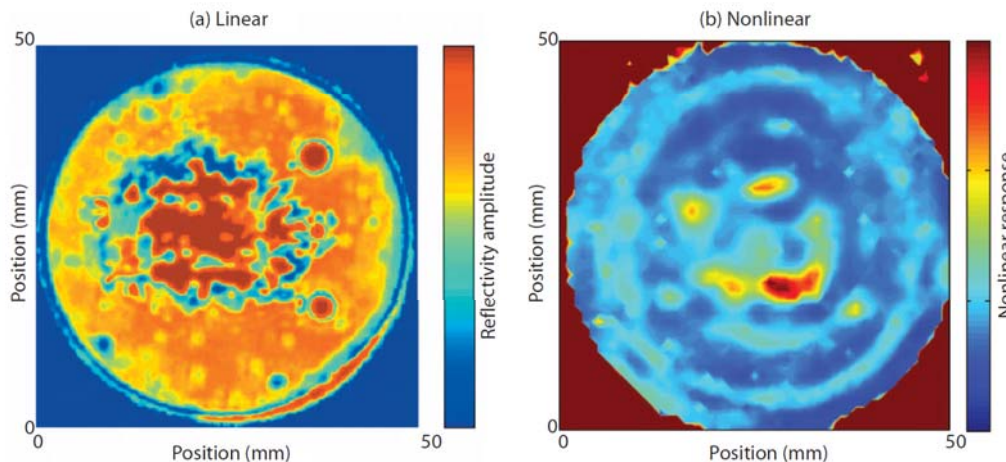
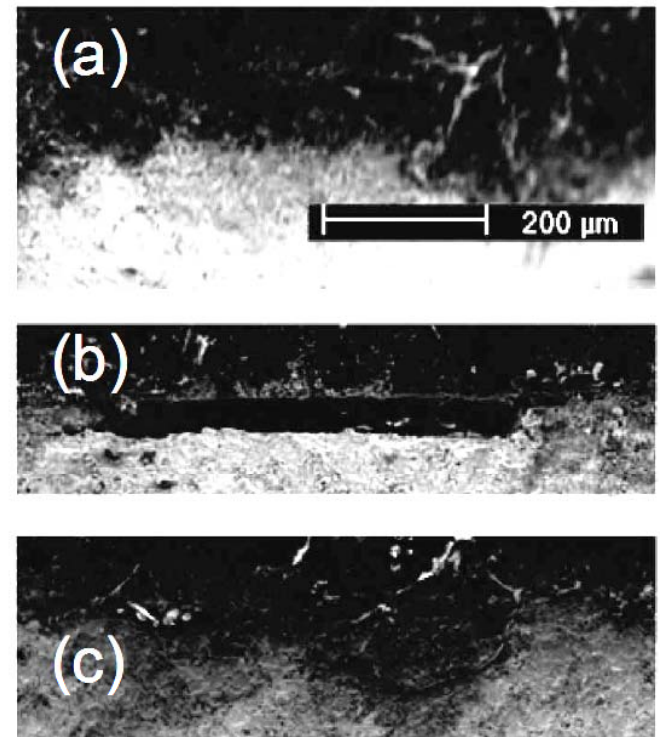


crack

Imaging of Delamination Edges Using Time Reversal and Nonlinear Spectroscopy

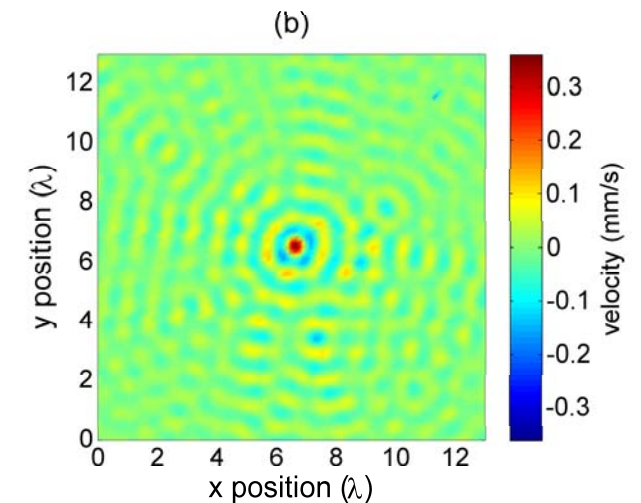
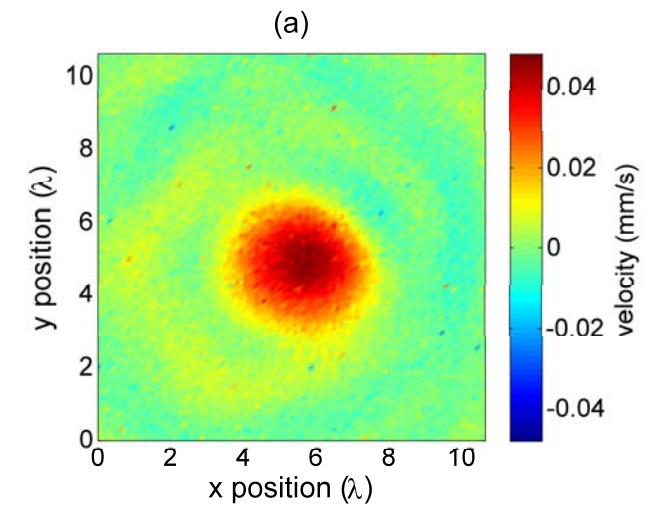
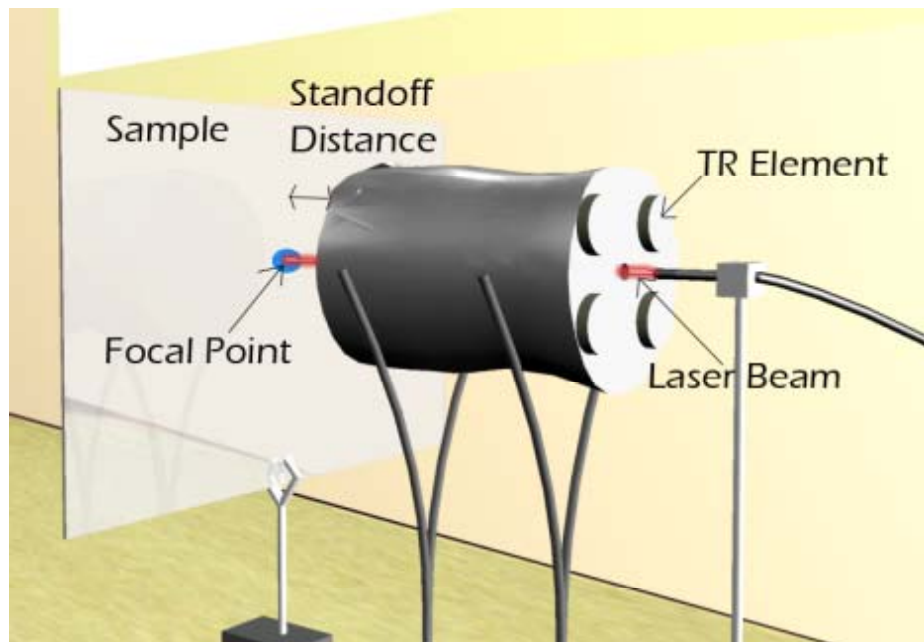
- Two metal disks were diffusion bonded together.
- A linear C-scan imaged voids.
- A nonlinear TR scan imaged edges.
- Small cores were taken to verify findings.

SEM Photos



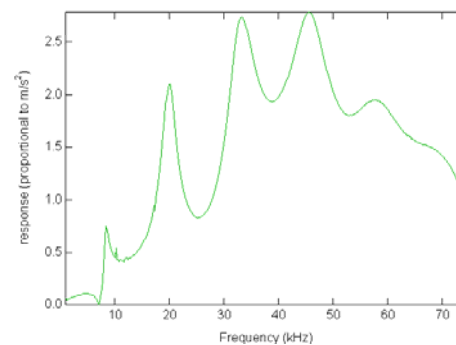
Ulrich *et al.*, Patent Application, (2011).
Le Bas *et al.*, LDRD-ER, (FY12-FY14).

Time Reversal Acoustic Noncontact Source

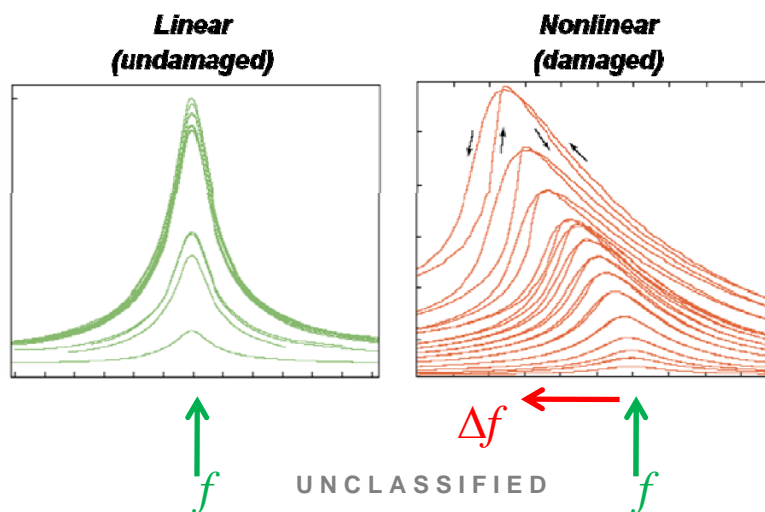


Material Property Determination: RUS & NRUS

- We measure elastic properties of samples using Resonant Ultrasound Spectroscopy (RUS).



- We also measure the nonlinearities in a sample (crack density, damage indicator, etc.) using Nonlinear Resonant Ultrasound Spectroscopy (NRUS).



Conclusions

- Time reversal yields source localization and source characterization, or it may be used to focus high amplitude sound for damage interrogation.
- We use linear and nonlinear acoustic techniques to locate delaminations and cracks.
- Our nonlinear techniques are very sensitive to damage detection.
- Noncontact acoustic source allows sample inspection without contact.
- The goal is to be able to inspect samples for delaminations and cracks without touching them.