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Title: Parametric interaction of Waves in rocks

Author(s): Pierre-Yves Le Bas
James A. TenCate
Robert A. Guyer
Paul A. Johnson

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Parametric interaction of sounds in rocks

Pierre-Yves Le Bas
James A. TenCate
Robert A. Guyer
Paul A. Johnson
Los Alamos National Laboratory, EES-17, MS D443, Los Alamos, NM 87545 USA
(+1) (505) 665-6272, pylb@lanl.gov

Previous measurements of the characteristics of the parametric array in sandstone by Johnson and Shankland [J. Geophys. Res., 94, 17729-17734 (1989)] were difficult to perform and, given the apparatus of the day, only qualitative. Since then, memory effects have been found to play a strong role in the dynamic behavior of rocks. We describe 2 experiments of nonlinear interaction of sounds by sounds in rocks. The first experiment consists of an array of PZT disk transducers (every other one broadcasting one of two frequencies) that was epoxied to a large block of Berea sandstone (1.2x0.4x0.4 m). The two primary frequencies were near 100kHz and chosen to produce a difference frequency around 15kHz. Using a scanning laser vibrometer (Polytec), several scans of the beam patterns were made at the opposite end of the rock and the results compared with calculations based on those commonly used for parametric arrays in water. A narrow beam generated from the two primaries was measured and the beam pattern compared with those of the primaries. The agreement is surprisingly good using a beta of around 200 and a Q of about 50. The second experiment looks at the interaction of two non collinear beams, one longitudinal and one transverse (shear). A third (longitudinal) beam is then created and propagates in a direction defined by the ratio of the two initial frequencies and the ratio of longitudinal speed over transverse speed.

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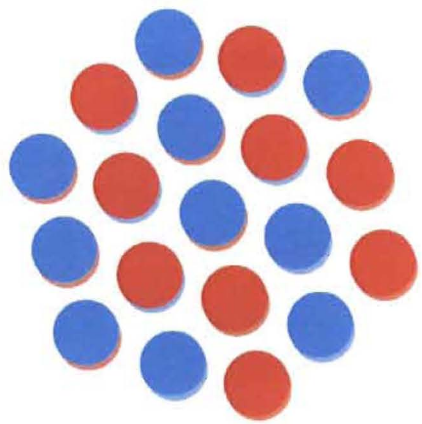
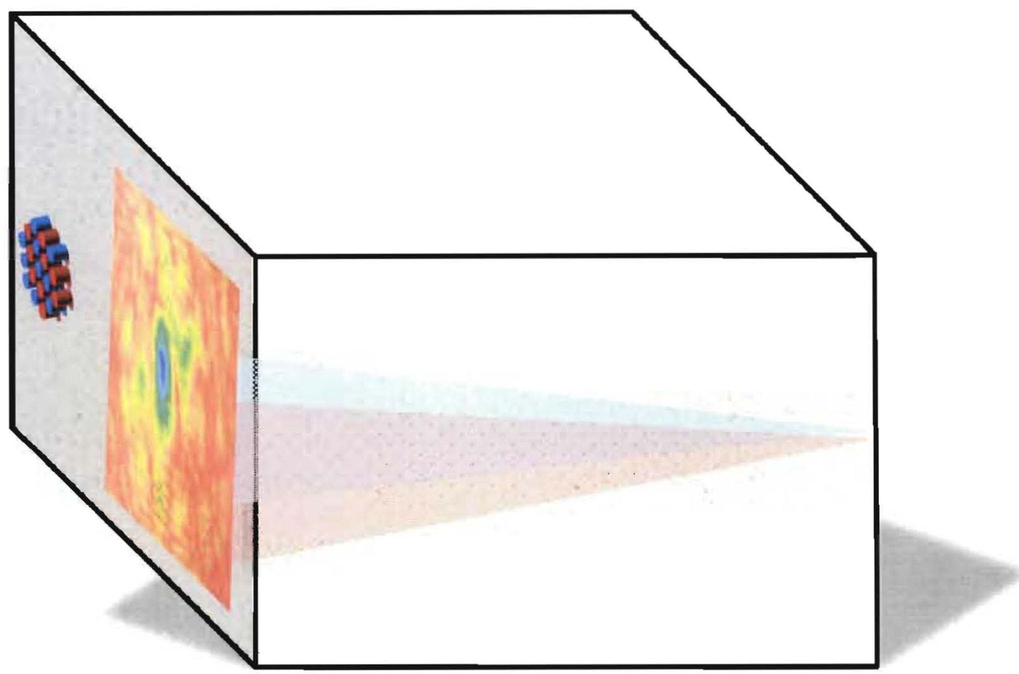
Outline

- Parametric array
    - Beam patterns
    - Extraction of nonlinear parameter
    - Steering the beam
    - Application
- Noncollinear mixing
    - $L+T \rightarrow L$
    - $L+L \rightarrow T$
- Conclusion and applications

Parametric array, principle

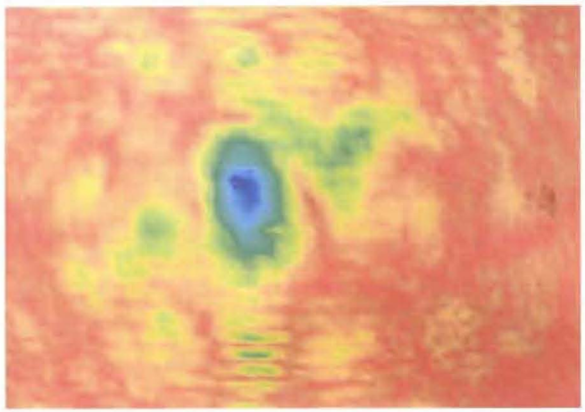




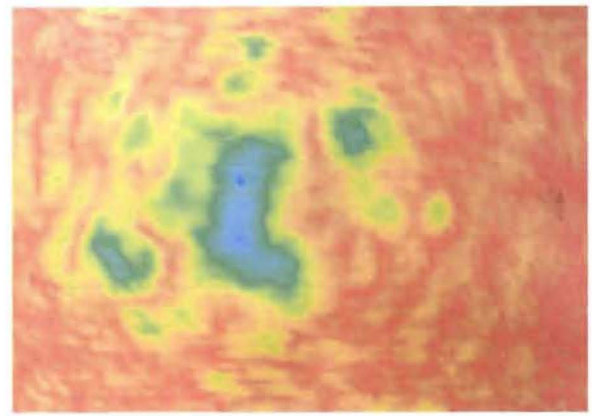
Actual setup

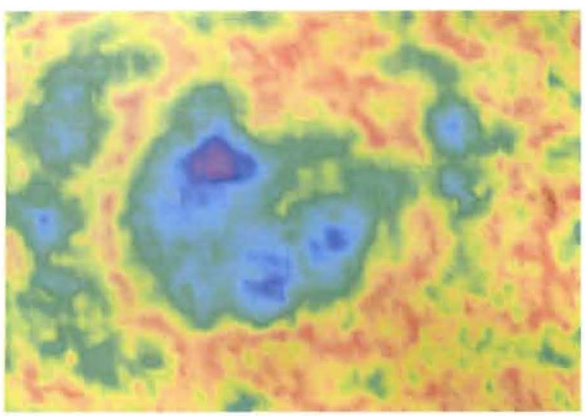
Beam patterns for primary frequencies 170 & 190 kHz

170 kHz

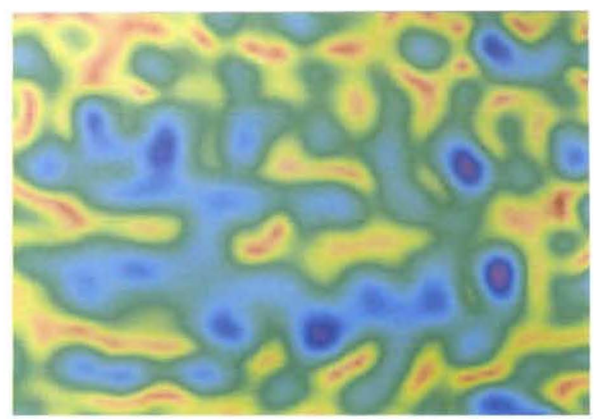


190 kHz



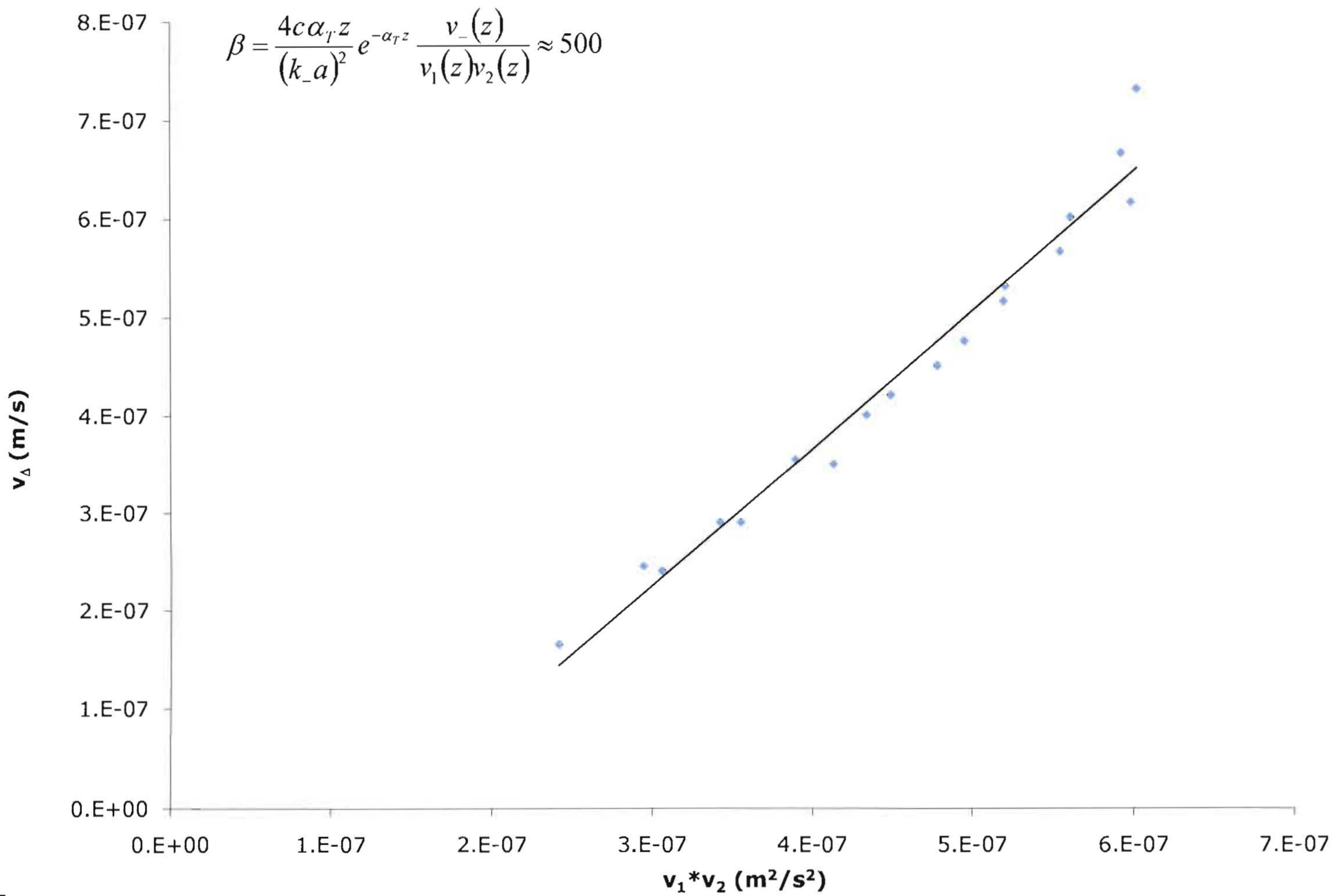


Difference frequency 20 kHz

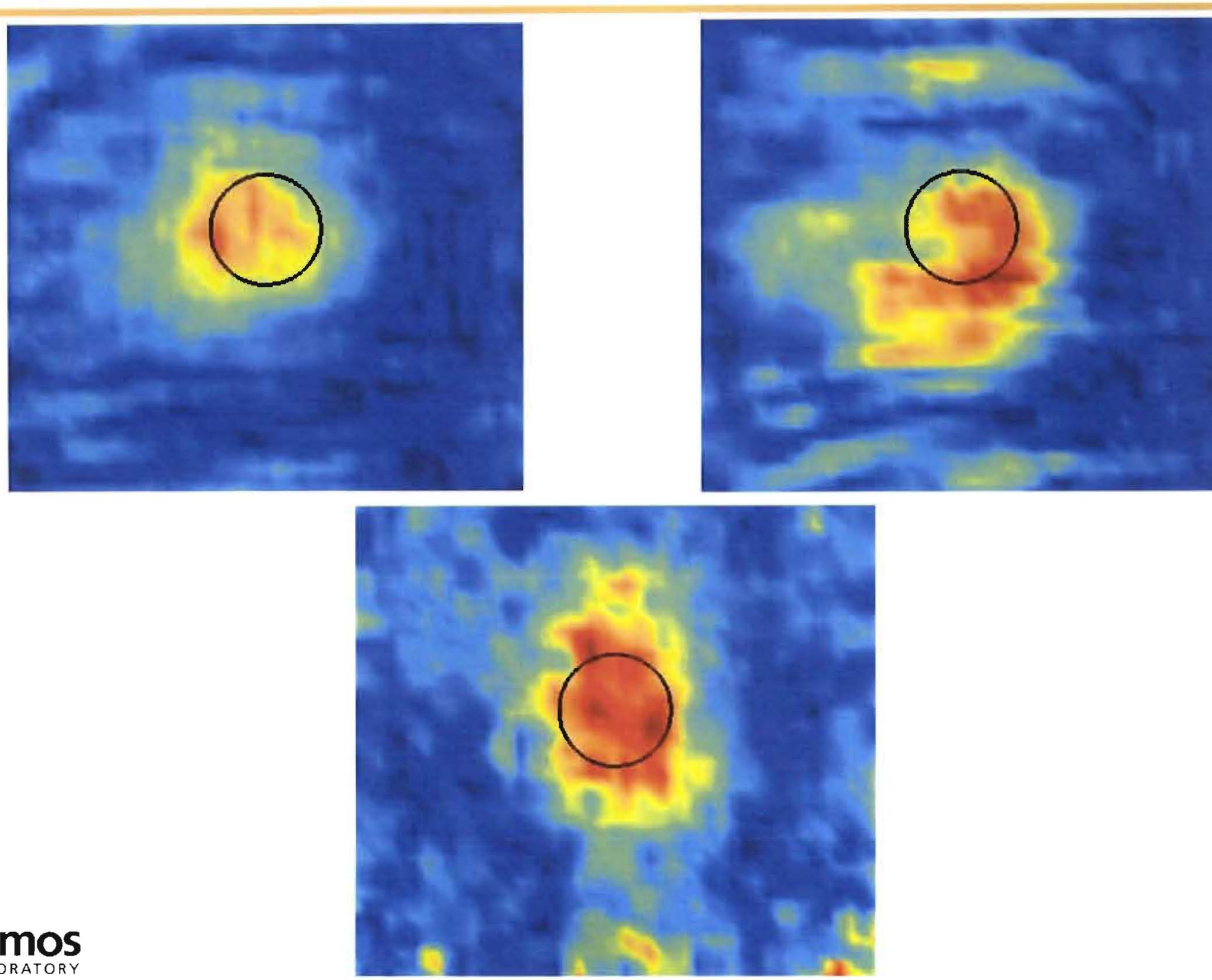


Broadcast of 20 kHz

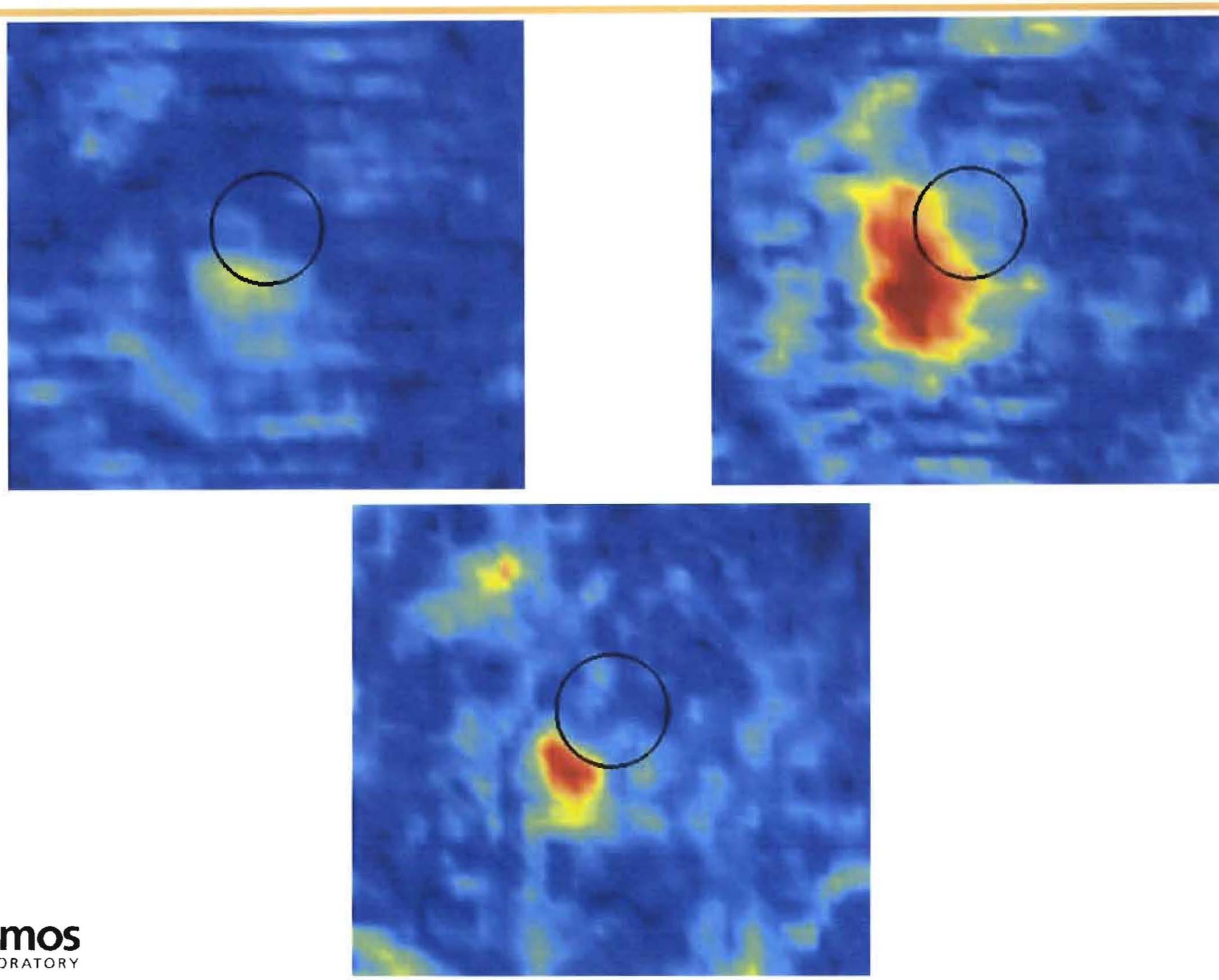
Nonlinear parameter for primary frequencies 80 & 95 kHz



Primary frequencies 60-65kHz: no steering

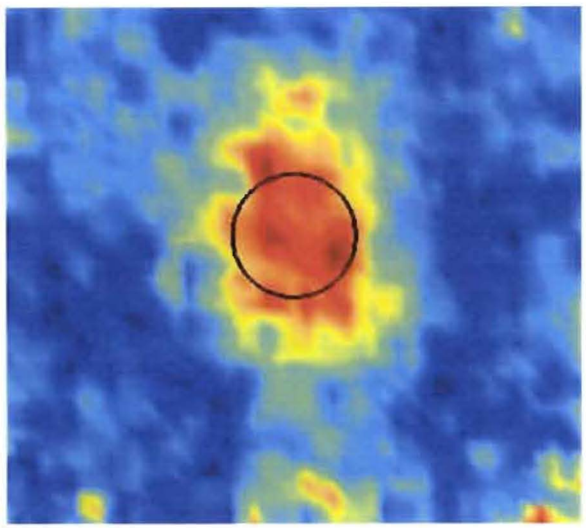


Primary frequencies 60-65kHz: 15° steering

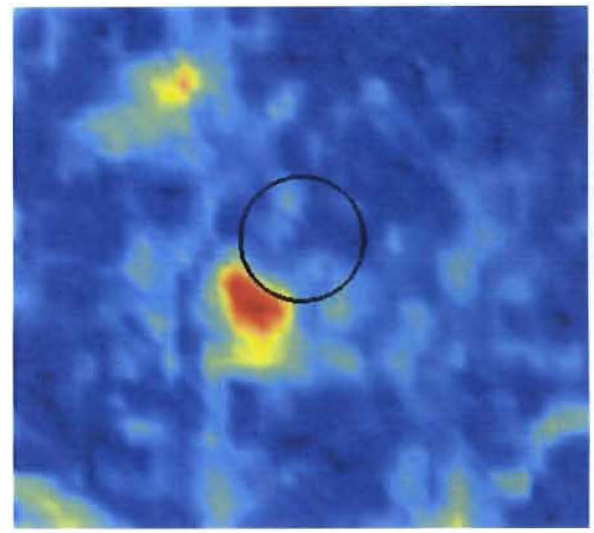


Steering at 60-65kHz: comparison

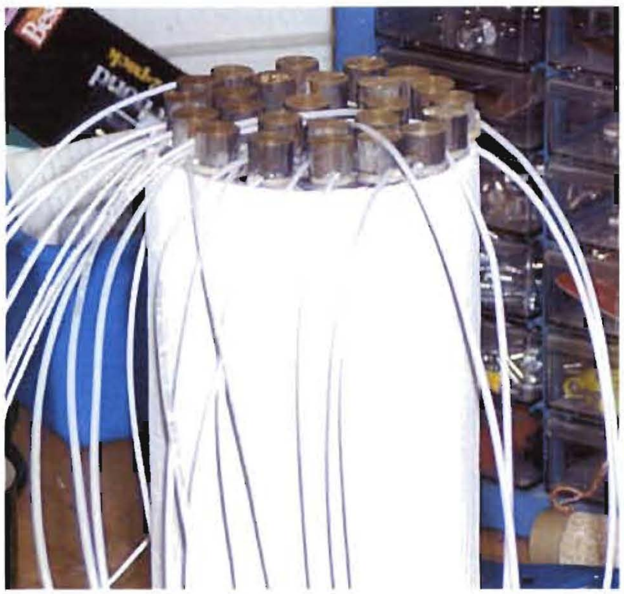
0°

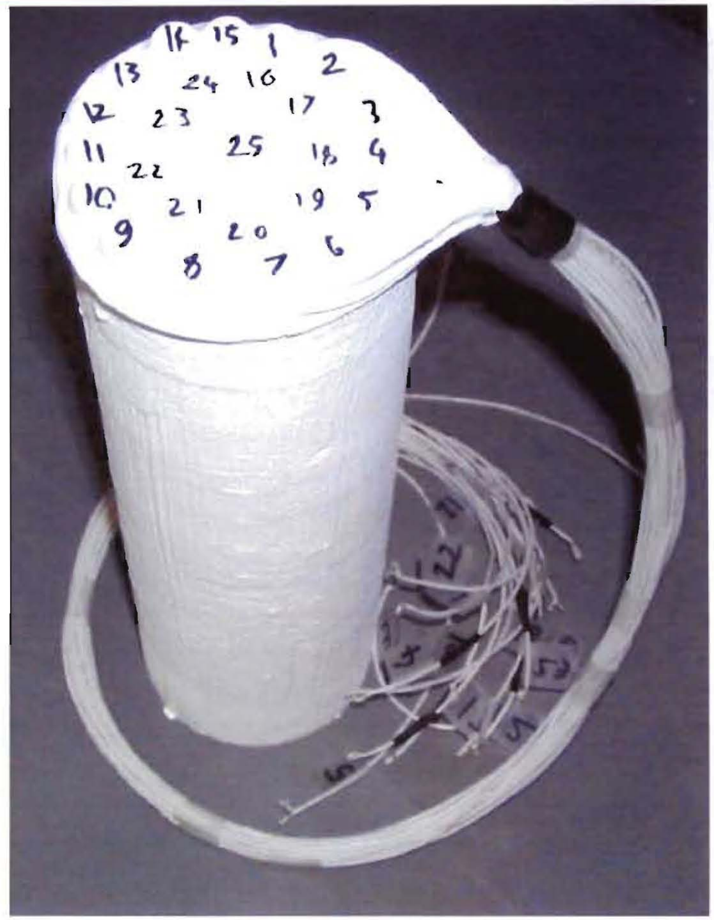


15°

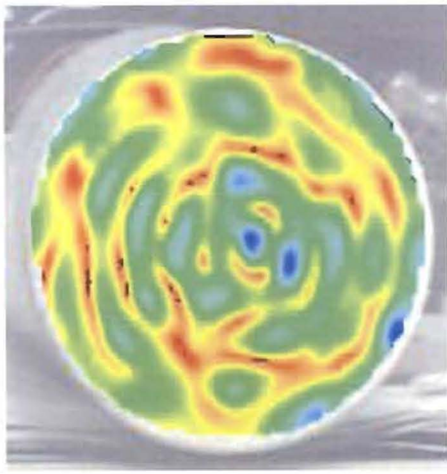


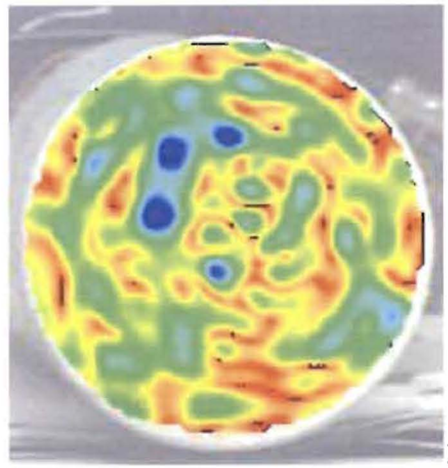
25 transducers approx 1 cm diam, each with a small brass backload and each driven independently at either f_1 or f_2



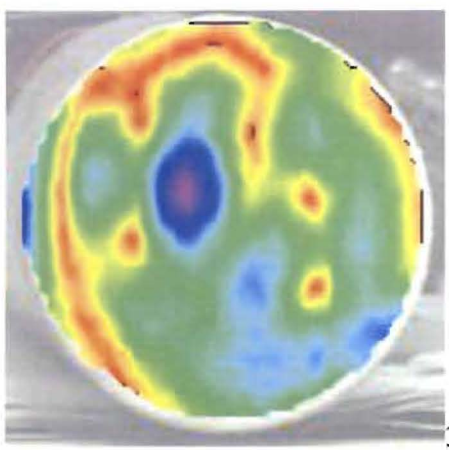


primaries, laser vibrometer scans of the end, broadcasting into air:

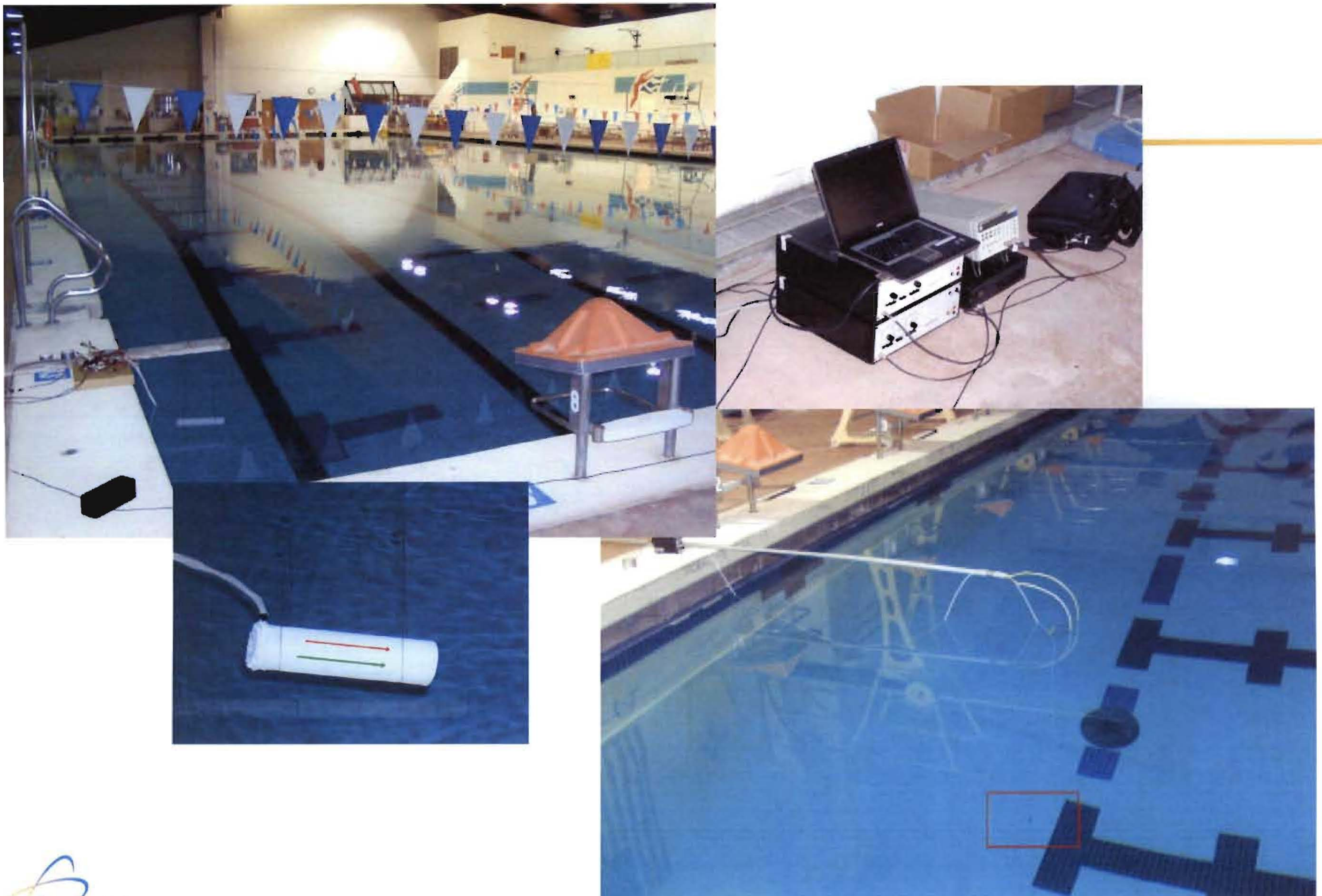

98 (4mm/s)


140 (1.7mm/s)

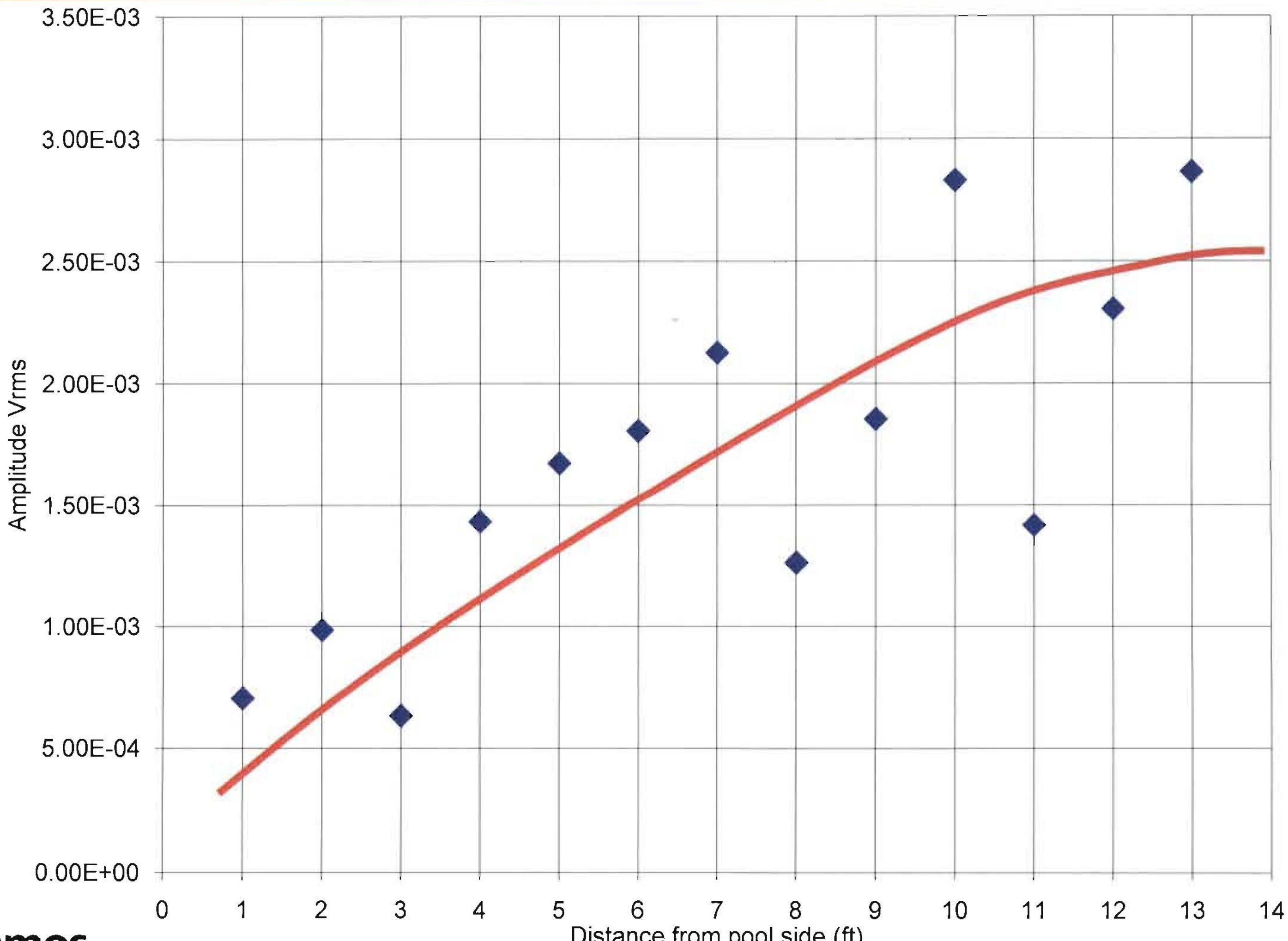
Selected frequency pair: 98 kHz, 140 kHz


140-98 (60um/s)

Difference frequency of 42 kHz, λ ~ 4.3 cm
Berea sandstone: *L*=30 cm
Diameter = 10 cm
β ~ 1400



38 ft away (farthest distance), 1/2 beampattern



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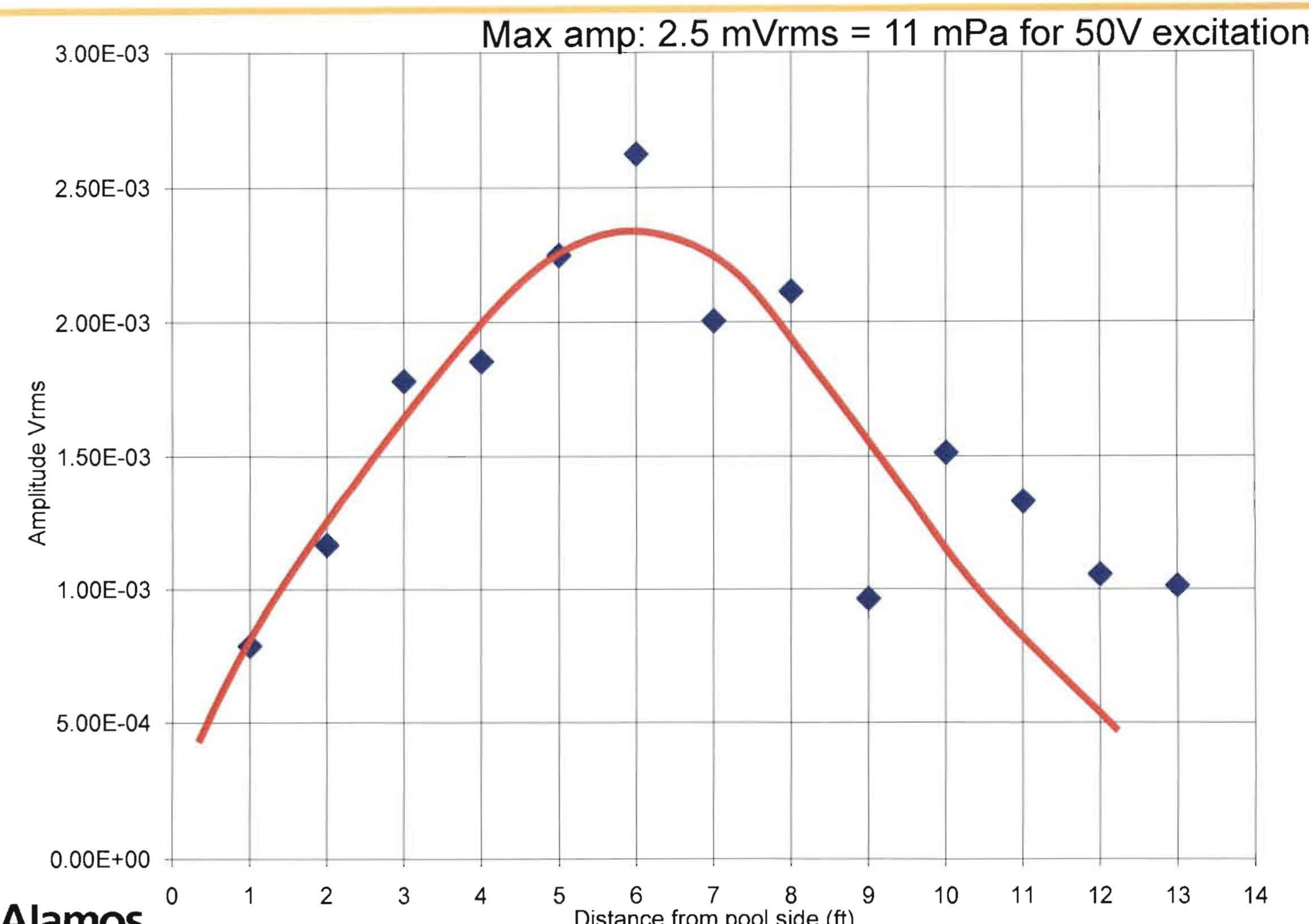
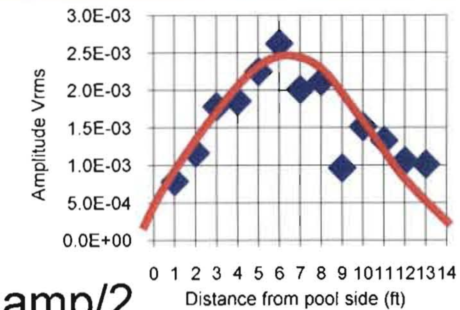
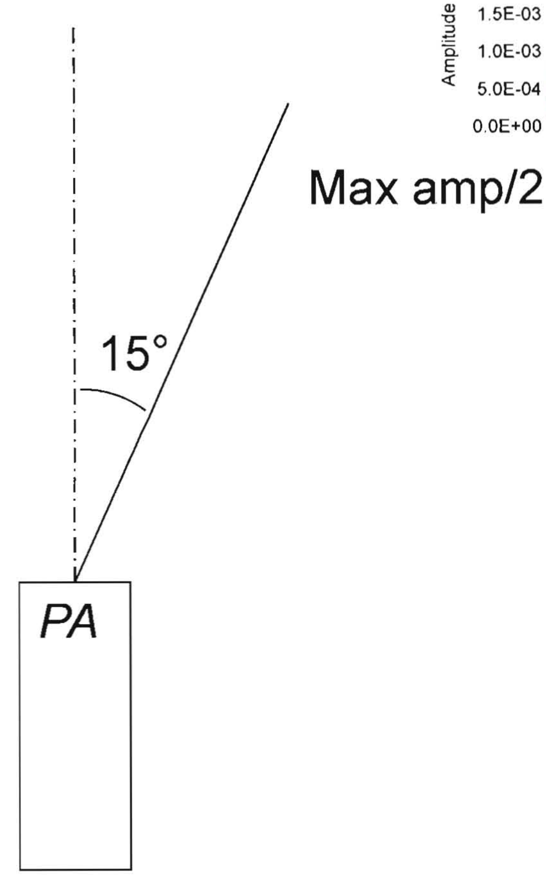
16 ft away (nearest distance)



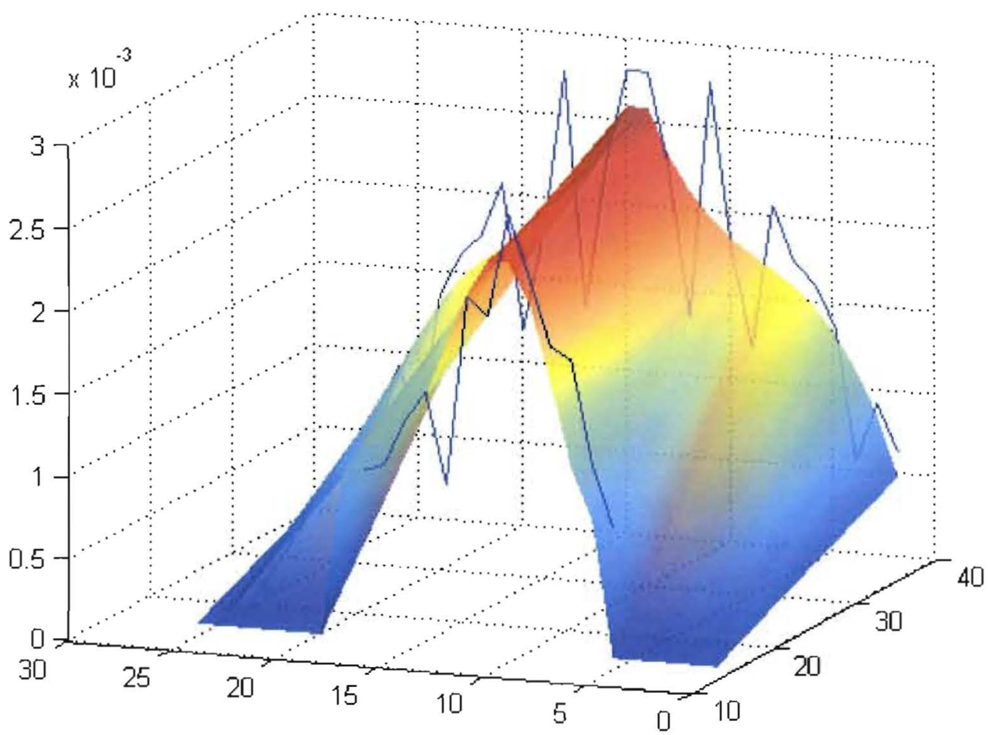
Directivity/Beamwidth?

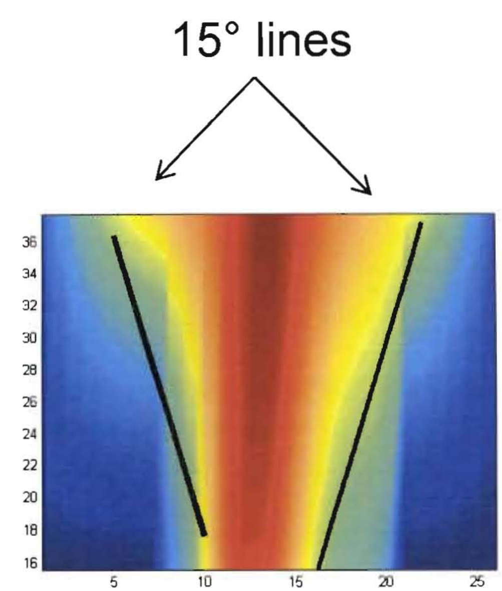
Half max amplitude width:
8 feet at 16 feet
20 feet at 38 feet



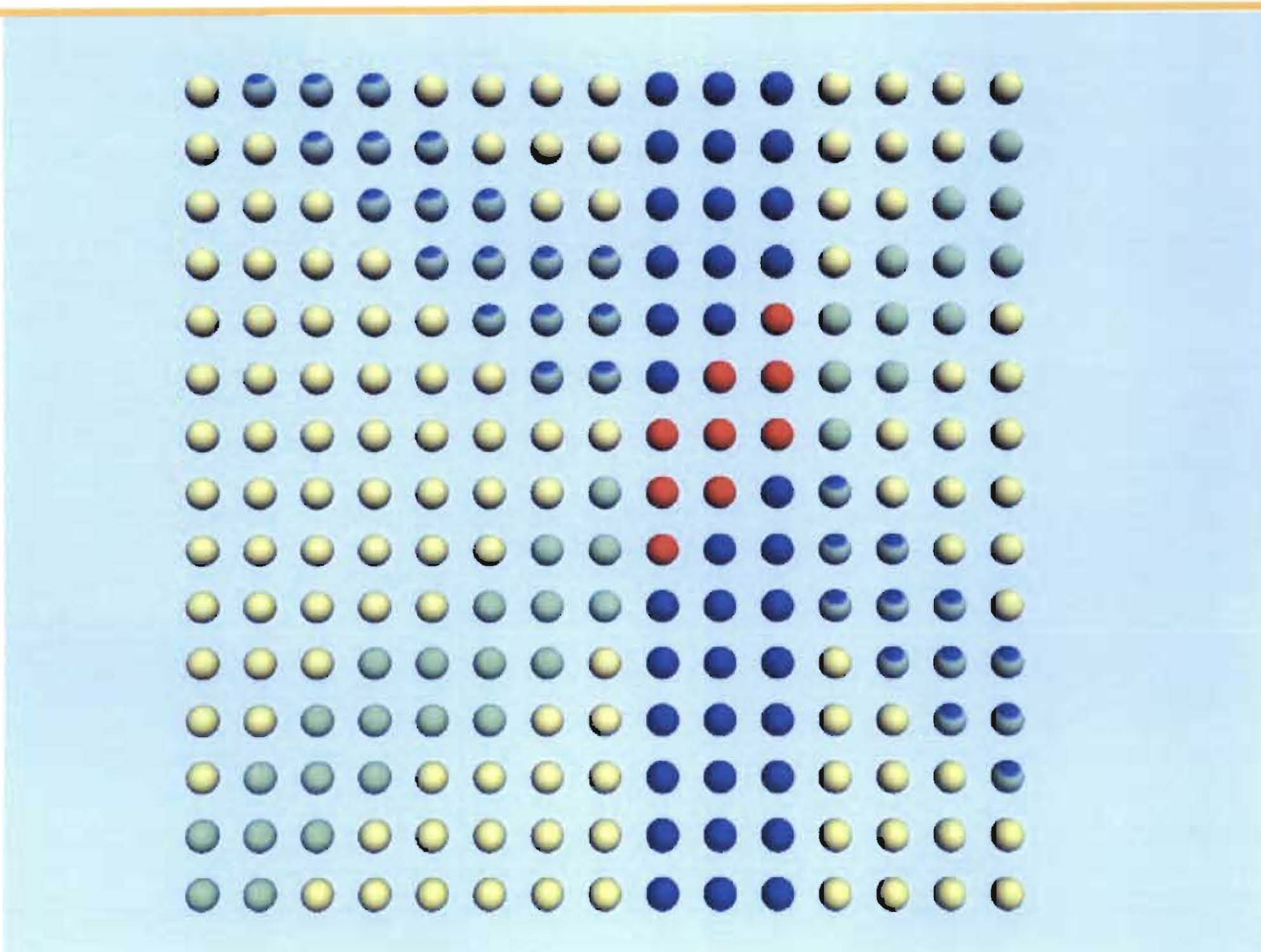


Centering 16 feet results and "symetrizing" 38 feet results + fit and interpolation



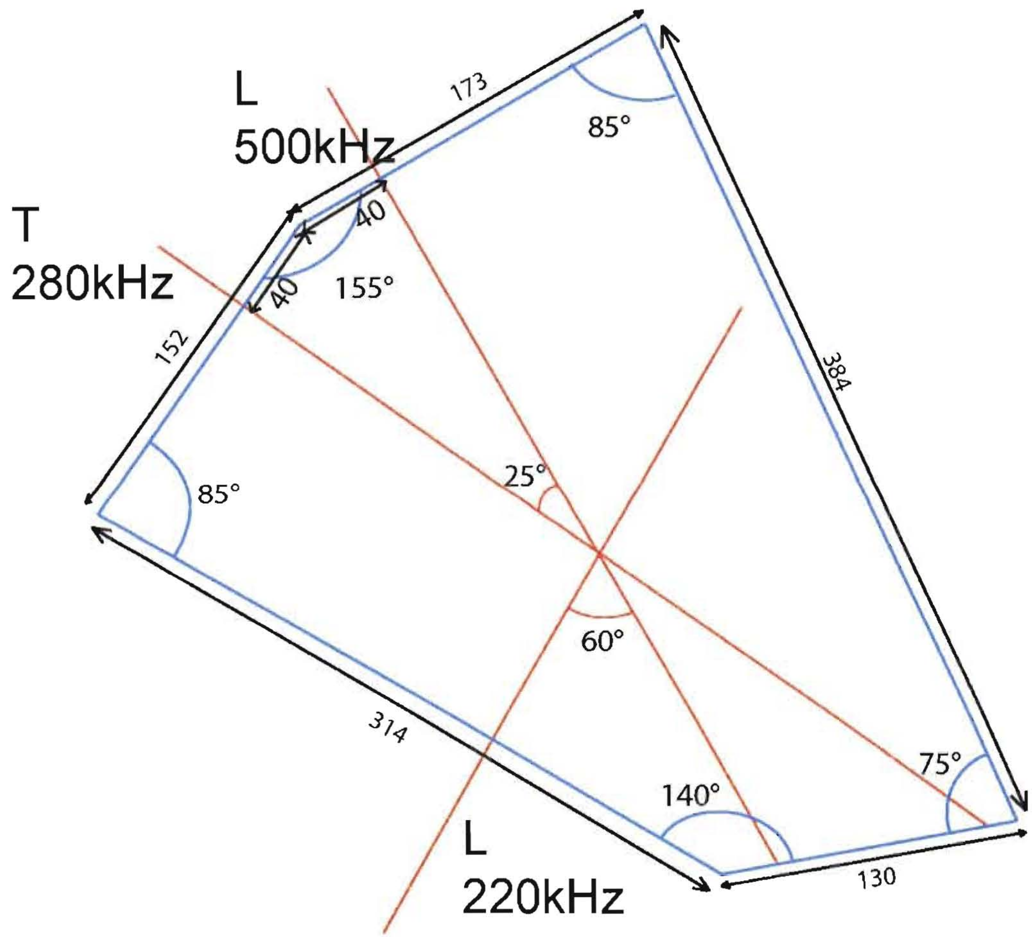


Crossbeam experiment revisiting Johnson and Shankland[1]

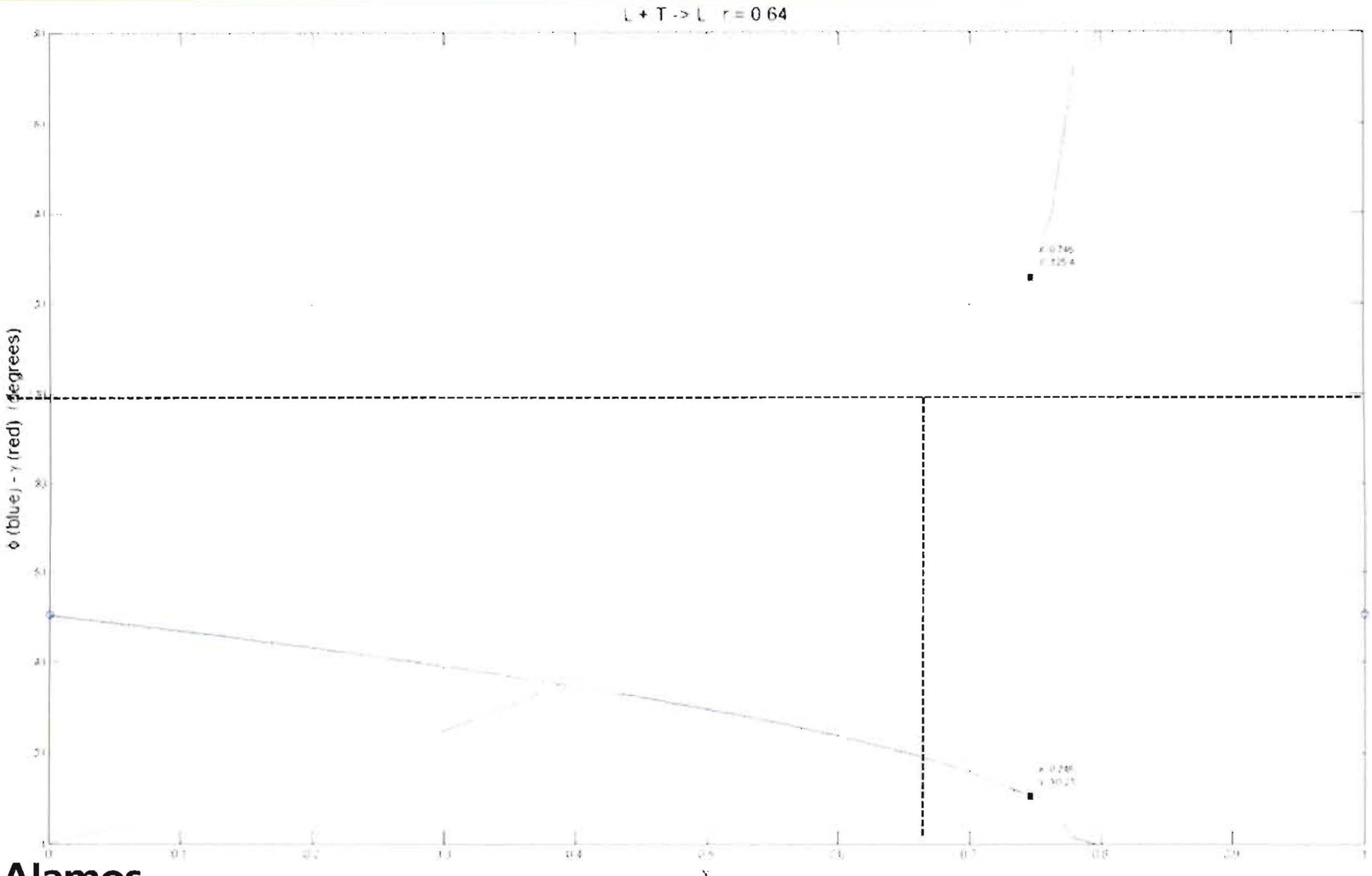


1. Nonlinear generation of elastic waves in granite and sandstone: continuous wave and travel time observations. Journal of Geophysics research, 94, no B12, pp17729-17733, December 10,1 989

Geometry
L+T→L



L+T→L



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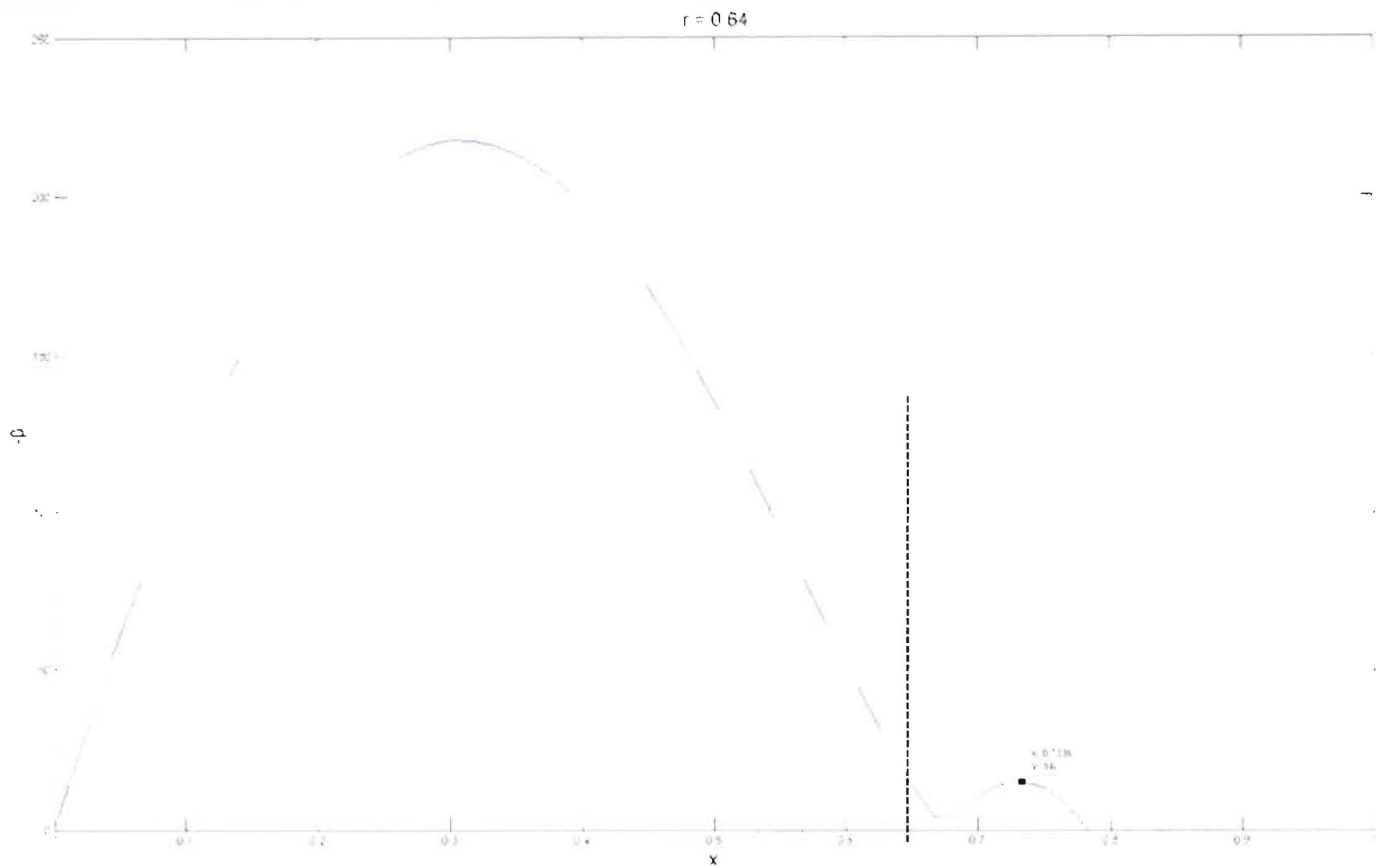
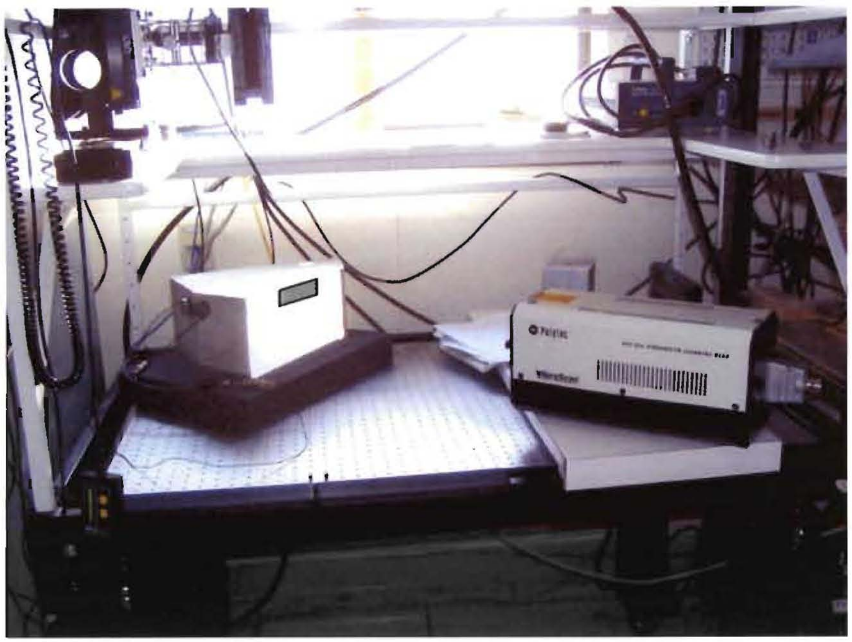
L+T→L

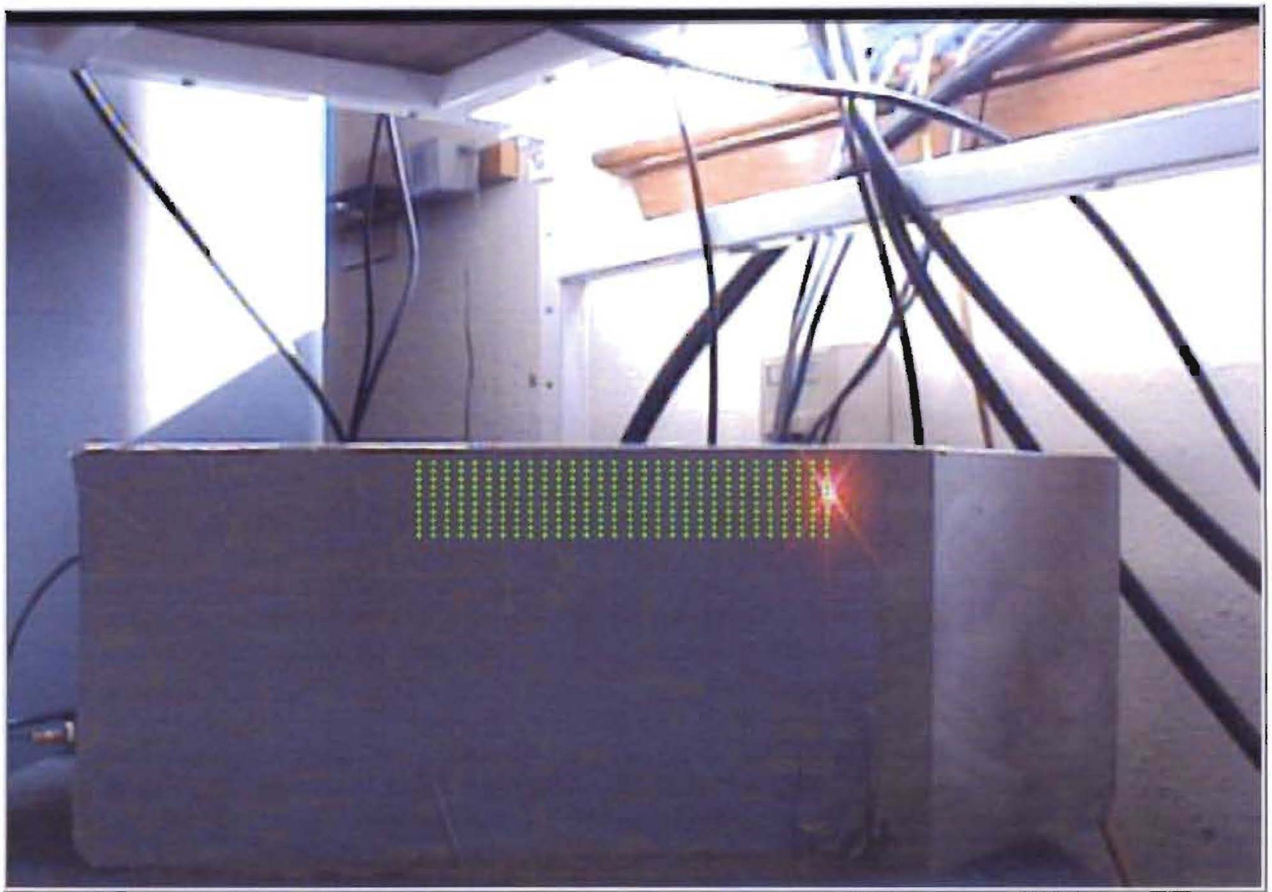


Setup
L+T→L

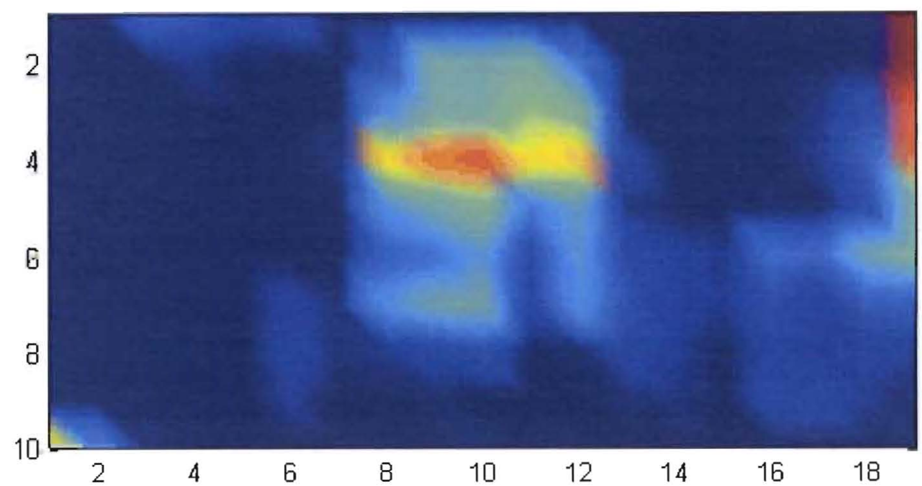


f_1=500kHz (L)
f_2=280kHz (T)
Δf=220kHz (L)

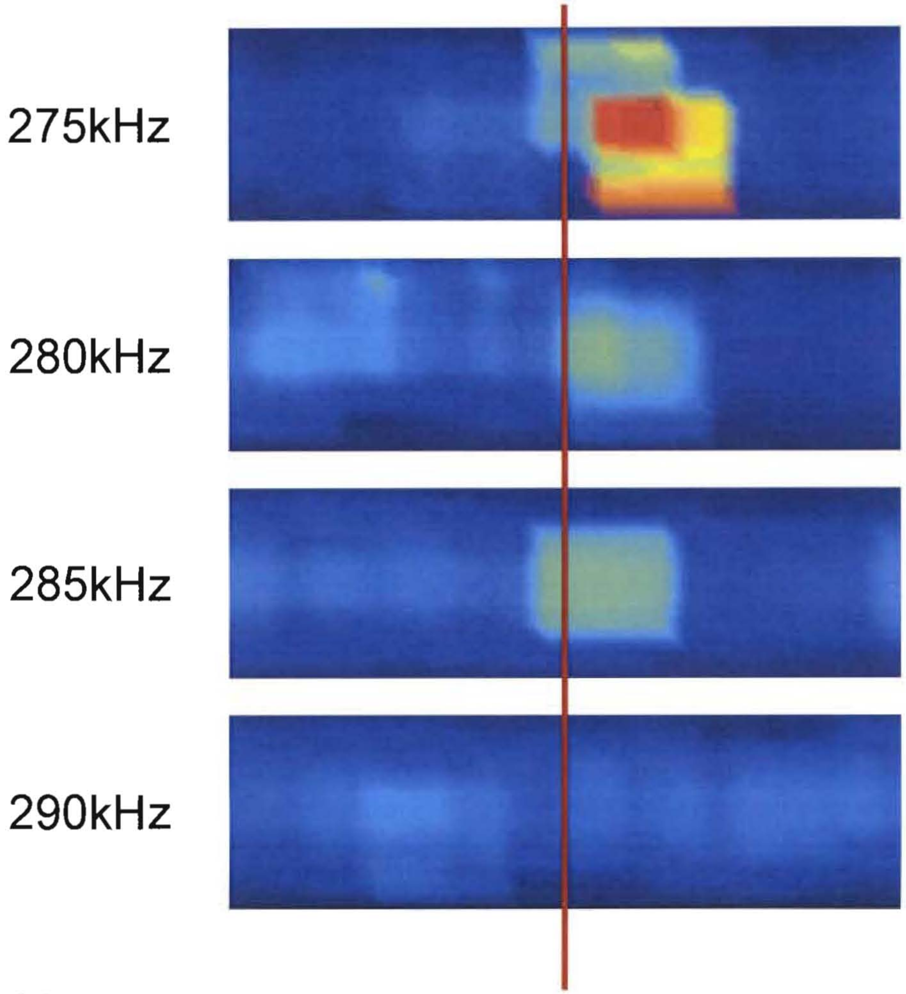
L+T→L



L+T→L



L+T→L changing f_2



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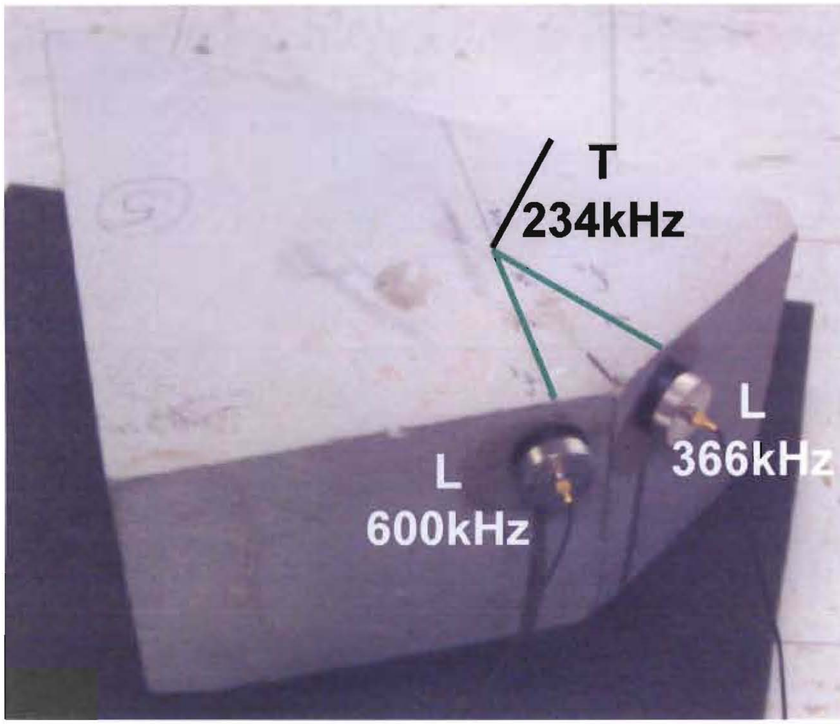
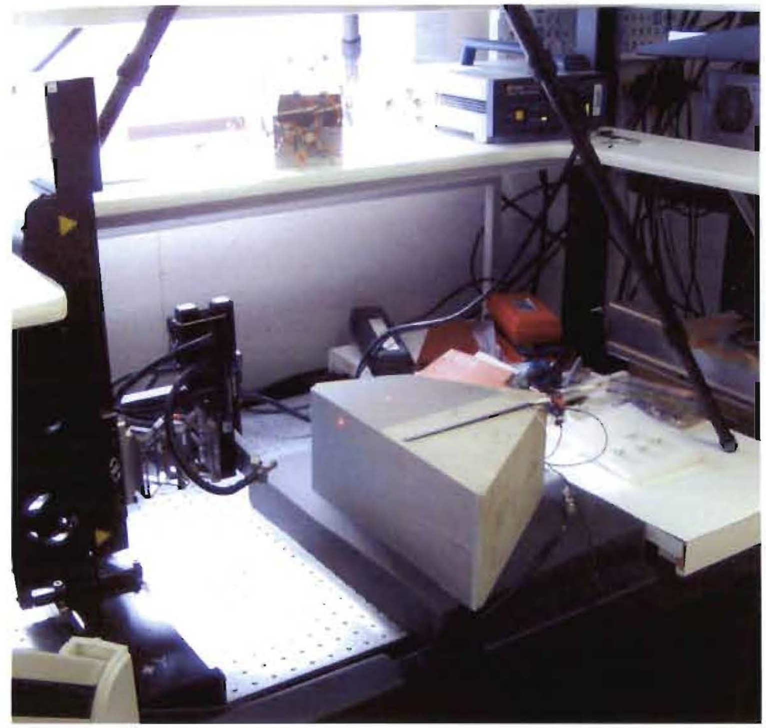
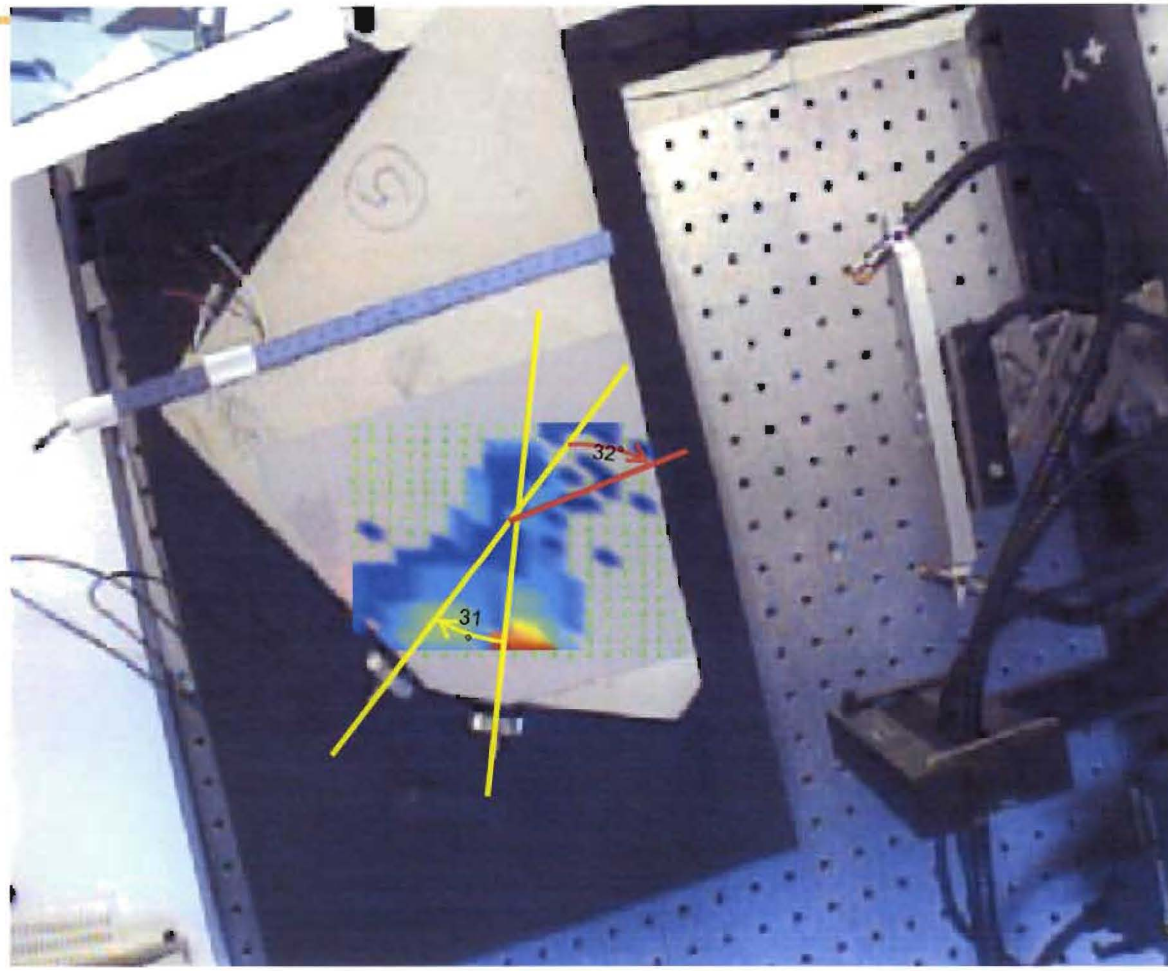
Cross beam L+L→T



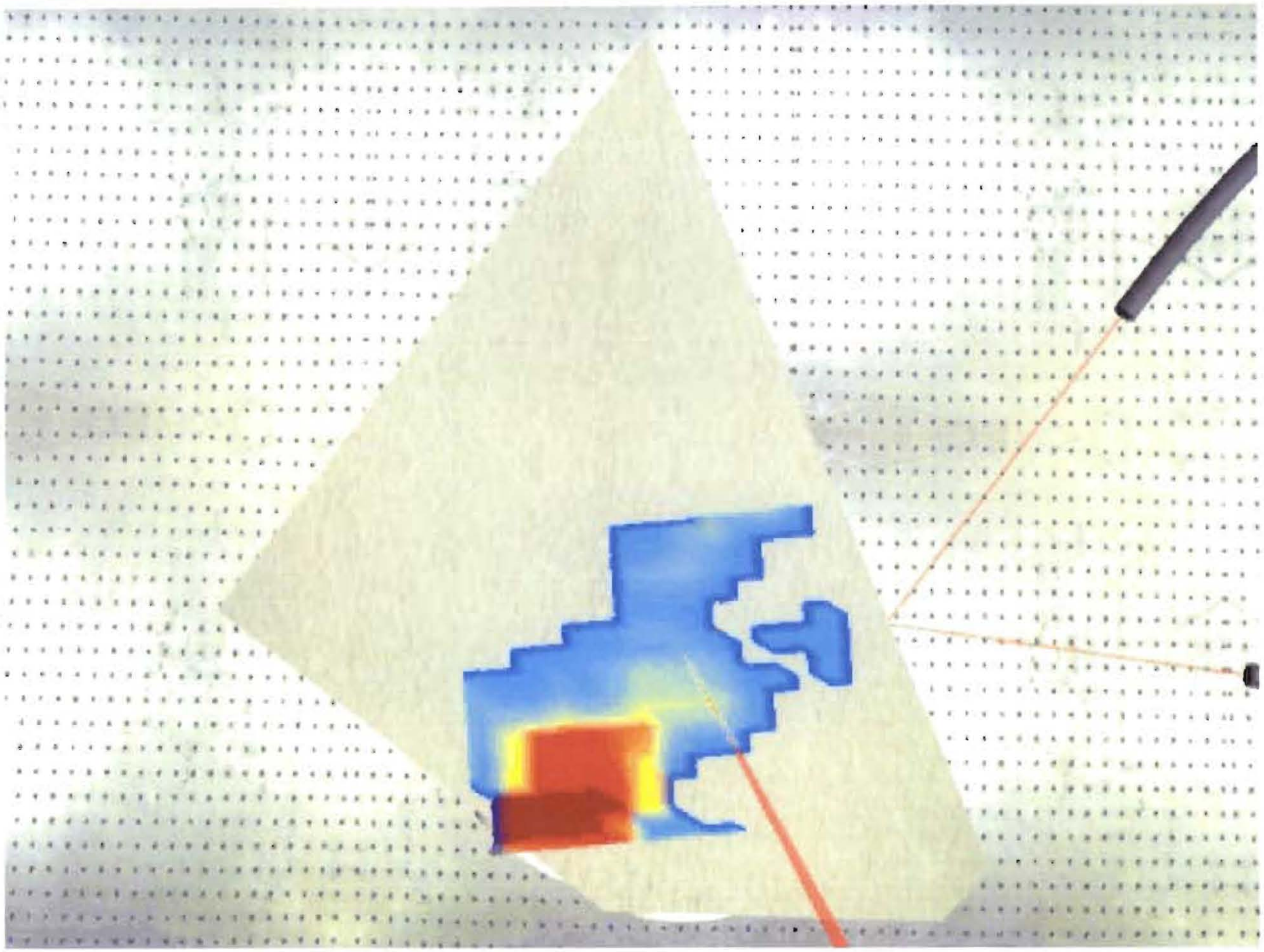


pulse duration: 210us

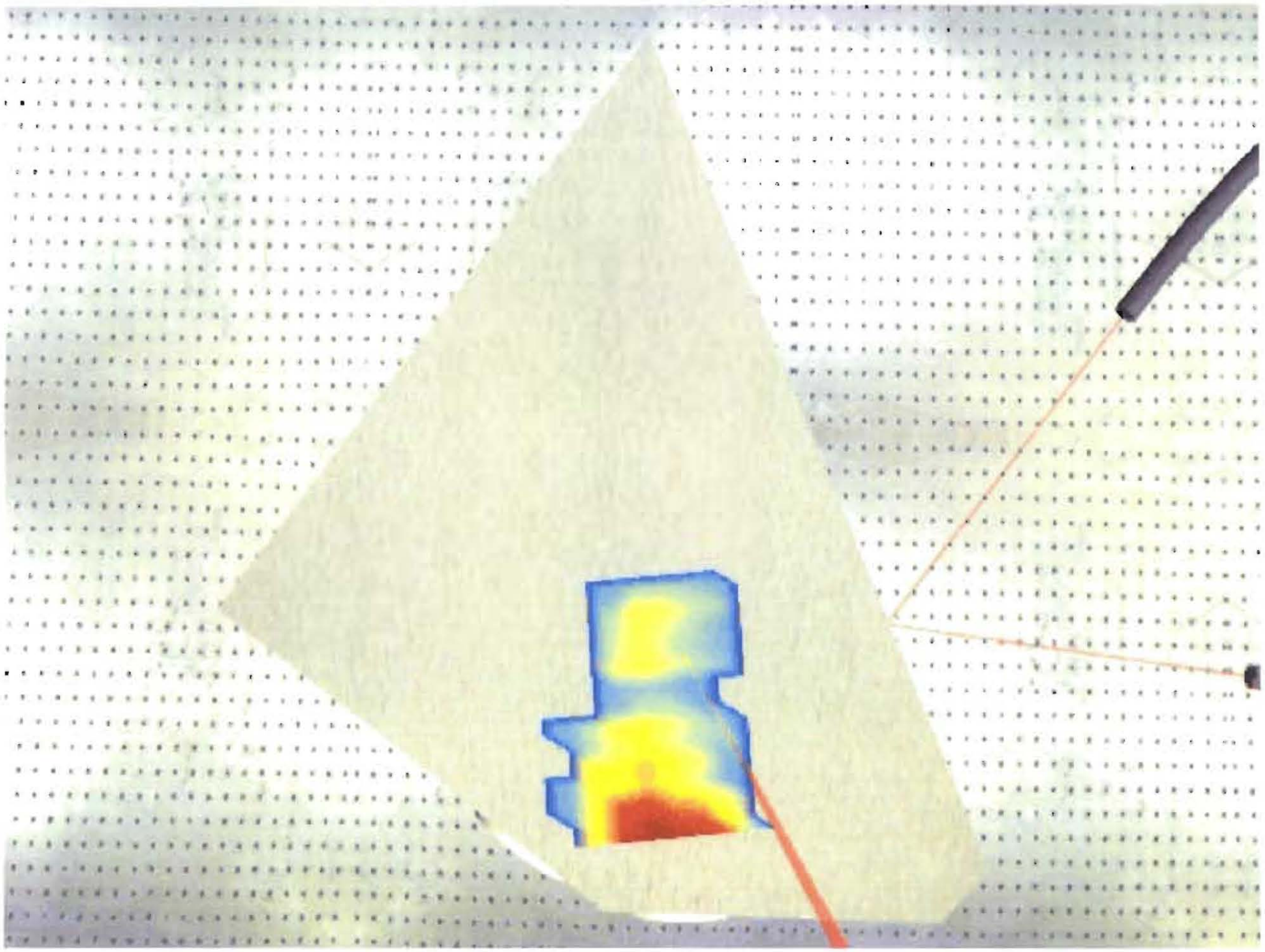
L+L→T



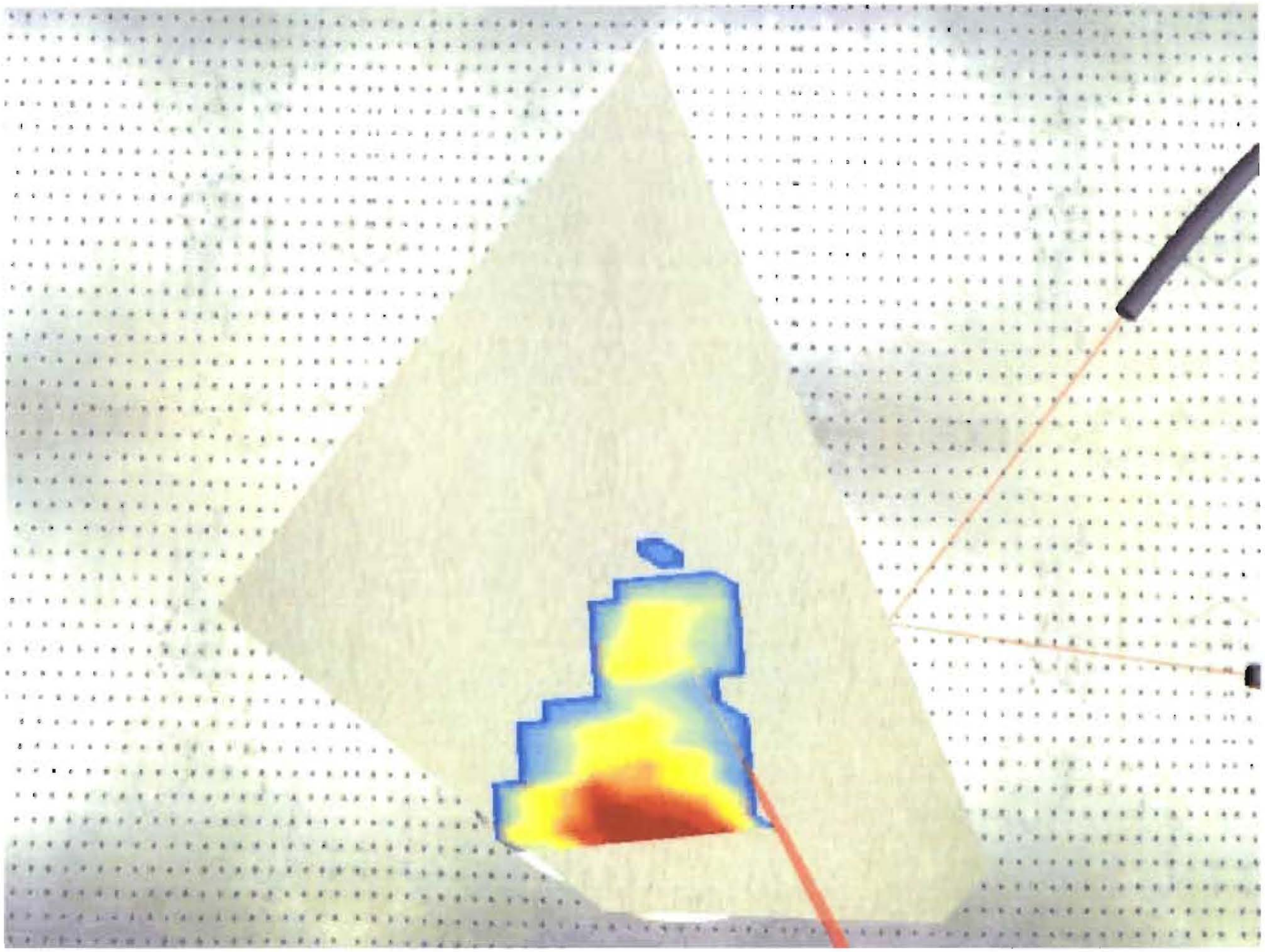
$L+L \rightarrow T$
f_1=600kHz



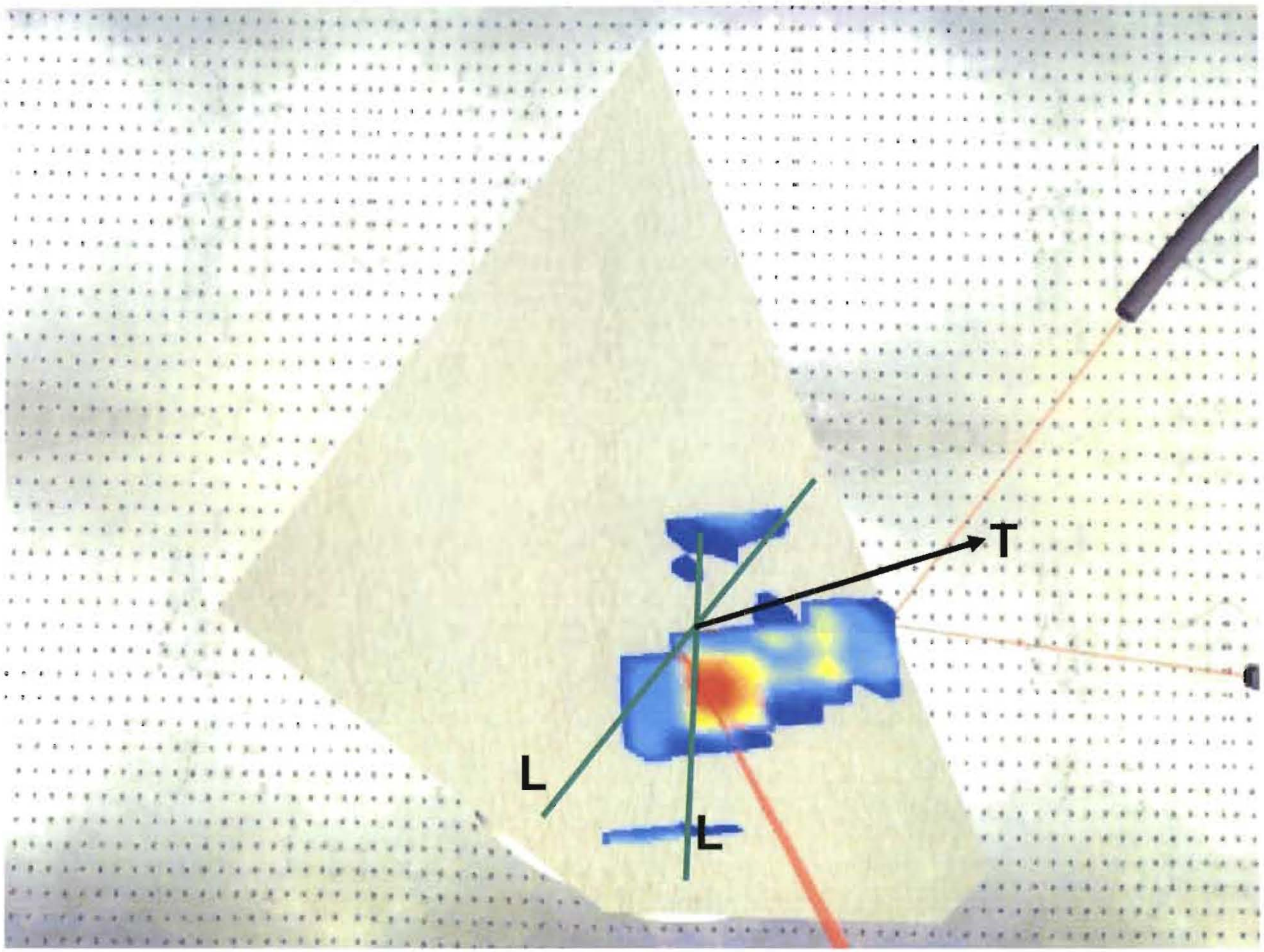
L+L→T
f_2=366kHz

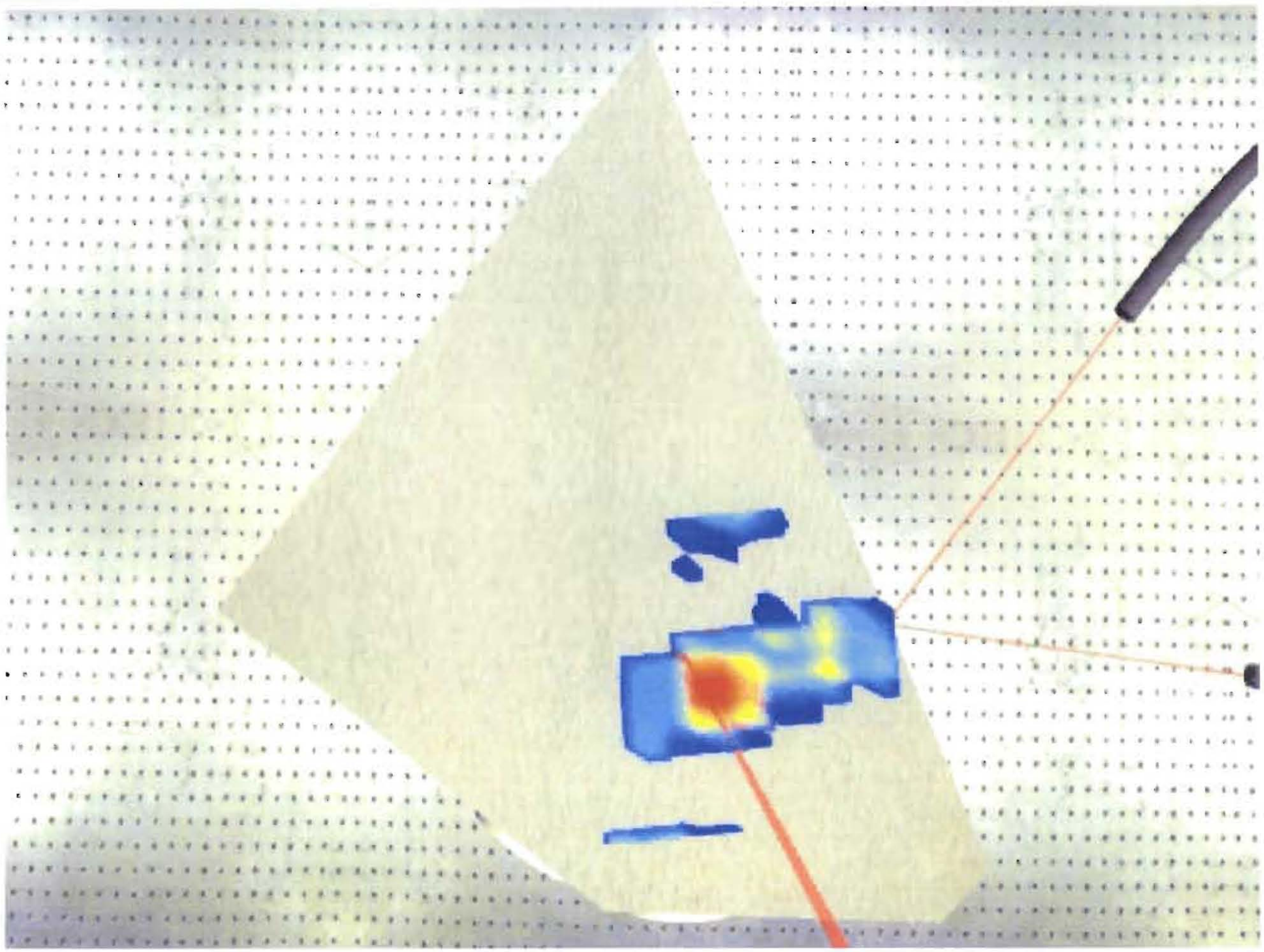


$L+L \rightarrow T$
f_1+f_2

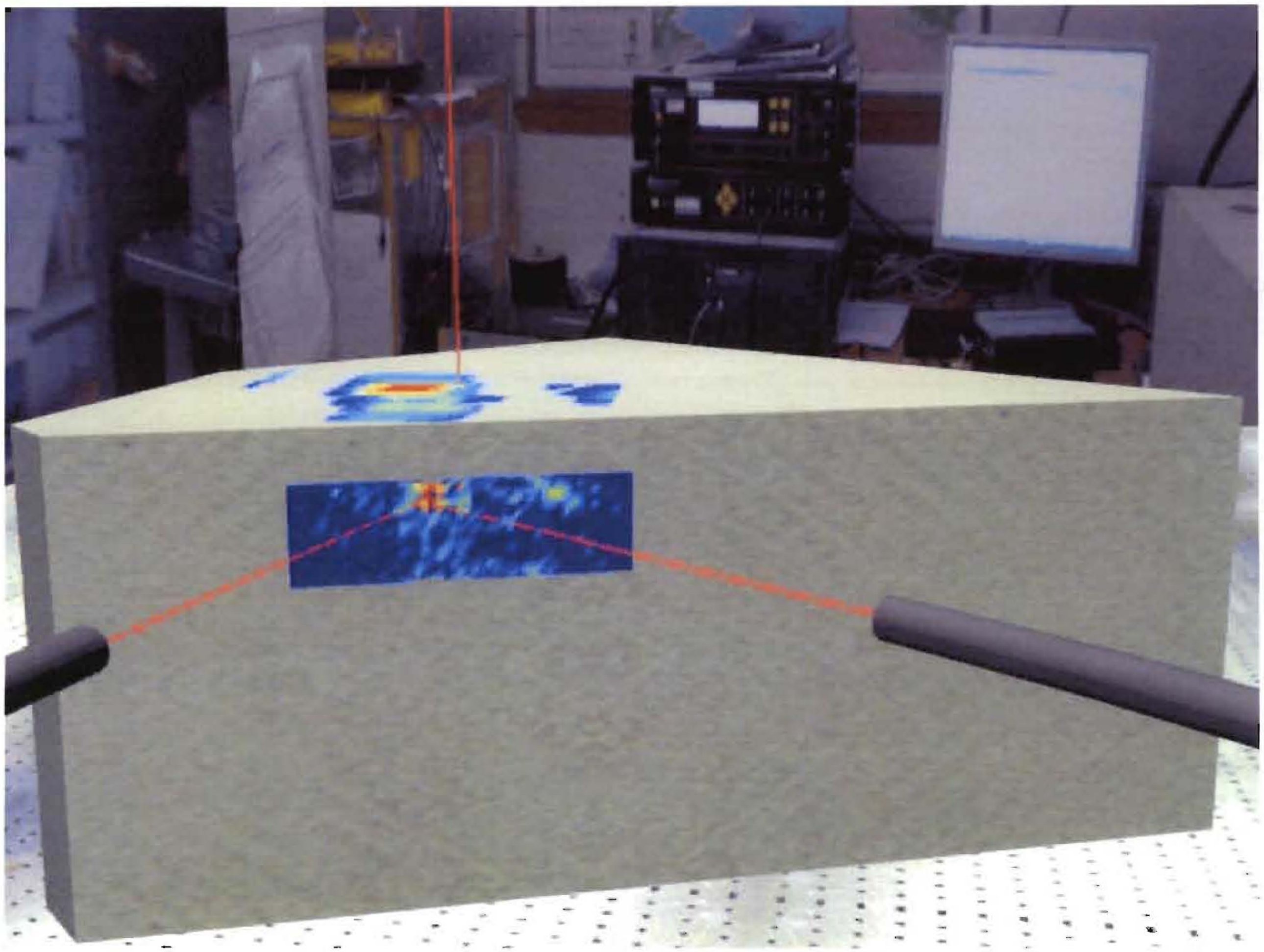


L+L→T
f_1+f_2 filtered





L+L→T



Conclusion

Parametric interaction in rock allows probing the nonlinearity of the rock

Demonstrated crossbeam for several frequencies

Quantitative demonstration of the parametric array

Future work

Currently exploring possible applications