5-18-2015

Use of Evanescent Plane Waves for Low-Frequency Energy Transmission Across Material Interfaces

Daniel C. Woods
Purdue University, woods41@purdue.edu

J Stuart Bolton
Purdue University, bolton@purdue.edu

Jeffrey F. Rhoads
Purdue University, jfrhoads@purdue.edu

Use of Evanescent Plane Waves for Low-Frequency Energy Transmission across Material Interfaces

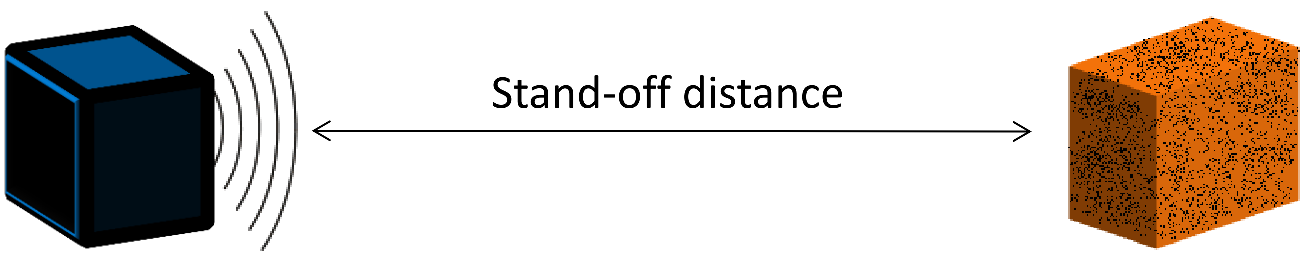
Daniel C. Woods, J. Stuart Bolton, and Jeffrey F. Rhoads

School of Mechanical Engineering,
Birck Nanotechnology Center,
and Ray W. Herrick Laboratories
Purdue University
West Lafayette, Indiana, USA

May 18, 2015

Premise and Motivation

- High impedance-difference interfaces
- Methods for increased stand-off pressure and energy transmission
- Applications to trace vapor detection:



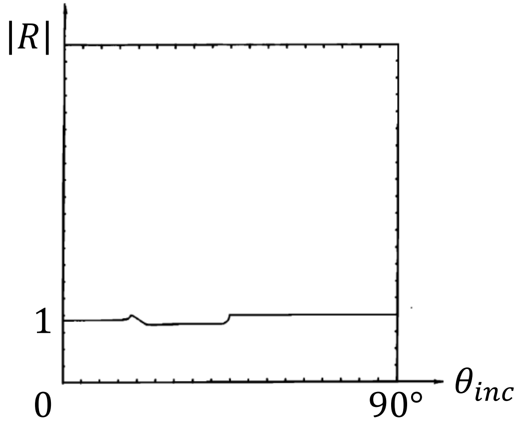
Low-frequency source

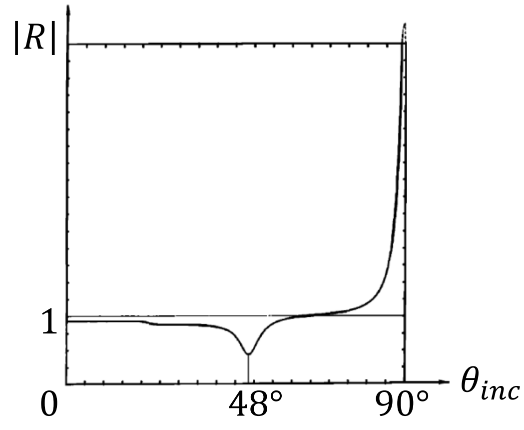
Energetic material
- Increase in temperature
- Increase in vapor pressure

Premise and Motivation

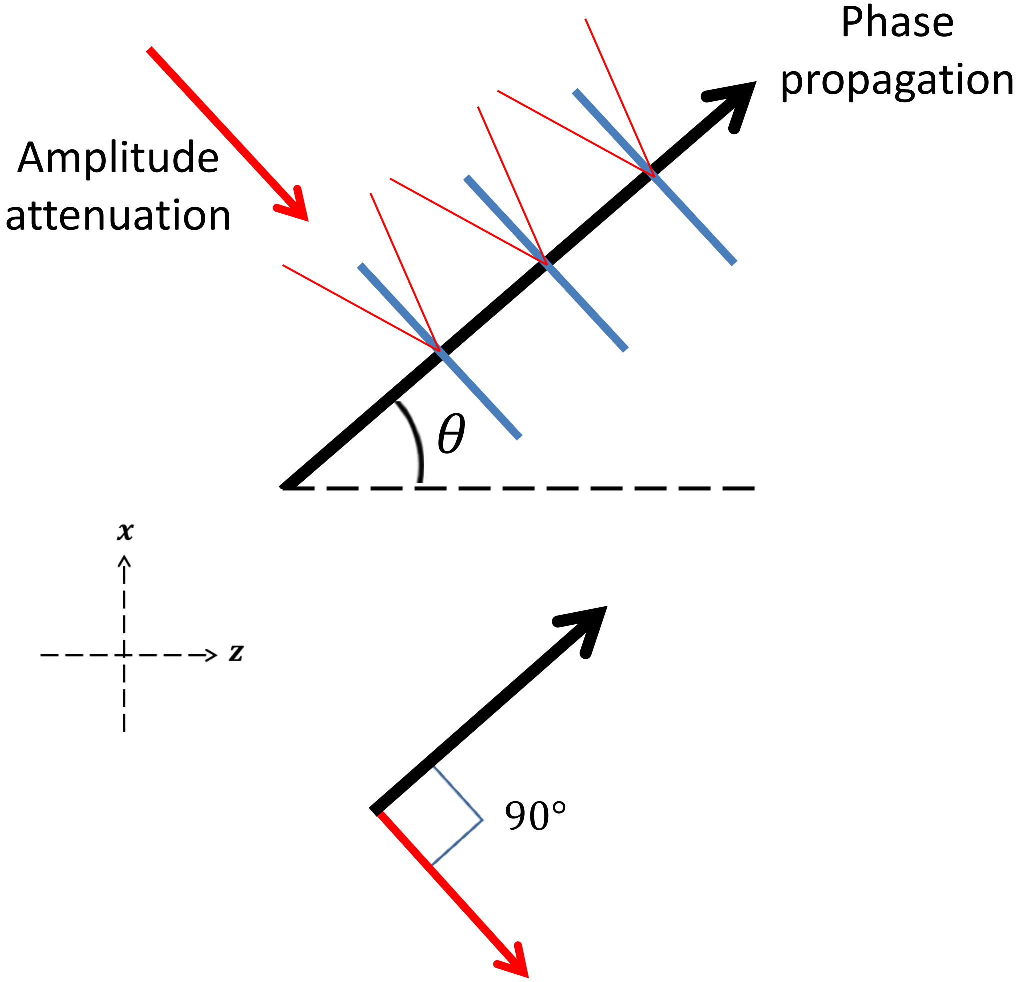
- Propagation of evanescent plane waves
  (*Brekhovskikh, 1960; Bertoni & Tamir, 1973*)
- Transmission across high impedance-difference interfaces
  (*Chapman et al., 1992; Godin, 2008, 2011*)
- Energy flux in elastic media and reflection/refraction
  (*Hayes, 1980; Leroy et al., 1988; Deschamps, 1994*)

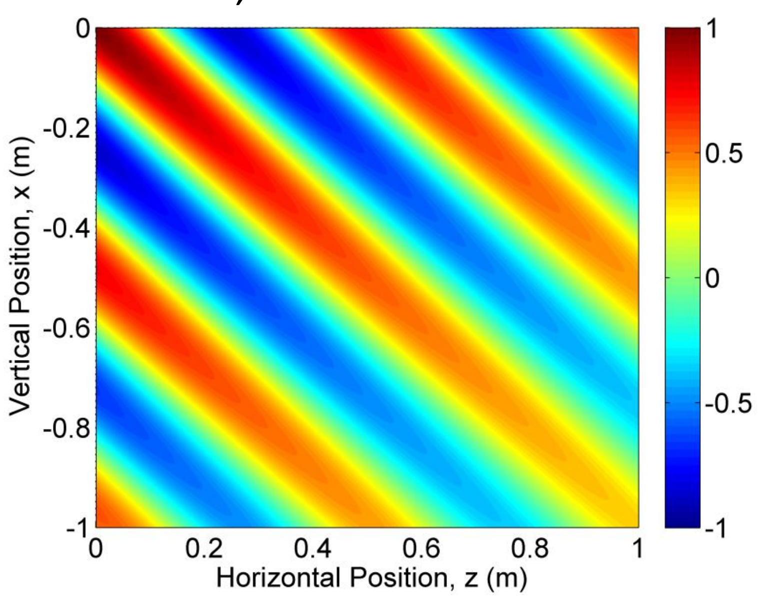
(Adapted from *Leroy et al., 1988*)





Evanescent Plane Waves





Evanescent Plane Waves

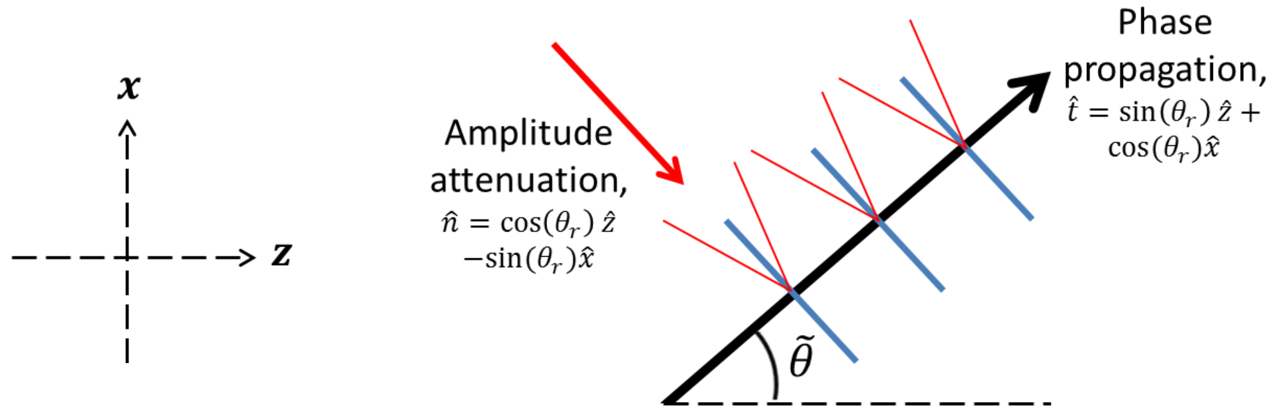
- Complex angle representation

$$\tilde{\theta} = \theta_r + j\theta_i$$

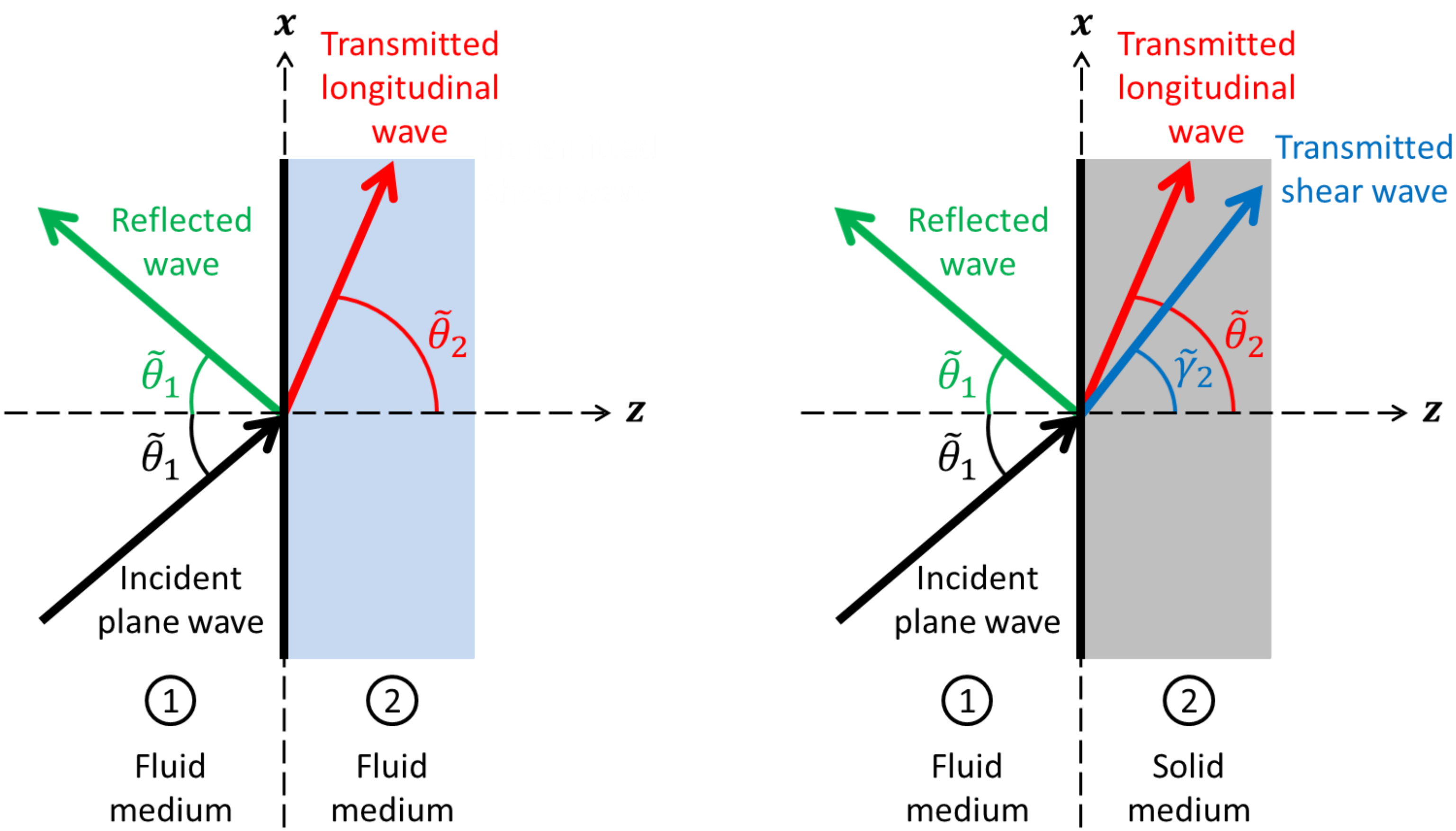
$$\tilde{k}_x = k\cosh(\theta_i)\sin(\theta_r) + jk\sinh(\theta_i)\cos(\theta_r)$$
$$\tilde{k}_z = k\cosh(\theta_i)\cos(\theta_r) - j\boxed{k\sinh(\theta_i)}\sin(\theta_r)$$

Evanescent decay parameter, β

$$\tilde{p} = \tilde{A}e^{-\beta\hat{n}\cdot\vec{r}}e^{-jk\cosh(\theta_i)\hat{t}\cdot\vec{r}}$$



Material Interfaces



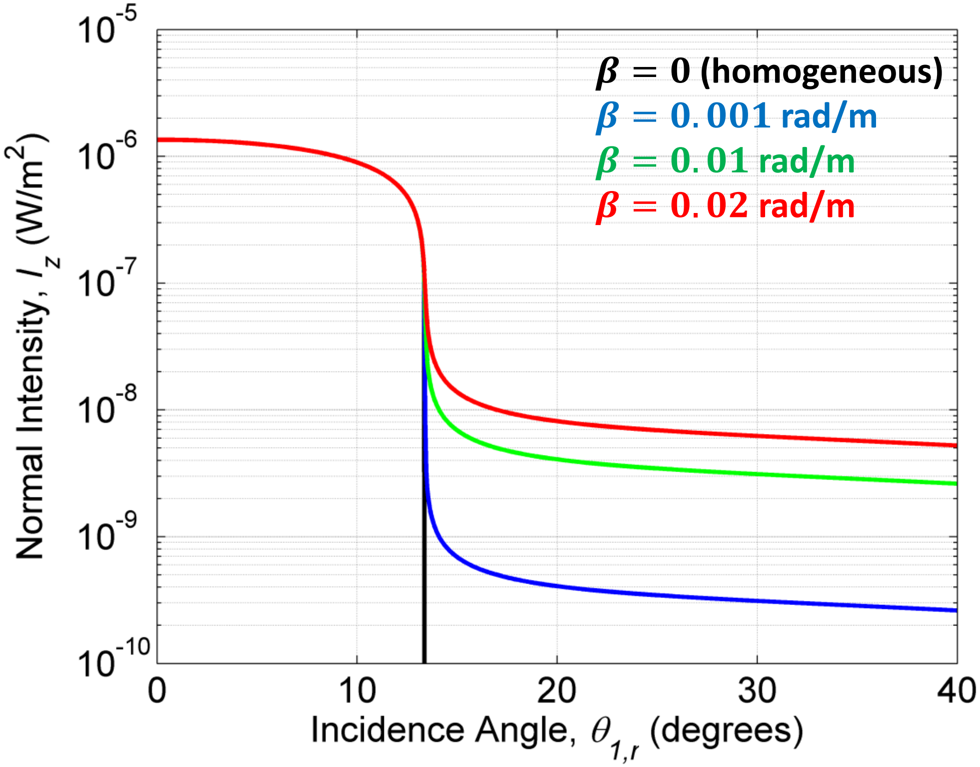
Trace wavenumber continuity

$$k_1 \sin(\tilde{\theta}_1) = k_2 \sin(\tilde{\theta}_2) = \kappa_2 \sin(\tilde{\gamma}_2)$$

Numerical Results: Air-Water

Transmitted Normal Intensity (W/m^2)

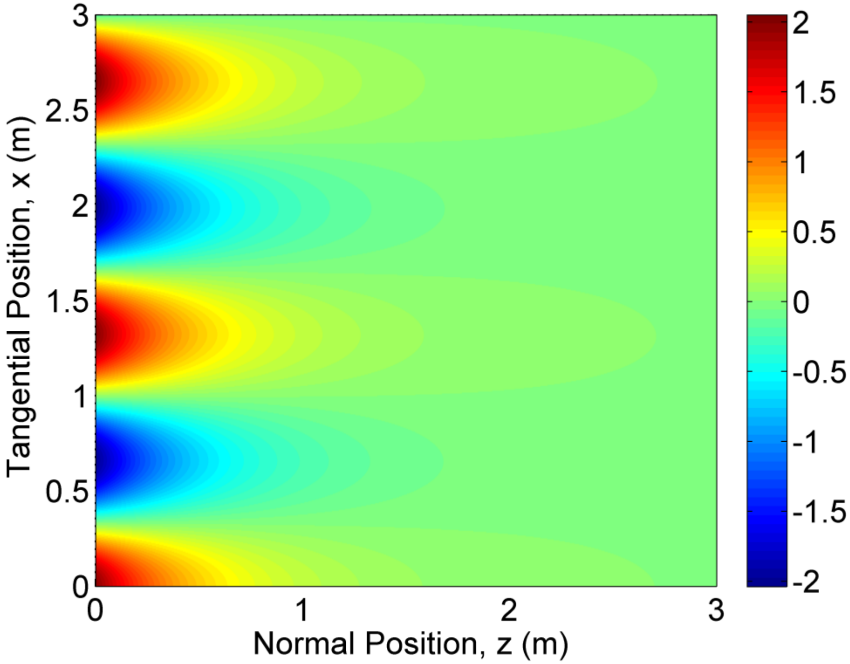
1-Pa, 1000-Hz incident wave



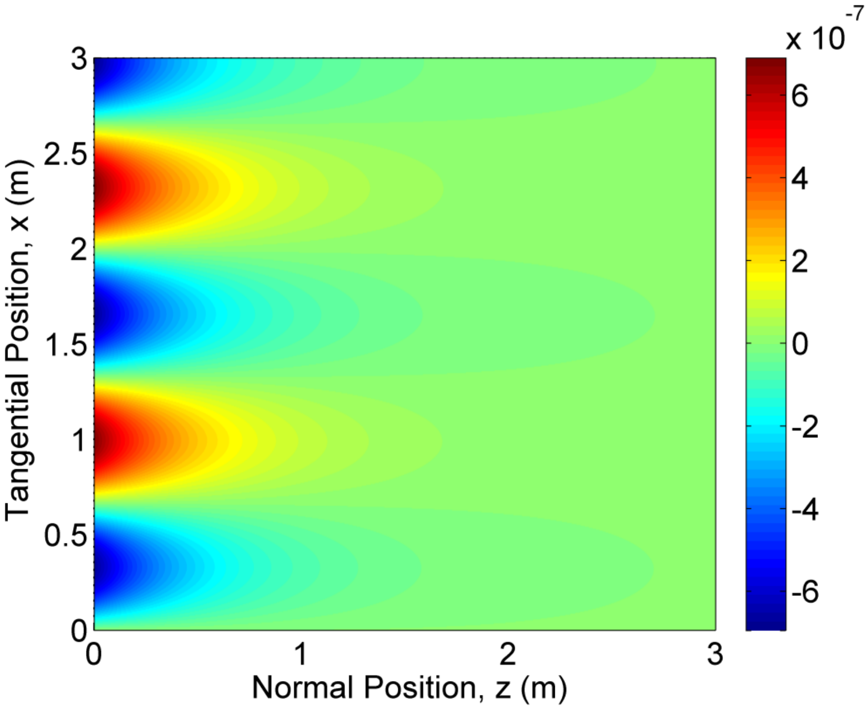
$$I_z = \frac{1}{T}\int_0^T p v_z \, dt$$

Numerical Results: Air-Water

Transmitted Pressure (Pa)



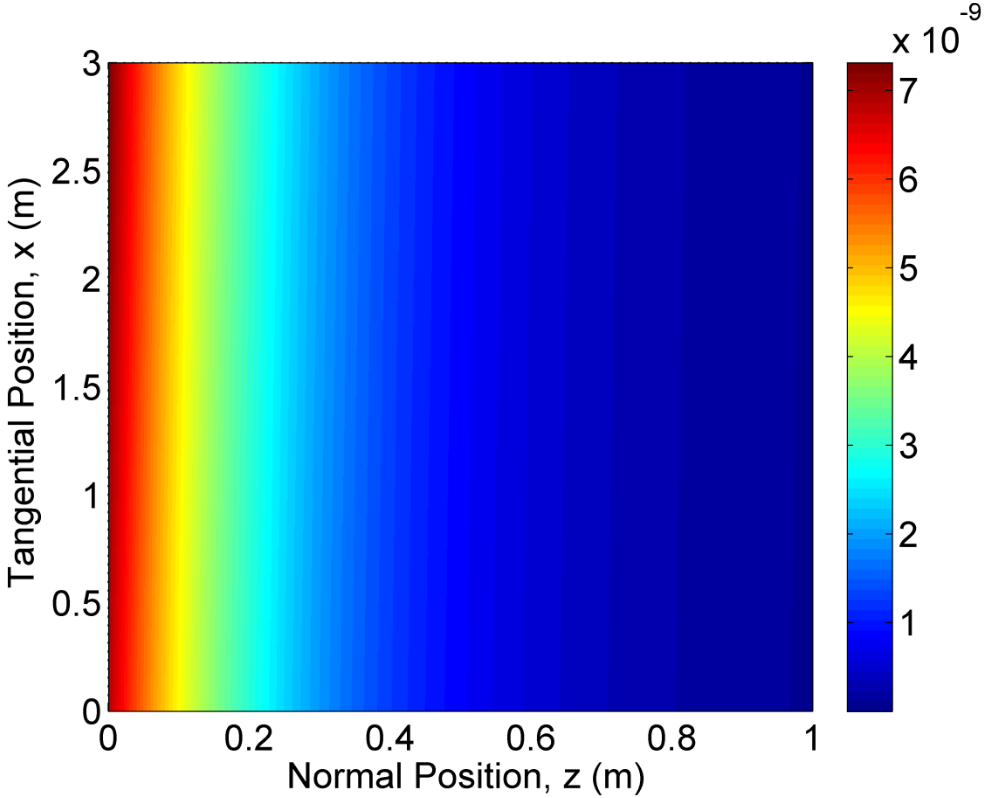
Transmitted Normal Velocity (m/s)



$\theta_{1,r} = 15°, \beta = 0.01$ rad/m

Numerical Results: Air-Water

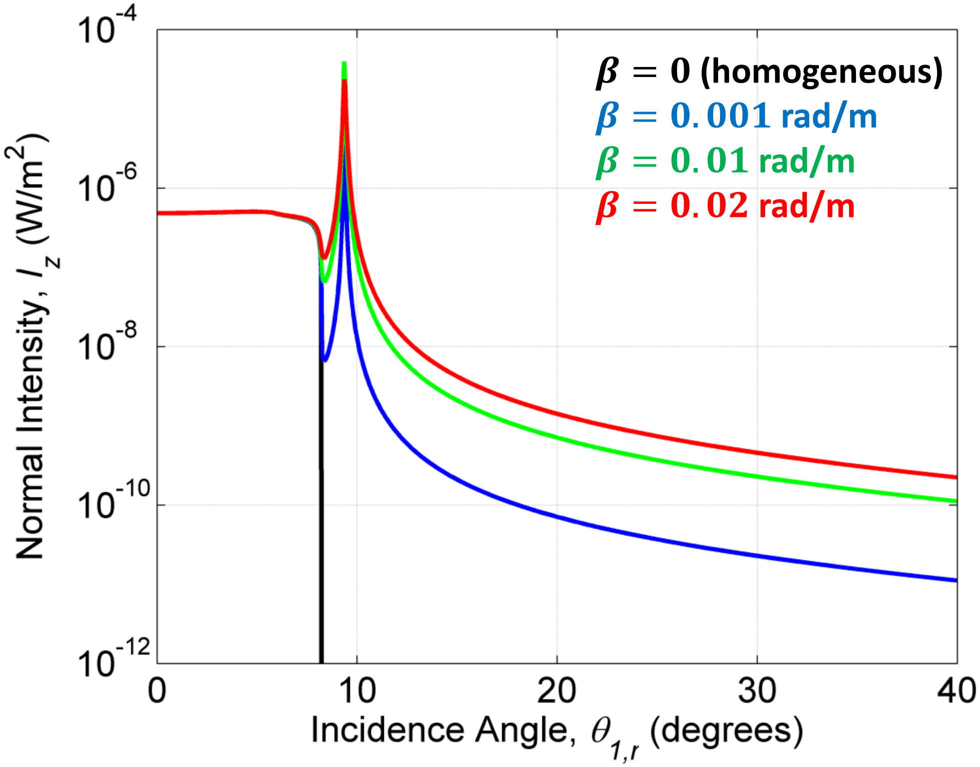
Transmitted Normal Intensity (W/m²)



Numerical Results: Air-Solid

Sample solid
$\rho = 1000\rho_{air}$
$c = 10c_{air}$
$b = 7c_{air}$

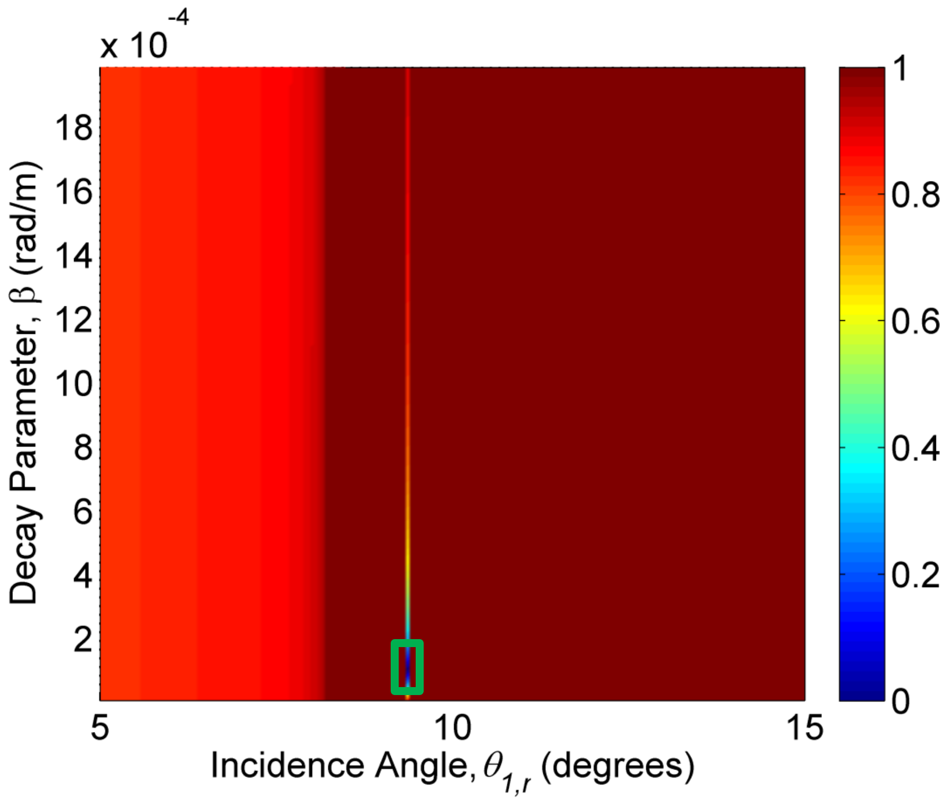
Transmitted Normal Intensity (W/m²)
1-Pa, 1000-Hz incident wave



$$I_z = \frac{1}{T}\int_0^T -(\sigma_z v_z + \tau_{xz} v_x)\,dt$$

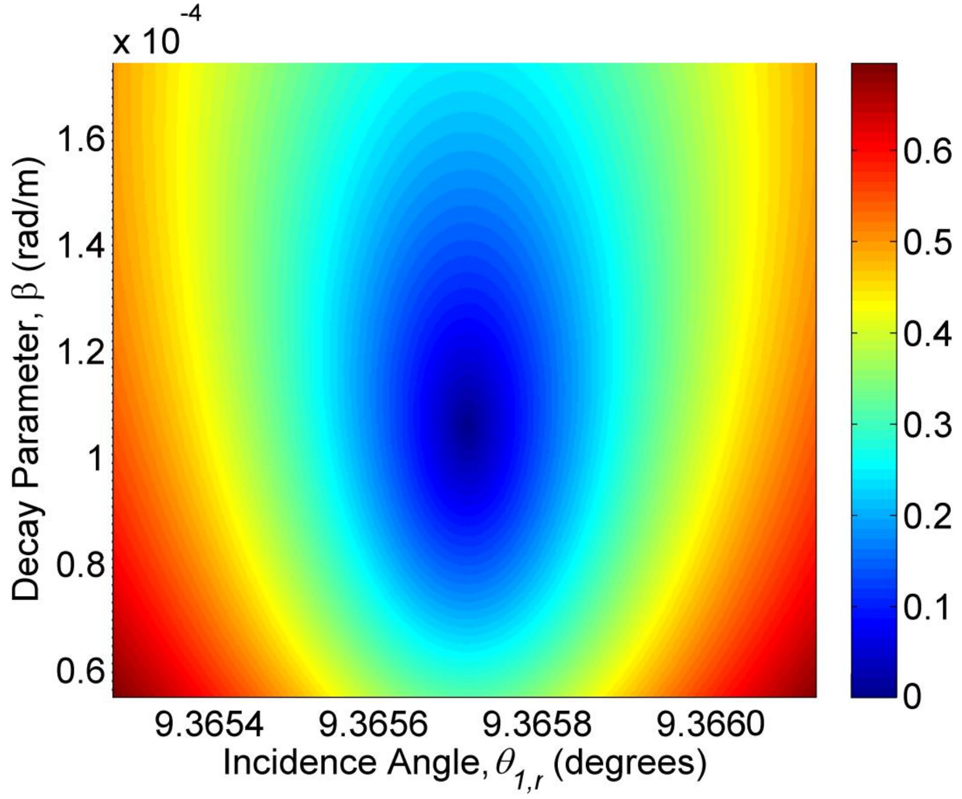
Numerical Results: Air-Solid

Magnitude of Reflection Coefficient (1000 Hz)



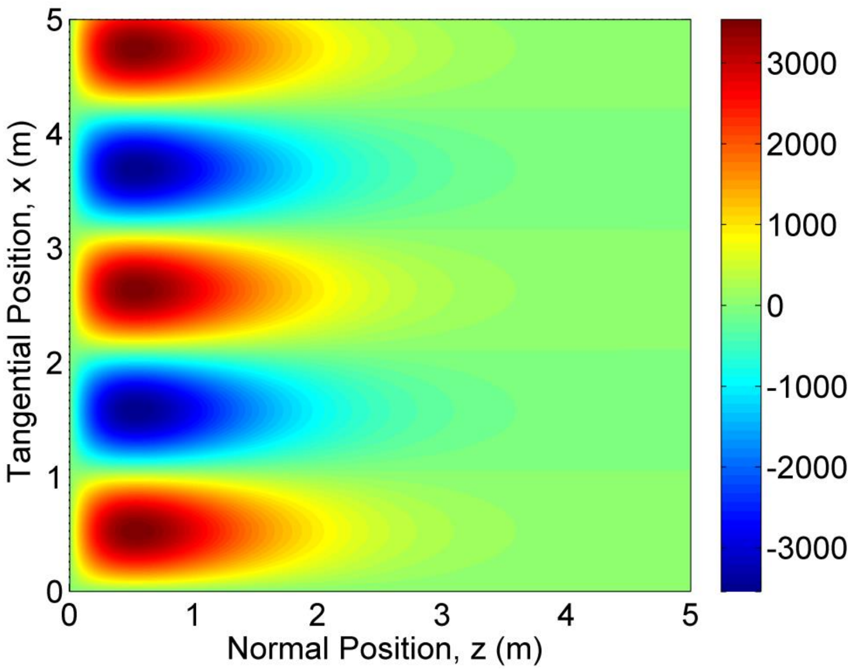
Numerical Results: Air-Solid

Magnitude of Reflection Coefficient
Near Rayleigh Angle

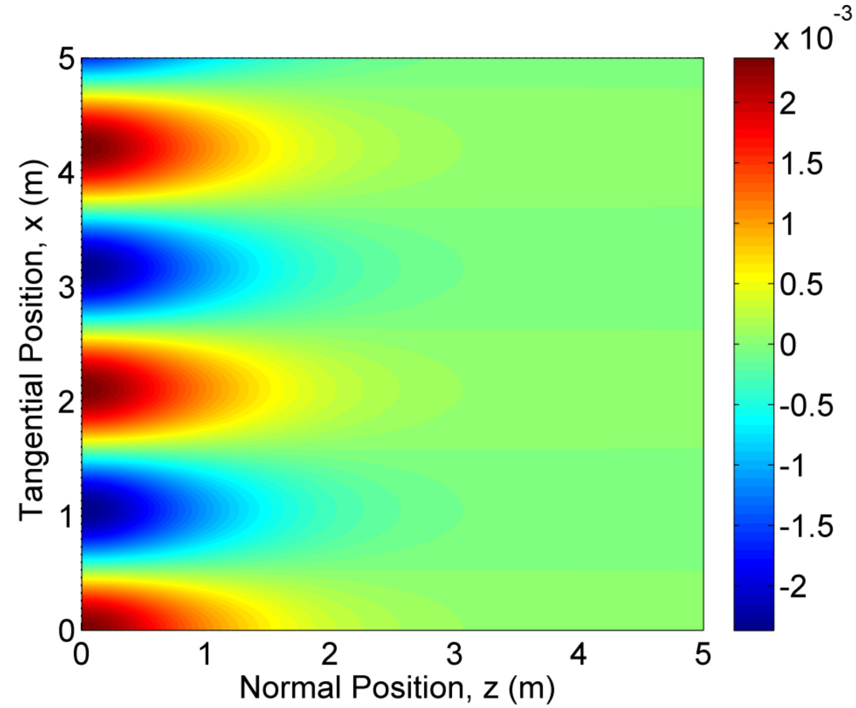


Numerical Results: Air-Solid

Transmitted Normal Stress (Pa)



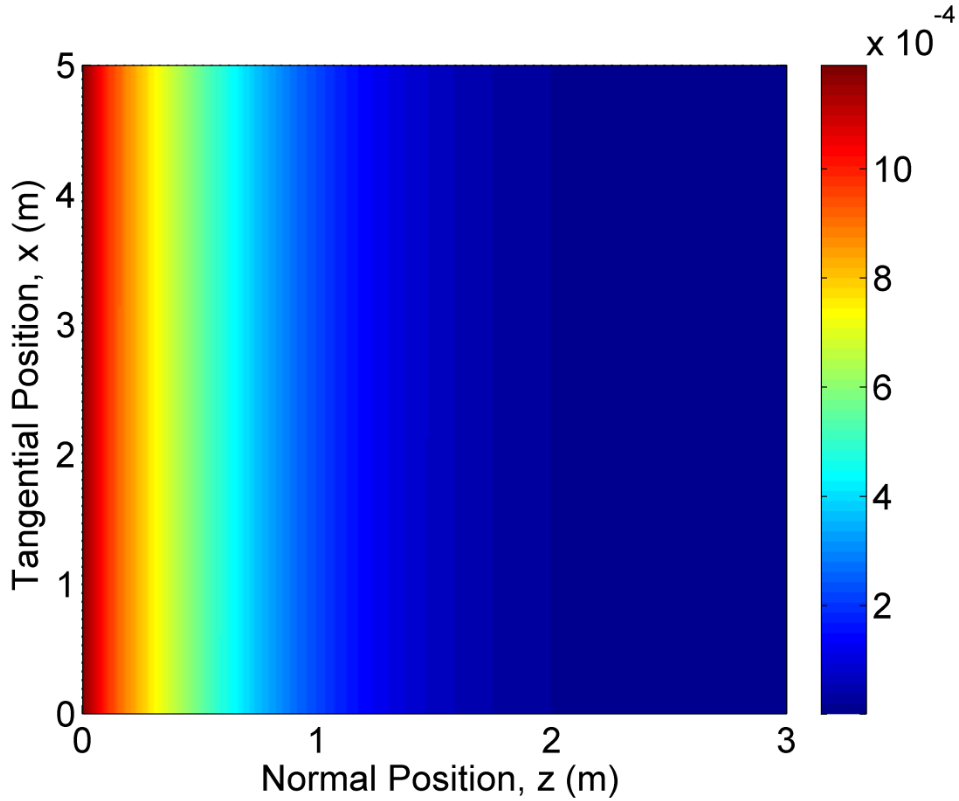
Transmitted Normal Velocity (m/s)



$\theta_{1,r}^{*} \approx 9.3657°, \beta^{*} \approx 1.07 \times 10^{-4}$ rad/m

Numerical Results: Air-Solid

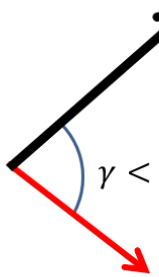
Transmitted Normal Intensity (W/m²)



Compare with $\sim 5 \times 10^{-7}$ W/m² for homogeneous waves below the critical angle

Conclusions

- Evanescent plane waves incident at material interfaces
  - Nonzero energy flux for all oblique incidence angles
  - Significant transmission increases near the Rayleigh angle and the critical decay rate
- Future work:
  - Propagation in linear viscoelastic materials
  - Measurements of stress and intensity transmission in energetic materials



Acknowledgement

The authors would like to thank the U.S. Office of Naval Research for its support of this research under ONR Grant No. N00014-10-1-0958