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Modeling of Micromachined Acoustic Bandgap Structures and Devices

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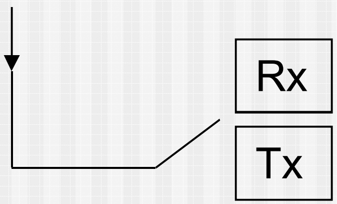
Acoustic Bandgap Crystals:

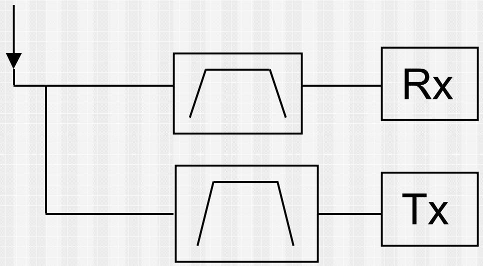
Why, What, and How?

❖ ***Motivation: Telecom (the why):***

- **Radio/Cellular Operation:**



Half Duplex

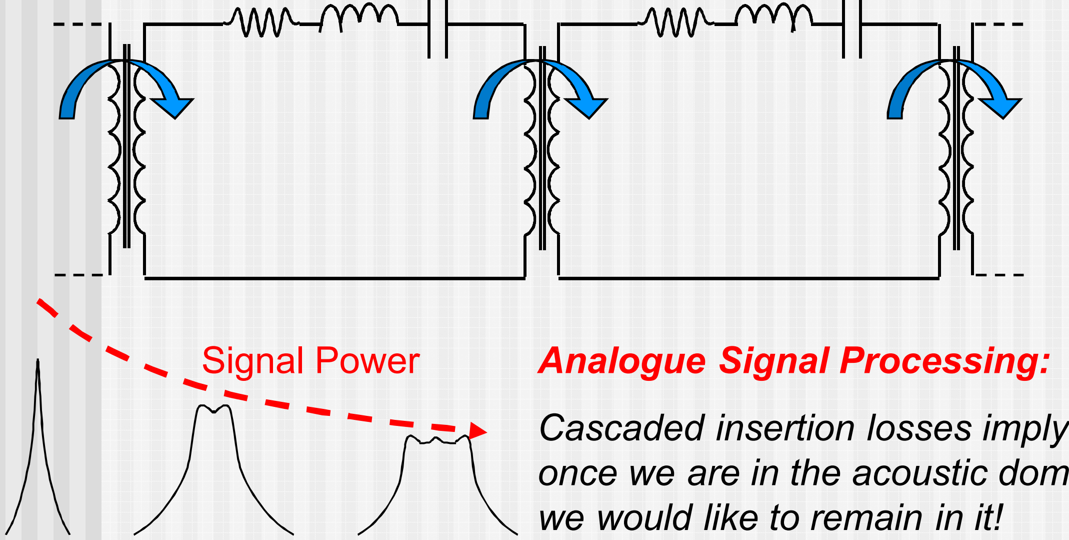


Full Duplex:

⇒Requires high resolution steep filtering

⇒Figure of merit Q≈1000-2000

- **Electro-Acoustic Coupling Losses:**



Why not Digital Signal Processing:

Requires high power at high frequencies.

Analogue Signal Processing:

Cascaded insertion losses imply that once we are in the acoustic domain we would like to remain in it!

Acoustic Signal Processing

⇒ ABG's

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Acoustic Bandgap Crystals:

Advantages of ABG Circuitry

Miniature

- Filters
- Delay Lines
- Phase Shifters
- Acoustic Signal Processing
- Power Combiners/Dividers

- Speed of Light = $3x10^8$ m/s
- Speed of Sound in SiO_2 = $5.8x10^3$ m/s
- Optical Delay Line of 1 µs = 300 m
- ABG Delay Line of 1 µs = 5.8 mm
- ***ABG delay line is 52,000 times smaller than an optical one!***

Micro-strip

Added Benifets of the Acoustic Domain:

- High-Q distributed ABG filters at GHz frequencies at significant improvement over current FBAR technologies resulting in new low power radio architectures.
- Integration of multiple components on one chip with little or no losses at a size that is 10^4-times smaller than current optical or micro-strip technology
- Allows for distributed circuit techniques that are commonly used in microwave circuit design to be applied to lower frequency systems (such as cell phones and WLAN) using acoustic rather than EM waves.

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Acoustic Bandgap Crystals:

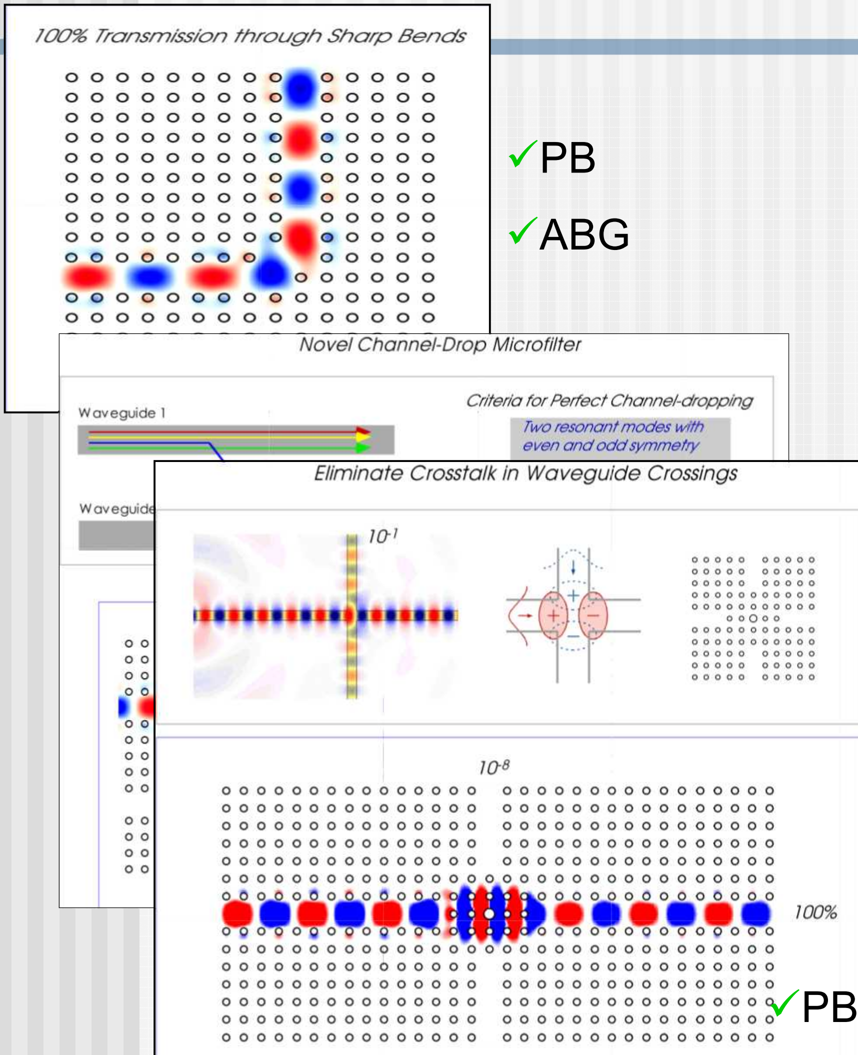
The What

- ***What does this have to do with PBG's?***
  - Direct analogy between 2D Acoustic (phononic) and photonic crystals.
  - Wealth of Literature on 2D PC that can be used as a first iteration for the design and study of ABG crystal applications.

PBG Photons	***ABG Phonons***
2nd order coupled victor equations with 2 polarizations	*2rd order coupled Tensor Equations with 3 polarizations*
Light line constraints and ability to couple to free space modes mandates that full control of waves can only be achieved in 3D devices	*Mechanical wave nature and low coupling to air modes along with the possibility of vacuum packaging allow for full control using only 2D devices*
No inherent structural resonances. Finite size leads only to evanescent mode issues.	*Inherent physical size dependent structural resonances.*
THZ applications require sub-micron length scales	*GHZ applications require sub-micron length scales*
Inherently linear	*Inherently non-linear*

Acoustic Bandgap Crystals:

Contrast to Photonic Bandgap Crystals



✓PB

✓ABG

✓PBG

✗ABG

- ***ABG = Superposition of Bragg and Mie Scattering:***
  - A cermet topology (disconnected) of high density inclusions in a low density background matrix.
  - Acoustic impedance mismatch between the inclusions and the matrix.
  - A maximization of the gaps is achieved by requiring the ration of the longitudinal velocity c_l to the shear velocity c_s values in both the matrix and inclusion to be as close to the fundamental limit of a hard scatterer $\sqrt{2}$.
- ***Challenges:***
  - **Finding high Q pair systems.**
  - **Compatibility with AlN and Si-processing techniques for integration**
  - **Scaling to um size designs.**

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Acoustic Bandgap Crystals:

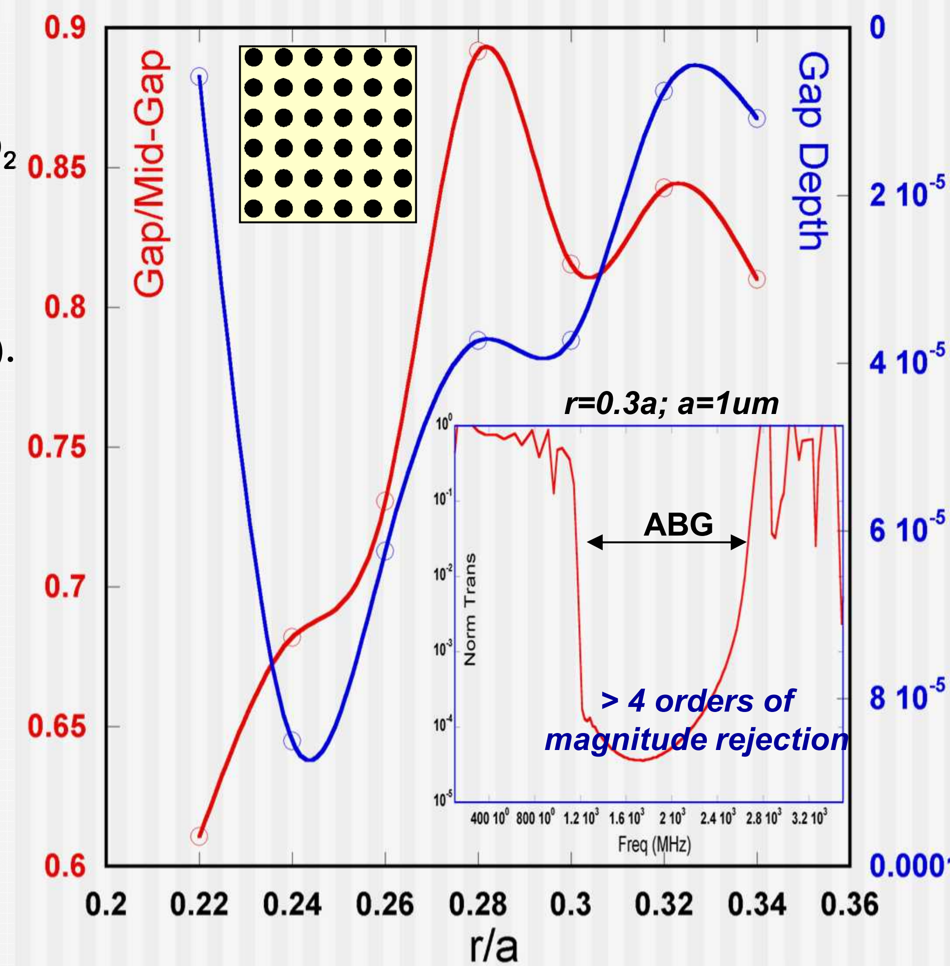
The Path to GHz ABG's

❖ *Proposed System:*

- Suspended membrane topology of 2D rod arrays of W (ρ = 19,300 kg/m3, Z = 89 MΩ) in SiO_2 (ρ = 2,200 kg/m3, Z = 13 MΩ) matrix (both are high Q materials).
- AlN Piezoelectric transducers (allows us to leverage FBAR low insertion loss technologies).
- 1st generation: MHz devices using a 7 Levels Post-CMOS Compatible process See poster B25.

❖ *Modeling:*

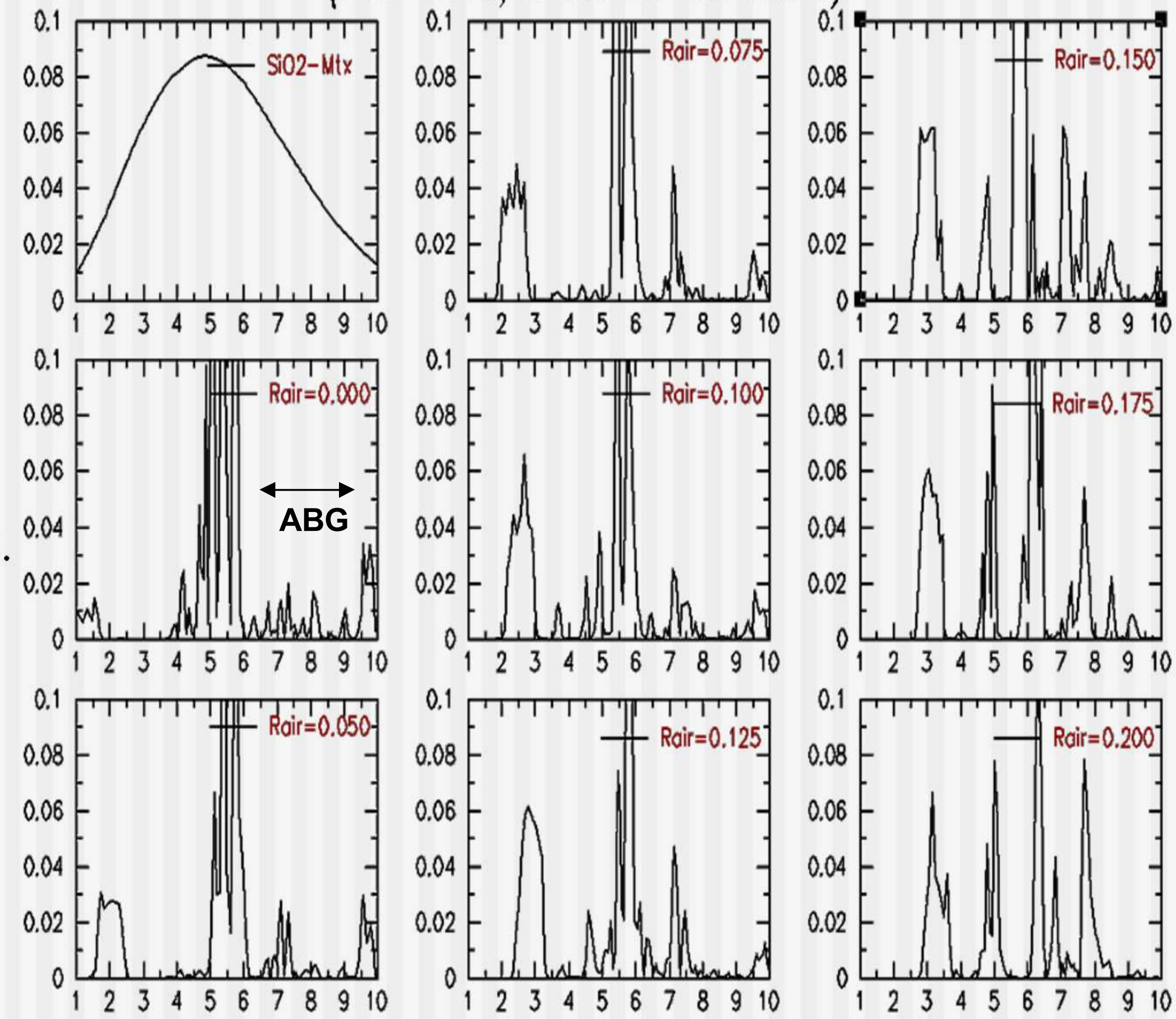
- FDTD algorithm for the temporal integration of the full elastic wave equation that incorporates both Lame coefficients.
- Periodic boundary conditions are used at the edges of the cell along the *x* and *y* directions and space is terminated along the *z* axis (direction of propagation) by Mur's first order absorbing boundary.
- The time series results collected at the detection point are converted into the frequency domain using the fast Fourier



Acoustic Bandgap Crystals:

MHz Test ABG Structures

Square Lattice of W Rods in SiO_2 Matrix
(Rw=0.3a; a=lattice constant)

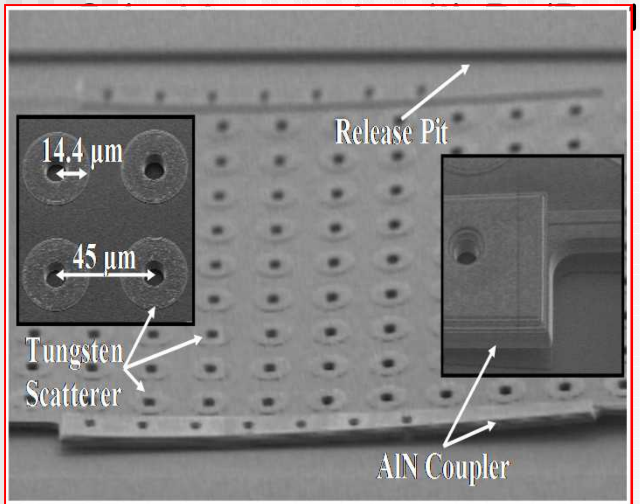


❖ Fabrication Limitation:

- Release holes!
- Will not exist in GHz regieme.

❖ Effect of release holes MHz test systems:

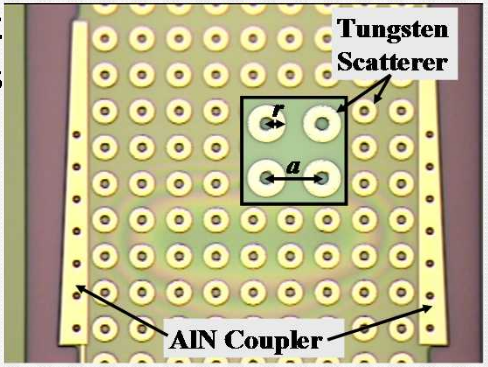
- Below a threshold value no effect.
- Introduction of hopping modes.

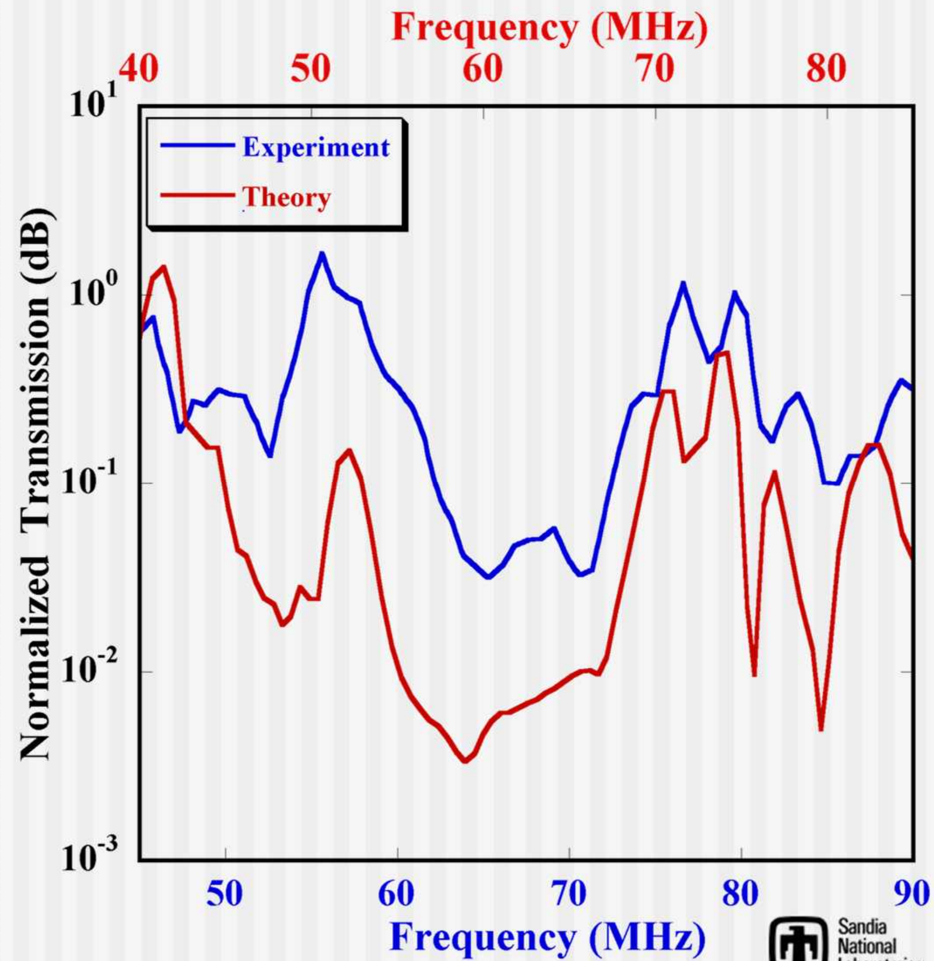


Acoustic Bandgap Crystals:

Theory Versus Experiment

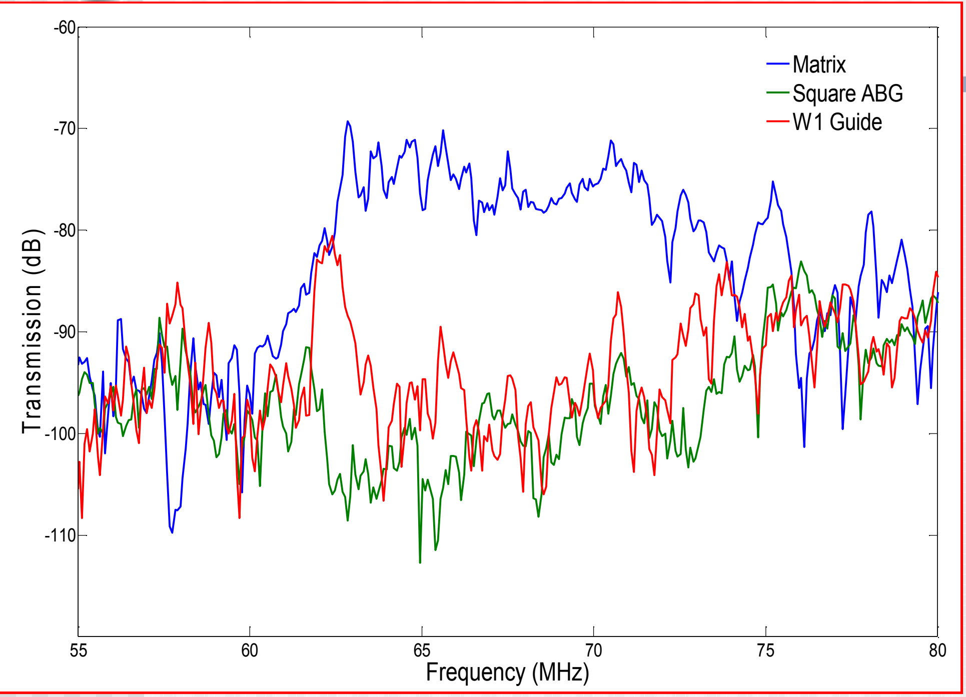
- ***Excellent Qualitative Agreement.***
- ***Differences due to:***
  - Use of bulk properties in the simulation versus actual measuerd values of the deposited materials.
  - Theoretical gap appears to be wider, (low frequency end is red-shifted and high frequency end is blue shifted), can be attributed to:
    - Use of lossless materials in model.
    - Infinite siz
      dimensions

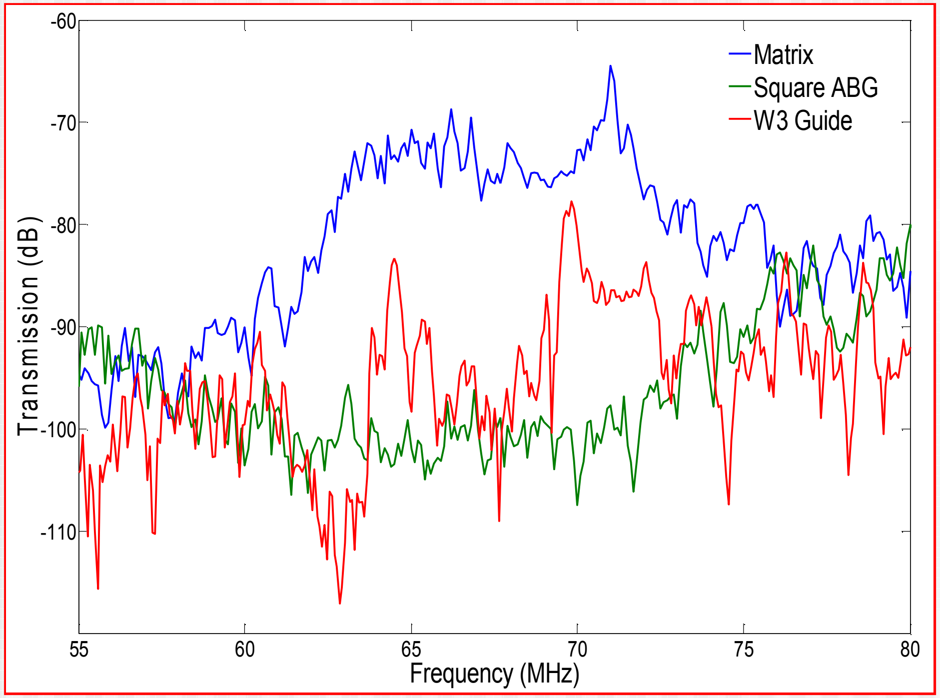




Acoustic Bandgap Crystals:

Line Defects: Theory v.s. Experiment





Acoustic Bandgap Crystals:

Summary and Conclusion

- ***Demonstrated the first MHz Acoustic band gap device.***
- ***Good agreement between theory and experiment.***
- ***Preliminary Results on line defects.***
- ***Moderate point defect Q's much improvement needed***
- ***Successful implementation of ABG technology will allow for distributed circuit techniques that are commonly used in microwave circuit design to be applied to lower frequency systems (such as cell phones and WLAN) using acoustic rather than EM waves.***

The End

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