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Piezocomposite Design/Selection Process

Ultrasound System Design Reality

- Most Acoustic Imaging Systems Utilize Piezoelectric Materials in the Transducers to Generate and Receive the Acoustic Signals
- The Transducers Determine the Performance Limits of the Overall System
- Transducer Performance is Limited by the Transduction Material Characteristics
- Piezocomposite is an Enabling Improvement in Sonar and Ultrasound Transducer Performance

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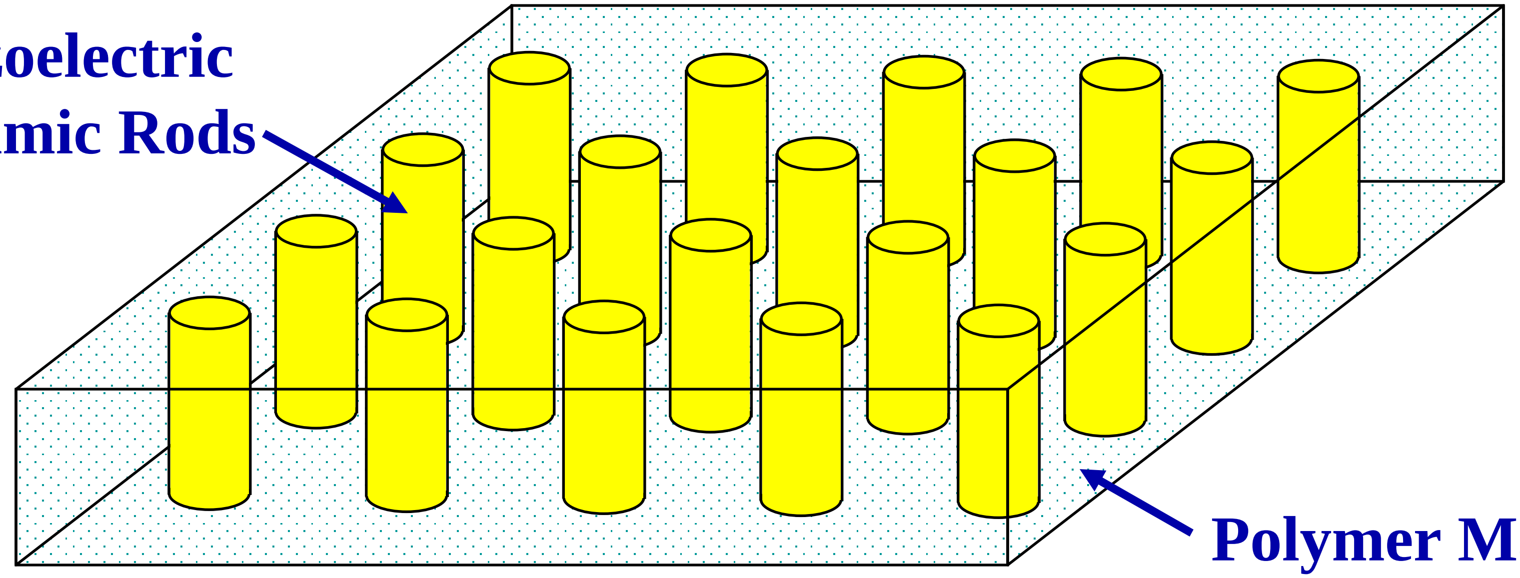
Advantages of Piezocomposite Transducers: Imaging Sonars

- Increased Sensitivity
- Broader Bandwidth
  - Better resolution
- Reduced Sidelobes
  - Improved image contrast
- Improved Impedance Match to Water
  - Better efficiency
  - Increased signal to noise
- Low Interelement Cross Talk
- Greater Element to Element Phase and Amplitude Uniformity
- Low Cost Construction

1-3 Piezocomposite



- Piezoelectric Ceramic Rods in a Polymer Matrix
- Model as an Effective Homogeneous Medium
- Properties determined by
  - Piezoelectric Ceramic type
  - Polymer properties
  - Volume fraction of Piezoelectric Ceramic (v)

Piezocomposite Provides a Large Number of Design Parameters Which can be used to optimize Performance for your Application

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Piezocomposite Design Goals

Parameter	**Desired Value**
Capacitance	Maximize
Electrical Impedance	Match to System
Acoustic Impedance	Match to ~1.5 MRayls (water)
Electromechanical Coupling	Maximize
Electrical Loss Tangent	Minimize
Mechanical Loss ($1/Q_m$)	Minimize

Any composite design is a compromise among these parameters.

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Piezocomposite Capacitance

$C = \varepsilon \cdot \text{Area/Thickness}$ ε is the permittivity [F/m]

Model piezocomposite as parallel capacitors

$$\varepsilon_{composite} = v\varepsilon_{Piezoelectric\ Ceramic} + (1-v)\varepsilon_{polymer}$$

$$\varepsilon_{Piezoelectric\ Ceramic}\ (100\text{'s} - 1000\text{'s}) >> \varepsilon_{polymer}\ (1 - 10)$$

$$\varepsilon_{composite} \approx v\varepsilon_{Piezoelectric\ Ceramic}$$

Maximize ε

- High Volume Fraction of Piezoelectric Ceramic
- Use Electrically 'Soft" Piezoelectric Ceramic's (eg. MSI-53)

Piezocomposite Acoustic Impedance

$$Z = \rho c$$

ρ is the density
c is the sound velocity

Model piezocomposite as parallel springs

$$Z_{composite} = vZ_{Piezoelectric\ Ceramic} + (1\text{-}v)Z_{polymer}$$

$$\rho_{Piezoelectric\ Ceramic}\ (6 - 8\ g/cm^3) > \rho_{polymer}\ (1 - 2\ g/cm^3)$$

$$c_{Piezoelectric\ Ceramic}\ (3000\ m/sec) > c_{polymer}\ (1000 - 3000\ m/sec)$$

$$Z_{composite}\ (4 - 15\ MRayl) < Zp_{iezoelectric\ Ceramic}\ (20 - 30\ MRayl)$$

Minimize Z (~1.5 Mrayl for water)

- Low Volume Fraction of Piezoelectric Ceramic
- Use Mechanically Soft Polymer

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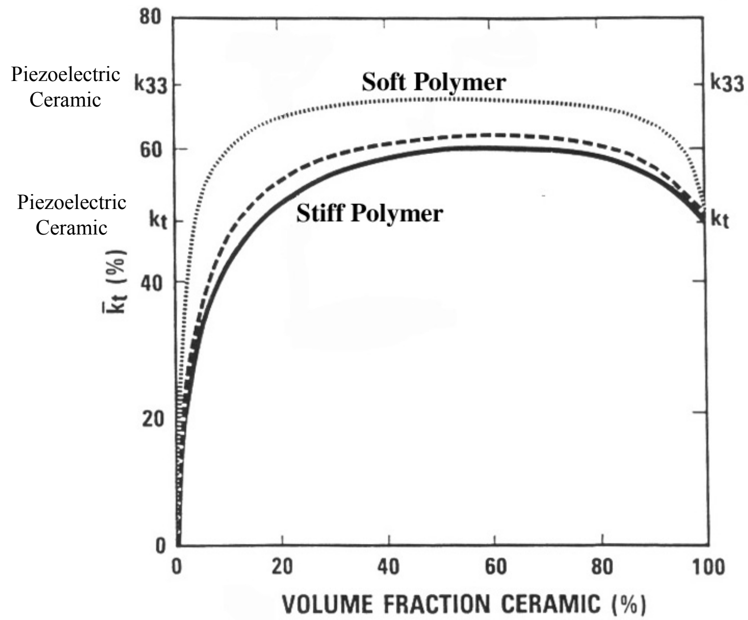
Electromechanical Coupling



$k_t = e_{33}^2 \, c_{33}^D$

Bandwidth ~ k_t

Efficiency ~ k_t^2

$k_{t \text{ Piezoelectric Ceramic}}$ (45 -50%) < $k_{t \text{ composite}}$ (60 - 70%) < $k_{33 \text{ Piezoelectric Ceramic}}$ (70 - 75%)

Maximize k_t

- Moderate Volume Fraction
- Use Mechanically Soft Polymer

Ref.: W.A. Smith, "The Application of 1-3 Piezocomposites in Acoustic Transducers," Proceedings of the 1990 IEEE International Symposium on Applications of Ferroelectrics, 145-152 (1991)

Electrical And Mechanical Losses

Electrical

$\tan \delta_{\text{Piezoelectric Ceramic}} < 2\%$ $\tan \delta_{\text{composite}} < 2\%$

Mechanical

$(Q_m^{-1})_{\text{Piezoelectric Ceramic}} \sim 1\%$ $(Q_m^{-1})_{\text{composite}} \sim 2 - 50\%$

Minimize Loss
• Achievable With Care

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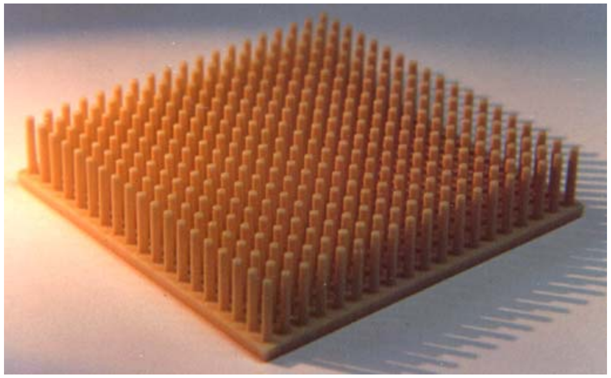
Matrix Material Selection

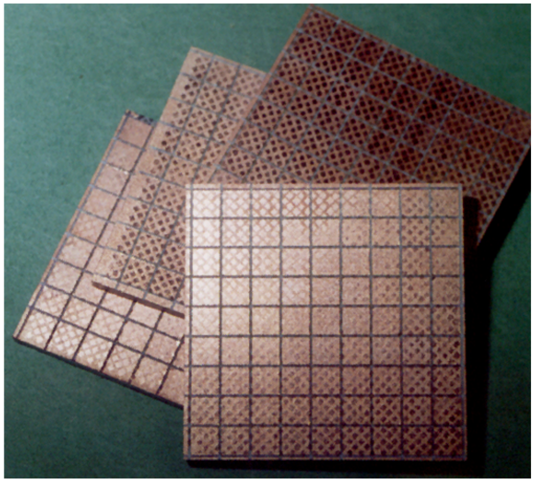
Piezocomposite Type	Applications
Soft Matrix – Ultrahigh receive sensitivity (+10dB re: ceramic) – Moderate pressure capability – Excellent inter-element decoupling – Requires careful design for deep water applications	– Surface ship sonar – Commercial seismic arrays – Selected submarine applications – Industrial proximity sensors
Hard Matrix – High receive sensitivity (+5 dB re: ceramic) – High pressure capability (>1000 psi) – Good inter-element decoupling with proper design	– All submarine sonars – Most ocean bottom applications – Deep commercial sonar
Ultrahard Matrix – Good receive sensitivity (~ ceramic) – Durable under extreme conditions – Ultrahigh pressure (>20,000 psi)	– Industrial sensors – Oil & gas drilling – High temperature environments
All Types – High transmit performance – Conformal	

Piezoelectric Ceramic Volume Fraction Selection

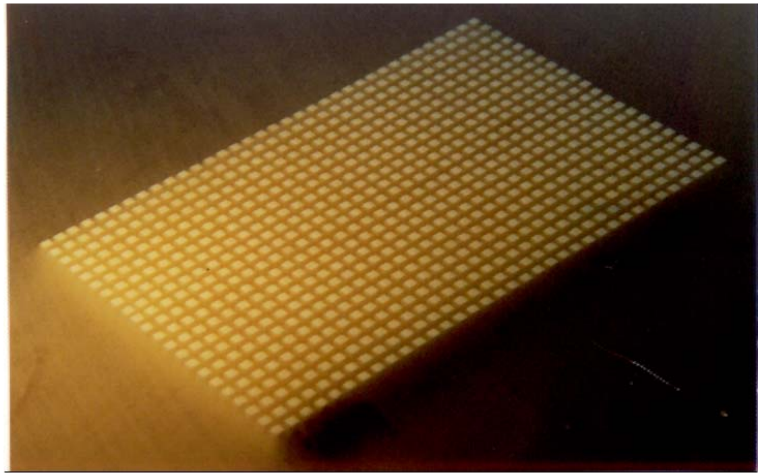
Receive
15 - 25 % Piezoelectric Ceramic



Transmit
>50 % Piezoelectric Ceramic



Transmit/Receive
30 - 50 % Piezoelectric Ceramic



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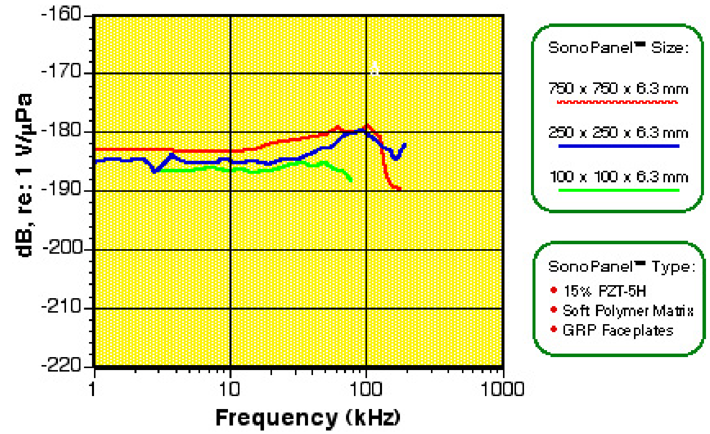
Receive Applications

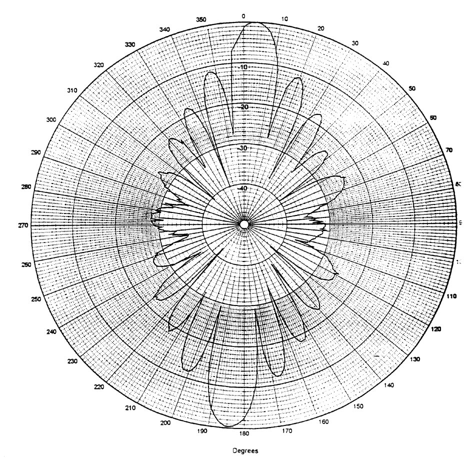
- Piezocomposite Design Attributes
  - Very broad bandwidth
  - High sensitivity
  - Beam patterns derived from standard aperture calculations
  - Aperture shading by electrode patterning (apodizing)

- Depth Rating
  - Select among hard and soft polymer matrix
    - Trade off between sensitivity and pressure resistance

Very Broad Bandwidth



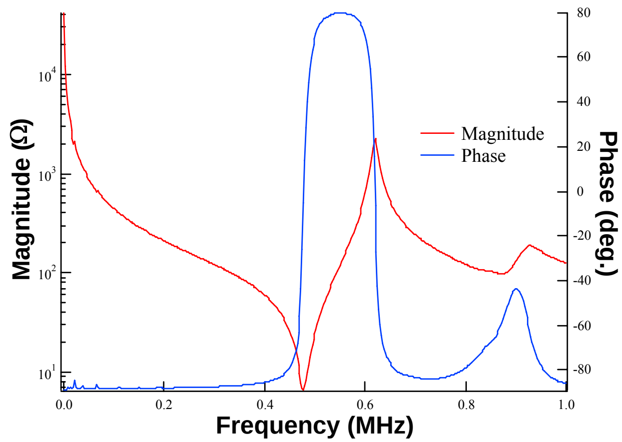
Predictable Beam Patterns



Transmit and Transmit/Receive Applications

- Piezocomposite Transmitters Must be Designed Properly
  - Require high ceramic volume fractions
  - Designed for at-resonance operation
    - Process to precise thickness
    - Control composite geometry to isolate thickness mode resonance
    - Broad bandwidth can be achieved with proper backing and matching layers

Properly Designed Composite



- Depth Rating
  - Select among hard and soft polymer matrix
    - Trade off between sensitivity and pressure stability

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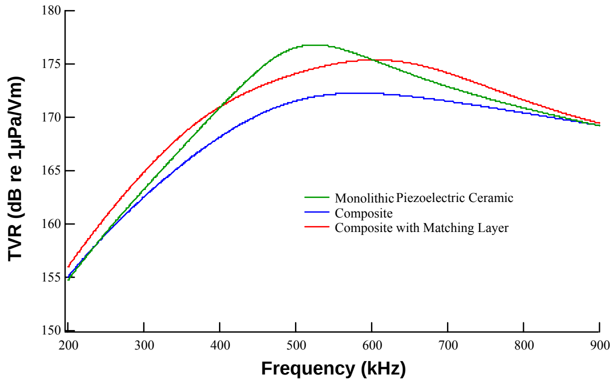
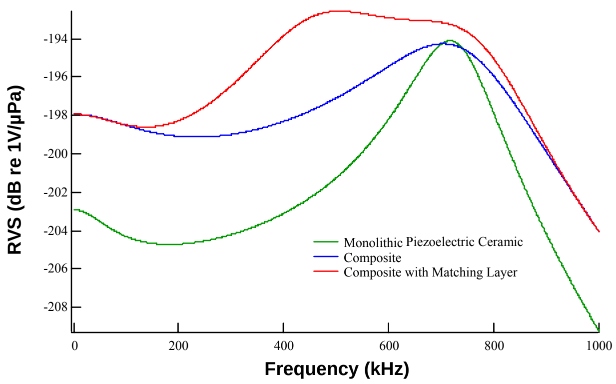
Matching Layers

- Increase Coupling Efficiency
- Increase Bandwidth
- Reduce Electrical Impedance
  - Lower voltage transmitters
  - Lower voltage connectors
  - Reduced electromagnetic pickup
  - Lower cost drive electronics
- Same Design Criteria As Monolithic Ceramics
  - Requires new lower impedance materials
  - Custom polymers available

Design Examples





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Backing Structures

- Absorbing Backing
  - Provides the maximum bandwidth
  - Same design criteria as monolithic ceramics
  - Custom backings available

- Resonant Backing
  - Increases efficiency at the expense of bandwidth
  - Same design criteria as monolithic ceramics

Design Example