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Suppressing Fine-Frequency Modes in Aluminum Nitride Microresonators

Darren W. Branch and Roy H. Olsson

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dwbranc@sandia.gov

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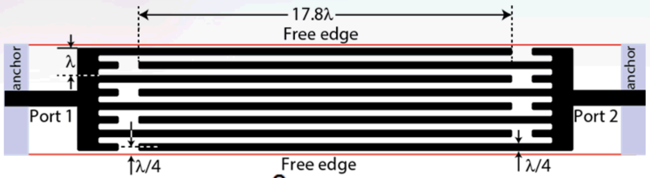
Sources of Spurious Modes

In Width Extensional (WE) AlN Microresonators

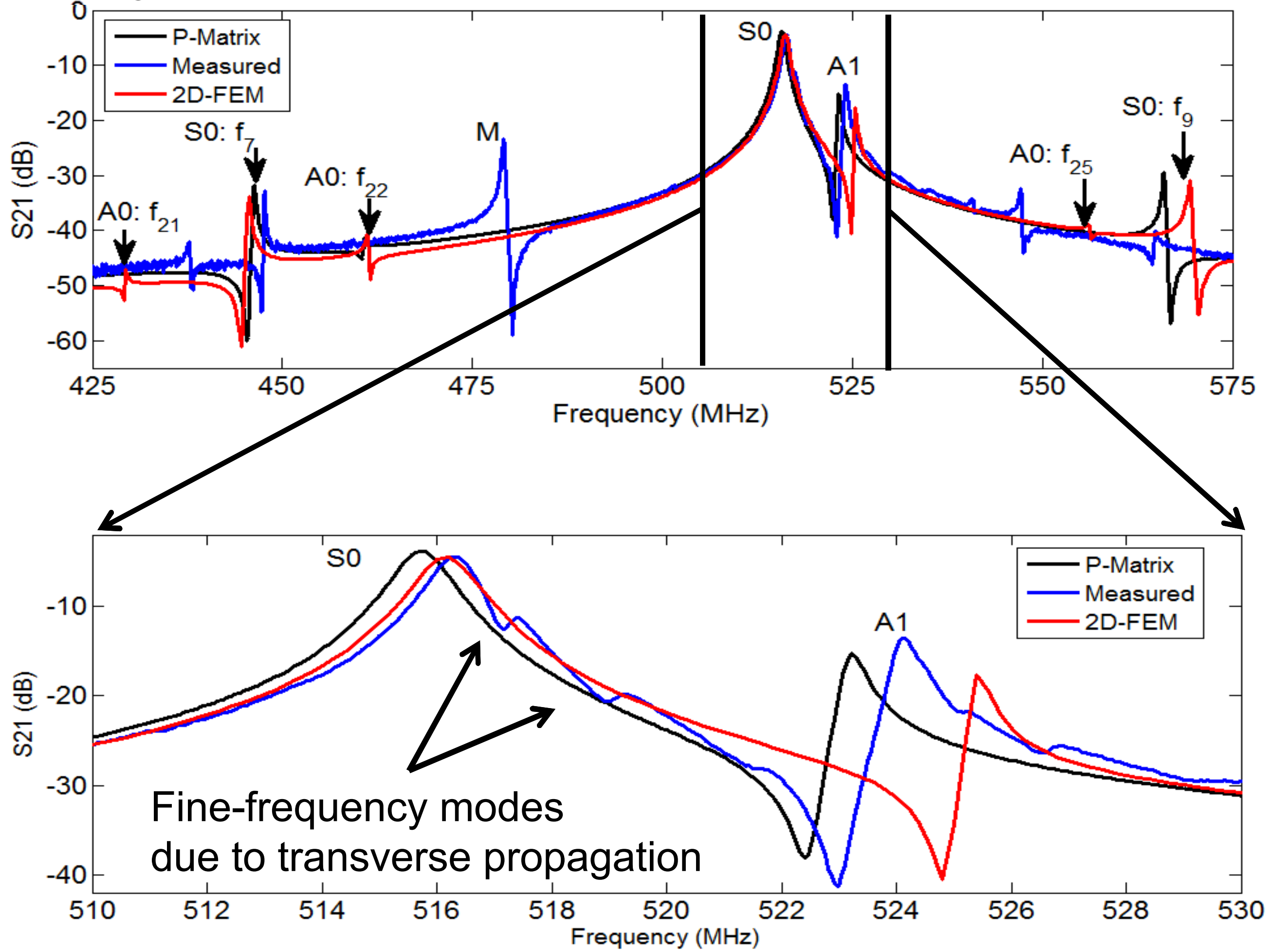
- Flexural waves
- Mode conversion
  - Free-plate edges
  - Between propagating modes in the laminate
- Transverse waves
  - Acoustic interactions with busing
  - Interconnects and anchoring

Case Study: Spurious Modes



AlN Microresonator with $N_t = 8$ fingers

D. W. Branch, et al. IEEE UFFC, 2014



Mitigation and Methods to Transverse Modes

Mitigation: reduce energy leakage into the bussing

- Narrowing the aperture ~ λ: Increases insertion loss, matching
- Dummy fingers: Only permits selective mode suppression
- Apodization: Degrades Q and increases insertion loss
- Alter velocities in domains to satisfy: $v_t < v_b < v_f$

Methods:

- 3D FEM: Computationally slow (5 minutes/frequency point)
- Scalar potential theory: fast
- 2D P-matrix: intermediate
- 2D COM: intermediate

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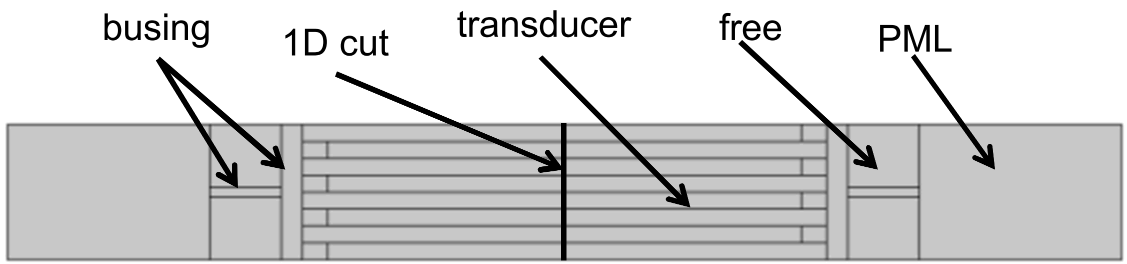
Two-Dimensional Coupling of Modes (2D COM)



2D COM Equations:

$$\nabla\cdot j\begin{bmatrix}\begin{bmatrix}0 & 0\\ 0 & \frac{\gamma_a}{2k_o}\end{bmatrix} & [0]\\ [0] & \begin{bmatrix}0 & 0\\ 0 & -\frac{\gamma_a}{2k_o}\end{bmatrix}\end{bmatrix}\begin{bmatrix}0\\ \frac{\partial A^+}{\partial y}\\ 0\\ \frac{\partial A^-}{\partial y}\end{bmatrix}+\nabla\cdot\begin{bmatrix}1 & 0\\ 0 & 0\\ 0 & 1\\ 0 & 0\end{bmatrix}\begin{bmatrix}A^+\\ A^-\end{bmatrix}+j\begin{bmatrix}\delta & \kappa_{12}\\ -\kappa_{12}^* & -\delta\end{bmatrix}\begin{bmatrix}A^+\\ A^-\end{bmatrix}=\begin{bmatrix}\alpha\\ \alpha^*\end{bmatrix}\begin{bmatrix}V\\ -V\end{bmatrix}$$

Detuning parameter: $\delta = k - k_o - j\gamma$

Once the fields are known, then the current can be computed

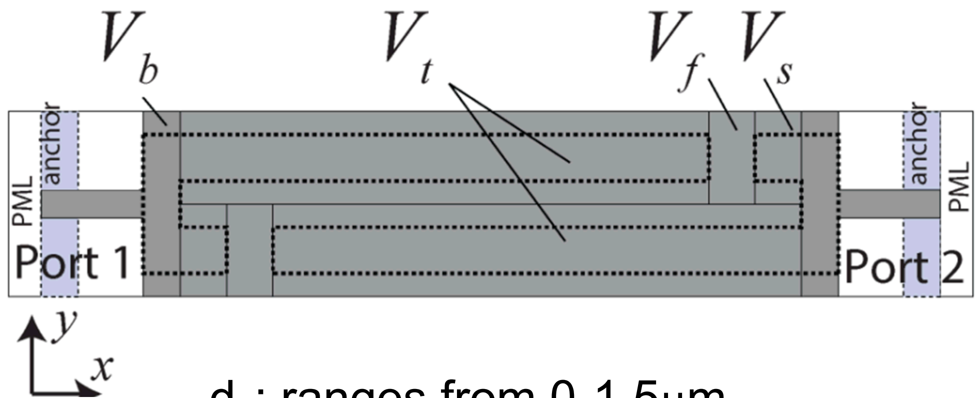
Currents:

$$I_i(\omega) = \iint \left(2\alpha^* A^+ + 2\alpha A^- + j\omega C(x,y)V_i\right)dx\,dy$$

$$I_o(\omega) = \iint \left(2\alpha^* A^+ + 2\alpha A^-\right)dx\,dy$$

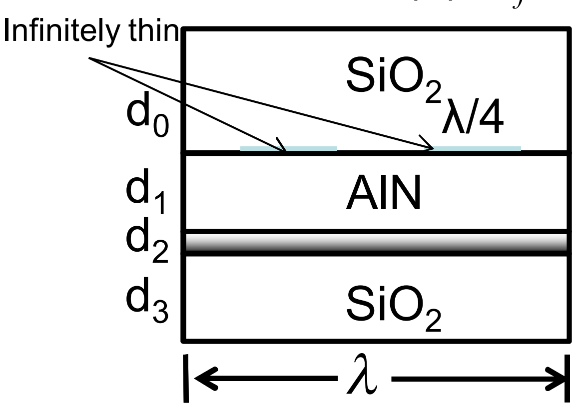
PML: $k(r) \rightarrow k_f(1 - j\eta(r)) = k_f\left(1 - j\eta_o \frac{|r - r_i|}{d}\right)$

Approximate Acoustic Velocities in the Domains

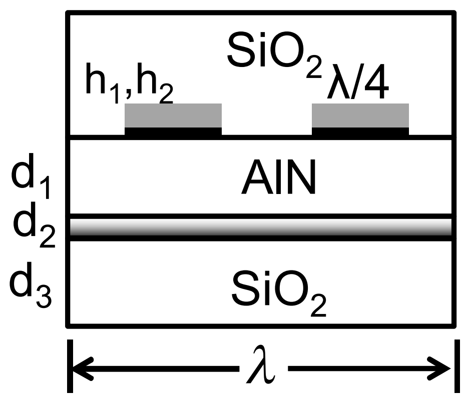


d_0: ranges from 0-1.5μm

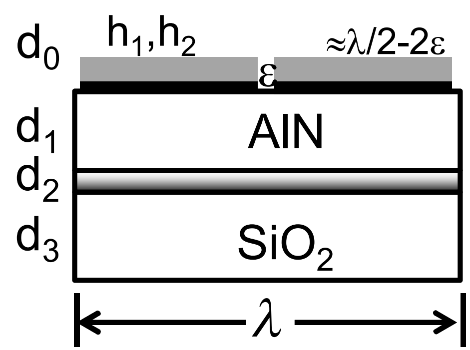
Free Domain (1): V_f:



Transducer Domains: V_t, V_s:



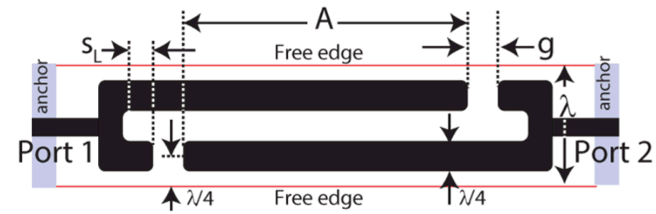
Buss Domains: V_b :



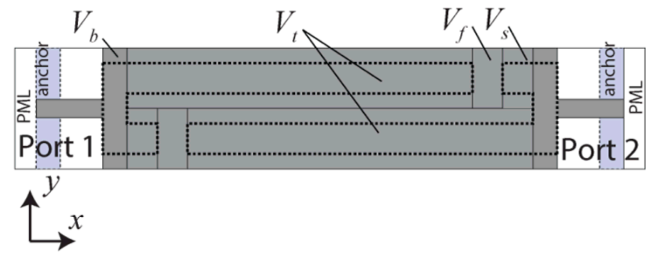
AlN Microresonator Geometry

COM Parameters					
Domain	**δ**	**v (m/s)**	**$\kappa_{12}p$ (%)**	**$\lvert\zeta p\rvert^2/\omega C_s$ ($m^2\Omega^{-1/2}$)**	**C_o (pF/p/m)**
Transducer	$k_t - k_o - j\gamma$	7873	-0.08	0.004	512.3
Buss	$k_m - k_o - j\gamma$	7828	0	0	512.3
Free Space	$k_f - k_o - j\gamma$	7910	0	0	0
Stub	$k_s - k_o - j\gamma$	7873	-0.08	0.004	512.3

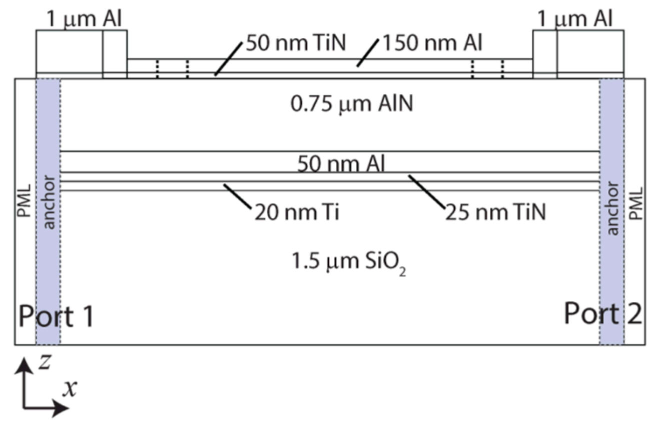
Layout



Equivalent Field Model Layout



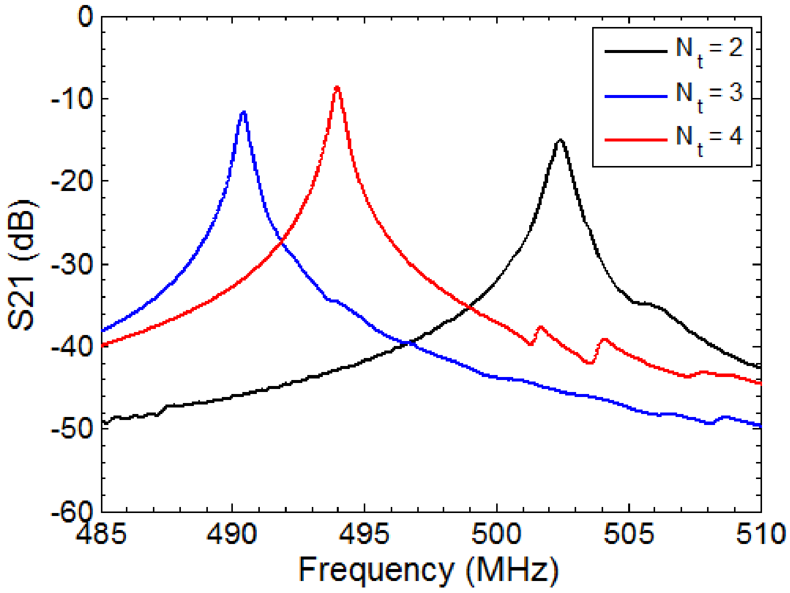
Cross-Section



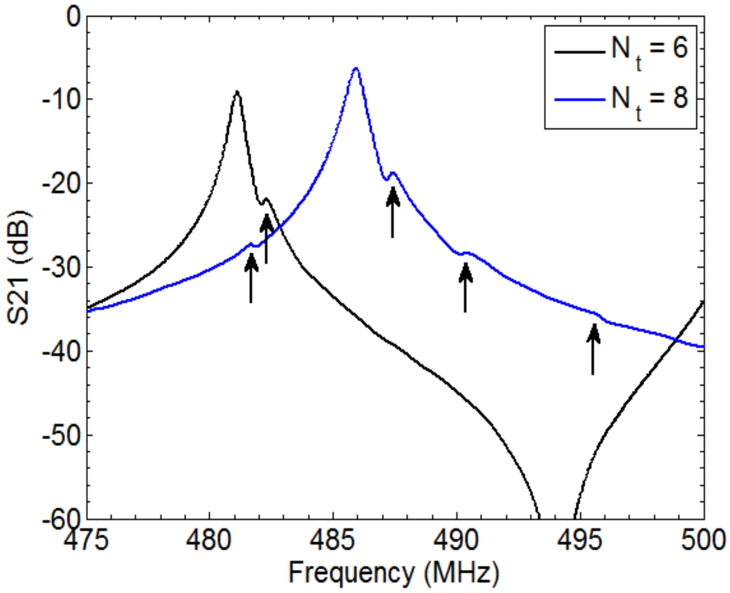
S21 Response versus Finger Number

- When $N_t > 4$, the fine-frequency modes (arrows) appear near the fundamental resonance.
- The acoustic length of the buss and its properties contribute to the spurious modes.

Spurious modes are far from resonance

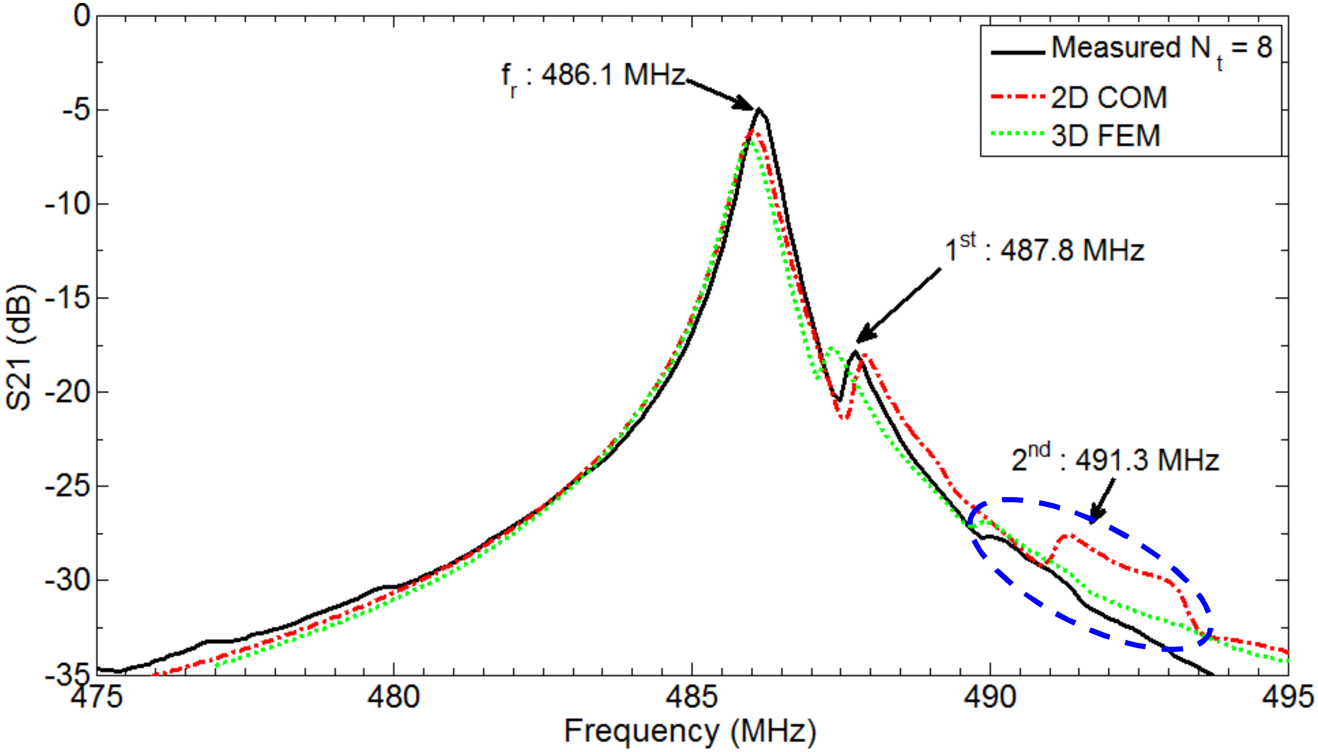


Spurious modes are within ~25 dB of resonance



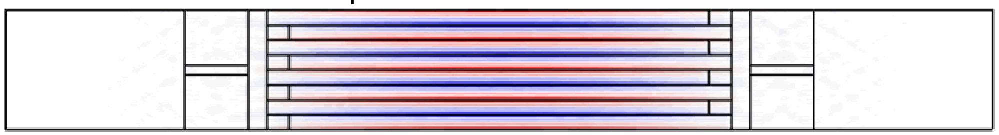
Experimental and Simulated S21 Response from 2D COM/3D FEM

- The 2D COM simulation predicted two distinct spurious modes at 487.8 MHz and a second at 491.3 MHz and tracks the measurement well.

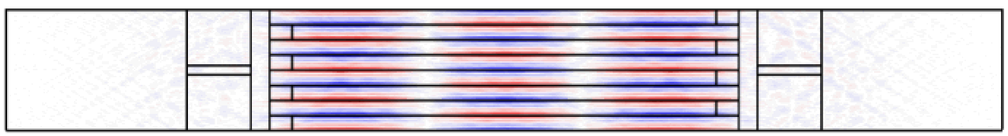


Transverse Modes from 2D COM

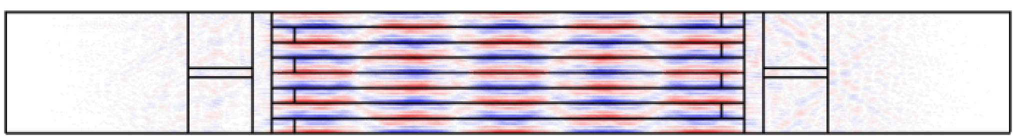
f_r =486.1 MHz

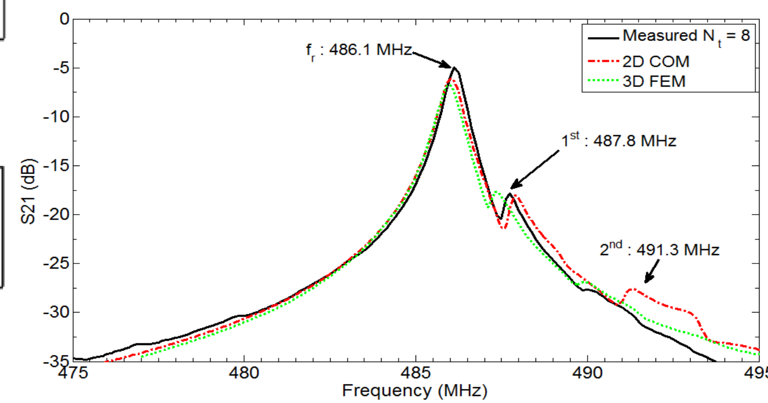


f_r =487.8 MHz



f_r =491.3 MHz





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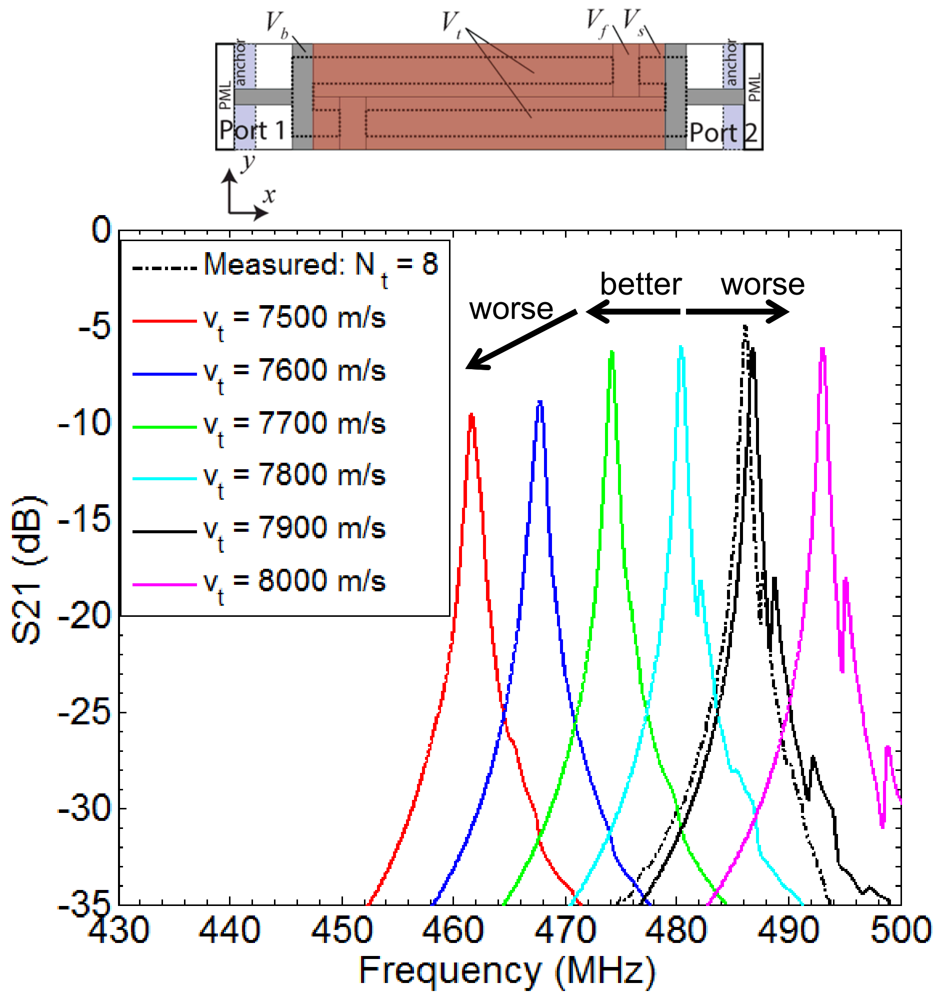
Suppression of Spurious Modes

Depositing silicon dioxide in the transducer domain corresponds to reducing the velocity in this domain:



- There was a narrow velocity range where the spurious modes are suppressed.
- After this point, S21 degrades due to impedance mismatch.

Thank You!

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