Characterization of Viscoelastic Damping in an Antenna Structure

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Abstract

The dynamics of a ribbed antenna structure are examined. The symmetry of the structure generates repeated natural frequencies and hence a "beating" phenomena in the dynamic response of the structure. Two of the antenna's ribs are replaced with passively damped ribs which are treated with a constrained viscoelastic material. Since these repeated natural frequencies cannot be identified using standard frequency domain techniques, a time domain metod, the Eigensytem Realization Algorithm (ERA), is employed to measure damping in the repeated and closely spaced natural frequencies. A comparison is made between ERA and the Polyreference identified modal parameters. Consideration is given to a slight structural modification to increase the ineraction between the damped and undamped antenna ribs, thereby increasing the overall performance of the viscoelastic damping in each mode.

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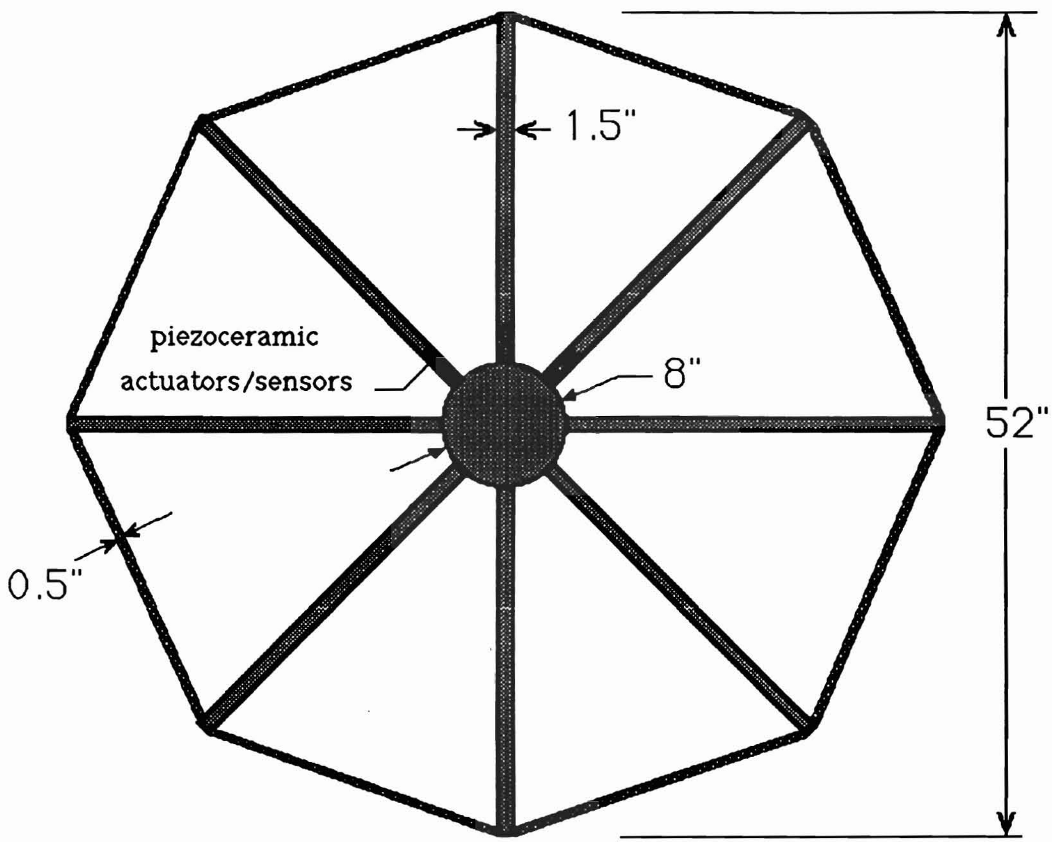
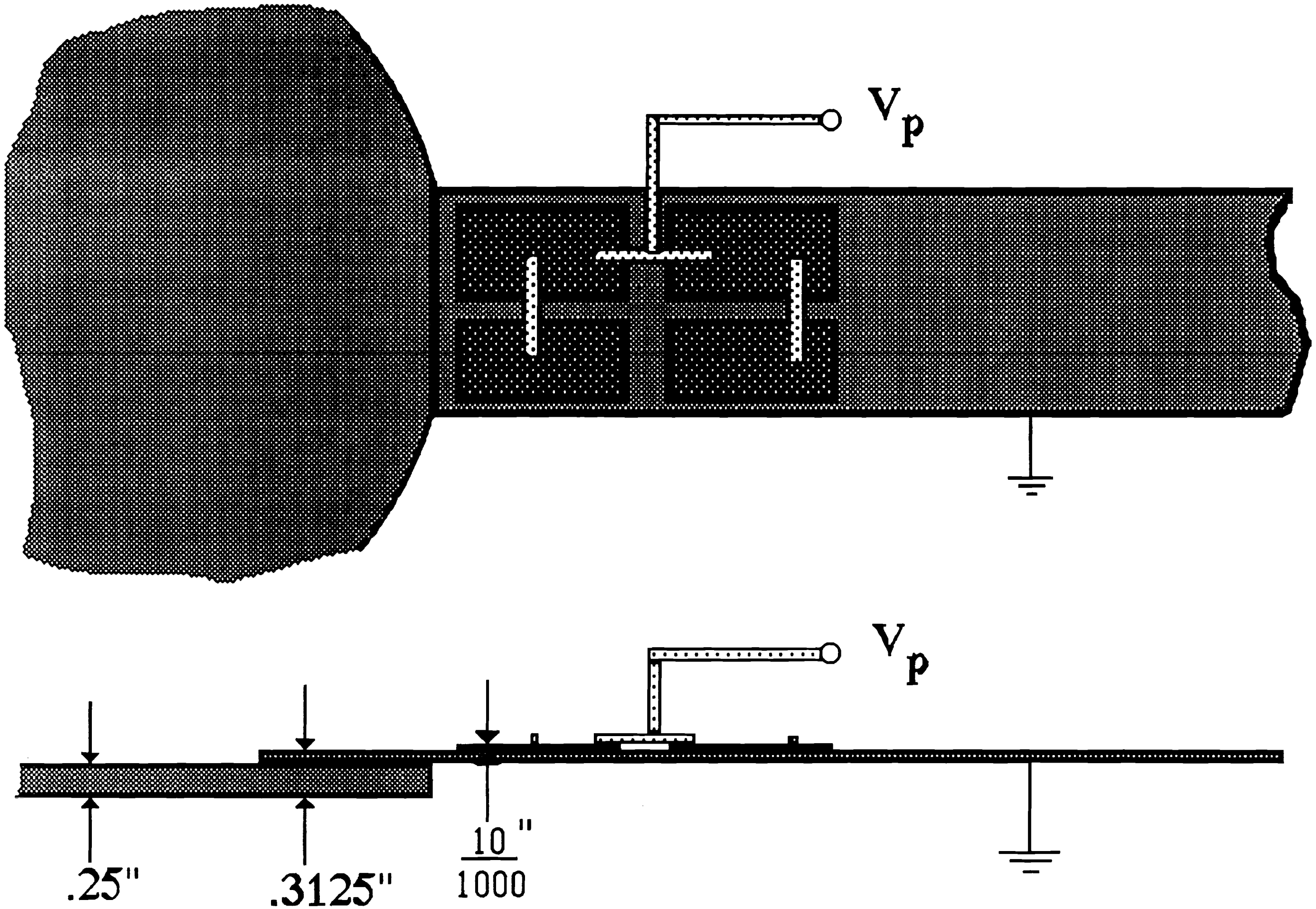
Antenna Model Schematic



- lightweight, flexible aluminum structure
- modelled after CSI Evolutionary model, built by NASA
- why piezoceramics?
    - lightweight - negligible added mass
    - dual capabilities: actuator and sensor

Piezoceramic film elements



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- as a sensor: strain-induced voltage as output
- as an actuator: voltage-induced strain as input

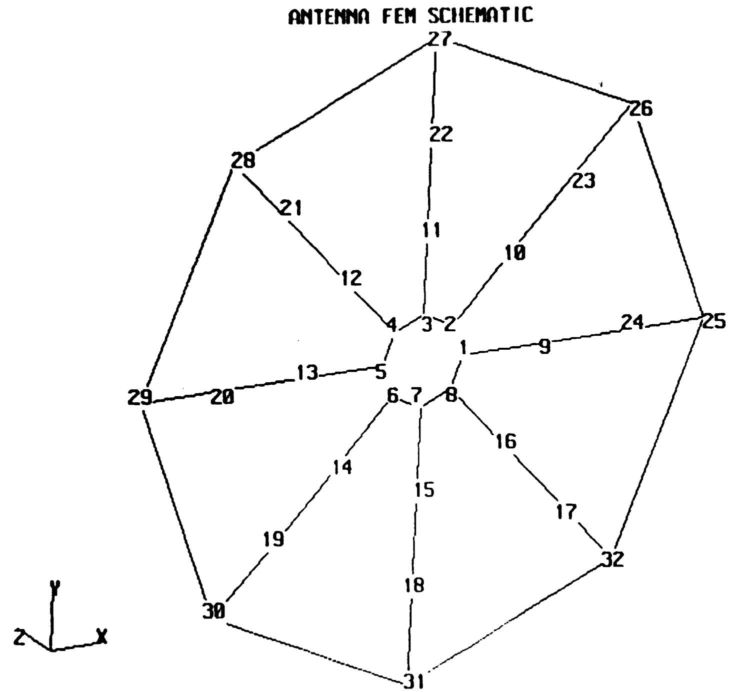
Polyreference and Analytical Modal Parameters

• Comparison of the undamped antenna model and the Polyrefence identified frequencies.

Frequency (Hz)

FEM	Polyreference
3.093	
3.314*	3.314
	3.559
4.443*	4.277
	5.595
6.686*	6.613
	7.619
8.511	8.243
	18.45
	19.16
	20.51
	21.52
22.84	22.18
23.11	22.54

* denotes repeated natural frequencies



•exact symmetry of FEM yields repeated natural frequencies and orthogonal mode shapes

•inaccuracies in physical model yield closely spaced natural frequencies

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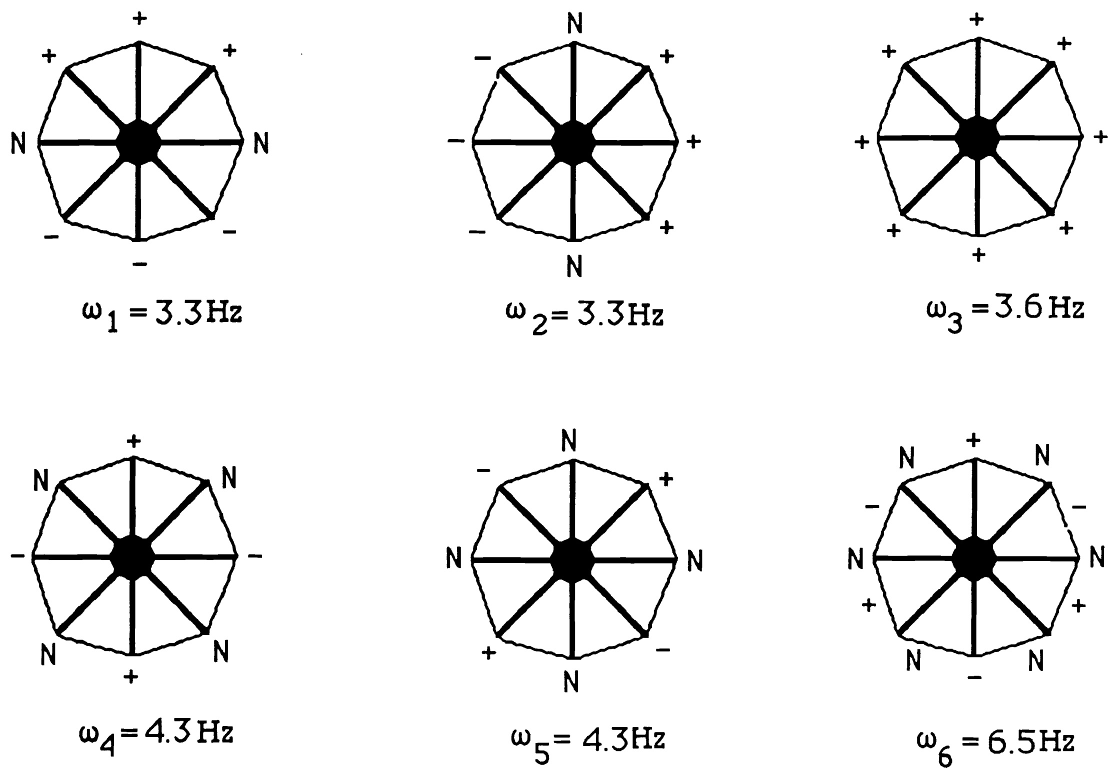
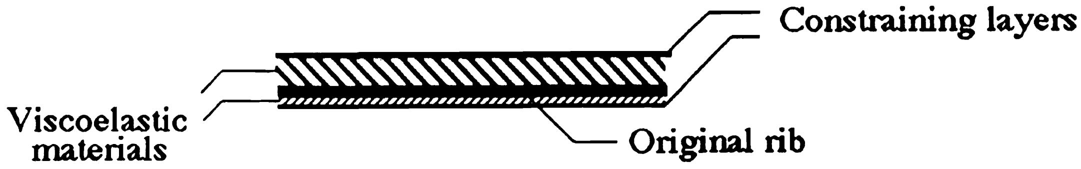
Experimentally Verified Mode Shapes



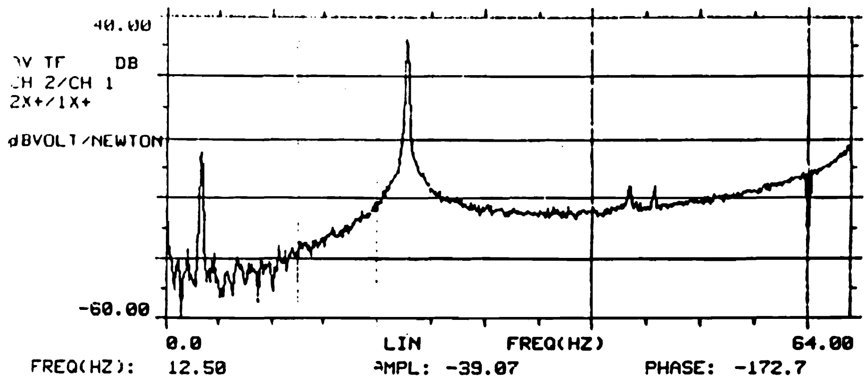
- mode shapes exhibited by both the FEM and physical model
- symmetry yields orthogonal mode shapes and closely spaced natural frequencies

Multiple Layered Damped Antenna Rib

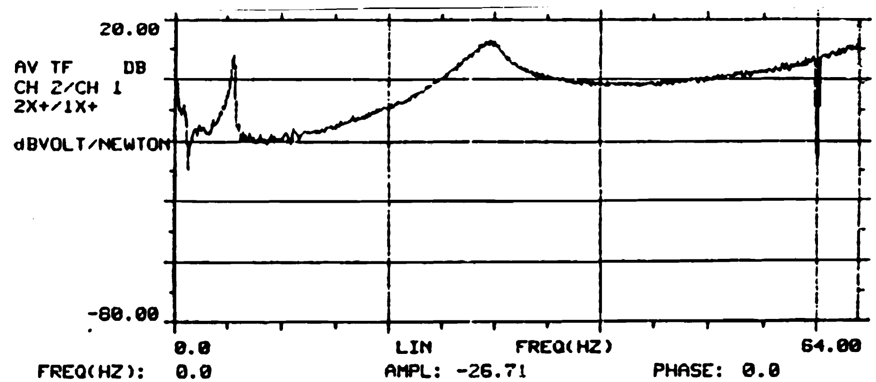


- Scotchdamp (SJ-2015X, 112) for high frequency damping
- rubber for low frequency damping

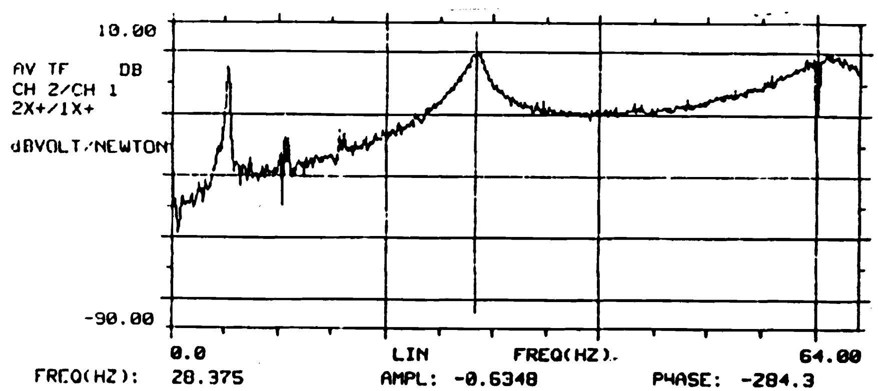
- single rib, undamped



- rib w/ rubber as constraining layer



- rib w/ rubber and Scotchdamp



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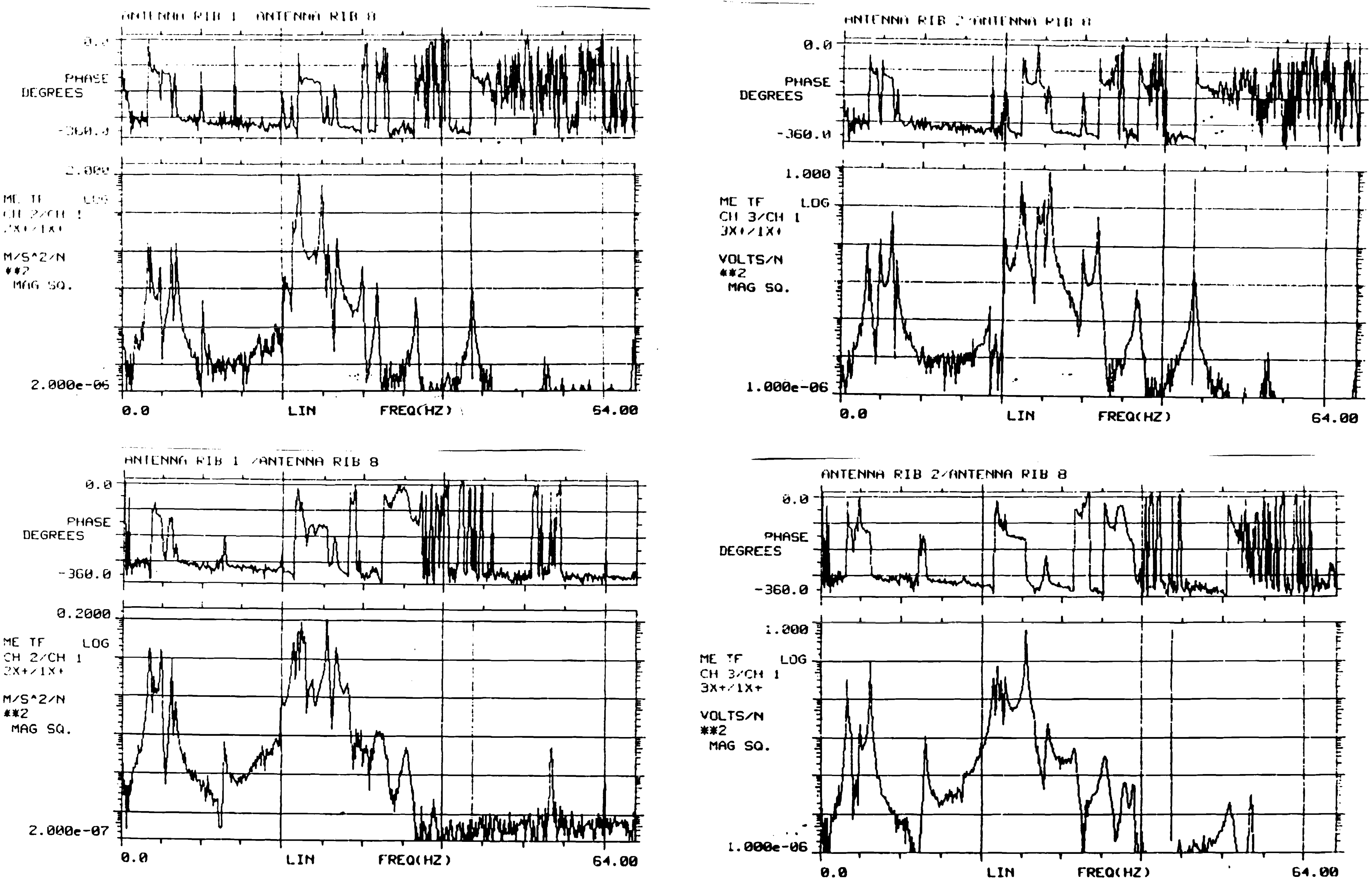
Polyreference Identified Modal Parameters

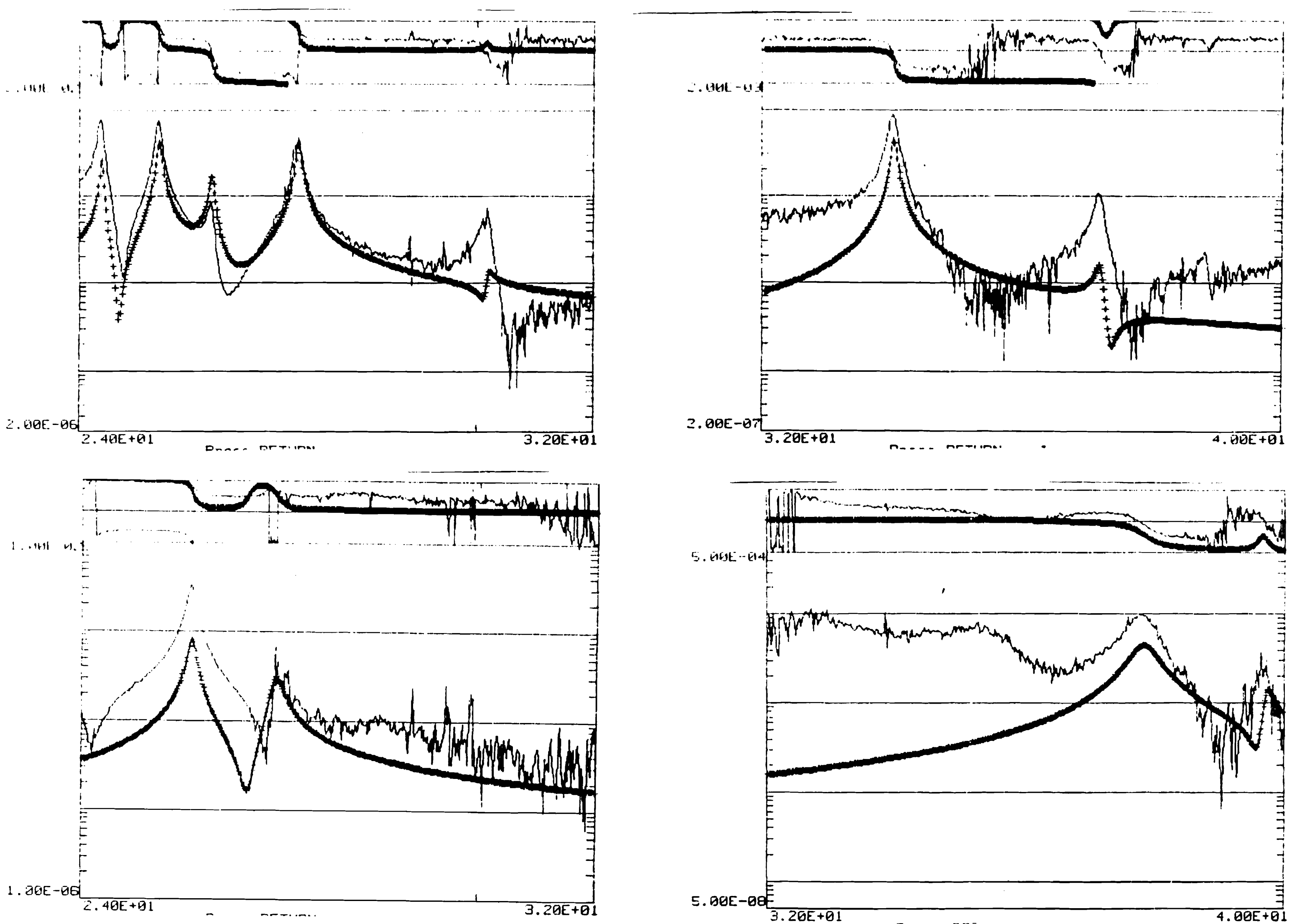
Frequency (Hz)		Damping ratio ζ (% critical)		Percent increase in ζ
Undamped	Damped	Undamped	Damped	
3.41				
4.27	4.53	0.0029	0.0067	131.
5.60	5.51	0.0018	0.0064	256.
6.61	6.94	0.0005	0.0104	1980.
7.62	7.84	0.0010	0.0042	320.
8.51		0.0013	>>	>>
18.44	18.93	0.0023	0.0031	35.8
20.51		0.0010	>>	>>
21.53	22.04	0.0016	0.0034	113.
22.18	22.38	0.0014	0.0016	14.3
22.53	22.85	0.0018	0.0023	27.8
24.30	23.65	0.0009	0.0039	333.
25.10	25.54	0.0014	0.0023	64.3
25.87		0.0014	>>	>>
27.15	26.81	0.0015	0.0018	20.0
30.17		0.0019	>>	>>
33.86	35.27	0.0011	>>	>>
37.00	37.63	0.0016	0.0060	275.
43.94	41.94	0.0013	0.0067	415.

- Effects of structure modification: two damped rib elements
  - frequency shift due to added mass
  - significant increase in global damping
  - some highly damped modes poorly identified - denoted by ">>"

Frequency Response Functions for Undamped(top) and Damped (bottom) Antenna,0-64 Hz



Polyreference-derived Analytical Curve Fits for Undamped (top) and Damped (bottom) Antennas, 24 - 40 Hz



ERA Summary (Juang and Pappa, 1985)

- Impulse Response function → Markov Parameters

$$[\ Y(k)\ Y(k+1)\ Y(k+2)\ \ldots\ ]\ \text{- time histories}$$

- Form a Block Data (Hankel) Matrix

$$H_{mn}(k) = \begin{bmatrix} CA^kB & CA^{k+1}B & \ldots & CA^{k+n}B \\ CA^{k+1}B & CA^{k+2}B & \ldots & \\ \vdots & & & \vdots \\ CA^{k+m}B & CA^{k+m+1}B & \ldots & CA^{k+m+n}B \end{bmatrix}$$

- time domain data

- Singular Values from the SVD of the Hankel matrix are used to determine a "good" model order and a minimum order realization.

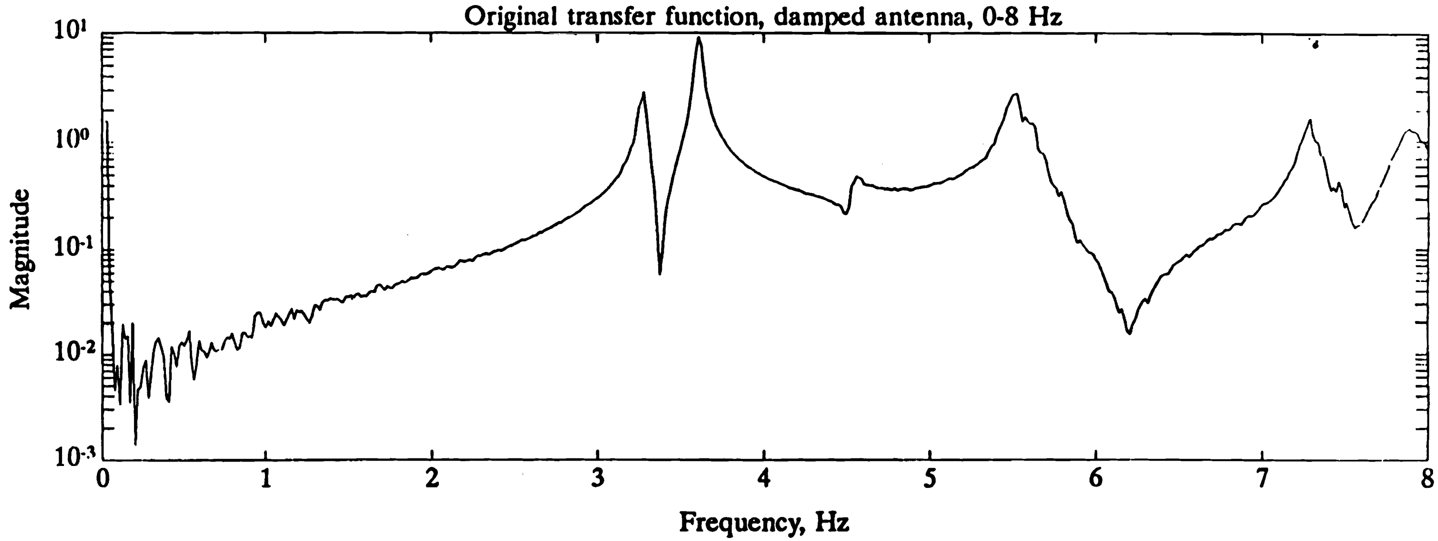
$$H_{mn}(k) = PDQ^T\ ;\ \ D = \text{diag}[\sigma_1, \sigma_2, \ldots, \sigma_n]$$

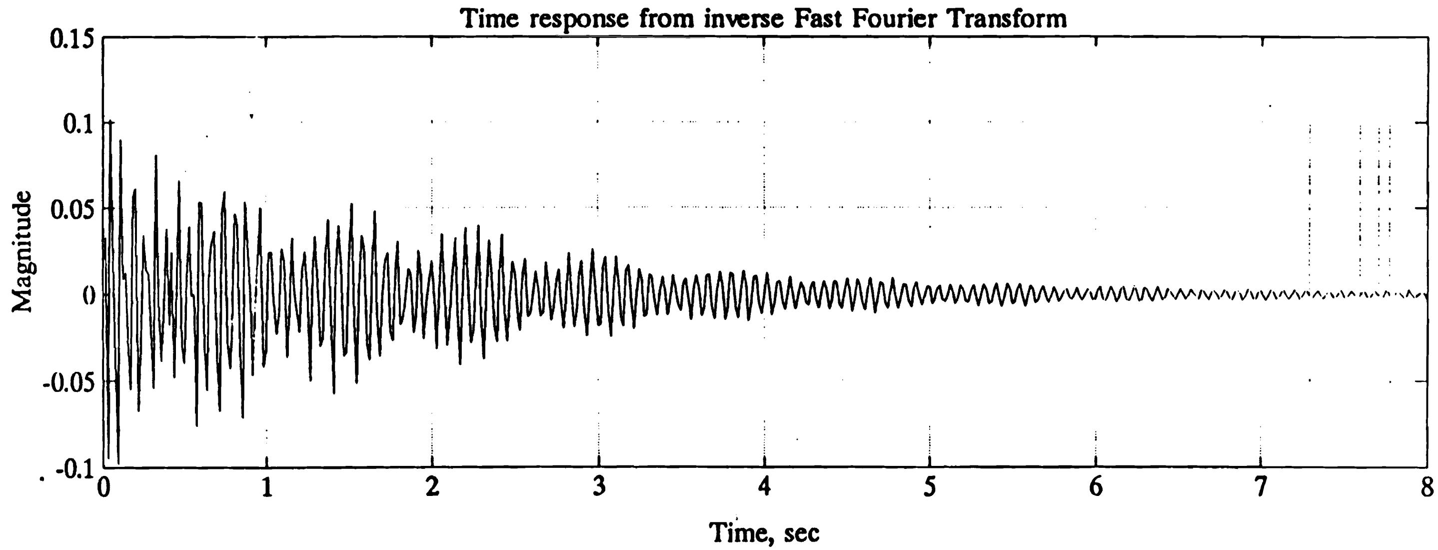
- The Eigensystem Realization Algorithm (ERA) finds a triple [A, B, C] based on the experimental data in $H_{mn}(k)$, i.e.,

$$\begin{aligned} Y(k+1) &= CA^kB \\ &= E_p^T P D^{1/2} [\ D^{-1/2} P^T H_{mn}(1) Q D^{-1/2}\ ]^k D^{-1/2} Q^T E_m \end{aligned}$$

- Eigenanalysis of the realization yields modal parameters for the system - $\{\zeta_i, \omega_i, MCF_i \text{ and } \phi_i(x)\}$.

• Typical ERA run:





Modal Parameters: Polyreference and ERA

- Undamped, 0-8 Hz

Frequency (Hz)		Damping ratio ζ		Modal confidence factor	
Polyref.	ERA	Polyref.	ERA	Polyref.	ERA
3.31	3.31	0.011	0.003	0.912	1.000
--	3.41	--	0.002	--	1.000
3.56	3.57	0.006	0.003	0.948	1.000
4.28	4.27	0.003	0.003	0.993	1.000
5.60	5.57	0.002	0.003	0.993	1.000
6.61	6.61	0.000	0.002	0.985	1.000
7.62	7.62	0.001	0.002	0.993	1.000

- Damped, 0-8 Hz

Frequency (Hz)		Damping ratio ζ		Modal confidence factor	
Polyref.	ERA	Polyref.	ERA	Polyref.	ERA
3.26	3.27	0.003	0.006	0.995	1.000
3.60	3.60	0.003	0.006	0.999	1.000
4.53	4.54	0.007	0.019	0.993	0.932
5.52	5.51	0.006	0.007	0.996	1.000
5.73	5.69	0.000	0.011	0.973	0.979
6.94	--	0.010	--	0.834	--
7.29	7.29	0.006	0.005	0.997	1.000
7.84	7.85	0.004	0.010	0.995	0.999

- inverse Fourier transform on frequency domain data (ERA) allows comparison with time domain data (Polyreference)
- good agreement between the two methods
- modal confidence factor: ratio from 0 to 1 describing accuracy of results obtained
    - generally higher mcf's for ERA method

Closing Remarks

- Successfully applied two identification schemes to examine the effects of constrained layered damping in a model of a complex, ribbed antenna structure

- Since global modes are a sum of simpler substructure modes, "high" damping must be obtained in those fundamental modes of the substructure in order to achieve "high" damping in the global modes. The substructure modes in this structure are that of a cantilever beam. The global modes are combinations of these simpler modes.

- Viscoelastic antenna ribs improved the dynamic response slightly in the lower modes and significantly in the higher modes