# Perturbation and Simulation Field Measurements in RF Cavities


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## Introduction

Throughout installation in the APS, 2.85 GHz cavities operating at the $2\pi/3$ mode underwent unpredicted gravitational deformations leading to variation in electrical center and dipole kick induced emittance growth and beam loss. Methodologies for simulation and measurement based field mapping and resonant mode qualification were developed to investigate these effects.

## Theoretical Background

Given a resonant cavity with resonant frequency $f_0$, the relative frequency shift, Δf, is given in general by

$$\frac{\Delta f}{f_0} = -\frac{\int_V(\Delta\epsilon \vec{E}\cdot\vec{E}_0^* + \Delta\mu\vec{H}\cdot\vec{H}_0^*)\cdot dV}{4W} \qquad (1)$$

where W is the stored energy in the cavity. Measuring the frequency shift along an axis allows one to map the relative field strength in a cavity, and quantitatively classify modes in a cavity by their R/Q given by

$$\frac{R}{Q} = \frac{1}{2\pi\epsilon_0}\left(\int\sqrt{\frac{\tan\Delta\phi}{2Q_L}}\frac{dz}{F_1}\right)^2 \qquad (2)$$

## Bead Characterization

Simulations and measurements were compared to analytical solutions for metallic and dielectric beads geometrically designed to isolate certain components of electric and magnetic fields.

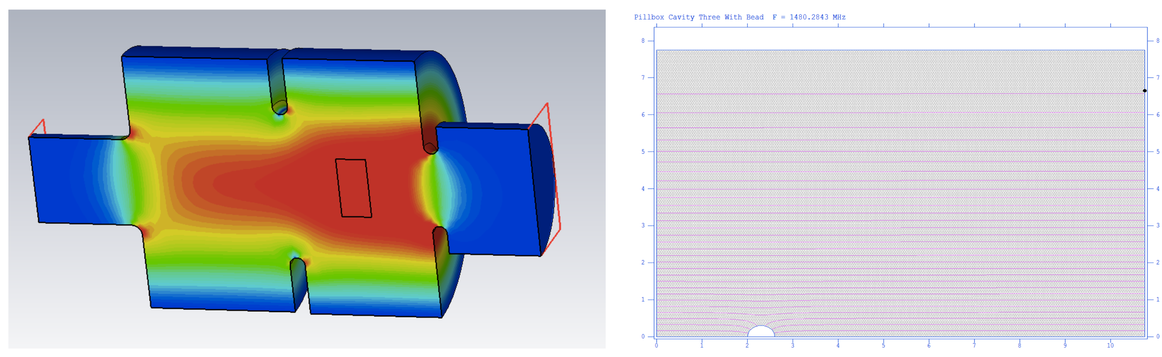

**Figure 1: Unperturbed S-Band cavity in Microwave Studio (left) and perturbed Poisson Superfish cavity (right)**

A bead-pull apparatus implementing LabView for data acquisition was installed. Frequency was indirectly obtained from the precision Network Analyzer by

$$\frac{\Delta f}{f_0} = \frac{1}{2Q}\tan(\Delta\phi) \qquad (3)$$

where $\phi$ is the phase of the transmission coefficient, and Q is the loaded Q of the cavity.

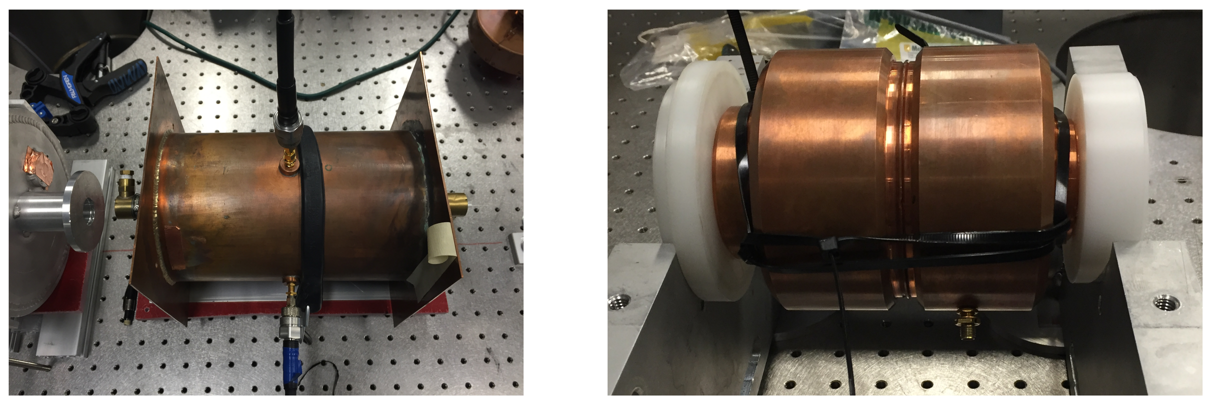

**Figure 2: Bead-Pull L-Band (left) and S-Band (right) cavities**

Data analysis was performed to compare our measured responses from cavity perturbation with simulation and analytical results.

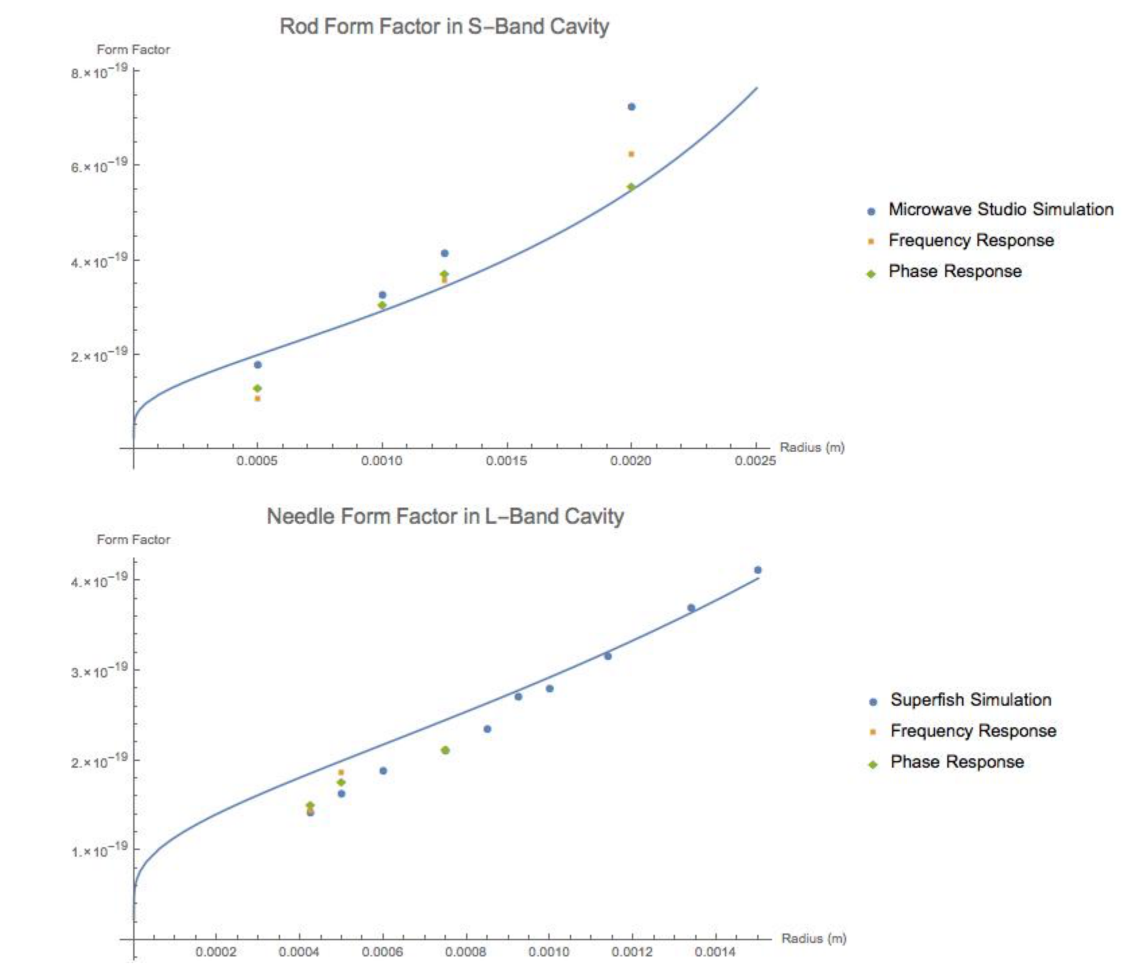


**Figure 3: Comparison of results for metallic rods (top) and hypodermic needles (bottom)**

## Mode Identification

Care was taken to distinguish between Transverse Electric (TE) and Transverse Magnetic (TM) modes. The $TM_{010}$ mode is useful for calibrating beads in a known field, while the $TM_{110}$ mode allows one to locate electrical center.

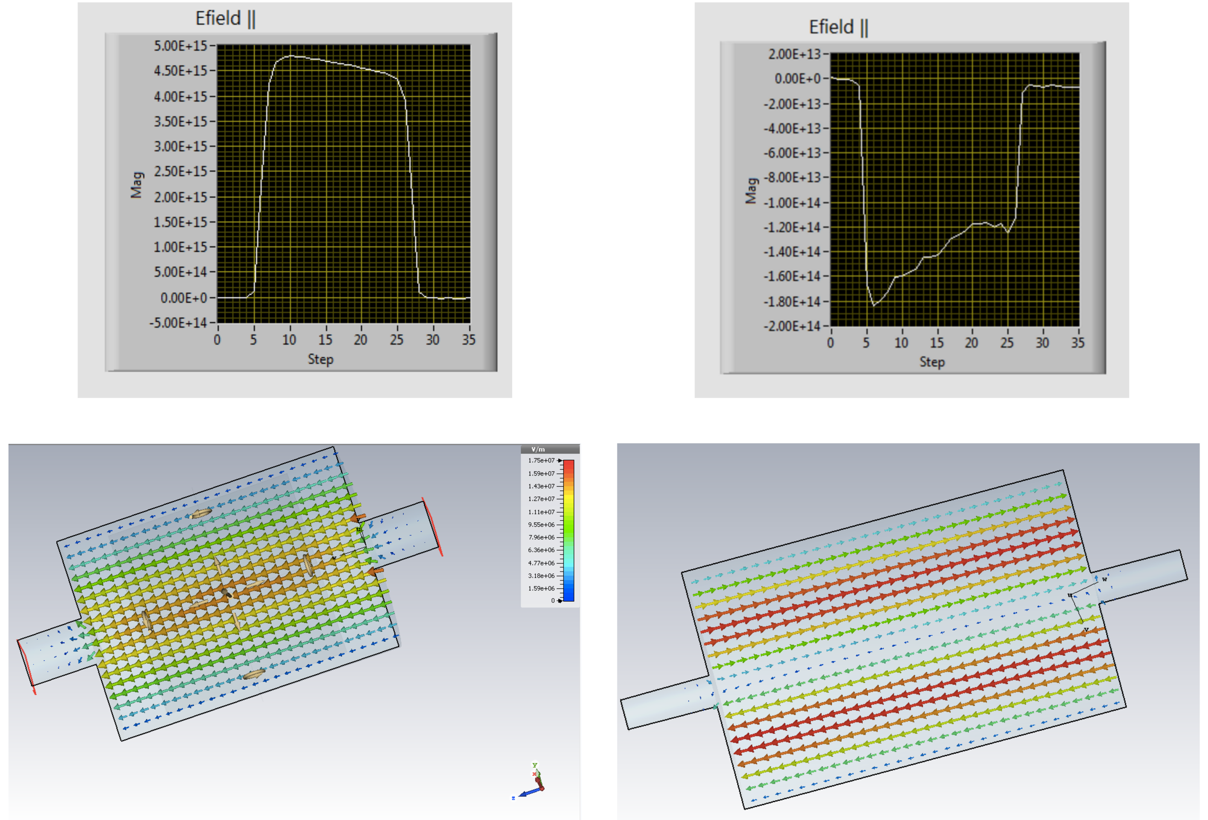


**Figure 4: $TM_{010}$ mode with on axis data (left) and $TM_{110}$ (right) with off axis data**

## Standing and Travelling Wave Cavities

Standing wave pillbox cavities allowed for analysis of higher order modes (HOMs) with measurement of transmission coefficient, $s_{21}$. Travelling wave structures did not couple strongly with HOMs, but were still compatible with measurement of monopole R/Q.

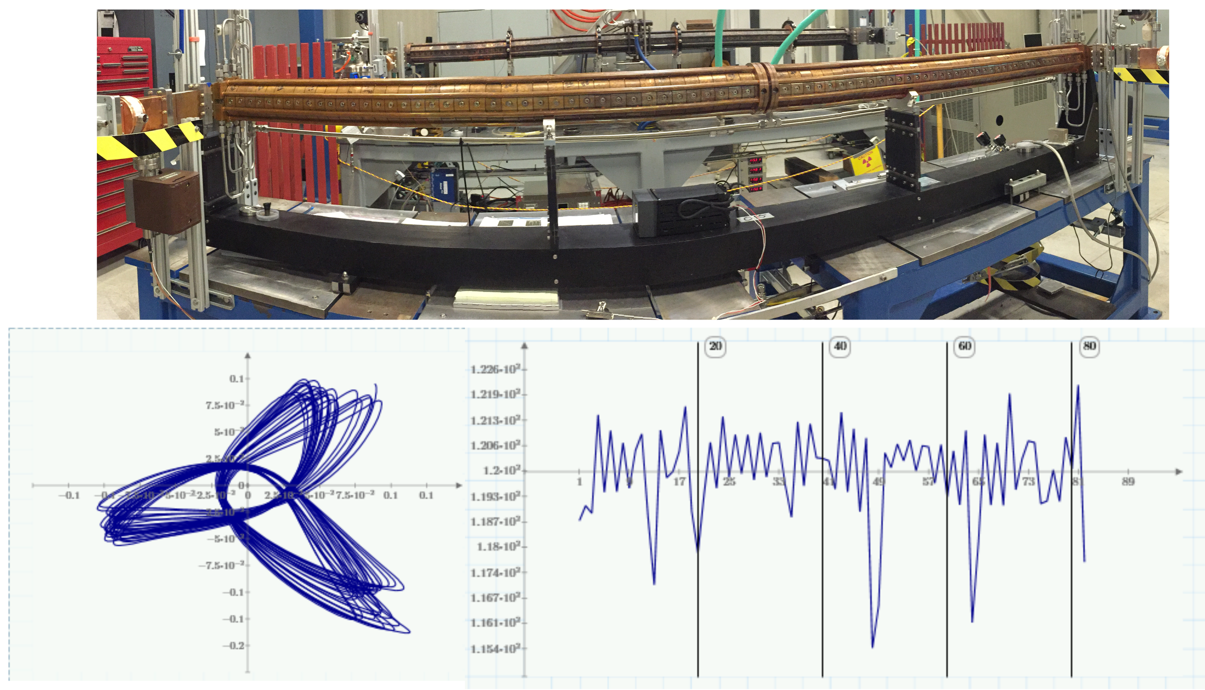

**Figure 5: 2.856 GHz $2\pi/3$ structure (top) and corresponding phase advance data (bottom)**

Transverse mapping of the dipole mode was used to locate the electrical center of the cavity. This methodology will be used to measure the strength of dipole kick to beam in a newly manufactured single cell cavity.

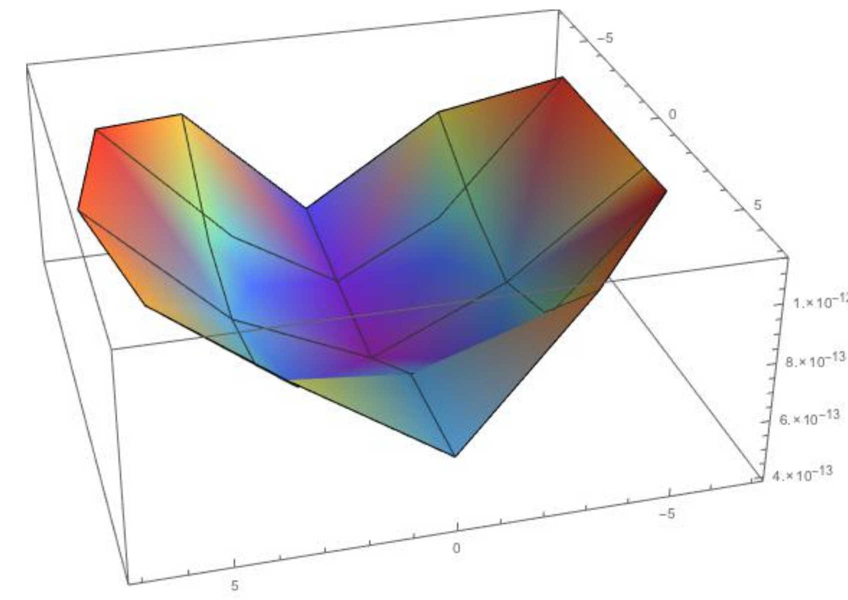

**Figure 6: Magnitude of Longitudinal component of dipole E-field in the transverse plane**


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## References


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