Experimental Measurement of Ultrasound Beam Profiles

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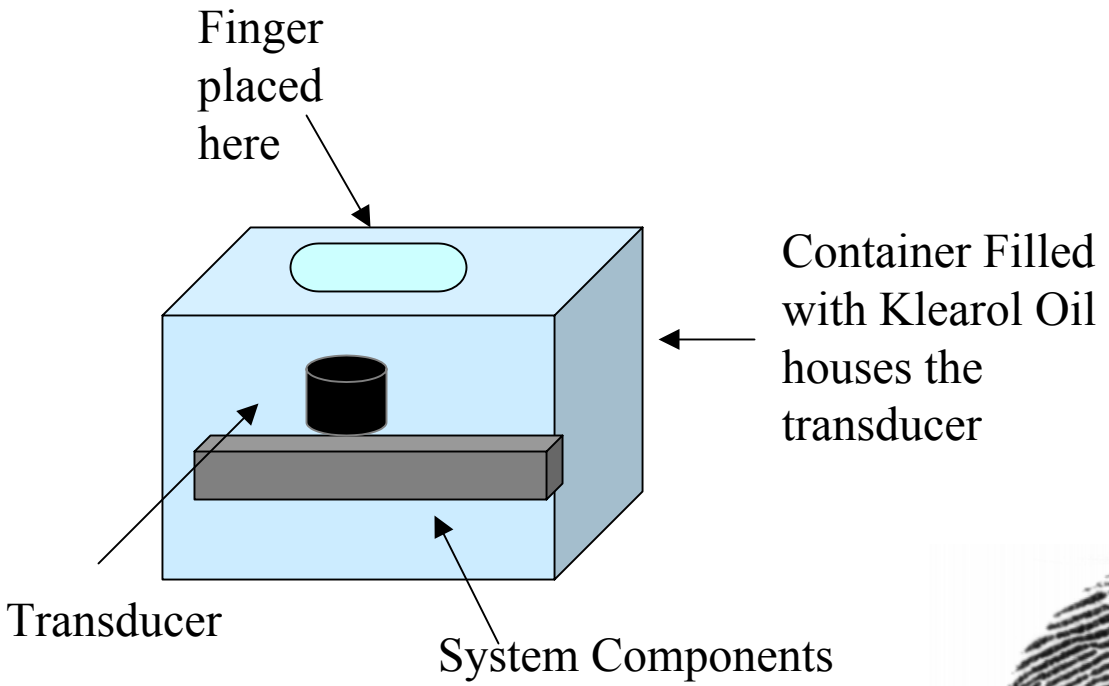
Overview

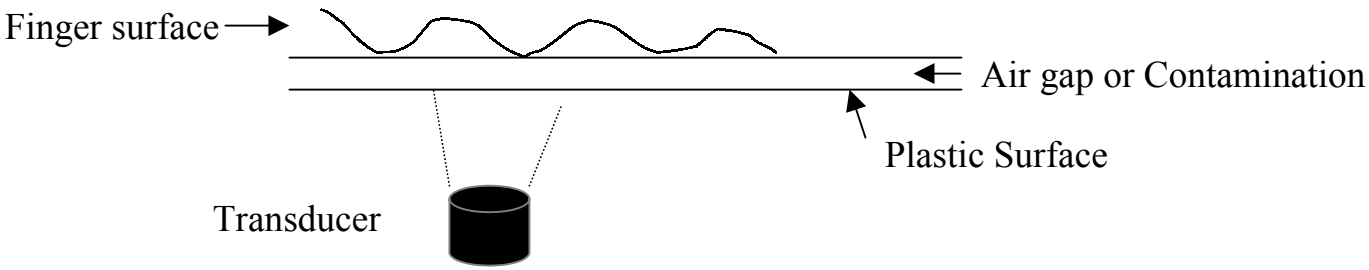
- Motivation
- Theory
- Experimental Setup
- Data Processing, Data Display and Filtering Noise
- FWHM and Misalignment Analysis
- Alternative Technique
- Theoretical Calculations
- Analysis of the Wire Target
- Modulation Transfer Function
- Conclusions and Future Studies

Motivation

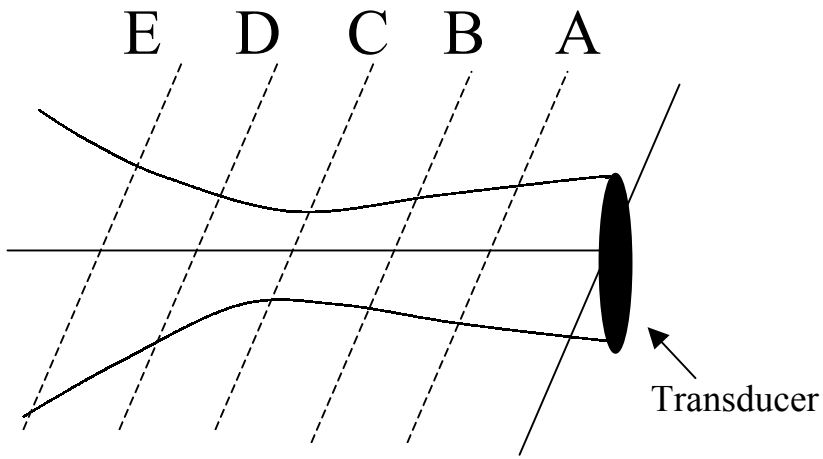
•Transducer beam characteristics important in resolution of overall imaging system.

Goal – Determine LSF and MTF for transducer in Fingerprint Imaging System





Theory – Focused Transducer



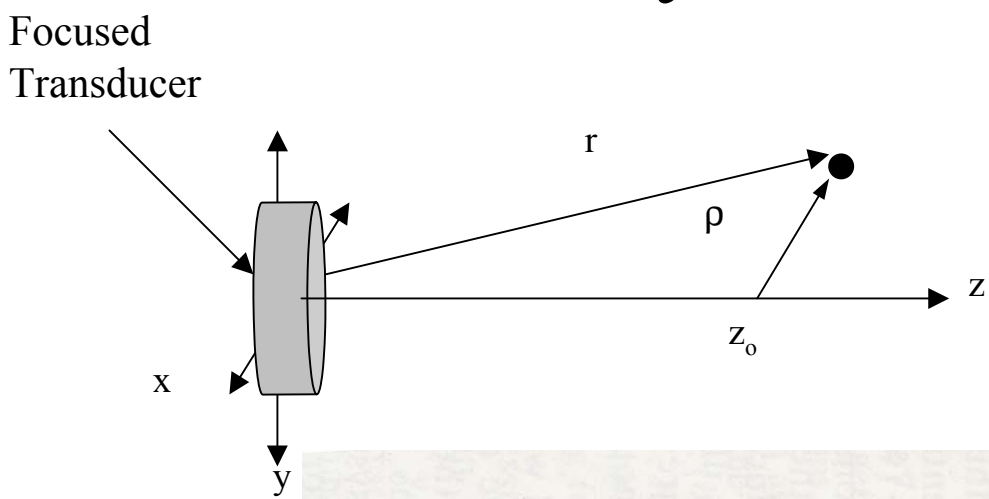
Focused Transducer Beam Profile

A, B = Near – Field

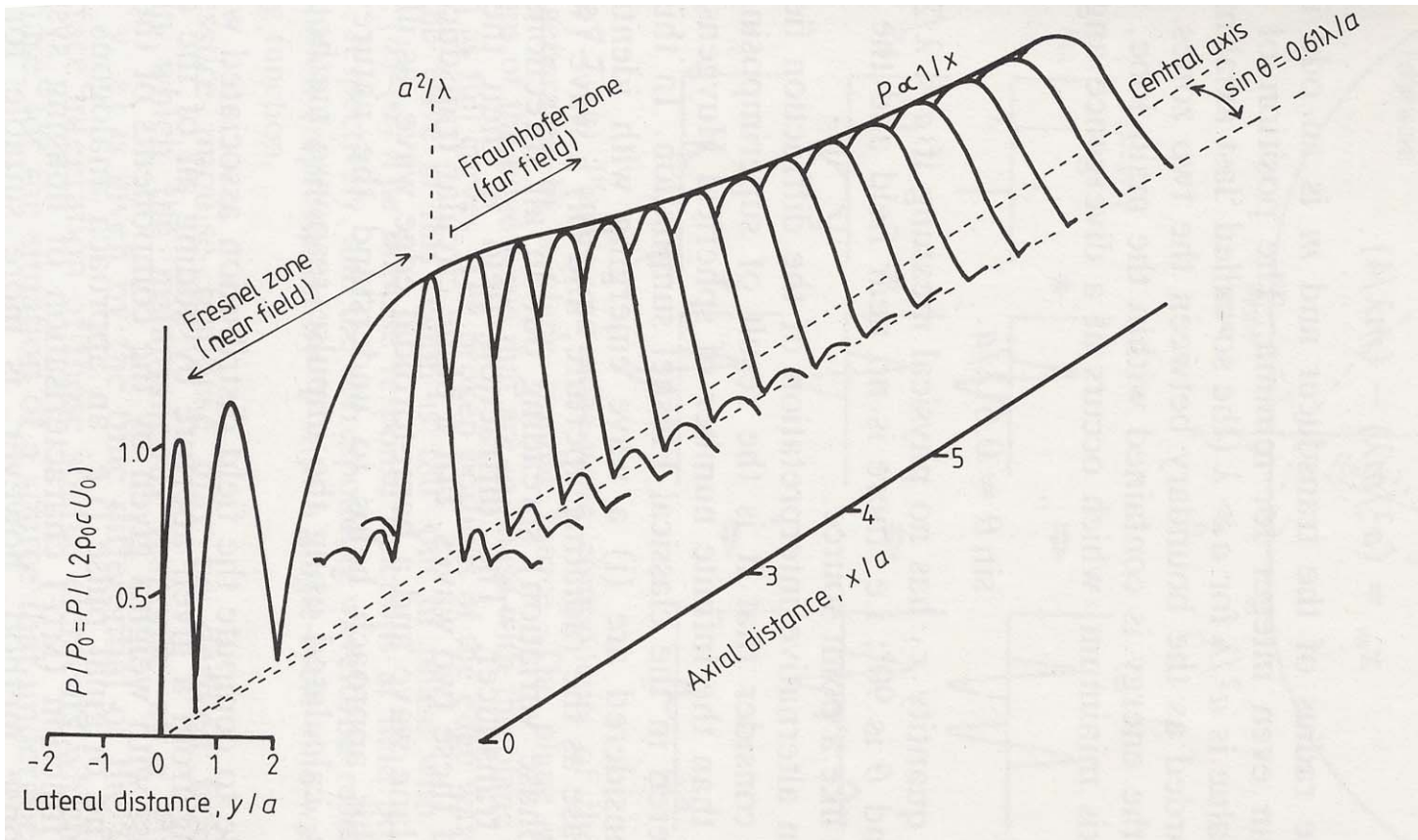
C = True Focus

D, E = Far - Field

Theory – Diffraction



Diffraction governs the variation of Beam Profile with Z-distance.



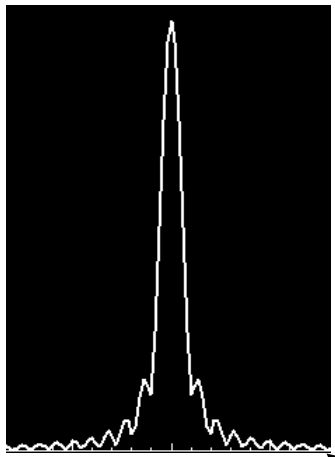
Theory – LSF and MTF

LSF → Response of imaging system when scanning the image plane with a line target of infinitesimally small width

Fourier Transform of LSF yields MTF

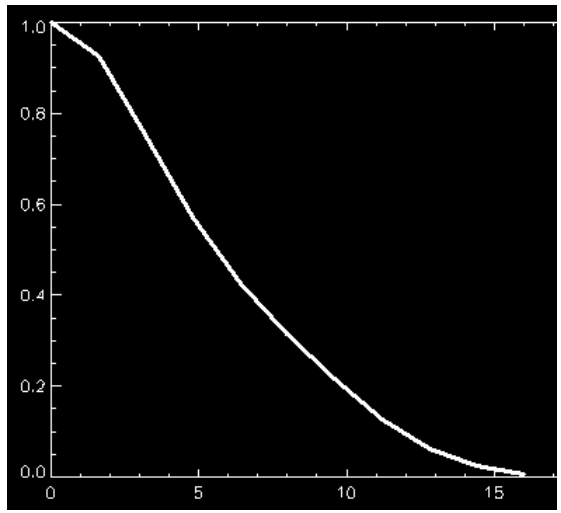
$$\text{MTF} = \frac{\text{Output Modulation}}{\text{Input Modulation}}$$ → Reduction in contrast of spectral components as they pass through the system

Theory



Line Spread Function

Fourier Transform



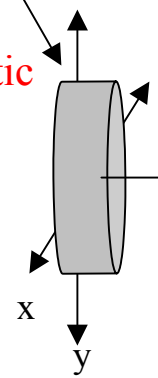
Modulation Transfer Function

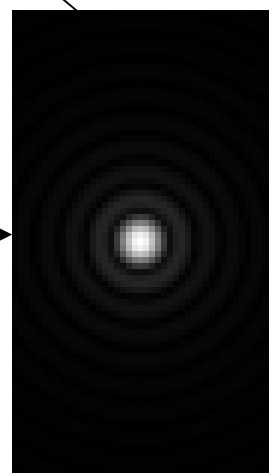
Projection

Focused Transducer

Monochromatic

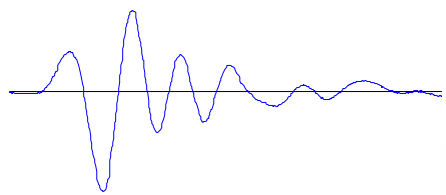
Short Pulse





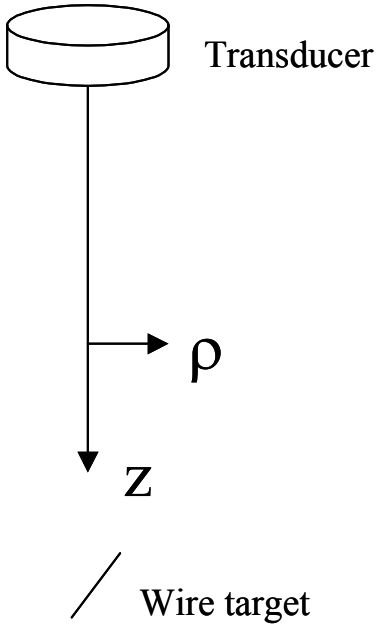
Lommel Diffraction

1 Frequency

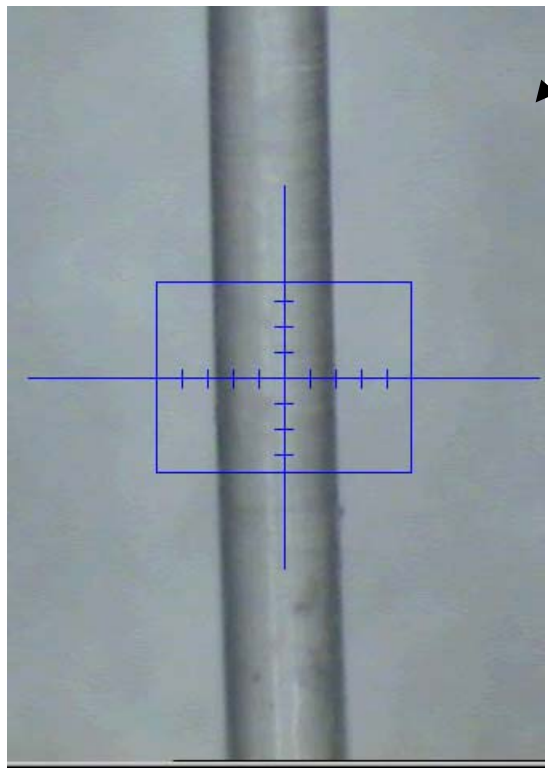


Numerous Frequencies for each ρ and Z Measurement

Experimental Setup

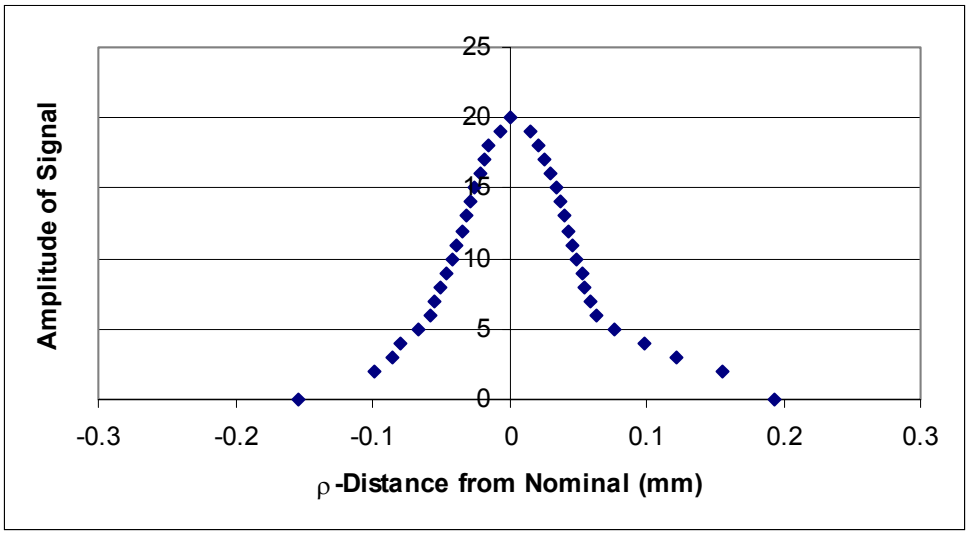


- Circular Disk Focused Transducer
- 125 μm diameter nylon wire target shown at 200X magnification



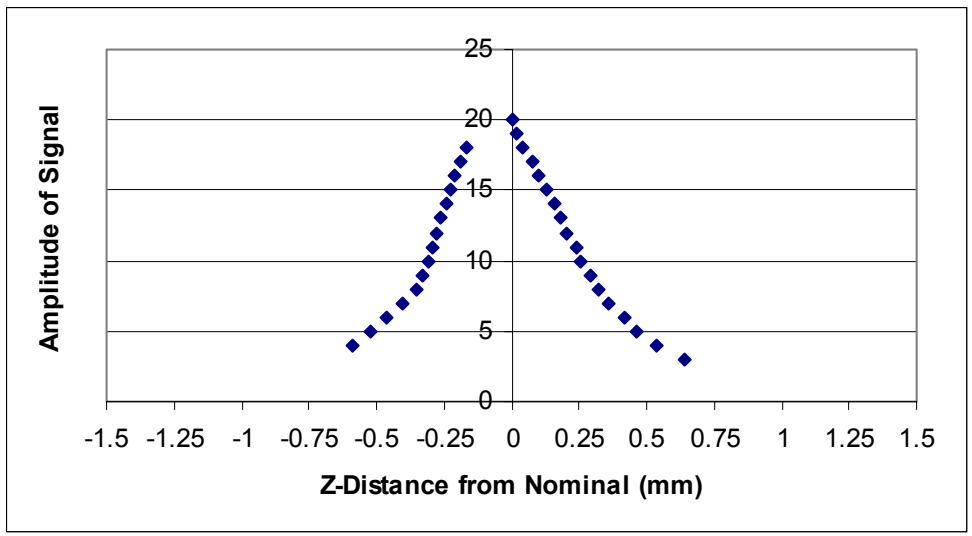
- Wire located in plastic container filled with Klearol Oil
- Micrometers allow motion in Z and ρ direction

Defining the Experiment



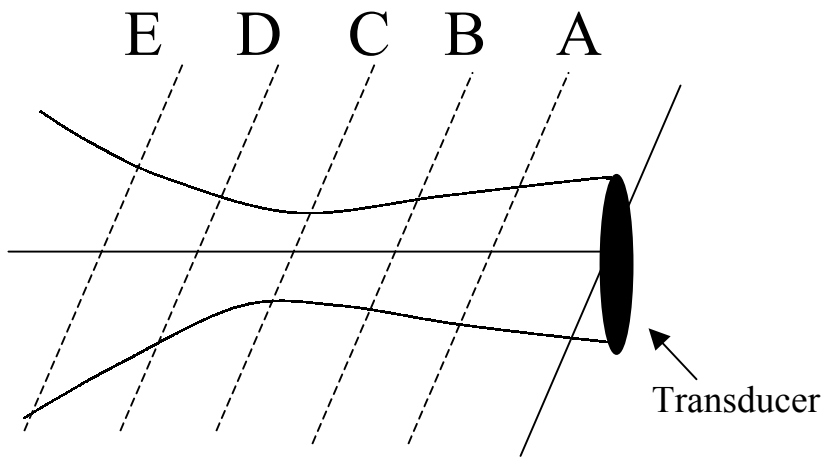
Identify location of maximum amplitude signal

Amplitude decreases as distance from nominal location increases for both ρ and Z

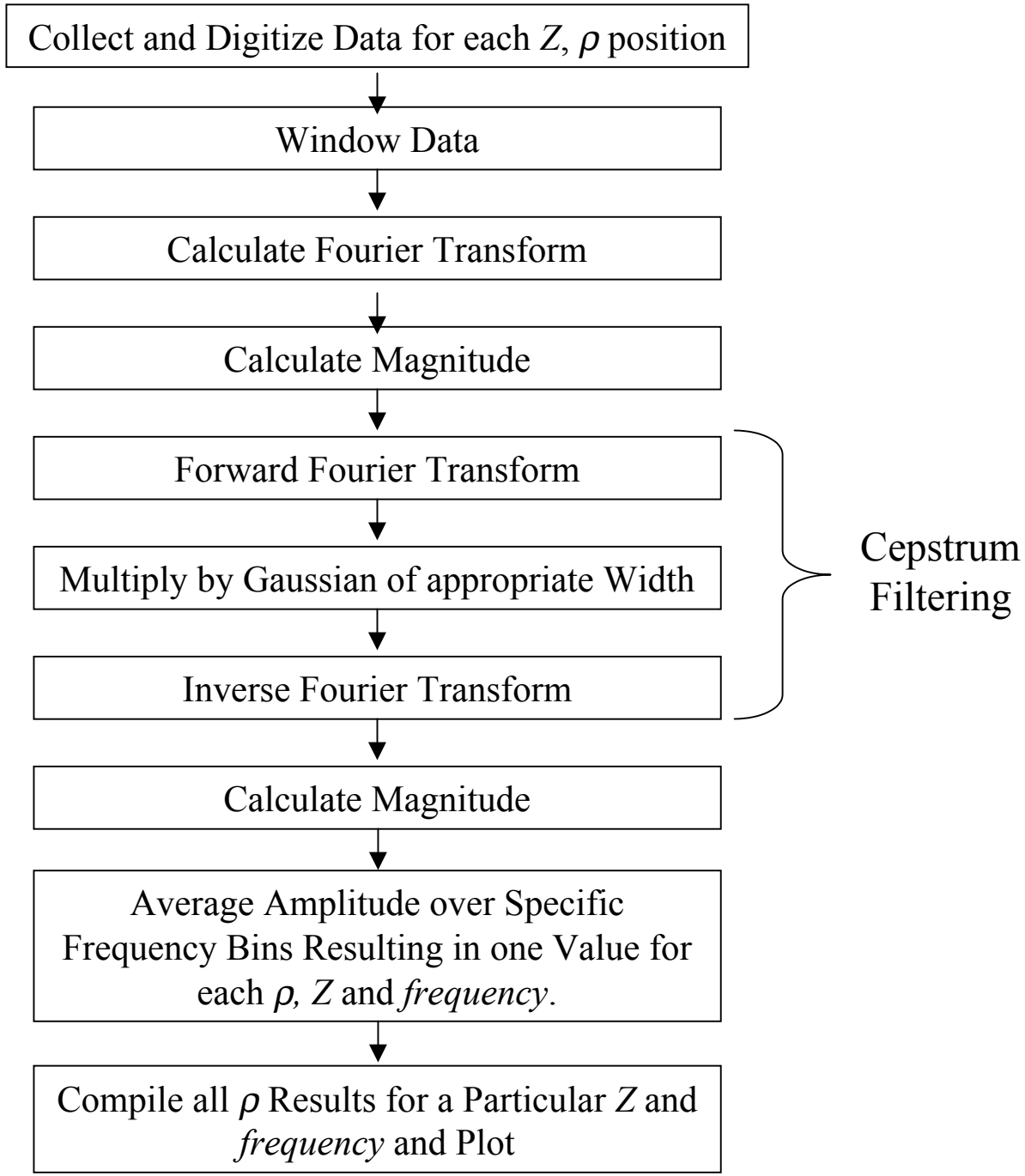


Experimental Plan

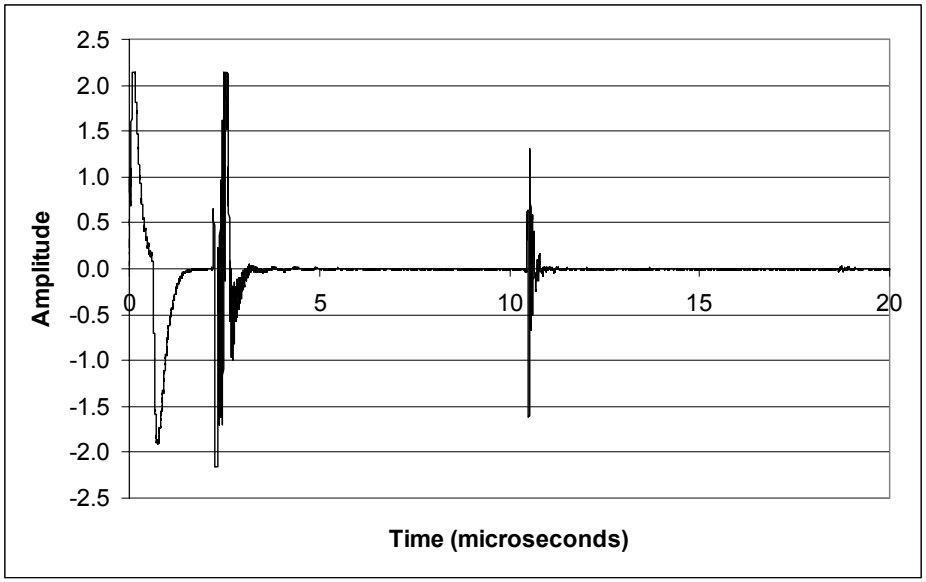
Label	Vertical Distance (z) from nominal (μm)	Distance between ρ measurements (μm)	Range of ρ measurements (μm)	Number of Measurements
A	-500	5	±250	100
B	-250	5	±245	98
C	0	5	±225	90
D	250	5	±213	85
E	500	5	±225	90



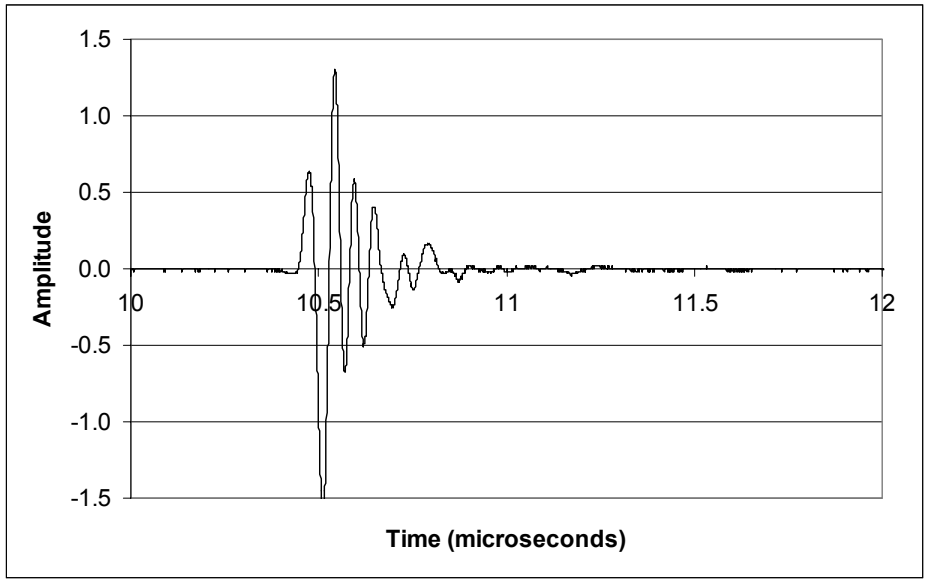
Processing Plan



Initial Results



Entire Digitized Signal

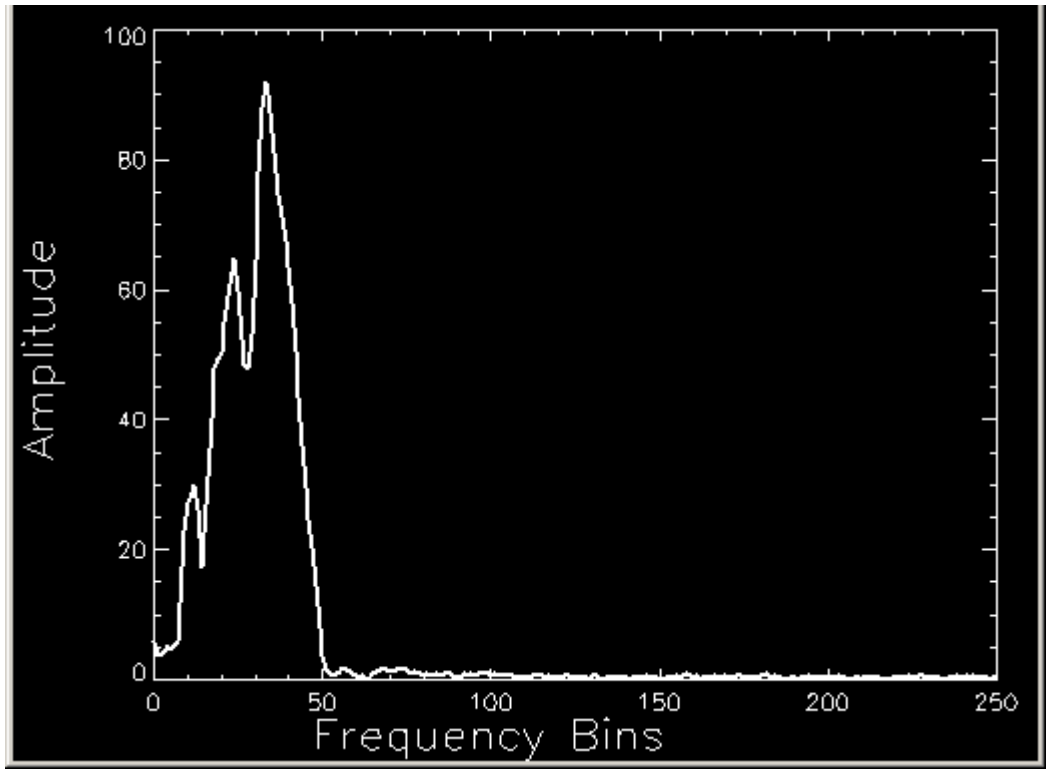


Windowed Data

Data was windowed to the signal from the wire.

Appropriate windows required time-gating independently for each Z position.

Data Processing



Fourier Transform and magnitude of time-gated signal.

Periodic noise observed.

Filtering

Noise observed is possibly due to overlapping multiple reflections from the edges of the wire target.

3 Attempts to Remove the Noise

- **One dimensional convolution kernel**

  Ineffective: removed noise but also smoothed spectrum data

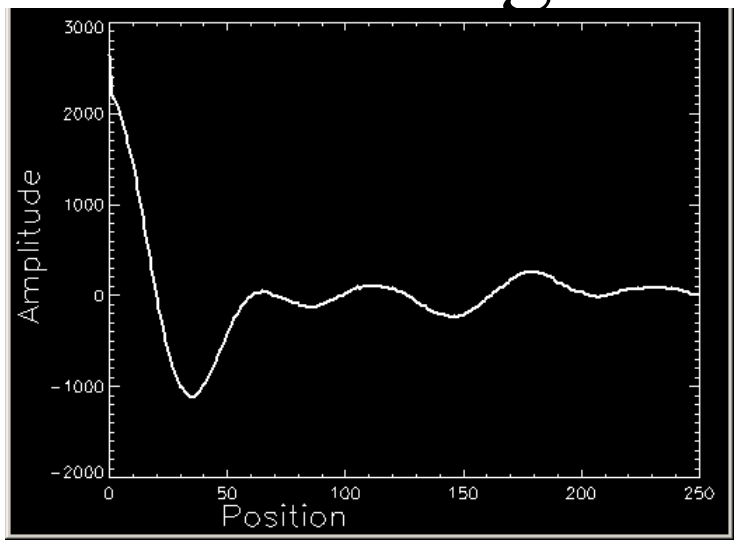
- **Cepstrum Filtering**

  Useful if additive components in spectrum. Process involves taking FFT, applying a filter, and then inverse FFT.

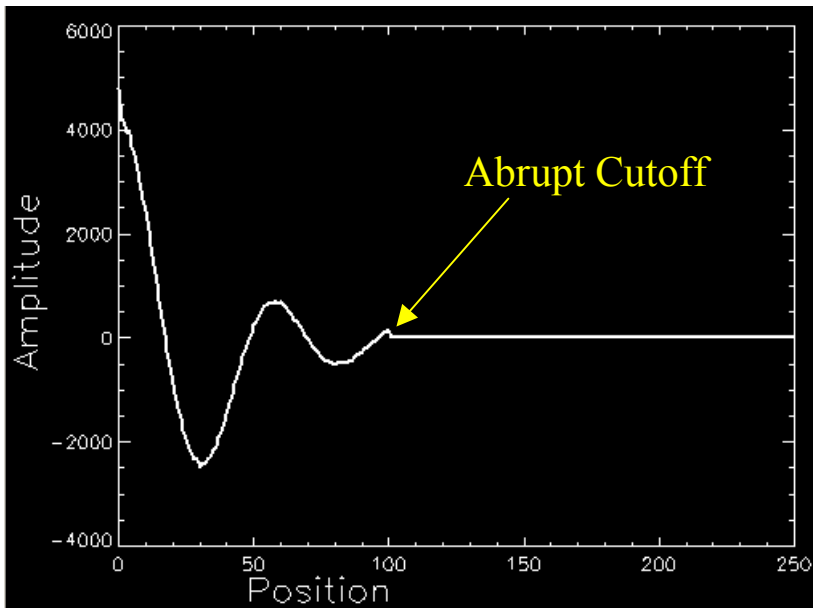
- **Homomorphic Filtering**

  Useful if spectrum composed of multiplicative components. Process involves calculating log, taking FFT, filtering, calculating inverse FFT, and calculating exponential.

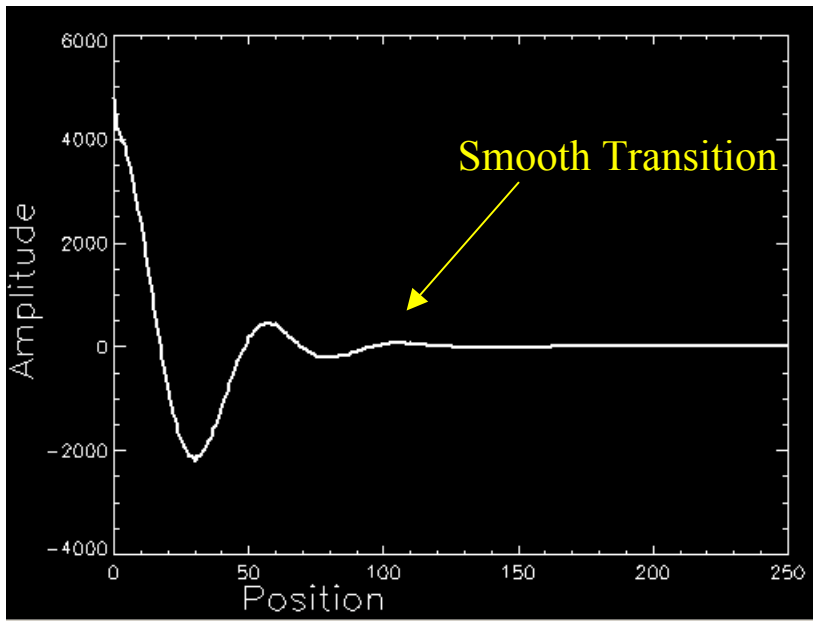
Filtering



Forward FFT of Noisy Data



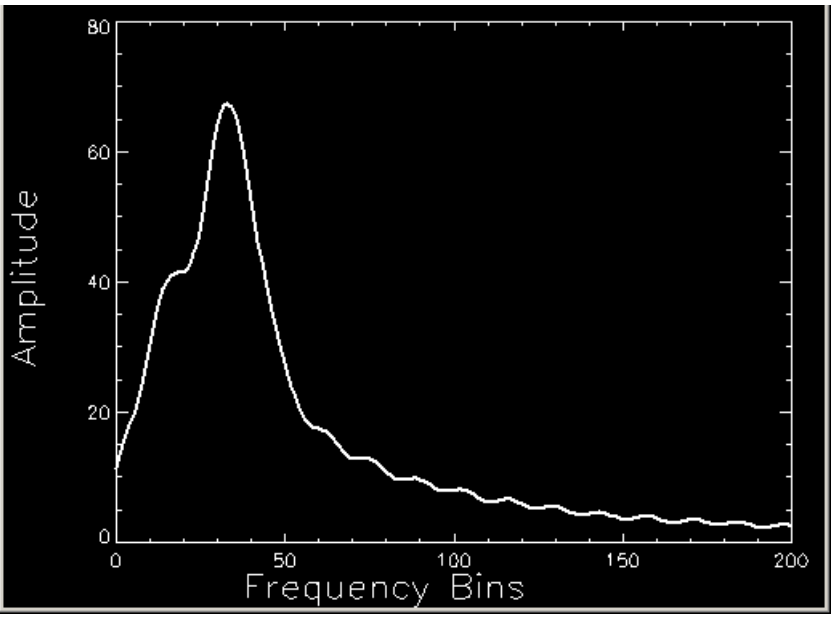
Filtered with Rect



Filtered with Gaussian

Filtering

- Abrupt cutoff causes ringing in spectrum
- Must optimize width to eliminate noise but minimize reduction in amplitude



Spectrum after filtering with Rect of width 150

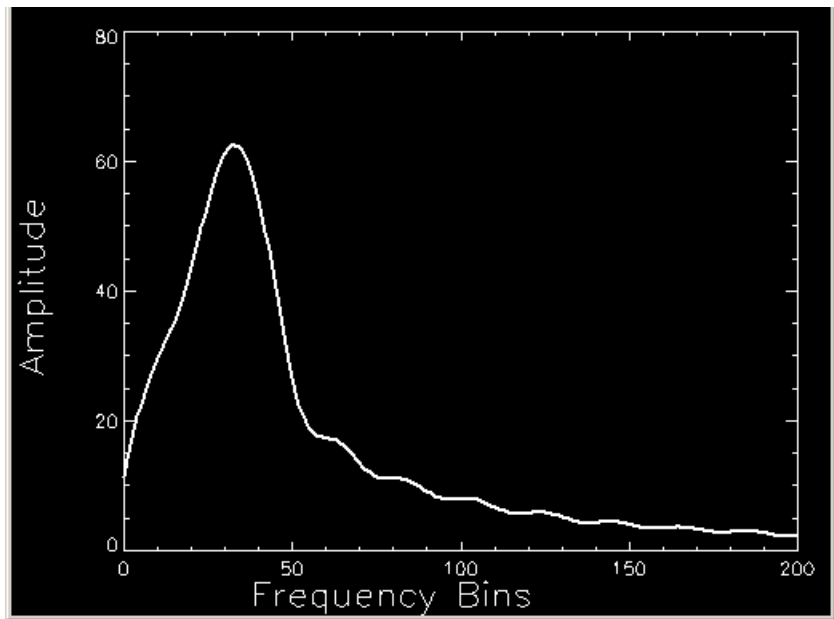
←

Noise Remains

Spectrum after filtering with Rect of width 100

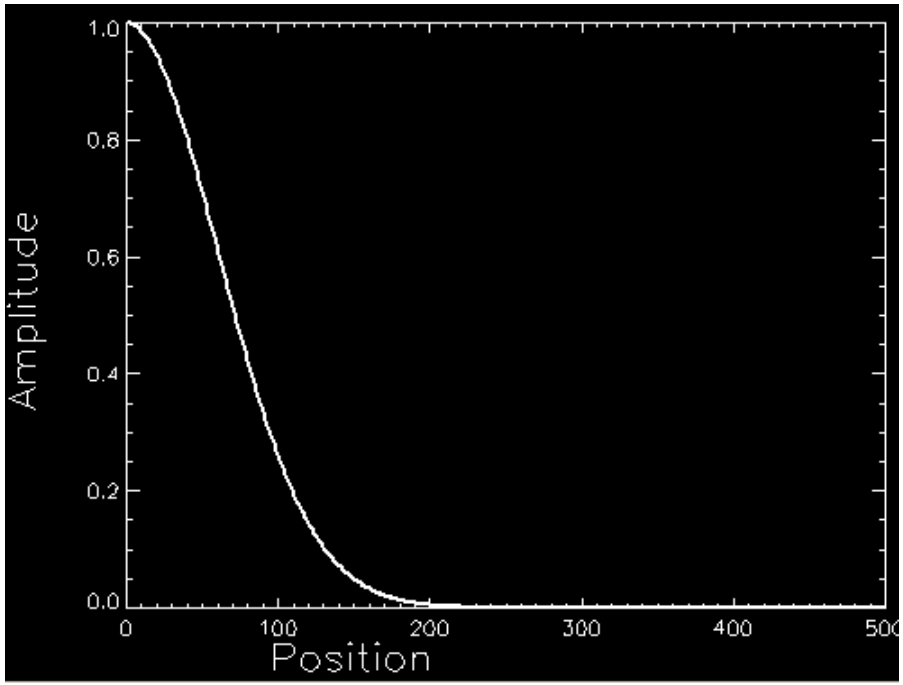
→

No noise but slight decrease in amplitude

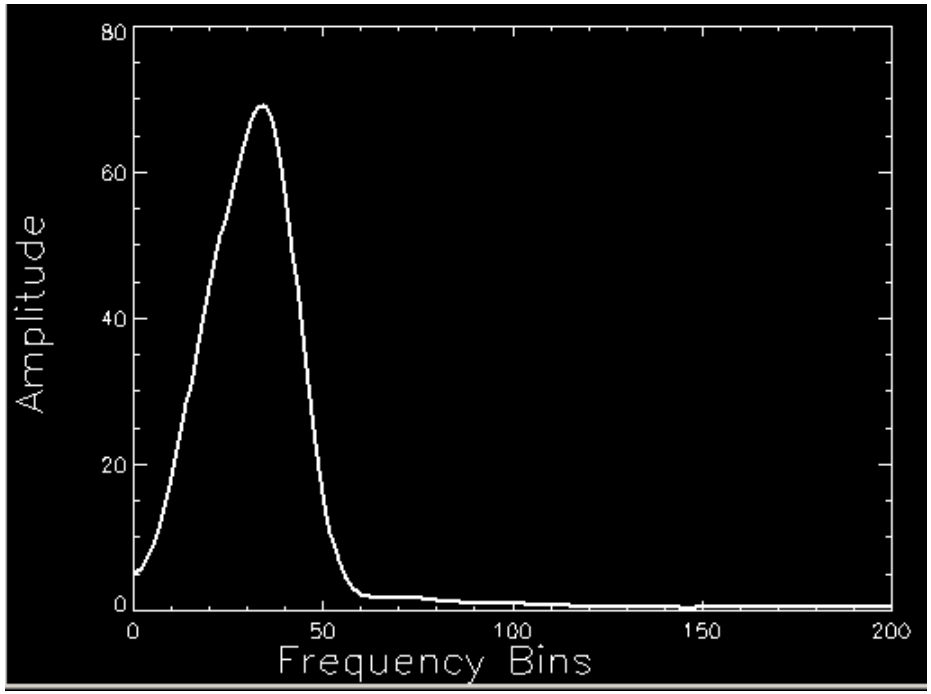


Filtering

Gaussian used to filter



Ringing not observed in Spectrum



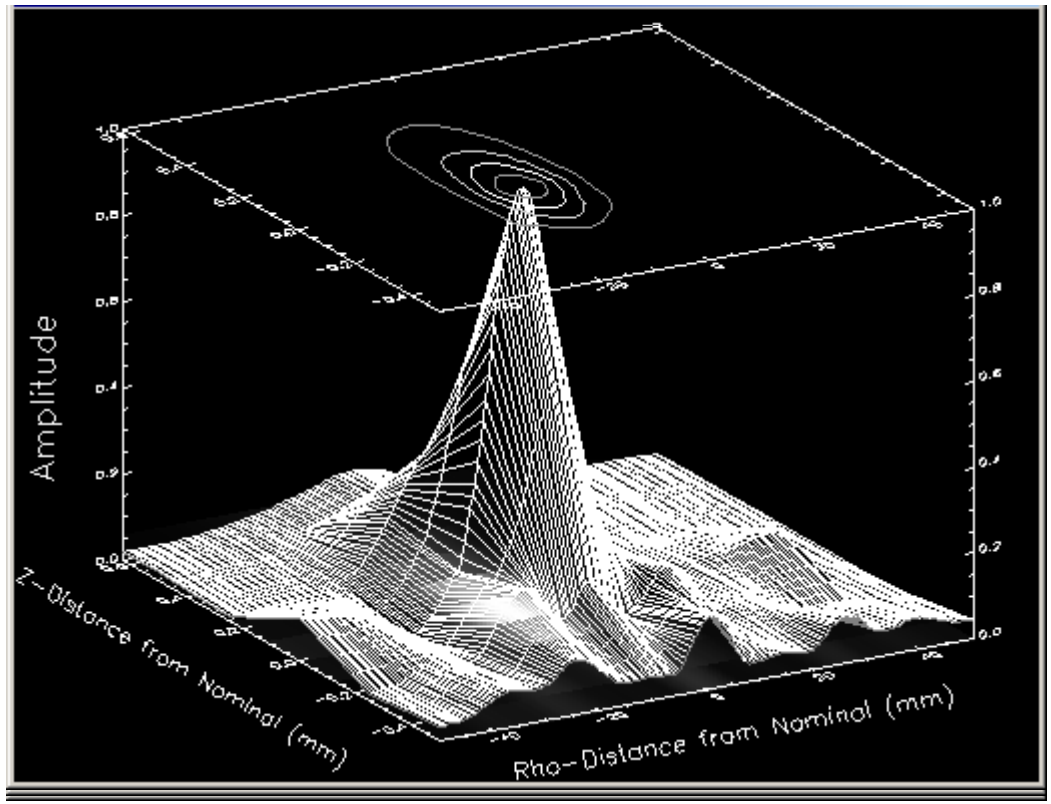
Data Processing

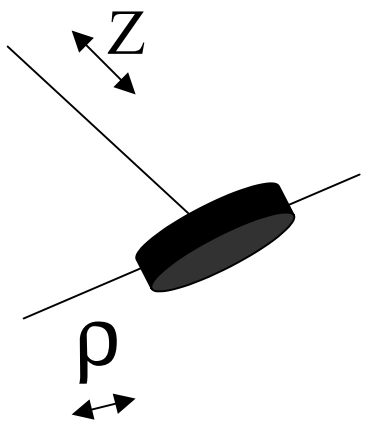
Average amplitude values over specific frequency bins were calculated for 10 frequency values.

Nominal, ±2MHz, ±4MHz, ±6MHz, -7MHz, +8MHz, +9MHz

Amplitude at each ρ for each Z location and a specific frequency were plotted

Data Display

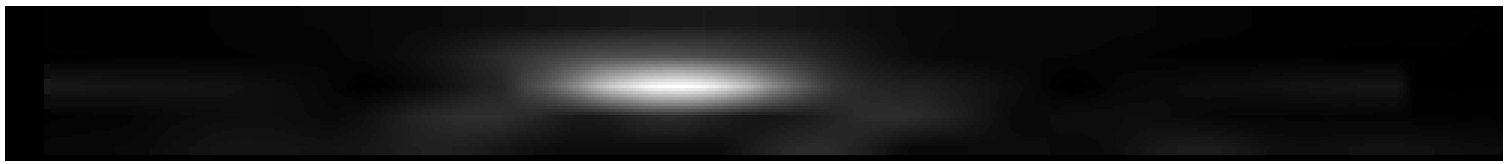


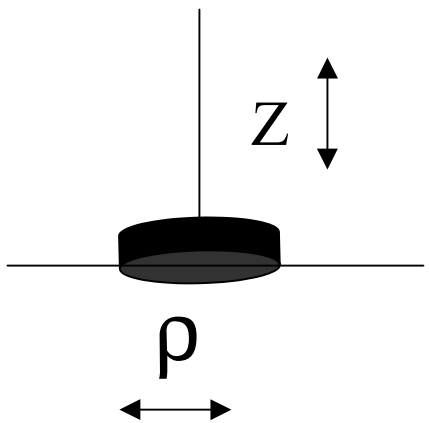


Tri-Level Display from –7MHz to +9MHz

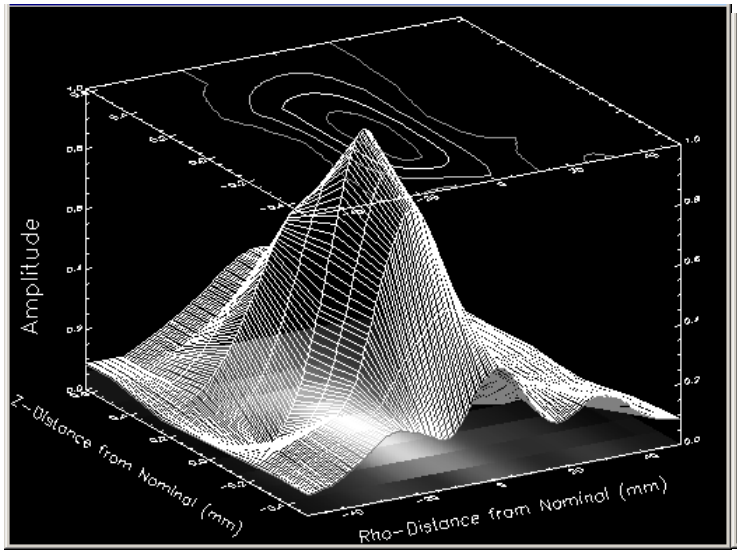
Data Display

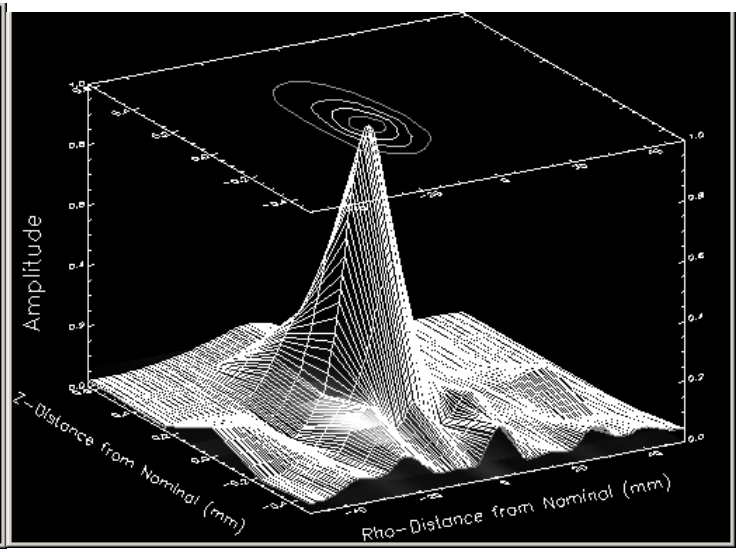
Top Down View from –7MHz to +9MHz





Data Display



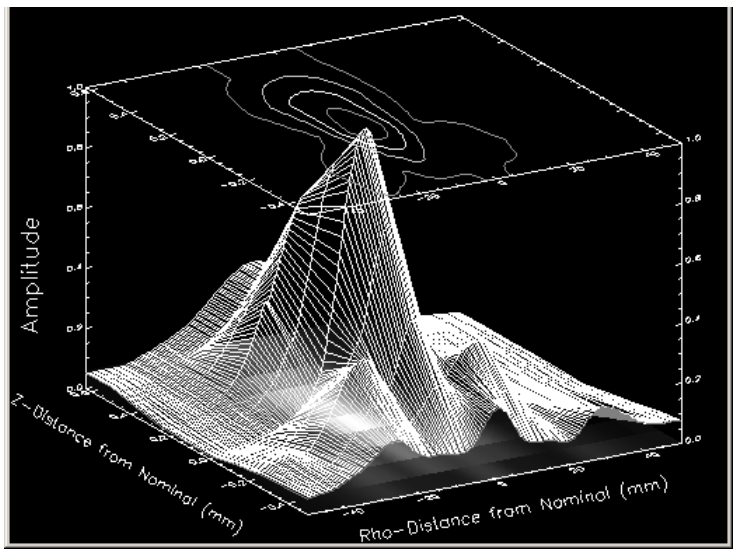


Broad beam profile

-7 MHz

+9 MHz

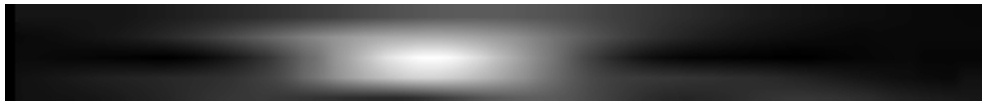
Near-field Diffraction Effects



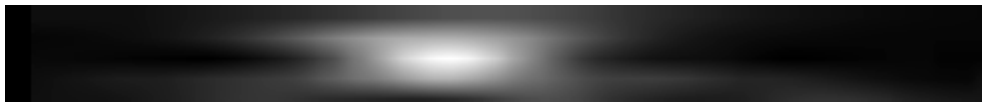
Nominal

Data Display

Low Frequency = Broad Profile

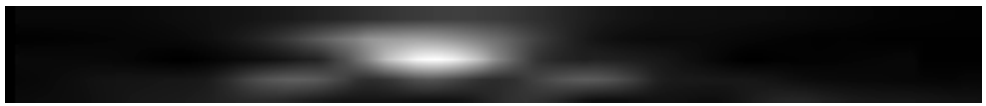


-7MHz

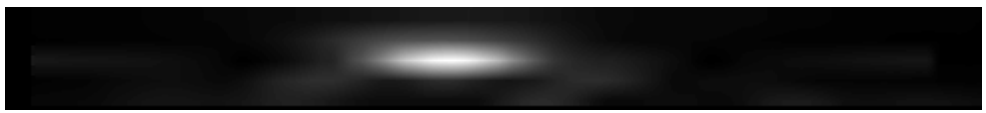


-4MHz

Nominal

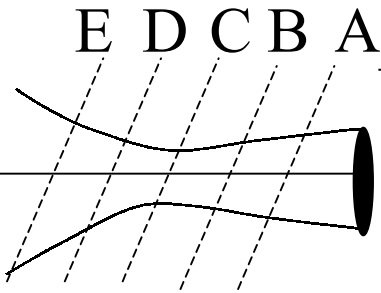


+4MHz



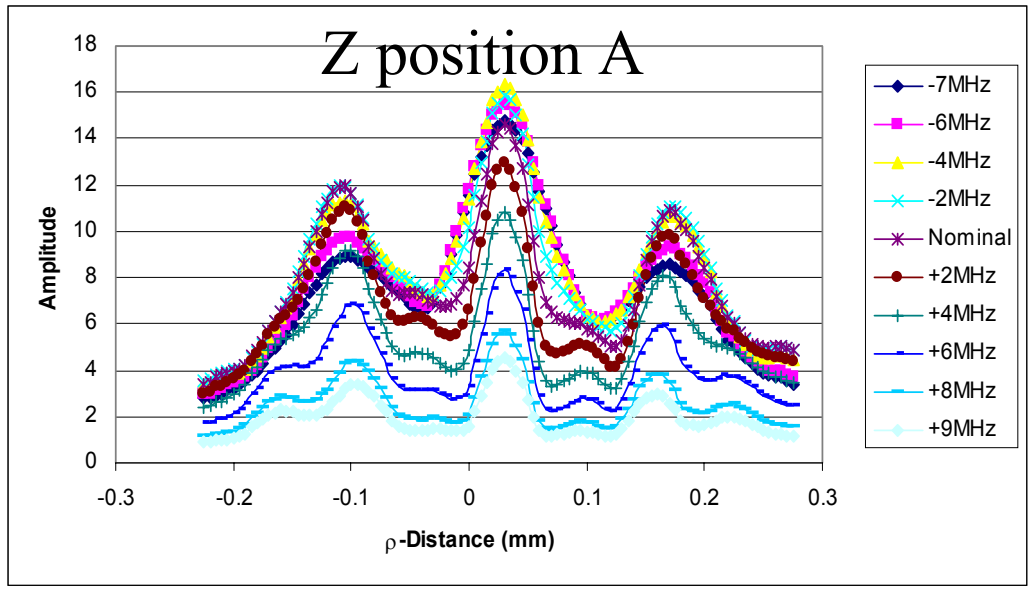
+9MHz

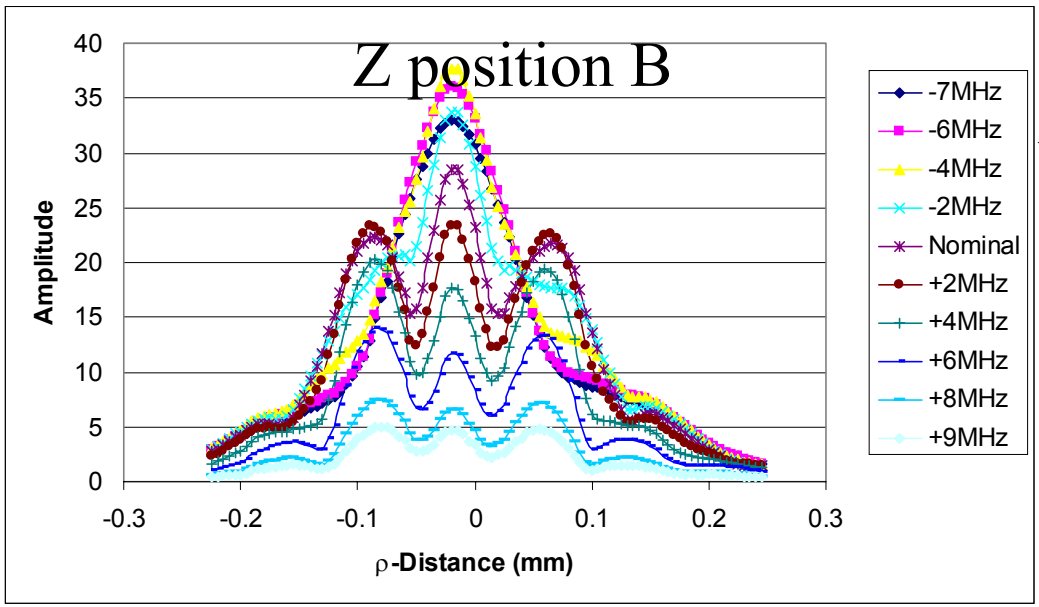
High Frequency = Tight Profile



Near Field Diffraction Effects

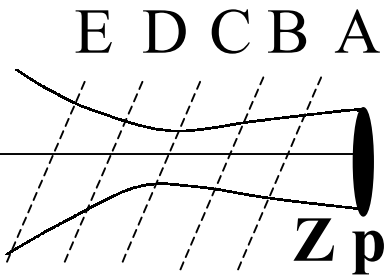
Near Field Diffraction Effects Apparent →





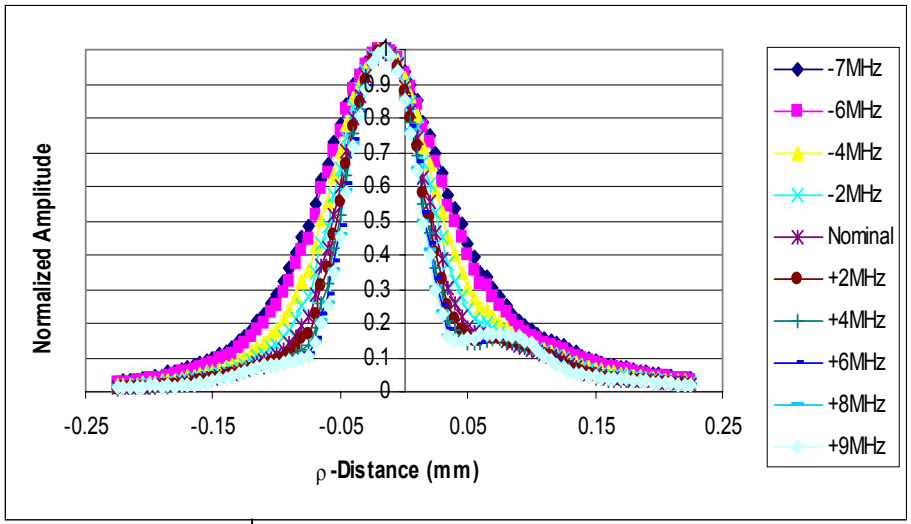
← Near Field Diffraction Effects not apparent for –7, -6 or –4 MHz

Identification of near-field, true-focus or far-field must be based on Z-position and Frequency.

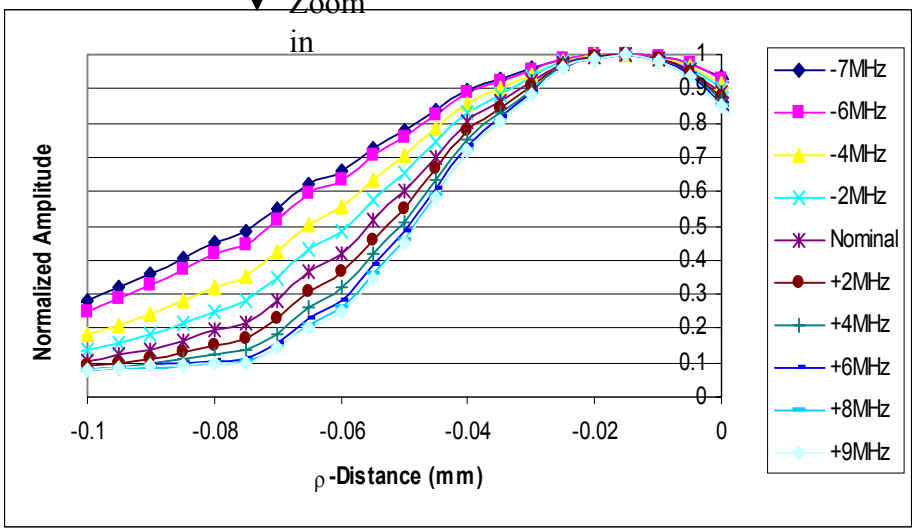


Beam Profiles

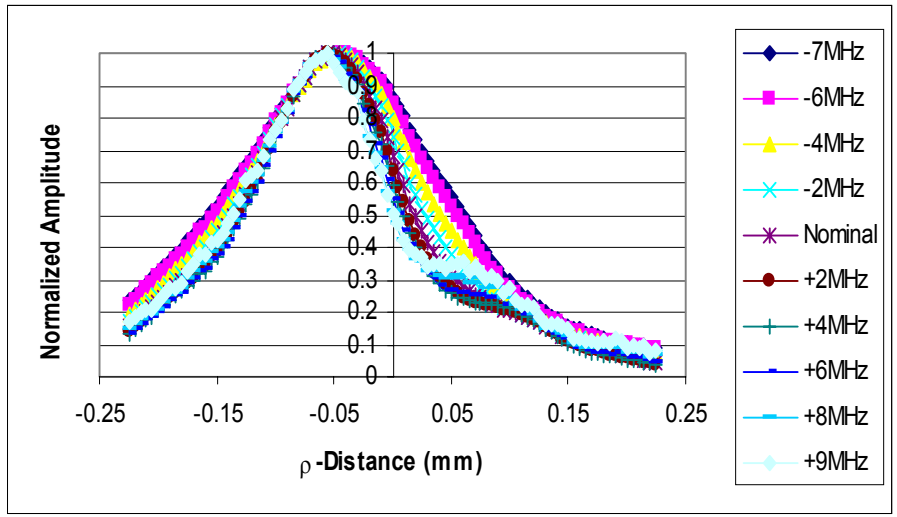
Z position C



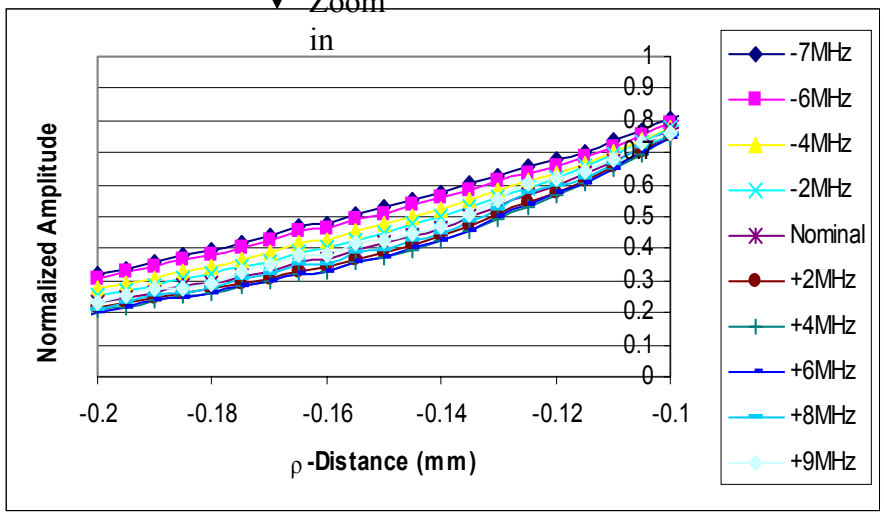
Zoom in

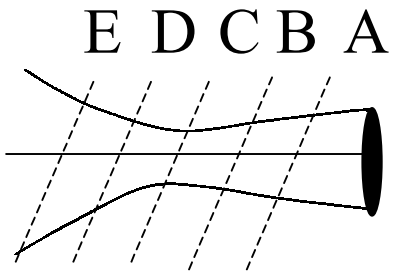


Z position E

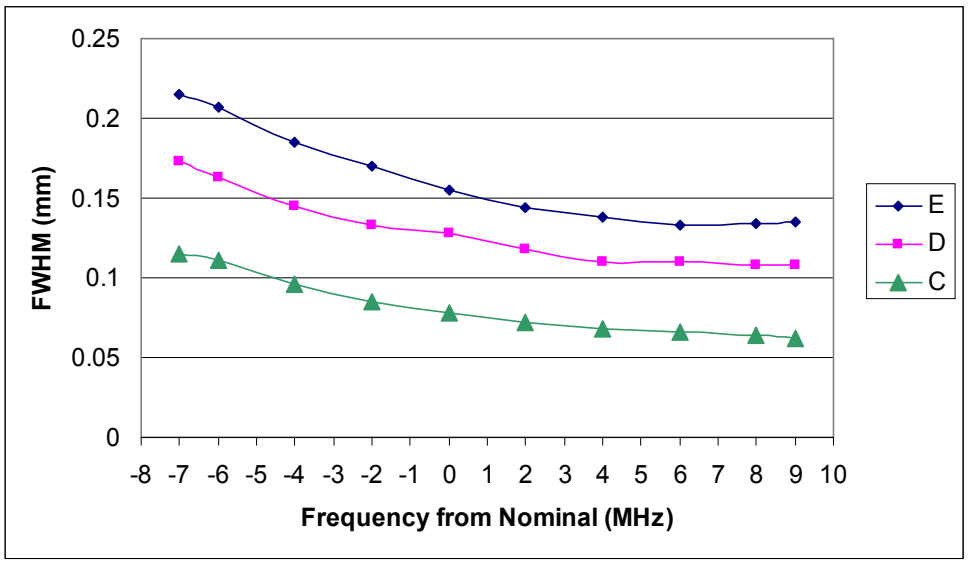


Zoom in





Full-Width Half Maximum

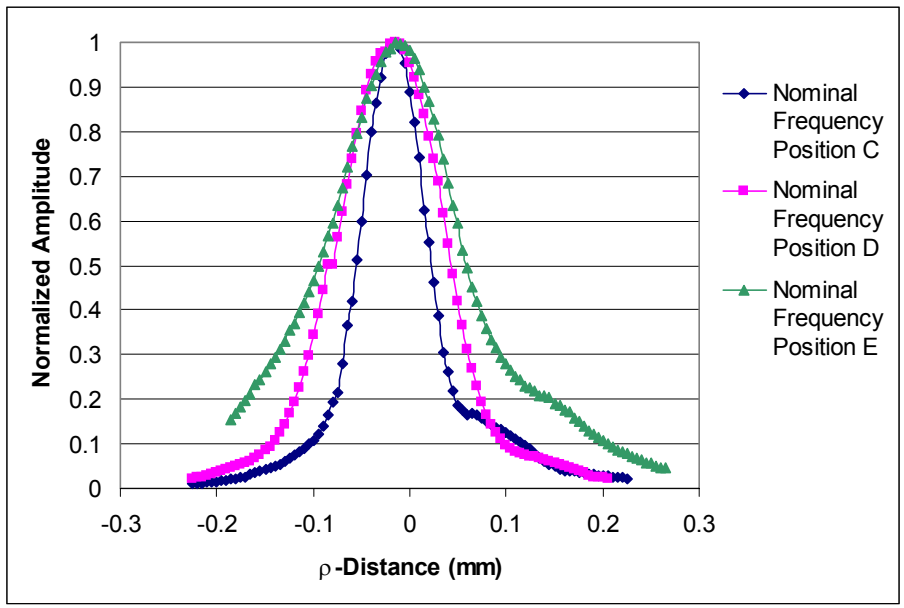


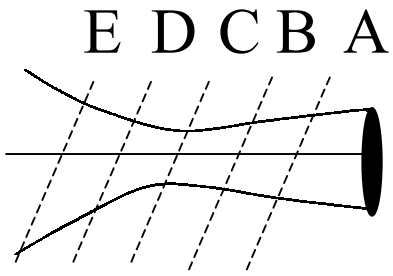
Position C = True Focus

Positions D,E = Far Field

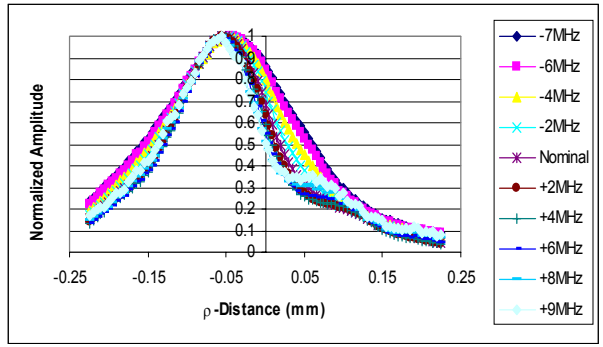
Far Field = high FWHM

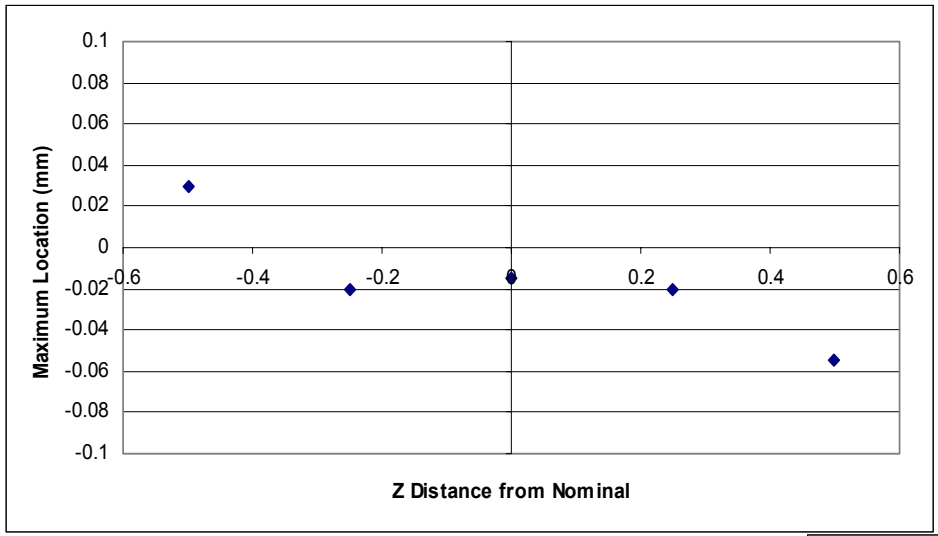
True Focus = low FWHM





Misalignment





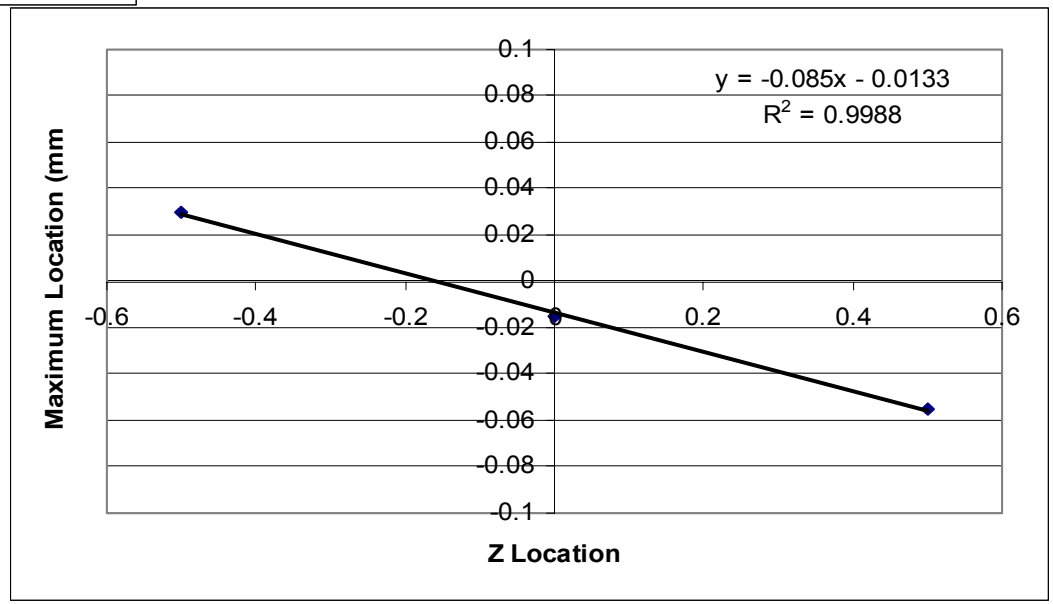
The transducer and wire are slightly misaligned

Position A – Peak shifted Right

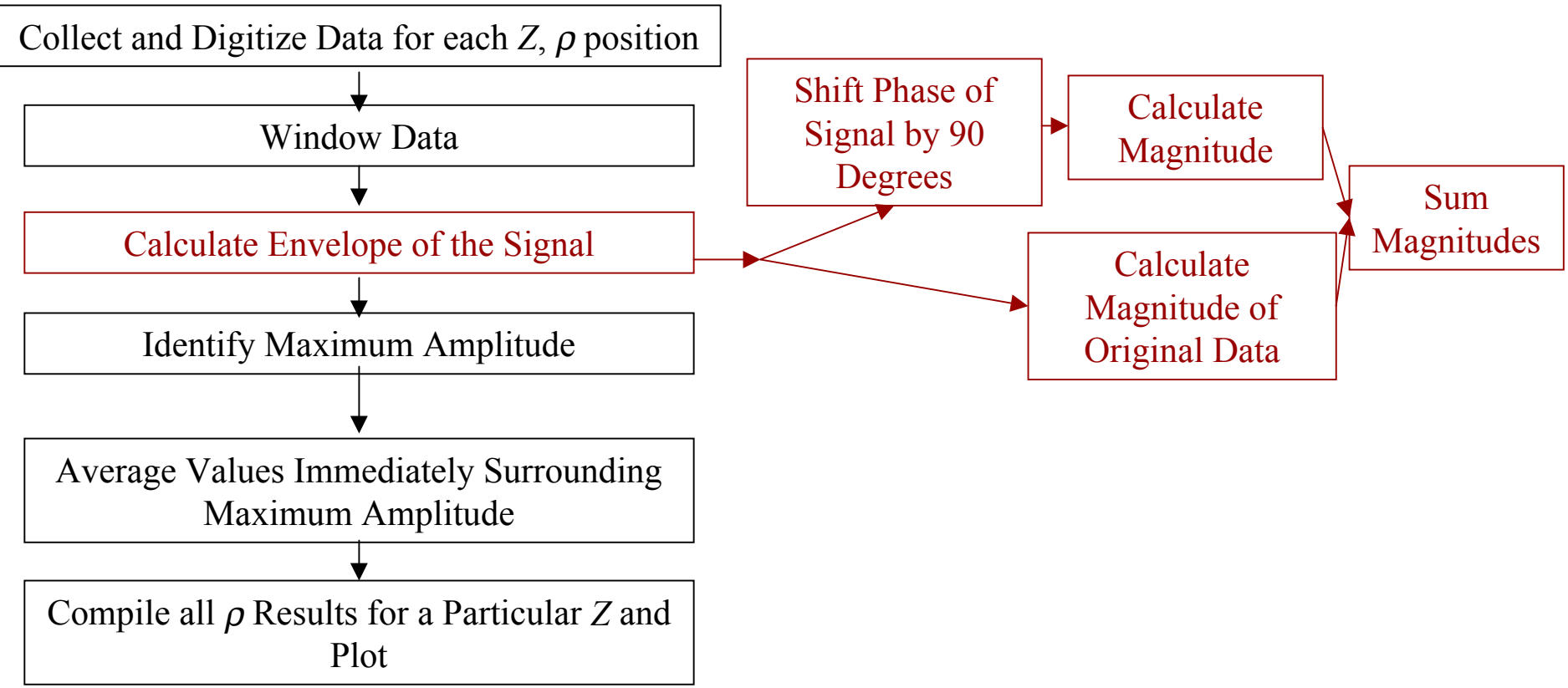
Position E – Peak shifted Left

Calculation indicates transducer is 4.8 degrees misaligned from wire.

⇒ Inconsequential



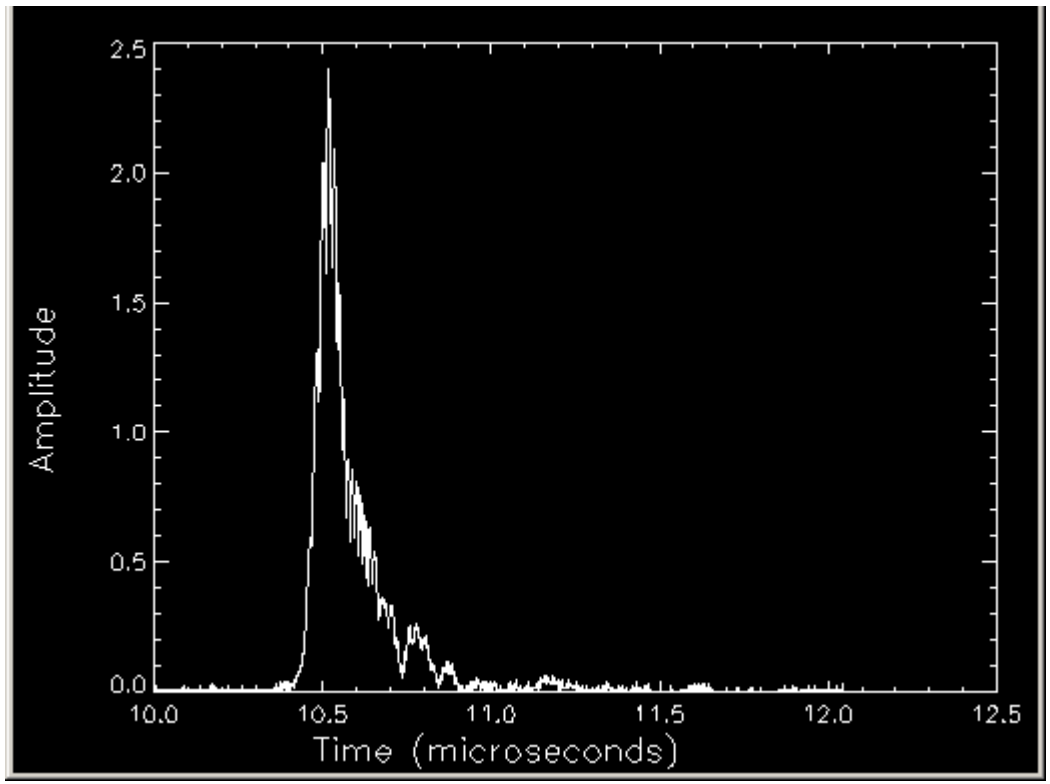
Alternate Technique

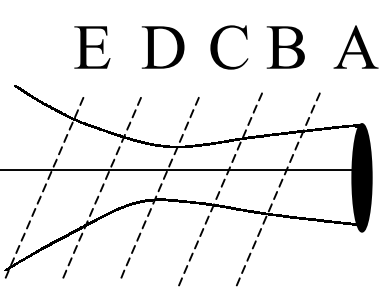


Manufacturer uses envelope of signal in data processing

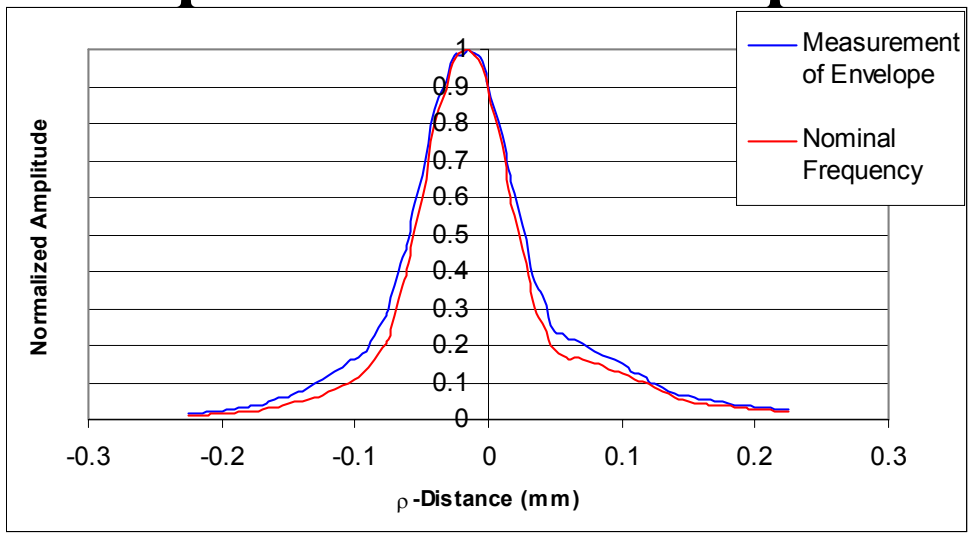
Alternate Technique

Envelope of the Windowed Data

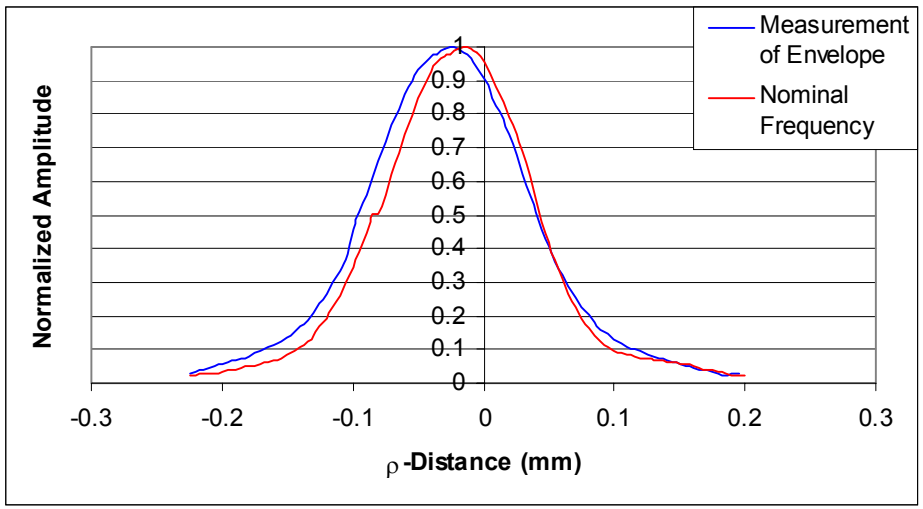




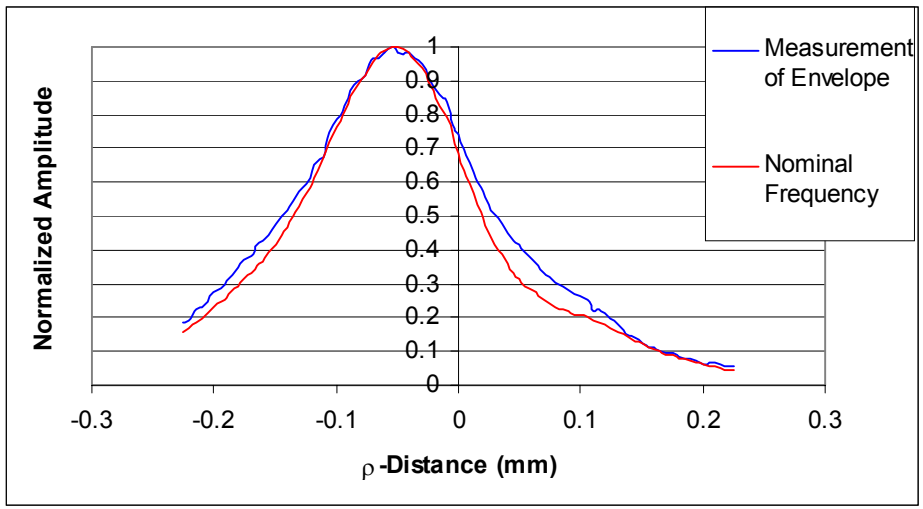
Compare Techniques



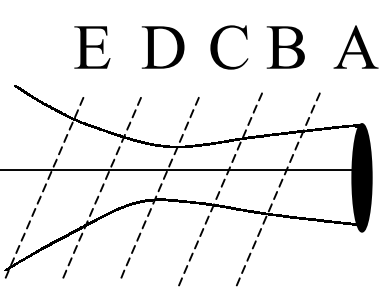
Position C



Position D



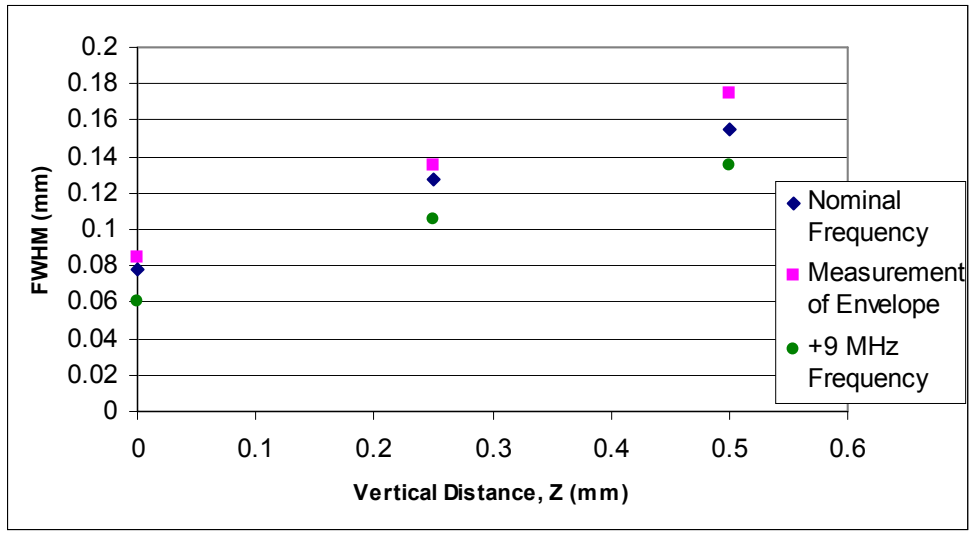
Position E



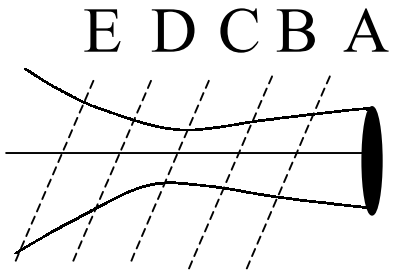
Compare Techniques

Nominal Frequency and Measurement of Envelope may be Statistically Equivalent

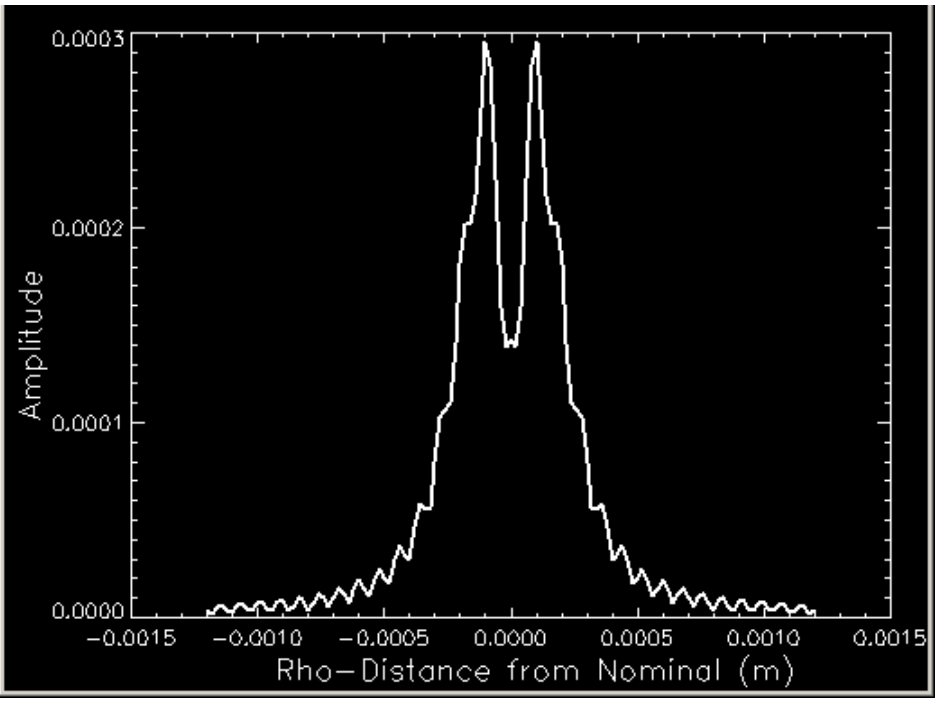
+9MHz is Significantly Improved

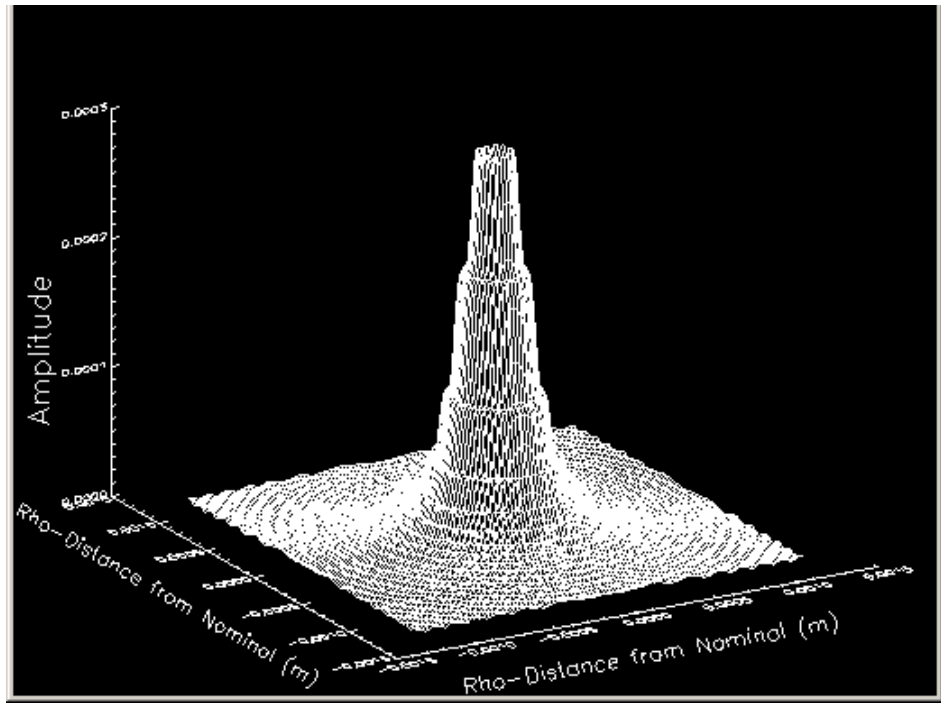


Z Location	Measurement of Envelope FWHM (mm)	Nominal Frequency FWHM (mm)	+9MHz Frequency FWHM (mm)
C	0.083	0.08	0.06
D	0.135	0.13	0.105
E	0.17	0.16	0.135



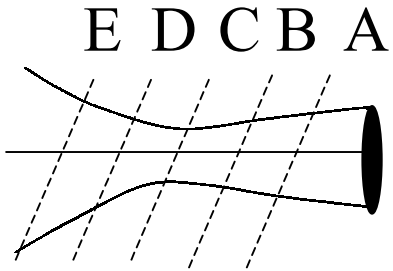
Theoretical Calculations



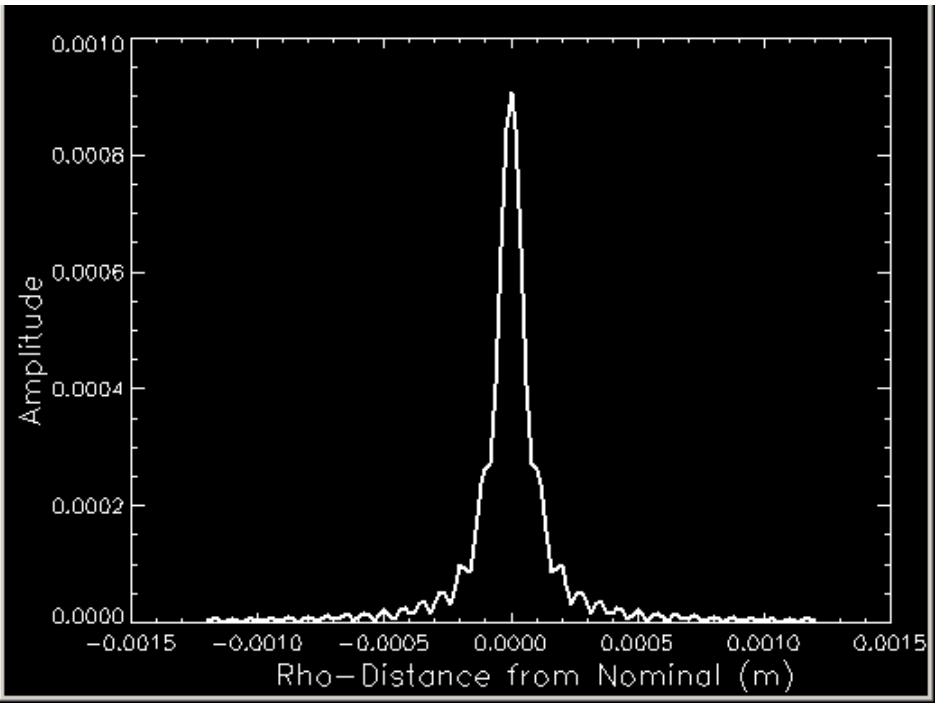


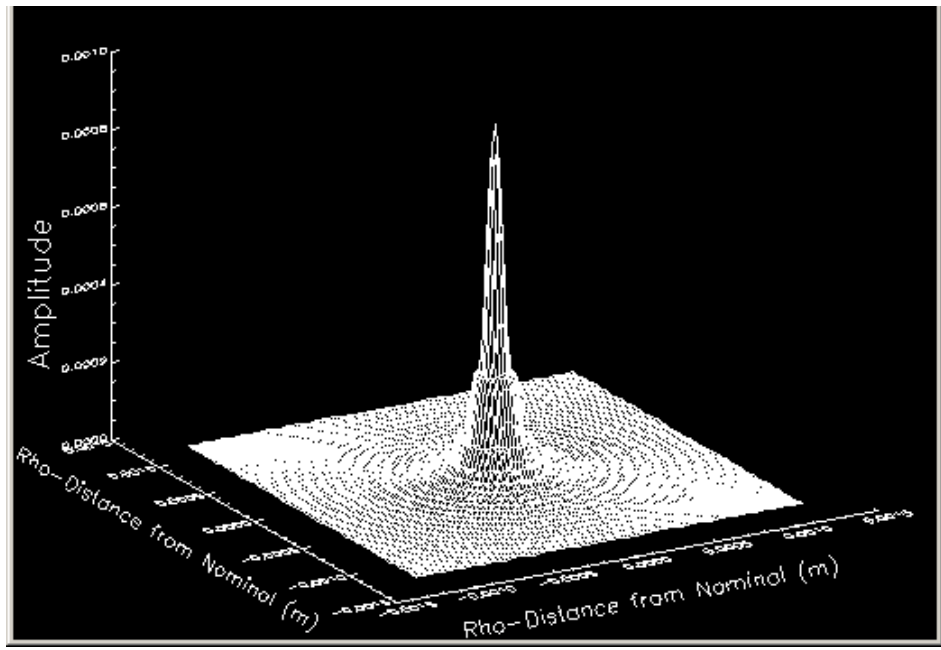
Z Position A

Near Field Diffraction Effects

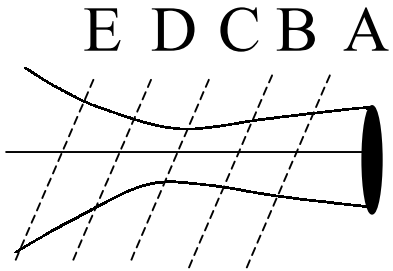


Theoretical Calculations

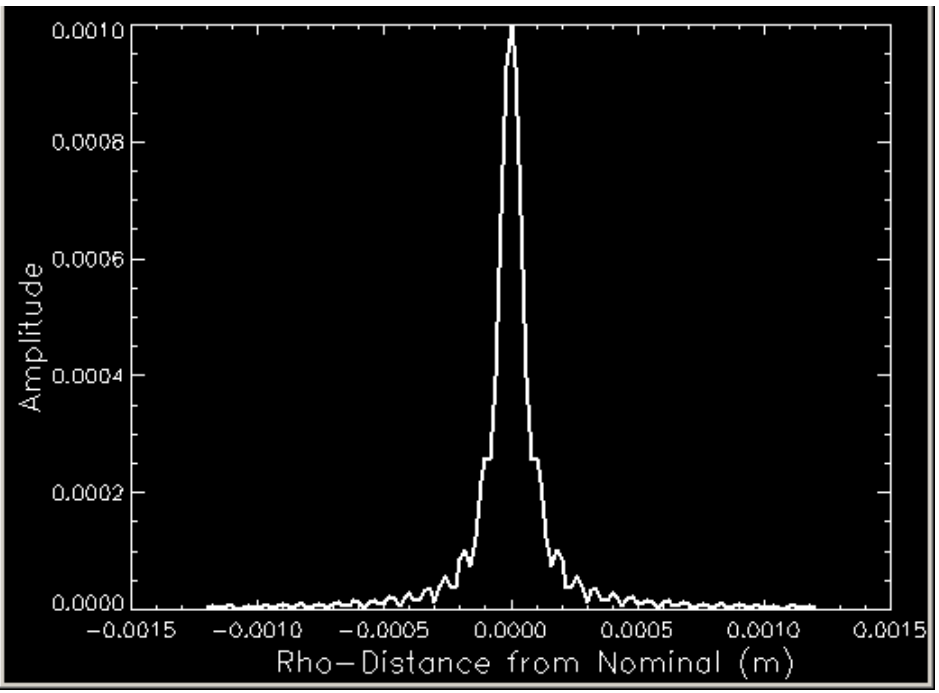


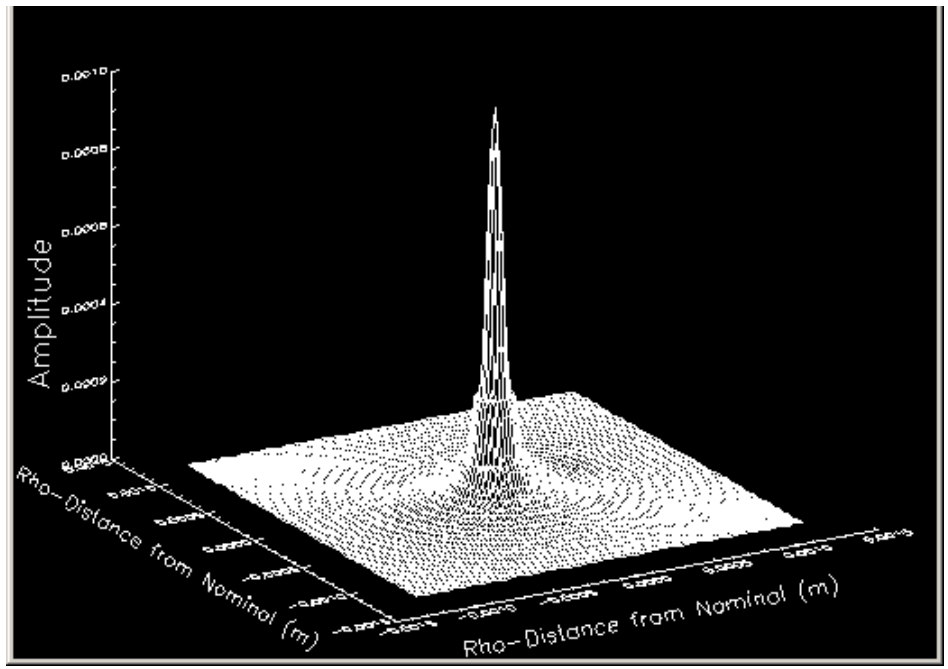


Z Position B



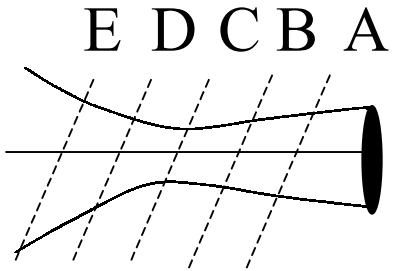
Theoretical Calculations



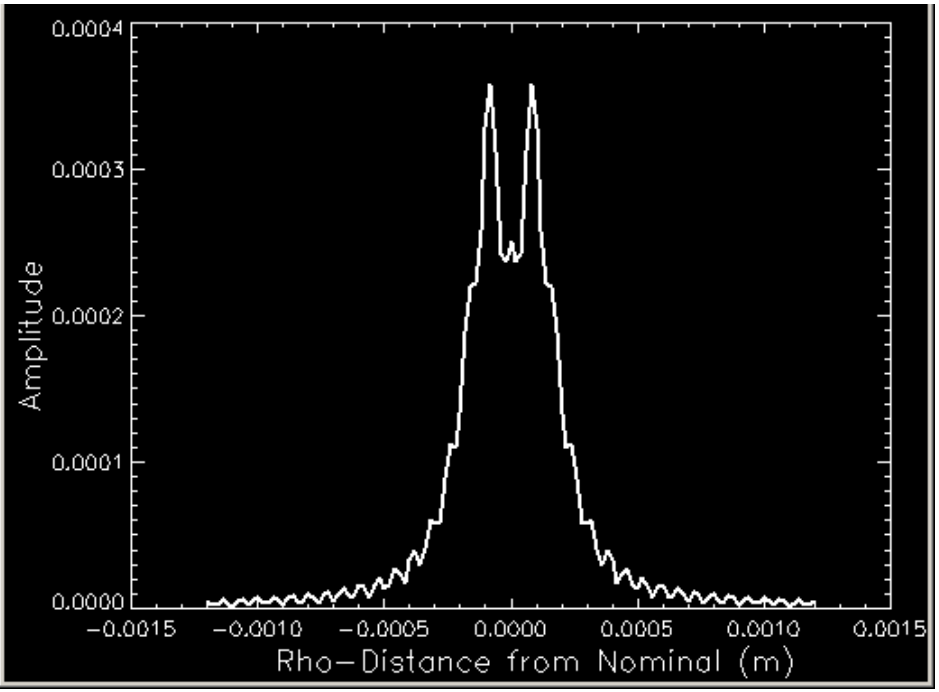


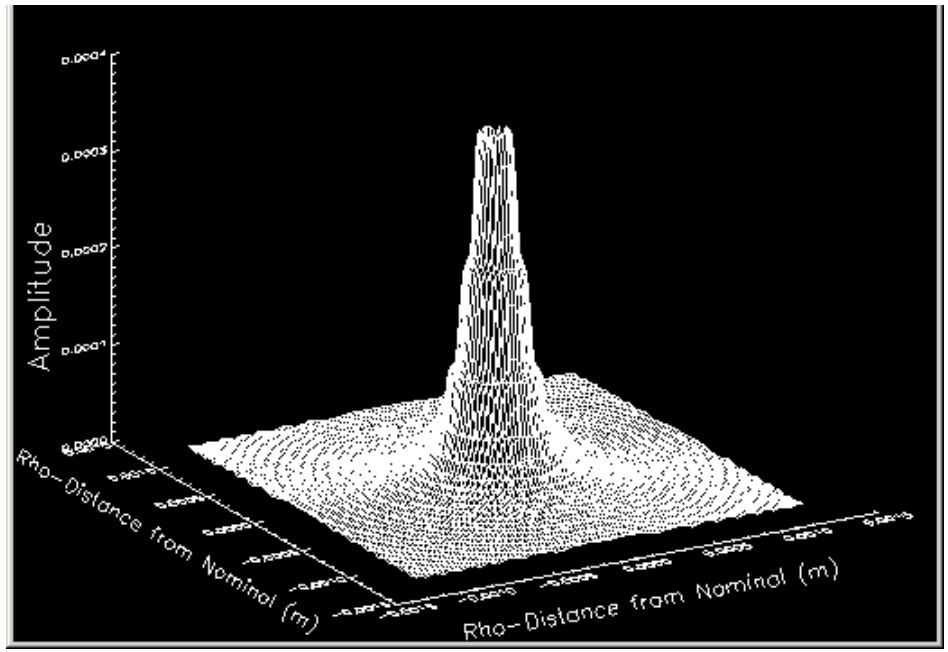
Z Position C

True Focus



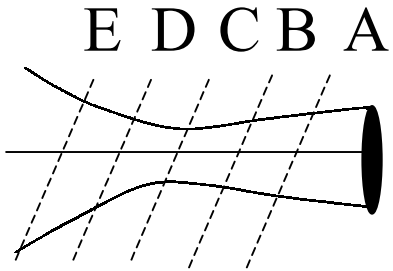
Theoretical Calculations



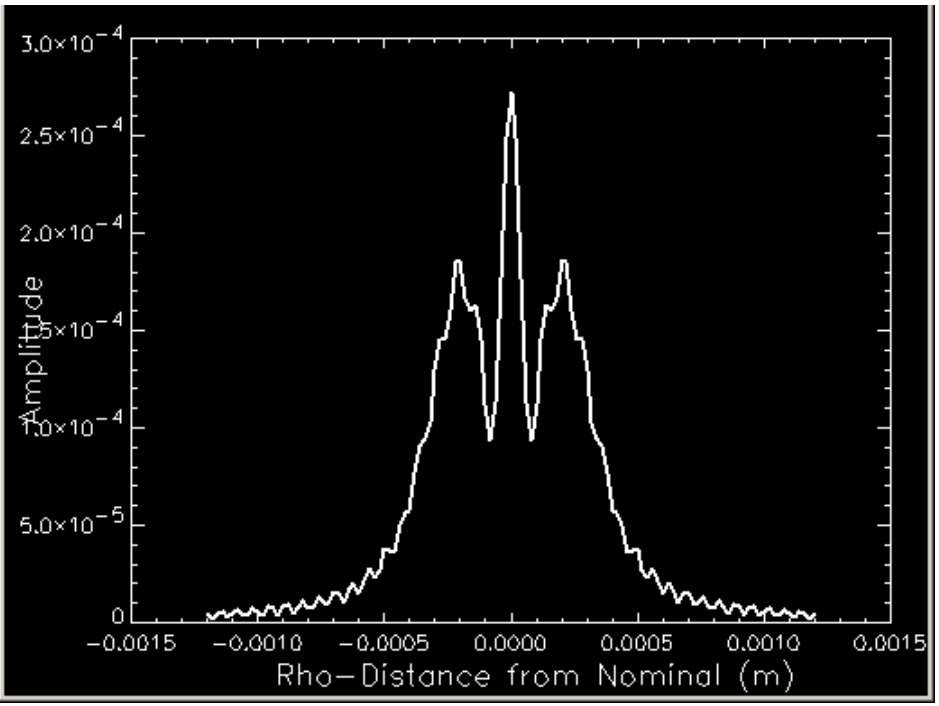


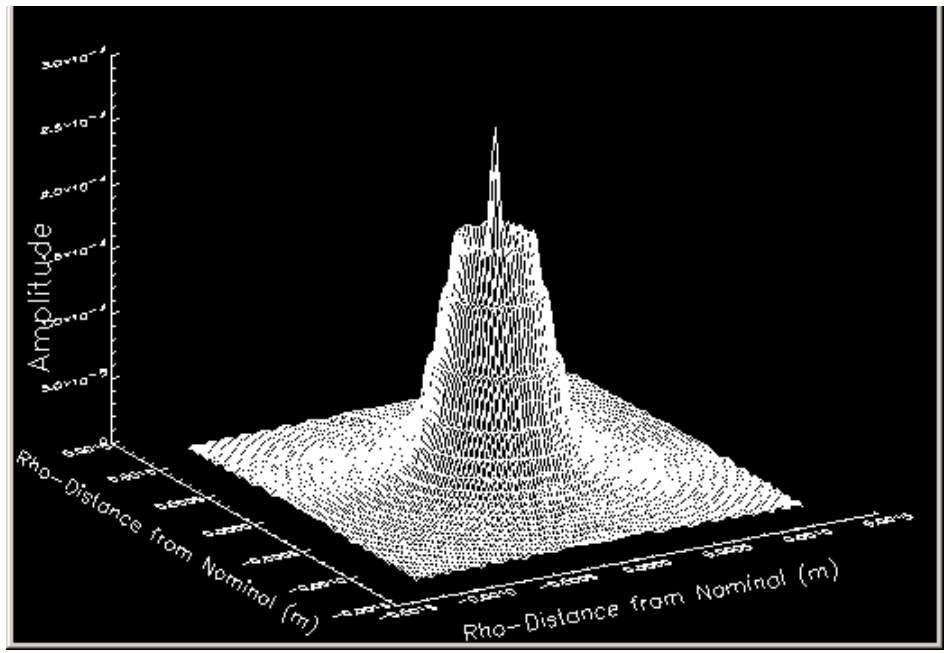
Z Position D

Far Field



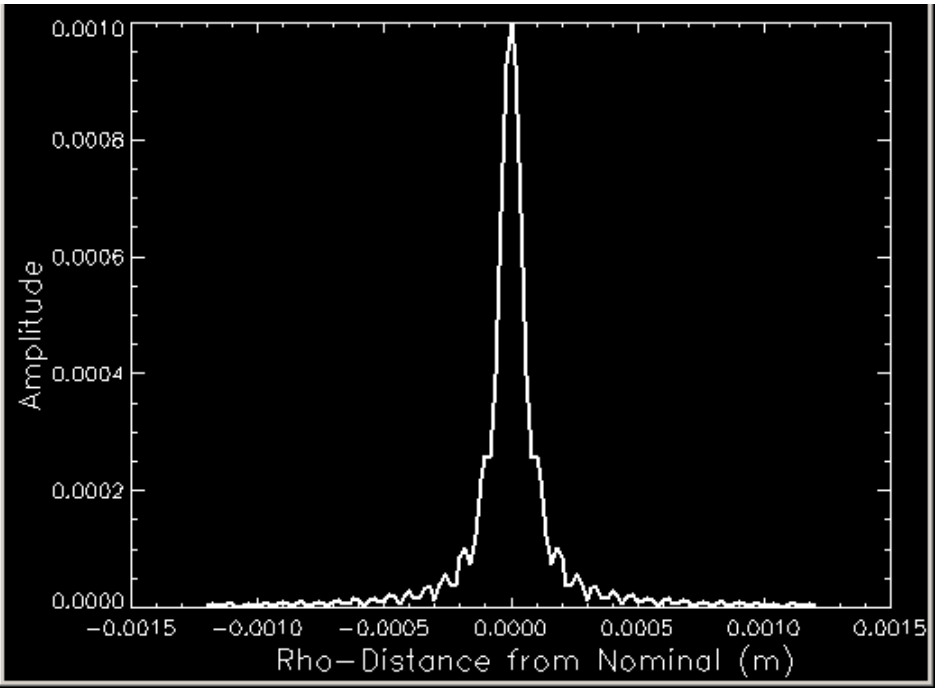
Theoretical Calculations

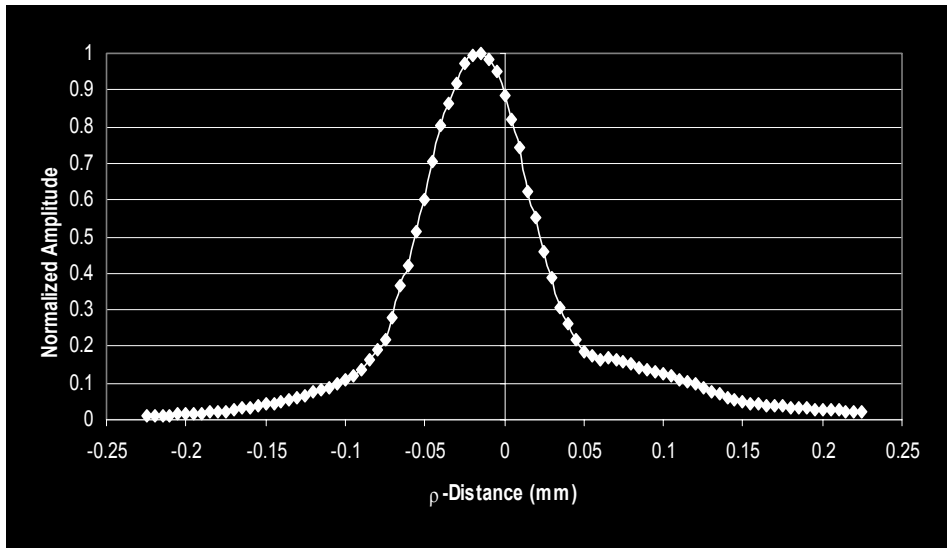




Z Position E

Theoretical Vs. Experimental At Nominal Z



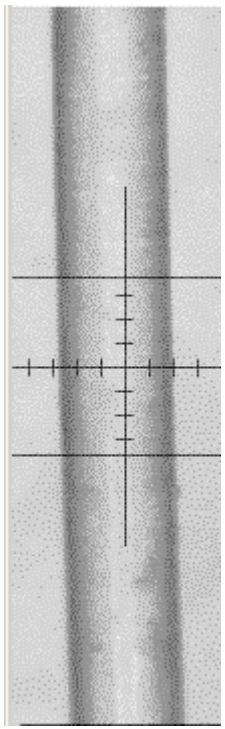


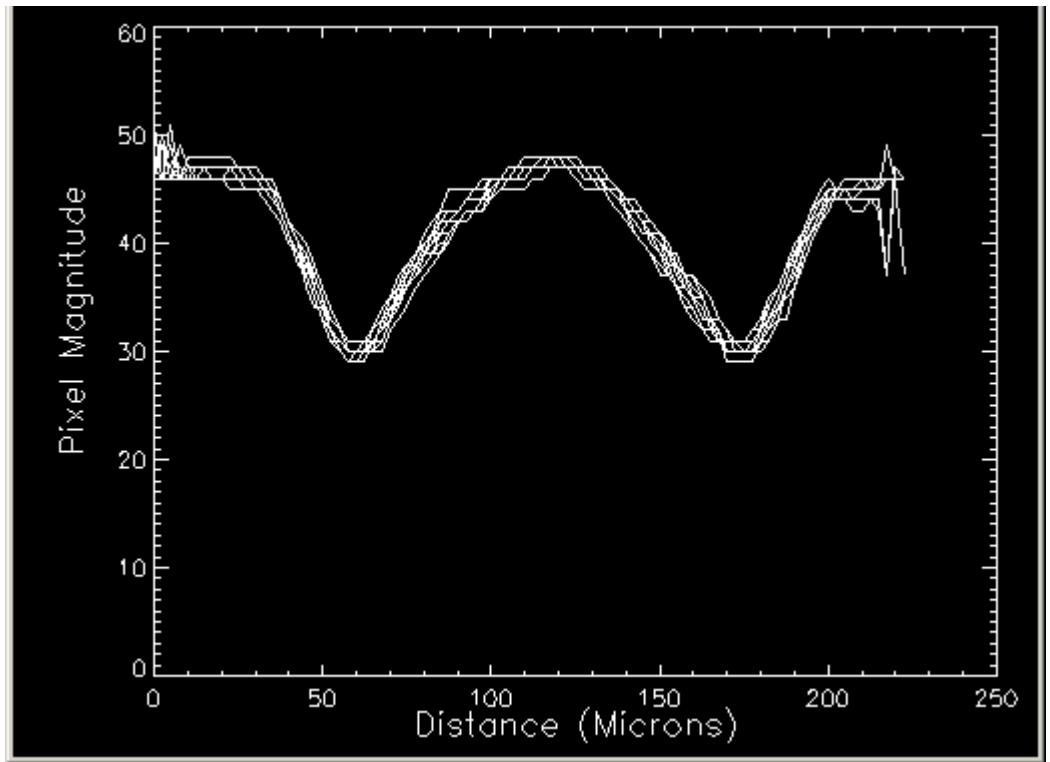
- No Side-lobes in experimental results
- Transducer is apodized to reduce side-lobes but this increases the width.
- Apodization also would change 'Effective Transducer Diameter'
- Apodization is an unknown parameter in the design

Wire Target Analysis

Another possible cause of the larger FWHM is the thickness of the wire target.

There may be overlapping multiple reflections from the edges of the wire!





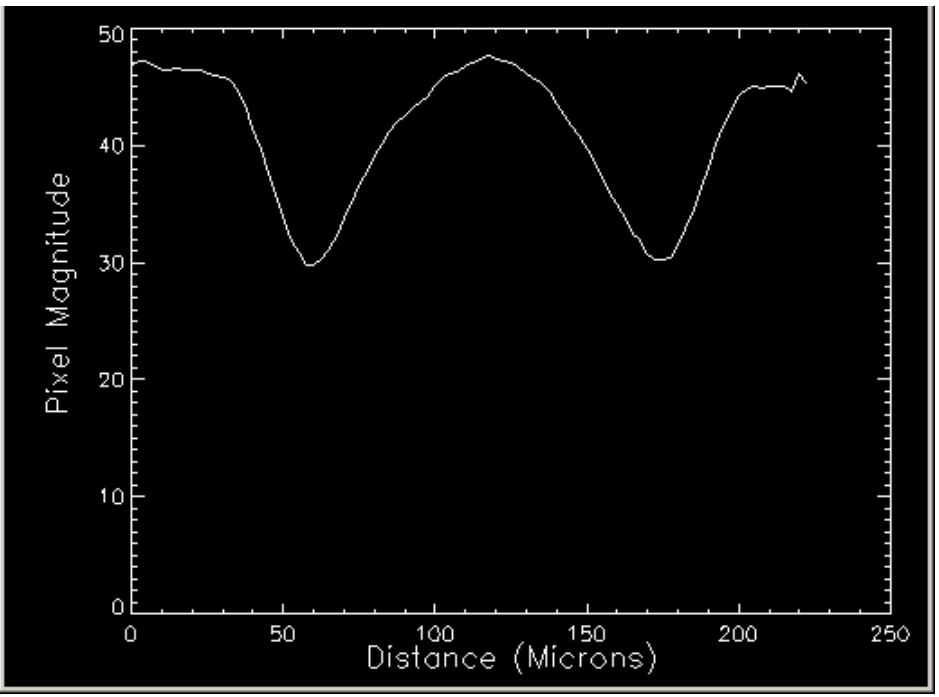
Wire Target Analysis

Measured Wire Diameter = 125 microns

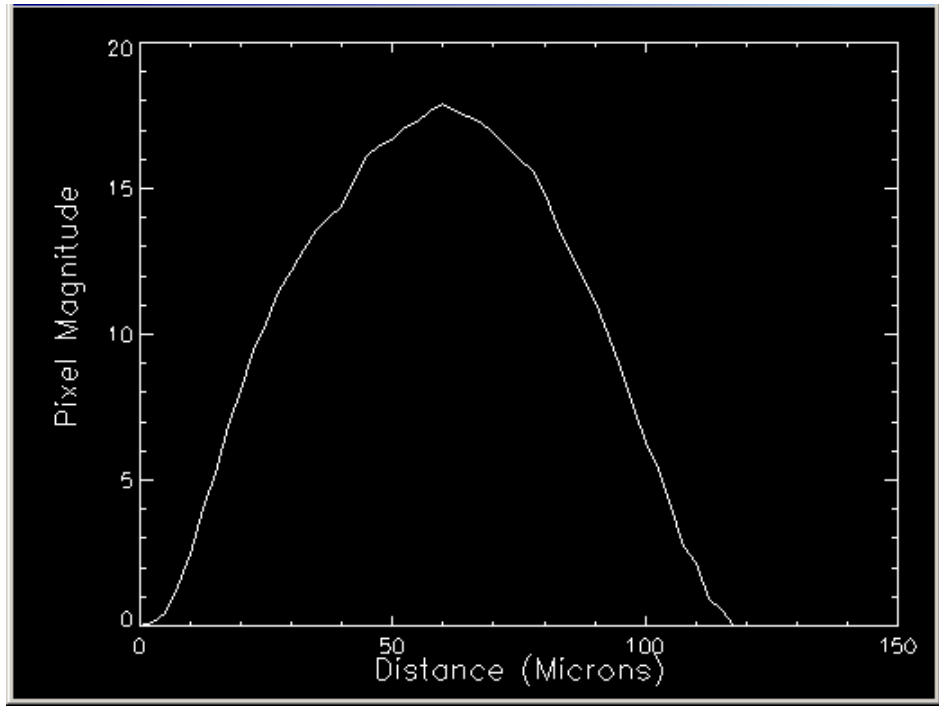
Full Width Half Maximum of pixel profile = 75 microns

Effective width (where specular reflection takes place) = 20-30 microns

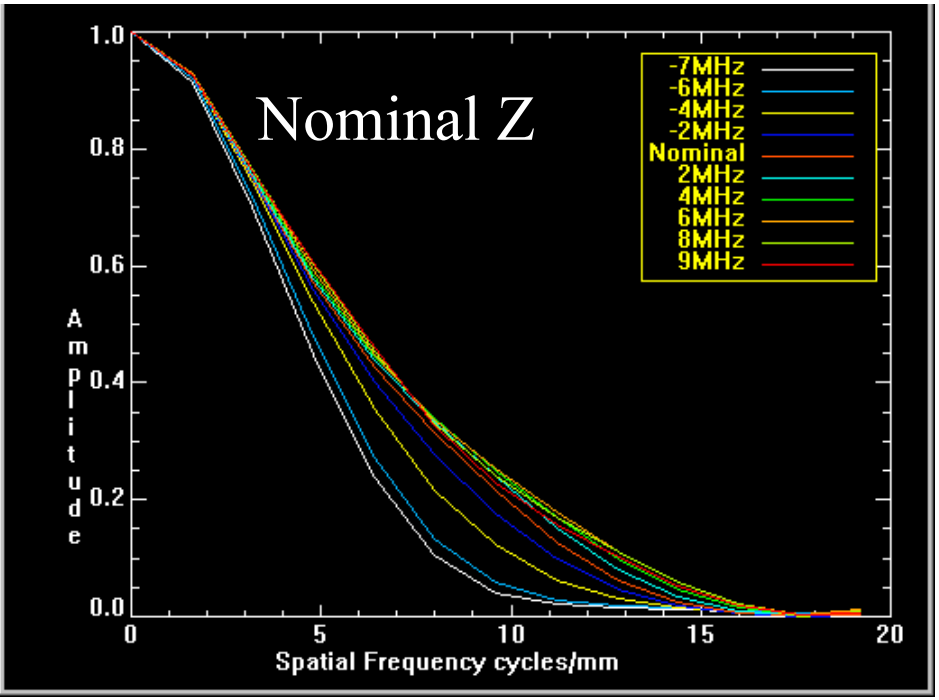
Average of pixel profiles



Zoom In



Modulation Transfer Function



MTF = Fourier Transform {LSF}

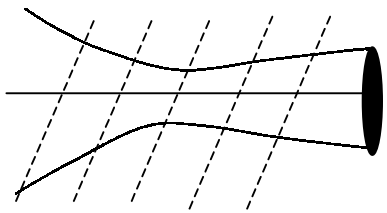
Higher Frequency or

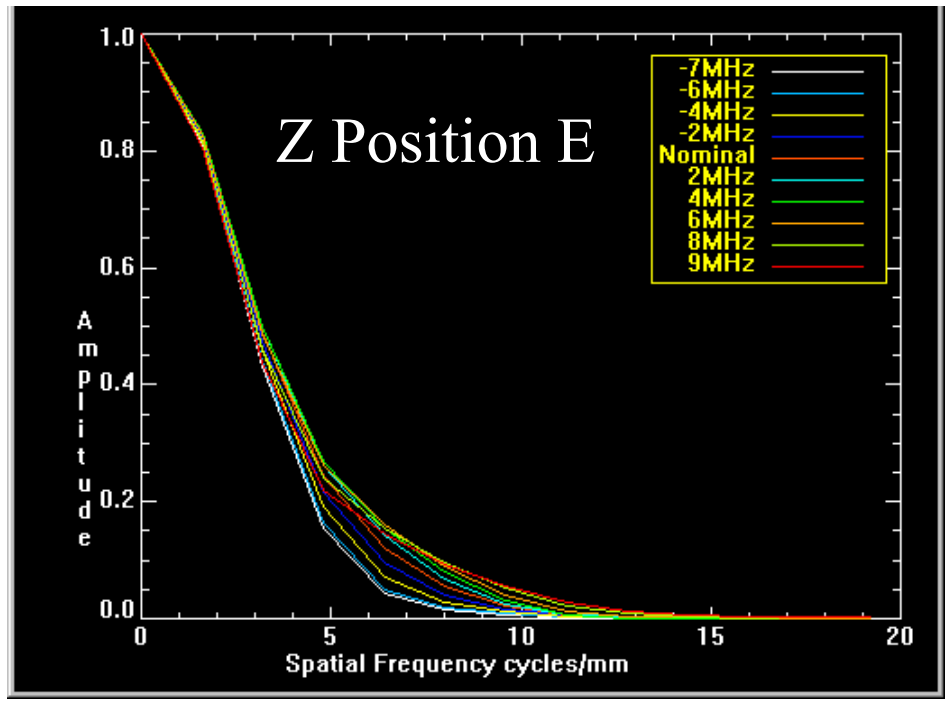
Z closer to nominal =

Higher Cutoff Frequency

Nominal Z = MTFs more spread out as a function of frequency

E D C B A





Conclusions

- Transducer Beam profile is Frequency and Depth Dependent
- Measuring Signal from a thin wire target is effective technique for focused high frequency transducer
- Cepstrum filtering useful in removing periodic noise
- MTF varies with frequency and Z-position
- +9MHz would be improvement over envelope measurement

Future Studies

- Repeat experiment with a 10-20 micron wire (not easy)

- Evaluate Edge Spread Function with glass slide and calculate derivative to determine MTF

- Measure LSF and MTF for entire Fingerprint Imaging System and compare to results found for the transducer