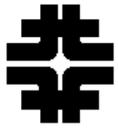




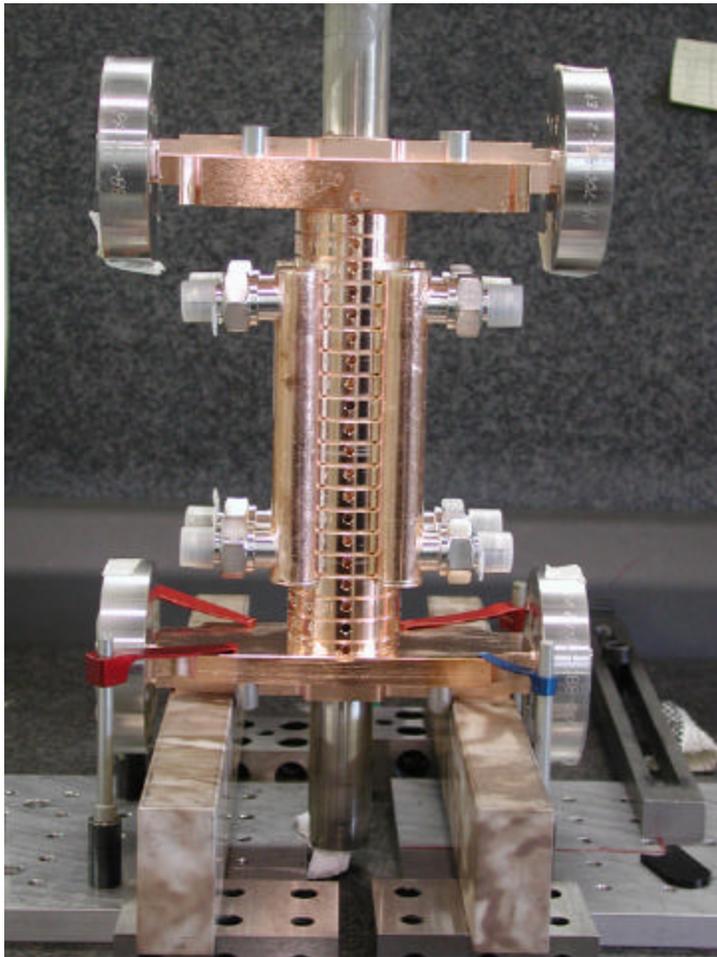
Status of X-Band Structure Fabrication at Fermilab

- Our First X-Band Structure
- Progress of RF Factory at IB4
- Making FXA-001
- Measuring FXA-001
- The Next Steps and The Plan





Fermilab has its first X-Band structure.



- It is about 20 cm long.
- It is named FXA-001.
- Note the cells, couplers, rf flanges, water pipes, beam tubes.
- It took about a year.

FXA-001 Setup for Mechanical QC at Fermilab

Technical Division, 08/01/01

October 25, 2001

David Finley to NLC MAC @ SLAC

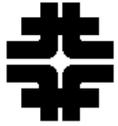
Slide 2



Status of X-Band Structure Fabrication at Fermilab

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RF Factory Elements (Norbert Holtkamp, David Finley)

From David Finley's Presentation at the May 31, 2000
NLC Collaboration Meeting at Fermilab

- Seven Elements of the RF Factory
 - RF Design
 - Produce Copper / Machine Copper
 - RF Measurements & Development / Low Power
 - Structure and Vacuum
 - Mechanical Measurements of Straightness
 - Brazing / Bonding Facility
 - High Power Processing

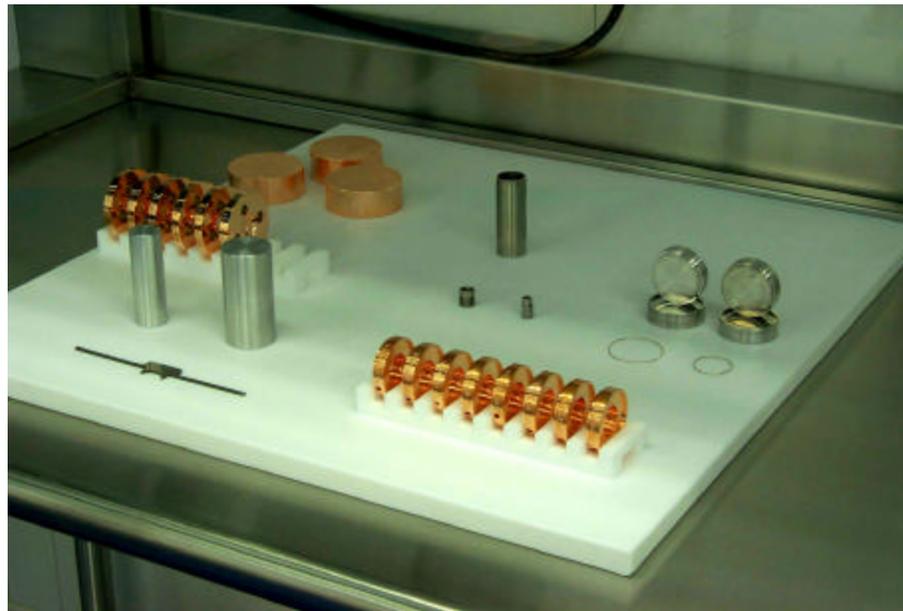


Copper Material and Some Copper Parts (Tug Arkan, SLAC, KEK, Gregg Kobliska & Co.)



9 copper bars ~10 feet long each.

Ordered enough bars for ~10K disks (~100 meters total).
Parts machined in US industries.



Have made both RDDS diamond turned disks, and conventional machined high gradient test disks.

ETF needed ~5K disks.
Eight Pack Test needs ~1K disks.
NLC needs ~1M disks (for 500 GeV center of mass.)



Mechanical Measurements of RDDS Profiles (Tug Arkan, Gregg Kobliska & Co.)

Measured four profiles along the tear-drop shaped iris of the rf surfaces of six RDDS disks.



Results reported in D. Sun et al PAC01.

Zeiss machine costs ~\$500K.

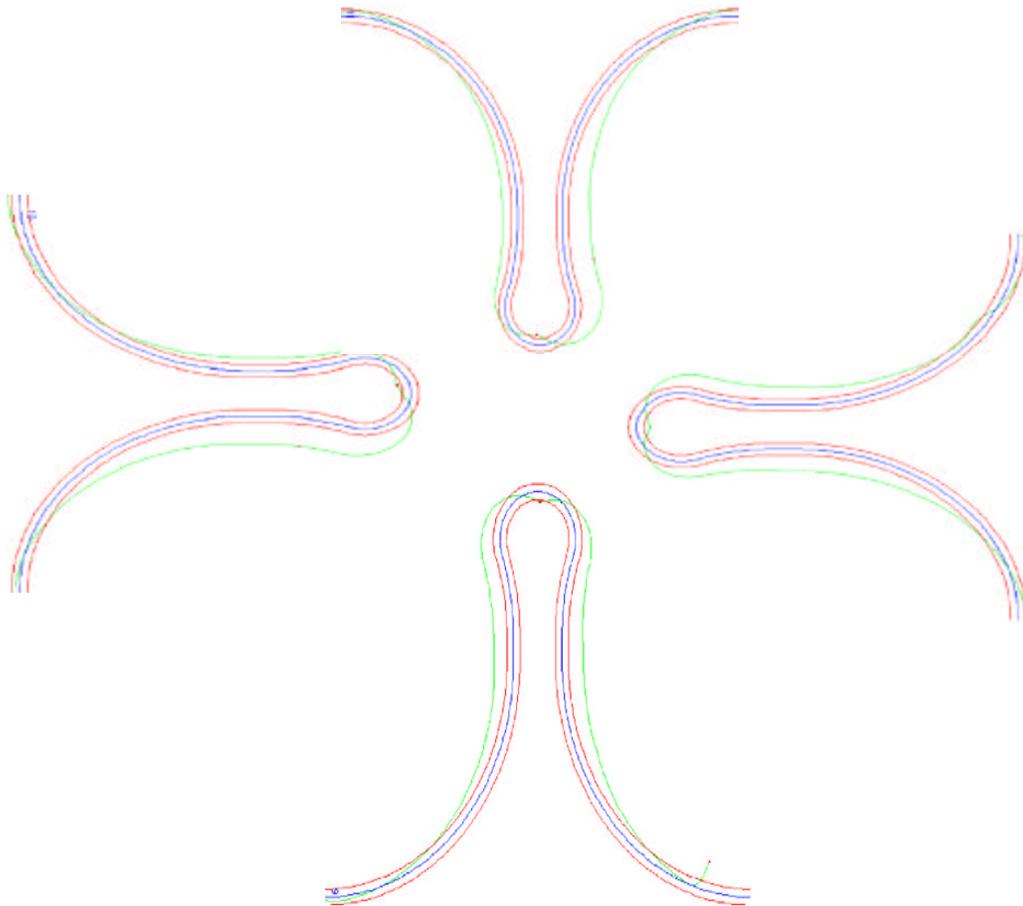


Might (or might not) buy Zeiss machine because it is a general purpose light touch 3D coordinate measuring machine.



Mechanical Measurements of RDDS Profiles

Four measured profiles (see below) along the tear-drop shaped iris of the rf surfaces for one RDDS disk.

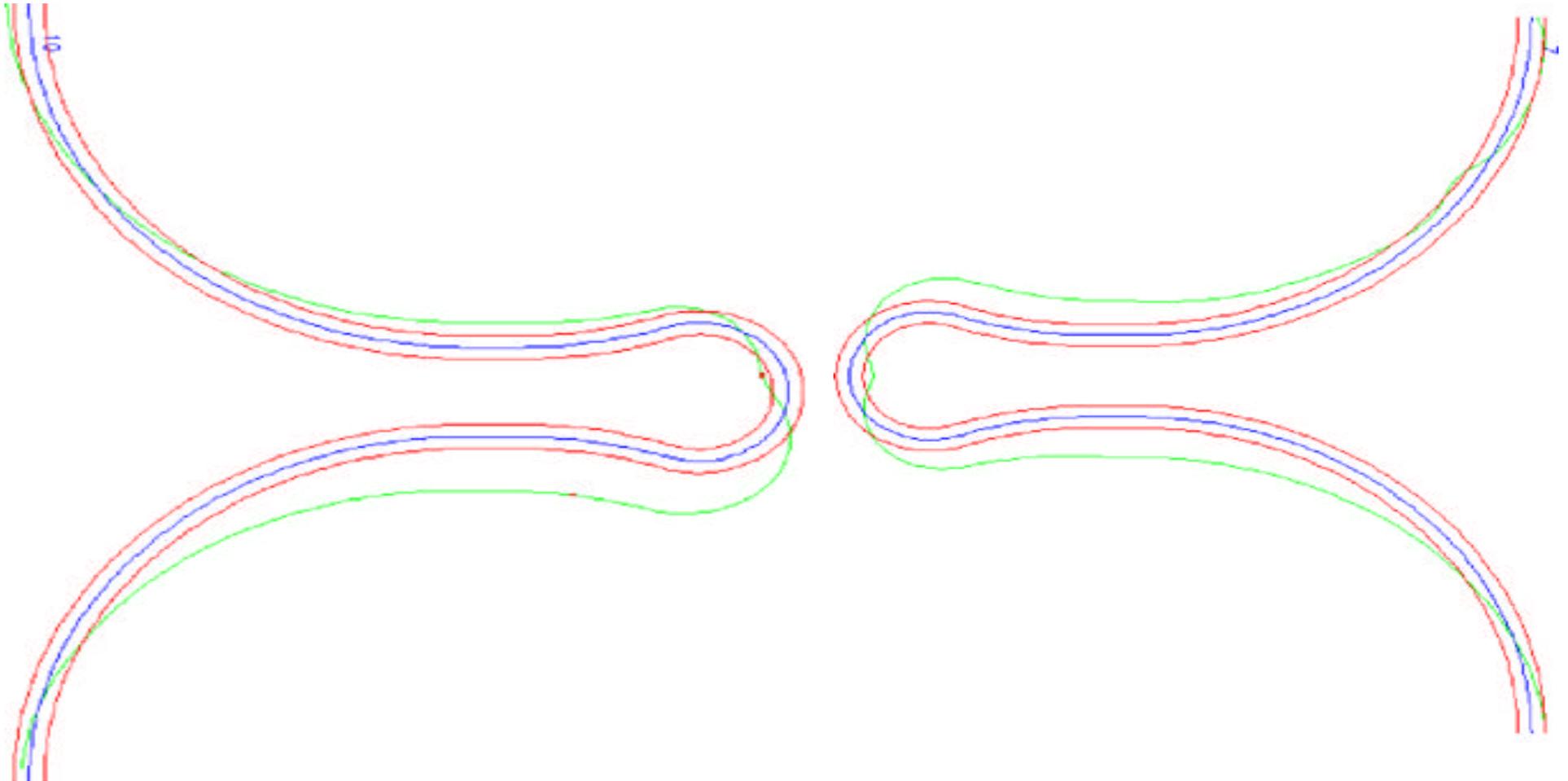


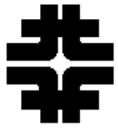
Contours of RDDS disk # C001 taken from D. Sun et al PAC01. (1 of 6 disks.)
green: measured, blue: design, red: tolerance (± 1 micron)

Note: The four measured shapes are artificially displaced toward the beam line for clarity of presentation.



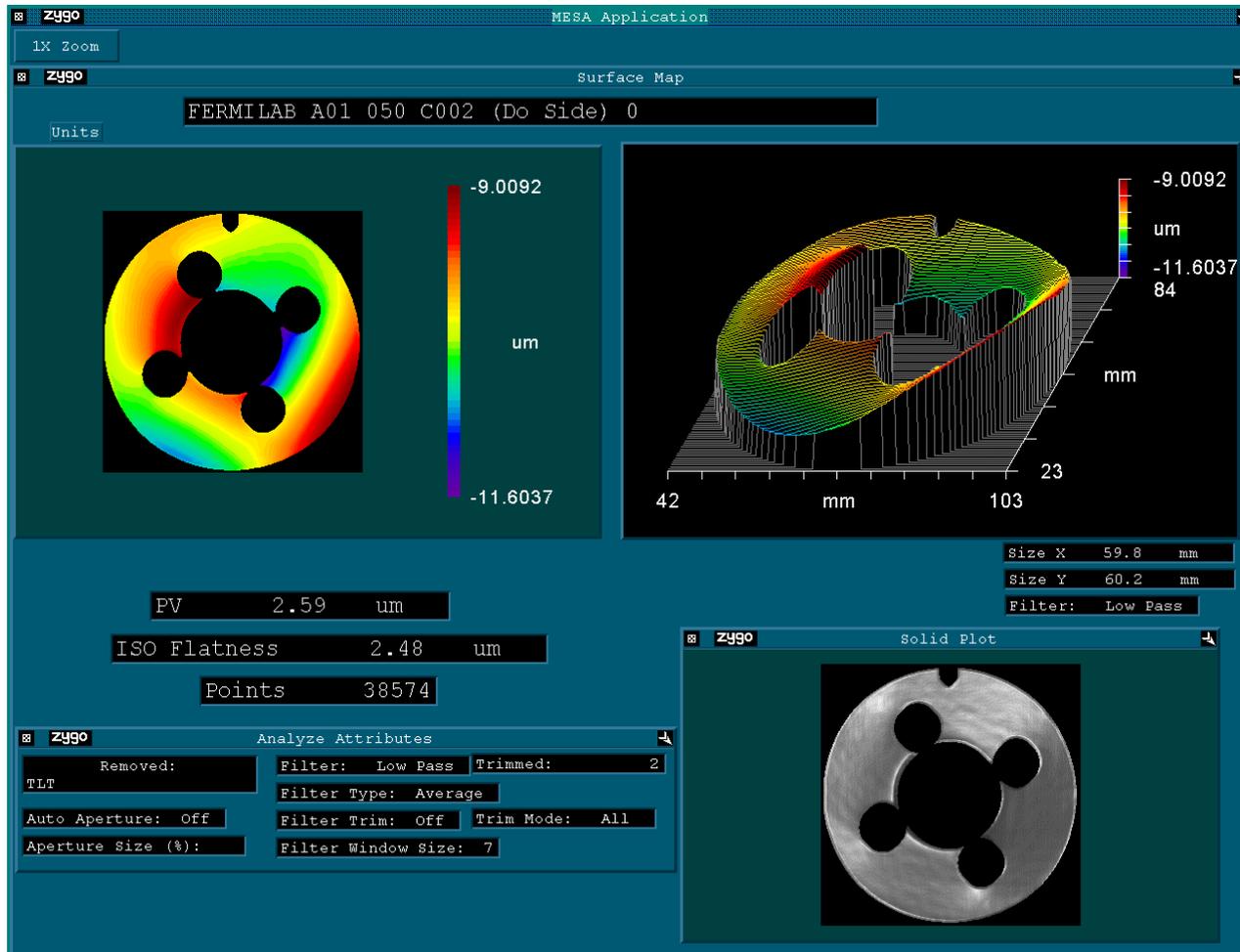
(Not Necessarily to Scale) Blown Up RDDS Profiles





Mechanical Measurements of Flatness of RDDS Disks (Tug Arkan, Gregg Kobliska & Co.)

Zygo machine measures flatness well enough.



Zygo machine costs ~\$400K.



Not going to buy Zygo machine until we know we are doing diffusion bonding rather than brazing.



NICADD Furnaces

(Jerry Blazey, Steve Holmes, Tug Arkan, Gregg Kobliska & Co.)

- The small furnace in place in IB4.



- Will be for bonding and brazing studies.
- Will be used to make X-Band sub-assemblies.
- Will likely also be used for electron cooling and maybe scrf.
- Need full sized furnace for final X-Band assemblies.
(March 2002.)

October 25, 2001

David Finley to NLC MAC @ SLAC

Slide 10



Status of X-Band Structure Fabrication at Fermilab

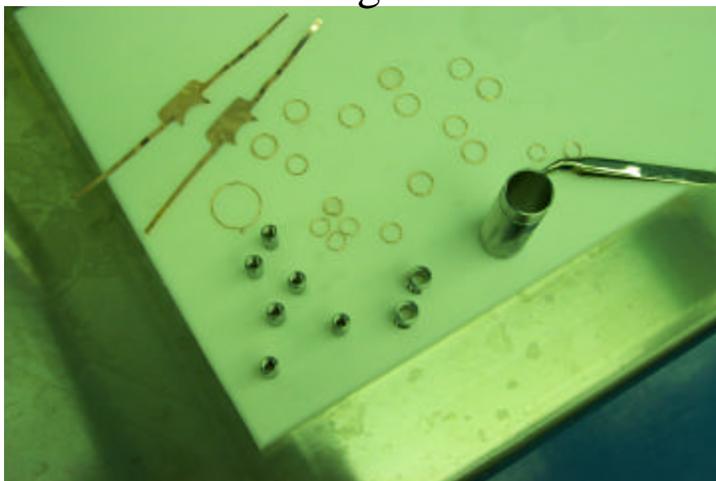
- Our First X-Band Structure
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- The Next Steps and The Plan



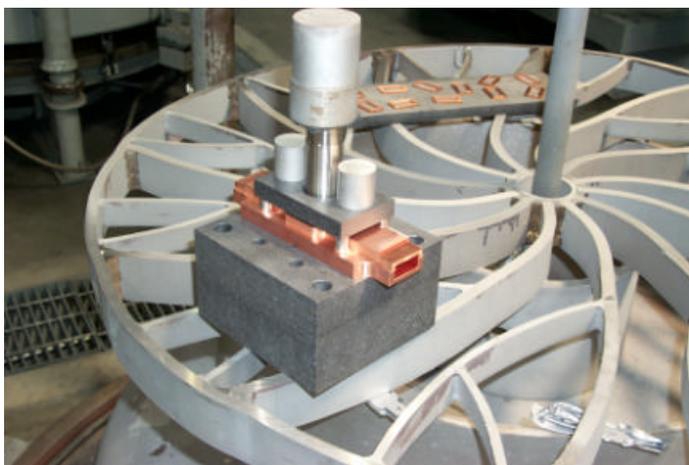
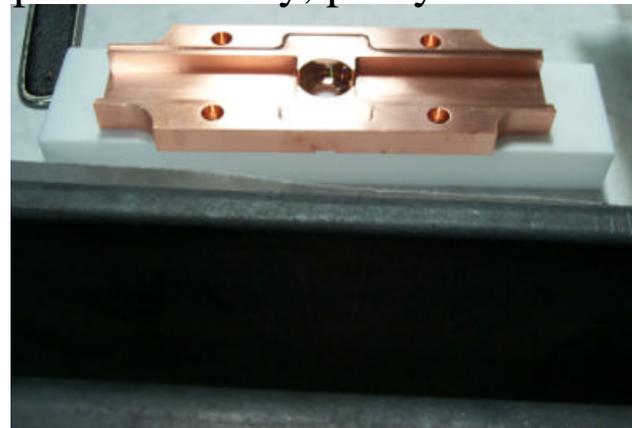


Couplers, Disks, Brazing Materials for FXA-001 (Tug Arkan, Gregg Kobliska & Co., Brian Smith, Danny Snee.)

Some brazing materials etc.



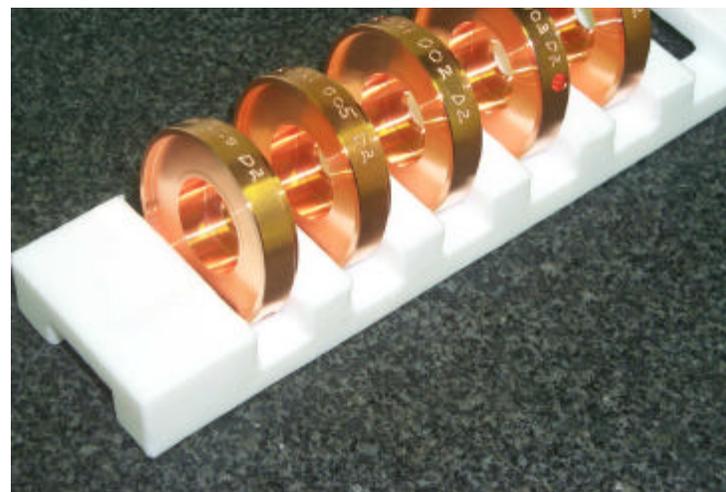
Coupler main body, partly diamond turned.



Coupler and beam tube subassembly.

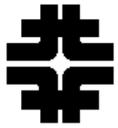
October 25, 2001

David Finley to NLC MAC @ SLAC



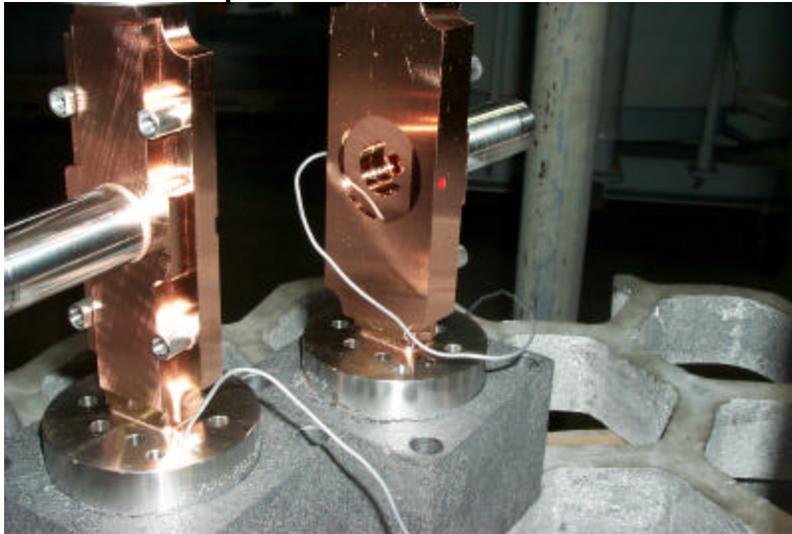
45 mm OD disks for high gradient tests

Slide 12



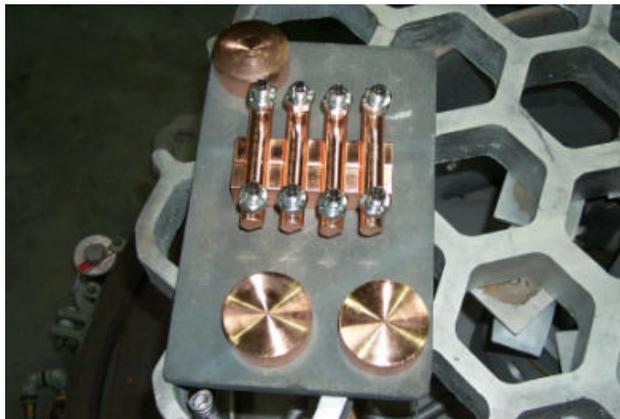
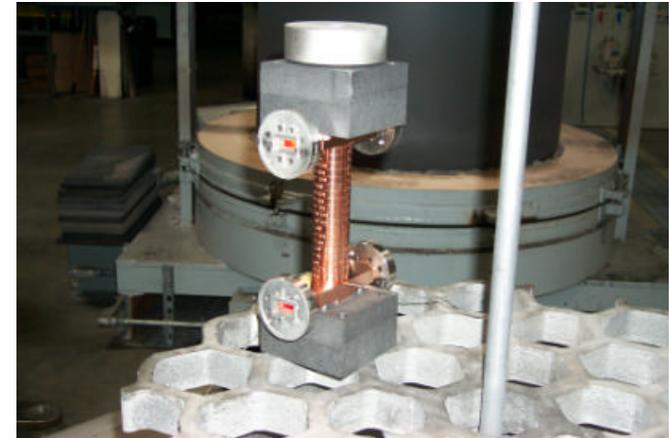
Sub-Assemblies at Alpha Braze (Fremont, CA) (Tug Arkan, Brian Smith, Danny Snee)

Both Couplers with beam tubes.

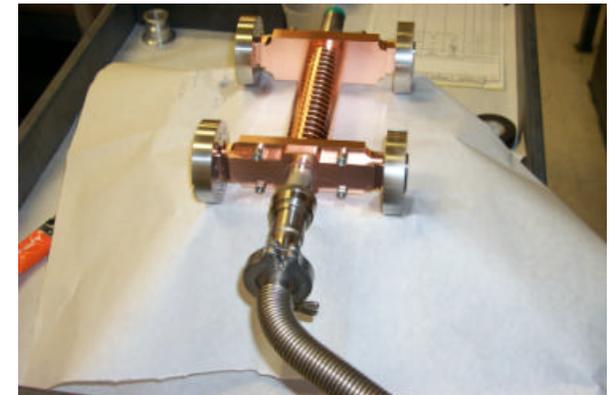


<<< Note
mirror quality
rf surfaces
provided by
diamond
turning
machining.

Couplers and disks.



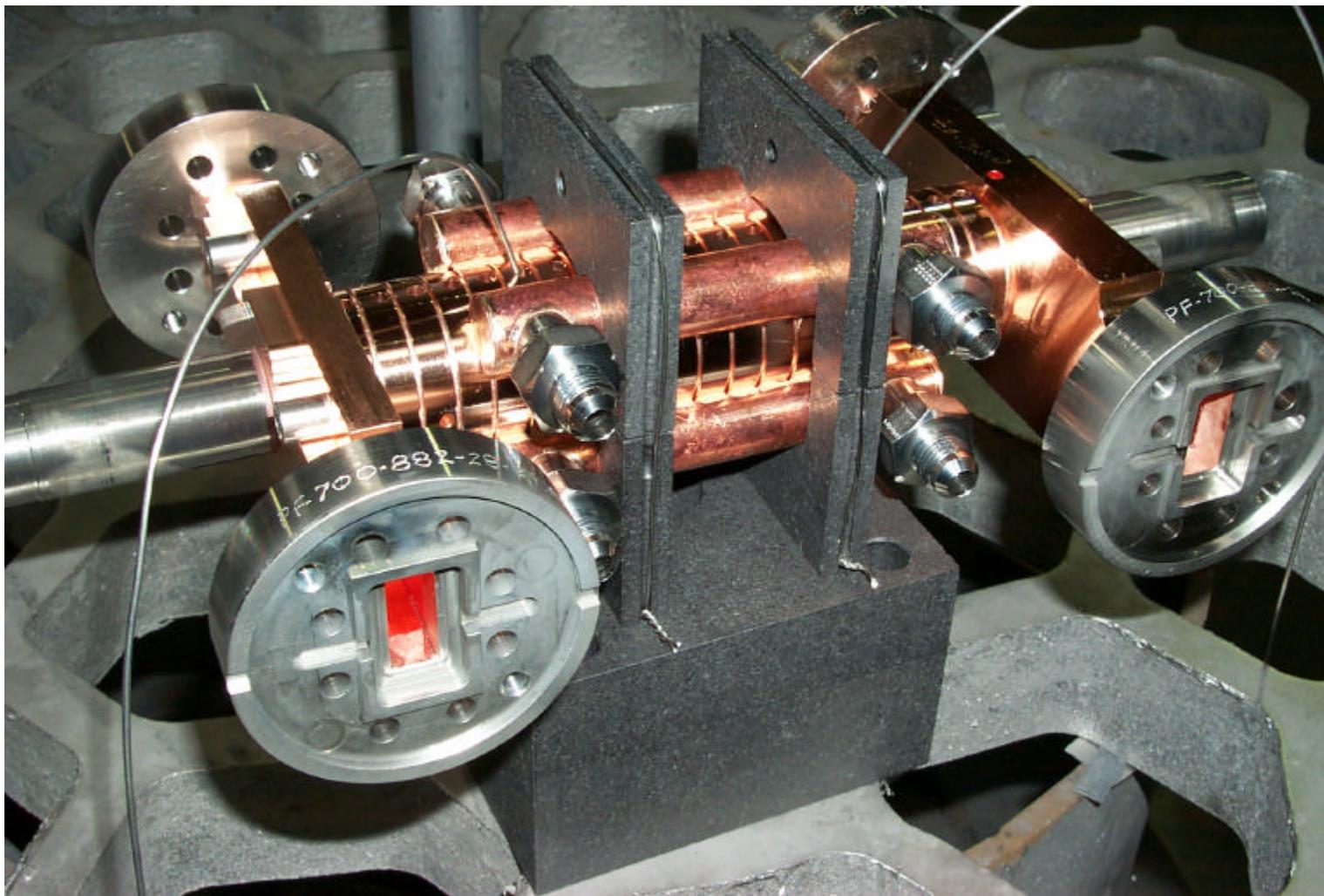
Cooling water tubes and test blocks.



Leak Check.



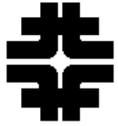
Final Assembly at Alpha Braze (Fremont, CA) (Tug Arkan, Brian Smith, Danny Snee)



October 25, 2001

David Finley to NLC MAC @ SLAC

Slide 14



Status of X-Band Structure Fabrication at Fermilab

- Our First X-Band Structure
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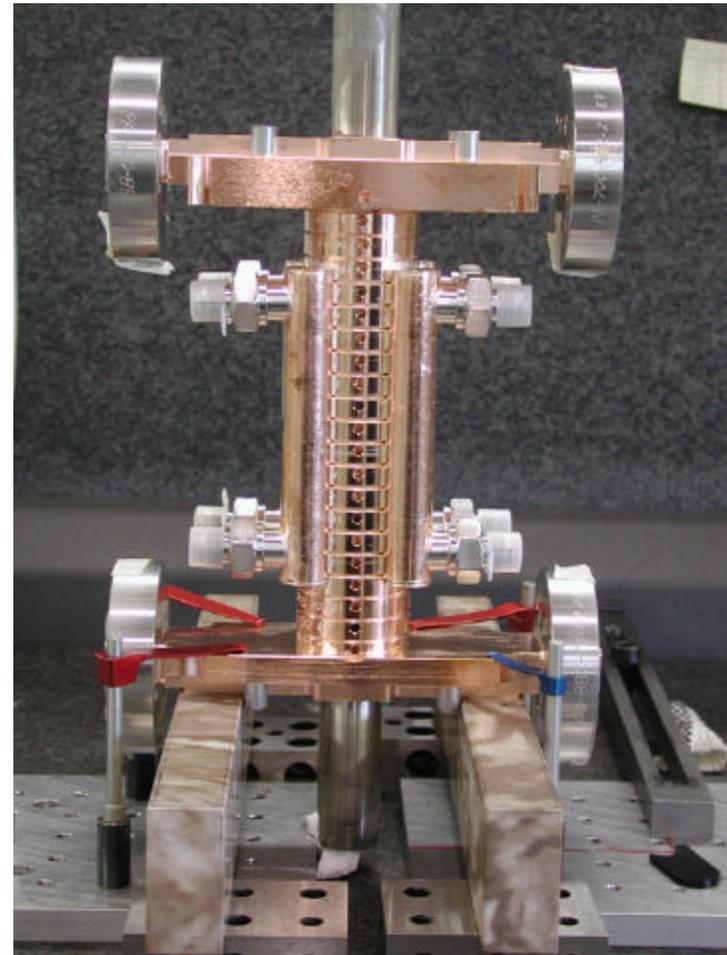
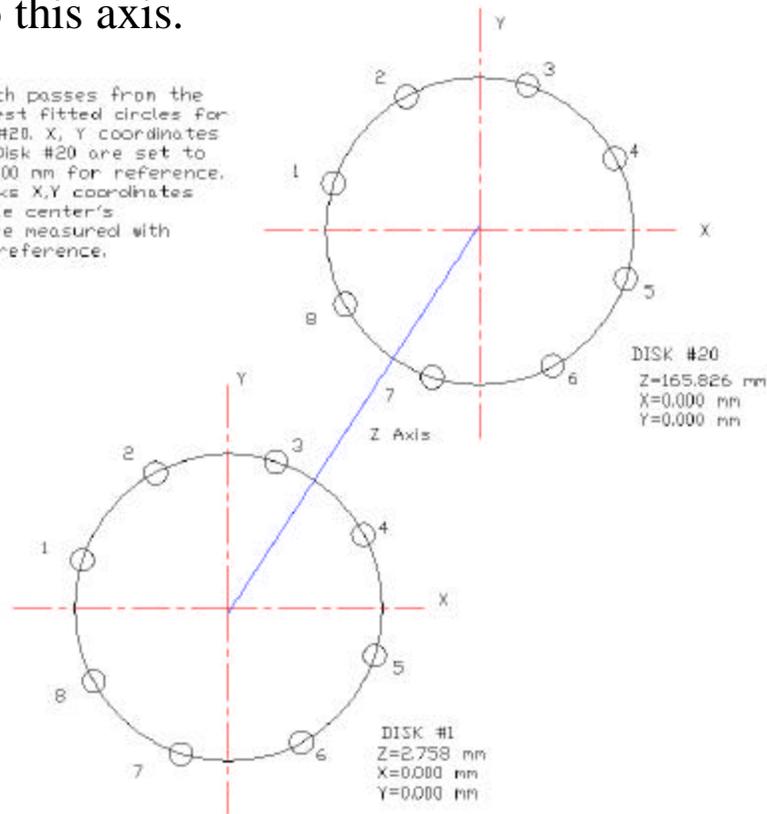


Straightness QC on FXA-001 in IB4 (Tug Arkan, Ted Beale, Rob Riley, Harry Carter)

Define the z axis based on disks #1 and #20.

Measure the centers of the other 18 disks relative to this axis.

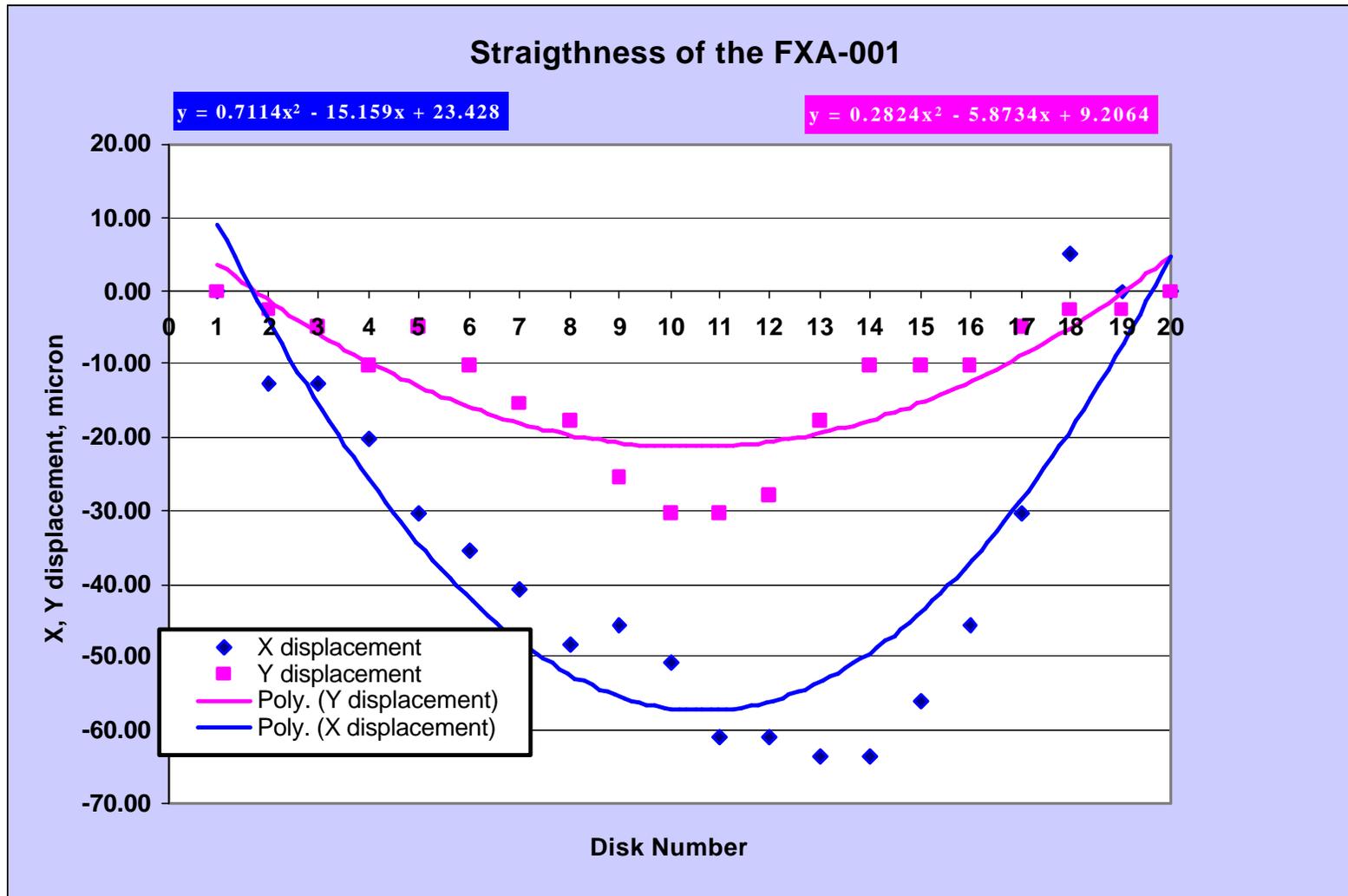
Z is the axis which passes from the center of the best fitted circles for Disk #1 and Disk #20. X, Y coordinates for Disk #1 and Disk #20 are set to equal 0.000 mm, 0.000 mm for reference. All the other disks X,Y coordinates (best fitted circle center's displacements) were measured with respect to this reference.



FXA-001 Setup for Mechanical QC at Fermilab Technical Division, 08/01/01



Straightness QC on FXA-001 in IB4





RF Measurements on FXA-001

(Gennady Romanov, Ding Sun, Ivan Gonin, Timergali Khabiboulline)

Bead Pull Principle

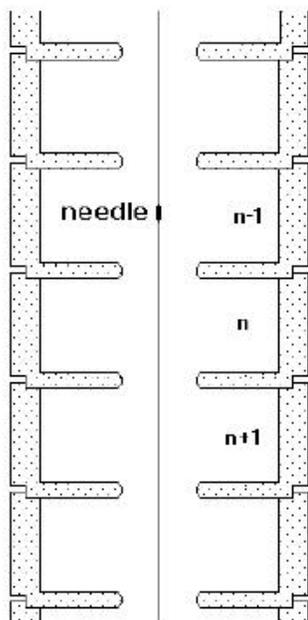


Figure 2.1. Bead-pull measurement.

With the bead-pull method we can measure and calculate amplitudes and phases of the field in the centers of the cells: $A_1 e^{j\phi_1}$, $A_2 e^{j\phi_2}$, $A_3 e^{j\phi_3}$, For two neighboring cells with number $n-1$ and n , let us consider this values as a superposition of forward and backward waves: $a_n e^{j(-2\pi/3(i-n)+\psi_n)}$ and $b_n e^{j(2\pi/3(i-n)+\phi_n)}$, which has passed through n -th disc (between cells $n-1$ and n).

$$A_{n-1} e^{j\phi_{n-1}} = a_n e^{j(2\pi/3+\psi_n)} + b_n e^{j(-2\pi/3+\phi_n)} \quad 3.1$$

$$A_n e^{j\phi_n} = a_n e^{j\psi_n} + b_n e^{j\phi_n} \quad 3.2$$

The solutions of these two complex equations are:

$$a_n e^{j\psi_n} = (A_{n-1} e^{j(\phi_{n-1}-\pi/2)} + A_n e^{j(\phi_n-\pi/6)}) / \sqrt{3} \quad 3.3$$

$$b_n e^{j\phi_n} = (A_{n-1} e^{j(\phi_{n-1}+\pi/2)} + A_n e^{j(\phi_n+\pi/6)}) / \sqrt{3} \quad 3.4$$

From formula (3.4) we can find the amplitude b_n and phase ϕ_n of the backward wave which passed the n -th disc (between cells $n-1$ and n). For the next $(n+1)$ disc we can use the formula (3.4) to calculate the backward wave:

$$c_n e^{j\eta_n} = (A_n e^{j(\phi_n+\pi/2)} + A_{n+1} e^{j(\phi_{n+1}+\pi/6)}) / \sqrt{3} \quad 3.5$$

Let us calculate the difference of these two backward waves in the plane of the n -th diaphragm. The phase shift per cell is about $2\pi/3$ and if attenuation can be neglected we can write:

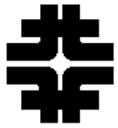
$$S_n e^{j\theta_n} = b_n e^{j\phi_n} - c_n e^{j(\eta_n-2\pi/3)} \quad 3.6$$

- A network analyzer puts an rf wave into the structure composed of cells and couplers. Some of the wave is transmitted, some is reflected. The reflected wave is measured and analyzed.

- A metal “bead” (shown as “needle” in the figure) is pulled along the length of the structure and disturbs the rf wave.

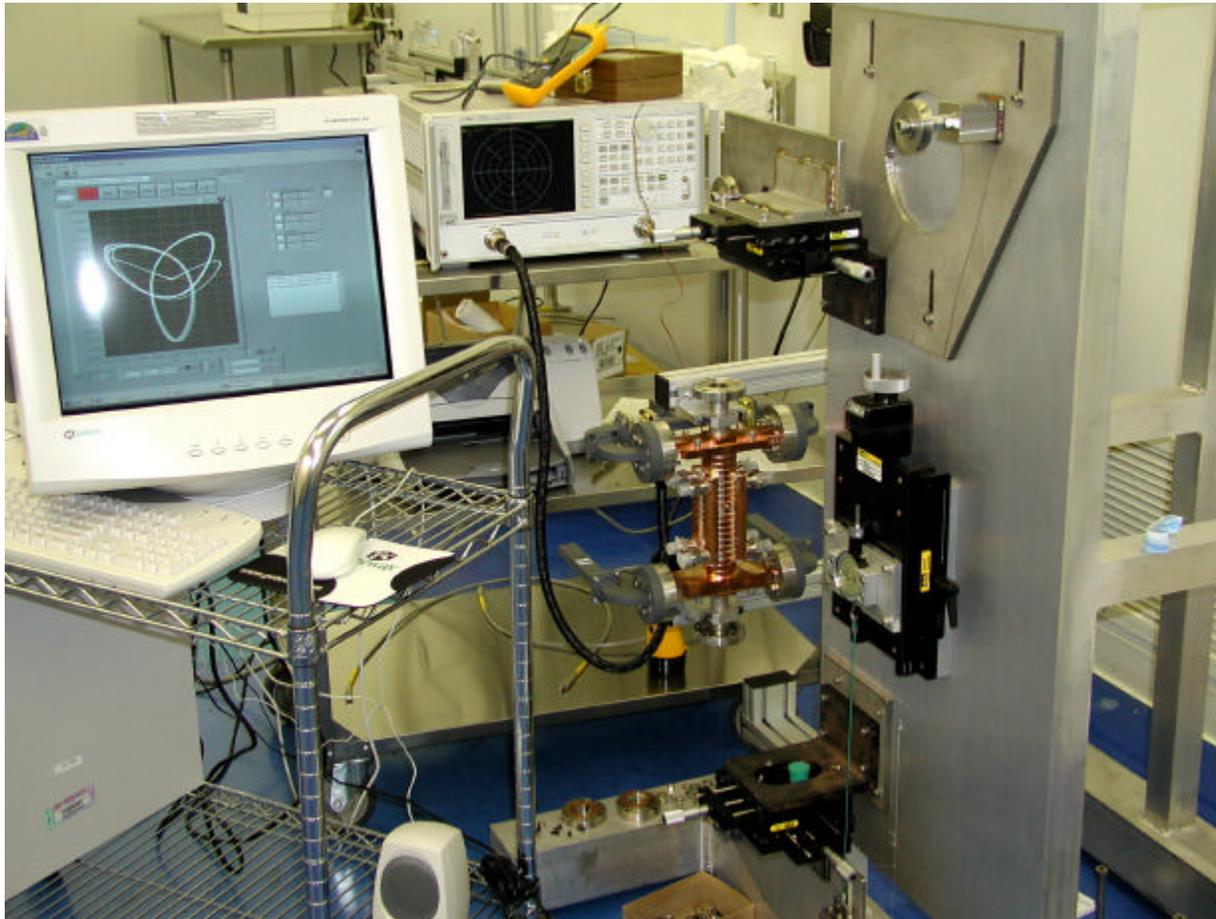
- The analysis yields the amplitude and phase of the reflected wave.

• From PAC95 T. Khabiboulline et al., on DESY LC S-Band setup



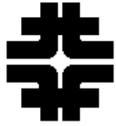
RF Measurements on FXA-001

- Bead pull setup in RF Factory Clean Room A.



- Note network analyzer (from Beams Division), bead pull support, pulley, data on computer screen, and FXA-001.

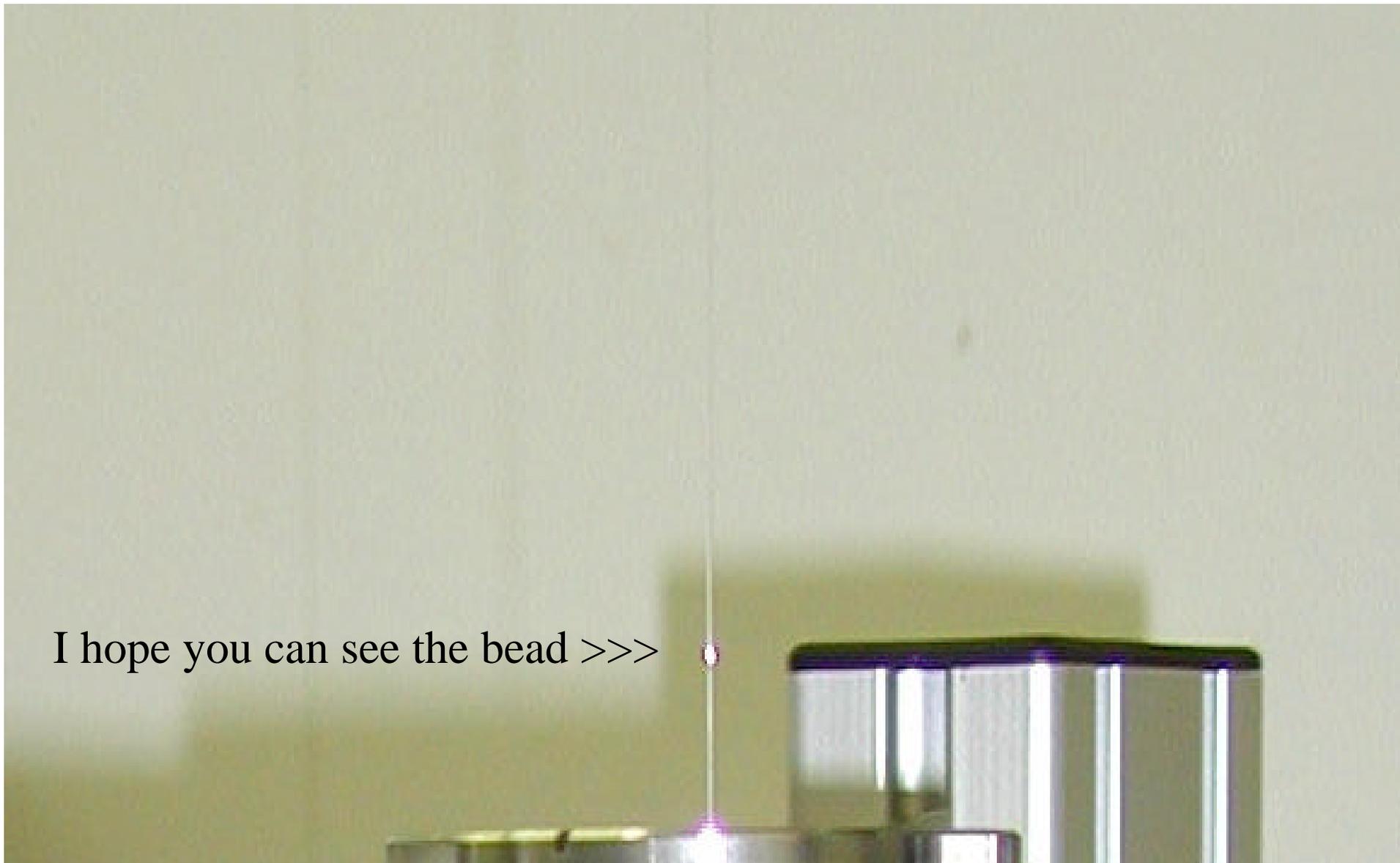
RF Measurements on FXA-001



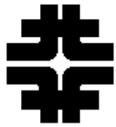
- Here, the bead is (barely) visible against the shadow just above the beam pipe flange. (Closer look on next slide.)
- D. Sun 10 Oct 2001 email:
 - “The bead is cut from a medical needle (stainless Steel). So it is a "cylinder". So far we are using: DIA 0.020" and length 0.040".
 - The line is a nylon fishing line (mono-line). DIA 0.0095"



RF Measurements on FXA-001



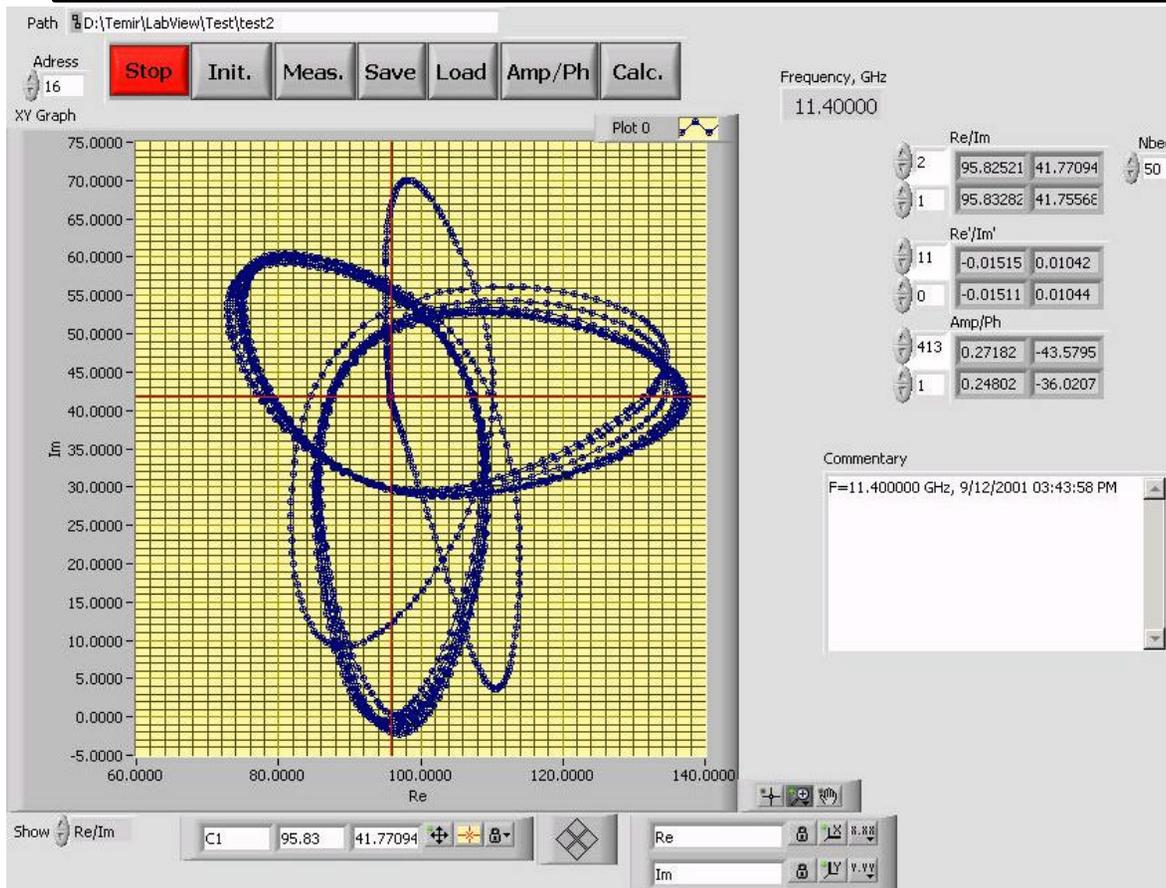
I hope you can see the bead >>>



RF Measurements on FXA-001

Im vs. Re part of reflected rf wave at 11.400 GHz before tuning.

Note: You want 11.424 GHz; thus these untuned cells are about 24 MHz low.

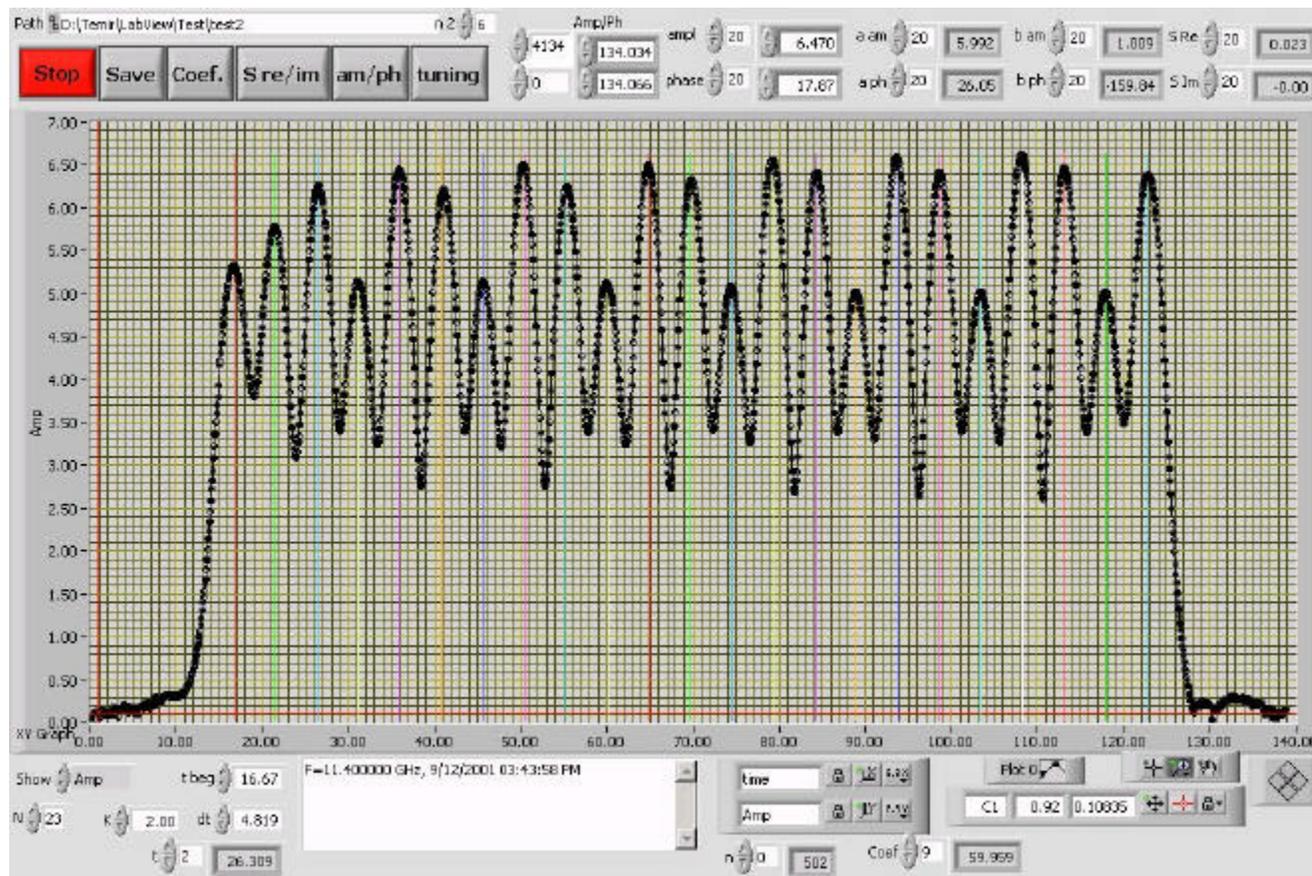


- The bead is pulled through the structure at a constant speed over about 140 seconds.
- Data is taken at constant time intervals and plotted.
- The data taking window is about 10 msec.



RF Measurements on FXA-001

Amplitude of reflected rf wave at 11.400 GHz before tuning as a function of time.



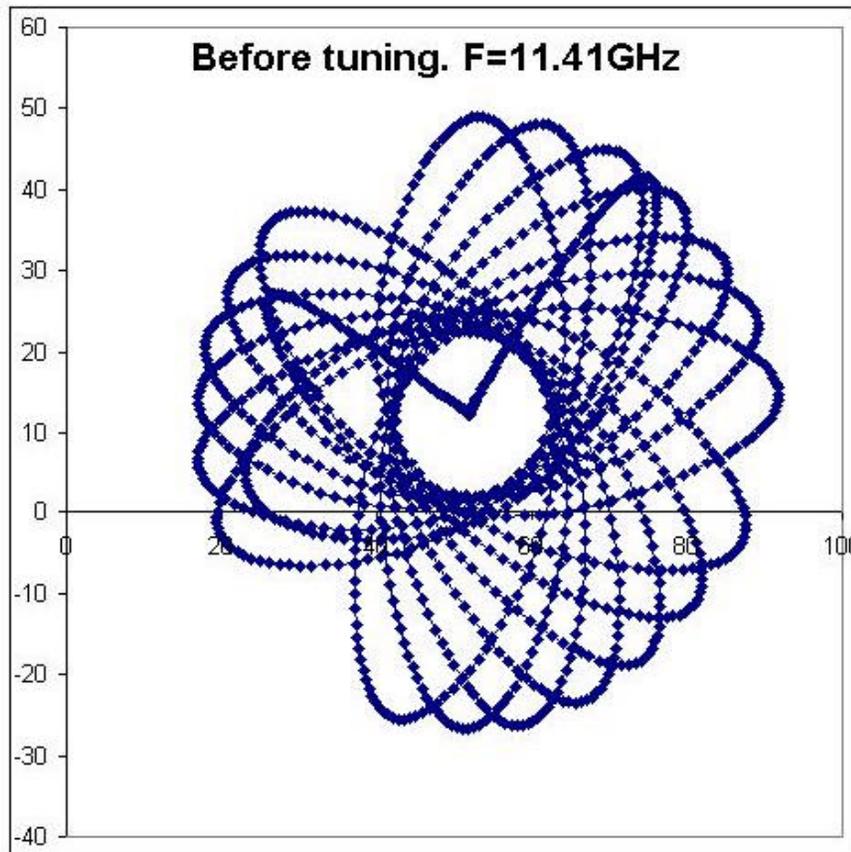
- You want this to be flat - which it isn't.
- This is the same measurement as the previous slide but this display makes it easier to see that every third peak is smaller than the other two.



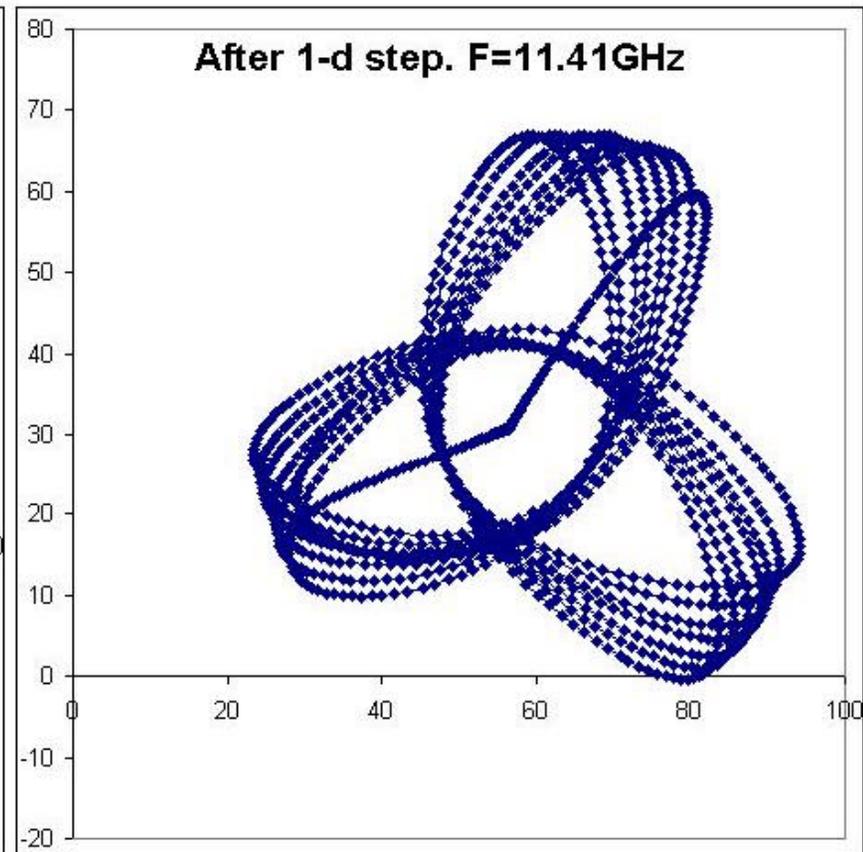
RF Measurements on FXA-001

First Tuning Step: Set analyzer at 11.410 GHz, a 10 MHz step.

Before



After

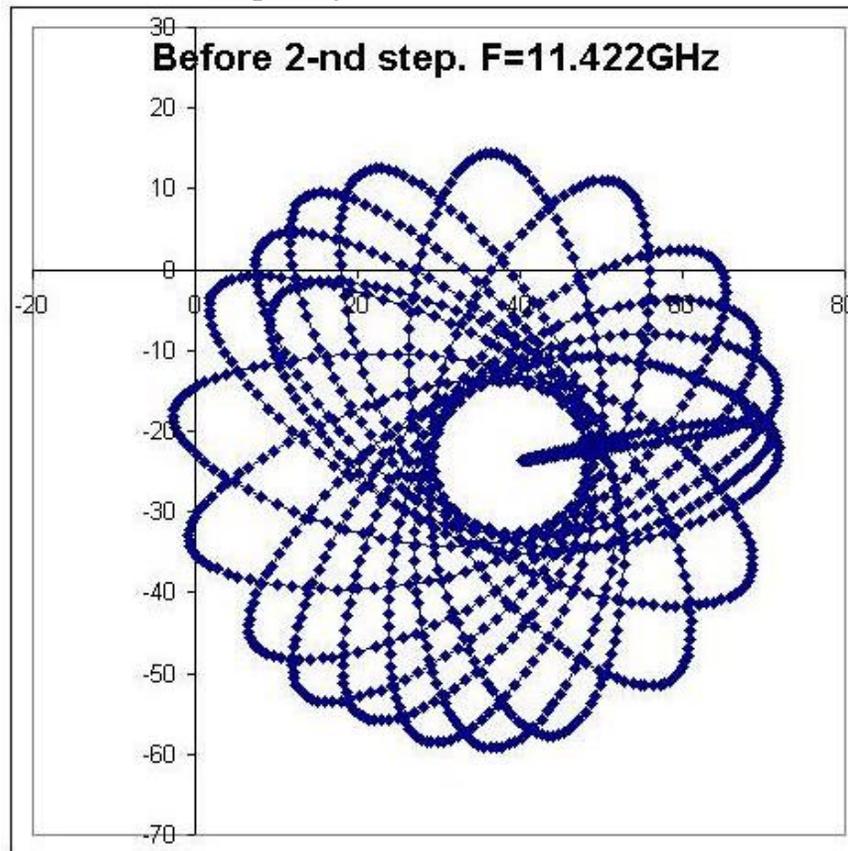




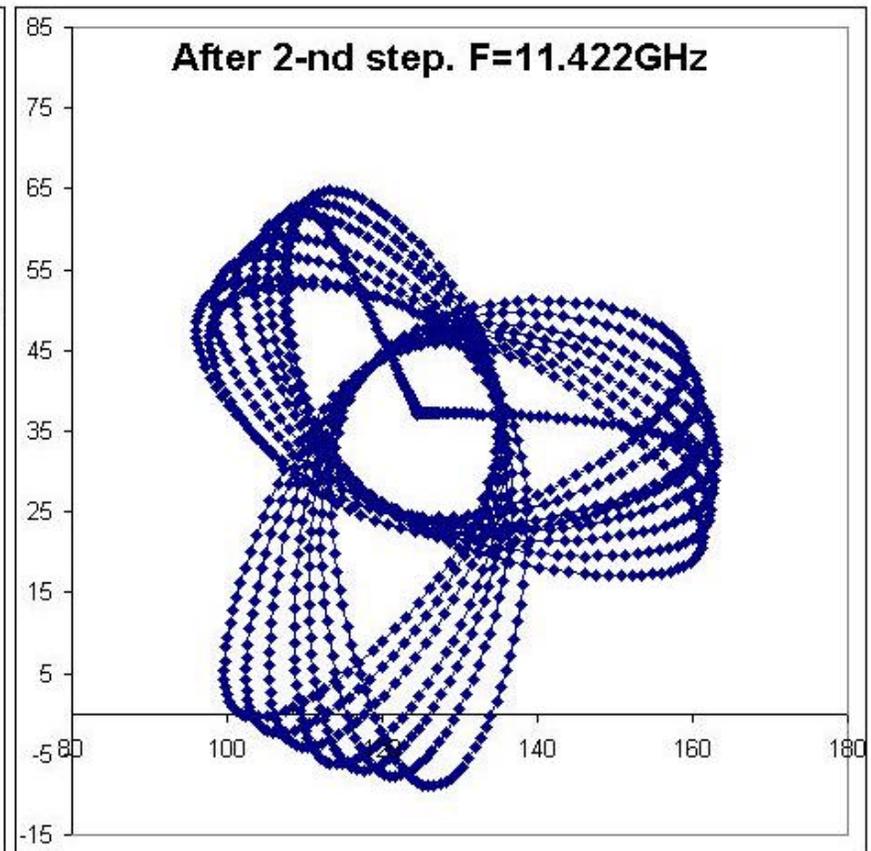
RF Measurements on FXA-001

2nd Tuning Step: Set analyzer at 11.422 GHz, an additional 12 MHz step.
Before

Note: The structure is the same as “After” on the previous slide, but the frequency is different.



After



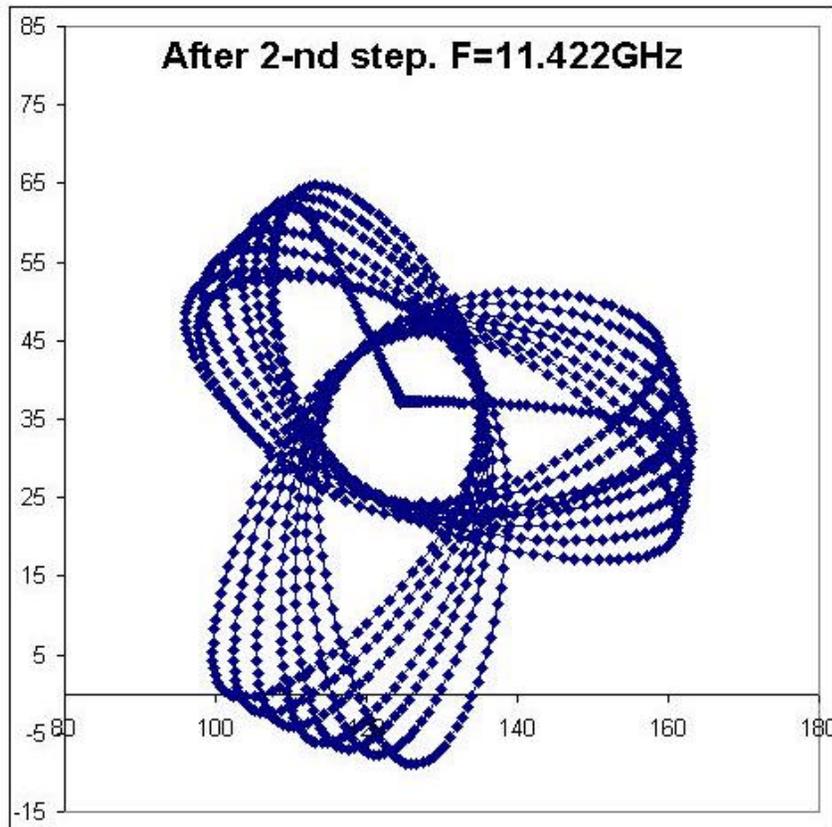


RF Measurements on FXA-001

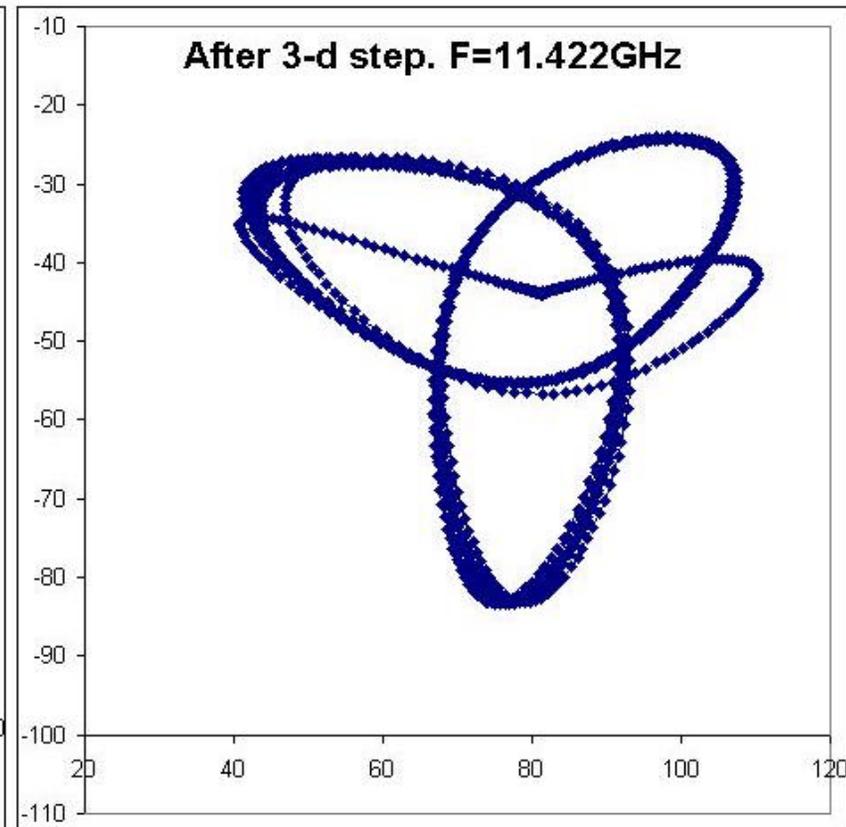
3rd Tuning Step: Stay at 11.422 GHz, and tweak cells again.

Before

(Same data as “After” on previous slide)



After



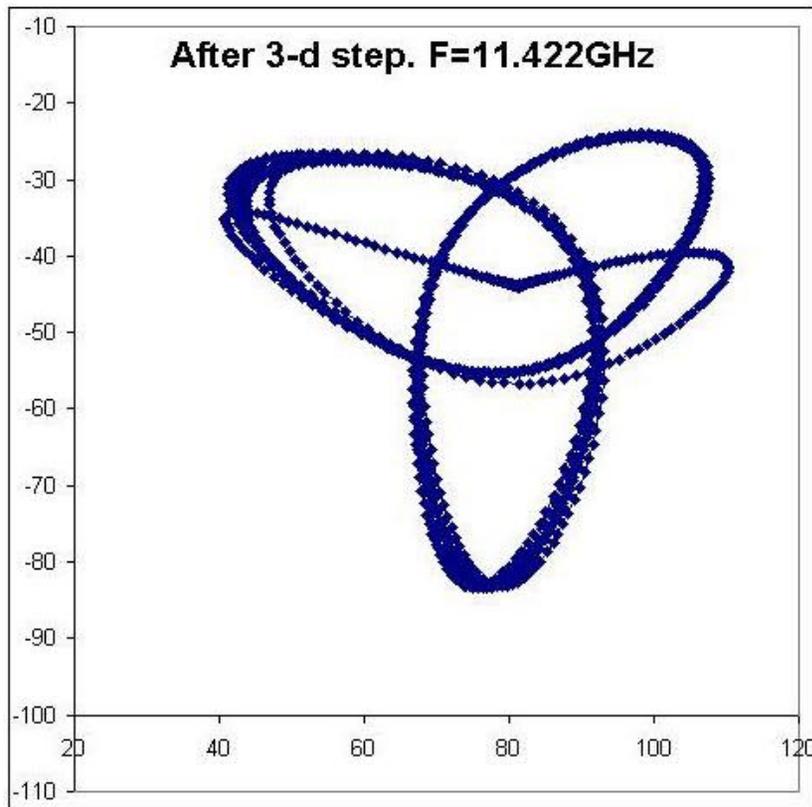


RF Measurements on FXA-001

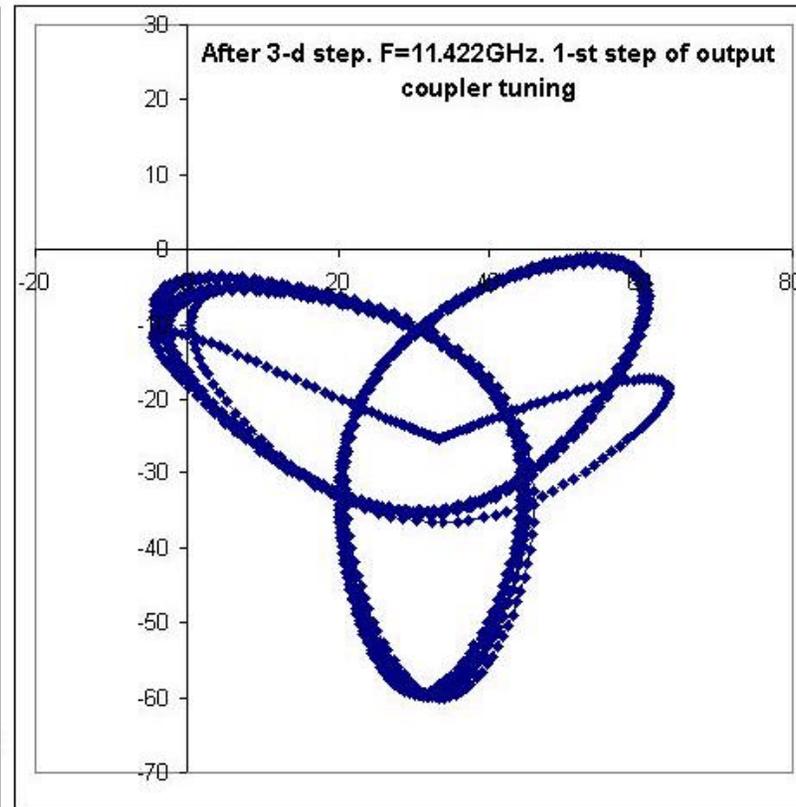
Another Tuning Step: Stay at 11.422 GHz, and tune couplers.

Before

(Same data as “After” on previous slide)



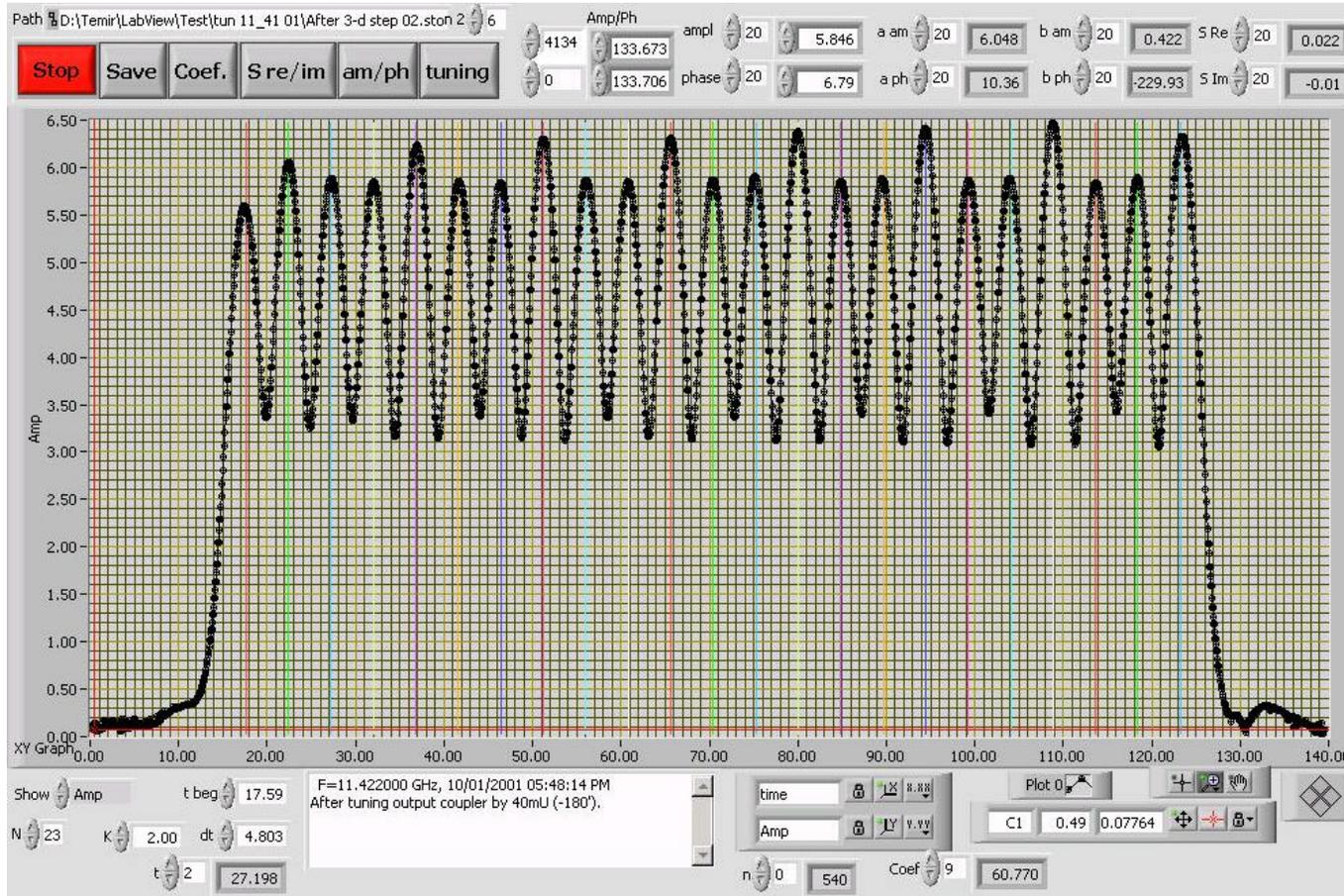
After





RF Measurements on FXA-001

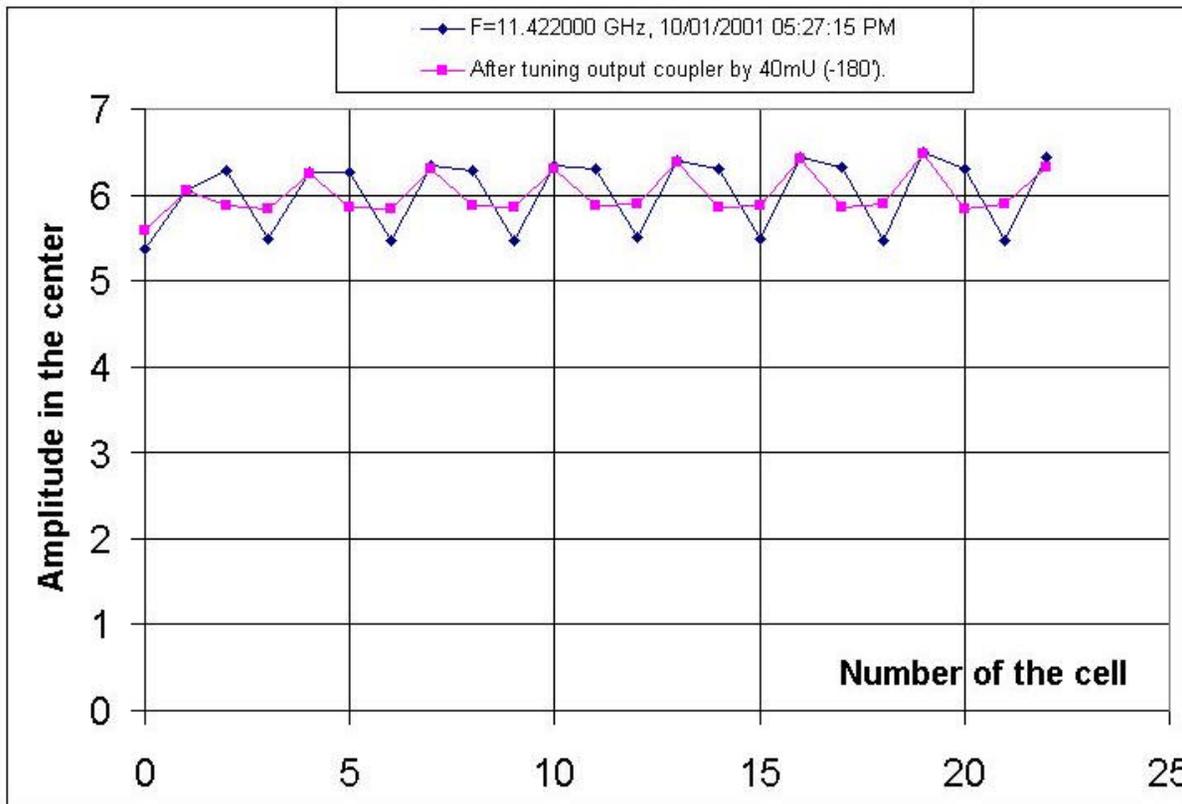
- Amplitude vs. time after coupler tuning at 11.422 GHz.



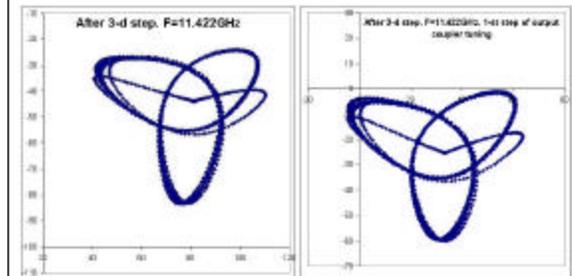


RF Measurements on FXA-001

- Amplitude vs. cell number at 11.422 GHz before and after tuning output coupler.



- Same data as:

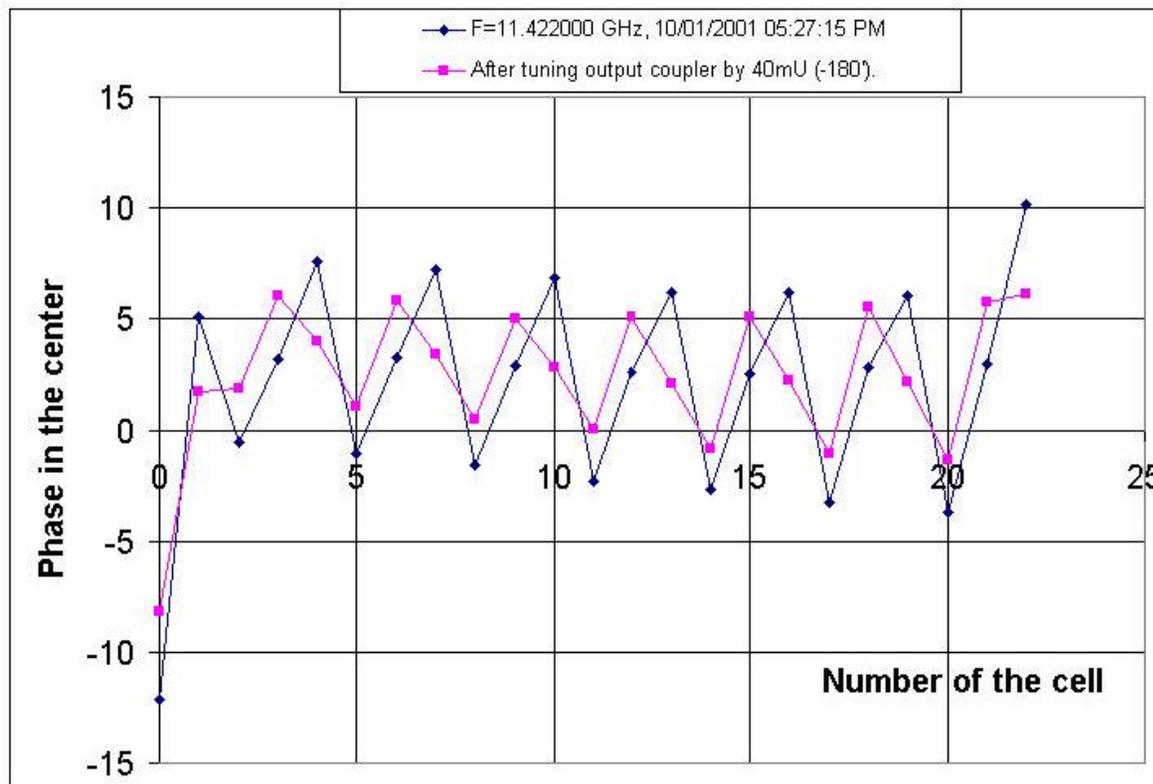


from two slides ago
... but the
differences are
shown more clearly
in this plot.

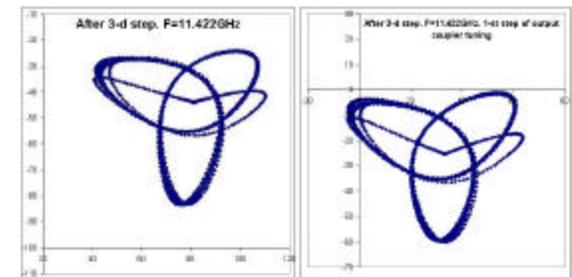


RF Measurements on FXA-001

- Phase vs. cell number at 11.422 GHz before and after tuning output coupler.



- Same data as:



from two slides ago
... but the
differences are
shown more clearly
in this plot.



Using Both Mechanical and RF QC on FXA-001

(Nikolay Solyak, Gennady Romanov, Tug Arkan, Harry Carter, Ivan Gonin et al.)

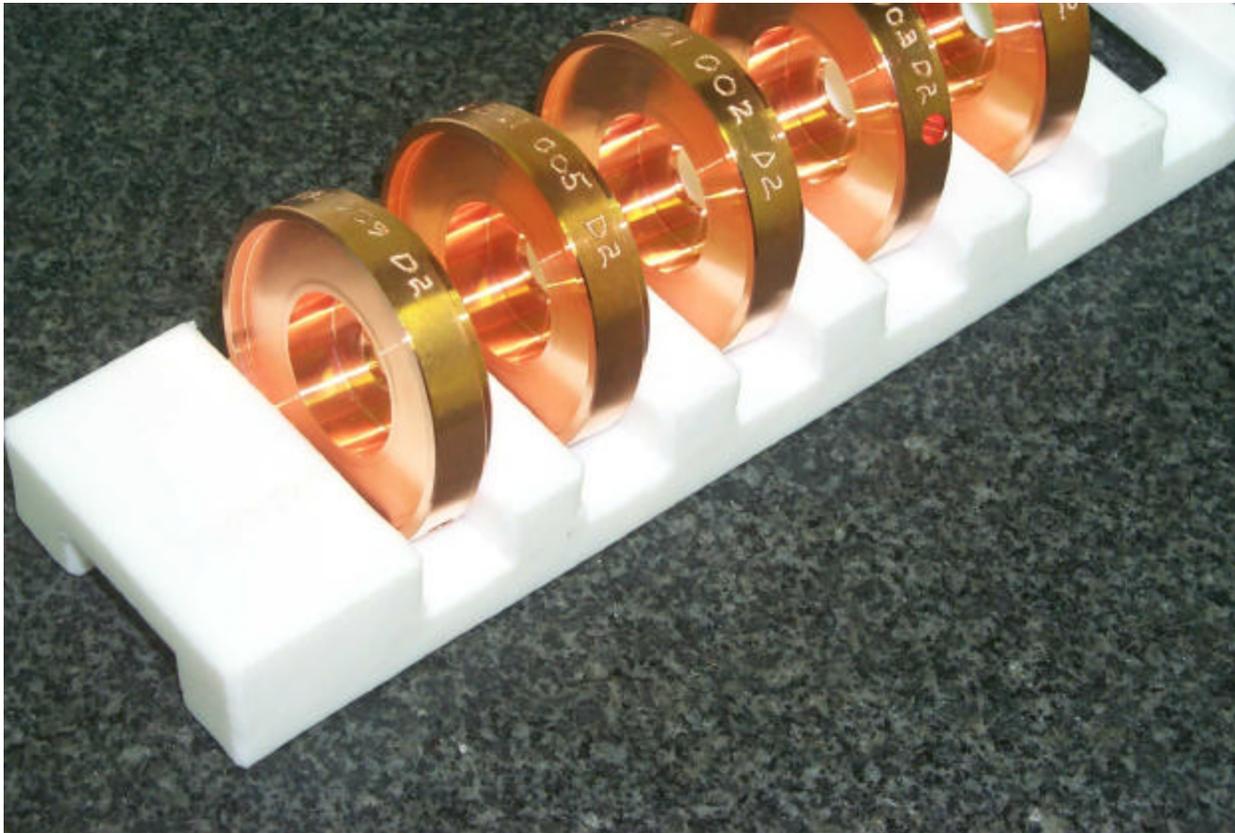
Investigating the “20 MHz” error.

- The individual disks in FXA-001 were low by ~20 MHz.
- After being assembled into the structure they were still low by ~20 MHz.
- If the error is all in (2a or 2b) you’d need about (-80 or +32) micron differences in (2a or 2b). This is way beyond the tolerances (all tolerances are +/- 5 microns).
- If it were due to temperature you’d need ~ minus 100 degrees Centigrade. This is not reasonable.

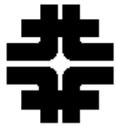


Investigating the 20 MHz error.

- Recall what the real FXA-001 disks look like.

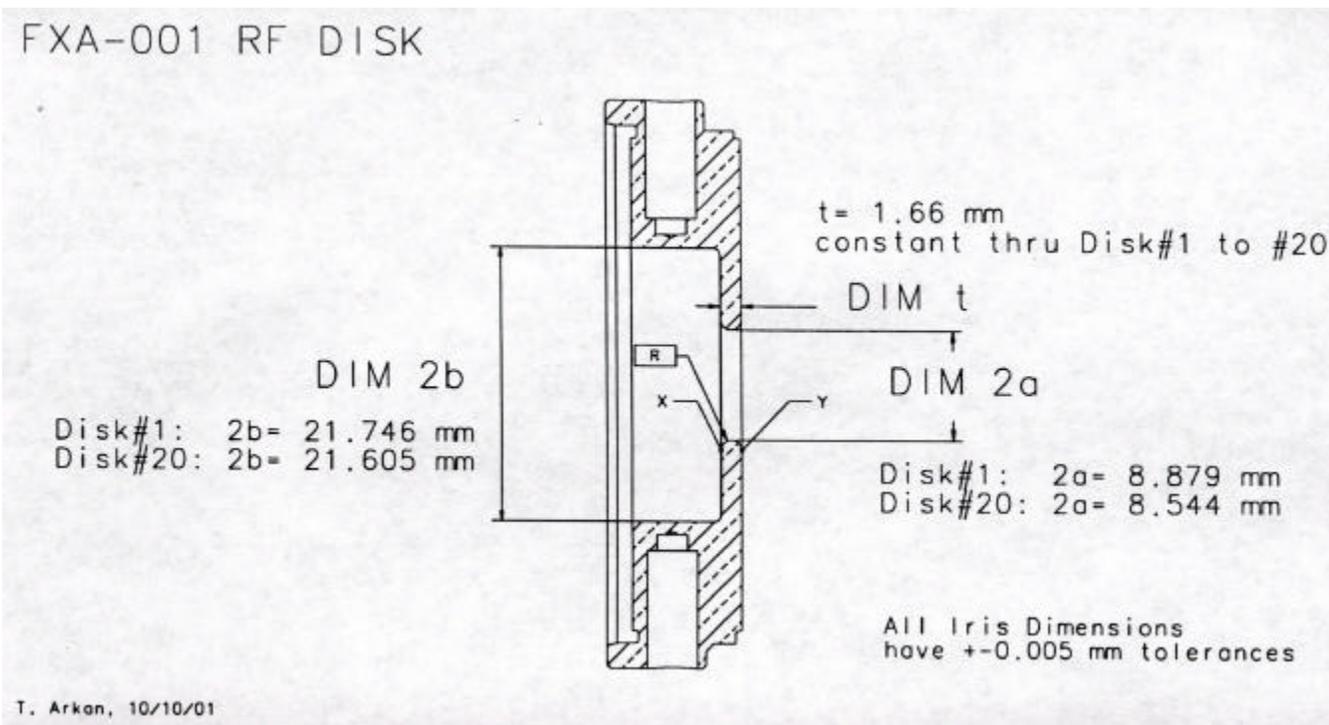


- They are “simple” ... at least compared to RDDS disks.

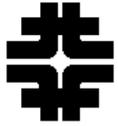


Investigating the 20 MHz error.

- Note 2a, 2b, thickness, and round iris.

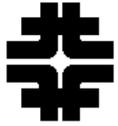


- Also note thickness $t = 2 R = 1,660$ microns (for later reference).
- We don't have the light touch \$500K Zygo 3D CMM so ...



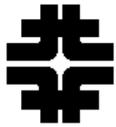
Investigating the 20 MHz error.

- We took other individual disks (made by the same manufacturer at the same time), cut them apart (with an EDM), and inspected them by CMMs (optical and touch probe).
- 2a was OK. 2b was OK. The thickness of the iris was OK.
But ...



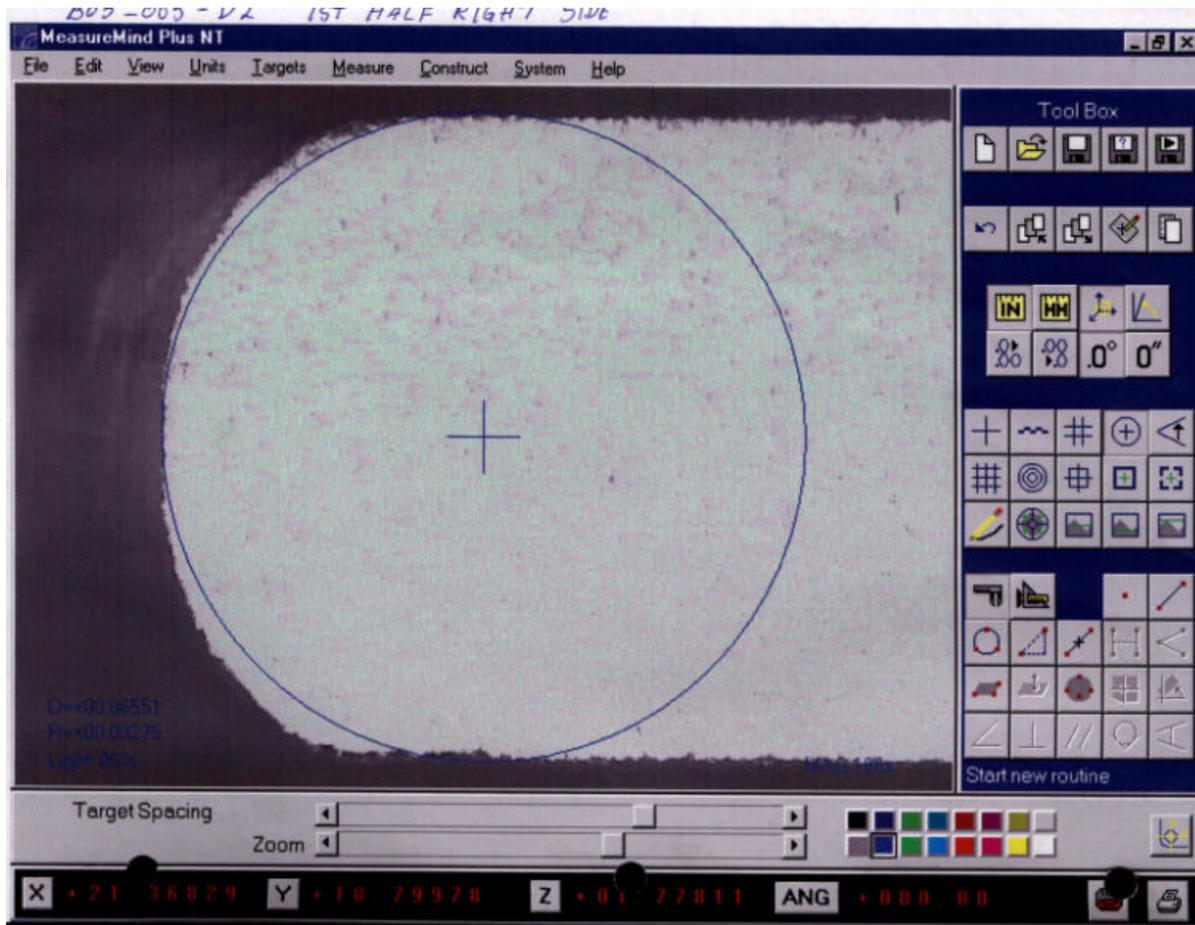
Investigating the 20 MHz error.

- The combination of optical and touch probe CMM showed errors on the circular part of the profile of the iris in excess of 50 microns. (**Five times the tolerance.**) (See next slide.)
- We used MAFIA to calculate the frequency difference for the measured shape. (See two and three slides from now). MAFIA says:
 - 11417.54 MHz for design profile
 - 11394.16 MHz for measured profile
 - 20 MHz difference <<< Good enough evidence for me!
- **AND THE CMM SHOWS A NON-SMOOTH TRANSITION WHERE THE ROUND AND FLAT PARTS OF THE IRIS JOIN**
...which made us disqualify FXA-001 from high power consideration. (See next three slides.)

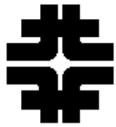


Investigating the 20 MHz error.

- Measured iris profile with design circle imposed.

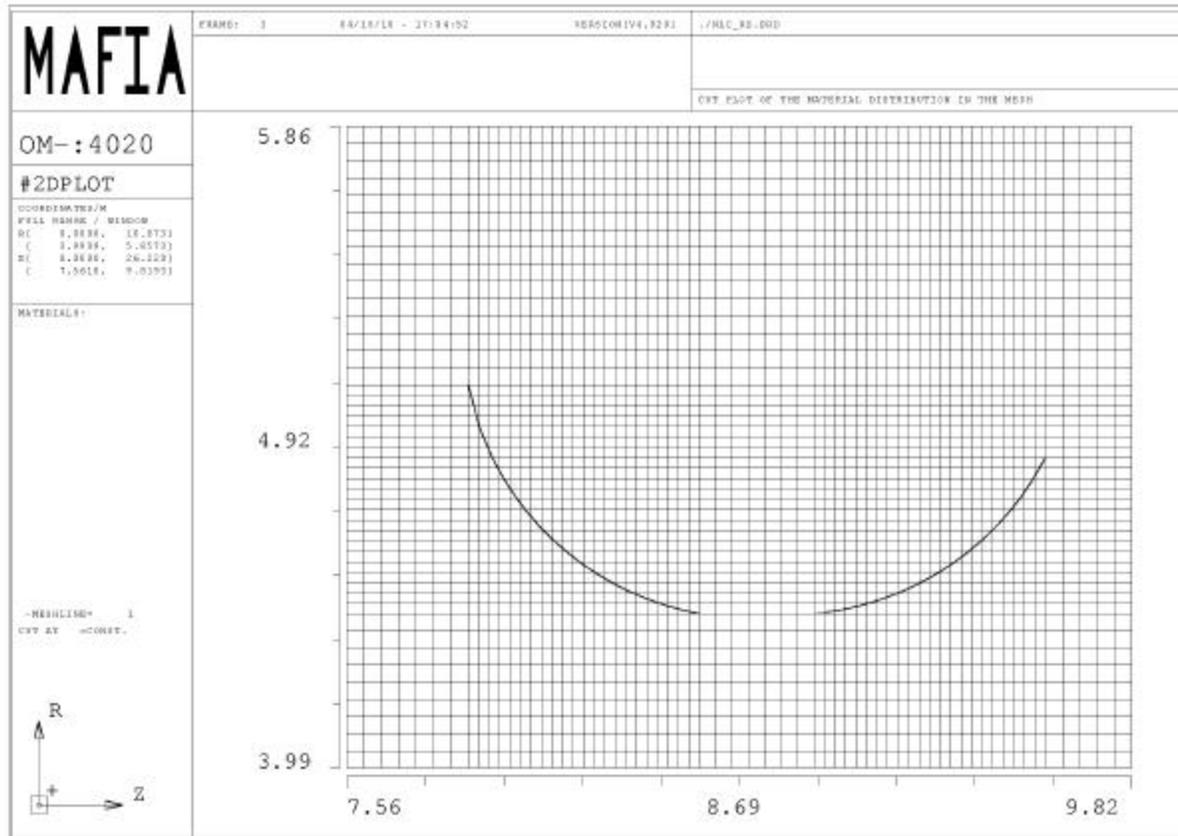


- 2a is OK. The thickness is OK.
- But ... (recall the diameter of the circle is 1660 microns and the tolerance is 10 microns) the blob at the bottom left is about 50 microns thick over about 500 microns of length.
- Also note the non-smooth transition between the round and flat surfaces.



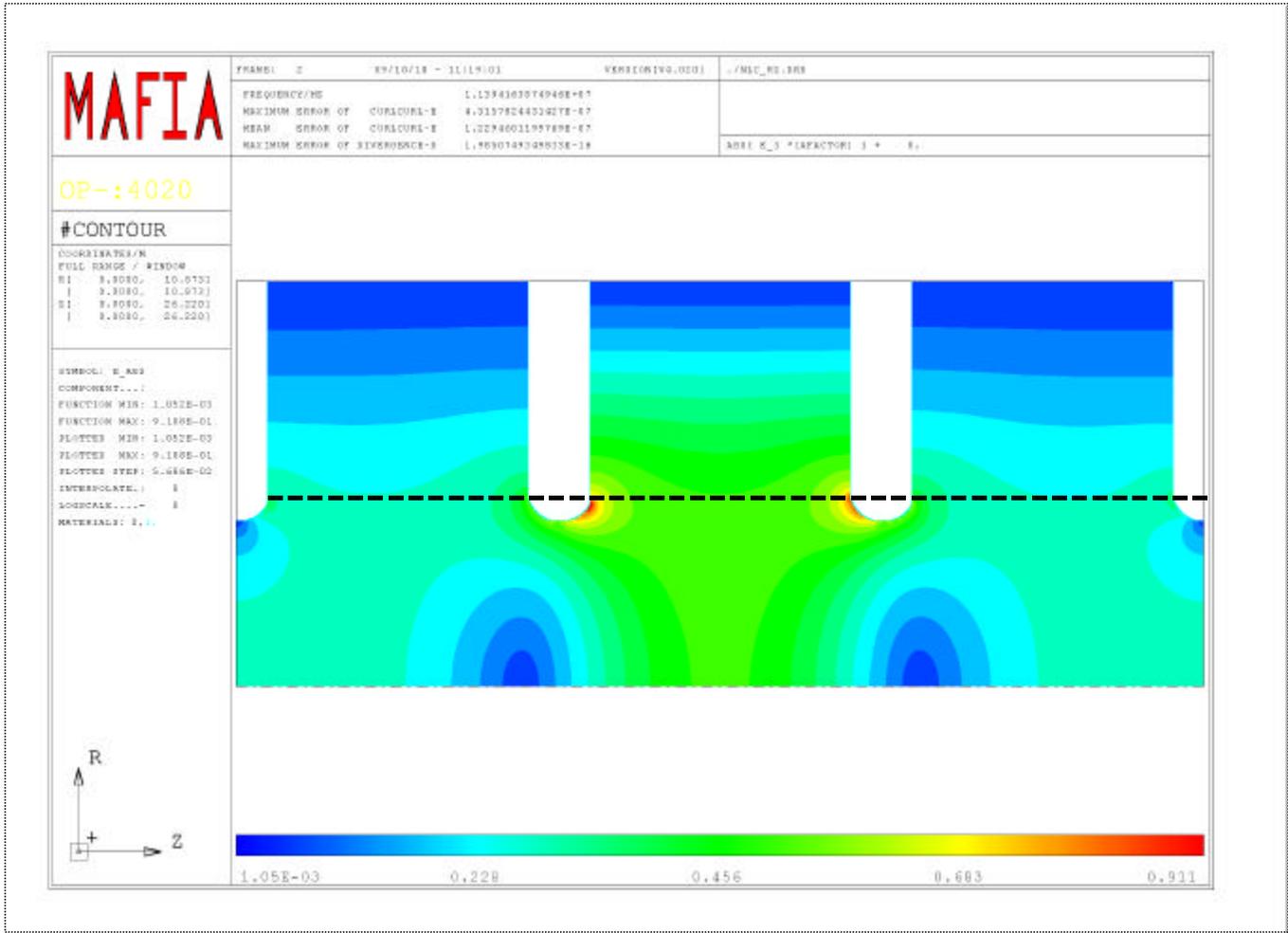
Investigating the 20 MHz error.

- The grid used to specify the measured profile to MAFIA.





Investigating the 20 MHz error.

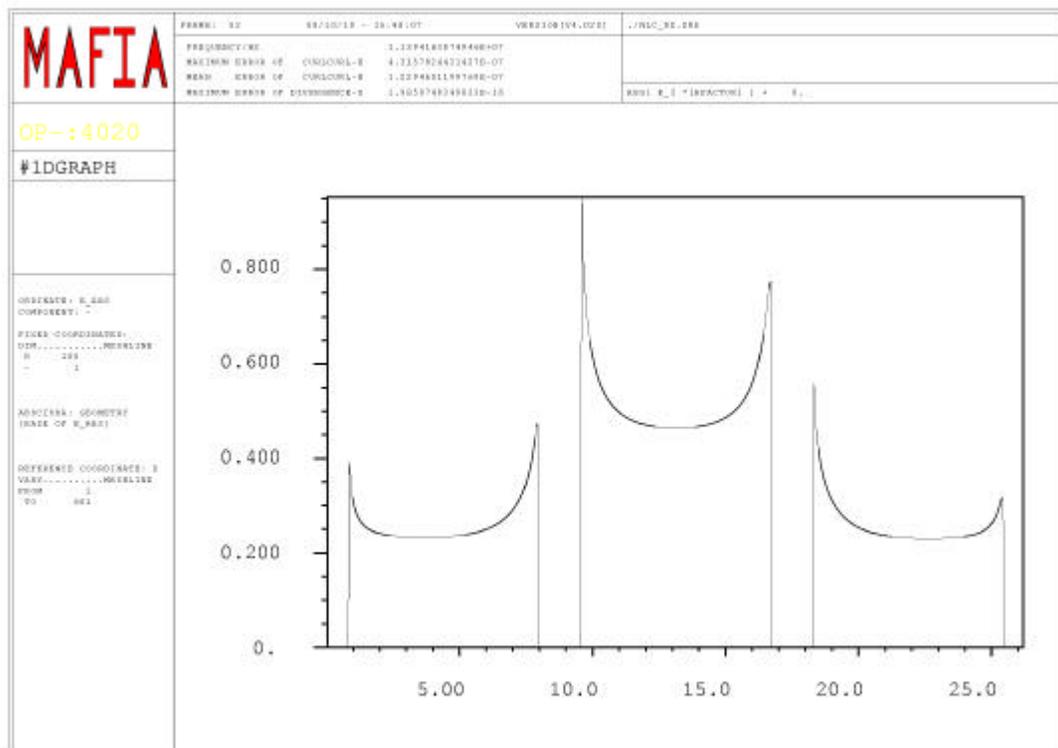


- Magnitude of electric fields.
- Note dotted line which is sketch of reference for next slide.



Investigating the 20 MHz error.

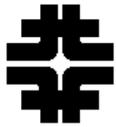
- Magnitude of the electric field along “the dotted line from previous slide”.



- Note: It is not symmetric.

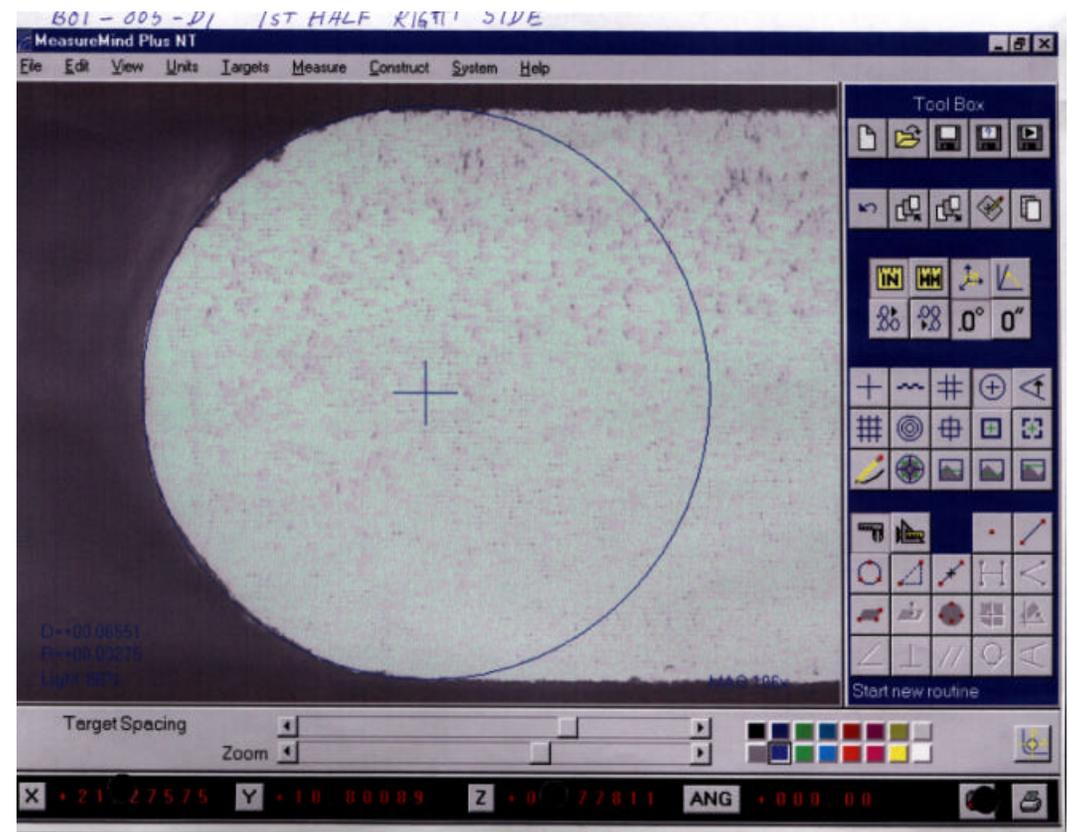
- The calculation also says the “ratio of the peak surface field to the field on the axis” is 5% higher than design.

- However, if a finer grid were used one would get more than 5%. **This is why we disqualified it for “high gradient” testing.**



Investigating the 20 MHz error.

- Before ordering parts for FXA-002 and 003, we're iterating with the manufacturer.
- There is hope because this is what another manufacturer delivered ... looks pretty good.
- But ... this is only ONE disk.
- And the RF single disk QC on ALL disks showed too much variation disk-to-disk as a group.
- So as a group these were rejected for use in FXA-001.





Status of X-Band Structure Fabrication at Fermilab

- Our First X-Band Structure
- Progress of RF Factory at IB4
- Making FXA-001
- Measuring FXA-001
- The Next Steps and The Plan





The Next Steps and The Plan

First, Look at the Forest not the Trees ...

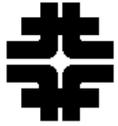
- Seven Elements of the RF Factory
 - RF Design
 - Produce Copper / Machine Copper
 - RF Measurements & Development / Low Power
 - Structure and Vacuum
 - Mechanical Measurements of Straightness
 - Brazing / Bonding Facility
 - High Power Processing

- The middle five elements are beginning to function.
- The Individual People are becoming a Team.



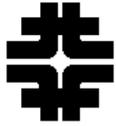
Summary From Making FXA-001 (David Finley's Observations and Tactics)

- We have started to learn enough to begin to join copper parts together.
 - But we have not yet made an accelerating structure, and we have not even made one good enough to be useful for “high gradient” structure tests.
- However ... next, we will:
 - make FXA-002 and FXA-003 “the same but better than” FXA-001 ... at least good enough for high gradient testing,
 - make 90 cm structures at rate of 1 / month rather than ~1 / year,
 - make structures for high gradient testing,
 - make structures good enough for the NLC Main Linac,
 - make two girders with six structures on each girder.



The Next Steps for X-Band Structures at Fermilab (David Finley, Harry Carter et al)

- Engineering Teams (Harry Carter)
 - Present emphasis is on Technical Division LC effort
 - Note: Engineering Teams include TESLA work
 - FY02 NLC R&D Budget includes 180 FTE-days at SLAC
- Make Structures for the Eight Pack Test
 - Still involve industry as much as possible
 - For example, SBIRs
 - Note: No longer talking about ETF at Fermilab.



Engineering Teams

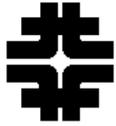
- Recently conceived (in August 2001) to help
 - focus on **Technical Division FY02-03 goals for Linear Collider R&D**
 - to promote better NLC R&D collaboration (particularly the Fermilab and SLAC connections)
- Almost immediately, it expanded to include
 - more than just Technical Division
 - more than just NLC R&D
- And it is a **moving target** at this time.

Aligned

For Reference ...

Fermilab's Linear Collider R&D Goal (as stated by Steve Holmes):

By the end of 2003, complete the R&D work leading up to CD-1.



Engineering Teams (as of October 4, 2001)

For X-Band (NLC)

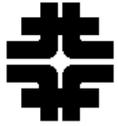
- **Fermilab RF Factory**
- **Structures (Mechanical)**
- **Structures (Electrical/RF)**
- **Girders**
- **Vacuum System**
- **Cooling Water System**
- **Specifications Development**
- **Quality Assurance Development**
- **8 Pack Integration**

For LC (TESLA and NLC)

- **FNAL Cleaning Facility**
- **SBIRs**
- **Permanent Magnets**
- **Demonstration of Remote Accelerator Operation**
- **Siting LC's near Fermilab**
- **Etc etc**

A Growing List

- Yes, there are names of people associated with each team and they are NOT all from Fermilab in most cases ... because the world's best expertise in all these areas does not yet reside at Fermilab.



Engineering Teams (as of October 4, 2001)

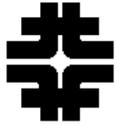
For X-Band (NLC)

- • **Fermilab RF Factory**
- • **Structures (Mechanical)**
- • **Structures (Electrical/RF)**
- • **Girders**
- **Vacuum System**
- **Cooling Water System**
- • **Specifications Development**
- • **Quality Assurance Development**
- • **8 Pack Integration**

For LC (TESLA and NLC)

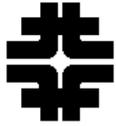
- • **FNAL Cleaning Facility**
- • **SBIRs**
- **Permanent Magnets**
- **Demonstration of Remote Accelerator Operation**
- **Siting LC's near Fermilab**
- **Etc etc**

→ Topics Addressed at X-Band Structures Workshop October 22-23,2001



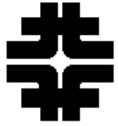
Present Plan for Structures for Eight Pack Test

- Eight Pack Test at SLAC (Dave Schultz, next talk)
 - In Phase II, a “pack of eight klystrons” will feed
 - 11.424 GHz X-Band power into
 - a simplified DLDS system and
 - power two girders worth of structures
 - with the full power and energy required by the NLC design.
 - The goal is to be done by the end of FY03
 - Which is not likely given the present level of support and expertise
- Girder A: 6 High Gradient Test Structures (FXBs)
- Girder B: 6 NLC Main Linac Structures (FXCs)



The (Fermilab) Plan for X-Band Structures

- In FY02 (with \$1.95M)
 - Make FXA-002 and FXA-003 (Short ones)
 - 20 cm long, conventional machined, high gradient tests, 45 mm OD
 - Make FXB-001 thru 003 (Full length, but not yet accelerator quality)
 - 90 cm long, conventional machined, high gradient tests, 61 mm OD
 - If I have to: Use same coupler design we had in FY01 (aka “Sparky”)
 - Start on FXC (The Real Thing ... No More Excuses!)
 - Final NLC Main Linac Design
 - 90 cm long, assume diamond turned, real accelerators
 - Need design (including couplers) by July 2002 (?)
 - Need to decide on bonding vs brazing (required straightness) and then learn how to do it by September 2002 (?). (Is this a sensible short term goal?)
 - Or we won't have a prayer of making the “By the end of 2003” goal.



The (Fermilab) Plan for X-Band Structures

- In FY02 (with \$1.95M)
 - Make FXA-002 and FXA-003
 - Make FXB-001 thru 003
 - Start on FXC (The Real Thing)
- In FY03 (with \$x?xM)
 - Make FXB-004 thru 006 (plus two extras)
 - Assume better coupler design than we had in FY01.
 - Make FXC-001 thru 006 (plus two extras)
 - See how many we actually have in mid to late FY03 and decide what to do in FY04.



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The End.

