Tuning of TD31 CC #1 and #2

26.05.2021

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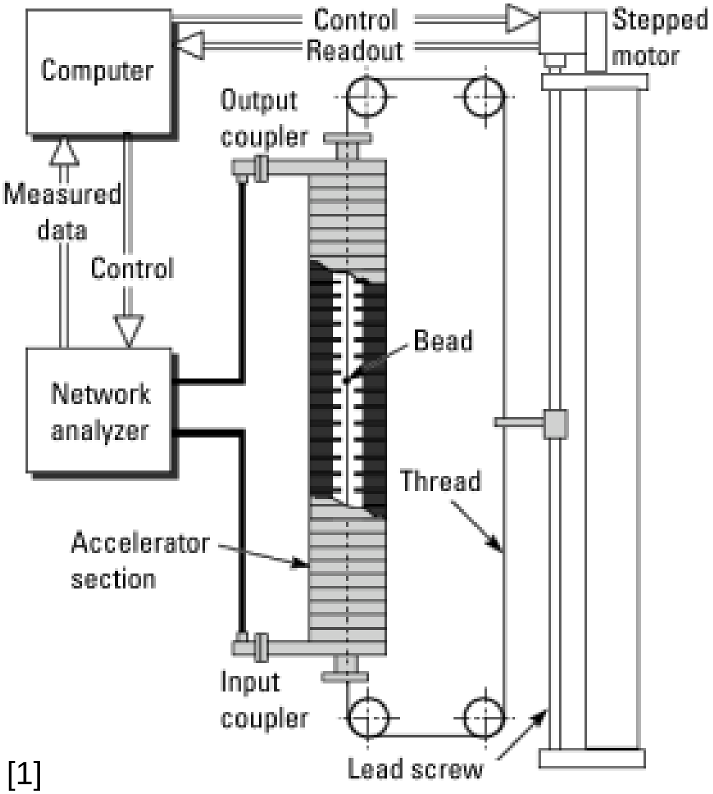
Outline

- Bead-pull & Tuning Setup
- Tuning of TD31 #1 and #2
  - RF Check of TD31 #1-2 Before Bonding
  - TD31 CC #1 – Tuning Process
  - TD31 CC #2 – Tuning Process
- Metrology Results of TD31s’ Straightness
- Summary of Tuning Records
- Conclusion & Remarks

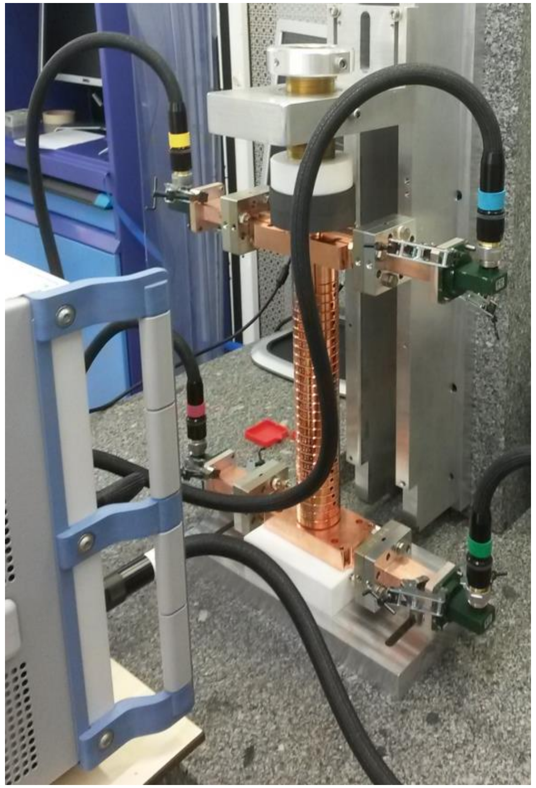
Bead-pull & Frequency Tuning Setup (1)

Bead-pull Block Diagram

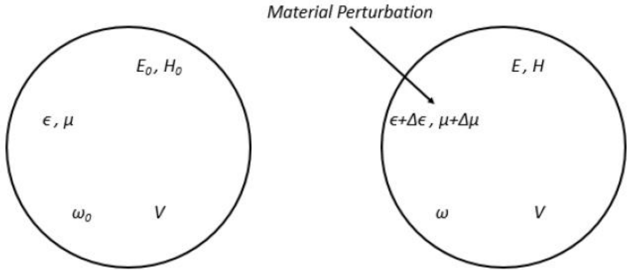


[1]

Structure at Bead-pull Test



- Based on non-resonant perturbation theory; obtaining an approximate solution by adding a small perturbation to the exact solution.
- Entering to a volume containing EM field by a small object (bead), causes energy change and deviation in frequency.



$$\frac{\Delta f}{f_0} = \frac{\oint_{\Delta V} (\mu_0 |H|^2 - \epsilon_0 |E|^2)\, dV}{\oint_{V_0} (\mu_0 |H|^2 + \epsilon_0 |E|^2)\, dV}$$ [2]

- The aim of bead-pull measurement is to obtain the field profile inside the structure.
- Both metallic or dielectric bead can be used according to field which desired to be measured.

1-Hanna S., *RF Linear Accelerators for Medical and Industrial Applications*; Artech House: Boston, 2012
2-Pozar D., “Microwave Resonators”, *Microwave Engineering*; John Wiley & Sons: Hoboken, 2012, p 308

Bead-pull & Frequency Tuning Setup (2)

Example Tuning: TD26 N3 Tuning Report, CERN EDMS:1626878, Rolf Wegner

Before Tuning

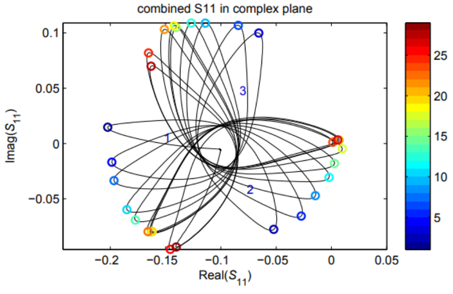
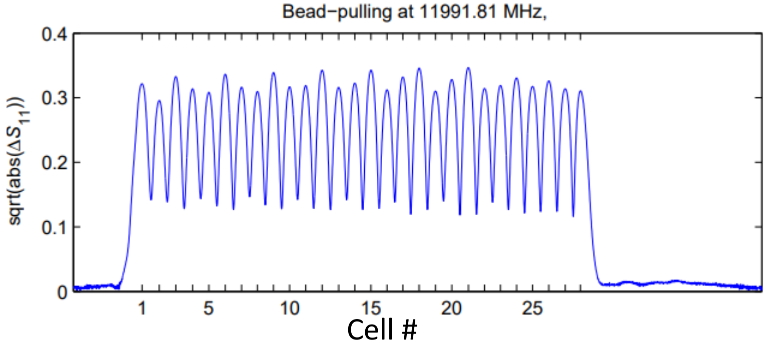


Figure 12: Bead-pulling at 11991.81 MHz

E-field profile of TD26 N3 Before Tuning



After Tuning

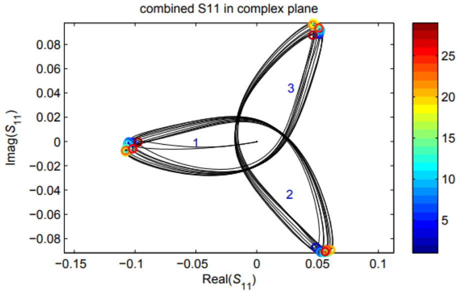
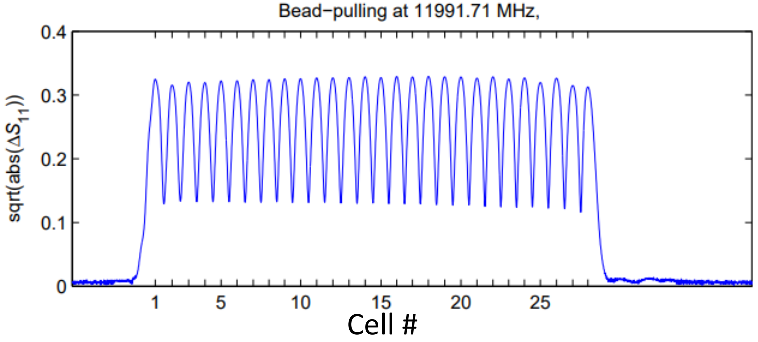
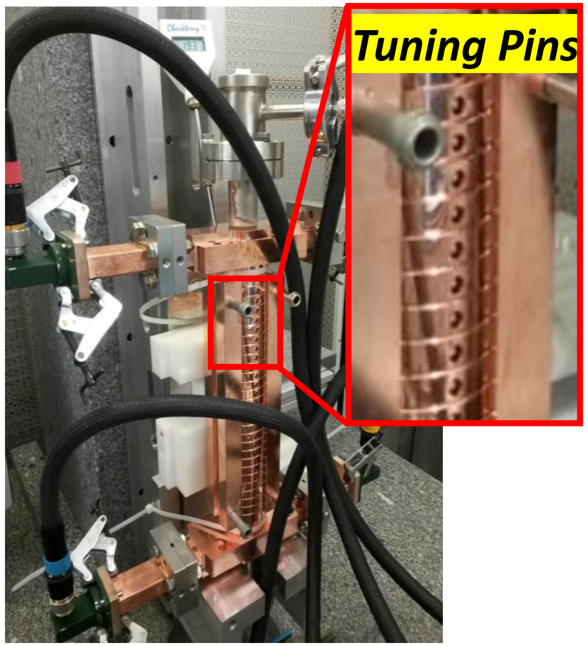


Figure 12: Bead-pulling at 11991.71 MHz

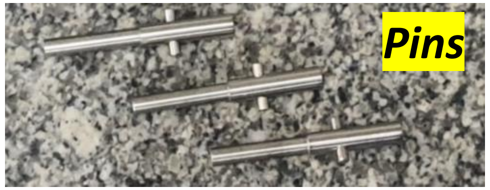
E-field profile of TD26 N3 After Tuning



Tuning Process



- Final step of the X-Band structure production before high power test.
- Sequential process with observing E-field from bead-pull data.
- Push-pull of tuning pins with a special hammer to change the internal volume of cells.



- Using a tuning code developed by Jiaru Shi
- Correcting frequency & phase & E-field profile

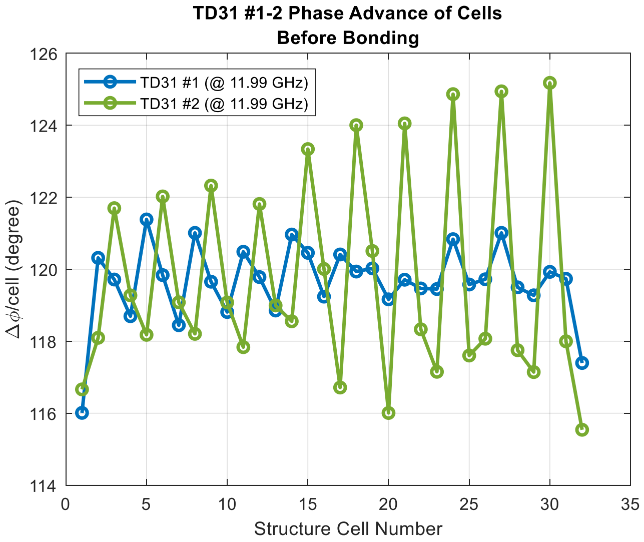
For more info: J. Shi, A. Grudiev, W. Wuench, *Tuning of X-band traveling-wave accelerating structures*, DOI: 10.1016/j.nima.2012.11.182

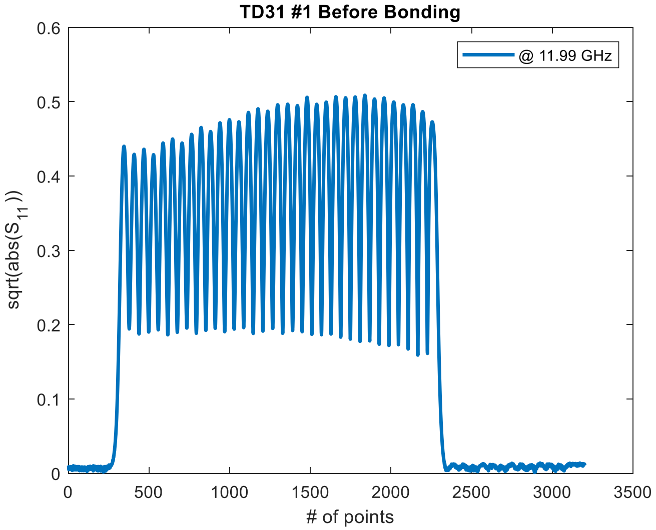
RF Check of TD31 #1-2 Before Bonding

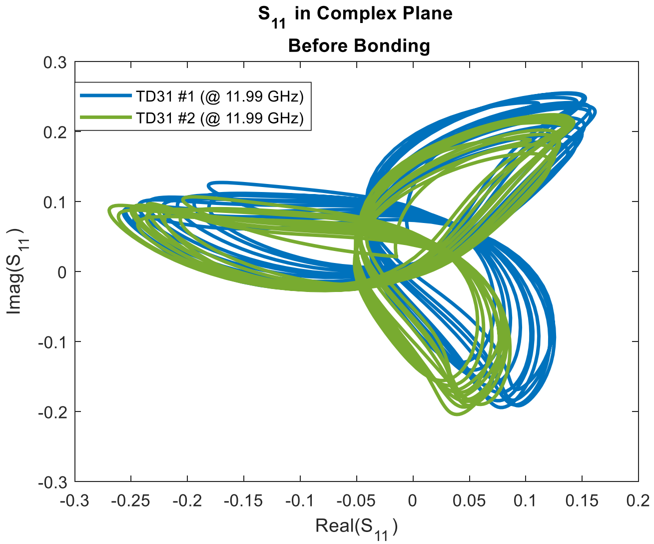
Measurement setup

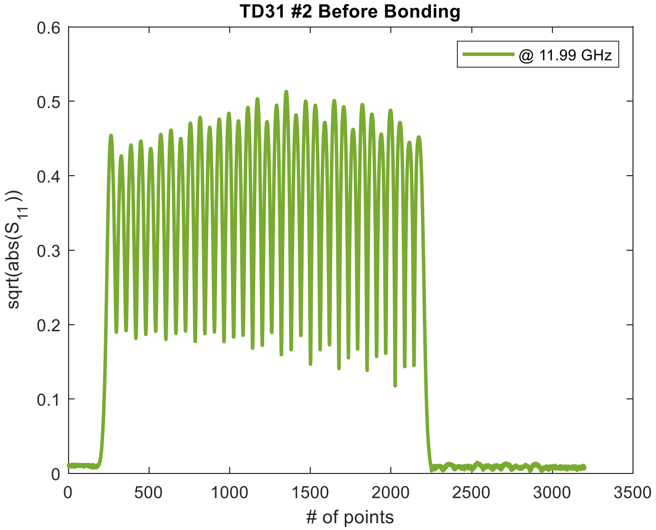
- RF check on horizontal bead-pull setup
- Pre-check of the prototype structure before bonding (to give ‘OK!’ for bonding)
- #1 has better E-field profile, #2 has more fluctuations on peaks.
- Phase advance of cells are smaller in structure #1.

TD31	Ave. Phase Advance (°)
#1	119.85
#2	119.96

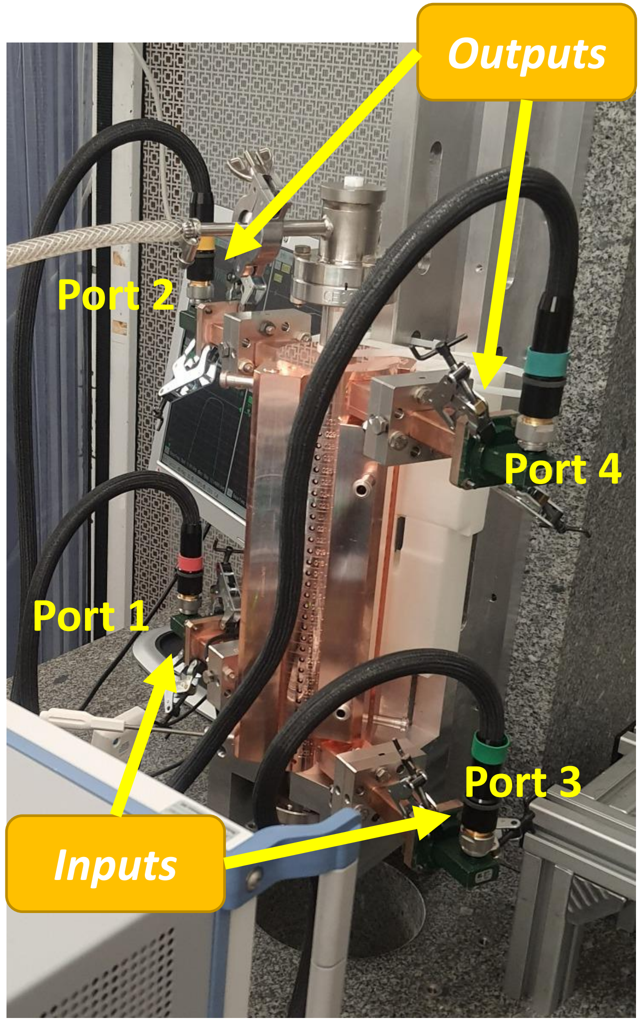








TD31 CC #1



General Info on Structure

RF Design	*: EDMS 1772531*
Design Frequency	*: 11.994 GHz*
Phase advance per cell	*: 120^o*
Operation Temperature	*: 30 ^{o}C*
Structure Temperature (during RF meas)	*: … ^{o}C*
Gas in structure (during RF meas)	*: N_2*

Δf calculation before RF measurement

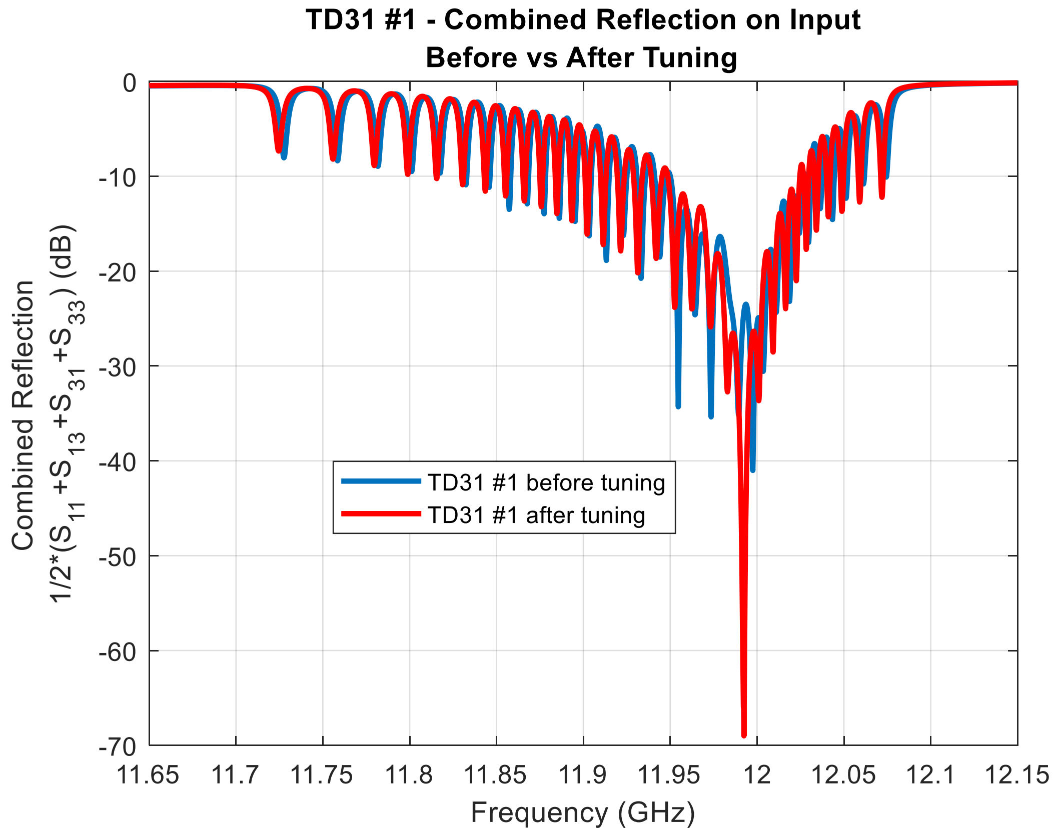
Before Tuning		*After Tuning*	
Δf (change vacuum to N_2)	-3.48 MHz	Δf (change vacuum to N_2)	-3.48 MHz
30.0 ^{o}C -> 19.1 ^{o}C	*: +2.17 MHz*	*30.0 ^{o}C -> 19.2 ^{o}C*	*: +2.15 MHz*
Δf (wire for bead-pull)	*: -0.43 MHz*	*Δf (wire for bead-pull)*	*: -0.43 MHz*
Total	*: -1.74 MHz*	*Total*	*: -1.76 MHz*

Measurement frequency in lab conditions; (Before Tuning)
11992.26 MHz (with wire, *19.1 ^{o}C , N_2*)
11992.69 MHz (without wire, *19.1 ^{o}C , N_2*)

Measurement frequency in lab conditions; (After Tuning)
11992.24 MHz (with wire, *19.2 ^{o}C , N_2*)
11992.67 MHz (without wire, *19.2 ^{o}C , N_2*)

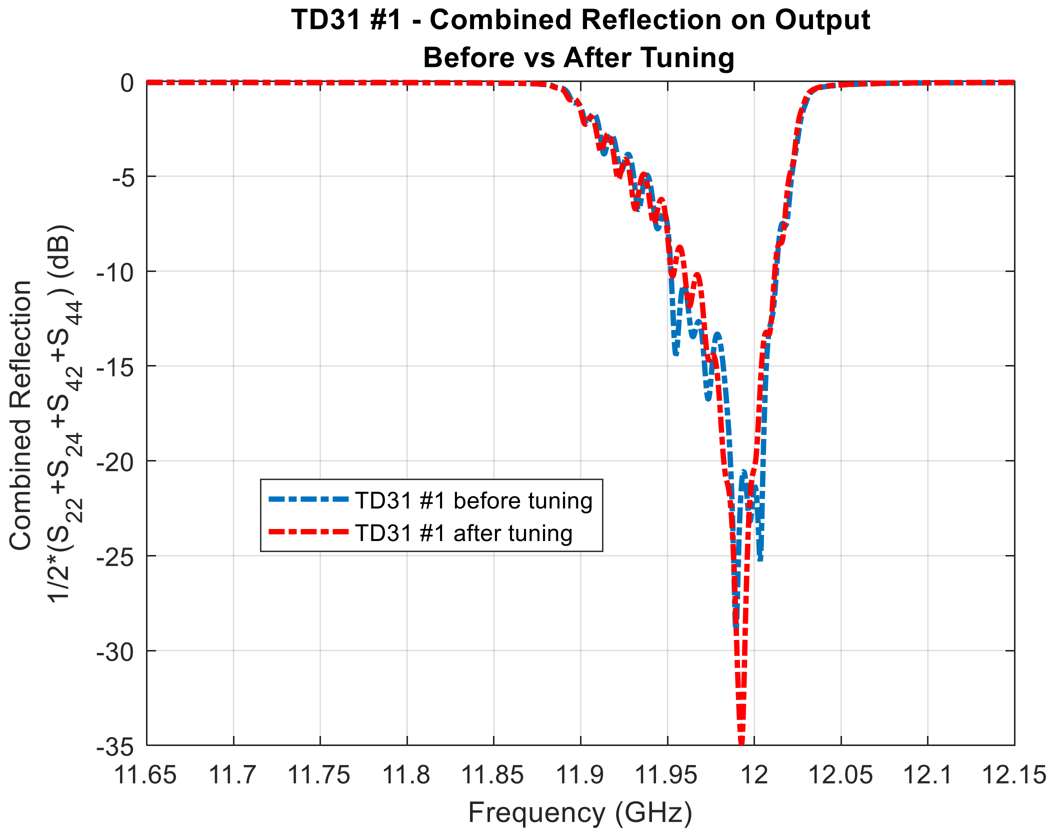
Tuning Report: https://edms.cern.ch/document/2517248/1

TD31 CC #1



@11.9927 GHz

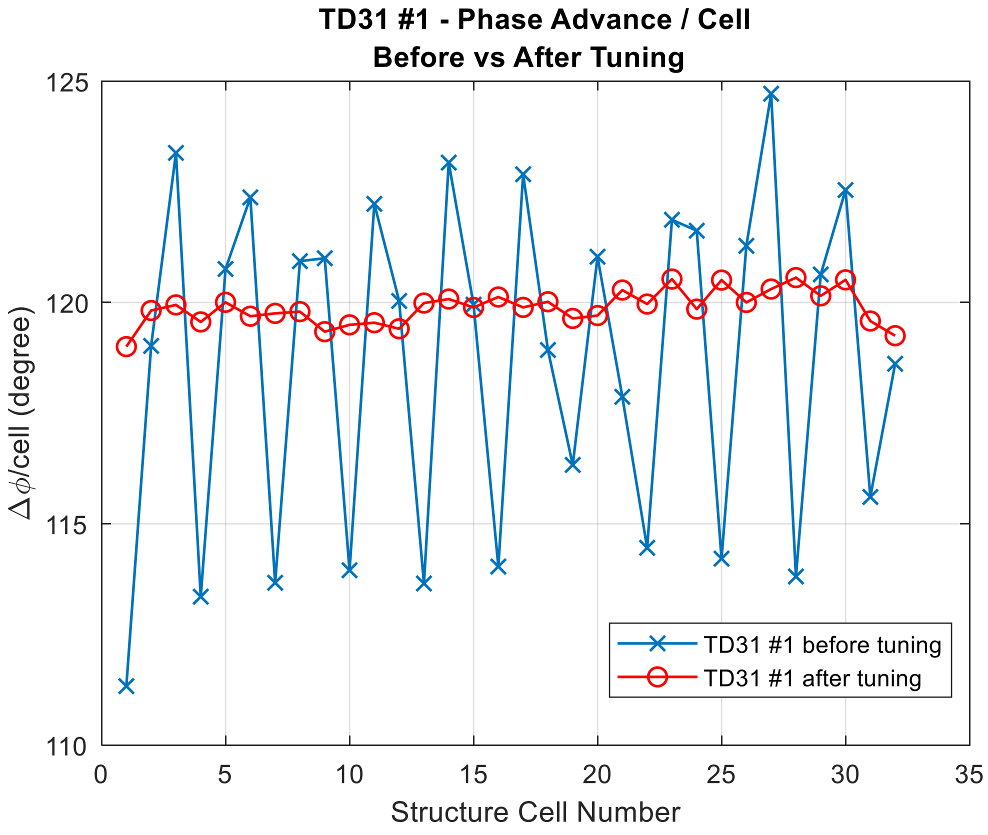
Before tuning -> -25.5 dB
After tuning -> -57.7 dB

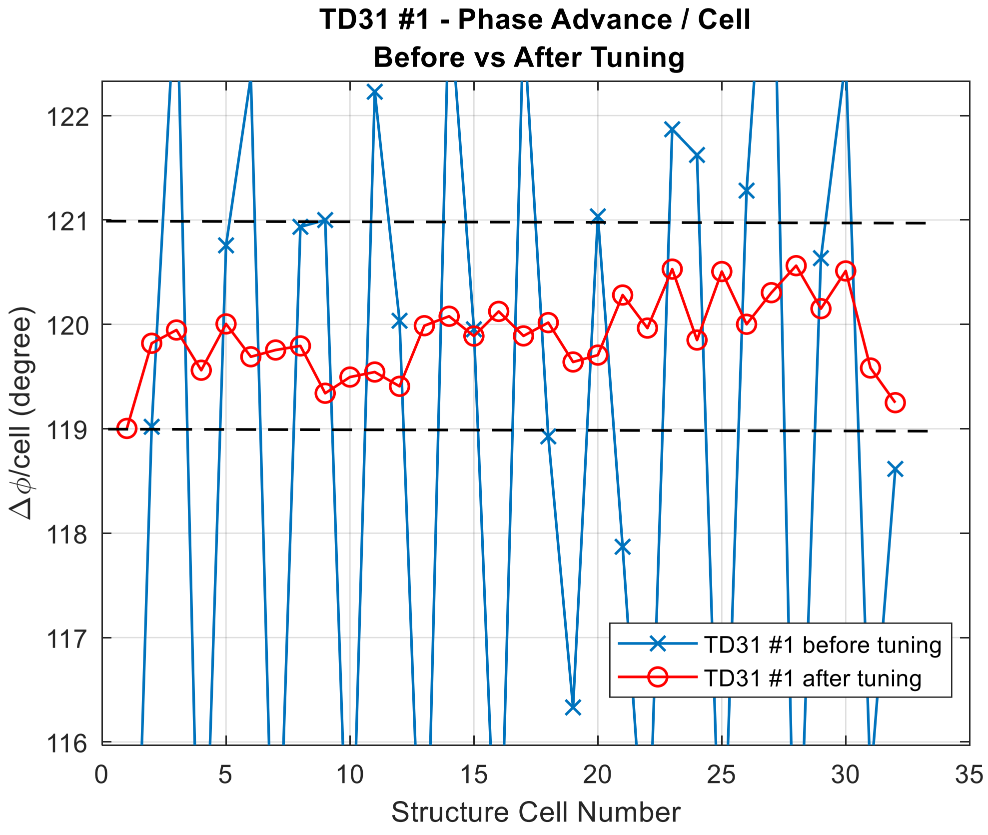


@11.9927 GHz

Before tuning -> -22.0 dB
After tuning -> -35.4 dB

TD31 CC #1





- 12 sequential bead-pull measurements

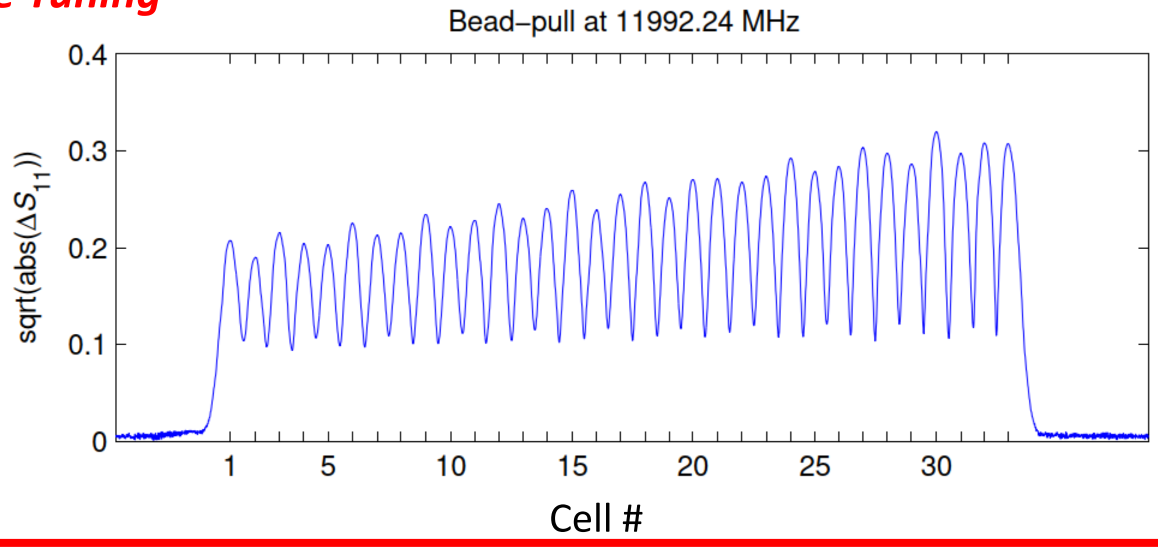
Average Phase Advance

Before tuning (@ 11.9923 GHz) -> 118.98°

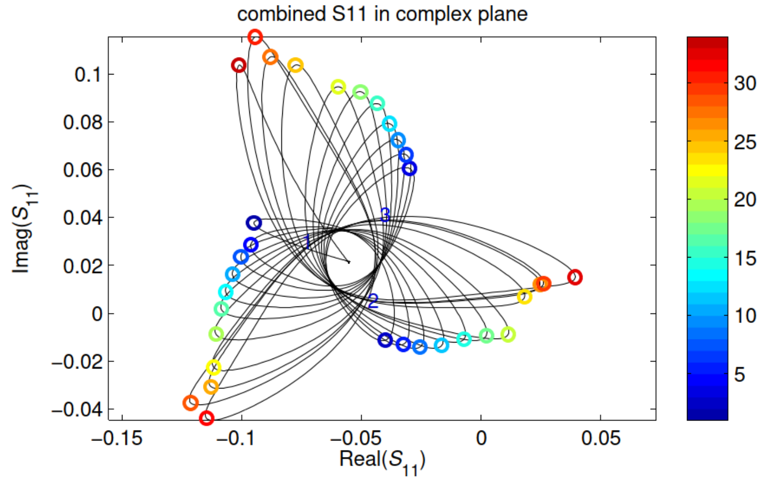
After tuning (@ 11.9922 GHz) -> 119.93°

TD31 CC #1

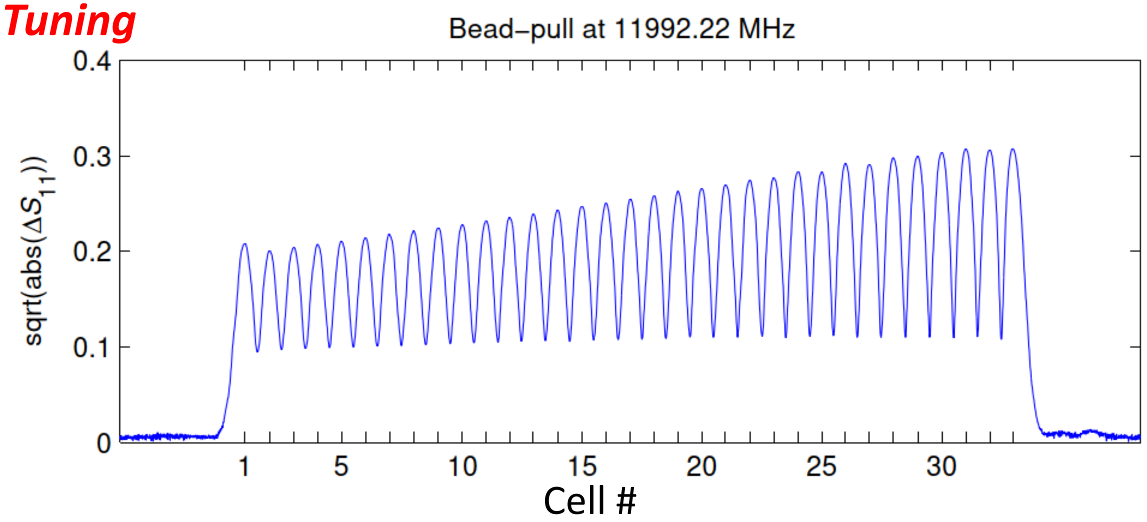
Before Tuning



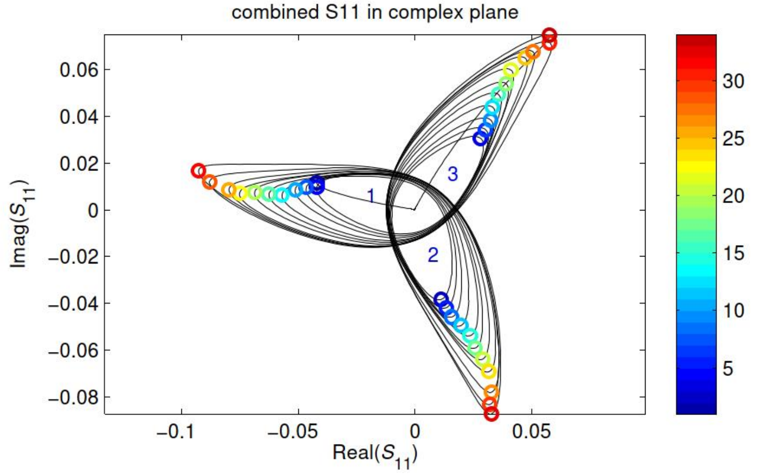
Bead-pull @ 11992.2 MHz (<->11994.0 MHz @ 30 °C)



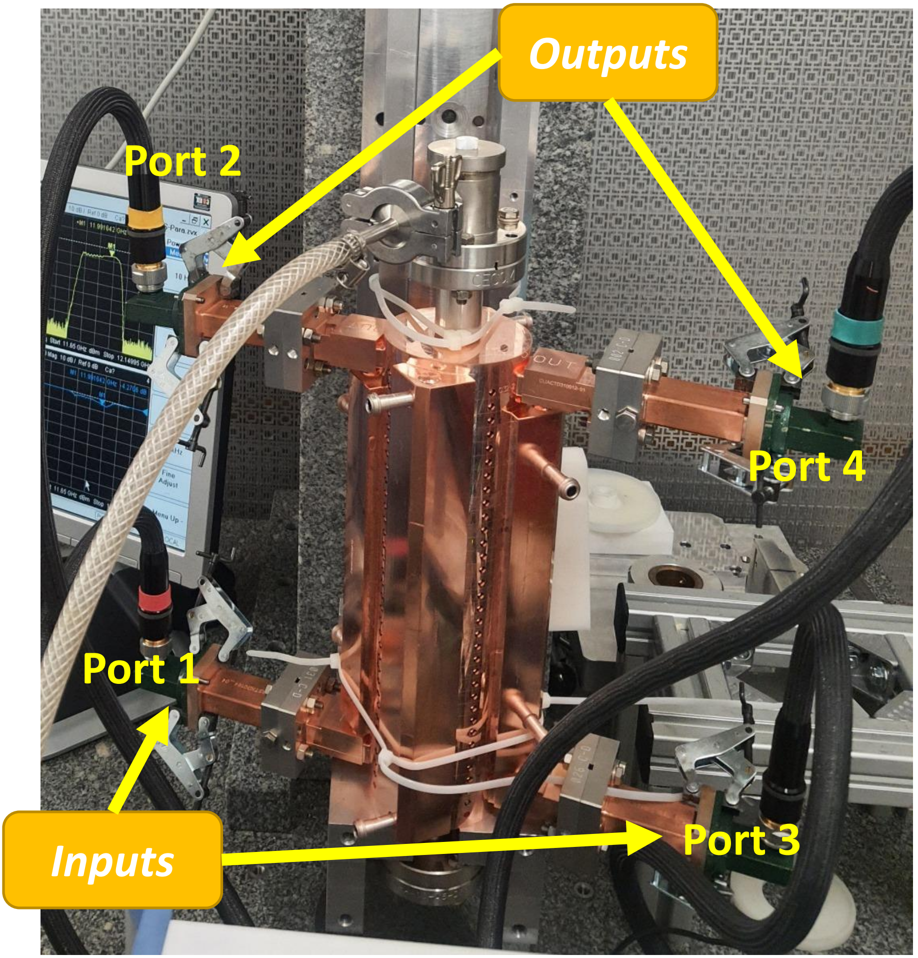
After Tuning



Bead-pull @ 11992.2 MHz (<->11994.0 MHz @ 30 °C)



TD31 CC #2



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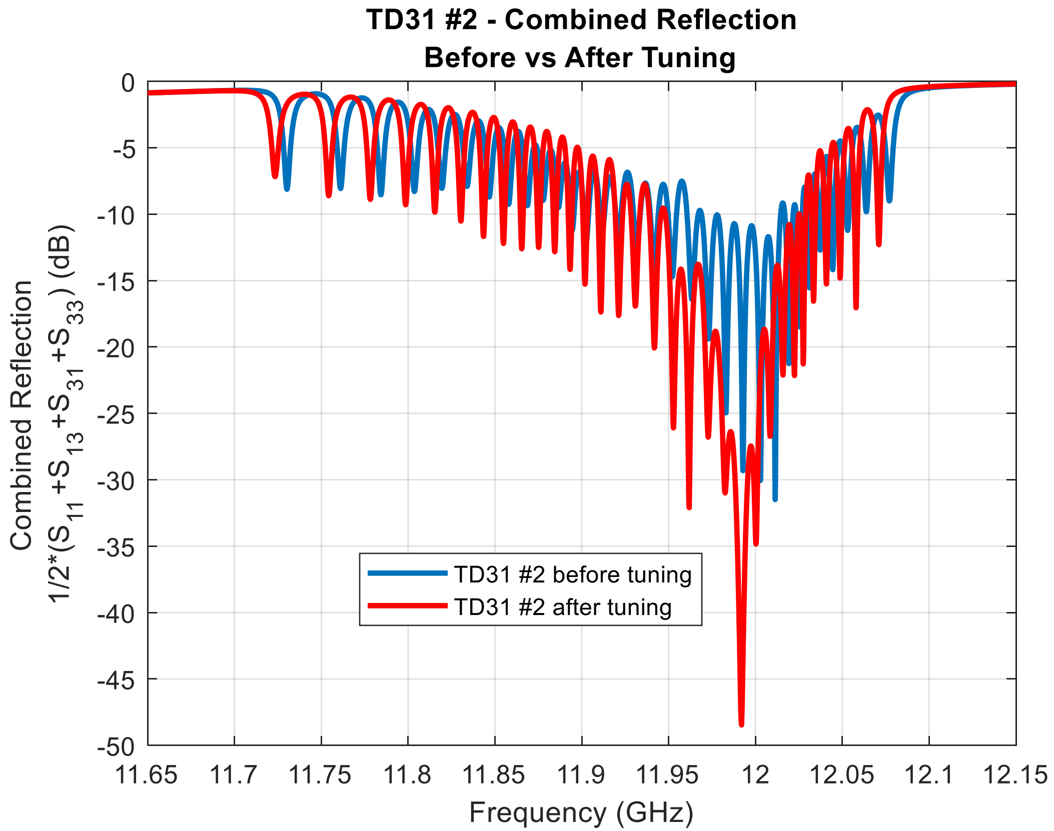
Δf calculation before RF measurement

Before Tuning		**_After Tuning_**	
Δf (change vacuum to N_2):	-3.48 MHz	Δf (change vacuum to N_2):	-3.48 MHz
30.0 ^{o}C -> 19.7 ^{o}C	*: +2.05 MHz*	*30.0 ^{o}C -> 20.4 ^{o}C*	*: +1.91 MHz*
Δf (wire for bead-pull)	*: -0.44 MHz*	*Δf (wire for bead-pull)*	*: -0.44 MHz*
Total	*: -1.87 MHz*	*Total*	*: -2.01 MHz*

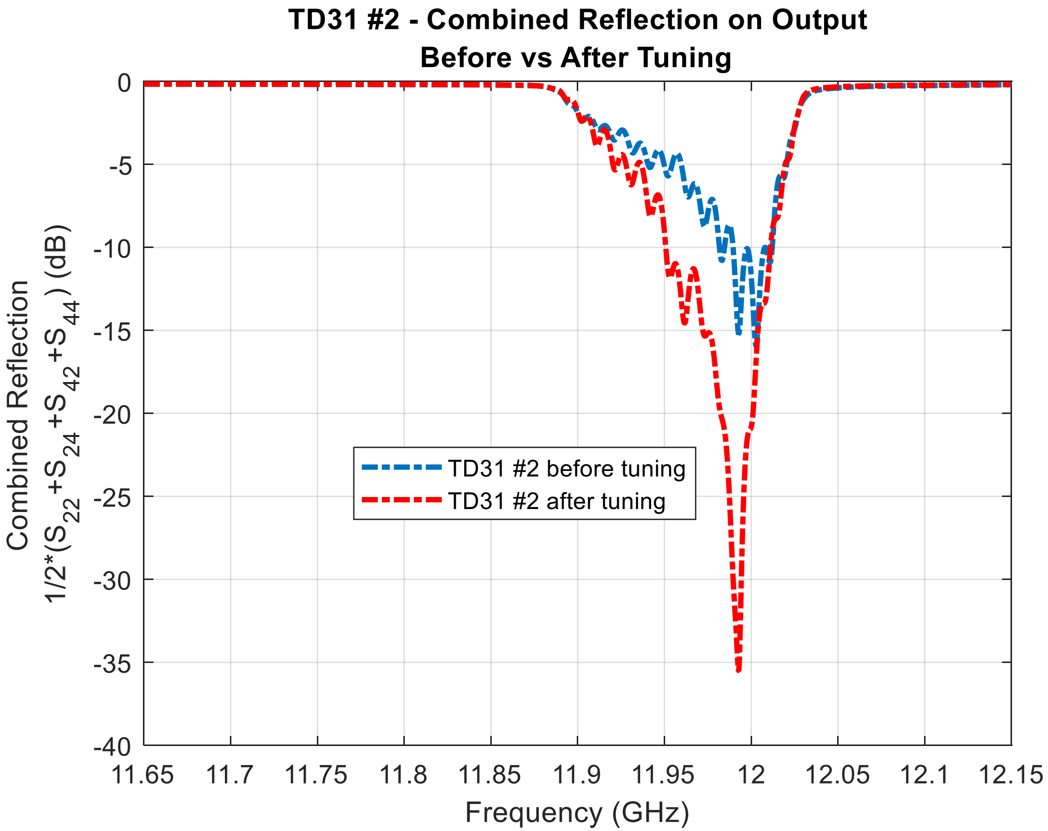
Measurement frequency in lab conditions;	*Measurement frequency in lab conditions;*
11992.13 MHz (with wire, *19.7 ^{o}C , N_2*)	11991.99 MHz (with wire, *20.4 ^{o}C , N_2*)
11992.57 MHz (without wire, *19.7 ^{o}C , N_2*)	11992.43 MHz (without wire, *20.4 ^{o}C , N_2*)

Tuning Report: https://edms.cern.ch/document/2573735/1

TD31 CC #2

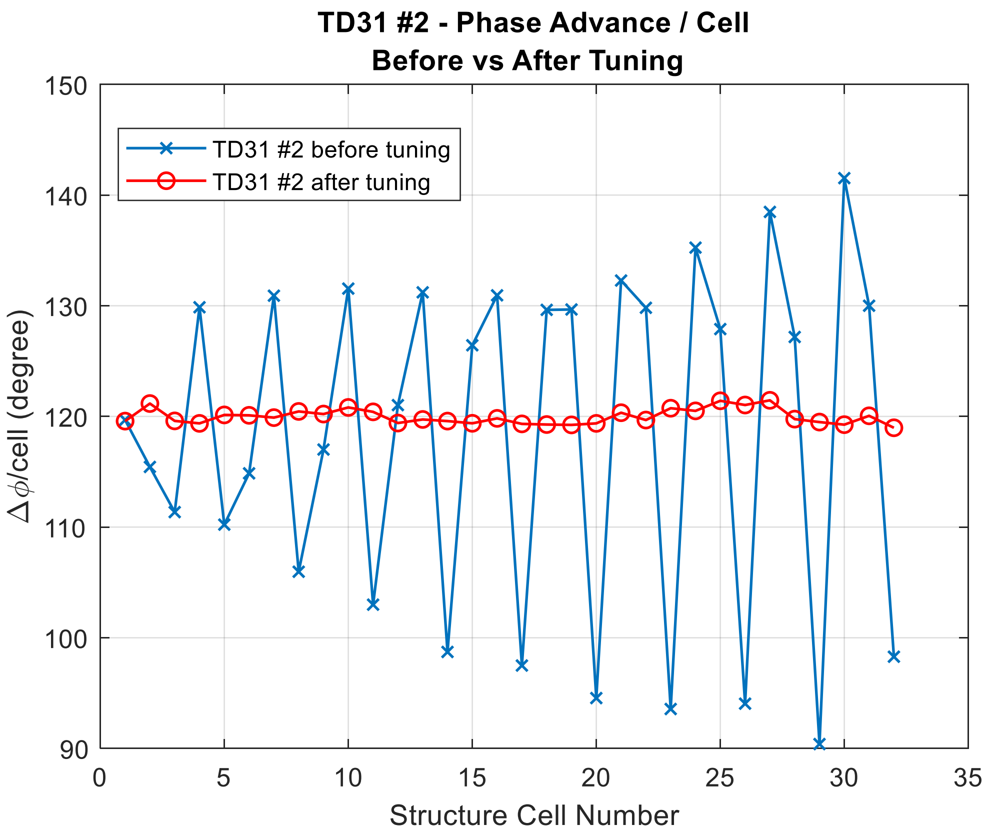


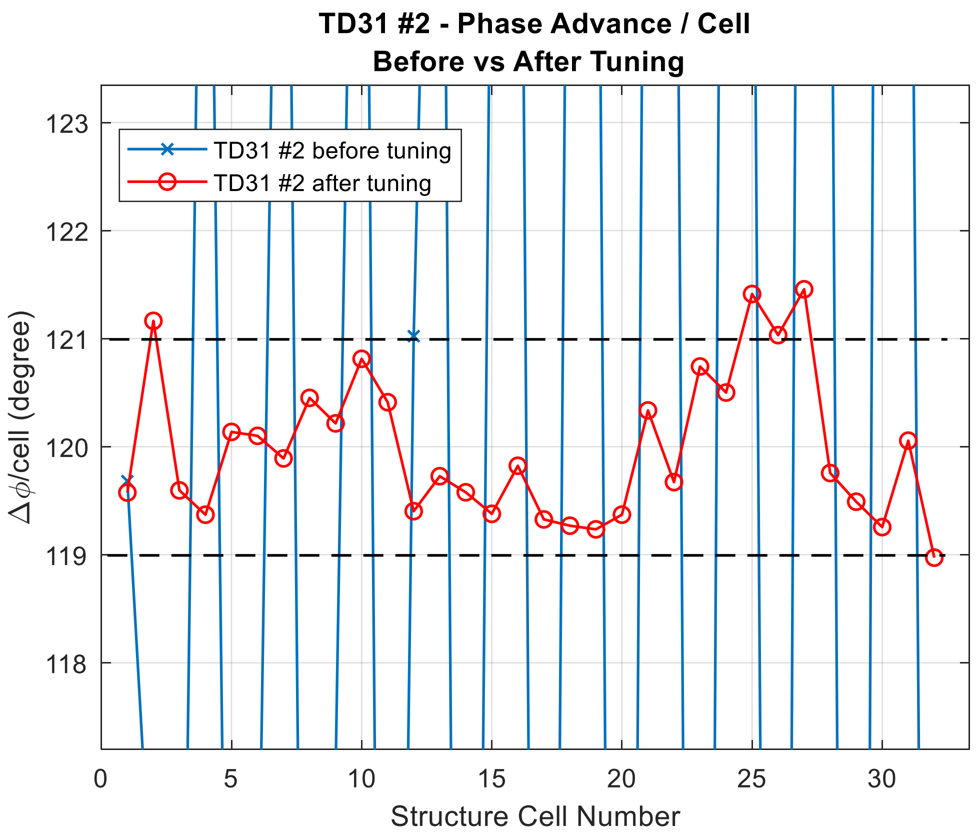
@11.9926 GHz, *19.7 °C* Before tuning -> -28.5 dB
@11.9924 GHz, *20.4 °C* After tuning -> -45.7 dB



@11.9926 GHz, *19.7 °C* Before tuning -> -15.2 dB
@11.9924 GHz, *20.4 °C* After tuning -> -35.3 dB

TD31 CC #2





Average Phase Advance

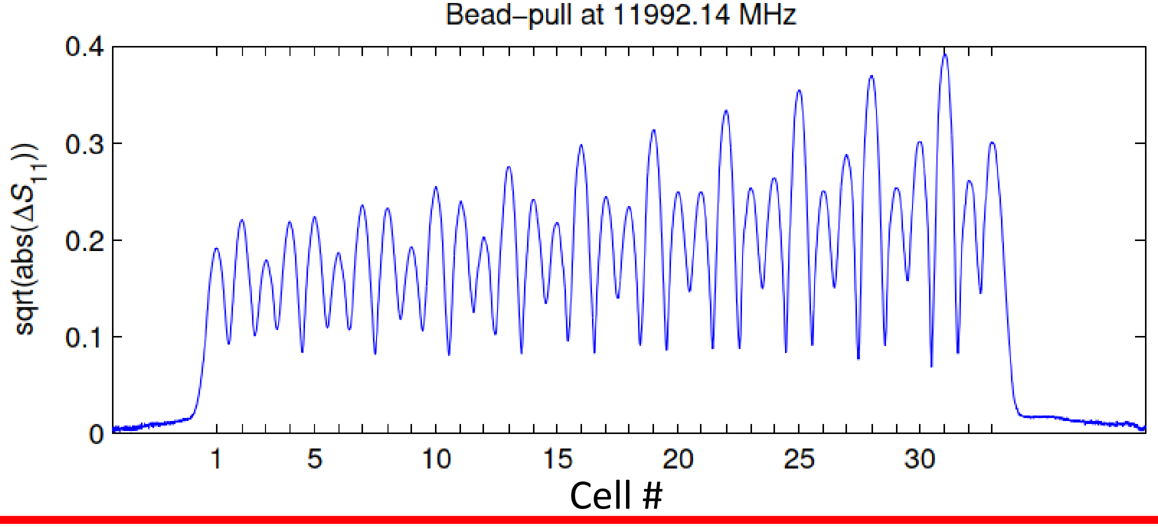
Before tuning (@ 11.9921 GHz) -> 119.01°

After tuning (@ 11.992 GHz) -> 120.03°

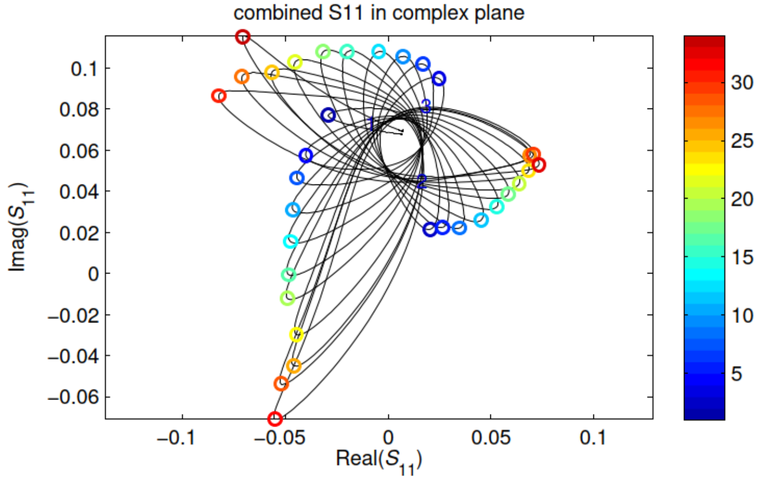
- 12 sequential bead-pull measurements

TD31 CC #2

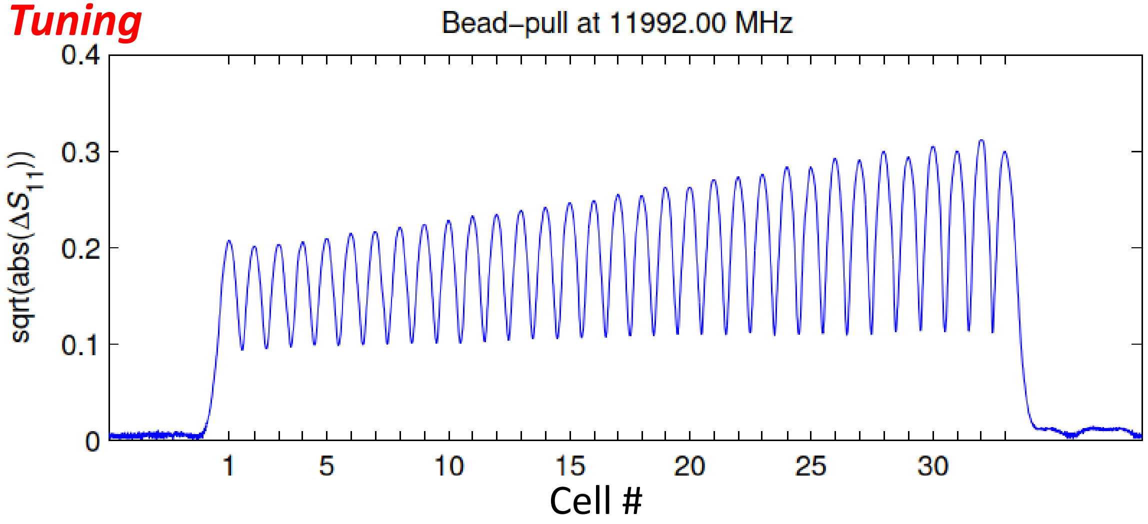
Before Tuning



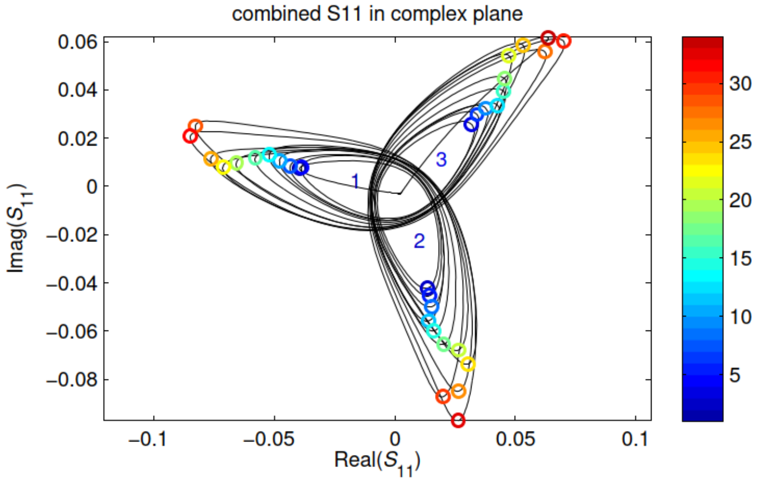
Bead-pull @ 11992.1 MHz (<->11994.0 MHz @ 30 °C)



After Tuning

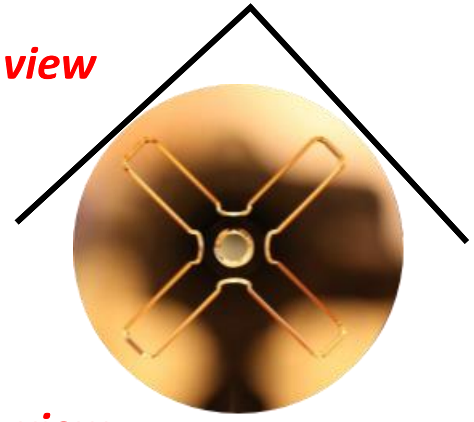


Bead-pull @ 11992.0 MHz (<->11994.0 MHz @ 30 °C)

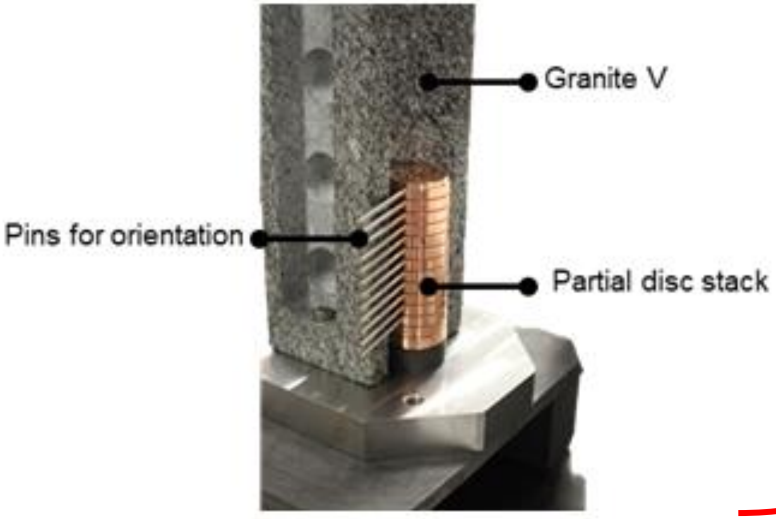


Alignment and Straightness Measurement

Top view

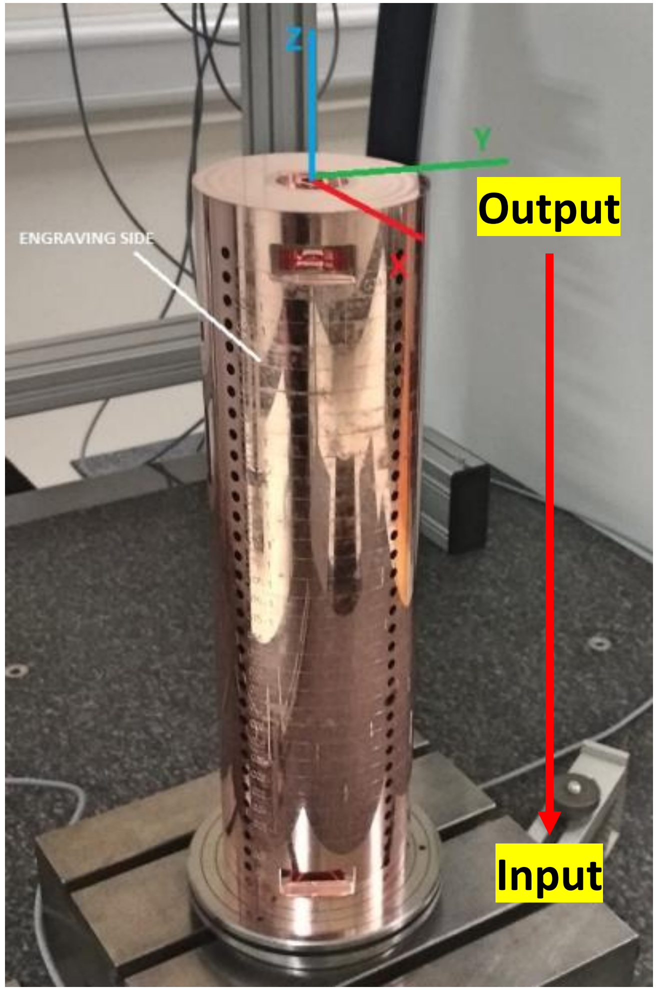


Side view



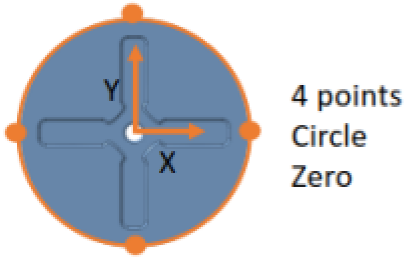
Photos from Joel Sauza Bedolla

BONDING

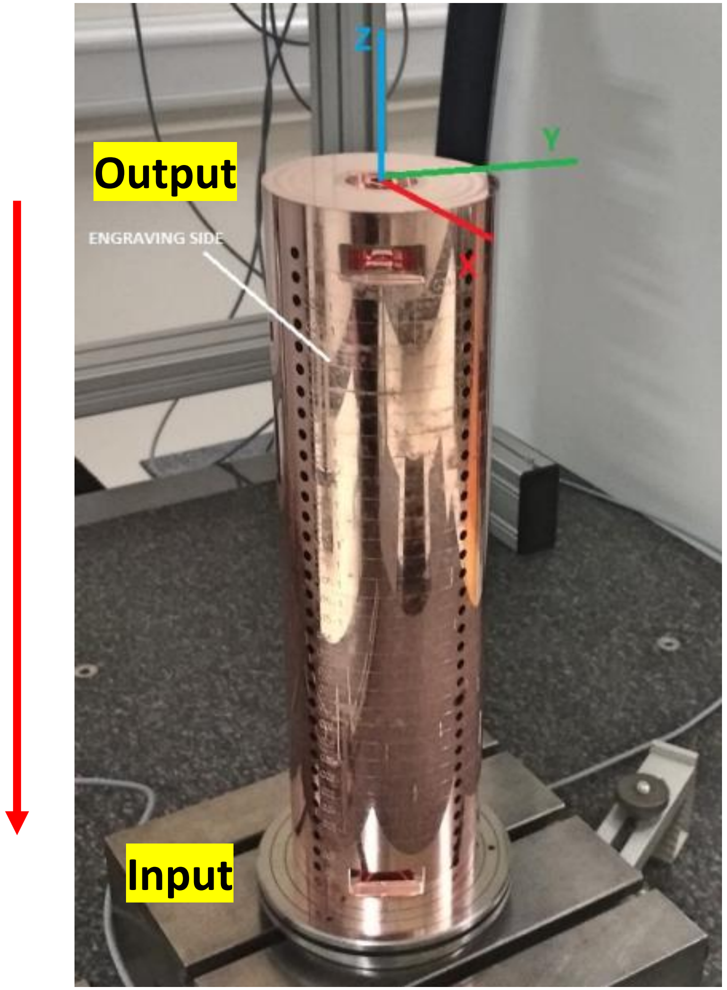


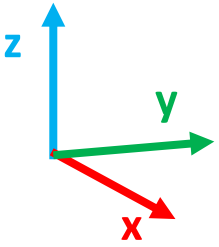
Metrology Setup

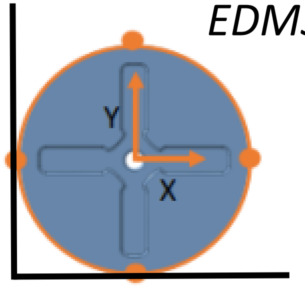
- Measurement from output to input
- 4 points for each disc along structure w.r.t. reference coordinate system on top.



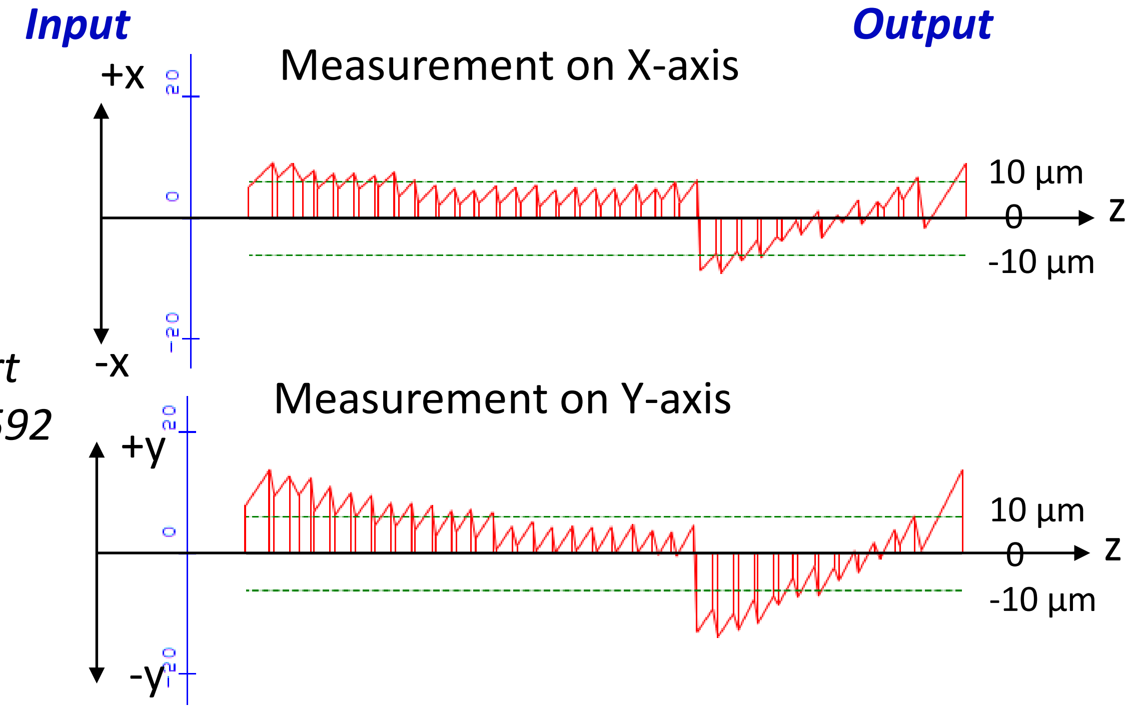
Straightness Measurement of TD31s #1

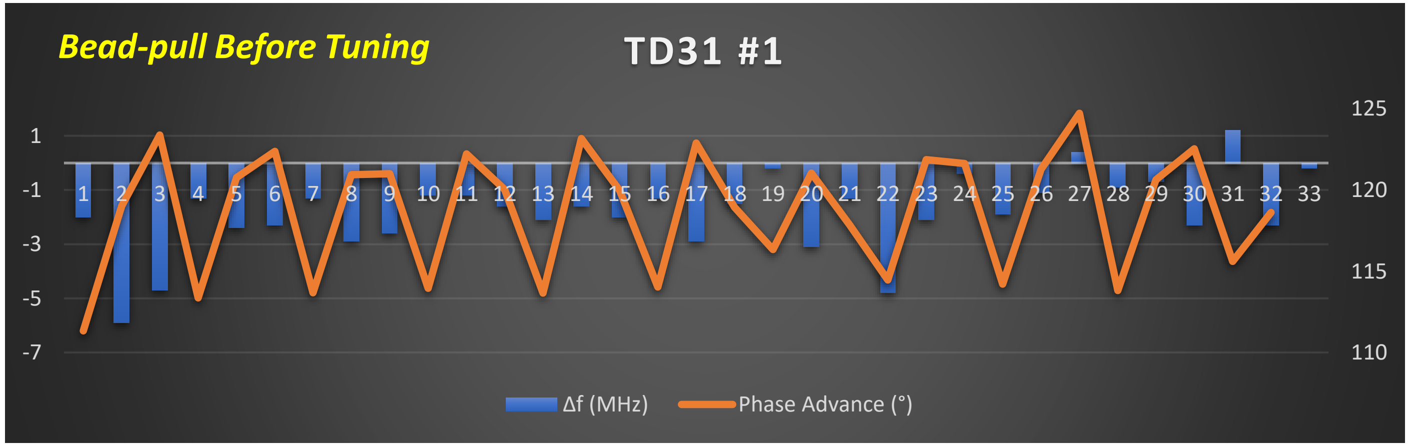






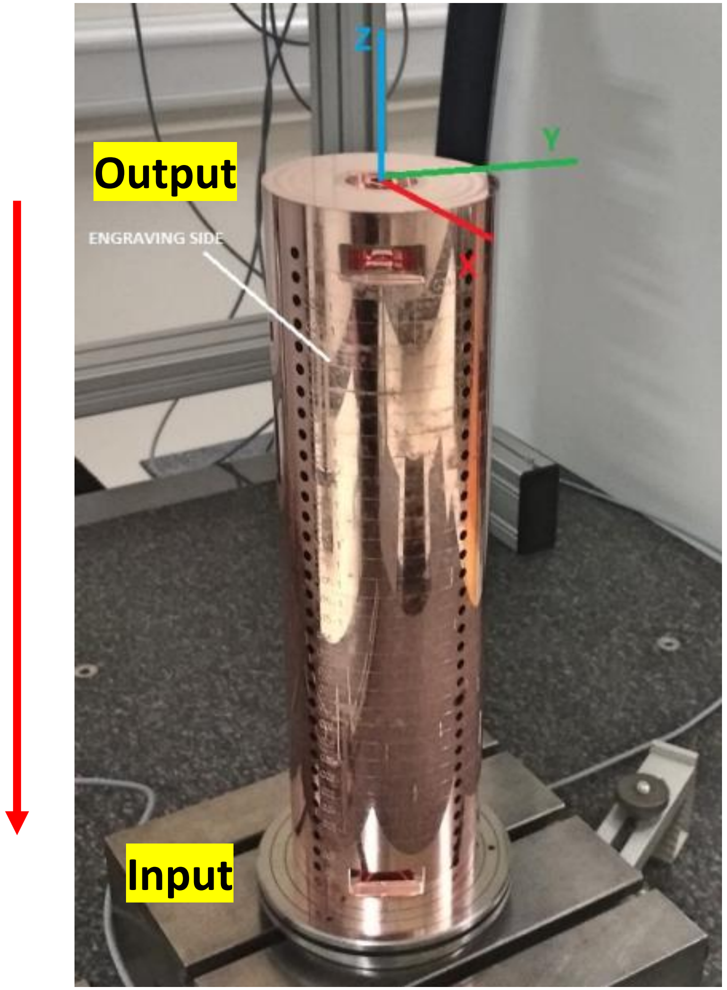
Metrology Report
EDMS No: 2243592

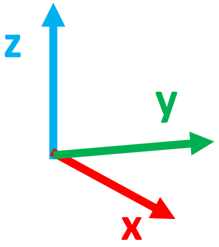


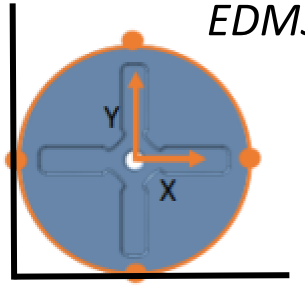


Reports from Joel Sauza Bedolla

Straightness Measurement of TD31s #2







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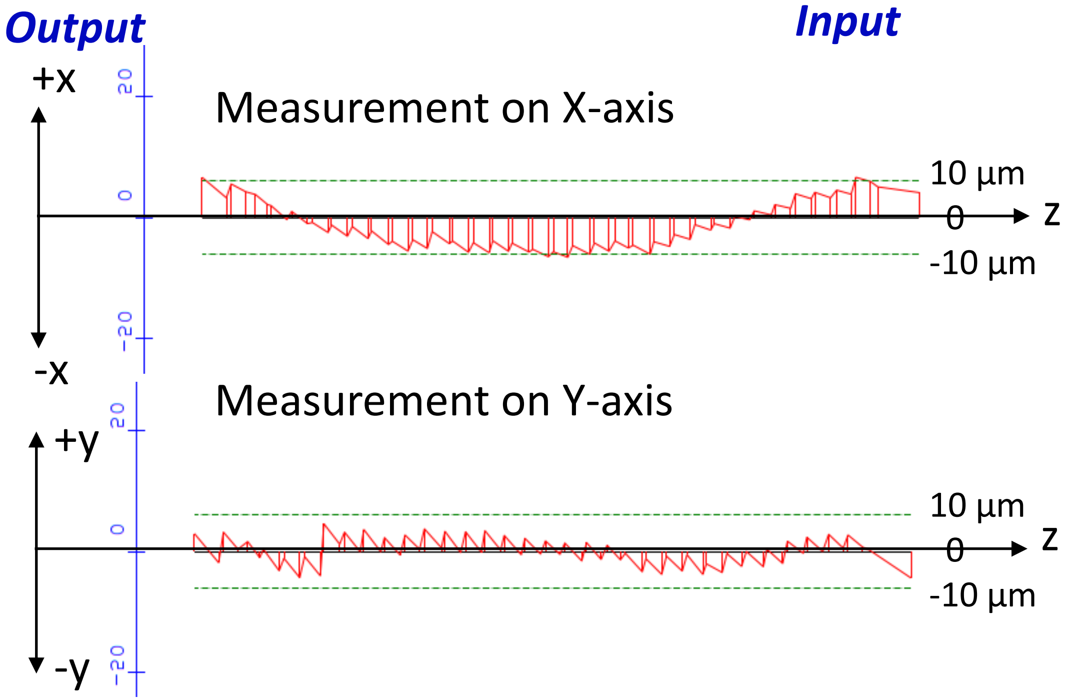

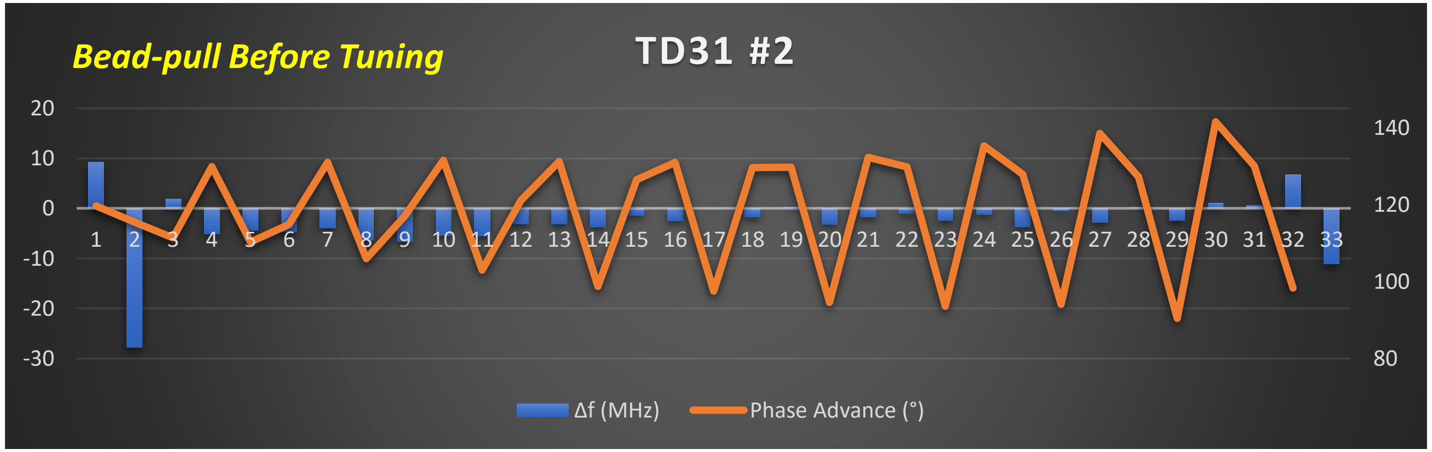

Reports from Joel Sauza Bedolla

Summary of Tuning Records (1)

Tuned main linac prototypes

Record from Rolf Wegner

Conclusion & Remarks (1)

- The tuning of both TD31 structures was more challenging than T(D)24 and T(D)26 structures due to;
  - A systematic frequency shift corresponding to ~1.0^o phase advance increase
  - The rising amplitude and phase sensitivity toward the structure output (~last quarter)
- TD31 #2 had a strong standing wave pattern that the bead-pull couldn't be performed.
  - A pre-tuning step was required, reducing the reflection measured from the output by tuning the last two cells (last regular + output matching).
  - After this pre-tuning, the spectrum and E-field distribution was still distorted but allowed to perform bead-pull (see slides 10-13).

Conclusion & Remarks (2)

- Both TD31 structures could be tuned to the desired average phase advance per cell of 120.0° ±0.1° for the operating conditions (11.994 GHz at 30°C under vacuum).
- The individual phase advance between cells of the TD31 #1 are within ±1.0° for all regular cells (see slide 8).
- However, the range [-1.0^{o} to +1.5^{o}] was required for TD31 #2 to compensate for problematic parts (input around cell #2 = first regular cell and cells 25 to 27).
  - *Note: The compromise chosen for the TD31 #2 considers the phase advance and the electric field profile along the entire structure. Reducing the phase advance for the 4 cells outside the +1.0° range increases the ripple on the electric field locally and spoils the profiles in amplitude and phase toward the input of the structure due to the increased backward wave from the problematic region.*

Thank you for your attention!