The HOM measurement of a TESLA cavity (Z84) for HOM-BPM and cavity alignment

Ken.Watanabe : GUAS/AS (KEK) : presenter

Hitoshi.Hayano, Shuichi.Noguchi, Eiji.Kako, Toshio.Shishido (KEK)

Joint DESY and University of Hamburg Accelerator Physics Seminar 25, September, 2007, DESY

abstract

abstract:

Measurements of HOMs for the HOM BPM and the cavity miss-alignment was made with TESLA cavity (Z84) at KEK in this summer. The measured passbands were TE111, TM110 and TM011.

When HOM in multi-cell cavity is used as cavity BPM and cavity miss-alignment, the following are important:

(1) The polarization angle of used dipole mode at each cell has same angle. X and Y polarizations are separated.

(2) How much is difference in the electrical mode center and the mechanical center at each cell ?

We tried to measure them by using bead-pull method and antenna scan.

In addition, my group of KEK is developing the STF shape cavity (S.Noguchi, E.Kako et al) for ILC.

We have made a comparison of the HOM performance of STF cavity and TESLA cavity.

This presentation will be report the result of HOM measurement at KEK.

content

(1) Introduction and Purpose

(2) Measurement list

2-1. Checked accelerating mode: frequency and field flatness

2-2. Main HOMs passband : comparison in STF cavity

2-3. Qext value of HOMs : comparison in STF cavity

2-4. Polarization direction measurement

2-5. Difference in electrical center and mechanical center of dipole modes

(3) Conclusion

1. Introduction and purpose

At FLASH, HOM study group is doing the HOM BPM study and HOM based on cavity alignment study.

When HOM in multi-cell cavity is used as cavity BPM and cavity miss-alignment measurement,

the following are important:

(1) The polarization angle of used dipole mode at each cell has same angle.

X and Y polarizations are separated.

(2) How much is difference in the electrical mode center and the mechanical center at each cell ?

We tried to measure them by using bead-pull method and antenna scan by used TESLA cavity (Z84) for HOM BPM and HOM base cavity alignment !!!

And my group of KEK is developing STF TESLA shape cavity (S.Noguchi, E.Kako, H.Hayano et al) for ILC. We have made a comparison in the HOM performance of STF cavity and TESLA cavity.

2. Measurement list

(1) Checked the accelerating mode: frequency and field flatness (important !!!)

(2) Measured HOM passband : TE111, TM110, TM011, etc…

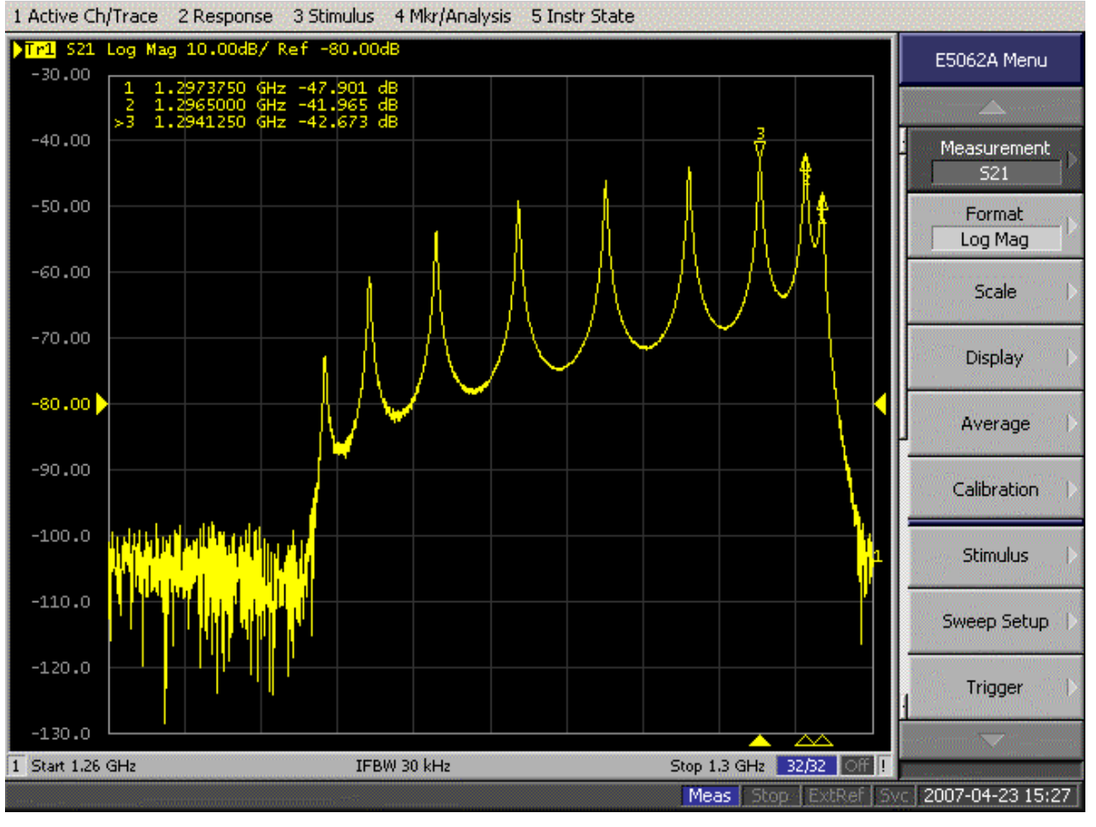
(3) Measured HOM Qext value : comparison in STF cavity

(4) Measured the Polarize direction of Main dipole modes : bead-pull method

(TE111 and TM110 passband, distribution of each cell and each mode)

(5) Difference in Electrical mode center and Mechanical center : antenna scan method

2-1. TM010 passband



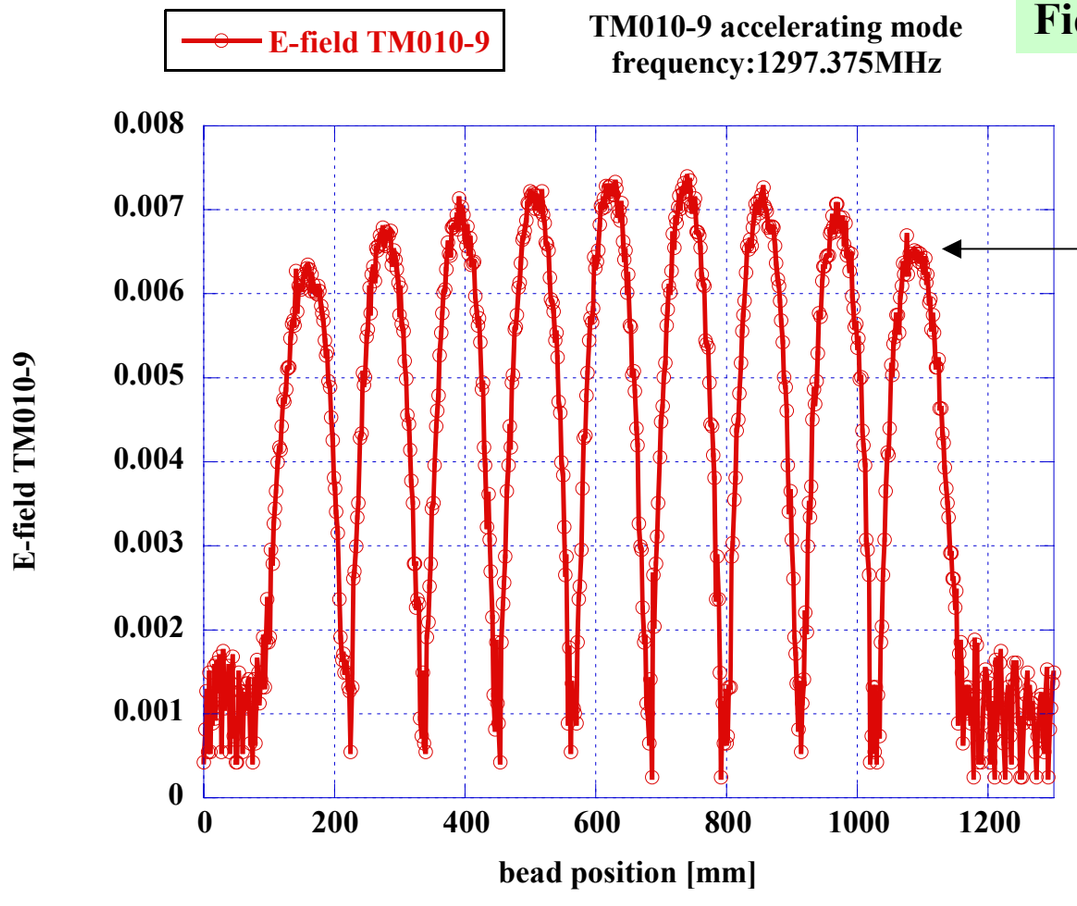
TM010 pass band

[MHz]

TM010-1	1271.350
TM010-2	1273.675
TM010-3	1277.175
TM010-4	1281.475
TM010-5	1286.050
TM010-6	1290.425
TM010-7	1294.125
TM010-8	1296.500
TM010-9	1297.375

Good frequency tuning for accelerating mode

2-1. TM010 field pattern



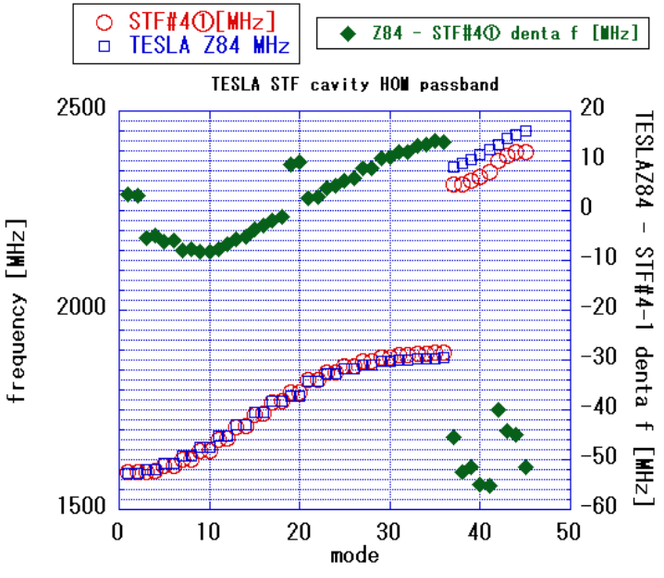
Field flatness was about 90 %

Amplitude of End cells were lowering in comparison with a center cells.

After EP, STF cavity also has a same tendency.

2-2. Main HOM passband

Frequency distribution of main HOMs



mode	TESLA [MHz]	STF [MHz]
TE111	1590 to 1780	1590 to 1770
TM110	1785 to 1880	1795 to 1895
TM011	2360 to 2450	2310 to 2400

Few MHz change due to EP and many pre-tuning.

R/Q comparison in TESLA and STF

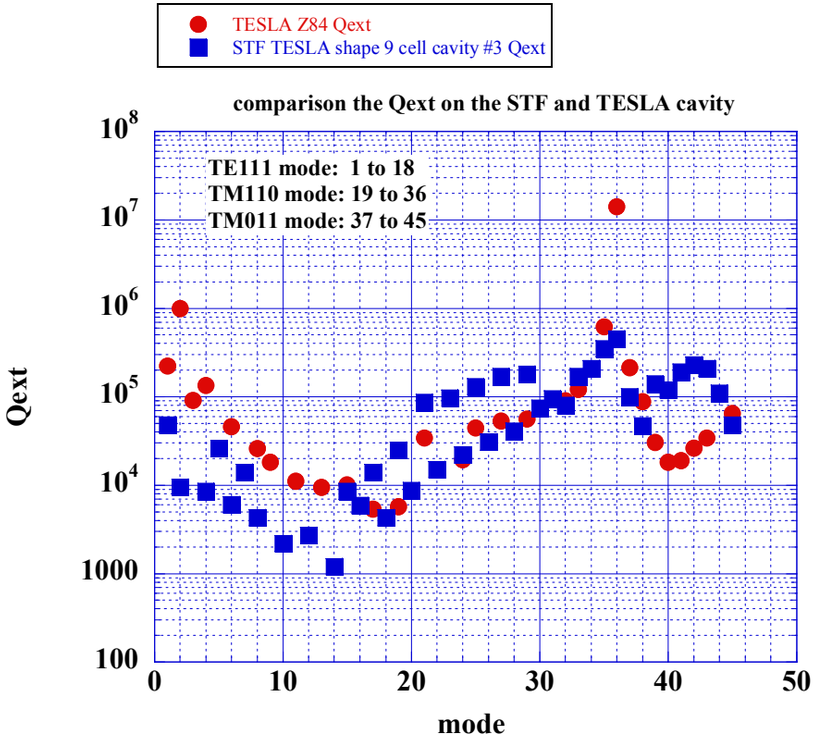
Mode dipole	TESLA R/Q [Ω/cm²]	STF R/Q [Ω/m]
TE111-1 (π/9)	0.01	22.4
-2	0.14	23.6
-3	0.03	43
-4	0.75	58.7
-5	0.04	46.1
-6	10	549
-7	15.4	2100
-8	2.23	793
TE111-9	1.4	43.2
TM110-1	0.71	119
-2	0.45	89.1
-3	0.33	52
-4	6.47	864
-5	8.75	1270
-6	1.83	394
-7	0.1	0.28
-8	0.18	20
TM110-9 (π/9)	0.01	0.0005

Mode Mono	TESLA R/Q [Ω]	STF R/Q [Ω/m]
TM011 -1(π)	0	0.33
-2	0.17	0.11
-3	0.65	3.31
-4	0.65	0.84
-5	2.05	8.65
-6	2.93	6.26
-7	6.93	37.8
-8	67.0	188
-9 (π/9)	79.5	96.8

Note: dipole mode unit is different.

Calculated by Anton (DESY) and E.Kako (KEK)

2-3. Qext value of HOMs



TM011 damping is weak in STF cavity.

More improvement as like a TESLA

(rotation angle etc…)

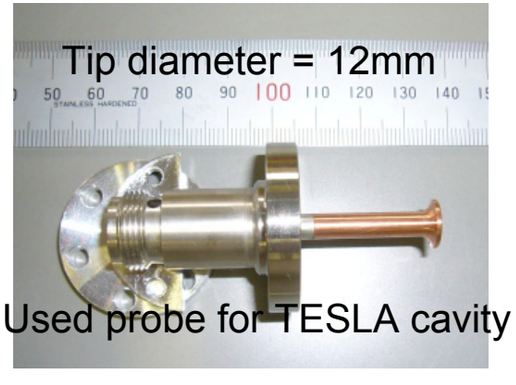
TE111 and TM110 is all most same.

Probe conditions:

TESLA Z84 : probe 12 mm, gap 0.3mm

STF #3 : probe 12mm, gap 2mm

STF cavity has a broad gap.



Used probe for TESLA cavity

both cavity were measured by room temperature

2-4. Polarization direction measurement

Important point : for HOM BPM etc…

1) The polarization angle of used dipole mode at each cell has same angle.

(linear polarize)

2) X and Y polarizations are separated for used dipole mode. 90 deg ?

(HOM BPM case : TE111-6)

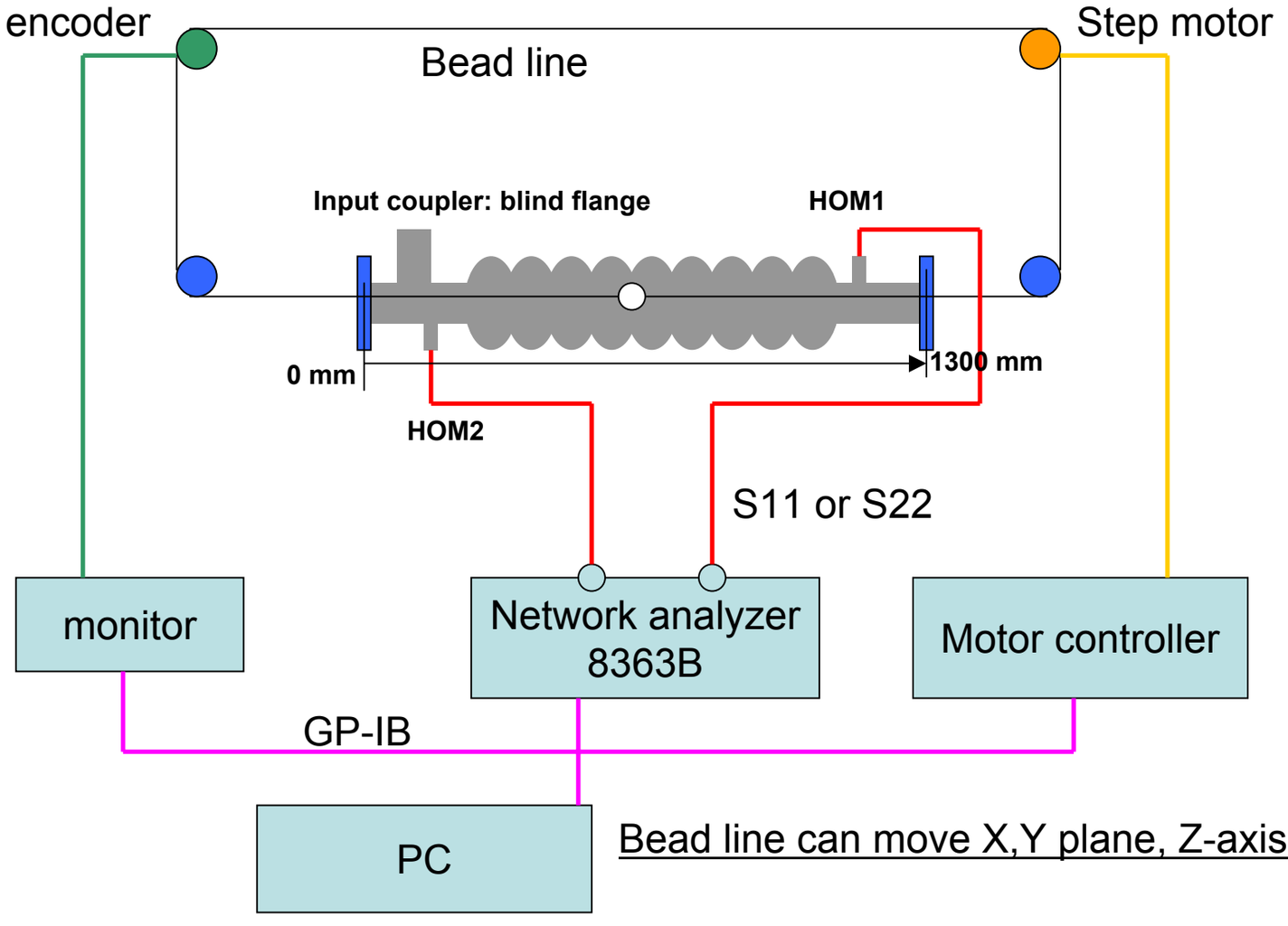
To check them, try to measure by using bead-pull method (off center scan).

Of course, we were known that TE111-6 mode can be used as HOM BPM. (good V-curve and phase response). But, to search the field distribution in inside cavity is important, and is useful to estimate the reasonable of the this mode.

Note : this measurement was one cavity only and room temperature.

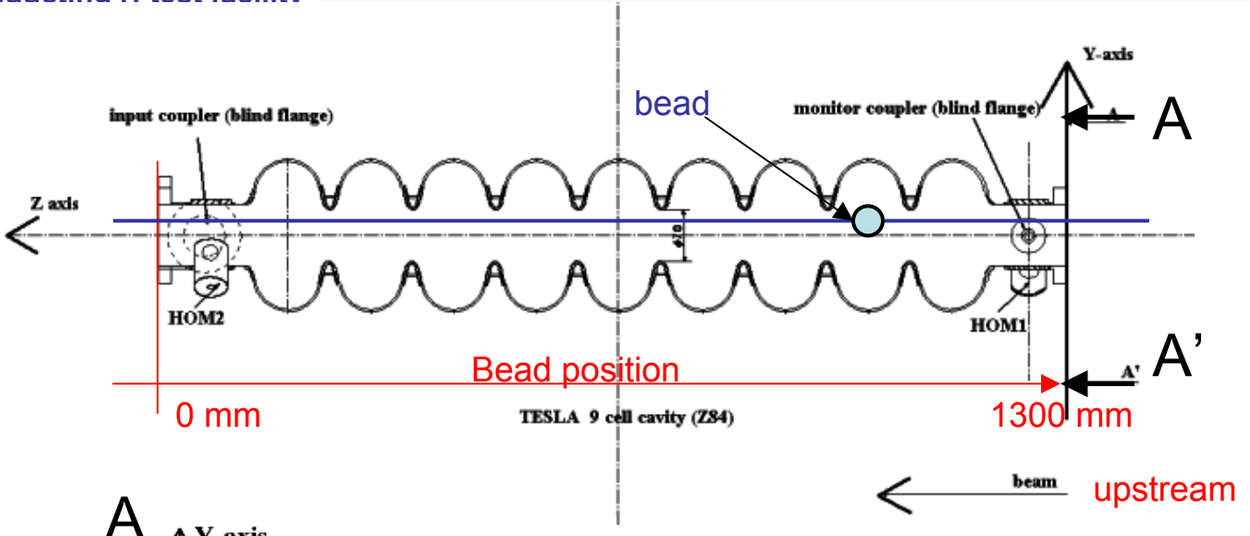
When 2K, the coupling beta of modes are changing. (so possible to change a polarization ?), But, 2K measurement is difficult. (beam ?)

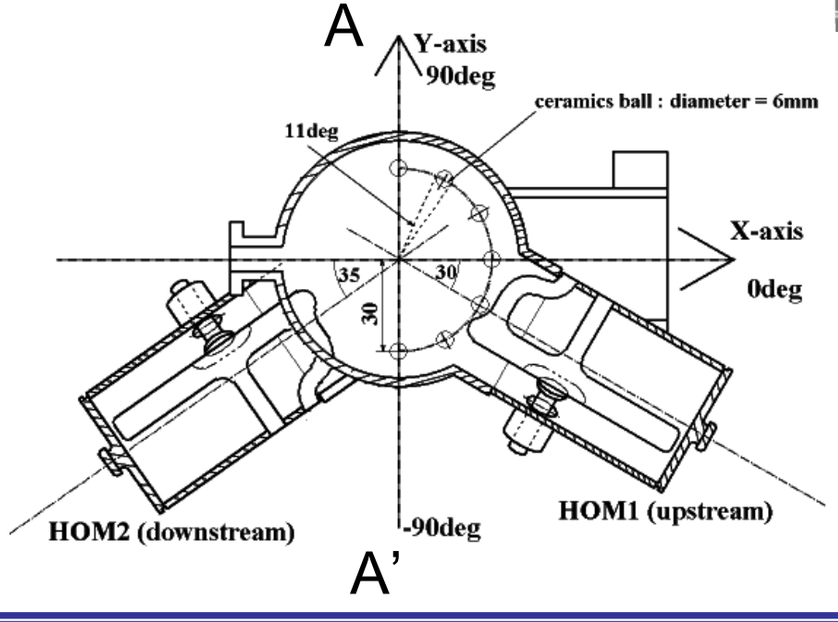
Set up (bead-pull measurement)



Bead line can move X,Y plane, Z-axis scan.

Define of polarize direction





Scan position

:off-center 30mm (+ - 0.4 mm, 1deg error)

:angle 90 to –90 deg, step 30 deg

(temperature: + - 0.2 degC / scan)

Total 7 scans per one mode.

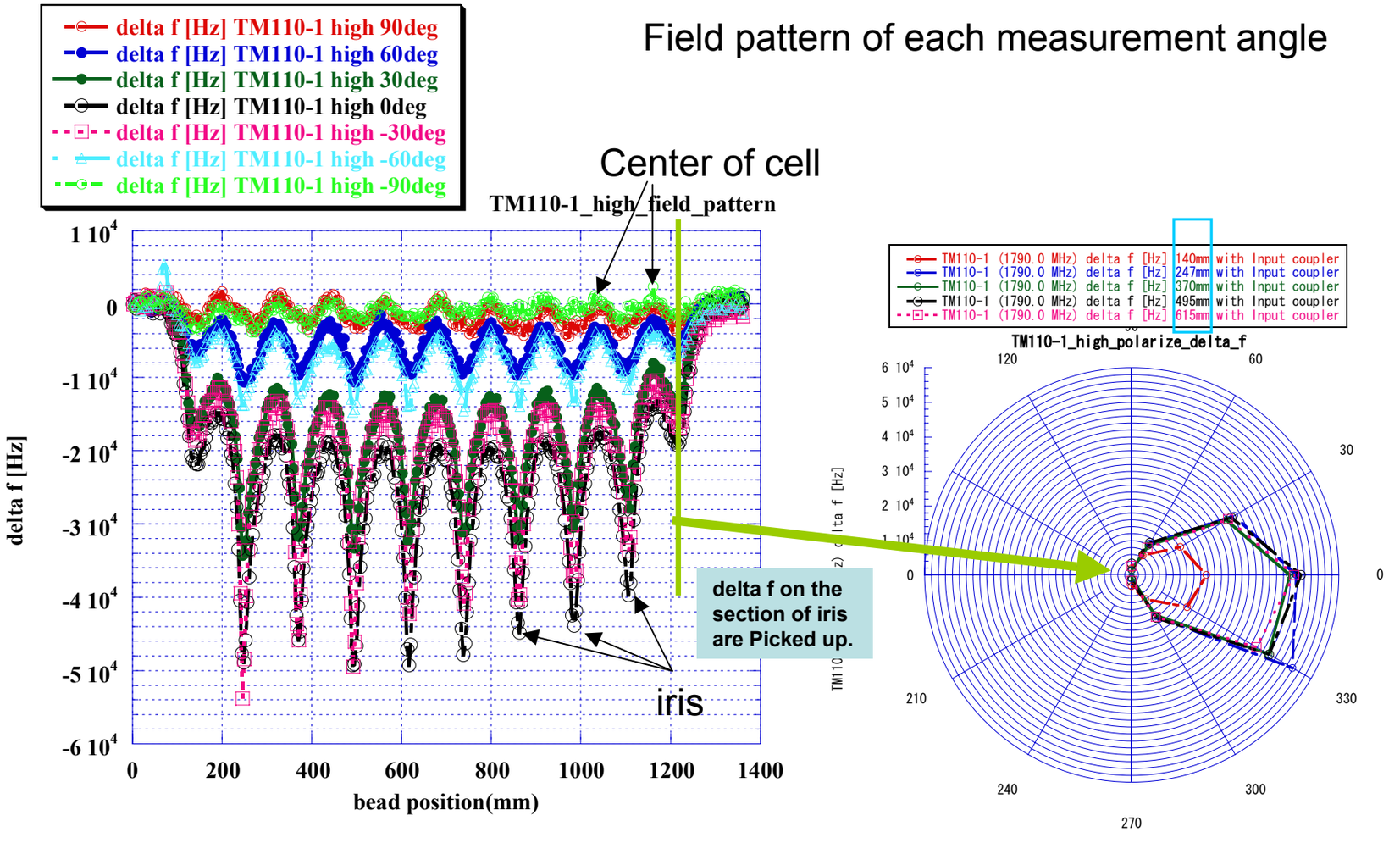
Bead : ceramics ball , diameter 6 mm

(only detect E-field for polarize measurement)

Measurement error : about < + - 7 deg.

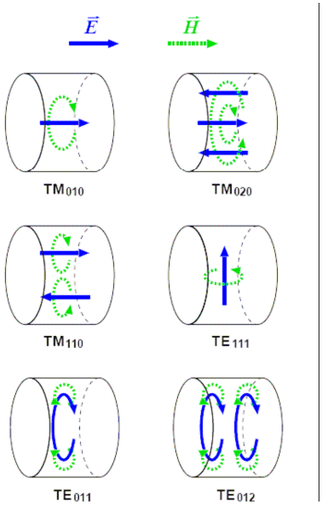
Sample: measurement data : TM110-1 (pi-mode)

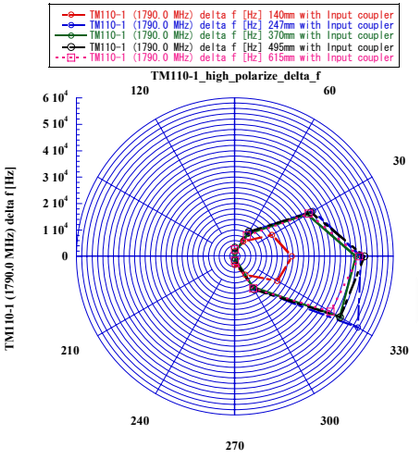
Field pattern of each measurement angle

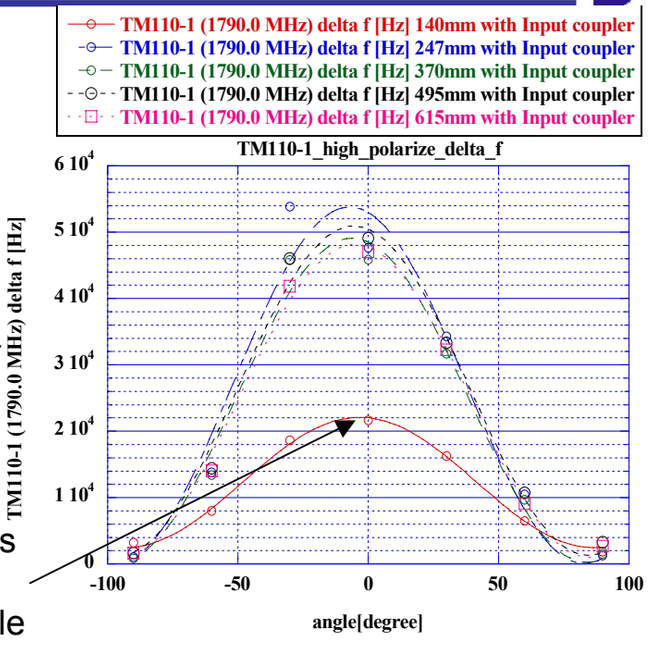


Plotted the polar coordinate

Sample: Data pick-up and fitting







Peak value is defined with polarize angle

TE11 and TM11 mode case :

E_ϕ in the R=R ?,when Z (beam axis) and R (off cebter) are decided, finally

$E_\phi \propto \cos(n\phi)$ or $-\sin(n\phi)$

From the relation of $E \propto (\text{delta f} / \text{f0})^{1/2}$

Become fitting function as

$\text{delta f} \propto A\cos^2(\phi+\xi)$

Where A is delta f, ξ is polarize angle.

Polarize angle and fitting error

y = m1*cos(m0+m3)^2+m4	値	エラー
m1	19030	624.61
m3	3.2516	1.0289
m4	2462.6	955.89
カイ２乗	1.4964e+6	NA
R	0.99799	NA

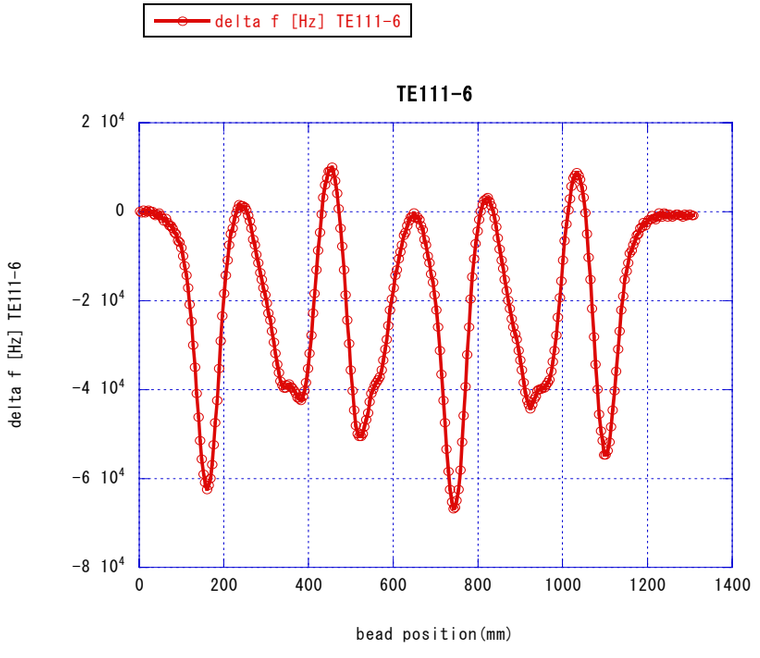
y = m1*cos(m0+m3)^2+m4	値	エラー
m1	53743	5954.9
m3	7.1084	3.5447
m4	57.458	3381
カイ２乗	1.3446e+8	NA
R	0.9764	NA

y = m1*cos(m0+m3)^2+m4	値	エラー
m1	48818	3515.2
m3	6.0963	2.3127
m4	263.29	1995.1
カイ２乗	4.706e+7	NA
R	0.98982	NA

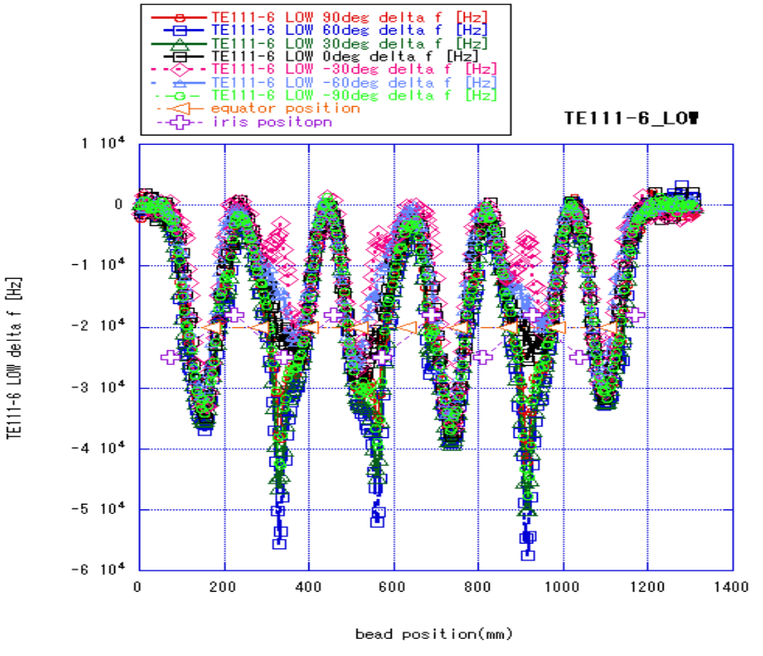
y = m1*cos(m0+m3)^2+m4	値	エラー
m1	49607	2912.2
m3	5.5219	1.8893
m4	1310.4	1652.5
カイ２乗	3.2372e+7	NA
R	0.99319	NA

y = m1*cos(m0+m3)^2+m4	値	エラー
m1	47150	1864.6
m3	5.0986	1.2744
m4	974.72	1057.9
カイ２乗	1.3291e+7	NA
R	0.99689	NA

Z84 TE111-6 low (1) by using HOM BPM



Center scan (metal ball diameter 6 mm)

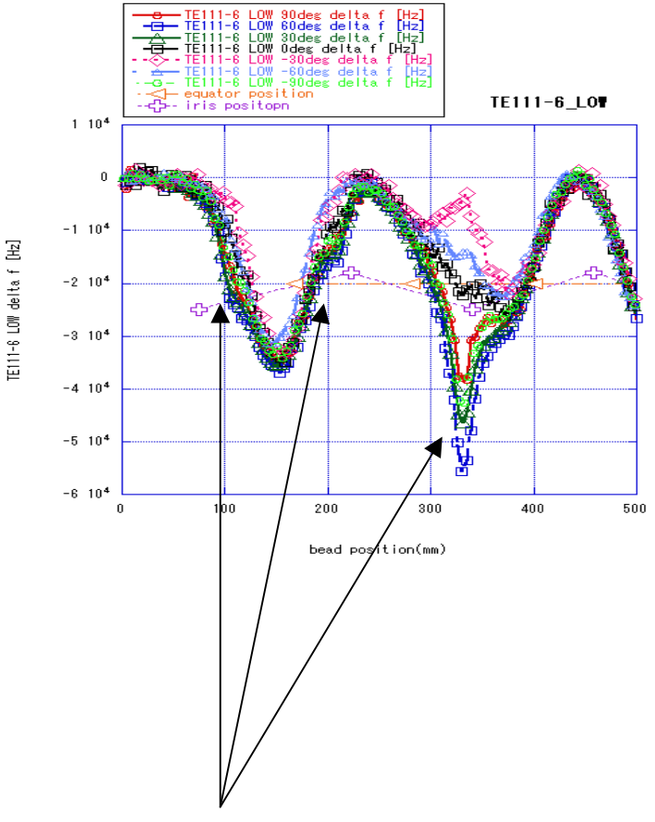


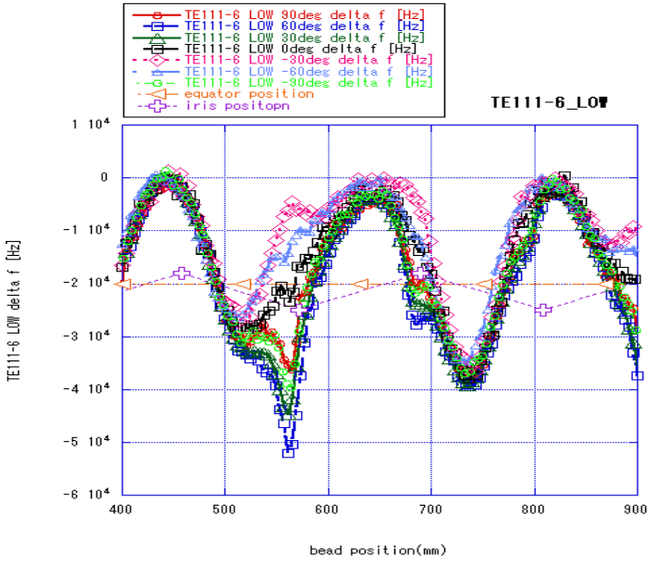
Off center scan

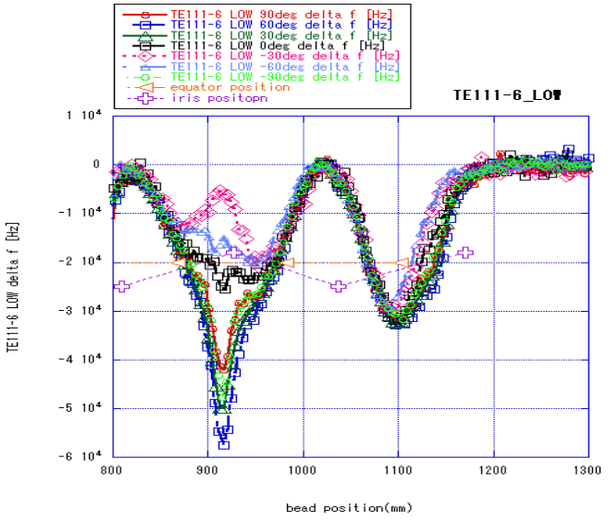
(ceramics ball diameter 6 mm)

Iris part changes delta f.

Z84 TE111-6 low (2)

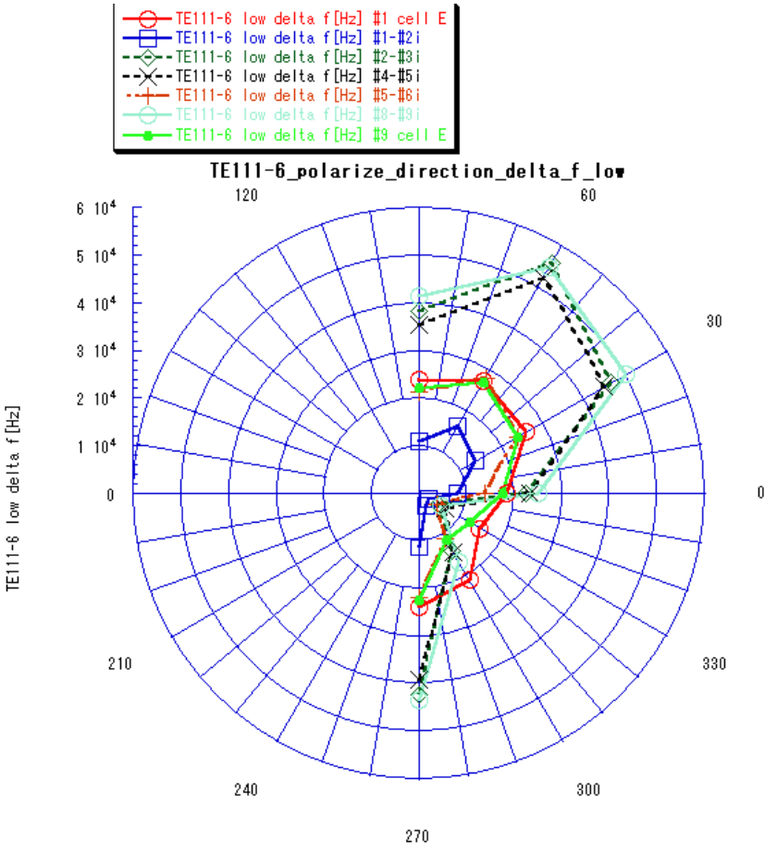


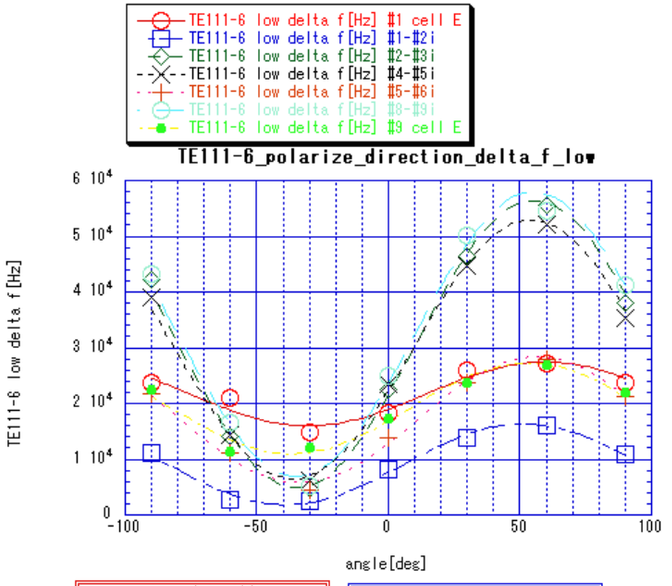




Polarize directions : Z84 TE111-6 low

superconducting rf test facility





y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	11453	1788.6
m3	-59.492	4.1866
m4	15986	1125.1
カイ２乗	1.0126e+07	NA
R	0.955	NA

y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	14507	826.6
m3	-51.063	1.4558
m4	1851.2	505.53
カイ２乗	2.0702e+06	NA
R	0.99359	NA

y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	51476	1833.3
m3	-55.366	0.92882
m4	4895.7	1136.9
カイ２乗	1.0372e+07	NA
R	0.99749	NA

y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	46404	1660.4
m3	-54.067	0.92647
m4	6486.3	1025.2
カイ２乗	8.4529e+06	NA
R	0.99746	NA

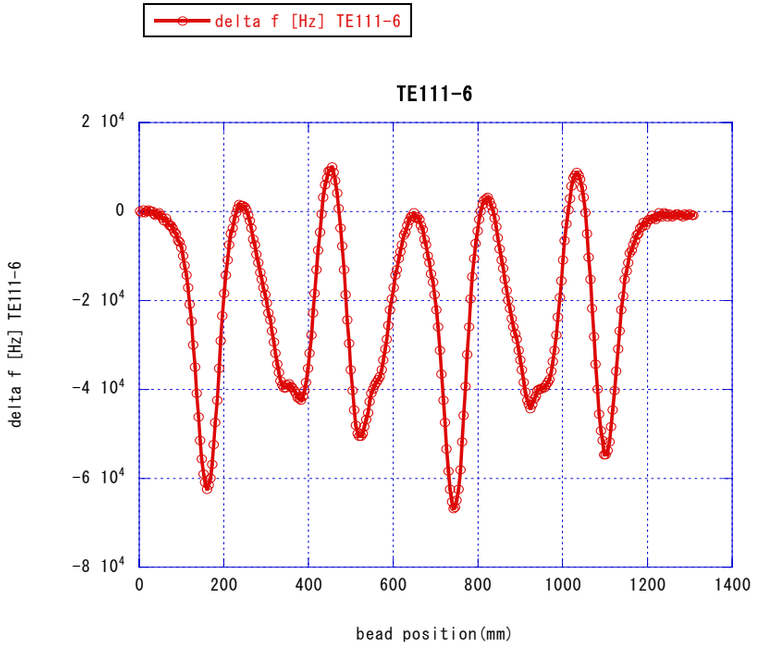
y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	22581	1171.8
m3	-56.293	1.361
m4	5803.4	728.95
カイ２乗	4.2594e+06	NA
R	0.9947	NA

y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	50979	2563.7
m3	-55.083	1.3094
m4	6941.1	1588.3
カイ２乗	2.0254e+07	NA
R	0.99501	NA

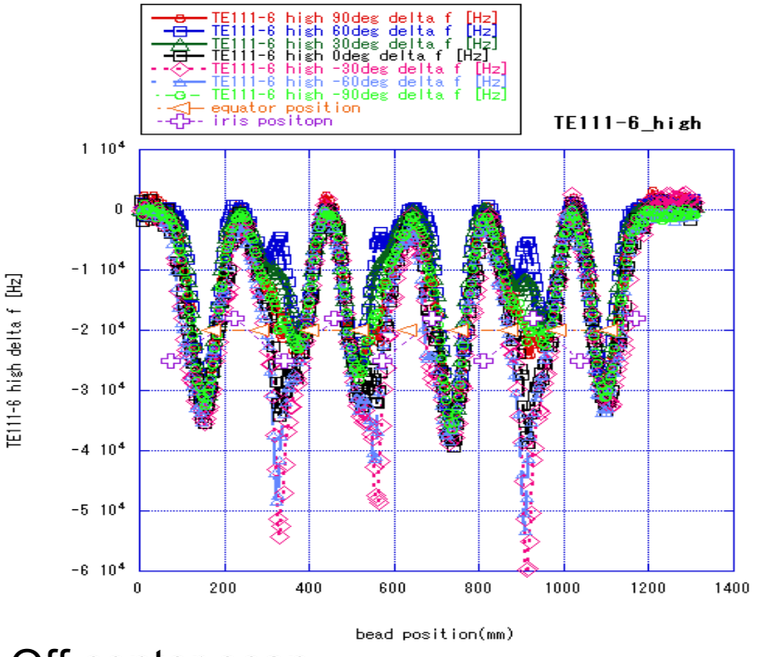
y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	16296	1687.8
m3	-53.09	2.6688
m4	10956	1038.9
カイ２乗	8.6966e+06	NA
R	0.9793	NA

Polarize angle is 55 deg

Z84 TE111-6 high (1) by using HOM BPM



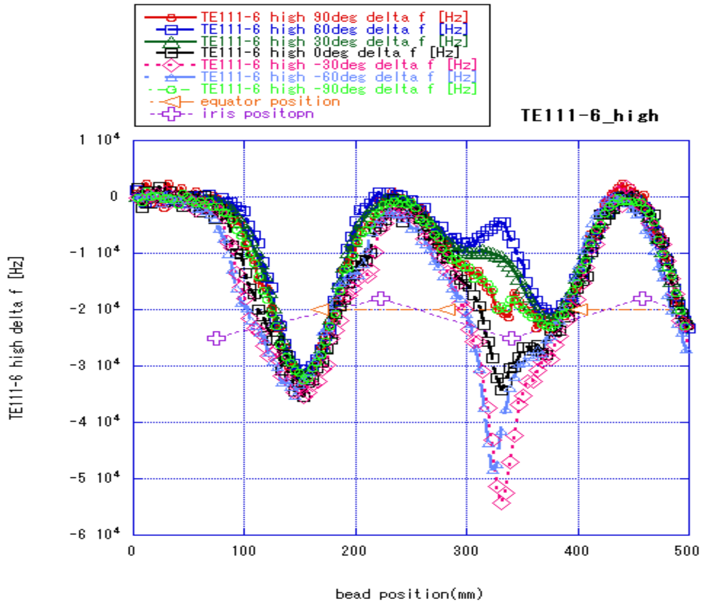
Center scan (metal ball diameter 6 mm)

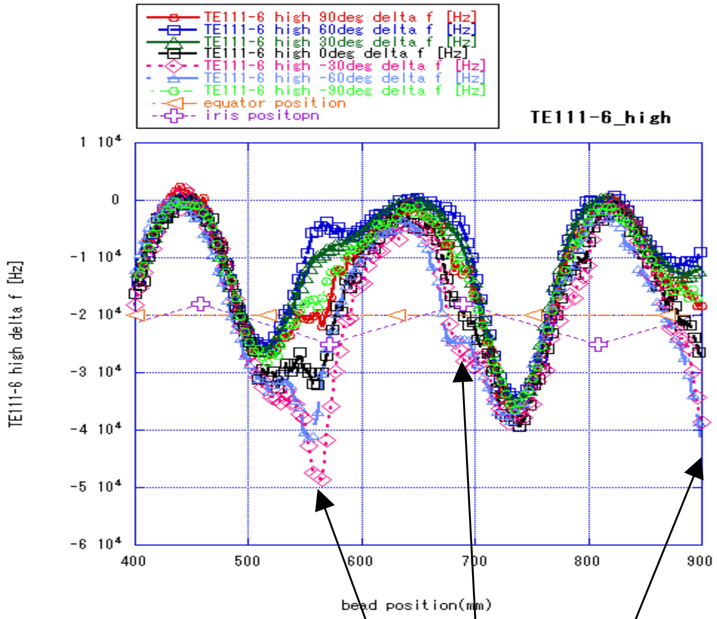


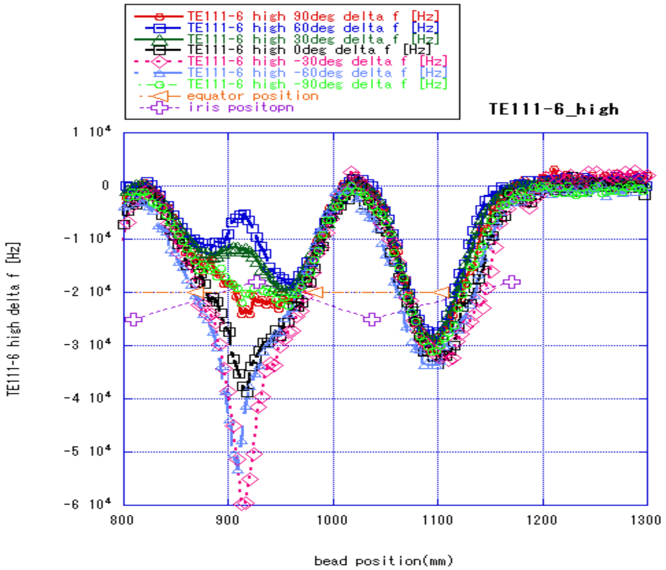
Off center scan

(ceramics ball diameter 6 mm)

Z84 TE111-6 high (2)

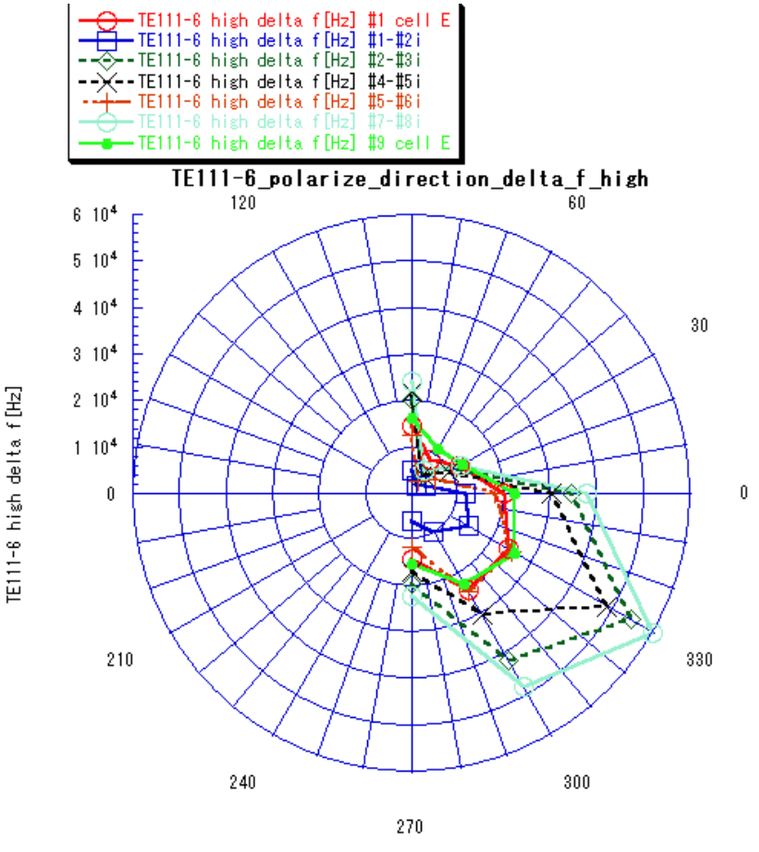


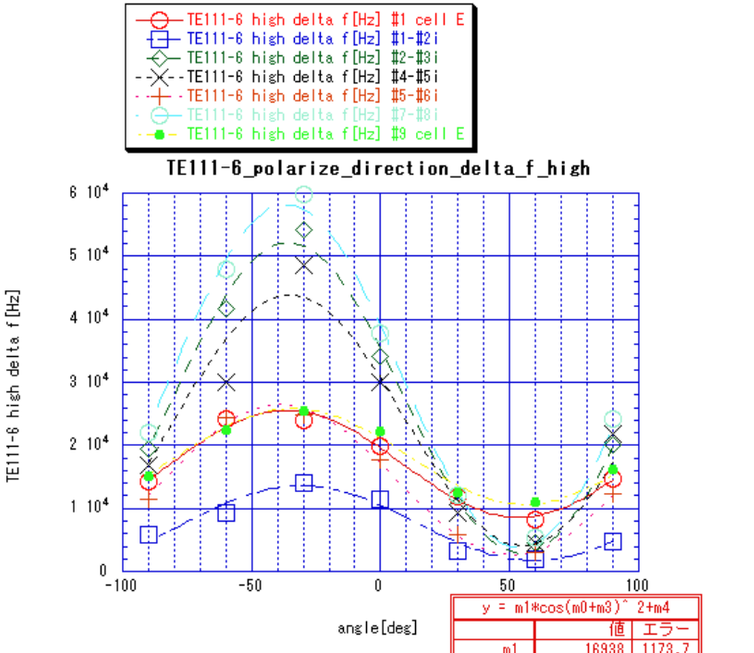




Iris part

Polarize directions : Z84 TE111-6 high





y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	16938	1173.7
m3	36.462	1.7893
m4	8590.5	691.05
カイ２乗	4.2132e+06	NA
R	0.99058	NA

y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	11854	1370.2
m3	30.741	3.0933
m4	1748.7	797.9
カイ２乗	5.9324e+06	NA
R	0.97458	NA

y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	49254	2207.6
m3	35.666	1.1622
m4	2886.8	1297.7
カイ２乗	1.4961e+07	NA
R	0.99603	NA

y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	39739	5555.6
m3	35.165	3.6348
m4	4114.9	3262.3
カイ２乗	9.498e+07	NA
R	0.96329	NA

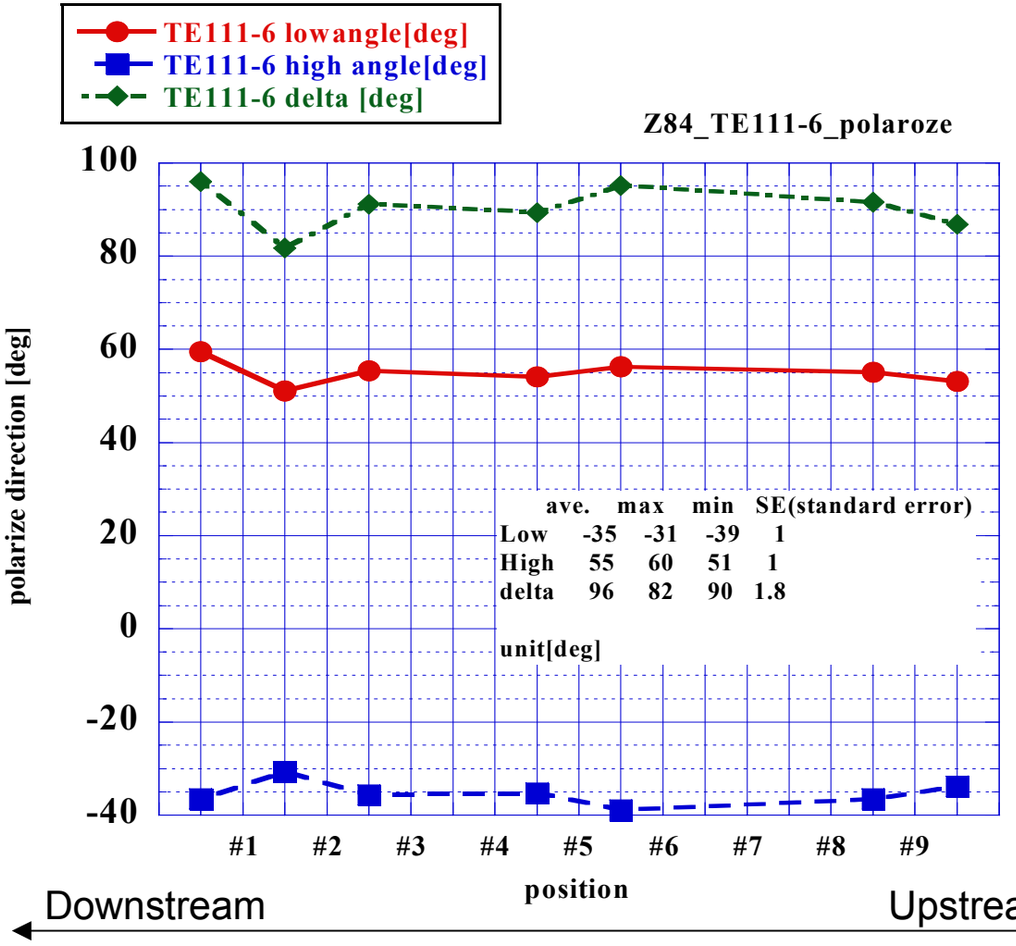
y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	23789	1017.3
m3	38.871	1.0928
m4	2674.2	602.13
カイ２乗	3.136e+06	NA
R	0.99637	NA

y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	54394	2065.6
m3	36.479	0.98052
m4	3795.3	1216.2
カイ２乗	1.3049e+07	NA
R	0.99714	NA

y = m1*cos(m0+m3)^ 2+m4		
	値	エラー
m1	15163	1019.3
m3	33.835	1.7616
m4	10678	596.97
カイ２乗	3.2201e+06	NA
R	0.99115	NA

Polarize angle is -35 deg

Polarize direction in Z84 TE111-6 : each cell distribution



Same polarize angle at each cell. (Linear polarize)

And separated X and Y polarization. (90deg)

STF cavity also was same tendency.

Summary table of polarize angle in each mode

Mode No.	TE111 : ave. (error), max, min [deg.]				TM110 : ave. error, max, min [deg.]		
	Low	High	Delta		Low	High	Delta
1	Ave. 19 (1.5) Max:23, Min:13	Ave. -68 (0.8) Max:-66, Min:-72	87 (2.0) Max:95,Min:80		Ave. 86 (0.6) Max89, Min:83	Ave.-1 (0.8) Max:3, Min:-4	87 (1.2) Max:92,Min:82
2	Ave. 23 (0.3) Max:24, Min:22	Ave. -67 (0.6) Max:-65, Min:-69	90 (0.8) Max:92,Min:88		Ave. 16 (0.4) Max:18, Min:14	Ave. -69 (1.1) Max:-60, Min:-73	86 (1.3) Max:90,Min:76
3	Ave. 18 (1.5) Max:28, Min:14	Ave. -76 (0.8) Max:-74, Min:-82	94 (2.1) Max:110,Min:90		Ave. -56 (0.3) Max:-54, Min:-58	Ave. 40 (0.7) Max:43, Min:37	96 (0.7) Max:99,Min:93
4	Ave. 17 (0.6) Max:21, Min:16	Ave. -74 (0.4) Max:-73, Min:-76	90 (0.6) Max:94,Min:89		Ave. 77 (0.8) Max:82, Min:74	Ave. 4 (1.4) Max:13, Min:0	74 (1.7) Max:80,Min:63
5	Ave. 49 (0.5) Max:52, Min:46	Ave. -45 (0.6) Max:-43, Min:-48	93 (1.0) Max:99,Min:89		Ave. 27 (1.7) Max:31, Min:12	Ave. 87 (3.2) Max:111, Min:77	60 (4.1) Max:82,Min:47
6	Ave. 55 (1.0) Max:60, Min:51	Ave. -35 (1.0) Max:-31, Min:-39	91 (1.8) Max:96,Min:82		Ave. 93 (1.1) Max:98, Min:86	Ave. 9 (1.0) Max:15, Min:5	84 (1.9) Max:93,Min:74
7	Ave. 52 (0.9) Max:56, Min:49	Ave. -38 (0.5) Max:-36, Min:-40	91 (0.9) Max:93,Min:86		Ave. 115 (1.0) Max:119, Min:109	Ave. 30 (1.0) Max:37, Min:27	86 (1.9) Max:92,Min:73
8	Ave. 43 (0.5) Max:45, Min:41	Ave. -46 (0.5) Max:-43, Min:-49	90 (0.5) Max:92,Min:88		Ave. 81 (2.7) Max:96, Min:69	Ave. -5 (0.9) Max:-2, Min:-9	86 (3.0) Max:100,Min:72
9	Ave. 37 (0.6) Max:40, Min:35	Ave. -49 (0.6) Max:-46, Min:-51	86 (1.1) Max:91,Min:81		Ave. 97 (2.5) Max:107, Min:88	Ave. 13 (1.3) Max:17, Min:10	82 (3.5) Max:91,Min:72

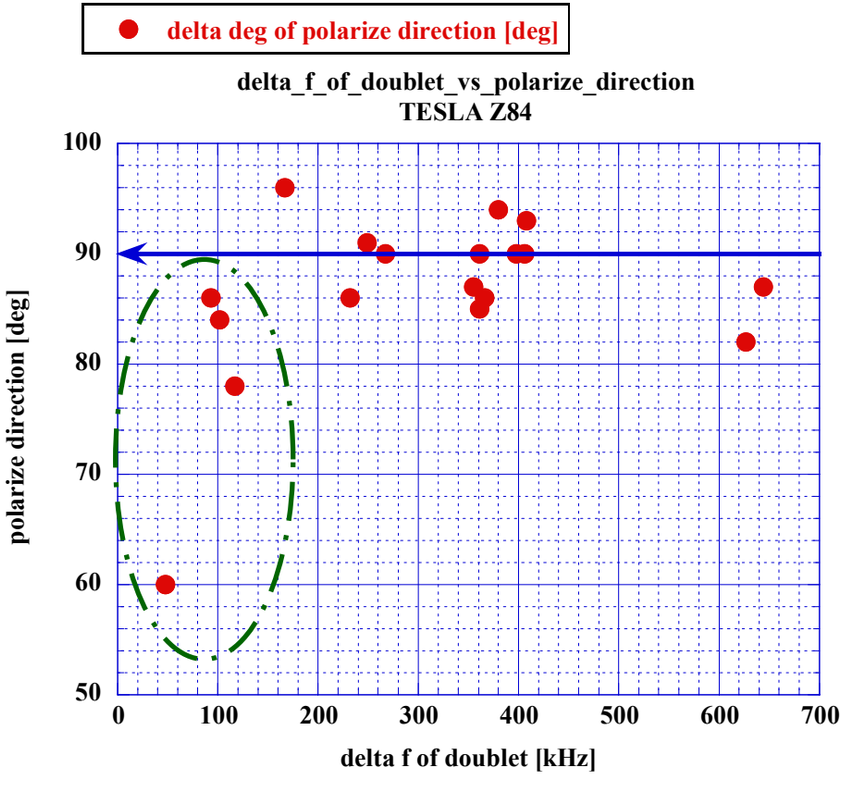
TE111-1,2,3,4 were same, and TE111-5,6,7,8,9 were same.

TM110 modes had a various angle.

Error: standard error,

Delta: High – Low [deg]

Delta f [Hz] vs delta angle [deg] in doublet of dipole mode



When the delta f [Hz] of doublet is small less than about 100 kHz, its delta angle is not 90 deg. due to the overlap each other of doublet.

mode	Delta f [kHz] of doublet	Delta angle [deg] of doublet
TE111-1	644	87
-2	361	90
-3	380	94
-4	249	91
-5	408	92
-6	398	90
-7	406	90
-8	267	90
-9	366	86
TM110-1	355	87
-2	361	85
-3	167	96
-4	117	78
-5	48	60
-6	102	84
-7	232	86
-8	93	86
-9	627	82

2-5. Difference of Electrical mode and Mechanical center

To used HOM as cavity alignment, agreement of electrical mode and mechanical center is important.

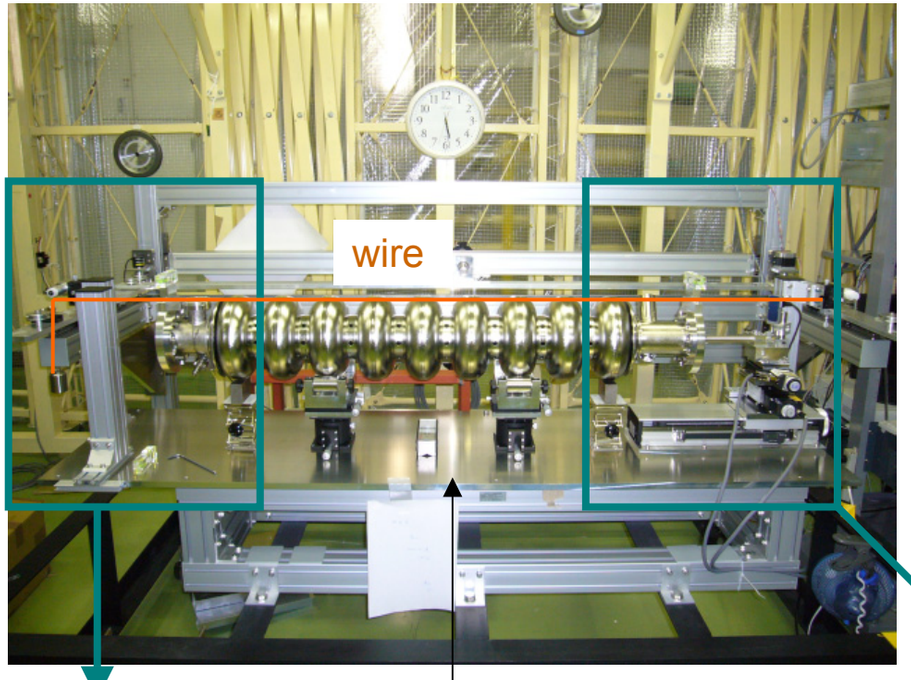
We tried to be measurement it by using antenna scan method.

How does it see a result ?, Is this method possible ?

In addition, we tried to be cross-check the polarize direction by measured bead-pull method.

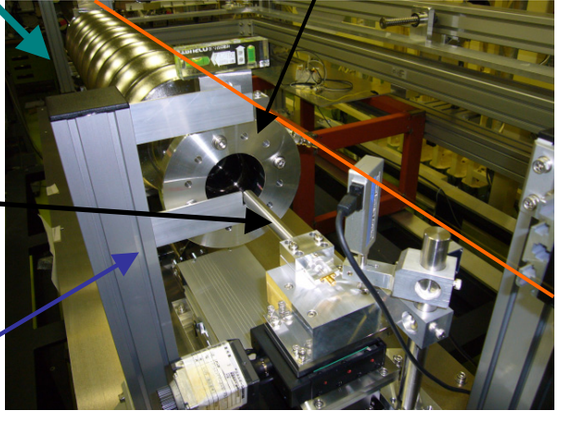
Measured polarize direction by bead pull method and the orthogonal axis of it scanned.

Picture of antenna scan system (HOM stand at STF)



Dummy flange : Alignment target

Wire (diameter = 70 um)



Reference plane (plate)

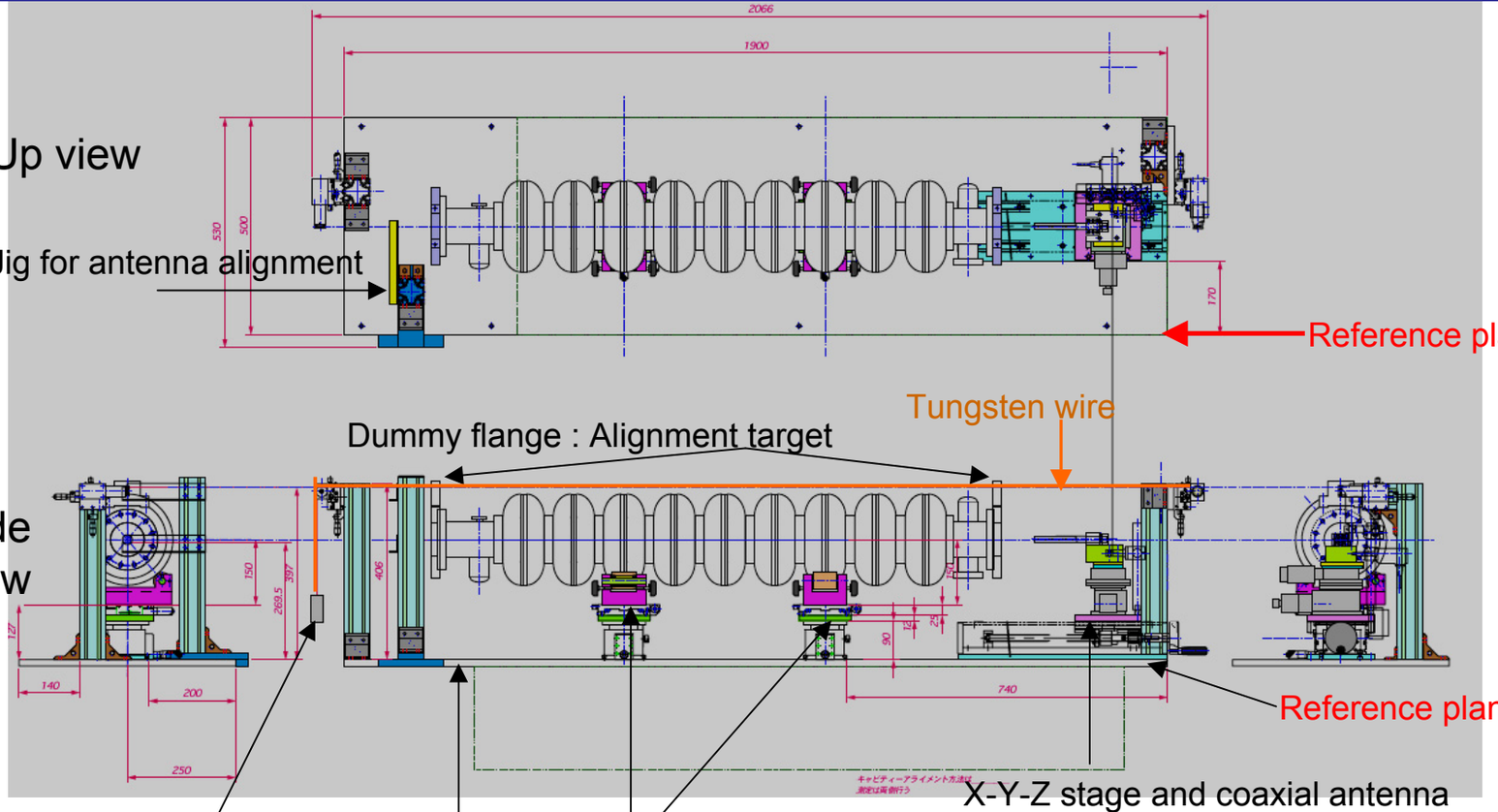
Coaxial antenna

Rotate reference :
Input coupler

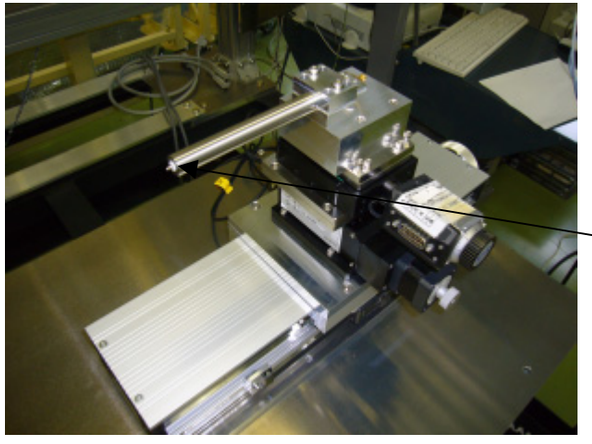
Jig for alignment

Detail setup

Alignment target (antenna center and cavity center [beam pipe center]): <100 um

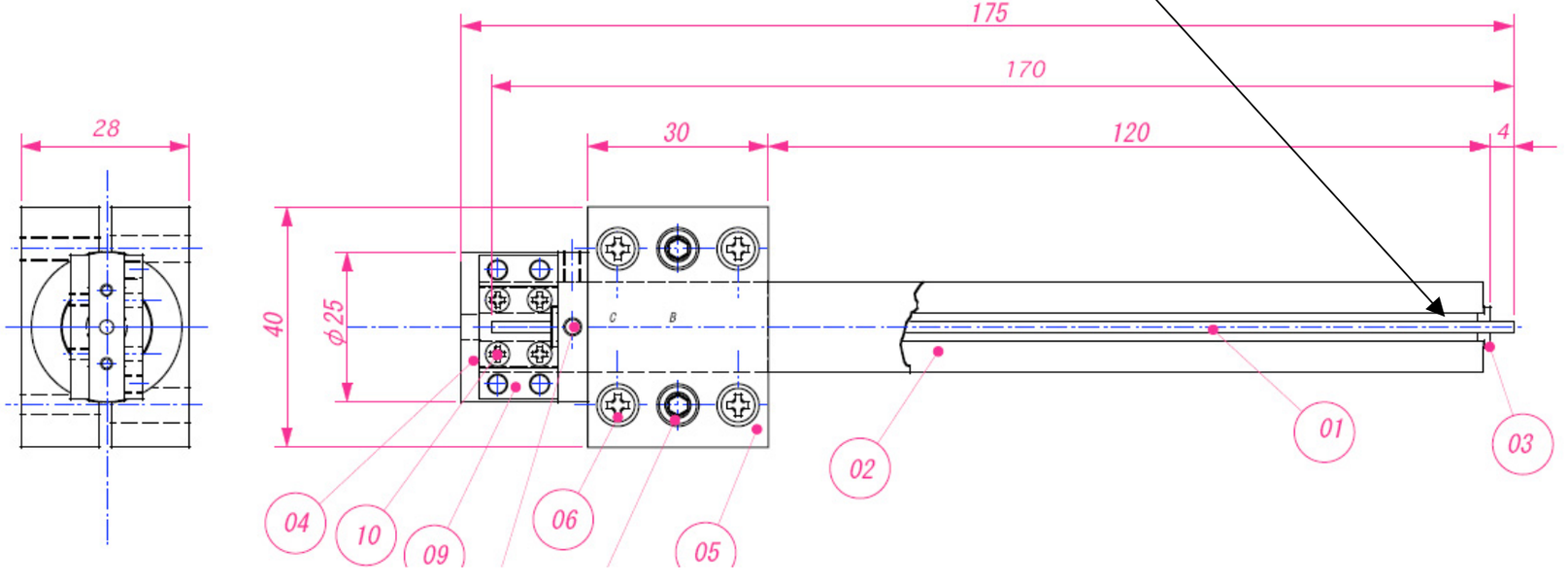


Coaxial antenna for antenna scan

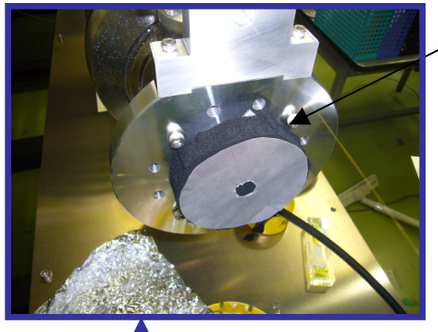


Concentricity target : 100 um

Machinable ceramics

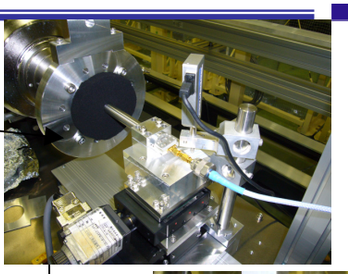


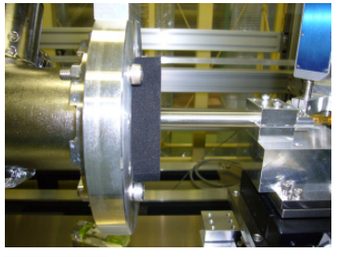
condition-1

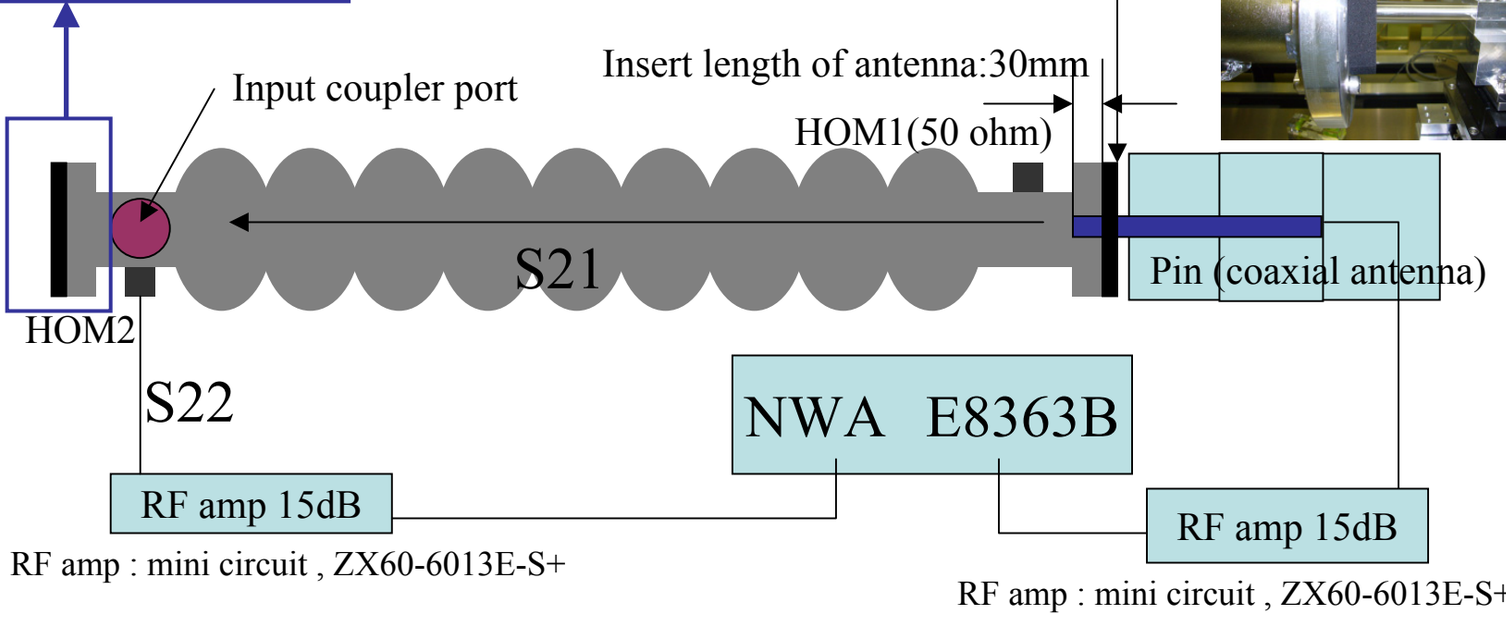


Microwave absorber

To stabilize a RF signal.



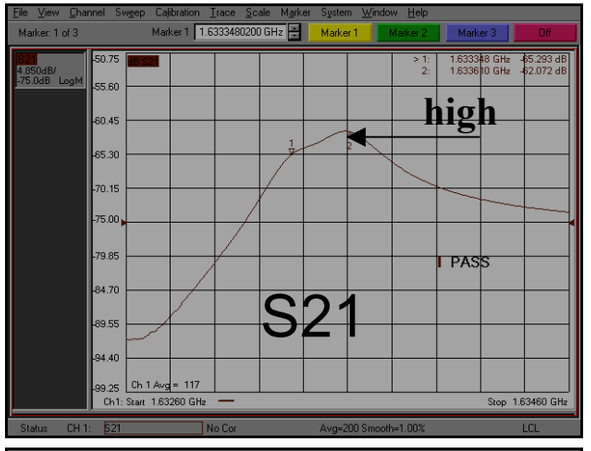


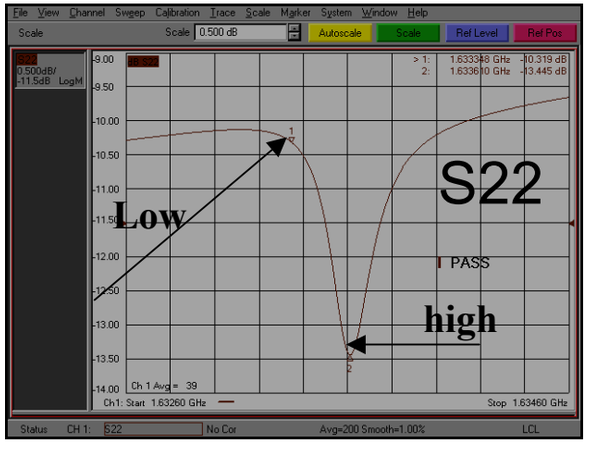


Measured S21(transmission) max search vs antenna position

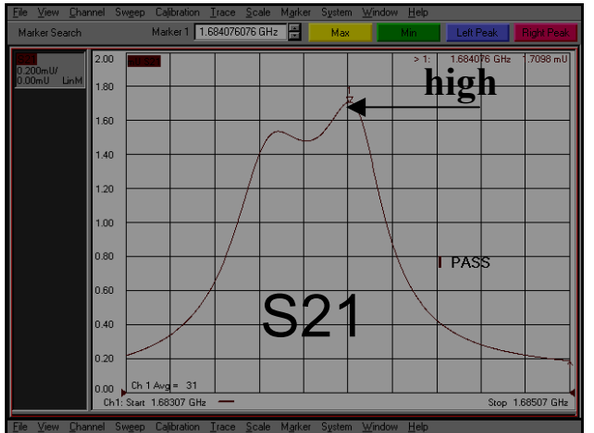
Spectrum of condition-1 (HOM2 S22 and S21)

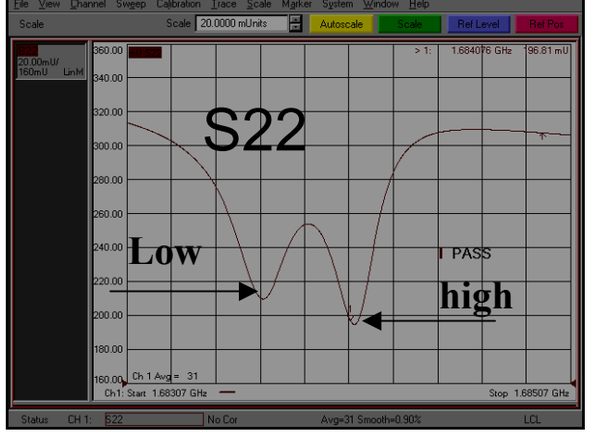
Single peak (TE111-4)





Twin peak (TE111-6)

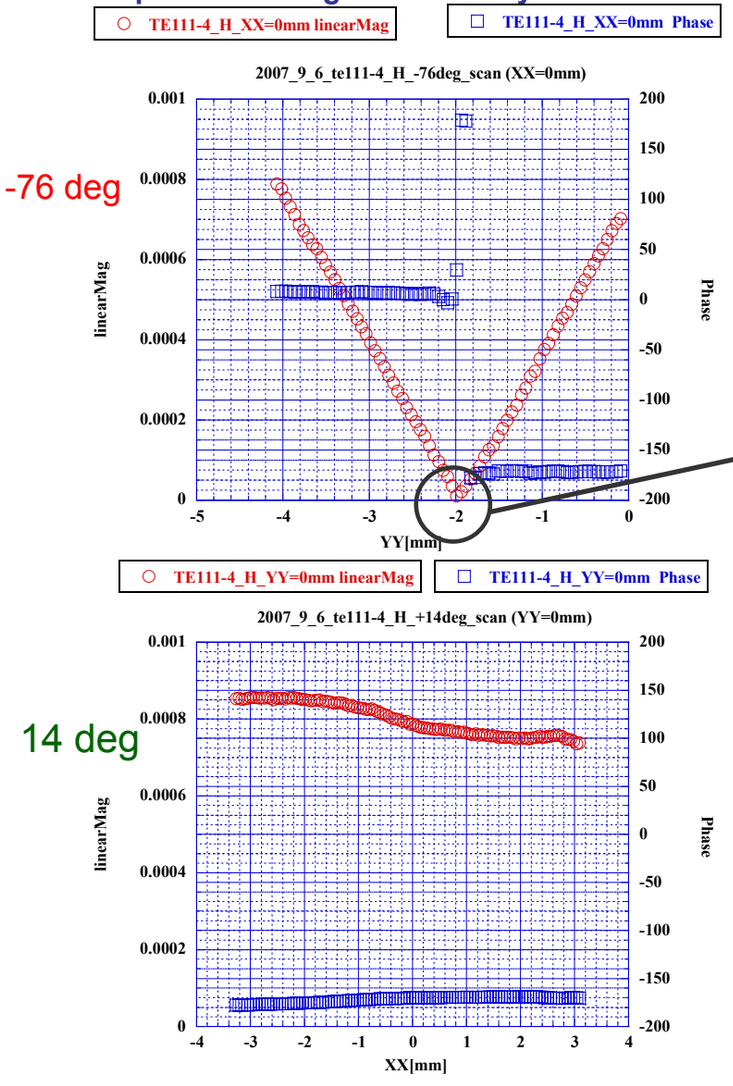


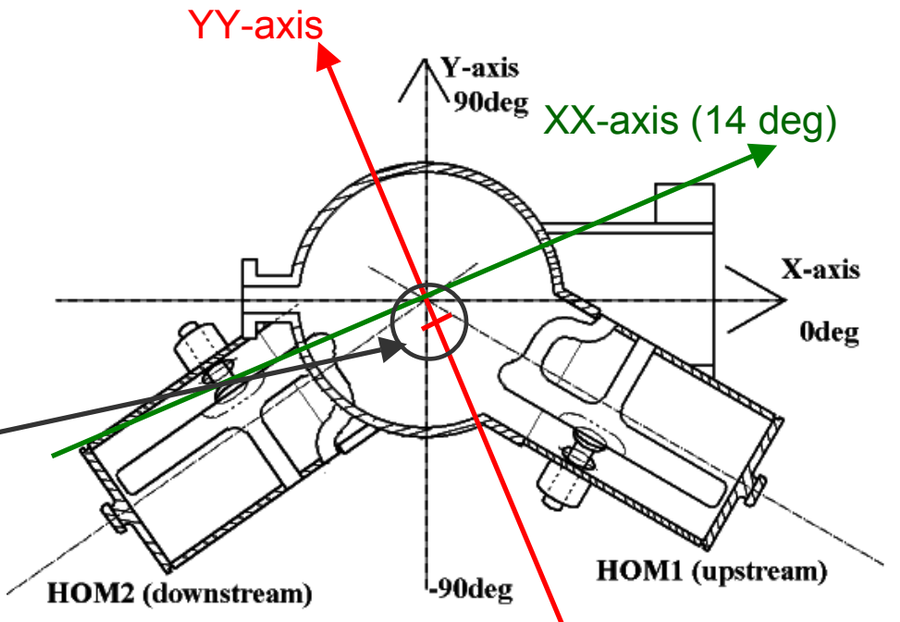


Spectrum pattern (S22) dependent on the polarize direction

Try measurement with both case

Single peak (mode : TE111-4 high peak)





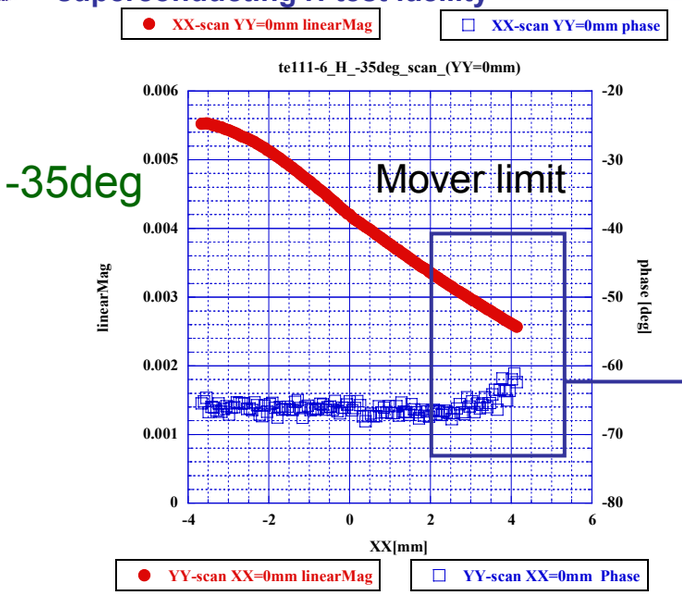
High peak: polarize direction = -76 deg

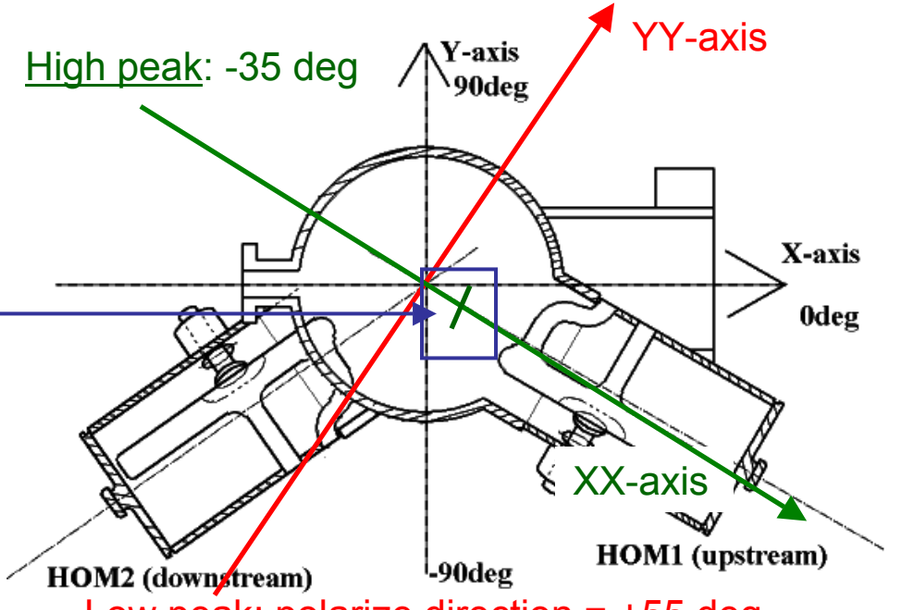
Measured by bead-pull method

This mode could be observed V-curve, this signal was very good. And orthogonal axis of YY scanned, XX-axis was no response to amplitude and phase.

Measured polarize angle by bead-pull method, and antenna scan result was same polarize angle. Could be cross-check to both method result.

Twin peak (mode : TE111-6 high peak)





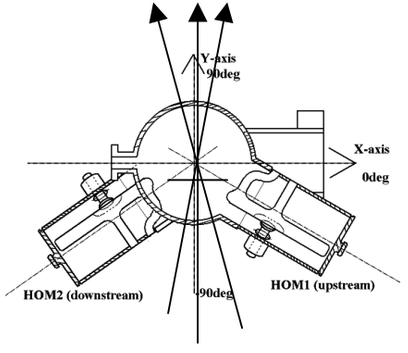
Low peak: polarize direction = +55 deg

High peak and Low peak is orthogonal.

This mode had the response (amplitude and phase), but could not be observed V-curve at the mover area. However, in scanning the orthogonal axis of YY, had the phase response. Maybe signal had a possibility mode mix.

Result of condition-1

mode		HOM2 (reflection) condition-1	Polarize direction (bead)	Off-center [deg]
TE111-1		Single peak : High	L: 19deg, H: -68 deg	- 2.6 mm
TE111-2		Single peak : High	L: 23deg, H: -67 deg	- 2.4 mm
TE111-3		Single peak : High	L: 18deg, H: -76 deg	- 1.5 mm
TE111-4		Single peak : High	L: 17deg, H: -74 deg	- 2.0 mm
TM110-4		Single peak : Low	L: 77deg, H: 5 deg	- 0.5 mm
TM110-5		Single peak : High	L: 27deg, H: 87 deg	- 1.5 mm
TM110-6		Single peak : Low	L: 93deg, H: 9 deg	- 1.0 mm
TM110-8		Single peak : Low	L: 81deg, H: -4 deg	+ 0.8 mm
TM110-9		Single peak : Low	L: 98deg, H: 13 deg	- 0.4 mm



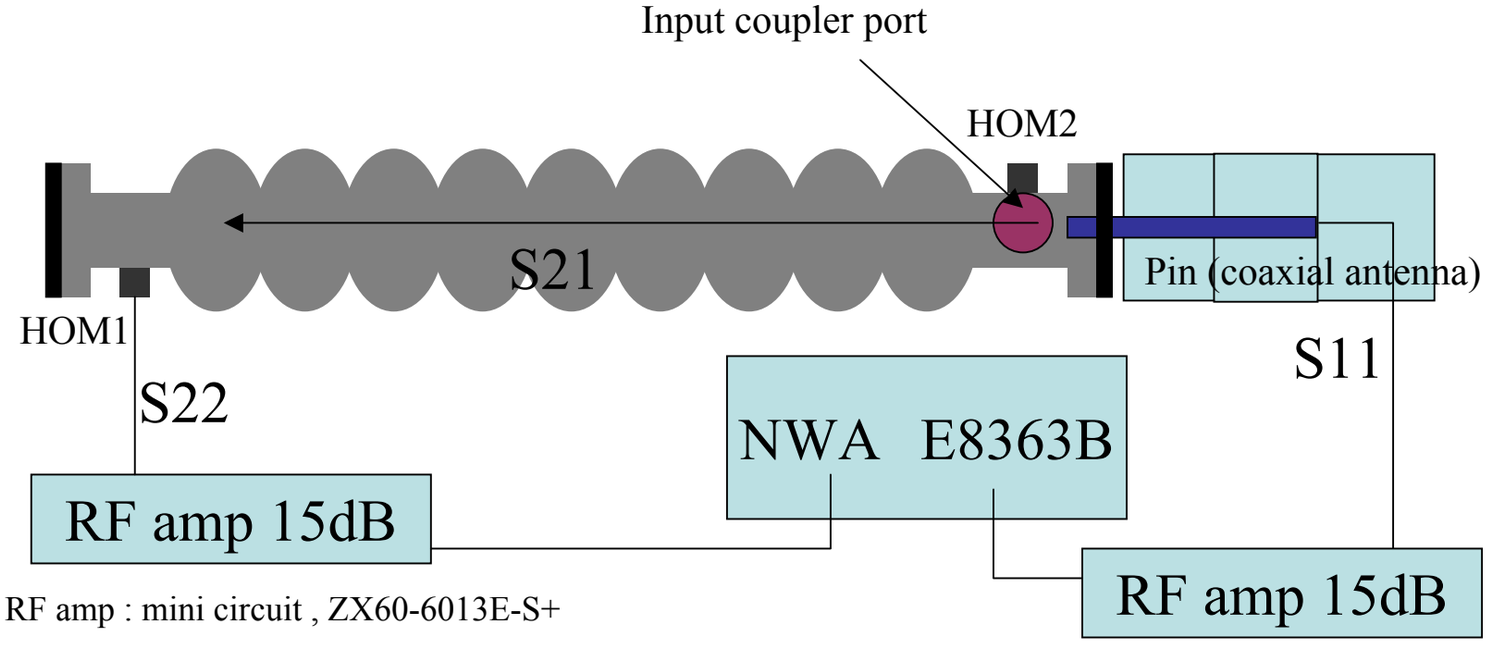
Could be measured a single peak coupling mode only. Other modes were twin peak at HOM2 reflection.

Twin peak case, could be seem response of dependence antenna position, but could not observe a V-curve.

The off-center had the shifting HOM coupler side, about few millimeters.

Note, this measurement has the strong effect of the end cell, not all cells.

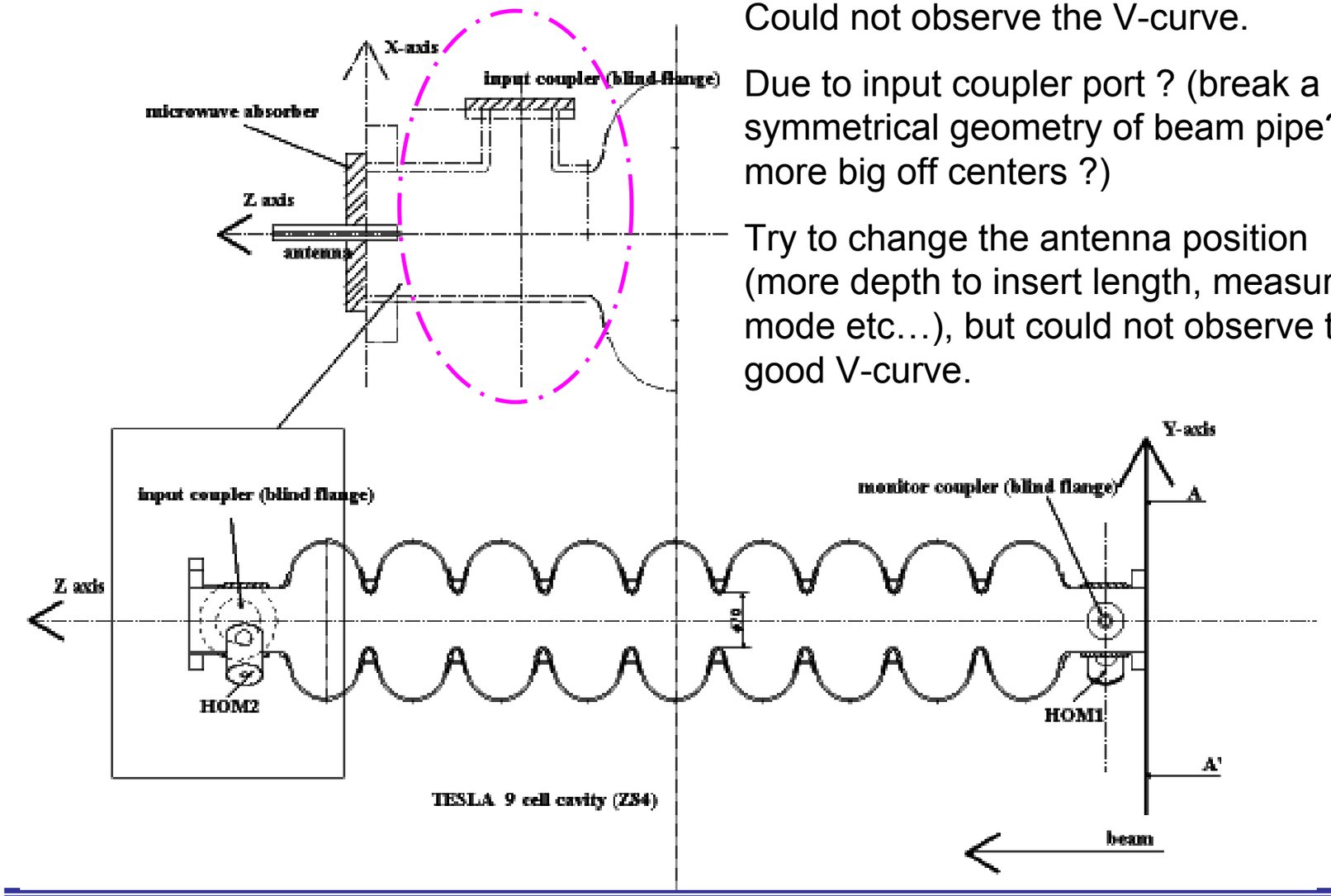
Condition-2



Changed cavity position!!

Excited from HOM2 side, pick-up from HOM1 port.

Result of condition-2



Could not observe the V-curve.

Due to input coupler port ? (break a symmetrical geometry of beam pipe? Or more big off centers ?)

Try to change the antenna position (more depth to insert length, measured mode etc…), but could not observe the good V-curve.

3. Conclusion

Measurements of HOMs for the HOM BPM and the cavity miss-alignment was made with TESLA cavity (Z84) at KEK in this summer.

1) Accelerating mode frequency was very good for 2K operation. Field flatness was about 90%.

2) TE111 and TM110 passband was all most same, but TM011 was different about -50 MHz lower than TESLA.

3) TE111 and TM110 Qext was all most same, but TM011 was weak in STF cavity, more improvement to obtain the strong damping as like the TESLA.

4) All dipole mode polarize direction at each cell were the linear polarize. Not circular polarize. Made a table all TE111 and TM110 passband of polarize directions.

When the doublet delta f [Hz] is small less than 100 kHz, its delta angle is not 90 deg. Due to the overlap each other of doublet.

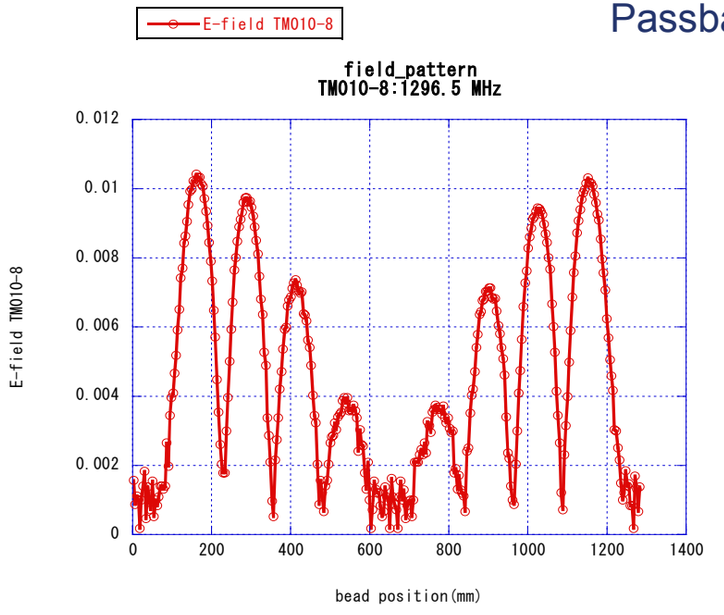
5) Measured polarize angle by bead-pull method, and antenna scan result was same polarize angle. Could be cross-check from both method result.

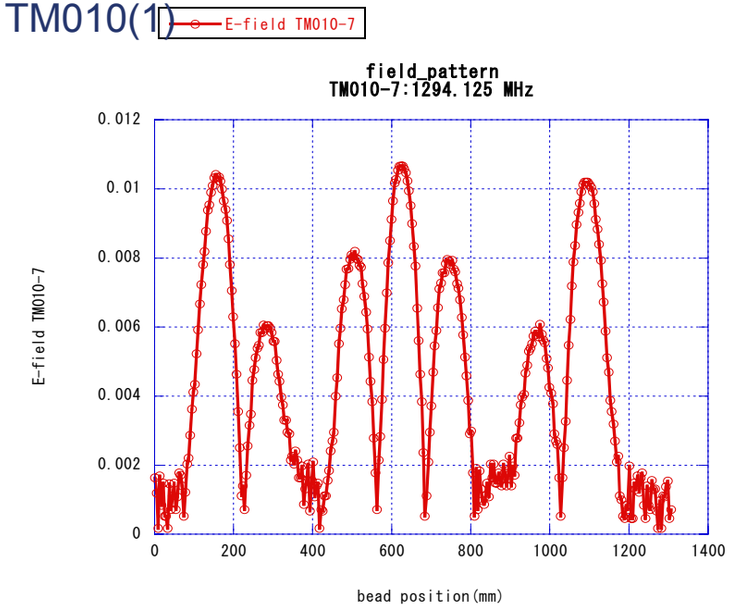
Could observe the V-curve at single peak coupling modes, in this case, off-center had the shifting HOM coupler side, about few millimeters. However, this measurement has the strong effect of the end cell.

The twin peak mode and HOM2 side exited case could not measure these.

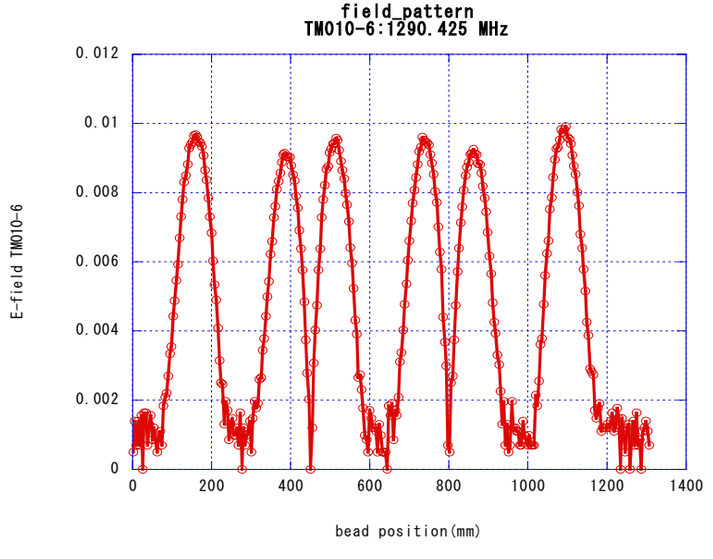
Thank you for your kind attention !!

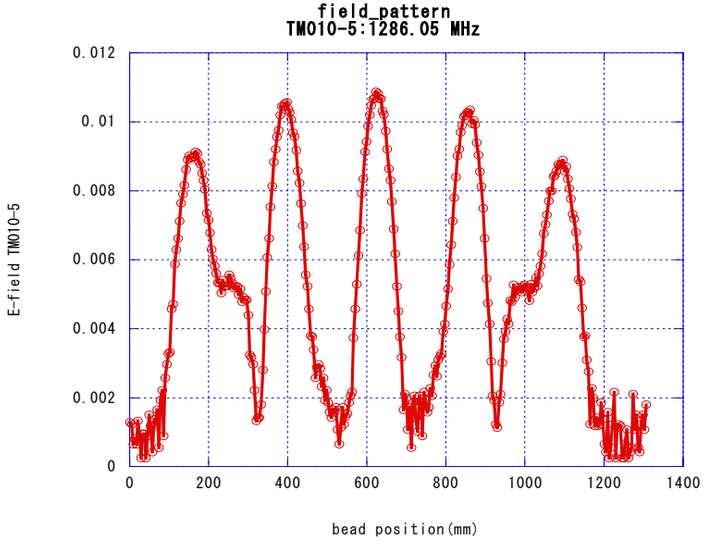
Passband TM010(1)



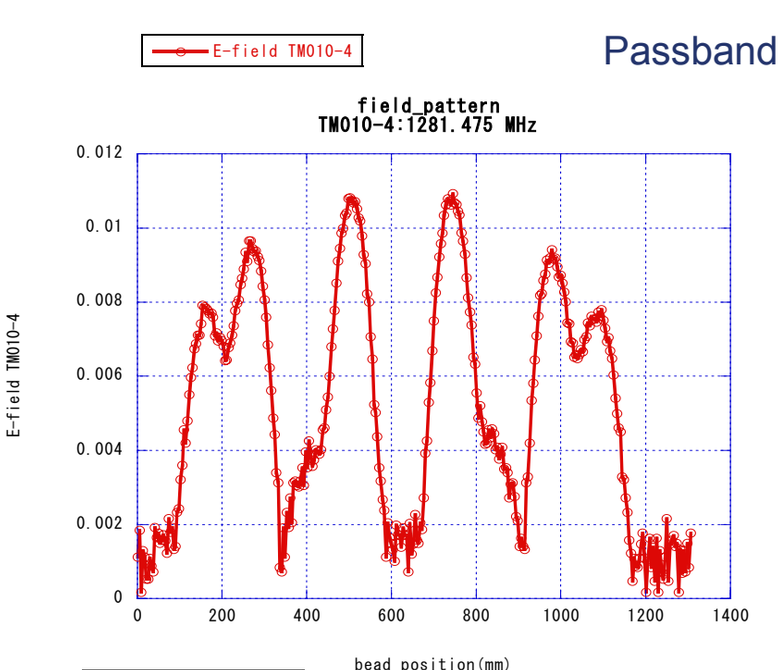


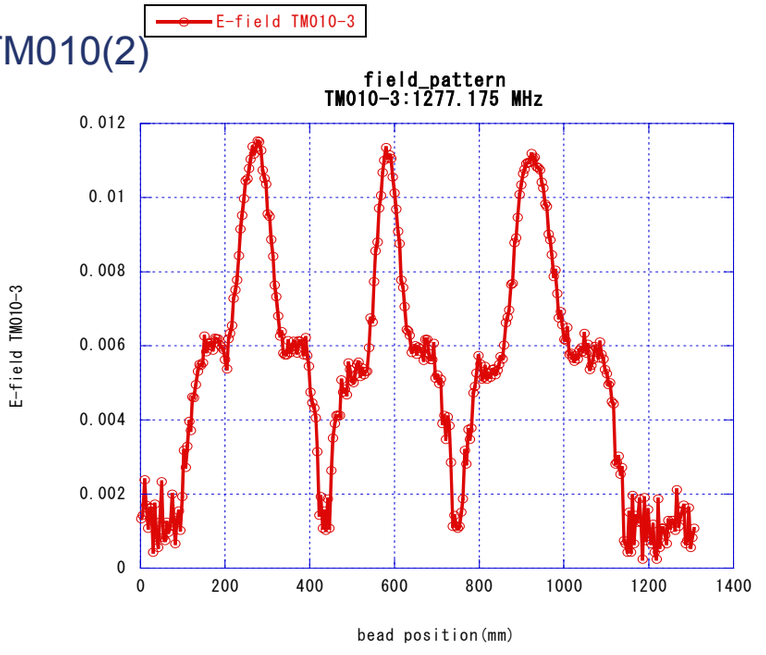
Metal ball, diameter =6mm, center scan



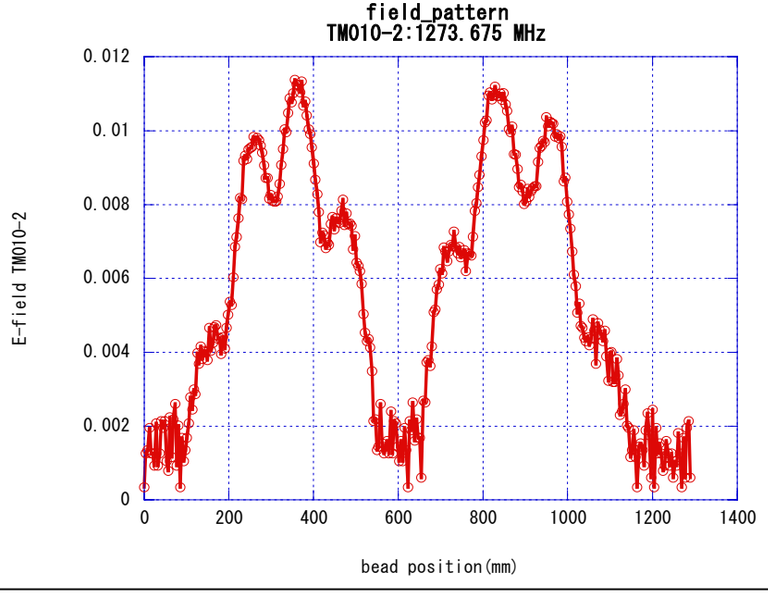


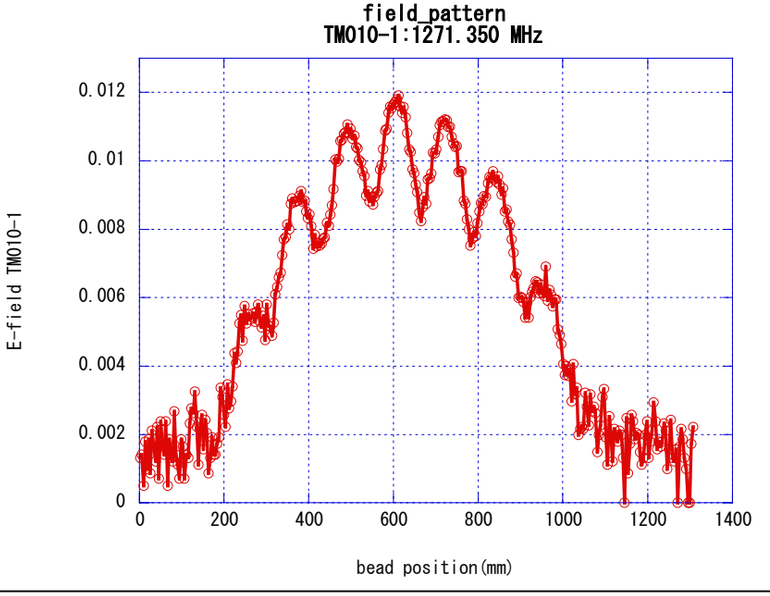
Passband TM010(2)



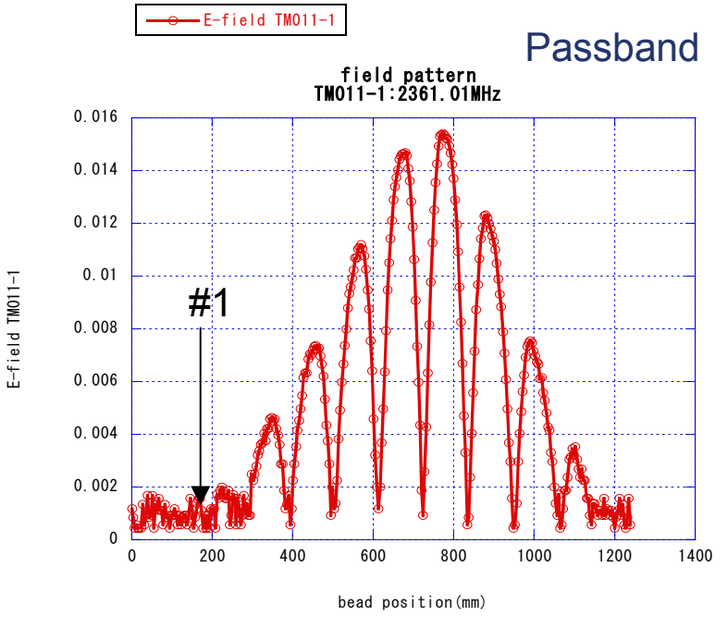


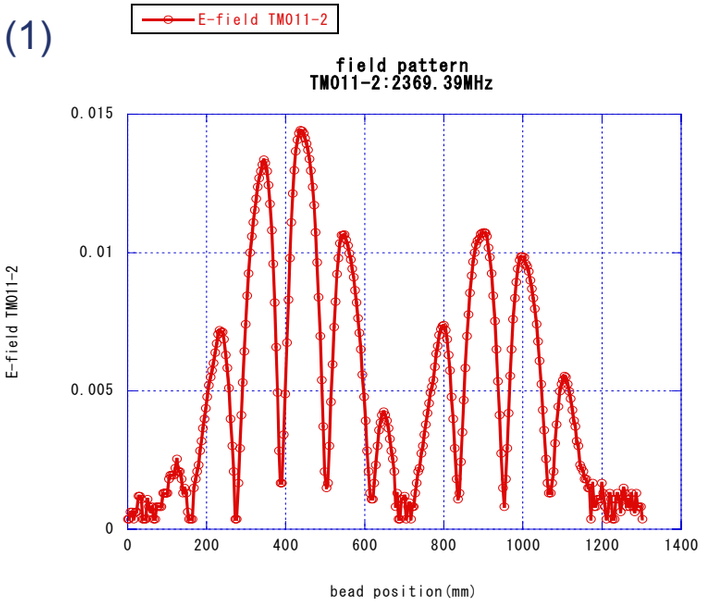
Metal ball, diameter =6mm, center scan

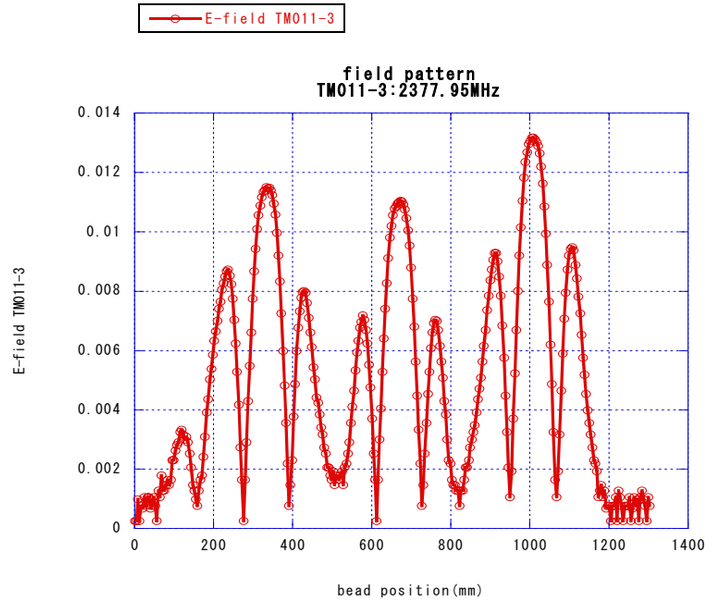




Passband TM011(1)

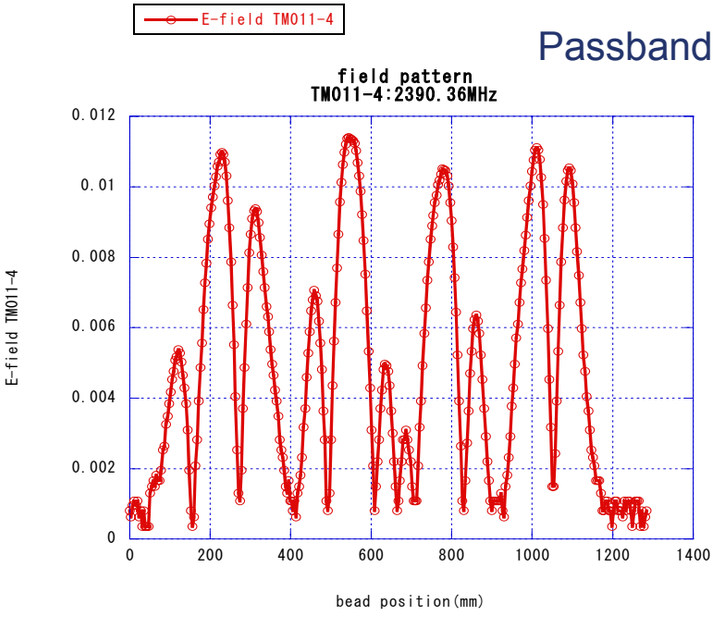


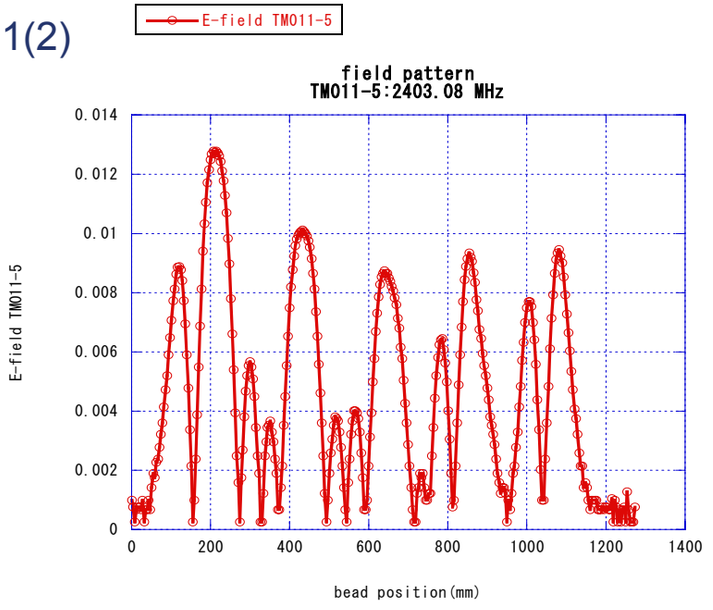


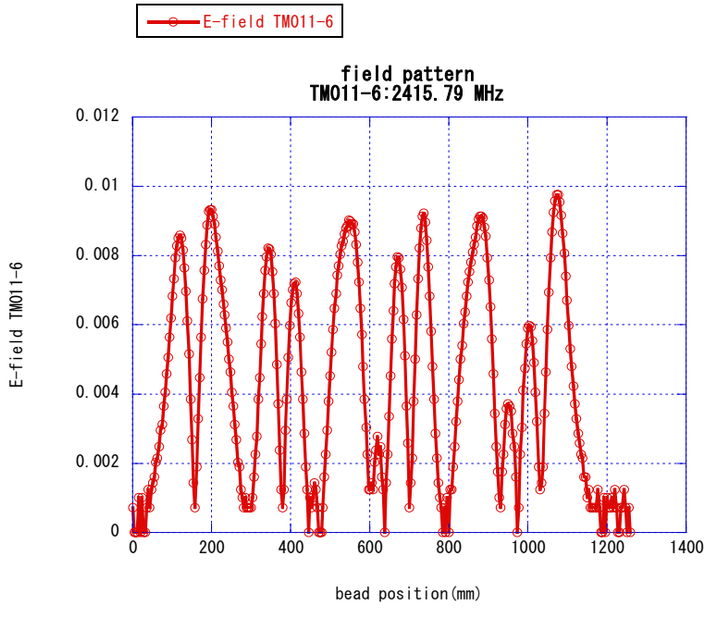


Metal ball, diameter =6mm, center scan

Passband TM011(2)

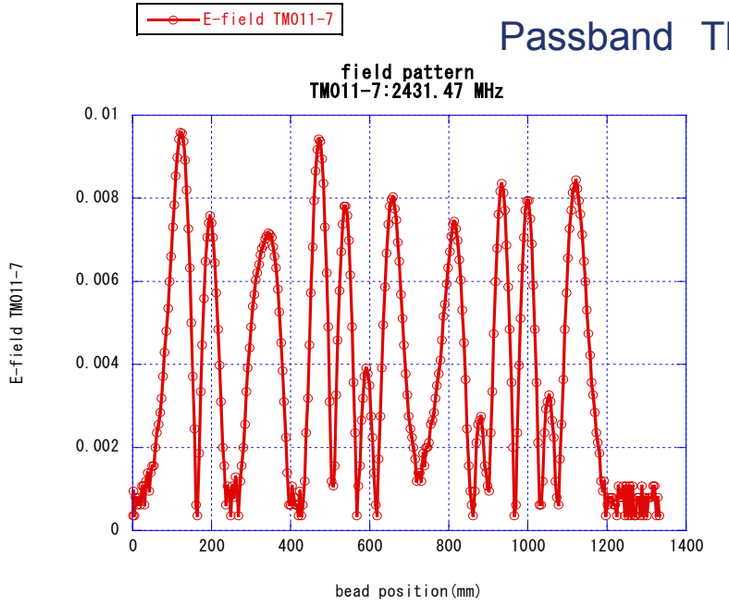


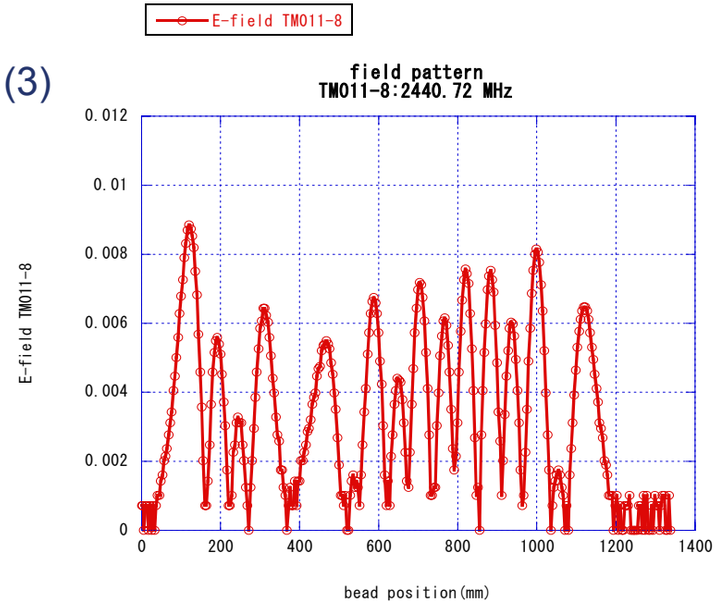


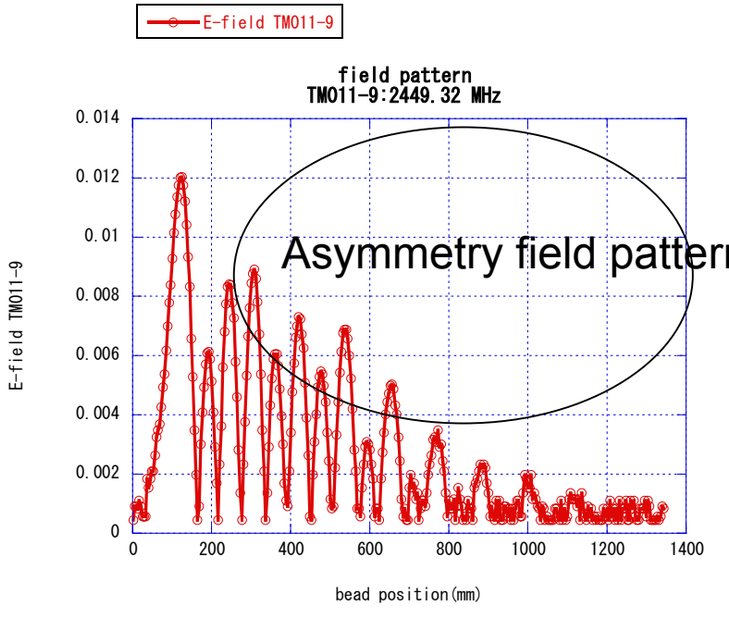


Metal ball, diameter =6mm, center scan

Passband TM011(3)



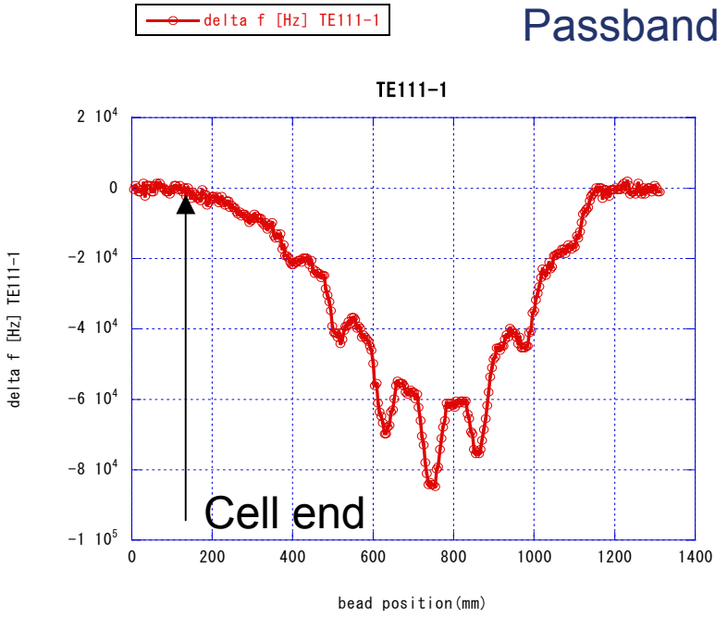


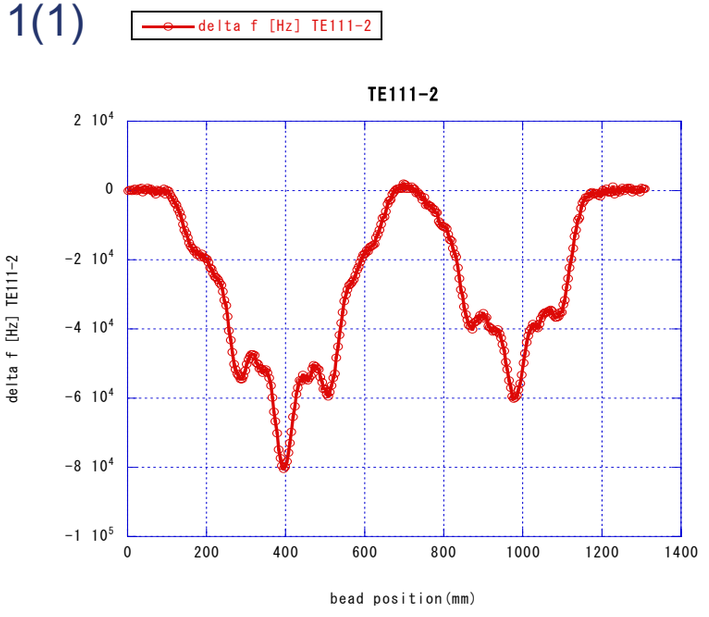


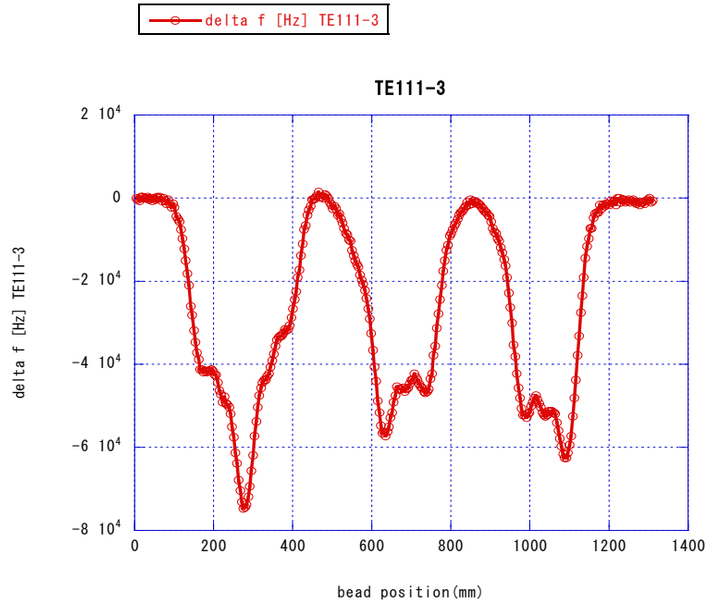
Asymmetry field pattern

Metal ball, diameter =6mm, center scan

Passband TE111(1)

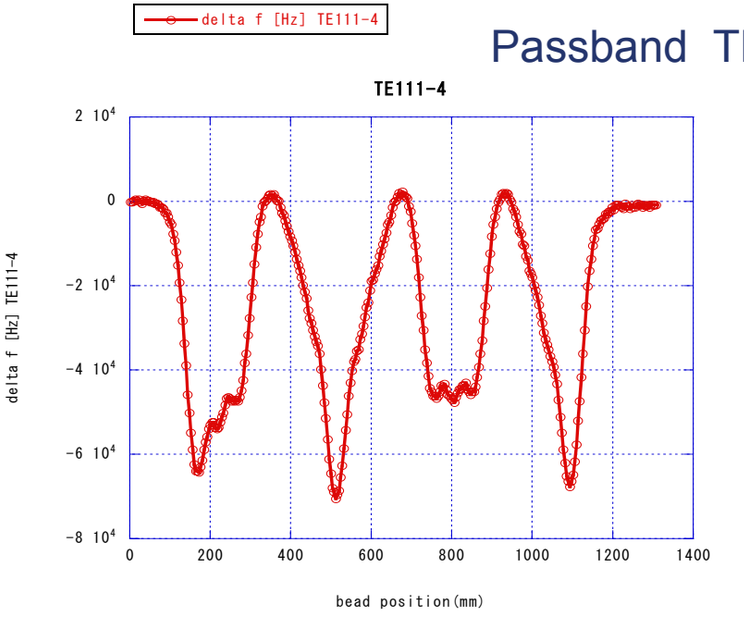


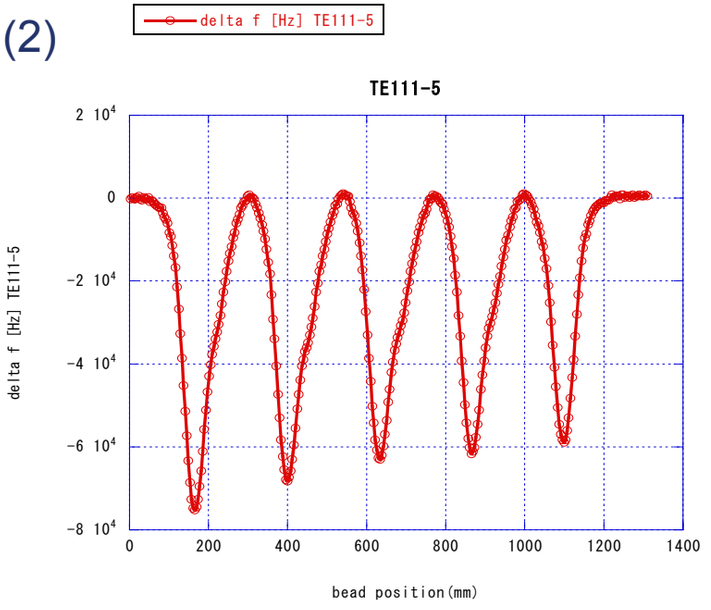


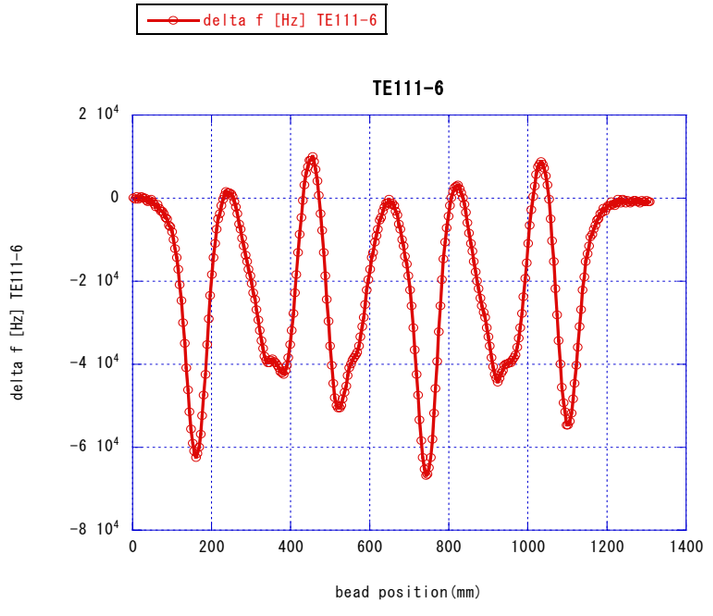


Metal ball, diameter =6mm, center scan

Passband TE111(2)

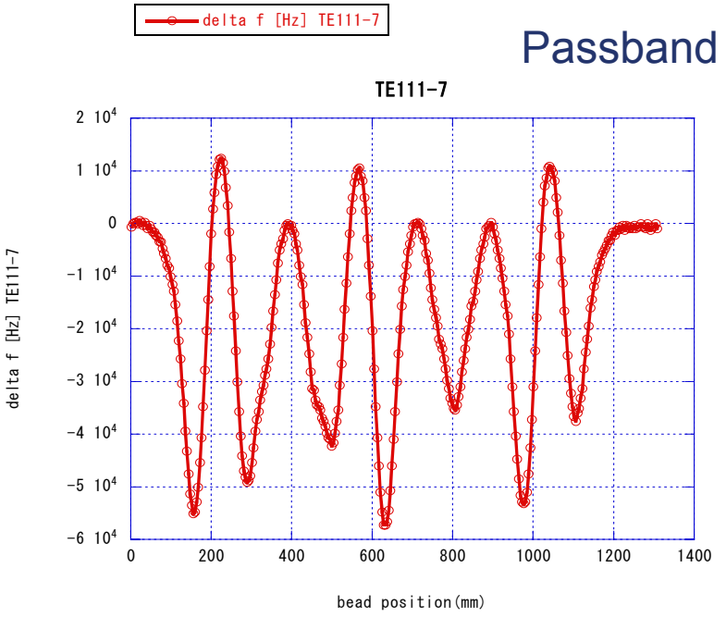


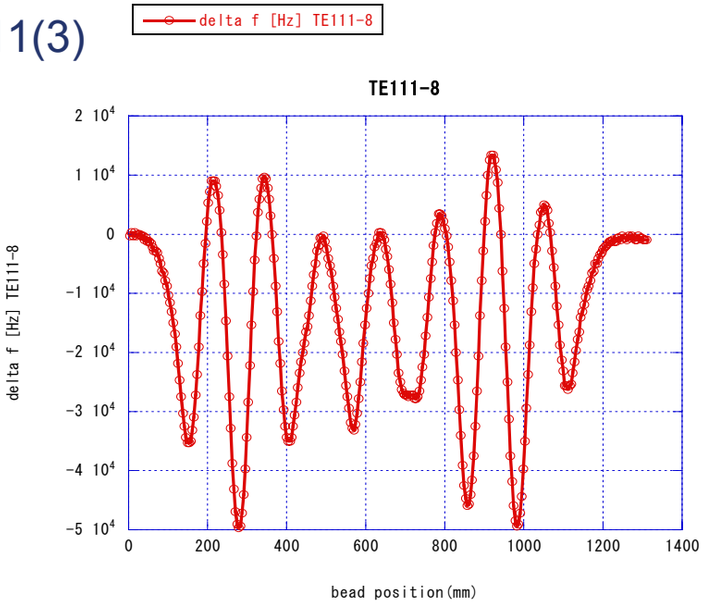


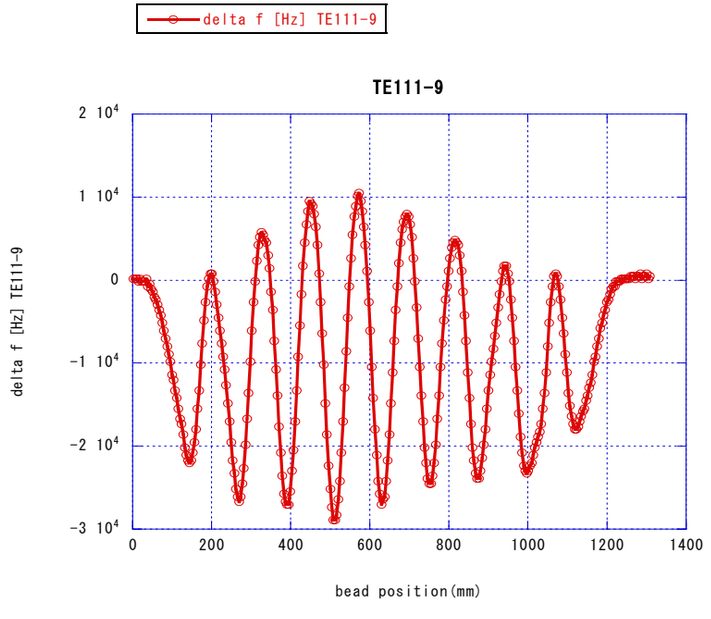


Metal ball, diameter =6mm, center scan

Passband TE111(3)

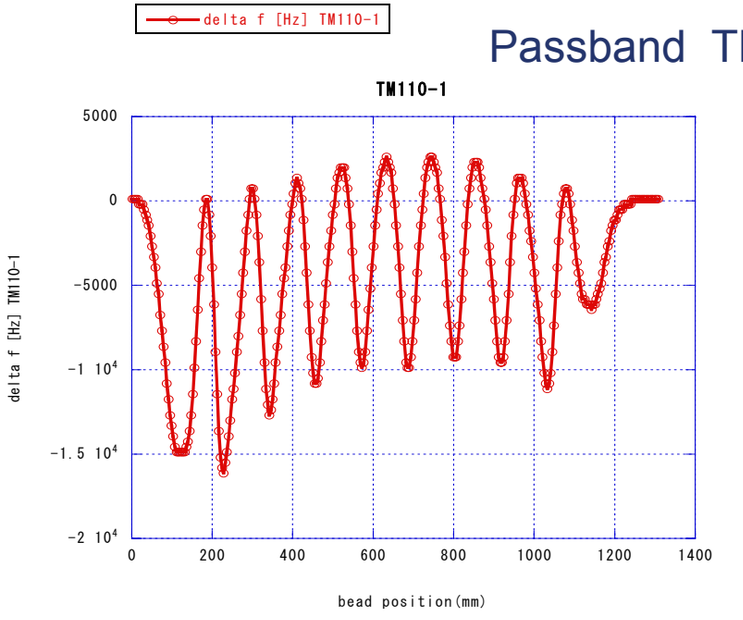


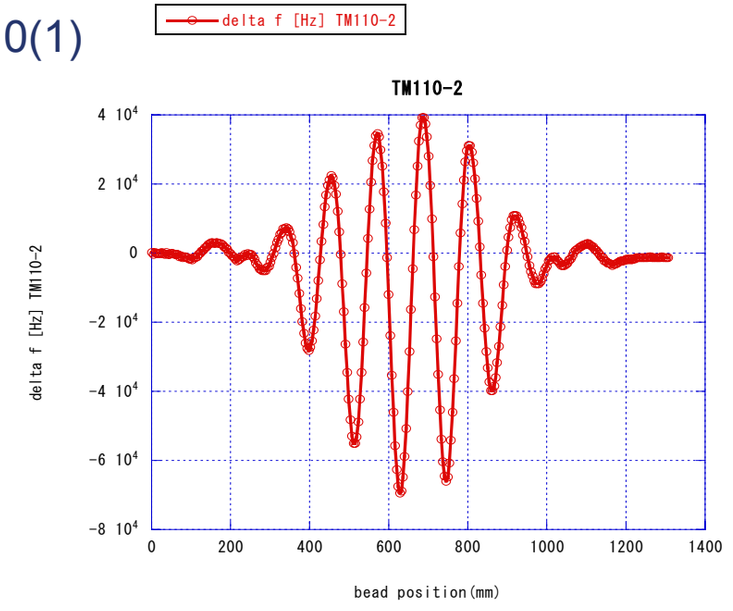


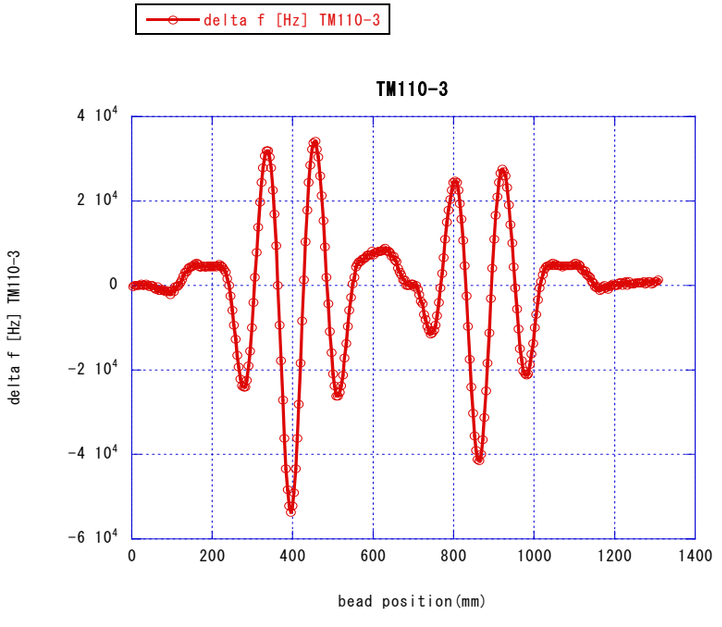


Metal ball, diameter =6mm, center scan

Passband TM110(1)

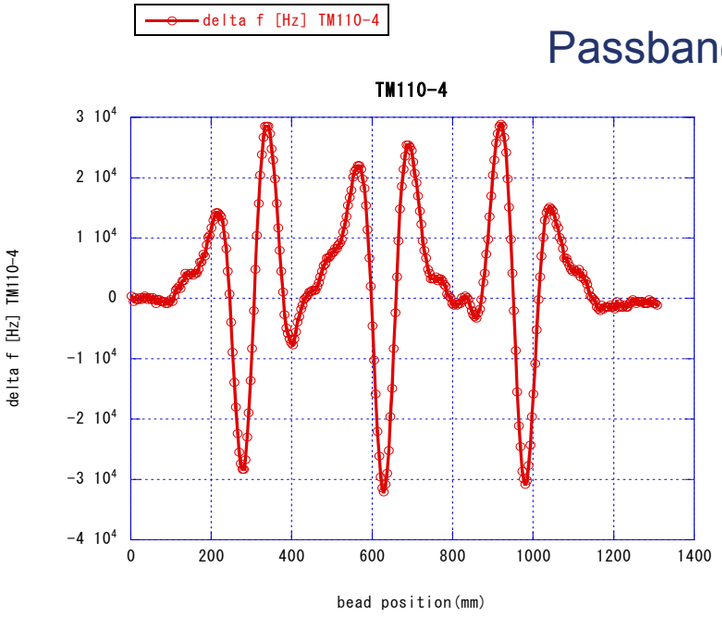


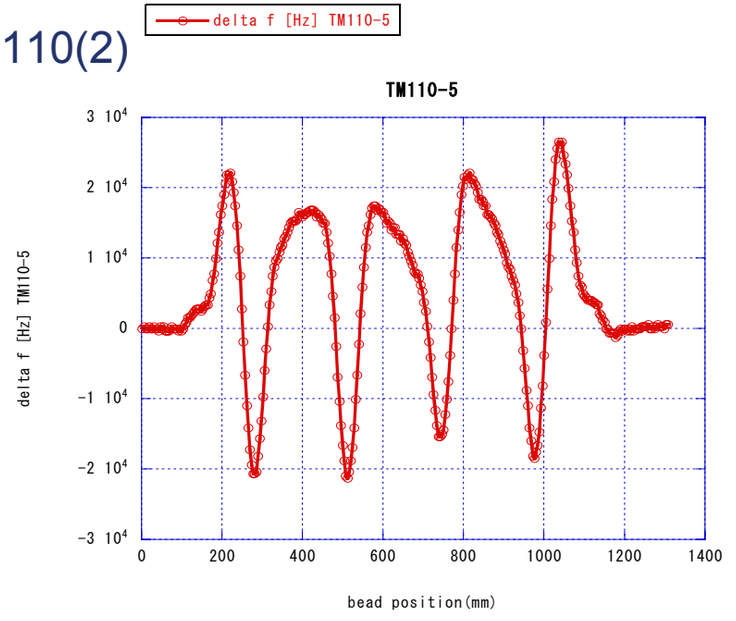


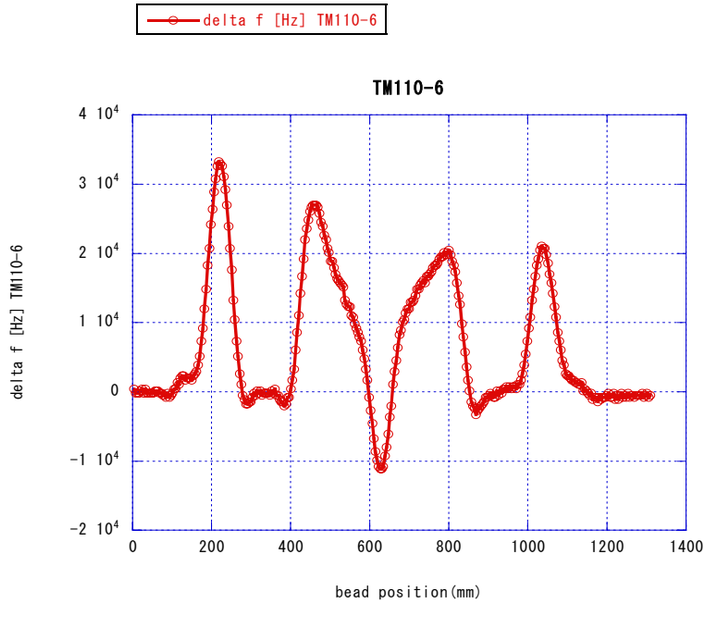


Metal ball, diameter =6mm, center scan

Passband TM110(2)







Metal ball, diameter =6mm, center scan

Passband TM110(3)