# Performance measurements and models of Tianma Radio telescope(TM65m)

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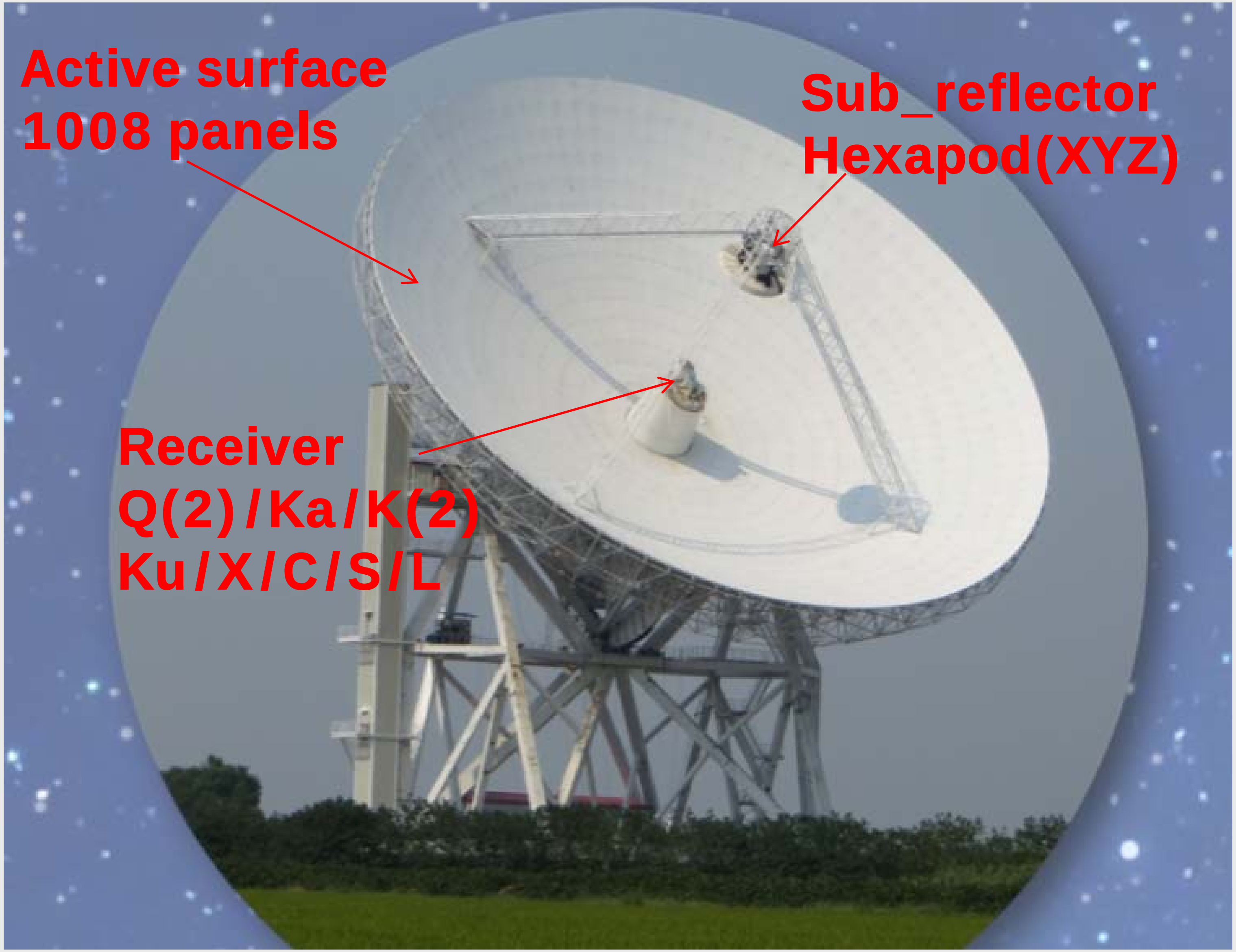
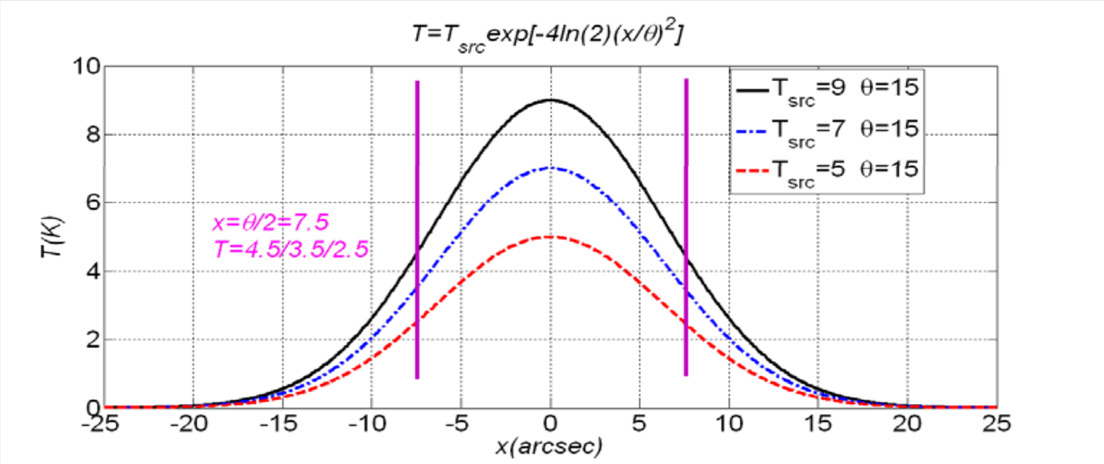
**Shanghai Astronomical Observatory**

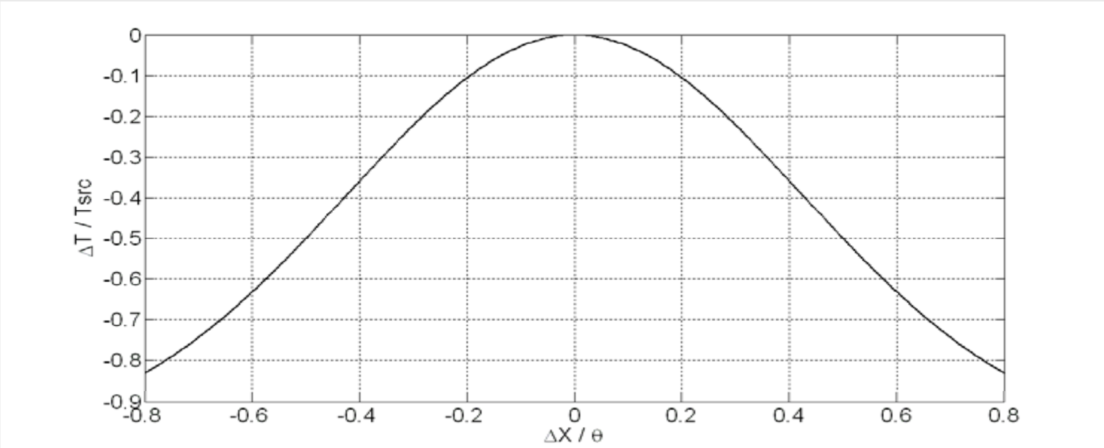
**2016 September 20 Green bank**

- Pointing model
- Sub_reflector model
- Efficiency/system noise temperature/SEFD
- Surface measurement by holography and gravity model


Active surface
1008 panels
Sub_reflector
Hexapod(XYZ)
Receiver
Q(2) / Ka / K(2)
Ku / X / C / S / L

# Pointing VS efficiency



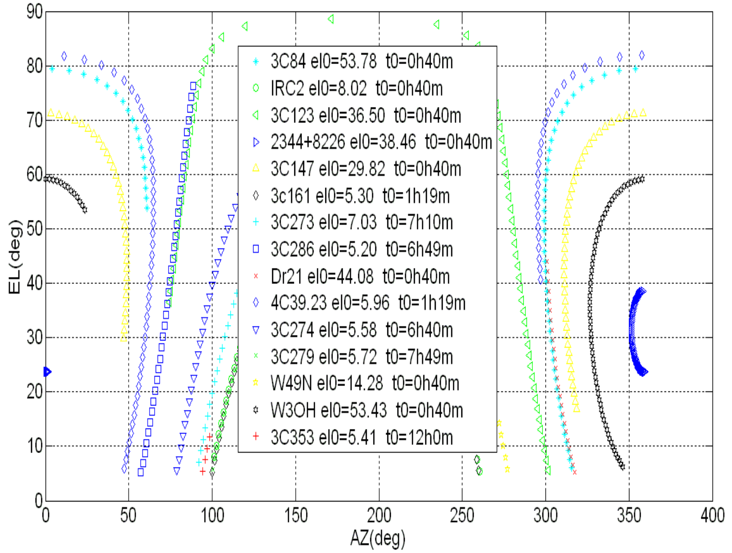



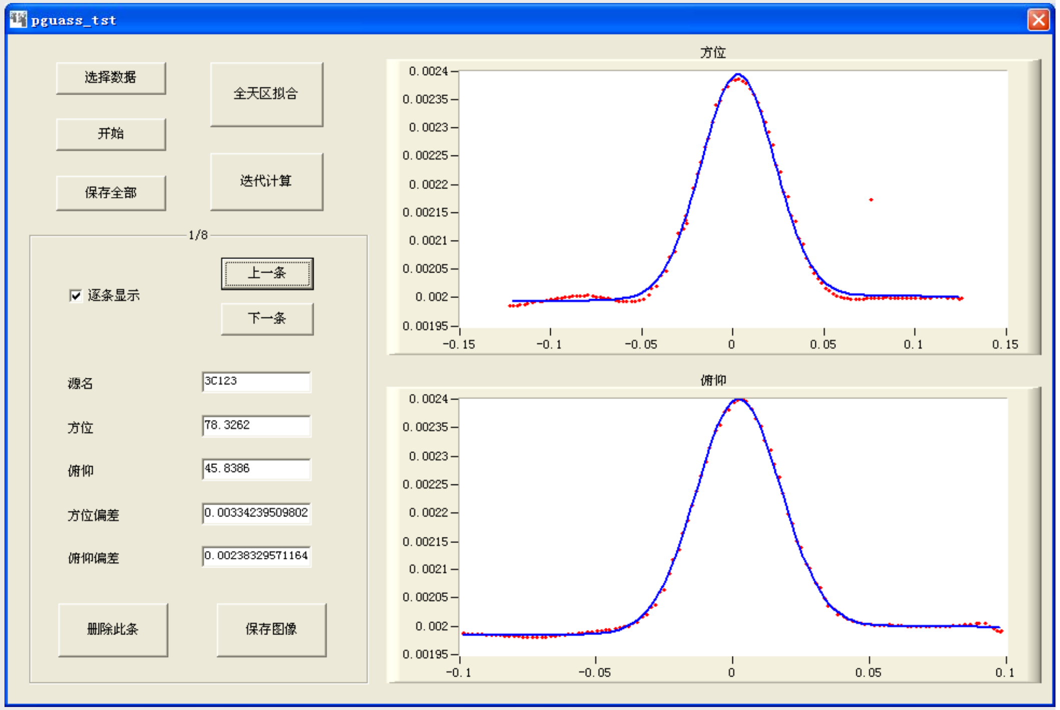

| Pointing error/beam width | 0.1 | 0.2 | 0.3 | 0.4 | 0.5 |
|---|---|---|---|---|---|
| Loss of gain | 0.027 | 0.105 | 0.22 | 0.36 | 0.5 |

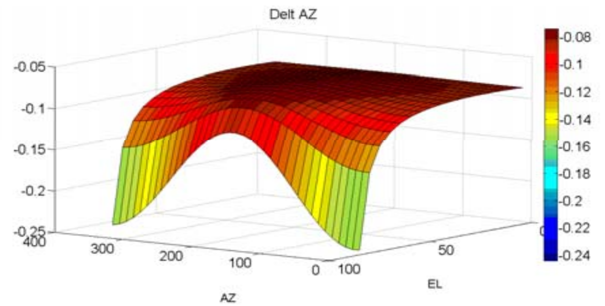
## Pointing error main comes from:

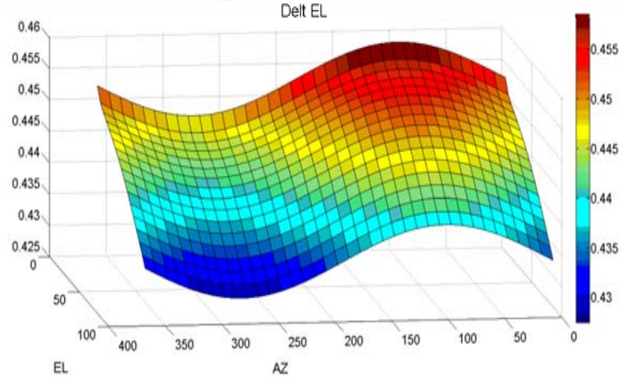
1) Mechanical error [model,titlemeter]
2) Encoder accuracy and stability
3) Servo system
4) Sub_reflector XY offsets [model,PSD]
5) Active surface[model]
6) Temperature [model,titlemeter,sensor,PSD]
7) Wind[PSD,half_power track]

# Pointing Model measurement



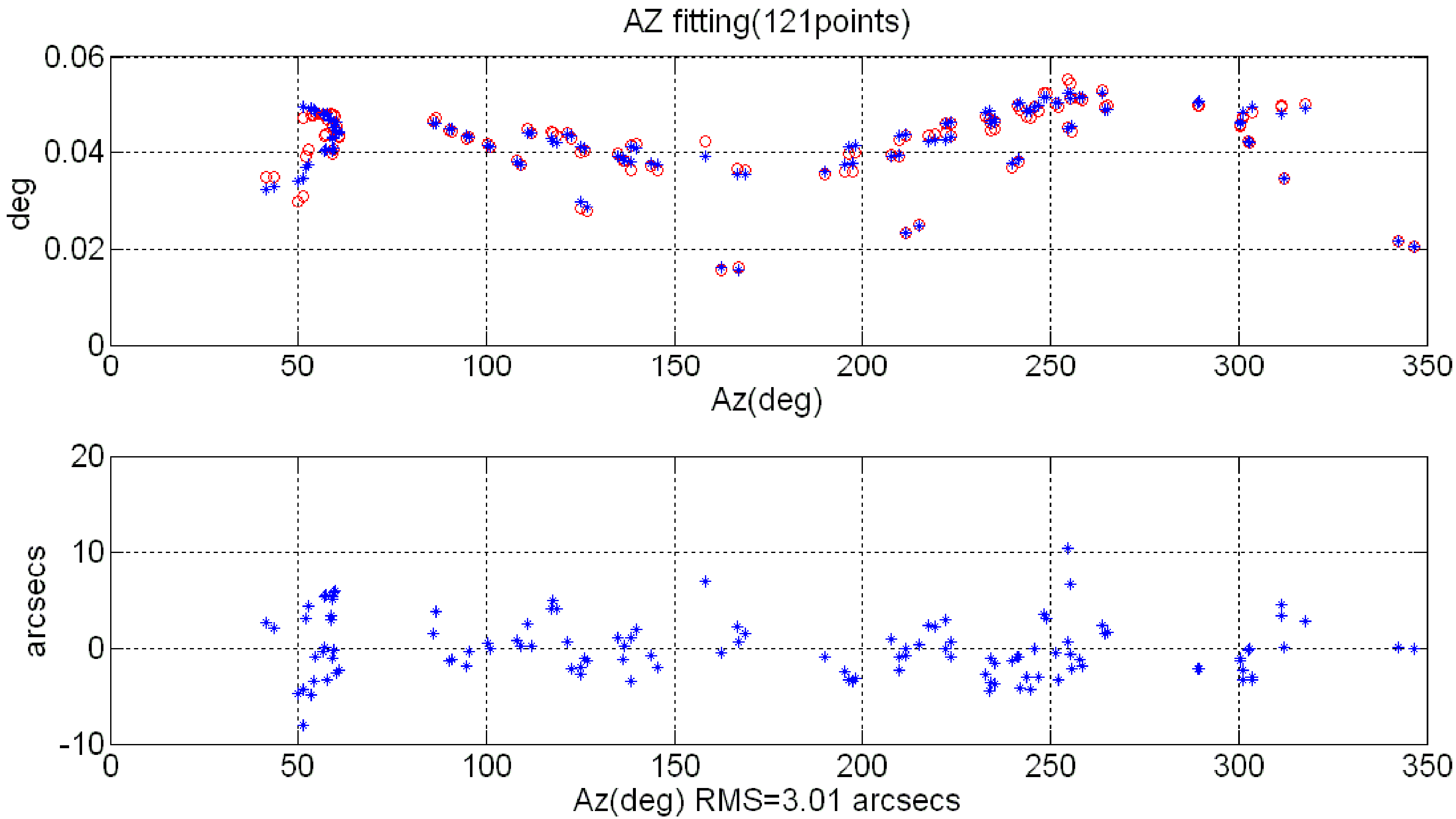



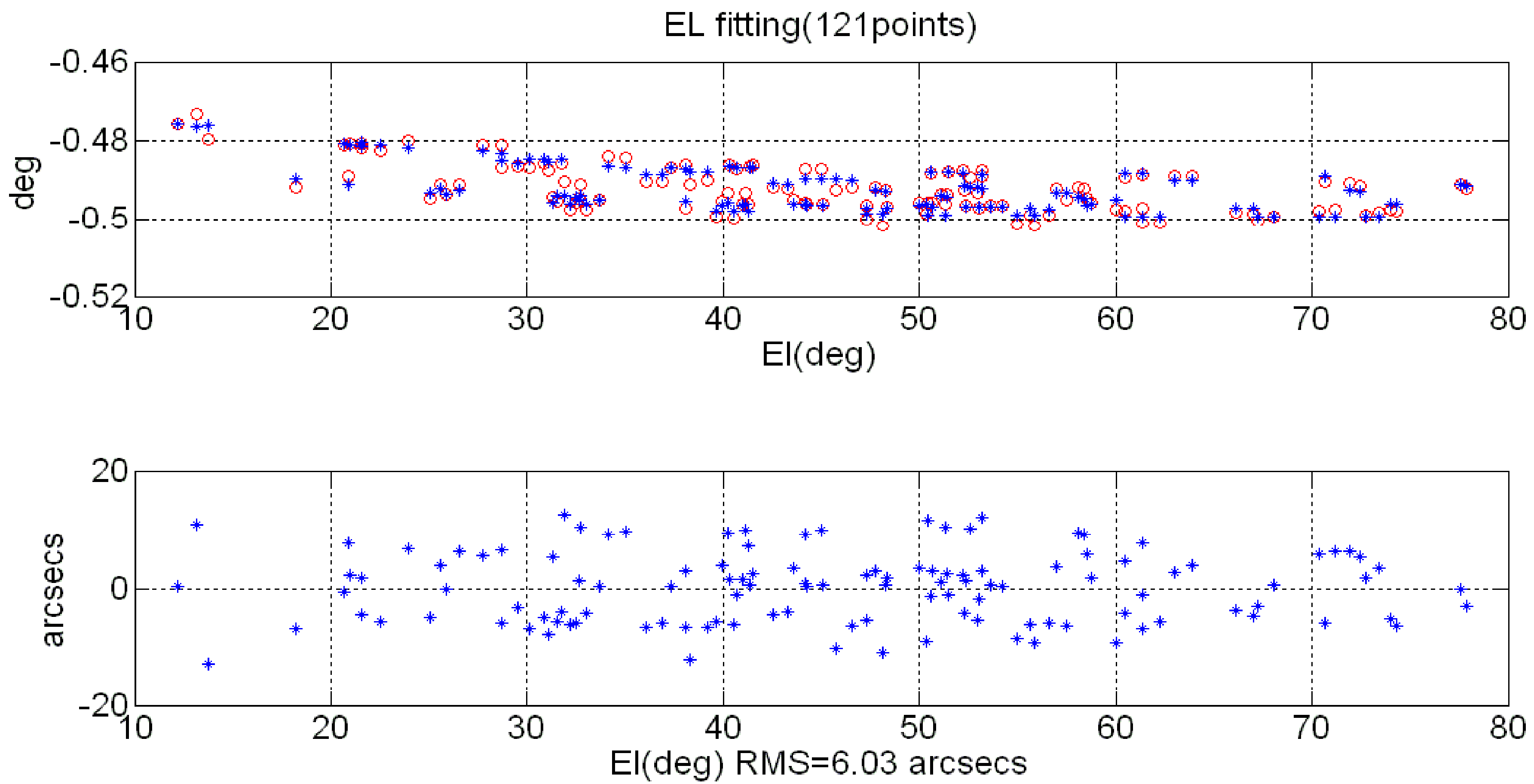




$$Delt\_AZ = C1 + \tan(E0)*\cos(A0)*C3 + \tan(E0)*\sin(A0)*C4 + \tan(E0)*C5 - 1/\cos(E0)*C6$$

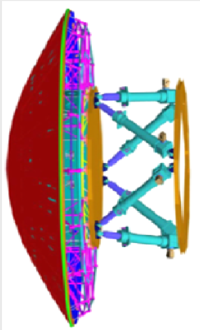
$$Delt\_EL = C2 - \sin(A0)*C3 + \cos(A0)*C4 + \cos(E0)*C7 + C8/\tan(E0)$$

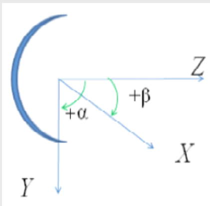
# K band pointing model (sub_reflector enable)

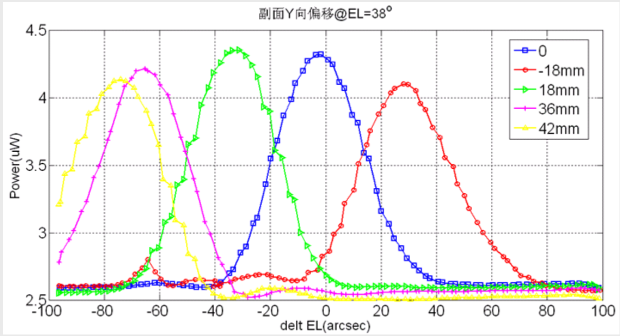


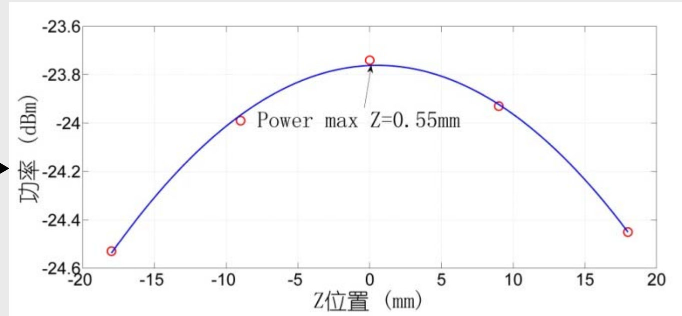

EL fitting(121points)
-0.46
-0.48
-0.5
-0.52
deg
10
20
30
40
50
60
70
80
El(deg)
20
0
-20
arcsecs
El(deg) RMS=6.03 arcsecs

# Sub_reflector Model

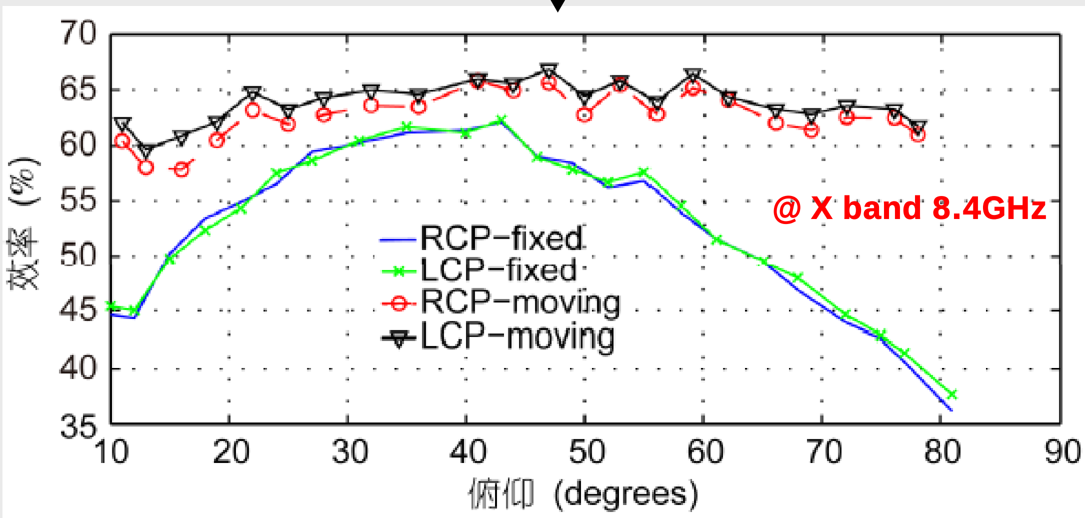




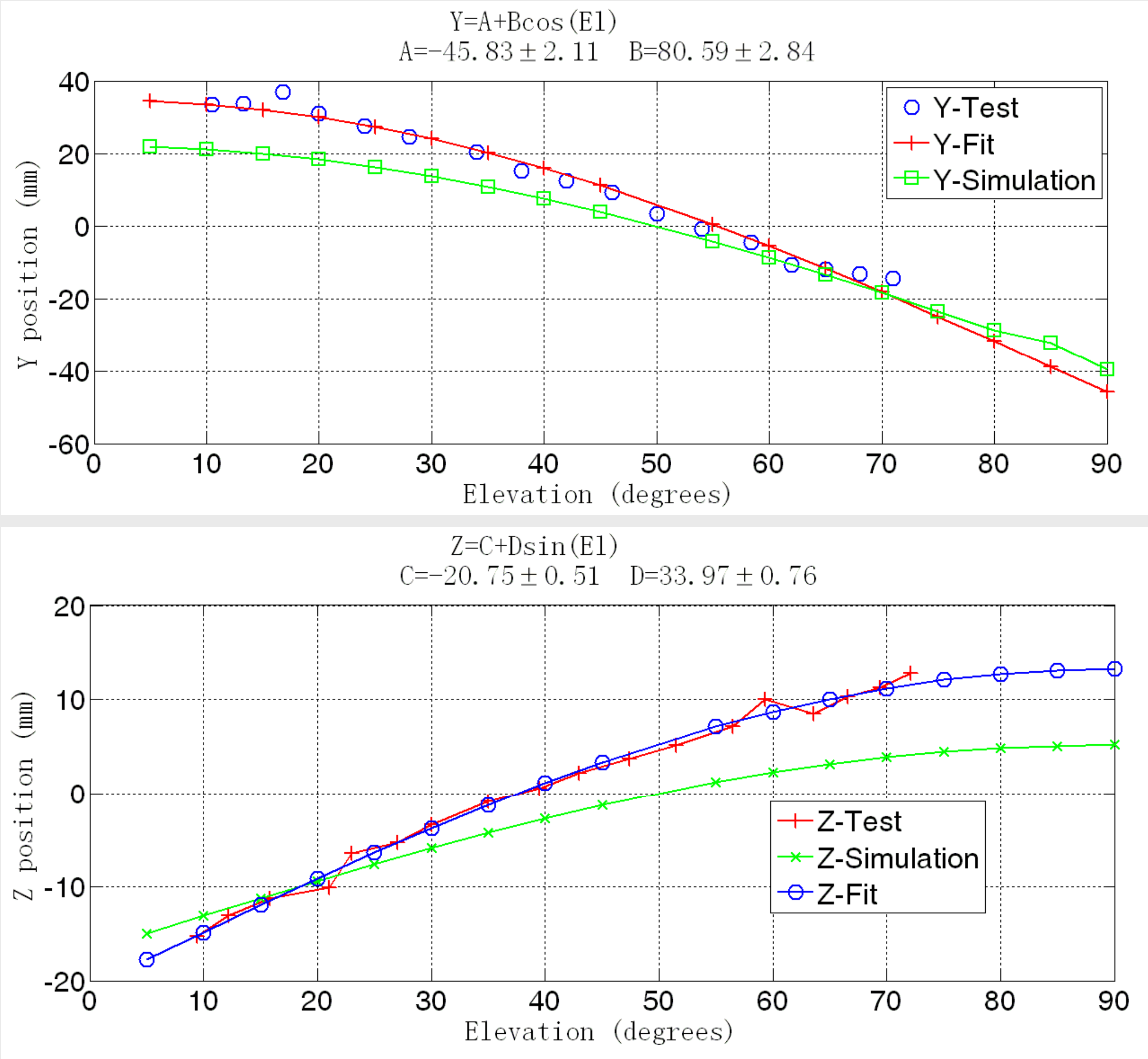



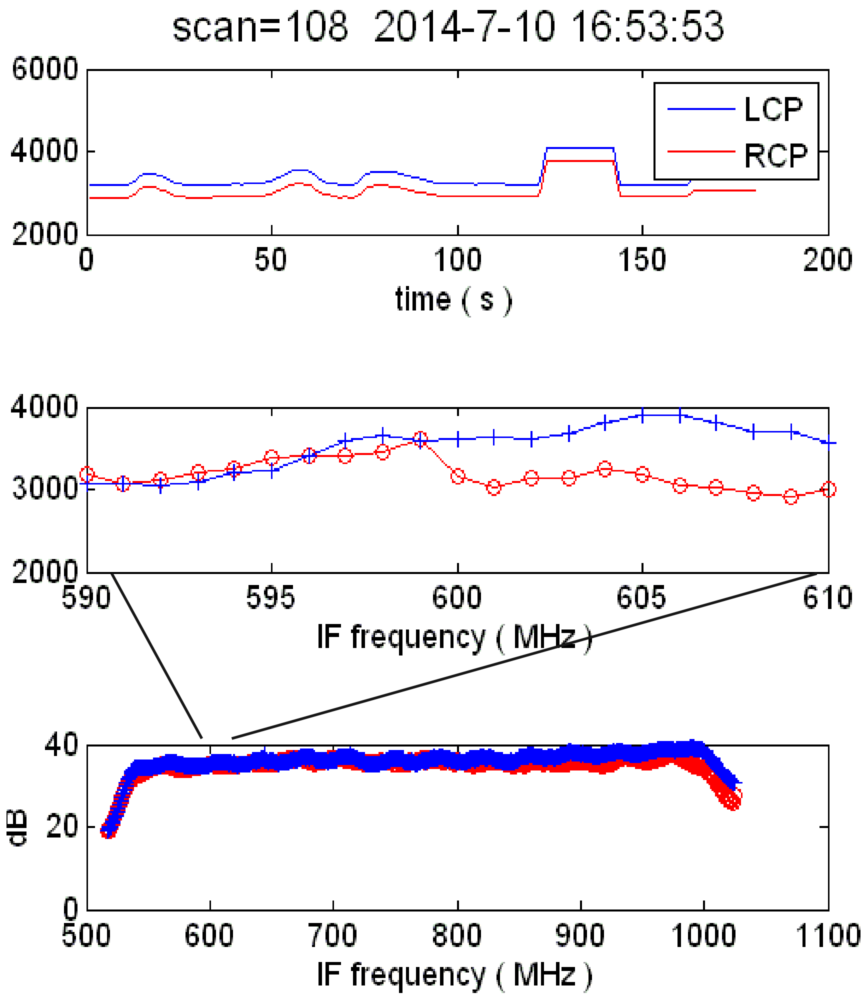

$$\Delta Y = A + B\cos(EL) \qquad \Delta Z = C + D\sin(EL)$$

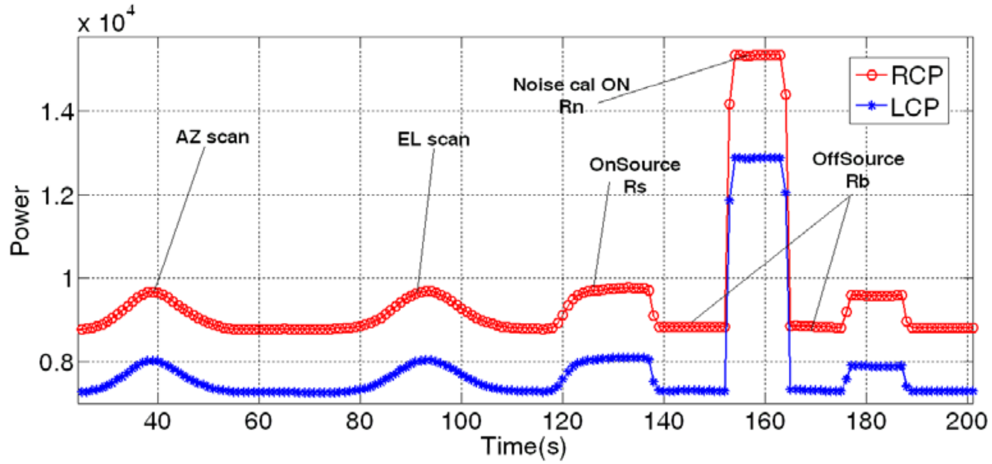


# Tested model VS FEM simulation



# Efficiency & Tsys measurement



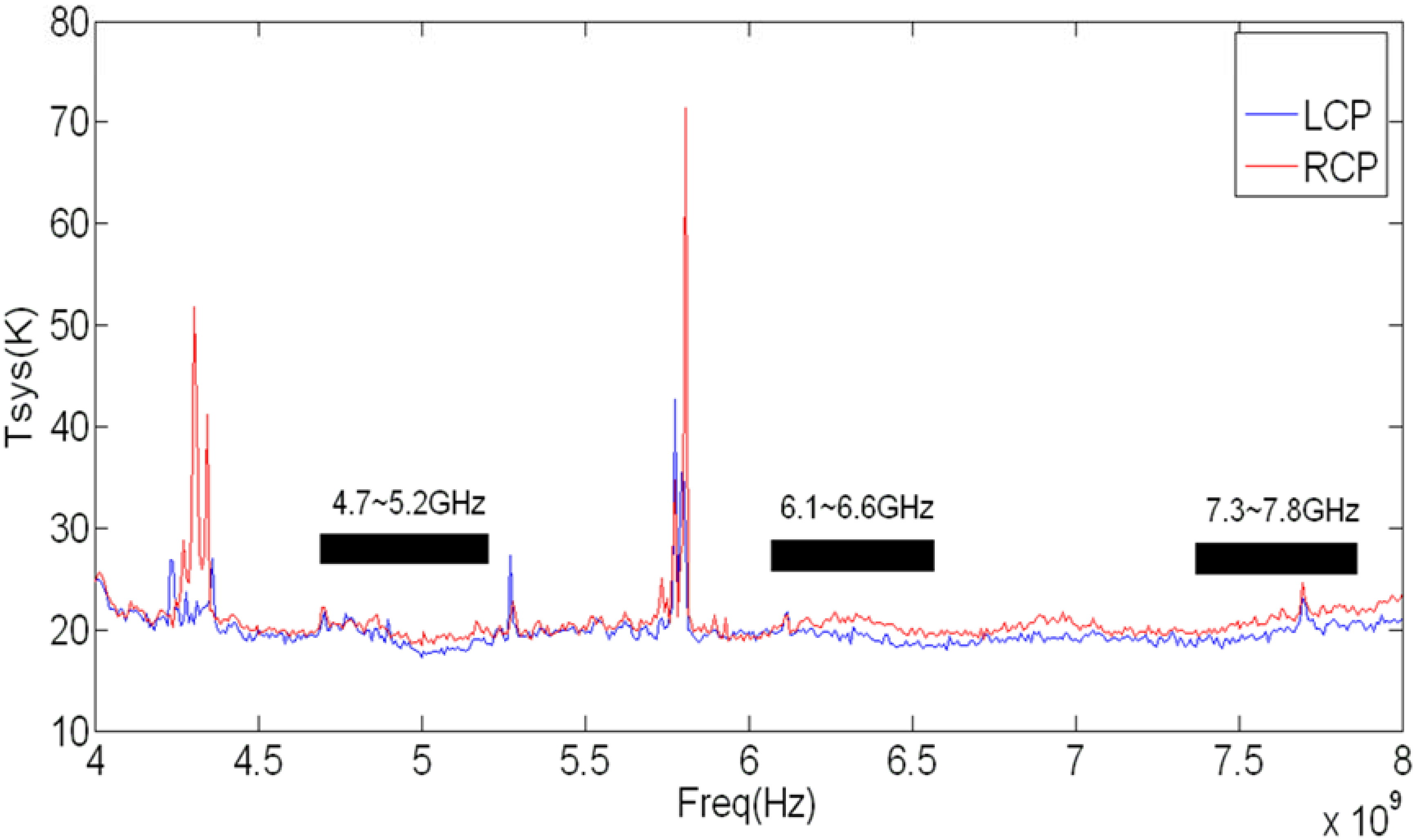

$$\eta(\varphi) = \frac{2kT_{as}(\varphi)K_1K_2K_3K_4K_5}{SA_g}$$

$$T_{as} = \frac{(R_S - R_b)}{R_N - R_b}T_{cal}$$

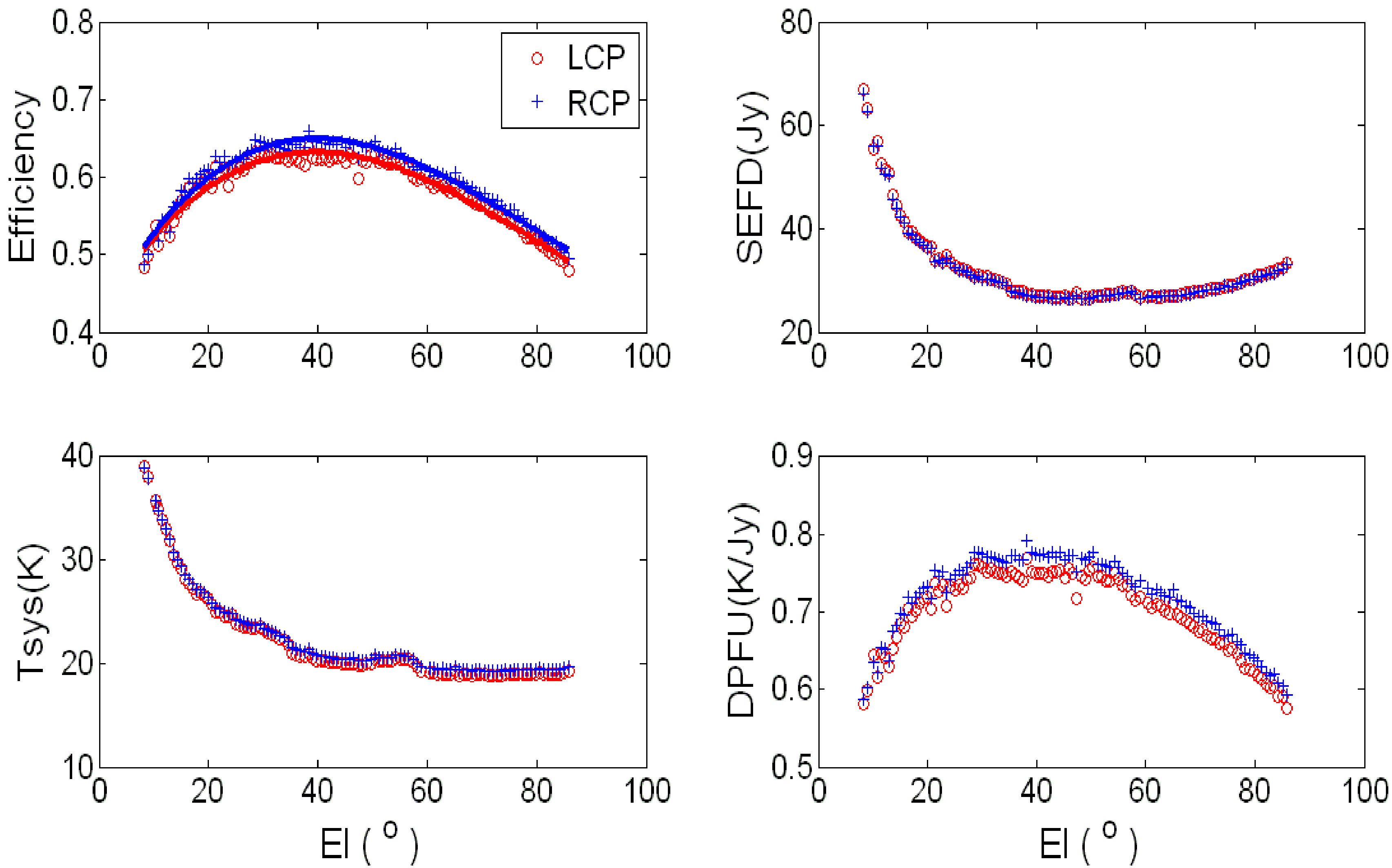
$$S' = S \cdot \exp(-\tau_0/\sin El)$$

$$T_{sys} = \frac{R_b - R_0}{R_N - R_b}T_{cal}$$

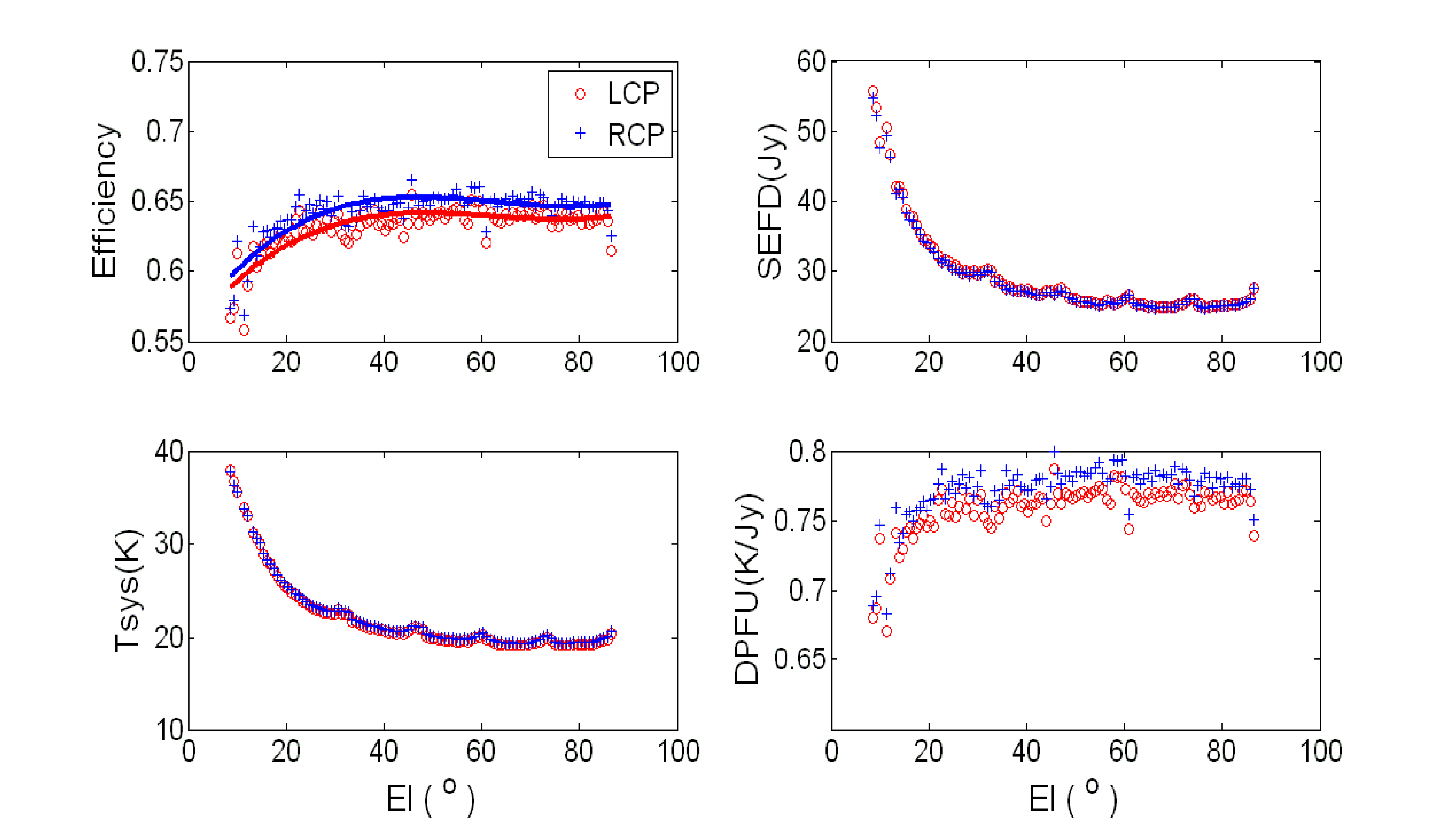
# C band(4GHz-8GHz)
# system noise temperature



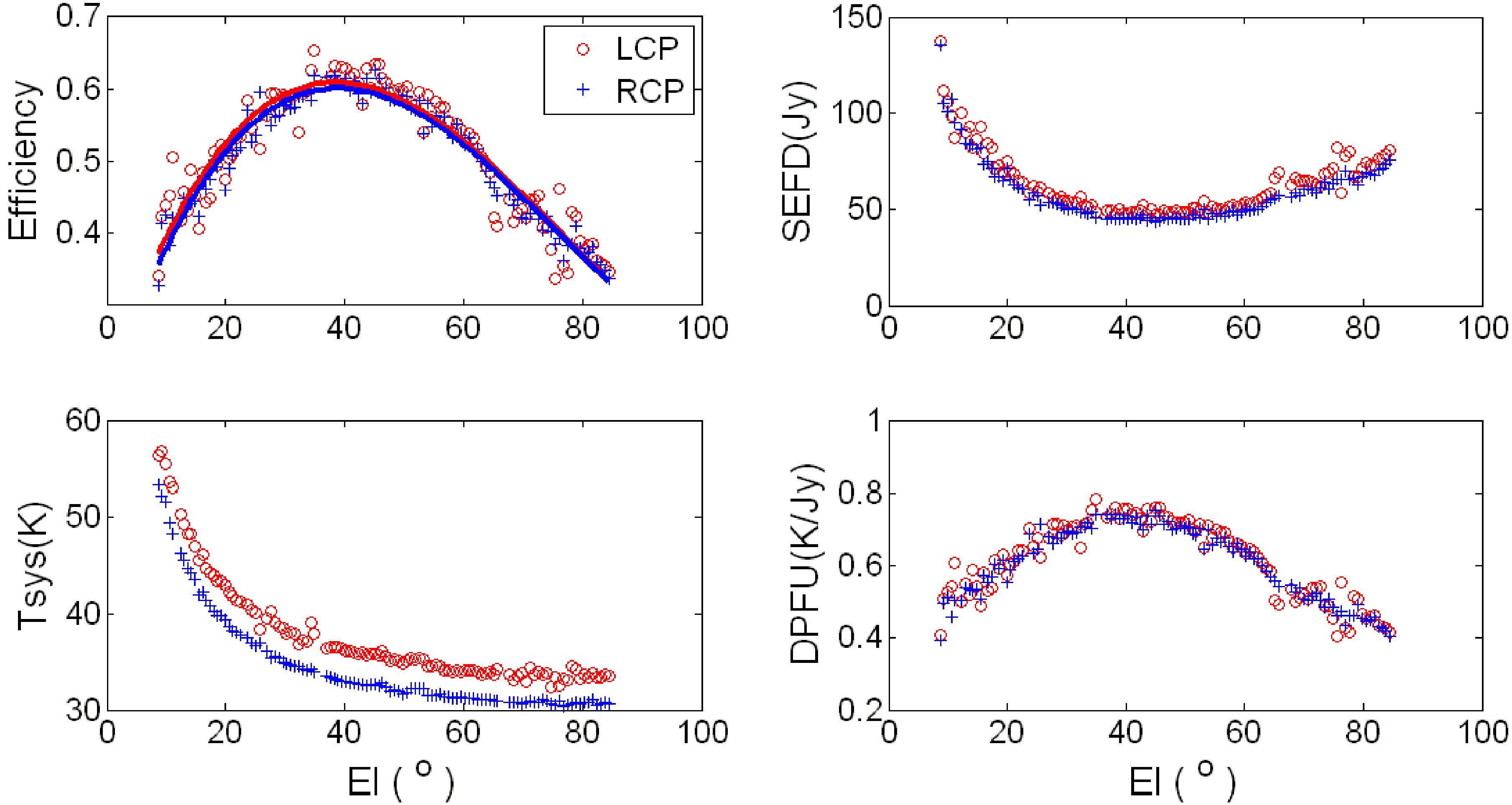
# C band performance
# Sub_reflector fixed @4.8GHz 20MHz Bandwidth



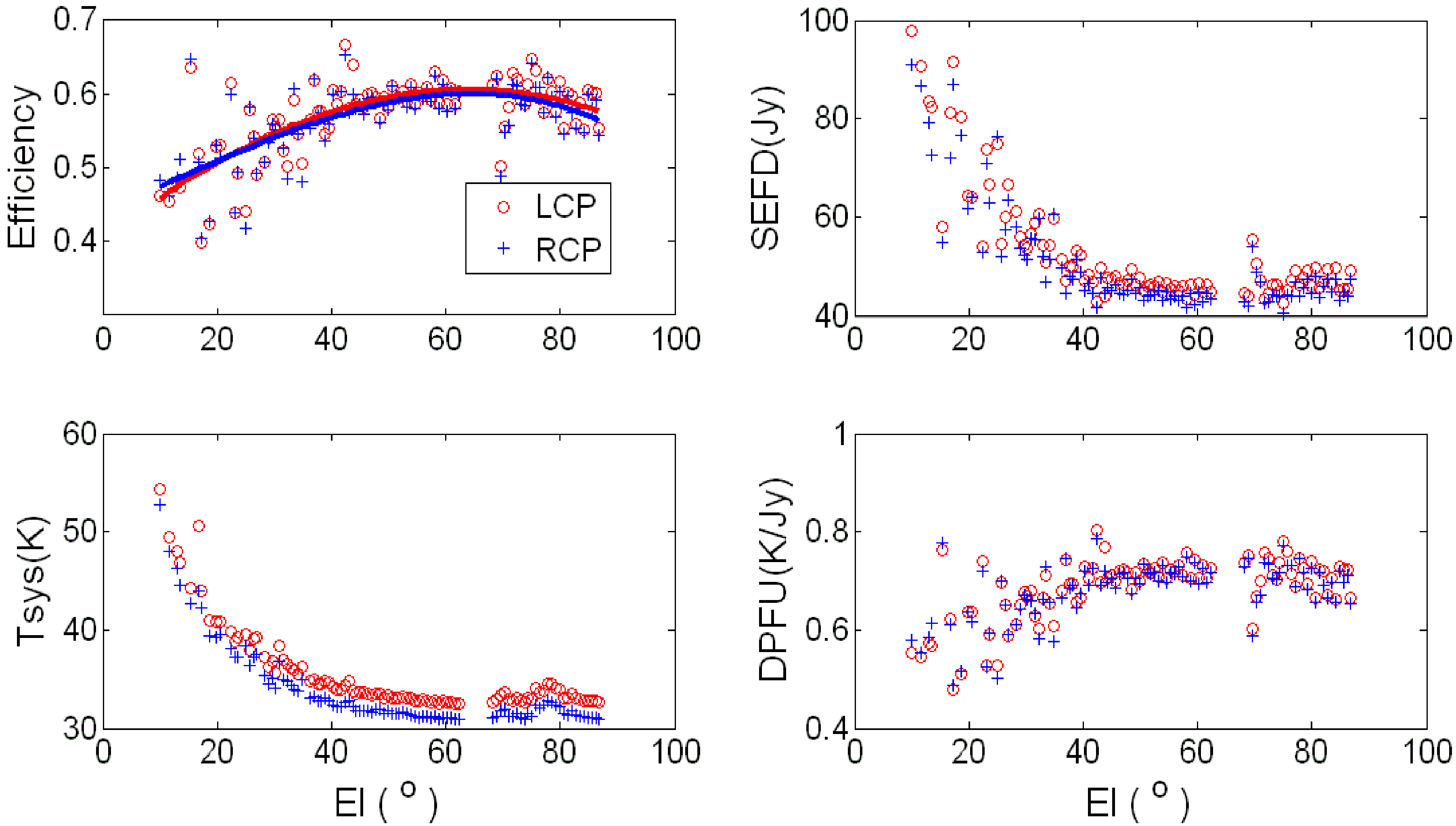
# C band performance
# Sub_reflector Enable @4.8GHz 20MHz Bandwidth



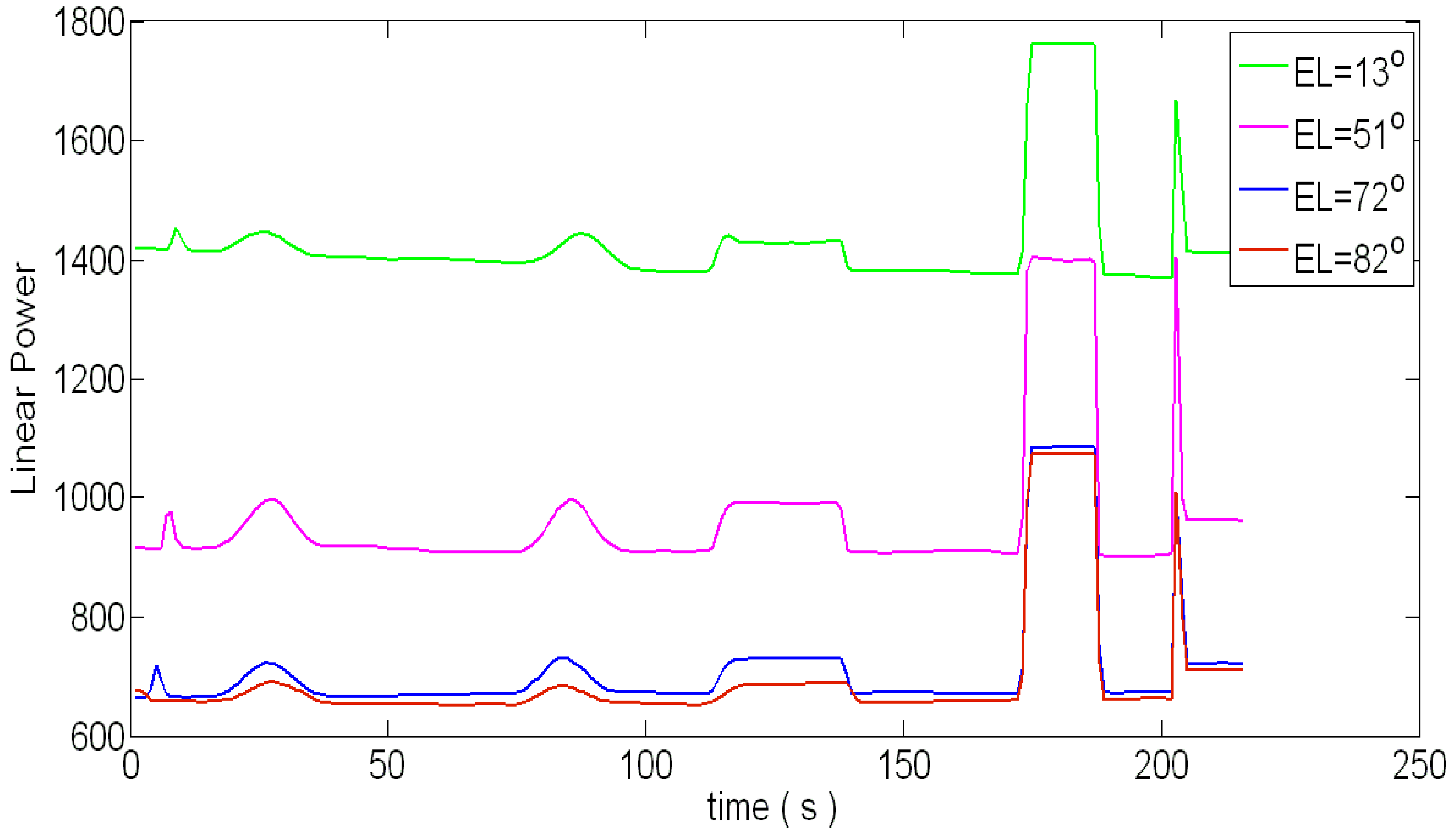
# X band performance
# Sub_reflector fixed @8.75GHz 20MHz Bandwidth



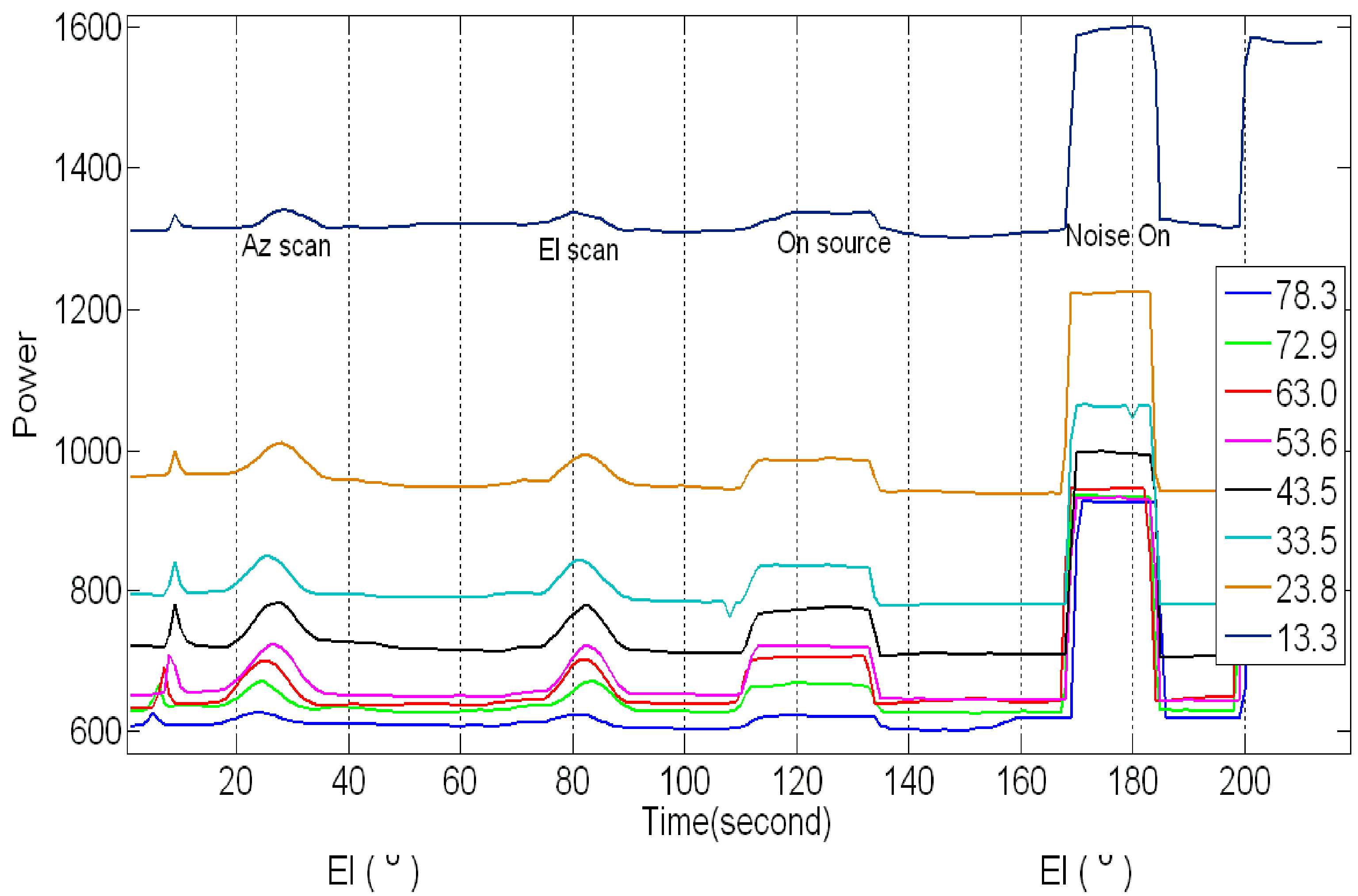
# Sub_reflector Enable @8.75GHz 20MHz Bandwidth



# Ku band performance
# Sub_reflector Enable @15.6GHz 20MHz Bandwidth



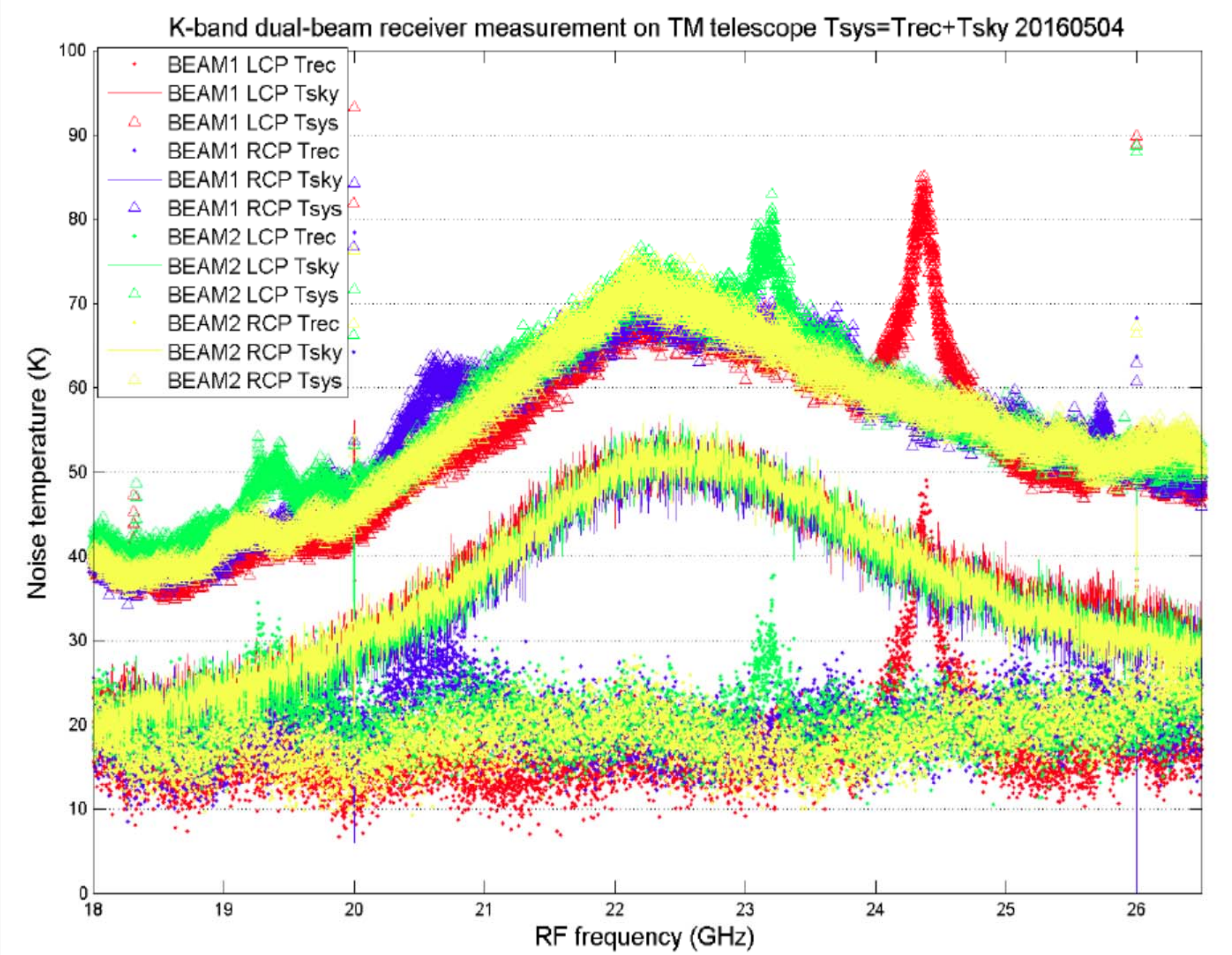
# Ka band performance
# Sub_reflector Enable @31.1GHz 20MHz Bandwidth



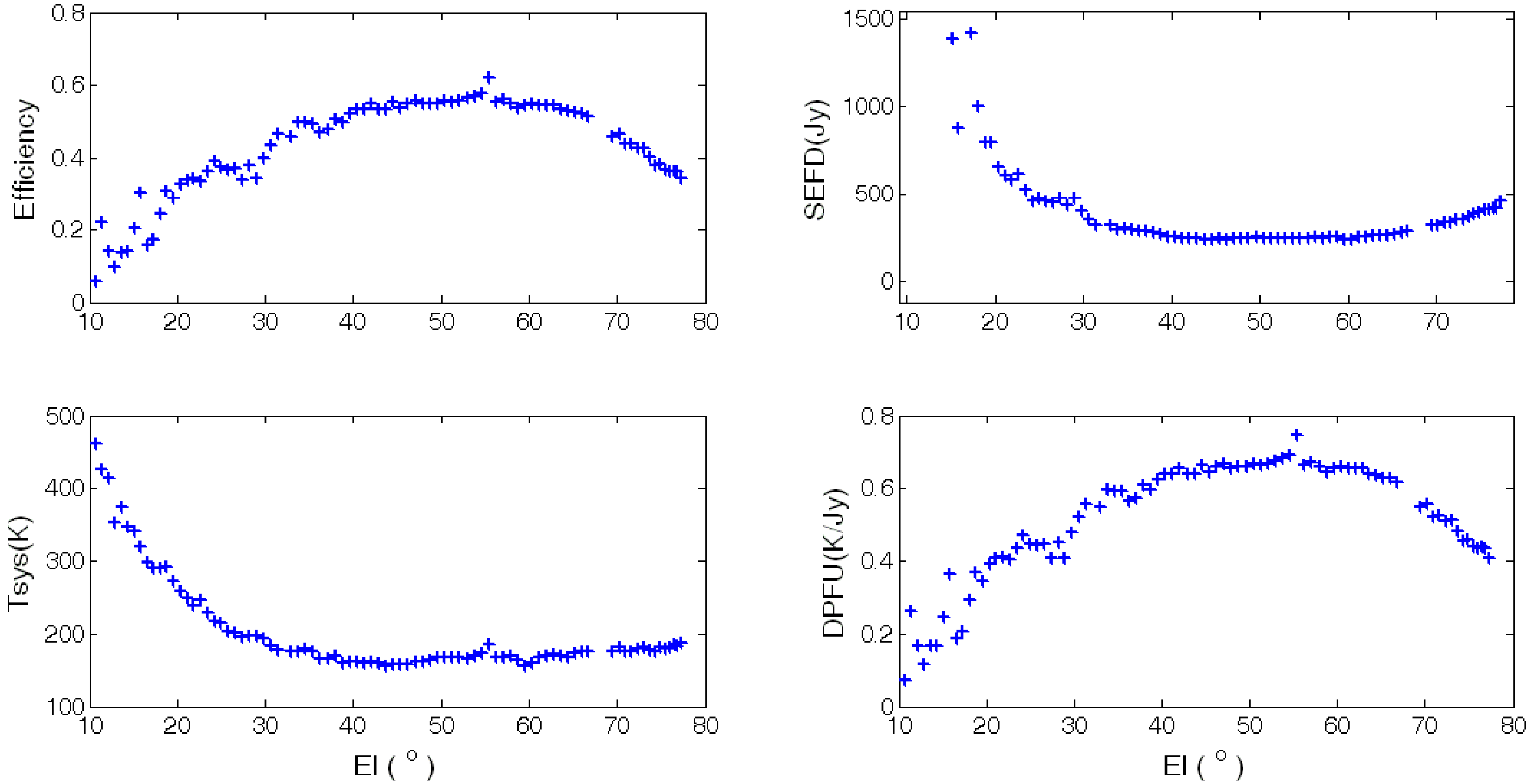
# L/C/S/X/Ku/Ka bands performance

| Band | Sub _reflector | Frequency (MHz) | Tsys @Zenith | DPFU (K /Jy) | Efficiency max | 归一化 Poly($aX^3+bX^2+cX+d$) (X=Elevation/degree) | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | a | b | c | d |
| L(V) | fixed | 1488 | 32 | 0.768 | 0.64@El=46.4 | 1.6E-6 | -3.6247E-4 | 0.02326739 | 0.54048039 |
| L(H) | fixed | 1488 | 30 | 0.796 | 0.66@El=43.4 | 2.05E-6 | -3.565E-4 | 0.01929101 | 0.66628028 |
| S(LCP) | fixed | 2265 | 50 | 0.680 | 0.57@El=9.463 | 5.0E-8 | -9.83E-6 | -0.00143989 | 1.01446614 |
| S(RCP) | fixed | 2265 | 52 | 0.709 | 0.59@ El=9.463 | 7.0E-8 | -1.197E-5 | -0.00158865 | 1.01604279 |
| C(LCP) | move | 4800 | 20 | 0.771 | 0.64 @El=48.7 | 6.4E-7 | -1.1908E-4 | 0.00705175 | 0.86551495 |
| C(RCP) | move | 4800 | 20 | 0.785 | 0.65 @El=47.1 | 6.8E-7 | -1.2899E-4 | 0.00759555 | 0.85688260 |
| C(LCP) | move | 6425 | 19 | 0.719 | 0.60 @El=54.7 | 3.0E-8 | -3.028E-5 | 0.00303171 | 0.91954072 |
| C(RCP) | move | 6425 | 19 | 0.708 | 0.59 @El=54.7 | 1.5E-7 | -4.839E-5 | 0.00395895 | 0.90378113 |
| C(LCP) | move | 7500 | 17 | 0.764 | 0.64 @El=55.3 | 1.7E-7 | -6.686E-5 | 0.00585544 | 0.85217763 |
| C(RCP) | move | 7500 | 17 | 0.715 | 0.60 @El=56.9 | 9.0E-8 | -5.493E-5 | 0.00537263 | 0.85531771 |
| X(LCP) | move | 8400 | 33 | 0.789 | 0.66 @El=60.1 | -1.99E-6 | 2.4240E-4 | -0.00757999 | 1.01166495 |
| X(RCP) | move | 8400 | 31 | 0.782 | 0.65 @El=60.9 | -1.99E-6 | 2.4415E-4 | -0.00763073 | 1.00900602 |
| Ku(LCP) | move | 15600 | 25 | 0.807 | 0.67@ El=50.877 | -5.13E-6 | 0.00039693 | -0.00038984 | 0.66734680 |
| Ku(RCP) | move | 15600 | 30 | 0.850 | 0.71@ El=51.738 | -4.71E-6 | 0.00030573 | 0.00616772 | 0.51438883 |
| Ka(LCP) | move | 31100 | 80 | 0.560 | 0.47@ El=48.211 | -6.14E-6 | 0.00022601 | 0.02134805 | 0.13347055 |
| Ka(RCP) | move | 31100 | 70 | 0.563 | 0.47@ El=48.937 | -6.35E-6 | 0.00026943 | 0.01925549 | 0.15628293 |

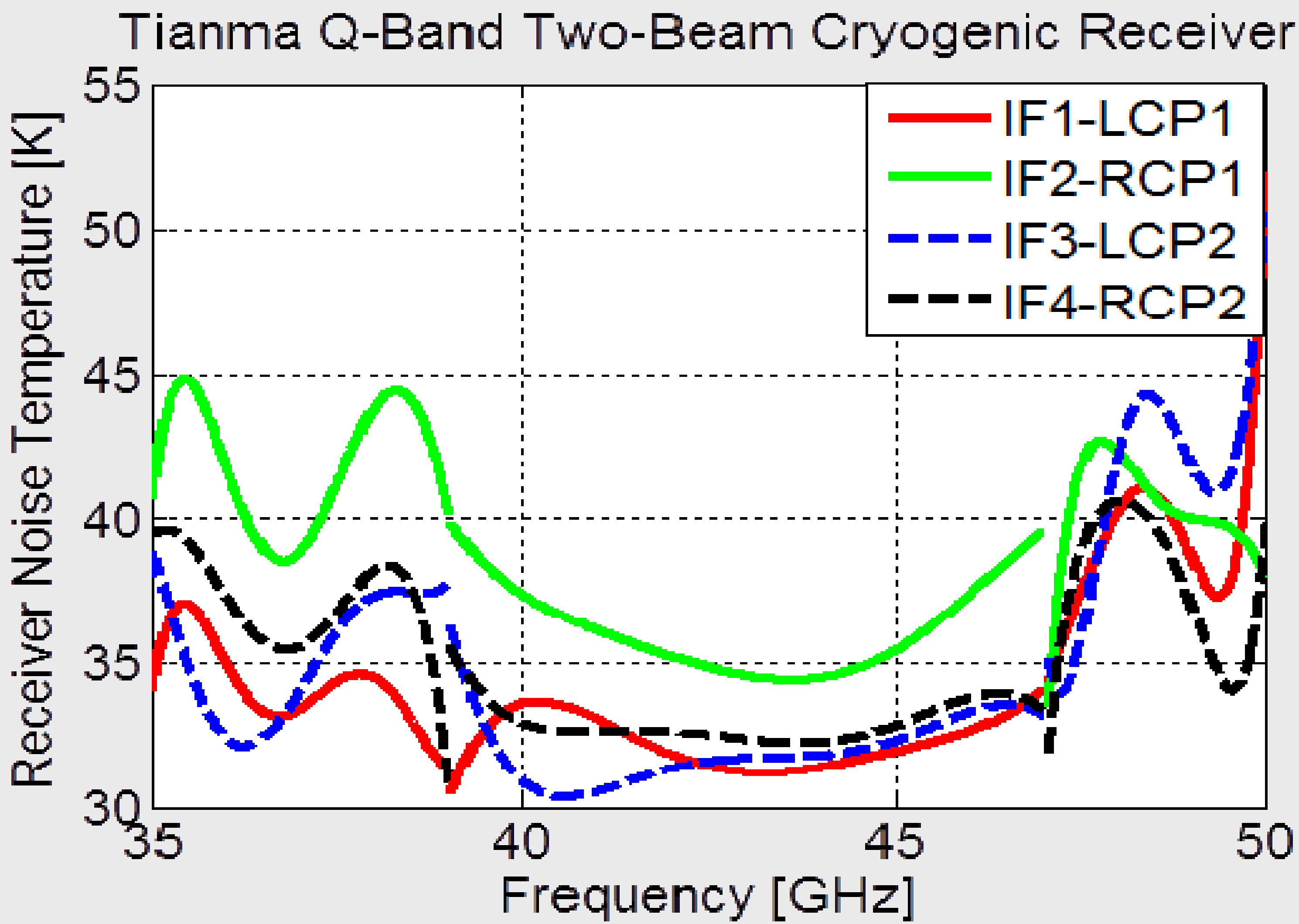
# K band dual beam Tsys/Trec/Tsky



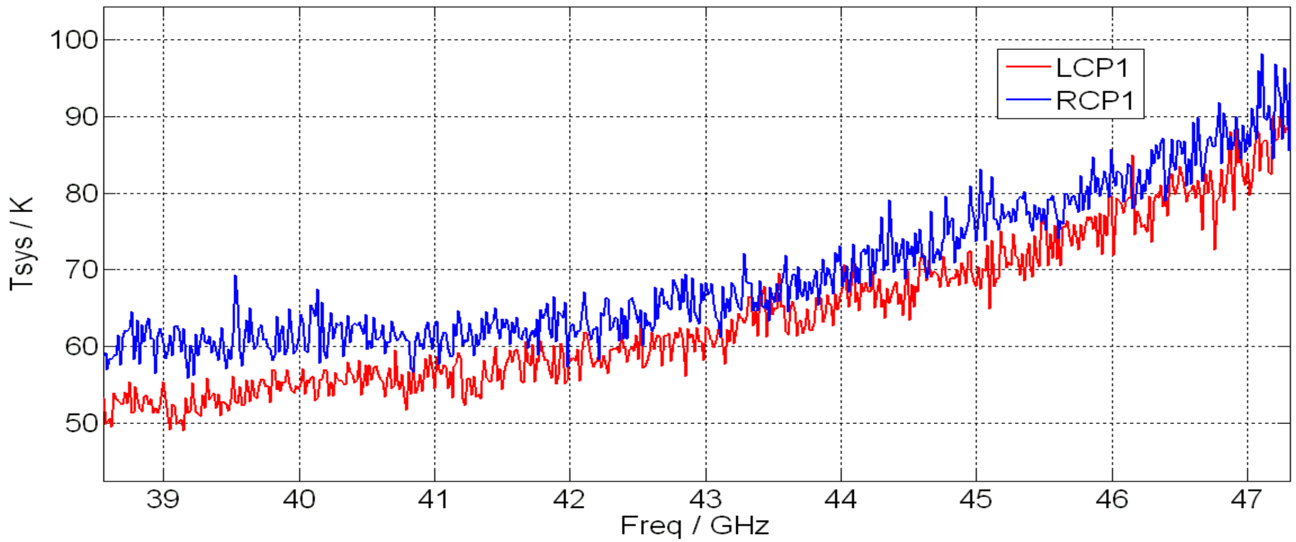
# K band Beam1-RCP @19.45GHz 16y8m25 cloudy

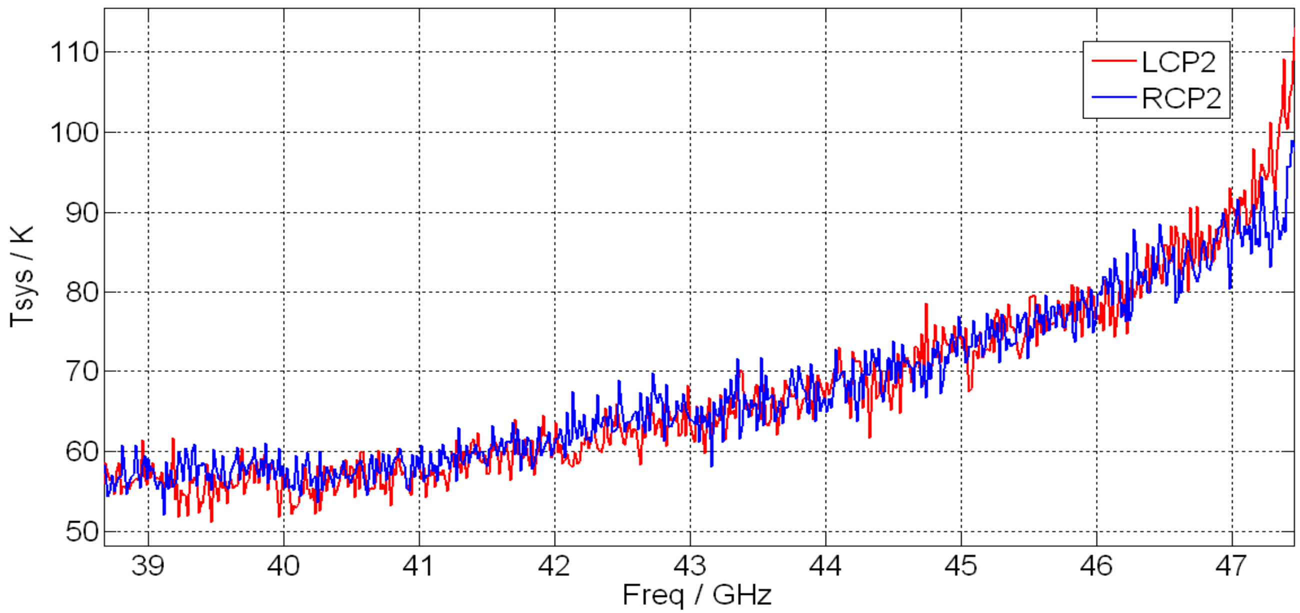


# Q band dual beam Receiver
# Noise Temperature



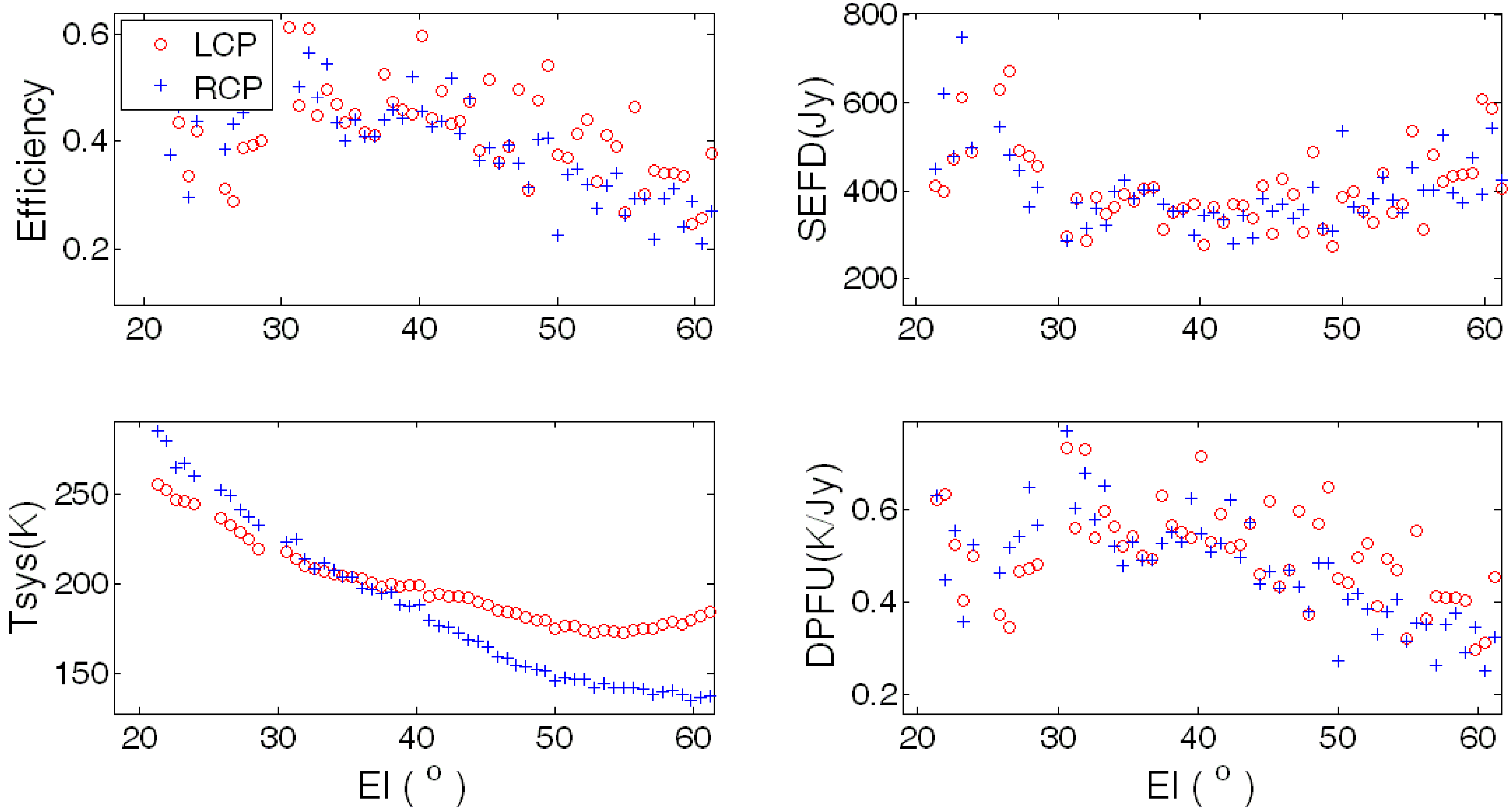
# Q band(38-48GHz) dual beam System noise temperature



# Q band Beam1 performance @43GH

2016y8m6 cloudy



# Microwave Holography on TM65m
# for surface error measurement

- Phase coherent

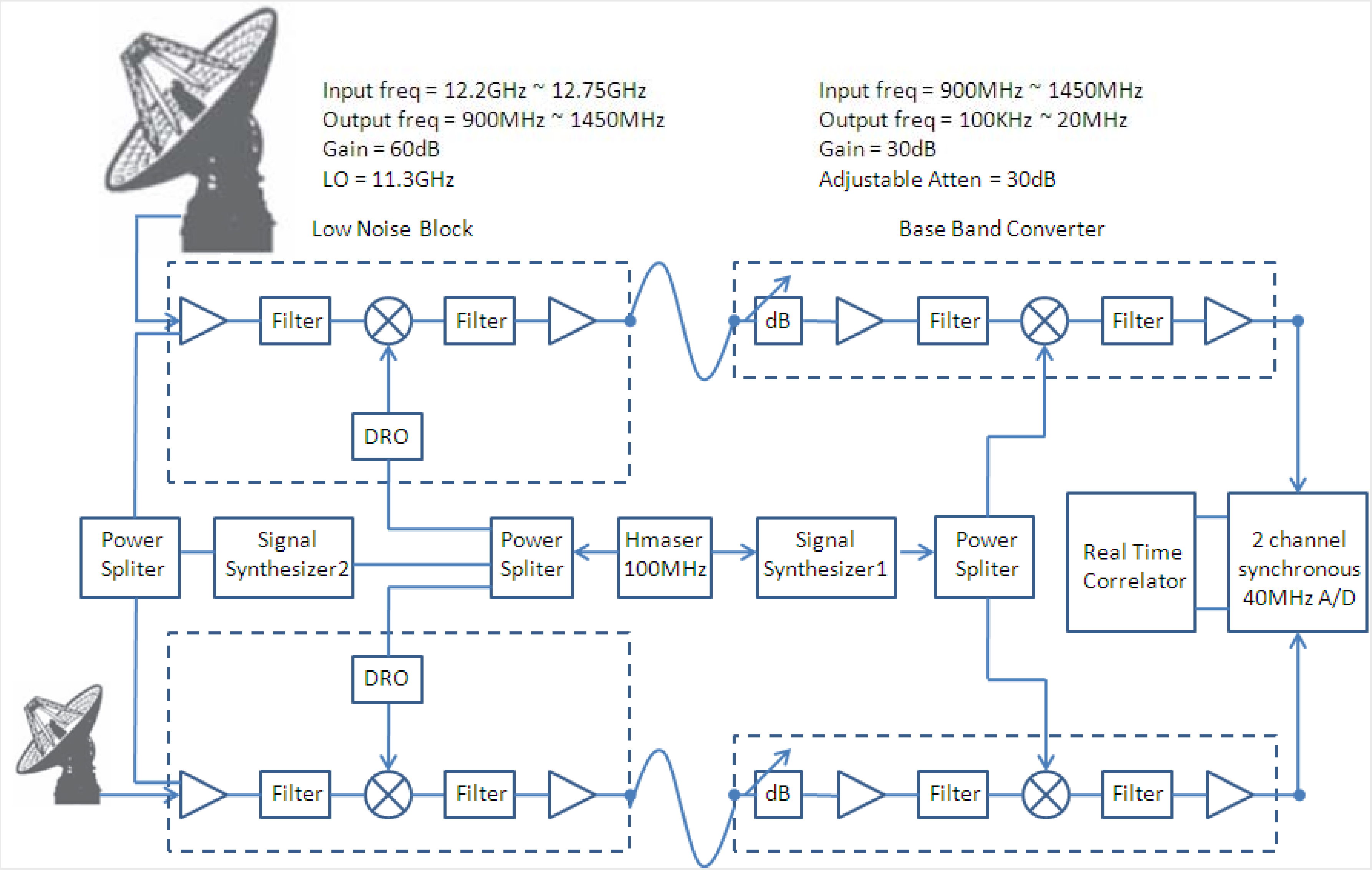
  satellite __ high accuracy pannel setting

  radio source (VLBI)__ gravity deformaiton

- Phase Retrieve

  OOF __ gravity deformation & real-time detection

  [See Dr. JianDong's poster]

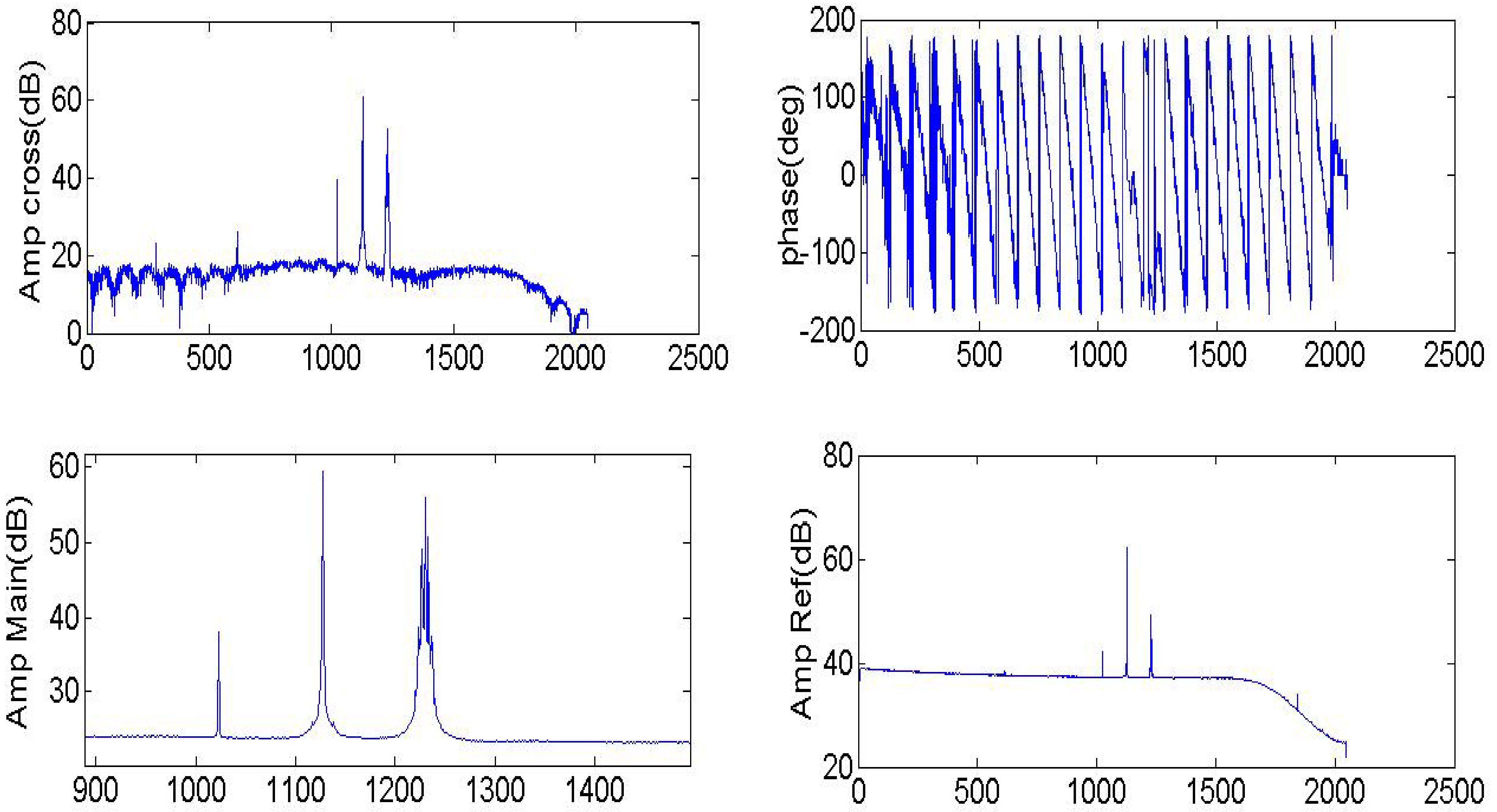

Input freq = 12.2GHz ~ 12.75GHz
Output freq = 900MHz ~ 1450MHz
Gain = 60dB
LO = 11.3GHz
Low Noise Block
Input freq = 900MHz ~ 1450MHz
Output freq = 100KHz ~ 20MHz
Gain = 30dB
Adjustable Atten = 30dB
Base Band Converter
Filter
Filter
DRO
dB
Filter
Filter
Power Spliter
Signal Synthesizer2
Power Spliter
Hmaser 100MHz
Signal Synthesizer1
Power Spliter
Real Time Correlator
2 channel synchronous 40MHz A/D
DRO
Filter
Filter
dB
Filter
Filter


65m Ku LNB

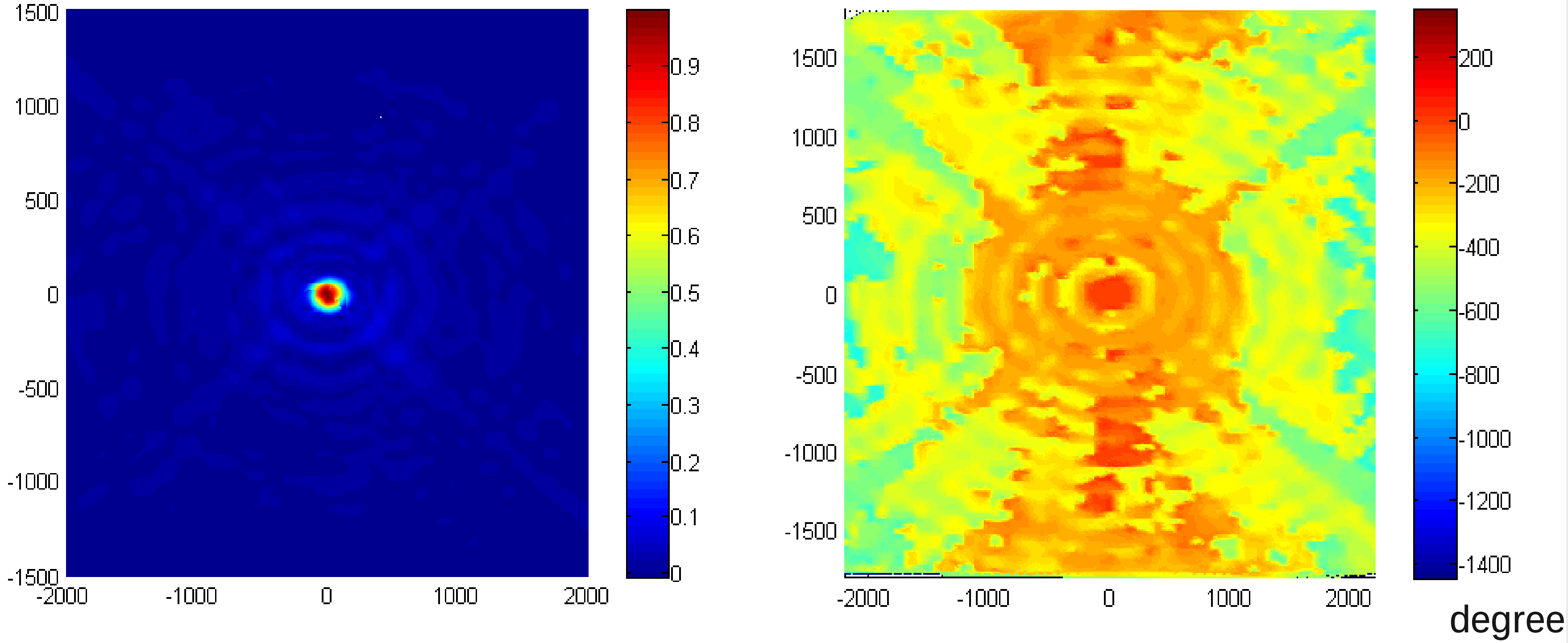

Reference
antenna
Ku LNB

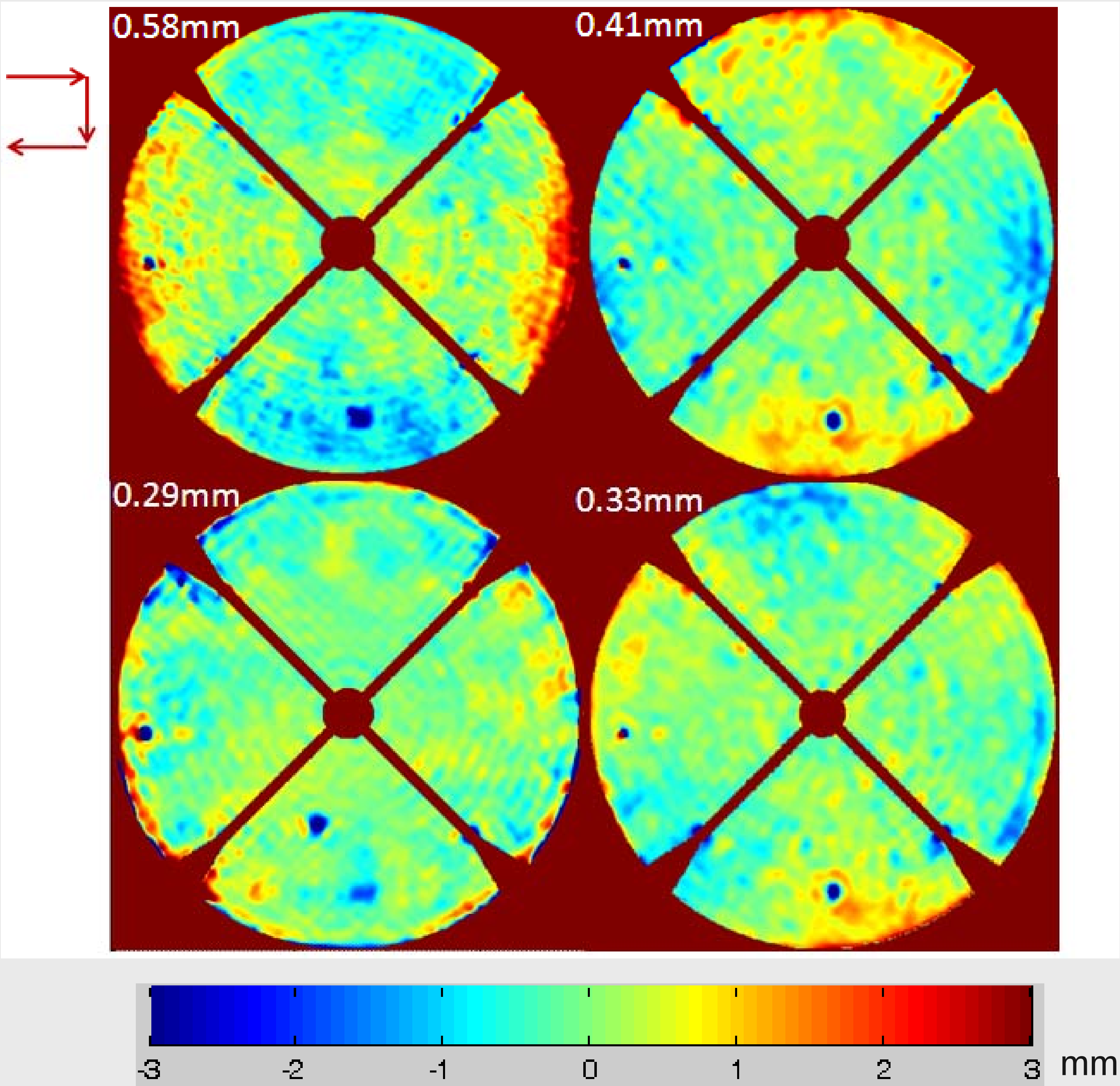

双通道基带变换器
Base Band
Converter
上海天文台
Real- time
correlator
SUPERMICRO
100MHz-distributor
100MHZ分配单元

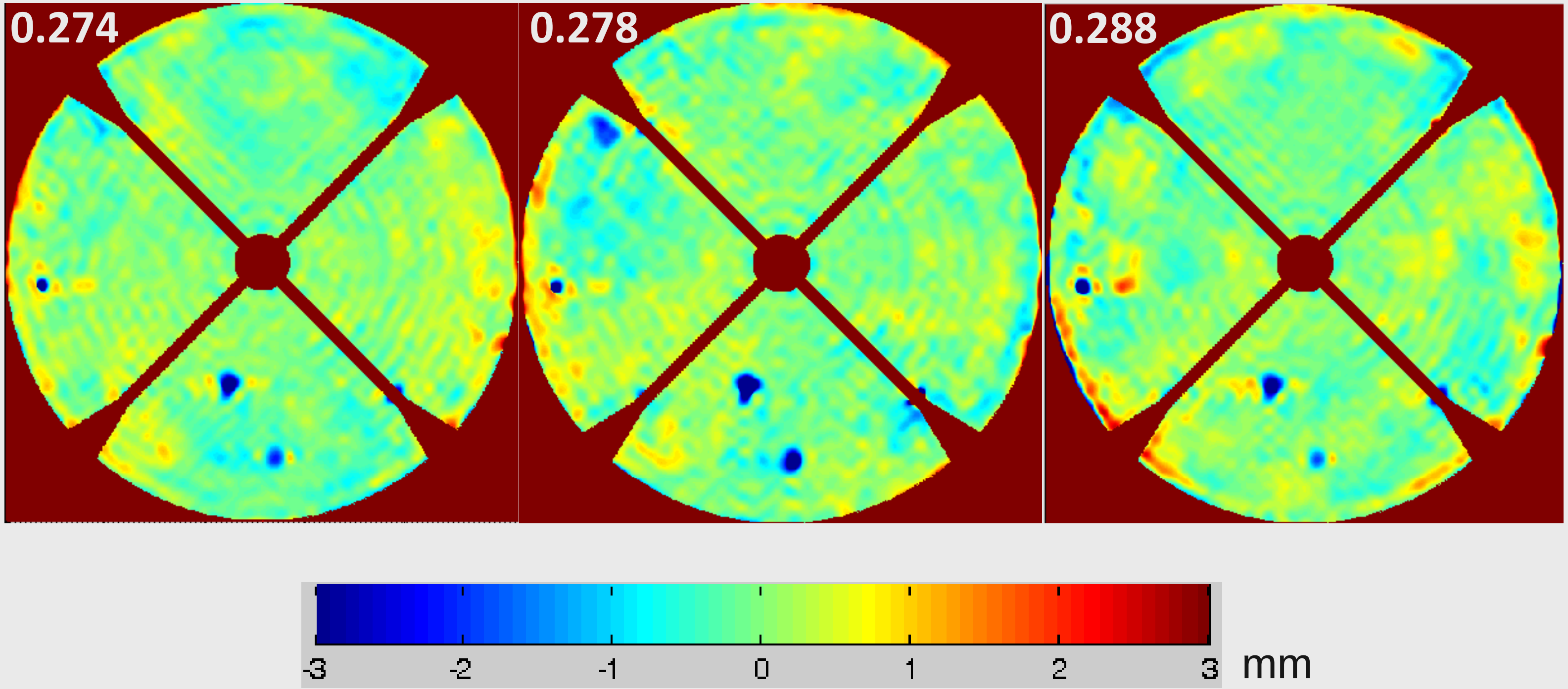
# Asia4 Ku beacon (12.25GHz)



# Far Field
# Amplitude and Phase

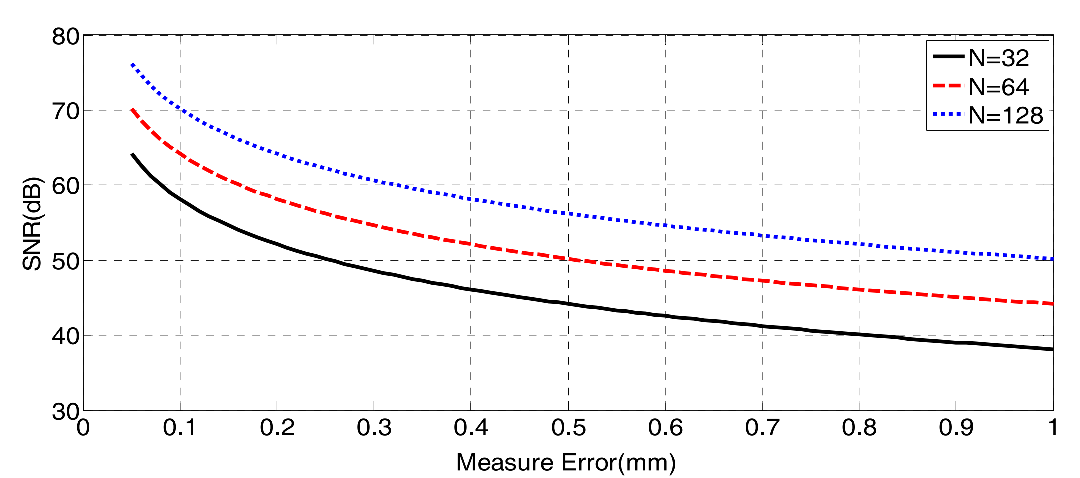



0.58mm
0.41mm
0.29mm
0.33mm
-3
-2
-1
0
1
2
3
mm

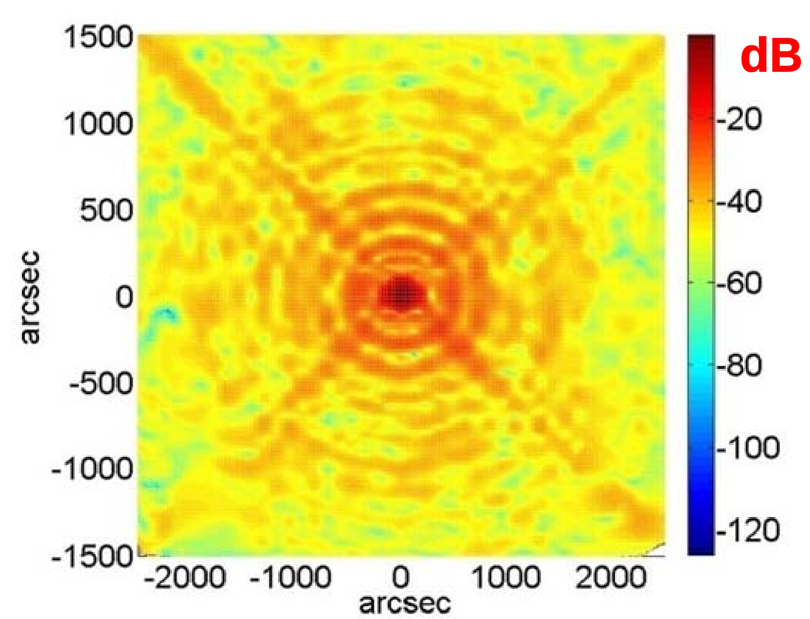


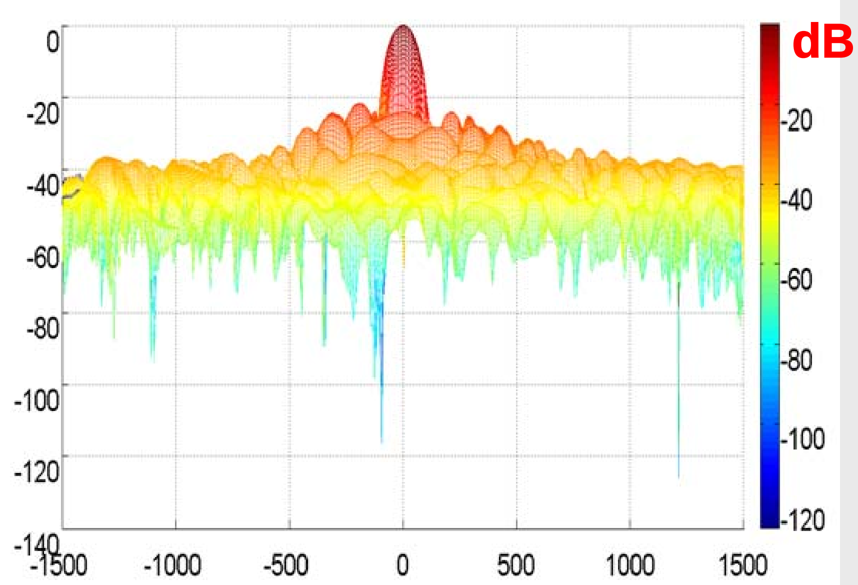

| D（m） | 65 | 63 | 60 | 58 | 56 | (UT) |
|---|---|---|---|---|---|---|
| RMS(mm) | 0.274 | 0.267 | 0.257 | 0.251 | 0.243 | 16y1m19<br>09:16-11:40 |
| | 0.278 | 0.270 | 0.263 | 0.260 | 0.255 | 16y1m19<br>14:44-17:06 |
| | 0.288 | 0.281 | 0.273 | 0.263 | 0.256 | 16y1m27<br>11:24-13:54 |

# Measurement Error

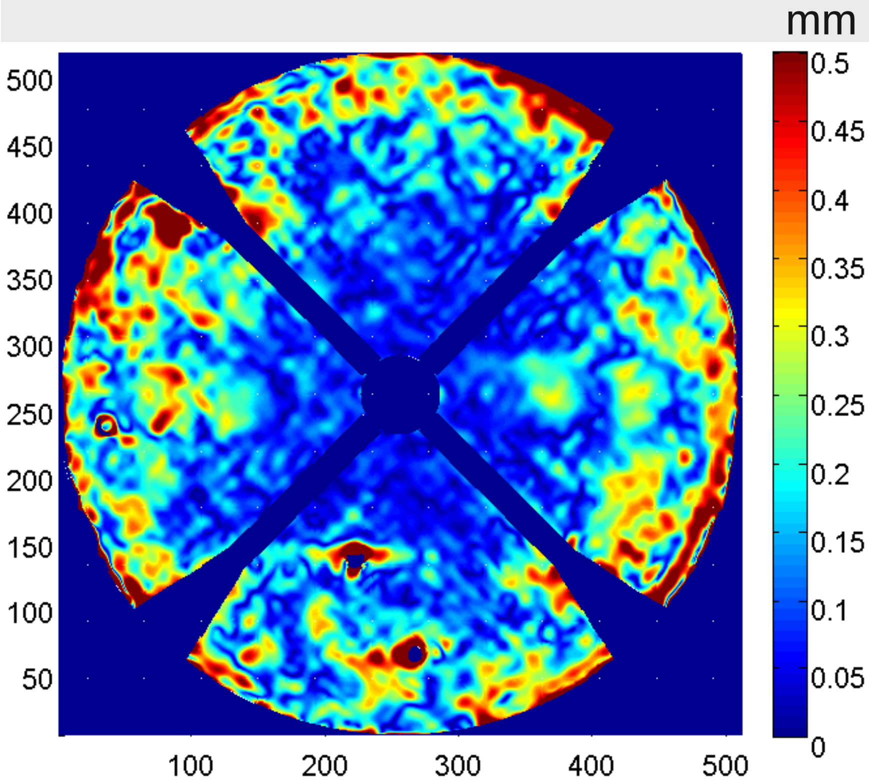


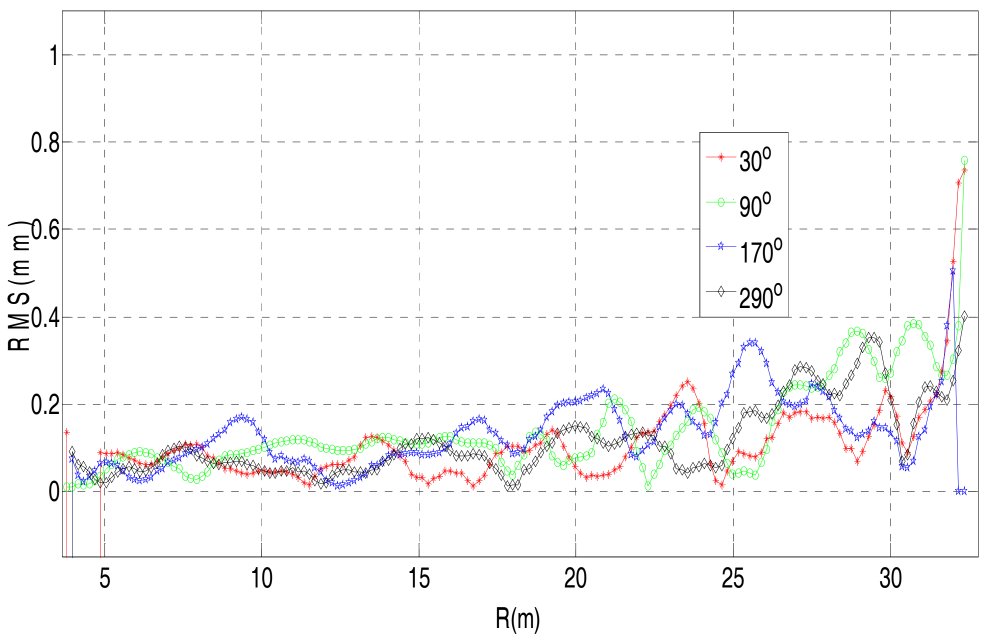

$$e_s = \frac{N\lambda}{2\pi\, SNR(O)}$$



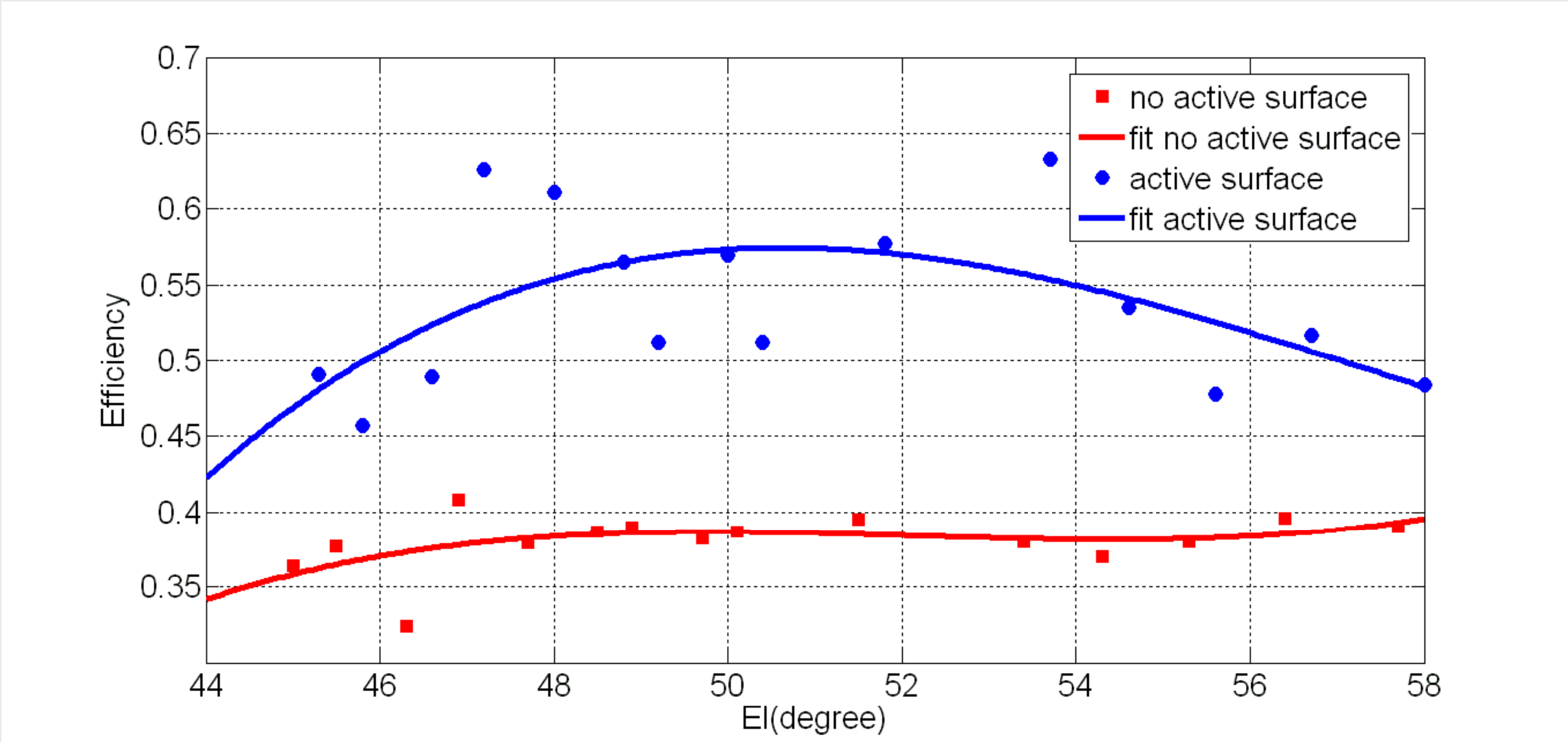
# Repeated measurement error by 3 times independent tests



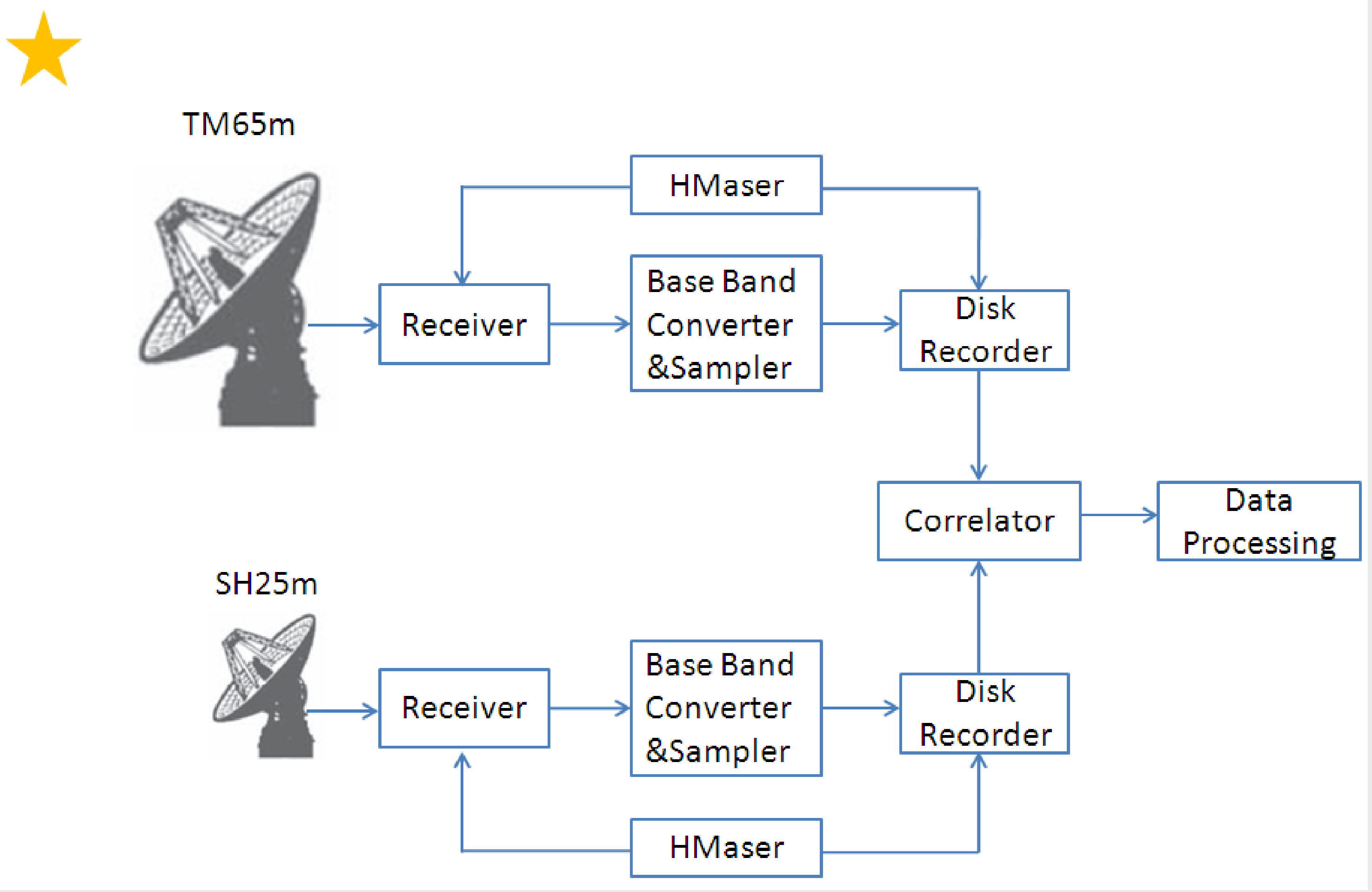

| **D（m）** | **65** | **63** | **60** | **58** | **56** | **53** | **50** |
|---|---|---|---|---|---|---|---|
| RMS（mm） | 0.132 | 0.121 | 0.113 | 0.109 | 0.106 | 0.099 | 0.093 |

# Ka efficiency improvement @31.15GHz



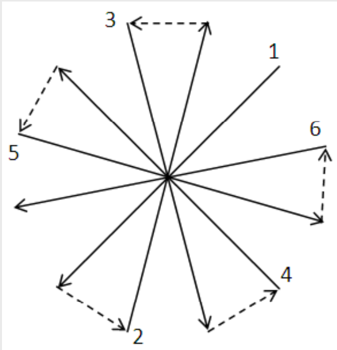

Ka 31.15GHz efficiency improvement in theory：
36%（0.58mm）-> 54%（0.3mm）

# Main Surface Gravity Model Measurment by Short Baseline(~6km) VLBI

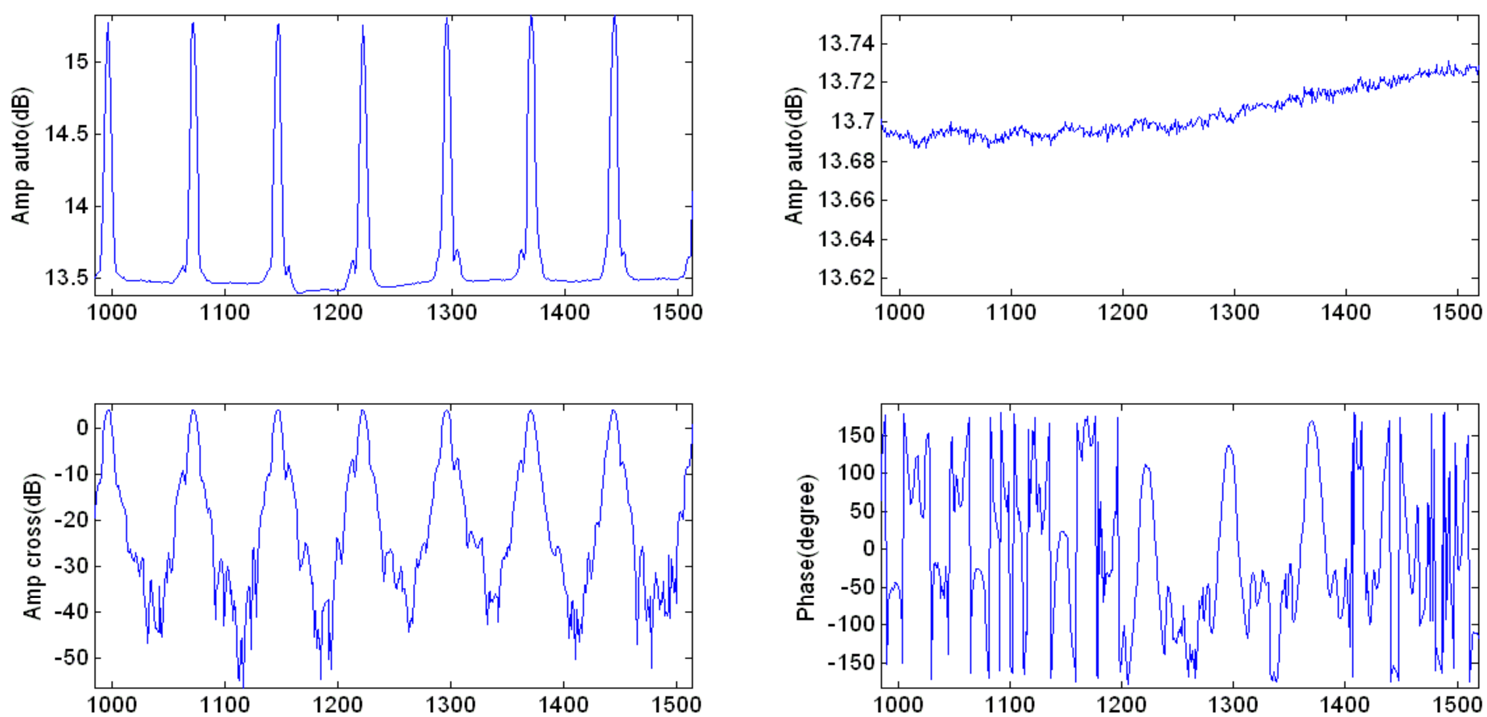


# Radial sweep scans and correlation

Radial sweep




One pattern:~20minutes
Resolusion:~3m
Meaure error:~0.17mm
Radio source:3C84
Integeration time:1second
Freq&Bandwidth:8.4GHz&16MHz



# Gravity model simulation and measurement

left： FEM simulation files

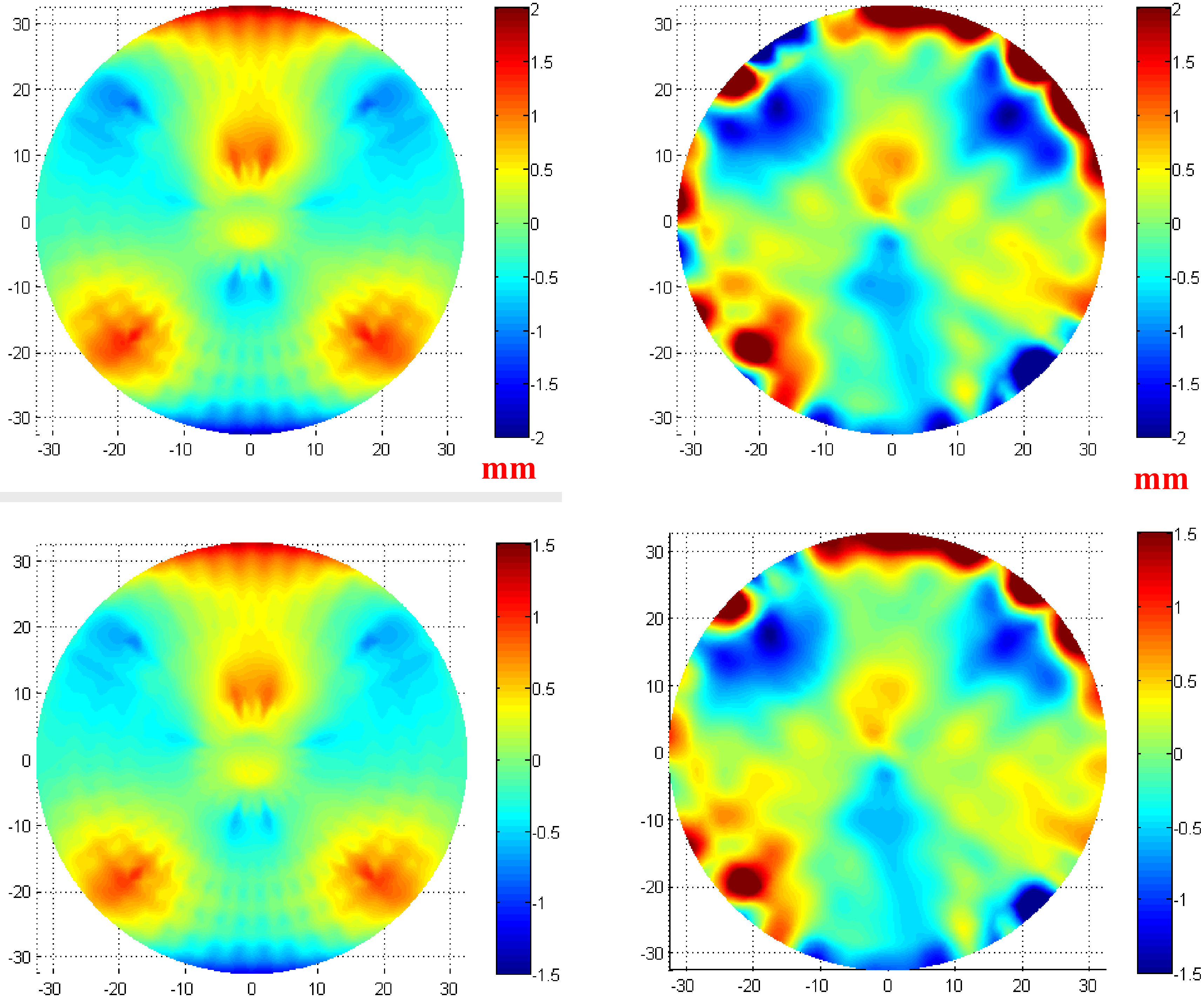
```
'E:\65m\主动面\促动器调整量(原始)\5° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\10° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\15° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\20° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\25° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\30° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\35° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\40° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\45° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\55° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\60° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\65° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\70° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\75° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\80° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\85° 仰角促动器调整量.txt';
'E:\65m\主动面\促动器调整量(原始)\90° 仰角促动器调整量.txt';
```

right： measurement file

| | EL |
|---|---|
| 'D:\share\2015y8m20\1453\Activesurface.txt'; | 17.6 |
| 'D:\share\2015y8m20\1524\Activesurface.txt'; | 22.9 |
| 'D:\share\2015y8m20\1555\Activesurface.txt'; | 28.1 |
| 'D:\share\2015y8m20\1626\Activesurface.txt'; | 33.9 |
| 'D:\share\2015y8m20\1657\Activesurface.txt'; | 39.4 |
| 'D:\share\2015y8m20\1728\Activesurface.txt'; | 45.4 |
| 'D:\share\2015y8m20\1759\Activesurface.txt'; | 51.4 |
| 'D:\share\2015y8m20\1830\Activesurface.txt'; | 57.1 |
| 'D:\share\2015y8m20\1901\Activesurface.txt'; | 62.4 |
| 'D:\share\2015y8m20\1932\Activesurface.txt'; | 68.3 |
| 'D:\share\2015y8m20\2003\Activesurface.txt'; | 73.3 |

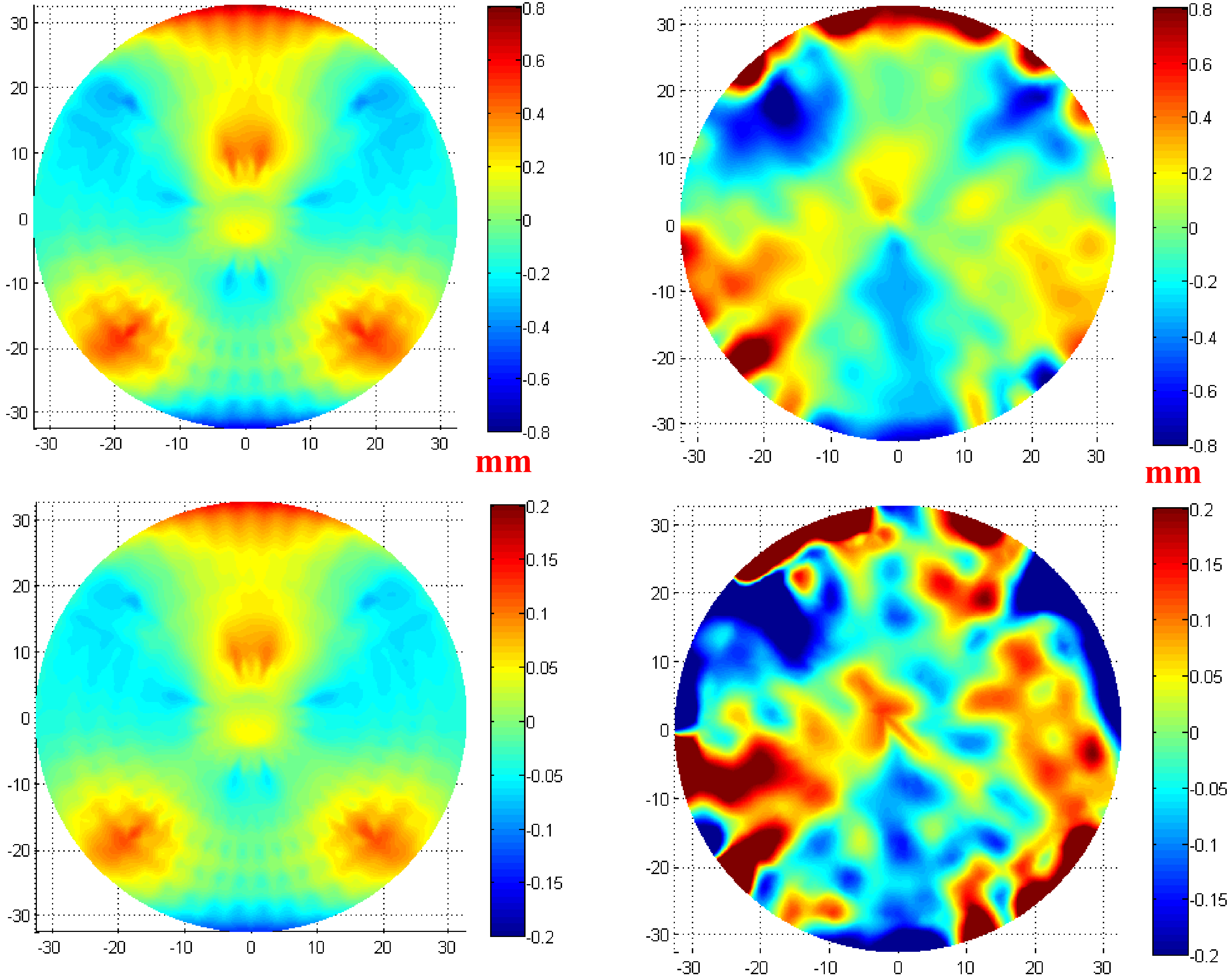
83

73

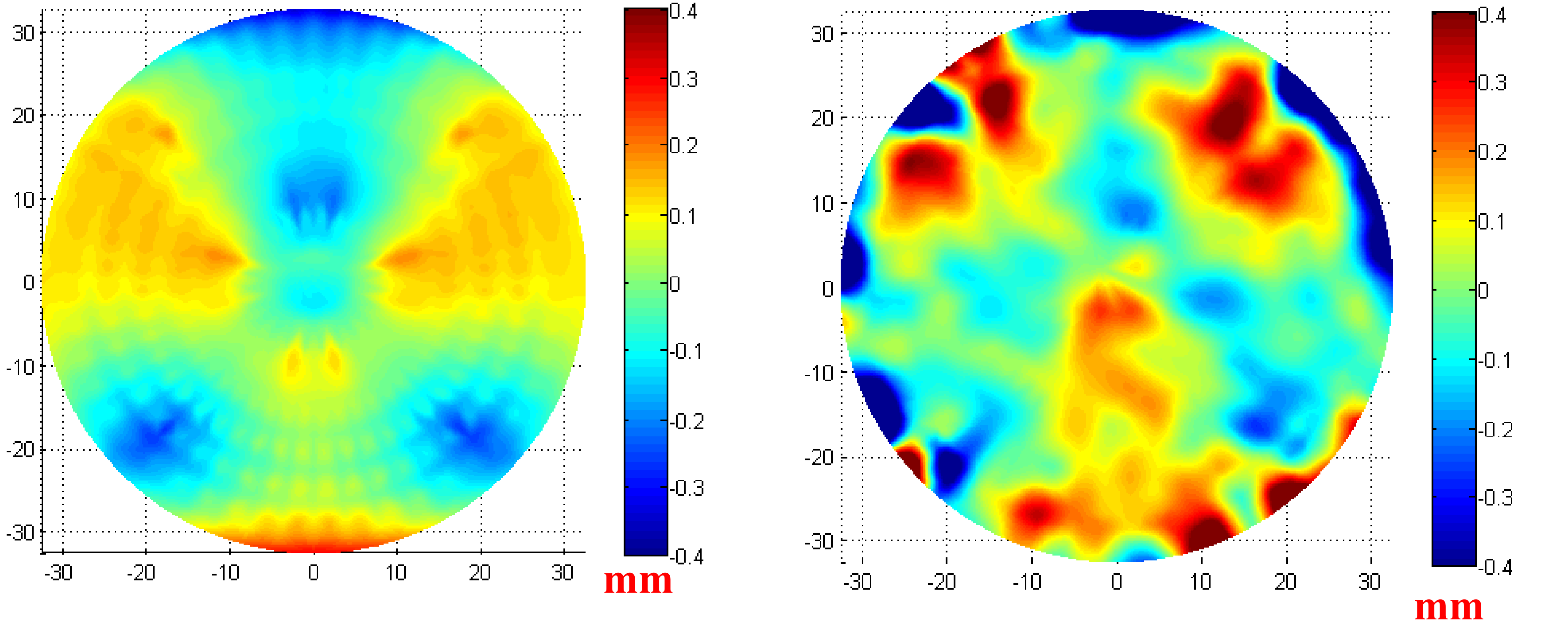


63

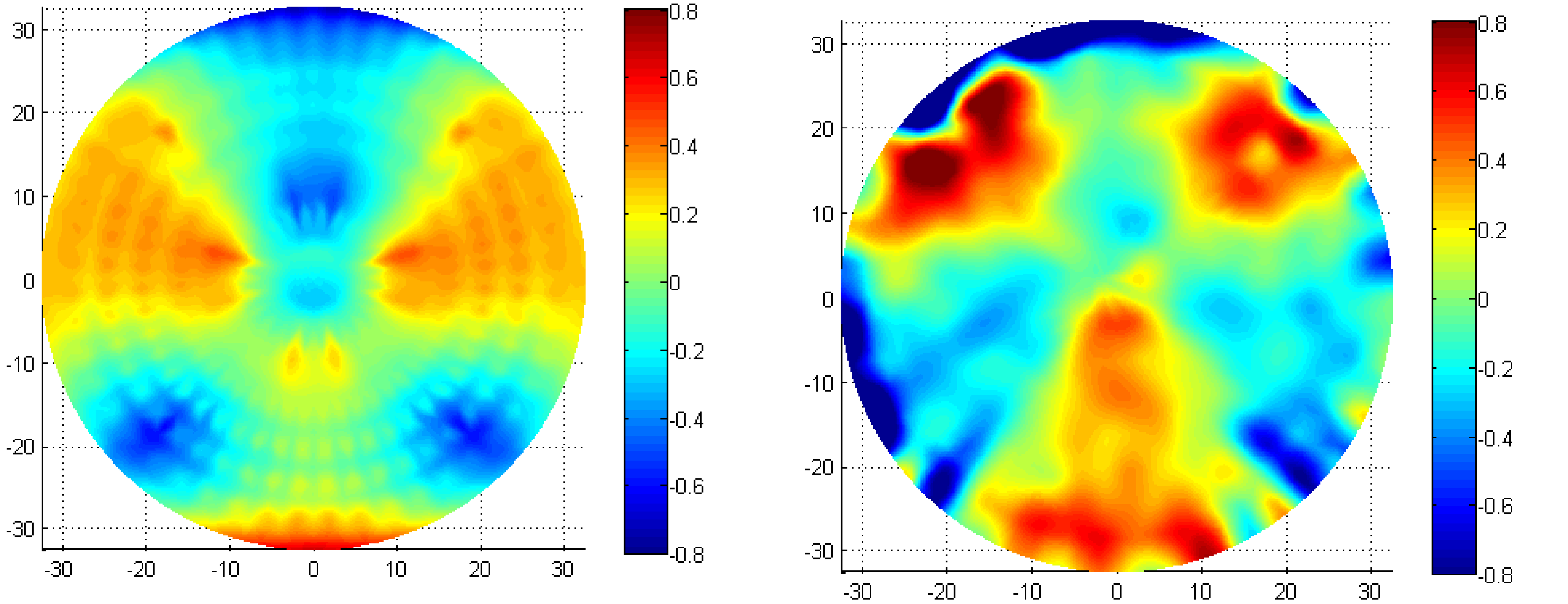
53

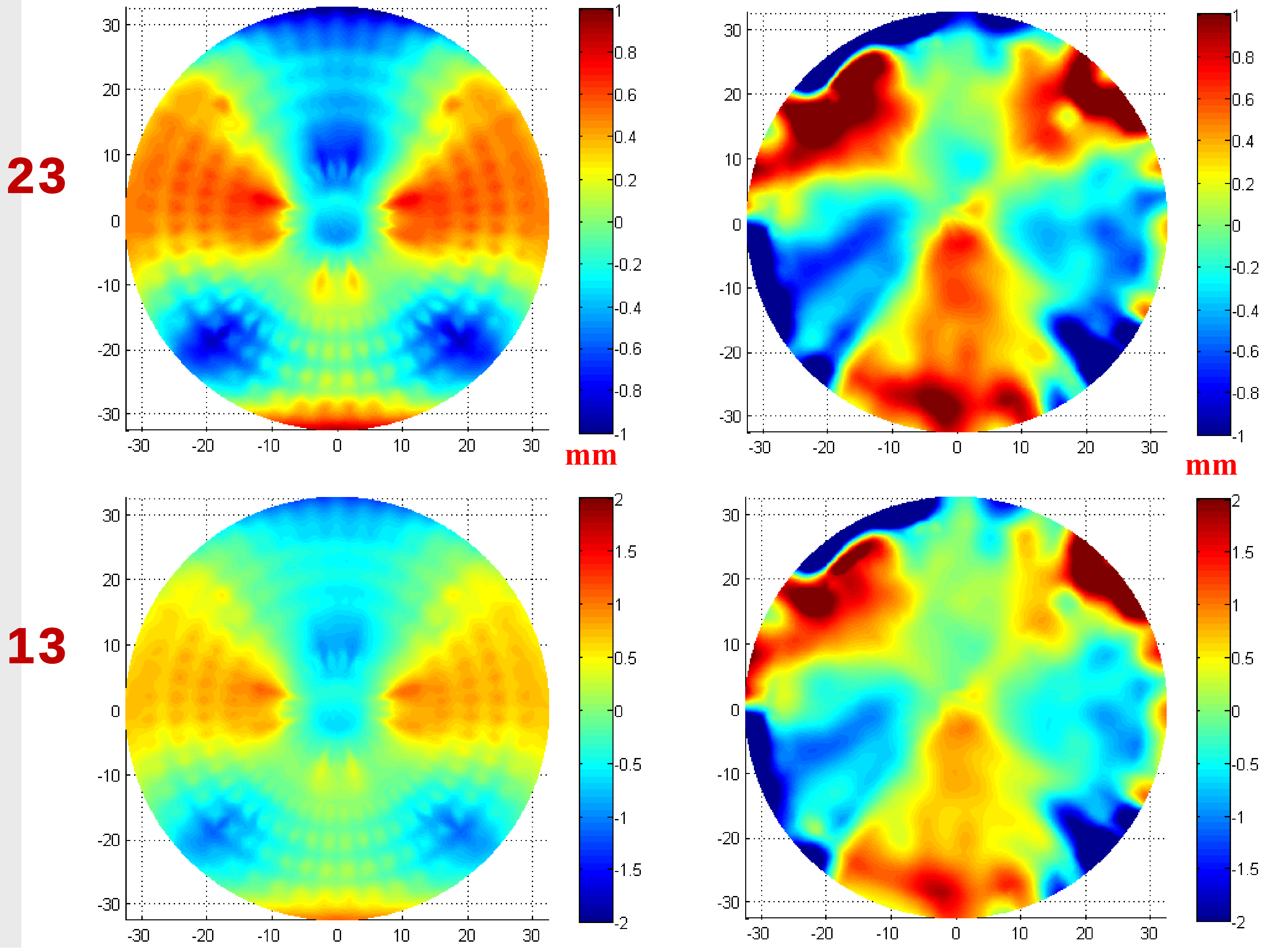


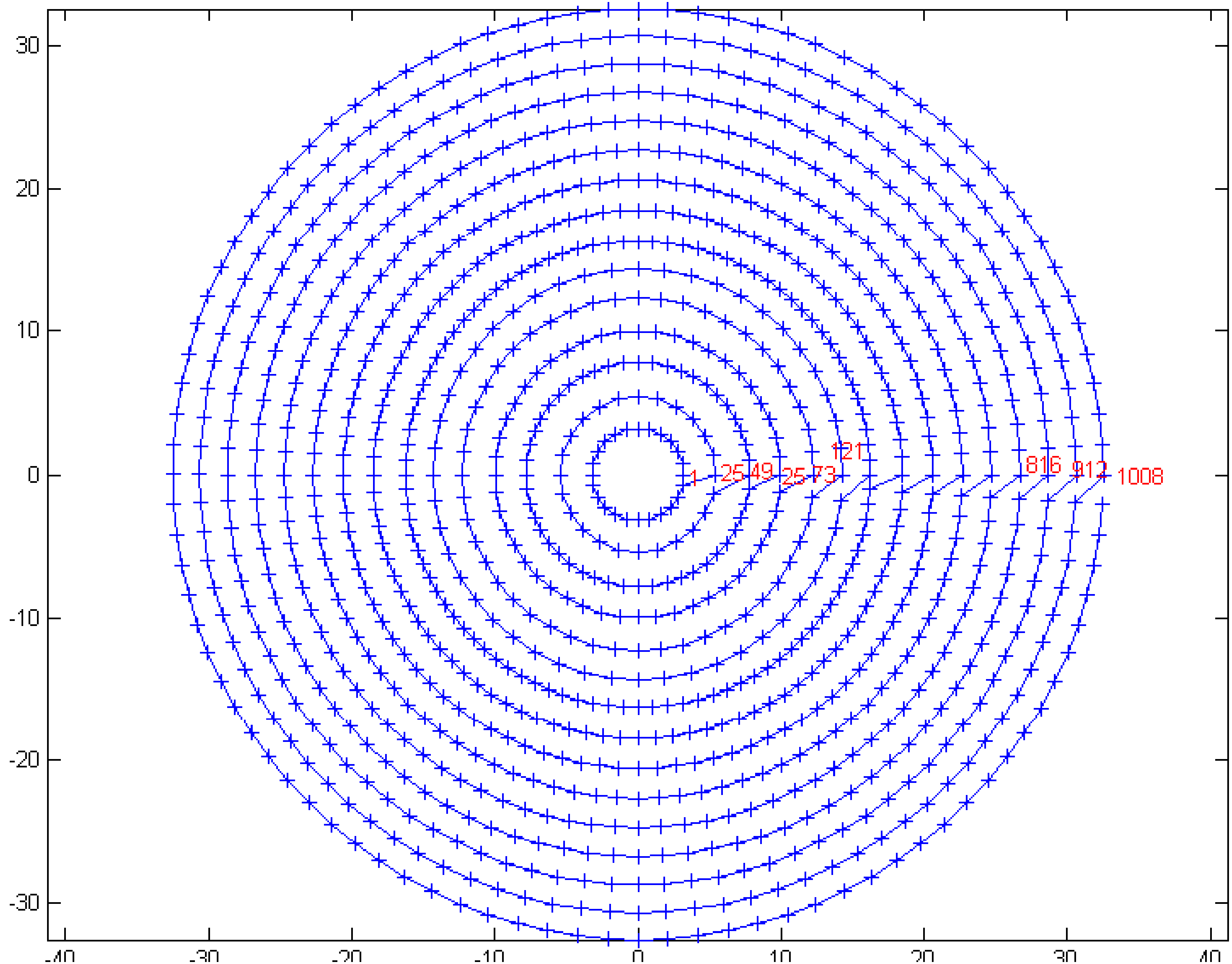
**43**



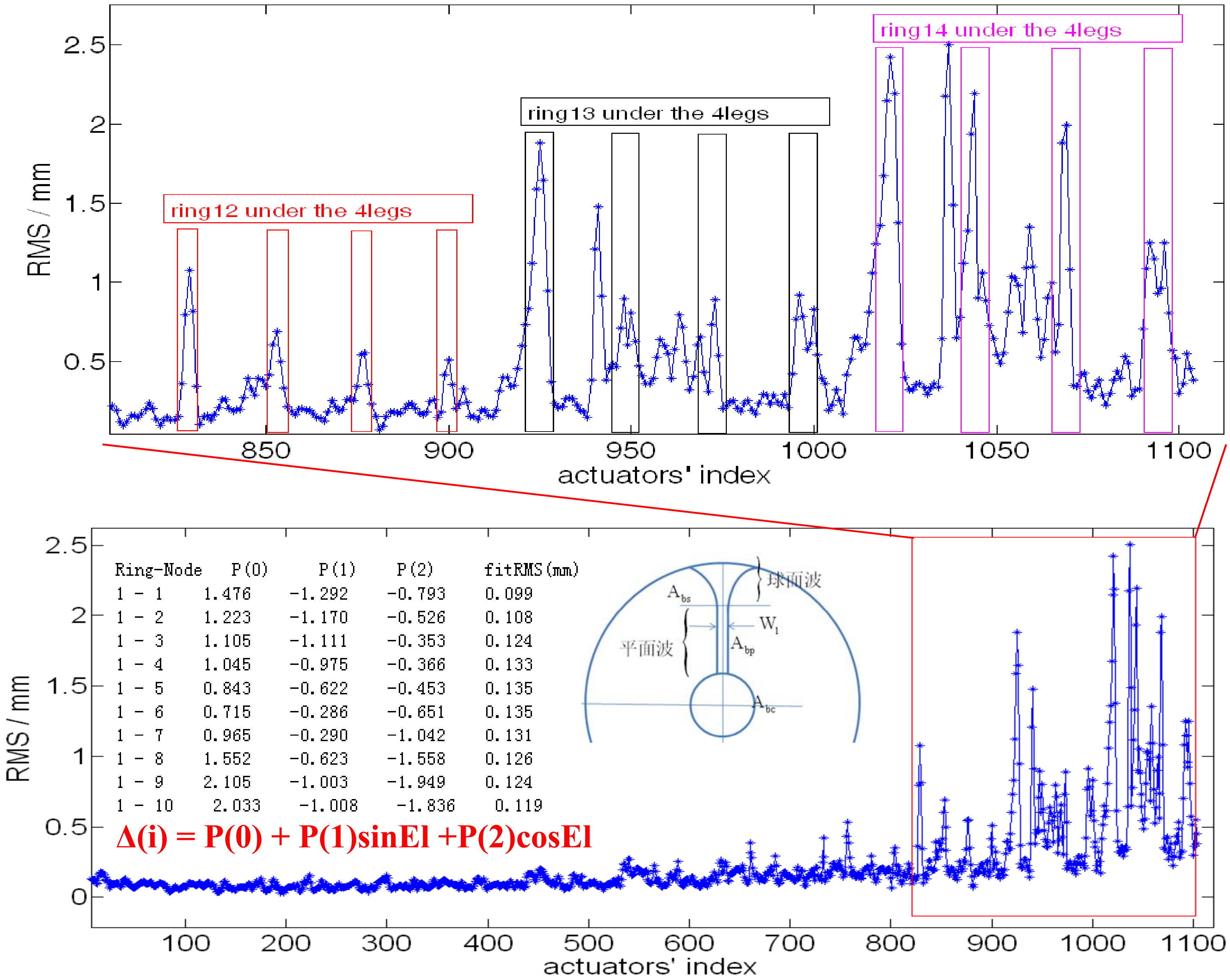

**33**




23
13
mm
mm



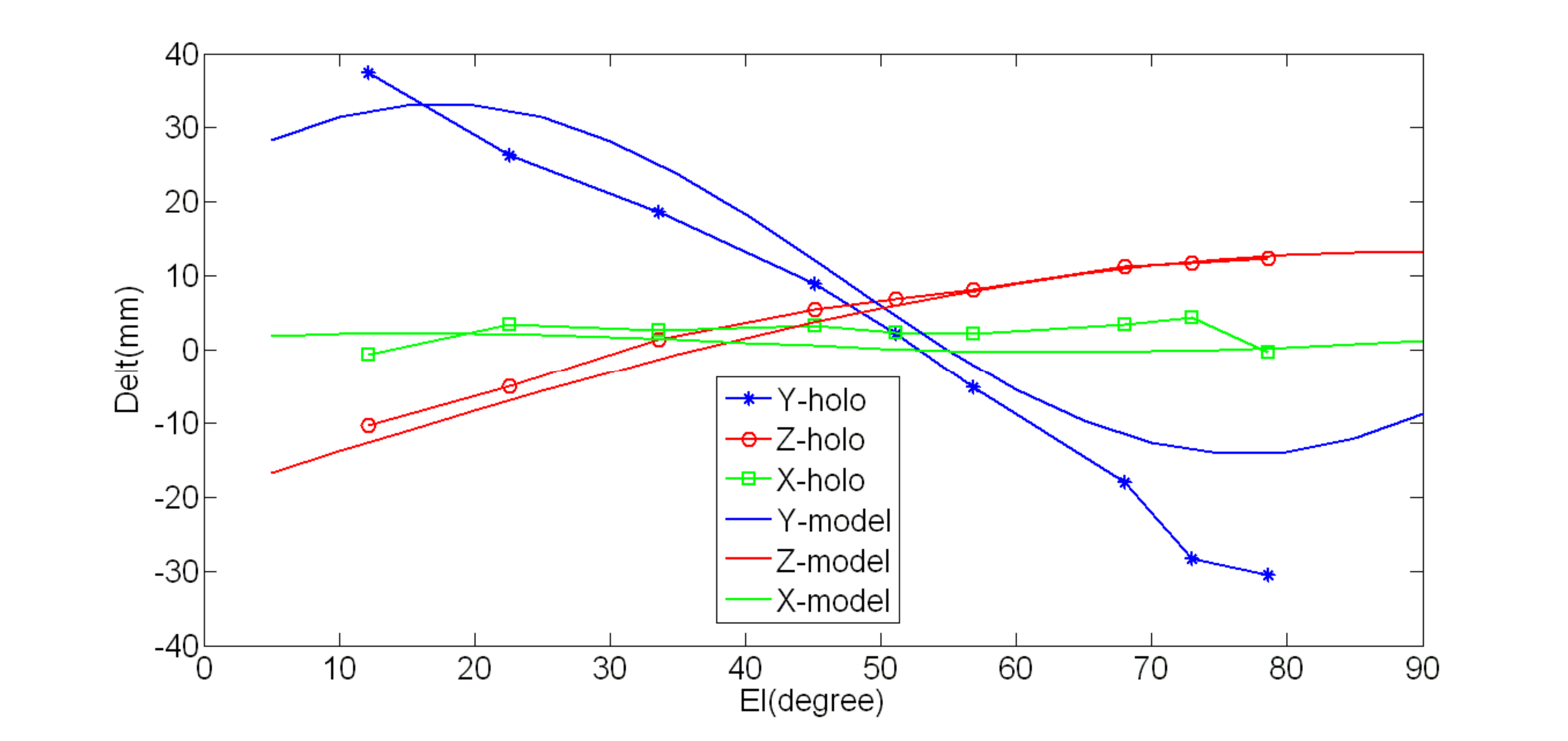
30
20
10
0
-10
-20
-30
-40
-30
-20
-10
0
10
20
30
40
1
25
49
25
73
121
816
912
1008




| Ring-Node | P(0) | P(1) | P(2) | fitRMS(mm) |
|---|---|---|---|---|
| 1 - 1 | 1.476 | -1.292 | -0.793 | 0.099 |
| 1 - 2 | 1.223 | -1.170 | -0.526 | 0.108 |
| 1 - 3 | 1.105 | -1.111 | -0.353 | 0.124 |
| 1 - 4 | 1.045 | -0.975 | -0.366 | 0.133 |
| 1 - 5 | 0.843 | -0.622 | -0.453 | 0.135 |
| 1 - 6 | 0.715 | -0.286 | -0.651 | 0.135 |
| 1 - 7 | 0.965 | -0.290 | -1.042 | 0.131 |
| 1 - 8 | 1.552 | -0.623 | -1.558 | 0.126 |
| 1 - 9 | 2.105 | -1.003 | -1.949 | 0.124 |
| 1 - 10 | 2.033 | -1.008 | -1.836 | 0.119 |

$$\Delta(i) = P(0) + P(1)\sin El + P(2)\cos El$$

## Sub-reflector XYZ position derived from holography aperture phase VS the sub-reflector model constructed from amplitude sweeps



# conclusions

- All receivers have been installed. K and Q bands need more testing for the weather and pointing problems
- Introduced the performance of pointing, surface accuracy and models construction
- Elevation pointing error needs more improvement and verification in servo control, encoder setup and models
- Both phase coherent and phase retrieve holography are adoped for pannel setting and gravity deformation model construciton. The surface accuracy is better than 0.3mm(RMS) at elevations around $53^{o}$ . For higher and lower elevations we need more testing and verification for the accuracy improvements

# *Questions…*