Performance measurements and models of Tianma Radio telescope(TM65m)

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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

\[ T = T_{\text{src}} \exp(-4\ln(2)(x/\theta)^2) \]

<table>
<thead>
<tr>
<th>Pointing error/beam width</th>
<th>0.1</th>
<th>0.2</th>
<th>0.3</th>
<th>0.4</th>
<th>0.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loss of gain</td>
<td>0.027</td>
<td>0.105</td>
<td>0.22</td>
<td>0.36</td>
<td>0.5</td>
</tr>
</tbody>
</table>
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

\[ \text{Delt}_{AZ} = C1 + \tan(E0) \cdot \cos(A0) \cdot C3 + \tan(E0) \cdot \sin(A0) \cdot C4 + \tan(E0) \cdot C5 - 1/ \cos(E0) \cdot C6 \]

\[ \text{Delt}_{EL} = C2 - \sin(A0) \cdot C3 + \cos(A0) \cdot C4 + \cos(E0) \cdot C7 + C8/\tan(E0) \]
K band pointing model
(sub_reflector enable)
Sub_reflector Model

\[ \Delta Y = A + B \cos(EL) \]

\[ \Delta Z = C + D \sin(EL) \]

@ X band 8.4GHz
Tested model VS FEM simulation

\[ Y = A + B \cos(\theta) \]

\[ A = -45.83 \pm 2.11 \quad B = 80.59 \pm 2.84 \]

\[ Z = C + D \sin(\theta) \]

\[ C = -20.75 \pm 0.51 \quad D = 33.97 \pm 0.76 \]
Efficiency & Tsys measurement

\[
\eta(\varphi) = \frac{2kT_d (\varphi) K_1 K_2 K_3 K_4 K_5}{\Sigma A_g}
\]

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

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

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

[Graphs showing efficiency, SE=DI, Tsys(K), DPFU(K/Jy) vs. EI (°)]
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

<table>
<thead>
<tr>
<th>Band</th>
<th>Sub_reflector</th>
<th>Frequency (MHz)</th>
<th>Tsys @Zenith</th>
<th>DPFU (K/ly)</th>
<th>Efficiency max</th>
<th>归一化 Poly(aX^2+bX^2+cX+d) (X=Elevation/degree)</th>
</tr>
</thead>
<tbody>
<tr>
<td>L(V)</td>
<td>fixed</td>
<td>1488</td>
<td>32</td>
<td>0.768</td>
<td>0.60 @ El=46.4</td>
<td>1.6E-6, -3.6247E-4, 0.02326739, 0.54048039</td>
</tr>
<tr>
<td>L(H)</td>
<td>fixed</td>
<td>1488</td>
<td>30</td>
<td>0.796</td>
<td>0.60 @ El=43.4</td>
<td>2.05E-6, -3.565E-4, 0.01829101, 0.66628028</td>
</tr>
<tr>
<td>S(LCP)</td>
<td>fixed</td>
<td>2265</td>
<td>50</td>
<td>0.880</td>
<td>0.570 @ El=9.463</td>
<td>5.0E-8, -9.83E-6, -0.00143989, 1.01446614</td>
</tr>
<tr>
<td>S(RCP)</td>
<td>fixed</td>
<td>2265</td>
<td>52</td>
<td>0.709</td>
<td>0.59 @ El=9.463</td>
<td>7.0E-8, -1.197E-5, -0.00158865, 1.01694279</td>
</tr>
<tr>
<td>C(LCP)</td>
<td>move</td>
<td>4800</td>
<td>20</td>
<td>0.771</td>
<td>0.64 @ El=18.7</td>
<td>6.4E-7, -1.1909E-4, 0.00706175, 0.86551465</td>
</tr>
<tr>
<td>C(RCP)</td>
<td>move</td>
<td>4800</td>
<td>20</td>
<td>0.785</td>
<td>0.65 @ El=47.1</td>
<td>6.8E-7, -1.2899E-5, 0.00759555, 0.85688260</td>
</tr>
<tr>
<td>C(LCP)</td>
<td>move</td>
<td>6425</td>
<td>19</td>
<td>0.719</td>
<td>0.56 @ El=54.7</td>
<td>3.0E-8, -3.02E-5, 0.00303171, 0.91954072</td>
</tr>
<tr>
<td>C(RCP)</td>
<td>move</td>
<td>6425</td>
<td>19</td>
<td>0.708</td>
<td>0.59 @ El=54.7</td>
<td>1.6E-7, -4.839E-5, 0.00396896, 0.90378113</td>
</tr>
<tr>
<td>C(LCP)</td>
<td>move</td>
<td>7500</td>
<td>17</td>
<td>0.764</td>
<td>0.64 @ El=55.3</td>
<td>1.7E-7, -6.086E-5, 0.00585544, 0.85217763</td>
</tr>
<tr>
<td>C(RCP)</td>
<td>move</td>
<td>7500</td>
<td>17</td>
<td>0.764</td>
<td>0.64 @ El=55.3</td>
<td>1.7E-7, -6.086E-5, 0.00585544, 0.85217763</td>
</tr>
<tr>
<td>X(LCP)</td>
<td>move</td>
<td>8400</td>
<td>33</td>
<td>0.789</td>
<td>0.66 @ El=50.1</td>
<td>-1.99E-6, 2.4240E-4, -0.00757999, 1.01186495</td>
</tr>
<tr>
<td>X(RCP)</td>
<td>move</td>
<td>8400</td>
<td>31</td>
<td>0.782</td>
<td>0.65 @ El=50.9</td>
<td>-1.99E-6, 2.4415E-4, -0.00763073, 1.0090602</td>
</tr>
<tr>
<td>Ku(LCP)</td>
<td>move</td>
<td>15600</td>
<td>25</td>
<td>0.807</td>
<td>0.670 @ El=50.877</td>
<td>-5.13E-6, 0.00039693, -0.00038884, 0.66734680</td>
</tr>
<tr>
<td>Ku(RCP)</td>
<td>move</td>
<td>15600</td>
<td>30</td>
<td>0.850</td>
<td>0.710 @ El=51.738</td>
<td>4.71E-6, 0.0003573, 0.00617772, 0.51436883</td>
</tr>
<tr>
<td>Ka(LCP)</td>
<td>move</td>
<td>31100</td>
<td>80</td>
<td>0.600</td>
<td>0.470 @ El=48.211</td>
<td>-6.14E-6, 0.00022601, 0.02134806, 0.13347056</td>
</tr>
<tr>
<td>Ka(RCP)</td>
<td>move</td>
<td>31100</td>
<td>70</td>
<td>0.563</td>
<td>0.470 @ El=48.937</td>
<td>-6.35E-6, 0.00025843, 0.01525549, 0.15628293</td>
</tr>
</tbody>
</table>
K band dual beam Tsys/ Trec/ Tsky
K band Beam1-RCP @19.45GHz

16y8m25 cloudy
Q band dual beam Receiver
Noise Temperature

Tianma Q-Band Two-Beam Cryogenic Receiver

Receiver Noise Temperature [K]

Frequency [GHz]
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 panel setting
  - radio source (VLBI) ___ gravity deformation

- 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

Input freq = 900MHz ~ 1450MHz
Output freq = 100kHz ~ 20MHz
Gain = 30dB
Adjustable Attenu = 30dB
65m Ku LNB

Base Band Converter

Real-time correlator

Reference antenna
Ku LNB

100MHz-distributor
Asia4 Ku beacon (12.25GHz)
Far Field
Amplitude and Phase
<table>
<thead>
<tr>
<th>D (m)</th>
<th>65</th>
<th>63</th>
<th>60</th>
<th>58</th>
<th>56</th>
<th>(UT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS(mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0.274</td>
<td>0.267</td>
<td>0.257</td>
<td>0.251</td>
<td>0.243</td>
<td>16y1m19 09:16-11:40</td>
<td></td>
</tr>
<tr>
<td>0.278</td>
<td>0.270</td>
<td>0.263</td>
<td>0.260</td>
<td>0.255</td>
<td>16y1m19 14:44-17:06</td>
<td></td>
</tr>
<tr>
<td>0.288</td>
<td>0.281</td>
<td>0.273</td>
<td>0.263</td>
<td>0.256</td>
<td>16y1m27 11:24-13:54</td>
<td></td>
</tr>
</tbody>
</table>
**Measurement Error**

\[ e_s = \frac{N \lambda}{2 \pi \text{SNR}(O)} \]

![Graph showing SNR vs. Measurement Error with different N values](image)

![Graph showing dB vs. arsec with color scale](image)
Repeated measurement error by 3 times independent tests

<table>
<thead>
<tr>
<th>D (m)</th>
<th>65</th>
<th>63</th>
<th>60</th>
<th>58</th>
<th>56</th>
<th>53</th>
<th>50</th>
</tr>
</thead>
<tbody>
<tr>
<td>RMS (mm)</td>
<td>0.132</td>
<td>0.121</td>
<td>0.113</td>
<td>0.109</td>
<td>0.106</td>
<td>0.099</td>
<td>0.093</td>
</tr>
</tbody>
</table>
Ka efficiency improvement @31.15GHz

Ka 31.15GHz efficiency improvement in theory:
36% (0.58mm) -> 54% (0.3mm)
Main Surface Gravity Model Measurement by Short Baseline (~6km) VLBI
Radial sweep scans and correlation

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

Radial sweep

![Graphs showing amplifier and phase data over time]
Gravity model simulation and measurement

left: FEM simulation files

right: measurement file

E:\65\主动面\促动器调整量(原始)\5’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\10’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\15’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\20’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\25’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\30’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\35’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\40’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\45’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\50’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\55’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\60’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\65’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\70’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\75’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\80’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\85’ 仰角促动器调整量.txt
E:\65\主动面\促动器调整量(原始)\90’ 仰角促动器调整量.txt

D:\share\2015y\6m\20\1453\Activesurface.txt
D:\share\2015y\6m\20\1524\Activesurface.txt
D:\share\2015y\6m\20\1555\Activesurface.txt
D:\share\2015y\6m\20\1626\Activesurface.txt
D:\share\2015y\6m\20\1657\Activesurface.txt
D:\share\2015y\6m\20\1728\Activesurface.txt
D:\share\2015y\6m\20\1759\Activesurface.txt
D:\share\2015y\6m\20\1830\Activesurface.txt
D:\share\2015y\6m\20\1901\Activesurface.txt
D:\share\2015y\6m\20\1932\Activesurface.txt
D:\share\2015y\6m\20\2003\Activesurface.txt

17.6
22.9
28.1
33.9
39.4
45.4
51.4
67.1
62.4
68.3
73.3
\[ \Delta(i) = P(0) + P(1)\sin El + P(2)\cos El \]
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 adopted for panel setting and gravity deformation model construction.

The surface accuracy is better than 0.3mm (RMS) at elevations around 53°. For higher and lower elevations we need more testing and verification for the accuracy improvements.
Questions...