Multi-frequency mm-wave radio telescopes
& other software controlled operations

A quasi-optical system of KVN for
millimeter VLBI

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October 6th, 2015
Outline

- Design quasi-optic circuit
- Test results of optical circuit
- Observational results
- Global collaborations for optics design
- Summary
Conceptual design of simultaneous multi-frequency bands millimeter wave receivers

- Conceptual design came out in April 2003

Beams from antenna

- 22, 43, 86, 129GHz

Ellipsoidal Mirrors 1

- 43, 86, 129GHz

Ellipsoidal Mirrors 2

- 86, 129GHz

Ellipsoidal Mirrors 3

- 129GHz

LPF1

22GHz

LPF2

43GHz

LPF3

86GHz

129GHz

22GHz

43GHz

86GHz

129GHz
Frequency Independent beam waist Image + Gaussian Beam Telescope (GBT)
- Wide band application -

Frequency independent beam waist mage

Gaussian Beam Telescope (GBT)

Detail described the paper

Seog-Tae Han, et al
“Millimeter-wave Receiver Optics for Korean VLBI Network”
Beam Parameters

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Quasi-optics design has been carried out by using Gaussian Beam Propagation (IRMW 2008, Seog-Tae Han)

April 2003 ~ November 2005 (2 and half years)
Test of Quasi-optical circuit
Gaussian beam measurement system

- Homemade to be used quasi-optics test only

- Radiation patterns of feed horns
- Ellipsoidal mirrors
- Dielectric lens
- LPF(Dicroic filter)

- Beam pattern
- Transmission Loss
- Reflection Loss
- Cross-polarization
Quasi-optics circuit test

December 2005 ~ May 2011 (5 and half years)

43GHz Receiver
LPF2
22GHz Receiver
LPF1
LPF3
129GHz Receiver
86GHz Receiver
Mr. Ji-Man Kang


Comparison theoretical and experimental beam radii near the focus

- Differences between two values (measure-design) are less than 2mm of beam radius
- Optical circuit and its components are properly designed.
- Gaussian beam transmission theory is very powerful tool to be used quasi-optics design

<table>
<thead>
<tr>
<th>TABLE 1</th>
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<tr>
<td>COMPARISON BETWEEN THE DESIGNED AND MEASURED BEAM RADI</td>
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<td>Frequency (GHz)</td>
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<td>43</td>
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<td>86</td>
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<tr>
<td>129</td>
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Note.—Due to mechanical interference with mirror mounts, each band has a different measurement plane.

Seog-Tae Han, et al
“Korean VLBI Network Receiver Optics Simultaneous Multi-frequency Observation
Beam axises alignment for among 4 beams (22/43/86/129GHz)

- Circular shaped of beam pattern: alignment is correct
- Lateral offsets are within less than 1mm among 22/43/129GHz beam centers referred to beam center at 86GHz
- Can make simultaneous observation four channels such 22, 43, 86 and 129GHz bands

Seog-Tae Han, et al
Losses of transmission and reflection at LPFs

**TABLE 3**

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>LPF1 LCP (%)</th>
<th>LPF1 RCP (%)</th>
<th>LPF2 LCP (%)</th>
<th>LPF2 RCP (%)</th>
<th>LPF1+LPF2 LCP (%)</th>
<th>LPF1+LPF2 RCP (%)</th>
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<td>3.11</td>
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**TABLE 4**

<table>
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<th>Frequency (GHz)</th>
<th>LPF1+flat mirror LCP (%)</th>
<th>LPF1+flat mirror RCP (%)</th>
<th>Flat mirror+LPF3 LCP (%)</th>
<th>Flat mirror+LPF3 RCP (%)</th>
<th>LPF1+LPF3 LCP (%)</th>
<th>LPF1+LPF3 RCP (%)</th>
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<td>134</td>
<td>6.5</td>
<td>6.3</td>
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<td>1.8</td>
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<td>10.6</td>
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</table>

Freq. [GHz] | Transmission and/or Reflection Loss [%] (LPF1+ LPF2/LPFs) | Tnoise @300K [K] |
-------------|---------------------------------------------------------------|-----------------|
22           | 3.30 (Transmission only)                                      | 9.90            |
43           | 3.74 (Transmission + Reflection)                              | 11.1            |
86           | 9.60 (Reflection + Transmission)                              | 28.8            |
129          | 5.60 (Reflection only)                                        | 16.8            |

Needed cooling down to cryogenic temperature
Test Observation Results
Simultaneous observation receiver systems

KVN Yonsei Radio Observatory
Simultaneous observation results at Orion KL for 22GHz, 43GHz, 86GHz and 129GHz receivers

April 2003 ~ May 2011 (8 years)

simultaneous 4 spectral lines
Radiation patterns for 22GHz, 43GHz, 86GHz and 129GHz

- The measured beam sizes at 22GHz, 43GHz, and 129GHz are 5-8% are smaller than those of theoretical ones.
- The first side-lobe levels of about 12 -13dB due to shaped reflector both sub- and main reflectors.

<table>
<thead>
<tr>
<th>Frequency (GHz)</th>
<th>Obs. date</th>
<th>Source name</th>
<th>Elevation (degree)</th>
<th>Source size (arcsec)</th>
<th>Beam size (arcsec)</th>
<th>First sidelobe level (dB)</th>
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<td>86.243</td>
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<td>Mars</td>
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Seog-Tae Han, et al
“Korean VLBI Network Receiver Optics
Simultaneous Multi-frequency Observation
- Beam offsets among four bands and aperture efficiencies

**TABLE 5**
BEAM ALIGNMENTS OF THE 22/43/129 GHz BANDS

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<th>Frequency (GHz)</th>
<th>Obs. date</th>
<th>Source name</th>
<th>Elevation (deg)</th>
<th>Source size (arcsec)</th>
<th>Brightness temperature (K)</th>
<th>Aperture efficiency (%)</th>
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<td>22.235</td>
<td>2012 Oct 25</td>
<td>Jupiter</td>
<td>30–60</td>
<td>46.1</td>
<td>134 ± 4 (P03)</td>
<td>65 ± 1</td>
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<td>43.122</td>
<td>2012 Oct 25</td>
<td>Jupiter</td>
<td>30–60</td>
<td>46.1</td>
<td>150 ± 15 (G94)</td>
<td>62 ± 2</td>
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<td>86.243</td>
<td>2012 Oct 25</td>
<td>Venus</td>
<td>30–60</td>
<td>13.7</td>
<td>357.5 ± 13 (U80)</td>
<td>57 ± 2</td>
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<td>129.363</td>
<td>2012 Oct 25</td>
<td>Venus</td>
<td>30–60</td>
<td>13.7</td>
<td>331 (F92)</td>
<td>38 ± 3</td>
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</table>

**NOTE.**—Errors of aperture efficiencies are 1σ, not including systematic errors arising from uncertainties in the brightness temperatures.


- Pointing accuracy ~ 1/10 of HPBW (30arcsec at 130GHz)
- Can do simultaneous observation with four bands!!!!!!

- Aperture efficiencies
Global collaborations for optics design
Beam parameters of VERA: 22/43GHz simultaneous observation optical circuit

- Designed and installed only optical circuit, Not receivers
Quasi-Optics for VERA Mizusawa site

Optical circuit test as KASI’ Lab, Korea

Installed on Mizusawa observatory of VERA

H₂O/SiO Simultaneous fringes of ORION-KL
Quasi-optical circuit of K/Q-band simultaneous observation for VERA, Japan

* Installed October 2015
* Under the installing just now

Will be Installed 2016
Optical circuit and its beam parameters for Yebes 40m radio telescope

- Designed and installed only optical circuit, Not receivers
Simultaneous observation at Orion-KL Jan.12/2015

Optical circuit test at KASI’s Lab,, Korea.

Installed on Receiver cabin of Yebeș antenna
Nobeyama 45m radio telescope, Japan

- Optical circuit only will be designed like Yebes observatory did.

- Both Optical circuit and receivers will be designed
  - Considering both ways.
  - Be powerful tools 86GHz VLBI with KVN + Nobeyama 45m antenna
Shanghai 65m radio telescope, China

- Quasi-optical circuit and 22/43GHz Receivers
9. Summary
My dream

3 more 21m radio telescope for E-KVN

Dream comes true !!!!!
Summary

- Beam alignment among several channels
  - Has to be aligned at least 1/10 of HPBW of antenna

- Losses at quasi-optical circuit
  - Mainly due to LPFs 0.1 ~ 0.2 dB
  - Cooled down to 20K to improve receiver noise temperature

- Incident angle of LPF
  - less than 20 degree
  - To avoid cross-pol. and reflection and transmission losses

- Required more compact system design
  - compact, reduce receiver noise temperature
  - Introduce to compact cryogenic optical circuit,
    next my talk in this afternoon
Thanks for your attention