Status report on observations with the GGAO-Westford VGOS systems

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Outline

- Implementation of Broadband Signal Chain on GGAO12M and Westford
- Results
- Plans
- Observation, correlation, and analysis
Special thanks

• Chris Beaudoin, Chris Eckert, Mark Derome – Broadband signal chain design and implementation
• Chet Ruszczyk, Jason Soohoo, Mike Poirier, Katie Pazamikas, Jay Redmond, Russ McWhirter – observing session setup and operation
• Ed Himwich – antenna checkout for GGAO12M and Westford and Field Station modification for Broadband
• John Gipson – *sked* modification
• Mike Titus – correlation (understatement of effort!)
• Brian Corey – station performance analysis and amplitude calibration
• Roger Cappallo – *difix* and *fourfit* modifications
• David Gordon – data base modification and creation
• Sergei Bolotin – *nuSolve* creation and processing
• Bill Petrachenko – brilliant ideas, continued encouragement
• Chopo Ma and John Labrecque for funding the Proof of Concept development and the GGAO-Westford systems
• And others!
Observing Frequency Bands

Phase

PHASE (Arbitrary Units)

- 2.2–14 GHz Spanned RF Bandwidth
- Group delay (slope)

S-Band: Serious RFI

X-Band

2 Frequency (GHz) 14
Broadband System Diagram

*Haystack implementation
MIT Haystack / NASA Implementation

- Prototype systems
  - 12-meter Patriot antenna at GGAO and 18-meter Westford antenna at Haystack
    - QRFH feed and two LNAs from Caltech
    - Separate low- and high-band RF downlinks for each polarization (need phasecal)
    - Four RDBE-G digital backends
    - One Mark6 recorder
Recent observations - 1

- **VGOS Data Series**
  - Work towards operational broadband observing.
  - Have observed one hour sessions about every two weeks since 2014 December (9 successful sessions).
  - The most recent sessions have been run under Field System control, including UDCs, RDBEs, and Mark6.
  - Center frequencies for the four bands:
    - 3.3 GHz  5.5 GHz  6.6 GHz  10.5 GHz
Recent observations - 2

- VGOS Data Series (cont’d)
  - Median delay uncertainty per scan is ~1 psec.
  - Correction for phase variation across the bands and with time would raise this to a few psec (see previous 64-channel *fourfit* figure).
  - With re-weighting by additive delay to the geodetic estimation, the WRMS post-fit delay residual is typically 6 psec (compared to a few times 10 psec for current S/X sessions using ~20-meter antennas).
Post-fit delay residuals V15034 2014FEB03  48/50 obs retained

WRMS 6.8 psec

10 psec

1 hour
Recent observations - 3

- **VGOS Data Series (cont’d)**
  - Baseline length is 601 km.
  - For six (good) sessions, the position uncertainties for GGAO with 1 to 1.5 hours of data are:
    - Up/East/North (UEN): 3-7 mm, 1-2 mm, 1-2 mm
    - Length: 1-2 mm
  - The RMS scatters in components and length are approximately:
    - UEN: 4 mm, 2 mm, 2 mm
    - Length: 1 mm
Plans

- VGOS Demonstration Series (VDS)
  - Continue bi-weekly 1-hour sessions till VGOS operations are ‘routine’.
  - Enhance operations software (sked/FieldSystem/correlator-related) to accommodate Broadband VGOS systems.
  - Increase duration of sessions.
  - Include other VGOS-capable antennas in test sessions.
  - Migrate to regularly scheduled 24-hour sessions.
Yet to do or understand (partial)

- **Instrumentation**
  - Add cable delay measurement systems.
  - Upgrade UDCs to Kokee version.
  - What causes freq. dependent phase distortion?

- **Analysis/understanding**
  - How should the broadband delay uncertainty be determined for input to estimation?
  - How can sky coverage be improved in scheduling programs?
  - What is the best way to determine the polarization delay and phase offsets?
Broadband observing - 1

- Geodetic VLBI session procedures
  - Schedule \((sked)\)
  - Observe
  - Correlate
  - \textit{fourfit}
  - \textit{calc/nuSolve}
- Highlight differences for Broadband
Broadband observing - 2

- **Schedule** (*sked*)
  - New broadband section added to allow for Mark6 recording
  - 8 Gbps onto single module
  - Buffering time of about scan length required
  - Modify input parameters to compensate for high data rate in each band
  - Use S-band and X-band flux densities but 3GHz and 10GHz system characteristics to calculate minimum scan lengths
Broadband observing - 3

- **Data acquisition format**
  - Four bands with two polarizations each band
  - Total data rate 2 Gbps per band (1 Gbps per polarization)
  - Only 15 good channels per pol’n for polyphase filter bank (PFB) but get 16 channels per band using half of the channels in each band.
  - See next figure
    - Layout for 16*32MHz recording
    - Minimum redundancy frequency per band
Broadband correlation - 1

- **Correlation procedures**
  - *gather* Mark6 data from raw format to linux files
  - Correlate all four bands simultaneously (or each band separately and then *fourmer* into one file)
  - Correlate HH/VV/HV/VH within each band
Broadband correlation - 2

- Correlation procedures (cont’d)
  - Extract all phase cal tones for every channel in both polarizations
    - Six or seven tones for each channel
    - Use all non-corrupted tones for multitone phase cal delay and phase for each channel (exclude tones with spurious signals)
  - Run difx2mk4 on correlator output files to allow additional processing with the standard HOPS package (as used for S/X geodesy)
*fourfit* differences between broadband and S/X

- **Phase cal**
  - Apply multitone pcal to align the four bands.
  - Input *a priori* cable delay for each station (maser-antenna-DBE) to provide resolution of multitone delay ambiguity (1/4 * 200 nsec for 5 MHz spacing).

- **Uncalibrated delay and phase offsets between polarizations**
  - Correct for RF path length through the feed and before phase cal injection.
Polarization delay offset
Post-correlation analysis - 1

- **fourfit** *(assume 64-ch correlation)*

  - Use all four polarization products to determine delay and phase differences between polarizations for each antenna
    - **fourfit** one or more strong sources for HH and VV to determine dTEC (for S/X determined from S and X)
    - **fourfit** HV and VH at that dTEC to get delay and phase differences between polarizations for each antenna
    - **fourfit** all 128 channels (4 bands * 8 channels * 4 pol’n products) to estimate group delay and consistent total electron content difference (dTEC) between the sites

  - Example **fourfit** plot in next slide
Combined polarization data

RMS 7.2°
Source structure phase

0149+218

visibility (Jy)

bsln: 6400 km

0248+430

visibility (Jy)

bsln: 6400 km
Post-correlation analysis - 2

- **calc/nuSolve**
  - Create database (required modification of dbedit)
  - (Currently) use nuSolve for preliminary analysis
  - Use single time interval for the full session
  - Estimate:
    - Position of GGAO (Westford fixed)
    - Clock offset at GGAO (plus second order polyn)
    - ZWD at one site (since baseline is so short)
    - Troposphere gradients at both sites
Frequencie
(frequency sequence)

512 MHz
LSB (NZ2)

15 14 13 12 11 10 9 8 7 6 5 4 3 2 1 0

32 MHz → 1024 MHz
sample clock → 16 MHz

4*f(UDC)-22500 = LO

1 selected channels
Channels in packet

H

VDIF packet

V

2015 May 18

EVGA15May 26
Better late than never!
Patriot 12M Antenna @ GGAO

Courtesy Wendy Avelar