VLBI 2010
Summer Intern Orientation

June 6th, 2012

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VLBI 2010

VLBI2010 is an enabling technology upgrade to an existing worldwide network. The concept of VLBI2010 was developed by Working Group 3 of the International VLBI Service (IVS) - 16 September 2004. Technical development continues at Goddard and Westford MA.

Achievements & Status:

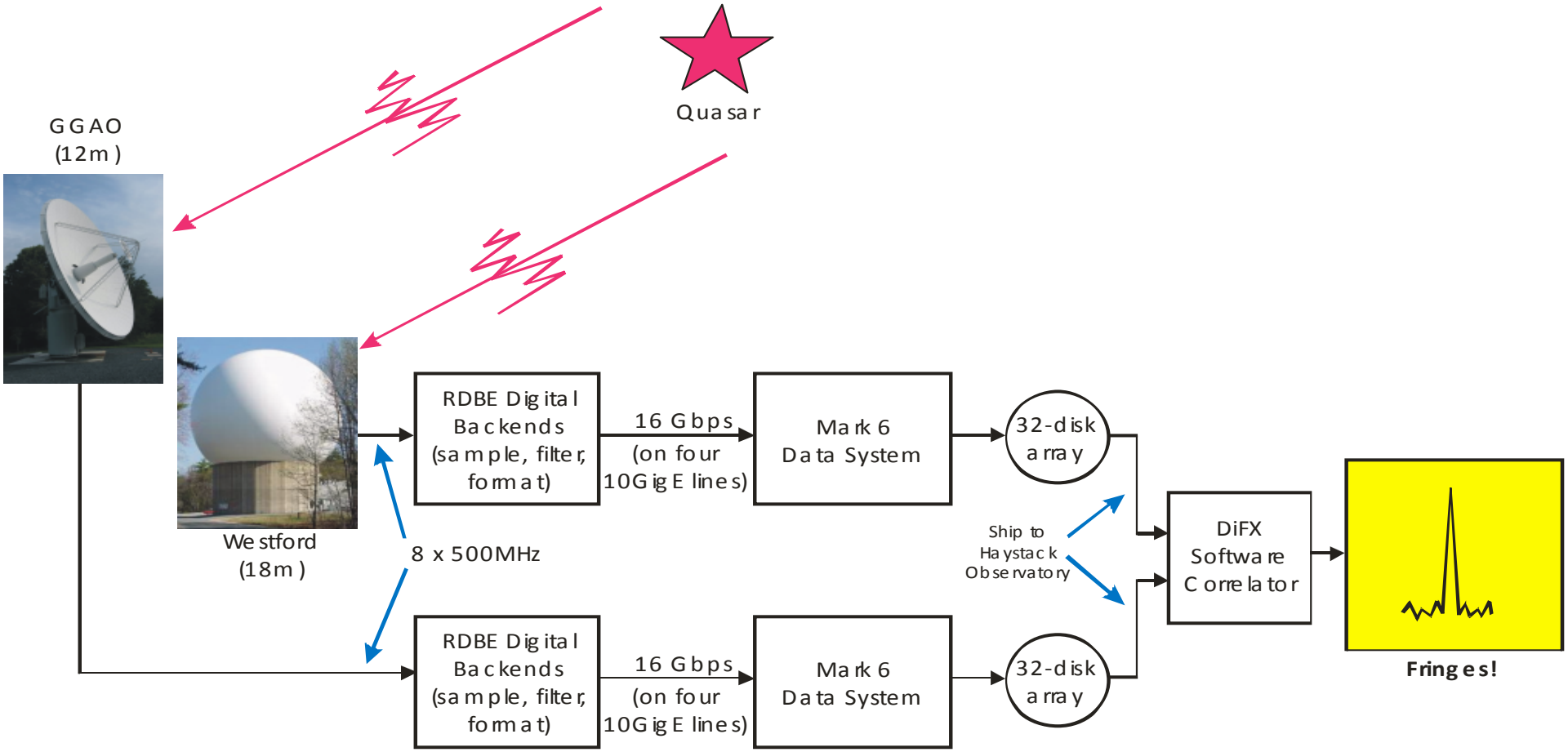
- 60% Aperture efficiency has been demonstrated on the GGAO Antenna
- 5 degree/sec azimuth slewing has been demonstrated on the 12 meter Antenna Control System
- Wideband data collection of 8 MBPS at both Westford and GGAO
- The Westford –GGAO correlation has demonstrated 4 picosec uncertainty in group delay.

System Features:

- 12 meter / 5 degree slew enables a greater availability of RF sources w/ acceptable signal to noise for correlation by worldwide network
- Standardization and commercial off the shelf availability of many key components will lead to lower operating/replication costs
- Selectable bandwidth data will include legacy systems and better tolerate radio frequency interference
- This improvement in group delay will enable 1 mm position determination when the VLBI2010 technology is infused in the worldwide network.

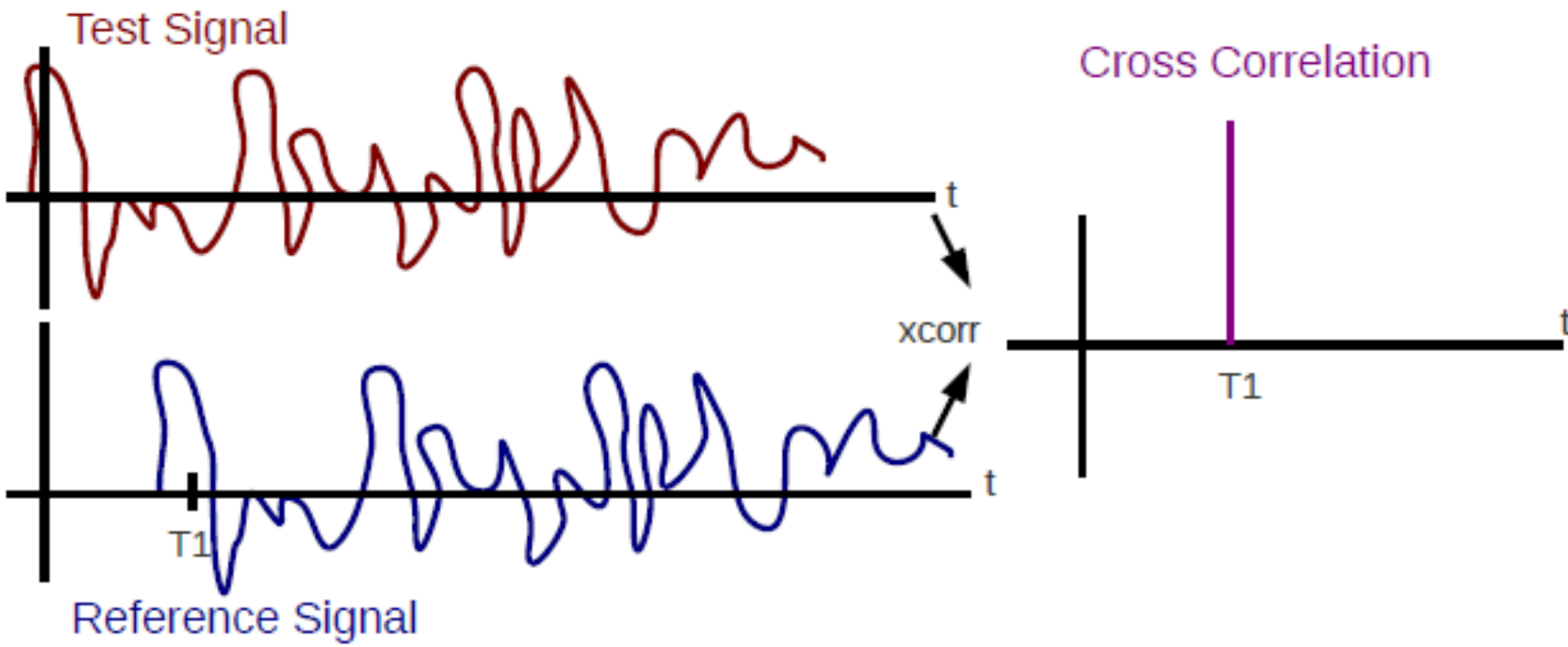
First 16 Gbps VLBI Demonstration

24 Oct 2011: Westford to GGAO



(Mark 6 data system is joint development of Haystack Observatory and NASA/GSFC High-End Computer Networking Group)

Data Processing: Cross Correlation



- Phase of one antenna is meaningless
- Need a second antenna to provide a reference point

VLBI2010 Organization: Development Team

GSFC

VLBI Network Analysis Lead
Chopo Ma
Larry Hilliard/David Rubincam
NVI/ITT Teams

lead
1.2.2.1.5 MASER
1.2.2.1.8 Command and Data Handling (Scheduling)
GGAO/KPGO/
Westford coordination

Haystack Observatory

Broadband Development Lead
Arthur Niell
Chris Beaudoin-

lead
1.2.2.1.2 Antenna
1.2.2.1.3 Front End
1.2.2.1.4 Back End
1.2.2.1.7 Correlator

Honeywell

Integration and Test Lead
Mark Evangelista -
Irv Diegel – Monitor and Control Infrastructure
Jay Redmond

lead
1.2.2.1.6 MCI
1.2.2.1.9 Integration & Test (I&T)

Acronyms

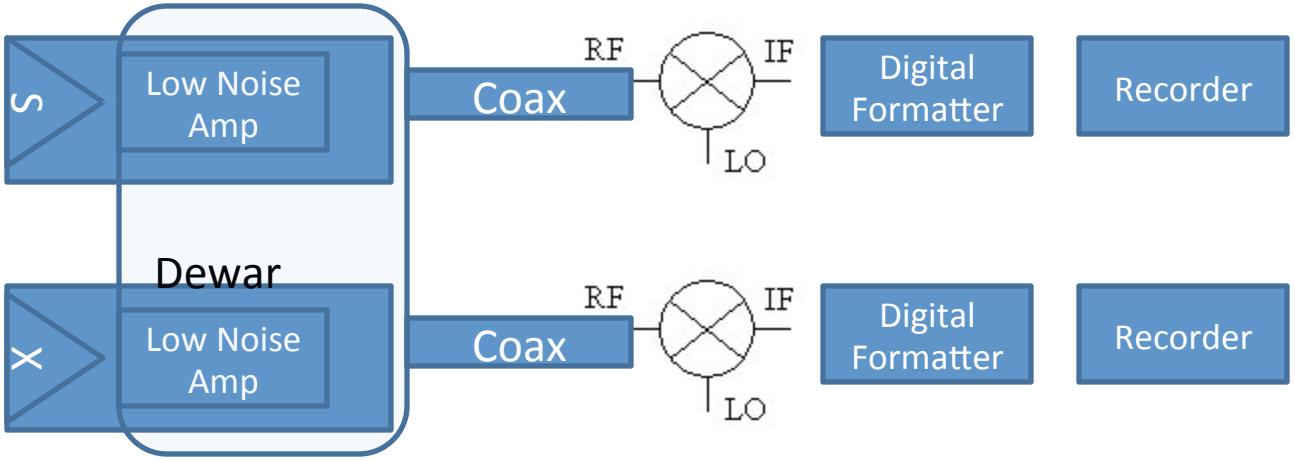
C & DH	Command and Data Handling
FIR	Finite Impulse Response
FPGA	Field Programmable Gate Array
GGAO	Goddard Geophysical and Astronomical Observatory
GSFC	Goddard Space Flight Center
HQ	NASA Headquarters
JPL	Jet Propulsion Laboratory
LNA	Low Noise Amplifier
MASER	**M**icrowave **A**mplification by **S**timulated **E**mission of **R**adiation
MCI	Monitor and Contol Infrastructure
NASA	National Aeronautics Space Administration
NGSLR	Next Generation Satellite Laser Ranging
NOA	New Obligation Authority
PFB	polyphase filterbank
QRFH	Quad Ridge Flared Horn
RDBE	ROACH Digital Back End
ROACH	Reconfigurable Open Architecture Computing Hardware
SEFD	System Equivalent Flux Density
SGP	Space Geodesy Project
SLR	Satellite Laser Ranging
SMD	Science Mission Directorate
SWC	Software Correlator
VLBI	Very Long Baseline Interferometry

- **Interferometric visibility**
- The **interferometric visibility** (also known as "interference visibility" or "fringe visibility" or just "visibility") quantifies the contrast of interference in any system which has wave-like properties, such as optics, quantum mechanics, water waves, or electrical signals.
- **Group delay and phase delay**
- In signal processing, **group delay** is a measure of the time delay of the amplitude envelopes of the various sinusoidal components of a signal through a device under test, and is a function of frequency for each component. **Phase delay** is a similar measure of the time delay of the phase, instead of the delay of the amplitude envelope, of each sinusoidal component.

VLBI Legacy Functional Block Diagram

- Mobile VLBI station supporting Crustal Dynamics Project.

MV3 - 5 meter at GGAO



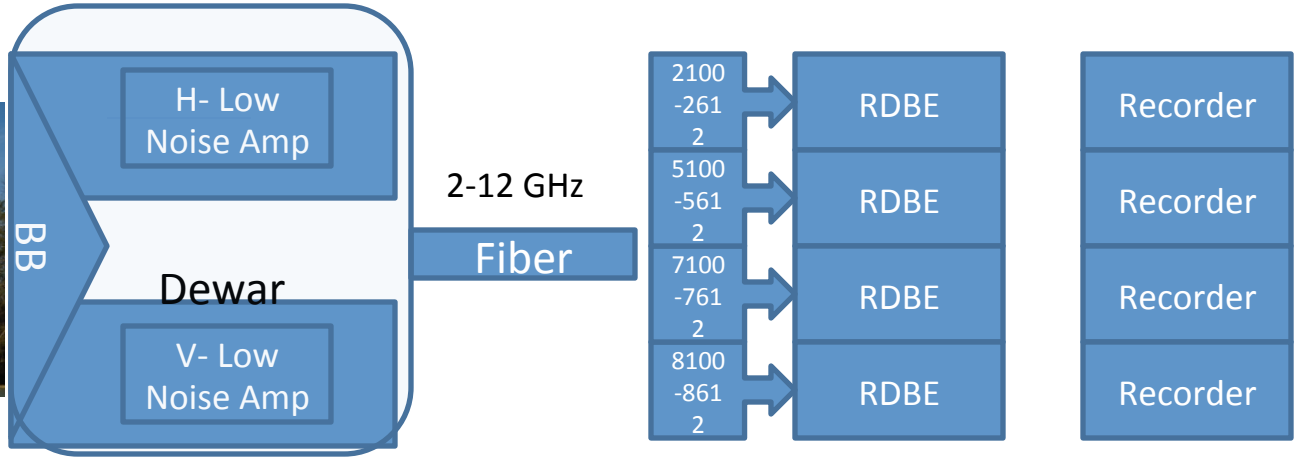
5 meter reflector - 2 feeds	Front End	Down Converter	Intermediate Frequencies	Data Acquisition
Subreflector feed S-Band coax	LNA 2200-2400 MHz	Derived from 5 MHz Reference	270 ±50 MHz	600 (5 min) sec x 50M = 3G
X-Band horn to waveguide	LNA 8100-8900 MHz		300 ±200 MHz	600 (5 min) sec x 200M = 12G

VLBI2010 Functional Block Diagram

- Agile Pointing, Broadband, Selectable Channels

Frequencies going into RDBEs should be considered possible (but not likely) frequencies.

12meter VLBI2010 Antenna



Broadband Reflector and Feed	Dewar w/Feed & LNA	Up/Down Converter	RFI Selectable channels	Data Acquisition
12 meter reflector and subreflector procurement. CalTech QRFH	Feedhorn with V & H ports	Four 512-MHz ch. X 2 pol	16- 32 MHz channels / 512 MHz IF	30 sec x 2G = 60 G
	Dedicated LNA for H&V polarization			

WBS **1.2.2.1.2** - 12 meter Antenna

- Strategy: Patriot antenna pointing system is capable of 5 deg/sec in Azimuth and 1.5 degrees /sec in Elevation

  - 12 meter installation to pedestal in October 2010
  - ~ 60 per cent aperture efficiency across 3-11 GHz in August 2011
  - Field measurement of Receiver Noise, System Equivalent Flux Density (SEFD), and aperture efficiency

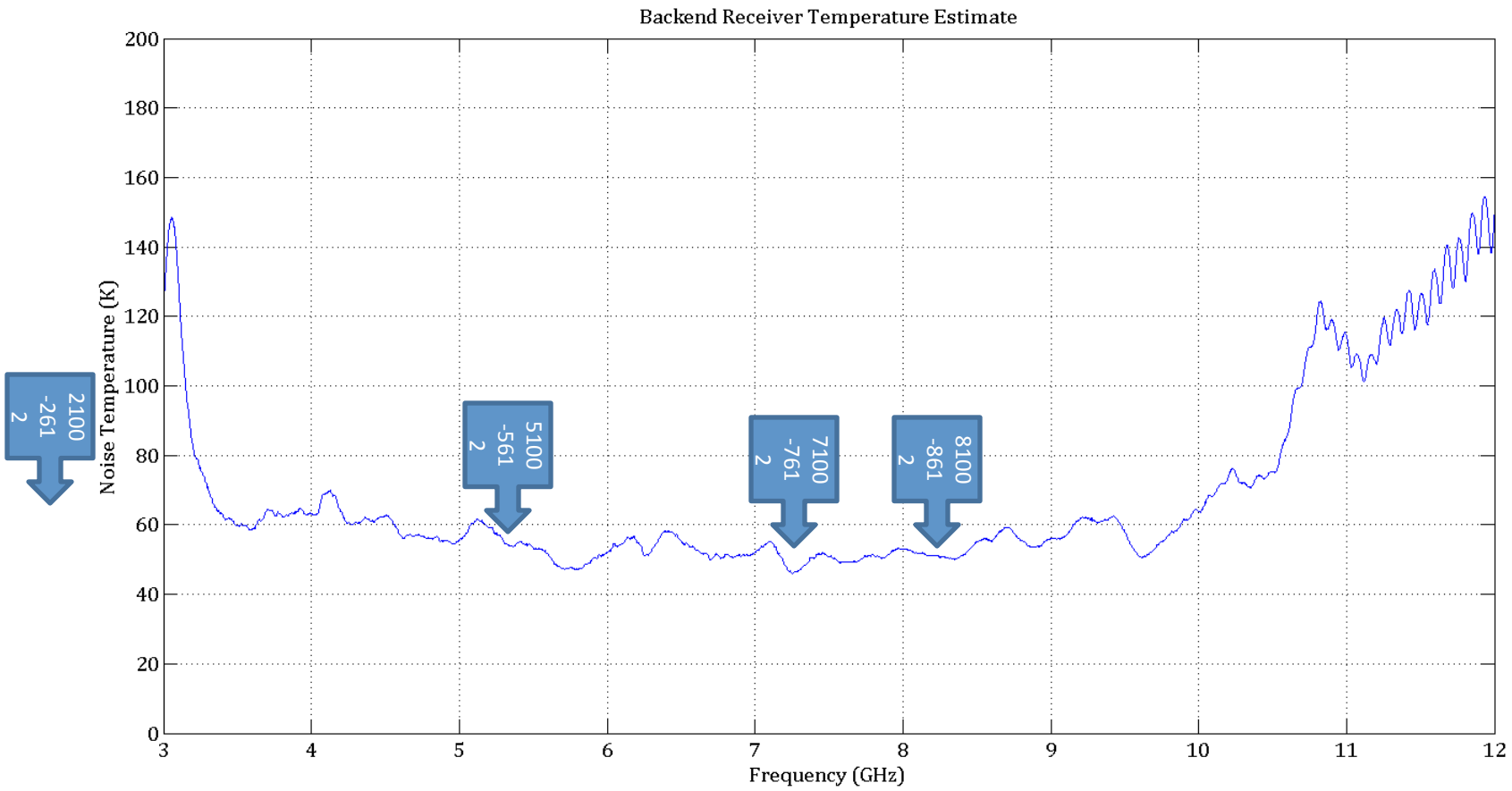
- Current and near Future Work: Fix on elevation creep

.3-Dewar Electronics

- Strategy: Caltech feed and Low Noise Amplifier simplifies the broadband signal path

  - "11 feed" Predecessor had 8 LNAs , this feed has 2 ports – 1 V polarization, 1- H polarization
  - Delivered to Haystack / Characterized at Temperature in Spring 2011
  - September 2011 SEFD and Noise measurements
- Current and near Future Work:
  - Isolate Radio Frequency Interference (RFI) and filter inside dewar
  - Design in Monitor and Control Infrastructure (MCI) electronics

Preliminary broadband data as received at the GGAO up/down converter

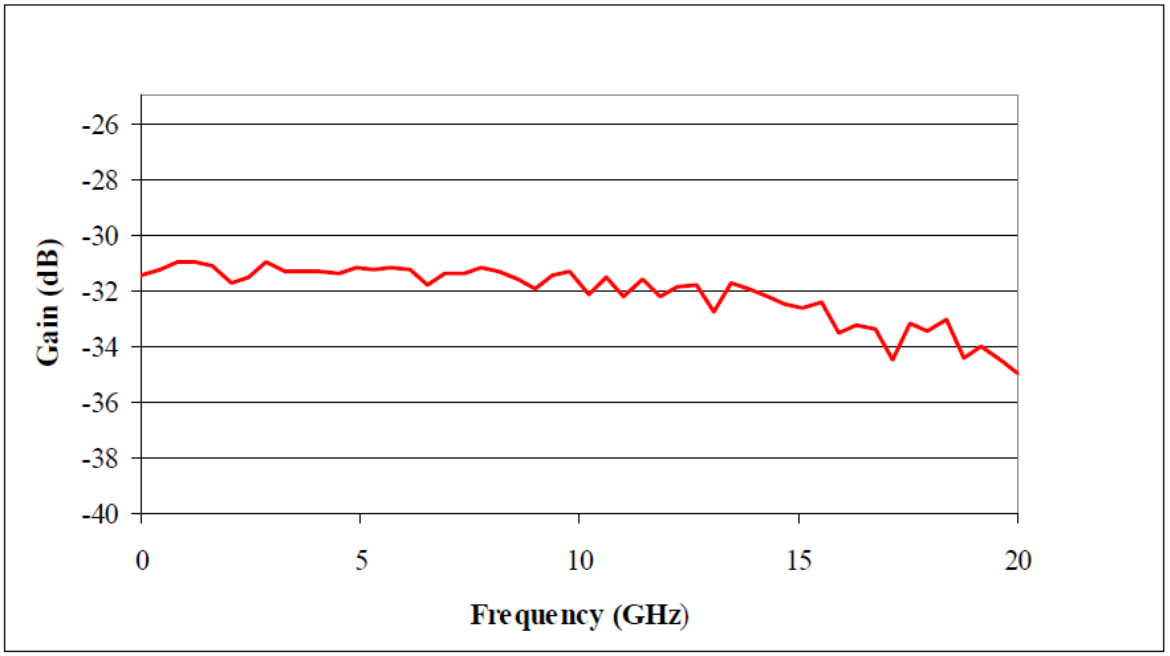


.3- Post Dewar Electronics (PDE)

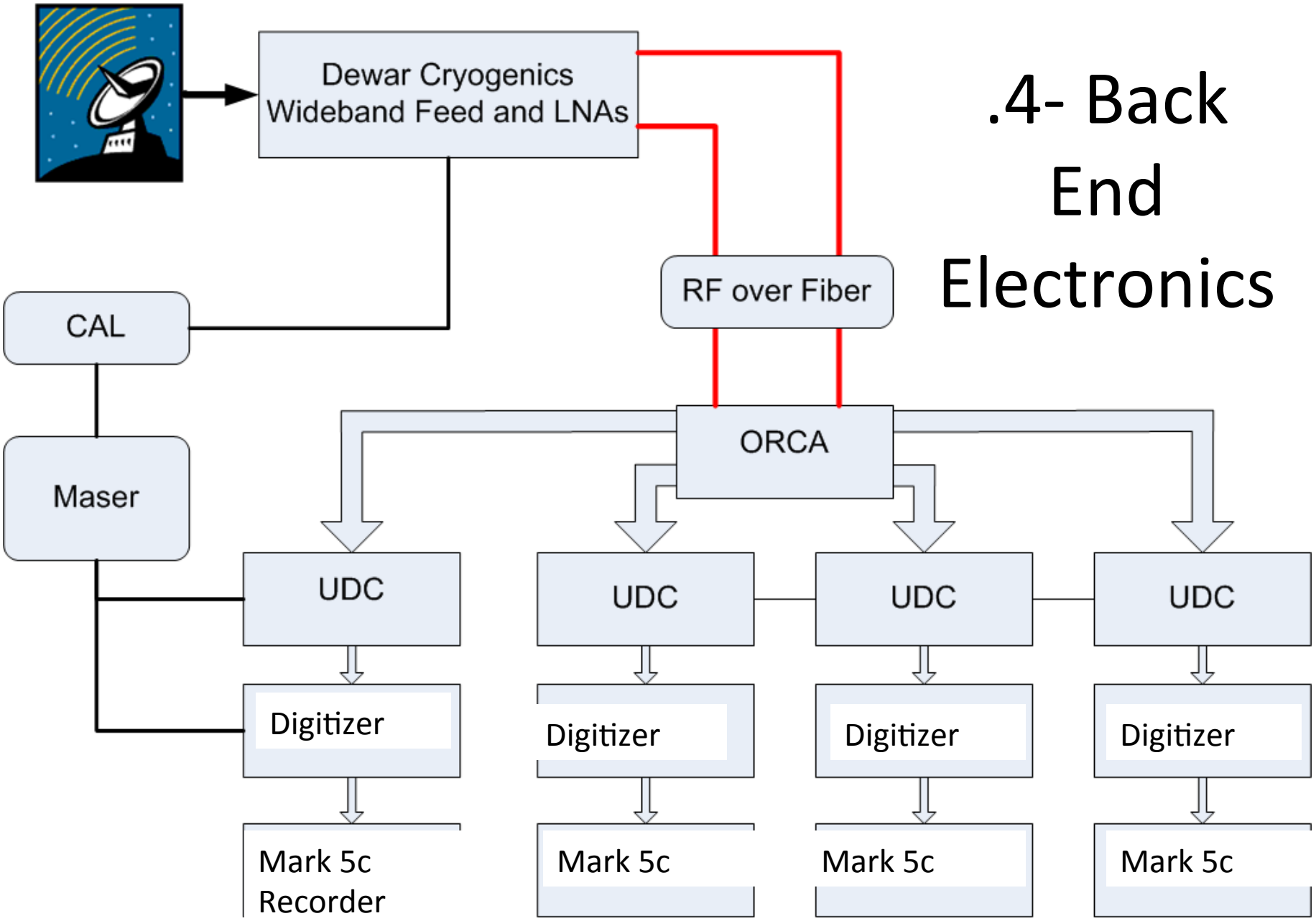
- Strategy: Honeywell fabrication of Haystack designs
  - Calibration Signal Source
  - Power Conditioning for Front End amplifiers
  - Pre-amp and filtering
  - Houses fiber optic transmitter
- Current and near Future Work:
  - Isolate Radio Frequency Interference (RFI) and filter outside dewar
  - Design-in Monitor and Control Infrastucture (MCI) electronics
  - Accommodate compressor and dewar travel from service position to dewar at broadband focused position

.3 - Fiber optic link and ORCA

- Strategy: Photonic Systems, Inc. Supplier
- May be a different supplier … as of last week
- Current and near Future Work:
  - **PSI-1600-20L SERIES for better broadband**
  - **MICROWAVE PHOTONIC LINK**



.4- Back End Electronics

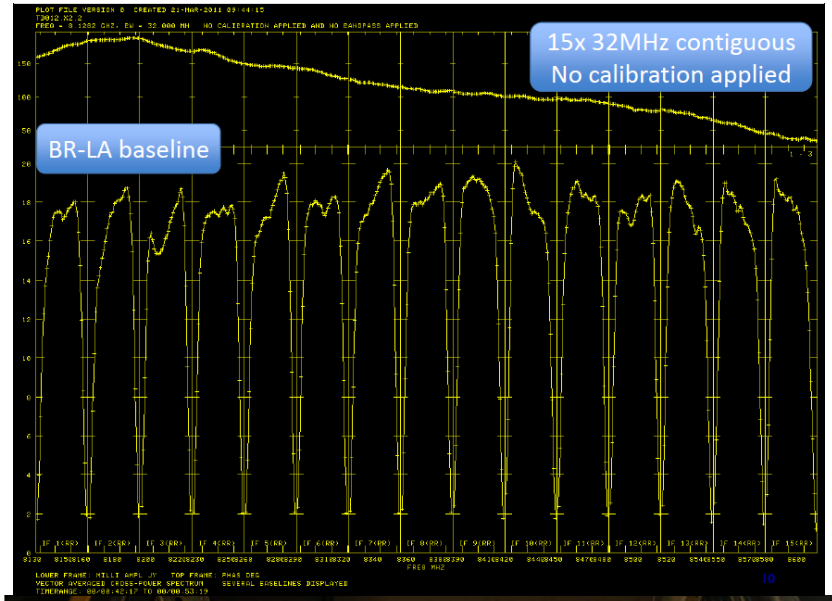


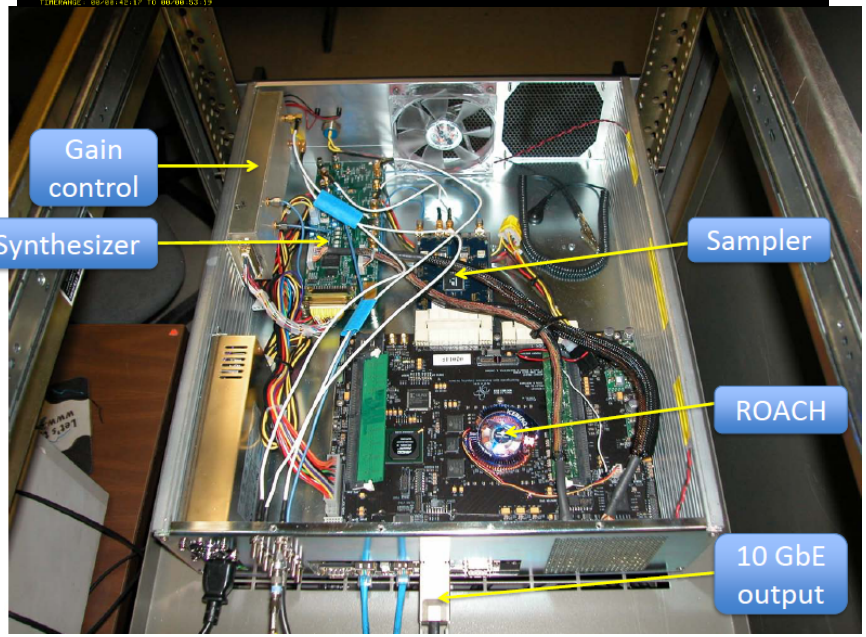
.4- Up down converters

- Strategy: Haystack has developed the ORCA, Up/ Down Converters, RDBE, and Mark 5c together using commercial hardware and custom firmware/software
- Current and near Future Work:
  - Up/Down converters programmable to S/X band for compatibility to legacy sites
  - New bands may be selected for RFI tolerance/avoidance (e.g. WiFi /DirectTV emerging at S-Band)

.4- RDBE

- Strategy: Product available commercially through Digicom, NRAO & Haystack developed firmware and chassis
- A complete digital back end in one 3U box2x 512-1024 MHz anti-aliasing filters (in NRAO units only)
  - 2x 0-31 dB selectable attenuation
  - 2x 1024 Msps8-bit samplers
    - ROACH-1 boardVirtex5 FPGA (SX95)
    - PowerPC (PPC) CPU
- Current and near Future Work:
  - Firmware for VLBI2010 in CMD test verification at Haystack
- ROACH = Reconfigurable Open Architecture Computing Hardware





.4-Recording

- Strategy: Mark 5B+ to Mark 5c upgrade available from Conduant
- Current and near Future Work:
  - Record and Playback code at Haystack for VLBI2010
  - Hardware at GGAO will be uploaded as Mark 5c

.5- MASER

- Strategy: Procurement of a MASER is included to complete the fundamental station. It will be used as a spare
- Status: Procurement package is being processed.

.6-Monitor and Control Infrastructure (MCI)

- Strategy: Use of Arduino open source electronics prototyping platform, allowing re-use of existing hardware/software development.
- Status: High level block diagrams have been created. Front end sensors are being prioritized and circuitry is being developed and tested.

1.2.2.1.7 Correlator

- Strategy: Haystack Observatory has adapted DiFX to VLBI2010 requirements
  - Back compatibility to S/X receivers
  - Forward compatibility to broadband systems
  - Select ability for unique station environments (e.g. RFI)

- Status: Fringes have been

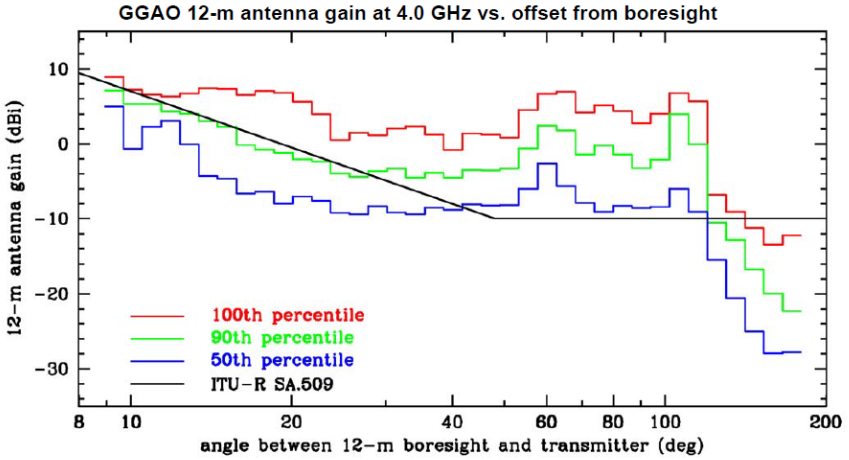
1.2.2.1.8
Command and Data Handling

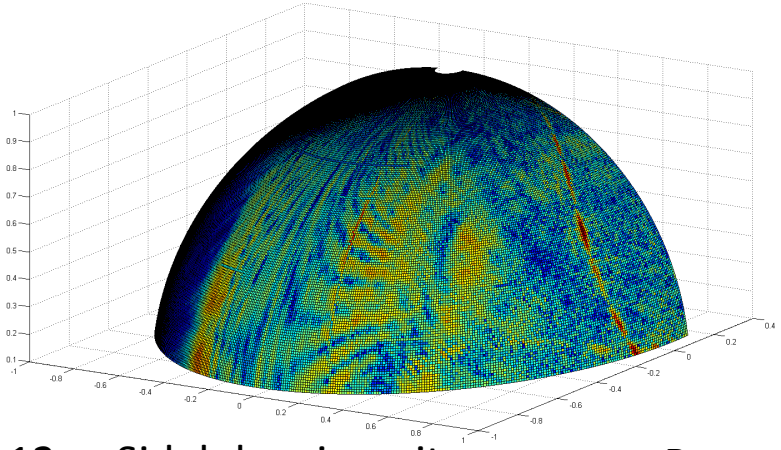
- Strategy: Field System and Scheduling will remain with the GSFC/ NVI team
- Status: Field System has developed masks for safe simultaneous operation of VLBI 12 meter antenna and NGSLR and MOBLAS7 radars.
- SKED will be planning for combination existing S/X band and new broadband observing schedules

Highlights in the Development of Sked	
1978	Basic program created (Nancy Vandenberg) command line input manual selection of scans catalogs for sources, stations, equipment
1981	Automatic calculation of antenna motion and tape handling
1988	Automatic selection of observations (Autosked) Heinz Steufmehl of the University of Bonn, Geodetic Institute. Optimization by strict covariance.
1992	Evaluation of schedules using SOLVE simulations Creation of pseudo-databases to evaluate formal errors.
1993	Autosked merged into standard version. "Strange" schedules
1995	Beginning of rule based schedules.
1996	Mark IV/VLBA recording mode support added Last time sked documentation updated.
1997	Numerous changes Support for VEX files Y2K fixes, new Java-based catalog interface S2 and K4 support
2002	John Gipson takes over development/maintenance Fill-in mode Best-N Source Selection
2004	Linux port Alexey Melnikov IAA Beginning of death of HP-sked Astrometric option Specify min, max observing targets for set of sources.
2005	Full support of Mark5A disk-based recording
2006	Downtime Ability to specify when an antenna is unavailable.
2007	Resurrection of covariance optimization. Found and fixed various bugs in algorithms. Still not used routinely. By-product: sked can predict formal errors internally.
2008	Master command Read session setup from master file. Check session against master file.
2009	Station limit raised from 32→64, and made parameter.

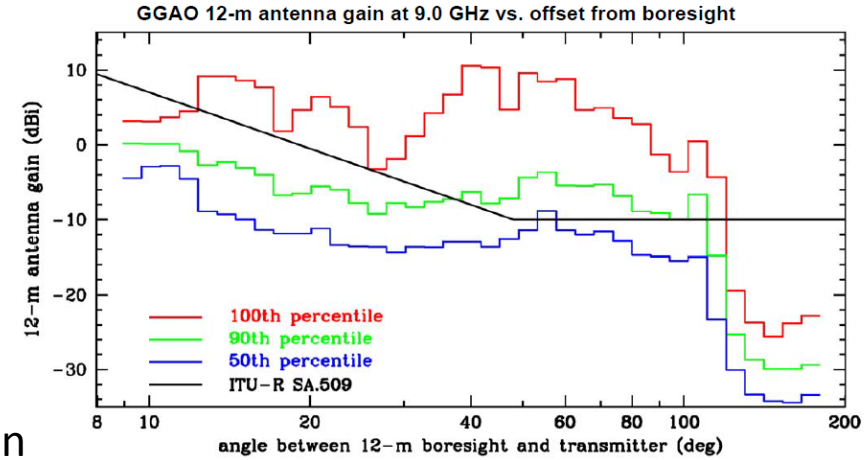
12 Meter side lobe characterization at GGAO

antenna gain vs. angle between 12-m boresight and transmitter. The data have been binned by angle into 40 bins equispaced in log(angle).
The 4 "curves" are
red 100th percentile in each bin (i.e., max gain)
green 90th percentile
blue 50th percentile (i.e., median gain)
black ITU-R SA.509 standard for the 90th percentile of the far-field gain of a large antenna





12 m Sidelobe views it peripherally in the North

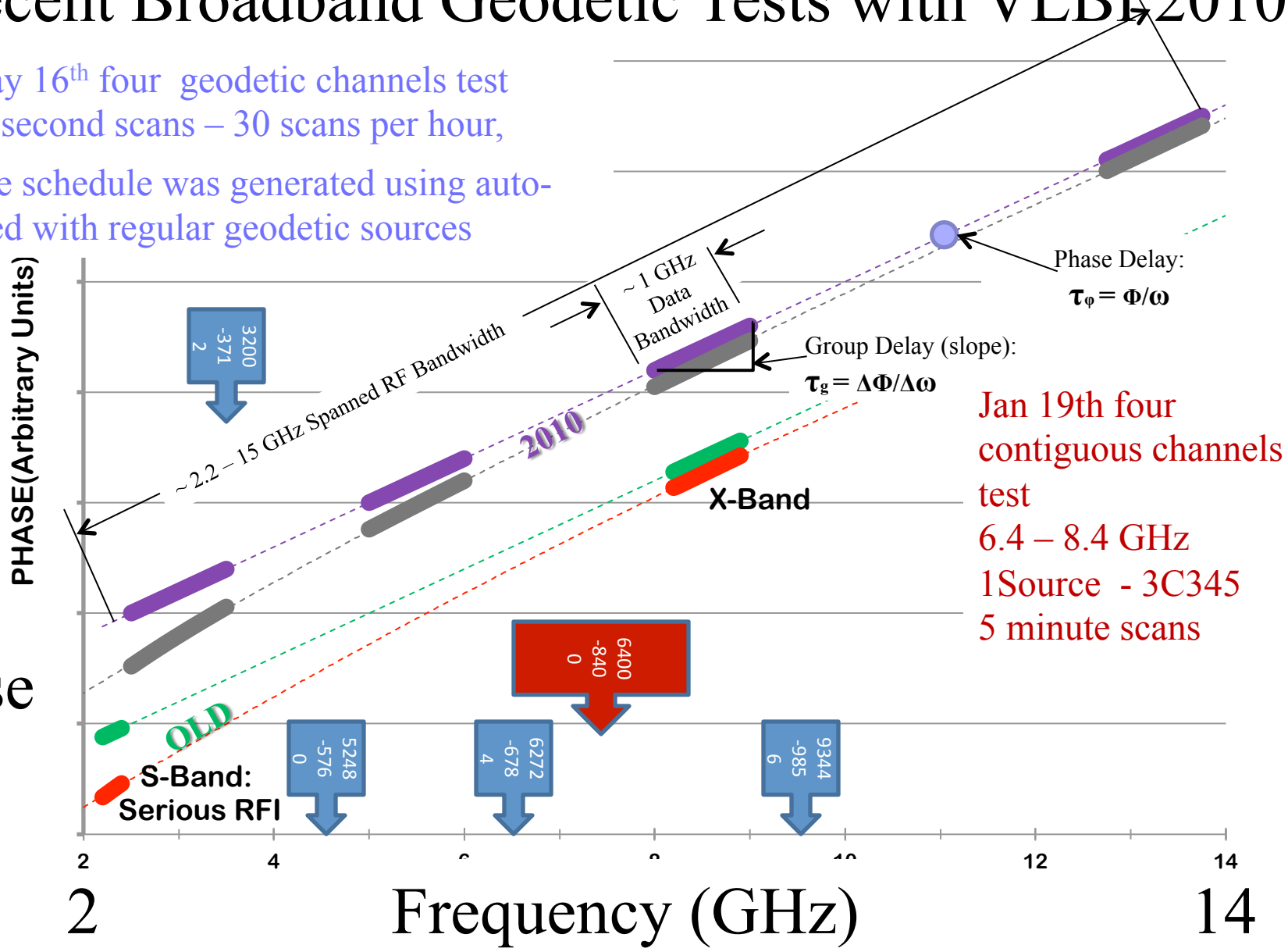


Beacon in the East

Recent Broadband Geodetic Tests with VLBI2010

May 16th four geodetic channels test
30 second scans – 30 scans per hour,

The schedule was generated using auto-sked with regular geodetic sources



Jan 19th four contiguous channels test
6.4 – 8.4 GHz
1Source - 3C345
5 minute scans

Phase