Concepts for a Next-Generation VLBA

2018 USNC-URSI National Radio Science Meeting

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VLBA: Major Historical Points

- Inaugurated August 1993.
- Transition to Mark 5A disk-based recording (2005-07).
- "VLBA Upgrade" — only large-scale instrumentation project:
  - Proposed 1999 / funded 2007 (AUI & NSF).
  - Digital channelization system / Mark 5C recorder / DiFX correlator.
  - *Design* goal "4 Gbps by 2011" met; available funding limited implementation to 2 Gbps.
  - Partially complete 2010 / Nearly complete 2012.
- New / upgraded receivers:
  - 80-96 GHz* (2000) / 21-24 GHz* (2007-08) / 4-8 GHz (2011-12).
    - * Made possible by substantial contributions from MPIfR.
- Recent astro-political event:
  - NSF "Portfolio Review" (2011-12) recommended "divestment" of VLBA.
  - As of 2016/10/1, 50% of prior NSF funding is now provided by USNO.
  - Up to 50% of observing time available to USNO.

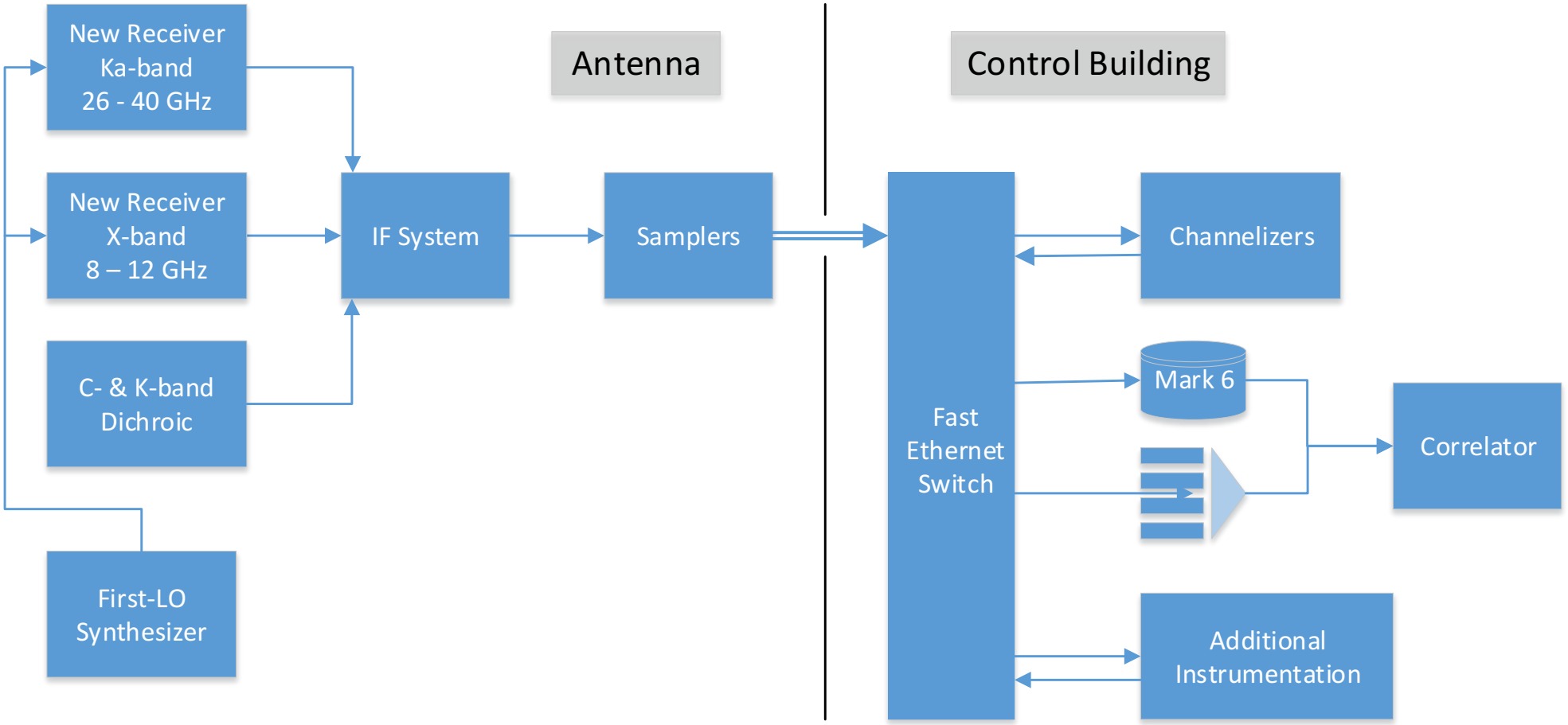
Scope of this talk

- Title of preliminary concept document may have been misleading.
- Was not intended as a parallel (or input) to "ngVLA" concept.
  - ngVLA effort is working toward a much more extensive plan, aimed at submission to a 2020-era decadal survey.
  - ngVLA *may* include partial or complete replacement of the VLBA; some options will be presented in the following talk.
  - ngVLA funding is probably at least a decade in the future.
- *This* talk is an overview of concepts for more immediate major replacements of current VLBA instrumentation, which are:
  - Urgently needed to maintain competitiveness with advancing worldwide VLBI capabilities, AND
  - Potentially feasible under new VLBA funding arrangements.

New VLBA Funding Options

- Despite reduced funding for general astronomical VLBI …
  - New arrangements can break through limitations of sole NSF/NRAO funding.
  - Similar, related overall instrumental requirements can benefit all parties.
- However, new arrangements also complicate new implementations.
  - New collaborators' interests likely to focus on specific elements of the overall data matched to their requirements
  - Separate, asynchronous implementations may be necessary.
  - Temporary over-design may be necessary at some points.
- Established standards will help maintain overall structure.
  - Standards selected to support maximum capabilities required by all involved.

Concepts for a Next-Generation VLBA



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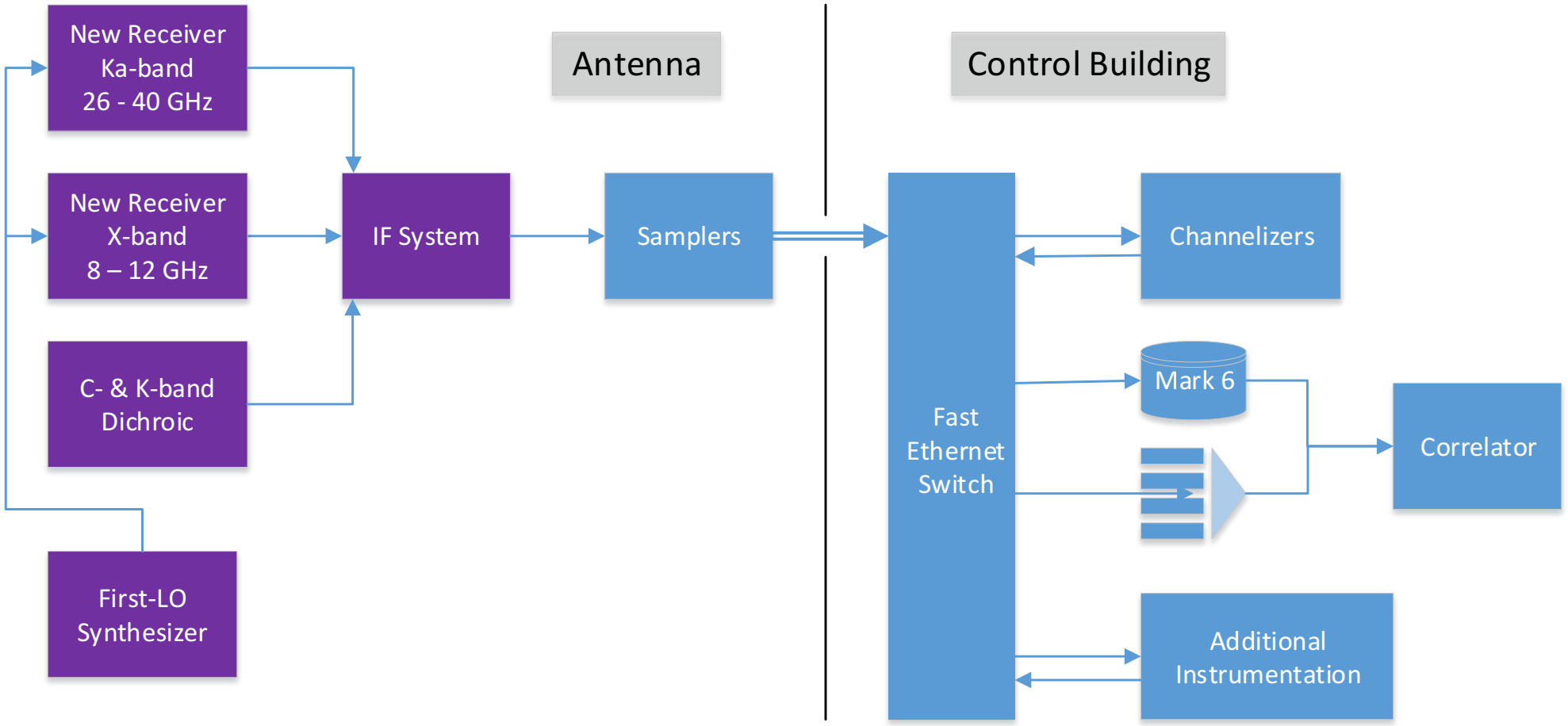

New Receivers

- Receivers are expensive! … especially for a 10-station array.
  - Most of VLBA's current suite (except for recent 4-8 GHz system) were built with 1980s technology.
  - New wider-bandwidth designs are available from the recent EVLA upgrade, and even newer, wider concepts are being planned for the ngVLA proposal.
  - Ka- and X-band systems have high priorities:
    - Ka-band 26-40 GHz considered optimal for high-precision astrometry, advocated by some major users for maintaining and upgrading the ICRF.
    - X-band 8-12 GHz would immediately match data-transmission bandwidth proposed below.
    - Less expensive C-K option for 6 & 24 GHz dichroic system also under consideration.
- Modern wideband designs generally process linear polarization.
  - … primarily to fit into multi-band cryostat by eliminating large phase shifter required for conversion to circular.
  - But not necessarily an issue anyway, if software translation of polarization states can be made to work universally.

New First-LO Synthesizer

- Current synthesizer produces coarsely quantized frequencies.
  - Alternating steps of 200 and 300 MHz.
  - Matches poorly with 128-MHz maximum channelizer bandwidth.
- New, infinitely tunable design already exists.
  - Tested, re-designed to minimize temperature dependence.
  - Ready to fabricate and install.

New IF System

- Current 512 MHz analog IF bandwidth, x2 IFs (or x4 in a few cases), seriously limits downstream capacity.
- Proposed new system:
  - Would replace IF conversion in individual receivers by a single fixed block up/down converter to 8-12 GHz.
  - Output filtering would provide IF ranges 512-1024, 1024-2048, possibly 2048-4096 GHz
  - Would reduce cost of all new receivers after the first.

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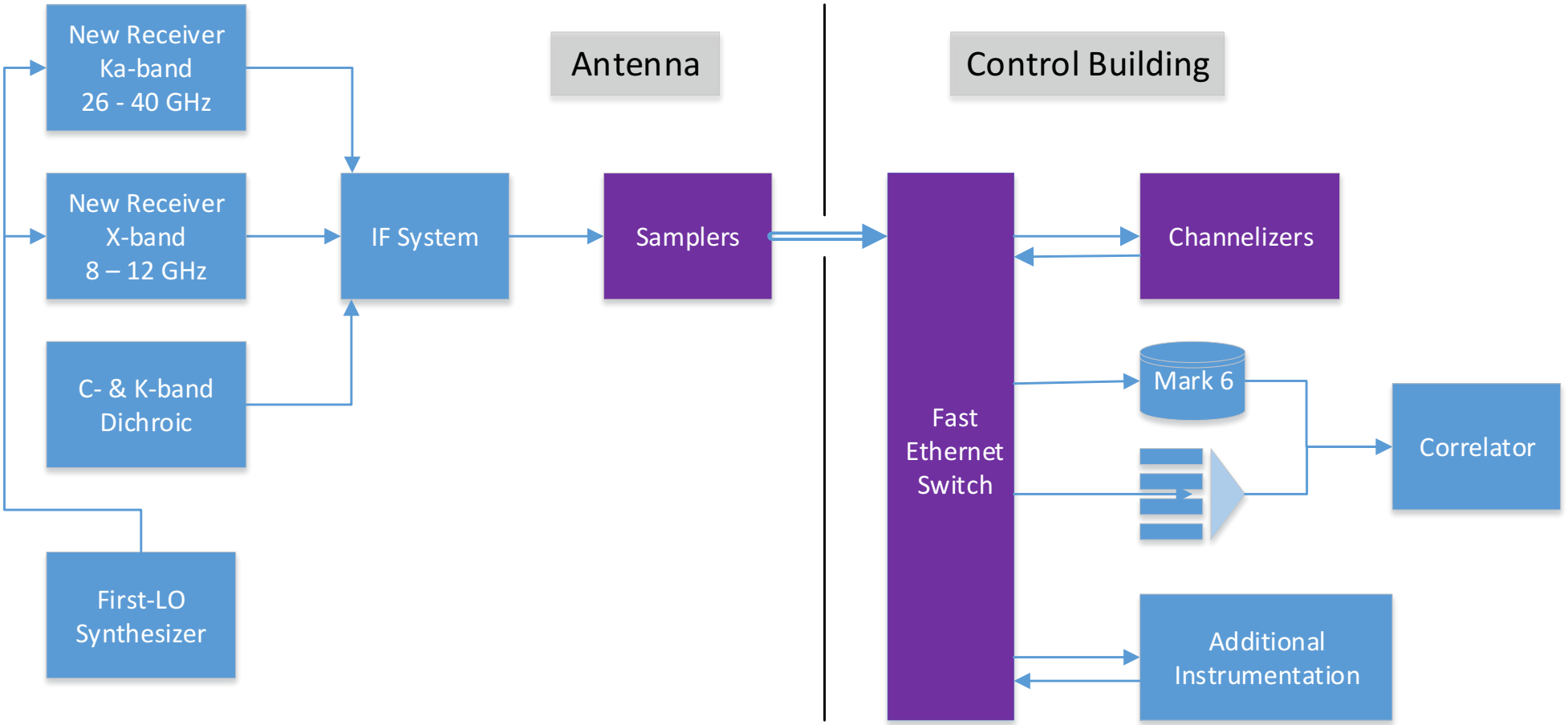

New Sampler / Channelizer Subsystems

- Current VLBA data path combines two logical functions in a single unit.
  - *Samplers* extract digital samples, with desired number of bits, at rate appropriate to entire bandwidth of incoming analog IF.
  - *Channelizers* derive digital signal streams, in desired frequency subsets of specific IF sample streams, with user-specified frequency resolution, requantized as necessary.
- These functions could be implemented near the receiver in the antenna, or in the control/instrumentation building, or divided between locations.
  - Choice of locations raises differing concerns about the final digital signals.
    - Incorporation of interference from digital hardware into final signals.
    - Introduction of unknown delay offsets in long transmission lines (up or down).
  - Location choices depend in part on what techniques are well understood by the implementing organization.
    - NRAO/LBO have achieved adequate RFI shielding at reasonable cost, but are dubious about stable delays in long analog signal transmission lines.
    - Others are dubious about RFI shielding, but have had successful experience with RF-over-fiber transmission over long fibers.
  - Decision may depend on scope of processing achievable in suitable and easily obtainable units.

New Sampler / Channelizer Subsystems

- Current concept separates these subsystems at two different locations.
- **Samplers** located in VLBA antenna vertex cabin, in heavily shielded enclosure.
  - Output samples framed as VDIF Ethernet packets, with precise time stamps.
  - Anticipated output rates: 4 IF × 3.2 Gsps × 12 bits
- Sampled packets transmitted to station control building over multi-mode fibers already in place.
- Ethernet switch, with fast backplane and hardware crossbar switching, supports flexible reorganization of sample streams, also various additional instrumentation.
- **Channelizers** (and additional data-analysis instrumentation) located in control building.
  - Enhanced replacement for existing DDC personality of RDBE.
  - VLBI outputs: 16 channels @ 1, 2, 4, 8, 16, 32, 64, 128, 256 MHz bandwidths, flexibly tuned.
  - Additional instrumentation could include interference excision, and support for non-VLBI applications.
- Test/demonstration hardware in hand or anticipated.

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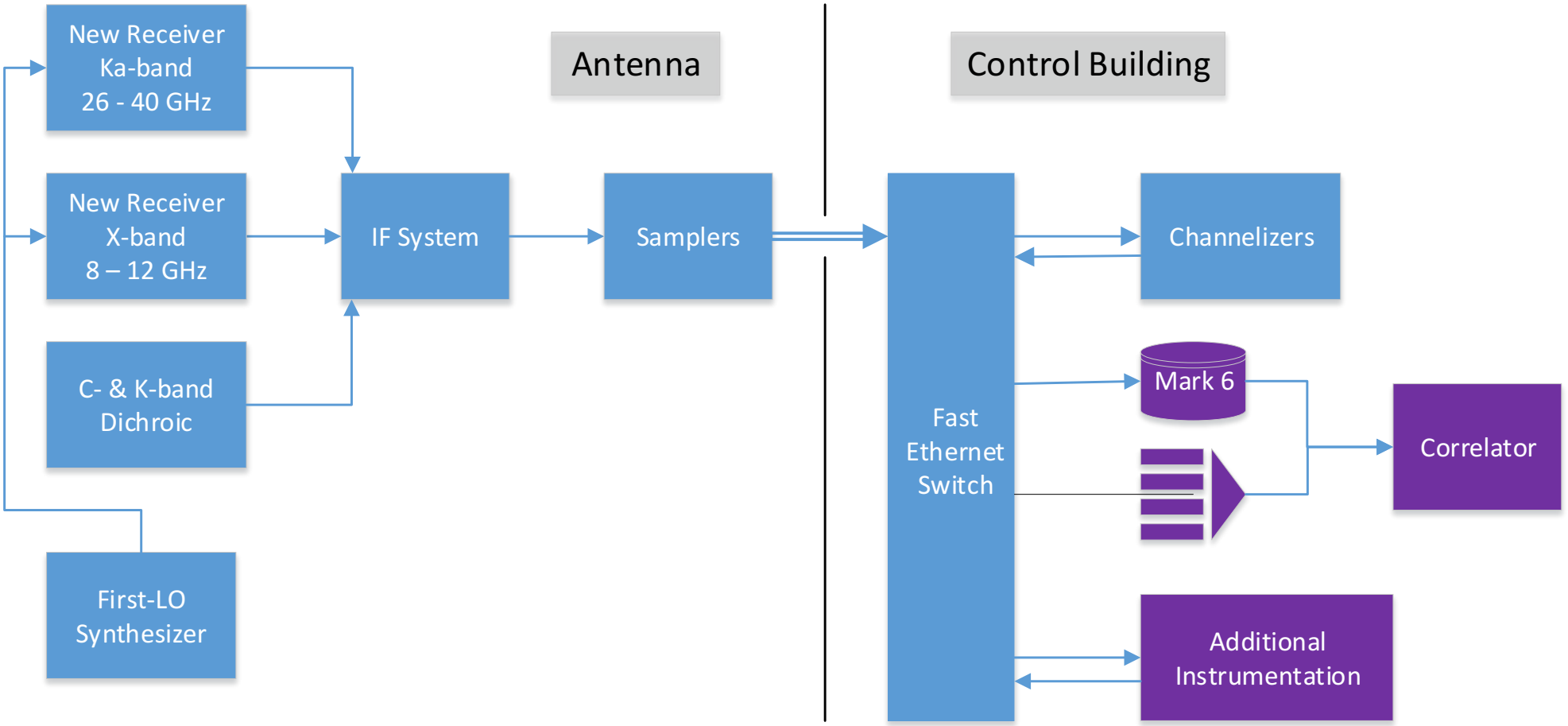


Mark 6 Recording System

- Chosen for this block as "shovel-ready" wideband recorder.
  - Specified to support 16 Gbps recording.
  - Procurement of a large- (but not full-) scale Mark 6 system currently under way.

Internet Portal

- Shown on block diagram for completeness at this time.
  - No current plan to implement on VLBA-wide basis.
  - At least 3 past studies – going back to era of 1-Mbps maximum data rate – showed fiber transmission not cost-effective for VLBA.
  - Margin of comparisons definitely decreasing — but desired maximum data rates also increasing.
- NRAO computing staff are monitoring options for future implementation.

Correlator

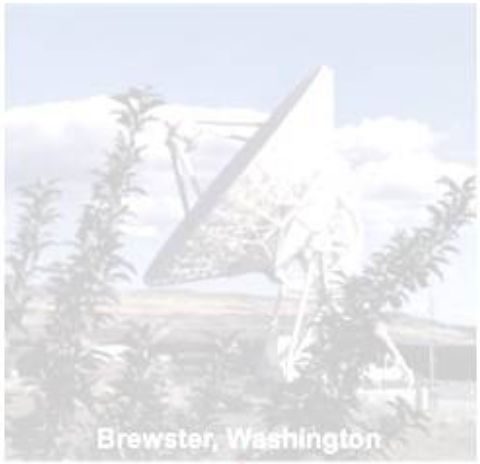
- The DiFX software correlator has fulfilled its promise to provide incrementally increasing capacity to match input data bandwidth.
  - The VLBA's current system should have sufficient capacity to support the upgraded systems described earlier in the data path.
  - Simple upgrades providing additional processors will suffice for further expansions.

Summary

VLBA Elements Requiring Major Updates to Support an "ngVLBA"

- Receivers
- First LO Synthesizer
- IF System
- Samplers
- NEW: Ethernet Switch
- Channelizers
- Disk Recording System

Owens Valley, California


Brewster, Washington

North Liberty, Iowa


Hancock, New Hampshire

Mauna Kea, Hawaii

Thank you

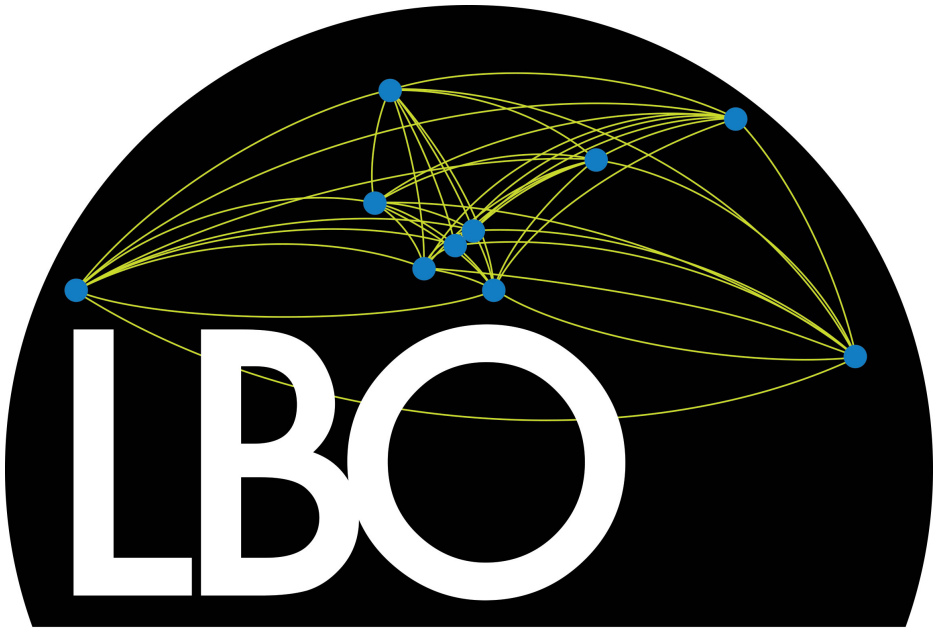
Los Alamos, New Mexico

Kitt Peak, Arizona


Pie Town, New Mexico

Fort Davis, Texas

St. Croix, Virgin Islands



LONG BASELINE OBSERVATORY

www.lbo.us

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