Mark 5 –
Status and Developments

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Mark 5A Data Acquisition System
(introduced 2002)
Main features of Mark 5A Data System

- Direct plug-compatible replacement for 64-track Mark4 or VLBA tape drives
- Record/Playback at rates up to 1024 Mbps
- Two independent ‘8-pack’ disk modules can be used in ‘ping-pong’ fashion for nearly continuous recording
- Records 8, 16, 32 or 64 tracks from Mark4 formatter (1024 Mbps max) or VLBA formatter (512 Mbps max)
Current Mark 5A Status

- ~150 Mark 5 systems deployed; >95% of tape systems have been replaced
- ~1300 Mark 5A ‘8-pack’ disk modules deployed (>2 PB of storage!); growing rapidly!
- 1 Gbps experiments are now routine for both geodesy and astronomy
- VLBA has converted to Mark 5; all VLBA stations have Mark 5A, but correlator is fitted with only enough to process VLBA stations
- Correlator efficiency has improved by factor of ~2 over tape!
- Challenge – support of systems in field!
  - Mostly due to large variety of system configurations
Mark 5B Data System Features

- Full VSI-H compatibility
- Same chassis as Mark 5A; uses same disk modules; requires Mark 5B I/O card
- 1024 Mbps record/playback
- Eliminates need for external formatters, but requires sampler adapter for Mark 4/VLBA DASs to provide VSI-compatible output
- Station Unit capabilities for connection to Mark 4 correlators is designed into Mark 5B
- Extensive built-in phase-cal extraction and state counting on both data record and data playback
- Front-panel status display – 8 tri-color LEDs
- DIM and DOM capabilities are separate FPGA downloads
- FPGA is programmable via software

Development support 2001-2004 from Mark 5 development consortium – NASA, NRAO, USNO, MPI, BKG, EVN, KVN, JPL
Figure 1: VSI-H Functional Block Diagram

Notes:
1. Shaded items are for illustrative purposes only.
2. PVALID is optionally transmitted from DIM to DOM.
3. PDATA is optionally transmitted from DIM to DOM.
4. Data delay in DOM is required only for storage-based systems.
5. See text for discussion of use of optional use of P/QSPARE1/2 signals.
6. If DIM/DOM in single box, ALT1PPS/DPSCLOCK/DPS1PPS share single MDR-14 connector.
7. This diagram does not show all functions and options – see VSI-H specification for details.
Mark 4 Station Unit emulation

Disks → Playback → Apply delay model → Station delay model → Phase-cal extraction (16 tones/chn) → State counting → Station unit function

Phase, delay model (per channel) → Insert → To correlator (16 channels)

Mark 4 Station Unit
Mark 5B I/O Board

- FPDP
- VSI Output
- VSI Cntl/Mntr
- VSI Input
- PCI Connector
- 256MB memory
Mark 5B Status

- Mark 5B fully tested and operational
- Mark 5B DIM software is complete except for phase-cal extraction
- Direct connection to Mark 4 correlator is operational at Haystack; has proven to be extremely reliable and repeatable
- ~15 Mark 5B I/O boards have been distributed to Mark 5 development consortia members
- Mark 5B system and Mark 5A→Mark 5B upgrade now available from Conduant Corp (already ~30 delivered)
- Mark 5B system is in routine use at Westford
- Mark 5B support on correlators
  - Haystack supports Mark 5B (including phase-cal/state-count)
  - MPI and USNO in process of upgrading to support Mark 5B
  - JIVE correlator has committed to Mark 5B upgrade, but schedule unknown; will use Mark 5A+ in meantime
  - NRAO will use Mark 5A+ for foreseeable future
Reasons to adopt Mark 5B

• Eliminate need for expensive external formatters; particularly important for new stations or stations without existing Mark 4 or VLBA formatters
• With a 14-BBC Mark4 or VLBA4 system, up to 1792 Mbps can be recorded with two parallel Mark 5B systems; current 14-BBC systems can only generate a maximum of 1024 Mbps of formatted data
• Extensive phase-cal extraction and state counting capabilities for better diagnostics and better system calibration
• Replace unreliable Station Units on Mark 4 correlators; SU capability is built into Mark 5B
• Stepping stone to Mark 5B+ (2Gbps)
Mark 5A/B Compatibility

Problem: Mark 5A cannot playback Mark 5B recordings – how can Mark 5B recordings be processed on correlators that support onlyly Mark 5A?
Solution: Mark 5A+ (upgraded FPGA code for Mark 5A)

- Upgraded Mark 5A (“Mark 5A+”) can play:
  - All Mark 5A recordings
  - All Mark 5B recordings, playback is in VLBA-track-format
- Mark 5A+ design complete and tested
- Mark 5A+ not compatible with 2Gbps recording from Mark 5B+

Bottom line: Mark 4/VLBA correlator with only Mark 5A units can process data from both Mark 5A and Mark 5B units during transition period to Mark 5B.
Mark 5B+ (2048Mbps)

- Conduant has introduced an upgraded StreamStor (dubbed “Amazon”) that supports up to ~3 Gbps on FPDP2 interface, which supports FPDP clock at 64 MHz
- Mark 5B I/O card has been designed and tested to support input VSI-H clock rate of 64MHz, as well as FPDP2 compatibility, to support max recording rate of 2048 Mbps
- Can record to one disk module at 2Gbps; plan to support recording across 2 disk modules (16 disks) for improved robustness in face of slow disks
- Playback is limited to 1024 Mbps
- Compatibility: Mark 5B+ recordings compatible with playback on Mark 5B and Mark 5A+ (except 2048Mbps)
- Mark 5B+ is operational and has been used in a number of experiments with DBEs
- Mark 5B+ is available from Conduant Corp as system or upgrade
How to upgrade a station from Mark 5A to Mark 5B

• Purchase Mark 5B upgrade kit (includes front-panel LED status panel and rear-panel I/O adapter)

• Options to create VSI-H data source:
  1. Modify Mark 4 formatter to “VSI4 Sampler Adapter”
     – Two VSI-H outputs; 1792Mbps total
     – Cost ~$2K (board and new rear panel from Haystack)
     – Pretty much irreversible
  2. Acquire Digital Back End unit
  3. Acquire VSI-C adapter to VLBA samplers
  4. Acquire Japanese VSI-H sampler unit
How to upgrade a Mark 4 correlator to support Mark 5B recordings

• Option 1
  1. Purchase Mark 5B upgrade kit (includes front-panel LED status panel and rear-panel I/O adapter)
  2. Procure Correlator Interface Unit from Haystack, plus upgraded Serial-Link boards from MPI (if necessary)
  3. Discard Mark 5 Station Unit
  4. Upgrade correlator software (significant work)
  5. Advantage: Supports Mark 5B+ recording at 2048Mbps

• Option 2
  1. Upgrade Mark 5A units Mark 5A+ (FPGA code upgrade)
  2. Upgrade correlator software to support Mark 5A+ (minor upgrade)
Mark 5C (under development)

- Amazon StreamStor board with new 10GigE daughter board (no separate I/O board – unlike Mark 5A/B/B+)
- Will accept single-stream 10 Gigabit Ethernet (OSI Layer 2)
- 4096 Mbps max data rate to two standard Mark 5 disk modules
- Record-only through SS 10GigE interface
- 10GigE packet specification will be VSI-E subset
  - Will support an arbitrary # of channels
    (i.e. not constrained to $2^n$ like current VSI-E, Mark 5A/B)
  - Will require extension of VSI-E specification
- Data format on SS disk currently under design
  - A Mark 5B compatibility mode will be supported
    (i.e. $2^n$ channels; will be readable on Mark 5B)
- Playback will be through host computer
  - Natural for software correlators
- Prototype expected by ~early 2008
Generalized 10GigE Data Distribution Concept

4 x 1000MHz IF
Station 1PPS
H-maser 5/10MHz

4 x 1000MHz IF

Channelized Ethernet packets

DBE

10GigE 8 Gbps
10GigE 8 Gbps

Standard 10GigE Switch

10GigE 8 Gbps
10GigE 8 Gbps
10GigE 4 Gbps

Mark 5C

Mark 5C +

Mark 5C
### Mark 5A/B/B+/C System Comparisons

<table>
<thead>
<tr>
<th></th>
<th>Mk5A</th>
<th>Mk5B</th>
<th>Mk5B+</th>
<th>Mk5C (under development)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Data Interface</strong></td>
<td>Emulates Mk4/VLBA tape transport</td>
<td>VSI-H (64MHz max clock rate)</td>
<td>VSI-H (64MHz max clock rate)</td>
<td>10 GigE (OSI Layer 2)</td>
</tr>
<tr>
<td><strong>Max data rate</strong></td>
<td>1024 Mbps</td>
<td>1024 Mbps</td>
<td>2048 Mbps</td>
<td>4096 Mbps</td>
</tr>
<tr>
<td><strong>Record modes</strong></td>
<td>8, 16, 32, 64 “tracks”</td>
<td>1,2,4,8,16,32 bitstreams</td>
<td>Same as Mk5B</td>
<td>—</td>
</tr>
<tr>
<td><strong>Disks</strong></td>
<td>Mk5 “8-pack”</td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td><strong>Chassis</strong></td>
<td>Mk5</td>
<td>Same</td>
<td>Same</td>
<td>Same</td>
</tr>
<tr>
<td><strong>I/O card</strong></td>
<td>Mk5A</td>
<td>Mk5B</td>
<td>Mk5B</td>
<td>None</td>
</tr>
<tr>
<td><strong>SS card</strong></td>
<td>XF2</td>
<td>XF2</td>
<td>Amazon</td>
<td>Amazon</td>
</tr>
<tr>
<td><strong>I/O-SS intf</strong></td>
<td>Modified FPDP</td>
<td>FPDP</td>
<td>FPDP2 (clocks on both edges)</td>
<td>10GigE Direct to Amazon</td>
</tr>
<tr>
<td><strong>Max playback rate</strong></td>
<td>1024 Mbps (to VSI-H)</td>
<td>1024 Mbps (to VSI-H)</td>
<td>1024 Mbps (to VSI-H)</td>
<td>~4Gbps (to host)</td>
</tr>
<tr>
<td><strong>Playback Compatibility</strong></td>
<td>Mk5A (to VSI-H)</td>
<td>Mk5A+ (to VSI-H)</td>
<td>Mk5B</td>
<td>—</td>
</tr>
<tr>
<td></td>
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</table>
## Mark 5 Upgrade Costs

<table>
<thead>
<tr>
<th>Target</th>
<th>Mk5A</th>
<th>Mk5B</th>
<th>Mk5B+</th>
<th>Mk5C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existing</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>0</td>
<td>Unavailable</td>
<td>$20.8K</td>
<td>~$22.3K</td>
<td>$20-25K</td>
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<tr>
<td>Mk5A</td>
<td></td>
<td>~$3.5K</td>
<td>~$13K</td>
<td>Est. $12-14K</td>
</tr>
<tr>
<td>Mk5B</td>
<td></td>
<td></td>
<td>~$9.6K</td>
<td>Est. $12-14K</td>
</tr>
<tr>
<td>Mk5B+</td>
<td></td>
<td></td>
<td></td>
<td>Est. $2-4K (10GigE DB)</td>
</tr>
</tbody>
</table>

Note: Costs do not include cost of creating data source
Disk-Media Status

- Hard disk price vs capacity/performance continues to drop
  - Now below ~$0.50/GB and continue to drop
    (Mark 4/VLBA tape is ~$2.00/GB)
- 400 GB disks are commonly used –
  Two 8-packs of 400GB disks comparable to ~13 VLBA/Mark 4 tapes
- 750 GB disks now available –
  Two 8-packs of 750GB disks comparable to ~24 VLBA/Mark 4 tapes;
  ~26 hours @ 1 Gbps unattended!
Tape vs. Disc Price Comparison

Year

log($/GB)

Disc Drive Street Prices

Computer Tape Media

Mark IV/VLBA/K4 Media

S2, S3 Media

Disc industry Projections

1998 IBM Disc Projection

1998 NSIC Disc Projection

LTO Media Projection

Disk-Media Reliability

- Based on statistics collected at Haystack, average disk drive failure rate is ~0.5% per year
- Failure rate of Hitachi 250GB was higher than average, but now believed stabilized
- Disk reliability at high altitudes (Mauna Kea summit) was investigated prior to UVLBI experiment; only Hitachi 250GB disks passed.
Disk-Media Reliability

• Based on statistics collected at Haystack, average disk drive failure rate is ~0.5% per year
• Failure rate of Hitachi 250GB has been higher than average
• Conduant has qualified drives from Maxtor, WD and Seagate
  • 400GB – Seagate
  • 250GB – Western Digital RAID Edition (high-reliability)
  • 250GB – Maxtor Maxline III (high-reliability)
• Conduant is shipping these disks in assembled Mark 5 disk modules
• Disk reliability at high altitudes is under investigation
Mark 5 file access

- Conduant working on upgrade to allow Mark 5 scans to be accessed as standard Linux files
- Probably will be read-only (similar to CD-ROM)
- Will be targeted at upgraded Mark 5 data-directory structure
- Convenient for e-VLBI and software correlators
- Availability ~end 2007
SATA disk module

- Now available from Conduant
- Interchangeable with PATA disk module
- New mechanical design allows very easy access to insert/remove individual disks; increased module stiffness for better mechanical stability


Summary

- Transition from tape to disk is nearly complete at nearly all stations and correlators
- Mark 5B is ready for prime time; in routine use at Westford antenna
- Upgrading to Mark 5B is not necessary at all stations, but may be advantageous; will be required for use with DBE
- Mark 5B+ (2 Gbps) is also operational and has been used extensively for astronomy observations
- Mark 5C (4 Gbps) is currently under development to support industry-standard 10GigE interface
Questions?