MBARI 4K ROV Camera Project Concept Review

November 13, 2019

It is vital that this project produce a camera system that produces the highest quality image but also is fully operational on a day-to-day basis, compatible with both ROV's and supportable over it's operational life.

It is important at this early stage that necessary features to allow this can be incorporated into the requirements from the beginning.

Attendees

- Operations
  - ★ Ben Irwin
  - ★ Dave French — conflict
  - ★ DJ Osborne
  - Mike Burczynski
  - Craig Dawe
  - Bryan Shaefer
- Science
  - ★ Jim Barry
  - ★ Steve Haddock
  - Kim Reisenbichler
- Video Lab
  - ★ Lonny Lundsten
- Engineering
  - Andy Hamilton — conflict
  - ★ Francois Cazenave
  - ★ Paul Roberts
  - Todd Walsh — conflict

★ project team

Post-review notes (by Paul Roberts) have been added to notes section of slides!

Major action items from review notes:

1. *Set camera operating temp range max. to GOC surface temp.*
2. *Work with Ricketts to set maximum size envelope allowed.*
3. *When a better total power requirement is known work with Ventana and Ricketts on electrical connector and voltage specification. Seacon MINK 10#20 is preferred.*
4. *Dual focus rate controls on lapbox.*
5. *Lens position feedback required.*
6. *Flare shroud must accommodate different laser arrangements. (easily swapped?).*

- MC: Mark Chaffey
- DJ: DJ Osborne
- CD: Craig Dawe
- JB: Jim Barry
- BE: Ben Erwin
- FC: Francois Cazenave
- MB: Mike Burczyski
- KR: Kim Reisenbichler
- LL: Lonny Lundsten
- SH: Steve Haddock
- BS: Bryan Shaefer

902001 ROV 4k Camera Project Summary

- Both DMO and the Video lab recommended MBARI start working toward incorporating 4k or UHD video into our vehicles.
- We tank tested cameras from Sulis, SubC, DSP&L and Insite Pacific.
  - Sulis and DSP&L had pretty good optics but very poor zoom and focus controls.
  - SubC and Insite Pacific had poor optics and very poor zoom and focus controls.
- We were unable to identify a commercial product significantly better than the existing Zeus Plus HD cameras.
- A 2020 project was proposed and approved to build a high quality 4K camera system.
  - Some project funds have been moved to 2019 buy-ahead.
  - Prior to committing funds – and development direction – review is needed.

Goals of the Meeting

- Update on the current status of the ROV 4k camera project.
  - Overall plan of action.
  - Schedule.
- Review the camera system requirements – ESPECIALLY the operational requirements.
  - Size and weight limitations.
  - Connector specifications
  - Fiber compatibility.
  - Vehicle interchangeability.
  - "Maintainability"
- Review the current system design.
  - Camera and lens selection.
  - Size and weight estimates.
  - Telemetry system.
  - Optical dome port and housing.
  - Topside control box.
  - File recording and transfer.

SH: operation requirements only for this meeting?
MC: Requirements doc have the full requirements

DJ: No other nibbles except for DSPL?
MC: DSPL is contracted so we are paying them

BE: What rights will DSPL have?
MC: They will provide housing and optics and may sell cameras using the design to others

KR: Wouldn't folks be better off buying later?
MC: Maybe, but don't tell them :)

JB: Details haven't been worked out in MBARI recovering NRE but we would recoup from the cost if other groups buy these cameras as well.

SH: have the sensor and optics been decided
MC: Basically yes, they have.

Project Plan of Action

- MBARI will build and integrate the camera system.
  - Modify standard camera to fit in the smallest housing feasible.
  - Design and build all other internals and telemetry.
- Deep Sea Power & Light will design and the build housing.
  - Optical dome port.
  - Relay optical system and mounts.
  - Titanium housing.
- *Actively seeking additional users to share in NRE costs (OET, SIO, etc.)*

Development Schedule

The following dates reflect the current schedule. They are may change, but the plan is to adhere to this schedule if possible.

- First release RFP for optics and housing to potential vendors. September 20, 2019. (done)
- Deadline for initial vendor response. October 10, 2019. (done)
- Final vendor selection. October 31, 2019. (done)
- MBARI releases final housing internal diameter and internal length. January 24, 2020.
- Critical design review (CDR) of complete design including vendor optical and housing design and MBARI camera system. Final review of all interfaces, connector ports, lens alignment fixtures, chassis to housing interface, etc. February 20, 2020.
- Release to fabrication following the resolution of any issues raised in the CDR. ASAP following CDR.
- Final assembly of all camera system components (MBARI and vendor) August 12, 2020.
- At-sea testing completed. September 4, 2020.

Camera System Requirements

- Full camera systems requirements are here:
  \\Atlas\ProjectLibrary\902001_4K_ROVCameraDevelopment\EngineeringDesignDocuments\4KCameraRequirements\4KCameraMBARIRequirements.pdf
- Important operational requirements – lens control…

1.7. **Lens control**. MBARI takes pride in the quality of the control servos that are used on our camera systems. We support full position control for the lens focus and variable rate control for the zoom position. This increases the quality of our in-house recordings by providing for the best possible focus control as the image moves in relation to the camera – as ROV imaging subjects often do. It also allows professional videographers to get the most out of the system. Many alternative lens control strategies use simple on-off toggles for moving the lens elements which is not acceptable.

1.7.1. The lens follow focus control shall have variable position servo control, i.e. the focus must smoothly and quickly ramp to a commanded focus position without detectable lag, drift, overshoot or "hunting".

1.7.2. The lens zoom control shall have a variable rate servo control for zoom position without detectable lag, drift, or overshoot.

1.7.3. The lens focus and zoom positions shall be digitally encoded and available on a EIA 232 or Ethernet standard interface in the ROV control room for logging lens position for quantitative video applications. *Note: still reviewing the position reporting requirement, it may not be required.*

Lens position logging still a requirement?

CD: The focus of the old Sony was super camera control, since then haven't experienced anything as good. Huge effort and it was great.

MC: That level of control is a requirement.
MC, SH, CD, KR: need to have focal setting of the lens relayed back to the system to be recorded and used later (scale est, etc)

SH: Even the current controller can be improved. Hard to focus on the photophore of fish. Didn't have fin enough control.

JB: Would be nice to have control of the fineness of focus (coarse or fine).

MC: Rate control for the zoom is very important.

JB: Could have a coarse and fine slider

DJ: These control are even more import for 4k resolution.

Camera controls

Focus example
https://www.youtube.com/watch?v=X8oWnbcLI40
(2,794,882 views)

MC: What about the box overall

SH: Lot of wasted space

BE (and many): unused controls

DJ, BS BE, MC: iris control is required BS others can be remoted

MC: sony controller is too big to fit in box, but the subset can fit,

SH: iris, white balance and gain are required

MC: Would be nice not to have to hack it

Camera System Requirements continued…

- Important operational requirements – Status monitoring.

1.8. **Camera system status monitoring and alarms**. It is required that the camera housing include sensors for water intrusion, housing internal pressure, humidity and temperature and that there be a system for alerting the operators if any of these values exceed safe operational limits. In addition, the camera module shall be automatically powered down if the internal housing temperature exceeds the camera manufactures maximum environmental operating temperature specification.

Add allowable seawater operating temperature range for camera system? What should it be? See below also.

MC: thermal shutdown

DJ: you'd still have comms to the camera?

MC: yes

SH: does higher temperature cause red shift?

MC: I'm not sure, they work hard to maintain image quality over temperature range

DJ: I thought it was 50 W

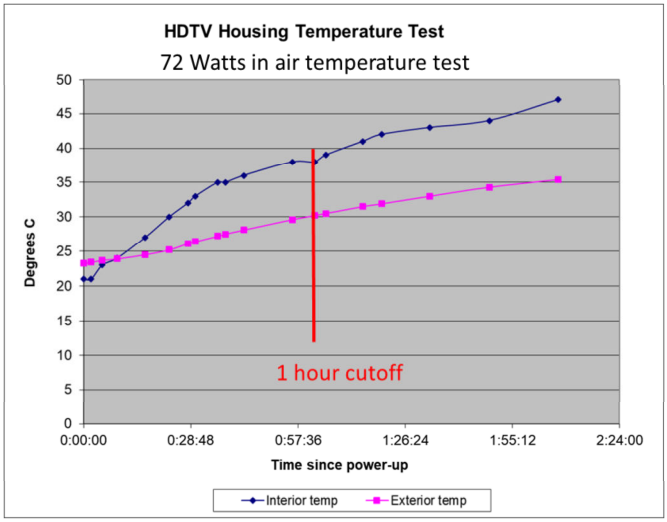
MC: maybe up to 80

DJ: we may need a different connector
MC: not really anyway around the power draw

(Many): temperature shutoff is a great idea!

Titanium Housing in Air Example

- Auto shutdown requirement protects against:
  - If cooling fan fails.
  - If camera is accidently left on in air.
- Overheating above 40 degrees C will permanently damage electronics.



Camera System Requirements continued…

- Important operational requirements – Telemetry system

2. **Video uplink/Control link**.
   - 2.1. The video uplink shall transmit the full baseband video signal to the ROV control room using an industry standard format such as Quad 3G-SDI (SMPTE 424M), 12G-SDI (SMPTE ST-2082) or HDMI 2.0. Note: Quad 3G-SDI or 12G-SDI/SMPTE ST-2082 is preferred.
   - 2.2. The video uplink shall operate over 5000 meters of single mode optical fiber and provide a minimum link optical budget of -20dB. Note that to assure reliable operation the fiber optical properties of material and chromatic dispersion at the operating wavelengths need to be taken into account to assure reliable system operation at the transmitted bit rate.
   - 2.3. The optical system transceivers shall use SFP modules and transmit the system signals on the following Coarse Wave Division Multiplexing (CWDM) channels conforming to ITU-T Recommendation G.694.2:
     - 2.3.1. Video uplink signal on wavelength TBD.
     - 2.3.2. Communications uplink on wavelength TBD.
     - 2.3.3. Communications downlink on wavelength TBD.

Question: Are we all OK with a single-mode “dark” fiber?

BE: on Ricketts will always have dedicated fiber

DJ: this is also true on Ventana

MC: like to keep it at single fiber and power

(Many): best compatibility from single fiber

JB: likely want to have multiple cameras soon after deployment

Camera System Requirements continued…

- Important operational requirements - Housing

3. **Camera housing requirements.**
   - 3.1. **Housing material**. 6AL4V Titanium (Glass, Delrin and other corrosion resistant materials may be used for the optical dome, retaining rings, etc).
   - 3.2. **Depth Rating**. The working depth is 4000 meters of sea water (5800psi). The design safety factor for the housing and optical dome shall be a minimum of at least 1.25 times working depth before failure or yield (7250psi).
   - 3.3. **Housing optical port**. Suitable for the lens specified and meeting the optical requirements.
   - 3.4. **Working life**. Housing and dome shall be designed for a minimum working life of 5 years with a mechanical reliability of 99.5%, assuming an average of 130 pressure cycles per year from 0 to 4000 meters ocean depth.
   - 3.5. **Pressure rate-of-change.** The maximum rate of change for pressure cycling in operation and testing shall be less than or equal to 200 p.s.i per minute.

CD: What is the port lifetime based on?

MC: Depends on the method used to test the port

SH: 99.5% is over the 5-years or per dive?

MC: over the 5-years

CD: cost of domes is around $6000 so not too expensive

Camera System Requirements continued…

- Important operational requirements - Housing

3.6. **Size**. Housing and dome combination should be anticipated to be designed for a maximum preliminary size camera module of 20 inches internal length from the front optical element and 7.0 inches internal diameter. The exact housing size will be determined when the camera chassis and lens element spacing designs are complete.

3.7. **Weight**. Housing and dome combination should be custom designed for the required depth rating to allow for minimum possible weight.

It has been pointed out that this does not specify a maximum external size. There is a more detailed discussion on size in the system design below. Having DSP&L design the housing makes this specification more important and we need to set a maximum operational size specification.

MC: DSPL needs an envelope for size

BE: we already have some size issues.

Additional notes on size (mark). Heard comments that diameter was not as much as issue as length. Craig D. commented that he did not think that the old HD camera was necessarily too large for Ventana, replacement was more of a reliability move. Also mentioned that problems may have been due to vibr-coring and shaking the camera.

Bryan S. thought that size was defiantly an issue on the Ricketts, especially length. They have about an inch clearance front and back. When panning and tilting.

Camera System Requirements continued…

- Important operational requirements - Housing

Add seawater temp range for camera operation? 27 C might be hard to do….

3.8. **Temperature**. The housing must maintain water integrity at specified depths across a temperature range of -8 to +27 degrees Centigrade.

3.9. **Interface connectors**. The housing interface shall include one Titanium Brantner/SeaCon "MiniCon" MINK19#22FCR bulkhead connector and one Titanium Brantner/SeaCon "MiniCon" MINF-1-FOSM-FCRL bulkhead connector. Alternate connectors may be substituted with MBARI written agreement.

Change to Seacon MINK10 (2#14, 8#20) FCR? Can this connector on the ROV provide 70-80 Watts (3.4A @ 24V)? Best voltage range for ROV?

MC: need to add camera temp operation requirement

JB, many: gulf of california should set the upper limit

Connectors:

MC: compatibility

DJ: don't have to use the MINK19

DJ: MINK10-L might be a good option gigabit path

BE: have several paths for MINK10-L

BE: but our MINK10-L ar AC 110

DJ: Same as our ports

MC: Let's continue to work on connector options

DJ: One option is to use a mink10 and double up the pins

MC: what about Seacon?

(Many): all manufacturers have supply issues these days

MC: Should have RA connectors for both fiber and power

(Many): agree

DJ: Buy in on seacon fiber connector?

(Many): Yes

Camera System Requirements continued…

- Important operational requirements – *Additional*

- *Include provision for laser mounting on the same plane as the camera in the dome support and hood design. (DJ).*
- *Power supply*
  - *18 to 36 VDC at 70-80 Watts.*
  - *What is the best voltage range for the ROV's?*
- *Any requirements needed for seamless Ricketts to Ventana compatibility.*
- *Specific requirements for maintenance and support?*
- *Other missing requirements?*

MC: What about voltage?

(Many): most likely 24V is okay

MC: most likely 16-36 switcher in the housing.

MC: I'll add the laser mount provision in the flare guard

DJ: Want to move the lasers to the hemisphere

BS: Ours are off the side

MC: any shroud design needs to take into account mounting the lasers on the side

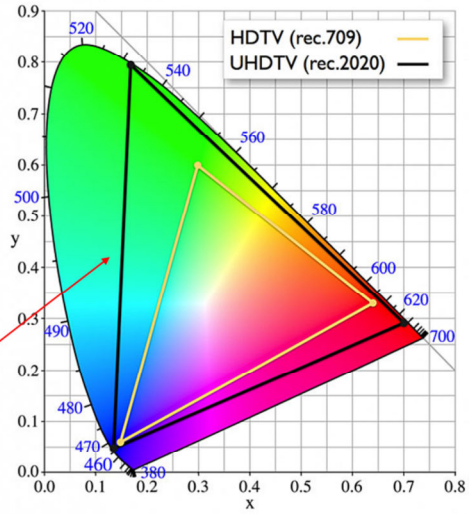
(Many): multiple lasers

MC: Multiple shrouds for different lasers

Best Candidate Camera Module

- Sony HDC-P50
  - 2/3" 3-Chip CMOS imager
  - 4096x2018 progressive scanning @ 60 frames/sec.
  - Box camera version of HDC-3000/5000 top of the line portable cameras
  - Global shutter
  - ITU-R BT.2020 color gamut
  - High Dynamic Range (HDR) capable
- Lenses
  - Fujinon UA13x4.5 BERA 4K UHD Wide ENG style lens with 13x Zoom
  - Canon CJ12ex4.3B 4K UHD wide-angle lens with 12x Zoom

BT.2020 color space
Vs
BT.709 color space



CIE Chromaticity Diagram (1931). The three dimensional color space CIE XYZ is the basis for all color management systems. This color space contains all perceivable colors - the human gamut – based on experiments with actual human vision. Many of them cannot be shown on monitors or printed.
The two dimensional CIE chromaticity diagram xyY (above) shows a special projection of the three dimensional CIE color space XYZ.

Camera Sensor

MC: Want to use the latest HDC-P50 Ony camera, heli, wire cams, sports

BE: There's a big advantage for the framerate and resolution at 60 FPS 4k

SH: What about low light sensitivity?

MC: About the same as the ikegami, f11, 2000 lux

JB: gain control?

MC: looks really good at gain +6

BE: Should we look at montior color space support

MC: yes

SH: color bit depth?

MC: I think it's 10 bits, which is greater than the human eye

MC: HDR is perhaps a big improvement

(Many) need to discuss HDR options for monitors

SH: Does HDR impact frame rate

MC: no, it's a different gamma setting, no frame to frame processing

Lens

MC: Lens?

JB: hate to give up zoom

SH: like to have close focus

MC: Jim you want more zoom?

JB: we want to get in as close as we can for distant targets but also don't want to compromise other features

MC: we'll look at zoom options

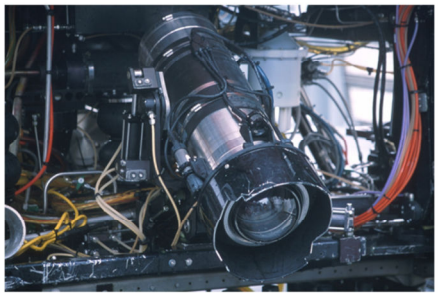
MC: Lenses are super wide, can we stop them down

DJ: more is better but the same works

Long discussion about how wide to go

MC: TBD on this question

Size and Weight Estimates



- Original HD camera was too large for best integration.
- Zeus Plus size/weight successful on both vehicles.
- 4K camera needs a 6" ID dome for not compromising the optical design, the same dome size as original HD camera.
- Careful design of the 4K dome retainer and glare shield should result in a overall size similar to Zeus Plus.
- *Need to specify in detail maximum dimensions for camera package to provide guidance for DSP&L design effort.*

Target camera size

Actual and Estimated Housing Sizes - 4000 meters							
	Diameter ID Inches	ID mm	OD Inches	OD mm	Length internal Inches	Length internal mm	Notes
Our old HD (Sony HDC-750)	7.72	196.1	8.67	220.2	20.0		
Insite Zeus (Ikegami)	6.75	171.5	7.75	196.9	19.0	482.6	
Sony P-50 w/o moving center	7.72	196.1	8.67	220.2	19.0		
Sony P-50 with moving center	6.75	171.5	7.75	196.9	19.0		project plan
Sony P-50 w/o moving center but custom chassis	7.1	180.0			19.0	483	with internal connector clearance

DJ: will the shroud be inside or outside of the current round shroud

MC: it won't be any larger in any dimension.

MC: I'm happy with the camera.

DJ: cost?

MC:$70k, but we can get them for ~$30k

MC: Go on record that the current housing is too big. The Zeus seems to be a workable size

MC: The goal is to get it in the Zeus size

(Many): Cool!

SH: PT has some vibration now and needs to be fixed.

BE: We're looking into to the ROS PT options to reduce vibration

MB: How many cameras will we have?

MC: three, so we will have a spare

BE: Length is the bigger limit

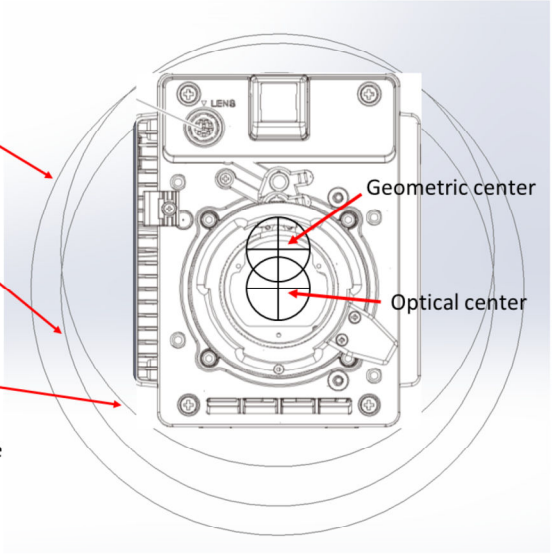
SH: What is the length of camera+lens?

BE, BS: going to square shroud will buy us inches

MC: Shorter is better, but I think it will fit in Zeus housing

The Challenge of a Small Housing with the P-50 Camera

- No camera modifications
  - Housing internal diameter 7.72 inches (same as original HD camera).
- Do not move optical block
  - Requires more space in upper chassis
  - Housing internal diameter 6.75 inches (same as Zeus Plus).
- Move optical block up 15.5mm
  - Probably not possible. But 5-10mm may be OK.
  - Still will require upper chassis modification.
  - Housing internal diameter 6.75 inches (same as Zeus Plus).
- Final design will compromise by moving the optical block up slightly and modifying the upper chassis frame also. *Maximum target internal diameter is 7 inches.*



DJ: What does service look like

MC: Board swap red/green light for status, user service is straightforward

DJ: Can we vibercore with it?

MC: sounds like a bad idea

JB: is there a way to add bumpers to isolate the camera from vibration,

BE: depends on wavelength of vibration

SH: is there any smaller camera with the same specs?

MC: not that I know of

CD: can the camera fit unmodified in the larger housing?

MC: could you tolerate a larger housing?

(many): some agreement

CD: can Ricketts handle it?

BS: maybe, but can do it without a shorter housing.

DJ: thinking of a product, the smaller housing is a benefit

MC: also nice to have a drop in replacement

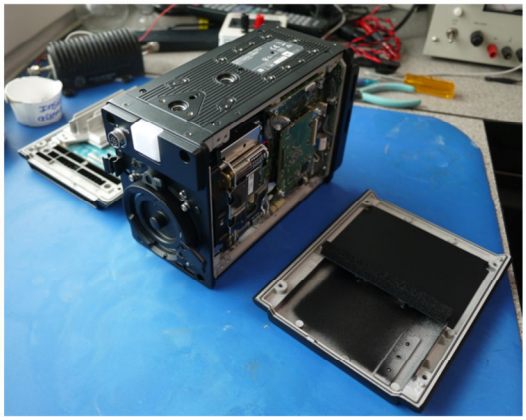
CD: drop-in with a larger housing might be more appealing.

JB: Action item: what are the size and weight limits for the ricketts

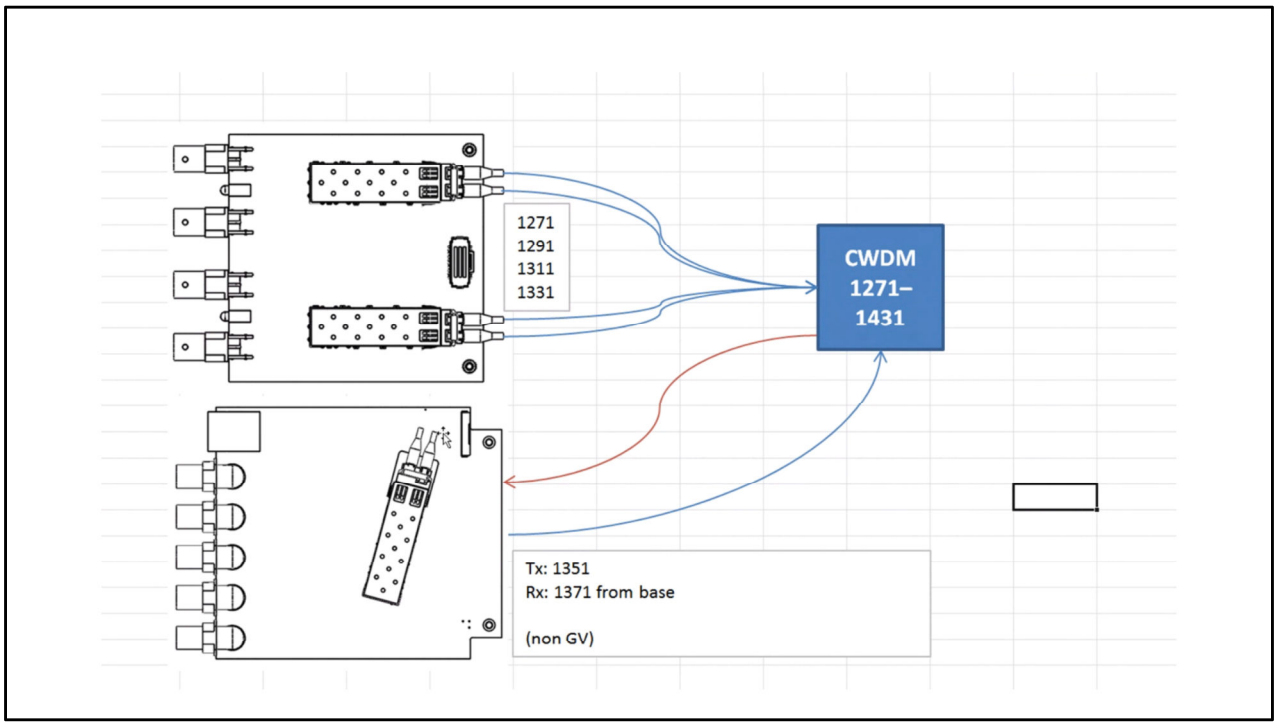
(Many): Advantages to smaller size and some disassembly

Chassis Modifications

- Anticipate custom front, rear and top chassis frame elements.
- Maintaining designed airflow is critical.
- Advantages of modification.
  - Smaller, lighter housing.
- Dis-advantages of modification.
  - Will Sony provide repair service?
  - May have to re-assemble in original frame for factory service (1-2 hours of careful effort).

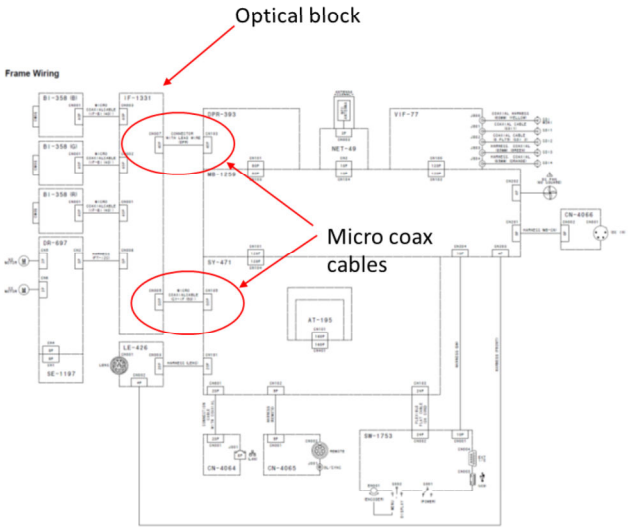



CHAFFEY X1708


1271
1291
1311
1331
CWDM
1271–
1431
Tx: 1351
Rx: 1371 from base
(non GV)

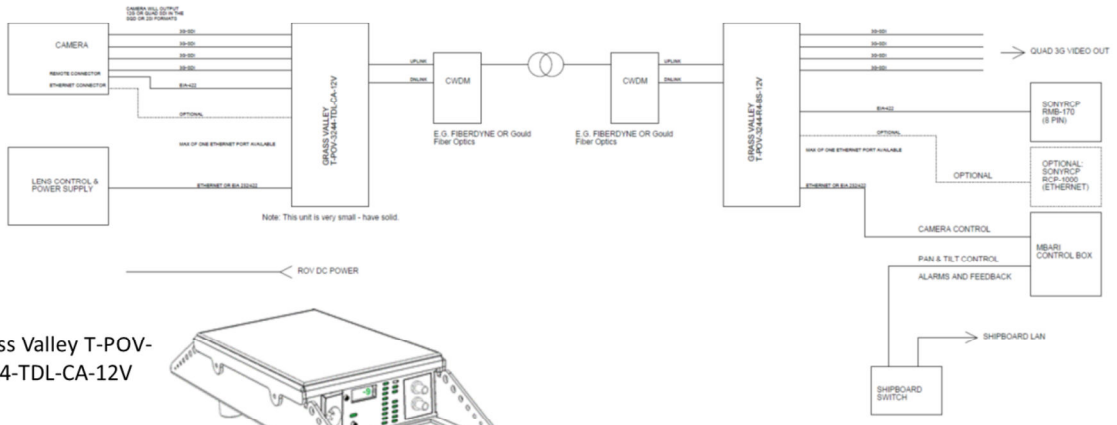
Argument for Modifying Frame

- Camera electronics are all digital and on four main PCB's.
  - Less tuning than previous cameras.
- Existing cables are long enough.
  - High speed coax cables extremely hard to modify.
- Board level diagnostics and service manual support in-house service if necessary.
  - Vector scope and standard tools are all that is required.
- Careful design – especially maintaining temperature control – should result in a very reliable system.



Telemetry System - Top to Bottom Architecture with Off-the-Shelf Grass Valley / Telecaster Telemetry

OPTION 2 - USE T-POV ONLY FOR RCP AND LENS CONTROL



Grass Valley T-POV-3244-TDL-CA-12V

Telemetry

Telecaster option

MC: simplest, least risky option for 4k

SH: zoom, focus, iris would talk to telecaster?

MC: yes

BS: is camera control over ethernet?

MC: it would be over serial, and that should be better for lag

MC: Andy has a micro in mind for this

Optical Dome Port and Housing

- Deep Sea Power & Light is designing and building the housing assembly.
  - Optical dome port.
  - Relay optical system and mounts.
  - Titanium housing.
  - Will retain the optical engineer MBARI used for i2MAP (Remijan).
  - Providing a One year warranty on design and materials, following with time and materials repair and replacement.
- Why use outside vendor?
  - Vendor can provide on-going maintenance and repair support for the optics.
    - Requires clean-room environment.
    - Parts stock.
    - More important with multiple operational units, i.e. at least two cameras.
  - Reduces MBARI technical risk.
    - Accelerates schedule.
    - Vendor has direct experience.
  - Use of vendor increases chances of additional users signing on to share NRE.
- MBARI is performing the final camera systems integration and testing.

Vendor

(many) Good idea to use outside vendor and DSPL is a good option

Camera controls

To add stand-alone capability, add alarm lights for:

1. Over-temperature
2. Humidity alarm (>20%?)
3. Water alarm

Topside Box

MC: plug compatible with existing box

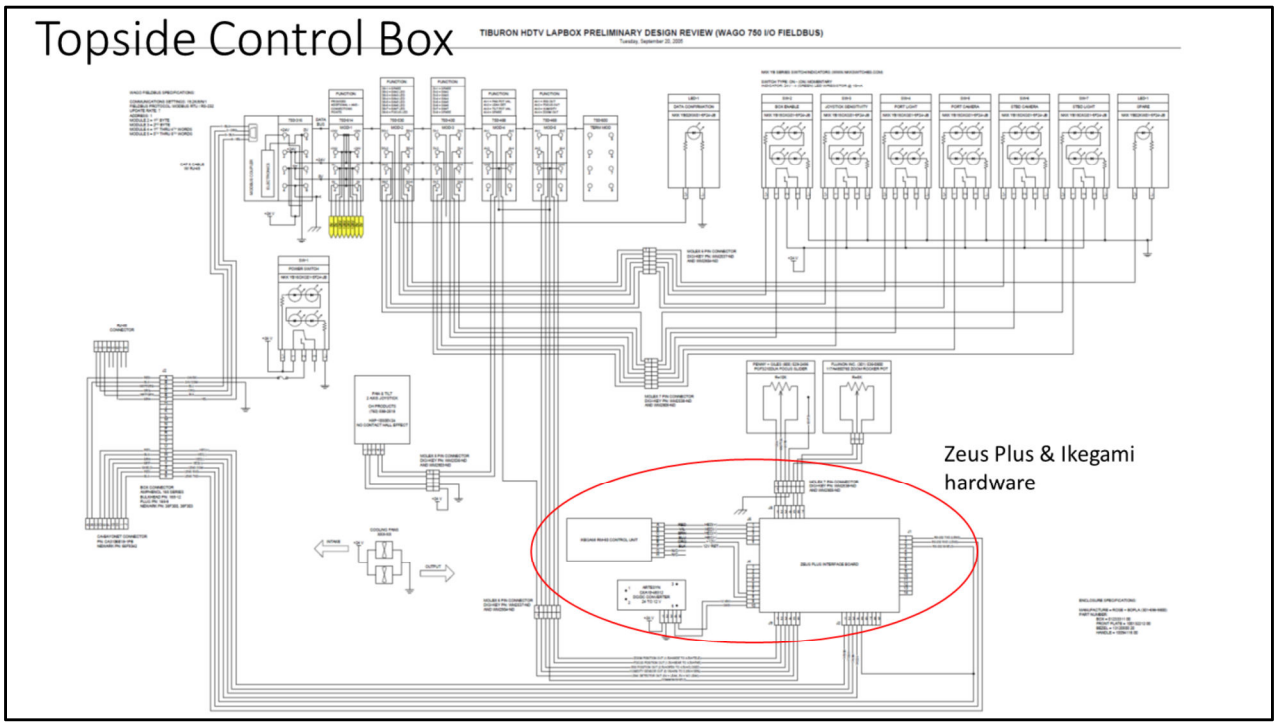
SH: but without ikegami?

MC: yes

SH: should have an open slate for new focus controls

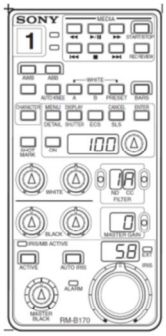
MC: Yes, but vehicle comms should be compatible with existing one.

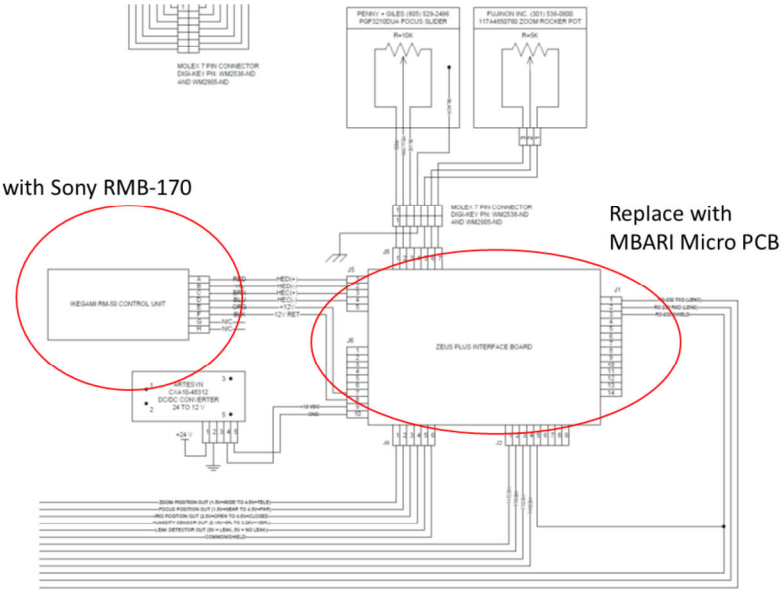
Topside Control Box



Current Lapbox Design Detail

Replace with Sony RMB-170

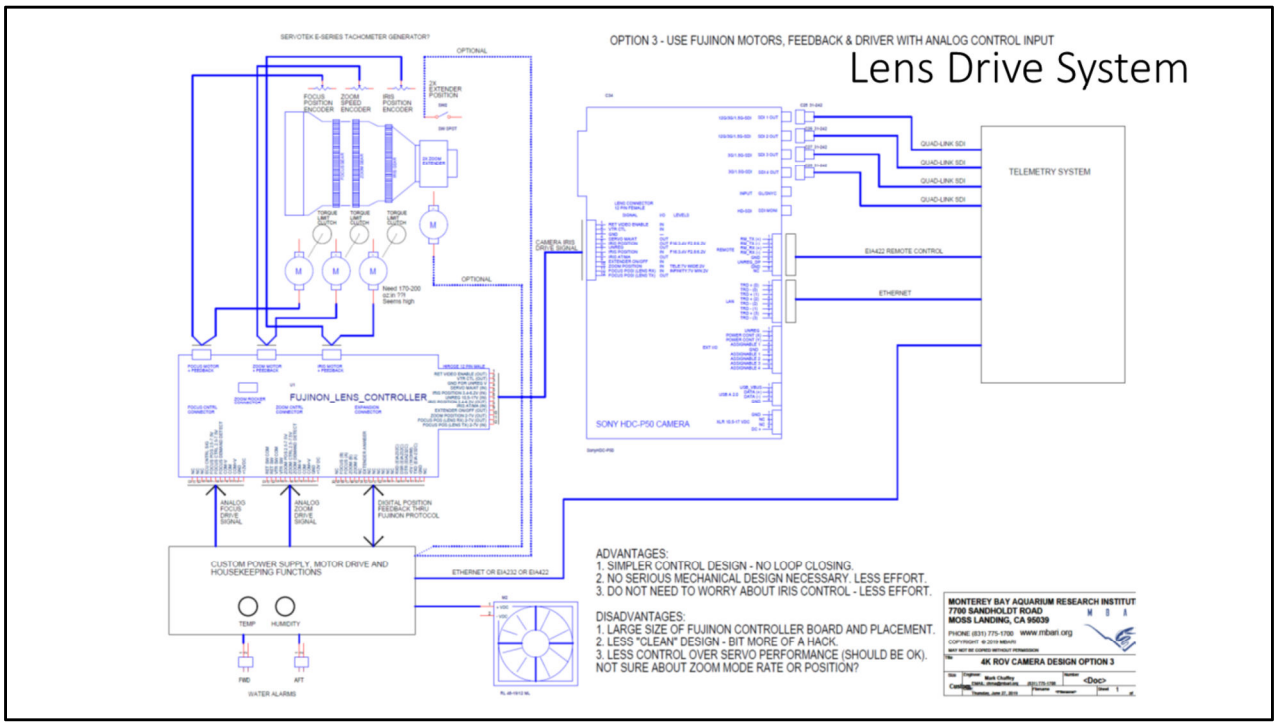




Replace with
MBARI Micro PCB

Lens Drive Servos and Housekeeping

- MBARI in-housing PCB provides the following functions.
  - Analog lens drive signals for zoom and focus.
  - Power conversion and monitoring.
    - Over-temperature camera shutdown.
  - Local environmental monitoring.
    - Temperature.
    - Humidity.
    - Pressure.
    - Water alarms.



Lens Drive

SH: can you still get the lens settings read out with analog control?

MC: likely yes, control with analog and read out on 232

MC: 232 control does not look very good

MC: proposed action is to use the analog control input and 232 to read position

KR: so the lens has their own feedback and control?

MC: yes, that's how they get the super fine control

SH: what about bringing up the controls all the way up to topside?

MC: if you lied their controls then that might be feasible

JB: it would be nice to see how good the fujinon controls are

JB, SH: like having dual sliders

SH: what other controls are there?
MC: Camera controls are on the smaller sony box

File capture and transfer -- M3RS

M3RS (replaces video tapes)

- Shipboard, lab, mobile versions (e.g. miniROV)
- Records current camera stream and future cameras (up to 4K)
- Records multiple streams, 2 now, up to 16
- Recorded to HDD RAID now, LTO-8 in near future

Recording

LL: planning to use M3RS can support up to 16 4k feeds

BE: worry about rack and loose thunderbolt cables

LL: the new rack mount will have BNC

BS: the only issues have been user error

DJ: Mark is there money with topside upgrades?

MC: no

BE: Monitors would be good

SH: what about overlay?

BE, BS: we are working on that

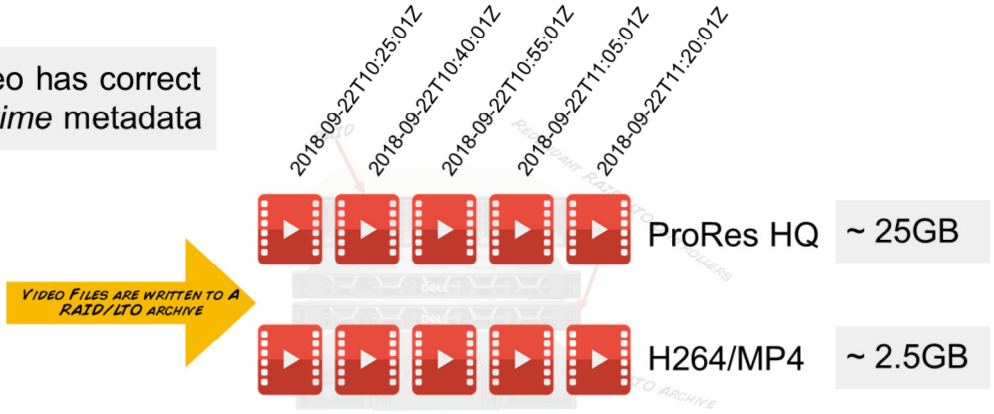
SH: can you fly with 4k overlay

BS: Yes, but there is work to do for upgrades next year

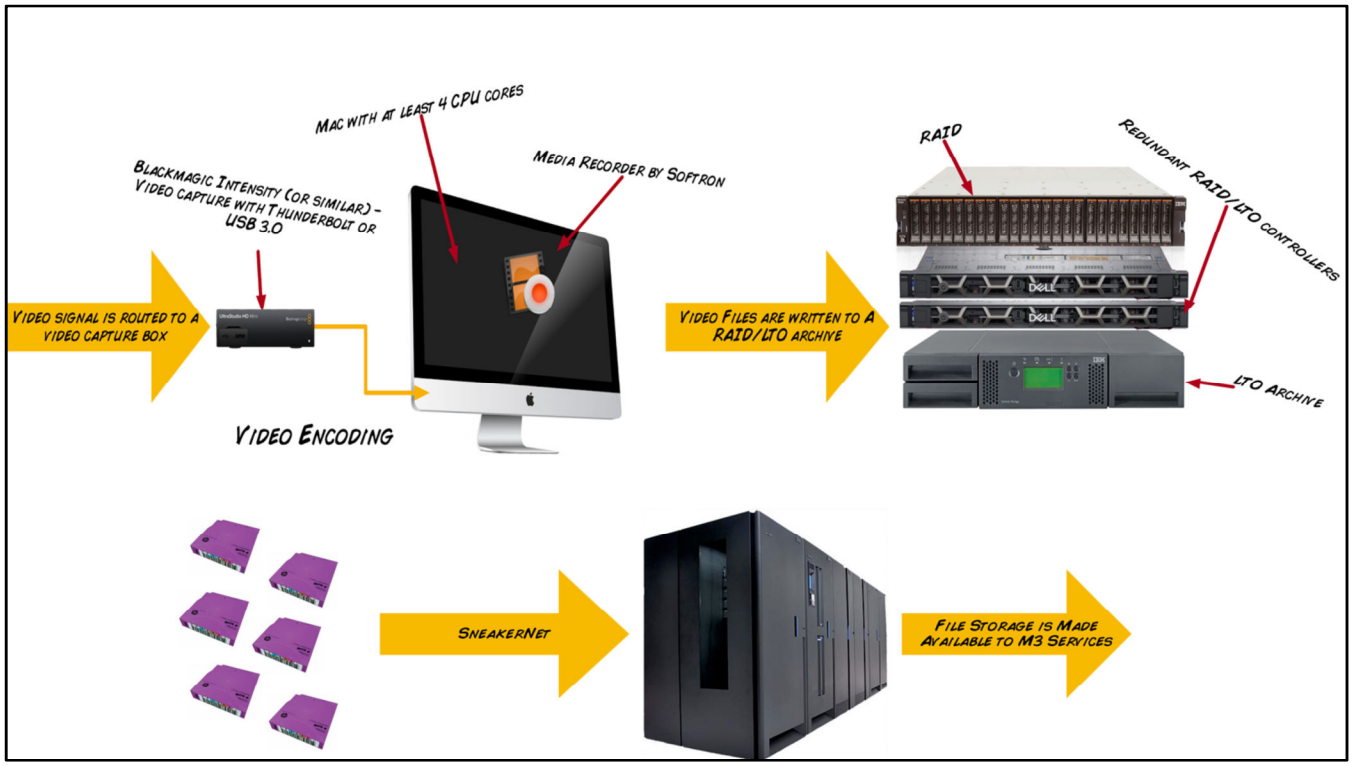
DJ: sounds like there is time to adapt to 4k

MC: glad to hear the file capture is going well

Each video has correct *creation-time* metadata



Video is recorded in 15 minute chunks


Mac with at least 4 CPU cores
Media Recorder by Softron
Blackmagic Intensity (or similar) - Video capture with Thunderbolt or USB 3.0
Video signal is routed to a video capture box
Video Encoding
RAID
Redundant RAID/LTO controllers
Video Files are written to a RAID/LTO archive
LTO Archive
SneakerNet
File Storage is Made Available to M3 Services

Technical challenges including long term data storage

- 4K video at 60 frames per second (4096 x 2160 60p) is a very large jump in the amount of data.
  - Master level Apple ProRes Codec 422 HQ is about 848 Gigabytes per hour.
  - Mezzanine level H.264 or H.265 Codec is around 10:1 or 85 Gigabytes/hr.
- The MBARI Titan network share system has the capacity to support 4K video acquisition on MBARI's main vehicles for at least 10 years.
- Over a period of time the video data would grow to be by far the largest data share at MBARI.
- Are there responsible ways to reduce the 4K total video data volume while preserving the value of video data thereby lowering the resource and capital cost?

Next Steps

- Update requirements.
  - Add new and refine existing requirements.
  - Generate interface control document with DSP&L.
- Order camera and lens.
- Begin chassis design.
- Finalize telemetry and electrical system design.
- Order telemetry system components.

Summary

MC: need to formalize the connector issue and size of housing

MC: plan is to capture everything in 4k, 4k backup will always be kept, PI may decide to only keep some 4k.

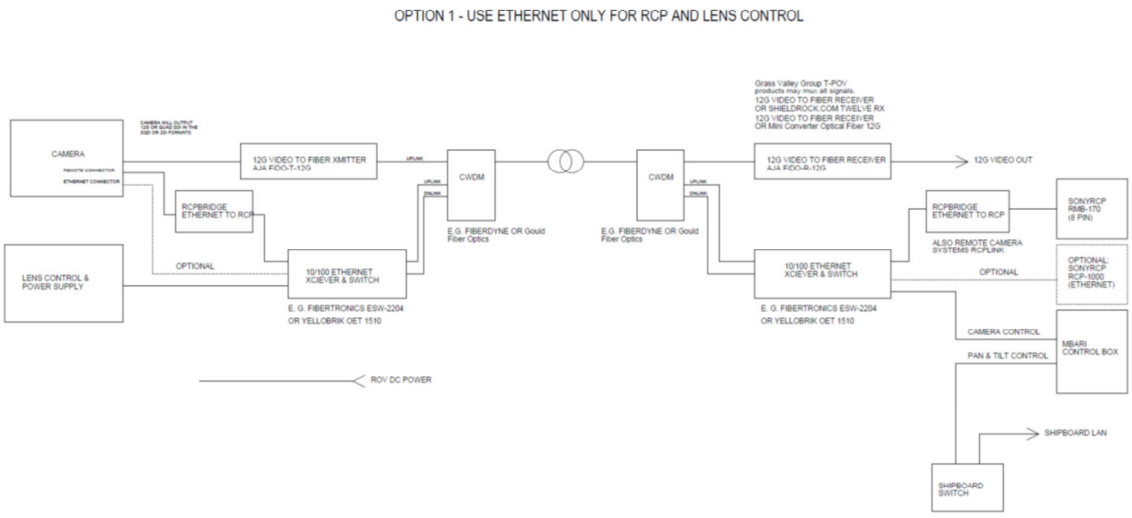
MC: 840 GB / hour / vehicle, Todd has converted our system to be able to handle it easily.

MC: data will be hand carried over from ship, storage problem is solved at mbari

JB: about EOY spending, don't buy unless you know it's the one.

END

Top to Bottom Alternative Architecture



Cost Models for Handling 4K Video Data from the MBARI ROV's

To examine possible strategies for reducing the cumulative data storage requirements for 4K video four different technical approaches and their respective cost models were examined:

- **Model A** – Keep all 4K video data at the Master (and Mezzanine) level.

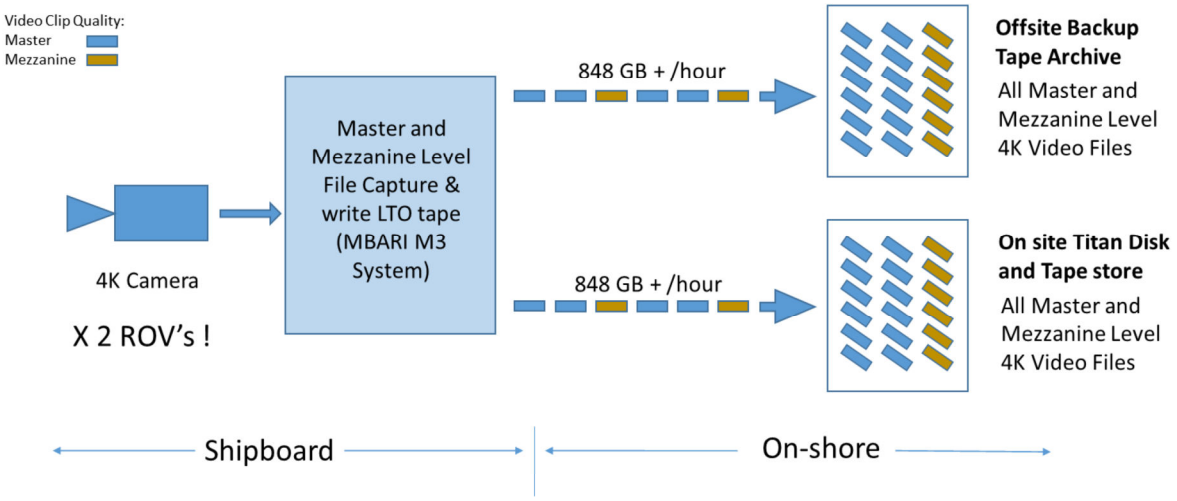
- **Model B** – During annotation flag 15 minute clips for keeping in 4K, otherwise transcode to LT level.
  - Requires extra labor and computing time ($).
  - LT Clips can still be edited.
  - All off-site backups are still 4K and could still be retrieved if necessary.

Four Different Cost Models for Handling 4K Video Data from the MBARI ROV's, continued..

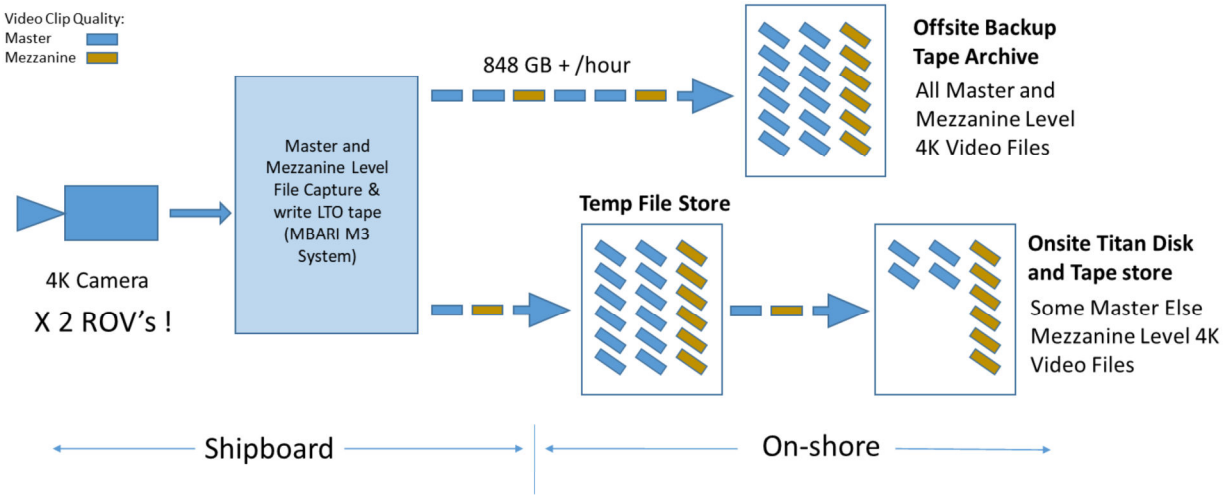
- **Model C** – While recording on the ships, select recording (Codec) format.
  - Master = Apple ProRes HQ (848 GB per hour) + Mezzanine.
  - LT level = Apple ProRes LT (394 GB per hour) + Mezzanine.
  - Once selection is made backups and on-line video will only be in the selected mode.

- **Model D** - During annotation flag 15 minute clips for keeping in 4K, otherwise discard 4K and only retain Mezzanine level.
  - Cost model assumes LTO tape can be re-used.
  - Mezzanine level difficult to edit/copy (inter-frame encoding optimized for streaming).
  - All off-site backups are still 4K and could still be retrieved if necessary.

Cost Model A – Keep all 4K Video at Master Level



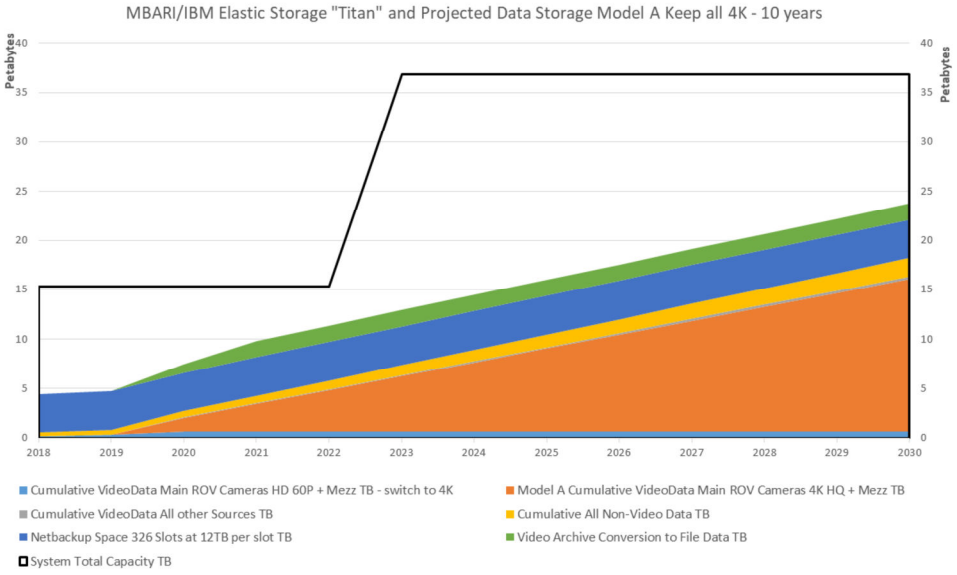
Cost Model D – Annotation Selects 4K Video at Master Level, All Else Mezzanine (H.265?) Only



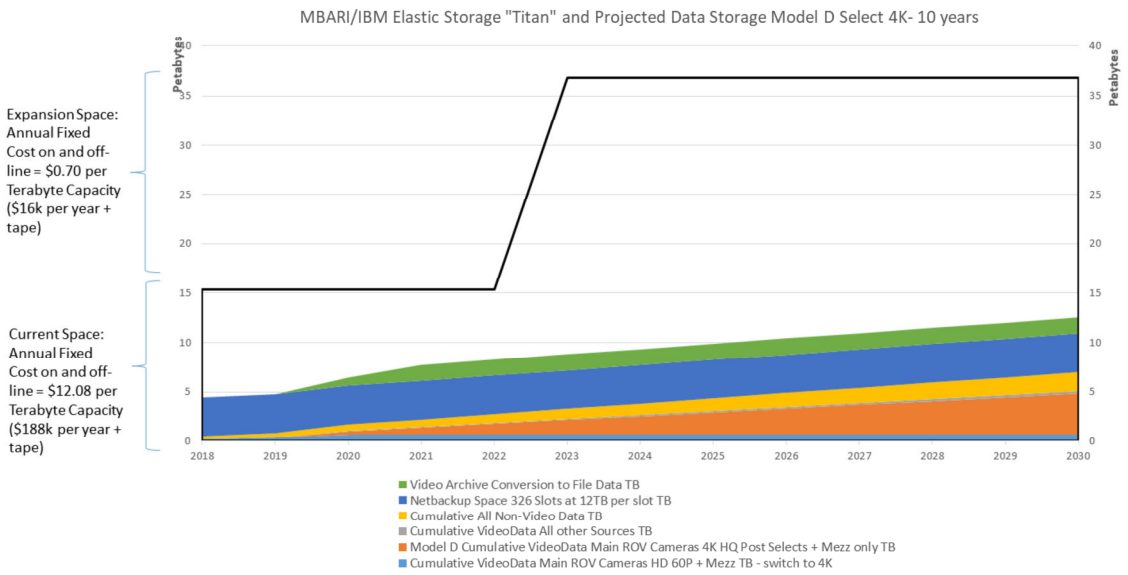
Annual Costs Model A: All Data + 4K ROV Cameras (4028 60p) + Converting Archive to Files

Expansion Space: Annual Fixed Cost on and off-line = $0.70 per Terabyte Capacity ($16k per year + tape)

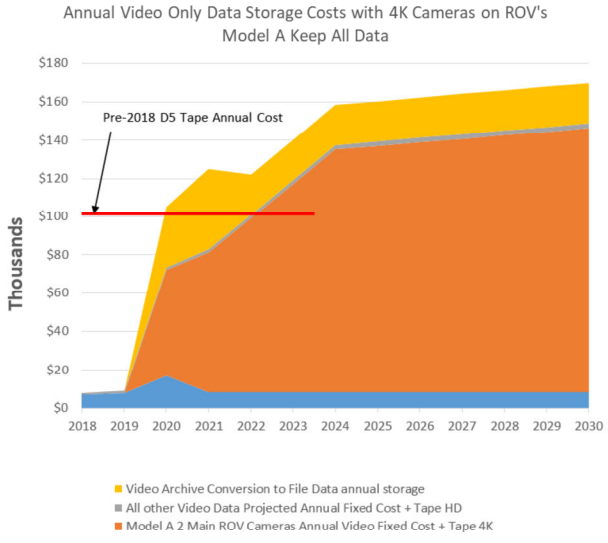
Current Space: Annual Fixed Cost on and off-line = $12.08 per Terabyte Capacity ($188k per year + tape)

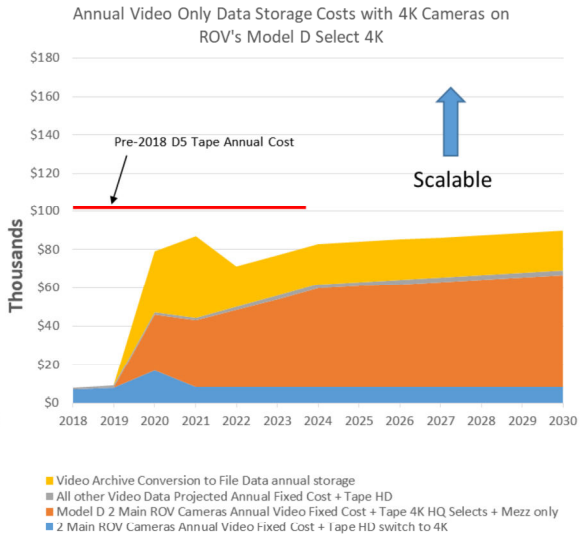


Model D Video Only Storage Volumes with 20% 4K Annotation Selects + Mezzanine

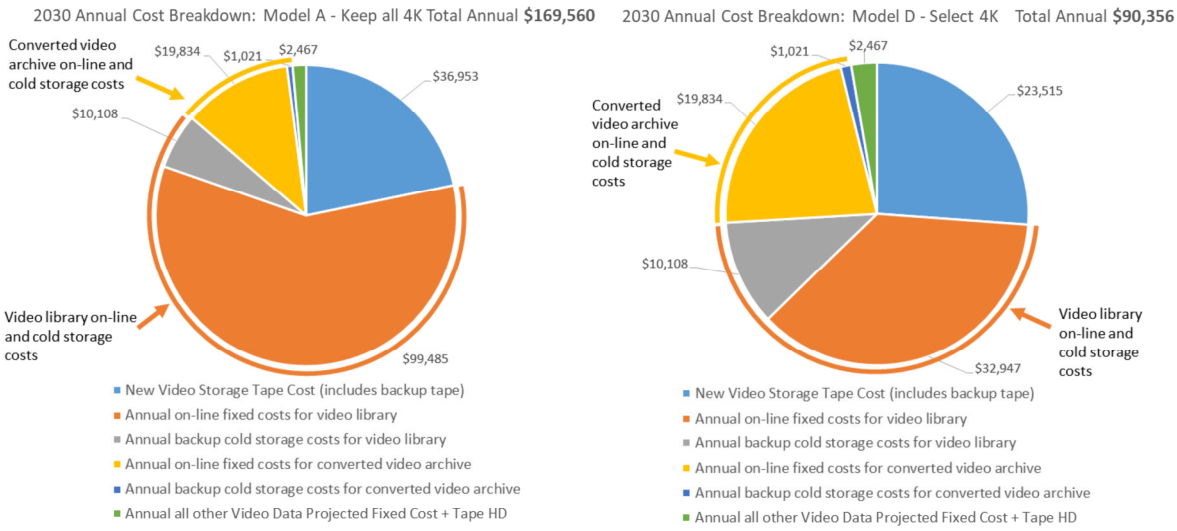


Model D - Video Only Storage Costs with 20% 4K Selects 80% Mezzanine vs. Model A – Keep All 4K Video





2030 Storage Costs **Model A**, keep all 4K **vs Model D**, 4K selects



Other camera projects