AUV Technology and Application Basics
Section 3

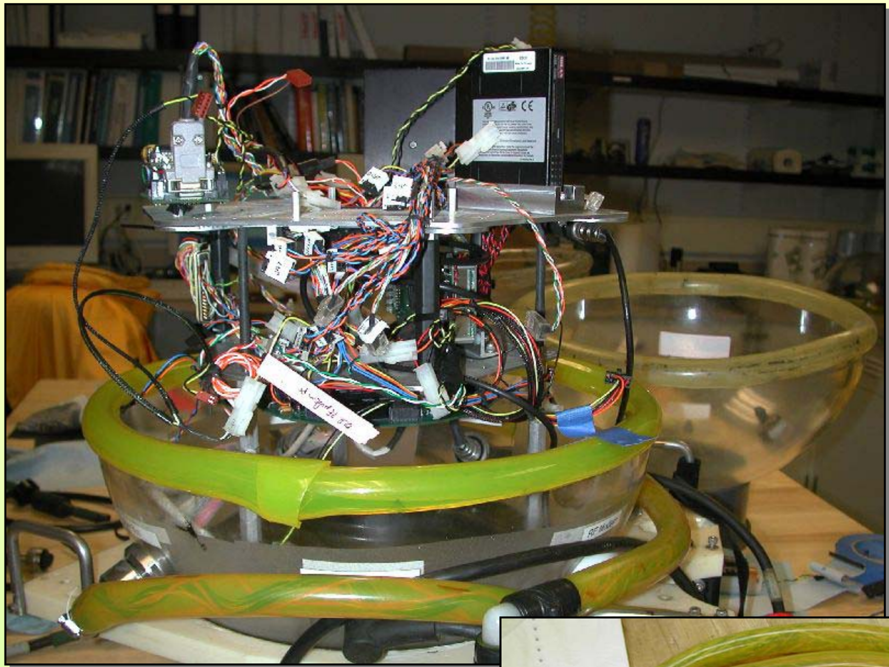
William Kirkwood, Mark Sibenac,
Hans Thomas, and Dr. James Bellingham

Monterey Bay Aquarium Research Institute
7700 Sandholdt Rd.
Moss Landing, Ca. 95039

www.mbari.org

Electrical Systems and Instrumentation

- Energy sources
- Electrical connectors
- Scientific instrumentation
  - Upper water column
  - Mid water column
  - Benthic
  - Special topic: hysterisis
- Common vehicle instrumentation
- Timing and synchronization of instrument data



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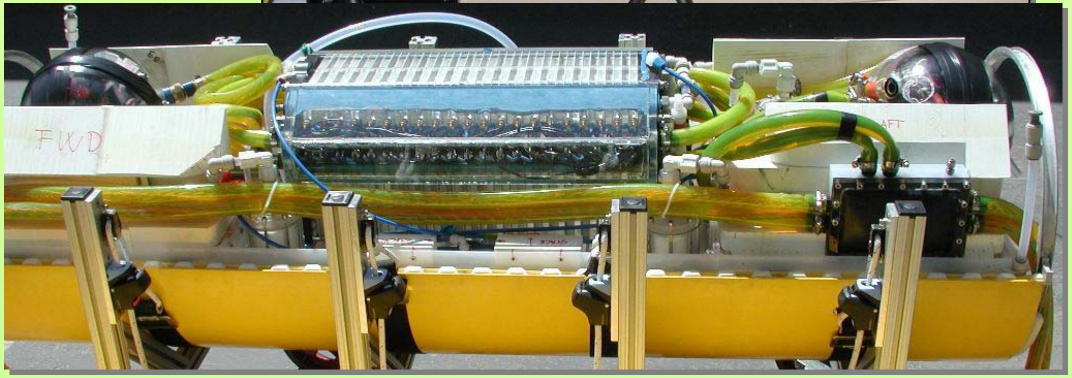
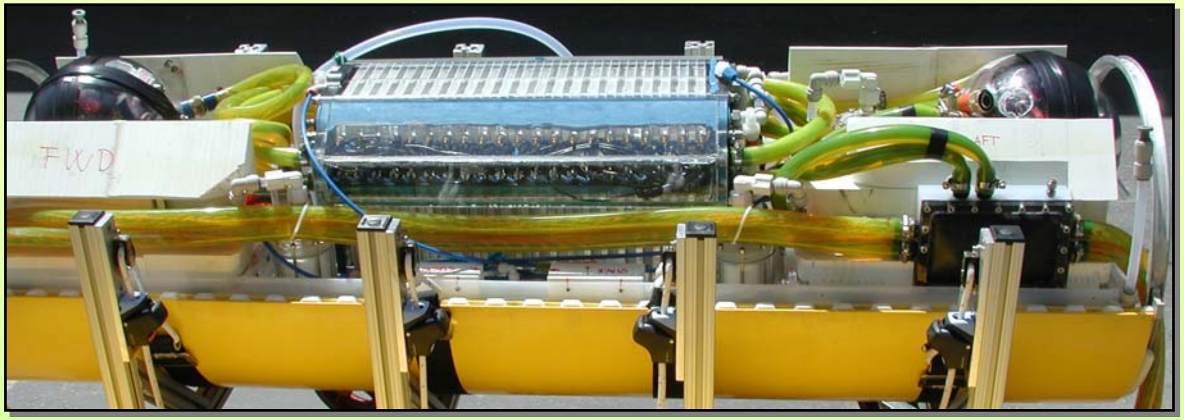
Energy Sources

- Lead-Acid
  - ABE
  - Remus
- Ni-Cd
  - Ocean Explorer
  - Odyssey
  - Hugin
- Ag-Zn
  - Odyssey
- Alkaline
  - Autosub
- Lithium Ion
  - Remus
  - ABE
  - Dorado and Bluefin AUVs
- Semi-fuel cell
  - Hugin
  - ALTEX AUV

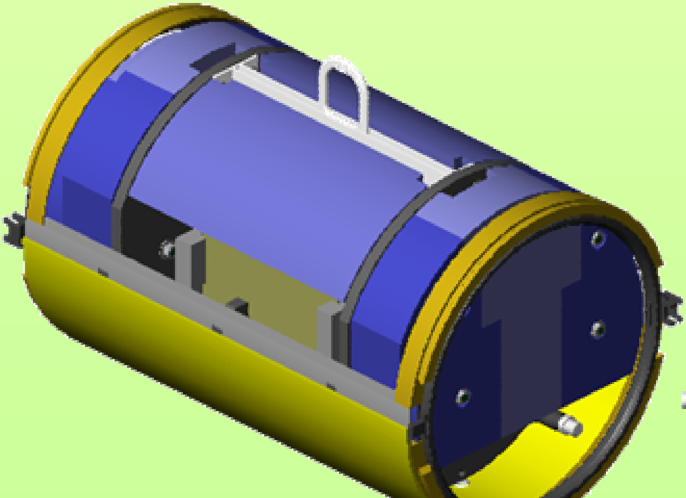


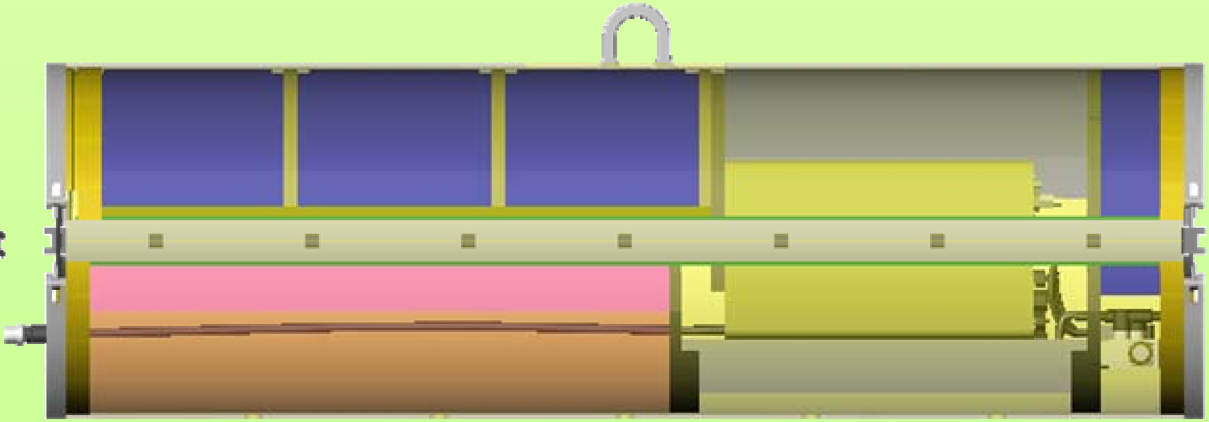
Energy Systems - Issues



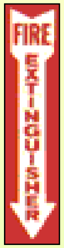
Issues

- Safety & Failures
- Energy Capacity
- Lifetime
- Cost
- Technician support
- Support equipment
- Shipping
- Storage





Energy Systems - Safety & Failure Modes



Failure Modes

- Open or short circuit
- Charge mode and discharge mode failure
  - Permanent cell damage

Safety

- Shipboard hazards
  - Fire during charge
  - Fire caused by a short circuit
  - No good way to put out a Lithium fire
  - Sensors should monitor each battery under charge
- AUV hazards
  - Fire on vehicle under deployment could mean 100% loss
  - Electronic circuits on each cell provide protection
  - Sensors monitor batteries when discharging
  - Fuses are used to protect batteries from anomalies found on DC bus

Energy Systems - Energy Capacity

<u>Energy Capacity</u>

- Specific energy is measured in Watt hours per kilogram (Whr/kg)

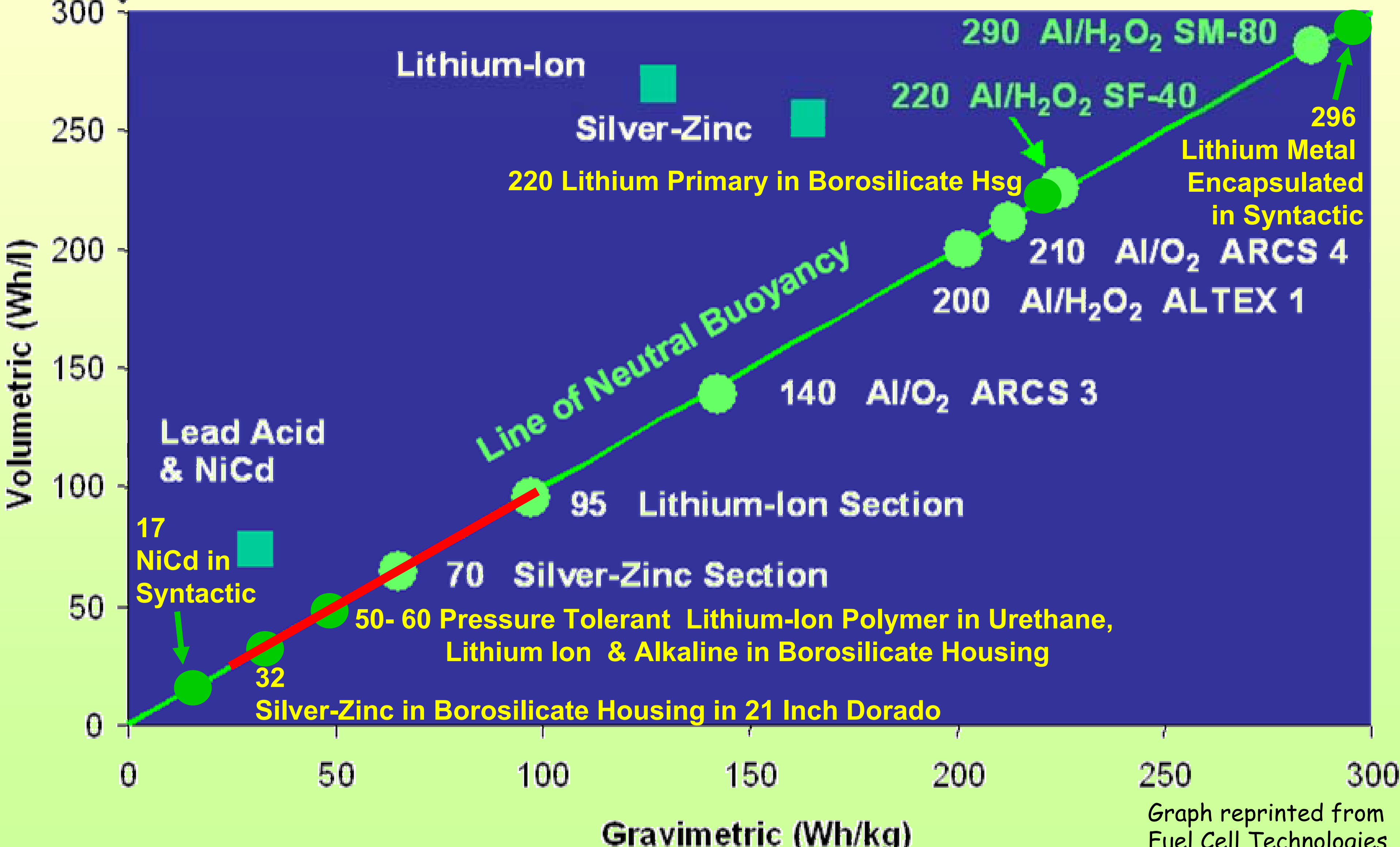
- Lithium primary cells are the most dense (530 Whr/kg)

- Lead-acid rechargeables are the least dense (70 Whr/kg)

- Importance is really with neutrally buoyant density (Whr/liter)
  - Dependent on packaging
  - Pressure tolerant batteries require large amounts of secondary buoyancy

- Semi-fuel cells show potential to be very efficient

Energy Systems - Specific Energy



Graph reprinted from Fuel Cell Technologies

Energy Systems - Lifetime

<u>Lifetime</u>

- Primary batteries – no recharge
  - Alkaline Manganese
  - Lithium

- Secondary batteries – multiple recharges
  - Silver-Zinc (~50 recharges)
  - Lead-acid (~200 recharges)
  - Lithium Ion (~1000 recharges)

- Fuel-cells – multiple cycles
  - Semi-fuel cells
    - Recharge with chemical liquids
    - Need to replace stack often

Energy Systems - Cost

Cost of energy source

- Need to consider operational scenario first
- Need to add in cost of support technicians, storage, transportation, etc.
- Need to add in costs during recharge time

Chemistry	Capacity (kWhr)	Average Cost/kWhr	Cycles	Cost/kWhr cycle	Initial Cost 3kWhr	Cost of 10x5yr cycles 3kWhr	Cost of 180x5yr cycles 3kWhr
Lithium Primary	1	$ 300	1	$ 300	$ 1,000	$ 45,000	$ 810,000
Alkaline Primary	0.018	$ 56	1	$ 56	$ 167	$ 8,333	$ 150,000
Lithium Ion	1	$ 10,000	1000	$ 10	$ 30,000	$ 30,000	$ 30,000
Silver Zinc	0.054	$ 3,704	50	$ 74	$ 11,111	$ 11,111	$ 200,000

Energy Systems - Technician Support

Technician Support

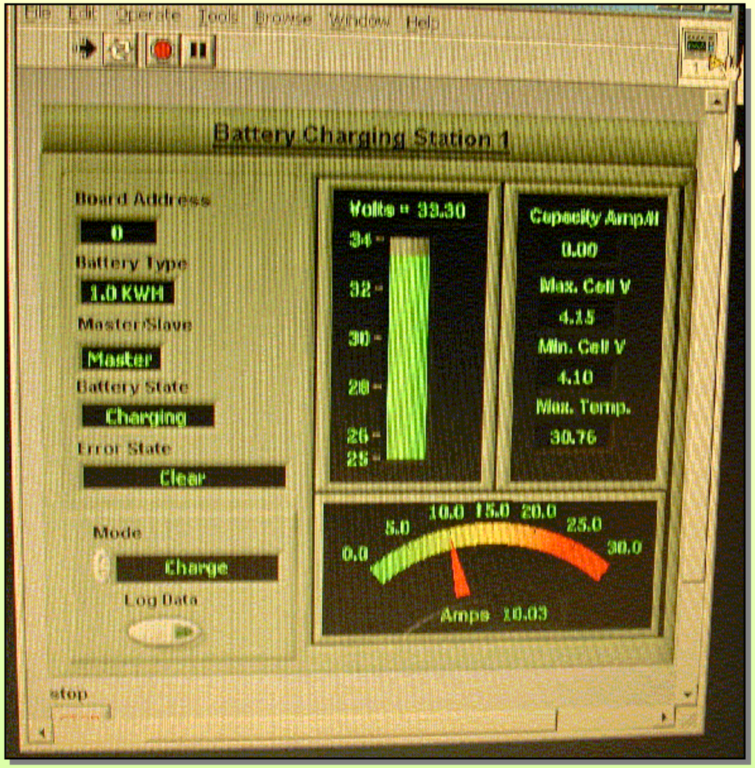
- Primary batteries must be completely replaced
- Silver Zinc batteries require cell monitoring at charge rates of C/25
  - Alkaline chemistries off-gas when charging
  - Need to open pressure housings
- Lithium Ion batteries require lots of monitoring at charge rates of C/4
  - Li-Ion Batteries do not off-gas unless they overcharge
  - Do not need to open the vehicle

- Fuel cells require training in hazmats
  - A spill of 50% H_2O_2 or KOH is hazardous
  - Stack replacement can take hours
  - Solids management is still being worked out

Energy Systems - Support Equipment

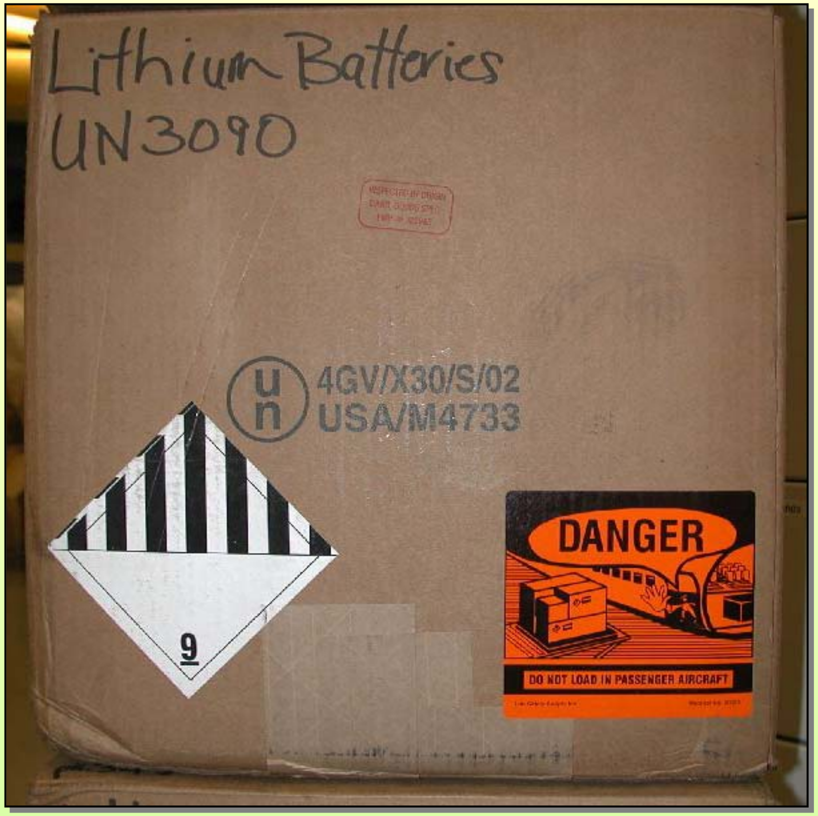
<u>Support Equipment</u>

- Battery storage for primary cells
  - Alkaline batteries are big and heavy
- Chargers and outlets with high capacities
  - Typical charge rates of C/4 need 2000 W
- Charge controllers
  - Built into battery or charger
  - Separate application on a PC (Labview, text-based, GUI)



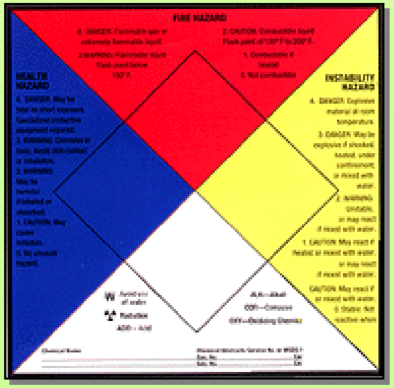
- Chemical containers
  - 25 gallon containers for fuel cell reactants
  - Oil for PBOF (pressure balance oil filled) systems

Energy Systems - Shipping



Shipping

- Primary Alkalines can be massive
- CFR 1068 Part 3
  - Regulates shipments of Lithium in air
  - Over 25g of Lithium is considered hazmat in air
  - Gram equivalent of Lithium is 0.3 x AmpHr rating
  - Up to 2kWhr Lithium ion battery can be airshipped
- Chemicals for fuel cells are considered hazmat



Energy Systems - Storage

<u>Storage</u>

- Rechargeable batteries must be monitored regularly
  - Most batteries are damaged when voltage drops below a certain potential

- Charging/monitoring stations should be nearby batteries in storage

- Batteries will self-discharge
  - Freezing some batteries reduces self-discharge

Energy Systems - Example

- Example: optimum speed (for energy)
  - Horizontal distance is 120km
  - Yo-yo profile at 30° dive and ascent angles
  - AUV calculated distance = 120km / cos(30°) = 140km
  - Hotel power = Σ Instrument power + Σ Control electronics
  - Propulsion power = k * Speed^3
  - Time = Distance / Speed
  - Energy = (Hotel power + Propulsion power) * Time
  - Optimum energy usage when hotel power is 2 x propulsion power

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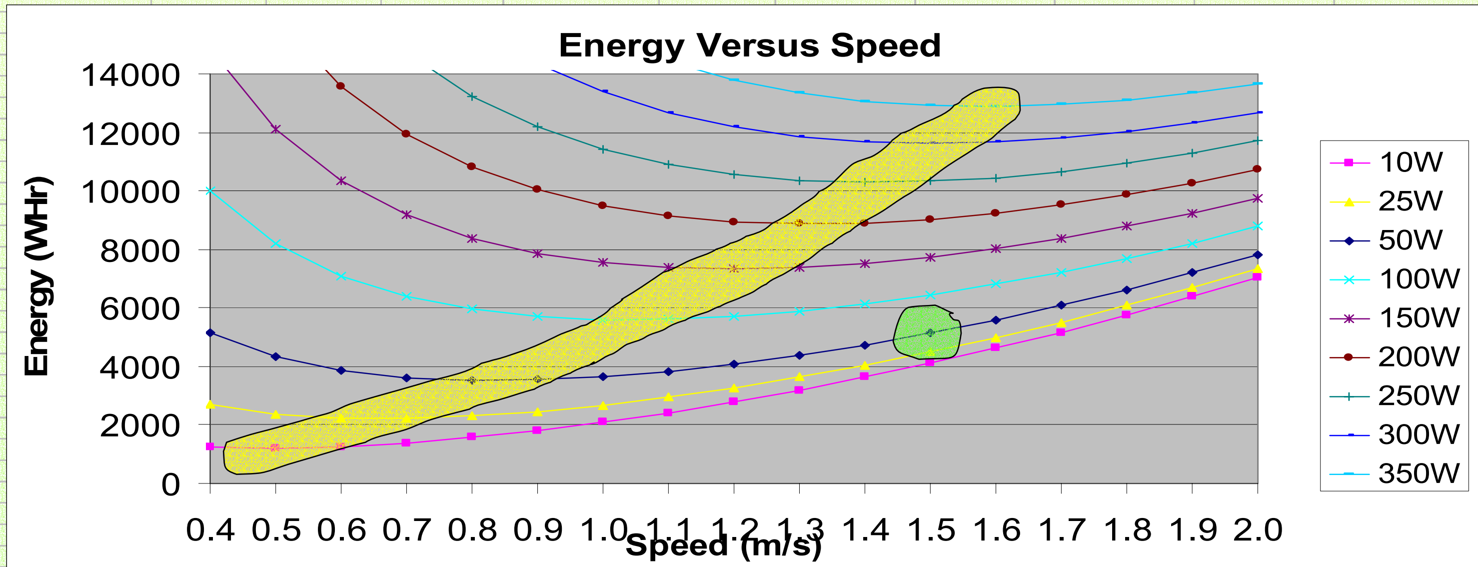
Energy Calculation

Hotel Load	10	25	50	100	150	200	250	300	350	Propulsion
Speed(m/s)										
0.4	1246	2704	5135	9996	14857	19718	24579	29440	34302	3
0.5	1206	2372	4317	8206	12094	15983	19872	23761	27650	6
0.6	1264	2236	3857	7097	10338	13579	16820	20060	23301	10
0.7	1394	2227	3616	6394	9172	11950	14727	17505	20283	15
0.8	1581	2310	3526	5956	8387	10817	13248	15678	18109	23
0.9	1818	2466	3546	5707	7867	10028	12188	14349	16509	32
1.0	2100	2683	3656	5600	7544	9489	11433	13378	15322	44
1.1	2424	2954	3838	5606	7373	9141	10909	12677	14444	59
1.2	2788	3274	4084	5705	7325	8945	10566	12186	13807	76
1.3	3191	3640	4388	5883	7379	8875	10370	11866	13362	97
1.4	3632	4048	4743	6132	7520	8909	10298	11687	13076	121
1.5	4109	4498	5146	6443	7739	9035	10331	11628	12924	149
1.6	4624	4988	5596	6811	8026	9242	10457	11672	12887	180
1.7	5174	5517	6089	7233	8376	9520	10664	11808	12952	216
1.8	5760	6084	6624	7704	8785	9865	10945	12025	13106	257
1.9	6382	6689	7201	8224	9247	10271	11294	12317	13341	302
2.0	7039	7331	7817	8789	9761	10733	11706	12678	13650	352
K			44							
Distance			140000							



Electrical Connectors - Issues

<u>Issues</u>

- Importance
  - Nivek's Law: 90% of the problems in any complex system are connections.
  - Poor connector choices result in more down-time and more technician time
- PBOF (pressure balance oil filled) versus potted
- Junction boxes
- Modularity and Isolation

Electrical Connectors - PBOF v. Potted

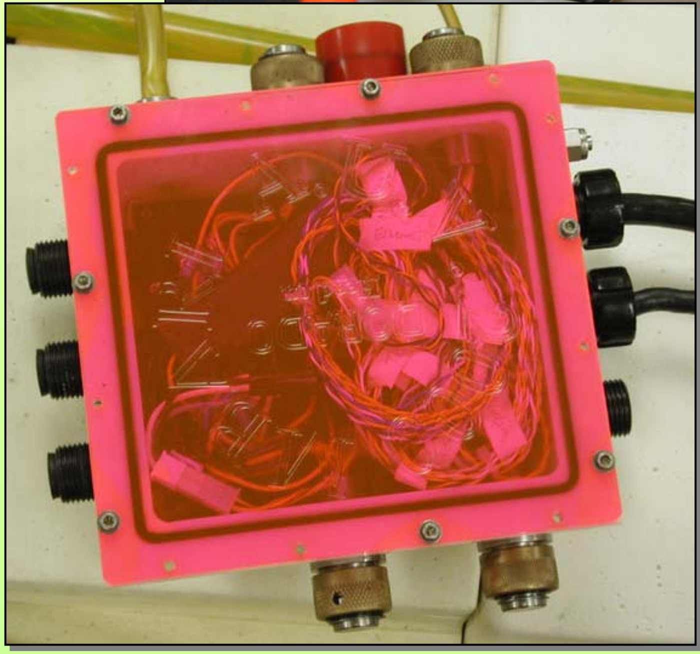
PBOF

- Allows access to wires to lengthen or re-terminate
- Needs to only hold back less than 10 psi of pressure difference
- Easy to fix cabling in the field
- Able to accommodate custom wiring quickly
- Allows the transport of compensation oil to other sections
- Extremely messy

Epoxy potted

- Best choice for production system with polyurethane jacketed cable
- Connectors usually need special tooling for the molds
- Potting compounds can be hard to acquire
- Potting compound takes time to set up and harden - bad for field work
- Process can be done at the factory

Electrical Connectors - Junction Boxes



<u>Junction Boxes</u>

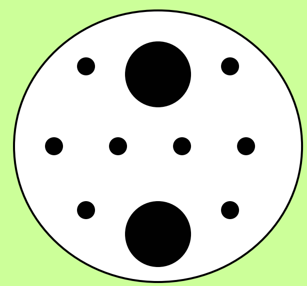
- Oil filled
  - Provide for changes in the future
  - Changes can be made quickly in the field
  - Sealing surfaces are prone to problems
  - Messy because of oil weepage and draining

- Epoxy potted
  - High reliability
  - Sealed against water intrusion
  - Impossible to service the box

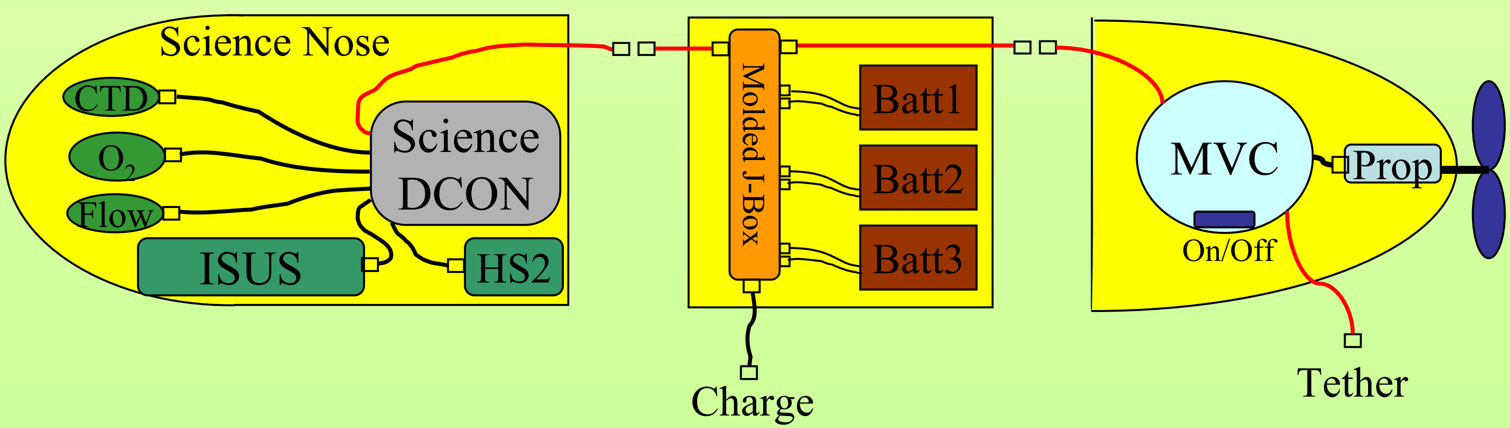
Electrical Connectors - Modularity and Isolation

Modularity and isolation

- One cable provides power and comms
- Standard circular connector for bus
- Comms are CANbus and Ethernet
- Galvanic isolation



- 2 pins power
- 4 pins ethernet
- 2 pins CANbus
- 1 pin shields
- 1 pin enable



Instrumentation - Introduction

- Upper and mid water instrumentation
- Benthic instrumentation
- Hysterisis in measurements
- Common vehicle instruments
- Timing and synchronization of instrument data

Instrumentation Types - Upper and Mid Water

Upper and mid water columns

- CTD (Conductivity, Temperature, Depth)
- ADCP (Acoustic Doppler Current Profiler)
- LISST - particle size analyzer
- Flourometer
- ISUS (In-Situ Ultraviolet Spectrometer)
- Optical backscatter
- Bathyphotometer
- pH and O_2

Bathyphotometer

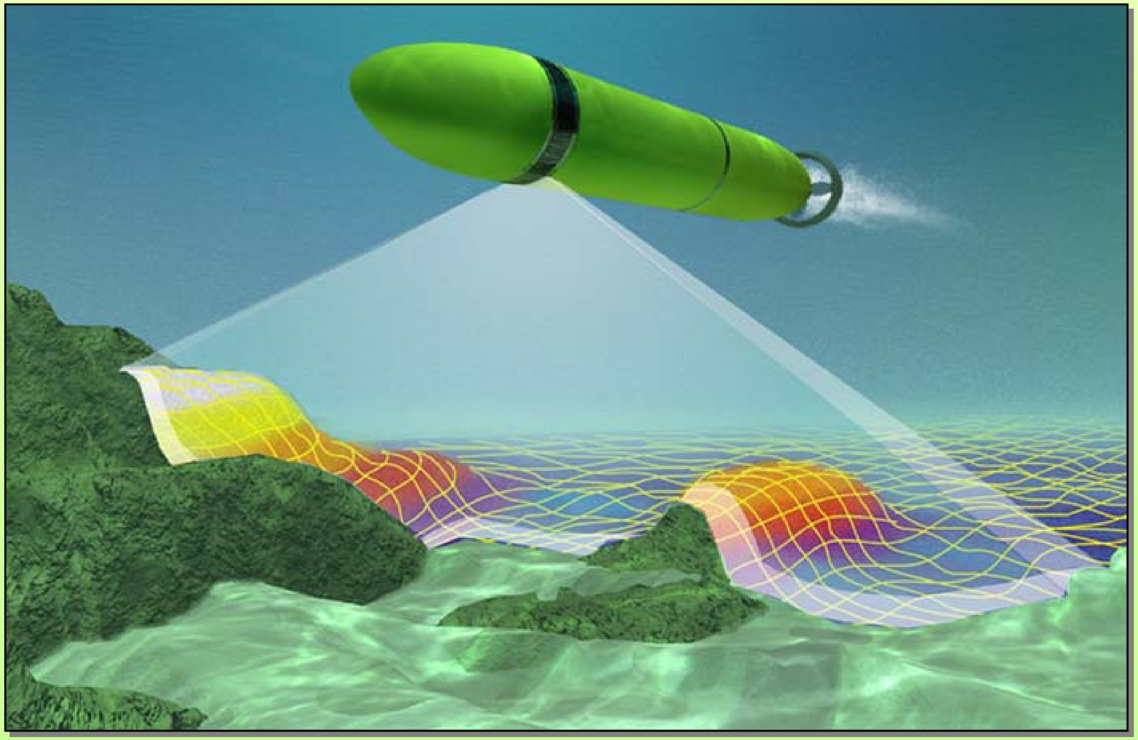
ADCP

CTD

Instrumentation Types - Benthic

<u>Benthic and mapping</u>

- Multibeam sonar
- Chirp sub-bottom profiler
- Side-scan sonar
- Digital camera
- Chemical sensors: pH, O_2, CO_2, methane, sulfide, nitrate, etc.



Multibeam Sonar Example

- Left – hull mounted sonar
- Right – towfish with corrected navigation
- Location – Loihi Seamount near Hawaii
- AUVs can collect much higher resolution data

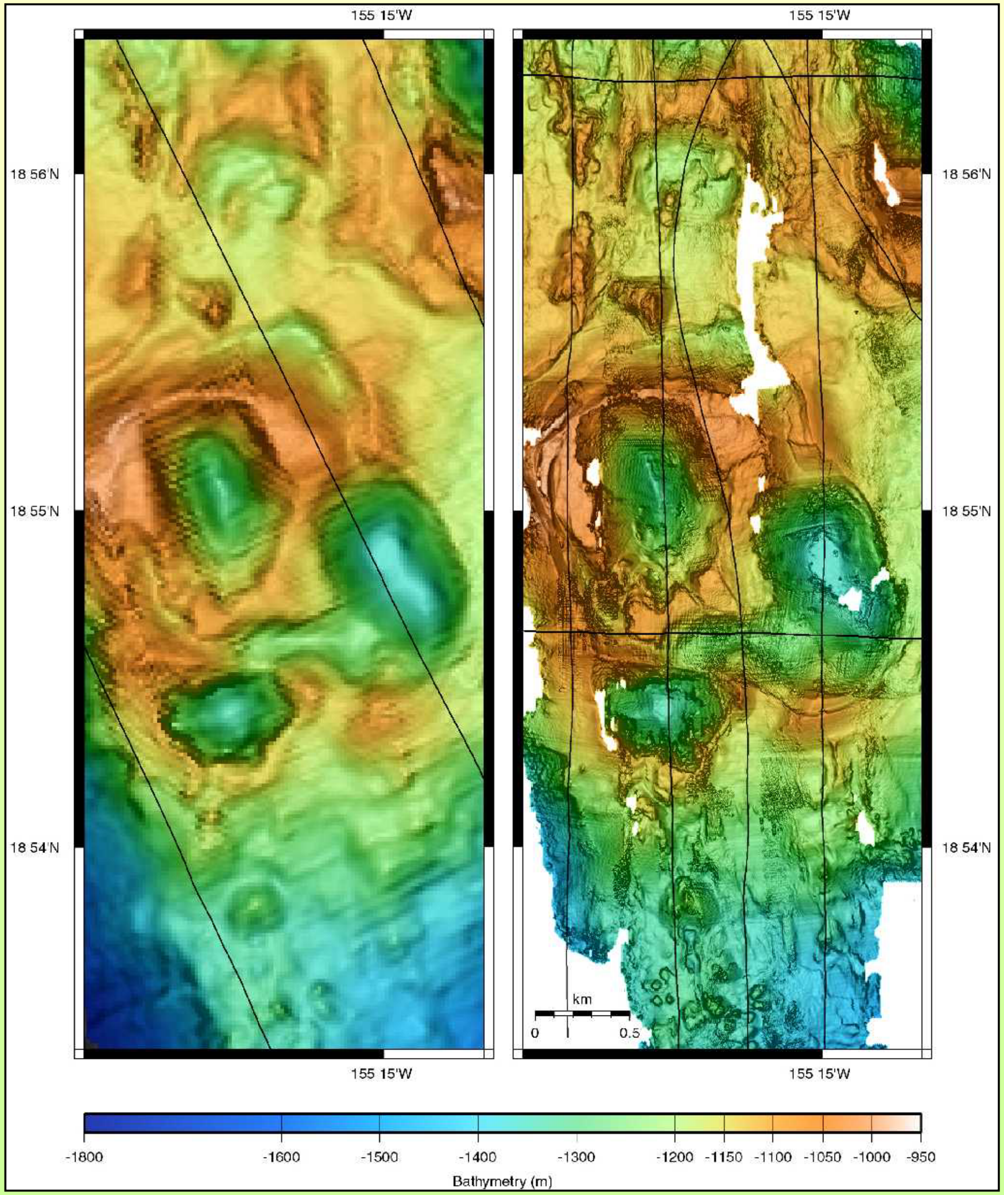
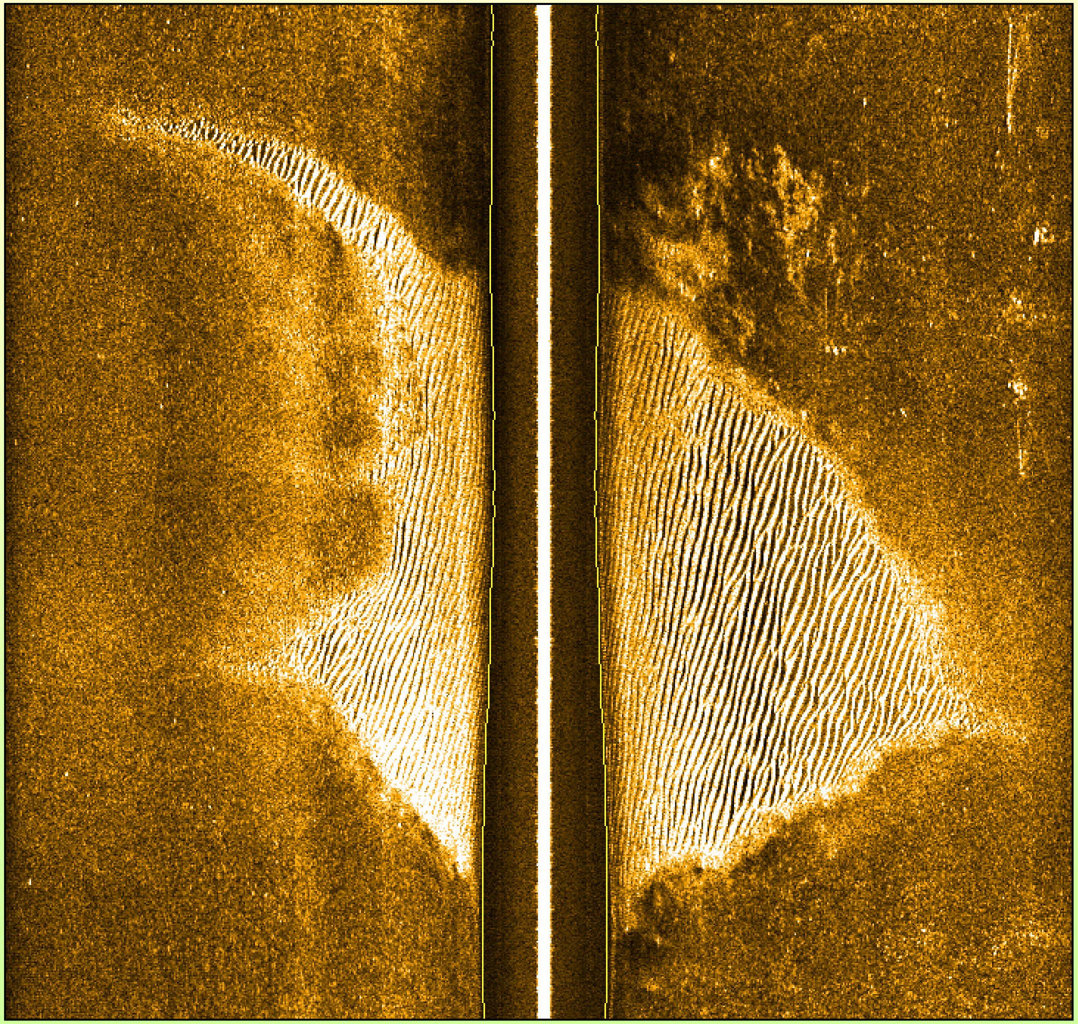


Image courtesy David Caress

Side-Scan Sonar Data Example



The sonar is in high-resolution mode
Data was taken in March 2001 offshore San Diego
Resolution is 3 by 4 inch   Range is 50 meters per side.

Data courtesy:

Bluefin

Instrumentation - Hysterisis

- *Special topic -* Hysterisis caused by lags in pumped water systems

Common Vehicle Instrumentation

- Pressure sensors
  - Errors
  - Atmospheric corrections
  - Temperature
  - Temperature rate of change
- Sound velocity
  - Conductivity temperature depth (CTD)

Seabird Instruments

Parosci DigiQuartz Pressure Sensor

Common Vehicle Instrumentation

- Navigation instrumentation
  - GPS
  - Dopper Velocity Logger (DVL)
  - Attitude Heading Reference System (AHRS)
  - Altimeter / obstacle avoidance sonar
  - Ultra short baseline (USBL)

Datasonics Altimeter

Crossbow AHRS

ORE Multibeacon

RDI DVL

Bluefin GPS Antenna

Common Vehicle Instrumentation

- Communications
  - Acoustic
  - RF

Bluefin RF Antenna

Benthos Acoustic Modem

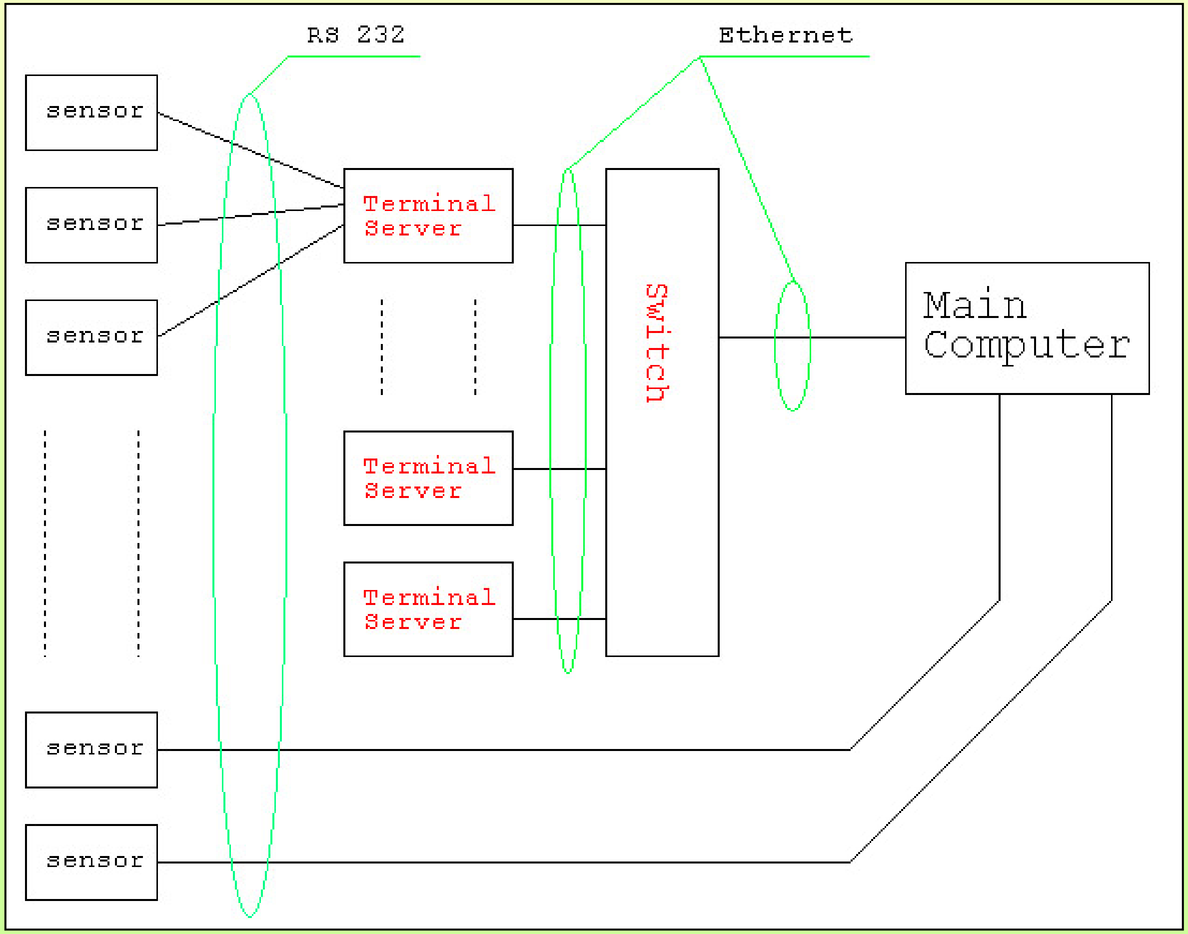
Timing and Synchronization - Issues

<u>Issues</u>

- Importance
- Buffering
- Sensors
  - Directly connected to main computer
  - Connected through multiplexors
- Example of how timing affects data processing
- Timing strategies

Timing and Synchronization - Buffering

- How does buffering affect the spatial precision?
  - Serial data buffering
  - Operating system buffers and priorities

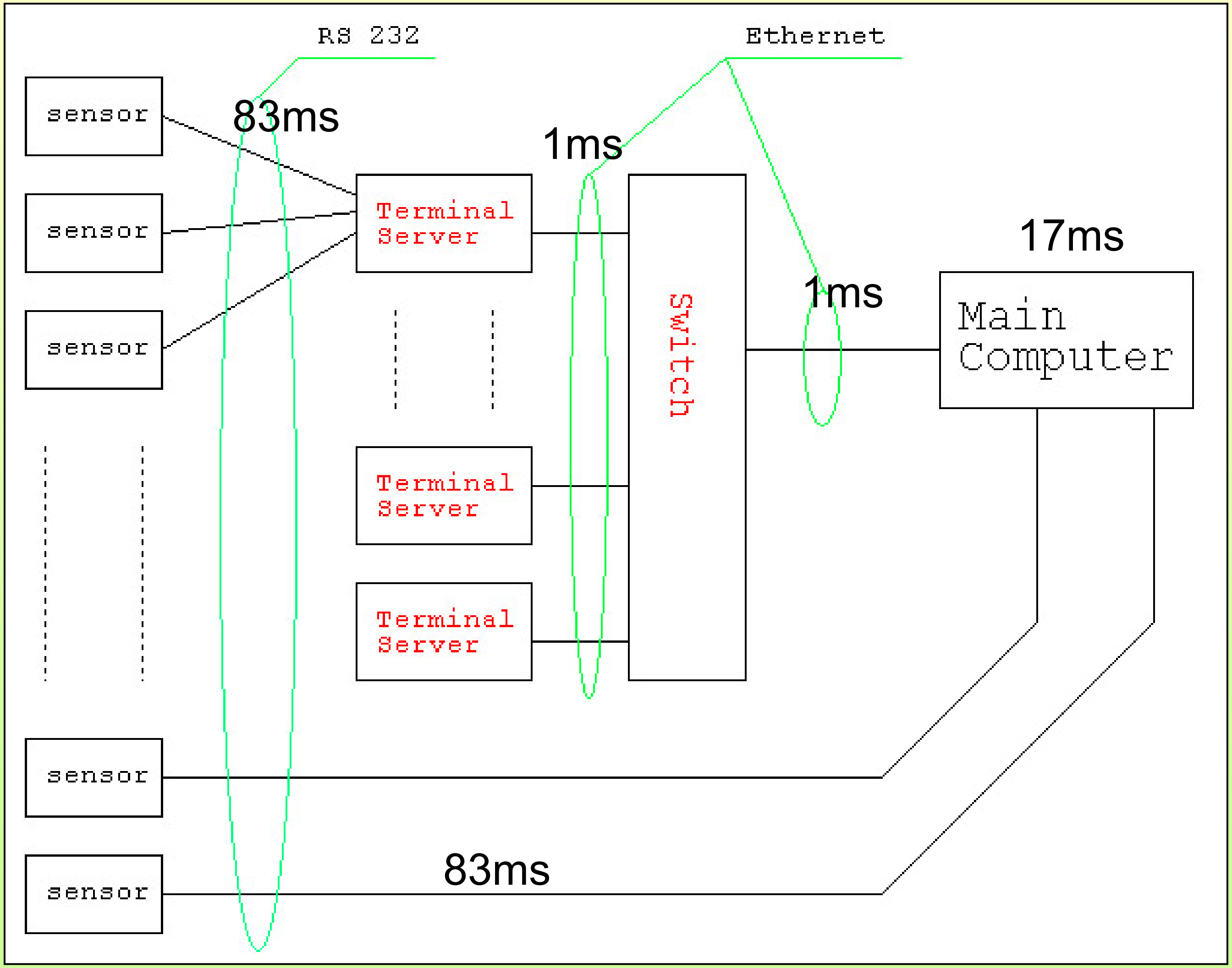


Timing and Synchronization - Example

- When and where were the measurements taken?
  - Example – Thin structure profiliing
    - Vertical speed = 1.0 m/sec
    - CTD data packet of 40 bytes at 4800 bps (83ms of data transmission)
    - Vehicle travels 8.3cm vertically during data packet transfer from instrument to RS-232 serial input device

Timing and Synchronization - Delays

- Worst case delay = 83 + 1 + 1 + 17 = 100ms (10cm vertical)



Timing and Synchronization - Solutions

- How to synchronize the data samples to the main clock
  - Poll the instruments at a known time
  - Locate precision clocks at each instrument
  - Use a multi-drop bus with broadcast synchronization messages; i.e. CANbus

Questions?