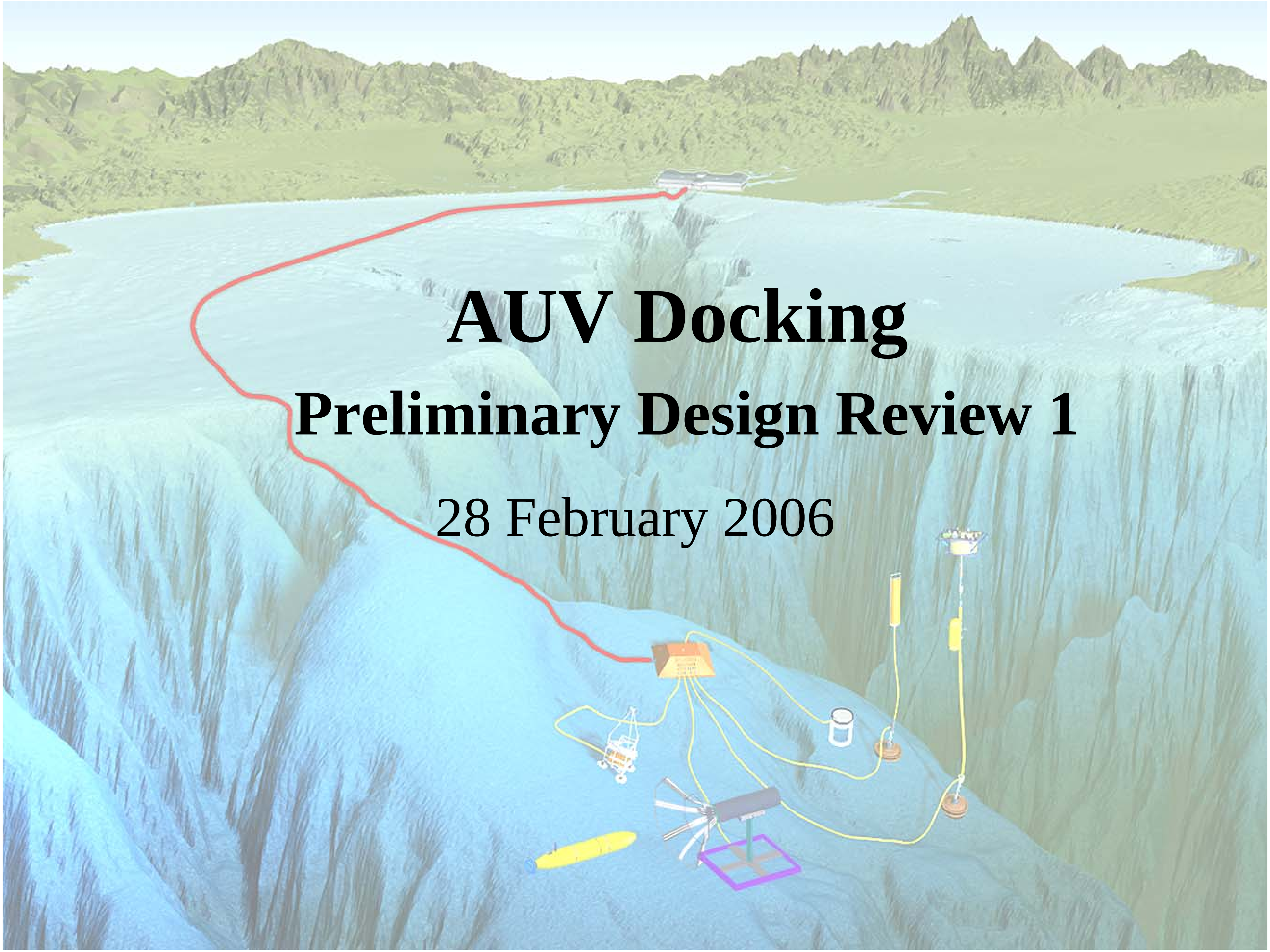


# AUV Docking

## Preliminary Design Review 1

28 February 2006

# AUV Docking Team (2006)

- PI: Jim Bellingham
- PM: Brett Hobson
- ME: Jon Erickson, Farley Shane
- Controls E: Rob McEwen
- EE: Lance McBride, Thomas Hoover
- AUV E: Hans Thomas
- External Advisor: Steve Rock (Stanford)

# What are we doing today?

- Update on overall strategy
- Reviewing proof-of-concept design
  - Presentation
  - Request for Action sheets
  - Detailed exchange off-line

# Project Goals

- To make our AUVs part of Seafloor Observatory systems.
  - Use to provide event response capability.
  - Use to reduce the cost of time-series operations by avoiding ship costs and schedules.
  - Use to provide survey presence in otherwise unobservable regions.

# Background

- Cabled observatory movement growing
  - Observatories installed or funded include LEO-15, MVCO, MARS, Antarctic, Aloha, VENUS, NEPTUNE Canada, NEMO-SN1, and more on the way…
  - NEPTUNE, ESONET, and Japanese initiatives…
- Docking competition real
  - Shallow water dock under development for Navy SEAL delivery vehicle, with plans for use in MVCO.

# Strategy

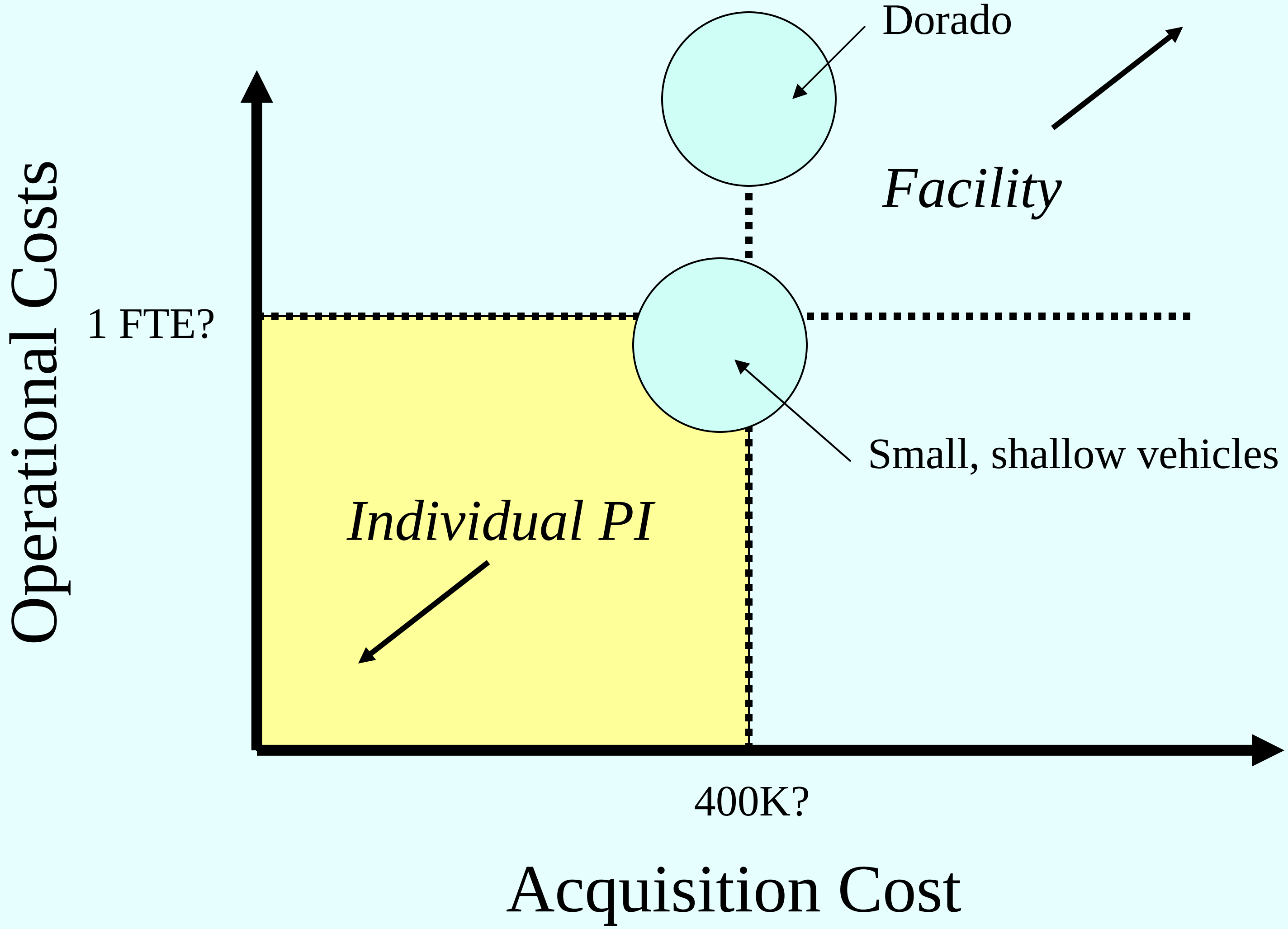
- Build on successful elements of prior docking efforts.
- Buy don't build, when possible.
- Work with existing AUV.
- Demonstrate capability early.
- With experience will likely come a refined understanding of what a docking AUV & dock need to do.
- Have system adopted by larger community.

# Where are we?

- Project renewed this year – two months into three year effort.
- Year 1:  demonstrate docking in shallow water (use MISO)
- Year 2:  put docking capability on MARS.
- Year 3:  put docking on MOOS.

After year 2, it should be possible to take a docking system to other cabled observatories.

# Cost Factors



# Tech Transfer

- Demonstrate a operational docking capability.
- Keep dock simple and cheap.
  - Low buy-in cost (<< AUV)
  - Get dock installed early and often.
- Build consortium with science operators of Dorado vehicles.
- Work with cabled observatory installers to ensure compatibility.
- Represent docking capability to ORION community.
- Offload docking system to some other entity (Commercial? Observatory facility operator?)
- Generate some positive publicity.

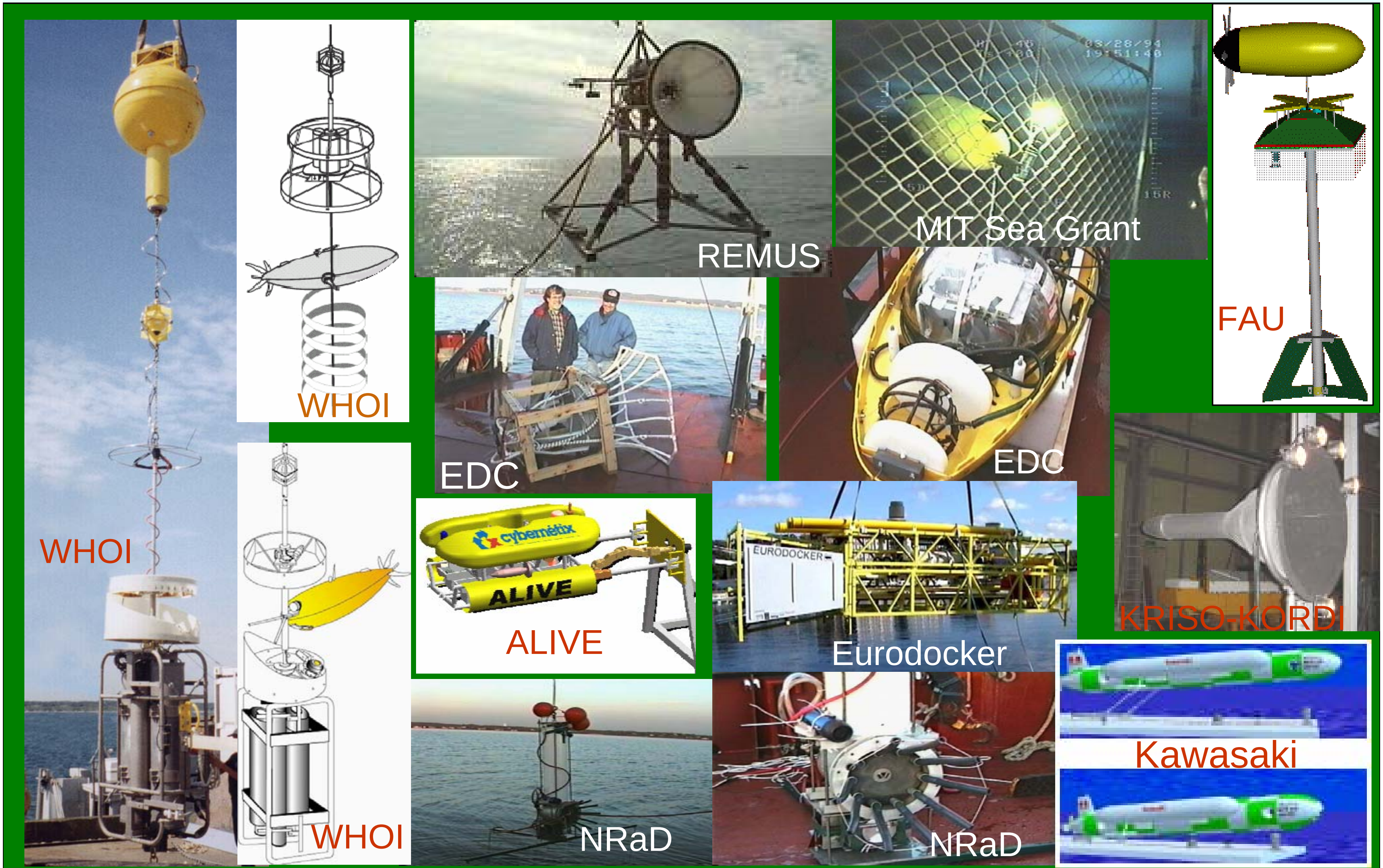
# Proof of Concept PDR-1

- Present overall design
- Review what options were considered
- Look at proposed design in detail
- Address PDR Issues
- Describe Test and Deployment Plan
- Questions

# Progress to date

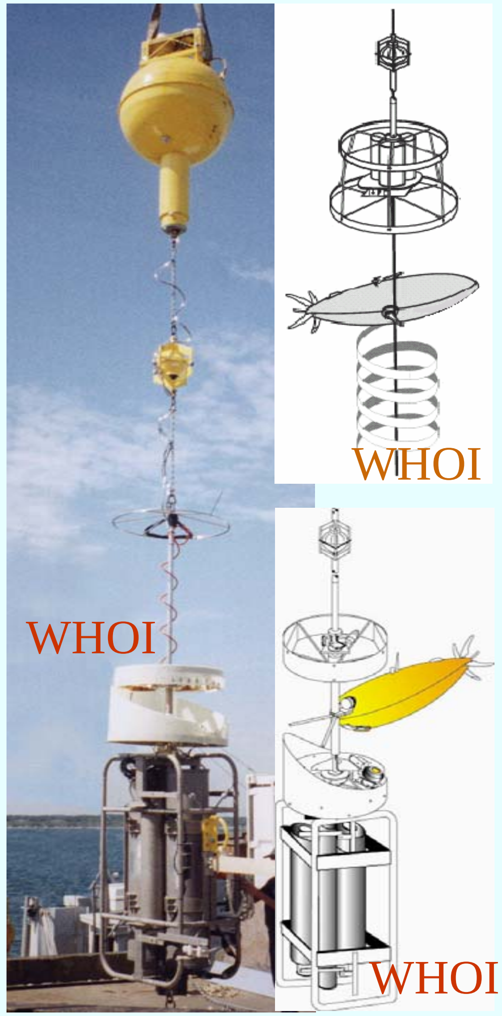
- Surveyed previous AUV Docking Concept demonstrations to extract what worked and what didn't
- Analyzed candidate missions and the economics of docking
- Looked at the technology options for the key components:
  - Dock Design
  - Homing System
  - Power and Data Transfer Systems
  - Homing and docking control software
- Constructed a dedicated Docking AUV, using existing components, and performed acoustic homing tests with a COTS USBL (demo unit)
  - We demonstrated homing from 2 km to within 30 cm of a Homer transponder
- Designed a proof of concept docking system for experiments in shallow water

# Previous Dock Concepts



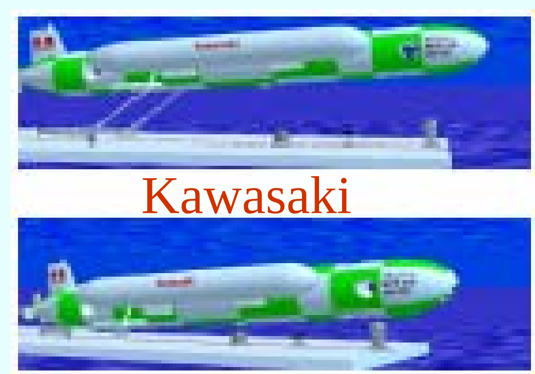
# Dock Concepts Summary

- Pole dock

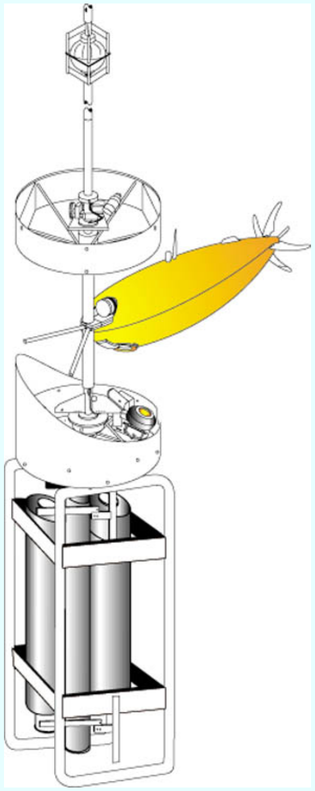


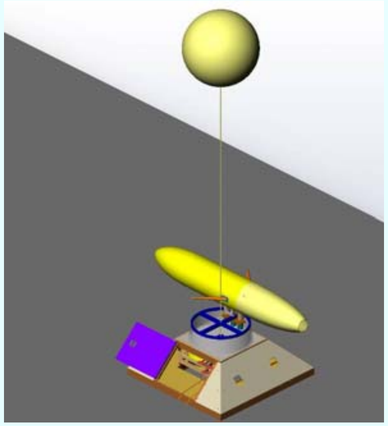

- Cone dock


- Tail hook



# Dock Concepts: Pole Dock





Advantages:

- Vehicle can approach from any direction (lands into the “wind”).
- Large allowable variation in depth control.

Disadvantages:

- Vehicle must be equipped to capture the pole
- Difficult to make power/data connection since vehicle is not rigidly attached.

# Dock Concepts : Fixed Cone

REMUS

KRISO/KORDI

Advantages:

- Vehicle can be captured and parked securely.
- Power and data connection easier.
- Dock can be simple.
  - No moving parts.

Disadvantages:

- Vehicle must fly a precision near-bottom approach.
- Vehicle may have to approach in a "cross wind."
  - Control loop must crab the vehicle.

# Dock Concepts: Weathervane Cone

Florida Atlantic University (FAU)

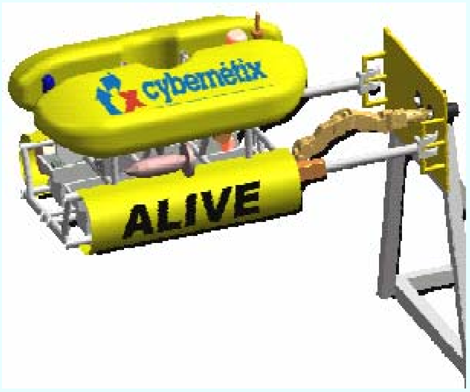
Advantages: Same as fixed cone plus

- Vehicle approaches upwind.

Disadvantages:

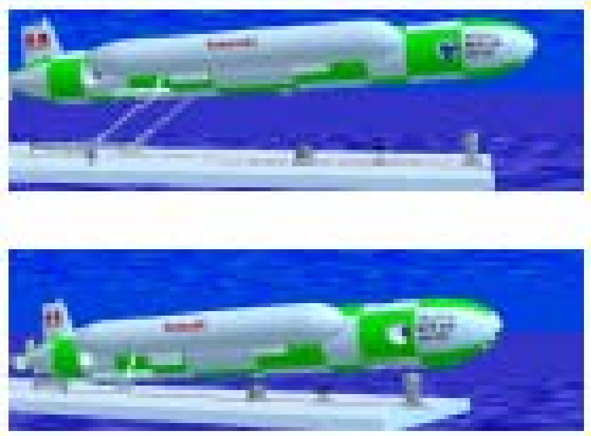
- Dock is more complex.
  - Dock must communicate its heading to the vehicle.
  - Power and data must pass through a slip-ring type and a rotary brake must be engaged during docking.

# Other Designs



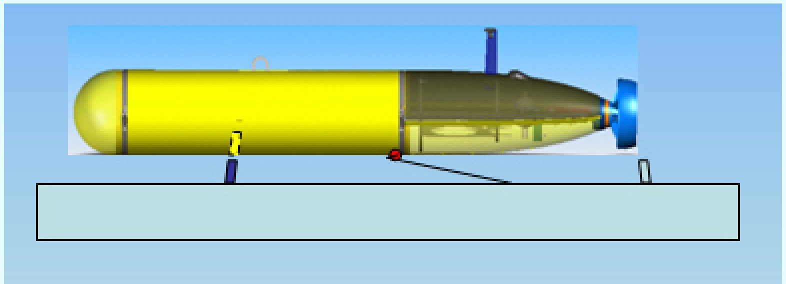

ALIVE Dock

- Hovering flight required.



Kawasaki Docking System

- Precise low-altitude flight
- Power and data transfer challenging



# Key Dock Design Trade-Off

To maximize the reliability of the Docking System:

Put the complexity on the vehicle, not the dock

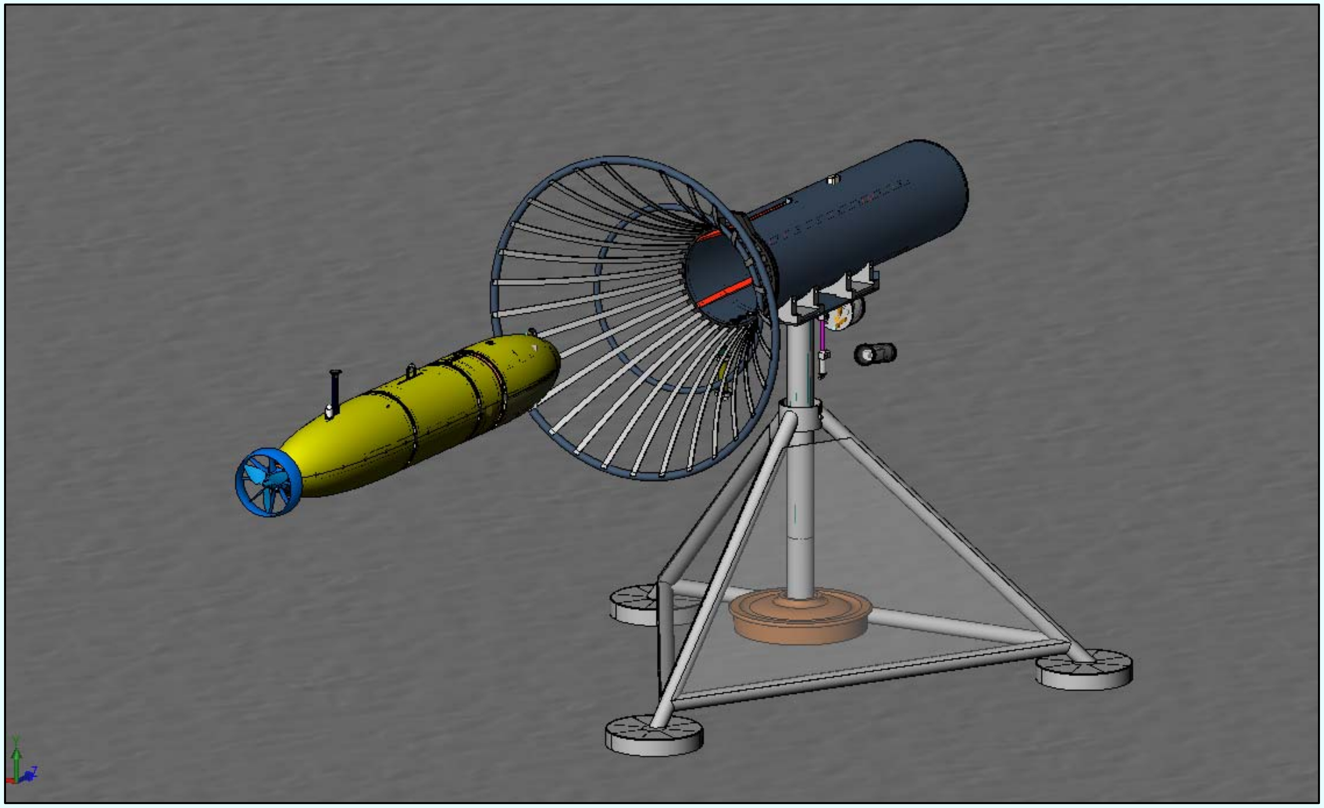
AUV is relatively easy to maintain/repair

The cost is that the AUV cost, complexity, weight and power consumption all go up

Try to use the simplest Dock design – fixed cone

And address disadvantage, e.g. cross currents with vehicle control: “crab and flair”

# Proof-of-Concept AUV Dock Design



- Dorado add-on docking module
- Fixed benthic cone dock with an actuated retention pin, inductive charge system and high speed wireless data transfer

# Homing Systems

locate and guide the AUV precisely to the dock - GPS-DR and a DVL

- Acoustic
  - Long range (+1km) ~2 deg accy., COTS avail.
    - USBL: LinkQuest, Sonardyne, Sonatech
    - Acoustic Vector Sensor
      - Very small, inexpensive, but significant dev. required
    - 2 Beacon LBL, USBL on dock with modem
- Electro-Magnetic: Heavy, short range ~30m
- Optical: short range, high update, water clarity/bio-fouling issues

# Sonardyne I-USBL

- COTS
- 4000m depth rated
- 1 Hz update, 2 km range, 0.2 degree accuracy
- Uses standard Homer transponders
- 32 lbs in air, 12 lbs in water
- 6.37” dia., 23” long

# Power Transfer

450 W for 11 hours, 400 or 48 VDC

- Direct Connect - no efficiency losses; Uses AC or DC, very high
  - Could be combined with Data Transfer
  - COTS: ODI or Seacon underwater mate-able ~ $4k
  - Long-term reliability issue on Dock side (100 cycles, 2 years)
- Inductive - Contact-less, high reliability
  - Conversion to AC incurs efficiency losses between 10 and 30%
  - Adapt and existing system
    - electric vehicle charge puck - Consultant contacted
    - Hire developer of MIT's IPT from '97 to design a custom system
    - Use/adapt system developed at FAU
- Other
  - Optical: Light to solar cells
  - Mechanical: motor to generator

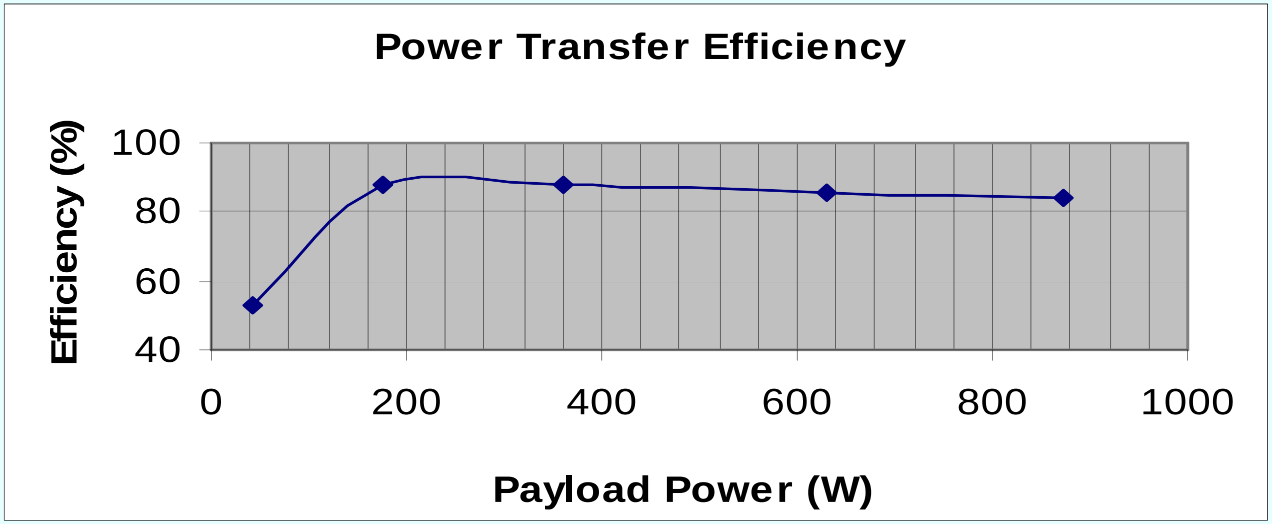
# Inductive Power Transfer System (IPT)

- Developed at FAU with ONR funding
- 4 sets of inductive coil/core pairs
  - Maximum field overlap
- 4.25 kHz
- 45-55 V input to docking station
- Programmable output from docking payload
  - Up to 1000W
  - 0-70 V
  - 0-30 A

# Inductive Power Transfer Results

| Dock Voltage (Volts) | Dock Current (Amps) | Dock Power (Watts) | Payload Voltage (Volts) | Payload Current (Amps) | Payload Power (Watts) | Efficiency (%) |
|---|---|---|---|---|---|---|
| 49.4 | 1.68 | **83.0** | 10.1 | 4.32 | **43.6** | **52.6** |
| 48.9 | 4.12 | **201.5** | 20.1 | 8.8 | **176.9** | **87.8** |
| 48.4 | 8.44 | **408.5** | 30.5 | 11.8 | **359.9** | **88.1** |
| 48.6 | 15.12 | **734.8** | 40 | 15.76 | **630.4** | **85.8** |
| 50 | 20.72 | **1036** | 47.4 | 18.44 | **874.1** | **84.4** |

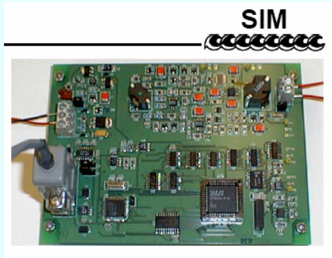
*Measured & Reported by FAU



# Data Transfer

6 Mbps minimum, Ethernet

- Direct Connect
  - Combined with power
- RF
  - Functional systems at 100kHz, 14 MHz, 433MHz
    - custom devices, fairly low speed
  - 2.4 GHz – 802.11 (WiFi)
    - Many COTS components available – radios, software, antennas, amps
    - OSU and FAU have used this, though no documentation
    - Custom antenna or antenna packaging

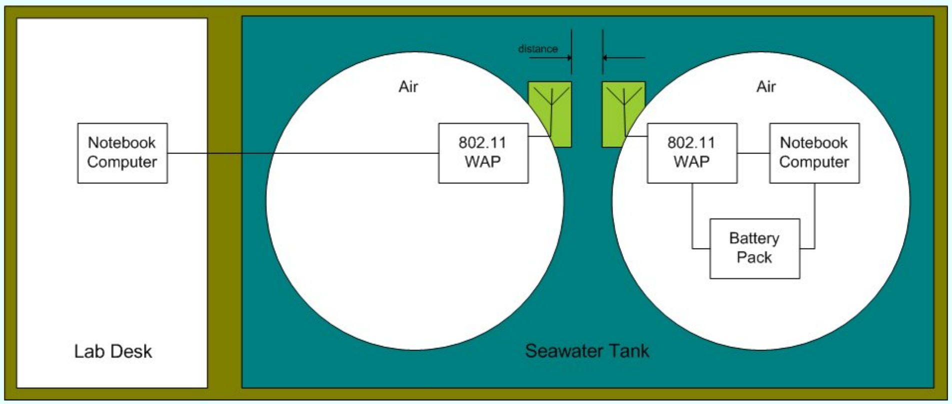


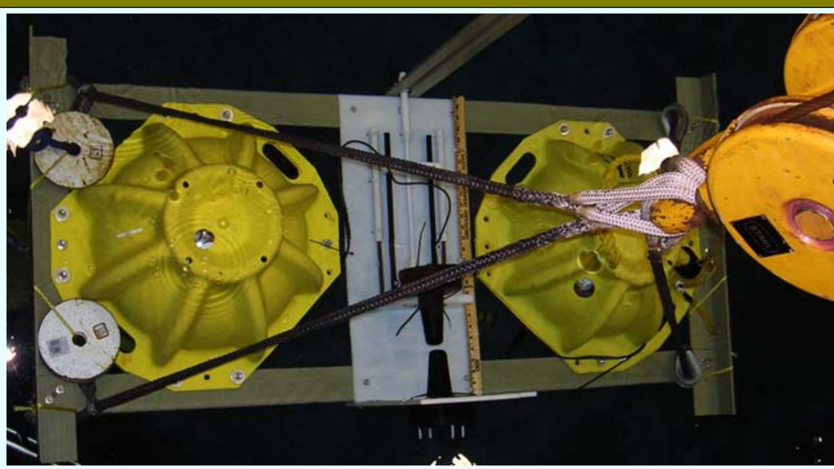

- Inductive
  - COTS Seabird: 1.2 kbps, future upgrade to 33.6 kbps
  - AURA Communications 57kbps now, upgrading to 1 Mbps
    - Driver ICs available and tested and they will help select COTS ferrits
- Optical
  - IrDa – up to 10 Mbps +
    - Susceptible to bio-fouling
  - Laser
    - Ambalux has a near-COTS system with 10 Mbps data
      - $20k+, 36 watts, - could provide short-range homing info

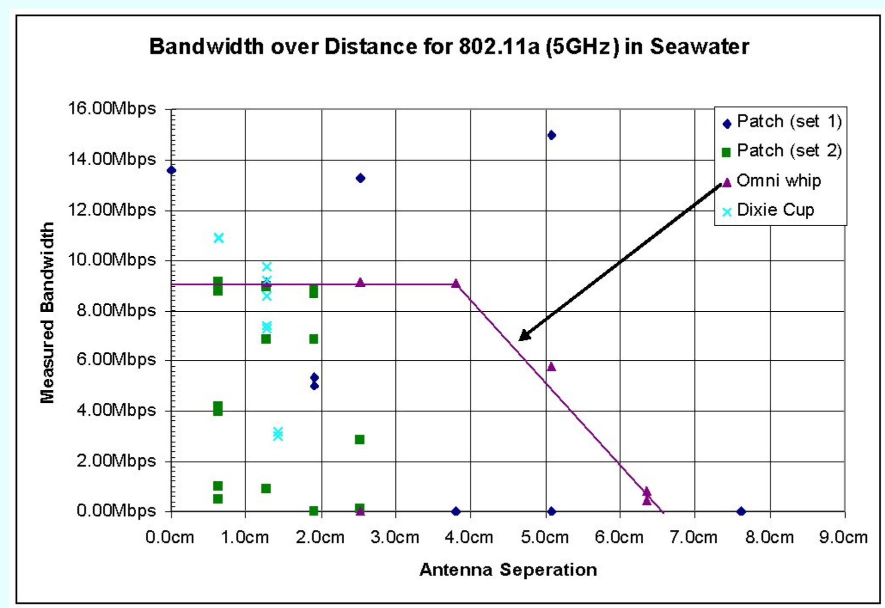
# RF Data Transmission Performance

- COTS WiFi Technology
  - Custom omni-directional whip antennae
- Currently achieve 9Mbps @ 4cm w/o amplifiers
- Should achieve 11Mbps @ 6.4cm w/amplifiers

| | |
|---|---|
| Max Tx Power | +18dBm |
| Feed-line Losses | -1.8dB |
| Tx Amplifier Gain | +12dBm |
| Antenna Gain | -19.3dB |
| Path Loss for **6.35cm** | -79.1dB |
| Antenna Gain | -19.3dB |
| Rx Amplifier Gain | +20dBm |
| Feed-line Losses | -1.8dB |
| Rx Signal Strength | -71dBm |
| Rx Sensitivity @ 11Mbps | -88dBm |
| **Link Margin @ 11Mbps** | **16.7dBm** |

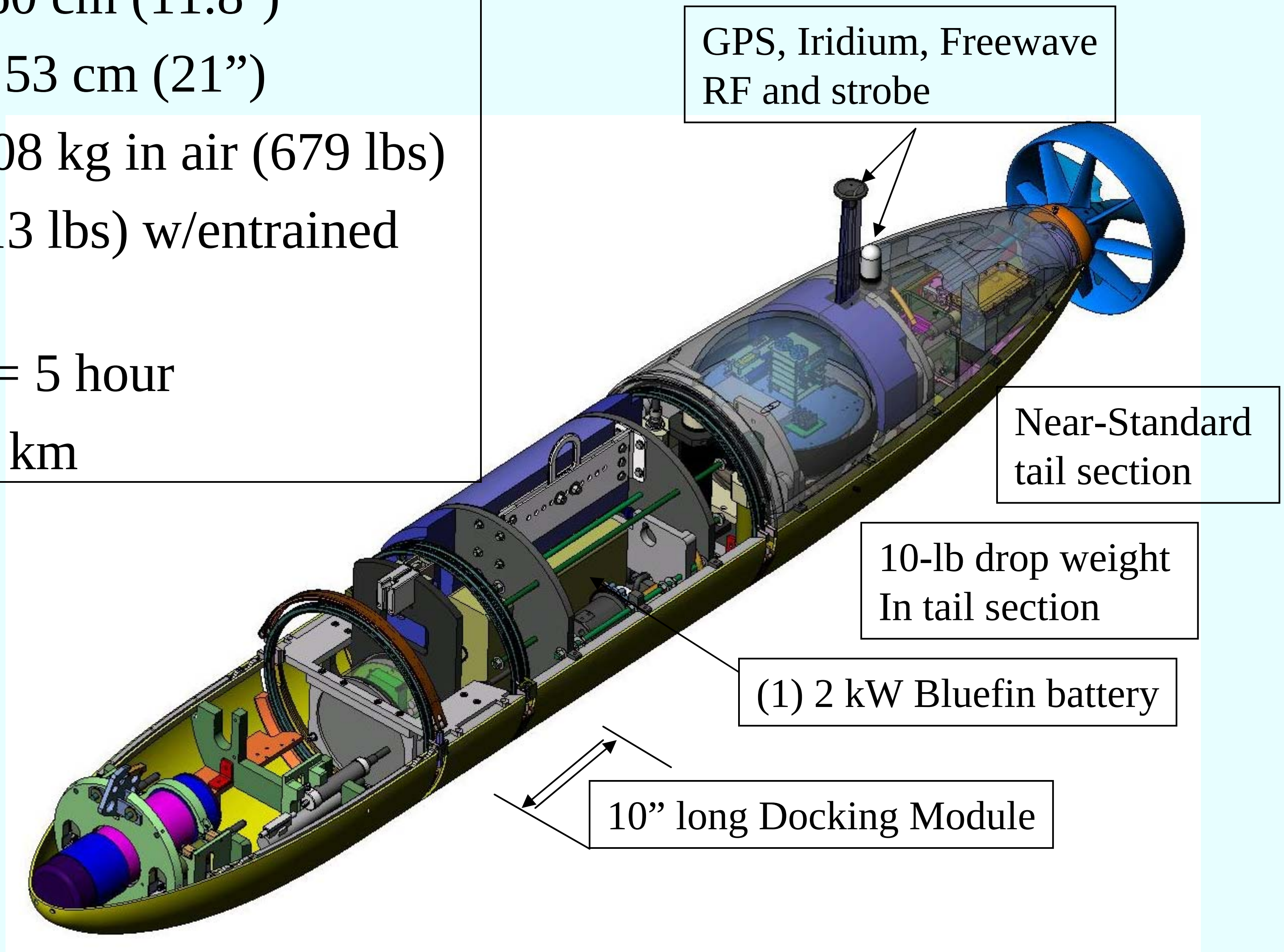




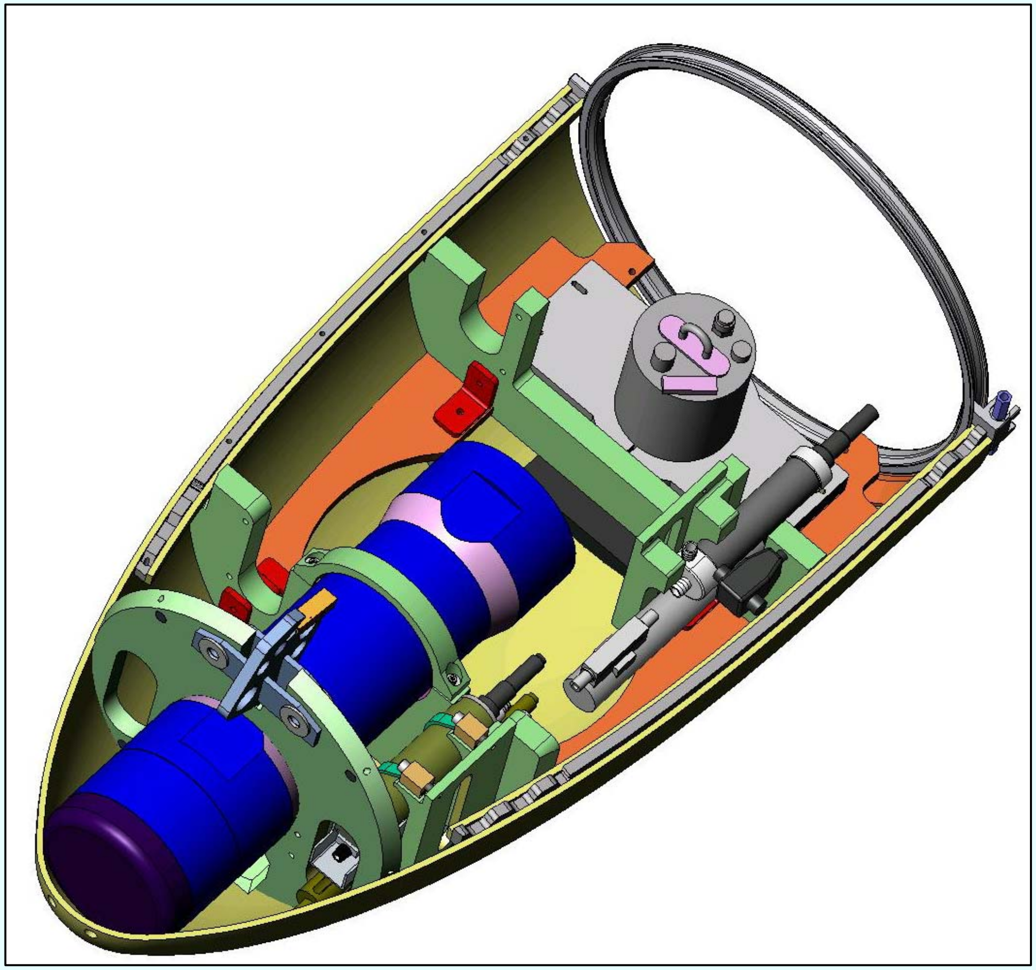
# Docking AUV

- Length = 360 cm (11.8’)
- Diameter = 53 cm (21”)
- Weight = 308 kg in air (679 lbs)
- 641 kg (1413 lbs) w/entrained water
- Endurance = 5 hour
- Range = 20 km



# Docking AUV - Nose Section

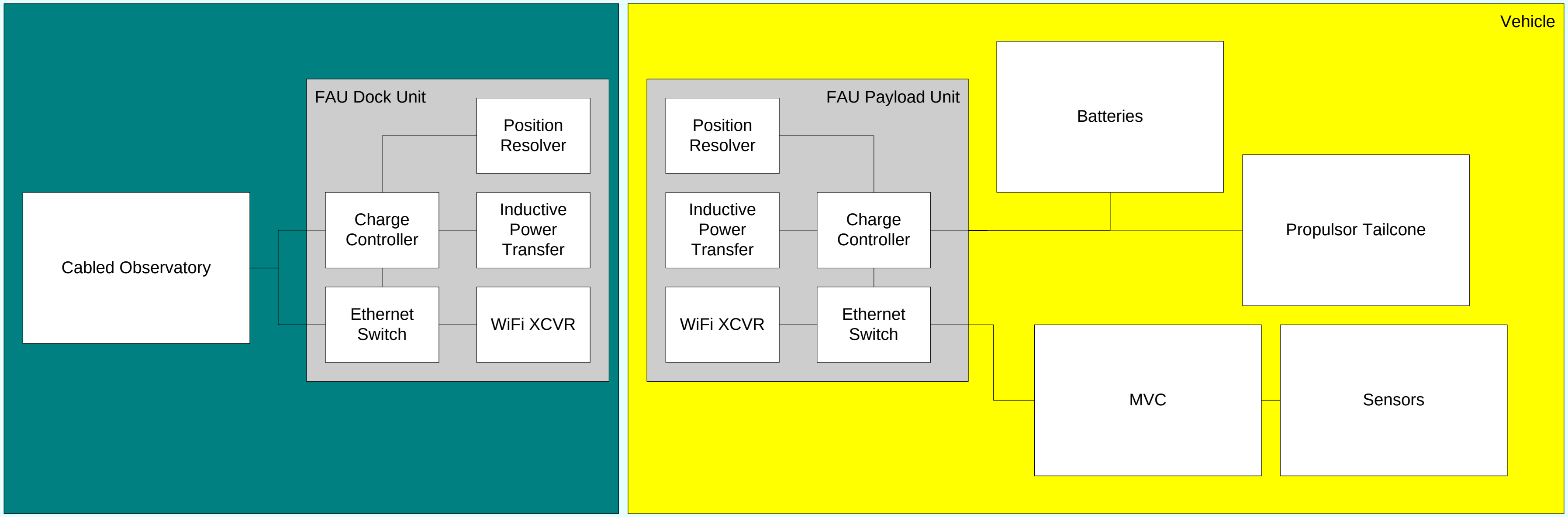
Sonardyne USBL Homing sonar



Seabird Flow-thru CT + DO
- Same system used in the CTD-AUV
- flow sensor
- redundant pair not installed

Hobi Labs HS-2
- Fluorometer
- 2 channel Backscatter

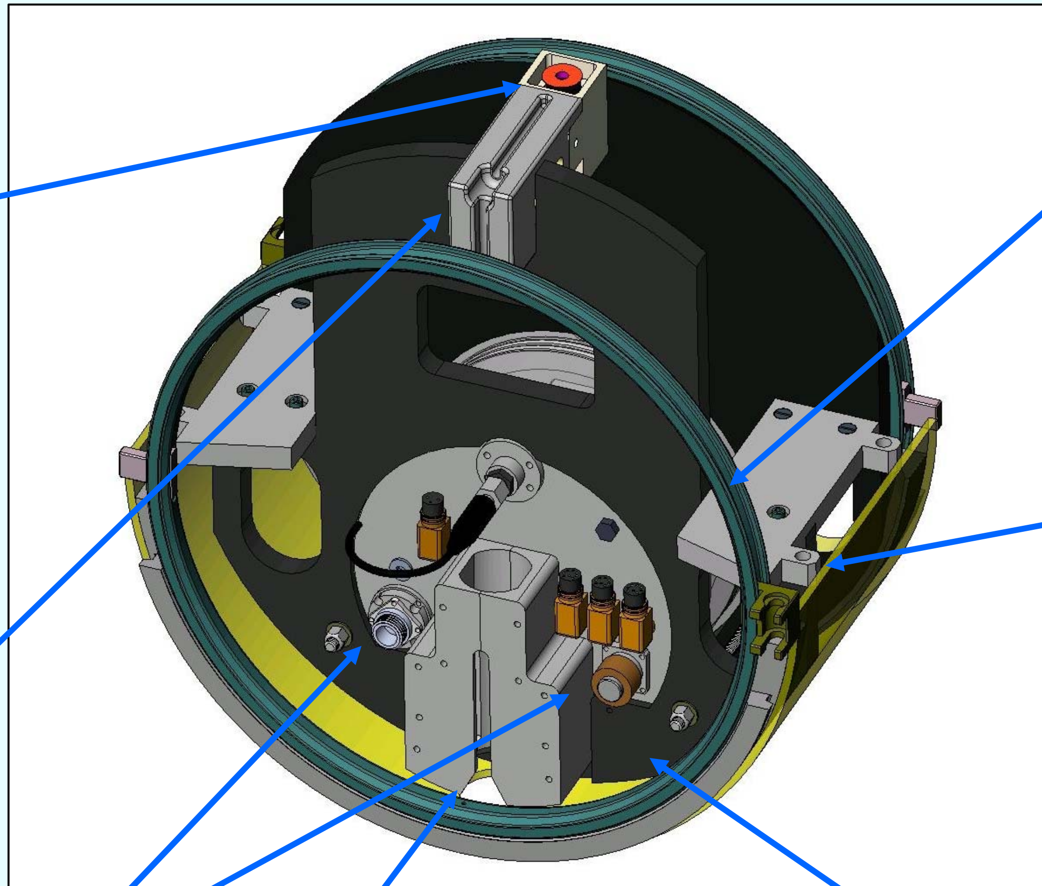
# Simplified Electrical Functional Block Diagram



# Docking AUV - Docking Section

Position sensor
- slave sensor
- Position measured by dock
- 3-states:

0.0” < Near < 0.5”
0.5” < Far < 1.5”
Null



10” dia.
Aluminum
PV – 300m depth limit

“standard” drop-in Payload mounts

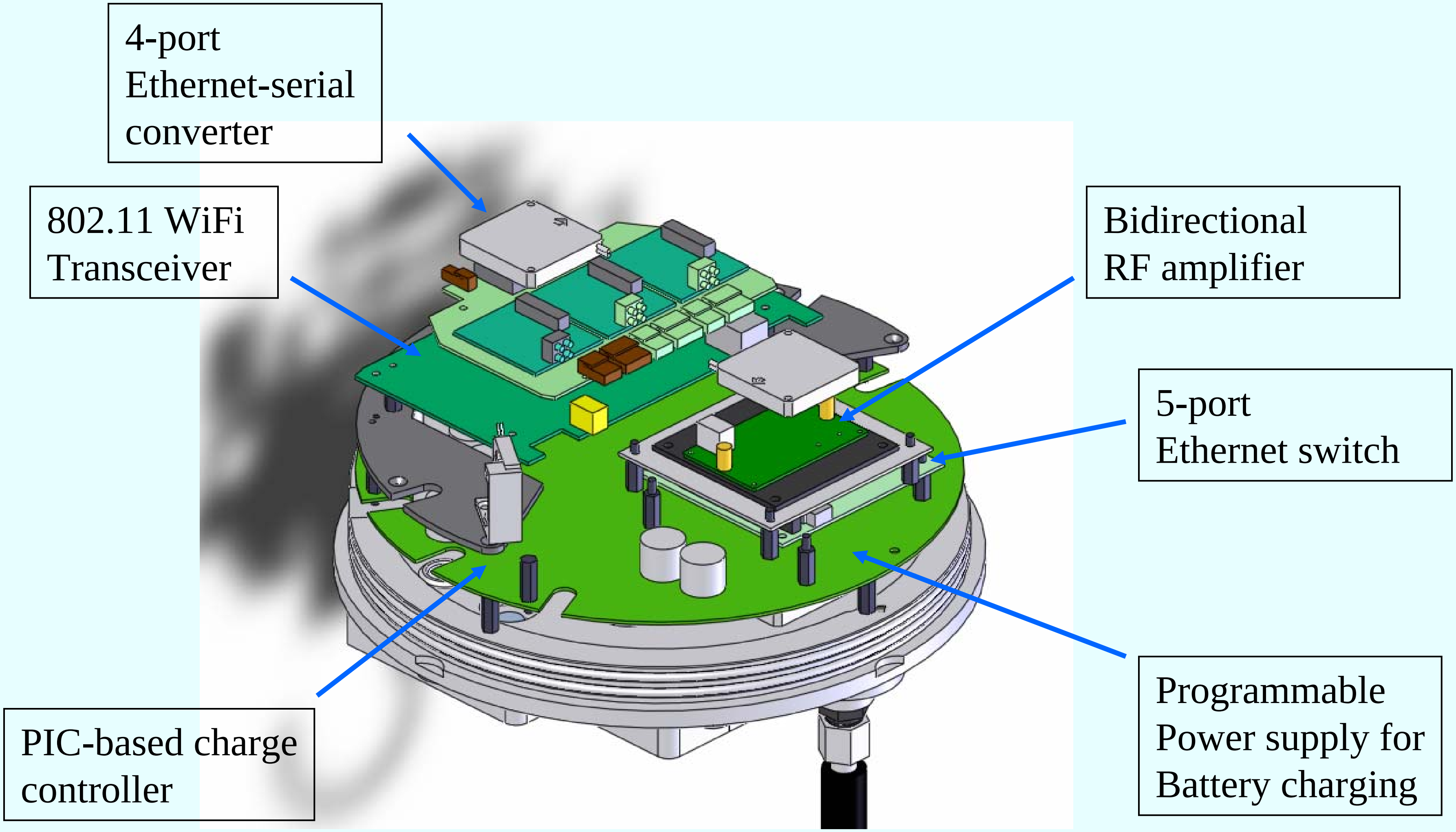
RF Antenna
- whip potted in PVC block

“standard” AUV bus cable in and out

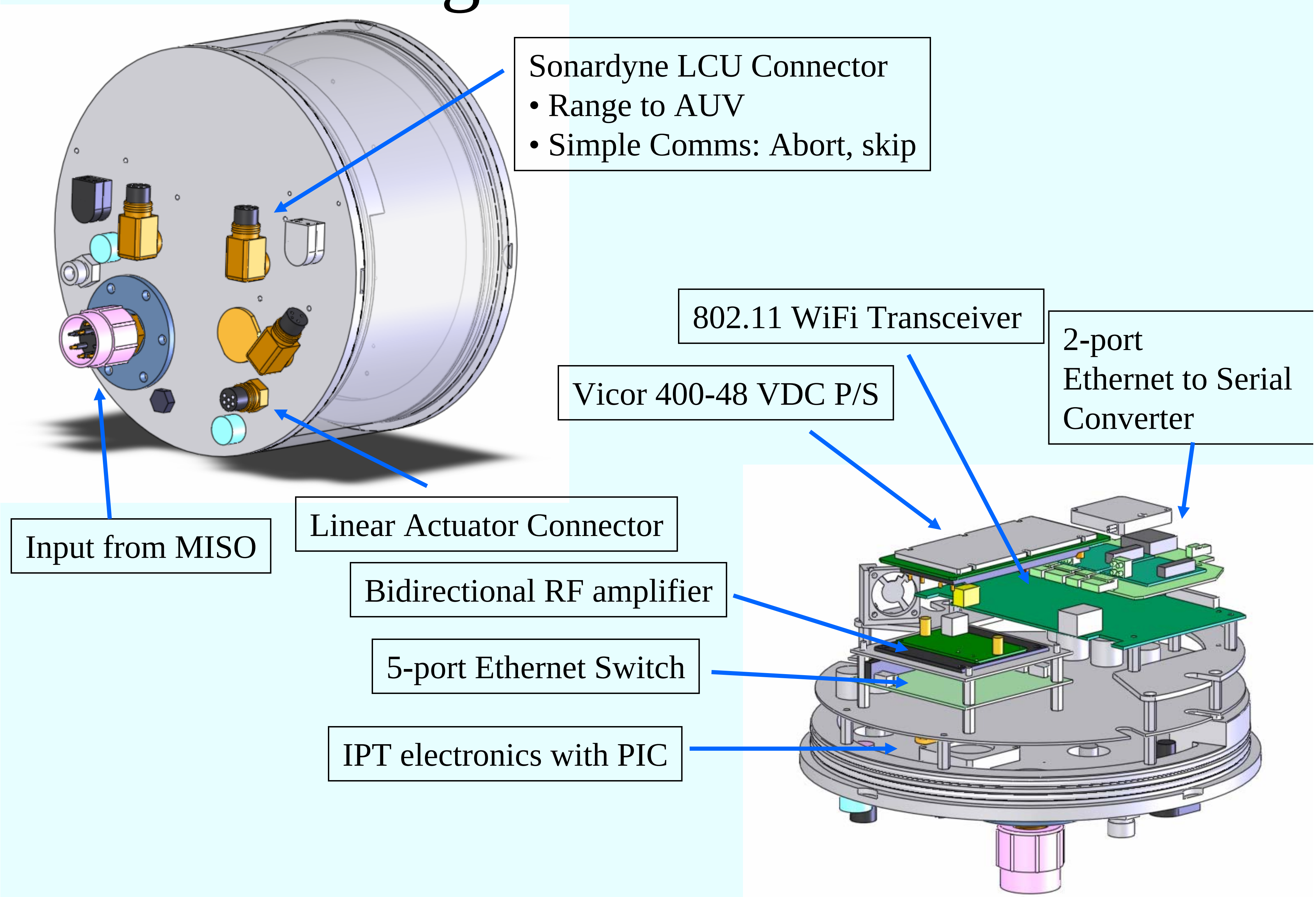
Receiver for inductive Charge probe

(3) Accessory serial ports
- Fwd. Looking sonar
- HS-2
- Spare

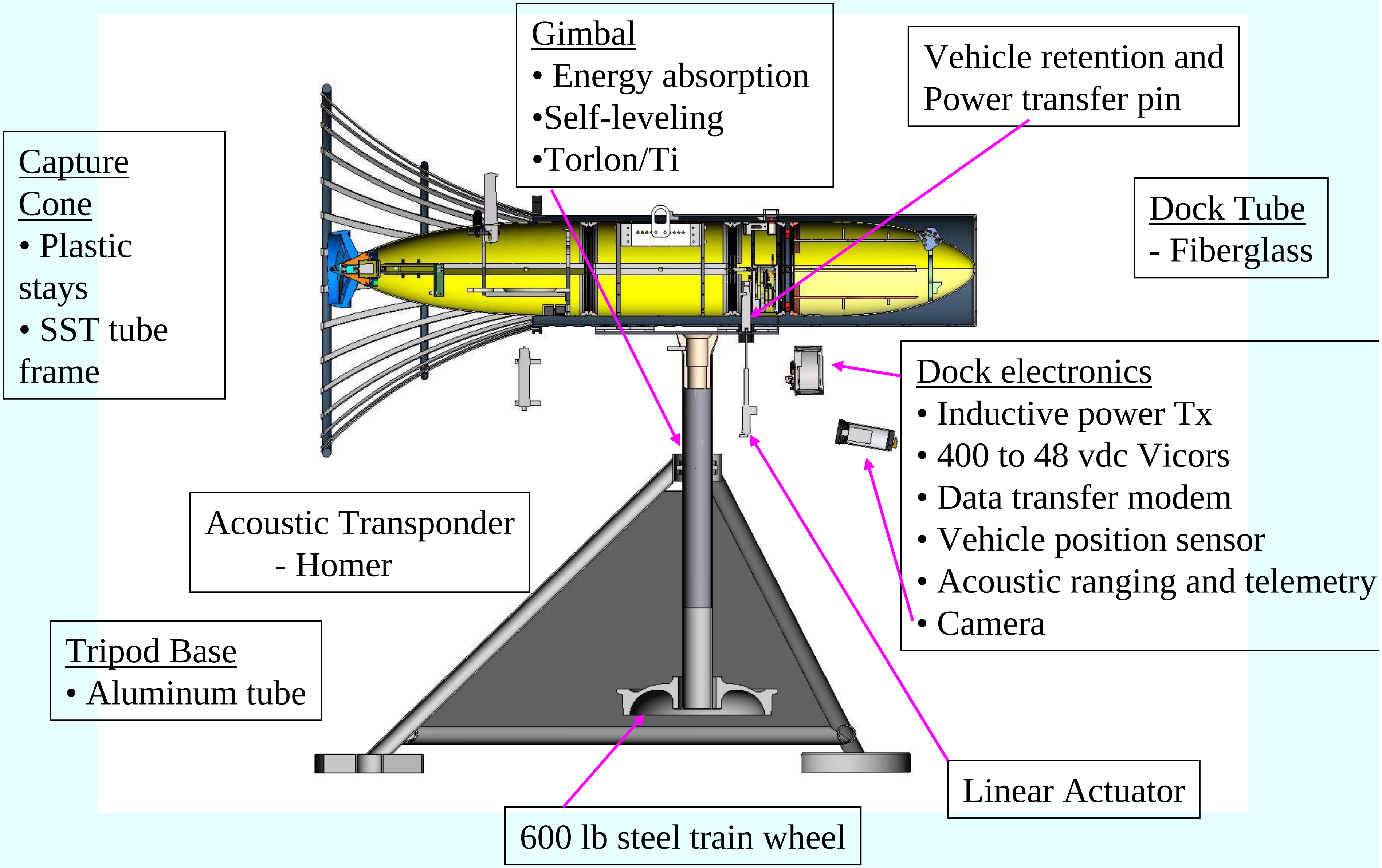
# Docking Payload Electronics



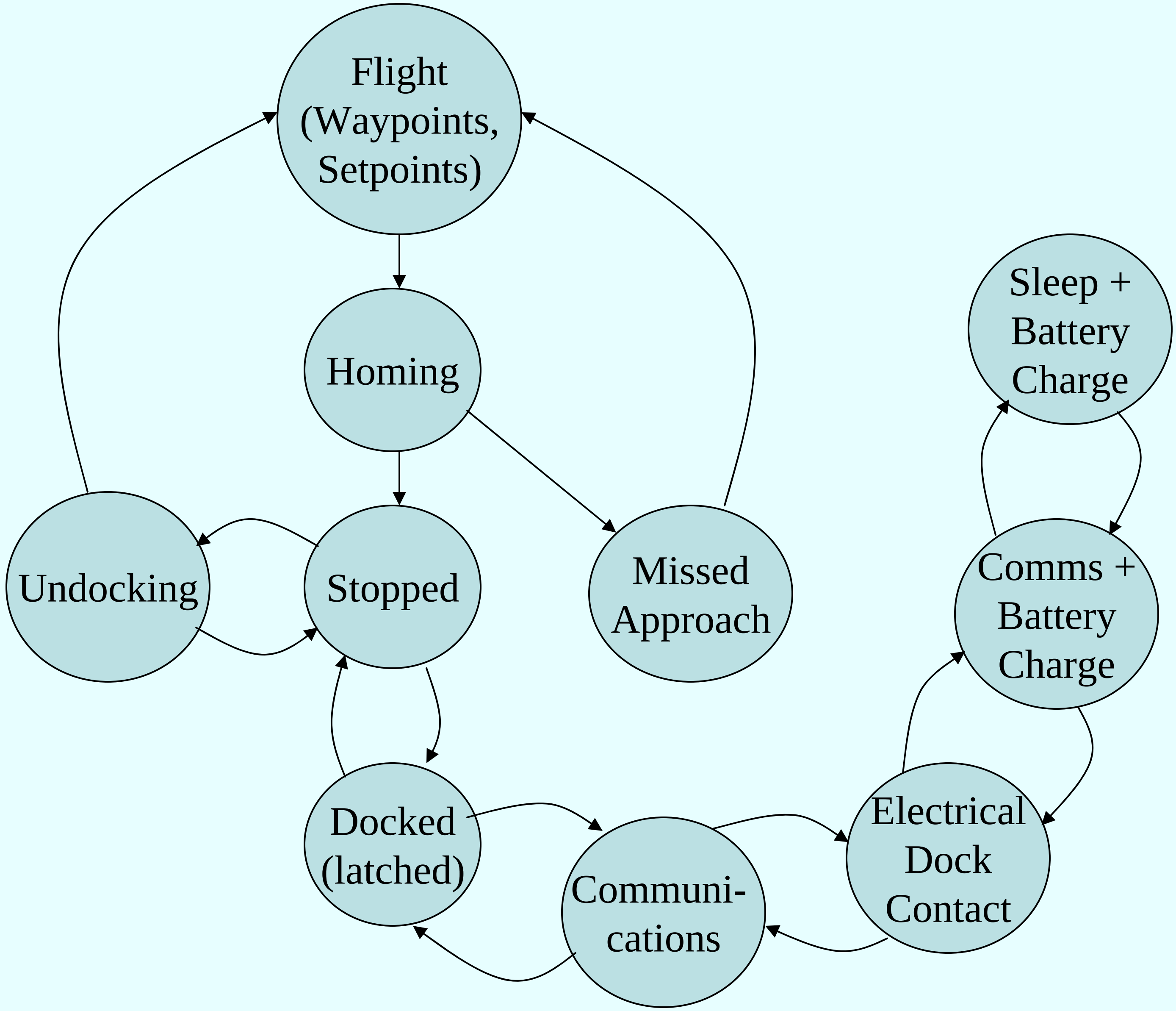
# Docking Station Electronics



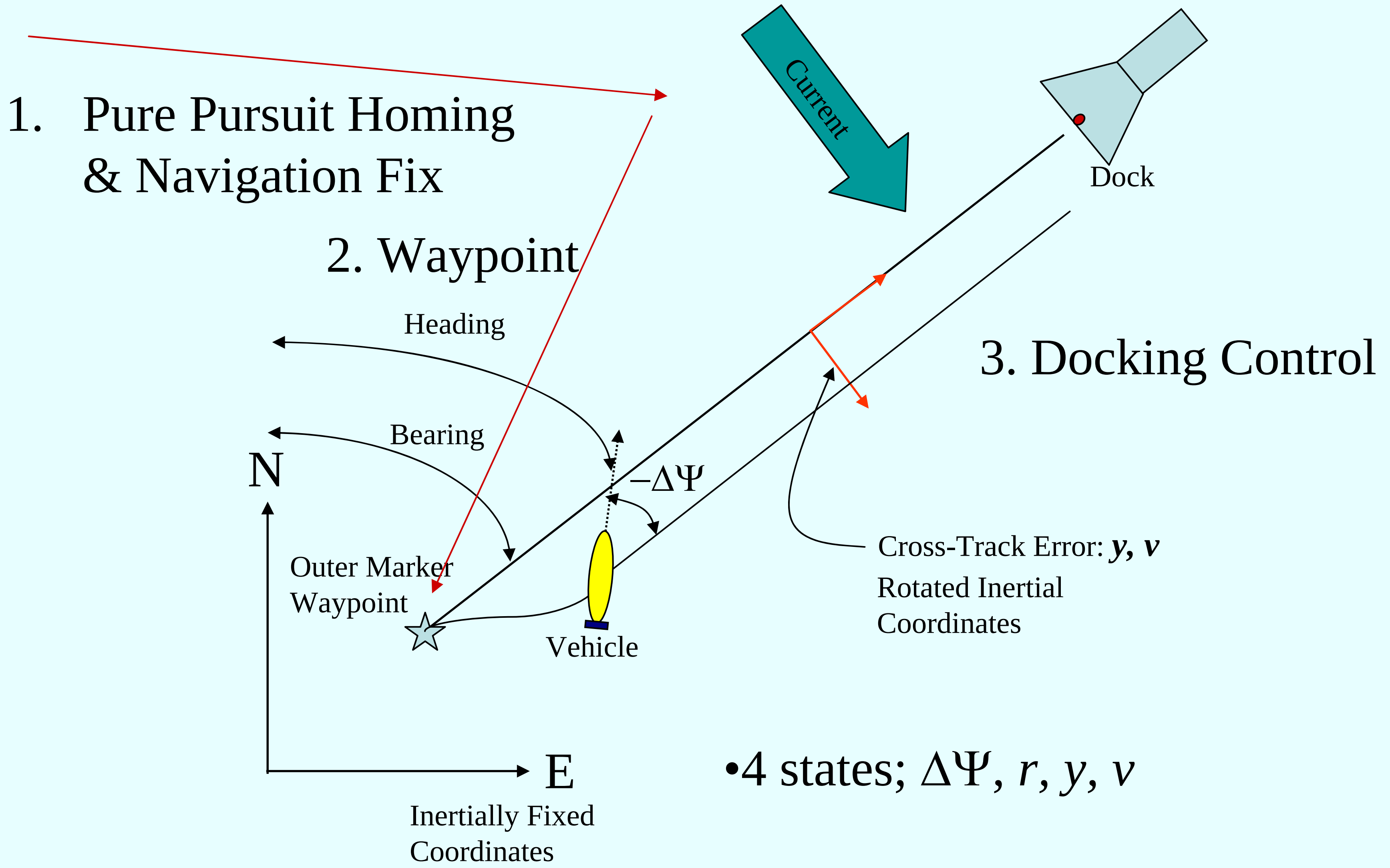
# AUV and Dock X-section



# Docking System State Diagram



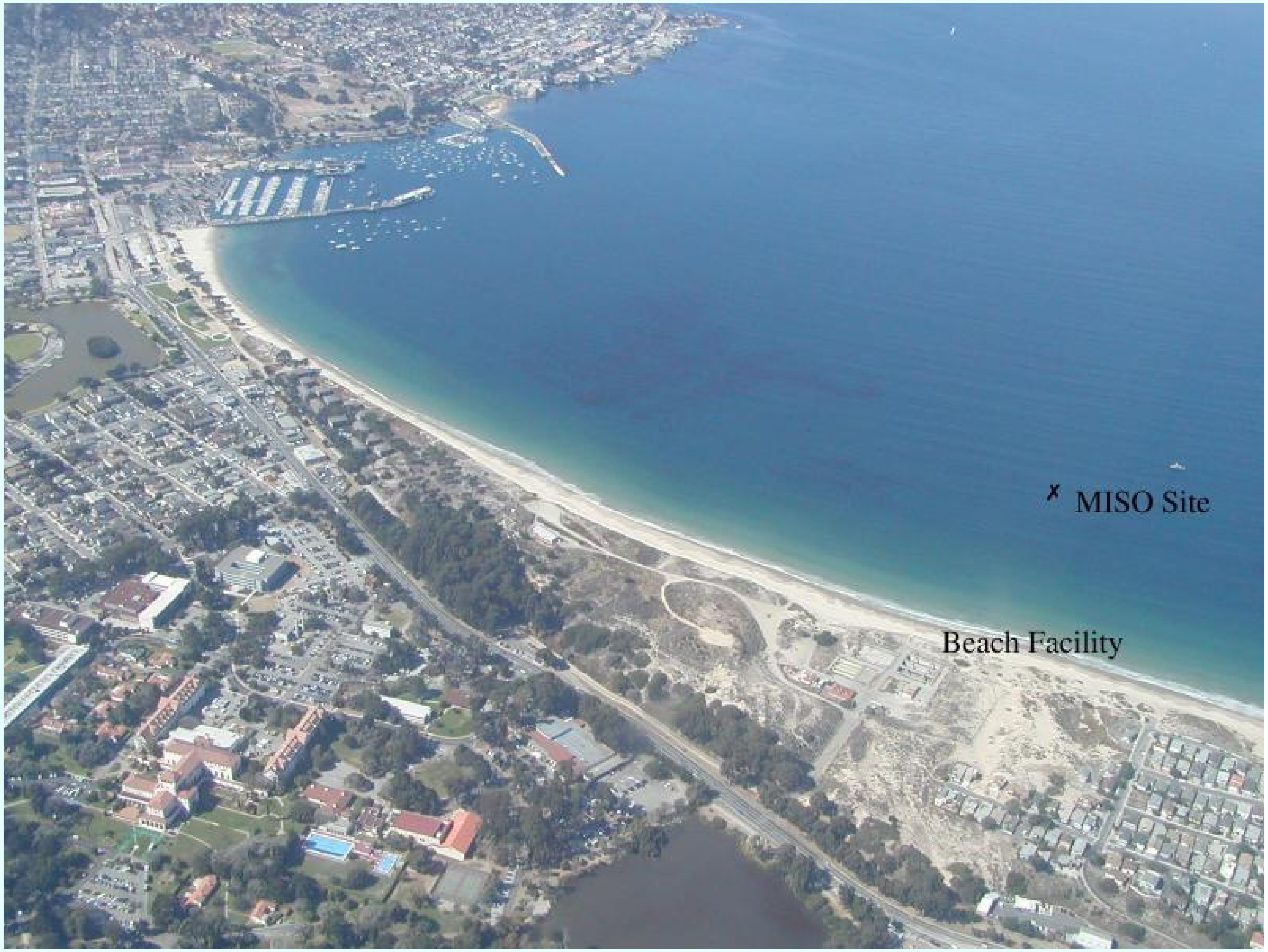
# Docking Behavior Sequence



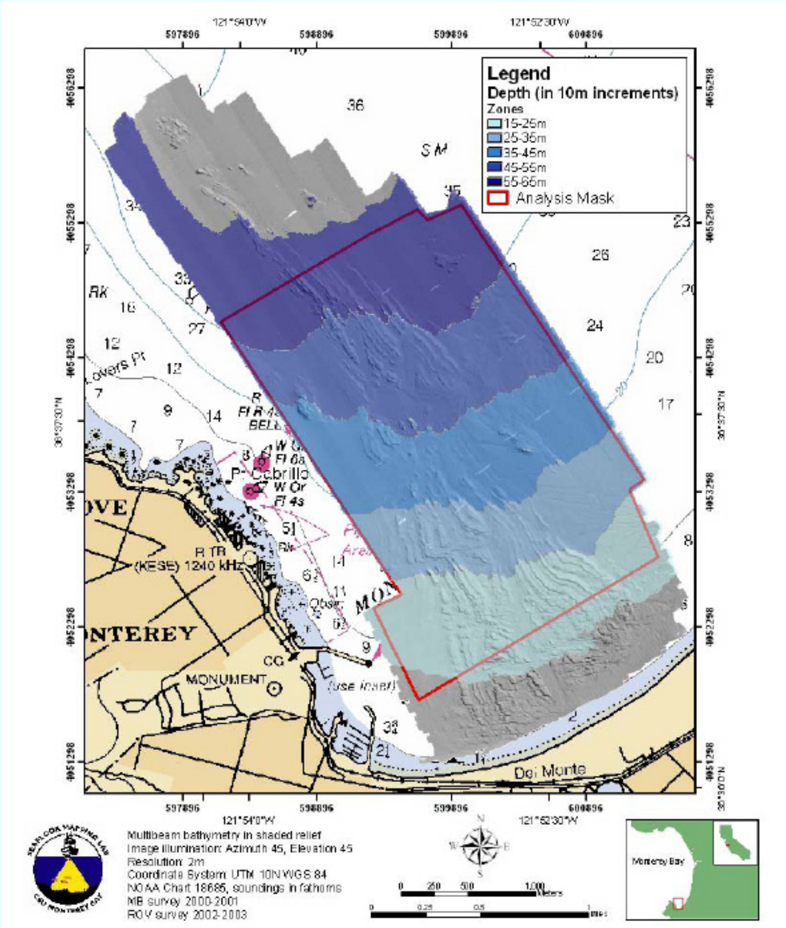
# MISO - Prototype Test Site

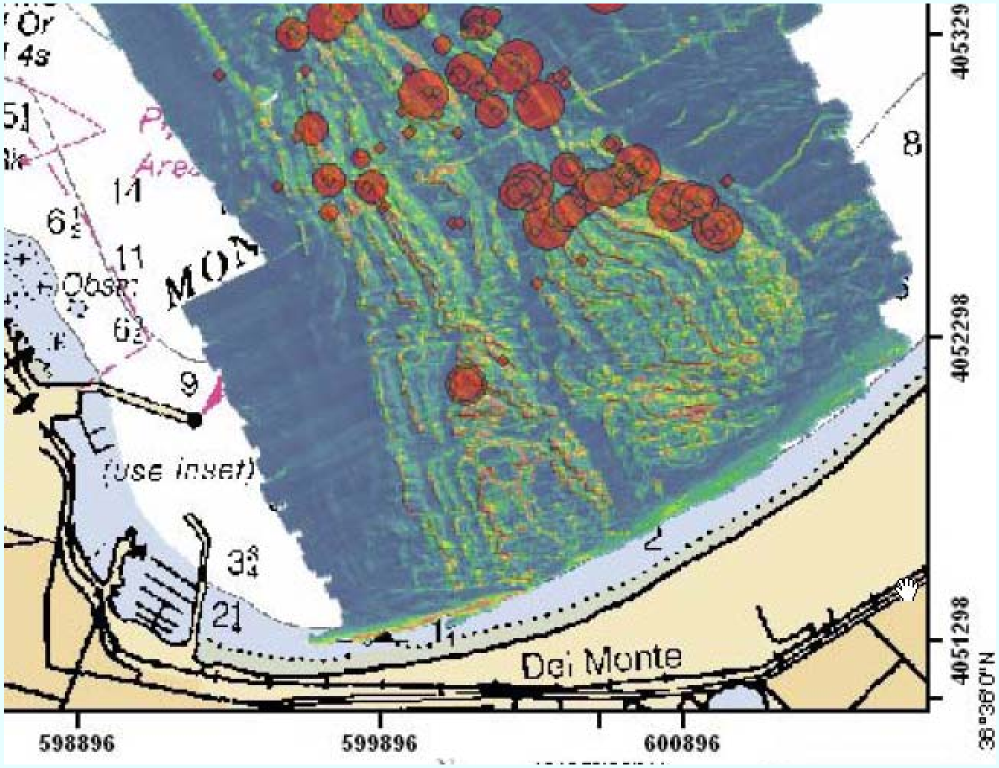
## Monterey Inner Shelf Observatory

- NPS (Stanton)
- Ethernet and Power avail.
- 14 m depth
  - Diver depth
- Wave motion
- Bio-fouling



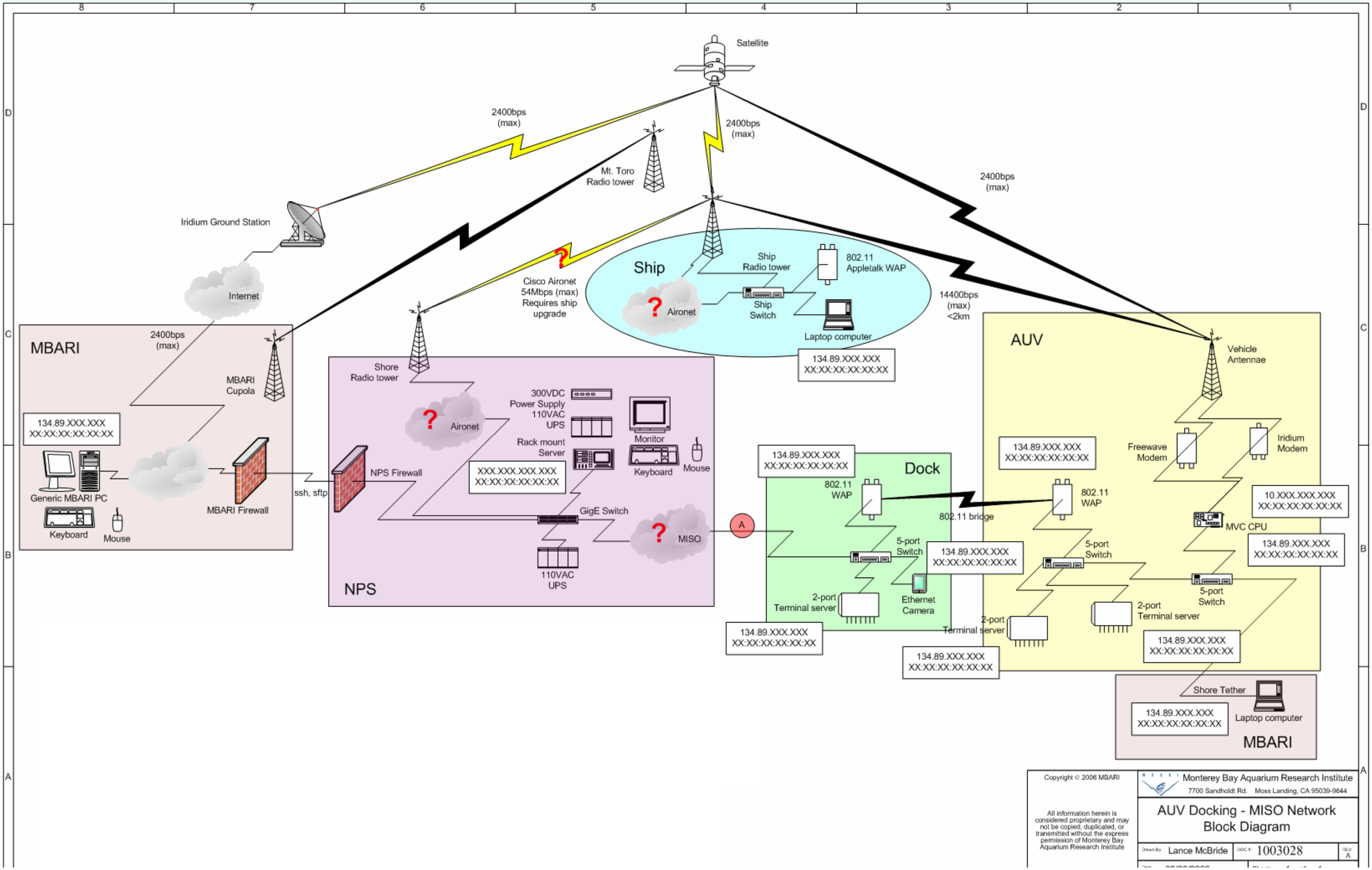
# MISO - Bathymetry



# MISO – approach and hazards

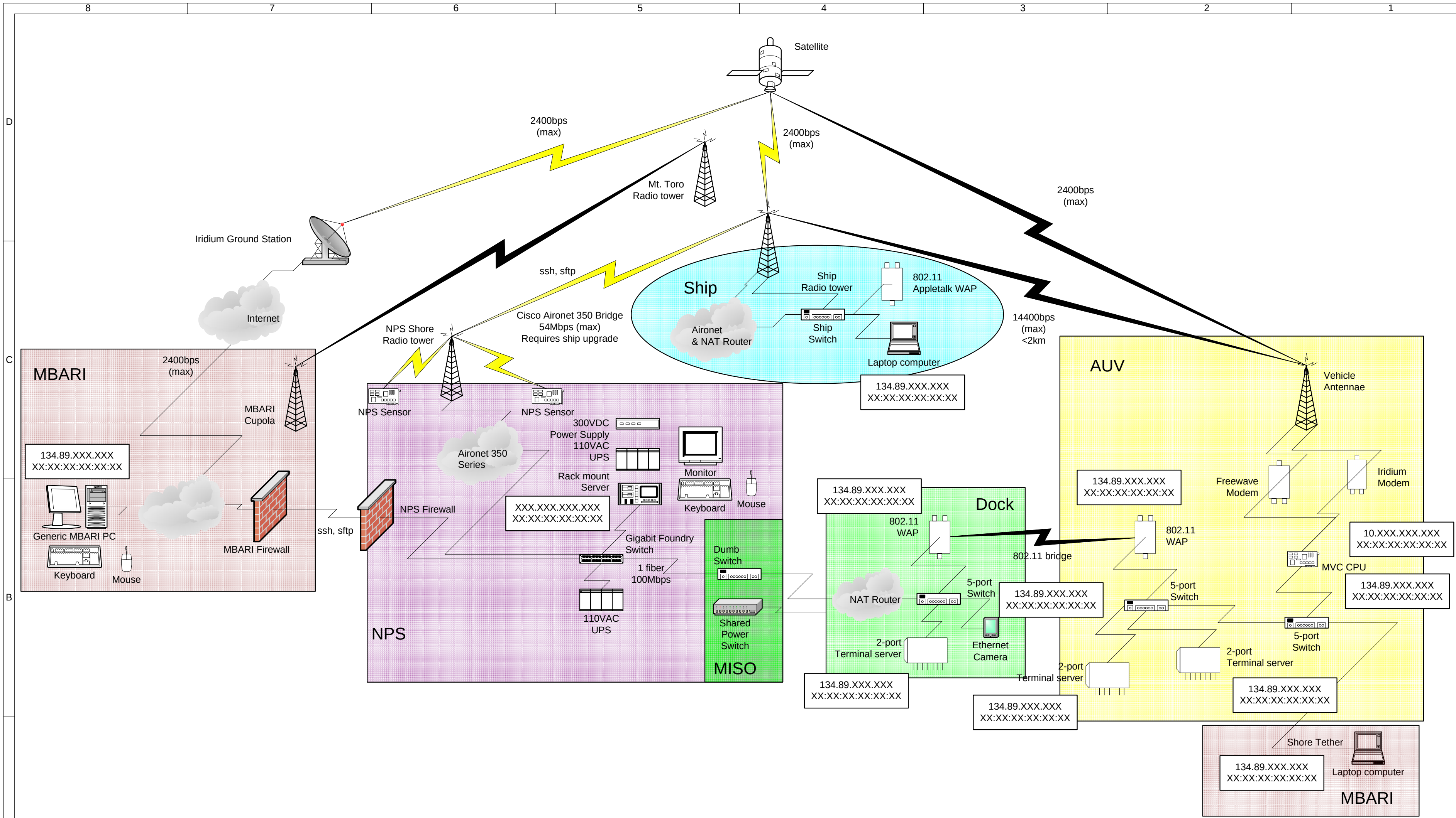
# MISO Network Block Diagram



# Interfaces

- Docking components to AUV
  - Ethernet comms and 36VDC through standard MINK10L connector
  - Standard hull section hoop attachment
- Dock to AUV
  - 802.11g wireless comms, FAU Inductive power probe
- Dock to observatory - MISO, MARS, MOOS
  - Cable plug-in: Impulse IL8M – 2 power + ethernet
  - 110 VAC to MBARI 400 VDC P/S
  - Control with a PC terminal via ftp over ethernet
- Observatory to MBARI/Internet
  - SSH, SFTP
- Dock to Deployment vessel (Zephyr)
  - Lifting eye on top of dock, through J-frame sheave to deck winch

# MISO Network Block Diagram






Monterey Bay Aquarium Research Institute
7700 Sandholdt Rd. Moss Landing, CA 95039-9644

AUV Docking - MISO Network Block Diagram

Drawn By: Lance McBride | DOC #: 1003028 | REV. B

Date: 02/28/2006 | Sheet: 1 of 1

# Docking Missions Requirements

**from Case Studies**

- 12 hour long missions * 5 hour mission in Y1
- 60 km range * 20 km range in Y1
- 180 watts for science sensors, 2.2 kW total
- 420 watts with multibeam sonar, 5 kW total
- 180 MB/km max data rate, 11.6 GB total
- 480 MB/km with multibeam sonar, 31 GB total

---

To prepare AUV for next mission in 12 hours:

- Minimum power transfer rate: 450 watts/hr
- Minimum data transfer rate: 5.7 Mbps

# Opportunities (Constraints)

- Plug into MARS, then other RCOs, and MOOS
  * not in Y1
- Use MBARI AUVs

# User/High Level Requirements

- conduct multiple missions without human presence

  * not in Y1
- Able to communicate with the vehicle to trigger missions, recover data, and download new mission scripts and commands.
- Able to recharge AUV batteries
- Able to dock autonomously

# Requirements

- Failure modes should be minimized.
- The dock must protect a sleeping vehicle
- One hundred dock/undock cycles *Target in Y1 is 10 cycles
- Docking system failures should be detectable by the vehicle/dock system and be recoverable * no on-board failure detection and recovery in Y1
- Able to release a dead AUV using the ROV * Diver-based in Y1
- *Nice if* a dead AUV could be released w/o an ROV *not addressed in Y1
- Must have comms to the AUV while docked
- *Nice if* we had comms to the AUV during a mission
- Minimize AUV power consumption in the dock
- Able to recharge batteries
- Able to survive power outages at the observatory
- *Nice if* the dock could be used under ice (Arctic) *not addressed in Y1
- *Nice if* the dock could be used to recharge benthic instruments *not addressed in Y1
- *Nice if* the dock could be adapted for 12” AUVs *not addressed in Y1
- *Nice if* the dock architecture could support multiple vehicles *not addressed in Y1

# Requirements

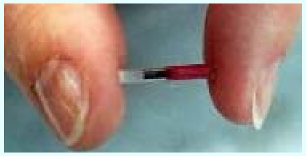
- Operating depth: 250 m to 4000 m * 300m depth limit in Y1
- **Operating current 0 to 1.0 knot**
- **The dock shall be resistant to bio-fouling and debris fouling and high sedimentation rates**
- **The dock shall be functional when operated in an area with:**
  - **Maximum of 2 degree slope ** will be revised to 8 deg**
  - **No features greater than 1 m high within 200 m of the dock**
  - **Typical sediments and sedimentation rates**
- **Minimize System maintenance**
  - Target AUV maintenance interval is: >6 months * Little attention in Y1
  - Target Docking station maintenance interval > 2 years * Little attention in Y1
- Able to deploy from the R/V Western Flyer
- ***Nice if* the docking system could be deployed from Zephyr**
- *Nice if* the dock could be "kicked off the stern" * not addressed in Y1

# Docking AUV Specifications

- **The Docking AUV shall:**
  - ➢ **Be based on the Dorado vehicle design**.
  - ➢ Have rechargeable batteries that provide 12 hour Mission capability * 5 hour mission in Y1
  - ➢ **Have navigation sensors**
    - **Onboard AHRS (compass) 1 deg minimum accuracy**
    - **Onboard DVL**
    - **ARGOS or Iridium transmitter**
  - ➢ Be trimmed neutrally buoyant with an automatic emergency drop weight * Not addressed in Y1, though Dorado LS will address this.

# High Risk Elements

- Unanticipated problems
- MISO specific challenges
  - AUV operations near the beach, wave action - Operations will be conducted only during calm weather
  - bio-fouling: the dock will only be deployed for a maximum of two months
  - kelp entanglement: Careful use of time-outs, frequent GPS nav updates and strict operations procedures
  - Trawl damage: keep dock in sand channel but on the shoreside of kelp line
  - Vandalism: Don't mark dock directly
- Vehicle failures due to impact with dock
  - Install shockwatch go/no-go shock sensors on all sensitive equipment



  - Integrate Andy's accelerometer data logger – configured for 100 hz
- Software
  - Project only has a controls engineer – nobody to develop drivers, GUIs or automated processes – command line terminal mode only: Requesting time from Rich Henthorn

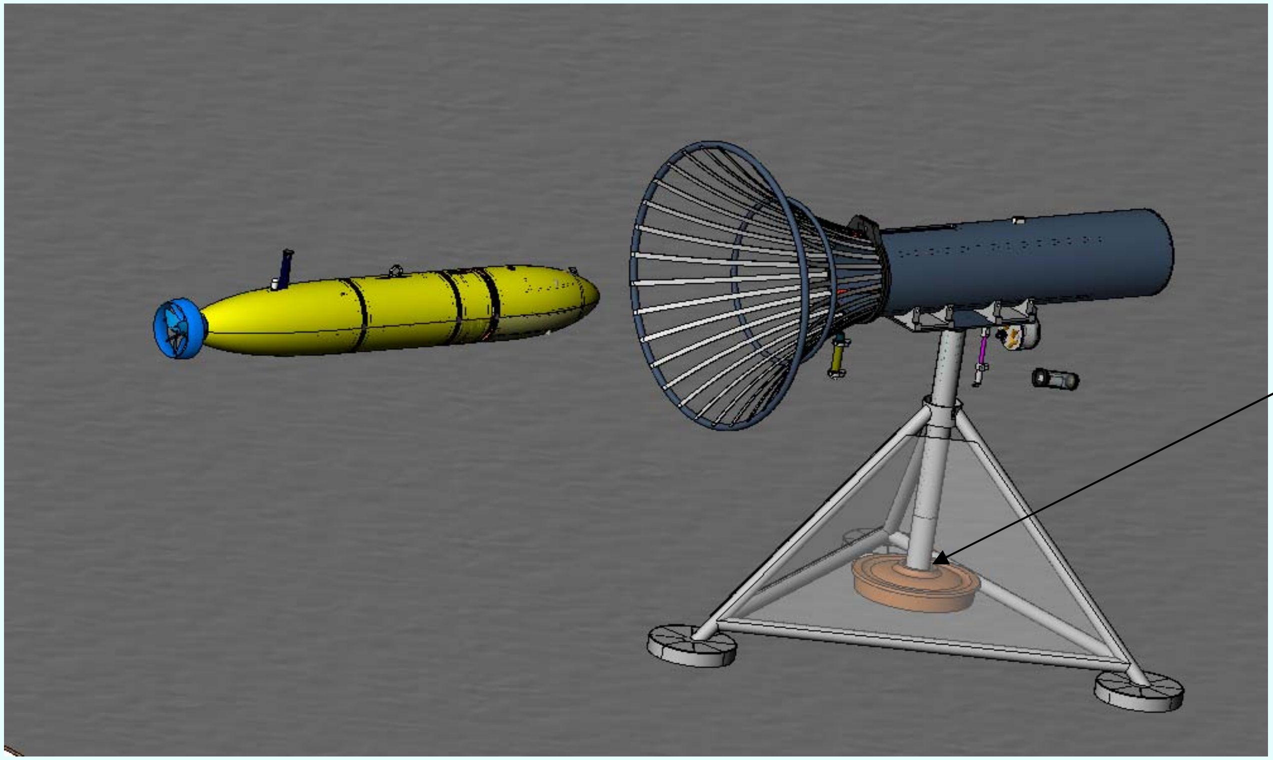
# Compromises in Y1

- Docking actuator is on dock, not AUV
- Vehicle/Dock position is measured on dock side
- Inductive Power Transfer system PV are 300m
- Single 2 kW Battery limits endourance
- Limited sensors: 1 set of CTDo, no ISUS, Backscatter,
- Forced to contend with wave action and bio-fouling

# Planned upgrades in Y2

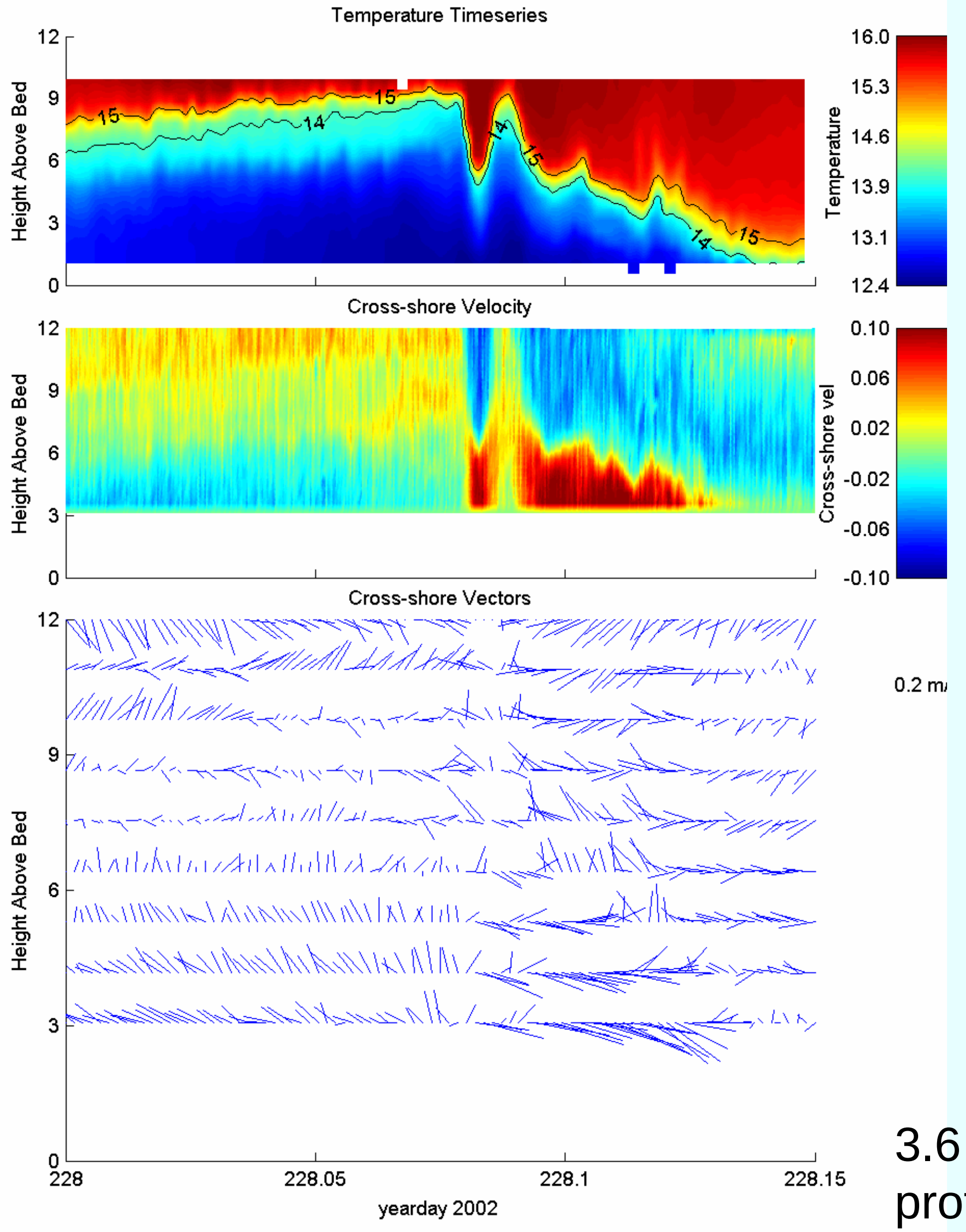
- Address issues discovered in Proof of Concept
- Rugged-ize system design to increase reliability and maintenance interval
- Re-configure IPT for vehicle-centric dock
- Re-package IPT in 4000m housing
- Increase battery capacity to meet Requirements

# Year 3 Upgrades



# Questions?

- Thank you very much for your input and patience!

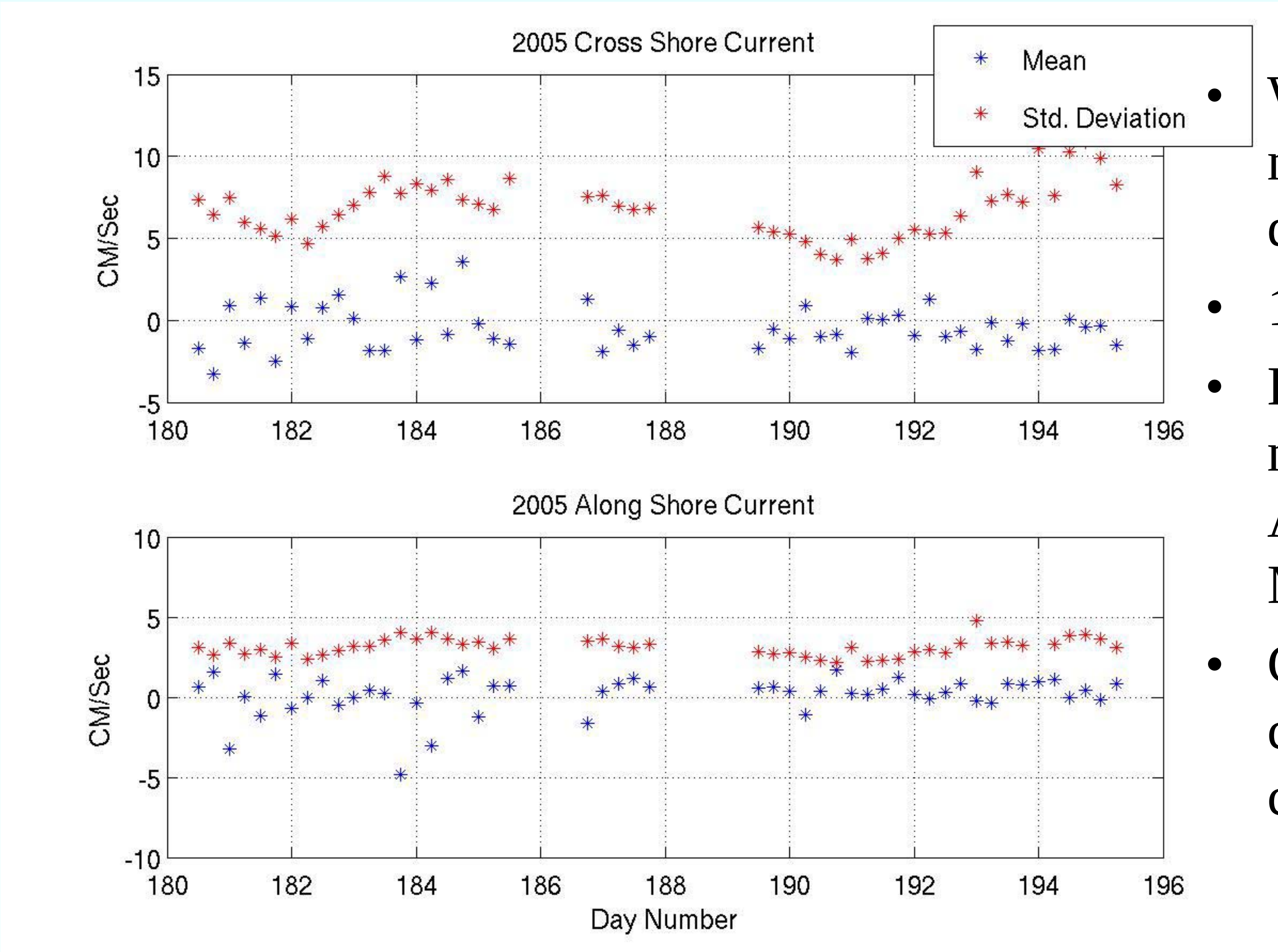



# Temperature and Current Profile Timeseries of an Internal Bore and Leading Edge Soliton at MISO

Tim Stanton, NPS
stanton@nps.edu

3.6 hours of 2 minute profile observations

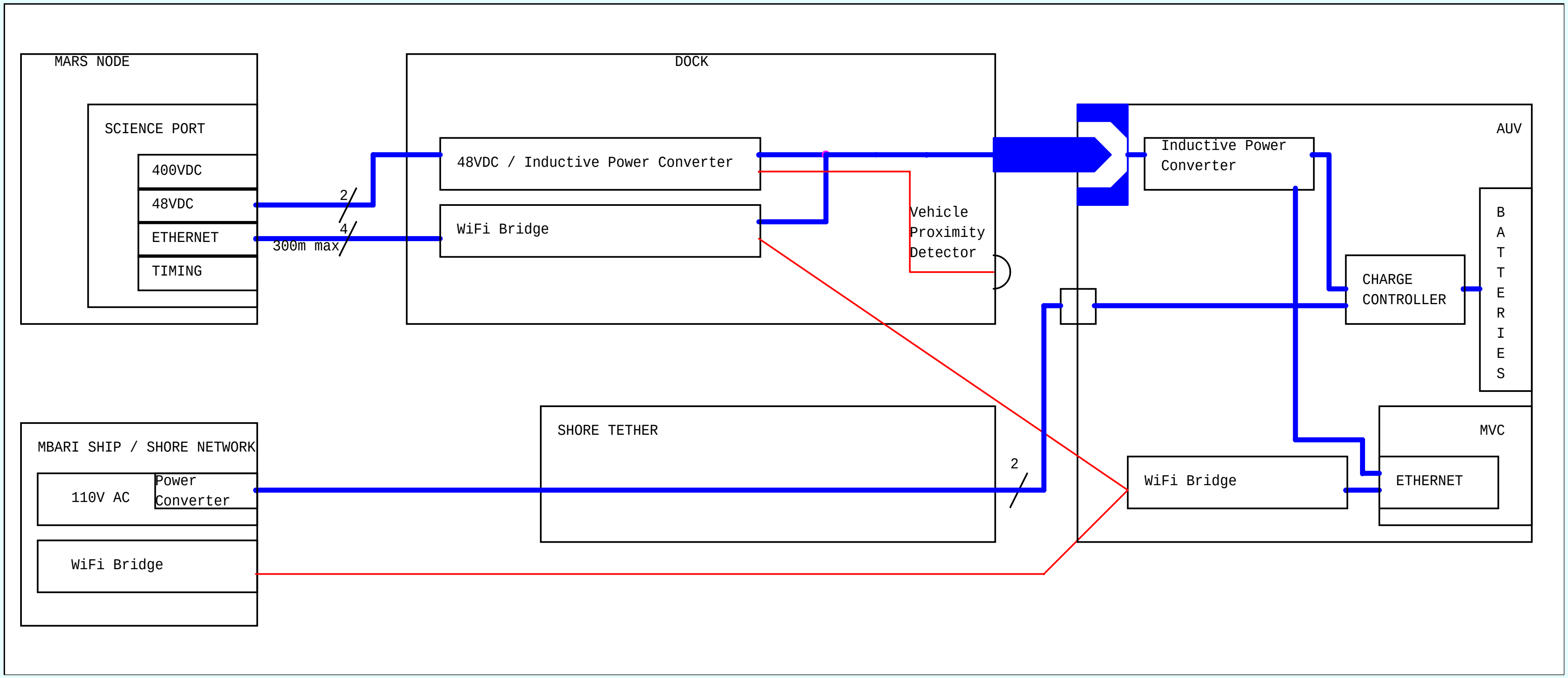
# MISO - Currents



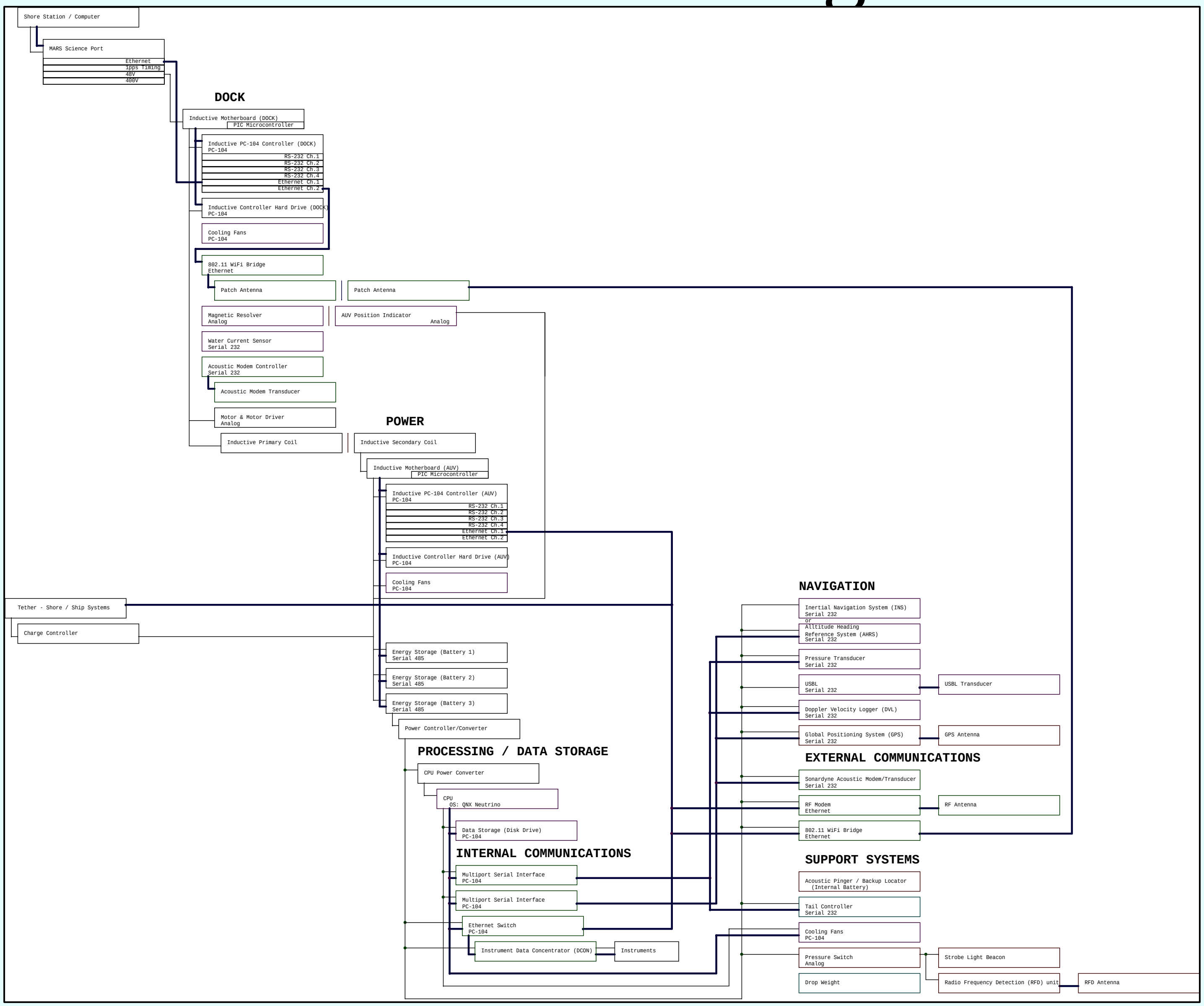

- Wave motion dominant.
- 12 m depth.
- Bottom mounted ADCP near Monterey.
- Cross-shore can go to 50 cm/sec.

Data courtesy of Tim Stanton, NPS

# Electrical Dock Components Conceptual Block Diagram



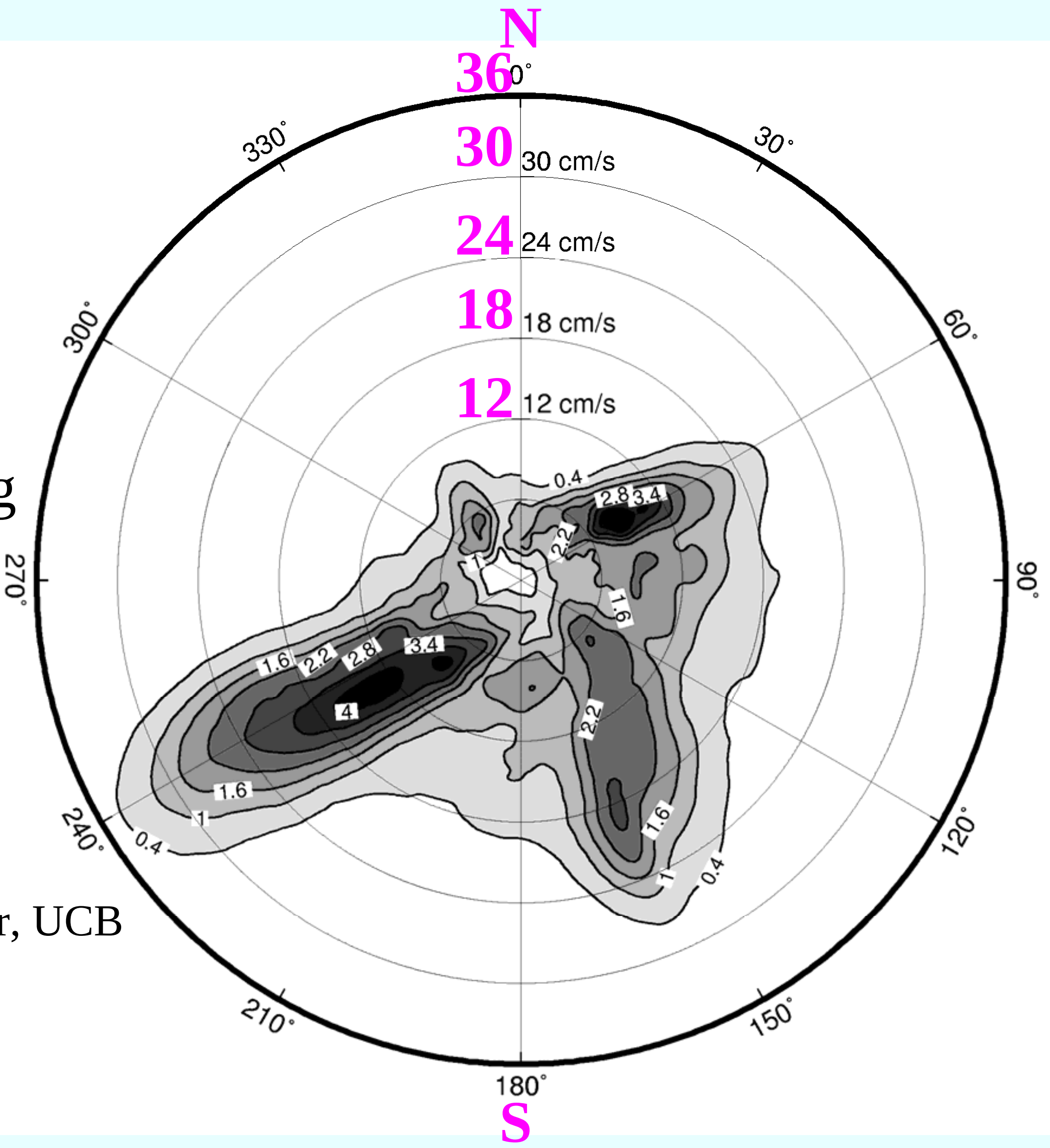
# Docking System Detailed Block Diagram



# Expected Currents at Smooth Ridge

- Max. current 36 cm/sec.
- Tidal semi-diurnal motion 60/240 Deg.
- 1 Yr of data, sampling period 1 second.
- 1 meter off seafloor
- Contours are probability density.

Plotted by B. Uhrhammer, UCB



# Slope near MARS