Florida Atlantic University

Energy Systems for FAU AUVs

Ed Henderson, Tom Pantelakis, Edgar An
Ocean Engineering, Florida Atlantic University
Email: ean@oe.fau.edu

Collaborators: NPS, VPI, MIT, WHOI, USF, UM, SOC U.K.
Funding Source: ONR

Main Campus - Boca Raton

SeaTech – Dania Campus

AUV Energy Systems

Requirements

- Energy capacity
  - Spatial/temporal surveys
    - Military (VSW MCM) > 12 hours, oceanographic > 24 hours
- Wide range of operations
  - Standby, transit, survey, etc (different discharge rates)
- Vehicle turn-around time
  - Down time for servicing and changing energy sources
- Small AUV form factor
  - Less space for storing energy sources
- Safety and reliability

Remarks

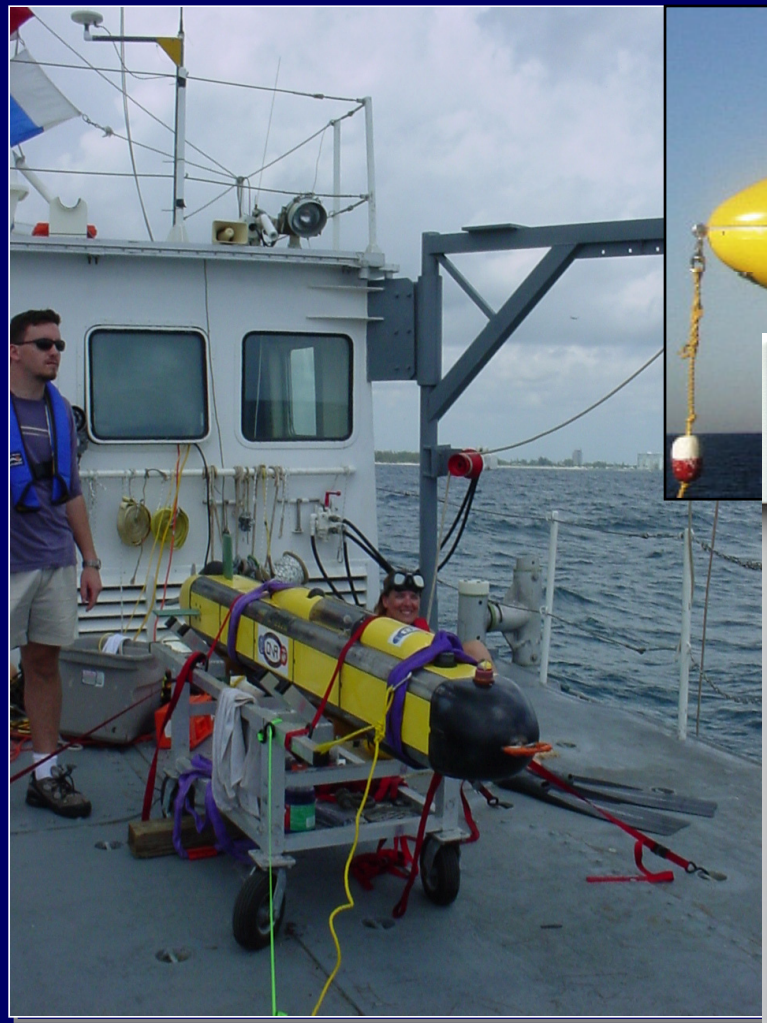
- Conflicting requirements
- Most popular energy choice
  - batteries

Battery Chemistry Comparison

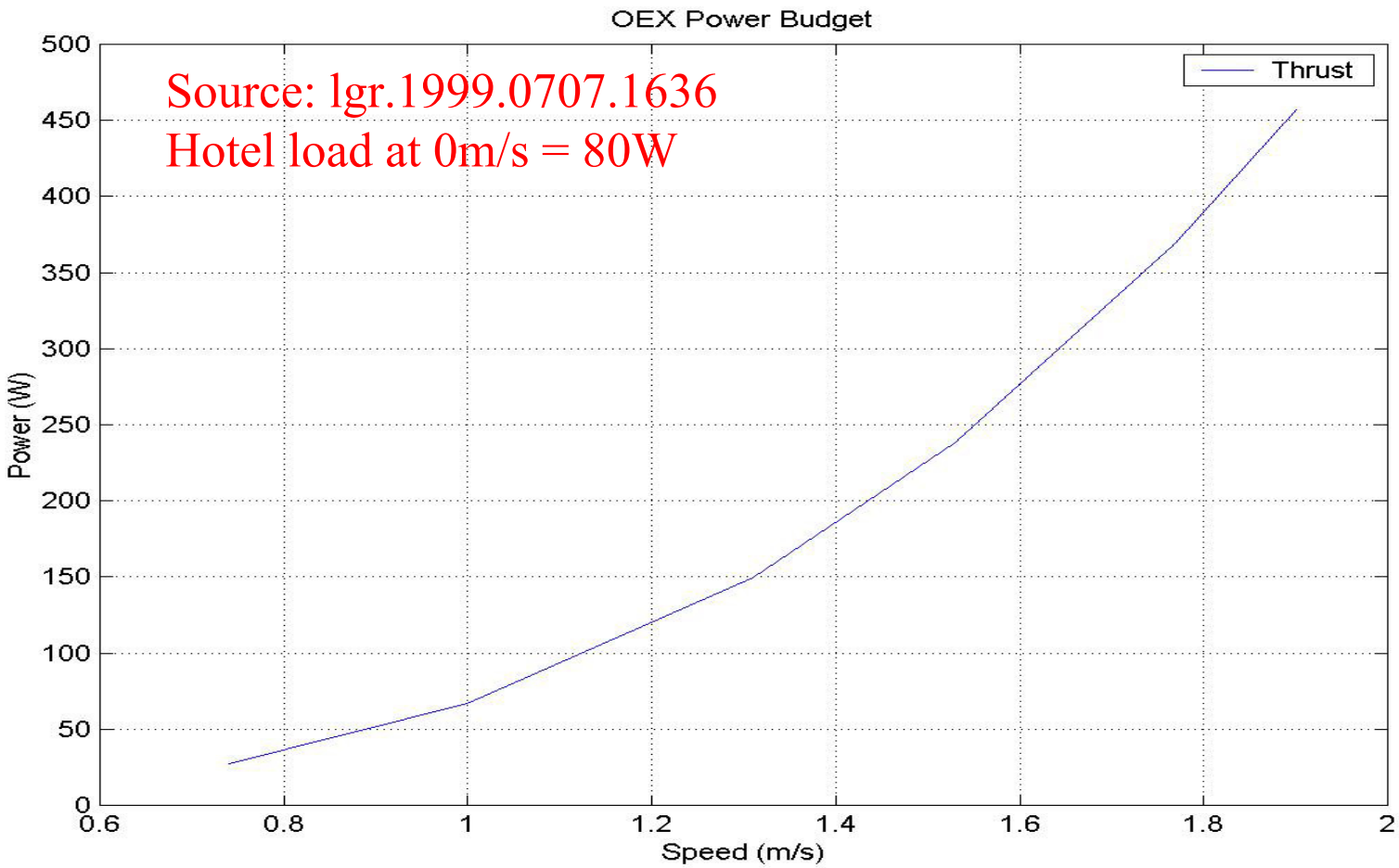
	Vendor Part No.	chemistry	Voltage (V)	Capacity		Weight (gm)	Volume (cm3)	Energy (WHrs)	Energy Density	
				AHr	Hr Rate				WHr / kg	WHr / L
primary	Duracell MX1300	Zn / MnO_2	1.5	-	212	147	56.4	21.2	144	376
	Ultralife U3360HCES	Li / MnO2	3.0	11	5.5	117	52.7	33	282	626
secondary	Hawker Cyclon 0810	Sealed Lead Acid	2.0	2.5	10	178	56.5	5	28	88
	Moltech (OEXB) EC-5000D	Sealed Ni-Cd	1.2	5	5	140	46.5	6	43	129
	Panasonic (Mor) HHR380A	Sealed Ni-MH	1.2	3.8	5	53	15.2	4.6	87	303
	Moli-Energy ICR-18650G	Li- Ion	3.75	1.8	5	45.5	16.9	7.5	165	444
	Sanyo (OEXC) HR-4/3FAUX	Sealed Ni-MH	1.2	4.1	5	62	17.2	4.9	79	285
	Ultralife UBC44106102	Li Ion Polymer	3.8	3.8	5	108	47.6	14.4	134	303

Florida Atlantic University

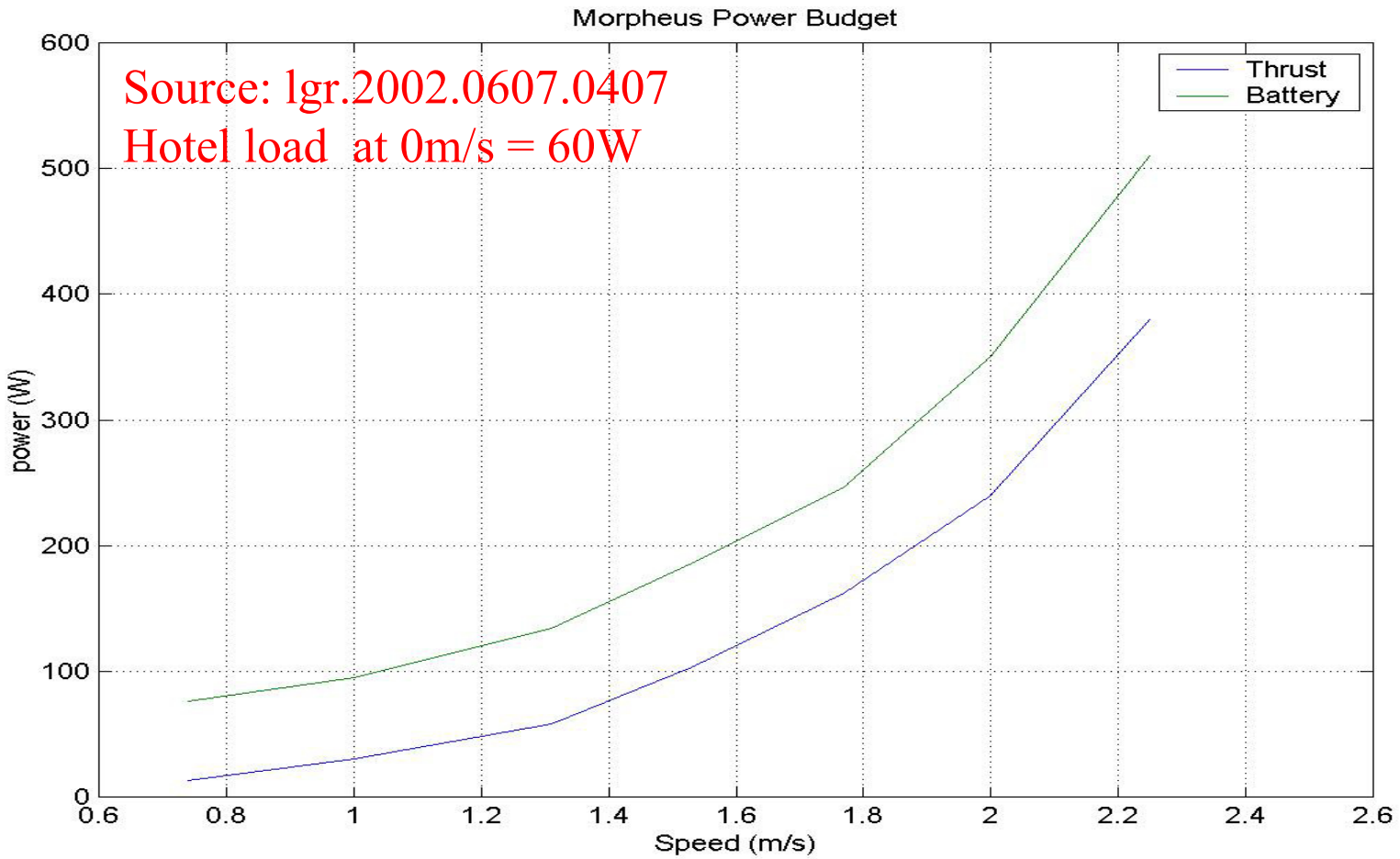
FAU AUVs



OVII/OEX Power Budget

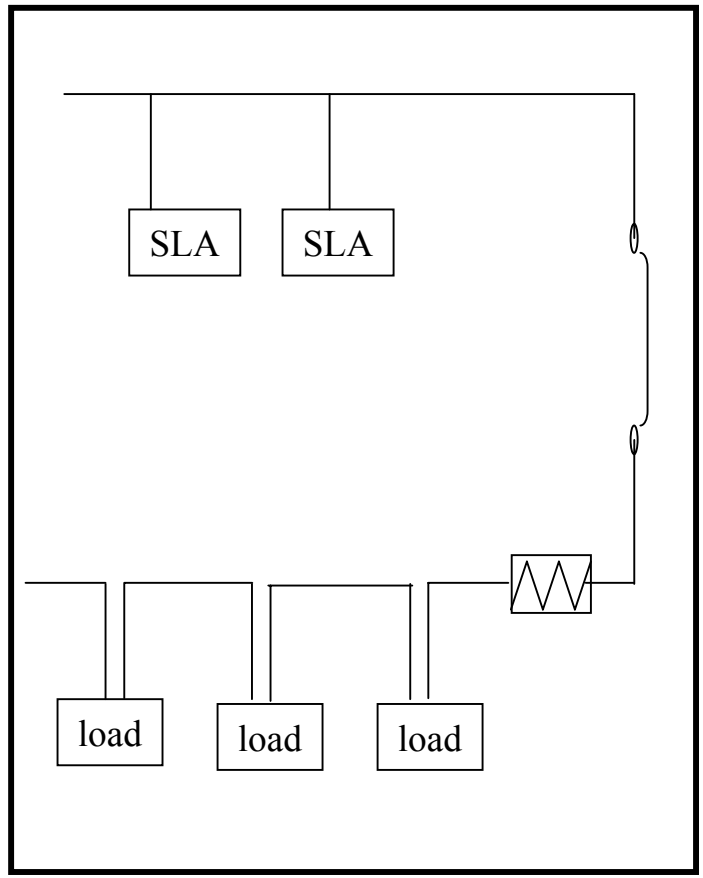


Morpheus Power Budget



OVII Energy System

- Individual battery pack
  - 5 12V lead acid (12Ah) in series
  - Nominal voltage = 60V (50-72V)
  - Total energy = 720WHrs
- Total energy
  - a maximum of two packs in parallel: 1440WHrs (~4.5 hours @ 3knots)
- Power distribution
  - daisy chained connection to loads w/ a 15A master circuit breaker
- Features
  - Battery packs are not modular
    - No PVs for individual packs
    - No intelligence built in battery packs
    - No in-situ charging (standard chargers to each cell)
  - Vehicle monitoring and control
    - Monitor bus voltage
    - Abort on low voltage



OEX Energy System

- Individual battery pack
  - 42 1.2V Ni-Cd (5Ah) in series (wide range of discharge rate)
  - Nominal voltage = 50V (42-60V)
  - Total energy = 250WHrs
- Total energy
  - Basic configuration 8 packs in parallel: 2KWHrs (~6 hours @ 3knots)
  - Additional number of packs in mid-section: 8
- Features
  - Battery packs are modular
    - PVs for individual packs
    - Intelligence built in battery packs w/ LonTalk PLC
    - In-situ charging

Ocean Explorer Power Distribution

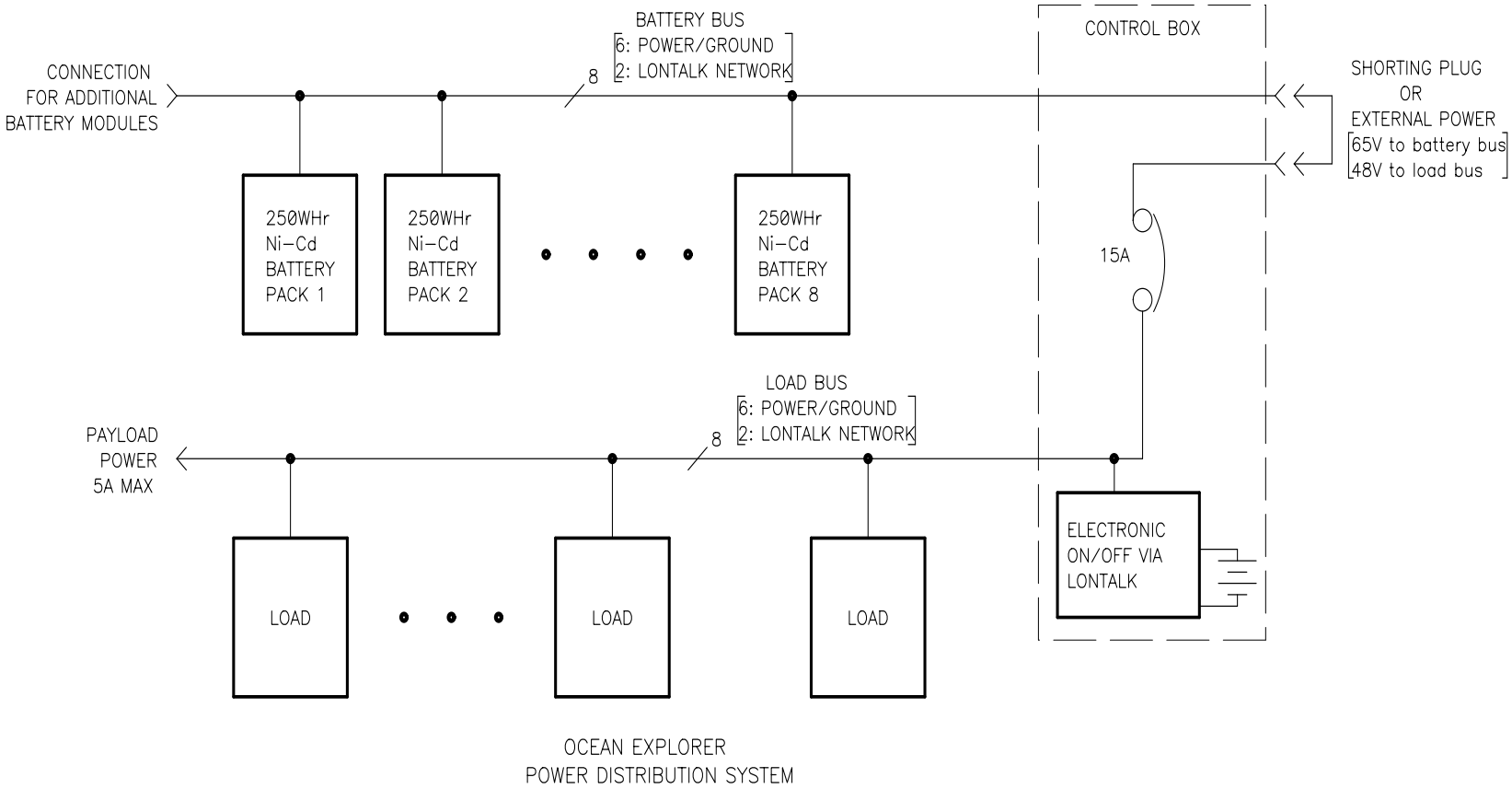


Figure : A power distribution system for Ocean Explorer

OEX Battery Monitoring & Control

- Monitoring
  - Voltage every 6 cells in the 42 cell series
  - Discharge battery current
  - Pack temperature, leakage, humidity, and bus voltage
  - Simple gas gauge
    - No self-discharge, temperature and discharge rate variation, and assume constant charge rate
- Control
  - Electronic on-off switch (from control box)
  - Electrical fuse and thermal fuse for safety
  - Low voltage diodes for paralleling multiple packs
  - A 10A electronic circuit breaker (max 500W throughput)
- Charging
  - 1A constant current source for charging (0.2C rate)
  - Allows up to 8 packs to be charged simultaneously

Morpheus Power System

- Individual battery pack
  - 42 1.2V Ni-MH (3.8Ah) in series (wide range of discharge rate)
  - Nominal voltage = 50V (42-60V)
  - Total energy = 190WHrs
- Total energy
  - Single module: 3 packs in parallel: 570WHrs (~3 hours @ 3knots)
  - Maximum number of modules: 4 (total energy: 2.3KWHrs)
- Additional Features
  - Bi directional current controller
    - Higher or lower external voltage source for charging
    - Require only a single supply for powering the vehicle and charging the batteries

Item	Weight (gm)	Quantity	Total Weight (gm)	Total Weight (lbs)	Percent of Total			
Battery Panasonic HHR450A	60	42	2520	5.544	75.52%	Pancake Energy	211.68	Whrs
HPSN	57	1	57	0.1254	1.71%	Specific Energy	28.83	Whrs/lb
Battery Connector Board	5	14	70	0.154	2.10%			
Motherboard	300	1	300	0.66	8.99%	2 pancake Energy	423.36	Whrs
Battery End Plates	120	1	120	0.264	3.60%	Vessel Weight	14.68	lbs
Battery Support Plates	80	2	160	0.352	4.79%			
Fan	20	3	60	0.132	1.80%	3 pancake Energy	635.04	Whrs
Hardw are	50	1	50	0.11	1.50%	Vessel Weight	22.02	lbs
	Pancake Weight gms/lbs		3337	7.3414				
Battery Panasonic HHR380A	53	42	2226	4.8972	73.15%	Pancake Energy	186.48	Whrs
HPSN	57	1	57	0.1254	1.87%	Specific Energy	27.86	Whrs/lb
Battery Connector Board	5	14	70	0.154	2.30%			
Motherboard	300	1	300	0.66	9.86%	2 pancake Energy	372.96	Whrs
Battery End Plates	120	1	120	0.264	3.94%	Vessel Weight	13.39	lbs
Battery Support Plates	80	2	160	0.352	5.26%			
Fan	20	3	60	0.132	1.97%	3 pancake Energy	559.44	Whrs
Hardw are	50	1	50	0.11	1.64%	Vessel Weight	20.08	lbs
	Pancake Weight gms/lbs		3043	6.6946				
Battery Panasonic HHR210A	38	42	1596	3.5112	66.14%	Pancake Energy	105.84	Whrs
HPSN	57	1	57	0.1254	2.36%	Specific Energy	19.94	Whrs/lb
Battery Connector Board	5	14	70	0.154	2.90%			
Motherboard	300	1	300	0.66	12.43%	2 pancake Energy	211.68	Whrs
Battery End Plates	120	1	120	0.264	4.97%	Vessel Weight	10.62	lbs
Battery Support Plates	80	2	160	0.352	6.63%			
Fan	20	3	60	0.132	2.49%	3 pancake Energy	317.52	Whrs
Hardw are	50	1	50	0.11	2.07%	Vessel Weight	15.93	lbs
	Pancake Weight gms/lbs		2413	5.3086				
Battery Molicel ICR-18650	44	42	1848	4.0656	61.50%	Pancake Energy	233.10	Whrs
HPSN	57	1	57	0.1254	1.90%	Specific Energy	35.26	Whrs/lb
Charger/Monitor Board	30	14	420	0.924	13.98%			
Battery Connector Board	5	14	70	0.154	2.33%	2 pancake Energy	466.20	Whrs
Motherboard	200	1	200	0.44	6.66%	Vessel Weight	13.22	lbs
Battery End Plates	120	1	120	0.264	3.99%			
Battery Support Plates	80	2	160	0.352	5.32%	3 pancake Energy	699.30	Whrs
Fan	20	4	80	0.176	2.66%	Vessel Weight	19.83	lbs
Hardw are	50	1	50	0.11	1.66%			
	Pancake Weight gms/lbs		3005	6.611				

Morpheus Pack Design

			MEASURED 10/22/99					
Item	Weight (gm)	Quantity	Total Weight (gm)	Total Weight (lbs)	Percent of Total			
Battery Panasonic HHR380A	54	42	2268	4.9896	74.41%	Pancake Energy	186.48	Whrs
HPSN	57	1	57	0.1254	1.87%	Specific Energy	27.81	Whrs/lb
Battery Connector Board (201-108)	165	1	165	0.363	5.41%			
Battery Connector Board (200-108)	178	1	178	0.3916	5.84%			
Battery Mounting Plate (201-116)	67	2	134	0.2948	4.40%	2 pancake Energy	372.96	Whrs
Battery Controller Board (200-118)	161	1	161	0.3542	5.28%	Vessel Weight	13.41	lbs
Fan	19	2	38	0.0836	1.25%			
Hardware	47	1	47	0.1034	1.54%	3 pancake Energy	559.44	Whrs
						Vessel Weight	20.12	lbs
	Pancake Weight gms/lbs		3048	6.7056				
			ORIGINAL ESTIMATION					
Battery Panasonic HHR380A	53	42	2226	4.8972	73.15%	Pancake Energy	186.48	Whrs
HPSN	57	1	57	0.1254	1.87%	Specific Energy	27.86	Whrs/lb
Battery Connector Board	5	14	70	0.154	2.30%			
Motherboard	300	1	300	0.66	9.86%	2 pancake Energy	372.96	Whrs
Battery End Plates	120	1	120	0.264	3.94%	Vessel Weight	13.39	lbs
Battery Support Plates	80	2	160	0.352	5.26%			
Fan	20	3	60	0.132	1.97%	3 pancake Energy	559.44	Whrs
Hardware	50	1	50	0.11	1.64%	Vessel Weight	20.08	lbs
	Pancake Weight gms/lbs		3043	6.6946				

Ni-MH Bench Discharge Results

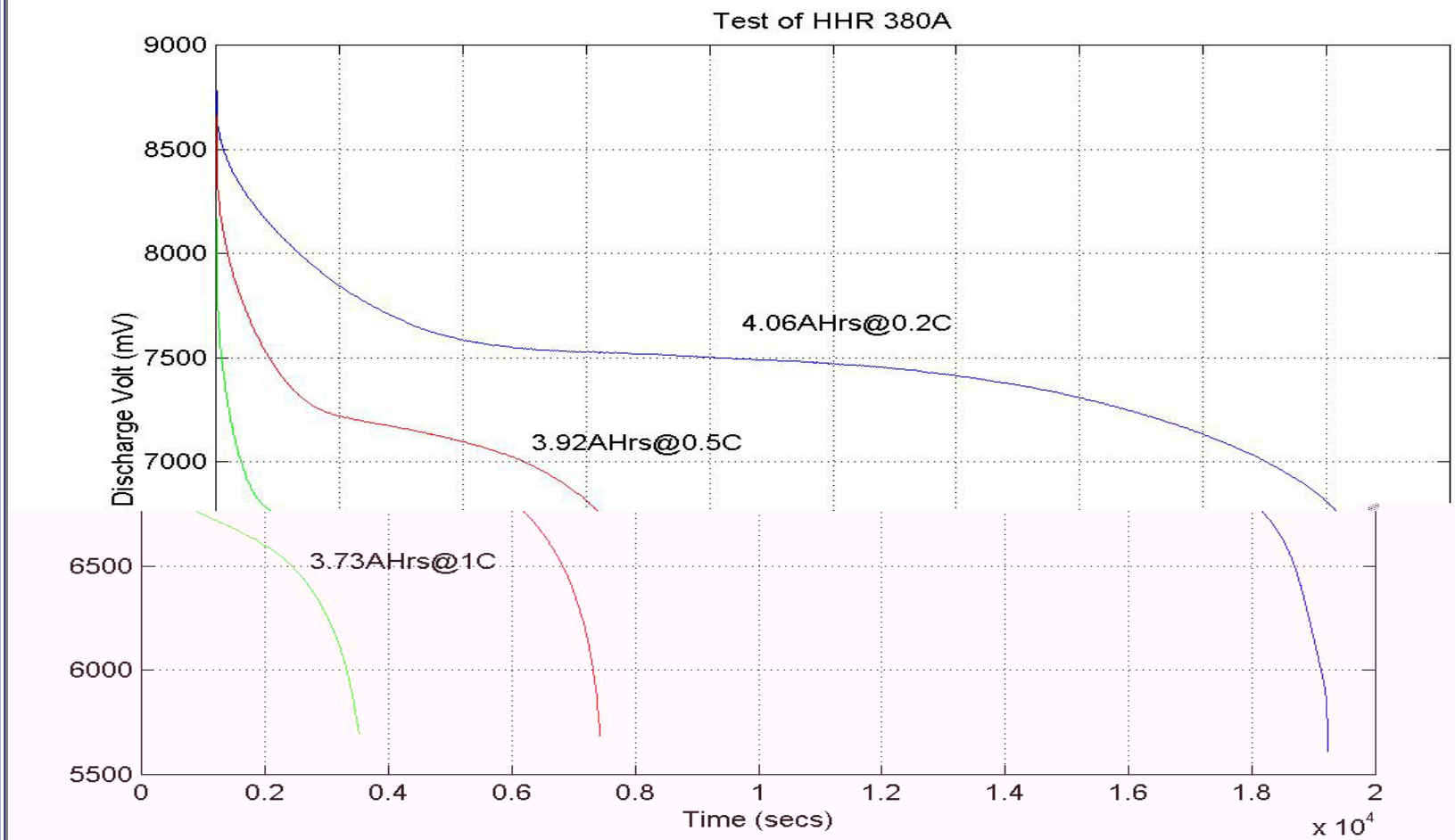


Figure 3: Bench test results at different discharge rate using 6 Panasonic HHR380A NiMH cells in series. The nominal cell voltage is 1.2V.

Morpheus Power Distribution

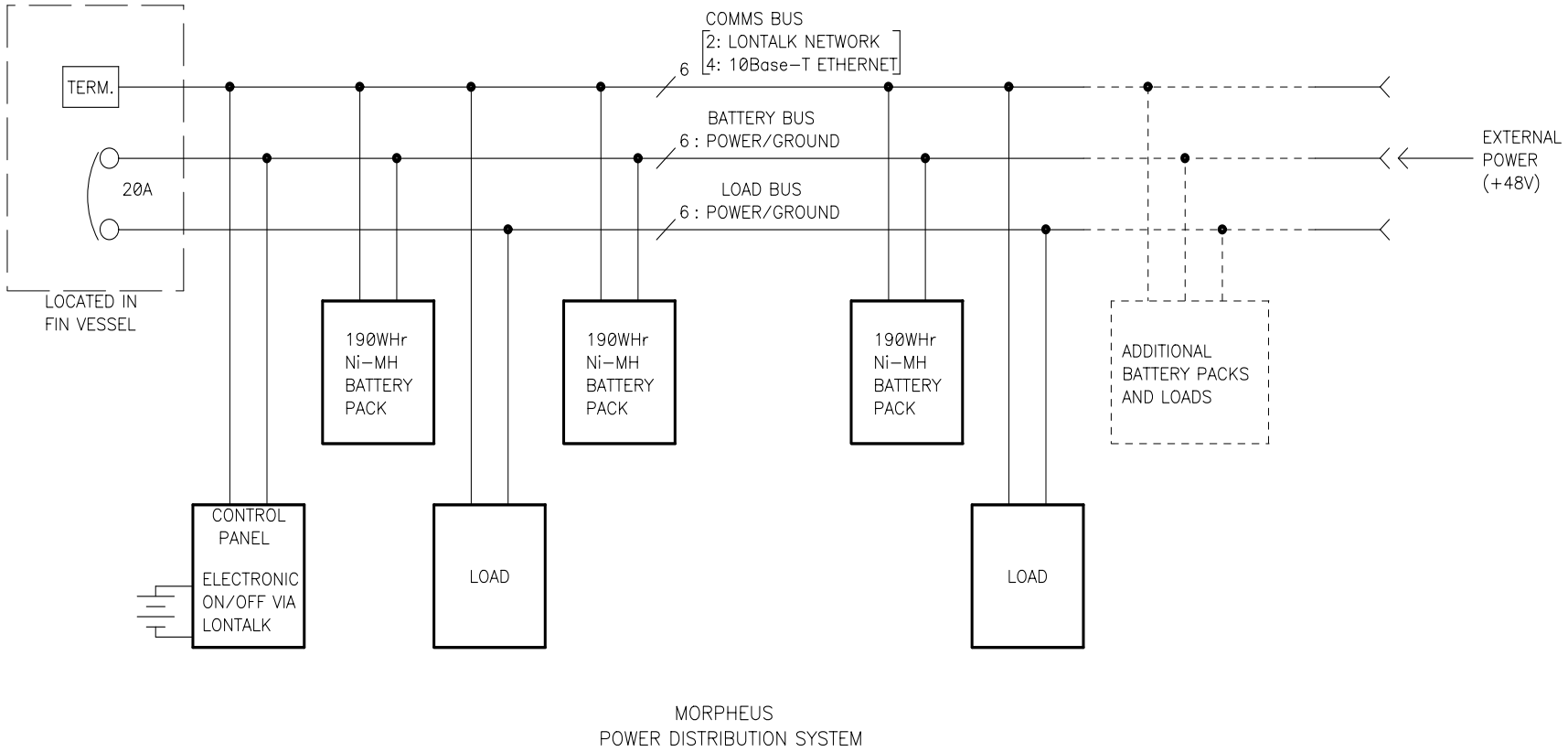


Figure 2: A power distribution system for Morpheus

Morpheus Monitoring & Control

- Monitoring
  - Voltage every 4 cells in the 42 cell series
  - Discharge battery current
  - Pack temperature, leakage, humidity, and bus voltage
  - Improved gas gauge
    - Account for self-discharge, charge/discharge current sense, temperature and discharge rate variation
  - Estimate end of discharge/charge conditions
- Control
  - Electronic on-off switch with soft start
  - Electrical fuse and thermal fuse, pressure sensors / port for safety
  - Low voltage diodes for paralleling multiple packs
  - A 0-8A programmable current limit with preset time out (max 400W throughput)
- Charging
  - 0-4A programmable constant current source for charging (typical 0.5C rate)

Morpheus Monitoring and Control

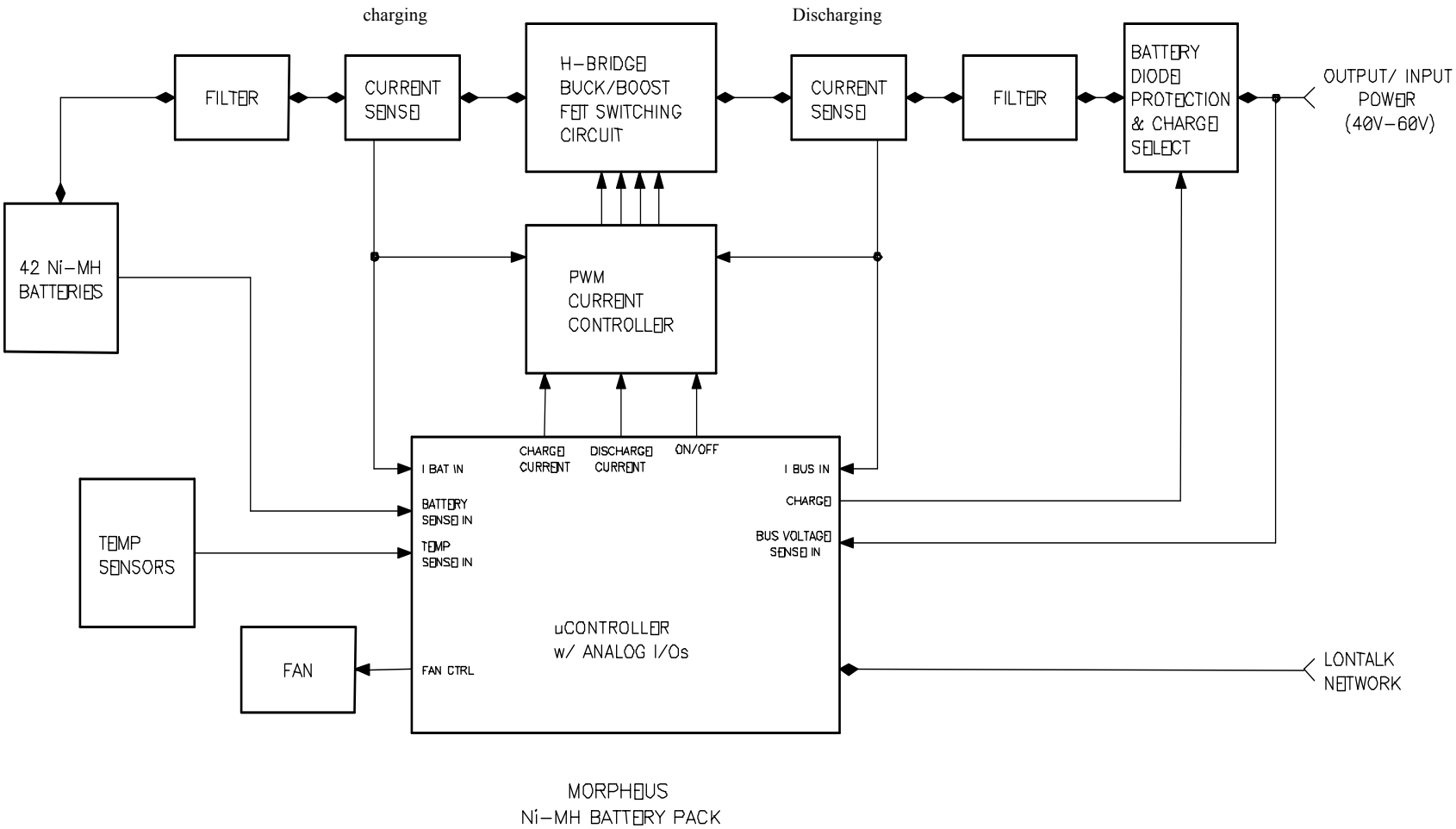
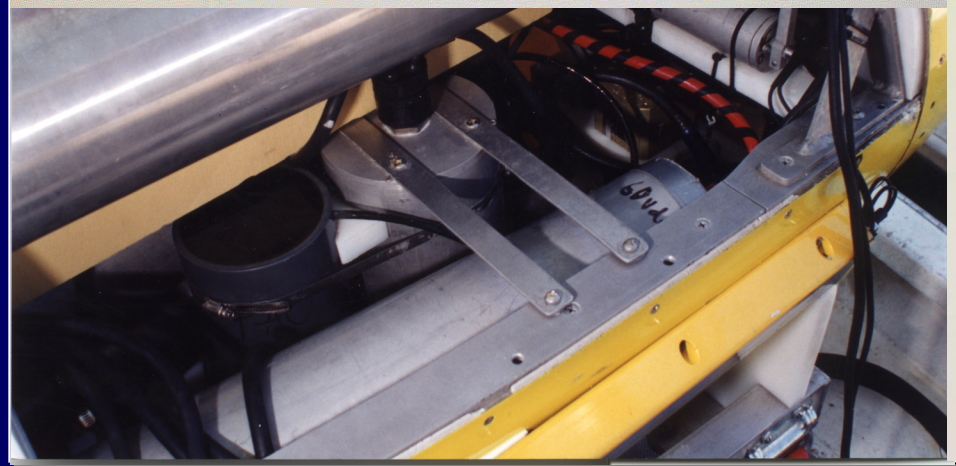
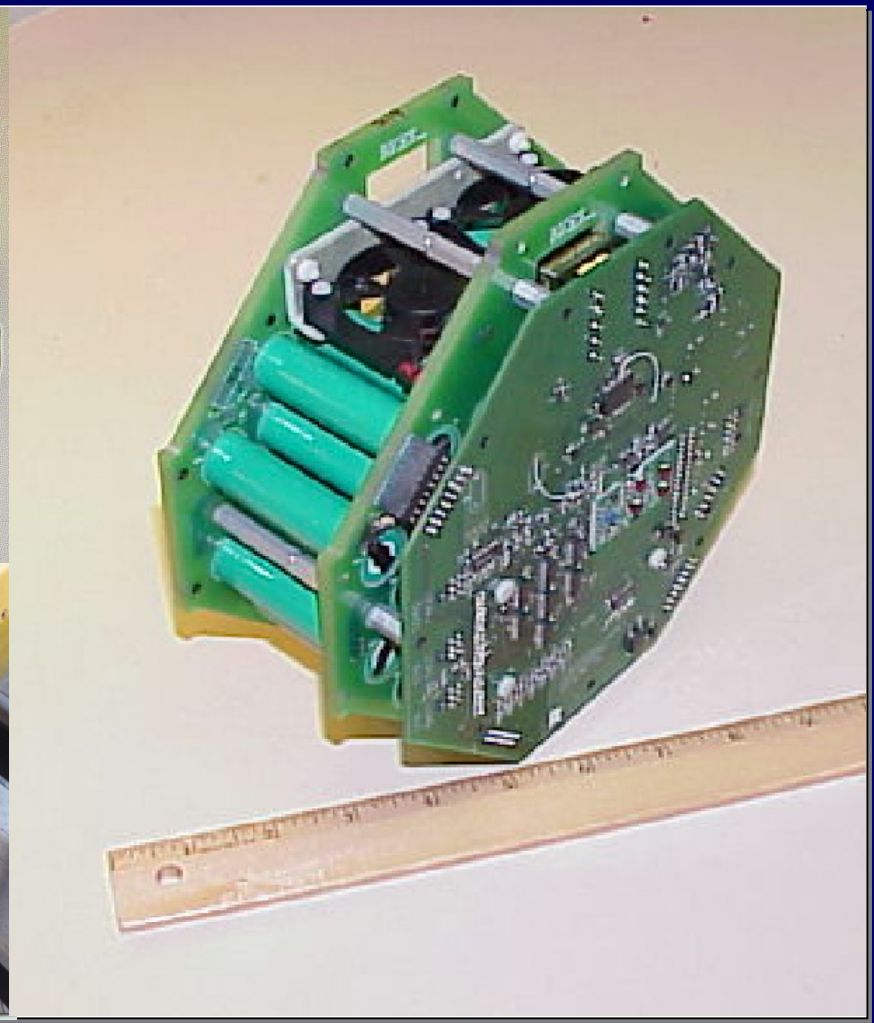


Figure 4: Morpheus monitoring and control mechanism

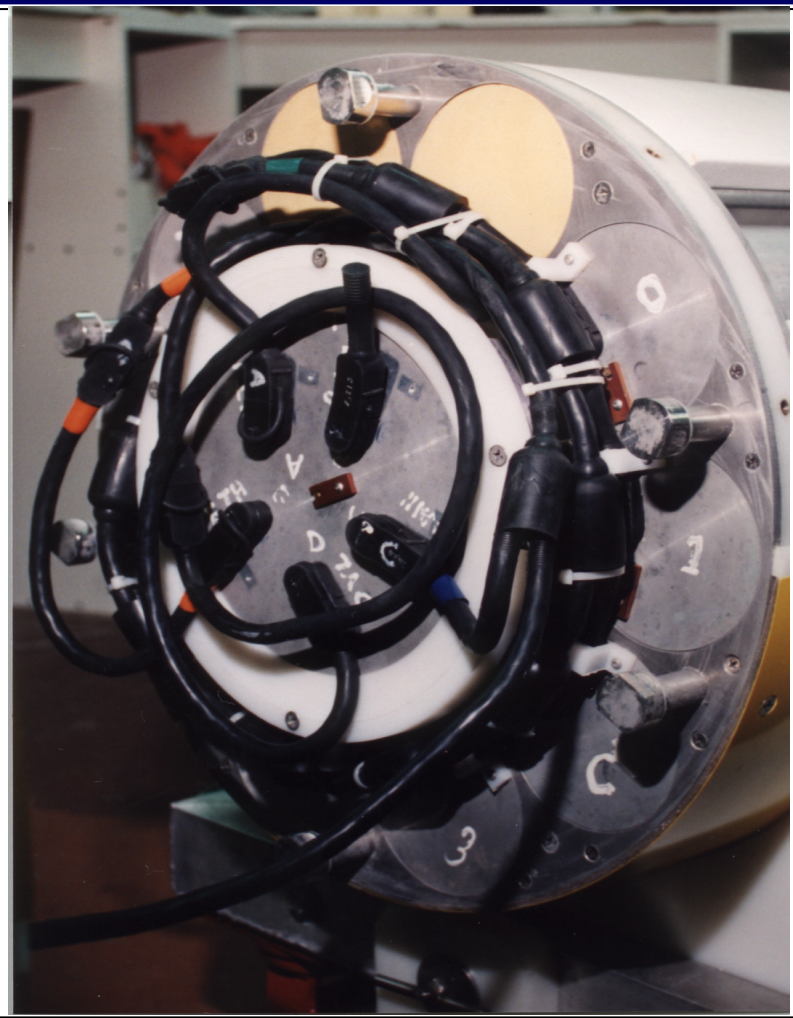
Florida Atlantic University

AUV Battery Packs





OEX Battery Pack Arrangement



Remarks on FAU Energy Systems

- FAU Energy Systems Features
  - Modularity
    - OEX and Morpheus
    - Intelligence localized
    - Each pack is a node on the network
    - Support scalability and re-configurability
    - Can accommodate new battery chemistry available
  - Reliability
    - Demonstrated from the at-sea operations
    - Built in safety features: fuses, circuit breaker, current limit w/ time out, pressure relief port, pressure/humidity/leakage/temperature sensors for fault detection

Future Battery Chemistry

- Lithium Polymer
  - Flexible form factor (low profile)
  - Solid polymer (can eliminate the metal shell)
  - Better safety (e.g. over-charge and leakage)
  - Expected improvements in 5 years
    - Cost will go down
    - Energy density will go up
    - Cycle count will go up
  - Special Advantages for AUV applications
    - Can better handle pressure
    - Fit better in small AUVs
    - More safe and energy density
    - Less magnetic signature