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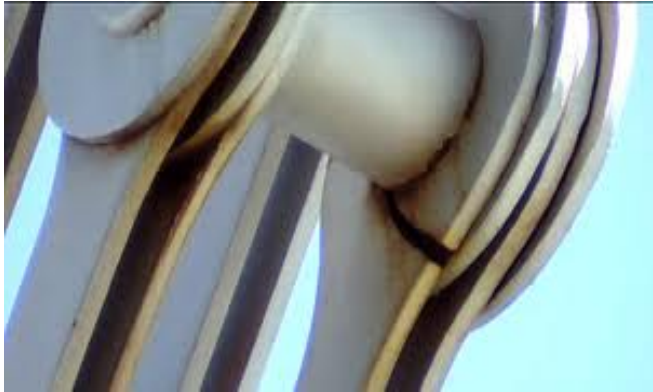
# Self-Powered Wireless Sensor Network for Structural Bridge Health Prognosis

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Mistras Group Inc., Princeton Junction, NJ, USA

**NIST Civil Infrastructure Showcase 2014**

We want to detect and monitor these...



...to avoid these!



- **IN 2009 NIST FUNDED THE PROJECT “SELF POWERED WIRELESS SENSOR NETWORK FOR STRUCTURAL HEALTH PROGNOSIS” THROUGH ITS TECHNOLOGY INNOVATION PROGRAM (TIP)**

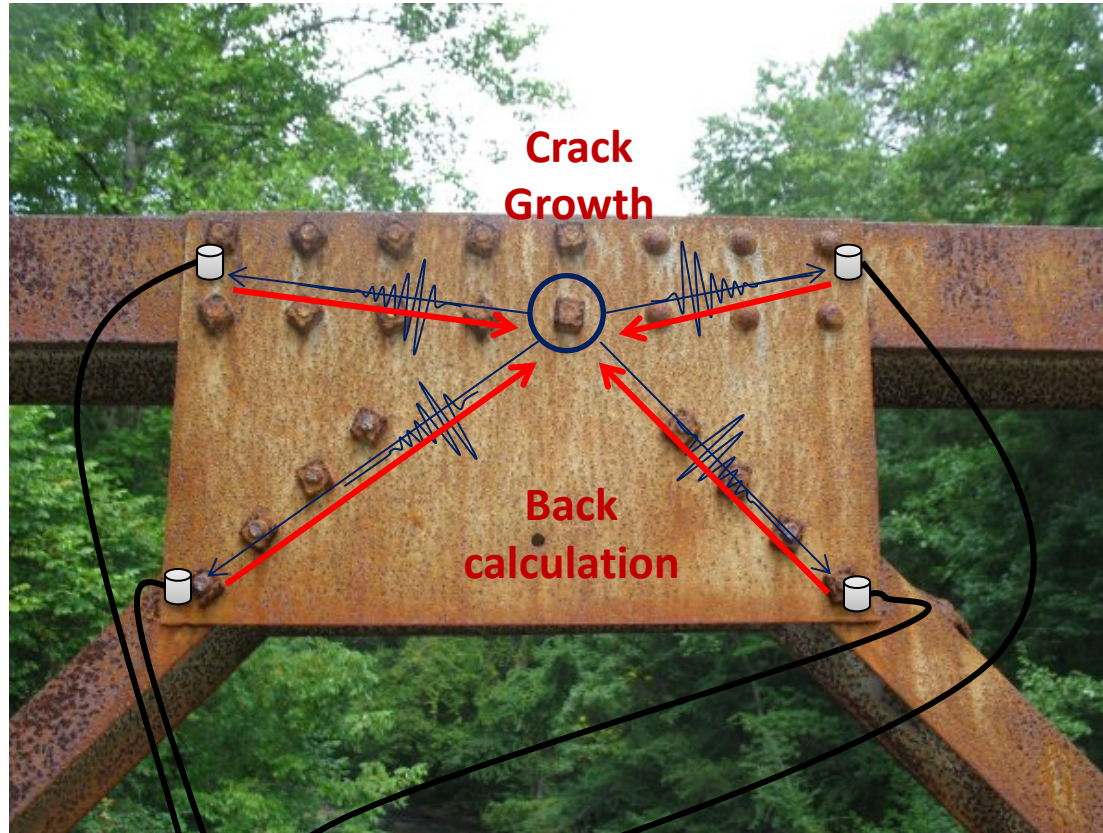
- **TWO MAJOR GOALS**

– Transforming unused ambient structural energy into power using energy harvesters for powering a newly developed data fusion wireless sensor node

– Interpretation of fused sensor data for identifying structural damage and deterioration through specially developed models and algorithms

- **ONE FINAL OBJECTIVE**

– To deliver a commercially viable self-powered data fusion wireless sensor node with built-in predictive models and decision algorithms for bridge component health prognosis.



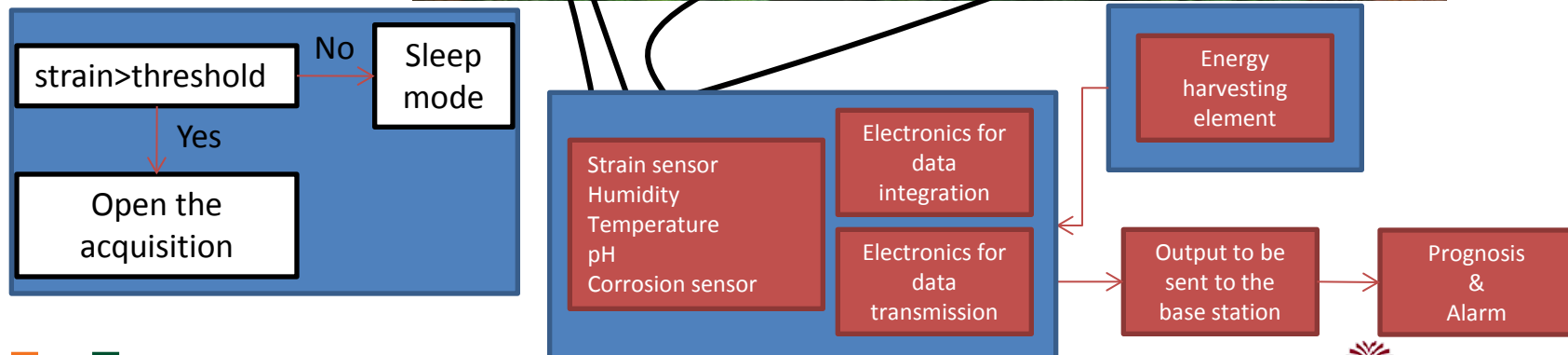
AE sensor-1

AE sensor-4

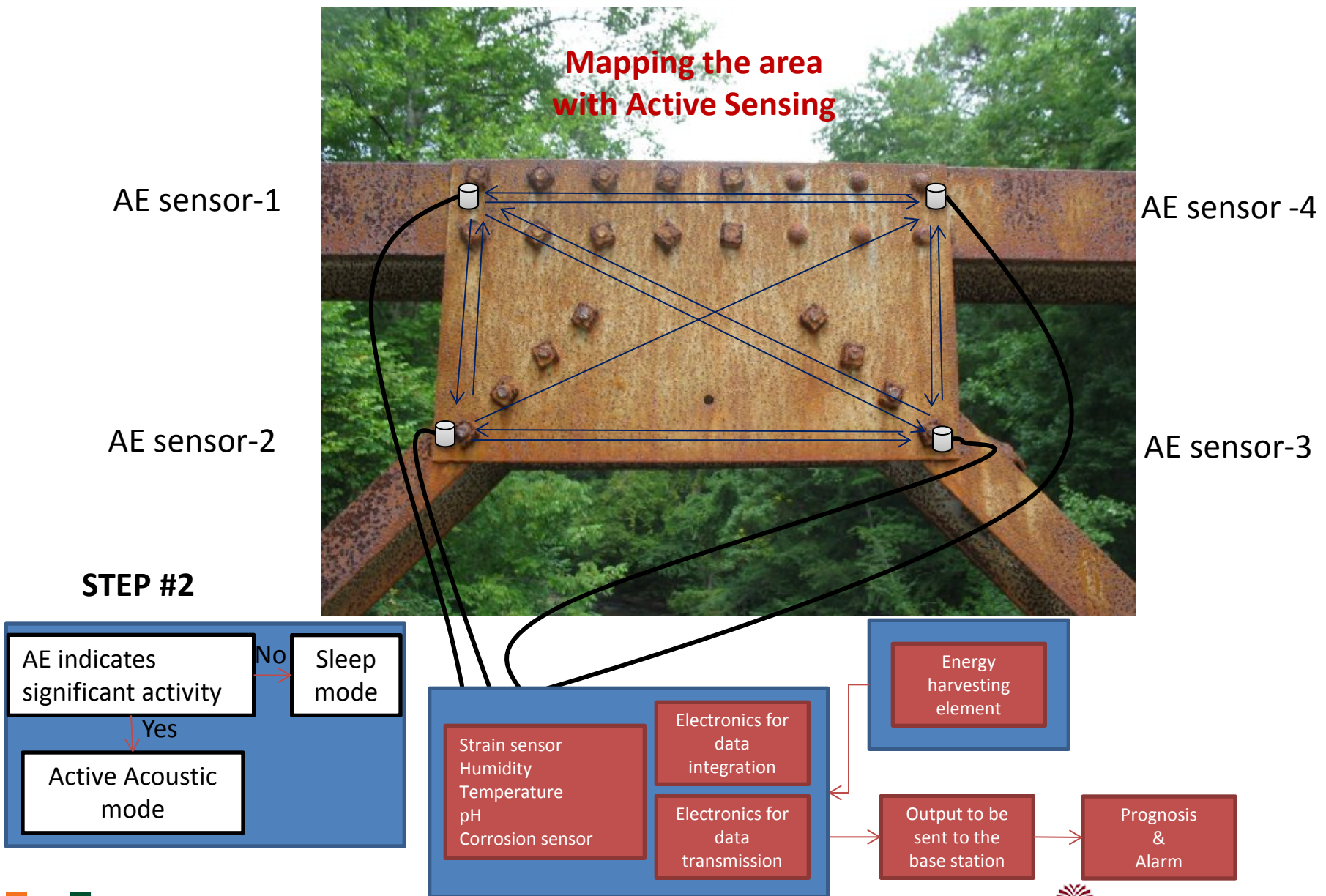
AE sensor-2

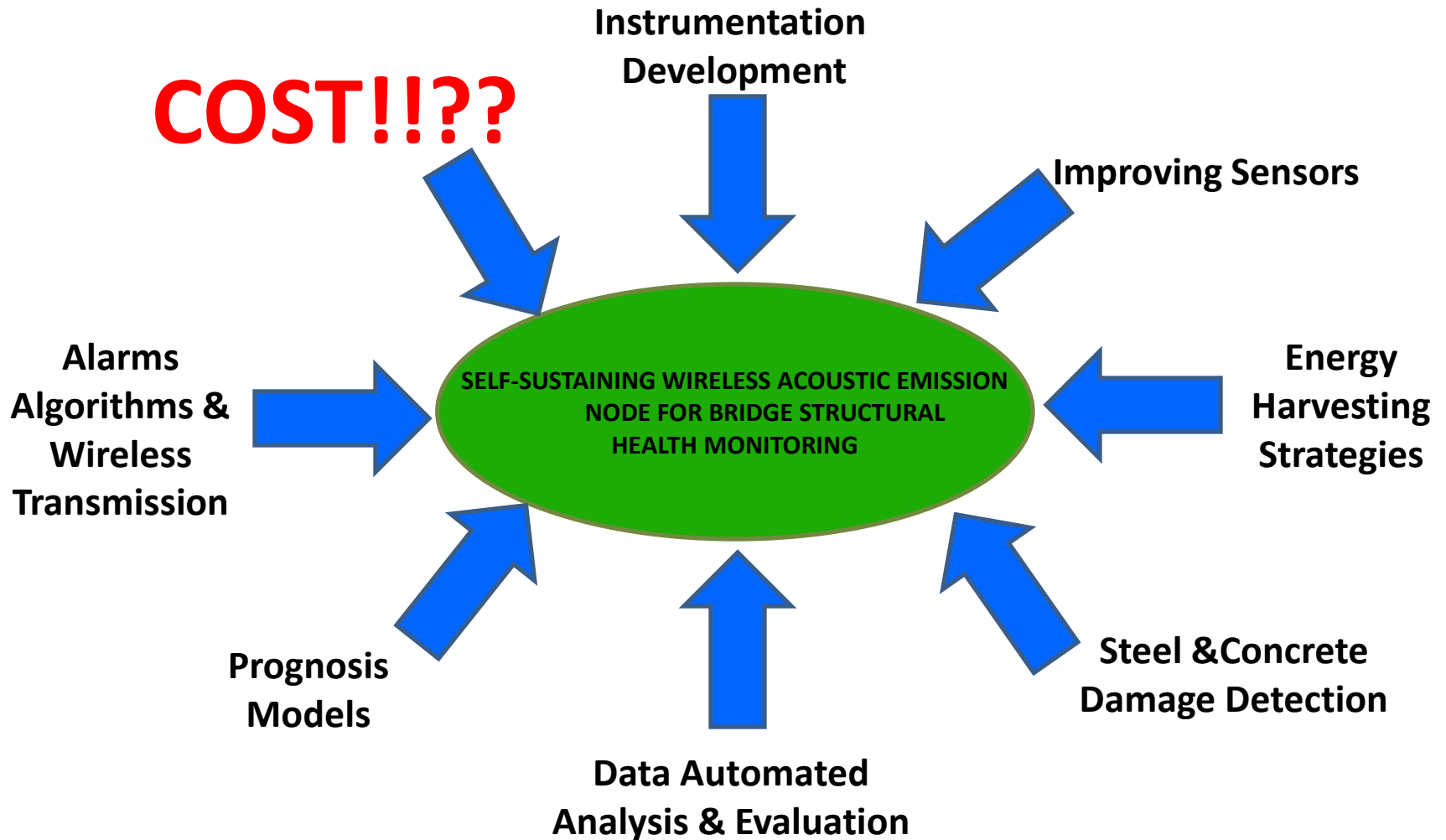
AE sensor-3

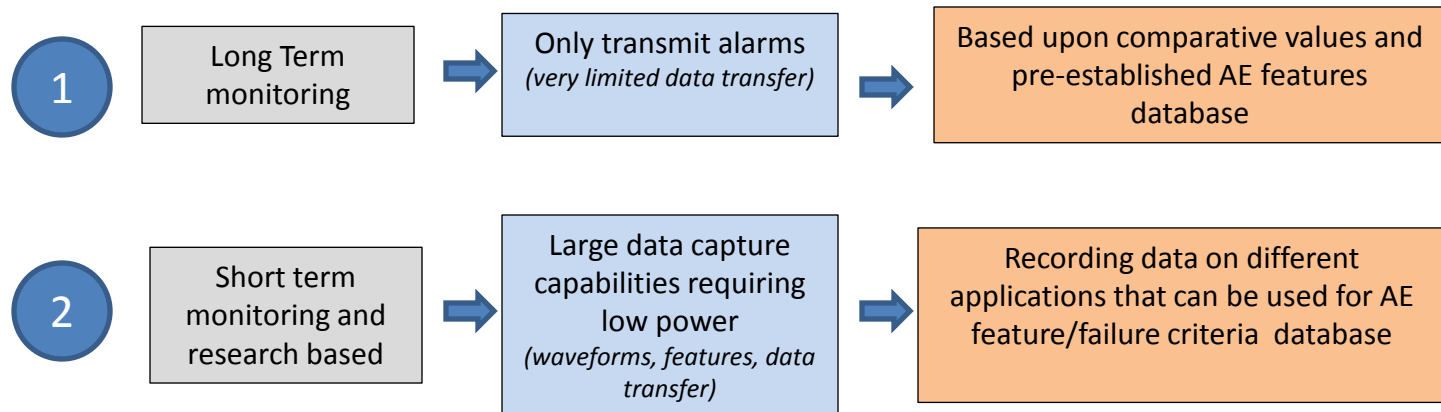
## STEP #1









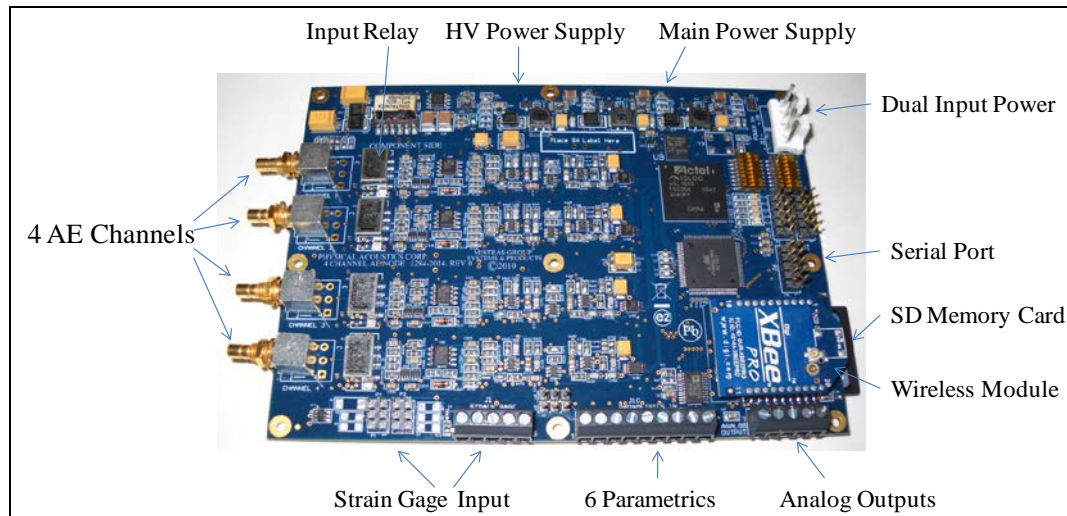


### General capabilities that requiring improvement

- Reduce power consumption of strain gauge module
- Develop the framework for user defined power saving capabilities (awake/sleep conditions) based upon AE features and or rate, parametric and strain gauge comparative values
- Investigate multiple commercial powering options to offer with the node based upon application requirements

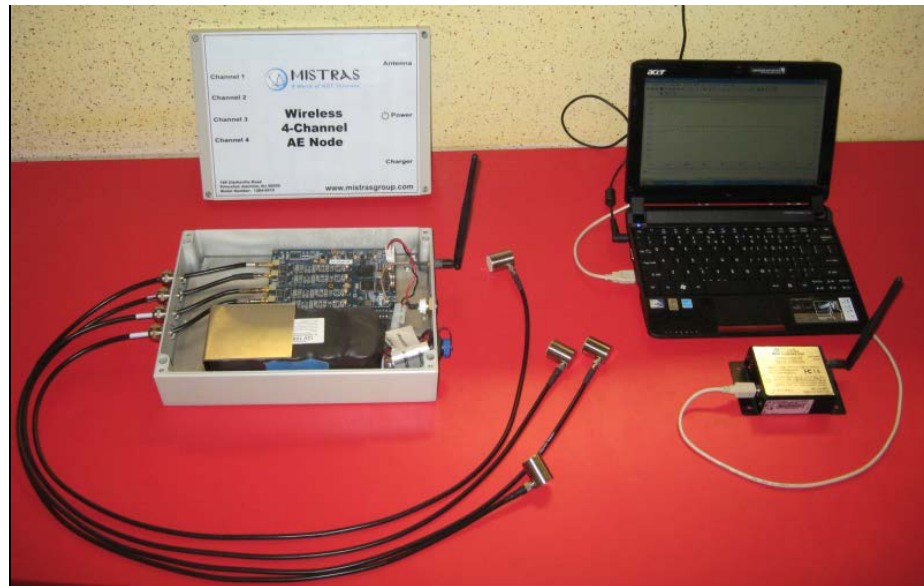
## 4-CHANNEL AE WIRELESS NODE (1284)

- This system is the **SMALLEST, LOWEST POWER**, full capability AE system ever developed
- Being developed as a standalone prognostic system with capability to built in computer, processing and decision making.
- Input for energy harvesters
- The latest technology is used to reduce cost and size and improve performance.
- Several parametrics available including Strain gage, Temperature, Pressure, etc.



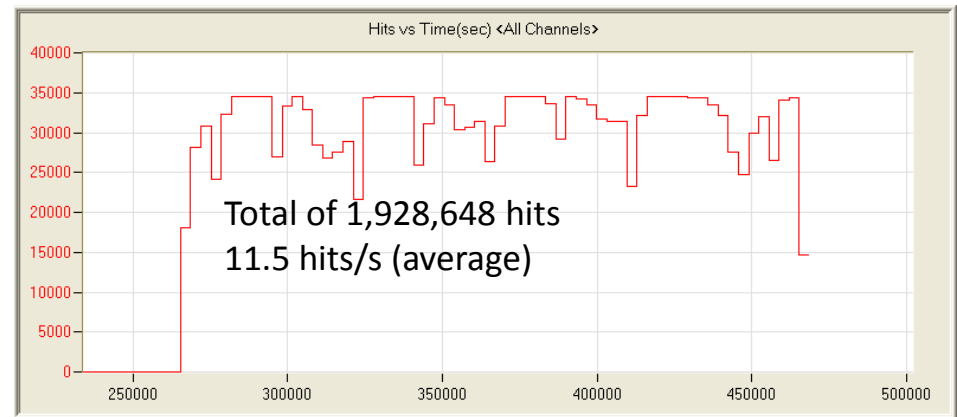


|                           |   |
|---------------------------|---|
| Board Size                | 4in x 5.5in   |
| Weight                    | Less than 0.5 lbs   |
| Power Requirements        | 5-18 volts (2 inputs, largest will power the node)  |
| Power Consumption         | 170 mW at full power (at 10 or less hits/sec)<br>50 mW in sleep mode with hit or parametric wakeup<br>10 mW in sleep mode with timer wakeup |
| Operating Temperature     | -40° F to 158° F (-40° to 75° C)  |
| AE bandwidth              | 1 kHz to 250 kHz  |
| Acousto-Ultrasonic Pulser | Adjustable, 5 to 40 volts, adjustable toneburst (frequency and number of cycles) on individual channels                                     |
| Parametric Channels       | 6 (voltage & current)   |
| Strain Gage Channels      | 1   |
| Memory Card               | SD Memory card slot for mass storage  |



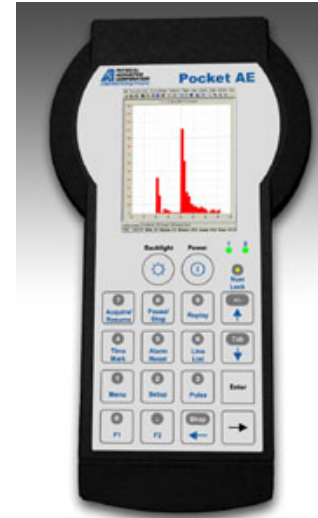
| Capabilities   |
|--|
| AST on user demand   |
| Full watch mode capability to connect and disconnect from unit during testing. |
| Sleep-Wake up mode based on parametric input values (defined on factory)       |
| User alarm definition and wireless alarm transmission                          |
| Measurement of 6 voltage inputs and 1 strain gauge                             |
| Dedicated parametric for measuring battery voltage                             |
| Capability of auto resetting   |
| Improved ESD resistance (8KV)  |
| Capability of file data transfer when not in acquisition                       |

- The wireless transmission protocol for the 1284 was selected based AE data set rate needed, maximum range of communication, and energy consumption.
- The interface selected was XBee at 900 kHzA, with a range of 600 m, interface data rate of 57.6Kbps with a maximum AE data set rate of 250 AE hits per second.
- The 1284 was deployed at the Rosenstiel School of Marine and Atmospheric Science (RSMAS) of the University of Miami for a period of two months to test the wireless communication and battery life.
- The results show the rechargeable battery lasted approximately 5 days transmitting data wirelessly at a data rate of detection of 11 AE hits per second.





**Pocket AE**



## 1/5 of the energy used by the Pocket AE

### Capability of

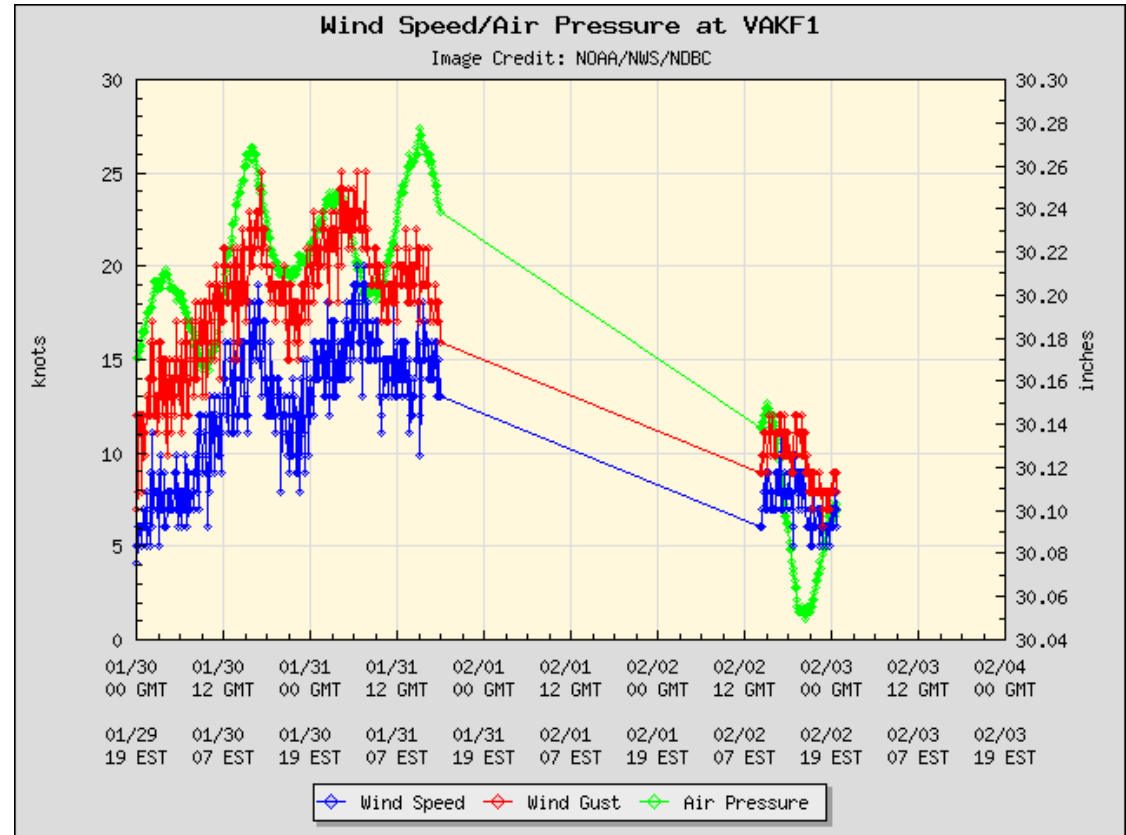
- Data transmission real time and offline
- 4 channels/6 parametrics/ 1 strain gauge
- Waveform saving (11 hits per ch (wf)/s, 80 hits per ch/s)
- Power saving capabilities (programmable)

### Capability of

- Data storage
- 2 channels/2 parametrics
- Waveform saving (100 hits per ch/s (wf))
- FFT

1 knot = 1.15 mph

Increased friction between gears and nacelle in lower wind turbine, leads to better operation at higher wind speeds.

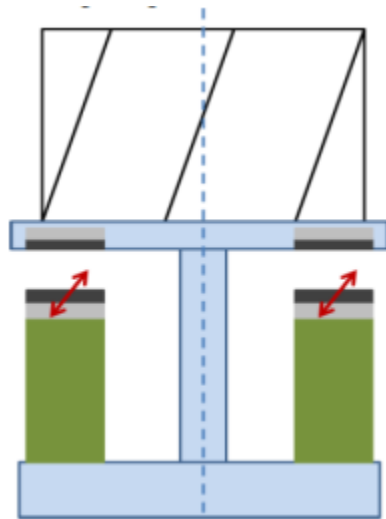


[http://www.ndbc.noaa.gov/show\\_plot.php?station=vakf1&meas=wdpr&uom=E&time\\_diff=-5&time\\_label=EST](http://www.ndbc.noaa.gov/show_plot.php?station=vakf1&meas=wdpr&uom=E&time_diff=-5&time_label=EST)

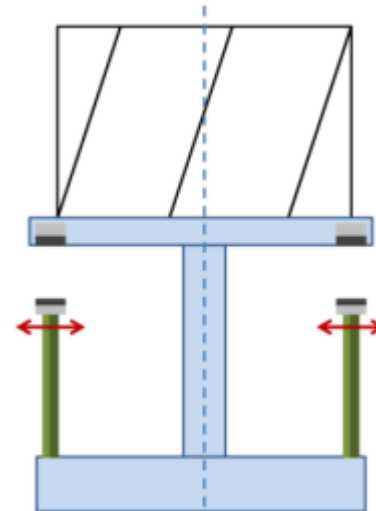
Wind Tunnel Experimentation revealed that the best performing SWEPT is capable of producing electrical power in the range of 100-700 mW when the wind speed is between 6-11 mph.



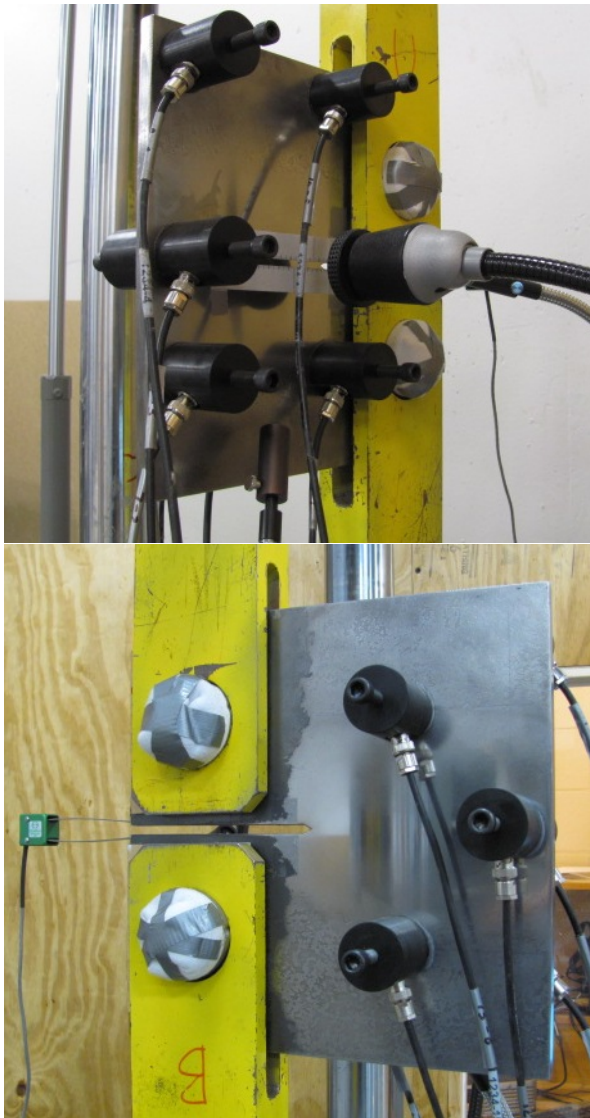
- Developed novel concept of nonlinear piezoelectric wind turbine, successfully modeled this concept, and verified predicted phenomena experimentally.
- 10 mW at simulated 5 mph wind speeds from piezoelectric wind turbine (3" x 3" x 8" volume).



Radial Configuration



Tangential Configuration



***AE monitored fatigue tests for the determination of critical cracking level, and prediction of fatigue life***

➤ **Approaches for signal identification and AE data reduction**

- Friction emission tests to understand characteristics of noise;
- Eliminating AE collected below 80% of peak load to minimize grating signals;
- Swansong II filter to minimize mechanical noise;
- Waveform investigation to evaluate quality of AE data
- Software packages: AEwin, Noesis

# Corrosion Detection in Prestressed Concrete

## Medium-scale Prestressed Girders

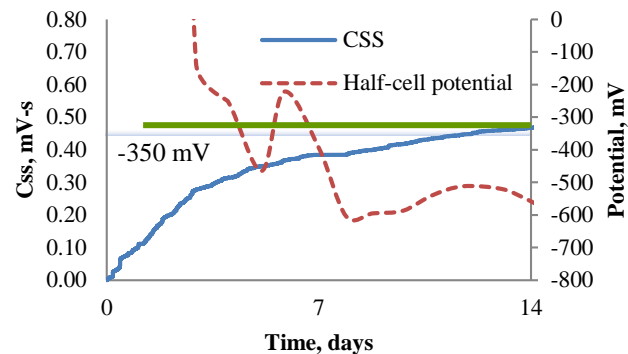
**Corrosion:** Long-term cyclic exposure (6 mo.) to 3% saline solution.

**Monitoring:** Daily electrochemical measurements and continuous AE.

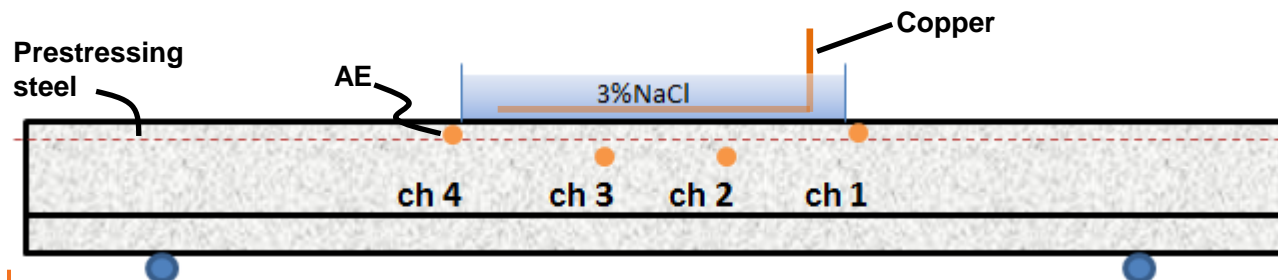
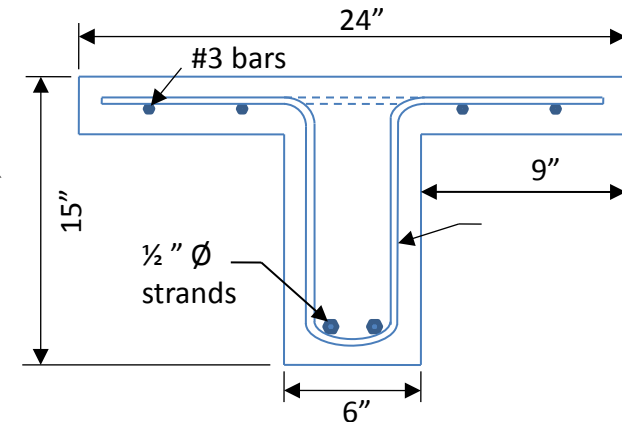
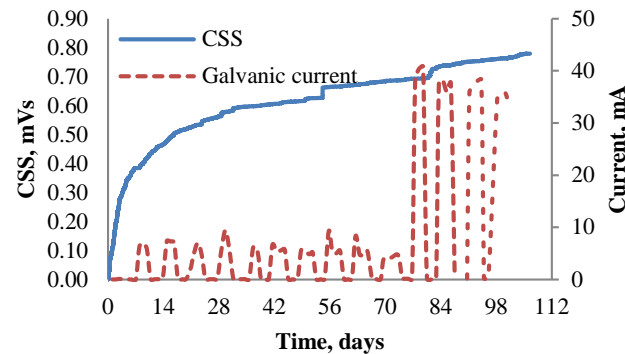
**Beam types:** Three flexure girders 16'- 4" with varying crack widths and one 9'-8" shear/bond.

**Load test:** Specimens (plus control) subjected to increasing amplitude cyclic loading.

0.032 in. Cracked Beam, Corrosion Initiation



0.032 in. Cracked Beam for 15 wet/dry cycles



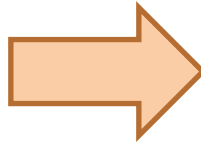
The limitations of the 1284 node are the result of the need of maintaining the power consumption down, so the battery life can be extended as long as possible.

- The hit rate (or maximum number of hits that can be processed, recorded and transferred by the unit per unit time) is determined by the capability of the FPGA (field programmable gate array), which is linked to their power consumption.
- Data transmission is limited to having a base station in range. Different protocols can be used but require more power.
- The type of FPGA used in the 1284 node does not maintain date and current time, so synchronizing multiple units together is not possible.
- Waveforms are only saved into the node's SD card, this brings potential difficulties when setting up the node for a new application



## Site Characteristics:

- Accessibility
- Secure area
- Controlled Environment



## RASMAS

*Rosenstiel School of Marine and  
 Atmospheric Science  
 Key Biscayne, FL*



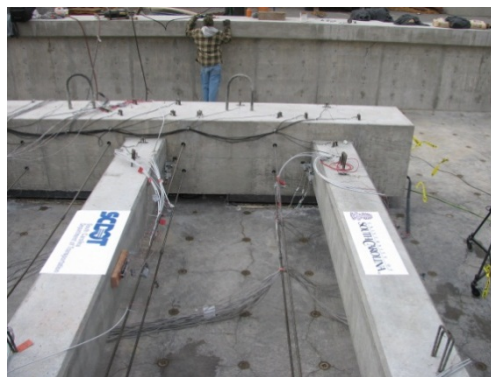
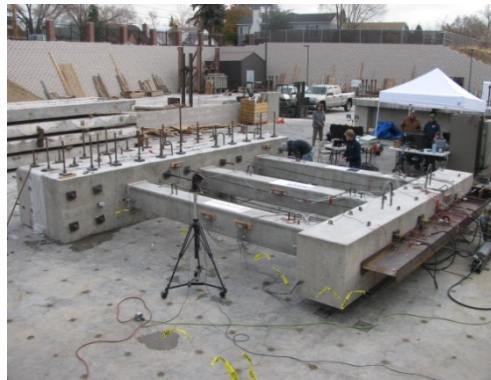




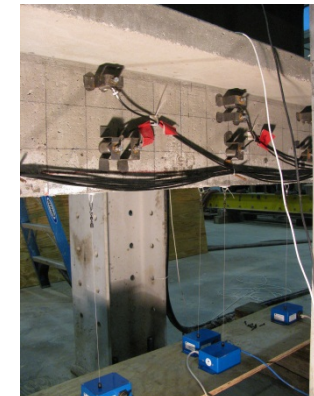




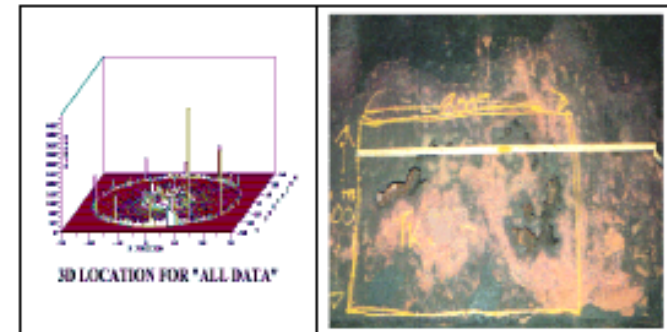
Both Wired and Wireless Systems Used to Monitor I-77 Steel Girder Bridge Near Rock Hill, SC.



- Medium scale T-beams U.S.C Structures Lab
- 3-Pile test UN Reno



- Monitoring of portable/prefabricated bridges (use of alarming capabilities)
- Wind turbine monitoring (crack detection, Ice formation)
- Detection of active corrosion in tanks and vessels (alarming if corrosion rates change).
- Use as data logger for recording different quantities in remote structures
- Monitoring underwater structures (Riser and anchor chain monitoring; Continuous flooded member detection, splash zone)
- Leak detection in pipelines
- Monitoring in flight operations





# AE INSTRUMENTATION ON THE WIND TOWER

**Ruggedized Computer**



**Cellular gateway**



**Wireless Receiver**



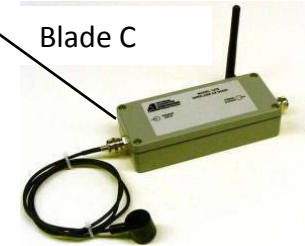
**Blade A**



**Blade B**



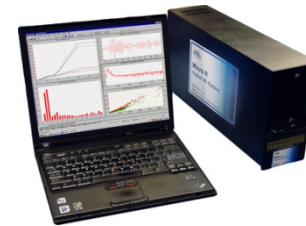
**Blade C**



# Extending the applicability of AE

- Laboratory testing
- Manufacturing (Quality control)
- Service inspection
- In-flight

No limitation on  
size of the system



Need of a smaller foot  
print with all the  
capabilities



In-flight inspection of these systems can reduce the inspections time and increase reliability.

“Future efforts should concentrate on reducing the total system susceptibility and vulnerability”

*DoD's Unmanned Systems Roadmap 2007-2032*



- Laboratory studies in the detection of delamination and crack initiation and propagation in aerospace composites using acoustic emission has been documented extensively.
- Its implementation in flying aircraft has been limited because of the size and weight of the equipment commercially available and its power demand.
- Because of its small size, weight, low power consumption and powerful data processing capabilities, the 1284 is the first AE instrument with real potential to be used in real SHM of aircraft.
- In order to demonstrate the feasibility, a 3 point bending test on a carbon composite bonded joint was monitored using both the 1284 and a regular AE system.
- The composite joint was similar to the ones found in the wing box of a particular model of Unmanned Aerial Vehicle (UAV).

- For 4ft × 50ft drone wings, sensors will be placed on the dry sides of the two spars which will be not in full contact with fuel.

- Assuming ribs are used every 4-6 feet, a grid of 36 sensors per wing could be sufficient to inspect the entire length of the wing. Several 1284 systems will be used to cover the whole area.

- For this geometry, in each location along the length of the wing two sensors on the spar, one on the top and one on the bottom skin-spar interface will be placed, close to each skin-rib bonded joints.

- The system will be able to perform real time 2D location of monitoring data, will be able to switch between passive and active mode. Allowing the identification of skin-rib joints in wing-box areas that appeared most active during flight.

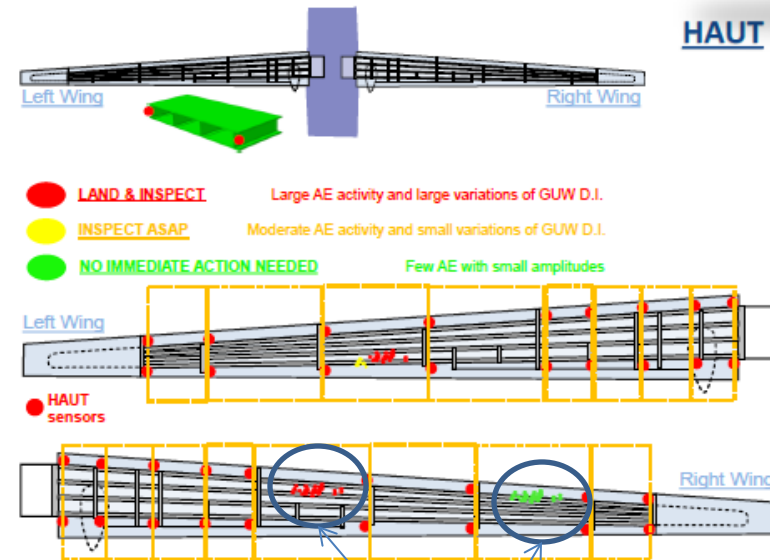
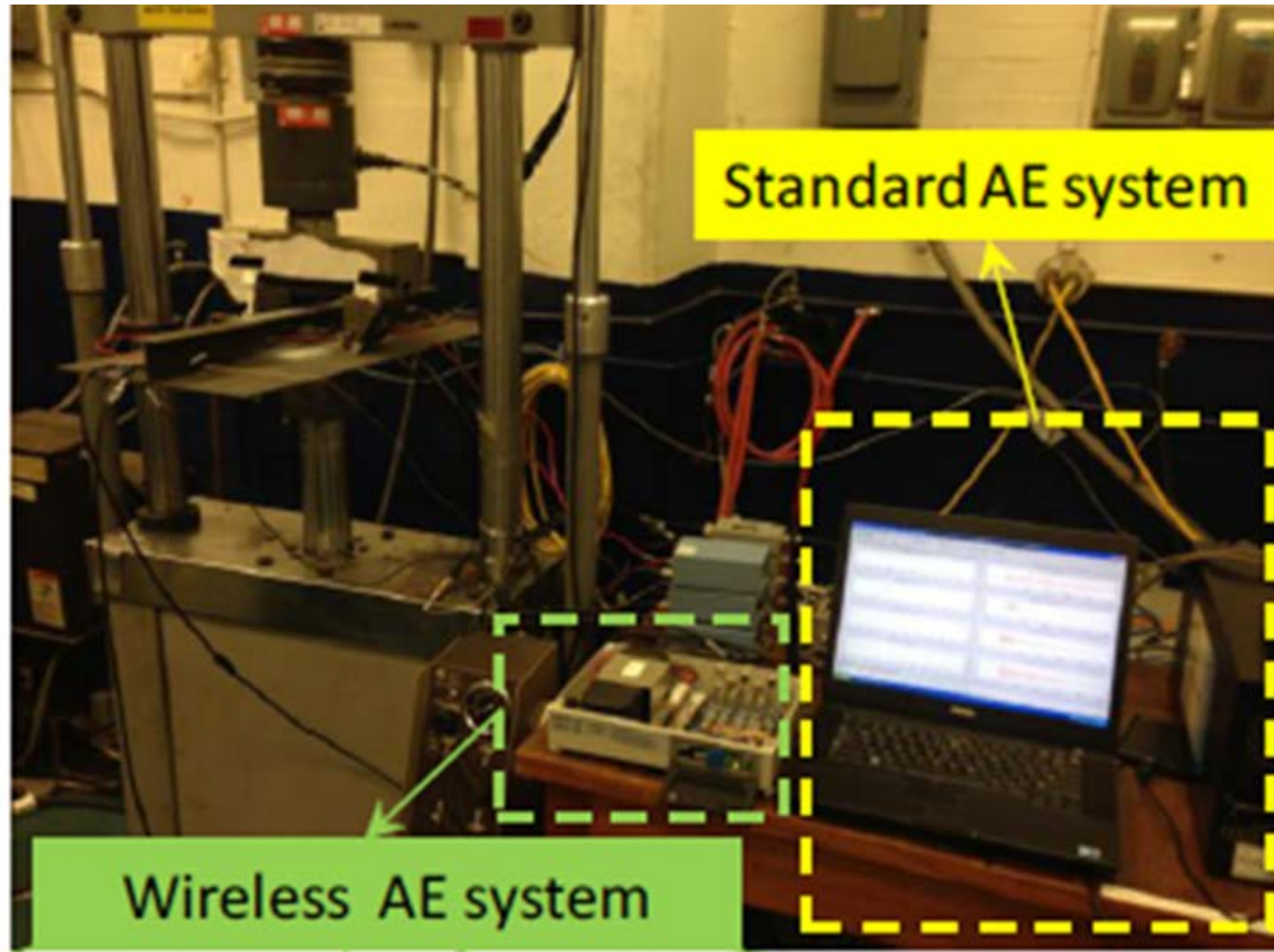
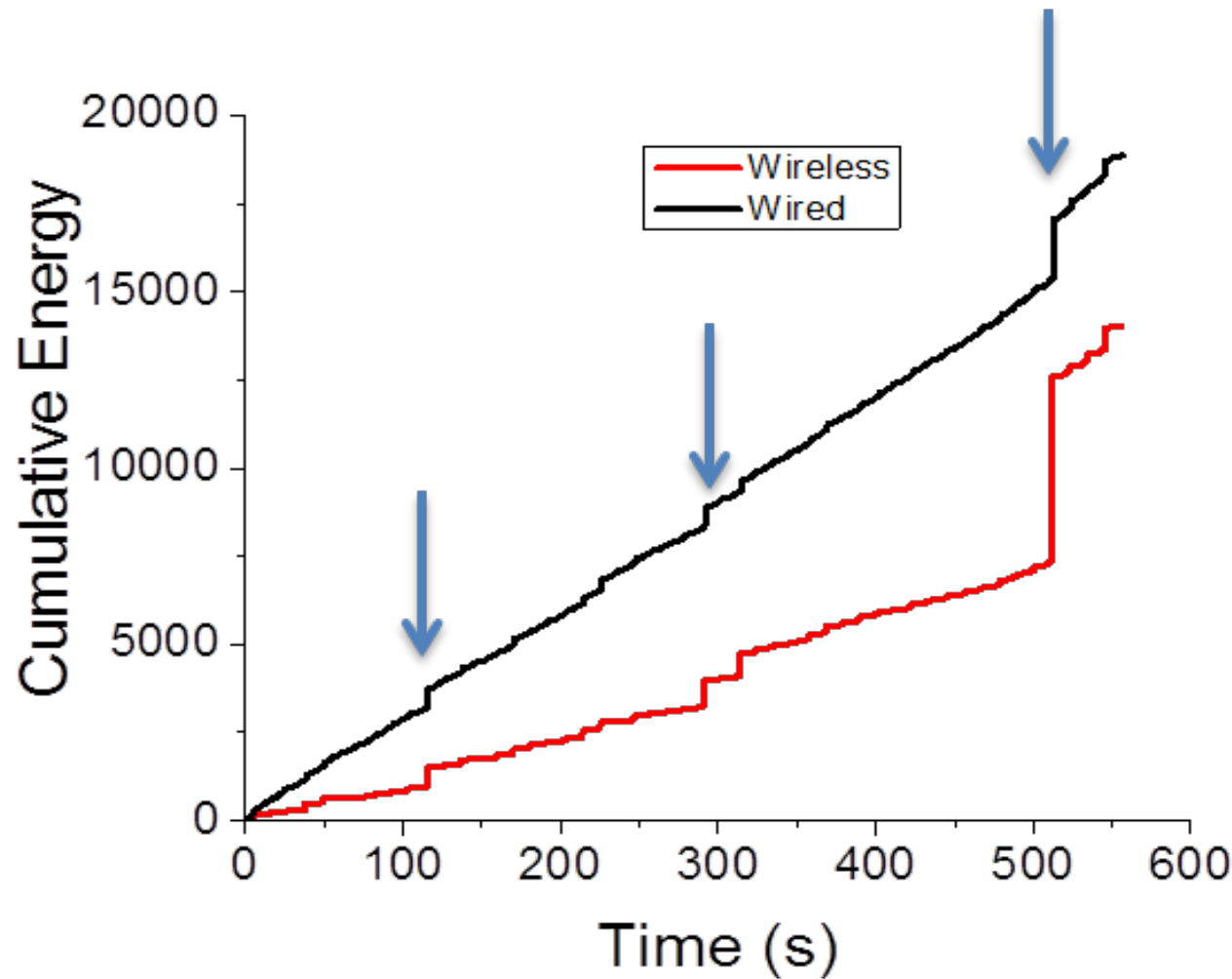


Figure 3. Operator's view of the proposed HAUT for bondline integrity monitoring

Areas showing different energy and activity level, which require different response from the user





Cumulative AE energy as measured by the standard AE system (black) and the 1284 node (red) during the three point bending test. Notice the jumps (arrows) indicative of damage growth at different points during the test.

- During the four-year project “Self-powered Sensor Network for Bridge Health Prognosis”, sponsored by NIST through its TIP program, Mistras Group Inc. developed the smallest lowest power, full capability AE system with on-board signal processing capabilities comparable to those found in large commercially available AE multichannel boards.
- The 1284 is designed to work in two different modes: as a unit transmitting processed data wirelessly to a remote location, which is accessible via internet gateway or cellular modem, or as a collector unit which saves data in the memory card for later retrieval.
- The applications for the 1284 extend beyond the area of bridge health monitoring into the generalized structural health monitoring of very diverse structures. The data obtained in the three point bending test of a composite sample shows that the 1284 node has the capability for SHM of composite components in flying aircraft.
- The 1284 is ready for deployment on offshore oil platforms, composite ships, combat deployable bridges and wind turbine.



This project was sponsored by the National Institute of Standards and Technology (NIST) through the Technology Innovation Project Grant (TIP) #70NANB9H007.

Institutions collaborating:

University of Miami (Prof. Antonio Nanni)

University of South Carolina (Prof. Paul Zheil)

Virginia Tech (Prof. Dan Inman)