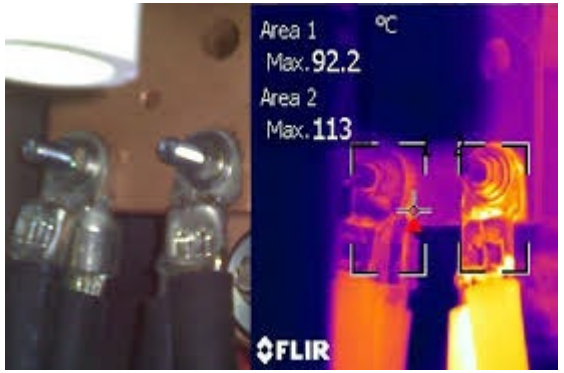
NSRP RA 2025-04:
INSTALLATION OF A DISTRIBUTED TEMPERATURE SENSING SYSTEM FOR ELECTRICAL PLANT MONITORING

ELECTRICAL TECHNOLOGIES PANEL MEETING
December 12, 2025



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Team Members:
- NAVSEA 05Z33
- NSWC PD
- NSWC DD
- Austal USA
- Leonardo DRS
- Penn State U ARL
- *AP Sensing*
- *ChemPro Technologies*

PTR: Vincent Mangino, Electric Boat
ATI PM: Nick Laney

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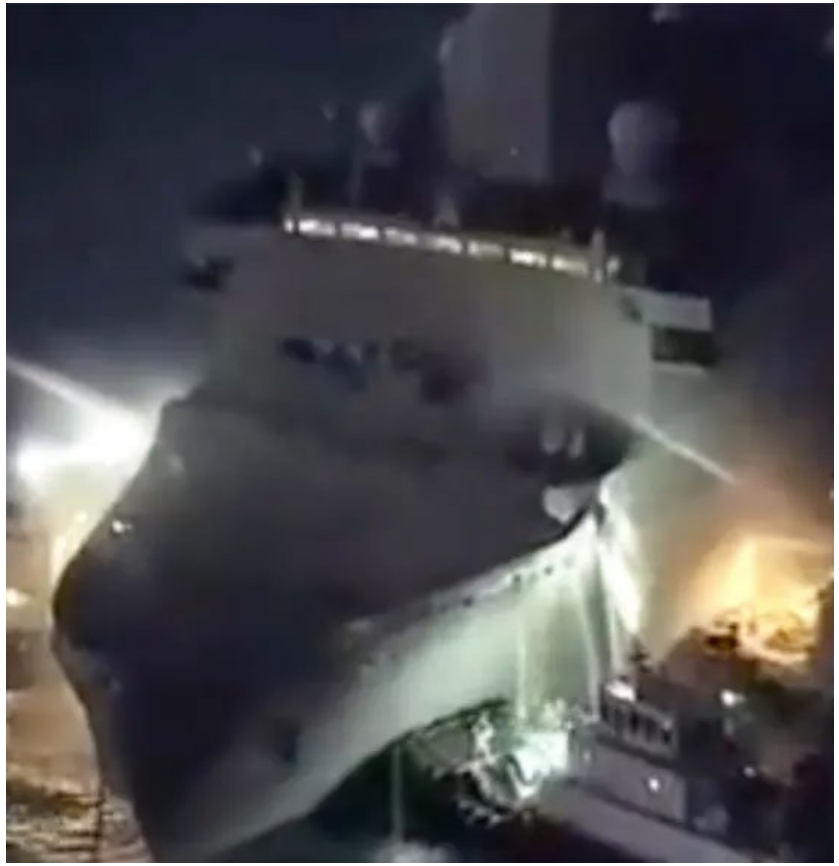
BACKGROUND - The Need for Distributed Sensing

RSL ADVANCED LIGHTING TECHNOLOGIES

Damage Control & Condition Based Maintenance

- 8 Arc faults average per year throughout the U.S. Navy fleet switchboards and load centers.[1]
- Electrical fires cost $6 billion over 12 years period.[2]
- Ford class carrier generates three (3) times the power of a Nimitz class.
- USS New Orleans Fire in August 2025 which lasted 12 hours and resulted in injuries to two sailors.
- USS Bonhomme Richard fire in 2020, which burned for five days and led to the total loss of the ship.
- USS Miami submarine fire in 2012, which caused over $700 million in damage and resulted in the vessel's decommissioning.

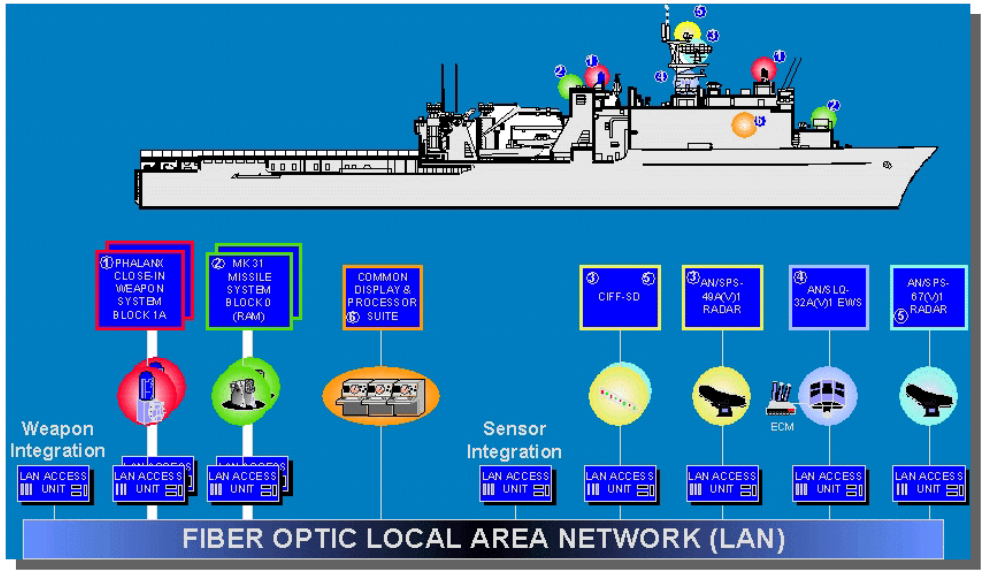
Traditional sensing mechanisms lack the coverage necessary to transition to an intelligent ship paradigm.

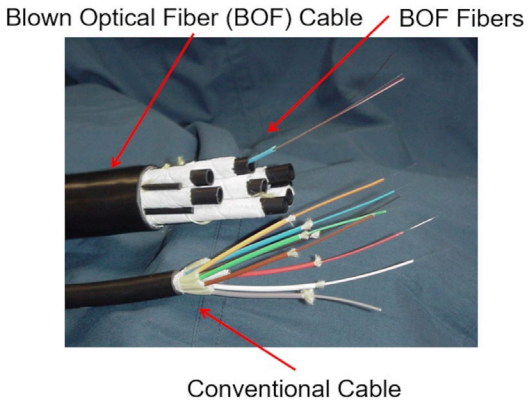


1. J. Callen, Penn State Electro-Optics Center, "Distributed Temperature Sensing for Inspection of Electrical Panels on Navy Ships", NSRP Meeting, March 2017.
2. Naval Sea Systems Command Office of Corporate Communications, "NAVSEA establishes new group to improve industrial fire safety", December 6, 2021.

Shipboard Fiber Optic Networks

- Approximately **1,220 Km (4 million ft)** of Optical Fiber on Ford Class Carrier[1]
- New shipboard cable designs have upwards of **432 fibers**.
- These existing shipboard fiber optic infrastructures have the capacity for the creation of a shipboard "nervous system" through a network consisting of Distributed Fiber Optic Sensing (DFOS) technologies combined AI or ML discerning algorithm.[2]
- DFOS uses laser pulses to transform fiber optic cable into continuous, distributed sensors, providing a comprehensive sensing coverage utilizing preexisting fiber.





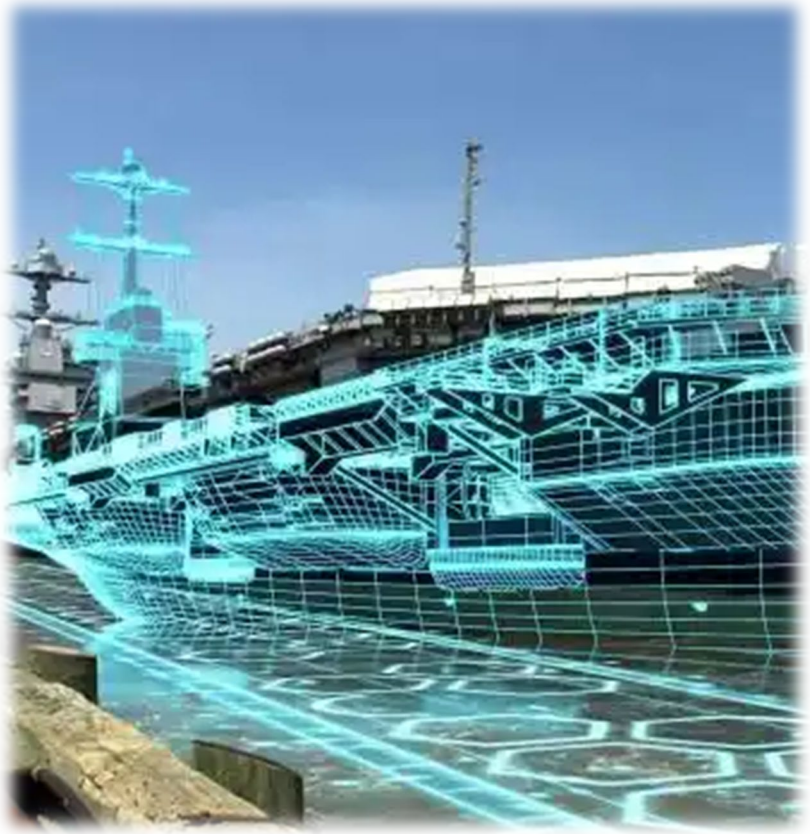
1. Huntington Ingalls Newsroom January 11, 2016
2. Joshua Carter, NSWCDD "Towards an Intelligent Shipboard Nervous System: Distributed Fiber Optic Sensing", 24 October, 2022

CBM + DFOS + Digital Twin → A Paradigm Shift

ADVANCED LIGHTING TECHNOLOGIES

CBM+

- U.S. Navy is transitioning from a traditional, reactive maintenance model to a proactive, data-driven approach
  → **Condition-Based Maintenance Plus (CBM+).**
- Aim is to increase *operational availability and reduce costs*.
  - Operations & Support → 65% to 80% of Lifecycle Costs[1]
  - U.S. Navy spent $ 25.9 Billion in maintenance from FY 2020 to FY 2023.[2]
  - 73% of officers indicated spare parts shortages hinders maintenance.[2]



Digital Twin via Enterprise Remote Monitoring (eRM v4)

- **Digital Twin**: a computer model trained on historian HM&E system operational data, which can be deployed shipboard within eRM to predict nominally healthy performance and indicate when anomalies are occurring that need to be addressed.
- Leverages *operational data* and reports from embedded sensors to produce virtual replicas of physical assets. These digital twins provide a powerful simulation and analysis *tool for predicting equipment failures* long before they occur.
  - *Requires 3000-5000 sensors.*

1. DoD Condition-Based Maintenance Plus Guidebook, August 2024
2. https://www.gao.gov/products/gao-25-106990

ELECTRICAL SWITCHBOARDS

PROBLEM STATEMENT

1. **Potential of electrical system faults can not be predicted in real-time.**
   - Periodic open-door maintenance inspection of all connections are required every 6 to 12 months.
2. **Faults are expensive!**
   - Repairs + availability delays.
3. **Current inspection methods do not support CBM+**

SOLUTION – DISTRIBUTED TEMPERATURE SENSING

- Mature technology:
  - Commercial: **TRL 9**
  - Navy: TRL 6 → After LBES Install: **TRL 7**
- Monitors temperature in **real-time** using entire length of the fiber.
- *Detect faults, isolate location, determine severity and define action.*
- Used extensively in commercial applications: **data centers**, fire detection, machinery, pipelines, oil exploration...

MIL-DTL-32772: 3.6.13 Non-contact thermal sensors. When specified (see 6.2), fiber optic temperature sensors or other technologies shall be provided to determine temperatures of selected current carrying joints or expected hot spots (see 4.4.3.8.7). ***Temperature sensors shall be permanently mounted***

Priority	Temp Rise or ΔT	Operational Assessment	Severity Code	Action
1	≥ 70°C	Failure Imminent	****	Equipment should be secured immediately and not operated until repairs are complete.
2	40°C to < 70°C	Failure Almost Certain	***	Equipment should be secured if operating conditions permit otherwise monitored until corrective action can be taken.
3	20°C to < 40°C	Failure Possible	**	Corrective action should be taken as soon as feasible.
4	10°C to < 20°C	Performance Degraded	*	Corrective action should be taken at next scheduled routine maintenance period or as schedule permits.
	< 10°C	N/A	N/A	No corrective action required; note for future reference.

Table 7.1 from NAVFAC P-604 E-SAFE (2019)

NSRP PROJECTS HISTORY

Inspection of Electrical Assets

OBJECTIVES:

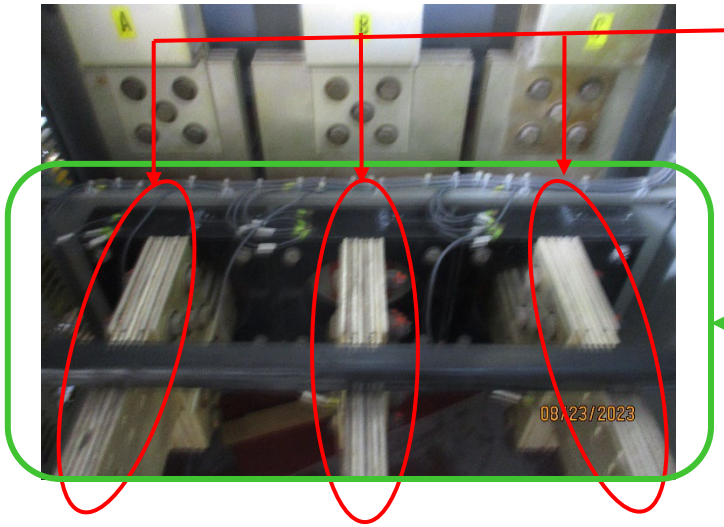
- Prevent damage due to loosened connections (arcing).
- Reduce risk to personnel.
- Reduce maintenance costs.
- **Perform Condition Based Maintenance (CBM).**

- **2015 – PSU EOC**, HII-Ingalls, SUPSHIP GC: Reduce risk of inspection of MV Electrical panels by use of windows for IR thermal imaging.
- **2015 – RSL Fiber Systems** presents fiber optic Raman DTS at NSRP Electrical Technologies Panel mtg (San Diego).
- **2017 – PSU EOC**, HII-Ingalls, SUPSHIP GC: Evaluation of DTS for monitoring MV electrical panels.
- **2019*** – **Hepburn & Sons**, RSL FS: Raman DTS to monitor connections of Insulated Bus Pipe (IBP).
- **2020* – Hepburn & Sons**, RSL FS: Raman DTS to monitor IBP connections to equipment.
- **2023 – RSL Fiber Systems**, NAVSEA 05Z33, NSWC PD, BIW, PSU EOC: DTS Integration into Electrical Plant Controls.
- **2025* - RSL Fiber Systems**, NAVSEA 05Z33, NSWC PD, NSWC DD, Austal, Leonardo DRS, PSU EOC, AP Sensing: DTS Installation on DDG 51 Land site.

* NSRP Research Announcements

NSRP RA 2025-04 METHODOLOGY

Monitor the temperature of busbars in real time to detect abnormal temperatures at the individual busbar and differences in temperature between the three (3) phases.



Zones 1, 2, 3: Individual Busbars
Temperature of Each Busbar (T)
Rate of Temperature Change (ΔT/Δt)

Zone 4: Three Phase Busbars (3)
Difference in Temperature between Three Busbars (ΔT)

ZONE #	ZONE NAME	START	END	MONITORING	Pre-Alarm @ Temp	Alarm @ Temp
1	Connection 1	76.7	78.7	Min & Max T, ΔT/Δt	> 50°C & ΔT/Δt > 5/60	> 80°C & < 10°C
2	Connection 2	71.6	73.6	Min & Max T, ΔT/Δt	> 50°C & ΔT/Δt > 5/60	> 80°C & < 10°C
3	Connection 3	66.2	68.7	Min & Max T, ΔT/Δt	> 50°C & ΔT/Δt > 5/60	> 80°C & < 10°C
4	Busbars 1-2-3	66.2	78.7	ΔT between C1, C2, and C3	Δ>10°C	Δ>25°C
5	Full Panel	20	120	T, ΔT, ΔT/Δt in Panel	> 50°C, > 5/60, & Δ>10°C	> 80°C, > 10/60, & Δ>25°C

NSRP RA 2025-04 OUTLINE

OBJECTIVE: configure, install, and operate a DTS system at a Navy land facility for hands-on experience and to identify modification(s) required for installation on an in-service vessel through a Ship Change Document (SCD) for a Temp Alteration.

- Eliminate arc faults.
- Perform CBM before damage occurs.

TASKS

Task 1 – Configure the Sensing Assemblies.

Task 2 – Configure the DTS Sensing Interrogator Hardware.

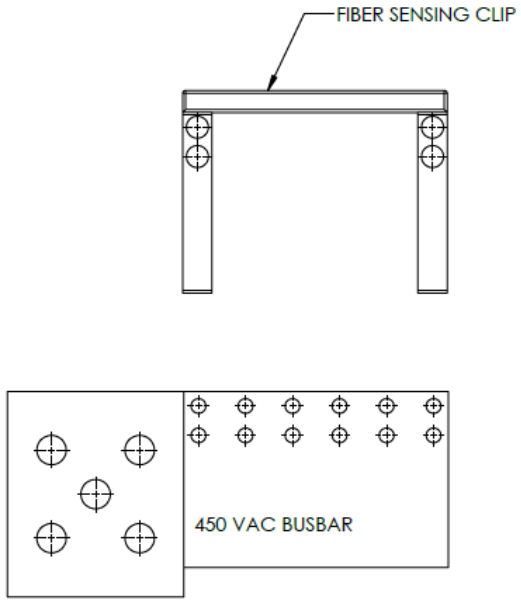
Task 3 – Configure the Monitoring Software and Graphical User Interface.

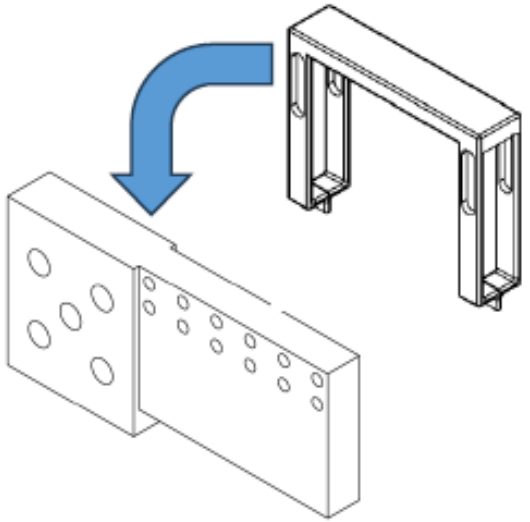
Task 4 - System Installation on at the DDG 51 land-based facility in Philadelphia.

DELIVERABLES

- DTS System Configuration
- Assembly Design
- GUI Design
- DTS System Installation, Operation, and Verification Plans and Implementation
- Tech Transfer Plan

TASK 1 - ASSEMBLY DESIGN – Sensing Clips





- Sensing Clips to MIL-M-24519 (Materials used in Electric and Electronic Equipment).
- Attachment to Busbar to meet MIL-STD-901D Shock and MIL-STD-810 Vibration.
- Build assembly prototypes and confirm fitting on Tactical LV Switchboards at LBES.

- Developing test method to determine heat transfer from loosening bolt(s) to sensing fiber.

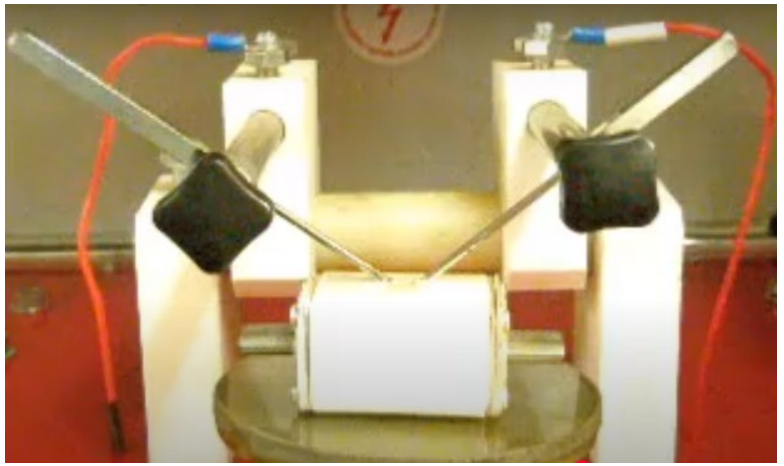
TASK 1 - ASSEMBLY DESIGN – Cable Materials

OBJECTIVE – Prevent fiber cable from causing arcing between energized busbars.

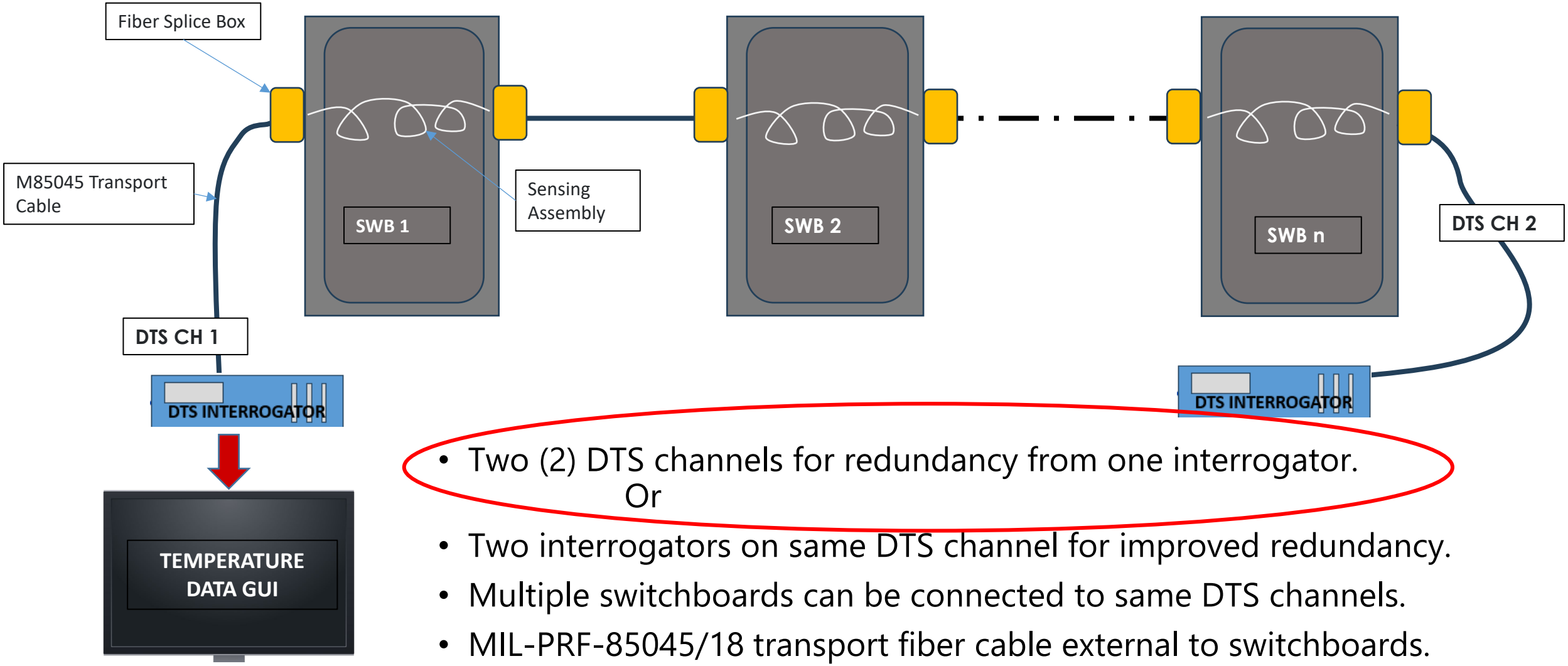
- Identified two (2) jacketing materials from Gendon with high Arc-Tracking resistance.
- Obtained sample of M85045/16 cable jacket compound from Prysmian.

PLAN

- Test to ASTM D 495 – Dry Arc Resistance of Solid Electrical Insulation.
- Use M85045/16 for LBES LV installation.
- Determine if suited for MV applications or if new compounds are preferred.

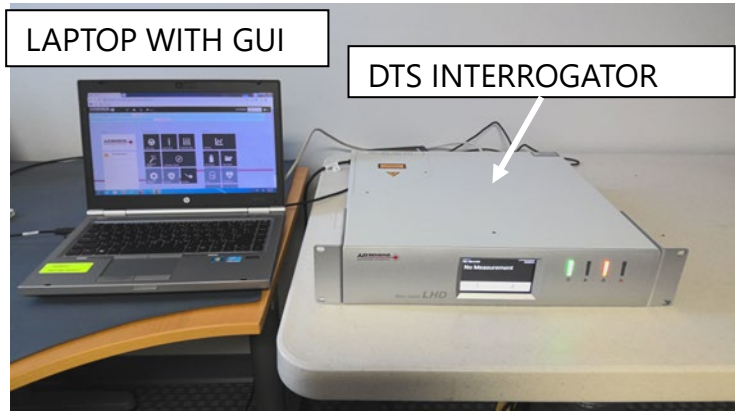


TASK 2 – DTS SYSTEM CONFIGURATION

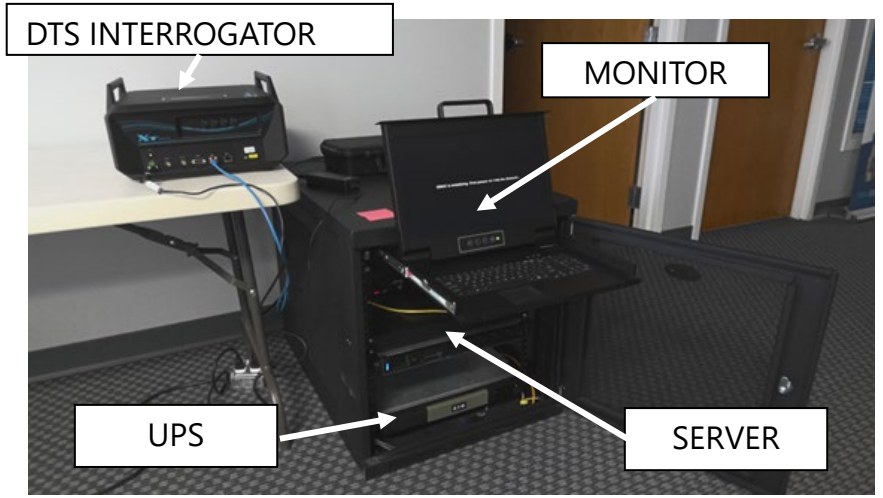


- Two (2) DTS channels for redundancy from one interrogator.
  Or
- Two interrogators on same DTS channel for improved redundancy.
- Multiple switchboards can be connected to same DTS channels.
- MIL-PRF-85045/18 transport fiber cable external to switchboards.
- M85045 cable spliced to internal fiber optic sensing cable assembly.

TASK 2 – DTS SYSTEM – HARDWARE SELECTION



AP SENSING DTS SYSTEM TESTED



SILIXA DTS SYSTEM TESTED

Item	Manufacturer	AP SENSING	Silixa
1	Model No.	N4585A	Ultima M
2	Max. Meas. Range	2, 4, 8 Km	10 Km
3	No. Channels	4	4
4	Meas. Accuracy (°C)	< 0.1°C	0.01°C
5	Length of fiber required for sensing (minimum definable zone length)	2 m	>1 m
6	Sensing Zones x Channel	2,000	Up to 40,000
7	Sampling Interval	0.25 m	0.25 m

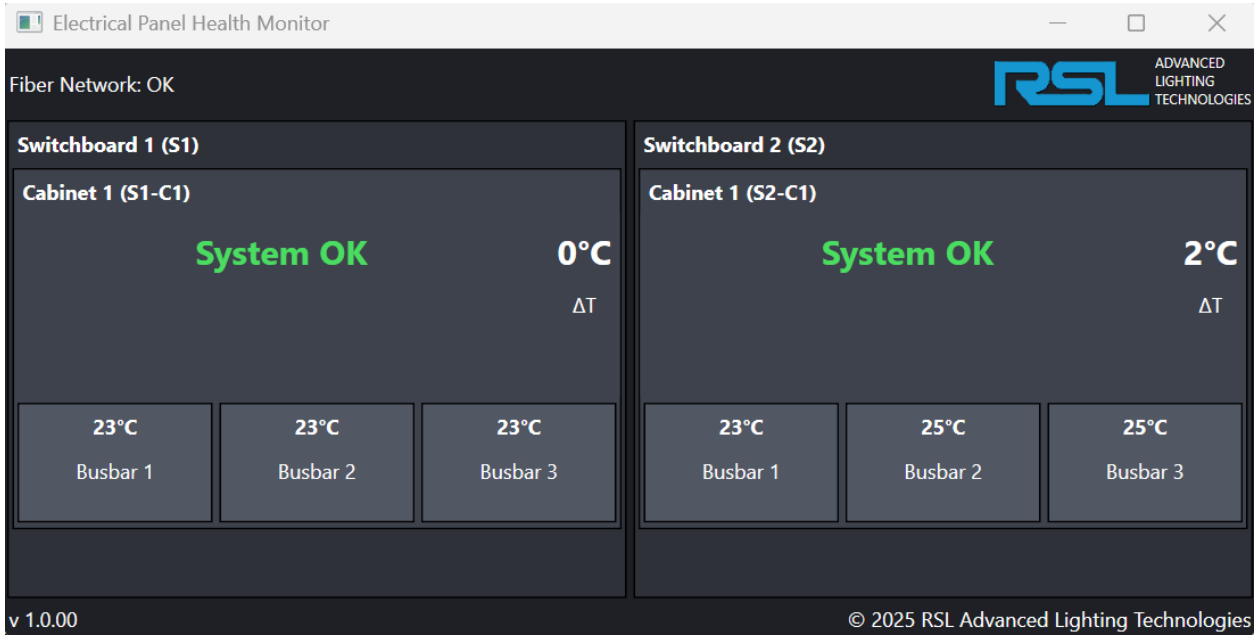
Manufacturer	SILIXA		AP SENSING N4585A-xxx		
Model No.	Ultima M	XT-DTS M	-R02	-R04	-R08
Measurement Range (meters)	10,000	10,000	2,000	4,000	8,000
	Cost Ea.		Cost Ea.		
Interrogator	$70,205	$72,437	$24,659	$28,182	$34,171
4 Sensors Channel			$5,474	$5,474	$5,474
Integrated Interface			$577	$577	$577
Server	$4,800	$4,800			
Software License	$47,187	$47,187			
Rack Housing w/integrated display			$166	$166	$166
	$122,192	$124,424	$30,876	$34,400	$40,388

TASK 3 – CONFIGURE SOFTWARE AND GUI

- AP Sensing SmartVision suited for large area systems (Pipelines, Powerplants, Power Grids…)
- Not able to compare different sensing zones.
- Visual Technologies, Inc. contracted to develop software and GUI.
- Modbus Communication protocol.

GUI MIL-STDs

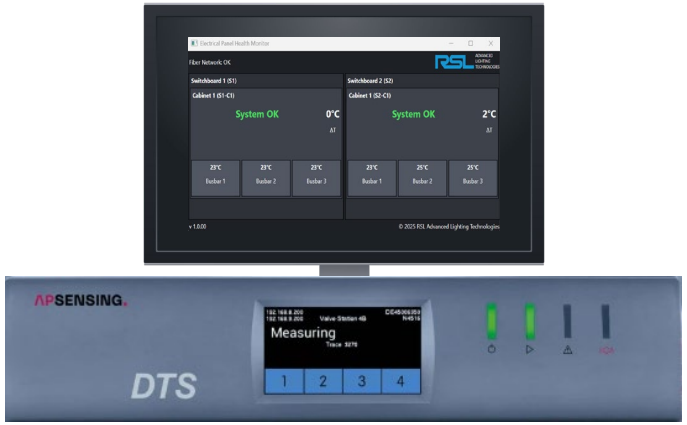
- MIL-STD-1472H “Department of Defense Design Criteria Standard Human Engineering”
- MIL-DTL-32483 “Detail Specification: Switchgear, Power, Hard-Mounted, Medium Voltage, Naval Shipboard”



TASK 4 – INSTALLATION AND IMPLEMENTATION

- **Finalize Assembly Design**
  - One half (1/2) day on site to fit assembly prototype on busbars and finalize design.
- **Installation**
  - Up to two (2) days to install, set-up, and commission equipment.
- **Operation**
  - **No interference** with other functions/tests.
  - **Twin DTS** operational in RSL Fiber Systems lab.
- **Maintenance / Repairs**
  - No maintenance required / anticipated for duration of project.
- Leave in place or remove at end of project (~ ½ day required for removal)

TASK 4 SUPPORT – Twin DTS System



- Busbars Mock-up built for RSL Fiber Systems lab.
- 2nd AP Sensing DTS System purchased by RSL.
- Modify GUI & Software based on LBES Team feedback.
- Evaluate heat transfer from bolted connection to sensing fibers.

NEXT STEPS

1. Configure the software and preliminary GUI **[WIP]**
2. Build prototype assemblies w/ molded parts **[WIP]**
3. Schedule meeting at the Philadelphia LBES to confirm proper fit of assemblies **[w/o December 15 / 22 / 29 ?]**
4. Perform ASTM D 495 on Gendon materials and M85045/16 jacket compound **[December 2025]**
5. Finalize assembly design and build final parts **[December 2025 – January 2026]**
6. Configure the twin DTS system in RSL Fiber Systems' lab **[December 2025 – January 2026]**
7. Installation in the DDG 51 LBES Tactical LV Switchboards **[February 2026?]**
8. Operation at the LBES **[March 2026]**

		25-Dec	26-Jan	26-Feb	26-Mar
1.0	Configure the software and preliminary GUI				
2.0	Build prototype assemblies				
3.0	Meeting at LBES to fit assemblies				
4.0	Perform ASTM D 495 on jacket materials				
5.0	Finalize and build assemblies				
6.0	Configure twin DTS system in RSL lab				
7.0	Installation in DDG 51 LBES LV Switchboards				
8.0	Operation in LBES				

TECHNOLOGY TRANSFER

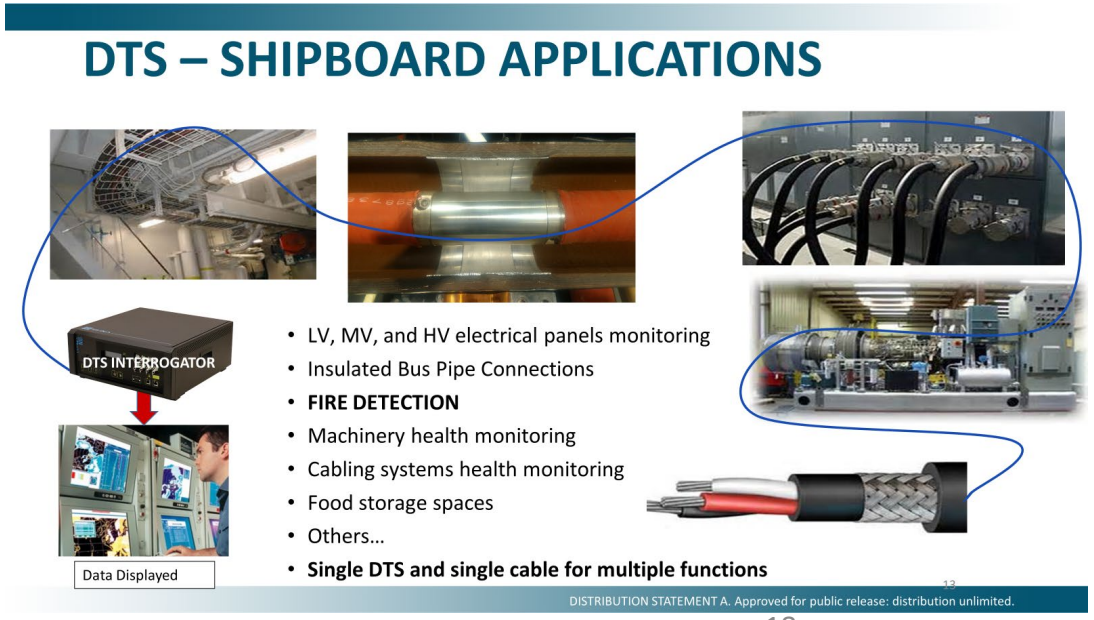
- Presentation at Machinery Failure Prevention Technologies 2025 Conference, May 2025, Virginia Beach, VA (G. Tomasi & C. Nemarich)
- Presentation at ASNE Fleet Maintenance & Modernization Symposium 2025, September 2025, San Diego, CA (G. Tomasi, J. Carter, C. Nemarich)
- RA 2026-02 Installation on In-Service Vessel (EPF Fast Transport Vessel)

MFPT ANNUAL CONFERENCE

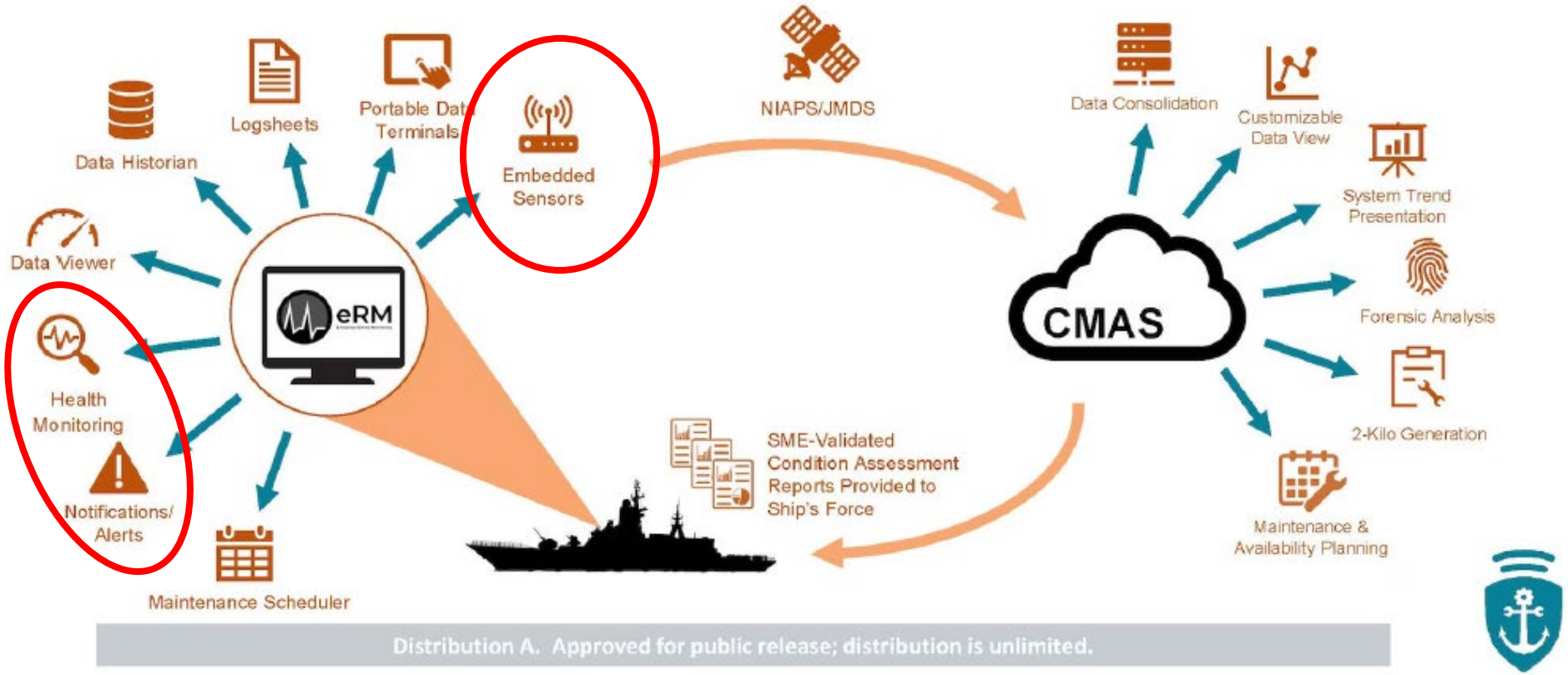
Diagnostics, Prognostics, and Failure Prevention Where Theory Meets Practice

Network, exchange knowledge, and collaborate with professionals interested in machinery failure prevention technology.

AMERICAN SOCIETY OF NAVAL ENGINEERS



CBM+ES Ecosystem



NAVSEA NEWS | Nov. 16, 2023
www.navsea.navy.mil/Media/News/Article-View/Article/3590550/nswcpd-engineers-spearheading-condition-based-maintenance-cbm-program-for-us-na/

QUESTIONS?

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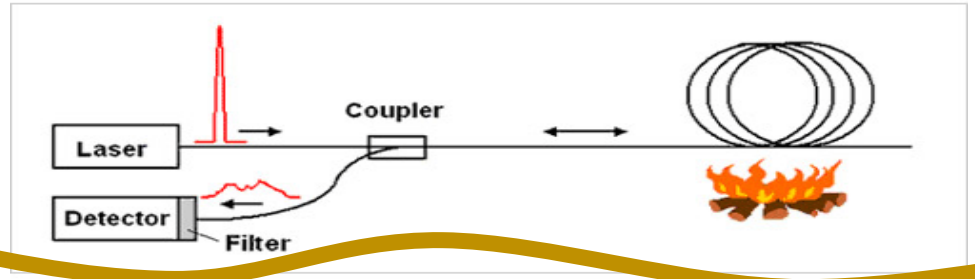
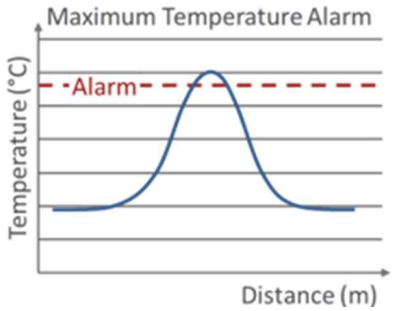
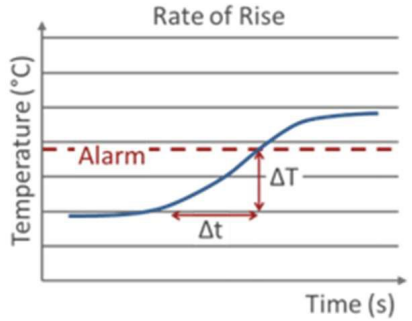
FIBER OPTIC DISTRIBUTED TEMPERATURE SENSING

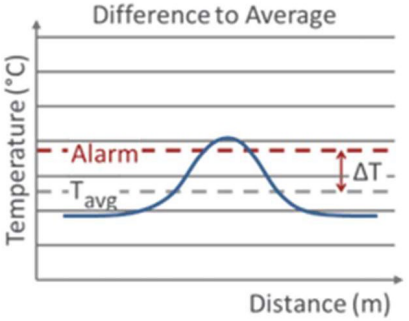
ADVANCED LIGHTING TECHNOLOGIES

DTS INTERROGATOR









- Based on Raman Scattering.
- Entire fiber is the sensing unit – up to 10,000 programmable zones per fiber channel.
- Zones can overlap and encompass multiple zones.
- Multiple warnings / alarms can be set in each zone.
- Standard MM 50/125, 62.5/125 or SM fiber.
- Up to 30 Km MM, 40 Km SM - real time monitoring across entire length.
- Temperature rise of 0.1°C
- Spatial Resolution down to 50 cm.