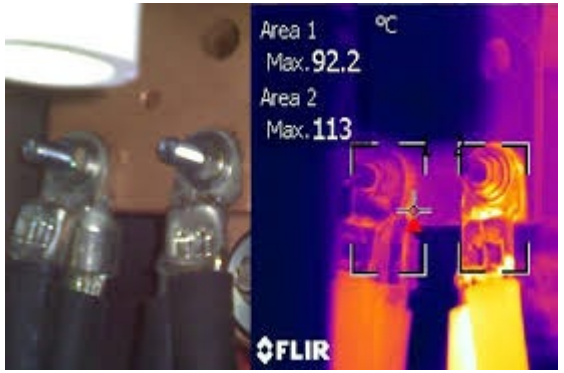
NSRP RA 2025-04:
INSTALLATION OF A DISTRIBUTED TEMPERATURE SENSING SYSTEM FOR ELECTRICAL PLANT MONITORING

ELECTRICAL TECHNOLOGIES PANEL MEETING
Manchester, NH August 13-14, 2025



Giovanni Tomasi
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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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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:
  - Putting personnel at risk of injury.
  - Maintenance costs an average of $3 million/year to surface fleet[1].
- Increasing complexity of ship's electrical systems will make the problem worse.

2. Faults are expensive!

- Arc faults average 8/yr throughout the U.S. Navy fleet switchboards and load centers [2].
- Electrical fires cost $6 billion over 12 years period [3].
- $3 million/year estimated cost arc fault repairs and availability delays.

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)

3. Current inspection technologies do not collect data to support Condition Based Maintenance

1) Based on avg. 15 switchboards per ship, 16 hrs. inspection, $ 80/hr., 157 surface combatants, 1 inspection per year.
2) J. Callen, Penn State Electro-Optics Center, "Distributed Temperature Sensing for Inspection of Electrical Panels on Navy Ships", NSRP Meeting, March 2017.
3) Naval Sea Systems Command Office of Corporate Communications, "NAVSEA establishes new group to improve industrial fire safety", December 6, 2021.

SOLUTION - DISTRIBUTED TEMPERATURE SENSING

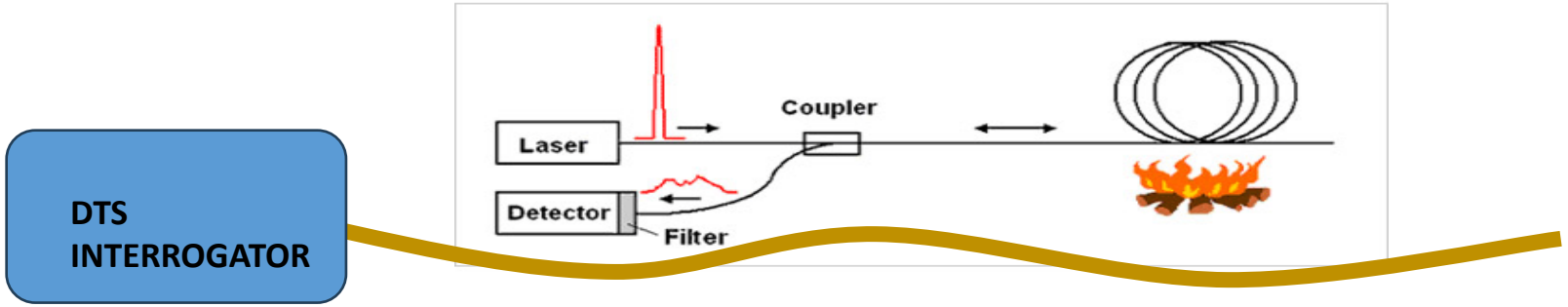
- **Distributed Temperature Sensing (DTS)**
  - Mature technology:
    - Commercial: **TRL 9**
    - Navy: TRL 6 → After LBES Install: **TRL 7**
  - Monitors temperature in **real-time** using entire length of the fiber.
  - *Detect faults, isolate location, determine severity and define action.*
  - Used extensively in commercial applications: **data centers**, fire detection, machinery, pipelines, oil exploration…
  - Viability for electrical switchboards verified by **four (4) previous NSRP projects**.
  - **Fully non-metallic, non-conductive** sensing assemblies.
  - **Passive, No interference** with other operations.

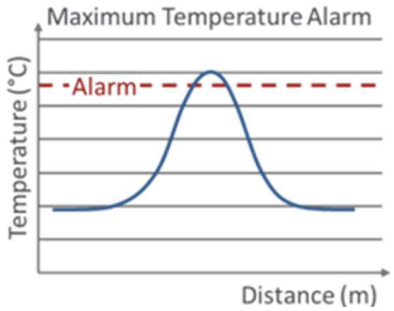
MIL-DTL-32772

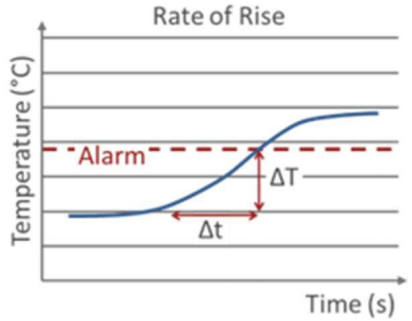
3.6.13 Non-contact thermal sensors. When specified (see 6.2), fiber optic temperature sensors or other technologies shall be provided to determine temperatures of selected current carrying joints or expected hot spots (see 4.4.3.8.7). ***Temperature sensors shall be permanently mounted*** …

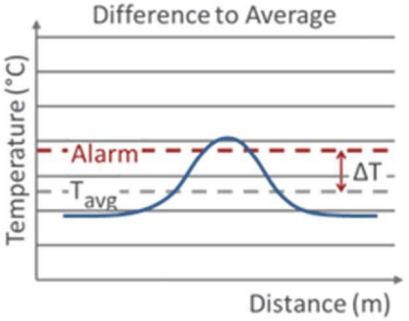
FIBER OPTIC DISTRIBUTED TEMPERATURE SENSING

ADVANCED LIGHTING TECHNOLOGIES

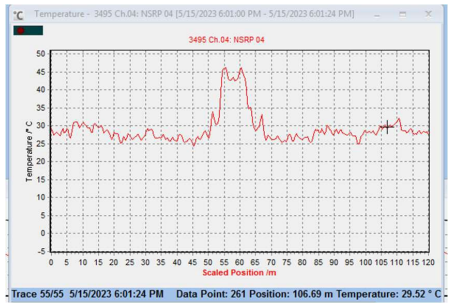


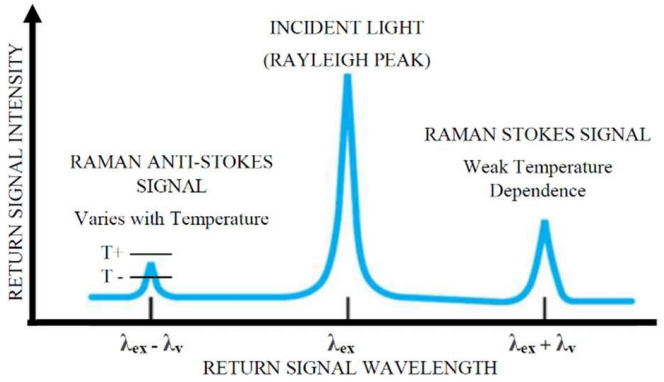




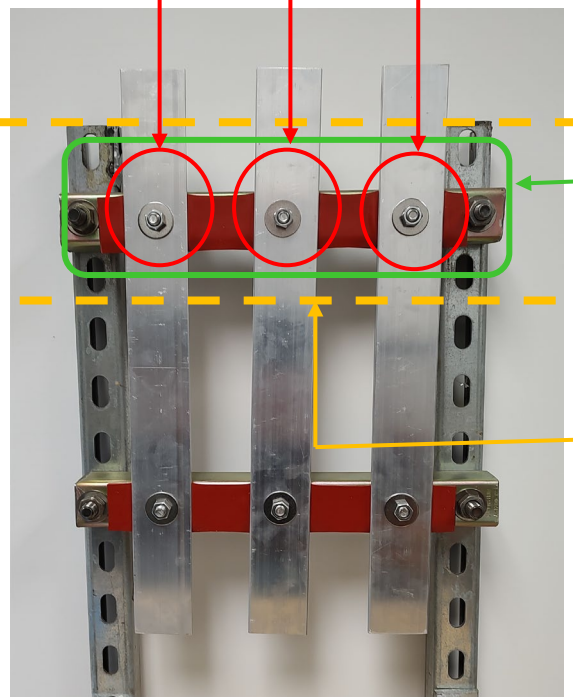


- Based on Raman Scattering.
- Entire fiber is the sensing unit – up to 10,000 programmable zones per fiber channel.
- Zones can overlap and encompass multiple zones.
- Multiple warnings / alarms can be set in each zone.
- Standard MM 50/125, 62.5/125 or SM fiber.
- Up to 30 Km MM, 40 Km SM - real time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





3 PH. SWITCHBOARD – ZONES WARNINGS AND ALARMS



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

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

Zone 5: Entire Switchboard (all Busbars + Connections)
Temperature within entire Switchboard (T)
Difference in Temperature (ΔT)
Rate of Temperature Change (ΔT/Δt)

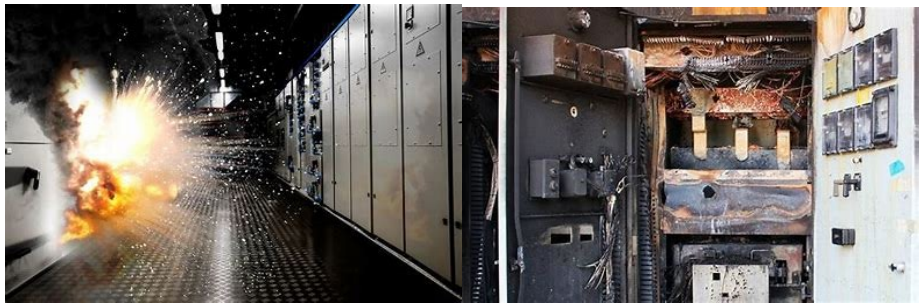
ZONE #	ZONE NAME	START	END	MONITORING	Pre-Alarm @ Temp	Alarm @ Temp
1	Connection 1	76.7	78.7	Min & Max T, ΔT/Δt	> 50°C & ΔT/Δt > 5/60	> 80°C & < 10°C
2	Connection 2	71.6	73.6	Min & Max T, ΔT/Δt	> 50°C & ΔT/Δt > 5/60	> 80°C & < 10°C
3	Connection 3	66.2	68.7	Min & Max T, ΔT/Δt	> 50°C & ΔT/Δt > 5/60	> 80°C & < 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 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).**

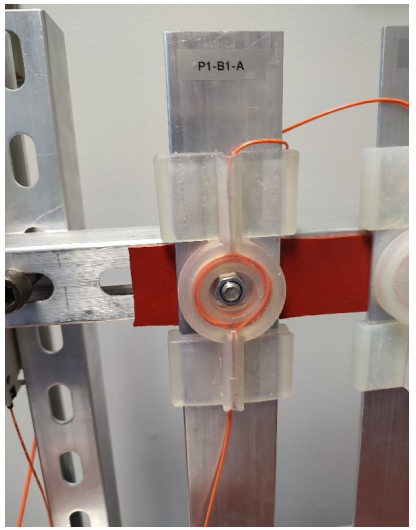


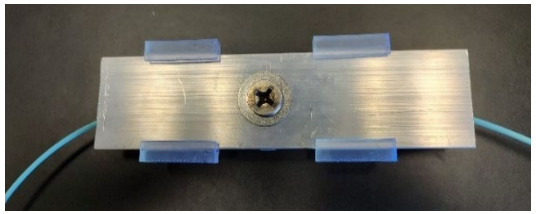
- **2015 – PSU EOC**, HII-Ingalls, SUPSHIP GC: Reduce risk of inspection of MV Electrical panels by use of windows for IR thermal imaging.
- **2015 – RSL Fiber Systems** presents fiber optic Raman DTS at NSRP Electrical Technologies Panel mtg (San Diego).
- **2017 – PSU EOC**, HII-Ingalls, SUPSHIP GC: 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 DTS PROJECTS SUMMARY

- Baseline construction for assemblies identified.
  - Molded assemblies, **removable, fully non-metallic**.
  - **Install assemblies after power cables** to prevent fiber damage.
- Control system configuration:
  - **Dedicated processor & display** to simplify cybersecurity requirements.
- Basic GUI to **inform, identify location, determine severity, define action.**
- DTS Implementation steps defined:
  - Pre-installation inspection for detailed work instructions.
  - Configure assemblies to specific switchboard(s).
  - Configure DTS equipment and GUI.
  - Installation and commissioning.
  - Maintenance / repair plan.





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 at the DDG 51 LBES 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 CONSTRUCTION AND DIMENSIONS

RSL ADVANCED LIGHTING TECHNOLOGIES

APPLICABLE REQUIREMENTS

- **MIL-DTL-32483 SWITCHGEAR, POWER, HARD-MOUNTED, MEDIUM VOLTAGE, NAVAL SHIPBOARD (08-NOV-2013)**

- **MIL-E-917E ELECTRIC POWER EQUIPMENT BASIC REQUIREMENTS (06-AUG-1993)**

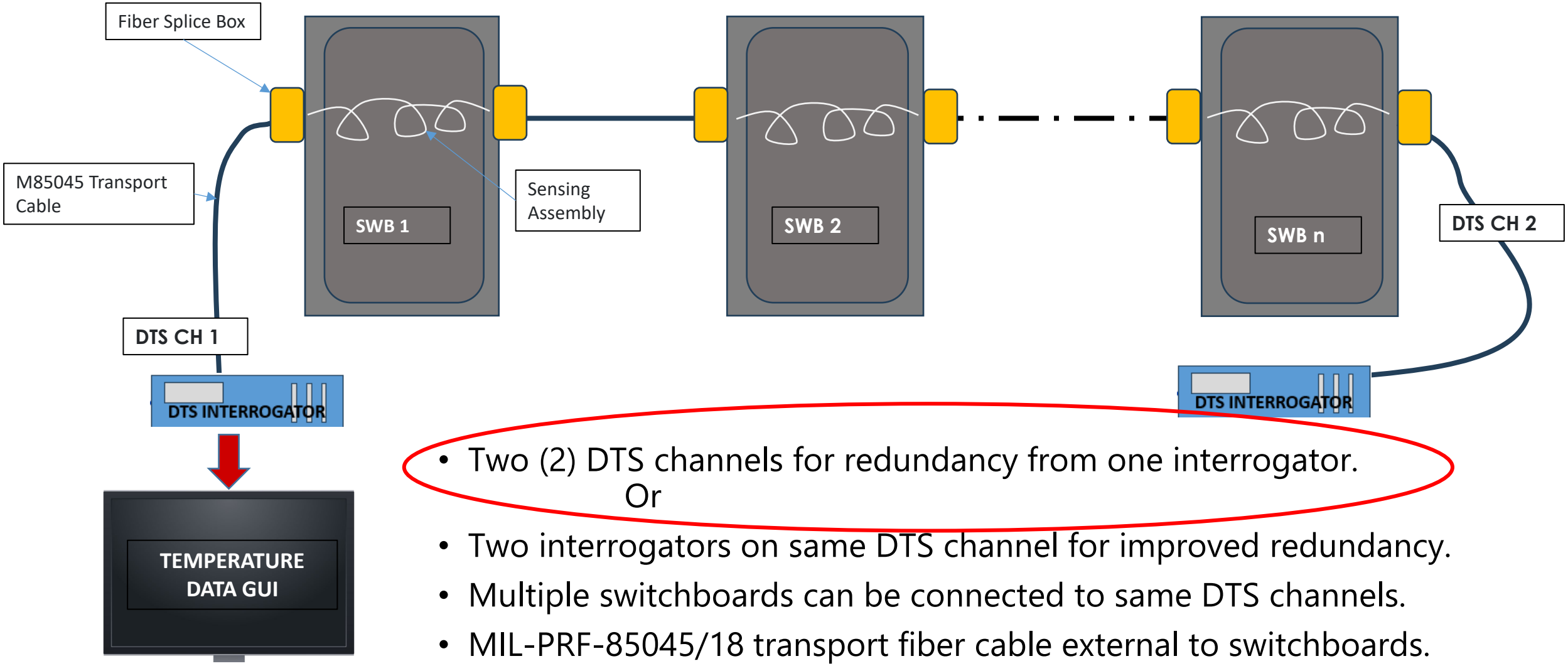
Known:

- Materials composition of all switchboard hardware
- Nuts & Bolts sizes
- Bolts Torque Specs
- Number of bolted connections per busbar assembly

Unknown:

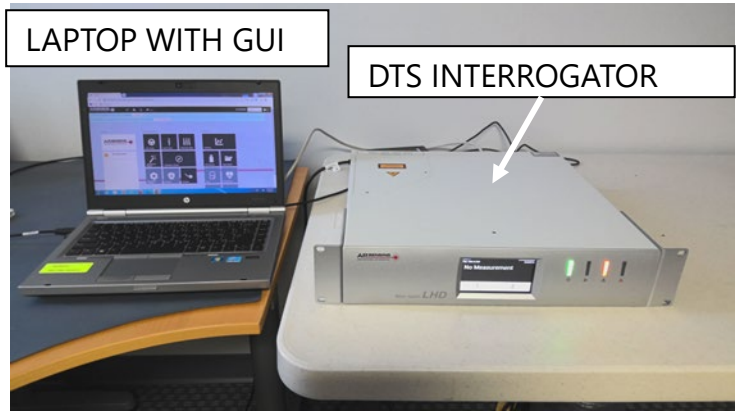
- **Switchboard(s) to be monitored**
  - Bus Bars' exact dimensions.
  - Spacing between the 4 bolt patterns on joints and terminations.
  - Location and number of connections per busbar monitored.
  - Total number of connections to be monitored per switchboard.
  - Boot sizes/dimensions.
  - **Dielectric and creepage requirements for cable assembly materials.**

TASK 2 – DTS SYSTEM CONFIGURATION

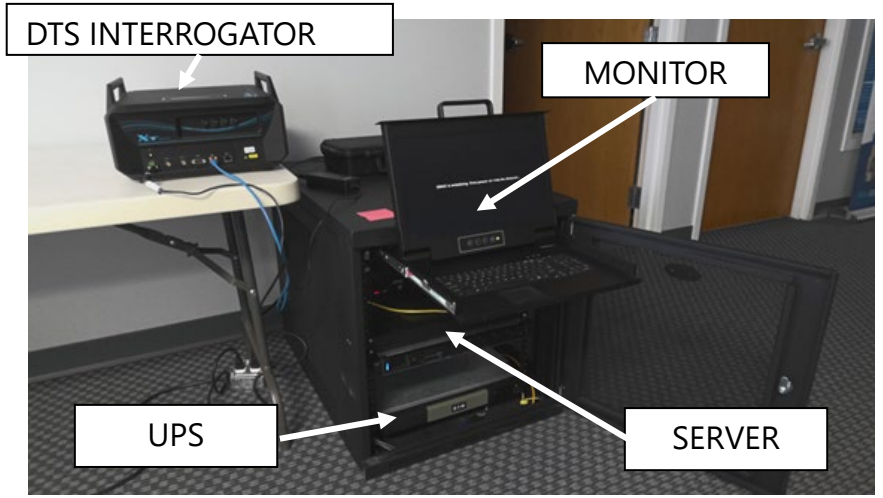


- Two (2) DTS channels for redundancy from one interrogator.
  Or
- Two interrogators on same DTS channel for improved redundancy.
- Multiple switchboards can be connected to same DTS channels.
- MIL-PRF-85045/18 transport fiber cable external to switchboards.
- M85045 cable spliced to internal fiber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

TASK 2 – DTS SYSTEM – HARDWARE SELECTION



AP SENSING DTS SYSTEM TESTED



SILIXA DTS SYSTEM TESTED

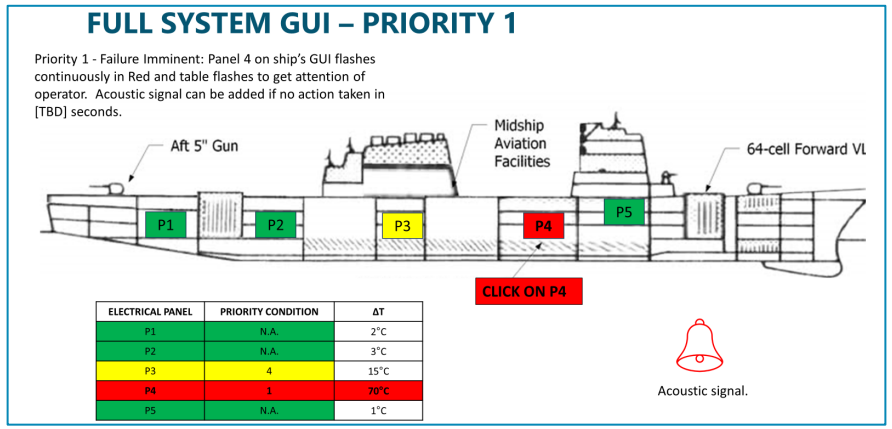
Item	Manufacturer	AP SENSING	Silixa
1	Model No.	N4585A	Ultima M
2	Max. Meas. Range	2, 4, 8 Km	10 Km
3	No. Channels	4	4
4	Meas. Accuracy (°C)	< 0.1°C	0.01°C
5	Length of fiber required for sensing (minimum definable zone length)	2 m	>1 m
6	Sensing Zones x Channel	2,000	Up to 40,000
7	Sampling Interval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

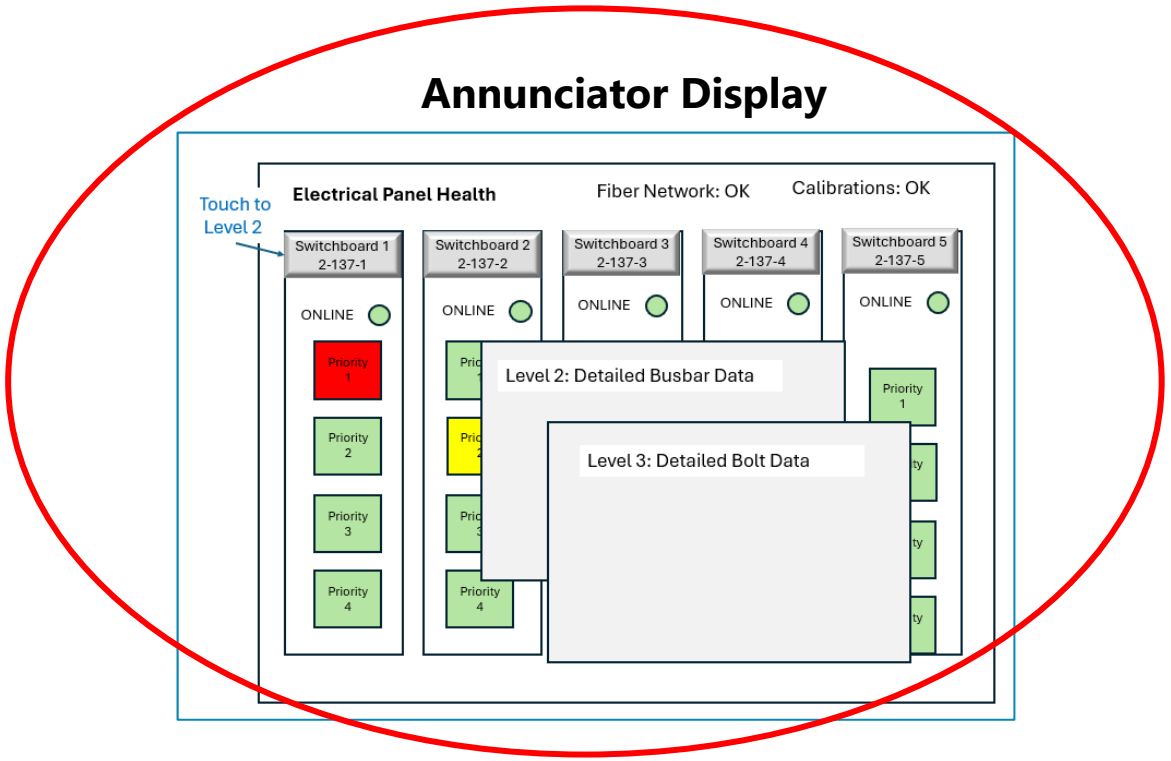
TASK 3 – CONFIGURE SOFTWARE AND GUI

Ship Outline Display

(Initial conceptual created under NSRP 2019-477-004)



Annunciator Display



GUI MIL-STDs

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

Display Considerations:

- Ease of development and customization.
- Reduce information complexity (visual noise) on display.
- Support immediate response to location of alarm.
- Minimize significant display redesign effort and costs between ship classes.

TASK 4 – INSTALLATION AND IMPLEMENTATION

- **Finalize Location**
- **Planning**
  - One (1) day on site to identify equipment and finalize assembly design.
- **Installation**
  - Up to two (2) days to install, set-up, and commission equipment.
- **Operation**
  - **No interference** with other functions/tests.
- **Maintenance / Repairs**
  - No maintenance required / anticipated for duration of project.
- Leave in place or remove at end of project (~ ½ day required for removal)

PROJECT SCHEDULE & CRITICAL PATH

Description	Apr-25	May-25	Jun-25	Jul-25	Aug-25	Sep-25	Oct-25	Nov-25	Dec-25	Jan-26	Feb-26	Mar-26
Kick-off Meeting	X											
Task 1 – Configure the Sensing Assemblies	X	X	X	X	X							
Assemblies' Physical Construction	X	X										
Assemblies Manufacturing Process	X	X										
Sensing Assembly Materials		X	X									
Assembly Installation Process			X	X	X							
Task 2 – Configure the DTS Interrogator Hardware	X	X	X	X								
Task 3 – Configure the Monitoring Software and GUI			X	X	X	X						
Task 4 - System Installation on a Test Site					X	X	X	X	X	X	X	X
Installation Location					X							
Installation Planning						X	X	X				
Installation, Set-Up and Commissioning								X	X			
System Operation									X	X	X	X

CRITICAL PATH

- **Installation Location**
  - Assembly attachment to busbar
  - Assembly final design

TECHNOLOGY TRANSFER

- Presentation at Machinery Failure Prevention Technologies 2025 Conference, May 2025, Virginia Beach, VA (G. Tomasi & C. Nemarich)
- Plan to present at ASNE Fleet Maintenance & Modernization Symposium 2025, September 2025, San Diego, CA (G. Tomasi, J. Carter, C. Nemarich)
- Propose 2026 NSRP PP to investigate other DFOS applications (Jointly w/NSWCDD).

MFPT ANNUAL CONFERENCE

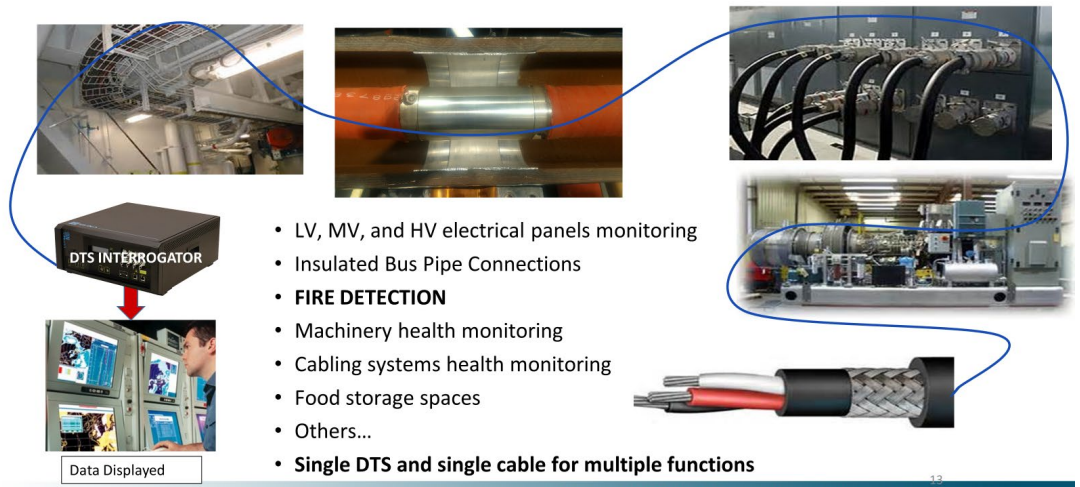
Diagnostics, Prognostics, and Failure Prevention
Where Theory Meets Practice

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

YEAR 2: INSTALL on In-Service Vessel

(Proposed 2026 NSRP RA)

DTS – SHIPBOARD APPLICATIONS



- LV, MV, and HV electrical panels monitoring
- Insulated Bus Pipe Connections
- **FIRE DETECTION**
- Machinery health monitoring
- Cabling systems health monitoring
- Food storage spaces
- Others…
- **Single DTS and single cable for multiple functions**

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DISTRIBUTION STATEMENT A. Approved for public release: distribution unlimited.

QUESTIONS?

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