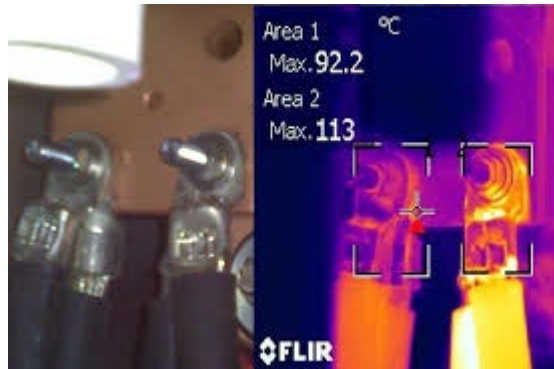


NSRP RA 2025-04: INSTALLATION OF A DISTRIBUTED TEMPERATURE SENSING SYSTEM ON NAVAL VESSEL FOR ELECTRICAL PLANT MONITORING



NSRP All Panels Meeting, Charleston, SC February 27, 2025

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- NAVSEA 05Z33
- NSWC PD
- NSWC DD
- Austal USA
- Leonardo DRS
- Penn State U ARL
- Silixa USA

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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⁾.

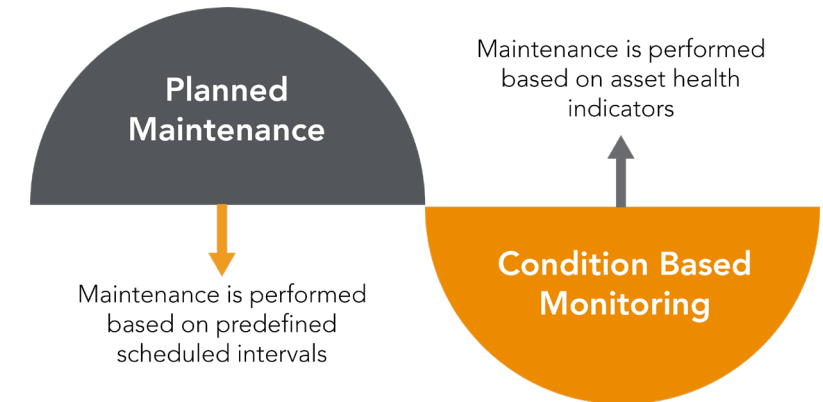


- Increasing complexity of ship's electrical systems will make the problem worse.

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

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 past 12 years** ⁽³⁾.
- **\$3 million/year** estimated cost arc fault repairs and availability delays.



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.

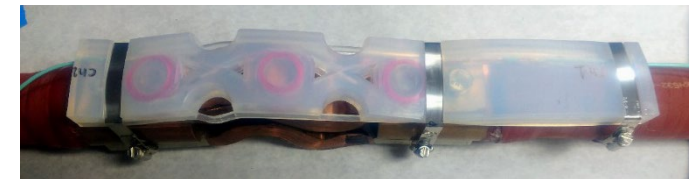
NSRP PROJECTS HISTORY

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, Silixa: DTS Installation on DDG 51 Land site.



* NSRP Research Announcements

SOLUTION - DISTRIBUTED TEMPERATURE SENSING

• Existing Smoke and Corona Detectors

- Identify fault(s) once they become critical limiting time to remediate.
- Do not provide exact location of requiring the open-door inspection of all connections.



• Distributed Temperature Sensing (DTS)

- Monitors temperature in real-time using entire length of the fiber.
- Enables personnel to detect faults, isolate location, determine severity and define action.
- Collects historical data for further analysis and prediction of potential future events.

• DTS Technology at a readiness TRL 9

- Used commercially in applications such as fire detection, data centers, machinery.
- DTS sensing assembly viability proven by 3 NSRP projects.
- ***Can be ready for full shipboard implementation w/in 3 years of RA project start.***

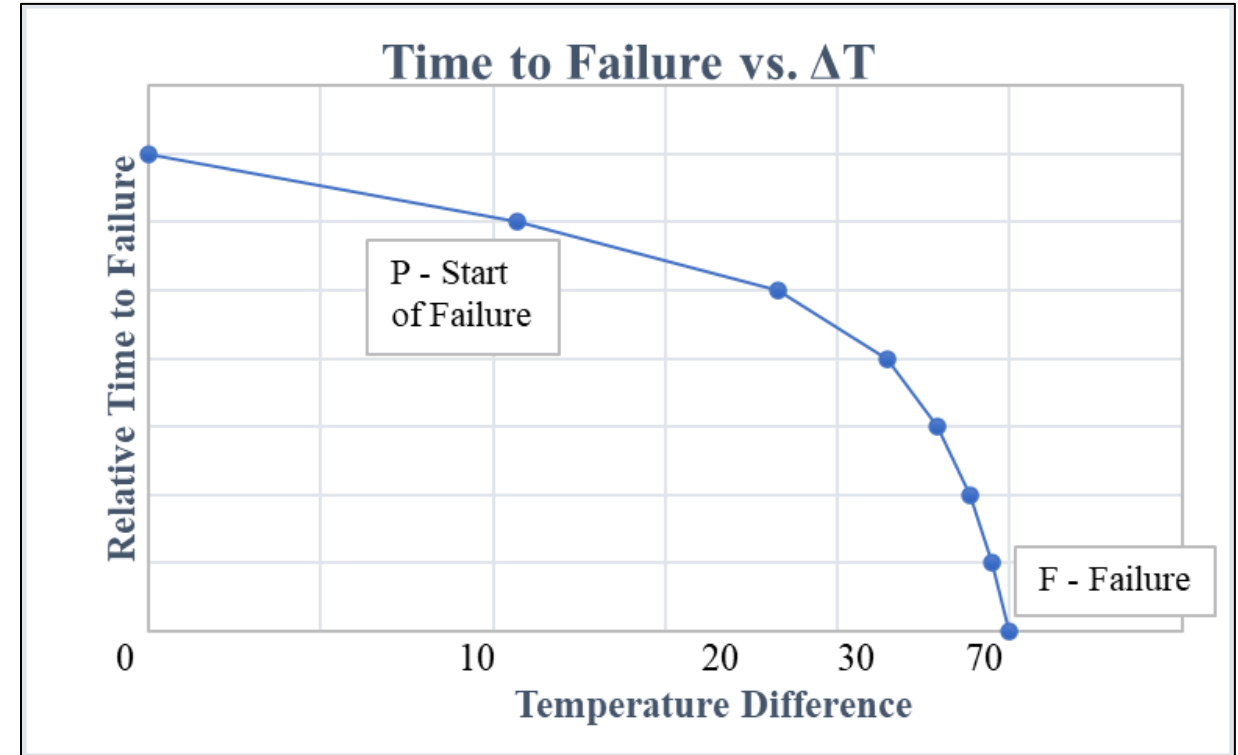
• NSRP Technology Investment Plan (TIP/SIP 7.3) Focus Areas

- Enhance occupational health, safety;
- Implement new inspection and maintenance processes;
- Improve early condition assessments and prognostic monitoring tools to support condition-based maintenance and structural health.

DTS DATA FOR CONDITION BASED MAINTENANCE

Define Prevention – Failure (P-F) curve for LV, MV, and HV electrical panels from data collected by DTS interrogators.

Priority	Temp Rise or ΔT	Operational Assessment	Severity Code	Action
1	$\geq 70^{\circ}\text{C}$	Failure Imminent	****	Equipment should be secured immediately and not operated until repairs are complete.
2	40°C to $< 70^{\circ}\text{C}$	Failure Almost Certain	***	Equipment should be secured if operating conditions permit otherwise monitored until corrective action can be taken.
3	20°C to $< 40^{\circ}\text{C}$	Failure Possible	**	Corrective action should be taken as soon as feasible.
4	5°C to $< 20^{\circ}\text{C}$	Performance Degraded	*	Corrective action should be taken at next scheduled routine maintenance period or as schedule permits.
	$< 5^{\circ}\text{C}$	N/A	N/A	No corrective action required; note for future reference.

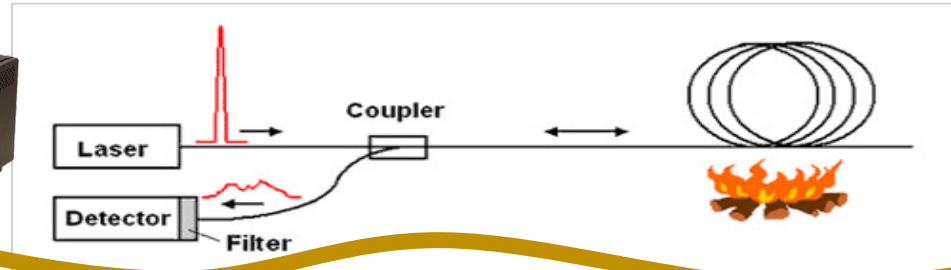


NOTE: Graph for illustrative purpose only. Not based on actual data.

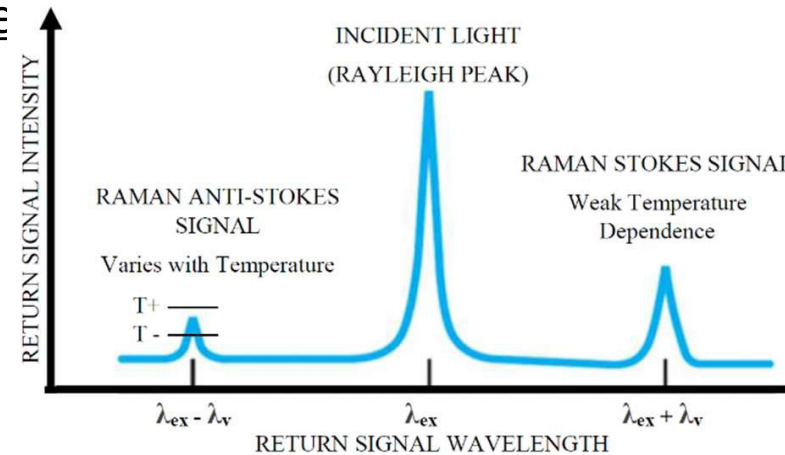
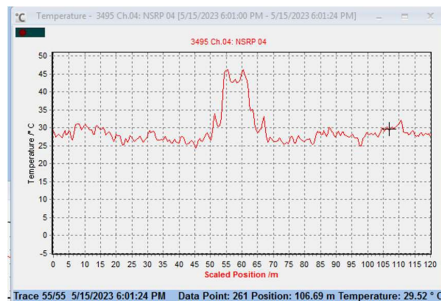
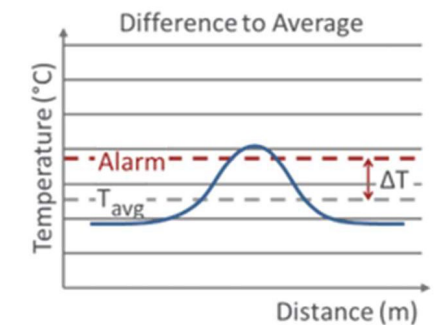
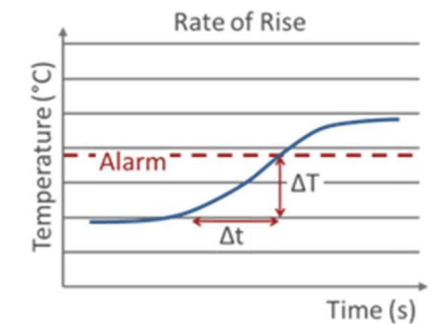
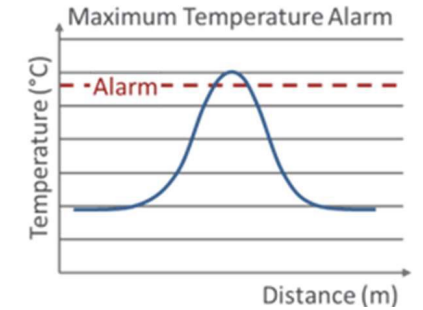
Table from MIL-STD-2194*

(*) Obsolete but same table used in other MIL STD documents.

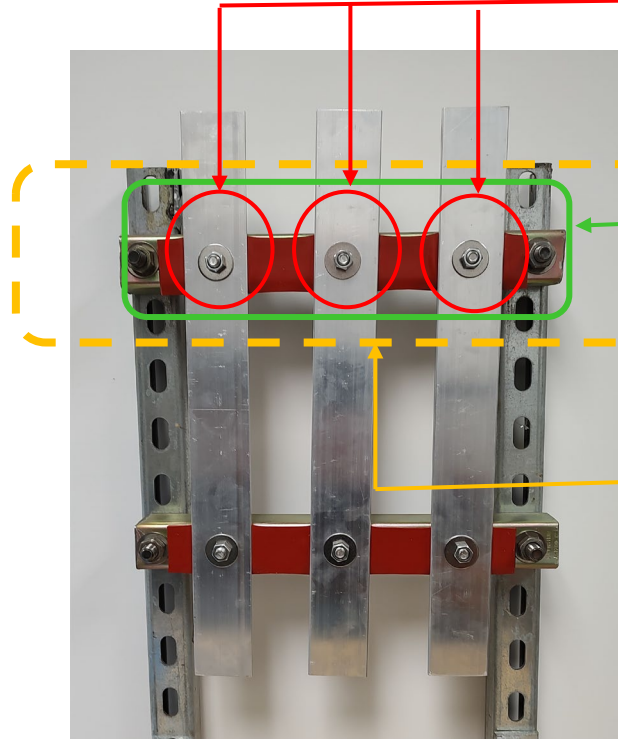
FIBER OPTIC DISTRIBUTED TEMPERATURE SENSING



- 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
- Temperature rise of 0.1°C
- Spatial Resolution down to 50 cm.



DTS EXAMPLE – DEMO OF 3 PH. PANEL



Zones 1, 2, 3: Individual Connections

Temperature of Each Connection (T)
Rate of Temperature Change ($\Delta T/\Delta t$)

Zone 4: Three Phase Busbars (3)

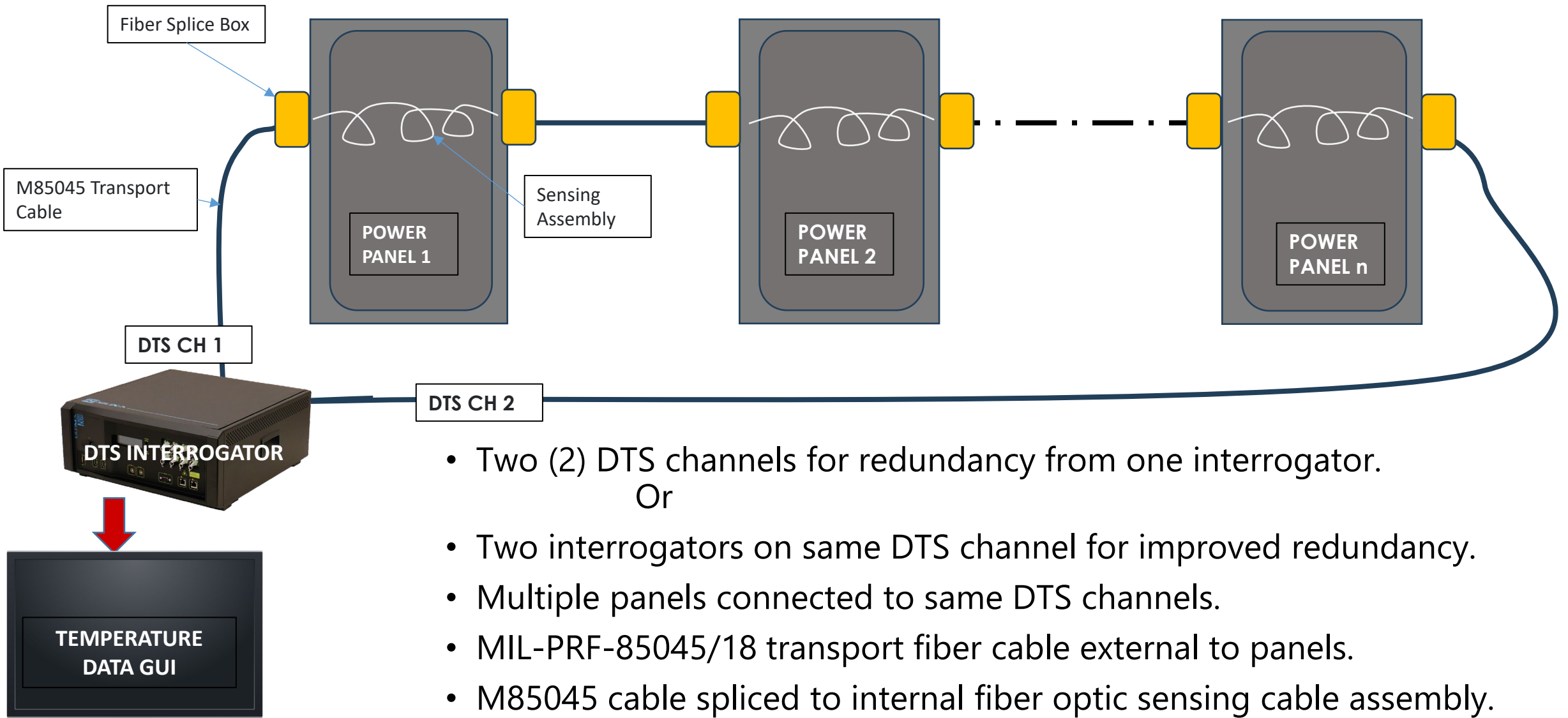
Difference in Temperature between Three Connections (ΔT)

Zone 5: Entire Panel (all Busbars + Connections)

Temperature within entire Panel (T)
Difference in Temperature (ΔT)
Rate of Temperature Change ($\Delta T/\Delta t$)

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

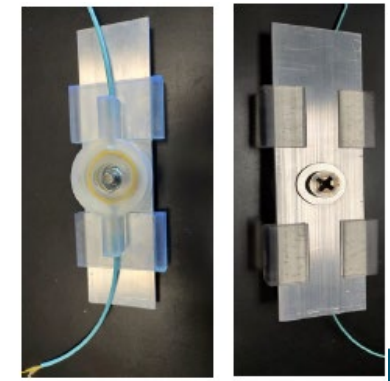
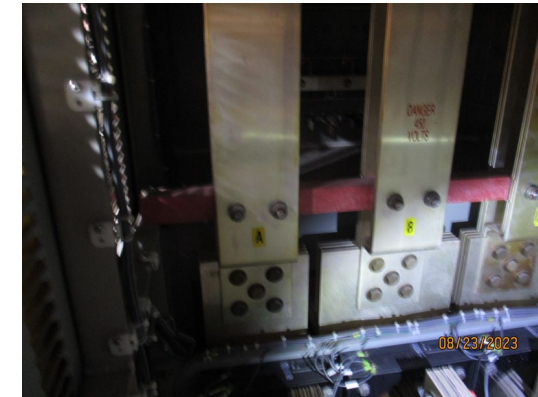
DTS – BASELINE SYSTEM CONFIGURATION



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

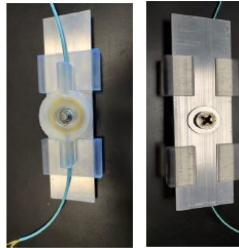
2023 NSRP DTS PP 2019-477-004 OUTCOME

- Three (3) Hands-On System Demonstrations + one (1) On Ship Visit.
 - Use a **dedicated processor & display** not connected to the shipboard network to simplify cybersecurity requirements.
 - **LV panels (450 VAC)** also candidate for DTS → many on ships w/ faults most common.
 - Pre-installed fiber sensing assemblies may get damaged when installing power cables.
 - **Install assemblies after power cables.**
 - Metal straps used in the IBP may cause arcing in MV and HV panels.
 - Use molded assemblies' shapes to **attach without straps.**
 - Use materials **for 90°C Max normal operation and 120°C Max excursions.**
 - Data from NSRP 2019-477-03 Cable Jacket Panel Project to identify materials.
- Developed outline for Graphical User Interface.
- Developed outline for DTS Implementation → system **configuration, installation, commissioning, and maintenance.**
- Created **baseline for 2025-04 RA:** DTS Installation DDG 51 land test site.

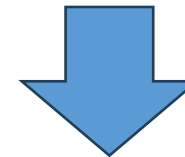


NSRP RA 2025-04 OUTLINE

- **Task 1 – Configure the Sensing Assemblies**
 - Attachment methods
 - Materials
- **Task 2 – Configure the DTS Sensing Interrogator Hardware**
 - Single unit with 10,000's zones vs. multiple units w/fewer zones.
- **Task 3 – Configure the Monitoring Software and Graphical User Interface**
 - To inform with actionable data.



- **Task 4 - System Installation on DDG 51 land-based facility in Philadelphia.**
 - Define methods and configuration for on-ship installation.
 - Run system to verify operation before on-ship installation.
 - Define Baseline for Ship Change Document (SCD) for Temp Alt.



YEAR 2 → INSTALL ON IN-SERVICE DDG 51 / USCG Vessel / MSC Vessel

FULL SYSTEM GUI – PRIORITY 1

Priority 1 - Failure Imminent: Panel 4 on ship's GUI flashes continuously in Red and table flashes to get attention of operator. Acoustic signal can be added if no action taken in [TBD] seconds.

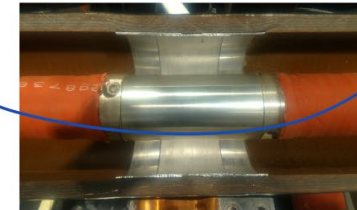
ELECTRICAL PANEL	PRIORITY CONDITION	ΔT
P1	N.A.	2°C
P2	N.A.	3°C
P3	4	15°C
P4	1	70°C
P5	N.A.	1°C

- Detect
- Identify location
- Determine severity
- Define action

TECHNOLOGY TRANSFER

- Presented at **MFPT 2023**
[Co-Authors: G. Tomasi, C. Nemarich]
- Presented at **SNAME SMC 2023**
[Co-Authors: G. Tomasi, C. Nemarich and R. DeLoge]
- Presented at **ShipTech 2024**
[Co-Authors: G. Tomasi, C. Nemarich and R. DeLoge]
- Paper to be Published in **ASNE Journal** [Co-Authors: G. Tomasi, C. Nemarich, B. Whaley, and R. DeLoge]
- Planning to present at **MFPT 2025**
[Co-Authors: G. Tomasi, C. Nemarich, TBD]

DTS – SHIPBOARD APPLICATIONS



Data Displayed

- 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**



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

QUESTIONS?

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BACKUP SLIDES

DTS IMPLEMENTATION

1 - INTERROGATOR CONFIGURATION

DATA COLLECTION

- Define temperature sampling rates.
- Set data retention requirements for data analytics.

DATA DISPLAY

- Set warnings and alarms.
- Configure HMI / GUI for Actionable information.
- Provide "Maintenance" option for systems check.

2 - INSTALLATION

FIBER OPTIC ASSEMBLIES

- Connections / zones configuration management.
- Assembly P/N based on panel type.
- Fiber cable assemblies' installation procedure.
- Fusion splicing connections to external fiber optic cable.

DTS INTERROGATOR

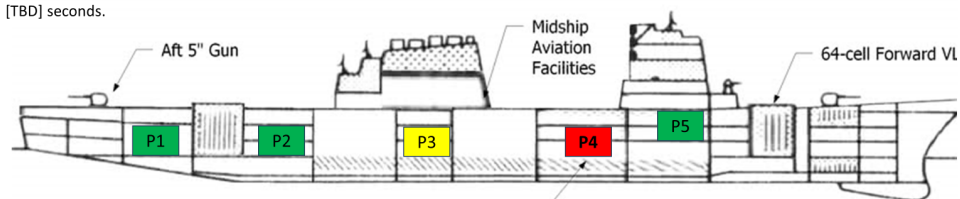
- Interrogator and GUI / HMI device location.

TRANSPORT FIBER OPTIC CABLE

- Cable routing.
- Splicing fiber pigtails for connection to DTS interrogator.

FULL SYSTEM GUI – PRIORITY 1

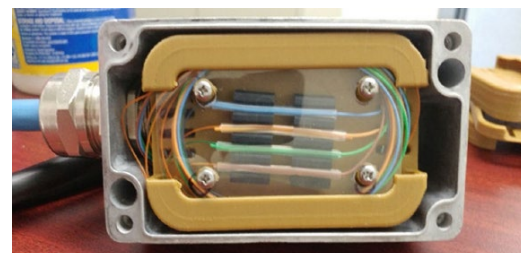
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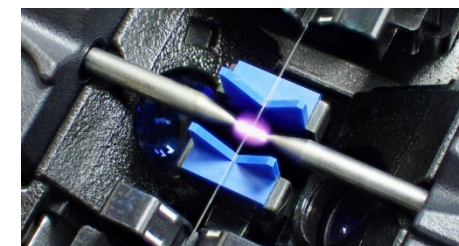
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P1	N.A.	2°C
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P3	4	15°C
P4	1	70°C
P5	N.A.	1°C



Acoustic signal.



2019 PSU EOC NSRP Panel Project: Fusion Splice Enclosure at Equipment



2021 HII – Ingalls NSRP Panel Project: Evaluation of Splice-On Connectors and Termini for Shipboard Applications

DTS IMPLEMENTATION

3 - SYSTEM COMMISSIONING

ZONES IDENTIFICATION

- Identification methodology of panels and sensing zones.
- Verification of correct attachment for sensing assemblies.

SYSTEM ACCEPTANCE TEST

- Run system acceptance testing procedure with OTDR.
- Verify correct temperature detection.



2019 Kitco Panel Project
Fiber Optic Testing Enhancement for Cost Reduction

4 - IN-SERVICE OPERATIONS

MAINTENANCE

- Interrogate system for maintenance.
- Verify system integrity.
- Data Analytics for CBM definition.

FIELD REPAIRS

- Field repairs of assemblies.
- Reconfiguration process for sensing zones if cables cut / damaged.
- Capability for the addition of new panels or sensing zones.