2012 Conference Training
203 - Thermal Planning
Instructor- David Gratton

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Agenda

• The Case for Thermal Planning
• The Science Behind Thermal Planning
• Practical Application
How hot is TOO hot?

Engineers design the electronics we install with specific operating temperature ranges based on the components used and the platform they are used in.

Diagram 1: Typical Device Breakdown

The Case for Thermal Planning
“Reliability Through Thermal Management”
How hot is TOO hot?

The finished goods are engineered and manufactured to perform properly in a predetermined thermal environment.

Installation documentation communicates the required environment in a variety of ways. Ranging from…

The Case for Thermal Planning
“Reliability Through Thermal Management”
How hot is TOO hot?

Detailed technical specifications...

<table>
<thead>
<tr>
<th>Environmental Considerations:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating</td>
</tr>
<tr>
<td>: Temperature -15 deg. C to +55 deg. C</td>
</tr>
<tr>
<td>- Humidity up to 95%</td>
</tr>
<tr>
<td>Storage</td>
</tr>
<tr>
<td>: Temperature -20 deg. C to +60 deg. C</td>
</tr>
<tr>
<td>- Humidity up to 95%</td>
</tr>
<tr>
<td>IP Rating</td>
</tr>
<tr>
<td>: Protection: IP66 front - IP22 rear (EN60529)</td>
</tr>
</tbody>
</table>

**Safety Considerations:**

Even although the test conditions for bridge units provide for a maximum operating temperature of 55°C, continuous operation of all electronic components should, if possible, take place at ambient temperatures of only 25°C. This is a necessary prerequisite for long life and low service costs.

The Case for Thermal Planning
“Reliability Through Thermal Management”
How hot is TOO hot?

To Decidedly Vague Directions…

The unit can be mounted on the deck, a desktop or on a bulkhead. Take special note that the [HOLE] IS NOT WATERPROOF. Select a mounting location considering the points below:

- Select a location where temperature and humidity are moderate and stable.

It is the installer’s responsibility to install the product in a manner that will allow the unit to perform reliably with the intended service life.

So we need to determine what the requirements are for each piece of equipment that we install

_The Case for Thermal Planning_
_“Reliability Through Thermal Management”_
How hot is TOO hot?

Back to our first example, sometimes there is fine print…

### Environmental Considerations:
- **Operating**: Temperature -15 deg. C to +55 deg. C
  - Humidity up to 95%
- **Storage**: Temperature -20 deg. C to +60 deg. C
  - Humidity up to 95%
- **IP Rating**: Protection: IP66 front - IP22 rear (EN60529)

### Safety Considerations:
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The Case for Thermal Planning
“Reliability Through Thermal Management”
How hot is TOO hot?

Since $55^\circ C = 131^\circ F$, that’s not too bad,

but what did the fine print say?

**Safety Considerations:**
Even although the test conditions for bridge units provide for a maximum operating temperature of $55^\circ C$, continuous operation of all electronic components should, if possible, take place at ambient temperatures of only $25^\circ C$. This is a necessary prerequisite for long life and low service costs.

$25^\circ C$ is ONLY $77^\circ F$, Now we have to consider reduced serviceability and longevity if the ambient operating temperature is above $77^\circ F$. That could be a problem depending on the project.

**The Case for Thermal Planning**
“Reliability Through Thermal Management”
How hot is TOO hot?

Here is some interesting reading regarding the effect of thermal environments on electronic components…

“85°F is the maximum recommended constant operating temperature for most equipment; it will help provide a long service life for the equipment inside an enclosure. Why 85°F? Most studies have shown that for every 10°F rise over 85°F, digital equipment life is reduced by approximately 40%!" - Bob Schluter, Middle Atlantic Products

“…from the quality assurance department's point of view, if we can lower the temperature by 10 degrees, we'll double the reliability." – Steve Somers, Extron

The Case for Thermal Planning
“Reliability Through Thermal Management”
The first law of thermodynamics states that energy may be transferred or changed, but cannot be created or destroyed.

This is often referred to as the conservation of energy and implies that the total amount of energy in the universe is constant and merely changes from one form to another.

The Science Behind Thermal Planning
“Reliability Through Thermal Management”
The second law of thermodynamics pertains to heat energy transfer. For any spontaneous process there will be an increase in entropy. Entropy is a measure of the amount of disorder in a system.

Other equivalent ways to consider the second law are:
a) heat flows only from a warm body to a colder body;
b) not all heat may be converted to useful work;
c) all isolated systems become disordered in time;

The second law most notably applies in our understanding of heat engines and the direction of heat transfer.

The Science Behind Thermal Planning
“Reliability Through Thermal Management”
The third law describes the relationship of thermal motion and temperature as we measure it. When all thermal motion of molecules stops, a condition of absolute zero is attained. Absolute zero represents 0° Kelvin, or -273.15° C. The estimated temperature of empty space in the universe is about 2.7 Kelvin.
The concept of equilibrium implies a MOST fundamental law preceding the first law of thermodynamics. The concept is: If, at the same time, two systems are in thermal equilibrium with a third system then all three systems are in thermal equilibrium with each other. Being so fundamental, this concept has been coined as the "zeroth law of thermodynamics".

The Science Behind Thermal Planning
“Reliability Through Thermal Management”
Why Do I Care?

The Marine Electronics Installers Law of *Thermo-catastrophe*

How electronics are designed

X

How electronics are installed

No bearing on how well they work/last

Of course we know better, but what really needs to be done to ensure proper operation?

*The Science Behind Thermal Planning*

“Reliability Through Thermal Management”
Why Do I Care?

I am convinced that the single most effective way for manufacturers to present information in a manner that will be completely ignored is…

**WARNING**

- Keep units other than the radar antenna away from the rain and water.
  
  Fire or electrical shock can occur if water gets inside the equipment.

- Do not disassemble or modify the equipment.
  
  Fire or electrical shock can occur if the equipment is disassembled or modified.

- Do not operate the equipment with wet hands.
  
  Electrical shock can occur.

**PLEASE READ!**

Important Addendum to Your Product Manual

You may use the two 0.5" (12.5 mm) holes in the antenna frame (see Figure 1) to hoist the antenna to its mounting location, if necessary. DO NOT use any other structure inside the antenna — doing so might damage the antenna.

As marine electronics professionals, we are OBLIGATED by our contract to the customer (and our manufacturer partners) to review and consider any relevant technical data that is provided!

**The Science Behind Thermal Planning**

“Reliability Through Thermal Management”
Bringing It All Together

The Science Behind Thermal Planning
“Reliability Through Thermal Management”

from Thermal Management Part 2: How Hot Is Too Hot? By Steve Somers, Vice President of Engineering
### Thermal Conductivity of Common Materials (at 25° C)

<table>
<thead>
<tr>
<th>Material</th>
<th>Conductivity (Watts/meter-°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acrylic</td>
<td>0.200</td>
</tr>
<tr>
<td>Air</td>
<td>0.024</td>
</tr>
<tr>
<td>Aluminum</td>
<td>250.000</td>
</tr>
<tr>
<td>Copper</td>
<td>401.000</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>54.000</td>
</tr>
<tr>
<td>Concrete</td>
<td>1.050</td>
</tr>
<tr>
<td>Glass</td>
<td>1.050</td>
</tr>
<tr>
<td>Gold</td>
<td>310.000</td>
</tr>
<tr>
<td>Nickel</td>
<td>91.000</td>
</tr>
<tr>
<td>Paper</td>
<td>0.050</td>
</tr>
<tr>
<td>PTFE (Teflon®)</td>
<td>0.250</td>
</tr>
<tr>
<td>PVC</td>
<td>0.190</td>
</tr>
<tr>
<td>Silver</td>
<td>429.000</td>
</tr>
<tr>
<td>Steel</td>
<td>46.000</td>
</tr>
<tr>
<td>Water</td>
<td>0.580</td>
</tr>
<tr>
<td>Wood</td>
<td>0.130</td>
</tr>
</tbody>
</table>

from Thermal Management Part 2: How Hot Is Too Hot? By Steve Somers, Vice President of Engineering

**The Science Behind Thermal Planning**

**“Reliability Through Thermal Management”**
Bringing It All Together

The Science Behind Thermal Planning
“Reliability Through Thermal Management”

Fourier’s Law of Conduction: \( q = -(kA\Delta T)/s \)

- **q** = heat transferred per unit time (Watts)
- **k** = thermal conductivity of material in Watts/m·°C
- **A** = heat transfer area in square meters
- **Δ T** = temperature difference across material in °C
- **s** = material thickness in meters

from Thermal Management Part 2: How Hot Is Too Hot? By Steve Somers, Vice President of Engineering
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$k = \text{Thermal conductivity of the material (wood} = 0.130 \text{ watts/m-}°\text{C})$

$A = \text{Heat transfer area in square meters (assume a volume of } 3''\times10''\times12'' = 0.24 \text{ sq. meters)}$

$\Delta T = \text{Temperature difference across the material (temperature differential is } 40 \text{ (spec)} - 25 \text{ (amb air)} = 15°\text{ C)}$

$s = \text{Material thickness in meters (thickness} = 0.75 \text{ inch or } 0.019m)$

from Thermal Management Part 2: How Hot Is Too Hot? By Steve Somers, Vice President of Engineering
Bringing It All Together

\[ q = -\left(0.13 \times 0.24 \times 15\right)/0.019 = -24.6 \text{ watts.} \]

This tells us that the wooden podium is capable of transferring up to 24.6 watts into the external environment with an internal temperature of 40°C. Suppose the equipment item is a computer video interface that only uses 12 watts. We have a 2:1 design factor or we know that the internal podium temperature will be lower. No fan is required.

from Thermal Management Part 2: How Hot Is Too Hot? By Steve Somers, Vice President of Engineering

*The Science Behind Thermal Planning
“Reliability Through Thermal Management”*
Thermal Planning
“Reliability through Thermal Management”

Practical Application
Definitions & Constants

**CFM** - Cubic feet per minute, of airflow  
**Ton** - One “Ton” of air conditioning = 400 CFM (on most units)

**BTU/Hr.** - British thermal units per hour, of heat  
12,000 BTU/Hr. = 1 “Ton” of air conditioning

**Watt** - One Watt of current draw (Volts X Amps) = 3.413 BTU/Hr.

**Space** - Enclosure, cabinet, for housing electronic equipment

**Measured Power** – Actual current draw measured by an amp meter to determine waste heat, for all equipment other than amplifiers

**Nameplate Rating** – A power, voltage and frequency rating used for regulatory approval [should not be exclusively used for waste heat calculations]

Practical Application

“Reliability Through Thermal Management”
Waste Heat Calculation

When considering thermal management systems, it is critical to ensure that heat be removed adequately. However whether a passive or active system of removal, you must determine the amount of heat generated by the specific components being installed.

Waste heat output will vary greatly between different types of equipment, therefore consideration must be given to the individual components as well as how they act as part of the whole system in each rack or enclosure.

Practical Application
“Reliability Through Thermal Management”
Most equipment converts almost all of the power drawn into waste heat.

In calculating BTU/Hr, output for most equipment is simple: the more current it draws, the more BTU/Hr. will be produced.

One Watt of current equates to 3.413 BTU/hr

At 117 volts, each ampere of current drawn produces exactly 400 BTU/Hr. of heat output.

Practical Application
“Reliability Through Thermal Management”
Consider a common black box processor running a 25kW radar which consumes 249W:

$$3.413\text{BTU/hr} \times 249\text{W} = 850 \text{BTU/hr}$$ of waste heat.

This amount of waste heat needs to be considered and addressed when planning the layout of your installation.

Furthermore, you need to consider ALL generation of waste heat in the spaces where you will be placing electronics components.

*Practical Application*

*“Reliability Through Thermal Management”*
A common question is: Should I separate each item in the rack by at least one rack unit space?

The right answer depends on several factors, such as:

- Whether adjacent items are significant generators of heat, since the resulting heat will physically transfer from a hotter box to a colder box.
- How items are vented individually. If there are vents on top and/or bottom, do not defeat them by stacking the item.
- The power rating on each item. Keep in mind the 400 BTU/hour per ampere of line current (115VAC), which translates to 115 watts draw.

**Practical Application**

“Reliability Through Thermal Management”
Airflow Considerations

There are three airflows involved in a thermal system:

How the heat is produced by the equipment

How the air moves throughout the space

How space heat is removed.

The interactions between these airflows are important, and must be considered when taking a systems approach.

Practical Application
“Reliability Through Thermal Management”
How is the equipment designed to dissipate waste heat?

- Radiation (from the device)
- Conduction (utilizes heat sinks)
- Convection (utilizes fans)

In general heat sinks are used to increase the heat dissipation from hot devices because the heat dissipation between the heat sink and the surrounding air is more efficient than between the device and the surrounding air. The thermal energy transfer efficiency of heat sinks is due to the small thermal resistance between the heat sink and the air.

*Practical Application*

“Reliability Through Thermal Management”
How does air move throughout the space?

Best Enclosure Airflow Methods

Front to Rear
Front to Top
Front to Top and Rear

Practical Application
“Reliability Through Thermal Management”
Design Considerations

How is waste heat removed?

ACTIVE (forced air)

PASSIVE (convected air)

Practical Application

“Reliability Through Thermal Management”
Design Considerations

Whether you will be using a forced air or convection system to manage your waste heat for your installation, there is one important rule to keep in mind:

DO NOT ALLOW HOT SPOTS TO OCCUR!

Improper thermal planning can actually create heat build up that would not have existed if you had done nothing.

Practical Application
“Reliability Through Thermal Management”
Static Pressure
Static pressure (S.P.) is the pressure or suction the fan is capable of developing. In a rack, it is the measurement of resistance to airflow.

There is system impedance involved with forced-air cooling. As air travels through intake vents and filters, the air pressure drops. The system impedance is the sum of all pressure drops. The fan selected must be capable of operating at this static pressure, or the CFM will drop. All fans have performance curves, which show how much CFM will be delivered at various static pressures.

Practical Application
“Reliability Through Thermal Management”
Design Considerations

In this example, there are several problems:

• Vent placement which renders the pulling action of the fan useless;

• If the venting fan fails, the fans on the front of the equipment cannot handle high static pressure and heat builds up;

Practical Application
“Reliability Through Thermal Management”
**Design Considerations**

In a corrected system, the fan is not rendered useless and the venting will not produce heat build up in the event of a forced air fan failure.

**Practical Application**

“Reliability Through Thermal Management”
Design Considerations

Practical Application

“Reliability Through Thermal Management”

Going “fan crazy” is not an effective method of thermal management either.

Here we see fans installed irrespective of total system flow.
In a corrected system, high heat producing amplifiers (heat sinks in back) are placed at the bottom of the rack and create a convective airflow which is enhanced by the overall venting.

**Do:** Leading amplifier manufacturers recommend stacking amplifiers on top of each other.

**Fully Or Partially Vented Rear Door**

**Vented Rack Face**

Practical Application

“Reliability Through Thermal Management”
In this example the fans are doing a very nice job of re-circulating the cooling air from outside of the rack which is completely useless.

At the same time this system is creating a region of static pressure which keeps the convective airflow from cooling the equipment.

Ultimately heat will build up and equipment will be damaged.

**Practical Application**

“Reliability Through Thermal Management”
Design Considerations

The corrected system with properly placed venting, intake, and exhaust fans.

Practical Application

“Reliability Through Thermal Management”
Summary

Know the requirements of equipment you are installing

Consider the ambient environment of your installation

Calculate how much heat you will produce

Determine how the ambient space will react to that heat

Design & deploy a thermal management system which will accommodate all of the above considerations!

Practical Application
“Reliability Through Thermal Management”
Resources

Major Sources Used

**Extron**
www.extron.com/company/article.aspx?id=thermalmgt1_ts
www.extron.com/company/article.aspx?id=thermalmgt2_ts

**Middle Atlantic Products**

*Practical Application*

“Reliability Through Thermal Management”
Questions?