

Thermal Integration and Testing Magnetospheric MultiScale (MMS) Observatories Using Digital 1-wire Sensors

Jason Solimani and Santino Rosanova
Vertex Aerospace, LLC

AGENDA



45th International Conference on
Environmental Systems

- Introduction
- About 1-Wire
- 1-Wire Preparation for Space Application
- MMS Application
- Documentation
- GSE Hardware/Software
- Lessons Learned
- Summary

Introduction



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- The MMS mission uses four identically instrumented observatories to perform the first definitive study of magnetic reconnection in space
- Magnetic reconnection is the primary process by which energy is transferred from the solar wind to the Earth's magnetosphere
- Magnetic reconnection is also fundamental to the explosive release of energy during sub storms and solar flares
- MMS will test critical hypotheses about reconnection.
- The MMS mission successfully launched all four observatories on March 12, 2015 at 10:44 P.M. Eastern from Cape Canaveral, Florida



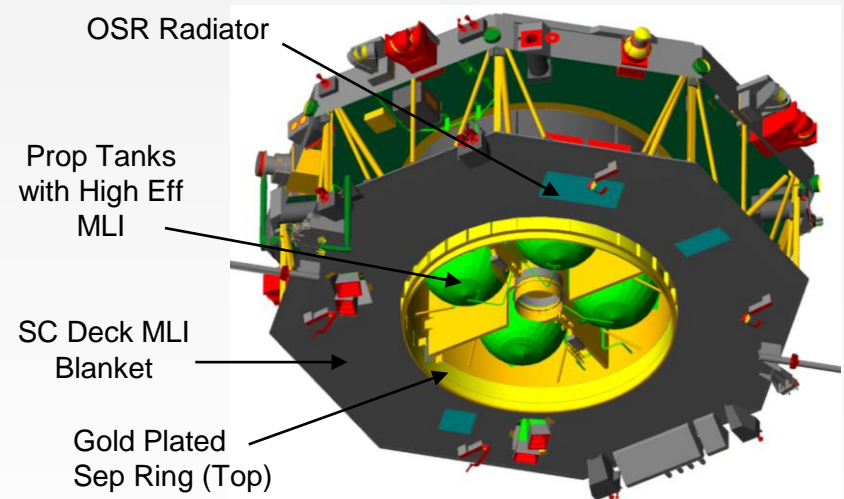
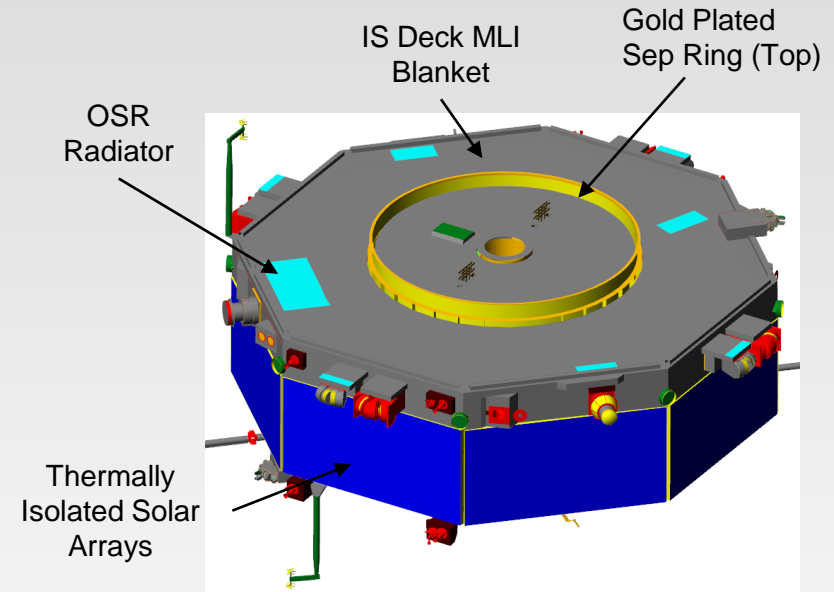
Introduction



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MMS has a passive thermal design that include:

- Optical Solar Reflector (OSR) radiators on the instrument and spacecraft decks to reject heat from avionics and instrument electronics during hot environments.
- Thermal Gaskets to conductively couple electronics to their respective radiators.
- Multi-layered Insulation blankets cover all exterior surfaces except for instrument apertures, solar arrays, and radiators.
- Titanium isolators separate the Solar Arrays from the spacecraft to minimize heat loss in eclipse.
- High-efficiency blankets on hydrazine propulsion tanks minimize heat loss in eclipse.
- Ultem Isolators on propulsion lines and thruster valves minimize conductive losses in eclipse.
- Gold plated thrust tube rings and separation system rings.



Introduction



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- The MMS thermal design relies heavily on passive thermal control techniques. Therefore, it is essential to make sure assumptions on conductivities, optical properties and overall heat flows are in line with model predictions in order to ensure a reliable thermal model of the spacecraft.
- The significant number of instruments and components on the spacecraft required the usage of over 350 thermal sensors per spacecraft.
- Due to the intensive process of building four large spacecraft at once, a decision was made early on to simplify the integration process where possible. The flexibility the 1-wires afford was seen as a prudent way to speed up thermal subsystem integration and improve reliability.
- Along with the 1-wire sensors, a series of other thermal sensors were used for MMS.
- There are over 75 thermistors and PRT's that are used during flight, but model correlation requires more information than can be provided by these flight sensors.
- Thermocouples were used as backups to 1-wire sensors in sensitive locations and where a GSE heater was controlled

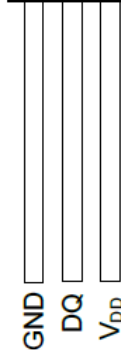
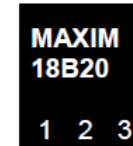
About 1-Wire



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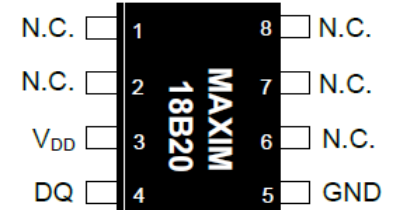
- 1-wire refers to the technology being used, not the physical number of wires the sensors possess.
- The basis of the technology is a serial protocol using a single data line plus ground for communication.
- Parasitic Power Mode requires only 2 Pins for operation (Data and Ground)
- Each 1-Wire device has a unique 64 bit Serial Code Stored in On-Board ROM
- The 1-Wire sensors draw their power via the bus and usually operate over a range of 3.0 to 5.5 V.
- 1-wire devices are designed with contact applications in mind
- The sensor head is TO-92 plastic packaged with an interface surface of approximately 5mm x 5mm
- Each sensor has an operating range of -55 °C to +125 °C and is accurate to within ± 0.5 °C over the range of -10 °C to +85 °C

PIN CONFIGURATIONS

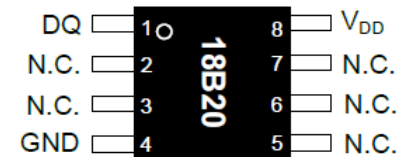


(BOTTOM VIEW)

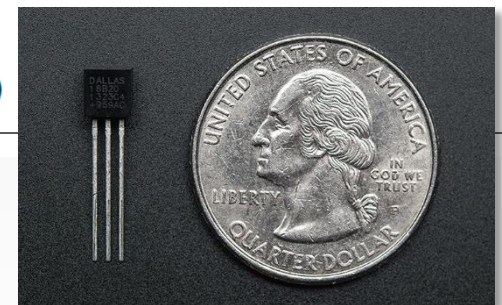
TO-92
(DS18B20)



SO (150 mils)
(DS18B20Z)



μSOP
(DS18B20U)



Bonding 1-Wires



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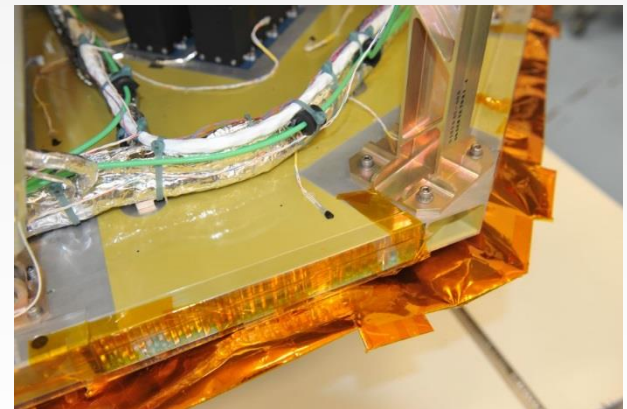
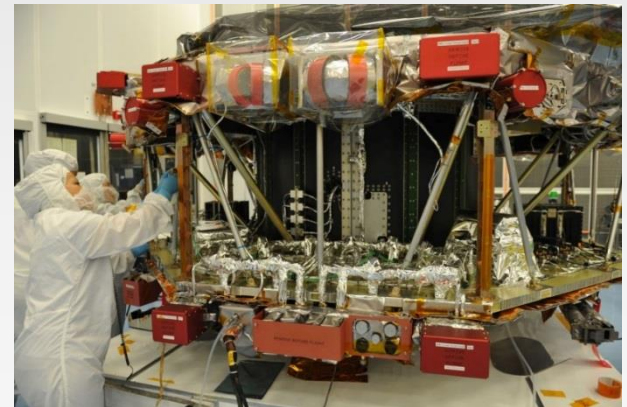
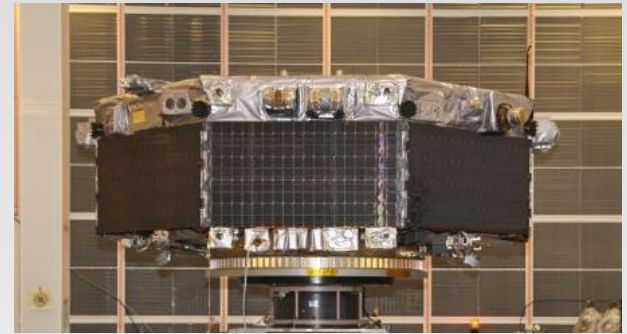
- Prior to bonding and staking of the 1-Wire Harness, a geometrical routing of the harness was designed on the computer and then taped into place on the MMS spacecraft decks using 1" strips of kapton tape that were "tabbed" for easy removal after epoxies had cured, usually about 24-36 hours after initial bonding occurs.
- 1-Wire sensors require a thermally conductive bonding medium for adhesion to the working surfaces of components. MMS used a combination of Stycast 2850 and Hysol 9394, based on availability of the epoxies to the project. Arathane 5753 with 14% cab-o-sil was used to stake down the harness length along the spacecraft and instrument decks and the propulsion mechanical structures.
- Hardware prep for 1-Wire sensor bonding included a thorough cleaning of the surface with IPA (Isopropyl Alcohol) wipes to ensure no debris was present that could potentially compromise the bonding of the sensor.
- The MMS Solar Arrays were a special case where the substrate was a composite which required a roughing of the surface with sandpaper to ensure a good adhesion.
- A clean room vacuum was set up during sanding operations to reduce particulate generated from this activity.
- Once complete a thorough cleaning with an IPA wipe is performed

MMS Application



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- For the purpose of thermal testing DS18B20 sensors were used on the MMS mission.
- The 1-Wire sensor harness for MMS used all three wires:
 - Pin 1 is the ground (GND)
 - Pin 2 is for Data (DQ)
 - Pin 3 is for Power (V)
- The 1-wire technology allows for easy use with a laptop computer as the computer USB port typically has enough power to support a simple 1-wire bus.
- Multiple sensors can be daisy chained along common three wire bus (i.e., Data, Power, Ground)
- Unique serial code allows easy identification of sensor location
- Four (4) Observatories (300+ sensors per Observatory)
- Each instrument performed three (3) thermal vacuum (TV) tests
 - Instrument Level TV Test
 - Payload Level TV Test
 - Observatory Level TV Test



MMS 1-Wire Bus

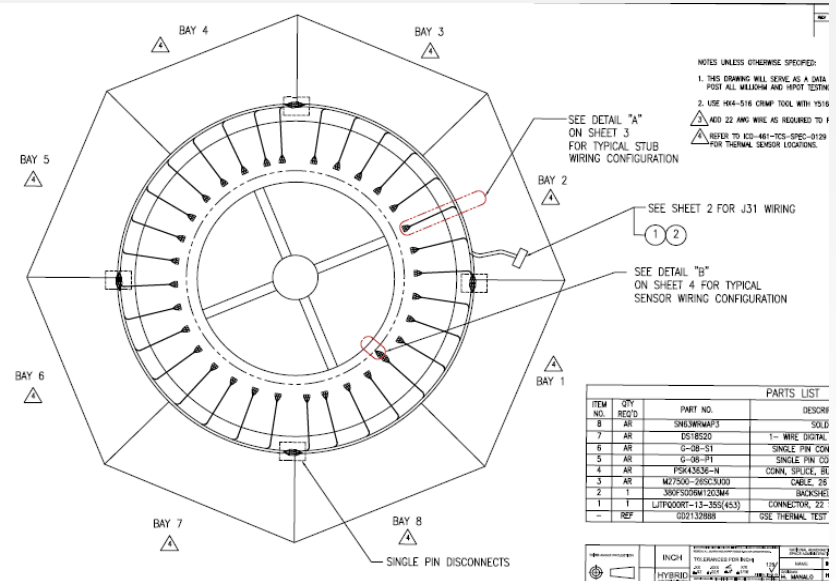


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- 1-wire sensors have some advantages over thermocouples that led to the MMS thermal team's decision.
- 1-wires can be spliced and daisy changed together via a bus, reducing significantly the number of wires exiting the spacecraft and thus reducing GSE hardware heat leaks.
- 350 thermocouples (TCs) would require 700 wires to be routed out of the spacecraft.
- The MMS 1-wire Bus Design consisted of six (6), sixty-four (64) 1-wire sensor buses that interface to a three (3) wire (Data, Ground, Power) 1-wire bus harness that fed to an eighteen (18) pin connector.
- The MMS 1-Wire harness was grouped into three (3) subsystems, Instrument, Spacecraft, and Propulsion

Pros / Advantages

- The six (6) MMS 1-wire buses reduced the number of wires exiting the spacecraft from the potential 700 wires to 18 wires
- Prior spacecraft integration experience provided insight into the fragile nature of thermocouple sensors, as some had been broken or damaged during installation.
- 1-wires feature a more robust design that significantly reduced the number of repairs needed during integration

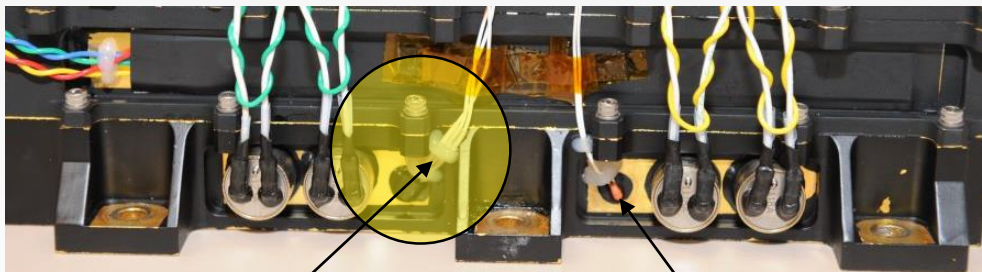


MMS Application



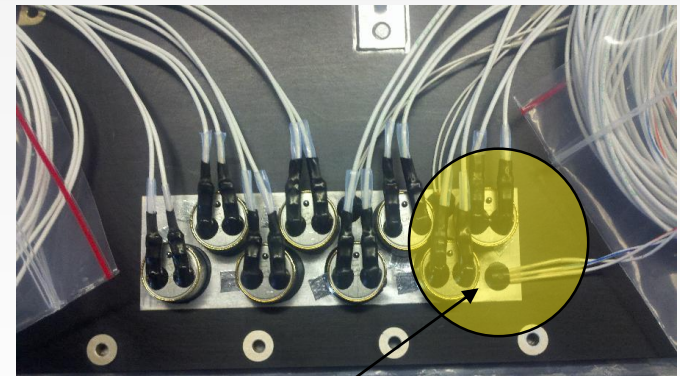
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- This harness design allows for quick and easy manipulation of the 1-Wire harness if a situation were to arise where a sensor needs to be added or removed.
- In cases where sensors had to be easily removed and reattached, as was the case of the MMS Solar arrays, a pin and socket design was used to allow for detachability without compromising the functionality of the harness.
- The MMS 1-wire sensors were installed to flight specifications since they would not be removed prior to flight. However, since they were not being used to read temperature during flight operations, the 1-wire connector had a grounding plug installed before launch.



1-Wire Temperature sensor

YSI Flight Thermistor



1-Wire Temperature sensor

More Advantages



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- Barrel splices are used for permanent connections along the harness, while a pin and socket set up is used for removable sensor splicing. Having the luxury of such a dynamic set lends nicely to a situation where troubleshooting is required.
- The thermal team performed two separate tests of the propulsion subsystem where 1-wires were used in conjunction with thermocouples to verify sensor accuracy.
- Each electronics box underwent thermal cycling and balance with the use of thermistors and 1-wire sensors.
- TVAC testing was performed on all four (4) observatories utilizing 1-wires.
- Localized tests in ambient temperatures were performed on numerous boxes as these components were installed, uninstalled and then reinstalled again multiple times.
- 1-Wires were used in ambient testing to make sure limits of components were not violated when cold temperatures from the LN2 spray or A/C system was utilized.
- The MMS mission consists of four (4) DTU Star Cameras that are similar to the DTU Star Cameras that will be installed for ICON. The photo below shows 1-wire temperature sensors installed on the MMS Camera Head Units (CHU).
- The NASA/GSFC ICON Mission has adopted the 1-wire sensors.

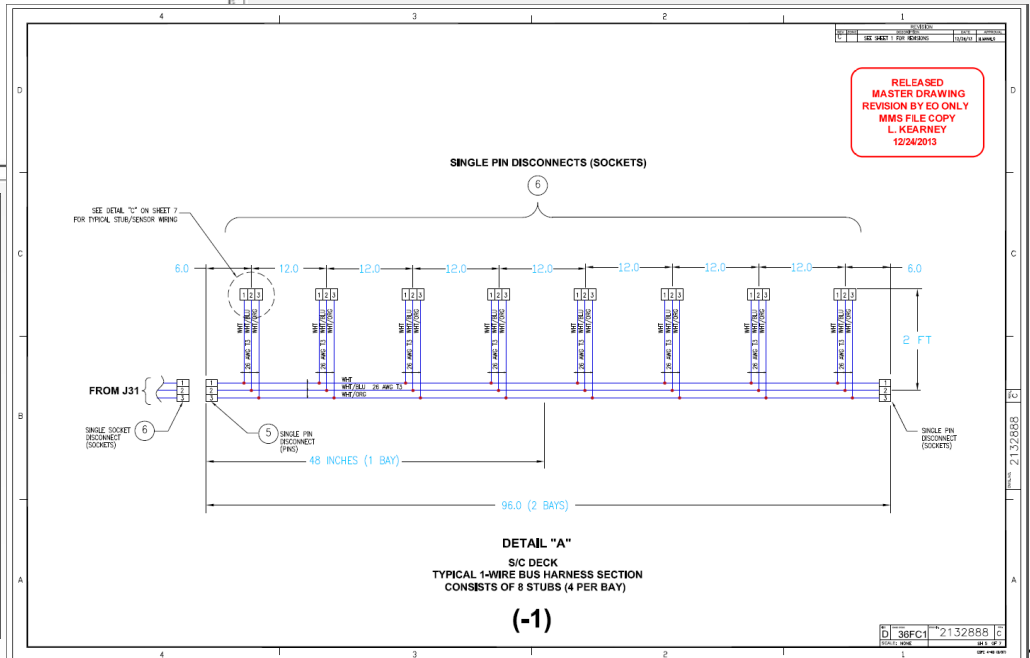
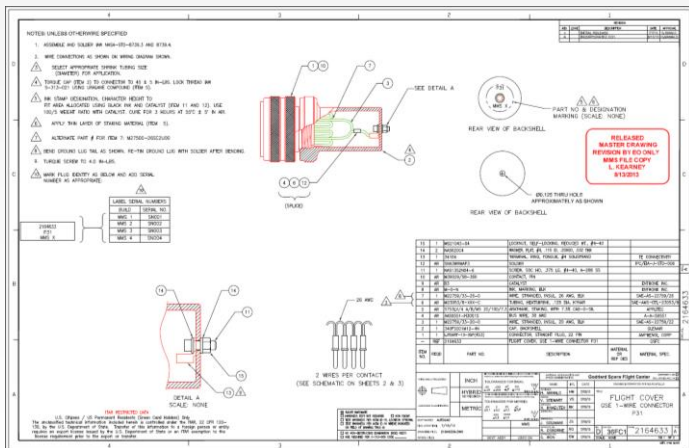
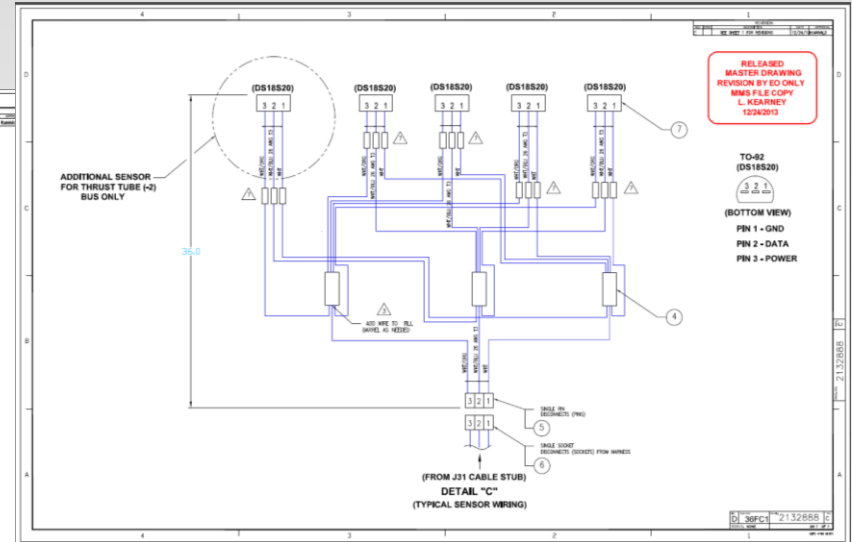
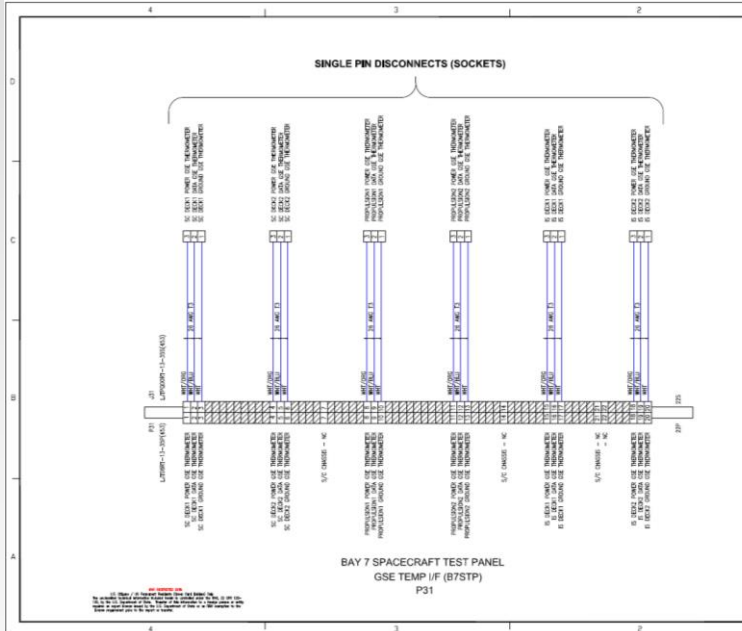


Documentation



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- Detailed Wire and Connector Drawings

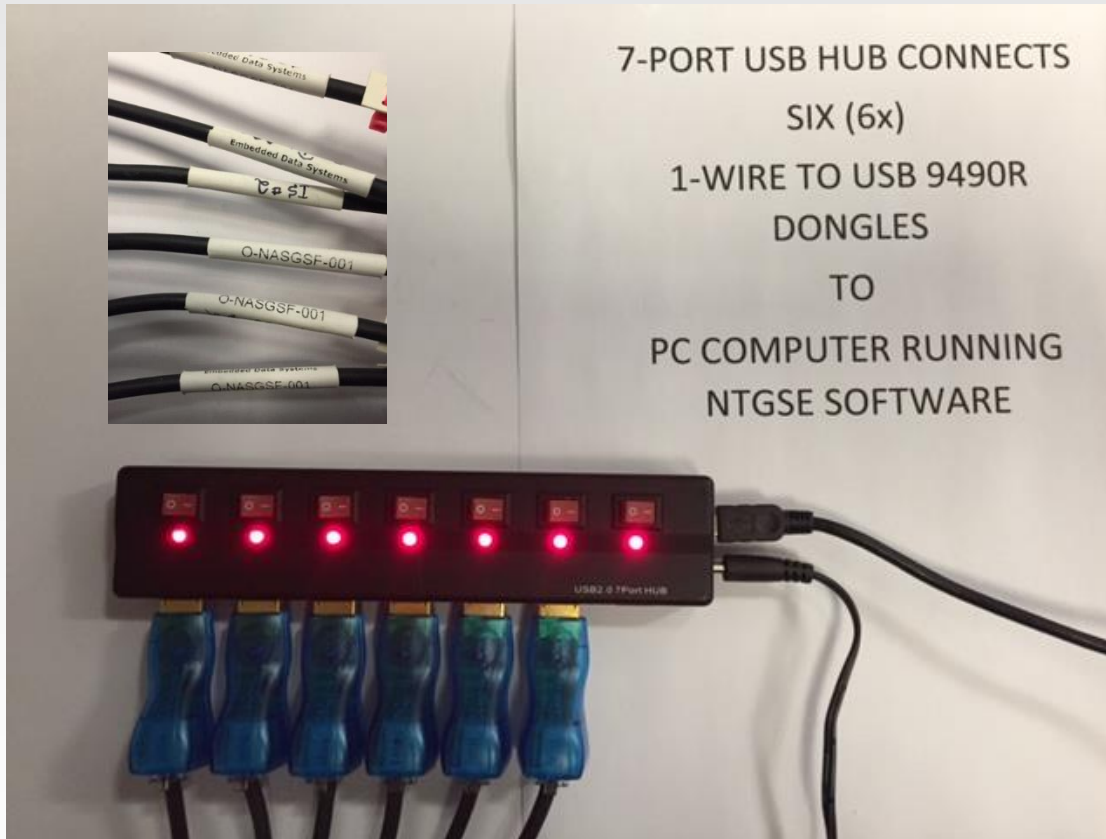


GSE Hardware



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- External cable includes custom RJ-12 cables (O-NASGSF-001) from commercial vendor to interface TVAC 1-Wire cables to DS9490R 1-Wire to USB connectors

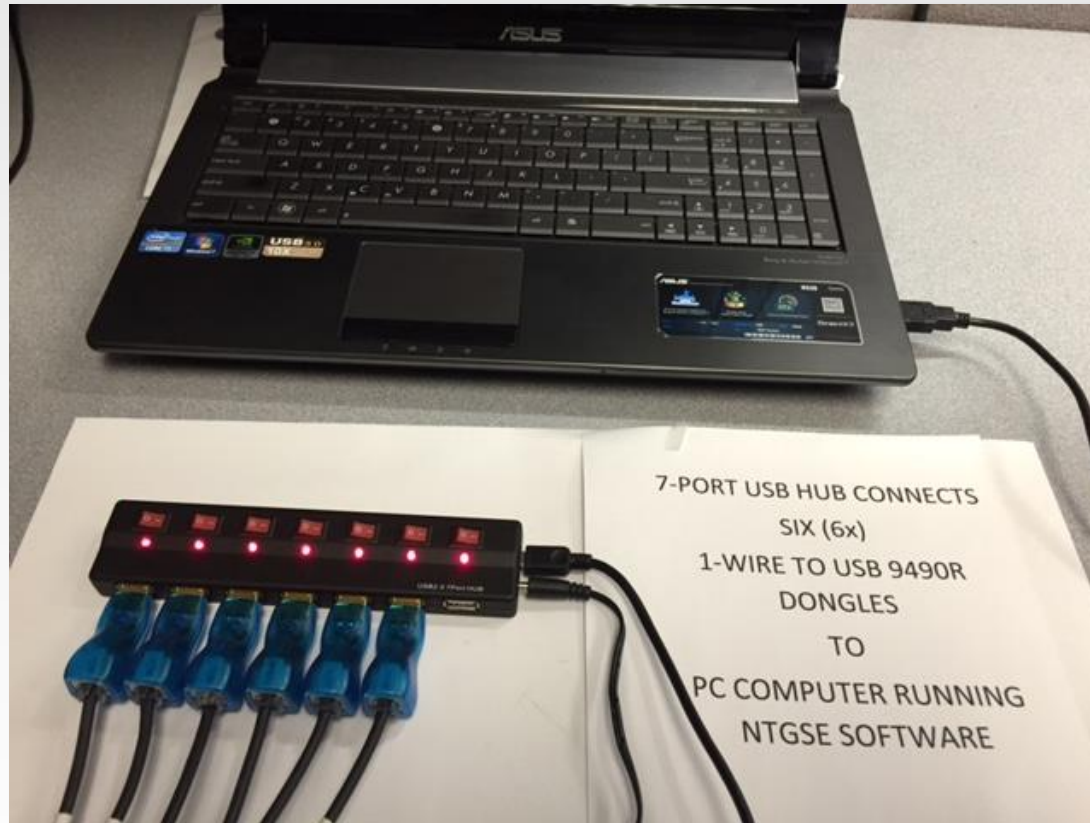


GSE Hardware



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- 7-Port USB HUB directs six (6x) 1-Wire bus (with up to 64 sensors per bus) to PC computer using a single mini-USB connector. USB Hub also provides 5V power.



GSE Software



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- Windows 7/8 Compatible NTGSE Software (NASA/GSFC).

The screenshot shows a Windows 7 desktop environment. The desktop background is a scenic landscape with a lake and mountains. The taskbar at the bottom contains icons for the Start menu, QuickBooks Pro 2014, Welcome to ASUS Product, CONFIG_1..., Boeing-PIM..., CBS, Boom Flex, and ABSTRACT... Harness Da... The taskbar also shows the system tray with the date and time: 9:04 AM, 4/23/2015.

The main window is titled "NTGSE Event/Cmnd Window (NTGSE 4.1, Oct 15 2010)". It displays the following text:

```
File Edit DataBase DisplayPage Chart Archive About
113-09:03:59:951 OPENED Event Log File: events.log
113-09:03:59:967 **** 1-Wire Temperature [Version 1.0 Nov 9 2010] ****
113-09:04:00:170 1-Wire initialized [port 2]
113-09:04:00:263 KEYBD: RESTORE default.dc
113-09:04:00:279 KEYBD: START startup.prc
113-09:04:00:279 Starting Script startup.prc
113-09:04:00:373 startup.prc: limits on
113-09:04:00:373 Limit Checking Enabled.
113-09:04:00:920 Exiting procedure startup.prc
```

The right-hand window is titled "1wire_auto" and displays the following data:

Record Status	Stopped
Rate Time	09:04:24
Rate Interval	10
Rate update in...	6
Sensors	Celsius
HARNESS_SENSOR_1of2	22.563 0.063
HARNESS_SENSOR_2of2	22.688 0.000
Groups	Celsius
HARNESS_AVG	22.625 0.031
Switches	Status

The desktop also features a vertical sidebar on the right side with a clock, system information (CPU Usage 10%, Core 1 3%, Core 2 0%, Core 3 44%, Core 4 3%, Core 5 27%, Core 6 0%, Core 7 3%), and weather information for Annapolis (9°C, Cloudy, Feels Like 7°C, Wind 6mi/h, Humidity 38%, Precipitation 0%).



- Windows 7/8 Compatible NTGSE Software (NASA/GSFC).

```
NTGSE Event/Cmnd Window ( NTGSE 4.1, Oct 15 2010 )
File Edit DataBase DisplayPage Chart Archive About
113-09:03:59:951 OPENED Event Log File: events.log
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113-09:04:00:279 Starting Script startup.prc
113-09:04:00:373 startup.prc: limits on
113-09:04:00:373 Limit Checking Enabled.
113-09:04:00:920 Exiting procedure startup.prc
113-09:04:46:502 KEYBD: 1wire
113-09:04:46:502 1WIRE COPY_NEW [SWITCH]
113-09:04:46:502 1WIRE DEG <C | F>
113-09:04:46:502 1WIRE INIT
113-09:04:46:502 1WIRE KILL
113-09:04:46:502 1WIRE LIMITS <name> [<C | F> <rl> <yl> <yh> <rh>]
113-09:04:46:502 1WIRE LIST [group name]
113-09:04:46:502 1WIRE RATE <interval | MARK>
113-09:04:46:502 1WIRE RECORD <interval | NEW_FILE | STOP>
113-09:04:46:502 1WIRE SWITCH [ENABLE|DISABLE]
113-09:04:46:502 1WIRE SWITCH <name> <ON|OFF|RELEASE>
113-09:04:46:502 1WIRE SWITCH <name> <control name> <C|F> <on#> <off#>
==>|
```


1-Wire Data



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- Windows 7/8 Compatible NTGSE Software (NASA/GSFC) Excel Interface.

Time	HARNESS_SENSOR_1of2	HARNESS_SENSOR_2of2	HARNESS_AVG
4/23/2015 9:05:39	22.625	22.688	22.656
4/23/2015 9:05:49	22.625	22.688	22.656
4/23/2015 9:05:59	22.688	22.688	22.688
4/23/2015 9:06:09	22.688	22.750	22.719
4/23/2015 9:06:19	22.688	22.750	22.719
4/23/2015 9:06:29	22.688	22.750	22.719
4/23/2015 9:06:39	22.688	22.750	22.719
4/23/2015 9:06:49	22.688	22.750	22.719
4/23/2015 9:06:59	22.688	22.813	22.750
4/23/2015 9:07:09	22.750	22.750	22.750
4/23/2015 9:07:19	22.750	22.813	22.781
4/23/2015 9:07:29	22.750	22.750	22.750

Lessons Learned



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- Utilizing 1-wire sensors simplified many processes for the thermal team and easily provided robust data. However, there are lessons learned that if carried over to future projects will make the usage of 1-wire sensors even better.
- Early on in the design process using 1-wires should be decided upon. Each subsystem of the spacecraft should be made aware of the decision and have inputs in the routing and execution of using the 1-wire buses.
- Earlier coordination with the electrical harness team may have provided a 1-wire bus with a more seamless integration into the harness as opposed to being laid on top as an afterthought during the harness integration.
- This could reduce overlap between the thermal team and electrical team during integration as the harness on MMS was accessed frequently.
- Additionally, the routing of the 1-wire buses and branches could have been better laid out with assistance from the other subsystems.
- For example, twelve (12) thirty-two (32) sensor harness as apposed to the six (6) x sixty-four (64) sensor MMS bus

Lessons Learned



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- Shorting a sensor or incorrectly connecting one of the 3 (Data, Power, Ground) wires of a sensor can kill the functionality of the entire bus.
- During integration an engineer should check the viability of the sensor and the bus after every new sensor is added. This can simply be done using a laptop computer and a USB to 1-Wire sensor connector with the DS18B20 temperature sensor.
- Make plans early in the project to ensure the software capabilities for the 1-wires meet requirements. The software had limited plotting capabilities which could have been upgraded with additional software code.
- Just as with thermocouple wires thermal shorts can arise if the 1-wire harness is not properly routed. During testing of the isolative thermal standoffs for the propulsion lines, it was learned that an improperly routed 1-wire harness almost doubled the expected conductivity at one of the isolative standoffs.
- 1-wires typically use a thicker gauge of wire, which can cause a larger heat leak due to the added thermal mass and cross sectional area of the wire

Summary



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- The MMS project was impressed with the 1-wire capabilities and how they improved the temperature sensor monitoring during TVAC.
- As with any hardware integrated to a spacecraft, careful planning is a must in order to maximize effectiveness.
- Careful planning of the 1-wire harness routing in conjunction with other subsystems is of utmost importance as to being able to successfully coexist with these other systems.
- It is essential to be attentive to the sensor integration procedure for the 1-wire bus to avoid sensor shorts and conductive shorts.
- With this knowledge in hand, and effective testing routines performed on hundreds of 1-wire sensors other NASA/GSFC have started to adopt the 1-wire temperatures sensor approach – ICON mission.
- The flexibility and dynamic nature of these sensors should pave the way for 1-wires to be a reliable alternative to costly thermocouples for test temperature sensors and thermistors for flight operations.



The authors would like to express their sincere gratitude to all of the support personnel that contributed to the successful thermal vacuum testing program for the Magnetospheric MultiScale (MMS) project at the NASA/GSFC. There are so many individuals that participated in the enormous thermal vacuum and thermal balance testing campaign for MMS and the success of the thermal control system (TCS) is due to the hard work and dedication of the entire MMS team

