

EDISOFT

DEFENCE & AEROSPACE TECHNOLOGIES

A THALES Group Company

RTEMS Qualification Extensions

ESTEC, Final Presentation Days

Friday, 10th June 2016

Agenda

- | Overview
- | RTEMS by EDISOFT
- | RTEMS Qualification Extensions Overview
- | MIL-STD-1553B Driver
- | SpaceWire Driver
- | Monitoring Tool
- | Study Conclusions
- | Future Work

RTEMS Qualification Extensions

OVERVIEW

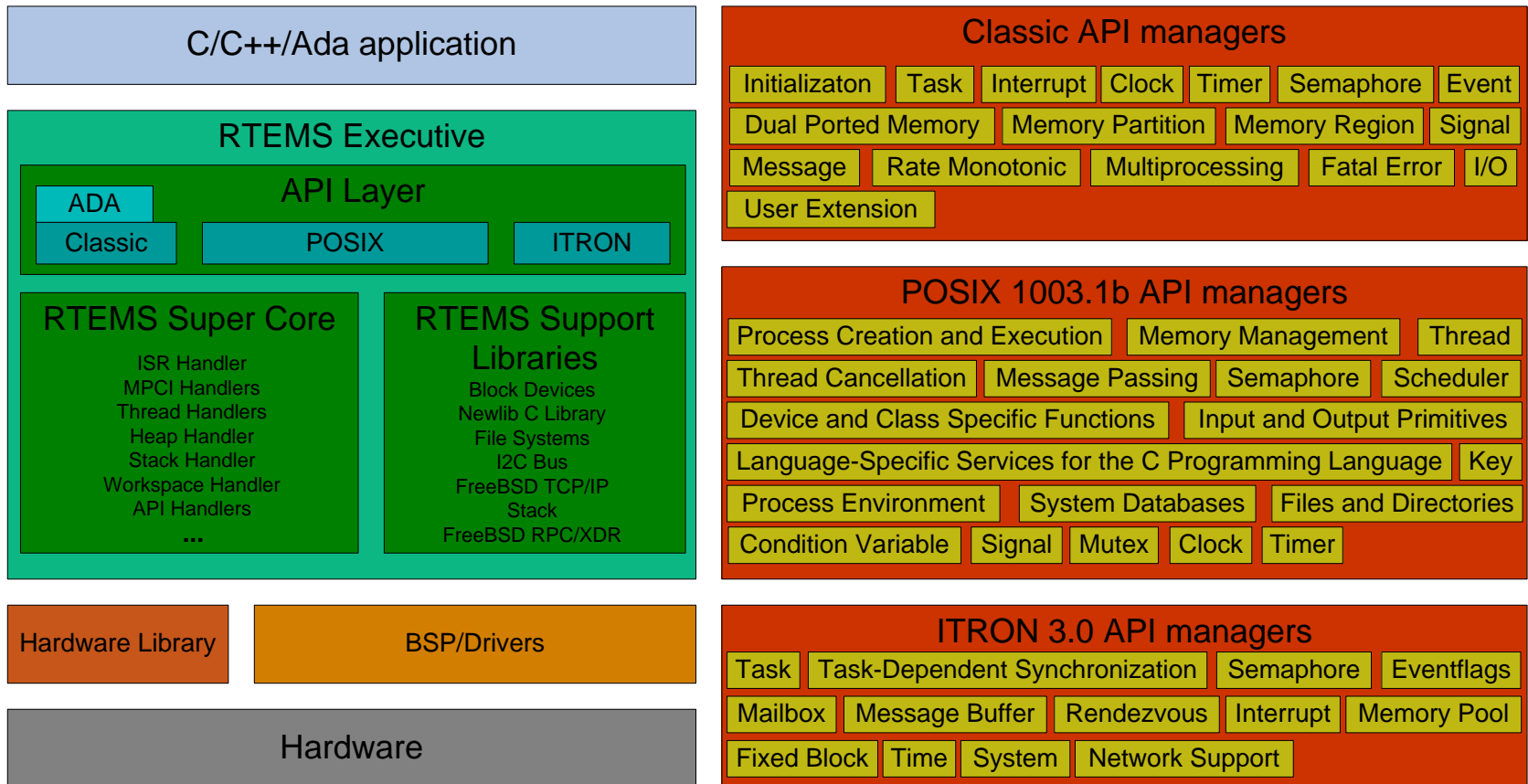
RTEMS Qualification Extensions

- **ESA Contract Number 4000112530**
- **General Support Technology Programme (GSTP)**
- **Start: 19th November 2014**
- **End: 1st April 2016**

Real-Time Operating System for Multiprocessor Systems (RTEMS)

- **Community: www.rtems.org**
- **RTEMS CENTRE: <http://rtemscentre.edisoft.pt>**

RTEMS Overview





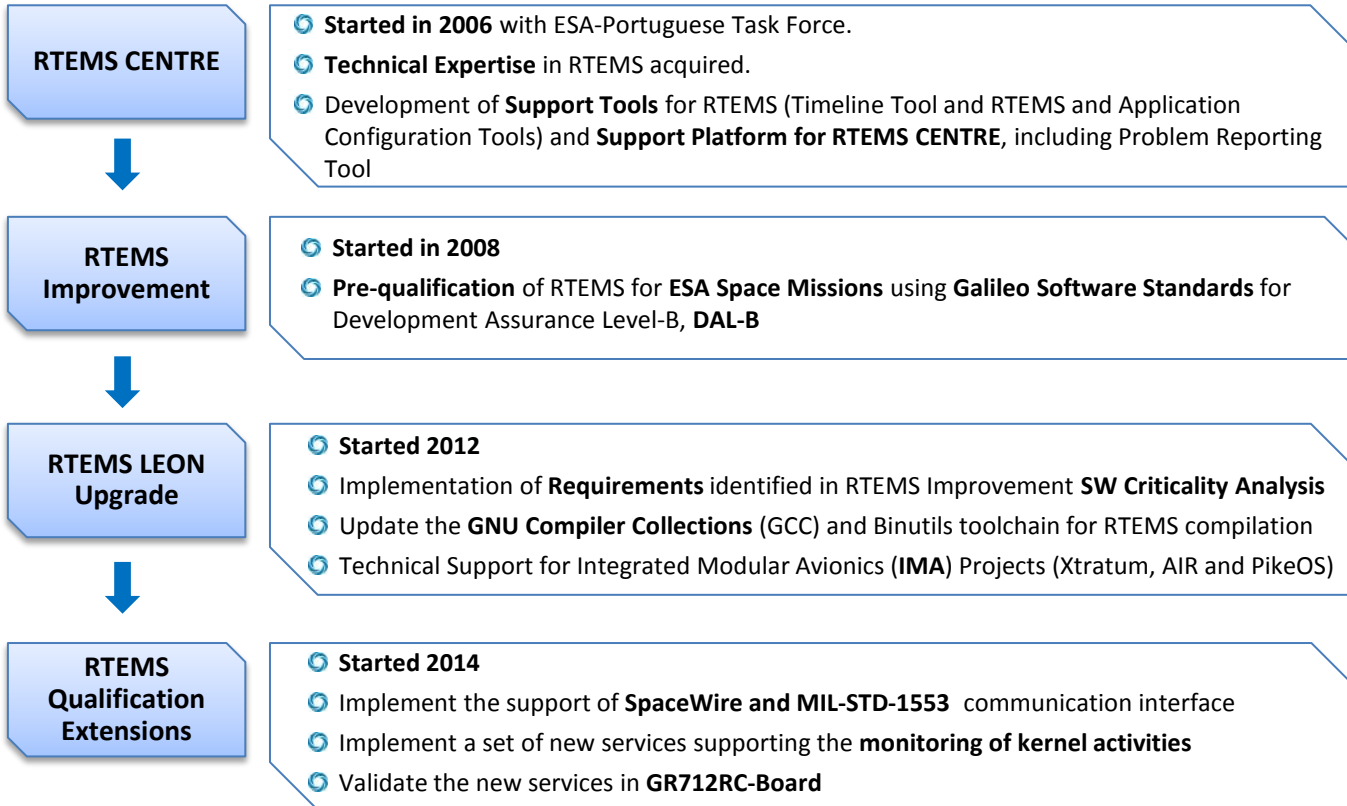
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RTEMS Qualification Extensions

RTEMS BY EDISOFT

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Context



FACT SHEET

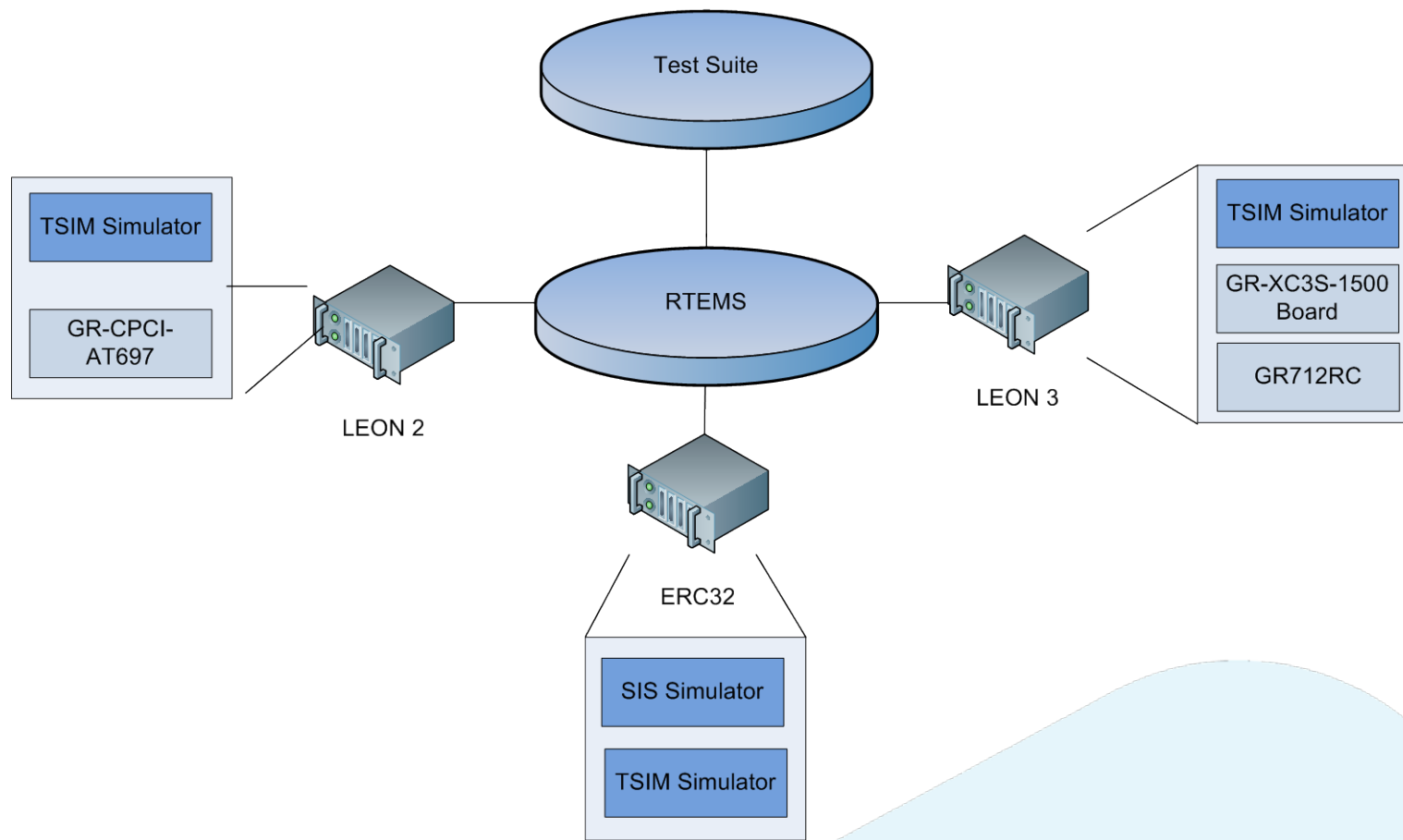
- ✓ RTEMS Tailored from 450KLOCs to 12KLOCs
- ✓ TestSuite six times the size of RTEMS Tailored
- ✓ 1 page of Documentation per Line of Code (32 documents)
- ✓ Validation in ERC32, LEON2 and LEON3
- ✓ Four Simulators and Three Boards (LEON2 and LEON3)
- ✓ TestSuite Developed from Scratch
- ✓ 100% Source Code Statement Coverage & Decision Coverage



RTEMS (Real-Time Operating System for Multiprocessor Systems)

- RTEMS Community Version (<https://www.rtems.org/>)
- RTEMS Improvement (<http://rtemscentre.edisoft.pt>)







Sentinel 2



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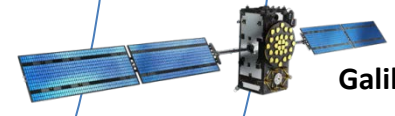
Galileo FOC 1



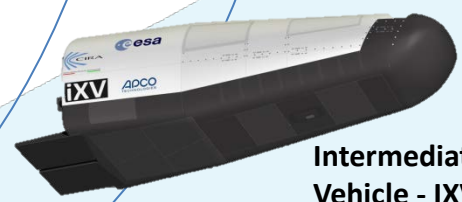
Galileo FOC 2



Galileo FOC 3



Galileo FOC ...

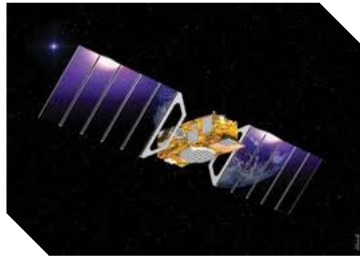


Intermediate eXperimental Vehicle - IXV

RTEMS by EDISOFT Space Missions



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Galileo FOC



smallGEO



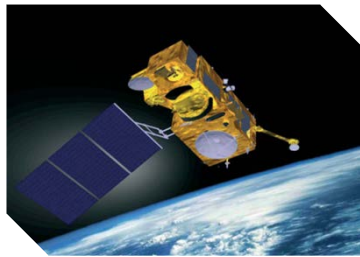
EUCLID



EarthCARE



MTG



Sentinel2



IXV



Solar Orbiter



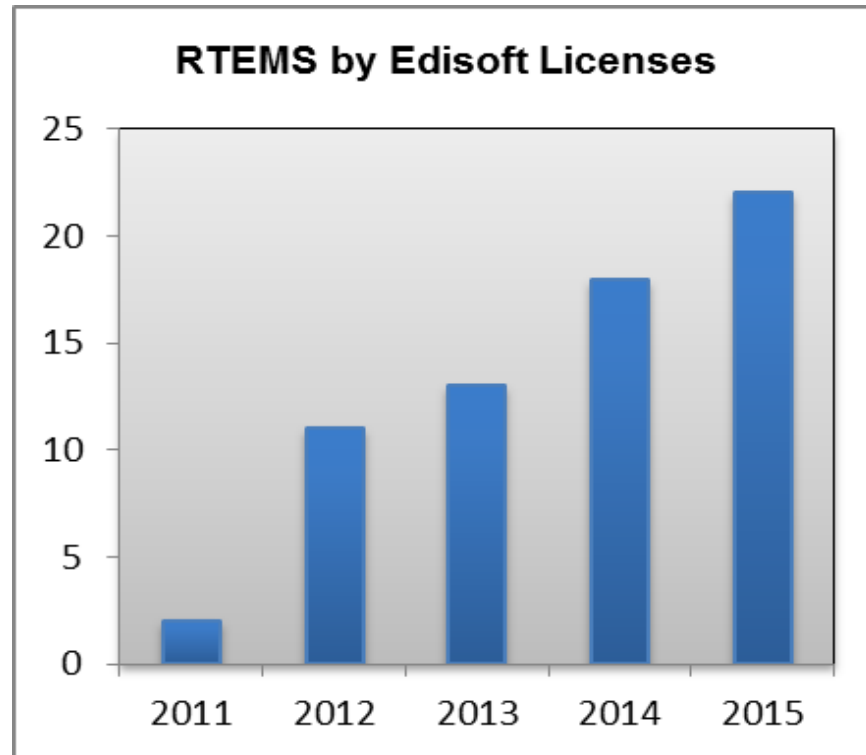
GOKTURK3

 ... and more

RTEMS by EDISOFT Licenses



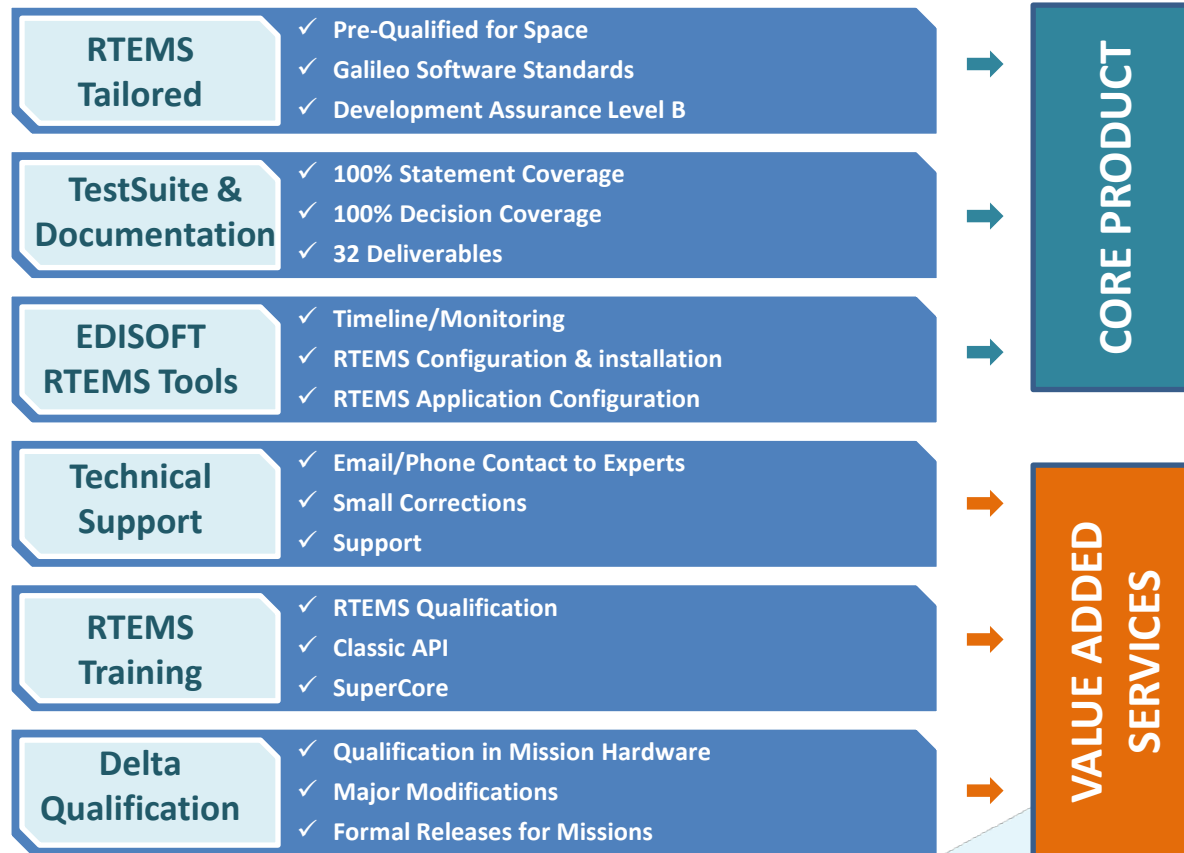
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RTEMS by EDISOFT Solution



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RTEMS by EDISOFT

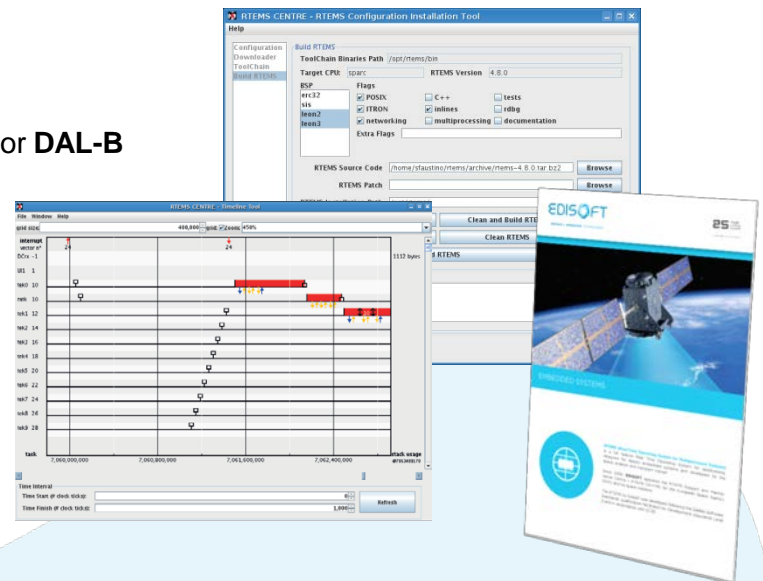
- Pre-qualified Real-Time Operating System for Critical Missions
- Galileo Software Standards for **Development Assurance Level-B**
- 32 Documents** available
- TestSuite**

Key Benefits

- Open source** for embedded systems
- Applications** running in **Hard Real Time**
- Qualification facilitated** for space missions (tested and documented) for **DAL-B**
- 100% Source Code Statement**
- 100% Coverage & Decision Coverage**
- Adapted to the specific requirements of the space missions
- Very Competitive** with commercial closed source solutions

Main Features

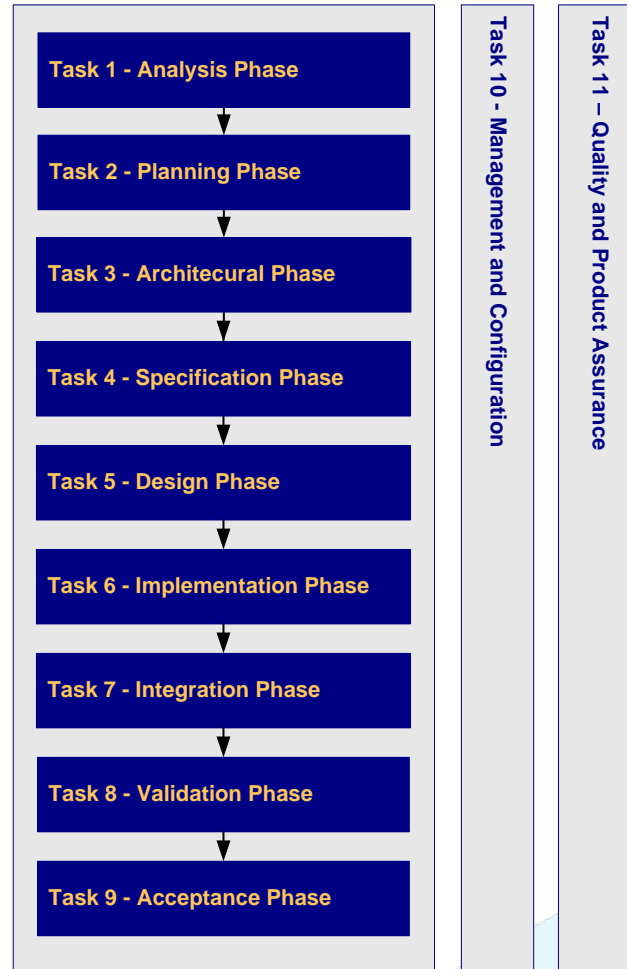
- Supports **multiple platforms**: ERC32, LEON2 and LEON3
- Delivery of all code** and test documentation
- Development process compliance **verified by TUV**
- Independent Software verification by **CAPTEC and SpatioIT**
- Tools for configuration, installation and implementation



RTEMS Qualification Extensions

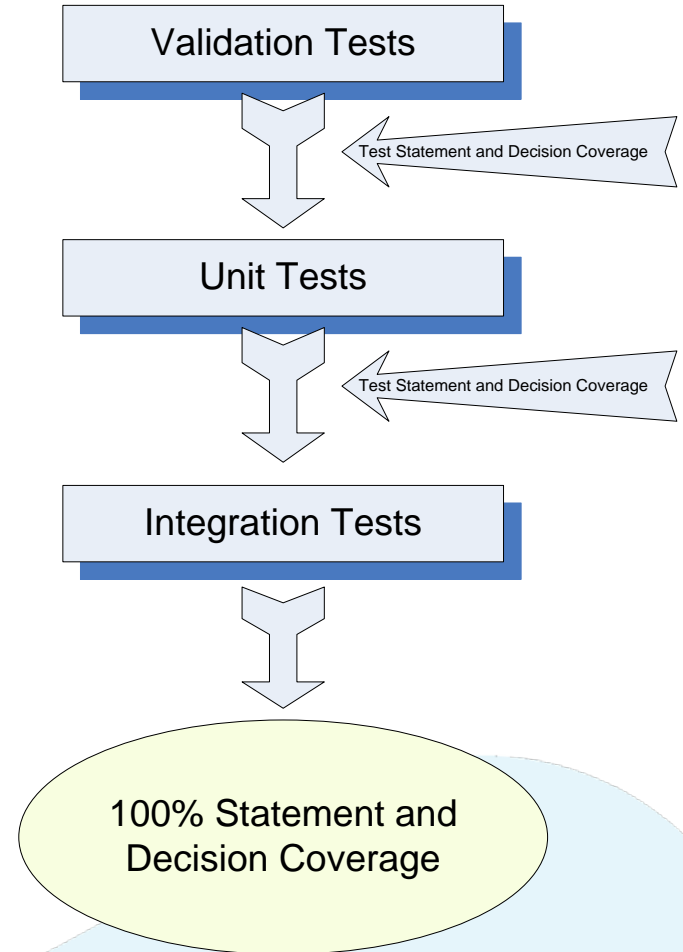
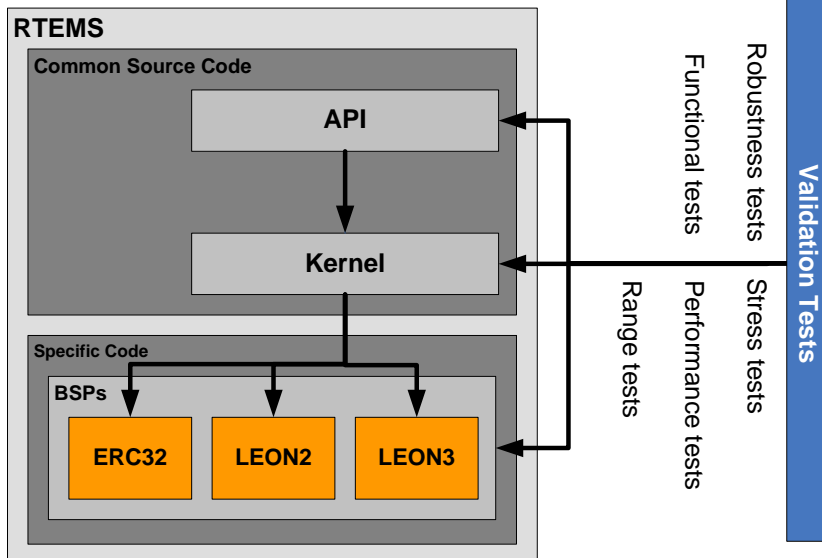
RTEMS QUALIFICATION EXTENSIONS

RTEMS Qualification Extensions – Study Logic



<i>Deliverable Item</i>	<i>Deliverable Item</i>
Analysis of Communication Interfaces and Kernel Services	RQE Software Development Plan
RQE Software Requirements Document	RQE Configuration Management Plan
RQE Software Design Document	Review Plan
RQE Validation Test Specification	Progress Report
RQE Unit Test Plan	RQE Software Configuration File
RQE Integration Test Plan	RQE SOC with GSWS
RQE User Manual Design Notes	RQE Software Product Assurance Plan
RTEMS Tailored	RQE Software Product Assurance Report
TestSuite	Monitoring Tool
RQE Validation, Unit and Integration Test Report	Monitoring Software Requirements Document
RQE Software Budget Report	Monitoring Software Design Document
RQE Software Acceptance Test Plan	Monitoring User Manual Design Notes
RQE Acceptance Data Package	Monitoring Tool
RQE Procured Software Justification File	Monitoring TestSuite
RQE Verification Report	Monitoring Test Report

<i>Operational Software</i>	<i>Operational Hardware</i>
RTEMS 4.8	Spartan 3 – GR-XC3S-1500 (LEON 3 GRLIB – 1.0.15-b2149)
Binutils 2.18	Leon 2 – GR-CPCI-AT697
GCC 4.2.1	Leon 3 – GR712RC development board
Newlib 1.15.0	
Autoconf 2.61	
Automake 1.10	
GCOV 4.2.1	
Enscript 1.6.4	
Perl 5.10	
TSIM ERC32 2.0.19 (standard edition)	
TSIM Leon2 2.0.8 (standard edition)	
TSIM Leon3 2.0.11 (standard edition)	
SIS 3.0.5	
GRMON 1.1.38	
UnderstandC 2.5	
Linux as host environment (Debian distribution, Lenny version)	



Communication Interfaces in Space Missions

Mission	1553	SpaceWire	RS-422	RS-485	SPI	GPIO	Ethernet	UART	CAN
Solar Orbiter – EPD		Yes			Yes	Yes		Yes	
Solar Orbiter – STIX		Yes							
Solar Orbiter – METIS	Yes	Yes							
IXV avionics	Yes		Yes				Yes		
MTG DPU MASW	Yes	Yes						Yes	
MTG	Yes	Yes							
ESail			Yes	Yes					Yes
IBDM	Yes		Yes						
PROBA3		Yes	Yes		Yes				
ExoMars	Yes	Yes							
EarthCare	Yes								
TAS	Yes	Yes							

Space Missions Boards and Processors

Mission	Board/Processor
Solar Orbiter – EPD	LEON2 (developed internally and based in RTAX FPGA)
Solar Orbiter - STIX	LEON3 FT with 16GB of flash storage memory and 128MB of operating memory
IXV avionics	LEON2-FT CPU microprocessor core operating at 50 MHz
MTG DPU MASW	Specific board
MTG	AT7913E processor for the SpW and a customized FPGA to control a 1553
ESail	GR712RC
IBDM	LEON2FT CPU (ATMEL AT697) with 128KB OTP-PROM, 4MB FLASH, 64MB SDRAM, cPCI
PROBA3	GR712 with an additional FPGA
ExoMars	Internal design based on AT697F
EarthCare	ASIC LEON2FT
TAS	EPICAnext

RTEMS Qualification Extensions

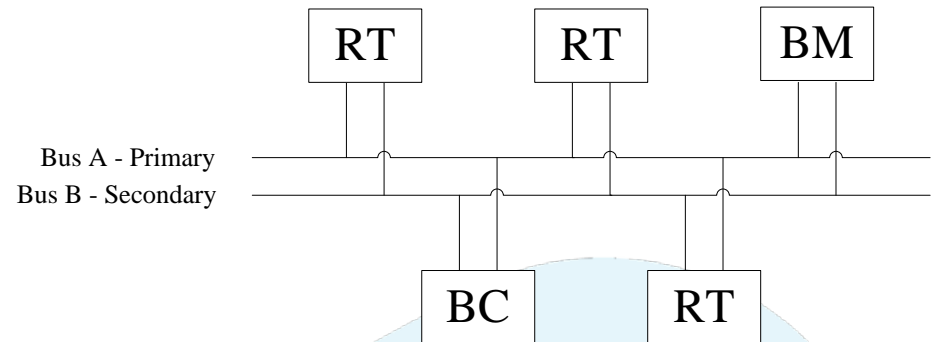
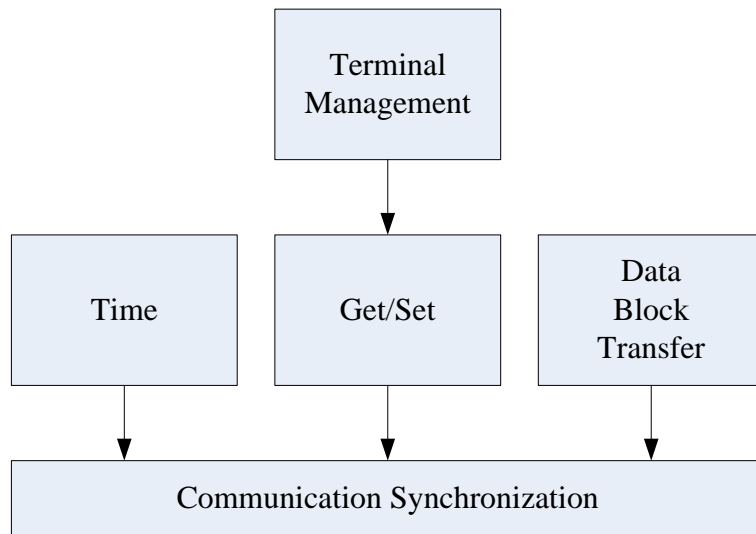
- **Most Used Communication Interfaces**
 - MIL-STD-1553B
 - SpaceWire
- **Several Missions develop their own boards “flavor”**
- **Most common board/processor: GR712RC**
- **Monitoring Tool**

RTEMS Qualification Extensions

MIL-STD-1553B DRIVER

MIL-STD-1553B

- MIL-STD-1553B notice 2
- ECSS-E-ST-50-13C: Interface and communication protocol for MIL-STD-1553B data bus onboard spacecraft

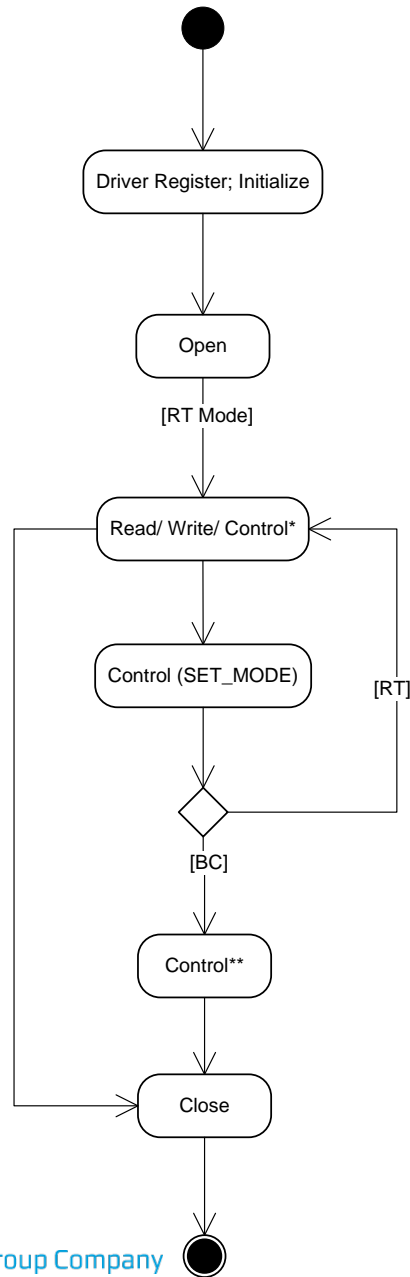


Space Missions MIL-STD-1553B Services

Mission	Services
MTG DPU MASW	Communication Synchronization, Get Data and Set Data services
MTG	Time, Communication Synchronization, Get Data, Set Data, Data Block Transfer and Terminal Management services
ExoMars	Time, Communication Synchronization, Get Data, Set Data, Data Block Transfer and Terminal Management services
TAS	Time, Communication Synchronization, Data Block Transfer and Terminal Management (only a subset, eg Reset Service) services
Solar Orbiter – METIS	Time, Communication Synchronization, Get Data, Set Data, Data Block Transfer and Terminal Management services

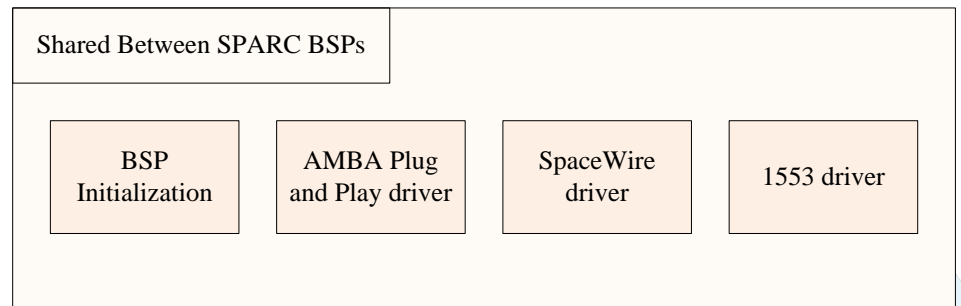
RTEMS Qualification Extensions MIL-STD-1553B low-level functionalities

- **Driver operates always in MIL-STD-1553 B**
- **Broadcast mode always enabled**
- **Sub-addresses 0 and 8 illegalized (This allows for a bus monitor to uniquely differentiate Command Words from Status Words)**
- **RT only responds to ECSS-E-ST-50-13C mandatory mode codes:**
 - Mode Code 2 – Transmit Status Word
 - Mode Code 4 – Transmitter Shut Down
 - Mode Code 5 – Override Transmitter Shut Down
 - Mode Code 17 – Synchronize With Data Word
 - Mode Code 18 – Transmit Last Command
- **RT to RT transfers functionality removed**
- **Data Wrap-Around in sub-address 30 implemented**
- **Message retries removed**
- **Selection of DMA size (default 128KB) and Clock (default use division of system clock)**



* BRM_SET_MODE
 BRM_SET_BUS
 BRM_SET_RT_ADDR
 BRM_TX_BLOCK
 BRM_RX_BLOCK
 BRM_CLR_STATUS
 BRM_GET_STATUS
 BRM_SET_EVENTID

** BRM_SET_MODE
 BRM_SET_MSGTO
 BRM_TX_BLOCK
 BRM_DO_LIST
 BRM_LIST_DONE
 BRM_CLR_STATUS
 BRM_GET_STATUS
 BRM_SET_EVENTID



RT Initialization Default Configuration

- **Broadcast Enabled** – the broadcast mode is enabled
- **Bus A and B both enabled**
- **RT address to 1**
- **Read and Write calls in blocking mode**
- **The following interrupts unmasked:**
 - Illegal command;
 - Sub-address accessed;
 - Terminal Address Parity Fail
 - DMA Fail
 - Wrap Fail
 - Message Error
- **Sub-address 31 used for mode code commands**
- **Sub-address 30 used for the Data Wrap-Around service**
- **Sub-addresses 0 and 8 illegalized**
- **Mandatory mode codes are executed**

MIL-STD-1553B Driver Functions

- **rtems_device_driver brm_initialize** - Initializes the driver and BRM core
- **rtems_device_driver brm_open** - Opens a BRM core
- **rtems_device_driver brm_close** - Closes a BRM core
- **rtems_device_driver brm_read** - Reads the commands and data received/sent by the BC to the BRM core operating as RT
- **rtems_device_driver brm_write** - Writes data to the transmit sub-addresses of the BRM core operating as RT
- **rtems_device_driver brm_control** - Miscellaneous operations on a BRM core

MIL-STD-1553B Control Commands

- **Set Device Operating Mode**
- **Enable/Disable Buses**
- **Set No Response Time-Out**
- **Set RT Address**
- **Set RT Write calls/BC List Processing Blocking/Non-Blocking Mode**
- **Set RT Read Calls Blocking/Non-Blocking Mode**
- **Start 1553 Messages List Execution**
- **End of List of 1553 Messages Processing Verification**
- **Clear Error Status Bit Mask**
- **Get Error Status Bit Mask**
- **Set Event Signaling Task**

Unit Tests

unt_06_04_020 1553 AMBA Information Retrieval
unt_06_04_030 1553 No Devices Found
unt_06_04_040 1553 RX semaphore creation error
unt_06_04_050 1553 TX semaphore creation error
unt_06_04_060 1553 Device semaphore creation error
unt_06_04_070 Opening the core in BC mode
unt_06_04_080 Minor greater than the number of cores
unt_06_04_090 Write invalid message descriptor
unt_06_04_100 Control with NULL argument and invalid command
unt_06_04_110 Invalid mode selection
unt_06_04_120 Set Bus functionality errors
unt_06_04_130 Set Message Timeout functionality errors
unt_06_04_140 Set Bus functionality errors
unt_06_04_150 Set invalid RX/TX mode
unt_06_04_160 Set and Start list of 1553 messages execution functionality errors and RX Mode Code with no data
unt_06_04_170 Verify end of list of 1553 messages execution functionality errors
unt_06_04_180 Get Status functionality with NULL buffer

Integration Tests

int_06_04_020 Driver Semaphores creation
int_06_04_030 Read function in blocking mode
int_06_04_040 Write function in blocking mode
int_06_04_050 Hardware Errors Interrupts Handling, Clear/Get Status Bit Mask and Set Event ID Operations
int_06_04_060 List of 1553 messages execution blocking mode
int_06_04_070 BC broadcast mode and Error Interrupts Handlers
int_06_04_080 List of 1553 messages processing failure in blocking mode
int_06_04_090 1553 ISR with Wrong Vector
int_06_04_100 Block Accessed Bit 0 and invalid descriptor



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Validation Tests

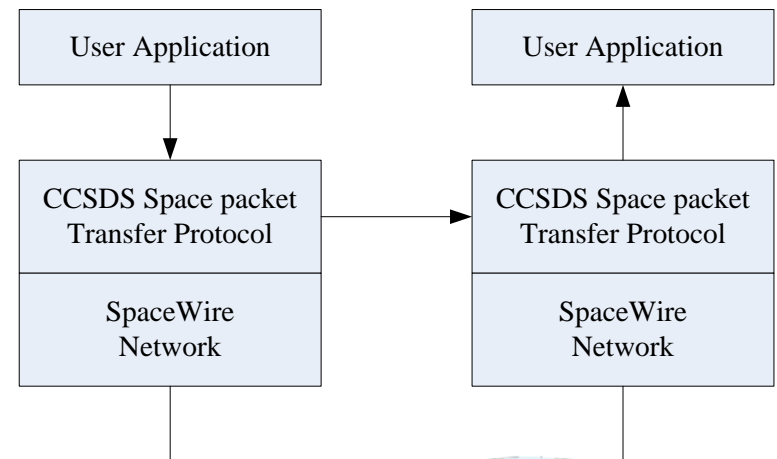
val_06_04_010 Driver Register and Initialization
val_06_04_020 Frequency and system clock division selection
val_06_04_025 Frequency and 1553 dedicated clock selection
val_06_04_030 Number of devices found and minor number assigned
val_06_04_040 DMA configuration
val_06_04_070 Core Resetting
val_06_04_080 Open and Close functionality
val_06_04_090 Read function in non-blocking mode
val_06_04_110 Event Queue Overflow
val_06_04_120 Write function in non-blocking mode
val_06_04_140 Operating Mode and Buses Enabled
val_06_04_150 Select No Response Time-Out
val_06_04_160 Select RT Address
val_06_04_180 List of 1553 messages execution non-blocking mode
val_06_04_200 RT Functionality
val_06_04_210 Not Implemented Features: RT-RT transfers, Message retries and not used Sub-addresses
val_06_04_220 Data Wrap-Around
val_06_04_240 RT Error Interrupt Handlers
val_06_04_250 16K Memory Configuration
val_06_04_260 Stress Test in RT mode
val_06_04_270 Stress Test in BC Mode
val_06_04_280 Stress Test with SpaceWire and BRM core (as BC)
val_06_04_290 Stress Test with SpaceWire and BRM core (as RT)

RTEMS Qualification Extensions

SPACEWIRE DRIVER

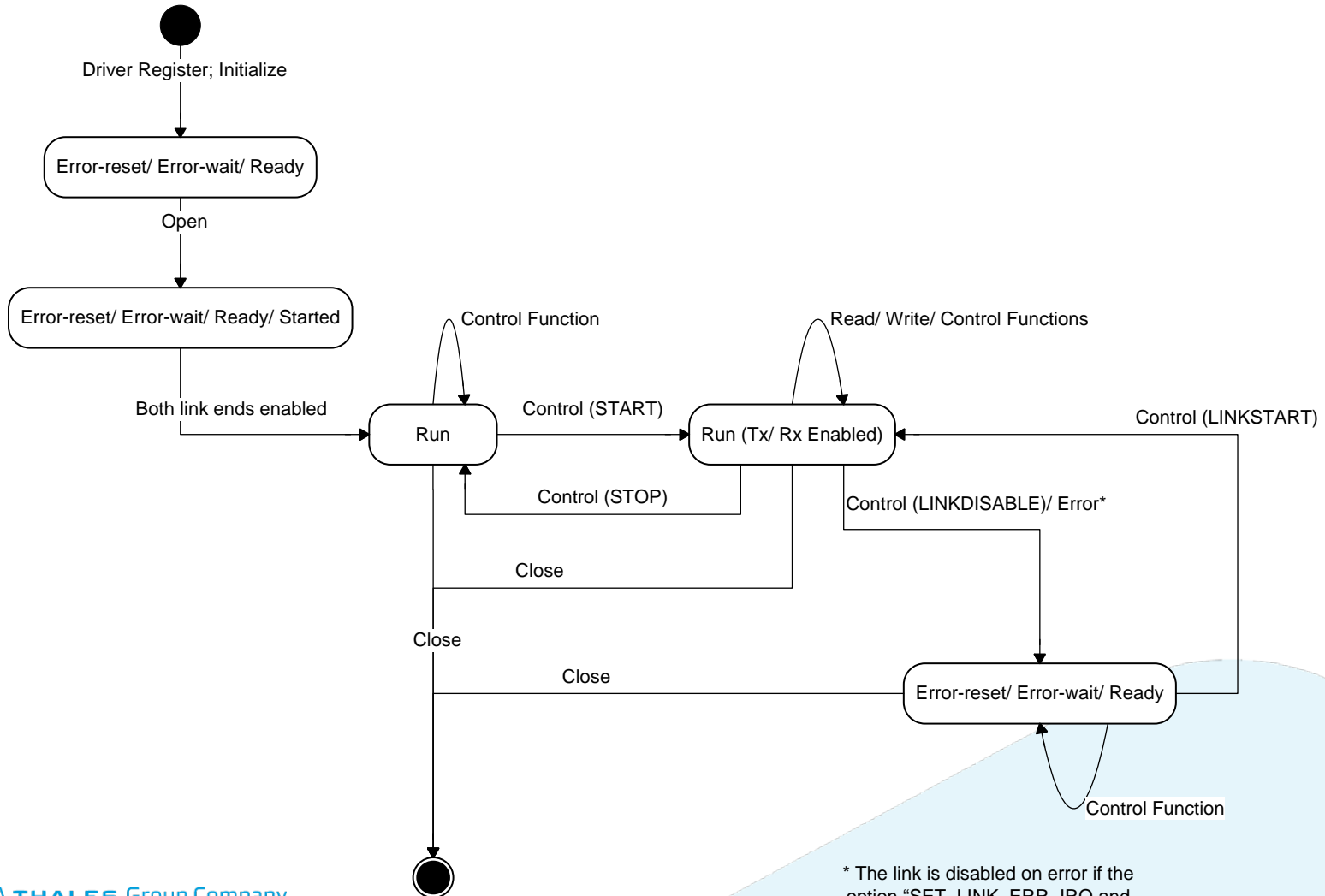
SpaceWire

- IEEE 1355-1995 - Standard for Heterogeneous InterConnect
- ANSI/TIA/EIA-644 - Low-voltage differential signaling
- ECSS-E-ST-50-12C - Links, nodes, routers and networks
- ECSS-E-ST-50-51C - protocol identification
- ECSS-E-ST-50-52C - Remote memory access protocol (RMAP)
 - Write command
 - Read command
 - Read-modify-write command
- ECSS-E-ST-50-53C - CCSDS packet transfer protocol



Space Missions SpaceWire Services

Mission	Protocols
Solar Orbiter – EPD	CCSDS
Solar Orbiter – STIX	CCSDS, future missions will also use RMAP
Solar Orbiter – METIS	CCSDS and RMAP
IBDM	RMAP, future missions will also use CCSDS
PROBA3	CCSDS
ExoMars	CCSDS
TAS	RMAP
MTG	CCSDS



* The link is disabled on error if the option "SET_LINK_ERR_IRQ and SET_DISABLE_ERR" are set.

SpaceWire Driver Functions

- **rtems_device_driver grspw_initialize** - Initializes a GRSPW2 core
- **rtems_device_driver grspw_open** - Opens a GRSPW2 core
- **rtems_device_driver grspw_close** - Closes a GRSPW2 core
- **rtems_device_driver grspw_read** - Reads from a GRSPW2 core
- **rtems_device_driver grspw_write** - Writes to a GRSPW2 core
- **rtems_device_driver grspw_control** - Miscellaneous operations on a GRSPW2 core

SpaceWire Control Commands

- **Set Node Address**
- **Set Receptions Blocking Mode**
- **Set Destination Key**
- **Set Clock Division**
- **Set Promiscuous Mode**
- **Set RMAP Handler**
- **Set RMAP Multiple Buffers**
- **Set RMAP CRC Error Check**
- **Set Protocol ID Removal**
- **Set Transmission Blocking Mode**
- **Set Link Disable on Error**
- **Set Link Error Interrupt**
- **Set Event ID for Error Events**
- **Get Core/ Link Status**
- **Get Config**
- **Send Packet**
- **Link Disable**
- **Link Enable**
- **Set Transmission Blocking Mode on Full**
- **Set Start Clock Division**
- **Set Node Mask**
- **Set Time-code Callback**
- **Set Time-code Capabilities**
- **Set and Send Time-code**
- **Get Time-code**
- **Start Link**
- **Stop Link**

Validation Tests

val_06_03_010 RTEMS IO Register
val_06_03_015 RTEMS IO Register Deterministic Behaviour
val_06_03_017 SpW Not Enough Semaphores Available
val_06_03_020 Driver Register
val_06_03_030 Driver Initialization
val_06_03_040 Default Core Configuration
val_06_03_050 SpW Link Start and Stop
val_06_03_060 Retrieve Link Status
val_06_03_070 Set Node Address
val_06_03_080 Set Node Mask
val_06_03_090 SpW Packet Send
val_06_03_100 Receiving Blocking Mode
val_06_03_110 Transmission Blocking Mode On Full
val_06_03_120 Transmission Blocking Mode
val_06_03_130 Remove Packet Protocol ID
val_06_03_140 Link Error IRQ
val_06_03_150 Disable Link on Error
val_06_03_160 SpW Promiscuous Mode
val_06_03_170 Core Opening Restrictions
val_06_03_180 GR712RC RMAP Handler
val_06_03_190 GR712RC CRC Check
val_06_03_200 SpW Remaining Control Options
val_06_03_205 SpW Time-codes
val_06_03_210 SpW Buffer Limit
val_06_03_220 SpW Stress Test

Unit Tests

unt_06_03_010 SpW Cores Not Available
unt_06_03_020 Too Many SpW Cores
unt_06_03_030 SpW DMA Control Not Writable
unt_06_03_040 SpW Node Address Not Writable
unt_06_03_050 SpW Destination Key Not Writable
unt_06_03_060 SpW Clock Division Not Writable
unt_06_03_070 SpW Control Not Writable



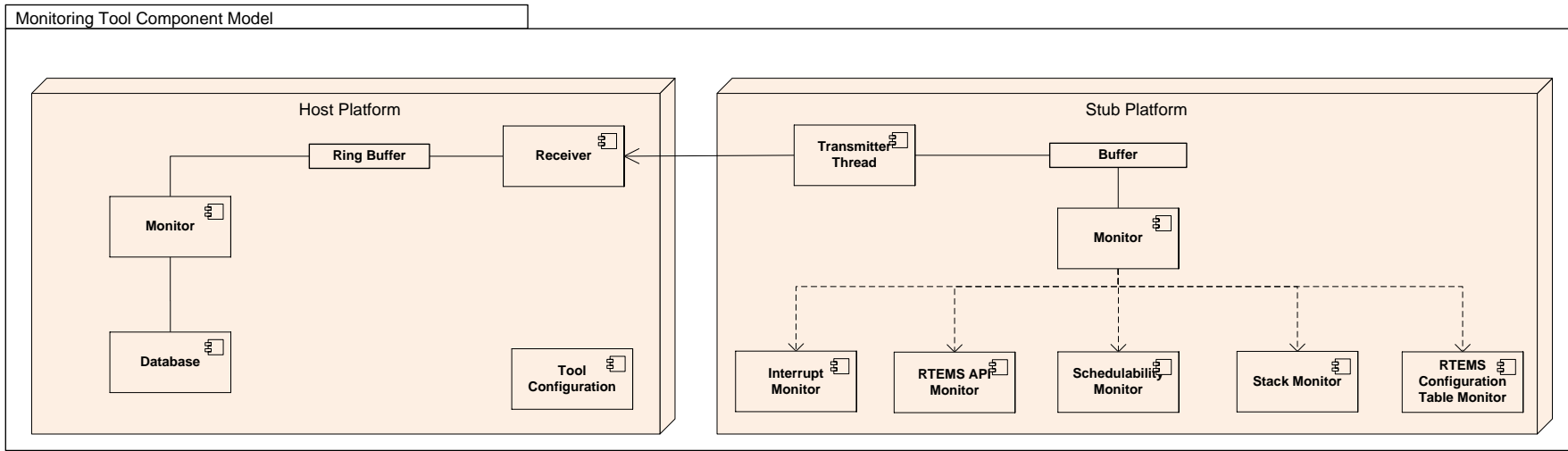
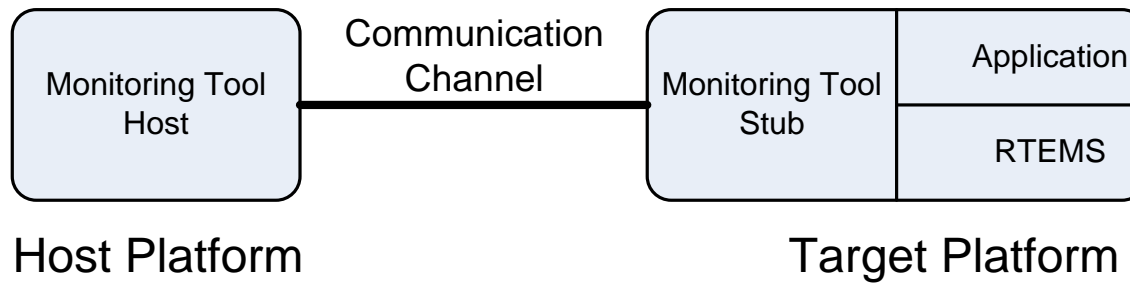
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RTEMS Qualification Extensions

MONITORING TOOL

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Monitoring Tool Platform



Monitoring Tool Measurements:

- **Scheduling Monitor**
- **RTEMS API Managers**
 - Task Manager
 - Interrupt Manager
 - Clock Manager
 - Timer Manager
 - Semaphore Manager
 - Message Queue Manager
 - Event Manager
 - IO Manager
 - Error Manager
 - Rate Monotonic Manager
 - User Extensions Manager
- **Hardware Interrupts**
- **Thread Stack Monitor**
- **RTEMS Configuration**
- **User Messages from Application**

Monitoring Tool Demo Video



monitoring.mp4

RTEMS Qualification Extensions

STUDY CONCLUSIONS

RTEMS Qualification Extensions Study Conclusions

- **New release of RTEMS by EDISOFT (09060101-039-14.SFW – version 14)**
- **Galileo Software Standards DAL-B**
 - 100% Statement Coverage
 - 100% Decision Coverage
- **133 New Requirements for SpaceWire and MIL-STD-1553B**
- **36 New Requirements for Monitoring Tool**

RTEMS Qualification Extensions Product Assurance

- Concerning **Functionality**, the **code is complete and correct** for all targets
- The code can be **considered reliable** as the values for **structural coverage** meet established targets
- The metrics related to **maintainability** of the code (RTEMS and Test suite) are **not fully compliant with the thresholds** defined by GSWS. However it should be highlighted that only a **small fraction (~<3%) of RTEMS has lower maintainability values** and it was considered that **the risk to improve these modules outcomes the benefits**
- The metrics for Requirements stability, code comment frequency and RIDs status demonstrate that the **documentation quality is good**
- It has been demonstrated that the **code is safe**
- The results of the **milestone tracking** demonstrate that the system engineering effectiveness **process can be improved**

Goal Properties	Related Properties	Associated Metrics	Id	Result
Functionality	Completeness	Requirements Allocation	FUN_CM_1	OK
		Tests and Valid. Coverage Completn.	FUN_CM_2	OK
	Correctness	SPRs/NCRs Trend Analysis	FUN_CR_1	OK
		Testing/Validation Progress	FUN_CR_2	OK
Reliability	Reliability Evidence	Structural Coverage	REL_RE_1	OK
Maintainability	Analyzability	Cyclomatic Number	MAIN_AN_1	Partial
		Nesting Levels	MAIN_MO_1	Partial
	Modularity	Modularity Size Profile	MAIN_MO_2	Partial
		Number of Exit	MAIN_MO_3	NA
		Number of Entry	MAIN_MO_4	NA
	Adaptability	Average SPR/NCR Turn Around Time	MAIN_AD_1	OK
Documentation Quality	Requirements Quality	Requirements Stability	DOC_RQ_1	OK
	Developm. & Maintenance	Code Comment Frequency	DOC_AD_1	OK
	Documentation quality			
	Operation-related Documentation quality	RIDs Status	DOC_OR_1	OK
Suitability for Safety	Safety Evidence	Safety Activities Adequacy	SAF_SE_1	OK
System Engineering Effectiveness	System engineering process evidence	Code Size Stability	SEE_SE_1	OK
		Milestone Tracking	SEE_SE_2	Partial
		Action Status	SEE_SE_3	OK
		SPRs/NCRs/Software Modification Rate	SEE_SE_4	Partial

RTEMS Qualification Extensions Budget Report

- CPU Usage**

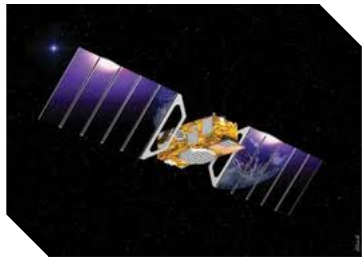
Task Period	Maximum CPU Usage[%]					
	5ms		10ms		100ms	
	OAR 4.8.0	Tailored 14	OAR 4.8.0	Tailored 14	OAR 4.8.0	Tailored 14
RTEMS version	OAR 4.8.0	Tailored 14	OAR 4.8.0	Tailored 14	OAR 4.8.0	Tailored 14
TargetSimERC32	0.94[%]	0.56[%]	0.47[%]	0.28[%]	0.047[%]	0.028[%]
TargetSimLeon2	0.42[%]	0.12[%]	0.21[%]	0.06[%]	0.021[%]	0.006[%]
TargetSimLeon3	0.58[%]	0.34[%]	0.29[%]	0.17[%]	0.029[%]	0.017[%]
TargetBoard1Leon3	0.76[%]	0.44[%]	0.38[%]	0.22[%]	0.038[%]	0.022[%]
TargetTsimERC32	1.22[%]	0.8[%]	0.61[%]	0.4[%]	0.061[%]	0.04[%]
TargetBoard1Leon2	0.26[%]	0.18[%]	0.13[%]	0.09[%]	0.013[%]	0.009[%]
TargetBoard2Leon3	-	0.36[%]	-	0.18[%]	-	0.018[%]

- RTEMS Timing**

- 229 times RTEMS 4.8.0 was faster than RTEMS Tailored 14 and 365 times RTEMS Tailored 14 was faster than RTEMS 4.8.0
- RTEMS by EDISOFT is faster in the interrupts, context switch, IO, Task, Event, Rate Monotonic and Message Queue operations;
- RTEMS 4.8.0 is faster in Clock and Semaphore operations

RTEMS Qualification Extensions Lessons Learned

- **Independent teams** for the realization of the **project** and for the **support** of the RTEMS by EDISOFT **users**
- **Not having independent teams** have caused **RTEMS Qualification Extensions delays** in the execution of the project, since team elements were shifted between project and support
- **In the end of the project**, it was found that **team maturity is improving** and team is becoming **redundant** in several **technical aspects**.

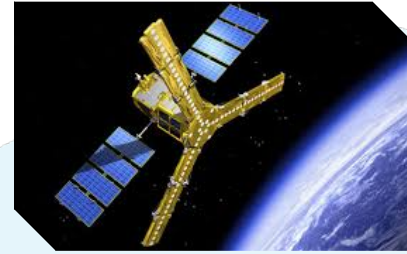
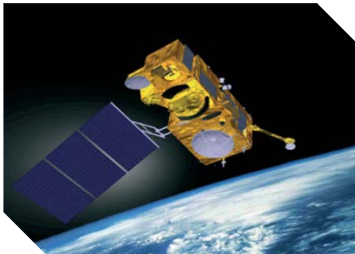


RTEMS Qualification Extensions

FUTURE WORK

RTEMS Qualification Extensions Future Work

- **Objective 1 – Maintain the support standards**
 - RTEMS product maintenance and support activities
 - Correction of the open Software Problem Reports
 - Support RTEMS regular releases for the space community
 - Study and improve the delivery process to cope with customers' demand to reduce releases time
- **Objective 2 – Improvement to cope with new space missions requirements**
 - Adaptation of RTEMS product to comply with multi-core processors (LEON3 and LEON4)
 - Develop and facilitate the qualification for new device drivers (e.g. RS422 and CAN)
 - Integrate new support platforms in the RTEMS product
 - Include new libraries (e.g., math libraries and PUS (Packet Utilization Standard))
 - Development new tools to support the validation and verification activities of the RTEMS space missions



10th June - Day of Portugal, Camões, and the Portuguese Communities

Arms and the Heroes,
who from Lisbon's shore,
Thro' seas where sail was never spread before,
Beyond where Ceylon lifts her spicy breast ...

The Lusiad, Luis Vaz de Camões



DEFENCE & AEROSPACE TECHNOLOGIES

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