

# MARTe

## Multi-platform Real-Time Framework

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EFDA  
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# Outline



- What is MARTE?
- MARTE foundations - RT Library
- Components description
- Interfacing with MARTE
- Vertical Stabilisation – an example
- Future developments
- Conclusions

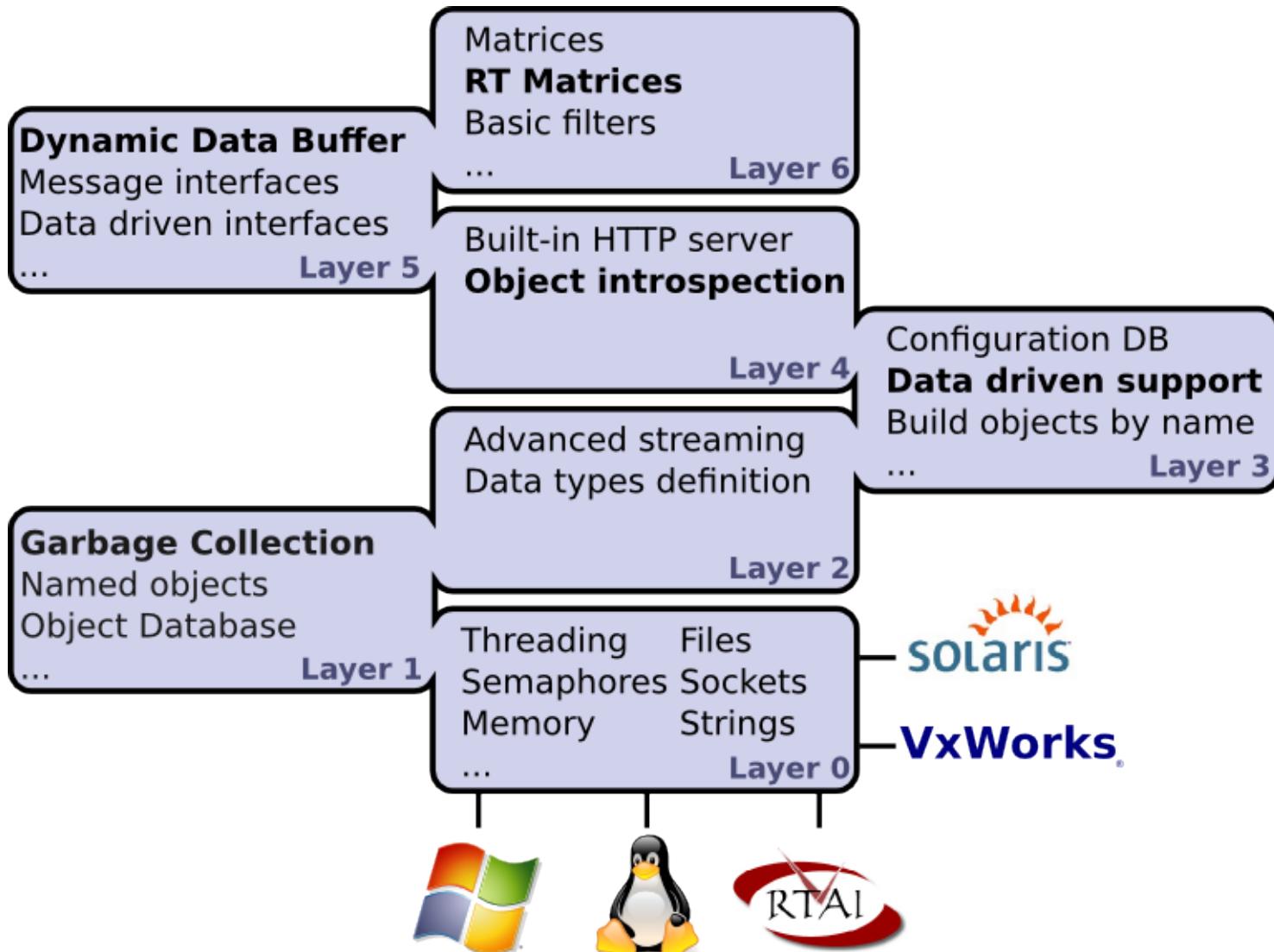
# What is MARTe?



- **Multi-platform C++ real-time framework**
  - Modular
    - Clear boundary between algorithms, hardware interaction and system configuration
    - Reusability and maintainability
    - Simulation
  - Develop / debug in non real-time environments
  - Data driven
  - Provide live introspection tools
    - HTTP (+CINT), logging

# BaseLib2 – support library

EEA JET

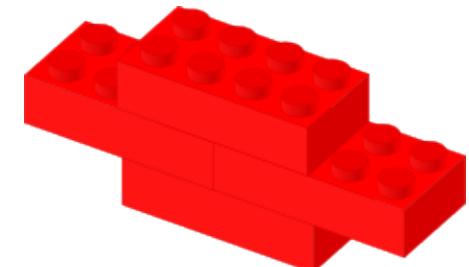
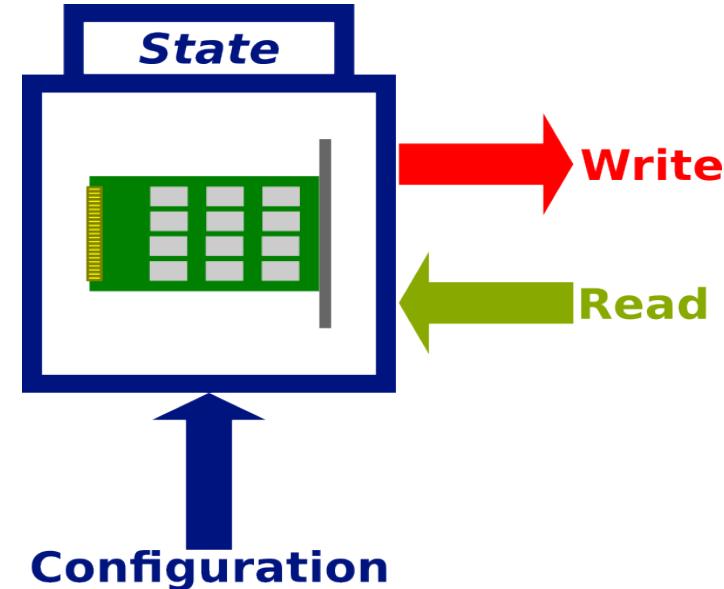


# Generic Application Module(GAM)

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JET



- Atomic block
  - Algorithms
  - Hardware interface
- Only piece of the system which may need to be developed
- Data driven configuration
- Can be inserted and removed at *anytime*
- Consume and produce data



# Object Configuration



- Structured syntax
- Similar to XML
- Classes are automatically created
- Configuration is validated by the created object
- Asserting and parsing functions available

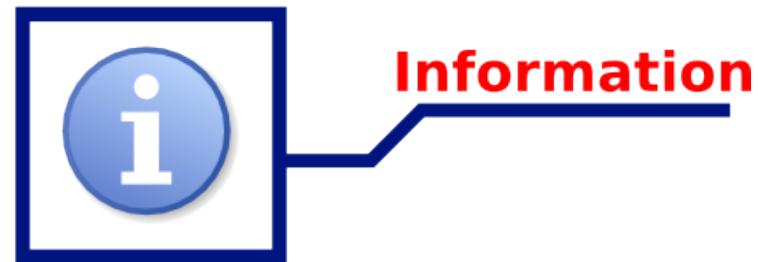
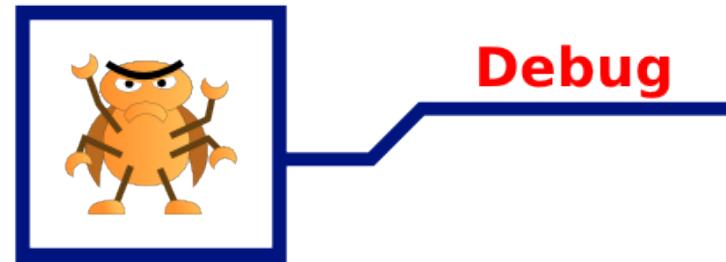
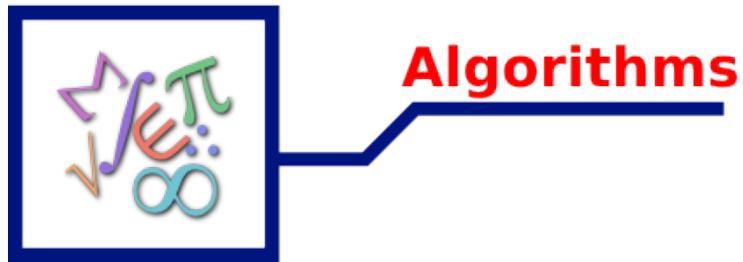
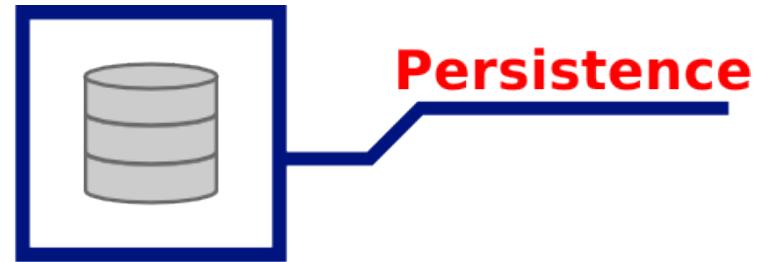
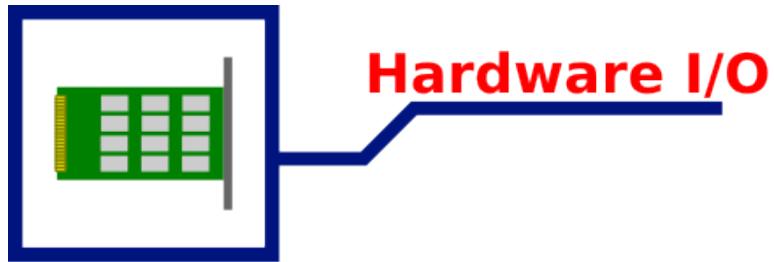
```
+HttpServer = {  
    Class = HttpService  
    Port = 8084  
}  
...  
+Control = {  
    Class = ControlIGAM  
    Controller = {  
        NoPlasmaVelocityGain = 0.0  
        NoPlasmaCurrentGain = 40.0  
        IPWaveform = {  
            Times      = {0 120}  
            Amplitudes = {0.5 0.5}  
            Rounding   = 50  
        }  
    }  
    ...
```

# GAM features



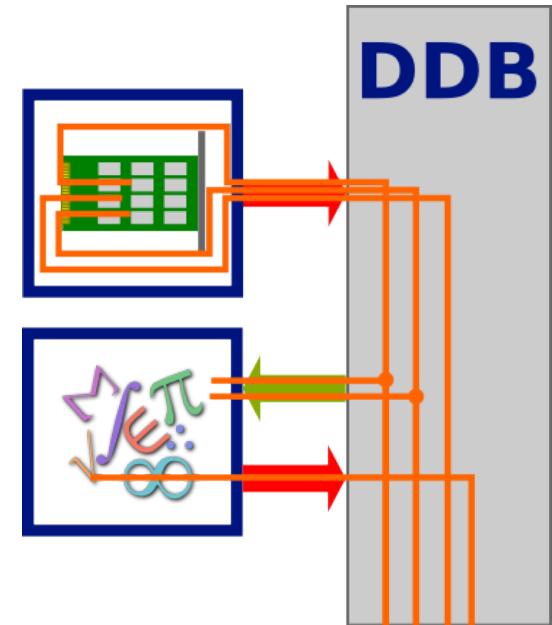
- Large part of the code expected to be executed during configuration phase
  - Trap errors as soon as possible
- Special kind of GAMs provide interface with hardware
  - Unique high level interface to any kind of hardware
  - Clear boundary between algorithms and hardware
- Simulation
  - GAMs to simulate the inputs (replacing the hardware)
  - Predict the output of the system using models
  - Live swap of GAMs when required
  - Debug and error tracking

# Common GAMs

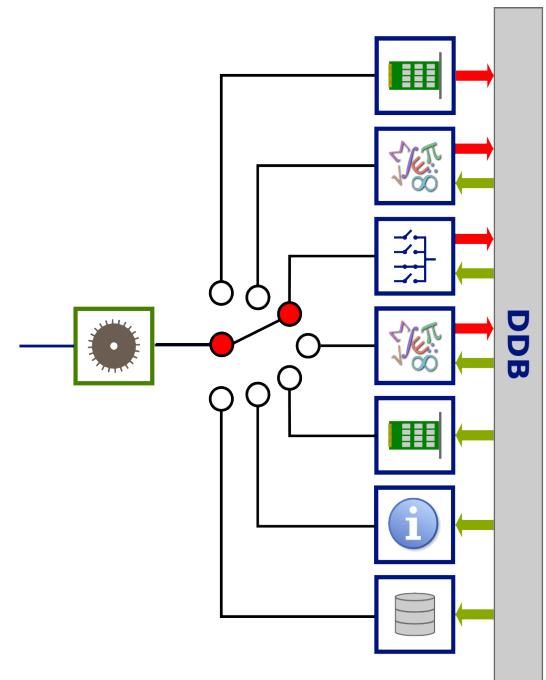


# Dynamic Data Buffer

- GAMs shared data through a memory bus
- MARTe guarantees coherency between requested and produced signals
- Set of GAMs allow to stream data to different MARTe systems

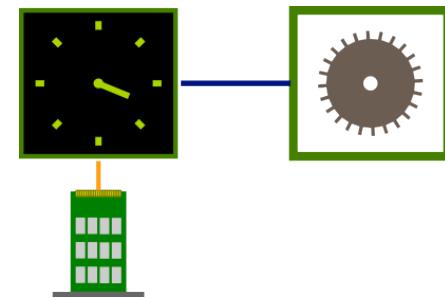


- Sequentially executes GAMs
  - Works as micro-scheduler
  - Can be allocated to specific CPUs
- Keeps accurate information about execution times
- Requires an external time and triggering mechanism

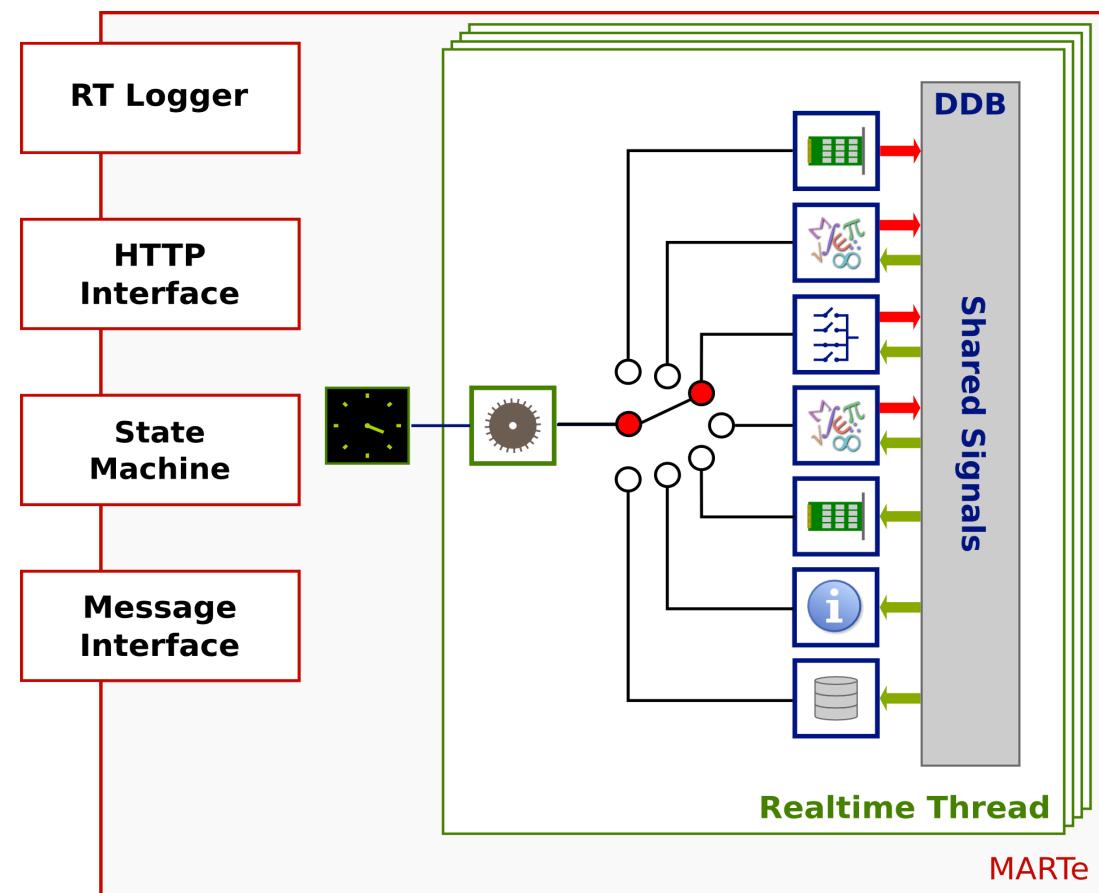


# Synchronisation

- Timing for the real-time thread(s)
- Usually provided by an external hardware
- Cycle time can be specified
  - Defines when a new cycle should start
- MARTE supports polling and interrupt based sources



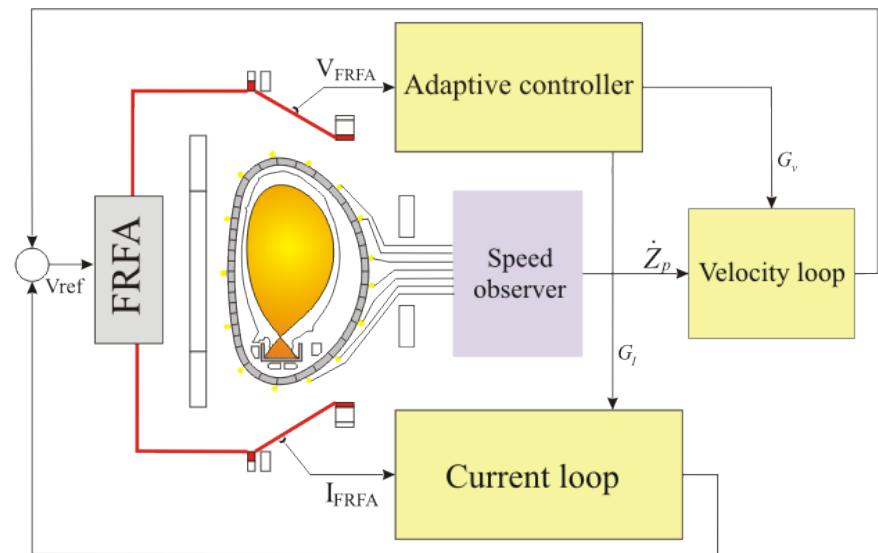
- At least one RT-Thread
- RT-Threads can execute in parallel
- Several utility components available
  - Logger
  - HTTP server



- The preferred way is through a *Message Interface*
  - High level protocol
  - Implemented in BaseLib2
- HTTP interaction is widely used for retrieving information
  - Can also be used to change values
    - GAMs configuration
    - State machine
    - ...

# Vertical Stabilisation

- Elongated tokamak plasmas are susceptible to a vertical axisymmetric instability
- Dedicated Vertical Stabilisation System required
- Essential system for operation
- Growth rate of  $1000\text{s}^{-1}$
- Loss of control can produce forces in the order of the 100's of tonnes

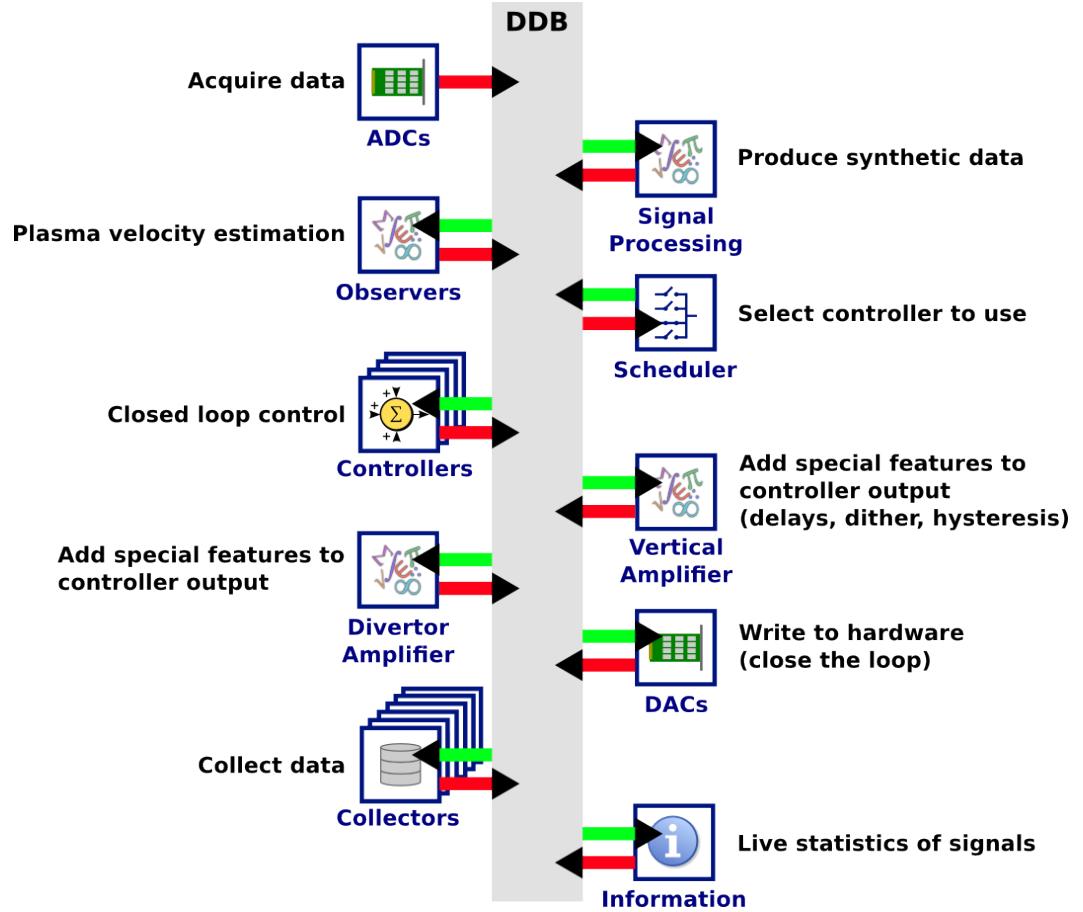
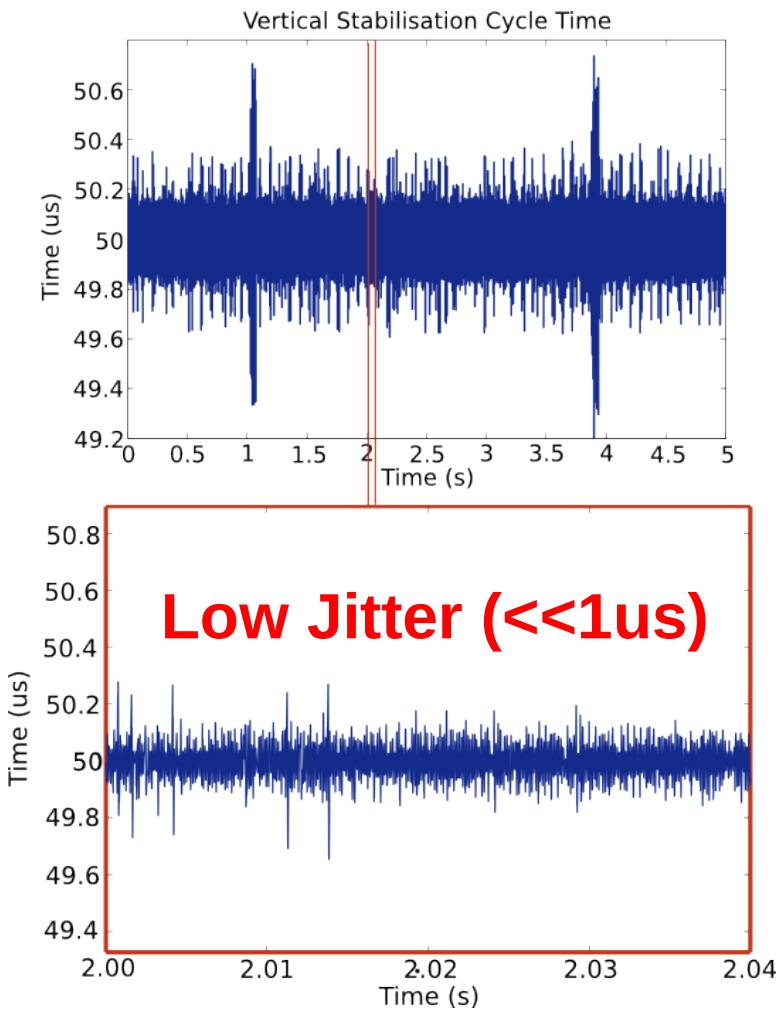


# VS - An example



- Closed loop
  - $50 \pm 1 \mu\text{s}$  (with max. jitter of  $2.5 \mu\text{s}$ )
- 18 GAM instances
  - Altogether execute in less than  $40 \mu\text{s}$
  - Synchronization always achieved within  $0.8 \mu\text{s}$
- 192 signals acquired by ADCs and transferred at each loop
- Always in real-time (**24 hours per day**)
  - **$1.728 \times 10^9 \text{ } 50 \mu\text{s cycles per day}$**

# VS Execution



- System is always RT
  - JET is a pulsed based machine
  - ITER will have very long pulses
- First tests with continuous data streaming
  - **Without compromising RT**
  - Bandwidths of ~70MBytes/s
  - To be published
- Testing remote driving of systems

# Conclusions

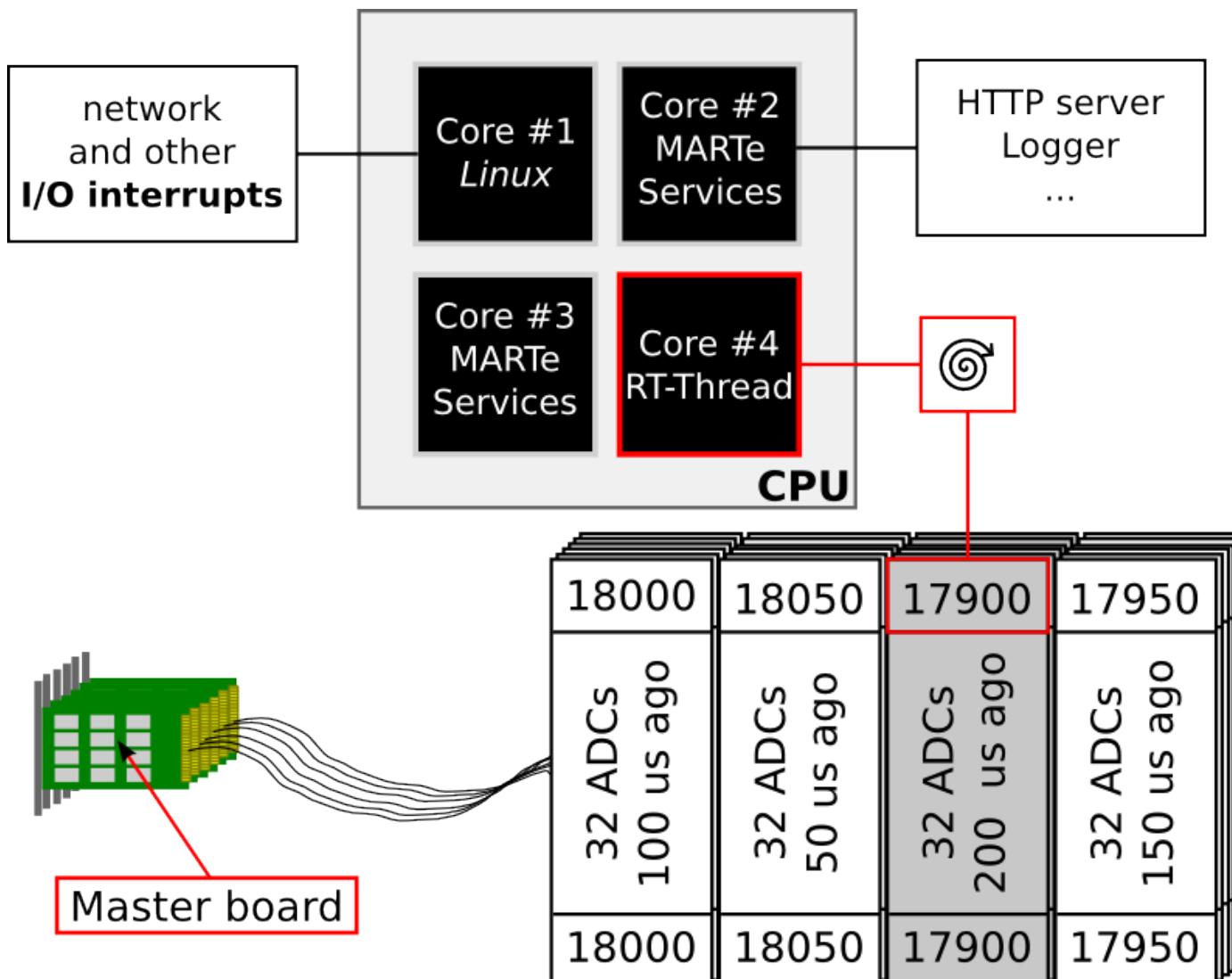


- Modular C++ framework
  - Based on multi-platform RT library
  - Built over data driven modules
  - Clear boundary between hardware and algorithms
  - Interface and behaviour fully configurable
- Drives the VS system
  - Essential system, faults are not acceptable
  - **50µs loop cycle with a jitter inferior to 1µs**
    - Average jitter in the order of 200ns

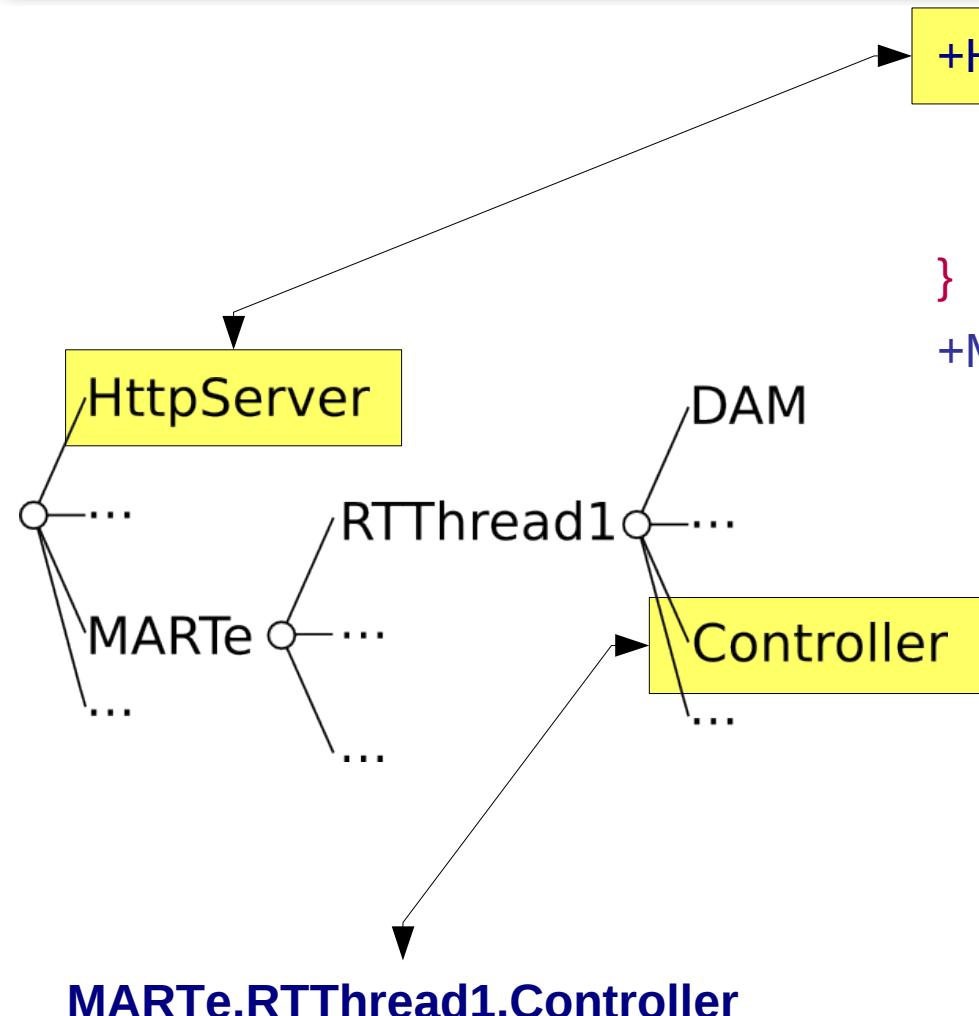
# Support slides



# Hardware Synchronization



# Configuration DB



```
+HttpServer = {  
    Class = HttpService  
    Port = 8084  
}  
+MARTE = {  
    Class = MARTEContainer  
    +RTThread1 = {  
        Class = RealTimeThread  
        +Controller = {  
            NoPlasmaCurrentGain = 40.0  
            IPWaveform = {  
                Times      = {0 120}  
                Amplitudes = {0.5 0.5}  
            }  
            ...  
        }  
    }  
}
```

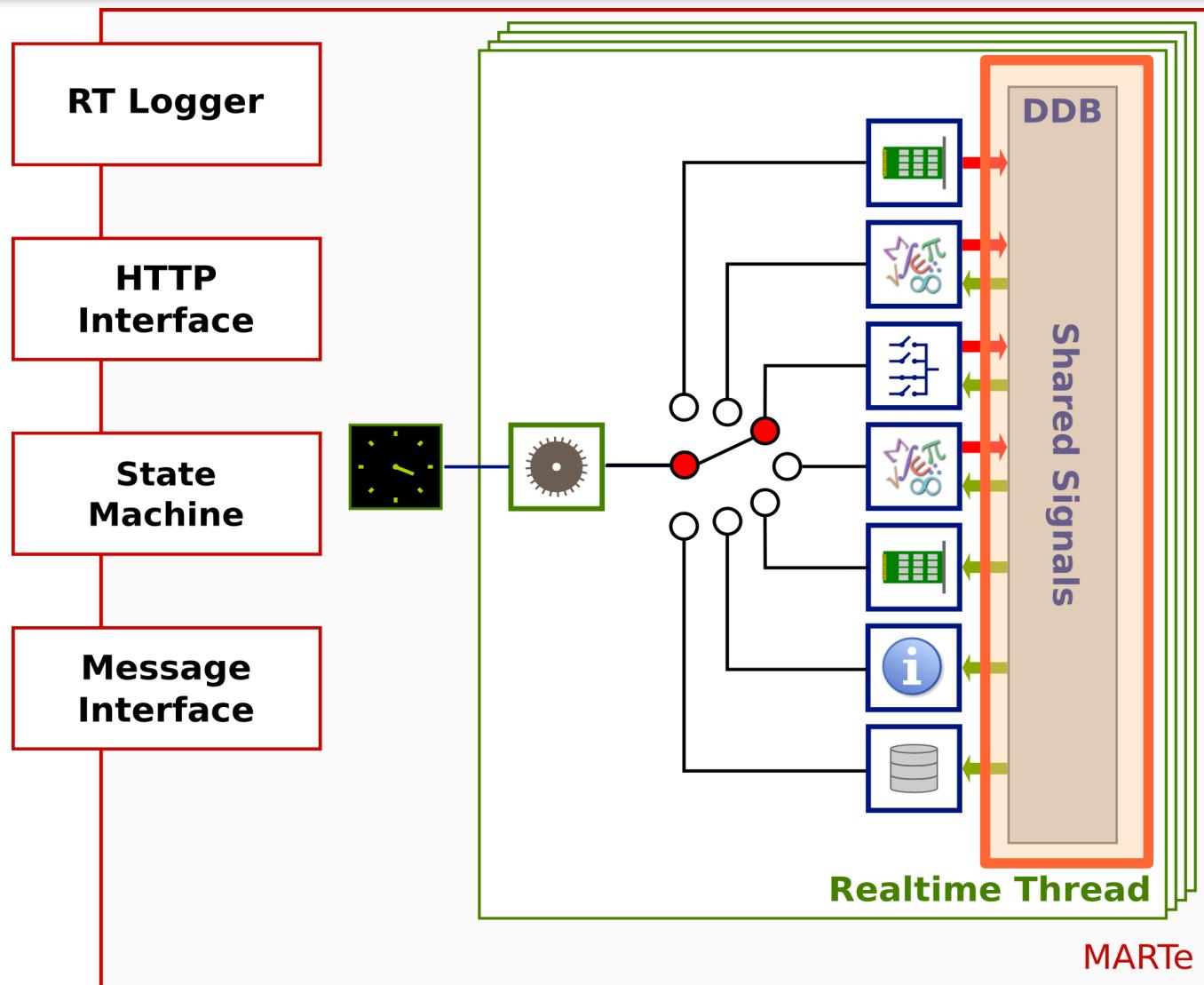
# Messages



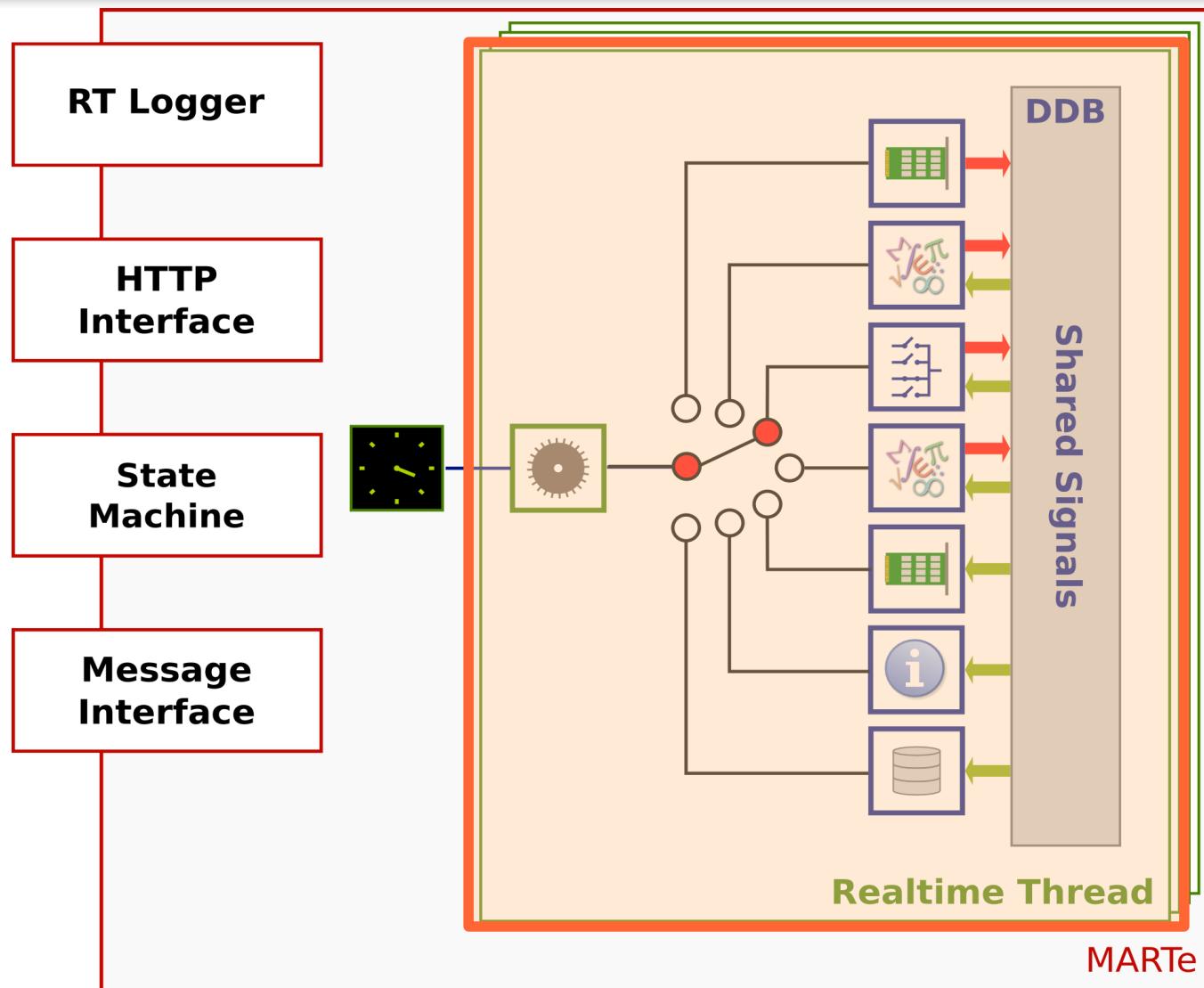
- Objects that implement the **Message Interface** are able to send and receive synchronous and asynchronous messages
- Messages allow to interface by protocol
- Messages can contain object configurations
- Can be sent through the network
- Important mechanism in the design of MARTe

- **Closed loop**
- Only possible because RT processes aren't disturbed
- Full access to the computer without compromising RT
- **50µs loop cycle with a jitter inferior to 1µs**

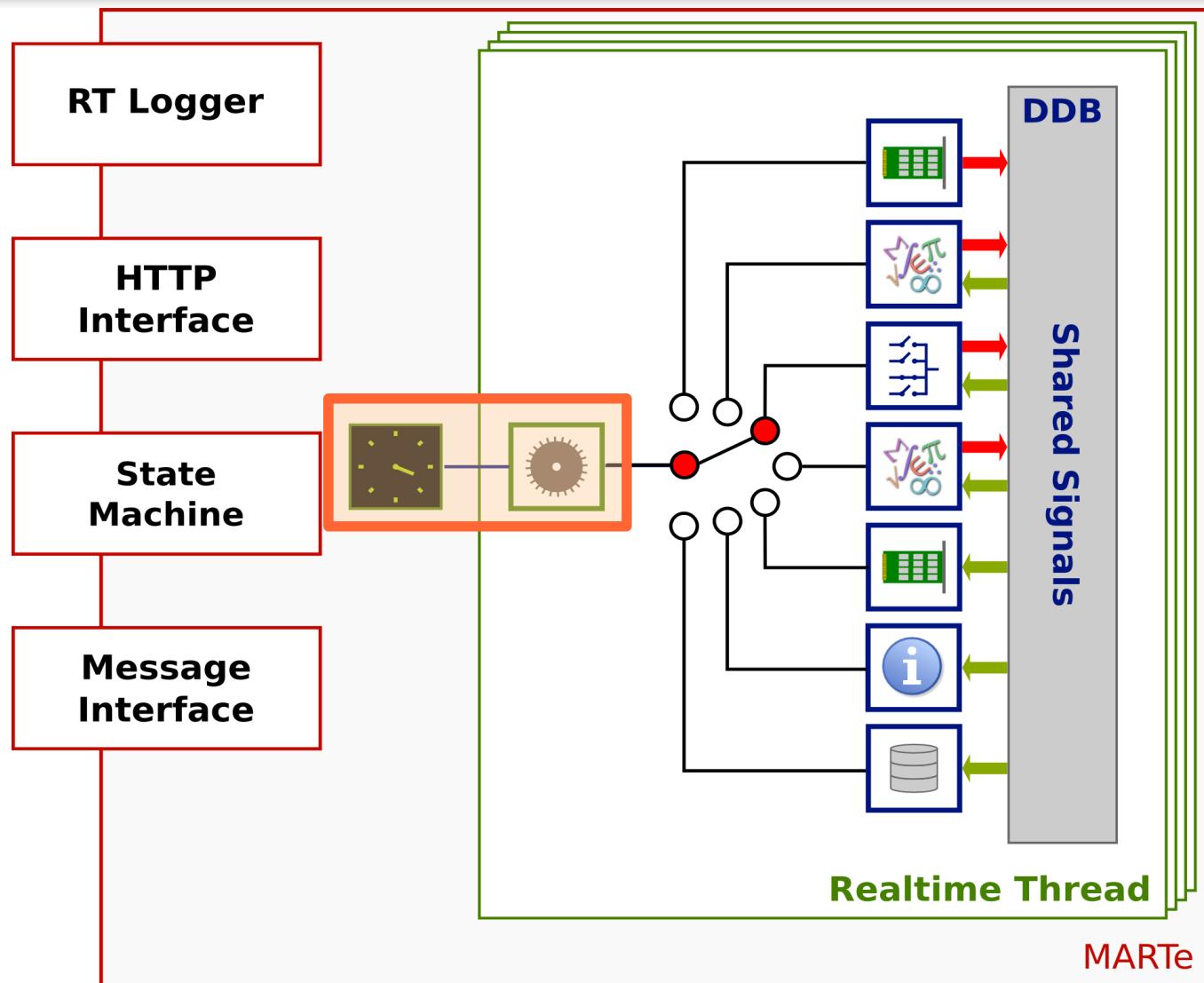
# Dynamic Data Buffer



# Real-time thread



# Synchronisation



**Automatically built**

BACK REFRESH

(MARTEContainer) MARTE > W

- (MenuContainer) MARTE > W
- (GCReferenceContainer) DriverPool
- (GCReferenceContainer) Messages
- (DataPollingDrivenTTS) ExternalTimeTriggeringService
- (RealTimeThread) Thread\_1 > W
- (DDB)
  - (TimeInputGAM)
  - (SignalProcessingGAM) SPGAM > W
  - (VSObserverGAM) VSOobserver
  - (SchedulerGAM) Scheduler > W
  - (ControlGAM) Control > W
  - (Dum1ControllerGAM) Dum1
  - (Dum2ControllerGAM) Dum2
  - (Dum3ControllerGAM) Dum3
  - (VAMGAM) VAM > W
  - (DAMGAM) DAM > W
  - (OutputGAM)
  - (DataCollectionGAM) Collection > W
  - (DataCollectionGAM) ControllerSignals > W
  - (DataCollectionGAM) DebugSignals > W
  - (DataCollectionGAM) Performance > W
  - (EventCollectionGAM) AsyncSignals
  - (DataCollectionGAM) WaveformCollection

Done

Parameter	Value (abs)
Max current gain	30.000000
Min current gain	0.000000

**Saturations**

**VS1 current adaptation parameters**

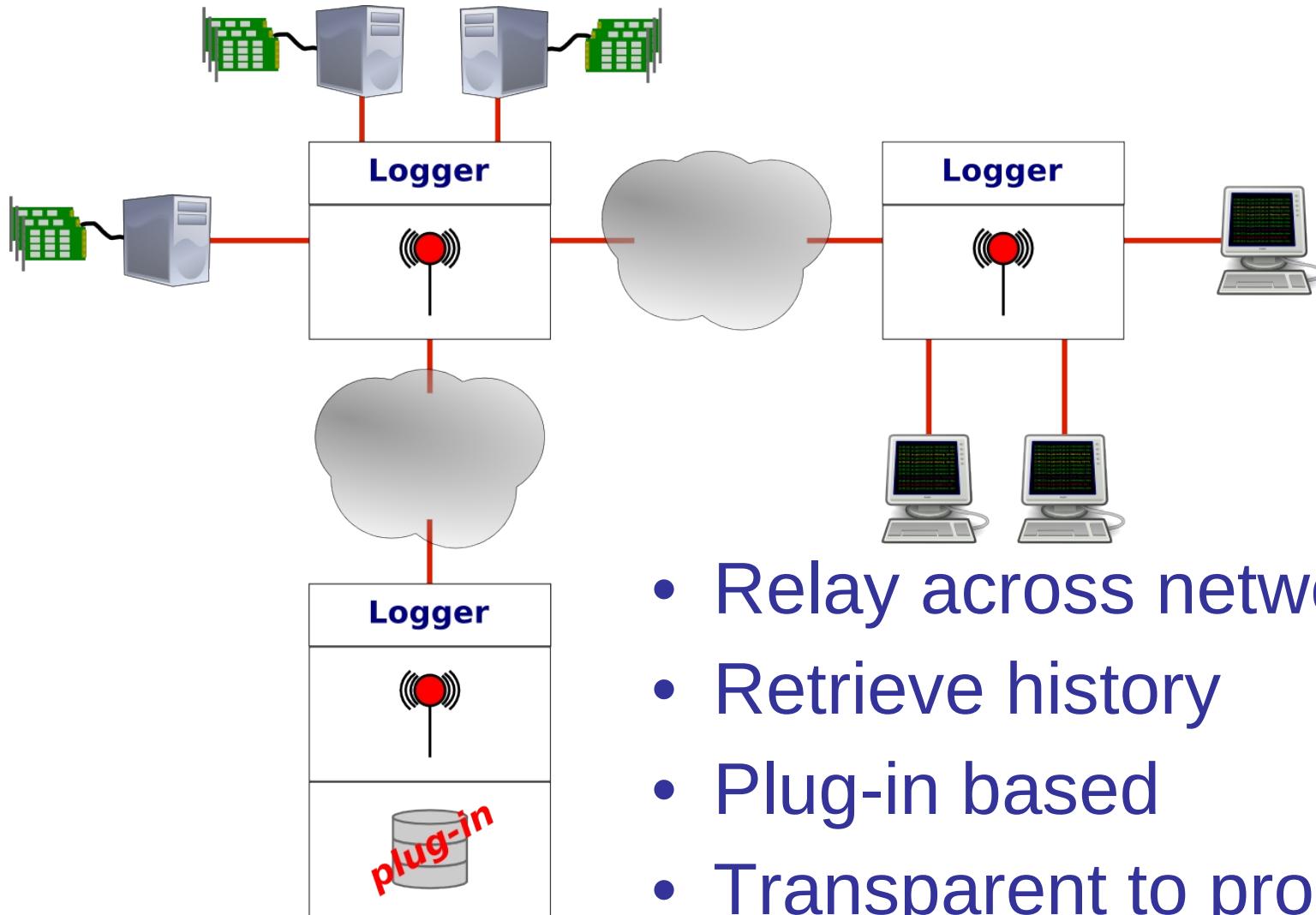
Parameter	Value
Voltage delta threshold	50000.000000
High gain	-10000.000000
Low gain	-5000.000000
Keep low gain for	12000 usecs

**PCU1 current adaptation parameters**

Parameter	Value
Amplifier current saturation index threshold	2500.000000
High gain	-15000.000000
Low gain	-5000.000000
Alpha	0.500000
Beta	0.800000

**PCU2 current adaptation parameters**

# MARTE tools - logger



- 6 ATCA Data Acquisition Boards
- 2MSPS - 18 bit ADCs
- PCIe interface
- Intel Core 2 Quad
- Digital I/O
  - Connection to new amplifier
- See **FESPP-25** in the Poster Area



# JTLogger



JTLogger 4.8 / 8.2 MB

- Loggers
  - vx\_ppccvsc.jet.uk - 0x0
  - vx\_efcc.jet.uk - 0x0
  - vx\_walls.jet.uk - 0x0
  - localhost.localdomain - 0x0
  - pc-rtdn-on-08.jet.uk - 0x5b
  - pc-rtdn-on-10.jet.uk - 0x61
  - pc-rtdn-on-05.jet.uk - 0x5f
  - pc-rtdn-on-04.jet.uk - 0x5e
  - ax\_ppccv5.jet.uk - 0x0
- Threads
  - 0xc9b76200
  - 0xca284f40
  - 0xca286740
  - 0xca287740
  - 0xca288740
  - 0xca288f40
  - 0xca289740
  - 0xca28f740
  - HS\_USER\_LISTENER\_THREAD
- Errors
  - 1
  - 0
  - 4
  - 3
- Class
- Object
- GLOBAL
  - 0xca389440
    - Threads
      - ! Errors
      - Class
  - 0xca305640
  - 0xca304040
  - 0xca3058c0
  - 0xca305740
  - 0xca304140
  - 0xca3892a4
  - 0xca389340
  - 0xca388140
  - 0xrc260f10

```
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(VSObserver *)0xa407980:Input linear combination
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(VSObserver *)0xa4079c0:Input linear combination
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(VSObserver *)0xa408b00:Input linear combination
[2:46:52]:ax_ppccv5.jet.uk:Warning:tid=0xc9b76200:cid=0x0:obj=GLOBAL:GAM::RemapInterfaces: No Remappings specified for this interface
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(VSObserverGAM *)0xa388740:ObjectLoadSetup::Success
[2:46:52]:ax_ppccv5.jet.uk:Warning:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler::Initialise: Scheduler KickPeriodicElmSensit
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler FastStopWindow: VAMstatus=0, DAMstatus=0
[2:46:52]:ax_ppccv5.jet.uk:Warning:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler::Initialise: Scheduler KickPeriodicElmSensit
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler SoftStopWindow: VAMstatus=0, DAMstatus=0
[2:46:52]:ax_ppccv5.jet.uk:Warning:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler::Initialise: Scheduler KickPeriodicElmSensit
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler TimeWindow0: VAMstatus=0, DAMstatus=0
[2:46:52]:ax_ppccv5.jet.uk:Warning:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler::Initialise: Scheduler KickPeriodicElmSensit
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler TimeWindow1: VAMstatus=0, DAMstatus=0
[2:46:52]:ax_ppccv5.jet.uk:Warning:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler::Initialise: Scheduler KickPeriodicElmSensit
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler TimeWindow2: VAMstatus=0, DAMstatus=0
[2:46:52]:ax_ppccv5.jet.uk:Warning:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler::Initialise: Scheduler KickPeriodicElmSensit
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:Scheduler TimeWindow3: VAMstatus=0, DAMstatus=0
[2:46:52]:ax_ppccv5.jet.uk:Warning:tid=0xc9b76200:cid=0x0:obj=GLOBAL:GAM::RemapInterfaces: No Remappings specified for this interface
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(SchedulerGAM *)0xa40a640:ObjectLoadSetup::Success
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(Filter *)0xca3618d8:Creating Filter of size 1 1
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(Filter *)0xca3618d8:Filter Filter = {
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(Filter *)0xca3618d8:1.000000e+000
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(Filter *)0xca3618d8:-1.000000e+000
[2:46:52]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(Filter *)0xca3618d8:}
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(ControlGAM *)0xca361740:ObjectLoadSetup::Successful
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(DummyControllerGAM *)0xa40b2c0:ObjectLoadSetup::Successful
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(DummyControllerGAM *)0xa40b440:ObjectLoadSetup::Successful
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(DummyControllerGAM *)0xa40b5c0:ObjectLoadSetup::Successful
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:KickWaveform::ObjectLoadSetup: did not specify
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:VAMGAM::Initialise: VAM: successfully initialised 1
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:KickController::ObjectLoadSetup: Successfully initialised
[2:46:53]:ax_ppccv5.jet.uk:Warning:tid=0xc9b76200:cid=0x0:obj=GLOBAL:KickController::ObjectLoadSetup: ELMSensitive is specified
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:KickController::ObjectLoadSetup: Successfully initialised
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:KickController::ObjectLoadSetup: Successfully initialised
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:KickController::ObjectLoadSetup: Successfully initialised
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=GLOBAL:RemapInterfaces: No Remapping specified
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(VAMGAM *)0xca3fb740:ObjectLoadSetup::Successfully initialised
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(DAMOperatingSpace *)0xca40bec0:DAMOperatingSpace
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(DAMOperatingSpace *)0xca415fc0:DAMOperatingSpace
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(DAMOperatingSpace *)0xca415fc0:DAMOperatingSpace
[2:46:53]:ax_ppccv5.jet.uk:Information:tid=0xc9b76200:cid=0x0:obj=(DAMOperatingSpacePool *)0xa40bd40:DAMOperatingSpace
```

16:47:16] UDP Broadcaster is now ok! Sleeping for: 121 ms N Packets=4287578

# The Goal

- Use MARTE to run the JET Vertical Stabilisation

Essential system for operation

Closed loop control cycle time:

**Target:**

$50 \pm 1 \mu\text{s}$

(with max. jitter of  $2.5 \mu\text{s}$ )

**Achieved:**

$50 \pm 0.10 \mu\text{s}$

(max jitter of  $0.80 \mu\text{s}$ )

