# Test System Architecture for AOCS Testing

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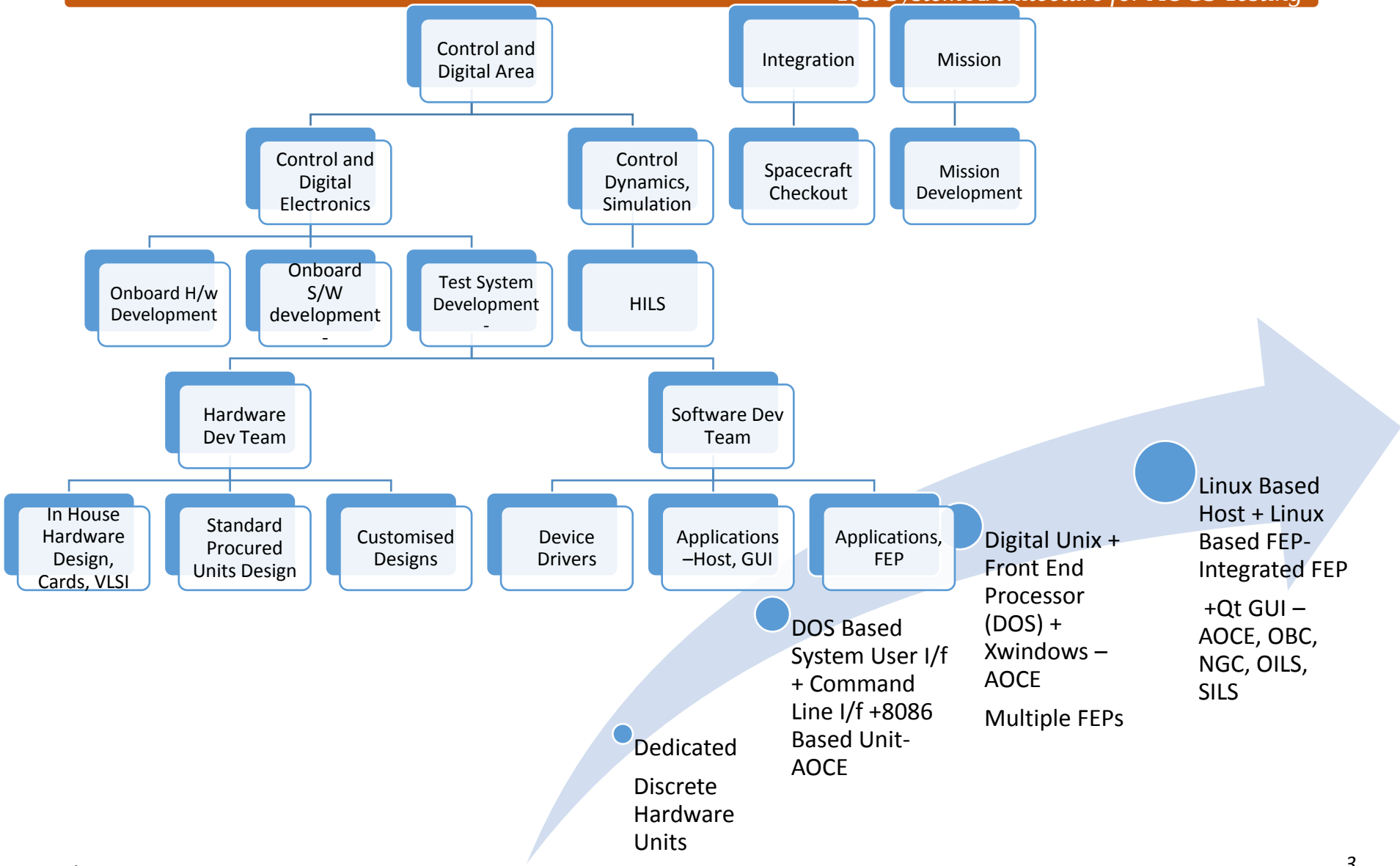
# Agenda

- *Introduction*
- *AOCS Test Requirements*
- *Architecture*
- *Design of Various Features*
- *Summary*

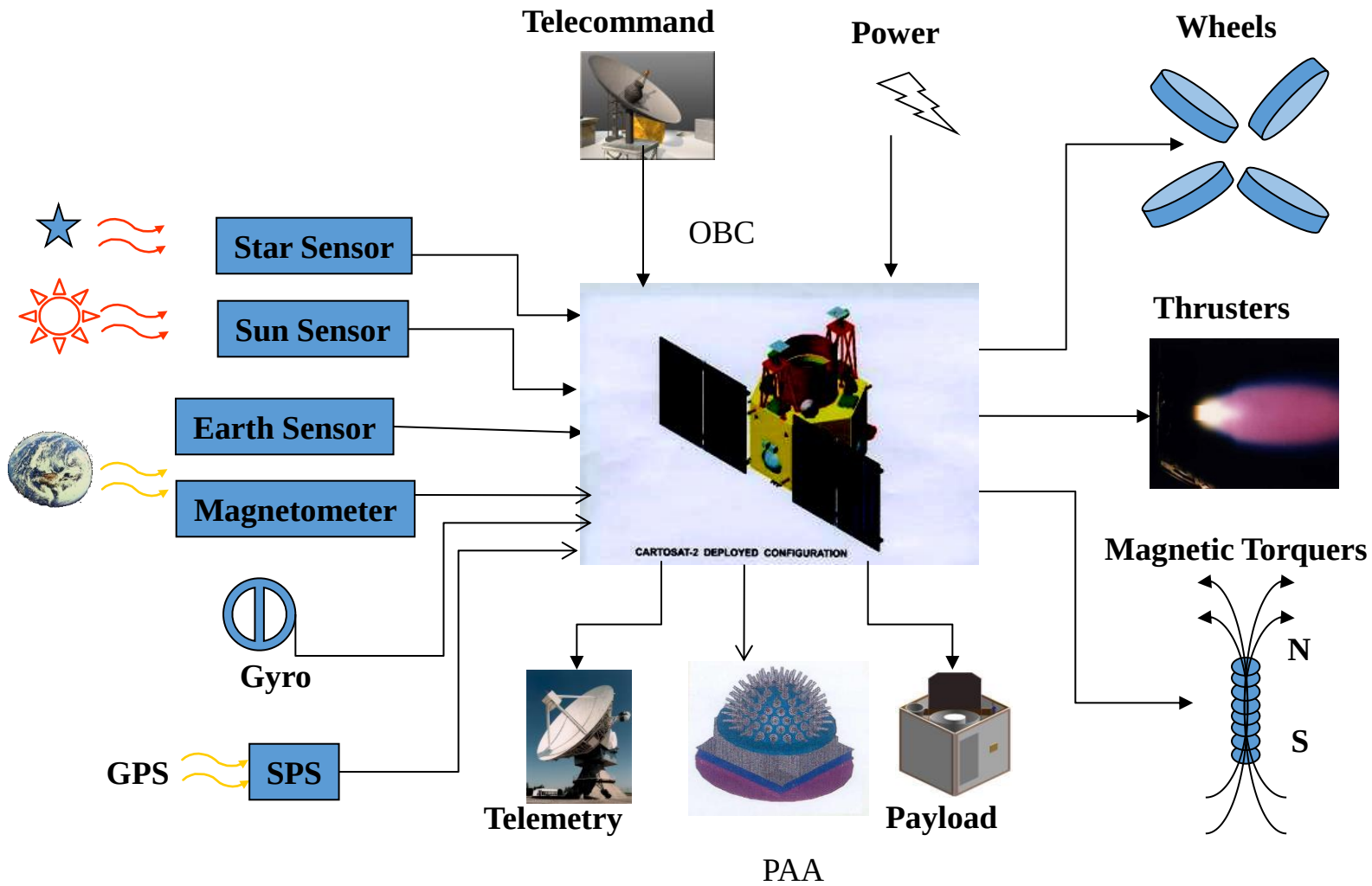
# Ground Systems Development Areas (AOCS Related)

*Test System Architecture for AOCS Testing*



# AOCS – On Board Computer

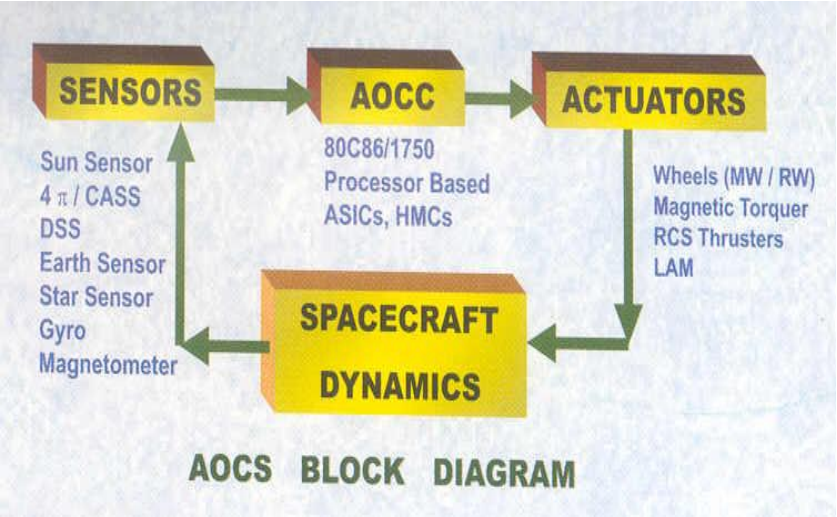
*Test System Architecture for AOCS Testing*



# AOCC Functions



- Attitude and Orbit Control, Controllers, Filters, Estimators , Acquisition, Onorbit Modes, Station Keeping Modes
- Sensor Interface - Earth Sensor, Star Sensors, Coarse Analog Sun Sensor, 4pi Sun Sensor, FASS, Solar Panel Sun Sensor, Digital Sun Sensor, Inertial Reference Unit , Accelerometer
- Actuator Interface – Reaction Wheels (RW) , Reaction Control Systems (RCS), Apogee Motor (LAM), Torquer (MTC) , Antenna Pointing Mechanism (APM)
- Onboard Time Reference
- Attitude Reference generation – Model / Profile Based for Normal Pointing, Imaging, Orbit Maneuver
- Orbit Reference generation Model / Profile / GPS Based
- TC, TM
- Mil Std 1553B Bus Control
- Solar Array Drive , Antenna Control
- Safety Logics, FDIR, Autonomy
- Operational Autonomy – Launch Phase Sequencer, LEB sequencer, Payload Sequencer



# Testing Aspects – Different Phases



**With Test System**

- Hardware Tests
- Software Unit Level Tests
- Functional checks Input , output , Logical, computational Checks
- Software –HW Integrated Tests
- Open Loop Tests – Static
- Open Loop – Dynamic - Tests – Simulated Input Profile (SIP) Tests
- Closed Loop Dynamic Tests – On Board Computer In loop simulation (OILS) Tests
- Mission Scenario Tests
- Environmental Tests
- Operational Validation Tests

**Without Test System**

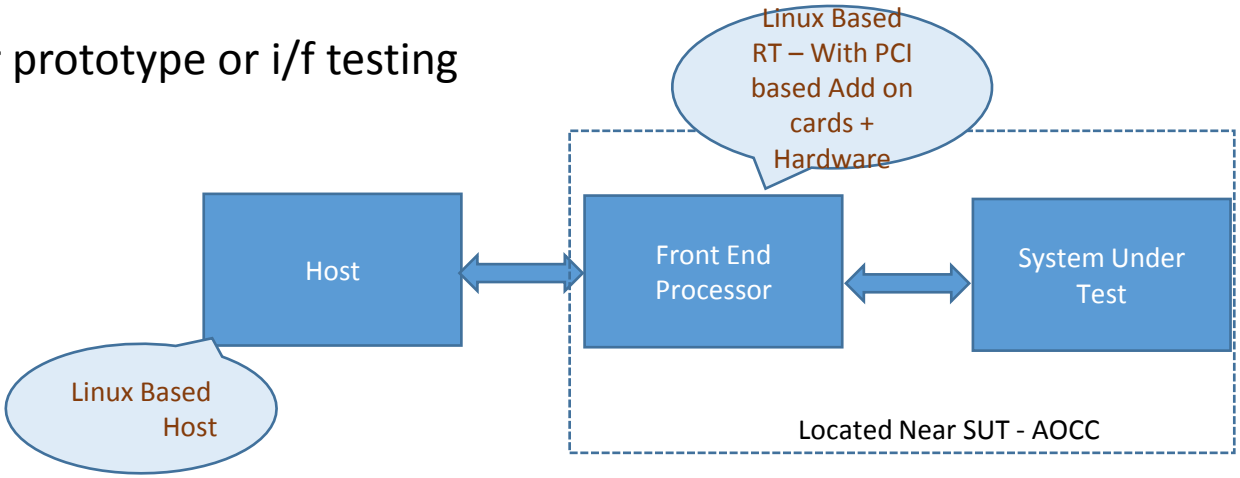
- HILS- Hardware In Loop Simulation Tests
- Integrated Spacecraft Tests

# Ground Test System Design

*Test System Architecture for AOCS Testing*

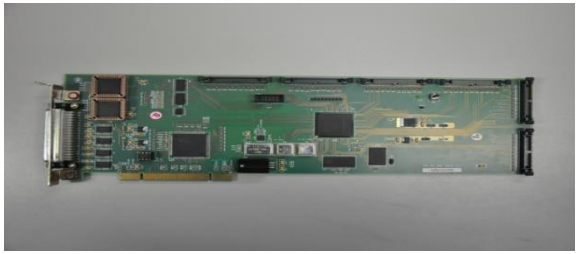
- Test System Provides
  - All Electrical I/f, Power I/f, Loads
  - Multi RT Simulator + Bus Monitor (1553)
  - Electrical Stimuli + Measurements
  - Instruments
  - Supports Open Loop /Closed loop Testing
  - Interface verification
  - Timing Verification
  - OBC/AOCC Simulators for prototype or i/f testing of other subsystems
- Software for
  - Interface Simulation
  - Sensor, Actuator Models
  - Orbit Model, Sun Model
  - Dynamics Simulation
  - Automatic Testing
  - GUI, RT Plot, Display, Data Logging and Retrieval
  - Mil 1553 Bus Monitor

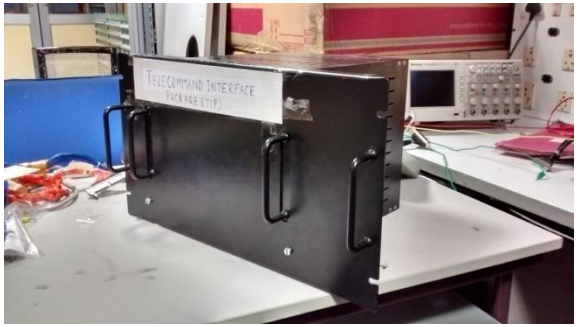
- **Distributed Architecture**
  - Host System – Data Processing, User Interface, Simulation
  - FEP ( Front End Processor) System – Data Acquisition, System Interface
  - Dedicated Ethernet Interface

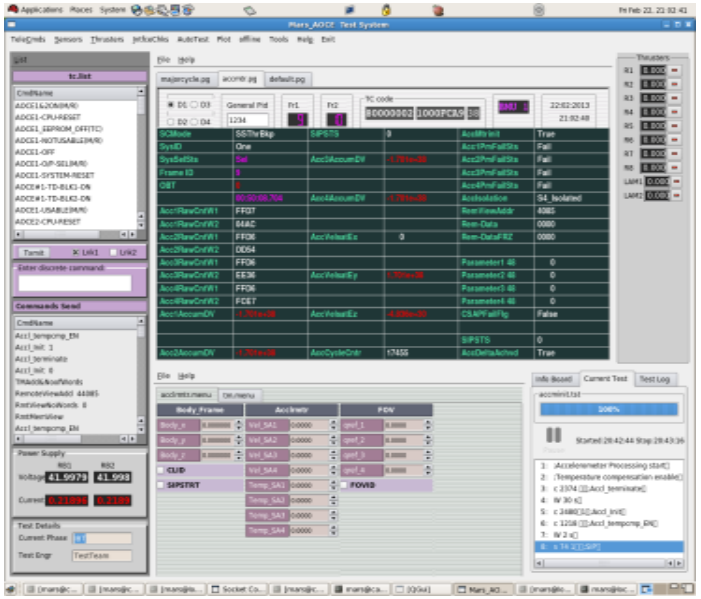


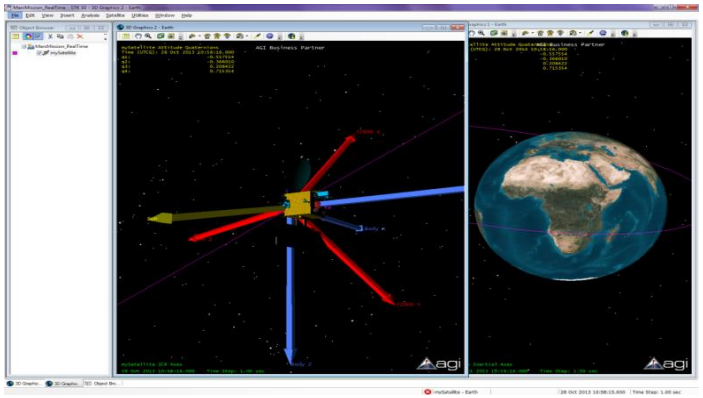
# Ground Test System Elements

*Test System Architecture for AOCS Testing*



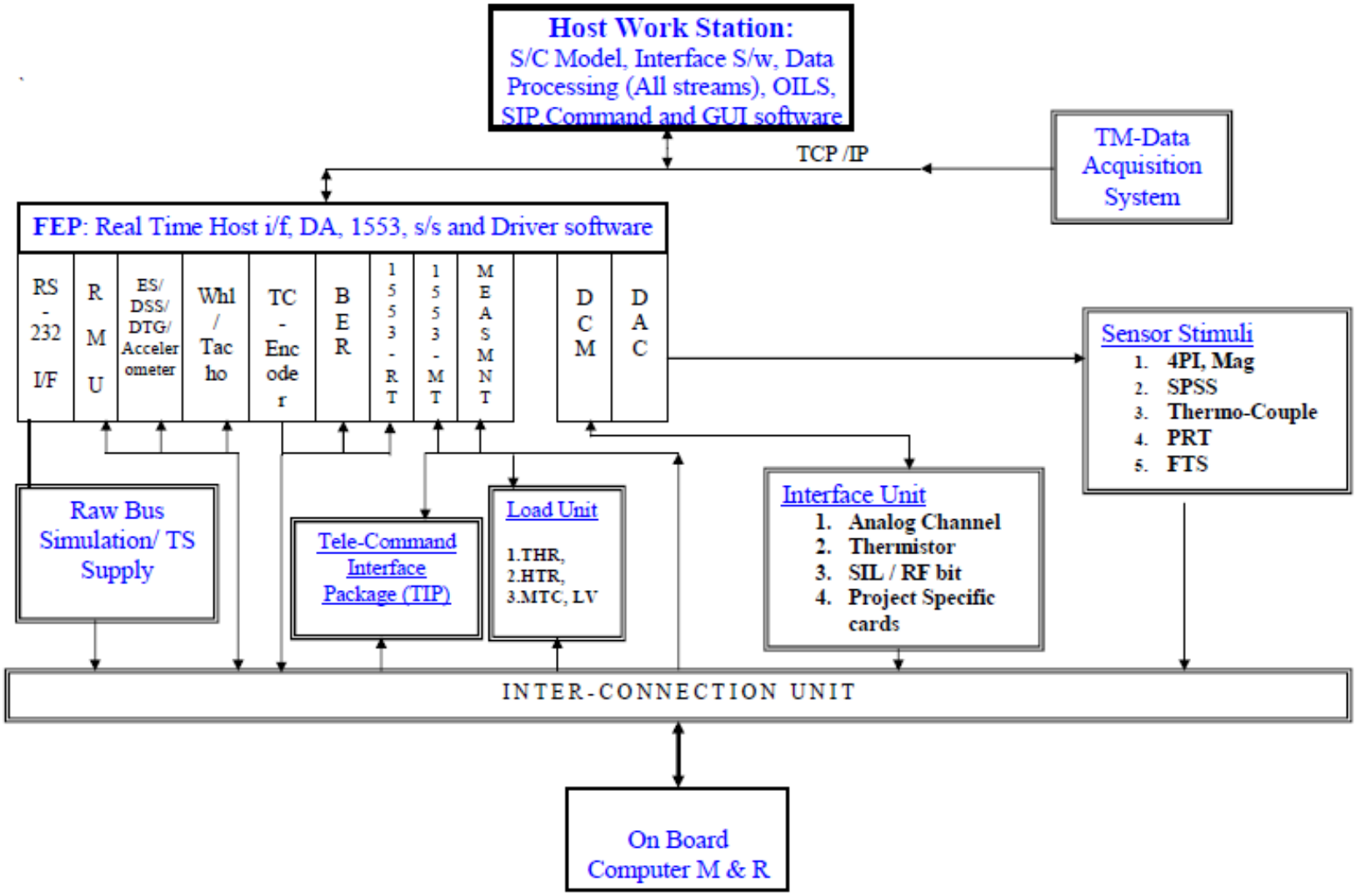






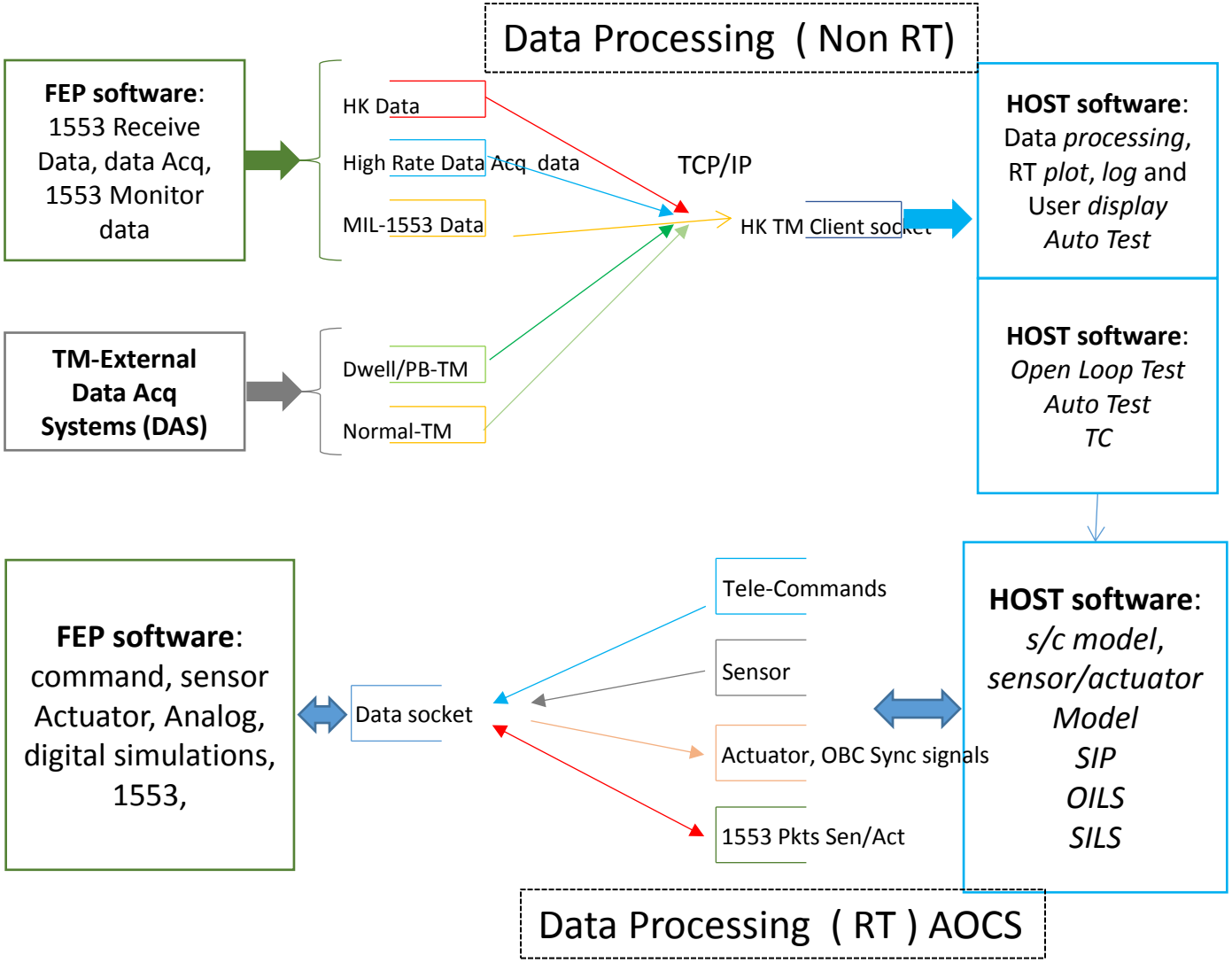
# Typical Test System Architecture

*Test System Architecture for AOCS Testing*



# Software Architecture

*Test System Architecture for AOCS Testing*



# Real Time / Non Real Time Management



**Realtime Management**

- Processes segregated to RT, Non RT
- Priorities maintained accordingly
- Scheduling - FIFO
- Inter Process communication
    - Shared Memories
    - Message Queues
    - Semaphores
- Kernel Preemption enabled
- Memory Locks provided
- Double buffered interfaces
- RT Diagnostics
    - Deadline Miss Counters
    - Parallel Integration in TS to compare with Flight

**Realtime Processes**

- FEP Software
- FEP Communication Software at Host
- Sensor, Actuator, Mil 1553 Interface Software
- Spacecraft Model Software
- OILS, SIP Interface Software

**Data Processing Software + GUI**

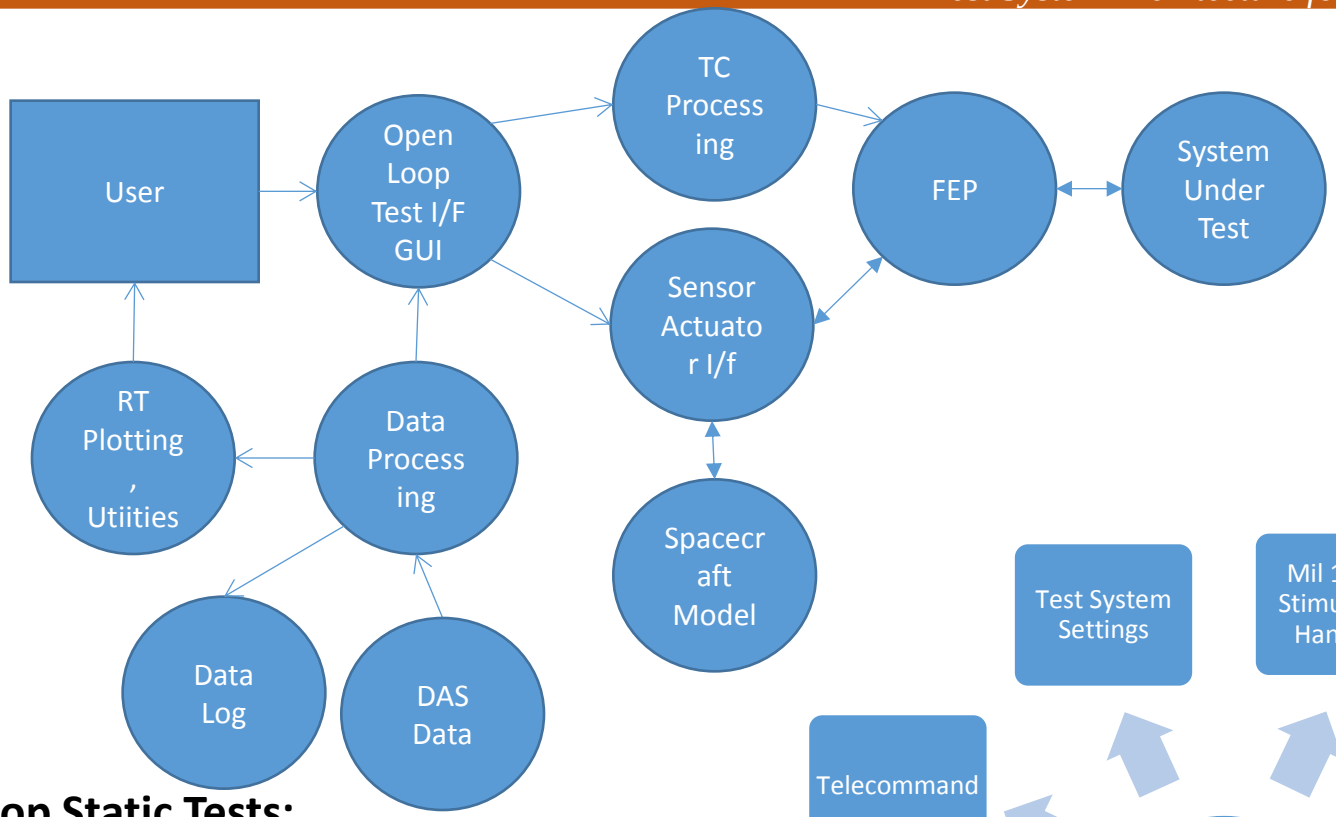
- Telemetry, Data Stream Acquisition Software.
- RT Plotting
- GUI
- Page Display
- Command, Open Loop test software

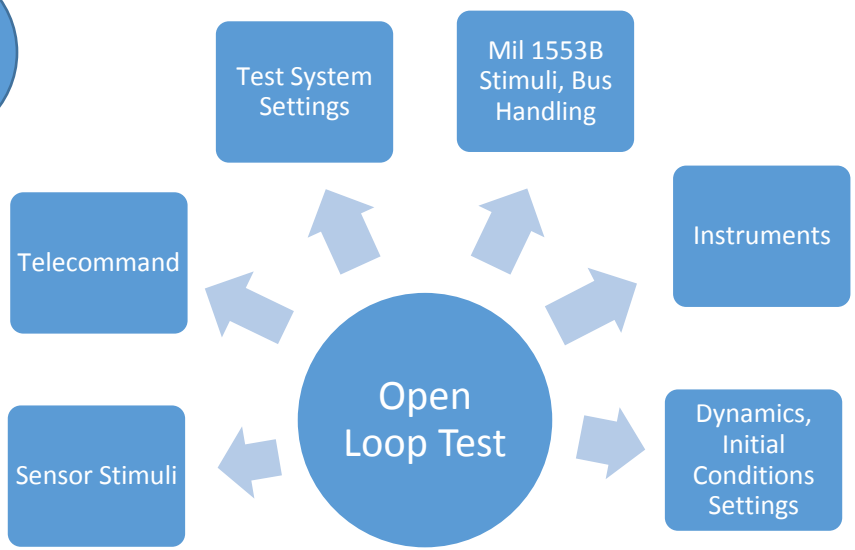
**Offline – Non RT**

- Logging + offline software

# Different Processes Organisation – For open loop

*Test System Architecture for AOCS Testing*



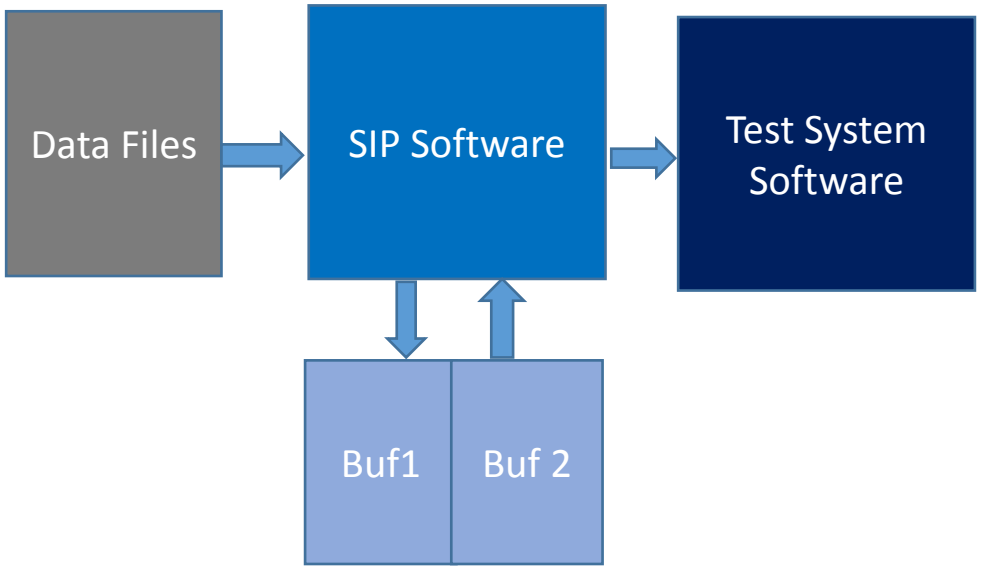

**Open Loop Static Tests:**

- All Logical Tests for Sensor Inputs and Actuator Outputs
- Performance of AOCS – Gains verification
- Open Loop AOCS mode Test Vector reading, processing, Verification
- Sync with Onboard wherever required.

# Simulated Input Profile – Open Loop Dynamic Tests



- Validates the AOCS / NGC Loops
- Open Loop Dynamic Testing
- Actuator to Sensor Closed loop is by Simulated Profile ( i.e Loop through Test System is opened)
- Every Sensor Step input is simulated
- Requires high Real Time Performance + Synchronised to Onboard




- RT Techniques Employed
  - Double Buffering
  - File readout + Update Test system I/f
  - Onboard Sync handling with real time sampling
  - Process Priority Management
- Sync With onboard
  - Advanced Information from Onboard
  - Advanced Data Update to onboard

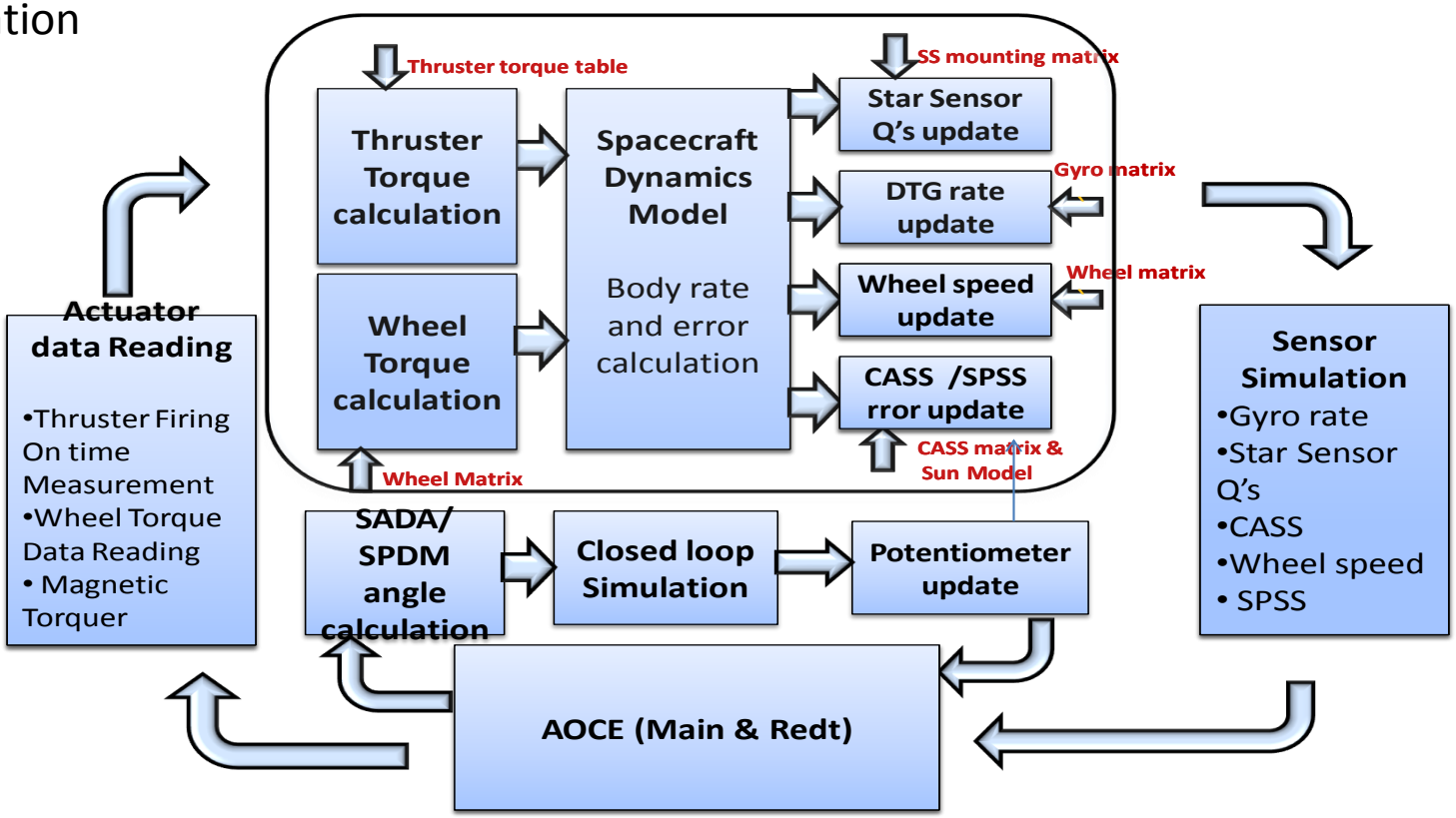
# Typical Onboard Computer In Loop Simulation



**OILS**

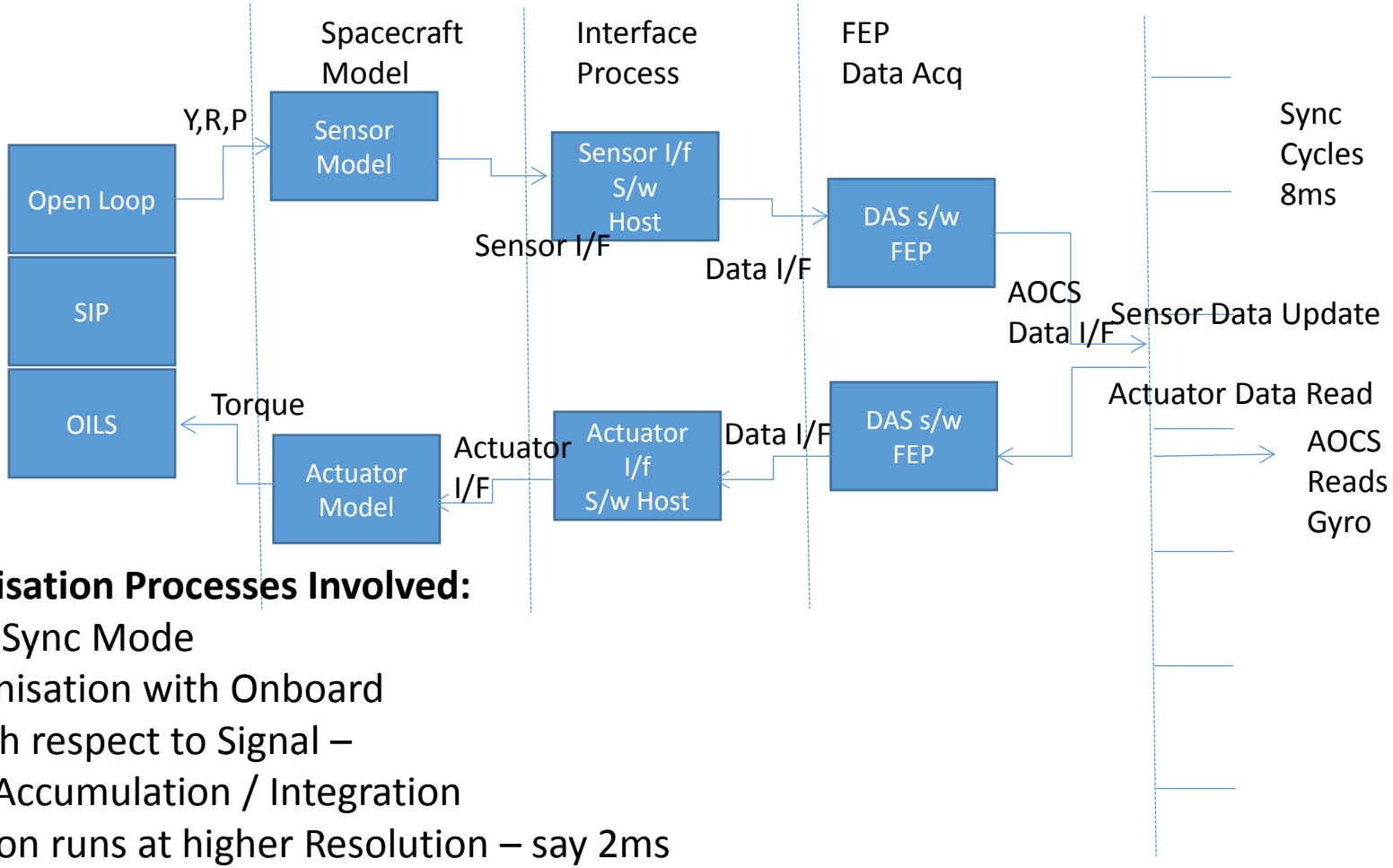
- All Dynamics Logics verified.
- Interface simulations remain same
- Inputs for Interface simulation arrive from OILS
- For Closed Loop NGC Six D Dynamics are simulated + Accelerometer + GPS data simulation

**Fig 2.0 OILS (On Board In Loop Simulation)**



# Data Scheduling & Synchronisation

*Test System Architecture for AOCS Testing*




**Synchronisation Processes Involved:**

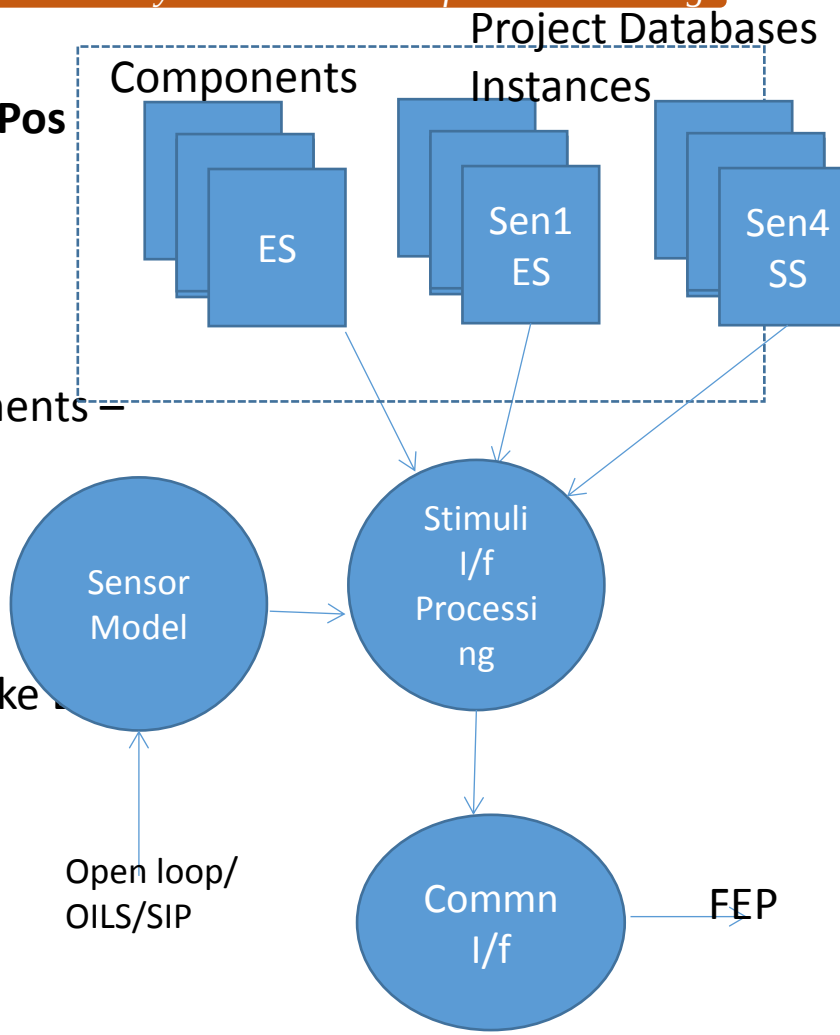
- Async / Sync Mode
- Synchronisation with Onboard
- Sync with respect to Signal –
- Parallel Accumulation / Integration
- Simulation runs at higher Resolution – say 2ms
- Integration cycle is submultiple of onboard clock – To ensure proper Integration & transfer of data wherever required.

# Interface Simulation Software -Sensors

*Test System Architecture for AOCS Testing*

**Sensors / Any Input Stimuli**

- **e.g. Star Sensor, Battery Current, Solar Array Drive Pos**
- OO Based approach
- Component - Database Driven
  - Component Data Base – Describes Types
    Earth Sensor / Star sensor
  - Project Database – Objects from above components – Declared – Each instance of sensor + other Info
- Shared Memory for Interface Level inputs
  - User Input / OILS / SILS Input
    - All Sensor Interface Inputs
    - Bias, Correction, Scale factor Provisions. (like Misalignment etc)
    - Update Rates ( If variable)
    - Sensor Modes (If variable)
    - Latency ( If required)
  - Inputs for FDIR Simulation
    - FDIR at Interface Level simulation
- Output for
  - FEP communication Interface



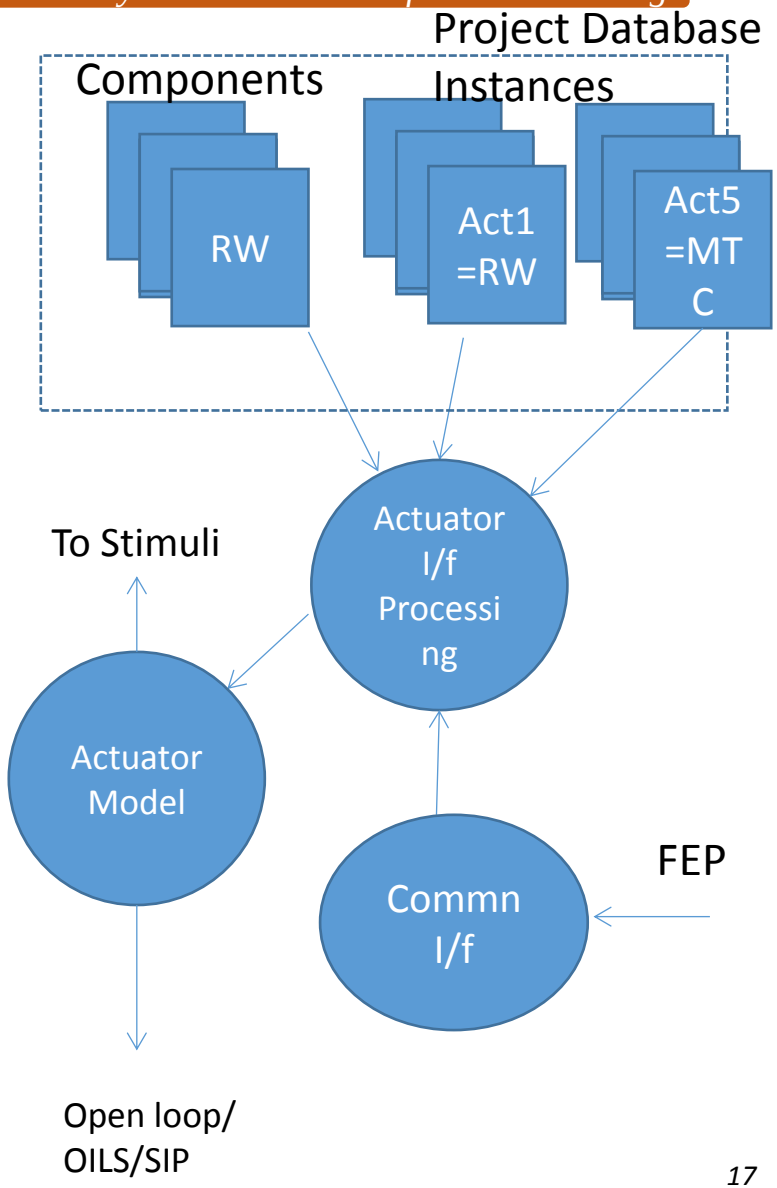
# Interface Simulation Software -Actuators

*Test System Architecture for AOCS Testing*

**Actuator / Any Output**

- **e.g. Reaction Wheel, Torquer, Thruster , Solar Array Drive, Antenna Control**

- OO Based approach
- Component based - Database Driven
  - Component Data Base – Describes Types Wheel, Thruster
  - Project Database – Objects from above components – Each instance of Actuator + Other Info
- Shared Memory for Interface Level inputs
  - Output to OILS
  - Inputs for FDIR Simulation
    - Failure simulation for Actuators
- Output for
  - Actuator Model



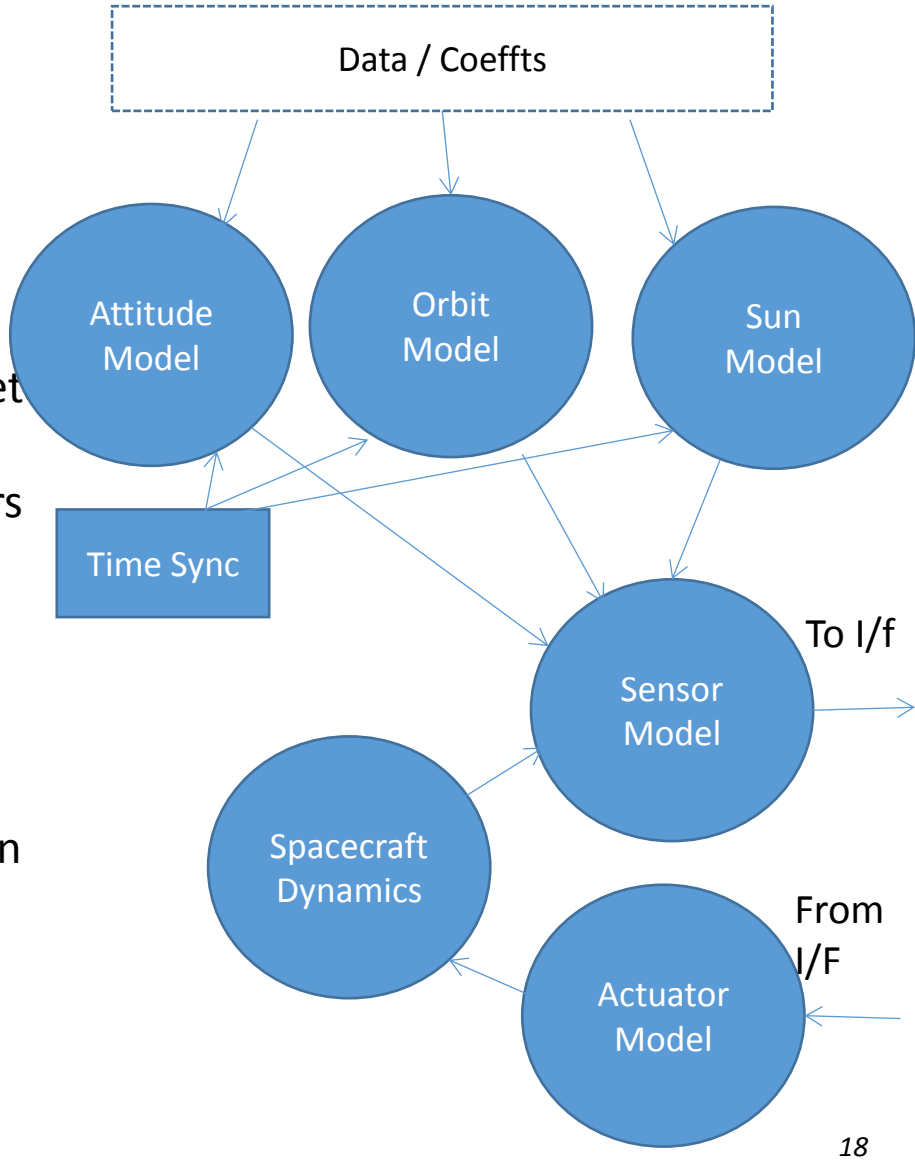
# Spacecraft Model Process

*Test System Architecture for AOCS Testing*

**Models for Open Loop Testing:**

- Orbit Model
  - Orbit Profiles
  - Selection for Orbits
  - Sun Model
- Attitude Reference Model
  - Attitude Reference Profile
  - Functional – sun Pointing, Earth Pointing et
- Sensor Model
  - Mounting, Bias, Misalignment, Scalefactors
  - Sensor Modes
  - Noise Model
- Actuator Models
  - Mounting, Dynamics Model
- Specific Models
  - Solar Array Drive to Array Angle generation

- **For Closed Loop testing**
- Sun and Earth Reference for Validation
- Spacecraft Dynamics
- Six D Dynamics for Navigation Computer.



# Time Sync Interfaces

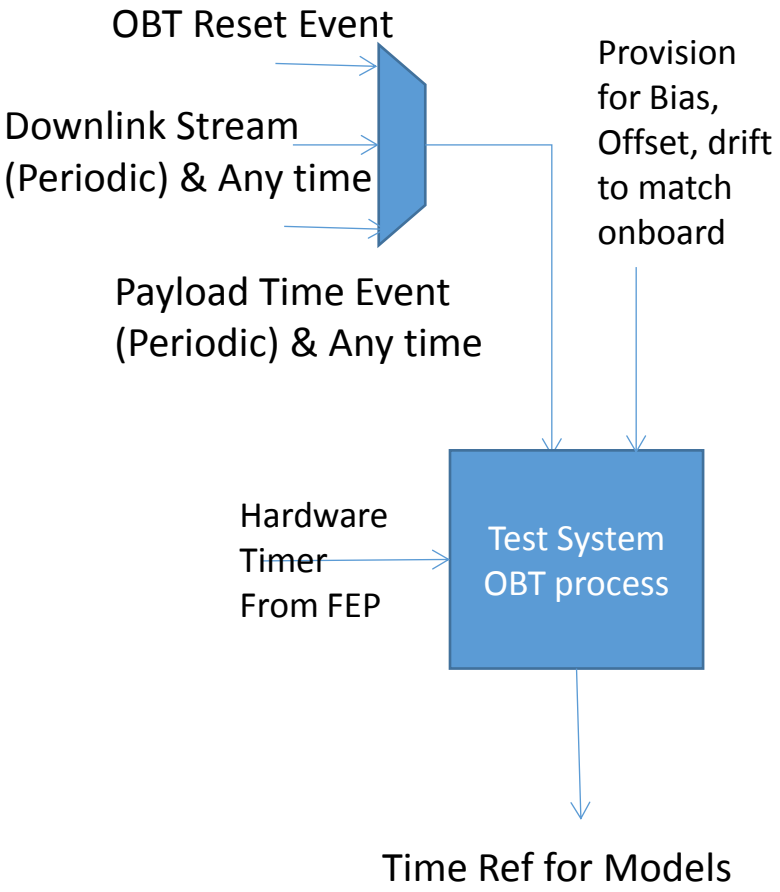


**Time Synchronisation Interfaces**

- Test System Maintains separate Time
  - Counter at FEP
  - Transferred to host at Actuator cycle
- Time Synchronisation
  - Time sync done at Host
  - Provision to offset, Sync, Start with a particular Date to simulate Overflow etc.
  - Normally one time sync and Periodic Verification
- On Board Time Sync
  - Through Discrete I/O ( at OBT Reset)
  - Through TM Stream – As carried out in Mission
  - From Payload Time sync Transfer

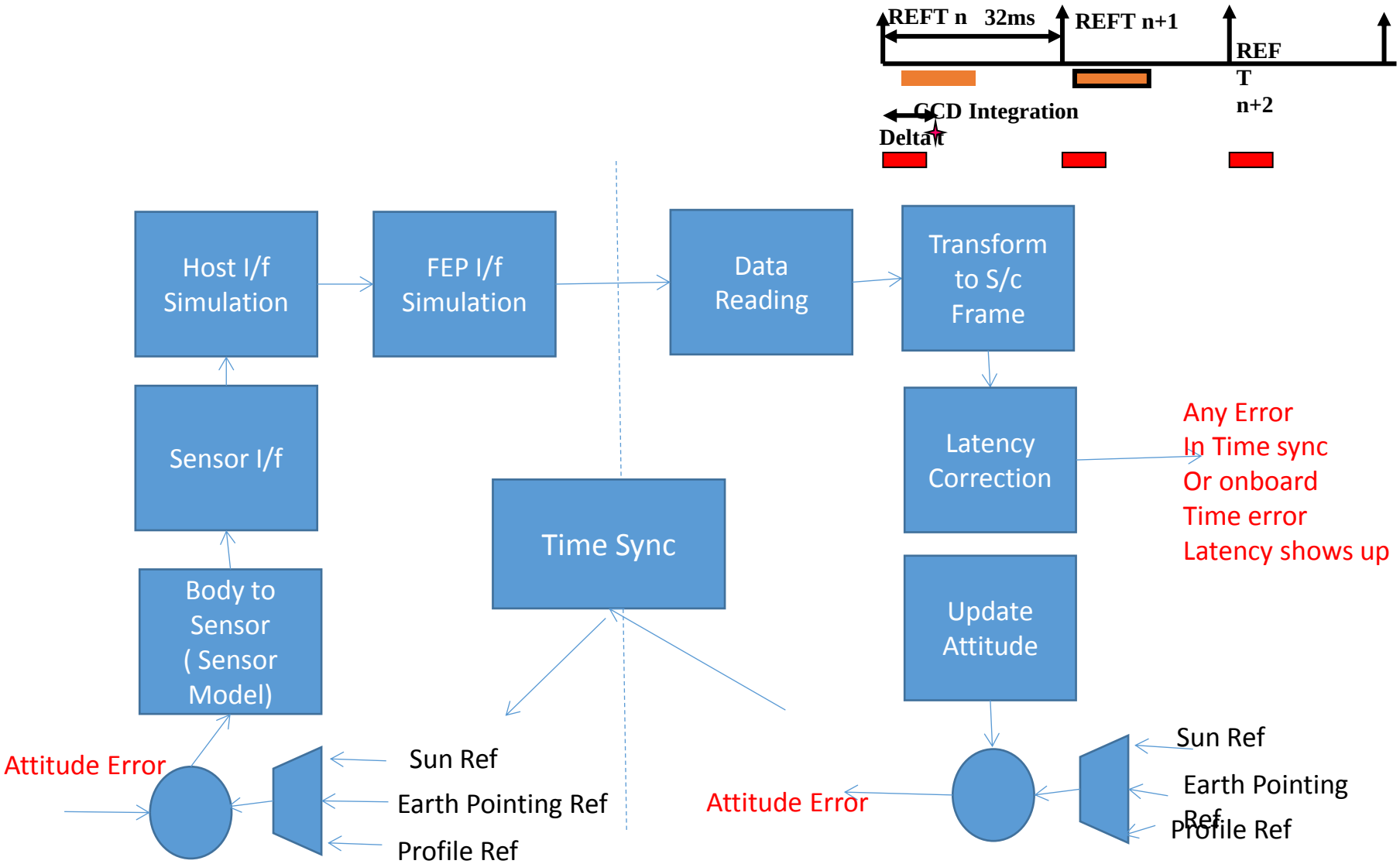
For Events

- Advanced Event Info like Navigation Start
- Maneuver Start for Profiling Error



# Typical Star Sensor Simulation

*Test System Architecture for AOCS Testing*



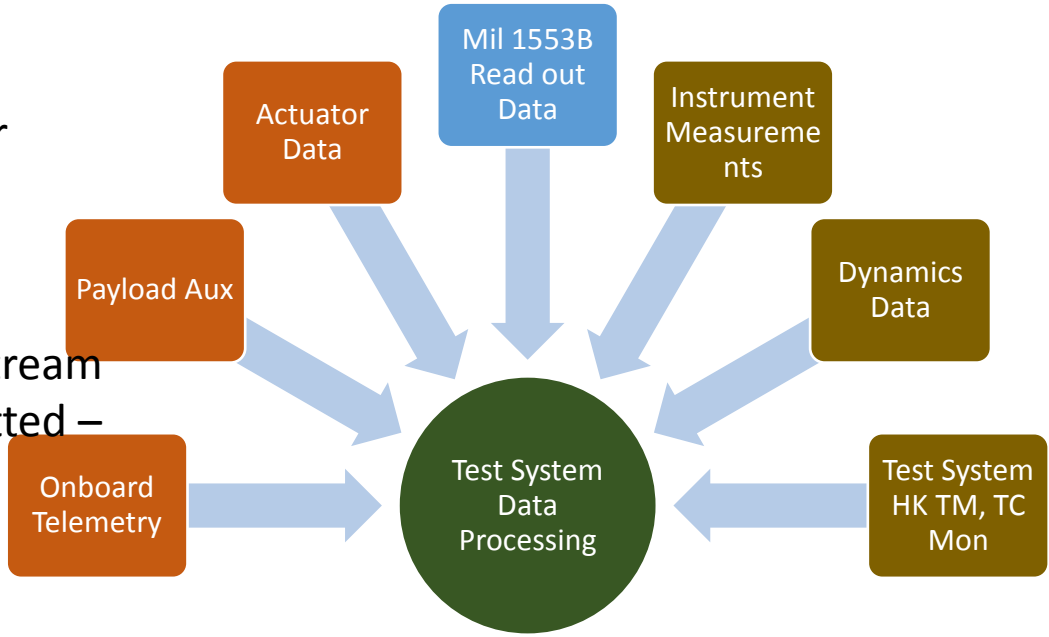
# Data Processing Software



**Data Processing Software**

- **Real Time - For OILS, Open Loop tests**
  - Thruster On time data
  - Motor Pulse data
  - Torque Data from Wheel, Torquer

- **Non Real Time**
  - Telemetry Streams – Typical 6,
  - Test System House Keeping – 1 Stream
  - Actuator Data – Sampled, Formatted – Wheels, Antenna Drive for open loop Validation
  - Mil 1553 Data Received by RT
  - Payload Aux Data
  - Dynamics Data




- **Processing Data Base Driven (Parameter IDs)**
- **Map Info provides mapping from Stream data format to TS channels**

# Data Processing Databases



**Typical**

- Upto 50 Streams ( 25 Typical)
- Data Rates 4kbps – 32kbps
- Multiple Frames
- Typical 10000 TS channels
- Typical 100 Post Processing channels
- 6000 PIDs
- Upto 40 Processing Types
  - Bit Info
  - Byte/ Word
  - Hex, Decimal
  - 2'scomp, Bin
  - IEEE, 1750 Formats
  - Time formats

Typical Stream Info

```
STREAM 0
FRSYNCNO 3
FRSYNCCODE AC_CA_1F_
FRID 4
NOOFFRAMES 64
WORDSPERFRAME 128
PROCESSRATE 128
DWELL 1
FRSYNCCHK 1
WRDSFROMIF 66
RAWDISP 1
MAPCHANNEL 0
DEFCHAIN 0
DEFLOG 1
DEFPROC 1
MAPSTART 0
MAPSIZE 4900
MAPCODE P
POSTPROCSTART 9500
POSTPROCSIZE 200
ALWAYSPROCSTART 9698
ALWAYSPROCSIZE  196
```

Typical PID Structure

```
typedef struct
{
   Value PIDValue;
   char cParameterName[PARAMETER_SIZE];
   char cDisplayValue[DISPLAY_SIZE + 10];
   char cOldValue[DISPLAY_SIZE + 10];
   int iDisplayInfo;
   int iPlotCounter;
                        /* counter to indicate plotting for
the PID is
                          requested by the clients */
   int iAnamoly;
   int iFilter;
   float resolution;
    int DataType;
   /*verification */
   int iVerify_reqd;          // 1 or 0
   int iVtype;               // 1: int, 2: float, 3: compare
   Value Verify_value;
   float deviation;
   char Verify_attr[DISPLAY_SIZE + 10]; // 0: OK, 1:
Not OK, 3: No Verification
  /*log on change */
}
```

```
BPTCUpSVSts1  No:1901 type:9 wno:3582,3433     And:80 shift:7 Data:2 data:string
AORSteps      No:1902 type:11 wno:3564,3421    data:ushort
PosX_OrbtCtrl No:1903 type:16 wno:3566,3423    A:0.305185 B:0.000000 UL:10000.000000 LL:-10000.000000 Err:0.100000 Unit:kms data:float
PosY_OrbtCtrl No:1904 type:16 wno:3568,3425    A:0.305185 B:0.000000 UL:10000.000000 LL:-10000.000000 Err:0.100000 Unit:kms data:float
PosZ_OrbtCtrl No:1905 type:16 wno:3570,3427    A:0.305185 B:0.000000 UL:10000.000000 LL:-10000.000000 Err:0.100000 Unit:kms data:float
```

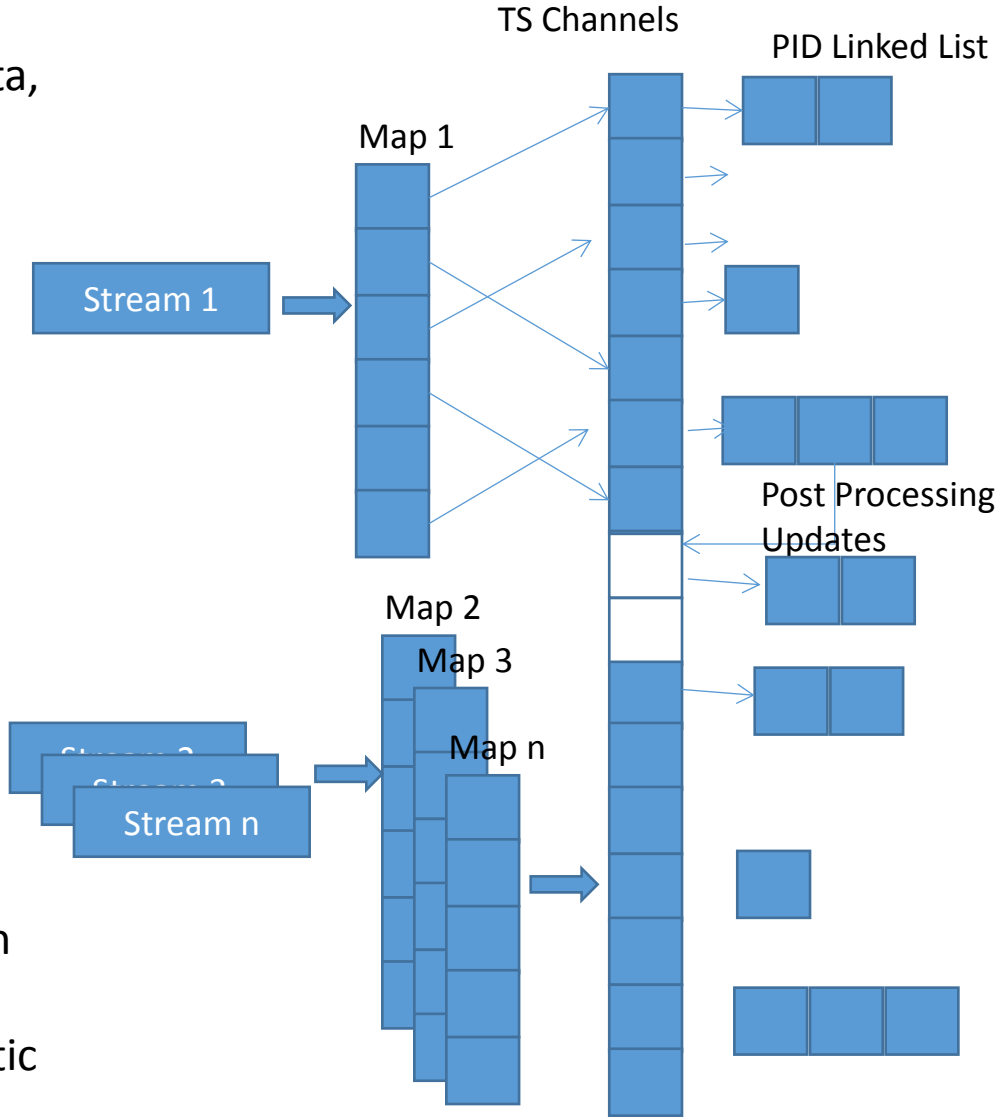
# Typical Data Processing Software



**Initialisation**

- Read Data Bases PID Data, Map Data, Stream Info
- Create Linked Lists, Cross Ref Lists

- **On Receiving Stream Data**
  - Log the Stream Data
  - For Every Sub Block of Stream Data
    - Map the Stream Data to TS Channels
    - For Each TS Channel Updated
      - Process all Affected PIDs
    - For all the Post Processing TS Channels Updated
      - Process all Affected PIDs
    - Update the PID Data for all the Logging Plotting Utilities through Queue ( RT Plotting, Anomaly, Automatic Testing inputs)



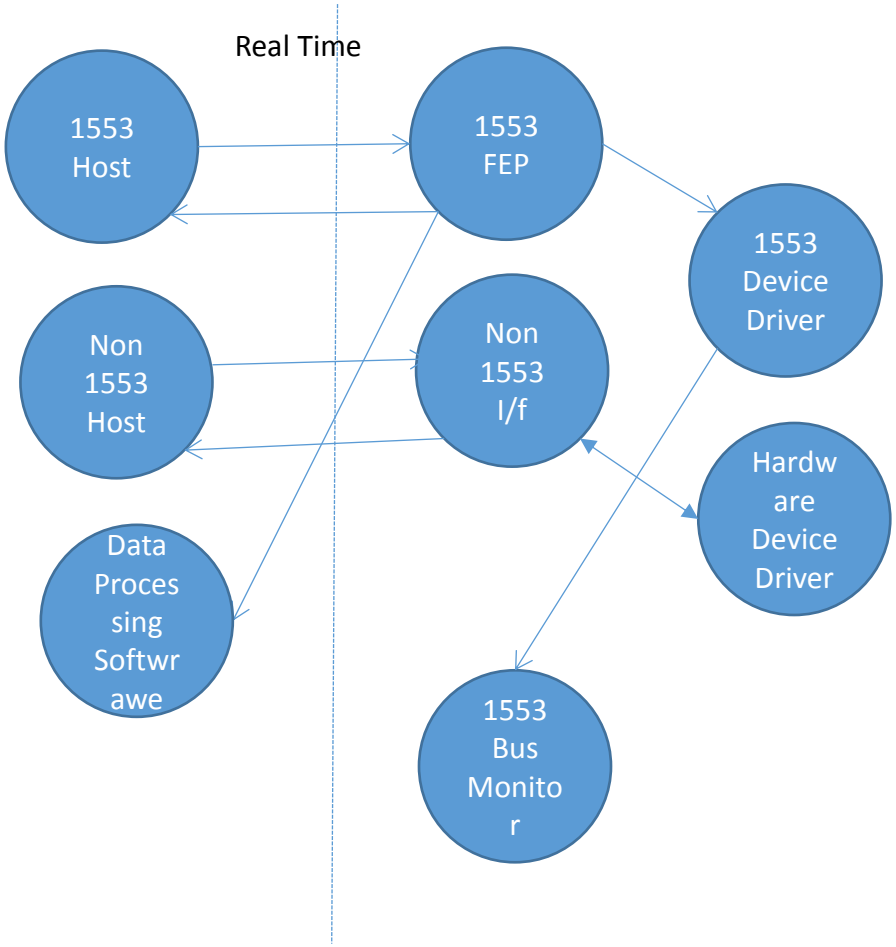
# Front End Processor Software

*Test System Architecture for AOCS Testing*

**Device Drivers**

- Mil 1553B Multi RT Simulator
- TC Encoder
- ISR 1ms
- Data Acquisition Driver Analog, Digital
- Functions for Sync Mode with SUT / Non Sync Mode

- **Applications**
  - Host – FEP Communication 1
  - Mil 1553 B Handling and Host Communication 2
    - For Real Time Data
    - For Stream Data ( Non RT)
  - Mil 1553 Bus Monitor
  - Instruments Readout
    - Power Supply, Current Meters



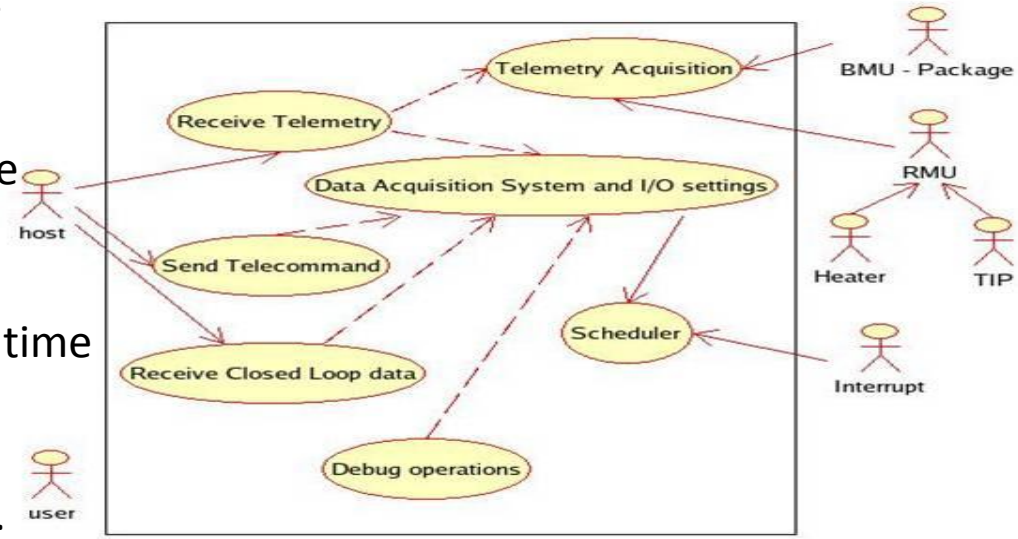
**FEP Software Features**

- Multithreaded architecture with pthread level synchroniszation between threads.

- Data Acquisition + Simulation with a granularity of 1ms with Hardware interrupt.

- Time Synchronization option with GPS time source.

- Real time I/O performance is required.

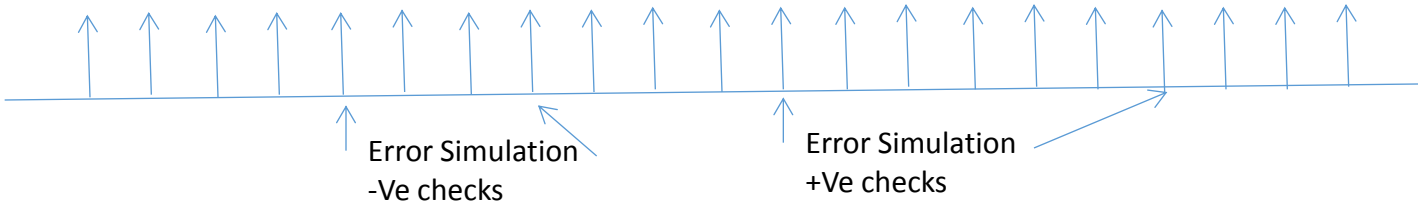



- Intel/AMD processors and real time variants of Linux - used in test beds.

**FDIR Logics**

- Requirements for providing all Interfaces for FDIR
- Nominal and Non Nominal Simulations
- Negative checks verification
- Verification of Time checks – require synchronised Real time simulation. ( Carried out in the lines of SIP mode)
- Event Handling - Time line to be simulated in TS
  ( To simulate exact action)
- Interface Level failures simulation
  - Checksum errors
- Latency Errors Simulation
  - Complex with Multiple Buffers

On Board Cycle and TS cycle synchronised
For simulations



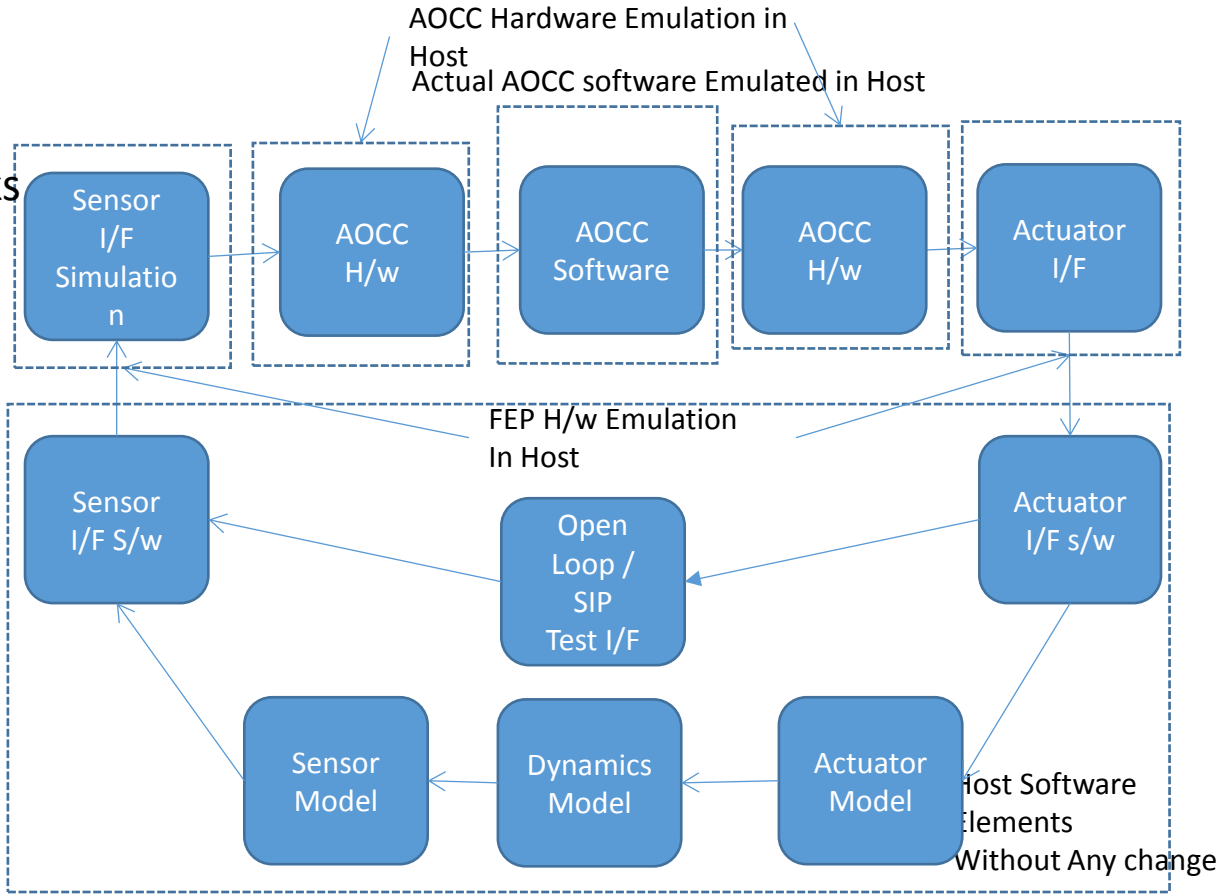
## Software In Loop Simulation

- Full Software Platform to Test all AOCC Software Functions
- Simulation of All Hardware / Interface Elements by Software

  Aimed mainly at :

  - Logical Checks
  - Computational checks
  - Data Formats
  - Mil 1553 I/F
  - HK Data Checks

- Platform for Mission Operations Simulation



# Verification for critical Mission Phases

*Test System Architecture for AOCS Testing*

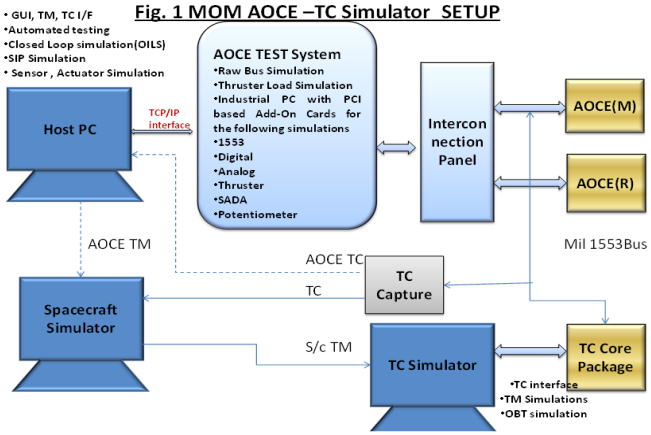
Hardware Verification if Required

Software Verification in All Phases

- Integrated Spacecraft Test – Simulations if any.
- Launch Phase
- Sequence of Events Verification
- Payload Operations Profile Verification
- Safety Logics / FDIR logics Verification
- Critical operations like MOM EBN, TMI, TCM, MOI Phase
  - Rehearsal of Operations
  - Profile Validation, Accuracy Establishment
- Programmable Autonomy like

  Event Based Command logic verification
- Remote / Patch Update Verifications

Fig. 1 MOM AOCE –TC Simulator SETUP



# Other Features

**Test System Features**

- Page Display
- Real Time Plotting
  - Inter Message Queues between RT Plot and Data Processing Software
- Data Logging
- Real Time Commanding, Delay Simulation
- Off Line Data Processing
  - Same as RT Data Processing – Data received from File
- Automatic Testing
  - Testing of Open Loop Test Vectors
  - Automatic Verification OK/Not OK
  - Auto Test Language with Script Files with various Features.

**Other Test Systems**

- BC Simulators ( OBC Simulators)
- Test System for Motor Drive Electronics ( Antenna Control, Payload Platform Control)

# Major causes of Error in Testing / Simulation



Test Level

- Simulation Assumptions / Actual Information not available
- Time Synchronisation Errors
- Scenario / Sequence Coverage
- Accuracy, Precision, Sampling Simulation Errors
- Test coverage is not complete/insufficient test cases
- Actuator I/f clearance with Diagnostic TM rather than actual actuator output.
- Insufficient Test – especially less critical ones like TM
- Independent Tests – Interrelated effects missing
- Test Limitations
- Simulation Errors

Solutions

- Proper ICDs
- Mission Scenario Tests
- Operational Validation
- Identification of simulation limitations and addressing alternate methods of validation
- Analysis, Review and Process Implementation
- Test case generation from requirements /Test Review Boards/Test procedure review/ Automation of testing / Test Results Review
- Observations tracking and guidelines/check list generations

# Summary & Future Enhancements.



- The Distributed Test System Architecture has been used extensively for AOCS, Integrated OBC, NGC applications
- With little modifications, same frame work is being used for HILS.
- Continuous improvements in terms of Automation, Simulations, Data Presentations, Validations are being done.
- Increased real time performance, Inclusion of Flexibility dynamics for Closed loop simulation & higher models - the requirements for AOCS are being continuously improved / added.
- Software In Loop simulation – being developed for Testing, Operational requirements. Hardware Modelling is also being attempted.
- Standard Auto Test Languages, Databases are to be explored.
- Miniaturisation in Hardware is being attempted.

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