Evolution of real time computer systems for test benches

A computer system for a test bench – spoilt for choice

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March 18, 2016

1 Abstract

This paper covers the development of computer systems during the course of the last 25 years for the Ariane project ESA test benches P5, P4.1 and P4.2. On these test benches the DLR-teams are testing and qualifying the rocket engines "Vulcain2", "Vinci" and "Aestus". Twenty-five years ago the criteria for specification and procurement for test bench computer systems was very different from today.
Mostly the systems were custom made and very often the component interfaces had to be developed specifically for the site. Systems offering high reliability, that would run 24 hours a day and on 365 days a year were very much the exception.
The preventive and reactive maintenance were not only cost intensive but also very complicated and labour-intensive. The provision of spare parts was also a critical point. The necessity of ensuring that parts were available in good time was also an expensive option.
The hardware was sometimes only of limited use since even the production batch numbers of components had to be taken into account. The situation has changed dramatically during the course of the last ten years.

- The processing power of CPUs has risen due to the enormous increase in clock rates.
- Multiuser and multitasking have become the standard modes of computer operation.
- The costs associated with processors have fallen due to the effects of mass production.
- Commercial operating systems have no problem with the management of computer memories measured in GBytes.
- The probability of failure associated with electronic components is much lower.

The procurement lead-time for components has been reduced. An Internet connection allows a permanent connection between customer and supplier. The thermal effects on the system have been reduced dramatically due to the reduction in the amount of internally generated heat within the components. The operation of a system no longer requires specialist knowledge since the man machine interfaces have been designed to be as intuitive as possible. The operator is guided through the steps required to perform a particular operation.
New criteria, but with weaknesses emerging, for example:

- Hardware aging – the replacement of monitors, graphic cards, hard disks and memory cards needs to be carried out regularly, due support no longer being available.
- Support for PC operating systems is often available only for a limited duration. Operating system updates and software migrations after an operating system change bring with

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them additional costs and operational downtime.

- The access to systems allowing maintenance, to be performed remotely, must be implemented and possibly guaranteed. This method allows workload to be reduced on site on behalf of the maintenance company but it does mean, that customer staff must be available to assist when necessary.

To define only one type of computer-system (including the measurement- and command equipment), from one supplier, with one maintenance contract and one spare part stock for all test benches of one test area would be the ideal solution. Each test bench has a purpose and you need a tailored system for this – not only from the technical aspect.

2 Three generations of Computer Systems

2.1 Retrospective - 25 years ago

Definition: Computer System for a test bench = full room-filled electronic system; 25KW exothermic output

Operating system: Sintran III, not really a standard operation system outside the Scandinavian countries, for the team it was learning by doing

Programming languages: Planc for real time programming on multicore system, F77 derivate for programming the test sequences, LCE tool boxes and modules for special jobs like logbook management and valve control handling

Data management: relational data base SIBAS, a powerful working environment and a product for future trends

Data security, backup & restore: on 1/2 inch tapes and later as an improvement, on SCSI tape - but it was a two hour job after test for one person

MMI: A computer mouse wasn't available → semigraphical lightpen system; weight of one monitor r.a. 50kg

Memory: 4 ... 6 MByte; software very compactly programmed

Motherboard: a set of more then 20 "backing trays"

Hard Disk: 150MB for the operating system, 450MB for the archived data from test (weight: 20kg)

HF data archiving: on 8 magnetic tape device with 12 tracks; LMS data evaluation system for HF

Costs for manpower: full-time job for two persons per test - for two days only for HF data handling and providing

Costs for the maintenance per year: additional costs for the HF data system maintenance

Costs for the magnetic tapes and transport to the customer per test:

COTS: impossible ... most of the components and subsystems were unique

NCR System: NCR management on paper, later on a decentralised PC system

Configuration management: performed by CEM- & DMI-meetings between the DLR and the customer

2.2 Retrospective - 10 years ago

Definition: low cost PC terminals for the user and UNIX server for real time management, reflective memory ring for the front-end; front-end and amplifiers on the test bench → complete new philosophy and architecture

Operating systems: UNIX and Windows - standards, common knowledge available

Programming language: C derivate

Data management: relational database

Data security, backup & restore: MOPS and NAS; no waiting time after test, direct data transfer from the front-ends to the backend system

MMI: the beginning of high resolution synoptics → easy handling by the test team

Memory: no criteria due to the size or data access time

Motherboard: compact on one standard board per front-end

Hard disk: no criteria due to the size anymore

Costs for procurement: 41% compared to the forerunner

Costs for maintenance per year: 75% compared to the forerunner

HF data archiving: on disk, no additional costs for manpower and material

COTS: a crucial point, makes the system price lower and the availability of components higher

NCR system: database, contact with the supplier by eMail, maintenance and checks by remote access possible

Configuration management: by DLR without the customer

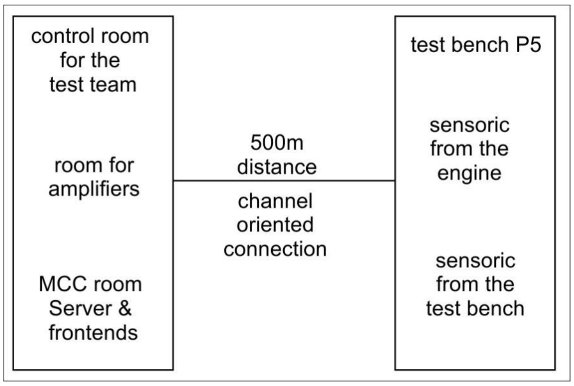
2.3 Real time systems do not need ...

- extreme high clock rate for CPU → see PC commercial presentations ... higher clock frequency because better for ... what? (in fact for graphical applications, games)
- SIO, PIO and DMA hardware modules→ the real time systems need buffers for the archived data, fast link (optic fiber) between front-end and back-end system
- high resolution graphic, more than 256 colours are not necessary (for levels of gray, the limit for our eyes is 1024) → a commercial gimmick only

2.4 The best location for the front-ends

There are two possibilities for locating the measurement data acquisition, conditioning and digitalisation.

The situation on the P5 test bench:



The front-end is 500m away from the test bench. We have to transmit signals in the range between 1mV and 20V and (4-20)mA for industrial transmitter.

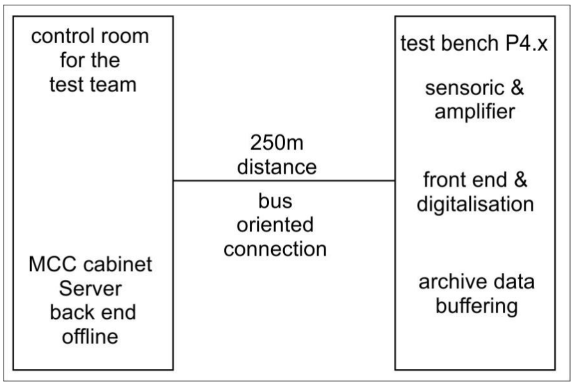
Advantages:

- Good handling and working in the time of test preparation and NCR treatments.
- During the test (chill down phases) free access to the amplifiers in case of doubts on the measured signal by the test leader (chill down criteria, unexpected pressure in a pipe).
- Quick status check of the amplifier conditions (without MCC).
- Quick status check of the sensor signal quality or cable condition (short cut/broken).
- synchronism between the LF- and HF data is given

Disadvantages:

- Long cabling – high costs for material, cable chute and installation.
- A big challenge for an undisturbed signal transmission.
- The exact grounding of two systems with a distance of 500m is complicate.

The situation on the test benches P4.1 and P4.2 (including the steam generator):



The distance between the object in the test cell and the front-end is r.a. 30m.

Advantages:

- short length of cabling, uncritical signal transmission – lower costs for mechanical supports and cable routing
- no serious problems with grounding, the connection to the amplifier is in the same facility
- digitalized data are stored in the front-end; after the archiving the front-end sends the data to the back end system by an Ethernet link

Disadvantages:

- From the point in time when the test leader starts the chill down of the test bench we do not have an access to the front-end room.
- In case of an exchange of amplifier boards the MCC must be stopped. After the EG the MCC should remain untouched for the test.

Conclusion:

- Both solutions are acceptable from our experience.
- If the distance - between test bench and test control/MCC room - is greater than 500m, the front-ends should be integrated on the test bench (it means the amplifiers for the measured signals must be installed in the same building), because the synchronism between the LF-and HF-data could be critical.

2.5 The current MCC systems on the P5 test bench

Definition: compact system; for P5 – in summary: 5 servers, 7 front-ends and switches for data traffic and log messages piping. For a remote maintenance a KVM terminal is available.

Operating system: LINUX on the data midlevel system, Windows 7 for the user terminals, on the front-ends RTX

Programming languages: ST-language with functional block diagrams

Data management: by a relational data base

Data security, backup & restore: archived data available on the main and redundant server, outsourcing of archived data to a NAS, data restore from the NAS possible

MMI: Labview product

Memory: GByte - unlimited

Motherboard: per front-end a compact CPU board → for 2016 an upgrade is scheduled, a „Quad-Core-Processors“ for RMS calculations in real time is to be installed

Hard Disk: this is not a criteria anymore

Costs for the procurement: 17% (in relation to the first MCC)

Costs for maintenance per year: 154% (in relation to first MCC)

HF data archiving: on two front-ends for 96 channels with the limit of 5 MSamples/s

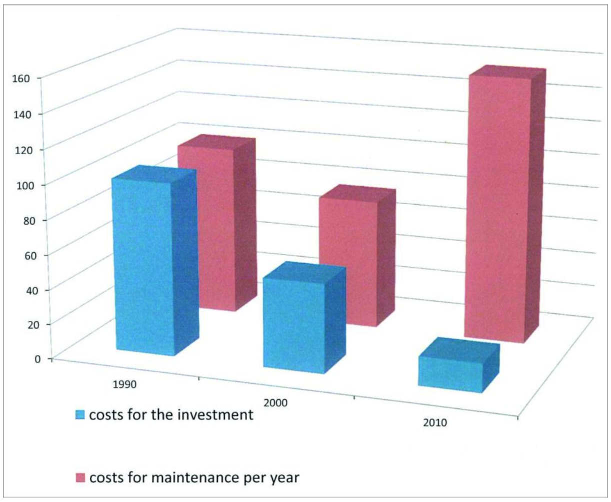
COTS: the components and subsystems are available from stock, but the delivery time by the supplier must be respected

NCR System: JIRA software, remote access to the system on demand for the error analysis, tracing of the most important task

Configuration management: if test benches get the same setup as P5, a common configuration management will be recommended

3 Evolution of costs for investments and maintenance

In steps of years we invested into the computer systems for our test benches.



For the computer systems - for the last two test benches in Lampoldshausen - more companies submitted an offer, a better competition (win-win philosophy) was possible. The customer had a choice. We do not need a good deal, we are looking forward to cooperating successfully with suppliers during the course of the next years.

conclusion:

- decreasing costs for investment

  The reasons for this trend are:

  - Availability of hight quality COTS computer hardware.

  - The customer-tailor-made software solutions, are based on software standards (e.g. Labview, RTX, ARECA). The suppliers job is the adaptation of the software to the customers requests.

  - During system acceptance, it's not necessary to check the complete software body - only the relevant requested parts must be presented and tested.

  - The new task for the supplier is the embedding of the new system into an already working infrastructure - **adaptation** is the key word.

- according to operational experience we can point out the increasing importance of maintenance

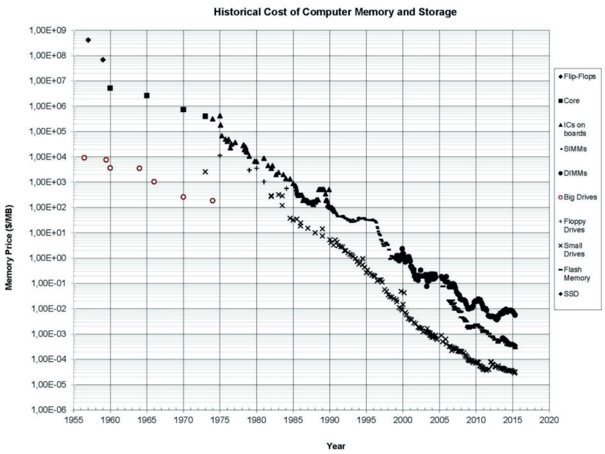
  The reasons for this trend are:

  - higher quality is requested; we are ISO9001 certificated and this status requests a professional quality assurance (and more paper)

- more engineering from the supplier expected (improvements, studies regarding obsolescence)

- shorter reaction times regarding on-line support, spare part provision and on-site interventions

- In case of serious problems, the maintenance team must be active onsite. The tools, the methods and the technological knowledge is entirely different to that of 25 years ago. The hardware is more compact and the software is more complex.



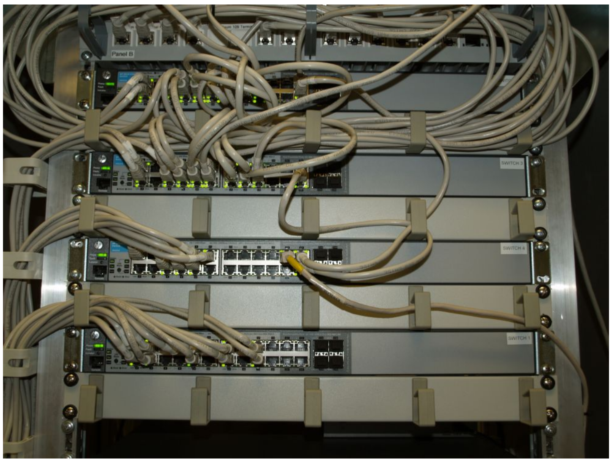
The costs associated with computer hardware is decreasing at an ever increasing rate. From the diagram above you can see the trend for costs of usual in trade storage media.

Computer system on the P5 - designed and built between 1985 and 1989 - Norsk Data, data base oriented data management and real time compliant. The system consist of the data preparation part, the data acquisition computer, the process interface (data buffer system for acquired measured low frequency data and digital events) and the multicore real time computer for the performance of the tests on the test bench.

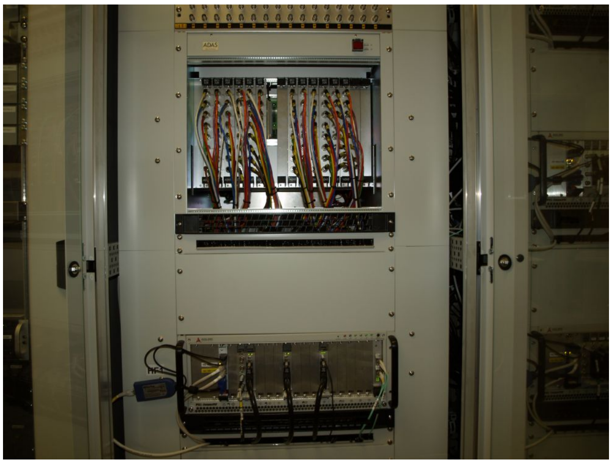
The front-end system for LF data archiving, command sending with a precision of 1ms, event receiving and control of 12 regulation valves.

The HF data archived was performed by 8 EMI/Thorn magnetic tape devices, with 12 tracks and a bandwidth of 20 kHz. The time synchronization between the Norsk Data Computer System and the archiving of data on the tapes was implemented by the IRIG-B code with a precision of 1ms.

The next generation, after 19 years, the Norsk Data System was replaced. The data and the configuration servers were designed for redundancy on the P5.



New components for a new generation of electronics: reflective memory ring, fiber optic interfaces and cabling. The data traffic will be managed by intelligent switches.



The front-end of the new system consists of 7 racks - the HF data acquisition for 96 channels is already included.

4 Criteria for a new MCC system

4.1 The purpose of a MCC system

- synchronized archiving of LF- and HF-data
- calculation of RMS values for majority logics and monitorings
- synchronized archiving of commands and feedback signals, synchronous to the archived LF/HF data
- commanding of valves and relays based on a fix time regime
- all instructions should be sent from the system by a sequence (real time task) on a fix time regime
- all instructions should be sent interactively from terminals by an operator test team
- a logbook management for events and messages from the system and the sequences
- control of regulation valves
- interactive communication on terminals between the test team and the processes
- display of the measured parameters and the system states
- provision of the archived data
- data management - based on a database
- version management for a traceable workflow

4.2 Real Time functions

- a unique and defined time base (Time Code Generator), count down and universal time management
- calculation of fictive parameters, definition of calculation time and real time task priorities
- handling of majority logics
- monitoring of assorted digital and analogue parameters
- loop management, cycle time definition

4.3 Archiving

- definition of the maximal test duration
- definition of archive plans and rates
- definition of the number of analogue parameters
- definition of the number of fictive parameters
- archiving of system and process logs and messages from sequences and operators

4.4 I/O channels

All channels between the test bench and the front-end - if not situated in one building - must be galvanically separated.

- number of analogue input channels LF; voltage signal
- number of analogue input channels LF; current signal (industrial transmitter technology - fixed measurement ranges)
- number of pulse channels (e.g. count function from flow meters and rotation modules)
- number of analogue input channels HF; voltage signal
- number of analogue output signals; voltage signal
- number of analogue output signals; current signal (broken wire check)
- number of digital input channels; the EX zone protection must be respected
- number of digital output channels; the EX zone protection must be respected

4.5 Data management

4.5.1 Data evaluation

- plot function on the operators terminals for an assorted group of measured channels under the real time condition
- quick look function for an initial data evaluation → main focus: data format definition
- scientific data evaluation - main focus: data format definition/adaptation, use of existing systems
- transfer of the test data to the customer

4.5.2 Data integrity

- Definition of safety measures for data keeping in the worst case.
- Creation of a data backup system, with full, differential and incremental backup features.
- Creation of a data restore system (logical and physical).
- RAID configuration of disks

4.6 Watchdog system

The watchdog function monitors the MCC system, but we have to arm the watchdog first. Only if the MCC has the command over the test bench can a watchdog signal be generated.

We have to demonstrate that in any case the test bench and the test is under control.

In fact the watchdog is a complex boolean logic, inside the real time treatment front-end system. It's a combination of different healthy-, heartbeat- and be-ready signals.

In the case of the signal being lost between the healthy MCC and the safety shut down system a watchdog event occurs, this causes the safety procedures to be performed.

Electrically, the 28V DC required for the MCC command channels is disconnected by a switch conductor. The 28V is then handled by the safety shut down system.

The watchdog monitors the state of the hardware and software critical to the performance of a test on the test bench. Examples of critical elements include the MCC, software tasks, power supplies for command and feedback signals. If one of the critical elements causes the watchdog to trigger, the control of the test bench is switched automatically to the safety shut down system. If the watchdog has been armed the safety shut down system continuously monitors the state of the MCC watchdog signal.

The safety shut down system stops the running test in any phase immediately by stopping the engine (propellant and oxidation flows). In the following steps the safety system shuts down the engine and test bench ensuring a safe status (purged pipes, nominal working condition in the test and the other test bench floors).

4.7 Interfaces to other systems

4.7.1 Manual switching panel

A manual switching panel is the operators **working tool number one** if the MCC is engaged with other tasks.

During the course of test preparation (data base modification, sequence programming) the MCC is not available all of the time, but a lot of jobs are necessary (tightness checks, tank filling, functional checks on subsystems) on the test bench and on the engine.

For these performing jobs a manual switch panel is the best solution. It is strongly recommended, that only one system - the MCC or the manual switch panel - is able to send a command to the test bench, never both at the same time.

The voltage for sending the commands must be switched over from one system to the other e.g. by the test leader. This switch-over-logic has to be installed on the MCC.

4.7.2 Time Code Generator

Each computer system has a system time process/server. The process is not synchronized by a central time generator. It's the local universal time and can be set by the computer administrator.

For our work on the test bench we not only need universal time, we also need the count down time time. All time depended systems need the same time and the time must have a central time reference (DCF signal or GPS). That's the reason why we need a time code generator. It could be an in the MCC integrated system (scheduled for 2016 on P5) or an external device with an interface to the MCC as now on the P5 (see the picture above).

4.7.3 Remote access for maintenance

Whilst a test is in progress the MCC is completely disconnected from external links and terminals outside of the control room and the test bench. In case of preventive or curative maintenance it's very helpful to establish a remote access for the supplier (ILAN link). It reduces costs associated with down time on the system and travel costs occurred by on site visits.

5 Outlook

CPU-power, clock frequency and memory size are not critical parameters for future design anymore.

In the near future we expect crucial conceptional modifications in four fields:

- bus oriented commanding of test benches and bus oriented interface (command/analogue data acquisition) between the product under test and the MCC

  - channel oriented commanding between the on-board computer and sensors/valves is not what we expect in the flight hardware

  - we have to distribute the analogue data acquisition from the flight hardware (only one sensor) to the on-board computer, to the telemetry, to the MCC & including the critical parameter limit observation systems

- increasing of the number of measurement channels with attention to the available local space and the requested precision of measurement

- The era of checking out principle functional behaviors of a complex MCC system is over. In future we will be busier with fine tuning and alignments of the system.

- We do not need cheap systems, a cheap system does not offer the long term benefits required. We need the best system, a modularly designed system for diverse applications. A system that ensures data quality as well as offering value for money.

6 Acronyms

ARTA	accompaniment for research & technology for "Ariane 5" ®
CEM	Commission between customer and supplier for modifications and improvements on the test benches
COTS	Commercial product off-the-shelf
CPU	Central process unit
DLR	Deutsches Zentrum für Luft- und Raumfahrt
DMA	Direct memory access, operating mode for a fast data transfer between memory and IO-interface
DMI	test bench modification process and documentation system
F77	Fortran 77 - standard computer language
HF	High frequency data; dynamic pressure, vibrations - cut off frequency of 20kHz
LCE	computer language for real time sequences
Labview	Software product
LMS	Leuven measurement system and software - LMS®
MCC	Computer System for Measurement, Command and Control
MMI	Man-Machine-Interface
MOPS	magneto-optical system
NAS	Network attached system
NCR	non conformance report - a documentation of anomalies
P4.1	test facility for testing the "VINCI"® engine
P4.2	test facility for testing the "AESTUS"® engine
P5	test bench for "Vulcain 2"® tests
RTX	Real Time Operating System
PIO	Parallel input/output - fast standard computer interface
SCSI	computer interface for auxiliary devices (small computer system interface)
SIO	Serial input/output - standard computer interface