An Overview of Low-Cost EGSE Architectures Improvement

Sándor Szalai[1], János Nagy[1], István Horváth[1], Bálint Sódor[1], Gábor Tróznai[1], Kálmán Balajthy[2], János Sulyán[2]

[1]Wigner Research Center for Physics, Konkoly-Thege u. 29-33, 1125 Budapest, Hungary, E-mail: {szalai.sandor, nagy.janos, horvath.istvan, sodor.balint, troznai.gabor}@wigner.mta.hu

[2]SGF Ltd., Pipiske u. 1-5/20, 1125 Budapest, Hungary; {balajthy, sulyan}@sgf.hu

Abstract: this article presents EGSE architecture improvement from the 1980s until nowadays following hardware development. In EGSE development we looked for cost-effective solutions by applying available industrial products. We started EGSE development for VEGA-Halley mission in the 1980s, based on a microprocessor standalone system. The next stages of EGSE architecture were based on IBM compatible PCs with dedicated interface cards. The subsequent generation of EGSE consisted of two physical units, one was a commercial computer and the other one was an embedded processor card for signal level simulation. There was a serial communication line between the units. The fourth generation of EGSE contains high speed bus for internal communication and the use of embedded processor made simulation and data acquisition possible in real-time. The software was developed in assembly in the first generation of EGSE. The further operating software runs on a distributed intelligence system containing Windows and real-time Linux platforms.

Keywords: EGSE; VEGA-Halley; Spectrum-X-Ray-Gamma; Rosetta; Comet; Churyumov–Gerasimenko; lander

1 Introduction

The task of EGSE (Electrical Ground Support Equipment) is to support the development and test of flight units. The EGSE supports all phases of assembly, integration and final validation test. In this paper, we present improvements in EGSE architecture development over the past 30 years. The subsequent EGSE architecture for missions followed hardware performance improvement, and software technology also followed the improvements provided by the hardware. During these three decades we worked with four different EGSE generations. In the 1980s we started EGSE development for the VEGA-Halley mission, based on a microprocessor standalone system. In the next stages of EGSE architecture to reduce development costs they were based on commercially available computers – typically IBM compatible PCs – extended with dedicated interface cards, which used the resources of standardized computers. The next generation of EGSE consisted of two physical units, one was a commercial computer, the other one was a signal level simulator controlled by an embedded processor. This latter one contained either dedicated interface cards – partly self-developed – or widely used industry-standard cards – for signal level, a simulation standardised serial communication line was used between the units. The fourth generation of EGSE contains high-speed bus (Ethernet) for internal communication. The use of an embedded processor made simulation and data acquisition possible in real-time.

The software work started during assembly in the first generation of EGSE. Current operating software runs on a distributed intelligence system containing Windows and real-time Linux platforms. Running Windows on a commercial computer offers the advantages of user-friendly interface of Graphical User Interface (GUI) based on LabWindows or Java, efficient data storage, and processing capability. A wide range of graphic software development tools is available for Windows, which helps the fast and efficient development of GUI. Linux, extended with real-time facilities allows for the running of real time simulation and data acquisition on the embedded processor. The software environment insures a lot of advantages: the user can control all functions through GUI, definition timed sequence of commands, decoding and visibility of housekeeping packets, mathematical operation can be performed on data, e.g. polynomial interpolation, Fourier transformation, etc. Commands can be contained in a macro file with pre-written timings. The housekeeping data can be displayed in user- friendly form. The conversion is controlled by a simple structured file, which can be easy modified even by a non-skilled user.

Depending on actual space-probe and onboard instruments some functions can be left out (Sensor Stimulator) or can be multiplied (Fast and Slow telemetry or SpaceWire and Mil1553).

In this article, we present how EGSE which has been developed for our projects to test space instruments has changed since the early 1980s till nowadays as a result of technical development.

Figure 1 simplified functional block diagram of EGSE.

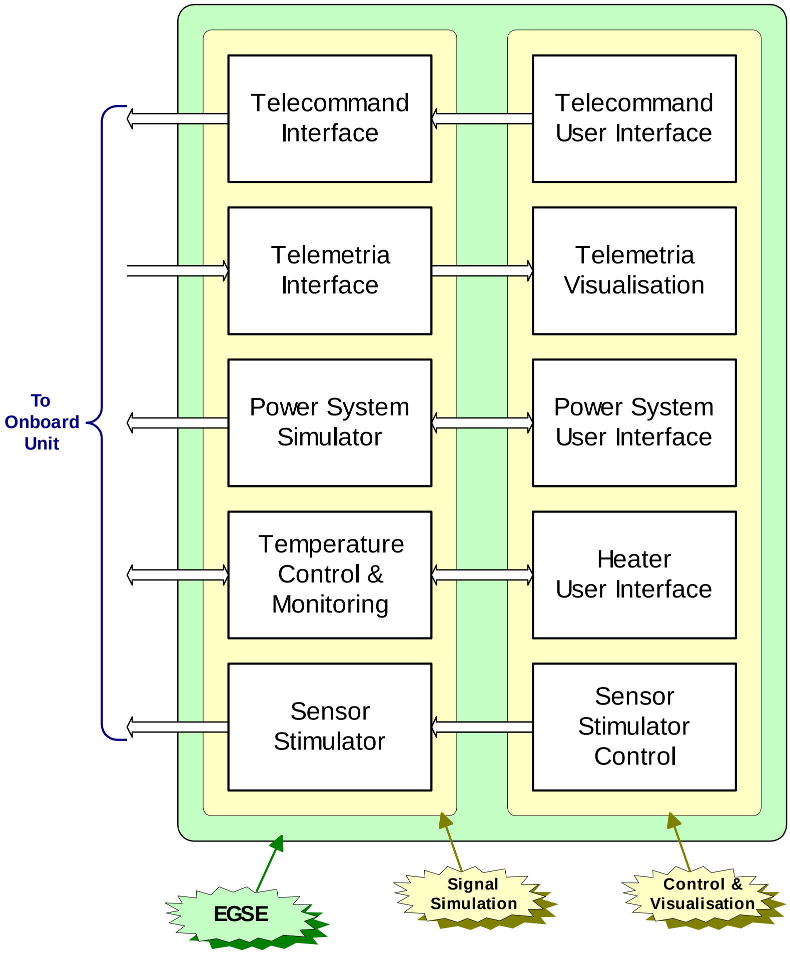

Figure 2
Simplified functional block diagram of EGSE

2 EGSE from the 1980s

Our institute joined the experiment Halley-VEGA in the 1980s: we took part in television system development [1, 2, 3]. The mission was aimed at investigating and observing the comet Halley, and to broadcast pictures of the comet during its approach. Key dates of the project include launch December 1984 and flyby March 1986. The mission ensured double redundancy by doubling the probe. The probes were called VEGA1 and VEGA2. The distance of the nearest approach was 8,900 km by VEGA1 and 8,030 km by VEGA2. Our institute designed and built several instruments for the VEGA mission, e.g. the electronics of imaging and tracking system, the so-called TV system. The onboard television system controlled the approach phase in the near region of the comet. During this phase the transmission time of commands between the space probe and the ground control center required too much time in comparison with flyby times. The close approach duration was three hours. It was the first time in the history of space exploration when autonomous control was based on a real-time image processing. For testing the tracking system (hardware and software) we had to realize not only usual EGSE, but a special tracking loop including optical parts to simulate the accurate movement (relative orbit) of comet nucleus in the field of view of the TV system.

This time different autonomous simulators were used to test the onboard equipment. Embedded 8 bit microprocessor based systems were developed to test every single research equipment. The control of tested instruments was realized by knobs and switches; the interpretation of telemetry information occurred on indicator lamps.

The test equipment had different jobs which ensured testing comet recognition using hardware and software as well as checking and calibration of the onboard system. The features of the test system are aimed at simulating operation circumstances. The EGSE of TV system (the Russian abbreviation of EGSE is KIA) was based on a microprocessor system. The core of test equipment was a Z80 processor with individual UMDS bus (Universal Microprocessor Development System) developed by our Institute. It was able to test and control all interfaces of the TV system. A second microprocessor generated the nucleus orbit images for testing the tracking accuracy. The operation system Z80-RIO (Re-locatable Modules and I/O Management) was also individually developed. It enabled monitoring and debugging functions. The structured software contained elements to test either individual units of the TV-System or perform complex tests of several units working together or the entire system’s combined cooperation. The embedded software was developed in assembly language.

Figure 3

The autonomous test equipment for the Tünde instrument of VEGA-Halley mission, the top box of the EGSE is the Power Supply Simulator

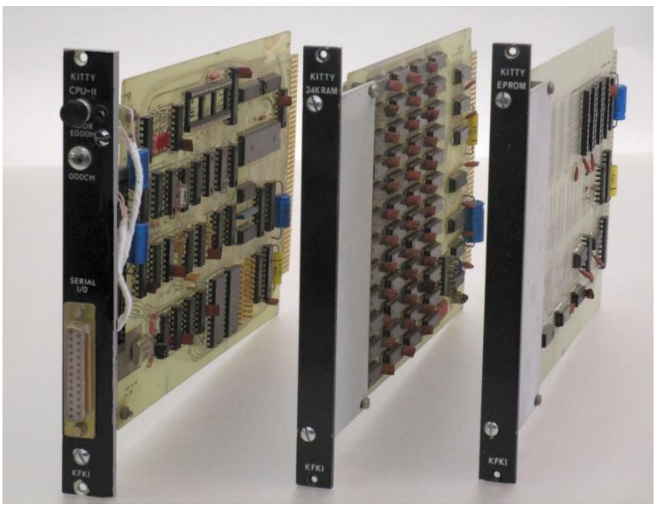

Figure 4

Test cards for VEGA experiment

3 EGSE in the First Half of the Nineties

The project was an international astrophysical project. The space probe was originally planned to be launched in 1998. However, the mission was cancelled after a ten-year delay. The scientific objects of the project included observation of known, as well as discovery of new gamma sources. In our institute the onboard data acquisition computer BIUS and other instruments and their EGSE were prepared. Besides Spectrum-X-Ray-Gamma, in the nineties we took part in other missions where similar structures of EGSE were applied. These missions were MARS96 and Cassini. The dedicated interfaces which simulated a certain electric surface of spacecraft was connected to the standardized PC bus (so-called ISA bus). Through this ISA bus the simulator units could use resources of the PC. The telemetry simulator interfaces used the PC memories through Direct Memory Access (DMA).

Basic activities of BIUS are the following:

- collecting scientific and technical data from the experiments and storing them in the on-board storage memory,

- preprocessing science data and sending them to the Earth over radio link,

- controlling scientific experiments according to a predefined cyclogram or the uplinked Earth commands.

As a result of the spread of PCs in the early nineties, PCs were introduced to and applied in many fields. Instead of processor unit development, PCs offered a quick alternative to the realization and implementation of control, management and data collection with computers.

The electrical ground support equipment is an IBM-PC based test system, in which special interface cards simulate the space probe's electrical signals. The system includes the following individually developed circuit cards:

1. On-board data acquisition and control bus simulator;
2. Analogue telemetry and relay command simulator;
3. Coded command and on-board time;
4. Fast telemetry simulator;
5. Slow telemetry simulator;
6. Inner bus simulator ("processor bus").

The operating software of the EGSE was written partly in Borland C++. The software is menu-driven, window oriented, quasi-real time and interactive. The control commands are generated through the keyboard and forwarded to the Coded-Command and time simulator card by programmed (polled) method. It sends them by hardware method to the on-board system. Receiving fast telemetry signals is organized as a background job (direct memory access).

There are more advantages of using a PC in EGSE: possibility of applying industrial cards for interface testing, well defined bus system and great volume of software support on the widely available hardware structure, which supported software development, evaluation and data acquisition.

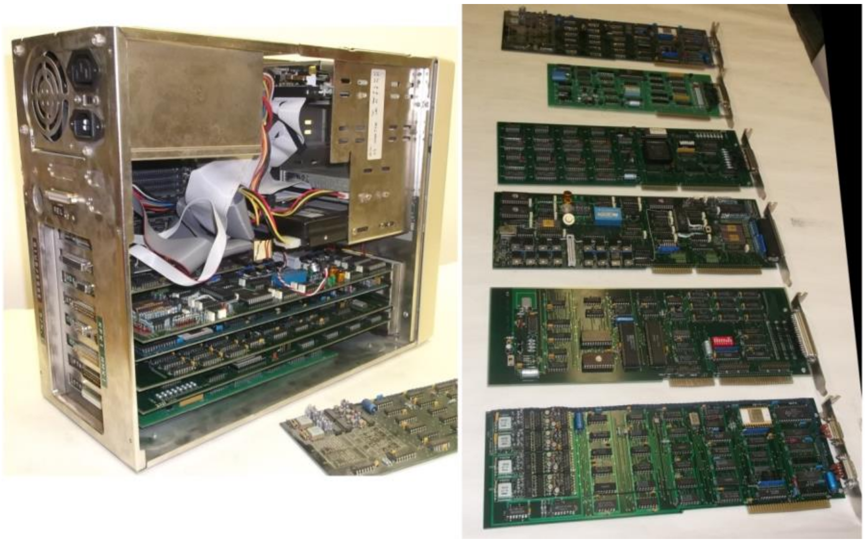

Figure 5

EGSE of Spectrum-X-Ray-Gamma EGSE. It was based on a commercial PC with industry made and self-developed extension cards.

4 EGSE in the late Nineties

The development of the Rosetta mission of the European Space Agency started in the nineties. The space probe consists of two parts: the Rosetta orbiter and the Philae lander. The journey started toward ***Comet* Churyumov–*Gerasimenko*** on 2nd March, 2004.

The Philae lander is the first set of research equipment in the history of space exploration that gently descends to a comet core where it can investigate changes in the activity of a comet. All the equipment on the lander is connected to the CDMS (Command and Data Management System) which is the central data acquisition and control computer of the lander. Communication goes through the orbiter to the Earth.

During tests the system had five dedicated computers and units developed for EGSE system. Figure 6 shows the onboard bus simulator unit of EGSE for RPC (Rosetta Plasma Consortium) and its block-scheme seen on Figure 5 [4].

The RTI (Rosetta Telemetry Interface) simulator is an embedded processor system with its own embedded software and its own embedded processor and data clock line (131 kHz) common for command/telemetry, plus an on-board clock line, and several other signals. This is the interface toward the Rosetta Onboard Bus. The communication toward the EGSE PC goes on another, RS-232 bus. This interface is galvanic isolated by opto-couplers because RTI simulates the Rosetta Orbiter onboard bus with both its command bus and telemetry bus. The received telemetry data are converted and stored in RAM that are sent to EGSE PC upon software request. Commands, prepared by EGSE software are sent to RTI, stored in RAM, and converted to serial packets according to Onboard bus standard, and sent to it serially.

The graphical user interface was developed in LabWindows CVI of National Instrument development environment and it runs in Windows XP. A similar EGSE hardware configuration was designed for CONSERT instrument however, the graphical user interface software was different.

During the implementation we had to meet many requirements. The attached Figure 7 shows the grounding solution between EGSE and of the measured device. The galvanic isolation protects the electronics from any errors spreading.

The CDMS (Command and Data Management System) is the onboard computer of Rosetta Lander. The name of Rosetta Lander is Philae. It was designed by our institute in cooperation with SGF Ltd.

The Rosetta Lander Simulator carries the check of CDMS.

Tasks of Rosetta Lander Simulator are the following:

- staff training,
- testing operational schedules,
- performing long term tests,
- performing endurance tests,
- performing data transfer tests,
- running and testing telecommand sequences,
- testing software of the onboard computers, and
- reproduction of events recorded from the probe.

Complex tasks of testing are distributed among five computers in the lander simulator are as follows: one computer is used by operator to steer simulation and archive results for evaluation. Another one simulates the onboard data handling. It is connected to CDMS of the RPS bus simulator through RS-232 line. The other three computers simulate the following interfaces:

1. PC:
    a. Power Sub System (PSS)

   b. Thermal Control Unit (TCU),

2. PC:
   a. Active Descent System (ADS)
   b. Landing Gear (LG)
   c. Anchor
   d. Sampling and Drilling System (SD2),
3. PC:
   a. Scientific equipment (APX, CIVA/ROLIS, CONSERT,COSAC, MUPUS, PTOLEMY, ROMAP, SESAME),
4. PC controls the telecommand and telemetry simulator
5. PC controls the all simulation and archives measured data.

The application of 5 PCs make possible to follow all service data parallel on different displays at the same time.

During system design, the main aspect was flexibility. Besides current application this system can be adapted to simulate other complex systems. The modular structure of the system provides the possibility for developers to work on modules simultaneously and mainly independently from each other. During a long development phase involving international cooperation, e.g. the project Rosetta, its design flexibility has shown to be an important advantage. The XML based script language makes it easy to define simulations without changing the source code of any of the programs. The creation of the simulation script files does not require advanced programming skills from the different operators who are involved in the project during the long term of the mission. The software elements of the special tasks are mainly independent from the simulated system. In the case of development of difficult modules there is an opportunity to use a C++ API which supports the developers to integrate a new complex module easily into the system. Rosetta Lander Simulator is a shared computer network consisting of five computers. CDMS message handler is based on a transputer. The control PC software was developed in C language (National Instrument LabWindows). It controls the PWC activity using an XML file to ensure user friendly environment for operators.

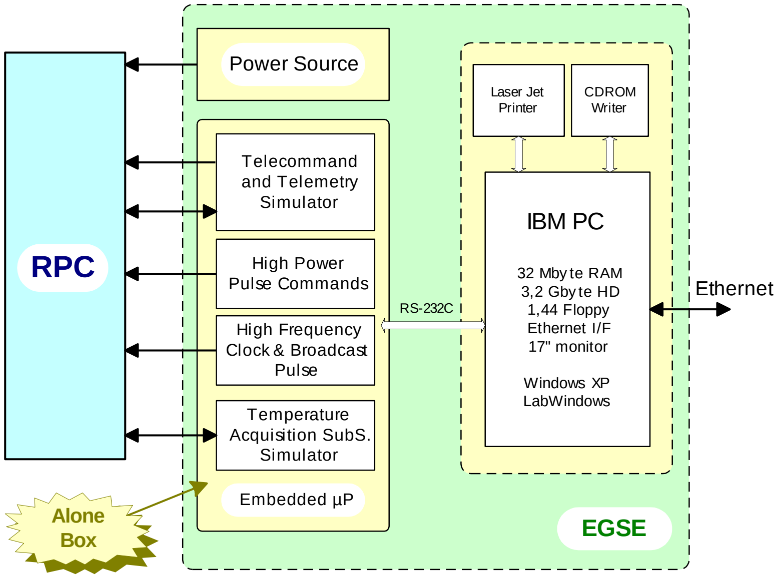

Figure 5
The Blockscheme of TEGSE for the RPC instrument for Rosetta

Figure 6
Photo of the realized EGSE

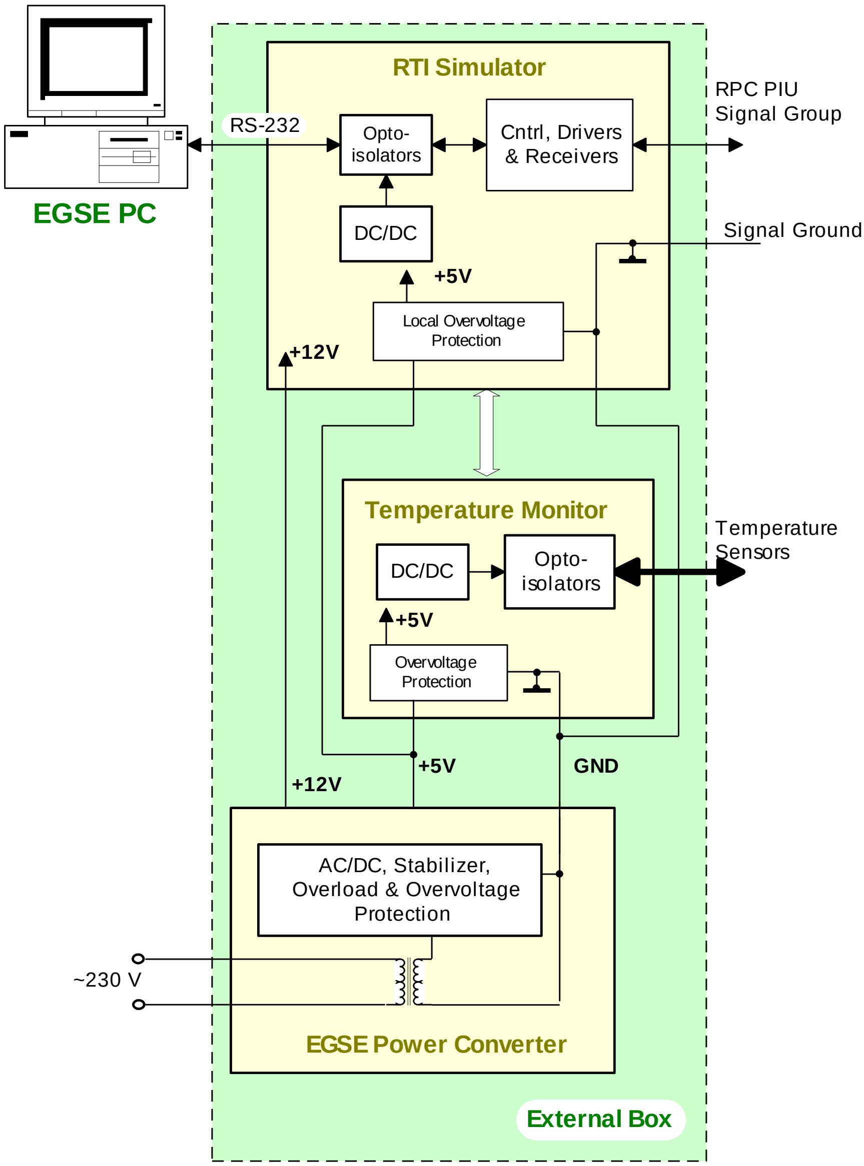

Figure 7
Grounding solution of EGSE for Rosetta orbiter

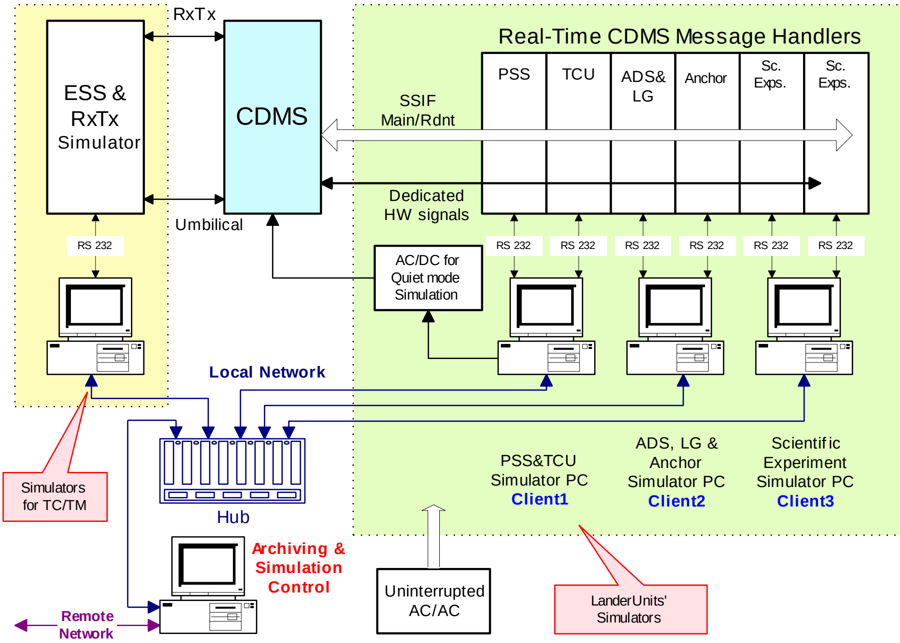

Figure 8
Blockschme of test environment of CDMS

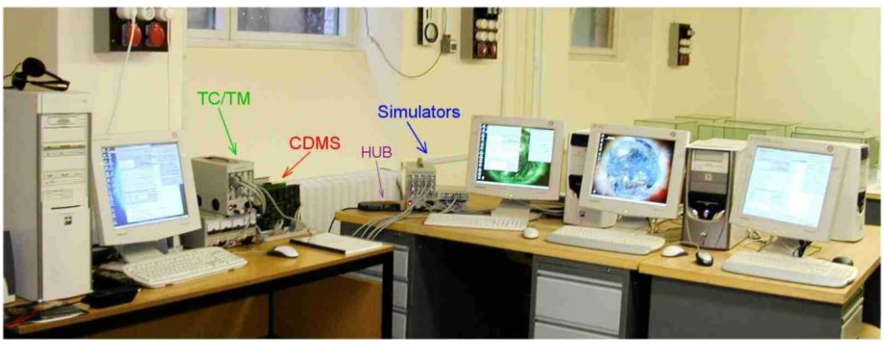

Figure 9
Lab appearance during testing of the fault tolerant central computer for Philae

5 EGSE after 2000

Our institute and SGF Ltd. participate in the development of the Obstanovka, (Obstanovka is a Russian word, it means enviroment, the other term for it is PWC (Plasma Wave Complex) was also used) system to measure particle and electric environment of the ISS (International Space Station). The PWC contains three computers working as a distributed intelligence system and eleven sensors. One computer BSTM (Block of Storage of Telemetry Information Unit) is located inside the ISS (International Space Station), two other ones called DACU1 (Data Acquisition and Control Unit) and DACU2 with connected sensors are outside on two branches [5, 6, 7]

The widespread application of embedded processors has enabled engineers to integrate processors on individual cards. It improves intelligence and computational power of any particular card or unit.

The full checkout of Obstanovka requires several functional units, power supply units and communication channel simulators (onboard Ethernet network, amateur radio channel, bit serial data acquisition system and the so-called analog monitoring system). The EGSE has to simulate the data flow of sensors, too. Simulators have to represent real hardware interfaces. Generally the EGSE of any onboard data acquisition system has four interfaces:

1. User interface to monitor and control the system (display and keyboard);
2. Instrument (space craft) interface, realized on dedicated hardware elements;
3. Data flow source (data simulators of sensors, most cases dummy data flow is satisfactory);
4. Network interface to distribute and archiving the TM (Telemetry) data flow (Ethernet).

The PWC-EGSE system simulates the data traffic of the experiments and ISS onboard equipment connected to the PWC computers BSTM, DACU1 and DACU2. The EGSE system consists of an embedded PC104 computer producing the data traffic in real-time, and a connected User InterFace computer (UIF). This commercially available computer displays data sent to the ISS onboard system, enables switching of power supplies and sends commands and parameters to the experiments upon user interaction. The EGSE for Obstanovka (and for its data acquisition and control computers) consists of two main units: a commercially available computer PC with Ethernet interface, and a stand-alone box which contains an ISS signals simulator part (OMTC Onboard Monitoring Telemetry Interface signals) and simulators of sensor units. The standalone box realizes a low level simulation of signals connecting to the BSTM and DACUs units. This low-level signal simulator box contains a removable hard disk drive (HDD), enabling offline telemetry data read-out and provides for the possibility of preparing measuring control sequences to be delivered onboard. The PC implemented software code enables the EGSE to process and analyze housekeeping and science data either in real-time or from archives in off line mode. The delivered configuration has adequate storage capability for temporary data storage, while permanent data storage is performed by the UIF computer. The possible sensor stimulators are not part of the EGSE, they are provided by the experimenter teams.

The Onboard Monitoring Telemetry Interface (OMTC) unit has four different types of data acquisition channels:

1. "Analogue housekeeping" data monitoring system simulator;
2. Bit serial digital interface (special serial bus);
3. Amateur radio interface channel;
4. ISS Ethernet network.

Data stream acquired by the instrument interface unit is transferred to PC via Ethernet communication channel. The sensor simulators send out adequate signals for BSTM and DACUs. The OMTC simulator and the sensor simulators are built in a common box. The functional units of this stand-alone box are shown in the Figure above.

An embedded processor controls both simulators. The processor unit is built on an Intel type microprocessor running a real-time multitasking Linux based operating system. The embedded processor and the UIF PC are connected through Ethernet using TCP/IP protocol. The standalone box can be used also as the instrument interface of the Obstanovka system, excluding the sensor simulator part.

The "user interface" program runs on the PC under Windows operating system. It is a graphical interface to control the system activity and to visualize the telemetry data flow. The software was developed in C language using the National Instrument's LabWindows/CVI development tool.

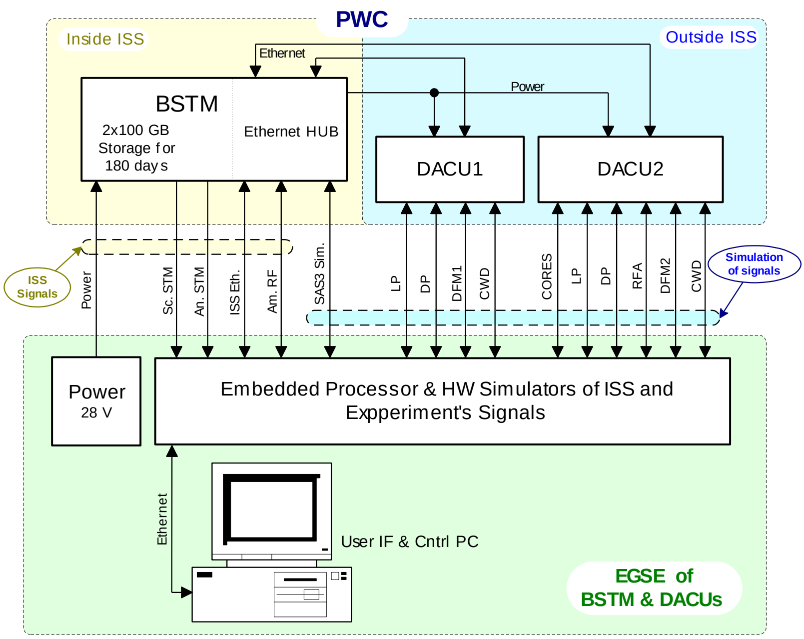

Figure 10
Test arrangement of Obstanovka computers with EGSE during test

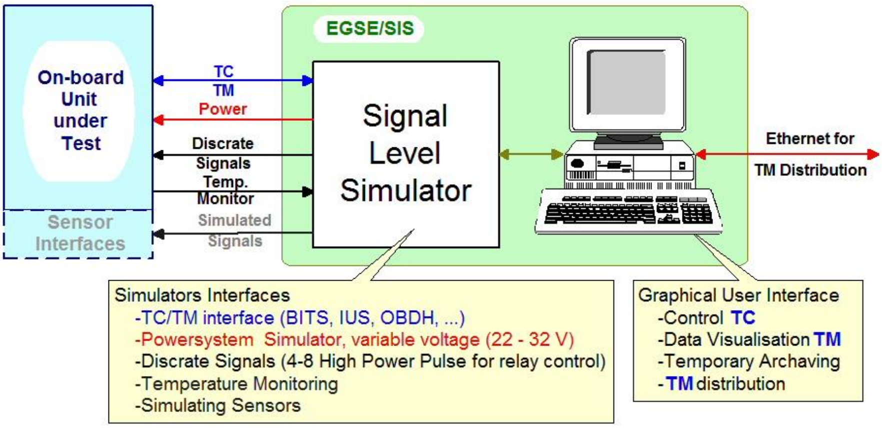

Figure 11
Detailed functional Blockscheme of EGSE

Figure 12
Photo of realized EGSE of Obstanovka

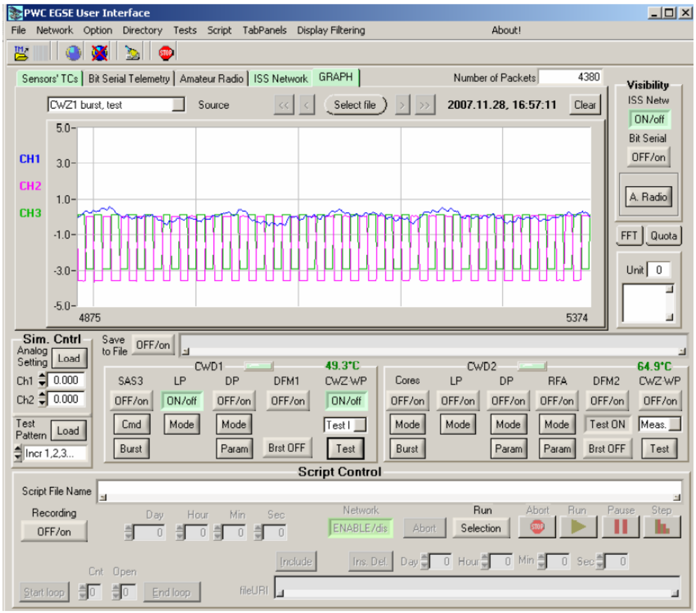

Figure 13

Screen of EGSE software, the picture shows the test of CWZ WP sensor

Application EGSE for OBSTANOVKA and Results

Two sets of EGSE for Obstanovka were used in Budapest and two other sets in Moscow. Their task included testing devices, proving functionality and finding accidental malfunctions.

The main functions of EGSE makes a wide range examination of flight hardware possible, which we present shortly. The User Interface of EGSE is based on the so-called panel (like windows) oriented graphical interface (Figure 13).

By using different areas of the GUI panel the operator can make a selection of control instructions in order to perform a desired action. Operator can perform multi-sided investigation by EGSE software features which are the following:

- save, open and decode TM (telemetry) and HK (housekeeping) data files and set IP adddresses of Ethernet channels,

- can select data received through different communication channels, (Sensor TM, BITS (Bit Serial System), Amateur Radio, onboard Ethernet) for vizualisation on display.

- visibility control can be activated or deactivated to simulate connection state between onboard channels and Earth receiver station,

- if sensors are simulated by EGSE different simulated data patterns can be selected in order to be sent by the simulated sensor,- sensor control buttons to power on/off real sensors or simulated sensors,

- Script Control, a series of commands to set working modes of sensors can be written in a file and commands can be executed by the given timing,

- quota is in connection with TM data archiving, determines the memory size for sensor data. Qouta can be switched off for test purposes,

- FFT button displays the spectrum window and enables the Fast Fourier Transformation for CWD1 (Combined Wave Sensor), CWD2, and DFM1 (Flux gate magnetometer) devices,

- TM flow archiving (save to file),

- preloaded binary commands, each of these files describes a typical command sequence of BSTM. In case of a typical command sequence a preloaded command file can be executed from the GUI with one TC instead of sending the commands of the typical sequence one by one,

- EGSE can perform data distribution through TCP/IP server port. User program running on EGSE can not only save data in files and display them according to the filtering item setting, but EGSE program can run like a server and forward measured data towards network from where they can be achieved by other computers connected to Ethernet. The other computer can receive data of any experiment by setting the IP and port address.

During test procedure after inspection several physical parameters, power transients at switching, EGSE test starts with investigating data transmission through the five communication channels of onboard devices. There are three Ethernet channels and two others using special protocol, they are BITS and OMTS (Onboard Monitoring Telemetry System). The channels are driven by data streams selected by the operator who investigates data traffic on PC screen and the waveforms with scope, too.

The EGSE can simulate high precision onboard clock and operator examines whether the onboard computers can synchronize their inner clocks to onboard clock by reading message of BSTM. Synchronizing the OBSTANOVKA clock to exact onboard clock is important for reconstruction place of data acquisition in orbit around the Earth, based on orbit parameters and saved sampling time.

EGSE software makes possible to test the onboard computers simulating sensors and sensors can be examined by it, too.

The same tests are repeated by placing the OBSTANOVKA components in thermo-vacuum chamber where the pressure is below 10^{-4} milibar. The mechanical fastening surface temperature is regulated as if it were the contact surface of ISS. The vacuum test lasts for a week since temperature transients are slow.

After vibration stress the electronic tests are repeated, too.

As usual in space developments different models of OBSTANOVKA were built, they are Technological Model, Engineering Model (identical with Flight Model) and Flight Model. All of them went through a long test procedure with EGSE here, in Budapest and the equipment was tested with EGSE in Moscow for months and after successful EGSE tests with maker of the Russian Segment of ISS.

After the successful verification procedure OBSTANOVKA was carried onto ISS by a Progress spaceship on the 11th February, 2013. The devices were placed in order through a six-hour spacewalk on 19th April, 2013. After the placement OBSTANOVKA worked properly. However, a failure occurred six months after placement onto the external wall of ISS. The operating temperature of one of sensors began to warm up slowly for two weeks and later it stopped working. Later the power supply unit of DACU1 had a sudden drop out for an unknown reason, and then it started to work again, afterwards, the analogue-digital converter fell out with its corresponding sensors, but LP1, and DP1 continued to work.

Evaluation of measurement data provided by the OBSTANOVKA is still going on, during its operation many interesting phenomena were revealed.

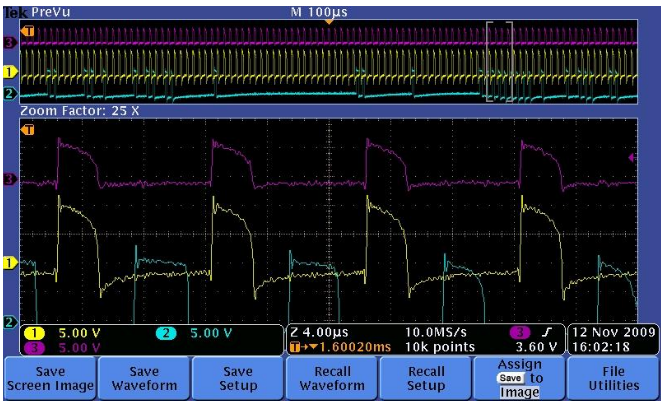

Figure 14

Examination of BITS signals

Figure 15
Assembly of OBSTANOVKA on external wall of ISS during six-hour spacewalk

Conclusions

EGSE (Electrical Ground Support Equipment) is the test device developed in order to support the development and test of flight units. EGSE task in space engineering is to simulate onboard interfaces connecting with space instruments.

The tasks they perform are:

- simulation of onboard Power Supply,
- simulation of Interfaces,
- functional test of units,
- possibility to measure important parameters,
- availability of “go” or “not go” test,
- to ensure verification within possible range of operation,
- receiving and evalutation data.

As, new computer technologies and hardware elements are applied in research instrument development the naturally have to be applied in EGSE development, too. The first EGSE devices were standalone dedicated systems of which development required a lot of engineering capacity. Involvement of PC, industrial standard buses with ready made industrial cards and later application of embedded computers enhanced effectiveness and the realisation of sophisticated intelligent systems.

The advancement of hardware was followed by that of software. In stand alone systems of the eighties the operation system was individually mostly developed in assembly language. Application of industrial standards accelerated the software development by applying Windows, Linux and C language in preparation of EGSE software.

Application of embedded systems converted EGSE in distributed intelligence systems in which the operator can control all functional tests of research equipment and signal level simulation of sensors. Adavantages of EGSE after 2000 are presented in the OBSTANOVKA experiment. OBSTANOVKA EGSE contains PC and embedded processor for control and evaluation of data and for real-time simulation onboard environment and sensors to ensure comprehensive and true to real application test.

Acknowledgement

Our jobs were supported by the Hungarian Space Office and the NKFI A (National Research, Development and Innovation Found).

References

[1] R. Z. Sagdeev, F. Szabó, G. A. Avanesov, P. Cruvellier, L. Szabó, K. Szegő, A. Abergel, A. Balázs, I. V. Barinov, J. L. Bertoux, J. Blamont, M. Detaille, E. Demarelis, G. N. Dulnev, G. Endrőczy, M. Gárdos, M. Kanyó, V. I. Kostenko, V. A. Krasikov, T. Nguyen-Trong, Z. Nyitrai, I. Rényi, P. Rusznyák, V. A. Shamis, B. Smith, K. G. Sukhanov, S. Szalai, V. I. Tarnapolsky, I. Tóth, G. Tsukanova, B. I. Valnicek, L. Várhalmi, Yu. K. Zaiko, S. I. Zatsepin, Ya. L. Ziman, M. Zsenei, B. S. Zhukov: Television Observation of Comet Halley from VEGA Spacecraft, Nature Vol. 32l, l5 May l986, pp. 262-266

[2] S. Szalai: The Imaging System on Board the VEGA Spacecraft, Images of the Nucleus of Comet Halley, ESA SP-1127, 1996, Vol. 2, pp. 20-32

[3] Balázs A., Breuer P.,Erényi I., Gárdos M., Hamza E., Kovács G., Pongrácz J., Rényi I., Szalai S.: A VEGA TV-rendszer földi támogatása. Mérés és Automatika, 33. évf., l985. l-2 szám, 38-52. old.

[4] S. Szalai, A. Balazs, A. Baksa, G. Tróznai: Rosetta Lander Software Simulator, 57th International Astronautical Congress, Valencia, Spain, 2006 (on DVD of 57 IAC)

[5] Horváth, Lipusz, Nagy: Űrkutatás – magyar részvétel a Nemzetközi Űrállomáson, adatgyűjtő és vezérlő számítógép az Obsztanovka-kísérlethez, Elektronet 2004/4 91-93

[6] Balajthy K., Szalai S.: A nemzetközi űrállomásra kerülő „Obsztanovka" kísérlet földi ellenőrző berendezése, Elektronet, 2004 8. szám, 19-20 oldal

[7] Adatgyűjtő és vezérlő számítógép a Nemzetközi Űrállomás Obsztanovka kísérletéhez Balajthy Kálmán, Endrôczi Gábor, Nagy János *KFKI Részecske- és Magfizikai Kutatóintézet,* Horváth István, Lipusz Csaba, Dr. Szalai Sándor *SGF Kft.,* Híradástechnika 2006/4 17-22