AMS-02
TRD
Gas Slow Control System
Specifications
v 4.2

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1. Abstract

The description of the TRD Gas Control System is structured as follows. The next section contains a functional description. Section 3 contains the details of the electrical controls. The components are listed in Section 4. Testing and verification are in Section 5 and Operations are in Section 6. Appendix A contains a list of contact persons for the TRD Gas Slow Control System, and Appendix B contains the weight estimate for the TRD Gas Slow Control System

2. Gas System Functional Description

The TRD Gas System performs the following functions:
Stores sufficient gas for the 3-5 year AMS-02 mission with a safety margin of four.
Transfers new gas to the TRD each day.
Circulates the gas and monitors the gas content continuously.

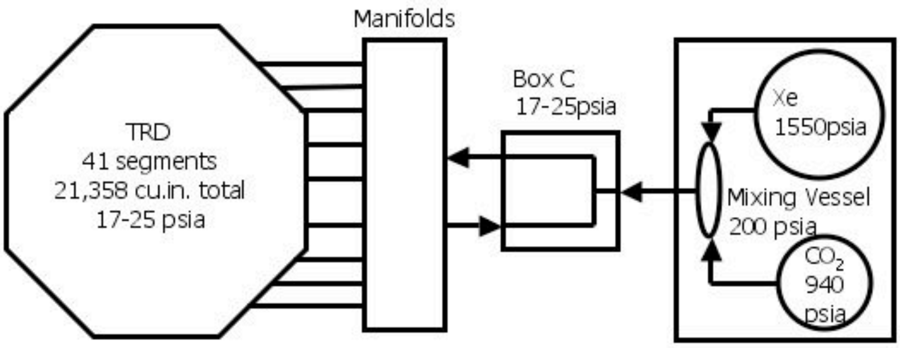

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Fig. 1 TRD Gas System general layout.

The 41 TRD segments are connected through manifolds to Box-C containing controls, monitors, and circulation pumps. Box-S provides Box-C with pre-mixed gas from gas supplies in a limited transfer volume (approx. 1 liter). Computer activates a feed control between Boxes S and C approximately once a day. The general layout is shown in Fig. 1. The 41 sealed TRD segments of approx. 430 cu. in. each are held at 17.4 psi. Box-C has an estimated volume of less than 150 cu. in., held below 25 psia by relief valves.

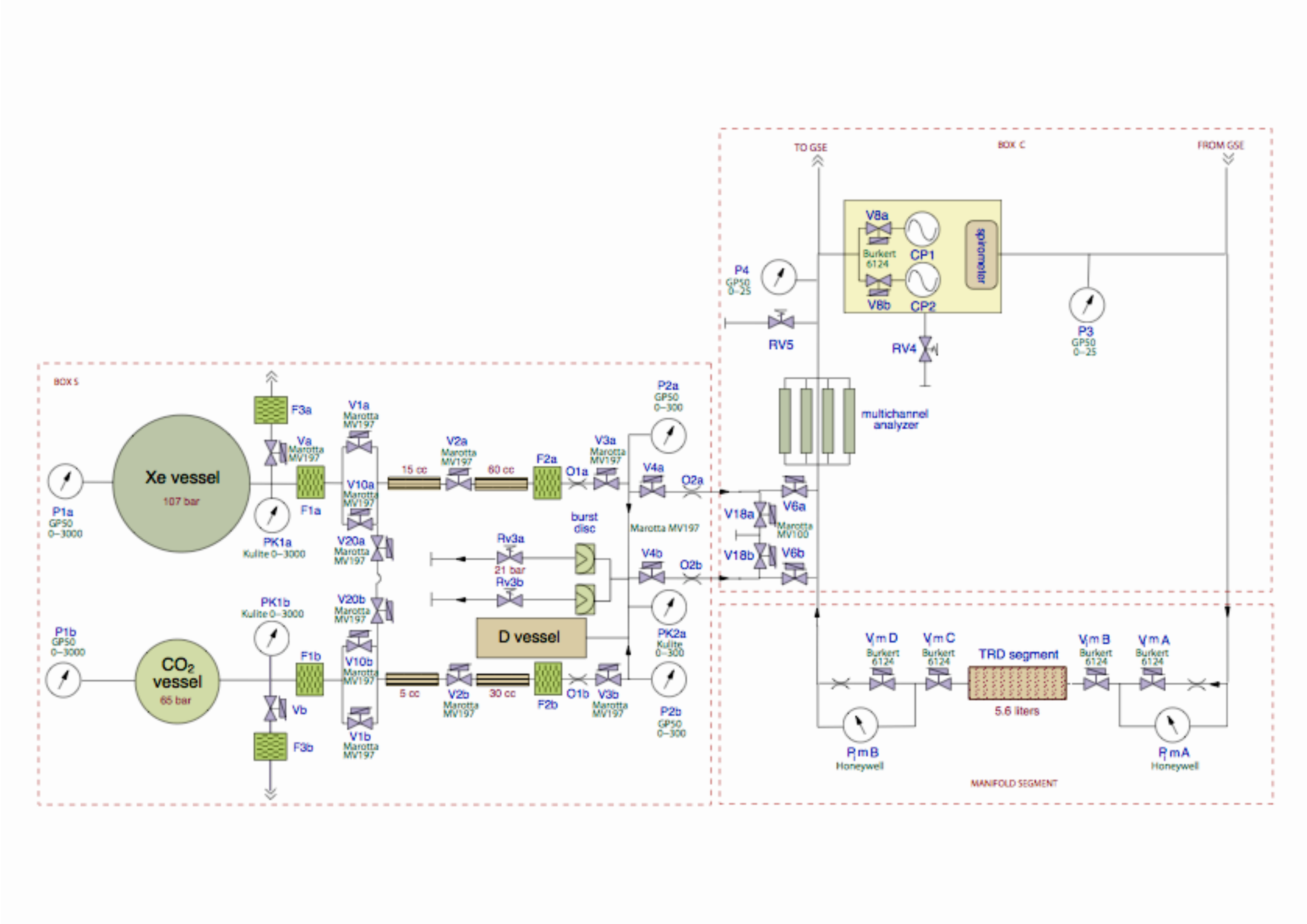

Fig. 2 Gas System

Fig. 2 shows the schematic for Box-S and Box-C. Two storage vessels store the Xenon and Carbon Dioxide separately. Two mixing circuits convey the gases to the mixing vessel where the 4:1 mixture is made. A system of valves then allows the transfer of the gas from the mixing vessel to Box-C. At all points, the valves have a two-fold redundancy. Leak-before-burst vessels ensure safety in the event of high temperatures causing overpressure in the vessels during a time when gas cannot be vented, such as when the system has no electrical power. Gas from Box-S passes through the transfer valves V4a-b and V6a-b. Two pumps circulate the gas through the TRD volume in order to keep the gas mixed, allow the CO_2 sensor and gain monitor tubes to assess the properties of the gas. The pumps and CO_2 sensor are mounted inside a gas tight vessel; in the event of a pump or valve failure, pressure integrity of the system will not be lost.

Fig. 2 shows one manifold segment. Each manifold segment has two valves and one pressure sensor at each end. The valves allow the isolation of the corresponding TRD segment in case a leak occurs and the pressure sensors allow detection of leaks. All valves are computer controlled; if there is a large leak in any segment, that segment is closed by the control computer.

3. Gas Control System

The TRD Gas System is controlled via the TRD Gas System Electronics crate (UG). The crate layout is given in Fig. 3. The double redundant UGBS cards control Box-S, Box-C by the double redundant UGBC cards and the manifolds by the double redundant UGFV cards.

This System includes the Monitoring and Control Computer (JMDC) and the Power Distribution Box (PDB), which provides 28 VDC power from the 120 VDC, supplied from the Space Station. Fig. 4 shows the architecture of the TRD Gas Control System.

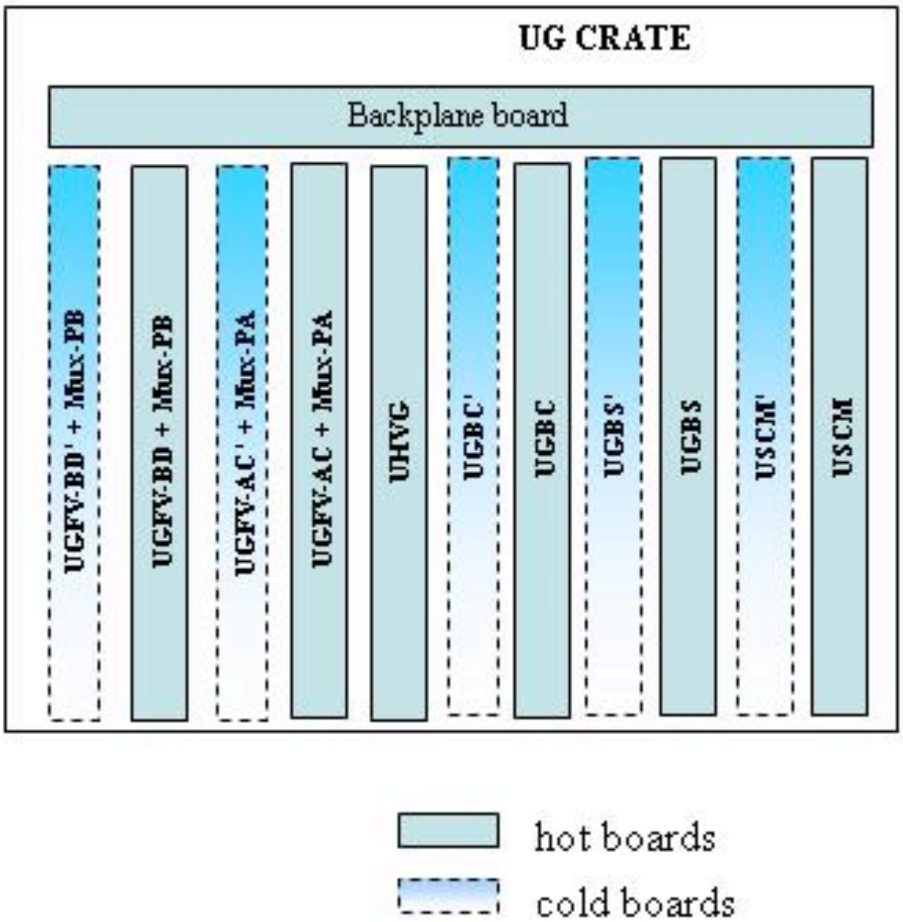

Fig. 3 Gas System Electronics Crate layout (UG crate).

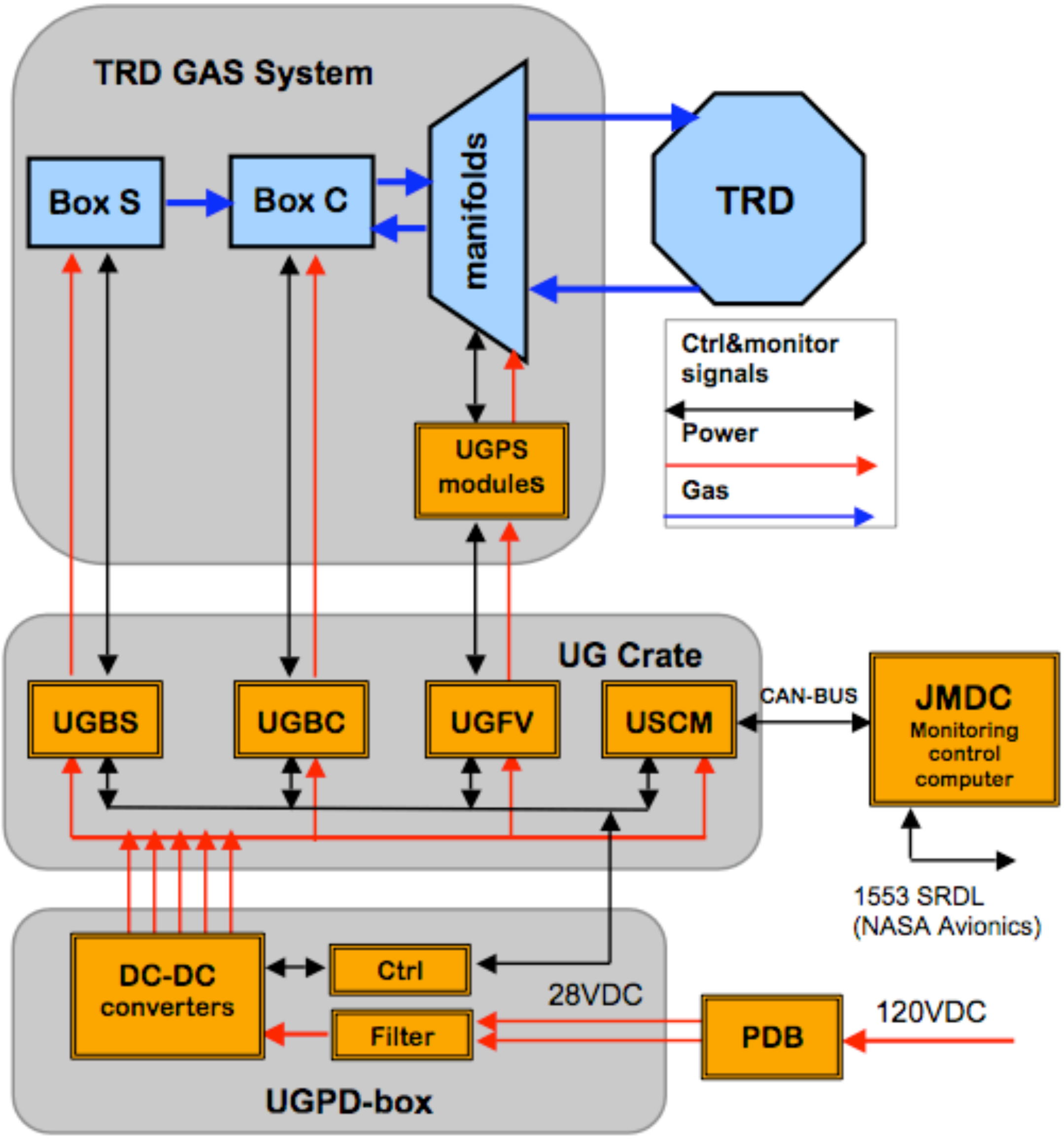

Fig. 4 TRD gas system command and control architecture (see text). The black lines indicate the control and monitor signal, the red ones the power supply.

As outlined above, the Gas Slow Control System is composed by the following elements: UG Crate, Crate Back-Plane (UGBP) and the following modules: USCM, UGBS, UGBC, UHVG, UGFV, UGPS modules. Redundancy is implemented by duplicating all boards except UGPS modules since the manifolds themselves are redundant.

Each board type will be described in § 4. A short description is given below.

USCM[1] (Universal Slow Control Module) The USCM is connected to the Monitor and Control Computer and main data acquisition via CAN-BUS and to the gas system control electronics via a dedicated custom bus (USCM I/O and CTRL in Fig.4). The USCM provides output ports to command external devices and input ports to acquire control data.

The circuit boards UGBS, UGBC, UHVG, UGFV and UGPS provide an electronic interface between USCM and electromechanical gas system devices. Their functions are:

UGBS[2] (TRD Gas Control Board for Box-S): located in the UG Crate (TRD Gas Crate**)** near the Box-S, it will control its operations i.e. providing the correct gas mixture to refill the TRD, monitor the pressure and filling status. One hot and one cold UGBS board and cables are used to implement system redundancy.

UGBC (TRD Gas Control Board for Box-C): located in the UG Crate near the Box-C, it will control its operations, i.e. running the pumps, opening valves to refill the TRD and monitor gas pressure. In case of overpressure, a relief valve will be opened. One hot and one cold UGBC board are used to implement system redundancy.

Two sets of boards control and monitor the isolation valves and the pressure sensors of TRD manifolds; they are the UGFV and UGPS boards.

UGFV controls the activation of the manifold flipper valves (164 in total) and multiplexes the 82 manifold pressure sensor signals coming from the UGPS modules (located closer to the manifold, see after) to the USCM ADC. Each board will control 41 valves pairs (for each segment valves A and C, or B and D are activated or deactivated with the same command) so that four identical boards (2 hot and 2 cold) are used (UGFV-AC, UGFV-BD).

UGPS: this board sits close to the detector near the sensors and contains the circuits to adapt the pressure sensors output signals to the USCM inputs. This electronics has to operate in an external magnetic field B ≅ 200 Gauss directed along the axis of the manifold.

UHVG: The UHVG board generates the high voltage power supply necessary for the BOX-C monitor tubes.

UG Crate (TRD Gas Control Crate): This crate locates all the electronic boards previously described with exception of UGPS modules. This crate allocates also a TRD Gas Control Backplane board **(UGBP)** to distribute the power supplies and USCM custom bus signals to all UG boards. Most of the TRD electronics is hosted in a single crate capable to host 12 boards, 6U-height. The standard AMS crate will be used.[3] The *standard* crate has a board-to-board pitch of 20.32 mm. The *standard* board will have two 3×32 VME connectors (0.1” pitch). The allowable height for components on component side is 11.4

[1] USCM Universal Slow Control Module for AMS 02; III Physikalisches Institut RWTH Aachen

[2] In this case and in all acronyms starting with UG, U stands for *Ubergangstrahlung*

[3] For more details: http://ams.cern.ch/AMS/Electronics/mech

mm and on solder side is 5 mm. It has a board thickness of 1.6 mm and a front panel width of 20 mm, with a clearance of two times 1 mm on each side.

UGPD Box (Gas Power Distribution Box): This box allocates all filters, control electronics and DC-DC converters. It provides voltage and current to operate valves, pumps, other components of the TRD gas system and the command electronics. Power is derived from the Power Distribution Box (PDB) @28V, supplied from the Space Station. Converters are needed for 120, 30, 12, 5.0, 3.3 VDC.

All control and monitor electronics (except UGPS modules, already specified) operate in an external magnetic field B approximately of 160 to 200 Gauss.

All boards previously described will be designed using redundancy criteria to cope with failure of one element at the time. No provision is made for two or more failures on the same board. To implement this feature, for every board in operation, *hot board,* a standby unit, *cold board,* will be provided. The UGPS modules, sitting on the manifolds, will not have a cold unit, since doubling pressure sensors and valves in the manifold already provides redundancy.

Hot and cold boards can be controlled by either USCM.

4. Control System Components

a. Universal Slow Control Module (USCM)

The USCM contains the interface to the JMDC, which tests the status information of the gas system against pre-conditions and executes commands. The conditions and commands are stored in form of decision tables.

Its duties are:

- execute the software of the control system;
- control and command the sensor, valves, and pump interface;
- integrate through a serial bus (CAN-BUS) the TRD gas system in the AMS general command and control system.

Two replica of the USCM, the hot and the cold (dashed box in figure refers to cold boards), are used for redundancy. These two boards control all the other boards presents in the crate. The USCM bus signals will be distributed through the backplane to all the other boards in the crate so that they could be accessed through a memory mapped I/O mechanism. All the boards will be based on the same Bus I/O interface (Le Croy protocol) implemented in an ACTEL A54SX32A FPGA.

b. Box-S Control Board (UGBS)

The main task of this board is to control the valves present in Box-S (V1a, V10a, V1b, V10b, V2a, V3a, V2b, V3b, V20a, V20b, V4a, V4b) with the following function

- open the valves (normally closed otherwise) for a programmable period ranging from 50 to about 60000 ms

This control is handled from a dedicated ACTEL A54SX32A FPGA interfacing the USCM I/O. The FPGA pilots also the two switches used to control each valve (24 in total). For each valve one switch (SW-1) is used to connect the valve to the 30 VDC power supply line, while the other switch (SW-2) it is used to open the valve for the programmed time, if connected to the 30 VDC (see Fig. 5).

A voltage comparator (LM239) checks if the second switch (SW-2) is closed during the open command. The status of the SW-2 switch is accessible in two different ways by USCM:

1. *current* status register allows the USCM to have information of the status of all SW-2 switches at the reading phase.
2. *event* register will report, for all switches, if a close event occurred in the past. To this end, the switch transitions to the close state are stored into a 12 bits register.

The register reading operation by the USCM resets it to zero. Comparing these two registers, a monitor of command flow and of the working condition is possible.

The ADCs necessary to convert the output signals from 4 GP50 pressure sensors (P1a, P2a, P1b, P2b) and from 3 KULITE pressure sensors (PK1c, PK1d, PK2c) are also present on the board.

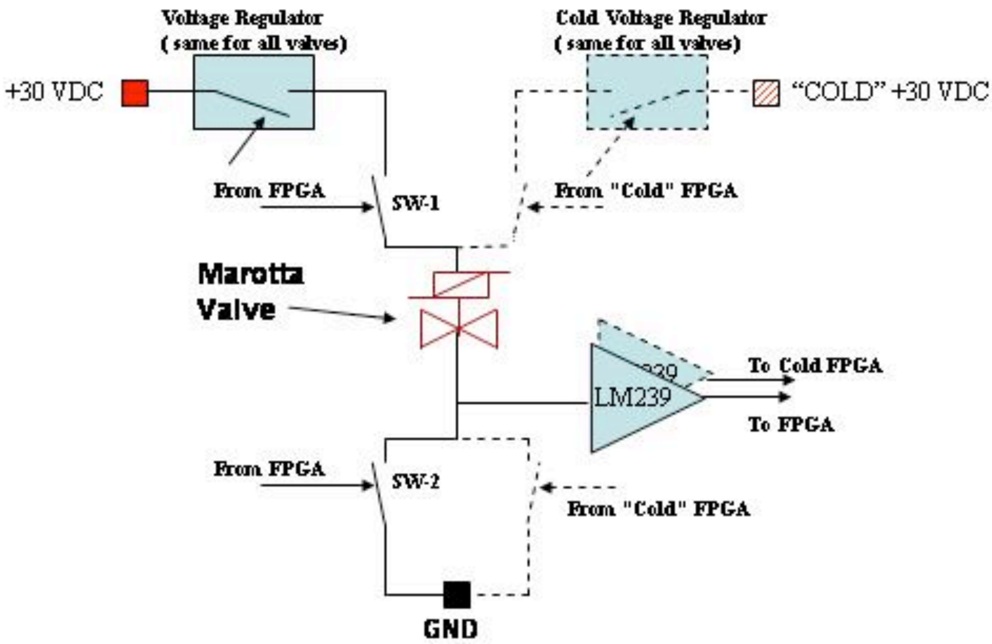

Fig. 5: Marotta Valve Circuit

The USCM does not give direct commands to the valves. The USCM will operate on valves, and on all the other devices, through I/O operations, using the Lecroy bus, at the UGBS addresses, according to the following commands table.

When opening valves, software program should take care of switching off heaters.

Table 1 – Box-S Commands

Command	Function	Comment
MVENW	Enable Valves (close SW-1)	12 bits specify valves to be enabled (connected to 30 VDC)
MVENR	Enable valve status (SW-1 status)	Use 12 bits to return which of the 12 valves is enabled
OPEN_V1a	Open valve V1a	16 bits set the open period (SW-2 is closed for the specified period) (ms)
OPEN_V2a	Open valve V2a	"
OPEN_V3a	Open valve V3a	"
OPEN_V4a	Open valve V4a	"
OPEN_V10a	Open valve V10a	"
OPEN_V20a	Open valve V20a	"
OPEN_V1b	Open valve V1b	"
OPEN_V2b	Open valve V2b	"
OPEN_V3b	Open valve V3b	"
OPEN_V4b	Open valve V4b	"
OPEN_V10b	Open valve V10b	"
OPEN_V20b	Open valve V20b	"
OPEN_V20a&V20b	Open both valves V20a and V20b	"
OPEN_SPARE		
SW2CURRD	Read the actual status of the SW-2	14 bit are used to report info for all SW-2 switches in a single reading
SW2EVERD	Read the event register for the SW2 switches	"
VRENWR	Enable Board Voltage Regulators	2 bits are used to switch on/off the 5V and 30V voltage regulators
VRENRD	Read Voltage Regulators Status	2 bits are used to report info about 5V and 30V regulators
READ_P1a	Read P1a	The 12 output bits of the ADC are returned to the USCM
READ_P2a	Read P2a	"
READ_P1b	Read P1b	"
READ_PK1c	Read PK1c	"
READ_PK1d	Read PK1d	"
READ_PK2c	Read PK2c	"

Four cables (JS1A, JS1B, JS2, JS3) connect the UGBS boards to the Box-S and micro-D socket connectors are used for connection on both sides; the pin-out of such connectors is stated in the following tables.

Table 2 – JS1 Pin Assignment

JS1A and JS1B (37 pin)	
Pin #	Connection
1	unconnected
2	V1a +Excitation Voltage
3	V10a +E.V.
4	V3a +E.V.
5	V20b +E.V.
6	V3b +E.V.
7	V4a +E.V.
8	VSpare1 +E.V.
9	Unconnected
10	Unconnected
11	V1a –E.V.
12	V10a –E.V.
13	V3a –E.V.
14	V20b –E.V.
15	V3b –E.V.
16	V4a –E.V.
17	VSpare1 –E.V.
18	Unconnected
19	Unconnected
20	V20a +E.V.
21	V2a +E.V.
22	V1b +E.V.
23	V10b +E.V.
24	V2b +E.V.
25	V4b +E.V.
26	VSpare2 +E.V.
27	Unconnected
28	Unconnected
29	V20a -E.V.
30	V2a -E.V.
31	V1b -E.V.
32	V10b -E.V.
33	V2b -E.V.
34	V4b -E.V.
35	VSpare2 –E.V.
36	Unconnected
37	Unconnected

Table 3 – JS2 Pin Assignment

JS2 (21 pin)	
Pin #	Connection
1	Unconnected
2	H1 +E.V.
3	H2 +E.V.
4	H3 +E.V.
5	HSpare1 +E.V.
6	HSpare2 +E.V.
7	Unconnected
8	Dallas1 VCC
9	Dallas1 GND
10	Dallas1 IO
11	Unconnected
12	H1 –E.V.
13	H2 –E.V.
14	H3 –E.V.
15	HSpare1 –E.V.
16	HSpare2 –E.V.
17	Unconnected
18	Dallas2 VCC
19	Dallas2 GND
20	Dallas2 IO
21	Unconnected

Table 4 – JS3 Pin Assignment

JS3 (31 pin)	
Pin #	Connection
1	Unconnected
2	P1a +Excitation Voltage (+10V)
3	P2a +E.V. (+10V)
4	P1b +E.V. (+10V)
5	P2b +E.V. (+10V)
6	PK1c +E.V. (+30V)
7	PK2c +E.V. (+30V)
8	PK1d +E.V. (+30V)
9	P1a +Output
10	P2a +Output
11	P1b +Output
12	P2b +Output
13	PK1c +Output
14	PK2c +Output
15	PK1d +Output
16	Unconnected
17	P1a –E.V. (GND)
18	P2a –E.V. (GND)
19	P1b –E.V. (GND)
20	P2b –E.V. (GND)
21	PK1c –E.V.(GND)
22	PK2c –E.V. (GND)
23	PK1d –E.V. (GND)
24	P1a –Output (GND)
25	P2a –Output (GND)
26	P1b –Output (GND)
27	P2b –Output (GND)
28	PK1c –Output
29	PK2c -Output
30	PK1d -Output
31	Unconnected

c. Box-C Control Board (UGBC)

In the following, we summarize the devices controlled by the UGBC board with the relative control functions:

- n.4 Marotta MV100 solenoid valves (V6a, V6b, V18a, V18b)
    - open the valves (normally closed otherwise) for a programmable period ranging from 10 to about 60000 ms
    - test the mechanical status of the valves
    - test the energizing status of the valves
- n.2 Burkert 6613 flipper valves (V8a, V8b)
    - open the valves
    - close the valves
- n.2 KNM pumps (CP1, CP2)
    - turn on/off the pumps
    - change pump speed
- n.3 GP50-7900 pressure sensors (P3, P4)
- n.4 monitor straw tubes
    - signal shaping and multiplexing towards the MCA.

n.1 MCA interface through RS232 connection.

n.1 CO_2 analyser through RS232 connection.

This control is handled from a dedicated ACTEL A54SX32A FPGA interfacing the USCM I/O. The FPGA acts on the MV100 valves and on pumps using the same control scheme described in the previous paragraph. Two different power voltages (24 and 12 Volts) change pumps speed.

No direct command from USCM is given to valves. The USCM operates on valves through I/O write and read operations at the UGBC addresses, according to the following tables.

Table 5 – Box-C Commands

Command	Function	Comment
MVENW	Enable Valves (close SW-1)	4 bits specify valves to be enabled (connected to the 30 VDC)
MVENR	Enable valves status (SW-1 status)	Use 4 bits to return which of the 4 Marotta valves is enabled
OPEN_V6a	Open valve V6a	16 bits set the open time (SW-2 is closed for the specified time)
OPEN_V18a	Open valve V18a	"
OPEN_V6b	Open valve V6b	"
OPEN_V18b	Open valve V18b	"
OPEN_V6a&V18a	Open both V6a and V18a valves	"
OPEN_V6b&V18b	Open both V6b and V18b valves	"
CURSTRD	Read the actual status of the Marotta valve	12 bits used to report all information
EVENTSTRD	Read the past status of the Marotta valve	"
OPCL_V8a	Open or close V8a	3 bits specify if the valve should be open or closed
OPCL_V8b	Open or close V8b	"
PENWR	Set the pumps status	4 bits specify pump enable (connection to power supply) and pump speed (24V or 12V)
PENRD	Read pump status	"
RUN/STOP_CP1	Start or stop CP1	1 bit specifies if pump should be turn on or off
RUN/STOP_CP2	Start or Stop CP2	"
MCASELW	Select the monitor tube to be connect to the MCA	4 monitor tubes are present in BOX-C and one at the time could be connected to the MCA
MCASELRD	Reports the monitor tube connected to the MCA	"
VRENWR	Enable Board Voltage Regulators	3 bits are used to switch on/off the 5V, 12V and 24V voltage regulators
VRENRD	Read Voltage Regulators Status	3 bits are used to report info about 5V, 12V and 24V voltage regulators
RS232WR	Set the status of the serial port	One serial port is used to connect the USCM to the MCA or to the CO_2

		analyzer
RS232RD	Report the status of the serial port	"
READ_P3	Read P3	The 12 output bits of the ADC are returned to the USCM
READ_P4	Read P4	"

Three cables (JC1, JC2, JC3) connect the UGBC boards to the Box-C and micro-D socket connectors are used for connection on both sides; the pin-out of such connectors are defined in the following tables.

Table 6 – JC1 Pin Assignment

(Power)

JC1 (21 pin)	
Pin #	Connection
1	unconnected
2	CP1 –E.V.
3	CP1 +Excitation Voltage
4	P3 & P4 -E.V. (GND)
5	unconnected
6	V8a +E.V.
7	V8b +E.V.
8	CO_2 +E.V. (8.5V)
9	MCA –E.V. (GND)
10	Tube amps –E.V. (GND)
11	unconnected
12	CP2 +E.V.
13	CP2 –E.V.
14	P3 & P4 +E.V. (12 V)
15	unconnected
16	unconnected
17	V8a –E.V.
18	V8b –E.V.
19	CO_2 –E.V. (GND)
20	Tube amps +E.V. (5 V)
21	MCA +E.V. (12 V)

Table 7 – JC2 Pin Assignment

(Marotta valves)

JC2 (9 pin)	
Pin #	Connection
1	V6a +Excitation Voltage
2	V6a –E.V.
3	V6b +E.V.
4	V6b –E.V.
5	V18a +E.V.
6	V18a –E.V.
7	V18b +E.V.
8	V18b –E.V.
9	Unconnected

Table 8 – JC3 Pin Assignment

(Signals)

JC3 (25 pin)	
Pin #	Connection
1	Unconnected
2	CO_2_RX.
3	Unconnected
4	Unconnected
5	Unconnected
6	Amp. Enable 2
7	Amp Enable 4
8	Unconnected
9	P3 +Output
10	P3 –Output (GND)
11	Unconnected
12	Unconnected
13	Unconnected
14	Unconnected
15	MCA_TX
16	MCA_RX
17	Unconnected
18	Amp Enable 1
19	Amp Enable 3
20	Unconnected
21	Unconnected
22	Unconnected
23	P4 +Output
24	P4 –Output (GND)
25	CO_2_TX

d. Manifold Control Boards

This electronics, as mentioned in the introduction, controls the flipper valves (FV in the following) and conditions the pressure sensors output signal (PS in the following) of manifold TRD electronics.

From a mechanical point of view, manifold devices are arranged in 8 Input modules and 8 Output modules. With reference to Fig. 2, each Input module contains the FVA, FVC and PSA for 5 or 6 segments while each Output module contains FVC, FVD and PSB for 5 or 6 segments. In addition, the electronics will use such modularity.

PS output signals are handled in two sections: the UGPS modules and UGFV boards.

UGPS modules are designed to adapt the signals to USCM ADC input while the UGFV boards are used to multiplex them to the USCM ADC input lines. FV control commands (Close and Open) coming from the USCM are decoded in the UGFV boards The UGFV generates the necessary valve control signals.

In the following paragraph, we discuss the pressure sensor readout (UGPS modules and UGFV board) and then the flipper valve control board (UGFV board).

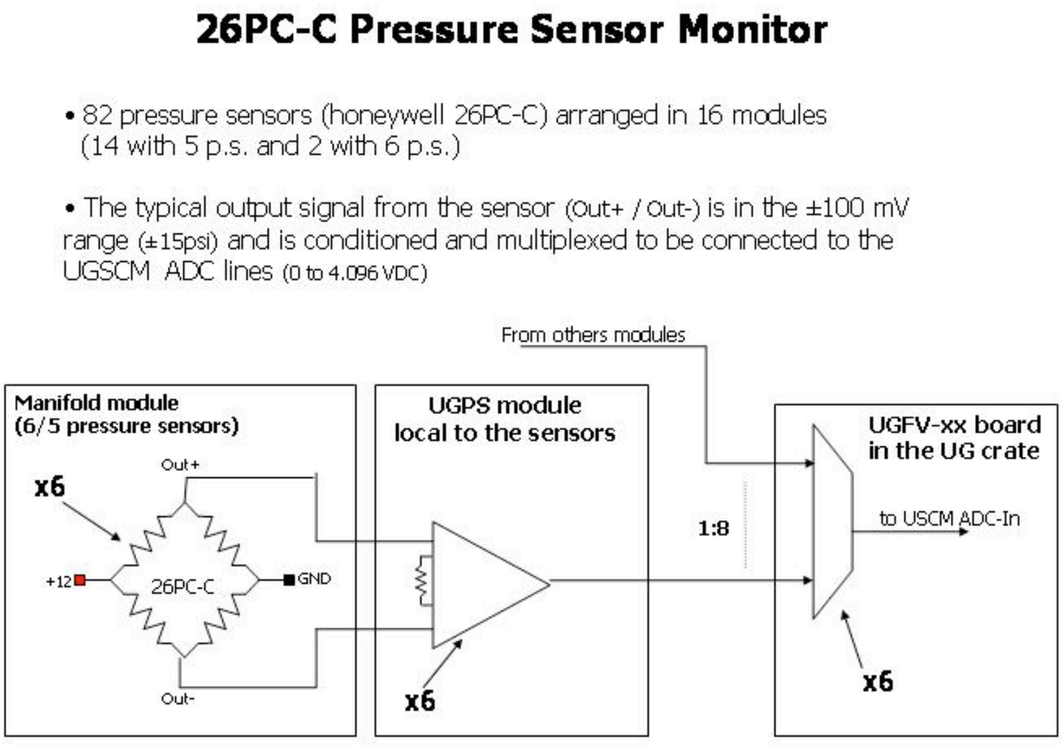

Fig. 6: 26PC-C pressure sensor output signal conditioning.

e. Manifold Local Modules (UGPS):

In this paragraph, we describe the first part of readout electronics for the pressure sensors. The duty of this module is to transform the bipolar signal coming out from pressure sensors to a unipolar signal suitable as USCM ADC input (signal conditioning). This electronics sits as close as possible to pressure sensors and will use the same modularity used in the mechanical assembly of the sensors.

Presently five Pressure Sensors (PS) and 10 Flipper Valves (FV) are mechanically assembled together in 14 manifold modules. Two additional modules assembe 6 PS and 12 FV.

Each UGPS module will provide signals conditioning for the pressure sensors that are assembled together. In such way the readout electronics of pressure sensors belonging to different segments, (i.e. P5A, P7A, P8A, P38A, P40A for module 1) are grouped in the same UGPS module, with the same modularity of sensors. The 82 sensors are grouped in 16 modules, namely 2 boards with 6 pressure sensors and 14 with only 5.

The pressure sensor (Honeywell 26PC-C) measures the difference of the pressure between the two sides of the sensor as DC voltage difference around -100 mV to +100 mV before conditioning, 0-4 V after conditioning. The typical range, the voltage corresponding to the maximum differential pressure measured, is 100mV (97 Min, 103 Max) for a pressure of 15 psi. The sensor signals are transformed to a single ended signal in the range 0 to 4.096 V VDC, resolution ±1 mV, suitable as USCM ADC line input. Then the 82 signals are multiplexed in the ADC input (6 of the 32 lines are used). This schematic is represented in Fig. 6. The output signals of pressure sensors, indicated as Out + and Out – in Fig. 6, are amplified and transformed in a single ended signal in the UGPS module and then are multiplexed to six different USCM ADC lines.

The UGPS module is connected through a single cable (JMx-xx) to the corresponding UGFV board and such cable is used also to connect the flipper valve located on the associated module (see next paragraph).

f. Manifold Control Boards (UGFV)

There are four UGFV boards located in the UG-Crate, all implementing the same functions. Two (one hot and one cold) named UGFV-AC are used to pilot all the "A" and "C" FV and to interface all the PS located in the 8 Input manifold modules (PAx). The other two (one hot and one cold) named UGFV-BD are used to pilot all "B" and "D" flipper valve and to interface all the PS located in the Output manifold modules (PBx) (see fig 2).

One of the functions of the UGFV board is to multiplex the 41 conditioned PS signals, coming from the 8 UGPS modules associated to the UGFV board, to 6 ADC input port of USCM (see Fig. 6). It is possible to read simultaneously all the 26PC-C pressure sensors located on the same manifold module using this scheme.

A dedicated UGFV board command allows the USCM to select the desired module (see command list, Table 13).

Through the backplane board, each UGFV board is connected to six different USCM ADC input line and in particular :

UGFV-AC (hot) will use ADC input line 0 to 5

UGFV-AC (cold) will use ADC input lines 8 to 13

UGFV-BD (hot) will use ADC input lines 16 to 21

UGFV-BD (cold) will use ADC input lines 24 to 29

The following tables state the correspondence between modules, PS (plus relative TRD segments) and USCM ADC Input lines

Table 9 – Correspondence PS-ADC Inputs

UGFV-AC hot (UGFV-AC cold)						
MODULE	**ADC-0 (8)**	**ADC-1 (9)**	**ADC-2 (10)**	**ADC-3 (11)**	**ADC-4 (12)**	**ADC-5 (13)**
1	PS-5A	PS-7A	PS-8A	PS-38A	PS-40A	N.U.
2	PS-10A	PS-16A	PS-18A	PS-25A	PS-25A	N.U.
3	PS-12A	PS-14A	PS-20A	PS-22A	PS-29A	N.U.
4	PS-6A	PS-31A	PS-37A	PS-39A	PS-41A	N.U.
5	PS-1A	PS-3A	PS-9A	PS-24A	PS-34A	PS-36A
6	PS-11A	PS-17A	PS-19A	PS-26A	PS-28A	N.U.
7	PS-13A	PS-15A	PS-21A	PS-23A	PS-30A	N.U.
8	PS-2A	PS-4A	PS-32A	PS-33A	PS-35A	N.U.

UGFV-BD hot (UGFV-BD cold)						
MODULE	**ADC16 (24)**	**ADC17 (25)**	**ADC18 (26)**	**ADC19 (27)**	**ADC20 (28)**	**ADC21 (29)**
1	PS-5B	PS-7B	PS-8B	PS-38B	PS-40B	N.U.
2	PS-10B	PS-16B	PS-18B	PS-25B	PS-25B	N.U.
3	PS-12B	PS-14B	PS-20B	PS-22B	PS-29B	N.U.
4	PS-6B	PS-31B	PS-37B	PS-39B	PS-41B	N.U.
5	PS-1B	PS-3B	PS-9B	PS-24B	PS-34B	PS-36B
6	PS-11B	PS-17B	PS-19B	PS-26B	PS-28B	N.U.
7	PS-13B	PS-15B	PS-21B	PS-23B	PS-30B	N.U.
8	PS-2B	PS-4B	PS-32B	PS-33B	PS-35B	N.U.

The other function of this board is the main control of flipper valve status. An ACTEL A54SX32A FPGA is used to interface the USCM I/O bus and to drive the switches used to control each flipper valve.

UGFV boards will be used to open or close each segment independently and in particular UGFV-AC boards will act simultaneously on FVA and FVC while UGFV-BD boards on FVB and FVD.

USCM will open or close the valve through an appropriate command as specified in the following UGFV command table.

Table 10 – Manifold Commands

Command Name	Function	Comment
OP/CL_MOD1	Open or close valves on module 1	6+3 bits specify valves (segments) to be opened or closed
OP/CL_MOD2	Open or close valves on module 2	"
OP/CL_MOD2	Open or close valves on module 3	"
OP/CL_MOD4	Open or close valves on module 4	"
OP/CL_MOD5	Open or close valves on module 5	"
OP/CL_MOD6	Open or close valves on module 6	"
OP/CL_MOD7	Open or close valves on module 7	"
OP/CL_MOD8	Open or close valves on module 8	"
VRENWR	Enable Board Voltage Regulators	2 bits are used to switch on/off the 5V, and 12V voltage regulators
VRENRD	Read Voltage Regulators Status	2 bits are used to report info about 5V and 12V voltage regulators
PSMUXWR	Select the module to connect to the USCM ADC inputs	15 bits allows to specify which module should be connected
PSMUXRD	Report number of modules connected to the USCM ADC inputs	"

The manifolds are controlled through the UGVF cards. One USCM scans the readings of the pressure sensors in the manifolds. The readings are reported to the main AMS-02 data computer (JMDC). If the JMDC detects a leak, it will close the corresponding manifold valves to isolate the leaky segment. This operation can also be performed from ground.

Eight cables (JM1 to JM8) connect the UGFV boards to the corresponding 8 manifold modules and for connection on both sides micro-D socket connectors are used. The pin-out of such connectors are defined in the following tables.

Table 11 – JM1 Pin Assignment

JM1 (21 pin)	
Pin #	Connection
1	PS5 Single Ended Output
2	PS7 S.E.O.
3	PS8 S.E.O.
4	PS38 S.E.O.
5	PS40 S.E.O.
6	Unconnected
7	PS +Excitation Voltage (12V)
8	FV5 +E.V.
9	FV7 +E.V:
10	FV8 +E.V.
11	FV38 +E.V:
12	FV40 +E.V.
13	Unconnected
14	FV5 -E.V.
15	FV7 -E.V:
16	FV8 -E.V.
17	FV38 -E.V:
18	FV40 -E.V.
19	Unconnected
20	PS -E.V. (GND)
21	PS -E.V. (GND)

Table 12 – JM2 Pin Assignment

JM2 (21 pin)	
Pin #	Connection
1	PS10 Single Ended Output
2	PS16 S.E.O.
3	PS18 S.E.O.
4	PS25 S.E.O.
5	PS27 S.E.O.
6	Unconnected
7	PS +Excitation Voltage (12V)
8	FV10 +E.V.
9	FV16 +E.V:
10	FV18 +E.V.
11	FV25 +E.V:
12	FV27 +E.V.
13	Unconnected
14	FV10 -E.V.
15	FV16 -E.V:
16	FV18 -E.V.
17	FV25 -E.V:
18	FV27 -E.V.
19	Unconnected
20	PS -E.V. (GND)
21	PS -E.V. (GND)

Table 13 – JM3 Pin Assignment

JM3 (21 pin)	
Pin #	Connection
1	PS12 Single Ended Output
2	PS14 S.E.O.
3	PS20 S.E.O.
4	PS22 S.E.O.
5	PS29 S.E.O.
6	Unconnected
7	PS +Excitation Voltage (12V)
8	FV12 +E.V.
9	FV14 +E.V:
10	FV20 +E.V.
11	FV22 +E.V:
12	FV29 +E.V.
13	Unconnected
14	FV12 -E.V.
15	FV14 -E.V:
16	FV20 -E.V.
17	FV22 -E.V:
18	FV29 -E.V.
19	Unconnected
20	PS –E.V. (GND)
21	PS –E.V. (GND)

Table 14 – JM4 Pin Assignment

JM4 (21 pin)	
Pin #	Connection
1	PS6 Single Ended Output
2	PS31 S.E.O.
3	PS37 S.E.O.
4	PS39 S.E.O.
5	PS41 S.E.O.
6	Unconnected
7	PS +Excitation Voltage (12V)
8	FV6 +E.V.
9	FV31 +E.V:
10	FV37 +E.V.
11	FV39 +E.V:
12	FV41 +E.V.
13	Unconnected
14	FV6 -E.V.
15	FV31 -E.V:
16	FV37 -E.V.
17	FV39 -E.V:
18	FV41 -E.V.
19	Unconnected
20	PS –E.V. (GND)
21	PS –E.V. (GND)

Table 15 – JM5 Pin Assignment

JM5 (21 pin)	
Pin #	Connection
1	PS1 Single Ended Output
2	PS3 S.E.O.
3	PS9 S.E.O.
4	PS24 S.E.O.
5	PS34 S.E.O.
6	PS36 S.E.O.
7	PS +Excitation Voltage (12V)
8	FV1 +E.V.
9	FV3 +E.V:
10	FV9 +E.V.
11	FV24 +E.V:
12	FV34 +E.V.
13	FV36 +E.V.
14	FV1-E.V.
15	FV3 -E.V:
16	FV9 -E.V.
17	FV24 -E.V:
18	FV34 –E.V.
19	FV36 -E.V.
20	PS –E.V. (GND)
21	PS –E.V. (GND)

Table 16 – JM6 Pin Assignment

JM6(21 pin)	
Pin #	Connection
1	PS11ingle Ended Output
2	PS17.E.O.
3	PS19.E.O.
4	PS26.E.O.
5	PS28.E.O.
6	Unconnected
7	PS +Excitation Voltage (12V)
8	FV11 +E.V.
9	FV17 +E.V:
10	FV19 +E.V.
11	FV26 +E.V:
12	FV28 +E.V.
13	Unconnected
14	FV11 -E.V.
15	FV17 -E.V:
16	FV19 -E.V.
17	FV26 -E.V:
18	FV28 -E.V.
19	Unconnected
20	PS –E.V. (GND)
21	PS –E.V. (GND)

Table 17 – JM7 Pin Assignment

JM7 (21 pin)	
Pin #	Connection
1	PS13 Single Ended Output
2	PS15 S.E.O.
3	PS21 S.E.O.
4	PS23 S.E.O.
5	PS30 S.E.O.
6	Unconnected
7	PS +Excitation Voltage (12V)
8	FV13 +E.V.
9	FV15 +E.V:
10	FV21 +E.V.
11	FV23 +E.V:
12	FV30 +E.V.
13	Unconnected
14	FV13 -E.V.
15	FV15 -E.V:
16	FV21 -E.V.
17	FV23 -E.V:
18	FV30 -E.V.
19	Unconnected
20	PS –E.V. (GND)
21	PS –E.V. (GND)

Table 18 – JM8 Pin Assignment

JM8 (21 pin)	
Pin #	Connection
1	PS2 Single Ended Output
2	PS4 S.E.O.
3	PS32 S.E.O.
4	PS33 S.E.O.
5	PS35 S.E.O.
6	Unconnected
7	PS +Excitation Voltage (12V)
8	FV2 +E.V.
9	FV4 +E.V:
10	FV32 +E.V.
11	FV33 +E.V:
12	FV35 +E.V.
13	Unconnected
14	FV2 -E.V.
15	FV4 -E.V:
16	FV32 -E.V.
17	FV33 -E.V:
18	FV35 -E.V.
19	Unconnected
20	PS –E.V. (GND)
21	PS –E.V. (GND)

The following scheme draws the cable connection between UGFV boards, one Input, and one Output manifold module.

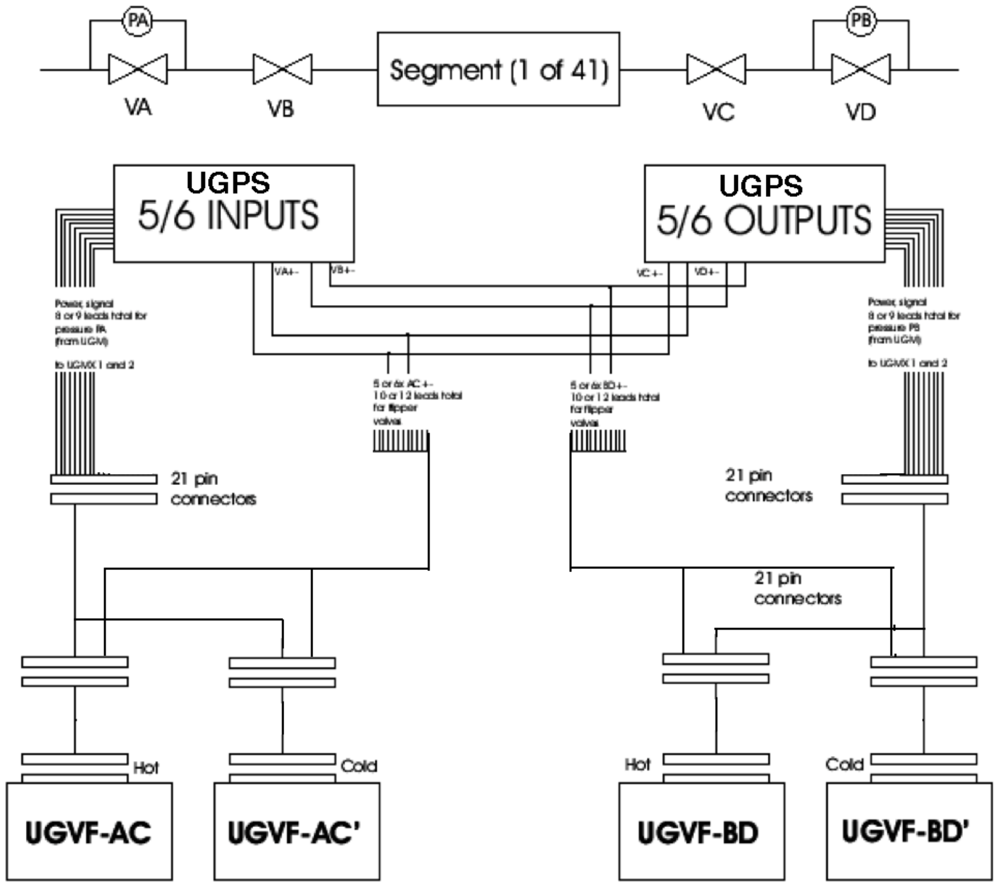

Fig. 7: Manifold electrical cabling layout.

g. High Voltage board (UHVG)

The UHVG board generates the high voltage that gives power to the Box-C monitor tubes. It is based on the LeCroy MHV100 High Voltage Controller/Generator [ref. 3], a custom CMOS integrated circuit that integrates all digital communications, digital-to-analog and analog-to-digital converters, the analog feedback loop and output drivers required to implement a single high voltage converter channel.
In the UHVG, 7 chips are used to implement 7 independent high voltage channels, that can be programmed and used independently.
A maximum of 2000 VDC can be delivered by each channel.

The main features that the board provides are the following:

- set overcurrent value (common to all channels)
- set overvoltage value (common to all channels)
- for each channel:
    - set high voltage value on the corresponding chip's DAC
    - enable HV output
    - disable HV output
    - read back the HV value set in the DAC

If a voltage value higher than the overvoltage is sent to output, the chip will trip.

The UHVG needs as power input 3.3 VDC and, in addition, 5.0 VDC and 120 VDC with a common, independent ground (AGND).

Table 19- UHVG commands

Command	Comment
Select LeCroy chip	select 1 to 7 HV output
Set HV	set HV output value
Set OVC	set overcurrent value
Set OVV	set overvoltage value
ENABLE	enable HV output
DISABLE	disable HV output
Get HV status	HV on/off
Get LC chip status	get error status if OV or OC

h. Power Distribution Box and DC-DC Converters (UGPD)

The UGPD (UG crate Power Distributor) generates all the necessary power supplies for the UG crate. It receives two +28 VDC lines from the PBD (Power Distribution Box); one line used to generate the "hot" voltages required in the UG crate and the second one for the "cold" modules.
Fig. 8 illustrates the block diagram of UGPD.

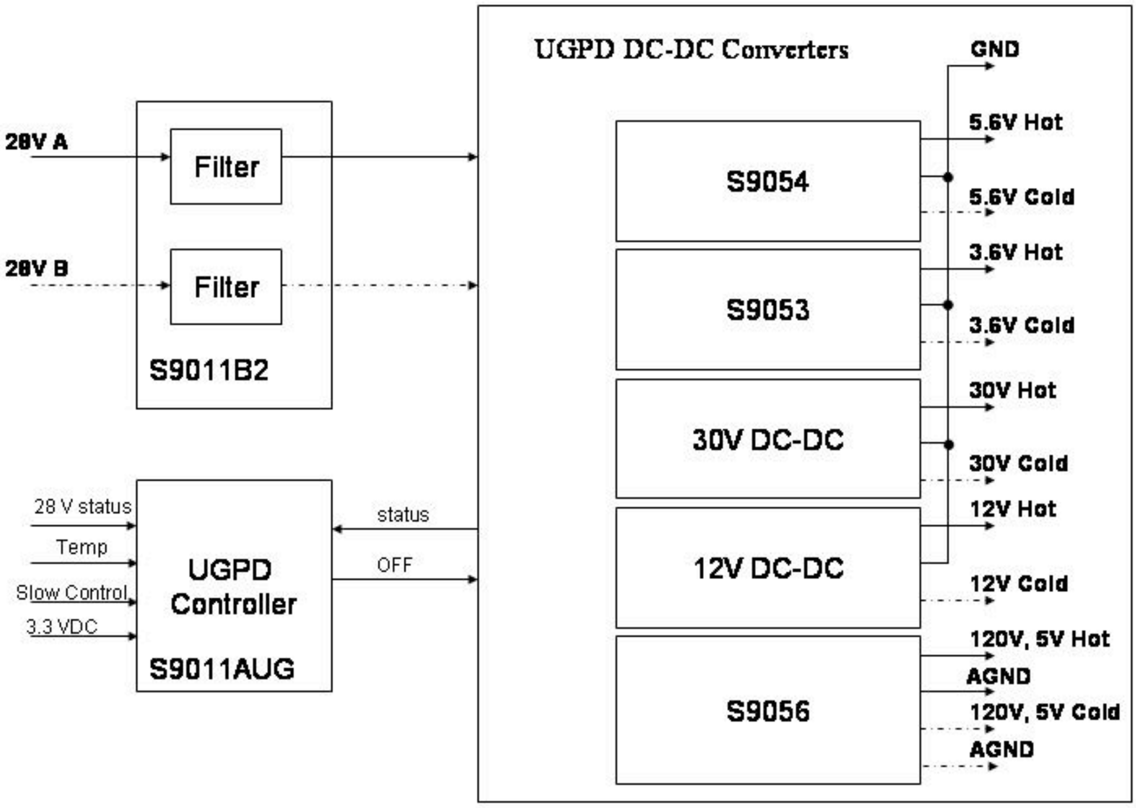

Fig. 8: Block diagram of the power distribution box UGPD.

The UGPD is made up of:

1 double filter board (CAEN S9011B2)

1 double control board (CAEN S9011AUG)

1 double +5.6 Volts converter (CAEN S9054)

1 double +3.6 Volts converter (CAEN S9053)

1 double +120 Volts converter (CAEN S9056)

2 +12 Volts converters (INTERPOINT SMLFHP2812S/HR)

2 +30 Volts converters (INTERPOINT SMLFHP2815D/HR)

The main functions that the controller board must perform are:

- controlling the DC-DC converter status
- controlling the DC-DC converters turning on/off
- controlling the UGPD boards temperature

The DC-DC converters chosen are compliant with the power supply requirements of the TRD Gas system stated in the following table.

Table 20- Power Supply requirements

Voltage/ destination	Nominal (W)	Peak (W)	Continuous (W)
30 Volt			
2xMarotta Valves	60.00	60.00	0.00
3xKulite PS	0.60	0.60	0.60
2xHeater	20.00	0.00	0.00
Pump (24V operation)	0.00	2.50	2.50
Electronics	1.20	1.20	1.20
Total	n.a.	64.30	4.30
12 Volt			
2xFlipper Valve	3.00	3.00	0.00
MCA	0.00	0.30	0.30
Spirometer (8,5V)	0.00	0.85	0.85
6xGP50	7.50	7.50	7.50
82x26PCC	2.00	2.00	2.00
Pump (12V operation)	0.00	1.25	1.25
Electronics	0.72	0.72	0.72
Total	n.a.	15.62	12.62
5 Volt			
Electronics	5.00	5.00	5.00
3,3 Volt			
Electronics	8.00	8.00	8.00
Gran total		**92.92**	**29.92**

i. Electromechanical components. Specifications

Table 21 – Components BOX-S

#	Item	n.	Power	Output	Input	Timing	Freq.	Redun.	Maker
1	Valves MV197	12	30W; @30±2V	switch on/off	18-30V	100±20 ms	5/d	yes	Marotta
2	Pressure GP50 Sensor 7900	4	0.14W @ 10±1 V	0-5V, ±0.1%	n.a.	< 4 ms	continuous	yes	GP:50
3	Pressure Sensor ETM-86-375-300A	3	@30±2V		n.a.				Kulite
4	Temperature Sensors DS1820	4					1/30 m		Dallas

Table 22 – Components BOX-C

#	Item	n.	Power	Output	Input	Timing	Freq.	Redun.	Maker
1	Valves MV100	4	30W @30±2V 1A	switch on/off	18-30V	100±10 ms	1/d	yes	Marotta
2	Pressure Sensor 7900	3	0.14W @10VDC	0-5V, 0.1%		< 4 ms	continuous	yes	GP:50
3	Flipper valves 6123	2	1.5 W @12V 125mA	n.a.	open: +12±1V close: -12±1V	<100ms	1/d	yes	Burkert
4	Diaphragm pump, UNMP30KNDC	2	2.5 W @ 24V 1.25 W @12V		0-12-24V±10%	CC	continuous half speed	yes	KNF-Neuenmberg
5	Spirometer 2115	1	4.8 W, @8V	RS-232			off when not in use	no	Square One Technology
6	MCA 8000A (?)	1	300 W @9V, AC adapter (115 V)	RS-232, 4.8-115.6 kb/s	0-+5 V or 0-+10 V	250 ns peak time	off when not in use	no	Amptek (?)
7	Monitor tubes (+1 µCi Fe^{55} source)	4	1100-1400 V				continuos	no	MIT
8	UGHV	1	120V				continuos	no	Aachen
9	Preamp monitor tubes	1	20mA @5V	n.a.	n.a	CC	off when not in use	no	MIT

Table 23 – Components Manifolds

#	Item	n.	Power	Output	Input	Timing	Freq.	Redun.	Maker
1	Pressure Sensors 26PC-CCFA6D	82	25 mW @10±1 V	0-0.1 V		1±0.1ms	1/5 min	yes	Honeywell
2	Flipper valves 6123	164	1.5 W@12±1V 125mA			<100 ms	1/d	yes	Burkert

Note: Burkert valves could be closed all at once within few seconds

5. Control System Testing and Verification

Tests for qualification and acceptance should conform to the following guidelines:

- For EMC qualification test, the Space Station Electromagnetic Emission and Susceptibility Requirement (SSP30237) paragraphs RS02, RS03, RE02 should be used.
- For vibration qualification and acceptance test, a 3D sine-random-sine test sequence with sine 10-2000 Hz constant acceleration of 0.5 g and 90 seconds random peak vibration level of 0.4 g^2/Hz from 80 to 500 Hz, g_{rms} equal to 6.8 g, should be used.
- For qualification thermo-vacuum test, a pressure value p<10-5 mbar, a temperature range of -45 to 85 °C and a test time of 36 hours will be required.
- For acceptance thermo-vacuum test a pressure value p<10-5 mbar, a temperature range of -40 to 80 °C and a test time of 24 hours will be required.

6. Control System Operations

The TRD Gas System is controlled by the AMS-02 slow control system via the UGBC, UGBS and UGVF cards in the TRD gas system electronics crate. The system has been designed in such a way to be safe in all circumstances, even when the AMS-02 is out of contact with ground control or the ISS, or during interruption of power to the TRD gas system.

a. Ground operations

The ground operations consist of three tasks: TRD testing, gas filling and gas recovery. TRD testing is the operation of the TRD during functional testing of AMS-02 prior to processing and is similar to on-orbit operation.

From the functional point of view, the tasks are described in the TRD Gas System document [ref.1]. Software commands and procedures are described in the TRD GAS Slow Control Commands and Operations [ref.2].

b. Flight operations

Flight operations can be classified in four categories: normal data taking, normal filling, startup and shutdown. Normal data taking is the normal operation of AMS-02 with the gas circulating via Box-C and Box-S dormant. For Box-C and Manifolds, normal in-flight operation consists of recording information from all pressure and temperature sensors continuously and to periodically check the gas analyzer and the multichannel analyzer.

From the functional point of view, the tasks are described in the TRD Gas System document [ref.1]. Software commands and procedures are described in the TRD GAS Slow Control Commands and Operations [ref.2].

c. List of macro commands

Commands to Box-S

- BSC1. Open Xe vessel to fill mixing vessel D
- BSC2. Open CO_2 vessel to fill mixing vessel D
- BSC3. Power on heaters
- BSC4. Monitor pressure in D vessel
- BSC5. Open valves V4/V6 to fill Box-C
- BSC6. Open valves V4/V18 to empty/adjust pressure in mixing vessel D
- BSC7. Pressure and temperature measurements
- BSC8. High rate scan cycle of pressure and temperature measurement
- BSC9. Low rate scan cycle of pressure and temperature measurement

Commands to Box-C

- BCC1. Start gas circulation, open valve V8, power on pump CP1 or CP2
- BCC2. Vary pump speed
- BCC3. Pressure and temperature measurements
- BCC4. Monitor gas composition

Commands to Manifold

- BMC1. Leak test in segment n
- BMC2. Close segment n
- BMC3. Test valves open/close
- BMC4. Pressure monitoring

NB: each command has an alternative command for failure recovery.

7. Gas Control System Safety

During Flight:

The gas system electronics is designed so that the gas system is automatically taken to a "Safe Mode" in case of communication failure.

For Box-S this means all valves closed. The Marotta MV197 solenoid valves in Box-S are normally closed and remain in that state if there is a power loss.

For Box-C *to be defined*

For Manifolds *to be defined*

Appendices

References

[1] U.Becker, J.Burger, P.Fisher: *TRD Gas System Summary and Specifications*; MIT internal note, April 4, 2003.
[2] F. Bucci, S. Gentile, A. Lebedev, F. R. Spada: *WINCAN v.2.2 A Linux-based Slow Control interface for the AMS TRD Gas System;* INFN RM1 internal note, April 20, 2006.
[3] http://ams.cern.ch/AMS/Electronics/Slow/MHV100.pdf

Weight Estimate for Gas Control System

Crate xPD	Qty	Function (tot det)	Slots	Cards	USCM	CAN	28V in	Nominal Heat (W) Unit	Nominal Heat (W) Sum	CURRENT Kg Unit	CURRENT Kg Subsys
UG-Crate	1	TRD Gas Elect	12	11	2	2		13.2	18.7	6.5	11.3
UGPD			7	7			2	5.5		4.8	
Gas System											