(Draft V.1.1)

Daya Bay RPC Gas System User's Manual

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1. Introduction

The baseline RPC gas mixture is Ar/R134A/Isobutane/SF6 (65.5/30/4/0.5) [1], which has been approved by Daya Bay safety officer as a non-flammable gas.

The RPC gas system will be similar to that used in the BELLE [2] and BABAR [3] experiments, in which a gas mixing system distributes the gas mixture to the individual RPCs through simple "flow resistors", with the output flow from each flow branch being separately monitored by a low-cost digital bubbler [4].

Mixing of the chamber gases is performed with mass flow controllers. The electronic bubbler system monitors the chamber gas flow by counting gas bubbles in a small oil bubbler as they pass a photogate. The output gas bubbling rate will be sent to a centralized MySQL database. Any other authorized networked PC can obtain all data through this MySQL database. Four gases will be input from four auto/manual switchover panels to minimize interruptions of the gas flow during chamber operation. The gas mixing ratio is also tested once every two hours by a local GC (Varian GC430). The test results are stored into the same MySQL database. On the local gas control PC the bubbling rate and gas mixing ratio are displayed and updated.

An extensive detector safety and fire safety system with status monitors and interlocks is implemented via four gas control crates: gas flowmeter crate; gas pressure crate; gas system power supply crate and the gas system status crate.

1. Daya Bay RPC gas system

The gas system building blocks are shown in figure 1. In the following sections we'll describe each block in details.

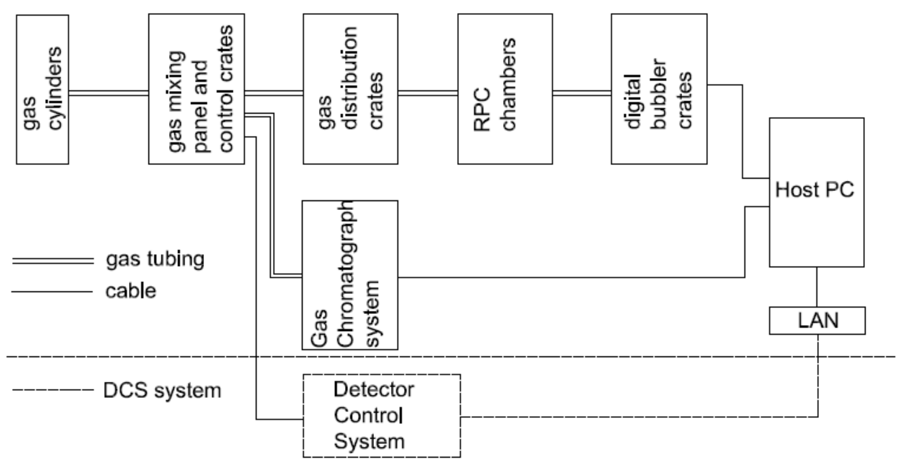


Fig. 1. Daya Bay RPC gas system building blocks.

2.1 Gas cylinders

2.1.1. Gas cylinder switchover panel

Four gases are used for Daya Bay RPC gas mixture. To eliminate the down time when the depleted gas cylinder is replaced, for each gas line a gas switchover panel is equipped. For the argon gas an automatic gas switchover panel is used, it is shown in figure 2. For the other three gases the manual switchover panel is employed, shown in figure 3.

2.1.1.1. Automatic switchover panel

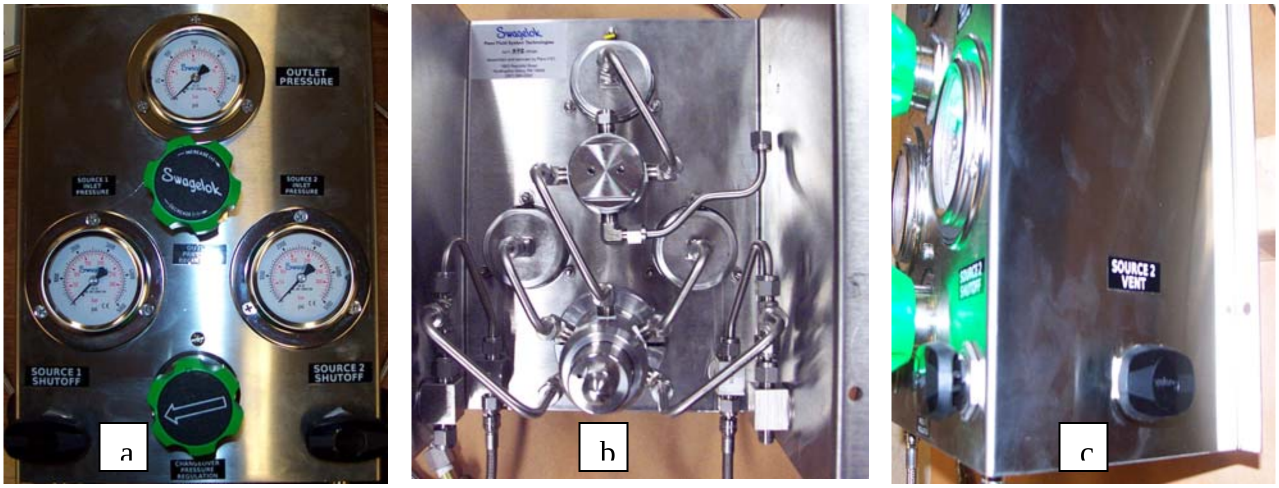


Fig. 2. Argon cylinder automatic switchover panel. (a) Front; (b) Rear; (c) Side.

Operation procedure of this panel is as follows:
The illustration of various parts of this switchover panel is sketched in figure 3.

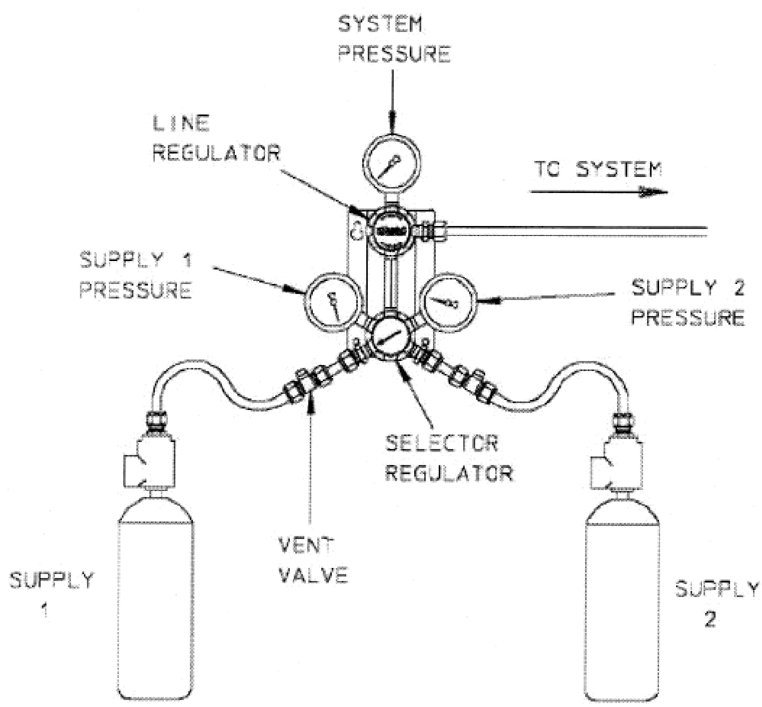


Fig. 3. Illustration of various parts of argon automatic switchover panel.

Once installed and before pressurizing , ensure that:

1. The line regulator is in the shut or closed position by turning the hand knob counter clockwise until it stops;
2. The selector regulator knob is fully turned to the inlet port of the bottle that you wish to use first.

After connect the argon gas manifolds to each side of the panel, and all argon gas cylinders are hooked up to the manifolds, use the ResTek Leak Detector careful check and fix any leakage immediately.

Purge the connecting pipe every time the gas cylinder has been replaced and the air has entered the pipe. Each side the panel provided a VENT valve, which is shown in figure 2(c). Open the inlet isolation valve on both supply sides, then slowly open the vent valve, let argon gas flowing through the pipe for a few seconds, thus the leftover air will be carried away from the pipe. Close the vent valve afterwards. Repeat this procedure for other side of the panel. Now the manifold is fully pressurized and ready to supply the downstream system.

The outlet pressure will be shown on the line regulator and controlled by its knob. rotating the knob clockwise to increase the pressure.

When the supply side pressure drops to 100 psig, the selector regulator is then internally switched to the other side of the gas supply. The respective inlet pressure gauges show two sides gas pressures, therefore the operator will know which side is depleted, and can replace the bottles.

To change the depleted bottles:

1. Shut off the main isolation valve on the depleted side;
2. Turn the selector knob so that it is now pointing towards the full bottles side;
3. Shut off the valves on all bottles of depleted side;
4. Replace the depleted bottles;
5. Open the main isolation valve on the just replaced bottle’s side;
6. Purge this side supply line.

Now this side is fully prepared to be used in next round of switchover.

2.1.1.2. Manual switchover panel

Two types of manual switchover panel are used, one with the solenoid valve at the outlet, shown in figure 4, is used for Isobutane gas; the other one w/o solenoid valve is used for both R134a and SF6.

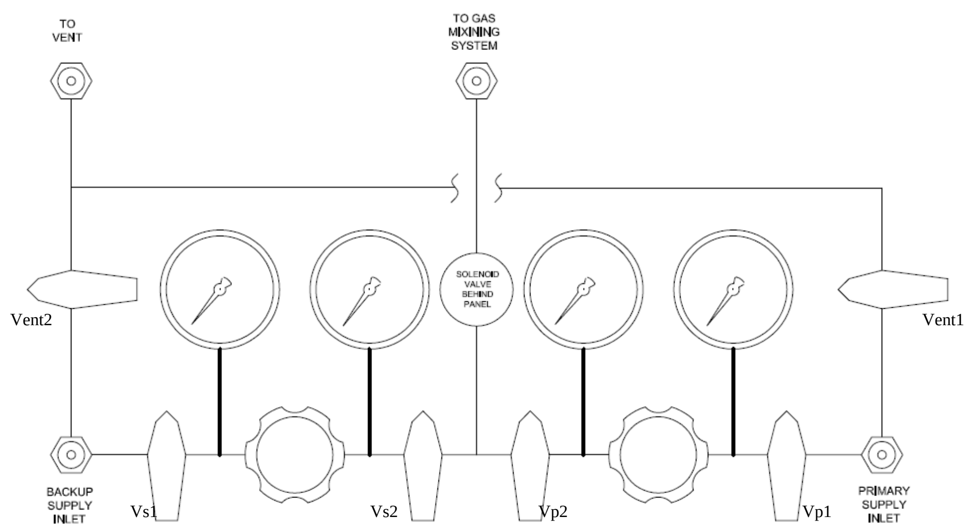


Fig. 4. Manual gas switchover panel used for isobutane.

The isobutane gas switchover panel is installed in the gas cabinet, shown in figure 5.

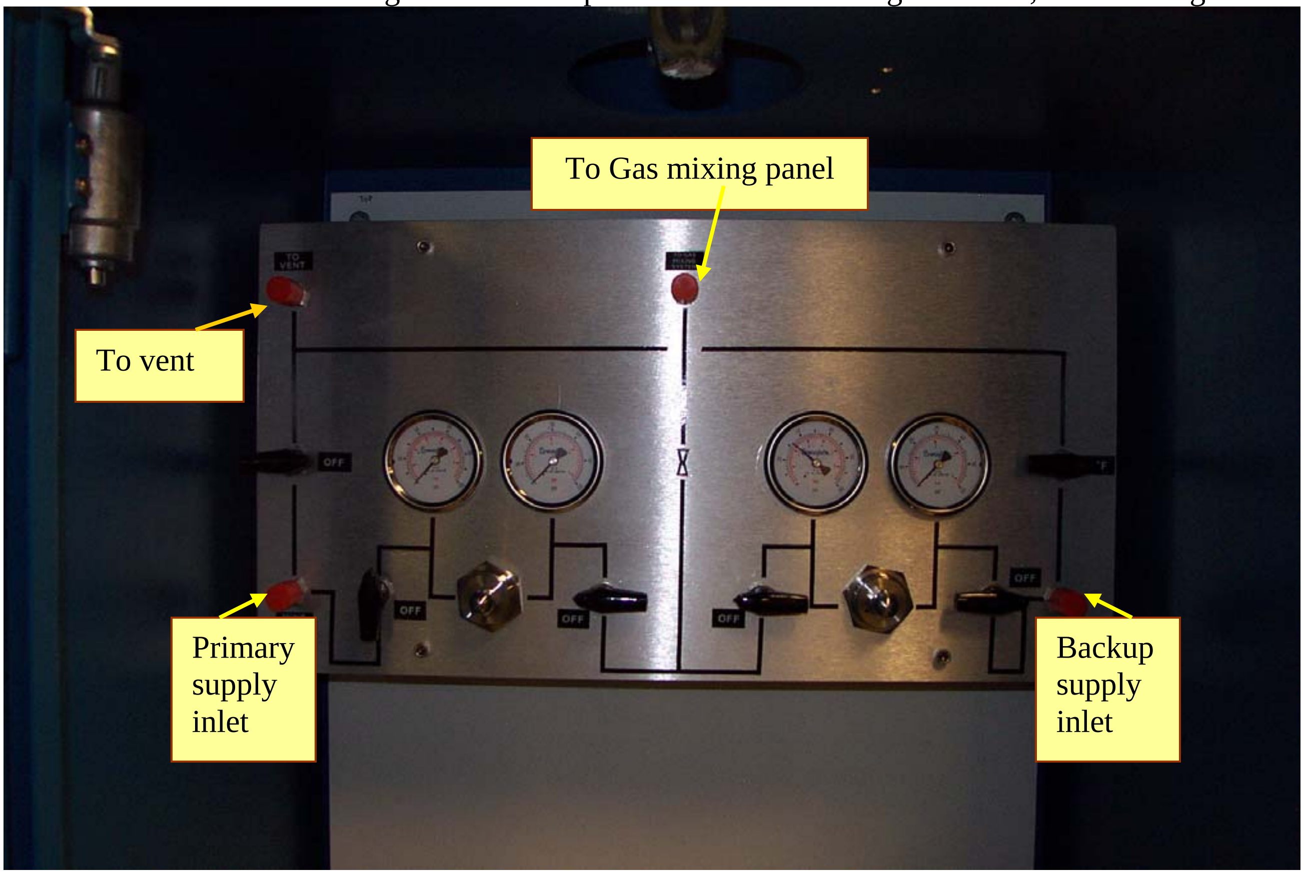


Fig. 5. Isobutane gas switchover panel mounted inside of the gas cabinet.

The solenoid valve controls the isobutane gas outlet. In emergency case the gas control system will shutoff the power of this valve, therefore no isobutane gas will flow into the gas mixing panel.

Operation procedure of this panel is as follows:

The primary gas supply cylinder is weighted by an explosion proof digital scale, when its weight drops to a preset limit, the status crate of gas control system will show a warning light, at the same time the detector control system will issue a warning sign on shifter's monitoring screen to remind the shift taker to replace the depleted isobutane cylinder. Follow the steps below to replace the cylinder:

1, Check the weight of the backup isobutane cylinder, make sure this cylinder has enough isobutane left over. If its net weight is less than 5lb, replace this cylinder first, then replace the primary cylinder, otherwise direct proceed to step 2;

2, To replace the depleted isobutane cylinder first shutoff Vp1 and Vp2 valves, then open Vs1 and Vs2 valves. Now the backup cylinder is temporally supplying isobutane to the gas mixing panel;

3, Close the isobutane cylinder valve. Disconnect the flexible hose from the cylinder, remove the depleted cylinder from the scale, hook up a new cylinder. Open the cylinder valve, check the leakage to make sure there is no any detectable leakage with Restek leak detector on any relevant connector;

4, Open Vent1 valve for few seconds to purge the air in the gas pipe, then shutoff Vent1;

5, Close Vs1 and Vs2, open Vp1 and Vp2. Now the primary isobutane cylinder is back to work.

The operation for other two gas switchover panels (R134A and SF6) is the same.

2.1.2. Digital scale

Two types of digital scale are used in this system. An explosion proof scale (Force Flow SOLO XT 200MAR-1) is used for isobutane cylinder and two regular digital scales (Scaletron Model 2310) are used for R134A and SF6.

2.1.2.1. Explosion proof digital scale

This scale is installed inside of the gas cabinet. A pneumatic load cell is mounted underneath of the platform, through a 12 ft long PVC covered copper pipe the cell is connected to a SOLO XT indicator, which is mounted on the gas status crate.

The warning limit for the net weight is set at 5lb. Please don't touch any button on the SOLO XT indicator or you'll alter the setting, which may cause the scale malfunction. There are two "C" cell ALKALINE batteries located behind the keypad/display. To replace the depleted batteries, unscrew bezel ring and allow keypad/display to fall forward. Remove old batteries and replace with new ALKALINE batteries. Carefully reinstall keypad/display. Screw bezel ring down until finger tight to insure proper sealing.

The PVC coated copper pipe is filled with fluid, which is used to transmit the pressure from load cell to the sensor in the indicator. Please don't disassemble the fittings on this pipe, otherwise the fluid in the tube will be leaking out, the scale will loose its accuracy.

Detailed operation manual can be found in the Appendix (7).

2.1.2.2. Regular digital scale

The other two digital scales are Scaletron model 2310 electronic single cylinder scale, they are used for R134A and SF6. The procedure for replacing the depleted cylinder is similar to the previous scale, we won't repeat here. Detailed information about this scale can be found in the Appendix (8).

2.2 Gas mixing and control system

After the cylinder switchover panels, four gases are connected to the inlets on the gas mixing panel via 6mm Swagelok fittings.

This system consists of gas mixing panel and four crates: flowmeter crate, pressure crate, power supply crate and gas status crate.

2.2.1. Gas mixing system

2.2.1.1. Gas mixing panel

The picture of the gas mixing panel is shown in figure 6 and the block diagram is shown in figure 7. Figure 8 shows the schematic of the mixing panel.

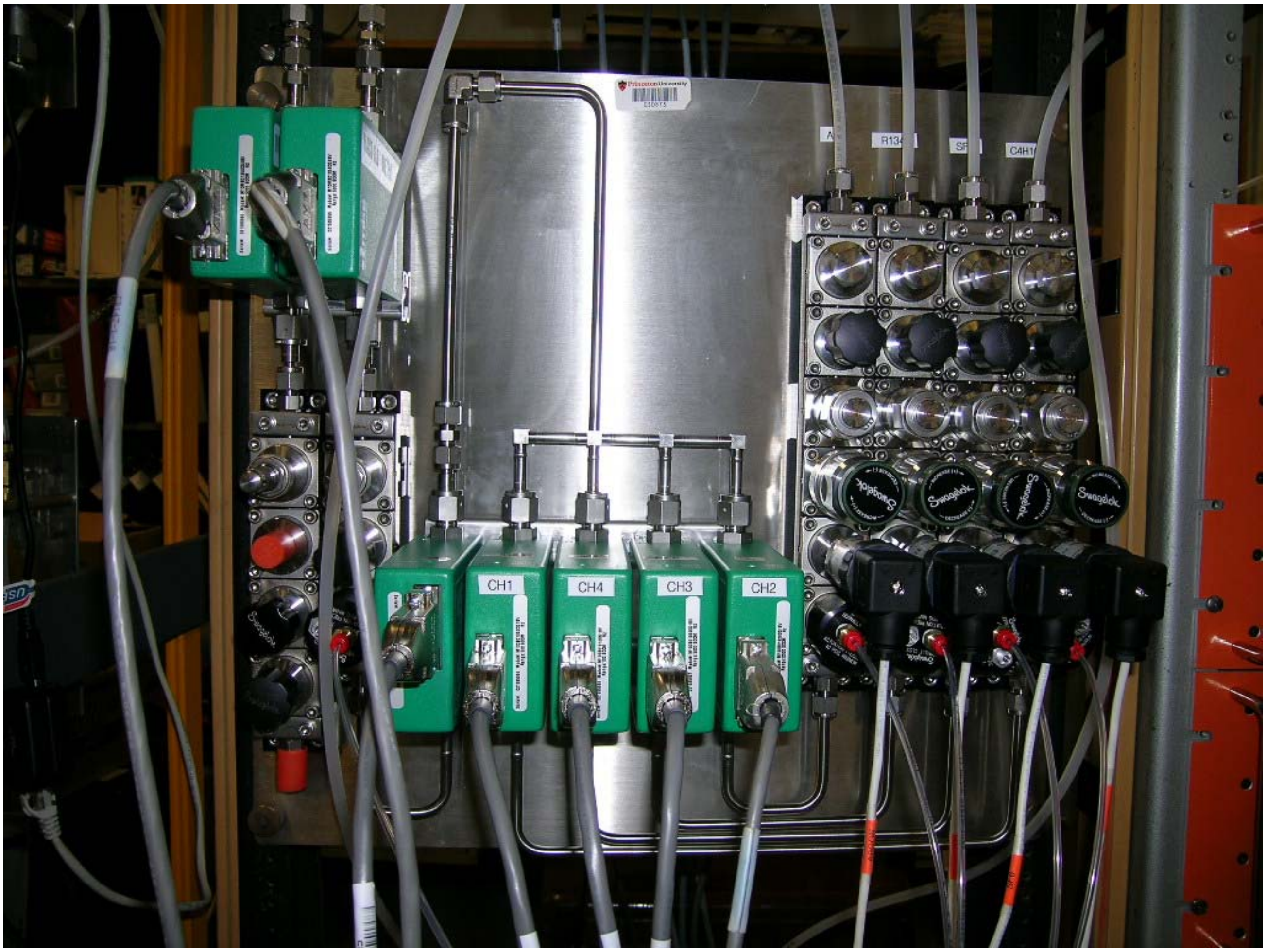
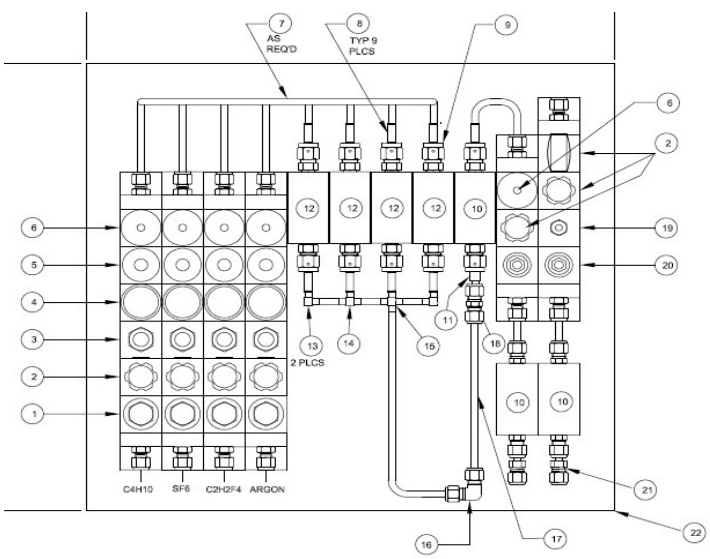


Fig. 6. Gas mixing panel (Penn Fluid System, ASY-550).



ITEM	P/N	QTY
1	SS-MPC-CH4-2	4
2	SS-MPC-ODK-2	7
3	SS-MPC-4TF-2-05	4
4	KCP1EF5MA2P10000	4
5	PTI-S-NG50-35AQ	4
6	SS-MPC-T2A-2-C-PI	5
7	SS-T4-S-035 (1/4 x 035 SS Tubing)	As Req'd
8	316L-4-VCO-3A	9
9	SS-4-VCO-4	10
10	M10MB01353CG3BV (MKS Mass-Flo Meter)	3
11	SS-4-VCO-3-4TA	1
12	M100B013xxCG1BV (MFM where xx = 52, 12, 53, 23)	4
13	6LV-4MW-9	1
14	6LV-4MW-3	3
15	6LV-4MW-4	1
16	SS-400-9	1
17	K-04669-56 MIXER, 1/4" Tube	1
19	SS-MPC-DM-1-S4	1
18	SS-400-6	1
20	SS-MPC-M-2	2
21	SS-6MO-R-4 (6mm ADAPTER)	2
22	Panel, 19" W x 18" H, 304 Stainless Steel	1
	MPC Flow Components	As Req'd
	MPC Substrate	As Req'd

Fig. 7. Block diagram of the gas mixing panel.

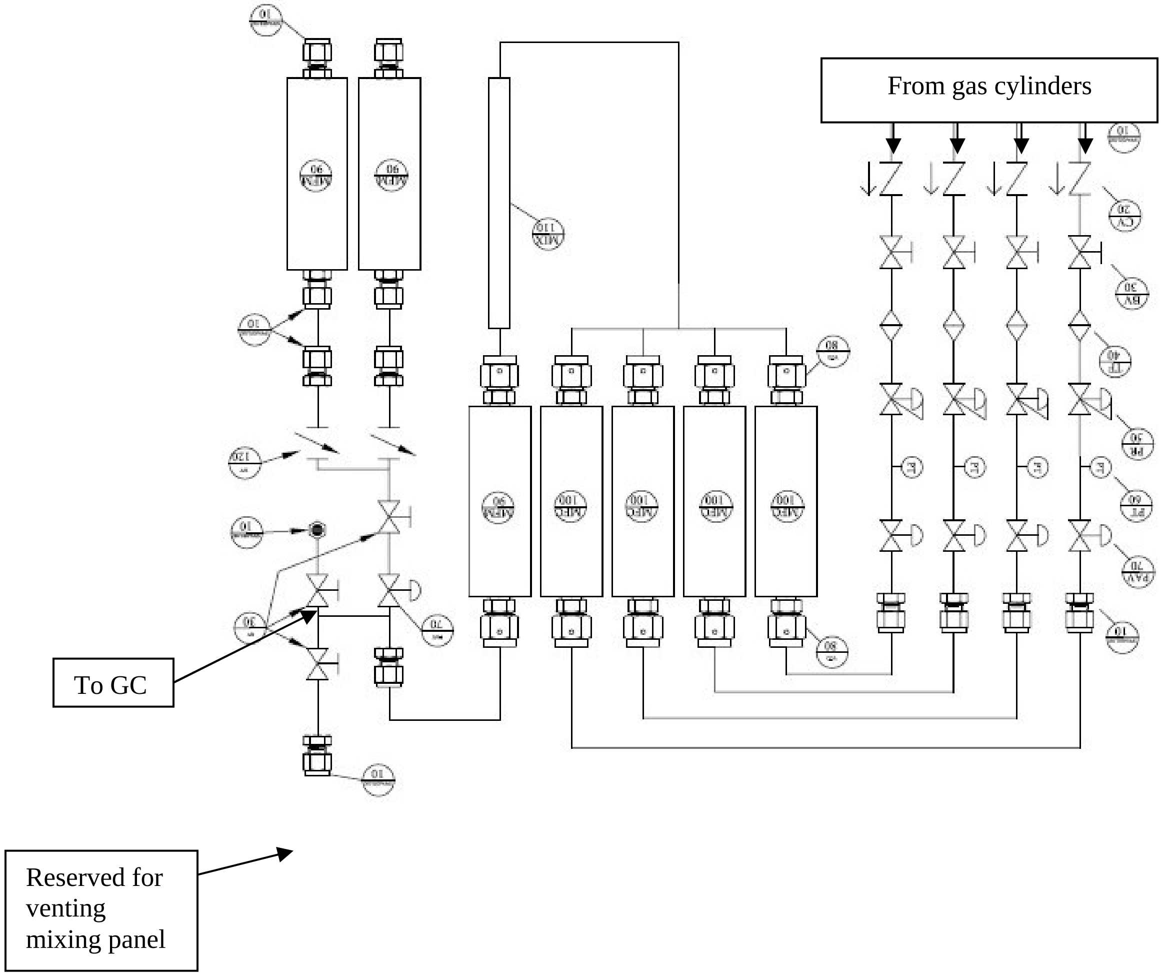


Fig. 8. Schematic of the gas mixing panel.

The gas mixing panel has incorporated the BaBar RPC/LST gas system experience and Daya Bay RPC system's requirement. This mixing panel can mix 4 gases, including small amount of SF_6, which is in 0.5% of total flow rate level. To mitigate the possible down time due to malfunction of the gas flow controllers the major part of the system is constructed with the Modular Platform Components(MPC), and surface-mounted on a substrate. All components can be replaced from top that makes replacement easier and faster. There are two additional outlet ports on the lower-left corner in figure 8. One port is connected to a GC system to check the gas mixing ratio once every two hours. The other port is reserved for venting the gas mixing system in certain circumstance. Please be advised that when you are doing the venting additional gas tubing must be provided between this port and the room ventilation pipe.

All four gas inlets are controlled by pneumatic valves (labeled as pav/70 in figure 8), which are actuated by pressurized air or nitrogen cylinder at 100psi via a solenoid valve. The later is controlled by the power supply crate that will be mentioned later. With this arrangement all gas components will be turn on/off at the same time, the mixing ratio won't be changing after the system interruption.

The pressure sensors (pt/60 in figure 8) will send the output signal to the gas pressure crate, where the signals are compared to the preset normal pressure operating range and displayed on the Simpson controllers.

Mass flow controllers send the measured signal to the flowmeter crate , where the flow rates are checked if they are within the preset normal ranges.

The mass flow controllers are MKS products. Four mass flow controllers are controlled by MKS 247D, see figure 9.

Full flow ranges of the gas flow controllers and flowmeters are as follows:

Ch.1 Tetrafluoroethane ($C_2H_2F_4$) - 0-5000 sccm N_2 Flow
Ch.2 Sulfur Hexafluoride (SF_6) - 0-100 sccm N_2 Flow
Ch.3 Isobutane (C_4H_{10}) - 0-500 sccm N_2 Flow
Ch.4 Argon (Ar) - 0-2000 sccm N_2 Flow

The gas flow controllers have been calibrated by soap bubbler. The calibrated Scaling Control Fact (SCF) for four channels is summarized in Table 1.

Channel #	Gas	Full range for N_2 (sccm)	Gauge factor	Gas Correction Factor*	Calculated Scaling Control Factor (SCF)**	Set the rear Scaling Control Pot***	Calibrated at flow rate (sccm)
1	C_4H_{10}	500	50	0.273	13.65	152	150
2	Ar	2000	200	1.4119	300	035	1000,250
3	R134A	5000	50	0.3115	16.8	175	500
4	SF_6	100	100	0.2502	26.99	035	20

Table 1. Gas flow controller's parameters.

*Obtained from:
http://www.teledyne-hi.com/Manual/Flow/111-052007%20Nall%20Mass%20Flowmeter.pdf
The Gas Correction Factor listed in the table is calculated for 0ºC temperature, for other temperature it should be corrected as follows: G.C.F. (@T_1) = G.C.F.(@0 ºC) x (273 + T_1)/273.
** The Scaling Control Factor (SCF) are shown on the 247D rear panel potentiometers. The SCF is the *product* of the Gauge Factor for the MFC in use and the Gas Correction Factor for the gas in use:

SCALING CONTROL FACTOR = GAUGE FACTOR x GAS CORRECTION FACTOR

The calculated SCF in the table assumes T_1 = 21.5 ºC.
In this table the calculated SCFs and the set SCFs have some discrepancy. The set SCF means adjusting the rear Scaling Control Pot (full range is 1000) to this value the displayed flow rate will be same as calibrated flow rate.
*** There are certain level of discrepancy between the set value and the calculated value. Be aware when we make the comparison, we only care about three numbers in the set value, not their absolute value. For example, we now set the rear pot of argon channel at 035, we also can set it at 350, the front LED will give you one more digit display accuracy, but limited by the maximum number 2000 can be displayed, if we do need the flow rate greater than 2000sccm, we have to reduce the rear pot to 035 as we do here.

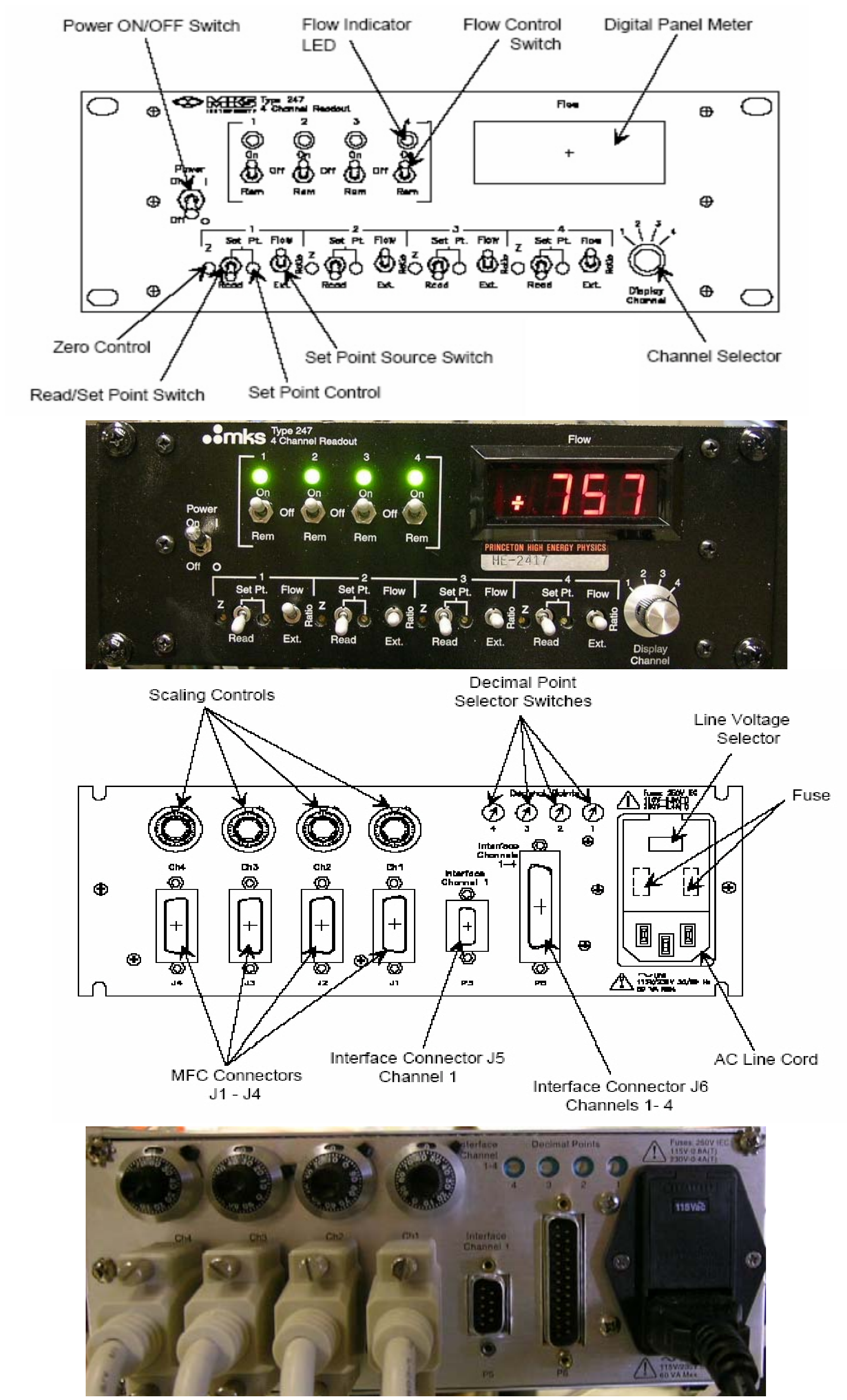


Fig.9. MKS 247D four-channel readout box, (Top) front panel, (Bottom) rear panel.

Detailed information on using this box can be found from “MKS Type 247D Four-Channel Readout Instruction Manual”. Here we just give a brief description of this control box. MKS 247D is designed as power supply/readout and set point source for four analog mass flow controllers. The 247D unit consists of a power supply, four signal conditioning channels, four set point circuits, and a digital panel meter (DPM) to display the flow rate of any single channel of a MFC.

The rear panel provides four connectors, via cables they are connected to four mass flow controllers.

The following test results are obtained with Daya Bay gas mixture. Since isobutane is a flammable gas, its ratio in a gas mixture needs to be strictly controlled below its flammable limit. Unless you are experts and authorized to do the system adjustment, you are not supposed to touch ANY of the dials, knobs and switches on both front and rear panels. Otherwise you might change the mixing ratio and make a flammable gas mixture without your notice. Please take it seriously! The only thing you are supposed to do if you are on shift is choosing each channel by rotating the channel select knob, and read the digital meter. Compare these numbers with the preset value, and the displayed numbers on “Gas Flowmeter Crate”, all three sets of numbers should be very close. The Simpson controllers on “Gas Flowmeter Crate” have been adjusted at the total flow rate of 2000sccm. If you are running the system at different flow rate, these readings might be somewhat different from 247D and could be a few percent of deviation. This is due to the fact that Simpson Controller is only making linear extrapolation for running at different full ranges, but 247D will have more sophisticated correction.

The operation of MKS 247D is set in the ratio mode, the channel #1 (Isobutane) is the master channel; the other three channels are slaves. On the front panel the Set Point Source Switch is set at “Ratio” position for channel #2, 3, 4, and at “Flow” position for channel #1. If you need to change the total flow rate and maintain the mixing ratio unchanged, you only need to change the flow rate of the first channel by adjusting its potentiometer “Set point” on front panel of 247D.

A Varian 430 GC system has been used to verify the mixing ratio. Test results show that from 100sccm to 1000sccm of the total flow rate the mixing ratio holds reasonably well as shown in figure 10(A). We also tested the gas mixture in different total flow rate for a 2m x 1m IHEP RPC, the plateau curves are very similar, see figure 10(B). That means the gas mixing ratios in the mixtures are pretty much similar.

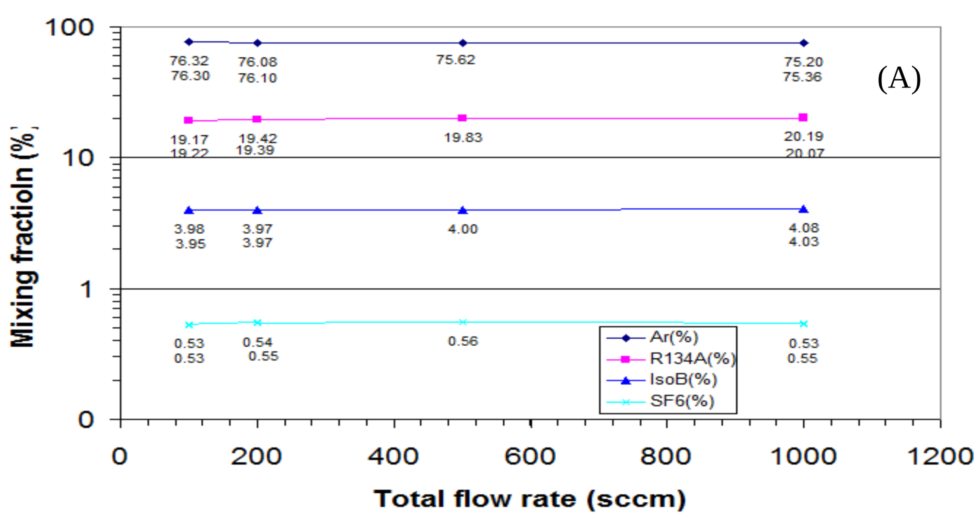


Fig. 10. (A) Gas mixing fraction in different total flow rates (OPERA gas mixture).

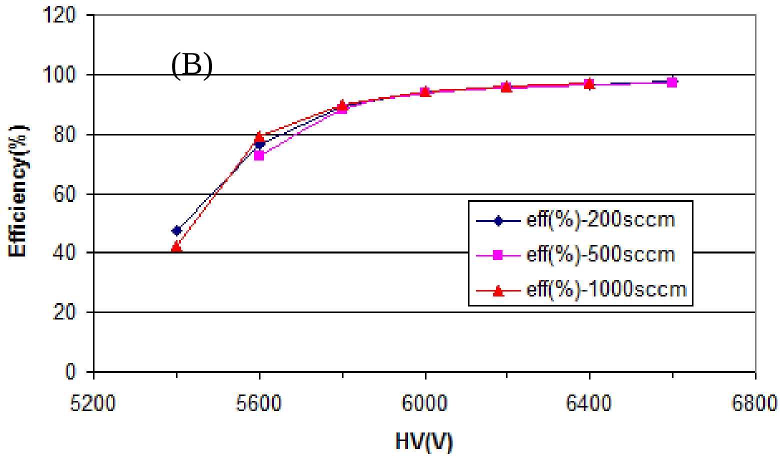


Fig. 10. (B) Efficiency plateau of a 2m x 1m RPC chamber in different total flow rate (OPERA gas mixture).

2.2.1.2. Water bubbler

Based on BaBar RPC running experience we decide to add ~4000ppm water vapor into the gas mixture. The original gas mixture is split into two branches: one branch of the gas will be bubbling through water. The water vapor saturated gas mixture is then mixed with the dry gas mixture in the other branch. By adjusting the flow rate in two branches we can easily obtain the water content in the gas. Figure 11 shows a picture of this system.

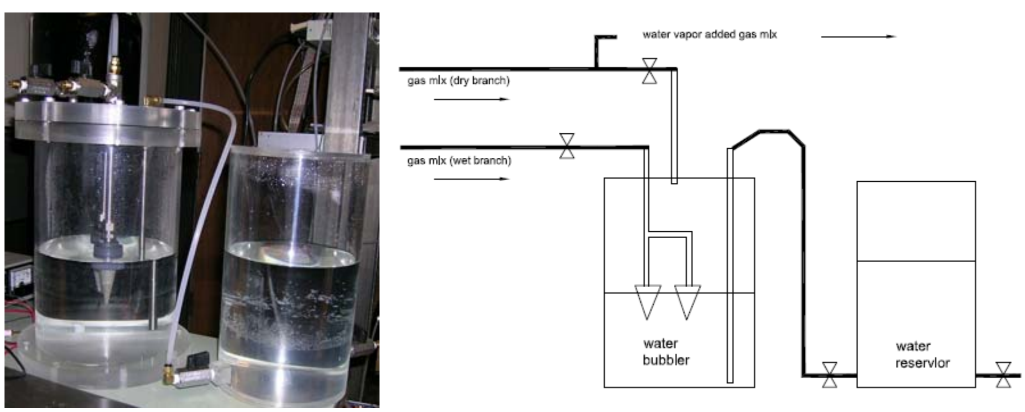


Fig. 11. Water bubbler.

The left tank is the water bubbler, gas mixture is flowing through a sintered metallic bubbler head and entering the water, getting saturated water vapor in it, then flowing out the tank. The right tank is used as a water reservoir. There is a tube connecting two tanks through a valve. Keep the water level in the reservoir always higher then the level in the water bubbler. Anytime if we need to add water into the bubbler, we only need to open the valve and let the water flow from reservoir to bubbler.

2.2.2. Gas control system

The gas control system includes four crates, they are: Gas flowmeter crate; Gas pressure crate; Power crate and Gas system status crate. The logic diagram is shown in figure 12.

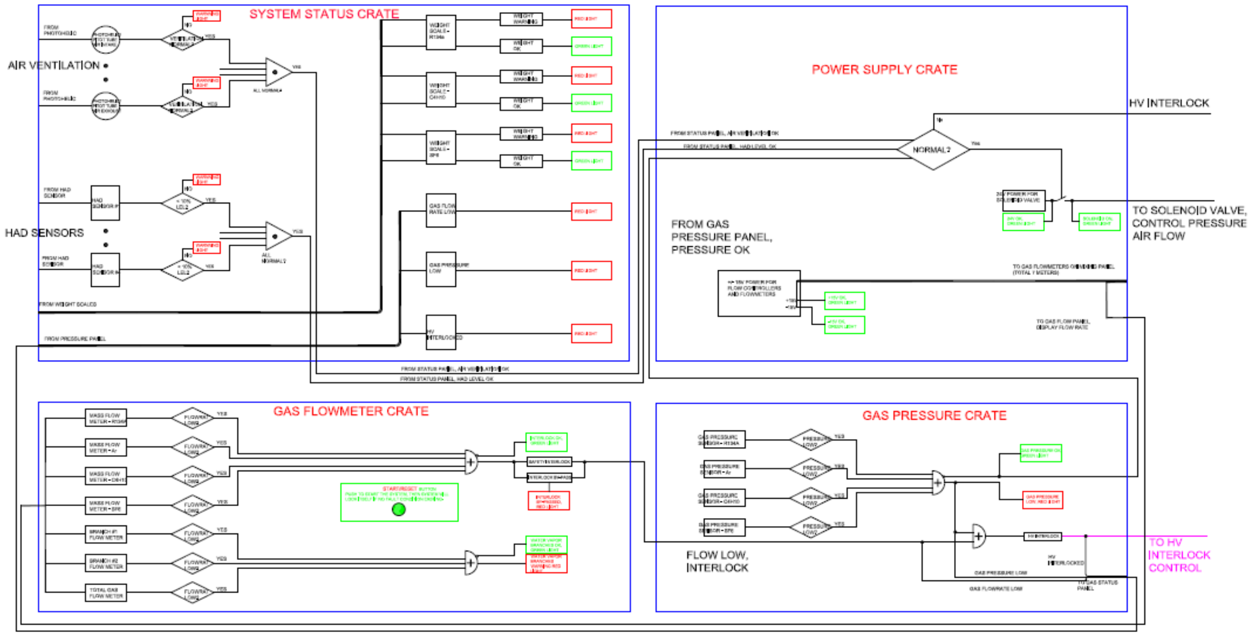


Fig. 12. Logic block diagram of four gas control crates.

2.2.2.1. Gas flowmeter crate

The gas flowmeter crate is used to display the gas flow rate from four mass flow controllers and three flow meters, which are for the water vapor control branches: total, dry branch and water vapor added branch. Simpson model H335 controller unit is used for the flow rate display and safety control. A normal flow rate band is defined for each of seven flow meters through the Simpson controller, if the flow rate is out of this preset band, the build-in relay of the Simpson controller will be acting accordingly. Figure 13 shows the schematic of this crate[1].

[1] See Appendix (2) Flowmeter_E.pdf for large scale schematics.

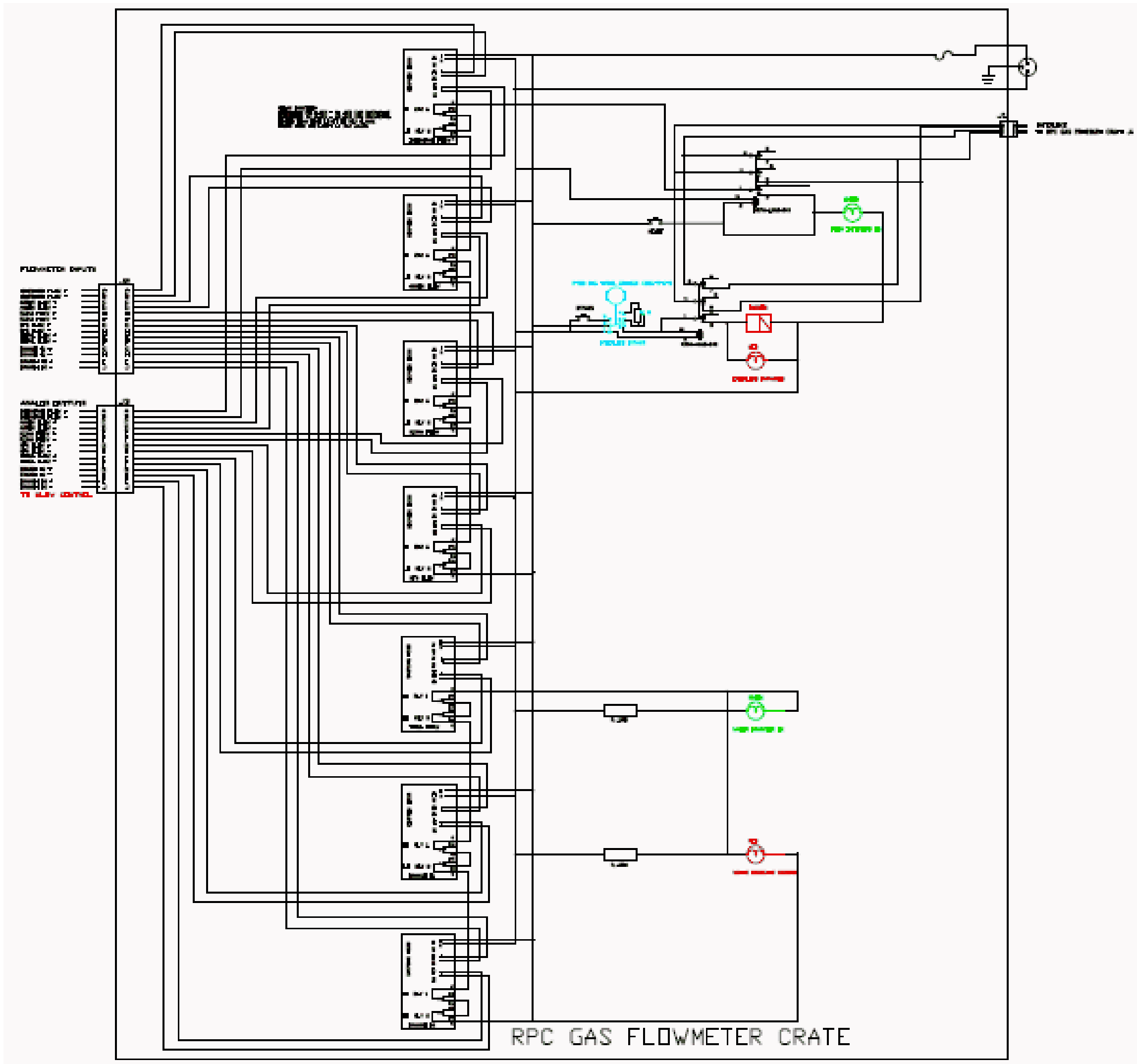


Fig. 13. Gas flow meter crate.

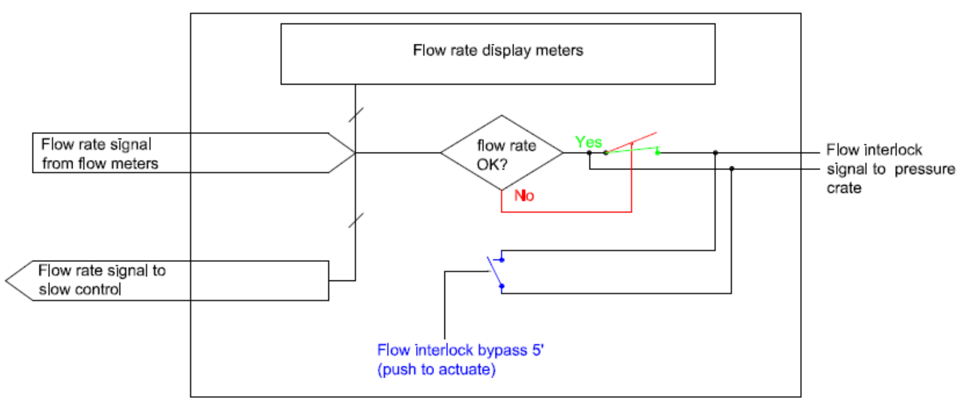


Fig. 14. Logic diagram of the flowmeter crate.

This crate displays the gas flow rate measured by the flow controllers/meters, controls a relay contact that closes on normal flow rate and opens on bad flow rate. Send this signal to gas pressure crate, which will control the solenoid valve. The abnormal flow rate/pressure signal will shut off the solenoid valve, which in turn will close all gas inlets to the mixing panel. In reality the gas flow rate/pressure fluctuation due to power supply glitch and/or atmospheric pressure sudden change is quite often during certain season. To eliminate this type of interfere there is a "BYPASS TIMER" push button, push this button can bypass the status check logic for 5 minutes (meanwhile a buzzer will be actuated to remind you that the bypass is acting), keep the solenoid valves open for such time period. Usually within this period the environmental fluctuation would calm down and return to normal, therefore the gas system will continually operate w/o interrupt. When you see all flow rates and pressures show normal value, the Simpsons show no warning signs on the right side bar, you should push the RESET/START button, and the "Flow Interlock OK" green light should be back on.

There is a RESET/START button on the front panel. When the entire gas system is just powered up, push and hold this button down until all seven flow rates displayed on the Simpson meters reach normal value (no warning sign on any of the meters), then release the button. By doing this the system will lock itself in a normal operation mode until the next abnormal state occurs. After you push this button, the green light labeled as "Flow Interlock OK" should be on. Also the water branches green light should be on, red light should be off.

The water branches are used for adding water vapor into the gas mixture. There are three Simpson meters to display the flow rate for branch #1, #2 and the total. Branch #1 gas mixture will be bubbling through water, then combine with the dry gas mixture from branch #2. The metering valves on branch #1 and #2 can adjust the flow ratio between them, thus adjust the water vapor content in the mixture.

Figure 15 shows the picture of the front and rear panels of the flowmeter crate.

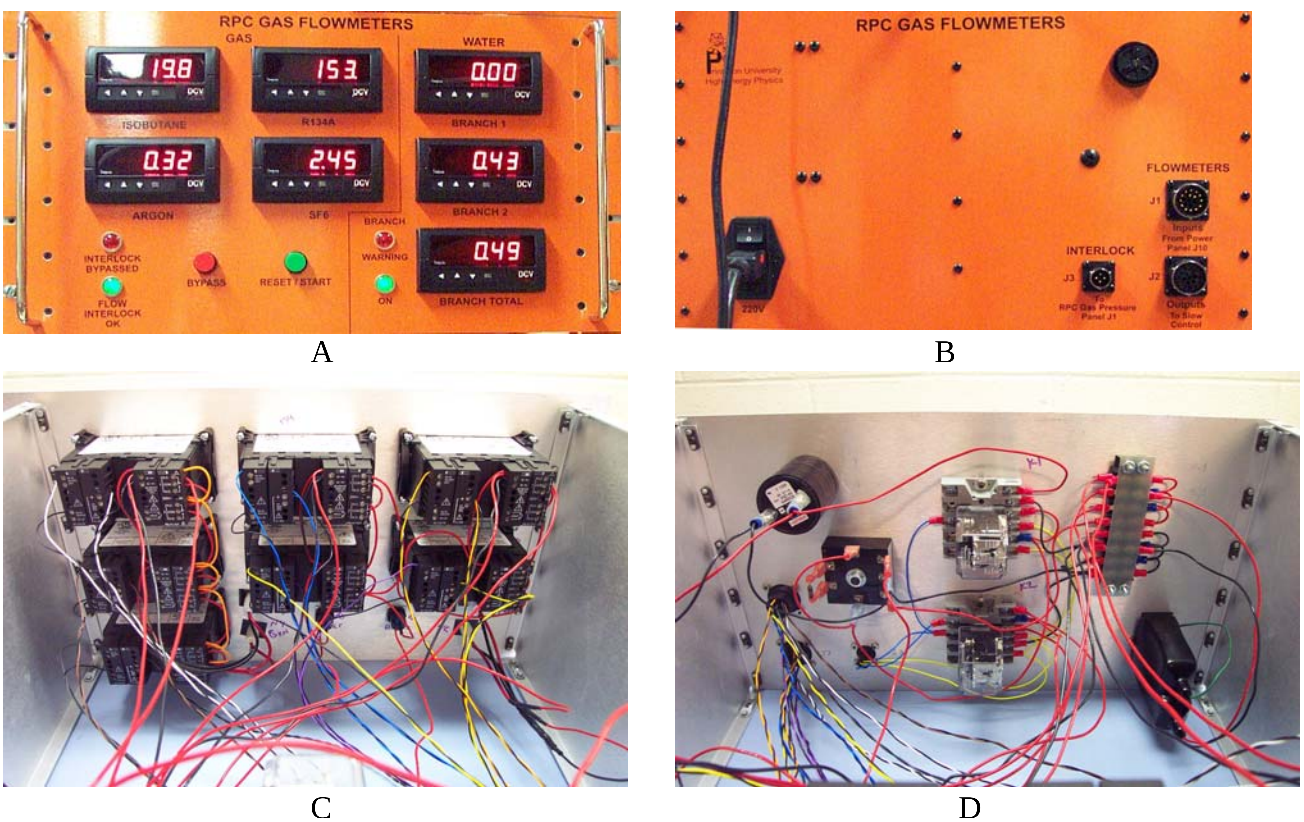


Fig. 15. Gas flowmeter crate, A. Front; B. Rear; C. Internal front; D. Internal rear.

2.2.2.2. Gas pressure crate

The gas pressure crate is used for displaying the gas pressure at the upper stream of the flow controller for each gas. The gas pressure sensor is Swagelok S model transducer that uses psi Gauge reference (PTI-S-NG50-35AQ)[2], it means the ambient pressure will read as 0 psi. When any gas shows lower than preset pressure limit, this crate will generate warning signal, shut off the solenoid valve that will in turn shut off all gas inlet ports on the gas mixing panel. Figure 16 shows the schematics of this crate[3].

The pressure can be adjusted by four gas regulators on the gas mixing panel. All gas pressures are maintained around 20 psi, don't let the gas pressure goes higher than 23 psi since at higher pressure isobutane might be liquefied at lower temperature. Go to web site http://e-data.jp/vpcal2/e/ to calculate the vapor pressure for Isobutane. At 20 ºC the vapor pressure of isobutane is 2267.55mmHg, if the ambient pressure is 760mmHg, the pressure sensor should read as ~29 psi. At 15 ºC the vapor pressure should read as 22.88 psi. If we set the pressure at 23 psi, when the room temperature drops to 15 ºC, Isobutane vapor will start to be liquefied.

Only the lower limit for the pressure display/control Simpsons is set, the upper limits are set at much higher value, under no circumstance such over pressure warning will occur. If the pressure is below the lower limit it means the gas cylinder will be completely depleted in short time, you should check the cylinder immediately. In normal case this scenario shouldn't happen because we have set the automatic switchover pressure at much higher value for argon and weight limit at ~2lb for other three gases. Before hitting these four preset limits the gas pressure should be stable.

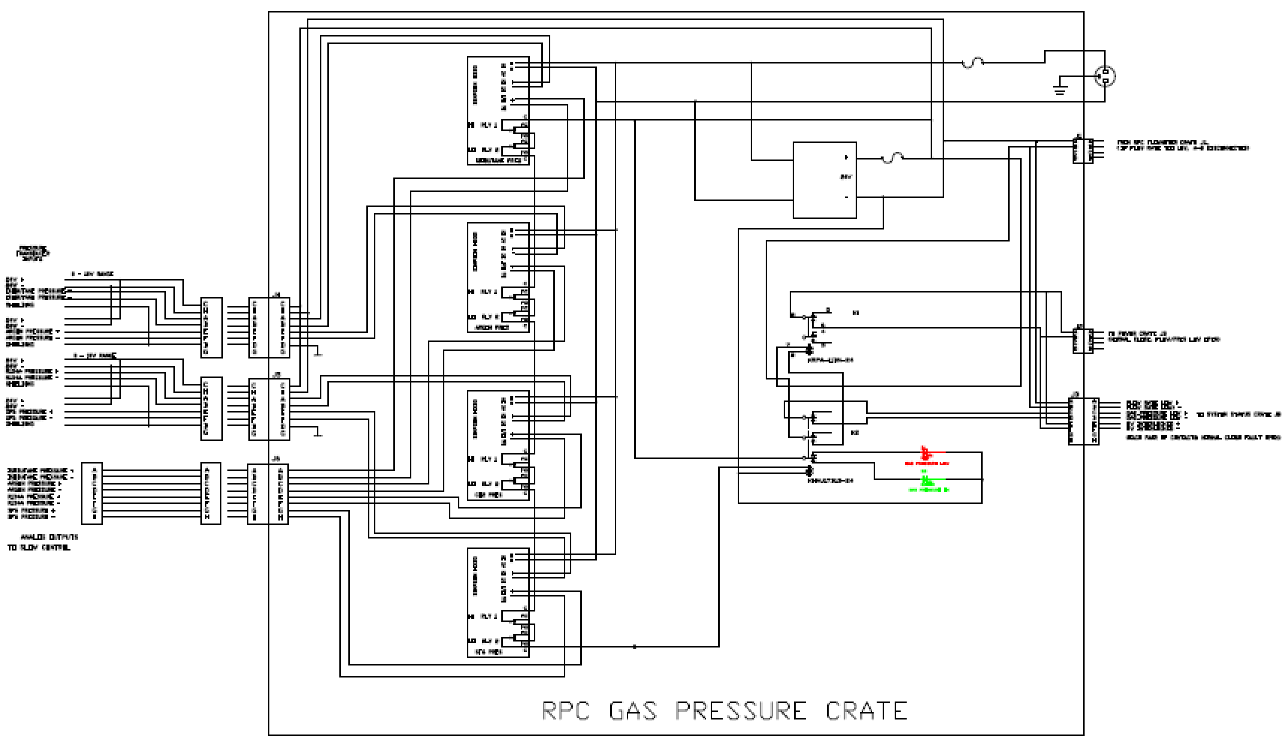


Fig. 16. Gas pressure crate.

[2] See the catalog page of the pressure sensor: http://www.swagelok.com/downloads/webcatalogs/EN/MS-02-225.pdf
[3] See Appendix (3) Pressure-E.pdf for details.

The logic diagram of this crate is shown in figure 17.

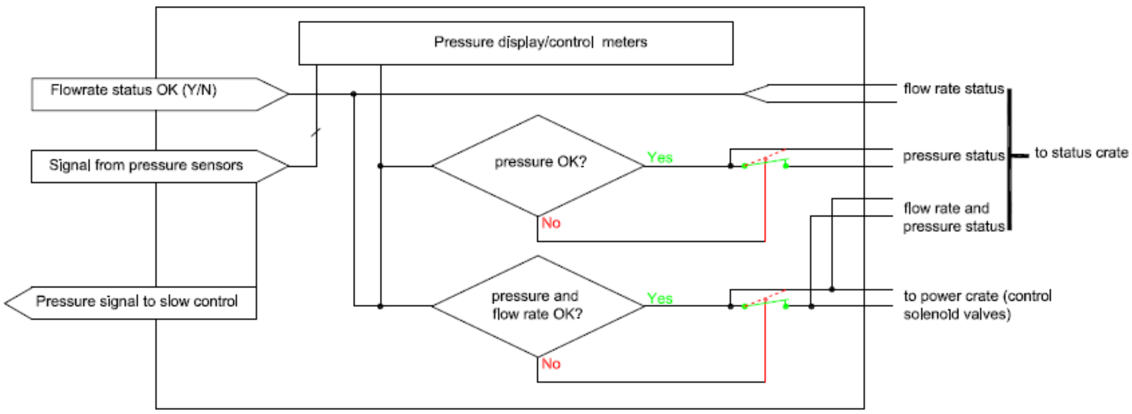


Fig. 17. Logic diagram of the gas pressure crate.

The gas pressure display and control is also accomplished by Simpson H335 controllers. In case of either flow rate or gas pressure is out of normal range this crate will send signal to power supply crate to shut off the solenoid valve and consequently shut off all four gases. This crate sends the analog signals of gas pressure to slow control system for on-line display.

The front and rear panels for the pressure crate is shown in figure 18.

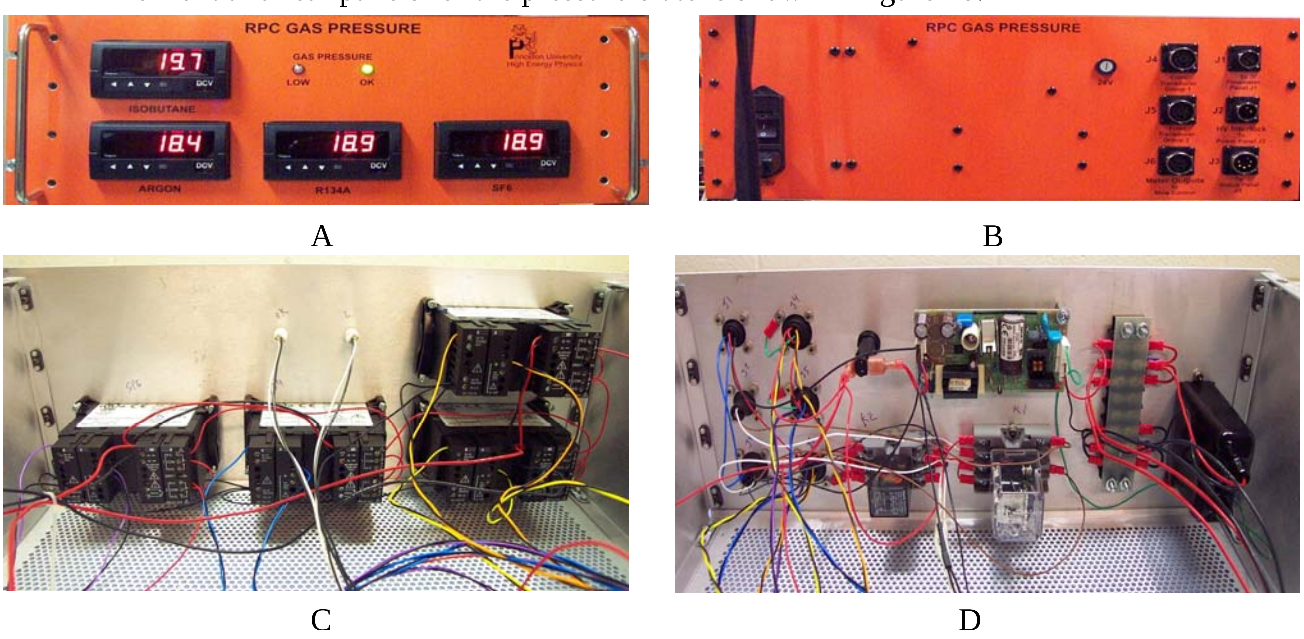


Fig. 18. Gas pressure crate, A. Front; B. Rear; C. Internal front; D. Internal rear.

2.2.2.3. Gas system power supply crate

The power supply crate provides the DC power to all flow meters, solenoid valves. Figure 19 shows its schematics[4].

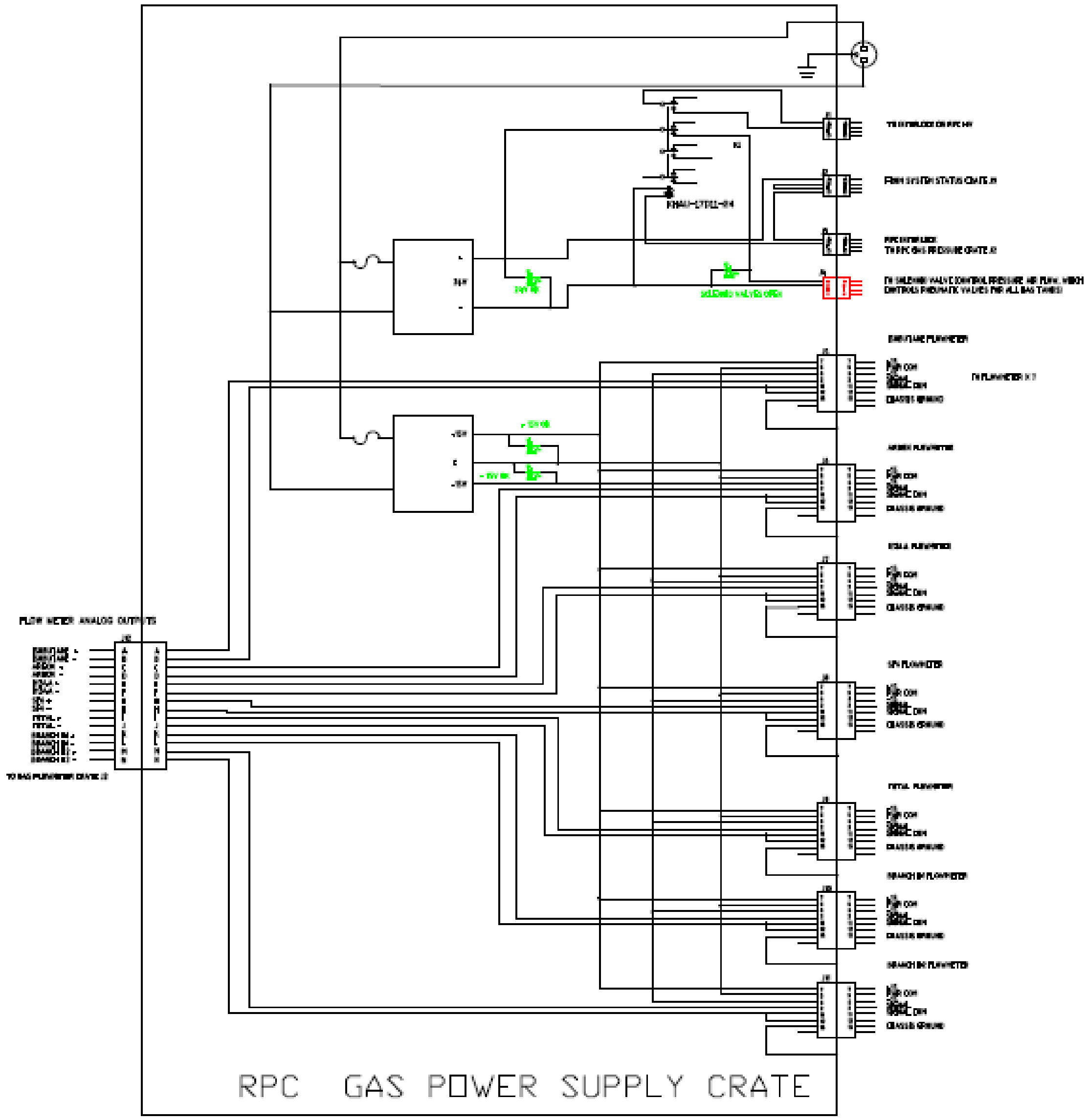


Fig. 19. Gas system power supply crate.

The logic diagram of this crate is shown in figure 20.

[4] See Appendix (4) Power-E.pdf for details.

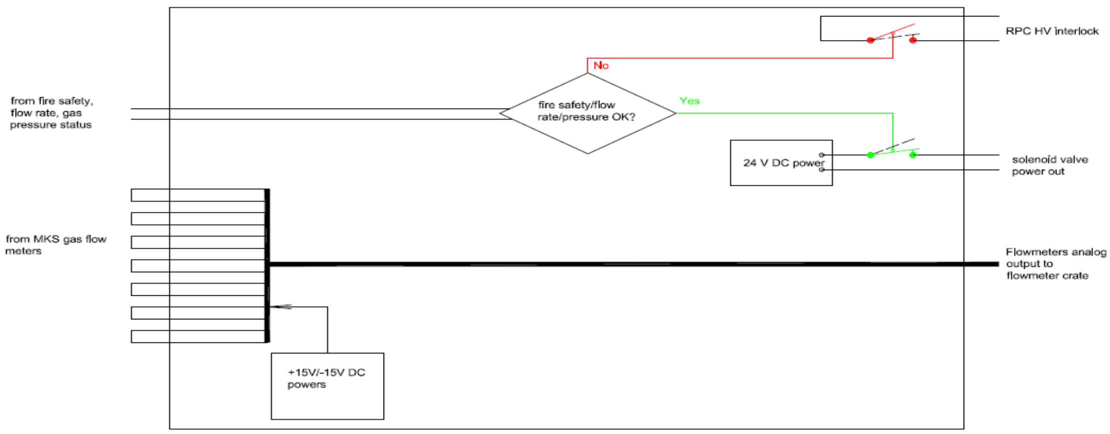


Fig. 20. Logic diagram of the gas system power supply crate.

Power supply crate provides DC power (+/- 15V) to three MKS flow meters. It also provides +24V DC power to the solenoid valve. It takes status information from flow crate, pressure crate, then controls RPC HV interlock and solenoid power output. In case of any abnormal state occurring, such as low flow rate, low pressure warning, it will actuate the RPC HV interlock, shut off solenoid valve.

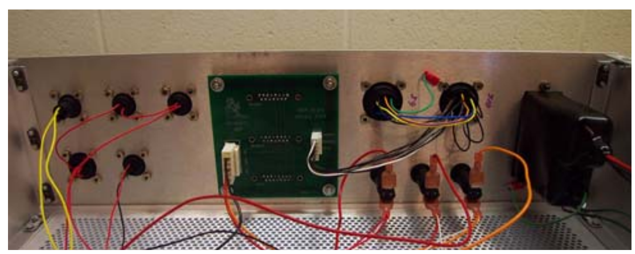
There are four lights on the front panel: +15V, -15V, +24V, (solenoid) Valves open. In normal case all of them should be on.

Figure 21 shows the front and rear panels of the power supply crate.

A

B

C



D

Fig. 21. Gas power supply crate, A. Front; B. Rear; C. Internal front; D. Internal rear.

2.2.2.4. Gas status crate

Fig. 22 shows the gas status crate.

The front panel of the gas status crate is divided into two regions: the right region displays RPC gas system status and the left region is fire safety system status.

Gas system status region shows: 1, Actual weights of isobutane, R134A and SF6 gas cylinders and their weight low warning LEDs. Any of these three gas cylinders hits its preset low weight limit, this warning red LED will light up to warn you it is the time for replacing the depleted gas cylinder. Two adjustable black knobs are used to zeroing R134A and SF6 scales. Place an empty gas cylinder on scale then adjust the knob until displaying 0.0 on the weight window. By doing this the measured weight on the scale will be the net weight of the content left in the cylinder. The low weight limit has been set at ~1kg. If the net weight reaches ~1kg, the respective weight low LED will turn on. The isobutane scale is different because of its flammable nature. A Force Flow XT200MAR-1GC digital cylinder scale is used. The cabinet platform with hydraulic load cell is installed inside of the gas cabinet. Since there is no electrical element is used for the load cell it is safe in the hazardous environment. The SOLO XT digital indicator is mounted in the Gas Status Crate, which is located outside of the gas cabinet, through a 6 ft long tubing filled with pneumatic fluid the indicator is connected to the load cell. Although a quick connector is used at the indicator side, we can easily disconnect the tubing from the indicator, but don’t leave it disconnected for more than 5 minutes. 2, Relative humidity of the fresh gas mixture (flowing into the RPC module) and the return gas mixture (flowing out the RPC module). Two gas sub-branches are monitored. By rotating the Gas Humidity switch the % of relative humidity for channel #1 or channel #2 will be displayed on the Simpson controllers.

Fire safety system region displays % of LEL measured by HAD #1 and #2, gas cabinet air ventilation velocity. HAD sensor #1 is installed at lower section inside of the gas cabinet, HAD sensor #2 is mounted outside of the gas cabinet. They have been calibrated to % of isobutane LEL. When the measured level reaches 10% LEL, the warning LED will turn on. If the level reaches 25% LEL, the solenoid valve that controls the opening of all four pneumatic valves in front of each gas inlet will shut off, thus all gas inlet ports on the gas mixing panel will shut off. The gas cabinet air ventilation is monitored by a Pitot tube, which is installed inside of 6” diameter ventilation pipe. This 6’ long ventilation pipe is hooked up to the exhausting port on the top of the gas cabinet. At the end of this pipe a 6” diameter explosion proof fan is used to suck the air out of the gas cabinet. By measuring the air flow velocity in the ventilation pipe we’ll be able to tell if the air flow rate meets the Uniform Fire Code requirement: 150 - 200 linear ft/min of air through the window opening. The window opening is 13” × 17” = 7.8 × area of 6” diameter pipe, therefore the minimum air flow velocity needs to be ~ 1100 ft/min. The manufacture provided curves of air velocity vs. gauge reading with Pitot tube[5] are shown in Fig. 23. We set the ventilation warning limit at 0.075” water, which is corresponding to 1100 ft/min air flow velocity.

[5] http://www.dwyer-inst.com/PDF_files/160_IOM.pdf

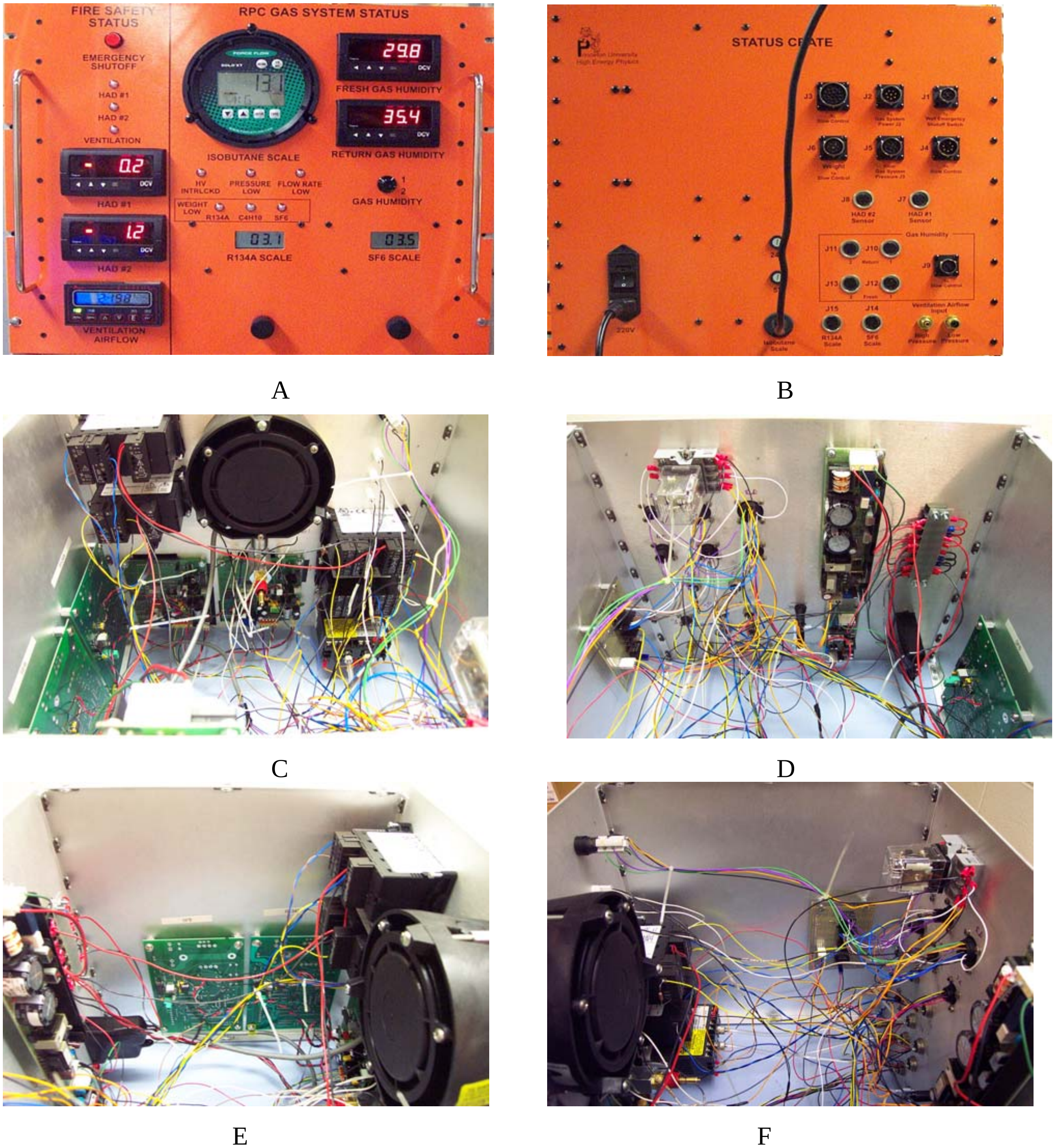


Fig. 22. Gas status crate, A. Front; B. Rear; C. Internal front; D. Internal rear; E. Internal left; F. Internal right.

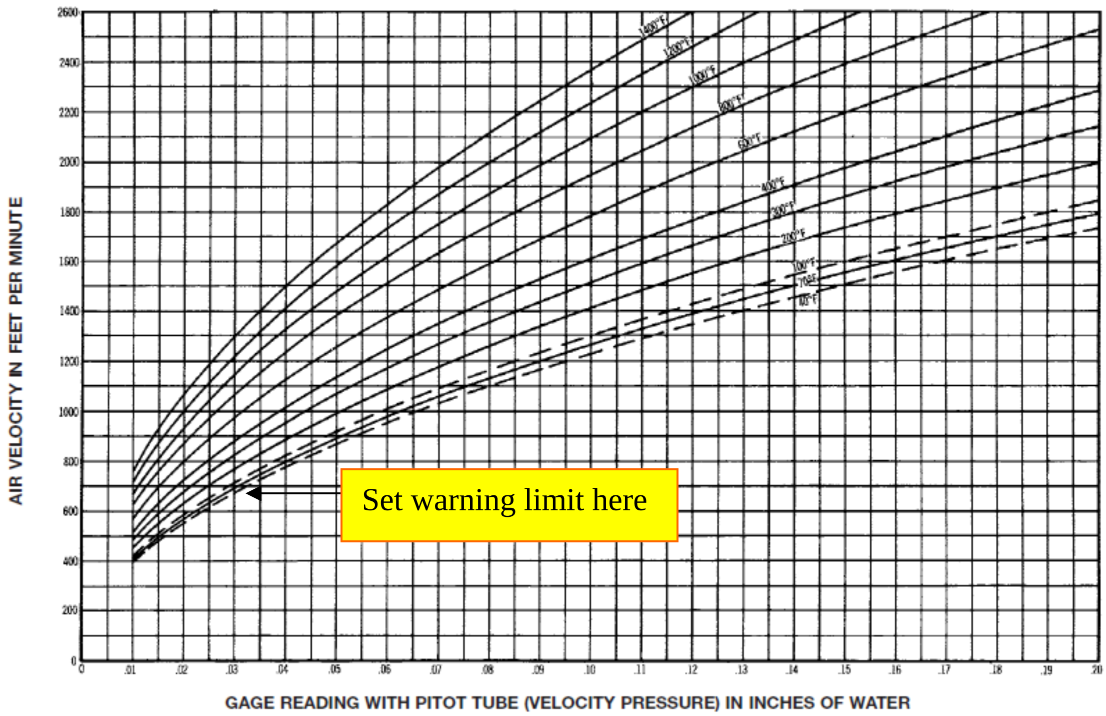


Fig. 23. Air velocity vs. gauge reading with Pitot tube.

The gas mixture flowing out of the mixing system needs to be distributed to every RPC in an experimental hall. The design goal of the gas distribution system can be summarized as follows:

- Uniformly distribute the gas mixture to every RPC in the system;
- Divide the RPC gas flow in one experimental hall into several panel-branches, of which each will be further split to 16 sub-branches. In case of one sub-branch having leaky RPC the rest of the system should not be affected;
- At the end of each sub-branch should implement a monitoring device to check the gas tightness for this sub-branch.

The Daya Bay near hall gas distribution/digital bubbler system consists of seven panel-branches. A sketch diagram of this system is shown in figure 24.

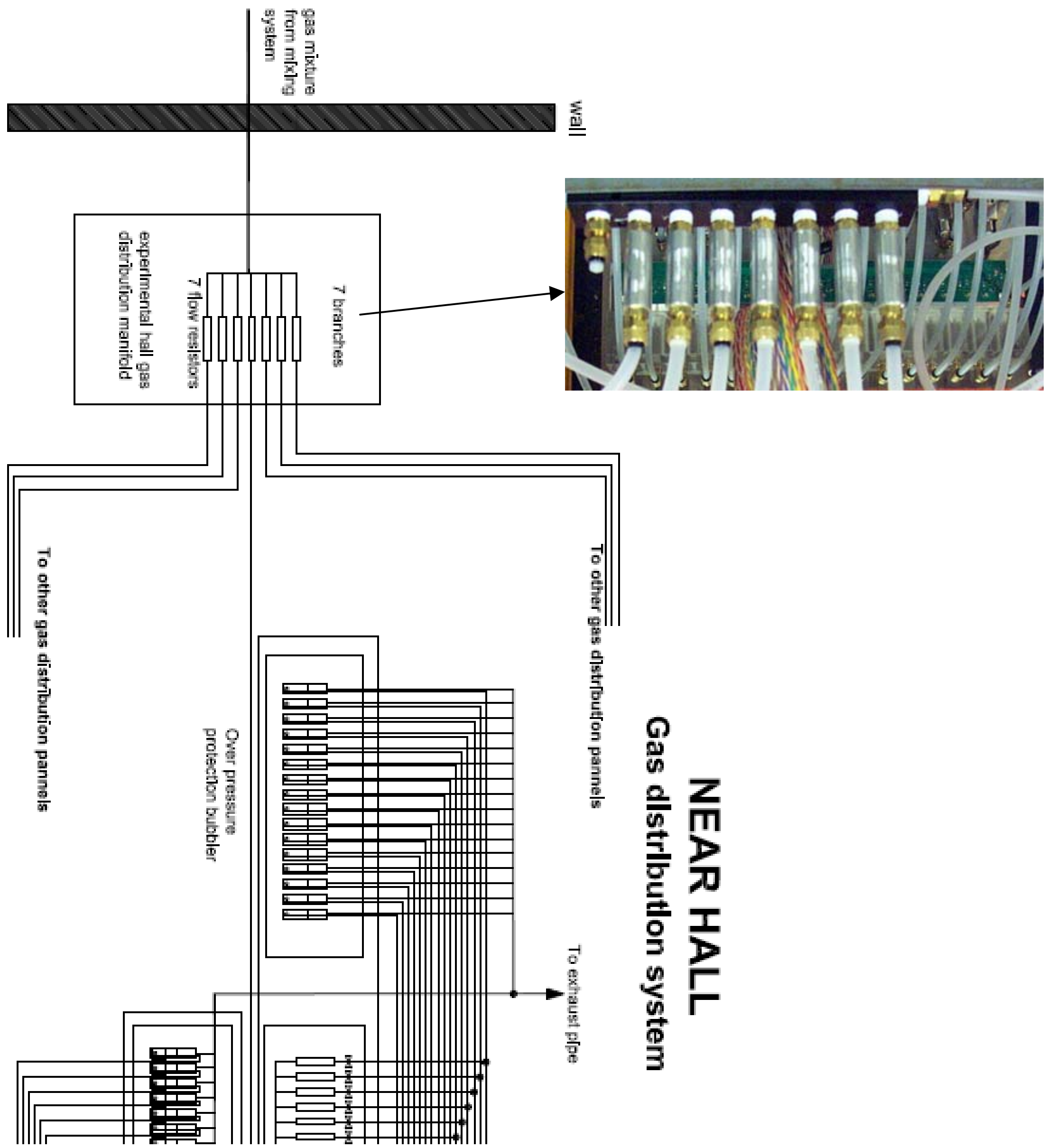


Fig. 24. Daya Bay near hall RPC gas distribution system (part).

We split the gas flow into 7 panel-branches with a gas distribution manifold that is shown in the insert of Fig. 24. Because it is hard to control all downstream gas flow resistors having same flow resistance, it has been revealed that some distribution panels are having higher flow resistance than others, so the overall flow rate for 7 panel-branches won't be the same. It can be seen in Fig. 25 bottom plot. The solution is adding an additional flow resistor to each branch of the gas manifold. These flow resistors are made of 5cm long, 0.5mm ID S.S. tubes. With these flow resistors the uniformity of the bubbling rate distribution among all 112 channels is much better, see the top plot of Fig. 25.

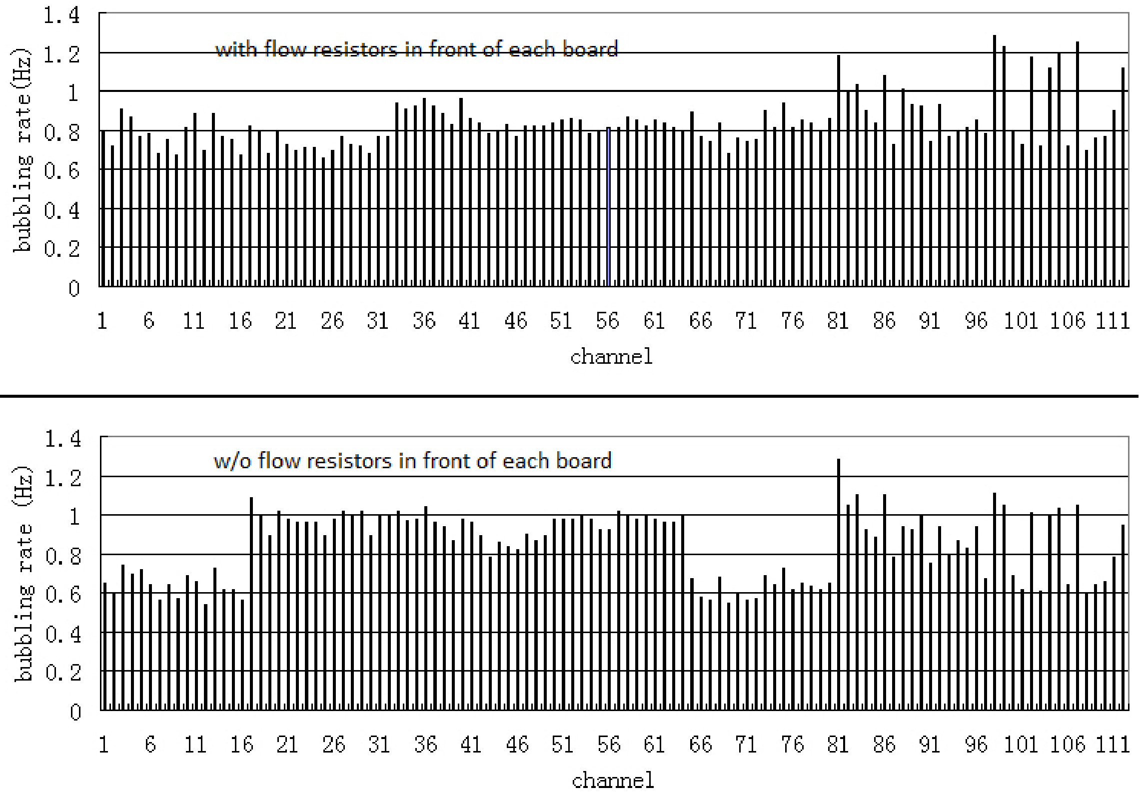


Fig. 25. The gas bubbling rate distribution for 112 channels. Top plot: with the flow resistors; bottom plot: w/o the flow resistors.

One panel-branch of gas distribution/digital bubbler system is sketched in Fig. 26(A), its photo is in Fig. 26(B).

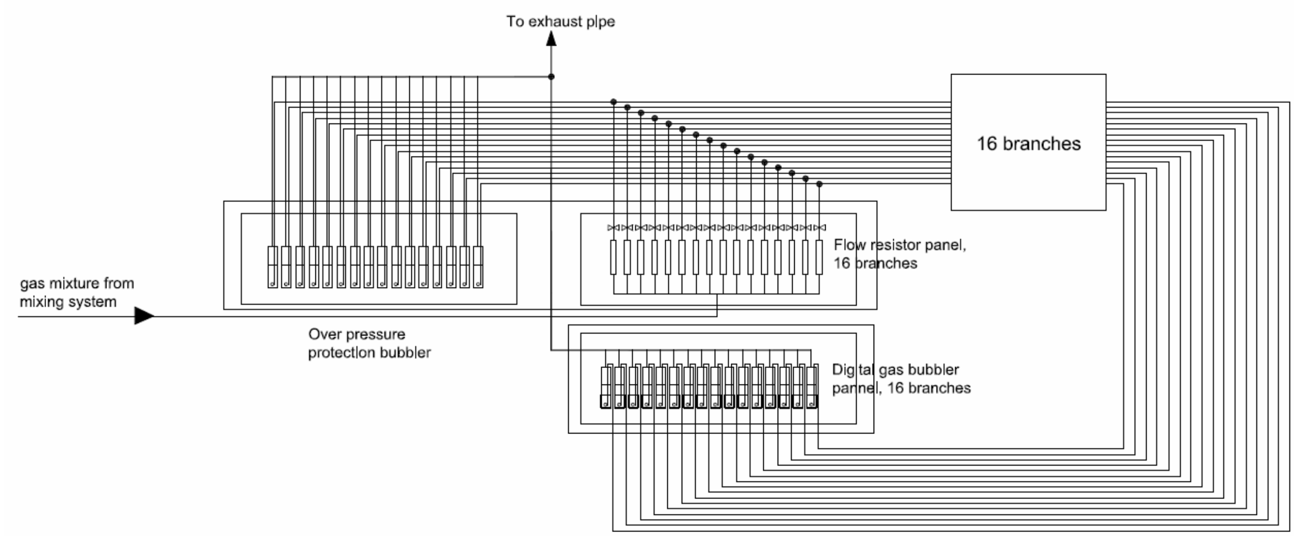


Fig. 26(A). One panel-branch of gas distribution/digital bubbler system

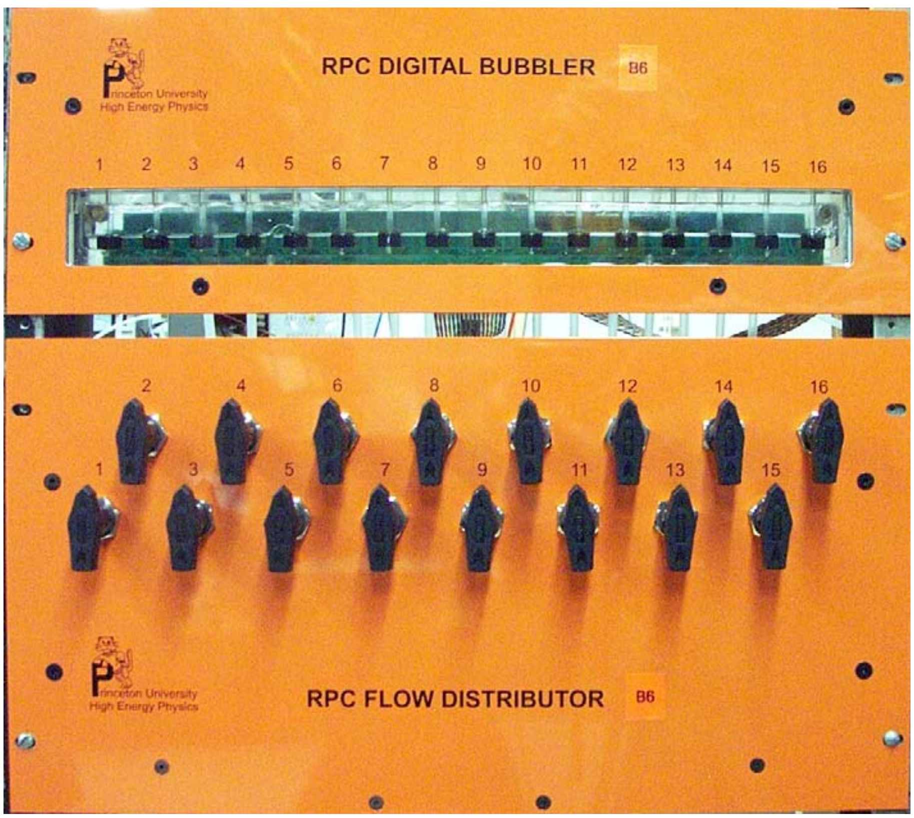


Fig. 26(B) Gas distribution (bottom) and digital bubbler (top) panels.

2.3.1 Flow resistor and inlet overpressure protection bubbler

We have calculated the pressure drop ΔP for the RPC gas flow path. The RPC itself won't bring in noticeable pressure drop due to large cross section. The major pressure drop is coming from the long tubing. A CERN web site provides a calculator to calculate such pressure drop:

http://detector-gas-systems.web.cern.ch/detector-gas-systems/Tools/deltaP.htm

Figure 27 shows the verification of this calculator with some real test done by Bob Messner[6] of BaBar. Since the pressure drop is proportional to d^4 a small variation of the tube's ID can make big difference to the pressure drop as illustrated in Fig. 26. For the same 1/4" OD tubing the Polyflo tubing has smaller ID, its pressure drop is almost twice as higher than Teflon tubing.

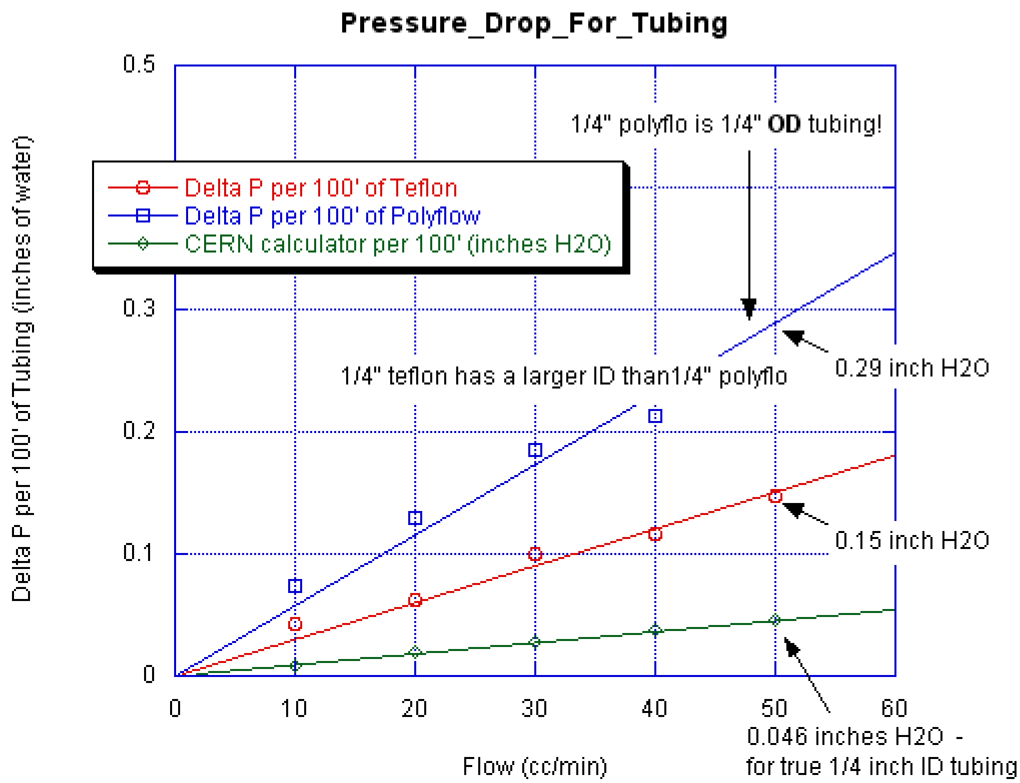


Fig. 27. Verification of CERN pressure drop calculator.

This tool can calculate up to three gas components. We use it to calculate a gas mixture (66/30/4 Ar/R134A/Isobutane) that is very similar to Daya Bay RPC gas mixture. For 2 volume changes/day the flow rate in each sub-branch (4 RPCs) will be 5.6 sccm . The calculated pressure

[6] Bob Messner, private communication.

drop through 30m long, 4mm ID (1/4' OD) Polyflo tubing (30m long tubing is about the round trip of the gas flow path) ΔP = 0.29cm WC. The digital bubbler's oil height is set at 0.5cm. Total pressure drop through the system is 0.8cm WC. After the flow resistor an inlet bubbler is implemented in parallel to RPC, it is used as the inlet overpressure protection for the RPC. We set the overpressure protection bubbler at 3cm WC.

We use Upchurch Scientific U-101 S.S. tube as the flow resistor, which is 0.01” bore diameter and 5cm long. The pressure drop with normal flow rate would be 29 cm WC that is more than 100 times of the pressure drop for 30m long 1/4” Polyflo tubing, it means the flow resistance for the entire gas flow path is dominated by the flow resistor.

Figure 28 shows an inlet protection bubbler crate. Each crate consists of 16 channels. For each channel a straw tube is dipped into an oil well with a depth of ~ 3cm. The inlet gas pressure will be manifested as the gas column in the straw tube above the oil level (indicated as h in the insert). The maximum inlet pressure will be limited at ~3cm oil. If the gas pressure overpasses this limit, the gas mixture will escape through this protection channel, thus the RPC chambers won’t suffer the overpressure.

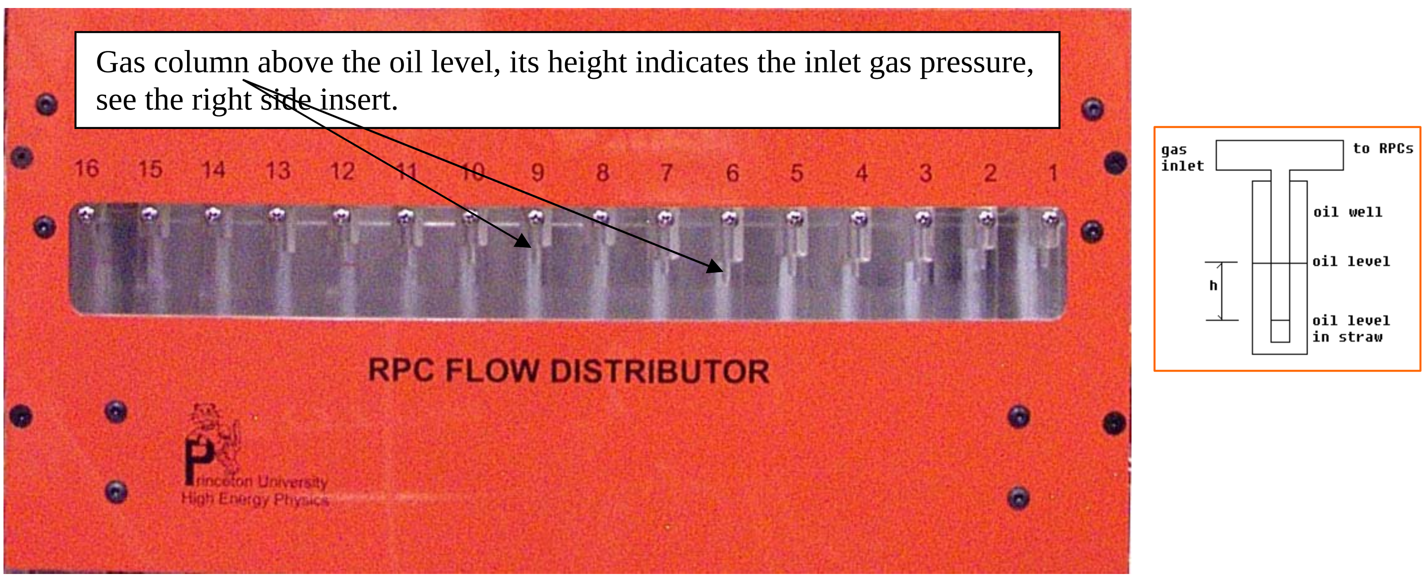


Fig. 28. Gas inlet overpressure protection bubblers.

2.3.2. Digital bubbler

For a gas detector system the oil bubblers are always used at the outlets of the chambers to isolate the gas chamber from air. Besides this basic function the digital gas bubbler can provide a quick on-line diagnosis of gas flow; according to BaBar and Belle it turns out to be a very useful system. We use a similar digital bubbler design as Belle RPC used [6]. In this system the bubblers are instrumented with photogates. Its working principle is illustrated in figure 29. Without gas bubble the light reaches the photogate through oil without interruption. When a bubble passes, it will reflect partial light, and the light intensity at that moment would be reduced, thus generates a pulse signal to the photogate PC board.

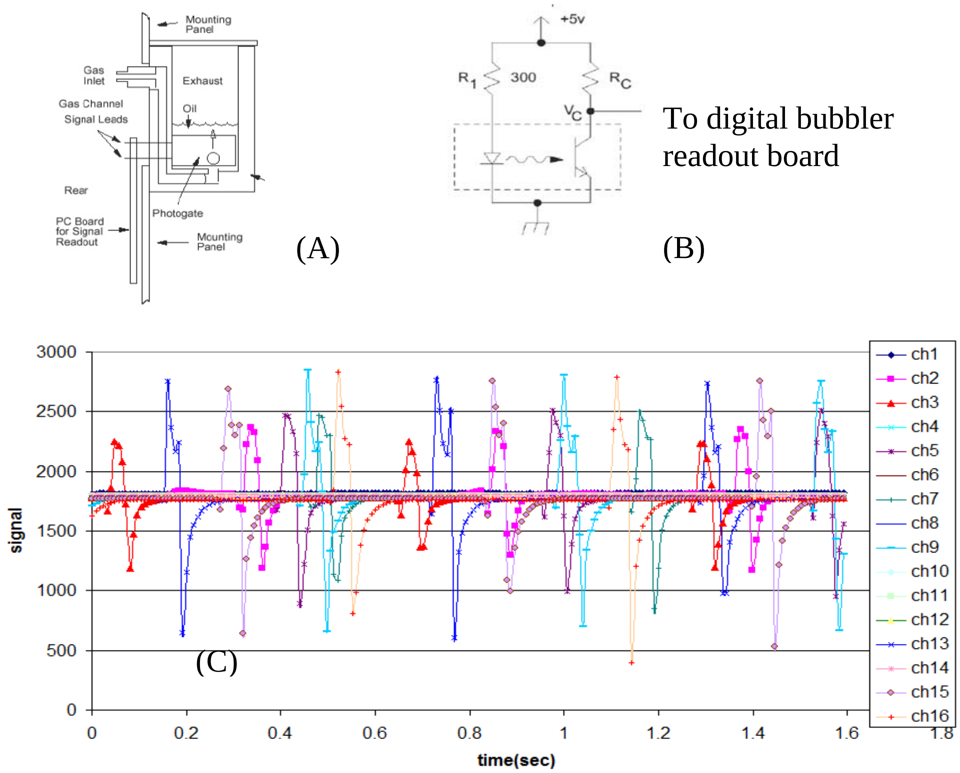


Figure 29. Digital gas bubbler. (A) Mechanical structure of the bubbler (for illustration purpose only, not the same as used in our gas system); (B) Working principle of the photogate; (C) The digital bubbler output signal recorded by microcontroller, it shows 8

A schematic of the digital bubbler photogate PC board is shown in figure 30. This is a 16-channel board that provides input signal to the microcontroller readout board. Each of the microcontroller board can handle 16 channels. TI MSP430F1611[7] microcontroller is used on the board, figure 31(A) shows the functional block diagram of MSP430x161x chip. It has 10KB RAM and 48KB flash memory. The build-in 12-bit ADC can sequentially sample 8 channels of the input at one moment with the sampling rate set by a 32768-Hz (2^{15}) watch crystal oscillator. When the ADC finishes the sampling for the first 8 channels it will generate a switch signal that subsequently will be sent to two MAX4674 multiplexer chips, each of which can handle 4 channels. Thus the next 8 channels will be sampled by the ADC. The system will be running for a few seconds that is long enough to collect several cycles of the bubbles. All the data is stored in the RAM memory of the microcontroller. At the end of the data taking cycle the program will set all 8 bits up to 1 for a specific register U1TXBUF that is the serial port interface on the microcontroller. A host PC is supervising the microcontroller readout board through RS232 port. It checks U1TXBUF routinely, if all 8 bits are up, it will readout the data from RAM and store the data in the PC, then starts over the whole process again. A USB extender pair is used to connect the USB port on PC to a USB hub with 7 USB slots. The CAT5E cable used to connect the pair of USB extender can be as long as 100ft. Each USB slot through a USB to RS232 convertor cable is connected to a digital bubbler readout board. For the far hall we need 11 16-channel bubblers, and for the near hall we need 7 16-channel bubblers. Therefore at near hall we only need one such hub, and at far hall we need two hubs to handle all digital bubblers.

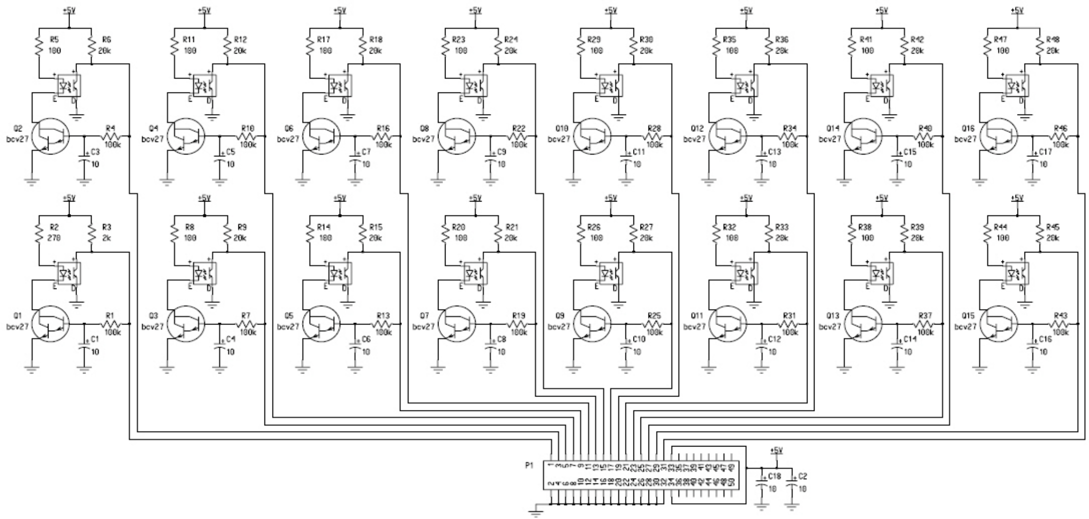


Fig. 30. Digital bubbler photogate PC board schematics.

The hardware of the16 channel digital bubbler with the oil catcher is shown in figure 31.

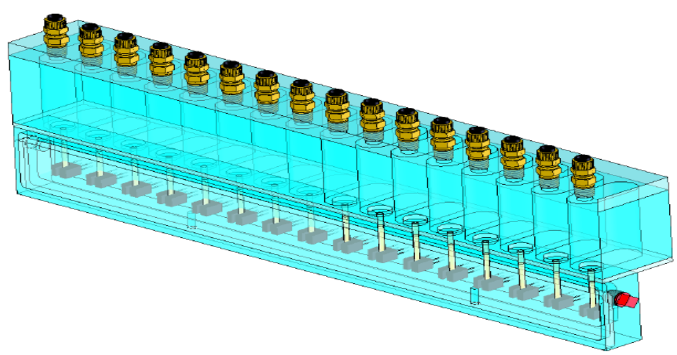


Fig. 31. 16-channel digital bubbler with oil catcher.

The schematic of the microcontroller readout test board and its picture are shown in figure 32(B, C). Figure 33 is a photo of this system.

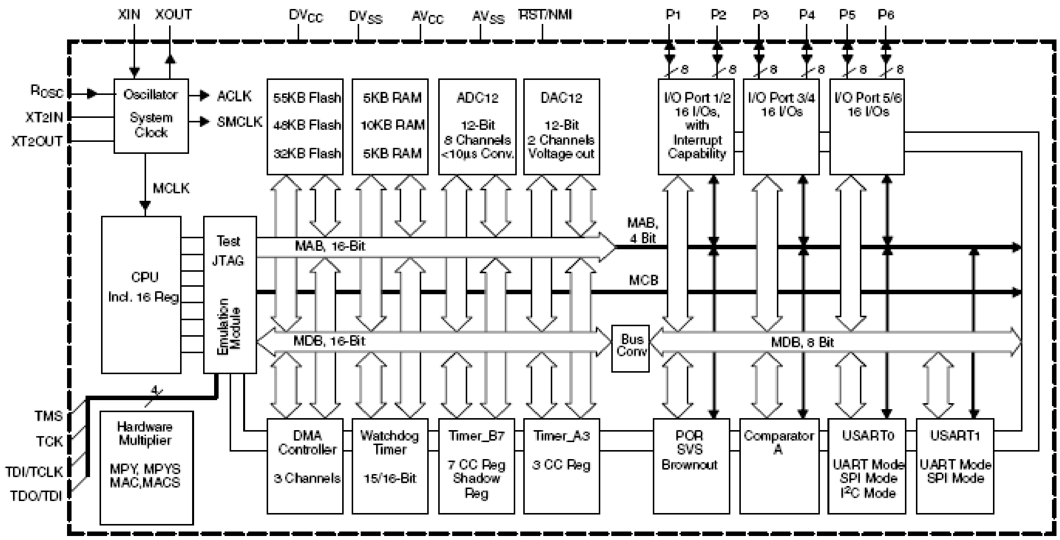


Fig. 32(A) MSP430x161x functional block diagram.

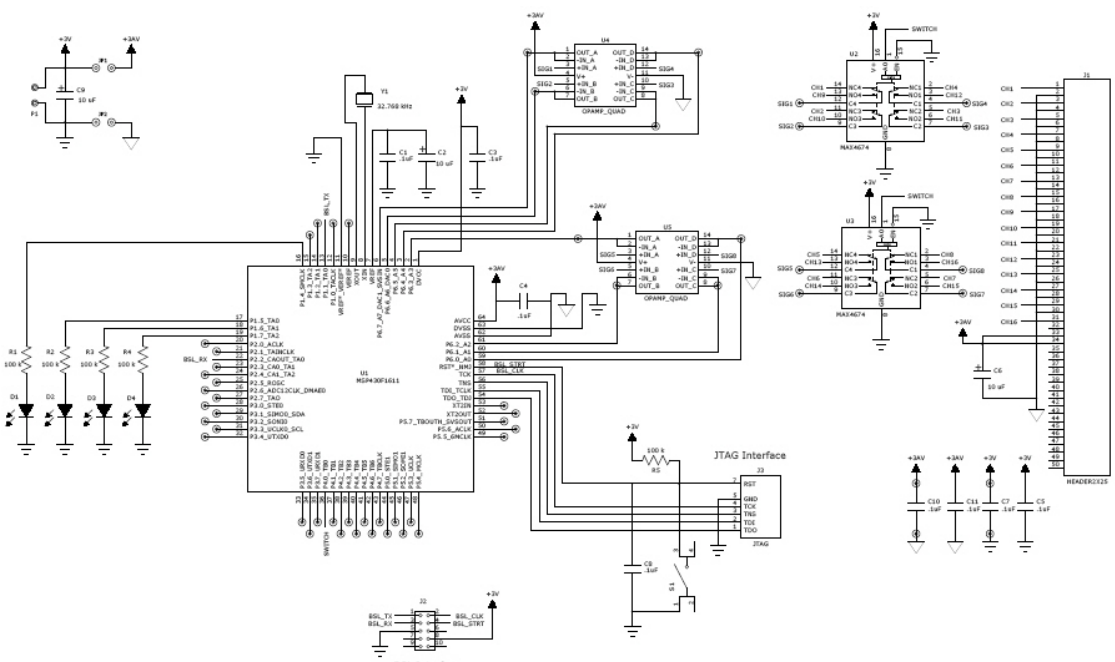


Fig. 32(B) Digital bubbler readout board schematic

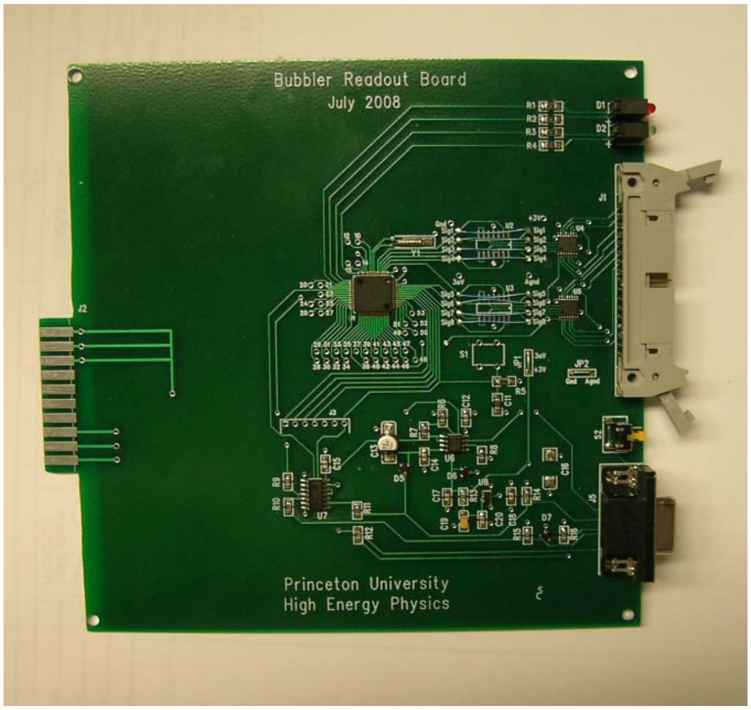


Fig. 32(C). Photo of the digital bubbler readout PC board

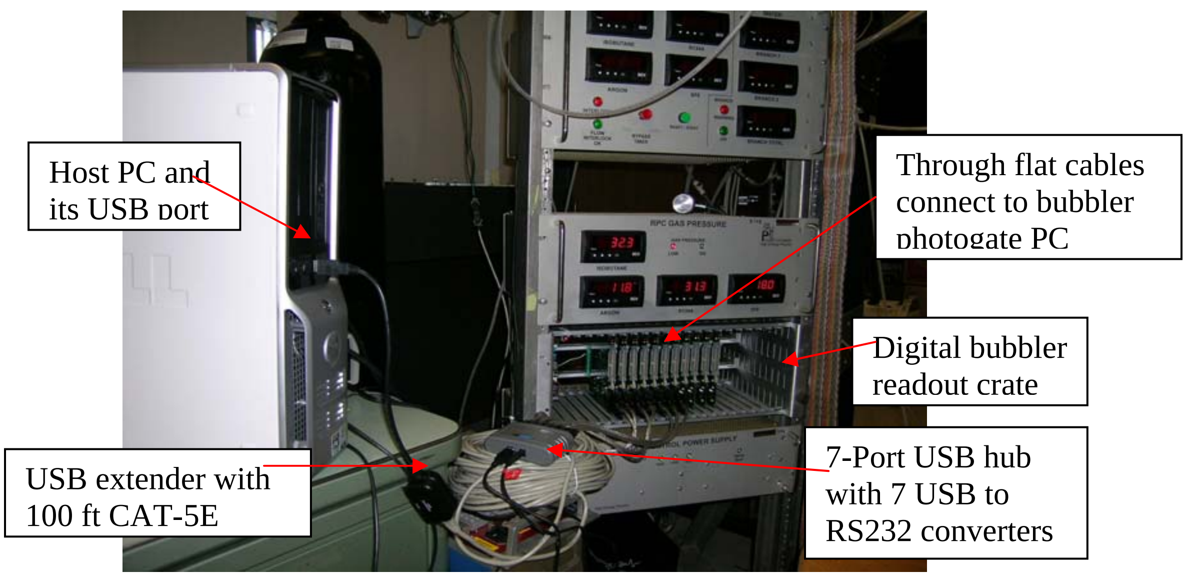


Fig. 33 Digital bubbler readout crate and its host PC with USB extender/100 ft long CAT-5E cable.

The cable interconnection of the digital bubbler system is shown in figure 34.

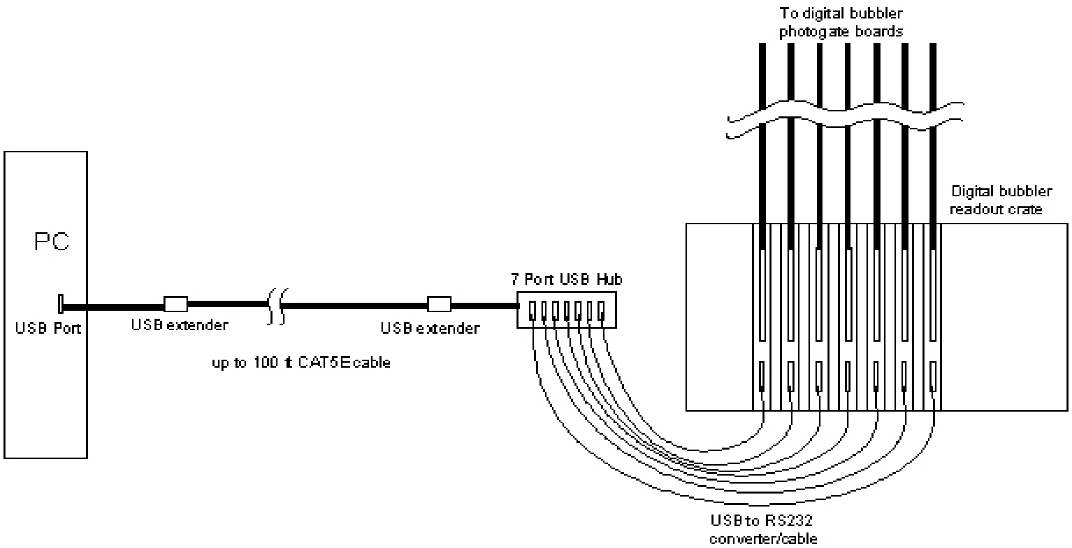


Fig. 34 Interconnection of the digital bubbler system.

The host PC will be in electronics room, the digital bubbler hardware and readout crate will be located on the RPC module supporting platform, the distance between two locations is around 20m. Use of the USB extender and one 100 ft CAT5E cable should be long enough to link them together.

2.3.3. TI microcontroller readout software

The software development tool for the TI microcontroller readout board is IAR Embedded Workbench. The version 3.30A is a free distributed version. Please don't upgrade to newer free distributed version that won't work properly for the bubbler readout program. Click the icon 

on the Desktop, it will pop up the following window:

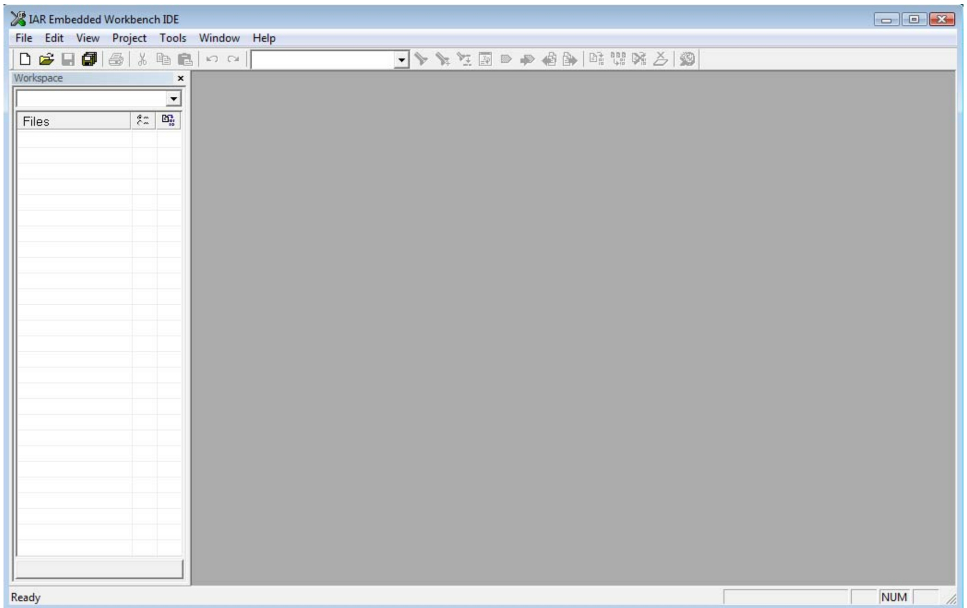


Fig. 34. IAR Embedded Workbench window.

Click File on the top menu bar, then Open|Workspace, the bubbler software workspace is in the following directory: C:\ Bubbler16ch-TI-Readout\bubbler16ch-v2.eww. The opened workspace is shown in Fig. 35. The program is written in C.

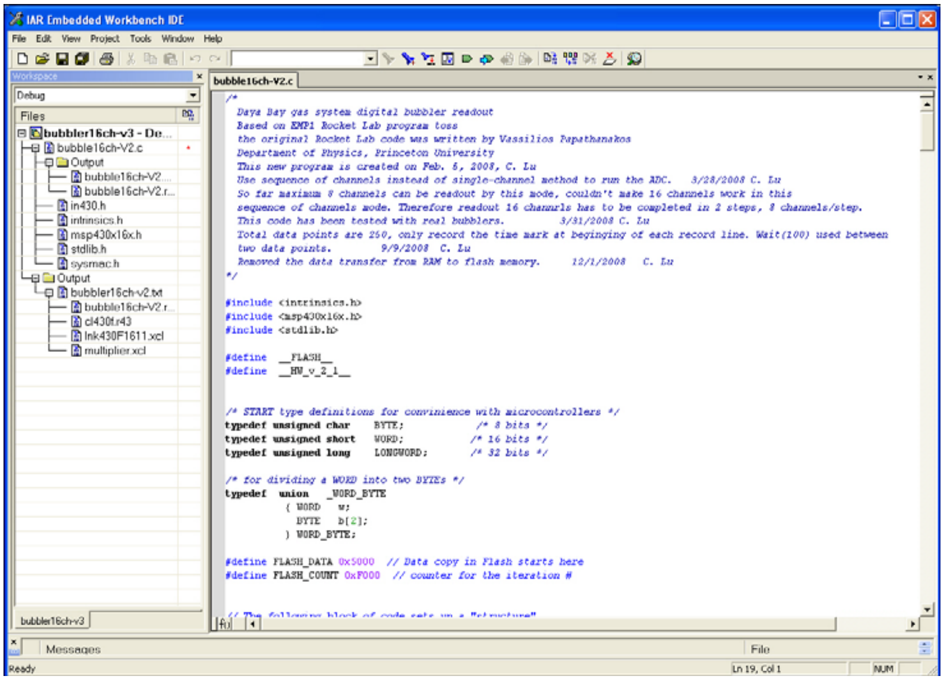


Fig. 35. Workspace of TI microcontroller readout software: bubbler16ch-v2.eww.

2.3.4. Digital bubbler GUI

To open the digital bubbler GUI go to directory C:\DayaBay Bubbler GUI\ as shown in figure 36, click setup.exe, it will bring up the bubbler GUI window as shown in figure 37 (please be advised the Date Modified of setup.exe might be different from what we show here).

You also can simply click Daya Bay RPC Gas Bubbler icon  on the desktop, it will popup the same window.

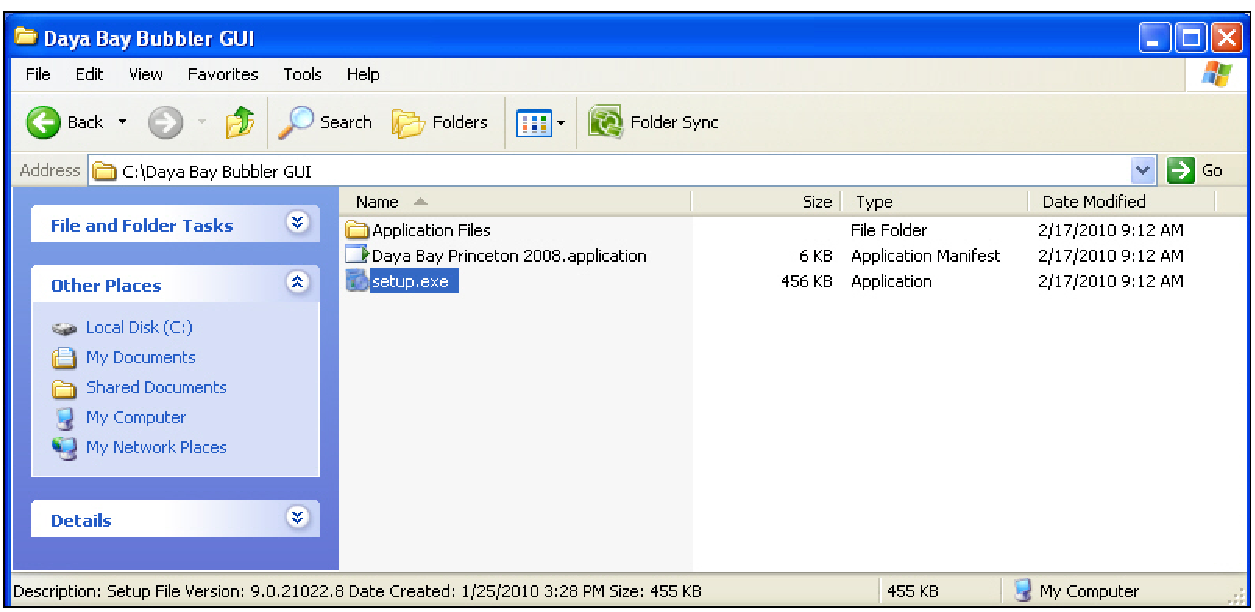


Fig. 36. Directory of the digital bubbler GUI program

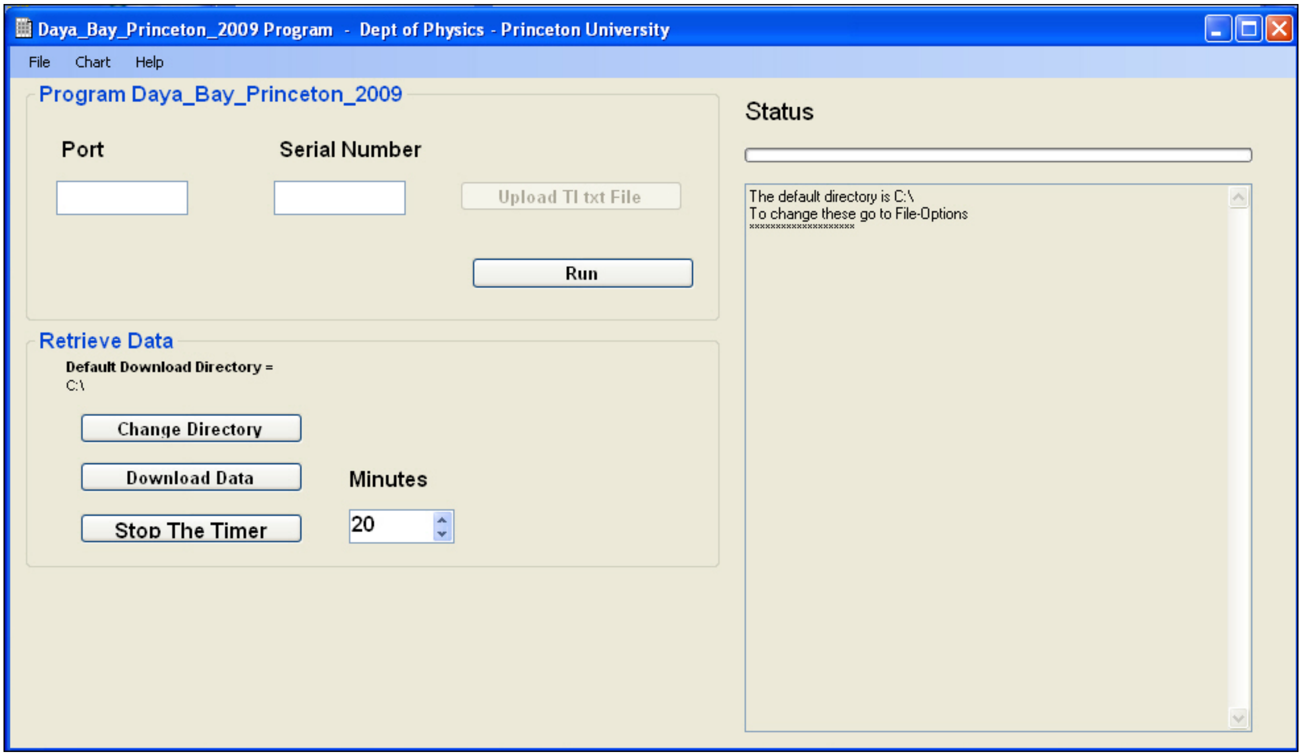


Fig. 37. Bubbler GUI window

Click File on the top menu bar will bring up a drop-down menu with five choices: Open – open the executable TI microcontroller acquisition program and wait for uploading to its flash memory; Close – close the Bubbler program, the Bubbler Program window will disappear immediately; Check communication – test the RS232 connection between microcontroller and the host PC, in this version the COM ports we used are starting from COM21 up, in case of bad communication you may want to check the host PC Ports setting, which can be accessed through Start | Control Panel | System | Hardware | Device Manager | Ports (COM & LPT). Click on + sign on the left of Ports, it will expand the Ports to show all Com Ports, where you can check if COM Port names are from COM21 up in sequential order; Option – select the number of boards to be used in the run; Set-Check Serial Number – Set each COM Port with a unique name and upload the executable TI txt file to the readout board connected to this Port. In the following we'll go through the process step by step:

1) Click Open, select file C:\bubbler16ch-TI-Readout\Debug\Exe\bubbler16ch.txt, and click it to highlight, then click Open;
2) Type 21 into the small window under Port, BD01 (must be capital BD) into the small window under Serial Number, click Upload TI txt File button, it will upload the txt file to the microcontroller's flash memory. When finish the window should look like figure 37. The TI txt file will remain in the flash memory until you upload a different TI txt file to change it. If you have 7 boards, you need to repeat this procedure for other 6 boards.

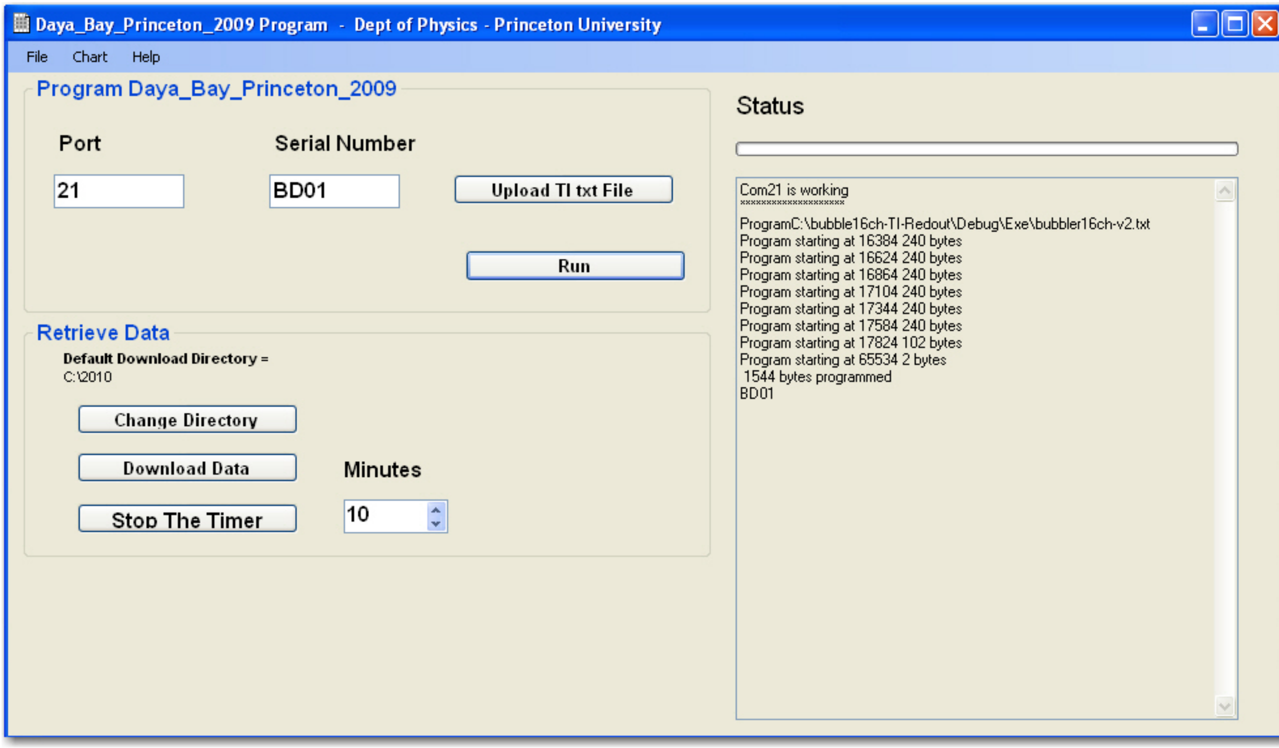


Fig. 38. The TI microcontroller data acquisition program has been uploaded to board #1.

3) Click × on the upper-right corner of the window to close it;
4) Open the bubbler GUI again as mentioned at the beginning of 2.3.3. the window shown in figure 37 will appear again;
5) Click Run button, it will run the uploaded program on the readout boards you have selected, the LEDs in front of these boards will flash for a few seconds. On right pane of the window "Com21 is working", …, "Com27 is working" displays the progress as shown in figure 39;

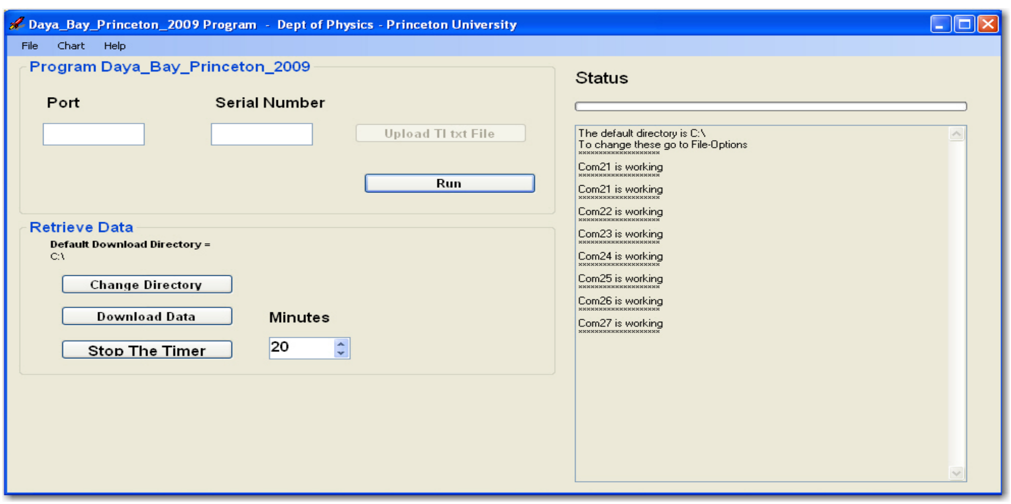


Fig. 39. GUI finishes the data taking.

6) Wait for a few more seconds to let the microcontroller finish the data taking, then click **Download Data** button. (If the data taking process has not finished while you move the mouse point over **Download Data** button, it won't change shade of the box, and has no effect if you click.) The data in RAM memory of the microcontroller will be transferred to host PC meanwhile the progress bar on top of **Status** pane will show the transferring status. Upon finishing the data transfer a 12 column-plots will popup. Each plot shows 16 vertical bars, each of which represents the bubbling rate for its corresponding sub-branch. Click on each histogram a larger histogram will popup, which is clear enough to read the bubbling rate. Click ✕ sign on the upper-right corner of the large plot will close this window. An example is shown in figure 39.

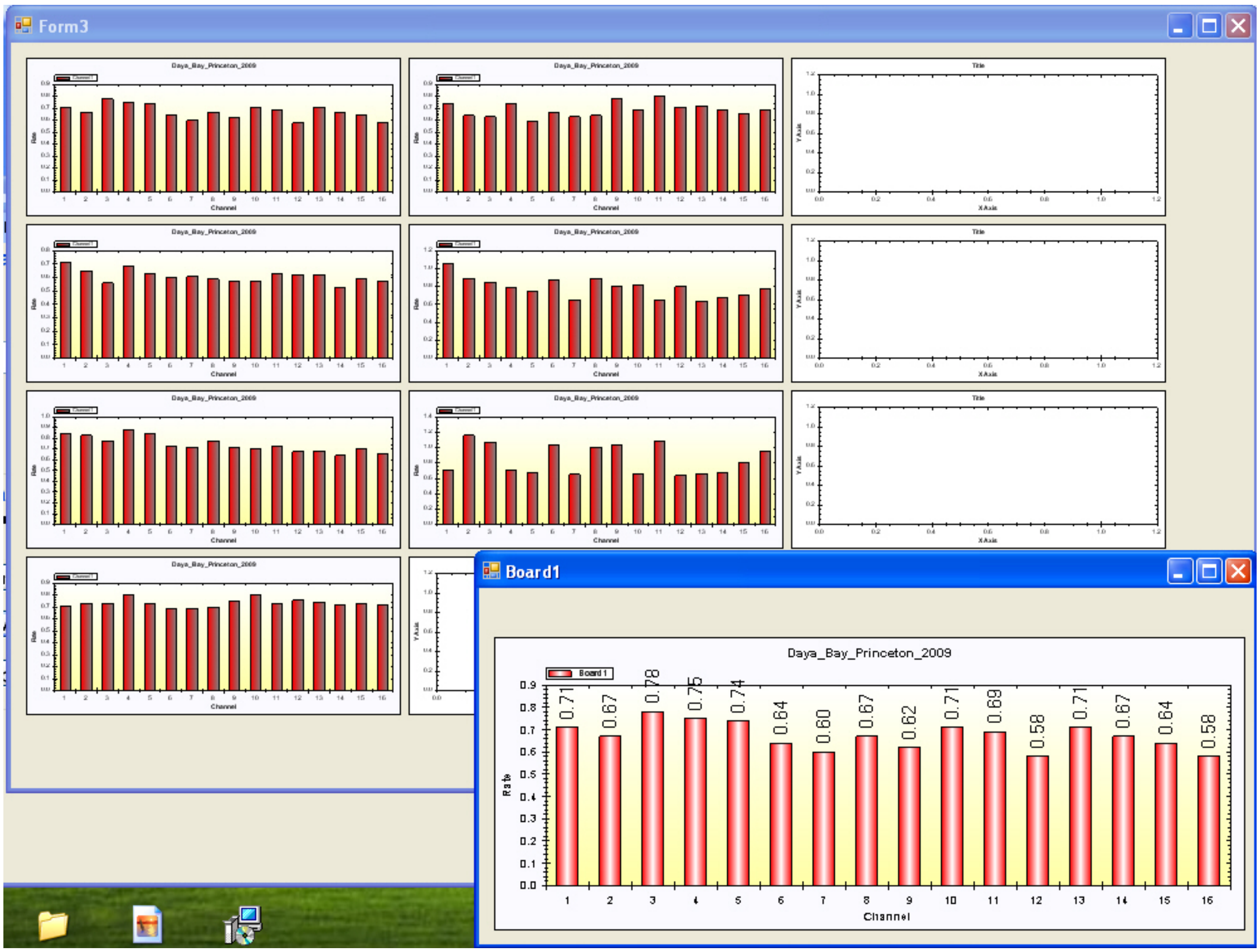


Fig. 40. Flowrate plots for all 112 channels.

In figure 37 there are several other buttons. The **Minutes** window is used for setting the time interval between each data taking. After click the **Download Data** button the program will automatically repeat the data download/data taking cycle according to this **Minutes** setting. To stop the timer click **Stop The Timer** button, it will halt the program and change the label to **Start The Timer**. Click the button again will resume the program.

2.3.5. Access the data with database program MySQL v5.0

The bubbling frequency data are collected in a database called **dayabay**, table name is **dyb_gas_dybnearbubbler**, **dyb_gas_dybfarbubbler or dyb_gas_lanearbubbler** according to the location of the gas system. The raw data files, which can be used to plot the pulse curve for each channel, are stored in subdirectory C:\yyyy\mmddyyyy\hh_mm_ss. Each day has a subdirectory such as C:\2010\04212010, and each run has next level of subdirectory, such as …\20_46_43. Files with _p attached are ascii data files, which can be directly read by Excel. From any networked computer you can access this database if MySQL v5.0 and MySQL GUI Tools software are installed. These software can be downloaded from web for free. To run the database query click on MySQL Query Browser icon displayed on the left pane after click Windows Taskbar Start button. It will bring up a MySQL Query Browser window as shown in figure 41.

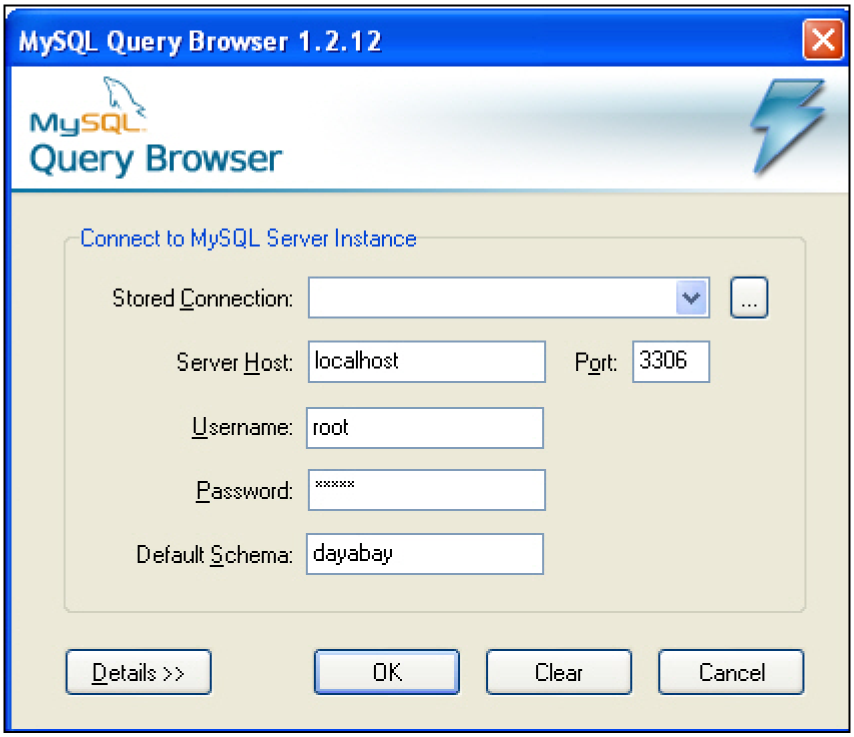


Fig. 41 MySQL Query Browser window

In this window the name of Server Host should be replaced by the host PC's IP address, such as 128.112.84.90, which is the IP address of the host PC on Princeton network, and type in the password. Click OK a Query Browser window will pop up as shown in figure 42.

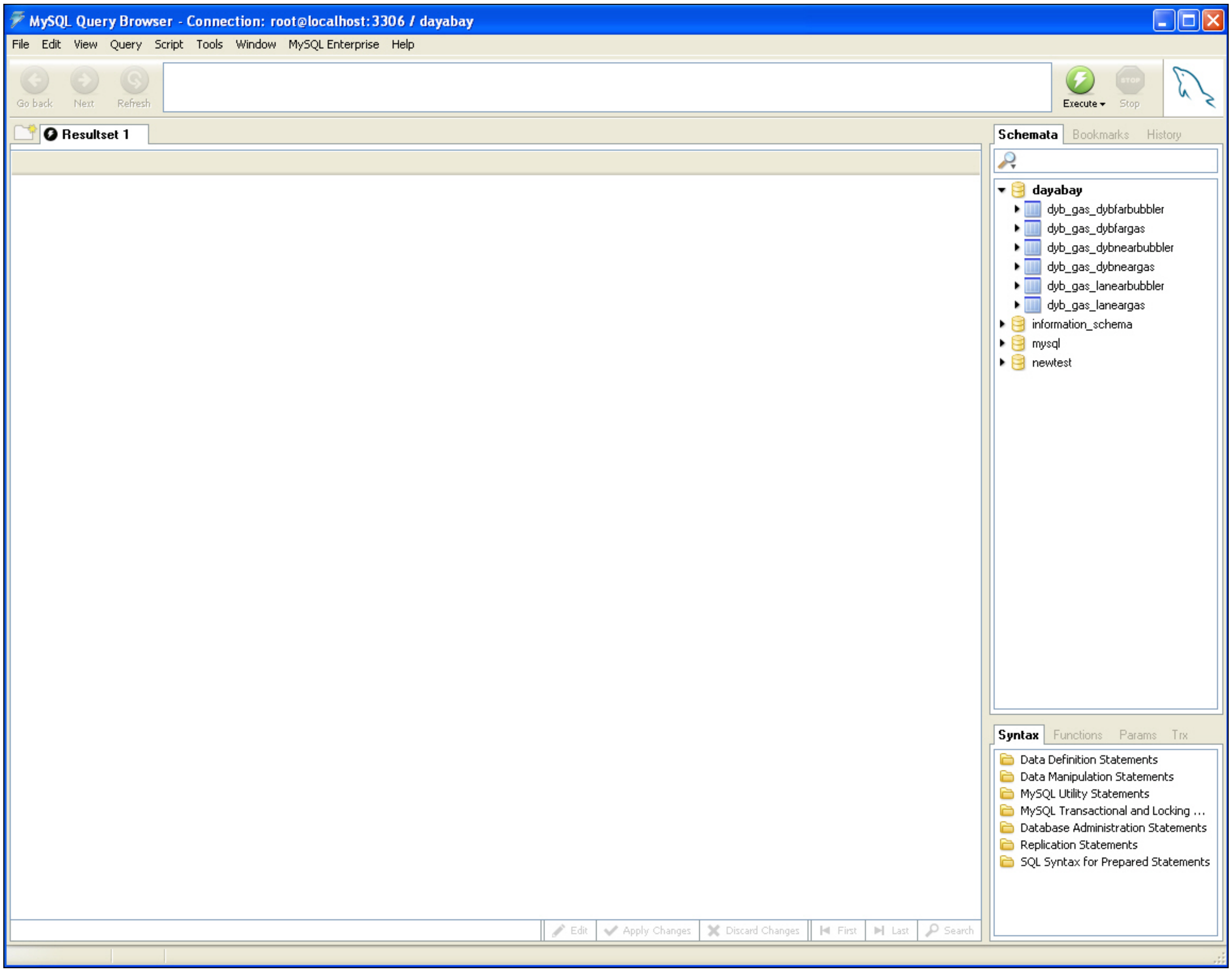
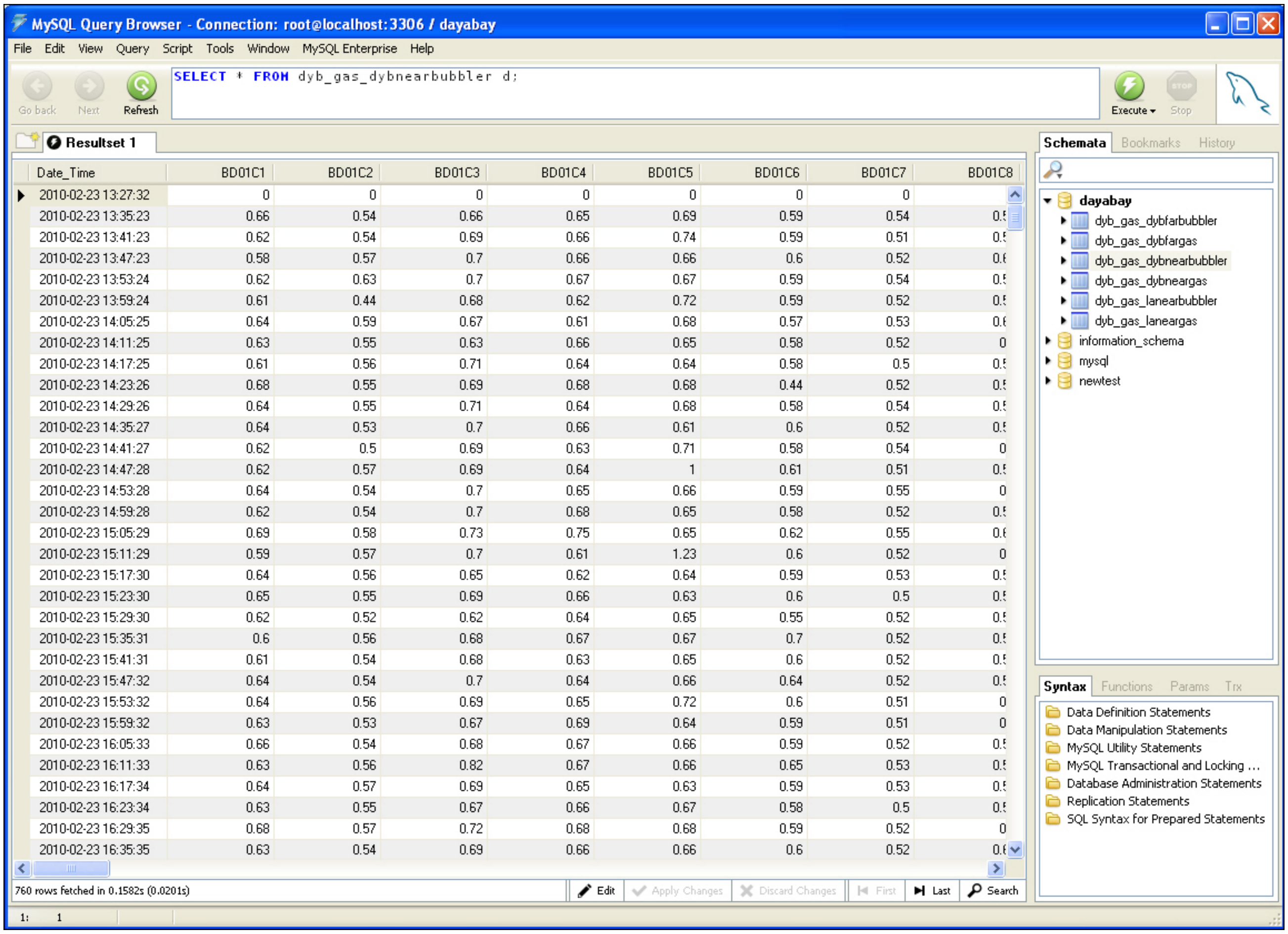


Fig. 42 MySQL Query Browser intial window

On the right pane of this window under database "dayabay" there are 6 tables: dyb_gas_dybfarbubbler, …. Move mouse to any table's name, click and hold, then move the point to the empty window on the top, several buttons will show up on the bottom of the window. One of the buttons is SELECT, move the point to there, then release the mouse, a command line "SELECT * FROM dyb_gas_dybnearbubbler d;" automatically created in this empty window, click the Execute button on the right, the database window will fill up with the recorded data for the selected table as shown in figure 43.



Date_Time	BD01C1	BD01C2	BD01C3	BD01C4	BD01C5	BD01C6	BD01C7	BD01C8
2010-02-23 13:27:32	0	0	0	0	0	0	0	
2010-02-23 13:35:23	0.66	0.54	0.66	0.65	0.69	0.59	0.54	0.
2010-02-23 13:41:23	0.62	0.54	0.69	0.66	0.74	0.59	0.51	0.
2010-02-23 13:47:23	0.58	0.57	0.7	0.66	0.66	0.6	0.52	0.
2010-02-23 13:53:24	0.62	0.63	0.7	0.67	0.67	0.59	0.54	0.
2010-02-23 13:59:24	0.61	0.44	0.68	0.62	0.72	0.59	0.52	0.
2010-02-23 14:05:25	0.64	0.59	0.67	0.61	0.68	0.57	0.53	0.
2010-02-23 14:11:25	0.63	0.55	0.63	0.66	0.65	0.58	0.52	0
2010-02-23 14:17:25	0.61	0.56	0.71	0.64	0.64	0.58	0.5	0.
2010-02-23 14:23:26	0.68	0.55	0.69	0.68	0.68	0.44	0.52	0.
2010-02-23 14:29:26	0.64	0.55	0.71	0.64	0.68	0.58	0.54	0.
2010-02-23 14:35:27	0.64	0.53	0.7	0.66	0.61	0.6	0.52	0.
2010-02-23 14:41:27	0.62	0.5	0.69	0.63	0.71	0.58	0.54	0
2010-02-23 14:47:28	0.62	0.57	0.69	0.64	1	0.61	0.51	0.
2010-02-23 14:53:28	0.64	0.54	0.7	0.65	0.66	0.59	0.55	0
2010-02-23 14:59:28	0.62	0.54	0.7	0.68	0.65	0.58	0.52	0.
2010-02-23 15:05:29	0.69	0.58	0.73	0.75	0.65	0.62	0.55	0.
2010-02-23 15:11:29	0.59	0.57	0.7	0.61	1.23	0.6	0.52	0
2010-02-23 15:17:30	0.64	0.56	0.65	0.62	0.64	0.59	0.53	0.
2010-02-23 15:23:30	0.65	0.55	0.69	0.66	0.63	0.6	0.5	0.
2010-02-23 15:29:30	0.62	0.52	0.62	0.64	0.65	0.55	0.52	0.
2010-02-23 15:35:31	0.6	0.56	0.68	0.67	0.67	0.7	0.52	0.
2010-02-23 15:41:31	0.61	0.54	0.68	0.63	0.65	0.6	0.52	0.
2010-02-23 15:47:32	0.64	0.54	0.7	0.64	0.66	0.64	0.52	0.
2010-02-23 15:53:32	0.64	0.56	0.69	0.65	0.72	0.6	0.51	0
2010-02-23 15:59:32	0.63	0.53	0.67	0.69	0.64	0.59	0.51	0
2010-02-23 16:05:33	0.66	0.54	0.68	0.67	0.66	0.59	0.52	0.
2010-02-23 16:11:33	0.63	0.56	0.82	0.67	0.66	0.65	0.53	0.
2010-02-23 16:17:34	0.64	0.57	0.69	0.65	0.63	0.59	0.53	0.
2010-02-23 16:23:34	0.63	0.55	0.67	0.66	0.67	0.58	0.5	0.
2010-02-23 16:29:35	0.68	0.57	0.72	0.68	0.68	0.59	0.52	0
2010-02-23 16:35:35	0.63	0.54	0.69	0.66	0.66	0.6	0.52	0.

Fig. 43. MySQL query results window.

The database table consists of 113 columns: Date_Time – the data created Date and Time; DB01C1,…, DB07C16, total 112 columns, each column records the bubbling rate for the corresponding channel. Click File and highlight Export Results, click it, on the drop-down menu you can select various file format. For example if you want to export the data to Excel format, click the fourth line. If you already checked the Query Options | Open results in associated application after export (Click Tool menu, then Options), it will direct open an Excel file with the data set you have selected. A sample Excel strip plot is shown in figure 44, we can see the bubbling rate distribution among 112 channels measured by the digital bubbler is reasonably uniform. The flow rate vs. bubbling rate from 500sccm to 3.5slm range is shown in figure 45. Below 2 SLM the linearity is quite good, thereafter the flow rate becomes lower than linear extrapolated value, it could be the gas volume for each bubble might not be same under different flow rate.

Below 2 SLM the linear fitting is F.R. (SLM) = $0.883*x – 0.213$; above 2 SLM the fitting becomes quadruple F.R. (SLM) = $0.713*x^2 – 2.75*x +4.44$, where x is the bubbling rate in Hz unit.

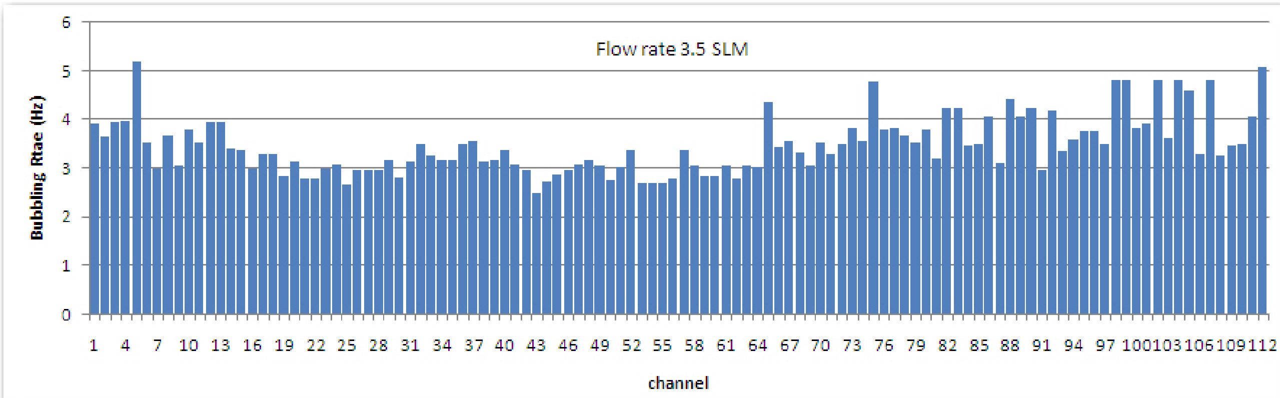


Fig. 44 Bubbling rate distribution of 112 channels.

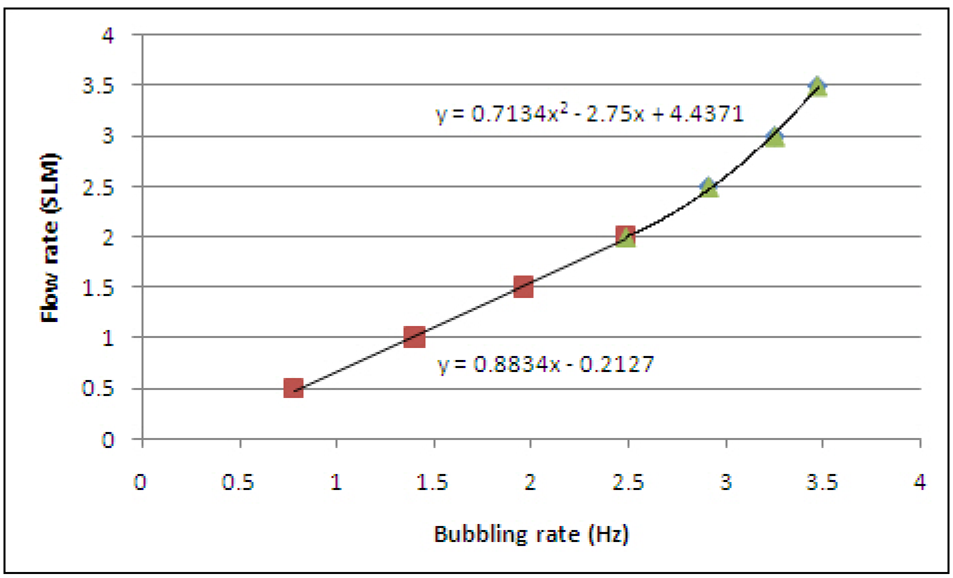


Fig. 45. Gas flow rate vs. bubbling rate.

2.3.6. The developing tool of the GUI — Microsoft Visual Studio 2008

The GUI is written in C# with the software development tool Microsoft Visual Studio. Click **Start** on Windows, then click the icon on the left pane (this icon also available on the desktop), Visual Studio 2008 window will pop up as shown in figure 46.

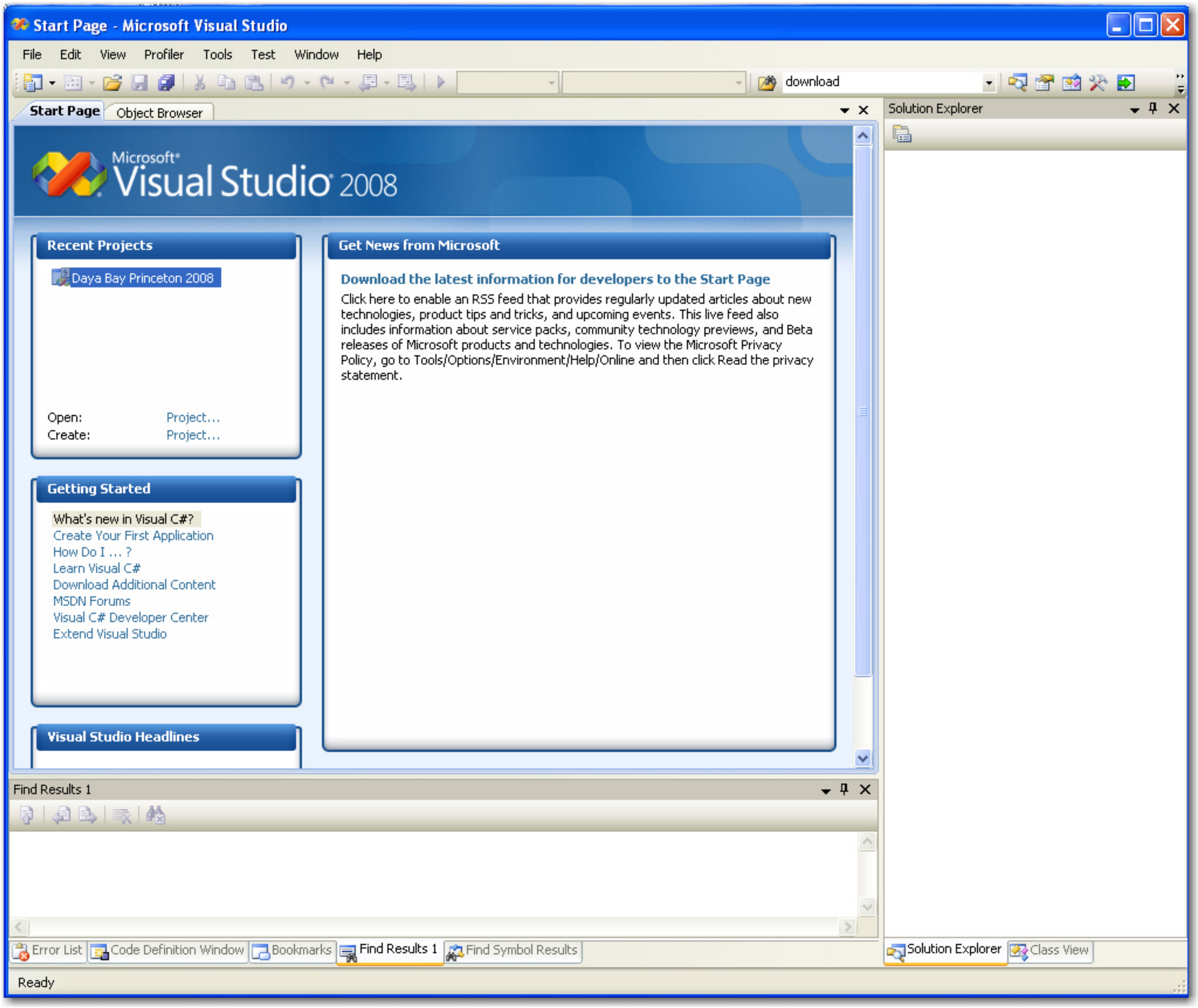


Fig. 46. Visual Studio 2008 window.

On the left side Recent Projects pane, there is one existing project name **Daya Bay Princeton 2009**, move mouse over it, on the bottom of the Visual Studio window it will show the solution file's name with its directory tree: C:\...\Desktop\Visual Studio 07312009\Projects\Daya Bay Princeton 2008\Daya Bay Princeton 2009.sln, click it, it will open the entire solution/project as shown in figure 47.

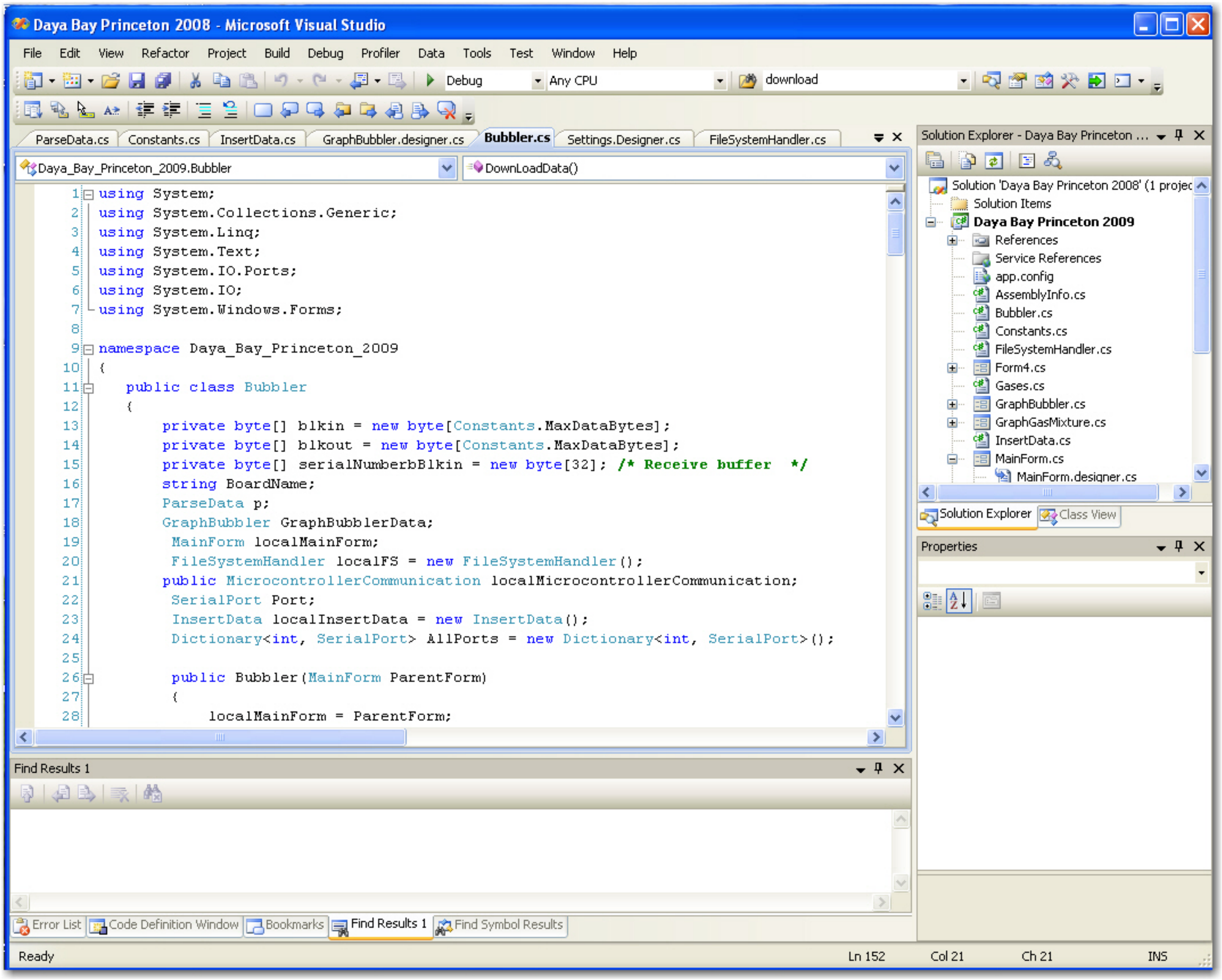


Fig. 47. Solution "Daya Bay Princeton 2008" opened in Visual Studio.

3. Interface to the Detector Control System (DCS)

Daya Bay RPC gas system will send signals to the detector control system for on-line monitor and emergency control. The following is a list of items to be sent to the DCS:

- Gas flow rate for all four components, the total flow rate and dry/wet branches flow rate for the gas mixture;
- Gas bubbling rate for every sub-branches to locate the leaking RPC module;
- Gas mixture humidity;
- Gas pressure before the mass flow controller;
- Cylinder weight for Isobutane, R134A and SF_6;
- Ventilation air flow rate monitoring;
- HAD sensors monitoring;
- Stand-alone weather station device in the gas room will monitor the room temperature/air pressure.

All of these signals are summarized in the table 2.

Source Crate	Connector	Name	Signal Type	Signal Range	Slow Control
Flowmeter crate	Flow crt - J2	Flow rate(Isobutane)	DC level	0 - 10V	1
	Flow crt - J2	Flowr rate(Argon)	DC level	0 - 10V	1
	Flow crt - J2	Flow rate(R134A)	DC level	0 - 10V	1
	Flow crt - J2	Flow rate(SF6)	DC level	0 - 10V	1
	Flow crt - J2	Total flow rate	DC level	0 - 10V	3
	Flow crt - J2	Branch #1 flow rate	DC level	0 - 10V	3
	Flow crt - J2	Branch #2 flow rate	DC level	0 - 10V	3
Pressure crate	Prs crt - J6	Pressure(Isobutane)	DC level	0 - 10V	2
	Prs crt - J6	Pressure(Argon)	DC level	0 - 10V	2
	Prs crt - J6	Pressure(R134A)	DC level	0 - 10V	2
	Prs crt - J6	Pressure(SF6)	DC level	0 - 10V	2
Gas status crate	Stts crt - J3	HAD sensor status	switch	O(alarm)/C(normal)	4
	Stts crt - J7	HAD #1 analog out	DC current	0 - 5V	4
	Stts crt - J8	HAD #2 analog out	DC current	0 - 5V	4
	Stts crt - J3	Ventillation status	switch	O(alarm)/C(normal)	4
	Stts crt - J3	Ventillation status	DC current	4 - 20mA	4
	Stts crt - J3	Emergency shutoff(out)	switch	click set/reset	10
	Stts crt - J4	Flow rate status	switch	O(alarm)/C(normal)	1
	Stts crt - J4	Pressure status	switch	O(alarm)/C(normal)	2
	Stts crt - J4	HV interlock	switch	O(alarm)/C(normal)	7
	Stts crt - J6	R134A weight	DC current	4 - 20mA	5
	Stts crt - J6	Isobutane weight	DC current	4 - 20mA	5
	Stts crt - J6	SF6 weight	DC current	4 - 20mA	5
	Stts crt - J9	Humidity(fresh)	DC level	0 - 5V	6
	Stts crt - J9	Humidity(return)	DC level	0 - 5V	6
Weather information	Tong Guan U.	Temperature(storage)			8
	Tong Guan U.	Humidity(storage)			8
	Tong Guan U.	Atm. pres.(storage)			8
	Tong Guan U.	Temperature(mix)			8
	Tong Guan U.	Humidity(mix)			8
	Tong Guan U.	Atm. pres.(mix)			8
Digital bubbler	LAN	bubble rate	Database	Database	9
GC430	LAN	Gas mixing ratio	Database	Database	4

Table 2. Signals sent to Detector Control System.

Warning!!! The table shown above might be only part of its original excel file, to get the excel file please move the mouse at any place inside the table and double click, the original excel file will show up. You can move to any cell to look at the content in that cell. The slope column lists various physical parameters, such as weight, air flow velocity, % of isobutane Lower Exposure Limit (LEL), relative humidity, etc. and their calibration curves. Slow control system can use these curves to calculate the physical parameters from the output analog signals (DC voltage or current). They should match the display on the controllers of various gas control crates. For your convenience we reproduce these calibration parameters as follows:

- Isobutane flow rate: 20 sccm/V;
- SF6 flow rate: 2 sccm/V;

- Argon flow rate: 2 slm/V;
- R134A flow rate: 200 sccm/V;
- Branch (wet and dry) and total flow rate: 2 slm/V;
- Gas pressure: P = 20 psi/V;
- Hazardous gas sensor: % of isobutane LEL = 20% LEL/V;
- Ventilation air flow velocity: $V(m/min) = -0.0666*I(mA)^4+3.0867*I^3-53.24*I^2+434.05*I-1064.5$;
- R134A, SF6 weight scales: W(kg) = 3.102*I(mA)-12.465;
- Isobutane scale: W(kG) = 4.119*I(mA)-16.59;
- Humidity sensors: R.H. (%) = 20% R.H./V;
- Ventilation Open(alarm)/Close(normal) contact = $\sim\infty\ \Omega/\ \sim0\Omega$;
- Gas flow rate, pressure, HAD sensor Open(alarm)/Close(normal) contacts = $\sim\infty\ \Omega/\ \sim25\Omega$.

4. Troubleshooting

This section is evolving with the running experience; your feedback is most welcome.

Symptoms	Possible cause	Remedy
All gas flow meters show zero flow rates.	(1) The solenoid valve doesn't open, all pneumatic valves are closed. (2) Nitrogen gas cylinder does not have enough gas pressure (< 4 atm). (3) Any gas channel has lower than preset lower flow limit, thus shut off the solenoid valve.	(1) Check if all four gases have pressures higher than low limits. (2) Change N2 cylinder. (3) Check 247D to see if there is any switch unintentionally being turned off.
Buzzer activated.	Bypass button has been pushed unintentionally.	After 5' it will turns off automatically.
Histograms show all zero	COM port lost connection.	(1) Check COM port communication: Start|Control Panel|System|Hardware|Device Manage, click Ports(COM & LPT) to see if all required COM ports are there and in right Order. Unplug the USB cable, then plug in, sometime it may solve the problem. (2) Sometime the electric interference, such as plug a new device into the same power strip, may disturb the COM port communication. The above method may also solve the problem.
No data file saved In the relevant subdirectory, but the database records are OK.	A possible minor software bug may be the cause, a single bad data blocked the following data file operation.	Restart the Bubbler GUI may solve this problem. Will fix the software bug.
Solenoid Valve Open LED not on, no any other warning light on, but there is no gas flow in all 4 channels.	Check with detector control system to make sure they are not activating the emergency shut off state and the wall mounted fire emergency push button is not on.	

5. Appendixes

(1) SystemLogic_E.pdf , SystemLogic_E.dwg
(2) Flowmeter_H2.pdf, Flowmeter_H2.dwg
(3) Pressure_H2.pdf, Pressure_H2.dwg
(4) Powersupply_H3_1.pdf, Powersupply_H3_1.dwg
(5) status_H1_4.pdf, status_H1_4.dwg
(6) UL compliance

All parts used in the gas system are checked for their UL compliance, detailed information is summarized in Marking of Gas_PanelsV2.xls. All parts are UL compliant.

(7) msp430f1611.pdf ("MSP430x15x, MSP430x16x, MSP430x161x Mixed Signal Microcontroller"): http://focus.ti.com/lit/ds/symlink/msp430f1611.pdf
(8) SOLO XT Chlor-scale 150, installation & operation manual (XT 150-manual.pdf)
(9) Scaletron Model 2310 electronic scale manual, (2310-operating-instructions.pdf)
See also here: http://www.scaletronscales.com/pdf/2310-operating-instructions.pdf

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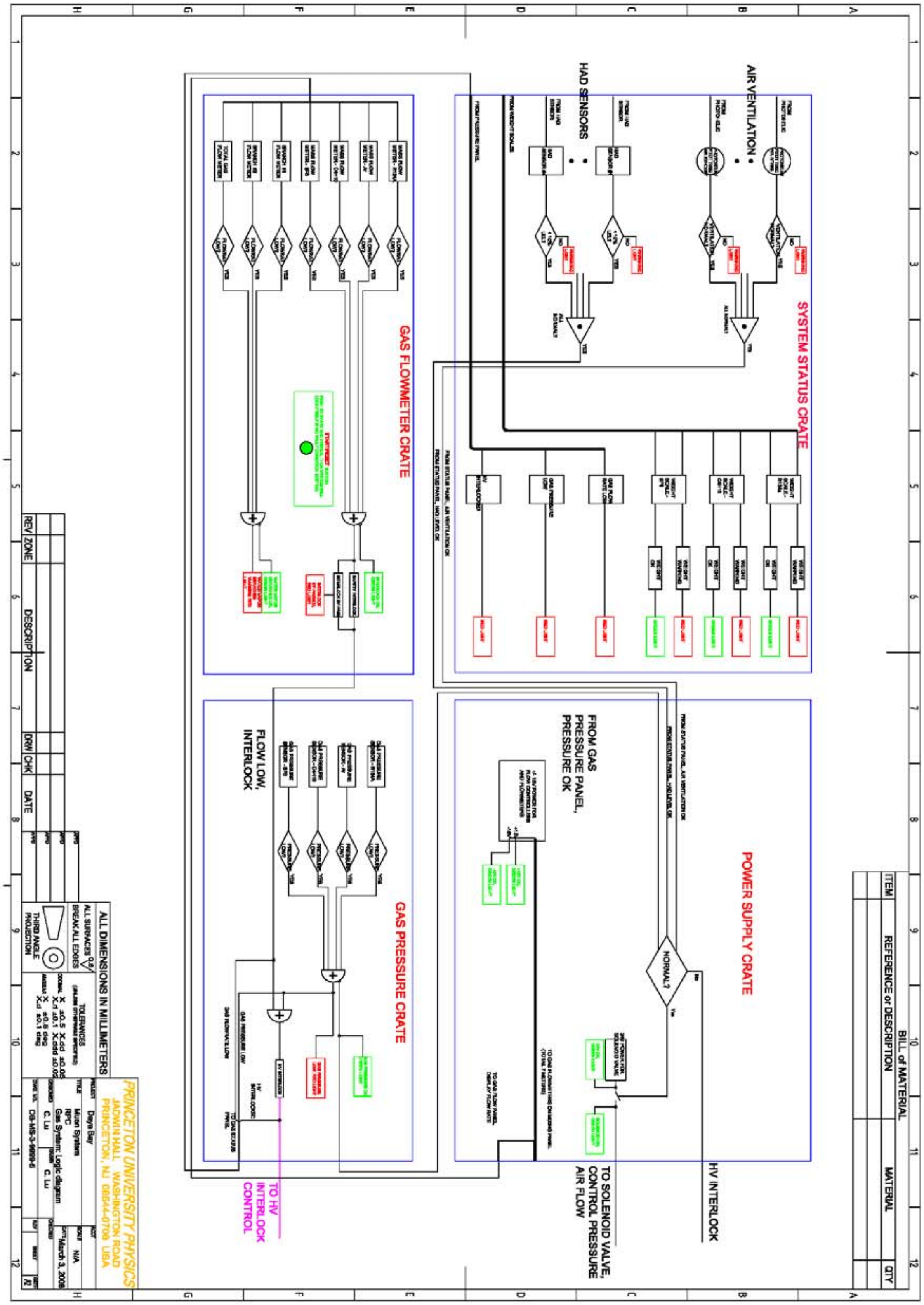
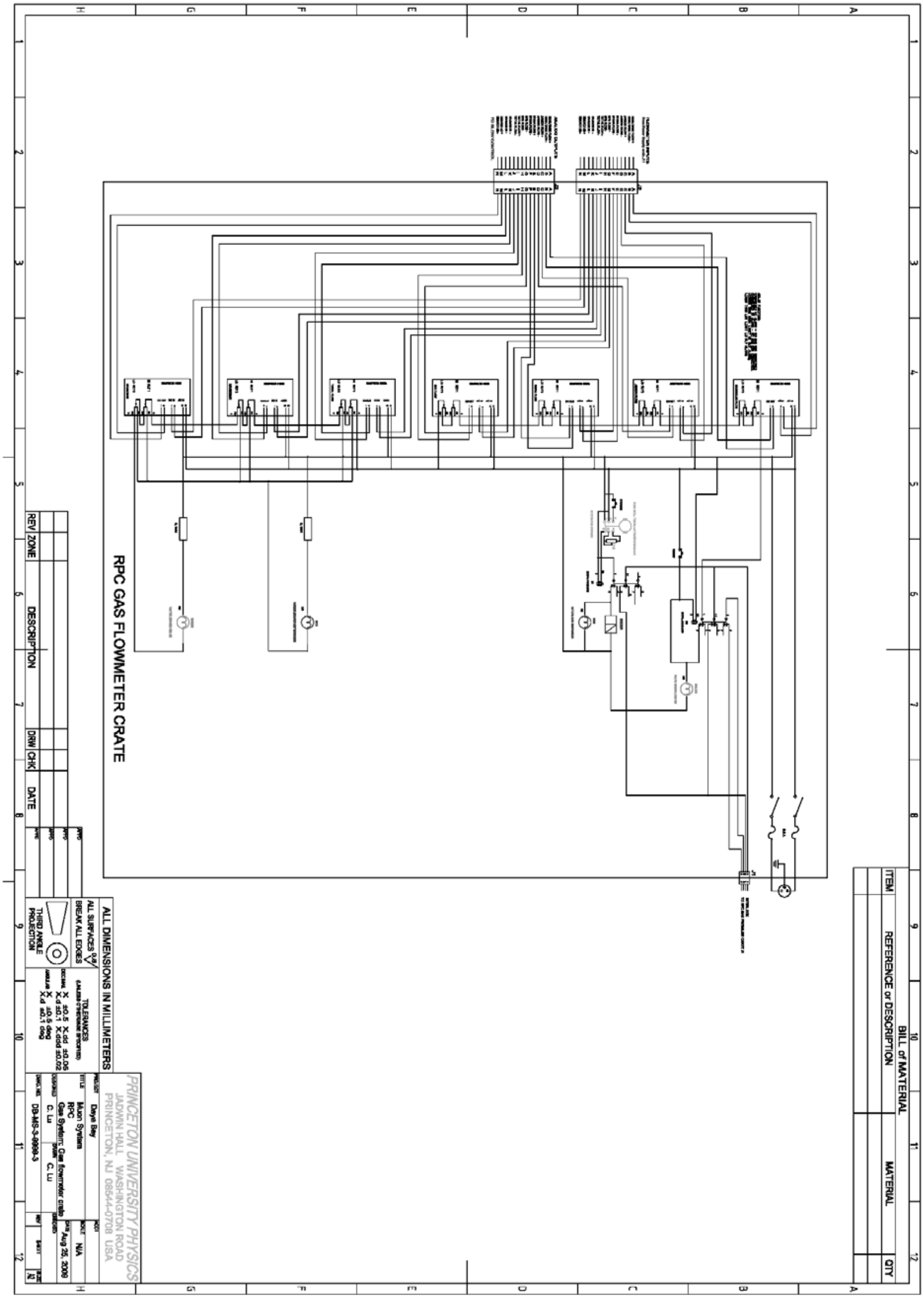
1. C. Lu and K. McDonald, DayaBay RPC Gas Safety System Design (June 19, 2008), DocDB #2691.
2. A. Abashian *et al.*, Nucl. Instr. Meth. **A449**, 112 (2000).
3. S. Foulkes *et al.*, Gas system upgrade for the BaBar IFR detector at SLAC, Nucl. Instr. Meth. A **538**, 801 (2005).
4. M. Ahart *et al.*, Flow Control and Measurement for RPC Gases, Belle Note 135 (Aug. 26, 1996), http://wwwphy.princeton.edu/~marlow/rpc/gas/flow.ps
5. A. Paoloni et al. Gas mixture studies for streamer operation of Resistive Plate Chambers at low rate, NIM A583(2007)264
6. Daniel Marlow, "Glass Resistive Plate Chamber in the Belle Experiment", Seminar at Rice University, July 9, 1999. http://wwwphy.princeton.edu/~marlow/talks/rice/rice.pdf
7. "MSP430x15x, MSP430x16x, MSP430x161x Mixed Signal Microcontroller", Texas Instruments.

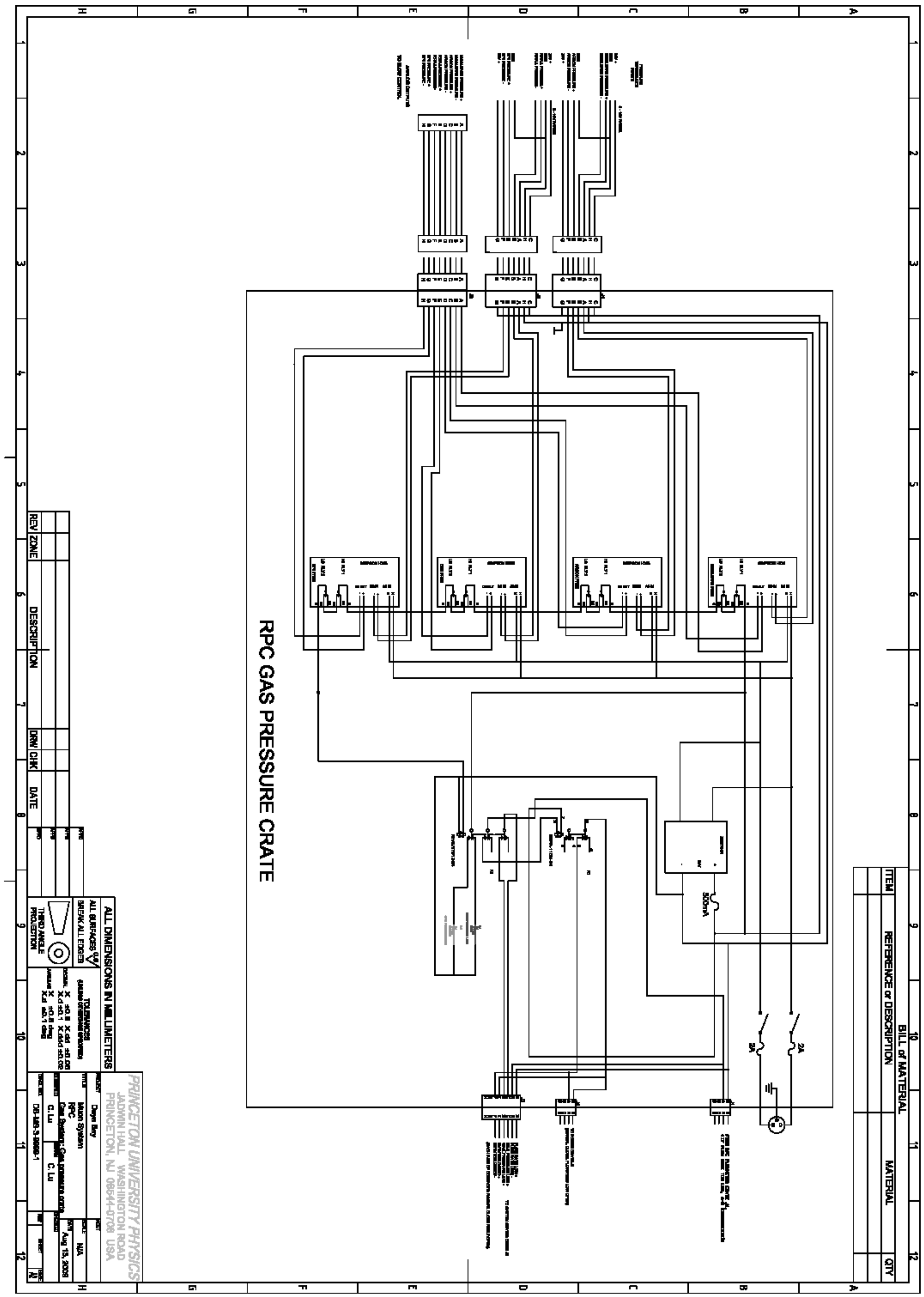
Appendix (1) SystemLogic_E.pdf (Double click on the plot will show the original pdf file)



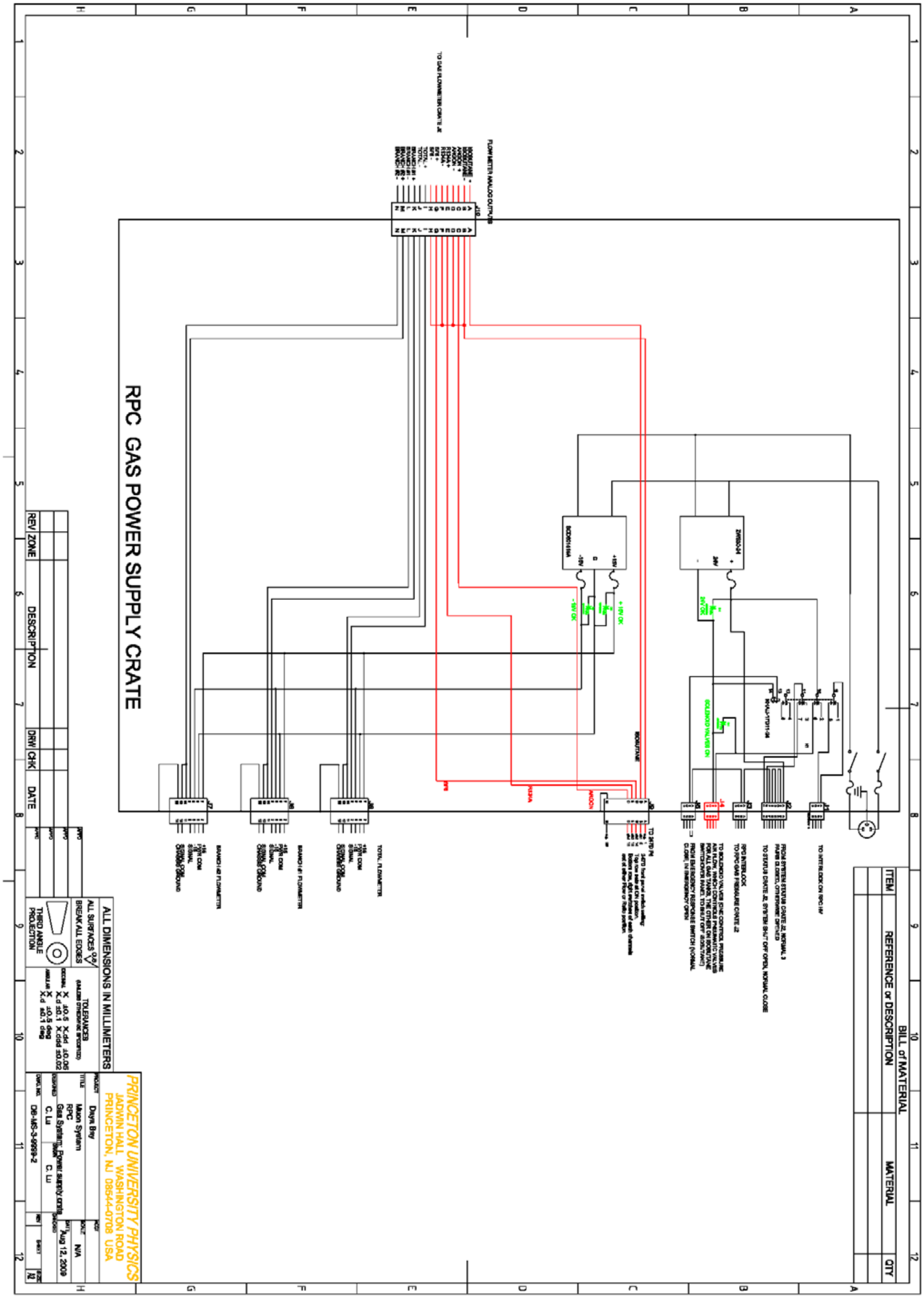
Appendix (2) Flowmeter_H2.pdf (Double click on the plot will show the original pdf file)



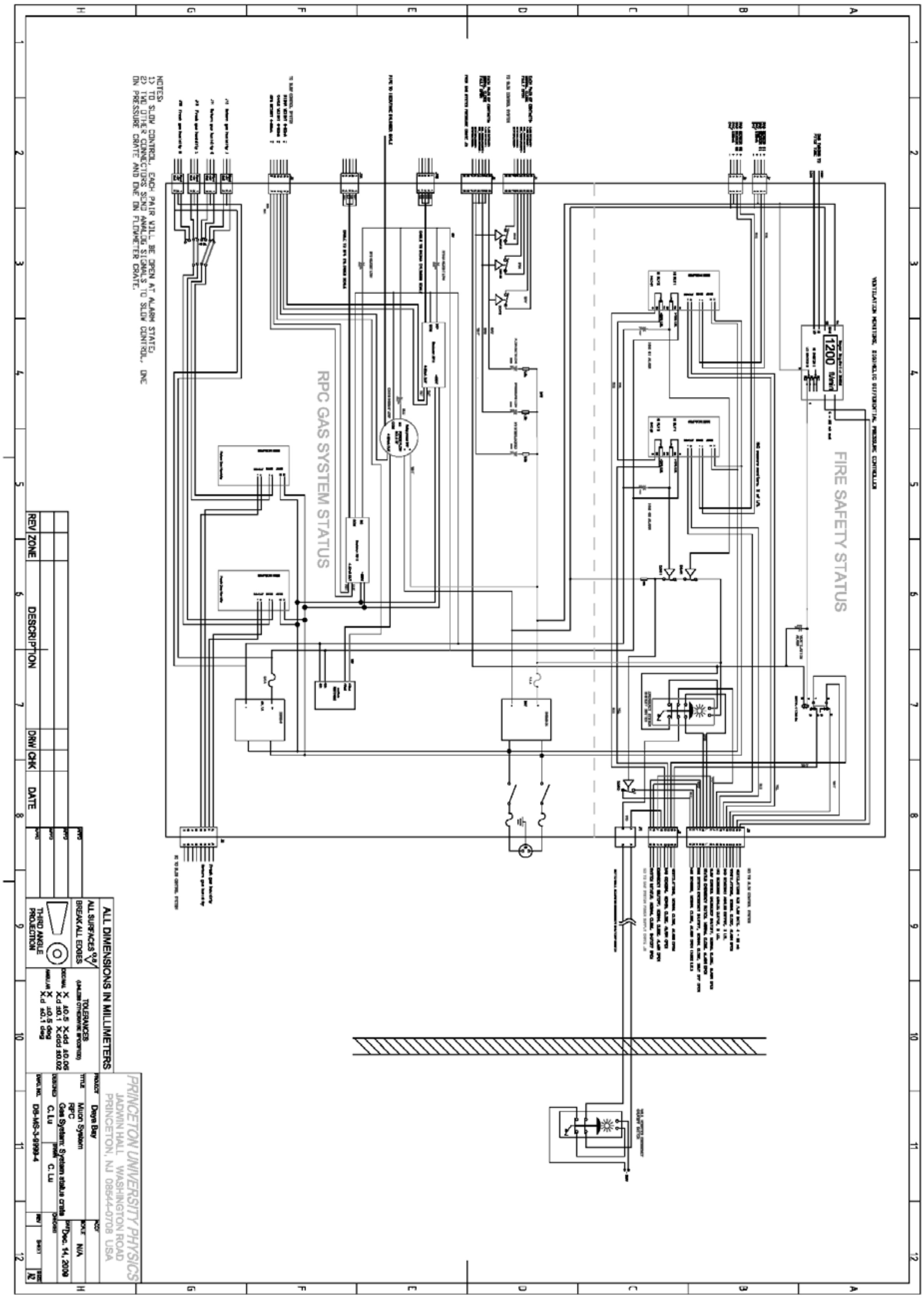
Appendix (3) Pressure_H2.pdf (Double click on the plot will show the original pdf file)



Appendix (4) Powersupply_H3_1.pdf (Double click on the plot will show the original pdf file)



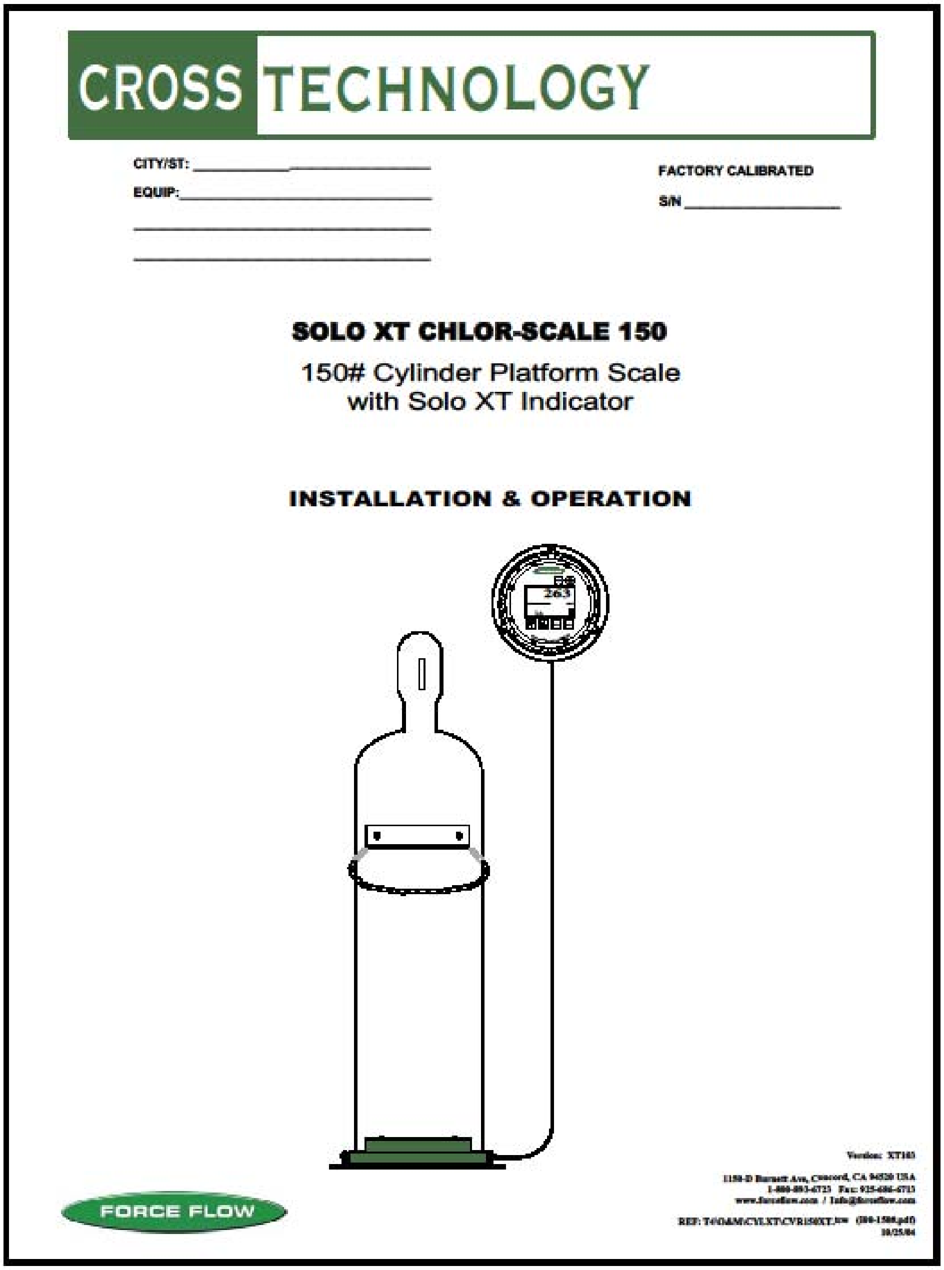
Appendix (5) status_H1_4.pdf (Double click on the plot will show the original pdf file)



Appendix (6) UL marking of gas system control crates components

PART # Discription	QTY	DISTRIBUTOR	DISTRIB #	MFG - PN	VOLTAGE	MARKINGs	ASSEMBLY
						*Data Sheet or Web Page	
						UR is a UL symbol for components.	
12V converter	1	Newark	72K1628	Lambda ZWS5-12	220V	*UL(UR) CSA CE	Power Crate
15V/-15V converter	1	Newark	72K0352	Lambda SCD601515	220V	*UL(UR) CSA CE	Power Crate
24V Power Supply	1	Newark	72K1614	Lambda ZWS10-24	220V	*UL(UR) CSA CE	Pressure Crate
Piezo Transducer	1	Allied	854-0047	Mallory SC250PR	220V	*UL(UR)	Interlock Crate
LED Lenses	1	Newark	26K6372	VCC CMS442CTP-PK10			Pwr & Press
LED Cable Assembly	1	Newark	88K1063	VCC CNX440X024112-PK10	< 5V		Pwr & Press
LEDs	10				< 5V		Pwr & Press
Fuse Holder	5	Newark	67K0275	Littelfuse H3453LS7	220V	*UL(UR) CSA	All
Fuse	5	Newark	26K8480	Littelfuse 313xxxP	220V	UL CSA	All
Relay khau-17d11-12	1	Newark	16M9048	Tyco KHAU-17D11-12	12V	*UL(UR) CSA	Power Crate
Relay Socket 14Pin	2	Avnet	27E166	Tyco 27E166	24V	*UL	Pwr & Press
RELAY RETAINING CLIP	2	Newark	57F3402	Tyco 20C217			Pwr & Press
Relay khau-17d13-24	1	Newark	16M9052	Tyco KHAU-17D13-24	24V	*UL(UR) CSA	Pressure Crate
Relay krpa-11dn-24	1	Newark	21F1087	Tyco KRPA-11DN-24	24V	*UL(UR) CSA	Pressure Crate
Relay Socket 8Pin	1	Newark	57F3431	Tyco 27E122	24V		Pressure Crate
Relay krpa-14ag-240 (240V)	2	Newark	21F1098	Tyco KRPA-14AG-240	220V	*UL(UR) CSA	Interlock Crate
Relay Socket 11Pin	2	Newark	57F3432	Tyco 27E123	220V	*UL(UR) CSA	Interlock Crate
Relay Hold-Down Clip	3	Newark	57F3400	Tyco 20C176			Interlock Crate
Panel Indicator Red	2	Allied	679-9768	CML 1031D1	220V	*UL CSA	Interlock Crate
Panel Indicator Green	2	Allied	679-9771	CML 1033D5	220V	*UL CSA	Interlock Crate
Power Socket	3	Newark	94F083	Switchcraft EAC309	220V	UL CSA	All
PushBotton Switch	1	Allied	814-1069	IDEC AB6M-M1P-G	220V	*UL(UR)	Interlock Crate
Simpson H335	11	Newark	60M3124	Simpson H335-4-13-2-2-0	220V	UL CE	Press & Interlock
Terminal Block 8	2	Newark	28F717	Cinch 8-141	220V	*UL CSA	Press & Interlock
Timer 0-15 min	1	Newark	86K9982	ARTISAN CONTROLS 438US	220V	*UL	Interlock Crate
Pot 5M Ohms 2W	1	Allied	753-1248	Honeywell 53C35MEG			Interlock Crate
Knob/Dial	1	Newark	95F7003	EHC EH712F2S			Interlock Crate
PCB for DB15 Conn	1	PCBExpress		29 sq in	15V		Power Crate
Chassis 17"x 5.25"x 14"	1			Proline 10-006ca			Power Crate
Chassis 17"x 7"x 14"	1			Proline 10-010ca			Pressure Crate
Chassis 17"x 10.5"x 14"	1			Proline 10-018ca			Interlock Crate
Conn Circular 19	3	Newark	16F5736	Souriau UTG616-19PN	24V	*UL	Inter & Pwr
Conn Circular 19 Wall Mount	3	Newark	16F5728	Souriau UTG016-19S	24V	*UL	Inter & Pwr
Conn Circular 19	1	Newark	16F5744	Souriau UTG616-19SN	24V	*UL	Inter & Pwr
Cable Clamp Size:16	3	Newark	16F5825	Souriau UTG16AC			Inter & Pwr
Cable Clamp Size:12	9	Newark	16F5823	Souriau UTG12AC			Pressure Crate
Conn Circular 8	9	Newark	16F5734	Souriau UTG612-8PN	24V	*UL	Pressure Crate
Conn Circular 8 Wall Mount	9	Newark	16F5726	Souriau UTG012-8S	24V	*UL	Pressure Crate
Conn Circular 8 Wall Mount	1	Newark	16F5718	Souriau UTG012-8P	24V	*UL	Pressure Crate
Conn Circular 8	1	Newark	16F5742	Souriau UTG612-8SN	24V	*UL	Pressure Crate
Cable Clamp Size:10	8	Newark	16F5822	Souriau UTG10AC			All
Conn Circular 4 Wall Mount	8	Newark	16F5725	Souriau UTG010-4S	24V	*UL	All
Conn Circular 4	8	Newark	16F5733	Souriau UTG610-4PN	24V	*UL	All
Crimp Pin AWG26-24 pkg25	1	Newark	93K6211	Souriau SM24ML1D70	24V		All
Crimp Socket AWG26-24 pkg25	1	Newark	88K2682	Souriau SC24ML1D70	24V		All
Crimp Pin AWG22-20 pkg25	1	Newark	93K6208	Souriau SM20ML1D70	24V		All
Crimp Socket AWG22-20 pkg25	1	Newark	88K2677	Souriau SC20ML1D70	24V		All
Conn DB15	7	Newark	42K6543	Tyco 1-5747299-4	15V	*UL CSA	Power Crate
Conn Housing 3Pin	1	Newark	38C8766	Molex 09-50-3031	220V	*UL	Power Crate
Conn Housing 6Pin	1	Newark	38C8769	Molex 09-50-3061	15V	*UL	Power Crate
Conn Header 6Pin	1	Newark	13C2876	Molex 26-60-4060	15V	*UL	Power Crate
Crimp Term AWG20-18 pkg100	1	Newark	35C3725	Molex 08-52-0113			Power Crate
Pin Header 6Pin	1	Newark	27C1933	Molex 22-23-2061	15V	*UL	Power Crate
Conn Housing 8Pin	2	Newark	13C2635	Molex 10-11-2083	220V	*UL	Pwr & Press
Conn Housing 6Pin	1	Newark	35H6565	Molex 10-11-2063	15V	*UL	Power Crate
Conn Housing 4Pin	2	Newark	13C2636	Molex 10-11-2043	24V	*UL	Pwr & Press
MKS 247D 4-channel readout box	1	MKS			220V	A similar device 247C has past BNL safety te	

Appemdix (8) SOLO XT150 digital scale manual.



Read XT150-manual.pdf for the details.