G2

User Guide

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Document History

Revision History

Revision Number	Revision Date	Summary of Changes	Author
preliminary	08 Apr 2016	Initial	Bob

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1 Introduction

The RH Systems G2 Humidity Generator is a system capable of continuous, high-accuracy humidity generation over a wide range of humidity, temperature, and flow rates. The G2 design is an RHS hybrid two-pressure two-temperature system based on the fundamental two-pressure principle originally developed by NIST. The basis of this principle and its original development are discussed below.

1.1 Background of Humidity Generation

In 1948 at the U.S. National Bureau of Standards (now the National Institute of Standards and Technology), E.R. Weaver and R. Riley developed a "pressure method" for the generation and control of humidity. Their method, termed the *two-pressure principle*, was derived from measurements of temperature and pressure rather than requiring measurements of water vapor.

Using their technique, air or some other gas was saturated with water vapor at high pressure and then expanded to a lower pressure. When saturation and expansion were performed under constant-temperature conditions, the resulting relative humidity of the gas was simply the ratio of the lower pressure to the higher pressure (or at least very nearly).

Their equipment was designed for low rates of gas flow and was used under ambient temperature conditions. Their saturator was a small cylinder containing water and filled with fragments of pumice or stream-washed gravel through which the gas could be bubbled under pressure. This device was developed primarily for the calibration of electrically conductive hygroscopic films used in the measurement of water vapor in gases.

In 1951, also at the National Bureau of Standards, the two-pressure principle was the foundation on which A. Wexler and R.D. Daniels developed a new "pressure–humidity apparatus" with higher air-flow capability. Another significant improvement was the incorporation of temperature control. Developed primarily for hygrometer research and calibration, it was capable of producing atmospheres of known relative humidity from 10 %RH to 98 %RH over a fairly wide temperature range –40°C to +40 °C.

After about twenty-five years of service, this pressure-humidity apparatus was replaced by a newer model, the Mark 2 (which was later referred to as Mark II). This Mark II generator allowed for a wider range of temperature and humidity with improved uncertainty in the generated output.

1.2 The RHS Hybrid Two-Pressure Two-Temperature Principle

In an ideal two-pressure two-temperature system, a stream of gas at an elevated pressure and initial temperature is saturated with respect to the liquid or solid phase of water and then expanded to a lower pressure and secondary temperature. Measurements of the pressure and temperature of the gas stream, both at saturation and after expansion, are all that is required to determine the resulting humidity content of the expanded gas stream. A simplified two-pressure system is shown in Figure 1.

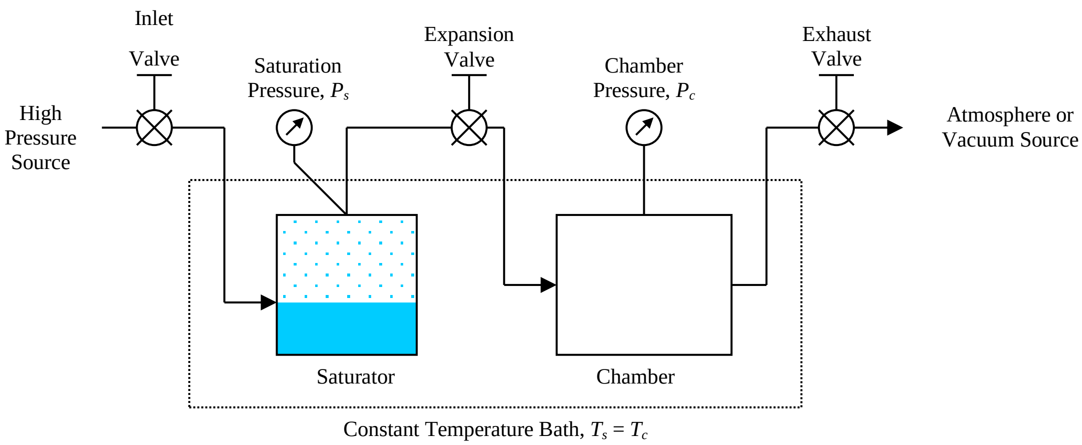


Figure 1—Simplified schematic diagram of the two-pressure principle where $T_s = T_c$.

A two-pressure generator is commonly used in the generation of a range of relative humidity values at various temperatures. If the saturator and chamber are at the same temperature, the generated relative humidity may be approximated by the ratio of the measured saturated gas-stream pressure (saturation pressure) to the measured chamber pressure, and expressed by the following simplified equation:

$$RH = \frac{P_c}{P_s} \times 100$$

where P_c is the absolute chamber (or final) pressure

P_s is the absolute saturation pressure.

Please note that the above expression is only an approximation. More exacting equations are presented below that take into account the differences temperature between the saturator and the final point of use, and the non-ideal properties of water-vapor when admixed with a carrier gas (such as air).

In an RHS hybrid two-pressure two-temperature system, the addition of temperature differences are considered and utilized to further quantify the generated humidity. Rather than expecting the saturation and final temperatures to be equal, the hybrid design anticipates that the gas undergoes a change in temperature as it makes its way to the final point of use. By measuring these two different temperatures precisely, the generated humidity can be further modified by the saturation vapor pressures at these two temperatures. The hybrid equation may be expressed by the following:

$$RH = \frac{P_c}{P_s} \times \frac{é_s}{é_c} \times 100$$

Where P_c is the absolute final pressure

P_s is the absolute saturation pressure

$é_s$ is the effective saturation vapor pressure computed at the saturation temperature

$é_c$ is the effective saturation vapor pressure computed at the final (or chamber) temperature

1.3 Common Defining Equations

The following equations of R. Hardy for saturation vapor pressure, enhancement factor, and temperature (from saturation vapor pressure) are common and fundamental to most of the humidity calculations presented here.

1.3.1 Saturation Vapor Pressure over Water

Saturation vapor pressure over *water* at a given ITS-90 temperature in the range –100 °C to +100 °C is defined by the formula

$$e = \exp\left(\sum_{i=0}^{6} g_i T^{i-2} + g_7 \ln T\right) \tag{1}$$

where e is the saturation vapor pressure (in Pascals) over liquid water in the pure phase

T is the temperature in Kelvin

and
$g_0 = -2.8365744 \cdot 10^{3}$
$g_1 = -6.028076559 \cdot 10^{3}$
$g_2 = 1.954263612 \cdot 10^{1}$
$g_3 = -2.737830188 \cdot 10^{-2}$
$g_4 = 1.6261698 \cdot 10^{-5}$
$g_5 = 7.0229056 \cdot 10^{-10}$
$g_6 = -1.8680009 \cdot 10^{-13}$
$g_7 = 2.7150305$

1.3.2 Saturation Vapor Pressure over Ice

Saturation vapor pressure over *ice* at a given ITS-90 temperature in the range –100 °C to 0.01 °C is defined by the formula

$$e = \exp\left(\sum_{i=0}^{4} k_i T^{i-1} + k_5 \ln T\right) \tag{2}$$

where e is the saturation vapor pressure (in Pascals) over ice in the pure phase

T is the temperature in Kelvin

and
$k_0 = -5.8666426 \cdot 10^{3}$
$k_1 = 2.232870244 \cdot 10^{1}$
$k_2 = 1.39387003 \cdot 10^{-2}$
$k_3 = -3.4262402 \cdot 10^{-5}$
$k_4 = 2.7040955 \cdot 10^{-8}$
$k_5 = 6.7063522 \cdot 10^{-1}$

1.3.3 Enhancement Factor

The “effective” saturation vapor pressure over water or ice in the presence of other gases differs from the ideal saturation vapor pressures given in Equations 1 and 2. The effective saturation vapor pressure is related to the ideal by

$$\acute{e} = e \cdot f \tag{3}$$

where $\acute{e}$ is the “effective” saturation vapor pressure

e is the ideal saturation vapor pressure (as given in Equation 1 or 2)

and f is the enhancement factor

The enhancement factor, for an air and water-vapor mixture, is determined at a given temperature and pressure from the formula

$$f = \exp\left[\alpha\left(1 - \frac{e}{P}\right) + \beta\left(\frac{P}{e} - 1\right)\right] \tag{4}$$

with $$\alpha = \sum_{i=0}^{3} a_i T^i \tag{5}$$

and $$\beta = \exp\left(\sum_{i=0}^{3} b_i T^i\right) \tag{6}$$

where P is the total pressure in the same units as e

T is temperature in Kelvin

and a_i, b_i depend on temperature range and are given as

for water:

223.15 K to 273.15 K (–50 °C to 0 °C)	273.15 K to 373.15 K (0 °C to 100 °C)
$a_0 = -5.5898101 \cdot 10^{-2}$	$a_0 = -1.6302041 \cdot 10^{-1}$
$a_1 = 6.7140389 \cdot 10^{-4}$	$a_1 = 1.8071570 \cdot 10^{-3}$
$a_2 = -2.7492721 \cdot 10^{-6}$	$a_2 = -6.7703064 \cdot 10^{-6}$
$a_3 = 3.8268958 \cdot 10^{-9}$	$a_3 = 8.5813609 \cdot 10^{-9}$
$b_0 = -8.1985393 \cdot 10^{1}$	$b_0 = -5.9890467 \cdot 10^{1}$
$b_1 = 5.8230823 \cdot 10^{-1}$	$b_1 = 3.4378043 \cdot 10^{-1}$
$b_2 = -1.6340527 \cdot 10^{-3}$	$b_2 = -7.7326396 \cdot 10^{-4}$
$b_3 = 1.6725084 \cdot 10^{-6}$	$b_3 = 6.3405286 \cdot 10^{-7}$

for ice:

173.15 to 223.15 K (–100 °C to –50 °C)	223.15 to 273.15 K (–50 °C to 0°C)

$a_0 = -7.4712663 \cdot 10^{-2}$	$a_0 = -7.1044201 \cdot 10^{-2}$
$a_1 = 9.5972907 \cdot 10^{-4}$	$a_1 = 8.6786223 \cdot 10^{-4}$
$a_2 = -4.1935419 \cdot 10^{-6}$	$a_2 = -3.5912529 \cdot 10^{-6}$
$a_3 = 6.2038841 \cdot 10^{-9}$	$a_3 = 5.0194210 \cdot 10^{-9}$
$b_0 = -1.0385289 \cdot 10^{2}$	$b_0 = -8.2308868 \cdot 10^{1}$
$b_1 = 8.5753626 \cdot 10^{-1}$	$b_1 = 5.6519110 \cdot 10^{-1}$
$b_2 = -2.8578612 \cdot 10^{-3}$	$b_2 = -1.5304505 \cdot 10^{-3}$
$b_3 = 3.5499292 \cdot 10^{-6}$	$b_3 = 1.5395086 \cdot 10^{-6}$

1.3.4 Temperature from Saturation Vapor Pressure

Equations 1 and 2 are easily solved for saturation vapor pressure over water or ice for a given saturation temperature. However, if vapor pressure is known and temperature is the unknown desired quantity, the solution immediately becomes complicated and must be solved by iteration. For ease of computation, the following inverse equation is provided. This equation is generally used to find the dew point or frost point temperature when the vapor pressure of a gas has been determined. When vapor pressure is known, use the water coefficients to obtain the dew point and use the ice coefficients to obtain the frost point.

$$T = \frac{\sum_{i=0}^{3} c_i (\ln e)^i}{\sum_{i=0}^{3} d_i (\ln e)^i} \qquad (7)$$

where T is the temperature in kelvin

and e is the saturation vapor pressure in pascals

with coefficients

for water:	for ice:
$c_0 = 2.0798233 \cdot 10^{2}$	$c_0 = 2.1257969 \cdot 10^{2}$
$c_1 = -2.0156028 \cdot 10^{1}$	$c_1 = -1.0264612 \cdot 10^{1}$
$c_2 = 4.6778925 \cdot 10^{-1}$	$c_2 = 1.4354796 \cdot 10^{-1}$
$c_3 = -9.2288067 \cdot 10^{-6}$	$c_3 = 0$
$d_0 = 1$	$d_0 = 1$
$d_1 = -1.3319669 \cdot 10^{-1}$	$d_1 = -8.2871619 \cdot 10^{-2}$
$d_2 = 5.6577518 \cdot 10^{-3}$	$d_2 = 2.3540411 \cdot 10^{-3}$
$d_3 = -7.5172865 \cdot 10^{-5}$	$d_3 = -2.4363951 \cdot 10^{-5}$

1.4 Humidity Equations

The following equations are used in the G2 to calculate various humidity parameters. These equations are not approximations, but rather account for the temperature differences between the saturator and chamber, and the non-ideal behavior of water vapor when admixed with air or other gases.

1.4.1 Relative Humidity

Percent relative humidity is the ratio of the amount of water vapor in a gas to the maximum amount possible at the same temperature and pressure. For two-pressure, two-temperature systems, it is defined by the equation

$$RH = \frac{P_c}{P_s} \cdot \frac{e'_s}{e'_c} \cdot 100 \qquad (8)$$

which then expands to

$$RH = \frac{P_c}{P_s} \cdot \frac{f_s}{f_c} \cdot \frac{e_s}{e_c} \cdot 100 \qquad (9)$$

where P_c is the absolute chamber pressure

P_s is the absolute saturation pressure

f_c is the enhancement factor at chamber temperature and pressure

f_s is the enhancement factor at saturator temperature and pressure

e_c is the saturation vapor pressure at chamber temperature

and e_s is the saturation vapor pressure at saturator temperature.

1.4.2 Dew Point Temperature

Dew point temperature is the temperature to which a gas must be cooled to initiate condensing water vapor in the form of dew (note that dew point temperature can exist above or below 0°C). Dew point temperature is obtained with the following iterative steps.

a. Make an educated guess at the dew or frost point enhancement factor f_d. Setting $f_d = 1$ is a suitable first guess.

b. Next, compute the dew or frost point vapor pressure of the gas with the formula

$$e_d = e_s \cdot \frac{f_s}{f_d} \cdot \frac{P_c}{P_s} \qquad (10)$$

c. Use the dew or frost point vapor pressure e_d determined in the previous step, along with Equation 7 for water, to compute T. Call this value the dew point temperature T_d.

d. Use the dew point temperature T_d, chamber pressure P_c, and Equation 4 for water to compute the dew or frost point enhancement factor f_d.

e. Converge to the proper dew point temperature T_d by repeating steps b through d several times, as necessary.

1.4.3 Frost Point Temperature

Frost point temperature is the temperature to which a gas must be cooled to begin condensing water vapor in the form of frost or ice. Frost point exists only at temperatures below freezing. Frost point is obtained with the following iterative steps.

a. Make an educated guess at the dew or frost point enhancement factor f_d. Setting $f_d = 1$ is a suitable first guess.

b. Next, compute the dew or frost point vapor pressure of the gas with the formula

$$e_d = e_s \cdot \frac{f_s}{f_d} \cdot \frac{P_c}{P_s} \qquad (10)$$

c. Use the dew or frost point vapor pressure e_d determined in the previous step, along with Equation 7 for ice, to compute T. Call this value the frost point temperature T_f.

d. Use the frost point temperature T_f, chamber pressure P_c, and Equation 4 for ice to compute the dew or frost point enhancement factor f_d.

e. Converge to the proper frost point temperature T_f by repeating steps b through d several times, as necessary.

1.4.4 Vapor Concentration

Vapor-concentration, traditionally referred to as parts per million by volume (ppm_v), is a ratio relating the number of moles of water vapor to the number of moles of the remaining constituents in the gas (the dry gas component). Once established by the following formula, the vapor concentration is insensitive to further changes in pressure or temperature, provided there is no subsequent condensation.

$$\text{vapor concentration} = \frac{f_s \cdot e_s}{P_s - f_s \cdot e_s} \cdot 10^6 \ \mu\text{mol/mol} \qquad (11)$$

1.4.5 Humidity Ratio

Humidity ratio w is defined as the mass of water vapor to the mass of the dry gas; it is computed with the formula

$$w = \frac{M_w \cdot f_s \cdot e_s}{M_g\left(P_s - f_s \cdot e_s\right)} \ \text{g/g} \qquad (12)$$

where M_w is the molecular weight of water vapor, 18.02

M_g is the molecular weight of the carrier gas (28.9645 for air).

Humidity ratio may also be computed and expressed in grams per kilogram and micrograms per gram. When expressed in micrograms per gram, humidity ratio is traditionally referred to in parts per million by weight (ppm_w).

1.4.6 Absolute Humidity

Absolute humidity d_v is defined as the mass of water vapor to the unit volume of humidified gas and is computed with the formula

$$d_v = \frac{M_w}{R \cdot T_c} \cdot \frac{f_s \cdot e_s \cdot P_c}{P_s} \text{ g/m}^3 \qquad (13)$$

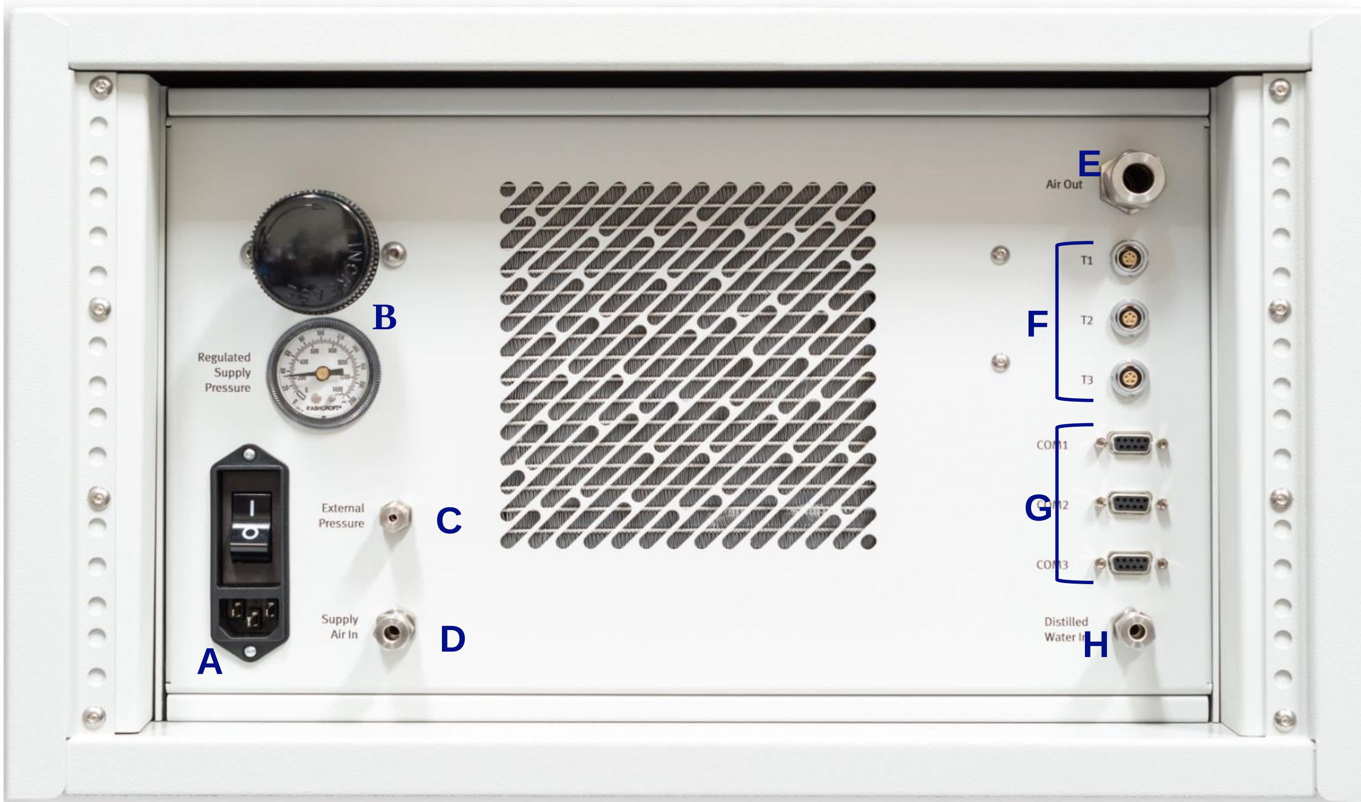
where R is the molar gas constant 8.31472

1.4.7 Specific Humidity

Specific humidity q is defined as the mass of the water vapor to the total mass of the gas mixture and is computed with the formula

$$q = \frac{M_w \cdot f_s \cdot e_s}{M_g (P_s - f_s \cdot e_s) + M_w \cdot f_s \cdot e_s} \text{ g/g} \qquad (14)$$

2 G2 Back Panel



Connection panel side of instrument showing:

A. AC power receptacle and power switch
B. Inlet pressure regulator and indicator
C. External pressure sampling port, ⅛" Swagelok
D. Compressed air supply input, ¼" Swagelok
E. Humidity controlled air output, ½" Swagelok
F. External temperature sensor connections (3)
G. RS-232 serial communication ports (3)
H. Distilled water inlet, ¼" Swagelok

2.1 Back panel connections

2.1.1 AC power receptacle and power switch

The AC receptacle is used for connection of the input power cord. Power requirements are identified in section 3.1.1

The power switch is used to turn the G2 on/off. It is also a 15 amp circuit breaker and is a protection against over current conditions.

2.1.2 External Pressure

Measurement from the External Pressure sensor is used for all calculations of humidity including %RH and dew point. With no connection to the *External Pressure* port, the sensor measures atmospheric pressure and uses it from computations of humidity. If humidity measurement and control is desired at a specific location, such as inside a remote chamber, a 1/8" sampling tube should be connected between the *External Pressure* port and the remote chamber. This allows the G2 to measure the pressure inside that chamber in order to calculate and control humidity accordingly. Typical pressure range of the external pressure sensor is in the barometric pressure range 0.8 to 1.2 kPa absolute (approximately 12 to 17 psia). Other pressure ranges are available.

2.1.3 Supply Air In

The *Supply Air In* port is a ¼" Swagelok fitting for connection of the compressed air input. Specifications for the compressed air are found in section 3.1.2. The G2 can handle a maximum inlet pressure of 1.7 MPa absolute (250 psia). Depending on the specific G2 system, flow rates as high as 100 liters per minute will be required at this port.

2.1.3.1 Regulated Supply Pressure

The G2 requires a constant pressure source in order to properly generate stable humidity values. An internal pressure regulator is built in for this purpose. Compressed air or gas connected to the *Supply Air In* port feeds the input of the G2's pressure regulator. The black knob in the G2 back panel is used to set the regulated pressure as indicated on the *Regulated Supply Pressure* dial. This regulated supply pressure is also measured internally by an electronic pressure transducer. By setting the regulated supply pressure of the G2 to a value below the lowest expected pressure from your air compressor system, the G2 can then regulate this to a constant value, enabling the system to generate stable humidity values.

2.1.4 Air Out

Humidified gas from the G2 is available at the *Air Out* port using a ½" Swagelok fitting. A tube may be connected to this port to direct the gas to the location of choice (such as a chamber). Use of ½" tubing is recommended if the G2 is being operated at high flow rates in order to reduce the pressure drop within the tubing. If the G2 is operated at low flow rates, smaller tubing may be used.

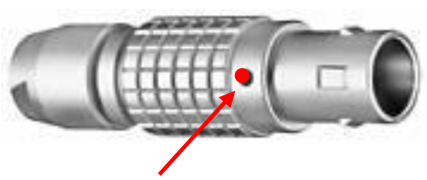
The *Air Out* port is not heated on most G2 systems, so generated dew point values should remain at a value below the room temperature to prevent condensation inside the tubing.

2.1.5 T1, T2, T3

External thermometers T1, T2, and T3 are used for temperature measurement of external chambers or devices and are required for determination of Relative Humidity values RH1, RH2, and RH3 respectively. If %RH is not to be computed, then these external thermometers are not required.

The G2 is typically supplied with one external thermometer. Additional thermometers are available for purchase, or you may connect your own 100 ohm platinum resistance thermometers provided you use the following connection scheme.

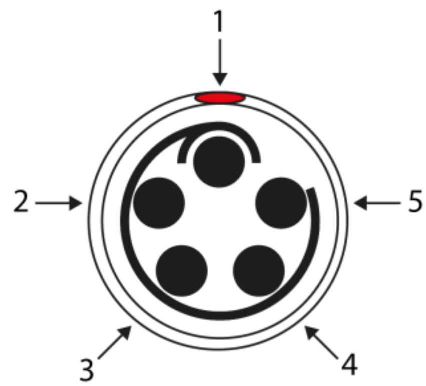
2.1.5.1 Thermometer wiring



Red Dot aligns with Pin 1

If you wish to attach your own 100 ohm 4-wire thermometers to the G2, you'll require a 5-pin LEMO connector (www.lemo.ch), part number FGG 1B 305 CLAD42.

Pin	Signal	Description
1	Shield	No connection
2 3	X	Connect to one side of the PRT
4 5	Y	Connect to the other side of the PRT



When viewing the solder tubs of a disassembled 5-pin LEMO connector, pin 1 is usually identified with a full or partial circle drawn around it. Pin 5 should have no identifier. When wiring the cable, note that the pin numbering of the socket mounted in the back panel of the G2 starts at the top (pin 1) and goes counter-clockwise. The view above is looking at the inside (wire side) of the plug.

When the LEMO connector is properly assembled, the red dot of the connector housing should be directly above pin 1.

2.1.6 Com1, Com2, Com3

The RS-232 serial ports, Com1 through Com3, are for communication with external computers. The ports are identical in function and wiring, yet completely independent from one another, allowing up to three individual PC's to communicate simultaneously with the G2. Any response from the G2 to a command or query will be directed to the port that issued the command or query. For example, a request for data from a PC on Com2 will be directed back to Com2, while Com1 and Com3 will have no idea the Com2 communication took place. The exception to this is with regard to commands that alter the condition or state of the G2. For example, if a PC connected to Com1 is sending commands to change the RH settings, and a PC connected to Com2 is changing Dew Point settings, both setpoint commands will be honored and executed. However, the command arriving latest, regardless of port number, will be the ultimate victor. If planning to connect more than one computer to the G2, you should decide which of these computers you prefer to use as the master controller, and allow the other computers to only send requests for data.

Connect to an external PC using a standard 9 pin RS-232 extender cable. The extender cable is wired straight through with a male connector on one side and a female connector on the other.

2.1.6.1 RS-232 cable wiring

If making your own RS-232 cable for Com1-3 connection, refer to the following pinout. Note that pins 2, 3 and 5 are the only connections required. All other pins are optional and not utilized by the G2.

D9 male	Signal	D9 female
1		1
2	Tx	2
3	Rx	3
4		4
5	Common	5
6		6
7		7
8		8
9		9

2.1.7 Distilled Water

An external supply of distilled water is required and must be connected via a suction tube ($^1/_8$" or ¼" diameter tube is sufficient) to the *Distilled Water In* port. The distilled water is used as the source of water vapor in humidity generation.

3 Installation

3.1 Facility Requirements

Prior to arrival of your G2 instrument, preparations should be made to ensure you have the proper facilities available at the desired instrument location. The G2 will require the following for initial connection and continuous service.

3.1.1 Power

200-240 VAC, single phase, 15A, 50/60 Hz

3.1.2 Compressed Gas Supply

Supply gas should meet the following specifications:

Supply pressure	approximately 75 to 200 psi (500 to 1400 kPa), regulated prior to the G2
Flow rate	up to 100 l/min (depending on model) while maintaining regulated pressure
Pressure dew point	5°C or lower when measured at the inlet pressure
Oil-free	No mist or oil vapors
Connection	¼" Swagelok fitting

3.1.3 Distilled Water

Initial supply	~1 gallon (~4 liters) of distilled water
Connection	¼" Swagelok fitting

Use distilled water only. Use of deionized water is not recommended as it tends to be chemically aggressive to stainless steel and may cause pitting of the saturator. The G2 requires enough distilled water for its initial fill of the presaturator, then a small on-going supply for continuous humidity generation.

3.1.4 Rack Space / Bench Space

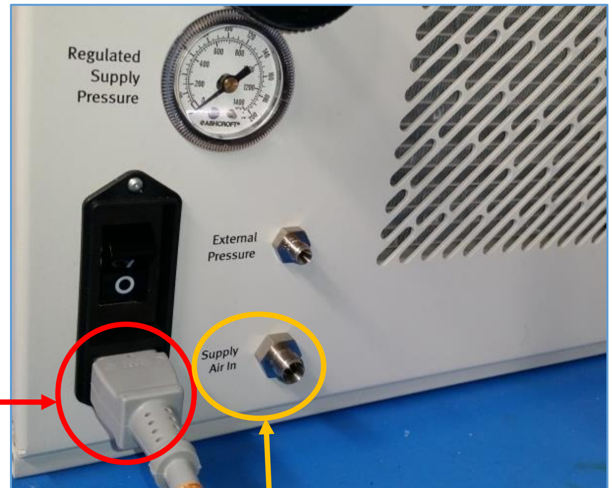
System dimensions are 22" x 16.75" x 10.5" (560 x 425 x 267 mm). If installing the G2 in a 19" rack system, it requires a minimum 6U of vertical rack space. Allow adequate space to the rear and top of the unit during operation for proper ventilation, service, and utility connections.

3.2 Utility Connections

3.2.1 AC Power Connection

The G2 requires 200-240 VAC, 15 A, 50/60 Hz, single phase power. AC input may be connected in either of two configurations

- LINE1, LINE2, GND (as is often the case for connection in the U.S., Canada, Mexico, Japan, and Taiwan where LINE1 and LINE2 are of opposing phase while each is approximately 100-120 VAC with respect to GND), or
- LINE, NEUTRAL, GND (often for Europe and many countries of Asia when LINE is approximately 200-240 VAC with respect to NEUTRAL, with NEUTRAL and GND at the same potential).



Using a standard power cord, plug the system into the appropriate AC power. It is recommended (and may be required by your local electrical codes) to install a Ground Fault Circuit Interrupt (GFCI) breaker at the load center which feeds power to the G2.

3.2.2 Gas Supply Connection

The G2 requires a clean, dry, oil-free, compressed gas source of air or nitrogen. Connect the gas to the *Supply Air In* port of the G2. Adjust the *Regulated Supply Pressure* using the black knob to a value below the inlet gas pressure.

3.2.3 Distilled Water Connection

Connect the distilled water source via a suction tube ($^1/_8$" or ¼" diameter tube is sufficient) to the *Distilled Water In* port of the back panel. A simple water bottle or tank may be used for this purpose. The pump is capable of pulling water to a height of about 2 meters (6 feet), so placement of the water tank is of little concern.

While the initial fill of a new system may require up to 2 liters of distilled water, ongoing water usage by the system is rather low. A user-supplied tank of at least 1 liter size is recommended. Refill the tank at any time to maintain a minimum water level of at least a few centimeters in the tank at all times. The suction tube opening must always remain below the water level to prevent pulling air into the pump. Both the initial fill and maintenance level control are handled automatically by the system.

3.3 Initial Preparation

3.3.1 Computer Connection

Plug a USB/RS-232 converter into the PC. Using a standard 9-pin RS-232 extender cable, connect from the USB/RS-232 converter to any of the G2 communication ports *Com1* through *Com3*. To communicate with the G2, use any serial terminal application with settings of 9600 baud, 8 data bits, no parity, 1 stop bit, no flow control.

While there are many serial terminal applications available for download on the internet, CoolTerm is one such application available as freeware at http://freeware.the-meiers.org.

3.3.2 Presaturator Fill

Initial fill of the presaturator will require approximately 2 liters of water and will fill automatically once the G2 is commanded to run. Prior to initial operation, the high pressure pump described in section 5.3.2 must be purged of air pockets and may require priming.

3.3.2.1 Purge the tube of air pockets

1. Ensure a tube is connected to the *Distilled Water In* port of the G2 (section 3.2.3), with the other end in the bottom of a bottle of distilled water.
2. From the computer, send the commands
```
presatpump.runtime=20
presatpump.run =1
```
3. The pump should run for 20 seconds. During this time, water should be sucked into the tube and into the G2, removing all air bubbles in the line.
4. If water is sucked up into the tube, but air pockets remain, repeat step 2 another time until all the air is out of the suction tube and the tube is filled completely with distilled water.
5. Mark the water level on the outside of the bottle. Once the system is running, this will enable you to see if the water level is dropping, indicating the presaturator is filling. It should take no more than about 2 liters.

3.3.2.2 Prime the pump

If, during the above procedure, water did not suck into the tube while the pump was running, the pump is likely dry and must be primed.

1. Locate the supplied syringe with the attached silicone tube and Swagelok fitting.
2. Fill the syringe with distilled water and attach the Swagelok fitting to the G2's *Distilled Water In* connector.
3. From the computer, send the commands
```
presatpump.runtime=20
presatpump.run =1
```
4. The pump should run for 20 seconds. As the pump is running, apply light pressure on the syringe's plunger to force water into the tube. (Too much pressure will simply force the tube off the end of the syringe.)
5. Repeat steps 3 and 4 until the syringe is nearly empty.
6. Disconnect the syringe from the *Distilled Water In* fitting.
7. Repeat procedure 3.3.3.1, Fluid Loop Initial Filling Procedure.

3.3.3 Fluid Fill

Prior to normal operation, the G2 must be filled with coolant fluid.

The G2's internal fluid tank allows for expansion of the coolant fluid used for temperature control. The tank must be filled with water. Clean, filtered, or distilled water is recommended. Use of de-ionized water is not recommended.

3.3.3.1 Fluid loop initial filling procedure

1. From the top of the G2, remove the plastic lid from the water tank. Remove and save the shipping plug for possible use later.
2. Using a funnel, fill the tank to just below the upper inlet fitting. Keep the water jug and funnel handy as the water level will require nearly constant filling during the first several seconds of fluid pump operation.
3. Run the fluid pump with the command
   `Pump.run = 1`
4. Fill the tank as needed to prevent it from running dry.
5. After several seconds, water should begin to enter the tank from the small upper inlet fitting.
6. Fill the tank to about 5 mm (1/4") below the upper inlet fitting.
7. Stop the pump with the command
   `Pump.run = 0`
8. Screw the cap onto the tank (do not insert the shipping plug).

3.3.4 External Temperature Connections

If %RH is to be controlled or queried from the G2, external temperature probes should be connected to T1, T2, and/or T3. You may use a probe supplied with the system, or install your own using the wiring diagram shown in section 2.1.5.1

4 Operation

The G2 may be operated from a PC using any of the three serial ports. It may be commanded directly via RS-232 commands, or operated through the supplied Gecko software.

Before proceeding, ensure that the system has already been connected and prepared as outlined in sections 3.2 and 3.3.

4.1 Getting Started (using RS-232 commands)

Using a serial terminal application, the G2 can be instructed to generate specific humidity values. You'll find list of all available commands in *Chapter 6 Serial Communication* as well as a full description of the protocol. More detailed information may also be found in the *G2 Programmring Reference*.

Note that each command should be terminated with a carriage return character <CR> (0x13) or a carriage return/line feed <CR><LF> (0x13 0x10). Most serial terminal programs send <CR> or <CR><LF> when the ENTER key is pressed. Also note that the G2 serial communications are case insensitive, so any mixture of upper/lower case is acceptable.

4.1.1 Connect to the G2 (via a serial port)

Plug a USB/RS-232 converter into the PC. Using a standard 9-pin RS-232 extender cable, connect from the USB/RS-232 converter to any of the G2 communication ports *Com1* through *Com3*. To communicate with the G2, use any serial terminal application with settings of 9600 baud, 8 data bits, no parity, 1 stop bit, no flow control.

While there are many serial terminal applications available for download on the internet, CoolTerm is one such application available as freeware at http://freeware.the-meiers.org

While they all serve the same basic purpose, each serial terminal application looks and operates differently. Using the methods specific to your serial terminal application, establish a connection to the G2 via the PC com port associated with your USB/RS-232 converter.

Check your serial connection to the G2 by sending the Serial Number query

```
SN?
A15-11006
```

4.1.2 Generating humidity

Set the RH to 40%, saturation temperature to 20 °C, and flow setpoint to 25 l/min

```
RH1set = 40
TsSet = 20
FlowSet = 25
```

Query them back to be sure they set properly

```
RH1Set?
40

TsSet?
20

FlowSet?
25
```

Start the generator

```
Run = 1
```

The G2 will start up, and within several seconds humidity will be generated based on your previously entered setpoints.

4.1.3 Reading generated values

Determine the generated values, such as RH, dew point, external pressure and flow rate values with the following queries

```
RH1?
39.8464

DP?
5.95221

Pc?
101291.6

Flow?
25.2124
```

4.1.4 Stopping humidity generation

The system may be shutdown, stopping all humidity, temperature, and flow control using the command

```
Run = 0
```

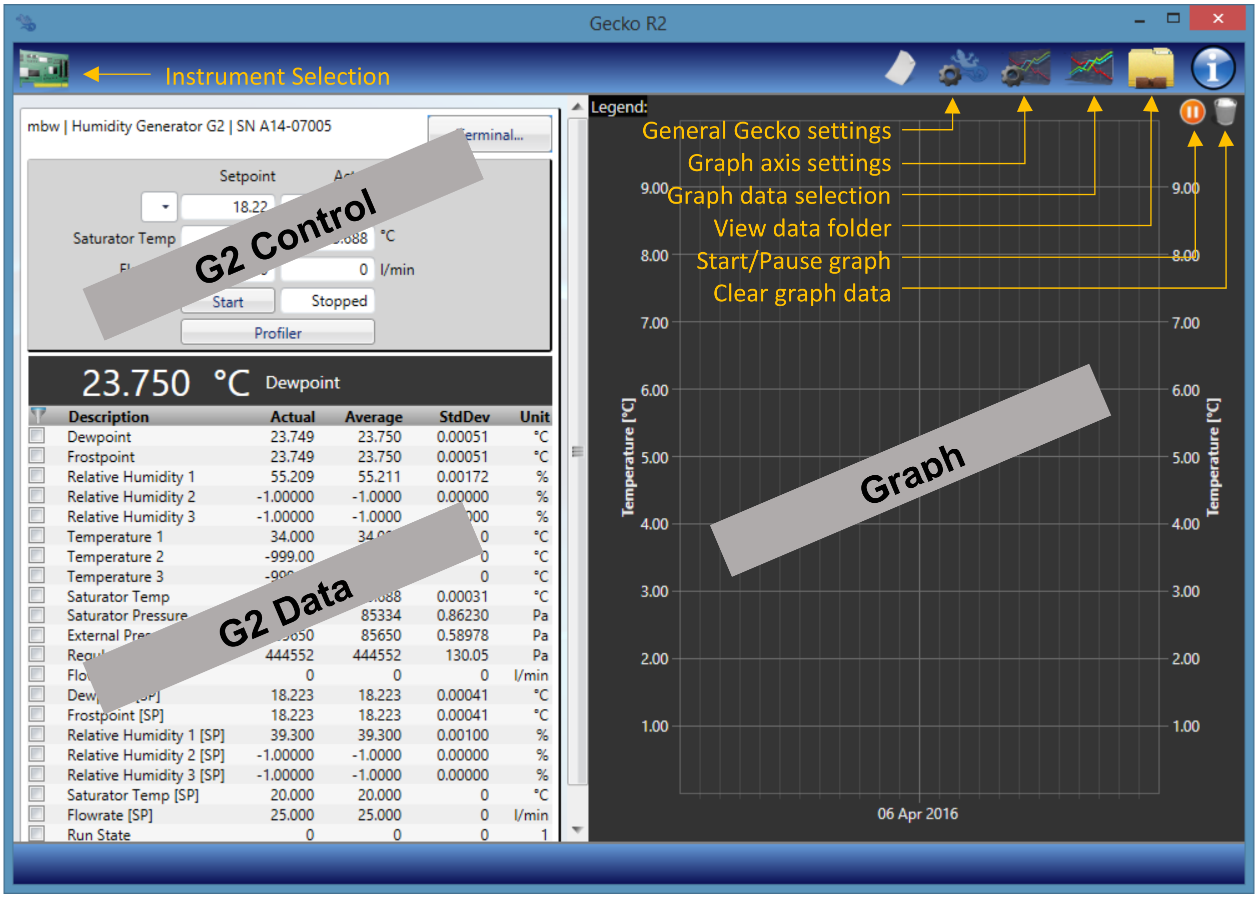
The control functions cease. The expansion and flow valves close. Query the status with the command

```
Run?
0
```

4.1.5 G2 Command set

Most common G2 serial commands are listed in section 6.4.1. A complete set of G2 commands is available in the *G2 Programming Reference*.

4.2 Getting Started (using Gecko software)



4.2.1 Install the Gecko program

The Gecko program is available on the provided CD. Copy the entire Gecko folder from the CD and paste it to a location on your PC hard drive that has full permissions, such as your **My Documents** folder.

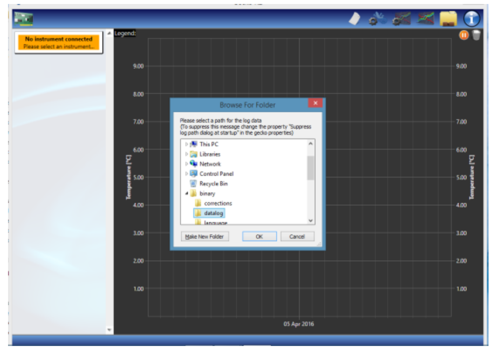
4.2.2 Connect to the G2 via a serial cable

Plug a USB/RS-232 converter into the PC. Using a standard 9-pin RS-232 extender cable, connect from the USB/RS-232 converter to any of the G2 communication ports *Com1* through *Com3*.

4.2.3 Establish Gecko-G2 communication

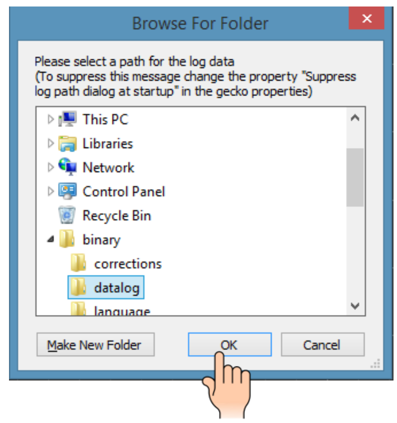
Using the power switch at the back panel, turn the G2 on.

Start the Gecko program on the PC. The Gecko program will open and prompt you for a file storage location.



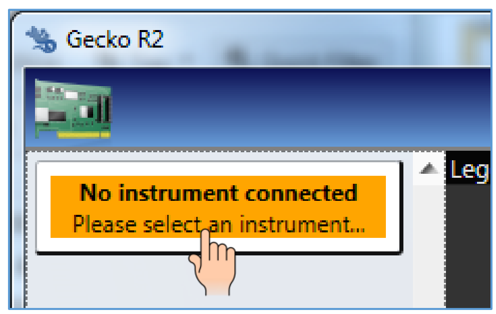
Select a folder where you'd like your data files to be saved. A default location is already selected and is generally sufficient.

Click the Ok button.

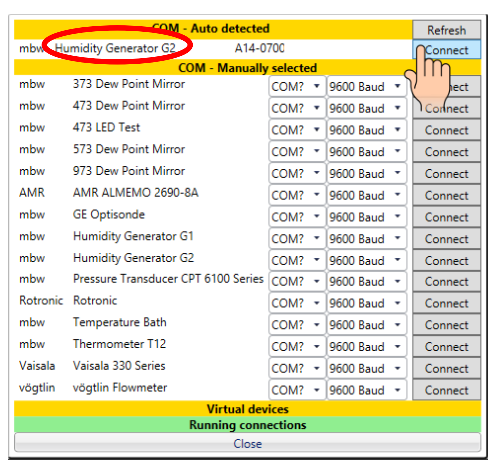


Click the yellow button to select an instrument.

The available serial ports will be searched automatically, and then any recognized instruments will be displayed.

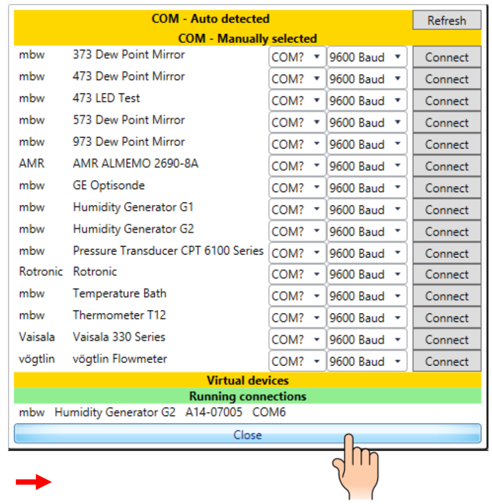


Locate **Humidity Generator G2** at the top of the window and click it's **Connect** button.

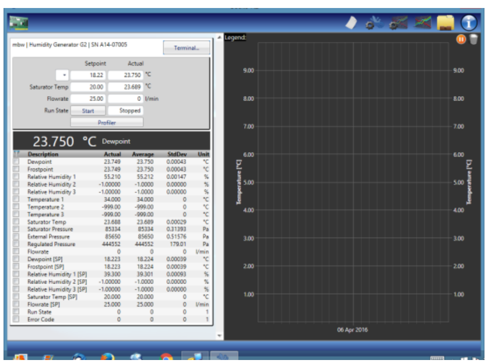


Once connected, note that the G2 name, serial number and PC com port information appears under the **Running connections** area.

Click the **Close** bar at the bottom. This window will close and the G2 control settings and readings will now be displayed.



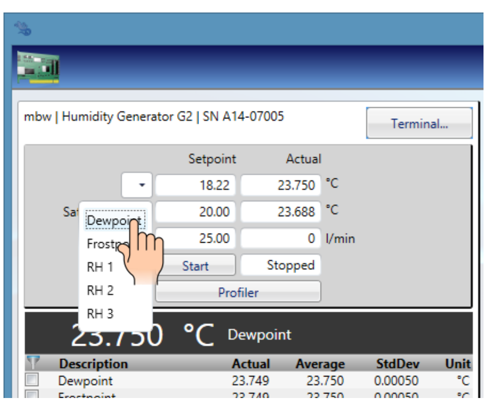
4.2.4 Generating Humidity



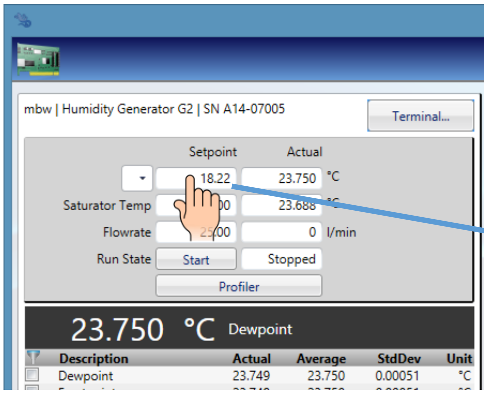
The G2 Control panel displays the control set points and current values.

The G2 Data panel displays the available measurements from the generator. There will also be a data panel for any other connected instruments.

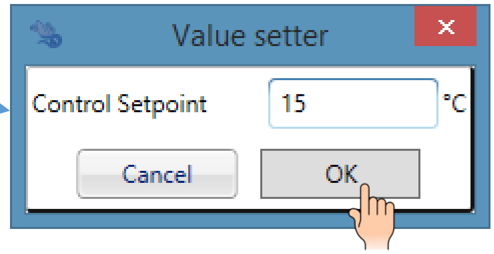
The area to the right can graphically display any of the values read from the connected instruments.

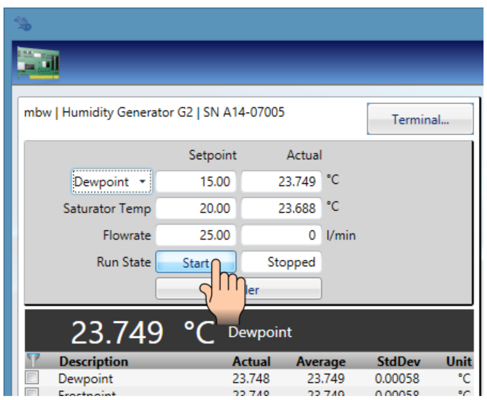


The left column (the **Setpoint** column) lists the control set points for the generator. Select the desired control mode (Dew Point, Frost Point, RH 1, RH 2, or RH 3) from the drop down list box left of the top setpoint.



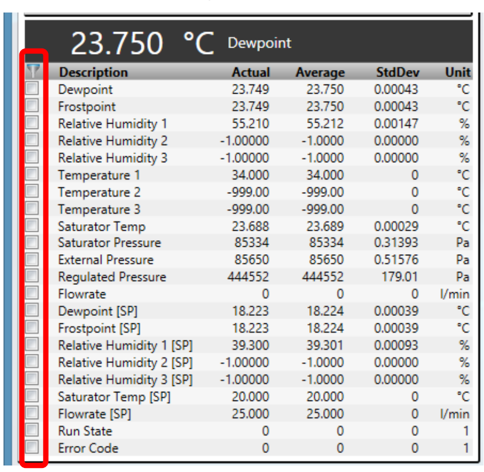
Click on the various setpoint values to change them. Before running, enter the desired humidity, Saturator Temp, and Flowrate setpoints.





Click the **Start** button to start the machine and generate the desired humidity.

4.2.4.1 Displayed Values



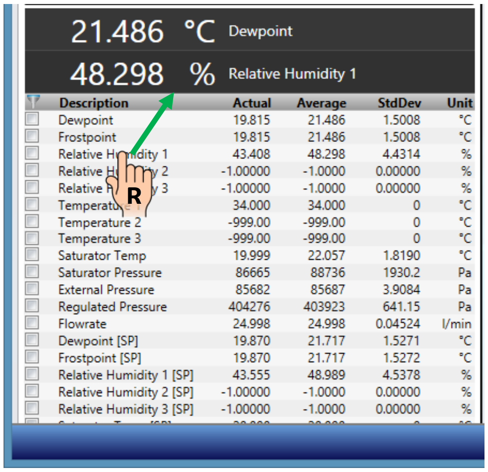
Description	Actual	Average	StdDev	Unit
Dewpoint	23.749	23.750	0.00043	°C
Frostpoint	23.749	23.750	0.00043	°C
Relative Humidity 1	55.210	55.212	0.00147	%
Relative Humidity 2	-1.00000	-1.0000	0.00000	%
Relative Humidity 3	-1.00000	-1.0000	0.00000	%
Temperature 1	34.000	34.000	0	°C
Temperature 2	-999.00	-999.00	0	°C
Temperature 3	-999.00	-999.00	0	°C
Saturator Temp	23.688	23.689	0.00029	°C
Saturator Pressure	85334	85334	0.31393	Pa
External Pressure	85650	85650	0.51576	Pa
Regulated Pressure	444552	444552	179.01	Pa
Flowrate	0	0	0	l/min
Dewpoint [SP]	18.223	18.224	0.00039	°C
Frostpoint [SP]	18.223	18.224	0.00039	°C
Relative Humidity 1 [SP]	39.300	39.301	0.00093	%
Relative Humidity 2 [SP]	-1.00000	-1.0000	0.00000	%
Relative Humidity 3 [SP]	-1.00000	-1.0000	0.00000	%
Saturator Temp [SP]	20.000	20.000	0	°C
Flowrate [SP]	25.000	25.000	0	l/min
Run State	0	0	0	1
Error Code	0	0	0	1

The data panel initially displays all measurements data available from the G2. For each measurement the columns indicate the current value (**Actual**), the average (**Average**), the standard deviation (**StdDev**), and the displayed unit of measurement (**Unit**).

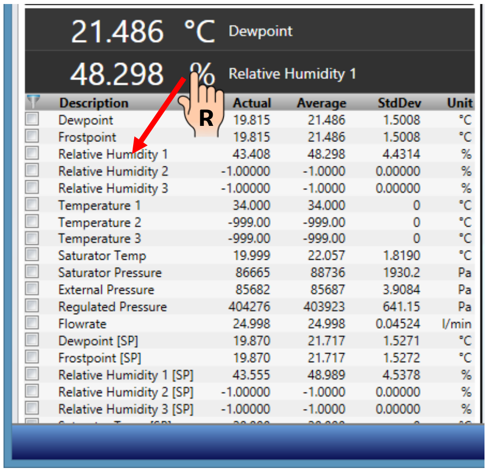
To display only certain values and hide the others:

1. Check the boxes left of the values you want displayed.
2. Click the filter icon  above the checkboxes. Any value that was not clicked will be hidden.
3. Click the filter icon again to restore all values.

4.2.4.2 Promote/Demote Values

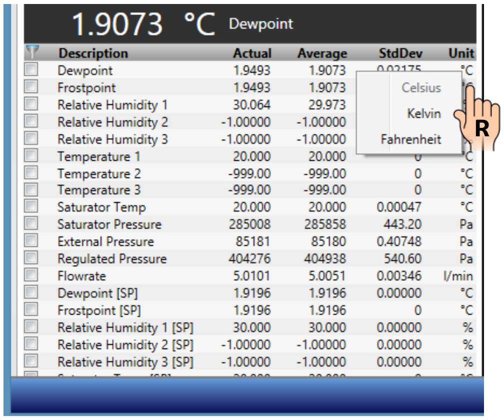


Promote a value to make it appear large and at the top. To promote a value, right click on its name.



To demote a value, right click on the promoted line.

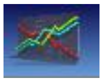
4.2.4.3 Units



Change the displayed units by right clicking a label in the **Units** column. Select the new units from the drop list.

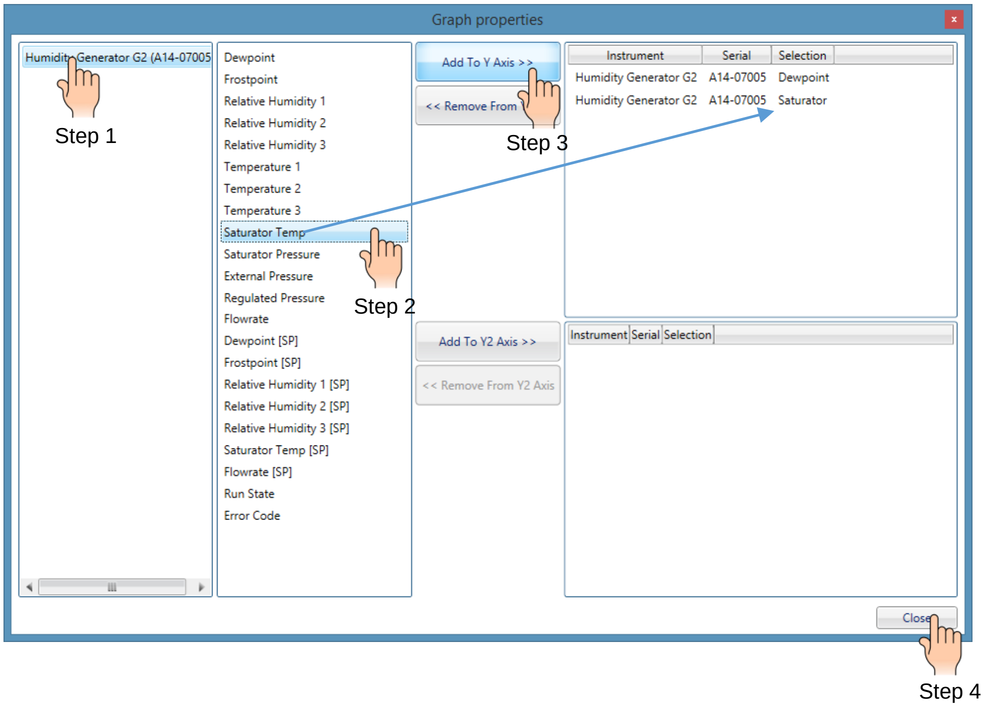
Units are global, so all parameters of that same type will change. For instance, if you change from **°C** to **°F**, all temperature values (Dew Point, Frost Point, Sat Temp, T1, T2, T3, etc.) change as well.

The units settings affect all data displayed. However, data which is being sent to a data file (discussed later) is always in standard units regardless of the units selected here.



4.2.4.4 Graphing Data

Click the graph data icon in the ribbon to select items for graphing. The graph selection window appears.



To choose an item for graphing, follow the steps shown.

To remove an item, select a value in the right box and click **Remove from Y Axis**.

There are two separate vertical axes, Y and Y2. Add data items to one or both as desired.

Close the window.

The selected measurements are now displayed on the graph.

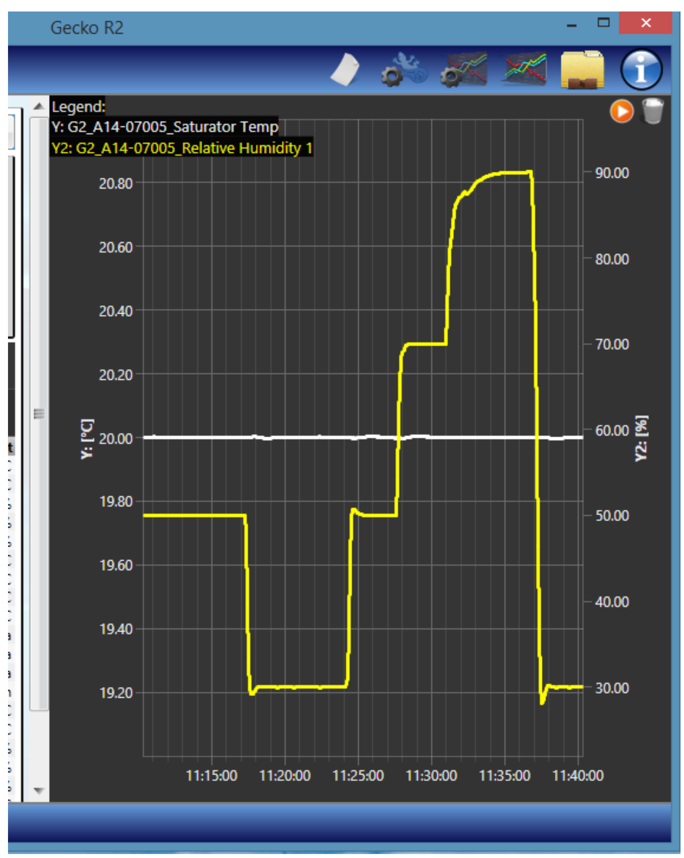
The legend at the top of the graph indicates which line corresponds to each measurement. The Y axis on the left of the graph and the Y2 axis on the right can change independently. In this way large and small values can be displayed together on one graph. For instance, "Saturator Temp" can be selected on the Y axis with "Relative Humidity" displayed on the Y2 axis and both may be scaled independently.

Zoom in by dragging a rectangle.

Spin the scroll wheel to zoom in/out.

Right drag to pan up/down/left/right.

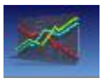
Double click to fit all.



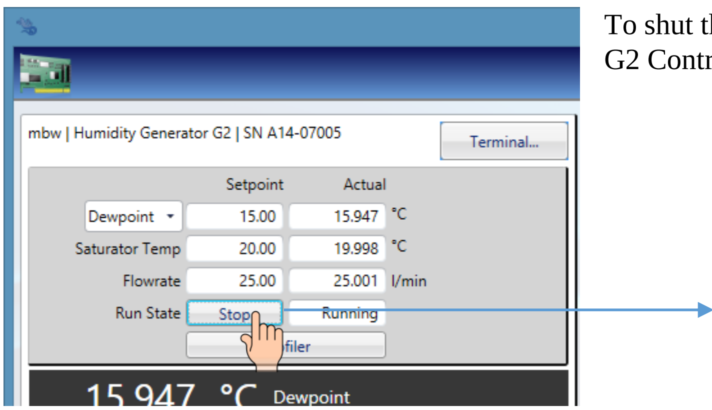
 Click the red play/pause icon to enable/disable real-time graph updates.

 Click the TRASH icon to clear the graph and start over with a new data set.

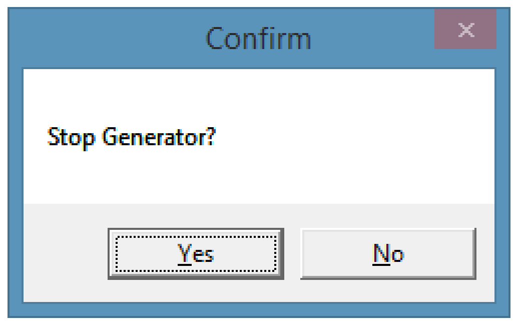
 Click the graph setting icon to set graph axes numerically.

 Click the graph data icon to select/deselect items to graph.

4.2.5 Shutdown

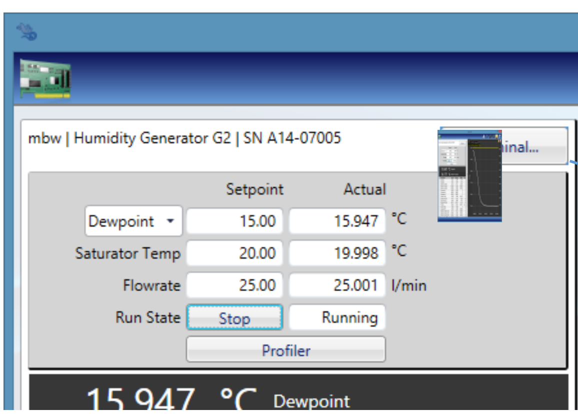


To shut the system down, press the **Stop** button on the G2 Control panel.

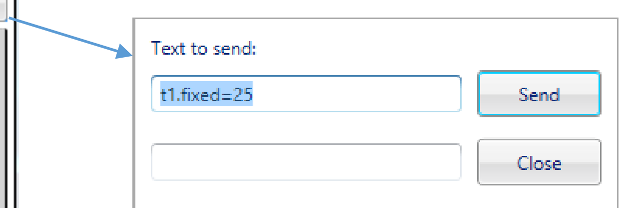


Before stopping the system, it is recommended that you lower the temperature to approximately room temperature. This will prevent unwanted condensation inside the system gas path.

4.2.6 Terminal application



The Terminal application can be useful for entering and querying values and functions beyond those programmed into Gecko. Common commands are listed in section 6.4.1.



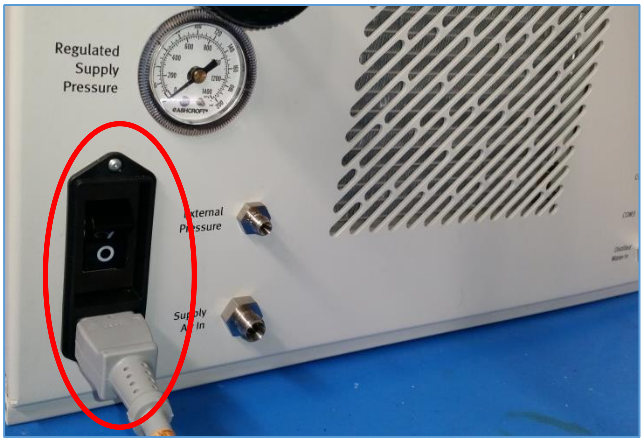
5 Model G2 Sub-Systems

This section provides details of the functional systems within the G2. These subsystems include the Electrical System, Pneumatic System, Fluid System, Refrigeration System, and Heaters.

5.1 Electrical System

The G2 requires 200-240 VAC, 50/60 Hz, single phase power. Configuration for the AC input can be either

- LINE1, LINE2, GND (as is often the case for connection in the U.S., Canada, Mexico, Japan, and Taiwan where LINE1 and LINE2 are of opposing phase while each is approximately 100-120 VAC with respect to GND), or
- LINE, NEUTRAL, GND (often for Europe and many countries of Asia when LINE is approximately 200-240 VAC with respect to NEUTRAL, with NEUTRAL and GND at the same potential).

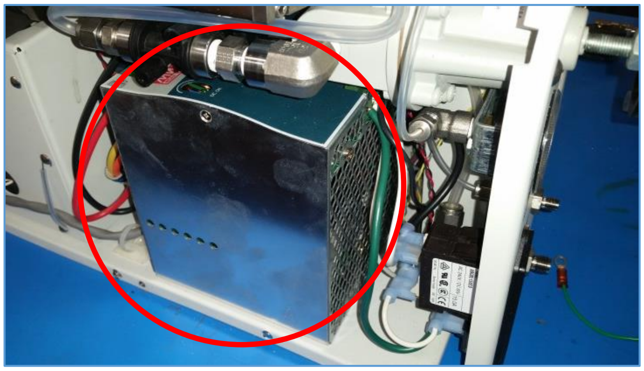


AC power enters the system via the power connector located at the back panel, transferring AC into the system via a two-pole 15 amp circuit breaker. When the breaker is turned on, power is also applied to the input of the 24 VDC power supply and to the presaturator and fluid heaters via their series connected Solid State Relays.

5.1.1 *Power Supply, 24 VDC*

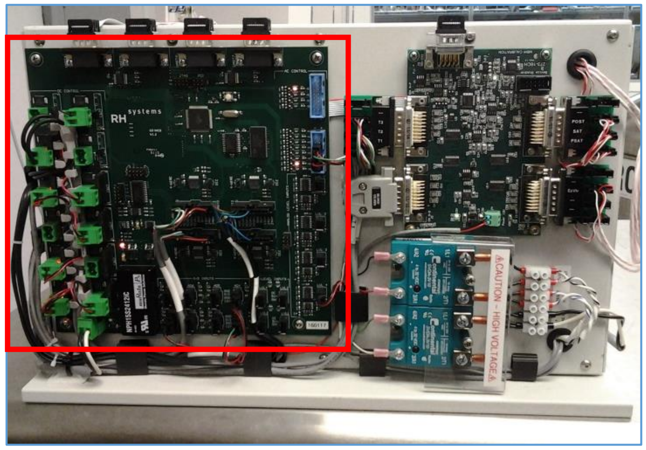
200-240 VAC is supplied via the power switch to the 24 VDC power supply. 24 VDC is then supplied to the ECB, the Refrigeration Control Board, and the two Stepper Motor Controllers. The system should have 24 VDC whenever there is AC power applied to the system.

The power supply is internally protected against short circuit or over-current operation by an internal crowbar circuit that blocks DC output in the event of a DC circuit fault.



5.1.2 Embedded Control Board, ECB

The Embedded Control Board, ECB, operates the Model G2 by performing all functions required for system control and humidity generation. All temperature, pressure, flow, and liquid levels are continuously monitored and controlled by actuation of valves, relays, pumps, heaters, and other outputs. It communicates to the outside world (for instance, to a PC) through one of three independent bidirectional RS-232 serial communication ports. All data and control parameters are communicated via these ports.



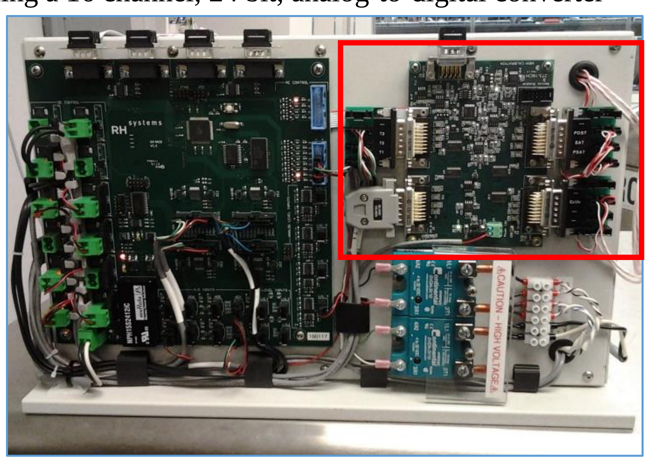
The G2's embedded controller software resides within the ECB's Flash memory. The embedded controller software consists of RHS custom developed code, coupled with a high-speed multi-tasking real-time operating system. Via this multi-tasking embedded software, the controller orchestrates the second-to-second operation of the G2 based on command input from any of the RS-232 ports. Using a variety of communication methods (Terminal Emulator, a custom written PC program, or our Gecko program), set points (RH, Dew Point, flowrate, etc.) are transmitted to the controller board. The job of the controller board is to accept these set points, continuously measure the various analog and digital sensors, and control the various electro-mechanical actuators in order to bring about and maintain the desired set point conditions.

Instrument specific configuration and calibration information, such as sensor coefficients, may also be written and read via any of the three RS-232 ports and resides within the ECB's Electrically Erasable Read Only Memory (EEPROM).

Voltage regulators on the Controller Board take the 24VDC input power and generate +12VDC, +5VDC, and +3.3VDC needed for various components on and off the board. DC power for sensors, relays, pumps, and others are supplied directly from the ECB.

5.1.3 Precision Resistance Measurement Board

A Precision Resistance Measurement Board containing a 16 channel, 24 bit, analog-to-digital converter measures all temperature sensors. Two of the 16 channels are dedicated to system reference resistors. In addition to the reference resistors, the following temperature probes are measured:



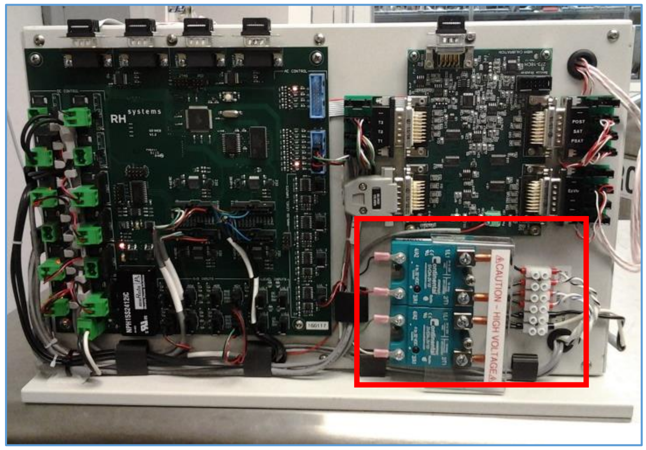
- T1, T2, T3 (External thermometer connections)
- SAT (Fluid thermometer for measurement of saturation temperature)
- PRESAT (Presaturator temperature)
- TSO (Saturator Outlet Tube temperature)
- TEV (Expansion Valve temperature)

All temperature sensors in the G2 are 100Ω Platinum Resistance Thermometers (PRT's). The board measures all thermometers using full current reversal DC pulse mode excitation and reports these raw values to the ECB via an internal RS-232 connection. The ECB ratio-metrically compares these raw probe measurements to measurements of the precision reference resistors to determine their precise resistance values. The resistance values are then computed into individual temperatures using each probe's specific coefficients.

The Precision Resistance Measurement Board requires 12 VDC which is supplied from the ECB.

5.1.4 Solid State Heater Relays

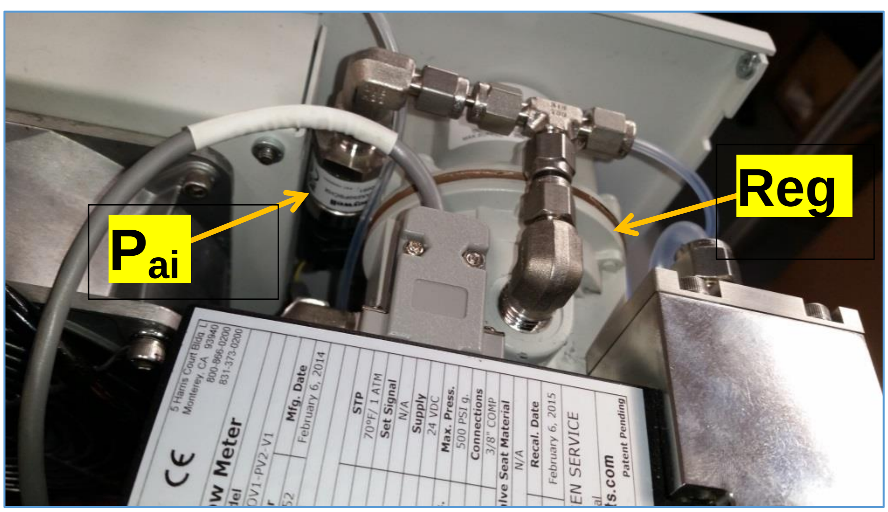
The Solid State Heater Relays are controlled by the ECB to apply pulse width modulated AC power to heat the presaturator and the fluid coolant loop of the G2. The upper relay controls the fluid coolant loop heater. The lower relay controls the presaturator heater. When DC is applied to the left side, pins 3-4, AC power is allowed to flow through the associated heater via pins 1-2. The relays are connected in series with their heaters.



5.2 Pneumatic System

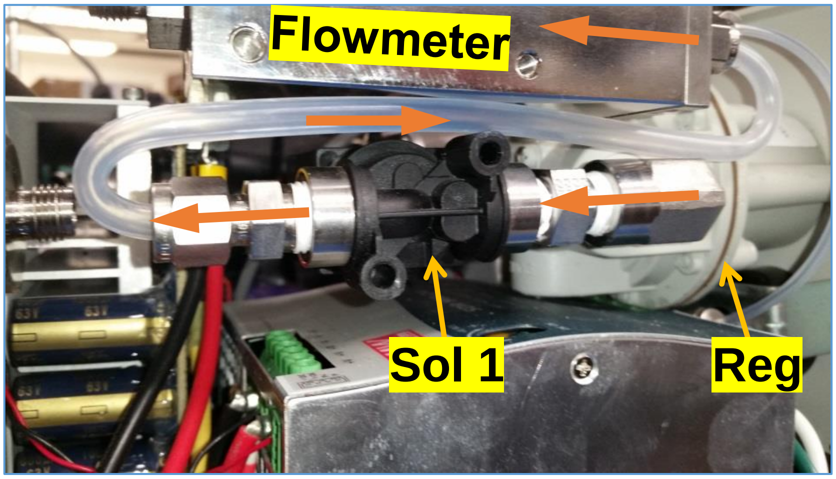
The pneumatic system is responsible for control of gas flow and pressures throughout the system. The pneumatic system consists of the following major components: air inlet circuit, pressure regulator, flow meter, flow control valve, presaturator, saturator, expansion valve, and gas outlet.

Compressed air enters the system at the back panel fitting labeled *Supply Air In*. From there it flows to the pressure regulator, Reg, which is adjustable from 0 to 200 psig via a knob on the back panel. The pressure regulator is used to regulate the system pressure, isolating it from upstream pressure variations.



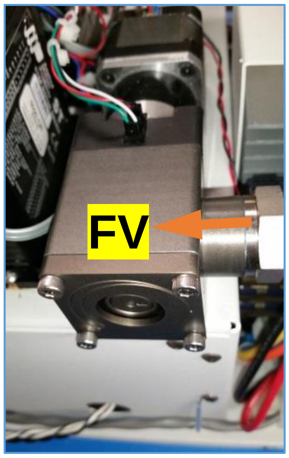
The pressure regulator also sets the maximum operating pressure of the system which is then measured by the air-in pressure sensor, P_{ai}. A mechanical pressure gauge, labeled *Regulated Supply Pressure*, is mounted to the back panel and is also pneumatically connected to the regulator's pressure output.

Upon leaving the pressure regulator, the gas flows through the air-inlet solenoid, Sol 1. This solenoid is only open (energized) during system operation (while generating humidity). During times the system is idle, or the power is off, this solenoid remains closed, removing inlet pressure from the remaining portions of the system.



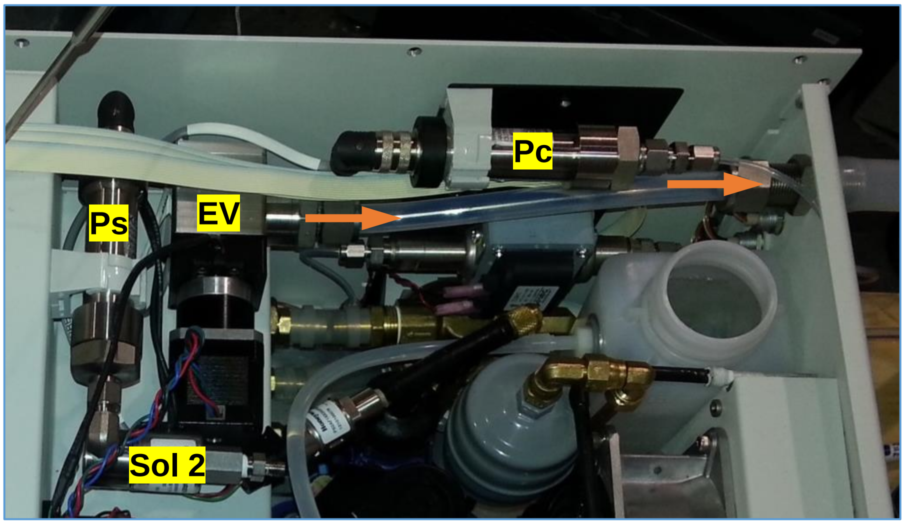
During operation, when the Air Inlet Solenoid, Sol 1, is turned on, the gas then flows through the flow meter. The flowmeter is a thermal mass-flow type meter that transmits its flow measurement readings to the embedded controller via a serial (RS-232 or RS-485) connection.

Gas travels through the flowmeter to the flow control valve.



The flow control valve, FV, is a specially designed stepper-motor-driven graduated-orifice plug valve, used for controlling flow rates as low as approximately 1 l/min to as high as 100 l/min (depending on system design). To increase system flow rate, the stepper motor will rotate the plug to a position with larger orifice. To reduce the flow rate, the stepper motor will rotate the plug in the opposite direction to a position of smaller orifice. Flow rate is therefore maintained by the rotational position of the plug. The position is controlled by the stepper motor, under control of the embedded controller board, using feedback from the flowmeter.

Leaving the flowmeter, the gas then flows through the presaturator (to humidify the air), through the saturator (to precisely stabilize the air temperature and condense out any excess water vapor), and finally to the expansion valve, EV. Like the flow control valve, the expansion valve is also a specially designed stepper-motor-driven graduated-orifice plug valve. The expansion valve is used as a back-pressure regulator to control the pressure of the gas flowing through the saturator. Saturator pressure is controllable from near ambient to nearly as high as the regulated inlet pressure. Saturator pressure control is achieved and maintained, at a given flow rate, by the rotation position of the plug which is set by the stepper motor under control of the ECB using feedback from the Saturator Pressure Sensor, P_s.



As the high pressure gas from the saturator passes through the expansion valve, EV, it is expanded to a lower pressure, typically ambient pressure. After leaving the expansion valve, the gas passes through to the back panel access port (Air Out).

A normally-open solenoid valve, Sol 2, is used to depressurize the saturator during shutdown and whenever the G2 is powered off.

External (or chamber) pressure is measured by the External Pressure Sensor, Pc.

5.2.1 Air-In Pressure Sensor, P_{ai}, [AD3]

The Air-In pressure sensor, P_{ai}, measures the inlet pressure after the regulator. Readings from this sensor are in gauge (relative) pressure and should agree with the mechanical pressure indicator on the back panel of the G2. The sensor is powered from 12 VDC and has a 4-20 mA output. The sensor is connected to the ECB at A/D INPUTS – AD3. Power for the sensor is applied from AD3 12V+. Current flows through the sensor and returns to AD3 SIG, then passes through a 250 ohm resistor to AD3 GND. The voltage sensed at AD3 SIG is a result of the 4-20 mA signal dropped across the 250 ohm series resistor, resulting in a voltage of approximately 1-5 VDC that is proportional to pressure.

5.2.2 Air-Inlet Solenoid, Sol 1, [RLY 5]

The Air-Inlet solenoid valve, Sol 1, allows airflow to the system. When the G2 is generating, the ECB's DC CONTROL – RLY 5 sources 24 VDC to activate the Air-In solenoid. An LED at RLY 5 also indicates the relay status.

5.2.3 Vent Valve, Sol 2, [RLY 3]

The vent valve, Sol 2, is used to vent pressure from the saturator during shutdown and whenever the system is not generating humidity. It is configured as a normally-open valve, meaning that it vents whenever it is de-energized (whenever there is no power applied). When the G2 is generating humidity, Sol 1 is energized to allow the saturator to pressurize normally. When the G2 is generating, the ECB's DC CONTROL – RLY 3 sources 24 VDC to energize the vent solenoid causing it to stop venting. An LED on RLY 3 also indicates the relay status. When the LED is on, the solenoid coil is energized and the valve is not venting. Note that during normal operation of the G2, the coil is energized causing the valve will be very hot to the touch.

5.2.4 Flow Meter, [UART 0]

The flow meter measures the flow rate of the incoming gas stream at the inlet of the presaturator. It is powered from 24 VDC and is read via RS-232 communication. It is connected directly to the ECB's UART0. 24 VDC to the flowmeter is provided by UART0 24+ and UART0 24- (this pin is actually the 24 ground, not -24 V). Measurements from the flow meter are queried and received via RS-232. Queries go out from the ECB on UART0_Z. Replies from the flow meter are received on UART0_A. Signal ground connection is at UART0_GND. Typical communication is at 9600 baud, 8 data bits, 1 stop bit, no parity.

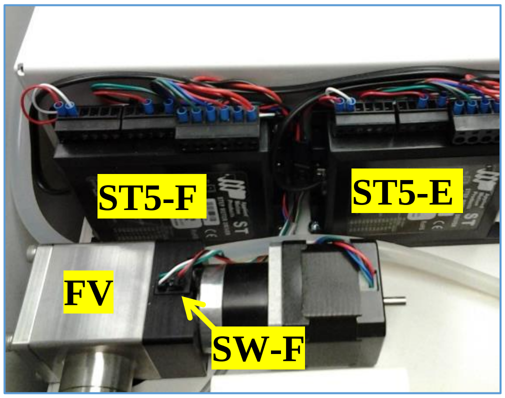
5.2.5 Saturator Pressure Sensor, Ps, [UART 1]

The saturator pressure sensor, Ps, measures the saturation pressure. It is powered from 24 VDC and is read via RS-485 communication on device address 01. It is connected directly to the ECB's UART1. 24 VDC to the pressure sensor is provided by UART1 24+ and UART1 24- (this pin is actually the 24 ground, not -24 V). Measurements from the pressure sensor are queried and received via addressable RS-485, 2-wire, half-duplex mode. RS-485 connection between the ECB and pressure sensor on UART1 _Z and _Y. Communication parameters are typically set at 9600 baud, 8 data bits, 1 stop bit, no parity. Since UART1 is configured for RS-485 communication, it connects to both the saturation pressure sensor (using address 01) and the external pressure sensor (using address 02).

5.2.6 External Pressure Sensor, Pc, [UART 1]

The external pressure sensor, Pc, is connected to the *External Pressure* port at the back panel and typically measures the ambient environment pressure. If a tube is connected to this port, and then connected to an external chamber, the external pressure sensor will measure that external chamber pressure. The pressure sensor is powered from 24 VDC and is read via RS-485 communication on device address 02. It is connected directly to the ECB's UART1. 24 VDC to the pressure sensor is provided by UART1 24+ and UART1 24- (this pin is actually the 24 ground, not -24 V). Measurements from the pressure sensor are queried and received via addressable RS-485, 2-wire, half-duplex mode. RS-485 connection between the ECB and pressure sensor on UART1 _Z and _Y. Communication parameters are typically set at 9600 baud, 8 data bits, 1 stop bit, no parity. Since UART1 is configured for RS-485 communication, it connects to both the saturation pressure sensor (using address 01) and the external pressure sensor (using address 02).

5.2.7 Flow Control Valve, FV, [UART 2]



The flow control valve, FV, is a stepper-motor-drive valve used for controlling flow rate through the system. The stepper motor is positioned by a stepper controller, ST5-F. The ECB communicates with the stepper controller via UART2 configured for RS-232. Commands are sent to the stepper controller from UART2_Z. Responses are received from the stepper controller on UART2_A. Signal ground is connected at UART2_GND.

Based on positioning commands from the ECB, the stepper controller actuates the stepper motor. A single, optical limit switch, SW-F, connects to the stepper controller and identifies the valve's fully closed (home) position.

The stepper controller requires 24 VDC which is fed directly from the system's 24 volt power supply.

5.2.8 Expansion Valve, EV, [UART 3]

The expansion valve, EV, is a stepper-motor-drive valve used for controlling saturation pressure at any given flow rate through the system. The stepper motor is positioned by a stepper controller, ST5-E. The ECB communicates with the stepper controller via UART3 configured for RS-232. Commands are sent to the stepper controller from UART3_Z. Responses are received from the stepper controller on UART3_A. Signal ground is connected at UART3_GND.

Based on positioning commands from the ECB, the stepper controller actuates the stepper motor. A single, optical limit switch, SW-E, connects to the stepper controller and identifies the valve's fully closed (home) position.

The stepper controller requires 24 VDC which is fed directly from the system's 24 volt power supply.

5.3 Fluid System

There are two separate and distinct fluid systems in the G2. The fluid circulation system, utilizing water or a mixture of water and anti-freeze, is used to control the temperature of the saturator. The fluid in this system, while thermally coupled to the saturator, never comes in direct contact with the gas stream.

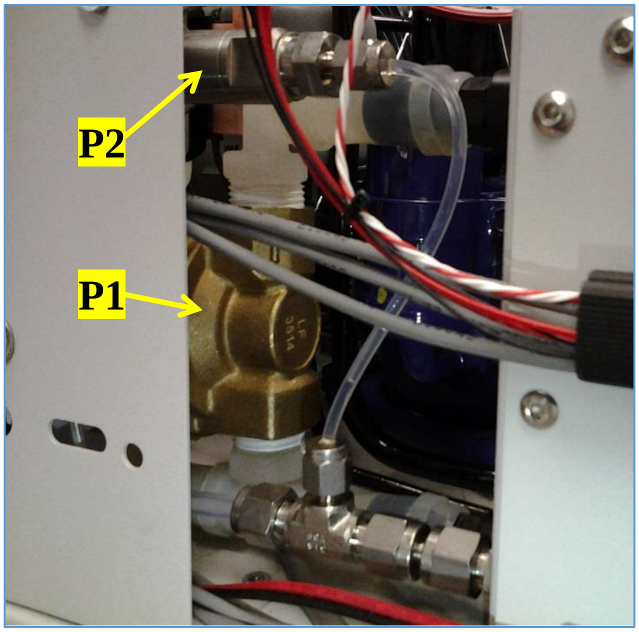
A separate fluid system, utilizing distilled water only, is used to humidify the incoming gas, and is the main source of humidity in the system's outgoing gas stream. Humidification is accomplished by maintaining a set water level within the presaturator. This liquid level control system requires the connection of a distilled water supply to the *Distilled Water In* port at the back panel.

5.3.1 Distilled Water Supply

An external supply of distilled water is required and must be connected via a suction tube ($^1/_8$" or ¼" diameter tube is sufficient) to the *Distilled Water In* port of the back panel. A simple water bottle or tank may be used for this purpose. The operator is responsible for maintaining distilled water in this tank, filling it when required. While the initial fill of a new system may require up to 2 liters of distilled water, ongoing water usage by the system is rather low. A tank size of at least 1 liter minimum is recommended. The tank may be refilled (or topped-up) at any time, even while the system is running. The distilled water supply tank should always have a minimum level of at least a few centimeters of water, with the suction tube opening below the water level. It is the responsibility of the operator to ensure that there is sufficient water in this supply tank at all times.

Use of deionized water is not recommended as it tends to be ionically aggressive to stainless steel and may cause pitting of the saturator. Distilled water, even that which is purchased at local grocery or discount stores, is generally preferred over deionized water.

5.3.2 Presaturator Liquid Level System



The presaturator liquid level system maintains the water level within the presaturator. This is done automatically utilizing an electronic liquid level sensor and a high pressure pump, P2. When activated, the pump pulls from the distilled water supply, through a suction tube connected to the *Distilled Water In* port, through the pump, and into the presaturator. Since this high pressure pump can fill the presaturator while the system is generating humidity, the system can operate for extended periods without the need to shut down.

The water level of the presaturator is detected by the ECB with a conductivity measurement technique through ANALOG LEVEL INPUTS - LVL 4. This circuit converts the conductivity analog signal to a digital signal level and routes it through jumper 4 to the digital LEVEL INPUTS –

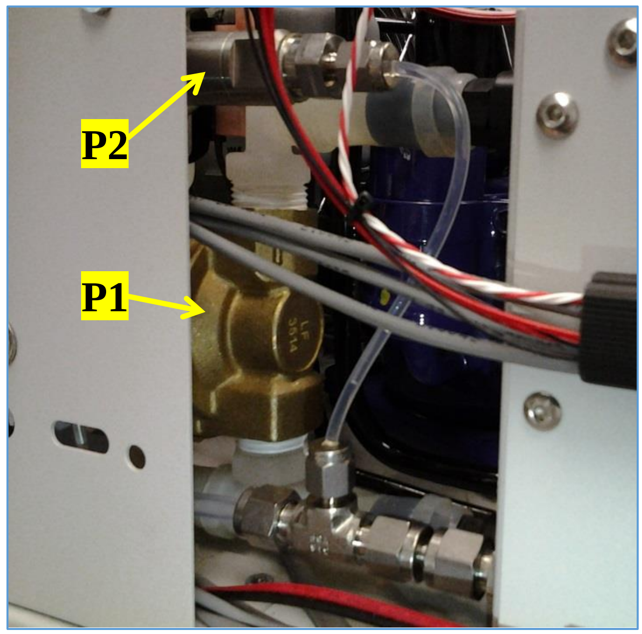
LVL4 to be sensed by the ECB software. An LED at LEVEL INPUTS - LVL4 indicates a low water level when ON. This low presaturator water level is sensed by the ECB software which then activates the high pressure pump, P2, by creating a 24 VDC square wave on DC CONTROL - RLY 6. The square wave sequentially activates/deactivates the solenoid of P2 causing it to pump water into the presaturator. When water is detected at the level sensor, the LED turns off. Pumping is then halted by the software by deactivating the square wave at RLY 6. When not actively pumping, the output of RLY 6 is off, and the pump's solenoid remains in a de-energized state.

Note that the pump does not have dry-run capability and may be damaged if allowed to run dry for extended periods of time. If it runs dry, it must be re-primed in order to resume normal pumping operation. Priming procedures are found in the Quick Start Guide.

The back panel is also fitted with a drain valve and port, labeled Presat Drain, and is used to manually drain water from the preset if desired.

5.3.3 Fluid Circulation System

The Fluid Circulation System is a circulating medium of water (or a mixture of water and anti-freeze) used to control the temperature of the saturator. Controlling the temperature of the fluid controls the temperature and stability of the saturator and the resulting generated humidity. The fluid circuit consists of several significant components; fluid pump, heater, refrigeration evaporator, saturator, and the fluid expansion tank.



Water circulated from the fluid pump, P1, exits the top of the pump, passes through the fluid heater, and is heated as necessary. The fluid then passes through the refrigeration evaporator, cooling as necessary. From there, it flows through the saturator and ultimately back to the inlet at the bottom of the pump.

A small expansion tank is also connected to the bottom pump inlet allowing for temperature induced variation in the overall fluid volume. A small tube is also connected between the top most point of the saturator and the top of the expansion tank. A small amount of fluid continually flows through this tube and into the tank, automatically purging the fluid system of any entrapped air. This small fluid flow into the tank also provides a visual indication of proper pump operation.

When the system is generating, 24 VDC is sourced from the ECB's DC CONTROL – RLY 9 to the fluid pump P1. An LED at RLY 9 indicates when it is active and power is applied to the pump. Note that the fluid pump has built-in circuitry to protect against dry run conditions, and may therefore take several seconds to power up to full speed when activated.

If your unit is so equipped, an LED is attached to the expansion tank to aid in visibility of the water level. Whenever the G2 is powered on, 24 VDC power for the tank LED (and fan) is sourced from the ECD's DC CONTROL – RLY 11. An LED at RLY 11 indicates when it is active and power is being applied to the tank LED and fan.

5.4 Refrigeration System

The refrigeration system is a hermetically sealed, closed-loop cooling system used to cool the circulation fluid. The refrigeration system is charged with 340 grams of R134A refrigerant (only 120 grams for older systems with serial numbers starting with A13 and A14).

Refrigerant is compressed into a heat-laden high pressure gas by the R134A Compressor. The high pressure hot gas is passed through the air-cooled condenser. The refrigerant cools and condenses to a high pressure liquid as it passes through the condenser. The high pressure liquid accumulates in the filter/dryer (and in the receiver tank installed only on newer systems with serial numbers A15 and higher). This high pressure liquid is then metered into the evaporator via the Sat Cool solenoid, absorbing heat (cooling) as it expands to a low pressure gas. The low pressure, heat-laden gas is then returned to the suction side of the R134A compressor where the process repeats itself. This suction side pressure is measured by a pressure transducer, Prl.

The Sat Cool solenoid is controlled by the ECB using pulse width modulation based on the bath temperature.

5.4.1 Compressor

The R134A compressor is a hermetic refrigeration compressor that is capable of pulling to low pressures on the input side, and high pressures on the discharge side.

During times of normal cooling demand, the compressor runs continuously. Once steady-state operation is achieved (system is steady at one temperature), the compressor speed will be reduced to slow idle, significantly reducing its power consumption. When there is no cooling demand for a period of time, such as when the system is being heating to a warmer temperature, the compressor is turned off completely until the system once again requires cooling control.

The compressor motor is operated by its compressor controller board which is powered by the G2's 24 VDC power supply. The compressor controller board operates as a VFD (Variable Frequency Drive) motor controller giving it the ability to change motor speed.

The refrigeration compressor is activated by activating the ECB's DC CONTROL – RLY 2, which applies a ground to the RLY 2(-) output. This ground signal is applied the RUN input of the compressor controller board, causing the compressor to run.

Compressor speed is selected by the ECB's AC CONTROL – A1(-) digital output. This output is connected to the compressor controller board's SPEED input. A high at the A1(-) output causes the compressor to run at full speed. A low at the A1(-) output causes the compressor to operate at idle. Decisions regarding compressor speed are made by the ECB based on cooling demand. Under high cooling demand, the compressor is run at full speed. Under low cooling demand, when simply maintaining the system at the setpoint temperature, the compressor runs at idle to conserve power and compressor life.

5.4.2 Condenser and Fan

The refrigeration condenser cools the high pressure high temperature gas output from the refrigeration compressor, condensing it into a room temperature liquid. Heat from the condenser is exhausted into the room by the condenser fan. The fan runs continuously whenever power is applied to the system. 24 VDC power for the fan is sourced from the ECB's DC CONTROL RLY 11. In addition to powering the fan, RLY 11 also powers an LED attached to the fluid expansion tank. An LED adjacent to RLY 11 provides visual indication of the relay state. If the LED is on, the fan should be running.

5.4.3 Sat Cool Solenoid, Sol 3, [RLY 12]

The saturator temperature is maintained by heating or cooling the circulating fluid as needed. Cooling is accomplished by refrigerant injection through the sat cool solenoid valve, Sol 3. This valve is actuated by a 24VDC pulse width modulated signal. When energized, the valve opens allowing refrigerant to be injected into the evaporator, causing it to cool the circulating fluid. The pulse width of the valve directly controls the amount of refrigerant injected, thereby affecting the temperature of the bath fluid. The valve is generally pulsed at a fixed interval with varying pulse width. When the system requires cooling, the ECB's DC CONTROL – RLY 12 sources 24 VDC to the sat cool solenoid, causing it to open and inject refrigerant into the evaporator. An LED at RLY 12 also indicates the relay status.

5.4.4 Evaporator

The refrigeration evaporator is a brazed plate heat exchanger thermally coupling the bath fluid with the R134A refrigerant system. One side of the evaporator is connected to the refrigeration system, while the circulating fluid flows through the other side. As liquid refrigerant is injected into the evaporator, it expands into gas. This expansion causes cooling (by absorbing heat), which lowers the temperature of the circulating fluid flowing through the other side.

5.4.5 Refrigeration Low-side Pressure Sensor, Prl

The refrigeration low-side pressure sensor, P_{rl}, measures the suction side pressure of the refrigeration compressor. Readings from this sensor are in gauge (relative) pressure. The sensor is powered from 12 VDC and has a 0-5 VDC output. The sensor is connected to the ECB at A/D INPUTS – AD0. Power for the sensor is applied from AD0 12V+ and AD0 GND. The sensor's voltage output in the range of 0 to 5 VDC is connected to AD0 SIG.

5.5 Heaters

The G2 requires several different heating zones to properly create and maintain humidity without fear of adverse condensation. Heating is required in the presaturator, circulating fluid, saturator outlet tube, and expansion valve.

5.5.1 Presaturator Heater, [A3]

The presaturator warms the incoming gas to oversaturate it with water vapor. This is accomplished through heating of the presat water. A 1500 watt insulated immersion heater provides this function. The preset water is warmed to and maintained at setpoint through pulse width modulation of the heater using feedback from the preset temperature sensor, Tp. When heating is required, the ECB's AC CONTROL - A3 digital output activates solid state relay SSR2 which completes the AC current path to the presaturator heater. A3's digital output is visually indicated with an adjacent LED. The heater ON status is also indicated with an LED on the solid state relay.

5.5.2 Circulating Fluid Heater, [A4]

The saturator temperature is maintained by heating or cooling the circulating fluid as needed. Heating is accomplished by activating a 500 watt insulated immersion heater, inserted in the circulating fluid through a thermal well. The circulating fluid temperature is warmed to and maintained at setpoint through pulse width modulation of the fluid heater using feedback from the saturator temperature sensor, Ts. When heating is required, the ECB's AC CONTROL – A4 digital output activates solid state relay SSR1 which completes the AC current path to the fluid heater. A4's digital output is visually indicated with an adjacent LED. The heater ON status is also indicated with an LED on the solid state relay.

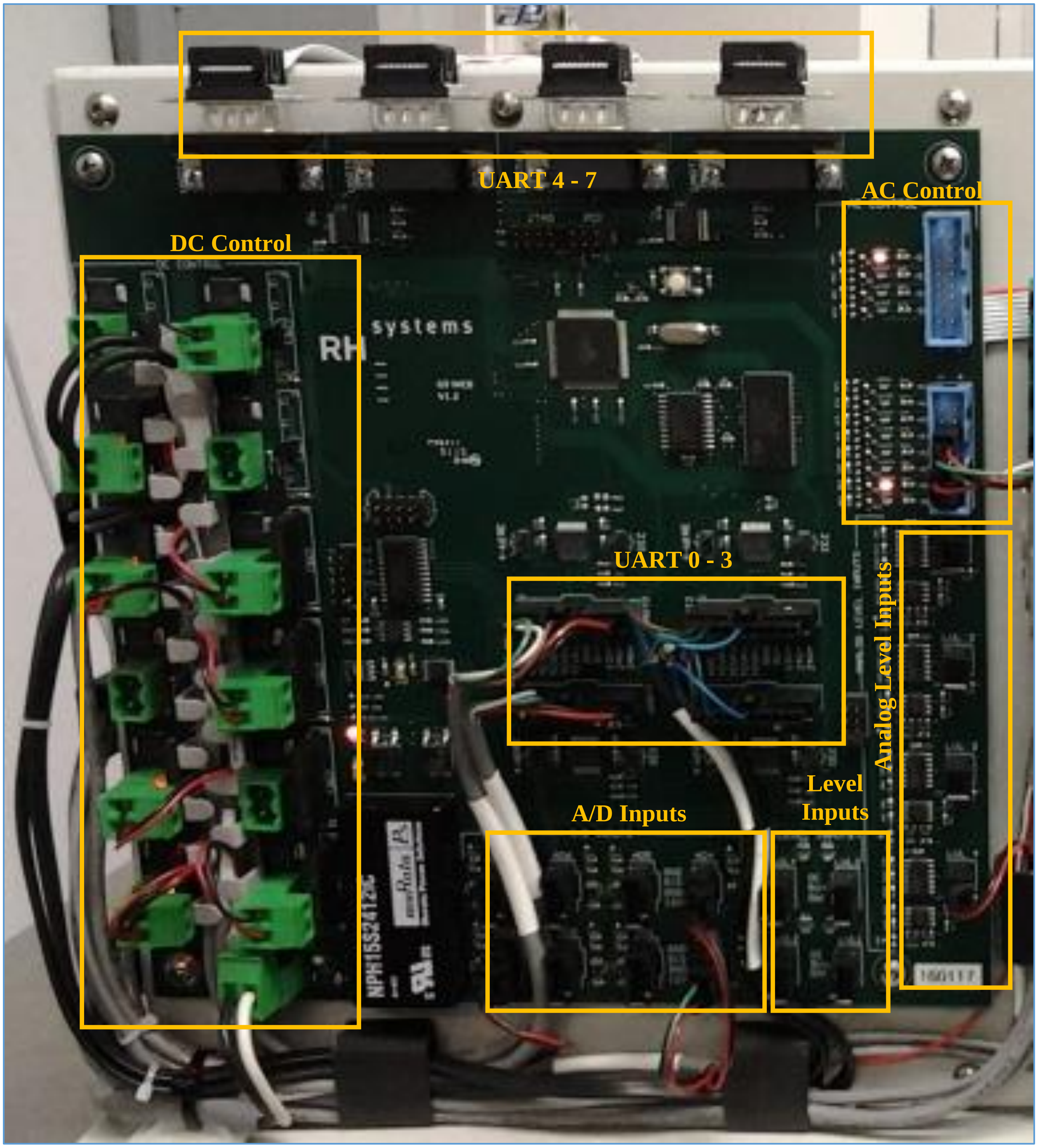
5.5.3 Saturator Outlet Tube, Tso, [RLY 8]

To prevent unwanted condensation once the gas leaves the saturator, the saturator outlet tube, Tso, needs to remain above the temperature of the saturator. The outlet tube is wrapped with an insulated heating wire. Tube heating is accomplished by activating the ECB's DC CONTROL – RLY 8 to source 24 VDC to the heater. RLY 8's output is visually indicated with an adjacent LED. The temperature of the outlet tube is heated and maintained through pulse width modulation of RLY 8 using feedback from the outlet tube temperature sensor, Tso.

5.5.4 Expansion Valve Heater, Tev, [RLY 10]

As the gas expands from a high pressure to a lower pressure, it cools. To offset this cooling effect, and also to prevent unwanted condensation in the expansion valve, the valve is heated. Two heaters, one installed in the valve plug and one on the outside of the valve body are connected in parallel. Expansion valve heating is accomplished by activating the ECB's DC CONTROL – RLY 10 to source 24 VDC to the heaters. RLY 10's output is visually indicated with an adjacent LED. The expansion valve is heated and maintained at temperature through pulse width modulation of RLY 10 using feedback from the expansion valve temperature sensor, Tev.

5.6 Connections to the ECB



The Embedded Controller Board (ECB) has many different inputs and outputs used to operate the G2. Grouped by functional type, the following tables in this chapter list the various inputs and outputs of the ECB and reference the specific sections of this manual where each input or output is discussed.

5.6.1 DC CONTROL

The ECB's DC CONTROL section (RLY1 through RLY12) powers valves, motors, heaters, fan, etc. These devices receive their 24 VDC power directly from the relay connector. These relay outputs power their connected devices directly, sourcing up to 2 amps each. . The (+) pin of each relay connector is hard wired to 24 VDC. The (-) pin of each channel switches in ground via the relay. Each output channel has an adjacent LED. When an LED is on, it indicates that the connector's (-) pin is pulled to ground, allowing current to flow through a connected device

Relay	Description	Reference
RLY 1		
RLY 3	Pressure vent solenoid	Section 5.2.3
RLY 5	Air-inlet solenoid	Section 5.2.2
RLY 7		
RLY 9	Fluid Pump	Section 5.3.3
RLY 11	Fan/Tank light	Section 5.4.2

Relay	Description	Reference
RLY 2	Compressor enable	Section 5.4.1
RLY 4		
RLY 6	Presat fill pump	Section 5.3.2
RLY 8	Post Sat Heat	Section 5.5.3
RLY 10	Expansion valve heat	Section 5.5.4
RLY 12	Sat cool solenoid	Section 5.4.3

5.6.2 AC CONTROL

The ECB's AC CONTROL section (A0-A7 and B0-B3) are digital outputs at a 5 volt logic level. They are primarily used as the control signals for high power AC relays. LEDs adjacent to each output indicate the status. When an LED is on, it indicates the digital output (-) pin is being pulled to a logic low. The (+) pin of each digital output is hard wired to +5 VDC.

Digital Output	Description	Reference
A7		
A6		
A5		
A4	Circulating Fluid Heater	Section 5.5.2
A3	Presat Heater	Section 5.5.1
A2		
A1	Compressor Speed	Section 5.4.1
A0		

5.6.3 A/D INPUTS

The ECB's A/D INPUTS section (AD0-AD7) has an 8 channel, 14 bit, 5 volt analog to digital converter system. Each connector also has 12 VDC power available to directly power the connected devices or sensors.

Analog Input	**Description**	**Reference**
AD0	Refrigeration Low-side Pressure Sensor	Section 5.4.5
AD1		
AD2		
AD3	Air-in Pressure Sensor	Section 5.2.1
AD4	Temp board power only	Section 5.1.3
AD5		
AD6		
AD7		

5.6.4 LEVEL INPUTS

The ECB's LEVEL INPUTS are 5 volt digital inputs used for liquid level controls. The G2 does not use these digital inputs directly. On the G2, an analog liquid level probe is used. For this configuration, the analog probe is connected to the ANALOG LEVEL INPUTS section of the ECB. The output from this analog section is a digital signal which is then tied to the digital LEVEL INPUTS section via a jumper.

Digital Input	**Description**	**Reference**
LVL1		
LVL2		
LVL3		
LVL4	Presat level from ANALOG LEVEL INPUTS – LVL 4	Section 5.3.2

5.6.5 ANALOG LEVEL INPUTS

The ECB's ANALOG LEVEL INPUTS are configured for capacitive liquid level probes. A comparator in the circuit converts the analog signal to a digital output. A jumper associated with each channel then allows the digital output from an analog circuit to be fed into the associated digital LEVEL INPUTS channel (see section 5.6.4).

Analog Input	Description	Reference
LVL 1		
LVL 2		
LVL 3		
LVL 4	Presat level probe	Section 5.3.2

5.6.6 UARTs

The ECB contains 8 fully independent Universal Asynchronous Receiver Transmitter (UART) serial ports which are configurable for either RS-232 or RS-485 communication. The following table lists the configuration and connected devices for each of these serial ports.

Serial Port	Connected devices	Configuration	Reference
UART0	Flowmeter	RS-232	Section 5.2.4
UART1	Pressure sensors, Ps, Pc	RS-485, addressable	Sections 5.2.5, 5.2.6
UART2	Flow Control Valve	RS-232	Section 5.2.7
UART3	Expansion Valve	RS-232	Section 5.2.8
UART4	Com1	RS-232	
UART5	Com2	RS-232	
UART6	Com3	RS-232	
UART7	Temperature Board	RS-232	Section 5.1.3

5.7 Temperature Measurements

The Precision Resistance Measurement board is a 16 channel, 24 bit, A/D converter system used to measure all temperatures in the G2. It connects to the ECB via its RS-232 port. While two of the A/D converter channels are configured for reference resistor measurements, the remaining channels are configured for connection of 100 ohm platinum resistance thermometers (PRTs). The following table lists the probe channels and functions of the G2.

Channel	Probe name	Function	Reference
CH 0	Ref Ohms Low		Section 5.1.3
CH 1	Ref Ohms High		Section 5.1.3
CH 2			
CH 3			
CH 4	T1	T1	Section 5.1.3
CH 5	T2	T2	Section 5.1.3
CH 6	T3	T3	Section 5.1.3
CH 7			
CH 8			
CH 9	Post Sat	Tso	Section 5.5.3
CH 10	Sat	Ts	Section 5.5.2
CH 11	PreSat	Tp	Section 5.5.1
CH 12			
CH 13	ExVlv	Tev	Section 5.5.4
CH 14			
CH 15			

All probes are wired to the temperature board as 4-wire, 100 ohm PRTs. There are four 26 pin D connectors on the board. Three intermediary interface boards connect to three of these D connectors. All probe connections are then made via straight single row Molex plugs via the intermediary interface boards. The remaining D connector is used for connection of a reference resistor pack. The reference resistor pack houses two individual reference resistors (RefOhmsLow and RefOhmsHigh). The reference resistors are known resistances, whose values are programmed into the ECB for use in determining resistances of the PRTs.

The Precision Resistance Measurement board communicates via RS-232 to the ECB UART 7.

6 Serial Communication

The G2 is equipped with 3 independent bidirectional RS-232 communications interfaces that allow it to be connected to remote computers. This section is intended to provide basic necessary information for programmer's regarding the use of the interface, including the hardware connections, communications settings, and command syntax.

6.1 Hardware Connection & Cabling

Connect a computer to the G2 using a standard *RS-232 9-pin extender cable*. The extender cable has a male connector on one end and a female connector on the other end. It is wired straight through with pins 1 through 9 on one end wired to pins 1 through 9 on the other end.

The G2 ignores the DSR and CTS handshaking signals. While there is no harm in connecting all 9 pins, the G2 only requires connection of three of the pins (pins 2=Tx, 3=Rx and 5=Common). For your reference, the complete connector pin-out is listed in section 2.1.6.1.

6.2 Communications Settings

To communicate with the G2, set your computer to the following settings.

Baud Rate:	9600
Data Bits:	8
Parity:	None
Stop Bits:	1
Handshaking:	None

6.3 Command Syntax

This section details the general syntax guidelines regarding termination, leading and trailing spaces, case sensitivity, and numeric values. Throughout this section, characters originating from the computer will be shown for illustrative purposes in **`this font`**. Characters originating from the G2 will be shown in `this font`.

6.3.1 General Usage

All commands require either a question mark or an equal sign to indicate whether you are requesting data or sending new setpoints or values.

When requesting data from the G2, follow the command with **`?`**, the question mark character. For example, the following requests the current flowrate setpoint.

```
FlowSet?
25
```

The G2 replies with the current flowrate setpoint (25 liters/minute in this example).

When setting new values or parameters, use **=**, the equal sign. For example, the following command changes the flowrate setpoint to 50 liters/minute.

`FlowSet=50`

Most commands that can be set with an equal sign, such as the one in the above example, may also be read with the question mark. That makes sense. However, there are several commands that are considered read only, and have no corresponding ability to be set. For example, to read the measured flow rate (as opposed to the flow setpoint), you'd send the **`Flow?`** command.

```
Flow?
49.254
```

So while it is perfectly valid to read measured flow rate with a command such as **`Flow?`**, it obviously makes no sense to be able to send a flow measurement to the G2. Therefore, a command such as **`Flow=1.23`** is considered invalid, and will simply be ignored by the G2.

Likewise, measurements such as T1, T2, T3, Pc, Dew Point, and others may be read. But any attempts to send the G2 values with these commands are simply ignored.

6.3.2 Termination Characters

All commands must be terminated with either a carriage return ␍ or a carriage return linefeed combination ␍␊.

Regardless of the command sent, the G2 will reply with a carriage return linefeed **␍␊** at the end of the response, provided the command is recognized as valid. Here is an example:

`DP?␍`	(query sent by the computer to the G2)
`-10.015␍␊`	(response from the G2)

Even if the command is not a request for data, but rather is a command to change a setpoint or parameter, the G2 still responds with a carriage return line feed combination. The following sets the RH setpoint to 20%. Notice that no data is returned, but the G2 sends a ␍␊ acknowledgement that the command was valid.

`RH = 20␍`	(sent by the computer to the G2)
`␍␊`	(the acknowledgement from the G2)

However, if the command is unrecognized, the G2 does not respond. See the example.

`Abcdef?␍`	(invalid command sent from the computer)
	(no response from the G2)

6.3.3 Leading and Trailing Spaces

The G2 ignores leading and trailing spaces. It also ignores spaces before and after equal signs and question marks. For example, each of the following commands is perfectly valid.

```
Dp?CR
  Dp  ? CR
T1.avg=10CR
   T1.avg    =       10   CR
```

However, the following commands are invalid since spaces are embedded within the keywords.

```
D p?CR
T1 .avg=10CR
```

6.3.4 Case Sensitivity

All commands are insensitive to case. In other words, it does not matter if the command is sent in upper case letters, lower case letters, or as some combination of the two. For example, the commands **DP?**, **Dp?**, **dP?**, and **dp?** are identical to the G2 and will return the measured dew point value.

6.3.5 Numeric Values

All numeric data sent to or received from the G2 is done so in either standard or scientific notation. Sending a number as **12.34** is the same as sending it as **1234e-2** or as **1.234e1**. Depending on the value of numeric responses the G2 sends out, it may send the numbers in either standard or scientific notation.

Numeric data is never appended with text of any kind. In other words, if requesting a temperature related value, only the numeric portion of the value is sent. The units are assumed but never sent.

The following table lists the units that numeric data adheres to. When sending or receiving numeric data of any kind, the units are implied.

Parameter	Units via RS-232
Temperature	°C
Pressure	Pa
Flow	l/m
RH	%
Volume Ratio	PPMv
Weight Ratio	PPMw
PRT Resistance	Ohms

Some values simply require integer numbers such as 1 and 0 for On and Off, while others might need real numbers with a decimal point. The G2 recognizes both types of numbers and will attempt to convert the values you send to the correct format. For example, the number 0 means *Off*, while 1 or any other real or integer value means *On*.

6.3.6 String Values

Some commands work only with string values. Serial Number and Control Mode commands are two such examples.

6.4 Command Reference

The available commands listed here are grouped by function. If a command is considered as a read only value, then it is shown with a question mark only. For instance, the following is considered as read only and does not have the ability to be set.

```
Dp?
```

A command that has both read and set capability is shown in a slightly different manner. The question mark and equal signs are shown for illustrative purposes within brackets. Those brackets indicate that either one or the other is required. Furthermore, **`[=i]`** indicates that the value is an integer, while **`[=n]`** indicates that the value may include a decimal point.

Consider a command with syntax listed in the manner

```
T1.useFixed[=i][?]
```

This indicates the following valid possibilities.

```
T1.useFixed = 0
T1.useFixed = 1
T1.useFixed?
```

Now consider a command with syntax listed as

```
DpSet[=n][?]
```

Any of the following are valid possibilities.

```
DpSet?
DpSet = 5
DpSet = -10.25
```

Note that a value entered as **`5.00`** would be equally as valid as **`5`**. The syntax listing **`[=n]`** indicates any real number, either positive or negative, with or without a decimal point.

If a string values is required, it is identified by [=s]. The control mode command is an example.

```
CtrlMode[=s]?
```

Any of the following would be valid, provided the string sent is accepted as valid.

```
CtrlMode?
CtrlMode = DP
CtrlMode = FP
```

6.4.1 *Typical Commands Listed By Functional Group*

6.4.1.1 Measurement Data

Syntax	Function
DP?	Generated Dew Point, °C
FP?	Generated Frost Point, °C
RH?	Alias for RH1?
RH1?	Generated Relative Humidity @ T1, %
RH2?	Generated Relative Humidity @ T2, %
RH3?	Generated Relative Humidity @ T3, %
VP?	Vapor Pressure, Pa
Ps?	Saturation Pressure, Pa
Pc?	External (or chamber) Pressure, Pa
Flow?	Flow Rate, l/m
Ts?	Saturation Temperature, °C
Tp?	Presaturator Temperature, °C
Tso?	Saturator Outlet Tube Temperature, °C
Tev?	Expansion Valve Temperature, °C
T1?	T1 Temperature, °C
T2?	T2 Temperature, °C
T3?	T3 Temperature, °C

6.4.1.2 Sensor Fixed (Measurement-Override) Data

Syntax	Function
Pc.Fixed[=n][?]	Fixed PC value
Pc.UseFixed[=i][?]	1→Pc uses fixed value 0→Pc uses measured value
T1.Fixed[=n][?]	Fixed T1 value
T1.UseFixed[=i][?]	1→T1 uses fixed value 0→T1 uses measured value
T2.Fixed[=n][?]	Fixed T2 value
T2.UseFixed[=i][?]	1→T2 uses fixed value 0→T2 uses measured value
T3.Fixed[=n][?]	Fixed T3 value
T3.UseFixed[=i][?]	1→T3 uses fixed value 0→T3 uses measured value

6.4.1.3 Control

Syntax	Function
CtrlMode[=s][?]	Control mode (DP, FP, RH1, etc.)
Run[=i][?]	1→run, 0→stop

6.4.1.4 Setpoints

Syntax	Function
DPSet[=n][?]	*Dew Point setpoint, °C
FPSet[=n][?]	*Frost Point setpoint, °C
RhSet[=n][?]	**Alias for RH1Set[=n][?]
RH1Set[=n][?]	*RH @ T1 setpoint, %
RH2Set[=n][?]	*RH @ T2 setpoint, %
RH3Set[=n][?]	*RH @ T3 setpoint, %
PsSet[=n][?]	*Sat Pressure setpoint, Pa
FlowSet[=n][?]	Flow rate setpoint, l/min
TsSet[=n][?]	Saturator temperature setpoint, °C

*Note that changing the indicated setpoints above also changes the CtrlMode. For example, sending **FpSet=10** also changes the CtrlMode to FP. Querying a setpoint has no effect on the control mode.

Since **RhSet is an alias for **RH1Set**, sending an **RhSet** command changes the CtrlMode to RH1.

6.4.1.5 Saturator Pressure Calibration Coefficients

Syntax	Function
Ps.a0[=n][?]	Saturator pressure 0^{th} order coefficient
Ps.a1[=n][?]	Saturator pressure 1^{st} order coefficient
Ps.a2[=n][?]	Saturator pressure 2^{nd} order coefficient
Ps.a3[=n][?]	Saturator pressure 3^{rd} order coefficient
Ps.offset[=n][?]	Saturator pressure offset, Pa
Ps.avg[=n][?]	Saturator pressure averaging value
Ps.band[=i][?]	Saturator pressure averaging band, Pa
Ps.save=RHS	Permanently save changes

6.4.1.6 External (Chamber) Pressure Calibration Coefficients

Syntax	Function
Pc.a0[=n][?]	Chamber (external) pressure 0^{th} order coefficient
Pc.a1[=n][?]	Chamber (external) pressure 1^{st} order coefficient
Pc.a2[=n][?]	Chamber (external) pressure 2^{nd} order coefficient
Pc.a3[=n][?]	Chamber (external) pressure 3^{rd} order coefficient
Pc.offset[=n][?]	Chamber (external) pressure offset, Pa
Pc.avg[=n][?]	Chamber (external) pressure averaging value
Pc.band[=i][?]	Chamber (external) pressure averaging band, Pa
Pc.save=RHS	Permanently save changes

6.4.1.7 Air-In Pressure Calibration Coefficients

Syntax	Function
Pai.a0[=n][?]	Air-in pressure 0th order coefficient
Pai.a1[=n][?]	Air-in pressure 1st order coefficient
Pai.a2[=n][?]	Air-in pressure 2nd order coefficient
Pai.a3[=n][?]	Air-in pressure 3rd order coefficient
Pai.offset[=n][?]	Air-in pressure offset, Pa
Pai.avg[=n][?]	Air-in pressure averaging value
Pai.band[=i][?]	Air-in pressure averaging band, Pa
Pai.save=RHS	Permanently save changes

6.4.1.8 Refrigeration Low Pressure Calibration Coefficients

Syntax	Function
Prl.a0[=n][?]	Refrigeration low pressure 0th order coefficient
Prl.a1[=n][?]	Refrigeration low pressure 1st order coefficient
Prl.a2[=n][?]	Refrigeration low pressure 2nd order coefficient
Prl.a3[=n][?]	Refrigeration low pressure 3rd order coefficient
Prl.offset[=n][?]	Refrigeration low pressure offset, Pa
Prl.avg[=n][?]	Refrigeration low pressure averaging value
Prl.band[=i][?]	Refrigeration low pressure averaging band, Pa
Prl.save=RHS	Permanently save changes

6.4.1.9 Saturator Temperature Calibration Coefficients

Syntax	Function
Ts.R0[=n][?]	Saturator temperature CVD R0 coefficient
Ts.a[=n][?]	Saturator temperature CVD A coefficient
Ts.a[=n][?]	Saturator temperature CVD B coefficient
Ts.a[=n][?]	Saturator temperature CVD C coefficient
Ts.offset[=n][?]	Saturator temperature offset, °C
Ts.avg[=i][?]	Saturator temperature averaging value
Ts.band[=n][?]	Saturator temperature C averaging band, °C

6.4.1.10 Presaturator Temperature Calibration Coefficients

Syntax	Function
Tp.R0[=n][?]	Presaturator temperature CVD R0 coefficient
Tp.a[=n][?]	Presaturator temperature CVD A coefficient
Tp.a[=n][?]	Presaturator temperature CVD B coefficient
Tp.a[=n][?]	Presaturator temperature CVD C coefficient
Tp.offset[=n][?]	Presaturator temperature offset, °C
Tp.avg[=i][?]	Presaturator temperature averaging value
Tp.band[=n][?]	Presaturator temperature C averaging band, °C

6.4.1.11 T1 Temperature Calibration Coefficients

Syntax	Function
`T1.R0[=n][?]`	T1 temperature CVD R0 coefficient
`T1.a[=n][?]`	T1 temperature CVD A coefficient
`T1.a[=n][?]`	T1 temperature CVD B coefficient
`T1.a[=n][?]`	T1 temperature CVD C coefficient
`T1.offset[=n][?]`	T1 temperature offset, °C
`T1.avg[=i][?]`	T1 temperature averaging value
`T1.band[=n][?]`	T1 temperature C averaging band, °C

6.4.1.12 T2 Temperature Calibration Coefficients

Syntax	Function
`T2.R0[=n][?]`	T2 temperature CVD R0 coefficient
`T2.a[=n][?]`	T2 temperature CVD A coefficient
`T2.a[=n][?]`	T2 temperature CVD B coefficient
`T2.a[=n][?]`	T2 temperature CVD C coefficient
`T2.offset[=n][?]`	T2 temperature offset, °C
`T2.avg[=i][?]`	T2 temperature averaging value
`T2.band[=n][?]`	T2 temperature C averaging band, °C

6.4.1.13 T3 Temperature Calibration Coefficients

Syntax	Function
`T3.R0[=n][?]`	T3 temperature CVD R0 coefficient
`T3.a[=n][?]`	T3 temperature CVD A coefficient
`T3.a[=n][?]`	T3 temperature CVD B coefficient
`T3.a[=n][?]`	T3 temperature CVD C coefficient
`T3.offset[=n][?]`	T3 temperature offset, °C
`T3.avg[=i][?]`	T3 temperature averaging value
`T3.band[=n][?]`	T3 temperature C averaging band, °C

6.4.1.14 Expansion Valve Temperature Calibration Coefficients

Syntax	Function
`Tev.R0[=n][?]`	Tev temperature CVD R0 coefficient
`Tev.a[=n][?]`	Tev temperature CVD A coefficient
`Tev.a[=n][?]`	Tev temperature CVD B coefficient
`Tev.a[=n][?]`	Tev temperature CVD C coefficient
`Tev.offset[=n][?]`	Tev temperature offset, °C
`Tev.avg[=i][?]`	Tev temperature averaging value
`Tev.band[=n][?]`	Tev temperature C averaging band, °C

6.4.1.15 Saturator Outlet Tube Temperature Calibration Coefficients

Syntax	Function
`Tso.R0[=n][?]`	Tso temperature CVD R0 coefficient
`Tso.a[=n][?]`	Tso temperature CVD A coefficient
`Tso.a[=n][?]`	Tso temperature CVD B coefficient
`Tso.a[=n][?]`	Tso temperature CVD C coefficient
`Tso.offset[=n][?]`	Tso temperature offset, °C
`Tso.avg[=i][?]`	Tso temperature averaging value
`Tso.band[=n][?]`	Tso temperature C averaging band, °C

6.4.1.16 Flow Calibration Coefficients

Syntax	Function
`Flow.a0[=n][?]`	Flow rate 0^{th} order coefficient
`Flow.a1[=n][?]`	Flow rate 1^{st} order coefficient
`Flow.a2[=n][?]`	Flow rate 2^{nd} order coefficient
`Flow.a3[=n][?]`	Flow rate 3^{rd} order coefficient
`Flow.offset[=n][?]`	Flow rate offset, Pa
`Flow.avg[=i][?]`	Flow rate averaging value
`Flow.band[=n][?]`	Flow rate averaging band, Pa

6.4.1.17 System Identification

Syntax	Function
`ID?`	Instrument verbose name, string
`IDN?`	Instrument short name, string
`Version?`	Software version number, string
`SVNVersion?`	SVN Version Control number, string
`SN?`	Serial Number, string

7 Preventative Maintenance

The G2 requires little maintenance. The following list give recommended maintenance checks and intervals.

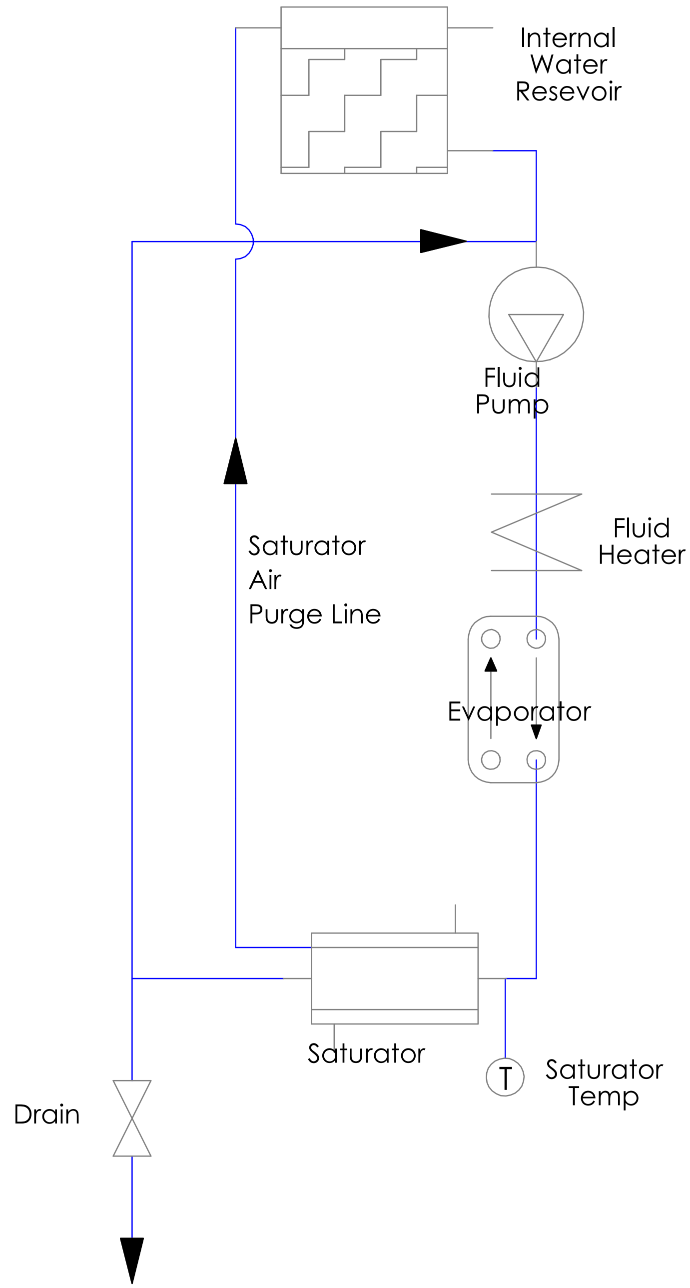
Task	Interval
Check coolant loop tank level	Weekly
Check for external fluid leaks	Weekly
Check for fluid leaks inside the main housing	Monthly
Clean inside main housing	Quarterly
Lubricate air inlet regulator handle	Yearly
Drain and refill pre-saturator	Yearly
Drain and refill coolant loop	Yearly

8 Spare Parts List

There are generally no consumable parts used in the G2. However, the following lists parts that might be considered for local stock.

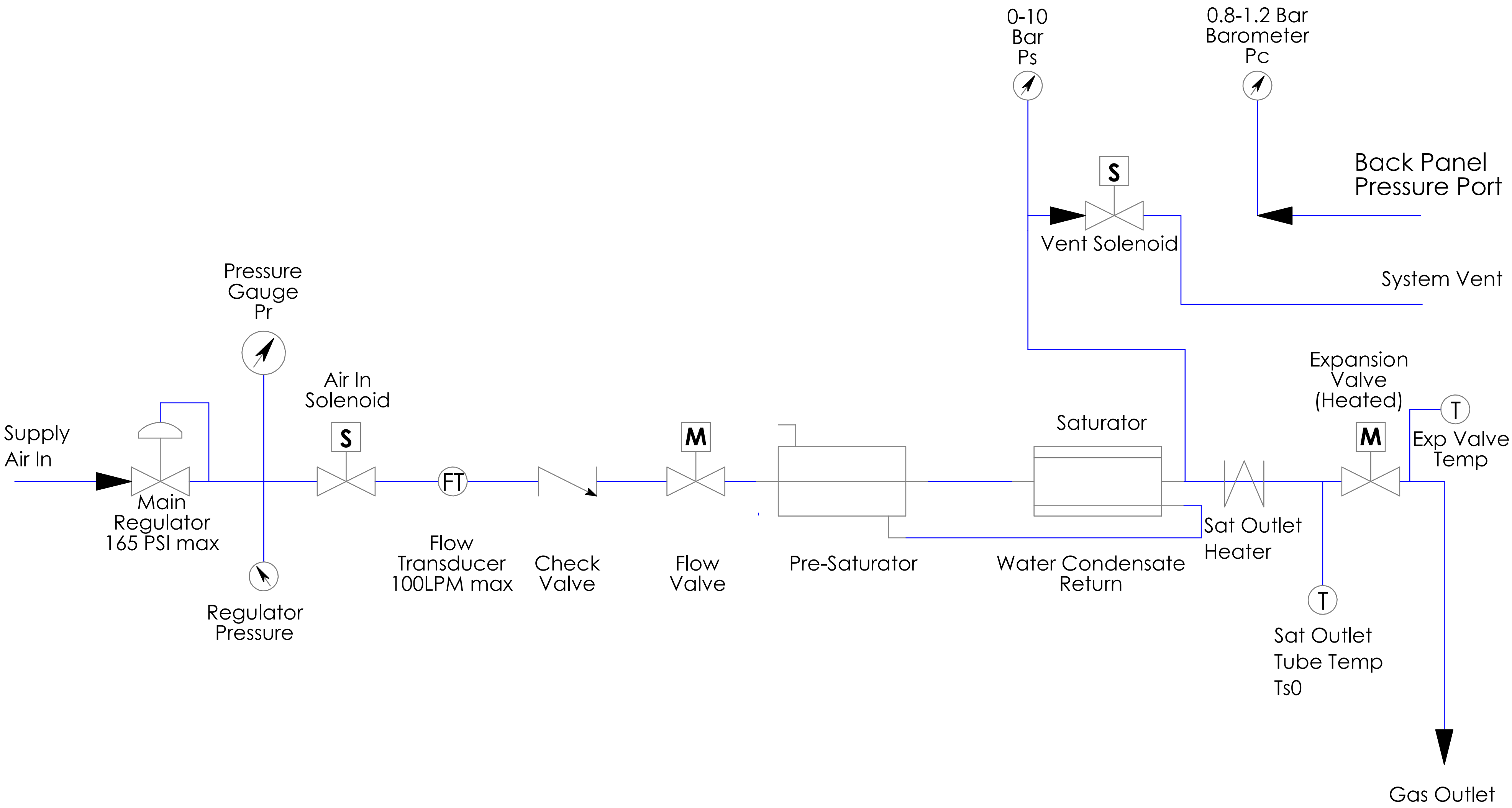
Description	Part Number
Expansion Valve Assembly	RHS-A-RH0028
Flow Valve Assembly	RHS-A-RH0030
Stepper Motor Controller	RHS-ST5-S
Flow Meter	RHS-A-RH0022
Inlet Pressure Regulator	RHS-960-152-000
External Pressure Transducer	RHS-PA33X10BAR
Saturator Pressure Transducer	RHS-PA33X10BAR
Air Inlet Pressure Transducer	RHS-PX2AN2XX250PSCHX
Pre-Saturator Fill Pump	RHS-ETG150
Liquid Coolant Loop Pump	RHS-LMB15107995
External Temperature Probe	RHS-R02000000483

9 Drawings



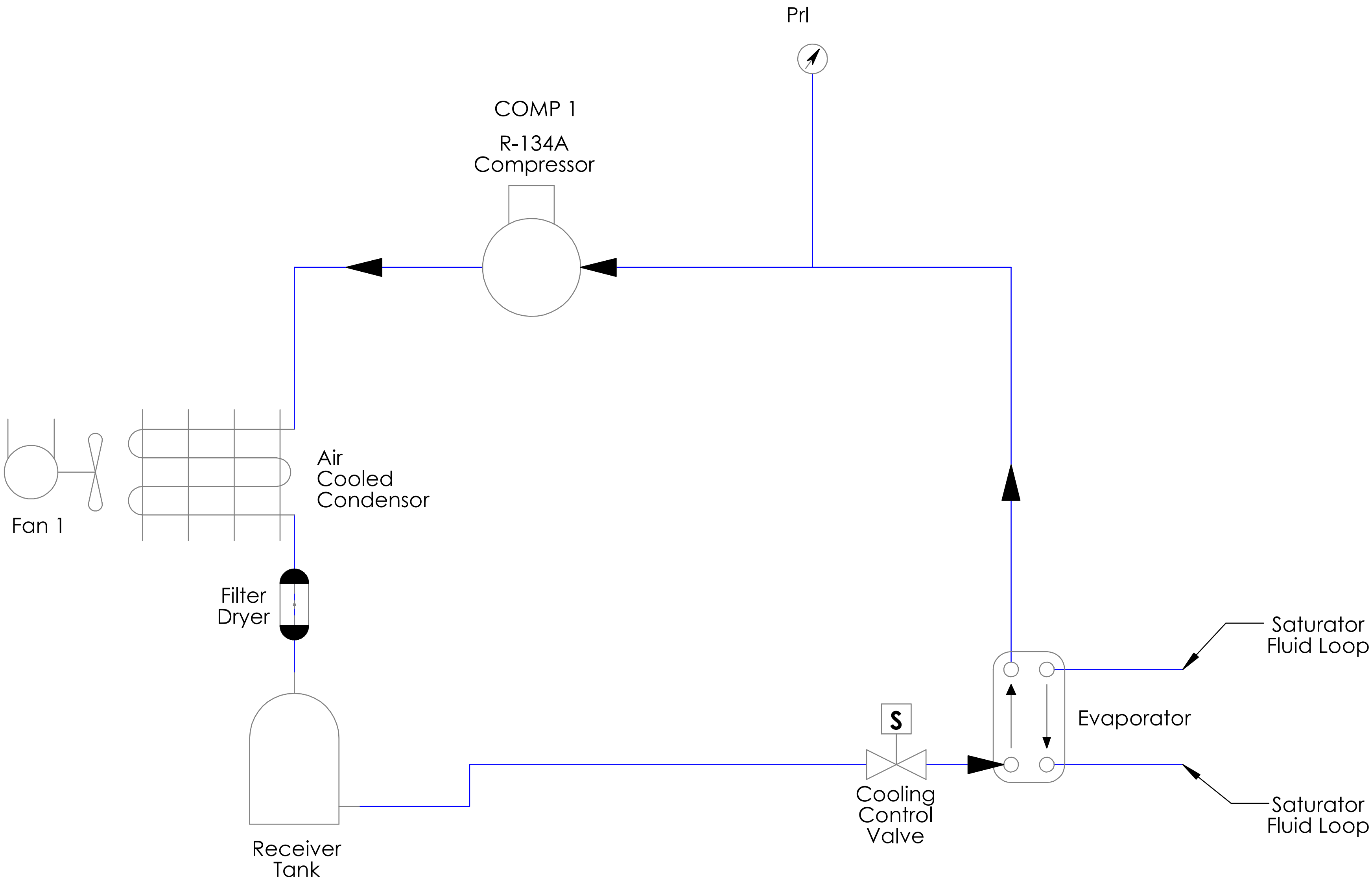
RH systems

Lego SPG Fluid System	DRAWING NO: LEGO-F-0001	REV: A	DATE: 13 Aug 2013	DRAWN: DRH	SHEET 1 OF 1



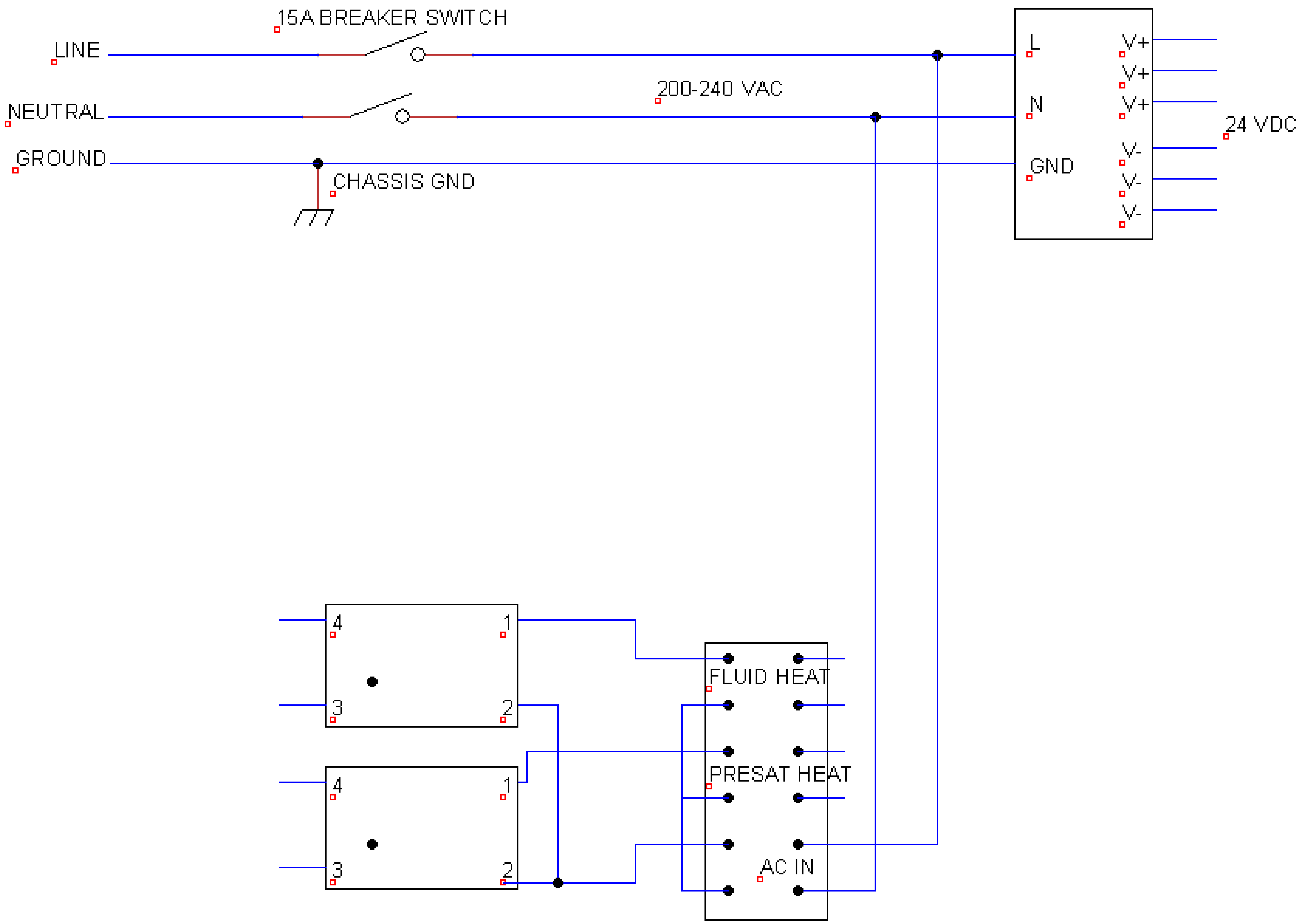
RH systems

Lego SPG Pneumatic System	DRAWING NO: LEGO-P-0001	REV: A	DATE: 13 Aug 2013	DRAWN: DRH	SHEET 1 OF 1



RH systems

LEGO SPG Refrigeration System	DRAWING NO: LEGO-R-0001	REV: A	DATE: 13 Aug 2013	DRAWN: DRH	SHEET 1 OF 1



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Author RH SYSTEMS	
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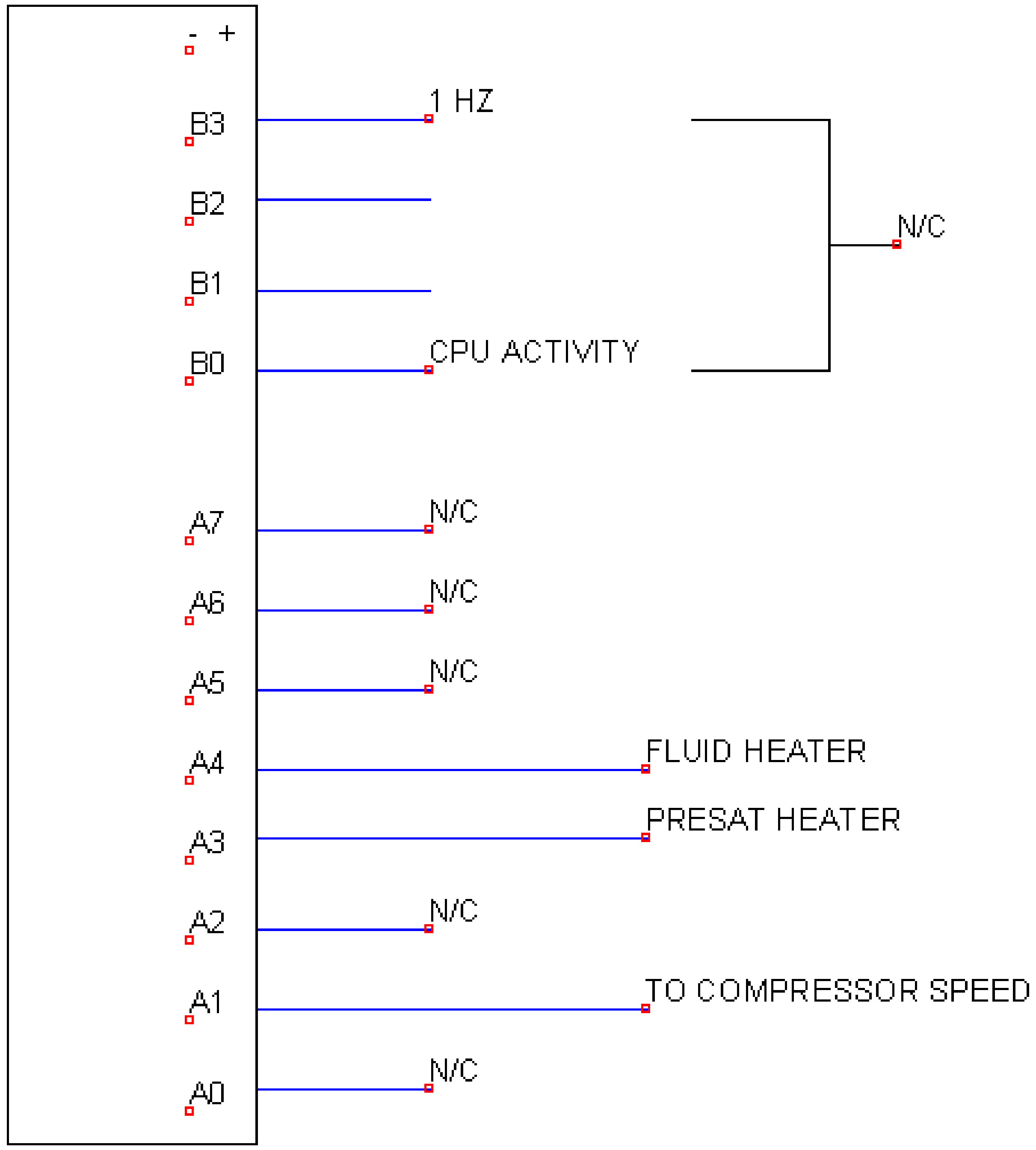
Revision 1.0	Date	Sheets 1 of 1



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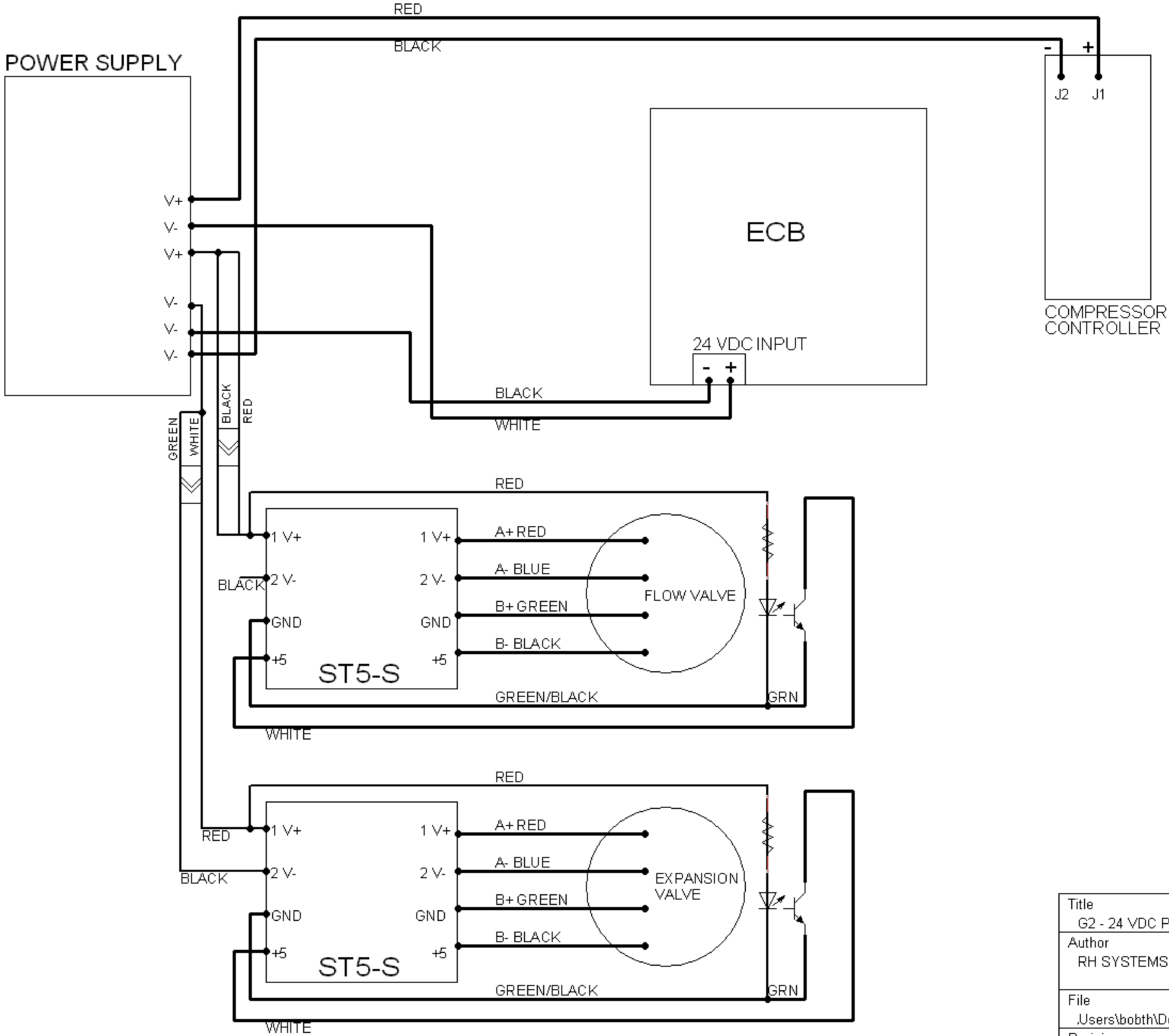
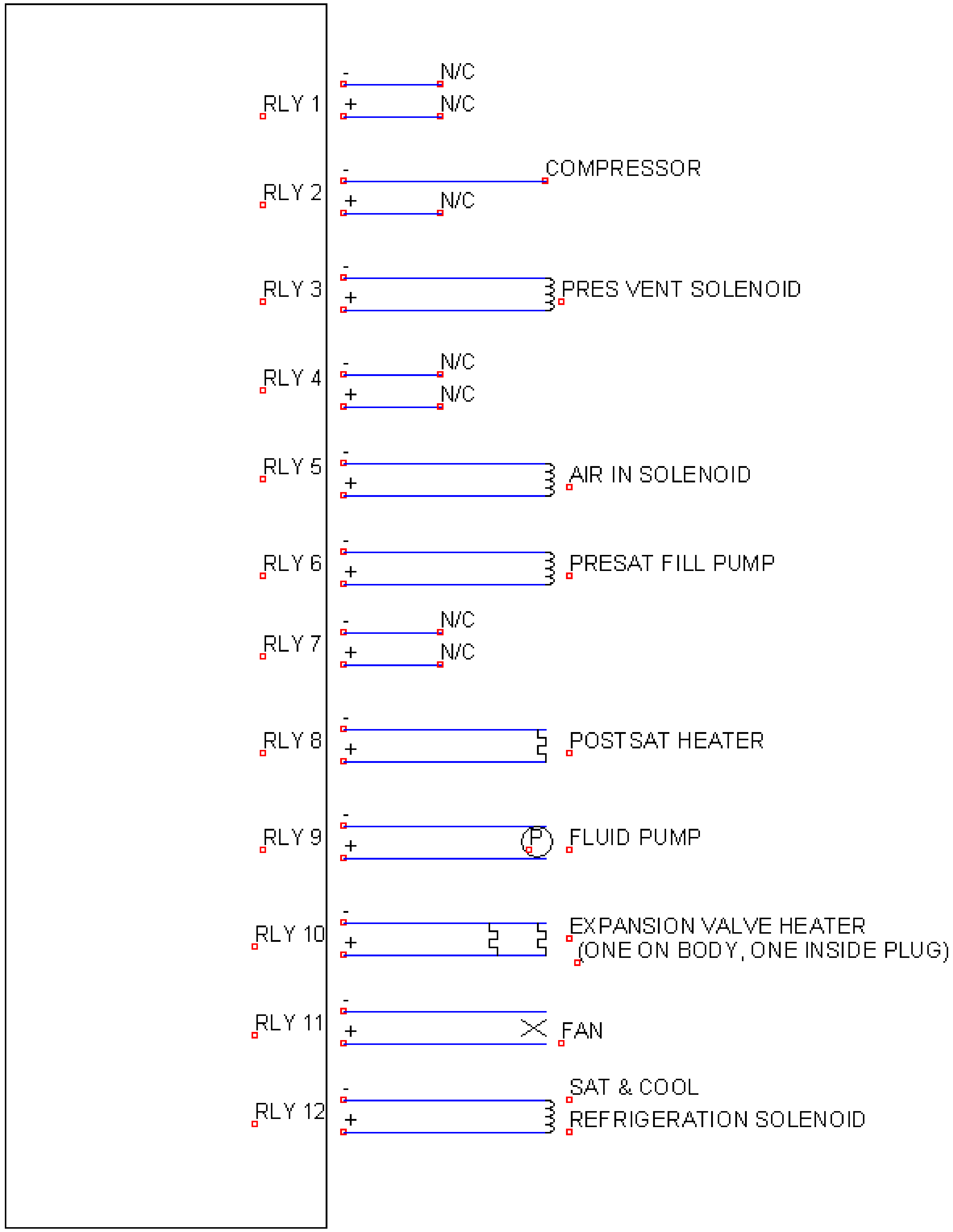
Author RH SYSTEMS		
File C:\RHS\G2-AC CONTROL		Document
Revision 1.0	Date	Sheets 1 of 1



Title	
G2 - 24 VDC POWER/STEPPER MOTORS	
Author	
RH SYSTEMS	
File: .Users\bobth\Desktop\G2 Revised\G2 24VDC.dsn	Document
Revision: 1.0	Date	Sheets: 1 of 1



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Author RH SYSTEMS		
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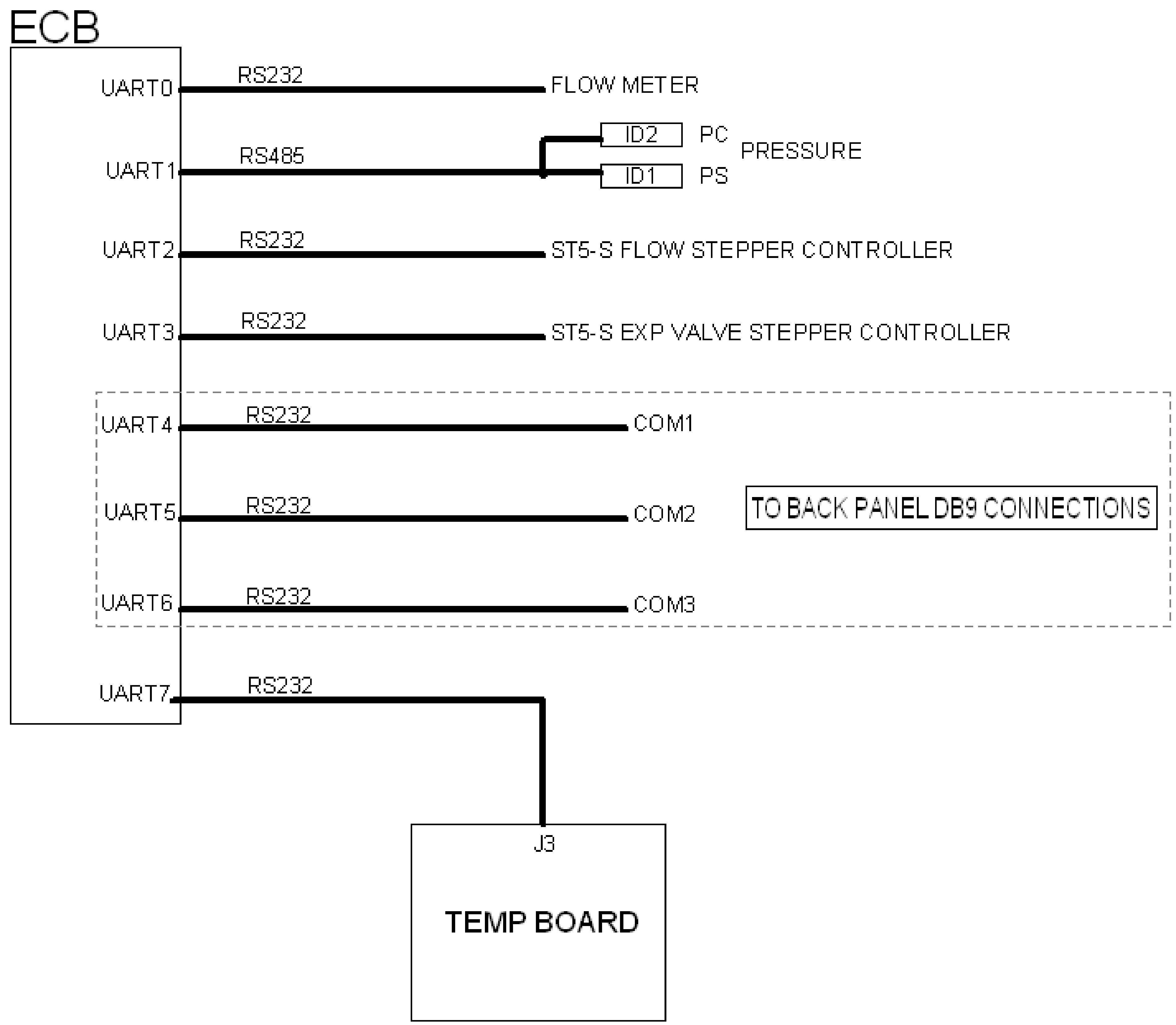

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Author RH SYSTEMS		
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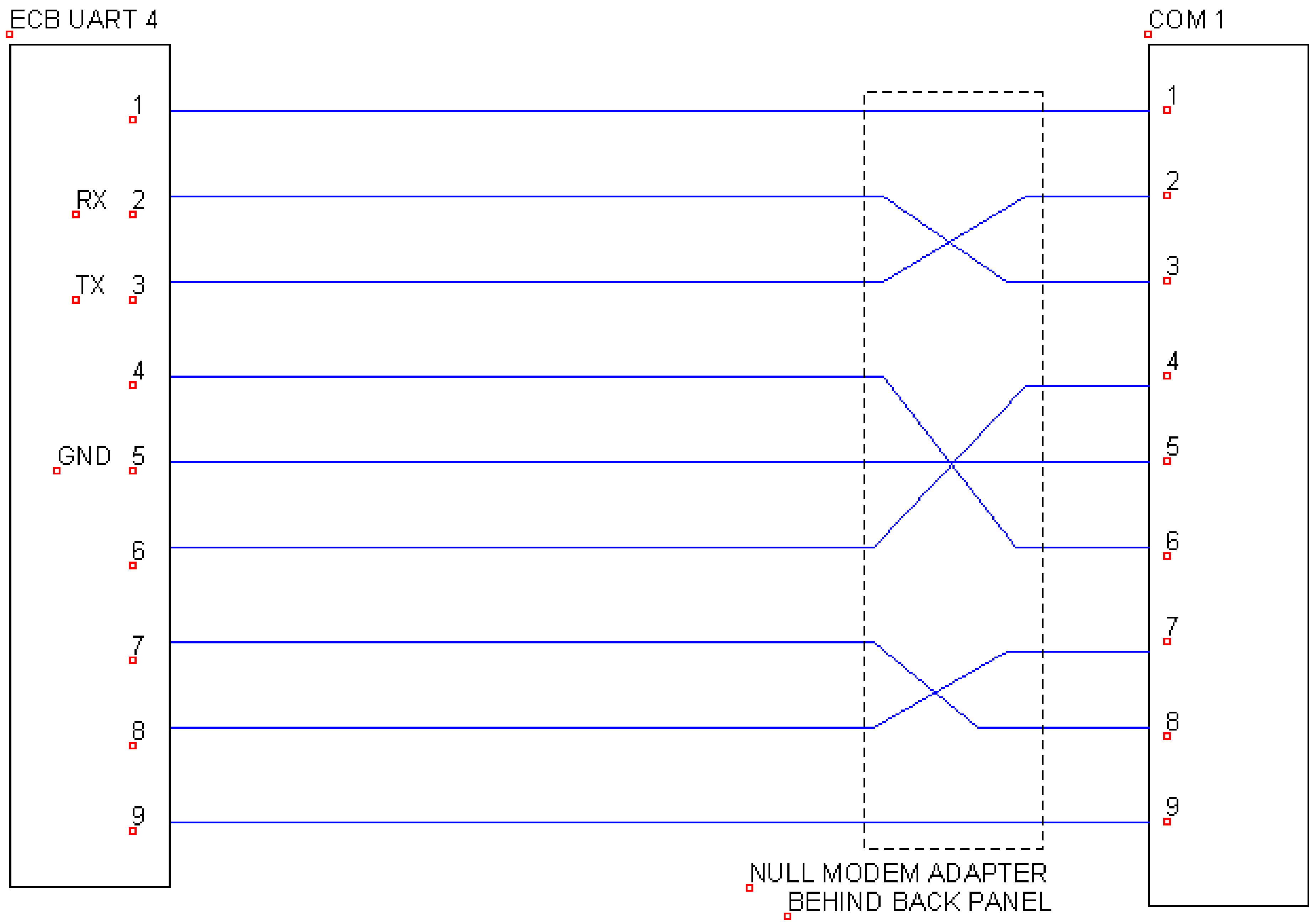

UART 5 AND UART 6 ARE IDENTICAL TO UART 4

Title		
G2 - ECB UART 4,5,6		
Author: RH SYSTEMS		
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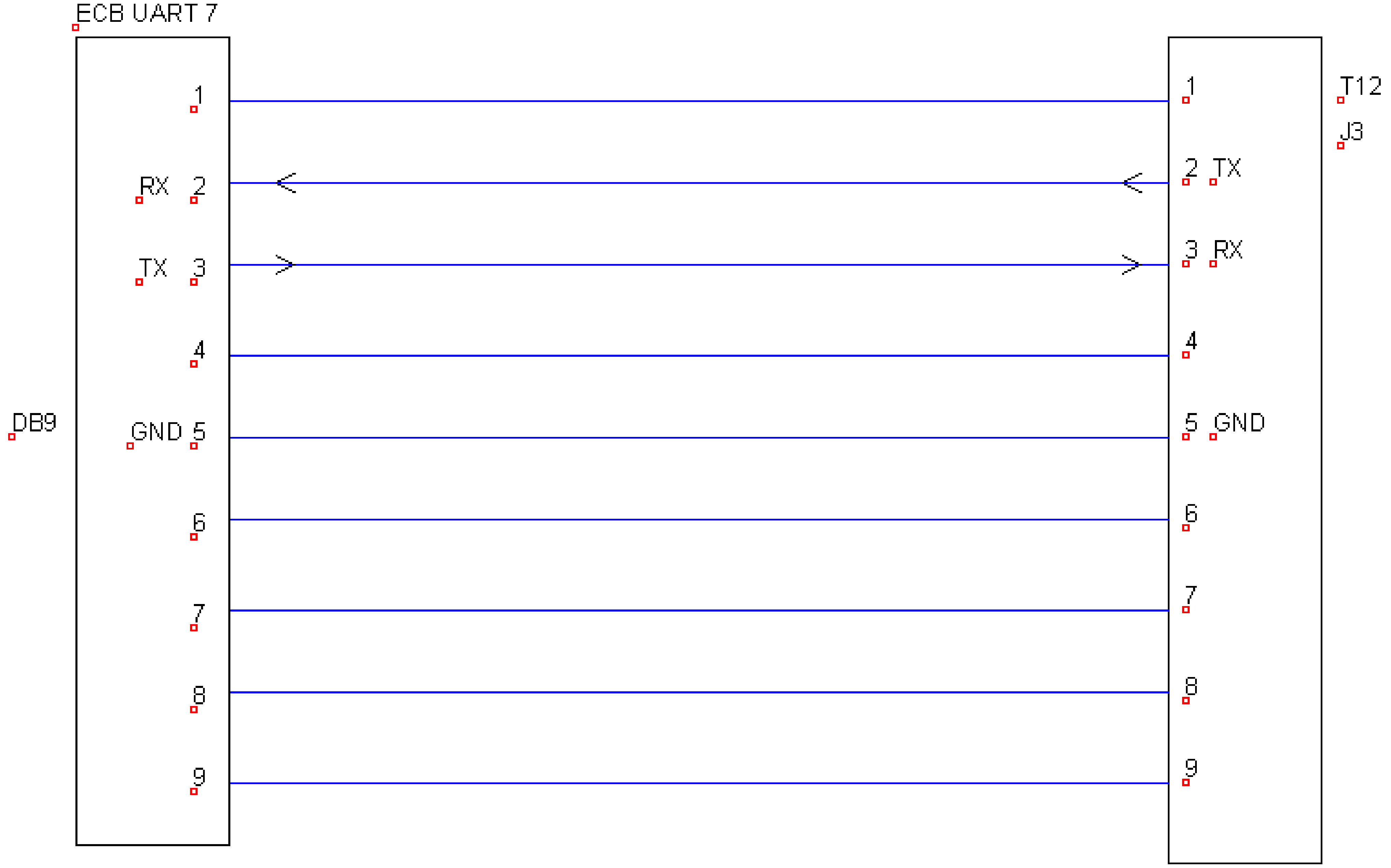
Revision: 1.0	Date	Sheets: 1 of 1



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Author RH SYSTEMS		
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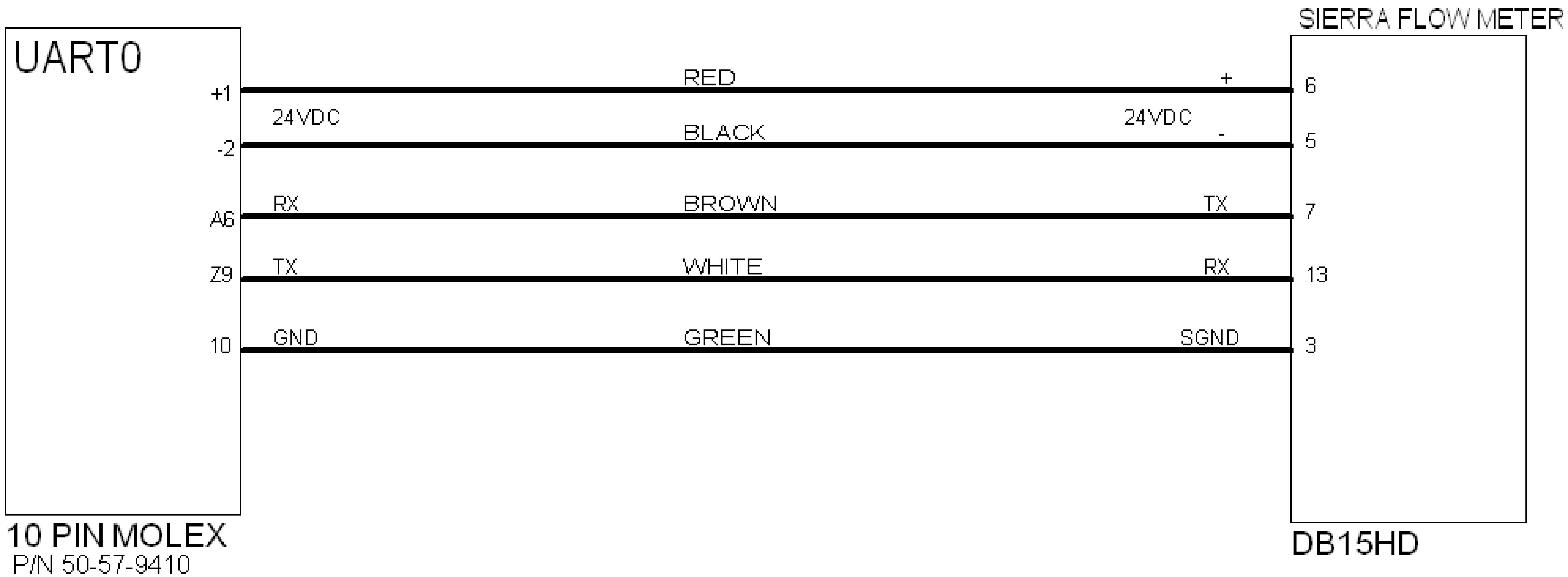
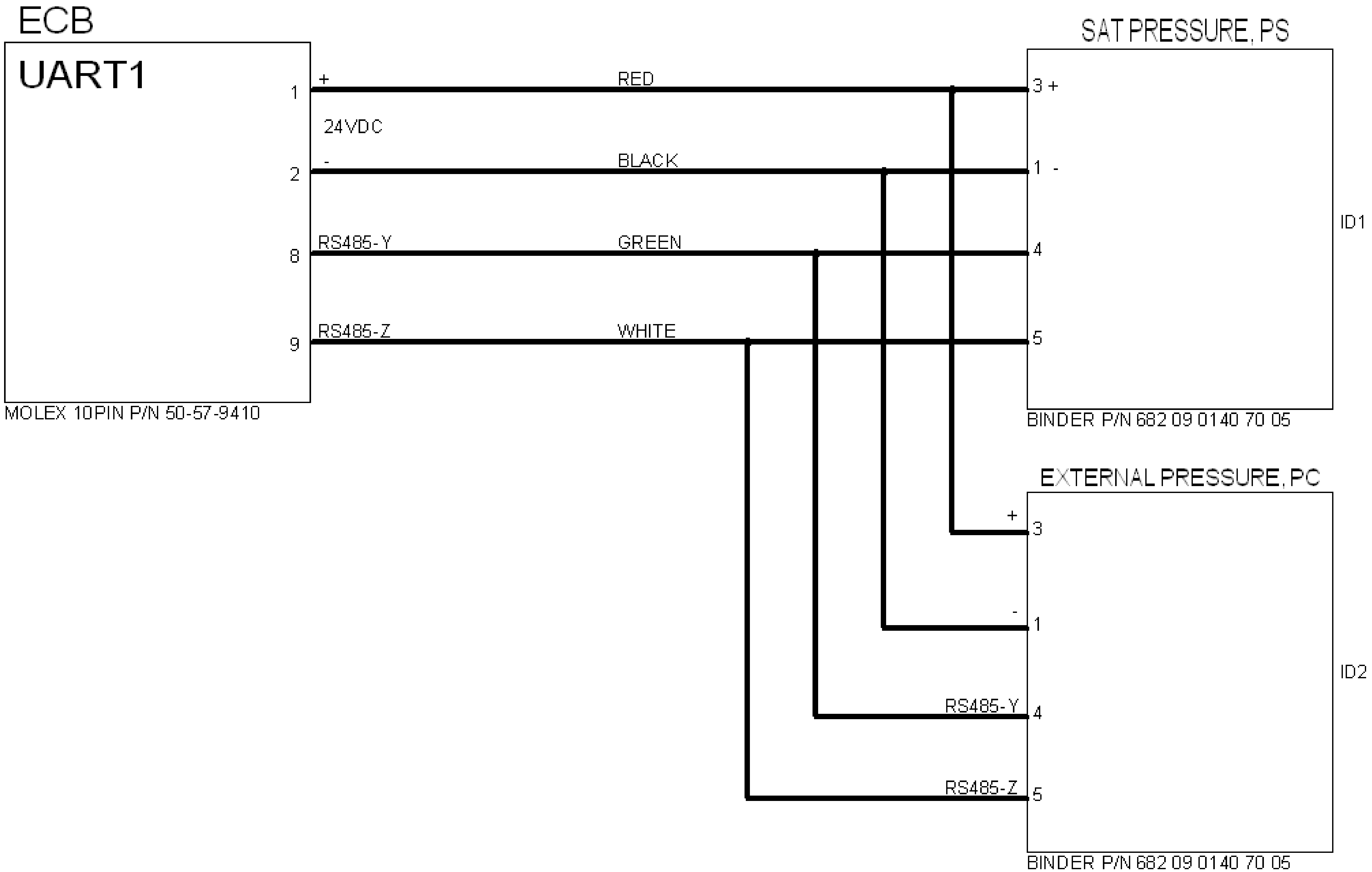
Revision 1.0	Date	Sheets 1 of 1



9600 BAUD
8 BITS
1 STOP
N PARITY
N FLOW CTRL

Title G2 - FLOW METER		
Author RH SYSTEMS		
File obth\Desktop\G2 Revised\G2-FLOW METER.dsn		Document
Revision 1.0	Date	Sheets 1 of 1



RS485 - 2 WIRE
9600 BAUD

Title G2 - PRESSURE SENSORS	
Author RH SYSTEMS	
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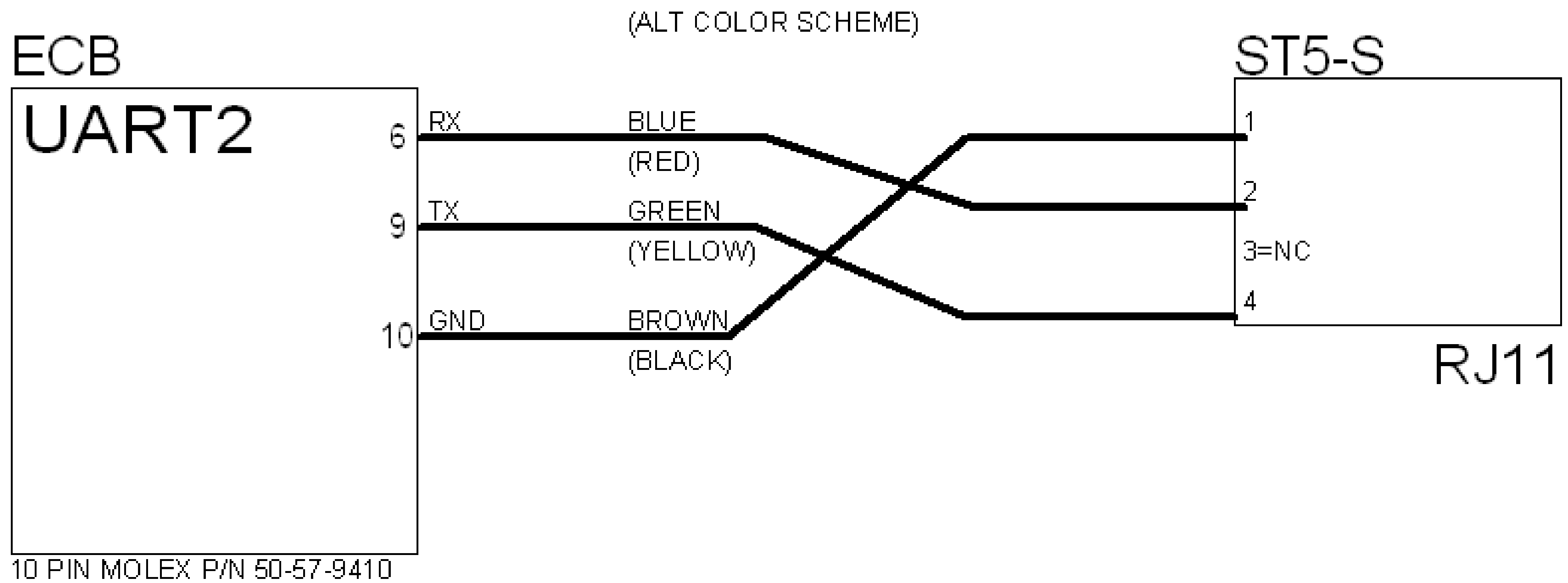
Revision 1.0 Date	Sheets 1 of 1



RS232
9600 BAUD
8 BITS
1 STOP
N PARITY
N FLOW CTRL

UART 3 EXPANSION VALVE IS IDENTICAL TO UART 2

Title G2 - STEPPER CONTROLLERS		
Author RH SYSTEMS		
File s\bobth\Desktop\G2 Revised\G2-STEPPERS.dsn		Document
Revision 1.0	Date	Sheets 1 of 1