ASVCO2 GEN 2 USER MANUAL

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Engineering Development Division

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REVISION HISTORY

NAME	DATE	CHANGES	FW VERSION
M. Casari	7/18/2019	First release	1.0
M. Casari	8/5/2019	New error code and FLAGS field formatting	1.1
M. Casari	8/9/2019	Flow Control Auto-Recovery added	1.2
M. Casari	8/23/2019	New States and Timing	1.3
M. Casari	8/23/2019	Changes to latest states & timings	1.4
M. Casari	3/18/2021	Updating coefficients naming. Adding tsq mode.	1.7
M. Casari	3/29/2021	Changing Mode to State. Add Flow Diagrams. More detail on Error/Flags.	1.7
M. Casari	4/13/2021	Multiple changes to report, menu. Adding sdata & idata.	1.8
M. Casari	8/8/2021	NetCDF Template Notes, Manufacturer data	1.8-13
M. Casari	9/14/2021	Baud rate changes, ATRH auto-populated serial number,	1.9
M. Casari	7/22/2022	Idata and sdata updates. Sample rate updated. SPON time now settable.	1.10
M. Casari	7/21/2023	Purge cycles added. New method for logging.	1.11

Overview

There is a current need to quantify the daily to inter-annual variability in air-sea CO_2 fluxes and understand the mechanisms controlling these fluxes. The carbon group at the Pacific Marine Environmental Laboratory (PMEL) within the National Oceanic and Atmospheric Administration (NOAA) has mounted sensors on moored buoys to provide high resolution time-series measurements of atmospheric boundary layer and surface pCO_2. This data is used to evaluate the temporal variability in air-sea CO_2 fluxes and to assist in examining the mechanisms controlling CO_2 fluxes. NOAA has made improvements to a design originally developed by MBARI, and previously worked with Battelle to manufacture the MApCO_2 system[1].

The latest ASVCO_2[2] sensor is designed to measure the partial pressure CO_2 concentration of sea water and surrounding air. From these measurements an evaluation of the temporal variability in air-sea CO_2 fluxes can be used to assist in identifying the associated air-sea exchange mechanisms.

This ASVCO2 sensor is a modification of the original pCO_2 system developed by PMEL and Battelle in 2009. By eliminating non-pCO_2 capabilities (e.g., SSTC, Iridium, etc.), this sensor is a dependant sensor which requires other data-logging and telemetry systems. Additionally to calculate pCO2 and fCO2, sea surface temperature and salinity measurements are required.

Specifications

Power Requirements	
Voltage Requirement	6 - 18V DC
Average Run Current per sample (~18.167 minutes)*	90mA
Average Run Current (1 sample/hour)*	27mA
Peak Current per sample*	685mA
Sleep Current * **	4mA
Communication	
Digital Format - Command	RS-232

[1] Sutton, A.J., C.L. Sabine, S. Maenner-Jones, N. Lawrence-Slavas, C. Meinig, R.A. Feely, J.T. Mathis, S. Musielewicz, R. Bott, P.D. McLain, J. Fought, and A. Kozyr (2014): A high-frequency atmospheric and seawater pCO2 data set from 14 open ocean sites using a moored autonomous system. Earth Sys. Sci. Data, 6, 353–366, doi: 10.5194/essd-6-353-201.

[2] Sabine, C., A.J. Sutton, K. McCabe, N. Lawrence-Slavas, S.R. Alin, R.A. Feely, R. Jenkins, S. Maenner, C. Meinig, J. Thomas, E. van Ooijen, A. Passmore, and B. Tilbrook (2020): Evaluation of a new carbon dioxide system for autonomous surface vehicles. J. Atmos. Oceanic Tech., 37(8), 1305–1317, doi: 10.1175/JTECH-D-20-0010.1.

Digital Format - Console	USB (Virtual Serial Port)
Measurement	
Average Sample Run Time	18 minutes, 30 seconds
Sampling Frequency	2 hertz

* Running at 12V DC nominal

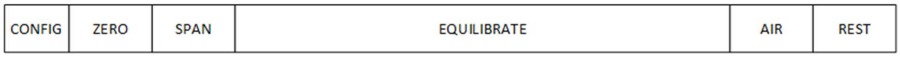
** Sleep current is not optimized, so unit should be shut off between runs.

Operational Theory

The ASVCO2 Sensor has six states of operation during a standard sample. The following diagram depicts the states in order of operation with an attempt at graphically indicating the lengths of each state. The *config* and *rest* states are overly exaggerated to fit the text within the blocks, while the *equilibrate* state is underexaggerated due to size restrictions.

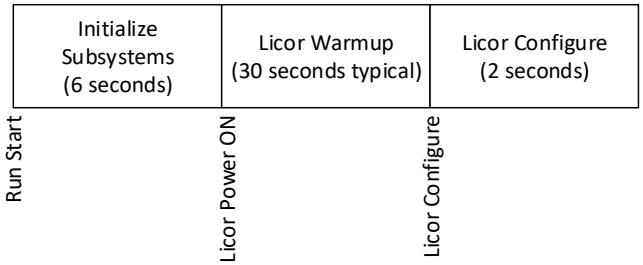
Note: In the state diagrams following, any words in red indicate variable times that can be set by the user. Some of these variables are used in other states (i.e., warmup, pumpon, etc.), and can affect the operation of the system significantly.

Full Run



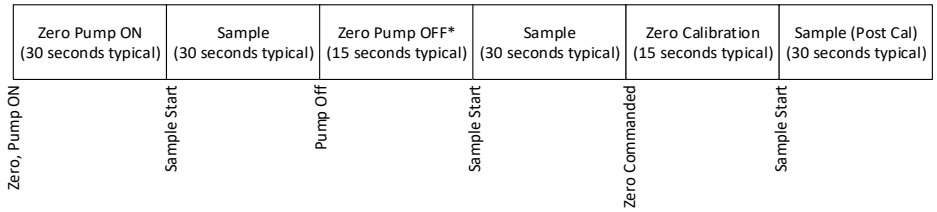
Config State

The *config* state configures the sensor for the requested run. When a run is requested, all sensor variables are locked.



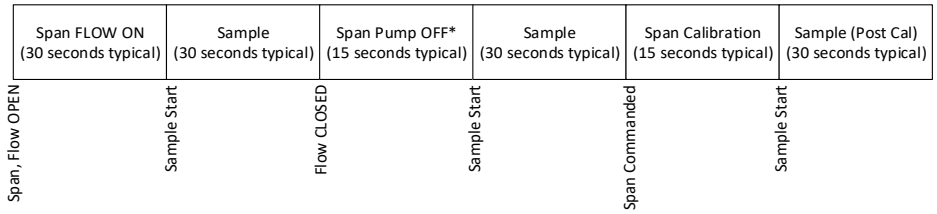
Zero Position (ZP) State

During the *Zero* state, the flow control module is commanded to run atmospheric air through the dryer and the soda lime, creating an air sample devoid of CO2 with extremely reduced relative humidity. This sample is used to provide a reference setting to the Li-COR NDIR CO2 sensor.



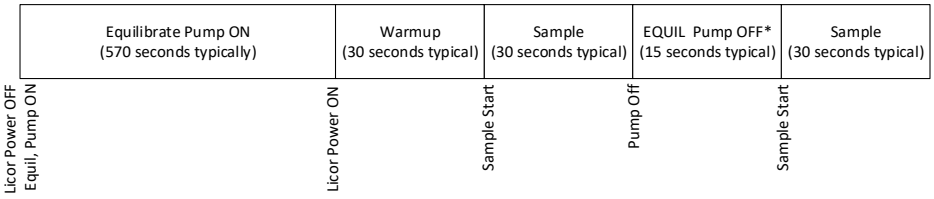
Span Position (SP) State

The *Span* State is used to calibrate the Li-COR NDIR CO2 sensor with a known CO2 concentration sample. The flow control unit is commanded to route the bottled CO2 standard through the dryer and into the Li-COR



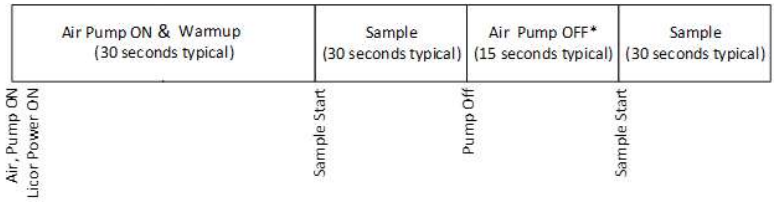
Equil Position (EP) State

The *equil* (equilibration) state is where the seawater CO2 concentration is measured. A clean air sample (from the atmosphere) is bubbled in the equilibrator to equalize the partial pressures of the water sample and the trapped air. This is typically the longest state in the process as the equilibration process requires a significant amount of time.



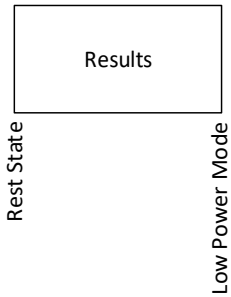
Air Position (AP) State

The *air* state is where the atmospheric CO2 is measured. The flow controller routes the atmospheric air through the dryer and into the Li-COR for measurement. After the atmospheric CO2 is measured, the sensor recalibrates the O2 sensor.



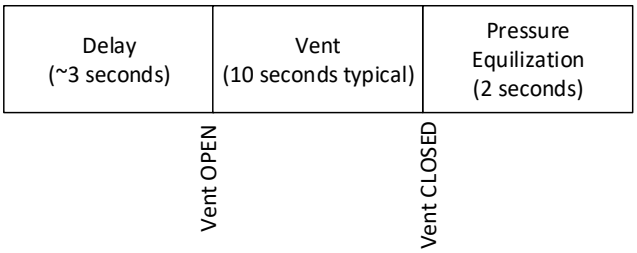
Rest State

At the conclusion of the sample, the sensor is put into the *rest* state. The flow controller closes all valve entries from exterior to prevent water damage to the sensing system.



Pump Off (Substate)

In the previous states, a sub-state labeled "Pump OFF*" was shown. The following timing diagram shows the components of the pump-off sub-state:



Purge State (Optional)

The purge state is added to a run by running the "TSP" or "TSQP" commands. This state is used to help remove any moisture buildup in the tubing. PURGE TIME and VENT TIME are variable. Following the purge, the system is put into rest state.

Valve Position [ABABAA] Pump ON (40 seconds)	Valve Position [BAABBA] Pump OFF (PURGE TIME)	Valve Position [BABAAA] Pump OFF (20 seconds)	Valve Position [BBBAAA] Pump ON (VENT TIME)

Valve Position [ABBAAA] Pump ON (VENT TIME)	Valve Position[REST MODE] Pump OFF (60 seconds)	Valve Position [BBBABB] Pump OFF (PURGE TIME)	Valve Position [ABBAAB] Pump ON (VENT TIME)

User Interface(s)

I. Physical Interface - Bulkhead Connectors

The ASVCO2 Gen 2 sensor has a single 8-pin Subconn MCBH8M bulkhead connector used for all power and communications. See Section II. for communication setup.

Pin #	Function	Limits/Notes
1	GND	System Ground
2	Tx	RS232 Transmit (to user)
3	Rx	RS232 Receive (from user)
4	+V	Input Voltage (6-18VDC)
5	+5VDC	USB Power (+5VDC)
6	D-	USB Data (Negative)
7	D+	USB Data (Positive)
8	GND	USB Ground

Subconn MCBH2M Bulkhead Connector Pins

Mating parts for bulkhead connector:

Part Number	Qty	Description
MCIL8F	1	Mating Cable
MCDLS Snap Ring	1	Locking Sleeve Snap Ring
MCDLS-F	1	Locking Sleeve

II. Physical Interface - PCB

The ASVCO2 Gen2 sensor has two interfaces, command port (RS232) and console port (USB), used to connect to users and control systems.

Command Port

The command port (Connector receptacle J1 on the PCB) is a combination power and serial port which is intended for M2M communications, i.e. control by autonomous vehicle or buoy controller.

Pin #	Function	Limits/Notes
1	GND	System Ground
2	Tx	RS232 Transmit (to user)
3	Rx	RS232 Receive (from user)
4	+V	Input Voltage (6-18VDC)

Command Port Connector Pins

RS232 Property	Setting
Baud Rate	115,200
Data bits	8
Parity	None
Stop bits	1
Flow Control	None
Termination Character(s)	CR & LF (\r\n)

Command Port Serial Connection Settings

Console Port

The Console port (USB) was designed for system configuration and testing during the manufacturing phase. A USB-to-Serial integrate circuit allows the ASVCO2 to show up as a Virtual COM port on a PC.

USB Property	Setting
Baud Rate	115,200
Data bits	8
Parity	None
Stop bits	1
Flow Control	None
Termination Character(s)	CR & LF (\r\n)

Console Port Serial Connection Settings

III. Hotkeys (Console Port Only (USB))

When the system is woken up (by sending any character) from Low Power Mode (LPM) it enters a wait state where it is looking for a user command for the next 5 seconds, or it will go back to the LPM. The following commands are available during this wait state:

Command	***Action***	***Definition***
?	Show Help Menu	Show List of Hotkey Commands
R	Start Sample Run	Start a full cycle pCO2 measurement run with normal sample periods
u	Start sample, quick test	Start a quick pCO2 measurement test with fast sample periods
O	Calibrate O2 Sensor	Pump atmospheric air through O2 sensor for 30 seconds and calibrate ADC for 20.947 %O2.
T	Console Terminal Mode	Enter the console terminal for full-featured configuration menu.
t	Get Time	Get the current RTC time.
S	Current Sampling Mode	Which Mode the system is currently in (Fast, Normal or Deploy) *(Not currently implemented)*
s	Current Sampling Schedule	Show the current scheduler functions with start times *(Not currently implemented)*
d	Get System Settings	Return a list of configurable system settings.
A	Air Mode (Purge)	Runs Air Mode to purge Licor of possible condensation
q	Return to Sleep Mode	Exit program and return to LPM.

IV. The Terminal: Console & Command Port Commands

The Terminal can be entered through both the Console Port (USB) or the Command Port (RS232). To enter from the Console port, a wakeup key (any key) followed by a "T" will bring up the terminal. From the Command port, a wakeup key (any key) will automatically enter the Terminal.

Once the terminal is entered, a '>' will be shown. If the sensor has previously been assigned a serial number, the serial number will precede the '>'.

Both ports will return to sleep after a period of inactivity. For the both console (USB) and command(RS232), this is approximately 60 seconds.

The following commands are available from the **Terminal**:

System Commands (Read Only):

Command	*Action*	*Definition*
?	Show Help Menu	Show List of Hotkey Commands
Ctrl-C (ASCII 0x03)	Reset System	Restart System
q	Exit Terminal Mode	Exit Terminal and return to Low Power Mode
report	Get System Settings	Return a list of configurable system settings.
ver	Show Firmware Version	Show the firmware version running on this device
i2cfail	Show the number of I2C failures	Show the number of I2C failure/restarts since power-up
startup	Show the number of system startups	Show the number of systems startups since the device was programmed

System Commands

Command	*Action*	*Definition*
serial	Show Serial Number	Show the device serial number
serial= XXXXXXXX	Set the serial number	Set the device serial number [18 characters max] [For PMEL Devices, this should be ASVCO2xxxx. Xxx can be 12 char long]
sreset	Software Reset	Reset the device by using the software reset (Quick response)
time	Show current time	Show the current RTC time (ISO-8601 format)
time= yy mm dd hh mm ss	Set current time	Sets the current datetime (yy mm dd hh mm ss)
Baud	Show Serial Baudrate	Shows the current buadrate setting
baud= X	Set Serial Baudrate	Set the serial port baudrate (2400, 4800, 9600, 19200, 28800, 38400, 57600, 115200)

TELOS Compliant Commands

Command	*Action*	*Definition*
cshow	Show COM Data	Report dummy TELOS COM data
gps	GPS Data	Always reports -2 for PCO2 Sensor
time	Sensor Date & Time	Time in format (yy mm dd hh mm ss)
time=	Set Sensor Date & Time	Time in format(yy mm dd hh mm ss)
idata	Iridium Data	Show the iridium (real-time) data
sdata	Sample Data	Show the high frequency data set

who	Serial Number	Show the system serial number

pCO2 Configuration Commands

Command	*Action*	*Definition*
span	Show the Span Gas Concentration	Show the span gas concentration (µmol mol^{-1}) stored in memory
span= XXXXX.XX	Set the span gas concentration	Set the span gas concentration in µmol mol^{-1}. (Default: 300umol mol^{-1})
span2	Show the Secondary Span Gas Concentration	Show the Secondary Span gas concentration (µmol mol^{-1}) stored in memory
span2= XXXXX.XX	Set the Secondary Span gas concentration	Set the secondary span gas concentration in µmol mol^{-1}.
spandiff	Show the Span Pressure Difference (kPa)	Show the minimum pressure difference between SPON and SPOFF that allows for automatic span calibration during a run. If this pressure difference is not exceeded, the calibration (span) gas cylinder is likely empty..
spandiff= XXX.XX	Set the span pressure difference	Set the pressure difference that determines if the system span calibrates during a run. In kPa. [default= 0.4kPa]
equil	Show equilibration pump time	Show the length of the equilibration pump time in seconds
equil= SSS	Set the equilibration pump time	Set the length of the equilibration pump time in seconds
warmup	Show the LICOR warmup time	Show the length of the LICOR warmup time in seconds
warmup= SSS	Set the length of the LICOR warmup	Set the LICOR warmup time length in seconds
pumpon	Show the pump on time	Show the length of pump on time during a sample cycle in

		seconds. Pump on time also controls the flush time for the span gas. CO2 is not sampled during the pump on time.
pumpon= SSS	Set the pump on time	Set the length of pump on time during a sample in seconds
pumpoff	Show the pump off time	Show the length of pump off time during a sample in seconds. Pump off times encompasses: 1) a pressure settle period (set as a constant in the firmware of 3 sec), 2) user defined vent period (see below), 3) followed by 2nd pressure settle period (length of this period is pumpoff time minus (vent time + 3 secs)
pumpoff= SSS	Set the pump off time	Set the length of pump off time during a sample in seconds
sampleco2	Show the data sample length time	Show the length of time the sample is collected during a sample in seconds in its current state.
sampleco2= SSS	Set the data sample length time	Set the length of time the sample is collected during a sample in seconds in its current state.
vent	Show the vent delay time	Show the length of delay time between vent open/close events in seconds
vent= SSS	Set the vent delay time	Set the length of delay time between vent open/close events in seconds
heater	Show the LICOR heater state	Show the current ON/OFF state of the LICOR Heater
heater= X	Set the LICOR heater state	Set the LICOR heater state (0=OFF, 1=ON). Heater default state is OFF since the heater is not used in the field.

Logging Commands

Command	*Action*	*Definition*
ts	Take sample	Start a sample run immediately
tsq	Take sample – Quiet Mode	Start a sample run immediate: only show only display start and stop of run on Command port. No other messaging. Can send an "sdata" or "idata" command after the run is complete. Start indicated by "Starting Sample - Quiet Mode" Complete indicated by "Sample Complete"
tsp	Take sample w/Purge	Start a sample run immediately and run the purge routine when complete.
tspq	Take sample w/Purge – Quiet Mode	Same as "tsq" with the purge routine run prior to completion.

Test Mode Commands

Command	*Action*	*Definition*
test	Enter TEST mode	Put system in TEST mode
stream	Stream Data	Stream system data (any key to exit)
norm	Enter Normal Mode	Return from TEST mode into Normal mode

Flow Control Module Commands - Requires System in TEST MODE

Command	*Action*	*Definition*
flowon	Turn Flow Control Module ON	Set relay to apply power to the Flow Control Module(MUST BE IN **TEST** MODE)

flowoff	Turn Flow Control Module OFF	Clear the relay to cut power to the Flow Control Module(MUST BE IN **TEST** MODE)
fpulse	Flow Control Pulse Length	Sets the flow control pulse length (10-100ms)
fcurrent	Flow Control Current Setting	Sets the flow control current setting (0-7)
flowpass	Flow Control Passthrough	Allows direct UART access to the Flow Controller in the field
fpurge	Flow Control Purge	Run the purge routine

Valve Setting Commands - Requires System in TEST MODE

Command	***Action***	***Definition***
tpos	Start data streaming	Starts in REST mode, use following keys to cycle between modes (MUST BE IN **TEST** MODE)
q	Exit	Exit TPOS mode
p	Toggle Pump	Toggles Pump OFF/ON in positions that utilize the pump
a	AIR Positions	Cycles through AIR Positions (APON, APOFF).
e	EQUILIBRATE Positions	Cycles through EQUIL Positions (EPON, EPOFF).
r	REST position.	Sets REST position.
z	ZERO Positions	Cycles through ZERO positions (ZPON, ZPOFF, ZPPCAL).
s	SPAN positions	Cycles though SPAN positions (SPON, SPOFF, SPPCAL).
0	Perform ZERO Cal	Send the Licor a re-zero command
1	Perform SPAN Cal	Runs the LI-COR SPAN

		Calibration
2	Performs SECONDARY SPAN Cal	Runs the LI-COR SECONDARY SPAN Calibration

Licor Testing Commands – Requires System in TEST MODE

Command	*Action*	*Definition*
licoron	Turn LICOR ON	Set relay to apply power to LICOR (MUST BE IN **TEST** MODE)
licoroff	Turn LICOR OFF	Clear relay to remove power to LICOR (MUST BE IN **TEST** MODE)
licorcfg	Configure LICOR	Run LICOR initial configuration (MUST BE IN **TEST** MODE)
likzero	READ CO2KZERO	Read co2kzero value from LI-830
likzero= n.nnnnnnnn	SET CO2KZERO	Set co2kzero value on LI-830
likspan	READ CO2KSPAN	Read co2kspan value from LI-830
likspan= n.nnnnnnnn	SET CO2KSPAN	Set co2kspan value on LI-830
likspan2	READ CO2KSPAN2 (Secondary Span)	Read co2kspan2 (Secondary Span) value from LI-830
likspan2= n.nnnnnnnn	SET CO2KSPAN2	Set co2kspan2 value on LI-830
lisample	Sample the LICOR	Read a LICOR sample (MUST BE IN **TEST** MODE) *(Not currently implemented)*
heateron	Turn LICOR heater ON	Turn LICOR Heater on (requires high current input) (MUST BE IN **TEST** MODE)
heateroff	Turn LICOR heater OFF	Turn LICOR heater off (MUST BE IN **TEST** MODE)
lipass	LICOR COMS passthrough	Create a tunnel to the LICOR to directly talk to the sensor through the terminal (MUST BE IN **TEST** MODE)
liver	LICOR firmware version	Read the LICOR firmware version number.

Oxygen Sensor Commands - Requires System in TEST MODE

Command	*Action*	*Definition*
O2	Read O2 Sensor	Read the O2 Sensor value in %. (MUST BE IN **TEST** MODE)
O2volt	Read O2 Sensor Voltage	Read the O2 sensor voltage in volts. (MUST BE IN **TEST** MODE)
o2cal	Calibrate O2 Sensor	Run the O2 Calibration Routine. (MUST BE IN **TEST** MODE)
anaon	Turn the analog port ON	Apply power to the analog voltage reference. (MUST BE IN **TEST** MODE)
anaoff	Turn the analog port OFF	Clear power to the analog voltage reference. (MUST BE IN **TEST** MODE)

Relative Humidity Sensor Commands - Requires System in TEST MODE

Command	*Action*	*Definition*
rh	Read the RH sensor	Read the relative humidity sensor in %RH. (MUST BE IN **TEST** MODE)

Real-time Clock Commands

Command	*Action*	*Definition*
rtccal	Set RTC Calibration	Turns on the 32kHz signal on the RTC output used for calibrating the crystal. System then waits for next field to be entered:
XXXXX.XX	Program the RTC	Enter the actual frequency of the crystal measured to auto-calculate the RTC offset for most accurate timing
treg	RTC Register Value	Shows hex values of RTC registers (for debugging purpose)
tcon	Charge RTC Cap	Applies voltage to the RTC SuperCap
tcoff	Stop Charge RTC Cap	Turns RTC SuperCap off
tcal	Autocal RTC RC Osc	Autocalibrates the RTC osciallator

Manufacturer Configuration Commands

To access these commands you need to first unlock them using the "mconfig" command, you then have USB= 60sec & RS232 = 10sec to enter the commands before your access expires and you need to reenter the "mconfig" command.

These commands are used for NetCDF generation

Command	***Action***	***Definition***
mconfig= PMEL	Allow Access to Manufacture Commands	Simple password protection for remainder of Manufacturer Configuration Commands (use "mconfig= PMEL" to see the values)
ssct	Read secondaryspan_calibrated_temperature	Show the Licor temp at the time that the Secondary Span Coefficient was set.
ssct= x.xxx	Write secondaryspan_calibrated_temperature	Record the Licor temp at the time that the Secondary Span Coefficient was set.
sscsc	Read secondaryspan_calibrated_spanconcentration	Show the concentration of the span gas used during the Secondary Span calibration routine. (This is the concentration for the mid-level span1 gas).
sscsc= x.xx	Write secondaryspan_calibrated_spanconcentration	Record the concentration of the span gas used during the Secondary Span calibration routine. (This is the concentration for the mid-level span1 gas).
lssc	Read last_secondaryspan_calibration	Show the date of the last secondary span calibration.
lssc= YYYY-MM-DDThh:mm:ssZ	Write last_secondaryspan_calibration	Record the datetime of the secondaryspan calibration.
lsstds	Read last_secondaryspan_temperaturedependantslope	Show the date of the last Secondary Span temperature dependant slope determination.
lsstds= YYYY-MM-DDThh:mm:ssZ	Write last_secondaryspan_temperaturedependantslope	Record the date of the last Secondary Span temperature dependant slope

		determination.
sstds	Read secondaryspan_temperaturedependantslope	Show the secondary span's temperature dependant slope, which is defined as the Licor's linear fit between the Secondary Span Coefficient and detector temperature between 0 and 40 deg C. presented as change in secondary span coefficient value per deg. C. This slope may be applied during the post processing of the data to improve measurement accuracy.
sstds= x.xxxxxxxx	Write secondaryspan_temperaturedependantslope	Record the secondary span's temperature dependant slope, which is defined as the Licor's linear fit between the Secondary Span Coefficient and detector temperature between 0 and 40 deg C. presented as change in secondary span coefficient value per deg. C. This slope may be applied during the post processing of the data to improve measurement accuracy.
sstdsf	Read secondaryspan_temperaturedependantslopefit	Show the R^2 linear fit of the secondary span's temperature dependency determination.
sstdsf= x.xxx	Write secondaryspan_temperaturedependantslopefit	Record the R^2 linear fit of the secondary span's temperature dependency determination.
sscrh	Read secondaryspan_calibrated_RH	Show the RH of the gas stream in the licor when the Secondary Span Coefficient was set.
sscrh= x.xx	Write secondaryspan_calibrated_RH	Record the RH of the gas stream in the licor when the Secondary Span Coefficient was set.
sscssn	Read	Show the serial number of the

	secondaryspan_calibrated_spanserialnumber	span gas (S0) bottle used while setting the secondary span.
sscssn=	Write secondaryspan_calibrated_spanserialnumber	Record the serial number of the span gas (S0) bottle used while setting the secondary span.
ssconc	Read ASVCO2_secondaryspan_concentration	Show the concentration of the secondary span gas used to set the Secondary Span Coefficient. This will be the highest concentration gas. An example might be 2500 µmol mol^{-1}.
sssn	Read ASVCO2_secondaryspan_serialnumber	Read the serial number of the secondary span gas (S1) bottle used while setting the secondary span.
sssn=	Write ASVCO2_secondaryspan_serialnumber	Record the serial number of the secondary span gas (S1) bottle used while setting the secondary span.
ssn	Read ASVCO2_span_serialnumber	Read the serial number of the span gas (S0) bottle used in the ASVCO2 system
ssn=	Write ASVCO2_span_serialnumber	Record the serial number of the span gas (S0) bottle used in the ASVCO2 system
avalid	Read last_ASVCO2_validation	Show the last time that the ASVCO2 system was validated against a suite of WMO certified gas standards.
avalid= YYYY-MM-DDThh:mm:ssZ	Write last_ASVCO2_validation	Record the last time that the ASVCO2 system was validated against a suite of WMO certified gas standards.
pbias	Read pressure_bias	Show the bias of the Licor pressure sensor. Obtained when the ASVCO2 system is open to the atmosphere (APON state) and its pressure is compared to a certified barometer. This bias is applied during the post processing process to

		determine the partial pressure of CO2.
pbias= x.xx	Write pressure_bias	Record the bias of the Licor pressure sensor. Obtained when the ASVCO2 system is open to the atmosphere (APON state) and its pressure is compared to a certified barometer. This bias is applied during the post processing process to determine the partial pressure of CO2.
lpbm	Read last_pressure_bias_measured	Show the date of the most recent pressure bias determination.
lpbm= YYYY-MM-DDThh:mm:ssZ	Write last_pressure_bias_measured	Record the date of the most recent pressure bias determination.
atrhs	Read ASVCO2_ATRH_serial	Show the serial number of the internal ASVCO2 AT/ RH sensor.
atrhs= ssssssss	Write ASVCO2_ATRH_serial (Currently User Disabled)	Placing the system in [TESTMODE] will save the attached ATRH sensor's serial number
o2s	Read ASVCO2_O2_serial	Show the serial number of the internal ASVCO2 oxygen sensor.
o2s= sssssss	Write ASVCO2_O2_serial	Record the serial number of the internal ASVCO2 oxygen sensor.
mfr	Read ASVCO2_manufacturer	Show the manufacturer of the ASVCO2 system.
mfr= sssssssssssssss	Write ASVCO2_manufacturer	Record the manufacturer of the ASVCO2 system.

DATA Format

All data reported during a run is returned with the "Data:" tag and has the following form:

DATA: State,TS,SN,CO2(ppm),Li_temp,Li_pres,Li_RawSample,Li_RawReference,RH(%),RH_T(C),O2(%)

Where:

State – Current pCO2 sample mode
TS – Timestamp (in ISO-8601 format, YYYY-MM-DDTHH:MM:SSZ)
SN – Serial Number of pCO2 sensor
CO2(ppm) – CO2 concentration in parts per million (ppm)
Li_temp(C) – LICOR CO2 sensor chamber temperature in degrees C
Li_pres(kPa) – LICOR CO2 sensor chamber pressure in kilopascals
Li_RawSample – LICOR CO2 sensor raw data measurements
Li_RawReference – LICOR CO2 reference data
RH(%) – Relative humidity percentage
RH_T(C) – Relative Humidity sensor temperature measurement in degrees C
O2(%) – Percentage Oxygen measured

Example:

DATA: APOFF , 2021-03-29T23:25:29.5Z, ASV1007, 438.470, 21.157, 101.506, 5488897, 5920678, 43.409, 20.468, 20.907

STATS Format

All statistical data (mean and standard deviation of measurements) reported during a run is returned with the "STATS:" tag and has the following form:

STATS:
State,SN,Timestamp,Li_Temp_ave(C),Li_Temp_sd,Li_Pres_ave(kPa),Li_Pres_sd,CO2_ave(PPM),CO2_SD,O2_ave(%),O2_SD,RH_ave(%),RH_sd,RH_T_ave(C),Rh_T_sd,Li_RawSample_ave,Li_RawSample_sd,Li_RawDetector_ave,Li_RawReference_sd

Where:

State – Current pCO2 sample mode
SN – Serial Number of pCO2 sensor
TS – Timestamp (in ISO-8601 format, YYYY-MM-DDTHH:MM:SSZ)
Li_Temp_ave(C) – Licor mean temperature (degrees C)
Li_Temp_sd – Licor temperature standard deviation (degrees C)
Li_Pres_ave(kPa) – Licor mean pressure (kPa)
Li_Pres_sd – Licor pressure standard deviation (kPa)
CO2_ave(PPM) – Licor mean CO2 (ppm)
CO2_SD – Licor CO2 standard deviation (ppm)
O2_ave(%) –Mean Oxygen (%O2)
O2_SD –Oxygen standard deviation (%O2)
RH_ave(%) – Mean Relative Humidity (%RH)
RH_sd – Relative Humidity Standard Deviation (%RH)
RH_T_ave(C) - Mean Relative Humidity Temperature (degrees C)
Rh_T_sd - Relative Humidity Temperature standard deviation(degrees C)

Li_RawSample_ave – Licor Mean Raw1 reading
Li_RawSample_sd – Licor Raw1 reading standard deviation
Li_RawDetector_ave – Licor Mean Raw2 reading
Li_RawReference_sd - Licor Raw2 reading standard deviation

Example:

STATS: SPON , ASV1007, 2021-03-29T23:10:50Z, 20.573, 0.021, 102.904, 0.006, 503.835, 0.605, 20.984, 0.051, 43.421, 0.051, 20.194, 0.011, 5422553, 601, 5925315, 457

LOG Format (only available in Console/USB)

All mode and engineering data are returned with the "LOG:" tag. The messages are designed to be human-readable and have no specific format. They are prepended with the timestamp for diagnostic purposes.

Example:

LOG: 2019-05-22T11:24:39Z, Start ZERO PUMP ON
LOG: 2019-05-22T11:24:40Z, Start Pump 30 seconds
LOG: 2019-05-22T11:25:10Z, Sample - Real Time
LOG: 2019-05-22T11:25:11Z, Sample Data 30 seconds

DRY Format

At the end of each sample, the dry Atmospheric and Water CO2 measurements are computed and displayed to the user using the "DRY:" tag and the following format. **NOTE: If spandiff is not met, the DRY field will not be displayed.**

DRY: TS, SW_xCO2(dry), Atm_xCO2(dry)<CR><LF>

DRY: YYYY-MM-DDTHH:MM:SSZ, xxx.xxx, yyy.yyy<CR><LF>

Where:

YYYY - Four-digit year
MM - Two-digit month
DD - Two-digit day
HH - Two-digit hour (24-hour clock)
MM - Two-digit minute
SS - Two-digit seconds
xxx.xxx - Floating point Seawater pCO2 value (ppm)
yyy.yyy - Floating point Atmospheric air pCO2 value (ppm)

Example:

DRY: TS, SW_xCO2(dry), Atm_xCO2(dry)
DRY: 2019-05-21T15:13:31Z, 198.01, 253.79

REPORT Format

Sending the hotkey command “d” or the console command “report” returns the system variables. The format is as follows:

ASVCO2v2<CR><LF
serial= CCCCCCCCCCCCCCCCCCCC<CR><LF>
ver= CCCCCCCCCCCCCCCCCCCC<CR><LF>
startup= UUUUUUUUUUUUUU<CR><LF>
gps= -2<CR><LF>
time= YYYY-MM-DDTHH-MM-SSZ<CR><LF>
span= FFFF.FFFF<CR><LF>
spandiff= F.FFFF<CR><LF>
equil= UUUU<CR><LF>
warmup= UUUU<CR><LF>
pumpon= UUUU<CR><LF>
pumpoff = UUUU<CR><LF>
sampleco2= UUUU<CR><LF>
vent= UUUU<CR><LF>
heater= U<CR><LF>
sample= UUUU<CR><LF>
LI_ser = CCC-CCCC<CR><LF>
LI_ver = C.C.C<CR><LF>
LI_ccva1= F.FFFFF<CR><LF>
LI_ccva2= F.FFFFF<CR><LF>
LI_ccva3= F.FFFFF<CR><LF>
LI_ccva4= F.FFFFF<CR><LF>
runtime-= HH:MM:SS<CR><LF>
secondaryspan_calibrated_temperature= F.FFF<CR><LF>
secondaryspan_calibrated_spanconcentration= F.FF<CR><LF>
last_secondaryspan_calibration= YYYY-MM-DDTHH:MM:SSZ<CR><LF>
last_secondaryspan_temperaturedependantslope= YYYY-MM-DDTHH:MM:SSZ<CR><LF>
secondaryspan_temperaturedependantslope= F.FFFFFFFF<CR><LF>
secondaryspan_temperaturedependantslopefit= F.FFF<CR><LF>
secondaryspan_calibrated_rh= F.FF<CR><LF>
secondaryspan_calibrated_spanserialnumber= CCCCCCCCCCCCCCCCCCCCCCCC<CR><LF>
ASVCO2_secondaryspan_concentration= FFFF.FF<CR><LF>
ASVCO2_secondaryspan_serialnumber= CCCCCCCCCCCCCCCCCCCCCCCC<CR><LF>
ASVCO2_span_serialnumber= CCCCCCCCCCCCCCCCCCCCCCCC<CR><LF>
last_ASVCO2_validation= YYYY-MM-DDTHH-MM-SSZ<CR><LF>
pressure_bias= F.F<CR><LF>
last_pressure_bias_measured= YYYY-MM-DDTHH-MM-SSZ<CR><LF>
ASVCO2_ATRH_serial = CCCCCCCCCCCCCCCCCCCCCCCC<CR><LF>
ASVCO2_O2_serial= CCCCCCCCCCCCCCCCCCCCCCCC<CR><LF>
ASVCO2_manufacturer= NOAA/PMEL

Where:

ASVCO2v2 is the sensor version
serial= The sensor serial number (up to 20 characters)
ver= Firmware Version Number (up to 20 characters)
startup= Number of time system has been started (ASCII represented unsigned integer)
gps= -2 (Constant used in PMEL systems)
time= ISO-8601 Timestamp format. UTC Time.
span= Span CO2 Concentration (ppm, ASCII represented floating point)
equil= Equilibration time (seconds, ASCII represented unsigned integer)
pumpon= Pump ON time (seconds, ASCII represented unsigned integer)
pumpoff= Pump OFF time (seconds, ASCII represented unsigned integer)
sampleco2= CO2 sample time (seconds, ASCII represented unsigned integer)
vent= Sensor vent time (seconds, ASCII represented unsigned integer)
heater= Heater Set state (0=OFF, 1=ON)
sample= Licor Sampling Frequency (Hz, ASCII represented unsigned int)
LI_ser = Licor Serial Number
LI_ver = Licor Firmware Version
LI_ccva1 = Licor CO2 calibration value #1
LI_ccva1 = Licor CO2 calibration value #2
LI_ccva1 = Licor CO2 calibration value #3
LI_ccva1 = Licor CO2 calibration value #4
runtime= Estimated time for a full sample (seconds)
secondaryspan_calibrated_temperature= Temperature recorded during secondary cal (degC)
secondaryspan_calibrated_spanconcentration= CO2 Concentration used at secondary cal (ppm)
last_secondaryspan_calibration= Datetime of secondary cal
last_secondaryspan_temperaturedependantslope= Datetime of secondary span fit calc
secondaryspan_temperaturedependantslope= Slope of secondary cal temperature fit
secondaryspan_temperaturedependantslopefit= Offset of secondary cal temperature fit
secondaryspan_calibrated_rh= RH at secondary cal (%RH)
secondaryspan_calibrated_spanserialnumber= RH sensor serial number used for secondary cal
ASVCO2_secondaryspan_concentration= Secondary span conc used for calculation co2 (ppm)
ASVCO2_secondaryspan_serialnumber= Serial number of secondary span gas
ASVCO2_span_serialnumber= Serial number of span gas onboard sensor
last_ASVCO2_validation= Datetime of last validation
pressure_bias= Pressure bias of calculation
last_pressure_bias_measured= Datetime of last pressure bias measurement
ASVCO2_ATRH_serial = ATRH used Serial Number
ASVCO2_O2_serial= Onboard O2 sensor Serial Number
ASVCO2_manufacturer= NOAA/PMEL

Note:

LI_ser, LI_ver, LI_ccva1, LI_ccva2 LI_ccva3, LI_ccva4, are all directly read from the Licor on the first Licor config/power-up.

Example:

ASVCO2v2
serial= ASV2001
ver= v1.8-12-g001ac12
startup= 2
gps= -2
time= 2000-01-06T18:29:15Z
span= 500.000000
spandiff= 0.400000
equil= 600
warmup= 30
pumpon= 30
pumpoff= 15
sampleco2= 30
vent= 10
heater= 0
sample= 2
LI_ser= CGA-5180
LI_ver= 1.0.4
LI_ccva1= 0.10000
LI_ccva2= 1.80000
LI_ccva3= 0.45000
LI_ccva4= 18.00000
runtime= 00:18:30
secondaryspan_calibrated_temperature= 27.300
secondaryspan_calibrated_spanconcentration= 2102.80
last_secondaryspan_calibration= 2021-08-04T09:32:23Z
last_secondaryspan_temperaturedependantslope= 2021-08-01T17:11:32Z
secondaryspan_temperaturedependantslope= 9.10000100
secondaryspan_temperaturedependantslopefit= -3.810
secondaryspan_calibrated_rh= 47.20
secondaryspan_calibrated_spanserialnumber= CO2SP1a800
ASVCO2_secondaryspan_concentration= 2101.32
ASVCO2_secondaryspan_serialnumber= CO2SP2a210132
ASVCO2_span_serialnumber= CO2SP2a05119
last_ASVCO2_validation=
pressure_bias= 2.3
last_pressure_bias_measured= 2021-08-01T16:43:11Z
ASVCO2_ATRH_serial = RH218139aa80
ASVCO2_O2_serial = T23Aca8ad
ASVCO2_manufacturer= PMEL/EDD

SLEEP Format

SLEEP indicates the microcontroller is in low-power "sleep" mode. This is the only mode where power-off is considered safe.

COEFF Format

During the run, the ASVCO2 sensor will report the coefficients generated by the Licor and the O2 sensors in both the Console and Command ports. These coefficients are needed during the data QC process and are important for the interpretation of raw data, the ability to re-calculate xCO2 from raw counts, and should be stored with the archived data. The format of the string for the Licor is:

The coefficients are returned as follows

COEFF: Licor -
COEFF: CO2LastZero: DD MMM YYYY
COEFF: CO2kzero: f.ffffffffE+dd
COEFF: CO2LastSpan: DD MM YYYY
COEFF: CO2LastSpan2: YYYY-MM-DD
COEFF: CO2kspan: f.ffffffffE+dd
COEFF: CO2kspan2: f.ffffffffE+dd
COEFF: O2 -
COEFF: co2cal= f.fff

Where:
f.fff is a single precision float number
f.ffffffffE+dd is a double precision number in exponential format
DD is the two digit day
MM is the two digit month
YYYY is the four digit year

Example:

COEFF: Licor -
COEFF: CO2LastZero: 13 APR 2021
COEFF: CO2kzero: 1.20267850E+00
COEFF: CO2LastSpan: 06 APR 2021
COEFF: CO2LastSpan2: 2020-11-10
COEFF: CO2kspan: 5.45022040E+03
COEFF: CO2kspan2: 1.00100000E+02
COEFF: O2 -
COEFF: o2cal= 3.219

The ASVCO2's xCO2 values during the different states within a measurement run are calculated using the coefficients as detailed below. "Old" designates the coefficients stored on the licor from the last time the licor was calibrated, this will be the previous measurement run unless the system experienced a calibration error flag. The secondary span is calibrated and set in the lab before each instrument deployment.

ZPON- old zero, old span, lab secondary span
ZPON - old zero, old span , lab secondary span
ZPPOFF **- new zero**, old span , lab secondary span
SPON - new zero, old span , lab secondary span
SPOFF - new zero, old span , lab secondary span
SPPCAL- new zero**, new span** , lab secondary span

EPON - new zero, new span , lab secondary span
EPOFF - new zero, new span , lab secondary span
APON - new zero, new span , lab secondary span
APOFF - new zero, new span , lab secondary span

V. TELOS/Post-Sensing data

After a "ts" or "tsq" command is sent and the sensor completes a run, the sample data and the TELOS compliant "iridium" data are stored for future use. Only the previous run is stored; once another "ts" or "tsq" is commanded the memory is cleared.

"sdata" Format

The high frequency data (2Hz) is collected in memory during the run (ts/tsq) so that the data can be retrieved after the run using the "sdata" command. "ts" or "tsq" must be run before this data is valid. The data has the following format:

"State,TS,CO2(ppm),Li_Temp(C),Li_Pres(kPa),Li_Raw,Li_Ref,RH(%),RH_T(C),O2(%),xCO2(dry),xCO2(wet), co2kzero, co2kspan, co2kspan2, errors"

Where:

State – Current pCO2 sample mode
TS – Timestamp (Integer values in 0.5second increments)
CO2(ppm) – CO2 concentration in parts per million (ppm)
Li_Temp(C) – LICOR CO2 sensor chamber temperature in degrees C
Li_Pres(kPa) – LICOR CO2 sensor chamber pressure in kilopascals
Li_Raw – LICOR CO2 sensor raw data measurements
Li_Reference – LICOR CO2 reference data
RH(%) – Relative humidity percentage
RH_T(C) – Relative Humidity sensor temperature measurement in degrees C
O2(%) – Percentage Oxygen measured
xCO2(dry) - Calculated Atmospheric CO2 values
xCO2(wet) - Calculated Water CO2 values
co2kzero - Licor CO2 kzero coefficient
co2kspan - Licor CO2 kspan coefficient
co2kspan2 - Licor CO2 kspan2 coefficient
errors - Error Flags (string)

"idata" Format

The real-time data, or "Iridium" data is collected during the run when the STATS are computed. After a run is complete, the "idata" command can be sent to retrieve the STATS data. "ts" or "tsq" must be run before this data is valid.. The data has the following format:

"State,Li_Temp_ave(C),Li_Temp_sd,Li_Pres_ave(kPa),Li_Pres_sd,CO2_ave(PPM),CO2_SD,O2_ave(%),O2_S,RH_ave(%),RH_sd,RH_T_ave(C),Rh_T_sd,Li_RawSample_ave,Li_RawSample_sd,Li_RawDetector_ave,Li_RawReference_sd, SW_xCO2(dry),Atm_xCO2(dry),co2kzero,co2kspan,co2kspan2,eFlags"

Commented [1]: @Matthew.Casari@noaa.gov maybe we need a table at the beginning summarizing all these data output options? Do we have a preferred data option?
Assigned to Matthew Casari - NOAA Federal

Commented [2R1]: @noah.lawrence-slavas@noaa.gov I'm not following what you're asking for. What do you mean by preferred data option?
Reassigned to Noah Lawrence-Slavas - NOAA Federal

Commented [3R1]: You have added the sdata and idata commands, which behave very differently from the rest of the data formats you are talking about here. This section needs some clarification for how / when the user sees these formats, i.e. report, idata and sdata need to have commands sent to retrieve them. I believe all the other data formats are just printed to the screen after the ts command is given at various times during a measurement cycle. I think a brief headed paragraph explaining this would be very helpful for this section.

Where:

State – pCO2 sample mode
Li_Temp_ave(C) – LICOR CO2 sensor chamber temperature in degrees C (mean)
Li_Temp_sd - Standard deviation of Licor Temperature
Li_Pres_ave(kPa) - Licor Pressure measured (mean) (kPa)
Li_Pres_sd - Standard Deviation of Licor Pressure measured
CO2_ave(PPM) - CO2 concentration measured (PPM) (mean)
CO2_sd- Standard Deviation of CO2 concentration measured
O2_ave(%) - Percentage Oxygen measured (mean)
O2_sd(%) - Standard deviation of % Oxygen measured.
RH_ave(%) - Percent Relative Humidity measured (mean)
RH_sd - Standard Deviation of Relative Humidity
RH_T_ave(C) - Relative Humidity Sensor Temperature (degC) (mean)
RH_T_sd - Standard Deviation of Relative Humidity Temperature
Li_RawSample_ave - Licor Raw Sample values(mean)
Li_RawSample_sd - Standard deviation of Licor Raw Sample values
Li_RawReference_ave -Licor Raw Reference values (mean)
Li_RawReference_sd - Standard Deviation of Licor Raw Reference
SW_xCO2(dry) – pCO2 value for Seawater
Atm_xCO2(dry) – pCO2 value for Atmosphere
co2kzero - Licor CO2 kzero coefficient
co2kspan - Licor CO2 kspan coefficient
co2kspan2 - Licor CO2 kspan2 coefficient

NetCDF Template Notes

For the Netcdf template we have added a state called 'summary' to the other states (i.e. SPON,SPOFF....). The 'summary' state includes the Dry xCO2 values, the Licor calibration coefficients, the error flags, and the O2cal information for each run. Additionally the NETCDF template includes a 'none' state that is used as a filler value for when the ASVCO2 system is not running.

ERROR FLAGS Format

At the end of each run, a string containing eight (8) bit-field error code flags is printed. The format of this string is as follows:

FLAGS: [0x0001] [0x0002] [0x0004] [0x0008] [0x0010] [0x0020] [0x0040] [0x0080]

Where [0x0001], etc. correspond to the error sub-types (as documented below in the Error Format subsection). Each bit-field is represented as a hexadecimal value. The flag is the bit-wise **OR** of the errors within the sub-type. For example, a string:

FLAGS: 0000 0000 0400 0000 0000 0000 0201 0000

Would show errors in the 3rd and 7th flags.

A breakdown of these errors would be:

[0x0001][0x0000] - PCO2 General Errors: NONE
[0x0002][0x0000] - PCO2 Zero Errors: NONE
[0x0004][**0x0400**] - PCO2 Span Errors: ***PCO2 Span Diff Not Met – Span Cal Skipped***
[0x0008][0x0000] - PCO2 Span2 Errors: NONE
[0x0010][0x0000] - PCO2 Equilibration & Air Errors: NONE
[0x0020][0x0000] - RTC Errors: NONE
[0x0040][**0x0201**] - Flow Controller, RH & O2 Errors: ***RH I2C Failure + FLOW Failed to Init***
[0x0080][0x0000] - Licor Errors: NONE

The 3rd flag corresponds to the PCO2 Span errors. In this case, 0400 is the "Span Diff Not Met – Span Cal Skipped " error, which indicates that the pressure in the Licor was not sufficiently high enough to allow Span calibration.

The 7th flag was 0201. The 7th flag, or the 0x0040 sub-types (Flow Control, RH & O2 errors) shows a compound error of 0x0200 | 0x0001 (OR'ed). When split, 0x0200 is a RH I2C Failure and 0x0001 is FLOW Failed to Init. This would indicate a RH connection error, typically when the RH sensor is not attached to the pCO2 sensor, and a Flow initialization error typical of when the Flow Control is not electrically attached to the pCO2 board.

ERROR CODE Format

Any errors that occur during a system run will be displayed as follows:

ERR: [ERROR_CODE] [ERROR_DESCRIPTION]

The ERROR_CODE is broken down as follows:

[ERROR_CODE] = [ERROR_SUBCLASS][ERROR_VALUE]

Where:

ERROR_SUBCLASS and ERROR_VALUE are two 16-bit value in hexadecimal form, concatenated together.

The following is a list sub-classes of errors (First 4 hexadecimal digits in error code):

[0x0001] – PCO2 General Errors
[0x0002] – PCO2 Zero Errors
[0x0004] – PCO2 Span Errors
[0x0008] – PCO2 Span2 Errors
[0x0010] – PCO2 Equilibration & Air Errors
[0x0020] – RTC Errors
[0x0040] – Flow Controller, RH & O2 Errors
[0x0080] – Licor Errors

A list of all errors values (last 4 hexadecimal digits) follow in the next section.

EXAMPLE:

The following message would indicate that the Li-COR NDIR Sensor failed during an attempt to calibrate the sensor with the Span gas:

ERR: 00040040 PCO2 Span Failed

This would be broken down as:

ERROR_SUBCLASS = 0x0001
ERROR_VALUE = 0x0040

So the subclass fall under PCO2 General Errors, and the Error Value indicates PCO2 Span Fail

ERROR Codes

PCO2 General Errors (0x0001)

(**XXXX** 0000 0000 0000 0000 0000 0000 0000)

CODE	Error String	Description
0001**0001**	00010001 PCO2 Licor Init Fail	Error starting the Li-8x0 Sensor
0001**0002**	00010002 PCO2 Flow Init Fail	Error starting the Flow Control Module
0001**0004**	00010004 PCO2 RH Init Fail	Error starting the Relative Humidity Sensor
0001**0008**	00010008PCO2 DL Init Fail	N/A
0001**0010**	00010010 PCO2 Config Fail	PCO2 Sensor Configuration Error
0001**0020**	00010020 PCO2 Zero Fail	PCO2 Sensor Failure During Zero state
0001**0040**	00010040 PCO2 Span Fail	PCO2 Sensor Failure During SPAN state
0001**0080**	00010080 PCO2 Span2 Fail	PCO2 Sensor Failure During SPAN2 state
0001**0100**	00010100 PCO2 Equil Fail	PCO2 Sensor Failure during Equilibration state
0001**0200**	00010200 PCO2 Air Fail	PCO2 Sensor failure during Atmospheric air sampling state
0001**0400**	00010400 PCO2 Rest Fail	PCO2 Sensor failure to enter rest state
0001**0800**	00010800PCO2 Deploy Fail	PCO2 Sensor failure to enter deploy state.
0001**1000**	00011000 PCO2 Flow REST Fail	PCO2 Flow Control Module failure to enter rest mode
0001**2000**	00012000 PCO2 Flow DPLY Fail	PCO2 Flow Control Module failure to enter deploy mode
0001**4000**	00014000 PCO2 Invalid Mode	PCO2 Invalid state/mode commanded

PCO2 Zero Errors (0x0002)

(0000 **XXXX** 0000 0000 0000 0000 0000 0000)

CODE	Error String	Description
0002**0001**	00020001 PCO2 Licor Zero Fail	Error zeroing the Li-8x0 Sensor
0002**0002**	00020002PCO2 Zero Flow	PCO2 Failure to set Zero flow with pump on in flow

	ZERO_ON Fail	controller
0002**0004**	00020004 PCO2 Zero SAMPLE 1 Fail	PCO2 failure to read sample from Licor for Zero setting
0002**0008**	00020008 PCO2 Zero Flow ZERO_OFF Fail	PCO2 Failure to set Zero flow with pump off in flow controller
0002**0010**	00020010 PCO2 Zero Flow PRECAL Fail	PCO2 Failure to set pre-calibration mode for zero in flow controller
0002**0020**	00020020 PCO2 Zero SAMPLE 2 Fail	PCO2 failure to sample pre-calibration
0002**0040**	00020040 PCO2 Zero CAL Fail	PCO2 failure to calibrate Licor
0002**0080**	00020080 PCO2 Zero Flow POSTCAL Fail	PCO2 failure to set post calibration mode
0002**0100**	00020100 PCO2 Zero SAMPLE 3 Fail	PCO2 failure to sample post zero calibration

PCO2 Span Errors (0x0004)

(0000 0000 **XXXX** 0000 0000 0000 0000 0000)

CODE	Error String	Description
0004**0001**	00040001 PCO2 Licor Span Fail	Error Spanning the Li-8x0 Sensor
0004**0002**	00040002 PCO2 Span Flow SPAN_ON Fail	PCO2 failure to set span mode with open flow from gas canister
0004**0004**	00040004 PCO2 Span SAMPLE 1 Fail	PCO2 failure to sample with flow open during span
0004**0008**	00040008 PCO2 Span Flow SPAN_OFF Fail	PCO2 failure to close flow from canister during span
0004**0010**	00040010 PCO2 Span Flow PRECAL Fail	PCO2 failure to set pre-calibration mode (vent)
0004**0020**	00040020 PCO2 Span SAMPLE 2 Fail	PCO2 failure to sample during pre-calibration during span
0004**0080**	00040080 PCO2 Span CAL Fail	PCO2 failure to calibrate Licor SPAN
0004**0100**	00040100 PCO2 Span Flow POSTCAL Fail	PCO2 failure to set post-calibration mode for SPAN
0004**0200**	00040200 PCO2 Span SAMPLE 3 Fail	PCO2 failure to sample after calibration for span
0004**0400**	00040400 PCO2 Span Diff Not Met – Span Cal Skipped	The differential pressure (spandiff) was not exceeded (indicating that the span cylinder is likely empty), and the Span calibration was skipped.

PCO2 Span2 Errors (0x0008)

(0000 0000 0000 **XXXX** 0000 0000 0000 0000)

CODE	Error String	Description
0008**0001**	00080001 PCO2 Licor Secondary Span Fail	N/A (Future Use)
0008**0002**	00080002 PCO2 Secondary Span Flow SPAN_ON Fail	N/A (Future Use)
0008**0004**	00080004 PCO2 Secondary Span SAMPLE 1 Fail	N/A (Future Use)
0008**0008**	00080008 PCO2 Secondary Span Flow SPAN_OFF Fail	N/A (Future Use)
0008**0010**	00080010 PCO2 Secondary Span Flow PRECAL Fail	N/A (Future Use)
0008**0020**	00080020 PCO2 Secondary Span SAMPLE 2 Fail	N/A (Future Use)
0008**0040**	00080040 PCO2 Secondary Span CAL Fail	N/A (Future Use)
0008**0080**	00080080 PCO2 Secondary Span Flow POSTCAL Fail	N/A (Future Use)
0008**0100**	00080100 PCO2 Secondary Span SAMPLE 3 Fail	N/A (Future Use)

PCO2 Equilibrate & Air Errors (0x0010)

(0000 0000 0000 0000 **XXXX** 0000 0000 0000)

CODE	Error String	Description
0010**0002**	00100002 PCO2 Equil Flow EQUIL_ON Fail	PCO2 failure to set equilibration mode with pump on
0010**0004**	00100004 PCO2 Equil SAMPLE 1 Fail	PCO2 failure to sample during equilibration mode
0010**0008**	00100008 PCO2 Equil Flow EQUIL_OFF 1 Fail	PCO2 failure to shut pump and valves during equilibration mode
0010**0010**	00100010 PCO2 Equil Flow VENT Fail	PCO2 failure to set vent state during equilibration
0010**0020**	00100020 PCO2 Equil Flow EQUIL_OFF 2 Fail	PCO2 failure to shut pump during equilibration mode
0010**0040**	00100040 PCO2 Equil SAMPLE 2 Fail	PCO2 failure to sample during equilibration while vented
0010**0200**	00100200 PCO2 Air Flow EQUIL_ON Fail	PCO2 failure to set atmospheric air pump mode
0010**0400**	00100400 PCO2 Air SAMPLE 1 Fail	PCO2 failure to sample during atmospheric pumping
0010**0800**	00100800 PCO2 Air Flow AIR_OFF 1 Fail	PCO2 failure to
0010**1000**	00101000 PCO2 Air Flow VENT Fail	PCO2 failure to vent during air mode
0010**2000**	00102000 PCO2 Air Flow AIR_OFF Fail	PCO2 failure to turn pump off during air mode
0010**4000**	00104000 PCO2 Air SAMPLE 2 Fail	PCO2 failure to sample while vented during air mode

RTC Errors (0x0020)

(0000 0000 0000 0000 0000 **XXXX** 0000 0000)

CODE	Error String	Description
0020**0002**	00200002 RTC Alarm Before Current Time	Alarm is set for before the actual current time

0020**0004**	00200004 RTC Alarm After Current Alarm	Alarm is set for before the expected alarm
0020**0008**	00200008 RTC Alarm Repeat = 0	N/A
0020**0010**	00200010 RTC Invalid Month	Month is outside of 1-12
0020**0020**	00200020 RTC SQW Invalid Pin	Invalid pin to set square wave for RTC on
0020**0040**	00200040RTC Alarm Invalid Pin	Invalid pin to set alarm pin
0020**0080**	00200080 RTC Msg Too Long	Message too long for RTC transmission
0020**0100**	00200100 RTC Msg Length > Buffer	Message length is longer than buffered data
0020**0200**	00200200 RTC Msg Length Too Short	Message length is shorter than buffered data
0020**0400**	00200400 RTC I2C Transmission Error	I2C transmission error between microcontroller and RTC
0020**0800**	00200800 RTC I2C Receive Error	I2C receive error between microcontroller and RTC
0020**1000**	00201000 RTC I2C Hang	I2C is inoperable

Flow Controller, RH & O2 Errors (0x0040)

(0000 0000 0000 0000 0000 0000 **XXXX** 0000)

CODE	Error String	Description
0040**0001**	00400001 FLOW Failed to Init	Failed to Initialize the Flow Controller
0040**0002**	00400002 FLOW Failed on Startup	Flow controller failed on startup
0040**0004**	00400004 FLOW Invalid Flow State	Invalid command state for flow controller
0040**0008**	00400008 FLOW Mode Set Failure	Failure to set mode in flow controller
0040**0010**	00400010 FLOW Message NACK	NACK received from flow controller

0040**0020**	00400020 FLOW Message Not Sent	Failed to send message to flow controller
0040**0040**	00400040 FLOW Mode Not Received	Timeout after sending message to flow controller
0040**0100**	00400100 RH Sensor Error	N/A
0040**0200**	00400200 RH I2C Failure	RH Sensor I2C fail to connect
0040**1000**	00401000 O2 Sensor Failure	N/A

Licor Errors (0x0080)

CODE	Error String	Description
0080**0002**	00800002 Invalid Sensor Type	Invalid Licor type specified
0080**0004**	00800004 Invalid XML Parent Tag	Failure generating Licor XML parent tag
0080**0008**	00800008 Invalid XML Child Tag	Failure generating Licor XML child tag
0080**0010**	00800010 Invalid XML LVL3 Tag	Failure generating Licor XML level 3 tag
0080**0020**	00800020 Invalid XML Combo	Failure generating Licor XML combination
0080**0040**	00800040 Invalid XML Level 1	Failure validating Licor XML Level 1 tag
0080**0080**	00800080 Invalid XML Level 2	Failure validating Licor XML Level 2 tag
0080**0100**	00800100 Invalid XML Level 3	Failure validating Licor XML Level 3 tag
0080**0200**	00800200 Invalid XML Level 4	Failure validating Licor XML Level 4 tag
0080**0400**	N/A	N/A
0080**0800**	N/A	N/A
0080**1000**	N/A	N/A

Appendix A

Acronyms

ADC - Analog-to-digital Converter

ASVCO2 – Autonomous Surface Vehicle Carbon Dioxide [Sensor]

CO2 – Carbon Dioxide

GPS – Global Positioning System

H20 – Water

ISO-8601- Date Time standard [https://en.wikipedia.org/wiki/ISO_8601]

kPa – kilo-pascals

LPM – Low Power Mode

mA – milli-amp

M2M - Machine to Machine

MBARI – Monterey Bay Aquarium Research Institute

NOAA - National Oceanic and Atmospheric Administration

O2 - Oxygen

PCB - Printed Circuit Board

pCO2 – Partial pressure of Carbon Dioxide

PMEL - Pacific Marine Environmental Laboratory

ppm – Parts per million (equivalent to µmol mol^{-1})

RH – Relative Humidity

RTC - Real-time Clock

Span – Calibration of CO2 sensor with precision WMO certified CO2 concentration sample

uA – micro-amp

VDC – Volts Direct Current

XML – Extensible Markup Language

WMO – World Meteorological Organization

Zero – Calibration of CO2 sensor with known concentration of ~0.0µmol mol-1

Appendix B

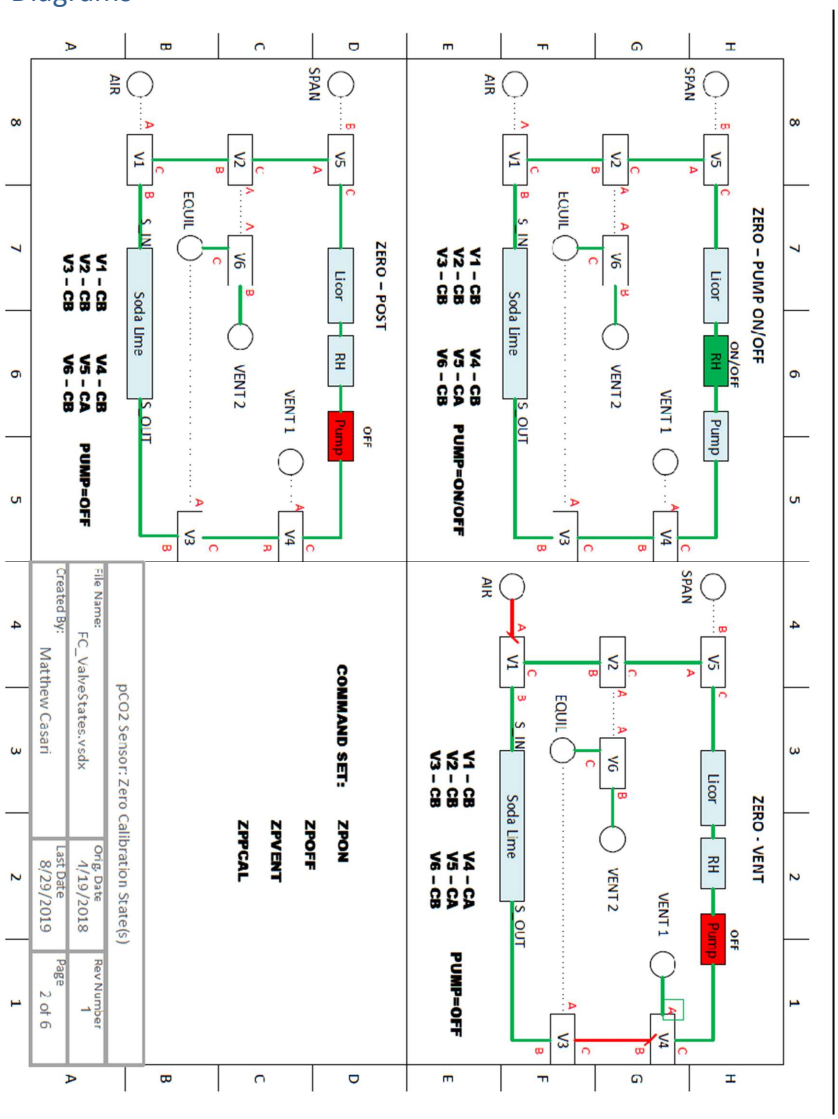
Li-Cor Configuration

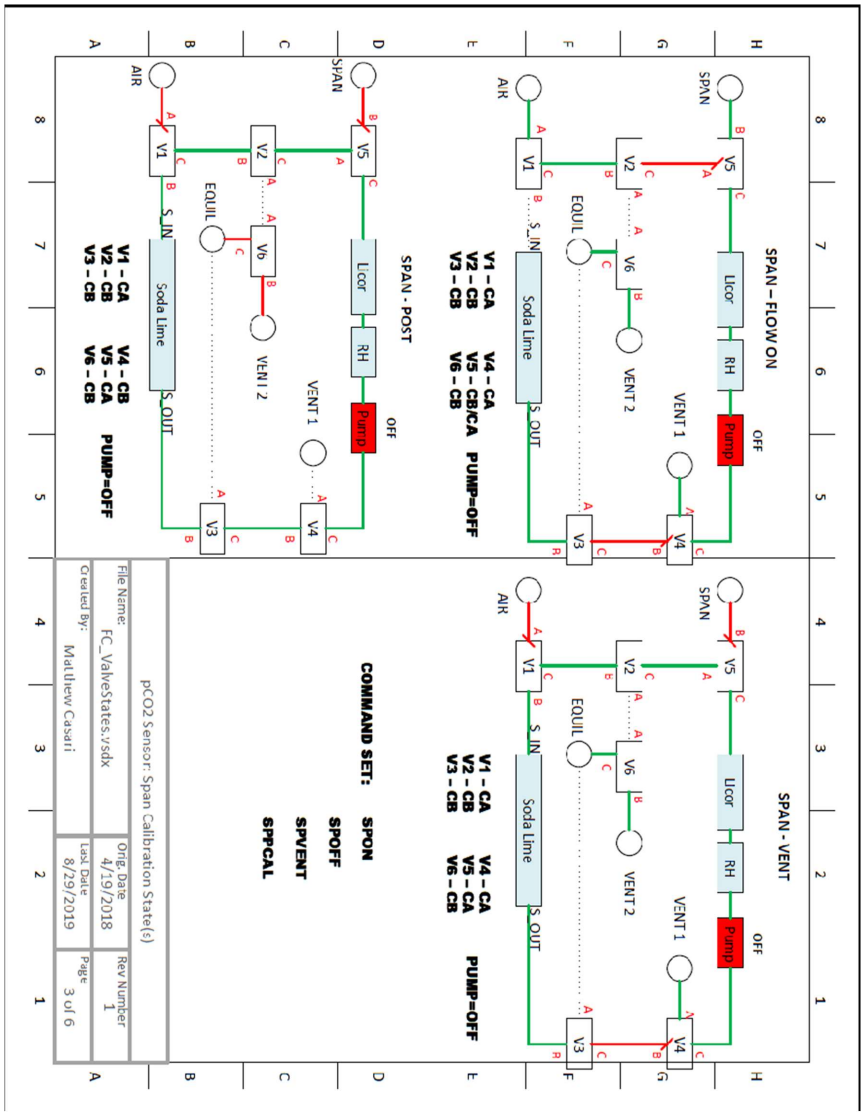
The following is the list of the Li-Cor configurations set prior to a sample. All have a root of li830.

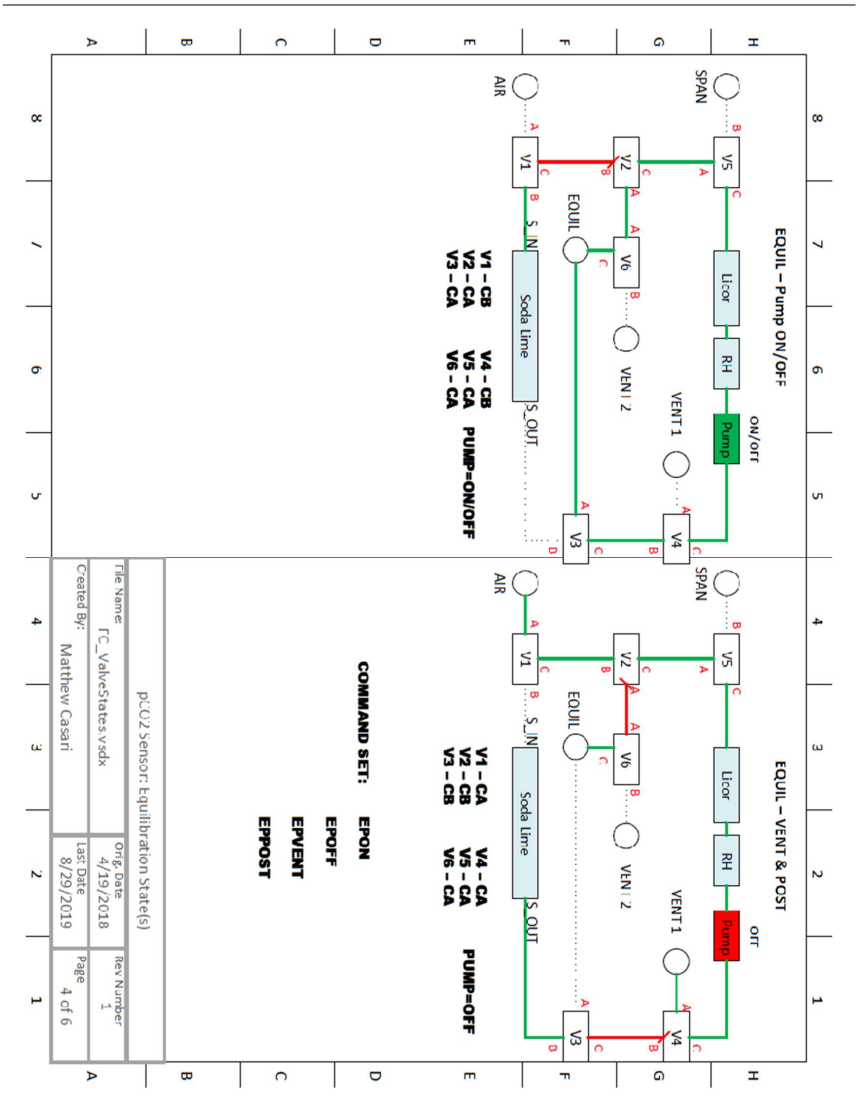
Parent	Child	Value	XML
rs232	co2	true	<li830><rs232><co2>true</co2></rs232></li830>
rs232	co2abs	true	<li830><rs232><co2abs>true</co2abs></rs232></li830>
rs232	celltemp	true	<li830><rs232><celltemp>true</celltemp></rs232></li830>
rs232	cellpres	true	<li830><rs232><cellpres>true</cellpres></rs232></li830>
rs232	ivolt	true	<li830><rs232><ivolt>true</ivolt></rs232></li830>
rs232	echo	false	<li830><rs232><echo>echo</echo></rs232></li830>
rs232	strip	false	<li830><rs232><strip>false</strip></rs232></li830>
rs232	flowrate	false	<li830><rs232><flowrate>false</flowrate></rs232></li830>
rs232	raw	true	<li830><rs232><raw>true</raw></rs232></li830>
cfg	outrate	0.0	<li830><cfg><outrate>0.0</outrate></cfg></li830>
cfg	heater	false	<li830><cfg><heater>false</heater></cfg></li830>
cfg	pcomp	true	<li830><cfg><pcomp>true</pcomp></cfg></li830>
cfg	filter	0.0	<li830><cfg><filter>0.0</filter></cfg></li830>
cfg	bench	14	<li830><cfg><bench>14</bench></cfg></li830>
cfg	alarms	false	<li830><cfg><alarms>false</alarms></cfg></li830>
cfg	span	0.0	<li830><cfg>0.0</cfg></li830>

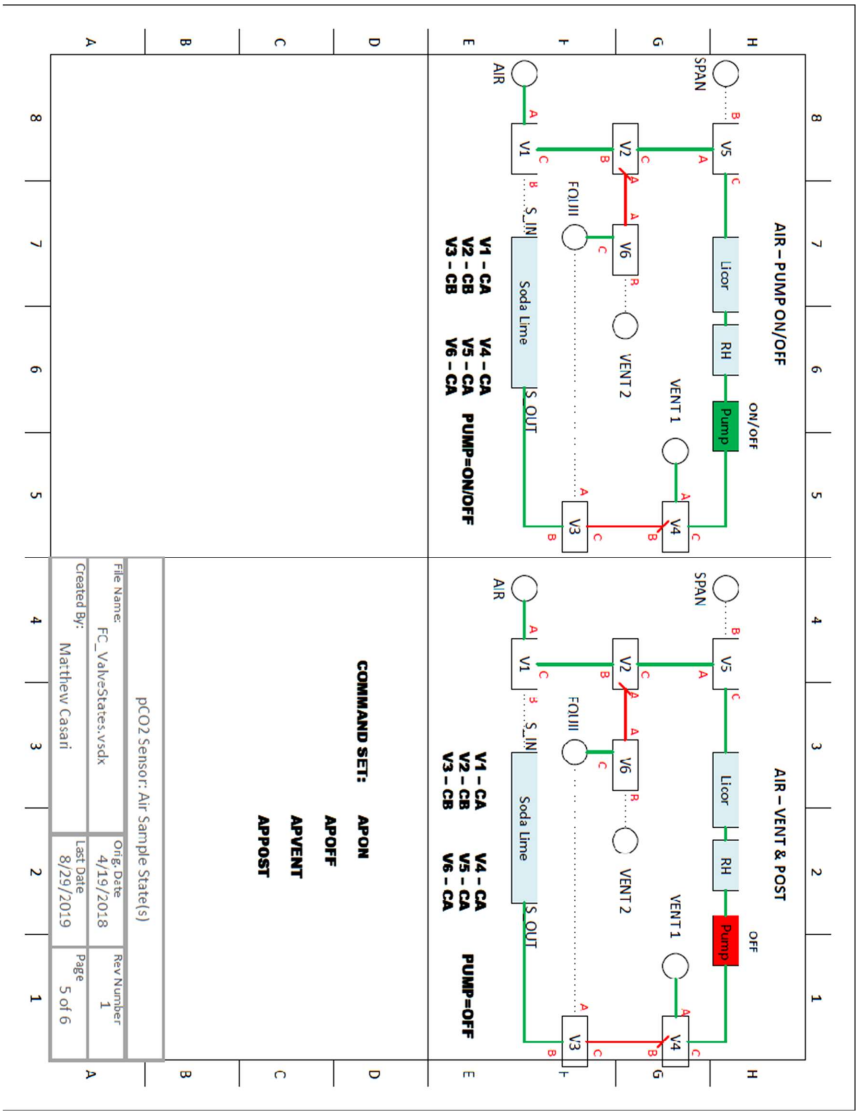
Appendix C

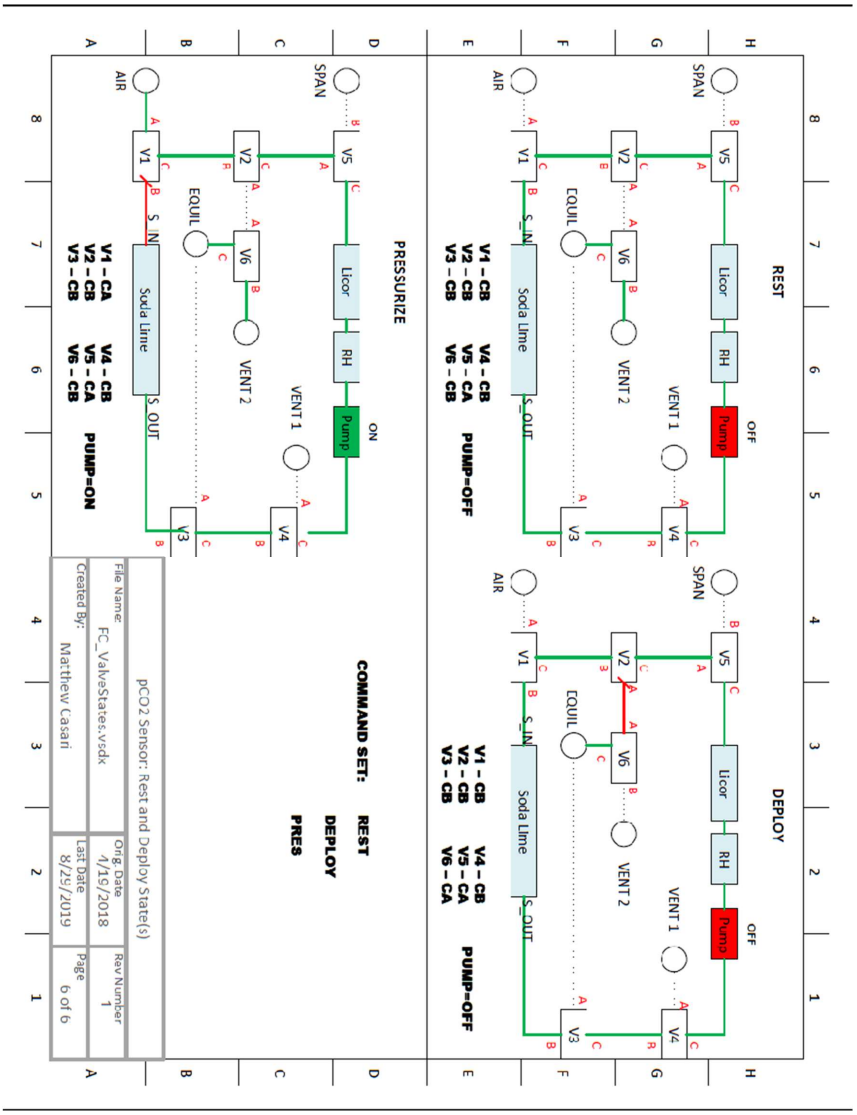
Flow Diagrams




SPAN – FLOW ON
SPAN
AIR
V5
V2
V1
V6
V4
V3
Licor
RH
Pump
Soda Lime
VENT 1
VENT 2
EQUIL
S_IN
S_OUT
OFF
V1 – CA
V2 – CB
V3 – CB
V4 – CA
V5 – CB/CA
V6 – CB
PUMP=OFF
SPAN - VENT
SPAN - POST
COMMAND SET:
SPON
SPOFF
SPVENT
SPPCAL
pCO2 Sensor: Span Calibration State(s)
File Name:
FC_ValveStates.vsdx
Org. Date
4/19/2018
Rev Number
1
Created By:
Mat Urew Casari
Last Date
8/29/2019
Page
3 of 6


EQUIL – Pump ON/OFF
ON/off
SPAN
AIR
EQUIL
VENT 1
VENT 2
Licor
RH
Pump
Soda Lime
S_IN
S_OUT
V1
V2
V3
V4
V5
V6
V1 – CB
V2 – CA
V3 – CA
V4 – CB
V5 – CA
V6 – CA
PUMP=ON/OFF
EQUIL – VENT & POST
OFF
V1 – CA
V2 – CB
V3 – CB
V4 – CA
V5 – CA
V6 – CA
PUMP=OFF
COMMAND SET:
EPON
EPOFF
EPVENT
EPPOST
pCO2 Sensor: Equilibration State(s)
File Name:
FC_ValveStates.vsdx
Org. Date
4/19/2018
Rev Number
1
Created By:
Matthew Casari
Last Date
8/29/2019
Page
4 of 6


AIR – PUMP ON/OFF
AIR – VENT & POST
SPAN
AIR
Licor
RH
Pump
ON/OFF
OFF
VENT 1
VENT 2
FOUT
Soda Lime
S_IN
S_OUT
V1
V2
V3
V4
V5
V6
V1 – CA
V2 – CB
V3 – CB
V4 – CA
V5 – CA
V6 – CA
PUMP=ON/OFF
PUMP=OFF
COMMAND SET:
APON
APOFF
APVENT
APPOST
pCO2 Sensor Air Sample State(s)
File Name:
FC_ValveStates.vsdx
Orig. Date
4/19/2018
Rev Number
1
Created By:
Matthew Casari
Last Date
8/29/2019
Page
5 of 6


REST
OFF
SPAN
Licor
RH
Pump
VENT 1
VENT 2
EQUIL
Soda Lime
S_IN
S_OUT
AIR
V1
V2
V3
V4
V5
V6
DEPLOY
V1 – CB
V2 – CB
V3 – CB
V4 – CB
V5 – CA
V6 – CA
PUMP=OFF
PRESSURIZE
ON
COMMAND SET:
REST
DEPLOY
PRES
V1 – CA
V2 – CB
V3 – CB
V4 – CB
V5 – CA
V6 – CB
PUMP=ON
pCO2 Sensor: Rest and Deploy State(s)
File Name:
FC_ValveStates.vsdx
Org. Date
1/19/2018
Rev Number
1
Created By:
Matthew Casari
Last Date
8/25/2019
Page
6 of 6