SSSG Flowmeter

T. Thiel – 2017-12-15

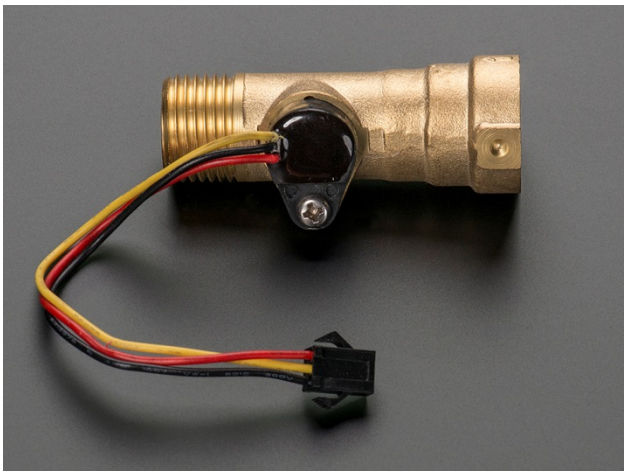
Introduction

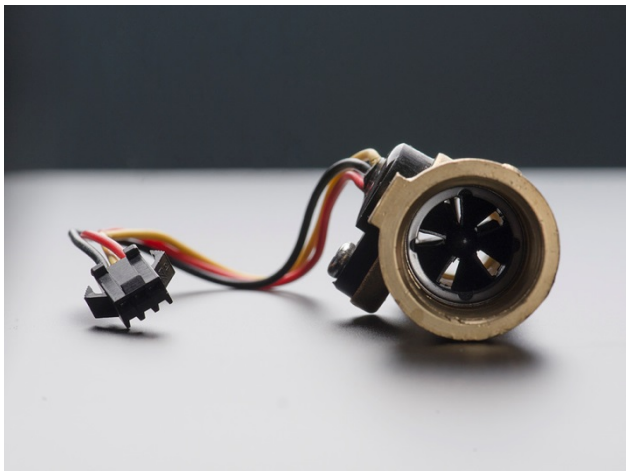
This manual will document the operation of the SSSG Flowmeter system.

System Architecture

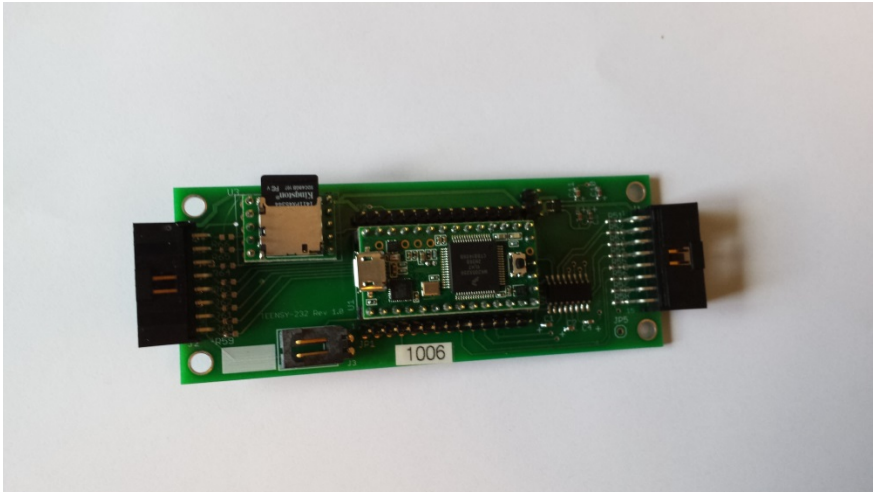
The flowmeter system uses a Hall Effect sensor. The sensor contains a mechanism (either a paddle wheel or propeller) with small magnets integrated into the moving mechanism. When the system is powered a logic-level pulse is generated each time one of these magnets passes the sensor. A microcontroller is used to detect and count the generated pulses and use the pulse rate to compute the rate of flow for the liquid passing through the sensor.

Initial implementation is based upon a sensor from Adafruit.





The microcontroller board is shown here:



Flowmeter Data

The microcontroller provides a serial data stream indicating the current flow rate along with indications of the averaged flow rate over the previous minute, hour, and 24-hour period. The data is transmitted at 9600 baud at RS232 levels. The data format is as follows:

$FLOWRATE, CC, CCCC, SSS.S, MMM.M, HHH.H, DDD.D, TTT.TTT<CR><LF>

- **CC** – The most recent count of pulses over a second long interval.
- **CCCC** – The cumulative count of pulses. This number will eventually rollover. It is primarily for use in debugging and calibration.
- **SSS.S** – The current rate of flow in mL/second.
- **MMM.M** – The rate of flow in mL/second averaged over the previous minute.
    - During the first minute after a restart the **MMM.M** value will be the average of the **SSS.S** values that have been measured since system startup.
- **HHH.H** – The rate of flow in mL/second averaged over the previous hour.
    - During the first hour after a restart the **HHH.H** value will be the average of the **MMM.M** values that have been measured since system startup.
    - During the first minute after a restart the **HHH.H** value will be set to the current **MMM.M** value.
- **DDD.D** – The rate of flow in mL/second averaged over the previous 24 hours.
    - During the first 24 hours after a restart the **DDD.D** value will be the average of the **HHH.H** values that have been measured since system startup.
    - During the first hour after a restart the **DDD.D** value will be set to the current **HHH.H** value.
- **TTT.TTT** – The elapsed time in seconds since start of program execution. Primarily for use in debugging and calibration.

A small sample of serial output is shown below.

```
$FLOWRATE, 29, 278, 71.3, 75.9, 75.9, 75.9, 9.000<CR><LF>
$FLOWRATE, 150, 428, 368.6, 105.2, 105.2, 105.2, 10.000<CR><LF>
$FLOWRATE, 60, 488, 147.4, 109.0, 109.0, 109.0, 11.000<CR><LF>
$FLOWRATE, 103, 591, 253.1, 121.0, 121.0, 121.0, 12.000<CR><LF>
$FLOWRATE, 73, 664, 179.4, 125.5, 125.5, 125.5, 13.000<CR><LF>
```

In a few instances on the R/V Armstrong in August and September of 2016 the pulse count (CC) was reported as a large negative number. To prevent these erroneous readings from throwing off the averaged values some gating logic was added to the processing of the readings by the microcontroller. If a reading of the flow sensor that is either negative or greater than 10,000 is encountered then the microcontroller will use the most recent valid value to compute the current flow rate and to maintain the averaged readings. In these cases the header string for the message is changed from "**$FLOWRATE**" to "**$BADFLOW**". The CC value reported will be the actual number returned when reading the sensor. The cumulative count of pulses (CCCC) will be updated using the most recent valid value.

dsLogCSV

Parsing rules associated with the flowmeter data have been developed for use in dsLogCSV. Each of the data fields is parseable using the following dsLogCSV rules:

- FLOW_RAW_COUNTS
- FLOW_CUMULATIVE_COUNTS
- FLOW_LAST_SECOND
- FLOW_LAST_ MINUTE
- FLOW_LAST_ HOUR
- FLOW_LAST_24HOURS
- FLOW_ELAPSED_SECONDS

System Commands

Each individual sensor unit must be calibrated in order to obtain accurate values of flow. The calibration process is discussed later in the document. There are only two user commands available to the user. Both are related to the calibration process.

- **CLEAR** Command
  - Syntax: "**CLEAR<LF>**"
  - <LF> is the linefeed character.
  - The "**CLEAR**" command zeroes out the cumulative counts field in the "FLOWRATE" message which is output each second.
- **SETCPL** Command
  - Syntax: "**SETCPL nnn<LF>**"
  - Example "**SETCPL 457<LF>**", will set the Counts per liter value to 457.
  - <LF> is the linefeed character.
  - This command sets the calibration constant used to convert raw counts to mL/second.
  - It is stored in flash memory. So, it only needs to be set if a new sensor is installed.
  - After entering a new value, power-cycle the board and verify the correct value is being used.

Startup serial traffic

At system startup the microcontroller will transmit some serial data including the following information:

- Board ID
- Board Revision
- Board Serial Number
- Firmware ID
- Firmware Version
- Date and time that Firmware was loaded onto Board
- The calibration value in "counts per liter" used to convert pulse counts to flow rates.

Here is the startup communications from the unit with S/N 1101:

```
**********************************************************************<CR><LF>
FLOWMETER - Rev. 0.006 - Built at Dec 12 2017 16:03:10 <CR><LF>
BoardId: TEENSY-232 - Rev. 1.1 - S/N 1101 <CR><LF>
<LF>
------------------------------------------------------<CR><LF>
CFG settingsVersion = 1<CR><LF>
CFG countsPerLiter = 407<CR><LF>
------------------------------------------------------<CR><LF>
<CR><LF>
$FLOWRATE, 0, 0, 0.0, 0.0, 0.0, 0.0, 1.000<CR><LF>
```

Calibration

To operate with maximum precision the sensor must be calibrated. The purpose of the calibration process is to determine the number of pulses generated by the Hall Effect sensor when a liter of fluid is passed through it. For the initial system deployment the calibration was performed in a simple manner. A known volume of water was passed through the system while accumulating a pulse count. Several iterations were performed for each sensor using a water bottle with one gallon capacity.

A preferred approach would be to pump water through the target device and then have a laboratory grade sensor which the same stream could pass through. By observing the measured flows through both systems, a quality calibration could be achieved.

The initial calibration for units A, B, C, and D was performed at WHOI's Environmental Systems Laboratory on 2015-10-13. Units E, F, G, and H were calibrated on 2016-09-21 in the Wet Lab on R/V Armstrong. Detailed calibration data is in the Appendices.

Here is a summary of the flow sensors available.

UNIT ID	Material	Cable Length	Connector	Calibration Value
A	Brass	36-inches	Mini-CPC	440
B	Brass	36-inches	Mini-CPC	457
C	Brass	4-inches	C-Grid	477
D	Brass	5-inches	C-Grid	456
E	Brass	36-inches	Mini-CPC	424
F	Brass	36-inches	Mini-CPC	440
G	Brass	36-inches	Mini-CPC	431
H	Brass	36-inches	Mini-CPC	424
J	Brass	36-inches	Mini-CPC	407
K	Brass	36-inches	Mini-CPC	427
M	Brass	36-inches	Mini-CPC	407

Electrical Specifications

- Supply voltage from 3 VDC to 24 VDC
- Serial data at 9600 baud.

Plumbing Issues

The brass flowmeter has an unusual fitting arrangement. The output end is a male 1/2inch BSPP (British Standard Parallel Pipe) fitting.

Here are links to adaptors.

- McMaster #4092K53 is the recommended adaptor.
- Other possibilities (not confirmed to work):
  - http://www.coleparmer.com/Category/British_Standard_Pipe_Tapered_Threaded_BSPT_Adapters/1473
  - http://www.coleparmer.com/Product/Threaded_adapter_stainless_steel_1_2_female_BSPP_to_1_2_male_NPT/EW-31830-73

Flow Sensor Specifications

https://www.adafruit.com/products/833

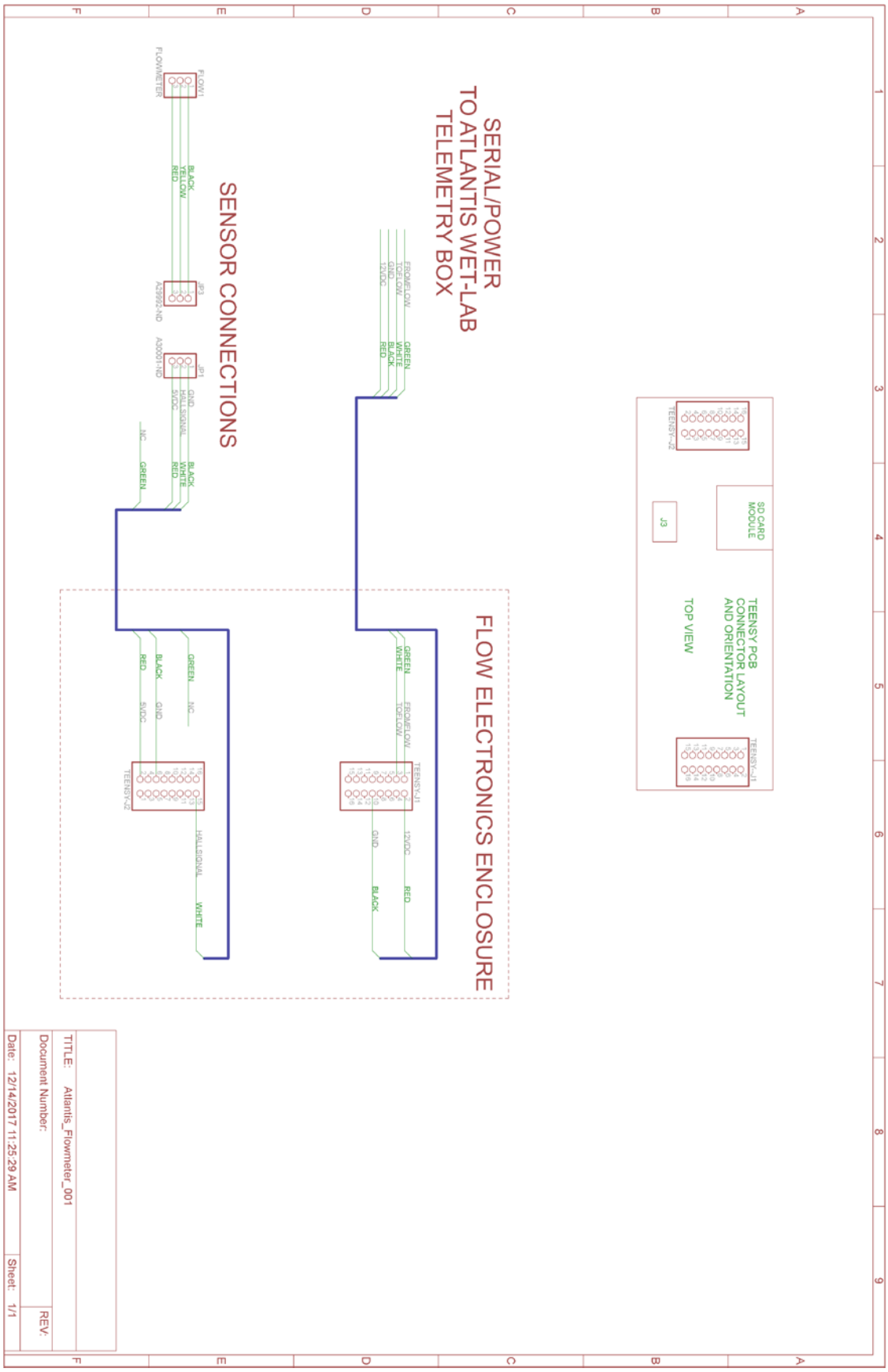
Electrical:

- Working Voltage: 5 to 18VDC
- Max current draw: 15mA @ 5V
- Output duty cycle: 50% +-10%
- Output rise time: 0.04us
- Output fall time: 0.18us
- Flow rate pulse characteristics: Frequency (Hz) = 8.1 * Flow rate (L/min) - 3
- Pulses per Liter: 485
- Durability: minimum 300,000 cycles

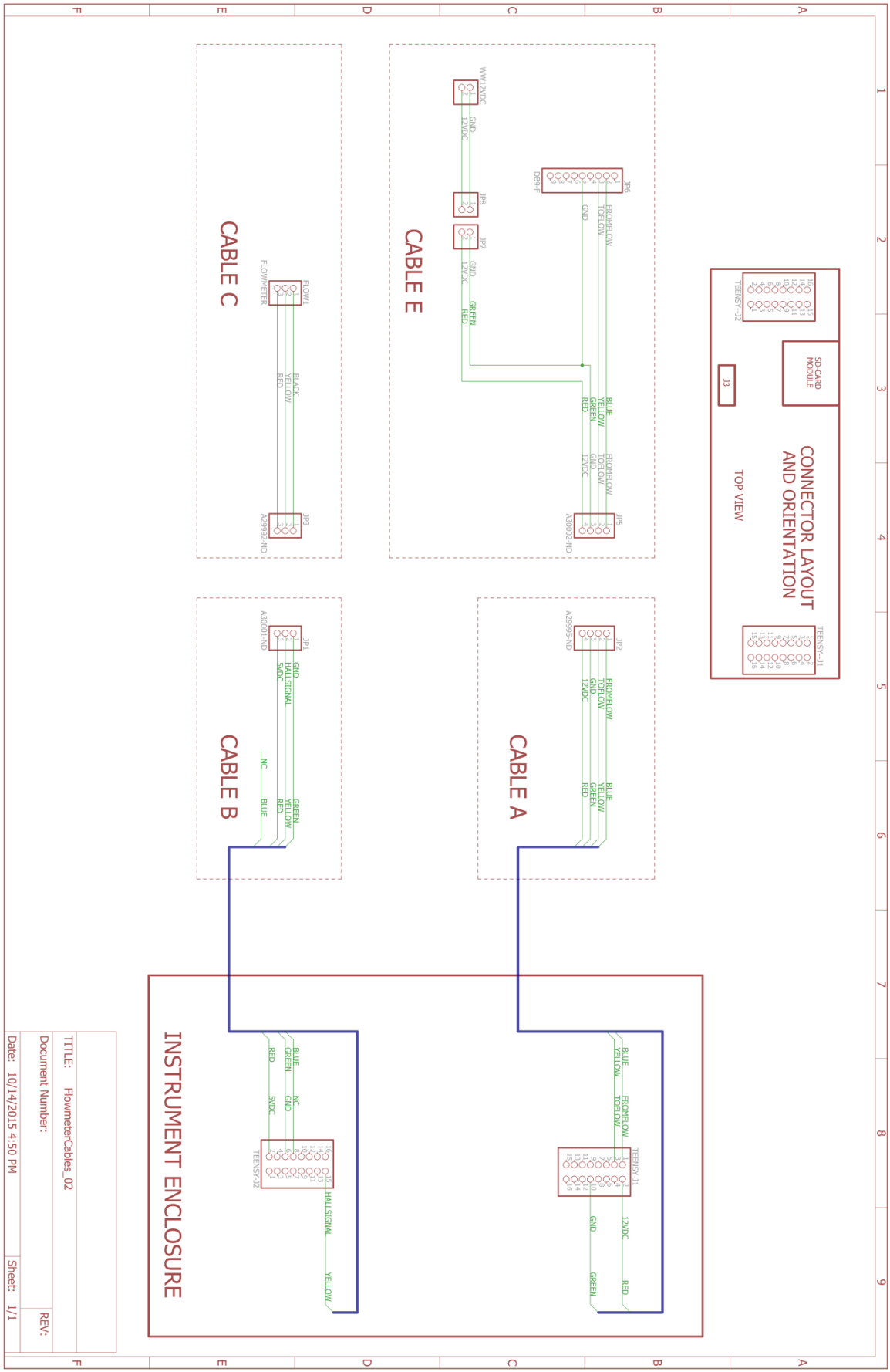
Mechanical:

- Working Flow Rate: 1 to 30 Liters/Minute
- Working Temperature range: -20°C to 80°C
- Working Humidity Range: 35%-80% RH
- Maximum water pressure: 1.75 MPa
- 1/2" nominal pipe connections, non-tapered, 0.78" outer diameter, 1/2" of thread
- The input of the flow meter is 1/2" NPT aka National Pipe Thread (tapered).
- The output of the flow meter is 1/2" BSPP aka British Standard Parallel Pipe (non-tapered).
- Size: 2.65" x 1.0" x 1.4"

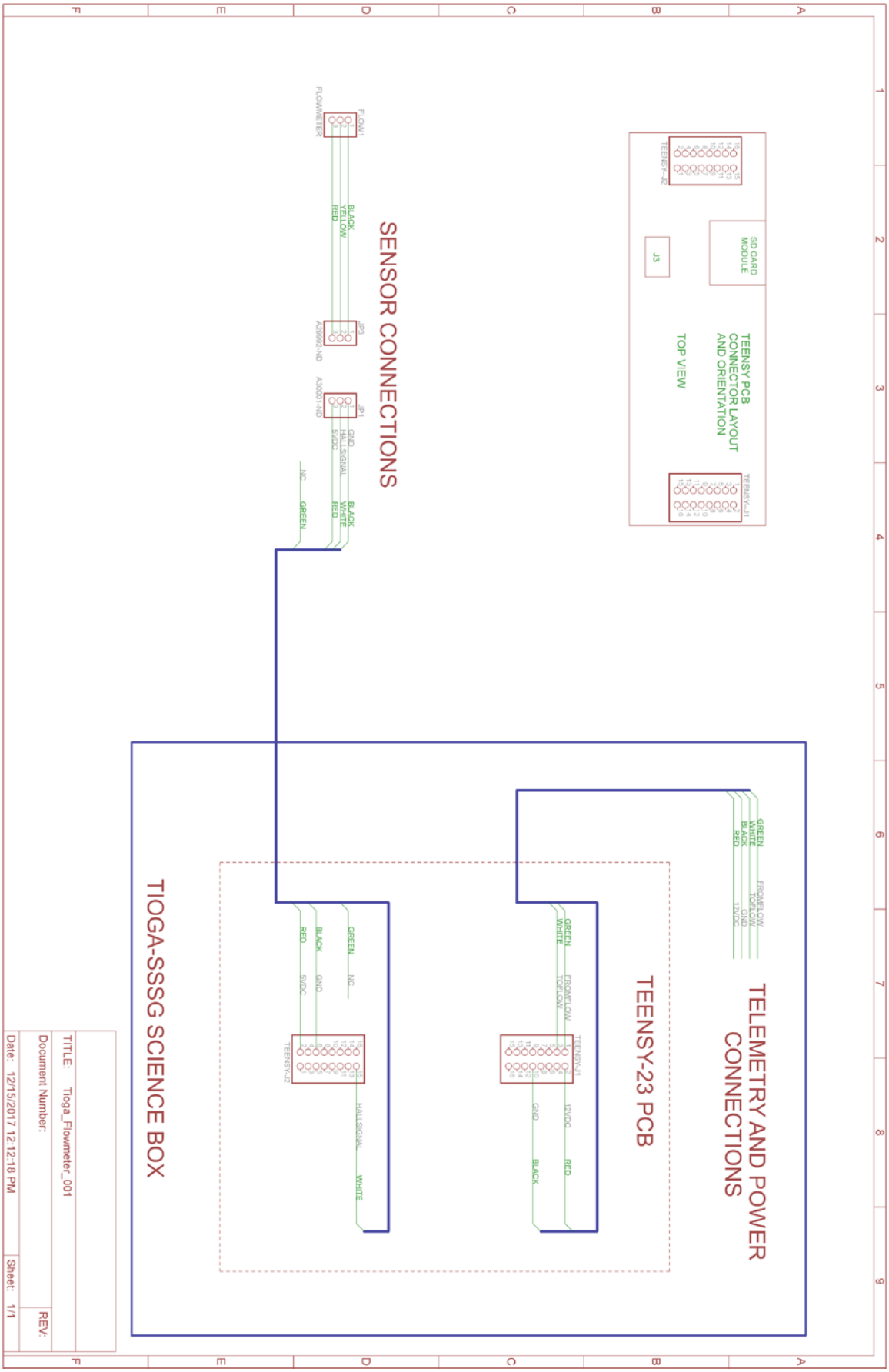
Appendix A – Flow wiring on Atlantis



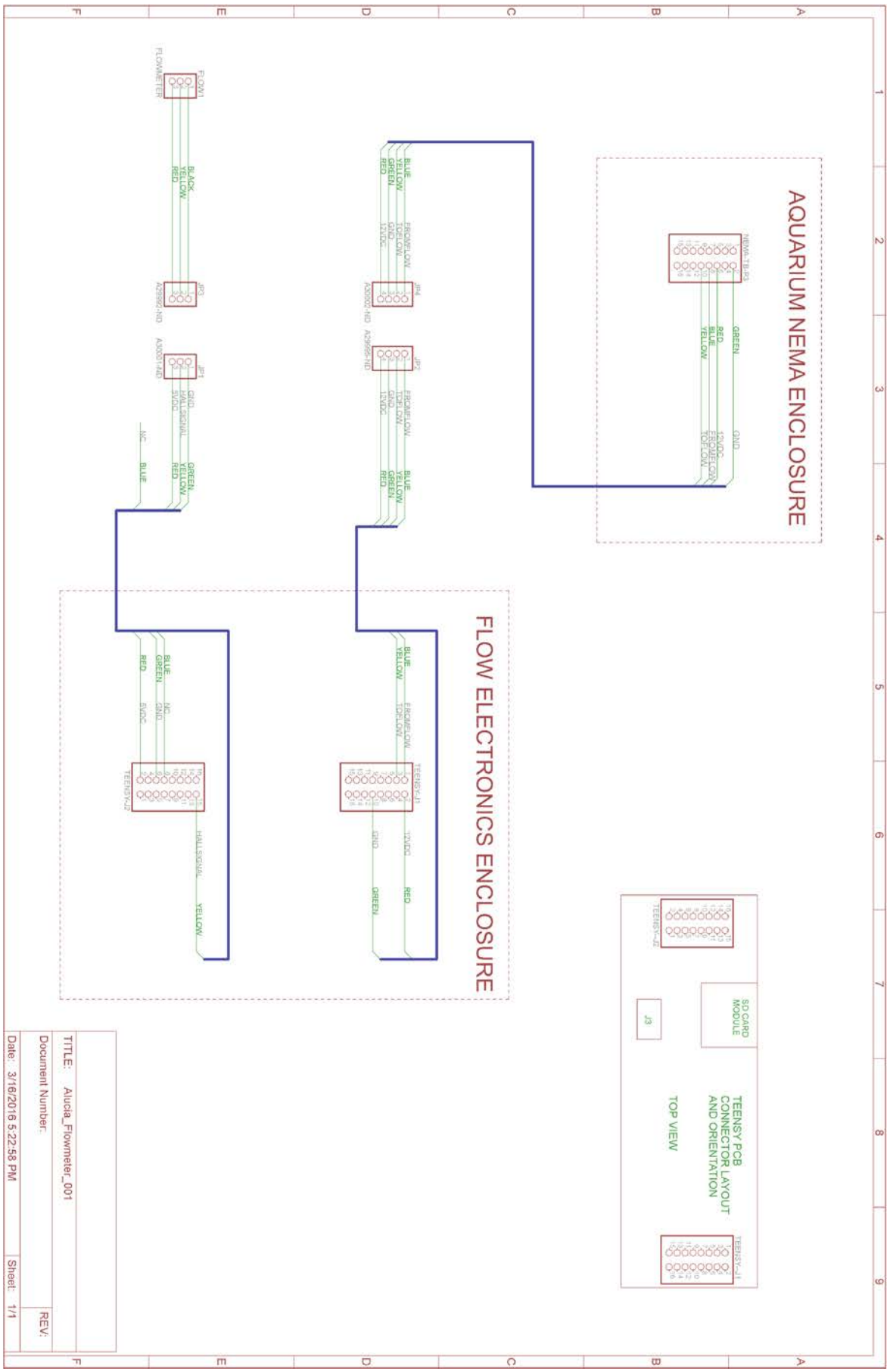
Appendix B – Flow Wiring on Armstrong



Appendix C – Flow Wiring on Tioga



Appendix D – Flow Wiring on Alucia



Appendix E – Deployment Log

- Please report changes so this info can be kept current.

Date	Location	Teensy S/N	Teensy FW Rev	Teensy CPL	Flowmeter ID
2016-09-22	R/V Armstrong	1102	0.005	477	C
2016-09-22	M/Y Alucia	1001	0.005	424	E or H
2016-09-22	SSSG Spare	1008	0.005	440	F
2017-12-15	R/V Tioga	1113	0.006	427	K
2017-12-15	R/V Atlantis	1114	0.006	407	J or M
2017-12-15	Atlantis (spare)	1101	0.006	407	J or M

Appendix F – Calibration Data from 2015-10-13

- Performed at WHOI Environmental Systems Laboratory.

ITERATION	SENSOR #	VOLUME (liters)	RAW COUNTS	COUNTS/LITER
1	A	3.7854	1655	437.2
2	A	3.7854	1677	443.0
3	A	3.7854	1645	434.6
4	A	3.7854	1672	441.7
5	A	3.7854	1670	441.2
1	B	3.7854	1713	452.5
2	B	3.7854	1740	459.7
3	B	3.7854	1753	463.1
4	B	3.7854	1729	456.8
5	B	3.7854	1716	453.3
1	C	3.7854	1787	472.1
2	C	3.7854	1811	478.4
3	C	3.7854	1791	473.1
4	C	3.7854	1820	480.8
5	C	3.7854	1819	480.5
1	D	3.7854	1727	456.2
2	D	3.7854	1733	457.8
3	D	3.7854	1719	454.1

Appendix G – Calibration Data from 2016-09-21

- Performed on R/V Armstrong at WHOI dock.
- Made two runs with flowmeter A to compare to results from 2015-10-13.

ITERATION	SENSOR #	VOLUME (liters)	RAW COUNTS	COUNTS/LITER
1	E	3.7854	1617	427.2
2	E	3.7854	1606	424.3
3	E	3.7854	1591	420.3
4	E	3.7854	1609	425.1
1	F	3.7854	1679	443.5
2	F	3.7854	1676	442.8
3	F	3.7854	1653	436.7
4	F	3.7854	1655	437.2
1	G	3.7854	1616	426.9
2	G	3.7854	1643	434.0
3	G	3.7854	1640	433.2
4	G	3.7854	1631	430.9
1	H	3.7854	1620	428.0
2	H	3.7854	1624	429.0
3	H	3.7854	1586	419.0
4	H	3.7854	1585	418.7
1	A	3.7854	1672	441.7
2	A	3.7854	1680	443.8

Appendix H – Calibration Data from 2017-12-14

- Performed at Thiel Engineering – Bourne, MA.

ITERATION	SENSOR #	VOLUME (liters)	RAW COUNTS	COUNTS/LITER
1	J	3.7854	1602	423.1
2	J	3.7854	1526	403.1
3	J	3.7854	1474	389.1
4	J	3.7854	1473	414.0
5	J	3.7854	1567	423.5
6	J	3.7854	1603	407.0
1	K	3.7854	1584	418.4
2	K	3.7854	1562	412.6
3	K	3.7854	1653	436.7
4	K	3.7854	1662	439.1
1	M	3.7854	1550	409.5
2	M	3.7854	1534	405.2
3	M	3.7854	1538	406.3
4	M	3.7854	1542	407.4

Appendix I – Bootup communications from Flow Controllers

For installation on Alucia – 2016-09-22

```
**************************************************************<CR><LF>
FLOWMETER - Rev. 0.005 - Built at Sep 19 2016 17:09:13 <CR><LF>
BoardId: TEENSY-232 - Rev. 1.1 - S/N 1001 <CR><LF>
<LF>
------------------------------------------------<CR><LF>
CFG settingsVersion = 1<CR><LF>
CFG countsPerLiter = 424<CR><LF>
------------------------------------------------<CR><LF>
<CR><LF>
$FLOWRATE, 1, 1, 2.4, 2.4, 2.4, 2.4, 1.000<CR><LF>
$FLOWRATE, 0, 1, 0.0, 1.2, 1.2, 1.2, 2.000<CR><LF>
```

SSSG Spare – 2017-12-15

```
**************************************************************<CR><LF>
FLOWMETER - Rev. 0.006 - Built at Dec 12 2017 16:03:10 <CR><LF>
BoardId: TEENSY-232 - Rev. 1.1 - S/N 1101 <CR><LF>
<LF>
------------------------------------------------<CR><LF>
CFG settingsVersion = 1<CR><LF>
CFG countsPerLiter = 407<CR><LF>
------------------------------------------------<CR><LF>
<CR><LF>
$FLOWRATE, 0, 0, 0.0, 0.0, 0.0, 0.0, 1.000<CR><LF>
$FLOWRATE, 0, 0, 0.0, 0.0, 0.0, 0.0, 2.000<CR><LF>
```

Document Revision Log

- 2015-10-03 – tt
  - Create document.
- 2015-10-14 – tt
  - Update message format.
  - Enter calibration values.
  - Add description of commands.
  - Add sample output messages.
  - Add wiring diagram.
- 2016-03-14 – tt
  - New output syntax
  - dsLogCSV section
  - Add McMaster fitting info
- 2016-09-19 – tt
  - Add description of gating logic on flow counts and associated “$BADFLOW” output.
  - Add calibration data for units E, F, G, and H.
  - Move detailed calibration Data to Appendices.
  - Add an appendix containing a deployment log.
- 2017-12-15 – tt
  - Add ship specific wiring diagrams.
  - Add electrical specifications.
  - Update screen grabs of startup comms.
  - Update Calibration Table.
  - Update Deployment Log.
  - Add new raw calibration data.