The Design and Function of the Gridded Retarding Ion Distribution Sensor (GRIDS)

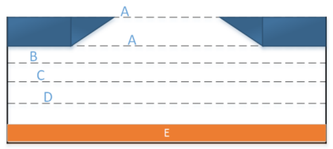
Authors: Anthony Swenson (AnthonyPSwenson@gmail.com), Ryan Davidson (ryan.davidson@usu.edu), Billy Hatch, Jorden Luke (jorden.luke@gmail.com), Bron McCall (mccallbron@gmail.com)

Abstract:

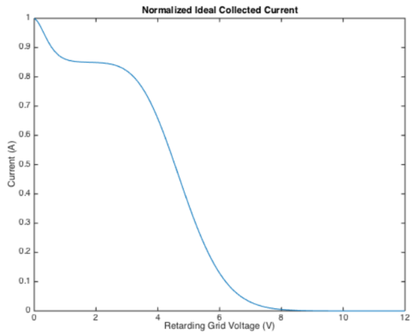
The Gridded Retarding Ion Distribution Sensor (GRIDS) is a CubeSat-compatible instrument currently being designed at the Center for Space Engineering at Utah State University. GRIDS combines the functionality of a Retarding Potential Analyzer and an Ion Drift Meter into one small form-factor suitable for small satellites. The sensor is capable of measuring the three-dimensional ion drift vector, ion density, and ion temperature when placed on a three-axis stabilized spacecraft with sufficient attitude control performance. An overview of the instrument is presented and summary of the testing the instrument has gone through to date.

Background & Science:

The Retarding Potential Analyzer (RPA) consists of a grid to which a retarding voltage is applied, a current collector plate, and an opening in the direction of motion of the satellite. The voltage applied to the grid sweeps across a range of values, reducing the number of ions that make it to the current collector as it is increased [2].



RPA Design [1]

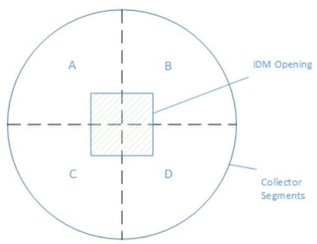


Normalized IV Curve [1]

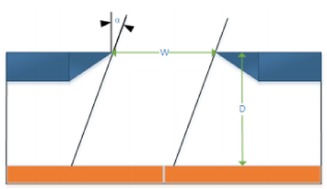
A plot can be made from the current-voltage (I-V) values and from this, much can be learned about the ions including:

- Ion concentration
- Ion temperature
- Mass ratios
- Ion drift velocity in ram direction

The Ion Drift Meter (IDM) also consists of an opening aperture, a grid with voltage applied to it, and a collector plate, however the collector plate is segmented in the IDM [3]. The RPA is able to measure the ion drift velocity in the look direction of the instrument, but cannot measure the ion drift velocity components in the other two directions. This is where the IDM has use. The segmented collector plate in the IDM allows the measurement of the ion arrival angle due to the ion beam entering the instrument hitting the collector plates in different amounts.



IDM Collector Segments [1]

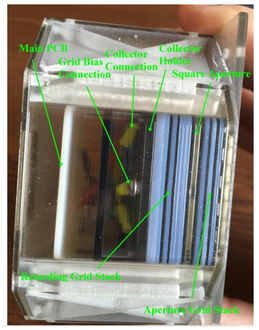


IDM Angles [1]

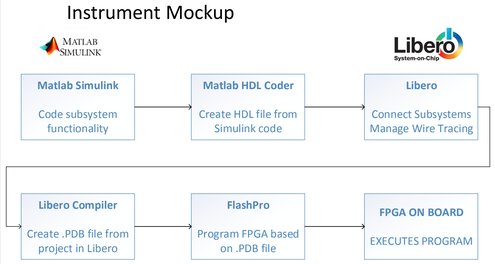
Instrument:

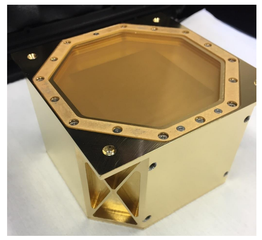
IDMs and RPAs have a long history of being flown together on large satellites with substantial budgets. GRIDS will have the combined functionality of the IDM and RPA instruments while being lightweight, small, and low power; qualities that are ideal for small satellites.

Parameter	Requirement	Design Goals
Mass	≤ 0.5 kg	0.4 kg
Power	≤ 1 Watts DC	0.65 Watts DC
Size	≤ 3.5'' x 3.5'' x 2''	≤ 3.5'' x 3.5'' x 2.5''
Survival Temperature	≤ -10°C	-35°C
Survival Temperature	≥ 40°C	80°C
Operating Temperature	≤ 5°C	-10°C
Operating Temperature	≥ 30°C	80°C
Telemetry Rate	≥ 16416 bits/s	115200 bits/s
Min Collector Currents	≥ 50 pA	50 pA
Max Collector Currents	≤ 1.2 uA	1.2 uA
Retarding Grid Bias	≤ 0 V	-13.5 V
Retarding Grid Bias	≥ 12 V	13.5 V
Suppressor Grid Bias	≥ 0 V	0 V
Suppressor Grid Bias	≤ -12 V	-13.5V
RG Sweep Points	≥ 32 Pts	50 Pts
RG Sweep Time	≤ 1 s	0.5 s
Collector Current Resolution	≥ 16 bits	20 bits



Instrument Mockup





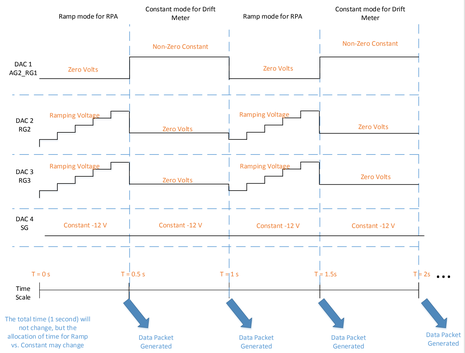
Built Instrument

Matlab was used for the FPGA design, which is able to auto-code HDL files from Simulink projects.

GRIDS runs for half a second in IDM mode, then half a second in RPA mode. During that half second the instrument makes 50 current measurements while adjusting the grid voltage. There is an additional mode that runs both the RPA and IDM ten times a second.

The current range that needs be measured is larger than the instrument can measure in any one configuration. To combat this the instrument has a built in ranging functionality.

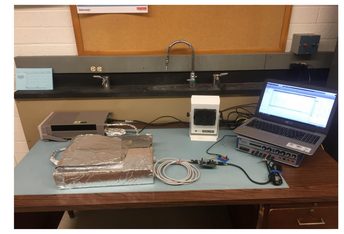
A data packet is generated every half second that contains housekeeping information, the raw measurement values, and extra information critical to converting the raw measurement values to a current.



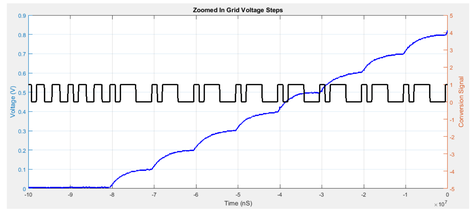
Packet Header Discription								
	0x0	0x1	0x2	0x3	0x4	0x5	0x6	0x7
0x0	Beginning Sync Word (0x53545254)				Packet Number Counter			
0x8	Packet Length (0x0400)		HK_VBUSMON		HK_3_3VDMON		HK_5VMON	
0x10	HK_15VMON		HK_DB_TMP		HK_TMP2		HK_TMP1	
0x18	DDC_RANGE							
Packet Body Discription								
0x1a	INT_APG2_RG1_1		INT_RG2_1		INT_RG3_1		INT_SG_1	
0x22	Data_1 (10 bytes)							
0x2a			IntegrationTimer		INT_APG2_RG1_2		INT_RG2_2	
0x32	INT_RG3_2		INT_SG_2		Data_2 (10 bytes)			
0x3a							IntegrationTimer	
...	...	...	...	...	...	...	...	...
0x1a + 0x14	INT_APG2_RG1_N		INT_RG2_N		INT_RG3_N		INT_SG_N	
	Data_N (10 bytes)							
			IntegrationTimer					

Testing:

For testing the National Instruments VirtualBench was used to measure test points on the GRIDS circuit boards. The serial output was routed into LabView to dissect the packets and plot the data. The Keithley 6221 DC and AC current source was used to input current into the instrument.

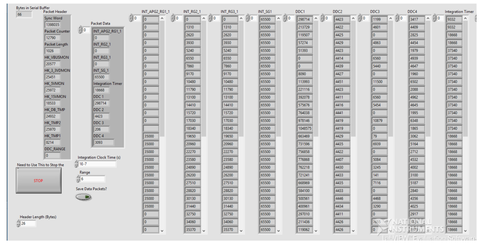


Testing Setup

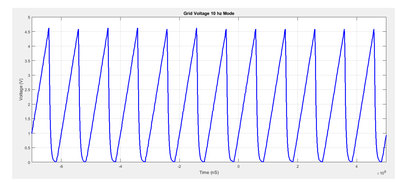


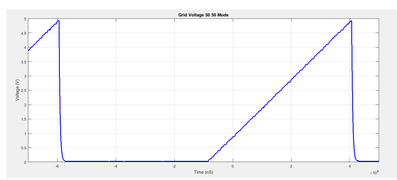
The blue signal shows the grid voltage and the black signal is the DDC conversion signal which indicates how long the instrument is measuring a current. The rise time associated with the grid voltage is taken into account for better measurements.

All the data GRIDS generates is read into a LabView program to ensure proper functionality. Plotting the data in real time is a very strong debugging tool.

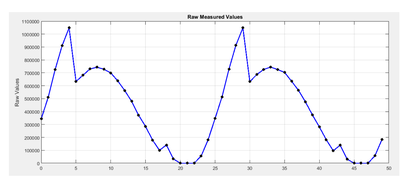


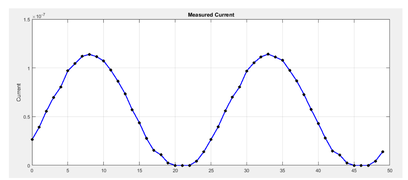
Grid Voltages measured in the two modes of GRIDS, 50/50 and 10 hz.





Raw values and converted current: (input 0-120 nA sine wave, 4 hz)





The current TRL level of the instrument is TRL 4. Plan are in place to send the instrument to Virginia Tech to test GRIDS in their space plasma chamber. This will raise the TRL of GRIDS to 6.

References:

[1] Plasma Velocity Vector Instrument for Small Satellites (PVVISS) by Hatch, William Smith, M.S., UTAH STATE UNIVERSITY, 2016, 79 pages; 10240865

[2] W. C. Knudsen, "Evaluation and demonstration of the use of retarding potential analyzers for measuring several ionospheric quantities, "Journal of Geophysical Research, vol. 71, no. 19, pp.4669–4678, 1966. [Online].

[3] R. A. Stoneback, R. L. Davidson, and R. A. Heelis, "Ion drift meter calibration and photo emission correction for the c/nofs satellite," Journal of Geophysical Research: Space Physics, vol. 117, no. A8, pp. n/a–n/a, 2012, a08323. [Online].