Applied Ion Systems
AIS-TR-009
AIS-gPPT3-1C Integrated Propulsion Module V4
Phase I - Lifetime Testing - 11/20/2019
Testing Report and Summary

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I. TEST PARAMETERS

- **System:** AIS-gPPT3-1C Integrated Propulsion Module V4
- **Main Bank Capacitor:** 0.047 uF C0G ceramic capacitor
- **Main Bank Charging Voltage:** 660V
- **Shot Energy:** 0.01J
- **Pulse Repetition Rate:** 3 Hz
- **Total Number of Shots:** 0
- **Maximum Chamber Pressure During Testing:** 1 x 10^-5 Torr
- **Testing Status:** COMPLETE - UNSUCCESFUL

II. OVERVIEW

This test represents Phase I ignition testing for the newest AIS-gPPT3-1C Integrated Propulsion Module V4. The purpose of the test was to establish reliable ignition with the new V4 board design, focusing on higher repetition rates than the prior gen versions, along with simplified circuitry and improved layout. Several changes and updates were made from the V3 to V4 boards to attempt to improve prior thruster shortcomings.

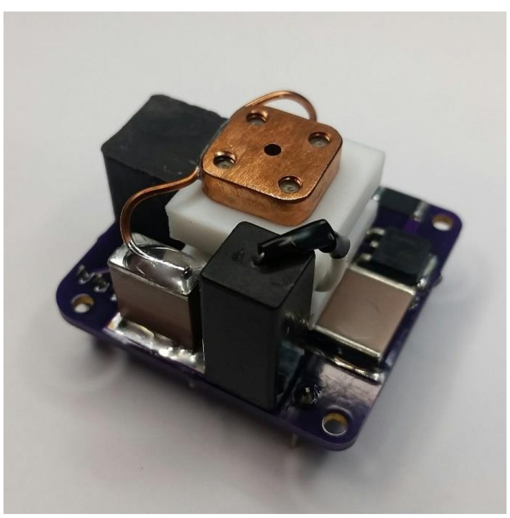
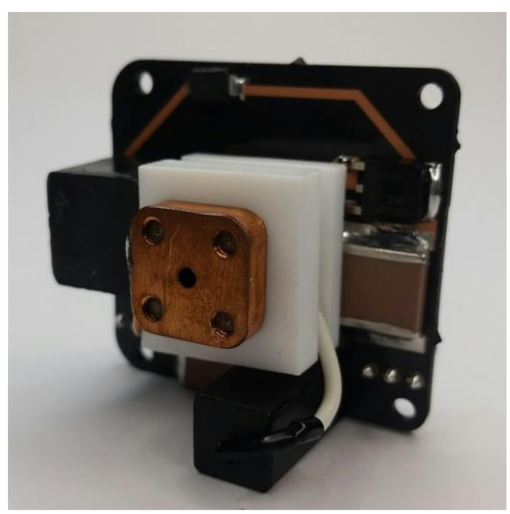

FIGURE 1: *AIS-gPPT3-1C Thruster Module – V3 (left), V4 (right)*

The high voltage charge circuitry was modified and simplified from V3 to V4. The original 2kV Q-series Emco supply was replaced with a 1.2kV Q-series Emco supply. The voltage divider for the ignition bank charging loop was also eliminated. At a repetition rate of 3 Hz at 3.3V in, this allows the main bank capacitor to be significantly under-driven to safe levels at 660V to minimize stress on the pulse capacitors and increase bank lifetime, while simultaneously increasing the voltage on the ignition bank input by a factor of two, leading to higher output ignition levels to hopefully improve ignition reliability at standard PQ bus voltages.

The primary bank capacitor was changed from two parallel 0.068uF capacitors vertically soldered, to a single 0.047uF capacitor mounted horizontally on the board. This allows for higher repetition rates, at the cost of impulse bit. However, based on prior performance projections, balance could be achieved where higher thrust is enabled at higher repetition rates, even at reduced impulse bit. This not only allows for finer control, but faster response of the module and higher total output. Using the lower voltage, higher current HV module for charging, the bank can be charged even faster, while further reducing peak and average power consumption during the firing cycles.

Figure 2 shows the PCB changes from V3 to V4 on the top of the boards where the charging circuitry is located.

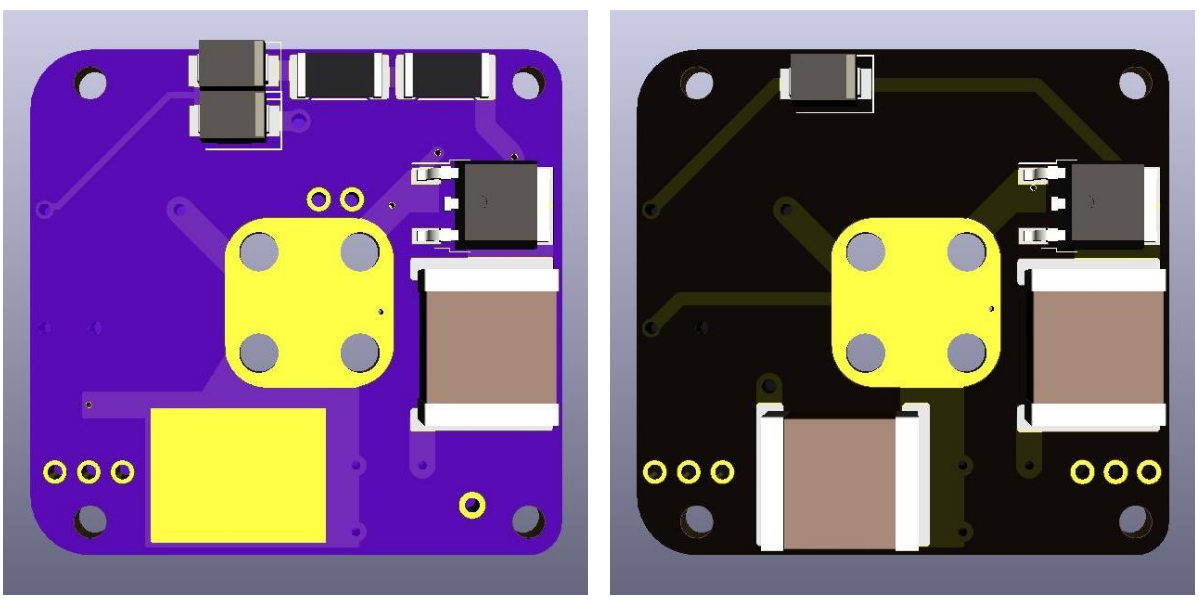

FIGURE 2: *AIS-gPPT3-1C Thruster Module PCB Front – V3 (left), V4 (right)*

While the load switch and high voltage monitoring dividers remained the same from V3 to V4, the IO pin layout was reworked on V4 for easier interfacing by keeping all control and monitoring pins in-line with each other. *Figure 3* shows a comparison between the V3 and V4 boards with the monitoring and IO interface layout changes.

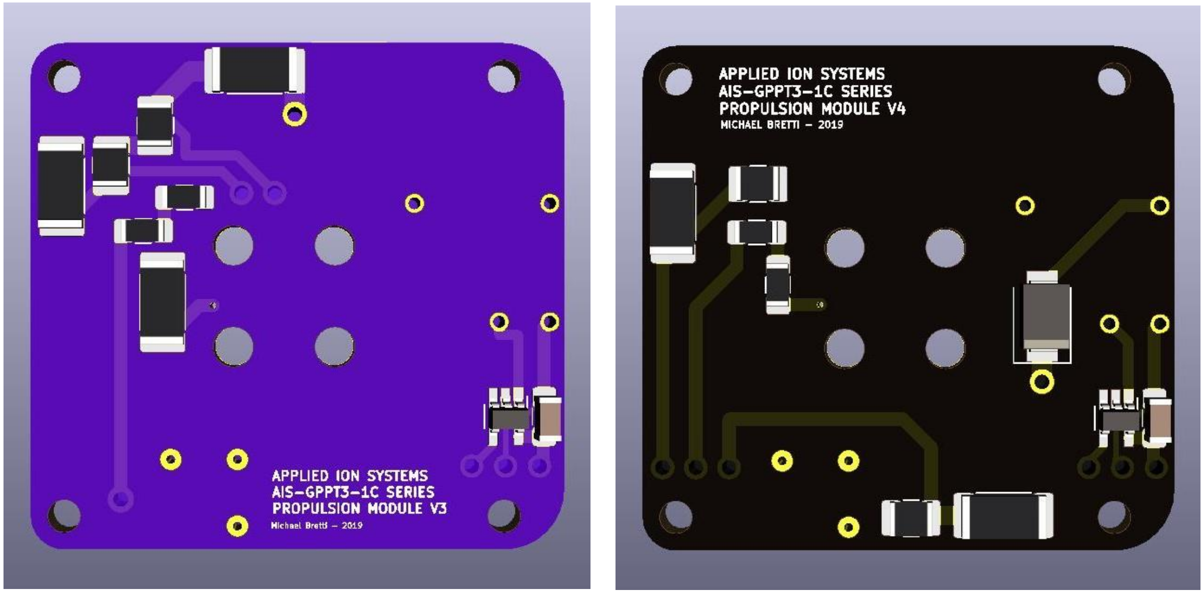

FIGURE 3: *AIS-gPPT3-1C Thruster Module PCB Back – V3 (left), V4 (right)*

III. TEST SETUP SUMMARY

The AIS-gPPT3-1C V4 thruster was mounted to a conflat feedthrough adapter utilizing a simplified direct feedthrough connection from the high voltage conflat feedthrough to a zero-clearance reducer on the micro propulsion testing chamber. 0.25"OD x 0.1875"ID Teflon tubes were used to secure and support the thruster to the feedthrough. 18 AWG bare copper wire with pin sockets soldered to the wire ends were used for all power and control inputs. Connection pins were soldered to the thruster to interface with the wire connections. Thruster mounting lengths were determined based on the length required to center the thruster in the adjacent 6" conflat viewport. This mounting setup is the same as all other prior testing with the gPPT3 series thrusters.

FIGURE 4: *AIS-gPPT3-1C V4 thruster centered in high vacuum chamber viewport.*

Testing was performed in the Micro Propulsion Testing Chamber using the Integrated High Vacuum Test Stand. Ignition testing vacuum levels were first verified at 1 x 10^-5 Torr before attempting ignition. During testing vacuum levels were unaffected from the thruster firing.

IV. TEST RESULTS

After pump-down was complete to appropriate vacuum levels, ignition testing on the thruster was started. Power was applied to the thruster, along with enable, and the trigger command at nominal repletion rates. However, no ignition was observed. After several pulse attempts at lower rates and longer intervals, input voltage was increased from 3.3V to 4V. Ignition at this level was still not achieved, and voltage was raised to the maximum of 5V, using both single pulses and pulse trains for ignition. Soon after, primary and ignition bank readouts dropped to 0V, indicating an onboard failure. At max input voltage, the un-attenuated 1.2kV would charge the ignition bank, where the trigger thyristor is rated for only 800V max. It was confirmed from later inspection and troubleshooting of the electronics board that the thyristor had failed.

V. CONCLUSION

Testing was performed on the new AIS-gPPT3-1C V4 Integrated Propulsion System. Unfortunately, ignition was not attained, resulting in an unsuccessful test. Raising the input voltage from nominal 3.3V to a max of 5V had caused the onboard trigger thyristor to fail. It is expected that due to the extremely low main bank energies of only 0.01J, at lower voltages of 660V, was too low for a main discharge to form through the fuel channel between the anode and cathode. At such, improvements for future iterations can include closer electrode spacing, higher ignition pulse energy, and a larger main pulse bank.

Currently, the primary focus of Applied Ion Systems has been on developing sub-Watt PPTs as the primary propulsion for PocketQubes, down to 1P systems. This has been done with the AIS-gPPT series. The thruster has evolved tremendously over the short period it has been worked on. It’s been quite a struggle, but the thruster has opened up many fantastic doors and opportunities. Significant data, test results, and improvements have come from this effort. Despite this, practical limitations of the technology need to be openly addressed.

Based on prior data and current trends of the design, at the present time it is concluded that a sub-Watt, sub-Joule PPT cannot reasonably scale to provide the necessary thrust and performance to act as the main propulsion for PocketQube satellites for lower altitudes that are commonly flown at in the 300-400km range. Based on data, preliminary simulations by others in the community, and anticipated propulsion requirements for nanosatellites in LEO, the extreme power restrictions do no give enough room for needed thrust levels at these lower altitudes, though at levels of 500km and up the prior gPPT3 V3 series thruster can reach required thrust for station keeping due to the extremely low levels of atmospheric drag faced in these conditions.

The AIS-gPPT3 series thrusters can also be used for low-power propulsion based Cubesat attitude control, though due to form-factor physical topology should be changed to be optimized for this use.

The gPPT series thruster is a fantastic learning tool that could enjoy a lot of use in educational labs and with enthusiasts who want to get started with electric propulsion. It is the stepping stone to show that advanced EP can be done at home and open-source at low-cost, rivaling and exceeding performance of comparable systems under large grant funding in traditional academic labs.

While PPTs remain a challenge to provide high performance at this extremely low power and energy level, there is plenty of opportunity to expand into multi-watt units for larger PocketQubes and small Cubesats. This potential development will build off the prior gPPT thruster, and look to optimize performance for possible main propulsion at the 2P and higher PocketQube level, while still keeping to an ultra-low cost, open source design. Such thrusters can also be the basis for powerful academic learning tools, allowing both students and enthusiasts to dive into advanced electric propulsion systems with minimal cost, using simplified designs.

Moving forward, Applied Ion Systems will effectively be shifting focus from this thruster class to several new areas of propulsion, including advanced ionic liquid ion source (ILIS) electrospray thruster technology, field emission electric propulsion (FEEP), and higher power PPTs, and retire development on the current line of gPPT series thrusters to pave way for these new exciting developments at the PQ level, and eventually scaling up to Cubesat compatible systems and clusters.