Micro Pulsed Inductive Thruster for CubeSat Application

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Abstract

CubeSAT projects have the potential to implement useful scientific projects at order of magnitude lower costs than traditional satellite missions. However currently, there are few low power, high performance propulsion devices which can be implemented on a CubeSAT due to the rigorous mass, size, and power constraints. Eagle Harbor Technologies is developing a Micro Pulsed Inductive Thruster (μPIT) based on the proven concepts of a Pulsed Plasma Thruster (PPT) to serve that purpose. PPTs are plagued by their low efficiency, due primarily to the Late Time Ablation (LTA) and large neutral production, neither of which significantly contributes to the thrust. Two methods of reducing the LTA and neutral production were designed for the thruster. An accelerator electrode was added onto the nozzle of the PPT to ionize neutral particles not ionized through the main discharge and Insulated-Gate Bipolar Transistors (IGBTs) were added to the circuit to prevent current from flowing after the peak of the discharge has passed. μPIT is predicted to have an I_{sp} of 1611 sec, impulse bit of 63.2 μN-s, and a maximum possible ΔV of 20 m/s. If testing this fall proves μPIT to be a successful design, future work will look to incorporate an inductive drive coil as the accelerator stage.

CubeSAT Propulsion: The Pulsed Plasma Thruster

At the onset of the CubeSAT program the intent was to provide universities with cost effective access to space to test student projects. No propulsion was required for these simple missions. However, as interest in CubeSATs increases from government and industry sources, the required capabilities are bound to increase as well. Basic satellite propulsion operation, such as orbit raising and attitude control are complicated due to the size and mass limitations on a CubeSAT. Propulsion systems are generally complex, involving multiple components and multiple propellants - making the integration of a traditional propulsion system into a CubeSAT nearly impossible. The standard 1U CubeSAT is a 10x10x10 cm (1 liter) cube, weighing 1 - 1.3 kg. 3U versions consisting of three 1U units integrated together have also been flown. Any CubeSAT propulsion device must fit within these mass and size considerations as well as within the power restraints. A typical satellite has a bus voltage of 28 V, however due to the limited available area for solar panels, the 3U CubeSAT bus is 5 V.

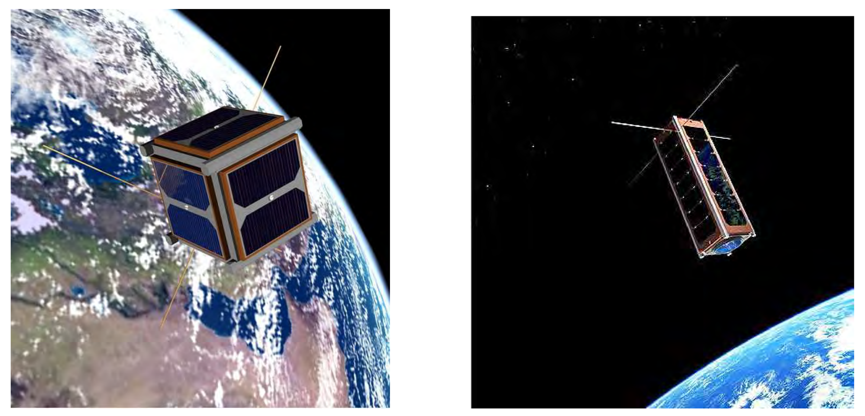

Figure 1: Artist drawings of 1U (left) and 3U (right) CubeSATs in Low Earth Orbit.

A Pulsed Plasma Thruster is one possible propulsion device for CubeSATs. PPTs are ideal for attitude control, orbit raising, and other low-thrust maneuvers for small spacecraft. The PPT is electromagnetic accelerator that employs solid Teflon propellant, a non-toxic high I_{sp}. A capacitor is charged to a few kV, then a spark plug is fired to initiate the discharge. The current pulse from the capacitor ablates material from the propellant surface, generating a Teflon plasma. Flowing upward in Figure 2, this current generates a magnetic field (out of the page) and the resulting j x B force drives the current sheet along the electrodes, expelling the ablated propellant at a high velocity.

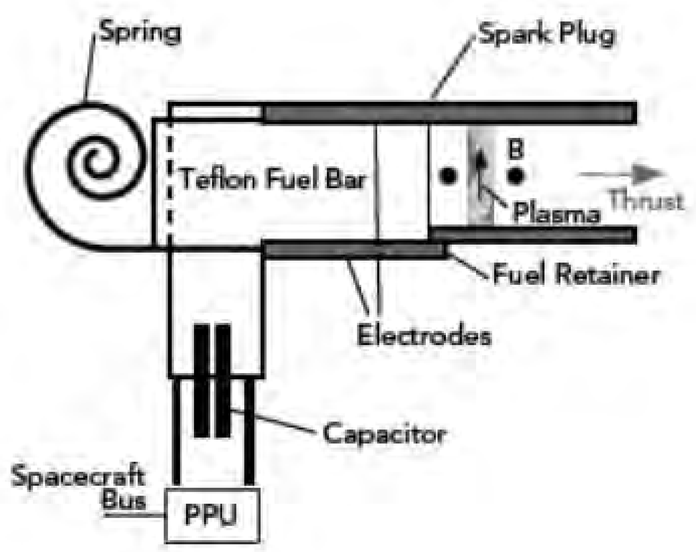

Figure 2: A schematic illustrating the main components and operation of a rectangular PPT.

PPTs are long standing electric propulsion thrusters that are reliable, relatively simple, and low cost. However a main concern with PPTs is its low efficiency, typically between 3 and 8%. One of the primary contributors to this low efficiency is LTA - the sublimation of propellant that takes place after the main discharge. This produces low speed gas and macro particles, neither of which contribute significantly to produce thrust. Additionally large numbers of neutrals are produced in the main discharge which also flow at low velocity, not contributing to thrust. μPIT aims at accelerating the late time ablation by employing an additional discharge (the accelerator stage) after the main discharge through a second electrode - similar to a coaxial plasma gun concept.

uPIT Electronics

The basic PPT circuit has two components: a starter arc and main discharge. μPIT adds the accelerator as a third stage. The capacitors on all three stages are charged to 1000 V and IGBT control circuits dictate when each capacitor can discharge and more importantly preventing late time ablation by stopping the flow of current soon after the main peak of the pulse passes. The IGBT circuits are operated through a fiber optic signal sent from a control computer. The direction of the current is also reversed from the standard PPT

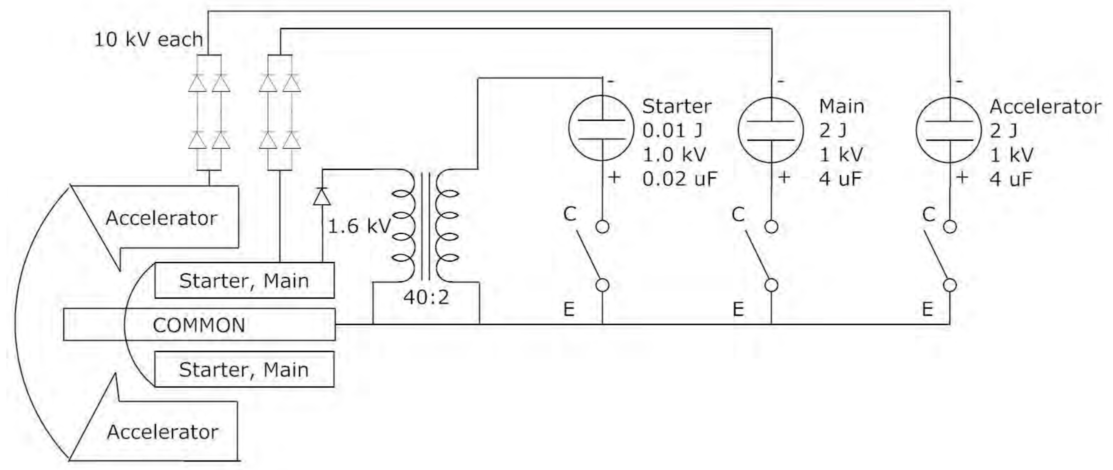

Figure 3: The μPIT electrical circuit has three separate components, the starter (left), main (center), and accelerator stages (right).

The 1000 V (357mA) from the starter arc is run through a 20:1 transformer increasing the voltage to 20 kV. A 1.6 kV diode is placed after the transformer to prevent the main or accelerator discharges from damaging the starter electronics. If the IGBT's were permanently shut the main and accelerator discharges would be triggered as soon as the spark plug ablates the initial Teflon, completing the circuit. Both of these circuits have four 10 kV diodes (2 sets of 2 in parallel) to prevent the high starter arc voltage from damaging their electronics.

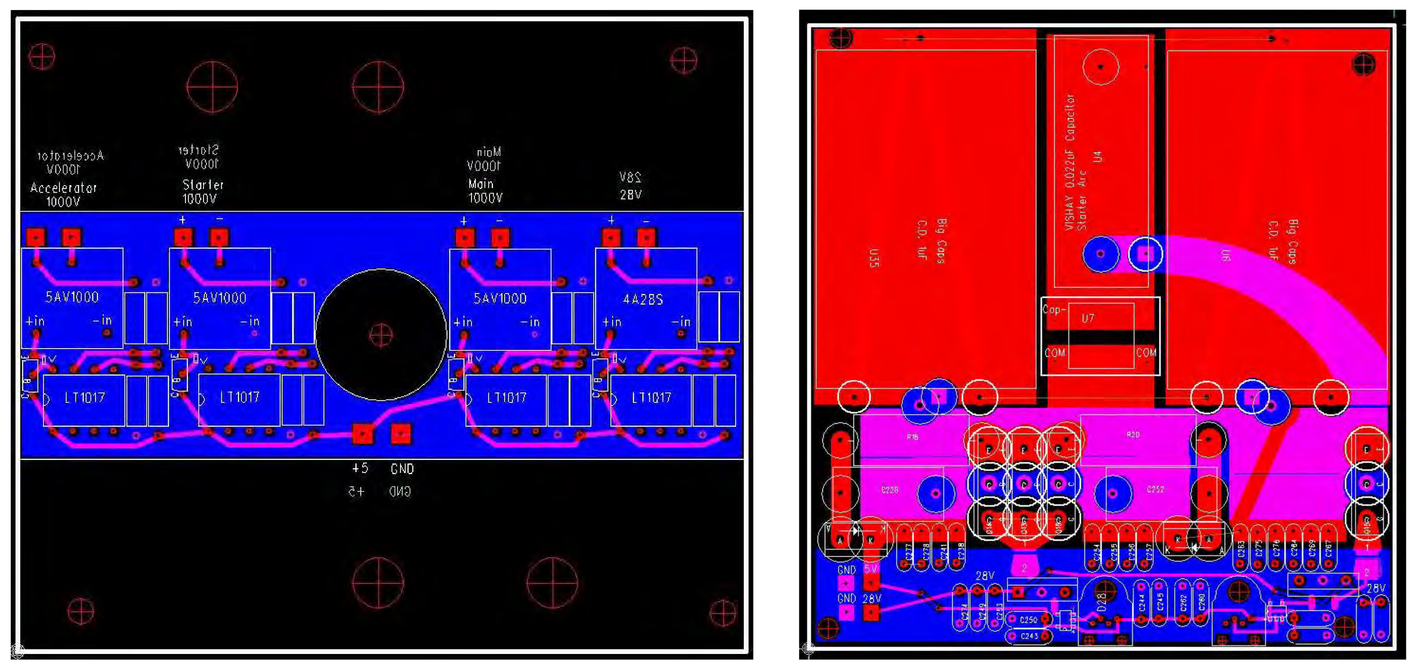

Figure 4: The power regulation PCB (left) attached vertically and the starter, main, and accelerator PCBs (right) attach horizontally with respect to the thruster. The blue represents traces on the bottom of the board, while the red shows the top. Pink represents traces on the top and bottom.

To fit the thruster within the CubeSAT dimensions, the electronics had to broken into three circuit boards. The power input and regulation board (7.6x9.2 cm) is shown in Fig. 4 on the left and attaches vertically to the front of the thruster. The main discharge and starter arc circuitry (9.2x9.7 cm) is shown in Fig. 4 on the right and attach horizontally below the thruster. The accelerator will use the same board design as the main discharge, but simply without the starter components attached will will be placed above the thruster. These three boards can be seen in relation to the thruster on the right in Fig. 5.

uPIT Mechanical Design

As shown on the left in Fig. 5, μPIT has three electrodes: a ground, starter and main (S/M), and an accelerator stage electrode. The S/M electrode is set 0.1 cm in front of the Teflon face and the accelerator electrode extends for 1.3 cm while flaring out at 10° As is standard with all PPTs, the 5.5cm long Teflon propellant is fed forward with a spring. The nine diodes can be seen surrounding the Teflon, behind the electrodes. The thruster is held together with Ultem, an amorphous material with high electrical standoff.

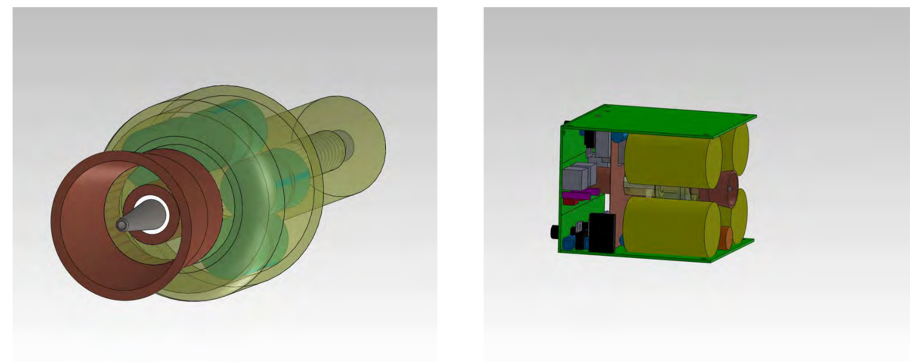

Figure 5: The 3 electrodes, Teflon surface, nine diodes, and Ultem housing is shown on the left. The PPT with associated electronics is shown on the right.

With these dimensions μPIT can fit into a standard 1U CubeSAT package as shown on the left in Fig. 6. μPIT can also be placed at the bottom of a 3U CubeSAT (Fig. 6 right) leaving the other two units open for scientific or communication packages. Neither the 1U or 3U package need to be modified to fit μPIT inside.

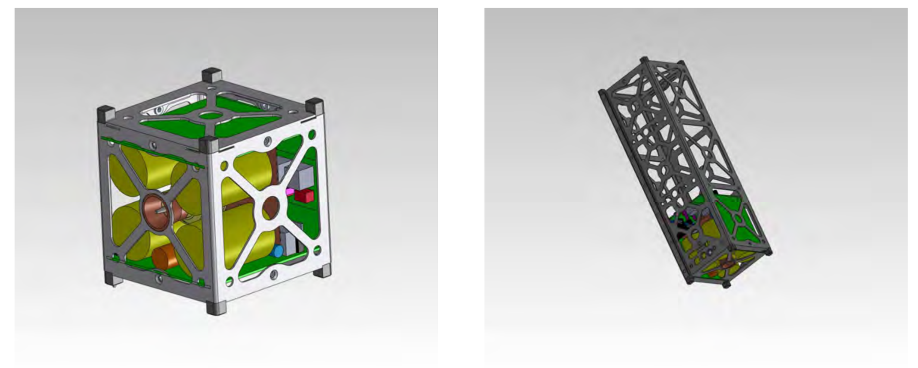

Figure 6: μPIT placed within the standard 1U (left) and 3U (right) CubeSAT packages.

Performance Estimates

Assuming we ablate 4 μg of Teflon with each shot and flow and accelerator efficiencies of 5 and 20%, respectively, the following expected performance characteristics were found.

- Power = 4 W
- C_e: 15.8 km/sec post accelerator (I_{sp}: 1611 sec)
- Impulse bit= 63.2 uN-sec
- Total Impulse = 123 N-sec
- ΔV = 20.6 m/sec

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