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Iodine RF Ion Thruster Development

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TECHNOLOGY DRIVES EXPLORATION

Non-Proprietary

Iodine RF Ion Thruster Development

Status Briefing
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BUSEK
Space Propulsion and Systems

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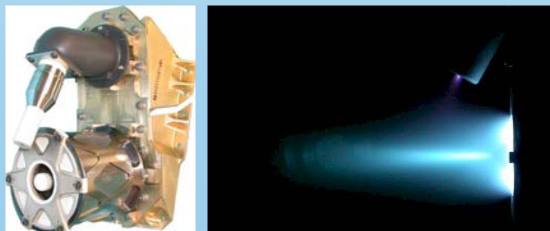
Busek Co. Inc. - History of Innovation

BHT-1500, Credit: National Geographic



BHT-200, Flight Heritage Thruster

Founded in 1985, ~50 Engineers, ~$10M, Small Business

Core Business – Spacecraft Electric Propulsion

- **Hall thrusters** – all US hall thruster originated at Busek
- **Electrospray Thrusters** – e.g. LISA Path Finder ...
- **Pulsed Plasma Thrusters** – e.g. FalconSat3..
- **Gridded RF Ion Thrusters – focus of todays talk**
- **Small "green" monoprops**
- **Unique space systems –** e.g. debris removal
- **High Isp CubeSat propulsion** –

BIT Series RF Ion Thrusters

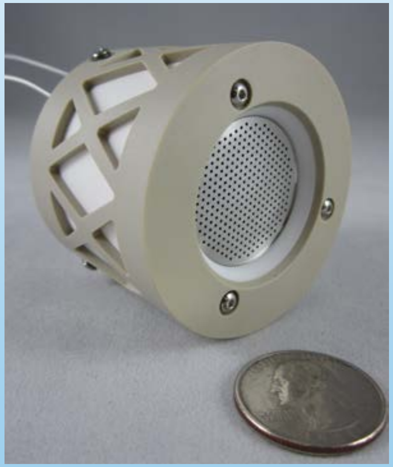
MODEL	BIT-1	BIT-3	BIT-7
Thruster Input Power	10 W	60 W	360 W
Ion Beam Current	1.5 mA	21 mA	157 mA
Propellant Flow (Xe)	0.05 sccm	0.4 sccm	3 sccm
Thrust	0.105 mN	1.4 mN	11 mN
Specific Impulse	2250 sec	3500 sec	3850 sec

Expertise in Miniature, High Isp RF Ion Thruster

- Currently the BIT (Busek Ion Thruster) family includes 1cm, 3cm and 7cm grid sized thrusters. Power ranges from 10-400W and Isp ranges from 2000-4000 seconds.
- The 3cm, 60W class BIT-3 thruster is the world's 1st iodine-fueled gridded ion thruster; its development was supported by NRA #NND14AA67C and NASA SBIR #NNX14CC99P (6U LunarCube) programs.

Why Iodine

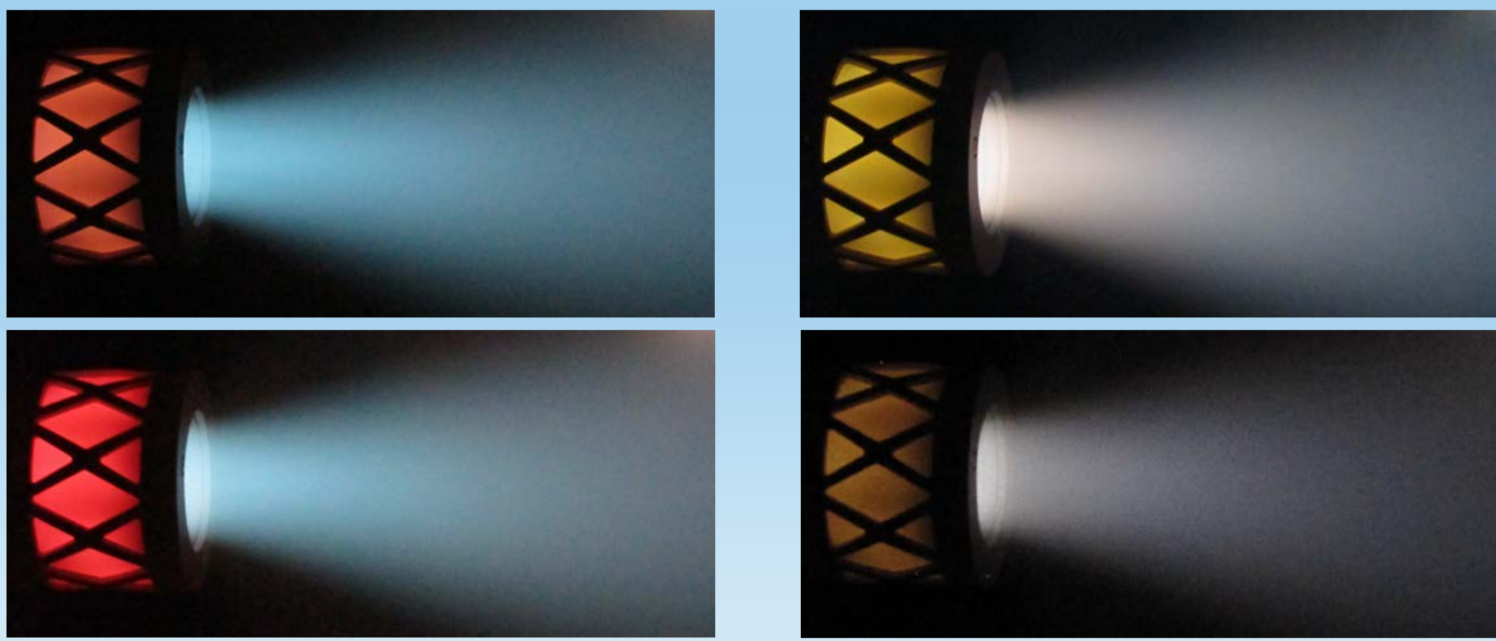
- Iodine is stored as a solid at room temperature.
  - This allows for lightweight and highly configurable tanks (not constrained to high pressure tank shapes).
  - No need for launch waivers as there is no pressure vessel.
  - Sublimes with minimal heat input to form iodine vapor which is then fed to the EP device.
- Busek has shown with HETs that iodine provides almost identical performance as with xenon (legacy EP fuel) – could potentially be a drop-in replacement.
- Iodine costs only 1/5 compared to xenon at today's rate – could be even less in quantity or at lower purity.
- Iodine's low vapor pressure suggests that plume condensation should not be a concern on s/c.
- Traditional high-Isp, gridded ion thrusters cannot run on iodine due to chamber material incompatibility. Busek's induction-type RF ion thrusters don't have such issue so it can take advantage of iodine's benefits while providing very high Isp (important for deep space missions).



BIT-3, World's First Iodine-Fueled Gridded Ion Thruster

BIT-3 Thruster Development

- BIT-3 thruster was designed for iodine compatibility, maximum efficiency & Isp, and nominally 50-60W operation that targets a 6U CubeSat as initial application platform.
- Successfully demonstrated BIT-3 on both Xe and I_2; verified that I_2 can be a drop-in replacement for Xe based on thrust-to-power data.
- Successful demo with I_2 helped shape the feed system design for a 6U CubeSat.

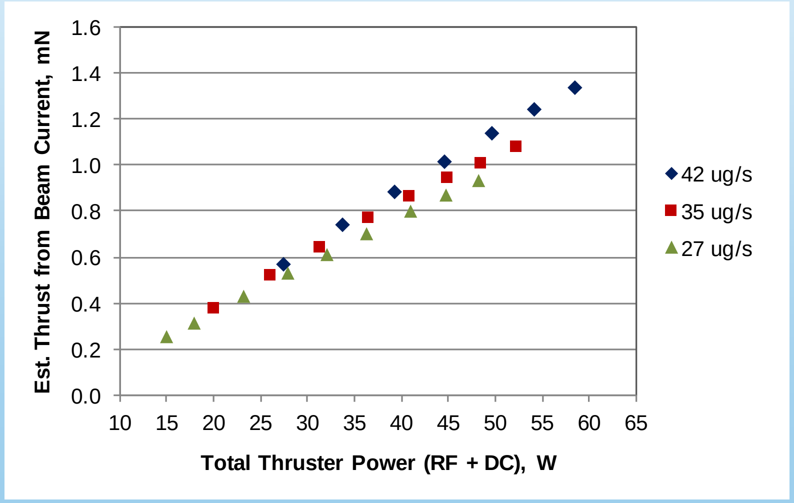


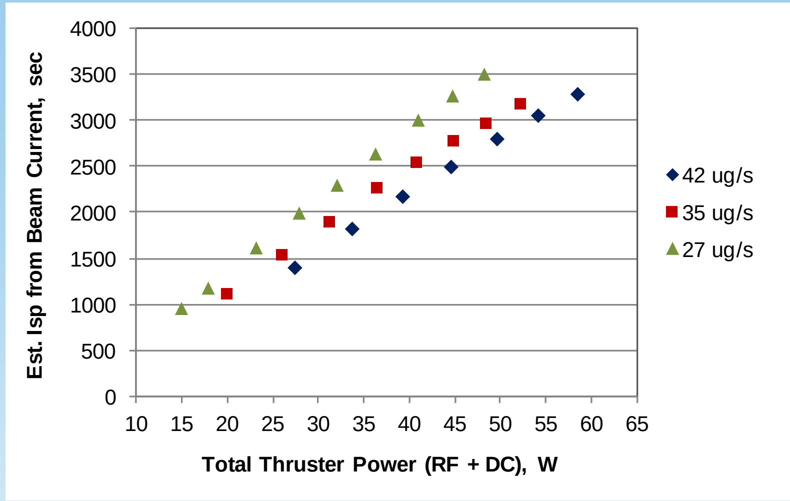
Xe 60W | **I_2 60W**

Xe 30W | **I_2 30W**

BIT-3 Thruster Performance

- BIT-3 has wide throttleability with I_2.
- For 6U CubeSat application, BIT-3 will likely be limited at 50W thruster power, which results in 1.2mN thrust and 2800sec Isp.
- At 50W thruster power, total propulsion system raw input power will be ~65W, which takes into account ~85% PPU conversion efficiency from bus voltage and ~6W neutralizer power.
- With a ~2U package (including 300cc/1.5kg iodine propellant), the BIT-3 system can provide 3km/s delta-V to a 6U/12kg CubeSat.

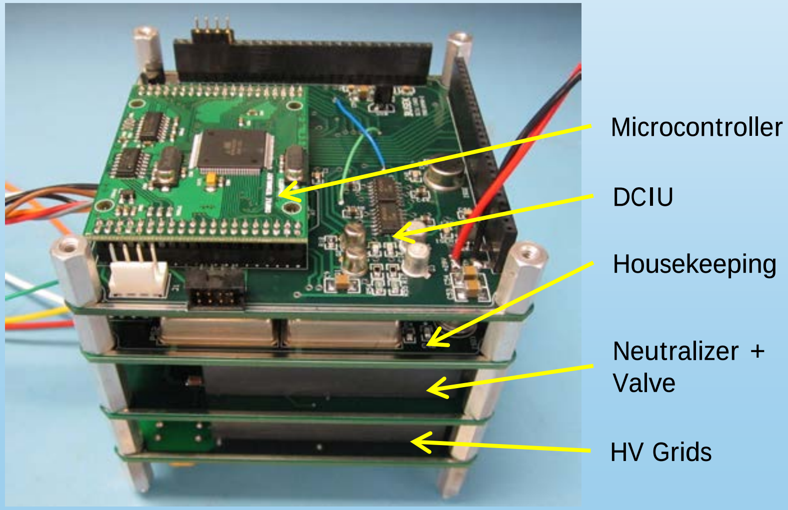




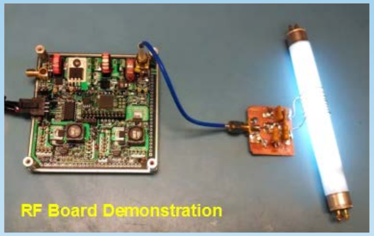
BIT-3 Performance with Iodine

BIT-3 PPU Development

- Electronics is a critical component of any EP system; miniaturizing PPU can be challenging.
- A CubeSat-style breadboard PPU has been developed for the smaller BIT-1 system.
  - Approximately 1.25U size and rated for 30W (10W RF + 20W DC).
- Feasibility study completed for scaling up to a BIT-3 compatible PPU; development pending.
  - 3/4U volume
  - 124W (40W RF + 84W DC).
  - 3-12V input okay. Integrated heat sink.
  - Efficiency to ~85%



BIT-1 System PPU Prototype with DC Components Shown on Top and RF Generator / Amplifier Board at Bottom

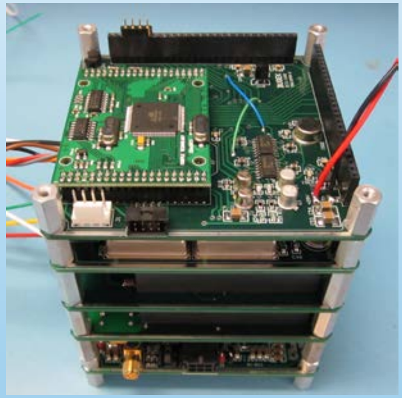


CubeSat Form Factor, Innovative RF Power Board for the BIT Series RF Ion Thrusters

Key Components for BIT-3 System

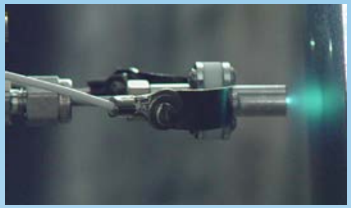

Busek 3cm RF Ion Thruster BIT-3; 50W Nominal at Thruster Head

Thruster



CubeSat Compatible Ion Propulsion PPU; (from top) DCIU, Housekeeping, Cathode/Valve, Grid HV, RF Generator & Power Amplifier

Power Processor

I_2-Compatible Subminiature Hollow Cathode as Ion Beam Neutralizer; Heaterless, 5W Nominal

Neutralizer

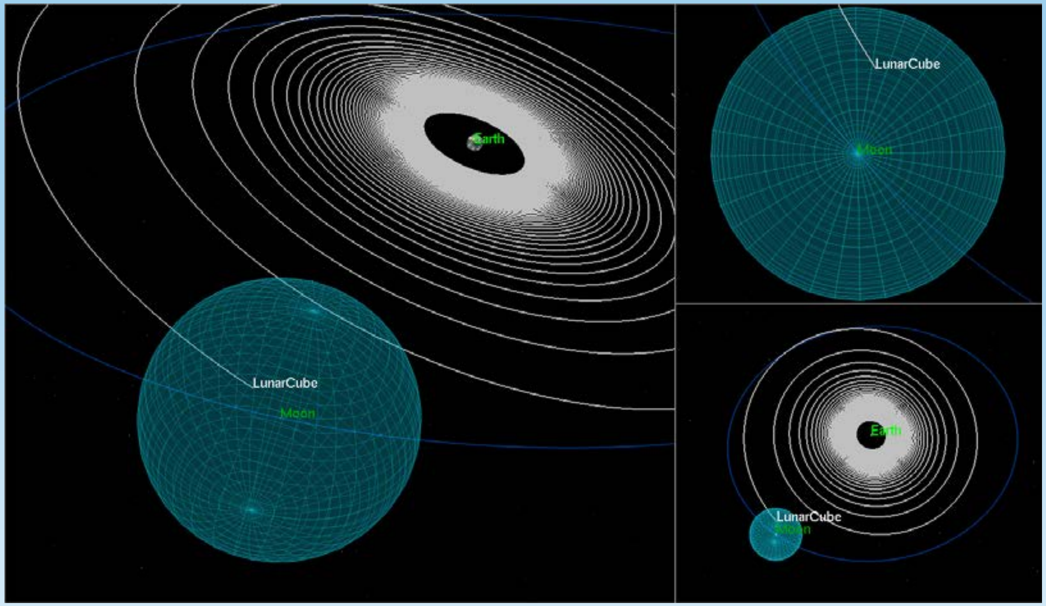
Zero pressure iodine tank

300cc Iodine Propellant Stored as Solid Crystals

Tank and Propellant

Example Mission 1: 6U CubeSat to the Moon

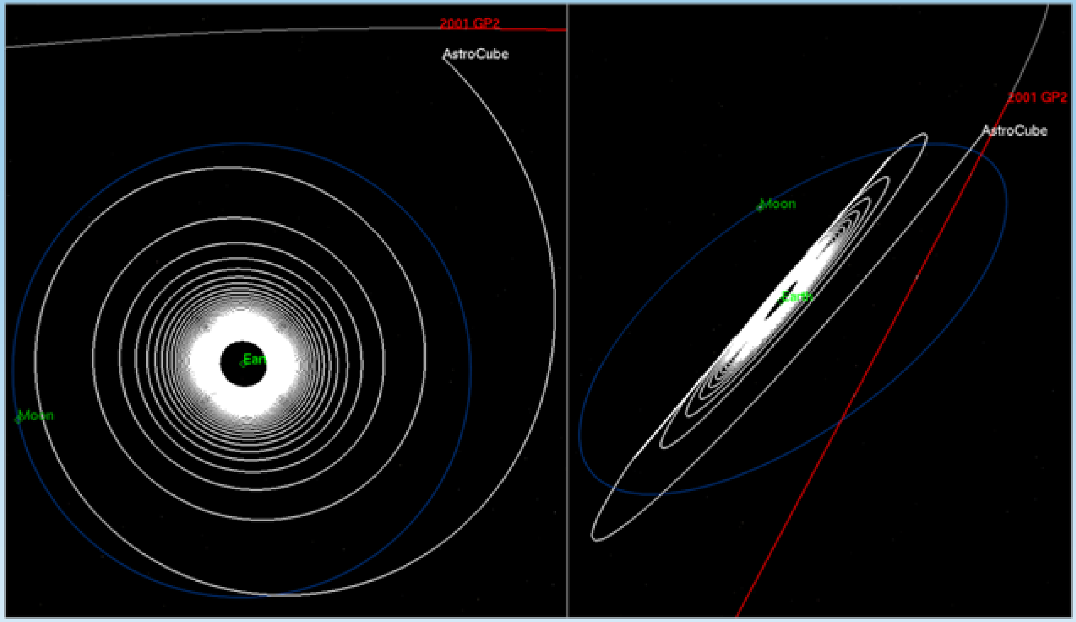
- With 3km/s delta-V capability, a 6U/12kg CubeSat can reach lunar orbit from GEO using the iodine BIT-3 propulsion system alone.
  - Transfer takes 258 days to complete.
  - GTO departure is possible with additional propellant or smaller P/L.
  - Starting from L1 transfer trajectory (e.g. recent Falcon9 mission) is possible.
  - Starting from SLS/EM-1 drop-off will result in excess delta-V margins (not a bad thing).
- The ability to get to the moon without a free ride (such as SLS/EM-1) is attractive to NASA and industry users eyeing future lunar missions with small robotic scout vehicles.



Example Mission Scenario Showing GEO-to-Lunar Capture Transfer Orbit of a 6U "LunarCube". Credit: NXTRAC

Example Mission 2: 6U CubeSat to Asteroid Rendezvous

- With 3km/s delta-V capability, a 6U/12kg CubeSat can rendezvous (not just flyby) with Asteroid 2001 GP2 during its next closest approach in October 2020.
  - Example mission scenario using departure from GEO; transfer takes 242 days to complete.
  - 2km/s of delta-V is spent climbing out of Earth's gravity well and re-aligning.
  - The additional 1km/s of delta-V is spent catching up to the asteroid. At rendezvous, both objects would be moving at a rate of ~2.5km/s with velocity vectors aligned. Landing will be possible.
- The 2001 GP2 asteroid rendezvous mission will also be possible by departing from L1 transfer orbit, SLS/EM-1 drop-off or direct injection.



Example Mission Scenario Showing GEO-to-Asteroid Transfer Orbit of a 6U "AstroCube". Credit: NXTRAC

Summary

- BIT-3 Thruster enables high energy (deltaV>several km/s) missions (cis-lunar space and interplanetary) using low cost, very small spacecraft (~10kg class)
- Iodine is game changing – high density, stored as solid, low cost, near zero pressure conformal tanks, no typical “secondary payload” and “launch safety” concerns
- NASA is supportive of Iodine as EP propellant – (iSat, 200W Hall thruster)
- As the general awareness of such propulsion system grows, so is the number of serious inquiries – mission planners “get it”!
- Hence investment to mature BIT-3 system and perform life test is needed (~$1M)
- Busek has all necessary talents, equipment and facilities to bring the BIT-3 system to flight

Thank You