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Electric Propulsion System for CubeSats - Hardware, Test Results and Current Development Activities

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Overview

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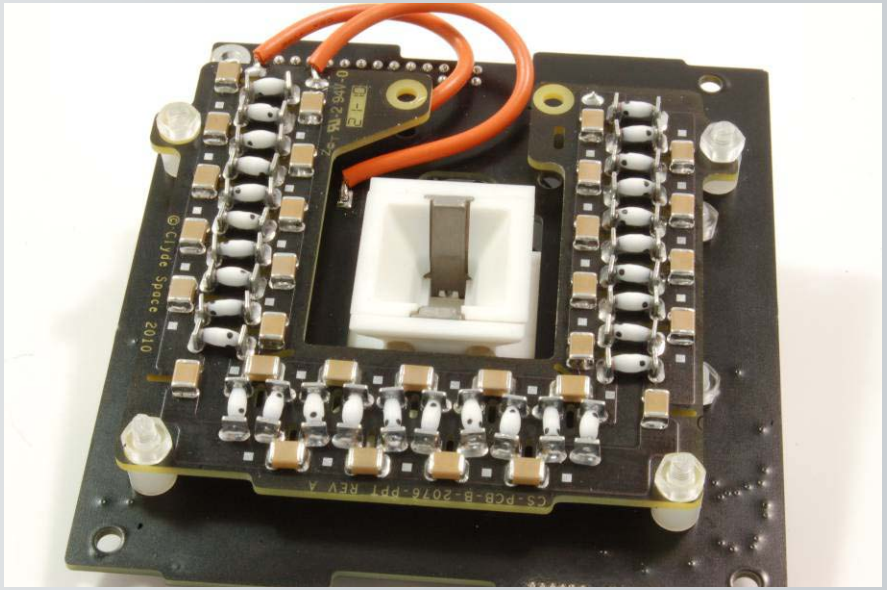
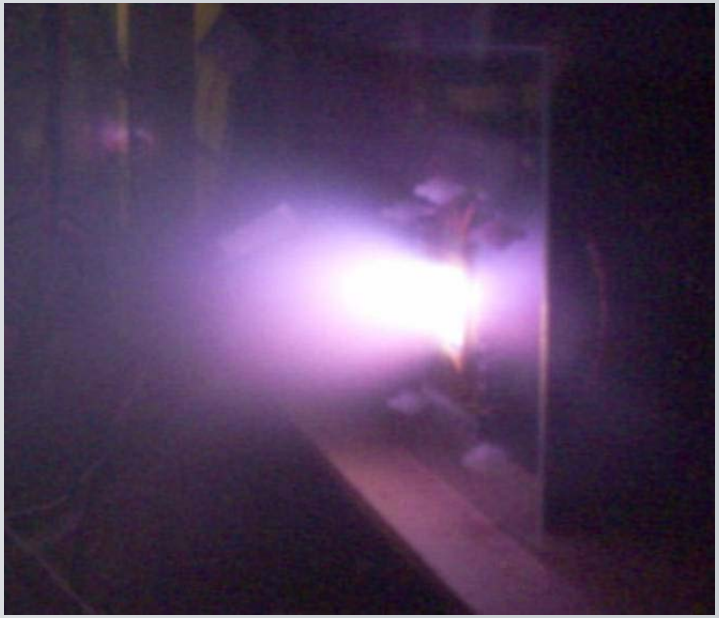
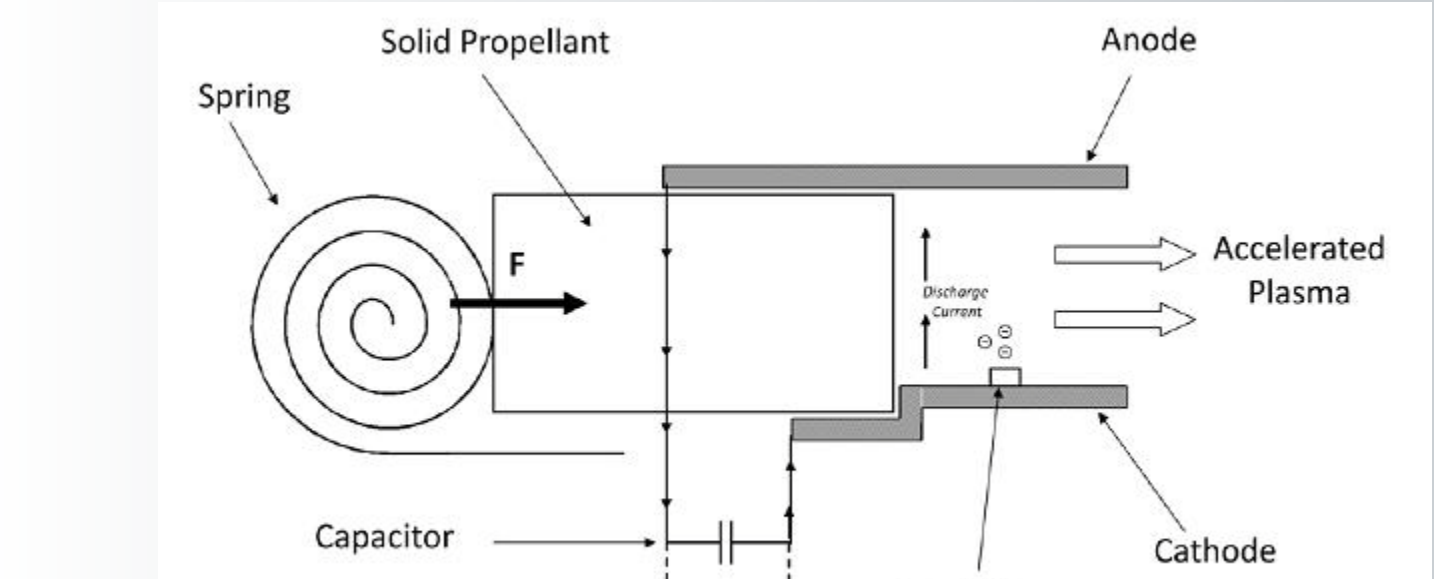
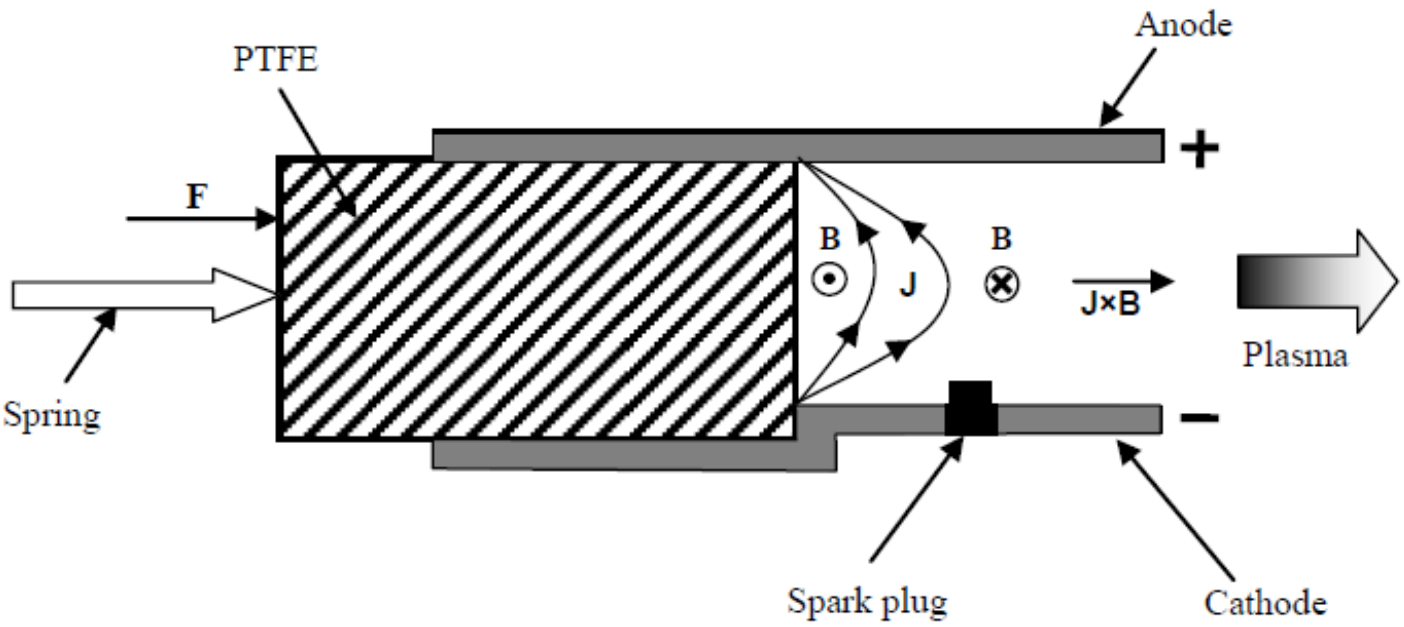
- Introduction
  - What is a PPT
  - Why PPT on cubesats
- Mission Requirements Definition
- Design
  - Discharge Chamber
  - Electronics
- Testing
  - Voltage and current curves
  - Impulse bit, mass bit, specific impulse
  - Vibration Test
  - Capacitor Selection
- Future work & Conclusion





what is a PPT ?


Solid Propellant
Anode
Spring
F
Accelerated
Plasma
Discharge
Current
Capacitor
Cathode


Anode
PTFE
+
F
B
J
B
J×B
Plasma
Spring
−
Spark plug
Cathode

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why PPTs ?

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Cubesats have no orbit control hence lifetime limited by drag deorbiting

Cubesat are normally into LEO orbits with a lifetime of some months up to some years

Need for highly scalable propulsion system

Pulsed Plasma Thruster (PPT)

Project Objective

Double a Cubesat lifetime compensating atmospheric drag

Mission Requirements

- ***A 3U Cubesats was analyzed for drag compensation on a nominal 600Km orbit***

- ***Dimensions***

  - Thruster assembly to be mounted on a PC104 PCB card with maximum volume is 90x90x27 mm
  - the thrust is directed along the 27mm direction
  - PCB 104 card has a thickness of 1.6 mm, hence maximum discharge chamber length is 25 mm

- ***Mass***

  •3U Cubesat mass is 3 kg. Hence the whole thruster assembly will be limited to 150 g (margins included).

  •The propellant (Teflon) mass will be limited to 10g.

- ***Performance***

  •Assuming c_D=2.2 on the total impulse needed to fully compensate drag will be 28.4Ns.

  •Considering a propellant mass of 10g, translates into a minimum specific impulse of 290 s.

- ***Power***

  •Maximum average power consumption limited to 0.3 W

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Discharge Chamber

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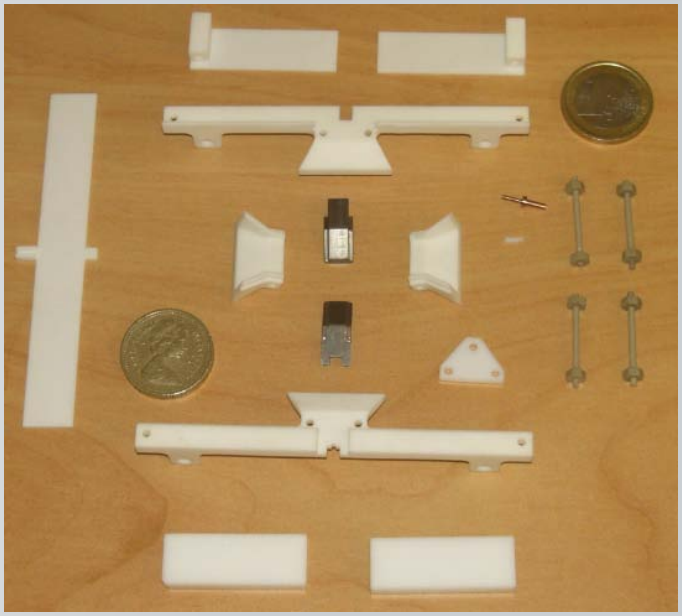
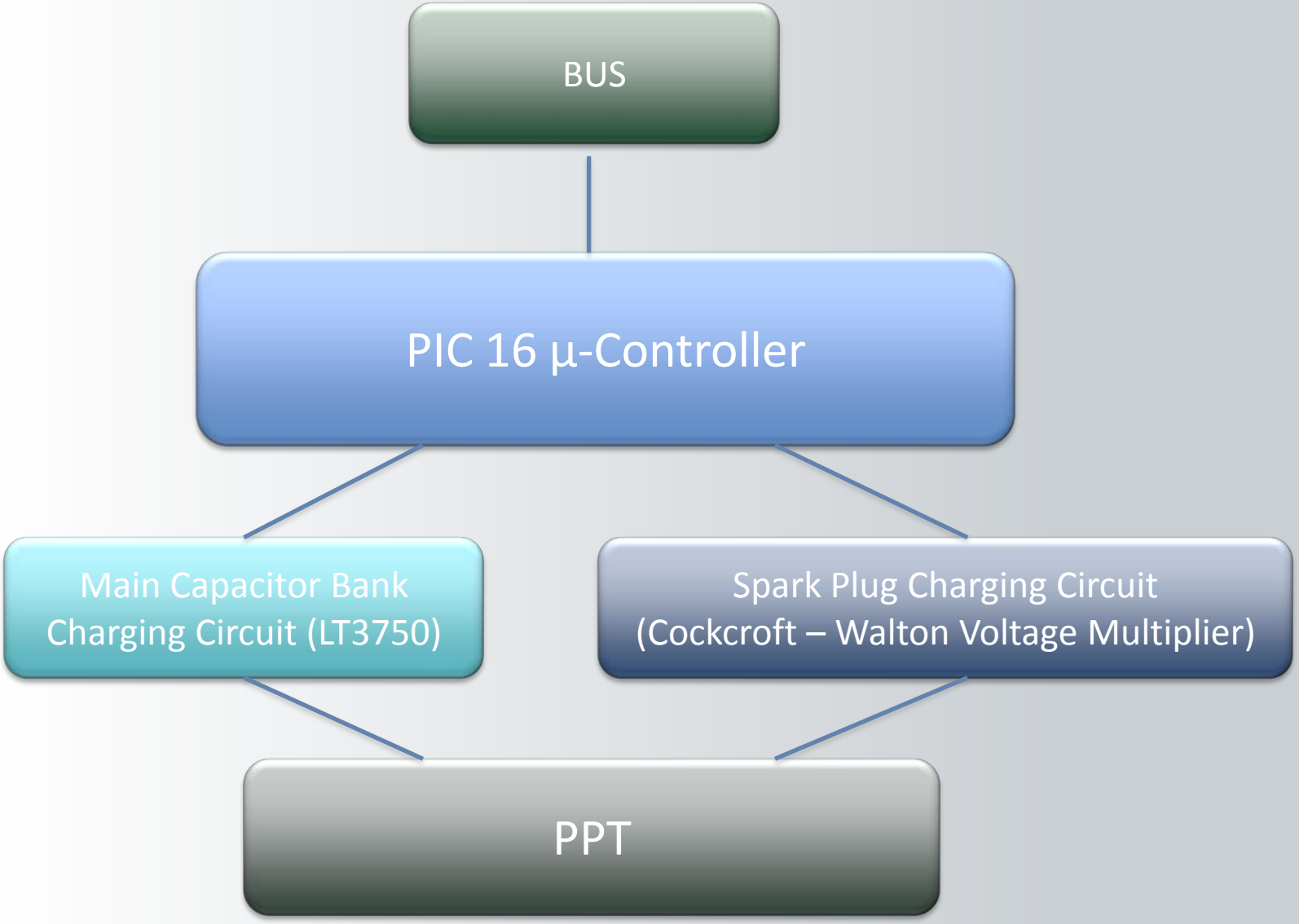
- Given the volume restrictions the PPT will have a side fed configuration
- The main driver for Isp is the E/A ratio
  - The propellant area A will drive the maximum amount of propellant that can be stored
  - The shot energy E will drive the capacitor mass
  - A value of 2 J/cm^2 has been chosen
- A propellant mass of 7.7g has been used equivalent to a minimum Isp of 400s
- An energy of 2J has been selected
- The PPT is expected to produce a specific impulse of 500s



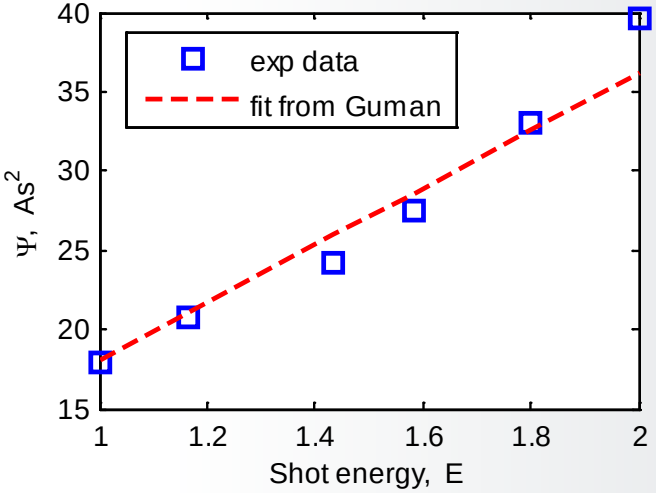
Electronics

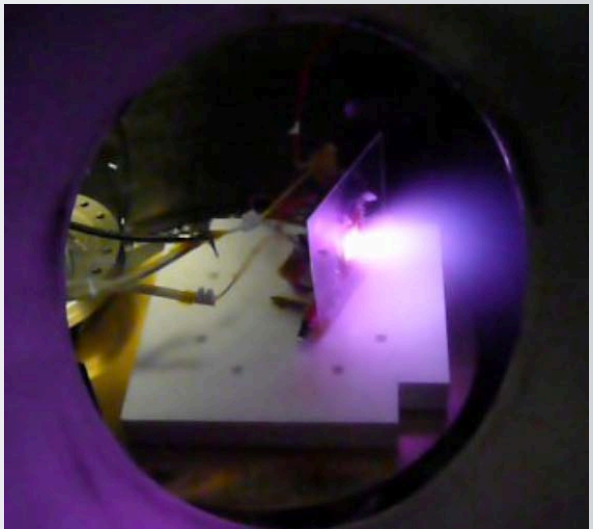


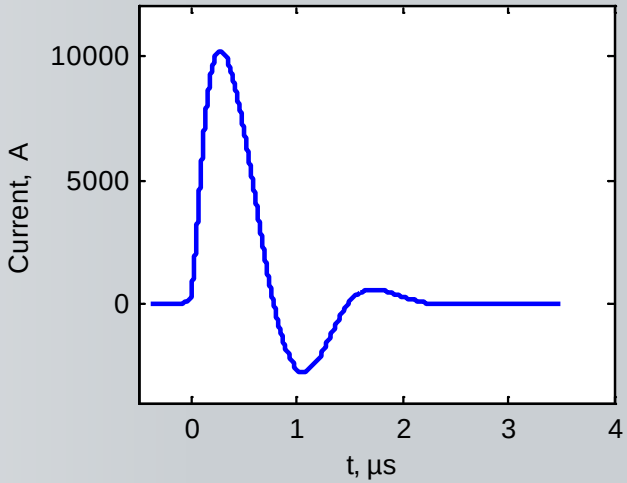
Discharge curves

- The thruster have been tested in the University of Southampton facilities
- The tests have been performed with a high inductance capacitor bank
- The spark plug showed reliable ignition from 3kV
- Current curves have been measured to have a damped oscillatory discharge behavior
- Ψ trend with E is found to be linear and in agreement with the formula reported by Palumbo and Guman

$$\Psi = 1.3\sqrt{\frac{C}{L_0}}E$$







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I_{bit} and Isp

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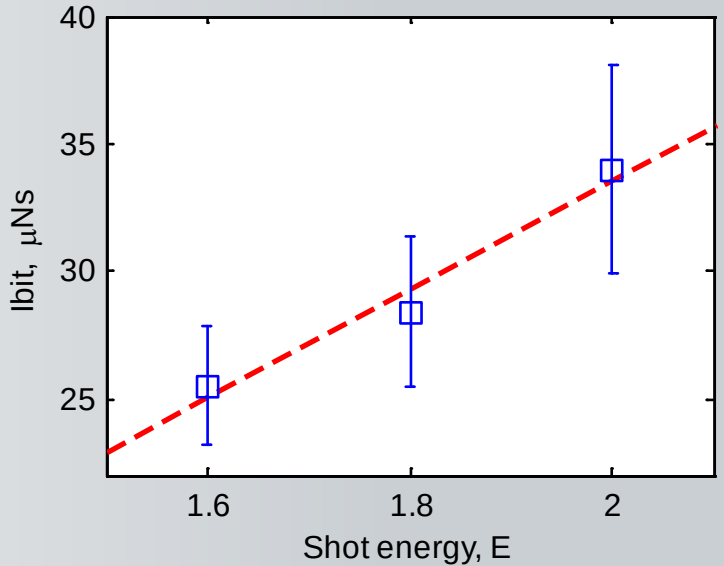
- Impulse bit measurements have being carried out at Institute of Space Systems, University of Stuttgart, Germany
- An Ibit of 34 μNs @ 2J has been measured
- Electromagnetic forces contribute for 30-50% of the total thrust
- Mass measurements have been performed at 1.8J of energy finding that 4.8 μg per shot
- This corresponds to an **Isp of 590s** (in comparison to a required 410s)
- Considering the available propellant a **total impulse** of **44Ns** can be delivered



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Launch Enviroment

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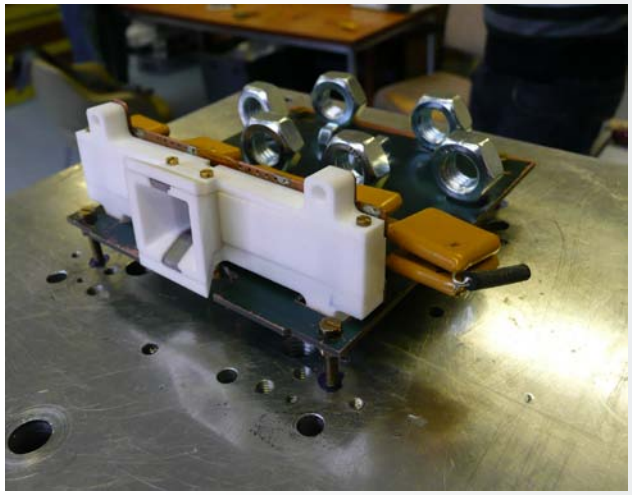
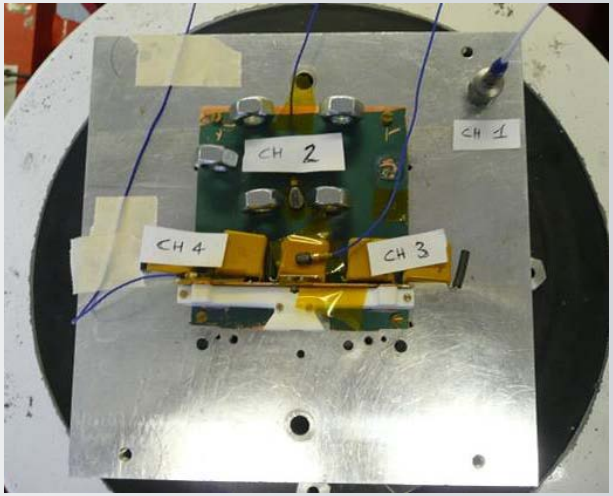
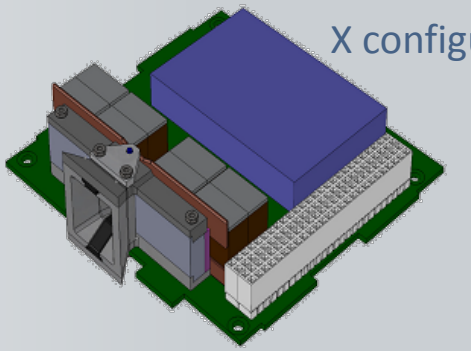
- Three configurations have been produced for UKube1
- The discharge chamber has been tested on a Y configuration mock-up to verify its natural frequencies and resistance to the launch loads

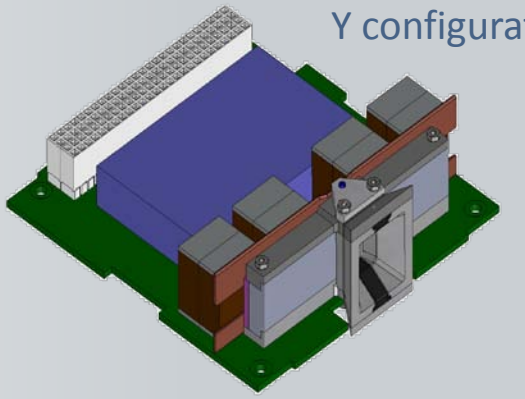




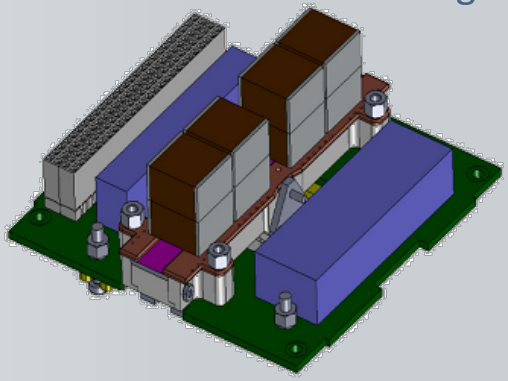
X configuration



Y configuration



Z configuration



- The natural frequencies have been found to be all in agreement with the UKube1 requirements
- The discharge chamber showed no sign of structural damage

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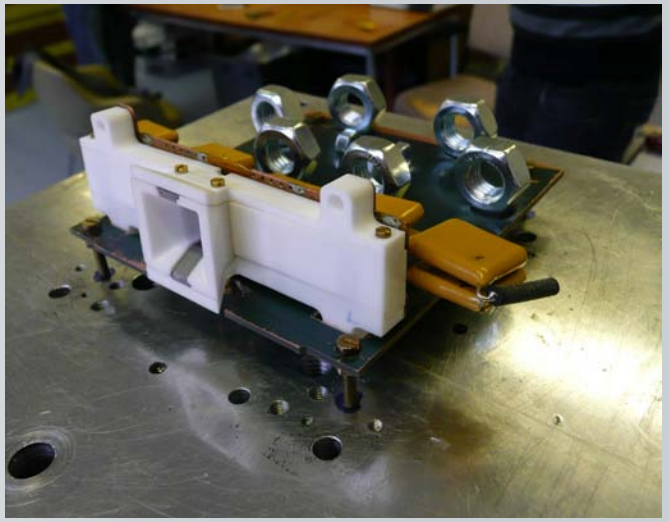
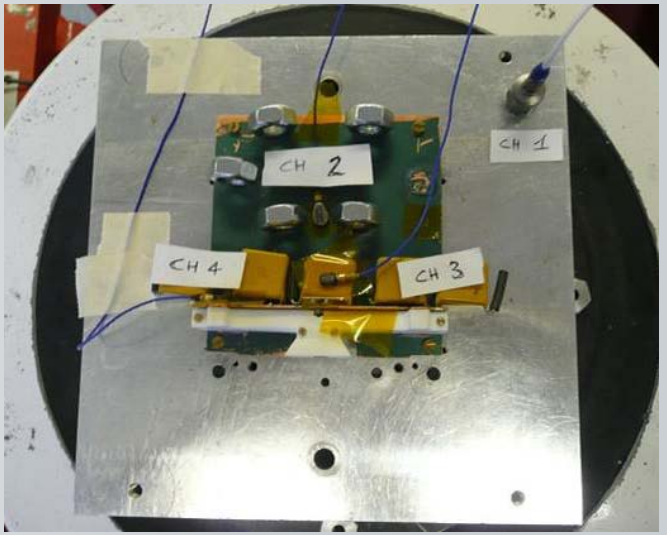
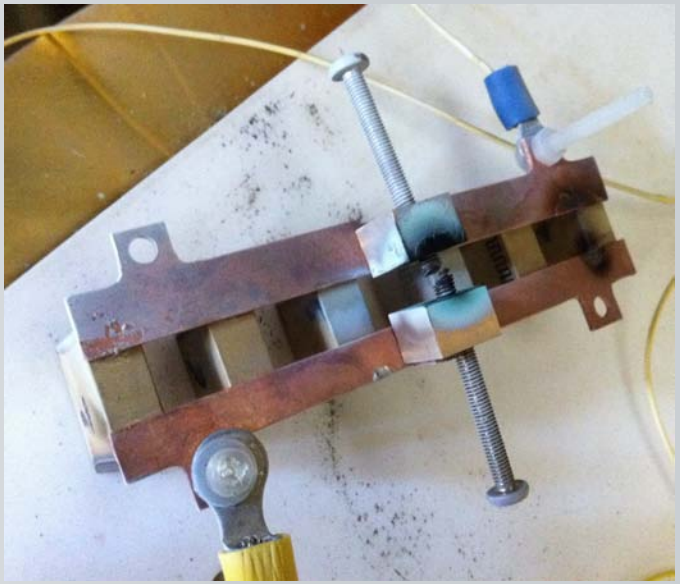


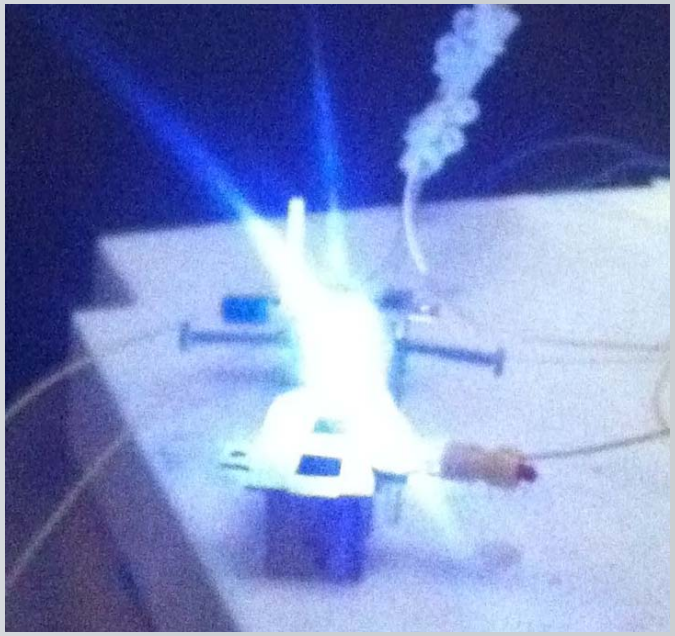


UKube 1 "flight" component	Vibration test component	Comments
Discharge chamber	ITI spare discharge chamber	Fully representative
Busbars	ITI spare busbars	Fully representative
Capacitor bank	ITI spare "test" bank	Representative volume. Weaker connection to the busbars. Higher mass.
PC104 board	COTS PCB	representative
Electronics	Dummy mass	Representative in terms of mass

Capacitor lifetime

- Candidate ceramic surface mount capacitors have been lifetested
- They have been mounted on busbars identical to the one used on the PPT connected to dummy electrodes
- The have been fired at a frequency of 2Hz with a charge voltage of about 80-100% of their rating
- Analysis of the discharge showed current levels in excess of 5kA
- The capacitors have up to now completed more than 2,000,000 shots without failure and/or degradation in performance





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PPT capabilities

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Altitude	Average orbit power for drag compensation	CubeSat Size	Natural Life	Life with μPPT	Life increase
250 km	2.4 W	1U	5.7d	17d	+200%
		2U	11d	22d	+100%
		3U	17d	28d	+66%
300 km	0.7 W	1U	21.6d	58d	+170%
		2U	1m 13d	2m 19d	+85%
		3U	2m 4d	3m 11d	+56%
350 km	0.26 W	1U	2m 8d	5m 21d	+150%
		2U	4m 16 d	8m	+75%
		3U	6m 24d	10m 8d	+50%
400 km	0.1 W	1U	6m 12d	1y 3m	+140%
		2U	1y 1m	1y 10m	+70%
		3U	1y 7m	2y 4m	+46%
450 km	0.04 W	1U	1y 5m	3y 3m	+133%
		2U	2y 10m	4y 8m	+67%
		3U	4y 2m	6y	+44%

100 cm^2 area, cD=2.2 NRLMSISE-00 atmosphere

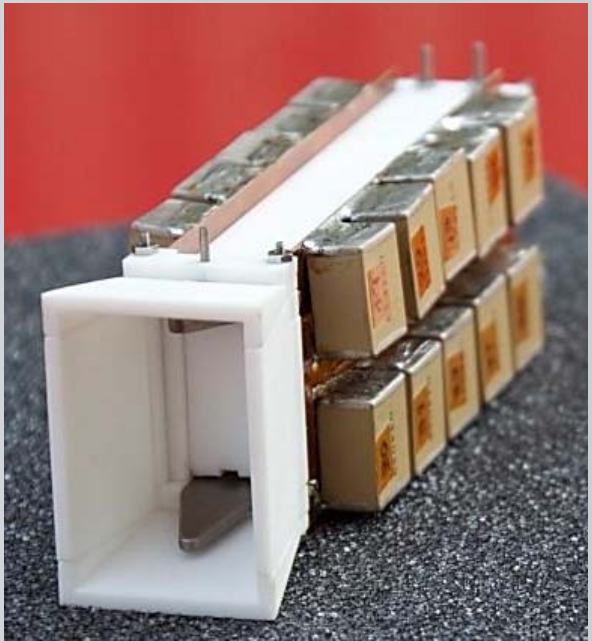
Present Work

Cubesat PPT (PPTCUP)

- A new PPT design has been produced with the aim of increase lifetime.
- New lighter capacitors has been found and are at present undergoing life-testing
- An updated electronics design has been produced and a breadboard prototype produced. The prototype is being currently being tested
- A thrust balance has been assembled and preliminary testing has been concluded. The balance will have an accuracy of 1μNs and will allow for measuring the PPT performance in house.

Nanosat PPT (NANOPPT)

- System of 6 PPTs to provide attitude control to 20Kg nanosats
- Each PPT: 500g mass, 140Ns total impulse, 2W, about 0.7U in volume
- The Nanosat PPT is currently being tested at the university of Southampton



Conclusions

- A PPT able to provide a total impulse of 44Ns with a specific impulse of 590s a maximum volume of 90x90x27 mm and a maximum mass of 180 g has been designed, built and tested
- The spark plug showed to work properly from 3kV onwards with respect to a maximum capability of 15kV
- The PPT measured performance are in excess of the requirement and sensible to further improvements
- Considering the measured performances the PPT is able to provide an orbit semi-axis change of up to 35 km on a 3U cubesat
- The PPT can be used to help the satellite de-orbiting
- A full qualification program has already stated with the aim of
  - Reducing the PPT mass (mainly operating on the spark plug circuit)
  - Verifying lifetime
  - Performing Full vibration qualification
  - Performing an assesment of EMC (even if the literature,EO-1 mission, indicates it should not be a problem)