TECHNOLOGY
FOR PROPULSION
AND INNOVATION

REGULUS

A simple, affordable and versatile solution to make your satellites dancing

Space mobility needs?

2019/2020

A BRIEF HISTORY

REGULUS is an innovative propulsion system resulting from more than 100'000 hours of engineering work and testing.

THE KEY FEATURES

REGULUS is a simple, versatile and affordable all-in-one propulsion unit based on a magnetically enhanced RF plasma technology.

WHAT CAN YOU DO LATER?

REGULUS opens up new and unconceivable mission scenarios and applications, such as VLEO maintenance, phasing, rising or formation flying.

REGULUS

Simple
Versatile
Affordable
Designed for smallsats

THRUSTING A DIFFERENT FUTURE

A brief history of Regulus

When we started in 2006 we were willing to develop propulsion systems with the potential of changing the world. We immediately recognized that, on one side, the market was full of high-performance motors designed to serve big satellites. On the other side, we saw that small Sats have the capability to make a real change. Nonetheless we noticed as well their strong limitations connected to the lack of suitable propulsion units compatible in terms of cost, size and performances with small Sats. In this context, we started looking into the problem and we realised that Radio Frequency-based thrusters could become an excellent option thanks to their intrinsic simplicity. In 2006 we started the first numerical studies on this new propulsion system within a project funded by the European Space Agency. In 2008 we coordinated a big European Consortium, in 2013 worked in scaling up the technology, and finally in 2016 started developing our first product. Since the beginning our approach was more practical than academic, and we had clear in mind that only simple things succeed. Our technology was born with a final target, binding together theoretical and experimental physics, theoretical analyses, experimental outcomes and system engineering. With the dream to see our propulsion system flying, we also developed our own code and dedicated innovative experimental set-ups. Thanks to this approach and to the dedication of the whole team, after thousands of hours of testing, we can proudly present our product REGULUS!

2006 – 2008

PRELIMINARY EXPERIMENTS

- First test bed
- 1-D code

2008 – 2012

FIRST PROTOTYPE

- Leading EC Consortium
- 3-D code
- New Technology
- First EM

2012 – 2015

GO TO HIGH POWER

- New materials
- Updated configuration
- Thrust balance
- First in-house RF-PPU

2015 – 2019

GO MINI

- Miniaturized PPU
- Miniaturized electronics
- EM, QM, FM

2020

LET'S FLY!

- IOD Q2/Q3 2020
- UniSat-7 mission
- Soyuz

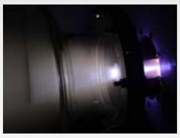
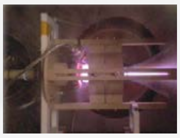
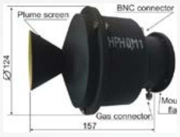
A brief history of me

DANIELE PAVARIN, CEO

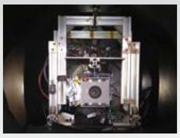
I started my PhD in 1997, at a time when nobody was fascinated by space propulsion in my University: surely my boss was not really happy about my passion. However, since life is too short not to follow a real passion, and after an intriguing experience in developing from scratch hypervelocity accelerators, I got the chance to work at the Oak Ridge National Laboratory in Tennessee, on the VASIMR program. Once back home I decided that I would have spent the rest of my life developing thrusters. After ten years of successful work in the hypervelocity field, once again from scratch, i founded a space propulsion group at University of Padua. With several former students, who are now my best colleagues, we established a new tecnology based on a new knowledge and finally we built up several motors. In 2014 I realized that the only way to really move forward and to go to space was to found a company and face the real market. That is where T4i started and that is why I am the CEO; only who has fought every day to make dreams real can lead people with enthusiasm towards the unknown.

REGULUS DEVELOPMENT STEPS

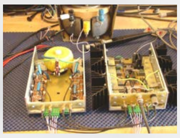
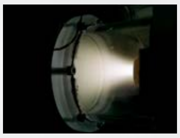
From TRL2 to TRL6 and beyond



Milestone	Results	Test	TRL	Time	Budget
M1. First Engineering Model (EM) released (Thruster)	A 50W power, 2 kg mass, S-Helicon thruster was built and extensively tested in a vacuum chamber for performance characterization.	Current measurements (400hrs). Thrust measurements (10hrs). Thermal tests (50hrs).	4	2012	2M
M2. Second engineering model (Thruster)	A 400 W power, 2 kg mass, S-Helicon thruster was designed and developed, extensive testing on a thrust stand.	Current measurements (200hrs). Thrust measurements (200hrs). Thermal tests (50hrs).	5	2014	200k
M3. Power Processing Unit Laboratory model (RF power electronic)	First Laboratory Model of the Power Processing Unit was designed, developed and tested.	Standalone electrical tests (50 hrs). Tests with thruster (50hrs) Vacuum tests (50 hrs).	4	2014	100k
M4. Optimisation of EM (Thruster)	The thruster was optimized to achieve lower mass, size and complexity. It was possible to achieve different thrust levels with very limited modifications. The thruster performance was increased and mapped with an extensive test campaign.	Thruster performance tests (Current + thrust measurement) (100 hrs).	5	2015-2016	100k
M6. 3r EM released (Thruster)	The third Engineering Model of the mini S-helicon system for micro satellites was manufactured and extensively tested.	Thrust and current combined test in vacuum (100 hrs).	6	2017	200k
M7. First Iodine fluidic laboratory model	An Iodine tank and a fluidic system suitable for micro satellites was designed and tested in a laboratory version.	Vacuum tests (50 hrs).	5	2018	200k

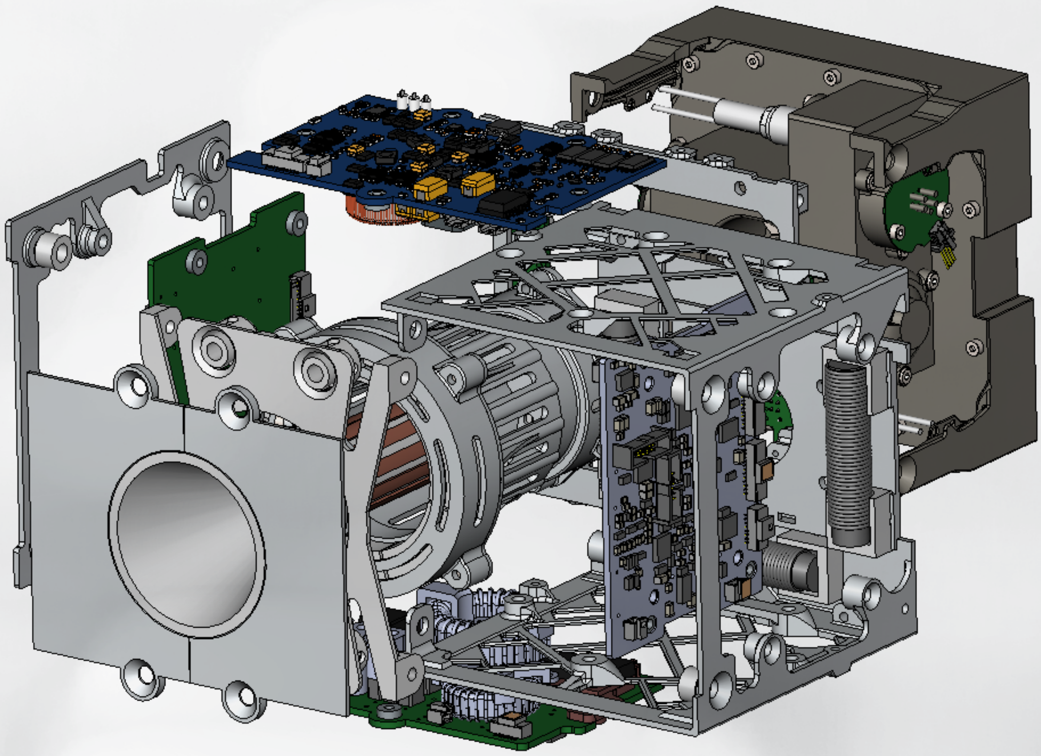




Milestone	Results	Test	TRL	Time	Budget
M8. Full scale EM manufactured and integrated (propulsion package)	Full scale thruster assembly including Power RF conditioning, control electronic and Iodine feeding line was designed, developed and tested.	Thruster performance tests (Current + thrust measurement) 100 hrs). Vacuum tests of electronic (50 hrs).	5/6	2018	400k
M9. Qualification Model (proto-flight) development (Propulsion package)	A Qualification Model is testing (Thermal Vacuum, Vibration, Electro- Magnetic-Compatibility, Life).	Performance tests (30 hrs). Vibration/thermal vacuum/EMC tests (100 hours). Life tests (500 hrs).	6	July 2019	300k
M10. Flight Model development (propulsion package)	First Flight Model will be developed and tested @ acceptance level (vibration, thermal vacuum).	Performance tests (10 hrs). Vibration/thermal vacuum/EMC @ acceptance level tests, (100 hrs).	7	Oct. 2019	200k
M11. Final Assembly	Regulus assembly into UniSat-7 dispenser.	Integration check tests.	7	Dec. 2019	200k
M12. In-Orbit Demonstration	Regulus will undergo a complex mission scenario with UniSat-7 (Soyuz launcher) after all of the host spacecraft will be delivered.	Unisat-7 orbit raising, orbit lowering, orbit maintenance @400km, @300km, decommissioning. Estimated mission duration 2 months with full thrust.	9	Jun. 2020	100k

KEY FEATURES

REGULUS

- Radiofrequency based
- Patented technology
- Iodine (I_2) fed
- Plug and Play design
- First Flight in 2020



MAIN COMPONENTS AND CHARACTERISTICS

- Discharge Chamber
- RF antenna
- Magnetic System
- Feeding system
- No Electrodes
- No Neutralizer
- No Erosion
- Multiple gases

The Thruster

The concept was initially based on the helicon technology. The idea was attractive: neutral plasma is accelerated into space; thus the system does not require a Neutralizer. Moreover, the acceleration takes place because of the interaction between the Electromagnetic Field of the antenna and plasma, thus the technology does not require electrodes. These two features make this system unique and particularly suitable for micro satellites, because they allow the development of low cost and reliable systems capable of using innovative propellants.

A helicon-based system is composed by very few elements. A ceramic discharge tube is surrounded by an antenna and by a magnetic system and a feeding system feeds the motor with its propellant. Since the neutralizer is not necessary, the motor requires only a single feeding line. The magnetic system can be made by coils or permanent magnets and needs to be compensated to avoid spurious magnetic moments. Moreover, the motor needs to be shielded to avoid electromagnetic interferences.

MARCO MANENTE

PLASMA PROPULSION MANAGER

"When I started to work to my Master Thesis with prof. Pavarin I discovered the world of electric propulsion. After some theoretical study, during my PhD, Daniele ask me to try to ignite the first plasma thruster at Padua University. At that moment it sounded crazy because no previous plasma experimental experience was never tried in aerospace laboratory at CISAS. Anyway the challenge and the reward were exiting: my passion for sailing to reach distant horizons were merged into my work! I started coding and designing thruster for space exploration.

My researches on plasma systems and the exploitation in REGULUS have turned to space in the spirit of the explorers of new worlds. "

FABIO TREZZOLANI

THRUSTER DESIGNER

"I have been a part of Professor Pavarin's research team since 2010 and I can tell you: since then, I never, never had a single boring day. T4i comes from this little crazy, dynamic and, yes, a little chaotic reality I have long been a part of, in fact I have personally taken part in its birth and first steps with my work! My main activity (and passion) have been since the beginning electric thrusters, which I develop as a designer and test engineer.

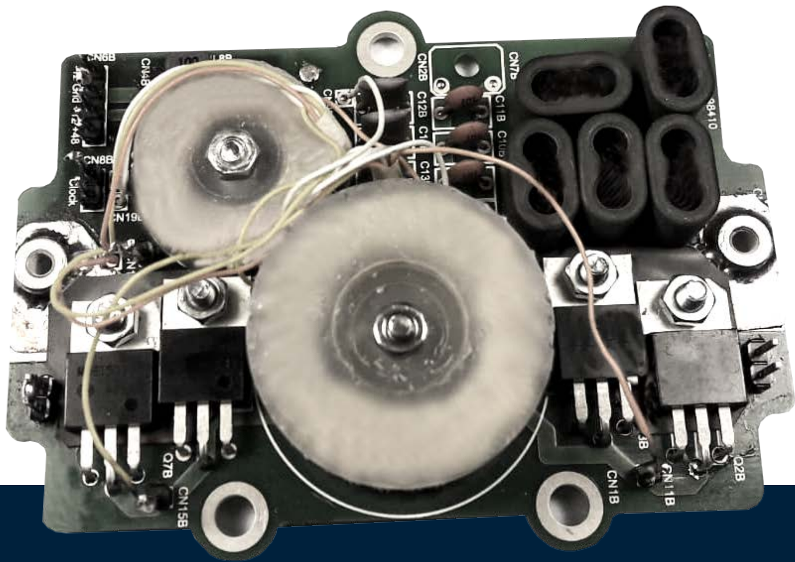
I am also the responsible of laboratory testing at our electric propulsion facility... meaning that any new idea sparking from our team sooner or later becomes work for me!

As the main designer of the miniature magnetically-enhanced plasma thruster, I am proud that it has become the heart of our REGULUS propulsion system!"

REGULUS KEY SUBSYSTEMS

The PPU-RF

Once people start developing thrusters, they first think that the motor has the priority, while the Electronics is considered a trivial subsystem that has nothing to do with real motor performances. But in the end the cold shower arrives when they realize that power electronics is complicate and expensive, and it might be a killing factor for the entire motor.
From the very beginning our approach was to see the motor and its electronic as a unique system. The choices regarding the antenna configuration had to consider also the feasibility of the final electronics package. Every choice about the thruster was done having in mind its impact on the electronic design. Moreover, we also manufactured our Power Processing Unit in-house, since we realized that costs were becoming excessive and not compliant with the product itself, making it less competitive in the market. We started very early in developing innovative electronic concepts. Our leading requirements were: (I) the capability of working with components easy to find on the market (COTS), and (II) robust layouts. The first model with the size of a shoes box was developed in 2015. Finally, after several models we ended up with a very compact device and high efficiency board, able to provide 50 W @ 1.5 MHz.



ANTONIO SELMO

R&D SENIOR ENGINEER

"Me and Daniele have always collaborated on complicated and challenging things, and my electronics has always supported his ideas. During the development of REGULUS I pushed hard to make T4i's team understanding the fundamental aspects and requirements of an electronic package suitable for satellites. I am proud to say that I contributed in making them better engineers, and in making Regulus a beautiful product."

DEVIS PAULON

ELECTRONIC ENGINEER

"I began this journey with my master thesis on the REGULUS electronics. From then, I joined T4I continuing the development of REGULUS electronics together with Antonio Selmo. I enjoy the troubleshooting of this complex system, in aim to make this product working at its best."

Iodine Feeding lines

At the very beginning, REGULUS was based on Xenon and it was working just fine. Nevertheless, we realized that a pressurized propellant such as Xenon, despite its operational simplicity, brings several critical aspects during the transportation and integration phases, which may drastically increase the final cost of the propulsion system. Moreover, in order to provide a very high total impulse, Xenon needs to be in a supercritical state, therefore introducing thermal control issues during the transportation and pre-launch phases. Iodine, thanks to its very high density and its solid state at room temperature, solves all the issues mentioned above, allowing the thruster manufacturer to deliver a motor already filled with propellant.
Despite its remarkable advantages, Iodine is an aggressive oxidizer with a lot of compatibility issues. To make operational the mass flow rate control system, we had to undertake a huge development effort, solving dozens of engineering problems. The final result is an unpressurized system with a simple layout capable of a very high total impulse.

RICCARDO MANTELLATO

PROJECT ENGINEER

"Iodine? Yeah right, why not Plutonium? This is what I answered when I was told I had to design a brand-new fluidic system to feed the new baby born at T4i. Half kilogram of highly corrosive propellant to be heated up at high temperature, a tiny mass flow rate that resembles the breath of a mosquito to be delivered with the strictest tolerance, unavailability of COTS, the need of advanced 3D-printing and machining techniques, countless little irksome problems to be solved, all packed up in less than half litre of space. Oh, and mind it: it must be cheap and ready in short time. Well, after all, why not? "

NICOLAS BELLOMO

REGULUS PM

"I work with Daniele since the beginning of my PhD and I am the CTO of T4i since 2017. I've always loved challenging things, and since I started working with Daniele every day was much tougher than the previous one. In T4i I can see my dreams being shaped and become reality."

First we make satellites dancing, later you can do...

SATELLITE POSITIONING

- In-plane maneuvers (e.g., orbit raising, decommissioning)
- Out-of-plane maneuvers (e.g., inclination changes, line of nodes)

SATELLITE STATION KEEPING

- Drag compensation in LEO, Orbit phasing, low Delta-V
- Formation flight, continue or periodical operations

CUBESAT CARRIERS POSITIONING

- In-plane maneuvers (e.g., orbit raising, decommissioning)
- Out-of-plane maneuvers (e.g., inclination changes, line of nodes)

EXAMPLES OF MISSION SCENARIOS

	Orbital changes	CubeSat decommissioning	Drag compensation
REGULUS-A Configuration	6U orbital changes* for a total of 500 km altitude in 1.7 months	6U decommissioning** from 750 km altitude in 1.6 months	6U 3 years life guaranteed @ 300 km 6U > 5 years life guaranteed @ 350 km
REGULUS-B Configuration	12U orbital changes* for a total of 950 km altitude in 6 months	12U decommissioning** from 1200 km altitude in 6.0 months	12U > 6 years life guaranteed @ 300 km
Notes	*Still propellant onboard for formation flying and/or decommissioning*	*Natural orbital decay of 1 month considered @350 km*	*1U life of 21.6 days @ 300 km without a propulsion system on board*

* Departure orbit @ 500 km
** Final orbit @ 300 km

Our Team

Our team comes from Research and Development, which means that every day people wake up in the morning aware that they will have problems to solve that probably nobody has solved before, and that they might have to do it by night. This is our soul, and we carry on with this determination in whatever we do.

DANIELE PAVARIN

CEO

He is the one who initiated the technology and who now is leading the company to conquer the market, "because life is too short not to make dreams come true."

NICOLAS BELLOMO

CTO

After more than ten years spent on making evrey type of thruster and motor work, he is now the robust backbone of the company.

ELENA TOSON

BD MANAGER

From a big company to a PhD, falling in love with the emotions of a start-up, she is now the vibrating core of the business development of T4i.

FRANCESCO BETTELLA

PRESIDENT

He is the president of T4i. He comes from a great experience of successful founding and leading a big company. He is now back to the challenges of a start-up.

MARCO MANENTE

PLASMA PROPULSION MANAGER

He is the responsible for the thruster research and development. He is the theoretical pillar of the company.

FABIO TREZZOLANI

THRUSTER DESIGNER

After more than ten years in testing many different types of plasma thrusters, he is the leading engineer in design and testing.

Our Company

MISSION

We bring space closer to look further
We develop innovative engines to serve small satellite platforms. We work with creativity, determination and commitment to open unexplored mobility forms to small satellites and unlimited windows to access space.

VISION

We dream the day when each of us will have a personal satellite to move in space and to look at the Earth with new eyes.

APPROACH

More than being a thruster provider we are willing to become a partner for our customers, to help them better understanding the criticalities related to a propulsion unit and how to get the best from it.

VALUES

- Creativity: We believe in creativity as the engine to make dreams real.
- Team: We believe in the team as the core element where diversities converge in a unique, strong and unified identity.
- Ethics: We believe in ethics as harmony among people, companies and society.
- Determination: We believe in unconditioned determination as the mean to tear down all the obstacles.
- Sustainability: We believe in human, economic and environmental sustainability to ensure next generations' future.

Internal Facilities

T4i has its own thermal vacuum equipment for environmental tests and a small electrodynamic shaker for testing components at subsystem level, because testing is everything....

External Facilities

T4i is supported by the facilities of the Center of Studies and Activities for Space (CISAS) of University of Padua, particularly: (I) Thrust balance facility, (II) Electro-dynamic-shaker for tests at system level, (III) White chamber.

Prizes

2016
- first place at Padova Innovation Day

2018
- 1st place at · Italian Master Startup Awards

2019
- 1st place · Social Competition – Instant Future
- Finalist Le Fonti Awards 2019
- 2nd place INNOspace Masters - OHB Challenge

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