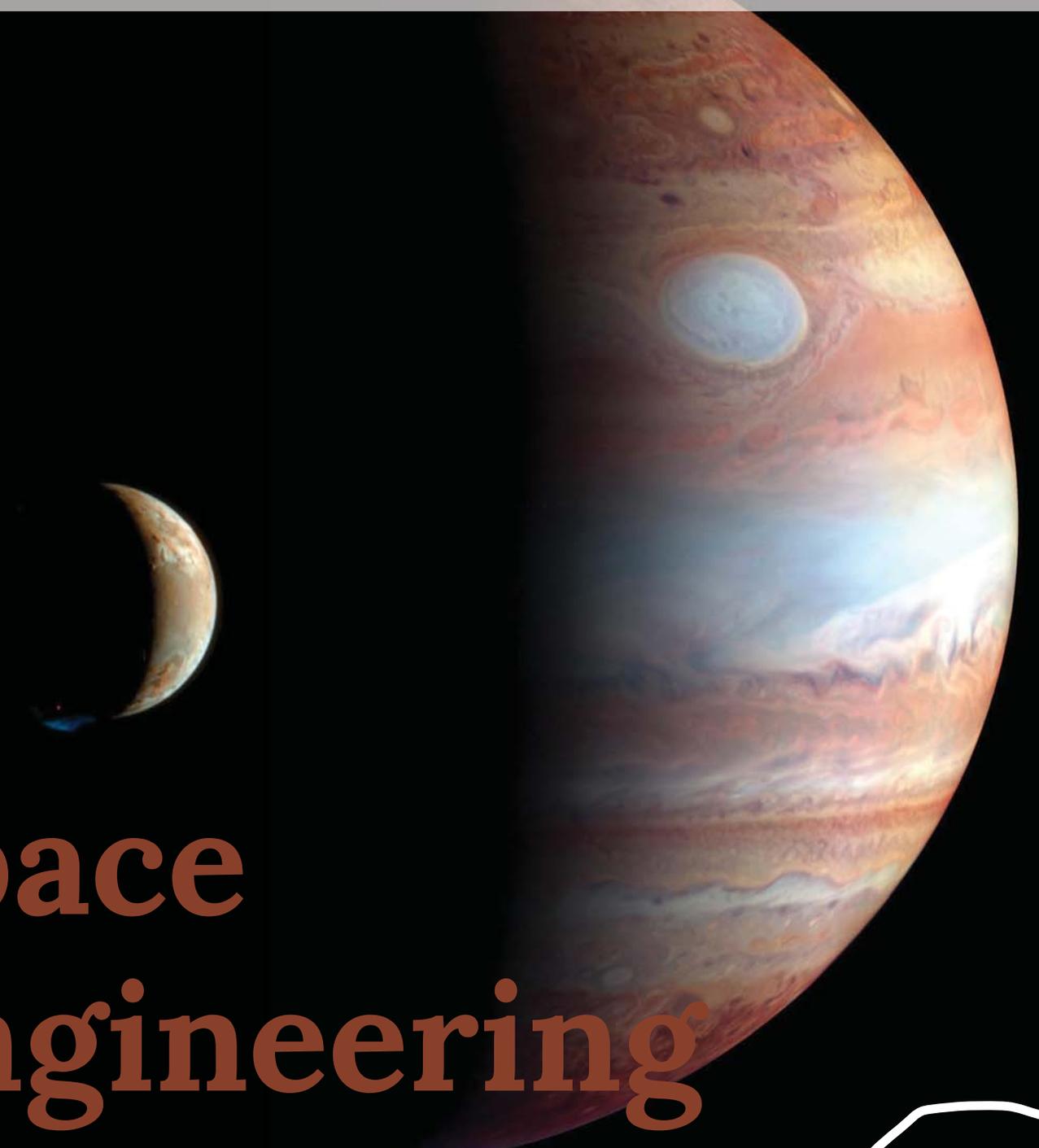# Maxwell

Space Engineering

TRXVU transceiver
Cubesat communications

DESHIMA
Cosmology with nanotechnology

Em. prof. dr. Jens Arnbak

is op 20 februari 2017 op 73-jarige leeftijd overleden.

* 10 december 1943
te Aarhus

20 februari 2017
te Den Haag †

Emeritus professor Technische Universiteit Delft en Eindhoven
Erelid der Electrotechnische Vereeniging
Eerste voorzitter van OPTA
Ridder in de Orde van de Nederlandse Leeuw

De heer Arnbak is van onschatbare waarde geweest voor de tele-communicatie en heeft zich sinds 1991 intensief ingezet als Erelid van de Electrotechnische Vereeniging. Tot op de dag van vandaag zijn wij hem hier dankbaar voor.

Ons medeleven gaat uit naar zijn vrouw Fleur Arnbak – d'Aulnis de Bourouill, zijn familie en alle betrokkenen.

Editorial

Once upon a time there was a big bang. Well, let me rephrase that. At the beginning of times there was a big bang. Fast forward a few years, say, a couple billion, and then there's us.

The sun, stars high up in the sky, our moon; we all explain it by the most wonderful stories. Then, as time goes on and technology allows looking further than our naked eye allows it, we discover, piece by piece, that it isn't that simple.

In an ever expanding universe, full of apparent emptiness, there seem to be uncountable numbers of planets, stars and galaxies.

By expanding our vision to wavelengths beyond our own capabilities, whole other worlds appear. Unsurprisingly, these worlds beyond earth supply plenty of fascinating topics.

In this edition of the Maxwell we dive into this with a diverse selection of articles, ranging from the detectors used in 'space science', to planetary defense. Furthermore: red-shift measurements with nanotechnology, cubesats, solar winds and DARE.

Tristan Wieffering
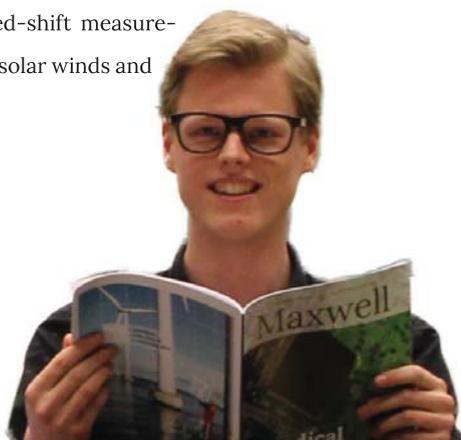
07 The next generation detectors for Space Science
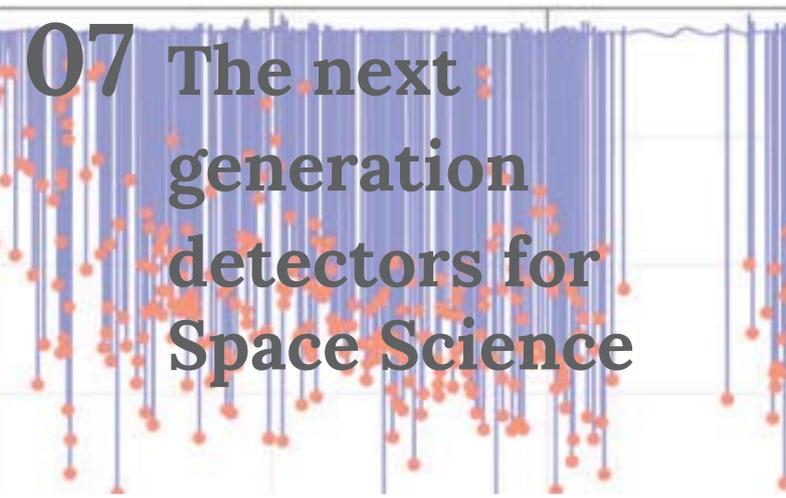
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16 DESHIMA

20 TRXVU Trans-ceiver

24 FLARE

30 cm

20 cm

10 cm

Sparrow ADCS

Lasercom Avionics stack
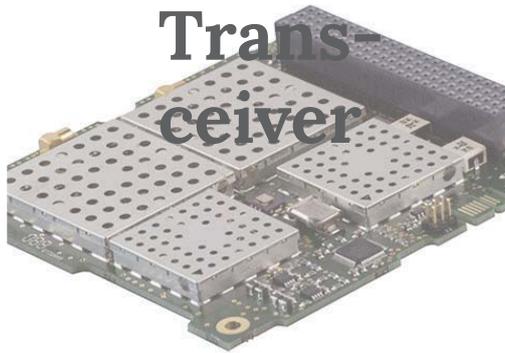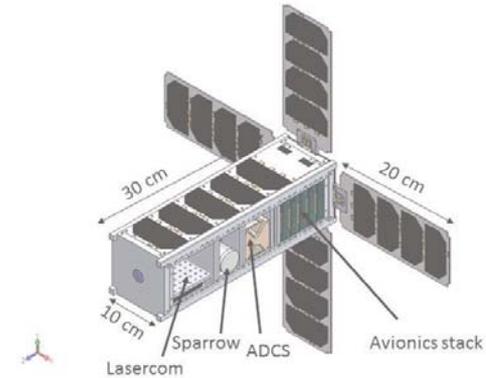
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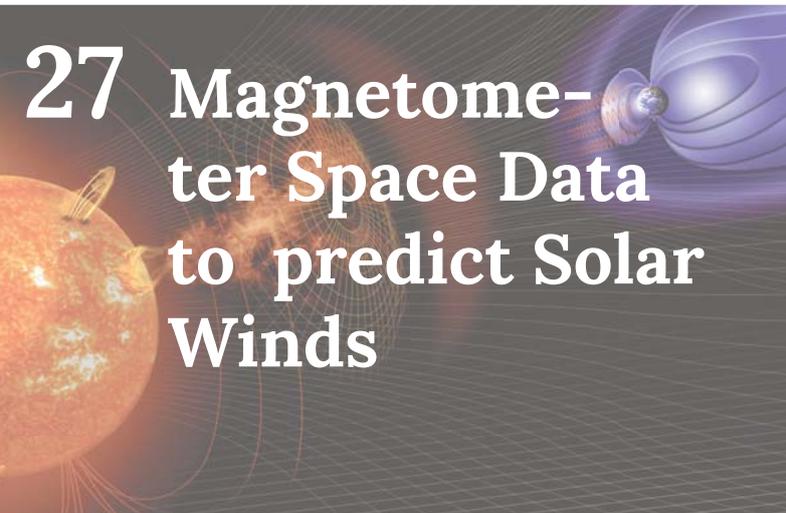
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From the board

Commissioner of Education

Lucas Enthoven

Hello everyone,

Again some updates from education-land! This time with a big update on Brightspace. Currently, the faculty of Industrial Design has largely shifted from Blackboard to Brightspace. This conversion started in February holiday and is still ongoing, without any significant hitches and people seem to be quite satisfied with the conversion. There are still some bugs in the new platform and some people are not able to find their regular courseware, but no big problems have arisen, and the current support provided is very good. This means that if everything goes according to plan and if there are enough student assistants to help, the entire TU Delft campus' shift to Brightspace this coming September will happen without problems, which is good news!

We are also considering playing a role in supplying high school graduates with information on the Bachelor in Electrical Engineering. Currently, a lot of information is provided via the Studiekeuzecheck and via open days. Together with the Director of Studies and Communications, we are looking into possible new ways to supply students with information. We want to ensure that everyone can easily find the information he/she needs and can understand the ins and outs of pursuing a degree in Electrical Engineering without too much effort. This will be combined with an update of the website.

In order to evaluate the quality of education, the standard approach is to gather students at a lunch session (during which lunch is provided of course!) and ask for feedback on courses. However, getting people enthusiastic about education evaluation has proven to be troublesome every now and then. That is why Education & Student Affairs together with the Commissioners of Education of EEMCS are looking into newer ways of evaluating education which require less effort on the part of students, while still providing the same level of feedback.

Finally, third year students who have followed a minor somewhere else are now returning to their trusted EEMCS building to come and study Electrical Engineering again. In this Maxwell issue, some of their experiences with their minor will be shared. If you are interested in finding out about more experiences, feel free to visit the ETV website.

Treasurer

Francesc Varkevisser

For the third edition in this year's Maxwell cycle, I was asked to give an update from the board. Spring 2017 has arrived! I for one am definitely excited for the upcoming outdoor activities!

While I write this, preparations are underway for one of our biggest yearly events: The EEMCS Recruitment Days, during which students get in contact with interesting companies. This year's edition is already considered a success since almost 500 students signed up for the event!

On a different note, earlier this quarter a group of 27 students went to Germany on Electrip to visit 6 big companies/institutions: Daimler, TU Darmstadt, BMW, Nokia, NXP and ESA. The trip was a big success, and both the students and companies were very excited about the visits. Furthermore, the yearbook committee is busy making this year's edition. The book will be presented at the Yearbook karaoke during our Dies celebration week. We expect to have a lot of fun and interesting activities so make sure to keep the second week of April free in your calendar!

The next generation detectors
for Space Science

Jochem Baselmans

Since the Dutch invention of the telescope, our understanding of the universe has been enormously enhanced. However, many questions remain that can only be answered by new instrumentation. Astronomy is a science that has always benefitted enormously from advances in technology.

SpaceKIDs was a 3 year project, funded by the EU, including 5 university groups and 2 industries from 4 countries. The goal of the project was to summarize the generic needs for future space-based scientific missions and to build a laboratory based demonstrator attaining these requirements. We considered two concepts:

i) an imaging instrument for far infrared astrophysics and

ii) a spectroscopic instrument for ice cloud measurements on earth. The astrophysics application was technologically the most interesting, so we focus on this one.

One of the key questions in astrophysics is the nature of the far infrared background, consisting of all radiation emitted in a 30µm - 300µm wavelength band. This radiation contains half the radiated energy of the universe. It is poorly studied for two main reasons:

- The earth atmosphere blocks virtually all radiation from reaching even the highest telescopes

- The detector technology is not mature

The solution to these 2 problems seems obvious: make a space-based telescope such as Hubble and make detectors that are sensitive enough to detect the background radiation of the universe itself. We call this method background limited radiation detection. This is not as simple as it seems at first hand: Any object emits thermal radiation, even the mirrors of a space telescope, and they need to be cooled to a temperature below 4K (-269°C) to bring this radiation below the radiation flux of the universe itself. So we have to make Hubble with a big refrigerator cooling its optics. Additionally, the detectors have to be very sensitive. Background limited radiation detection gets harder as the background power ➤
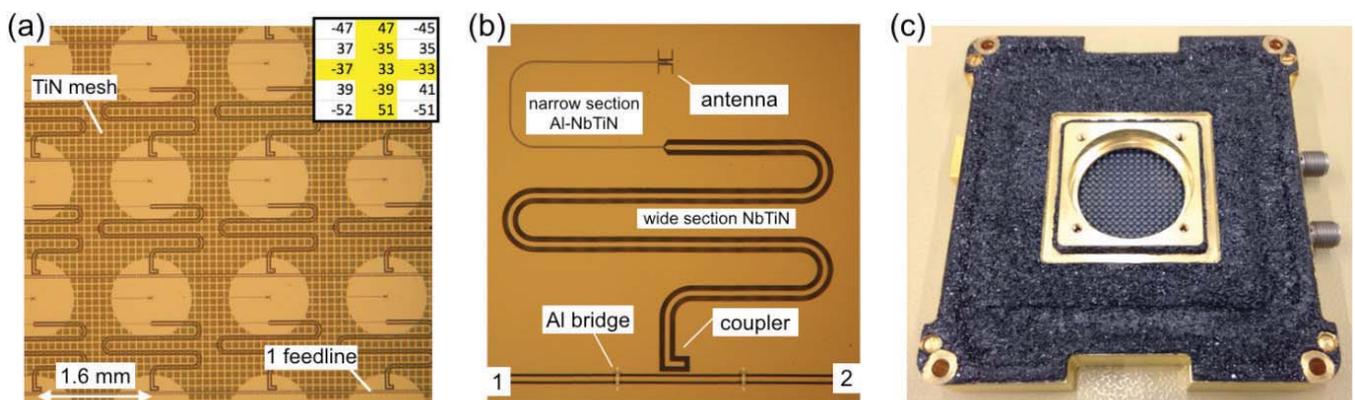
Figure 1: (a) Photograph of a section of the chip, taken from the backside of the transparent wafer where the lens array will be mounted, showing the MKIDs seen through the wafer. Also visible is the absorbing mesh layer, with the holes to allow the antenna beams to couple efficiently to the lenses. Note that all meandering resonators have a slightly different length to allow them to be read out at different frequencies. (b) Zoom-in on a single MKID detector, photographed from the front side of the chip. (c) Photograph of the chip-lens array assembly in its holder, with the lens array clearly visible. We can only illuminate a fraction of the pixels of the array.
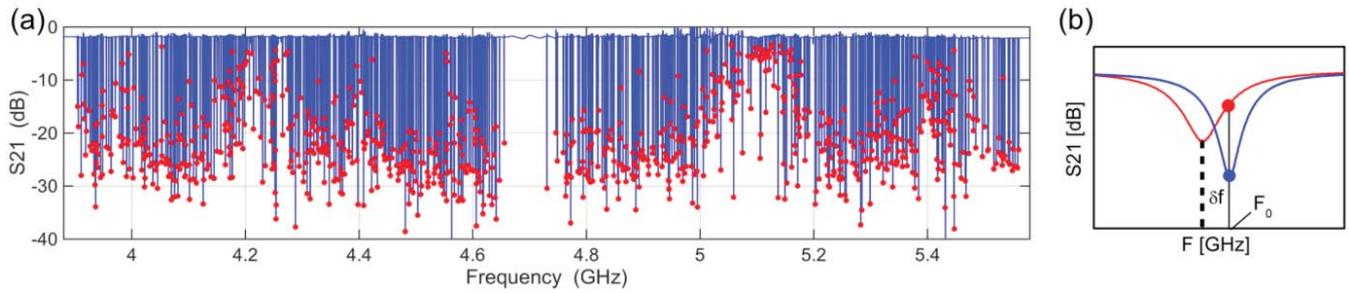
Figure 2: *(a) Measured data of the transmission of the readout line of the chip shown in figure 1 at 0.12 K inside a test cryostat. Each dip corresponds to an individual pixel. (b) Response to radiation of a single pixel, reading out the pixel at a single frequency F_0 will transform the measured change in resonance feature into a change in transmission at F_0.*

gets lower. For a detector in the far infrared operating in our super cool(ed) telescope the power falling on a single pixel is about 50 aW, i.e. $50 \cdot 10^{-18}$ W. This is only possible with superconducting detectors operating at 0.1K above absolute zero (-273°C). At the start of the SpaceKIDs project only 2 technologies had shown a sensitivity approaching background limited detection for such low power levels. Out of these two, we choose the so-called Microwave Kinetic Inductance detectors, because with these detectors it is much easier to make large arrays.

For the demonstration system we set ourselves a few key requirements which are representative for an imaging instrument on a future, cooled telescope:

•   array size on the order of 1000 detectors

•   data loss due to interactions with cosmic rays <10%

•   radiation detection from 1.4 – 2.8 THz, with a backup option of 800-900 GHz

•   dynamic range $>10^4$

•   background limited sensitivity for powers >50 aW, which means the detec-

tor noise equivalent power NEP$<5 \cdot 10^{-19}$ W/√Hz.

To put this work in perspective MKID technology at the start of the project had shown only single pixel result over a narrow bandwidth, with NEP = $2 \cdot 10^{-18}$ W/√Hz.

The final demonstrator array is shown in figure 1 and consisted of 961 MKID's all using the same design twin slot antenna with a small lens for radiation coupling. This design allowed efficient radiation

coupling over 800-900 GHz, but is relatively easy to manufacture. An individual MKID is a meandering, shorted coplanar transmission line coupled to a common feedline. Adjusting the MKID length allows it to be read out at a different frequency, as shown in figure 2.

Radiation detection in a MKID will change the resonance feature and thereby the transmission of a readout signal at a frequency F_0. To read out the entire array we build a readout system that can generate
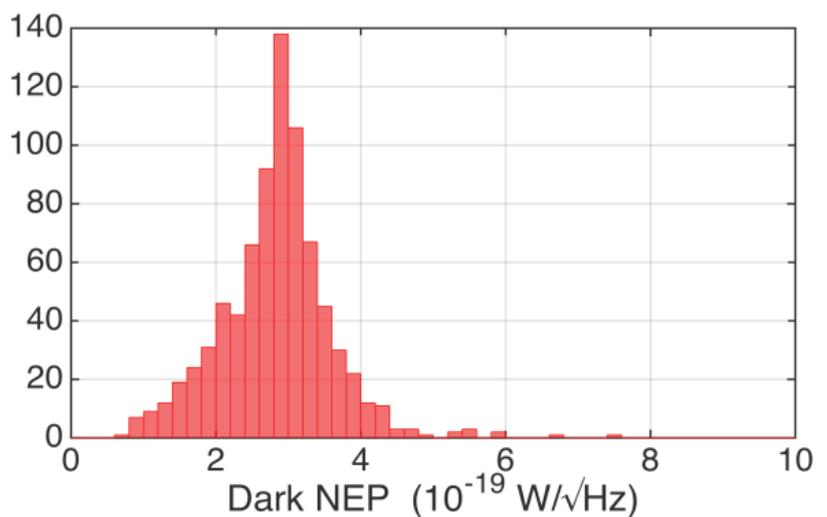
Figure 3: *Histogram of the chip sensitivity.*

and detect up to 4000 readout tones at specified frequencies. This readout is like 1200 network analyzers operating simultaneously, with a refresh rate of 156 samples/sec. The readout system makes ✈ this only possible by using ultra-fast ADC and DAC chips coupled to very large FPGA chips for data processing.

In figure 3 we show the measurement of the limiting sensitivity of the large chip, readout with the aforementioned readout system. This is the central result of the project, showing that we can reach the required sensitivity for a large imaging system, that is not just the chip, but also all its associated cooling and readout systems.
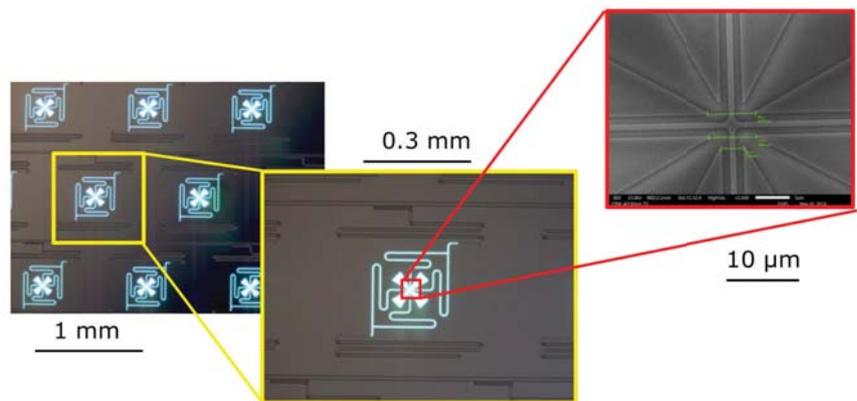
Figure 4: *Small array of leaky-wave antenna coupled MKIDs. The image is made on an optical microscope with front and backlight. The antenna structure is made on a thin, transparent, membrane, the rest of the chip on a thick Si wafer. This highlights the antenna. The top right image shows a zoom, indicating the small feature size and cross CPW feed of the antenna.*

The large imaging system fulfills also all other requirements for a future space-based imaging system and it is the most sensitive THz imaging system ever built.

However, the narrowband radiation coupling is not what we aimed for originally, but was chosen only for easier fabrication. In a parallel effort in the THz sensing group we developed a dual pole, broadband antenna operating from 1.4-2.8 THz. This so-called leaky wave antenna requires fabrication on a thin membrane making fabrication difficult. We did however succeed in making a small 27 pixel test chip, the images are given in figure 4. This antenna was recently tested and gives a similar sensitivity, but allows for dual pole radiation coupling over a broad bandwidth. ⌨

"The large imaging system fulfills also all other requirements for a future space-based imaging system and it is the most sensitive THz imaging system ever built."

Further reading:
For those interested the two main papers describing this work are:
J.J.A. Baselmans, J. Bueno, S.J.C. Yates, O. Yurduseven, N. Llombart, K. Karatsu, A.M. Baryshev, L.Ferrari, A. Endo, D.J. Thoen, P.J. de Visser, R.M.J. Janssen, V. Murugesan, E.F.C. Driessen, G. Coiffard, J. Martin-Pintado, P. Hargrave, and M. Griffin
A kilo-pixel imaging system for future space based far-infrared observatories using microwave kinetic inductance detectors
Astronomy and Astrophysics, prepublication (2017)
https://doi.org/10.1051/0004-6361/201629653
http://www.aanda.org/articles/aa/pdf/forth/aa29653-16.pdf

Joris van Rantwijk, Martin Grim, Dennis van Loon, Stephen Yates, Andrey Baryshev and Jochem Baselmans
"Multiplexed Readout for 1000-pixel Arrays of Microwave Kinetic Inductance Detectors"
IEEE Transactions on Microwave Theory and Techniques, 64, 1876 (2016)
http://ieeexplore.ieee.org/abstract/document/7445881/
http://arxiv.org/abs/1507.04151

Planetary Defense

How Engineers and Scientists Are Working to Prevent an Apocalypse

Farah Alibay, Aerospace Systems Engineer
Jet Propulsion Laboratory, California Institute of Technology

"Dinosaurs didn't have a space program." Most of us have seen the meme before: a friendly T-Rex staring up at the sky helplessly as a large asteroid hurtles towards Earth. As an aerospace engineer, I worry about the real threat of an impact from these celestial objects on a daily basis.

Yes, that's right, the main thoughts that usually accompany my morning coffee are not about the latest Kardashian gossip, or speculating about when it will finally stop raining in LA. My daily dose of caffeine fuels my brain to prepare for spending the day designing a potential mission to demonstrate an asteroid deflection technique. What exactly do aerospace engineers do to quietly prepare to save humanity from a potential apocalypse? The key to understanding our mandate to "save the world" can be decomposed in three parts: understanding the characteristics of potentially hazardous objects, mapping objects in our solar system and their trajectories to identify threats, and deflecting objects on a potential collision course with Earth.

Defining Potentially Hazardous Asteroids

First things first, let me reassure you: the international community is constantly monitoring the skies and there is currently no identified large object on a collision course with Earth. The scientific community has established two criteria for defining Potentially Hazardous Asteroids (PHAs) or Objects (PHOs). The first such criterion is the proximity of the asteroid's orbit around the Sun to that of the Earth. Any object whose orbit comes within 0.05 Astronomical Units (AU) of the Earth's or-
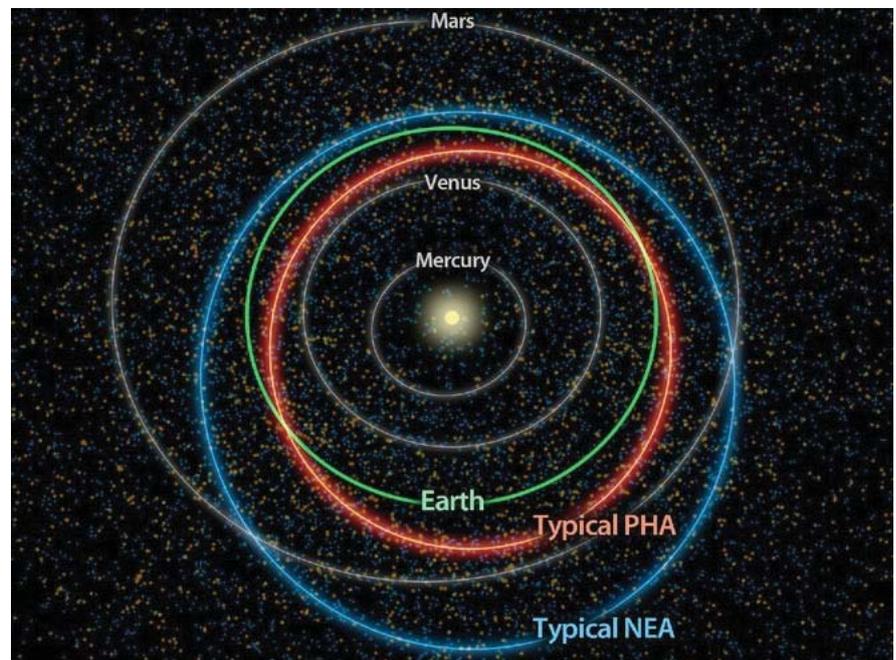
Figure 1: *This figure illustrates the differences between orbits of a typical Near-Earth Asteroid, or NEA (blue) and a Potentially Hazardous Asteroid, or PHA (orange). PHAs have two defining features: their orbit comes within 0.05AU of that of the Earth, and they have a diameter greater than 100 meters.*
Credit: NASA/ JPL-Caltech

bit is judged to be potentially hazardous (one AU is the average distance between Earth and the Sun). This is approximately 20 times the distance between Earth and the Moon. Asteroids and other objects in our solar system are tracked using various methods, which I will discuss next. For objects where we have obtained repeated observations, we are able to propagate the object's ephemeris (i.e. its celestial coordinates and path) for over a hundred years at high levels of confidence. By modeling potential errors and disturbances, we can therefore obtain a good understanding of the expected Earth impact probability of such objects within the next century.

The second criterion that defines a PHA is its size: in order to be a threat, the asteroid must be large enough to survive entry through Earth's atmosphere. The size of an object is typically defined by its diameter. However, for smaller distant objects with limited numbers of observations, the object's diameter can be difficult to estimate. Therefore, the scientific community typically uses Absolute Magnitude (H) [1], which measures luminosity on a logarithmic scale. This method places objects at a standard reference distance, where their luminosities can be compared directly on a magnitude scale; the more luminous (and therefore larger) the object, the smaller H is. More specifically, the Absolute Magnitude is defined as the brightness (or apparent magnitude) of the object if it were 10 parsecs (~30 light years) from the Earth. As a rule-of-thumb, objects with a diameter greater than 140m,
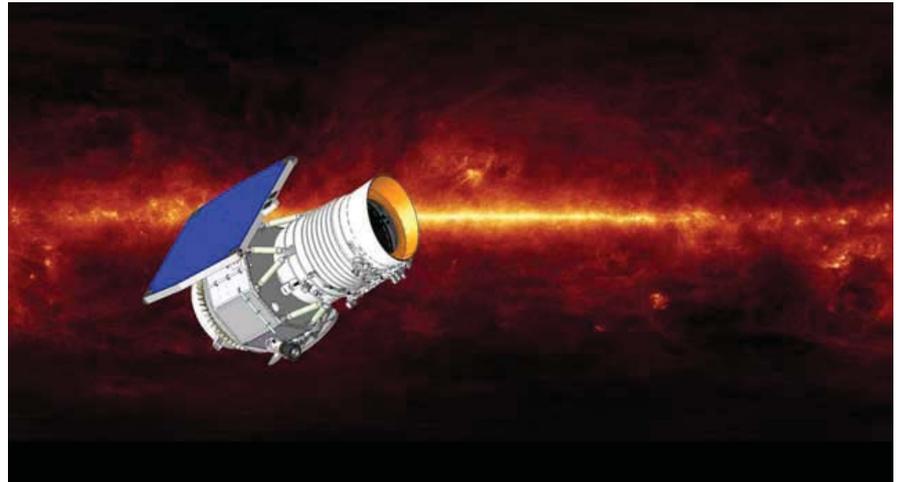
Figure 2: *Artist's rendition of the WISE spacecraft. Credit: NASA/ JPL-Caltech*

or H < 22, would cause regional disaster much greater than that of a nuclear bomb if it were to hit on land or an unprecedentedly large tsunami in the case of an ocean impact. Looking at larger objects, an impact by an asteroid with a diameter > 1 km, or H < 17, would cause global devastation, and possibly even the extinction of life on Earth.

It is currently estimated that there are approximately 5,000 PHAs, with around 30% of the population having been observed so far [2]. Of these, > 90% of the

continue our survey of the skies: the earlier the potential threat is identified, the longer we will have to prepare a mission to deflect it.

Detecting Asteroids

The orbits of asteroids and comets have been catalogued by the Minor Planets Center since 1947. Thus far, more than 10,000 asteroids have been documented, using a variety of ground observatories as well as space-based assets. One of the most prolific observers of Near-Earth Objects (NEOs) is the NASA NEOWISE

"Looking at larger objects, an impact by an asteroid with a diameter > 1 km, or H < 17, would cause global devastation, and possibly even in the extinction of life on Earth."

asteroids with a diameter larger than 1km have been identified. The challenge remains however to detect the asteroid population with diameters > 140 meters. One of the keys to protecting our planet from asteroid impact is therefore to

project, which is a clever continuation of the Wide-field Infrared Survey Explorer (WISE) mission [3]. WISE was launched in 2009, and spent its year-long primary mission surveying the sky in a variety of wavelengths. The NEOWISE project ✈

used the images from the spacecraft to deduce ephemeris and composition information on more than 158,000 objects, 34,000 of which were new discoveries. After it completed its search of the inner solar system and the frozen hydrogen cooling the telescope (to enable the longer wavelengths to be observed) was depleted, WISE was put in hibernation for two years. It was awoken from its deep sleep in 2013 for an ongoing extended mission. Thus far, the extended mission has mapped nearly 800 asteroids and NEOs, including discovering the PHA 2013 YP139.

While the NEOWISE program is soon coming to an end, NASA is currently studying a new potential mission: NEO-Cam [4]. The Near-Earth Object Camera mission's main goal would be to identify and characterize Near-Earth Asteroids, and assess both the risk of impact that they represent, as well as their suitability as future targets for human or robotic exploration missions. It would achieve this by performing a four-year sky survey using an infrared telescope and a wide-field camera operating at thermal infrared wavelengths; this heat-sensing camera could help us find even dark asteroids, which have thus far been the hardest to detect. The telescope would not only be able to measure the diameter of these objects, but also their ephemeris, shape, composition, and rotational state. The goal of the NEOCam mission is to achieve NASA's current mandate to identify >90%
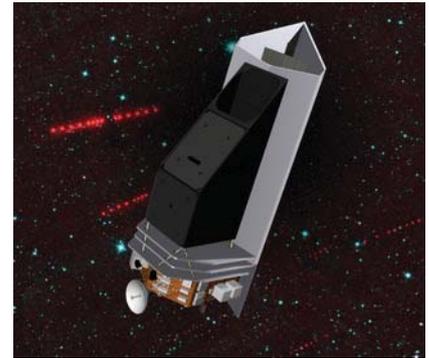
Figure 3: *Artist's rendition of the proposed NEOCam space telescope, which would survey the regions of space closest to the Earth's orbit, where potentially hazardous asteroids are most likely to be found. Credit: NASA/ JPL-Caltech*

of all NEOs with a diameter greater than 140m (H < 22). With the properties of

Asteroid Naming Conventions

When discovered, asteroids and other celestial bodies are given a name with the format "YYYY AB123," where YYYY is a year, AB are two letters, and 123 are one, two, or three numbers. An example is 1999 RQ36, which can be decoded as follows:

- YYYY is the year the body was discovered in. 1999 RQ36 was therefore discovered in 1999
- The first of the two letters indicate the half-month in which the asteroid was detected, where each half month is assigned a letter in alphabetical order and the letter I is skipped (A = Jan 1-15, L = Jun 1-15, Y = Dec 16-31, for example). Therefore 1999 RQ36 was discovered in the first half of September.
- The second letter and the numerical suffix indicate in what order in that half month the asteroid was discovered. The numbers indicate how many times (n) the A-Z sequence (excluding I) was cycled through, and the letter shows where in the n+1 sequence the asteroid was discovered. Therefore, 1999 RQ36 was the 916th asteroid discovered in that half month.

$$36 \times 25 = 900$$

Q is the 16th position in the A-Z cycle (17th letter in the alphabet, remove 1 for I)

$$900+16 = 916$$

1999 RQ36 was therefore the 916th asteroid discovered in the first half of the month of September 1999. Similarly, a hypothetical 2018 FL155 would be the 3886th body discovered in the second half of March 2018.

PHAs identified and their detection well under way, the one question that remains therefore is: what can we do if we discover an asteroid on a collision path with Earth, and how is the aerospace community preparing for this?

Deflecting Asteroids

Hollywood's favorite asteroid deflection method, as portrayed in the 1998 blockbuster *Armageddon*, involves the concept of detonating a weapon placed within or on the surface of an asteroid. In addition to deflecting the asteroid's path, this method supposedly breaks up the asteroid into smaller components, which would form a lesser threat for the planet. While this approach has great appeal for movies, it involves several challenges, including having to launch potentially dangerous explosives on a rocket, and not completely eliminating the risk of smaller asteroid fractions impacting the surface of the Earth and causing significant damage. Other concepts proposed in the literature have involved laser ablation, using a solar sail to propel the asteroid into a new orbit by taking advantage of solar pressure, or even "painting" part of the asteroid white or black to take advantage of the Yarkovsky effect (a force action on rotating bodies caused by the emission of thermal photons). There are two other methods, however, which have undergone detailed mission studies within the aerospace community.

The first such method is the concept of a kinetic impactor, which is particularly effective for smaller asteroids (< ~500-me-

Figure 4: *Artist's concept of NASA's potential Asteroid Redirect Robotic Mission capturing an asteroid boulder before redirecting it to an astronaut-accessible orbit around Earth's moon. Credit: NASA/ JPL-Caltech*

ter diameter). This involves using another massive object, such as a spacecraft or a small NEO, to impact the PHA and knock it off its collision course with Earth. The Asteroid Impact and Deflection Assessment (AIDA) mission concept is an international study for a mission that would perform and detect such a deflection [5]. The target for this mission would be Didymos, a binary asteroid system composed of a bigger (~800 meter) asteroid orbited by a smaller one (~150 meter). Didymos is not a PHA, therefore making this potential mission simply a technology demonstration, which would be safe for the Earth. The concept would be to send an orbiter, the Asteroid Impact Mission (AIM), which would orbit the asteroid, followed by an impactor, Double Asteroid Redirection Test (DART), which would impact the smaller asteroid at high relative velocity (> 2 km/s). AIM would be present during the impact to measure the change of ephemeris of the smaller asteroid as well

as, long term, that of the larger asteroid in the binary system. Furthermore, this mission would allow the community to establish how the plumes and craters are formed during such impact, as well as to evaluate the composition of the exposed material. These properties would enable us to better understand the efficacy of the kinetic impact approach, as well as potential uses beyond planetary defense, such as for asteroid mining or other scientific applications. While this method would be particularly practical if an asteroid impact with Earth was imminent, one of the current limitations of such an approach is the randomness with which the impacted asteroid might be deflected; without full knowledge of the asteroid size, mass, and composition, the effect of the impact cannot be accurately modeled, which could potentially lead to the risk of a PHA being on a more dangerous path than it previously was if such a method is used. ✈

The second method is called a "gravity tractor". This method is typically proposed for larger (> 500-meter diameter) asteroids and involves basic principles of physics to move an asteroid slowly over time. It is therefore a very accurate method, with much lower risk of inadvertent negative effects than the kinetic impact method, but it does require early detection of a PHA. The method uses a heavy robotic spacecraft that would hover close to the asteroid and gravitationally pull the asteroid into a different orbit using the mutual attraction between the spacecraft and the asteroid. In order to avoid the spacecraft impacting with the asteroid from this attraction, a constant thrust must be applied to offset the gravity pull on the spacecraft. A NASA mission concept called the Asteroid Robotic Redirect Mission (ARRM) [6], in which I have been personally involved, proposed a mission which would demonstrate this planetary defense method. The mission would propel a ~5 ton spacecraft using Solar Electric Propulsion (SEP) to a benign asteroid, nominally 2008 EV5. Once at the asteroid, the spacecraft would pick up a boulder from the surface of the asteroid, thereby increasing its mass and forming an

"enhanced gravity tractor." It would then spend some time in the close vicinity of the asteroid, using its Hall thrusters to offset the gravity pull from the asteroid, and thus deflecting the asteroid's path and demonstrating the gravity tractor technique. Once the deflection demon-

ensure that the spacecraft would have enough resources and fuel to complete its mission in the allocated time while being robust to unforeseen events once in flight. Therefore, every day at work, a cup of coffee in hand, I plan a mission that may someday demonstrate one of

"It is both an honor and absolutely terrifying to be part of a worldwide team of engineers and scientists working in the field of planetary defense."

stration is completed, the spacecraft would return the boulder to a passively safe orbit around Earth's Moon, where astronauts could rendezvouz with it to retrieve samples for detailed analysis on Earth.

As an aerospace engineer working at the Jet Propulsion Laboratory, my role on the ARRM concept team is my personal contribution to the field of planetary defense. As the Mission Planner, my role has been to plan the daily activities of the spacecraft during operations, based on constraints both from the flight system point-of-view and that of the ground crew operating the spacecraft. I also

the key methods by which we could deflect a large PHA, if such an asteroid were discovered. It is both an honor and absolutely terrifying to be part of a worldwide team of engineers and scientists working in the field of planetary defense. While it is no easy task to make sure that potentially hazardous asteroids are detected and characterized, and that we are prepared to deflect such PHAs if one is found to be on a collision course with the Earth, rest assured that there is a large team of *"rocket scientists"* across the globe working to avoid an asteroid-induced apocalypse! But if the zombies take over, sorry… we can't help you. ⌨

[1] http://www.minorplanetcenter.net/iau/lists/Sizes

[2] https://www.jpl.nasa.gov/asteroidwatch

[3] http://neowise.ipac.caltech.edu

[4] http://neocam.ipac.caltech.edu

[5] https://www.nasa.gov/planetarydefense/aida

[6] https://www.jpl.nasa.gov/missions/asteroid-redirect-robotic-mission-arrm

"FUTURISTIC TECHNOLOGY – THAT REALLY IS MY THING!"

TNO innovates with impact. By bringing together a wide range of disciplines in two areas of expertise and thereby tackling societal challenges within five current themes. Innovator Francesco Esposto works at TNO and is developing ground-breaking technology, which will be part of our everyday lives in a few years' time.

As an innovator on the Co-operative Mobility programme, Francesco is working on technology to enable self-driving cars to communicate with each other and with the infrastructure around them. "My main focus is the safety system, which ensures that the technology works in dangerous situations on the road. Another project I'm involved in, this time in Automotive, is the construction of a simulator to test self-driving cars. It's fantastic to be working on all this – we have so much to look forward to when it comes to self-driving cars. Some vehicles already have autonomous functions, but they're going to develop enormously over the next few years. So-called co-operative driving, especially, is really important for safety and traffic flows. That's the main thing we in Co-operative Mobility are working on. For most people this is very futuristic, but we're already developing the technology and we can see that it works."

FUTURISTIC TECHNOLOGY

"I studied electrical engineering at the university and I have a passion for cars. My thesis was about technology to repel intrusive or hostile drones. Futuristic technology – that really is my thing! After graduating, I chose TNO because I knew what brilliant things they do here, certainly in Automotive. In so many technologies, hardly anyone else is as far advanced as TNO. Here I can keep building my own body of knowledge, and make myself useful by putting it into practice straight away", Francesco explains.

FUTURE PROJECT MANAGER

For TNO innovation means demonstrating how significant knowledge is for society. Working at TNO means working in teams on inspiring assignments for multinationals, SMEs and government. You contribute directly to innovation and the ongoing development and application of knowledge. The assignments range from contract research to consultancy, from policy studies to testing. Francesco tells: "You never run out of things to learn here. We work on big projects involving a lot of people, who have to collaborate effectively to make real progress. Even though I'm still relatively new here, I'm already encountering many aspects of project management. That's important to me, because it's the direction I want to move in. Right now, some colleagues and I are working on a bid for a major European tender procedure. For that I have to consult with our consortium partners and come up with solid proposals."

THE PEOPLE OF TNO

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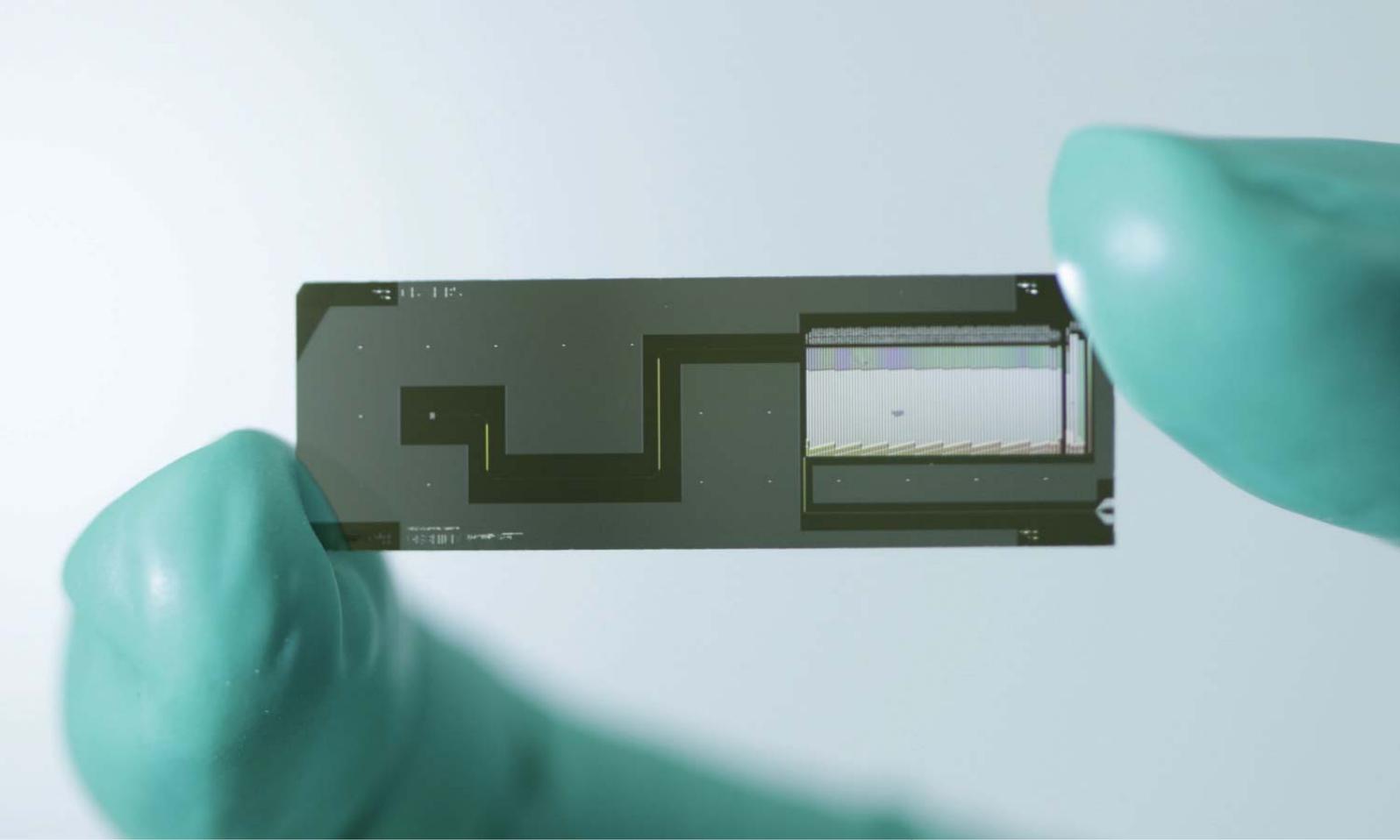
DESHIMA
Cosmology with Nanotechnology

Dr. Akira Endo, Delft University of Technology

Astronomical Instrumentation: Electrical engineering at its extreme
Electrical engineering is about the interaction between the electromagnetic field and matter, and its applications. Astronomical signal detection is one of the most extreme areas of electrical engineering, involving in a single experiment scales ranging from nanometers to gigaparsecs in length, microseconds to gigayears in time, and >10^{40} W to zeptowatts (10^{-21} W) in power. The electromagnetic signals that finally impinge on the detectors are so faint, that the quantum nature of light (photons) is no longer negligible, affecting the accuracy of measurements strongly.

The detectors, especially those for terahertz waves (frequency in the range of ~100-3000 GHz), are often based on superconductivity, which is in itself a manifestation of a macroscopic quantum effect. Indeed, the quest to detect the faintest signals from the most distant objects in our Universe involves a continuous push in what humans can observe, by combining fundamental solid state physics and advanced electromagnetism.

This article is about DESHIMA, a new type of astronomical spectrometer designed to measure the cosmological redshift of active galaxies in the early Universe. The development is centered at the Terahertz Sensing Group of the faculty of EEMCS, TU Delft, in collaboration with research-

◄ *Figure 3: Superconducting on-chip filterbank spectrometer chip held by two fingers.*

ers from SRON, Leiden University, University of Tokyo, and the National Astronomical Observatory of Japan.
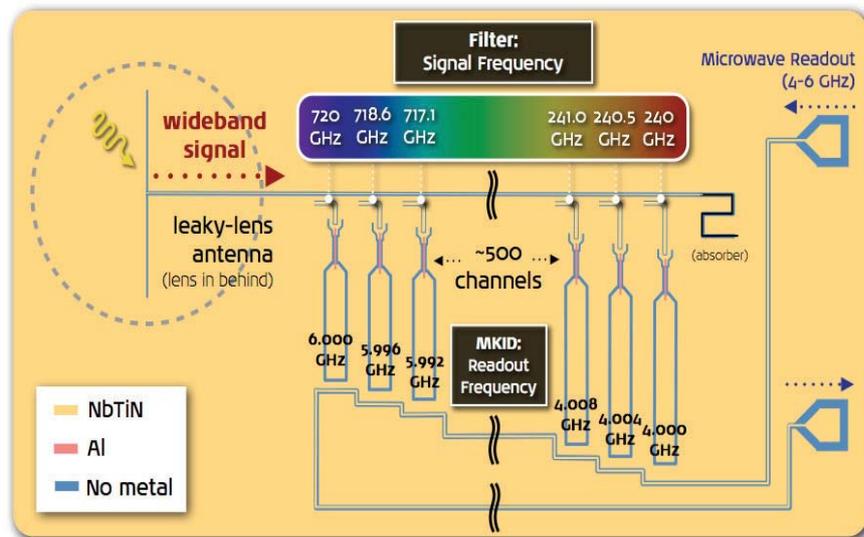
DESHIMA

Motivation: redshift measurement of submillimeter galaxies

How galaxies form and evolve is an active area of research in modern astronomy. In order to look into the past, we take advantage of an effect called cosmological redshift. Because the Universe is expanding, the wavelength of electromagnetic waves increases with time, or distance (Hubble's law). Hence, measuring the frequency shift of electromagnetic waves from a galaxy can tell us how far away the galaxy

> *"Astronomical signal detection is one of the most extreme areas of electrical engineering"*

is, and how long ago the electromagnetic wave was emitted. Using redshift as a probe of time, we want to study the evolution of galaxies in their size, properties, numbers, and distribution, throughout the history of the Universe.

Our aim is to apply this redshift measurement technique also to submillimeter galaxies: galaxies that are extremely bright in the terahertz band but almost invisible in the visual band due to their aggressive star-forming activity. Since thick clouds of dust enshroud these galaxies, the

Figure 1: *Conceptual drawing of the on-chip filterbank being developed for DESHIMA. The signal from the telescope, captured by a wideband antenna, is separated by a filterbank (an array of narrowband filters) and distributed to individual KID detectors. The entire filterbank will ultimately cover 240-720 GHz in a single shot with ~500 KID detectors.*

redshift cannot be easily measured with standard optical telescopes like the Hubble Space Telescope. On the other hand, existing terahertz spectrometers have insufficient bandwidth to search for an emission line without a priori knowledge of the redshift.

DESHIMA: Superconducting On-chip Filterbank Spectrometer

In order to break this deadlock to enable the creation of 3D maps of submillimeter galaxies, we are developing an ultra wideband terahertz spectrometer based on a completely new concept: a superconducting on-chip spectrometer as shown in Figure 1. The first idea is to take advantage of the kinetic inductance detector (KID) technology developed at TU Delft and SRON, which enables terahertz detector arrays with a few thousand

elements to be read out with only 1 pair of coax cables. The second idea is to integrate the frequency-selecting function on the same chip as the detectors in the form of a filterbank by using superconducting microresonators as narrow bandpass filters (Figure 2).

As a result, it becomes possible to integrate the functionality of an entire ✈
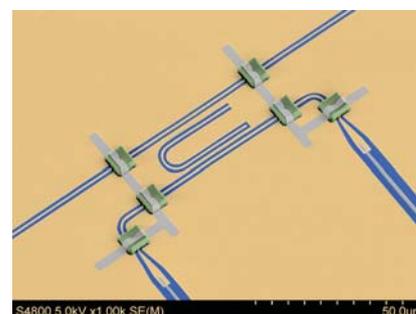
Figure 2: *Scanning electron micrograph of a typical 350 GHz coplanar-waveguide filter of DESHIMA.*

optical spectrometer onto small chips as shown in Figure 3.

On-sky experiment on the ASTE telescope in Chile (4800 m alt.)

After a successful proof-of-principle of the superconducting on-chip filterbank spectrometer concept [1], we are currently developing DESHIMA as the first astronomical filterbank spectrometer to be installed on the ASTE telescope in Chile (Figure 5). ASTE is a 10 m terahertz telescope that can operate up to about 1 THz. The telescope is located in the Atacama

Desert in Chile, known as one of the best sites for submillimeter wave observations due to the dry (and therefore transparent) atmosphere. The cryostat that cools the filterbank chip down to a temperature of 0.1 K is currently under development in the CryoLab in the Else Kooi Lab of EWI (Figure 4). We aim to bring DESHIMA with a prototype chip to the ASTE telescope in October 2017, to verify all sorts of interfaces between the DESHIMA instrument and the ASTE telescope, and in the best case make early astronomical science.

Powered by TU Delft students

While the TU Delft has a successful history of delivering superconducting detectors to the world's top astronomical observatories, including the Herschel Space Observatory and the Atacama Large Millimeter-submillimeter Array, DESHIMA is the first instrument in which the entire system, including the detector, the refrigerator, the optics, the back-end electronics, is being integrated and tested on the TU Delft campus. Of course this means that students are able to par-

Figure 4: Photograph of the DESHIMA cryogenic optics, housing the 100 mK stage on which the filterbank chip is mounted.

ticipate in the development on all levels. Indeed, many MSc and BSc students have made significant contributions to DESHIMA, in the filterbank chip, in the KID detectors, in the optics, and even in the astronomical science usage. Currently there are two instruments under development, DESHIMA and its upgrade MOSAIC. Interested? Feel free to contact us for possible projects. Extreme electrical engineering awaits you!

Figure 5: Members of the DESHIMA team at the ASTE telescope in 2016, in preparation for the installation test in 2017.

[1]   A. Endo, C. Sfiligoj, S. J. C. Yates, J. J. A. Baselmans, D. J. Thoen, S. M. H. Javadzadeh, P. P. van der Werf, A. M. Baryshev, T. M. Klapwijk, "On-chip filter bank spectroscopy at 600-700 GHz using NbTiN superconducting resonators," Appl. Phys. Lett. 103, 032601 (2013).

[2]   A. Endo, "Superconducting On-Chip Spectrometery for Millimeter-submillimeter Wave Astronomy," IEICE Transactions on Electronics E98.C, 219-226 (2015).

Minor Impressions

Biomedical Engineering
Nick Cancrinus

At the beginning of this academic year, I followed the minor Biomedical Engineering. In general, the subject of this minor is the application of technology in the medical world. This could be anything from minimally invasive surgery to MRI or CT scanners.

The minor can be divided into two parts. In the first part you follow three courses, which aim to give you a theoretical basis in Biomedical Engineering: Anatomy and Control, Orthopaedic Biomaterials and Imaging Techniques. As a student Electrical Engineering I found the course Imaging Techniques to be the most interesting. This course, among other things, explains the concepts behind different medical scanning modalities such as MRI, CT and ultrasound, and discusses various mathematical techniques such as frequency-domain methods that underlie their functionality.

In the second part you can apply the knowledge that you obtained in two projects. In the first, smaller project, you study in pairs a medical instrument of your choice and try to find common or possible risks that are associated with it. The second, larger project (the final part of the minor) is done in larger groups. Every year a list of possible assignments is made and you can pick what you think is most interesting. The list turned out to be quite diverse, so there should be something for everyone.

Overall, I am very happy to have chosen this minor. It is well organised and I found that it connected well to the bachelor Electrical Engineering. If you are considering applying your electro-technical knowledge in the medical domain, then this minor could open many doors for you.

Spaceflight
Jun Feng

As a third-year BSc student, I spent my last semester broadening my knowledge: I followed the Spaceflight minor at the faculty of Aerospace Engineering!

The minor consists of 6 courses. The first quarter kicked off with 4 courses. Introduction to Spaceflight covered some basic rocket science, orbital mechanics and space mission aspects while introducing spaceflight jargon. Earth Observation focused on sensing techniques, but was unfortunately poorly taught. The whereabouts and astronomy of our Solar system and the Universe was the subject of the high-quality Space Exploration course with interesting and diverse lectures.

Satellite Tracking & Communication lasted the whole minor and tied in with telecommunication and DSP. For example, we were given Arduinos to model a wireless satellite-to-ground station sun sensor and used a radar on EWI's roof to process the Doppler shift of a passing satellite signal. Applying EE skills to realistic situations was very enjoyable, although the lectures could be improved.

Figure 1: *The faint three-stripe curve shows Delfi-C3's satellite signal "Doppler-shifting" above EWI!*

During the second quarter Spacecraft Technology outlined core components of spacecraft like communication electronics and rocket design. It was interesting, but too simplistic sometimes. The concluding Spaceflight Assignment is an individual "deep-dive" into a specific spaceflight subject with a large range of possible projects varying from product prototype development to scientific research. For example, I did research on bitflip estimation models due to space radiation in SRAM memory using tools from ESA and MATLAB.

Overall, the Spaceflight minor was very broad with good-quality courses and satisfying (mini-)projects.

TRXVU Transceiver design
for CubeSat communications

RF&E Team, ISIS Space

The popularity of nanosatellite missions among universities and space research organizations has grown quite rapidly in the past decade. The focus of the nanosatellite missions has started to shift from educational, technology demonstration missions to more complex commercial, operational, scientific and security related missions.

There has been a paradigm shift in the way nanosatellites are being perceived. Space agencies have started to look at nanosatellites as being able to perform serious science missions and capable of replacing bigger satellites in near future. Over the last year or two, a new application for nanosatellites has evolved in the field of "Machine to Machine communications", where large constellations of nanosatellites are used to perform measurements or remote sensing and as a result demand high performance communication links. This was also very evident in the recent launch in February 2017 on the Indian Polar Satellite Launch Vehicle (PSLV), where more than 100 nanosatellites were launched in one go, out of which 88 satellites belonged to a constellation of nanosatellites intended to perform remote-sensing from Low Earth Orbit. ISIS – Innovative Solutions In Space B.V played a very crucial role in developing the deployers and launch sequencers for 101 satellites that formed the critical interface technology in putting the satellites into precise orbits without any collision. This upward trend in nanosatellite launches is set to continue, as shown in the 2017 nano/microsatellite Market Assessment study done by SpaceWorks projectsure (Figure 1).

Among the various subsystems that ISIS has developed for nanosatellites, the deployable VHF/UHF antenna system is a very popular subsystem which has a space heritage since 2010 and well over 250 units sold worldwide, of which 56 antenna systems are known to have been flown in various missions till date, with all of them successfully functioning in space. The first generation of transceivers developed by ISIS was the TRXUV (UHF uplink and VHF downlink) which has flight heritage since 2012 and 19 transceivers successfully operating in space till date. This article will however focus on a newer generation of transceiver developed by ISIS; TRXVU (VHF uplink and UHF downlink) transceiver that recently got its heritage in June 2016 and two of these transceivers were flown on satellites in the recent PSLV-C37 launch (February 2017). This article describes some of the design features of this transceiver and tests that were carried out on this transceiver to qualify it for space application. This radio is a variable data-rate full-duplex transceiver that can be used for both TT&C
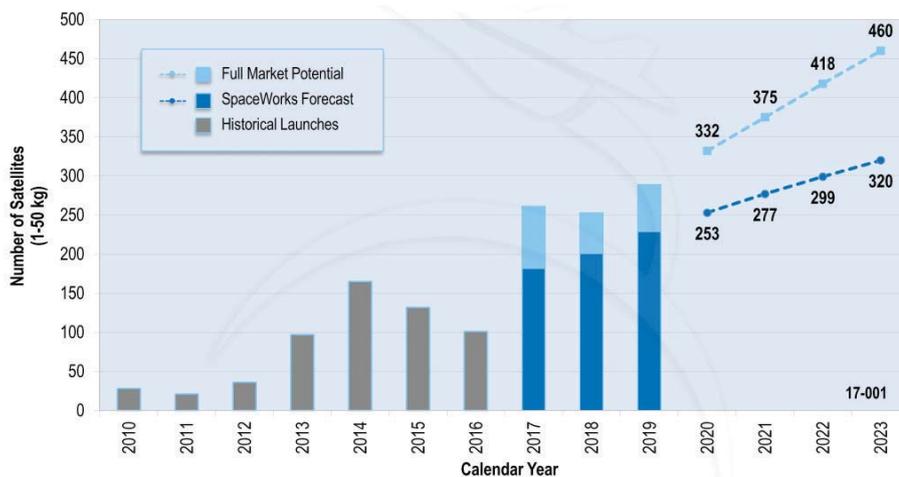

Figure 1: *Forecast of the number of nanosatellite to be launched (source: SpaceWorks Forecast)*

(Telemetry, Tracking and Command) and in some cases for payload downlink (maximum of 9600 bps).

About the product

The TRXVU is a VHF (Very High Frequency) band uplink and UHF (Ultra High Frequency) band downlink, variable data-rate, full-duplex transceiver implemented on a single Printed Circuit Board (PCB) . The internal structure of the TRXVU can be split into three parts: a receiver, a transmitter and a shared section. The shared section interfaces with the rest of the satellite, while receive and transmit sections communicate with the ground station radio. Receive and transmit sections are independent from each other featuring dedicated microcontrollers, synthesizer, commands and housekeeping. The transceiver communicates to the rest of the satellite through the I2C interface. Figure 2 shows a high-level block diagram of TRXVU. There are various parameters that can be configured in this transceiver even after launch, the downlink data rate is a key parameter that can be varied during the mission operations. The default data rate is 1200 bps, but this can be varied up to 9600 bps. It is also possible to change the downlink/uplink frequency on the fly, this gives the flexibility to switch frequency in cases where primary downlink/uplink frequencies are noisy, provided the secondary frequencies are coordinated. The modulation scheme used by TRXVU is BPSK for downlink and AFSK for uplink. The TRXVU uses the AX.25 protocol for communication with the ground station. The
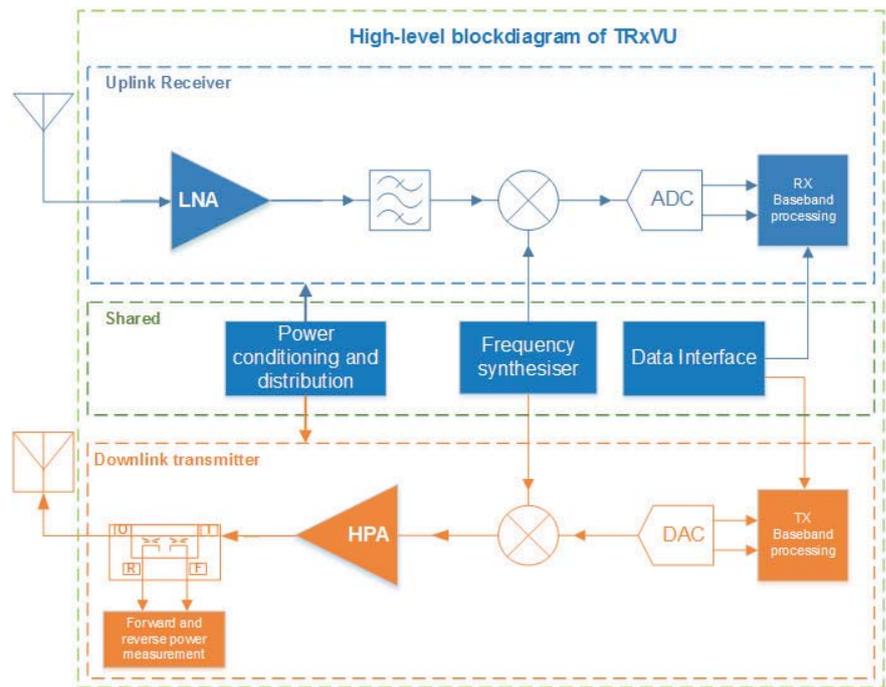
Figure 2: *High-level block-diagram of TRXVU (source: ISIS)*

complete transceiver consumes very low power with < 4 watts when both transmit and receive sections are active.

Design considerations

The design phase was started with summing up a list of design constraints and goals. In the section below an extraction of these design constraints are described. First of all, the TRXVU was designed for communication between the satellite and a ground station. The TRXVU was designed for easy integration within CubeSat structures and other existing CubeSat systems. This means that the TRXVU is equipped with the so-called Cube Sat Kit Bus (CSKB) interface connector for the interface between transceiver and the rest of the satellite, and that the envelope of the TRXVU shall not exceed 96 x 96 x 15 mm. The TRXVU was also designed

with ease of manufacturing and testing in mind. To avoid problems with obsolete components the TRXVU is designed with components that are recommended for new designs.

All products within ISIS are designed for use in space for a typical nanosatellite mission time. Because of the harsh environment in space the following environmental aspects need to be taken into account:

• **Temperature variation:** The TRXVU shall be operational at an environmental temperature between -20 and 60 degrees Celsius. This temperature range is considered as common in 2U and bigger Cube-Sats. And the TRXVU must stand a non-operational temperature range between -40 and 85 degrees Celsius. The TRXVU may experience temperatures outside its operational range ➤

during storage or in orbit and the board is not required to operate there, but it should start operating again while within the operating range.

- **Vacuum:** The TRXVU is operational at a pressure of far less than 1mBar and shall survive in the vacuum environment of space.

- **Vibration:** On its way to space, the TRXVU has to survive the launch vibration and shock loads.

- **Radiation:** Tolerant up to a certain level.

Testing

The test campaign of every product within the ISIS product line is split into two main sections. The design Qualification test and the Acceptance test.

Qualification test campaign

During qualification campaign a number of tests are performed to guarantee that by design the transceiver is able to perform as planned and survive the extreme environment during the launch and during its stay in space. The following tests were successfully performed on the qualification model of the TRXVU.

To prove that the TRXVU, shown below, will survive the launch load according to the internal ISIS standard, a vibration test

Figure 3: ISIS VHF uplink/UHF downlink Full Duplex Transceiver

with a predefined vibration pattern has been performed and the Radio under test has been visually inspected and functionally tested to prove to the designers that no damage has been caused by the vibration test.

To guarantee that the functional performance of the TRXVU covers the foreseen temperature conditions and does not degrade during temperature cycling, a thermal test is performed. The thermal test consists of a complete functional test while performing several thermal cycles within a climate chamber.

The last qualification test performed on the TRXVU is a radiation test to test the robustness of the components used in the TRXVU design. Although the robustness of the components used on this board has been proven in space on different designs, the TRXVU board itself has not undergone a formal radiation tolerance test before. This test has been performed in the proton beam test facility at Paul Scherrer Institute (PSI) in Switzerland. Although during Radiation test it was observed that the TRXVU Transmitter communication was lost and the current consumption increased, the TRXVU has passed the radiation test without any destructive event. No aging effect has been seen on the board after an equivalent dose of 1 year in space (~5.6kRad). Some latch-up events have been observed on the receive chain, but the receiver reverted back to normal operation after resetting.

Production aspects

One of the main aspects in TRXVU production is the possibility to be configured

by the client. The board has several optional features depending on software and others by hardware. There is flexibility in different elements such as the type of connector, the pinout used or the grounding scheme.

Those types of characteristics drove the way the system was designed, and this configurability drives how the system is produced. There are mainly two stages in production, with inspections and tests in between.

First, after a Quality Assurance (QA) inspection of the PCB and the numerous components that are going to be soldered, the board is populated as its basic configuration. No customization has been applied yet. Then, the board is verified again and a second step is performed, which involves soldering of specific hardware to create the customer specific configuration. The board is finalized by mounting the shielding cans, cleaning it completely and applying epoxy to sensitive components and parts of the board.

After the board is finalized, each transceiver produced by ISIS goes through a functional test to guarantee that when a radio is delivered it will behave in a nominal manner. These final functional tests are performed using the flight configuration requested by the customer to assure that flight parameters such as call-signs, watchdog timer and start up behaviour are configured as requested.

Acceptance test campaign

For the acceptance test campaign, a procedure is followed to inspect, test and accept the ISIS VHF-UHF Transceiver (TRX-

VU) to make sure it was built correctly and can be delivered for flight.

In case of the TRXVU, the acceptance test procedure actually forms an integral part of the production process. After initial inspection and electrical and functional tests are performed, and the customer configuration-specific parts have been fitted and verified, each transceiver will go through a thermal test procedure, to check and prove that the unit will perform well within the specifications defined. Vibration testing for acceptance is not performed, as the design has already been already qualified for that and a vibration test at satellite level after the board is integrated will be performed later. A final electrical and functional test at ambient conditions and full verification of the system completes the acceptance procedures, after which the unit is ready to be delivered.

In summary, a complete flow of the production and acceptance chain will be the following: initial inspection – initial soldering – inspection – initial electrical and functional testing – thermal testing – final electrical and functional testing. Such high level of testing is required to guarantee the proper operation of the unit in space later, which makes the production and acceptance process of space parts such as the transceiver labour intensive.

Summary of flight results

The TRXVU transceiver has been used already on several satellites, most recently on the DIDO-2 (Figure 4) and PEASSS nanosatellites. Both of them were launched on the 15th of February on the PSLV-

Figure 4: *Did0-2 CubeSat (right) and its orbital deployer (left)*

37 launch. After 1 month in flight, both transceivers have operated nominally and well according to expectations. For more analysis of their behaviour, it will be necessary to gather more data over the coming weeks and months. From the first flight of a TRXVU board however, on board the "Star of Aoxing" mission from the Northwestern Polytechnical University (NPU) from China, launched on June 25th, 2016, the design team has been able to analyse a larger flight data set that was kindly provided by the NPU team as reference. The satellite transmitted nearly 2 million frames, of which about 1057 frames were received and successfully decoded by the single ground station in China. From the analysis of the flight data, it can be concluded that within this project the TRXVU functioned as expected and provided the customer with a stable uplink and a strong downlink enabling them to successfully control and monitor their satellite at even the lowest elevation passes. And that is exactly what is needed to make the best of your nanosatellite mission!

Onwards and upwards to the next challenge; to design and build the next generation transceiver, but then in higher frequencies with (much) higher data rates!

If you would like to take part in this next challenge, as intern, for your thesis, or as part of your career, feel free to contact us through *recruitment@isispace.nl*

ISIS in brief

ISIS – Innovative Solutions In Space was founded on January 6th, 2006 as a spin-off from the Delfi-C3 nanosatellite project from Delft University of Technology in The Netherlands and it's one of the leading companies in the fast growing small satellite market. The company is vertically integrated and combines research and development, testing, launch services, and operation of small space systems in a single organization. This allows ISIS to provide the right solution for every customer, from subsystems to full turn-key missions and custom solutions

FLARE

The Free-space Lasercom And Radiation Experiment

Ashley Carlton & Angela Crews

The Free-space Lasercom And Radiation Experiment (FLARE) is a nanosatellite project under development by students at the Massachusetts Institute of Technology (MIT) in Cambridge, Massachusetts, USA. FLARE consists of two twin 3U CubeSats (30 cm by 10 cm by 10 cm) that will raise the technological maturity of two technologies: (i) an optical laser communications transceiver to enable high-data rates for small satellites, and (ii) a miniature, high-energy particle detector, called "Sparrow", to characterize the space radiation environment in a low size, weight, and power package. Sparrow will also be used to better understand the effects of radiation on the lasercom hardware.

Free-space optical communications systems offer advantages compared with traditional radio frequency (RF) systems, such as power efficiency, spectrum availability, and security. In addition, constellations of small satellites can enable global coverage with persistent or frequent revisits of storm systems or security assets. FLARE will demonstrate a laser communication intersatellite link between two CubeSats, using atmospheric drag to manage range between the spacecraft. The system is designed to demonstrate 5 Mbps at ranges from 25 km up to 500 km, with the reach goal of achieving a 25 Mbps data rate.

The Sparrow radiation sensor is valuable because the space environment continuously exposes spacecraft to radiation: the Sun blasts ionized, highly energetic particles towards Earth, and highly ener-

getic cosmic rays also come from exploding stars in distant parts of the galaxy. It is also possible for radiation in space to originate from manmade sources. While several notable missions collect valuable space weather monitoring data, the spacecraft are large and sparsely-distributed, with limited temporal and spatial resolution. In addition to providing valuable radiation environment data during the operation of the laser communication

"The Sparrow radiation sensor is valuable because the space environment continuously exposes spacecraft to radiation."

(lasercom) system components, Sparrow would be a first step toward deploying fleets with smaller radiation sensing instruments with capabilities that exceed current small dosimeter sensors.

The FLARE project was conceived by graduate students in the MIT Department of Aeronautics and Astronautics under

Prof. Kerri Cahoy, who leads the Space Telecommunications, Astronomy, and Radiation (STAR) laboratory. The FLARE team is participating in the Air Force Research Laboratory (AFRL) University Nanosatellite Program (NS-9), which started in January 2016. The team consists of both undergraduate and graduate students from more than four departments at MIT, to support the multiple disciplines necessary to design and build a stand-alone spacecraft. The FLARE team completed their Preliminary Design Review in March 2016 and is preparing for the Flight Selection Review in 2018, which will select missions for launch opportunities in the early 2020s.

Technology 1: Free-space Optical Communications Crosslink

The FLARE optical transceiver is based on a design MIT has developed for a LEO downlink experiment (Clements et al.,

2016). The optical transmit power is 200 mW and the full duplex design transmits and receives at 1565 and 1535 nm, respectively. FLARE has a 20 mm Keplerian telescope receive aperture to support 5 Mbps intersatellite laser communications at ranges of 25 to 500 km, with a stretch goal of achieving 25 Mbps. The CubeSats will adjust their range, first to 25 km and then out to >500 km using differential drag. The team is developing a custom actuated deployable solar panel system using shape memory alloy hinges, but range can also be simply adjusted by changing attitude. The FLARE design employs miniaturized star trackers (designed and built by the STAR Lab students), visible crosslink beacons at 800 nm with a beacon beam of 2.4° and 8640 arcsecond divergence angle, quadcell photodetectors, MEMS fine steering mirrors (FSMs), as well as radio frequency and GPS coordination.

Technology 2: Low SWaP Energetic-Particle Detector, "Sparrow"

The "Sparrow" energetic particle detector will demonstrate full heavy-ion spectroscopy in a 10 cm by 10 cm by 5 cm package, with an approximate mass of 0.4 kg, and a cost of less than $5000. The detector leverages recent advances in organic scintillator materials, silicon photomultipliers (SiPM), coincidence detection, and fast analog-to-digital conversion (ADC) readout to enable pulse shape discrimination for protons, electrons, and heavy ions. Sparrow is capable of particle discrimination, spectroscopy, and dosimetry of electrons with energies of 0.5 - 5 MeV and protons with energies of 10 - 30 MeV as well as a range of heavy ions. The instrument uses a USB 2.0 interface to the spacecraft bus to minimize the impact of incorporating the sensor on spacecraft.

Concept of Operations

Although the launch will not be determined until after UNP's Flight Selection Review (FSR), we have planned to have the twin spacecraft deployed initially fastened to each other from a NanoRacks deployer from ISS. After deployment of solar panels and detumbling, FLARE-A and FLARE-B will detach and enter commissioning individually, undergoing checkout via a UHF radio to the ✈

Figure 1: FLARE Team from left to right: Ashley Carlton (Project Manager), Mike Long (Lasercom), Riley Fitzgerald (Orbits/Navigation), Joe Figura (RF Communications and Ground Station), Armen Samurkashian (Avionics Hardware and Flight Software), Kerri Cahoy (Principal Investigator), Jim Clark (Power and Orbits), Angie Crews (Chief Engineer), Christian Haughwout (Sparrow), Derek Barnes (Structures), Greg Allan (RF Comm. and Ground Station), Charlotte Sun (Lasercom), Hailey Nichols (Structures and Thermal). Not pictured: Joe Murphy (Power), Bjarni Kristinsson (Power), Rachel Morgan (Lasercom), Maxim Khatsenko (Thermal), Raichelle Aniceto (Lasercom), Zach Hartwig (Sparrow payload), Caleb Ziegler (Lasercom), Hyosang Yoon (Attitude determination and control), Myron Lee (Avionics hardware)
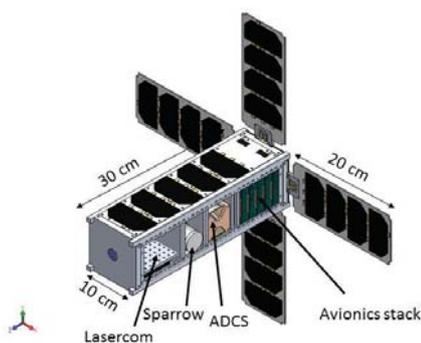
FLARE Concept of Operations
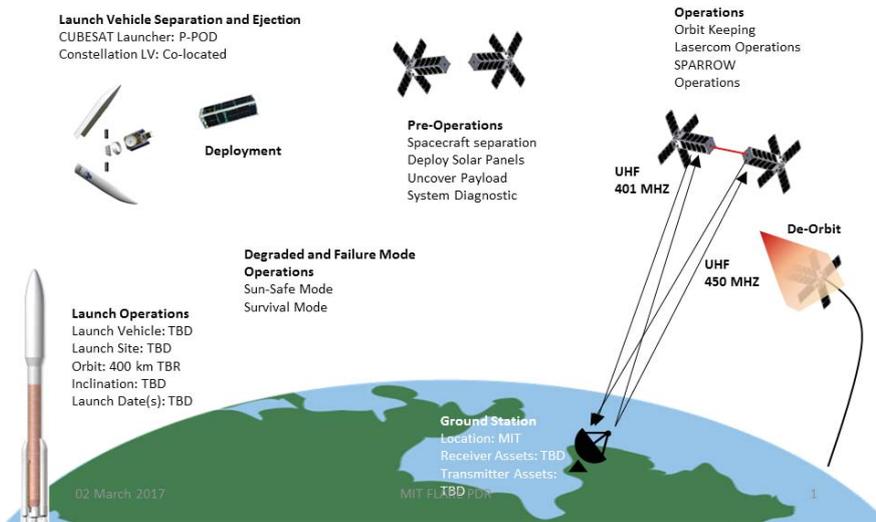
Figure 2: *The FLARE CONOPS depicts the mission phases throughout the FLARE lifetime (Image credit: Armen Samurkashian, March 2017).*

deployed solar panels), an electrical power system, and one 30 W-hr Lithium ion polymer battery. The power system will include inhibits compatible with ISS cargo deployers.

ADCS: The attitude determination and control system (ADCS) will provide determination with a custom built star tracker, IMU, magnetometers, GPS receiver, and four sun sensors. Actuators include three COTS 3-axis reaction wheels and magnetorquers for reaction wheel desaturation.

Avionics: FLARE will use the Raspberry Pi Compute Module 3 as its processor. The avionics stack will also include custom interface boards for power distribution and current limiting, thermal knife drivers for deployables, and interfaces with subsystem components.

Structures and Thermal: FLARE will be built to manage the intermittent thermal loading from the lasercom assembly. The initial CAD of FLARE is shown below in Figure 3.

This article is authored by Ashley Carlton (FLARE Program Manager) and Angela Crews (FLARE Chief Engineer). Both authors are Ph.D. candidates in the MIT AeroAstro department. Please direct communications regarding FLARE to *acarlton@mit.edu*.

MIT or Air Force ground stations. Once checkout is complete, the spacecraft will use the differential drag management of the solar panels to maneuver within RF communications range and refine the drag management approach to adjust intersatellite range before commissioning the laser communications experiment. After the lasercom intersatellite link is established, separation distances are modified. Data will be continuously collected from the Sparrow radiation sensor and downlinked via the UHF radio. At the end of the mission, the team may attempt a stretch goal of characterizing crosslinks through the atmosphere at a lower data rate. At the conclusion of the mission, the spacecraft will fully open its panels to maximize drag and ensure timely deorbit.

FLARE Subsystems

Power: The power system will consist of custom designed deployable solar panels (four body mounted panels and four 2U

Figure 3: *CAD external rendering of FLARE. Components from the +z face back include the lasercom payload, the Sparrow payload, ADCS, and avionics stack. Image credit: Derek Barnes, February 2017.*

E. Clements, et al., "Nanosatellite optical downlink experiment: design, simulation, and prototyping," SPIE Opt. Eng. 55(11), 111610 (Sep 13, 2016).

Space weather
## how could it affect us and how to predict it?

Lotfi Massarweh

It is a beautiful Sunday morning in the middle of May. After a very long week at work you are looking forward to lying down on the grass to enjoy a bit of sunshine in the nearest park. So you take your phone, you click on your favorite weather app and check the weather prediction. Sunny, incredibly sunny! 27 degrees and no wind, that's what you have been waiting for the entire week; nothing but fresh air and good weather. Well, unfortunately, reality has an annoying sense of humor, and astonishingly the only thing you can see is one of the biggest storms of the last few months. At that point your 'Sunday in the park' hopes disappear, your mood probably worsens and you wonder how weather prediction works, if it indeed works, and why it should really work.

In the last couple of decades, technology has become a huge component of our daily lives, particularly communication systems. Everything seems to work more or less perfectly, and we begin to imagine that technology has progressed so much that it is almost foolproof. It was March 13th 1989, almost 30 years ago, when a severe geomagnetic storm struck Earth, causing a 9-hour outage of Hydro-Québec's electricity transmission system. This is just one of the uncountable consequences of such a storm. Many short-wave radios cut out due to the interference and a number of satellites orbiting the poles totally lost contact with ground-stations. The first documented observation of these solar storms occurred around 130 years ago, by an English astronomer named Richard C. Carrington, and which are now called "Carrington Events" in his honor. Just a few years ago, on the 23rd of July 2012, a similar superstorm passed Earth's orbit, missing it by a margin of around 9 days. The financial impact of such a strike would have been between 0.6 and 2.6 trillion of dollars, more than ten times the monetary damage incurred by hurricane Sandy hitting the US East Coast some months later (October 2012). How is it possible to predict such a space superstorm, when scientists are yet to fully grasp the dynamics of our atmosphere? What could guarantee us safety from such a massive quantity of (space) matter and electromagnetic radiation?
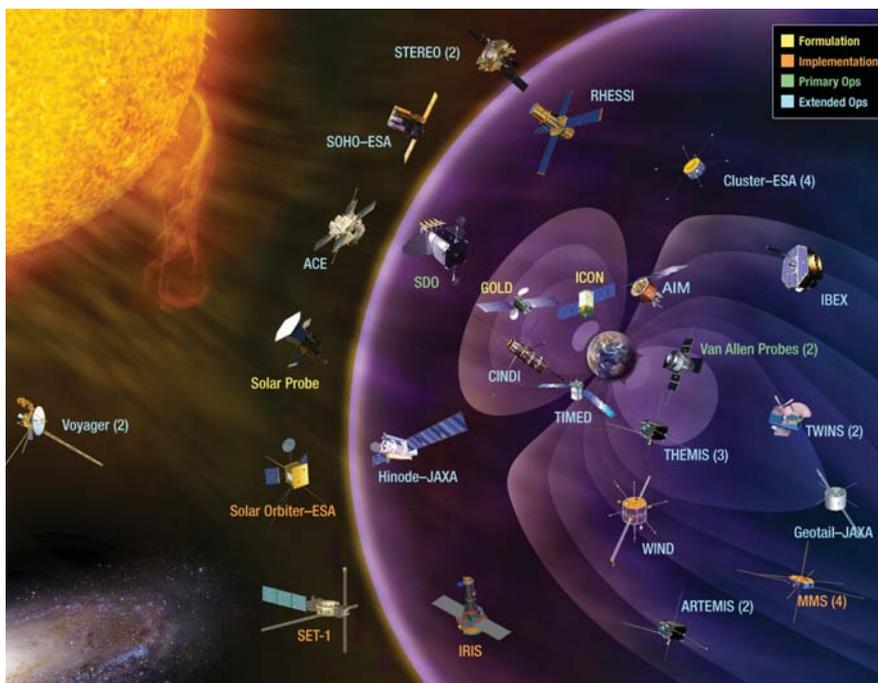
Figure 1: *The Helio-physics System Observatory (HSO), which is a fleet of satellites performing helio-physics science investigations. Credit: NASA.*
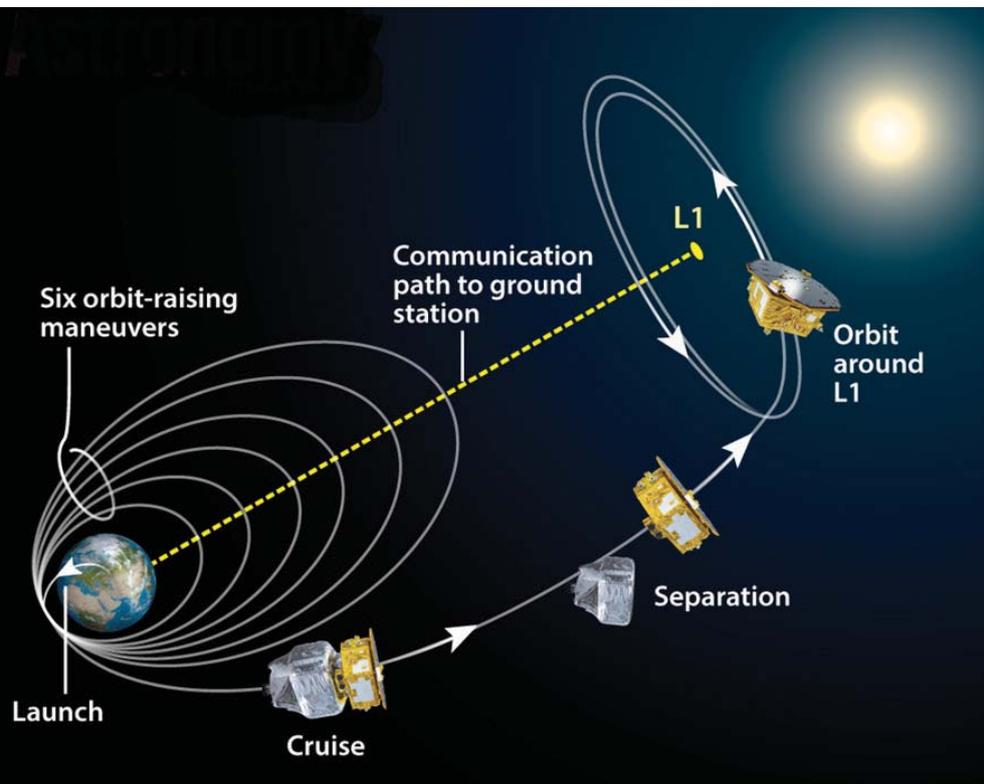
Figure 2: *The LISA Pathfinder mission with its orbital trajectory around L1, the first Lagrange point of the Sun-Earth system. Credit: NASA.*

Since 1995, all geomagnetic storms and major solar flares have been monitored by the Solar and Heliospheric Observatory (SOHO) space satellite, a joint project of National Aeronautics and Space Administration (NASA) and the European Space Agency (ESA). Throughout the years, many more satellites have been launched and most of them are located at the so-called first Lagrange point of the Sun-Earth system. This is essentially a point somewhere between Earth and Sun where the main gravitational forces are in equilibrium, thus allowing the satellite to orbit nearby for a long period without additional station maintenance costs. In Figure 1, we can see the entire fleet of past, active and future satellites, whose

purpose is to study solar system dynamics. Some of them are within the Earth's magnetosphere, a sort of shield originating from strong solar winds reaching Earth's orbit. As it turns out, a thorough understanding of helio-physics (in Greek "helio" means Sun) is quickly becoming crucial for our technology-dependent society since experience has shown that we cannot always rely on the Earth's magnetic shield.

Space weather can indeed affect several aspects of our modern lifestyles. Some examples are the effects on electric power transmission, high-frequency radio and satellite communications (nowadays almost indispensable), and radio naviga-

tion systems as GPS (Global Positioning System) or GNSS (Global Navigation Satellite System).

Currently, the Space Weather Prediction Center (SWPC), one of the nine centers under the National Centers for Environmental Prediction (NCEP) that is also part of the National Weather Service (NWS), is the official source of space weather alerts and warnings for the United States. Besides providing information on solar forecasts, it also tracks solar wind patterns in real-time whose data is primarily obtained from NASA's ACE (Advanced Composition Explorer) satellite, which has been orbiting around the aforementioned L1 point since 1997. The latter is located approximately 1.5 million kilometers in the direction of the Sun, thus providing information 30 to 90 minutes before the solar wind (mostly a plasma flow) hits the Earth. No matter how short the time-period before a solar wind event, it is fundamentally important to know in advance if such a "space weather event" is heading towards the Earth, in the same way knowing that it is going to rain could help us avoid getting soaked to the bone.

For a variety of spacecraft, onboard magnetometers serve other purposes in addition to performing scientific measurements and monitoring space weather monitoring. Current missions cannot provide perfect coverage for space events, while costs of flying additional missions are too high. Moreover, the response time in case one of the current missions fails will likely be too long, thus leaving the Earth without any warning system for possible solar storms.
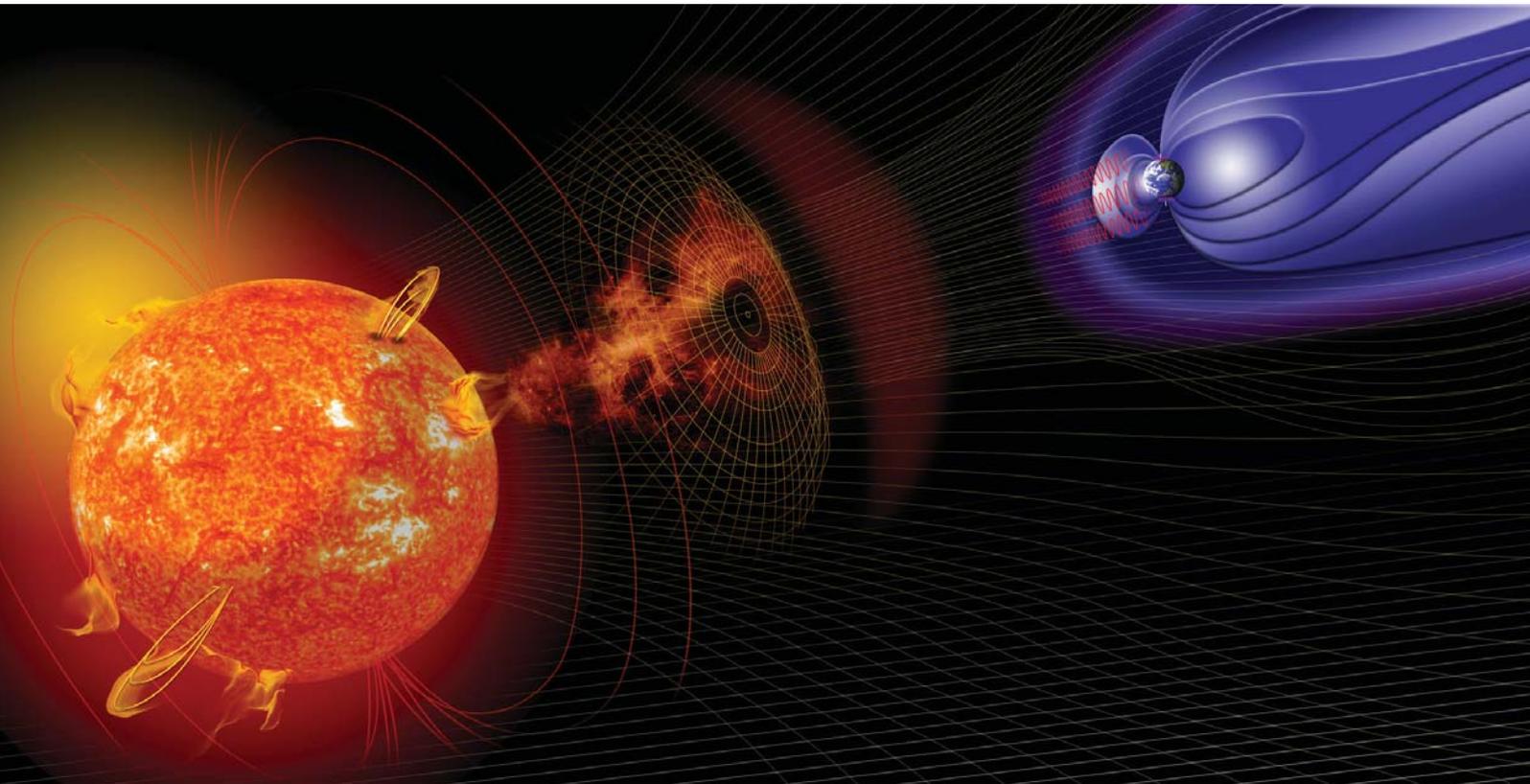
Figure 3: *Artistic illustration of strong solar flares that can provoke geomagnetic perturbations towards Earth. Credit: NASA.*

At the moment of writing, research is being conducted at the Delft University of Technology (in collaboration with the GFZ German Research Centre for Geosciences) to assess the feasibility of using platform satellites, usually equipped with magnetometers, in order to observe/predict Space Weather Events.

Worth mentioning is ESA's LISA Pathfinder mission (see Figure 2), which was launched in December 2015 and is currently the author's topic of investigation at TU Delft. The main purpose of this mission was to "validate important technologies to observe gravitational waves" during its first operational phase using the so-called LISA Technology Package, which was successfully completed on the 25th of June 2016. Since the mission is still in orbit, data from its magnetometers are nowadays being used for comparison studies given the incredible quality of results relative to other more sophisticated missions such as the aforementioned ACE satellite.

Since a lot of solar system physics is yet to be well understood, we still do not know if some day we will actually be able to obtain accurate space predictions based on a constellation of satellites. Further developments in the field might certainly prove useful, hence the necessity for continued research in order to one day be able to somewhat accurately predict these interplanetary events, in the same way we can to a certain extent tell if it's going to rain. Questions still remain on whether or not we will be able to adequately deal with the effects of space weather or will indeed succumb to its consequences. Only time will tell, and so space weather remains an active research area. ⬛

Advertorial
Flow-Based for Investments

TenneT TSO B.V.

Nowadays transmission networks are facing a complex dynamic environment influenced by political, regulatory, environmental and technological factors. The large scale deployment of intermittent renewable energy sources, the market-based cross-border flows, the increasing uncertainty and the generation far away from consumption create new operational challenges for the transmission system operators.

In order to find a balance between adapting to a new more demanding reality and maintaining security of supply as top priority, long-term network developments are required. Long-term network developments are often initiated by market oriented signals such as congestions or market indicators and aim to maximize market efficiency and social welfare. What is the additional cross border capacity that a new network development offers? This is often the question to be answered. A transparent, effective and accurate method is needed to outline the impact of a new network development on the actual market conditions.

TenneT TSO B.V. is developing an innovative concept where new investments are evaluated by using the principles of the operational Flow-Based method. The Flow-Based (FB) method is the current capacity calculation and allocation method in central western Europe (CWE: Germany, France, the Netherlands and Belgium), for day-ahead, and was successfully run for the first time on May 21st, 2015. The FB method considers the interdependencies between cross-border interconnections, respects the physical limits of the transmission networks and calculates the zone-to-zone transmission capacities. The accuracy and completeness of the FB method provides adequate insights on the available capacity between all CWE control zones.

However, nowadays network planning approaches are not aligned with the FB capacity calculation and allocation method, bearing the risk for both under-investments or over-investments. The concept that TenneT TSO B.V. is developing, aims to bring operational and planning reality of the transmission networks together. By extending the use of FB methodology to planning and investment evaluation, today's planning methods can be complemented with an additional insight on the interdependencies between zones of the interconnected grid. This new concept evaluates investments in a transparent way. It gives the possibility to observe and analyze how the initial power flows are influenced with the addition of the investment, if the network constraints change and what are the possible consequences of an investment from a cross-border transmission capacity point of view. The FB for investments method aims to quantify the effect of an investment throughout the whole common grid and to identify if the new investment leads to a larger or smaller zone-to-zone transmission capacity compared to the initial network. Any investment in the network can be evaluated: new line, new tie-line, new PST, new generator.

Flow-Based method

Every day, each participating TSO creates its individual network model based on the best forecast for the execution day, two days ahead of the execution day, and provides it to the FB computation. Additional input files for FB capacity calculation are the generation shift keys (GSKs), and the combinations of critical branches (CBs) and critical outages (COs). The Generation Shift Key (GSK) defines how a change in net position is mapped to the generating units in a bidding zone. Therefore, it contains the relation between the change in net position of the market zone and the change in output of every generating unit inside the same market zone. The critical branches (CBs) is a subset of all

network elements considered as critical by network operators and they are taken into account in the optimization process. CBs may be any interconnection and transmission network element, affecting zone-to-zone flows. The CBCO combinations take into account the N-1 criterion fulfilment, meaning that a critical branch is monitored under a critical outage and also critical branches in N situation, representing the network constraints from a cross-border capacity perspective.

The individual TSO network models are merged into one common grid model (CGM), which represents the best forecast of the corresponding hour of the execution day. Based on a DC load flow computation, the FB methodology computes the zonal power transfer distribution factors (PTDFs) and the remaining available margin (RAM) of the critical branches. These constitute the FB parameters. The RAM determines the remaining available capacity of a critical branch and the zonal PTDF shows how a change in the net position of the zone influences the power flow in this branch.

Flow-Based for Investments concept

The FB for investments concept uses the FB method to evaluate investment proposals. The first step of the method is to import the network model of the select-

ed date and hour and this initial model constitutes the base case. Then, the proposed investment is added to the grid and the new network situation represents the investment case. The next step is to compute the network sensitivities for both models: line outage distribution factors (LODFs), nodal power transfer distribution factors (PTDFs) and phase shifter distribution factors (PSDFs). Then, the critical branches are selected based on a set of criteria and in order to compare the base case with the investment case, a common CBCO list is created for both models. Together with the network model, the GSK values are imported as well. For the proof of concept operational network models and operational GSKs have been used, but future network planning models and adequate GSKs will be used for investment analyses. The next step is to compute the flow-based parameters and the capacity indicators for every CBCO for both models, by using the network sensitivities and the GSK values. In this concept two new capacity indicators have been developed that quantify the impact of a single network component (CBCO) on the overall remaining zone-to-zone transmission capacity.

Until this step of the method, the phase shifting transformers (PSTs) are kept at neutral taps, meaning that the network in both models has natural impedance. Ad-

ditionally, the method gives the option to perform a security-constrained optimization of the PST tap positions in both models, separately, in order to maximize the zone-to-zone transmission capacity for each border direction. In this way, the investment is compared with the base case not only at a neutral situation but also at their best possible network performance and the gain of the controllable assets is monitored. Of course the process has to be repeated for several timestamps, characterizing the impact of investment in each of them.

The Flow-Based for investments concept performs fast computations and is fully coherent with the Flow-Based method. Furthermore, this concept offers a transparent insight into the impact of a new investment on the whole common grid and gives the possibility via a linear PST optimization to compare the controllability of the installed assets with and without investment.

More information about the Flow-Based for investments concept can be found in: TenneT TSO BV, Using the flow-based method for network investments' evaluation – a new concept, Cigre Science & Engineering, N°7 February 2017 (via the link: *http://www.cigre.org/Menu-links/Publications/CIGRE-Science-Engineering/Issue-007-Feb.-2017*)

DARE
Pioneers in a new Space Age

Casper Klop & Kevin Eppenga

Delft Aerospace Rocket Engineering, also known as DARE, is a student rocketry society that designs, builds and launches rockets with the ultimate goal of being the first student team in the world that reaches space. DARE was founded in 2001 as a committee of the VSV (which is the student society of Aerospace Engineering) and DARE has been a D:Dreamteam since 2005. In 2009, DARE started off with the quest to reach space by launching Stratos I which reached 12.3 km in altitude, breaking the current altitude record for student rocketry. This record stood for 6 years straight, after which we broke it ourselves with Stratos II+ which reached 21.5 km in October 2015. Currently, DARE has a total of 120 active members and two big active projects: Project Aether and Project Stratos III. Project Aether, which is a technology demonstrator for future Stratos missions, features an active stabilisation system and new parachute recovery mechanisms. The goal of project Stratos III is to drastically decrease the amount of development time and launch a Stratos sized rocket within 1 year after the start of development.

With newer and more complicated systems, DARE needs an ever increasing amount of electronics. When you ask people about robotics, space robotics is normally not the first thing that comes to their mind. This is not surprising, since the satellites that provide us with, for ex-ample, our GPS signals, are far away from us. You can't see them, so it is hard to get an image of how it works. The same goes for the electronics of a rocket. The rockets that DARE is building are, in fact, robots. After it leaves the launch tower, it has to operate autonomously until it reaches the ground. On small scale rockets, this can be as easy as a timer that actuates a parachute deployment mechanism. On bigger rockets, however, data from several sensors needs to be used to assure that the rocket will operate safely. With speeds as high as 5 times the speed of sound and altitudes twice as high as the cruise altitude of a commercial airliner, you can imagine that there is little room for error.

In the Stratos rockets, the electronics not only acquire sensor data, but also control the engine. For a Hybrid rocket engine, a system of hoses and valves is used to guide the liquid oxidizer from the tank to the injector, which mixes the oxidizer with the solid fuel. The Engine Control Unit first allows the tanks to be filled, and then operates the valves with several solenoids and servomotors to ignite and start the engine at lift-off. During flight, the electronics read the sensor data and stay in contact with the ground. If anything seems to go wrong, the engine can be shut off. In the future, the electronics might also be used to throttle the engine or control a turbopump, to increase the performance of the engine even further. This makes the electronics a vital and complex part of the rocket.

This is even more the case with Aether's new, actively stabilised systems. On rockets that are actively stabilised, a PID controller actuates control surfaces, which can point the rocket in the upward di-
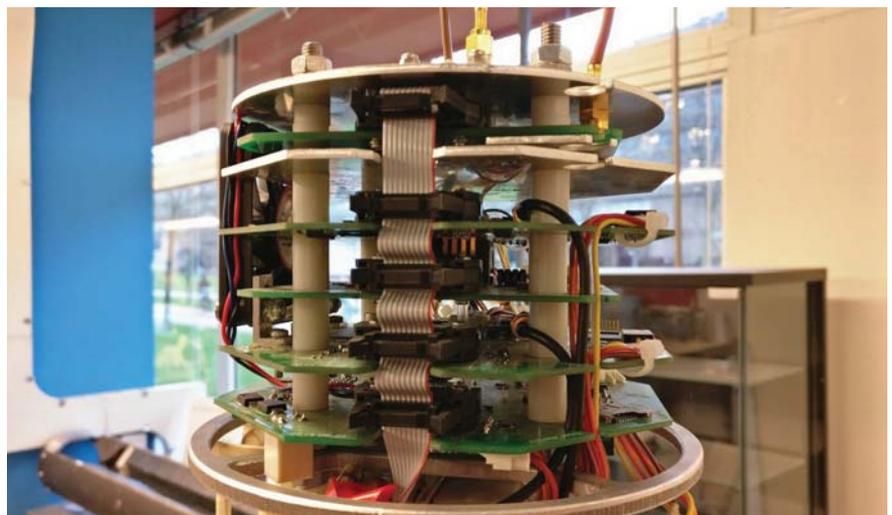
Figure 1: *The main Electronics Stack of the Stratos II+ mission*
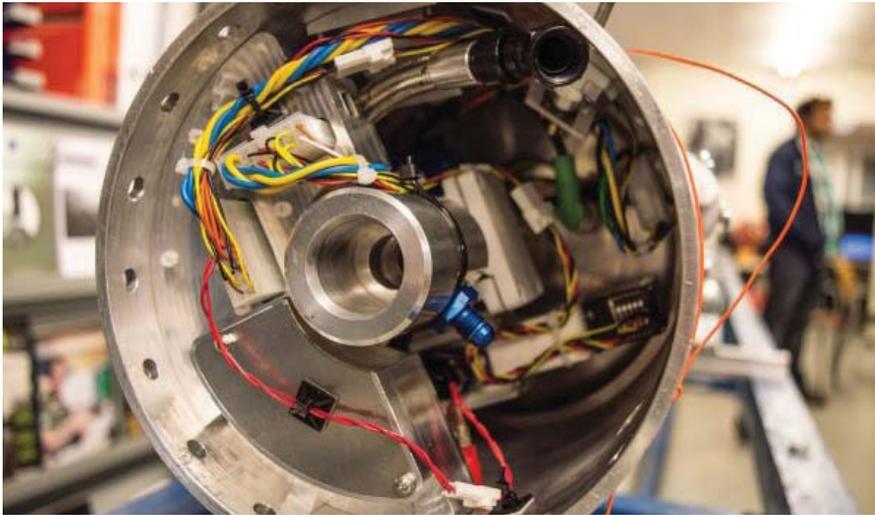
*Figure 2: The Engine Bay of Stratos II+, including the valves and actuators*

rection. Precise measurement systems like accelerometers are needed, to make sure that the PID controller properly actuates the control surfaces. These kinds of systems are needed because, to get as high as possible, you want to decrease the amount of horizontal distance as much as possible. Every meter you go sideways, you don't go up. With these systems, DARE can point the rocket straight up so that every Newton of thrust pushes our rocket to space.

With these new systems, our dedicated electronics team is working hard to provide the hardware that can hold up to the expectations of the other teams. Until recently, the electronics were designed with rocket specific software. The downside is that a proper test and verification of the electronics and software cannot be done, other than during the actual launch. To ease the manufacturing process, the team has been working on a generic stack of electronics that can be used for a wide range of rockets within the society, including software. The new set of electronics has the same software in every stack, which can be tested ex-

tensively and in flight, such that only the state machine will be different for each rocket. A main board and power board form the basic configuration of any rocket. When sensors are wanted to record data, one or more sensor boards can be stacked on top, equipping the rocket with a wide range of sensor inputs. Another commonly needed option is the actuation board, which can actuate four actuators of choice per board. In liquid rockets, these actuators are often (solenoid) valves and in the case of project Aether, the board is used to control four actively stabilised fins. At the top of the stack, a communications board can optionally be installed to have a live video link and real-time measurement transmitted from the rocket.

To summarize, the electronics used in DARE's rockets are used for many different purposes. They are required to control the engine, stabilize the rocket, deploy the parachutes and acquire important sensor data that is further used to improve the rockets that are being built. As such, electronic systems are a vital and complex part of DARE's quest to space. ⌨
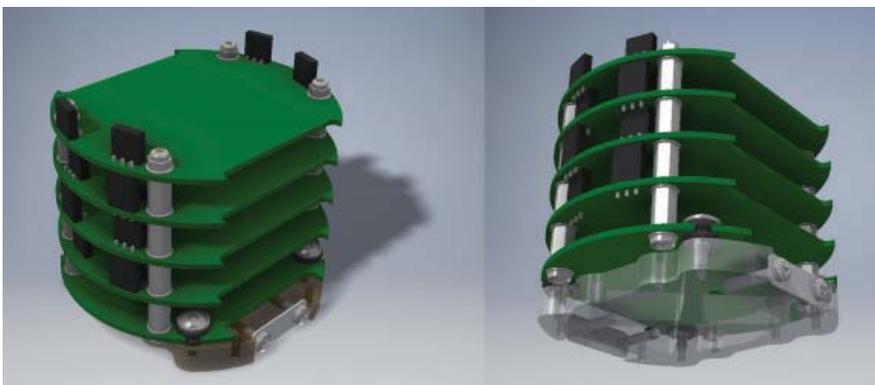
Figure 3: A render of the new modular electronics stack

Figure 4: A prototype of the new modular electronics stack

The Student Council

An update by ORAS

ORAS is the Student Council party with 44 years of experience within the Student Council of the TU Delft, which distinguishes itself by the value it attaches to room for extracurricular activities. According to the vision of ORAS, the following elements are necessary for the TU to turn you into a top engineer: a good and motivating education, sufficient proper facilities and opportunities to develop yourself within and next to your studies. This year ORAS can represent this vision with 7 seats in the Student Council. Some of ORAS big achievements are for example Collegerama, the XXL opening hours in the University Library and the opening of the auditorium during the weekends over exam periods.

Besides these big achievements, we also work on a lot of current affairs.

Two new LDE minors

ORAS has been dedicated for years to making it possible for students to take a broadening minor during their Bachelor studies. In addition to this, we are also very involved with the Leiden-Delft Erasmus minors and it is an ORAS initiative that made these LDE minors possible. As a result, two new minors are coming up starting 2017-2018 for which you can sign up this May: Frugal Innovation and Geo Resources.

Brightspace

From September 2017 all faculties will switch from Blackboard to Brightspace. With Brightspace, it's easier to keep track of your courses. An important aspect of Brightspace is its structure. The aim is to use modules that are as similar as possible for different courses. ORAS will continue the dialogue with the Brightspace team to make sure Brightspace meets the desires of students.

Laptop Project

Along with ICT staff ORAS annually presents a list of demands and wishes. Afterwards we make a choice of models. We usually opt for a high-end workstation with much power. The past few years, TU offered a high-end laptop more than 50% cheaper than retail stores. We have upgraded the service and now hardware can often be repaired within 48 hours. Last year 2,600 students bought a laptop through this project. Feel free to contact us if you have another idea.

Campaign

The Student Council elections are coming up! On the 17th and 18th of May you may vote for ORAS! Together with our successors we are already working really hard on the preparations. Our election promises will be made public soon so you can read all about our plans for next year.

Talk and symposium

ORAS has two committees: the talks committee and the symposium committee. Last week we had our symposium, which was a great success. The talks committee also has plenty of interesting events in store for you.

More information about ORAS can be found on our website or on Facebook. It's of course also always possible to email or call us, or to visit us in our office in building 26B.

An update by Lijst Bèta

Lijst Bèta has a clear vision for the future of education at the Delft University of Technology. We want to continuously improve education by implementing new methods of teaching. Students should be able to choose their own way of studying. Not every student studies by going to lectures, there are different ways to learn the material. In our ideal situation, every student can choose their own study path, eventually ending up with the same knowledge as everyone else. When you can choose your own method, you will be more motivated than if you are faced with all kinds of obligations. We also think it is important that your study challenges you to push limits even further. Besides that, you should have a clear goal of what you want to achieve; how are you going to apply the attained knowledge of a subject in your future job?

By now you probably have the feeling you are reading one of those very exaggerated campaign posts, with a lot of talk and no action. But nothing is farther from the truth! We have been working to achieve this perfect vision for almost six years now, and we already reached some of our goals. One of those was to increase the ability of professors to give lectures. A lot of professors never had any training at all, they just started teaching one day. Before Lijst Bèta was founded only 7% of all teachers had a standard qualification. Now this is over 70%, a tenfold increase!

This year we also started with new initiatives, for example 'evaluate your minor'. Regularly students figure out during their minor that it is not what they expected. We want to avoid this, because your minor is in most studies one of the only things you can choose yourself in the curriculum. This choice should be the right one, and we think we can make that happen by building a platform in which students can evaluate their entire minor. In this way, other students can make a better-informed decision and the DUT can improve their minors.

Next year our successors will carry on with our vision and come up with new initiatives to keep improving the Delft University of Technology. If you agree with our vision and would like to support us, you can vote for us on the 17th and 18th May!

Activities

Sinterklaas and Christmaslunch

Ivar Hendrikson

During the month of December, the usual festivities like Sinterklaas and Christmas are celebrated. The ETV also celebrates these in their own way. In the beginning of December the Dutch celebrate Sinterklaas. The ETV made it possible for students to create and decorate their own paper shoes, which were then put at a fireplace. A few days later, after Sinterklaas had stopped by, everyone could find their shoes at the Sinterklaas lunch, where they were filled with lots of presents and everyone could enjoy a nice lunch together.

Later on in the month, we celebrated Christmas. During this Christmas lunch, everyone could see each other for one last time that year, listen to Santa Claus' speech and enjoy drinking gluhwein together. All in all, these celebrations were very nice and a great way to spend some time with your fellow ETV members.

American drinks

Robbin van Dijk

On Thursday the 12th of January, the American themed drinks were held. In the context of the recent presidential elections this seemed like an applicable theme. The drinks started at 19:00 and of course featured unlimited all-American hamburgers.

After most ETV-members had arrived the pub quiz started. Everyone was allowed to participate in teams of 2-7 people. The participants were tested on their knowledge of Delft, the ETV and of course America! An important discovery for some was that EWI actually has 22 floors! The pub quiz ended with a ceremony where both the best and worst participants were rewarded for their extraordinary performance. Afterwards students had the opportunity to grab a drink with their fellow students or to play the American beer-pong game.

LAN-Party

Jennie Christiaanse

It's not important whether you're a member, or coming from Delft or Leeuwarden. When it comes to gaming, we are all the same. Even though we were divided into PC, console and even table top gamers, the bar provided us a platform where we could all share our gaming experiences. While wearing garments ranging in comfortability from pyjamas to penguin onesies, we could indulge ourselves in either shooting, racing, or the necessarily suggestive party games. That night I had brought a friend with me who, despite lacking the required skill in shooters, won the third prize for "Team Fortress 2". I too was quite successful too! Subsequently I received the bronze medal for "Genital Jousting". That is definitely an achievement worth honoring!

ElecTrip

Bram den Ouden

At 4 A.M. on Wednesday 22nd of February we set off on Electrip. We had a four-hour drive ahead of us to Darmstadt where we would visit the first company: ESA (ESOC). Among other things we were shown the main control room, which was amazing! After ESA, we visited TU Darmstadt for a tour around their faculty. The day after we visited Daimler, where we were taken on a tour around the factory, and the Nokia-Bell labs, where we were shown their remarkable research work. We spent the night in München and the next morning we headed out to visit the last two companies on the list: BMW and NXP. At BMW, we were shown around the factory. It was interesting to see the differences between the production processes at BWM and Daimler. Our visit at NXP started with a delicious lunch after which we were told all about their research and development. The final day of the trip was spent traveling back from Frankfurt to EWI, where the Electrip ended.

Ski Trip

Lotte Zwart

During the first week of February the annual ETV trip was held once again. This year the trip took us to Les Orres, France. In the weeks prior to leaving, the biggest fear was that there wouldn't be enough snow. Luckily, on the way to the ski area it started to snow heavily. However, this meant that our trip took way longer than planned.

The trip had ETV'ers of many different ski levels, from first-timers to veterans. This made it a diverse bunch and sometimes gave reason for a good laugh or a rather concerned look. And with 100 kilometers of green, blue, red, black and 'fermé' (which we assumed means quiet, but later discovered means closed) slopes, there was more than enough to do for everyone.

The day-to-day routine was quickly established and every morning the group split according to everyone's plans. In the evenings there was even time for après-ski on top or down the mountain.

Unfortunately, the snow that fell upon arrival was the only snow that fell the rest of the week. The slopes were mostly fine, but this lead to some equipment not going home in one piece. Luckily, no one had to be sent home by 'gipsvlucht'. It was once again a great success, and I'm definitely going again next year!

Don't just
come to work.
Come to change.
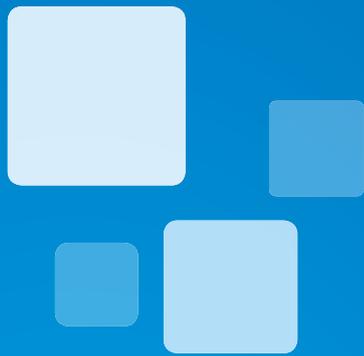
Internship at
McKinsey

www.mckinsey.nl

Maxwell, the legacy continues
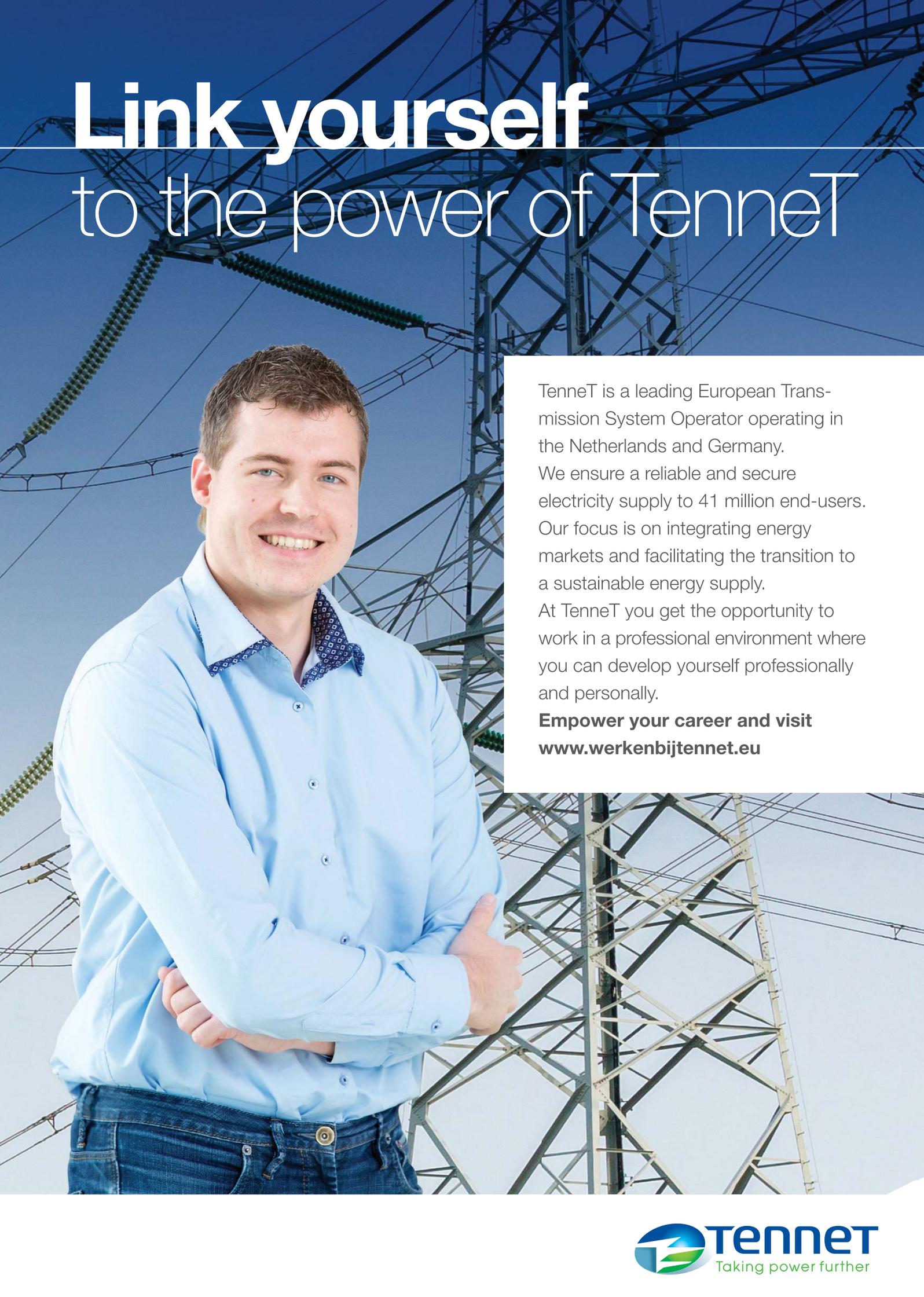## Will you make next year's Maxwells?

It has been a great honour being the editor of the twentieth generation of the Maxwell, but it time for the new generation. With them fresh ideas, new thoughts and sparkling creativity. It is them who are our future, it is they who will continue the path paved by years of hard work and it will be them who shall flouris.

The question is rather simple: will that be you?

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I WANT YOU FOR MAXWELL
NEAREST RECRUITING STATION

Link yourself
to the power of TenneT

TenneT is a leading European Transmission System Operator operating in the Netherlands and Germany.
We ensure a reliable and secure electricity supply to 41 million end-users.
Our focus is on integrating energy markets and facilitating the transition to a sustainable energy supply.
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