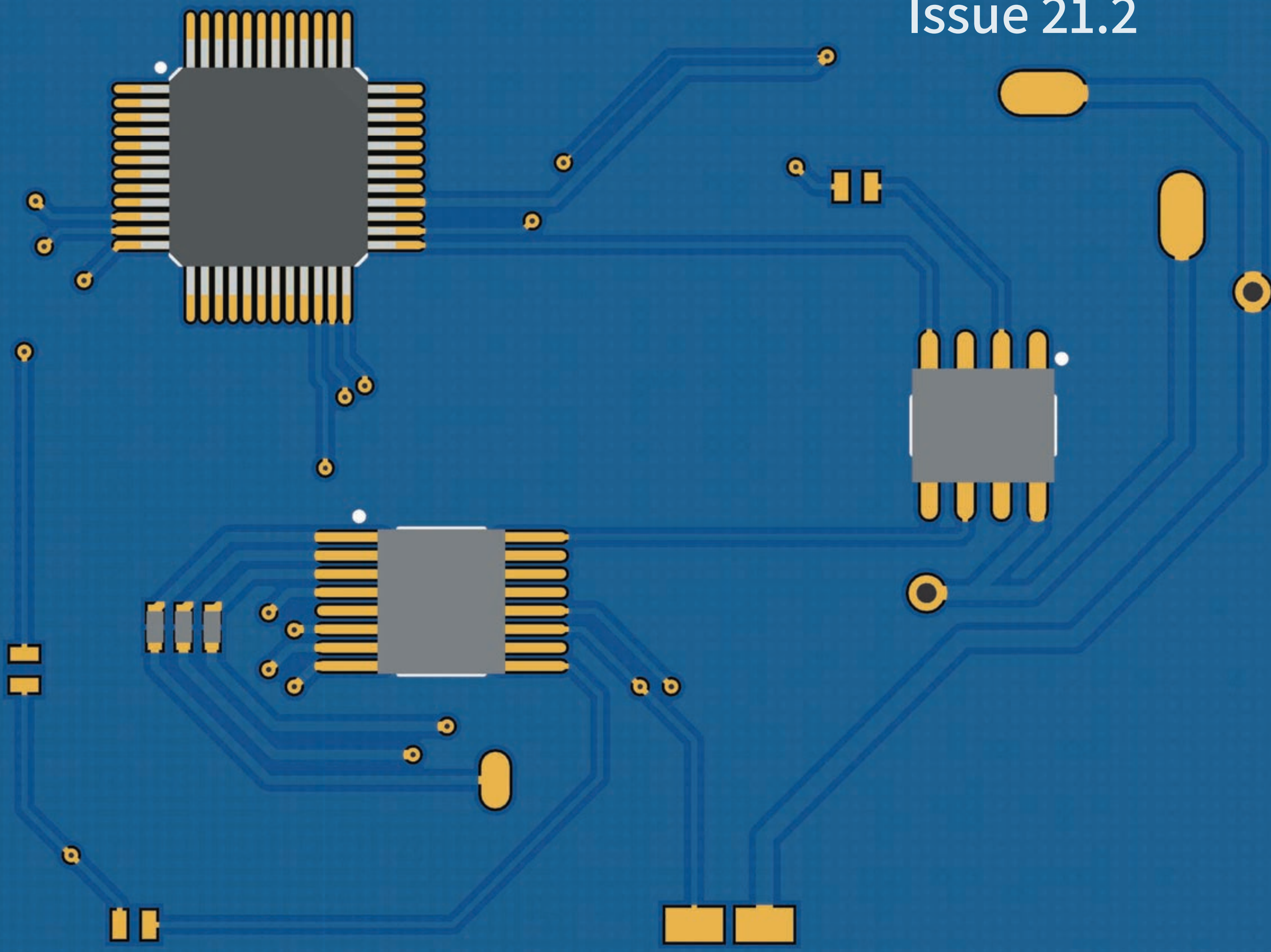
Electrotechnische Vereeniging

MAXWELL

CREATION

Issue 21.2



Resistors and compensators
High-precision measurements with high-precision resistors

Surface micromachining
Devices and machines built on nano technology

Forze hydrogen electric racing
What’s under the hood?

IN MEMORIAM

We deplore to announce that has passed away at an age of 89

Em. prof. ir. Jan de Haas

Emeritus Professor Delft University of Technology
Honorary Member of the Electrotechnische Vereeniging
Officer in the Order of Orange-Nassau

* July 4, 1928
Zaandam

December 29, 2017 †
Voorburg

Since 1981 the Electrotechnische Vereeniging has had the honour of having Mr. De Haas as Honorary Member. Our thoughts go to all involved.

Colofon

Year 21, edition 2, February 2018
Maxwell-ETV@tudelft.nl

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Advertisements
Page 2 – Prodrive Technologies
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Editorial

Dear reader,

I suppose you have seen the cover of this edition of the Maxwell before reading this. We, as editors, were struggling on the front page for this issue. We were not able to find a picture for the cover that satisfied all our demands, and of course, this edition's theme: creation. This theme gave us inspiration for the front page: create our own! We created it using PCB design software.

What is not there yet, should be created; and what is not how you want it to be, should be recreated. In this Maxwell edition, you can read articles about different creations and recreations, like the creation of Nano-machines or how the future power grid should be recreated.

Enjoy reading,

Duco Veldhuijzen

Dear reader,

During this technological era, people are constantly informed about new products, inventions and ideas. Nowadays, there is nothing strange about phone companies that release more than 10 models per year or scientific developments that did not even seem to be possible until recently.

Even though we are accustomed to these facts, think about these amazing advancements in humanity for a few moments. The reason for this is tied to our never-ending curiosity and it will continue to help us create new ideas.

This edition of the Maxwell will highlight some of the ways Electrical Engineering is used in present-day creation and production. Additionally, a project is included to create a device that hears our electronic items.

Happy reading.

Tom Salden

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From the Board

Commissioner of Education

Thomas Roos

Dear reader,

The sign up for the 2018-2019 cohort has been opened for our bachelor and master programs. Our faculty has already received relatively many enrollments, especially in the CS programs. It is, of course, great to have a lot of interest in our field of study, but it might get a bit "cozier" in the lecture halls.

For the past quarter, I have been helping with the creation of the next version of 'Zesje' [1]. Zesje is an exam grading software that makes it easier and faster to grade exams for teaching staff and enables students to get a better insight into the results of their exams. Learning from mistakes is a great way to learn, but in the current situation, not many students ever looked into their graded exams if they got a 6 ('zesje') or higher and will probably make the same mistakes in another course that builds on this existing knowledge. Zesje solves this problem by mailing the remarks of their exam.

Currently Zesje is in use in some courses at the faculties of AS and EEMCS but is not well known and albeit fully functional, not very refined yet. I would like to see Zesje being used a lot more in Electrical Engineering program by the end of this year. As Zesje is open source under the BSD-3 license, it can be found online [2]. Check it out if you are interested in using it for your own course or if you would like to help out on the development.

Like most softwares, Zesje is developed with the help of Git. Git is a popular version control system for managing source code of projects. Although Git is not taught during the EPO practicals, it can be of great help. Therefore, the ETV will organize a workshop on Git aimed at bachelor students. Interested? The sign up will open soon at the ETV desk.

If you have any questions or complaints regarding education, please send me an email at *education-etv@tudelft.nl*

[1] Low effort exam grading [*https://quantumtinkerer.tudelft.nl/blog/zesje/*]
[2] Zesje on GitLab [*https://gitlab.kwant-project.org/zesje/zesje*]

Secretary

Tijs Moree

Dear reader,

Creation is an interesting concept. Whatever you are looking at and not looking at has been created. I, myself, was created a few years ago, and since you are reading this, it means you were as well! We can, in our turn, create other things. As a student of Electrical Engineering, you can expect to create a lot of circuits.

Since I am part of the Board, my study is on pause for a year. The things I am creating now are way different from the soldering challenges the programme offers. As the Secretary, I am among other things responsible for keeping track of what is happening, all the mail-contact and promotion of events. During this year, I, therefore, create a lot of minutes, mails, letters, posters and flyers.

Using Adobe InDesign and Photoshop, you can create the best-looking posters, yearbooks and magazines like the Maxwell. The contrast with the study of Electrical Engineering is very big, but nonetheless, I really enjoy it. This terrific Maxwell proves the committee does as well!

Production in a " brighter" future

Abiseka Ganesan

The world in the last few decades has witnessed a steady growth in energy consumption owing to increasing population and improvements in quality of living. A significant part of this energy demand however, has been met by fossil fuels [1]. This has in turn led to explosive trends in global pollution levels and temperatures [2] that, if continued, can be prove to be detrimental to the environment . In recent years, the shift towards the use of renewable energies has shown definite promise with solar photovoltaics (PV) leading this shift, as evidenced by a 50% increase in installed capacity in 2016. China's investments in renewables to tackle its growing problem of environmental pollution has considerably increased in the last decade, making it the leader in the implementation of renewable energy. This has in turn led to a fall in the prices of solar PV cells to below 30 cents [3] aided vastly by an increase in the production volumes of PV cells. In 2016, crystalline silicon (c-Si) solar cells maintained the highest market share of close to 94% with the remaining 6% being shared by different thin film technologies [4]. A peek into the production of PV cells can help understand the current technologies in this market.

Silicon solar cells have evolved drastically over the last 50 years. From simple diffusion junctions in the early 1950s to the Passivated Emitter Rear Contact (PERC) cells available today, the number of processing steps involved in PV cell production has constantly increased in the hope of producing cells with higher efficiencies. The process flow for the production of conventional c-Si solar cells is shown in figure 2a. While the texturing of the top side of the solar cells improves light utilization, the application of a passivating anti-reflection layer (ARC) of silicon nitride (SiN) layer reduces reflection losses and surface recombination. The cofiring of the screen-printed metal contacts leads to the metallization of the front (silver) and back (aluminium) contacts and also alloys the aluminium on the back side. This allows the diffusion of aluminium into the silicon, leaving behind a p+ doped intermediate layer which acts as a back surface field (BSF) that partially reduces rear side surface recombination at the metal-silicon interface. The PERC cells on the other hand, additionally use a dielectric back surface passivation layer with a refractive index lower than that of silicon that enhances back surface metal reflection of light (figure 2b). This, coupled with a localized BSF through reduced back contact area further reduces rear recombination and increases light utilization which translates to an increase in efficiency by 1-2 absolute percentage points.

> *In recent years, the shift towards the use of renewable energies has shown definite promise with solar photovoltaics*

Poly c-Si solar cells that still control a majority of the market share of c-Si solar cells have lower efficiencies than their mono c-Si counterparts due to higher recombination rates of minority charge carrier at grain boundaries but their lower costs still make them competitive. With the

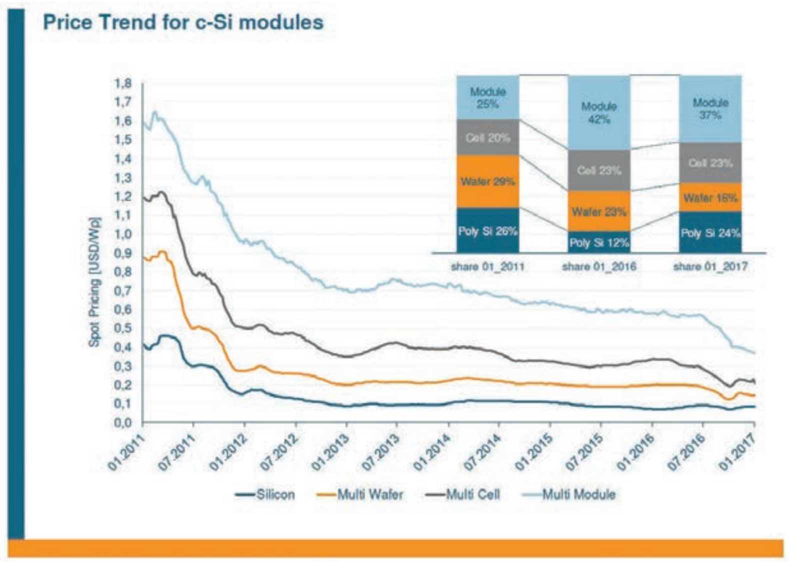

Figure 1. Price evolution of crystalline silicon in the last 8 years. Reprinted from ITRPV 2017 report, 8th edition.

popularity of PERC cells growing by the day, more and more manufacturers have been ramping up production lines to shift from production of PESC to PERC cells. Applied Material's fine line double printing and 2D patterning technology has helped produce PERL cells at low costs [6]. Meyer Burgrer's *Multiple Application inline Apparatus* (MAiA) platform provides efficient add-on machinery that can help existing silicon PV cell manufacturers expand their production lines to produce PERC cells with relatively low investment costs as seen in figure 2c [7].

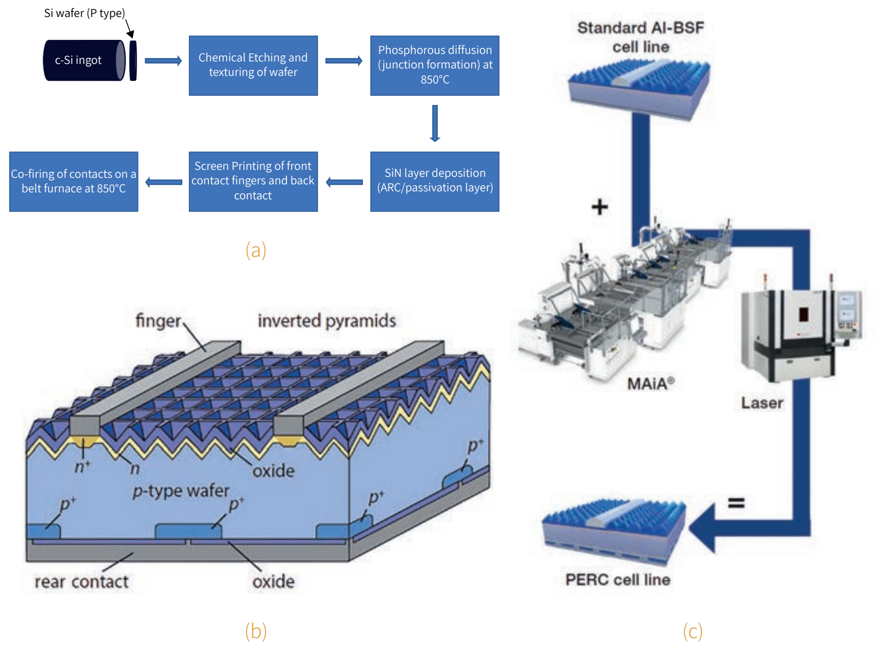

Figure 2. (a) Process flow of a standard PESC; (b) A Passivated Emitter Rear Locally diffused (PERL) c-Si solar cell that belongs to the PERC family of cells [3]; (c) The process flow of the Meyer Burger MAiA line to convert an existing Aluminium BSF solar cell production line to a PERC cell line [5].

Thin film solar cells gained a lot of momentum in the late 70s to tackle the high cost element of silicon wafer solar cells. With absorption coefficients higher than that of c-Si in the visible region, thin film solar cells utilize considerably lesser absorber material than c-Si solar cells. The mainstream thin film solar cells used in consumer markets are Cadmium Telluride (CdTe), Copper Indium Gallium Selenide (CIGS) and amorphous Silicon (a-Si) solar cells. CdTe solar cells have the highest market share among thin film technologies followed by CIGS and a-Si technologies though the best cell and module and cell efficiencies offered by CIGS are slightly higher than that of CdTe [4]. CdTe solar cells involve high throughput steps in their production such as CdTe deposition through closed space sublimation/vapour transport deposition on a transparent conductive oxide (TCO) coated substrate, CdCl2 chemical treatment of the absorber layer, intermittent laser scribing steps to produce individual cells that are interconnected via a series connection and back contact deposition through sputtering. First Solar Inc. is the biggest manufacturer of CdTe solar cells/modules with module costs of 0.7$/$W_p$ [5]. In spite of the taboo surrounding Cadmium use, CdTe has been proved to be non-carcinogenic, lesser prone to chemical leakage and much more stable than Cd at temperatures as high as 1000°C that makes its use safe within the regulations regarding environmental pollution. Barring the absorber layer deposition, CIGS solar cells utilize similar production steps. Since CIGS use 4 different elements (in a specific ratio), the absorber layer is deposited either in one single co-evaporation step or in successive steps of deposition (sputtering or evaporation) and selenization. While companies like Solibro, Würth Solar and Global Solar prefer co-evaporation techniques, Solar Frontier and Honda Soltec have used the latter approach [8]. The ability to manufacture these solar cells using automated processes has added to the attractiveness of these technologies. However, owing to the sharp decline in prices of c-Si solar cells in the last decade, thin film solar cells have lost out on the race to cost effective cells due to their considerably lower efficiencies.

"...CdTe has been proved to be non-carcinogenic, lesser prone to chemical leakage and much more stable than Cd at temperatures as high as 1000°C"

Figure 3. The ability of thin film photovoltaic materials to be printed on flexible substrates will revolutionize products and the energy industry in the coming years.

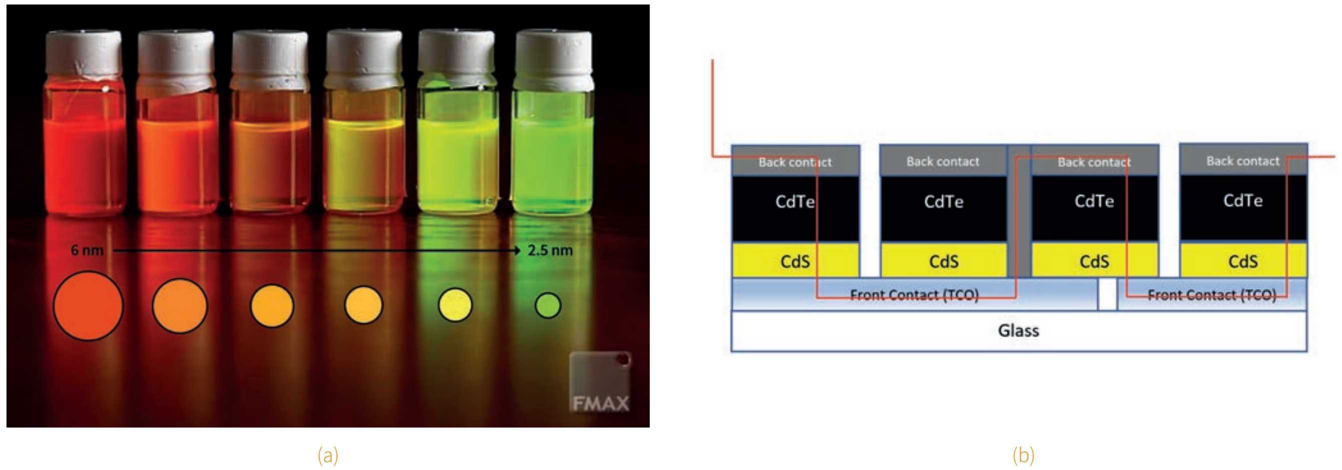

Figure 4. (a) A schematic of the series interconnections (red line) of neighbouring CdTe PV cells enabled by laser scribing; (b) Solution processed colloidal quantum dot semiconductor solutions. The bandgap of the semiconductor can be engineered by changing the size of the nanocrystals in the solution as can be seen in the picture.

New technologies like perovskites and quantum dot solar cells (figure 4b.) that utilize chemical synthesis methods are currently being explored in the lab scale and show good promise. In addition, their ability to be printed on substrates as thin films allows them to be merged into roll to roll manufacturing setups for the entire production process that can push down production costs drastically. Even in case of mature PV technologies, it can be noticed that the best lab level efficiencies are higher than the best industrial scale efficiencies by 3-5 absolute % points. This is because, cells produced industrially are limited by high speed industrial processing, required for profitable operation that otherwise limit the efficiencies of solar cells. Hence, there has to be urgency in developing efficient industrial processes and production lines that can close this gap and help in accelerating the charge led by solar PV technologies in adopting sustainable technologies to transition to a sustainable energy future.

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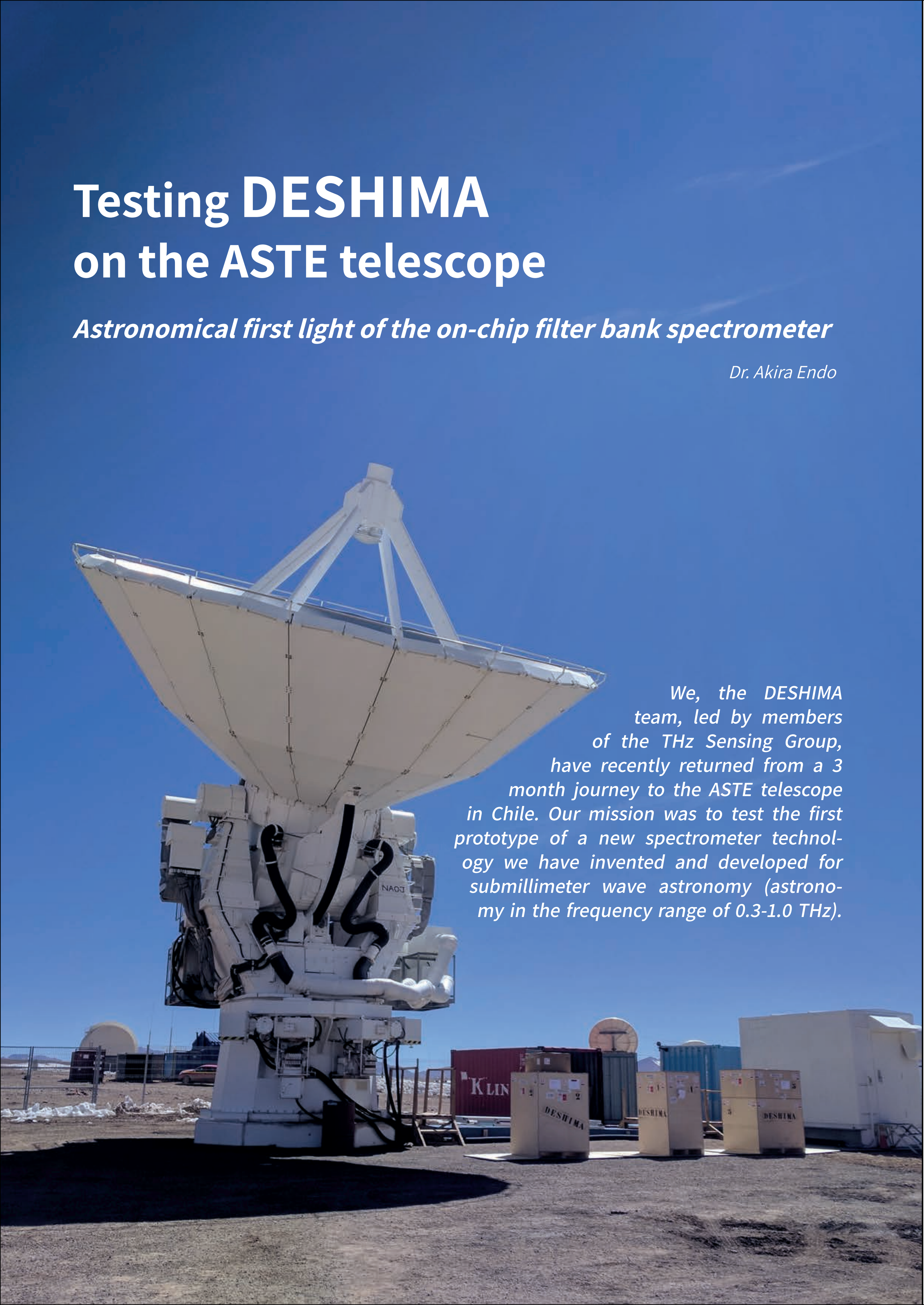


Testing DESHIMA on the ASTE telescope

Astronomical first light of the on-chip filter bank spectrometer

Dr. Akira Endo

We, the DESHIMA team, led by members of the THz Sensing Group, have recently returned from a 3 month journey to the ASTE telescope in Chile. Our mission was to test the first prototype of a new spectrometer technology we have invented and developed for submillimeter wave astronomy (astronomy in the frequency range of 0.3-1.0 THz).

Because it was the first time that the *on-chip filter bank spectrometer* (or any instrument based on kinetic inductance detectors) was installed on the ASTE telescope, the goal we had set prior to the campaign was to test whether various system components behave the same or differently compared to tests in the Cryolab of the Else Kooi Laboratory. Indeed, preparing and conducting cryogenic experiments at 4800 m altitude under low oxygen level, in a tiny telescope cabin that tilts and rotates, was a very interesting challenge, requiring also automation for remote control. Ultimately DESHIMA was able to make its astronomical 'first light', detecting a handful of astronomical objects, ranging from near-by to distant. Throughout the campaign, we enjoyed the fantastic collaboration with astronomers from Japan. While our results should soon appear in peer-reviewed scientific journals, in this article, we would like to introduce some of our live experience in conducting exact sciences outdoors, that you will not find in typical scientific literature.

DESHIMA: cosmology with nano-technology

DESHIMA, the **De**ep **S**pectroscopic **Hi**gh-redshift **Ma**pper, is an instrument and experiment that aims to measure the cosmological redshift of dusty, massive starburst galaxies (also known as 'submillimeter galaxies' for their brightness in the submillimeter part of the electromagnetic spectrum) in the early Universe, by mapping redshift to spectroscopic channels of a superconducting filter bank on a chip, in a 1:1 manner (Figure 1). By constructing a filter bank using superconducting microelectronics, DESHIMA aims to ultimately cover a frequency range of 240-720 GHz, which translates to a cosmological redshift of $z = 1.6\text{-}6.9$ (from 0.8 till 4 billion years after the Big Bang), if we use an emission line from C+ (1.9 THz at rest frame) as a tracer. This is a much wider instantaneous bandwidth, and hence a much broader redshift coverage, compared to heterodyne receivers or optical spectrometers that are currently being used in the field of submillimeter wave astronomy. The realisation of such an on-chip spectrometer has become possible with the world-leading technology at SRON (the group of Jochem Baselmans) and TU Delft (THz Sensing Group) of *kinetic inductance detectors*, which enable the integration of thousands of extremely sensitive submillimeter wave detectors in a scalable fashion. The ultimate goal of the DESHIMA project is to construct a 3D map of the dusty Universe, to unveil the dust-enshrouded part of the cosmic history of star- and galaxy-formation.

In figure 1, one can see that the signal from the telescope is focused onto an antenna, from which a superconducting transmission line extends. The signal is separated into individual frequency channels by means of superconducting NbTiN microresonators that act as narrow band-pass filters. At the end of each filter is a Microwave Kinetic Inductance Detector (MKID, or KID). The signal is absorbed in the Al section of the KID. The cone depicted above the chip (adopted and modified from the original article [1]) illustrates the redshift range that DESHIMA maps to the filterbank, when using the C+ line as a tracer.

The origin of the DESHIMA project dates back to around 2009, in a series of discussions among Akira Endo, Jochem Baselmans and Teun Klapwijk: this could be seen as a tripoint of astronomy, instrument science and solid state physics. The research and development of hardware for DESHIMA is currently ongoing in a collaboration between TU Delft (THz Sensing Group) and SRON, with strong involvement of students from TU Delft. The electromagnetic design of the filter bank chips and the optics are mainly done in the THz Sensing Group. The fabrication of the superconducting spectrometer chip is currently done in the clean rooms of TU Delft (Kavli Institute of Nanoscience) and SRON. The performance of these ▷

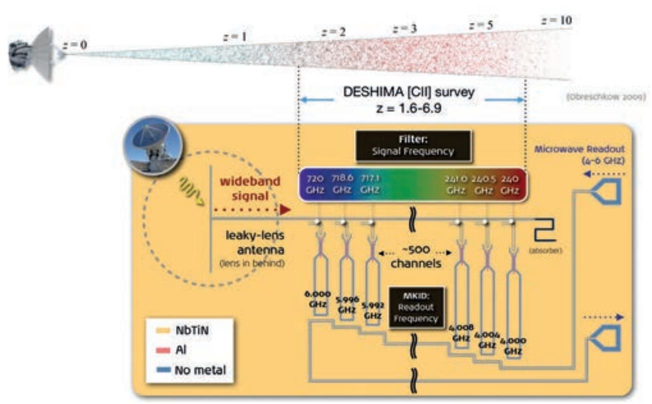


Figure 1. Conceptual drawing of the on-chip filter bank being developed for DESHIMA.

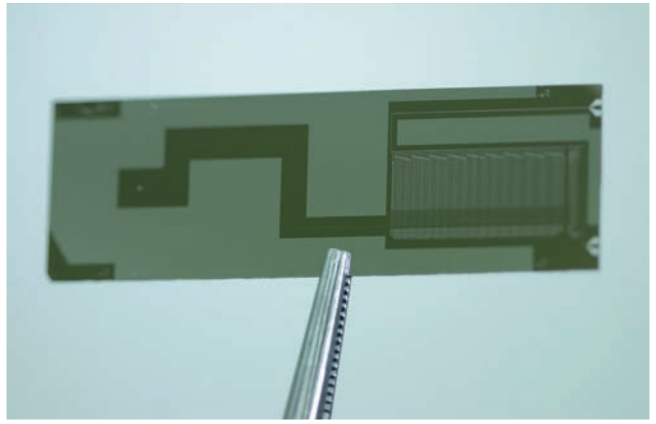


Figure 2. A DESHIMA filter bank chip, held by a pair of tweezers. The chip is 42 mm x 14 mm in size.

Figure 3. Transportation of the DESHIMA cryostat for installation requires a lot of care to avoid mechanical shocks.

chips are tested in the Cryolab located in the Else Kooi Lab of TU Delft, and in the laboratory at SRON. Advanced hardware for the cryogenic optomechanical setup and readout electronics was developed at SRON.

In the beginning of 2017, the entire system of DESHIMA, including the chip, optics, cryogenics and electronics became one in the Cryolab, and we could measure spectra of gas in the laboratory. The moment had come to take the instument out of the lab and point it at the sky.

Figure 4. Installation of the DESHIMA cryostat (protected in a plastic bag) to the ASTE cabin.

Preparing and running a cryogenic experiment in the desert of the Andean Mountains

An astronomical experiment like DESHIMA has many similarities to typical experiments in low temperature physics and circuit quantum electrodynamics (such as those being performed at QuTech of TU Delft), in the sense that they can use similar microwave circuit architectures, use similar cryogenics to cool the chip down, and use similar isolation techniques to reduce noise from the environment. Yet the most distinct difference that characterise astronomical experiments is that you always have a window from the chip to the external world, to allow your device to respond to the light from the sky: light that has travelled for many (sometimes even billions of) years since it was emitted. In addition, the experiment has to be taken out of the laboratory, and has to be performed at the focus of a telescope, which is typically a much harsher environment compared to a laboratory in a University building.

> *"Despite many critical moments in which one failure could terminate the entire mission, we were able to successfully install the DESHIMA system in the cabin"*

On October 6, we installed DESHIMA in the cabin of the ASTE telescope, a high-precision 10 m parabolic antenna operated by the National Astronomical Observatory of Japan (NAOJ). This involved many challenges that we experienced for the first time:

- Transporting massive, fragile equipment from the Netherlands to the Atacama Desert of Chile;
- Integration of the cryogenic optical structure in the basecamp located in the village of San Pedro de Atacama, and subsequently carrying it up the rough road on a 4WD truck;
- Lifting the cryostat to the cabin of the telescope using a forklift and scissor lift;
- Final assembly of components while adjusting our bodies to the low oxygen level; etc.

Despite the many critical moments in which one failure could terminate the entire mission, we were able to successfully install the DESHIMA system in the cabin, which was certainly nothing else than the result of good preparation and tremendous support from the staff of NAOJ.

On October 19, we made a scan over Saturn and saw the spectrometer responding strongly. This was the first astronomical signal captured by the new technology of on-chip filter bank spectrometer. Things had gone so unexpectedly smoothly, that we needed to ask one of the astronomers from Japan to come 1 week earlier than the original planning to start developing software pipelines for astronomical data reduction. After 34 days and nights of observation from then, DESHIMA has seen the Moon, planets, carbon star, red hypergiant star, star forming region , spiral galaxy, Ultra-Luminous Infrared Galaxy, and also performed 3-4 nights of ambitious long integration high redshift galaxies in very good weather. We are currently very busy analysing all the data that has been collected, which contain invaluable information for the next upgrade [2].

Figure 5. After a successful installation of the DESHIMA cryostat in the Cassegrain cabin of the ASTE telescope.

Team Spirit

Finally, I would like to express that it was an extreme pleasure to lead this team of extremely enthusiastic people with a diverse background, in terms of both profession and culture. Everybody was there with his own motivation, and multiple members convinced their host institutes to support their participation in this campaign, from around the world. Many people who I regard as friends, from different times of my carrier, came to do exciting science together. If you are a University student reading this article, one thing you should do during your studies is make many good friends who are different from yourself: those relations will become the treasure of your life. And last but not least, I would like to thank the family members of all participants, for their generous support at home that enabled this mission.

Figure 6. The DESHIMA team extremely excited to detect the first astronomical signal with an on-chip filterbank spectrometer.

[1] *Obreschkow et al., Astrophys Journal, vol. 698, p. 1467, 2009.*
[2] *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). See: http://bit.ly/2FNAk3C*

Further readings

Student projects

If you are interested doing a MSc. project in DESHIMA or another astronomical instrumentation mission, send an email to me (a.endo@tudelft.nl) or contact researchers in the THz Sensing Group. *http://terahertz.tudelft.nl/*

Kinetic inductance detectors (KIDs)

New 1000-pixel space camera system now mature enough.
http://bit.ly/2mGhqmw

Watch the video about the DESHIMA/ ASTE mission by TU Delft TV:

Forze

Hydrogen Electric Racing Team Delft

Jan Maarten Buis

Building a circuit-worthy racing vehicle can be an enormous technological, organizational and financial challenge, as the yearly estimated budget of any professional racing team (take F1 or Le Mans) will show you. A quick search learns that just 'your average' F1 team has a budget in the hundreds of millions of euros in funds. Teams consist of hundreds or even thousands of professionals, both engineers and managing staff. Now imagine designing and building a competitive vehicle with just eighteen full-time people that are only active for a year. And with no guaranteed funds or parts. And, more importantly, while discarding the traditional racecar engine layout and replacing it with an experimental in-house designed hydrogen fuel cell system.

Forze VII

Take these ingredients and you have Forze Hydrogen Electric Racing, a TU Delft student engineering team according to TU Delft's renowned Dreamteam formula. The team has been building racing vehicles with a hydrogen fuel cell at its heart for ten years now. Starting with small karts (which were the Forze I, II and III), then bigger, Formula Student Competition-style vehicles (Forze IV and V), to full-size racecars (Forze VI and the current Forze VII). With the Forze VII the team competed in the Gamma Racing Days in Assen against traditional gas-powered supercars, a world's first.

Fuel cell challenges

Most people see the well-rounded sky-blue curves of the Forze VII and hear the success stories, but few get to see what hides under the hood. A racing enthusiast who is hoping to catch a glimpse of a powerful gas engine in the front will be disappointed. Besides the fuel cell ('the stack'), which looks like a dark greyish block, the car's layout consists of a large DC-DC converter ('the Brusa'), which converts the fuel cell voltage to a higher voltage so it can be used as input for the motor controllers, that, in turn, drive the actual motors.

This is the central powertrain system of the car. What rests is all the equipment that is needed to power, control and cool these systems. And that is where the real challenge lies. Since the formation of electricity by recombination of hydrogen and oxygen is by itself a complex electrochemical process, the fuel cell system comes with its own grocery list of things that should be kept in mind when the system is in operation.

All the equipment that is needed to keep the fuel cell in its most productive point of operation is called the Balance Of Plant (BOP). The BOP consists of valves, pressure and mass flow meters, temperature and humidity sensors and the fuel cell cooling cycles. Since the fuel cell has a separate hydrogen (anode) and oxygen (cathode) side, the BOP consists of two sets of equipment. One to deliver hydrogen from the tanks (350 bar) at the right pressure to the anode side, the other to deliver enough air at almost equal pressure (via an air compressor) to the cathode side. The fuel cell is surely the most important but also the most complex part in the car.

Nervous system of the car

If we compare the fuel cell and powertrain system as the lungs, heart and muscles of the car, the nervous system of the car is where it should get interesting for an electrical engineer like myself. Two central CAN-buses form the spinal cord of the Forze VII. They contain the information stream that is driving the car's embedded systems. Throughout the CAN bus we find small embedded computers ('nodes') that read out and process sensor data and use this to maintain the control loops.

Figure 1. Dashboard of Forze VII with a driver interface on the steering wheel.

Nine ARM Cortex M4's form the backbone of the car's embedded system, running on EmbOS, a Real-Time Operating System (RTOS) created by Segger. The operating system does some memory management and scheduling of tasks, but not more than that, as to create minimal overhead and leave as much processing power as possible to the actual tasks.

The PCB that contains the M4 processor is mounted on a generic, in-house designed board that contains a power supply from two 24 V lines, some ADC's and reroutes most pins from the M4 to either soldering pads or directly to one of the connectors. Beneath that is a board that was specifically designed to read out sensors. Most of the low-level software contains code that drives the devices that are mounted on these PCB's. This way, the nodes can control and monitor both their own power electronics and their digital electronics. It also means that changing something in the hardware configuration of the nodes will require changes in the low-level code as well for it to work.

Limited number of sensors

Even while implementing more and more devices into one system makes for an interesting challenge, one must always keep in mind that every system has limits, e.g. the car's communication bus (and supplementing hardware) supports only so many sensor data objects.

As the car saw a steady increase in the number of implemented sensors over the past years, we now see that especially when it comes to logging, one of the nodes is continuously running on its toes. Therefore, this year we're hoping to make a start with slimming down the number of sensors in the car. It might be good to keep a sharp distinction between one-off sensor implementations that only last one specific test and more permanent solutions that keep an eye on previously unknown possibly critical systems.

Tomorrow's advanced packaging
for electronics and heterogeneous system integration

H. Yi, A. M. Gheytaghi, B. El Mansouri, L.M. Middelburg, B.Zhang

The Electronic Components, Technology and Materials group focuses on multi-disciplinary research on emerging materials, innovative microstructures and devices, and novel integration concepts for Health, Energy & Environmental applications. As part of ECTM, we work on Micro/Nano System Integration and Reliability of both Silicon and wide bandgap semiconductors.

Our major research activities on Micro/Nano System Integration and Reliability are:

- 3D wafer level integration with nano materials;
- advanced packaging level system integration (SiP);
- multi-material interface engineering of complex sensing systems;
- wide bandgap semiconductors components for harsh environment applications; design for component, product and complex system reliability;
- fast reliability qualification and testing.

Aiming to become the centre of excellence on heterogeneous electronics system integration and reliability, we developed a strong international network and close cooperation with the worldwide leading industries and research institutions. We provide two interactive MSc courses, covering in-depth knowledge and the state of the art industry practices on advanced packaging and reliability.

"…we have witnessed the quick development of a new area of micro/nanoelectronics beyond the boundaries of Moore's law"

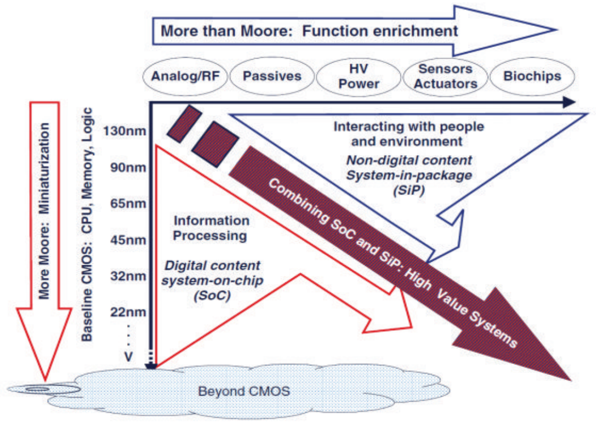


Figure 1. More Moore and More than Moore.

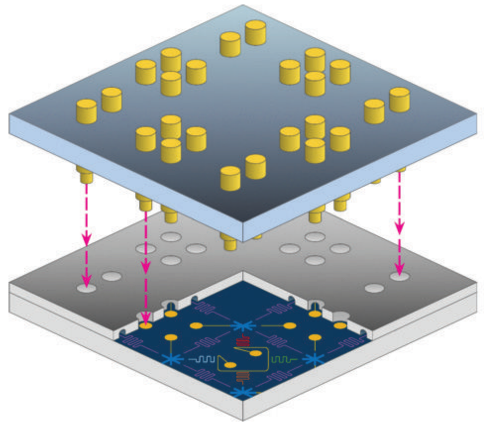


Figure 3. Extensible quantum-computing architecture.

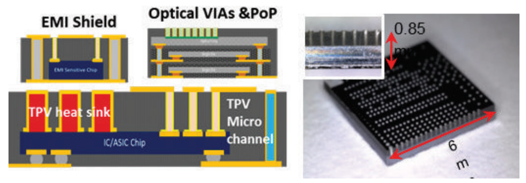


Figure 2. Realisation of Through-Polymer Via (TPV) technology.

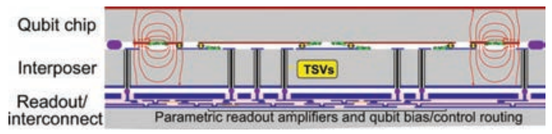


Figure 4. Qubit read-out and control using Through-Silicon Via Technology (TSV).

More than miniaturisation

Recently, we have witnessed the quick development of a new area of micro/nanoelectronics beyond the boundaries of Moore's law, driven by applications such as internet of everythings (IOE), big data, AI, smart city, smart home and autonomous driving. "More than Moore" (MtM) technology creates and adds various non-digital functionalities to semiconductor products and focuses on creating high value micro/nanoelectronics systems, leading to virtually unlimited technology possibilities and application potentials.

Packaging and heterogeneous electronic system integration became the key for future success of micro/nanoelectronics. The major scientific and technological challenges for packaging are much more than just miniaturisation as Prof. G.Q. Zhang, the chair professor for Micro/Nanoelectronics System Integration and Reliability, perceives. They are strongly associated with the facts that future packaging has the characteristics of multiple functionalities, multi-geometric scale, multi-materials, multi-interfaces, multi-variability, multi-damages and failure modes, multi-testing targets, for multiple applications/markets. Therefore, cross-boundary research by developing and integrating multi-disciplinary knowledge is a must, as can be recognized from the various research projects conducted by our group.

"…further miniaturization of electronic packages and ultra-high density of functionalities in a miniaturized package."

Play with 3D: heterogeneous system integration

3D integrated systems composed of heterogeneous devices, such as; logic, memory, analogue, RF and MEMS are expected to have a wide impact on applications, such as smart electronics, mobile communication and others which require miniaturized, multi-functional and energy-efficient electronics according to the ITRS roadmap. Furthermore, smart SiP's and RF systems, such as wireless communication devices, are occupying frequencies in the multi-gigahertz regime.

Through-Polymer Via (TPV) technology is a novel advanced packaging solution for various, multi-physical vertical interconnections utilized in both SiP or SoC situations. It has empowered "More than Moore" technology routine for further miniaturization of electronic packages and ultra-high density of functionalities in a miniaturized package. TPV's can be integrated to multiple physical domains, such as electric, fluidic, optic, mechanical or thermal, they can all be combined into a single system, providing the packaging designer tremendous freedom.

Quantum computing: superconductive interconnections

3D integration with vertical interconnect access (VIA) has been widely investigated and used recently due to smaller package size, higher interconnection density, and better performance in semiconducting devices. Presently, typical 3D-Via applications include MEMS, CMOS image sensor (CIS), stacked memories, hybrid memory cube (HMC), Sensors, RF filters and photonics.

Introducing the Super Conducting Via (SC-VIA) technology for scalable quantum integrated circuit architecture opens up a new window in applications. Building a quantum computer has been called the 'space race of the 21st century' - a difficult and ambitious challenge with the potential to deliver revolutionary tools for tackling impossible calculations.

Development of manufacturing process with superconductive material working in a cryogenic temperature by considering qubit compatibility is challenging. New material composition, such as nanoscale materials with superconductive metallic coating and potentially with metamaterial design is of great interest for further developing superconductive vertical interconnects (SC-VIAs).

Nano particle metals for interconnection

Interconnect material that can be fabricated in accurate nanoscale, with advanced properties is gathering heat among both research groups and industry. Heterogeneous integration including chip to wafer (C2W), wafer to wafer (W2W) and package on package stacking (PoP), requires interconnect structures with ultra-fine accuracy, profound electrical properties and better reliability. Current interconnect technology, such as wire bonding and flip-chip can no longer meet the need in feature size, reliability and electrical property for next generation electronics. Scientists have come up with the idea of using metallic nanoparticles for 3D heterogeneous integration. From both research and production point of view, this new method still has challenges to overcome.

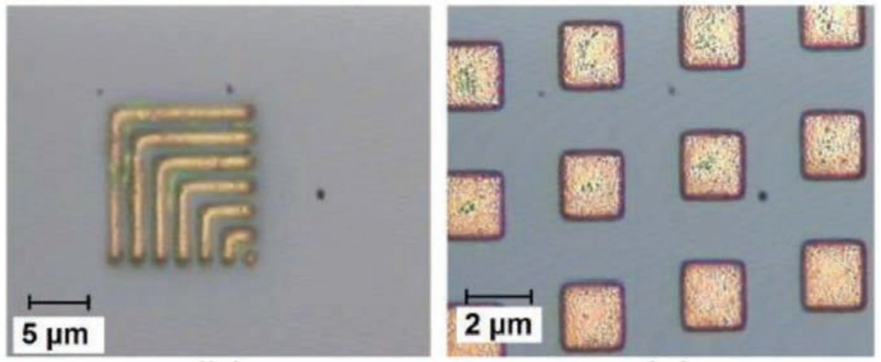


Figure 5. Patterened microstructrures from copper nanoparticles for wafer to wafer bonding.

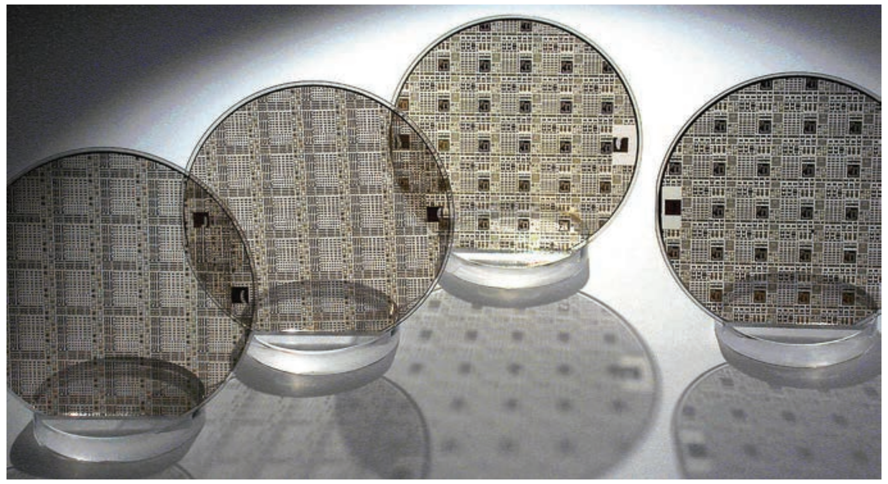


Figure 6. SiC wafers are, in contrast to silicon, mono crystalline silicon carbide transparent which brings additional challenges during processing in a silicon compatible infrastructure. (Source: ESA)

WBG materials for sensor applications

Wideband gap (WBG) semiconductors, such as GaN and SiC, have physical properties which are superior to silicon, such as increased thermal conductance, higher breakdown field and chemical inertness, and a higher Young's modulus. Furthermore, the WBG facilitates electronic behaviour far beyond 200 degrees Celcius, where leakage currents are inhibiting this for silicon electronics.

One of the leading research topics is about the power grid sensors which can be subjected to RF interference, highly corrosive environments, high humidity levels, vibrations, dirt and dust or other pollution which may result in malfunctioning of the sensors. Another WBG leading topic is dedicated to harsh environment compatible pressure sensors, intended for applications such as combustion monitoring and control, industrial applications, and geothermal and oil well measurements. Because of the harsh environment compatibility of the WBG substrate materials, the packaging scheme of WBG based sensors can be dramatically simplified. The substrate can be an integral part of the packaging in contrast to silicon sensors intended for harsh environments.

Surface Micromachining

Making of micro machines and micro electronic and mechanical structures

Amit Sangwan, University at Buffalo

In 1959, physicist Richard Feynman gave a lecture at Caltech called "There's plenty of room at the Bottom", stating that in the field of Nano-scale engineering there is a lot of space and scope for work that can be done to make Nano and micro functional structures which work in same way as their larger designs. Today, Nano-technology is enabling us to build more and more compact devices, but exactly how these Nano-structures are made is a matter of curiosity among a lot of people.

This article will discuss current and latest tools available for micromachining and standard flow of operations, followed by the latest research in scientific community which is enabling us to even make Nano-size molecular functional machines. This article will also talk about the Chemistry Nobel prize 2016 winning work and how it helped change Nano-machines designs from what we know today and have contributed to science by making molecular-motors, Nano-lift, and muscle like molecular Nano-structures.

Manufacturing microstructures

Most of today's surface micromachining is based on silicon wafer. Using multilayer deposition and graphic processing, a 3D micro mechanical structure is fabricated. The wafer itself is not being processed but the device is being formed by depositing thin films. The core technology that makes it possible is sacrificial layer technology which provides support for structure layers and is removed during final processing. In designing of any microstructure based design there are three major components:

1. Sacrificial layer: provides support
2. Microstructure layer: functional structure element
3. Insulating layer: ensures multiple microstructures can work unaffected by each other.

The process of manufacturing these Micro-structures involves a multi-stage process and can be explained as follows:

4. Bare films: These films act as guiding structures for the materials to be deposited. Usually there are multiple films for multiple layers to be deposited on surface of the wafer.
5. Deposited films: Using bare films as guiding structures, materials are deposited onto the wafer which takes shape of the particular geometry defined by films and these deposited layers are called deposited films.
6. Patterned by photolithography: Using light as source, the deposited photoresist film is given a shape.
7. Patterned sacrificial layer: Support layer for microstructure is made as per the desired design pattern.
8. Deposited mechanical structural film: This is a functional mechanical microstructure film.
9. Etching: All layers that are not required or that were used to support the microstructure formation are removed using chemical etching. Usually lower layers are corroded and only first layer is kept, this technique is known as sacrificial layer corrosion.

Relays and probes

Some interesting applications of this technology can be seen in manufacturing of micro structures such a Nano-electromechanical Relay [1]: A mechanically moving structure which moves because

> *"... molecular-motors, Nano-lift, and muscle like molecular Nano-structures."*

of the electrostatic force between gate and source and that acts as a relay; when switched on it connects source to drain and the circuit conducts. Another interesting application can be seen in the making of a 3D flexible multichannel neural probe array [2]. This is a specially designed probe for neural recordings and is better than a conventional probe as it is flexible and has moving structures that allow it to be easily implanted and opened to get precise readings without damaging brain tissues.

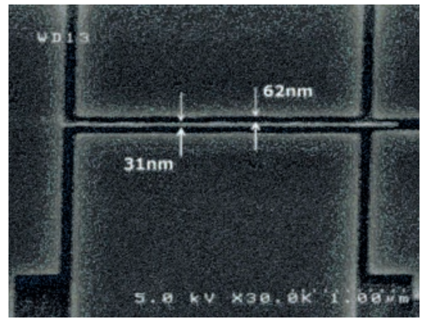


Figure 1. Close-up of a Nano-electromechanical relay. An electrostatic force closes the relay while an elastic force makes the strucute structure return to its original position.

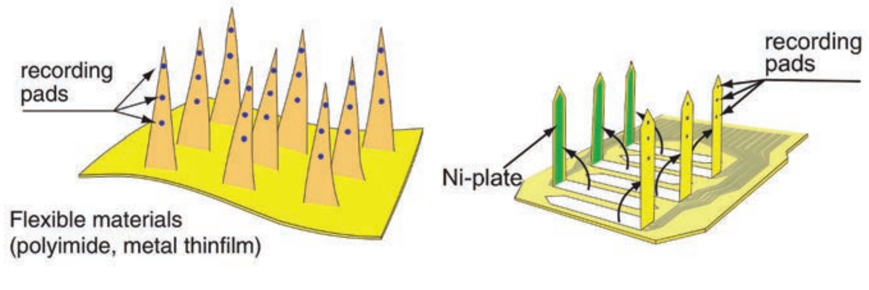


Figure 2. 3D flexible multichannel neural probe array: (a) concept and (b) end-of-fabrication result.

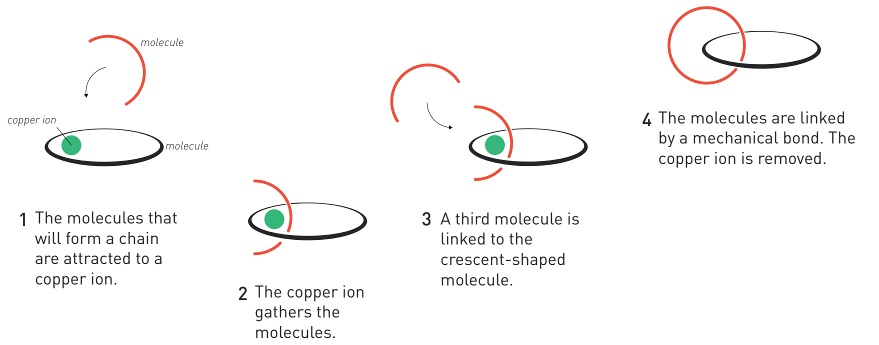


Figure 3. Mechanism for the formation of Catenante (molecular ring like structure). Source: Johan Jarnestad/The Royal Swedish Academy of Sciences.

Molecular machines

On a different approach, there are groups of scientists working from bottom up approach which is from molecules to the structure design. One of the major technological advancement that has been in molecular engineering side is also same as that got the Nobel prize of chemistry 2016, where the scientists were able to demonstrate ability to build molecular structures designed to function as per desired motion and structural assembly [3]. When we see a microstructure, its core is built using molecules and what if we could build a new form of molecules that we could use to build completely different type of structures!

Till mid 20th century, scientists were struggling with and were working to make such molecules that could be interlinked like chains. Then some groups in 1950-60 were able to get results but the yield was very low because they could make only few molecules in the entire experiment test tubes. A significant improvement was done by French research group led by Dr. Jean-Pierre Sauvage who used a copper ion to gather 2 crescent shape molecules to make a mechanical bond around a ring-shaped molecule. Once this mechanical bond was formed, the copper ion was removed and result was 2 interlinked rings-like structure (Catenane). Because of the copper ion, the yield of this reaction increased from a few percent to 42 per cent. Because the motion of one ring (part of the two interlinked rings) would constraint the motion of other ring, it fit the definition of a machine which should have parts that have constrained motion to each other. In 1994, his group succeeded in producing a Catenane structure in which one ring could be rotated in a controlled manner thus causing other interlinked ring to also rotate in the same direction, which laid foundation stones for molecular machines.

Second step in this molecular machine revolution is by Scotland based scientist Fraser Stoddard who developed a molecular structure in 1991 in which an open ring that lacked electron, was attracted to an electron rich rod like structure making the arrangement work as ring and axel arrangement. Later in 1994, the structure was optimized to be controllable and movement of ring could be controlled by application heat to move it forward and backward on axel. With numerous such structures and experiments Stoddart's research group was able to produce a Nano-lift that could move 0.7 nanometer above surface in a controlled manner and later in 2005 they progressed to make an artificial muscle. He also demonstrated production of a Rotaxane based computer chip with 20 kB memory which is a big leap compared to current size of transistor which is many fold larger compared to this.

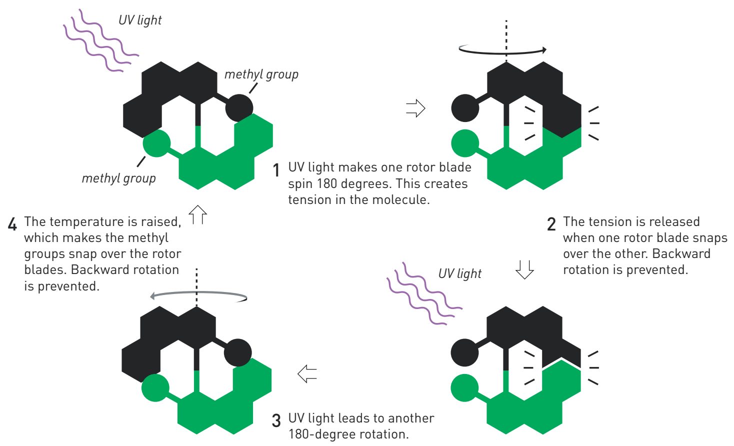


Figure 4. Working Mechanisms of a molecular motor. Source: Johan Jarnestad/The Royal Swedish Academy of Sciences.

"...a Rotaxane based computer chip with 20 kB memory which is a big leap compared to current size of transistor"

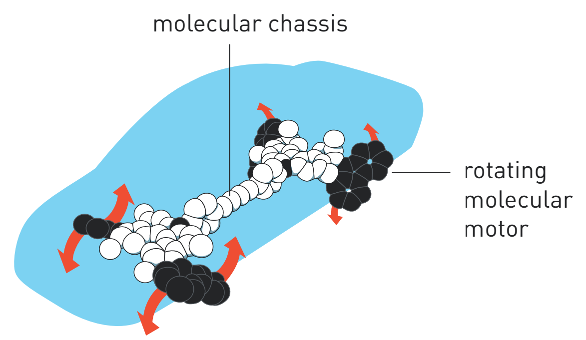


Figure 5. A molecular motor based 4-wheel drive Nano-car. Source: Johan Jarnestad/The Royal Swedish Academy of Sciences.

Third key contribution to this field comes from the Ben Feringa who was able to produce first molecular motor in 1999, which enabled controlled spinning of the molecular structure. Initially the motor would spin in any direction but he modified the structure such that the molecule could only spin in a particular direction when exposed to UV light. This was a huge leap. Later his group optimized the structure to spin at 12 million revolutions per second and they have also created a 4-wheel drive Nano-car utilizing the same structure which had 4 molecular motors spinning held together as Nano-wheels by a molecular chassis.

Promising Outlook

These fundamental blocks of technology given by chemistry laureates pave the way to the realization of advance Nano-structures that are functional and can produce much more featured and precise micro structures and redefine the production technology for the Nano, Micro level engineering as we know today. With more advancement in the current technology we can build more complicated machines such as the idea of Nano-machines presented by the Dr. J.M Jornet [4] which shows a glimpse of future for the medical, healthcare and advanced intra-body networks made from thousands of Nano-machines working together to keep out body healthy and monitor the systems.

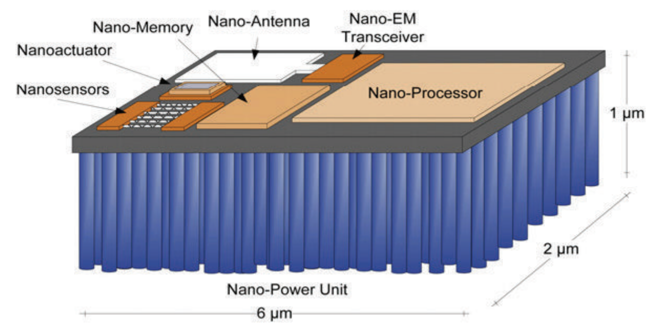


Figure 6. An integrated Nano-sensor.

[1] K. Yoo, D. Lee, R. Tiberio, J. Conway, H.-S. P. Wong, and, Y. Nishi, "Design and materials selection for low power laterally actuating nanoelectromechanical relays", in IEEE SOI Conference (SOI), 2012, pp. 1-2.

[2] S. TakeuWchi, T. Suzuki, K. Mabuchi, and H. Fujita, "3D flexible multichannel probe array," J. Micromech. Microeng., vol. 14, no. 1, pp. 104–107, 2004.

[3] Sauvage, J., Stoddart, S. and Feringa, B. (2016). The 2016 Nobel Prize in Chemistry - Press Release. [online] Nobelprize.org. Available at: https://www.nobelprize.org/nobel_prizes/chemistry/laureates/2016/press.html [Accessed 14 Dec. 2017].

[4] I. F. Akyildiz and J. M. Jornet, "Electromagnetic Wireless Nanosensor Networks," Nano Communication Networks (Elsevier) Journal, vol. 1, no. 1, pp. 3-19, March 2010.

Minor impressions

Advanced Prototyping

Tom Salden

After having studied Electrical Engineering for a few years, I enjoyed many subjects. The range of the subjects was very wide, but ultimately focused on theory. While this is understandable for a study program like Electrical Engineering, I wanted to broaden my practical skill-set and understand the limitations of some production techniques. The minor is a great opportunity for that and therefore, I chose to attend the Advanced Prototyping minor. This is a joined Industrial Design and Architecture minor that focusses on creating prototypes. The minor consists of four projects; two per quarter. There are some lectures about production and lessons in Rhinoceros (a 3D-surface modelling program) along with some workshops that show usable techniques for your prototypes.

During the first quarter, we made a lamp based on a chair. To help us make this, workshops with wood, laser cutting, plastic forming, and cement casting were given. Every week, the progress was discussed, and a new prototype had to be presented. The other project was a group project commissioned by various parties. The assignment of my group consisted of restoring cast-iron crowns on top of a monument. This had to be done by 3D scanning, 3D printing and casting the crowns.

In the second quarter, one of the projects was to make jewelry or something wearable. I decided to make cufflinks with inter-changeable top parts. For this, I used the lathe and milling machine a lot. The last project was a group project to make scale models of a watch tower.

Looking back, I am glad I chose this minor. I gained experience with some production techniques and it broadens my view on production. Afterwards, I will have to polish my knowledge on Electrical Engineering again, since I did not need that at all during the minor.

Computational Science and Engineering

Nuriel Rozsa

As a third-year BSc student, I have spent the first half of this academic year following the minor Computational Science and Engineering. In this minor, courses are given on how to write code that efficiently computes numerical solutions to mathematical problems.

To teach this, two different types of courses were given. The first type was computer oriented. In this course, it was shown how to efficiently program, what shortcomings a computer can have, and new programming tools were given. In the course, Scientific Programming, which was given in the first quarter, the tricks to writing a good scientific program were shown. In that same quarter, the course, Parallel Computing, was given, which gave tools for computing a program in parallel. In the second quarter of this academic year, the course, Object Oriented Programming with C++ was given, which showed techniques for writing an efficient object-oriented program using tools that C++ offers.

The second type of course was mathematical. In both, the first and second quarters, a course was given on how to convert certain types of mathematical problems into a numerical model, which can then be simulated in a computer program, like the heat equation, the wave equation or a stochastic particle model.

In the final project given in the minor, the knowledge acquired in both types of courses given was combined in an assigned research subject, which was then researched in a formed group consisting of different academic backgrounds, where the results were presented at the end of the semester.

In conclusion, I can say that this minor connected well with the bachelor program of Electrical Engineering and, in my opinion, gave a lot of tools which are useful in my major. I would highly recommend this minor to anyone.

Sailing Yachts

Jan de Jong

The last semester I did the Sailing Yachts minor and I have to say it was quite an experience. In the first quarter, the focus was to design a yacht with an existing yacht as a basis. The goal, however, was to meet the same speeds as the existing yacht, but the overall length had to be 2.5 feet shorter. This meant a lot of courses and lectures on hydro and aerodynamics, which for an electrical engineer is a whole different kind of subject material than we are used to but was easy getting used to.

In the second quarter, the main goal was to create a radio-controlled sailing boat model of 1 meter long and had to have a minimum weight of 4 kg. All the groups of our minor would compete in a contest where three different courses were sailed through. This all was done at the MARIN (The Maritime Research Institute Netherlands) in Wageningen where there was enough space for the boats to sail. Our design included wing sails (a wing used upright as a sail) because of the amount of sail surface could be drastically larger than conventional sails. This also meant we could accurately calculate certain sail positions for certain courses.

We also implemented a moving weight on board of our ship that was moved to one side of the ship to cancel the amount of heel. This also meant that if this weight was used properly, our ship would be more stable. In the end, we finished at the 2nd fastest in the finals but managed to also claim the prize for the most innovative boat. All in all, it was a very inspiring and informative minor with plenty of time to put the lectured material in practice.

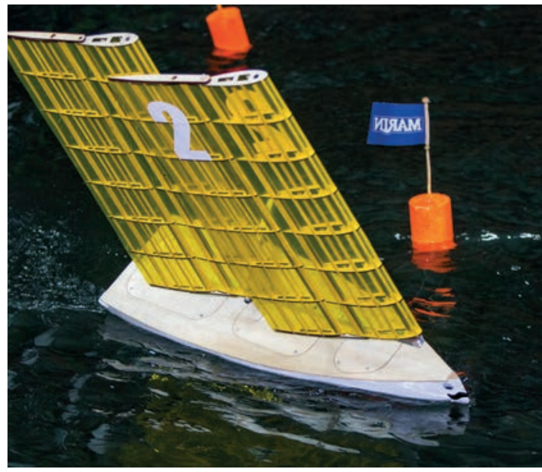


Figure 1. © Koen van den Ende

Robotics

Koen Peelen

The minor Robotics is about the development and building of robots with a multidisciplinary team. This team consists out of mechanical, industrial, computer and electrical engineers.

What kind of robot will be made depends on the customer. In my case, the customer was the ScienceCenter which wanted a host-bot. The requirements included the ability to tag customers, which can be used to offer services and be a representative for the museum.

To be able to do this, you get a few courses in the field of your colleagues, like Statics and Advanced Prototyping. When your detailed design is finished, you start building your robot. This is done in close collaboration with the customer which is comparable to a possible relation you might have with a customer in the designing field of work.

It also sometimes feels like an EPO project, except that there is nothing prepared. You don't have to work on a platform, you can make it all yourself. This causes some people to have troubles getting on track, or to get things working, but this freedom can also cause new and better plans.

Our robot is made out of two parts, the base and the head. Because we had the freedom, we could change the communication between the parts from a serial connection to a wireless link between two Raspberry Pis. This allowed a much cleaner look with only one cable connecting the parts. Eventually, all robots were presented on the robotics day, which the TU made quite happening.

Top performance in the field of mechatronics and motion control

Advertorial: Sioux and Kulicke & Soffa develop new wafer feeder

R&D manager Robbert van Leijsen of Kulicke & Soffa (K&S) and manager projects Jarno Lathouwers of Sioux leave no room for doubt. The development of K&S' new wafer feeder was no sinecure. It required constant interplay of their best people: commitment and engineering at the highest level. 'Masterpieces of this type are only possible if you operate as one team.'

K&S Eindhoven - formerly known as Assembléon - and Sioux are no strangers to each other. Sioux has been called in by the OEM in pick and place machines regularly since 2006, for example, as a development partner in software, electronics, remote connectivity, vision, and mathware. Over the last two years, the relationship has intensified during the development and construction of a state of the art wafer feeder.

Where the semicon industry is driven by miniaturization of integrated electronic circuits, smaller components must also be applied to PCBs. That calls for new requirements for surface mount technology, K&S' domain. In addition, classic wire bonding increasingly makes room for new advanced packaging technologies to connect and stack at die-level.

Figure 1. From left to right: Robbert van Leijsen & Jarno Lathouwers.

Fastest in the world

'The advanced packaging pick and place battle is fought from two sides,' according to Van Leijsen. 'High-precision machines are becoming faster, and fast machines are becoming increasingly accurate. Assembléon originated from the latter and proves very successful in this. K&S took us over in 2014, and rightly so. It gave us a boost on a number of fronts. This included the development of a new wafer feeder, almost a pick and place module placed for a pick and place machine. Wafers are inserted, fed through and stretched. Then a die is raised from the wafer. It is caught by a suction cup and handed to the pick and place robot. After passing through a flux dipping station and vision module, the die is placed. All in all, we have created one of the smallest horizontal wafer feeders in the world. It can compete with the fastest machines and pick up dies up to 0.5 by 0.5 millimeters.'

Competences and culture

At the start of the development process, one thing was clear to K&S: collaboration with a technology partner was essential. You simply cannot claim your entire engineering organization for a new project. The company almost immediately thought of Sioux, because of the clear match in competences and culture. The concept development took place at K&S and took three months. For the design phase and prototype building, the joint team was moved to Sioux and was scaled up to twenty people for several months. After the prototype, the 0-series has also been developed and built.

Lathouwers: 'The joint team performed at top level in the field of mechatronics. We assembled our best people because of the complexity of the project. First of all, there was a very challenging and inescapable restriction: the available space. Next to this, there were strict requirements in terms of speed, accuracy, robustness, product cost and development time. With so many variables, the trade-offs are almost infinite, and you may start to run in circles. So, apart from having to make keen choices from the first concepts onwards, you must also work with simultaneous solutions. This requires craftsmanship and a strong capacity for abstraction at system and detail level.

World-class performance

Thanks to parallel software integration and testing, K&S' new wafer feeder is ready for the market. This has resulted in a world-class performance, also from a time to market perspective. These masterpieces can only be created if you operate as one team. It involves more than just picking up a huge challenge and committing to it, which is usually not a problem if you have some technicians join a team. Creating the optimal architecture and detailing it further in the engineering is a constant process of resolving technical conflicts. To do that optimally, everyone must think the same way. You can see this at K&S and Sioux. Our engineers use uniform methods and standards and transfer their knowledge and experience to the new generation and each other. We speak the same language and show the same behavior. That pays off on the work floor, when people - often without making a fuss - take very practical decisions that connect seamlessly.'

"Masterpieces of this type are only possible if you operate as one team"

Resistors and compensators
Part 2

Text: Kees Pronk and Piet Trimp
Photos: Kees Pronk and Leo van Tuijl

In the second part of this two-part article we will discuss the construction and functioning of a so-called compensator. A compensator is a measuring device especially designed for measuring of voltages lower than 1 V. This article builds on the understanding of precision resistors as may be obtained from the first part of this article which appeared in Maxwell issue 20.4 (July 2017).

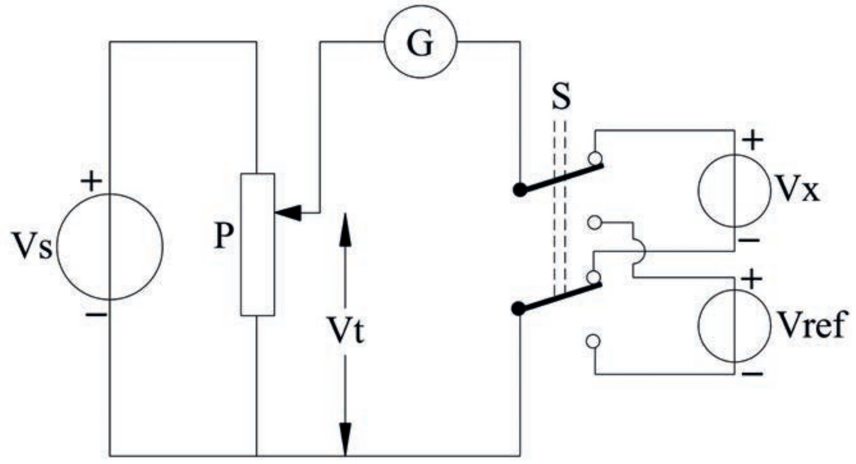


Figure 1. Basic schematic of a compensator.

History of the compensator

An important source of information for these two articles is the thesis of J.C. Deiman [1] who graduated in 1983 on the topic: *The History of the Compensator* (in Dutch). Parts of this article are taken directly from that thesis.

Further information may be obtained from the article by Luther [2]. Compensators have been built from about 1900 to 1960. Of course, no electronic devices such as digital voltmeters were available in those years.

Thermocouples

The interest in compensators arose because investigators were interested in measuring physical properties such as temperatures using thermocouples or Pt100 resistors and measurements of voltages produced by biological phenomena such as nerves and muscles.

The working of a thermocouple is based on the thermo-electrical effect in which a junction of two different metals produces a voltage which is a function of the temperature [3]. Usually a thermocouple measuring circuit consists of two junctions (e.g. copper to constantan and constantan to copper). One junction is kept at 0 °C (the cold junction) and the other junction is inserted in a flame or furnace to measure the temperature. Over a 0 to 1000 °C temperature range, a thermocouple generates a typical voltage of about 40 mV. To measure a temperature with 0.1% accuracy the compensator should have a resolution of at least 0.04 mV. For a correct determination of the temperature, it is important to measure the output voltage of a thermocouple without imposing any electrical load on the device.

◄ *Figure 4.* Detail of the back side of the switch in the Bleeker compensator.

“To measure a temperature with 0.1% accuracy the compensator should have a resolution of at least 0.04 mV”

Measurement principle of a compensator

Figure 1 gives the basic schematic of a compensator. Firstly, using the switch S, a reference voltage V_{ref} is connected to the compensator. This reference voltage is often produced by a Weston cell having an output voltage of 1.018656 V [4].

The tap on the potentiometer *P* is adjusted until the current through the galvanometer equals zero. The current through the V_{ref} then also equals zero. One could say that the voltage V_{ref} is compensated by the voltage V_t on the tap of the potentiometer, hence the name compensator for this measurement device. After compensation has been achieved, the value of the resistor below the tap is denoted (R_1).

The reference cell is then replaced by the unknown voltage V_x.

After compensation has been has been detected, again the value of the resistor below the tap is written down (R_2). It then holds that $V_x = (R_2 / R_1) \cdot V_{ref}$. It should be remarked that the battery voltage V_s drops out ▷

Figure 2. Wolff compensator KDE84.

Figure 3. Switch in a Bleeker compensator.

of the equation. To prevent thermal heating of the resistors, the battery is only connected to the compensator for a short period of time. Effectively, the source of the unknown V_x delivers no current as is required for thermocouples.

Construction of a compensator

The main difficulty in constructing a compensator usable in the laboratory and in the field, is the construction of the potentiometer *P*. A proper linear behavior cannot be achieved using a slide wire or wire wound potentiometer. The potentiometer should therefore be constructed using a system of (rotary decade) switches and precision resistors such as used in the decade resistor box discussed in part 1 of this article.

> *"The main difficulty in constructing a compensator usable in the laboratory and in the field, is the construction of the potentiometer"*

To understand the design and construction of a compensator, Figure 2 shows the front of a Wolff compensator, one of the most elaborate and precise compensators available in the Study Collection of EWI in Delft [5].

This 6-decade Diesselhorst type compensator model KDE84 made by Otto Wolff in Berlin has been built in a wooden box of 73 by 43 by 22 cm and weighs about 30 kg. The knobs marked with Roman numerals I to VI are the switches controlling the six decades of the potentiometer *P*.

The box only contains the resistors forming the potentiometer *P*. The galvanometer and the voltage sources are external to the box. This compensator has probably been constructed around 1950. In those days, the cost was around fl 20 000 (Dutch guilders). Nowadays the cost would probably be around € 100 000.

Low contact resistance switch

Replacing the potentiometer *P* by a voltage divider constructed with rotary switches and wire wound precision resistors however, opens up a box of Pandora. Such a switch should be very reliable and wear proof and it needs to have a very low contact resistance. Therefore, it has to be constructed from various materials other than copper. Figure 3 gives a detail of such a switch inside one of our Bleeker compensators (Diesselhorst Compensator, serial number 30466).

The fixed contacts of such a switch need to be made from some wear resistant material with good electrical conductivity, so presumably, some copper alloy is used. The spring making contact with the fixed contacts is probably made out of phosphor bronze. The copper alloy to phosphor bronze junction, however, shows up as source of thermoelectricity disturbing the measurement. Equally, the junction between the copper alloy and the Manganin used for the precision resistor shows up as a source of thermoelectricity. The value of the thermal electricity of the spring contacts is about 0.04 V per degree Celsius and this voltage is thus directly introduced into the measurement. The resistance of the switching contacts is about 0.2 mΩ. This value means that any resistor used in the voltage divider should have a minimal value of 2 mΩ.

Thermal isolation of the switch

The situation becomes worse when the switch is operated. The mechanical movement of the switch introduces heat and, therefore changes the amount of thermoelectricity produced by the alloys. Even the presence of a human hand operating the switch will produce heat. Several constructive counter measures have to be taken. The knob operating the switch should be thermally isolated from the switch by means of a thermal isolation layer. Additionally, one should make sure that both ends of the resistor are kept at equal temperatures. Figure 4 shows a detail from the construction of back side (resistor part) of the decade switch. This figure also shows the bifilar winding of the resistor. One should notice that the poles for the connections to the resistors are mounted directly on the contact blocks of the switch.

There are also other requirements to the voltage divider chain. The galvanometer often used in those days was a Deprez & D'Arsonval type. These types of galvanometers are undamped second order systems. The damping is to be provided by the resistors in the voltage divider. Therefore, the value of these resistors should not be too high. Secondly, the voltage divider is loading the battery. The load should not be too dependent upon the positions of the switches. And finally, the load resistance should be high enough not to deplete the battery too fast. In short, a number of contradictory requirements do exist.

It may be glimpsed from the figure that all internal wiring in the compensator consists of thick massive copper wires.

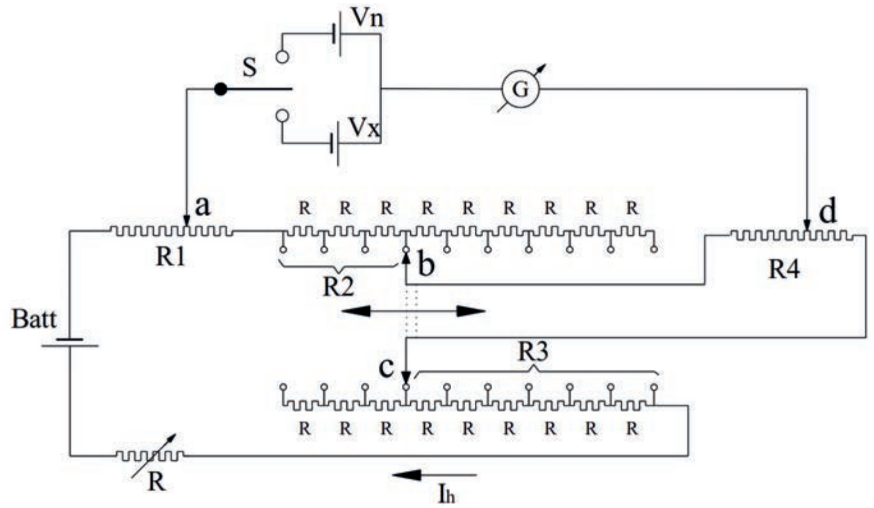


Figure 5. Feussner type decade switch.

Precursors to the Diesselhorst compensator

We will not mention all the designers having contributed to the development of the compensators described here. The interested reader is referred to the authors to obtain a copy of the Deiman thesis. Instead we will discuss shortly the Feussner decade, the parallel decade developed by White and then jump directly to the schematic of the compensator developed by H. Diesselhorst as described in [6]. The reader should verify that all the compensator developments described below contribute to resolving the requirements sketched earlier.

> *"The mechanical movement of the switch introduces heat and, therefore changes the amount of thermoelectricity produced by the alloys"*

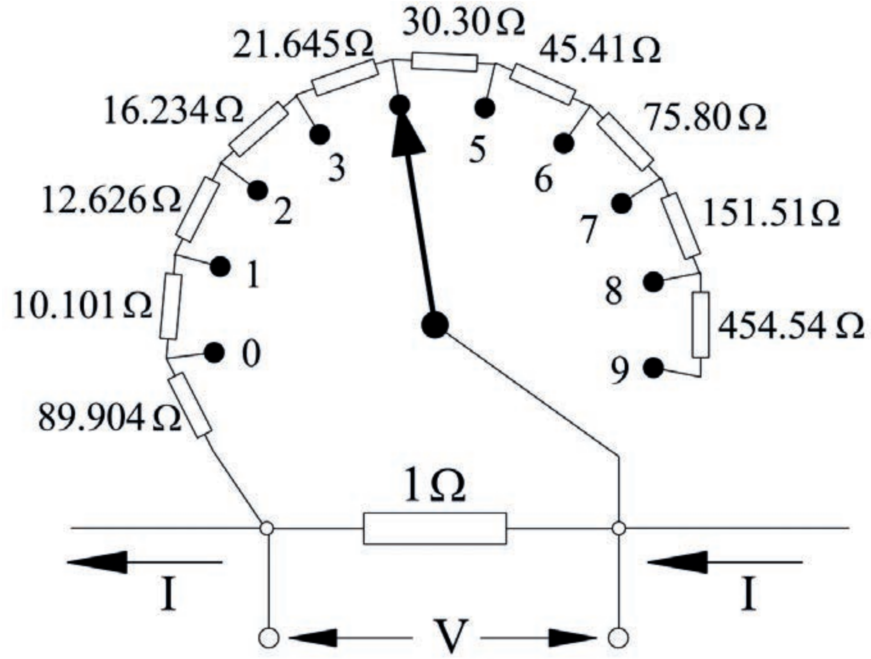


Figure 6. Parallel decade by White.

In the Feussner system (Figure 5, one decade only), the switch replacing the potentiometer is implemented as a twin switch. This principle has been used by many constructors of comparators.

In this figure, Batt is the stable voltage source, R_1 *to* R_4 are precision resistors, where $R_2 + R_3$ is constant. Resistors *a* and *d* are slide wires. The contacts *b* and *c* are moving together, hence the name twin switch. E_n is the Weston reference cell and E_x is the unknown voltage. The current I_h is set to 1 mA using potentiometer *R*. In this set-up the thermo-electrical effects of the switches *b* and *c* are cancelling each other. Additionally, the resistance of the divider chain is made independent of the position of the switches.

In the parallel decade by White (Figure 6), various resistors are switched parallel to a base resistor. The values of the resistors have been chosen such that the total resistance increases in equal steps. The reader is invited to check this out by calculating the resistance for each of the positions of the switch. The switch is only present in the parallel track and

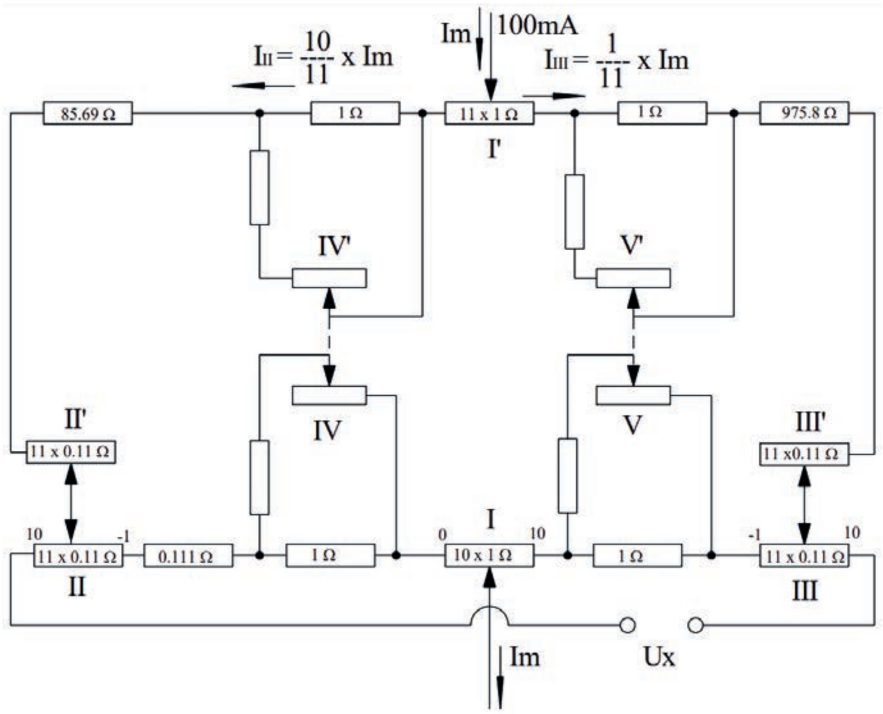


Figure 7. Diesselhorst compensator schematic.

the switch contacts do not contribute much to the total resistance. Additionally, the thermo-electric effects of the switch are weakened by the values of the resistors in the circuit.

Schematics of the Diesselhorst compensator

The 5 digit Diesselhorst compensator [6] as shown in Figure 7 is a very cleverly engineered combination of the above schematics: the Feussner twin switch and the parallel White decade. The reader is invited to study the schematic thoroughly and understand how the effects of thermoelectricity are minimized. The current I from the battery is split into two parts: $I_{II} = (10/11) \cdot I$ and $I_{III} = (1/11) \cdot I$. The accuracy of this split is very much dependent upon the values of the fixed precision resistors in the circuit.

The switches marked with Roman numerals I to V (as in Figure 2) are indicated in the schematics by the same numerals. The switches marked I and I' (and further to V and V') are the twin switches from the Feussner approach. The total resistance of the compensator is about 14 Ω.

Conclusion

The compensation technique has been used for many decades in the 20th century. In those days, this technique was the only reliable method to reliably and precisely measure low voltages such as those from thermocouples. The EWI Study Collection [5] in Delft guards several compensators from various famous manufacturers (Bleeker, Wolff, Dauphinee). Compensators according to Raps (not discussed here) and Feussner can be seen at the Academic Heritage Collection TU Delft in the library (upon appointment). All these compensators internally use the schematics by Feussner, White and Diesselhorst.

When you are interested to know more about compensators, you are always welcome to visit us on Mondays in the basement of the low building of EWI.

[1] J.C. Deiman: The History of the Compensator (1983), Thesis report (in Dutch), TH Delft.
[2] Präzisions-Gleichspannungskompensatoren, Konstruktionsmerkmale und gegenwärtiger Stand, Teil II; Helmuth Luther, Archive für technisches Messen, Blatt J931 – 11 January 1970.
[3] https://en.wikipedia.org/wiki/Thermocouple
[4] https://en.wikipedia.org/wiki/Weston_cell
[5] Study Collection EWI, TU Delft. http://www.ewi.tudelft.nl/en/the-faculty/studieverzameling/
[6] Thermokraft freier Kompensationsapparat mit fünf dekaden und konstantem kleiner Widerstand, H. Diesselhorst, Zeitschrift für Instrumentkunde, January 1908.

Energy storage for future sustainable power grids

Dr. Seyedmahdi Izadkhast and Prof. dr. Pavol Bauer

Are we able to increase the flexibility of electrical power grids in such a way that they can fully accommodate renewable energy sources , while simultaneously avoiding costly transmission & distribution reinforcements? To address this question, in this article we highlight energy storage as a key to flexibly create future sustainable power grids. An overview of energy storage technologies is provided, and then electricity services by these units are detailed. Finally, various research projects on energy storage within DCE&S are briefly discussed.

Current challenges

Figure 1 shows a schematic representation of existing power grids which mainly rely on conventional power plants using fossil fuels. Currently, electrical power grids are undergoing radical changes. At the generation side, the penetration rates of renewable energy sources like wind and solar, which have an intermittent and variable character, are dramatically increasing. At the demand side, the introduction of new loads like electric vehicles is resulting in an increased and unpredicted demand of electricity. These dramatic changes are leading to severe technical problems such as frequency variations, line congestions, voltage instabilities, and power quality issues in power grids which nowadays offer low levels of flexibility.

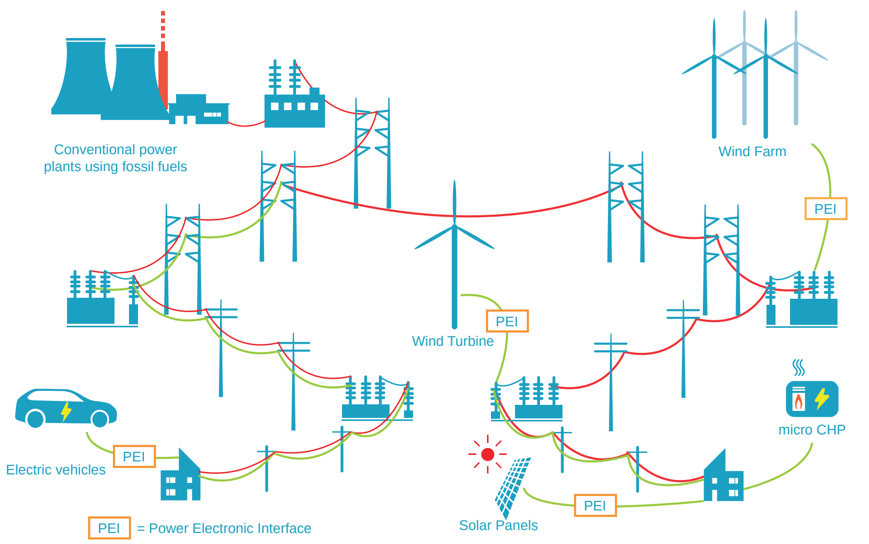


Figure 1. Existing power grids including conventional power plants using fossil fuels with low flexibility.

Future sustainable power grids

In figure 2, we show a future power grid which is fully powered by renewable energy sources. As can be seen, conventional power plants are replaced with larger-scale wind and solar farms. Also, the number of new technologies like electric vehicles are increased. To fully accommodate these technologies, it is required to dramatically increase the flexibility of current power grids. Energy storage systems can play a vital role in the future by providing high levels of flexibility to the grid. While at the transmission side, large scale centralized energy storage systems like pumped hydro energy storage (PHES)

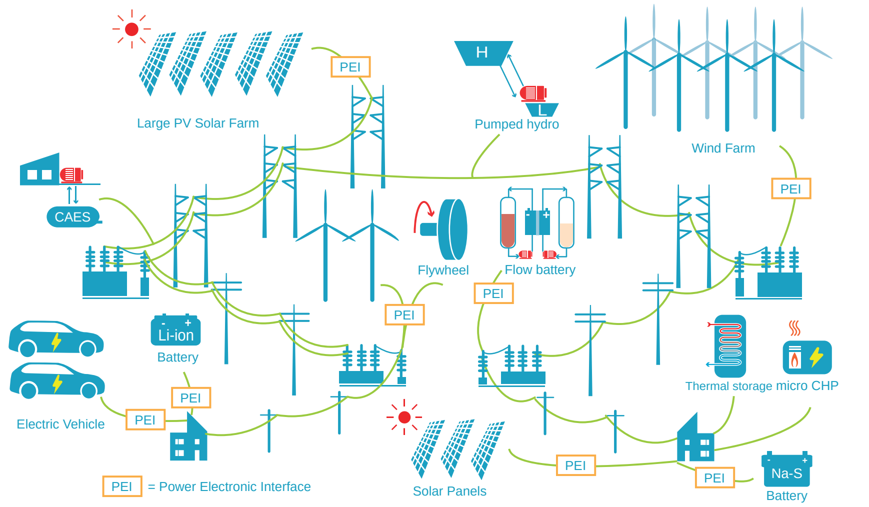


Figure 2. Future sustainable power grids including energy storage technologies with high flexibility.

and compressed air energy storage (CAES) can be used. At the distribution side, batteries and flywheels can be integrated in a decentralized fashion.

Energy storage technologies

There are various energy storage technologies which can be employed to increase the flexibility of existing power grids. PHES technology is one of the most popular technologies due to its large installed capacity (e.g., up to 5 GW). Nonetheless in the Netherlands, PHES has very little potential due to the small height differences. CAES is another type of storage which is mainly installed close to wind farms to mitigate their variable output power. Flywheel, super capacitors, and superconducting magnetic energy are other emerging storage technologies.

Moreover, electro-chemical energy storage systems are becoming very viable options for a wide range of electrical grid applications. In particular, Li-ion batteries have attracted a lot of research and industry attention due to their high energy densities. On top of this, it is expected that the manufacturing costs of Li-ion battery technology will be lowered in the coming years. According to the world energy council (WEC) forecasts, the costs of Li-ion batteries will be below 200 EUR / KWh by 2030. Bloomberg even predicts that at the moderate scenario the costs of Li-ion batteries will be below 120 $ per kWh by 2030. Another emerging technology is the flow battery which is a suitable option to enhance power quality and absorb large-scale intermittence of renewable energy sources. They provide high efficiency, end-less charge/discharge cycles, and good environmental performance.

Electricity services to stakeholders

Figure 3 shows 15 electricity services which can be provided by energy storage technologies to various power system stakeholders like system operators (SOs), utilities and end-use customers. Some storage technologies like PHES and CAES are mainly connected to high voltage transmission lines and are very location specific. As a result, they are able to only provide services to SOs at high voltage levels like peak load shifting, capacity firming, frequency regulation, transient voltage stability, and black start. There are storage technologies which are mainly connected to the medium voltage like flow batteries and fuel cells. Due to their connection to distribution grids, in addition to the SO's services, these technologies are able to provide a wider range of services such as power loss minimization, congestion management, and voltage control. Moreover, these technologies can enhance the possibility of islanded operation and defer investments in distribution cables and transformers. Finally, there are storage technologies like Li-ion and Sodium Sulphur that can be used for small scale applications like residential household. Due to their connection at the lowest level of the grid (low voltage), these storage units are able to not only procure both utility and SO's services, but also customer services such as emergency backup, increased self-consumption, and demand response. If these batteries are connected to a residential household from an electric vehicle then smart charging schemes can be provided.

Research activities on grid integration of energy storage

There are many research questions on the integration of energy storage technologies in electrical grids from technical, economical and regulatory points of view. The DCE&S group has conducted an extensive research with various projects such as Cellular Smart Grid Platform (CSGriP) project which has a close collaboration with industrial partners (e.g., Alfen, DNV GL, Alliander, WUR, Han, AVANS). Within CSGriP, TUD conducted research on frequency control, optimization and energy management, virtual inertia emulation, seamless transitions, and stability for the battery storage systems as well as electric vehicles. These developed solutions and control schemes were experi-

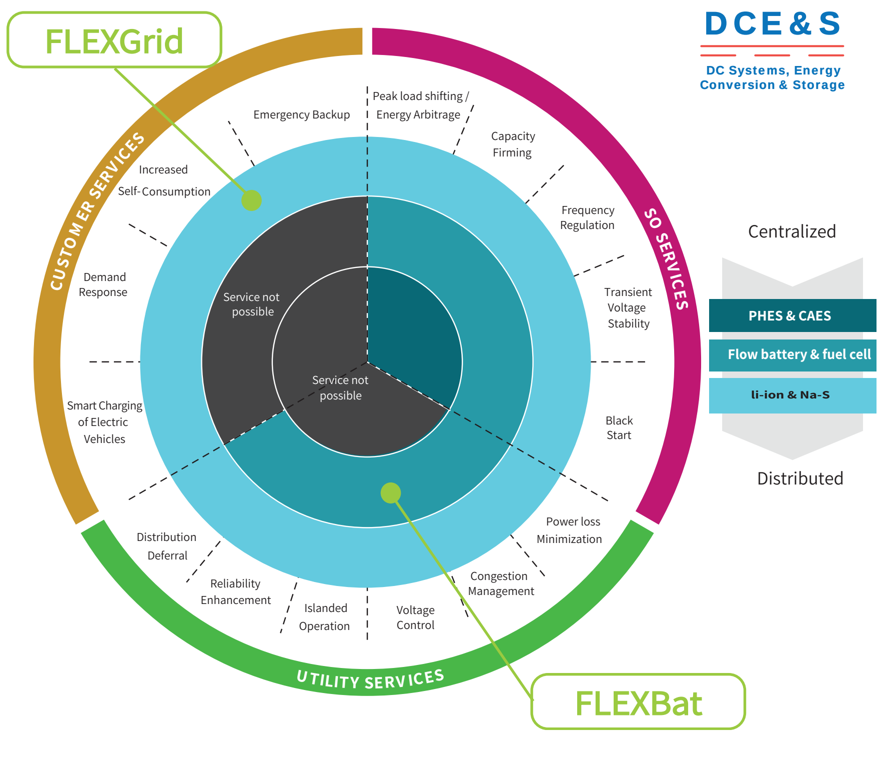


Figure 3. Electricity services by energy storage technologies to stakeholders like system operators (SOs), utilities, and end-use customers.

Figure 4. (Left) battery storage system installed by Alfen in Lelystad, the Netherlands, (right) electric vehicle and charging point at ACRRES site.

mentally verified at the Smart Energy Test Site of the Application Centre for Renewable Resources (ACRRES) in Lelystad, the Netherlands, in 2017, as shown in figure 4. Also, the CSGriP consortium successfully tested the islanded operation, black-start and self-healing process of the battery storage system (with the capacity of 0.5 MW using a complex local energy management algorithm).

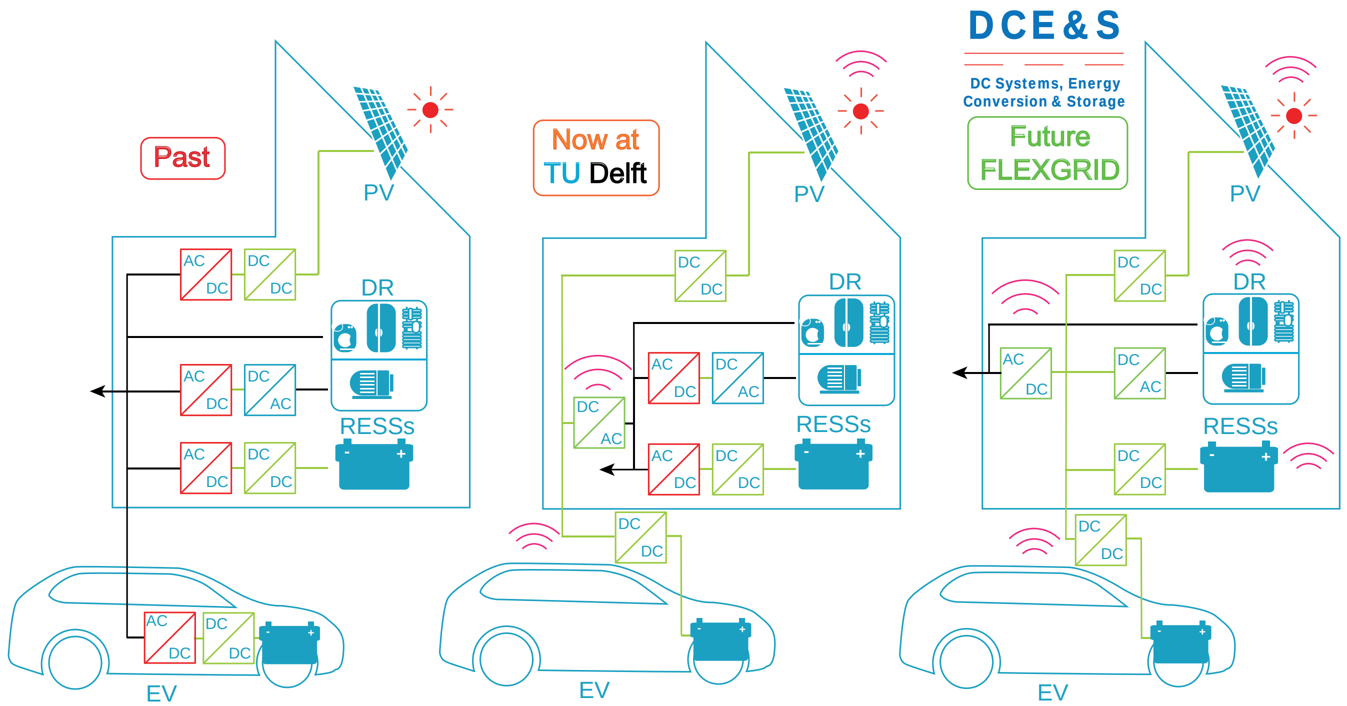
Our research on energy storage within the DCE&S group will be further strengthened, thanks to two recently accepted TKI Urban Energy projects, namely the FLEXBat & FLEXGRID. Note that within the Electrical Sustainable Energy (ESE) department, DCE&S will actively cooperate on the FLEXBat project with the IEPG group as well. As it is shown in figure 3, while the FLEXBat will focus on utility services at distribution level, the FLEXGRID will focus on customer services at integrated hardware level.

The main objective of the FLEXBAT is to create design rules, guidelines and techniques for the integration of battery energy storage systems in distribution networks. To achieve this, the specific objectives are formulated:

1. The best size and place of battery storage across the distribution grid through sophisticated optimization techniques
2. Appropriate behavior (power and energy management) strategies and a novel control platform for the operation of battery storage
3. New methods to properly aggregate battery storage systems throughout the distribution network
4. Novel business and market models articulated for battery storage
5. Verification of the developed design rules, guidelines and techniques and validation in a real-life system

The FLEXGRID is aiming to enable flexibility of residential distribution networks by developing and charging a novel modular sustainable system for integrated charging of EVs + residential energy storage systems (RESSs) with demand response (DR) schemes. Figure 5 shows the current status where PV, RESS, EV, and flexible loads are not controlled in either an individual or coordinated fashion. From being a distribution network asset for flexibility, they are a liability for the grid due to their uncontrolled operation. In the past, DCE&S has developed an integrated PV+EV for direct charging of EV from PV and the grid. It has the potential to integrate the PV and EV on DC and optimally charge the EV based on PV. But, it has a few limitations like it is not straightforwardly extendable for RESS and cannot capture full flexibility from an end-user for DR programs. In the FLEXGRID, the PV+EV hardware will be extended to a PV+RESS+EV+DR hardware with novel charging schemes to take advantage of the flexibility offered by future homes.

Figure 5. ▼ (Left) the past with no integrated hardware with poor efficiency, (middle) now at TU Delft with limited integrated EV+PV hardware, (right) Future FLEXGRID with novel integrated hardware with high efficiency using simultaneously three grid's flexibility options PV+RESS+EV+DR.



Maxwell 21.2
Energy storage for future sustainable power grids

Project: Electromagnetic listening

Hearing the world of Maxwell

Eray Albayrak

There are electromagnetic waves all around us being transmitted by our electronic devices. In this project, we will build the 'Elektrosluch', a device that makes it possible to listen to these EM waves.

The schematic we are using is a simplified version by 'Jonas Gruska' based on LOM instruments design.[1] This project uses around 20 components and can be completed in just a couple of hours.

The main elements of this project are:

Two 22mH inductors (L1, L2) which act as antennas to receive the EM waves.

The bottom cut-off frequency is defined by four capacitors (C1-C4). The capacitor value can be chosen higher to receive more bass frequencies, but this will be resulting in hearing the 50Hz frequency from the mains.

An operational amplifier is used as an inverting amplifier in combination with the resistors R1-R4. The result gain is -390 which means the signal is inverted, this, however, does not matter for this circuit. The original project uses an OPA1234 chip but in our case we use the LM358. Other operational amplifiers may be used, but make sure their pin layout matches or adjust the design.

To be able to use the operational amplifier for audio signals, we need a dual power source. This can be done with a DC battery, but a virtual ground circuit is needed to achieve the ±4.5 volts. The capacitors C5 and C6, and the resistors R5 and R6 are used for this.

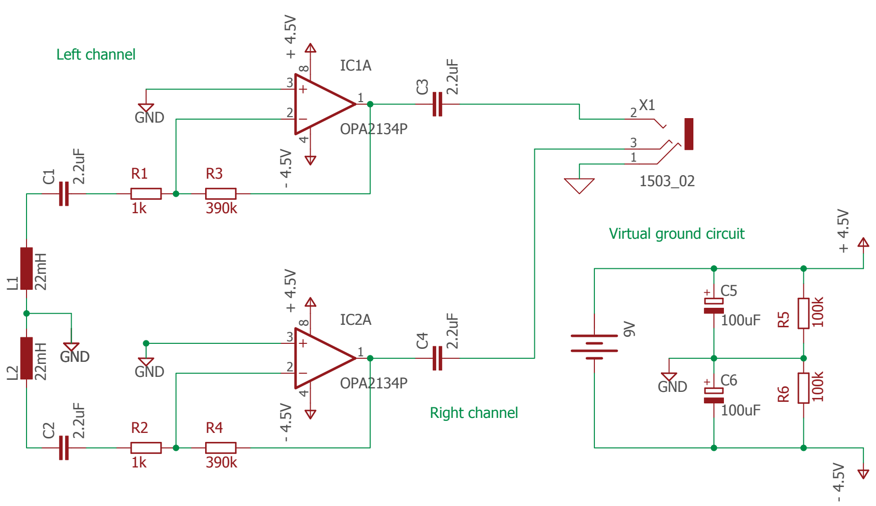
The project leaves enough room for expansion e.g. adding volume control, power switch and different cut-off frequency.

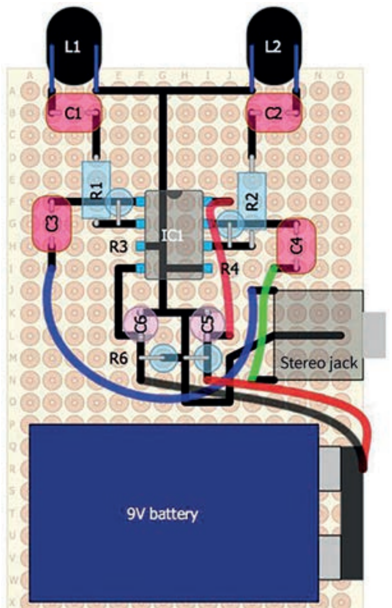
All components needed for the basic design can be found at 'Klushok', situated on the ground floor in the faculty of EEMCS, near the ETV boardroom.

[1] *https://makezine.com/projects/weekend-project-sample-weird-sounds-electromagnetic-fields/*

Components list:

- Perfboard at least 15×24 holes
- Resistors, 1kΩ, 1%, metal film (2)
- Resistors , 100kΩ, 1%, metal film (2)
- Resistors, 390kΩ, 1%, metal film (2)
- Capacitors, 2.2μF 10V (4) polypropylene, polymer or electrolytic
- Capacitors, 100μF 10V (2) low ESR electrolytic or polymer
- Inductor, 22mH, vertical type (2)
- IC socket, 8 pin DIL (1)
- Op-amp IC chip, OPA2134 (1) Other op-amps might work too — check the pinout!
- Stereo jack connector (1)
- 9V battery connector lead (1)
- 9V battery (1)
- Hook-up wire





Makerspace opening

Werner van Dijk

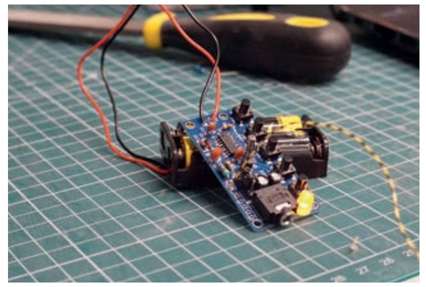
For years, the makerspace of the ETV, the Klushok, has been a place where the greatest ideas have been brought into existence. With the help of many tools and components, members of the ETV and others were able to create whatever they wanted. But the Klushok committee was well aware of the fact that the Klushok needed an upgrade to meet the requirements of today. The world of electrical engineering is growing every day and so should the Klushok.

In the past year, a few committed members of the Klushok committee contacted the FMVG and RS to make a great upgrade and a re-opening of the Klushok possible. On 15 December 2017, it finally happened, the Klushok was upgraded and is now ready to be used. The room was renovated entirely by the FMVG and they gave us some great new closets. Also, RS provided lots of components and some great and accurate tools and instruments. Finally, the Klushok committee made sure everything was stored in a well-organized and good-looking way.

To celebrate this joyful day, some activities were organized and of course, the red carpet was laid before the entrance of the Klushok. Anyone who was interested could join a soldering competition and make a radio receiver as fast as possible. The competition was won by Douwe van Willigen.

At 4 o'clock the party continued one floor lower, in the /Pub. The winner of the competition was announced and received his well-earned prize. Also, a representative of the RS was present who gave an inspirational speech and great promises for a collaboration in the future. Also, some men from the FMVG joined the celebration and together, we had some great tasting Prosecco to toast to, on the Klushok re-opening.

Anyone who could not be present at the re-opening is still welcome to see the new Klushok. Just ask for the Klushok at the ETV and you are allowed to use it at any time.



Activities

zAkCie trampoline jumping

On the 29th of November, the zAkCie organized the event of trampoline jumping for ETV members. We went with a small group to Jump XL in Rotterdam. The event was very nice and relaxing. It was nice to think of something else than studying. There was a great variety of trampolines, so you could do anything you wanted. There was space to do tricks and there was an obstacle course. Furthermore, there was a space where you could play dodgeball on the trampolines and at the same space, some basketball nets were placed, so you could dunk balls through them even if you weren't very good at playing basketball. Of course, there was also space to just jump around and relax. When the session nearly ended, there was a small sort of disco where some good music was played, and the lights created a very nice mood. It was a nice event, but it was very exhausting too.

Franck Kerkhof

Sint and Kerstlunch

To celebrate the Dutch holidays, "Sinterklaas" and Christmas, the ETV board organizes two annual lunches. These lunches bring all kinds of ETV and faculty members together and gives them an opportunity to mingle and enjoy the holiday spirit. As is tradition, this year's lunches were organized in the faculty pub on the 5th and 22nd of December. At the Sinterklaas lunch, members made shoes for the "Sint", so he could fill them with presents and goodies. At the Christmas lunch, everyone enjoyed some Glühwein and the board president, William, dressed as Santa Claus and read a Christmas story. The story was about a musician who was asked to play for the king during Christmas but refused the king's offer because he wanted to be with his family during Christmas. The musician kept refusing and the king kept offering him more and more money, but the musician still refused. In the end, the musician stayed home with his family for the holiday, emphasizing the importance of being with family during Christmas.

All in all, the Sinterklaas and Christmas lunch were nice, cozy and presented a nice opportunity to take a break from studying.

Philip Groet

EESTEC drinks

It is halfway through December and you have just pulled an all-nighter to learn the final few things for your last exam of the week. As you are stumbling out of the exam room with all the formulas still rumbling in your head, the realization slowly enters your mind: it is over! I did it! I am too smart for this stuff. Time to lose a few brain cells….

At least, that is what the EESTEC committee thought… That is why we organized a drink on the last exam day with free beer and games! All to give us the slightest possibility to promote EESTEC. Conchita did a wonderful job giving an introduction to EESTEC with a very interesting mini training. And you could experience Europe yourself by flying drones to the correct location on a huge map by taking part in the pub quiz.

EESTEC offers adventures across all of Europe and gives the possibility to meet a lot of new, awesome people and experiences, so why not try it, right? And it is all sponsored by the ETV and universities, so you spend almost nothing (yes, in the literal sense). So, come join the next drink for more information!

Koen Rodewijk

ETV Code party

The midterm exams were over, and it was the last week before the Christmas holidays. What better way to celebrate than a party with the ETV members together with Corpus Delicti, in Leiden. As always, it was a themed party: Show your Jack Sparrow! A pirate style party for everyone to blow off all the steam after the exams.

The party, itself, was a huge success, and the location belonged to a student society of Leiden, Quintus, where we were received with a warm welcome by the organizers. All night, there was good music, very cheap beer as well as good company, of course. But after a few good hours of partying, it was time to return to reality and head back home. And so, the journey back to Delft began. On the way back to the train station, students often get very hungry because of all the dancing, and the best option for a midnight snack is a nice kebab or 'kapsalon'.

Leiden is not that far away from Delft, only 20 minutes by train, making the trip back quite pleasant for the first part. The NS always closes the last part of the train tracks forcing everyone to take a bus for the last part of the trip. To avoid these buses, make sure you go back either very early or even better would be the next morning.

Laurens Vergroessen

wAkCie winters \Pubquizff

Every year, a group of first year Electrical Engineering students are brought together to form the Winter Activity Committee, better known as the WAKCie. This year their first activity was the organization of the pub quiz, which was held in the /PUB, in the basement of the EEMCS building. All participants were asked to form their own teams, with which they would compete against other teams. Among the participants were students, as well as teachers and personal of the EEMCS building.

The quiz consisted of 10 rounds of questions. At the end of each round, there was one question where the teams had to estimate the answer to a more difficult question, for example, the length of the world's biggest glacier. The team with the closest estimate, won a portion of bitterballen! This was, of course, a great way to keep the participants involved.

After lots of questions, including topography and even music knowledge of Winter themed songs, the third and second-best teams were announced, and given a small price. Lastly, the winning group was announced, and given what appeared to be a Matryoshka (Russian doll). After opening their prize, an even more amazing prize was found inside the box!

All participants would agree that the WAKCie pub quiz was a success. We are excited to see what other activities they will organize!

Mathijs van Geerenstein

Upcoming activities

For members of the Electrotechnische Vereeniging

Tijs Moree

Motivational Drinks

Motivation is a powerful, yet tricky beast. Sometimes it is really easy to get motivated, and you find yourself wrapped up in a whirlwind of excitement. Other times, it is nearly impossible to figure out how to motivate yourself. The ETV will help you out with the motivational drinks!

Monday, the 12th of February, from 17:30, there will be beer for 50 cents in the /Pub. Pizzas will be ordered.

HedoN Workshop

Electrical Engineering is full of theoretical concepts, but there is a big practical side to it as well. To bring some theory into practice, the ETV will oganize a workshop together with HedoN on Wednesday, the 28th of March, on the process of designing an electrical system.

We start with a real-life technical problem and use our knowledge to design a solution. Sign up at the ETV!

Git Workshop

Working together can be hard, but programming together is even harder. Usually, everybody is improving their own copy of the code, which creates lots of errors when combining. Git is a nice solution to this problem!

Git is a version control system for tracking changes and coordinating work on files among multiple people. We will explain it on Wednesday, the 4th of April.

EEMCS Recruitment Days

Looking for an internship, thesis project or job? Then sign up for the EEMCS Recruitment Days 2018! With five interview days and 45 participating companies, this year's edition will be the largest one yet – be sure not to miss it!

Registration for the EEMCS Recruitment Days can be done via *eemcs.com*. After signing up, you can upload your CV, read the profiles of all the companies and select the ones that sound most interesting to you. Vice versa, the companies will do the same thing, based on the CVs. Students and companies with a mutual interest in each other will be meeting each other in March!

The EEMCS Recruitment Days will take place from 19th until the 23rd. During this week, our faculty will be visited by dozens of companies. Everyday after the interviews, there will be the chance to have a drink with the recruiters as well!

Over the years, the EEMCS Recruitment Days have proven to be a very effective and fun way to meet your new employer. Are you ready to start building your future?