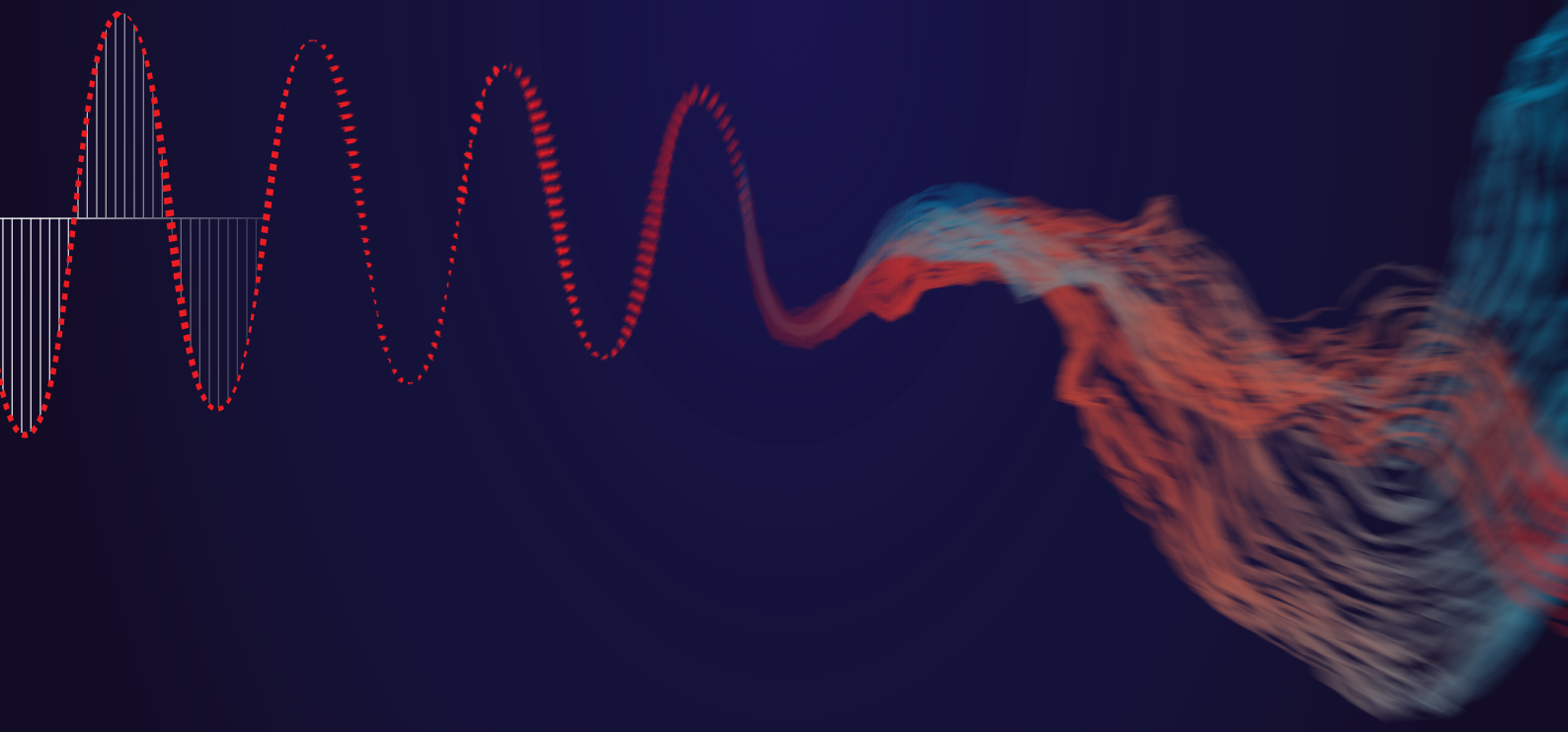
MAXWELL

Electrotechnische Vereeniging

Issue 22.3 | April 2019

Waves



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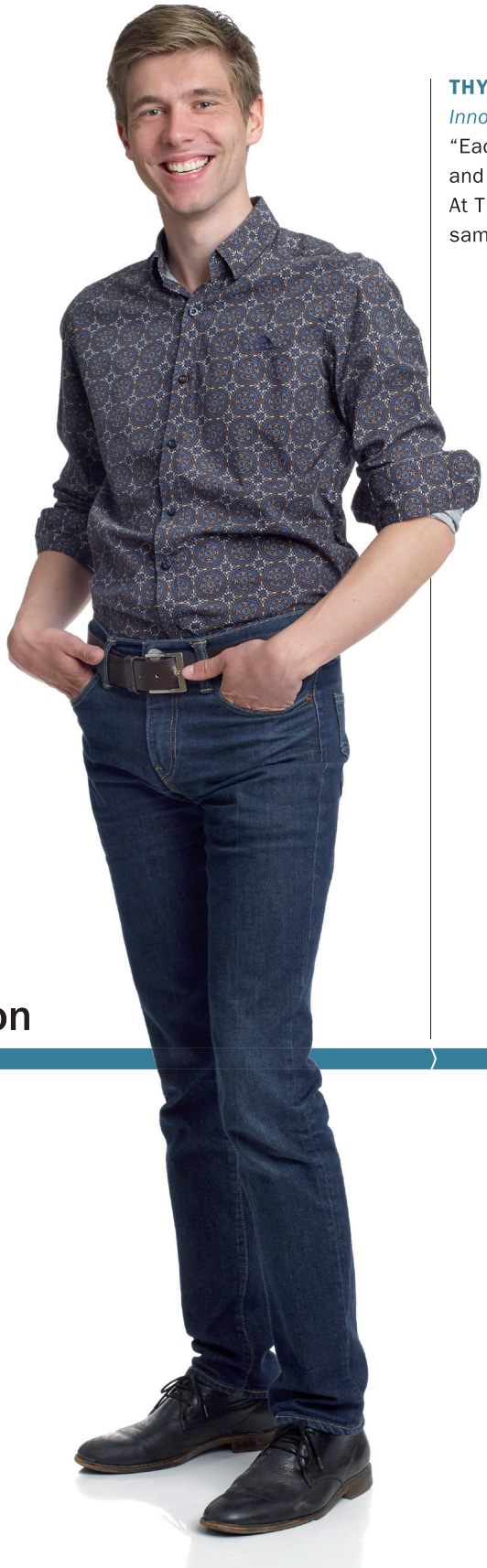

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From the Board

Commisioner of Education

Lotte Zwart

Dear reader,

The year is already progressing quite quickly and we're heading into the last quarter. This means summer holiday is almost upon us! Last quarter has been very buys, therefore I would like to thank everyone that made the time to come to EvaCie's and Focus groups! Without your feedback nothing would change in our studies. If you didn't have the time to come to the Focus groups, but you still want to make a comment on education or have an idea to make it better, you can also contact me via education-etv@tudelft.nl!

After the feedback of the freshman bachelors, there is already a plan in place to change the Brightspace course structure of (firstly) the freshmen's to make it equal among all courses. Talking about change in the freshman year: because of the results of this year it was decided to make a shift in the curriculum. From next year on Classical and Quantum Mechanics will be shifted to the third quarter. It will be switched with Digital Systems A, which will now be in the first quarter. To make the third quarter not too heavy Probability and Statistics will be shifted to the fourth quarter and Digital Systems B will be put in the third quarter.

To continue on feedback on Education: the teacher of the year election is almost upon us! Do you have a teacher that you particularly like? Perhaps a teacher that is so enthusiastic that he/she motivates you to study better, or just because his or her explanation is awesome. Every year students choose a new 'Teacher of the Year' to thank these great teachers. From the 6th of March onwards you vote via toty.ewi.tudelft.nl on your favourite teachers.

I wish you all the best in these last leg of the year! If you need a shoulder to cry on (and voice your complaints) or a lot of coffee to make it through these exams (and resits), you can always join us in the boardroom!

Treasurer

Willem de Laat

Dear reader,

Money has certain similarities with waves. It flows, sometimes in your bank account and sometimes out. The role of the treasurer is to make sure that these money flows run smoothly and that the association remains financially stable. I am grateful for the opportunity I have been given. It is a year full of surprises, wise lessons and many opportunities. I'm currently starting on big plans. For example, I am busy setting up a foundation for the /pub together with Christiaan huygens. Starting next year there will be a partial student board for the management of the /pub. There will be room for renovation and improvements to the current pub regarding for example the walls, the floor and the lights. There is also a possibility that the assortment will be expanded; more special beer! Would you like to join the board of the foundation or would you like more information about the /pub then give your details via etv.tudelft.nl/stichting-bestuurings. I am also looking into the possibility of purchasing a vehicle in the name of the ETV. So there is a bright future ahead of us with many changes!

Colophon

Year 22, edition 3, April 2019

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Editorial

Medha Subramanian

Dear reader,

One of the quotes used most often regarding waves is this one - "The breaking of a wave cannot explain the whole sea", by Vladimir Nabokov. I love how this could pertain to any topic, that one small aspect of something, does not define the entire field. That knowing just the tip of the iceberg in so many situations is not sufficient and knowing the depth of the domain is a necessity. And that is what we, as electrical engineers, strive for.

In this edition, with the aim of reaching out to the numerous and varying fields of Electrical Engineering, we chose the theme of Waves. This could be construed in many ways, ranging from waveforms, signals and ripples, or to actual waves and tides. Hence, you can find articles on topics like wave energy, quantum waves and much more!

We hope you enjoy reading this edition!

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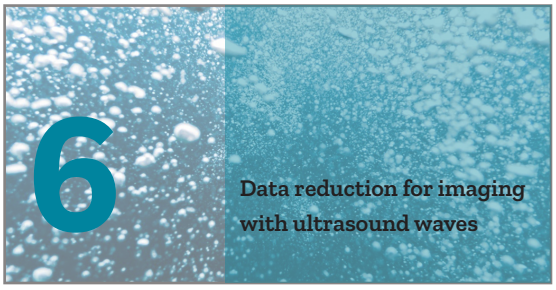
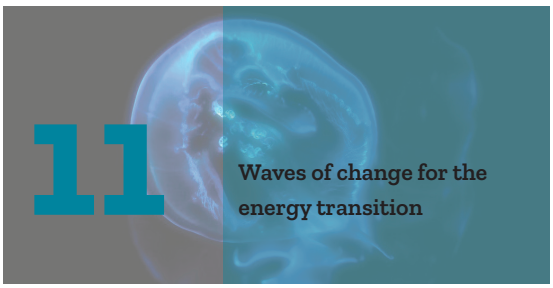
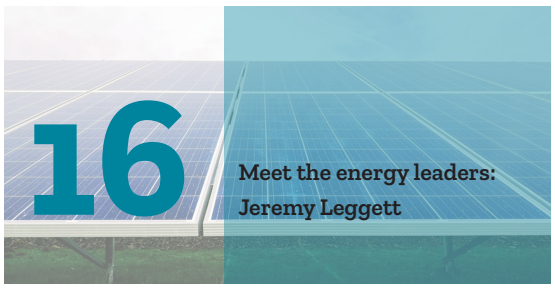
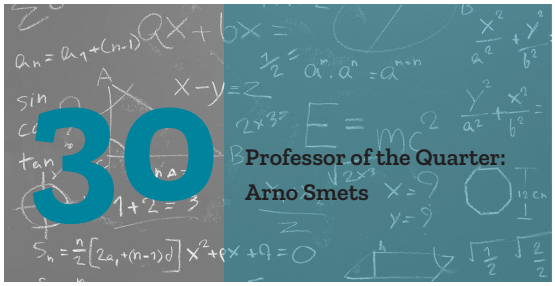








Data reduction for imaging with ultrasound waves

Prof. Dr. Ir. Geert Leus, Pim van der Meulen

Ultrasound imaging is typically performed using a large set of small ultrasound sensors to obtain an image for a doctor. Such an array of sensors can generate a lot of data, as together they are sampling both in time and space. To improve image quality, engineers tend to increase the number of sensors on a probe by decreasing the sensor size and by increasing the number of sensors. Continuing this way, this can reach the point where sensors become so small that they cannot be wired for readout anymore and the amount of data becomes enormous. Similarly, small ultrasound devices attached to medical catheters (for non-invasive surgeries) require so many cables that they do not fit in the catheter itself! Clearly, there is a need for data reduction without a loss in imaging quality. In this article, we take a look at one technique for data reduction for medical imaging with ultrasound waves.

The current engineering trade-off

Ultrasound waves are commonly used in hospitals to look inside a patient without cutting them open. Most people are familiar with the gynaecologist scanning a pregnant mother to inspect the unborn baby, yet ultrasound imaging is also used to image other parts of the body. Why don't doctors use other techniques, like MRI or CT? MRI machines are bulky and expensive, and typically only available in specialized environments within hospitals. When a single scan can take up to an hour, scanning becomes expensive and uncomfortable for the patient. On the other hand, ultrasound imaging provides images in real-time. Furthermore, an ultrasound machine is cheap, relatively small and does not need a specialized environment. Whereas CT machines typically use damaging X-rays to obtain an image, ultrasound waves are not harmful to the human body.

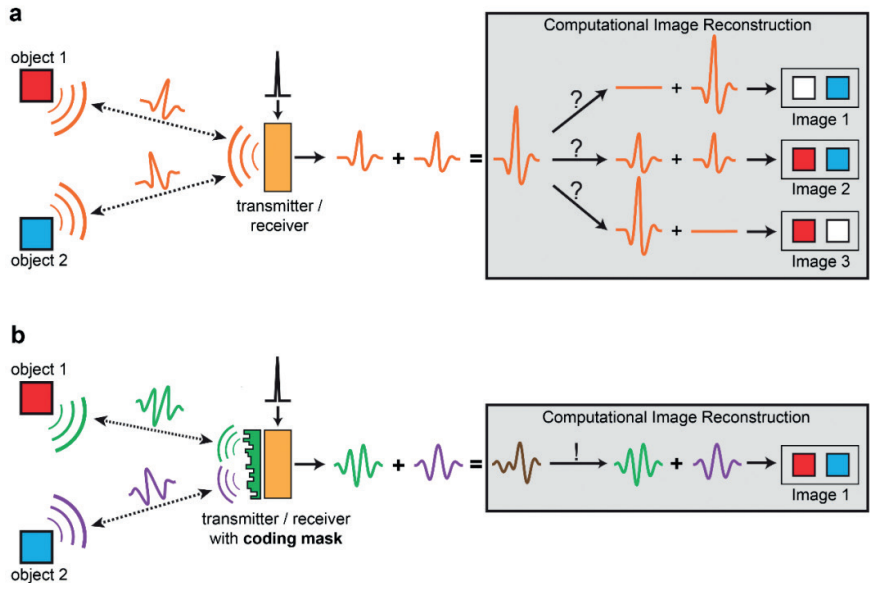


Figure 1. *Top: a single sensor with no coding mask will receive the same echo signal from each object at the same range. Bottom: a single sensor with a coding mask causes each object to reflect a different echo.*

Ultrasound's high imaging speed means that it is an ideal candidate for scenarios where, for example, a surgeon requires real-time feedback of what he or she is doing inside a patient. An interesting scenario is that of non-invasive imaging using a catheter. A thin and long tube (the catheter) is inserted into the human body and guided to, for example, the heart. Using tools attached to the catheter tip, the surgeon can perform the operation without cutting open the patient's body. To help the surgeon visualize what he or she is doing in real-time, a small ultrasound probe, consisting of an array of sensors, is integrated into the catheter tip. To increase the image quality, we would like to increase the number of ultrasound sensors in the probe. Clearly, the catheter has to stay as thin as possible to fit inside the blood vessels. This puts a limitation on the total number of cables that can be used for transporting the measured ultrasound waves to outside the body. How, then, can we increase the number of sensors without increasing the amount of measurement

data? Or, conversely, how can we reduce the number of sensors, without sacrificing image quality? In this article, we describe one way of doing this. But first, we will explain how ultrasound imaging is typically done.

Imaging using an array of sensors

The average ultrasound probe consists of an array of regularly spaced sensors. Together, they first transmit a pressure wave into the subject, after which they receive the reflected waves ("echoes"), see Figure 1 (left panel). These reflections occur, for example, when tissue changes from one type to another. Finding the locations of these reflections gives us the ultrasound image. The sensor array samples the reflected wave field in space and time. Suppose that there is a single reflector in the field of view, causing an echo. Assuming a constant speed of sound, each sensor knows the distance to (but not the direction of) the reflector based on the echo's time of arrival. In other words, we can draw a circle with a fixed distance around each sensor, and the intersection of these circles gives us the position of the reflector. This principle can be extended to scenarios with many reflectors and forms the basis for most imaging techniques using a sensor array.

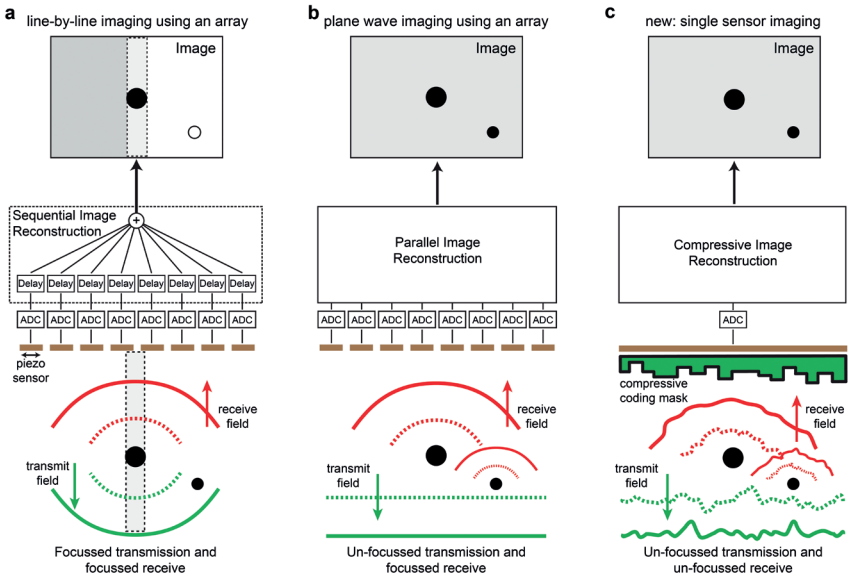


Figure 2. *Left: a typical imaging setup using an array of pressure sensors. Right: an imaging configuration using a single sensor with a coding mask.*

The most important message is that, in order to create an image, we need both temporal measurements to determine the distance to a reflector, and spatial measurements to determine the direction to the reflector. To avoid imaging artefacts, there are theoretical requirements on the number of sensors and their spacing (Nyquist sampling theorem translated to spatial sampling). To obtain better images without increasing the size of the probe, researchers try to fit more sensors in the same area.

In case of a catheter, we may have a small probe with many sensors, but not have enough space inside the catheter tube to fit all the cables required to read all the sensors. Hence, researchers are trying to find techniques to obtain the same quality images with reduced measurement data. However, note that there is not enough space inside the catheter to fit complicated electronic compression hardware. So how can we solve this problem? In the following paragraph, we will describe a method that, against everything we just described, is able to reconstruct an image with only a single sensor!

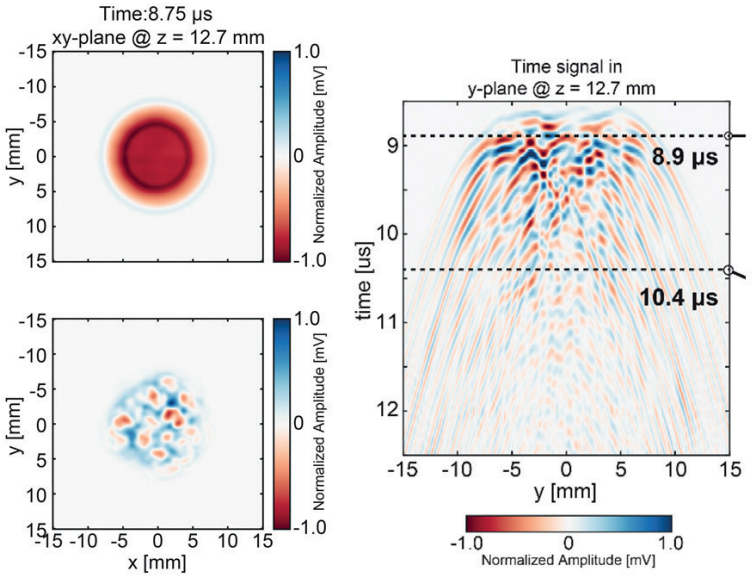


Figure 3. *Emitted pressure fields from a transducer with a mask. Top left: without a mask. Bottom left: with a mask. Right: measured ultrasound field on a line of sensors 12.7mm from the transducer.*

Imaging with a single sensor (and a 'coding mask')

So far, we have discussed how time-of-arrival, together with measuring at different locations, is sufficient to

localize the position of a reflector. However, there is a third dimension of information that can be exploited: the shape of the received echo. We can exploit the information residing in the waveform of the echo to determine the location it scattered from using only a single sensor.

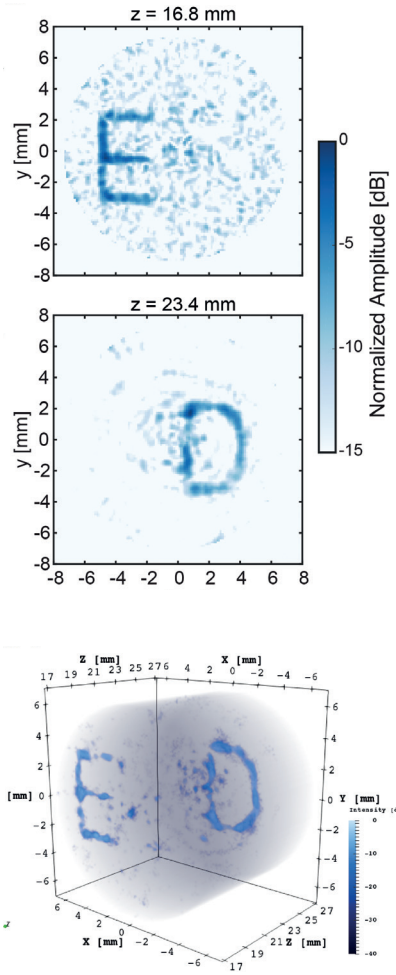
In a conventional imaging scenario, there is barely any information residing in the echo waveform. This is illustrated in Figure 1a, where two objects are reflecting the wave transmitted by the transducer. Since both objects are at the same distance (but possibly different angles), the received echo waveform looks the same for both objects. That is why under normal circumstances, we need to measure echoes at different points in space, as described in the previous section. Now, what if we can somehow design a measurement setup, such that the reflected echo waveform is different for different reflector positions? We would then be able to infer a reflector's position, purely based on the waveform of the echo!

"We can exploit the information residing in the waveform of the echo to determine the location it scattered from, using only a single sensor."

A very simple way to do this, is by placing an irregular layer of plastic in front of the transducer (Figure 1b and Figure 2, right panel). This "mask" has a different speed of sound than the surrounding medium. When the ultrasound wave passes through the mask, it is delayed differently in each part of the mask (based on the local thickness) and bounces around inside the mask, before finally being transmitted into the rest of the medium. The same process is repeated upon receive. Whereas engineers traditionally aim to design ultrasound transducers that transmit nicely uniform waves, we would rather scramble the wave field as much as possible before releasing it into the medium!

As a result, a complicated and scrambled pulse is transmitted, and a different echo waveform is reflected back from each position. We show this in Figure 3, where we visualized the measured pressure field in a plane parallel to the transducer surface, 8.75 microseconds after transmit. Notice how, without a mask, the field is very uniform, so that the same pressure field is incident on each pixel. With a mask, however, a more complicated field is incident on all pixels. With the right mask, this means a unique echo is reflected from each individual pixel.

To obtain an image, we first have to measure the unique response of each pixel individually, by placing a small point reflector in each pixel position. Using this codebook of echoes, we can then use least squares techniques to figure out which combination of pixels must have caused the measured echo of a real measurement. To demonstrate this approach with an imaging experiment, we tried to image two plastic letters submerged in water. Figure 4 shows a photograph of the measurement setup, and the final 3D imaging reconstruction.



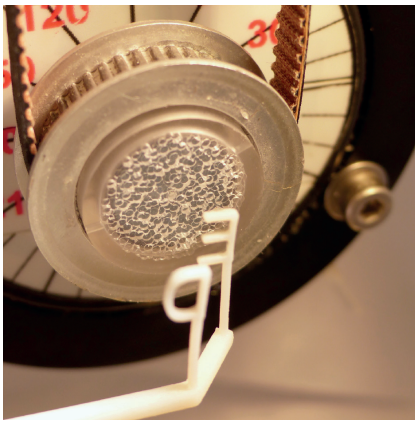


Figure 4. *Top and middle: reconstruction result for two plastic letters submerged in water. Bottom: transducer setup with a mask and two plastic letters.*

[1] This article is based on a collaborative study between the Circuits and Systems group in Delft, and the Biomedical Engineering group in Erasmus MC. For more information about this project, see DOI: 10.1126/sciadv.1701423.

Waves in Complex Media

and Efficient Ways to Compute Them

Dr. Ir. Rob Remis
Dr. Jörn Zimmerling

Waves come in all forms and shapes. Some are localized like the waves that make a drum vibrate. Others travel for long distances like the electromagnetic waves that transmit your latest snapchat message to your friend on the other side of this planet. Waves are often used to transport energy or information from one point to another, but can also be used to gather information about the location and constitution of some body or object of interest. With acoustic waves, for example, we can image a fetus inside a mother's pregnant belly, while seismic and electromagnetic waves may be used to image the subsurface of the Earth.

What acoustic, electromagnetic, and elastodynamic waves have in common is that in each case the waves are characterized by two fundamental wave field quantities. For acoustic waves these quantities are the acoustic pressure and the particle velocity, electromagnetic waves are characterized by the electric and magnetic field strength, and for elastodynamic waves the fundamental wave field quantities are the stress and the particle velocity again. In all three cases, these quantities are coupled through a set of first-order partial differential equations, which give a precise description of how first-order spatial variations of one field quantity are coupled to first-order temporal variations of the other quantity. In electromagnetics, for example, the curl or rotation of the magnetic field (a first-order spatial variation) is coupled to first-order temporal variations of the electric field (Maxwell-Ampere law), while the curl of the electric field is coupled to a first-order temporal variation of the magnetic field (Faraday's law).

To compute an acoustic or electromagnetic wave field in a complex medium, the governing wave equations have to be discretized in space resulting in large-scale systems of equations that can only be solved numerically on a computer. What constitutes a large-scale system is actually not precisely defined, but typically we think of systems with at least one million unknowns. In addition, these unknowns are time or frequency dependent and so we are actually dealing with millions of unknowns for each fixed time instant or frequency of interest. It is not difficult to imagine that computing an acoustic or electromagnetic wave field throughout a three-dimensional volume and on large time intervals or wide frequency ranges of interest is a formidable task.

"Typically we think of systems with at least one million unknowns."

Fortunately, in practice we can exploit the symmetry of the first-order wave equations in our computations and particular properties of the configuration or device of interest can be exploited as well. For example, energy conservation is related to a particular symmetry property of the wave equations and wave field reciprocity is linked to another symmetry property. Both of these properties can be used to develop very efficient solution strategies for large-scale wave field computations. When modeling wave propagation in complex media (or any other physical phenomenon) all relevant physical laws must be satisfied, of course, and symmetry that follows from these laws can be exploited to efficiently compute the wave field quantities of interest.

As an illustration of how we can exploit certain properties of a given configuration to efficiently compute required field responses, consider the configuration shown in Figure 1. The cylindrical bar in this figure is a golden nanobar (note the scale) and the small arrow located just above the bar represents an electric dipole source. This simple dipole model can be used to compute the spontaneous decay rate of a two-level quantum

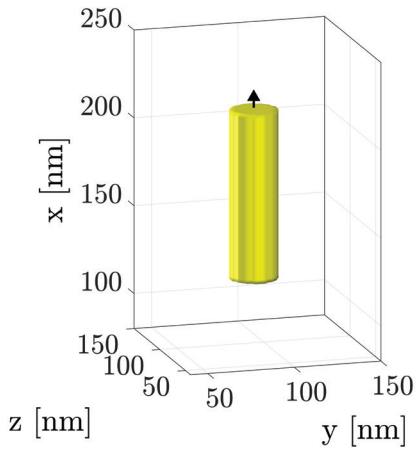


Figure 1. *Quantum emitter (arrow) located above a golden cylindrical nanorod (diameter 30nm, length 100nm). The emitter is located 10nm above the rod.*

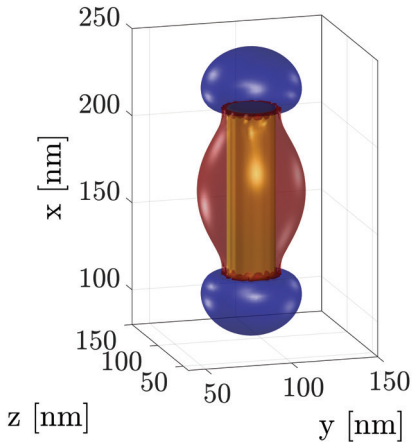


Figure 2. *Magnitude of the x-component of the electric field of the dominant quasi-normal mode.*

emitter (as represented by the dipole source). This decay rate depends on the surroundings of the quantum emitter and can be enhanced by placing the emitter in the neighborhood of the golden bar as illustrated in Figure 1. Enhancing the decay rate of a quantum emitter is exploited in many different areas in nano-optics and is utilized in light emitting diodes (LEDs), for example.

"We are essentially done in one step."

To determine this possible enhancement using classical electromagnetic field theory, it can be shown that the imaginary part of the projection of the electric field strength onto the electric dipole moment at the location of the dipole is required over a frequency interval for which enhancement is expected [1]. Now gold is a dispersive material meaning that its reaction to the presence of an electromagnetic field varies with frequency. Therefore, a straightforward approach would be to select a frequency from the interval of interest, compute the electric field strength at this frequency by solving the large-scale discretized Maxwell system for this configuration and repeat this procedure for all frequencies in the frequency interval. By following this approach, N large-scale Maxwell systems need to be solved for N frequencies of interest leading to prohibitively long computation times.

Fortunately, the spontaneous decay rate is essentially determined by a single so-called quasi-normal mode over the complete frequency interval of interest. This mode is a characteristic mode or natural vibration of the golden nanobar that is excited by the dipole source. The magnitude of the x-component of the electric field of this mode is illustrated in Figure 2. Therefore, a much more efficient approach is to compute this mode since then we are essentially done in one step. By exploiting the symmetry properties of Maxwell's equations this dominant field mode (and additional modes as well) can be efficiently computed. In other words, by exploiting physics-based symmetry the same spontaneous decay rate results can be obtained as with the above-mentioned brute-force approach, but at significantly reduced costs. The spontaneous decay rate of the emitter in case the nanobar is present normalized to the decay rate in case the emitter is absent is shown in Figure 3. The presence of the nanobar clearly enhances the decay rate of the quantum emitter on the frequency (wavelength) interval of interest.

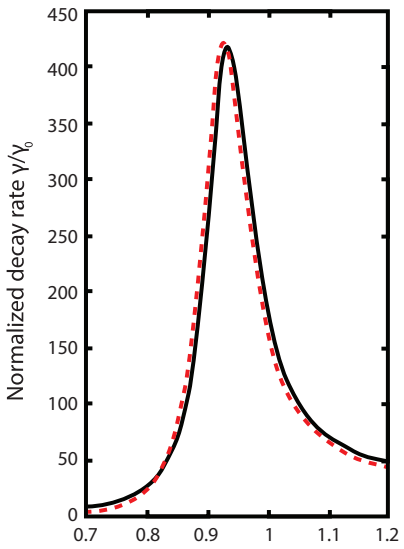


Figure 3. *Normalized spontaneous decay rate on wavelength interval of interest.*

This research is part of the research program Good Vibrations with project number 14222, which is financed by the Netherlands Organization for Scientific Research (NWO).

[1] L. Novotny, B. Hecht, Principles of Nano-Optics, Second Edition, Cambridge University Press, 2012.

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Waves of change for the energy transition

Dr. George Lavidas

Climate Change effects are felt throughout the world, and many countries have already taken bold steps in changing the way societies (will) produce and consume energy. The Energy Transition is happening, and in the decades to come, we have to adopt new innovative pathways that lead to decarbonisation. The ultimate goal is to provide carbon free energy, securely, consistently, with low environmental impacts when compared with the devasting effects of large-scale fossil fuels, and without the hidden security dangers [1] in nuclear power plants.

Renewable energies offer carbon free energy and a pathway that many have argued, can provide 100% of the energy needed for our ever-growing energy consumption [2]. The "first" steps for a renewable energy system in European countries, started with the adoption of the Kyoto Protocol and the targets of 2020. Although these targets will not be obtained by all Member States, they provided fertile grounds and have started policies for renewable energies.

Such efforts were significant and led to the commercialisation of renewable technologies, that until then were niche products. Onshore wind energy and solar were the first and most "ready" technologies to benefit from those developments and started gaining commercial success. These successes allowed to showcase that renewable energy can effectively contribute to the energy mix, but most importantly wind and solar reached maturity levels and created new industries.

While renewable energies have increased their efficiencies, they still have limitations and find opposition. Amongst most prevalent arguments is the intermittent nature of renewable energies and the level variable energy production they provide. Indeed, current energy systems require a spinning reserve that must be increased as more intermittent energies come to the grid [3]. They often imply that this can only be achieved by either adding more fossil fuelled and/or nuclear plants to act as base loads, or by adopting large storage as bulk management system. The first implies that we can never achieve a 100% renewable system, while the second is often limited by the availability of resources or suitable topologies for such installations.

These perceived limitations have been prolonged, due to the fact that our current renewable energy systems will depend on two renewable energies. However, emerging studies, decentralised real community pilot projects and data driven analysis showcase that multi-generation systems will be effective

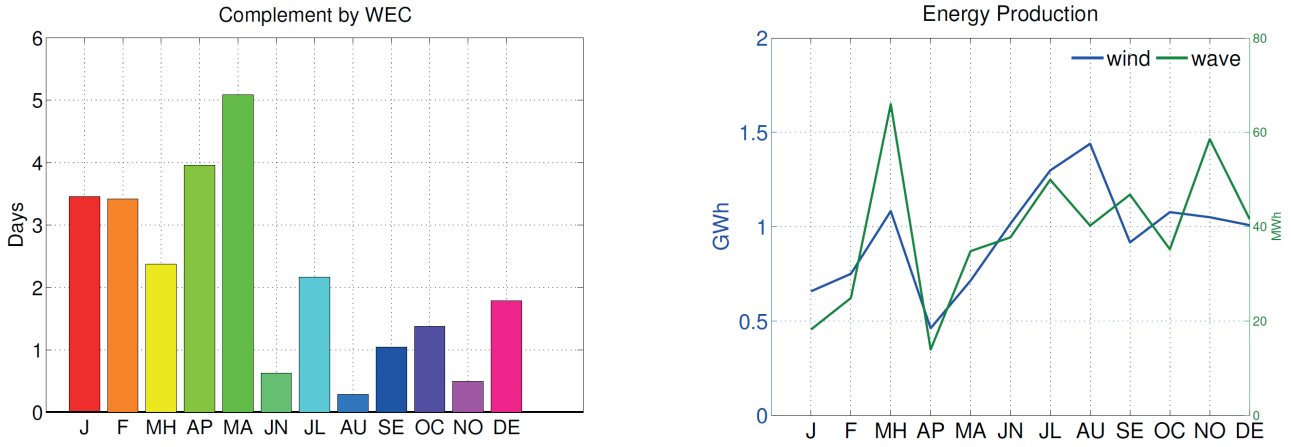

Figure 1. *Hours (in summed days per month) from the contribution of wave energy (right panel), and the monthly energy production in GWh on the left . [8]*

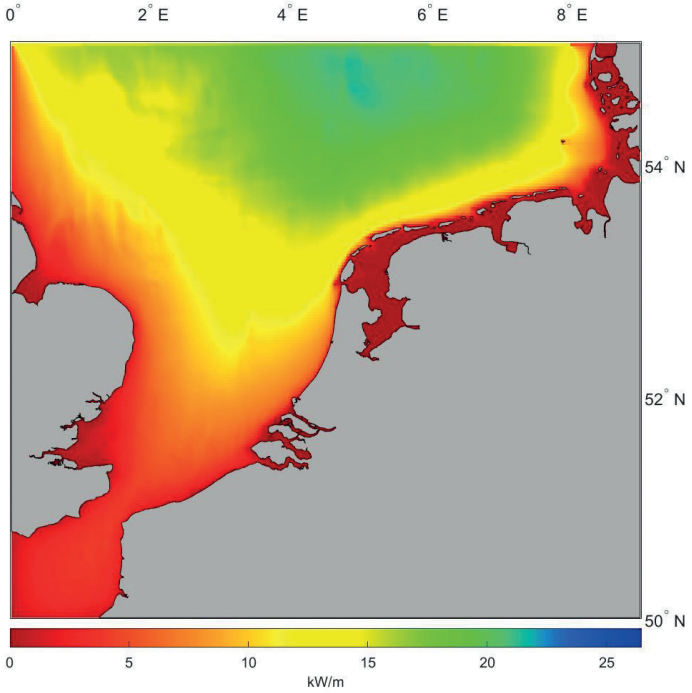

Figure 2. *Wave power flux around the Netherlands coastlines and the North Sea, for the year 2015.*

in counterbalancing intermittent production. Thus, these multi-generation systems help avoid the current stagnation of renewable energies, without any (or with less) requirements of spinning reserve. Technically, energy systems based on 100% renewable energy production are feasible and able to satisfy the global energy demand without the use of biofuels, nuclear, or coal with carbon capture. Evidence for this proposal has been outlined [4], improved upon [5] [6], and argued for.

The result of these thorough, evidence based approaches showcase that the energy transition is feasible through a holistic approach. This approach firstly utilises all indigenous renewable resources to their fullest potential and then incorporates stabilisation solutions such as energy storage on medium and large-scales. These technological solutions do not mean that the energy produced is non-viable in monetary terms, on the contrary in the long-term, the more renewable resources are introduced in the grid, the lower spot systems prices [7] can be achieved. Therefore, it is clear that the Energy Transition will require multi-generation and utilization of all indigenous resources.

Currently, the most dominant and mature renewables are wind followed by photovoltaic (PV) and solar. In terms of operating profiles PV/solar have a specific range of temporal operation. This is associated with hours of sunshine, hence predominately over a period of 8–9 AM to 18–19 PM. On the other hand wind generation is temporally more distributed. While this is a major benefit in terms of total production hours, the disadvantage of wind is its associated variability i.e. wind tends to change at rapid rates.

Wave energy is one of the most-untapped globally renewable resources, partly due to the complexity of its operation that led to high first-generation device costs. However, as we are moving ever close to the goal of 100% renewable energy systems, wave energy will be able to contribute to the stabilisation of renewable energy production and reduce variability.

Wave energy presents an untapped energy resource, which has a much higher energy density, than wind or solar. In addition, physical characteristics of waves make it less volatile than wind, and much more predictable. Particularly, at European coastlines wave energy flux ranges from 30-60 kW/m for the Atlantic coasts, to 3-20 kW/m in milder resources such as the North Sea and

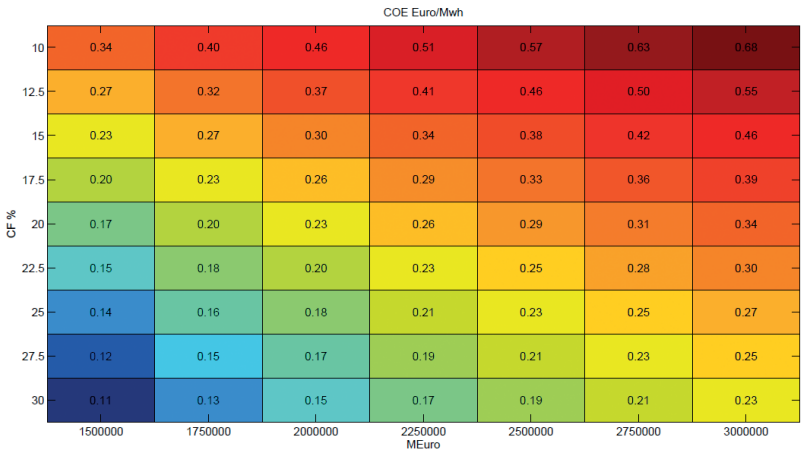

Figure 3. *Sensitivity analysis concerning the cost of energy (COE) in Euro per kWh produced, the x-axis has the Capital Expenditure (CapEx) and the y-axis the Capacity Factor. Each COE value is the results of the different costs and energy production. [9]*

the Mediterranean. Indirectly waves, due to their nature and properties act as a "storage" medium for wind energy. Wave velocities can exceed wind speeds, though most times the wave resource is propagated with a time-lag from its originating wind. This implies that huge amounts of energy can be extracted in a sustainable manner. So far, the wide disparity and non-convergence of wave energy converters (WECs) do not make it easy to select the best one for a given region.

Selection of a wave energy converter (WEC) depends highly on the location's metocean conditions, depth, and WEC characteristics (type of operation, power-take-off (PTO) etc.). Therefore, operating principles are vital to the proper selection of WEC, considering that there is a wide array of WECs that represent different technologies. Of course, considering the current status of renewables, wind energy will be the base load for any future system, with wave energy contributions on non-operative hours assessed in a complementary way. In fact, wind and wave energy converters can be "easily" combined or deployed in co or non-located offshore energy farm configurations. With production levels of contribution and cross-correlation based on selected WEC characteristics, providing additional electricity when the wind turbine is not operating. When properly selected, a WEC can offer significant coverage in non-operative hours by other renewables, reducing the necessity for large spinning reserves, see Figure 1. It must also be noted that prediction of wave conditions is very accurate for short-term forecasts and, unlike the volatile and fast changing wind resource, wave conditions are less volatile to magnitude and directional changes.

In particular the Dutch coastlines, on immediately accessible nearshore depths, have an average resource from 4000 to 8000 W/m, and from 15000 to 25000 W/m at deeper locations. With additional benefits being the high predictability and the low level of variation of waves. The consistency of the resource and predictable metocean conditions, allow us to optimally determine, size, and predict the energy production by various WECs in high fidelity temporal scales, therefore providing a better image on expected production and grid variations.

The proper selection of WEC will always depend on local conditions, with cost of energy (COE) dependent on the production at the site and cost of installation (see Figure 3). To estimate in more detail the Levelised Cost of Electricity (LCoE), we have to select a specific WEC so as to reduce uncertainties that include varied levels of infrastructure costs, failure rates, and production variation due to operational principles.

Diversification of the energy mix is expected to contribute to the increase of energy security (energy imports avoidance). However, at the same time stabilising the intermittent nature of renewable energy production will require more innovative approaches. The nature of wave energy can secure that the increasing energy demands can be met in a sustainable way.

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TU Delft Solar Boat Team

Sailing the seas in a modular trimaran

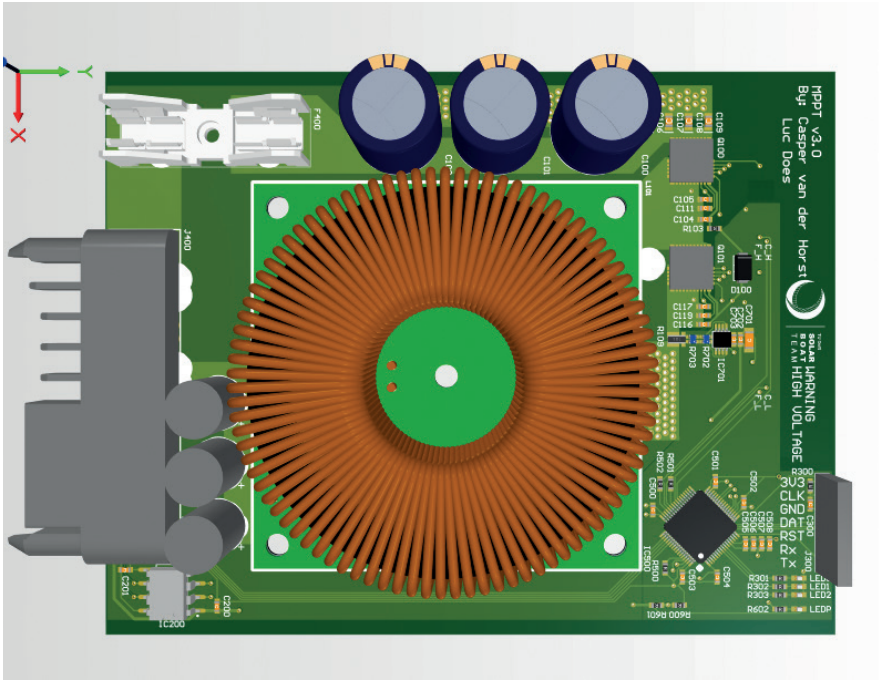
Mechteld Bakkenes

The TU Delft Solar Boat Team has been building solar powered boats since 2006 to compete in different solar boat races. In 2010, the TU Delft Solar Boat Team was the first to introduce hydrofoils - essentially wings, but then in water instead of air - into the competition, to reduce drag. At first we used a V-shaped wing together with a T-wing. To reduce the drag even more, two T-wings were used on the boat built in 2014. Even for hydrofoil boats, this configuration is quite unique and to this date only used by the TU Delft Solar Boat Team in the competition. With two T-wings the boat is in an unstable equilibrium during flight, and works essentially like a bicycle, using front steering and the pilot to actively keep the boat upright. The height of the boat is actively controlled by an autonomous and electronic height control system, which uses ultrasonic sensors and a motion sensor to determine the height and attitude of the boat. Electronic motors then actuate the wings to control stable flying height.

Conquering the Sea

Up until now, we have built boats specialized for competing in an inshore competition. However, this year, to spice it up, we compete in an offshore competition. This includes building a boat capable of sailing 96 km from Monaco to Cannes and back and 36 km from Monaco to Ventimiglia and back, all while carrying three persons of 80 kg. The boat therefore looks very different from previous years. The different competition has different rules and mostly, it means less rules. Therefore, the solar deck surface has seen an increase of about three times, up to 28 m^2 of silicon solar panels. Next to that, the motor is now capable of drawing up to 60 kW of power. To compensate for the larger solar deck and larger motor, the battery has seen an increase in size as well and can now store up to 20 kWh. To facilitate such a deck, the boat has been made much bigger in size, especially in width and is now about 8.5x6 m. That is about two lanes wide and therefore the boat made is a modular trimaran. This means it can be taken apart for transport. Also for added stability, the Solar Boat 2019 will have three struts and wings.

Figure 1. *A 3D rendering of the custom Maximum Power Point Tracker PCB.*



Efficiency

For maximum efficiency of the solar panels, Maximum Power Point Trackers, or MPPTs for short, are used. MPPTs improve power obtained from solar arrays by forcing the right combination of current and voltage from the solar panels. If you look at the I-V curve of solar panels, you can see that there is a point where I*V is at a maximum, which is the maximum power point. By making sure the solar panels always operate at this point, the power is maximized.

"This includes building a boat capable of sailing 96 km [...] all while carrying three persons of 80 kg"

Custom MPPTs

Our battery works up to 400V and our solar panel arrays deliver up to 100V. In this range, commercial MPPTs are hard to find. Luckily, last year our team has successfully made their own MPPTs, so that what will be done again this year.
Last year, a linear regulator was used to converted the battery voltage to our system's operating voltage. However, with the range we operate in now, a boost converter is used. A boost converter steps up the voltage and uses an inductor as an energy storage element.

There was no off-the-shelf inductor that met our requirements for the combination of the right inductance and maximum coil current, so we have made them ourselves.

Algorithm

To determine the maximum power point, the current and voltage have to be measured very precisely. We use a high resolution timer and fast switching GaNFETs to accurately find the moment we measure the voltage and current of the solar panels. The important thing is that this moment is always the same in our cycle. With the current and voltage measured, the power can be calculated. There exist several algorithms to find the maximum power point. The method used by us, is the perturb and observe method which slightly adjusts the voltage either up or down. If this results in a power increase, it will change the voltage in that direction more and otherwise go in the other direction.

Controls

Accurately controlling this system is where it gets difficult. The only thing that is really altered is the duty cycle of the GaNFETs. This in turn causes a difference in the current. By changing the current, the solar panels will deliver a different voltage and this can be used to control the power. So essentially, there are three different control loops running at the same time. One loop to control the current with the duty cycle, another to control the voltage via the current and a third loop to control the power with the current and voltage loops combined.

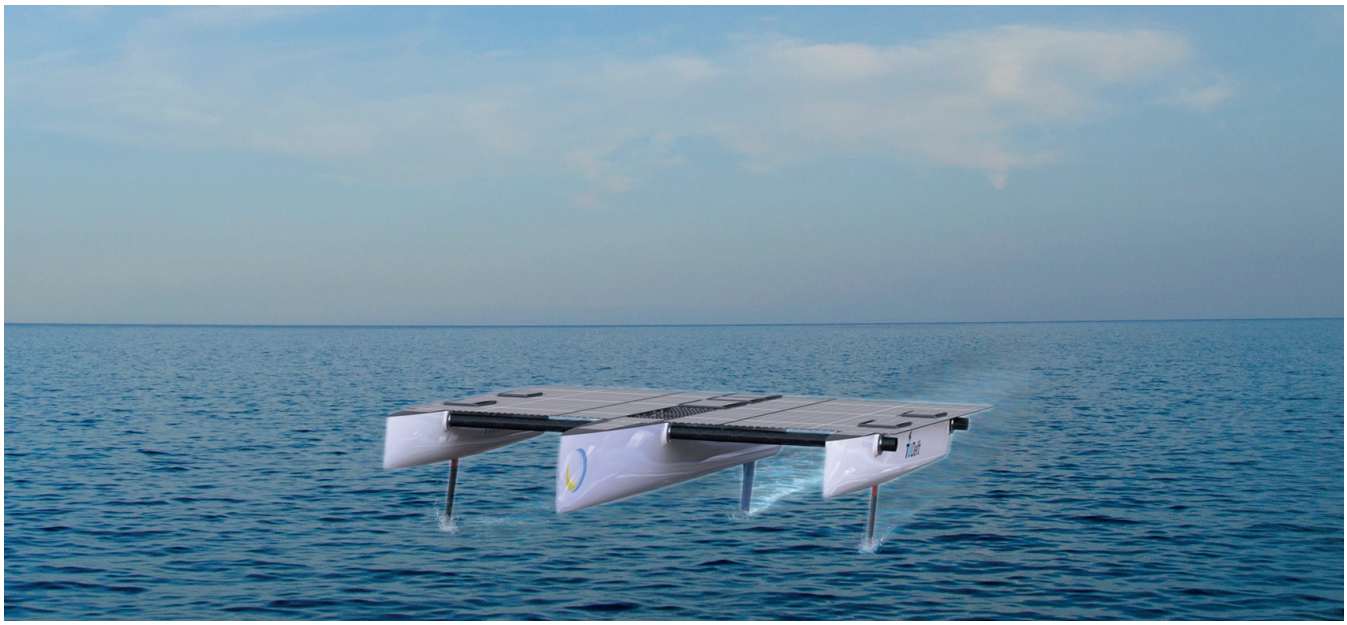
Figure 2. *Team picture at the design presentation ealier this year.*

> *"So essentially, there are three different control loops running at the same time"*

A World Record?

With our custom made MPPTs specialized for our electronic system, we aim to have an edge in our competition. We not only plan to win the world championship for solar boats in Monaco this summer, but we also plan to break a world record by crossing The Channel as the fastest solar boat in the world!

Figure 3. *A 3D rendering of this years design, sailing the sea!*



Meet the Energy Leaders: Jeremy Leggett

Medha Subramanian
Philip Groet

'Meet the Energy Leaders' is a series of guest lectures organized by the Delft Energy Initiative with support from the TU Delft Energy Club. They are hand-in-hand committed towards facilitating opportunities for sustainable energy enthusiasts. These guest lectures offer a platform for global leaders in the transition to a sustainable energy system. Jeremy Leggett is the first one to give a lecture in this series in 2019.
Jeremy Leggett is a British social entrepreneur and writer. He is the founder and a director of Solarcentury, an international solar solutions company (1997–present), and is the founder and chair of SolarAid, a charity funded with 5% of Solarcentury's annual profits that builds solar lighting markets in Africa (2006 – present). He is winner of the first Hillary Laureate for International Leadership in Climate Change (2009), a Gothenburg Prize (2015), the first non-Dutch winner of a Royal Dutch Honorary Sustainability Award (2016), and has been described in the Observer as "Britain's most respected green energy boss." The following are excerpts from an interview with him where he talks about his passions, his interests, and some great advice.

What really inspired you to get into charity work?
To solve many of the problems, you can't just think in terms of climate change, you have to think holistically. You have to think about the development and there has to be a prescription to develop and not on the same fossil fuel intense route that we have. So, that was the reason for wanting to contribute. And what

"I would argue that an interdisciplinary education is essential."

I'm really excited about are the projects in place, we're not just trying to stimulate markets at the bottom of the energy ladder and help people get jobs in solar, but we're in the level of Megawatts; community scale projects, with batteries and mini grids, where we're assisting whole villages with solar farms, and that too with the biggest operator in east Africa now. So, it's super exciting.

What is a valuable skill set for upcoming graduates to support the field of sustainability?
So many things are relevant. It is not just about the engineering and the science anymore. It is about the policy, the full spectrum of human activities, and the politics! That is important as well. I would argue that interdisciplinary education is essential, based on my experience. If you were just highly specialised in one field, it's very difficult to have a broad enough view, and see the bigger, holistic picture.

How did you grow into being this interested in all these climate related issues?
I was at the Imperial college, and it is a bit like this college, Science and Technology only, and I was a fully paid up academic. My research was funded by BP and Shell, and I was a hardcore geoscientist. My training in Oxford had a more general approach to geoscience and I wound up as a reader in stratigraphy. I got to worry about climate change through that. My point about having a broad enough view to see the big picture, comes up again. And I got very worried; so worried that I left, and joined GreenPeace. After GreenPeace, I went straight to setting up the company. That was because so many of the people I would talk to in the business world when I was a lobbyist and would say "Jeremy, at some point don't you think you should stop talking about all this theory and go and try and do it?" So ultimately, I took their advice.

Would you care to elaborate on your book writing process?
Yes, that is a good question! (Long pause) Well, I love to write! The books I've written, they're very personal. I sort of do an eye witness style, and I'm hoping, to be able to explain some of the things I've seen and their relevance going forward. And I can do that because while I am a player, I am not the head of state, or some famous politician or anything

like that. I get invited to go and observe often, and not take part. And I observe the big dramas. Like Paris. I was in Paris for two weeks, and no one writes about these incredible dramas. That's what I've done in my books, and just kind of explain the situation that way.

What is your goal behind these books? Is it to inspire people, policy makers, industry and so on?
Yes, and also to contribute to the way history is written. The first book I wrote, "The Winning of the Carbon War", it covers the climate negotiations from the beginning, about 1989 is when it kicked off and up to the Kyoto Protocol in 1997, and extended to 2000. So there's more than a decade of the early negotiations and I didn't fully realise it at the time, but nobody had written, many people had observed, but nobody had written the history of it. Many of the histories were written by academics, who had never or barely been to negotiations, who weren't players. And then they write learned papers on the legalities of climate conventions and everything else. I thought, you can write something that describes what it's like to be in the United Nations, and the way the Oil and Gas guys operate, they were quite brazen. There was an element in which I wanted to contribute to telling the history like it actually was.

You've had such a varied life with many different roles. What would you say is your favourite one?
Honestly, it has to be starting SolarAid. If ever I want to top up my batteries, I go to Africa and look at the work. Each one of those tiny little solar lights changes lives in incredible ways, right at the bottom of the energy ladder. So yeah, this would have to be my favourite role.

During your lecture, you talked about the fact that at some point there is something that will finally tip the balance in this everlasting energy debate. What are the various factors that play a role in this?
I can't see what the lever is, or what the trigger is. If I could, I would be much more effective. I think the analogy of the Berlin Wall is really relevant. You couldn't see then that it was going to come down.*Snaps Fingers* Especially as quickly as it did. What was the trigger for that? It was a mix of things that finally caused the break. One of the messages I was trying to put across was that if you imagine, you're the Chief Executive of an oil company, you may feel very comfortable today. But, look at the all the pressure from your shareholders, from your clients, staff, children at home, grandchildren even. At some point, you can't do it anymore. It's going to break. You talk to people in the financial services industry and they're worried. In the face of all that, the wall will come down. I'm convinced of it. But I don't know when and I don't know what the trigger of it will be.

"There's so much people can do with their spare time in environmental organisations, social organisations, charities of different kinds."

Do you think that switching from government to business side more is more effective since they might play a bigger role in solving these issues?
Well, I've never worked for the government, I've been on government advisory bodies. But, yes I suppose it is true. I do think that ultimately if we can beat this, this huge set of problems, it will have to come from everybody working in impressive ways, and I think the business sector can make the biggest difference. And the more success we have in the clean energy industries with rapid growth and showing what it can do. There's a saying we have, that "seeing is believing". When people look at solar and they don't know anything about it, and then they actually see it in use and begin to believe in it.

What do you think that we, as students part of study associations and organisations can do to play even the smallest of roles in this transition?
I would appeal to people to go beyond their studies. There's so much people can do with their spare time in environmental organisations, social organisations, charities of different kinds. Getting an education and career relevant to the global energy transition and it will keep you very busy. But even then you will have a bit of spare time, some of that should go towards the bigger picture, in the form of campaigning and reaching out to people and so on.

Else Kooi Laboratory

A peek inside an EEMCS Laboratory

Sten Vollebregt

The Else Kooi Laboratory (EKL, formerly Dimes), plays a fundamental role in all TU Delft research which focuses on silicon-based electronic devices and microsystems. It was named after Else Kooi, who invented the LOCOS process at Philips Semiconductors which was used in almost every CMOS chip until the mid-90s. Historically, the focus of EKL was on silicon bipolar transistors. But as the industry developed the "More than Moore" paradigm, which focuses on the integration of additional functionality on a chip beside the classical electronics, the focus of EKL changed.

As a result, the lab expanded its capabilities to micro-electromechanical systems (MEMS) for miniaturized (smart) sensors and actuators, solar cells, flexible electronics, new materials, and organ-on-chip technology. All while still being capable of fabricating integrated circuits in the same university lab, a combination which is unique in Europe. As the focus of the lab is on the fabrication of complex microsystems and the scaling up of technology together with industrial partners, the core of the lab uses equipment from the semiconductor industry. This core is combined with specific tools that allow, for instance, the deposition of carbon nanotubes and graphene.

Recent advances in EKL are the opening of the Polymer Lab, which supports research on flexible electronics and more recently organ-on-chip technology, a new platform which is being developed within the DMT initiative and focuses on creating valid human organ models on-chip to reduce animal testing towards personalized medicine. At the end of 2018 the startup 'Applied Nanolayers', which focuses on novel 2D materials like graphene, moved to EKL to accelerate the scaling of this emerging material to industrial relevant sizes. With these changes EKL will be able to keep offering its users a state-of-the-art environment to execute excellent research.

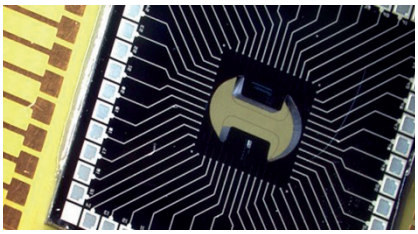


Figure 2. *Organ-on-chip module that can simulate the beating of the heart to study the impact of drugs on heart cells*

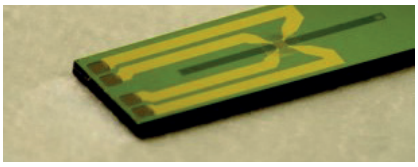


Figure 3. *Nano reactor to study chemical reactions in-situ in a TEM. These are now commercialized together with the start-up DENSsolutions*

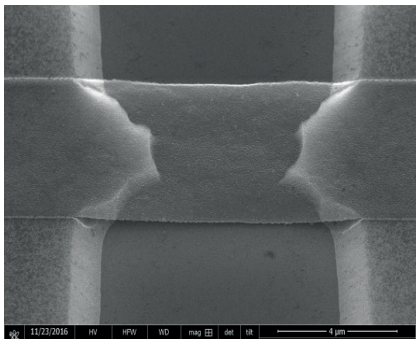


Figure 1. *Suspended graphene beam over a cavity etched in silicon dioxide which can be used as low-power pressure sensor*

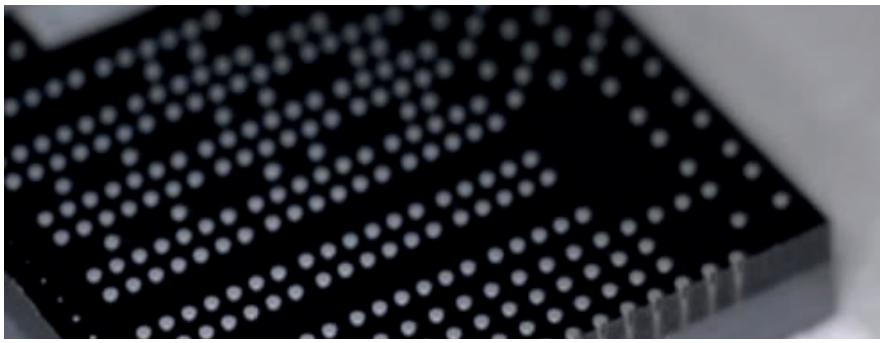
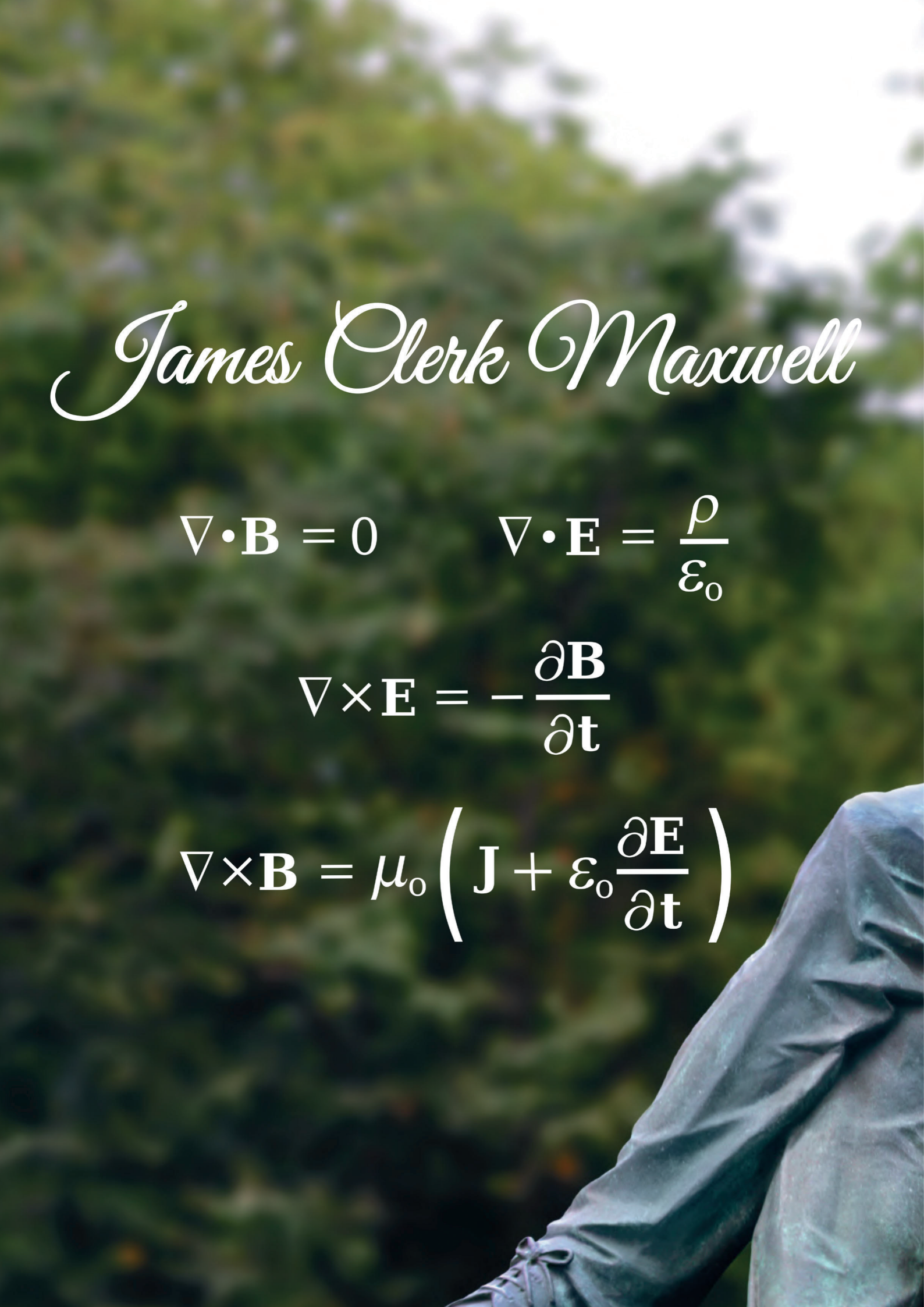


Figure 4. *High-density vertical interconnects created through the moulding of a chip package*


James Clerk Maxwell
$\nabla \cdot \mathbf{B} = 0$
$\nabla \cdot \mathbf{E} = \frac{\rho}{\varepsilon_0}$
$\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial \mathbf{t}}$
$\nabla \times \mathbf{B} = \mu_0 \left(\mathbf{J} + \varepsilon_0 \frac{\partial \mathbf{E}}{\partial \mathbf{t}} \right)$

Studying and rowing

Bachelor column: a peek into the world of Electrical Engineering students

Shea Haggerty

As you may have read in the last Maxwell, Mathijs started an interview chain which I will continue in this edition! I am Shea Haggerty, a second year bachelor student. My hobbies are playing the violin and piano, boxing, and I row at the student association Proteus-Eretes. In this edition, will answer Mathijs his questions and end my column with questions directed towards another student. Enjoy!

Shea: what kind of team are you in currently? How do you like it so far?
I row in the team called the 'dames-clubacht' of Proteus-Eretes, named CHAOS. It is essentially a team of eight girls trying to win the Kruithuis Cup! In order to win in this league, we have seven or eight races in which we must compete – the fun thing about these races is that they are spread out through the country, so one weekend you're racing on your own Schie and the other you have to travel to Groningen! As far as how I'm enjoying myself – I love it! The trainings can be quite tough, especially in the winter when you have to row in the freezing cold. However, rowing in the summer is one of the best things you'll ever do so it's all worth it in the end! What also helps to keep the spirits up are the parties at Proteus, which CHAOS always attends of course.

"we train five to six times a week, which can be demanding"

How do you time manage it together with your studies?
As I said, the trainings can get very tough at times: we train five to six times a week, which can be demanding. I especially feel the extra pressure in exam weeks when I have to study, but together with studying my trainings always stay a priority in those periods. I must admit that my schedule isn't as smooth as I would like it to be (think of forgetting trainings or lectures), but I try to plan my study moments for the whole week ahead to keep on track. What also helps is that my team and I enjoy studying together, so often after a training we head to the Fellowship to cram in a study session.

Do you already have an idea which minor you would like to do?
I think I have an idea of what I would like to do! I find Electrical Engineering quite tough at times, so I want my minor to be completely different from the subjects that I am doing now. An Industrial Design minor would suit me very well, as I like thinking creatively. Also the minors covering entrepreneurship seem interesting to me – I need to inform myself a little bit more before I make the big decision! I do know I want to stay in Delft though, I am enjoying myself too much here to move out of the country for half a year.

PS. Next editions columnist is still a mystery, find it out in the next edition!

Effective Time Management

Master student column: a peek into the world of EEMCS Master students

Adithya Vemuri

In the previous column, Getssy Pratibha talked about her experience prior to her master's degree and how it helped her with choosing her specialisation during the program. In this edition, Adithya talks about how he learnt to multi-task well and manage his time in a most effective manner. Interested in seeing how you can apply this for yourself? Continue reading!

Hi! I am Adithya Vemuri, a master's student in the field of sustainable energy technology - specializing in wind energy. I am in the secoWnd year of the programme and working on my master thesis. I would like to share my experience on how I manage to be effective in my coursework, my workload in a dream team and also my thesis.

Firstly, a bit about myself, prior to my master's programme I worked as an Application/R&D engineer at a tier-1 auto-ancillary company SIPL, in India. We supplied axles and driveshafts to original equipment manufacturers. My role was to quantify customer requirements in mechanical terms and apply an existing driveshaft with minor modifications, or design a new one, if necessary. The job demanded me to handle multiple projects at the same time, I learnt to organize and automate my work wherever I could. Slowly I turned it into a habit to work on multiple projects at the same time. During the 2nd year of my masters I decided to work on my thesis and also join the Delft University of Technology's formula student team (DUT'19). At the start of my 2nd year master programme I still had a 4-credit course left to do in quarter 1, planned on starting my thesis in September of quarter 1 and joined DUT in July before quarter 1. I also planned on auditing few courses in quarters 1 and 3. To manage these effectively, I decided to draw a framework and a detailed time-plan for my thesis considering flexible timeslots for DUT and my courses, that is for 9 months. Considering this time frame, I then decided on modifying the courses I planned on taking. Planning this wasn't a simple task, I dedicated about 2 weeks on coming up with a plan that could match my personality, I also had to consider for my laziness to actually follow the timeline. Fortunately the projects I am working on at the moment seem to do the trick. I planned it in such a way that I worked on my thesis from the afternoon until late in the evening, I try to average 6 hours of productive work, and I worked at DUT in the morning for about 5 hours, on 4 to 5 days a week. The team is supportive and flexible about timings when I am drowning in work. I try not to work on the weekends but when faced with challenges in my thesis or when my coursework deadlines come up, I use up all the time I can gather. Working at DUT is a joy for me, like a stress buster. The work is challenging and is a break from my thesis and courses, being in a completely different field. My role during the start of the DUT-year was as a design engineer in the Rims department to further optimize the existing rims. Later, we were shuffled to ergonomics in order to design the first ever carbon fibre seat in DUT-history. As a team we work on every project from scratch; conceptualize, trade-off, preliminary design, detailed design, drawings and production, all towards the common goal: To win at Formula student Austria and all other competitions we enter. I am currently part of the chassis production crew. I have worked with machines before but never with carbon fibre reinforced plastic (CFRP). It is fun when you can cut, drill and work with expensive CFRP! The experience of being a part of an 80-member team working together towards building the fastest DUT-car ever is surely motivational.

Advertorial

On being a Campus Brand Ambassador

Karen van der Werff

Hi there! My name is Karen and I'm a fourth-year student of Electrical Engineering at the TU Delft. After completing a full-time board year as Commissioner of External Affairs at the study association (ETV), this year is about finishing off my Bachelor and choosing the right EE-master to do after that. However, that is not all: after a year of maintaining numerous company relations, there was one in particular that I could not let go: Thales! Having become one of their Campus Brand Ambassadors, in this piece I will tell you a bit more about the company and my experiences there.

What does Thales stand for?

The company's mission is to help make the world a safer and better place to live in. In a time where everything becomes increasingly complex and high-paced, it is important to think smarter and act faster.

Thales' work can be found in radar systems for the navy and communication systems for the ground forces, yet also in a wide range of civilian applications. Whether taking the train to work, flying an airplane towards your holiday destination or surfing online, Thales provides the solutions to help you do so as safe and comfortable as possible.

What is the core business?

Thales is an international company that is active in five markets worldwide: Aerospace, Space, Transportation Systems, Defence and Security. With 80.000 employees working in about 65 different countries, it is an enormous network!
In the Netherlands, we have about 2000 people focusing on three of these markets: Defence, Security and Transportation Systems. Examples of the systems produced here are the well-known OV-poortjes, as well as radar systems for navy ships and communication systems between tanks, among many others. It is quite an extensive and diverse portfolio!

Where exactly is Thales Netherlands located?

There are four locations in the Netherlands where we can be found. As each location has their own specialization, let me give you an overview on what happens where:

- *Hengelo:* This is the headquarter of Thales Netherlands, with about 1500 employees active here. While the main building is very modern, you can also find almost a hundred years of experience and history on radar systems for navy purposes. The widespread terrain houses a lot of eye-candy for electrical engineers; the various anechoic chambers, labs and workspaces contain many high-tech innovations! Also, the location hosts an implementation of TACTICOS, their Combat Management System. So be sure to visit this site when you get the chance, and don't forget to test your navy strategy skills there too!
- *Huizen:* The second-largest facility houses about 300 people. Here you can find three main departments: Cyber Security with its own Security Operations Centre, Communication Systems and Networks, and Transportation Systems with the

OV-poortjes. As the maintenance of the gates is also done here, there are a lot of them in-house. Even the older ones, when they were still bright pink, can be found there and are quite museum-worthy!

- *Delft:* The Delftechpark near our campus is where you'll find the Delft site of Thales. The focus here is R&D, specifically for radar technology and systems. With a few tens of employees, there is a homely feel to this location where everyone knows each other well.

- *Eindhoven:* Lastly, there is the Thales Cryogenics facility situated in Eindhoven, that focuses on research and fabrication of cooling systems. Being the European leader in cryogenic technology, the 100 employees located here work hard to stay at the top of the range!

What can I expect from Thales as an employee?

Thales is a high-tech and innovative company, where employees enjoy a high degree of freedom and responsibility. Freedom to decide the direction of their development, and responsibility together with the team to ensure high-quality output. The challenging work keeps them sharp, the supportive and friendly culture keeps them happy. A good mix if you ask me - after all, a balanced work-life situation gives the best results!

Besides many full-time job vacancies, Thales has openings for interns and graduates as well. Newcomers can quickly get to know their colleagues through the various activities organized locally or by the international Young Employee Society. From ski-trips to lunch lectures and drinks afterwards - who said that work cannot be combined with fun?

How did you meet Thales?

I really got to know Thales last year, through my role as Commissioner of External Affairs at the Electrotechnische Vereeniging. Our study association and Thales have been working together for years already, so naturally I got in touch with the company as well. I experienced it to be very pleasurable to collaborate with them, and organizing joint activities turned out to be both fun and interesting. While getting to know more and more Thales-employees as well as the projects they worked on, I grew more fond of the company. Obviously, I was very happy when they asked me to apply for one of their Campus Brand Ambassador roles!

What is a Campus Brand Ambassador and how can you help students?

Together with five other students from the three Dutch technical universities, we started our job as Ambassador last year. The aim of our work is to bridge the gap between the Thales and students. As we can frequently be found somehwere on the campus, it makes it more accessible to get in touch the company. Being a student ourselves, we can easily find out what a someone is looking for and get them in touch with the right person!

Before becoming an Ambassador, we have had several extensive training days at three different sites: Hengelo, Huizen and Delft. Here, we have had tours and presentations from various people from various departments. From the CEO to the interns and from the high-tech labs to everyday offices; we have gotten to know it all! Through these training days, we got the chance to see the company from inside out. Therefore, we can tell you from our own experiences about aspects such as the facilities and the atmosphere on the workfloor, as well as the projects they are currently working on.

How can I get in touch with the Campus Brand Ambassadors?

We are more than happy to help you in answering any of your questions - that's what we're here for! You can contact me via e-mail or LinkedIn:

karen@thalesoncampus.nl
linkedin.com/in/karenvanderwerff/

Diamond colour centers for quantum internet and sensors

Oscar Tenorio Pearl, Roel Mouris and Dr. Ryoichi Ishihara

Diamond doped with impurity atoms: colour centres are promising materials for quantum internet, large-scale quantum computers and quantum enhanced sensors. Nanofabrication process technology on diamond will enable chip-scale integration of nanophotonic devices and provide a platform for compact and scalable quantum information processing and sensor systems.

Introduction

Quantum internet works by linking small quantum processors within a quantum network using remote entanglement of quantum bits or qubits via photons (Figure 1). This will create a fully secure communication channel between any two users of, for example, financial or government institutions, and also distributed quantum computation [1]. The use of a photonic channel enables flexibility in the design of a network from chip-based systems to networks using existing optical fibres or even free-space via satellites. However, while it is important to elongate the entanglement distance for wide-area-networks, it is critically important to integrate quantum network devices inside a chip for large-scale quantum processing.

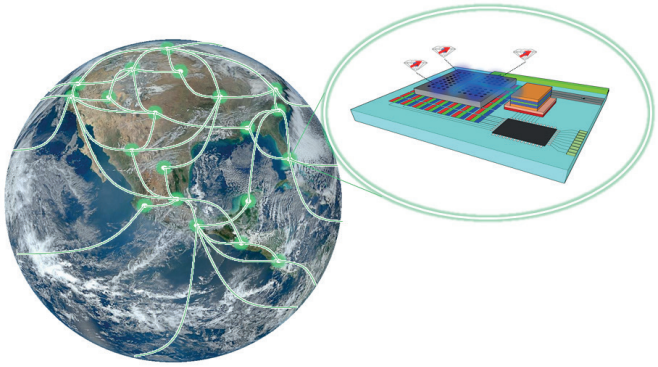


Figure 1. *Quantum Internet Network. A global quantum network is envisioned to be composed of multiple hubs which can be remotely entangled by photons. Each hub can be composed of on-chip sub-hubs which can also be entangled locally by means of planar photonic integration technology.*

> *"The colour centre in diamond also offers excellent magnetic, temperature and strain sensitivity."*

Quantum networks require long-lived qubits that are optically addressable and readable, and the most prominent material so far is diamond. When diamond is doped by impurity atoms, so-called colour centres are created, which have been proven to provide all essential requirements for quantum networks and information processing such as: storing, processing, and transmitting quantum information. Central to the operation of a colour centre is the spin-dependant fluorescence, which appears bright or dark depending on its spin state. Quantum entanglement and teleportation have been demonstrated between two diamond colour centres [2], but scaling to larger networks requires more efficient spin-photon interfaces, the predetermined positioning of the colour centres, and integration with photonic circuits inside a chip, which represent engineering challenges.

The colour centre in diamond also offers excellent magnetic, temperature and strain sensitivity. Since diamond is chemically inert and biocompatible, and the sensing capabilities are maintained at room temperature and even in a liquid environment, it is attractive for biological applications such as medical imaging. Since the colour centre is

an atomic-sized point defect, it could enable, for example, nanometric spatial resolution of molecules and MRI at the submicron length scale without using large magnetic coils. The strain sensitivity of diamond colour centres could be applied to accelerometer sensors for automotive airbag systems, or in our smartphones. The quantum sensing enhancement will break through the classical sensing limit and provide much greater accuracy than current existing solutions.

In this article, after introducing the amazing properties of the diamond colour centres, photonic crystal cavities in diamond will be reviewed, which will provide a diamond photonic integration platform inside a chip with high photon emission rates and collection efficiencies for scaling up the quantum network system. We will also review a quantum enhanced accelerometer with diamond, which operates at room-temperature, aiming for automotive applications.

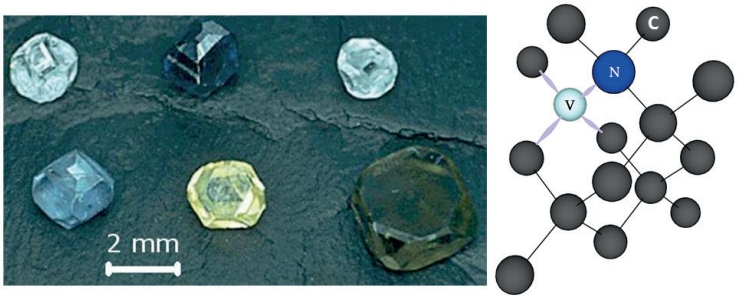


Figure 2. *Colour centres in diamond are localized defects in the lattice structure created by the combination of vacancies and substitutional atoms (right, nitrogen-vacancy centre) and different impurity atoms give difference colours (left)*

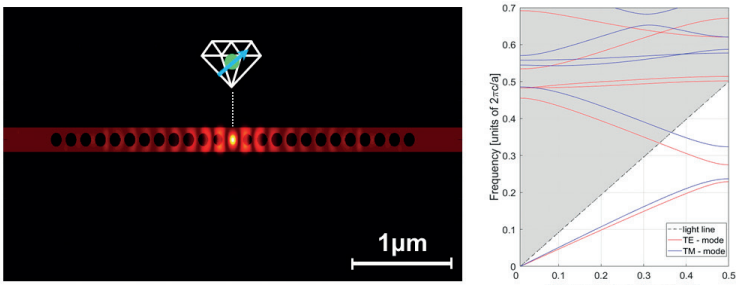


Figure 3. *Photonic crystal cavities (left) can confine photons of a specific wavelength in a small volume. Similar to semiconductor crystals, photonic crystal structures can possess a bandgap on their dispersion diagram (right).*

Diamond colour centres

Diamond is the ultimate engineering material due to its mechanical hardness, high power capability properties, high mobility and excellent heat conductivity. Because of its large bandgap, diamond is optically highly transparent, however impurities such as nitrogen, silicon, germanium and many other atoms give it colour, as shown in Figure 2. Colour centres are localized defects in the diamond lattice created by the combination of substitutional impurity atoms and missing atoms (called vacancies). As most of you remember from high school, colour is due to an electron that falls down from an excited energy state and emits the energy in the form of a photon. Due to its large bandgap, impurities in diamond can have optical transition energies between ground and excited states, within the optical spectrum. This allows the optical characterization of such impurities, even at room temperature, by their photoluminescence, which corresponds to the absorption of a photon and a consequent emission of another photon (usually with a longer wavelength). [3]

"Diamond is the ultimate engineering material due to its mechanical hardness, high power capability properties, high mobility and excellent heat conductivity."

The direct optical transition, which does not involve a phonon interaction and is known as the zero-phonon line (ZPL), has a sharp spectrum. An electron can also fall down without emitting a photon, owing to the interaction between the colour centres and the host diamond lattice, which broadens the total photoluminescence spectrum (known as phonon sideband). The charge state of the colour centres is quite important since it modifies their symmetry properties, and how we can interact with them by means of optical, magnetic and microwave fields. To understand this, we need to consider that besides having mass and electric charge, electrons possess spin, which is an intrinsic angular momentum property. Hence, depending on the number of electrons in a colour

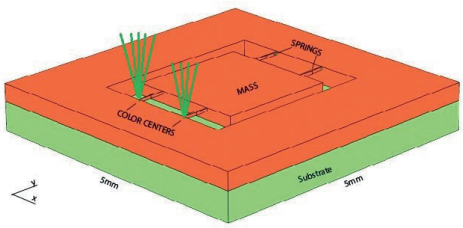


Figure 4. *Quantum enhanced accelerometer design with diamond colour centres.*

centre, the total spin can have different values, and the interaction with external fields could be different as well. The commonly used nitrogen vacancy (NV) centre has a total spin of S = 1 in its negatively charge state. This allows us to modify its energy levels by applying magnetic fields, by means of the Zeeman splitting effect, making them great candidates for ultrasensitive magnetic fields sensors. Exploiting this same effect, we can use two of the allowed spin states as the basis for a qubit even at room temperature. Moreover, the susceptibility of a colour centre to variations on its spatial symmetry brought up by deformations of the host lattice, allows us to use them as strain sensors.

Photonic crystal cavity with diamond

There are plenty of examples in the natural world in which objects appear to have different colours depending on the direction we look at them (e.g. opals and butterflies' wings). To understand this phenomenon we need to think of the way light scatters off such objects. When light waves travel between two mediums with different refractive index, the transmitted and reflected waves undergo constructive/destructive interference, depending on the angle of incidence, the wavelength of light, and the difference in refractive indices. In structures where the refractive index is periodic, propagation of light at certain wavelengths can be completely forbidden, depending on the angle of incidence. If there is no angle at which some wavelengths can be transmitted through a photonic crystal, we say that the structure has a photonic bandgap, much the same as when we talk about electronic bandgaps in semiconductor devices. In the lab we can exploit this phenomenon to artificially design 1D, 2D and 3D photonic crystals, engineering the bandgap at which we want to suppress transmission. Furthermore, we can create photonic crystal cavities, which basically consist of a photonic crystal structure with an artificial "defect" that confines photons of a specific wavelength in a really small volume.

A quantum system that is excited by the absorption of a quanta of radiation, will tend to spontaneously return to its equilibrium state. The rate at which this occurs, known as the spontaneous emission rate, depends on the number of available states for the system to return to. However, if we place the quantum system inside a resonant cavity, the spontaneous emission rate will be enhanced at the mode in which the cavity resonates. Moreover, if the cavity has a photonic bandgap, which is the case with photonic crystals for example, then the spontaneous emission rate of those modes inside the bandgap will be suppressed. [4]

The fabrication of a 2D photonic crystal cavity structure in diamond can be performed with nano-fabrication and thin film processes in a cleanroom. First we start making a mask with a sacrificial silicon-on-insulator (SOI) substrate. Using a combination of electron-beam lithography, focused-ion beam milling and reactive-ion etching, we can pattern and transfer the structure of the photonic crystal onto the crystalline layer on the SOI substrate. Finally, using hydrofluoric acid we can etch the buried oxide and undercut our structure. Later this structure can be placed on top of our diamond slab and act as a micro mask for nitrogen implantation for the colour centre at the desired location and also for pattern transfer into the photonic crystal shape by means of oxygen plasma etching.

"The diamond colour centre opens pathways towards implementing various sensing applications."

To measure the spectral response of the implanted NV centres within our photonic crystal cavity, we can employ a technique known as optically-detected magnetic resonance (ODMR). Using an external magnetic field aligned with the symmetry axis of the NV centre, the degeneracy between the spin states $m_S = \pm 1$ can be lifted. When a short green laser pulse is shone on the NV centre, it gets mostly polarised on the spin state $m_S = 0$. After this, if a second green laser pulse is shone on the NV centre, the photoluminescence that can be collected by a confocal microscope will be maximal. However, if in between laser pulses we apply a microwave signal with energy equal to the difference between the $m_S = 0$ and the $m_S = -1$ ($m_S = +1$) state, we will detect a dip in the photoluminescence. This is the basis on how we can detect the spin state of the NV centre in diamond.

Quantum enhanced accelerometer

The diamond colour centre opens pathways towards implementing various sensing applications. Using the atom-like property and coherent spin manipulation, sensitivity can exceed the classical limit, for example the thermal noise. One possible application is an accelerometer which senses strain applied to diamond operating at room temperature. As shown in Figure 4, we use a mass suspended by four tiny beams that are made inside the diamond slab. In case of an impact, the mass will move and this will result in a strain on the tiny beams. In each of these beams there is a colour centre that will have variations in its photoluminescence signal, detected by ODMR, when the strain is high due to changing the state of the spin.

One of the challenges in designing the structure is that we want a high strain in a few spots without breaking the device. These are also trade-offs between the read out-speed and the signal amplitude, and therefore the strain. Our design therefore focuses on read-out within one millisecond with the highest possible strain. This makes it possible to cover a wide range of sensitivity of accelerometers used in airbag sensing applications for automobiles and smartphones. We use beams that are thicker in the middle than at the endpoints. This guarantees that the beams will bend mostly at the endpoints, which means the strain is the highest at these endpoints. The structure will be fabricated in the cleanroom, by plasma etching the diamond and implanting the colour centres at the points where we try to read-out the highest strains in the sensor.

Challenges

Future challenges in the use of colour centres in diamond are: to have a scalable fabrication process at the wafer level, the deterministic positioning of oriented colour centres, and their integration with CMOS electronics. At the moment, one of the bottlenecks in the use of single-crystalline diamond is the small substrate size: typically a few mm. For industrialization purposes, a large size single-crystalline substrate or single-crystal islands of diamond grown at desired positions is desirable. For scaling up the number of qubits, deterministic positioning of colour centres is crucial. Also, current quantum information processing and quantum enhanced sensor systems with diamond use many bulky off-the-shelf instruments, such as lasers, filters, and detectors. This increases the system size and limits practical applications and scalability, and therefore, integration of the diamond devices with CMOS chips is highly desired. Nanostructuring processes, epitaxial growth and advanced packaging technologies will be the key to realize a large-scale quantum information processor on-chip and a compact quantum enhanced sensor operating at room temperature.

[1] 1.S. Wehner, et al., “Quantum internet: A vision for the road ahead.” Science, 362(6412), 1-9 (2018).
[2] 2.B. Hensen, et al., “Loophole-free Bell inequality violation using electron spins separated by 1.3 kilometres” Nature, 526, 682-686 (2015)

Professor of the Quarter

Arno Smets

Stefanie Brackenhoff
Sebastian Jordan
Bob van Nifterink

Every quarter, the Maxwell Committee interviews a Professor of the Quarter. This professor is chosen by asking Bachelor students which professors relating to either the current or upcoming quarter they like best. The professor of this quarter has been chosen to be: Arno Smets.
Arno Smets is a Professor in Solar Energy in the Photovoltaics Material and Devices group. His research focuses on processing of thin silicon films, innovative materials and new concepts for photovoltaic applications. Additionally, he teaches courses on Photovoltaics (PV) and sustainable energy on both bachelor and master level and has developed online courses on renewable energy to be able to reach students outside the TU Delft as well. We interviewed him about him, his life and his research.

How did you get involved with photovoltaics at TU Delft?
I think it has been a very slow process during my career. Over 20 years ago I finished my master thesis project in plasma physics at Eindhoven University. I then did a Ph. D. on processing silicon materials which could be used for photovoltaics. What I liked about the position was to work on research which was not just aimed at creating a gadget, but that it had the nice big goal of saving humanity. After that, I went to Japan

"It had the nice big goal of saving humanity."

for five years to work at the National Institute of Advanced Industrial Science and Technology at the research center of Photovoltaics. In those days that was the big group for PV technology. Afterwards I went looking for a new adventure and there was a position available in Delft in the field I was an expert on: PV and thin-film silicon. That is now nine years ago.

How does working in Japan compare to the TU Delft?
I was working at a research institute, so I did not interact with as many students as I would have at a University. The main difference between students in the Netherlands and in Japan is the hierarchy. If you get in an elevator in Japan and ask a student about their weekend they will give you a confused look. If you purely look at the job itself, being a Professor in Delft requires you to allocate a lot of time to the supervision of students. That also gives your work a different dimension: trying to inspire the youngsters.

There are more cultural differences of course. In the Western world, we have the illusion that everybody thinks like us, which is not the case. In our world there is only one truth and all logic has to arrive at that truth. In Japan, people can hold many truths without any problem. They also approach problems differently, which makes them better at solving some problems. As Westerners, we really have to understand everything before we can offer an answer. The Asian way works better for quickly tackling problems if you have enough manpower. If you want to have an overview, the Western approach works better.

"We have the illusion that everybody thinks like us, which is not the case."

Take China for example. About ten years ago the government there decided that they were going to invest a lot in the industry of manufacturing PV modules. That scaled up so fast that most of the module manufacturers in the US and Europe could not compete anymore and went down. The more you produce, the cheaper it gets. In Europe we might want to build a 10 GW plant on module manufacturing, but first we will spend 5 years fighting about where to build it. In China they just build it, no discussion needed. It is a faster and better system in the energy revolution. In the Netherlands you see that a lot of feelings start to influence the decisions about the en-

ergy transition, rather than facts. The public opinion is really indoctrinated by that. So you see how different systems can enhance or slow down technological advances and progress.

If you could invent anything, what would it be?

I would like to invent a way to easily store solar energy at home on seasonal timescales. A big problem with solar energy is that it is an experimentally proven fact that at night we do not have any sunlight. Therefore, we have to store solar energy somehow, which is were the bottlenecks are nowadays. Our campus is at a latitude of 52 degrees, therefore we have big seasonal changes. Wind and solar energy compensate each other because in the summer you have a lot of sunshine and not that much wind, while in winter time it is the other way around. However, you would like to store the excess of solar energy on seasonal timescales. In order to do this, it needs to be stored in chemical energy that you can burn again. There are more restrictions to storing the energy at home, however.. You cannot keep hydrogen in your backyard.

What do you like about working at the TU Delft?

That you have a lot of freedom to develop your own ideas and think out of the box. Over here, the opportunities were raised to start developing online courses. I think other Universities still do not pioneer with that as much as the TU Delft. Here you have those opportunities and if you take them, you can also get a lot of recognition from it.

I think one of the most important things in teaching is that you need to have a clear story. If you can show the students that you like and love what you are do-

ing, then students think: 'If he likes it, maybe I can like it.'. If I would stand in front of my classroom droning about solar panels, why should anybody else become enthusiastic?

What is the most exciting thing you have encountered during your career?
The impact online courses can make. The online students that really used the knowledge from our courses to build their own systems so they could improve their living standards. The students who started their own companies. You see that it is inspiration and awareness of people that we desperately need to make the next steps in the energy transition. Politics will not do it, they are too slow. Technology can do it, but we need investors for that. Another big challenge for the energy transition is human capital, the people who work on it. For instance, at the moments there are plans for the large scale utility of PV, but often the infrastructure is lacking. The ground in Groningen and Drenthe is cheaper because the population density is lower, so there you can make a lot of profit with large scale utility PV. However, the density of the grid is also lower because it was designed for the population density. On top of that, companies do not know where to get the people to install the PV. So human capital on all allocation levels will be one of the limiting factors in the next 10 or 20 years. Therefore, to see that you can inspire massive amounts of people is perhaps the most interesting thing to see. To see you can also make a change as a professor at Delft University and that you can inspire people and contribute on a bigger scale to the energy transition.

"if the whole world is thinking one way, it means the next step forward is somewhere where nobody is looking."

What do you think is the most important skill for an electrical engineer to have?
Short answer: all of them. However, creativity and thinking out of the box are the most important. Also in theory, if the whole world is thinking one way, it means the next step forward is somewhere where nobody is looking. That requires creativity in both designing and engineering. Creativity is also very important in supervising students. I remember when I was a master thesis student and I came to the famous plasma physics group in Eindhoven. The first two weeks I spent wondering what I was doing there and what everybody was talking about, whereas after two months I thought things like: 'That is stupid reasoning! I would not do that'. That is when I started to see that your intuition is quite good. So as a supervisor your task is to give students the platform to get the creative ideas out of them. If people believe in themselves and their own ideas, then you do not have to do anything as a supervisor. You can really see people grow in that way.

You are often seen at the /Pub. What do you like about that?
Input of the students at the bar, where you can have quite an open discussion about things teaches me a lot about the University and what is needed. The University has a lot of layers, and to know what is going on you should interact on all those layers.

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Klon clones

DIY project

Jippe van Dunné and Sebastian Jordan

For the last year, we comitted ourselves to the epic quest of recreating the mythical Klon Centaur, a guitar pedal that has been named "The pedal of the Centaury" by many guitarists.

What is a guitar effect?

For non guitarists, a guitar effect pedal is an electronic device that modulates the waveform of an electric guitar to alter its sound. There are many different types of effects, like an echo, filter, distortion or overdrive. The Klon is of the last type, which creates a warmer sound compared to a distortion. A distortion creates a very harsh sound by amplifying a signal and then clipping the peaks. An overdrive sounds warmer due to soft clipping, which means it does not clip the peaks with sharp edges, but smooths out those edges. The output signal therefore becomes less like a square wave and more like a compressed sine wave. An example can be een in Figure 1.

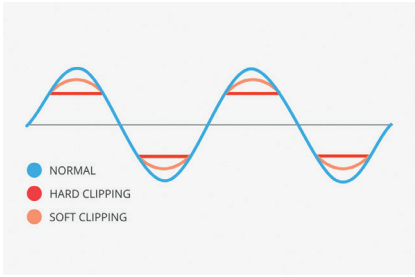

Figure 1. *Hard clipping versus soft clipping. [1]*

About the Klon

The Klon was first developed by Bill Finnegan in the early 90s and about 8000 original Klons were made. They are all hand built by him and resell nowadays from anywhere between 1500€ and 3500€ depending on version and state. The effect is renowned for its pleasing overdrive sound, but when it is slightly turned down, it gives a nice clean boost, which adds just a little bit of an edge to your sound. This slight edge can be heard in the work of a lot of famous guitar players, like John Mayer, Joe Bonamassa and Jeff Beck.

The pedal has become famous for this reason and thus has been copied by a lot of manufacturers, with varying success. These Klon-clones (or Klones) are still quite expensive, starting at around 100€ and do not give you the actual Klon sound. Therefore we decided to build our own!

Figure 2. *The finished pedal*

Build

The original Klon PCBs were covered in black resin to try and stop people copying the circuit. However, this resin was quite easy to remove and eventually the original Klon circuit got published on the internet. We found one of these schematics, shown in Figure 4, with a PCB, which we bought. We ordered the components from a few different vendors (Farnell, RS, etc.). However, due to some miscommunications, this took a couple months in itself.

In the end we had everything at our disposal and started! It soon appeared to us that all our components were too large for the pcb, which made it quite a challenge to find a fit for all the components, as can bee seen in Figure 3. When we had all the components installed and soldered, we were very content! However, this did not last too long as we soon found out it (of course) did not

work. Some mistakes were stupid, some were not, but after a good couple hours of tweaking and testing, we got a sound out of it! We put it in a standard aluminium case with a footswitch to operate it while playing, as is usual with guitar effects.

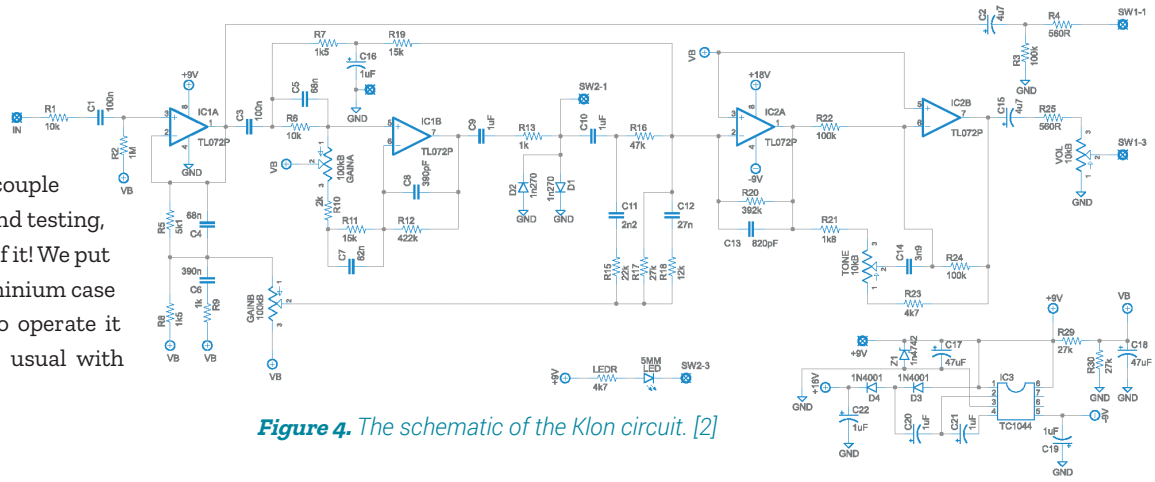

Figure 4. *The schematic of the Klon circuit. [2]*

Sound

It was an extremely harsh sound, which added an octave up version of the sound to it, which was very cool, but quite unwanted. We decided to try the effect on a tube amplifier instead of a transistor amplifier (tube amps are more conventional for guitar and sometimes interact differently with effects than transistor amps would) and this turned out to make a significant difference! The sound was still very loud and harsh, but after playing a little bit with the controls of the Klon, we found a sound which was not only usable, but actually very pleasing. We got very, very excited and, within five minutes, thought of ourselves as "geniuses" for getting it to work! We still both have it and enjoy using it a lot, we tried comparing the sound of our pedal to some pedals on the internet and it seems we made actually quite a good copy, since it sound very much like the original, which we both did not expect at all!

Conclusion

After over a year of ordering and sending back components, reading on the internet and many hours of soldering, we are very happy to say that we successfully completed our quest! The result is more than we could have dreamt of and with total costs of near 40€, this is probably our favourite and cheapest pedal by a long shot.

Anyone who was questions or is interested in building one him/herself is welcome to contact us!

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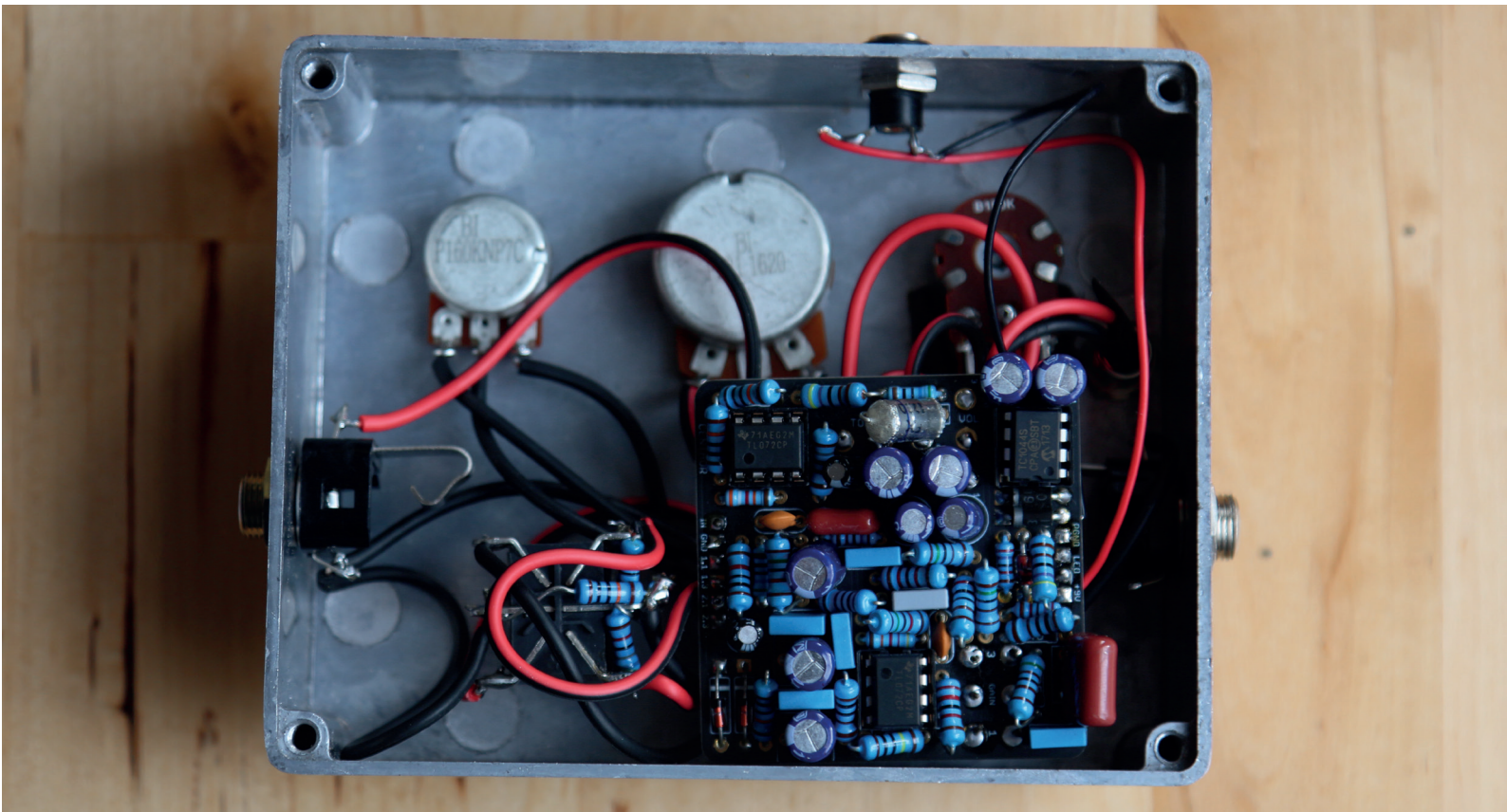
m.j.j.vandunne@student.tudelft.nl

[1] "Hard-clipping-vs-soft-clipping-diagram", Available: http://prosoundformula.com/wp-content/uploads/2016/06/Hard-clipping-vs-soft-clipping-diagram.png [Accessed: Mar. 19, 2019]

[2] "Refractor overdrive: Project Documentation", Aion Electronics, 2019. Available: https://www.dropbox.com/s/4xhwadzx-2rxbm8z/aion-refractor-centaur-documentation-v2.pdf?dl=1 [Accessed: Mar. 19, 2019]

Figure 3. *Gutshot of our Klon pedal*



Activities

An overview of last quarter's events

ElecTrip

25 February - 1 March

Every year, a group of bachelor students eager to broaden their electrical horizon embark on a road trip to a European city. This year, it brought us to Berlin. In this five day trip we visited a selection of companies which had roots in the field of Electrical Engineering.

The first day of our journey started in the early hours of the morning in the parking lot of EEMCS (everyone in suit of course) as we would visit our first company of the week a couple of hours later. BWM in Leipzig was the first stop on our list, and we received a private tour of the BMW Plant.

Other companies visited in this week were the relatively new 1aim, Inhouse Engineering and Tennet – the extremely detailed virtual reality which we could experience here left us talking about it for days. Lastly we couldn't resist a little visit to the Berliner Technik Museum, where the group concluded that the first computer ever was "just a few and-gates by the looks of it".

Although it is important to visit international companies, you can't visit Berlin without having seen the Brandenburger Tor and the Berlin Mall. Credits must be given to the tour guide of the cultural afternoon, because all this was done, plus the Terror Museum and Holocaust Monument within four hours (and don't forget the currywurst-break).

All in all the 2019 ElecTrip was a huge success: the companies were all vastly different, and the new Bluetooth buses were fully enjoyed, especially with carnaval just around the corner – the carnaval playlists were put on repeat the whole way back.

Shea Haggerty

CoDe cantus

12 February

Each year, a group of ETV students travels to Leiden for a certain event that is organised together with study association CoDe, the beer cantus. A cantus mainly involves singing and drinking beer. However, there are strict traditional rules which are governed by the so called "Praesidium". If the rules are disregarded, a typical punishment follows. This resulted in many tipsy students. Although it is an event that costs you a whole evening of productivity, a beer cantus is typically quite short (like 3 hours in total). Therefore, everyone went to the local pub of the CoDe association for a small beer afterwards. Some made their way back home, some did not, which will get my sincere respect. Overall, the cantus was a great success and an event to be remembered (or maybe not, by some people). See you next year!

Jetse Spijkstra

Di-Et-Tri pubcrawl
21 February

On Thursday, the 21st of February, the members of the Electrotechnische Vereeniging in Delft and the members of the bachelor Food Technology in Wageningen, went on a tour through several bars in Wageningen! The party already started during the way there, in a party bus with music and beers. Upon arriving in the agriculture-city, we were nicely welcomed by the Food Technology Board.

In the first bar, the two student groups were introduced to one another by couples, where the students of Delft got to be certain male characters of Disney movies, and the students of Wageningen the female couples of those characters. To promote the bonding, they received a free drink for each matching couple. The evening progressed very fast and we only managed to see one other bar, but all in all the evening was very successful and both student groups had a wonderful time!

Paul Kluge

EEMCS Recruitment Days
18 - 22 March

Every year, the ETV organizes the EEMCS Recruitment Days: it is the biggest career event for all master- and PhD-students of our faculty. During the course of one week, a diverse selection companies and students come by to find their perfect career match. After an extensive online selection done by companies and students, based on online profiles and anonymous CVs, the EEMCS Recruitment Days Team matches both parties while taking these preferences into account. During the event itself, the students and companies get to meet each other in 25-minute conversations.

This year again, six students worked hard to organize the event. With over 40 companies and 400 students, this year's edition was again a great success. The many smiling faces that could be seen after every meeting and the fun stories told at the informal drinks afterwards made it all worthwile!

Karen van der Werff

Family day
30 March

On Saturday March 30th, the annual family day took place at the ETV. The day started with two welcoming speeches from the President of the ETV, Laurens, and the Dean of EEMCS, John Schmitz. After this, the parents and their pupils went to the Tellegen Hall to solder their own metal detector. This was a nice way to show the practical part of our study! When this was done, it was time for lunch. Most students also used this time to show the campus to their parents.

As soon as every stomach was properly filled, it was time for a tour through the faculty. The high-voltage lab, the roof, the *studieverzameling* and again the Tellegen hall were visited. The second activity after the lunch break was an interesting lecture on bio-electronics given by professor Serdijn. Of course, the day ended with a drink in our own /Pub. All in all, it was a fun day for the parents and they got a good view on our lives as an Electrical Engineering student in Delft.

Owen van Hooff

A simplified skyline-based method for estimating the annual solar energy potential in urban environments

"Our fast approach integrated in software tools for calculating the solar energy potential can significantly facilitate design and distribution of buildings with integrated PV systems in urban planning frameworks. It will also help investors to take decisions on integrating PV systems in buildings and other urban locations."

Olindo Isabella
Head of the Photovoltaic Materials and Devices group

Read more on:
www.tudelft.nl/en/2019/tu-delft/a-new-approach-for-the-fast-estimation-of-the-solar-energy-potential-in-urban-environments

Upcoming activities

For members of the Electrotechnische Vereeniging

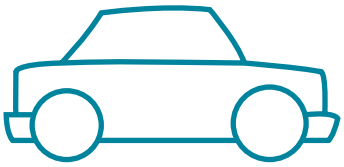
Lotte Zwart

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!

So join us in the /pub after your first lectures nd get motivated!

When: 23rd of April
Location: /Pub
Price: Beer €0,50 cents, pizza €5



Rally

Every year an enthousiastic committee organises one of the most epic activities of the ETV: the Rally! Think about who you want to form a team with, fix a car en puzzle your way through the Netherlands on this day. Who is the best driver? Who can puzzle the best? And of course, who can drink the best in the rear seat?

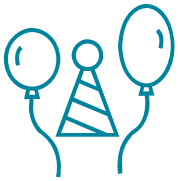
More information en the sign-up list will follow in april. Keep in mind: there's a maximum of 7 people per team.

When: 4th of May
Location: you'll have to find out yourself
Price: TBD

ETVehicle discussion

There will be an Discussion evening about an "ETVehicle". There will be discussions on various topics like, who can use the vehicle? Should there be sponsorship on the bus? Which characteristics should the vehicle have as a minimum? Will the maintenance be under a commission or do we want to do it with a company? Do you have an opinion on this or do you still have innovative ideas? come to the discussion evening! A snack and a drink will be provided.

When: 30th of April at 17:30 o'clock
Location: TBD
Price: Free



Dies Week

Every year the ETV gets a year older. This year on our birtday the 26th of March we turned 113! To celebrate this we have a Dies week full of activities. These activities consist, but are not limited to, a tasting session, the reception , a BBQ, a workshop and a special lunchlecture. So keep your eye out for the posters!

When: 13th-17th of May
Location: EWI
Price: TBD

Yearbook presentation

Last couple of years the yearbook was always presented in the DIES week. However, due to the special nature of the event, this year it will be seperated from the DIES. It will be presented on the 4th of June together with drinks and a BBQ.

Keep your eyes out for the posters!

When: 13th of June
Location: at the back of EWI
Price: Drinks free but BBQ probably €5,-

Sailing weekend

In recent years, it wasn't alway the case that the sailing weekend would take place. However, this year the committee has started full enthousiasm and the location and boats are already fixed.

The registration form will open the 27th of May and we have place for around 24 people.

When: 14th-16th of June
Location: Veerse Meer
Price: Around €70

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