# The Esiac-10 Algebraic Computer

## A theoretical decomposition by the Historic Collection

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# MAXWELL

Electrotechnische Vereeniging

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# Leap of Faith

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A theoretical decomposition of an analogue brain

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Mercedes-Benz Museum

# From the Board

Dear readers,

My Board year, together with my fellow 5 Board members, has come to and end at the time of writing.
It feels weird to have a 'last time' for things. This is also the time to look back at a year and see what we have accomplished. From our last meeting to our last full-time day at the Boardroom. We have organized so many activities, did some very special things like the installation of new Honorary members, had a very successful Recruitment Days and had so much fun doing all of it. We also met a lot of different people who we will be in contact with even after this year.

Now it is time to help the new Board the best we can to make sure that their year will be as good as ours was, maybe even better. Although I don't know if that is possible. Of course there have been some difficult moments and sometimes the fatigue was a little too much, but I can speak for my entire Board if I say that I haven't regretted my choice of doing a Board year. To everyone reading this Maxwell, enjoy your well-deserved vacation and thank you for an unforgettable year.

With Magnifying regards,

Mark Imhof
President of the 150th Board of
the Electrotechnische Vereeniging

*Mark Imhof*
*President*

*Evelien de Wolff*
*Secretary*

Dear readers,

The summer vacation has started as well as the end of my Board year. At the time of writing, there are still two big events we will organize but most of the year is done. And what a year it was, it started with organizing events on 1.50 m from each other, then we had a lockdown again and after that, we could start with organizing events without covid measures. This made the last quarter remarkably busy with almost two activities per week but also incredibly fun. To name some of the activities: the Dies week took place, we went on a sailing trip to Friesland, and we also went on an Electrip to Stuttgart. Organizing all this together with all the committees, I could say as the Board that I am immensely proud of everyone that put in the effort next to their studies to do this and organized something that made them proud and gave everyone an enjoyable time.

As Commissioner of External Affairs, I had this year more time to do other things than my main tasks as the contact person of all companies due to the extra board member Maxim we had this year. This gave me the time to create extra events and help committees by being their QQ (supervisor). I have had a lot of fun this year helping people with their careers by organizing excursions, workshops, and lunch lectures. Letting everybody see several cool companies that are out there and talking to engineers that have as much compassion as you for electrical engineering could give me a big smile on my face. Especially when the members talked after the event about how nice it was. Another thing I realized, about companies and working after your studies, is that working people aren't so scary, they are just a bit older but that's all.

The last thing I want to mention here is about my wonderful other board members. Mark, Maarten, Niels, Jorrit, and Maxim all have grown a lot as persons and in their Board functions this year. I often got the question: "Wow, isn't it difficult to be the only woman on your board?". The only way I could answer that question was 'no' because even though they sometimes wanted to stand their ground, they always saw me as part of the group and didn't treat me differently as they would do with another Board member. They are sweet guys and I hope you all have had the time to experience that, otherwise don't be scared to speak to us next year as we will still be walking around a lot at ETV events. That said, I wish you all a good vacation and see you next year!

With Magnifying regards,

Evelien de Wolff
Commissioner of External Affairs

# Colophon

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# Editorial

Dear readers,

Welcome to the third edition of the 25th Maxwell! With this edition, we bring you the most recent advancements in the constantly developing field of Electrical Engineering. We as the Maxwell committee believe that taking a leap of faith and throwing yourself into the unknown can be very rewarding. It means you fully surrender to all expectations you and others have ever had of yourself. It means that you allow yourself to start anew and feel completely free.

The autumn is here, and our vision for this edition was to put forward the stories of many interesting people and their projects which can collectively ameliorate these beautiful times. We reached out to researchers across diverse fields in electrical engineering ranging from the Energy Club, to a project on trolleybuses, to a discussion on a historical find in the basement of the EEMCS building at the Studieverzameling facility.

I want to thank all the contributors, especially my colleagues at the 25th Maxwell committee and the ETV board, who collectively worked to find the correct articles to engage and put together an exciting magazine for all of you, our readers. I hope that you enjoy it and happy reading!

*Mounik Garimella*

# INDEX

# The Esiac-10 algebraic computer

## A theoretical decomposition by the Historic Collection

*Kees Pronk and Piet Trimp*

From time to time, the volunteers of the Historic Collection in the basement of the EEMCS building come across unknown equipment. In this article, we discuss one such special find: the ESIAC-10 Algebraic Computer (Figure 1). We discuss the principles and operation of this analogue computer that is intended to solve algebraic equations such as those found in control engineering.

A short survey of the TU Delft archives has presented us with only one reference to this machine [1]. The ESIAC-10 analogue computer is mentioned in the book *Spanning* from 1998 by professor J. Davidse, but was already characterized as being overruled by the digital computers of that time. From further study, we presume that the machine was bought by prof. L.H.M. Huydts (honorary member of the ETV) around 1965.

A further literature study established that the ESIAC has been the subject of a thesis by M. L. Morgan in 1954 [2]. Around 1960, his prototype was converted into a commercial product. Several papers were devoted to the new computer to show its construction and advantages over earlier equipment [3, 4, 5]. We became aware of two publications by NASA [6, 7] showing the application domain of the machine: control theory, transfer functions, Bode plots (magnitude and phase vs. frequency) and root locus diagrams of dynamic systems.

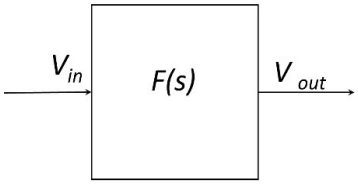


**Figure 3.** *Transfer function of a dynamic system*


**Figure 1.** *The ESIAC - 10 Algebraic Computer*

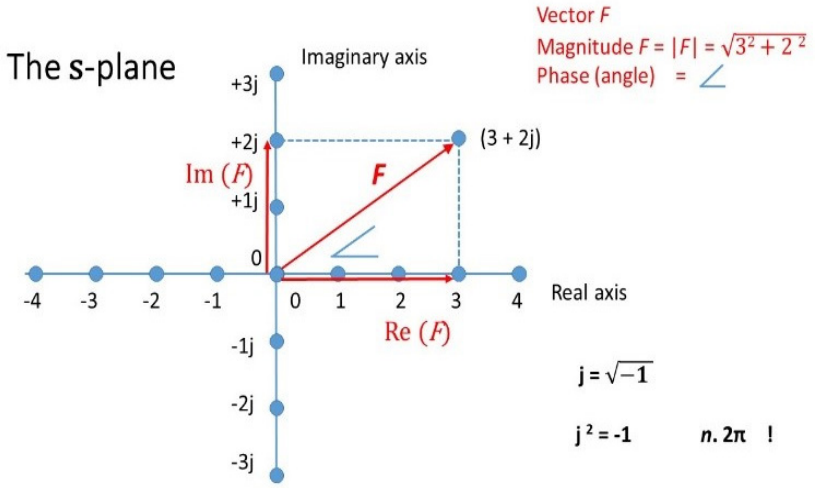


**Figure 2.** *The s-plane showing the vector F and its real and imaginary components*

### The mathematics of dynamic systems

The application domain of the ESIAC-10 is control engineering where so-called dynamic systems are studied. Such dynamic systems can be (electric) networks or feedback systems. Mathematically, dynamic systems are characterized by their transfer function: the quotient of the output voltage and the input voltage as a function of frequency. The transfer function $F(s) = V_{out}/V_{in}$ of a dynamic system (Figure 3) is given by the following formula:

$$F(s) = \frac{a_0 + a_1 s + a_2 s^2 + \cdots + a_c s^c}{b_0 + b_1 s + b_2 s^2 + \cdots + b_d s^d}$$

where $s$ equals the frequency, $j\omega$ or $z$ (as in sampled data systems).

The transfer function can be visualized as in Figure 3: a vector F in the s-plane. Note that the s-plane is of infinite size and that it is not possible to 'remember' how many rotations of $2\pi$ a vector has made.

The s-plane is inconvenient to use for calculating frequency and phase plots and root locus diagrams. In the next paragraph the function F(s) will be factorized into entities such as poles and zeros that are meaningful to the control engineer. To construct a useful tool, the s-plane will first be converted to a rectangular log s plane, followed by three transformations: a dual network transformation, a reciprocity theorem transformation and the introduction of a limitation of the boundaries of the infinite s-plane.

**Factorization**

This formula of the transfer function can be factored in two ways. Due to space restrictions, we do not present the second derivation, but restrict ourselves to give the outcome of the second factorization in the footnote below[1].

Using $K_2 = a_0/b_0$, we find the following equation:

$$F(s) = K_2\, s^{n_0}\, \frac{\left(1-\frac{s}{s_1}\right)^{n_1}\left(1-\frac{s}{s_3}\right)^{n_3}\ldots}{\left(1-\frac{s}{s_2}\right)^{n_2}\left(1-\frac{s}{s_4}\right)^{n_4}\ldots}$$

or alternatively:

$$F(s) = K_2\, s^{n_0}\, \prod_i (1 - s/s_i)^{n_i}$$

where $s_1$, $s_3$, … are called the zeros of the equation, $s_2$, $s_4$, … are called the poles of the equation and $n_0$ is the number of zeros minus the number of poles existing at the origin of the diagram. In these formulas all the $s_i$-'s are complex numbers. The meaning of these poles and zeros is as follows: when s equals $s_1$ or $s_3$ the value of the numerator of F(s) will be zero and therefore the output of the system will be zero. When s equals $s_2$ or $s_4$ the denominator of F(s) will have the value zero and therefore the output of F(s) will be infinite, or said in other words: the system will be unstable.

Taking the log of the latter equation we obtain a formula for the real part of the equation |F| and one for the imaginary part of the formula (the angle of F).

$$\log|F| = \log|K_2| + n_0 \log|s| + \sum_i n_i \log\left|1 - s/s_i\right|$$

$$\angle F = \angle K_2 + n_0 \angle s + \sum_i n_i \angle\left(1 - \frac{s}{s_i}\right)$$

In these formulas, all the variables are real numbers.

By taking the log, we obtain the following advantages: multiplication becomes addition (which is easier to implement given the electronic circuits of those days), we obtain a uniform accuracy over four decades and we will obtain more resolution near "zero".

When looking at Figure 4 we find on the right hand side of the machine, a set of controls to set the proper values of the sign of K, $n_0$ and the proper factoring method).

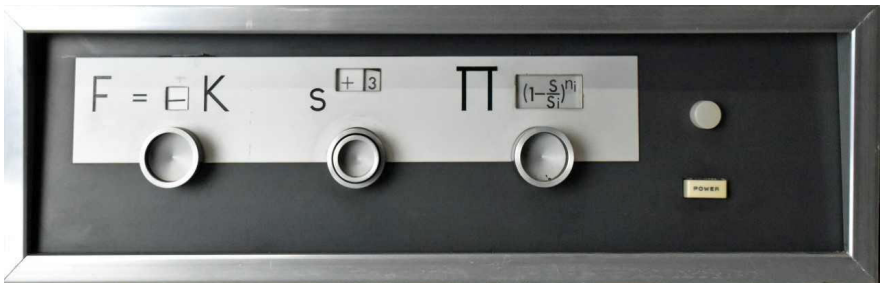


**Figure 4.** *Main control panel for the basic settings of the machine*

In the middle part of the machine (Figure 5), we find the plotting area with the control bar. To the left of the plotting area we see two sliders (potentiometers) marked K and angle(s). To the right of the plotting area we find two sliders marked |F| and angle(F). Please note the logarithmic scales on some of these sliders and the logarithmic scale on the paper spanning four decades on the X-axis. The vertical (Y) movement of the control bar may be coupled to one of the sliders. The horizontal (X) movement of the control bar is always coupled to s. The precise use of the control bar and the sliders depends upon the calculation to be done and cannot be detailed here.

Two null-balance meters, the s-scale and some switches are located in the panel shown in Figure 6. The use of the null-balance meters will be explained later.


**Figure 5.** *The plotting area of the Esiac - 10*

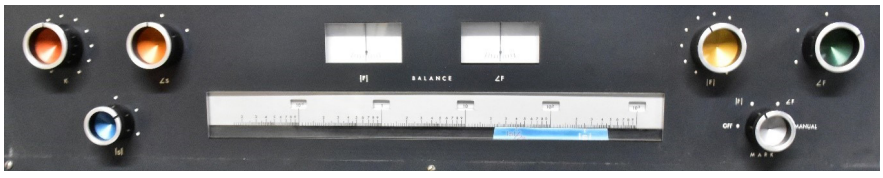


**Figure 6.** *The null-meters, the s-scale and various controls*

$$F(s) = K_1\, s^{n_0}\, \frac{(s-s_1)^{n_1}(s-s_3)^{n_3}\ldots}{(s-s_2)^{n_2}(s-s_4)^{n_4}\ldots} \quad \text{where } K_1 = \frac{a_c}{b_d}$$

[1] In the alternate factoring, we will find the above equation.

To the left and to the right side of the machine there are two grey areas. These areas are two sheets of two dimensional uniform resistance paper. On the left side the magnitude sheet; on the right side the phase sheet. Figure 7 shows how probes sensing the voltage on the phase sheet are coupled to either the zero or the pole bus bar. These probes are clamped to a moving frame with their tips sliding on the sheets. The probe clamping screw contains a small capacitor representing the exponent $n_i$. The moving frame can be considered as a coordinate system relative to which the centre of the sheets corresponds to the reading of the |s| and angle(s) scales. The frame is constrained to move in translation only, in the manner of a drafting machine, and the |s| and angle(s) scales are permanently coupled to its motion.

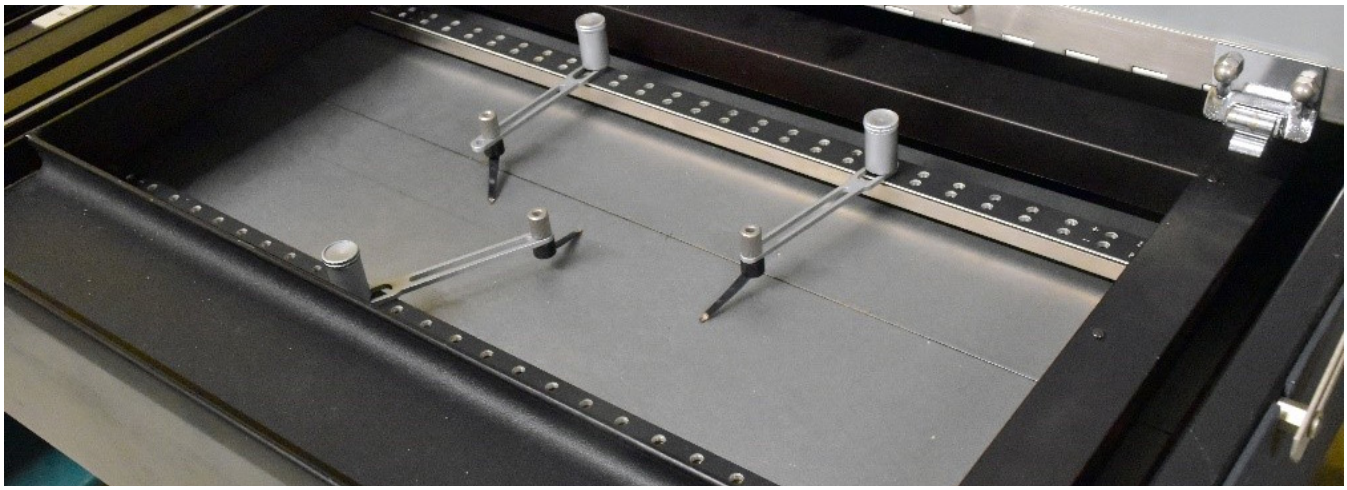

**Figure 7.** *The phase sheet containing three probes*

**Une Pièce de Résistance**

The publication by Sidney Darlington [8] describes how potential analogue planes have been used around 1960 to develop active networks. The important result of the potential analogue planes theory states the following: When electric current flows in a uniform layer or sheet of resistive material, the voltage contours (*equipotential lines*) and the *current streamlines* obey the same geometric laws as the *real* and *imaginary* components of analytic functions of a complex variable.

Complex variables, as present in our calculations, can thus be represented by voltages and currents in an isotropic uniform sheet of resistive material. The sheet material used in the ESIAC is so-called Teledeltos paper [9], which is visible in Figure 7.

Instead of reproducing the potential plane theory, we will suffice here with a simplified example. In Figure 8 we have a two dimensional resistance sheet where a current is flowing into the sheet at a point called a sink and (the same) current is flowing out of the sheet at a point called a source. Because of the voltage difference between the sink and the source, a current will flow (the green current streamlines) and an electric field will be present (the *equipotential lines* perpendicular to the *current streamlines*). The value of the electric field on any position on the surface can be measured by moving a voltage-sensing probe over the surface.

Please note that it is not possible to measure the current streamlines easily.

**Measuring the current stream lines; Introducing dual networks**

As said before, it is not possible to measure the current streamlines using a voltage probe. To resolve this problem, an old theorem of electrical theory is used in the ESIAC: Dual Networks (see Figure 9 and [11]). In a dual network transformation, a mesh is converted into a node, a resistor into a conductance, a voltage source into a current source and a connection is converted into an open circuit (cut). Figure 10 gives a step-by-step transformation from a Y-circuit containing three inductors to a network containing three capacitors in a delta configuration. Using the duality principle one can thus convert a current measurement into a voltage measurement such that we can measure the phase of equation, angle(F).

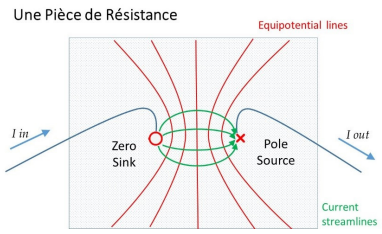


**Figure 8.** *Two-dimensional resistance sheet with a sink and a source*

| Element | Element |
|---|---|
| Electrical resistance | Conductance |
| Inductance | Capacitance |
| Switch Closed (connection) | Switch Open (isolation) |
| Mesh | Node |

**Figure 9.** *Dual network transformation*

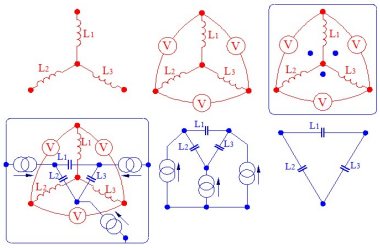

**Figure 10.** *Calculating the dual network - step by step*

The duality principle allows us to interchange equipotential lines and current streamlines. Figure 11 gives an explanation for this phenomenon. To explain this, we return to the s-plane. In the same figure we introduce the finiteness needed to make this principle a workable solution for a measuring instrument. This approximation is allowed when practical sources and sinks use only a small part of the conducting paper.

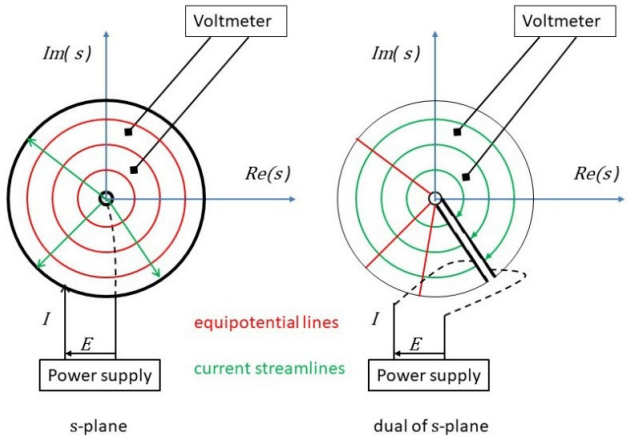


**Figure 11.** *Left hand side: normal s-plane; right-hand: side the dual of the s-plane*

In the normal s-plane (lhs) the voltage source inserts a current from the source formed by an outer conducting ring into the paper. This current flows to the sink formed by the small inner ring. The reader should study the forms of the *equipotential lines* and the *current streamlines*. In the dual of the s-plane (rhs) we want to interchange the *equipotential lines* and the *current streamlines*. We need to make an isolating cut in the dual of the s-plane. The reader should again study the forms of both lines. A voltmeter with two probes can be used to measure the potential between any two points on the s-plane. This cut is made always along *current streamlines* connecting the source and the sink. Whereas the mechanism is clear, it is not easy to extend this to multiple sources and sinks. For each new pair of sources and sinks we would have to make new cuts, which is highly impractical (see [2] for more details).

**The reciprocity theorem**

The Reciprocity Theorem [10], an old mechanism in electrical engineering, can resolve this problem.

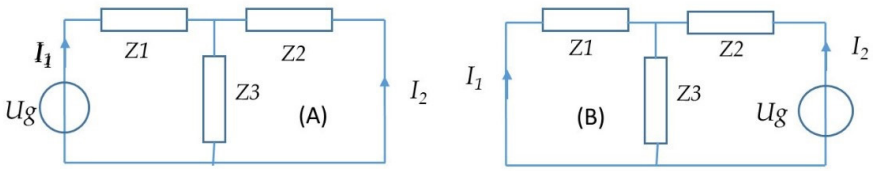


**Figure 12.** *The reciprocity theorem; a simple example*

In Figure 12 we notice on the left-hand side a simple T-network and a voltage source $U_g$ Two currents $I_1$ and $I_2$ are flowing (System A). By using the Kirchhoff laws one may calculate that it is possible to move the voltage source to another branch of the circuit without any changes in the both currents (System B). The Reciprocity Theorem generalises this result for many voltage sources as follows:

System A which loads currents $I_{n,m}$ in or out at points $s = s_{n,m}$ and were one measures the voltage $V_s$ at single point s may be replaced by System B which loads a single current $i_s$ in or out at point s, and the voltages $V_{n,m}$ are measured at the points $s_{n,m}$. A bit more abstractly, we find the following formula:

$$\sum_{n}^{m} i_{n,m} V_s = \sum_{n}^{m} V_{n,m} \; i_s$$

In this way, we are able to replace the set-up with many poles, many zeros and one sensor, by an equivalent network containing a single entry and exit point for the current and a sensor for each of the zeros and poles. That is precisely the set-up shown in figures 8 and 13.

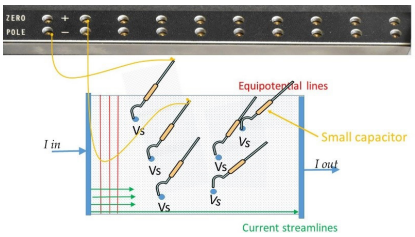


**Figure 13.** *The result of using the reciprocity theorem*

Now there is one more aspect to take care of: the necessity of the logarithmic scales. Without much explanation, we give the transformation to the log s scale on the magnitude sheet shown in Figure 14.

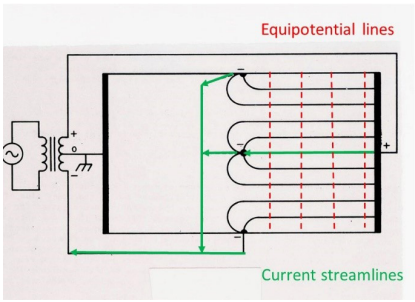


**Figure 14.** *Introducing the log s scale on the magnitude sheet*

Figure 15 shows the complete set-up of both the magnitude and the phase sheets. One can see that a connection in the magnitude sheet corresponds to an open circuit (cut) in the phase sheet etc. It should also be noted that the phase sheet consists of two parts. When measuring phase, one often needs more than a full phase circle and therefore each of the two halves of the phase sheet covers 360. Also, notice the logarithmic form introduced into the phase sheet.

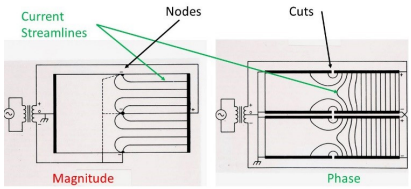


**Figure 15.** *Magnitude and phase sheet of the ESIAC*

**The electronics details**

Figure 16 shows the block diagram of the electronics for the magnitude sheet. First of all, it must be stated that the machine works on alternating current with a frequency of 50 or 60 Hertz. From the block diagram, one may notice that there are two (sets of) probes on the sheet in this example. A (zero) probe is connected to the zeros bus bar; a pole probe is connected to the poles bus bar. Both bus bars are connected to a differential transformer effectively taking the difference of both signals in accordance with formulas given earlier. Additionally, the signal $n_0 \log|s|$ is added to the zeros bus bar and the signal $\log|F| - \log|K|$ is added to the poles bus bar. These signals are generated by the potentiometers next to the plotter. This plotter is by no means an automatic instrument as we are nowadays used to. During a measurement experiment, the user manually operates these potentiometers and the control bar to obtain a null on the balance meters indicating a proper point for plotting has been reached. A similar block diagram exists for the phase-part. Due to space restrictions, this cannot be elaborated here.

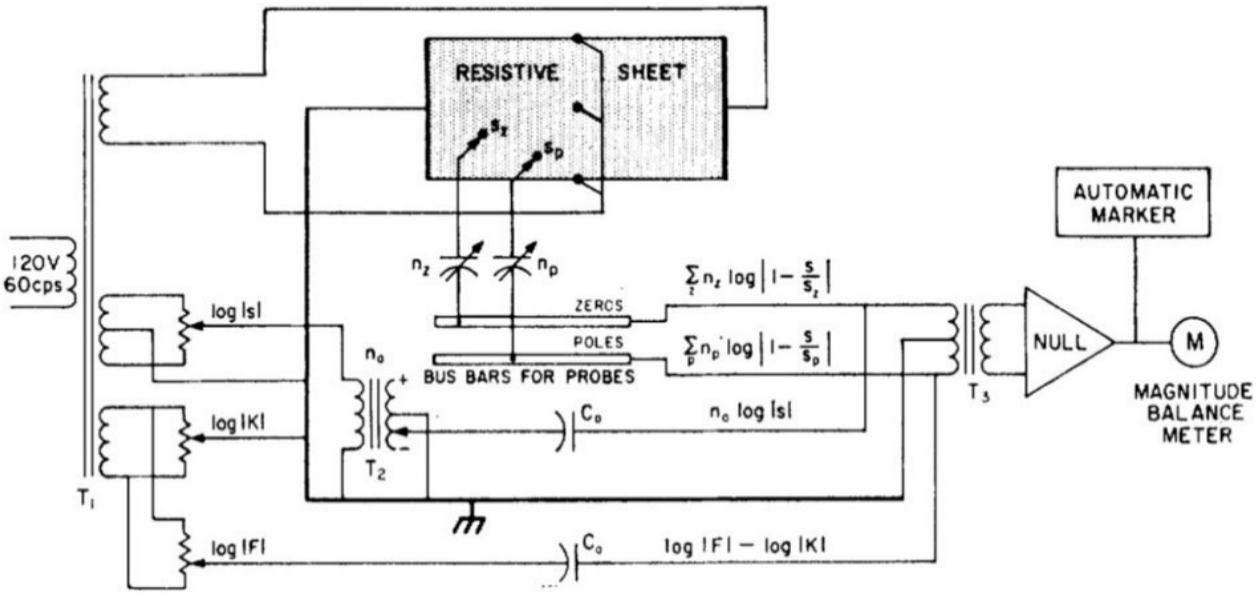


**Figure 16.** *Block diagram of the magnitude part of the electronics*

In Figure 17 the very modest electronic circuits in the ESIAC are shown. There are two sets of amplifiers (magnitude and phase), some synchronous detectors and a special circuit to take care of phase shifts greater than 3600. The amplifiers are built-up using germanium transistors equivalent to the AC127 as used in Europe.

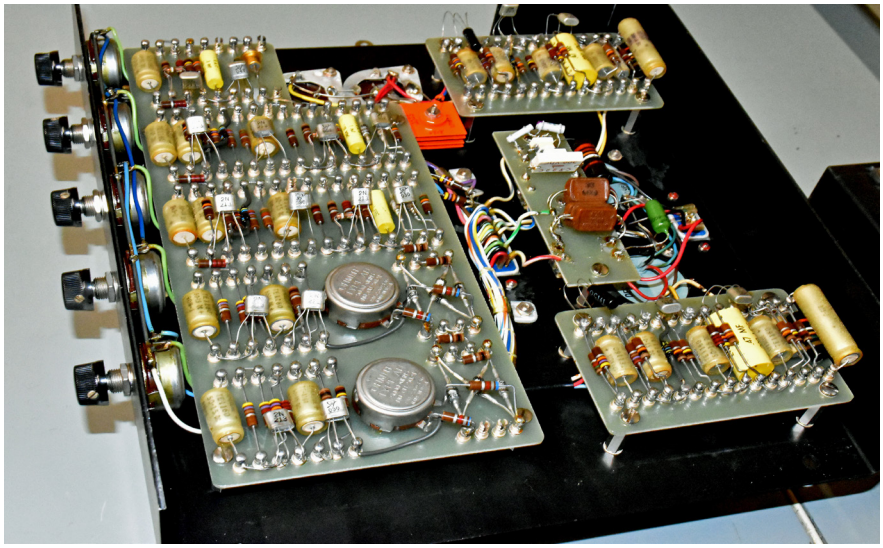

**Figure 17.** *The electronic circuits of the ESIAC*

**Conclusion**

The ESIAC-10 algebraic computer stands at the intersection of control technology (Bode plots, root-locus plots), theoretical electrical engineering (reciprocity theorem, dual networks) and applied electronics. The machine has been in use at the former electronics department of the TU Delft to study the principles and use of Bode-diagrams and root-locus plots; at that time a new subject developed in the area of control engineering. Apart from the above mentioned purposes of the machine, the ESIAC can be helpful with the factorization of polynomials and residue calculations. The accuracy of the electrical components of the machine is stated to be better than 0.1%. The main source of inaccuracy is the Teledeltos paper which has an accuracy of about 2.5 mm. In [3] it is promised that better resistance sheets

are on their way.

This article is based upon a presentation about the principles of the ESIAC-10 algebraic computer given by the first author in October 2021. Currently, we are trying to revive the machine. We retrieved the original service manual [12] and using that, we were able to find a mechanical problem in the machine. Having resolved that problem with the help of other volunteers, we are now striving to bring the machine into working order again. Should we succeed, we will be able to do network calculations such as Bode plots, root-locus plots, transfer functions and residue calculations of dynamic systems in the way envisaged by prof. Huydts around 1965.

The authors want to thank Bernhard Hoenders, Loek van Schie and Otto Rompelman for their help in preparing this material.

**Authors:**

**Kees Pronk**

**Piet Trimp**

*(EEMCS Historic Collection)*

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# PATS Indoor Drones

## Fast and accurate detection of pest insects in your crops

*Joëlle Holman*

An extraordinary invention often needs a complete plan to actually work out, but there are also exceptions. This idea was conceived in 2016 at a coffee machine at the TU Delft. Everyone is familiar with it; those warm summer nights where you toss and turn from the heat all night. When you finally fall asleep, the buzz of the biggest night disruptor starts: the mosquito!

The brothers Bram and Sjoerd Tijmons, together with Kevin van Hecke, are the driving forces behind PATS. Sjoerd and Kevin had a bad night of sleep due to the annoying buzzing of mosquitoes. They both worked at the drone lab (MAVLab) of the TU Delft, where they developed all kinds of drones, which ranged from very small to relatively big, and they all had the ability to perform autonomous tasks, both in indoor and outdoor settings. So why not develop a drone that hunts mosquitoes? It started with a simple toy drone of 4x4 centimeters, which the two researchers tinkered with and what has now become our “mechanical bat”.

Kevin van Hecke was a member at the ETV and has been able to carry out many different projects during his education at TU Delft. For example, he made a final assignment for MIT Space Systems Laboratory, where he, together with a small team, designed a drone (Sphere) that could navigate itself, using only a camera, inside the International Space Station (ISS). During his internship at the MAVLab, he also designed hydrogen-powered drones for Maritime Operations that can be deployed at sea. In addition, he is also one of the organizers of DroneClash, where According to Kevin, this is very important for the development of the acceptance of drones. It is how he made his way into the drone world and today the proud CTO of PATS.

Even though it’s a long way from the bedroom to the greenhouse, insect control can be applied in both environments. It soon became clear that

**Figure 1.** *PATS drone flying in a greenhouse*

greenhouse horticulture also suffers from various pest insects. We found out that these were not mosquitoes, but moths! The offspring of moths, caterpillars, are little monsters and rapidly cause damage to crops. Farmers try to control them with insecticides to minimize damages and crop losses. Now more than five years later, the company focuses entirely on pest insects in various greenhouses around the world. It may not sound special, but what if it can be done in a sustainable way? That is what makes PATS so unique. The drones are programmed in such a way that they collide with the moth in air and eliminate the moths through the impact of the small propellers, PATS! We do this with stationary cameras that through vision are able to detect and track the insect. Our software then classifies the insect species, and when labeled as a moth we predict its flightpath. When a succesful interception strategy is established, which is a matter of milliseconds, the camera system communicates with and controls the drone and launches it from its pad into the direction of the moth. During its flight it continuously updates the interception strategy, as the moth is moving through the image. The drone eventually collides with the insect, shredding it with its propellers. It takes a maximum of 2 seconds between the first detection of the insect and the collision between the drone and insect. Imagine how fast you need to duck when it comes

your way! After the drone finishes its mission, it returns to its pad and lands precisely to recharge the drone on this platform. This is a continuous process that keeps the drones charged at any time, realizing a fully autonomous drone system or better, fully


**Figure 2.** *Stationary camera that detects and tracks moths inside the greenhouse*

autonomous insect control platform. Note that our drones are very small (7x7 cm) and lightweight (30 grams), as we need them to be agile and perform fast interceptions. In some cases we measured a 5g acceleration! We also decided to take all the intelligence of the drones, and make this part of the stationary and study cameras. This all contributes to reducing the weight of the drones themselves, and to make the drones very cost-effective in itself. These insects are increasingly resistant to insecticides previously used in greenhouses. That is why the PATS drones are not only more effective, but also a more sustainable solution that truly brings the change long needed in horticulture. We are currently working on the roll out of the monitoring system and our drones. The base station PATS-C automates pest monitoring by small cameras attached to the greenhouse pole. The system consists of an infrared camera that detects the moths at night. As moths are brownish or gray in color, we need to use an infrared light beam that illuminates the insects such that the cameras can register these insects in the dark. The cameras monitor the greenhouse, the crop and provide a picture of the pest pressure. The system measures all flight movements, flight tracks and insect and flight characteristics of the adults and uses this to visualize the population development. We also use these characteristics to label insects, and train our models such that identification is automated, and to separate harmful from beneficial insects. This way we can quickly answer two questions: Is the pest present and how is the population developing? This information is shared with the customer through a digital dashboard that they use in their insect control strategy. Faster and accurate signaling is necessary for an effective approach with crop protection solutions. This way growers experience less crop damage

*"PATS is on a mission to revolutionize insect control in horticulture"*

and spend less time on insect control. Our drone PATS-X is placed on a small launchpad. This is the base for the drone, from here the drone will launch itself at lightning speed if an insect is spotted. With its mini propellers, it eliminates the moth and then flies back to its launchpad, all autonomously. The complete process of this may take less than ten seconds. The drone fits in the palm of your hand and weighs barely thirty grams. Our drone doesn't do much different than what bats do. We imitate nature and that is by far the most sustainable method to combat these small monsters. With automated monitoring we help farmers to reduce their crop loss, insecticide use and labor intensity.


**Figure 3.** *Moths being illuminated by infrared light (left) and the moths being tracked by the software (right)*

# Communication at TU Delft

## An interview with dr. Jorge Martinez and ir. Egbert Bol

*Kees Broek, Arman van Dijk and Arthur de Groot*

Delft University of Technology consistently ranks among the best technical universities in the world. In order to uphold and improve the quality that supports this status it is essential that the educational environment is constantly adapted in such a way that students can perform as optimally as possible. The key to knowing how and what to adapt is the facilitation of proper communication between students and professors through a transparent feedback system. Recently, this subject became more relevant than ever with the sudden spread of COVID-19. Among other things, the educational sector had to deal with the fact that physical education was no longer feasible. Drastic changes had to be made over the course of just a few days and more would follow in the coming weeks and months. During this period, it became even more evident that transparency from both sides was vital to sustaining the quality of education.

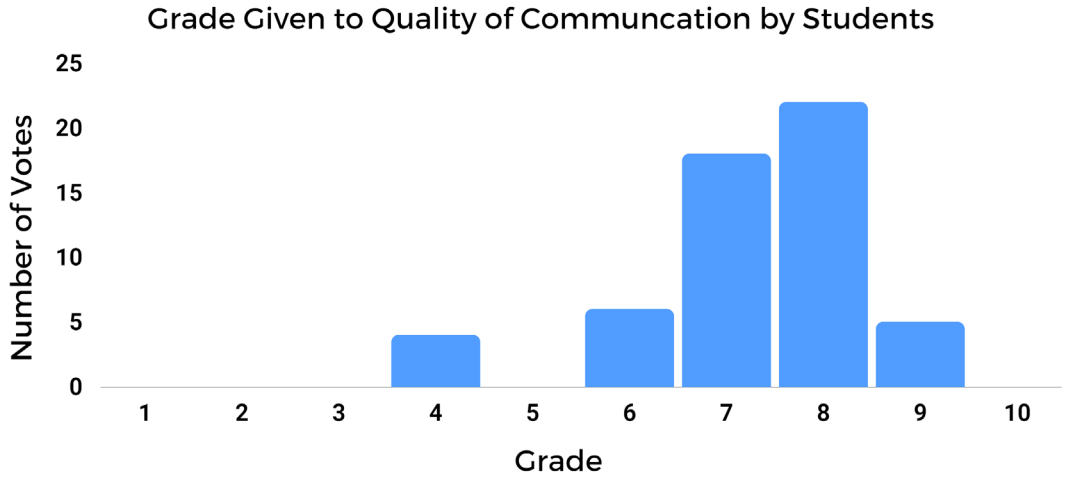
Anti-COVID measures have all but disappeared, and so have the majority of drastic changes with regard to education. Certain things, however, have remained, such as the widespread integration of digital communication platforms. These platforms have proven to be very beneficial, especially due to the fact that they are flexible in the ways that the platforms can be used and in the ways that they can be set up. This has also led to these platforms being set up in such a way that the gathering of important information, such as assignment requirements, might differ significantly across multiple platforms, even within the same educational program. Similarly, feedback is gathered in a multitude of different ways. Many students do not partake in related events, or they might not even know of their existence.

These circumstances have led to a small-scale investigation among BSc students within the Electrical Engineering program in the form of a survey. The resulting responses have been used in a discussion with dr. Jorge Martinez and ir. Egbert Bol in an attempt to inquire about the ins and outs of the feedback system and facilitate more transparency among both students and professors.

**Student Experience**

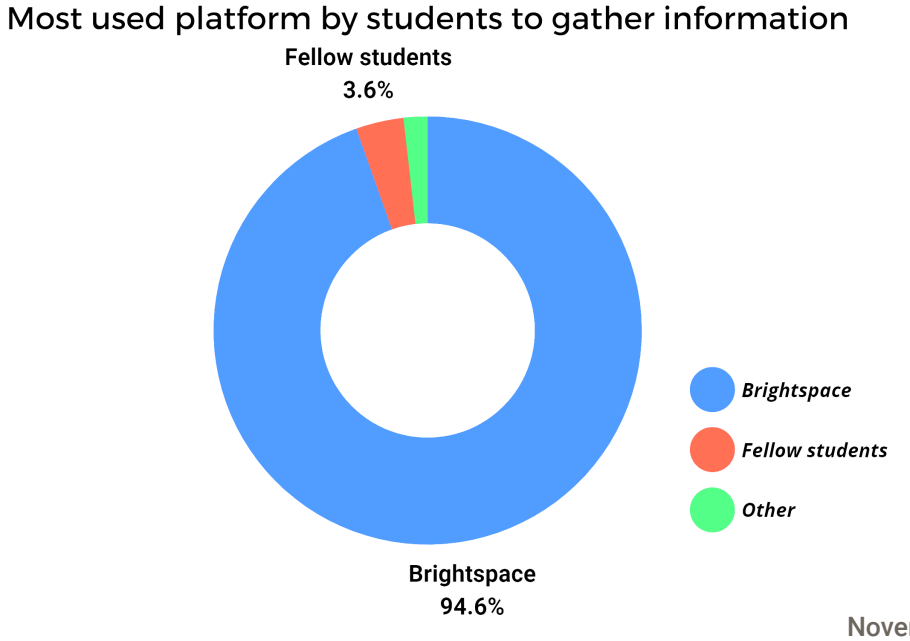
Although there is always room for improvement, and communication at Delft University of Technology is not an exception to this rule, it is important to note that far out most of the students are content with its current state. On average, the students grade the communication at a 7.3 out of 10 and 93% of students grade the communication as sufficient, but how can the student experience be improved even further?

The TU Delft supplies information through several platforms. This is mainly done through Brightspace, Webmail, the Study Guide, external course websites, live lectures and Collegerama. It is not surprising that, according to the results from the form presented in the figure on the next page , the most used platform regarding course information is Brightspace, since that is what the platform is made for.




Brightspace is a central location for all course material ranging from important dates, to lecture slides, to online meeting links and much more. It has many functionalities to facilitate the spread of information, such as a notification box for course announcements and student discussion forums. Naturally, it is of major importance to provide sufficient structure for such a platform.

The structure provided by the general layout of Brightspace is very well received among students. In addition to the course specific feedback, “Good” and “Fine” are common responses from students when they are asked about Brightspace in general. The results show that the provided digital infrastructure appeals to students but that miscommunication or inefficient communication is often course specific, but how can these specific courses be improved?



**The current feedback system**

The only way to improve courses and course specific communication of information is through a solid feedback system in which both the educators and students are represented. Students do notice the feedback system; it is hard to miss when every course sends a separate survey through Webmail. Furthermore, students can provide more in-depth feedback during 'College Response Group Lunches (CRG Lunches) and the board of the Electrical Engineering study association (ETV) has one commissioner of education. However, the system still has many imperfections.

Many students are unaware of what happens with the feedback that they give and they might feel that their time spent on giving feedback is wasted, because they do not see the effects.
This became apparent through the following quotes: "I have no clue what they do with it.", "They do nothing with your feedback", "I am not sure about how effective it is." The general sentiment is unfortunate considering that there actually is a functioning feedback system that reaches beyond the vision of students.

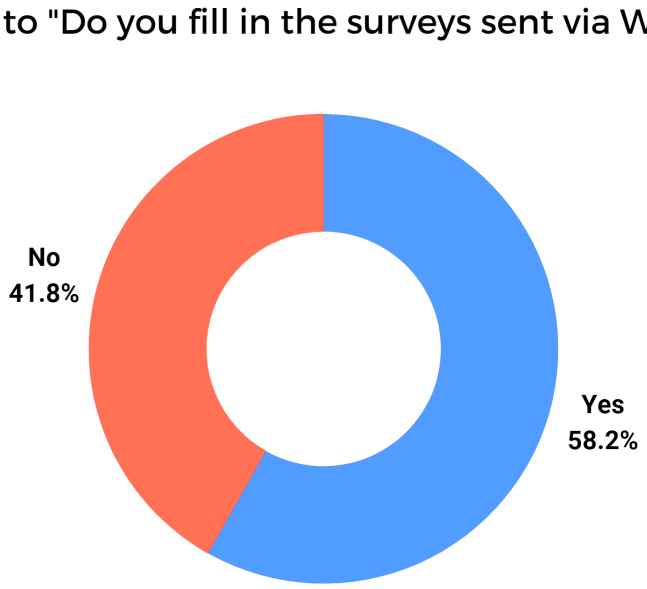
Currently, feedback and quality control is implemented according to an obligatory Plan Do Check Act cycle (PDCA). First, new education ideas are planned and implemented. Then, feedback is collected and action is taken if necessary. This cycle repeats every year and consists of a strict protocol that requires all involved parties to provide a signed reaction to the feedback. The process of properly following the procedure is checked and if regulations are broken or reactions are missing action is taken. This was described by ir. Bol as being 'inescapable'.

How does one convince students that their feedback is valuable and is actively considered in improving the study program? An option could be to make the documents and process 100% transparent to show what is done with the feedback. However, according to Jorge and Egbert, this comes with a lot of implications. "How honest can someone react to feedback when they know there is going to be a public listening?", Jorge stated. He is in favour of transparency but it should not compromise the process. He believes that the process could be made transparent for the Facultaire Studentenraad (FSR), so that they have insight into the process as well while dealing with this information in a responsible way. Egbert Bol states that he thinks publicly sharing the whole process would reduce the effectiveness of the feedback system: "Then we will get artificially desirable answers and think: 'What does that deliver?', I would not prefer that, but I do think that in some way or another we need to communicate to students what we have changed based on the feedback, for example at the beginning of a course.". "There has to be a certain trust that we deal with feedback with integrity, so we have to be transparent, but we should also communicate that better."

**EVASYS Lack of Response**

One of the ways the aforementioned feedback is collected is through Evasys survey. These surveys are sent to students via their university mail after a course is finished. They can then provide feedback on the quality of the course, the professor(s) teaching the course and teaching assistants to name a few examples. The professors responsible for the course can then use this feedback to improve their course in the future. Evasys surveys are the same over all faculties of the TUDelft, which allows for campus-wide comparison of course qualities; all in all, an amazing tool to process feedback.

There is however a glaring issue with these surveys, namely that they are rarely filled in by students. According to the survey, only 58% of students fill in the Evasys surveys, which can be seen in the figure above. When asked how often they fill in these surveys, most responses indicate students only fill in 30-40% of all the surveys they receive. This feedback system relies on survey responses, which means that with a low amount of responses the entire system is much less effective. Furthermore, Egbert has noted that some professors might pay less attention to survey responses when there is a low number of respondents.



Proper use of these surveys could result in a large improvement of the quality of courses, so why do students not fill them in more? There are numerous reasons as to why these surveys are filled in as little as they are now. Students mentioned reasons such as the surveys being long and tedious to fill in, only filling in the surveys when they had strong opinions about the course and the amount of surveys received are too plentiful. These reasons are all strengthened by the lack of knowledge students have over what is done with the feedback they give.

Egbert and Jorge hypothesised that the low amount of responses is due to the fact that professors and the university in general does not place enough emphasis on the importance of these surveys, leaving students confused about their actual purpose. Egbert also said: "It is very boring to fill in such a long and monotonous survey, especially when you're in the mindset of 'What am I doing this for?' "

There is a large amount of untapped potential in these surveys due to the lack of responses. Some measures need to be taken in order for more students to give their feedback about these courses and improve the quality of their study programmes. One of these measures which could prove very effective is to stress the importance of these surveys to students from the very start of their bachelor programme. According to Jorge, the number of responses is much higher when a professor explains the importances of these Evasys surveys to their students.

Giving students time to fill in surveys during instructions or lecture s near the end of the course also proves to be an effective method to generate responses. Egbert gives time to students to fill in the Evasys survey after the EPO-1 and says that there is "no other course with such a high amount of responses". Jorge also mentioned another example, where during a lecture he presented the students with a survey and a large amount of these students filled in the form.

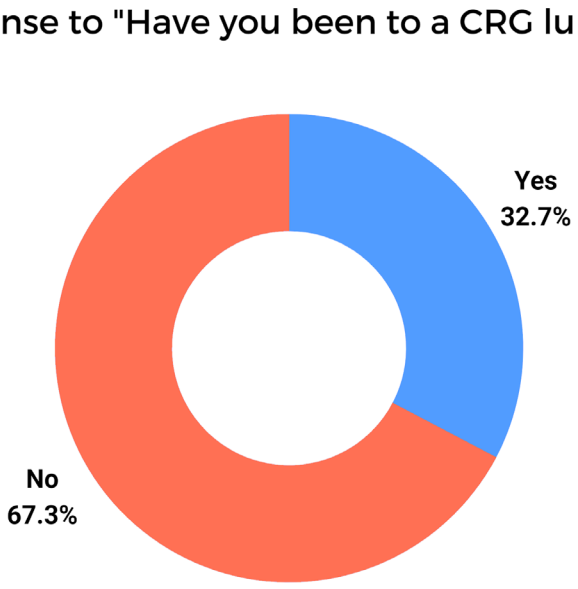
**CRG Lunch**

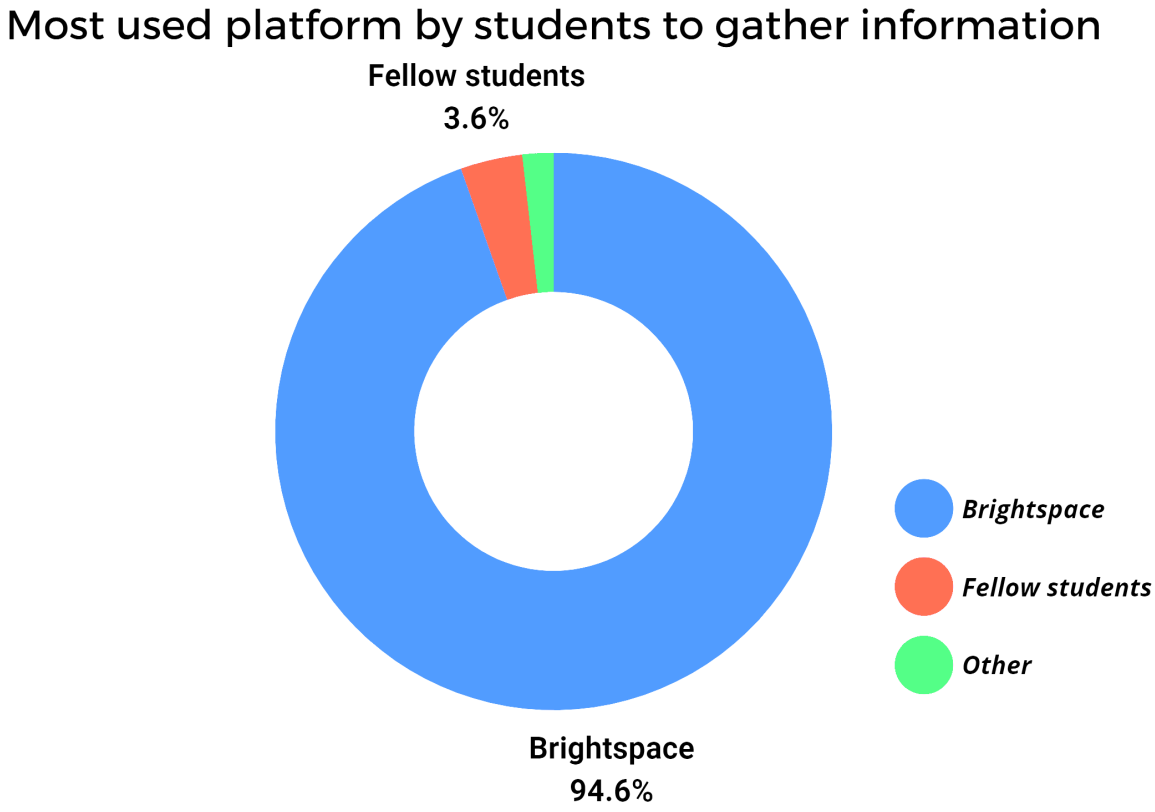
CRG Lunches are a powerful tool in collecting feedback about specific courses, the general studibility of a quarter and how well the taught subjects fit into the Electrical Engineering bachelor programme. It is organised by the Commissioner of Education from the ETV and free lunch is provided to students and the attending staff (Study Advisor and an associate of quality assurance). This setting creates an environment for more personal and specific feedback and allows discussions to exist which makes the feedback easier to understand and digest.

To get the most out of these lunches a sufficient number of people should be attending, which sadly was and sometimes still is not the case. The ETV has attempted to solve this problem a few years ago by introducing a new committee: the EvaCie. This committee's function is mainly to facilitate feedback and increase the attendance rates of the CRGs, but are there no other ways to do this?

From the form it follows that many students do not attend CRGs, since they are not sufficiently informed. The forms showed that 20% of the students have not heard of CRG Lunches and 67.3% of students have never attended. For this group, one of the most occuring reasons to not attend also showed that many do not understand what they are for and what a CRG Lunch looks like: "Didn't know of the existence", "I am not informed about how it looks like", " I went once because I was invited".

Currently, the announcements regarding CRGs are made in the Electrical Engineering groups chats by the ETV. They often only contain a date and time and are sent a few days before the actual CRG. More extensive, explanatory and enthusiastic announcements are expected to increase overall attendance. It is very likely that students will appreciate the CRGs more if they know why they are important and what they look like. Also, webmail could be used to reach those who miss the messages from the group chats.





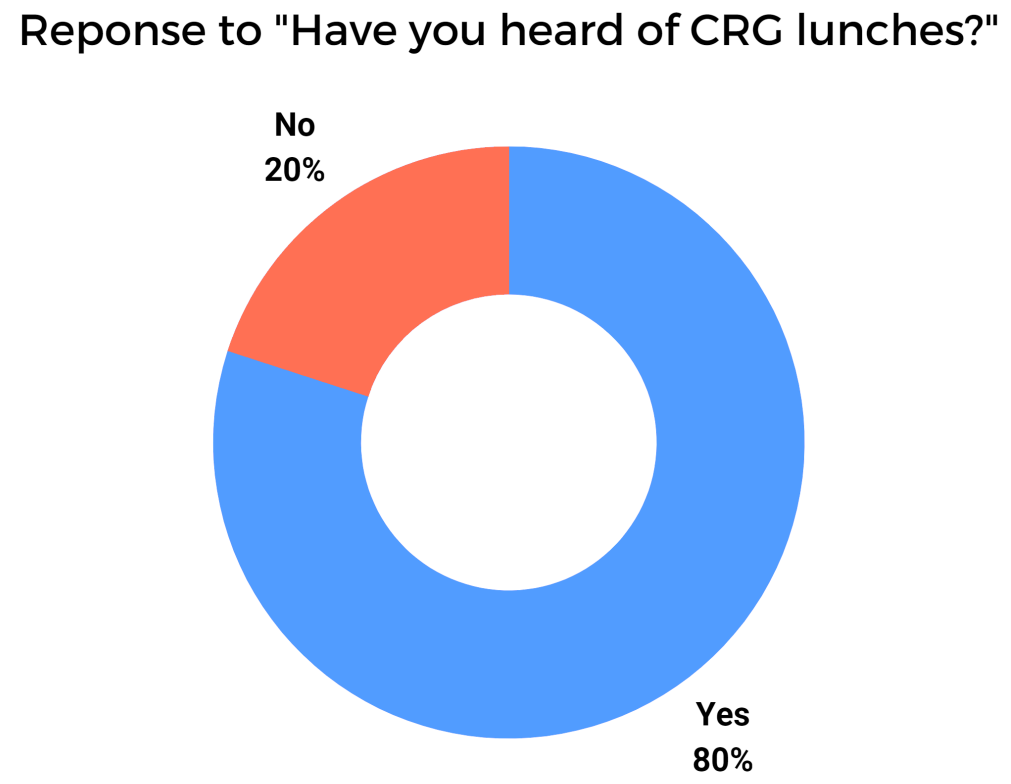

**Inconsistent Tools**

Communication between students and professors is not just about providing feedback, there is also the aspect of course information. Brightspace is the most commonly used tool for professors to communicate and share information about their course to students and it is also an effective tool; about 95% of all EE students use Brightspace as their main source of information which can be seen in the figure below.

There are some problems students experience while using Brightspace however, and that is the inconsistency in their layouts. Some students have responded that, at times, it can be quite difficult to find the information they need on Brightspace pages and that it is especially inconvenient that every course has its own, slightly different structure. While this problem is not experienced by all students, it would definitely help to create a universal page layout, in order to have every course's Brightspace page be structured in a similar way.

With the advent of online education, in large part due to the Covid-19 pandemic, new tools and platforms for communication were discovered and some are still being used. MS Teams and Zoom are two platforms that are still commonly used for online education. While these tools are useful for their respective uses, the problem of inconsistency between courses arises once more. Brightspace has been in use for quite a few years and professors have had the chance to get more experience with the platform and feedback to improve their layouts however, the new tools such as Teams have not (yet) had this time.

These issues could be solved by introducing a template or some stricter guidelines for professors to follow when designing their Brightspace or Teams environments. It could very well be worth the effort, according to Jorge, as students would only have to learn this template once during their time at the university. Using different platforms would also be no issue anymore, as the same template is used. It is however a difficult period of time to implement such a change. Jorge recalled the advent of smartphones and how people were not accustomed to using these devices. Nowadays mostly everyone knows how to use a smartphone, partly because most smartphones now use the same layout and share a lot of functionality. Similarly, a period of time is needed to experiment with templates for designing Brightspace pages, in order to find the one that works best.




**Going Forward**

The events and circumstances that initiated the creation of this article might have suggested that students would not be satisfied with the quality of the general communication at the university. Most students were actually relatively content with how everything is being organised and set up, even though the list of complaints was anything but short.

The majority of the problems that are related to the feedback system can be dealt with in a way that sounds rather simple on paper, but will take some genuine effort to accomplish. Most importantly, the facilitation of transparent communication in both directions should be emphasised. This could manifest in students encouraging each other to attend feedback sessions, fill out surveys and approach educators more regularly. At the same time, it is of major importance that educators make themselves easily approachable for simple, yet serious, matters. It would also be beneficial for educators to keep students updated on changes made to the courses. This would show that changes are being made with the feedback that is received, and what those changes are, hence improving the transparency.

A notable observation that resulted from the survey was the surprisingly large number of students that did not even know of the existence of feedback events, such as CRG lunches. Another reason for the low attendance rates was the lack of transparency regarding the processing and implementation of feedback. Additionally, most of the changes that are made in response to the given feedback are usually only realised after the majority of the students have already passed the course. Aside from being more easily approachable as an educator, it would be beneficial to discuss the feedback and the resulting changes more frequently, which could be easily done in the quarterly meetings for example. The importance of the feedback events should also be emphasised more, and information about these events should be shared more frequently through different media. Regarding the low completion rates of surveys, students should be given the opportunity to fill out these surveys during the active time of a course. A lecturer could reserve 10-15 minutes during a lecture, or students could fill out the survey during the lecture break. It has already been proven to be a legitimate strategy through its implementation in a first-year project course, which has higher completion rates than any other course in the bachelor of the study program.

This article is our contribution to improving the quality of education at the Delft University of Technology, and we sincerely hope that we have encouraged you, as the reader, to also do your part in improving the system, so that the following cohorts and generations can enjoy the best education that our university has to offer.

# Trolleybuses

## Here is why trolleybuses of the past will be the sustainable buses of the future

*Ibrahim Diab*

We live in a climate crisis. The shocking thing then, is that the transportation sector is a sector with growing emissions, rather than being a sector heading towards sustainability and carbon neutrality. As most of the renewable energy sources produce an electrical output, it is only logical that electrification of transportation is the efficient and sustainable way forward.

I am in my fourth and last year of my PhD, and my work for the past few years has been focused on trolleybuses. Trolleybuses run using electricity from overhead cables, like a tram does. They work best in hilly environments because their long periods of braking downhill generates electricity (regenerative braking) that can be shared with other buses that are accelerating uphill, without the need for a storage system in between. and that is also a main reason why we only see them in the Netherlands in the hilly city of Arnhem. In this article, I will go over some of the biggest reasons why this obvious path to sustainable electrical transport is sadly not being realized.

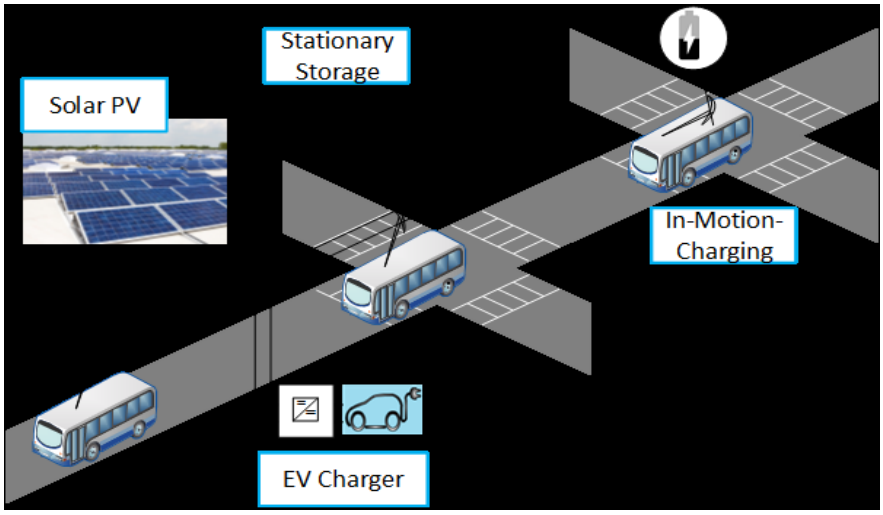



**Figure 1.** *The vision of the trolleybus of the future*

**Difference between various types of electric transport**

Transport networks with overhead cables, like trains and metros, have had their share of research and implemented storage and RES technologies. So why not trolleybuses? The key is in the stops. For a train, you can for the most part expect where it will stop and where it will accelerate: the train station! Of course, if you have ever been on a Dutch train, you know that you also stop somewhere along the tracks sometimes and get the famous "*We are stopped because of a red sign*" announcement. If you can choose where to put a storage system for a train or metro network, it is best to place it at the train station to maximize the recovery of the braking energy. For trolleybuses and trams, it is not as obvious, as these vehicles ride with the city traffic. It is almost unpredictable, really, where the trolleybus would brake, and when and where the trolleybus will be in a traffic jam. Naturally, people have not been bothering with this question, especially when you consider how little braking energy there is there to recover compared to a train once you account for all the losses. If you are thinking "well, why not put the storage on the bus itself?" then you're already thinking like a trolleybus operator!

You might even go further than that and think "*Well, why not just put a large battery on-board and forget about the overhead cables all together.*" Then, you're adopting the common ideology among today's transportation stakeholders.

The drive for sustainable urban bus transportation is undoubtedly spearheaded by the Battery Electric Bus (BEB). These are buses with massive batteries on-board that arecharged overnight, and then used to drive around all day. This sounds like a great idea, but the different emerging charging solutions nowadays confirm that people are already seeing the limitations of the BEB Firstly, the battery is hundreds of kilograms in weight, adding a traction load demand to the bus. This extra energy cost, however, is nothing in comparison to the battery cost itself, which is typically half of the cost of the BEB.

More charging solutions are emerging that allow you to reduce the battery size and compensating by charging more frequently. Examples of these methods are Opportunity Charging, Flash Charging, and Battery Swapping.

In Opportunity charging, the bus charges enough energy at the end of the line to go for a roundtrip or more (rather than a whole day's worth.) The main issue with this method, is the delay accumulation. If a bus arrives late, it must wait and charge fully before it can rejoin the service, rather than catching up for the lost time. By the end of the day, the accumulated delay can be of over an hour.

With Flash Charging, the bus charges in a flash. The flash being the few seconds when a bus is at a bus stop to let passengers out and in. This way, the bus can use a battery small enough to cover only the distance between chargers. However, this comes

at a high infrastructure cost, low route and re-routing flexibility, and a serious demand on the electricity grid (these chargers can take up to 600kW, which is equivalent to almost a thousand washing machines!).

Finally, Battery-Swapping is a solution mostly adopted in East Asian networks, where instead of a flash charge at the bus stop, a robot overhead quickly pops out the bus battery and replaces it with one that has been freshly charged (*check it out on YouTube!*). This has some of the advantages and disadvantages of the flash charging but can relieve the pulsating stress on the grid if the charging of the swapped batteries is done in an optimized manner.

An interesting method that has been gaining more momentum is the In-Motion-Charging (IMC) method. The IMC bus is a hybrid combination of a trolleybus and an e-bus: It has a battery large enough to move on battery-mode, but the battery is charged under long sections of overhead lines, called charging corridors. This method is the most promising for sustainable electrification among these bus solutions, and this is not a matter of costs and battery sizes only, but also a matter of electricity sources.

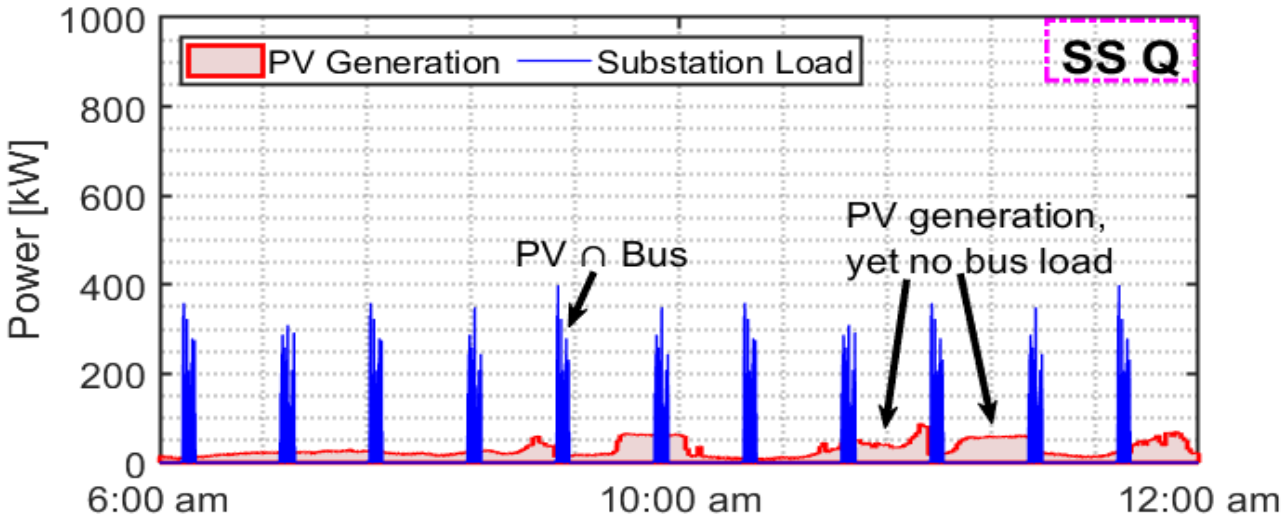



**Figure 2.** *Mismatch between PV generation and trolleybus power demand for a low traffic substation in Arnhem. The timetabling created periods of zero load at these substations, which is the biggest hurdle for RES integration*

**The sustainability of the future transport grid**

But why are electric buses not the easy sustainable future? An electrical system is only as sustainable as its electrical energy source. There is no point in driving an electrical car if the electricity to charge it is coming from a coal power plant. Creating a charging depot that is completely powered by intermittent renewables would require you to probably double your battery stock: you have to use the batteries charged yesterday to drive today. This brings you back to the basic form of electric buses with massive batteries on-board. Imagine the situation of a Flash Charger. The situation is hopeless with a PV system that is constantly wasting its power when there is no charging demand, or a massive storage system turning it into a battery-charging-batteries scenario with all its disadvantages of costs and inefficiencies. Me and my research group already show that a PV system can share only about 30% of its energy directly with a trolleybus in its vicinity, because of the mismatch between the intermittent PV generation and the bus scheduling.

Imagine now that you reduce the time a PV system meets a bus to the span of a flash charge, or an opportunity charging session. You will be left with almost no shared energy

**The non-technical challenges**

Finally, the obstacles for electrification of transportation are also non-technical. The first one is something I like to call the "*Diesel Mentality*". It is how bus stakeholders still approach the electrified bus network as a conventional diesel network, instead of opening up to (and factoring-in) all the possibilities of a smart, active electric grid. The trolleybus grid, or any catenary grid like trams, metros or trains, can be a multi-functional, active smart grid, integrating storage, renewables and Electric Vehicles (EV) chargers and such. EV chargers in themselves are a key advantage of these networks.

Currently, it can take you up to 6-8 years in Amsterdam to get an EV charger in your street because the grid is so congested and at its limit. Additionally, your EV charger will cost a lot of work, money, and permits in digging up streets and laying thick cables underground in residential areas. Meanwhile, the overhead cables of the transport grid capable of transporting hundreds of kWs of power are just sitting there most of the time when no public transport vehicle is around.

The synergy in connecting the EV chargers to these grids is not only in the cost sharing among the two systems, but it also offers the electrical base load to the transport grid that

was the bottleneck for the integration of renewables in it (the issue that the PV does not see a bus). This means lower costs, and more feasibility for sustainable solutions!

The second non-technical challenge is the licensing. There is a legal hurdle to EV chargers, that catenary operators face, stating that they cannot sell the energy from a catenary network (at a discounted rate) to third parties. There is a simple solution though: the EV charger can tell you how much energy it used, and discount that from their electricity bill. The problem is a contractual hurdle, and a consequence of this diesel mentality: they just never thought of this possibility, so currently all contracts forbid it! It is crucial to advocate these technologies to stakeholders before they re-write their contracts.

Finally, and even more seriously, there is the issue of "lifetimes". A municipality council is in charge for 4 years or so, a bus operator gets a contract for about 6 years, and the infrastructure lasts around 15 years. So who is going to take the burden of investing and implementing? A municipal council that wants to focus on certain projects this term, and avoid public backlash about hanging "ugly" wires around the city?

A bus operator that is not sure they would get the contract again and might end up with useless buses or selling them at a loss? A third-party entrepreneur that is there for leasing batteries and buses but needs to assure and be compensated for the quality of their fleet at the end of the operation? A bus manufacturing company that will come and install charging solutions only compatible with its buses and create a monopoly for its buses in that city?


**Figure 3.** *A trolleybus riding with the traffic in Genoa, Italy*

**Conclusion**

In conclusion, I would say the world of sustainable transportation needs as much technical work as non-technical work. People like me and my supervisors Dr. Gautham Ram Chandra Mouli and Prof. Pavol Bauer are working on the vision of the future, a multi-functional grid with IMC buses, renewables, storage, EV chargers and other base loads. On the other hand, people should be working on streamlining the tendering process between network operators, opening up to and facilitating collaborations between smart grid implementers (the EV charger operators should plan with the opportunity charger or catenary operators) and changing the mentality of both the population and the key stakeholders. Catenary systems are not an ugly thing of the past, they are the sustainable grids of the future!

# Energy Club

## Simplfying the energy transition puzzle

*Anusha Sheth*

**Figure 1**. *The board of 2022*

Fossil fuels accounted for 84.3 percent of global energy consumption in 2020. Despite the increasing growth of renewable energy production it still lags behind coal, oil, and gas who remain dominant in the global energy mix. What's more disparaging is we produce more each year and the overall fossil fuel output has surged in recent years. [1] More frequently sections of the world are experiencing significant heat waves [2] and others are facing water scarcity [3]. We can infer that the IPCC report "its code red for humanity" is accurate [4]. This brings up the question of what we can do to help reverse climate change? The best course of action is to find solutions that minimize carbon emissions.

As can be seen, the energy sector has the highest carbon emissions owing to fossil fuels [5], resulting in the need to accelerate the energy transition, a necessity to save today's society. But, what, exactly is an energy transition?

"The energy transition is a pathway toward transformation of the global energy sector from fossil-based to zero-carbon by the second half of this century." - IRENA

Energy transition is mainly defined by three D's - digitalisation, decarbonisation and decentralisation of the energy grid. Different solutions are being investigated, ranging from new renewable energy harvesting methods to better circuit designs. Utilizing new technologies, such as blockchain and artificial intelligence help make the grid more controllable and efficient. Other examples are finding new sources of energy generation such as airborne wind energy and working on new technology to store the energy. Even universities are focusing on educating students about it, as can be seen in TU Delft's 180th-anniversary lustrum celebration, whose theme is accelerating the energy transition.

From January 14th to June 9th, TU Delft is focusing on showcasing existing research, new initiatives, and laboratories, pushing to show itself as a frontrunner in the energy transition. This year, the student organization selected to support the topic and Lustrum is the TU Delft Energy Club. The Energy Club was created in 2009 with the goal of providing opportunities for anyone interested in sustainable energy. The 2022 board has established an updated goal of bridging the gap between students, industry, policymakers, and researchers in the field of energy. We plan on achieving this in many ways including hosting events, such as lunch lectures, excursions, and

**Figure 2.** *Total Energies presentation*

workshops with the finest in the energy industry.

The board kicked off the year by creating a brief series of lunch talks to showcase the research being done by the Energy Accelerator team. Some of the issues discussed were carbon removal, solar technology, and the need for storage in the energy transition. Furthermore, events were held to increase the exposure of Delft Energy Pillars (Powerweb Institute, Urban Energy Institute, Wind Energy Institute, E-refinery) by demonstrating their research to the students.

Aside from that, there have been excursions to learn about sustainable transportation (Hardt Hyperloop) and give students exposure to big companies while providing ample opportunity to network in industry. In Fig 3, during the Total energies event, we took the students to their hydrogen facility - where a talk on carbon capture, hydrogen storage and EV charging was given and a tour of their facility was a part of it as well.

Our goal for the second half of the year is to work on closing the gap even more by including additional departments in the energy transition. Currently, the majority of the energy club's members belong to EEMCS and TPM faculties and tracks related to energy. However, we hope to expand this by reaching out to students from IDE and other faculties to allow them to learn more about their role in the energy transition. We intend to do this by not just focusing on events, but also by establishing a community platform and clubhouse where like-minded students from other disciplines at TU Delft and from across the world may engage and share their ideas.

Apart from the technological difficulties, we believe that energy transition is also a societal problem. Today, women make up only 22% of the overall energy sector [6]. We want to enhance this figure and provide women with more opportunities in the energy industry. As a result, the Energy Club will highlight more women in our upcoming activities. For example, the international energy symposium is one of our largest events. This year, we aim to focus one of the symposium's subjects on women in the energy sector. In addition, we are preparing a special event for women's empowerment in November.

We also believe that, because climate change is such a critical issue, governments all over the globe should devote 100% of their attention to it and include it in every national strategy and plan. It is now challenging for customers to switch to green energy due to low gas and oil costs. Apart from the absence of subsidies and regulations to encourage renewable energy, scientists and researchers find it increasingly difficult to work on more effective renewable energy harvesting.

The field of the energy transition is not only challenging, but exciting at the same time, and as the Energy Club we strive to be the key facilitator in helping students who want to be a part of this transition by providing them the right opportunities and knowledge.

**Figure 3.** *Total Energy excursion*

**Figure 3.** *The KelpBlue event*

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1) https://ourworldindata.org/energy-mix#:~:text=Globally%20we%20get%20the%20largest,than%2080%25%20of%20energy%20consumption

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MAEVE®

AEROSPACE

# Are you ready for the challenge of your life?

## *Then lets push the boundaries of electric flight!*

*Advertorial*

*Maeve Aerospace*

**Aviation: blessing or curse?**
Being able to fly is one of the most important achievements of mankind of the past 100 years. Is it however, also an industry with huge CO2 emissions, that grows with 4% every year. If no action is taken, aviation will be responsible for 10% of all CO2 emissions worldwide, by 2040. That has to change!

Electric flight as a viable alternative
Battery technology has vastly improved over the past decade. From powering your phone, to electrification of nearly all road transport, and beyond. It is a matter of time until battery technology becomes good enough to power aircraft with increasing numbers of passengers. As battery technology further improves, aircraft range will also increase.

**Starting up**
Maeve Aerospace started in february of 2021 with a team of 10 aerospace engineers. Its aim: to find the boundaries of electric flight and deliver a first aircraft design. By November of last year, the team delivered what is now known as Maeve One: a 44-seat, all-electric aircraft capable of flying 550 km. To be launched before the end of the decade, Maeve One is zero-emission, 40% more silent and cheaper to operate compared to kerosene operated aircraft. Having closed its first multi-million investment round, Maeve Aerospace is currently ramping up the team.

Having offices at Yes!Delft, Maeve is a startup with a moonshot mission: to create aviation for a generation that wants to travel, not pollute."

**The road ahead**
Aircraft design generally follows a structured path. For an aircraft to be certified, it has to perform thousands of test flights. The preceding phase (referred to as 'Detail Design Phase') naturally invol ves delivery of flying prototypes. But before flight can take place, non-flying prototypes are constructed that will undergo rigorous testing, referred to as the Preliminary Design Phase.

However, it all starts with basic technology development. What is the architecture of an aviation grade battery pack? How is the power distribution of aircraft arranged in such a way, safety is ensured in every scenario imaginable? It's the Conceptual Design Phase. This is the phase where Maeve Aerospace now resides.

**From broad perspective to the smallest details**
From a very broad perspective, Maeve One is a 44-seat, all-electric aircraft with an intended range of 550 km. Being battery-electric, the take-off weight is considerably higher than normal at a target value of 45.000 kg. The battery system accounts for about 50% of the take-off weight, at 22.500 kg. Depending on battery energy density, approximately 6250 to 9200 kWh of battery capacity is planned. Take-off power in worse-case conditions is established at 9500 kW. Going a bit deeper, the Maeve engineering team is now establishing DC Voltage levels. Higher voltage implies less resistance losses, but higher insulation requirements and more difficult component selection, especially at voltages above 1200V DC. Another challenge is the fundamental design of a 9200 kWh battery system that has to perform in extreme conditions such as pressure loss, thermal runaway and crash situations. These fundamental challenges are to be tackled in the next 15 months.

**Join us!**
Maeve Aerospace is looking for the best and brightest engineers to solve world-class challenges. Are you interested in joining our ambitious team? Then contact us! We 'd love to hear from you and see if there is a fit.

Technolution

# $T^2 = (U+C \cdot n) \cdot (P+V)$

## De formule voor blije collega's en tevreden klanten

Als je ons vraagt hoe het is om te werken bij Technolution, hebben we daar een heel logisch antwoord op: $T^2 = (U+C \cdot n) \cdot (P+V)$

Want wij houden van formules, algoritmes en schema's. De formule staat voor: Typisch Technolution = unieke collega's die samen werken aan projecten die een vernieuwende blik verlangen. Deze formule zorgt voor blije collega's en tevreden klanten!

Word jij ook blij van deze formule, kijk dan op **technolution.com/formule**

Redefining **solutions**