Physics research at RVO-TNO during the early cold war

Teun Nooijen

Table of contents

Preface

Science, and more specifically physics within the context of society can be a curious thing. In the past, society has restricted developments in physics by for example initially rejecting the heliocentric model, but it can also spur on developments such as in the creation of the atomic bomb, which would have never been created as fast if there was no war going on at the time. Especially the latter case is interesting, since wars can have a very profound effect on scientific developments. The old saying goes '*Necessity is the mother of invention'*, and can you have more necessity than in times of war?

But especially in later times, another big factor for scientific developments was money. As our understanding of the world grew larger we needed better and more expensive technology to test our theories, and sometimes you cannot afford to spend money on research when there are battles to be fought. This is why the cold war is such an interesting war to look at. There were no actual battles fought, so money that would have been spent on that could partly be spent on research and development, but tensions were still at an all-time high. Both sides knew that at the flick of a button they could rain down hell upon another, and if they wanted any prospects of winning the war they knew they needed better technology and equipment to beat their opponent.

Especially in the U.S.A. obscene amounts of money were pumped into scientific development for warfare. The Manhattan project is of course world famous for being such a grand undertaking. Over the course of four years, it required the efforts of 150,000 people and over $2 billion was spent, which would translate to $29 billion in 2014.[1] Yet this was only the beginning, by 1957 the U.S.A. was already spending $5 billion annually on science research and development, which would be $42 billion in 2014.[2] Of course the situation was quite a bit different in Europe, having just been ravished by the Second World War they did not have much to spend in terms of research and development. This did not mean everything shut down though, sure it may have taken some time to get started again, but by the 1950s every country was very busy again with research & development, albeit on a much smaller scale than the U.S.A. and the Soviet Union.

In this thesis I will focus on the physics research and development done in the early cold war in the Netherlands. This because not a terrible lot has been written about this yet (whereas it has been with the U.S.A.). And because in the past the Netherlands had some very prominent physicists like Lorentz and van der Waals, but during the cold war no very big names or developments really came from the Netherlands, so it is interesting to see what did happen at the time. Plus the rise of digital computers made for a time with a lot of new technological possibilities. Specifically I will look at the physics done within the context of the cold war, by the so called RVO (National Defense Organization/*Rijks Verdedigings Organisatie*), which was a subsidiary of TNO (Netherlands Organization for Applied Scientific Research/*Nederlandse Organisatie voor Toegepast Natuurwetenschappelijk Onderzoek*), a non-profit organization that focuses on applied science.
The research done at RVO can be divided up into 4 types:

- Detection theory
- Telecommunications
- Information processing
- Operations research

I will be focusing on those four, broad areas. With detection theory, like the name suggest, it is all about the detection of objects. Mainly the detection of enemy vehicles, ships usually, as far away and as accurate as possible. Naturally in battle it is paramount to detect your opponent before they can detect you, so a lot of research and development was done to improve existing measuring applications and develop new methods of detection. Some important developments in this area were the use of infrared radiation to detect objects and the increasing use of semiconductors in detection equipment.

---

[1] Competing with the Soviets, Audra J. Wolfe, 2012, 10

[2] Competing with the Soviets, Audra J. Wolfe, 2012, 49

For telecommunications a lot of research was done into modulation. This is the altering of properties of a periodic waveform, so that it can be transmitted more easily. An example for this is the modulation of a analog lowpass signal, which then makes it possible for the new, modulated signal to be transmitted over a bandpass channel with a frequency, which was not possible for the original signal. This way signals which do not have the right frequency can still be transmitted over certain radio frequencies. Other big research topics were the usage of ultra high frequencies (UHF) to transmit signals. And transponders, which are devices that emit an identifying signal when they receive a signal, which is very useful for accurately identifying your own vehicles like helicopters and fighter jets.

Information processing was all about the rise of the digital computer, and how to integrate that in other areas of research. Such as the digital processing of radar information, and also the use of digital computing for fire-control systems, something in which RVO proved to be very innovative. I will also look at what ‘information’ actually is, how it was interpreted, and its curious relationship with thermodynamics.

Operations research was, just like information processing, a field of research that was very young, it only originated in the second world war. It is a method that uses mathematics to optimize decision making, so that the results are as efficient as possible. I will look at how it originated and what uses it had during the Second World War. And how RVO used it, which was by studying the fundamentals of game theory, which provided a deeper understanding of the underlying statistics involved. Most of the projects were devoted to how to most efficiently combat enemy submarines, by optimizing both the usage of sonar and fire-control systems.

I have managed to find a lot of data and literature concerning the research and development at RVO, but sadly I also know that much more data was unable for access, due to the files being classified (or in one case even because a collection of books at a library was unavailable because they were moving). So this serves as a disclaimer that everything I discuss will not be the entire picture; there will be stories left untold. I will also note that when I refer to the Royal Army or Royal Navy or Royal Air Force I will be talking about the Dutch versions of these, since they will obviously be the most prominent. If I’m talking about another country it will be mentioned.

The establishment of TNO

The origins of TNO lay in the First World War. Even though the Netherlands was neutral it had still been hit, and scarcity had struck. The Royal Academy of Sciences (KNAW) asked the government if it was not necessary to use all the power and experience of science we possessed to utilize the available resources for research and development optimally. The government agreed with this sentiment, and it established a commission with at the head famous Dutch physicist Hendrik Antoon Lorentz, professor of theoretical physics and at that time president of the physics department of the KNAW. A budget of around *ƒ* 100.000 was made available in 1918 (about € 620.000 in 2014). A similar amount was made available in 1919 and these large sums of money were meant for research and counseling. In 1924 the commission from Lorentz got involved with a commission from botanist Frits Went, and in 1930 this resulted in a report, which proposed the establishment of TNO. In May 10th 1932 this proposition was finalized, and TNO was officially established.[3]

TNO experienced a rough start, and part of the cause were the poor economic circumstances from the great depression. The expenses from the government were strictly controlled, and not much went to TNO. From a monetary point of view, the timing of the start of the organization could not have been worse. Hardly any resources were made available to start research or establish laboratories. Because of this, TNO also was not a desirable candidate to give assignments to or collaborate with, they simply had little to offer. In 1937, a proposal to let TNO coordinate a materials research group with a funding of *ƒ* 30.000 was accepted, but only *ƒ* 2.500 was made available by the minister of finances.[4]

But money was not the only issue, in the annual report of 1937 it can be read that significant difficulties were found in the changing of existing forms of management and working method.

---

[3] Tachtig jaar TNO, Harry Lintsen, 2010, 20

[4] Tachtig jaar TNO, Harry Lintsen, 2010, 23

Another problem was how to convince industry to help with the funding of research, because it did not seem to be the case that they would do this voluntarily. In any case, the government was the only one that could make a change, but the question was how they would do that. It was made clear that TNO would not have access to university laboratories nor industrial ones. A lot of effort was made by TNO executives to set up a network to collaborate with universities and industries though, but this would not be enough. If TNO wanted to become a proper organization, it needed to have its own research facilities. And this was the main problem. Even if the government had agreed to the establishment of TNO, they did not agree to the disposition of semi-governmental research facilities to TNO. But finally, in the year 1938, the government spent about *ƒ* 2,3 million to create and sustain an infrastructure of laboratories for TNO. [5]

The establishment of RVO

In 1946, right after the Second World War, RVO was established. And as with all organizations that are part of TNO, it had its roots in earlier institutions, mostly in test laboratories. The Royal Army for instance often used a chemical laboratory for their pyrotechnic demands. Three laboratories were transferred to RVO with its establishment, the physics laboratory, the technological laboratory (formerly the chemical laboratory), and the central laboratory.[6]

The physics laboratory had a curious background, in 1923 there was a British inventor called Harry Grindell Matthews that claimed to have invented a death ray. This was soon discovered to be a hoax, but nonetheless in 1927 a laboratory was founded to research physics and its uses for warfare. In 1941 this laboratory would be called the physical laboratory. Until 1945 the three laboratories were part of national defense, and to subsidize TNO with these laboratories had not even been thought of. RVO was a fairly unique organization, because usually military research was performed by the ministry of defense or the Royal Army. But TNO was another independent party, not directly affiliated with the government or the army. Minister of defense Kees Staf thought this was the right choice though, he reasoned that the organization of the army was based around one commanding force, and this would not work for scientific research. Research groups would operate optimally when working in smaller groups, and with a certain amount of freedom and independence. Another advantage was that the organization could satisfy the needs for the Royal Army, the Royal Air Force and the Royal Navy at the same level.[7]

This does however not mean that the army was completely detached from the research done at RVO. In practice RVO actually did not have that much freedom to work, as they were usually researching something in service of the Royal Navy or the Royal Army. Furthermore, every year the scheduled program of RVO required approval from the minister of defense. The executives only included four non-military members, who, just like all other members, had to swear an oath of secrecy. Besides the board there were two delegates in name of the minister of defense, which were supported by four replacing delegates. These six functionaries represented the three armed forces. Proposals for research were made by a commission made up of researchers from the laboratories, and representatives of the three armed forces. This commission also guarded the progress of the research. With all these rules in place, the establishment of RVO was acceptable for the military parties.[8]

For a small country like the Netherlands it was imperative that all scientific resources like laboratories were efficiently used. Laboratories in the Netherlands could be divided into 4 categories:[9]

- Governmental laboratories, for the official research in service of the state
- University laboratories, which of course mainly served educational purposes. It was possible to combine this with research activities, but they were not intended to expand and use for industrial means
- Industrial laboratories, like N. V. Philips' laboratory

---

[5] Tachtig jaar TNO, Harry Lintsen, 2010, 24
[6] Tachtig jaar TNO, Harry Lintsen, 2010, 165
[7] Tachtig jaar TNO, Harry Lintsen, 2010, 166
[8] Tachtig jaar TNO, Harry Lintsen, 2010, 167
[9] Documents at NA, 2.13.151, 6084, 66-S

- TNO laboratories, with the corresponding institutes like the fiber-institute, rubber-institute etc. These could be used for both research, toward industrial and private goals

One or more of these categories merging was not a possibility for the government, but an improved collaboration between the different laboratories would be possible with improved coordination.

Detection theory

Detection theory was something that was already being researched before the Second World War, mainly the use of infrared for detection was something that was early in development at that time. So when research started up again in 1946 the research into infrared detection also continued. Just before the Second World War Philips N.V. manufactured a infrared detector. But with it being a very early model the performance was still fairly poor, and left much to be desired. This is why a lot of early research went into the refinement of infrared detectors, because the projects did show a lot of promise theoretically.

A lot of international collaboration was done on the subject as well, an agreement was made with Sweden to exchange information and a visits to England also resulted in a lot of new information for RVO, since England was more advanced at the time. A lot of information also came from Germany, not through collaboration, but as remnants of the second World War.

Besides infrared radiation used for detection research was also done in the more traditional field of underwater acoustics and sonar, mainly concerning the detection of enemy submarines and sea mines.

Infrared

Infrared radiation is also known as heat radiation, since the temperature associated with infrared is higher than that of visible light. This makes infrared beams, which are easier to measure from a hotter object, a good way of detecting something hot (compared to its surroundings) without visible light. After the war an abundance of information on infrared research was made available, and because of this it was possible to get a global impression of new possibilities and developments, and how certain developments would perform best. Curiously enough it was German information that was the norm, for pretty much all facets.[10]

Certain tests had been performed at the physics laboratory as well, but this mainly proved how difficult it can be, especially technologically wise, to get good results for an infrared detection system. A lot of priority went to the performance of receivers, and even though there was a lot of literature available for that subject, researchers at RVO were not satisfied with the performance. The main issue was the relative processing speed, which receivers can achieve. If you work with receiving radiation that has longer wavelengths than the photo-electric cells cover (wavelength > 4 μm), then you need to use receivers that use the increase of temperature due to radiation absorption. But this effect is many orders of magnitude slower than the photo-electric effect.[11]

This causes that scanning an entire field, which is the only way to find small objects, can take large amounts of time, which is in most cases unacceptable. It should be said that there is still a certain amount of freedom in choosing the processing speed, with technological limitations pushing down the smallest scanning time interval to around 0.01 seconds. So imagine if we have a reception time of 0.01 s per pixel of an image, this still means if we have a field of only moderate sharpness, say 10^4 pixels, it would take $0.01 \cdot 10^4 = 100$ seconds. The sensitivity is then very low, and the device would only be able to pick up temperature differences of around 1 degree Celsius of a black body, of objects located a short distance from the detector.[12]

A different case is the detection of a far removed source of heat, for example the detection of a ship of medium size on sea. At RVO the expectation was that a detection distance of 10-15 kilometers would be possible to achieve with a proper seeking mirror, provided that you would allow a latency of

---

[10] Memorandum over mogelijkheden voor detectie door middel van warmtestralen, TNO rapport nr. 1951-4, 1

[11] Memorandum over mogelijkheden voor detectie door middel van warmtestralen, TNO rapport nr. 1951-4, 2

[12] Memorandum over mogelijkheden voor detectie door middel van warmtestralen, TNO rapport nr. 1951-4, 2

up to 1 second for the receiver. This was representative of the expectations people had for heat-detection devices.

It is clear that the scanning of a field would work fine ashore, but on a floating ship issues with stability will arise. The loss in accuracy because of this proved to be so large that this method was simply unsuitable for use on water. This is also why the Germans mainly used it for the coast guard. Then the field does not change and is simply a small strip near the horizon, so detections could even be done in a reasonable time. Consultation with French technicians confirmed the conclusions of RVO, since they also spent a lot of time researching this in France, and reached the same conclusions.[13]

But following the research, two new prospects were made, which were both still in the stage of early development. For the first one the idea was not to use thermo-elements and bolometers for the receivers, but photoresistors, made from lead selenide for example, and these would be faster by a couple orders of magnitude. Sources of 100-150° C could be detected just as good as with old models, but for lower temperatures they performed slightly worse. The question was if improving the processing speed would compensate for the loss in accuracy at lower temperatures, and this was what RVO set out to research.

The second prospect lay in the use of cathode ray tubes for infrared detection systems, which at the time only existed for near infrared. The idea was to make new cathode ray tubes which could also be used for medium infrared, and eventually even reaching wavelengths of $> 12\ \mu m$ for far infrared. The problem here was that it was unknown which materials best to use for the production of such tubes, a lot of fundamental research into the possibilities of materials had yet to be done, and this was not possible at the physics laboratory, so the idea was initially shelved, with the idea of returning to it when technology allowed.[14]

In 1948 the RVO started designing a device for detection at night, where a searchlight was used, but all the light from the visible spectrum was filtered out, so the more interesting, infrared part remains. The idea is very sound, and a lot of the research was spent to optimizing the design, by researching the needed filters, tubes for image conversion, types of searchlights etc. It was attempted to also use infrared detectors on ships on the ocean, but it seemed like the performance of those was heavily dependent of the atmospheric transmission above the sea, which was an unmanageable issue.[15]

The knowledge about infrared detectors was swiftly given to the industries though. The Royal Army had much use for these infrared detectors with their military equipment on land though. And so N.V. Philips manufactured many of these detectors, and different types as well, in 1953 the following types were being built for the Royal Army:[16]

- The Irovi-1 mounted on carbine and light machine gun
- The Irovi-2 mounted on anti tank guns
- The Irovi-3 mounted on tank cannons
- The Ivorij-1 mounted on non armored vehicles
- The Ivorij-2 mounted on armored vehicles
- The Irowa-1 mounted on terrain security, for a distance up to 500 meters

Collaboration with Sweden

Detection theory was a subject on which RVO also collaborated with other countries a lot. In 1952, from April 7th to April 9th a delegation from the Swedish research institute visited The Hague to consult about heat detection. The origins of the visit were in 1951, when vice-admiral L. Stam visited Sweden, and he was shown a prototype device which could detect things using heat rays. Placed on the shore, it could detect objects on sea at distances of about 10-15 kilometers, what the aforementioned literature suggested would be possible. Knowing that the physics laboratory was

---

[13] Memorandum over mogelijkheden voor detectie door middel van warmtestralen, TNO rapport nr. 1951-4, 3

[14] Memorandum over mogelijkheden voor detectie door middel van warmtestralen, TNO rapport nr. 1951-4, 4

[15] Physisch laboratorium 1927-1977, J.L. van Soest, 94

[16] Documents at NA, 2.13.121, 697

currently researching the same subject, he suggest that they should collaborate, and the Swedish research institute agreed. This meeting in The Hague was the first one.[17]

During this meeting three essential things were talked about:

1. The biggest issue for this detection method is the performance of detector itself. At the Swedish Research Institute they facilitated their own thermistor-bolometers (temperature dependant resistances), of which the sensitivity is acceptable in comparison with what the literature said about good detector values. At the physics laboratory it was also noticed that a detector of this type, if given they were reliable, would be preferred over other types because of simplicity of the circuitry and handling. However, the physics laboratory had poor experiences with bought copies, and they had not made their own, because that was left as a job for N.V. Philips, and those detectors never gave acceptable sensitivity values. The Swedish research institute apparently also had bad experiences with their branch of Philips. Because of this the physics laboratory bought a pneumatic-based detector from the U.S.A., which was apparently the most sensitive of its kind back then. When the Swedish delegation visited this sensitivity was also demonstrated. But the physics laboratory was still very interested in the thermistor-bolometers, because of the simplicity of the design. And because of this it was agreed that one or more of these Swedish detectors would be made available at the physics laboratory for research.[18]
2. Another thing necessary for a good detection device is a glass or metal mirror of good quality and size, which is metalized on the front. As a prototype, the Swedes used a German 40-cm searchlight mirror, which was metalized at the front. The definitive mirror would have to be a bit larger though, and made specifically for a certain experiment. The Swedes thought that the Dutch optic industry might be of service to them for this. The experiences of the physics laboratory on this subject weren't completely flawless though. A special metalized 60-cm mirror of glass was used, and it was concluded that it did not meet expectations. Because of this a special 60-cm mirror from France was bought, which could be used for the same things, but the quality was claimed to be much higher. With some experimentation this mirror also disappointed though, but there was still a noticeable improvement. The idea at the physics laboratory was that the mirrors could still be improved, and with this the sensitivity of the detectors as well. It was agreed upon that working with a glass mirror that would later be metalized was preferable over working with a fully metal mirror. The Dutch delegation said they would consult with French firms on how to improve these mirrors, and in the mean time the Swedes would look for ways to facilitate a better design.[19]
3. The sensitivity of the detectors, which was fairly low (especially compared to radio-equipment of the time), also resulted in the fact that the solid angle out of which radiation could be receiver was very small, it was only 10^{-5} to 10^{-6} steradian. And the measuring time was often very large as well, so that scanning even a small field would take multiple seconds, so aboard ships on sea a form of stabilization for the detectors was necessary. As said, this was a problem already found by the physics laboratory, but the Swedes also coped with stabilization issues. They needed a better form of stabilization for their therimistor-bolometers in the vertical direction. In Sweden no research was being done for this so far, so they requested Dutch aid for this, since the physics laboratory had already done some research for the Royal Navy on this subject. With consultation from the Royal Navy, it was determined that the technicalities of producing a complete central stabilizer would be far too expensive. However, information for an experimental and much simpler design were given to the Swedish delegation, which still met their request according to N.V. Hollandse Signaalapparaten. It was also advised to the leader of the Swedish delegation to establish contact directly with Hollandse Signaal. Agreed was that at the physics laboratory the pros and cons of the new

---

[17] Verslag van het overleg, gevoerd tussen een Zweedse en Nederlandse delegatie op 7-9 april 1952 te Den Haag over warmtedetectie, TNO rapport nr. 1952-21, 1

[18] Verslag van het overleg, gevoerd tussen een Zweedse en Nederlandse delegatie op 7-9 april 1952 te Den Haag over warmtedetectie, TNO rapport nr. 1952-21, 1

[19] Verslag van het overleg, gevoerd tussen een Zweedse en Nederlandse delegatie op 7-9 april 1952 te Den Haag over warmtedetectie, TNO rapport nr. 1952-21, 1-2

experimental design would be researched, and the results would be shared with the Swedish research institute.[20]

For both parties the meeting had been successful, and it was agreed upon that by correspondence and if possible the exchange of materials each other's progressions would be reported to one another.[21]

Collaboration with England

Sweden was not the only country RVO collaborated with, early in 1952 Ir. J. Piket and H. J. Dirksen from RVO visited England, to visit TRE (Telecommunications Research Establishment).The TRE was part of the ministry of supply and mainly worked for the English Royal Air Force. The physics department, led by Robert Allen Smith and with a staff of about 200 people, could be divided into two groups. One group was dedicated to the research of mm and deci-mm waves, and the other group was dedicated to researching infrared, and was lead by R. P. Chasmar, who also co-authored a book about infrared radiation along with Smith. A lot of emphasis was put on solid state physics, which was apparent by how the research group completely wanted to understand how the semiconductor photocells worked.[22]

For approximately one and a half day Piket and Dirksen were guests at the infrared department, and from this about one half day was spent consulting with each other on the research programs. Here as well a couple of essential points came forward:[23]

1. The research group lead by Chasmar was focused on studying and understand semiconductor photocells, and especially how to apply them in the field of heat detection.
2. Because of this, the following things were very important:
   a) Study of the theory of semiconductors and mechanical wave calculations (the theoretical was in charge of this). The applied physics and technology group were dedicated to the next points:
   b) Measurements of conductance, Hall-coefficients and thermal electromotive force from high to very low temperatures.
   c) Facilitation of single crystals of lead selenide and related types.
   d) Optical measurements of absorption and photoconductivity of single crystals.
   e) Facilitation and experimentation of as sensitive as possible polycrystalline cells and the necessary infrared-permeable cells.
   f) Where necessary development of instrumentation and testing equipment
3. Because of this rigorous research schedule the knowledge of the working of these infrared resistance-cells was increasing. One big obstacle however remains, and that is that reproducible and meaningful measurements are pretty much only possible with single crystals, and it has not seemed possible to make single crystal photoconductors with the same sensitivity of polycrystalline photoconductors. There is still within this context an essential role that the interfaces of the crystals have, which is not properly understood. Another problem which was unsolved was which combinations of elements of the periodic system would make for good photoconductors.
4. Partly on the basis of the knowledge that there are still problems, and because of the personalities of the research group leaders there was a lot of encouragement for outside research on these subjects.
5. The scale of the research was not something that could be replicated at the physics laboratory in Waalsdorp, so any type of support that were to be given would be in the form of very specific applications of the research. For example the usage of photoconductors in image receptors. This is however a very difficult subject, and because of that F. E. Jones (leader of the theoretical group) was very skeptical.

---

[20] Verslag van het overleg, gevoerd tussen een Zweedse en Nederlandse delegatie op 7-9 april 1952 te Den Haag over warmtedetectie, TNO rapport nr. 1952-21, 2

[21] Verslag van het overleg, gevoerd tussen een Zweedse en Nederlandse delegatie op 7-9 april 1952 te Den Haag over warmtedetectie, TNO rapport nr. 1952-21, 3

[22] Het contact met de infra-rood-groep T.R.E. Malvern, Engeland, TNO rapport nr. 1952-24, 1

[23] Het contact met de infra-rood-groep T.R.E. Malvern, Engeland, TNO rapport nr. 1952-24, 1-2

6. TRE was trying to take a regulation position on the testing of the qualities of photocells, and where they were facilitated, so the results would be easier to compare. This was already consulted with research groups from the U.S.A. and France, and they asked RVO to join, which was accepted.

Later that year, from April 16th to April 17th, R. A. Smith, R. S. Chasmar and F. E. Jones visited the physics laboratory in the Netherlands as well. During this visit the progress of the research in the photoelectric department was shown, and a lot of interest was shown for the lead sulfide photocells, and the cadmium selenide photocells, a couple of samples of these were exchanged. For the research into infrared viewers only academical interest was shown, because this area of research was something that was being handled by the English Royal Army. The aforementioned regulations of the testing of photocells was also discussed in more detail, because the French stance on the matter was by now more clear. The impression the physics laboratory seemed to make was good, it was perceived to be a small and humble laboratory in comparison to its English counterpart, but they were very impressed with the quality of the semiconductor research performed at the physics laboratory. The collaboration was found mutually beneficial, with the physics laboratory getting a lot of new knowledge, and the TRE gaining some support in the research of semiconductor photocells.[24]

Heat detection

After RVO had learned a lot about heat detectors, the interest of the Royal Navy was piqued, and they wanted the RVO to develop a device to detect heat, which could detect ships on the ocean. The first models were semiconductor bolometers, and to minimize noise issues, highly sensitive Golay cells were used as pneumatic detectors. A DC amplifier was developed, and an optical filter to absorb light from the visual spectrum, but let through infrared light. In 1957 it was made possible, with fairly crude materials, to detect ships on the horizon. A big breakthrough came in 1958, when the first indium antimonide detectors could be manufactured. With these newer and better detectors, the results were a lot better. In 1961 the first heat images were made.[25]

Picture 1: One of the First heat images of a man (1961)
Source: Physisch laboratorium 1927-1977, J.L. van Soest

With the detectors being much better, the size of the optics could be scaled back. And the best achievement of this is the CHIK (*Combinatie Helderheidsversterker Infrarood Kijker*). Developed in 1969, with one detector it managed to detect persons at 1000 meters and recognize them at 500 meters. Tanks could already be detected at 3000 meters. These tests weren't just to show the physics laboratory could make good detectors, but also to test important practical applications, like properly interpreting the data, counter measures, and tracking a target. Especially the Royal Navy was very interested in the counter measures, and since 1962 the protection of ships against infrared seeking weapons had a big priority. From 1966 onwards the Royal Army was often helped with infrared protection as well, many vehicles were outfitted with cloaking materials, and temperatures of vehicles were thoroughly checked by measuring in driving and non-driving situations and also when shooting or not shooting, to know how to compensate for these things.[26]

---

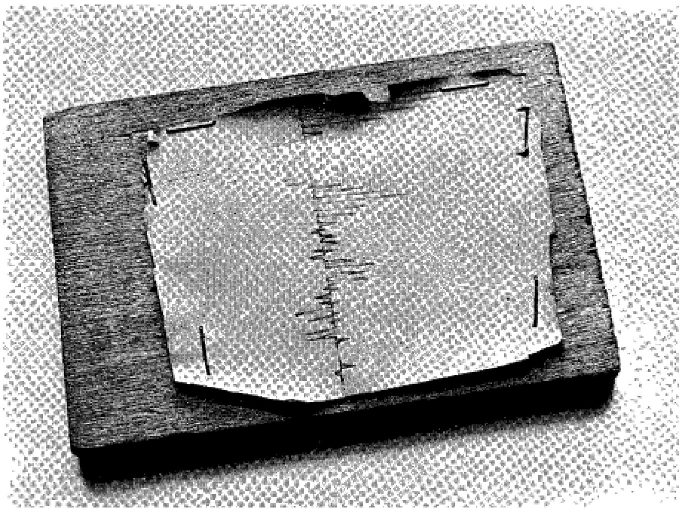
[24] Het contact met de infra-rood-groep T.R.E. Malvern, Engeland, TNO rapport nr. 1952-24, 3

[25] Physisch laboratorium 1927-1977, J.L. van Soest, 97-98

[26] Physisch laboratorium 1927-1977, J.L. van Soest, 98

Statistical detection theory

In 1955 a task force was established by J. L. van Soest, which was initially focused on information processing and operations research (more about those later). But another thing they researched were optical correlators. These were devices which use Fourier analysis to compare two or more signals with each other. A very common use for them is tracking an object, by comparing two signals with each other and looking at how they change with respect to one another you can derive the movement of a target, and thus track it. Especially for anti-ballistics guns this is of course very important. The task force started out with producing an electronic correlator, and later the research was more focused on the signal-noise relation of devices like it. With the device however, the first correlation function of a signal (in this case a noise signal) was produced. This was a proud achievement and the graph had hung on one of the walls in the laboratory for 20 years.[27]



Picture 2: The First correlation function calculated in the Netherlands (
Source: Physisch laboratorium 1927-1977, J.L. van Soest

It was remarkable how this came to be, since correlation was known only as a random term from mathematics, and it had not been applied to actual signals yet (in the Netherlands). It was van Soest who thought the correlation function could also be used for signal processing, and without him RVO would have probably been in the dark for quite a while longer. Eventually it seemed RVO was behind on research on this matter, especially compared to the U.S.A., where things like these were already very common in the 1950s. There was very little public literature on the subject at the time, and most of the literature that was available had a large emphasis on the underlying mathematics so the practical uses largely went over everybody's heads.[28]

Slowly but surely this changed though, partly because RVO managed to figure things out on their own, but also because 'statistical detection theory' finally began to be discussed in the world of literature. From 1957 to 1961 a lot of research was still done, and this even culminated in a course that was called 'statistical detection' that was given at the Technical University of Delft, in 1962. And while RVO obviously focused more on the applications possible with this new field, the study of the theory had always been something that was still on the agenda. From the research done in those 5 years, the idea to use a correlator as a pulse compressor was definitely the most important one. Pulse compression is a signal processing technique, which is achieved using pulse code modulation, something that will be discussed in the signal processing section. The result of the modulation is that the pulse energy of radars or sonars can be increased, while the overall power used to send the signal stays the same. There were a lot of positive prospects for this, and in 1960 one of the big discussions was to first apply this to either radar or sonar, and eventually the choice became sonar. The reasons for this were that the electronic problems of radar would be larger than those with sonar, and a measuring outpost in Hoek van Holland provided the opportunity to quickly do experiments with sonar. Only six years later did they revisit radar, only by this time it did not utilize pulse compression anymore, and why will become clear later.[29]

Because of the bandwidth of the signals used for the sonars (several 100 MHz), they were also referred to as broadband sonars, the reception of the signals happened with pulse compression correlators. At RVO they first looked at PM (Phase modulation) sonar, and not at FM (frequency modulation, more about these later as well) sonar, because FM sonars were already being studied by

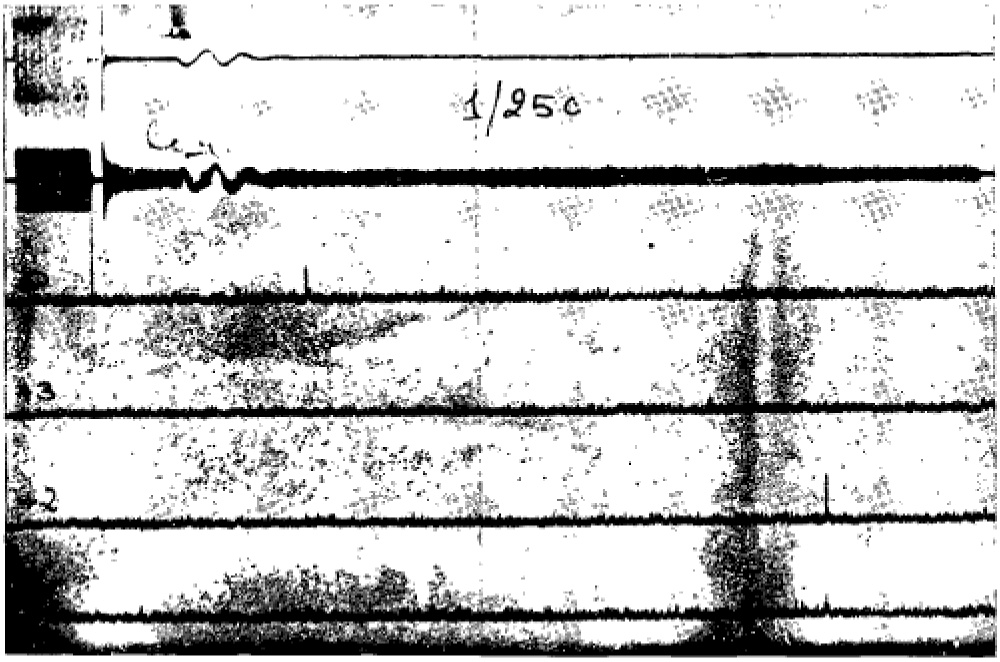
---

[27] Physisch laboratorium 1927-1977, J.L. van Soest, 143

[28] Physisch laboratorium 1927-1977, J.L. van Soest, 143

[29] Physisch laboratorium 1927-1977, J.L. van Soest, 144, 146

other European countries. And the advantage of PM sonar is that you not only get a good resolution for the distance, but also for the Doppler effect. Plus it aligned perfectly with the research group "acoustics" which was very familiar with Doppler-sonar. Later the need arose to compare PM with FM sonars, and this resulted in the fact that in 1968 most installations could send out 3 or 4 signals of every pulse type, and for every pulse type there would be a different receiver. The reason for the comparisons were problems with reverberation, which is the persistence of sound after it has been produced. If you have too much reverberation, your signal can become unreadable. On theoretical grounds the conclusion was that either with PM or with FM reverberation would be easier to suppress, but the experiments had to confirm it. The conclusion was that the FM system was superior, given that you worked with a good Doppler filter and had good control of the dynamics involved. These would have been some of the major problems with FM sonars, if not during that same time the FFT (Fast Fourier Transform) was invented in the U.S.A.. It was swiftly made clear that the usage of FFT along with digital filters made for the best tone pulse receivers, so the research into FM and PM sonars was cancelled. FFT was then also used for radar, which was the reason pulse compression was not used anymore.[30]



Picture 3: A detection of a submarine using PM sonar, against a noise background. The meaning of the lines is as follows, from high to low:

1. The raw echo-signal
2. The logarithmic echo-signal
3. The central Doppler-channel, which uses the Doppler effect for detection

4, 5 and 6. The other Doppler-channels

In the central Doppler channel you can see the response of the pulse to a reflection of the ocean floor. In the fifth channel you can see the echo of the submarine.

Source: Physisch laboratorium 1927-1977, J.L. van Soest

Underwater acoustics

Underwater acoustics had found a big practical application in the Second World War when trying to detect submarines or even regular ships. Sonars of two types were used, passive and active. In the first case the sound emitted by the source itself, by means of propulsion for example, is detected and

---

[30] Physisch laboratorium 1927-1977, J.L. van Soest, 146-147

measured. And in the second case a pulse is sound out, and the echo that returns from hitting the object is analyzed. The Royal Navy thought it was essential, because of the future importance of sonar, for RVO to have good knowledge and expertise regarding underwater acoustics. Because of that in1948 the physics laboratory was tasked with the research and development of a new active sonar. Neither the U.S.A. nor the British wanted to provide any relevant information for the project though, and because French research groups were in a similar position as RVO a collaboration was set up. This was not just for the development for transducers and hydrophones (underwater microphones), but also just for the exchange of experience and information regarding the research and development. The French research groups also let RVO use their testing facilities.[31]

RVO also wanted to be able to experiment in a more local area in the Netherlands, so for this end a fleet of pontoons was assembled. The fleet was stationed in the Waalhaven in Rotterdam, where it was also operational during the Second World War. With this fleet the physics laboratory could experiment with their developed transducers. Swiftly after, a second opportunity for experimenting originated, the Royal Navy came into possession of a 50 year old Norwegian whaler. Due to its age , it was initially thought that the ship was meant for demolition. But apparently the German Navy (Kriegsmarine) renovated the ship so it could be used for testing, and it was called the “Süd 3”. A lot of German sonar equipment was stationed aboard the ship, so it seemed logical to use the ship as a floating laboratory of sorts. Around 1950 the laboratory model of the anti-submarine installation (ADI/*anti-duikboot installatie*) was produced. It operated at a frequency between 17 and 35 kHz and a transmission power of 250 W. This ‘searchlight’ sonar was the state of the art at the time, and had pretty much anything that was required of a sonar. It had an electronic component, which was completely new for the time, and the used transducer was also completely developed by the physics laboratory. The ADI was successfully tested aboard the whaler on the North Sea, in front of the French coast near Brest, and even in the Mediterranean Sea. After the success the decision was made for Dutch industry to start producing the sonar, with the technical responsibilities lying with the physics laboratory. The produced prototype was then renamed DATO (Detection Device Against Submarines/*Detectie Apparaat Tegen Onderzeeboten),* and its performance was more than satisfactory. These installations have been used for a long time since, at least until far in the 1970s. On an international level the sonar also drew attention, the plans were sold to German, Swedish and other foreign navy’s. This was not just because of the good performance of the device, but also because of the ease in using it. It had specific instructions for the Doppler effect written on the cathode ray tube, and because of the electrical component it was possible to easily extract the data to be used for fire-control systems.[32]

In the meantime the physics laboratory was still trying to improve the active sonar, and from the designs of the DATO a newer, bigger model was made, the CWE-10. This model was equipped with a bigger transmitter, and a new, magnetostrictive transducer, which was able to convert magnetic energy to mechanical energy. The original transmission power of 250 W was cranked up to 10 kW. More research done into active sonar happened with the experimentations done with the ACP (Corrective Attack Plot/*Aanslag Correctie Plot*). Its development requested by the Royal Navy, this was a device to get an indication of the underwater trajectories of projectiles fired at enemy submarines, so with subsequent shots corrections can be made. The ACP receives its signals from a DATO installation, and to get a accurate time indication of the signals a connection with a distance measuring device was also needed. On the ACP you could find:

1. Display of the cathode ray tube (13 cm ⌀) with a cursor and distribution of degrees.
2. A switch to view the echoes in different situations.
3. Another switch with 2 stances:
    a) With this an image is produced, for which the entire time basis of the DATO is used, so the displayed inclination angles are not the real ones, because the horizontal and vertical scale are not equal. But you also get an overview of all present echoes
    b) With this an image is produced of a square, with a certain size at a certain distance. In this case the inclination angles are the true ones.

---

[31] Physisch laboratorium 1927-1977, J.L. van Soest, 152

[32] Physisch laboratorium 1927-1977, J.L. van Soest, 152-155

The ACP was tested aboard the Norwegian whaler as well, most noticeably in 1953 at Start Point in England. The tests were performed with a submarine to detect, and one of the results was that at the inclination angles of 0°, 90°, 180° and 270° the indications were much poorer than at other angles. This was pretty obvious however, because with a perpendicular incidence only a small part of the submarine is hit by the signal, so that part reflects much stronger than the rest of the submarine, which can easily lead to faulty data. The tests were performed at distances varying from 1000 meters to 2500 meters. The submarine circled around the ship at known velocity and radius, so the inclination angle was always known, and then the inclination angle measured by the ACP would be compared with it, and it proved to have a satisfactory accuracy. An issue was that sometimes multiple echoes would be received, because of different areas of the submarine reflecting in different ways, which makes the processing a lot more difficult. To get a good indication the main echo should be at least 3 or 5 times stronger than the other signals received.[33]

It seems that prominent military concerns of the time were naval warfare, because much of the research into detection theory was done with anti-submarine measures and ship detection in mind. But the research into infrared detection served a more general military purpose, with the Royal Army being very interested into infrared detectors as well. For infrared a lot of progress was made due to international collaboration, from Sweden a lot of technological knowledge was received. And from the visit to England a more fundamental knowledge of both the theory and technology which support infrared detection systems was obtained, and in the end RVO even innovated on the area of semiconductors, with new designs.

Telecommunications

Telecommunications is another area, just like detection theory, that was also being researched before the Second World War. Especially a lot of research was done for radar, and after the war one of the main goals was to try and utilize very high frequencies for the transmission of signals, so that they can be transmitted over larger distances. That was not the only research done on radars though, the refinement of existing radars, the better detection of small objects and even anti-radar materials were researched as well. Because radar applications typically use vacuum tubes as well, the knowledge gained by the earlier mentioned visit to England was very helpful for the research of telecommunications as well.

Another big subject was modulation, with a lot of attention going to newer forms of modulation. Amplitude modulation was the norm back then for radio’s, but frequency modulation and phase modulation and its applications were still not properly understood, so that was an exciting new field of research.

Modulation

Research done at the physics laboratory about proximity fuses, and building a transmitter for the Royal Army paved the way for an in-depth research on amplitude, frequency and phase modulation.[34] Modulation can be very useful for transmitting, because if you want to transmit a signal over a large distance it needs to have a large frequency, due to it needing more energy, and how energy related to frequency by Planck’s relation. A higher frequency or amplitude can also result in not needing very large antennas to receive the signal.

A modulated wave is a periodic wave, in which the amplitude, frequency or the phase is altered by the modulation frequency. The process of doing this is called modulation and encodes the signal in another signal that can be transmitted easier. The non-modulated component of a wave is also referred to as the carrier wave.. The modulating wave that is added to the signal of the carrier wave can either be a direct modulation of the original wave, or also one with a completely different carrier wave. This latter process is also called double modulation.[35]

---

[33] Aanslag Correctie Plot, Rapport TNO, 1954-1, 1-3

[34] Physisch laboratorium 1927-1977, J.L. van Soest, 104

[35] Radio en Radio-communicatie, J. Hagenaar, 1949, 314

A modulated current can be represented as:

$$i_m = I_m \cdot \cos(\omega t + \varphi)$$

In which I_m = the amplitude of the current, $\omega = 2\pi$ times the carrier wave frequency, t = the time and φ = the phase angle. With amplitude modulation the magnitude of I_m is altered, and with frequency modulation ωt is altered.

Amplitude modulation

For our amplitude we can write:

$$I_m = I_0(1 + m\ \cos(pt))$$

$$i_m = I_0(1 + m\ \cos(pt)) \cdot \cos(\omega t + \varphi)$$

And here I_0 = the amplitude of the non-modulated carrier wave, m = the change in amplitude from the modulating signal, also called the modulation factor, and p = the modulation frequency times 2π. With the right calibrations, the phase angle can be set to zero, so our formula simplifies to:

$$\begin{aligned} i_m &= I_0(1 + m\ \cos(pt)) \cdot \cos(\omega t) \\ &= I_0 \cos(\omega t) + \frac{I_0 m}{2}\cos(\omega t + pt) + \frac{I_0 m}{2}\cos(\omega t - pt) \end{aligned}$$

From this it is clear that the modulated carrier wave has 3 parts:

1: The original carrier wave $i = I_0 \cos(\omega t)$
2: A part $\frac{I_0 m}{2}\cos(\omega t + pt)$
3: A part $\frac{I_0 m}{2}\cos(\omega t - pt)$

Parts 2 and 3 are called the modulation sidebands of the modulated carrier wave, and they have the frequency of either the sum or the difference of the carrier wave and modulation frequency. The distance between both sidebands is also known as the bandwidth, and it is apparent that this is dependent on the modulation factor and frequency.[36]

Frequency modulation

With frequency modulation the frequency $\frac{\omega}{2\pi}$ gets altered in correspondence with the modulating signal, and the amplitude remains constant.

The modulation frequency now denoted the magnitude in which the frequency of the carrier wave changes. How much the frequency changes in comparison to the non-modulated signal is also referred to as the 'swing' in frequency. This is proportional to the amplitude of the modulating signal.[37] The new factor for the frequency of the modulated wave can be written as:

$$\omega_t = \omega + 2\pi\Delta f_z \cdot \sin(\omega_m t)$$

In which $\omega_t = 2\pi$ times the resulting frequency, $\omega = 2\pi$ times the carrier wave frequency, $\omega_m = 2\pi$ times the modulation frequency and Δf_z = the maximum swing in frequency, which is dependent on

---

[36] Radio en Radio-communicatie, J. Hagenaar, 1949, 315-316

[37] Radio en Radio-communicatie, J. Hagenaar, 1949, 323-325

the amplitude and not the frequency of the modulation signal. Returning to our original formula for a modulated current we can write:

$$i_m = I_m \cos(\omega_t t) = I_m \cos(\omega t + \frac{2\pi\Delta f_z}{\omega_m} \cdot \cos(\omega_m t))$$

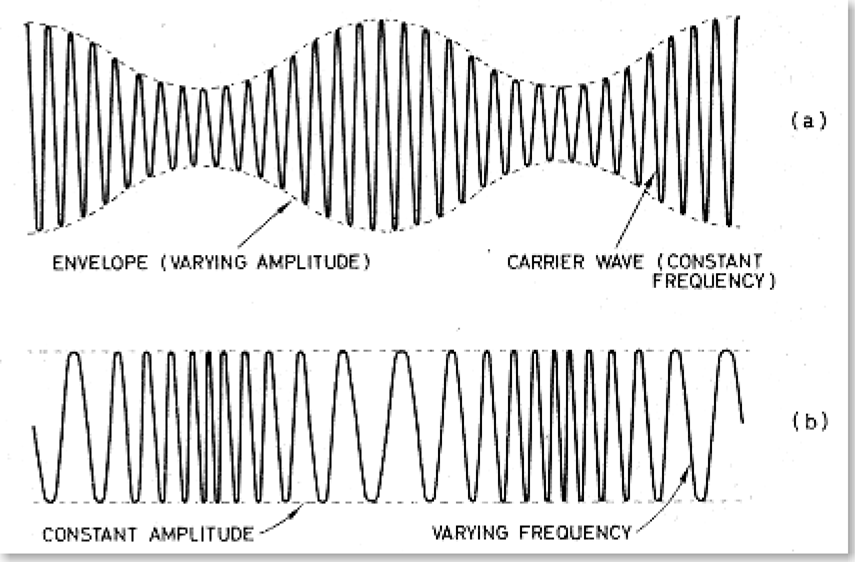
In which $\frac{2\pi\Delta f_z}{\omega_m}$ is the modulation factor, which I will from now on refer to as m_f. We can then write:

$$i_m = I_m(\cos(\omega t) \cdot \cos(m_f \cdot \cos(\omega_m t)) - \sin(\omega t) \sin(m_f \cos(\omega_m t)))$$

And these factors can be developed as a Taylor series. If we insert these series into our formula, terms will appear with frequencies of the sums and differences of a multiple of the modulated frequency, like: $\frac{\omega}{2\pi}, \frac{\omega \pm \omega_m}{2\pi}, \frac{\omega \pm 2\omega_m}{2\pi}$ etc. So for a frequency modulated carrier wave every low-frequency component has an infinite amount of sideband frequencies, as opposed to the amplitude modulating case. And the amplitude of these sidebands is determined by the modulation factor.[38]

AM vs. FM

Calculations and experiments have concluded that for AM, interfering signals on the same frequency band as the desired signal need to have an energy difference of 35 dB, otherwise the transmission is noticeably disturbed. For FM this is only 6 dB, because FM looks at frequency variations, and not at amplitude variations. Because of this, air disturbances and noise issues are greatly reduced when using FM. A second advantage is the larger distances can be covered by the signal, while still remaining receivable, because the ratio between signal and noise is much better. And lastly, once again because of the reduced noise, less energy is required to still broadcast a clear signal, reducing the costs for radio companies and such. The problem however is that most receivers at the time were AM receivers, and they would all have to be replaced with FM receivers. Eventually the costs of this will be balanced out by the gains of FM over AM, but it is not something done just overnight.[39]



Picture 4: Amplitude modulation (a), and frequency modulation (b)
Source: http://www.vintage-radio.com/images/figs/transistor/modulation.gif

Phase modulation

Phase modulation is relatively similar to frequency modulation, but now the phase angle of the frequency of the carrier wave gets varied. The associated formula for the modulated current is the same as that for a frequency modulated one, but the difference lies in the interpretation of the modulation factor m_f, now called m_p. With frequency modulation the modulating factor was determined by the frequency (Δf_z and ω_m). But with phase modulation the modulating factor is expressed in radians, of how the peak of the modulated function has shifted against the phase angle,

---

[38] Radio en Radio-communicatie, J. Hagenaar, 1949, 325-326

[39] Radio en Radio-communicatie, J. Hagenaar, 1949, 331

which is present even before the modulation. A phase modulated wave can be created by combining the output voltage of an amplitude modulator with a suppressed carrier wave with an non-modulated carrier wave which has a phase shift of 90° with the original carrier wave.

Here:
E_{d0} = the suppressed carrier wave
E_b = output voltage of the amplitude modulator
E_d = the added carrier wave
ψ = the phase angle

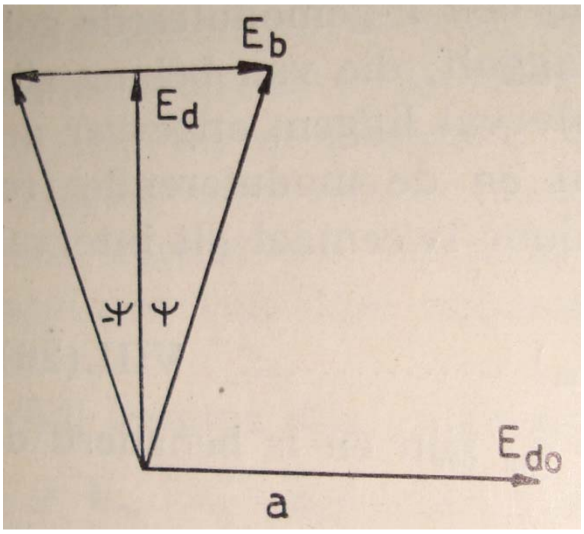
Then the phase angle can be written as:

$$\tan\psi = \frac{E_b\cos(\omega_m t)}{E_d}$$

And for small values of the angle:

$$\psi \cong \frac{\mathrm{E_b}}{\mathrm{E_d}}\cos(\omega_m t)$$

So the modulating factor is now determined by the constant carrier wave E_d and the peak E_b.



Picture 5: Source: Radio en Radio-communicatie, J. Hagenaar

UHF

The first UHF radar the physics laboratory got to work with after the war, in 1947, was a mobile 200 MHz radar from the Canadian Army. It was not operational and the request from the Royal Army was to get it working again. But there were no blueprints, parts were missing and it required a power supply of 2000 Hz and 1,5 kW, which was not available. Yet after a lot of hard work, from which a lot of knowledge was gained, it was once again functional, and it was seen as a great success that it could detect aircraft landing on Schiphol.[40]

Using the newly researched modulation techniques, in 1950 RVO started researching possibilities to transmit signals over large distances, ranging from 30 to 50 times the maximum radio distance. This research was started because the thought was that this technology would prove to be immensely useful for future military endeavors. Communication is of course very important, and especially with more emphasis lying on international collaboration quick communication between two countries is necessary. Important for this was the development of low noise receivers in the ultra high frequency range.

For this RVO collaborated with Norway. On the island Tromöy, a transmitter was built, with a frequency of 150 MHz. The distance between transmitter and receiver was approximately 800 kilometers. The large antenna in Norway had a power of around 2300 kW, and the receiving antenna was stationed in Waalsdorp, in the Netherlands. This connection was made in 1956 and cancelled in 1959, with the results being complete.[41]

In 1954, from April 21st to April 24th, a delegation of researchers from RVO visited the Norwegian research center Norks Forsvaret Forsknings Institutt (Norwegian Military Research Institute). Not only the UHF connection was talked about, other topics included forming a joint commission for research into guided projectiles, collaborative research into radar camouflage, and research concerning the propagation of sound underwater. The most prestigious and important project however was the UHF connection, which made use of tropospheric scattering, which is the phenomenon that radio waves randomly scatter as they pass through the upper layers of the troposphere. This can be used to make radio waves travel large distance over the Earth, which is of course spherical.[42]

---

[40] Physisch laboratorium 1927-1977, J.L. van Soest, 118
[41] Physisch laboratorium 1927-1977, J.L. van Soest, 105
[42] Documents at NA, 2.13.151, 6238, 165-X

In 1959, after the completion of the Netherlands-Norway collaboration, two tropospheric scattering installations were made available for the Dutch armed forces. In these installations frequency diversity was used, which means they used two channels with separate characteristics, to improve the reliability of the signal. Initially the idea was that these installations were to be used by the Royal Navy, but a few years later in 1963 they were dissatisfied with the installations, they did not function as required, mainly because of stability issues that arose from being above water. After that, from 1964 to 1967, the installations were thoroughly tested by the Royal Army. In 1967 the last operation was completed, where an installation was used for the so-called Seedorf trajectory, from the physics laboratory to west Germany, over a distance of about 300 kilometers. About 90% of the times a stable connection was made possible so the results were satisfying. Yet this was the last application of tropospheric scattering due to the rise of satellite communication, which proved to be much more effective.[43]

Another UHF project was not by using the troposphere to travel long distances, but by using a satellite. And not by man-made satellite, those were still very early in development, the first man-made satellite only launched 2 years prior, the Russian Sputnik. But in January of 1959 RVO collaborated with research groups from the U.S.A., using the moon to reflect radio waves and transmit them to another part of the Earth. There were some big problems though, one being that the moon is everything but a smooth sphere, so the signals fluctuated wildly. Another problem was the libration, the oscillation of the moon with respect to the earth, which makes it difficult to accurately aim. These problems quickly caused the termination of the project.[44]

Noise

An always present problem with equipment is noise, and especially when you need a very clear signal like with telecommunications it can be quite a problem. This is why at RVO a lot of research was done in radio noise and where it comes from, to understand how to minimize it. For radio, noise can be categorized in two groups: noise that is a consequence of the circuitry, and noise that is a consequence of the used vacuum tubes.

The circuitry noise emanates itself because of thermal fluctuations of electrons in the conductors. Because of this voltage differences manifest themselves which are of course undesirable. Physicist W. Schottky theoretically predicted this noise to be proportional with the resistance and the thermal characteristics of the circuit. He proposed that the voltage difference could be written as:

$$V^2 = 4\,K\,T\,R\,B$$

In which V = the voltage, K = the Boltzmann constant, T = the temperature in Kelvin, R = the Ohmian resistance and B = the bandwidth. In 1928 this relation was experimentally confirmed by J.B. Johnson, and because of that this type of noise is also known as Johnson noise.[45] The Johnson noise over a two-port network can be calculated as follows:

$$V^2 = 4\,K\,T \int_0^\infty Z_f^2 A_f^2 df$$

In which Z_f = the equivalent resistance of a series circuit with a frequency f, A_f = the amplification factor, which is dependent on the frequency f. For broadband amplifications Z_f will be constant and frequency independent, and we can just replace it in the integral with the Ohmian resistance R. The output voltage depends on the amplification factor, but is convenient to introduce an input voltage, before the amplification has taken place. If the average amplification is A_m then we can write:

---

[43] Physisch laboratorium 1927-1977, J.L. van Soest, 106

[44] Physisch laboratorium 1927-1977, J.L. van Soest, 107

[45] Radio en Radio-communicatie, J. Hagenaar, 1949, 404

$$V_i = \frac{V_u}{A_m}$$

$$V_i^2 = 4\,K\,T\,R \int_0^\infty \frac{A_f^2}{A_m^2}\,df$$

An amplification always works only on a certain given area, where the frequencies are limited. This frequency limitation is also called the bandwidth so we can simply replace the ratio in our integral with the bandwidth B. And then our integral simply reduces to:[46]

$$V_i^2 = 4\,K\,T\,R\,B$$

Which means to lower the voltage fluctuations you want a low temperature, resistance and bandwidth.

Apart from the Johnson noise, there is still the noise from the vacuum tubes as well. And generally this consists of emission noise, which originates because of fluctuations in the emission of the cathode, and because of partition noise, which originates because of fluctuations in the partition of current in tubes with more than one positive electrode.

So this noise is present with the commonly used triodes and pentodes. The partition noise is able to be minimized by limiting the screen grid current of the triode/pentode. The noise in a tube can be understood as the noise of an equivalent resistance R_e, which is connected in series with the grid of the tube. Physicists Thompson, North and Harris have empirically found that this resistance can be approximated by:

For the triode: $R_e \sim \frac{2,5}{S_d}$

For the pentode: $R_e \sim \frac{I_A}{I_A+I_{sg}}\left(\frac{2,5}{S_d} + \frac{20 I_{sg}}{S_d^2}\right)$

In which S_d = the height of the tube, I_a = the direct-current of the anode and I_{sg} = the direct-current of the screen grid. It was found that generally it is convenient to connect pentodes and also tetrodes as triodes instead, which can reduce the noise by a factor of 3 to 5, and made for even more accurate telecommunications systems.[47]

Transponders

In 1961 a system was created for better radar detection of small objects, what would later be known as the VESTA project. By request of the Royal Air Force, in that year research was started into better detection and recognition of radar-echoes from glider aircraft. For this, a glider plane was fitted with a radar transponder, a device that is a combination of a transmitter and a responder. If the glider receives a radar pulse, it responds by amplifying it and transmitting it in a new frequency to a ground receiver. This way the ‘echoes’ were amplified and visible on ground control. The project was a huge success, visibility of glider aircraft was improved significantly, especially because the glider echoes had a specific form which was instantly recognizable. However, despite the success, the Royal Air Force had lost interest in the project by the end of 1963, and it was terminated.[48]

But the positive results with the transponders did not go unnoticed by the Royal Navy. By request, they borrowed a radar transponder which were used to outfit a ship which went to measure the ocean floor, as part of the international NAVADO project, a project to research to ocean floor of the Atlantic ocean. The ship had to remain detectable at a distance of at least 19 kilometers from the coast. The current ship radar could not detect ships at that range anymore, but with the transponders this was not an issue anymore. After that success, the Royal navy was also interested in using transponders aboard helicopters. Especially for low altitude helicopters which were difficult to detect. In March

---

[46] Radio en Radio-communicatie, J. Hagenaar, 1949, 405

[47] Radio en Radio-communicatie, J. Hagenaar, 1949, 406

[48] Physisch laboratorium 1927-1977, J.L. van Soest, 108

1966 the Royal Navy gave an order to manufacture a transponder system to be used between helicopters and helicopter directing ships, this system was dubbed VESTA.[49]

After many tests, a new transponder was developed, with a peak power of 10 Watts, which meant the ship directing the helicopters could use two simple antennae (frequency diversity) to receive the transponder signals. With this system a range of around 56 kilometers was reached, with the helicopter flying at an altitude of about 120 meters, a massive improvement to say the least. Another important issue was the minimization of the blind spot the radars possessed. At a distance of about 5 kilometers, the blind spot was only 5 degrees whereas without transponders it was 45 degrees.

The Royal Navy was wholly convinced by the transponders, and decided to equip an amount of ships with them. They initially tried to have them manufactured by industrial companies, but after this failed they turned to the physics laboratory, and gave the order for 25 transponders. In 1968 this order was started, and it was partly outsourced to ENRAF-NONIUS in Delft. In May 1969 a prototype was successfully tested aboard a ship, and in 1970 six frigates were outfitted with the VESTA system. In 1972 the order was fully completed, and after that the further development of the system was handed over to the Electronics department within RVO, which even manufactured VESTA systems for foreign buyers.[50]

Material research

In 1951 development was also started for anti-radar measures, in this case a radar-camouflaging material, which was supposed to absorb radar transmissions (RAM/Radar Absorbing Material). Improving your own radar so it can more easily pick up enemy forces is of course important, but the enemy uses radar as well, so it is equally important to try and ‘hide’ your own forces. For thisIn 1952 a collaboration with N.V. Philips led to a good design for a broadband radar absorbing material. In the mean time research was also being done for ‘smallband’ material, where the purpose was to have a material that only worked in a small bandwidth, which is easier to manufacture and use, if you know the frequency the enemy uses. Proper microwave measuring materials were still hard to come by, so a lot of components necessary to research the materials had to be manufactured by the physics laboratory. The required precision of the instruments required a lot of competence and effort, and a lot of researchers managed to find creative and interesting solutions. Because of this a lot of results were also published in papers and presented at symposia, and even five dissertations came forth from the research.[51]

In 1953 a delegation of researchers from RVO visited Canada to among other things look at vacuum tube factories. These Canadian factories made a good impression, even though most of the components were acquired from the U.S.A., since large-scale production in Canada was not economically feasible. Research done by the Canadians into the development of vacuum tubes was largely absent, pretty much all of the manufactured vacuum tubes were copies of those used in the U.S.A. But there was one location where research was being done, the C.R.M.C. (Canadian Radio Manufacturing Corporation) in Toronto. That factory was actually property of N.V. Philips, and because of that there was a lot of contact between the Netherlands and that factory, engineers from Eindhoven regularly visited. Yet no vacuum tubes from Philips were actually manufactured there, because the production of European vacuum tubes is typically more complicated than those of the U.S.A., and the amount of produced vacuum tubes would be too small for an efficient production.[52]

The C.R.M.C. made an excellent impression, having an air-conditioned assembly room, and a self-feeding machine that wrapped the grids around the vacuum tubes, developed by the Canadians. Apart from that most of the machines came from Eindhoven. In one year, about two million transmission- and rectifier tubes were produced, separated in 58 different types. Apart from vacuum tubes the production of crystal diodes, hydrogen-fluoride crystals, and radio & television was also observed.[53]

---

[49] Physisch laboratorium 1927-1977, J.L. van Soest, 109

[50] Physisch laboratorium 1927-1977, J.L. van Soest, 109

[51] Physisch laboratorium 1927-1977, J.L. van Soest, 119

[52] Verslag van een bezoek aan Canada, TNO rapport nr. 1953-52, 1

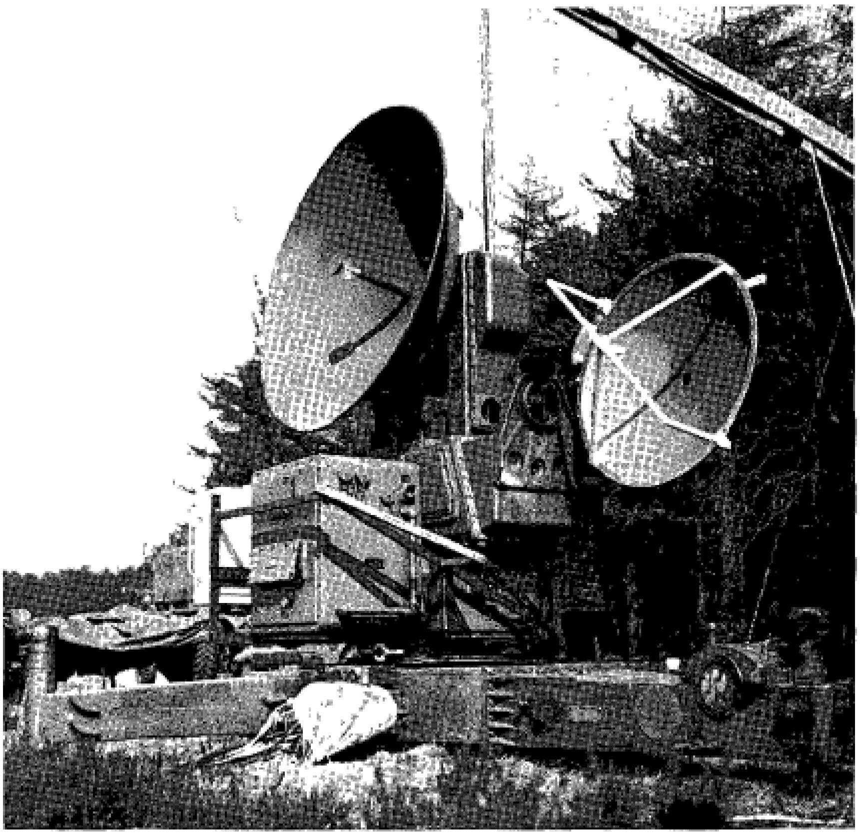
[53] Verslag van een bezoek aan Canada, TNO rapport nr. 1953-52, 2

Measuring radars

For the detection of radar reflection of objects above water, or in an open space (which means without background reflections), diverse measuring radars were developed. These radars could be categorized into three different types:

- The first type was used for measurements made in a laboratory environment. A fixed arrangement was used, which made it possible for a target of a limited size to be measured in all aspects.
- For targets above water a second type was developed for distances from 100 to 150 meters.
- The third type was made for longer distances, of above 700 meters. The focus was put on the mobility of this system, it started out as a system that was simply movable to being incorporated in a vehicle. This type was used for determining the reflection of objects in open space and above sea.

A big highlight was when it was made possible to reliably measure the reflection of a fast-moving object. The measuring radar and a AN/MPQ-10 tracking radar from the Royal Army were mechanically and electrically coupled, and this system proved to be a very successful and mobile measuring device, which is very useful to track enemy projectiles.[54]



Picture 6: The measuring radar coupled with an AN/MPQ-10 tracking radar
Physisch laboratorium 1927-1977, J.L. van Soest

Telecommunications link between ships

Communication between ships that could not be tapped has always been an important issue for many Navy’s, and the old signaling lamp is the proof for this. A signal lamp is however not a very efficient way for communication, and with the rise of radio the idea of using radio waves for communication

---

[54] Physisch laboratorium 1927-1977, J.L. van Soest, 119-121

between ships was swiftly thought of. After research done in 1952, towards the usability of visible light, infrared light and ultraviolet light, the idea came to utilize microwaves to communicate between ships. After some small tests had been done in 1954-1955, the Royal Navy, in 1956, came with an assignment for the complete development of a system, suitable for testing aboard ships. Researchers also wanted to evaluate the operational efficiency of such a telecommunications downlink, by looking at problems such as not exactly knowing the locations of the ships and maintaining the connection once established.

This led to a fairly complicated rotating antenna system, which was based on a Fresnel-lens. Because of the partition of the polarization two separate wave bundles were used, which made it possible for both stations to track one another. The desired size of the antenna made a small wavelength the optimal choice, which is why microwaves were used. To minimize the possibilities for listening in, the bare minimum amount of power for transmission was used. The construction of all the necessary components was a time-consuming process, and only in 1959 was the first system complete. Because of the small width of the wave bundles it was necessary that the stations were very stable, but as you might guess this is not very easy to achieve on open sea. Because of that problem and the frequent presence of anomalies on the sea the project was eventually cancelled.[55]

Since the second world war the knowledge on radar has come a long way, especially due to the research into UHF radars. The research done in modulation, and eventually the development of the FFT, facilitated the development of these radars. And even if a lot of the prestigious projects like using the troposphere or the moon to transmit signals ended up being cancelled, they did pave the way for what is now used globally for transmitting signals, satellite communications. The research done in modulation also led to the conclusion that frequency modulation is typically superior to amplitude modulation, which is why it nowadays is used as lot more.

Information/signal processing

With more advanced weapon systems on the rise since the First World war, the need for a good fire-control system had grown. But up until the Second World War these fire-control systems have all been mechanical. Shortly after the Second World War, the First Turing-complete computer, the ENIAC (Electronic Numerical Integrator and Computer) was developed. In February 1946 it was gifted in to the Moore School of Electrical Engineering of the University of Pennsylvania, where it was used for problems in fields like atomic energy, and ballistic trajectories, which is what the ENIAC was initially designed for.[56]

But the ENIAC was not made capable to directly calculate optimal trajectories for weapon systems, and this is what piqued the interest from the physics laboratory in the Netherlands. They were the First ones to head in this direction with digital computers. The ENIAC had around 18.000 electron tubes, and required a power of over 100 kW, which would make it cumbersome to work with for the military.[57]

Digital computers were still very new though, and a lot of research had yet to be done, since anolog computers were still the norm. But the benefits of digital computing were evident, the physics laboratory brought forth the following advantages:[55]

The accuracy of the calculations can be chosen better and it is not dependant on the physical parts of the computer, which was the case with analog computers.

A digital computer is flexible, it can make many subsequent calculations and changing the sort of calculation that needs to be done is possible.

Digital computers provided better possibilities of storage of data.

Digital computers are assembled by many, yet relatively simple and cheap parts that are easily obtainable.

Despite all these reasons, in 1948 an analog computer was built for the royal air force, for on-board navigation. This computer had some issues with accuracy though, which was another reason to

---

[55] Physisch laboratorium 1927-1977, J.L. van Soest, 122-123

[56] http://ftp.arl.mil/~mike/comphist/eniac-story.html

[57] Physisch laboratorium 1927-1977, J.L. van Soest, 130

look more into digital computing.[54] So research into changing from analog computing to digital had a high priority, and the branch of science called information theory was born, which concerned itself with signal processing. And because of these digital computers, it was very important to look at what information actually is.

Information

In July 1948, American mathematician Claude E. Shannon published an article called *A Mathematical Theory of Communication*[58], which many people view as the founding work of information theory.[59] Shannon described five basic steps for information, namely the source, the transmitter, the channel, the receiver and the destination. He also introduced the term information entropy (also known as Shannon entropy, or selective information), which is relatable to the thermodynamic kind, it is a measure of the uncertainty in a random variable.

Johannes Leendert van Soest, professor at the physics laboratory, outlined four steps for information, similar to those of Shannon. Information can be generated (source), stored (memory), transported (communication) and transformed (coding, modulation).[60] And especially the third step is an interesting one, which is also known as communication theory, something I have discussed prior.

Scientific information is a different term than the regular word information, which boils down mostly to semantics, which I will not consider here. But scientific information, which is what is used in information theory, can be broken up into 3 groups: Selective information, structural information and metric information.

Structural information

When we consider a source of information, the structural information is determined by the amount of independent details, or degrees of freedom. A simple example is that of a continuous signal *f(t).* It is evident that if the signal operates on a wider frequency range and for a longer time span that more structural information would be acquired. The following statement can be proven:

If *f(t)* is restricted in a frequency band 0-W, then f(t) is wholly determined by sampling, which is done with a distance of $\frac{1}{2W}$ with respect to each other. Proof:

$$f(t) = \int_{-\infty}^{\infty} F(v) e^{2\pi i v t} dv = \int_{-W}^{W} F(v) e^{2\pi i v t} dv$$

Here *F(v)* is the spectrum of the signal *f(t)*, and because of the restrictions of the frequency band we can let the integral run from –W to +W. If we then set the time t as $t = \frac{n}{2W}$ with n being an integer:

$$f\left(\frac{n}{2W}\right) = \int_{-\infty}^{\infty} F(v) e^{2\pi i \frac{n}{2W} v} dv$$

And make a Fourier expansion:

$$F(v) = \sum a_n e^{-2\pi i \frac{n}{2W} v}$$

With

$$a_n = \frac{1}{2W} \int_{-W}^{W} F(v) e^{2\pi i \frac{n}{2W} v}\, dv$$

---

[58] http://cm.bell-labs.com/cm/ms/what/shannonday/shannon1948.pdf

[59] Information Theory, Interscience 1965, Robert B. Ash

[60] Informatie- en communicatie-theorie, Prof. Dr ir J. L. van Soest, 1960, 5

So

$$f\left(\frac{n}{2W}\right) = 2Wa_n$$

$f\left(\frac{n}{2W}\right)$ determines a_n, and a_n determines *F(v)* and in turn *f(t)*.

If *f(t)* is restricted in W en also in time T, then *f(t)* is determined by 2WT samples. So we say that if *f(t)* is restricted in W and T, that we get 2WT units of structural information. This unit is called a logon, so if we have a sound with a frequency band of 10000 Hz, it produces 20000 logons per second.[61]

Metric information

With every logon from a source of information comes a certain amount of metric information. And while the addition of logons is pointless, the addition of units of metric information does make sense, if the metric information on the level of a power, intensity or energy is being examined. These units, called metrons, are not expressed in energy, but they are dimensionless. The unit is associated with the smallest measurable energies, which always exist due to thermal effects and quantum effects. So the unit always belongs to a finite amount of energy and the metric information over a finite amount of logons is also always finite. The big difference between logons and metrons are that logons are coupled with an a-priori angle, and metrons with an a-posteriori angle.[62]

Selective information

If we then examine the simple example of an electrical circuit with current I which has a resistance R in it and an ammeter. We know from Ohm's law that $V = I R$. And also the Johnson-Nyquist noise (discussed previously), which gives the fluctuations in potential when there is no current running, $V^2 = 4k_bTRW$, which is dependant on the temperature T and the width of the frequency band W. So we can write:

$$I = \frac{V}{R} = \sqrt{\frac{4k_bTW}{R}} = \sqrt{\frac{V^2}{4k_bTRW}}$$

This is half of the information lost in the circuit per logon. In a time of Δt there will be $2W\Delta t$ logons. So the loss of information would be:

$$\Delta J = -\frac{V^2}{k_bTR}\Delta t$$

And the warmth that has been dissipated in a time Δt can be written as $\frac{V^2}{RT}\Delta t$. So the change in entropy for the system is:

$$\Delta S = \frac{V^2}{RT}\Delta t$$

And logically:

$$k_b\Delta J + \Delta S = 0$$
$$k_bJ + S = constant$$

---

[61] Informatie- en communicatie-theorie, Prof. Dr ir J. L. van Soest, 1960, 10-11

[62] Informatie- en communicatie-theorie, Prof. Dr ir J. L. van Soest, 1960, 12

Which is completely in line with the laws of thermodynamics, the loss of information times the Boltzmann factor, is equal to the gain in entropy of the system. This all relates to the selective information from Shannon, also known as Shannon entropy. Information and entropy are two closely related things, you could say information is a measure of organization and entropy is a measure of disorganization.

If we consider a signal with 2 types of symbols, pulses measured in n_1 and non-pulses measured in n_0. Then we can say $N = n_1 + n_0$, and $1 = \frac{n_1}{N} + \frac{n_0}{N} \approx p_1 + p_0$, where p_1 and p_0 are the chances for those symbols. And we consider these pulses as individuals from a larger amount, M_1 and M_0 of available ones. Then the amount of possible combinations for a signal would be: $N' = M_1^n M_2^n$, and the entropy is:

$$S' = k_b \ln N' = k_b n(p_1 \ln M_1 + p_0 \ln M_0).$$

There are $N'' = \frac{n!}{n_1! n_0!} N'$ amount of individual telegrams, so the corresponding entropy with this is:

$$S'' = k_b \ln N'' \approx -k_b n(p_1 \ln \frac{p_1}{M_1} + p_0 \ln p_0/M_0)$$

Where we have used Stirling's formula in the last derivation. These entropies are both pseudo-entropies, and not real, physical entropies. The difference between these two entropies:

$$\Delta S = S' - S'' = k_b n(p_1 \ln p_1 + p_0 \ln p_0)$$

It is the difference between the entropy of the specific signal, and the general signal, i.e. the fluctuations in the signal. The specific signal has less chance to occur, so the entropy is also less. Physician Léon Brillouin calculated for more complex systems that:

$$\Delta S = k_b n \sum_i^n p(i) \ln p(i) = -k_b \ln 2\, n - \left(\sum_i^n p(i) \log p(i) \right) = -k_b \ln 2\, n\, H$$

Where Shannon has defined *H* as the Shannon entropy, which quantifies the expected value of the information in a signal. So there is a complementary relation between the decrease of information with the increase of entropy, analogous to the thermodynamic entropy.[63]

Coding

Now that we know what information is, it is important to know how it is represented. The binary numeral system is incredibly well known now, and it is hard to imagine another system on which a computer works. Yet when digital computers other numeral systems were considered. If we work with a ground-number *a*, then for every digit we would need *a* memory-units. So for p digits we would have *a p* = *x* memory units. Then for a number $N = a^p$, *x* reaches a minimum for a certain *a*. The most obvious candidates are the numbers 2, 3 and 4. To be able to at least calculate 10^{10} we have for *a* and *x:*

a = 10	*x* = 100
4	67
3	63
2	67

---

[63] Informatie- en communicatie-theorie, Prof. Dr ir J. L. van Soest, 1960, 13, 26-27

But if we consider that you do not actually need a memory-unit to display a zero, then we get:

$a = 10$	$x = 90$
4	50
3	42
2	34

And here we can see why the binary numeral system is being used today, simply because it is the most efficient, something which was not immediately evident. A disadvantage of the system was that to read the results, they first had to be converted to the base 10 system, which could then take such a long time that the time won because of using the binary system over the base 10 system was negligent.[64]

Fire control systems

After a lot of research done in the years 1947-1950, scientists realized that digital computers could not only be used for ballistics trajectories, like the ENIAC, but they could be used for a wide array of possibilities. In 1951 RVO made their first digital chronometer, a device that could measure time, for the Royal Army, to measure projectile speeds. The device was capable to measure the time, within microseconds of accuracy, of a projectile following a known path, far exceeding the accuracy of the until then used devices.[65]

The chronometer was a great success, and in the following years more were built for both the Royal Army and the Royal Navy, and every time with better performance. They all focused on calculating velocity and acceleration of projectiles, and apart from that a lot of focus was given to optical, magnetic and electromagnetic sensors, to boost the accuracy of the measurements. The production of these chronometers never became a full industrial operation because the amount required was still too small.

A second new-found application was aboard of ships designed to destroy submarines, the so called DICO was a computer designed to accurately calculate the depth of an enemy submarine. It did this in conjunction with onboard sonar, by using the temperature- and pressure gradients of the water, which distort sound waves. The difficult issue here was the input of information in the computer, since everything up till then was done in an analog way, so analog to digital converters were needed. Especially angles were a common input for computers. The physics laboratory made an important development for this, apparently around the same time as the Americans did, utilizing the same principles.[66]

On the axes that measures the angles, a glass disc was attached. On this disc a bunch of binary numbers are coded (black = 0, transparent = 1). Then the computer, using trigonometry, could convert the angle to a value, which could be read on a display. So the physical angle measured could be converted in real time to a visible value on a screen, a remarkable and very useful result.[67]

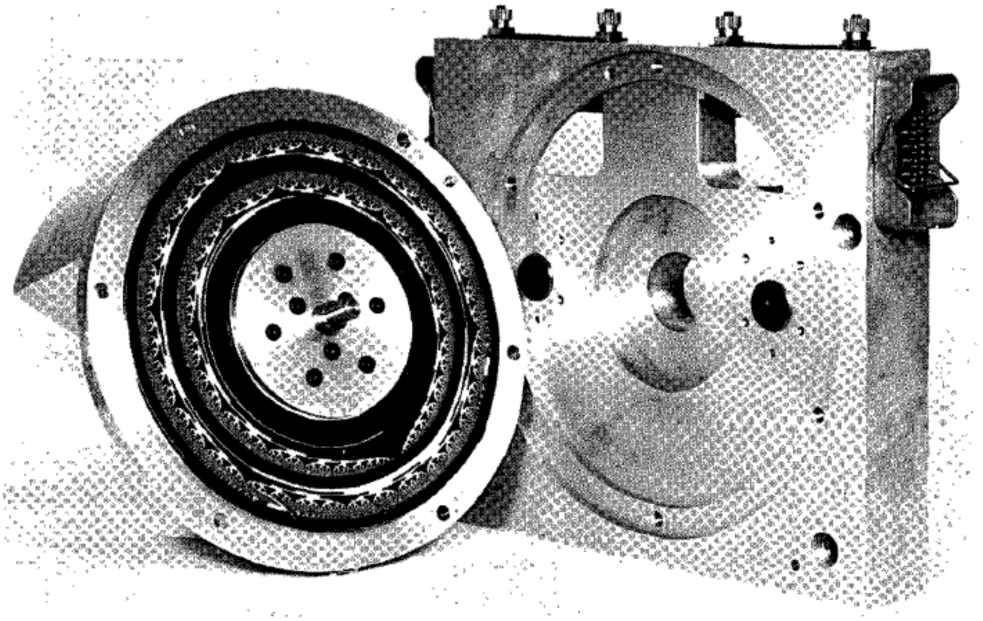
---

[64] Electronische rekenapparaten. Mathematische grondslagen. Tijdschrift van het Nederlands radiogenootschap. Deel XV-6, Nov. 1950, Blz 299-312

[65] Physisch laboratorium 1927-1977, J.L. van Soest, 130

[66] Physisch laboratorium 1927-1977, J.L. van Soest, 131

[67] Physisch laboratorium 1927-1977, J.L. van Soest, 132



Picture 7: An analog to digital converter, consisting of a disk with binary coded sine- and cosine tables, and a casing which has two displays to read the calculated values.
Source: Physisch laboratorium 1927-1977, J.L. van Soest

In 1953 the physics laboratory started working on a digital torpedo fire control system, one of the first digital fire control systems. The system was meant for torpedoes, that after being fired, still needed to change course by changing their angle, to more accurately hit their target. But this proved to be a difficult undertaking, the device was very complex and arduous to create, and required over 600 vacuum tubes to build. The principles behind the idea were sound, but the practicalities were still a problem.

But when in 1955 the first working transistors arrived at the physics laboratory, this problem practically vanished. The laboratory managed to develop a set of reliable transistor parts for the project, which led to the production of a fire control system for torpedoes, manufactured by N.V. Hollandse Signaalapparaten. In 1959 the project was successfully finished, but sadly enough it never went into use because the torpedoes for which it was developed were taken out of use because of bad performance.[68]

DIPHYSA

This was only the beginning though, in 1956 another, more important project was being developed, under the name DIPHYSA. Inspired by the torpedo fire control system, this was a fire control system for a 90 mm anti-aircraft gun, with a 3 Mk 7 radar as detection device. The project even attracted foreign attention, with mainly the U.S.A. being very interested in it, themselves having no experience with digital fire control systems yet. The project was so promising that the U.S.A. even funded part of it, wanting to obtain the same results as the Netherlands. It was agreed upon that by June 30th 1958 the physics laboratory would have a complete laboratory model of the 90 mm anti-aircraft gun, and finished testing it by the end of the year. Arrangements for a new, 40 mm anti-aircraft gun were also made, because the 40 mm guns have a longer useful life, and the 90 mm system was becoming obsolete.[69]

In 1955, June 27th, the costs expended by the Dutch government for the project were $60,345 ($526,717 in 2014), and the estimated cost of completing the project would be $523,000. The government of the U.S.A. would reimburse 46% of the actual costs related to the project that the

---

[68] Physisch laboratorium 1927-1977, J.L. van Soest, 133

[69] Documents at NA, 2.13.121, 696

Dutch government had, up to a cap of $245,000, and the Dutch government would pay the other part of approximately $278,000.[68]

The 90 mm gun model consisted of 4 principal components. An analog- to digital converter, a so called “tracker” which uses the detection principles earlier discussed, the lead angle computer and the digital- to analog converter. It was produced as a joint endeavor between the physics laboratory and Hollandse Signaalapparaten, where the latter was responsible for the lead angle computer. Preliminary testing in June 1958 went well, with known data being used as input for the computer, and the correct answers were displayed. Various other, more dynamic problems were inserted as input, and the output was deemed to be satisfactory.

The tracker and the lead angle computer consisted of about 3500 transistors and 9000 diodes. The three principal components of the computer were the arithmetic unit, the programmer and the memory unit. One of the main problems for the tracker were the usage of proper filtering constants. The filtering has the be done due to the presence of noise, and doing this process which takes about two seconds leads to much smoother results. The tracker has two modes of operation, namely auto-follow and regenerative. Switching between these two modes (to acquire a new target for example), is based on an arbitrary level of tracking error, which still required more evaluation to properly optimize. The lead angle computer has the traditional coordinate inputs, plus a correction for parallax. The maximum discrepancy of the accuracy seemed to be about 0.02 seconds, which is at maximum operating range. The biggest problem was the large size of the machine, but its functionality was more than satisfactory.[68]

With the DIPHYSA project being completed, so was the research at RVO into using digital computing for fire control systems. The know-how was transferred to Hollandse Signaalapparaten, and the further production of fire control systems was an industrial matter now.

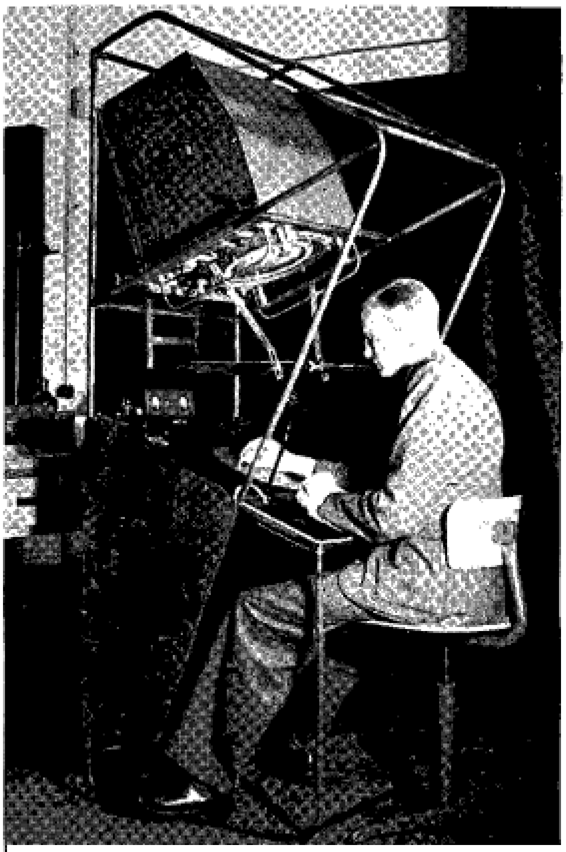
Radar information processing

However, in the 1950s not all of the attention was focused on fire control systems. Gradually digital computers appeared to be more and more useful. A research group was founded, carrying the names of Digital Arithmetic, then Digital Techniques, and lastly Information Processing Systems. The development of digital switches like the transistor also made it so that other already established research groups grew more interested in digital computing.

Since the Second World War, the usage of radar for military purposes (and in general) has vastly increased. At first, the person reading the Radar coordinates would verbally transmit them to so called “plotters”, who would manually make an image on a plotting table. It is easy to imagine that with more data and this becomes a very cumbersome process, and is also very prone to errors. So using digital computing for the processing of radar coordinates was a natural fit.

What happens with radar is that you’re asking for the time between a transmission from an impulse and the reception of the disturbed impulse. If you get a clear signal with minimal discrepancies then a line will be represented in signal space, around the point where the disturbed signal came from. This can be processed statistically and the previously mentioned point can be calculated.[70]

In 1950 the RVO started researching ways to do this digitally, because of interest of both the Royal- Navy and Army. The first idea was to see if it was possible to



Picture 4: A test set of the TELEPLOT
Source: Physisch laboratorium 1927-1977, J.L. van Soest

---

[70] Informatie- en communicatie-theorie, Prof. Dr ir J. L. van Soest, 1960, 84

project the radar image on a transparent sheet, then to code these coordinates onto the plate (like with the analog to digital convertor discussed earlier), and transform it into an electric signal. Then with this signal the image could be calculated and displayed digitally on a monitor. Data from multiple sheets could be read simultaneously, and the data could be displayed on multiple screens. In conjunction with N.V. Philips and N.V. De Oude Delft a large big screen projector was developed.[71]

Here as well the U.S.A. showed interest for the project, and also helped fund it. In 1954 the system, now called TELEPLOT, had begun development. The system was developed by N.V. Philips, under supervision of the physics laboratory, which also performed the testing. In 1958 the equipment was first put in use by the Royal Army in Nieuw-Milligen. Because of the needed bandwidth, the TELEPLOT could only be used as a local device. But the Royal Air Force also had radars stationed in Den Helder, and it was intended that the information from these radars would be used with the TELEPLOT, as an “early warning” device. Luckily, since digital techniques had become more prominent, this turned out to be quite easy. The coordinates from the Radars in Den Helder could be digitalized and modulated, and sent over to TELEPLOT using a simple phone line.[72]

The next big innovation for the TELEPLOT was that a computer was used to predict the movement of an object. Knowing an object’s velocity and acceleration one could calculate the position after a certain amount of time. The operator of the system would only have to verify the predicted position, and if needed make a small correction. In this system which was aptly called the TELETRACK, 60 of these “tracks” could be monitored at the same time. The TELETRACK was developed by the physics laboratory, and put into use in 1961. With both these systems there was always still a human component in play though, because the echoes still had to be detected amidst noise and interference. This is why around 1960 research started into automating this process, to both improve speed and accuracy. This was eventually made possible by using rotating radars coupled with so called ‘video extractors’.[73]

Unlike with detection theory and telecommunications, information processing was an entirely new field of research, and was not something that was done before the Second World War. The research was quickly picked up at the physics laboratory though, with the concept of information already being well understood, and the binary system already having been developed in 1950. RVO was especially innovative with the applications of the digital systems, with the use of digital computing for fire-control systems garnering a lot of attention from the U.S.A., who were completely unknown with the concept. A very impressive achievement, especially when considered that the U.S.A. had many more resources to their disposal for research and development. But digital computing was not only used for fire-control systems, the idea to use it for the processing of radar data was also very innovative.

Operations research

Another field of research that surfaced around the time of the Second World War was the so called ‘operations research’, which was devoted to utilizing advanced mathematics to optimize decision making. It is also known under the terms ‘management science’ and ‘decision science’. It was first developed as a response to the military needs in the Second World War, and while it had sparsely been used for industrial and governmental activities as well, its main origin is military.

But its uses far exceed those of only military kind. Professor George E. Kimball and physicist Phillip M. Morse laid the groundwork for operations research in their 1950 published book ‘Methods of Operations Research’, in which they give the definition: “*Operations research is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control*”.[74] Operations research uses mathematics, yet it is not a branch of mathematics. It uses the results of time and motion studies, yet it is not efficiency engineering. Just like civil engineering uses the results of science to build bridges, operations research utilizes science to help

---

[71] Physisch laboratorium 1927-1977, J.L. van Soest, 137-138

[72] Physisch laboratorium 1927-1977, J.L. van Soest, 138

[73] Physisch laboratorium 1927-1977, J.L. van Soest, 138-140

[74] Methods of Operations Research, Phillip M. Morse & George E. Kimball, 1950, 1

executives. The engineer is the consultant to the builder of a bridge, whereas the operations research worker is the consultant for the executive which uses equipment.

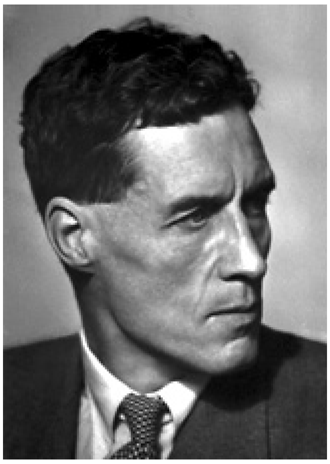
An important aspect is the definition of the term 'quantitative'. Certain aspects of practically every operation can be measured and compared quantitatively with other, similar operations, and those aspects can be studied scientifically. The phrase 'basis for decisions' implies that these quantitative results are not the only measure used to make decisions, and this is true, other aspects can also enter the fray, such a politics, tradition etc. The operations research group merely presents the quantitative data, which the executive then takes into account when making a decision.

The origin of operations research

Already before the start of the Second World War in 1939 research was being done in the United Kingdom, which would later be dubbed operations research. G. A. Roberts was concerned with how the detection method of aircraft using radar, which was brand new back then, could be used for the older, visual method of detection and identification. At the same time Eric C. Williams was comparing the performance results of the steadily increasing amount of radar stations, to improve the techniques used. When the war broke out, those two ideas were merged into a single division, which was part of the Telecommunications Research Establishment of the army. The first report of this division, which helped greatly during the battle of Britain, served as an example for later operations research groups.[75]

In 1940, famous physician Patrick M. S. Blackett got involved, and together with specialists from different fields, he formed his own group, the so called "Blackett's circus", to study the flow of information from radars. Quickly they devised the optimal location of gun batteries to protect London.[76]

The group was a large success, and led to many more groups being established. When Victory in Europe day arrived, over 350 researchers and 100 officers in the United Kingdom were involved with operations research.[77]



Picture 8: Patrick Blackett

Example: anti-submarine warfare

An important use of operations research in the Second World War was for anti-submarine warfare. Depth charges were commonly used, but it was made clear that charges that detonated at the surface of the water were not very effective, even direct hits would often not be fatal for the submarines. Charges that detonated slightly underwater had a much greater effect. This effect increased up until 30 meters or so underwater, at which a detonation at a distance of 6 meters from the submarine would practically always sink it. Because of this the first depth charges were built in such a way that they detonated between 30 and 50 meters underwater. The results of this were however disappointing. And after some use of operations research, it was clear why. It may be true that a bomb detonated at least 30 meters deep had a bigger effect, but at that depth the chances of actually hitting the submarine are vastly reduced. Research pointed out that 40% of the times a charge was released when the submarine was at the surface, 10% of the times when the boat was submerged, yet visible, and 50% of the times when submarine was so deep that it was indistinguishable. Furthermore the theoretical consideration that the chances of hitting at a bigger detonation depth were smaller were experimentally confirmed.[78]

In the former half of the cases, where the submarines were still detectable, the charges were detonated so deep, that the submarines often were merely mildly inconvenienced, instead of actually being hit. After some testing the optimal detonation depth was quickly found. 7,5 meters was the

---

[75] Operations Research, P. De Wolff, 1957, 4-5.

[76] The Origin of Operations Research and Linear Programming, a seminar given by R. De Leone in 2008. https://gol.dsi.unifi.it/gol/Seminari/DeLeone2008.pdf

[77] Operations Research, P. De Wolff, 1957, 5.

[78] Operations Research, P. De Wolff, 1957, 5-6.

result, and amusingly, that was not even a option on the setting mechanism, that is how wrong people were about the optimal depth. After this more suitable depth to detonate was adopted, the success rate of anti-submarine warfare more than doubled.[5]

The important thing to note here is that is no use to try and optimize one variable, for instance the depth. The importance lies in the combination of all present variables, and all present statistical information should be utilized, only then can a quantitative approach be meaningful.

Another issue that benefited greatly from operations research was again related to anti-submarine warfare. In this case it is about aircraft trying to detect submarines. To quantify the efficiency of these aircraft a certain type of detection measure needed to be introduced, the so called 'sweep rate'. This was the amount of detected submarines per 1000 flying hours, divided by the amount of submarines per 1000 square kilometers. The amount of submarines in an area was not well known, but it was not a complete mystery either. The reports from the British intelligence service gave at least an indication, however crude they may be.

The sweep rate was generally only 10% of what was theoretically feasible, if every submarine within a 15 kilometer radius was actually detected. This was a consequence of two factors: the submarines were often submerged, and the efficiency of the detection was certainly not perfect. Certain areas had a considerable worse sweep rate than others though, and for a long time the cause for this was unknown. Even the replacement of aircraft personnel by experienced pilots did not give a significant improvement. This made a perfect case for operations research, they analyzed the flying patterns and came to the conclusion that the coastal areas were more intensively surveilled than other areas. The reasoning for this was that the most submarine sightings had been in coastal areas. But further research proved that the amount of detections per flying hour were remarkably low, the only reason the detection rate was higher here was because of the more intensive patrols. When because of these results, the patrol schedule was changed, the discrepancy in sweep rates vanished.[79]

Operations research at RVO-TNO

Despite of the fast and positive results operations research had, it still took a while for it to be incorporated in the research program at RVO as well. Only in 1955 J. L. van Soest organized a task force, which was dedicated to the optimization of communication channels, where the factor of the transmitter and receiver had to be maximized, and the factor of noise had to be minimized. This was the first area they started with because of van Soest's background with communication science. The group had a lot of freedom in their research though, so they first chose to familiarize themselves with the mathematical knowledge needed, and extensively studied game theory.[80]

It was quickly made clear that game theory was not only applicable on games like poker, but could also be very useful for military applications such as optimizing torpedo targeting. Examples like those appeared to be part of a field called 'operations research', something about which almost nothing was known so far in the Netherlands. In 1950 a presentation about operations research was held for the Royal Dutch Society of Engineers, but it seemed to not have left a lasting impression, because nothing came out of it.[7]

After studying game theory and finding the link with operations research it seemed that this was only a small facet of operations research. But it was clear that operations research was something that could be very useful for Dutch military purposes, especially after literature from the aforementioned Morse and Kimball finally became available. Because the origin of operations research lay in radar applications, it seemed only natural to also incorporate this in the ongoing research of radar technology at RVO and also in fire-control systems research.

After a discussion in 1956 with engineer Maarten van Batenburg, an alumni of the Delft University of Technology, the Royal Army already had an assignment for the operations research task force. It once again involved anti-submarine warfare. The issue was to optimize the search procedure of sonars stationed on anti-submarine ships. After many hours of work the task force literally wrote down every possible combination of variables, a very cumbersome task. Because of the trouble this method of working brought forth, and the ever increasing mathematical complexities present for the

---

[79] Operations Research, P. De Wolff, 1957, 6-7.

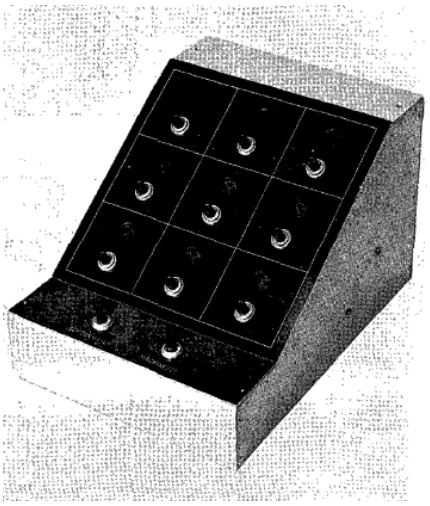
[80] Physisch laboratorium 1927-1977, J.L. van Soest, 168

possibilities, the idea of a simulation was brought forth. Nowadays a simulation seems a staple method of operations research, but back in 1956 it was quite a difficult task to accomplish. They simply started out with rolling dice, and later stepped over to using pseudo-random numbers, which was often mocked by the staff of the electronic department because of it being so cumbersome. But it succeeded, after 2 months of work they manually performed 45 simulations. The conclusion was that the difference between multiple searching strategies was negligible, which put quite an anticlimax on the research.[81]

In 1957 van Soest left the task force, and was replaced with engineer E. W. Gröneveld, who later became professor at the university of Twente. The first project with him at the helm was a tic-tac-toe machine, which could never lose, which of course utilizes game theory.

Zero-sum game.

The strategy behind tic-tac-toe might be rather simple, but programming a machine to always make the optimal move is no easy task. The problem is that in a game there is always an unknown factor, which cannot simply be described by a probability distribution. When player A makes a move, there are many possibilities for player B. But player A cannot give a probability distribution for this, because that would mean that player B would, in a certain situation, pick one move in 10% of the cases and another move in 20% of the cases etc. But this is a very unrealistic way of playing tic-tac-toe, player B will always play the move that is most likely to win him/her the game, and sometimes there is one single move that is better than all the others, so player B will always play that move.[82]



Picture 9: The tic-tac-toe machine
Source: Physisch laboratorium 1927-1977, J.L. van Soest

Game theory has analyzed games like these (tic-tac-toe, checkers, chess), and looked at the question if there is an optimal strategy to employ, and for certain games this is the case. The most simple case is a game between two persons, where the total winnings between both persons are independent of the outcome of the game. This is the case with tic-tac-toe, if you posit that the rules are that the winner gets 1 point, the loser gets -1 point and in case of a tie both players get 0 points. Then every game exactly 0 points are awarded, and because of this games like these are also known as zero-sum games.[83]

To devise an optimal strategy, one must first know every possible strategy. This might at first seem like a very difficult task, but using a simple artifice it is possible to set up a sort of table for every game of the same kind, which makes comparison and analysis very easy. The trick is to give the players a list of all of the situations that could happen in a game, and then ask them what their next move would be, every answer is a strategy. And if all strategies are known, a simulation between two strategies can be done, to see which one will be victorious. You could arrange every possible strategy of players A and B, where you could use all rows for player A and all columns for player B. If you would index the strategies from player A from 1 to n, and the strategies from player B from 1 to m, then you get a so called payoff matrix for player A. The payoff matrix from player B would be retrieved by simply turning all of the signs from matrix A, so we have all the information we need in matrix A. And from this matrix the strategy with the most amount of wins can be found.[84]

For a game of tic-tac-toe this is still relatively simple because of the limited amount of moves, but you can imagine that for a game of chess or the Chinese game Go these matrices would become enormous. But the method still works, even if it can take a lot of computing power. Until shortly seasoned chess players were still able to regularly beat computers and with Go seasoned players are

---

[81] Physisch laboratorium 1927-1977, J.L. van Soest, 169-170

[82] Operations Research, P. De Wolff, 1957, 28.

[83] Operations Research, P. De Wolff, 1957, 29.

[84] Operations Research, P. De Wolff, 1957, 30.

still able to reliably beat computers. The tic-tac-toe machine produced by the physics laboratory could measure up with humans though, it could not be defeated by anyone. A simple example like this machine showed how even problems that might not seem suitable for operations research can be tackled by using the right approach.

At this time the task force was not yet convinced that using digital instead of analog computing would be a good idea. This was mainly because of the practical issues involved, since computers from private corporations were still in a very early stadium, and computers from TNO had fixed wiring which could not be altered.

Naval research

In the end of 1956 the task force of operations research was renamed to “system research”, and was also dedicated to signal processing (noise detection specifically), and system research of analog fire-control systems on anti-submarine ships, to calculate optimal accuracy. The target surface was determined by, in a darkened room, drawing the contour of a shadow of a ship model, and by calculating the surface area for multiple inclination angles. With this data, and well known physical limitations of evasive maneuvers, a misconception of naval warfare which was a remnant of the Second World War was cleared up.[85]

Between 1956 and 1964 the task force solely worked for the Royal Navy. Besides sonar and fire-control systems a lot of attention initially went to the clearing of naval mines, and how to optimize this. With the known physical limitations and optimal mine sweeping plan was developed. A lot of probability theory was used here due to the built-in activation times the mines possessed. Once again game theory proved to be very useful. However, with the DIPHYSA project picking up steam, the mine sweeping project was relayed to a different department, and for the same reason a pending request from the Royal Air Force about the chances of survival of low-flying aircraft was relayed to the National Aerospace Laboratory.[12]

Digital computing

Because of the research done into anti-air artillery for the Royal Navy, a new assignment from the Royal Air Force came in, an evaluation of the 40 mm anti-aircraft guns. And this was the first assignment where a digital computer was used, the ZEBRA (Very Simply Binary Arithmetic Device/*Zeer Eenvoudige Binaire Reken Automaat)* from the Royal Navy. The conclusions were nothing remarkable, the guns had a reasonable accuracy. Pleased with the result however, the Air Force directly issued another assignment, this time to research the evasive maneuvers of aircraft. This turned out to be quite a spectacle, the operation called “Spiraal” had the Royal Army test out their anti-aircraft guns against the Royal Air Force[86]

As time went on the digital computer was used more and more for operations research. Besides the statistical processing of data, calculations were done about the visibility of targets in an area, because aerial photos from the topographical services were made available. These calculations were then checked on-site by viewing the sites from a balloon.[87]

Shortly after that the Royal Army assigned a massive new project, namely the choice of a new transportation vehicle for the corps. This assignment had an enormous scope, from the establishment of an actual model to the many, many things to be considered. Merely determining all the possible variables was already a big effort. The computers were still too weak to fully process something like this, so the project was divided into smaller sub-projects, so multiple computers could work the case at the same time. All of the results were put into a big file which would be one of the most read ones of the Royal Army. Hundreds of magnet strips were used and thousands of meters of graphs were plotted, but eventually, with a big sigh of relief, the file was finished and the project did come to an end. A couple of remarkable results were that for the medical services of the Royal Army they did not need

---

[85] Physisch laboratorium 1927-1977, J.L. van Soest, 171

[86] Physisch laboratorium 1927-1977, J.L. van Soest, 171

[87] Physisch laboratorium 1927-1977, J.L. van Soest, 172

more medical vehicles, which is what people thought, but a bigger capacity to perform surgery, something nobody would have expected at that time.[88]

Even though operations research was not picked up as quickly as information processing at RVO, it was eventually picked up and found its applications within the physics laboratory. It was something that could often be used to improve existing projects, mainly by minimizing noise issues, which were typically always at least a small problem. The study of game theory

Conclusion

While the physics laboratory and RVO were never very big establishments, especially compared to their contemporaries in countries like the United Kingdom and the U.S.A., a relative large amount of innovative research was still done. Even with limited resources and funding subjects like digital fire-control systems and sonar were often pioneered by the physics laboratory. Especially digital fire-control systems are a highlight, since nobody else in the world thought of the idea to use digital computers to more accurately calculate ballistics trajectories, something that is now of course used in every part of the world. The interest of the U.S.A. for the DIPHYSA project was a great testament to the project's innovation and legacy. The usage of correlators was another impressive feat, since even just the idea to use correlators for detection seemed to come out of the blue, but it has proved to be immensely useful, even if in hindsight it seemed like the U.S.A. was already fairly advanced on that subject as well, something that was not known in the Netherlands at the time.

And while in most areas of research the physics laboratory was fairly well advanced, on par with the rest of the world, there were still some areas where they were lagging behind a little bit. The most notable examples would be statistical detection theory, something that was already fairly big in the U.S.A., which took quite a long time to completely reach the Netherlands. When it finally did though, it was picked up swiftly, and its understanding was made apparent by the course about statistical detection theory given at the Technological University of Delft in 1962. Operations research was another field that was not immediately picked up by the physics laboratory, it was of course developed during the Second World War, but only around 1955 did it arrive in the Netherlands.

With a smaller establishment and less resources it would be expected for the physics laboratory to not make as many technological breakthroughs, but that still did not mean there weren't any. Even with the circumstances some very impressive inventions were made, like the cadmium selenide and lead sulphur semi-conductor photocells, with which the English researchers were very impressed.

A lot of research was done on behalf of the armed forces, and there seems to be a clear difference in how each three of the armed forces were dependent on said research. The Royal Navy made the most orders for the physics laboratory and also made the most use of the developments, they always seemed to be very keen on working together with the physics laboratory. The Royal Army still had its fair share of orders as well, but they were never as groundbreaking or innovative as those for the Royal Navy, more often they concerned the improvement of an already known design, and the development of an entire new one. The Royal Air Force seemed to have almost no association with the physics laboratory, almost no research was done or developments were made for them. Apparently it was (and still is) the case that the Royal Air Force, and to a lesser extent the Royal Army rely a lot more on foreign technology and advancements, and they will without much hesitations import the best equipment available, often from the U.S.A. The Royal Navy however had a different outlook, they thought that homemade equipment would be just as good, and also cost a lot less money. It of course also promotes scientific research in the Netherlands, which is a good thing. But when it came to operations research, the Royal Air Force had its fair share of projects for RVO as well, because in this case it was not about technology.

From the research done it was definitely noticeable that tensions in the world were high, due to the cold war. Most of it was done for security reasons, be it defense against submarines which was a prominent issue or faster and better interpretation of radar data. Not much research was done for offensive developments though, with the exception of the fire-control systems. This provides a stark

---

[88] Physisch laboratorium 1927-1977, J.L. van Soest, 174

contrast with research done in the U.S.A., where bigger and better weapons were of course a huge priority. This is also why the U.S.A. was so interested in the digital fire-control systems in the first place. Overall I would say the cold war has definitely boosted the amount and quality of research done in the Netherlands, with both funding from the government and from outside sources (U.S.A.) of course being higher than in ‘normal’ circumstances. Luckily though, as said, a lot of the research was not done for offensive purposes, and because of that a lot of it has also proved useful in other areas, like the development of better radars and in turn satellites, and research done into digital computing which helped computers be at the state they are today.

Acknowledgements

I would like to express my gratitude to my supervisors Jeroen van Dongen and Friso Hoeneveld for consultation and feedback on my research and paper. And I would like to thank Thomas Gerretsen for the provision of reports from the archives of TNO and the tour of the physics laboratory in the Hague.

References

Literature

A. J. Wolfe (2012), *Competing with the Soviets*
E. W. Gröneveld (1960), *Digitale rekentoestellen voor vuurleiding*
H. Lintsen (2010), *Tachtig jaar TNO*
G. J. Sizoo (1962), *15 jaar rijksverdedigingsorganisatie TNO*
I. J. Boxma (1950), *Electronische rekenapparaten. Mathematische grondslagen*
J. Hagenaar (1949), *Radio en Radio-communicatie*
J. J. A. Manders (1948), *Infra-rood stralers*
J. L. van Soest (1977), *Physisch laboratorium 1927-1977*
J. L. van Soest (1960), *Informatie- en communicatie-theorie*
R. B. Ash (1965), *Information Theory*
P. M. Morse & G. E. Kimball (1950), *Methods of Operations Research*
P. de Wolff (1957), *Operations Research*
P. J. J. Diks (1956), *De grondslagen der telecommunicatie*
R. W. Starreveld (1959), *De automatisering van de informatieverwerking*

Archives used

Nationaal Archief, The Hague
    2.13.121: 696 - Anti aircraft fire control equipment using digital computing techniques (DIPHYSA)
    2.13.121: 697 - Infra-rood apparatuur
    2.13.151: 5904 13-05 902 - Ontwerp rijksverdedigingsorganisatie toegepast natuurwetenschappelijk onderzoek
    2.13.151: 6084 66-S - Bijzondere organisatie TNO voor rijksverdediging
    2.13.151: 6199 208-T - Jaarverslag 1951, werkprogramma 1952 en researchbeleid rijksverdedigingsorganisatie TNO
    2.13.151: 6238 165-X - Samenwerking rijksverdedigingsorganisatie TNO met Noorwegen op het gebied van research
Archive of the Physics Laboratory RVO-TNO
    1951-4: Memorandum over mogelijkheden voor detectie door middel van warmtestralen
    1952-21: Verslag van het overleg, gevoerd tussen een Zweedse en Nederlandse delegatie op 7-9 april 1952 te Den haag
    1952-24: Het contact met de infrarood-groep van T.R.E. Malvern, Engeland
    1953-52: Verslag van een bezoek aan Canada
    1954-1: Aanslag Correctie Plot

Websites

http://gol.dsi.unifi.it/gol/Seminari/DeLeone2008.pdf
http://ftp.arl.mil/~mike/comphist/eniac-story.html
http://cm.bell-labs.com/cm/ms/what/shannonday/shannon1948.pdf