The Hammer Computer

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At the Study Collection, we were aware of a large machine (3.0 x 1.5 x 1.0 meters) standing in a dark corner. The origin and purpose of this machine had long been forgotten. Fortunately, an observant visitor was able to tell us where the device was built and who the designer was.
The device had been constructed around 1950 at the Nederlands Radar Proefstation (Dutch Radar Testing Station) in Noordwijk (now: Christiaan Huygens Laboratory in Katwijk) under the supervision of its designer ir. J. A. Hammer (figure 1). A brief description of the machine, as well as the author, is given in [3].
A literature study yielded two articles. The first article [1] is a report by Hammer at a scientific conference in France, expounding the scientific progress made by using this machine. In the accompanying survey article [2] more details of the machine are presented. After studying these articles and opening up the machine to examine its construction, gradually, a picture began to emerge of the purpose and structure of this analogue and mechanical calculator.

The construction of this machine started around 1950. To really know what we are dealing with, we must go back to that time to understand the development of radar technology and the construction of computers in those years. This whole exercise resembles technological archaeology: from the artifacts found, an image is formed of the operation of the machine, like a puzzle being slowly put together.

The Hammer computer was designed and built for a special purpose: the design and calculation of linear radar antennas. With radar transmission antennas, it is important to generate a beam of radiation that is as narrow as possible, without so-called "side lobes" (figure 2). Since the radiation pattern of a single antenna is relatively wide, an array of antenna-slots is used to achieve a narrow beam (figure 3). The total field generated by these antenna-slots is the sum of the contributions from all slots. Due to interference, the fields generated by the individual slots amplify each other in the antenna aiming direction and weaken each other in the other directions, thereby reducing the effect of the side lobes.

Rekenmachine van Hammer

Fig 1. Hammer's Calculator

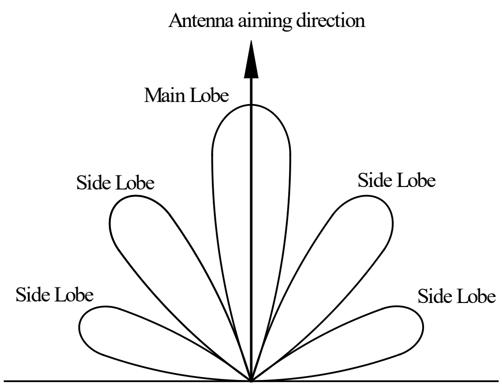

Fig 2. Radiation Diagram of a single antenna

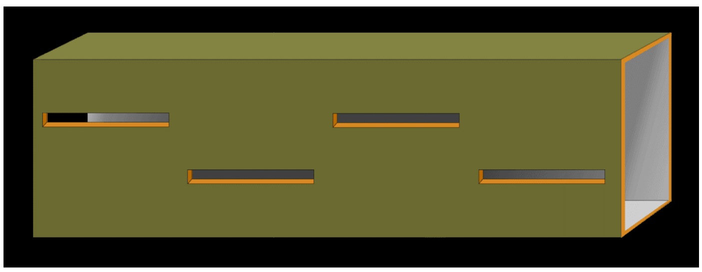

Fig 3. Example of a slotted antenna

The Design of the Computer

Hammer's computer is designed to perform two functions: (i) using up to 41 antenna slots, the machine calculates the field strength of the E-field, and (ii) starting from a prescribed radiation pattern, the machine calculates the needed contributions of the (at most 41) individual antenna slots. In other words, this unique mechanical / analogue machine simulates radar waves. The block diagram of the computer can be seen in figure 4. Whereas the frequency range of radar is around 30 GHz, here a frequency of 1000 Hz is used. The sine wave of 1000 Hz is presented to 41 parallel calculation channels via a signal distribution device These channels are numbered -20° .. 0° .. +20°. Each channel simulates one antenna slot.

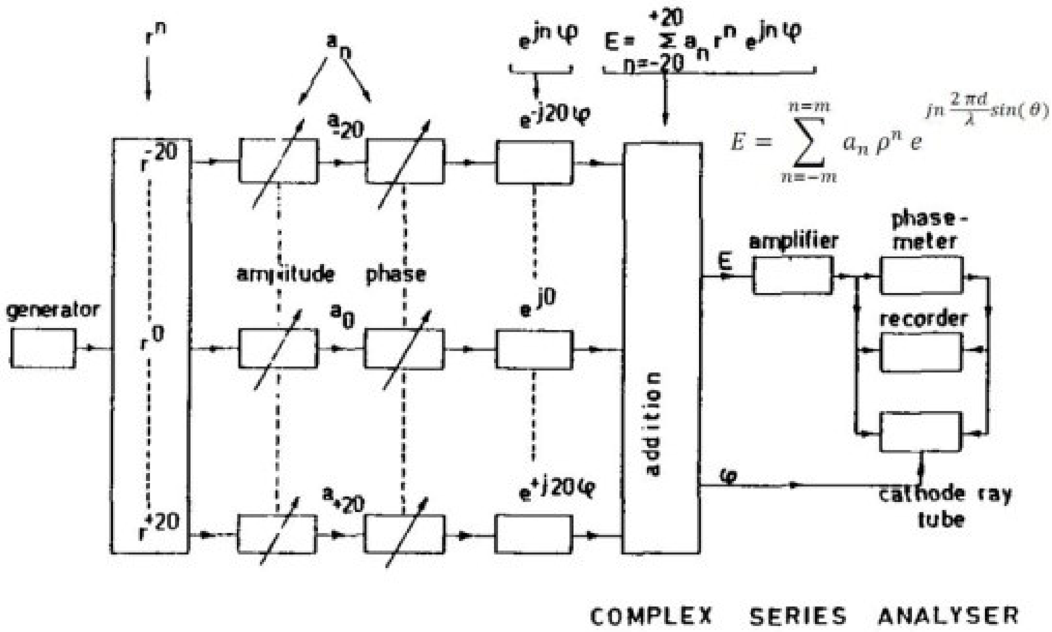

Fig 4. The block diagram of Hammer's machine. All calculations assume that the antenna slots are the same distance 'd' from each other

Fig 5. X-Y resolvers and the gear box. The positive resolvers rotate clockwise; the negative counter clockwise. The central resolver is stationary

To calculate the E-field the operator manually sets the amplitude and phase of each antenna slot on the computer. The amplitude for each channel can be set with a buffered 10-turn helipot.
Some more thought was put into setting the phase on this machine. Each channel is equipped with a so-called x-y resolver. The experimenter sets the desired value of the phase by manually turning the stator of the resolver. The rotor of each resolver is driven from a central gearbox with ratios 1: 2: 3: ..: 20. When the desired phase is set, the x-y resolver translates the mechanical angle between the stator and the rotor into two AC voltages [5]. Both, the resolvers and the gearbox, have been mounted on a very sturdy sub-chassis, so as to increase the accuracy of the computation. Figure 5 shows some resolvers and the gearbox.

The E- field is calculated for a large number of angles (θ = -30° , ... , + 30°) from the antenna aiming direction). The gearbox is driven by a central motor. This motor sets the angle θ from the aiming direction.
Using the formula

$$E = a_n \, \rho^n e^{-j\, n \frac{2\pi d}{\lambda} \sin\theta}$$

the strength of the E-field of the nth antenna slot is calculated. Subsequently, all field strengths are added together:

$$\sum_{-20}^{+20} a_n \, \rho^n \, e^{jn\phi}$$

The result is shown to the experimenter via an oscilloscope and/or a paper recording device (remember when paper recording was a norm?) as shown in figure 1. The addition of the signals is done via buffered amplifiers that use vacuum tubes. Figure 6 shows the bottom part of the electronic signal processing unit of eight resolvers.

The computer's second function of is calculating the amplitude and phase settings of the antenna slots starting with the prescribed E-field i.e. inverse processing. Towards this purpose, a so-called 'rootpot' is connected to the circuit [2]. The functioning of this part is based on finding the roots of the equation

$$\sum_{-20}^{+20} a_n \, \rho^n \, e^{jn\phi} = 0$$

Solving this equation using the 'rootpot' will give a number of complex roots. Although this part has been located in the machinery (figure 7), its precise operation is still unclear. Presumably the 'rootpot' is also used as the aforementioned signal distribution device.

Hammer's computer calculates the E-field in 12 seconds. Digital computers of that time (in 1955) needed 700 seconds for this calculation. The great developments that took place in digital technology later made this analogue / mechanical calculator from Hammer superfluous, and it was eventually donated to the Study Collection in Delft.

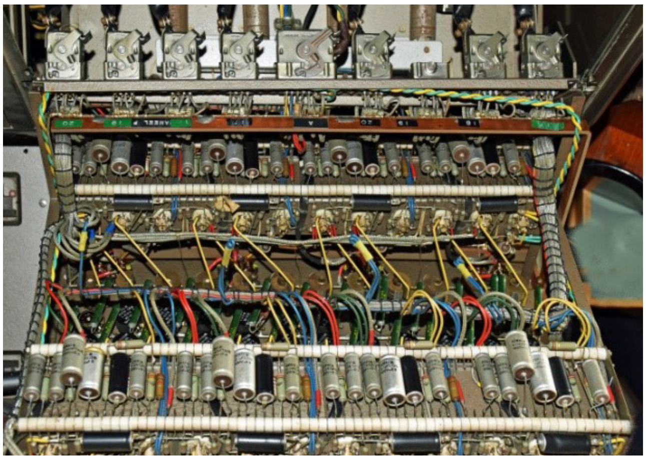

Fig 6. Electronics for signal processing of 8 resolvers

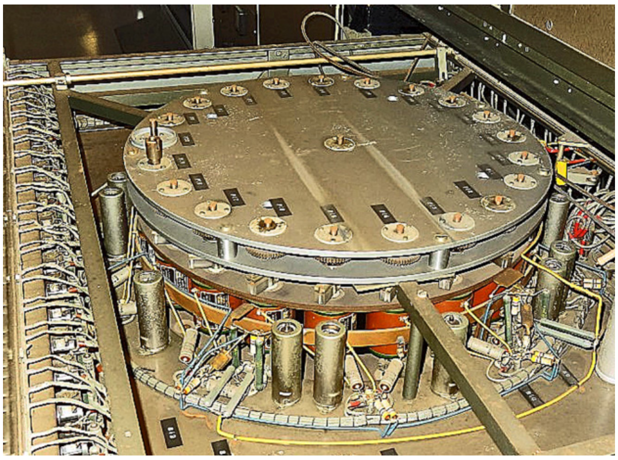

Fig 7. The Rootpot

Applications of Linear Radar Antennas

Various radar installations were constructed on the basis of experiments with Hammer's computer, both onshore and on frigates of the Royal Dutch Navy. Figure 8 shows an application of a linear radar antenna on the Dutch frigate zr. ms. Tromp (the black box on the stern, designed and produced by Thales in Hengelo). Of course, the most modern radar techniques have been used here. For more information on modern techniques, the reader is referred to [4].

Conclusion

During the Second World War, the development of radar technology in the Netherlands came almost to a standstill. After the war was done, it was decided that the Netherlands should start its own developments in this field. The Dutch Radar Test Station was established in 1947, and it started scientific and applied work on this subject. One of the developments was the creation of this analogue / mechanical computer by ir. J. A. Hammer in the years 1950-1955. It is remarkable that Dutch engineers were able to create this splendid example of electronic and mechanical design so shortly after the end of WWII.

Fig 8. zr. ms Tromp

Literature:

[1]The Evaluation of Diffraction Problems in Aerial Technology by Means of an Analyser for
Complex and Fourier Series, by: J. A. Hammer in: Principes fondamentaux: Équations de Maxwell, Principe de Huygens et Théorie de la diffraction en hyperfréquences (1956)

[2]Near Field Measurements and the Synthesis of Linear Arrays with Prescribed Radiation
Patterns: A Survey of some Early Work at the Christiaan Huygens Laboratory, by: E. Goldbohm (formerly professor at TUDelft) in: IEEE Antennas and Propagation Magazine, Vol. 35 No. 3, June 1993

[3]https://www.cryptomuseum.com/manuf/nrp/files/nrp_40.pdf

[4]https://www.museumwaalsdorp.nl/nl/radar-nl/radar-phased-array-onderzoek/

[5]X-Yresolver: https://en.wikipedia.org/wiki/Resolver_(electrical)
tennas and Propagation Magazine, Vol. 35 No. 3, June 1993