6.5.10 Piezoelectricity

Piezoelectricity is an effect in quartz and certain other crystals in which small deformations of the crystal lattice (due to exerted pressure) shift the relative positions of charged ions and produce large electric fields and voltages. Thus piezoelectric crystals make ideal sensors for pressure or acceleration, convenient microphones to convert acoustic vibrations to electrical oscillations, and compact generators for producing high voltages for other components. The effect also operates in reverse—an applied voltage produces a small deformation of the crystal. Therefore, electrically stimulated piezoelectric crystals can be used as actuators to make small, controlled motions, for example by fine-tuning the focus of optical systems, oscillating to generate sound waves, or maintaining a constant vibration frequency to serve as a time standard in a clock or watch.

Piezoelectricity was initially discovered by the French brothers Pierre Curie (1859–1906) and Jacques Curie (1856–1941) in 1880. Their discovery prompted further studies of piezoelectricity over the following decades in France, the United Kingdom, the United States, and elsewhere.

Yet it was especially in the greater German-speaking world that piezoelectricity received an enormous amount of research attention, with large numbers of scientists exploring natural and synthetic piezoelectric materials, devising theoretical explanations of piezoelectricity, and developing a wide range of applications for piezoelectric elements.[15] Some of the more prominent scientists are discussed below, and a few of them are shown in Figs. 6.133–6.135.

Woldemar Voigt (German, 1850–1919) was one of the first major scientists to study piezoelectricity in detail after its initial discovery. He spent many years conducting experiments on the topic, and he also developed the first good theoretical explanation for piezoelectricity. He published most of his insights in his 1910 textbook, *Lehrbuch der Kristallphysik.* Voigt used sophisticated tensor analysis to calculate piezoelectric effects, and he described 20 different classes of natural crystals that exhibited piezoelectric effects.

Independently of Voigt but in parallel with him, Wilhelm Röntgen (German, 1845–1923) also spent many years investigating piezoelectricity. He finally published most of his results in 1914. Directly through their teaching and mentorship, and indirectly through their publications, Voigt and Röntgen inspired large numbers of younger scientists throughout the predominantly German-speaking scientific world to study and harness piezoelectricity.

Scientists at Jena University and the Zeiss optical company in Jena collaborated to study piezoelectric vibrations and the optical effects they could produce. Those scientists included (in alphabetical order): H.E.R. Becker (German, 18??–19??), Eduard Gerber (German, 1907–1986), Ernst Grossmann (German, 18??–19??), Norbert Günther (German, 18??–19??), ?? Hehlgans (German, 18??–19??), Harald Straubel (German, 1905–1991), and Max Wien (German, 1866–1938). (After the war, Gerber led research on piezoelectric devices at the U.S. Army's Fort Monmouth lab [Fort Monmouth Historical Office 2008; Gerber-Stroh 2012].)

At Göttingen University, Elisabeth Bormann (German, 18??–19??), Max Born (German, 1882–1970, p. 1049), ?? Gockel (German, 18??–19??), Gustav Heckmann (German, 1898–1996), and Max von Laue (German, 1879–1960) worked out detailed theoretical explanations of piezoelectricity.

[15] Katzir 2006, 2018; BIOS 255; BIOS 552; BIOS 609; BIOS 724; BIOS 865; BIOS 1316; BIOS 1504; BIOS 1579; BIOS 1679; CIOS XXV-13; FIAT 575; FIAT 641; FIAT 642; FIAT 1098; NavTecMisEu 361-45.

Scientists at Breslau University developed piezoelectric devices for ultrasonic systems, acoustic levitation of small objects, and other applications. That research group included Hans Ludwig Bergmann (German, 1898–1959), Karl Bücks (German, 18??–19??), Erwin Fues (German, 1893–1970), ?? Kraefft (German, 18??–19??), ?? Lonn (German, 18??–19??), Hanfried Ludloff (German, 1899–1987), Hans Müller (German, 18??–19??), and Clemens Schaefer (German, 1878–1968).

At the Physikalisch-Technische Reichsanstalt (PTR), Udo Adelsberger (German, 1904–1992), Erich Blechschmidt (German, 18??–19??), Erich Giebe (German, 18??–19??), and Adolf Scheibe (German, 1895–1958) invented piezoelectric resonators that could be used as a very accurate frequency standard. Adelsberger later developed precise quartz clocks that were used to control timed reentry maneuvers by the U.S. Apollo spacecraft returning from the moon.

Working at Telefunken in Berlin, Rudolf Bechmann (German, 1902–1974), Kurt Heegner (German, 1893–1965), and Alexander Meissner (Austrian, 1883–1958) also created sophisticated piezoelectric resonators and conducted theoretical analyses of piezoelectricity. Bechmann continued his work in the United States after the war.

At Cologne University, H. R. Asbach (German, 19??–19??), Egon Hiedemann (German, 1900–1969), and K. H. Hoesch (German, 19??–19??) developed novel methods and applications involving the interactions of acoustic and optical waves in piezoelectric crystals.

Frankfurt University scientists such as Hermann Auer (German, 19??–19??), H. Doerffler (German, 19??–19??), and Richard Wachsmuth (German, 1868–1941) also carried out important work on piezoelectricity.

At Graz University, Berta Nussbaumer (Austrian?, 19??–19??) and Angelika Székely (Austrian?, 18??–19??) conducted experiments on piezoelectricity and its applications. Regrettably, historians of science seem to have paid little attention to these important female physicists.

Walter P. Kistler (Swiss, 1918–2015) developed sophisticated piezoelectric sensors before, during, and after World War II.

At Philips Eindhoven, B. van Dijl (Dutch, 19??–19??) and Balthasar van der Pol (Dutch, 1889–1959) studied and harnessed piezoelectricity.

There was a large research team working on piezoelectricity at Charles University and related institutions in Prague, carrying out X-ray studies and using piezoelectric vibrations. That team included ?? Dolejšek (Czech/Austrian, 19??–19??), ?? Jahoda (Czech/Austrian, 19??–19??), František Khol (Czech/Austrian, 19??–19??), Franz Krista (Austrian?, 19??–19??), Václav Petržílka (Czech/Austrian, 1905–1976), August Žáček (Czech/Austrian, 1886–1961), and L. Zachoval (Czech/Austrian, 19??–19??).

After World War II, large amounts of piezoelectric-related information, materials, and scientists were transferred from the German-speaking world to Allied countries (Fig. 6.136). See for example:

> BIOS 255. *Gas Turbine and Reciprocating Engine Activities.* [Piezoelectric sensors in engines]

BIOS 552. *Report on the Investigation on the Production of Synthetic Crystals in Germany and Copenhagen.*

BIOS 609. *Non-destructive Testing of Materials.*

BIOS 724. *Electronic Principles as Applied in Germany to the Testing of Materials.*

BIOS 865. *German Quartz Clocks and Frequency Standards.*

BIOS 1316. *German Quartz Clocks.*

BIOS 1504. *Industrial Applications of Ultrasonics.*

BIOS 1579. *Growing of Crystals.*

BIOS 1679. *Ultrasonic Material Testing and Other Applications.*

CIOS XXV-13. *Messrs. Steeg and Reuter Bad Homburg.* [Piezoelectrics and optical crystals]

FIAT 575. *Developments in Diesel Engineering.* [Piezoelectric sensors in engines]

FIAT 641. *The Interrogation of German Scientists Regarding Quartz Crystals and other Piezoelectric Materials.*

FIAT 642. *Measurement of Acceleration and Vibration.*

FIAT 1098. *Etch and Percussion Figures, and Twinning of Quartz.*

NavTecMisEu 361-45. *Piezo Pressure Measurements.*

Some of these documents also prove that German-speaking scientists developed piezoelectric sensors for aircraft engines and automobile engines before and during World War II, and that that technology was transferred to Allied countries after the war (Figs. 6.137–6.138). Piezoelectric sensors are now widely used in engines to optimize the operating conditions and report any problems.

See also the closely related research on sonar (p. 1250), ultrasound imaging (p. 1259), and other applications (p. 3199).

Please see Appendix B for much more information on some of the German-speaking creators and their creations in the field of microelectronics, as well as documents showing how those technologies were transferred to other countries.

Piezoelectricity

Rudolf Bechmann (1902–1974)

Erwin Fues (1893–1970)

Eduard Gerber (1907–1986)

Gustav Heckmann (1898–1996)

Kurt Heegner (1893–1965)

Egon Hiedemann (1900–1969)

Figure 6.133: Some creators who made important contributions to piezoelectricity included Rudolf Bechmann, Erwin Fues, Eduard Gerber, Gustav Heckmann, Kurt Heegner, and Egon Hiedemann.

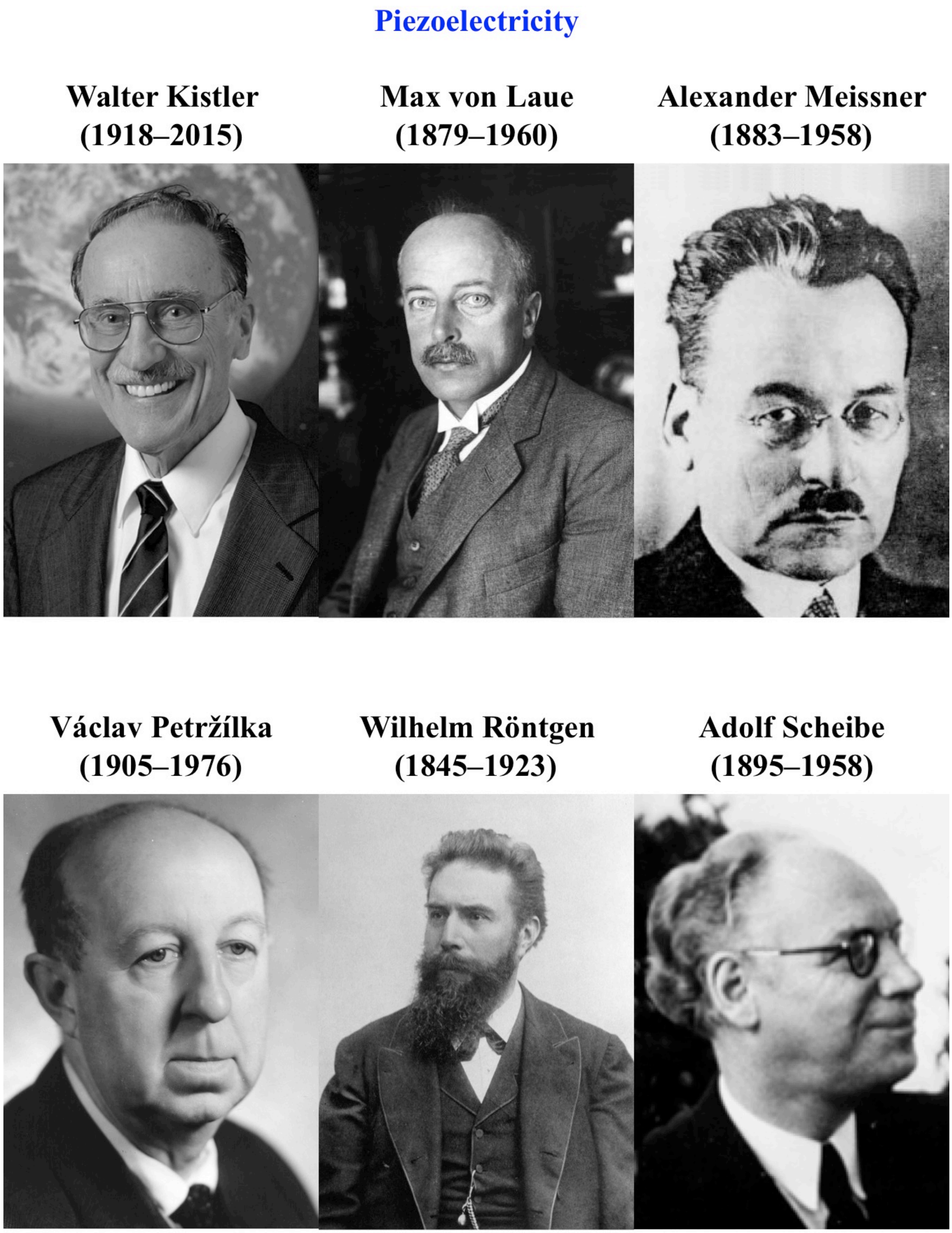

Figure 6.134: Other creators who made important contributions to piezoelectricity included Walter Kistler, Max von Laue, Alexander Meissner, Václav Petržílka, Wilhelm Röntgen, and Adolf Scheibe.

Piezoelectricity

Harald Straubel (1905–1991)

Angelika Székely (18??–19??)

Balthasar van der Pol (1889–1959)

Woldemar Voigt (1850–1919)

Richard Wachsmuth (1868–1941)

August Žáček (1886–1961)

Figure 6.135: Other creators who made important contributions to piezoelectricity included Harald Straubel, Angelika Székely, Balthasar van der Pol, Woldemar Voigt, Richard Wachsmuth, and August Žáček.

B.I.O.S. FINAL REPORT No. 724
ITEM Nos. 1, 7 & 9

ELECTRONIC PRINCIPLES AS APPLIED IN GERMANY TO THE TESTING OF MATERIALS

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Piezoelectricity

ITEM NO. 1, 7, 9
FILE NO. XXV - 13

MESSRS. STEEG AND REUTER BAD HOMBURG

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COMBINED INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON — H. M. STATIONERY OFFICE

F.I.A.T. FINAL REPORT No. 641

INTERROGATION OF GERMAN SCIENTISTS REGARDING QUARTZ CRYSTALS AND OTHER PIEZOELECTRIC MATERIALS

Report prepared by
FIELD INFORMATION AGENCY, TECHNICAL
UNITED STATES GROUP CONTROL COUNCIL
FOR GERMANY

"This report is issued with the warning that, if the subject matter should be protected by British and/or U.S. Patents or Patent applications, this publication cannot be held to give any protection against action for infringement."

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

Figure 6.136: Large amounts of information, materials, and scientists related to piezoelectric technologies were transferred out of the German-speaking world after World War II [BIOS 724; BIOS 1316; CIOS XXV-13; FIAT 641].

Piezoelectric sensors in engines

10. PIEZO-ELECTRIC PRESSURE-RECORDER (RGV)

Note that this apparatus was not seen and the following information was obtained from Dr Schmidt during interrogation on this and other topics.

The sensitive element of the pick-up was a ground quartz crystal subjected to engine cylinder pressure on one side transmitted through a metal diaphragm. The response of the instrument over a wide range of frequency was largely dependent on the resonant frequency of the diaphragm which was therefore kept high (about 100,000 c.p.s.). Moreover the support at the back of the crystal was made of lead, kept up to its duty by a spring. The lead not only assured uniform contact over the crystal on this side but produced a large measure of damping so that the peak of resonance was lowered to give a magnification of only ten at this critical frequency and very nearly unity response for a wide range of frequency below and presumably above this. The fit of the crystal to the diaphragm was found to be very critical if the quartz was not to be subjected to local or bending stresses with consequent parasitic or distorted signals and the best workmanship was necessary.

To avoid cavity resonances on the pressure side of the diaphragm, the latter was flush-mounted with the inner wall of the cylinder. With this arrangement, it was found easy to detect pressure waves and their reflections from the walls etc of the cylinder.

Unlike electromagnetic and some capacity and crystal pick-ups, the quartz crystal used in this way is a true displacement pick-up and the voltage appearing across the crystal is directly proportional to and (below resonance) in phase with the applied compression. To fully exploit the advantages of this, direct connected amplifiers were employed which retained the value of the steady pressure and would allow calibration at standstill conditions. The final voltage was the high one of 100,000 volts and this with the suitable cathode ray tube reduced the electron transit time to an absolute minimum so that pressure transients could be examined

- 17 -

FINAL REPORT No. 255
ITEM No. 26

with considerable accuracy. For checking the response curve of the pick-up, e.g. to examine the effect of the lead backing plate, the pick-up was used in reverse as a 'speaker' with an external voltage applied to the terminals.

RESTRICTED

GAS TURBINE AND RECIPROCATING ENGINE

ACTIVITIES

Figure 6.137: German-speaking scientists developed piezoelectric sensors for aircraft engines before and during World War II, and that technology was transferred to Allied countries after the war [BIOS 255].

Piezoelectric sensors in engines

IX - INSTRUMENTS FOR ENGINE RESEARCH

A. Electrical Pressure Indicators

(1) Condenser type electrical indicators have been constructed and built by Burmeister and Wain Co., Copenhagen, and also by Fiat Grandi Motori, Torine. These are built on the same principle and in similar construction already published in engineering literature. These indicators are used for measuring engine pressure variation during combustion, scavenging and in the fuel pipe of injection systems, and also to measure the injection needle lift.

For visual observation cathode ray oscillographs (e.g., made by the Philips Co.) for recording loop type oscillographs are used. Of the latter, the Siemens-Halske 14 loop oscillograph was stated to be satisfactory. In order to keep the supply voltage constant the "Stabilovolt" tube manufactured by Siemens-Halske is used.

(2) Piezo-Electric Indicators appear to have been the most widely used type of electrical indicators.

Much development work has been done on this type at the Polytechnic School in Dresden (especially by Dr. Meurer), at the Polytechnic School in Braunschweig (by Dr. Gohlke), and by FKFS (by Dr. Ing. Steiger). The articles describing the work of these men are available in the United States.

Dr. Nier in Dresden produced complete piezo-electric indicators commercially. An instrument made by him was seen at the Franz Lang Laboratory in Muenchen and appeared to be of careful design and construction. Dr. Nier built his own cathode ray oscillograph and also his own pickup, but obtained the quartz crystals from the firm of Dr. Steeg and Reuter in Bad Homburg v.d.H. which is one of the most important producers of crystals in Germany, not only for piezo-electric but also for radio, electronic and optical purposes. This company uses Brazilian quartz crystals which they cut, polish, silver plate and gold plate by their own processes in their well equipped small factory. They build complete pressure pickups in various sizes for a wide range of pressures (for scavenging and intake pressures up to 20 atm, for engine pressures up to 150 atm, and for injection pressures up to 500 atm.) for shocks (as in engine knocks) and for accelerations (for aeronautical and biological invesigations). (They are in contact with American authorities and have supplied various items to the AAF Aero Medical Center, Kaiser Wilhelm Institute, Heidelberg, Major Howard B. Burchell.) This company also builds direct current amplifiers (two stage and three stage) and other accessory devices. They do not build oscillographs. The firm Zeiss-Ikon, Dresden, also manufactures piezo-electric indicators which are well known in the U.S. A number of piezo-electric pickups and associated equipment are shown in Figs. 23-31.

In the mounting of the quartz crystals, important considerations are: (1) that the crystals are scrupulously clean, without a trace of grease or humidity which may short circuit the faces of opposed polarity, therefore the chamber in which the quartzes are located is closed and hermetically sealed so as to prevent any contamination by engine gases or by the atmosphere; (2) that a certain preload is given to the crystals, i.e., the direction of the load is not changed during operation only the magnitude of the load being affected by the varying engine pressures; therefore an elastic member is provided which may be either a flat membrane or a thin walled cylindrical capsule.

In general the quartzes are made in the shape of discs, the forces acting in the direction of the piezo-electric axis. A recent modification is to make the quartzes in the shape of long columns stressed in bending (buckling) by the force to be measured which is in the direction perpendicular to the piezo-electric axis.

Fig. 23 shows a pickup for very high pressures (fuel injection pressures), which are communicated by a piston to the quartz discs, which latter are preloaded by a membrane (MAN)

Fig. 24 shows a pickup for engine pressure which is transmitted to the quartz discs by means of a floating member mounted between two clamped membranes (to ensure axiality of motion) (MAN)

Fig. 25 shows a pickup for engine pressure. The quartz discs are enclosed within and preloaded by a thin walled cylindrical cartridge. Thislatter has a thick, rigid bottom, the axial motion of which is ensured by a thin, clamped membrane which also prevents the passage of hot and oily engine gases from coming in contact with the sidewalls of the cartridge (MAN)

Fig. 26 shows a two seated switch valve (MAN) acted upon on one side by the varying engine pressure and on the other side by a constant but manually adjustable measured balancing pressure. During the portion of the engine cycle, during which the balancing pressure is greater than the engine pressure, the valve is in its lowermost position and allows the engine pressure to act upon the piezo-electric pickup. During the portion of

FIAT FINAL REPORT 575

DEVELOPMENTS IN DIESEL ENGINEERING

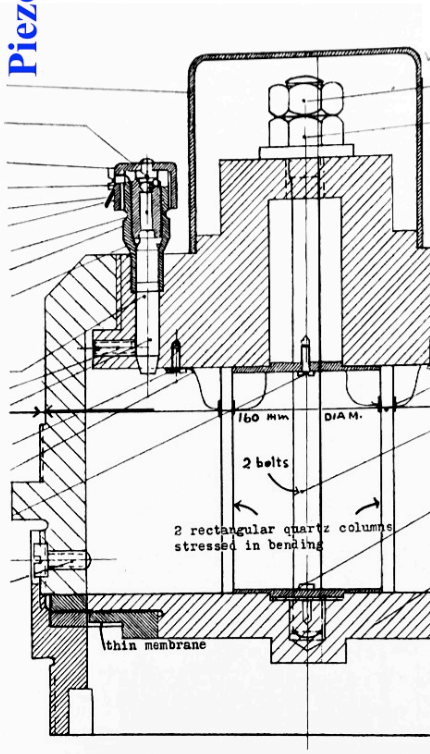


Fig. 31 - Pieze-electric pickup (Dr. Steeg und Reuter) Type 160-20-0.06. For accelerating force measurement in airplanes.

the engine cycle, during which the engine pressure is higher than the balancing pressure, the valve is in its uppermost position and shuts off the communication between the engine space and the piezo-electric pickup. This valve is useful for two purposes: (1) the high pressures are kept away from the pickup, therefore a sensitive pickup can be used which is capable of responding to small pressure variations such as occur during the intake and exhaust process (2) during the shut-off portion of the cycle, the oscillograph shows a horizontal line the height of which corresponds to the adjusted and measured balancing pressure which, therefore, represents a calibration of the pickup under actual working conditions.

Figs. 27, 28, and 29 show piezo-electric pickups (Dr. Steeg und Reuter) using quartzes enclosed in cylindrical cartridges, whereby the quartz discs are stressed in compression.

Figs. 30 and 31 show piezo-electric pickups (Dr. Steeg und Reuter) using quartzes enclosed in cylindrical cartridges; the quartzes are in this case in the form of comparatively slender columns which are stressed in bending (buckling) by the acting forces. The direction of force is perpendicular to the pieze-electric axis of the crystals. It is claimed that this construction is particularly suitable for the measurement of small forces.

Fig. 31 - is a special, very large pickup (Dr. Steeg und Reuter) intended for the measurement of accelerating forces. The general principle is the same as described above. In view of the comparatively small variation in acceleration, large mass and slender columns are used. (An engineer of Dr. Steeg und Reuter stated that this type was assumedly used for some aeronautical research, probably for the investigation of accelerations occurring during launching of a plane by a catapult, or picking up a glider by an airplane; they claimed not to have knowledge of the exact purpose).

(3) Photoelectric indicator has been developed by H. Maihak A.G., Hamburg, Figs. 32-38. It contains a stiff metal diaphragm as the pressure measuring element, the surface of which is polished to serve as a mirror. The convexity of the mirror increases with increasing pressure. A beam of light is directed on the mirror and is reflected by it on to a photo-electric cell. Due to the varying convexity of the mirror the photoelectric cell receives varying amounts of light and produces a current of varying intensity. This current, amplified, is fed to an oscillograph. This instrument is marketed complete with pickups for crank angle and piston

Figure 6.138: German-speaking scientists developed piezoelectric sensors for automobile engines before and during World War II, and that technology was transferred to Allied countries after the war [FIAT 575].

6.6 Infrared Vision and Targeting

German-speaking creators played crucial roles in the development of infrared technologies, from the initial discovery of infrared light to the invention of infrared systems for night vision, optical communications, and heat-seeking missiles.[16] Those technologies were developed in Germany and Austria (Section 6.6.1) and then transferred to other countries after World War II (Section 6.6.2).

6.6.1 Development of Infrared Technologies

Using spectroscopy to search for energy beyond the colors of visible light, Friedrich Wilhelm (William) Herschel (Hanover, 1738–1822) discovered infrared light in 1800 [Herschel 1800]. See Fig. 6.139. He also discovered the planet Uranus and made several other important astronomical discoveries (p. 809).

Technologies such as photoelectric cells (p. 1055) and cathode ray tubes (p. 1005) that had been invented by German-speaking scientists in the late nineteenth century and improved in the early twentieth century were later harnessed to detect infrared light for a wide variety of applications.

In 1941, Herbert C. J. Gaertner (German, 1906–19??) at the Zeiss optical company developed the Fahrgerät FG 1250 infrared vision system for nighttime driving. As shown in Fig. 6.140, the FG 1250 system combined a lamp that emitted only infrared light with a viewing scope that converted infrared to visible light. The FG 1250 system was also used for nighttime tank warfare (Fig. 6.141). Figure 6.142 shows an example of an armored vehicle with two FG 1250 infrared vision systems, one for a nighttime antiaircraft gun and another for nighttime driving.

The Uhu system was a closely related infrared vision system that was equipped with a larger nighttime infrared searchlight; see Fig. 6.143.

The Zielgerät 1229 Vampir (Vampire) infrared night-vision system for snipers was first operational in 1944. Figure 6.144 present photos of a ZG 1229 being demonstrated by a British soldier after the war. ZG 1229 and more advanced versions directly descended from it were rapidly adopted by Allied troops, and have been widely used ever since by everyone from soldiers to police to hunters.

Whereas the above systems all used relatively large viewing scopes, infrared viewing was also adapted to a compact binocular format, essentially producing the first infrared night-vision goggles. After the war, Allied investigators found prototypes of the infrared binoculars (Fig. 6.145) and used them as the basis for developing later versions of night-vision goggles.

Both infrared and visible light were employed for communications. In 1901, Ernst Ruhmer (German, 1878–1913) demonstrated a photophone that used visible light to transmit voice communications (Fig. 6.146). By World War II, the compact Zeiss infrared Lichtsprechgerät was used for efficient

[16] See for example: Benecke and Quick 1957; Herschel 1800; BIOS 2; BIOS 211; BIOS 1345; BIOS Misc 66; CIOS ER 160; CIOS XXIV-7; CIOS XXX-3; CIOS XXX-108; CIOS XXXI-14; CIOS XXXIII-9; FIAT 4; FIAT 708; FIAT 769; FIAT 1172; JIOA 5; NavTecMisEu LR 77-45; NavTecMisEu LR 228-45; NavTecMisEu 109-45; NavTecMisEu 127-45; NavTecMisEu 242-45; NavTecMisEu 273-45; NavTecMisEu 274-45; NavTecMisEu 488-45; NavTecMisEu 497-45; NavTecMisEu 518-45; NavTecMisEu 519-45; AFHRA B1975, frames 1325–1495; NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards.

optical transmission of voice communications over distances up to several kilometers; see Fig. 6.147. The Lichtsprechgerät was also demonstrated with visible light. These systems were the direct forerunners of fiber optic communications that are now employed worldwide, except the light signals were transmitted through air instead of through transparent optical fibers. Optical glass fibers were also invented in the German-speaking world (p. 686). More archival research is needed to determine if optical fibers were ever used or considered for use in conjunction with optical data transmission in wartime Germany.

Another important application of infrared was in heat-seeking missiles that could automatically home in on the heat emitted by the engines of their target. As shown in Fig. 6.148, Edgar Kutzscher (German, 1906–1997) developed and demonstrated infrared tracking systems for heat-seeking missiles during the war. In fact, at least half a dozen different types of heat-seeking missile guidance systems were developed and built during the war. Figures 6.149–6.151 show some of their designs and creators.

After the war, Edgar Kutzscher discussed the development of the infrared photocells that were used in these heat-seeking missile guidance systems [Benecke and Quick 1957, pp. 208–209]:

> Practically all infrared devices developed before and during the war in Germany, and especially the devices which were used for detection of or homing on aircraft, used as receiver elements these photoconductive cells which we had developed at the ELEKTROACUSTIC CO. in Kiel. Dr. GOTTFRIED SOMMER, Dr. PICK, and Mr. KURT JUNG were my main co-operators in this part of the development.
>
> The cells which were available during the war fulfilled sufficiently the requirements of such an infrared detector. Extensive research and development work was still going on at the end of the war. [...] The lead sulphide cell of the ELEKTROACUSTIC CO. was produced by using a chemical precipitation method. Cells with various sizes and shapes of the sensitive area have been made. A large scale production was under way. Similar cells were developed by Dr. GÖRLICH at the laboratories of ZEISS-IKON in Dresden. GÖRLICH refined and used an evaporation method which was developed by the late Prof. GUDDEN.
>
> Much time and effort was spent in continuously improving the paramount properties of both types of cells, especially by modifying the production parameters and introducing the right impurities in the optimum amount.
>
> The sensitivity of those cells could be increased by a factor of 10 to 20 by cooling them. Liquid air and later solid CO_2 were used as coolants.

Kutzscher also described some of the heat-seeking systems and their creators [Benecke and Quick 1957, pp. 215–216]:

> Homing systems based on the principles described were developed by the ELEKTROACUSTIC CO. in Kiel, under the name "HAMBURG". [...]
>
> For cases where the homing device detected the target before launching the missile, the homing device signals should be displayed to the pilot. For other cases, additional

infrared search devices installed in the aeroplane were developed. My main co-operators in the field of system development were Dr. RÜCKLIN, Dr. OCHMANN, Dr. AHRENS, Dr. HEITMÜLLER, and Dipl.-Ing. ORLICH.

Other infrared homing devices which were under development used in general the same principles we have discussed. The main difference between these various devices was the scanning method in order to obtain the angular information.

A device proposed by Dr. HILGERS of the AEG used a photocell with an area large enough to cover the total field of view in the focal plane. Two very narrow mechanical stops were moved perpendicular to each other across the cell. As soon as the image was covered by a stop a pulse was generated. [...] The firm KEPKA, in Vienna, used a similar principle by moving two narrow slits across the field. [...]

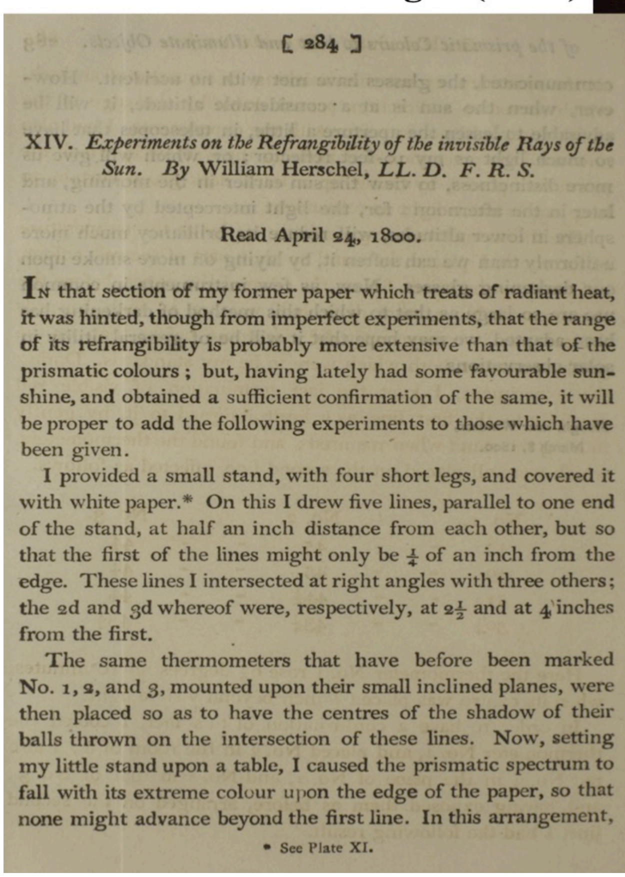
Mr. TRENKELFORD associated with RHEINMETALL-BORSIG developed a system for which the scanning was accomplished by two rotating discs, one of them having a spiral opening, the other one a slit. [...]

Dr. ORTHUBER of the AEG used a frequency modulation for scanning. The position of the target within the focal plane was given by a frequency, generated by two discs scanning the field of view. [...]

In conclusion, it should be noted that after considering the advantages and disadvantages of an infrared method and the results of the laboratory and field tests carried out on experimental devices, the people concerned were convinced in 1944 and 1945 that an infrared homing device constituted an excellent solution to certain guidance problems for missiles.

Friedrich Wilhelm (William) Herschel (1738–1822)

Discovered infrared light (1800)



[284]

XIV. *Experiments on the Refrangibility of the invisible Rays of the Sun. By* William Herschel, *LL. D. F. R. S.*

Read April 24, 1800.

In that section of my former paper which treats of radiant heat, it was hinted, though from imperfect experiments, that the range of its refrangibility is probably more extensive than that of the prismatic colours; but, having lately had some favourable sunshine, and obtained a sufficient confirmation of the same, it will be proper to add the following experiments to those which have been given.

I provided a small stand, with four short legs, and covered it with white paper.* On this I drew five lines, parallel to one end of the stand, at half an inch distance from each other, but so that the first of the lines might only be $\frac{1}{4}$ of an inch from the edge. These lines I intersected at right angles with three others; the 2d and 3d whereof were, respectively, at $2\frac{1}{2}$ and at 4 inches from the first.

The same thermometers that have before been marked No. 1, 2, and 3, mounted upon their small inclined planes, were then placed so as to have the centres of the shadow of their balls thrown on the intersection of these lines. Now, setting my little stand upon a table, I caused the prismatic spectrum to fall with its extreme colour upon the edge of the paper, so that none might advance beyond the first line. In this arrangement,

* See Plate XI.

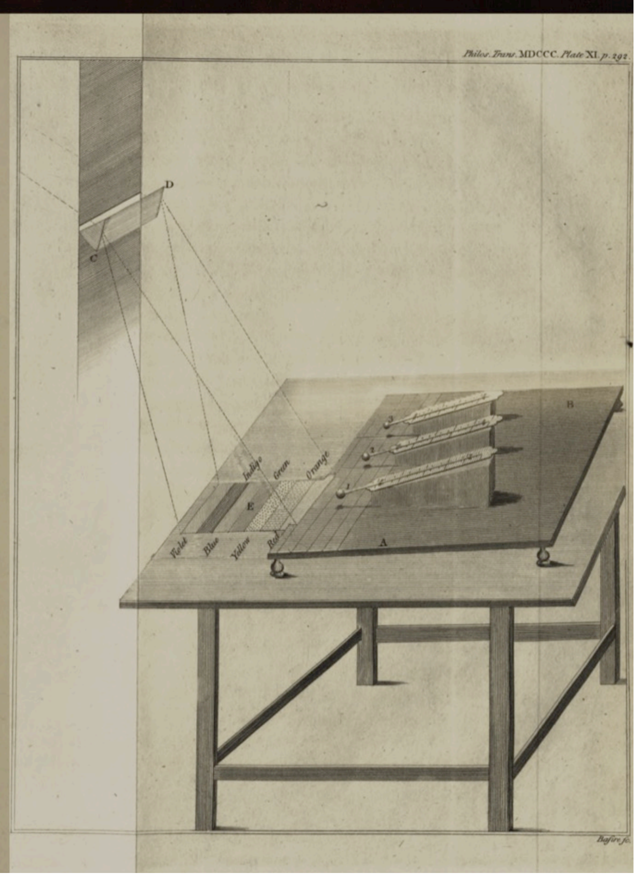


Figure 6.139: Friedrich Wilhelm (William) Herschel (1738–1822) discovered infrared light in 1800.

Herbert C. J. Gaertner
(1906–19??)

Fahrgerät FG 1250 infrared vision for nighttime driving

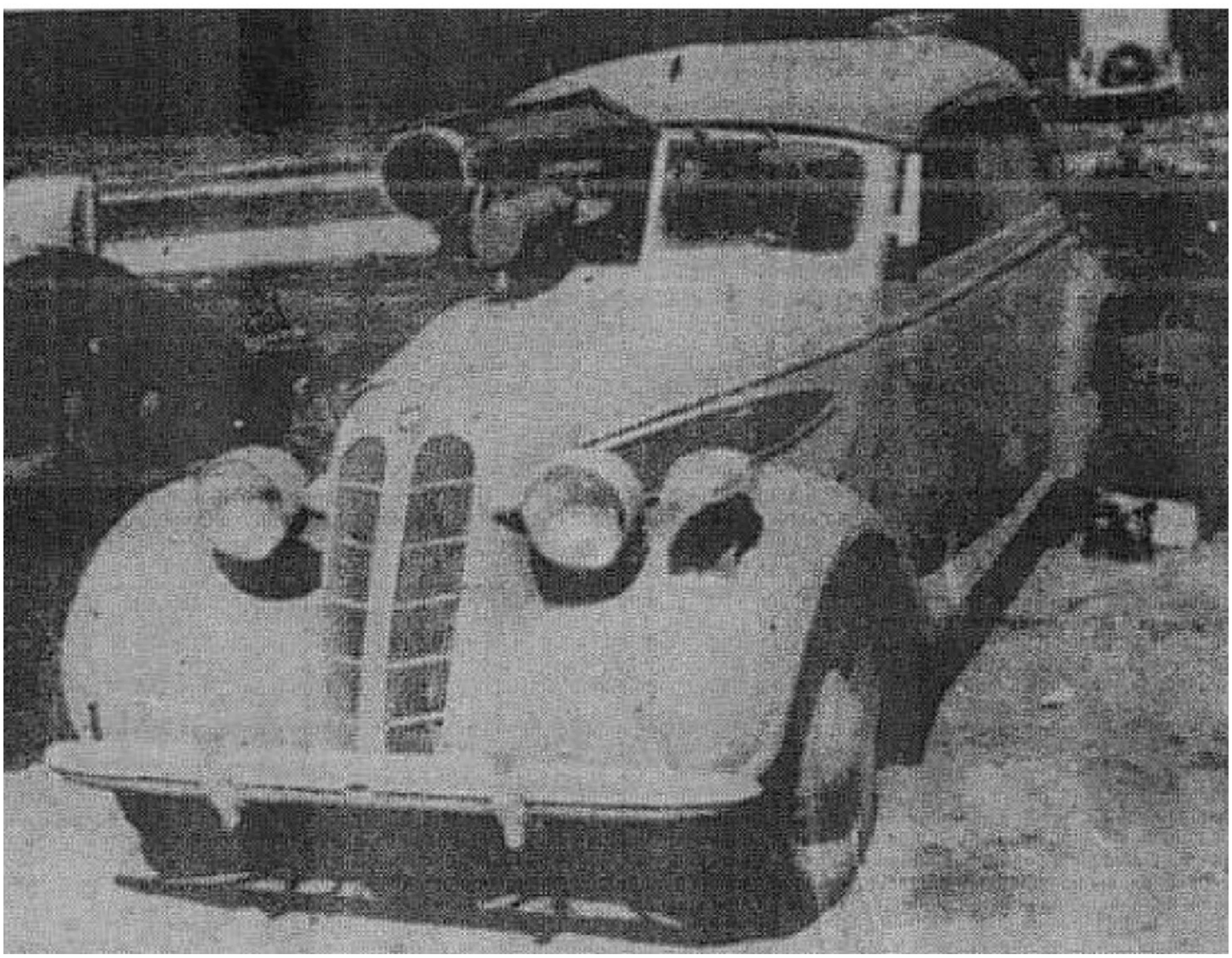


Figure 6.140: Herbert C. J. Gaertner developed the Fahrgerät FG 1250 infrared vision system for nighttime driving [BIOS Misc 66].

Figure 6.141: The Fahrgerät FG 1250 infrared vision system was also used for nighttime tank warfare.

Figure 6.142: Example of an armored vehicle with two Fahrgerät FG 1250 infrared vision systems, one for a nighttime antiaircraft gun and another for nighttime driving [BIOS Misc 66].

Figure 6.143: Uhu infrared vision system for nighttime searchlights.

Zielgerät 1229 Vampir infrared vision for nighttime snipers (1944)

Figure 6.144: The Zielgerät 1229 Vampir (Vampire) infrared night-vision system for snipers, first operational in 1944 [BIOS Misc 66].

Infrared night-vision goggles

3.8 BINOCULARS.

This is a pocket receiver, without transmitter, developed experimentally. It is the smallest equipment available. One half of the instrument is a night glass, the other half an I.R. receiver. Its performance was not assessed.

Figure 6.145: The first infrared night-vision goggles.

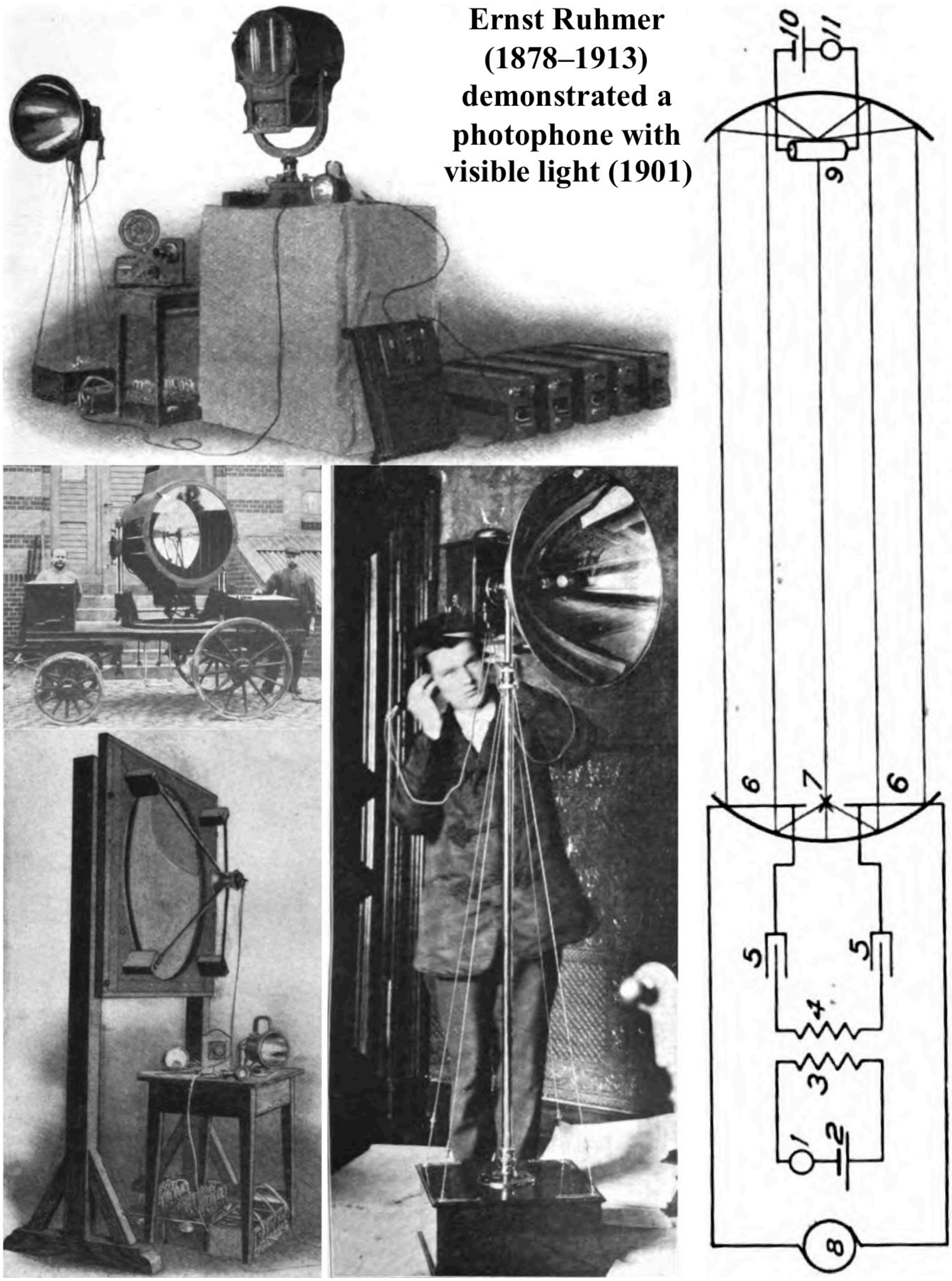


Figure 6.146: In 1901, Ernst Ruhmer demonstrated a photophone that used visible light to transmit voice communications.

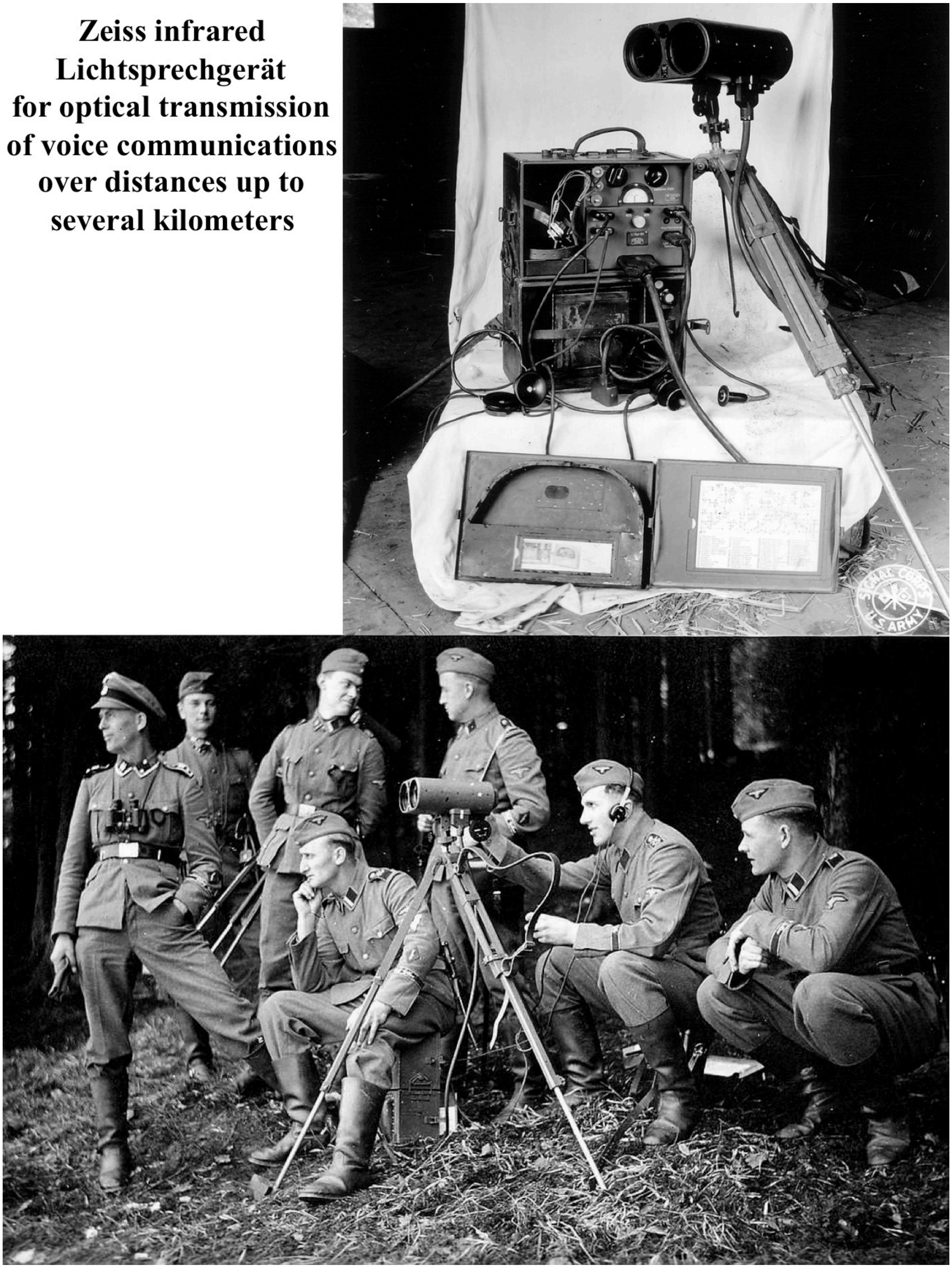
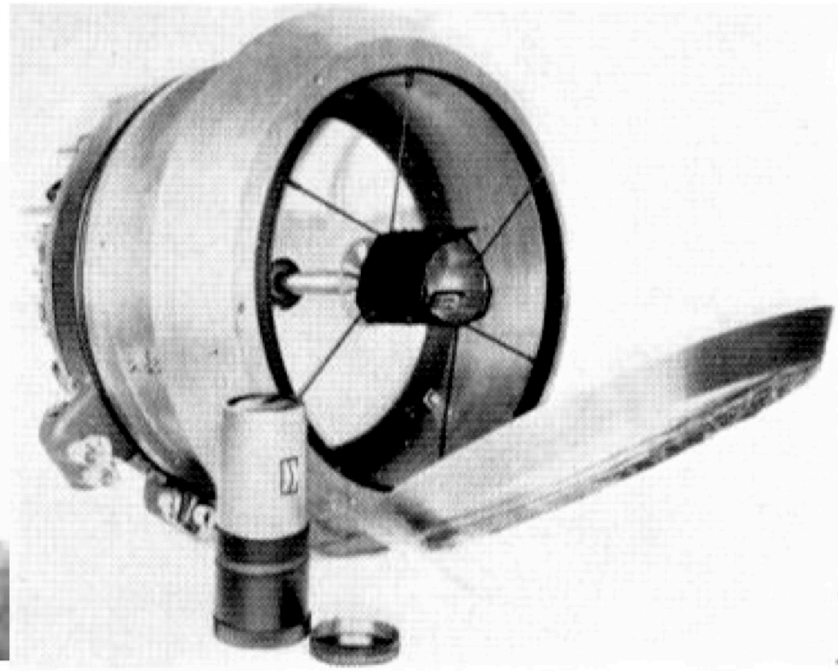


Figure 6.147: The compact Zeiss infrared Lichtsprechgerät allowed the efficient optical transmission of high-quality voice communications over distances up to several kilometers.

Edgar Kutzscher (1906–1997)

***Hamburg* heat-seeking system for Blohm & Voss BV 143 missile**



Blohm & Voss BV 143 missile

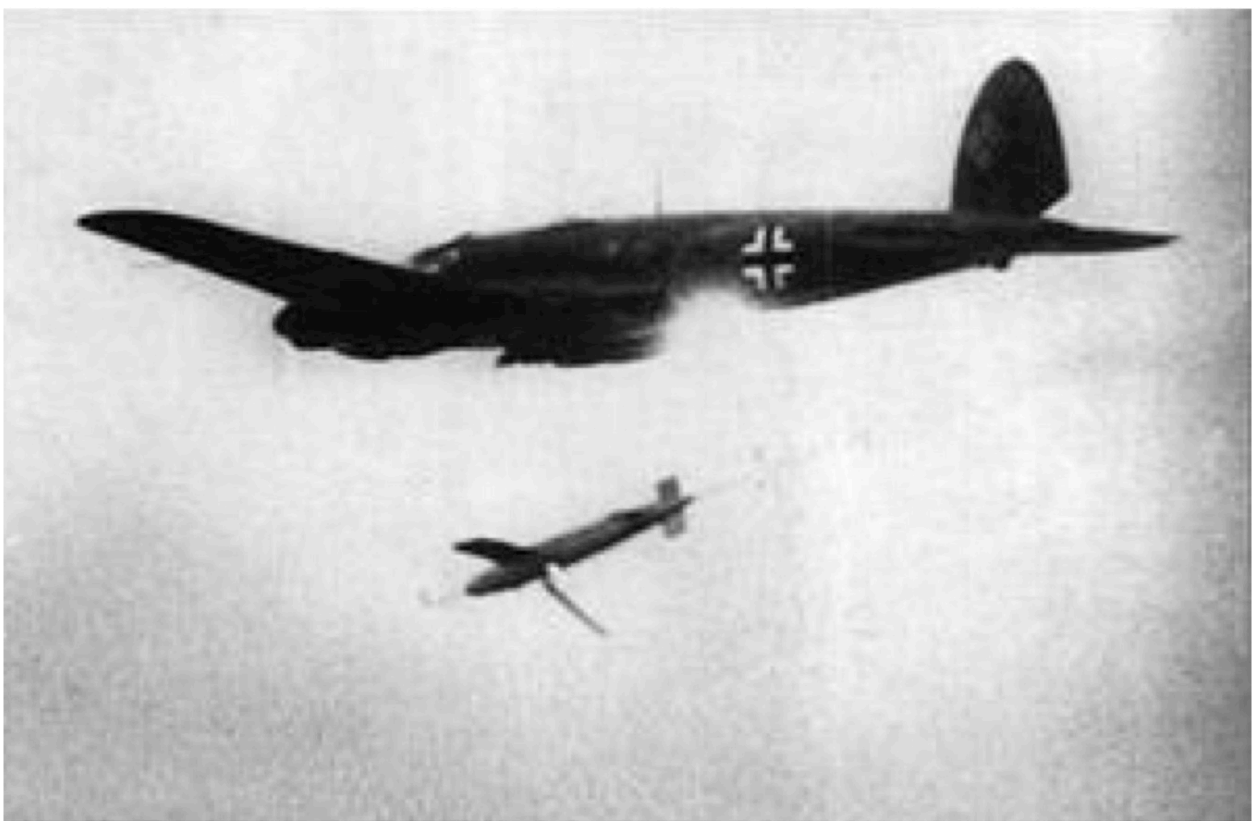


Figure 6.148: Edgar Kutzscher developed infrared tracking systems for heat-seeking missiles during the war.

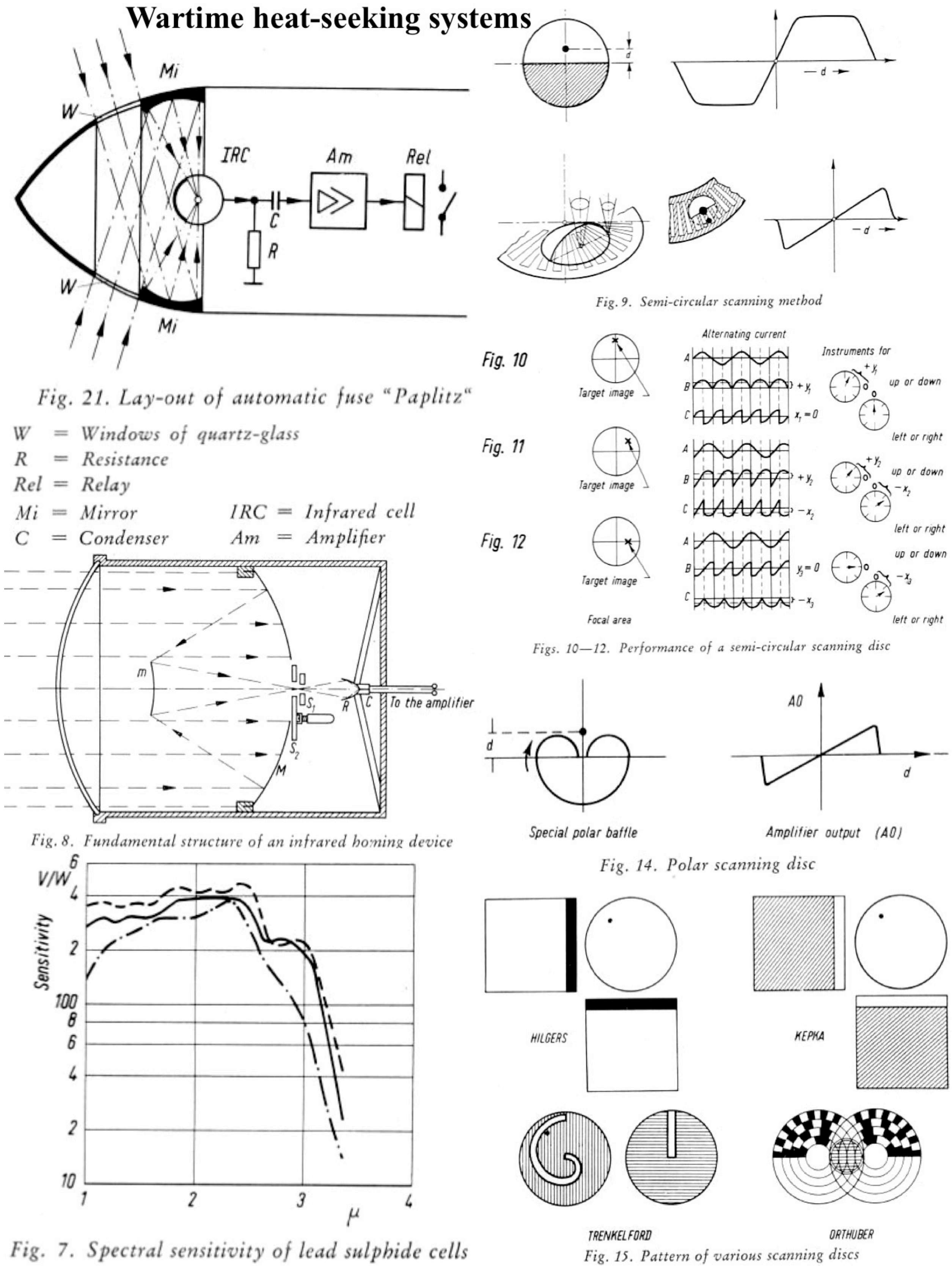


Figure 6.149: Designs for several different heat-seeking missile guidance systems that were developed during the war [Benecke and Quick 1957].

Heat-seeking missile guidance systems

?? Ahrens
(19??–19??)
Heat seeking systems

Habil Görlich
(19??–19??)
IR PbS photocells

?? Heitmüller
(19??–19??)
Heat seeking systems

?? Hilgers
(19??–19??)
Heat seeking systems

Kurt Jung
(19??–19??)
IR PbS photocells

?? Ochmann
(19??–19??)
Heat seeking systems

Figure 6.150: Some other German-speaking creators of wartime and postwar heat-seeking missile guidance systems.

Heat-seeking missile guidance systems

?? Orlich
(19??–19??)
Heat seeking systems

?? Orthuber
(19??–19??)
Heat seeking systems

Heinz Pick
(1912–1983)
IR PbS photocells

?? Rücklin
(19??–19??)
Heat seeking systems

Gottfried Sommer
(19??–19??)
IR PbS photocells

?? Trenkelford
(19??–19??)
Heat seeking systems

Figure 6.151: Some other German-speaking creators of wartime and postwar heat-seeking missile guidance systems.

6.6.2 Transfer of Infrared Technologies

At the end of the war, Allied scientists, engineers, and military personnel pored over the German infrared technologies for use in their own countries and wrote numerous reports. See for example Fig. 6.153 and the following reports:

BIOS 2. *German Photoconducting Cells for the Detection of Infra-Red Radiation.*

BIOS 211. *Infra-red Research, Dr. A. Becker, 36 Blumenthal Strasse, Heidelberg.*

BIOS 1345. *Some Developments in Infra-Red and Raman Spectroscopy in Germany.*

BIOS Misc 66. *German Infra Red Driving and Fire Control Equipment.*

CIOS ER 160. *German Infra-Red and Ultra-Violet Developments.*

CIOS XXIV-7. *German Infra Red Driving and Fire Control Equipment at Falling Bostel.*

CIOS XXX-3. *German Infra-Red Equipment in the Kiel Area.*

CIOS XXX-108. *German Infra-Red Devices and Associated Investigations.*

CIOS XXXI-14. *Binoculars for Night Seeing.*

CIOS XXXIII-9. *German Infra-Red Devices and Associated Investigations Report No. 2.*

FIAT 4. *German Infrared Targets in South Germany and Austria.*

FIAT 708. *A Survey of the Use of Infra-Red Spectra in Chemical Analysis in Germany.*

FIAT 769. *Electron Microscopy, Infra Red and Other Branches of Applied Physics.*

FIAT 1172. *Measurements of Threshold Sensitivity of the Human Eye in the Near Infrared.*

JIOA 5. *Infrared Targets at Hillersleben, Jena and Wetzlar. 19 Apr–May 4, 1945.*

NavTecMisEu LR 77-45. *Lead Sulphide Semi-Conductor Infra-red Cells for Homing Rockets.*

NavTecMisEu LR 228-45. *Infra-red Homing Devices.*

NavTecMisEu 109-45. *German Infrared Equipment in the Kiel Area.*

NavTecMisEu 127-45. *German Infrared Devices and Associated Investigations.*

NavTecMisEu 242-45. *"Paplitz" Infra-red Fuse Development of Elac.*

NavTecMisEu 273-45. *German Infra-red Homing Device "Emden."*

NavTecMisEu 274-45. *German Infra-red Homing Device "Karussell."*

NavTecMisEu 488-45. *A Review of Infrared Developments by Gema, of Berlin.*

NavTecMisEu 497-45. *A Review of the Infrared Work of the Electrical Testing an Experimental Office of the German Railways, "Elversa" (Elektro Technischos Versuchsamt Der Reichsbahn).*

NavTecMisEu 518-45. *German Progress in the Development of Heat Iconoscopes (Infrared Image Tubes Sensitive To Wavelengths Longer than 2 Microns).*

NavTecMisEu 519-45. *The Properties of Klieforth Infrared Transparent Glasses.*

After analyzing the German technologies, the U.S. Department of Commerce wrote an assessment (Fig. 6.152) praising how much more advanced they were than anything that the United States had possessed, and how much they would benefit the United States in the future [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards]:

> Information which has been secured concerning German developments accomplished in the field of infra-red light has proved to be of inestimable value to the military services of this country and will definitely effect an even greater contribution for our civilian purposes.
>
> Prior to the discovery of the German developments in this field, the United States had been unsuccessful in converting infra-red to visible light. Investigation has revealed that the Germans not only succeeded in converting infra-red light into visible light but also had been successful in its application for military purposes to a remarkable degree. They had applied this development in perfecting a spotlight which made possible the movement of army vehicles in total darkness without the use of visible illumination. By the use of another night-seeing device which the Germans used before the siege of Berlin, one of their tanks which was located in a woods, put sixty Russian tanks out of action by direct gunfire in total darkness as fast as the tanks came into view on a road which was a mile away from the German tank.
>
> The adaptation of similar device for use as a "sniperscope" enabled German snipers to fire effectively at Allied troops in total darkness at a range of 300 feet. Information obtained during interrogation of the first German prisoner who was captured with one of these units intact was immediately sent to this country where it was at first claimed that such a development was impossible. The device was then rushed to this country by air and production of it was started immediately. It was first used by American troops on Okinawa much to the bewilderment of the Japanese. Detailed information, including actual photographs of the captured German equipment is contained in Report No. PB-1587 made available by the Office of Technical Services of the Department of Commerce.

> The Germans also successfully applied infra-red light in the development of a device for voice transmission. This device permitted communication by means of an invisible light beam, without risk of interception, over short distances such as across rivers or valleys. A binocular attachment fitted with filters which made the infra-red beam visible, was used for focusing the wireless "telephone line". American industry is keenly interested in this device which has been evacuated to this country and is on loan to industry for test and research purposes. Information pertaining to this device is contained in Report No. PB-19746 published by the Office of Technical Services of the Department of Commerce.
>
> Some of the more obvious commercial applications of infra-red light developments thus revealed will be of inestimable value in the field of medicine, particularly in eye examination; and in the law enforcement field, where night-seeing can be employed in the detection of crime and the apprehension of criminals.

In addition to acquiring all of the infrared hardware, documentation, and information, the United States (and other countries) also hired many German-speaking experts to produce infrared systems after the war. Some examples include:

- Werner Karl Weihe (German, 19??–19??) developed infrared systems in Germany during the war, and at Wright Field, Ohio, after the war (Fig. 6.154).

- After the war, Hans K. Ziegler (German, 1911–1999) came to the United States in Operation Paperclip and became the Chief Scientist of a U.S. Army laboratory in Fort Monmouth, New Jersey, that employed many other German-speaking scientists and harnessed infrared and other technologies acquired from Germany and Austria [Fort Monmouth Historical Office 2008]. See Fig. 6.155–6.156.

- Edgar Kutzscher and other German-speaking creators used their wartime experience to develop postwar infrared heat-seeking missiles such as the U.S. Falcon and Sidewinder (Figs. 6.157–6.158).

- Heinz Schlicke (German, 1912–2006), an expert on infrared, electronics, and potentially nuclear-related technologies, arrived in the United States in May 1945 along with a whole German submarine filled with those technologies [AFHRA B1975, frames 1325–1495]. He spent the rest of his career in the United States. See pp. 4904–4938 for more information.

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NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards

VIII

INFRA-RED

Information which has been secured concerning German developments accomplished in the field of infra-red light has proved to be of inestimable value to the military services of this country and will definitely effect an even greater contribution for our civilian purposes.

Prior to the discovery of the German developments in this field, the United States had been unsuccessful in converting infra-red to visible light. Investigation has revealed that the Germans not only succeeded in converting infra-red light into visible light but also had been successful in its application for military purposes to a remarkable degree. They had applied this development in perfecting a spotlight which made possible the movement of army vehicles in total darkness without the use of visible illumination. By the use of another night-seeing device which the Germans used before the siege of Berlin, one of their tanks which was located in a woods, put sixty Russian tanks out of action by direct gunfire in total darkness as fast as the tanks came into view on a road which was a mile away from the German tank.

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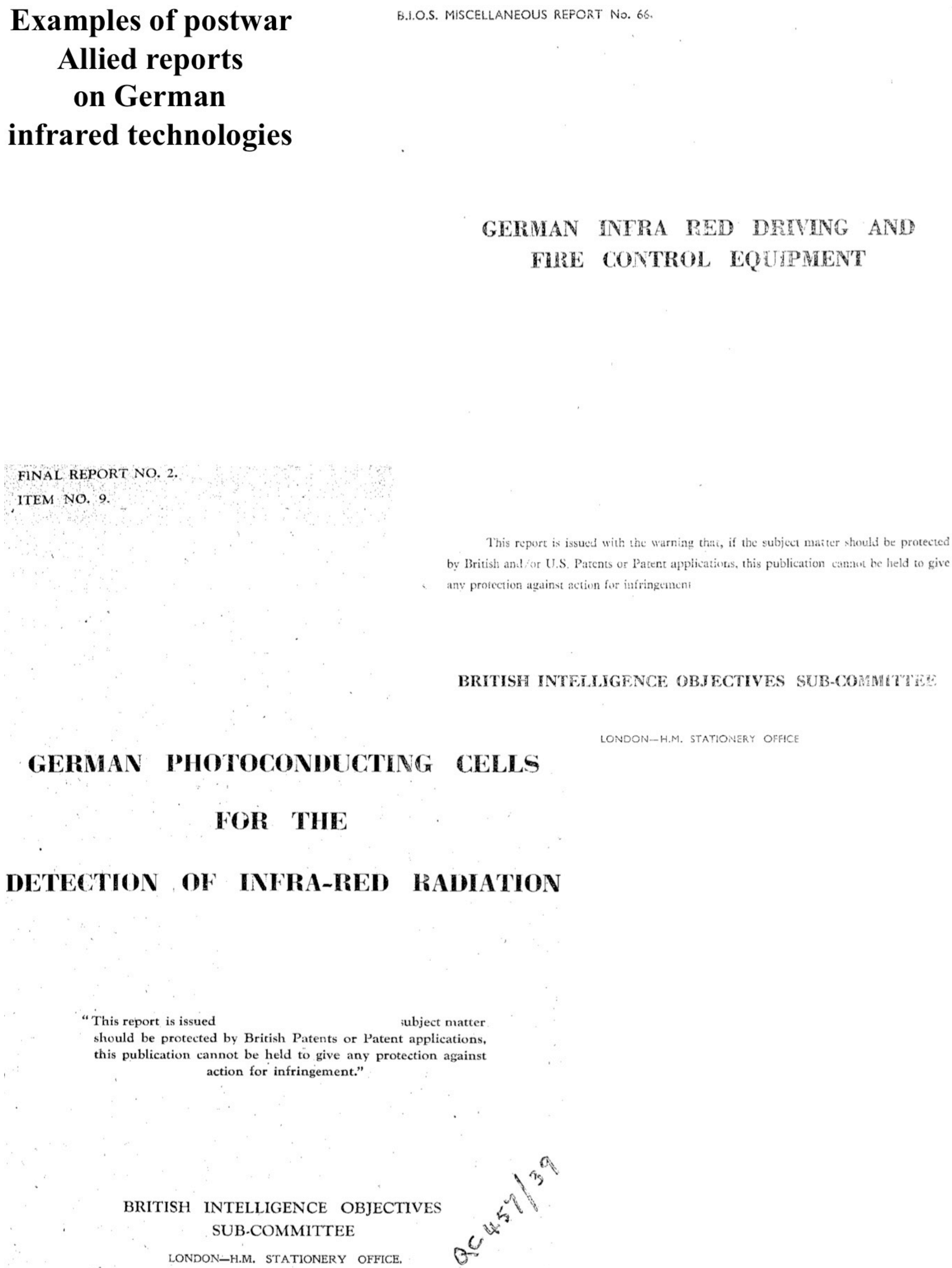
Some of the more obvious commercial applications of infra-red light developments thus revealed will be of inestimable value in the field of medicine, particularly in eye examination; and in the law enforcement field, where night-seeing can be employed in the detection of crime and the apprehension of criminals.

See attached letter.

Figure 6.152: A wide variety of revolutionary infrared technologies were developed in the German-speaking world and transferred to other countries after World War II [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].



Examples of postwar Allied reports on German infrared technologies

B.I.O.S. MISCELLANEOUS REPORT No. 66.

GERMAN INFRA RED DRIVING AND FIRE CONTROL EQUIPMENT

This report is issued with the warning that, if the subject matter should be protected by British and/or U.S. Patents or Patent applications, this publication cannot be held to give any protection against action for infringement

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE

FINAL REPORT NO. 2.
ITEM NO. 9.

GERMAN PHOTOCONDUCTING CELLS FOR THE DETECTION OF INFRA-RED RADIATION

"This report is issued subject matter should be protected by British Patents or Patent applications, this publication cannot be held to give any protection against action for infringement."

BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

LONDON—H.M. STATIONERY OFFICE.

QC457/39

Figure 6.153: Examples of postwar Allied reports on German infrared technologies [BIOS 2; BIOS Misc 66].

Werner Karl Weihe
(19??–19??)
Infrared systems

Figure 6.154: Werner Karl Weihe developed infrared systems in Germany during the war, and at Wright Field, Ohio, after the war [*Dayton Daily News*, 8 December 1946, p. 55].

Mr. O. W. Holloway   29 April 1948

Edwin Y. Webb

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NARA RG 40, Entry UD-75, Box 58, Folder Webb

As you know two representatives of the Signal Corp, Mr. Kaprillian, Chief of the Optical Division, and his assistant Dr. Keck, spent Monday, Tuesday and Wednesday opening and examining the contents of the trunks and documents stored at 15 Canal Street. So far, they have examined and labeled approximately 800 trunks. They were extremely complimentary of the cooperation given them by Mr. Sherwin and the men he assigned to assist.

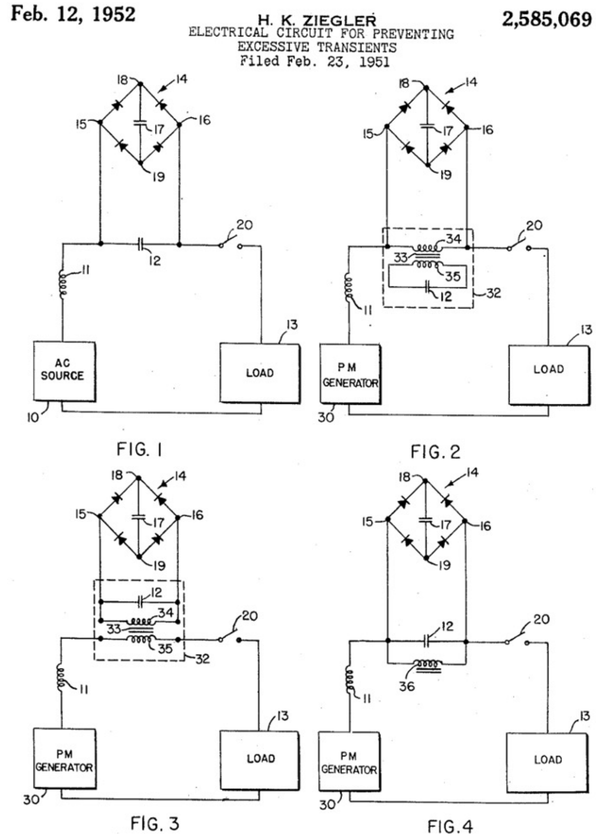
Mr. Kaprillian and Dr. Keck have now returned to Fort Monmouth but will continue their work here next week and the week following. Mr. Kaprillian states that he believes the material contained in these trunks is worth $100,000,000 and so far the one or two dozen trunks of optics material, which he has discovered, will save the Signal Corp $30,000 in research and development. One trunk which they opened containing microfilm reels is believed to be a copy of all documents in these trunks. Mr. Kaprillian will write a letter of thanks to the Office of Technical Services for the assistance and cooperation which he has been given.

I should like to have your acquiescence to permitting the Signal Corp to transport to Fort Monmouth, via Army Truck, the several trunks of optics material. The documents will then be examined in minute detail, copied and important ones translated, and a copy of all translations will be furnished The Office of Technical Services for publication and distribution. All documents will then be returned to 15 Canal Street at Signal Corp expense.

Figure 6.155: Hans K. Ziegler was the head of a largely German- and Austrian-derived research group at a U.S. Army laboratory in Fort Monmouth, New Jersey, that harnessed infrared and other technologies.

Fort Monmouth, NJ Army Lab
Lots of German scientists, hardware, documents, etc.

Hans K. Ziegler (1911–1999)
Head of German- and Austrian-derived research group



Ernst Baars	**Physical chemistry**
Eberhard Both	**Advanced ceramics/metals**
Rudolf Brill	**Semiconductor devices**
Wilhelm Buessem	**Advanced ceramics**
Eduard Gerber	**Piezoelectric devices**
Richard Glocker	**Metallurgy**
Georg Goubau	**Physics**
Richard Guenther	**Engineering**
Gunter Guttwein	**Magnetic data recording**
Georg Hass	**Optics**
Horst Kedesdy	**Physics**
Karl Kordesch	**Batteries and fuel cells**
Stanley Kronenberg	**Nuclear weapons**
Kurt Lehovec	**Semiconductor devices**
Gerhard Schwesinger	**Optics**
Helmut Weickmann	**Geophysics**
Etc.	

Figure 6.156: Hans K. Ziegler was the head of a largely German- and Austrian-derived research group at a U.S. Army laboratory in Fort Monmouth, New Jersey, that harnessed infrared and other technologies.

Falcon heat-seeking missile (1956)

Sidewinder heat-seeking missile (1956)

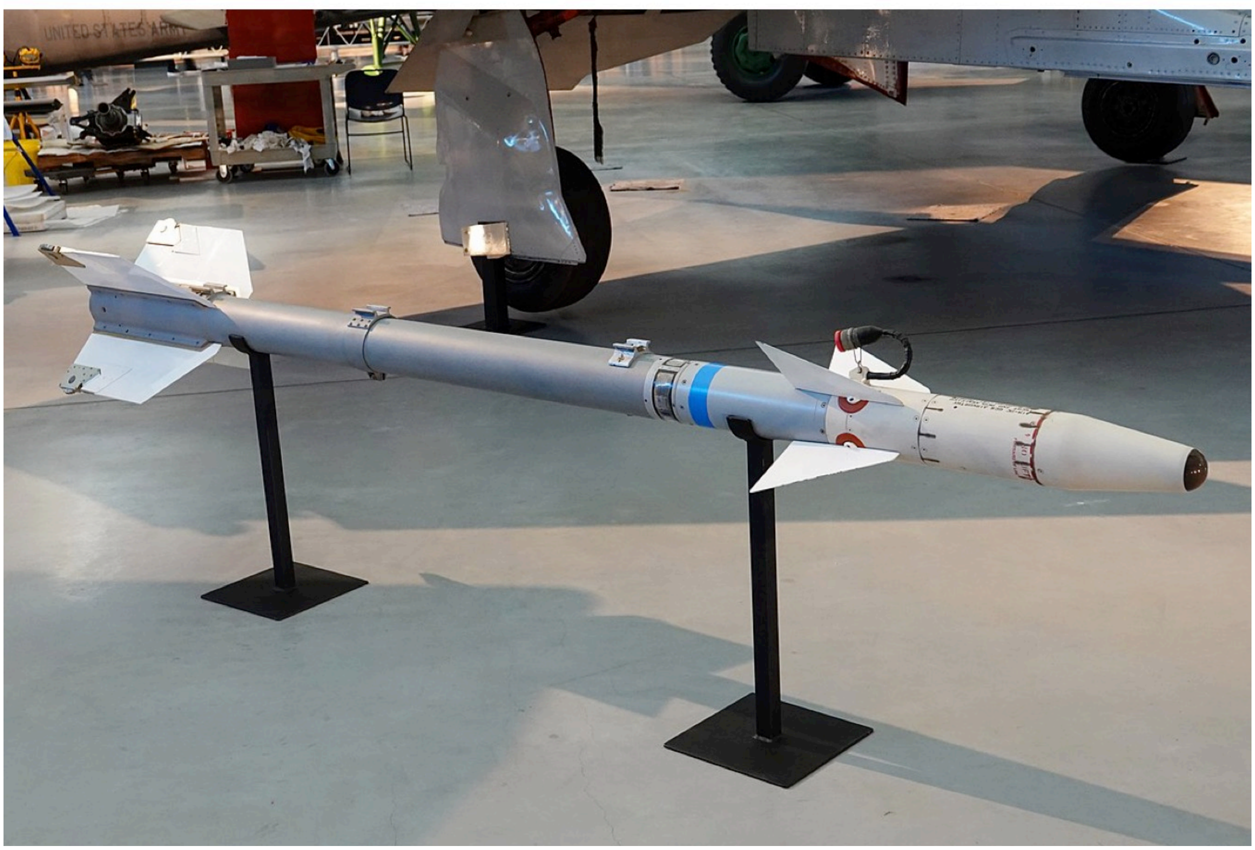


Figure 6.157: Edgar Kutzscher and other German-speaking creators helped to develop postwar infrared heat-seeking missiles such as the Falcon and Sidewinder.

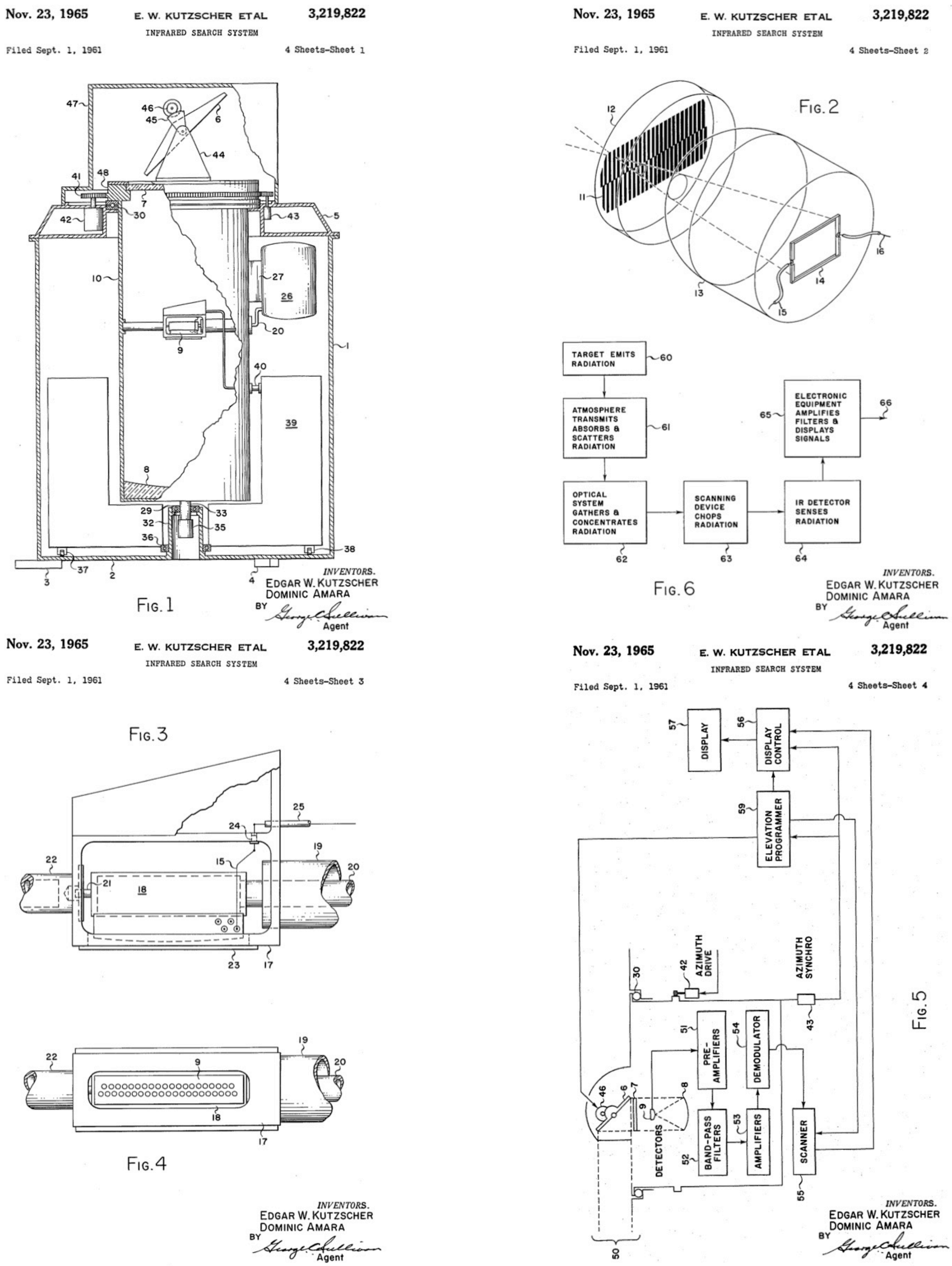


Figure 6.158: One of the postwar U.S. patents by Edgar Kutzscher on infrared targeting systems.

6.7 Computers and Robotics

While it is not widely known in the modern non-German-speaking world, German-speaking scientists and engineers made numerous incredibly prescient advances in:

6.7.1. Calculating machines

6.7.2. Computers

6.7.3. Cryptography

6.7.4. Robotics

6.7.1 Calculating Machines

As shown in Fig. 6.159, Wilhelm Schickard (Tübingen, 1592–1635) designed, built, and demonstrated the first calculating machines. Computer historian Herman Goldstine [Goldstine 1993, p. 6] explained how modern scholars rediscovered Schickard and his accomplishments:

> Our story really opens during the Thirty Years War with Wilhelm Schickard (1592–1635), who was a professor of astronomy, mathematics, and Hebrew in Tübingen. Some years ago (1957) Dr. Franz Hammer, then assistant curator of Kepler's papers, discovered some letters from Schickard to Kepler—both of whom were from Würtemberg—containing sketches and descriptions of a machine Schickard had designed and built in 1623 to do completely automatically the operations of addition and subtraction and, partially automatically, multiplication and division. The first letter was dated 20 September 1623, and a subsequent one 25 February 1624. In the first one, Schickard wrote of the machine that it "immediately computes the given numbers automatically, adds, subtracts, multiplies, and divides. Surely you will beam when you see how [it] accumulates left carries of tens and hundreds by itself or while subtracting takes something away from them. . . ."

Gottfried Leibniz (Saxony, 1646–1716) greatly extended Schickard's work (Fig. 6.160). He produced a machine that could add, subtract, multiply, and divide fully automatically. Leibniz also designed machines that could do algebra and calculus. He created binary mathematics, the base-2 system in which numbers are represented by strings of 0s and 1s, which forms the foundation for modern computers. Leibniz even developed mathematical logic functions (AND, OR, NOT, etc.) that are used by digital circuits and modern computers [Antognazza 2009]. Herman Goldstine [Goldstine 1993, pp. 7–9] praised all of Leibniz's contributions to computer science:

> [...] Gottfried Wilhelm Leibniz (1646–1716), another of the great universalists of his or indeed of all time, invented a device now known as the *Leibniz wheel* and still in use in some machines. The mechanism enabled him to build a machine which surpassed Pascal's in that it could do not only addition and subtraction fully automatically but also multiplication and division. [...]
>
> [...I]t was Leibniz who summed up the situation very well indeed when he wrote: "Also the astronomers surely will not have to continue to exercise the patience which is required for computation. It is this that deters them from computing or correcting tables, from the construction of Ephemerides, from working on hypotheses, and from discussions of observations with each other. For it is unworthy of excellent men to lose hours

> like slaves in the labor of calculation which could safely be relegated to anyone else if machines were used." [...]
>
> Leibniz's work did however stimulate a number of others to build improved machines, many of them ingenious variants of his. Today these machines are still with us and play a significant role for minor calculations. Indeed during World War II they were of greatest importance.
>
> It is also Leibniz, who in the grandeur of his genius realized, at least in principle, his Universal Mathematics. This was also to have greatest importance to our story—but much later. He wrote an essay in 1666 concerning Combinatorics, one of the great branches of mathematics, entitled *De Arte Combinatorica.* He described it as "a general method in which all truths of the reason could be reduced to a kind of calculation." [...] Thus Leibniz contributed very profoundly to computers. Not only by his machine but also by his studies of what is now known as symbolic logic. [...] In closing our few paragraphs on Leibniz, we feel it is worth emphasizing his four great accomplishments to the field of computing: his initiation of the field of formal logics; his construction of a digital machine; his understanding of the inhuman quality of calculation and the desirability as well as the capability of automating this task; and lastly, his very pregnant idea that the machine could be used for testing hypotheses.

Herman Hollerith (1860–1929) was born in the United States, but his parents were German immigrants, and his father, a professor, apparently played a major role in his education and training. Hollerith developed electromechanical punch card machines that were widely used (Fig. 6.161). The company he founded to produce them later became International Business Machines (IBM). Oxford University's *Biographical Dictionary of Scientists* described Hollerith's innovation process [Porter 1994, pp. 341–342]:

> He was probably the first to automate the large-scale processing of information, and as such was a pioneer of the electronic calculator, particularly its application to data handling in business and commerce.
>
> [...] Hollerith developed the idea of punching first a continuous roll of paper, and later individual cards the same size as a dollar bill, with holes to represent information. The quantities indicated by the holes were counted when the tape or cards passed through a device in which electrical contact was made through the holes. The passage of an electric current caused electromechanical counters to advance one place for each hole. The realization of these ideas in practical terms did not, however, come about in time for the processing of the 1880 [census] returns. [...]
>
> By 1889, he had developed not only his electrical machines for recording the information on punched cards, but also machines for punching the cards and for sorting them. [...]
>
> Hollerith soon realized that the age of large-scale data handling had begun, and in 1896 he formed the Tabulating Machine Company, to manufacture the machines and the cards they used. With the growth of business in this area, Hollerith's company was soon merged with two others into the Computing-Tabulating-Recording Company, which later became International Business Machines Corporation (IBM). [...]
>
> Hollerith stayed with IBM as a consultant engineer until his retirement in 1921.

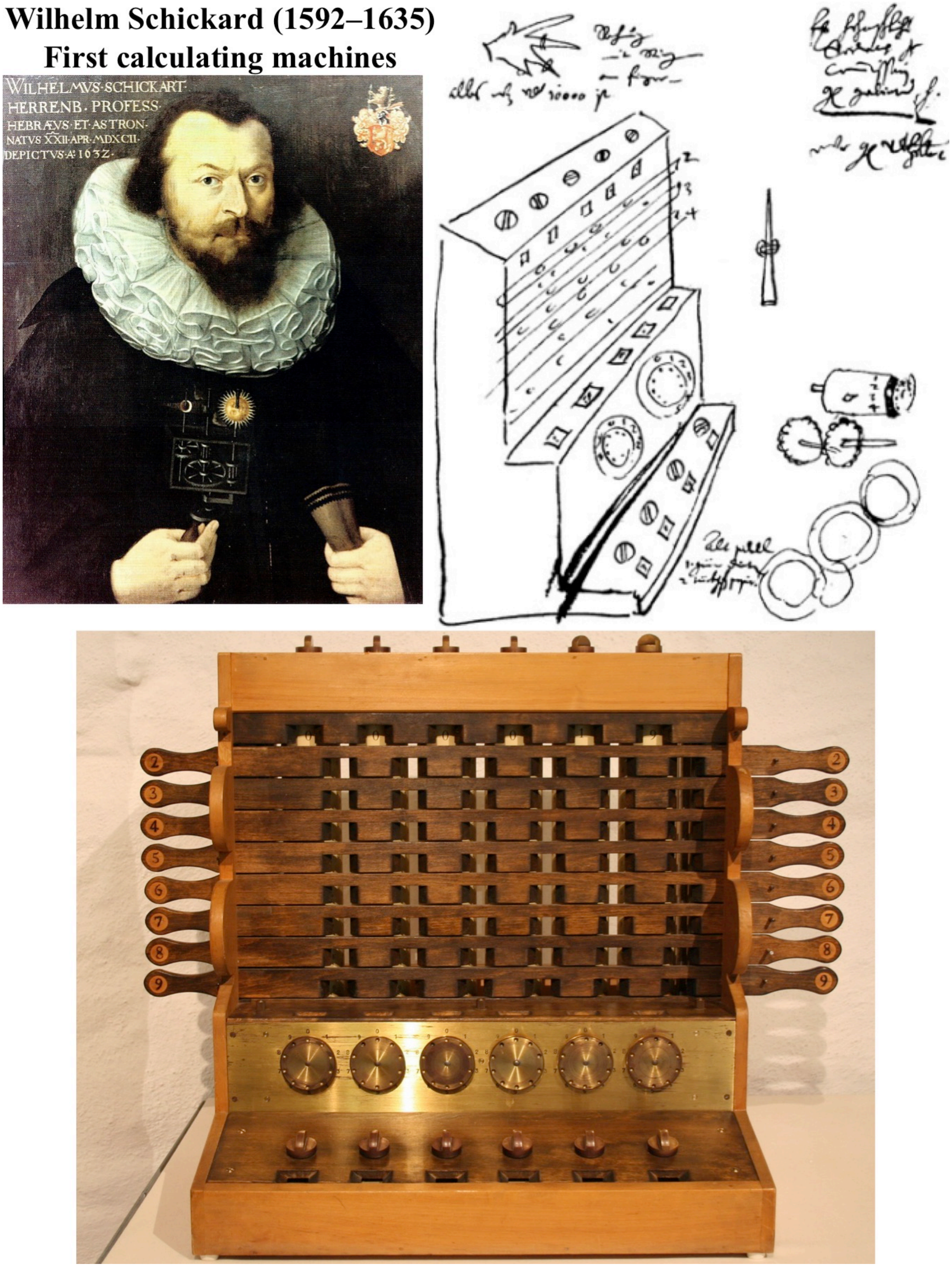


Figure 6.159: Wilhelm Schickard developed the first calculating machines.

Gottfried Leibniz (1646–1716) developed binary mathematics, produced a machine that could add, subtract, multiply, and divide, and designed machines that could do algebra and calculus

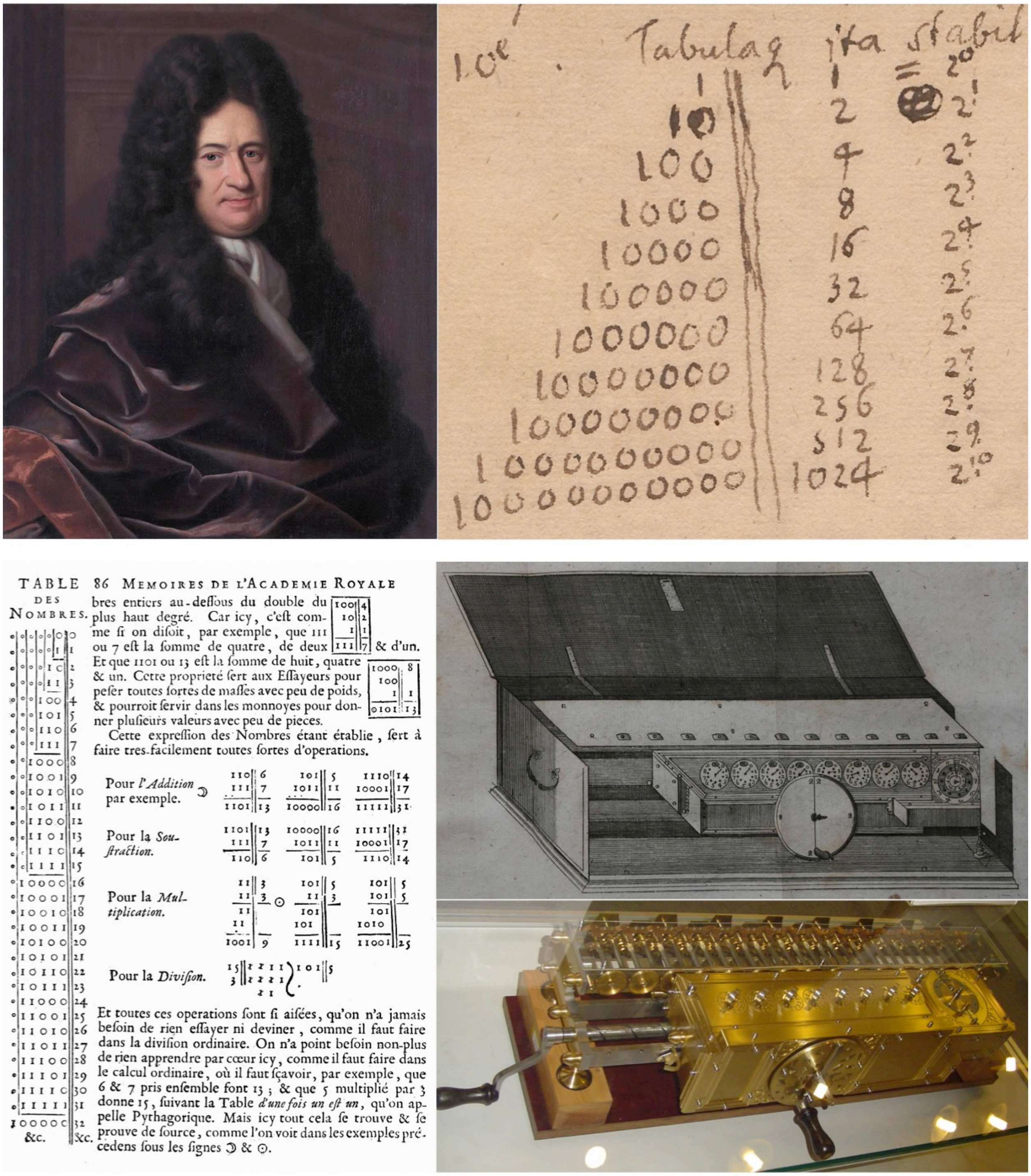


Figure 6.160: Gottfried Leibniz developed binary mathematics, produced a machine that could add, subtract, multiply, and divide, and designed machines that could do algebra and calculus.

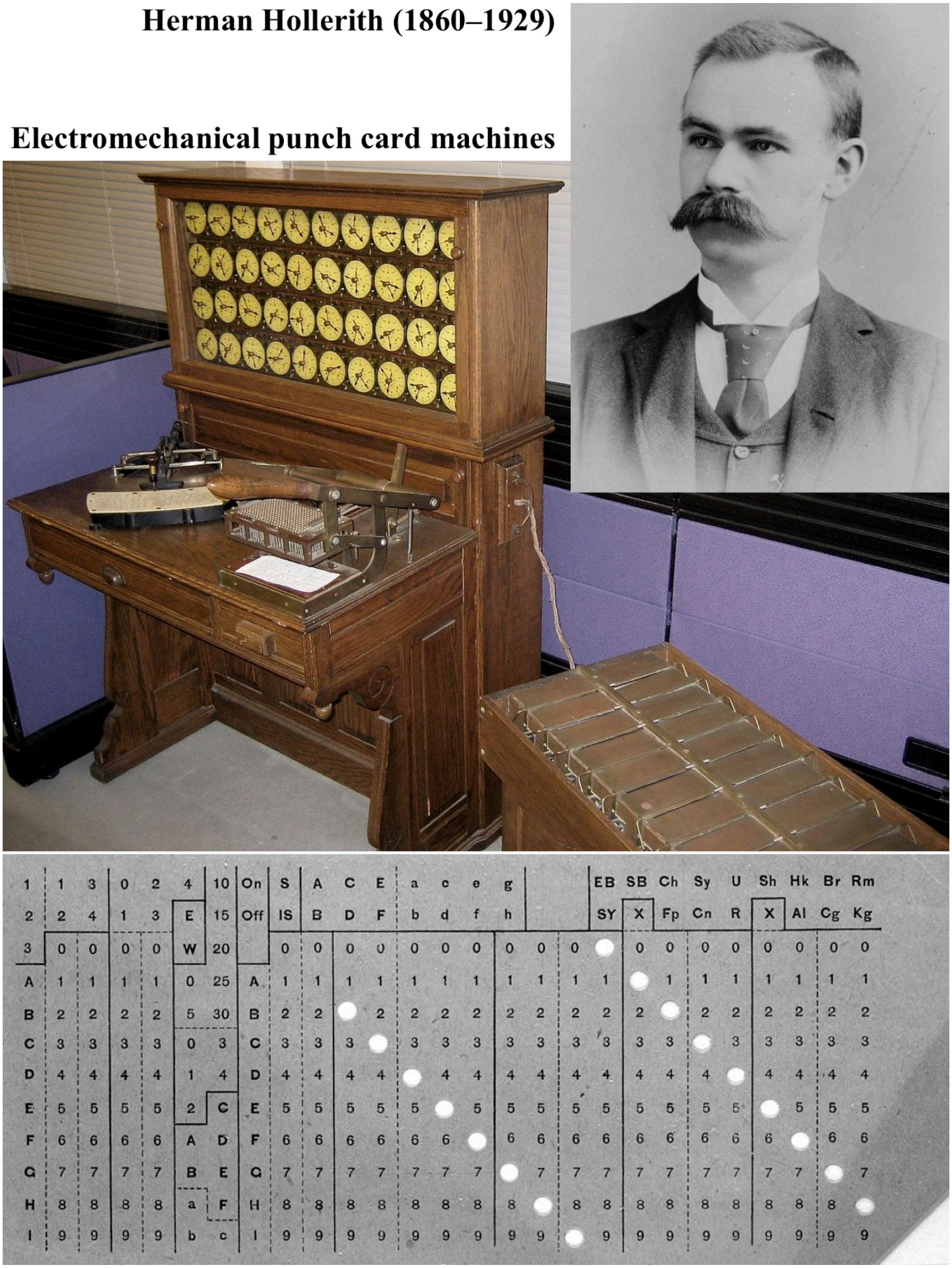


Figure 6.161: Herman Hollerith developed electromechanical punch card machines.

6.7.2 Computers

Gustav Tauschek (Austrian, 1899–1945) was an amazingly early, advanced, and prolific creator of computer technologies, as shown in Figs. 6.162–6.164 [Helfert et al. 2007]:

- From 1922 until his death in 1945, Tauschek designed, built, and patented a series of increasingly sophisticated programmable calculating machines that rivaled the computers that Zuse developed several years later, and surpassed any other computing machines in the world at that time.
- He invented the electric typewriter in 1927.
- Tauschek invented the world's first optical character recognition system in 1928.
- He also invented the world's first magnetic drum memories for computer data storage in 1929.
- IBM bought at least 169 of Tauschek's patents and used them as the basis of many of the machines that it built and marketed in the following decades.
- Along the way, Tauschek also invented lawnmowers, snowmobiles, the autopen or signing machine, and other devices.

Even though Tauschek's computer innovations were decades ahead of their time and exerted an enormous influence through his patents on IBM, and through IBM's products on the rest of the world, he has been virtually erased from history. Historians of computing worldwide should rediscover Tauschek and his work, and give him his proper place in the history books.

Konrad Zuse (German, 1910-1995), shown in Fig. 6.165, was another extremely early and important computer pioneer. He began designing and building prototype programmable digital computers in 1935. For his early Z1 and Z2 computers, he was assisted by people such as Helmut Schreyer (German, 1912–1984), who later developed his own computers. For his Z4 computer onward, he was assisted by people such as Heinz Rutishauser (Swiss, 1918–1970), who pioneered software and programming languages. Examples from Zuse's patents are provided in Fig. 6.166.

The first programmable digital computers built by Konrad Zuse included the:

- Z1 computer, which was first operational in 1938, was destroyed by Allied bombing during the war, and was rebuilt later as a museum piece (Fig. 6.167).
- Z2 computer, which was first operational in 1939, was destroyed during the war, and was never rebuilt (Fig. 6.167).
- Z3 computer, which was first operational in 1941, was destroyed in 1944, and was rebuilt after the war (Fig. 6.168).
- Z4 computer, which was first operational in 1944 and survived the war intact (Fig. 6.168).

- S1 special-purpose computer for measuring and calculating wing flutter, which was first operational in 1942, was destroyed in 1944, and was never rebuilt (Fig. 6.169).

- S2 special-purpose computer for measuring and calculating wing flutter, which was first operational in 1943 and was captured by Russian forces at the end of the war (Fig. 6.169).

In his autobiography, Zuse summarized the capabilities of the Z3 computer [Zuse 1993, pp. 62–63]:

> Z3 [...] was completed in 1941 and was the first fully operational machine to contain state-of-the-art versions of all the important elements of a program-controlled computing machine for scientific purposes[...] It had—in today's terminology—the following characteristics:
>
> - electromagnetic relay technology (600 relays in the arithmetic unit, 1400 relays in the memory unit)
> - binary number system
> - floating point
> - word length: 22 bits [...]
> - storage capacity: 64 words
> - control via an 8-track punched tape (i.e., a command is made up of 8 bits)
> - input entered via a special keyboard, through which the position of the points can be set relative to 4 decimal figures
> - output via display of results on a lamp strip, including the placement of the point
> - speed: approximately 3 seconds for multiplication, division or taking the square root
>
> [...] Yet the Z3 was relatively reliable. Unfortunately, I was the only one who could service it. [...]
>
> Aside from a few trial programs—programs to compute determinants or quadratic equations, for example—it was the program to compute a complex matrix that was of chief importance. This was an essential step in the computation of critical flutter frequencies of aircraft.

For the Z4 computer, Zuse increased the number of relays to approximately 2500 total, and the word length to 32 bits.

Zuse also developed the first high-level computer programming language, Plankalkül, in 1942 (Fig. 6.170). That was 14 years before IBM introduced the Fortran programming language, and may well have inspired and influenced the development of Fortran (through detailed postwar investigations of Zuse's work by Allied countries in general, and by IBM in particular).

In general, Zuse's first computers were years ahead of comparable technology that was later developed in the United States and other countries, and that was likely strongly influenced by Zuse's designs.[17] After the war, Zuse developed and sold a long series of commercial computers in Europe.

As illustrated in Fig. 6.171, Helmut Hölzer (German, 1912–1996) developed the world's first analog electronic computers beginning in 1939, including large mainframe computers and small onboard flight computers for rockets (p. 2826). Most of his work was conducted at and for the Peenemünde rocket research center [Tomayko 1985; https://www.cdvandt.org/v2__computer.htm]. After the war he went to the United States; in 1960 he became Director of Computers at the NASA Marshall Space Flight Center in Huntsville, Alabama.

Figure 6.172 presents some other early computer pioneers. Alwin Walther (German, 1898–1967) created and operated computers at Darmstadt for the Peenemünde rocket program during the war, and continued to develop computers after the war. Heinz Billing (German, 1914–2017) produced computers with magnetic drum and magnetic core memory, and later built the first laser-interferometer gravitational-wave detector; examples from his patents are shown in Fig. 6.173. Nikolaus Joachim Lehmann (German, 1921–1998) created computers in East Germany. As illustrated in Fig. 6.174, Walter Sprick (German, 1909–1989) developed computers ∼1939–1974; based on Sprick's designs, Heinz Nixdorf (German, 1925–1986) developed computers 1951–1986.

As shown in Figs. 6.176–6.179, creators who had been trained in the German-speaking research world also helped to develop computers in the United States. John von Neumann (Hungarian, 1903–1957) was involved in developing the first programmable digital computers in the United States, such as EDVAC (first operational in 1951). His wife, Klára Dán von Neumann (Hungarian, 1911–1963), was one of the first programmers on early computers such as MANIAC I (1952). Jan Rajchman (Polish, educated in Switzerland, 1911–1989) developed iron core computer memories and other computer technologies in the United States. Joseph Weizenbaum (German, 1923–2008) created the ELIZA software in 1965, a major step in the development of artificial intelligence.

It was German-speaking scientists who took magnetic computer memory from its very beginnings (Tauschek) to its most advanced form. Peter Andreas Grünberg (German, 1939–2018) discovered giant magnetoresistance, which can be used for high-density magnetic hard drives. For that discovery, he won the Nobel Prize in Physics in 2007. The Royal Swedish Academy of Sciences summarized his work [https://www.nobelprize.org/prizes/physics/2007/grunberg/facts/]:

> When materials are reduced to just a few atomic layers—a few nanometers in thickness—their properties change. Independently of one another, Peter Grünberg and Albert Fert discovered the phenomenon Giant Magneto Resistance (GMR) in 1988. GMR involves small changes in magnetic fields creating major differences in electrical resistance. It has also had an impact on electronics, especially read heads, where information stored magnetically is converted to electric current. Thanks to GMR, hard drives have become much smaller.

German-speaking scientists also developed magnetic tape, which for decades was used to store computer data as well as audio and visual signals (pp. 999, 1020).

[17] Ceruzzi 1998; Füßl (ed.) 2010; Goldstine 1993; Lyndon 1947; Mons et al. 2005; Rojas 2023; Zuse 1993, esp. pp. 113–118; BIOS 142; CIOS XXXI-83; NARA RG 330, Entry A1-1B, Box 186, File Zuse, Konrad.

Gustav Tauschek (1899–1945)

Invented world's first optical character recognition system (1928)

UNITED STATES PATENT OFFICE

2,026,329

READING MACHINE

Gustav Tauschek, Vienna, Austria

Application May 27, 1929, Serial No. 366,466
In Austria May 30, 1928

26 Claims. (Cl. 250—41.5)

This invention relates to improvements in machines which are provided with arrangements adapted to create ray-images, particularly light ray images, of character or indications so as to cause by a comparing mechanism certain actions to be instituted thereby effecting the reading of such characters or indications, and thus replace reading by a person.

In order to attain this object the arrangement according to the present invention is provided with cells, in which the electric conductivity is varied by radiation, and with comparison devices which on the arrival of certain rays influencing the cells direct or control the corresponding operations.

The invention can be utilized for controlling any desired machine, however it will be found very useful in connection with office-machines, which heretofore could be operated only by persons who were able to read. Further the machine may be used for testing and counting securities, bank-notes and so forth and for controlling automatons and the like.

One of the modes of carrying out the present invention is illustrated diagrammatically by way of example on the accompanying sheet of drawing in which:—

Fig. 1 shows a perspective view of one construction, and

Fig. 2 is a detail view.

The embodiment shown in Fig. 1 serves for controlling the counting mechanism of a calculating machine. The record or sheet 1, provided with characters or the numerals for calculation, is placed on a base or carrier 2 in such a manner, that the number to be read is disposed opposite the lens 3, the record being illuminated by a strong source of light 4. On the other side of the lens 3 a suitable distance away, is arranged a photo-electric cell 5, in front of which rotates a movable device such as a wheel 6 constituting a portion of a comparison device, provided with stencil-recesses corresponding to the numerals 0 to 9. The stencil-recesses are of such a size and are shaped according to the numerals and are distanced in such a manner from the lens 3 that for instance the image of the numeral 1 exactly coincides with the stencil-recess as soon as the latter is disposed at the corresponding place. A contact wheel 7, provided with nine contact-knives 8 and supplied with current by way of a brush 9, is connected with the wheel 6. A contact-spring 10 is arranged opposite the contact wheel in such a manner, that the knives 8 establish electric connection during the rotation of the said contact wheel. A wire of an operating circuit 11 leads from the contact spring 10 to a control-magnet 12 which on being charged with current attracts the armature 13 and by way of a link 14 forces a pawl 15 against the action of a spring 16 into a toothed feed-wheel 17 and feeds forward the latter for the extent of a tooth. A number-wheel or number representing or manifesting wheel 18 is connected with the feed-wheel 17 and accordingly is fed forward also the extent of one place. In the circuit of the photo-electric cell 5 are included a low frequency transformer 39 and a relay-magnet 19, which controls the current supply of the brush 9. During the rotation of the wheel 6, rays of light will periodically pass to the cell 5 by way of the successive stencil-recesses of the wheel 6. The cell 5 is subjected to full light if a blank place of the sheet 1 is disposed opposite the lens 3. However a numeral, for instance the numeral 1, does not completely fill the other stencil recesses as shown in Fig. 2 by way of example of the stencil-recess corresponding to the Figure 2. Therefore light of the white writing sheet still passes to the cell 5. However a minimum of illumination of the cell 5 will take place, as soon as the stencil-recess corresponding to the numeral to be read is disposed in front of the cell. The relay 19 in the control circuit 38 is adjusted to this illumination-minimum and allows the withdrawal of its armature 21 by means of the action of the spring 20. In this way the contact member 22 is released and thus the current-supply to the brush 9 is interrupted. Supposing the numeral 1 is to be read off, a contact-knife 8 would already have passed the contact-spring 10 at the time of the release of the relay-armature 21 and the figure-wheel 18 would have been fed forward for a unit by the generated current. The eight following contact-knives 8 would remain inoperative, because the current-supply to the brush 9 is interrupted. Supposing the numeral 3 is to be read off, three contact-knives would have become operative, the figure-wheel would have been fed forward for three units and so forth.

Two cams 23 and 24 return the parts 21 and 22 into the initial position after each revolution of the wheel 6.

The wheel 6 with the numerals or other characters thereon, constitutes a movable search member or character-bearing comparison device in the path of the rays of radiant energy. With said device move the wheel 7 and its contact knives or blades 8, said parts 7, 8 constituting

Fig.1

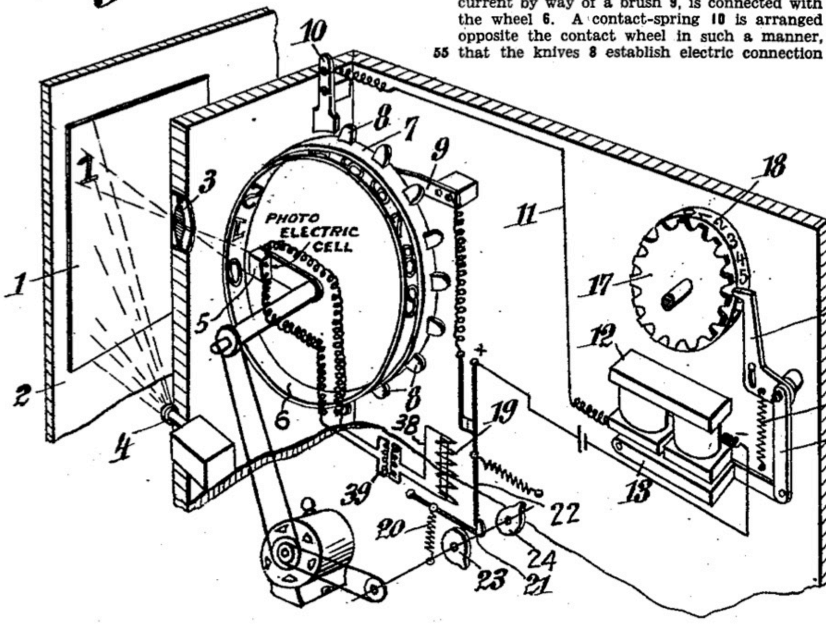
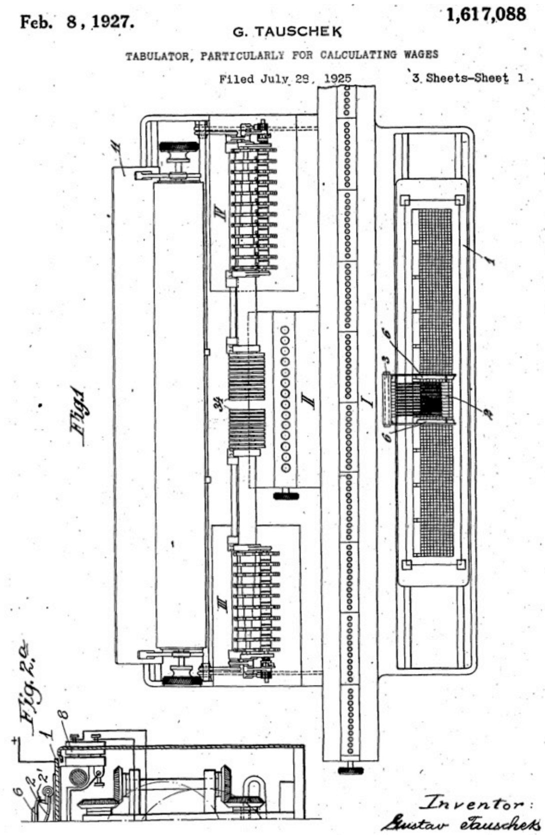
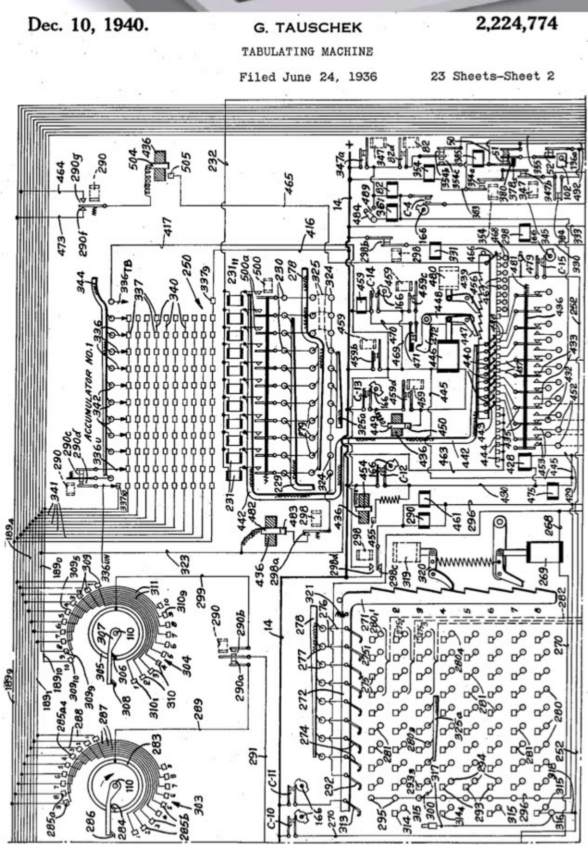


Fig. 2.

Figure 6.162: Gustav Tauschek pioneered numerous computer technologies, including the world's first optical character recognition system in 1928.





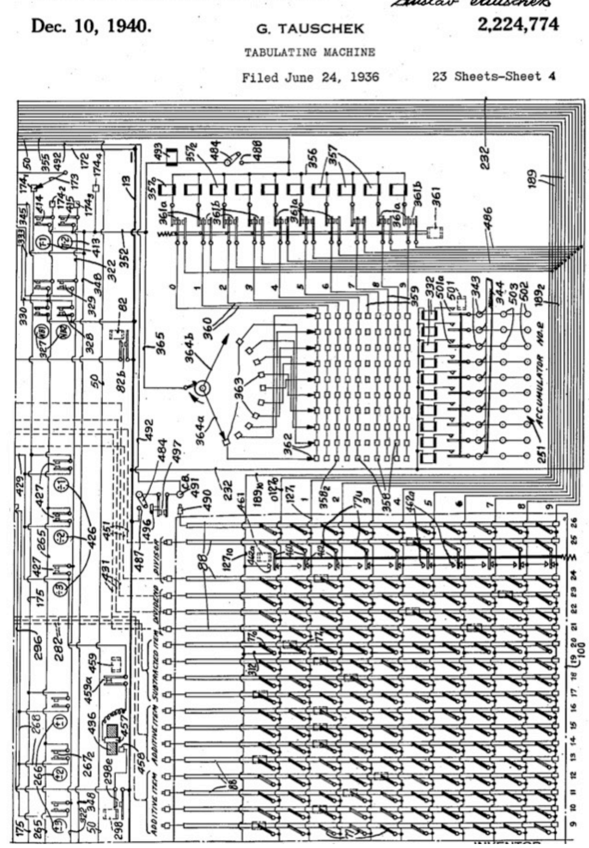
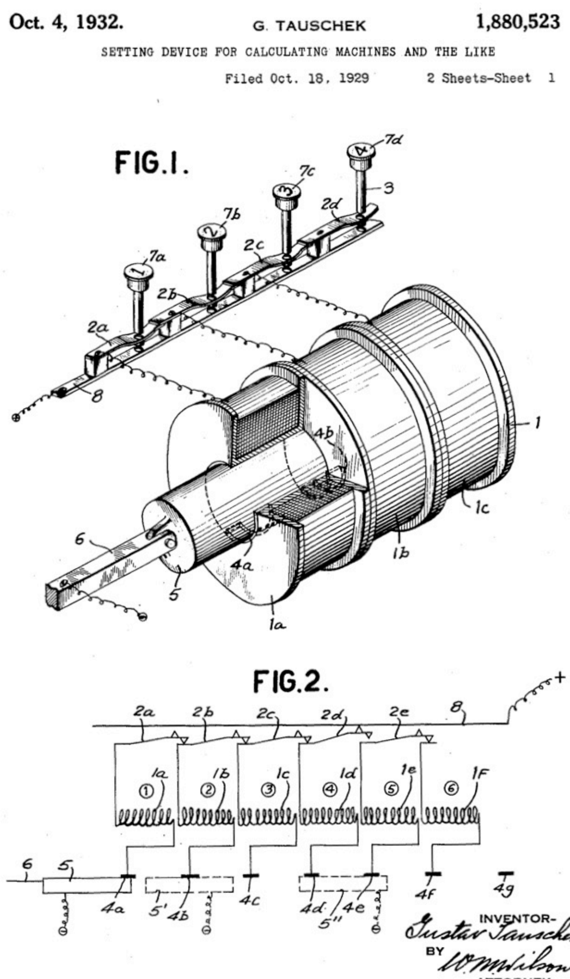


Figure 6.163: Gustav Tauschek designed, built, and patented a series of increasingly sophisticated programmable calculating machines between 1925 and 1945.

Gustav Tauschek with assistants

Invented magnetic drum data storage (1929)



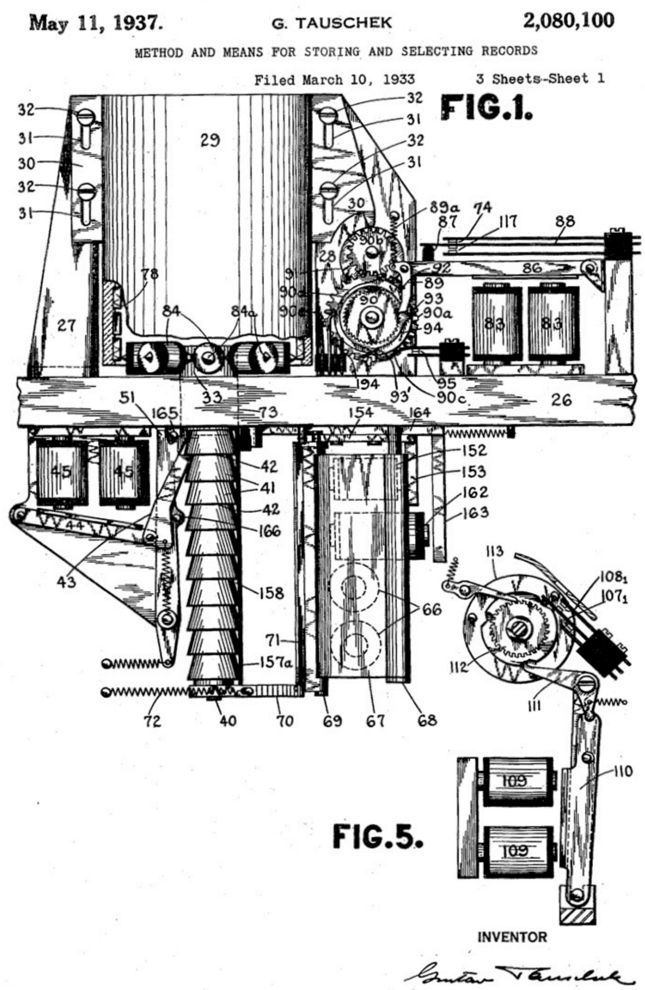


Figure 6.164: Gustav Tauschek also invented magnetic drum memories for computer data storage in 1929.

Figure 6.165: Konrad Zuse began designing and building prototype programmable digital computers in 1935. For his early Z1 and Z2 computers, he was assisted by people such as Helmut Schreyer, who later developed his own computers. For his Z4 computer onward, he was assisted by people such as Heinz Rutishauser, who pioneered software and programming languages.

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949
(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM 24. FEBRUAR 1955

DEUTSCHES PATENTAMT

PATENTSCHRIFT

Nr. 924 107

KLASSE **42m** GRUPPE 15

Z 395 IX b / 42 m

Dipl.-Ing. Konrad Zuse, Neukirchen (Kr. Hünfeld)
ist als Erfinder genannt worden

Zuse K.G., Neukirchen (Kr. Hünfeld)

Aus mechanischen Schaltgliedern aufgebautes Speicherwerk

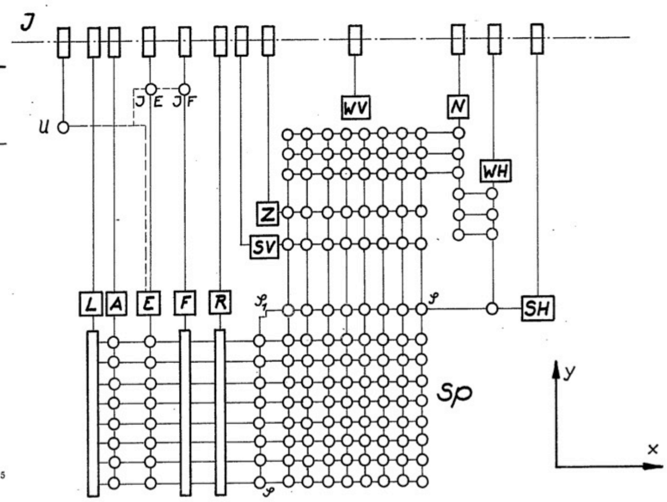
Zusatz zum Zusatzpatent 919 017
Patentiert im Gebiet der Bundesrepublik Deutschland vom 3. Juli 1937 an
Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet
(Ges. v. 15. 7. 51)
Das Hauptpatent 907 948 hat angefangen am 9. Mai 1936
Patentanmeldung bekanntgemacht am 18. Juni 1953
Patenterteilung bekanntgemacht am 13. Januar 1955

Im Patent 919 017 und dessen Hauptpatent 907 948 sind mechanische Schaltglieder beschrieben, deren Aufgabe es ist, zweifach variable Angaben ähnlich elektrischen Relais miteinander rechnerisch zu kombinieren. Beim mechanischen Schaltglied werden die Angaben durch Blechstellungen dargestellt, und die Übertragung bzw. Neubildung von Angaben erfolgt durch Blechausschnitte, die mit Stiften im Eingriff stehen. In den erwähnten Patentschriften sind in der Hauptsache drei Arten von Schaltgliedern beschrieben:

1. das Normalschaltglied, bei dem durch ein Steuerblech zwei senkrecht dazu bewegliche Bleche miteinander verbunden werden (Patent 907 948, Abb. 2),
2. das Verteilerschaltglied, bei dem Angaben von einem Blech auf ein anderes übertragen werden (Patent 919 017, Abb. 1, 2, 3, 5),
3. das Speicherschaltglied, das die Aufgabe hat, eine zweifach variable Angabe zu speichern (Patent 907 948, Abb. 3, 6, 7).

Zu der Patentschrift 924 107
Kl. 42m Gr. 15

Abb.1



ÖSTERREICHISCHES PATENTAMT

PATENTSCHRIFT NR. 172288

Kl. 42m, 12

Ausgegeben am 25. August 1952

DIPL. ING. KONRAD ZUSE IN WIEDEMEN (BAYERN, DEUTSCHLAND)

Vorrichtung zum Ableiten von Resultatangaben mittels Grundoperationen des Aussagenkalküls

Angemeldet am 2. April 1947. — Beginn der Patentdauer: 15. Feber 1952.

Die Erfindung betrifft eine Vorrichtung zum Ableiten von Resultatangaben aus irgendwelchen gegebenen Angaben nach einer Vorschrift. Unter einer Aussage (Angabe) ist beispielsweise jeder Satz zu verstehen, von dem es sinnvoll ist, zu behaupten, daß sein Inhalt richtig oder falsch ist. Aus mehreren Aussagen können nun durch Verknüpfungen (Operationen des Aussagenkalküls) wieder neue Angaben (Resultatangaben) gebildet werden, die richtig oder falsch sein können. Solche Grundoperationen des Aussagenkalküls sind beispielsweise:

1. Konjunktion: $A \& B$ (A und B)
2. Disjunktion: $A \vee B$ (A oder B)
3. Negation: $\overline{A}$ (nicht A)

Durch mehrfache Anwendung der Grundoperationen lassen sich komplizierte Angabenverknüpfungen (logistische Formeln mit einer Vielzahl von Variablen) bilden, aus denen nach Einsetzen bestimmter Werte (Ja-Nein-Werte) an die Stelle der beteiligten Variablen nach den Vorschriften des Aussagenkalküls eine Resultatangabe abgeleitet werden kann, die ihrerseits wieder eine Angabe über die Richtigkeit der in Frage stehenden logistischen Formel, also wiederum einen Ja-Nein-Wert darstellt.

Ein Beispiel soll dies veranschaulichen: Auf den üblichen Karteikarten zur Erfassung der Angestellten eines Betriebes sei auch eine Spalte vorgesehen, auf der untereinander die Buchstaben a bis i vermerkt sind, neben denen eine freie Stelle mit einem + oder — bezeichnet bzw. gelocht oder nicht gelocht ist.

Die Buchstaben bedeuten bestimmte Angaben, wie:

a = männlich
b = Inländer
c = verheiratet
d = abgeschlossene Hochschulbildung
e = bezieht ein Einkommen über 500 DM
f = über 10 Jahre im Betrieb
g = technische Fachkraft
h = kaufmännische Fachkraft
i = vollkommen gesund

Die Karteikarte des Angestellten M. sei folgendermaßen gekennzeichnet:

$a = +$
$b = +$
$c = -$
$d = +$
$e = +$
$f = -$
$g = +$
$h = -$
$i = -$

Demnach ist der Angestellte M. ein nicht verheirateter Inländer mit abgeschlossener Hochschulbildung, bezieht ein Einkommen über 500 DM, ist nicht über 10 Jahre im Betrieb und ist technische Fachkraft, nicht kaufmännische Fachkraft und nicht vollkommen gesund.

Es mag nun die Anweisung vorliegen, alle Angestellten auszuwählen, die bestimmten Voraussetzungen genügen, wobei diese Voraussetzungen in Form einer logistischen Formel (Auswahlformel) vorgeschrieben werden können, die etwa lautet:

$$(a \& b \& h) \vee (\overline{a} \& c \& f \& i) \vee (a \& \overline{c} \& d \& \overline{f} \& \overline{h})$$

Es werden also folgende Angestellte gesucht:

Männer, die Inländer und Kaufleute sind,
oder verheiratete Frauen, die über 10 Jahre im Betrieb und vollkommen gesund sind,
oder unverheiratete Männer mit abgeschlossener Hochschulbildung, die nicht über 10 Jahre im Betrieb und nicht kaufmännische Fachkräfte sind.

Der Angestellte M. fällt, wie eine Überlegung ergibt, unter die letzte Gruppe, genügt also der Auswahlformel.

Es ist der Zweck vorliegender Erfindung, solche logistische Aufgaben maschinell zu lösen, was erfindungsgemäß in der Weise geschieht, daß z. B. entsprechend gelochte Karteikarten maschinell abgetastet und verschiedene, den Lochstellen jeweils zugeordnete Relais zur Aufnahme der Eingangswerte hiebei an Spannung gelegt werden oder nicht. Über eine Verknüpfungsschaltung wird in zeitlicher Folge nach den

Nr. 172288
Kl. 42 m, 12

Fig. 30
Fig. 29

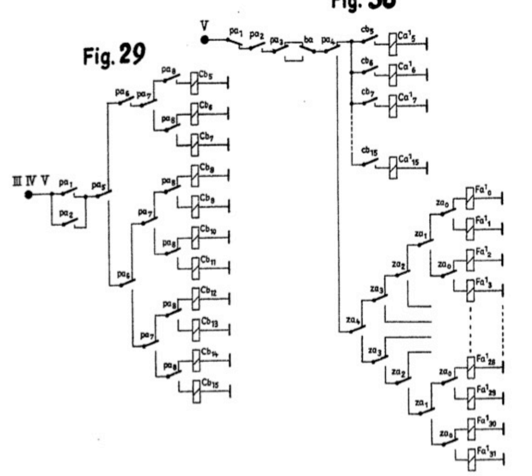


Fig. 31

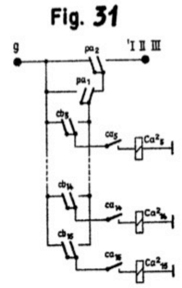


Fig. 32

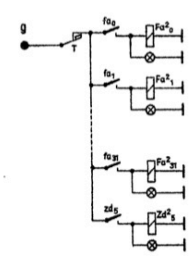
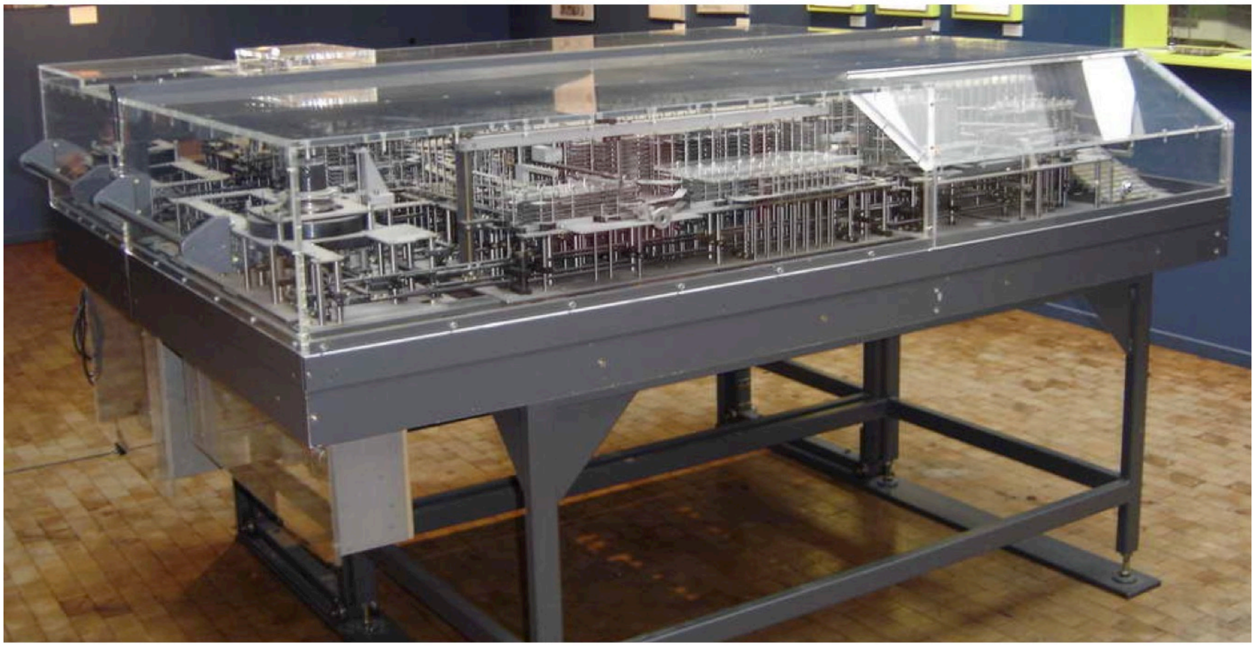


Figure 6.166: Examples from Konrad Zuse's patents on programmable digital computers.

Zuse Z1 programmable digital computer, first operational in 1938



Zuse Z2 programmable digital computer, first operational in 1939 (destroyed by Allied bombing)

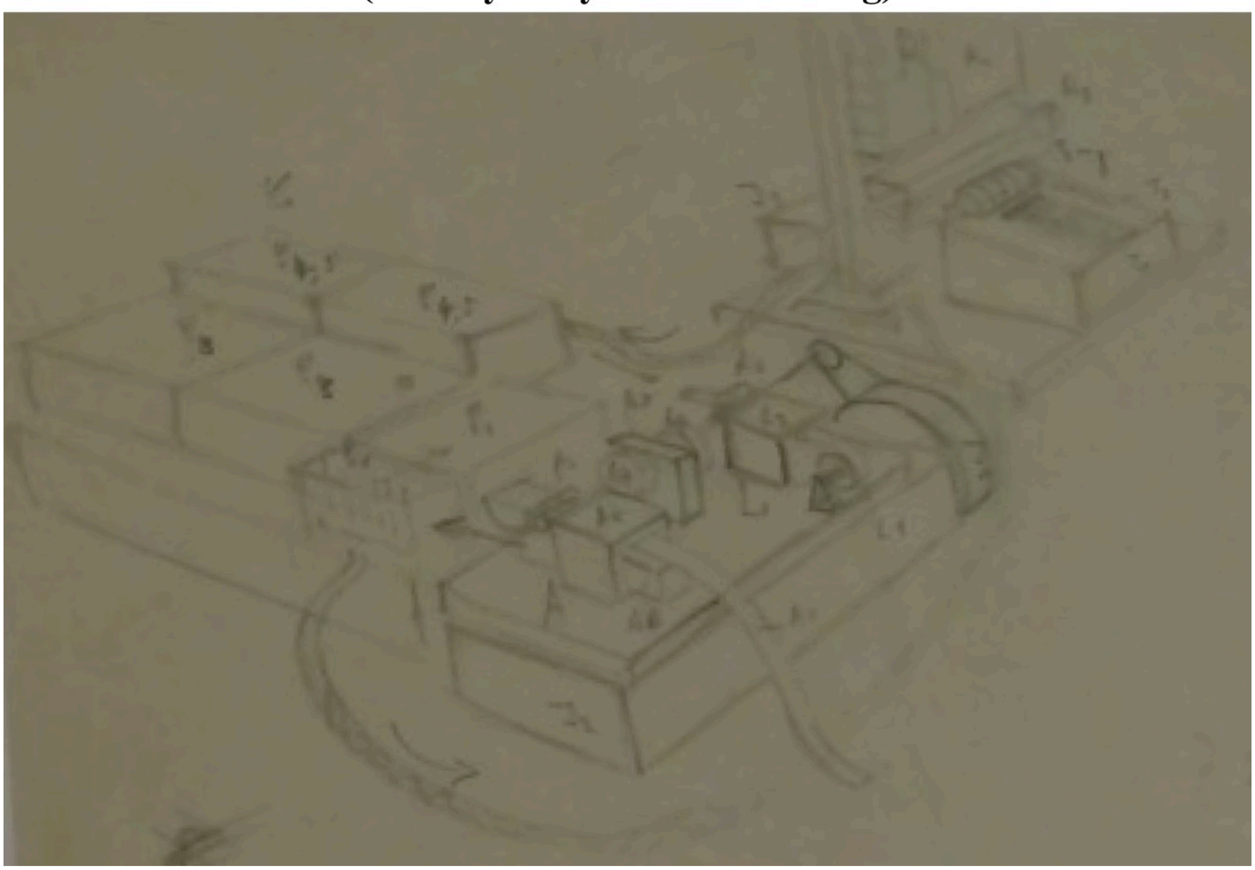
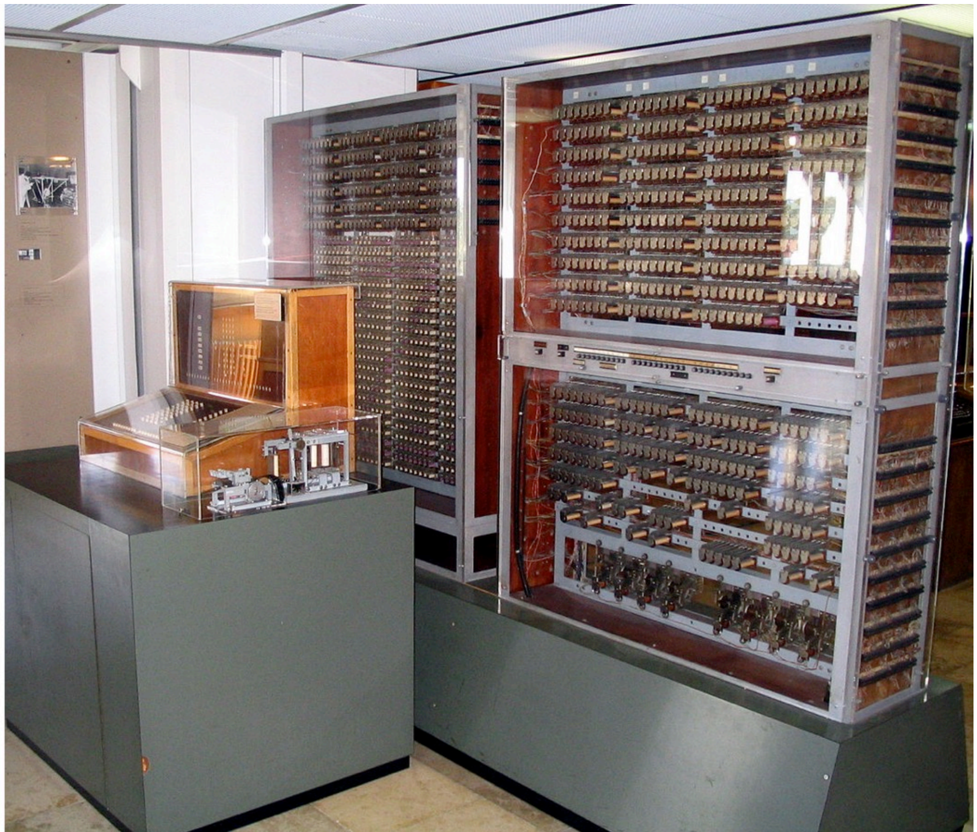


Figure 6.167: Programmable digital computers built by Konrad Zuse included the Z1 (first operational in 1938, destroyed during the war, and rebuilt later) and the Z2 (first operational in 1939, destroyed during the war, and not rebuilt).

Zuse Z3 programmable digital computer, first operational in 1941



Zuse Z4 programmable digital computer, first operational in 1944

Figure 6.168: Other programmable digital computers built by Konrad Zuse included the Z3 (first operational in 1941, destroyed during the war, and rebuilt later) and the Z4 (first operational in 1944).

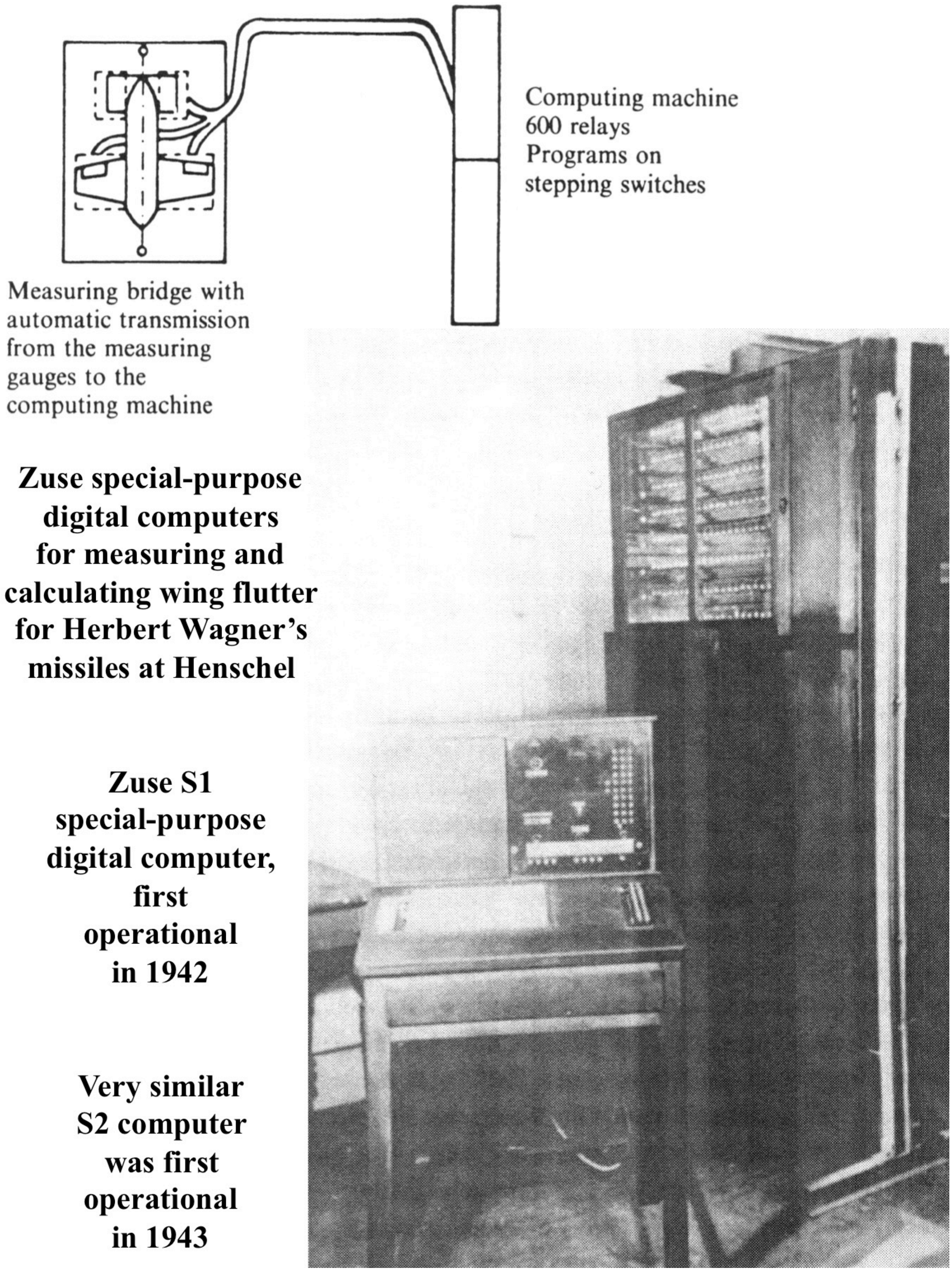


Figure 6.169: Konrad Zuse built special-purpose digital computers for measuring and calculating wing flutter for Herbert Wagner's missiles at Henschel: the S1 in 1942 and the S2 in 1943.

Konrad Zuse developed the first high-level computer programming language, Plankalkül (1942)

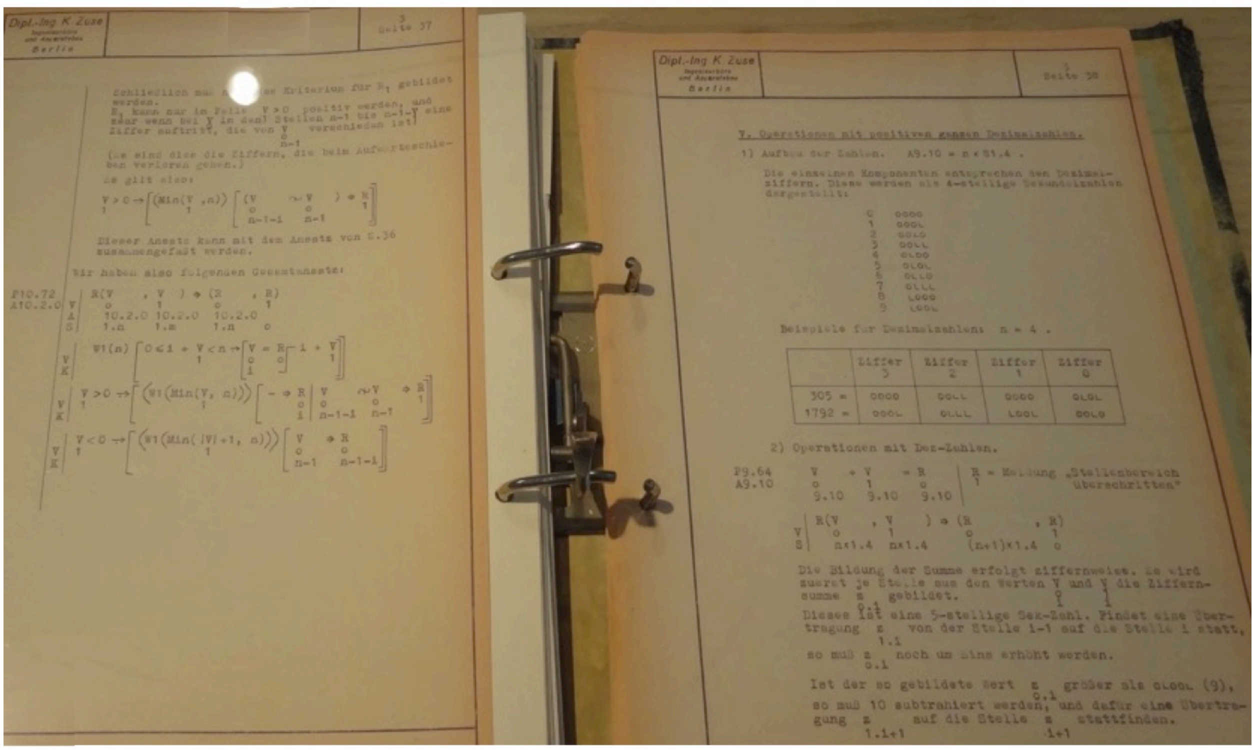


Figure 6.170: Konrad Zuse developed the first high-level computer programming language, Plankalkül (1942).

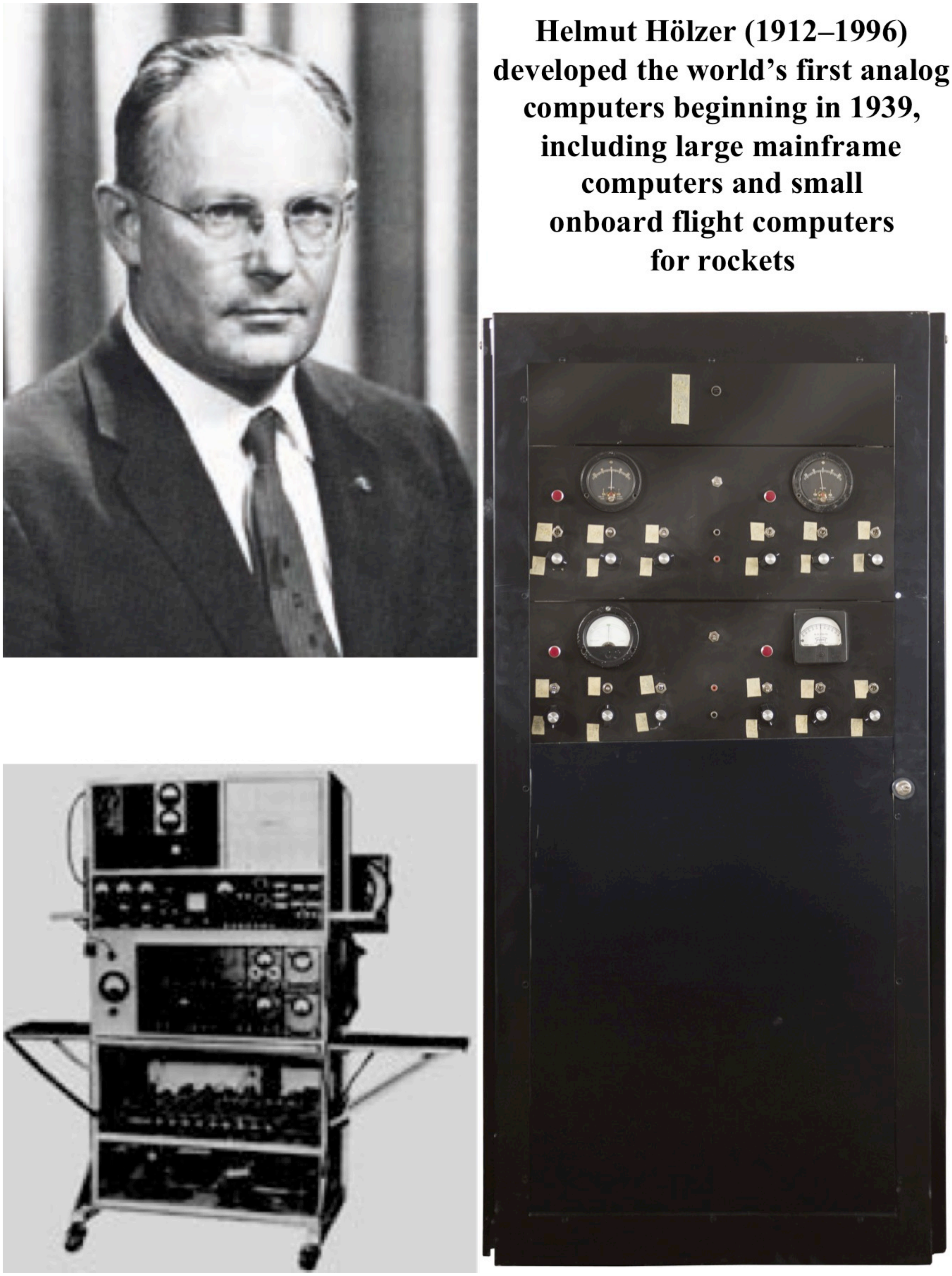


Figure 6.171: Helmut Hölzer developed the world's first analog computers beginning in 1939, including large mainframe computers and small onboard flight computers for rockets.

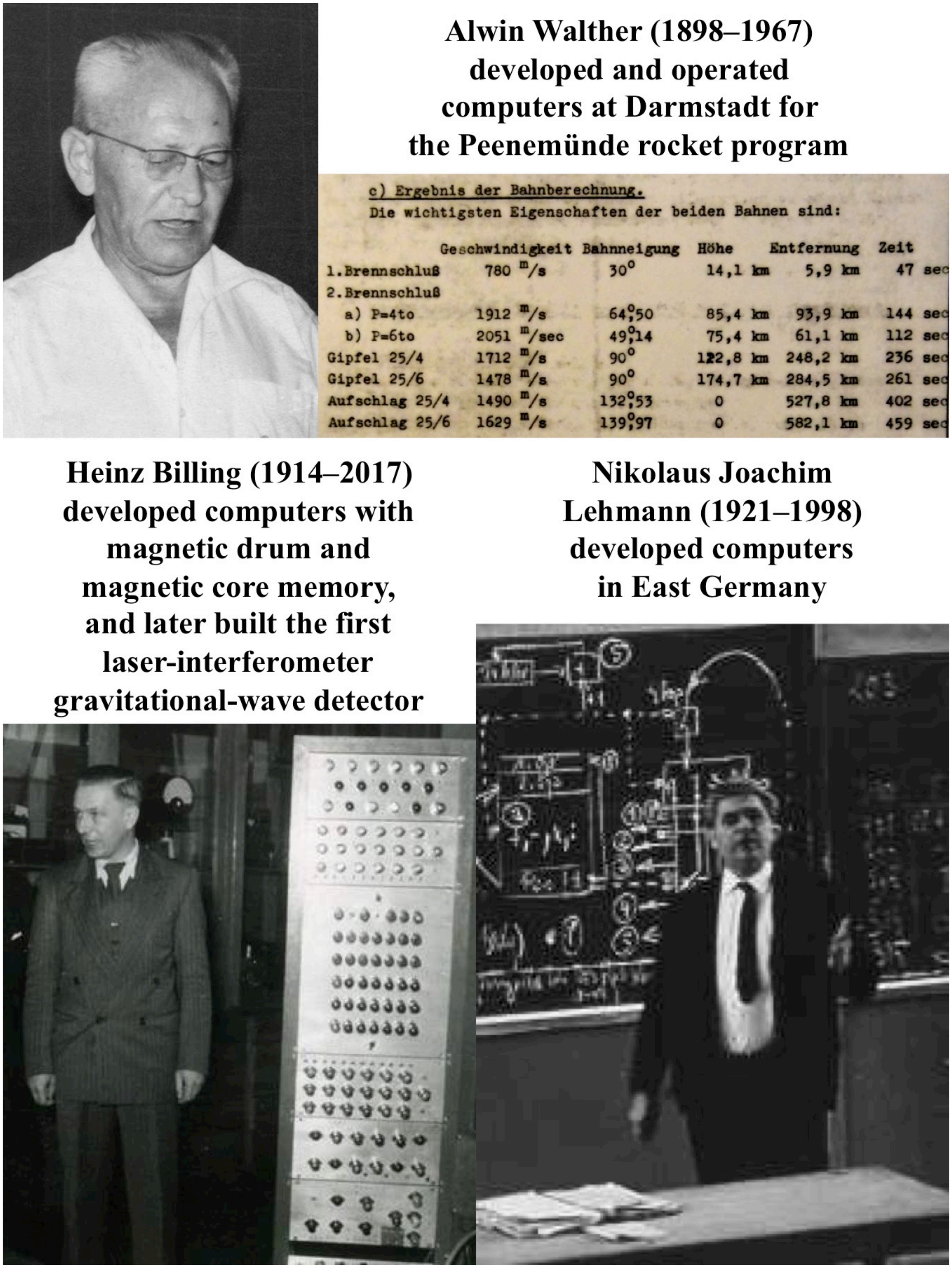


Figure 6.172: Some other early German computer pioneers included Heinz Billing, Alwin Walther, and Nikolaus Joachim Lehmann.

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM 27. JUNI 1957

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 965 925

KLASSE 42m GRUPPE 14

INTERNAT. KLASSE G 06f

M 19598 IX / 42m

Dr. Heinz Billing, Göttingen
ist als Erfinder genannt worden

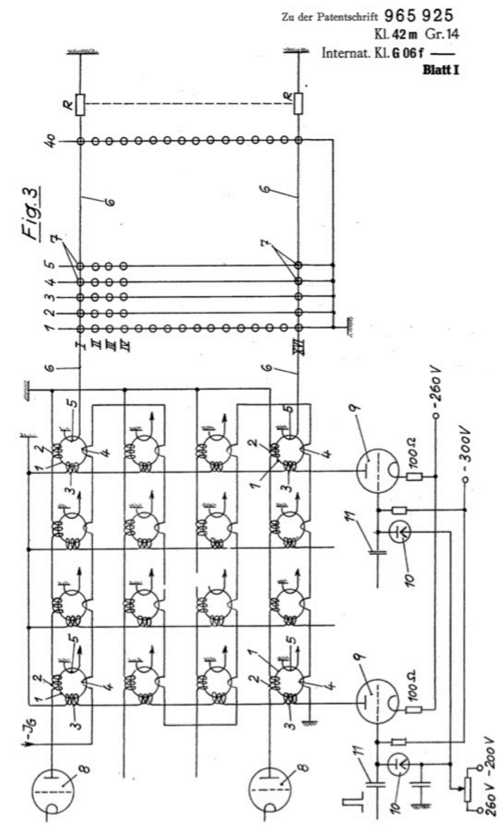
Max-Planck-Gesellschaft zur Förderung der Wissenschaften e. V., Göttingen

Aufrufvorrichtung für eine aus Magnetkernen bestehende Speichermatrix bei elektronischen Rechenmaschinen

Patentiert im Gebiet der Bundesrepublik Deutschland vom 4. August 1953 an
Patentanmeldung bekanntgemacht am 8. September 1955
Patenterteilung bekanntgemacht am 13. Juni 1957

Obwohl bereits eine große Anzahl von Speicherverfahren für elektronische Rechenmaschinen bekannt ist, stellt bei solchen Maschinen der Zahlenspeicher immer noch das kritischste Element dar. Die wesentlichen Anforderungen an derartige Speicher sind Zuverlässigkeit, Einfachheit und möglichst niedrige Zugriffszeit. Diese drei Forderungen werden besonders gut durch magnetische Zahlenspeicher erfüllt, bei denen für die Speicherung jeder einzelnen Dualziffer jeder Zahl ein besonderer Magnetkern vorgesehen ist. Für die Magnetkerne solcher Speicher werden Kernmaterialien mit möglichst rechteckiger Hysteresisschleife verwendet und die einzelnen Magnetkerne in Form einer Matrix, also in Reihen und Spalten, angeordnet. Jeder Magnetkern erhält dabei mindestens zwei Wicklungen und die eine Wicklung jedes Kernes wird jeweils mit den entsprechenden Wicklungen der übrigen Kerne der gleichen Reihe und die andere Wicklung jedes Kernes mit den entsprechenden anderen Wicklungen der übrigen Kerne der gleichen Spalte in Serie geschaltet.

Bei einer solchen Magnetkernmatrix können beispielsweise die Magnetkerne der einzelnen Reihen für das Speichern von einer mehrstelligen Zahl benutzt werden. Die in Serie geschalteten Wick-



United States Patent Office

2,996,700
Patented Aug. 15, 1961

1

2,996,700
ARRANGEMENT FOR CONTROLLING IN CALCULATING MACHINES, OFFICE MACHINES AND THE LIKE
Heinz Billing and Wilhelm Hopmann, Gottingen, Germany, assignors to Max-Planck-Gesellschaft zur Förderung der Wissenschaften e.V., Gottingen, Germany
Filed Nov. 29, 1955, Ser. No. 549,816
Claims priority, application Germany Nov. 29, 1954
4 Claims. (Cl. 340—174)

This invention relates to electronic computing, calculating, and similar machines, and more particularly to an improvement of their control organisms.

Such a machine comprises, in addition to storage units and calculating or computing units proper, a command organism which controls the succession of the several operations. This command center includes a command register into which are fed the various commands as may be required for a desired result in the shape of command keys, and also includes control arrangements which, dependent upon the command fed to the command center, control the other parts of the machine. The various control arrangements constitute the control organism or center and the invention relates more particularly to an improvement of this control.

The purpose of the invention will now be explained referring by way of example to a machine of the parallel operation kind. However, similar arrangements could be used in conjunction with series machines.

The problem to be solved and the fundamental operating principles will now be described with reference to FIGS. 1, 2 and 3 of the accompanying drawings, FIGS. 4 to 11 showing various embodiments of the invention.

FIG. 1 shows diagrammatically the combination and association of the various parts of a calculating machine;

FIG. 2 shows the interconnection between a command register and a control center of the machine;

FIG. 3 shows such a control arrangement of conventional design;

FIG. 4 is the diagram of an electronic control arrangement according to the invention;

FIG. 5 comprises curves showing how the potentials at certain points of FIG. 4 vary with time;

FIG. 6 is a diagram of a control including a branched chain arrangement;

FIG. 7 shows a further development including several branches;

FIG. 8 shows a ring chain arrangement;

FIG. 9 shows another embodiment in which certain portions of the chain can be omitted by skipping;

FIG. 10 shows a matrix suitable for controlling the first elements of a control chain; and

FIG. 11 shows the connection diagram for a deciphering unit suitable for operating the control chains.

The arrangement of FIG. 1 includes a storage unit **1** and a calculating unit with three readily accessible registers, namely a multiplicand register **2** which is also indicated M*d*, a multiplier register **5** also indicated M*r*, and an accumulator **4** also indicated A*k*. A command register **6** indicated B*r*, and an adding device **3** indicated A*d* are also provided.

The register **2** connected to the storage unit **1** is supplied with the multiplicand, and the register **5** is supplied with the multiplier if a multiplication is to be carried out. Between the M*d* register **2** and the accumulator there is an adding device **3** so that the contents of M*d* can be added to the accumulator as required, and the results of the various calculating operations appear in the accumulator.

The command register **6** is supplied with the various calculation commands before the start of each calculating operation. Each command comprises an address

2

portion constituted by the number of the storage unit, the contents of which is used for the calculating operation, and an operating portion which determines the kind of the calculating operation required. For instance a command LS*p* means "read the storing unit" or in other words transfer the contents of the storage unit indicated in the command register to the M*d* register. All the registers are so interconnected that the contents of one register can be transferred to any of the other registers if a suitable command is given. For instance, the command "M*d*→M*r*" means "shift the contents from M*d* to M*r*." Furthermore, the digits of a number within each register can be shifted to the left or to the right by a respective command. Such command may be M*d*→1 or M*r*→*r*, for instance. All the various calculating operations such as multiplication, division, square roots and so on, can be obtained by combining such sub-commands including addition, transfer, shifting, and other simple operations. The main command defines the actual calculation and is composed of a number of sub-commands.

For a better understanding two simple examples will now be described.

1st main command

Transfer a number from the storage unit designated in the command register to the accumulator and cancel multiplicand register.

This main command is composed of the sub-commands LS*p*, A*d*, M*d*→0.

The sub-command *Md*—0 results in the cancellation of the M*d* register.

2nd main command

Multiply the number from the storage unit designated in the command register by the number in the accumulator.

For greater simplicity it is assumed that both numbers are given in the dual or binary system and that each comprises twenty digits. This main command requires a sub-command A*d*?, meaning that the contents of M*d* should be added to the accumulator only if the lowest digit in the M*r* register is one. Then the main command "multiplication" is composed of the following sub-commands:

A*k*→M*r*, LS*p*, (A*d*?, M*r*→*r*, M*d*→1)

(A*d*?, M*r*→*r*, M*d*→1) . . . M*r*→0, M*d*→0

The sub-commands in brackets are repeated twenty-times so as to form and add together the partial products as is known in binary multiplication.

These examples show the main problem of the control centre which is to ensure the correct sequence of sub-commands in accordance with a main command introduced into the command register. Generally a subsequent sub-command must not be started before a previous sub-command is completed.

The problem of the invention will be further explained with reference to FIG. 2, which shows a command register **6** interconnected with a deciphering pyramid **7** for selecting one of thirty-two possible main commands **H1** to **H32**.

The squares **U1** to **U20** indicate elements or units for initiating twenty sub-commands. An intermediary control **8** interconnects the deciphering pyramid **7** with the sub-command elements. After a sub-command is completed a "finish" signal is returned to the control **8** which can now initiate a subsequent sub-command. With some kinds of control arrangements the "finish" signal can be dispensed with if a sufficient time interval between initiations of consecutive sub-commands is allowed to insure that one sub-command is completed before another one

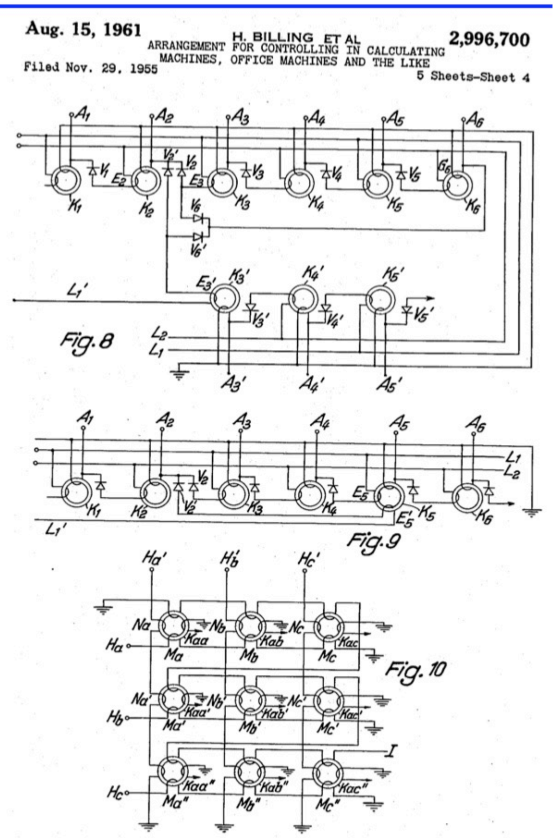


Figure 6.173: Computer patents by Heinz Billing.

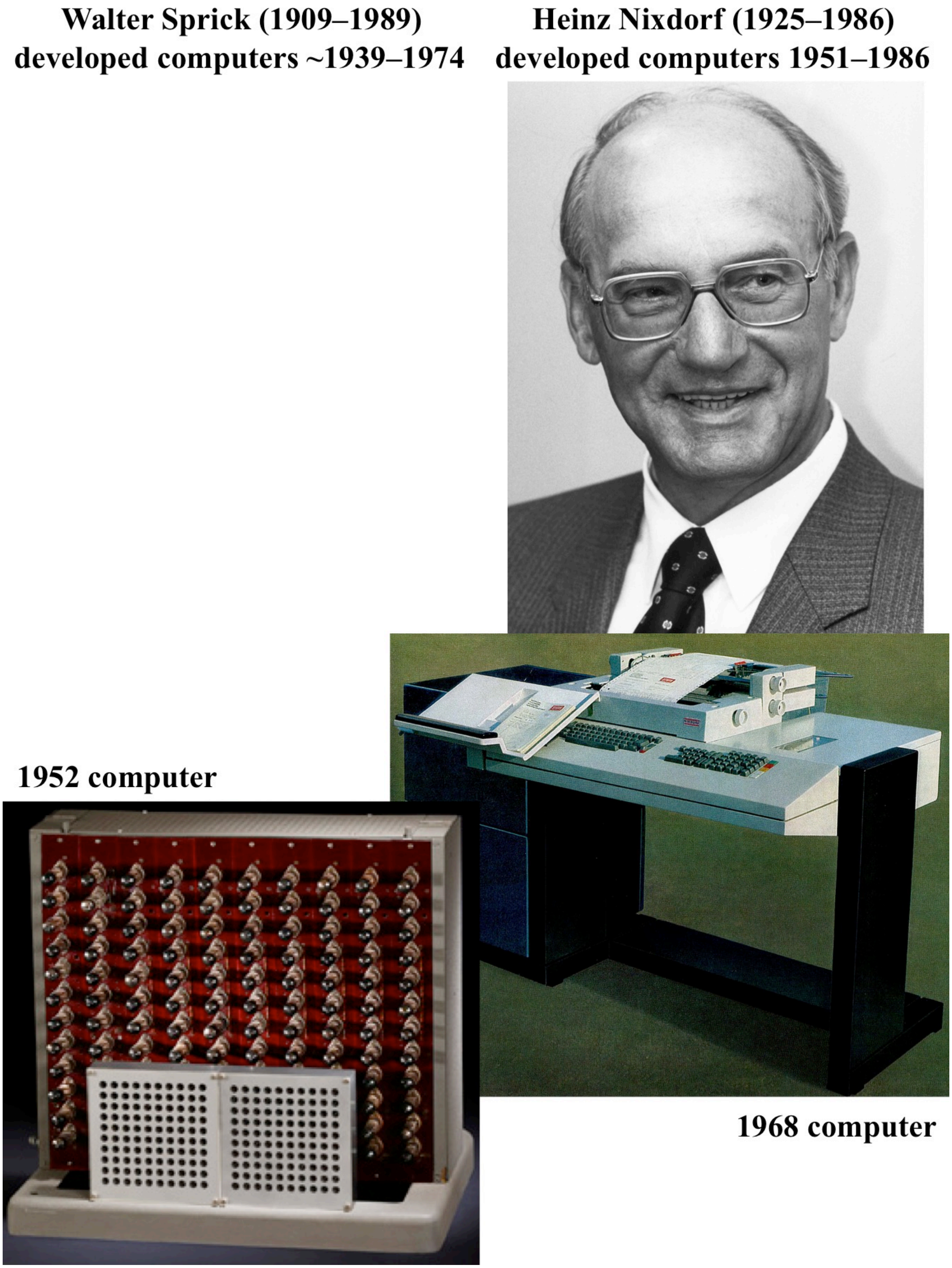


Figure 6.174: Walter Sprick developed computers ∼1939–1974. Based on Sprick's designs, Heinz Nixdorf developed computers 1951–1986.

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I

S E C R E T

Device For Transforming Spoken Words Into Recorded Legible Typewriting

One German wartime development which was discovered by one of the investigators for the Electronics and Communications Section is a device which has been the dream of American scientists in the communications field for a long time, one on which they have been working for many years, unsuccessfully.

Professor Oskar Vierling of the Feuerstein Laboratory at Ebermanstadt, Germany, developed the idea completely for the successful application of the fundamental principles to be employed in producing a device which will take the spoken word and transform it into the typewritten word on paper. The fundamental principles employed involve the separation of the sound waves produced by spoken words into nine bands of the sound range of the human ear and the actuation of a typewriting device by means of the transmission of the electrical vibrations resulting from the sound waves produced by the spoken words.

It is, therefore, readily discernible that the application of these principles will eliminate the need for stenographic transcription because it will provide the means for dictating a letter into a machine that will instantaneously reproduce in the form of a typewritten letter the words that are spoken into the machine. By the same token, a message dictated into a teletypewriter equipped with the device will appear simultaneously in typewritten form on every teletypewriter on a nationwide or worldwide network.

Transmission by means of this device can be accomplished with much greater speed than is otherwise possible. Consequently, the application of the device for transmission of messages by the communications companies will have further economic advantages because of the additional savings that can be accomplished in circuit use time. This is, of course, particularly true in the case of long-haul traffic handled on inter-city long distance communications channels.

Due to the possible application of this device for military communication purposes, the report containing detailed information pertaining to it is secret and is, therefore, not available to the public.

Figure 6.175: The first methods of electronic speech recognition were developed in the German-speaking world and transferred to other countries after World War II [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

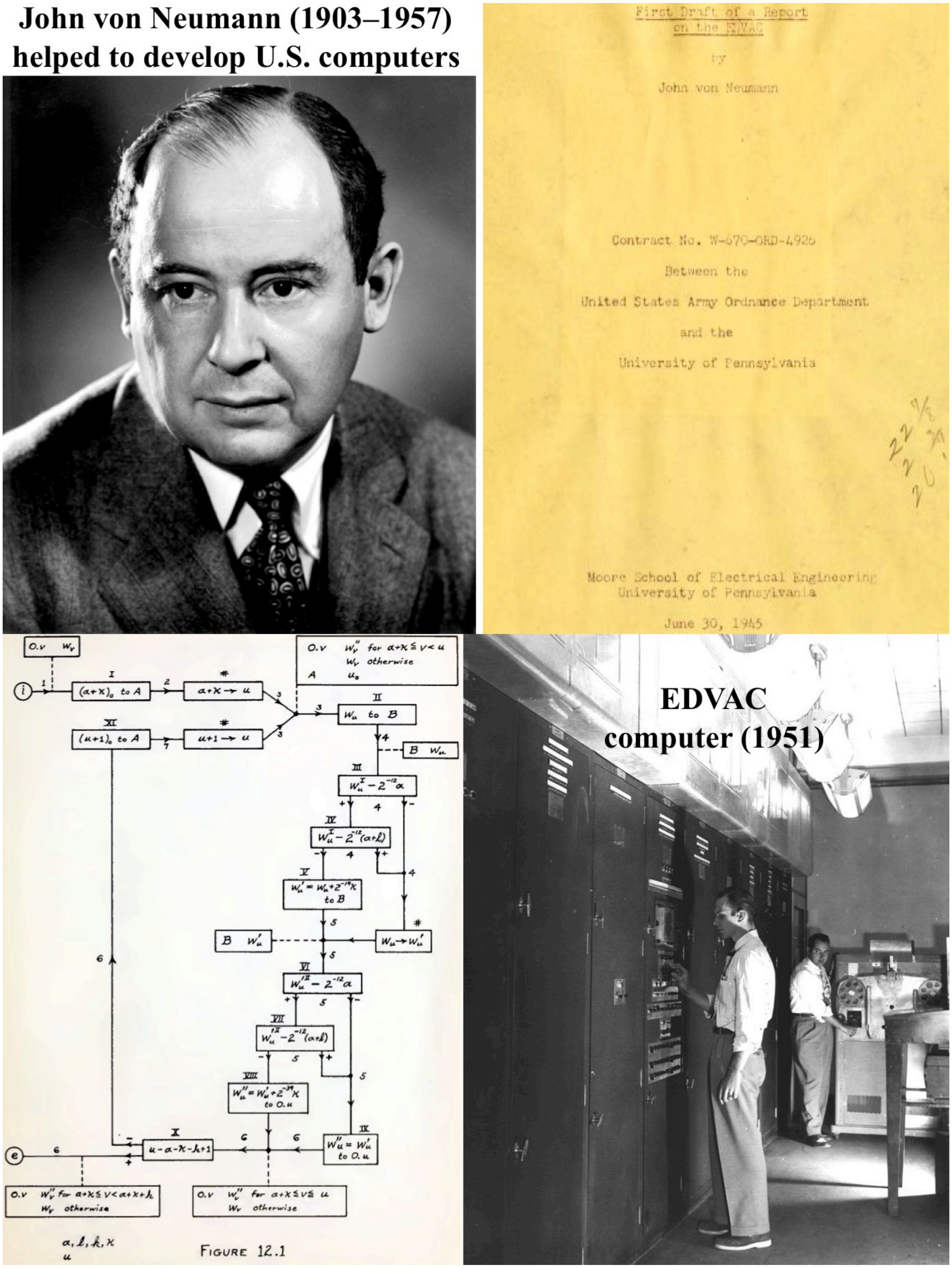


Figure 6.176: John von Neumann helped to develop the first programmable digital computers in the United States, such as EDVAC (1951).

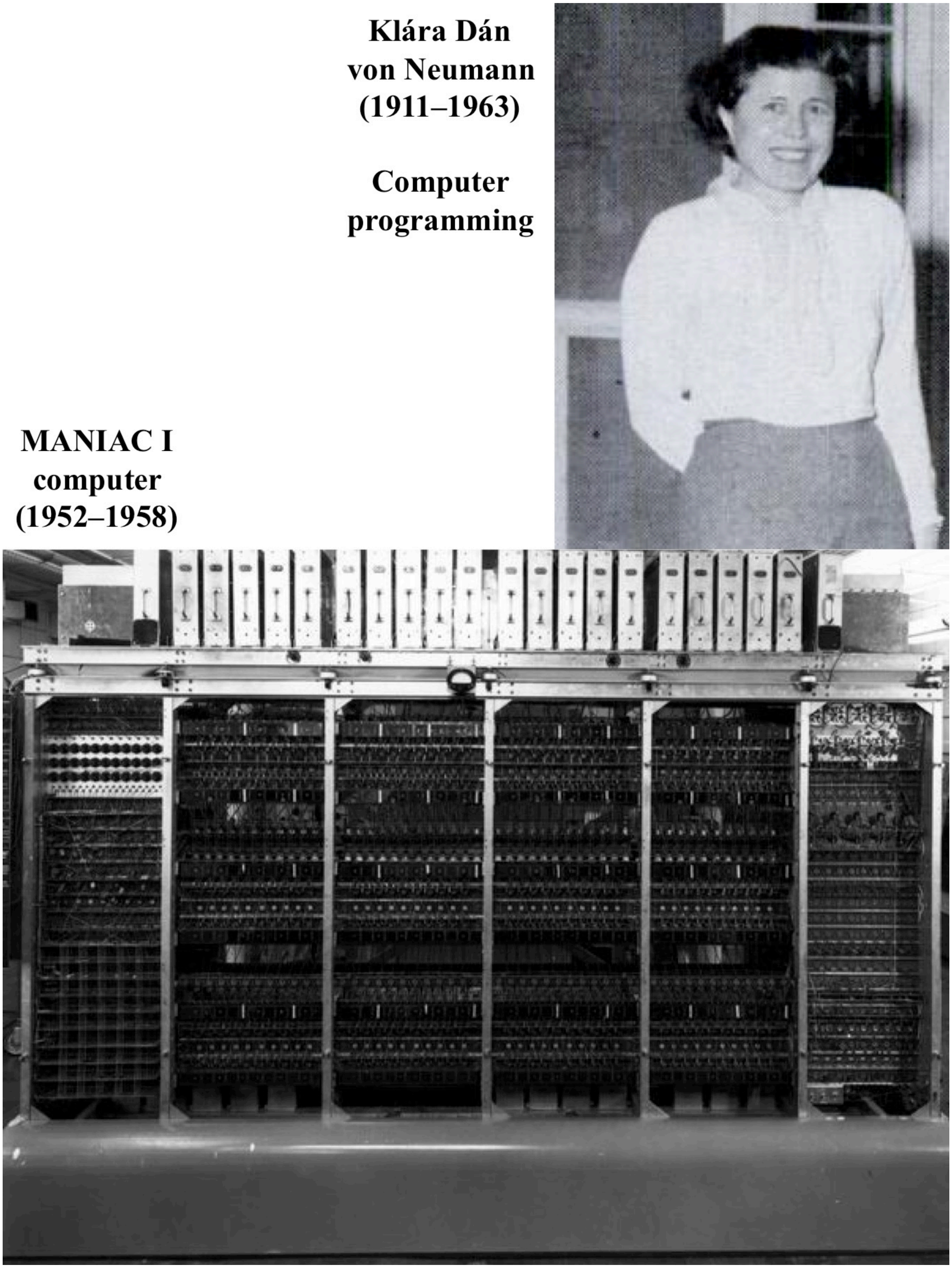


Figure 6.177: Klára Dán von Neumann was one of the first programmers on early computers such as MANIAC I (1952).

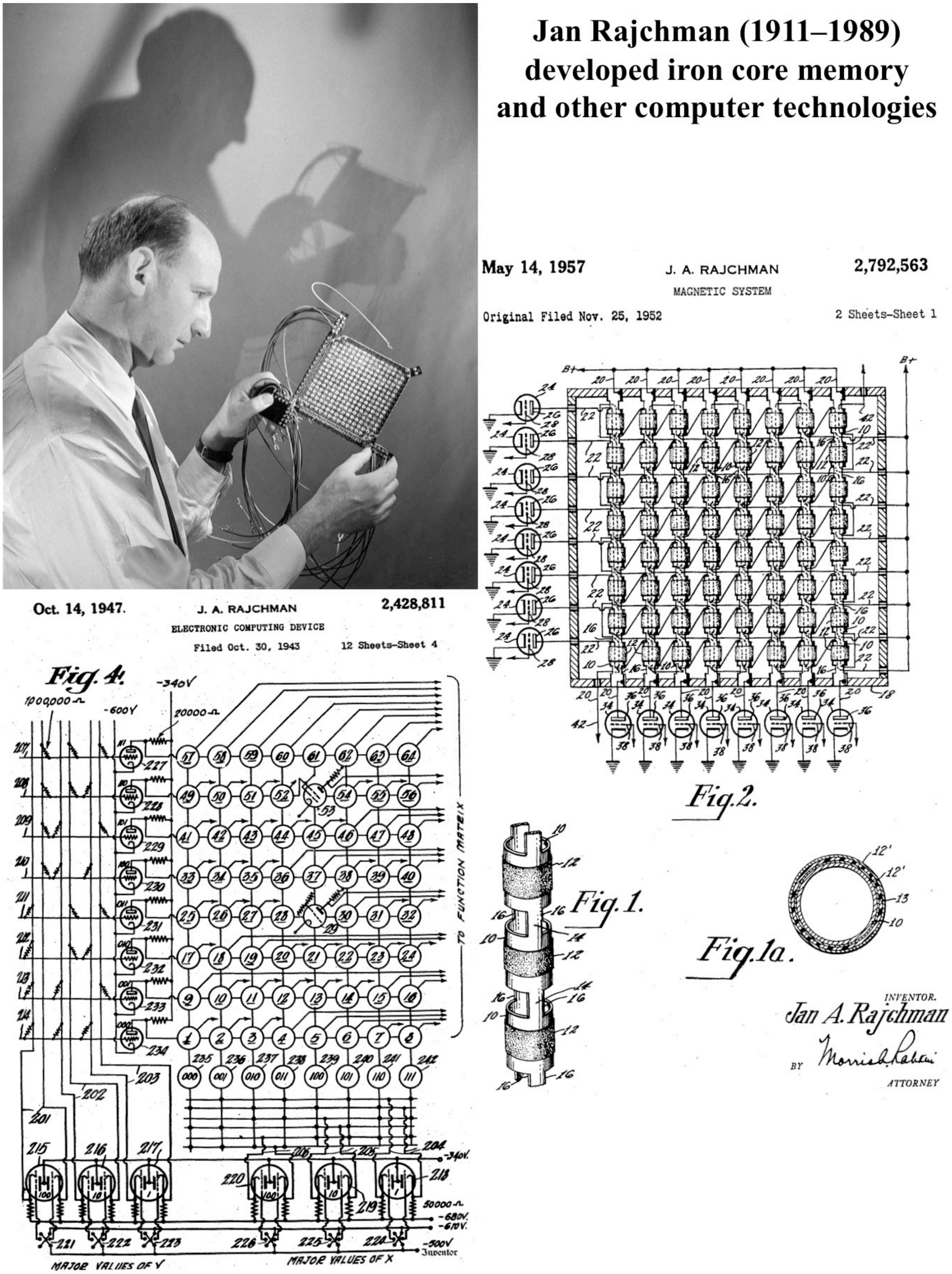
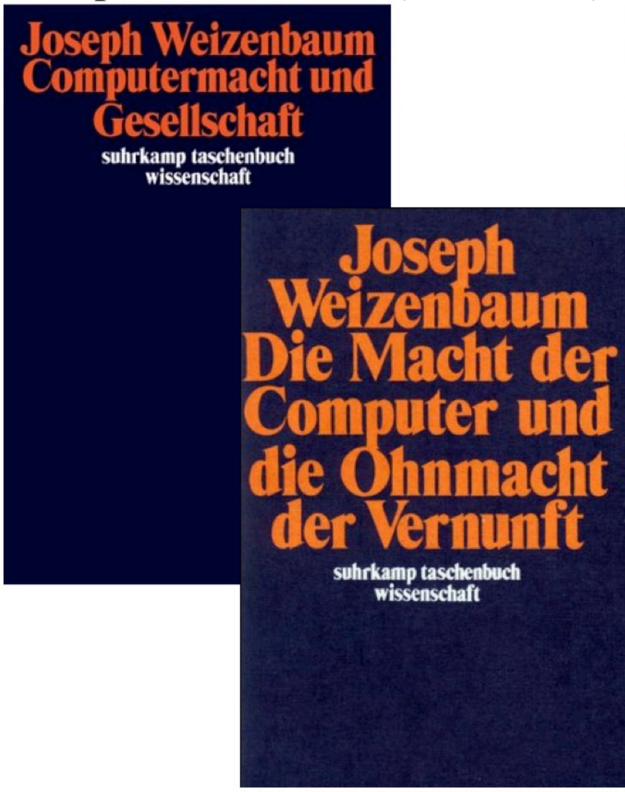
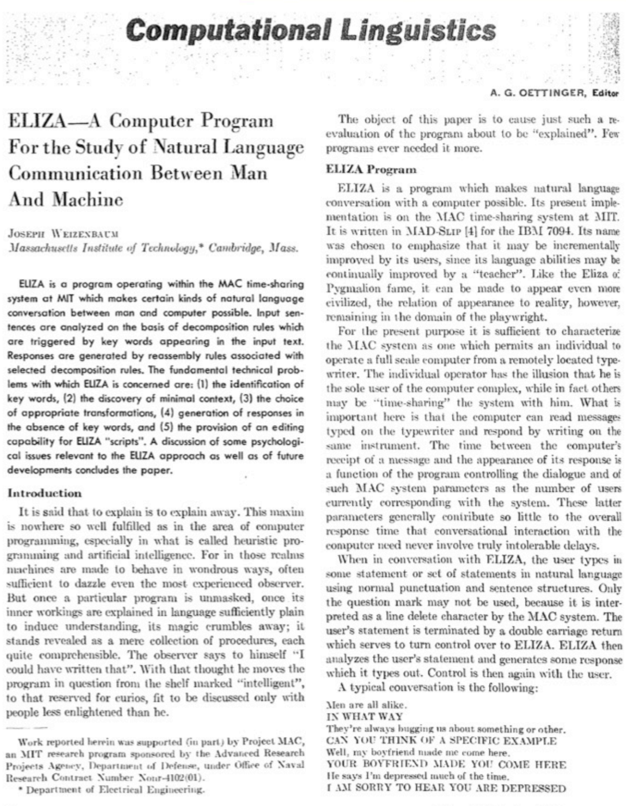


Figure 6.178: Jan Rajchman developed iron core memory and other computer technologies.

Joseph Weizenbaum (1923–2008)





Computational Linguistics

A. G. OETTINGER, Editor

ELIZA—A Computer Program For the Study of Natural Language Communication Between Man And Machine

JOSEPH WEIZENBAUM
Massachusetts Institute of Technology, Cambridge, Mass.*

ELIZA is a program operating within the MAC time-sharing system at MIT which makes certain kinds of natural language conversation between man and computer possible. Input sentences are analyzed on the basis of decomposition rules which are triggered by key words appearing in the input text. Responses are generated by reassembly rules associated with selected decomposition rules. The fundamental technical problems with which ELIZA is concerned are: (1) the identification of key words, (2) the discovery of minimal context, (3) the choice of appropriate transformations, (4) generation of responses in the absence of key words, and (5) the provision of an editing capability for ELIZA "scripts". A discussion of some psychological issues relevant to the ELIZA approach as well as of future developments concludes the paper.

Introduction

It is said that to explain is to explain away. This maxim is nowhere so well fulfilled as in the area of computer programming, especially in what is called heuristic programming and artificial intelligence. For in those realms machines are made to behave in wondrous ways, often sufficient to dazzle even the most experienced observer. But once a particular program is unmasked, once its inner workings are explained in language sufficiently plain to induce understanding, its magic crumbles away; it stands revealed as a mere collection of procedures, each quite comprehensible. The observer says to himself "I could have written that". With that thought he moves the program in question from the shelf marked "intelligent", to that reserved for curios, fit to be discussed only with people less enlightened than he.

Work reported herein was supported (in part) by Project MAC, an MIT research program sponsored by the Advanced Research Projects Agency, Department of Defense, under Office of Naval Research Contract Number Nonr-4102(01).
* Department of Electrical Engineering.

The object of this paper is to cause just such a re-evaluation of the program about to be "explained". Few programs ever needed it more.

ELIZA Program

ELIZA is a program which makes natural language conversation with a computer possible. Its present implementation is on the MAC time-sharing system at MIT. It is written in MAD-SLIP [4] for the IBM 7094. Its name was chosen to emphasize that it may be incrementally improved by its users, since its language abilities may be continually improved by a "teacher". Like the Eliza of Pygmalion fame, it can be made to appear even more civilized, the relation of appearance to reality, however, remaining in the domain of the playwright.

For the present purpose it is sufficient to characterize the MAC system as one which permits an individual to operate a full scale computer from a remotely located typewriter. The individual operator has the illusion that he is the sole user of the computer complex, while in fact others may be "time-sharing" the system with him. What is important here is that the computer can read messages typed on the typewriter and respond by writing on the same instrument. The time between the computer's receipt of a message and the appearance of its response is a function of the program controlling the dialogue and of such MAC system parameters as the number of users currently corresponding with the system. These latter parameters generally contribute so little to the overall response time that conversational interaction with the computer need never involve truly intolerable delays.

When in conversation with ELIZA, the user types in some statement or set of statements in natural language using normal punctuation and sentence structures. Only the question mark may not be used, because it is interpreted as a line delete character by the MAC system. The user's statement is terminated by a double carriage return which serves to turn control over to ELIZA. ELIZA then analyzes the user's statement and generates some response which it types out. Control is then again with the user.

A typical conversation is the following:

Men are all alike.
IN WHAT WAY
They're always bugging us about something or other.
CAN YOU THINK OF A SPECIFIC EXAMPLE
Well, my boyfriend made me come here.
YOUR BOYFRIEND MADE YOU COME HERE
He says I'm depressed much of the time.
I AM SORRY TO HEAR YOU ARE DEPRESSED

36 Communications of the ACM Volume 9 / Number 1 / January, 1966

Development of artificial intelligence, including ELIZA software (1965)

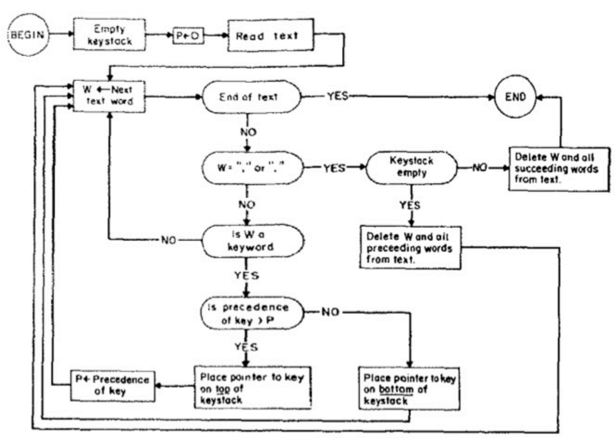
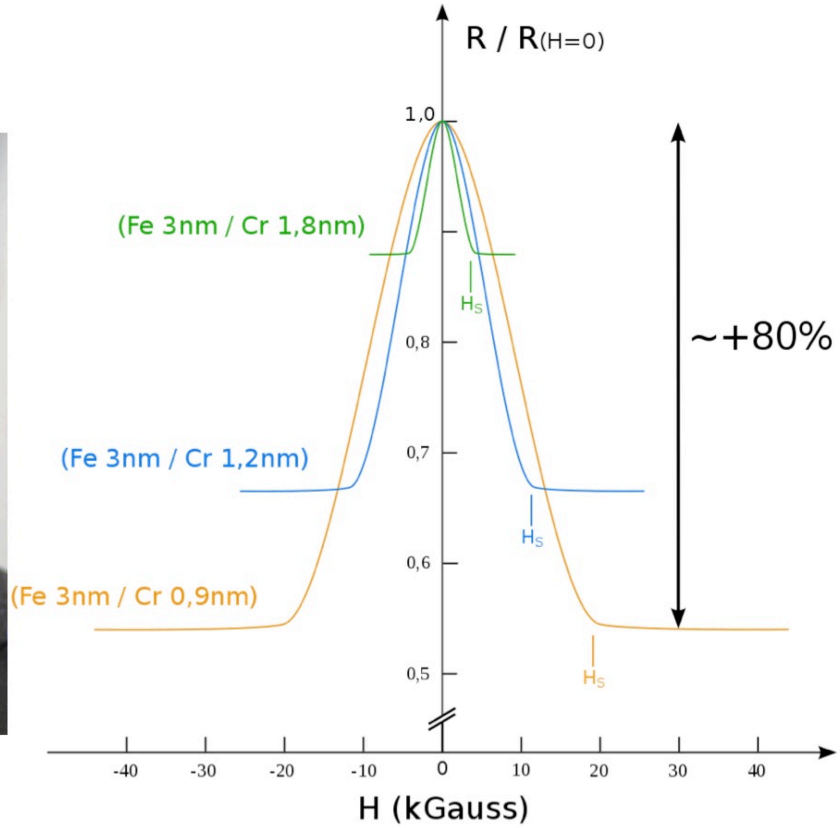


FIG. 2. Basic flow diagram of keyword detection

Figure 6.179: Joseph Weizenbaum created the ELIZA software in 1965, a major step in the development of artificial intelligence.

Peter Grünberg (1939–2018) discovered giant magnetoresistance, which can be used for high-density magnetic hard drives



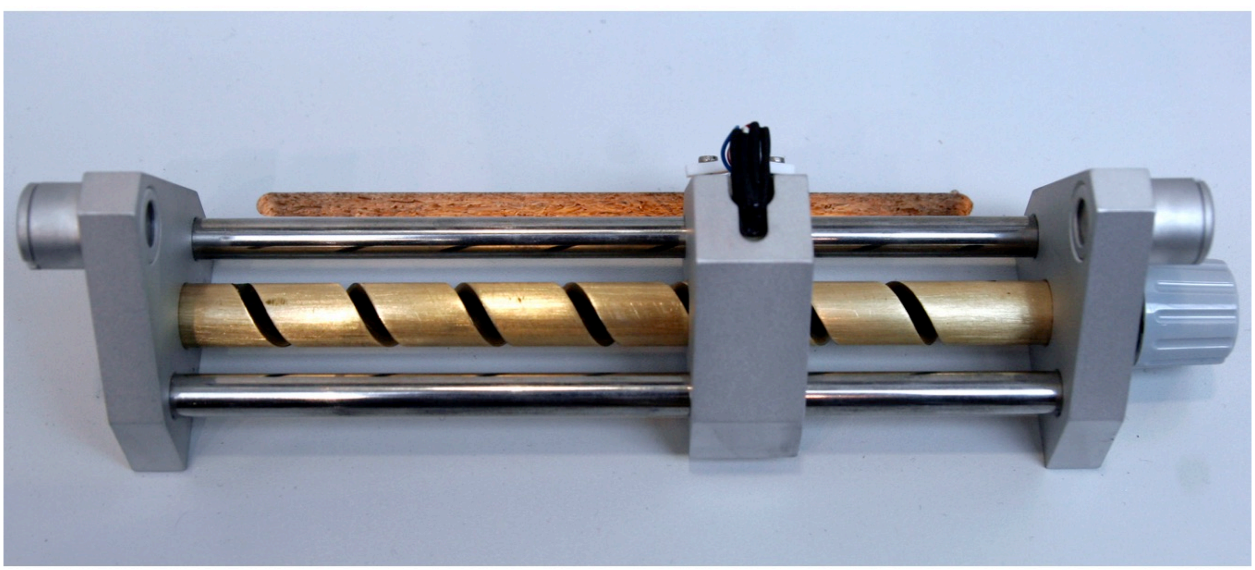


Figure 6.180: Peter Grünberg discovered giant magnetoresistance, which can be used for high-density magnetic hard drives.

6.7.3 Cryptography

German-speaking experts revolutionized cryptography from World War I through the Cold War.[18]

Arthur Scherbius (German, 1878–1929) developed and filed patents on Enigma cryptography machines beginning in 1918, as shown in Fig. 6.181. Despite being relatively small and inexpensive, the Enigma machines were so effective at encryption and decryption that it required two decades, millions of British pounds, hundreds of special-purpose calculating machines, and stolen Enigma machines and Enigma codes in order to reliably decipher the encrypted messages. The Enigma machines were a WW-I-era German technology that was so far ahead of its time that the machines remained useful into World War II.

In contrast to popular stories in the English-speaking world about codebreaking at Bletchley Park in the United Kingdom, even the key insights involved in breaking the Enigma code came from other creators from the greater predominantly German-speaking scientific world, especially Marian Rejewski (Polish, 1905–1980), Jerzy Różycki (Polish, 1909–1942), and Henryk Zygalski (Polish, 1908–1978) [Hinsley 1979, Vol. 3, Part 2, pp. 945–959]. See Figs. 6.182–6.183. Rejewski, Różycki, and Zygalski began breaking simple Enigma codes in 1932. As more and more complex Enigma codes were used by the German military, Rejewski, Różycki, and Zygalski's codebreaking methods grew more advanced. By 1938, they had designed and built a "Bomba" decoding machine that used electromechanical gears to run through possible combinations and decipher Enigma messages. Soon they were forced to flee to France and then the United Kingdom. Built with their assistance, the British "Bombe" (1940) scaled up the Rejewski/Różycki/Zygalski system with many identical subunits in parallel. Popular accounts depicting the British as having conceived and implemented the Enigma decryption methods on their own [such as Hodges 1983 and its 2014 film adaptation, *The Imitation Game*] deny proper credit to the real creators.

Another fact omitted from most popular English-language histories is that rather than stopping with Enigma, German-speaking experts went on to develop far more advanced cryptographic machines and methods before and during World War II. Their advanced encryption and decryption machines, and the German-speaking experts themselves, later became the foundation for Cold War cryptography in other countries in the following decades.

Some of the advanced German encryption machines included:

- The Siemens and Halske T-52 Geheimschreiber (Fig. 6.184).
- The Siemens Schlüssel-Fernschreibmaschine SFM T-43 Sägefisch (Swordfish, Fig. 6.185).
- The Lorenz Schlüssel-Zusatz SZ42 (Fig. 6.186).
- Other encryption systems that were developed and used by wartime Germany and then seized by Allied countries after the war (e.g., Fig. 6.187).

Those machines were captured by Allied countries at the end of World War II and formed the basis of Cold War encryption for many years thereafter.

[18] Bamford 2002; Faensen 2001; Hinsley 1979; Hodges 1983; Kahn 1998; Parrish 1985; Reuvers and Simons 2020; West 1999.

Along with the advanced encryption machines, German-speaking experts developed and used decryption computers to decipher coded transmissions from the United States, United Kingdom, Soviet Union, and other countries. Even highly secret coded messages between Washington and London were routinely intercepted and decrypted (Fig. 6.188). The German system for decrypting Soviet communications (sometimes called "Russian Fish") was especially advanced, and it accomplished a feat that the United States and United Kingdom had been unable to achieve (Fig. 6.189). That system was also captured by Allied countries and became the basis for much Cold War technology. Most of the details regarding the technology and its history remain secret even now.

In addition to the advanced encryption and decryption machines, Allied countries captured and utilized hundreds of highly skilled German and Austrian cryptographers. There were far too many of those cryptographers to list here, but some especially important ones who decrypted Allied coded communications during the war included Walter Fricke (German, 1915–1988), Erich Hüttenhain (German, 1905–1990), Kurt Vetterlein (German, 19??–19??), and Reinold Weber (German, 19??–19??), as shown in Fig. 6.189.

German-speaking creators such as Gustav Guanella (Swiss, 1909–1982) and Horst Feistel (German, 1915–1990) also made major contributions to cryptography after World War II. Fig. 6.191 presents examples from their patents on advanced cryptographic techniques.

Journalist James Bamford provided a rare glimpse into German cryptographic work that was discovered by the Allied TICOM (Target Intelligence Committee) team at the end of the war [Bamford 2002, pp. 8–18]:

> Colonel George A. Bicher, the director of the U.S. Signal Intelligence [Sigint] Division in Europe, conceived of TICOM in the summer of 1944. The organization was so secret that even today, more than half a century later, all details concerning its operations and activities remain classified higher than Top Secret by both the American and British governments. In 1992, the director of the National Security Agency extended the secrecy order until the year 2012, making TICOM probably the last great secret of the Second World War. [...]
>
> Although Bletchley Park had conquered the Enigma machine, the Germans had managed to go one better. They developed a new and even more secret cipher machine, the *Geheimschreiber*, or secret writer, which was reserved for the very-highest-level messages, including those to and from Hitler himself. German cryptographers called an early model Swordfish. The Americans and British simply called them the Fish. Unlike Enigma, the Fish were capable of automatically encrypting at one end and decrypting at the other. Also, rather than the standard 26-letter alphabet, the Fish used the 32-character Baudot code, which turned the machine into a high-speed teleprinter.
>
> TICOM's goal was to capture a working model intact and thus learn exactly how the Germans built such a complex, sophisticated encryption device. [...]
>
> With enough Fish and other equipment to keep the engineers busy for a long time at Bletchley, the team began a manhunt for key German codebreakers. On May 21, 1945, Lieutenant Commander Howard Campaigne and several other TICOM officers interviewed a small group of Siginit personnel being held in Rosenheim. They had all worked for a unit of the Signals Intelligence Agency of the German Abwehr High

Command, a major target of TICOM. What the prisoners told Campaigne would lead to one of the most important, and most secret, discoveries in the history of Cold War codebreaking. Their command, they said, had built a machine that broke the highest-level Russian cipher system. [...]

It was a massive haul of some 7½ tons.

Over the next several days the dark gray equipment was carefully lifted from its crates and set up in the basement of the building. Then, like magic, high-level encrypted Russian communications, pulled from the ether, began spewing forth in readable plaintext. [...]

The Russian system involved dividing the transmissions into nine separate parts and then transmitting them on nine different channels. The German machines were able to take the intercepted signals and stitch them back together again in the proper order. For Campaigne and the rest of the TICOM team, it was a once-in-a-lifetime discovery. Back in Washington, Campaigne would eventually go on to become chief of research at NSA. [...]

The discovery of the Russian codebreaking machine was a principal reason why both the U.S. and British governments still have an absolute ban on all details surrounding the TICOM operations.

All told, the TICOM teams salvaged approximately five tons of German Sigint documents. In addition, many cryptologic devices and machines were found and returned to Bletchley.

Equally important were the interrogations of the nearly 200 key German codebreakers, some of which were conducted at a secret location codenamed Dustbin. In addition to the discovery of the Russian Fish, another reason for the enormous secrecy surrounding TICOM may be the question of what happened to the hundreds of former Nazi codebreakers secretly brought to England. Were any of the war criminals given new identities and employed by the British or American governments to work on Russian codebreaking problems? Among those clandestinely brought into the United States was the top codebreaker Dr. Erich Huetterhain. “It is almost certain that no major cryptanalytic successes were achieved without his knowledge,” said one TICOM document.

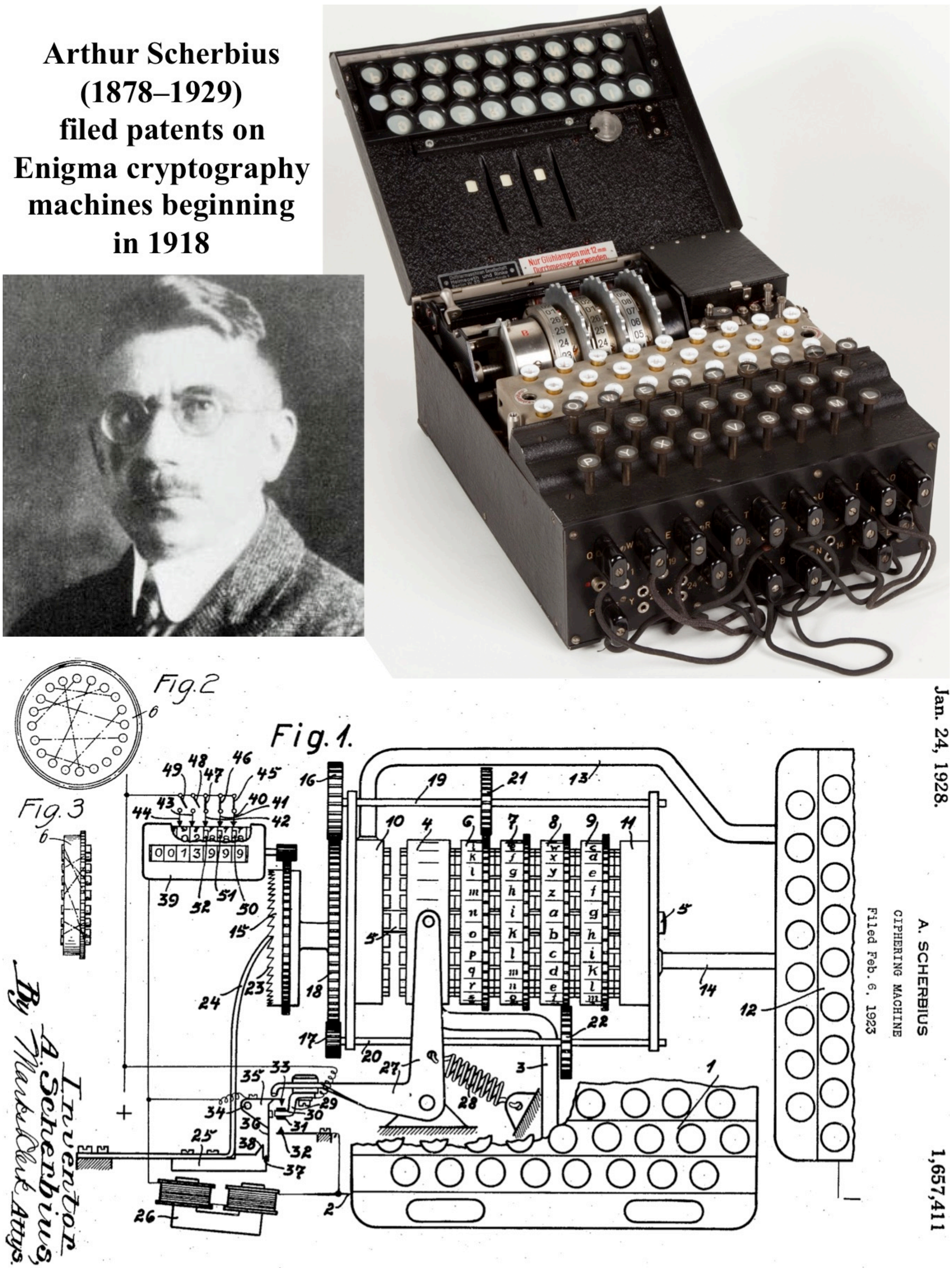
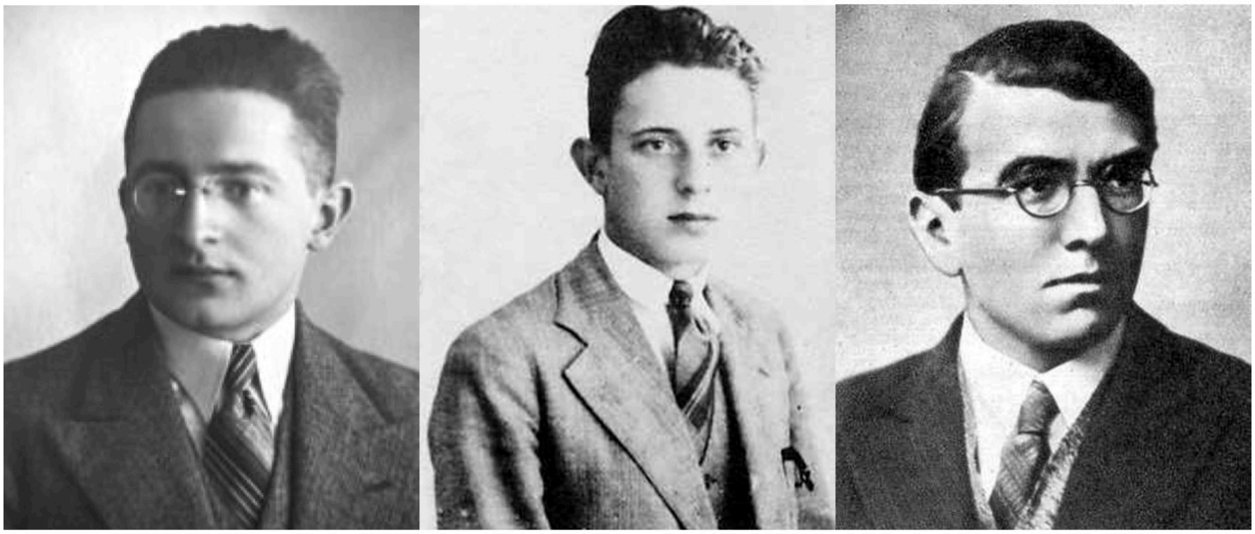


Figure 6.181: Arthur Scherbius filed patents on Enigma cryptography machines beginning in 1918.

Marian Rejewski (1905–1980) | **Jerzy Różycki (1909–1942)** | **Henryk Zygalski (1908–1978)**



**Plaque at Bletchley Park, United Kingdom:
"This plaque commemorates the work of
Marian Rejewski, Jerzy Różycki, and Henryk Zygalski,
mathematicians of the Polish intelligence service,
in first breaking the Enigma code."**

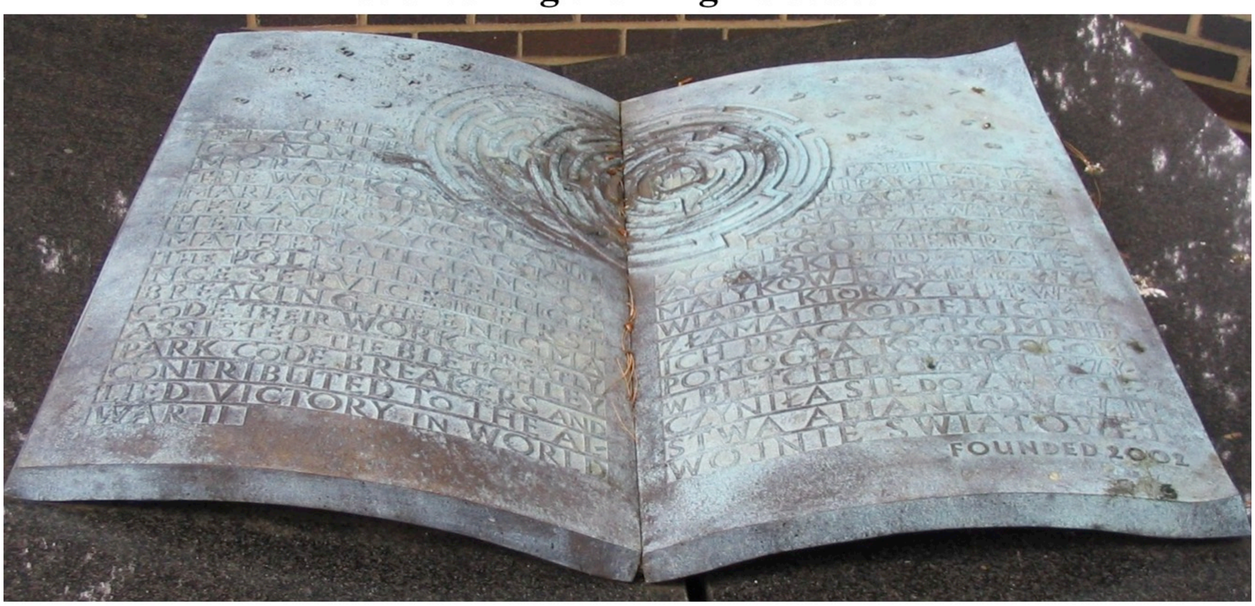


Figure 6.182: Marian Rejewski, Jerzy Różycki, and Henryk Zygalski were primarily responsible for breaking the Enigma code.

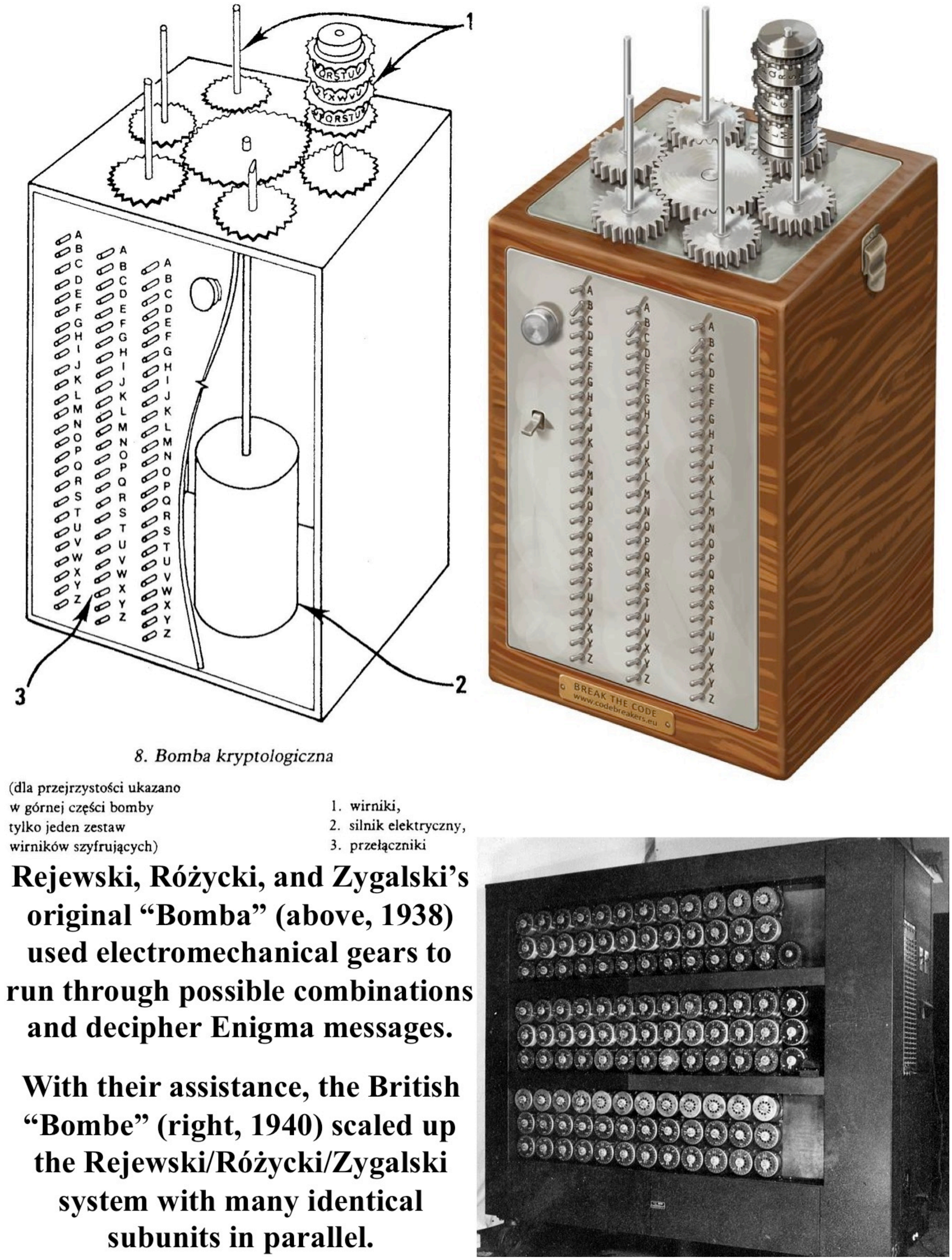


Figure 6.183: Rejewski, Różycki, and Zygalski's original "Bomba" (1938) used electromechanical gears to run through possible combinations and decipher Enigma messages. With their assistance, the British "Bombe" (1940) scaled up the Rejewski/Różycki/Zygalski system with many identical subunits in parallel.

Figure 6.184: Siemens and Halske T-52 Geheimschreiber (used from 1930 onward).

**Siemens Schlüssel-Fernschreibmaschine
SFM T-43 Sägefisch (1943)**

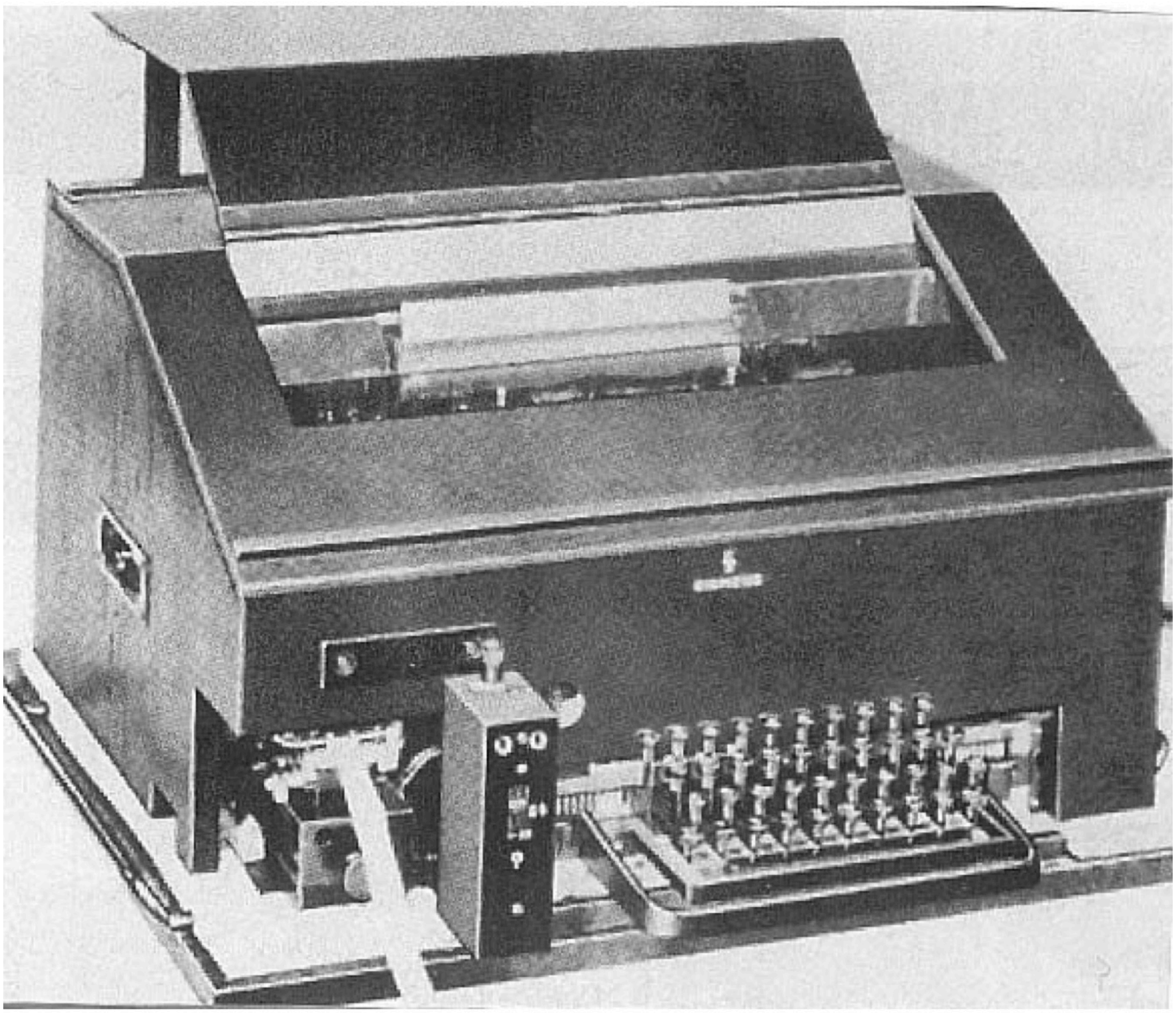


Figure 6.185: Siemens Schlüssel-Fernschreibmaschine SFM T-43 Sägefisch (Sawfish) encryption machine (1943).

Lorenz Schlüssel-Zusatz SZ42 (1942)

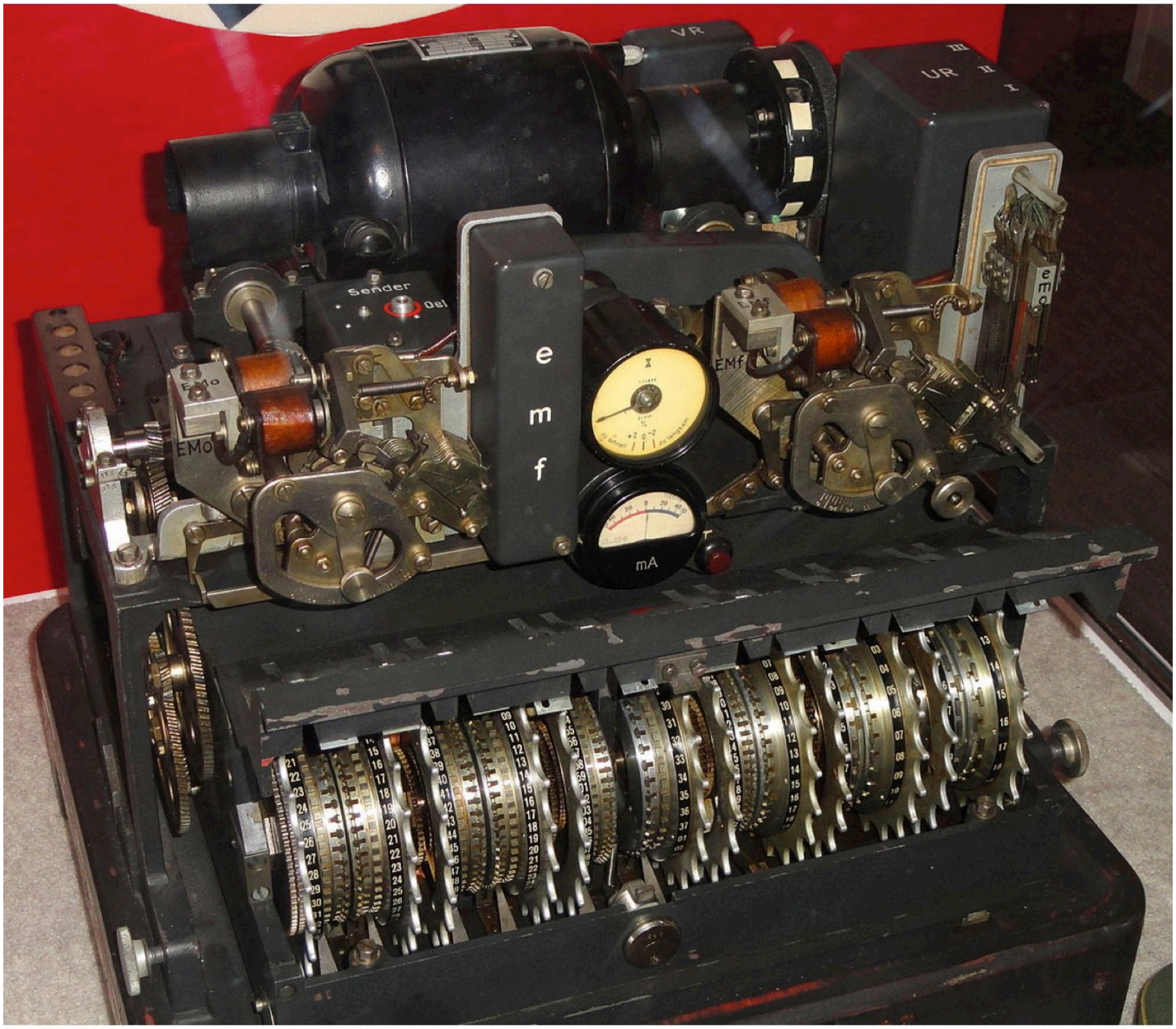


Figure 6.186: Lorenz Schlüssel-Zusatz SZ42 encryption machine (1942).

**NARA RG 40, Entry UD-75,
Box 58, Folder TIID Discards**

II

S E C R E T

COMMUNICATIONS SECRECY
SYSTEMS

Information which has been obtained pertaining to the communications secrecy systems developed by Professor Oskar Vierling in the Feuerstein Laboratory at Ebermanstadt, Germany, will prove to be of inestimable value for military purposes.

One of these systems which represents a modification of the usual plan for getting many sending frequencies from a single crystal resulted in the development of a compact multi-frequency crystal controlled radio set for the use of agents in enemy territory.

Another such development provided equipment whereby night fighter planes could be given instructions instantaneously by ground control intercept stations in much the same manner as the engine room of a ship receives operating instructions from the bridge. In night fighter operation, everything happens so quickly that it is of extreme importance to have the quickest possible ground-to-plane communications. This development provides an excellent answer to that problem.

In response to urgent wartime pressure resulting from the belief that coded telephone and teletypewriter messages were being decoded by the Allies, methods were developed by the Germans for increasing the effectiveness of the secrecy systems being used for that purpose. One of the systems the Germans developed for providing secrecy in telephone communications was very valuable due to the fact that anyone listening in to the scrambled speech thinks he hears perfectly good words, which are, however, quite wrong. The system that was developed for providing secrecy for teletype communications has also proved to be extremely effective.

Due to the possible military application of these developments, information pertaining to them is still classified as secret and is, therefore, not available to the public.

Figure 6.187: Advanced technologies for encrypting communications signals were developed in the German-speaking world and transferred to other countries after World War II [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

**German system for decrypting
trans-Atlantic Allied coded communications**

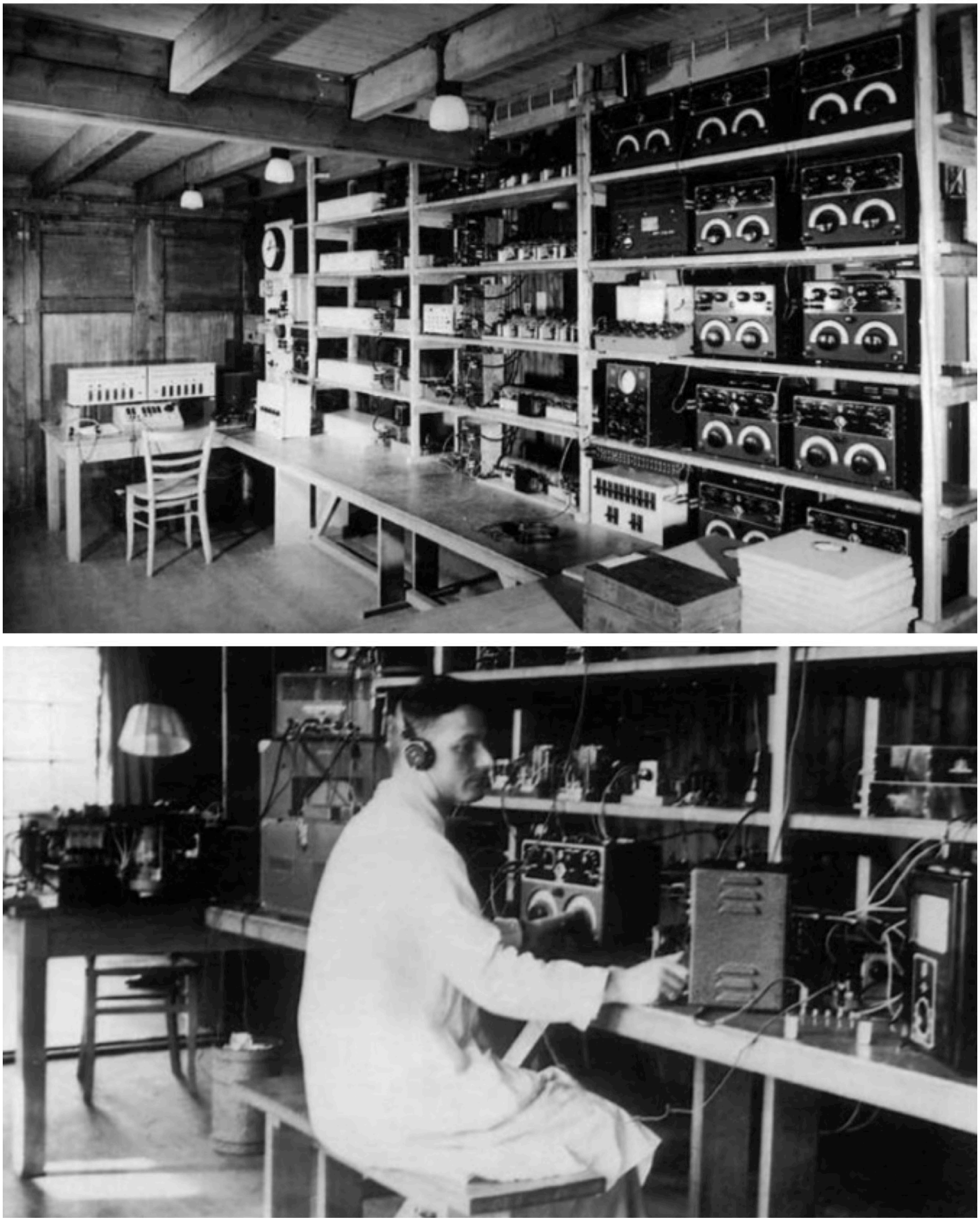


Figure 6.188: German system for decrypting trans-Atlantic Allied coded communications.

German system for decrypting Soviet coded communications

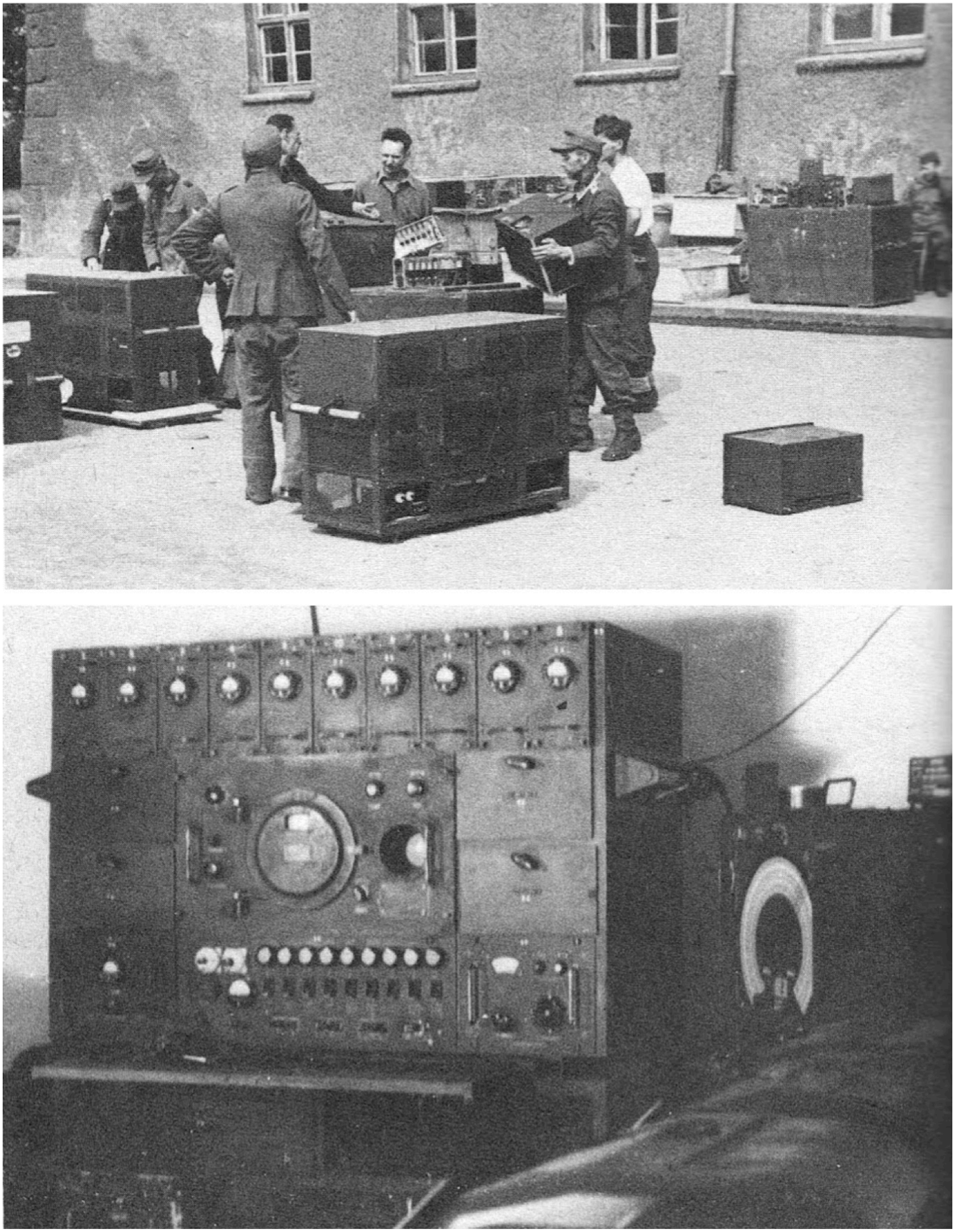


Figure 6.189: German system for decrypting Soviet coded communications (sometimes called "Russian Fish").

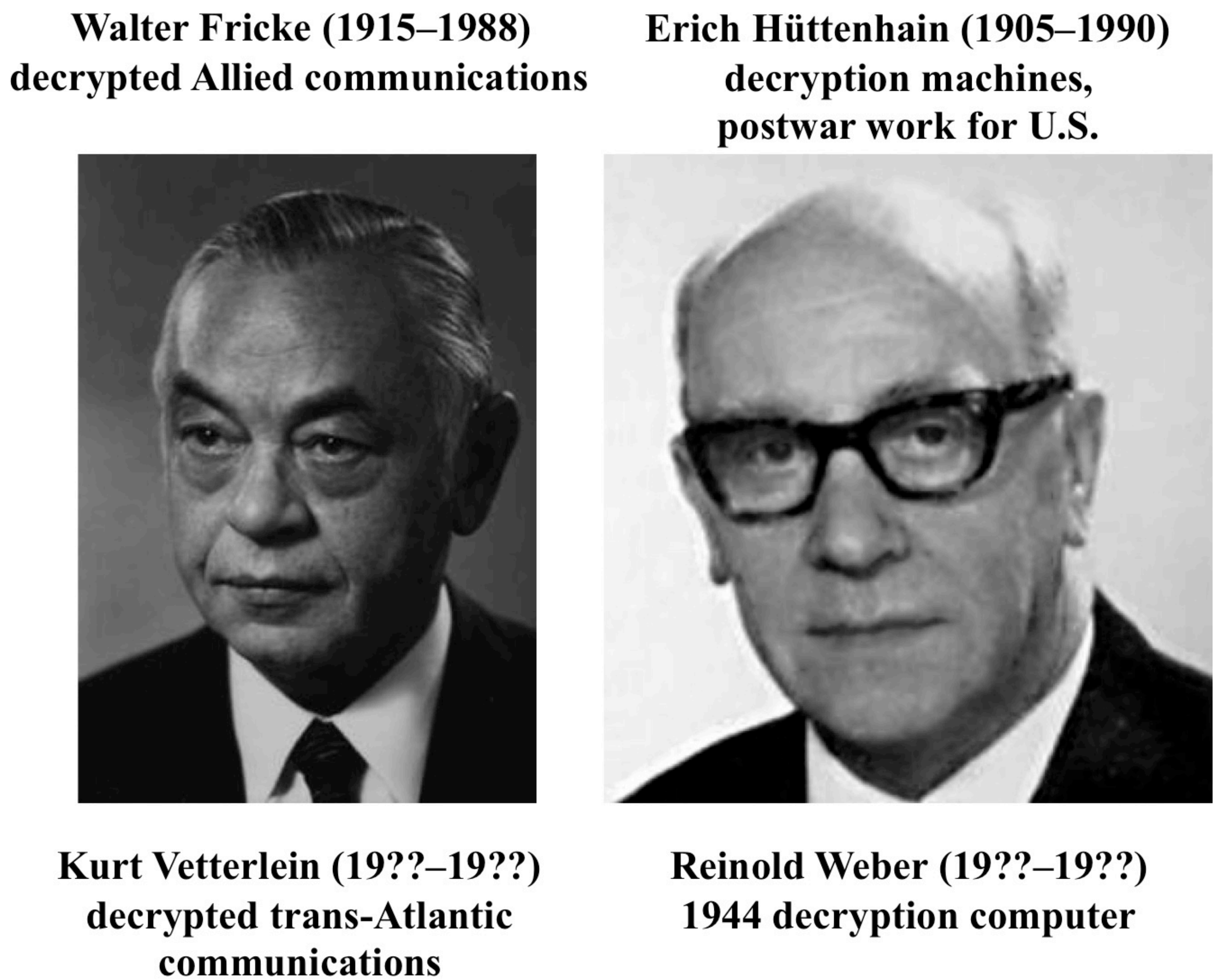
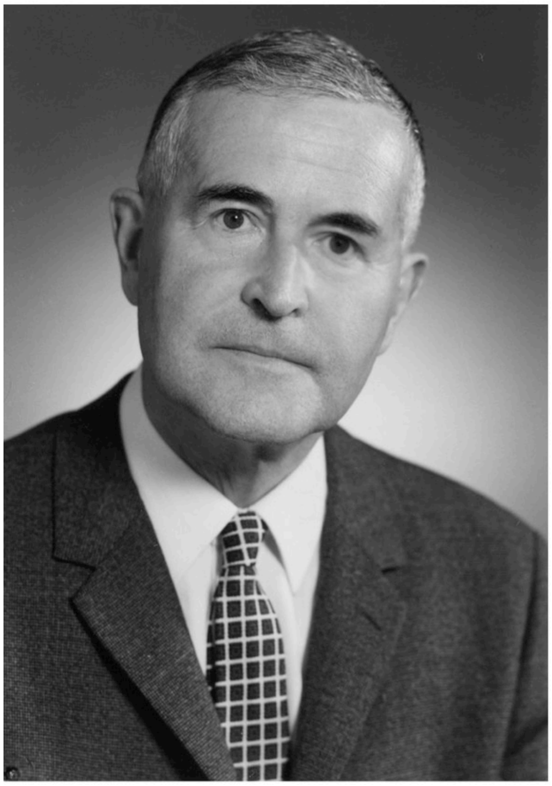
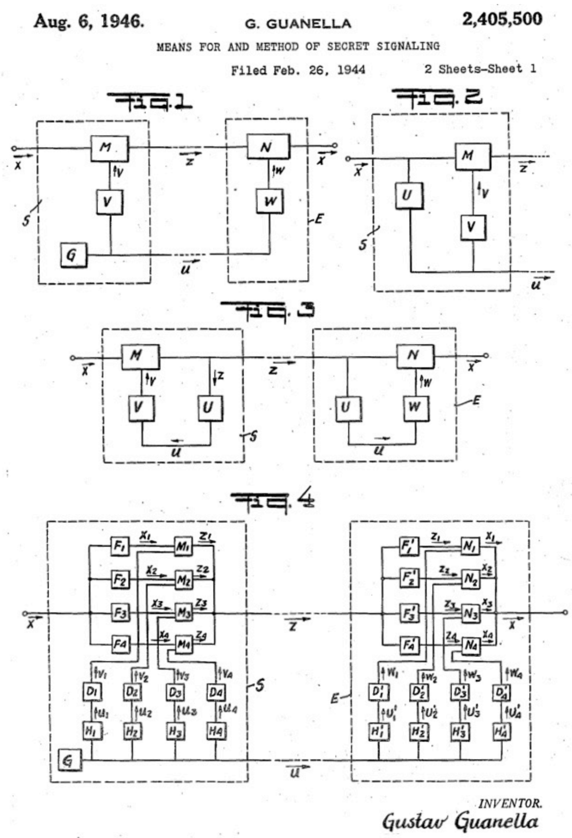


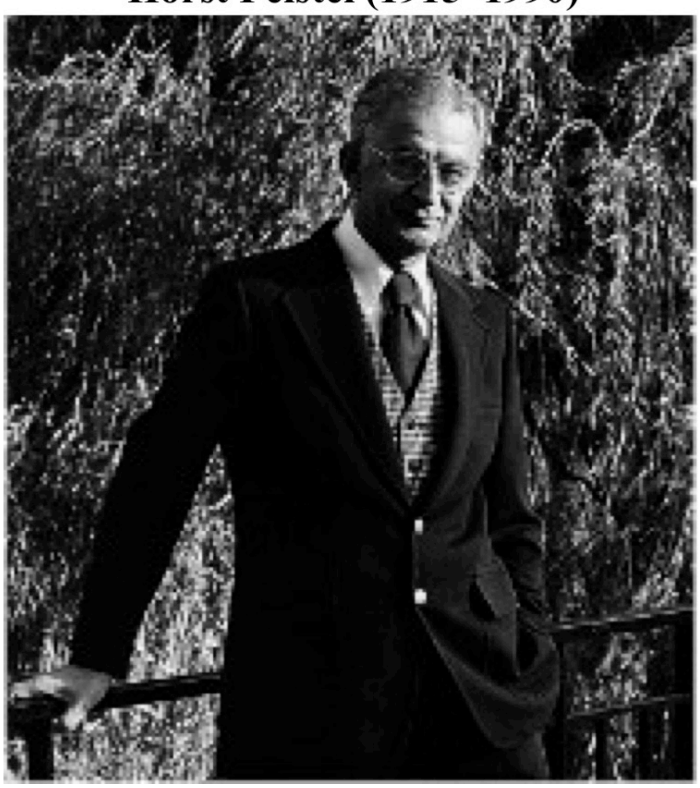
Figure 6.190: German-speaking experts who decrypted Allied coded communications included Walter Fricke, Erich Hüttenhain, Kurt Vetterlein, and Reinold Weber.

Gustav Guanella (1909–1982)





Horst Feistel (1915–1990)



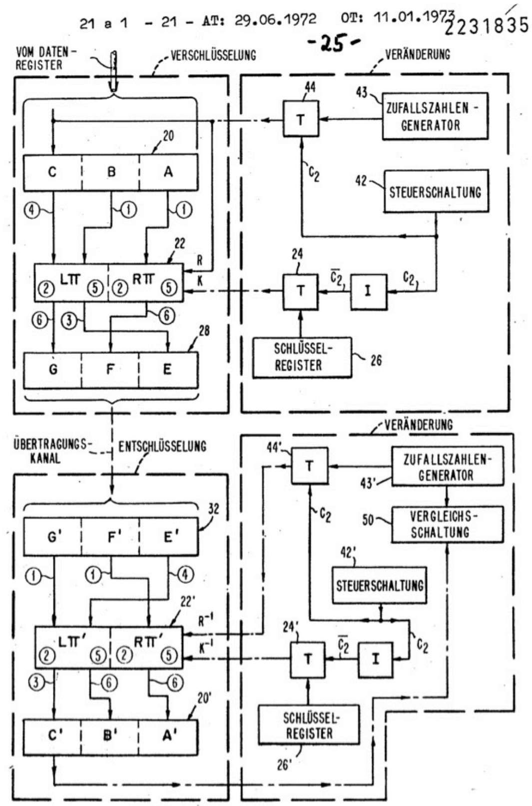


Figure 6.191: Other German-speaking pioneers of advanced cryptography included Gustav Guanella and Horst Feistel.

6.7.4 Robotics

The Jewish and greater German-speaking worlds had a centuries-long tradition of folklore regarding the creation of an artificial worker, or "Golem," out of inorganic materials (p. 2665). The concept of a Golem was especially prominent in the German-speaking world of the early twentieth century, featured in stories such as the 1913–1914 serialized novel *Der Golem* by Gustav Meyer/Meyrink (Austrian, 1868–1932) and in three films of the same name by Paul Wegener (German, 1874–1948) that were released in 1915, 1917, and 1920.

Apparently inspired by those stories, in 1920 Karel Čapek (Czech, 1890–1938) wrote the play *R.U.R. (Rossum's Universal Robots)*, in which he was the first to use the word "robot" to describe a factory-made artificial worker (Fig. 6.192) [Contrada 1995]. In Čapek's play, the manager of the factory producing the robots summarized the approach to creating them [Čapek 1923, Act I]:

> Young Rossum invented a worker with the minimum amount of requirements. He had to simplify him. He rejected everything that did not contribute directly to the progress of work. Everything that makes man more expensive. In fact he rejected man and made the Robot. My dear Miss Glory, the Robots are not people. Mechanically they are more perfect than we are; they have an enormously developed intelligence, but they have no soul. [...] Have you ever seen what a Robot looks like inside? [...] Very neat, very simple. Really a beautiful piece of work. Not much in it, but everything in flawless order. The product of an engineer is technically at a higher pitch of perfection than a product of Nature.

In the 1927 film *Metropolis*, Fritz Lang (Austrian, 1890–1976) and Thea von Harbou (German, 1888–1954) continued that theme by depicting the fictional creation of a robot (Maschinenmensch or machine-person) that was so lifelike that it could successfully impersonate a human woman (p. 1983).[19]

German-speaking scientists and engineers began making those general ideas a reality even before *R.U.R.* and *Metropolis* were released, and continued with even greater effort in the years afterward.[20]

In 1893, Nikola Tesla (Serbo-Croatian, educated in Austria, 1856–1943) began developing the world's first teleoperated robotic vehicles. By 1898, he patented and demonstrated a radio-controlled boat, and described how his approach could be extended to a wide variety of vehicles and much more elaborate control systems, and even to autonomously directed vehicles (Fig. 6.193). In his autobiography, Tesla summarized his work and his vision in the field of teleoperated vehicles and robotics [Tesla 1919, pp. 106–109]:

> The idea of constructing an automaton, to bear out my theory, presented itself to me early but I did not begin active work until 1893, when I started my wireless investigations. During the succeeding two or three years a number of automatic mechanisms, to be actuated from a distance, were constructed by me and exhibited to visitors in my laboratory. In 1896, however, I designed a complete machine capable of a multitude of operations, but the consummation of my labors was delayed until late in 1897. This machine was illustrated and described in my article in the Century Magazine of June, 1900,

[19] Bogdanovich 1967; Eisenschitz and Bertetto 1994; Eisner 1977; Jenkins 1981; McGilligan 1997.

[20] Cheney 1981; Cheney and Uth 1999; Everett 2015; Jaugitz 2001; Tesla 1919; Trenkle 1987.

and other periodicals of that time and, when first shown in the beginning of 1898, it created a sensation such as no other invention of mine has ever produced. In November, 1898, a basic patent on the novel art was granted to me, but only after the Examiner-in-Chief had come to New York and witnessed the performance, for what I claimed seemed unbelievable. I remember that when later I called on an official in Washington, with a view of offering the invention to the Government, he burst out in laughter upon my telling him what I had accomplished. Nobody thought then that there was the faintest prospect of perfecting such a device. It is unfortunate that in this patent, following the advice of my attorneys, I indicated the control as being effected thru the medium of a single circuit and a well-known form of detector, for the reason that I had not yet secured protection on my methods and apparatus for individualization. As a matter of fact, my boats were controlled thru the joint action of several circuits and interference of every kind was excluded. Most generally I employed receiving circuits in the form of loops, including condensers, because the discharges of my high-tension transmitter ionized the air in the hall so that even a very small aerial would draw electricity from the surrounding atmosphere for hours. Just to give an idea, I found, for instance, that a bulb 12" in diameter, highly exhausted, and with one single terminal to which a short wire was attached, would deliver well on to one thousand successive flashes before all charge of the air in the laboratory was neutralized. The loop form of receiver was not sensitive to such a disturbance and it is curious to note that it is becoming popular at this late date. In reality it collects much less energy than the aerials or a long grounded wire, but it so happens that it does away with a number of defects inherent to the present wireless devices. In demonstrating my invention before audiences, the visitors were requested to ask any questions, however involved, and the automaton would answer them by signs. This was considered magic at that time but was extremely simple, for it was myself who gave the replies by means of the device.

At the same period another larger telautomatic boat was constructed a photograph of which is shown in this number of the ELECTRICAL EXPERIMENTER. It was controlled by loops, having several turns placed in the hull, which was made entirely water-tight and capable of submergence. The apparatus was similar to that used in the first with the exception of certain special features I introduced as, for example, incandescent lamps which afforded a visible evidence of the proper functioning of the machine.

These automata, controlled within the range of vision of the operator, were, however, the first and rather crude steps in the evolution of the Art of Telautomatics as I had conceived it. The next logical improvement was its application to automatic mechanisms beyond the limits of vision and at great distance from the center of control, and I have ever since advocated their employment as instruments of warfare in preference to guns. The importance of this now seems to be recognized, if I am to judge from casual announcements thru the press of achievements which are said to be extraordinary but contain no merit of novelty, whatever. In an imperfect manner it is practicable, with the existing wireless plants, to launch an aeroplane, have it follow a certain approximate course, and perform some operation at a distance of many hundreds of miles. A machine of this kind can also be mechanically controlled in several ways and I have no doubt that it may prove of some usefulness in war. But there are, to my best knowledge, no instrumentalities in existence today with which such an object could be accomplished in

> a precise manner. I have devoted years of study to this matter and have evolved means, making such and greater wonders easily realizable.

As shown in Fig. 6.194, Anton Flettner (German, 1885-1961) filed patent applications on teleoperated robots beginning in 1906. He designed robots for various applications on land, in the water, and in the air. In 1915, he demonstrated a radio-controlled battlefield mini-tank with remote-controlled weapons (a blow torch in the demonstration model; the model is shown without its armored shell in Fig. 6.194). Flettner also invented rotor ships (p. 1494) and ultimately became most famous for creating helicopters (p. 1836). U.S. Navy robotics expert H. R. Everett presented information from several sources regarding the history of Flettner's work on teleoperated robots [Everett 2015, pp. 415–417]:

> In 1913, an up-and-coming German inventor named Anton Flettner [...] reportedly patented a radio-controlled "tank" in conjunction with the firm Felt-Guillaume-Lahnmeyer (Seydewitz and Doberer, 1937). Born into a family of ship owners on 1 November 1885 (Marine Review, 1926), Flettner grew up near Frankfurt on Main, where as a youth he became involved in the development and demonstration of radio control for riverboats (Hirschel et al., 2004, 299). As Flettner recounted in *Mein Weg zum Rotor*: "I was still a high school student in Hoechst on the Main when I made my first invention. I contrived to design a wireless distant control system whereby torpedoes, ships and other vehicles could be directed from a distance without any direct communication by wire or otherwise. My experiments were successful" (Flettner, 1926). [...]
>
> Following the outbreak of World War I, he was hired by the renowned Count Ferdinand von Zeppelin to investigate the feasibility of radio-controlled airships (Day and McNeil, 1996). [...]
>
> The gifted inventor's first brush with fame came the following year: "Flettner became known in his country and abroad in the summer of 1915, when a curious clumsy vehicle made its appearance in Berlin: a tank which could move in any direction without a crew. The whole program of the tank's maneuvers was being directed from an unknown spot in the distance" (Tokaty, 1994, 141). [...]
>
> In *Les rayons de la mort*, Seydewitz and Doberer (1937) indicate the tank was successfully controlled from a following car while crossing obstacles and breaching barbed wire. In addition to the basic mobility functions of *forward*, *reverse*, *left*, *right*, and *stop*, it also had an obstacle-clearing payload; Flettner (1926) described this feature in action: "In front of the wire entanglements constructed of angle iron the tank suddenly emitted the blinding hissing flames of an autogenous cutting device," and in a few minutes the obstacles were gone."

By the 1930s, Flettner had moved on to helicopters, but Werner Bergau (German, 1904–??), Robert Brüderlink (German, 1893–1978), Friedrich Gladenbeck (German, 1899–1987), and other German-speaking scientists and engineers took up Flettner's earlier work on robotic tanks (Fig. 6.195). They designed, built, optimized, and deployed rugged, teleoperated robotic systems to handle explosives and perform other complex tasks under actual battlefield conditions [Everett 2015; Jaugitz 2001; Trenkle 1987]:

- The small Leichter Ladungsträger Goliath was first deployed in 1942 (Fig. 6.195). It was primarily employed as a single-use vehicle to deliver demolition charges to bridges, enemy tanks, or other targets, although it was a versatile platform that could also be customized for other tasks. During the war, over 7500 Goliath units were produced and deployed to battlefields ranging from the Normandy beaches to the Eastern Front. It was the forerunner of, and remarkably similar to, modern teleoperated battlefield robots such as the U.S. Foster-Miller TALON (which was not deployed until six decades later, in 2000).

- The medium-sized Mittlerer Ladungsträger Springer was first deployed in 1944 (Fig. 6.196). Essentially it was a larger version of Goliath and was generally used operationally in very similar ways.

- The large Schwerer Ladungsträger Borgward B IV was first deployed in 1942 (Fig. 6.196). It served primarily as a reusable vehicle to remotely deliver demolition charges in vulnerable areas on the battlefield. Some models were also customized for other purposes, such as minesweeping and remote-controlled rocket-firing platforms.

While other countries were also experimenting with remote-controlled vehicles during World War II, the German systems were especially advanced, even including cameras (pp. 1007, 5486) and remote-controlled weapons. They were used extensively during the war, and they were closely studied by other countries after the war, leading to modern robotic systems.

Some modern readers may object that these early German robots were teleoperated, but so are many modern robots such as battlefield units, bomb squad robots, aerial drones, and remote-controlled manipulator arms. Moreover, the German-speaking world simultaneously invented and demonstrated sophisticated computers (p. 1171) that could ultimately serve as "brains" to allow robots to function autonomously.

There were also numerous examples of both teleoperated and fully autonomous robotic vehicles among the variety of German torpedoes (pp. 1478–1483) and missiles (pp. 1153, 1263, and 1847) that were developed before and during World Wars I and II. Indeed, Allied press and intelligence reports of autonomously guided German missiles commonly referred to them as "robots" (e.g., pp. 5058, 4748, 5376, 5719, 5720).

Karl Saur (German, ca. 1901–1978, not to be confused with the Karl Saur who was a high-ranking government official under Albert Speer) and Rudolf Nebel (German, 1894–1978) invented, built, and used industrial robotics technology from the 1930s to 1945.[21] From 1937 onward, they designed and built customized industrial robots to perform tasks at a number of German companies. During 1944–1945, they built 20 industrial robots to assemble components at the underground Mittelwerk plant in Nordhausen. See Figs. 6.197–6.202.

[21] Nebel 1972 https://blog.hnf.de/vom-automatischen-arbeiter-zum-industrieroboter/

Tina Kubot and Frank Dittmann. Geschichte einer Vision. *Kulture & Technik* (Deutsches Museum) 3/2016, p. 16. https://www.deutsches-museum.de/assets/Verlag/Download/Kultur_und_Technik/2016/2016-3.pdf

Frank Dittmann. 2022. Automatische Arbeiter für die Raketenproduktion des Mittelwerks. https://www.buchenwald.de/47/date/2022/04/13/technik-im-nationalsozialismus/

https://www.mdr.de/nachrichten/thueringen/nord-thueringen/nordhausen/roboter-kz-mittelbau-dora-wunderwaffe-nazis-100.html

In his autobiography, Rudolf Nebel summarized the history of his work on industrial robots with Karl Saur [Nebel 1972, pp. 147–153]:

> [1937] Bei Siemens in Berlin hatte ich Diplomingenieur Karl Saur kennengelernt. Er hatte eine Maschine konstruiert, die ein Uhrwerk automatisch zusammenbauen konnte. Die Idee der Automation packte mich sofort, und ich entschloß mich, den Siemens-Konzern zu verlassen und mich mit Saur selbständig zu machen. Wir eröffneten ein Ingenieurbüro in Berlin-Wilmersdorf und entwickelten einen "Automatischen Arbeiter", der zahlreiche Arbeitsvorgänge bewältigen konnte. Saur und ich entwarfen einen Prospekt, der den werbewirksamen Titel hatte: "1 Million Arbeitskräfte automatisch." In einer Zeit, wo die Handarbeit noch das Maß aller Dinge war, wirkte unsere Broschüre geradezu sensationell. Als Anwendungsmöglichkeiten unserer Erfindung schlugen wir unter anderen vor:
>
> 1. Montage von Maschinenelementen aller Art.
> 2. Gefährliche Arbeiten, wie Pulver pressen, Munitionsherstellung, Arbeiten mit Sprengstoff.
> 3. Montage elektrischer Teile.
> 4. Bedienung einer Fließstraße von halbautomatischen Maschinen, einschießlich Transport der Werkstücke. Eine ganze Anzahl solcher Maschinen kann durch eine Steuergruppe bedient werden, und zwar in der Reihenfolge, daß die Maschinen ununterbrochen Arbeit leisten.

> [1937] At Siemens in Berlin, I met engineer Karl Saur. He had constructed a machine that could automatically assemble a clockwork. The idea of automation immediately grabbed me, and I decided to leave the Siemens group and start my own business with Saur. We opened an engineering office in Berlin-Wilmersdorf and developed an "automatic worker" that could handle numerous operations. Saur and I designed a brochure that had the promotional title: "1 Million Workers Automatically." At a time when manual labor was still the measure of all things, our brochure had an almost sensational effect. As possible applications for our invention, we suggested, among others:
>
> 1. Assembly of all kinds of machine elements.
> 2. Dangerous work, such as [explosive] powder pressing, ammunition production, work with explosives.
> 3. Assembly of electrical parts.
> 4. Operation of an assembly line of semi-automatic machines, including transport of workpieces. A whole number of such machines can be operated by one control group, in order that the machines perform work continuously.

Wir verschickten rund 1000 dieser Broschüren an alle Firmen, die 1937 mit Rüstungsaufträgen beschäftigt waren. Natürlich gab es Proteste von den Arbeitsämtern, die zu dieser Zeit noch rund 400 000 Arbeitslose in ihren Karteien hatten. Ein Arbeitsamtsdirektor bekam bei einer Besprechung einen Wutanfall und schrie mich an: "Sind Sie wahnsinnig geworden? Kaum haben wir die furchtbare Arbeitslosenzeit hinter uns, da fangen Sie mit Robotern an, dieses Elend wieder heraufzubeschwören!" Doch in anderen Dienststellen hatte man nicht die Sorge, daß unsere Erfindung soziale Schwierigkeiten bringen würde. Sogar die NSDAP war auf unsere Automaten aufmerksam geworden und überlegte, wie man die neuartige Maschine im Rahmen des Vierjahresplanes für die Rüstung nützen könne. [...]

We sent out about 1,000 of these brochures to all the companies that were busy with armaments orders in 1937. Of course, there were protests from the labor offices, which at that time still had about 400,000 unemployed in their files. One labor office director threw a tantrum at a meeting and shouted at me: "Are you out of your mind? No sooner are we past the terrible unemployment period than you start conjuring up this misery again with robots!" But in other departments, there was no concern that our invention would bring social difficulties. Even the Party had become aware of our automation and was considering how the novel machines could be used for armaments within the framework of the Four-Year Plan. [...]

Bis Kriegsausbruch arbeitete ich nun mit Saur zusammen an der Entwicklung des "Automatischen Arbeiters". Wir bekamen Aufträge verschiedener Privatfirmen und konnten sorgenfrei leben, obwohl ich bei der Partei in Ungnade gefallen war. [...]

Until the outbreak of the war, I worked together with Saur on the development of the "automatic worker." We received orders from various private companies and were able to live without worries, even though I had fallen out of favor with the Party. [...]

Ich konnte während der nächsten Kriegsjahre weiter an meinen Erfindungen arbeiten. In einer kleinen Werkstatt in Berlin-Lichterfelde erstellte Saur mit fünf Mitarbeitern die Konstruktion für die Automaten, deren Anfertigung, Montage und Arbeiten ich bei unseren Kunden überwachte.

I was able to continue working on my inventions during the years of the war. In a small workshop in Berlin-Lichterfelde, Saur and five employees designed the automated machines, whose production, assembly, and operation I supervised for our customers.

Wir konnten unsere Arbeiten bis November 1943 fortsetzen. Am 23. November 1943 wurde das Berliner Konstruktionsbüro total ausgebombt, und Saur und ich verlegten unsere kleine Firma nach Bad Wilsnack an der Elbe. Wenige Tage vor dem Attentat auf Hitler am 20. Juli 1944—die Deutsche Propaganda stellte in dieser Woche die ersten Einsätze der V 1 groß heraus—rief mich Klaus Riedel im Büro an. Wir sprachen kurz über Kriegslage, und dann machte mir mein alter Mitarbeiter einer interessanten Vorschlag. Riedel sagte, er habe mit den beiden Chefs des geheimen "Mittelwerkes" gesprochen und sei auf großes Interesse gestoßen. Ich solle sofort mit meinem Raketenfilm und den Unterlagen über den "Automatischen Arbeiter" nach Berlin kommen. Direktor Sawatzki und Generaldirektor Rickhey seien gerade in den Borsigwerken, und es könne sein, daß sie mir einen Auftrag erteilen würden. [...]

We were able to continue our work until November 1943. On 23 November 1943, the Berlin design office was totally bombed out, and Saur and I moved our small company to Bad Wilsnack on the Elbe. A few days before the assassination attempt on Hitler on July 20, 1944—German propaganda that week gave great publicity to the first missions of the V-1—Klaus Riedel called me at the office. We talked briefly about the war situation, and then my old co-worker made me an interesting proposition. Riedel said he had talked to the two chiefs of the secret "Mittelwerk" and had met with great interest. I should come to Berlin immediately with my rocket film and the documents on the "Automatic Worker." Director Sawatzki and General Director Rickhey were at the Borsig Works at the moment, and they might be willing to place an order with me. [...]

Bei der Besprechung mit Rickhey und Sawatzki bekam ich den Auftrag, im "Mittelwerk" 20 "Automatische Arbeiter" zu bauen, für die Saur von Bad Wilsnack auch die Konstruktionszeichnungen zu liefern hatte. Meine Maschinen sollten bei der Fertigung der Rudermaschine für die "V 1" verwendet werden. Ich bezog ein Büro in Halle 40 der unterirdischen Rüstungsfabrik. Unter meiner Aufsicht arbeiten einige deutsche Techniker und 100 Häftlinge Tag und Nacht an der Montage der Automaten. Mit den Häftlingen hatte ich praktisch nie Kontakt, da ich ständig zwischen Bad Wilsnack und Nordhausen pendelte.

At the meeting with Rickhey and Sawatzki, I received the order to build 20 "automatic workers" in the "Mittelwerk," for which Saur from Bad Wilsnack also had to supply the design drawings. My machines were to be used in the production of the rudder machinery for the V-1. I moved into an office in Hall 40 of the underground armaments factory. Under my supervision, several German technicians and 100 prisoners worked day and night on assembling the automated machines. I practically never had any contact with the prisoners, since I was constantly commuting between Bad Wilsnack and Nordhausen.

Although Nebel (or his publisher) wrote “V 1” in the passage above in his 1972 autobiography, the industrial robots appear to have been intended to work on V-2 (A-4 rocket) parts. They may have been designed to fashion the graphite exhaust deflectors that required careful machining and shaping from several directions.

Future scholars should investigate whether these wartime German robotics projects directly or indirectly influenced postwar work on robotics by George Devol or others, in view of considerations such as these:

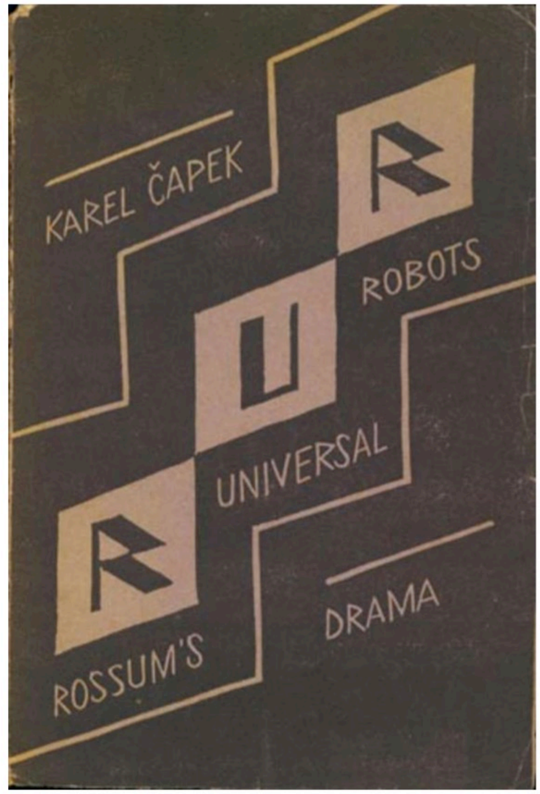
- U.S. forces seized control of Mittelwerk and the surrounding areas in April 1945 and shipped huge amounts of hardware and documentation back to the United States, which probably would have included the 20 “automatic workers” and any related information. (For other examples of the widespread removal of production machinery, see pp. 2087–2098.)

- The United States also confiscated all wartime German patents such as Saur’s patents on industrial automation (pp. 1224, 2120–2125).

- Saur, Nebel, and the other robotics engineers were likely interrogated by U.S. technical investigators after the war (e.g., pp. 2136–2148).

Karel Čapek (1890–1938)

Wrote the play *R.U.R. (Rossum's Universal Robots)* in 1920



Coined the word "robots" to describe factory-made artificial workers

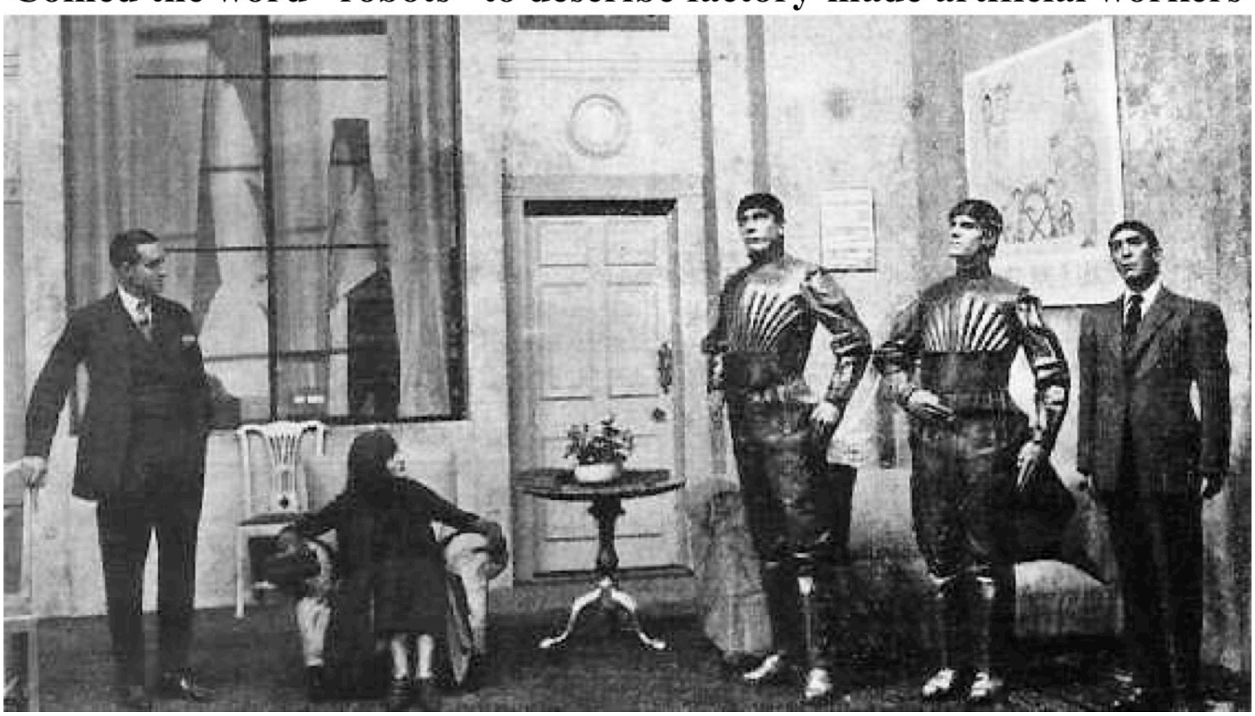


Figure 6.192: In 1920, Karel Čapek wrote the play *R.U.R. (Rossum's Universal Robots)*, in which he coined the word "robots" to describe factory-made artificial workers.

Nikola Tesla (1856–1943)
Patented and demonstrated radio-controlled boat (1898)

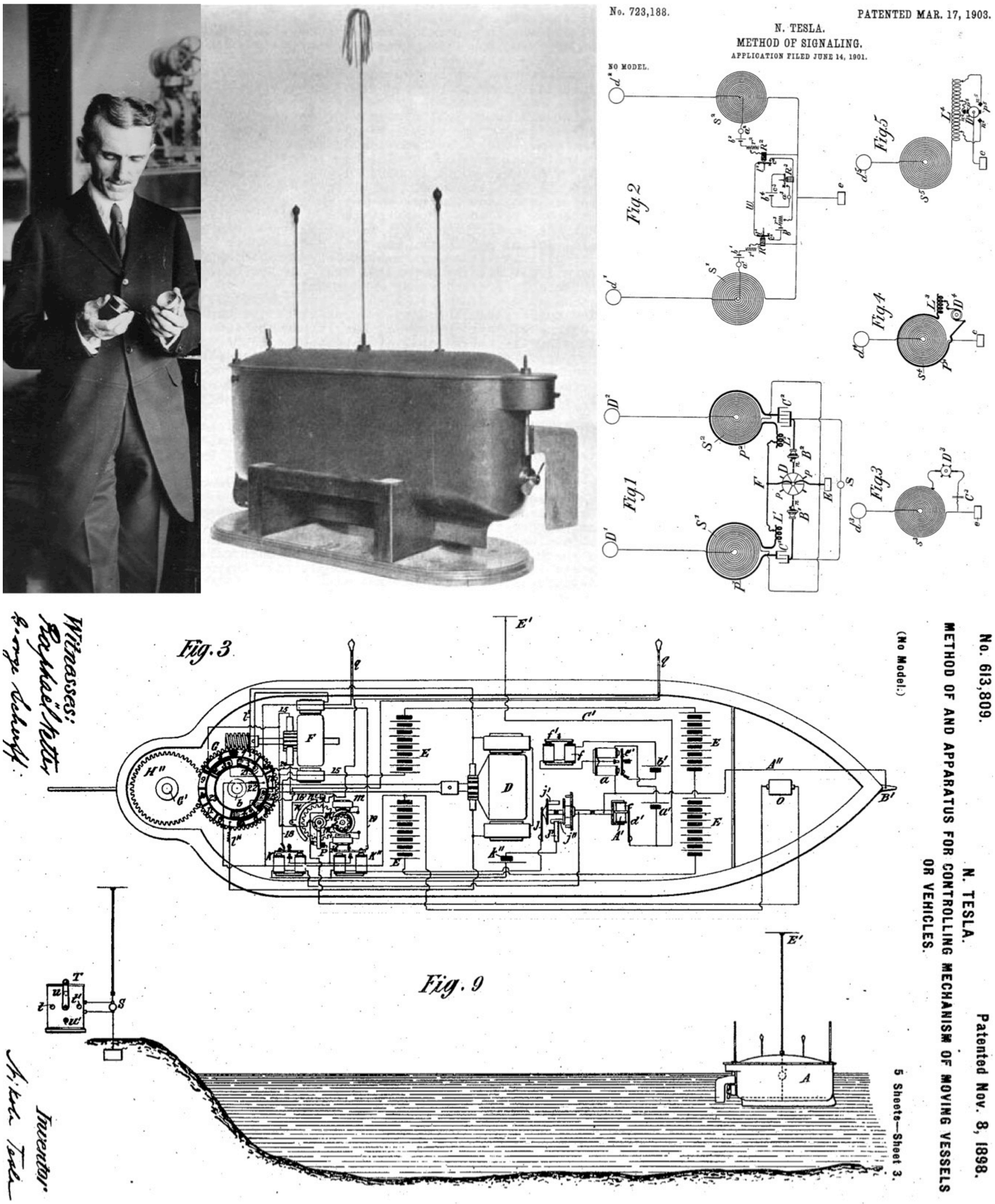
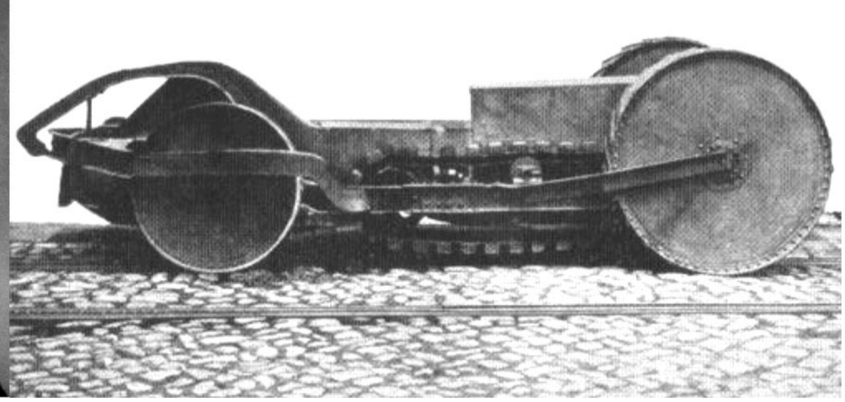


Figure 6.193: Nikola Tesla patented and demonstrated a radio-controlled boat in 1898.

Anton Flettner (1885–1961)

Demonstrated radio-controlled battlefield mini-tank with remote-controlled weapons (1915)



Filed patent applications on teleoperated robots (1906)

RÉPUBLIQUE FRANÇAISE.

OFFICE NATIONAL DE LA PROPRIÉTÉ INDUSTRIELLE.

BREVET D'INVENTION.

XII. — Instruments de précision, électricité.
7. — Applications générales de l'électricité.

N° 373.933

Procédé et appareil pour la commande à distance de moteurs et dispositifs analogues.

Société dite : FELTEN & GUILLEAUME LAHMEYERWERKE ACTIEN-GESELLSCHAFT et M. Anton FLETTNER résidant en Allemagne.

Demandé le 26 janvier 1907.
Délivré le 29 mars 1907. — Publié le 30 mai 1907.
(Demande de brevet déposée en Allemagne le 27 janvier 1906. — Déclaration des déposants.)

La présente invention a trait à la commande d'appareils, machines, etc., éloignés stationnaires ou en mouvement et cela sans fils conducteurs continus. D'après cette invention les signaux de contrôle et l'emploi d'impulsions télédynamiques d'espèces différentes sont rendus superflus, quels que soient le nombre et le genre des opérations à produire, par la disposition, au point de réception, d'un appareil préparant, en succession cyclique, les différentes connexions nécessaires à la production de ces opérations, de sorte que l'émission d'une impulsion produit, suivant le moment choisi, l'un ou l'autre des couplages et donne lieu, par conséquent, à l'une ou l'autre des opérations.

Le dessin schématique ci-joint représente, à titre d'exemple, l'application de l'invention à la commande du mécanisme de direction d'une torpille. Dans ce dessin, *a* représente le cohéreur qui, lorsqu'il est rendu conducteur par l'action d'ondes électriques, fait passer le courant de la pile *b* dans le relais électromagnétique *c*.

L'interrupteur à relais *e* est ainsi fermé et l'électro-aimant *f* reçoit pour la position de repos représentée du doigt *d*, le courant de la pile *g*, de sorte qu'il attire le verrou *h*; le disque *i* est donc libéré et tourne dans le sens de la flèche représentée, sous l'action d'un mouvement d'horlogerie ordinaire placé au-dessous de lui, jusqu'à ce que le verrou *h* tombe dans l'entaille *k* suivante de ce disque *i*. Ce dernier mouvement se produit sous l'action du ressort *l*, car le doigt *d* est entraîné à la position représentée en pointillé, lors de la rotation du disque *i* de 45° par exemple, par les chevilles *m* portées par ce disque *i*, le circuit *n o g e f* n'étant plus parcouru par le courant dès que le doigt *d* a abandonné le plot initial *n*.

Pendant la course du doigt *d*, on peut actionner, par des étincelles d'émission, l'appareil que l'on veut déclencher et commander par ondes électriques ou impulsions analogues.

On peut, par exemple, employer à cet effet la disposition suivante :

Quand le doigt *d* a dépassé le plot initial *n*, il arrive sur un des contacts *p* du frappeur, ce qui ferme le circuit comprenant l'auto-interrupteur *q* et la pile *r*, de sorte que le marteau *s* frappe le cohéreur *a*, lui enlevant ainsi sa conductibilité, ce qui fait que le circuit du cohéreur n'est plus parcouru par le courant et que l'interrupteur à relais *e* s'ouvre sous l'action du ressort *t*.

Prix du fascicule : 1 franc.

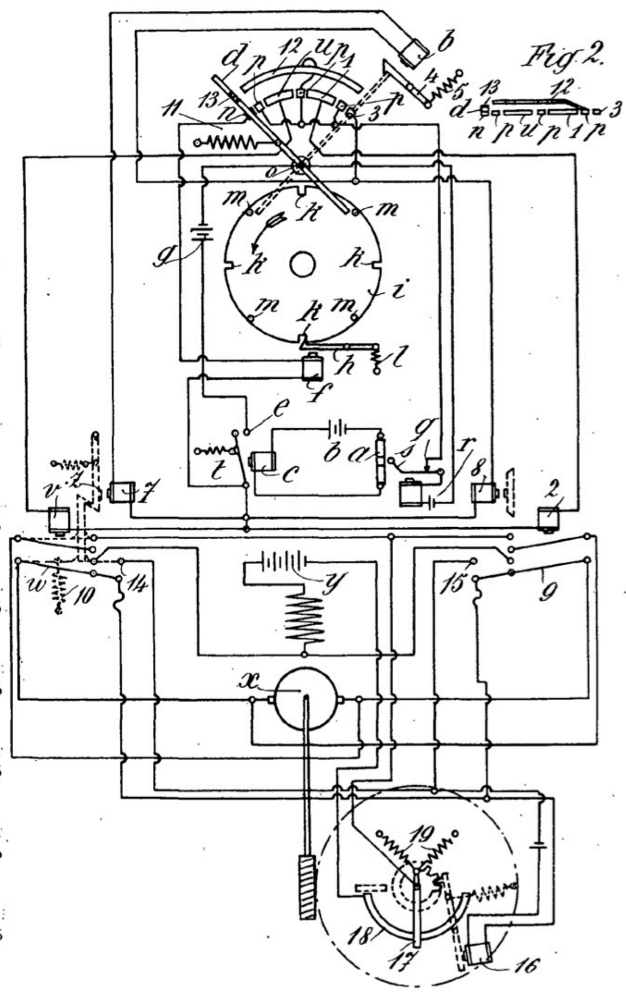
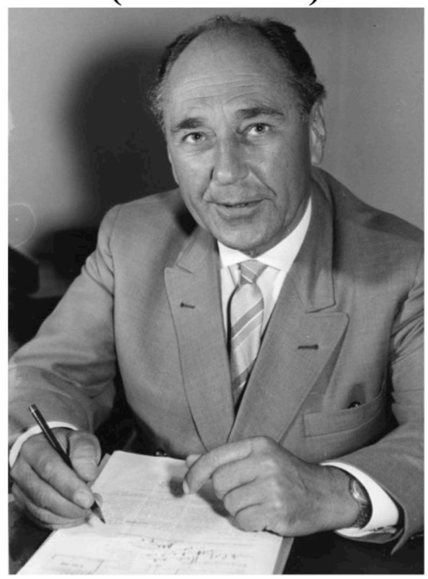
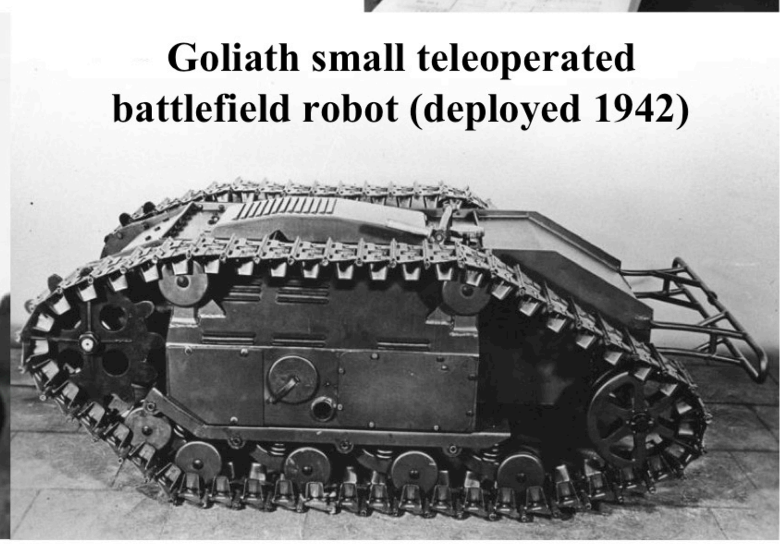


Figure 6.194: Anton Flettner filed patent applications on teleoperated robots beginning in 1906. He designed robots for various applications on land, in the water, and in the air. In 1915, he demonstrated a radio-controlled battlefield mini-tank with remote-controlled weapons (a blow torch in the demonstration model; the model is shown here without its armored shell).

Werner Bergau (1904–??) **Robert Brüderlink (1893–1978)** **Friedrich Gladenbeck (1899–1987)**





Cf. U.S. TALON teleoperated battlefield robot (deployed 2000)

Figure 6.195: Werner Bergau, Robert Brüderlink, and Friedrich Gladenbeck pioneered teleoperated battlefield robotics, such as the Leichter Ladungsträger Goliath, which was the forerunner of modern teleoperated battlefield robots such as the U.S. Foster-Miller TALON.

Springer medium-sized teleoperated battlefield robot (deployed 1944)

Borgward B IV large teleoperated battlefield robot (deployed 1942)

Figure 6.196: Larger teleoperated battlefield robots that were used in combat by Germany included the Mittlerer Ladungsträger Springer and the Schwerer Ladungsträger Borgward B IV.

Industrial robotics (1930s–1945)

Karl Saur (ca. 1901–1978)

Rudolf Nebel (1894–1978)

MITTELWERK

Gesellschaft mit beschränkter Haftung

Briefanschrift: Mittelwerk G. m. b. H.
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Postanschrift
Halle/Saale 2
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Firma
Saur & Nebel
Bad Wilsnack
Großestraße 46

Ihre Zeichen	Ihr Schreiben vom	Unsere Zeichen Bitte in Antwort anzugeben	Tag
./.	12.8.44	Saw./Bs.	12.8.1944

Betreff Betriebsmittel für die Rudermaschine 8401.

Hiermit erteilen wir Ihnen den Auftrag auf

20 automatische Arbeiter zur automatischen Montage der Rudermaschine 8401.

Ein detaillierter Auftrag geht Ihnen in den nächsten Tagen von unserer Abteilung Einkauf gesondert zu.

Heil Hitler!
Mittelwerk
G.m.b.H.

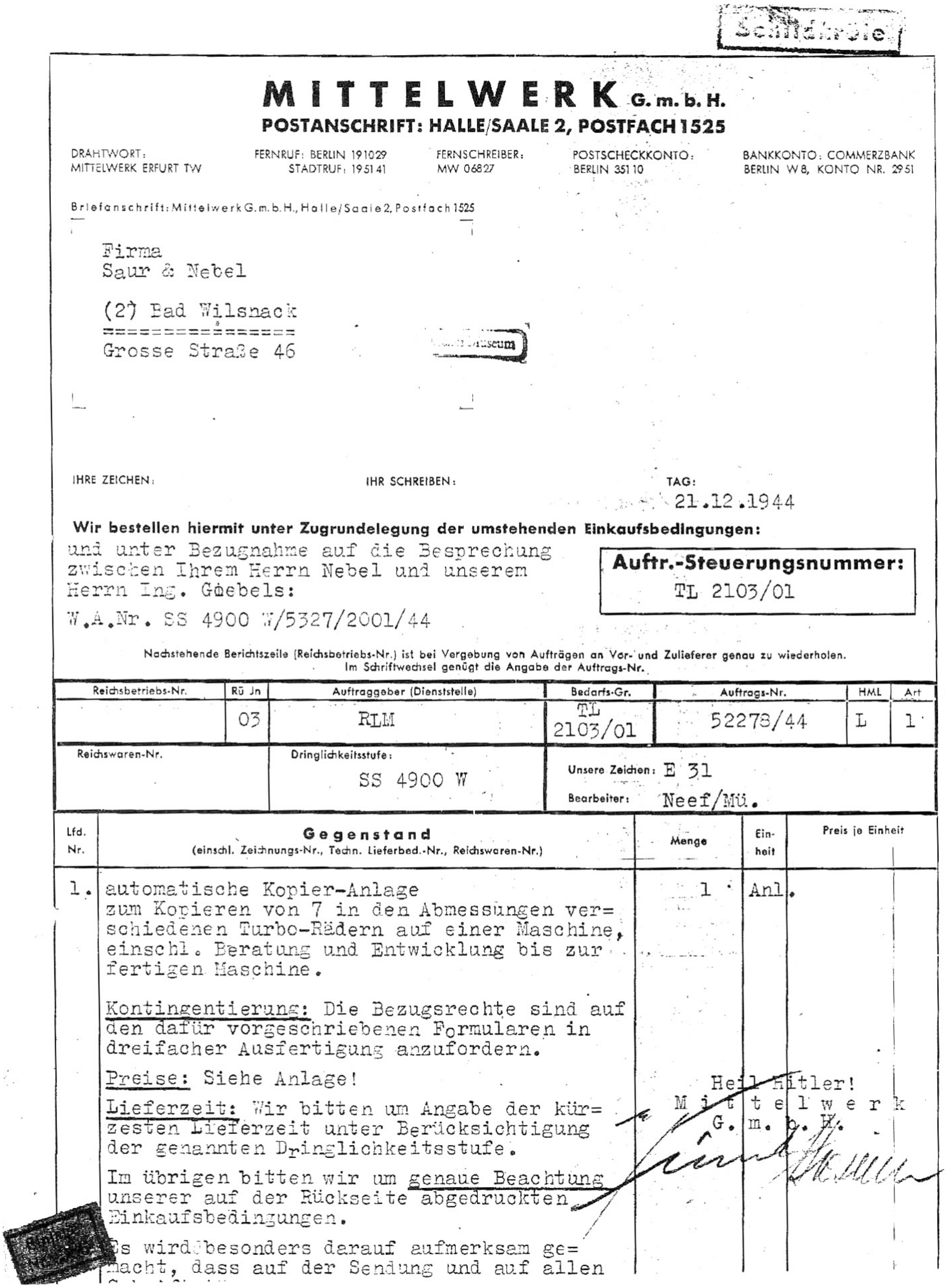
(Rudolph)

D/Einkauf E o

Drahtwort: Mittelwerk Berlin Fernruf: 31 81 21 Fernschreiber: 01 14 35 für Mittelwerk Postscheckkonto: Berlin 351 10 Bankkonto: Commerzbank, Berlin W 8 Konto Nr. 29 51

M W 50 000 XII.45. L/0658

Figure 6.197: Karl Saur and Rudolf Nebel invented, built, and used industrial robotics technology from the 1930s to 1945. During 1944–1945, they built 20 industrial robots to assemble components at the underground Mittelwerk plant in Nordhausen.



Schildkröte

MITTELWERK G.m.b.H.

POSTANSCHRIFT: HALLE/SAALE 2, POSTFACH 1525

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Briefanschrift: Mittelwerk G.m.b.H., Halle/Saale 2, Postfach 1525

Firma
Saur & Nebel

(2) Bad Wilsnack
===============
Grosse Straße 46

IHRE ZEICHEN: IHR SCHREIBEN: TAG: 21.12.1944

Wir bestellen hiermit unter Zugrundelegung der umstehenden Einkaufsbedingungen:
und unter Bezugnahme auf die Besprechung
zwischen Ihrem Herrn Nebel und unserem
Herrn Ing. Goebels:
W.A.Nr. SS 4900 W/5327/2001/44

Auftr.-Steuerungsnummer: TL 2103/01

Nachstehende Berichtszeile (Reichsbetriebs-Nr.) ist bei Vergebung von Aufträgen an Vor- und Zulieferer genau zu wiederholen. Im Schriftwechsel genügt die Angabe der Auftrags-Nr.

Reichsbetriebs-Nr.	Rü Jn	Auftraggeber (Dienststelle)	Bedarfs-Gr.	Auftrags-Nr.	HML	Art
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Reichswaren-Nr.	Dringlichkeitsstufe:	
	SS 4900 W	Unsere Zeichen: E 31 Bearbeiter: Neef/Mü.

Lfd. Nr.	Gegenstand (einschl. Zeichnungs-Nr., Techn. Lieferbed.-Nr., Reichswaren-Nr.)	Menge	Einheit	Preis je Einheit
1.	automatische Kopier-Anlage zum Kopieren von 7 in den Abmessungen verschiedenen Turbo-Rädern auf einer Maschine, einschl. Beratung und Entwicklung bis zur fertigen Maschine.	1	Anl.	

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Es wird besonders darauf aufmerksam gemacht, dass auf der Sendung und auf allen

Heil Hitler!
Mittelwerk
G.m.b.H.

Figure 6.198: Karl Saur and Rudolf Nebel invented, built, and used industrial robotics technology from the 1930s to 1945. During 1944–1945, they built 20 industrial robots to assemble components at the underground Mittelwerk plant in Nordhausen.

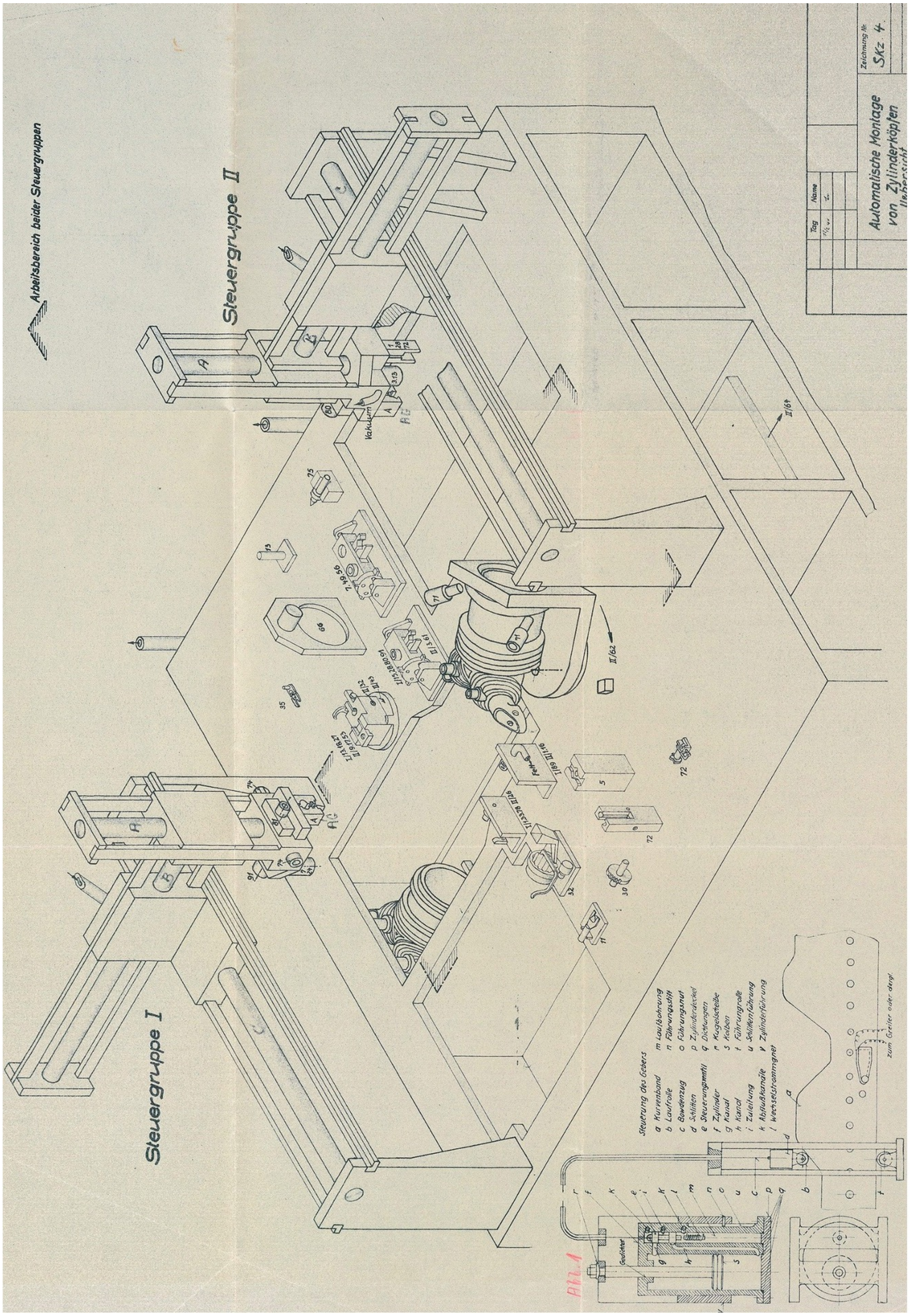


Figure 6.199: Part of the design drawings for one of the 20 industrial robots that Karl Saur and Rudolf Nebel built to assemble components at the underground Mittelwerk plant in Nordhausen.

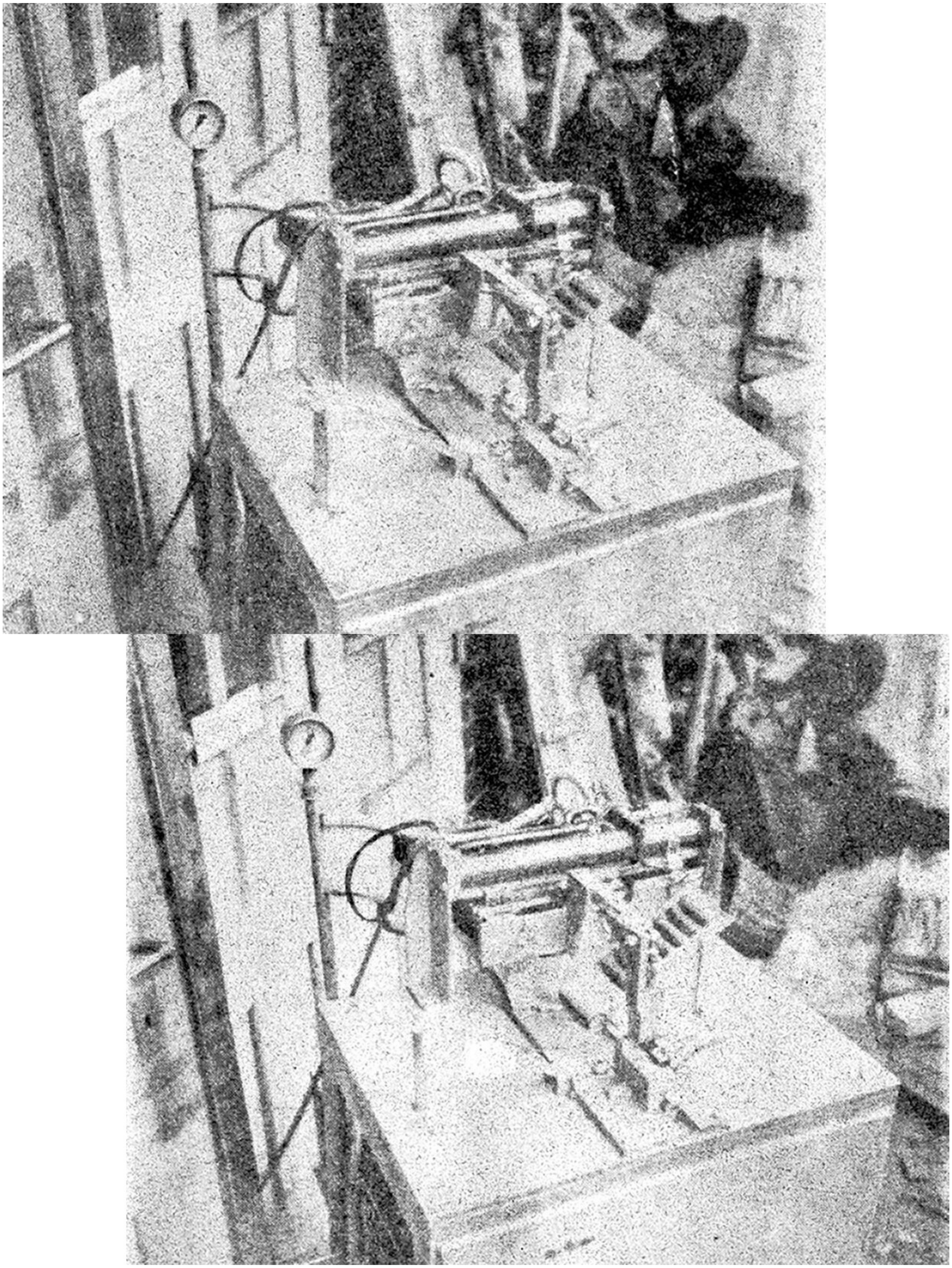


Figure 6.200: Photographs of one of the 20 industrial robots that Karl Saur and Rudolf Nebel built to assemble components at the underground Mittelwerk plant in Nordhausen.

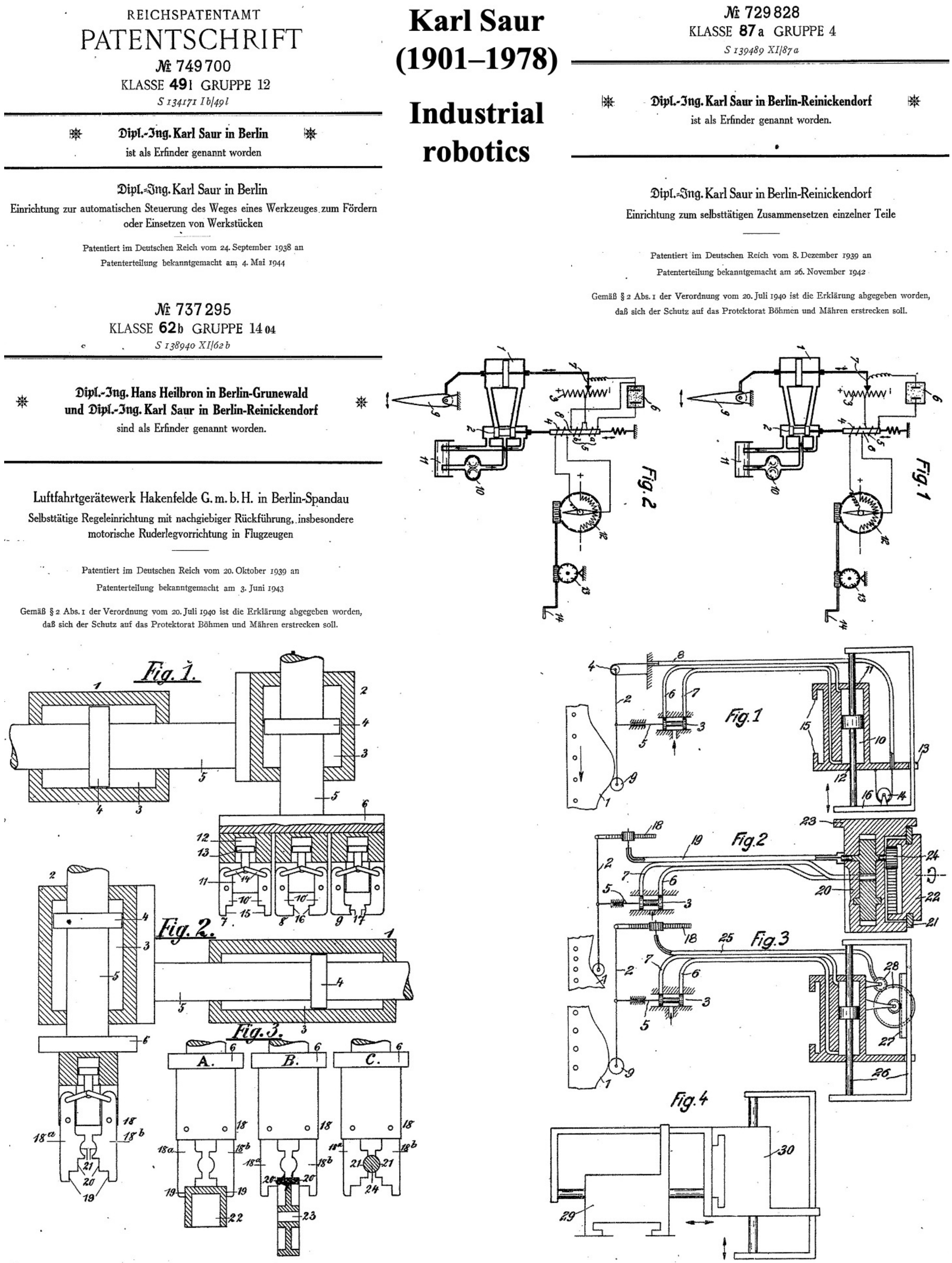
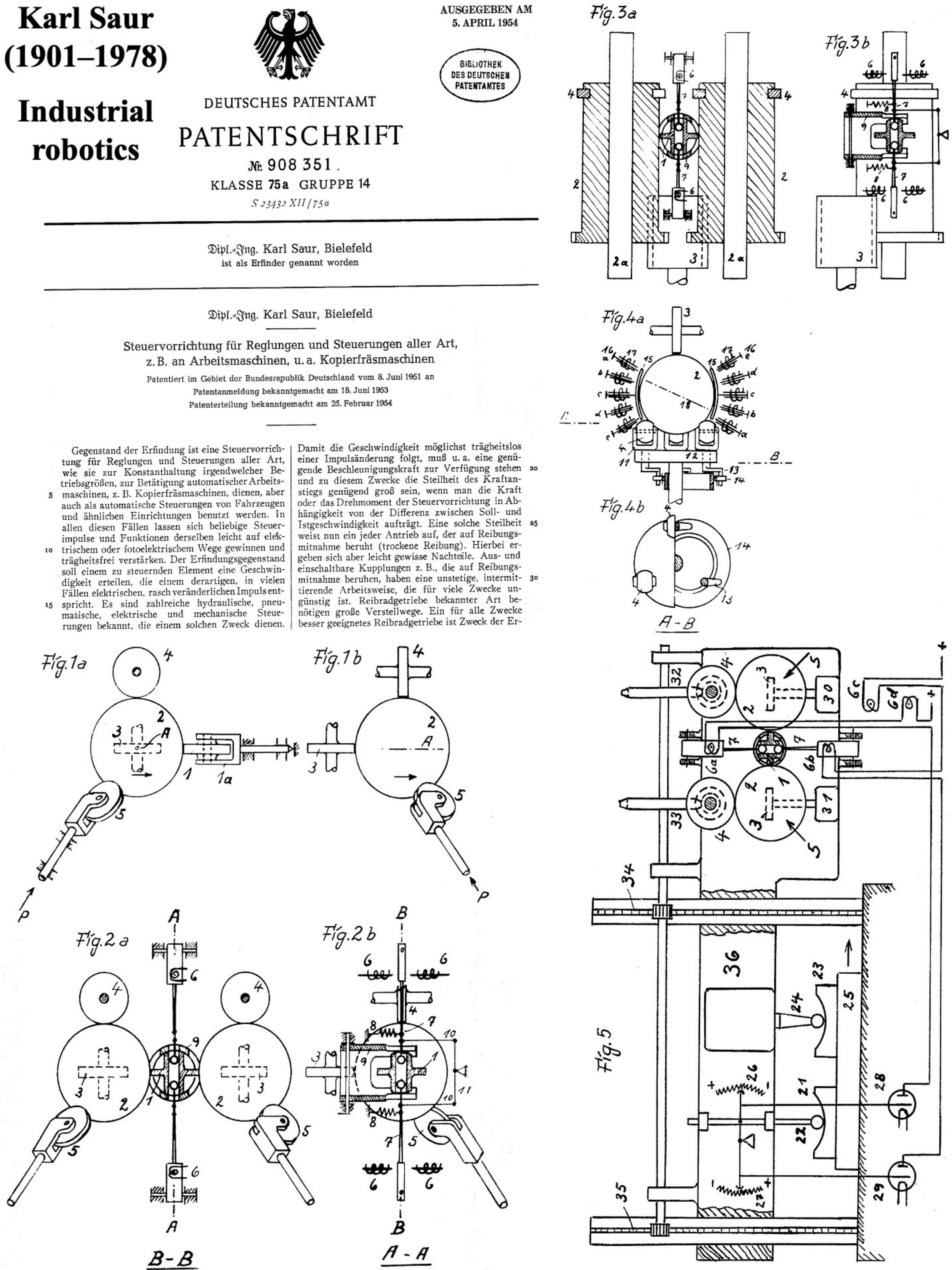


Figure 6.201: Examples of Karl Saur's wartime patents on industrial robotics.



Karl Saur (1901–1978)

Industrial robotics

AUSGEGEBEN AM 5. APRIL 1954

BIBLIOTHEK DES DEUTSCHEN PATENTAMTES

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 908 351

KLASSE 75a GRUPPE 14

S 23432 XII/75a

Dipl.-Ing. Karl Saur, Bielefeld
ist als Erfinder genannt worden

Dipl.-Ing. Karl Saur, Bielefeld

Steuervorrichtung für Reglungen und Steuerungen aller Art, z. B. an Arbeitsmaschinen, u. a. Kopierfräsmaschinen

Patentiert im Gebiet der Bundesrepublik Deutschland vom 8. Juni 1951 an
Patentanmeldung bekanntgemacht am 18. Juni 1953
Patenterteilung bekanntgemacht am 25. Februar 1954

Gegenstand der Erfindung ist eine Steuervorrichtung für Reglungen und Steuerungen aller Art, wie sie zur Konstanthaltung irgendwelcher Betriebsgrößen, zur Betätigung automatischer Arbeitsmaschinen, z. B. Kopierfräsmaschinen, dienen, aber auch als automatische Steuerungen von Fahrzeugen und ähnlichen Einrichtungen benutzt werden. In allen diesen Fällen lassen sich beliebige Steuerimpulse und Funktionen derselben leicht auf elektrischem oder fotoelektrischem Wege gewinnen und trägheitsfrei verstärken. Der Erfindungsgegenstand soll einem zu steuernden Element eine Geschwindigkeit erteilen, die einem derartigen, in vielen Fällen elektrischen, rasch veränderlichen Impuls entspricht. Es sind zahlreiche hydraulische, pneumatische, elektrische und mechanische Steuerungen bekannt, die einem solchen Zweck dienen. Damit die Geschwindigkeit möglichst trägheitslos einer Impulsänderung folgt, muß u. a. eine genügende Beschleunigungskraft zur Verfügung stehen und zu diesem Zwecke die Steilheit des Kraftanstiegs genügend groß sein, wenn man die Kraft oder das Drehmoment der Steuervorrichtung in Abhängigkeit von der Differenz zwischen Soll- und Istgeschwindigkeit aufträgt. Eine solche Steilheit weist nun ein jeder Antrieb auf, der auf Reibungsmitnahme beruht (trockene Reibung). Hierbei ergeben sich aber leicht gewisse Nachteile. Aus- und einschaltbare Kupplungen z. B., die auf Reibungsmitnahme beruhen, haben eine unstetige, intermittierende Arbeitsweise, die für viele Zwecke ungünstig ist. Reibradgetriebe bekannter Art benötigen große Verstellwege. Ein für alle Zwecke besser geeignetes Reibradgetriebe ist Zweck der Er-

Figure 6.202: Karl Saur filed this patent on industrial robotics after the (West) German patent office reopened, but it appears to be directly based on his wartime work.

6.8 Radar and Sonar Technologies and Countermeasures

Creators from the German-speaking world invented, developed, and demonstrated:

6.8.1. Radar

6.8.2. Radar countermeasures

6.8.3. Microwave heating

6.8.4. Sonar

6.8.5. Sonar countermeasures

6.8.6. Ultrasound imaging

6.8.7. Acoustic weapons

6.8.8. Radio and acoustic proximity fuses and homing devices

6.8.1 Radar

German-speaking scientists invented radar at the beginning of the twentieth century and developed sophisticated radar systems for a variety of applications through World War II (and afterward in Allied countries).[22]

Nikola Tesla (Serbo-Croatian, educated in Austria, 1856–1943, p. 963) proposed radar in 1900, although as far as is presently known, he did not actually build a working system. Tesla biographer Margaret Cheney provided some details of Tesla's proposal [Cheney 1981, p. 208]:

> In the circumstances, it is not surprising that when Tesla first began to speculate about military applications of radar, it was with respect to locating ships and submarines rather than to detecting enemy bombers. Tesla had predicted the general concept of radar in his sweeping article for *Century* magazine of June 1900: "Stationary waves . . . mean something more than telegraphy without wires to any distance. . . . For instance, by their use we may produce at will, from a sending station, an electrical effect in any particular region of the globe; we may determine the relative position or course of a moving object, such as a vessel at sea, the distance traversed by the same, or its speed...."

[22] Banneitz 1927; Bauer 2006; Blanchard et al. 2013; Louis Brown 2017; Bukowski 2007; Cheney 1981, Cheney and Uth 1999; Gregory Clark 2014; Gregory Goebel 2018; Goerth 2010; Guerlac 1987; Habann 1924, 1929; Hepcke 2012; Hollmann 2012; von Kroge 1998; Mergl 1998; Werner Müller 1998; Pritchard 1989; Sarkar et al. 2006; Swords 1986; Trenkle 1987; Raymond Watson 2009; Žáček 1924, 1936.

The world's first working radar system was created and demonstrated by Christian Hülsmeyer (German, 1881–1957) in 1903, decades before the widespread adoption of radar technology by other countries (Fig. 6.203). David Pritchard extensively researched Hülsmeyer's life and inventions [Pritchard 1989, pp. 16–17]:

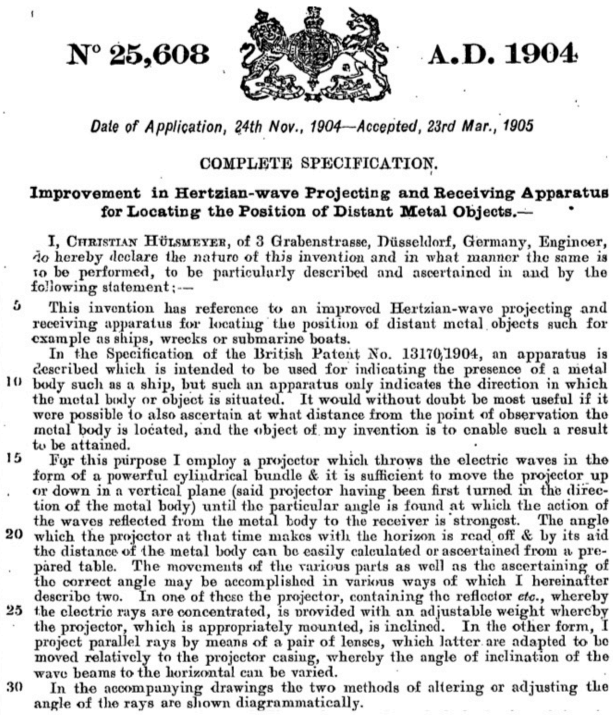
> [...] Hülsmeyer was promptly invited to demonstrate his equipment to the representatives of shipping companies. The *Kölnischer Zeitung* of 18 May 1904 carried the report:
>
>> The Telemobiloscope, an invention of engineer Christian Hülsmeyer, was demonstrated to representatives of Norddeutscher Lloyd and the Argo Shipping Company of Bremen and other invited gentlemen at the Dom Hotel yesterday morning at 11 o'clock. The discovery is based on the principle of wireless telegraphy and is intended to locate ships and other metallic objects at sea. The difference between the already existing employment of wireless telegraphy and this discovery is based on an exclusive and constructional change, in that wireless telegraphy employs a transmitter and receiver on separate ships but with the Telemobiloscope the transmitter and receiver are arranged on one and the same vessel. The electrical waves radiated from the transmitter cannot directly reach the receiver, but must be reflected from metallic objects on the sea, logically ships, and thus return to the receiver. The great advantage which the discovery offers lies above all in the fact that ships which are fitted with this system of transmitter and receiver can locate any other ship that does not carry the apparatus. Indeed, the captain on the bridge can be informed of the approach of another vessel and find its bearing up to a range of 5 kilometres, so that should his lights and fog signals fail to work he still has sufficient time to steer his ship on the correct course and thus prevent severe disasters in good time. Research with smaller apparatus calculated for shorter ranges have been perfectly successful. A company for the manufacture of the discovery has been formed under the title of The Telemobiloscope Company, Hülsmeyer and Mannheim.
>
> [...O]n Thursday, 9 June 1904, assisted by students of Delft University, Hülsmeyer assembled his equipment in the tender *Columbus* and cruised up and down Rotterdam Harbour detecting vessels at up to 5 kilometres' range with unerring accuracy. The only problem was that as eight technical representatives of foreign shipping companies were with him to witness the demonstration he was obliged to take out a similar number of foreign patents, and this cost more money.
>
> The representatives were however enthusiastic about the demonstration and showered Hülsmeyer with praise, and after a lecture in which he explained that even longer ranges were quite possible he waited for orders.

While Hülsmeyer was unable to find commercial customers for his new radar system, his public demonstrations, worldwide research contacts, press coverage, and numerous patents directly seeded and guided the further development and application of radar by many other people and organizations.

Hans Dominik (German, 1872–1945), an engineer who was better known for his science fiction stories (p. 1982), worked together with Richard Scherl (German, 18??–19??) to build and demonstrate another prototype radar system in 1915–1916.

Radar

Christian Hülsmeyer (1881–1957) invented radar in 1903



N° 25,608 A.D. 1904

Date of Application, 24th Nov., 1904—Accepted, 23rd Mar., 1905

COMPLETE SPECIFICATION.

Improvement in Hertzian-wave Projecting and Receiving Apparatus for Locating the Position of Distant Metal Objects.—

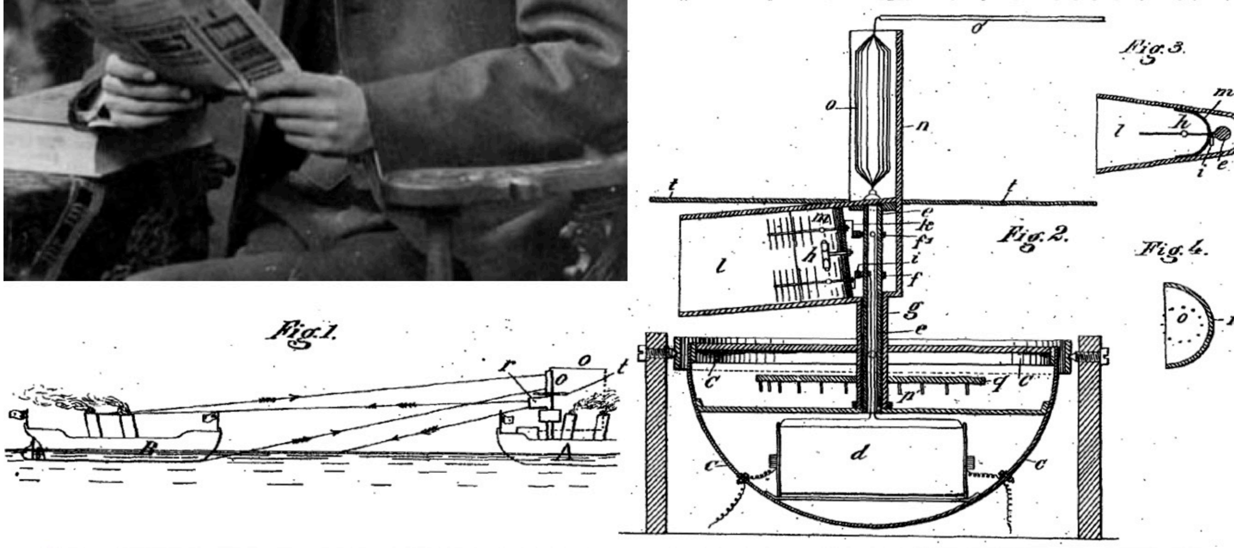
I, Christian Hülsmeyer, of 3 Grabenstrasse, Düsseldorf, Germany, Engineer, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

This invention has reference to an improved Hertzian-wave projecting and receiving apparatus for locating the position of distant metal objects such for example as ships, wrecks or submarine boats.

In the Specification of the British Patent No. 13170/1904, an apparatus is described which is intended to be used for indicating the presence of a metal body such as a ship, but such an apparatus only indicates the direction in which the metal body or object is situated. It would without doubt be most useful if it were possible to also ascertain at what distance from the point of observation the metal body is located, and the object of my invention is to enable such a result to be attained.

For this purpose I employ a projector which throws the electric waves in the form of a powerful cylindrical bundle & it is sufficient to move the projector up or down in a vertical plane (said projector having been first turned in the direction of the metal body) until the particular angle is found at which the action of the waves reflected from the metal body to the receiver is strongest. The angle which the projector at that time makes with the horizon is read off & by its aid the distance of the metal body can be easily calculated or ascertained from a prepared table. The movements of the various parts as well as the ascertaining of the correct angle may be accomplished in various ways of which I hereinafter describe two. In one of these the projector, containing the reflector *etc.*, whereby the electric rays are concentrated, is provided with an adjustable weight whereby the projector, which is appropriately mounted, is inclined. In the other form, I project parallel rays by means of a pair of lenses, which latter are adapted to be moved relatively to the projector casing, whereby the angle of inclination of the wave beams to the horizontal can be varied.

In the accompanying drawings the two methods of altering or adjusting the angle of the rays are shown diagrammatically.



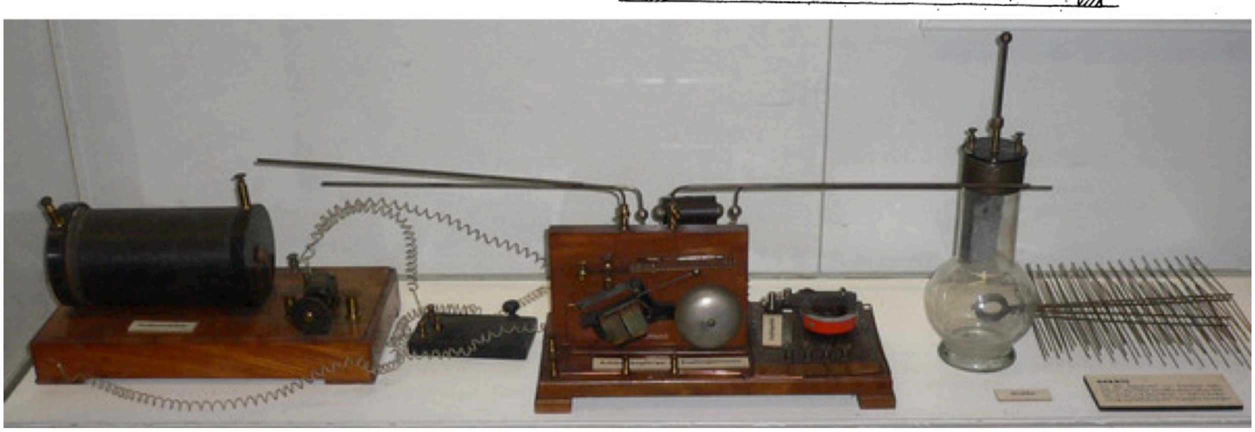


Figure 6.203: Christian Hülsmeyer invented and demonstrated radar in 1903.

One obstacle to the first radar systems was the military focus during World War I on trench warfare, which was not particularly in need of a technology such as radar. However, by the end of World War I, it became clear that aircraft and submarines would play key roles in future wars, providing a strong military incentive to develop radar systems that could be used against or by such vehicles.

The first radar systems had relatively little power, which meant that their radio waves could not travel very far, reflect off an object, and return without being too weak to detect. A solution to that problem was developed in 1920 by Heinrich Barkhausen (German, 1881–1956) and Karl Kurz (German, 1881–1960). They invented the 300–400 MHz Barkhausen-Kurz oscillator, which enabled high-frequency, high-power radar systems (Fig. 6.204).

An alternative approach that enabled high-power radar systems was the magnetron. As shown in Fig. 6.205, Hans Gerdien (German, 1877–1951) invented and patented the first magnetron in 1910. By 1924, Erich Habann (German, 1892–1968; see also p. 1069) and August Žáček (Czech/Austrian, 1886–1961; see also Section 6.5.10), working independently, had improved the performance of magnetrons to enable them to produce frequencies up to 1 GHz. In 1935, Hans Erich Hollmann (German, 1899–1960) invented, demonstrated, and patented the cavity magnetron, which used multiple cavities within a metal block to achieve very high frequencies and power levels (Fig. 6.206).

With the move toward German rearmament, several German companies began developing sophisticated radar systems in the early 1930s (Figs. 6.207–6.208). In January 1934, Rudolf Kühnhold (German, 1903–1992) of the government Nachrichtenmittel-Versuchsanstalt (NVA, Navy Transmissions Laboratory) supported Paul-Günther Erbslöh (German, 1905–2002) and Hans-Karl von Willisen (German, 1906–1966) in founding GEMA (Gesellschaft für Elektroakustische und Mechanische Apparate) to produce radar and sonar systems. Kühnhold led the development at NVA and GEMA of the Freya long-range radar, which was first demonstrated in early 1937.

At the rival Telefunken company, Wilhelm Runge (German, 1895–1987, son of the mathematician Carl Runge, p. 841) led the development of the Würzburg-Riese short-range radar, which was also first demonstrated in 1937. Some radar experts such as Hans Erich Hollmann worked on both the GEMA and Telefunken radar programs [www.radarworld.org/germany.html]. (After World War II, Hollmann moved to the United States and improved radar systems there [www.radarworld.org/hollmann.html].)

In fact, the initially rival GEMA Freya and Telefunken Würzburg-Riese radar systems ended up working very well together, since Freya could track targets at long ranges and Würzburg-Riese could provide more accurate location information at short ranges. Thus Freya and Würzburg-Riese systems were often located together (Fig. 6.209), and they were widely and effectively used throughout World War II against Allied air raids.

Creators such as Johannes Plendl (German, 1900–1991) also developed a variety of airborne radar systems, of which X-Gerät was probably the best known.

The traveling wave tube (TWT) was an important invention for radar as well as other transmission systems. A TWT combines aspects of a vacuum tube amplifier, a cathode ray tube, and a cavity magnetron into one complex device. Its unique design allows it to amplify radio and microwave signals over a wide spectrum up to frequencies of tens of gigahertz (GHz) and with powers up to tens of kilowatts (kW). Because of this combination of properties, a TWT can simultaneously send a very large number of signals at different frequencies with enough power to be received over very long distances. As such, TWTs are useful for transmitting not only complex and powerful radar signals, but also microwave communications beams carrying many different simultaneous audio, visual, and/or data channels. TWTs are widely used even today, since it has been difficult to create reliable solid state devices with the necessary combination of extreme properties.[23]

According to officials histories, Rudolf Kompfner (Austrian, 1909–1977, Fig. 6.210) first conceived of TWTs while he was a refugee in the United Kingdom during World War II, and he built the first fully functional TWTs in the early 1950s after he had been transferred to AT&T Bell Laboratories. Kompfner went on to have a long and productive career at Bell Labs.[24]

There is evidence that another team of German-speaking creators designed and demonstrated TWTs and transferred that technology to Bell Labs, all earlier than Kompfner did (Figs. 6.208 and 6.211–6.212). From the currently available archival and published documents, Herbert Schnitger (German, 19??–19??), Dieter Weber (German, 19??–19??), and their associates appear to have invented and demonstrated TWTs in Germany during the war, especially for the purpose of sending multiplexed control signals back and forth between ground stations and long-range missiles. In July 1945, the U.S. Army evacuated Schnitger, Weber, some of their other team members, and their equipment and documents from Thuringia ahead of the Russian occupation. In September 1945, an investigator from the Western Electric division of American Telephone & Telegraph (AT&T) expressed great interest in Schnitger and requested that he, his equipment, and his information be transferred to the United States. Then in July 1946, AT&T suddenly announced that it had just "invented" a revolutionary new device—the traveling wave tube. Schnitger and Weber seem to have lapsed into obscurity while AT&T achieved great fame and fortune with their work. For more details, see pp. 2950–2974.

Historians should thoroughly investigate the details of the wartime Schnitger-Weber work, its post-war transfer, and whether and how the wartime/postwar Schnitger-Weber and Kompfner research programs were interrelated.

Reinhold Rüdenberg (German, 1883–1961), an innovator in many areas of electrical engineering, emigrated from Germany to the United States in the 1930s. In the 1940s, he developed phased-array radar systems, as shown in Fig. 6.213.

[23]https://doi.org/10.1080/09205071.2020.1848643
https://www.analogictips.com/vacuum-tubes-traveling-wave-tube-part-1/
https://www.analogictips.com/vacuum-tubes-traveling-wave-tube-part-2/

[24]Gertner 2012; Kompfner 1964, 1976; Pierce 1983; 1991.

Radar

Heinrich Barkhausen (1881–1956)

Karl Kurz (1881–1960)

300–400 MHz Barkhausen-Kurz oscillator (first demonstrated 1920)

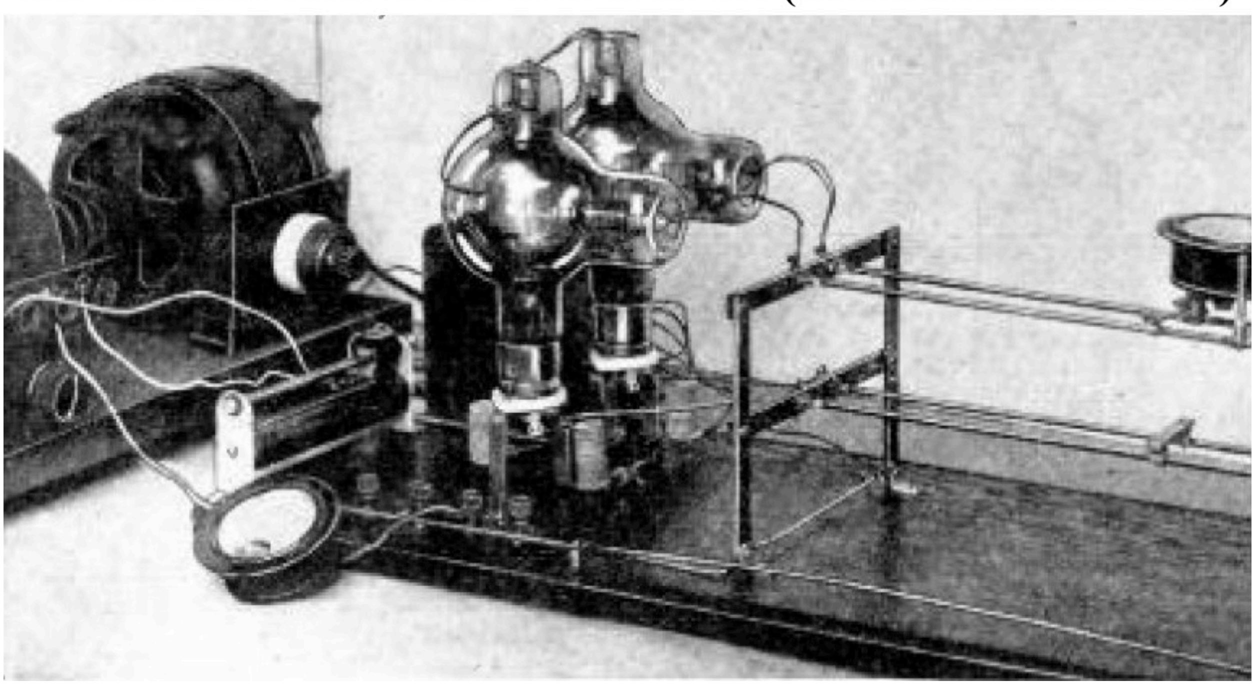


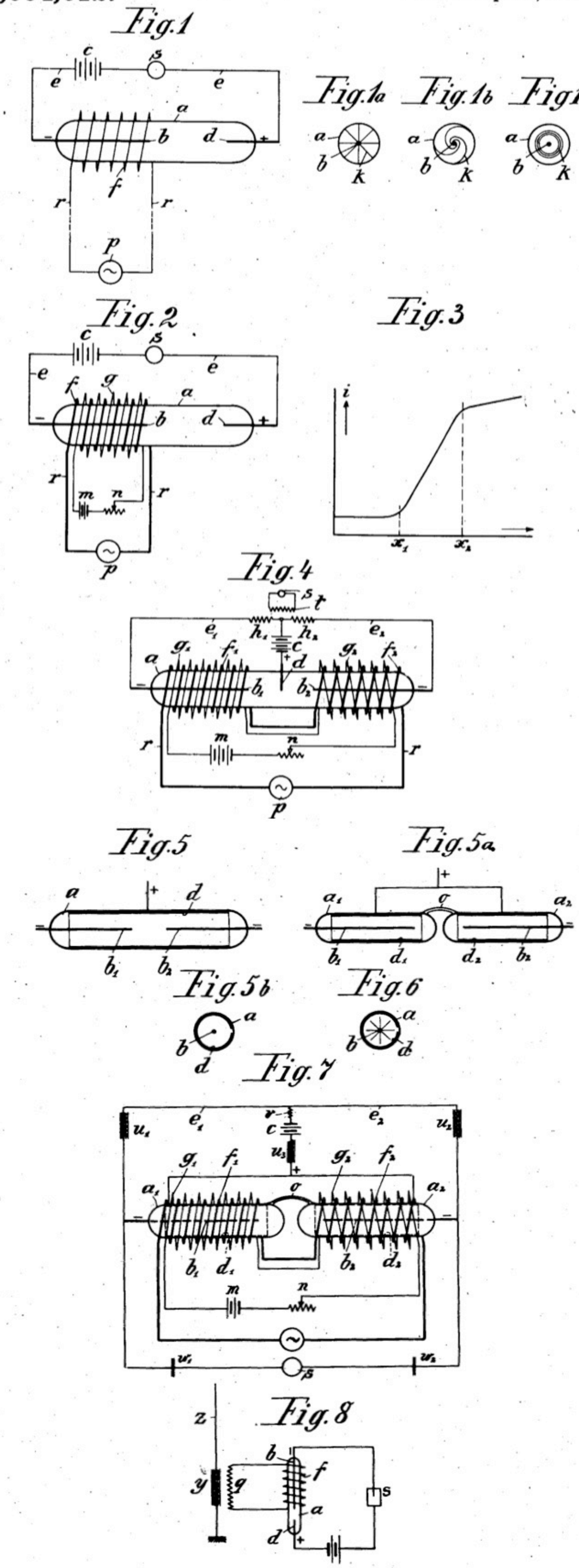
Figure 6.204: In 1920, Heinrich Barkhausen (1881–1956) and Karl Kurz (1881–1960) developed the 300–400 MHz Barkhausen-Kurz oscillator, which enabled high-frequency, high-power radar systems.

Hans Gerdien (1877–1951): magnetron (1910)

Radar

H. GERDIEN.
CURRENT RELAYING APPARATUS.
APPLICATION FILED JAN. 7, 1911.

1,004,012. Patented Sept. 26, 1911.



UNITED STATES PATENT OFFICE.

HANS GERDIEN, OF HALENSEE, NEAR BERLIN, GERMANY, ASSIGNOR TO SIEMENS & HALSKE, A. G., OF BERLIN, GERMANY, A CORPORATION OF GERMANY.

CURRENT-RELAYING APPARATUS. BEST AVAILABLE COI

1,004,012. Specification of Letters Patent. Patented Sept. 26, 1911.

Application filed January 7, 1911. Serial No. 601,443.

To all whom it may concern:

Be it known that I, HANS GERDIEN, a subject of the German Emperor, and residing at Halensee, near Berlin, Germany, have invented certain new and useful Improvements in Current-Relaying Apparatus, of which the following is a specification.

The subject-matter of my invention is means for producing great changes of energy in dependence on smaller changes of energy, the great changes of energy being to a certain extent proportional to the smaller changes of energy. Such means may be designated a quantitative relay in contradistinction to customary relays, in which the secondary changes of energy brought about by primary changes of energy are in no definite relation one to the other.

My means are particularly suitable for increasing the action of arriving waves in radiotelegraphy, for increasing the action of telephones, the action of telegraphs in cable telegraphy, for signaling, and for controlling machines from a distance, and the like.

According to my invention, for producing the great changes of energy a luminous discharge is used, whose strength is influenced by a magnetic field varied by small primary changes of energy. By luminous discharge is to be understood the electric current in a gas, in which the material of which the cathode is composed is not vaporized by the current and does not participate in the transmission of the current. In contradistinction thereto an arc is formed only when the material of which the cathode is composed is vaporized by the current.

Cathode rays are a constant accompanying phenomenon of luminous discharge. They are the carriers of a certain fraction of the luminous discharge and are that part of the whole luminous discharge which can be magnetically or electrically most readily influenced in its position and direction. In my present invention, however, the energy of the total luminous discharge, and not only the position and direction of the cathode rays, is directly influenced by a magnetic field.

Several illustrative embodiments of my invention are diagrammatically represented by way of example in the accompanying drawing, wherein:—

Figure 1 shows the simplest form of my invention; Figs. 1^a, 1^b and 1^c are sections through various vacuum tubes showing the course of the cathode rays under various conditions; Fig. 2 shows an embodiment similar to that shown in Fig. 1 but with the addition of an auxiliary circuit; Fig. 3 is a diagram; Fig. 4 shows another embodiment of my invention; Figs. 5 and 5^a show modified forms of vacuum tubes in sectional elevation; Figs. 5^b and 6 are sections through the tube shown in Fig. 5^a, and through a modified form of tube, respectively; Fig. 7 shows another embodiment of my invention, and Fig. 8 shows how my invention may be used in connection with radiotelegraphy.

Referring firstly to Fig. 1, *a* designates a closed glass tube containing a highly rarefied gas; *b* designates the cathode, *c* the source of current, *d* the anode, *e* the conductor connecting the electrodes to the source of current, and *s* a receiving apparatus, *e. g.* a telephone, interpolated in this conductor. These members form the secondary circuit. The primary circuit consists of the coil *f* mounted concentrically relatively to the cathode *b*, a sender *p*, *e. g.* an alternating current generator, and the conductors *r* connecting the sender with the coil *f*. By showing part of the conductors *r* in dotted lines it is intended to indicate that the sender *p* may be at a great distance from the coil *f*. When the coil *f* is currentless, cathode rays will go from the cathode *b* at right angles to the surface of the rod, *i. e.* radially, to the wall of the tube, as shown in Fig. 1^a. In this figure *a* designates the tube, *b* the cathode rod and *k* the cathode rays. If, on the contrary, a current traverses the coil *f*, the cathode rays are deflected and arranged curved around the cathode rod *b*, as shown in Fig. 1^b. When the field of the coil *f* is increased still more, the cathode rays no longer arrive at the wall of the tube at all, but are caused to arrange themselves in circles about the cathode, as represented in Fig. 1^c. As soon as the cathode rays are curved, the intensity of the total luminous discharge is simultaneously changed. To what this is due, is very difficult to determine; probably it is due to the cathode rays traversing within the tube a longer path in consequence of their being curved around the rod so that the gas in the tube is consequently more highly ironized, whereby an increase of strength of the total luminous discharge is caused. To every change of

Figure 6.205: In 1910, Hans Gerdien invented and patented the magnetron.

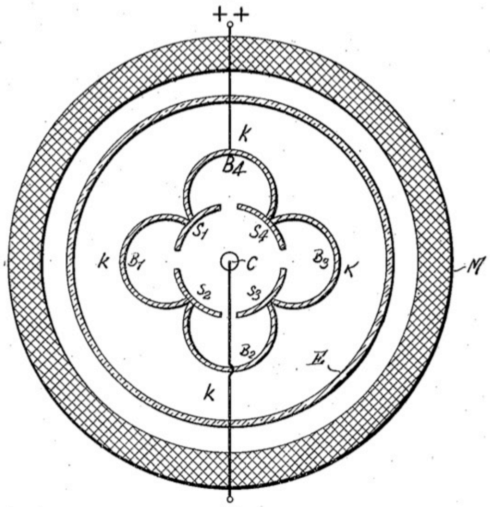
Radar Hans Erich Hollmann (1899–1960): cavity magnetron (1935)

July 12, 1938. H. E. HOLLMANN 2,123,728

MAGNETRON

Filed Nov. 27, 1936

Fig. 1



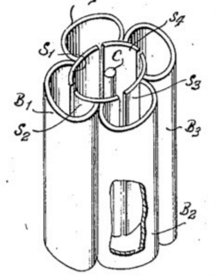
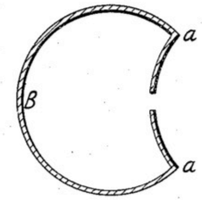


Fig. 3

Fig. 2



Patented July 12, 1938 2,123,728

UNITED STATES PATENT OFFICE

2,123,728

MAGNETRON

Hans Erich Hollmann, Berlin, Germany, assignor to Telefunken Gesellschaft für Drahtlose Telegraphie m. b. H., Berlin, Germany, a corporation of Germany

Application November 27, 1936, Serial No. 112,977
In Germany November 29, 1935

1 Claim. (Cl. 250—27.5)

My invention relates to electron discharge devices, more particularly to improvements in so-called magnetrons in which the electrode system is positioned in a magnetic field.

Investigations regarding the oscillation mechanism of magnetrons have shown that in a magnetron tube whose anode cylinder is divided by two or more slots into two or more segments, two different forms of oscillations of ultra short waves appear, in accordance with the chosen operating conditions, i. e. plate potential and strength of the magnetic field, and in accordance with the tuning of the outer resonance circuits connected to the segments. In one form of oscillation there is to be dealt with rotations of space charges produced by the action of the electrical field and the magnetic field extending at right angle to each other. This form of oscillation is not only attainable in a split anode magnetron, but also in a solid anode cylinder magnetron, and extends in the present state of the art downwards to waves of about one centimeter. The other type of oscillation has its actual origin in a negative electron resistance produced between the plate segments, and which excites the oscillatory system connected with the segments. The production of such negative electron resistance is to be found in the screw shaped course of the electron movement, such as result from the action of the radial and tangential electrical fields in the vicinity of the separation gaps of the segments in conjunction with the magnetic field extending substantially in the axial direction. This form of oscillation although not attaining the aforementioned high frequency owing to the natural inertia of the electron movement, produces however at 2 to 4 times longer waves a very much higher useful energy and a much more favorable efficiency.

The object of my invention is to provide an electrode arrangement and connection for a magnetron for increasing its efficiency.

To increase the efficiency and use of the energy of a magnetron I divide the plate cylinder into several segments, and so combine the segments that the negative electron resistances existing between the separating gaps of the segments, operate in parallel. However this can apparently only be assured when the high frequency potentials at all adjacent segment edges are of opposite phase. In order to secure this optimum state of oscillation of the segments, in the hitherto used structures of magnetron transmitters the segments situated diametrically opposite each other are connected together in pairs by means of one or several bent wire straps reaching around the plate cylinder. In a four part anode, two pairs of segments are obtained in this way each of which is connected to a pole of the resonance circuit to be excited.

When arriving at increasingly shorter waves, the natural frequencies of the small resonance circuits in the tube proper, and which are formed by the mutual capacity of the opposite segments, and the induction of the corresponding closing bend or connecting conductors, cause considerable disturbance, the more so since the connecting conductors when reaching at the outside around the anode cylinder must have a definite minimum length. Waves that are shorter than those which correspond to those small resonance systems thus either cannot be produced at all with such a tube, or only at a very poor useful effect.

Another drawback of these hitherto ordinary constructions of the anode segment system is to be seen in the fact that for instance with a four split anode, segments arranged diametrically opposite to each other have opposite high frequency potentials. This signifies however, that two adjacent segments have equal alternating potentials, and that the split portions situated between them cannot participate in the production of oscillations. Only the edges of the segments on both sides of the other two split portions actually carry opposite potentials and they alone must effect the excitation. Thus the tube is only unilaterally exploited and in an entirely incomplete manner.

By means of the arrangement of the connecting conductors described in the present invention, these drawbacks, namely the excessive length of the conductors as well as the various inclusions of the existing negative electron resistances in the building-up mechanism are safely eliminated. To this end, the invention is based upon the principle joining two adjacent segments by means of connection straps instead of connecting segments situated diametrically opposite to each other.

The novel features which I believe to be characteristic of my invention are set forth with particularity in the appended claim, but the invention itself will best be understood by reference to the following description taken in connection with the accompanying drawing in which Figure 1 is a diagrammatic transverse section of an electron discharge device embodying my invention, Figure 2 shows a detail of construction, and Figure 3 is a perspective of the mount shown in Figure 1 with a part broken away to show details of construction.

All of the four segments S_1 to S_4 around cath-

2 2,123,728

ode C are connected with each other by four conductors B_1 to B_4, whereby these conductors act, as previously, as inductances, and form small resonance systems with the mutual capacities of the segments. Electrode elements are mounted within an envelope E surrounded by the coil M for inducing a magnetic field parallel to the electrode elements within the envelope. Now when considering the incidental values of the high frequency potentials distributed over the segments, it can be seen that in fact all adjacent segments must oscillate in opposite phase, since at the ends of the bent straps or conductors, only voltages having opposite phase can appear when said ends oscillate in their natural frequency. When considering the electrode assembly, and hence also the state of oscillation as being completely symmetrical, oscillation anodes will be produced on all four culmination points k of the conductors. This means, that the inductance of the two adjacent conductor branches up to the culmination points, is to be considered as being placed in parallel to the inductance of each individual strap or conductor.

The arrangement must obviously not necessarily be such that, as indicated in the figure, the points at which the two connections meet the segment, coincide, the points may also be apart from each other, for instance moved towards the edges of the segments. Furthermore, if especially high frequencies are to be produced, it may eventually be of advantage, instead of passing the straps along the outside of the plate cylinder, to arrange them in the extended outer cylindrical surface in which the anodes are situated, and where they can be maintained much shorter. Such bent connections may also be arranged on both sides of the plate cylinder or segments.

In accordance with a further proposition, in place of the wire straps, sheet metal strips may be used to advantage, having the same width as the length of the electrode system for instance. The cross section through such a rosette shaped system remains thereby unchanged as indicated in the figure. The technical construction is especially simple if each strap forms a single piece with the two halves of the adjacent segments, and if the piece is riveted or welded at the bent edges, to the straps on both sides. Such structural part consisting of a strap and two segment halves thus has the cross section shown in Figure 2, and is joined to the following part at the edges a. Such sheet metal strips not only have the advantage of very low damping losses, but assure furthermore a uniform state of oscillation of the segments, and prevent undesirable longitudinal oscillations while assuring at the same time a favorable heat delivery, and high load capacity of the tubes.

In order to still further enhance the heat delivery, the straps may be formed as hollow bodies and have a suitable cooling means flow through them. Since the entire system is closed in itself, the cooling fluid may be suitably introduced for instance at the lower culmination point (see Figure 1) from where it will be branched towards the right and the left, and caused to leave at the upper culmination point. The principle of the construction of the segment set in accordance with the invention and relating to the high frequency part has no influence upon the other structures of the generator dealing with measures known as such, as for instance end plates maintained at suitable potential, or several filaments.

While I have indicated the preferred embodiments of my invention of which I am now aware and have also indicated only one specific application for which my invention may be employed, it will be apparent that my invention is by no means limited to the exact forms illustrated or the use indicated, but that many variations may be made in the particular structure used and the purpose for which it is employed without departing from the scope of my invention as set forth in the appended claim.

What I claim as new is:

An electron discharge device having a straight cathode, a plurality of pairs of sheet metal anode segments coextensive with each other and surrounding said cathode, conductors connecting adjacent anode segments, said conductors comprising sheet metal straps equal in width to the length of said anode segments, and means for producing a magnetic field parallel to said cathode.

HANS ERICH HOLLMANN.

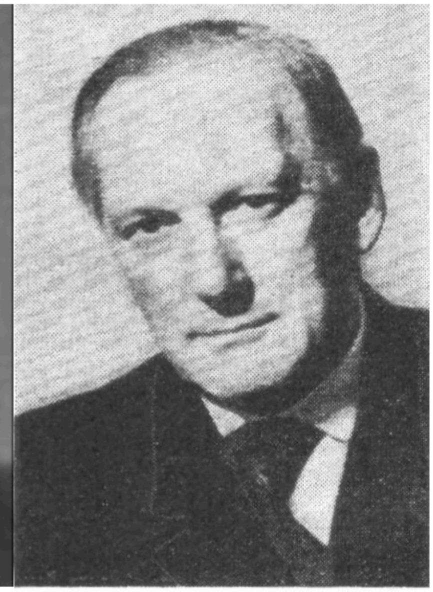
Figure 6.206: In 1935, Hans Erich Hollmann invented and patented the cavity magnetron.

Radar

Max Dieckmann (1882–1960)

Paul-Günther Erbslöh (1905–2002)

Erich Habann (1892–1968)



Rudolf Kühnhold (1903–1992)

Johannes Plendl (1900–1991)

Wilhelm Runge (1895–1987)

Figure 6.207: Other creators who developed radar systems included Max Dieckmann, Paul-Günther Erbslöh, Erich Habann, Rudolf Kühnhold, Johannes Plendl, and Wilhelm Runge.

Radar

Herbert Schnitger (19??–19??)

Theodor Jakob Schultes (1901–1981)

Wilhelm Stepp (18??–19??)

Dieter Weber (19??–19??)

Hans-Karl von Willisen (1906–1966)

August Žáček (1886–1961)

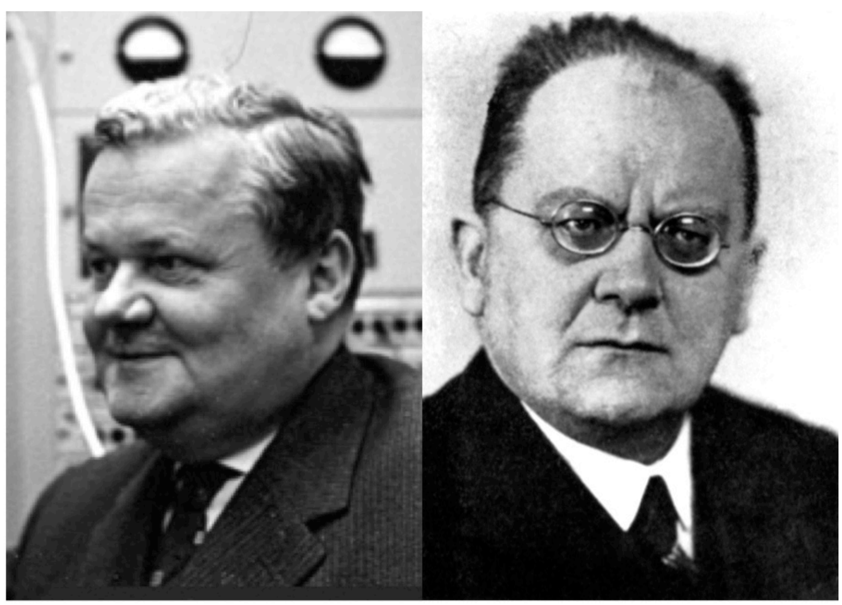


Figure 6.208: Other creators who developed radar systems included Herbert Schnitger, Theodor Jakob Schultes, Wilhelm Stepp, Dieter Weber, Hans-Karl von Willisen, and August Žáček.

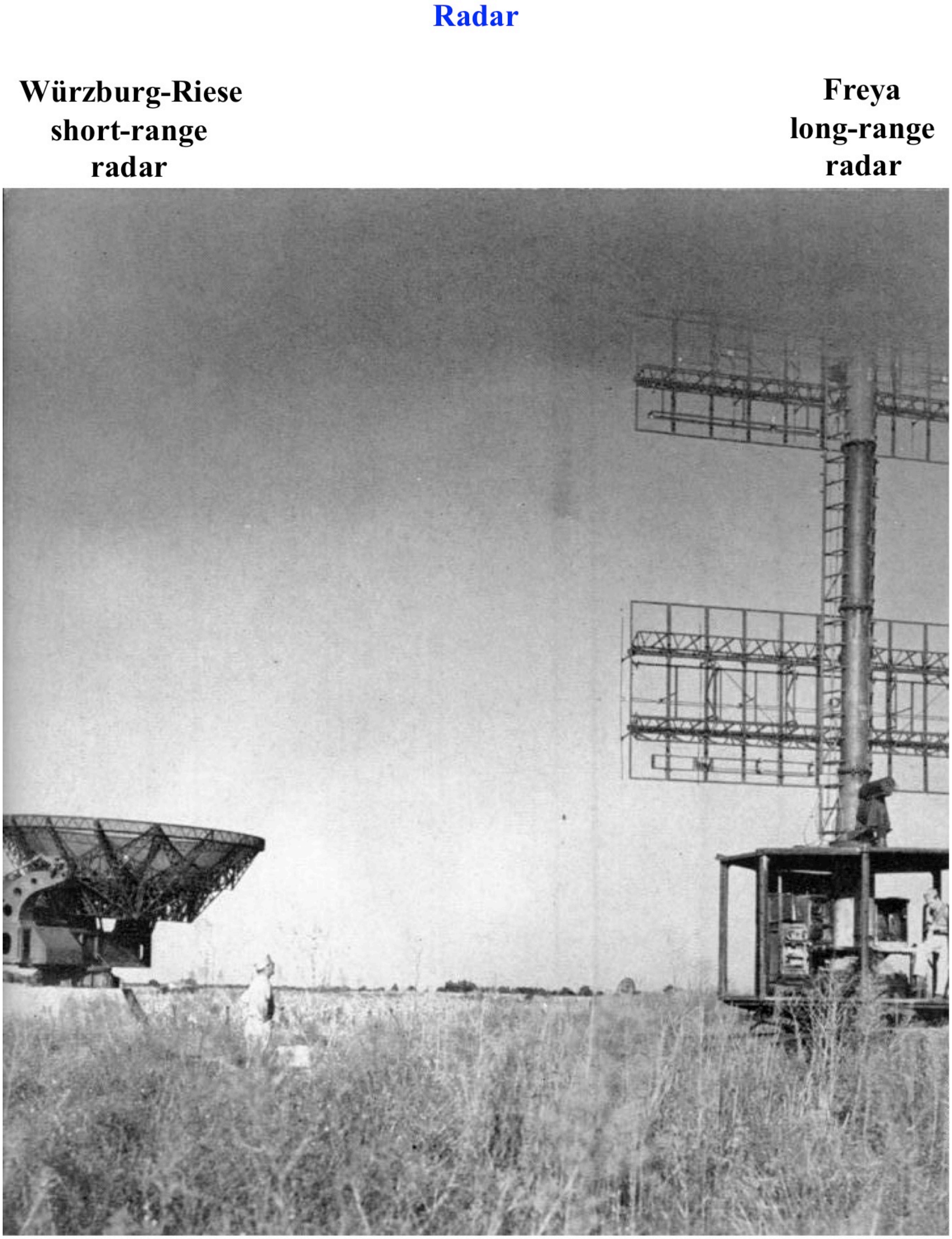


Figure 6.209: Examples of World War II German radar systems included the Würzburg-Riese short-range radar and the Freya long-range radar.

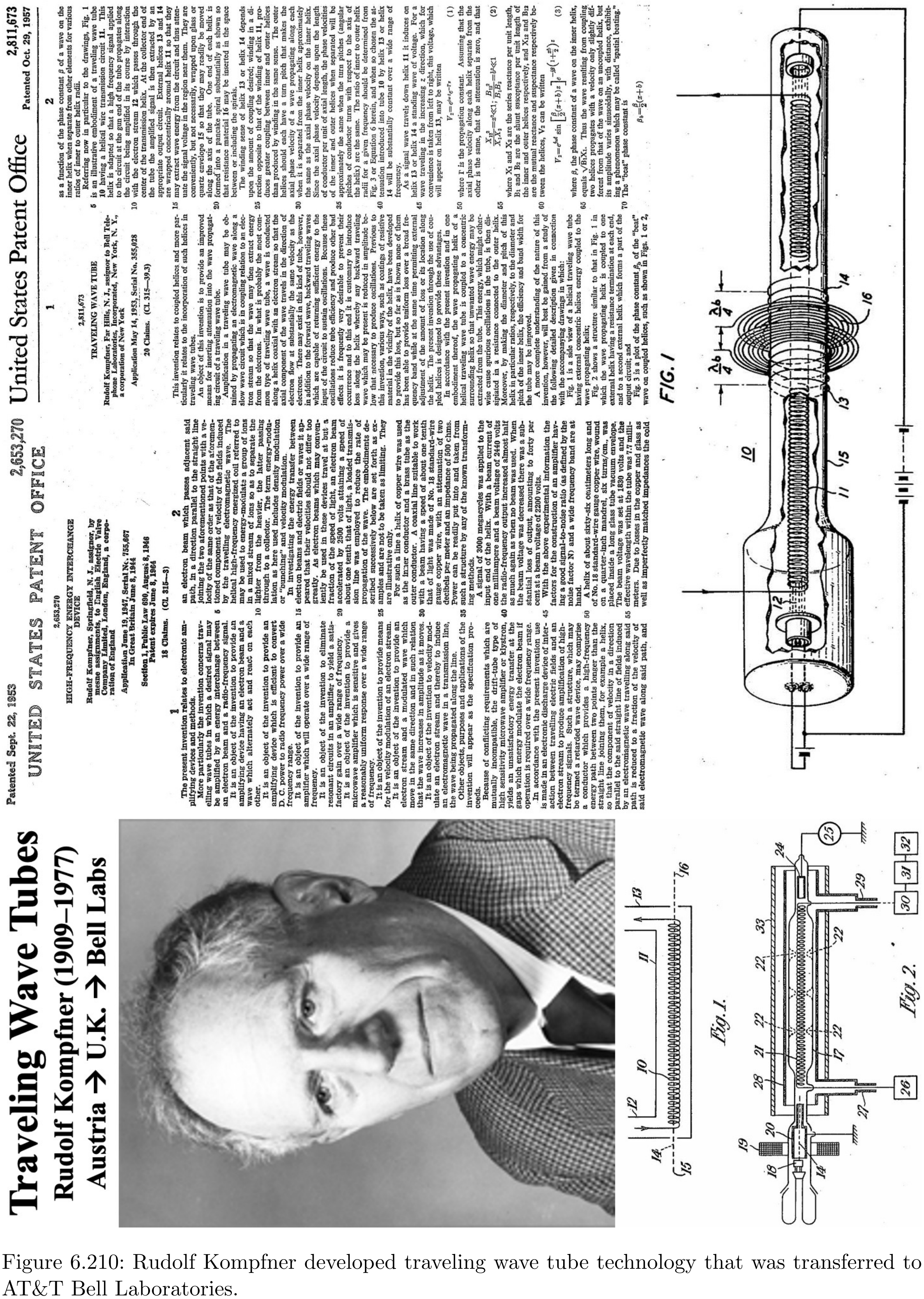


Figure 6.210: Rudolf Kompfner developed traveling wave tube technology that was transferred to AT&T Bell Laboratories.

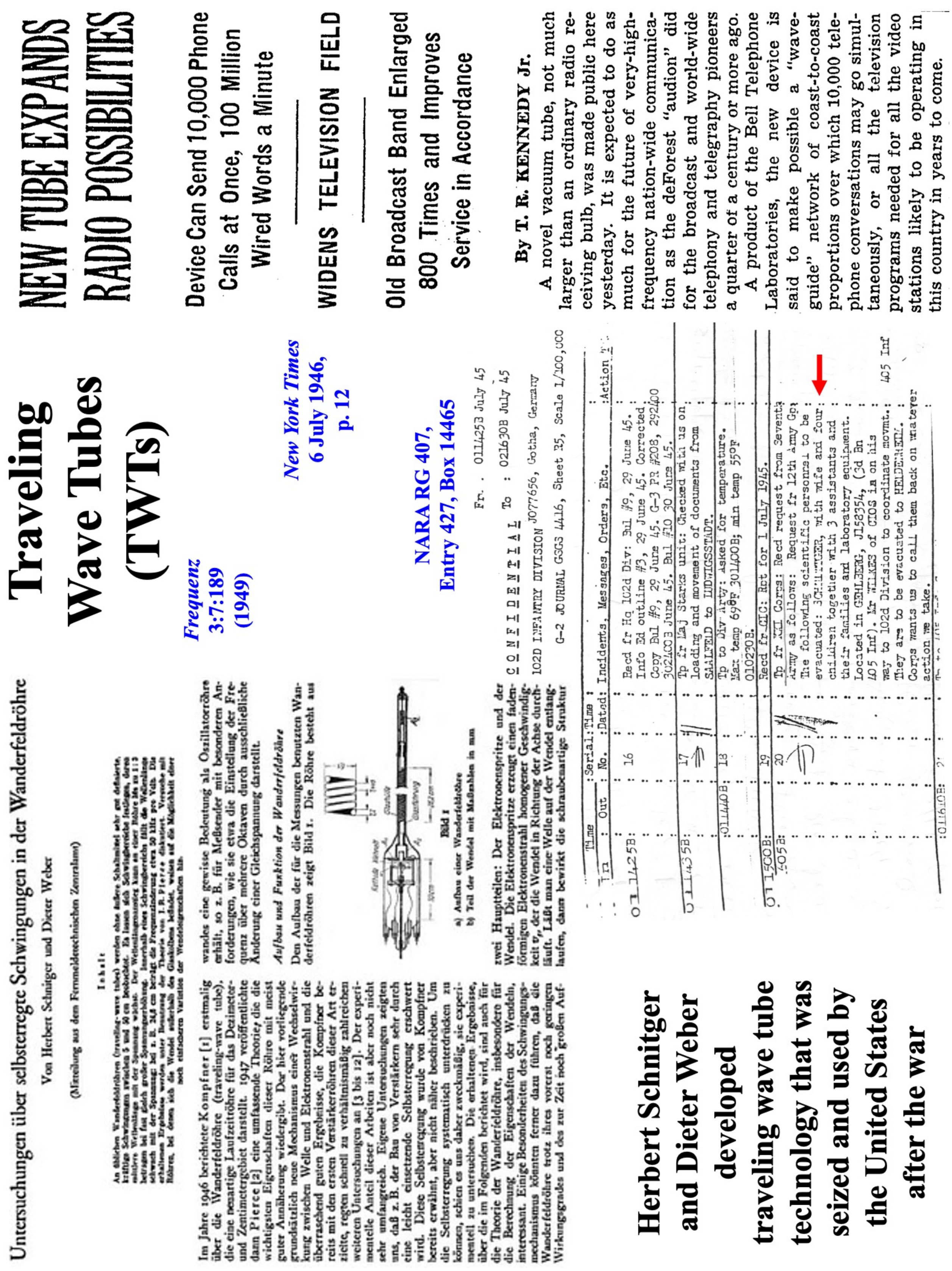
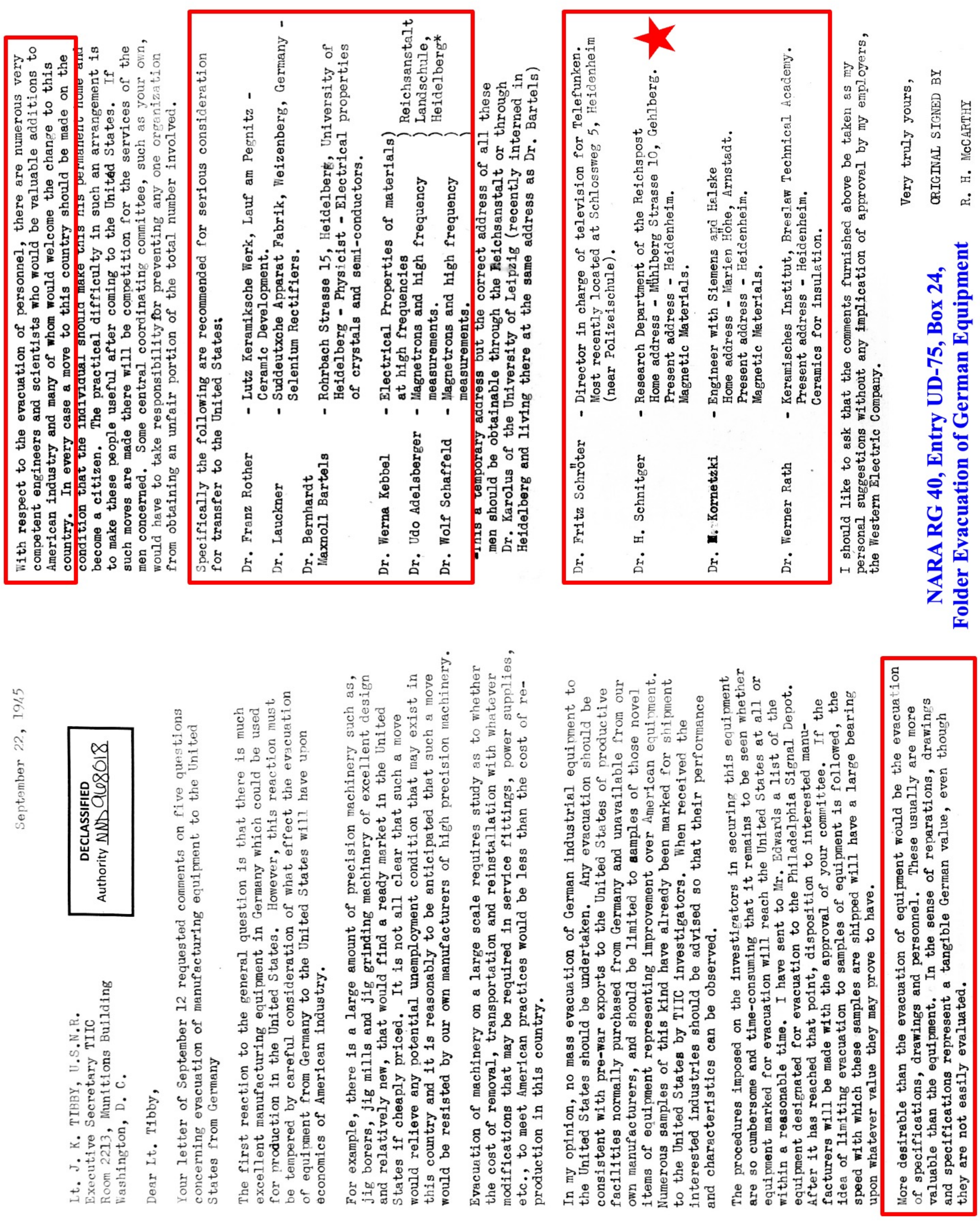


Figure 6.211: Herbert Schnitger and Dieter Weber in Germany developed traveling wave tube technology that was transferred to AT&T Bell Laboratories after the war [courtesy of Norberto Lahuerta].

Technology Transfer to AT&T Bell Laboratories



September 22, 1945

DECLASSIFIED
Authority NND968018

Lt. J. K. TIBBY, U.S.N.R.
Executive Secretary TIIC
Room 2213, Munitions Building
Washington, D. C.

Dear Lt. Tibby,

Your letter of September 12 requested comments on five questions concerning evacuation of manufacturing equipment to the United States from Germany

The first reaction to the general question is that there is much excellent manufacturing equipment in Germany which could be used for production in the United States. However, this reaction must be tempered by careful consideration of what effect the evacuation of equipment from Germany to the United States will have upon economics of American industry.

For example, there is a large amount of precision machinery such as, jig borers, jig mills and jig grinding machinery of excellent design and relatively new, that would find a ready market in the United States if cheaply priced. It is not all clear that such a move would relieve any potential unemployment condition that may exist in this country and it is reasonably to be anticipated that such a move would be resisted by our own manufacturers of high precision machinery.

Evacuation of machinery on a large scale requires study as to whether the cost of removal, transportation and reinstallation with whatever modifications that may be required in service fittings, power supplies, etc., to meet American practices would be less than the cost of re-production in this country.

In my opinion, no mass evacuation of German industrial equipment to the United States should be undertaken. Any evacuation should be consistent with pre-war exports to the United States of productive facilities normally purchased from Germany and unavailable from our own manufacturers, and should be limited to samples of those novel items of equipment representing improvement over American equipment. Numerous samples of this kind have already been marked for shipment to the United States by TIIC investigators. When received the interested industries should be advised so that their performance and characteristics can be observed.

The procedures imposed on the investigators in securing this equipment are so cumbersome and time-consuming that it remains to be seen whether equipment marked for evacuation will reach the United States at all or within a reasonable time. I have sent to Mr. Edwards a list of the equipment designated for evacuation to the Philadelphia Signal Depot. After it has reached that point, disposition to interested manufacturers will be made with the approval of your committee. If the idea of limiting evacuation to samples of equipment is followed, the speed with which these samples are shipped will have a large bearing upon whatever value they may prove to have.

More desirable than the evacuation of equipment would be the evacuation of specifications, drawings and personnel. These usually are more valuable than the equipment. In the sense of reparations, drawings and specifications represent a tangible German value, even though they are not easily evaluated.

With respect to the evacuation of personnel, there are numerous very competent engineers and scientists who would be valuable additions to American industry and many of whom would welcome the change to this country. In every case a move to this country should be made on the condition that the individual should make this his permanent home and become a citizen. The practical difficulty in such an arrangement is to make these people useful after coming to the United States. If such moves are made there will be competition for the services of the men concerned. Some central coordinating committee, such as your own, would have to take responsibility for preventing any one organization from obtaining an unfair portion of the total number involved.

Specifically the following are recommended for serious consideration for transfer to the United States:

Dr. Franz Rother - Lutz Keramiksche Werk, Lauf am Pegnitz - Ceramic Development.

Dr. Lauckner - Suddeutxche Apparat Fabrik, Weizenberg, Germany - Selenium Rectifiers.

Dr. Bernhardt Maxnoll Bartels - Rohrbach Strasse 15, Heidelberg, University of Heidelberg - Physicist - Electrical properties of crystals and semi-conductors.

Dr. Werna Kebbel - Electrical Properties of materials at high frequencies
Dr. Udo Adelsberger - Magnetrons and high frequency measurements.
Dr. Wolf Schaffeld - Magnetrons and high frequency measurements.
) Reichsanstalt Landschule, Heidelberg*

*This a temporary address but the correct address of all these men should be obtainable through the Reichsanstalt or through Dr. Karolus of the University of Leipzig (recently interned in Heidelberg and living there at the same address as Dr. Bartels)

Dr. Fritz Schröter - Director in charge of television for Telefunken. Most recently located at Schlossweg 5, Heidenheim (near Polizeischule).

Dr. H. Schnitger - Research Department of the Reichspost Home address - Mühlberg Strasse 10, Gehlberg. Present address - Heidenheim. Magnetic Materials.

Dr. [redacted] Kornetzki - Engineer with Siemens and Halske Home address - Marien Höhe, Arnstadt. Present address - Heidenheim. Magnetic Materials.

Dr. Werner Rath - Keramisches Institut, Breslaw Technical Academy. Present address - Heidenheim. Ceramics for insulation.

I should like to ask that the comments furnished above be taken as my personal suggestions without any implication of approval by my employers, the Western Electric Company.

Very truly yours,

ORIGINAL SIGNED BY

R. H. McCARTHY

NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment

Figure 6.212: Herbert Schnitger and Dieter Weber in Germany developed traveling wave tube technology that was transferred to AT&T Bell Laboratories after the war [NARA RG 40, Entry UD-75, Box 24, Folder Evacuation of German Equipment].

Reinhold Rüdenberg (1883–1961)
Phased-array radar systems

Patented Mar. 28, 1950 **2,501,876**

UNITED STATES PATENT OFFICE

2,501,876

RADIO SCANNING DEVICE

Reinhold Rüdenberg, Belmont, Mass.

Original application August 14, 1943, Serial No. 498,716. Divided and this application November 19, 1945, Serial No. 629,561

6 Claims. (Cl. 343—100)

1

This is a division of my co-pending application Serial Number 498,716, filed August 14, 1943, now abandoned.

The invention of the parent application is concerned with new methods of and apparatus for reproducing certain distinguishing qualities of distant objects, especially on or near the surface of the earth, on or near the surface of the water and also in the air.

A principal object of the invention disclosed in the said application is a new method of, and new apparatus for, producing a likeness or an image of a distant object; method and apparatus which are operable and effective even under adverse weather conditions—clouds, fog or rain for instance—or insufficient illumination, during the night, or owing to excessive illumination caused by conflagration or the like. More specifically it is an object of the said invention to reproduce as a visible image or representation of an object the electric pattern which corresponds to the contrasts in the electric and magnetic properties of the object.

For attaining to this end, I make use of the phenomenon that an object, such as the surface of the earth, when irradiated by means of electric waves reflects such incident electric waves due to its electric conductivity, magnetic permeability and dielectric constant, if these qualities are different from those of the air. Adjacent parts on the surface, as for example water, soil, rock, or structures of wood, brick, concrete, or metal, have different reflection coefficients. The electric wave reflection is slight at soil, strong at water surfaces, stronger at metallic bodies owing to their high electric conductivity, and particularly strong at iron structures owing to their high magnetic permeability. The reflected electric waves thus form a pattern similar to that of ordinary light. In contrast therewith however, even concealed structures such as steel structures embedded within the ground, a medium of low conductivity, or even on or below the surface of water, manifest themselves in this electric pattern. The present invention makes use of this phenomenon for producing an image of an object by transforming its electric pattern into a visible picture.

It is an object of the present invention to activate this pattern for thus enabling the observer to receive by means and methods disclosed in my aforesaid copending application at an observation or receiving station signals corresponding to this pattern and to transform these signals into a visible image of the object.

For this purpose, in accordance with the invention, the apparatus for activating or producing a radiant image of the electric pattern of a distant object, corresponding to the contrasts in the electric and magnetic properties thereof, in-

2

cludes an oscillator for producing electric waves, a directional electric wave converter connected thereto, and a scanner adapted to control by means of electric rhythms said converter so as to scan the pattern by means of said electric waves.

The term "electric wave converter," as used herein, is to comprise generally an electromagnetic device, such as an antenna, a dipole, a dipole array, or any other type of conductor or guide, or system of conductors or guides, linearly, areally, or spatially extended, which forms the source or the sink of the electric waves, or alternatingly both. This electric wave converter thus converts conductor-bound, -conducted or conductor-guided-, electric energy into free radiating energy or, vice-versa, receivers or collects free radiating energy and converts it into conductor-bound energy, or alternatingly both.

The devices of the invention may be employed for producing an image of the electric pattern of the distant object by focussing and irradiating the distant object with the waves produced in accordance with this invention. The signals emanating from the object and produced through this irradiation in accordance with the contrasts in space of the electric and magnetic properties of said object may then be received and converted into a scanned visible image of the pattern preferably by means of methods and apparatus disclosed in my aforesaid co-pending application Serial No. 498,716, filed on August 14, 1943.

A further object of the invention is the arrangement of a scanning device which includes a scanner for producing rhythmical scanning oscillations and a modulator coupled thereto and controlled thereby for displacing the phase of the wave oscillations within the elements of the electric wave converter and distributing over the various of said elements the phase modulating reaction in proportion to the respective positions of said elements within said electric wave converter and controlled in its intensity in accordance with the curve shape of the scanning oscillations and in the rhythm thereof.

Another object of the invention is the arrangement of a scanner which comprises a generator for rhythmic sweep oscillations for oscillating in the rhythm of the sweep oscillations a beam of electric waves converted by said converter and sweeping said beam across the distant object. The modulator is adapted to be excited from the conductor-bound energy of the waves converted in the wave converter and has control elements coupled to the generator for sweep oscillations, reactive elements and output elements, for phase modulating the oscillations within the wave converting elements by means of said reactive elements and controlling the phase modulating reaction in its intensity according to the

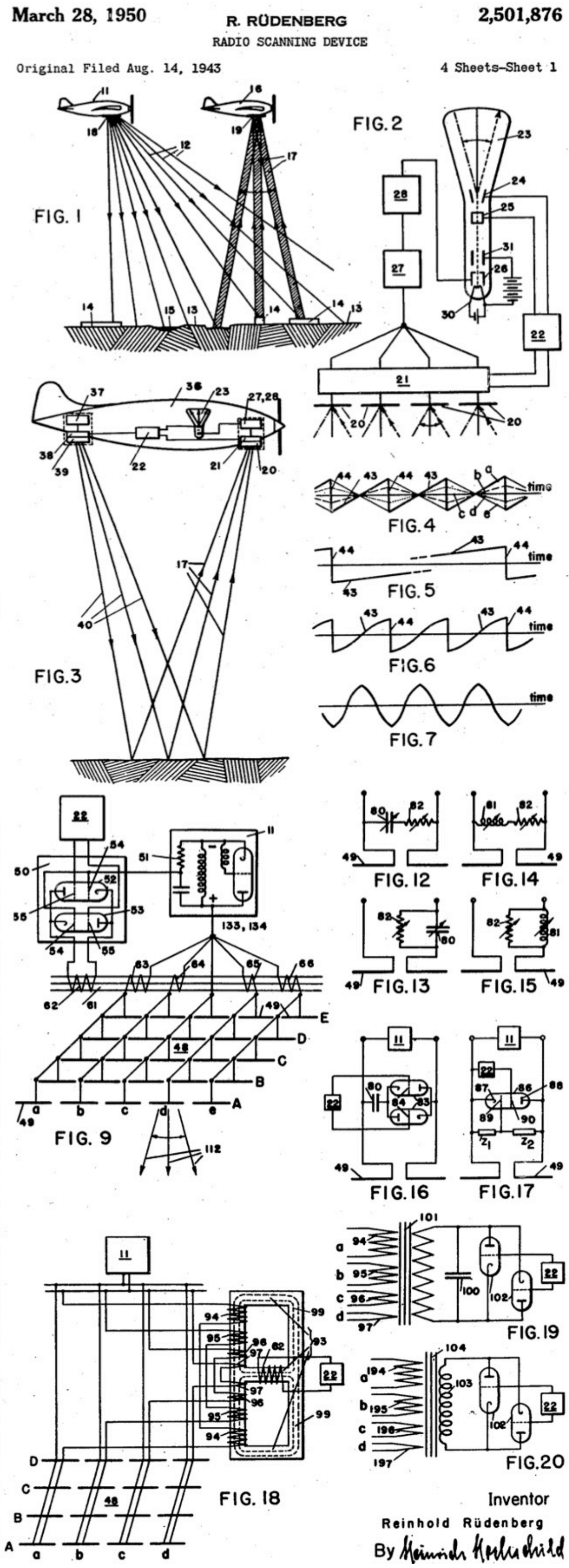


Figure 6.213: Reinhold Rüdenberg (1883–1961) developed phased-array radar systems.

In 1935, information on German radar development and testing reached the United Kingdom. In response, Robert Watson-Watt (Scottish, 1892–1973) began developing a British radar system. That program resulted in the Chain Home radar system. Chain Home was much more primitive than the German radar systems that had inspired it. Whereas the German radars had dishes that could be pointed in any direction or easily moved to other locations, Chain Home was just a series of simple vertical radio towers built at fixed locations on the U.K. coast; it could not be rotated or relocated, and it only detected aircraft over the sea, not over land.

Moreover, Chain Home used a wavelength of around 12 meters (frequency of 25 MHz), while Freya used a much shorter wavelength of around 2.4 meters (frequency of 125 MHz), and Würzburg-Riese had an even shorter wavelength of 0.54 meter (frequency of 560 MHz). That difference in wavelengths meant that the Chain Home antennas had to be 5–22 times larger than the German radar antennas, and Chain Home could only detect objects that were ∼6 meters or larger, whereas Würzburg-Riese could detect objects as small as ∼0.27 meter.

Despite its simplicity, Chain Home was used effectively in defending the United Kingdom from German air raids. In conventional histories written by English-speaking historians after the war, Watson-Watt was erroneously proclaimed to be the "inventor" of radar, and the supposed British lead in radar over Germany was cited as one of the reasons for the Allied victory in the war.

Moreover, in 1940, John Randall (English, 1905–1984) and Harry Boot (English, 1917–1983) began building simple cavity magnetrons for improved British radar systems. Their work was almost certainly based directly on the cavity magnetrons that had been invented, built, and patented internationally five years earlier by Hans Erich Hollmann (which in turn were based on the even earlier work by Gerdien, Habann, and Žáček). Famously, the British cavity magnetron designs were transferred to the United States by Henry Tizard's British Technical and Scientific Mission in September 1940. Most historians in the English-speaking world laud the work of Randall and Boot and the subsequent U.S. work that it inspired, while unfortunately ignoring the documented history of how that radar technology was actually invented years earlier in the German-speaking world and disseminated via international patents and publications.

Even Reginald V. Jones (English, 1911–1997), one of the top physicists in U.K. military science programs during World War II, tried later in life to correct the myths that had accumulated about the alleged British origins and alleged British superiority for radar technologies. In his foreword to David Prichard's *The Radar War*, Jones wrote [Pritchard 1989, pp. 7–8]:

> We in Britain are inclined to think that radar originated in Britain in 1935, stimulated by the threat from the Luftwaffe that was to materialize so dramatically in 1940. It may therefore come as a surprise to find not only that the basic idea of detecting objects by reflected radio waves had been conceived before the First World War, but also that it has been experimentally demonstrated as early as 1904 by a German engineer, Christian Hülsmeyer.
>
> In this book David Pritchard gives much the fullest account of Hülsmeyer's work that is available in the English language, and he then goes on to tell how radar was taken up by the German Armed Services in the years leading up to, and during, World War II. [...]
>
> As the story unfolds, with its many manifestations of German competence in the radio field, we in Britain can be increasingly thankful that the intensity of the Luftwaffe threat

> in the years leading up to 1939 brought our serving officers and scientists together at all levels into a close working relationship: it was this, more than any other factor, which resulted in our lead in the operational use of radar even though in some respects the German equipment was technically better.

The radar historian Pritchard described in detail how WWII British radar experts learned that German radar systems were much more advanced than British systems [Pritchard 1989, pp. 97–99]:

> It is no exaggeration to say that after examining the *Würzburg* [captured in the 28 February 1942 Bruneval raid] the British received quite a surprise.
>
> Even on the way home in the boat D. H. Priest, a radar specialist from TRE [Telecommunications Research Establishment] who had gone on the mission, had had time to examine it, and during an exchange of opinions with Cox came to the conclusion that the Germans had been making it for a long time, possibly even ten years.
>
> Cox, who had been in radio all his life, thought the *Würzburg* was a 'beautiful job', and was particularly impressed by the way it made use of unit construction for easy fault-finding and quick replacement, a view also shared by Jones. [...]
>
> The equipment had therefore to be made so well, and so easily replaceable if any part broke down, that the system could be operated by relatively unskilled personnel.
>
> The superiority of the engineering standard was indeed much higher than the British systems, and to ensure that no lack of morale appeared in engineering and (later) public circles, a story was disseminated (and still believed by some today) that German radar was much inferior to the British. That this was wildly inaccurate is however attested by those who at the time were in possession of the facts, as Jones points out:
>
>> ...the stability of every German radar station was better than that of the best instruments we had available to check them. In fact, Martin Ryle, afterwards to win a Nobel Prize for Radioastronomy, was one of our observers, and he told me that ever afterwards if he wanted to know whether a radar transmission was British or German, all he had to do was to check its stability.
>
> To achieve and maintain these standards, and even to improve upon them in the face of political and military dissension, and in spite of severe disruption of the production lines from Allied bombing, to say nothing of the strain of a war economy, must remain for all time a tribute to the skill and determination of all those involved in the German radar programme.

Because the wartime German radar systems had such advanced capabilities compared to British and American radar systems of the time, after the war they were transferred to other countries to be used and copied. Jones gave several examples [Jones 1978, p. 230]:

> If the German night interception procedure seemed unduly elaborate, the precision of the Giant Würzburg was not entirely wasted on the war: in 1945 specimens were brought to Britain and America and converted to radio telescopes for radioastronomy. Another specimen that remained on site in Holland was used by Dr. van de Hulst to discover the radiation coming in from the hydrogen atoms in the spiral arms of our galaxy on a wavelength of about 21 centimetres.

6.8.2 Radar Countermeasures

Scientists in wartime Germany pioneered radar countermeasures or stealth technologies. They created and tested a variety of radar-absorbing coatings, and gave the best ones names such as Eisenspane and Moltopren.[25] Germany successfully used those radar countermeasures on submarines, and it was developing and testing stealth aircraft as well; see pp. 1780, 1785–1786.[26]

Documentation, materials, and scientists from those wartime programs on radar countermeasures were acquired by Allied countries after the war and became the basis for modern stealth technologies. Some examples are below, but much more historical research on this topic should be conducted and published in the future.

Former Bell Laboratories scientist T. M. Odarenko gave an overview of some of the German programs in FIAT 61, *Radar Camouflage Radiation Absorption Materials*, pp. 1, 12–13:

> The problem of radar camouflage and radiation absorbers is not new to the radar workers in the U.S. The Radiation Laboratories and the War Committee on Dielectrics, among others, were concerned with it. [...] Because of the urgency of other problems, the work in U.S.A., however, did not progress very far. The Germans, on the other side, who placed high hopes in their submarine warfare, and whose submarines suffered severely from high losses due to the radar detection methods of the Allies, invested a great deal of efforts, and of scientific and of technological talents, into the anti-radar methods and devices. The results of their work prove to be of considerable interest to the allied intelligence organizations. [...]
>
> By the end of the European war, the Germans investigated the theoretical approach to the radiation camouflage quite exhaustively. Much practical data was accumulated by the Germans on the tuned and wide-band lossy "impedance-matching" absorbers. In addition, materials were produced successfully with permeability equal to dielectric constant and with reasonably high losses. As the side results of their work on the semiconductors, means were established of introducing high electrical losses into materials.
>
> As the result of the fundamental study of dielectric materials and various ferrites and oxides, new materials were obtained, the electromagnetic constants of which could be controlled by such factors as temperature, magnetic field, etc.
>
> The problem of an ideal radiation absorption material has not been solved in Germany. The Germans, however, went far enough to indicate that further researches on such materials are well worth while. Their failures with certain materials, and their successes with others, might assist this further work considerably if their results with complete reports and data are made promptly available to the proper research organizations in this country and in Great Britain.

[25] BIOS 132; BIOS 727; BIOS 869; BIOS 871; CIOS ER 4; CIOS XXVI-24; FIAT 61; NavTecMisEu LR 10-45; NavTecMisEu 90-45.

[26] Horten and Selliger 2012; Jorgensen 2009; Myhra 1998b; Shepelev and Ottens 2015.

> The importance of this work lies in the fact that the materials thus developed would be of interest not only in the strictly military field, where radars have proven of such value, but in the variety of other applications, such as selective shielding, static dissipators, tuned networks, etc.

BIOS 871, *Work of Professor Hüttig on Ferromagnetic Substances for Use in Radar Camouflage*, pp. 4–5, also described some of the wartime programs:

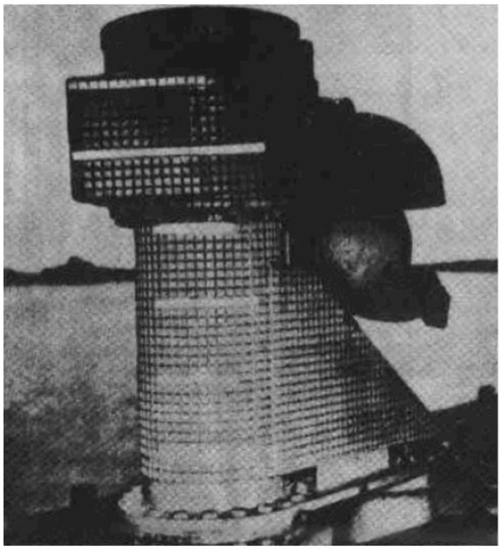
> Hüttig, who is essentially a physical chemist, and specialises in the properties of the solid state, worked on Schornsteinfeger in collaboration with a team including Professor Kafla, physicist, and Professor Flegler, who made the electro-magnetic absorption measurements. Their objective, as has already been noted, was the production of a ferromagnetic material with permeability and dielectric constant equal and high, and if possible lossy. The material first studied and developed to the production state, was gamma iron oxide, and this can be produced on a manufacturing scale with μ equal to *epsilon* equal to 6, with no loss. This material, known as W.61, was manufactured at the DEGUSSA works in Raudnitz-on-Elbe, and was rolled into Buna at Uhrineves, near Prague, giving a product containing 10% Buna and 90% W.61.
>
> Owing to the instability of gamma iron oxide and to the fact that the material is not lossy, attention was then turned to the development of ferrites. [...] A large number was prepared[...]
>
> Hüttig said that the most promising material was probably manganese ferrite from the point of view of giving the properties required, although for consistency in production, magnesium ferrite would be preferable. The best samples of manganese ferrites that his team had prepared had a permeability of 12 and a dielectric constant of 18 with magnetic and dielectric losses both equal to 0.35, the measurements being made at a wave length of 173 cm. [...]
>
> Hüttig was of the opinion that the system ferrous oxide–vanadium oxide was worth study, as the material had a very high ferromagnetism and formed solid solutions with metallic iron.

British Aerospace/BAE engineer Ronald Evans explicitly stated how dependent postwar Allied programs to develop stealth aircraft were on wartime German creations [Evans 2015, p. xv]:

> From 1978 until 2005, I was employed by British Aerospace and, after the merger with Marconi, by BAE Systems at their military aircraft site at Warton Aerodrome in Lancashire[...]
>
> I began work at Warton as a senior aerodynamicist in the Performance & Propulsion Group. [...] In 1980 I was tasked with running a radar stealth research programme. Capitalising on German development of radar-absorbing materials (RAM) during the Second World War, the UK became a world leader in reducing the radar signatures of its military aircraft during the 1950s and 1960s. [...] In 1962 there was a large exchange of information on the subject of radar stealth between the UK and US governments.

Radar countermeasures

CIOS XXVI-24



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Udo Adelsberger (19??–19??)

?? Friedrich (19??–19??)

?? Helmholz (19??–19??)

Figure 6.214: Many German-speaking scientists developed a range of radar countermeasures (stealth) technologies during World War II.

Radar countermeasures

Gustav Franz Hüttig (19??–19??)

?? Patat (19??–19??)

?? Schaffeld (19??–19??)

Heinz Schlicke (1912–2006)

Ludwig Wesch (19??–19??)

Karl Wolf (19??–19??)

Figure 6.215: Many German-speaking scientists developed a range of radar countermeasures (stealth) technologies during World War II.

6.8.3 Microwave Heating

According to conventional histories, in October 1945, Percy Spencer (1894–1970), an American with only a high school education working as a business manager at Raytheon, suddenly invented, built, demonstrated, and perfected microwave ovens.

In fact, it was large numbers of highly educated German-speaking scientists at Siemens, Telefunken, and other German companies who worked diligently over the course of a decade to:

1. Invent microwave heating in the 1930s.
2. Perfect and apply it to a wide variety of applications (food preparation, delousing of clothing, glue drying, etc.) during the war.
3. Transfer the technology under duress after the war to Allied countries, which then publicly claimed it as their own postwar invention.

BIOS 866, *High Frequency Heating*, is a key piece of evidence documenting that history (Fig. 6.216):

> [p. 1:] This report contains a survey of the activities in the field of high frequency heating of the German industry and it has been compiled from information gained at 18 targets in the British, U.S. and French zones. It deals chiefly with work at Radio Frequencies and is not concerned with the use of rotating machines.
>
> Most of the activity has been confined to the large electrical firms particularly SIEMENS SCHUKERT, A.E.G. and TELEFUNKEN, and mainly in the Berlin sections of these companies.
>
> It would appear that in 1939 the Germans were fully aware of the industrial possibilities of high frequency heating and were reasonably far advanced in the techniques involved. During the war practically all the effort was devoted to essential war work and development appears to have been impeded to a considerable extent by government restrictions on the use of valves.
>
> Practically no equipment was seen. It was reputed to have been destroyed by bombing or removed by the Russians. Sets up to 20 kW or thereabouts had been made in some quantities for surface hardening and larger sets up to 200 kW for this field had been planned.
>
> Dielectric heating had been experimented with in many fields such as wood gluing; drying of timber, cigarettes etc; plastics heating; lice-killing and food processing. Only wood gluing for aircraft and lice killing in soldiers' uniforms had been applied on any scale.
>
> [p. 16:] (ix) SIEMENS-SCHUKERT WERKE BERLIN-SIEMENSSTADT [...]
>
> Induction Heating had been applied to surface hardening of gears and other articles at frequency of 100-200 kc/s using powers up to 200 kW.
>
> Dielectric Heating had been tried with wood drying, wood gluing, rubber vulcanisation, tobacco drying, plastics heating, milk sterilisation, wheat drying, meat cooking and

drying, and killing of lice. Only wood gluing and lice killing had been put into practical application.

Personnel Interviewed.

Mr. BENKERT, director and works manager.
Dr. MAIER, assistant to Mr. BENKERT.
Mr. ASCHMANN, in charge of industrial applications.
Dr. SCHNECKE, in charge of equipment design.
Dr. TSCHERMAK, in charge of dielectric heating.
Mr. KEUTNER, dielectric heating.

[p. 18:] (a) Wood gluing: This was done chiefly for the aircraft industry and when the war ended 12 sets at 6 Mc and 20 kW had been installed for making plywood and general gluing of aircraft parts. [...]

[p. 19:] (b) Killing lice in garments: The sets operated at 25 Mc/s with a power of 30–40 kW and 3 stationary and 1 mobile equipments had been supplied to the WEHRMACHT for treating uniforms. The uniforms were sprayed with water then carried through a condenser field on a leather conveyor at the rate of 400 Kg of clothing per hour. It was claimed that lice, eggs and typhoid bacteria were all killed.

[pp. 22–23:] (xii) TELEFUNKEN.
BERLIN-SCHÖNEBERG, MAXSTRASSE 10. [...]

Dr. FRANZ stated that the limited resources available for H.F. Heating were being devoted in the first place to heating of foods with a view to making the most of the supplies available. After food heating work would be done on plastics.

In conjunction with SAROTTI, a subsidiary of NESTLES experiments were being done on pre heating grain or flour. It was found that Rye flour heated in this way to a temperature of 150^{o}C had improved quality and it could be used in place of wheat flour for making soups. Cereals treated similarly by H.F. heating could be kept easily and were in a pre-cooked state requiring little cooking when they were to be used.

The experiments were being done on a small scale with a 1 kW oscillator on a frequency between 15 and 30 Mc/s. About 0.5W per gm were required.

Dr. FRANZ considered that there was quite a future for this activity.

Demonstration experiments on cooking potatoes were mentioned. It had been found with H.F. heating that the water need not boil as long as in ordinary potato cooking. Thermocouple measurements had shown that with the H.F. heating the potato temperature was in advance of the water temperature.

These food experiments were being done in co-operation with the "Food Institute".

As the above document mentioned, German-speaking scientists also invented and perfected induction heating, which is now used in the most modern type of stovetops.

Microwave ovens were developed by 1939 by scientists at:

- **AEG**
- **Siemens Schuckert**
- **Telefunken**
- **Etc.**

Demonstrated applications:

- **Food preparation**
- **Wood glue drying**
- **Drying of timber**
- **Killing lice in clothing**
- **Etc.**

B.I.O.S. FINAL REPORT No. 866
ITEM Nos. 1, 7 & 9

Unclassified

416

HIGH FREQUENCY HEATING

363680

This report is issued with the warning that, if the subject matter should be protected by British Patents or Patent applications, this publication cannot be held to give any protection against action for infringement.

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BRITISH INTELLIGENCE OBJECTIVES SUB-COMMITTEE

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Personnel of Team.

M.R. Gavin.
J.F. Capper.
W.J.W. Dunstall.
J.R. Spanswick.

DURATION OF VISIT

HIGH FREQUENCY HEATING.

1. SUMMARY.

This report contains a survey of the activities in the field of high frequency heating of the German industry and it has been compiled from information gained at 18 targets in the British, U.S. and French Zones. It deals chiefly with work at Radio Frequencies and is not concerned with the use of rotating machines.

Most of the activity has been confined to the large electrical firms particularly SIEMENS SCHUKERT, A.E.G. and TELEFUNKEN, and mainly in the Berlin sections of these companies.

It would appear that in 1939 the Germans were fully aware of the industrial possibilities of high frequency heating and were reasonably far advanced in the techniques involved. During the war practically all the effort was devoted to essential war work and development appears to have been impeded to a considerable extent by government restrictions on the use of valves.

Practically no equipment was seen. It was reputed to have been destroyed by bombing or removed by the Russians. Sets up to 20 kW or there abouts had been made in some quantities for surface hardening and larger sets up to 200 kW for this field had been planned.

Dielectric heating had been experimented with in many fields such as wood gluing; drying of timber, cigarettes etc; plastics heating; lice-killing and food processing. Only wood gluing for aircraft and lice killing in soldiers' uniforms had been applied on any scale.

In the report below the activities are reviewed firstly under subject headings and secondly under target headings.

2. SUBJECTS/

Figure 6.216: Microwave ovens were developed no later than 1939 by scientists at AEG, Siemens Schuckert, Telefunken, and other laboratories. They were demonstrated to be effective for applications including food preparation, wood glue drying, drying of timber, killing lice in clothing, etc. The technology was transferred to Allied countries after the war [BIOS 866].

6.8.4 Sonar

German-speaking scientists invented underwater acoustic ranging and imaging technology in the early twentieth century and developed highly sophisticated and specialized systems by the 1930s and early 1940s.[27] This technology is now best known by the WWII-era American name sonar (originally an acronym derived from SOund NAvigation Ranging). In many early Allied documents, this technology was also called ASDIC (after the Anti-Submarine Division).

Alexander Behm (German, 1880–1952) invented and demonstrated sonar in 1912. Leo Löwenstein (German, 1879–1956) was another early German sonar pioneer. Independent work on sonar began in other countries within that same decade, especially in response to Germany's use of submarine warfare in World War I.

German-speaking scientists steadily improved sonar technology from World War I through World War II. By World War II, at least four companies had large programs developing and manufacturing sonar systems:

1. Atlas Werke based in Bremen.
2. Electroacustic Kommanditgesellschaft (ELAC) based in Kiel.
3. GEMA (Gesellschaft für Elektroakustische und Mechanische Apparate) based in Berlin.
4. AEG (Allgemeine Elektrizitäts-Gesellschaft) based in Berlin.

Improvements to German sonar technologies continued until the end of World War II, at which point they were transferred to Allied countries. For example, NavTecMisEu 530-45, *Sonar in the German Navy*, p. 2, stated:

> The GHG is the German counterpart of the multi-spot equipments which were abandoned in the U.S. before the war. The Germans, however, carried the principle to a much higher degree of development and appear to have attained excellent results. The GHG ordinarily permits detection at much longer range than supersonic [ultrasonic] listening or echo ranging gear.
>
> The other important class of German equipment is the S Anlage for echo ranging and supersonic listening. This apparatus was well designed, with emphasis on simplicity and reliability.

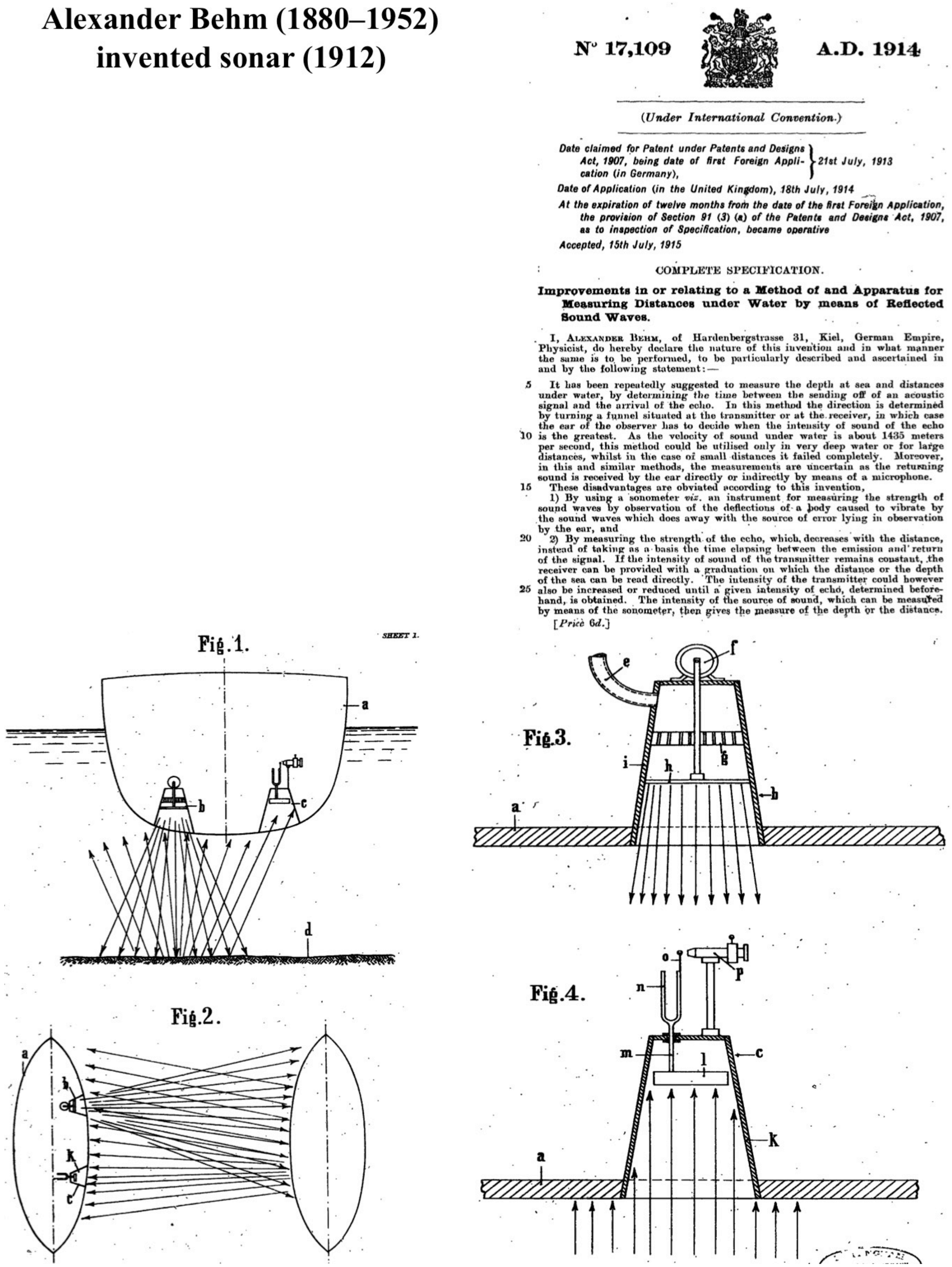
German companies also applied sonar methods to the air to create sonic altimeters for aircraft.[28]

After the war, many German sonar experts continued their work in Allied countries.

Robert Adler (Austrian, 1913–2007) invented ultrasonic remote control systems; see p. 1021.

[27] E.g., CIOS XXVIII-52, *German Submarine and Anti-Submarine Methods and Equipment*; NavTecMisEu 530-45, *Sonar in the German Navy.*

[28] CIOS XXXII-76, *A Sonic Altimeter for Aircraft*; NavTecMisEu 196-45, *A Sonic Altimeter for Aircraft (Landehoehenmesser).*



Alexander Behm (1880–1952) invented sonar (1912)

N° 17,109 **A.D. 1914**

(Under International Convention.)

Date claimed for Patent under Patents and Designs Act, 1907, being date of first Foreign Application (in Germany), } *21st July, 1913*

Date of Application (in the United Kingdom), 18th July, 1914

At the expiration of twelve months from the date of the first Foreign Application, the provision of Section 91 (3) (a) of the Patents and Designs Act, 1907, as to inspection of Specification, became operative

Accepted, 15th July, 1915

COMPLETE SPECIFICATION.

Improvements in or relating to a Method of and Apparatus for Measuring Distances under Water by means of Reflected Sound Waves.

I, Alexander Behm, of Hardenbergstrasse 31, Kiel, German Empire, Physicist, do hereby declare the nature of this invention and in what manner the same is to be performed, to be particularly described and ascertained in and by the following statement:—

It has been repeatedly suggested to measure the depth at sea and distances under water, by determining the time between the sending off of an acoustic signal and the arrival of the echo. In this method the direction is determined by turning a funnel situated at the transmitter or at the receiver, in which case the ear of the observer has to decide when the intensity of sound of the echo is the greatest. As the velocity of sound under water is about 1435 meters per second, this method could be utilised only in very deep water or for large distances, whilst in the case of small distances it failed completely. Moreover, in this and similar methods, the measurements are uncertain as the returning sound is received by the ear directly or indirectly by means of a microphone.

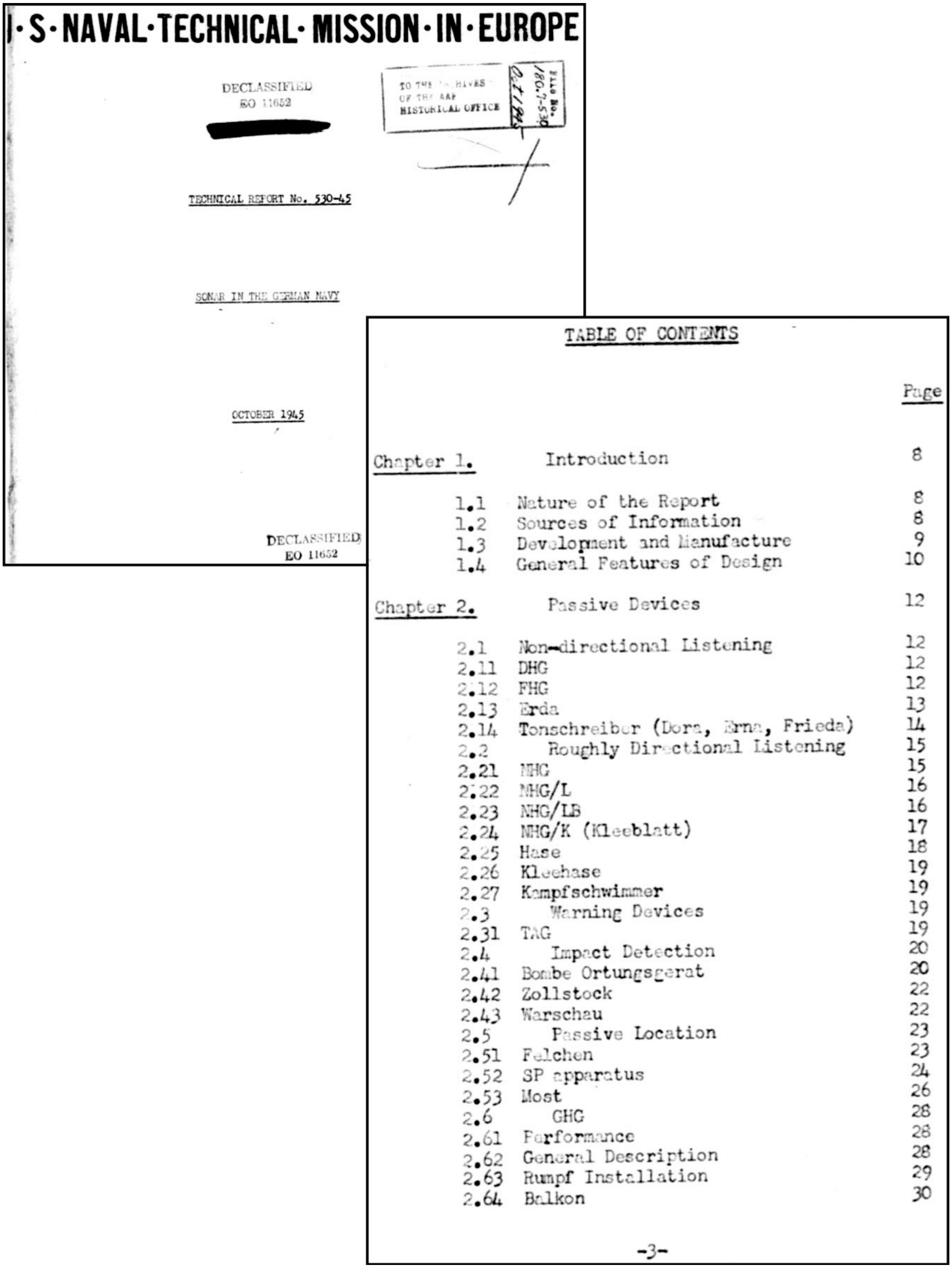
These disadvantages are obviated according to this invention,

1) By using a sonometer *viz.* an instrument for measuring the strength of sound waves by observation of the deflections of a body caused to vibrate by the sound waves which does away with the source of error lying in observation by the ear, and

2) By measuring the strength of the echo, which decreases with the distance, instead of taking as a basis the time elapsing between the emission and return of the signal. If the intensity of sound of the transmitter remains constant, the receiver can be provided with a graduation on which the distance or the depth of the sea can be read directly. The intensity of the transmitter could however also be increased or reduced until a given intensity of echo, determined beforehand, is obtained. The intensity of the source of sound, which can be measured by means of the sonometer, then gives the measure of the depth or the distance.

[*Price* 6*d*.]

Figure 6.217: Alexander Behm invented and demonstrated sonar in 1912, and filed patents on it in 1913.



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180.7-530
Oct 1945

TECHNICAL REPORT No. 530-45

SONAR IN THE GERMAN NAVY

OCTOBER 1945

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Figure 6.218: Atlas Werke, ELAC, GEMA, and AEG developed highly sophisticated and specialized sonar systems [NavTecMisEu 530-45].

Figure 6.219: Atlas Werke, ELAC, GEMA, and AEG developed highly sophisticated and specialized sonar systems [NavTecMisEu 530-45].

-6-

Figure 6.220: Atlas Werke, ELAC, GEMA, and AEG developed highly sophisticated and specialized sonar systems [NavTecMisEu 530-45].

1.2 Sources of Information.

The material contained in this report was gathered in the course of three field trips totalling 40 days in Germany. Equipment was inspected on board ships afloat and on the building ways, in warehouses, test laboratories, and factories of the leading manufacturers. Information was gathered from various personnel as well as from documents. The more important personnel interrogated include:

Konteradmiral Rhein of the CPVA (Chemische Physikalische Versuchs Anstalt)
Dr. Ing. Buchmann of the CPVA.

Dr. Ing. Bluschke of the CPVA.
Fr. Kapt. Meckel of the OKM (Oberkommando der Kriegsmarine).
Kapt. Von Linden of the SVK (Sperrversuchskommando).
Kapt. Hagemann of the SVK.
Oblt. Dr. Matusche of the Luftwaffe.
Dr. Ing. Karl Kupfmuller of the WFM (Wissenschaftlicher Fuehrungsstab der Kriegsmarine.)
Dr. Rudolf Kuhnhold of the NVK (Nachrichtenmittelsversuchskommando).
Dr. Phil. Friedrich Howey of the NVK.
Dr. Schmidt of the NVK.
Dr. Hans-Ulrich Meyer of the NVK.
Dipl. Ing. Hummel of the NVK.
Dr. Kurte Kalle of the Deutscheseewart.
Prof. Dr. Ervin Meyer of the Berlin Technische Hochschule.
Dr. Hermann Oberst of the Berlin Technische Hochschule.
Herr Nickelsen of Elecktroacustic.
Dr. Ing. Heinrich Hecht of Electroacustic.
Dr. Ing. F. A. Fischer of Electroacustic.
Dr. Ing. Fahrentholz of Electroacustic.
Dr. Ing. Karl Hecht of Electroacustic.
Dr. Ing. W. Kunze of Atlas Werke.
Dr. Ing. Kietz of Atlas Werke.
Dr. Ing. Grandiot of Atlas Werke.
Dr. Ing. Maass of Atlas Werke.
Dr. Ing. Theide of Atlas Werke.
Dr. Ing. Jenkel of Atlas Werke.
Dipl. Ing. Isola of Atlas Werke.

1.3 Development and Manufacture.

The majority of the German underwater sound equipment was developed and manufactured by the firms of Atlas Werke in Bremen and Electroacustic Kommanditgesellschaft (Elac) in Kiel. Each of these firms had dispersal plants in other areas. Elac has been in business since 1926 and Atlas even longer. The two firms operated under very keen competition before the war and furnished substantially equal quantities of similar equipment. At the start of the war the firm Gema (Gesellschaft fur elektroakustiche und mecanische Apparate mbH.) and

Figure 6.221: Atlas Werke, ELAC, GEMA, and AEG developed highly sophisticated and specialized sonar systems [NavTecMisEu 530-45].

6.8.5 Sonar Countermeasures

German-speaking scientists led by Erwin Meyer (German, 1899–1972) invented, perfected, and installed highly effective sonar-absorbing rubber coatings (code-named Alberich) on submarines such as U-480.[29]

BIOS 526, *Development and Manufacture of Alberich*, pp. 3–4, summarized the history of that program:

> 2. <u>Organisation:</u>
>
> Dr. Kieskalt was head of the section at I.G. Farben concerned with the development of anti-asdic coverings for submarines. The section was directly under the control of N.V.K. with Professor Erwin Meyer of the Technische Hochschule, Berlin, as Scientific Advisor. Professor Meyer was also in touch with the section through Dr. Oberst, a member of his team at the Hochschule.
>
> The scientific and development work was carried out at I.G. Farben at first by Dr. Brennschede, a physical chemist, and later by Drs. Patat and Mehnert. Patat, a physical chemist, was more concerned with the chemistry of the material, while Mehnert, a physicist under the guidance of Meyer was responsible for the designing and testing of the punched material. Dr. Ing. Laüer, who was employed at one time by Meyer, assisted Mehnert with the measurements which were made at Höchst and at Pelzerhaken.
>
> Engineering and workshop requirements were controlled by Ob. Ing. Geiger with Ing. Möller, Rechert, and Wieswar assisting. Geiger was a reserve U-boat Captain who was brought back at Kieskalt's request in April 1940. Rechert dealt with the firm of Sorst & Co., Hanover, who was responsible for the punching of the sheets. Wieswar was at Offenbach supervising the cementing of the sheets and Möller was responsible for the actual covering of the boats in the yards.
>
> The cements were manufactured at Höchst and were developed by Dr. Schaich, assisted by Dr. Koren.
>
> The buna sheet forming the basis of the material was manufactured by three or four specialist firms and sent to I.G. Farben at Offenbach, to be ground to the requisite thickness. Part of the material was then forwarded to Hanover to be punched by Ernst Sorst & Co., who returned it to Frankfurt where at I.G. Farben, Offenbach, the finished two-ply covering was produced and wrapped ready for shipment to the yards. Testing of samples was carried out at I.G. Farben, Höchst.
>
> Shortly before the end of the war plans were being made for the centralisation of the manufacturing processes in a new factory at Einbek, Hanover, to be under the direction of Sörst. A programme involving the covering of 80 boats was planned to take effect from April, 1945. Up to the cessation of hostilities with Germany only 10 boats had been covered, including two experimental models.

[29] Ruthven and Bardehle 2009; BIOS 210; BIOS 526; CIOS XXIV-8; NavTecMisEu 352-45.

3. Early attempts by I.G. Farben to solve the problem:

Kieskalt stated that early in 1940 he developed a sound absorbent surface for anti-asdic work which comprised a number of rubber cones filled with a plastic material, such as "Mowilith". Designed for a frequency range of 7–15 kc/s, said to be that of our asdics, the cones were about 100 mm. in height and spaced 50 mm. apart. Trials in the Baltic were carried out in the spring of 1941 with a submarine U-9 coated with the material but it was apparent that this solution was not a practical one.

4. Development of Alberich:

In 1941 Professor Erwin Meyer, in the search for a solution which could be used under operational conditions, introduced the idea of a resonant absorber composed of a two-ply rubber sheet, one ply of which is perforated. The theory underlying the operation of this material has already been discussed with Meyer (v. SRE/I/206) and Kieskalt had nothing further to add to this aspect of the problem.

5. Choice of raw material:

Preliminary experiments on this resonant type of absorber using existing rubber mixes, such as those prepared for the manufacture of linings for chemical engineering plant, enabled more precise requirements to be formulated. Important features, distinct from the dynamical properties of the material, were:-

(a) resistance to oil and sea-water.

(b) non-ageing.

(c) capable of being cemented to self and to the hull of a submarine.

(d) resistance to mechanical wear and abrasion.

6. Manufacture of sheet and cement:

[...]

After the war, scientists, materials, and information related to sonar countermeasures were transferred to Allied countries, guiding further work in this area.

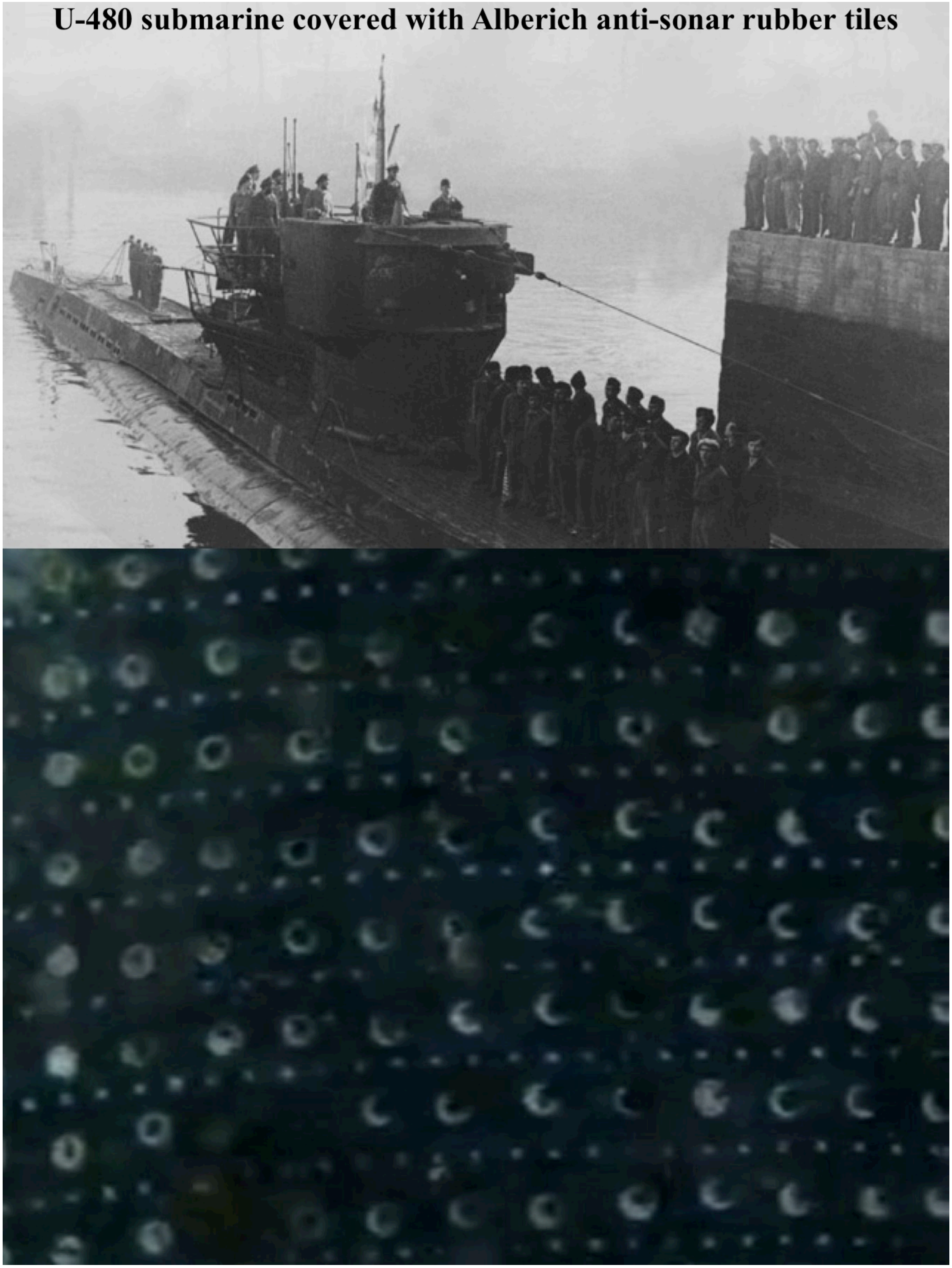


Figure 6.222: U-480 submarine covered with Alberich anti-sonar rubber tiles.

6.8.6 Ultrasound Imaging

During World War II, German-speaking scientists developed and demonstrated ultrasound imaging systems for both industrial and medical applications [Woo 2006; BIOS 609; BIOS 1679]. After the war, those technologies and in many cases the scientists themselves were transferred to Allied countries to optimize and commercialize ultrasound imaging in those countries.

Some of the major creators who developed ultrasound imaging systems included (Fig. 6.223):

- Karl Theodore Dussik (Austrian, 1908–1968) pioneered the use of ultrasound imaging for medical applications, beginning with his first research proposals in 1941, first hardware in 1942, and first experiments with medical imaging around 1945.
- Carl Hellmuth Hertz (German, 1920–1990), the son of Gustav Hertz (p. 901) and great nephew of Heinrich Hertz (p. 862), developed echocardiography, which uses ultrasonic waves and acoustic signal recording and imaging methods to analyze heart function. He obtained the first echocardiogram in 1953 (p. 338). He also developed inkjet printing.
- Theodor Hueter (German, 19??–19??) developed ultrasound imaging systems at Siemens during the war, and at MIT and Raytheon in the United States after the war.
- Paul Kretz (Austrian, 19??–19??) founded Kretztechnik after the war and produced ultrasound imaging systems for both industrial and medical applications.
- Carl Kretz (Austrian, 1932–20??), the nephew of Paul Kretz, joined Kretztechnik and took over the development of improved ultrasound imaging systems.
- Heinrich Netheler (German, 1909–1999) began developing ultrasound imaging systems for medical applications in 1943. After the war, he founded the company that ultimately became known as Eppendorf to continue developing that and other biomedical technologies.
- Reimar Pohlman (German, 1907–1978) at Siemens developed and demonstrated ultrasound imaging systems for industrial applications by 1943. See Fig. 6.224.

During World War II, German-speaking scientists also invented and successfully demonstrated acoustic systems for sonication of materials and for other applications. Those technologies were also transferred to Allied countries after the war.

For more information, see Section C.4.

6.8.7 Acoustic Weapons

Richard Wallauschek (Austrian/Czech, 1912–1962), a physicist from Telefunken, was funded by Albert Speer during the war to create acoustic weapons at a dedicated laboratory in Lofer, Austria. By 1945, he had developed and demonstrated an incapacitating weapon that could create a focused beam of sound waves with 134 dB (1 millibar) of intensity at a distance of 60 meters (Fig. 6.225). His technology was transferred to Allied countries [CIOS XXXII-77] and led to modern systems such as the Long-Range Acoustic Device (LRAD).

For more information, see Section C.4.

Ultrasound imaging

Karl Theodore Dussik (1908–1968)

Carl Hellmuth Hertz (1920–1990)

Theodor Hueter (19??–19??)

Carl Kretz (1932–20??)

Paul Kretz (19??–19??)

Heinrich Netheler (1909–1999)

Reimar Pohlman (1907–1978)

Figure 6.223: Creators who developed ultrasound imaging systems included Karl Theodore Dussik, Carl Hellmuth Hertz, Theodor Hueter, Carl Kretz, Paul Kretz, Heinrich Netheler, and Reimar Pohlman.

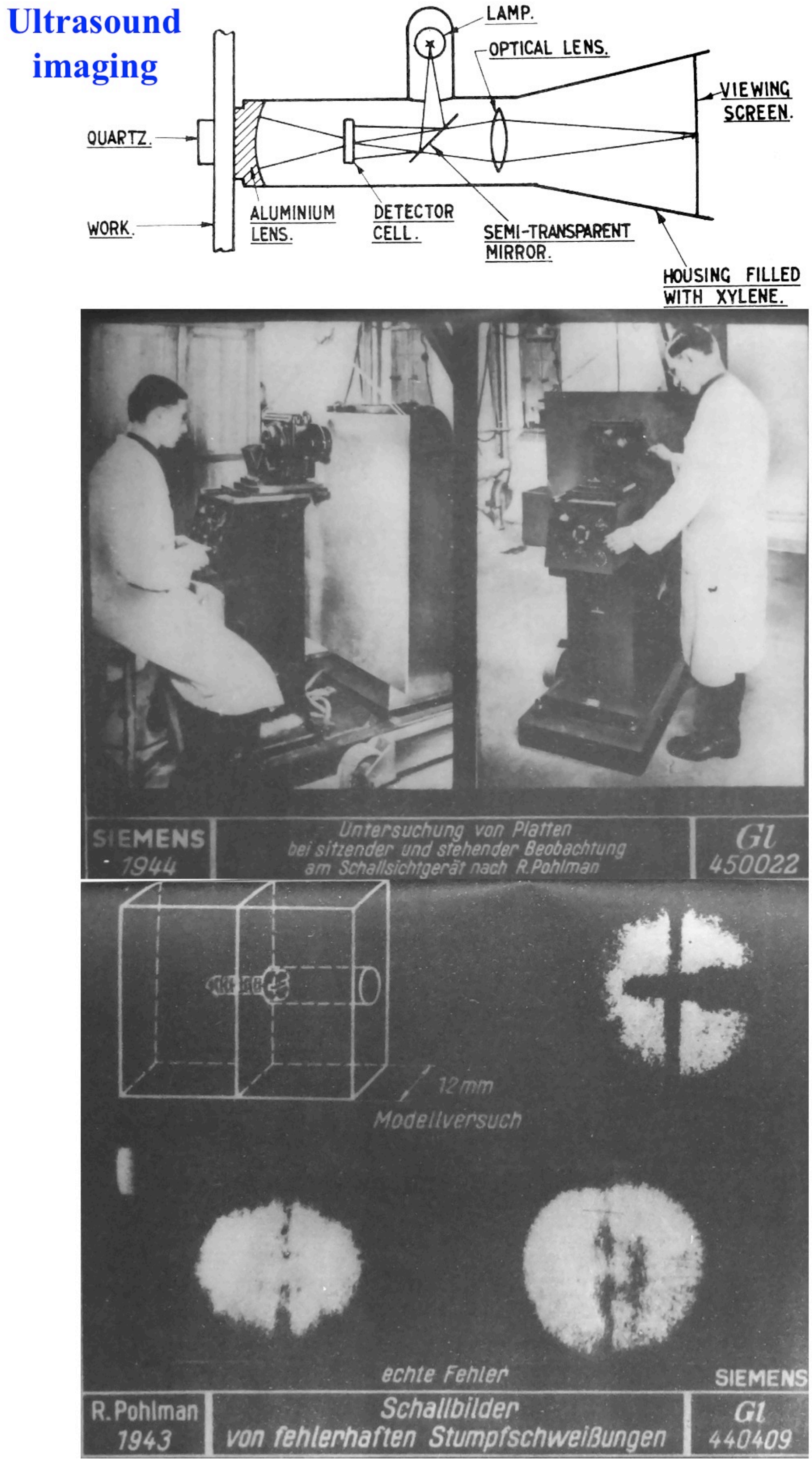


Figure 6.224: By 1943, Reimar Pohlman and other scientists had developed and demonstrated ultrasound imaging systems [BIOS 609; BIOS 1679].

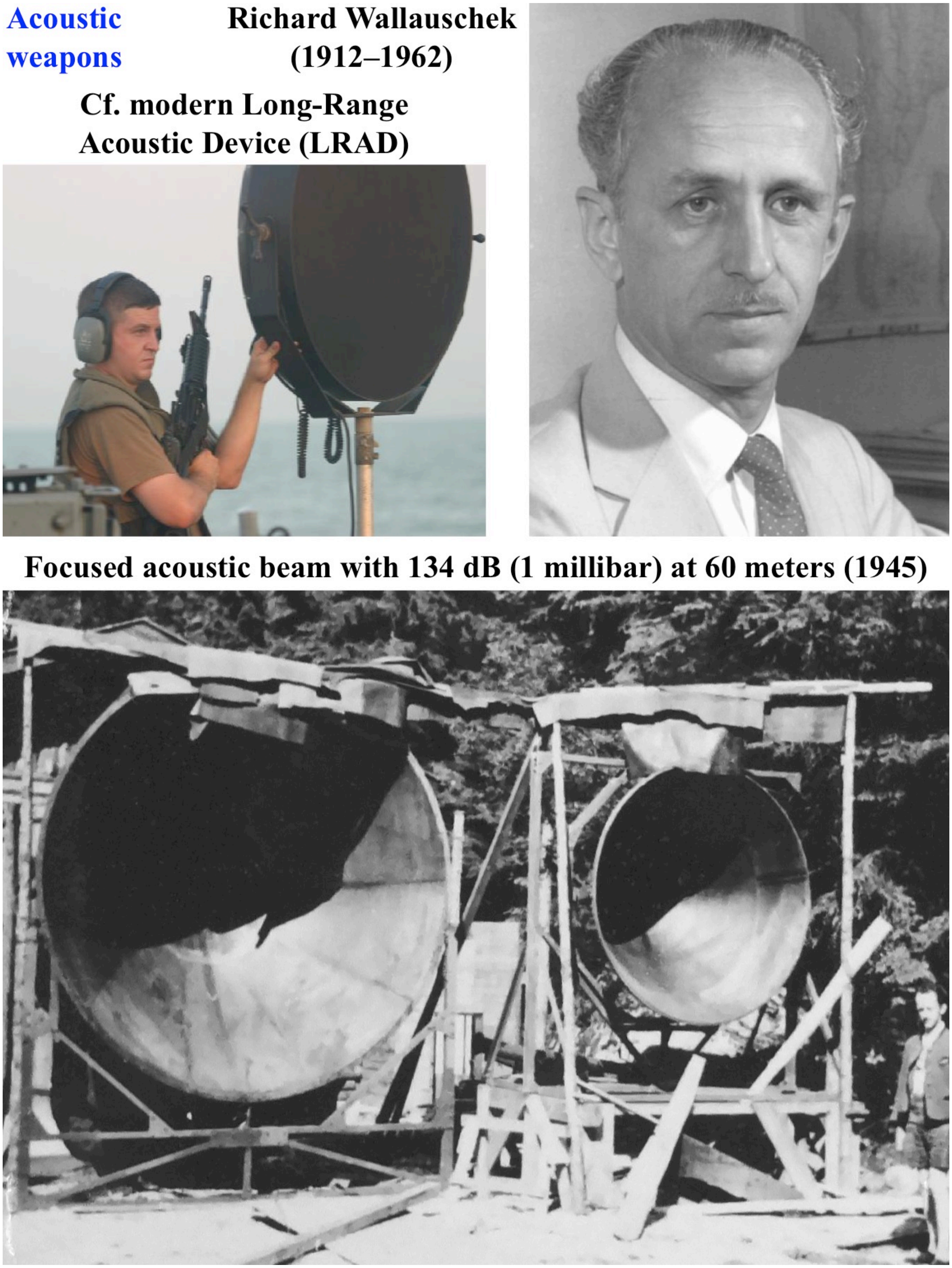


Figure 6.225: By 1945, Richard Wallauschek had developed and demonstrated an acoustic weapon that could create a focused beam of sound waves with 134 dB (1 millibar) of intensity at a distance of 60 meters [CIOS XXXII-77]. His technology was transferred to Allied countries and led to modern systems such as the Long-Range Acoustic Device (LRAD).

6.8.8 Radio and Acoustic Proximity Fuses and Homing Devices

As already covered, one postwar myth of Allied scientific superiority is that the United Kingdom invented radar and Germany lagged behind, even though there is abundant documentation that the opposite was true. A similar example of postwar historical revisionism by English-speaking historians is that Germany failed to develop a proximity fuse whereas the Allies did. (The Allied "VT" or Variable Time radar proximity fuse was deployed in 1944.)

In fact, scientists in Germany and Austria began work on proximity fuses and homing devices in the 1930s. From the 1930s to 1945, they invented a vast assortment of proximity fuses and homing devices. They created sensors based on active acoustic, passive acoustic, active radar, passive radar, electrostatic, infrared, remote television, and other approaches. They created sensors for guided missiles, smart bombs, artillery shells, and torpedoes. Those systems were documented in numerous postwar Allied reports such as:

> Theodore Benecke and A. W. Quick, eds. 1957. *History of German Guided Missiles Development*
>
> BIOS 249, *Rockets and Guided Missiles*
>
> BIOS 530, *Photosurfaces, a Report on German Developments of Photocells, Electron Multipliers, Television Pick-Up Tubes* [guided missiles]
>
> CIOS ER 259, *Private Investigators Working on Radar Control of a Guided Missile at Obersdorf bei Bad Aussee*
>
> CIOS ER 316, *Preliminary Report on Proximity Fuze Investigation at Rosenthal, Isolatoren, Selb, Bavaria*
>
> CIOS XXVI-1, *Proximity Fuze Development, Rheinmetall-Borsig AG, Mülhausen*
>
> CIOS XXVI-57, *German Development of Homing Devices*
>
> CIOS XXVI-65, *Findings on German Proximity Fuze Developments in 21 Army Group Area*
>
> CIOS XXVIII-41, *Institut für Physikalische Forschung, Neu Drossenfeld* [TV homing device]
>
> CIOS XXVIII-51, *Dipl. Ing. Hans Ludwig, Gross Quern* [missile homing device]
>
> CIOS XXXII-69, *Otto Acoustic Proximity Pistol for Torpedoes*
>
> CIOS XXXII-73. *The Development of German Optical Mine Firing Mechanisms.*

CIOS XXXII-78, *The Passive Acoustic Proximity Device "Kranich"*

CIOS XXXII-79, *Passive Acoustic Proximity Fuses for Use Against Bomber Formations*

CIOS XXXII-80, *Acoustic Steering Control for the X-4 Missile-Dogge*

CIOS XXXII-82, *German Acoustic Ground Proximity Fuse*

CIOS XXXII-88, *Stassfurter Rundfunk Stassfurt.* [Remote control for guiding bombs]

CIOS XXXII-123, *German Guided Missiles*

CIOS XXXII-125, *German Guided Missile Research*

NavTecMisEu LR 30-45, *German Air-to-Air Missile X-4*

NavTecMisEu LR 32-45, *Guided Missile, X4 Information Relative to*

NavTecMisEu LR 77-45, *Lead Sulphide Semi-Conductor Infra-red Cells for Homing Rockets*

NavTecMisEu LR 78-45, *German Pi-Berlin Acoustic Torpedo Pistol*

NavTecMisEu LR 79-45, *Development of Acoustic Torpedo Steering Control "Geier"*

NavTecMisEu LR 80-45, *Acoustic Torpedo Pistol "Otto"—Development of*

NavTecMisEu LR 81-45, *Guided Missiles—Report Interrogation of Personnel Concerned with*

NavTecMisEu LR 101-45. *"Influence Fuse" found at Unterluss.*

NavTecMisEu LR 228-45, *Infra-red Homing Devices*

NavTecMisEu 100-45, *German Development of Homing Devices*

NavTecMisEu 158-45, *Electronics as Applied to German Guided Missiles Volume II*

NavTecMisEu 161-45, *Otto Acoustic Proximity for Torpedoes*

NavTecMisEu 199-45, *Description of the Passive Acoustic Proximity Device-Kranich*

NavTecMisEu 200-45, *Passive Acoustic Proximity Fuses for use against Bomber Formations (Rheingold, Meise, Forelle, Kuckuck)*

NavTecMisEu 201-45, *Acoustic Steering Control for the X-4 Missile—Dogge*

NavTecMisEu 202-45, *General Survey of German Torpedoes*

NavTecMisEu 203-45, *German Naval Torpedo Pistols and Warheads*

NavTecMisEu 204-45, *German Naval Homing and Guided Torpedoes*

NavTecMisEu 225-45, *German Acoustic Ground Proximity Fuse*

NavTecMisEu 237-45, *Survey of Germany Activities in the Field of Guided Missiles.* See pp. 5499–5501 for some revealing quotes from this long report.

NavTecMisEu 242-45, *"Paplitz" Infra-red Fuse Development of Elac*

NavTecMisEu 273-45, *German Infra-red Homing Device "Emden"*

NavTecMisEu 274-45, *German Infra-red Homing Device "Karussell"*

NavTecMisEu 355-45, *Survey of the German Work on Proximity Fuses*

NavTecMisEu 356-45, *German Aircraft Acoustic Homing Torpedo—"PFAU"*

Alsos EOS 200 [NARA RG 38, Entry P-5, Box 8, Folder Alsos Mission Fuze Reports]

Alsos EOS 225 [NARA RG 38, Entry P-5, Box 8, Folder Alsos Mission Fuze Reports]

Alsos EOS 226 [NARA RG 38, Entry P-5, Box 8, Folder Alsos Mission Fuze Reports]

Alsos EOS 240 [NARA RG 38, Entry P-5, Box 8, Folder Alsos Mission Fuze Reports]

Alsos EOS 260 [NARA RG 38, Entry P-5, Box 8, Folder Alsos Mission Fuze Reports]

Alsos EOS 270 [NARA RG 38, Entry P-5, Box 8, Folder Alsos Mission Fuze Reports]

Alsos EOS 271 [NARA RG 38, Entry P-5, Box 8, Folder Alsos Mission Fuze Reports]

Alsos EOS 274 [NARA RG 38, Entry P-5, Box 8, Folder Alsos Mission Fuze Reports]

For example, CIOS XXXII-125, *German Guided Missile Research*, reported (p. 5481):

> A.E.G. have developed an electronic proximity fuse which was said to be in mass production. It consisted of a unipole mounted on the nose of a missile, and tightly coupled to a small CW oscillator. A second oscillator was also incorporated which ran at a

> frequency of 800 c/s less than that of the first. The beat frequency was obtained in a mixer. In the proximity of an aircraft or other large conducting body the frequency of the first oscillator was pulled by the change of aerial impedance and the beat frequency increased. The latter signal was passed through a 1000 c/s filter the output of which operated the fuse.

U.S. Army Air Forces Colonel (later General) Donald Putt noted [Putt 1946b]:

> The Hs-117 [...] was a ground-to-air missile. It was named Schmetterling or butterfly, and was a rocket-propelled, radio-controlled missile to be launched from the ground against bomber formations. It accelerated to a speed of 560 mph, and was steadied in flight by a pendulum device. The take-off rocket burned out and were jettisoned; the main propulsion unit then drove the missile until it was detonated by a proximity fuse. Large-scale production began January, 1945, in an underground factory in Nordhausen. [...]
>
> The Rheintochter [...] was a ground-to-air missile. It was a rocket-propelled anti-aircraft weapon and was controlled in flight by radio. It traveled at a speed of 1100 mph and carried an explosive charge of 330 lb, equipped with a proximity fuse, to a ceiling of 48,000 ft. The starting rocket, attached to the base, was blown off after combustion was completed. Development did not go beyond the test firing stage, but experiments were still being conducted as late as February, 1945.

In November 1945, General Henry Arnold reported (p. 5538):

> At lower right is the X-4, a wire controlled, rocket-propelled gyro-stabilized missile, to be launched from parent plane against bombers. X-4 was almost ready for use. [...] Potency of X-4 (right) was tremendously increased by proximity fuse.

In June 1945, General Carl Spaatz requested the air lift evacuation of Rheintochter missiles with proximity fuses (p. 5759):

> FOR WING COMMANDER WHEELER. INFORMATION HERE THAT RHEINTOCHTER HAS SEVEN EACH NEW TYPE ROCKETS. ANTI AIRCRAFT ROCKETS SUPPOSED TO USE PROXIMITY FUZE. SIGNAL ALLSTONT [?] AND LOCATION FOR AIR LIFT BY OUR AIRCRAFT.

In 1946, the U.S. Army Ordnance Department reported [https://digitalcommons.unl.edu/cgi/viewcontent.cgi?article=1059&context=dodmilintel]:

> In connection with the subject of proximity fuzes, the Germans had expended a vast amount of energy on the research and development of fuzes which would detonate ammunition without coming in physical contact with the target. We were far ahead of them on actually getting a proximity fuze into production and into active use during the war, they were very effective, particularly in antiaircraft use. However, at the time the war ended, the German research and development had progressed to such an extent

> that they had designs almost ready for production and had thoroughly investigated many of the possible types of proximity fuzes; e.g. acoustic, radio, photo-electric and electro-static types. [...]
>
> A number of rocket propelled missiles which could be guided from the ground and which would detonate by the use of a proximity fuze when coming within the danger area of one of our airplanes were developed to the production stage and one guided missile was actually in production at the end of the war. Our understanding of the way one was to have operated was by means of radar screen which could track both the target and the missile. The operator would have the necessary controls required to direct the missile and by watching the radar screen could take the necessary steps to bring the missile as close as possible to the airplane, at which time the proximity fuze would function and the airplane would disappear.

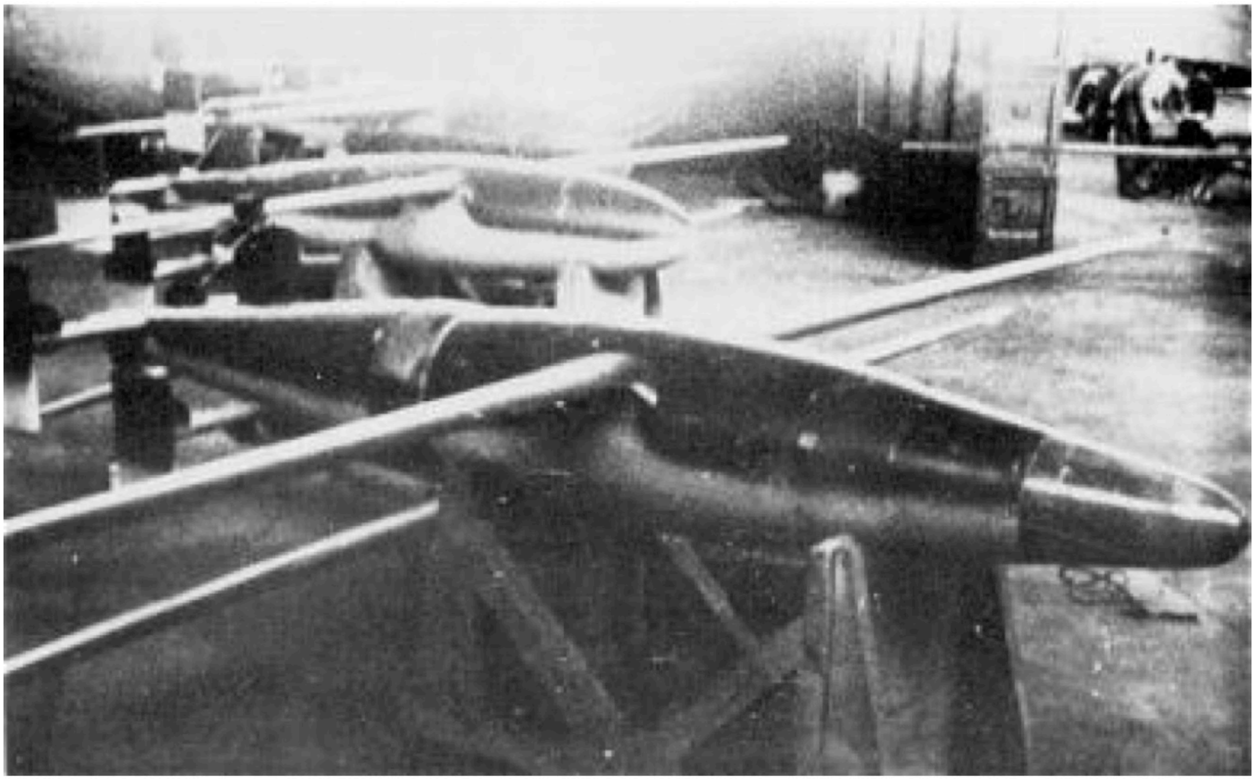
See also the statements of Hermann Goering (pp. 5254–5256).

The United States and United Kingdom developed a simple radar proximity fuse for artillery shells and employed it effectively for anti-aircraft fire. Germany developed an enormous quantity and variety of proximity fuses and homing devices, many of which were more advanced than the Allied proximity fuse. Few of the German proximity fuses and guidance systems appear to have been deployed during the war, but that was due to Allied bombing of the factories where those systems were being produced, as well as some of the decisions (or indecision) of German political and military leaders, not due to any failures of German and Austrian scientists.

As shown in Fig. 6.226, Germany also created the first High-speed Anti-Radiation Missile (HARM), designed to seek and destroy enemy radar systems. At least 1,000 units of the Blohm & Voss BV 246 Hagelkorn with a Radieschen guidance unit on the front were produced by the end of the war, though apparently none were used in combat. An anti-radar version of the Henschel Hs 293 was also developed (p. 5481). The BV 246 Radieschen and anti-radar Hs 293 were the foundation for postwar HARM weapons in other countries.

Because the proximity fuses and homing devices developed in wartime Germany were so advanced and so diverse, immediately after the war, Allied countries confiscated the documentation, hardware, and scientists from those programs, and used them to produce proximity fuses and homing devices in the United States, United Kingdom, France, Soviet Union, and other countries during the postwar period. (See also Sections 6.6 and 9.6.)

Blohm & Voss BV 246 Hagelkorn Radieschen (1945)
First High-speed Anti-Radiation Missile (HARM),
designed to seek and destroy enemy radar systems



Heinkel He 111 carrying 3 Blohm & Voss Hagelkorns

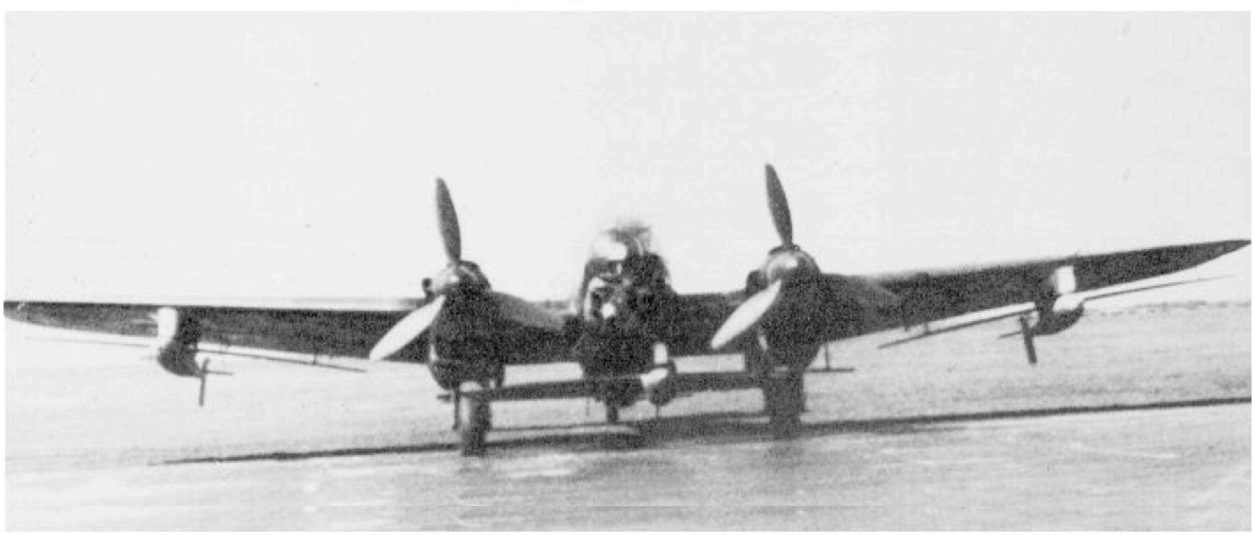


Figure 6.226: The Blohm & Voss BV 246 Hagelkorn with a Radieschen guidance unit on the front, mass-produced in 1945, was the first High-speed Anti-Radiation Missile (HARM), designed to seek and destroy enemy radar systems. It was also the foundation for postwar HARM weapons in other countries.

6.9 Microscopes, Telescopes, and Other Optical Instruments

Creators from the predominantly German-speaking scientific world dominated the development of optical microscopy methods, from inventing the first known microscope to obtaining the maximum theoretical resolution from a microscope to developing fluorescence and phase contrast microscope approaches that are now used worldwide. They also invented and developed telescopes as well as other methods and applications of optics.[30]

The first known telescopes were produced around 1608 by creators such as Hans Lipperhey (German states/Dutch, 1570–1619), Jacob Metius (Dutch, ca. 1571–1628), and Zacharias Janssen (Dutch, ca. 1585–<1632). See Fig. 6.227.

As shown in Fig. 6.228, Antonie van Leeuwenhoek (Dutch, 1632–1723) created the first known microscope and used it to observe numerous types of single-celled and multicellular organisms. The American Council of Learned Societies summarized his discoveries [ACLS 2000, pp. 528–529]:

> Built his first microscope (1671), a minute lens, ground by hand from a globule of glass, clamped between two metal plates, with specimen holder affixed; went on to grind about 550 lenses; the best that has survived has a magnifying power of 270 and a resolving power of 1.4μ. Believed inorganic and organic nature are similar and that all living creatures are similar in form and function. In 1674, recognized that microorganisms are alive; communicated observations on these "little animals" to the Royal Society (1676), causing a sensation. Subsequently described bacteria, protozoa, rotifers, and ciliate reproduction. From study of spermatozoa, postulated that these penetrate the egg[...] Investigated the transport of nutrients in plants and animals[...]

Joseph von Fraunhofer (German states, 1787–1826, p. 861) made a number of important discoveries and inventions in optics. He invented diffraction gratings, and he studied the diffraction of light of different wavelengths. He used a diffraction slit and prism to develop a spectroscope, which he and others then applied to make important measurements in physics and chemistry. He also created achromatic (non-color-distorting) lenses and other specialized lenses that greatly improved the image quality for both telescopes and microscopes. Oxford University's *Biographical Dictionary of Scientists* explained how he combined and advanced both experimental and theoretical optics [Porter 1994, pp. 251–252]:

> [H]is work laid the basis for subsequent German supremacy in the making of high-grade scientific and optical instruments. [...]
>
> Although he had little formal education, Fraunhofer sought to understand optical theory and apply it to the practical work of constructing lens combinations of minimum aberration. At that time there was little high-quality crown and flint glass, and methods of determining the optical constants of glass were crude, limiting the size and quality of lenses that could be produced and also confining instrument makers to trial-and-error methods of construction. Fraunhofer approached lens-making according to optical theory and set out to determine the dispersion powers and refractive indices of different

[30] Auerbach 1918, 1925; Daumas 1989; Dobell 1960; Gjudjenow and Meinl 2013; James Hansen 1974; Nigel Hawkes 1981; Korey 2007; Mills 1983; Petri 1896; Plaßmeyer2007; Stephenson et al. 2000; Turner 1981, 1989, 1998; Wimmer 2017.

> kinds of optical glass with greater accuracy. In collaboration with Guinand, he also sought to improve the quality of the glass used to make lenses.
>
> In 1814, Fraunhofer began to use two bright yellow lines in flame spectra as a source of monochromatic light to obtain more accurate optical values. Comparing the effect of the light from the flame with the light from the Sun, he found that the solar spectrum is crossed with many fine, dark lines. [...]
>
> In this way, Fraunhofer was able to make very accurate measurements of the dispersion and refractive properties of various kinds of glass, and in so doing he developed the spectroscope into an instrument for the scientific study of spectra.
>
> In 1821, Fraunhofer examined the patterns that result from light diffracted through a single slit, and related the width of the slit to the angles of dispersion of the light. Extending from a large number of slits, he constructed a grating of 260 parallel wires and made the first study of spectra produced by diffraction gratings. [...] By measuring the dispersion, he was able to determine the wavelengths of light of specific colours and the dark lines.
>
> Fraunhofer also constructed reflection gratings, enabling him to extend his studies to the effect of diffraction on oblique rays. By using the wave theory of light, he was able to derive a general form of the grating equation that is still in use today.

Simon Plössl (Austrian, 1794–1868) produced microscopes with achromatic objective lenses (Fig. 6.229). He also developed the now highly popular Plössl eyepiece design for telescopes, which offers an especially wide field of view.

Georg Johann Oberhäuser (German states, 1798–1868) and his successor Edmund Hartnack (German, 1826–1891) were other important early innovators in microscopy (Fig. 6.230). Edmund Hartnack produced the first water immersion lenses (putting a drop of liquid between the lens and the slide) to enable microscopes to see smaller details.

Carl Zeiss (German, 1816–1888, engineering and business), Ernst Abbe (German, 1840–1905, optical physics), and Otto Schott (German, 1851–1935, glass chemist) created and built up the Zeiss optical company, based in Jena, making it arguably the most advanced optical instrument company in the world. By the 1880s, they had perfected the diffraction-limited apochromatic microscope (Fig. 6.231), eliminating earlier flaws in lens design and glass composition in order to attain the maximum theoretical image resolution that can be achieved with visible light. That work remains the foundation of all modern optical microscope designs. They also developed a reputation for designing and manufacturing a wide range of other advanced optical instruments. The *Encyclopedia Britannica* explained some of the history [EB 2010]:

> Zeiss, Carl [...], German industrialist who gained a worldwide reputation as a manufacturer of fine optical instruments.
>
> In 1846 Zeiss opened a workshop in Jena for producing microscopes and other optical instruments. Realizing that improvements in optical instruments depended on advances in optical theory, he engaged as research worker Ernst Abbe, a physics and mathematics

lecturer (later professor) at the University of Jena, who in 1866 became Zeiss's partner. They engaged Otto Schott, a chemist, who developed about 100 new kinds of optical glass and numerous types of heat-resistant glass.

In the early 1900s, several scientists working at the Zeiss company made further significant advances in optical microscopy:

- In 1902, Richard Zsigmondy (Austrian, 1865–1929) and Henry Siedentopf (German, 1872-1940) invented the ultramicroscope for determining particle sizes in colloids; see Fig. 6.232.

- August Köhler (German, 1866–1948) and Moritz von Rohr (German, 1868–1940) invented the ultraviolet microscope in 1904, as shown in Fig. 6.233.

- August Köhler and Henry Siedentopf invented the fluorescence microscope in 1908 (Fig. 6.234). Fluorescence microscopes are now a widespread tool in biology laboratories because different cellular components can be labeled with different colors of fluorescent tags.

A Mach-Zehnder interferometer splits light into two beams, which travel different paths through transparent objects and then recombine, resulting in constructive and destructive interference patterns that can provide useful information about the objects (Fig. 6.63). Karl Bratuschek (German, 1865–1913) at the Zeiss company began trying to apply that same principle to microscopes but died before he could finish [Wimmer 2017]. Frits Zernike (Dutch, 1888–1966) continued that work and created the first phase contrast microscopes (1933), which were then mass-produced by Zeiss (pp. 1283, 2486–2496). Phase contrast microscopes make cells easily visible without having to add colored chemical stains. The chemical staining steps are not only cumbersome, but would usually kill the cells, so phase contrast microscopes are now a ubiquitous tool in biology laboratories worldwide to observe living cells. For the development of phase contrast microscopy, Frits Zernike won the Nobel Prize in Physics in 1953. Professor E. Hulthén of the Nobel Committee for Physics explained Zernike's work and noted how it built upon the earlier discoveries of Zeiss scientists such as Ernst Abbe [https://www.nobelprize.org/prizes/physics/1953/ceremony-speech/]:

> Probably no other instrument has been the object of so much technical and theoretical study as the microscope. The thorough theoretical foundation that we owe to the genius of Ernst Abbe of the famous Zeiss concern was followed at the end of the last century by a development of the microscope that brought its optical and illumination system very close to perfection.
>
> But even Abbe's theory had a gap, for it took into account only those conditions in which the microscopic objects appear against the background as a result of their contrasts in colour and intensity. Many microscopic objects, however, micro-organisms such as bacteria and cells, are colourless and transparent, and for this reason difficult to distinguish from their surroundings. Attempts have been made to overcome this difficulty with various methods of staining or with a special illumination system, the so-called darkfield illumination. The staining methods are not always suitable, as for example when we are dealing with living objects; and dark-field illumination easily leads to a misinterpretation of the finer details in the structural picture.
>
> It was this gap in Abbe's theory that in the 1930's led Zernike to re-investigate the refraction processes in the light that give rise to the image in a microscope. Even if

> the eye is not able to discern the change undergone by a beam of light when it passes through a transparent object, the change does nonetheless exist as a phase-difference of a quarter of a wavelength relative to the direct beam that does not pass through the object. The problem was thus to transform these otherwise imperceptible phase differences to visible contrasts in intensity. Zernike was able to show that this was possible, thanks to the fact that the two rays of light take different routes through the microscope before being reunited in the image. By interposing in the paths of the direct ray a so-called "phase-plate" which either further increases the phase-displacement to half a light-wavelength or smooths it out completely, Zernike attained the desired effect, so that the two rays either extinguish or reinforce each other. In this way the formerly invisible particle appears in dark or light contrast to the surroundings.
>
> I have deliberately dwelt upon the description of the phase-contrast microscope as the result of Zernike's method which is, so far, the most valuable. The phase-contrast method has, however, many other and increasingly important applications in optics. In addition to its capacity to render colourless and transparent objects visible in the microscope, it also enables one to detect slight flaws in mirrors, telescope lenses, and other instruments indispensable for research. In this connection, Zernike's phase-plate serves as an indicator which locates and measures small surface irregularities to a fraction of a light-wavelength. This sharpness of depth is so great that it penetrates to the point at which the atomic structure of the substance begins to become manifest.

Phase-contrast microscopy was adopted by Allied countries after they discovered some of the Zeiss phase-contrast microscopes at the end of World War II [FIAT 1059; pp. 2486–2496].

Carl Kellner (German states, 1826–1855), Ernst Leitz I (German, 1843–1920), and the son Ernst Leitz II (German, 1871–1956) created what came to be called the Leitz optical instrument company, which roughly paralleled the history and accomplishments of the Zeiss company. See Fig. 6.236.

- Ernst Arbeit (German, 18??–19??), Carl Metz (German, 18??–19??), and Felix Jentzsch (German, 18??–19??) developed microscopes at the Leitz company; see Fig. 6.237.

- In 1913, Oskar Barnack (German, 1879–1936) invented the first modern 35 mm still camera, which later was dubbed Leica (for Leitz Camera); see p. 643.

As shown in Fig. 6.238, John Jacob (Johann Jakob) Bausch (German, 1830–1926), Henry Lomb (German, 1828–1908), and Ernst Gundlach (German, 1834–1908) produced microscopes and other optical instruments at the Bausch & Lomb company in the United States.

In 1930, Bernhard Schmidt (German, 1879–1935) invented the Schmidt combination telescope and camera, which was adopted worldwide (Fig. 6.239). Oxford University's *Biographical Dictionary of Scientists* explained Schmidt's optical innovations [Porter 1994, p. 608]:

> After graduating in 1904 he stayed in Mittweida making lenses and mirrors for astronomers. One of his early accomplishments, in 1905, was a 40-cm/27-in mirror for the Potsdam Astrophysical Observatory. Schmidt worked independently, producing optical equipment of very high quality until 1926, when Schorr, the Director of the Hamburg Observatory, asked him to move into the Observatory and work there. Schmidt accepted the invitation. He worked on the mountings and drives of the telescopes, as well

> as on their optics. It was in Hamburg that he perfected his lens and built it into the Observatory telescope, specifically for use in photography. [...]
>
> It is usual for reflecting telescopes to have parabolic mirrors, rather than spherical ones; spherical ones are subject to an optical distortion known as spherical aberration. Parabolic mirrors too, however, suffer from their own optically distortive effect, 'coma'; but they provide an image that is at least centrally clear and focused. What Schmidt devised was a means of correcting the image formed by a spherical mirror—a disc-shaped lens thicker at the centre and edges than at half-radius. By replacing the parabolic mirror of a telescope with a spherical one plus his lens—his 'corrector plate', as he called it—he could produce an image that was sharply focused at every point (generally on a curved photographic plate, although on later models Schmidt used a second lens to compensate for the use of a flat photographic plate).

As illustrated in Fig. 6.240, Walther Bauersfeld (German, 1879–1959) developed the Zeiss planetarium projector Mark I (begun in 1912, delayed by World War I, and completed in 1923), Mark II (1930), and later models. Such planetarium projectors were adopted and used worldwide.

Wilhelm Schnittger (German, 19??–19??) invented advanced theodolites and cinetheodolites at Askania Werke in 1933 (Fig. 6.241). Askania instruments were used to monitor, measure, and guide test flights of A-4 (V-2) rockets and other aerospace vehicles during World War II. After the war, Askania theodolites were used for decades to track and film rockets and aircraft in the United States (Fig. 6.242). Askania instruments were also used by the Soviet Union and other countries after the war (e.g., pp. 2820, 4032, and 5617).

Alexander (or Olexander) Smakula (Austro-Hungarian, educated and worked in Germany, 1900–1983) invented antireflective coatings for lenses at Zeiss in 1935 (Fig. 6.243). His antireflective coatings were widely used in Germany during World War II. After the war, Allied investigators studied and copied Smakula's information on antireflective coatings, and he continued his work in the United States. Antireflective coatings have been used worldwide since then. For more information on the postwar transfer of this technology, see for example:

> BIOS 1183. *Anti-Reflection Surfaces on Glass, Optical Cements & Etching Resist for Fine Lines.*
>
> BIOS 1215. *German Methods of Rhodiumizing, Aluminizing, Anti-Reflection Surface Coating and Allied Subjects.*
>
> NavTecMisEu 461-45. *Methods of Film Coating for Low Reflection in the German Optical Industries.*

Marga Faulstich (German, 1915–1998) at the Schott glassworks developed improved optical lenses, incorporating not only Smakula's antireflective coatings but also new high-index-of-refraction materials such as Schwerflint 64 to make much thinner, lighter lenses for eyeglasses and other applications (Fig. 6.244).

After World War II, German high-quality plastic lenses and the technology to produce them were taken by the United States and directly copied by U.S. companies [NARA RG 40, Entry UD-75, Box 58, Folder Budget]. See Fig. 6.245.

Likewise, German optical and electron microscopes were seized by the United States and copied by U.S. companies [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards]. See Fig. 6.246.

German-speaking scientists even created gastroscopes or endoscopes that were appropriated by Allied countries after the war. For example, BIOS 874, *Computing and Testing Methods in the German Optical Industry*, p. 13, reported:

> [G. Wolf G.m.b.H. Berlin, a Zeiss subsidiary:] Probably the most interesting instrument is the Schindler flexible gastroscope, six to eight of which are being made monthly; thirty-eight glass elements are employed in the periscopic train, of which thirty-two are in the flexible portion, and a front negative lens is fitted to increase the visible field of view to 90^o. "Blooming" of the glass elements has not been tried.

Figure 6.227: The first known telescopes were produced around 1608 by opticians such as Hans Lipperhey, Jacob Metius, and Zacharias Janssen.

Figure 6.228: Antonie van Leeuwenhoek created the first known microscope and used it to observe numerous types of single-celled and multicellular organisms.

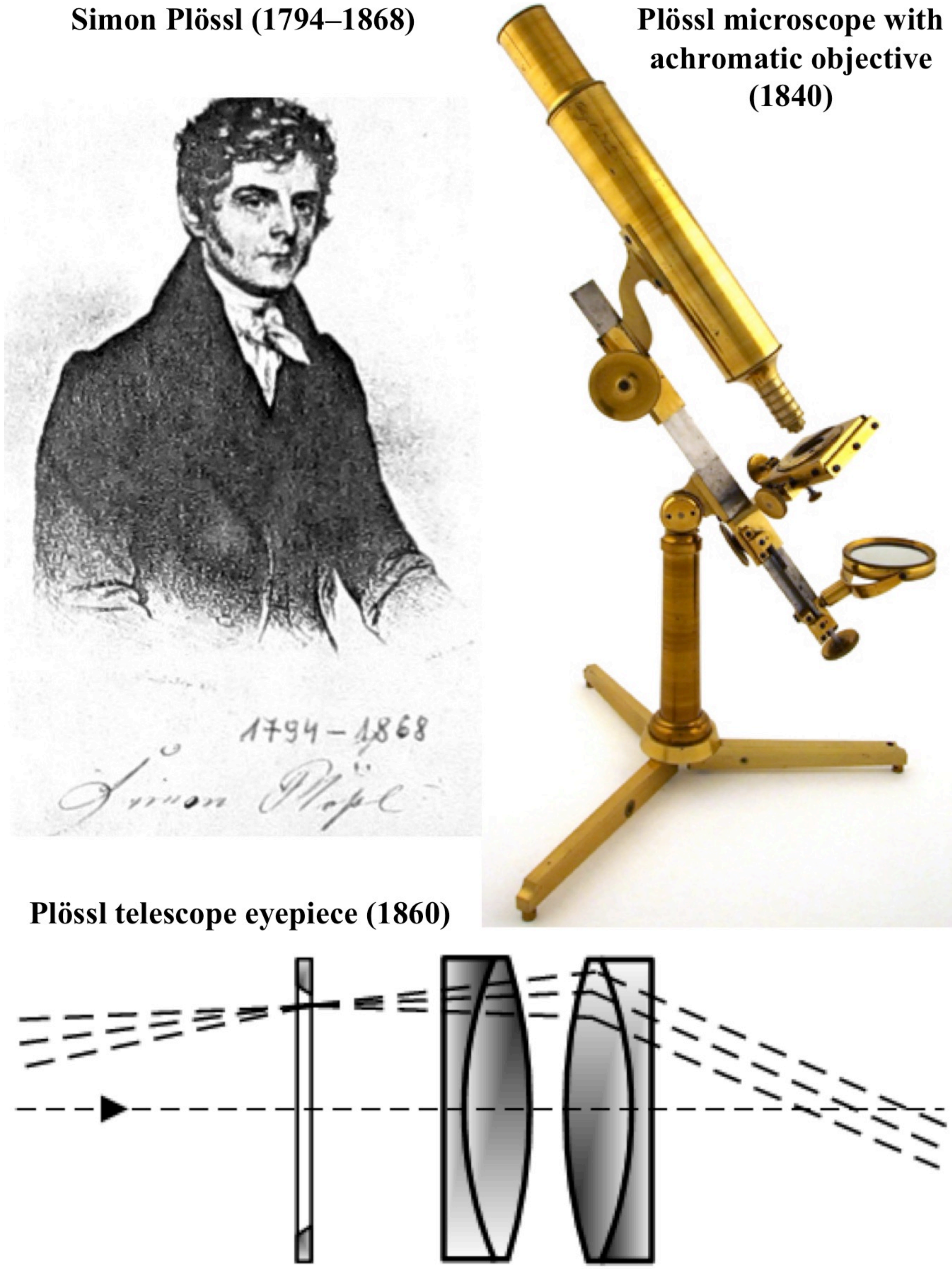


Figure 6.229: Simon Plössl produced microscopes with achromatic objective lenses, and also developed the now widely-used Plössl eyepiece design for telescopes.

Georg Johann Oberhäuser (1798–1868)

Edmund Hartnack (1826–1891) Immersion microscope objectives

Figure 6.230: Georg Johann Oberhäuser and Edmund Hartnack developed improved microscopes. Hartnack produced the first water immersion lenses (putting a drop of liquid between the lens and the slide) to enable microscopes to see smaller details.

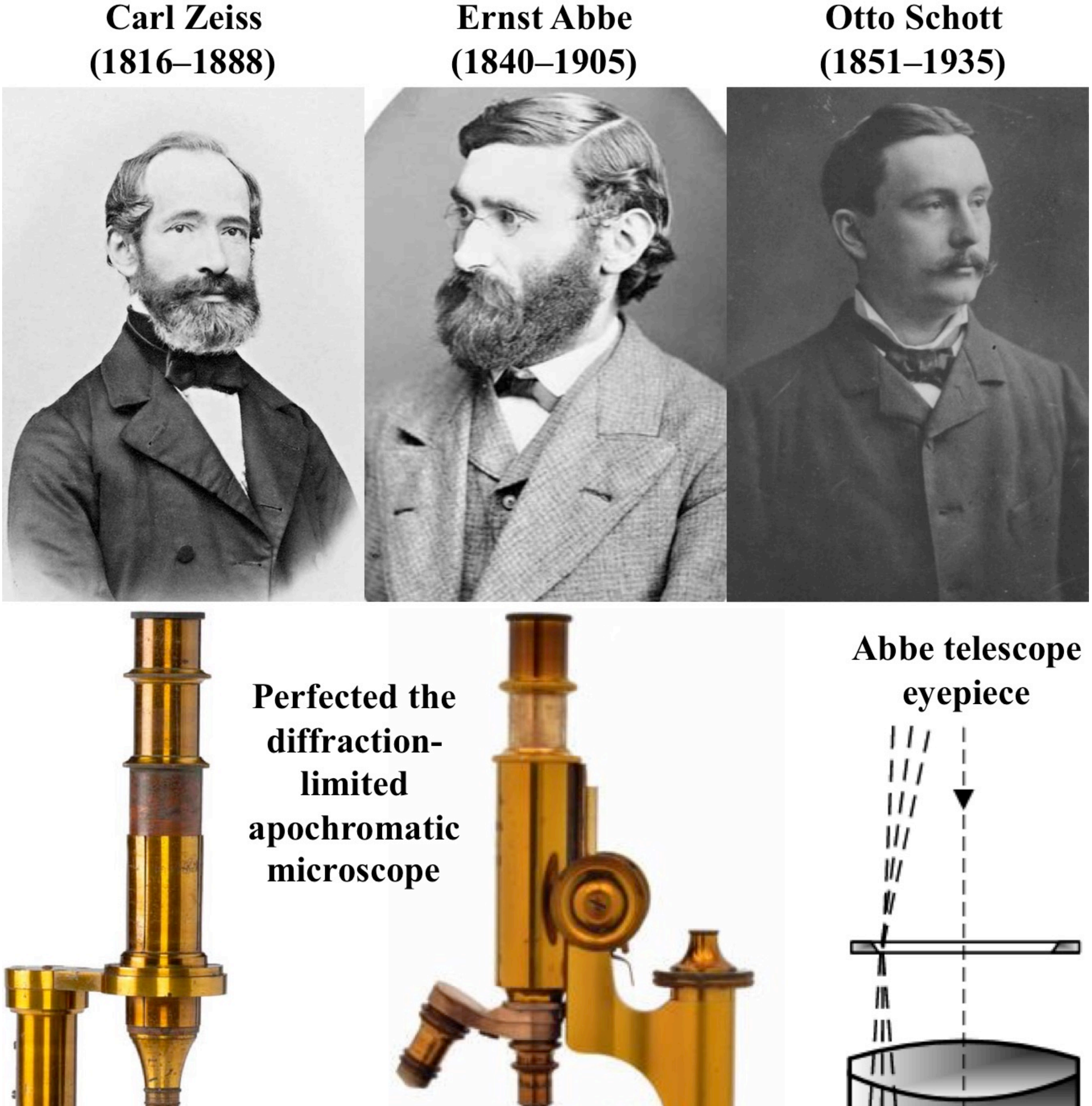


Figure 6.231: Carl Zeiss (1816–1888), Ernst Abbe (1840–1905), and Otto Schott (1851–1935) built up the Zeiss optical company, perfected the diffraction-limited apochromatic microscope, and produced other optical instruments.

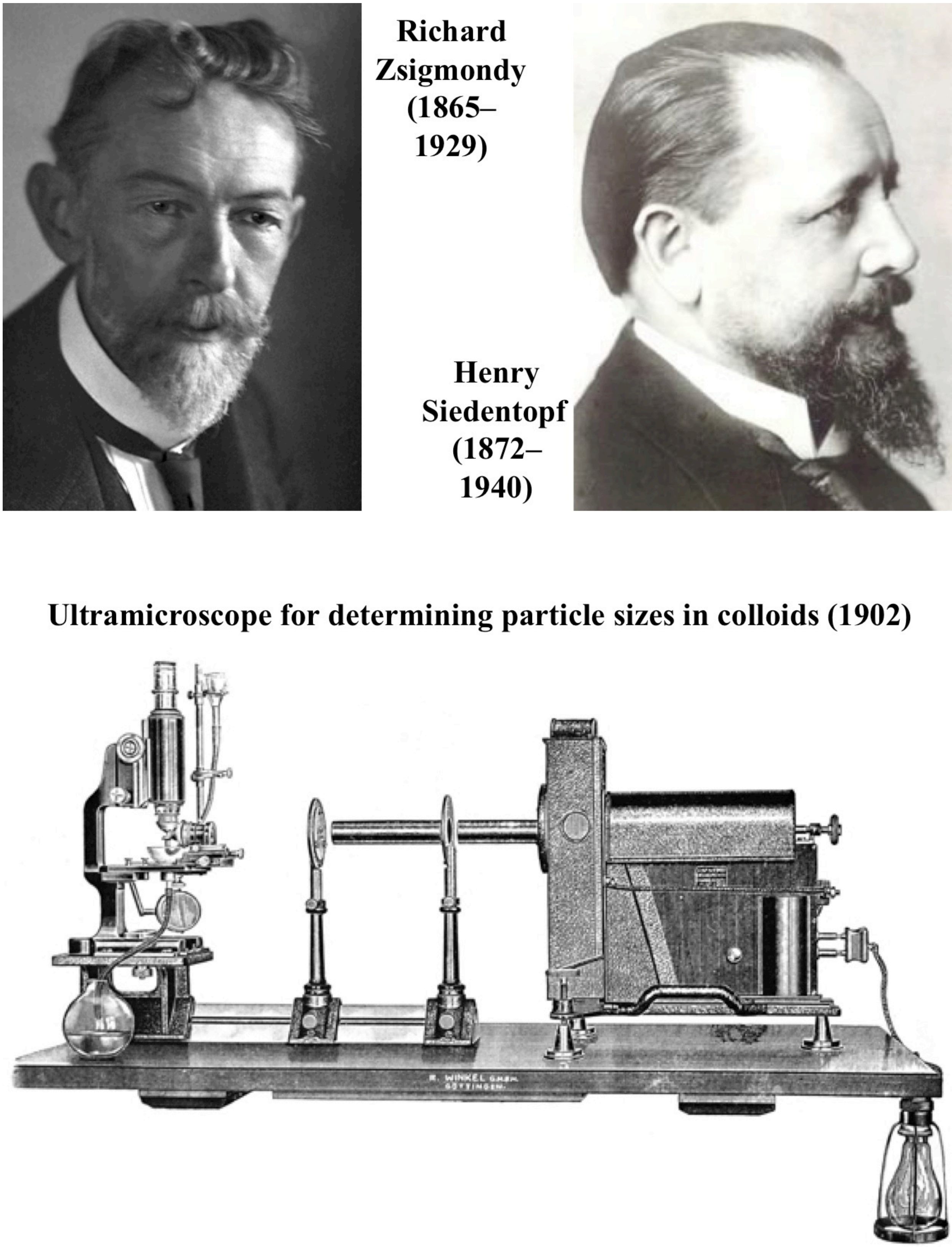


Figure 6.232: In 1902, Richard Zsigmondy and Henry Siedentopf invented the ultramicroscope for determining particle sizes in colloids.

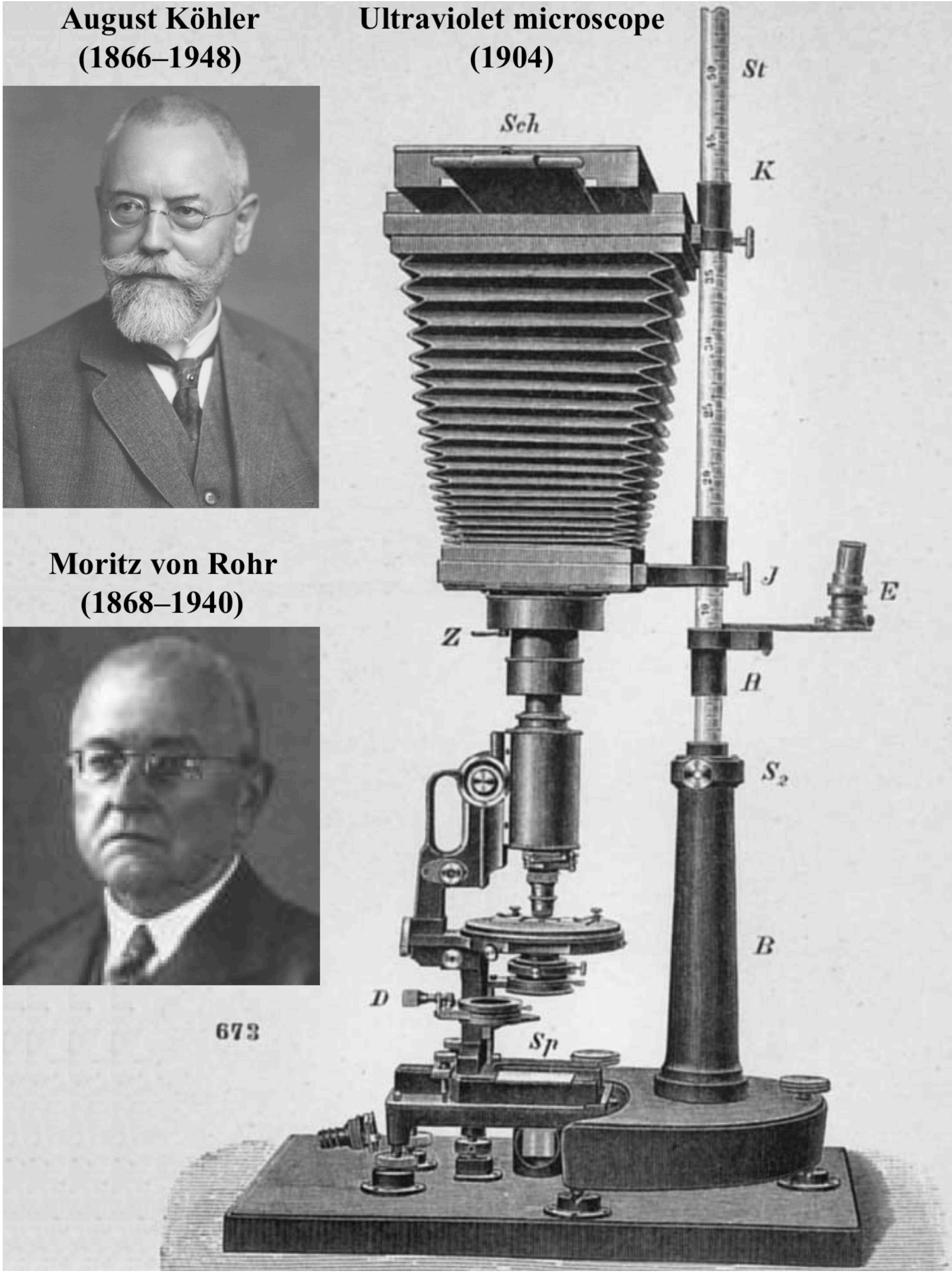


Figure 6.233: August Köhler and Moritz von Rohr invented the ultraviolet microscope in 1904.

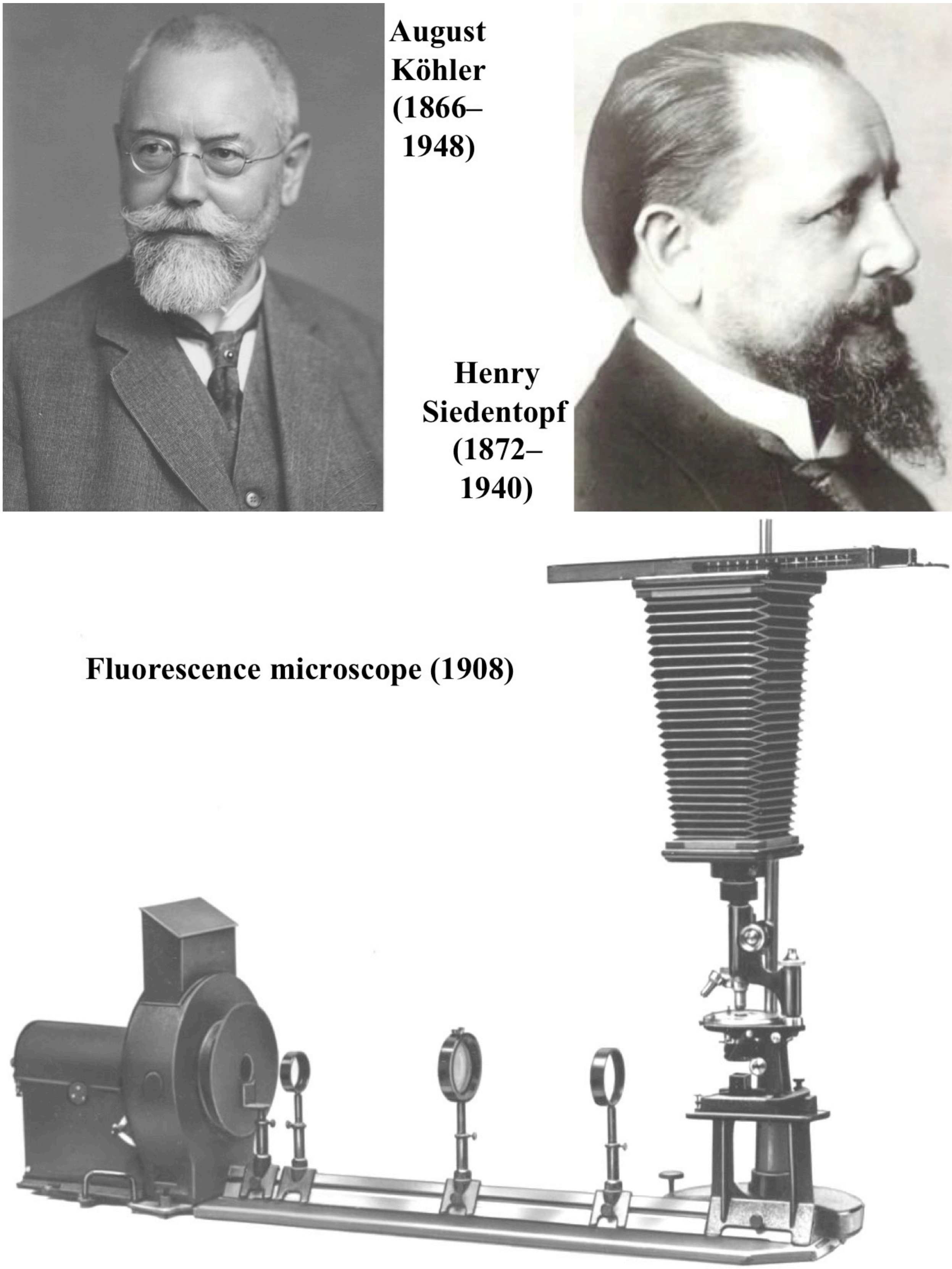
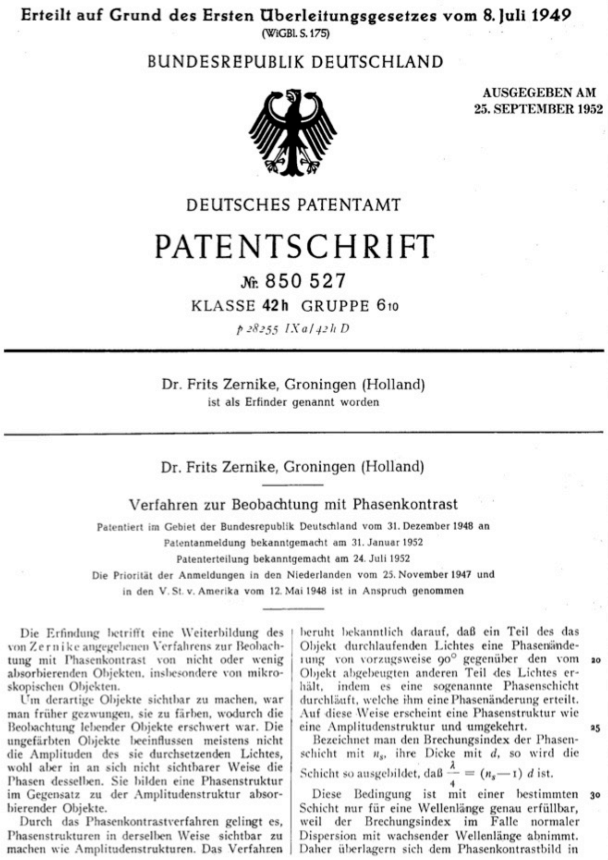


Figure 6.234: August Köhler and Henry Siedentopf invented the fluorescence microscope in 1908.

Frits Zernike (1888–1966) invented phase contrast microscopes (1933)



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25. SEPTEMBER 1952

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PATENTSCHRIFT

№ 850 527

KLASSE 42h GRUPPE 6₁₀

p 28255 IXa/42h D

Dr. Frits Zernike, Groningen (Holland)
ist als Erfinder genannt worden

Dr. Frits Zernike, Groningen (Holland)

Verfahren zur Beobachtung mit Phasenkontrast

Patentiert im Gebiet der Bundesrepublik Deutschland vom 31. Dezember 1948 an
Patentanmeldung bekanntgemacht am 31. Januar 1952
Patenterteilung bekanntgemacht am 24. Juli 1952
Die Priorität der Anmeldungen in den Niederlanden vom 25. November 1947 und
in den V. St. v. Amerika vom 12. Mai 1948 ist in Anspruch genommen

Die Erfindung betrifft eine Weiterbildung des von Zernike angegebenen Verfahrens zur Beobachtung mit Phasenkontrast von nicht oder wenig absorbierenden Objekten, insbesondere von mikroskopischen Objekten.

Um derartige Objekte sichtbar zu machen, war man früher gezwungen, sie zu färben, wodurch die Beobachtung lebender Objekte erschwert war. Die ungefärbten Objekte beeinflussen meistens nicht die Amplituden des sie durchsetzenden Lichtes, wohl aber in an sich nicht sichtbarer Weise die Phasen desselben. Sie bilden eine Phasenstruktur im Gegensatz zu der Amplitudenstruktur absorbierender Objekte.

Durch das Phasenkontrastverfahren gelingt es, Phasenstrukturen in derselben Weise sichtbar zu machen wie Amplitudenstrukturen. Das Verfahren beruht bekanntlich darauf, daß ein Teil des das Objekt durchlaufenden Lichtes eine Phasenänderung von vorzugsweise 90° gegenüber den vom Objekt abgebeugten anderen Teil des Lichtes erhält, indem es eine sogenannte Phasenschicht durchläuft, welche ihm eine Phasenänderung erteilt. Auf diese Weise erscheint eine Phasenstruktur wie eine Amplitudenstruktur und umgekehrt.

Bezeichnet man den Brechungsindex der Phasenschicht mit n_s, ihre Dicke mit d, so wird die Schicht so ausgebildet, daß $\frac{\lambda}{4} = (n_s - 1)\, d$ ist.

Diese Bedingung ist mit einer bestimmten Schicht nur für eine Wellenlänge genau erfüllbar, weil der Brechungsindex im Falle normaler Dispersion mit wachsender Wellenlänge abnimmt. Daher überlagern sich dem Phasenkontrastbild in

Phase contrast microscopes make cells easily visible without having to add colored chemical stains

Without phase contrast **With phase contrast**

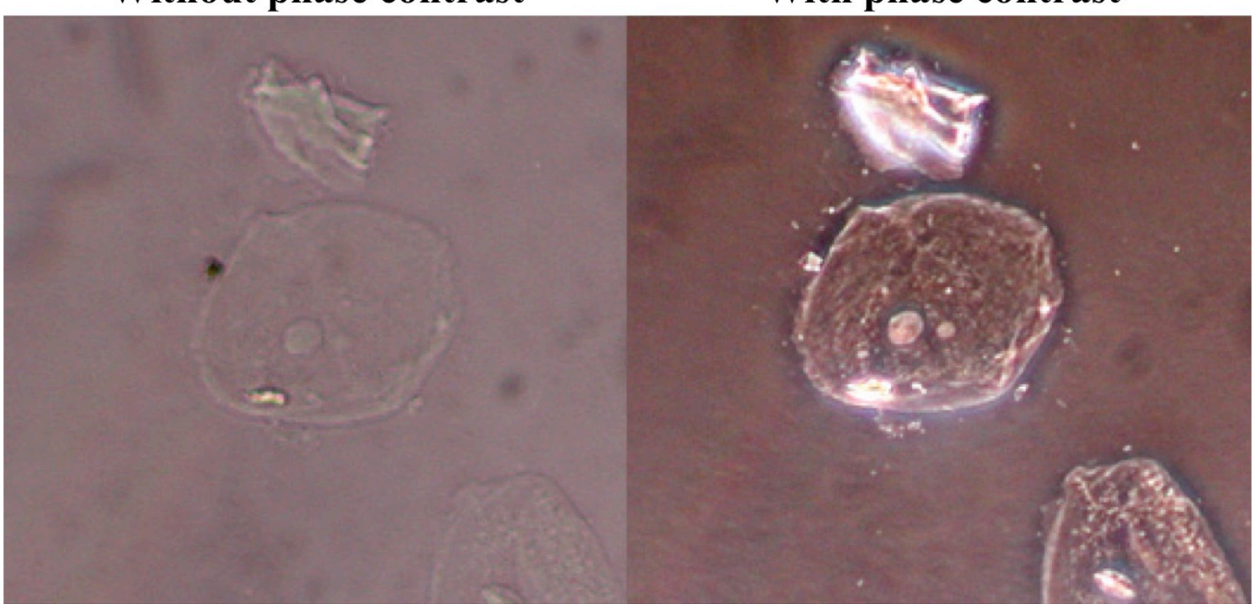


Figure 6.235: Frits Zernike (1888–1966) invented phase contrast microscopes in 1933, and they were mass produced by the Zeiss company. Phase contrast microscopes make cells easily visible without having to add colored chemical stains.

Figure 6.236: Carl Kellner, Ernst Leitz I, and the son Ernst Leitz II created what came to be called the Leitz optical instrument company.

Ernst Arbeit (18??–19??)

Carl Metz (18??–19??)

Felix Jentzsch (18??–19??) modern binocular microscope

Figure 6.237: Ernst Arbeit, Carl Metz, and Felix Jentzsch developed microscopes at the Leitz company.

John Jacob Bausch (1830–1926) **Henry Lomb (1828–1908)** **Ernst Gundlach (1834–1908)**

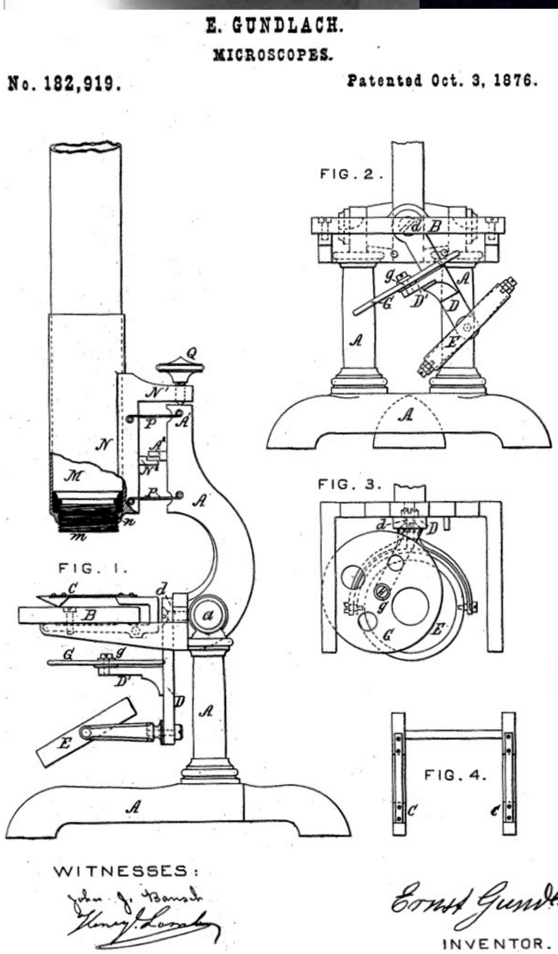


Figure 6.238: John Jacob Bausch, Henry Lomb, and Ernst Gundlach produced microscopes and other optical instruments at the Bausch & Lomb company in the United States.

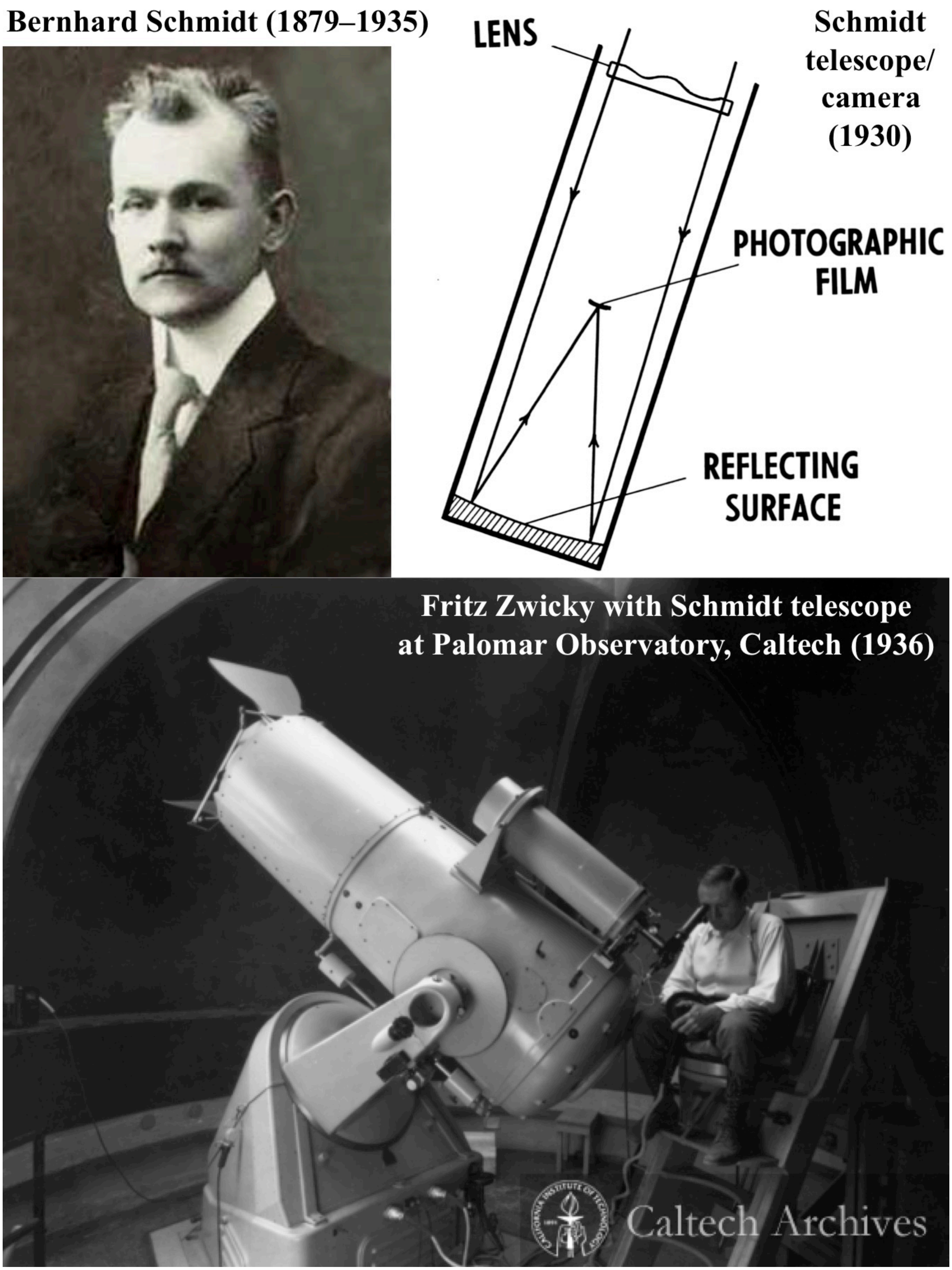
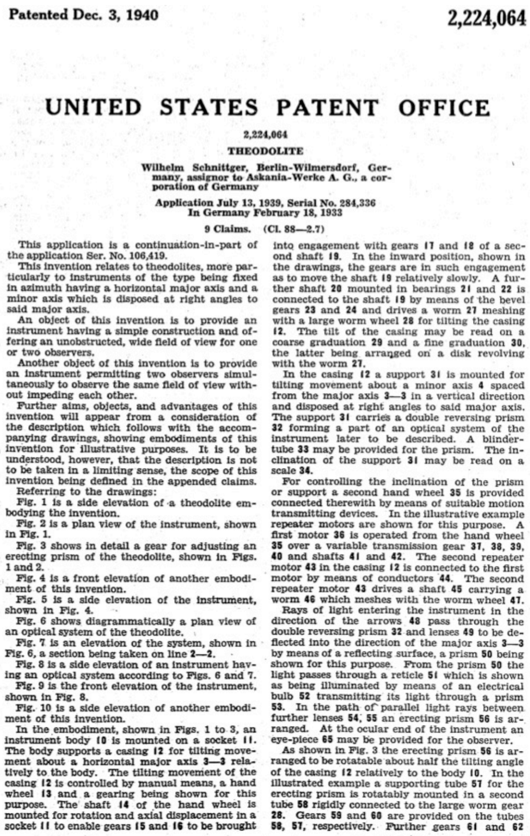


Figure 6.239: Bernhard Schmidt (1879–1935) invented the Schmidt telescope/camera in 1930.

Figure 6.240: Walther Bauersfeld (1879–1959) developed the Zeiss planetarium projector Mark I (1912–1923), Mark II (1930), and later models.

Wilhelm Schnittger (19??–19??) Advanced theodolites and cinetheodolites (1933, Askania)



Patented Dec. 3, 1940 2,224,064

UNITED STATES PATENT OFFICE

2,224,064

THEODOLITE

Wilhelm Schnittger, Berlin-Wilmersdorf, Germany, assignor to Askania-Werke A. G., a corporation of Germany

Application July 13, 1939, Serial No. 284,336
In Germany February 18, 1933

9 Claims. (Cl. 88—2.7)

This application is a continuation-in-part of the application Ser. No. 106,419.

This invention relates to theodolites, more particularly to instruments of the type being fixed in azimuth having a horizontal major axis and a minor axis which is disposed at right angles to said major axis.

An object of this invention is to provide an instrument having a simple construction and offering an unobstructed, wide field of view for one or two observers.

Another object of this invention is to provide an instrument permitting two observers simultaneously to observe the same field of view without impeding each other.

Further aims, objects, and advantages of this invention will appear from a consideration of the description which follows with the accompanying drawings, showing embodiments of this invention for illustrative purposes. It is to be understood, however, that the description is not to be taken in a limiting sense, the scope of this invention being defined in the appended claims.

Referring to the drawings:

Fig. 1 is a side elevation of a theodolite embodying the invention.

Fig. 2 is a plan view of the instrument, shown in Fig. 1.

Fig. 3 shows in detail a gear for adjusting an erecting prism of the theodolite, shown in Figs. 1 and 2.

Fig. 4 is a front elevation of another embodiment of this invention.

Fig. 5 is a side elevation of the instrument, shown in Fig. 4.

Fig. 6 shows diagrammatically a plan view of an optical system of the theodolite.

Fig. 7 is an elevation of the system, shown in Fig. 6, a section being taken on line 2—2.

Fig. 8 is a side elevation of an instrument having an optical system according to Figs. 6 and 7.

Fig. 9 is the front elevation of the instrument, shown in Fig. 8.

Fig. 10 is a side elevation of another embodiment of this invention.

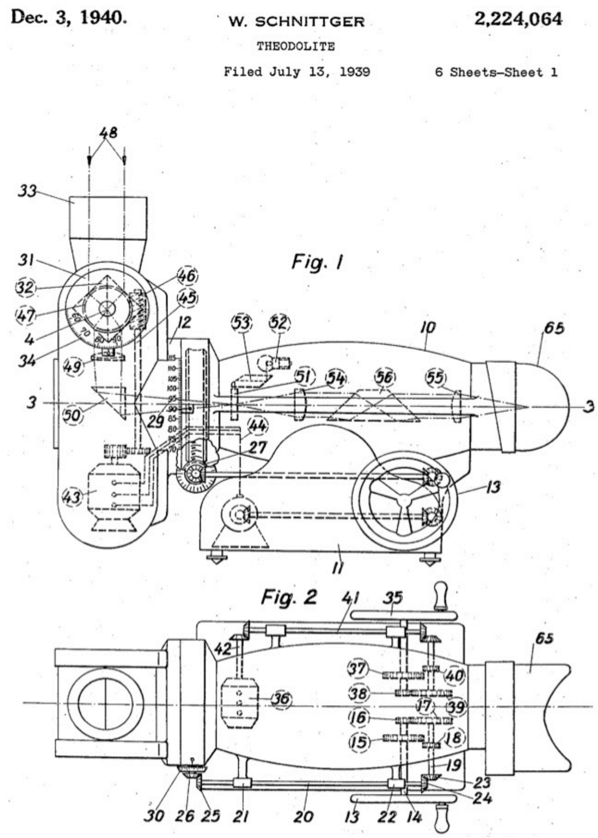
In the embodiment, shown in Figs. 1 to 3, an instrument body 10 is mounted on a socket 11. The body supports a casing 12 for tilting movement about a horizontal major axis 3—3 relatively to the body. The tilting movement of the casing 12 is controlled by manual means, a hand wheel 13 and a gearing being shown for this purpose. The shaft 14 of the hand wheel is mounted for rotation and axial displacement in a socket 11 to enable gears 15 and 16 to be brought into engagement with gears 17 and 18 of a second shaft 19. In the inward position, shown in the drawings, the gears are in such engagement as to move the shaft 19 relatively slowly. A further shaft 20 mounted in bearings 21 and 22 is connected to the shaft 19 by means of the bevel gears 23 and 24 and drives a worm 27 meshing with a large worm wheel 28 for tilting the casing 12. The tilt of the casing may be read on a coarse graduation 29 and a fine graduation 30, the latter being arranged on a disk revolving with the worm 27.

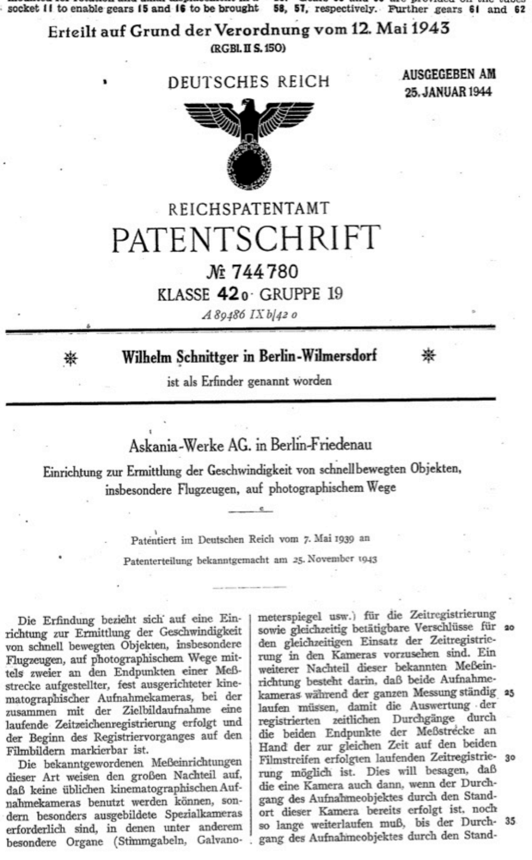
In the casing 12 a support 31 is mounted for tilting movement about a minor axis 4 spaced from the major axis 3—3 in a vertical direction and disposed at right angles to said major axis. The support 31 carries a double reversing prism 32 forming a part of an optical system of the instrument later to be described. A blinder-tube 33 may be provided for the prism. The inclination of the support 31 may be read on a scale 34.

For controlling the inclination of the prism or support a second hand wheel 35 is provided connected therewith by means of suitable motion transmitting devices. In the illustrative example repeater motors are shown for this purpose. A first motor 36 is operated from the hand wheel 35 over a variable transmission gear 37, 38, 39, 40 and shafts 41 and 42. The second repeater motor 43 in the casing 12 is connected to the first motor by means of conductors 44. The second repeater motor 43 drives a shaft 45 carrying a worm 46 which meshes with the worm wheel 47.

Rays of light entering the instrument in the direction of the arrows 48 pass through the double reversing prism 32 and lenses 49 to be deflected into the direction of the major axis 3—3 by means of a reflecting surface, a prism 50 being shown for this purpose. From the prism 50 the light passes through a reticle 51 which is shown as being illuminated by means of an electrical bulb 52 transmitting its light through a prism 53. In the path of parallel light rays between further lenses 54, 55 an erecting prism 56 is arranged. At the ocular end of the instrument an eye-piece 65 may be provided for the observer.

As shown in Fig. 3 the erecting prism 56 is arranged to be rotatable about half the tilting angle of the casing 12 relatively to the body 10. In the illustrated example a supporting tube 57 for the erecting prism is rotatably mounted in a second tube 58 rigidly connected to the large worm gear 28. Gears 59 and 60 are provided on the tubes 58, 57, respectively. Further gears 61 and 62





Erteilt auf Grund der Verordnung vom 12. Mai 1943
(RGBl. II S. 150)

DEUTSCHES REICH

AUSGEGEBEN AM
25. JANUAR 1944

REICHSPATENTAMT

PATENTSCHRIFT

№ 744780

KLASSE 42o GRUPPE 19

A 89486 IX b/42 o

Wilhelm Schnittger in Berlin-Wilmersdorf

ist als Erfinder genannt worden

Askania-Werke AG. in Berlin-Friedenau

Einrichtung zur Ermittlung der Geschwindigkeit von schnellbewegten Objekten, insbesondere Flugzeugen, auf photographischem Wege

Patentiert im Deutschen Reich vom 7. Mai 1939 an

Patenterteilung bekanntgemacht am 25. November 1943

Die Erfindung bezieht sich auf eine Einrichtung zur Ermittlung der Geschwindigkeit von schnell bewegten Objekten, insbesondere Flugzeugen, auf photographischem Wege mittels zweier an den Endpunkten einer Meßstrecke aufgestellter, fest ausgerichteter kinematographischer Aufnahmekameras, bei der zusammen mit der Zielbildaufnahme eine laufende Zeitzeichenregistrierung erfolgt und der Beginn des Registriervorganges auf den Filmbildern markierbar ist.

Die bekanntgewordenen Meßeinrichtungen dieser Art weisen den großen Nachteil auf, daß keine üblichen kinematographischen Aufnahmekameras benutzt werden können, sondern besonders ausgebildete Spezialkameras erforderlich sind, in denen unter anderem besondere Organe (Stimmgabeln, Galvanometerspiegel usw.) für die Zeitregistrierung sowie gleichzeitig betätigbare Verschlüsse für den gleichzeitigen Einsatz der Zeitregistrierung in den Kameras vorzusehen sind. Ein weiterer Nachteil dieser bekannten Meßeinrichtung besteht darin, daß beide Aufnahmekameras während der ganzen Messung ständig laufen müssen, damit die Auswertung der registrierten zeitlichen Durchgänge durch die beiden Endpunkte der Meßstrecke an Hand der zur gleichen Zeit auf den beiden Filmstreifen erfolgten laufenden Zeitregistrierung möglich ist. Dies will besagen, daß die eine Kamera auch dann, wenn der Durchgang des Aufnahmeobjektes durch den Standort dieser Kamera bereits erfolgt ist, noch so lange weiterlaufen muß, bis der Durchgang des Aufnahmeobjektes durch den Stand-

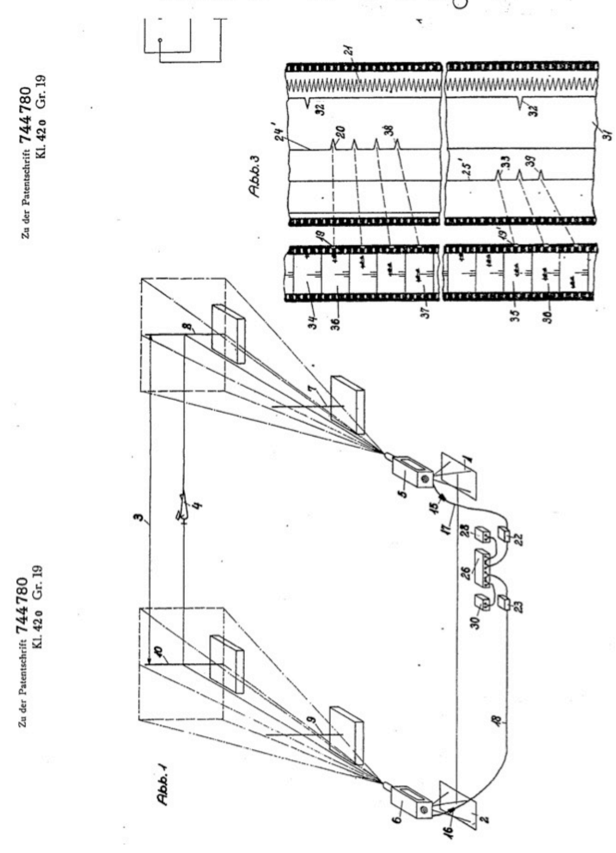


Figure 6.241: Wilhelm Schnittger invented advanced theodolites and cinetheodolites at Askania Werke in 1933.

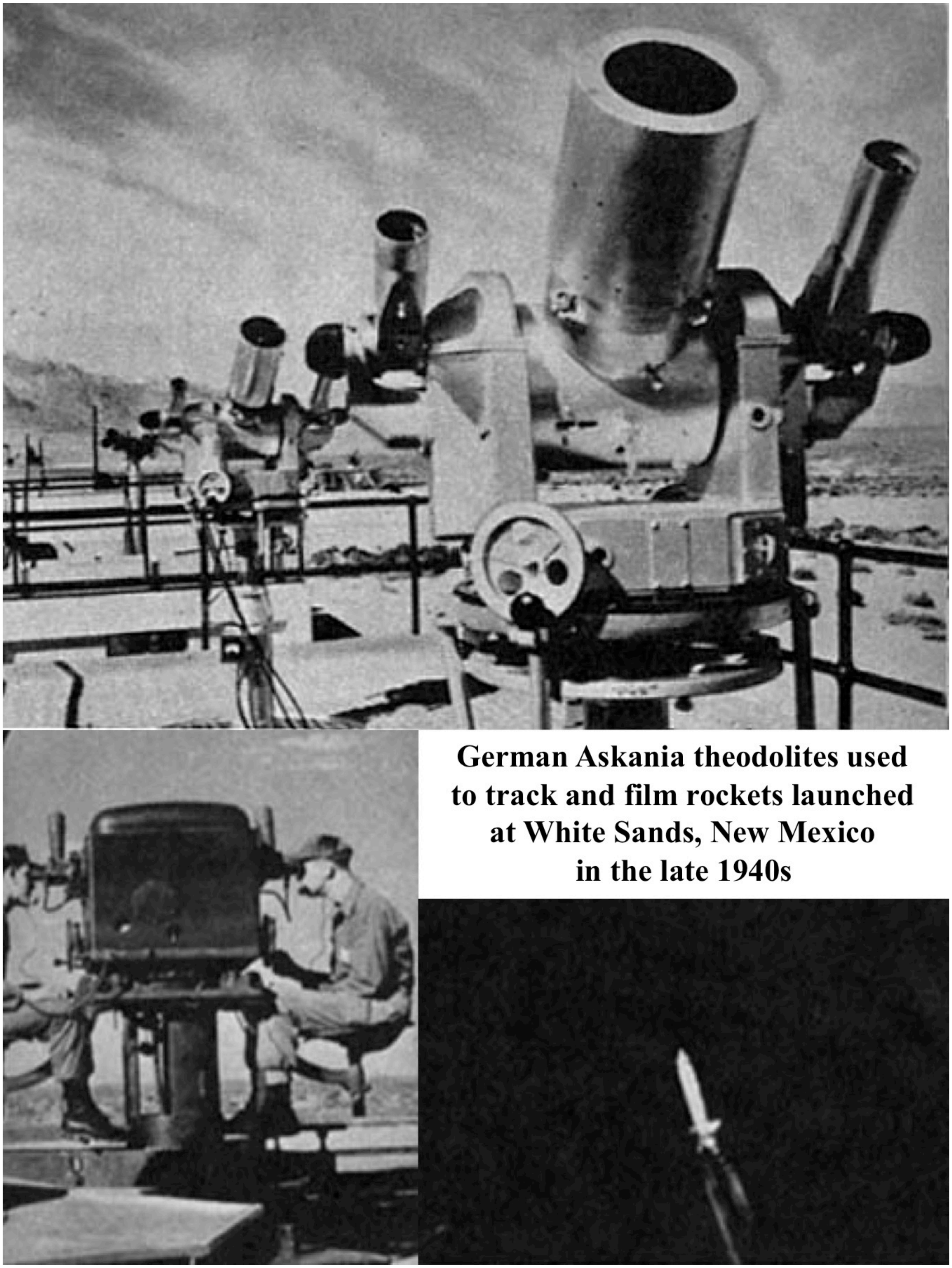


Figure 6.242: German Askania theodolites were used to track and film rockets launched at White Sands, New Mexico in the late 1940s, as well as many other U.S. aerospace vehicles in the decades following World War II.

Erteilt auf Grund der VO. vom 12.5.1943 — RGBl. II S. 150

AUSGEGEBEN AM 7. DEZEMBER 1953

REICHSPATENTAMT

PATENTSCHRIFT

№ 753 856

KLASSE 42h GRUPPE 38

Z 25270 IXa/42h

Nachträglich gedruckt durch das Deutsche Patentamt in München

(§ 20 des Ersten Gesetzes zur Änderung und Überleitung von Vorschriften auf dem Gebiet des gewerblichen Rechtsschutzes vom 8. Juli 1949)

Dr. Alexander Smakula, Jena

ist als Erfinder genannt worden

Fa. Carl Zeiss, Heidenheim/Brenz

Verfahren zur Verbesserung der Güte der von einem optischen System erzeugten Bilder

Patentiert im Deutschen Reich vom 18. Mai 1939 an

Patenterteilung bekanntgemacht am 17. August 1944

Es ist bekannt, daß man die Güte der von einem optischen System erzeugten Bilder durch zusätzliche Mittel verbessern kann, durch welche die das optische System durchsetzenden Wellen im Sinne einer Schwächung des Lichts von der Mitte nach dem Rande des diese Mittel enthaltenden optischen Elementes des Systems zu inhomogenisiert werden, wobei das genannte optische Element auch von einer oder mehreren zusätzlich zum optischen System hinzugefügten planparallelen Platten od. dgl. verkörpert sein kann. Diese Maßnahme hat die Wirkung, daß die Intensität der Beugungsfiguren, die mit Hilfe der äußeren, d. h. achsenferneren Teile des Systems von einem als Objekt dienenden Lichtpunkte erzeugt werden, im Verhältnis zur Intensität derjenigen Beugungsfiguren dieses Lichtpunktes geschwächt wird, die mit Hilfe der mittleren, d. h. achsennäheren Teile erzeugt werden. Die Verbesserung der Bildgüte beruht darauf, daß in der Abbildung des Lichtpunktes, die durch Übereinanderlagerung der verschiedenen Beugungsfiguren entsteht, die Intensitätsanteile, die aus achsennahen Teilen des Systems herrühren, verhältnismäßig stärker wirksam sind als die Intensitätsanteile aus den Randteilen. Die Gesamt-

Alexander Smakula (1900–1983)

Erteilt auf Grund der VO. vom 12.5.1943 — RGBl. II S. 150

AUSGEGEBEN AM 31. AUGUST 1953

REICHSPATENTAMT

PATENTSCHRIFT

№ 758 368

KLASSE 42h GRUPPE 1 01

Z 23786 IX/42h

Nachträglich gedruckt durch das Deutsche Patentamt in München

(§ 20 des Ersten Gesetzes zur Änderung und Überleitung von Vorschriften auf dem Gebiet des gewerblichen Rechtsschutzes vom 8. Juli 1949)

Dr. Alexander Smakula, Jena

ist als Erfinder genannt worden

Fa. Carl Zeiss, Heidenheim/Brenz

Optischer Teil, der gemäß dem Verfahren nach Patent 685 767 mit einer die Reflexion vermindernden Schicht versehen ist

Zusatz zum Patent 685 767

Patentiert im Deutschen Reich vom 28. März 1937 an

Das Hauptpatent hat angefangen am 1. November 1935

Patenterteilung bekanntgemacht am 2. November 1944

Im Hauptpatent 685 767 ist ein Verfahren angegeben, um die Reflexionsverluste, die beim Durchgang des Lichtes durch einen optischen Teil auftreten, bis auf etwa das 0,005fache des einfallenden Lichtes zu vermindern. Dieses Verfahren besteht darin, daß die Grenzflächen des optischen Teils mit einer zusätzlichen Schicht eines anderen Stoffes mit einem kleineren Brechungsexponenten, als der optische Teil hat, versehen werden. Es hat sich jedoch gezeigt, daß die damit erreichte Reflexionsverminderung in der Regel nicht dauernd erhalten bleibt, da die Metallteile, in denen der optische Teil gefaßt ist, gewöhnlich eingefettet sind, was zur Folge hat, daß das Fett im Laufe der Zeit über die zusätzliche Schicht wandert und sich außerdem auf dieser Schicht Fettdämpfe niederschlagen. Der so entstehende fettige Belag ändert die Brechungsverhältnisse in der Grenzzone zwischen der Luft und dem optischen Teil in dem Sinn, daß sich die Reflexionsverluste wiederum vergrößern.

Die Erfindung geht aus von einem optischen Teil, der gemäß dem Verfahren nach Patent 685 767 mit einer die Reflexion vermindernden

Antireflective coatings for lenses (1935)

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949

(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM 31. AUGUST 1953

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 883 063

KLASSE 39a GRUPPE 15

Z 594 XII/39a

Dr. Alexander Smakula, Auburndale, Mass. (V. St. A.)

ist als Erfinder genannt worden

Fa. Carl Zeiss, Heidenheim/Brenz

Verfahren zur Veränderung der Reflexion von Körpern aus organischem Kunststoff

Patentiert im Gebiet der Bundesrepublik Deutschland vom 22. Oktober 1944 an

Der Zeitraum vom 8. Mai 1945 bis einschließlich 7. Mai 1950 wird auf die Patentdauer nicht angerechnet

(Ges. v. 15. 7. 51)

Patentanmeldung bekanntgemacht am 30. Oktober 1952

Patenterteilung bekanntgemacht am 28. Mai 1953

Die Erfindung betrifft ein Verfahren zum Erzeugen einer Schicht von erhöhter Reflexion auf einem Körper aus organischem Kunststoff, insbesondere aus einem Vinylharz, einem Akrylharz, aus Cellulose oder einem ähnlichen Kunststoff. Es liegt nahe, in der bei Glas bekannten Weise den Körper dadurch mit einer solchen Schicht zu versehen, daß man einen Stoff von höherer Brechungszahl auf ihn aufbringt, z. B. indem man diesen aufdampft. Die mit einer dauerhaften Aufbringung verknüpften Umständlichkeiten kann man vermeiden und zugleich eine besonders dauerhafte Schicht erzielen, wenn man nach der Erfindung die Schicht aus dem betreffenden organischen Kunststoff selbst heraus bildet, indem man den betreffenden Körper, als Anode geschaltet, einer Glimmentladung aussetzt; es bildet sich dadurch eine dauerhafte Schicht von erhöhter Reflexion. Die Dicke der so gebildeten Schicht hängt von der Spannung und der Stromstärke der Glimmentladung sowie von deren Zeitdauer ab. So kann man z. B. bei einer Spannung von 3000 V und einer Stromdichte von 0,05 mA/qcm durch eine Entladung von 5 Minuten die Reflexion von Körpern aus Polymethacrylsäureestern um 2% erhöhen.

Handelt es sich darum, die Reflexion von organischem Kunststoff zu vermindern, so ist auch hierfür das erfindungsgemäße Verfahren von Nutzen. Es ist zwar bekanntlich möglich, diese Verminderung durch Aufbringen einer Schicht eines Stoffes

Erteilt auf Grund des Ersten Überleitungsgesetzes vom 8. Juli 1949

(WiGBl. S. 175)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM 23. FEBRUAR 1956

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 939 604

KLASSE 48b GRUPPE 11 03

Z 4637 VI/48b

Dr. Alexander Smakula, Jena

ist als Erfinder genannt worden

Fa. Carl Zeiss, Oberkochen (Württ.)

Verfahren zur Erzeugung einer die Reflexion vermindernden Schicht auf der Oberfläche eines optischen Elementes und Gerät zur Ausübung des Verfahrens

Patentiert im Gebiet der Bundesrepublik Deutschland vom 13. Februar 1940 an

Patentanmeldung bekanntgemacht am 18. August 1955

Patenterteilung bekanntgemacht am 26. Januar 1956

Bekanntlich können die beim Lichtdurchtritt durch die Oberflächen optischer Elemente auftretenden Reflexionsverluste dadurch vermindert werden, daß man die Flächen mit einer dünnen Schicht bestimmter Stoffe belegt. Das Aufbringen solcher Schichten erfolgt zweckmäßig durch Aufdampfen der Stoffe im Vakuum. Unter der Voraussetzung, daß die Lichtstrahlen im rechten Winkel zur Fläche einfallen, ergibt sich die maximale Reflexionsverminderung, wenn die folgenden Gleichungen erfüllt sind:

$$n_s = \sqrt{n} \qquad (1)$$

$$d = (2x - 1)\frac{\lambda}{4n_s}. \qquad (2)$$

In diesen Gleichungen bedeuten: n_s die Brechungszahl des aufgedampften Stoffes, n die Brechungszahl des optischen Elementes, d die Schichtdicke, x eine ganze positive Zahl und λ die Wellenlänge des Lichtes.

Aus den Gleichungen geht hervor, daß für Lichtstrahlen, die unter gleichen Winkeln einfallen, die Schicht eine über die ganze Lichtdurchtrittsfläche gleiche Dicke haben muß, wenn die maximale Reflexionsverminderung erreicht werden soll. Diese Forderung läßt sich leicht erfüllen, wenn die zu belegende Fläche eine konkave Fläche ist, indem man die Verdampfungsstelle im Krümmungsmittelpunkt der Fläche anordnet. Ist die zu belegende Fläche eben, dann ergibt sich beim Verdampfungs-

Figure 6.243: Alexander Smakula invented antireflective coatings for lenses at Zeiss in 1935.

Improved optical lenses, including antireflective coatings and high-index-of-refraction materials (e.g., Schwerflint 64)

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
14. FEBRUAR 1957

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 958 150
KLASSE 32b GRUPPE 1
INTERNAT. KLASSE C 03c ———
J 8259 IVc/32b

Marga Faulstich, Mainz
ist als Erfinder genannt worden

Jenaer Glaswerk Schott & Gen., Mainz

Optisches Glas

Patentiert im Gebiet der Bundesrepublik Deutschland vom 11. Februar 1954 an
Patentanmeldung bekanntgemacht am 9. August 1956
Patenterteilung bekanntgemacht am 24. Januar 1957

Die Erfindung bezieht sich auf ein optisches Glas, welches derart zusammengesetzt ist, daß es eine hohe Brechungszahl n_d aufweist, die größer als 1,745 ist, und welches eine beträchtlich geringere Lichtstreuung besitzt als die üblichen Schwerflintgläser.

Es sind Gläser dieser Art bekannt, die in der Hauptsache aus Bleiphosphat bestehen. Diese Gläser sind zwar durchaus farblos, jedoch so weich, daß ihre Verwendung für optische Zwecke nur bedingt möglich ist.

Es sind auch schon harte Gläser mit hoher Brechungszahl vorgeschlagen worden, die unter Verwendung großer Mengen von seltenen Erden gemeinsam mit Tantal oder Niob und Borsäure erschmolzen wurden. Diese Gläser sind jedoch sehr kostspielig.

Hochbrechende Gläser mit mittlerer Streuung wurden auch durch Zusätze von Cadmiumoxyd erhalten. Die Verwendung von Cadmiumoxyd ist jedoch ebenfalls verhältnismäßig kostspielig und zudem wegen seiner großen Giftigkeit bei der Handhabung unerwünscht.

Bekanntgeworden sind auch Gläser des Systems PbO-ZnO-B_2O_3. Diese Gläser haben sich aber für die Herstellung von optischem Glas als völlig ungeeignet erwiesen, da sie wegen ihrer äußerst geringen Viskosität bei der Gußtemperatur zu

BUNDESREPUBLIK DEUTSCHLAND

AUSGEGEBEN AM
7. MÄRZ 1957

DEUTSCHES PATENTAMT

PATENTSCHRIFT

№ 959 318
KLASSE 32b GRUPPE 1
INTERNAT. KLASSE C 03c ———
J 10382 IVc/32b

Marga Faulstich, Mainz
ist als Erfinder genannt worden

Jenaer Glaswerk Schott & Gen., Mainz

Glas für technische, insbesondere optische Zwecke

Patentiert im Gebiet der Bundesrepublik Deutschland vom 6. Juli 1955 an
Patentanmeldung bekanntgemacht am 6. September 1956
Patenterteilung bekanntgemacht am 14. Februar 1957

Die Erfindung bezieht sich auf ein Glas, welches für technische, insbesondere optische Zwecke bestimmt ist.

Die bekannten höher brechenden Gläser, die optische Werte für $n_D = 1{,}610$ bis $1{,}675$ und für $\nu = 50$ bis 44 aufweisen und als Barytflintgläser bezeichnet werden, enthalten größere Mengen an Bleioxyd und besitzen deshalb den Nachteil einer deutlich gelben Färbung.

Es wurde nun gefunden, daß man diese Färbung vermeiden kann und Gläser gleicher optischer Lage mit besonders vorteilhaften Eigenschaften erhält, wenn diese auf Aluminatbasis aufgebaut sind.

Erfindungsgemäß bestehen die Gläser zu mindestens 45 % aus Aluminiumoxyd, 25 bis 45 % aus Erdalkalien sowie 1 bis 17 % aus Alkalien. Der Rest kann durch SiO_2, GeO_2, ZnO, Bi_2O_3, La_2O_3, Ta_2O_5 oder ZrO_2 gebildet werden. Erfindungsgemäß werden die genannten Zusätze in folgenden Grenzen gehalten:

SiO_2 oder GeO_2	0 bis 15 %
MgO	0 bis 5 %
SrO und BaO	0 bis 12 %
ZnO	0 bis 4 %
Bi_2O_3, La_2O_3, Ta_2O_5, ZrO_2	0 bis 5 %

Von den Alkalien sind vorzugsweise 1 bis 7 % als Lithiumoxyd eingeführt. Besonders günstige Schmelz-

Figure 6.244: Marga Faulstich at Schott developed improved optical lenses, including antireflective coatings and high-index-of-refraction materials (such as Schwerflint 64).

NARA RG 40, Entry UD-75, Box 58, Folder Budget

PLASTIC LENS

The attached exhibit is a small plexiglas lens for use in opitcal instruments such as microscopes, cameras, and similar equipment.

The unique feature of this lens is that it was cut with a diamond tool from a heat-stablized plastic bar on a common spherical turning lathe. Such a lens was produced by the Germans at the rate of 4-5 per minute. This method of production eliminated the thermal and polymerization strains present in the blown, cast or pressed American lenses. These strains always effect the optical excellence of the finished product. Machining a lens from a heat treated bar eliminated this difficulty.

A development which had not yet reached production involved the cutting of non-spherical lenses for special purposes. Thus it would be possible to make certain corrections for normal optical distortion during the cutting of a lens for a particular purpose.

This item was picked up at the Walter Kopperschmidt Werke at Blumberg in southern Germany. It is reviewed by George Beiser in his report entitled "Plastic Aircraft Tooling and Tooling for Transparent and Optical Plastics", JIOA-71.

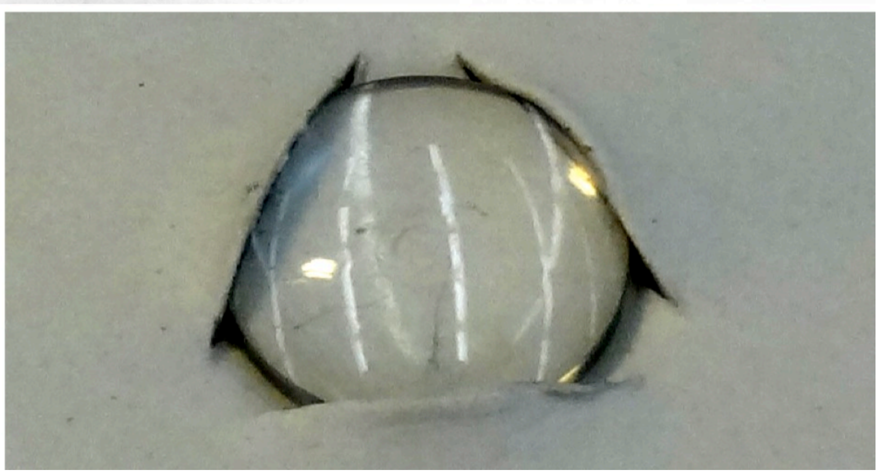


Figure 6.245: After World War II, German high-quality plastic lenses and the technology to produce them were taken by the United States and directly copied by U.S. companies [NARA RG 40, Entry UD-75, Box 58, Folder Budget].

**NARA RG 40, Entry UD-75,
Box 58, Folder TIID Discards**

IX

MICROSCOPES

Investigators of the Technical Equipment Section have discovered that the Germans have made remarkable progress in the field of microscopy as a result of their wartime research activities.

An interference microscope which was developed by the Carl Zeiss Company and which permits optical detection of interferences of twenty millionths of an inch in surface finishes has been evacuated to this country for exploitation by American industry. Domestic optical equipment manufacturers have expressed a keen interest in this device which is remarkably ingenious in that it employs the measurement of the interference of light beams caused by imperfections in surface finishes to indicate the depth of such imperfections in the surface being examined.

A phase-contrast microscope which permits the examination of biological specimens without staining or otherwise injuring the specimens has also been evacuated to this country for test and research purposes. The American optical industry and the National Bureau of Standards are very much interested in this device for there had been no such instrument available in this country prior to the discovery of the instrument produced by the Germans.

An electro-static electron microscope which had been used for developmental work at the A.E.G. Farben experimental laboratories at Helmsbrecht was discovered at the Kaiser Wilhelm Institute at Ochstadt. One of these instruments is being evacuated to the Naval Research Laboratory where it will be set up for inspection by American industry. Prior to the discovery of this instrument there had been no such instrument available in this country. On the basis of information which has been obtained thus far, indications are that this microscope will prove to be extremely valuable in cellular research. Consequently, there is reason to believe that it will contribute to a considerable extent in the work that is being done in this country in cancer research.

Information pertaining to the electro-static electron microscope is contained in Report No. PB-44667 published by the Office of Technical Services of the Department of Commerce.

Figure 6.246: After World War II, German optical and electron microscopes were taken by the United States and directly copied by U.S. companies [NARA RG 40, Entry UD-75, Box 58, Folder TIID Discards].

6.10 Electron Microscopes

Ordinary light microscopes use light waves to visualize objects. Visible light has wavelengths in the range of 400–700 nanometers, so it cannot image objects that are much smaller than those wavelengths. The minimum visible size is a little less than one hump of the wave, or a little less than half the wavelength, roughly 150 nanometers at the smallest. For comparison, most viruses are $\sim$ 20–150 nanometers wide, and individual atoms are $\sim$ 0.1–0.5 nanometers wide, so objects from atoms to viruses cannot be seen with light microscopes.

From quantum physics, small particles such as electrons can also behave like waves, and they can have wavelengths much smaller than those of light (p. 892). Moreover, one can build an electrostatic lens or a magnetic lens to focus a beam of electrons, just as a conventional optical lens can focus a beam of light (Fig. 6.247). Thus it is possible to build an electron microscope that uses electrostatic or magnetic lenses, fires a beam of electrons at tiny objects, collects the scattered electrons to detect the shape of the objects, and resolves objects far smaller than a light microscope could.

Just as most of the major developments in light microscopy and quantum physics came from the German-speaking world, most of the major innovations in electron microscopy also came from the German-speaking world, from the very first electron microscopes (Section 6.10.1) to electron microscopes powerful enough to see individual atoms (Section 6.10.2).[31] Electron microscopes have become indispensable for modern work in biology, materials science, microelectronics, and other fields.

6.10.1 Electron Microscopes and Scanning Electron Microscopes

As shown in Fig. 6.248, Hans Busch (German, 1884–1973) developed the first electrostatic and magnetic lenses for electrons in 1926. In 1928, Leo Szilard (Hungarian, 1898–1964) made the first known proposal to use such lenses to create an electron microscope.

Four different groups worked in parallel to build and demonstrate the world's first electron microscopes. All four groups were in the greater Berlin area:

1. A group at the Technische Hochschule Berlin produced electron microscopes from 1931 onward; see Fig. 6.249. The group included Max Knoll (German, 1897–1969), Bodo von Borries (German, 1905–1956), Ernst Ruska (German, 1906–1988), and Helmut Ruska (German, 1908–1973). Ernst Ruska played an especially large role in this group from the beginning, as well as later when this group closely collaborated with the Siemens & Halske group. Of all the earliest electron microscope builders, Ernst Ruska lived long enough to win the Nobel Prize in Physics in 1986. His brother Helmut took the first electron microscope

[31] von Ardenne 1990, 1997; von Ardenne and Pyl 1940; Barkleit 2008; von Borries and Ruska 1940a, 1940b, 1940c, 1944; Gelderblom and Krüger 2014; Gentile and Gelderblom 2014; Peter Hawkes 2013; Knoll and Ruska 1932a, 1932b; Krüger 2000; Lanouette and Silard 1992, pp. 94, 101; Lickfeld 1979; Maas and Hooijmaijers 2009, Chapters 5, 8; Pfankuch and Ruska 1947; Qing 1995; Ernst Ruska 1930, 1933a, 1933b, 1940a, 1940b, 1952a, 1952b, 1952c, 1952d, 1954, 1979; Helmut Ruska 1939; Helmut Ruska and Poppe 1947; Simmons 2002, pp. 270–274; Weber 1988; BIOS 1671; FIAT 765; FIAT 769.

pictures of viruses (p. 201). Professor Sven Johansson of the Royal Academy of Sciences praised the surviving Ruska as well as the other original developers of electron microscopy [https://www.nobelprize.org/prizes/physics/1986/ceremony-speech/]:

> This new development was the electron microscope. The electron microscope is based on the principle that a short coil of a suitable construction, carrying an electric current, can deflect electrons in the same way that a lens deflects light. A coil can therefore give an enlarged image of an object that is irradiated with electrons. The image can be registered on a fluorescent screen or a photographic film. In the same way that lenses can be combined to form a microscope, it was found that an electron microscope could be constructed of coils. As the electrons used in an electron microscope have a much shorter wavelength than light, it is thus possible to reach down to much finer details. Several scientists, among them Hans Busch, Max Knoll, and Bodo von Borries, contributed to the development of the instrument, but Ernst Ruska deserves to be placed foremost. He built in 1933 the first electron microscope with a performance significantly better than that of an ordinary light microscope. Developments since then have led to better and better instruments. The importance, in many areas of research, of the invention of the electron microscope should, by now, be well known.

2. Siemens & Halske developed electron microscopes from 1931 onward, first independently and then in close collaboration with personnel from the Technische Hochschule Berlin group (Fig. 6.250). Siemens & Halske personnel included Reinhold Rüdenberg (German, 1883–1961), Ernst Lubcke (German, 1890–1971), Walter Glaser (Austrian, 1906–1960), and Heinz-Otto Müller (German, 1911–1945).

3. A group at Allgemeine Elektrizität Gesellschaft (AEG) developed electron microscopes from 1931 onward, as shown in Fig. 6.251. The group included Hans Boersch (German, 1909–1986), Ernst Brüche (German, 1900–1985), A. Jakob (German?, 19??–19??), E. Johannson (German?, 19??–19??), Hans Mahl (German, 1909–1988), Carl Ramsauer (German, 1879–1955), and Otto Scherzer (German, 1909–1982).

4. Manfred von Ardenne (German, 1907–1997) created the first scanning electron microscope in 1937, and continued to develop electron microscopes after that. See Fig. 6.252. At the end of World War II, von Ardenne moved to the Soviet Union; he was awarded a Stalin Prize for building electron microscopes there.

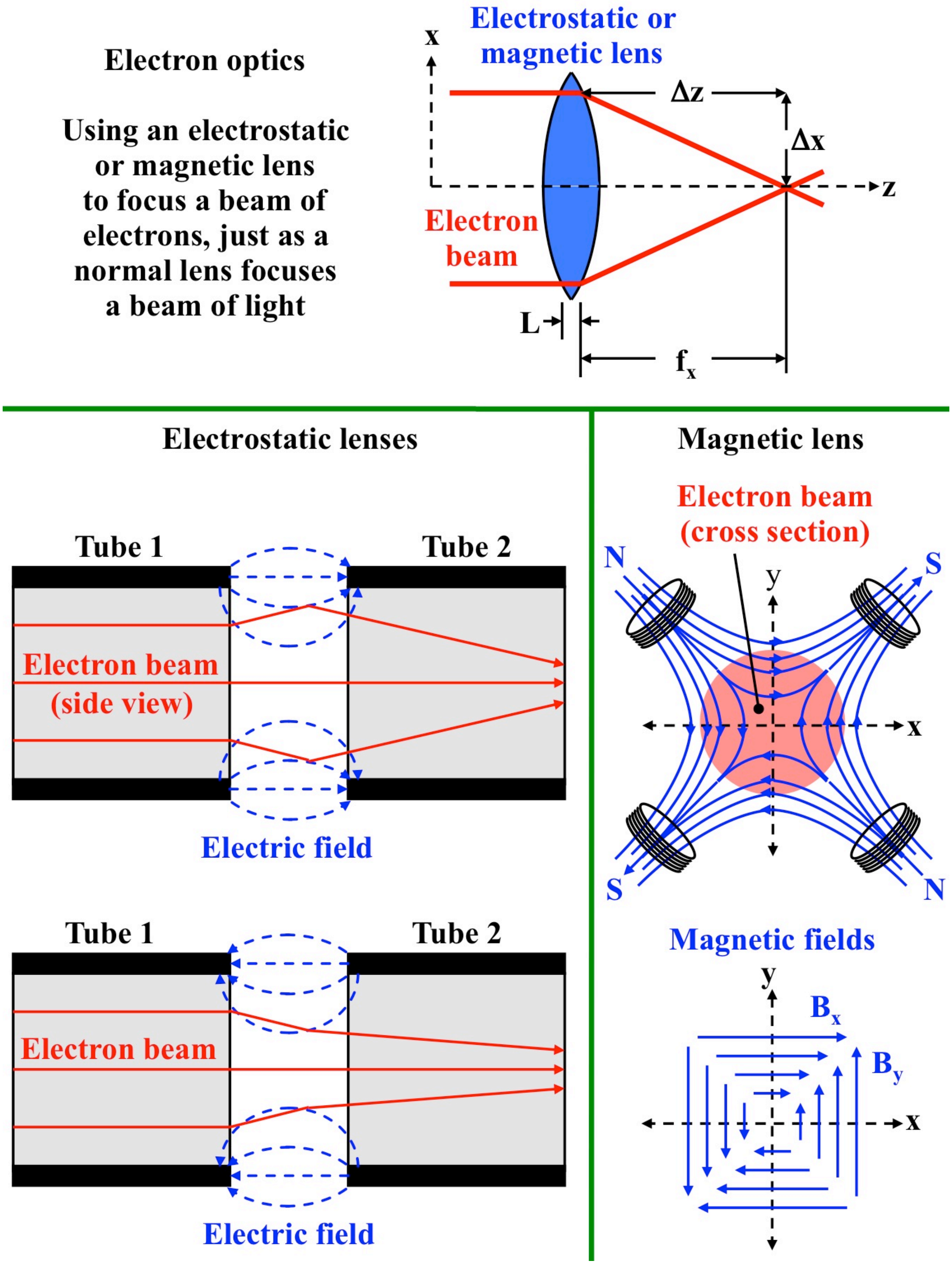


Figure 6.247: Electron optics uses an electrostatic or a magnetic lens to focus a beam of electrons, just as conventional optics uses a normal lens to focus a beam of light.

Hans Busch (1884–1973) created lenses for electrons (1926)

Leo Szilard (1898–1964) proposed electron microscope (1928)

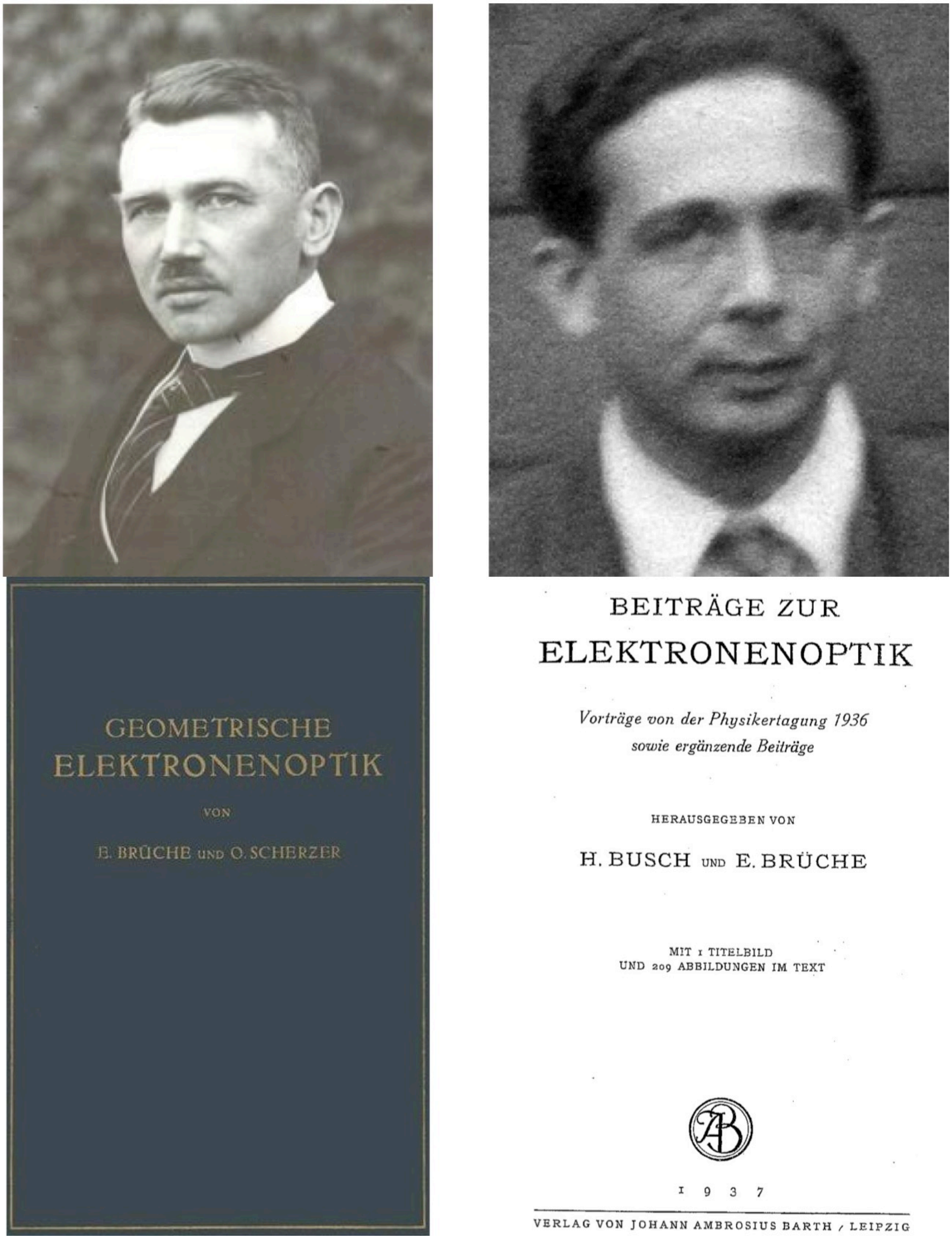


Figure 6.248: Hans Busch developed electrostatic and magnetic lenses for electrons in 1926. Leo Szilard proposed an electron microscope in 1928.

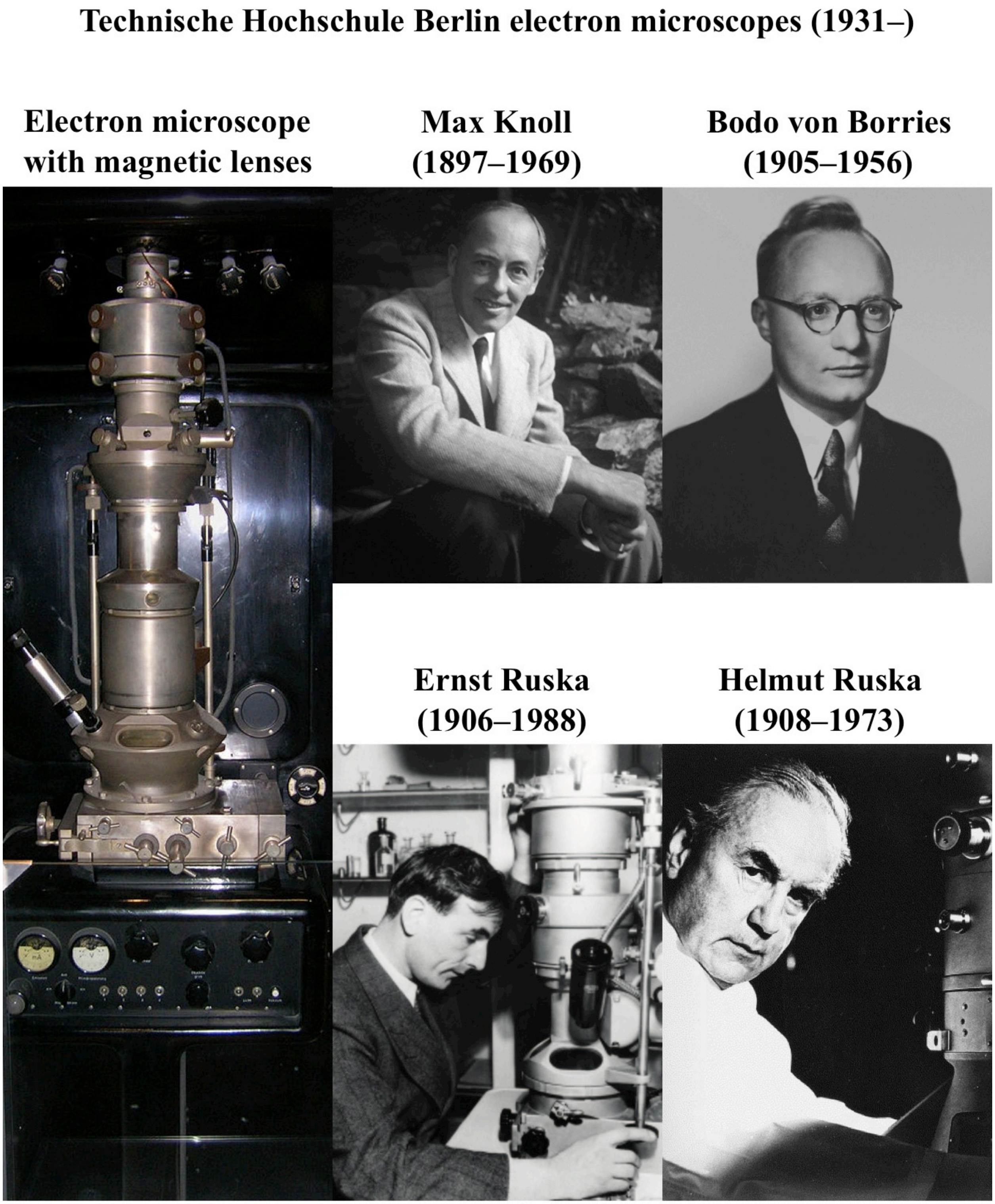


Figure 6.249: A group at the Technische Hochschule Berlin produced electron microscopes from 1931 onward. The group included Max Knoll, Bodo von Borries, Ernst Ruska, and Helmut Ruska.

Siemens & Halske electron microscopes (1931–)

Reinhold Rüdenberg (1883–1961)

UNITED STATES PATENT OFFICE

2,058,914

APPARATUS FOR PRODUCING IMAGES OF OBJECTS

Reinhold Rüdenberg, Berlin-Grunewald, Germany, assignor to Siemens-Schuckertwerke Aktiengesellschaft, Berlin-Siemensstadt, Germany, a corporation of Germany

Application May 27, 1932, Serial No. 613,857
In Germany May 30, 1931

12 Claims. (Cl. 250—27.5)

My invention relates to apparatus for producing images of objects.

Owing to the fact that in fieldless spaces electron rays travel, similar to light rays, in straight paths, an object impervious to the rays, when placed in a divergent bundle or beam of rays, produces an enlarged shadow on a fluorescent screen onto which the rays are projected.

In cathode-ray oscillographs, electro-magnetic fields surrounding the beam concentrically and causing a stricture of the beam are often employed. These fields have an effect on a beam of rays similar to that of an optical lens on a beam of light; they may cause the rays of the beam to become convergent or divergent. Consequently, with such stricture fields an enlarged or a reduced luminous image of the cathode ray beam is, according to circumstances, also obtained on the fluorescent screen.

This enlargement or magnification of shadows has hitherto been regarded only as a secondary phenomenon of minor technical importance in the use of electron rays. The reduction has in the past only been employed to obtain a sharply defined luminous spot (focus).

According to my invention, the effect, similar to that of lenses in optics, produced by fields of force surrounding concentrically a beam of electrons and exerting a radial influence on same, is utilized for enlarging objects in a manner corresponding to that obtained with optical magnifying glasses and microscopes. For this purpose the object to be enlarged is exposed to an electron ray or a beam of rays, and before or behind the object, the beam is by means of lens-like acting fields made convergent or divergent.

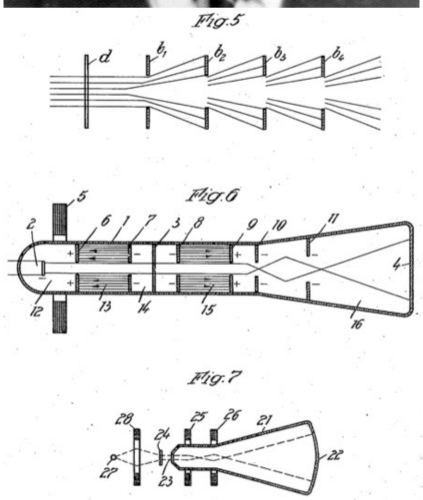
In Figures 1 to 5 of the drawings the principle of the invention is explained. Figures 6 to 11 illustrate various manners of carrying out the invention.

Fig. 1 shows a magnetic stricture coil, the length of which is small compared with the length of the path of the beam of rays. The rays are forced by the magnetic field toward the axis of the coil, coinciding with the axis of the beam, so that the rays meet in a focal spot or a focal line. ... of force. The charge on the stop a is assumed to be negative. When the electrons of a beam or bundle of cathode rays pass through the stop they are repelled by same. They are, therefore, deflected from their original paths, which are assumed to be parallel, towards the center and are assembled to a convergent beam meeting in the focal point 0, beyond which they then diverge. As the radial component of the field strength of the stop is zero in its axis and increases outwardly in linear proportion to the distance, the degree of deflection of the electron rays also increases with the distance from the beam and stop axis. This causes all the rays to meet in the same focal spot. To obtain with sufficient accuracy this proportional relation of the radial field strength to the distance from the axis, it is advisable to make the opening of the stop considerably larger than the diameter of the original beam, or, by choosing a special shape for the electrodes, to give the field the suitable shape.

If the potential of the diaphragm is assumed to be positive instead of negative, the electron rays will be attracted by the stop. The rays of the beam which till then were moving in parallel paths now become divergent, as shown in Fig. 3. The negative stop, therefore, has the same effect as a convex lens in optics, and the positive stop has that of a concave lens. By combining stops of that kind, all the devices known in optics and based on converging or diverging beams can be imitated for electron rays. It is in this manner possible, for example, to make a microscope or a telescope for use with direct or reflected electron rays, by proportioning the relative distances between the object, the diaphragm or stop and the projection screen in accordance with the general optical formula

$$\frac{1}{a}+\frac{1}{b}=\frac{1}{f}$$

in which a represents the distance between the object and the lens (in this case the diaphragm), b the distance between the lens and the screen, and f the focal length of the lens (in the present case the distance at which the charged diaphragm brings the parallel beam to a focal point).



Ernst Lubcke (1890–1971)

Walter Glaser (1906–1960)

Heinz-Otto Müller (1911–1945)

Figure 6.250: Siemens & Halske developed electron microscopes from 1931 onward, first independently and then in close collaboration with personnel from the Technische Hochschule Berlin group. Siemens & Halske personnel included Reinhold Rüdenberg, Ernst Lubcke, Walter Glaser, and Heinz-Otto Müller.

Allgemeine Elektrizität Gesellschaft (AEG)
electron microscopes (1931–)

Hans Boersch
(1909–1986)

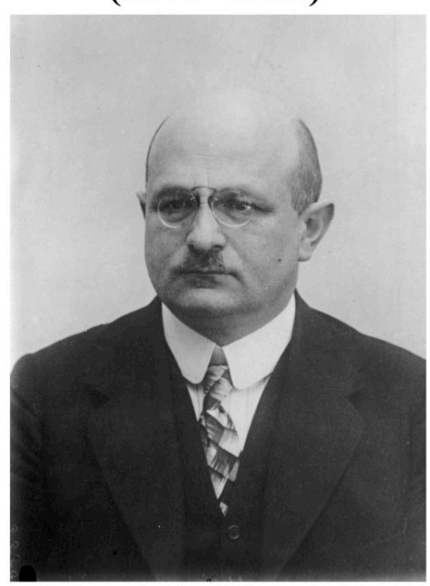
Ernst Brüche
(1900–1985)

A. Jakob
(19??–19??)

E. Johannson
(19??–19??)

Hans Mahl
(1909–1988)

Carl Ramsauer
(1879–1955)



Otto Scherzer
(1909–1982)

AEG electron microscope

Figure 6.251: A group at Allgemeine Elektrizität Gesellschaft (AEG) developed electron microscopes from 1931 onward. The group included Hans Boersch, Ernst Brüche, A. Jakob, E. Johannson, Hans Mahl, Carl Ramsauer, and Otto Scherzer.

Manfred von Ardenne (1907–1997) Scanning electron microscope (1937)

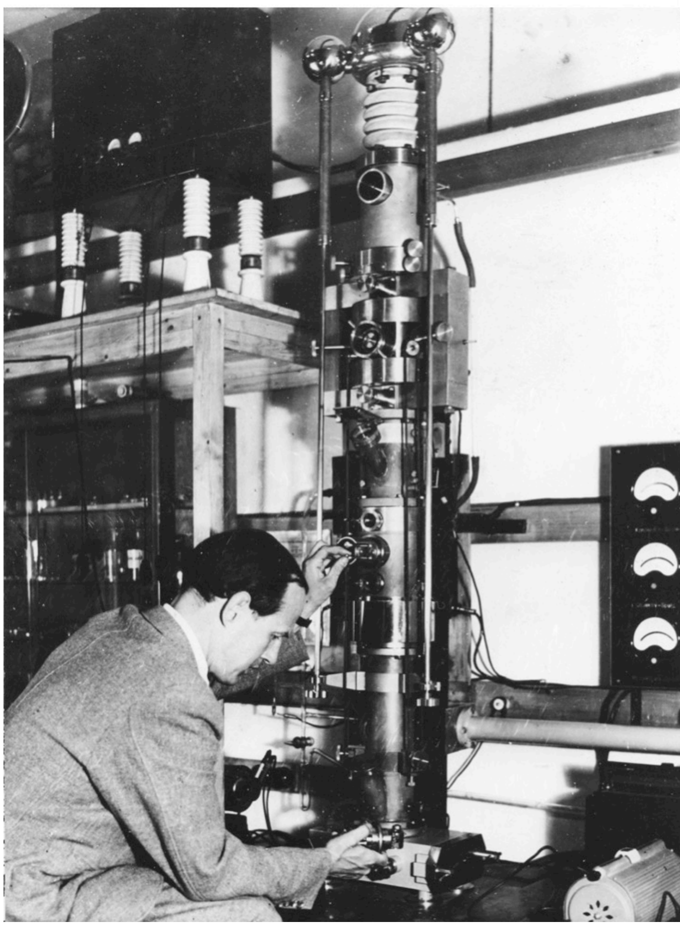
Das Elektronen-Rastermikroskop.
Theoretische Grundlagen.

Von **Manfred von Ardenne.**

Mit 14 Abbildungen. (Eingegangen am 25. Dezember 1937.)

Das Prinzip des Elektronen-Rastermikroskops. Herstellung der Elektronensonde. Herstellung des Rasters. Die verschiedenen Beleuchtungsarten. Untersuchung von Objekten in Luft. Die Grenzen für das Auflösungsvermögen des Rastermikroskops. Intensitätsfragen und Auflösungsvermögen. Zusammenfassung.

In einer vorausgegangenen Arbeit[1]) über die Möglichkeiten des Elektronenmikroskops wurde nachgewiesen, daß der durch unterschiedliche Abbremsung der Elektronen in der Objektschicht und in der Objektträgerfolie verursachte chromatische Fehler bei der Untersuchung vieler mikroskopischer Objekte, insbesondere bei der Untersuchung von Mikrotomschnitten, das erreichbare Auflösungsvermögen stark herabsetzt. Nur bei Objektschichten, die nicht viel dicker sind als die kleinste ohne Objektsgeschwindigkeitsstreuung auflösbare Strecke, ist die volle Leistungsfähigkeit des Elektronenmikroskops gegeben. Auf Grund der quantitativen Untersuchung dieser Zusammenhänge gelangte der Verfasser im Februar 1937 zu einem neuen Prinzip elektronenmikroskopischer Abbildung, bei dem neben anderen grundsätzlichen Vorteilen der chromatische Fehler durch Geschwindigkeitsstreuung der Elektronen im Objekt in Fortfall kommt.



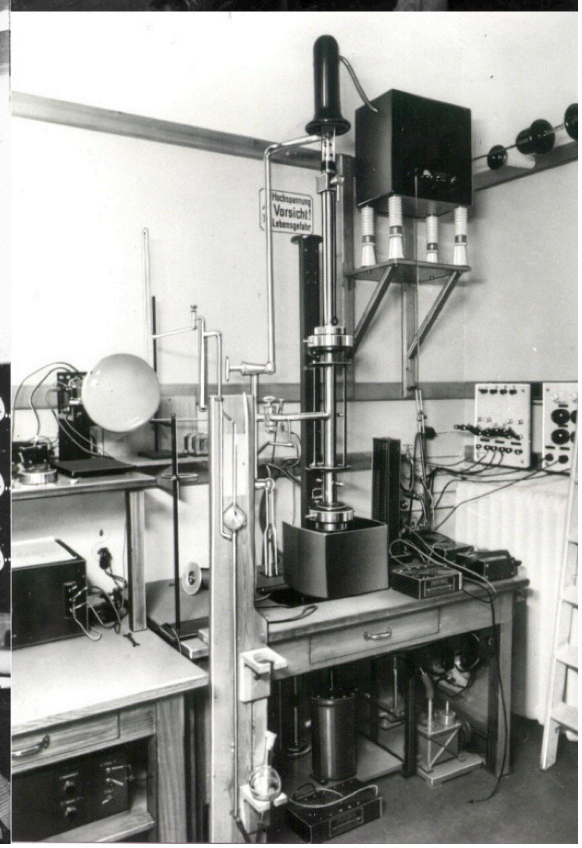


Figure 6.252: Manfred von Ardenne created the first scanning electron microscope in 1937, and continued to develop electron microscopes after that.

6.10.2 Scanning Tunneling Electron Microscopes and Atomic Force Microscopes

Although somewhat later than the time period that is the main focus of this book, in 1981, a group at IBM Zurich developed scanning tunneling electron microscopes powerful enough to see individual atoms (Fig. 6.253), as well as closely related atomic force microscopes. The group included Heinrich Rohrer (Swiss, 1933–2013), Gerd Binnig (German, 1947–), Christoph Gerber (Swiss, 1942–), and Edmund Weibel (Swiss?, 19??–). Rohrer and Binnig won the Nobel Prize in Physics in 1986, sharing the stage with Ernst Ruska. Professor Sven Johansson of the Royal Academy of Sciences explained the importance of their work [https://www.nobelprize.org/prizes/physics/1986/ceremony-speech/]:

> A crystal surface which appears completely flat in a microscope is seen with this instrument to be a plain on which atoms rise like hills in a regular pattern.
>
> Attempts by Russell Young and co-workers to realize these ideas revealed enormous experimental difficulties. The scientists who finally mastered these difficulties were Gerd Binnig and Heinrich Rohrer. Here it was a question of moving the needle over the surface of the sample and registering its vertical position, with great precision and without disturbing vibrations. The data obtained are then printed out, in the form of a topographic map of the surface, by a computer. The investigation may be concerned with a crystal surface, whose structure is of interest in microelectronic applications. Another example is the investigation of the adsorption of atoms on a surface. It has also been found to be possible to study organic structures, for example, DNA molecules and viruses. This is just the beginning of an extremely promising and fascinating development.

Heinrich Rohrer (1933–2013) **Gerd Binnig (1947–)** **Christoph Gerber (1942–)**



Edmund Weibel (19??–)

Scanning tunneling electron microscope (1981)

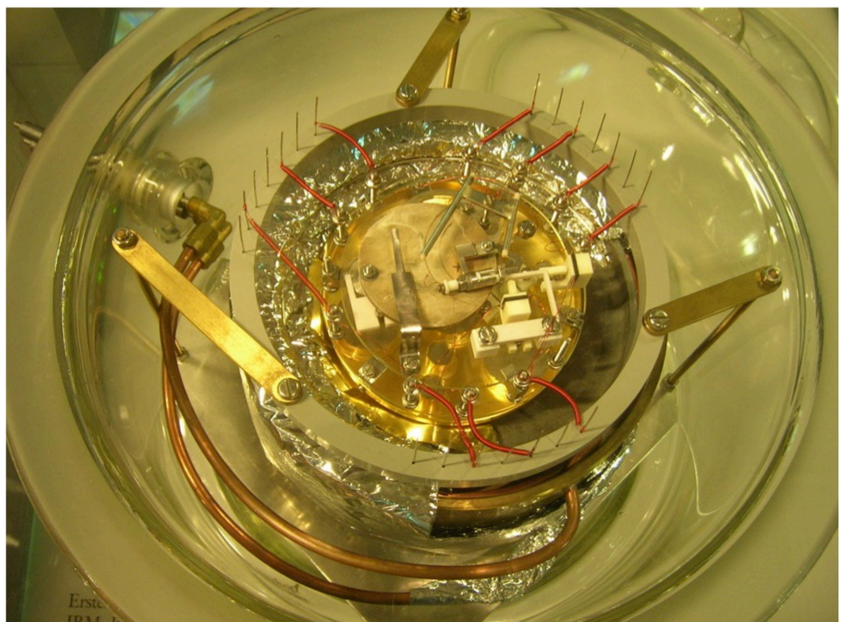


Image of individual atoms in a surface

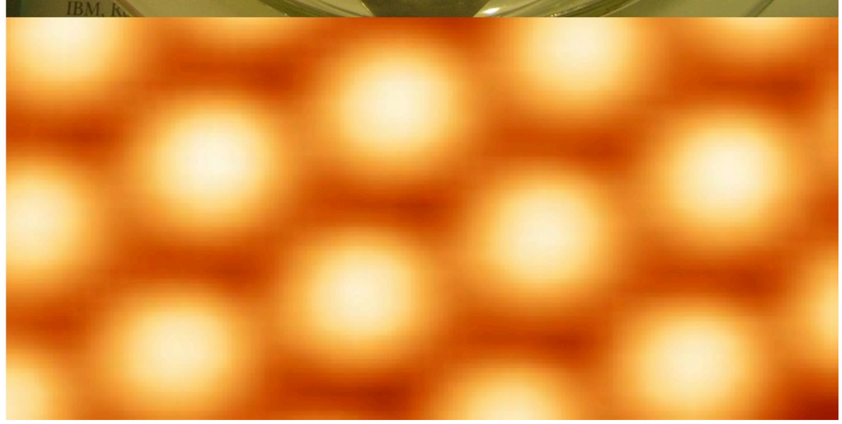


Figure 6.253: In 1981, a group at IBM Zurich developed scanning tunneling electron microscopes capable of imaging individual atoms. The group included Heinrich Rohrer, Gerd Binnig, Christoph Gerber, and Edmund Weibel.