Surprising Findings from the Hungarian Radar Developments in the Era of the Second World War

István Balajti[1] and Ferenc Hajdú[2]

[1]Military Science Faculty
National University of Public Services
Budapest, Hungary
E-mail: Balajti.Istvan@uni-nke.hu

[2]Editor-in-Chief of *Haditechnika*
H-1135, Budapest, Hungary
E-mail: Hajdu.Ferenc@hm.gov.hu

Abstract

New scientific findings always have historical roots that are important for researchers to know, of course including radar researchers. Different ideas and viewpoints from the early development of radar help us to get the full picture of our research subjects when we try to develop new radar systems based on modern technology. Until now, it was thought that Hungary had had a relatively small impact on radar technology compared to other countries, but it is clear today that this was not true. Hungarian experts and scientists achieved significant results. About one-third of Hungarian radar experts died during the Second World War, and another one-third immigrated to western countries and got a job in companies there. At the end of the Second World War, the former Soviet Union took all Standard Co. radio and radar manufacturing equipment, including the Tungsram Co. laboratories with the operational radars. Today, it is time to draw attention to the achievements reached by the Hungarian radar community. This paper is a brief summary of the facts that became public late after WW II. The authors hope that this article helps to open the archives of the successors of Tungsram Co., Standard Co., and Philips Co. to further investigate the remaining uncertainties of Hungarian radar developments, as well as the details of the first moon-detection trials of Dr. Bay's team.

1. Introduction

The invited paper on "Radar Developments in Hungary During World War II (WWII)," and its presentation during Microwave and Radar Week 2016, held in Krakow, May 2016, drew considerable attention [1]. The feedback received from the audience showed interest in a more detailed and comprehensive review of Hungarian microwave investigations, radar research, and development-related topics of that time. It inspired the authors to further investigate the subject. The number of publications that introduced the work of Hungarian scientists and engineers – or radar researchers with Hungarian roots – contributing to world radar technology was very limited. This article aims at reducing this gap by drawing attention to the Hungarian "hot spots" of radar historical roots, while enlightening Hungarian radar research, development, and manufacturing successes in the world's related global picture. Today, while the methodology of radar project management is at the focal point of customers' interests, details on Hungarian project-management standards in these times aim to give ideas for current top-level radar manufacturing management, i.e., how to increase the efficiency of modern radar projects. Limited information on the civilian aspect of Hungarian radar engineering was introduced in [2], while its list of references contains the names of today's civil-aviation contributions. Further information can be read in [3], which gave a short introduction to the Hungarian radar and air-defense system structure, but some technical information was obsolete. Very important books giving additional information on the matter were [4, 5].

2. Dr. Jáky and the Royal Hungarian Honvéd Institute of Military Technology

The Trianon treaty (paragraph 115) [6] deprived Hungary of the opportunity to create an army corresponding to the standard of that time. Military technological research

Figure 1. Dr. József Jáky, Hungarian radar developer, superior manager [7].

and development activities were also prohibited. Between the two world wars, the military leadership used every trick to circumvent the clauses of the treaty. To avoid the science of military technology being swept away by the army, dozens of well-educated officers who had gained experience in the battlefields of WW I were enrolled at the Royal Joseph Technical University in an organized manner [7].

At the focus of these military technical, scientific, and industrial achievements there was a Hungarian military engineer (Figure 1). He was a man whose course of life was almost unknown, not only to foreign specialists, but to the Hungarian scientific public life, as well.

József Janicsek was born on March 26, 1897, in Eperjes. His father, Dr. József Janicsek, was a high school teacher. The son changed his own name into the more-Hungarian Jáky. He passed high school in Eperjes with excellent grades, and he then registered with the Faculty of Natural History and Mathematics of the Pázmány Péter University. He gained admission to the Eötvös College. In 1915, he voluntarily joined up with the imperial and royal 34th infantry regiment, in which he passed six months at the Russian front line. After WW I, he was commanded to the Technical University, to be trained at the Faculty of Mechanical Engineering as a second-year student. In addition to this, he had to teach at the Ludovica Academy. Preparatory training was going on in all fields of military technical sciences (Figure 2).

In 1920, at a barracks besides the Technical University, the Institute of Military Technology (TEKI was the abbreviation of its Hungarian name at that time) was established. This was where considerable development activities were carried out for all fields of military science. In 1928, the of staff of TEKI numbered 47, comprising engineers and technicians. They worked on more than 100 development topics. This was only possible with the cooperation of professionals of science, industry, and the reorganization of the Royal Hungarian Army. Everything was secretly done, in spite of the controllers of the Entente Powers.

The Royal Hungarian Honvéd Institute of Military Technology (hereafter, IMT) was officially established. Its electronics laboratory began to work with the aim of establishing communications between troops, harmonizing theoretical problems and practical opportunities, designing components of wired and wireless communication, and bringing them into production. The IMT did experiments on Hungarian military radio equipment, e.g., the R7-type

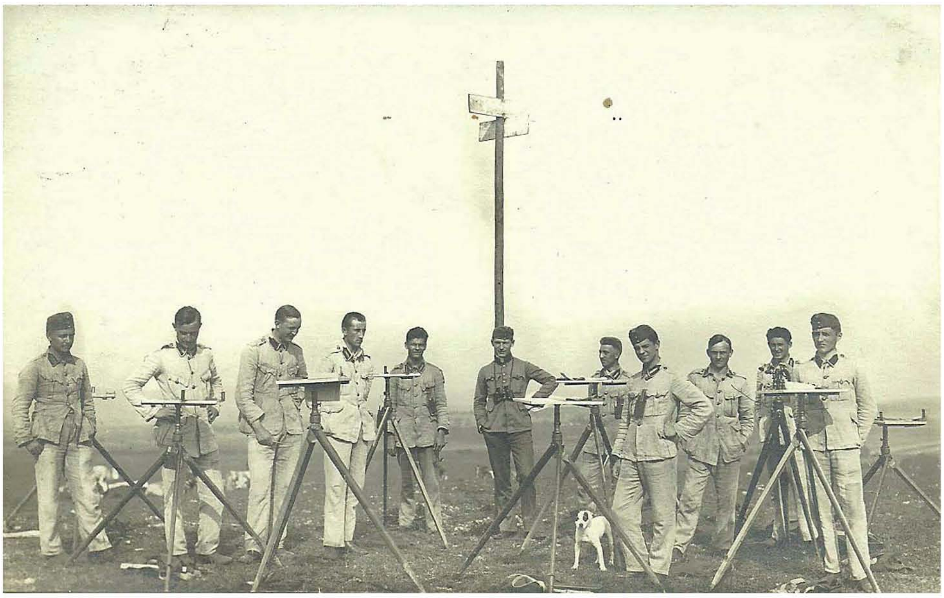

Figure 2. Capt. Jáky among future military signal engineers.

Figure 3. Maj. Jáky to the right, with the R7 type of Hungarian military radio.

radio (Figure 3), together with Edvin Istvánffy (Rainer), from the end of the 1920s, with whom this cooperation continued, as described later.

The young communications engineers worked together with János Csonka (1852-1939), also known from the Technical University. He manufactured a dynamo driven by an engine for charging the batteries of military radios. Experiments were also carried out on quartz-controlled military radios, but they were considered too expensive.

From October 1, 1938, Jáky was the appointed head of Department 4 of the IMT. He was promoted to Lieutenant Colonel in 1940, and then Staff Engineer Colonel in 1942. Having defended his thesis on electrical methods of measuring bullet/muzzle velocity, he obtained his Doctorate in Technical Sciences in 1941 [7]. Figures 4 and 5 show the antenna and the analog computer with the weather station on top of the bullet/muzzle-velocity-measurement equipment.

3. The Impact of World Historical Circumstances on the Initialization of Hungarian Radar Development

In September 1939, Germany requested Hungarian territory against the invasion of Poland. The request was rejected, and the border opened for 180000 Polish refugees. Hungarian-German relations cooled down in all fields of cooperation.

In August 1940, the relations between Hungary and Romania were close to local conflict, which could have cut Germany from access to the Romanian oil fields [8].

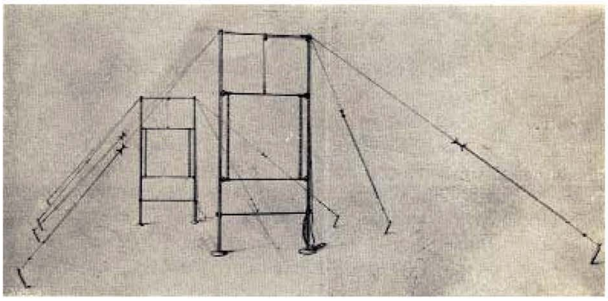

Figure 4. The antenna system of the bullet/muzzle-velocity measurement equipment.

The German government exerted political and economic pressure on Hungary to avoid a conflict. The Wehrmacht even got the task to develop a plan for the occupation of Hungary. The plan was shown to the Hungarian government.

On November 20, 1940, Hungary was forced by Germany to join the Allies of the Axis, but developed alternate plans to safeguard the independence of the country. One of the plans was the establishment of the Hungarian Emigrant Government in the USA, while an amount of 5 million USD (77 million to 80 million USD today) was transferred to the USA [8].

In March 1941, Germany requested Hungarian territory against Yugoslavia. This request was also rejected, and the Hungarian army partially mobilized to defend Hungarian territory.

On April 3, 1941, the questionable suicide of the Hungarian Prime Minister, Pál Teleki (1879-1941), resulted in Hungary joining the German attack against Yugoslavia.

On June 22, 1941, Germany attacked the Soviet Union, but Hungary remained neutral.

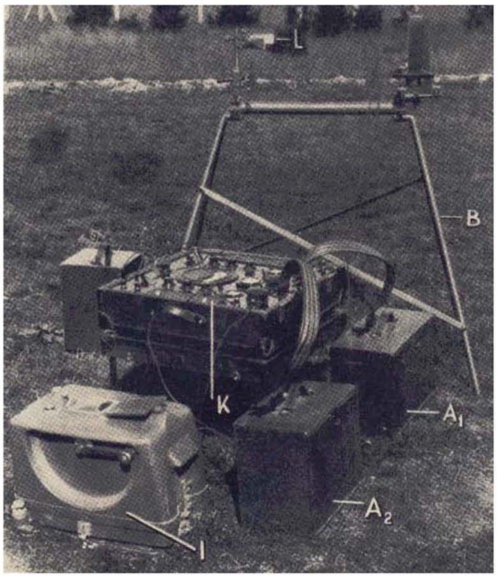

Figure 5. The bullet/muzzle-velocity measurement equipment with a weather station.

On June 26, 1941, bombers manufactured in the former Soviet Union bombed the Hungarian town of Kassa.

Hungary contacted its German ally in order to size up the opportunity to cooperate and share military technology.

During the Battle of Britain, the German and British adversaries got to know each other's radars to some extent: raids (e.g., Bruneval) and crashed aircraft (e.g., Rotterdam) also revealed technical details. Jamming only revealed that the opponent was aware of carrier frequencies and the mere fact that radar(s) were operating, without technical details. The only exception was that when the Hungarian radar developers got information on chaff dropped against the Würzburg radar, they acquired knowledge about the radar's operational carrier frequency [23]. Certainly, Hungarian analysts evaluated the collected information resulting from the Battle of Britain, and they came to the conclusion that air raids against Hungary were unavoidable. The application of radar could be the only opportunity for Hungary to effectively defend itself. Studies prepared by German, Italian, and Hungarian military experts showed that the air-defense environment needed radar. The question was, how to obtain it?

In December 1941, a Hungarian delegation, led by Major General Hellebronth, visited Germany. The members of the delegation were Staff Engineer Colonel Dr. József Jáky, head of the Electronics Department, and Staff Engineer Major Imre Balassa. During the presentation, they got to know the German Freya air-surveillance radar, the small "Würzburg" fire-control radar, the giant "Würzburg Riese" fighter-control radar, and the Lichtenstein airborne radar. Knowing the specifications of these radars, the leadership of the IMT made a plan for two variants for the air defense of Budapest and the whole country. They calculated the required quantity of radars for both cases. IMT experts considered that four air-surveillance radars, 30 fire-control radars, 10 fighter-control radars, and four airborne radars were necessary for the air defense of Budapest. As far as the air defense of the whole country was concerned, they requested 100 air-surveillance radars, 60 fire-control radars,

Table 1. A count of the number of staff of the IMT at the end of 1944.

Sections	Subsections	Officer	Civil	Enlisted Men
Staff	Staff of military senior engineer	2		5
	Command	7	3	46
	Finance office	2		11
I. Section	Ballistics	10		1
	Ammunition	14		
	Aim and sight	9		
II. Section	Military bridges and transport	8		1
	Military engineering	5		
	Prime mover	4		
	Camouflage	2		1
III. Section	Hand weapon	7		3
	Artillery and mortar	14		
	Aircraft weapon	6		
	Coaching of armaments industry	26		2
	Mobile repair team	5		2
	Archives and reproduction		4	8
IV. Section	Line signal devices	6		1
	Radio and microwave	5	1	2
	Aggregates	4		
V. Section	Armored vehicles	7		1
	Off-road vehicles	4		
	Engine	6		3
	Truck and superstructure	3		
VI. Section	Chemical	16		2
	Explosive	8		1
	Material	6		1
	Fuel and slush	7		1
VII. Section	Editing of technical specification	10		4
Test fields	Hand weapon (Örkény)	1		32
	Artillery (Hajmáskér)	2		90
	Engineer (Hárossziget)	3	1	33
	Aircraft weapon (Ferihegy)			8
	Armored vehicle (Hárossziget)	2		10
	Signal (Vác)			7
Total		**211**	**9**	**276**

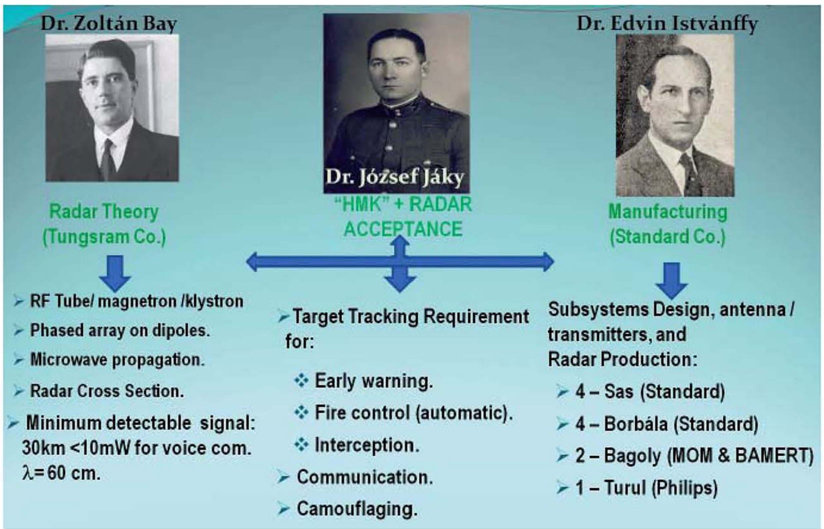

Figure 6. The organizational structure of the Hungarian radar production.

100 fighter-control radars, and 100 airborne radars. On the other hand, the German ally offered one Freya, three small "Würzburg," and two giant "Würzburg Riese" radars, for sale. As regards the Lichtenstein radar, Germany gave a cold shoulder to the request for the purchase of this type of radar, or for the purchase of licenses or technical cooperation.

This unfavorable result was far from the expectations of Hungary, since several modern Hungarian technical devices were supplied to German military industry. For example, there was an order placed from Telefunken to upgrade the mean time between failures of the LD-150 triode, which was less than 50 hours. Andor Budincsevics (1905-1995), an employee of the research laboratory of the Tungsram, got the task. Basic research was performed, and the new triode became so successful that since 1943, all Würzburg radars used these new tubes. Industrial opportunities launched other programs to construct an electron tube with special parameters "sensitive to blue light," and to enter it into production. This tube became the heart of the navigation system of the German V-2 ballistic missiles, and became known even to a Soviet military advisor in the middle of the 1950s [9].

Our allies this did not give, but took away. Although Dr. Jáky twice participated in a study tour in Germany, the Germans did not provide him with any technical information.

It may be assumed that the leadership of the IMT was ready for this eventuality, since the preparation of radar development lead by Dr. Bay and by Dr. Jáky was already underway in October of 1941, in spite of the leadership looking for opportunities to arrange German imports and cooperation. Knowing how the IMT functioned, we can safely say that Staff Engineer Colonel Dr. József Jáky was the father of the idea that home-developed radar could be (and should be) manufactured. He knew the domestic military demands and the domestic technical elite, and personally and together with colleagues of the Fourth Department of the IMT, he had a good scientific knowledge that enabled him to organize the work of scientists, engineers, technicians, and manufacturers, and to draw up military requirements [10]. The staff count of various sections of IMT by the end of 1944 is listed in Table 1 [11].

Dr. Jáky was appointed Ministerial Commissioner responsible for radar matters. Together with Prof. Dr. Zoltán Bay, Dr. Edvin Istvánffy, and his colleagues, he was charged with the task of launching the development and manufacturing of Hungarian radar. In this position, he was the military commander of Bay and Istvánffy. In 1943, when as members of a delegation they together visited Germany, the Freya and Würzburg radar were demonstrated to them from a distance. This made it quite clear that Germany would not furnish Hungary with radar, nor with technical assistance.

4. Organizational Structure of the Hungarian Radar R&D and Manufacturing

In order to achieve this goal, three teams were set up on Jáky's initiation, as Figure 6 shows. The team under Dr. Jáky's direction elaborated the military operational and technical requirements for the military radars to be developed. All military and technical requirements of the radars were combined in the statement of work (SOW), the so-called "HMK" (Common Military and Technical Requirements). The peculiarity of the "HMK" was the brief and compact nature of the structure, commonly written in 15-20 pages, with a focus on the benefit of the new equipment. It was compulsory to apply existing standards that were relevant to the subject matter. Using standards had the advantage that all contracted firms with IMT precisely knew not only the requirements, but also the required test procedures to be fulfilled. A further advantage of this type of SOW was that very complex and classified subjects, such as radar developments, could be subcontracted without giving details on the whole project.

Figure 7. The advanced Hungarian radio production company, Standard Co. (courtesy of Nándor Wlassits) [4]

The "HMK" prepared by IMT members was accepted, authorized by a committee with representatives of military users, main contractors, subject professional scientists, and IMT. The "HMK" became a partner of the contract after authorization. Dr. József Jáky's leadership developed the "HMK," resulting in the construction of the following four types of radars in Hungary: the Sas (Eagle) air-surveillance radar; the Borbála (Barbara) fire-control radar; the Bagoly (Owl) fighter-control radar; and the Turul (Hungarian mythological bird) airborne radar. Precise requirements for the airborne radar were taken over by Philips Hungary Co. Military requirements were formulated for target detection and tracking for early warning, fire control, and fighter control. Required communications among radars, fighters, and the air-defense command center located in Budapest for wired and wireless communications were constructed. Special attention was given to the camouflaging requirement. This team was responsible for project management, military acceptance tests, and handover of the radars to the military user, with all related training, documentation, and follow-on support.

The team of scientists was hallmarked with the name of Prof. Dr. Zoltán Bay, and located in the Tungsram Co. Without attempting to be comprehensive, we mention some names: Viktor Babics (1900-1982), Andor Budincsevics (1905-1995), György Dallos (1910-1945), Antal Horváth, György Papp (1912-1964), Ferenc Preisach, Károly Simonyi (1916-2001), Antal Sólyi (1913-1946), Zoltán Szepesi, Jenő Pócza (1915-1975) Ernő Winter (1897-1971), and István Barta (1910-1978). Their initial technical task was to clarify uncertainties required to detect targets located at a 100 km distance. They had to solve the problem of generating and receiving microwaves, find solutions for a powerful and reliable transmitter, an antenna system, the required receiver amplification at minimum noise level and optimal bandwidth, measure the peculiarities of RF signal propagation, determine the radar cross section of different target types, and measure the minimum detectable signal level required to detect targets at a 100 km range from the radar. The members of the team knew the limits of triode excitation of oscillations and the theoretical potentials of the magnetron and klystron. However, because of wartime and scarce resources, they decided to choose a triode solution. In the laboratory of the Tungsram Co., Winter, Dr. Szepesi, and Budincsevics developed the EC 102 electron tube, capable of delivering 2 W power at an anode voltage of 250 V and at a wavelength of 50 cm to 60 cm.

Dr. Zoltán Bay was born on July 24, 1900, in Gyulavári, Hungary. He graduated in Debrecen, at the Reformed College. He studied as physicist at the Budapest Scientific University. He then got the position of Director and Professor in the Theoretical Physics Department of Szeged Scientific University. Dr. Zoltán Bay became the Director of the Research Institute of the Tungsram Co. in 1936, and the head of the Nuclear/Atomic Physics Department of Budapest Scientific University in 1938. Between 1938 and 1944, he was a member of the Secret Scientific Committee of the Hungarian Institute of Military Technology. After the war, he left Hungary with his family for the United States. He was a professor at George Washington University until 1955. In 1955, Zoltán Bay became head of the Department of Nuclear Physics at the National Bureau of Standards (NBS, today called NIST), where he measured the velocity and frequency of light using a previously unknown measurement method. Because of Bay's research, the 1983 conference of the International Weights and Measures Bureau accepted the definition of a meter (metre) as recommended by Zoltán Bay as a standard. Dr. Bay died at the age of 92, on October 4, 1992 in Washington DC.

The industrial team was headed by Dr. Edvin Istvánffy, who was the technical director of the Standard factory. Lipót Aschner (1872-1952), the general director of the Tungsram company, was responsible for general

Figure 8. The advanced Hungarian radio production company: Tungsram Co. (courtesy of Nándor Wlassits) [4].

management of radar manufacturing, subcontractors, etc. Starting radar manufacturing proved to be a particularly complex task. Several small firms were contracted to produce various subassemblies and main components, while the assembly itself was carried out at the premises of the companies Bamert, Standard, and Philips. Lipót Aschner mentioned that he could never have thought he would finance a project of which he was not allowed to know the content. At many places, the work was done without knowing the final goal. This team, with Géza Sárközi (1903-1985) as a member, developed the planar phased array of the "Sas" air-surveillance radar. The Philips TB2/500 high-power tube was selected for its transmitter, because this powerful electron tube, used for broadcasting, needed a small modification to be implemented for "m" band (called the "VHF" band today) radar usage. This team carried out final assembling, installation, testing, and maintenance of different radar types, with the cooperation of team members of Dr. Bay.

Dr. Edvin Istvánffy was born on January 4, 1895, in Párkány, Hungary. He graduated as an engineer from the Budapest Technical University, and got his Masters in 1922. He got his first position at the Tungsram Co. From 1928, he worked for the Standard Co., where he became Technical Director in 1938. After WW II, he held different positions as head of microwave equipment research/develop establishments. From 1949, he became a lecturer and then, later on, a professor at different universities, such as the Technical University of Budapest. He got his doctoral degree in Technical Science in 1953. Dr. Istvánffy supervised the construction of the first powerful 120 kW broadcasting radio station in Hungary in 1933 (Figure 7). He played a significant role in the establishment of advanced Hungarian microwave technology. In his last 15 years, he focused his activities on problems related to antenna and other RF-component efficiency improvement, and on the education of the next engineering generation. Dr. Istvánffy died on the June 3, 1967, in Budapest.

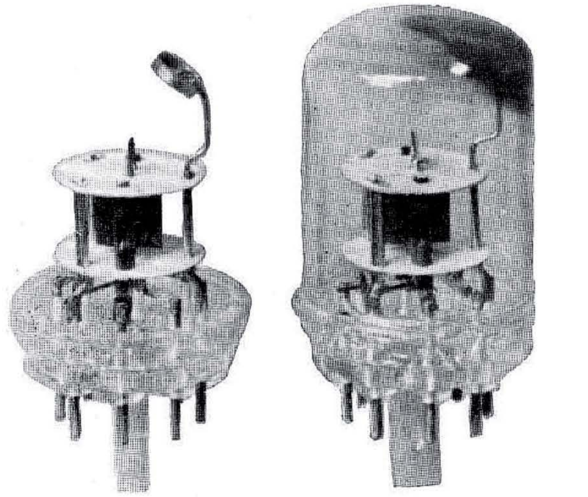

Figure 10. The EC 102 electron tube [13].

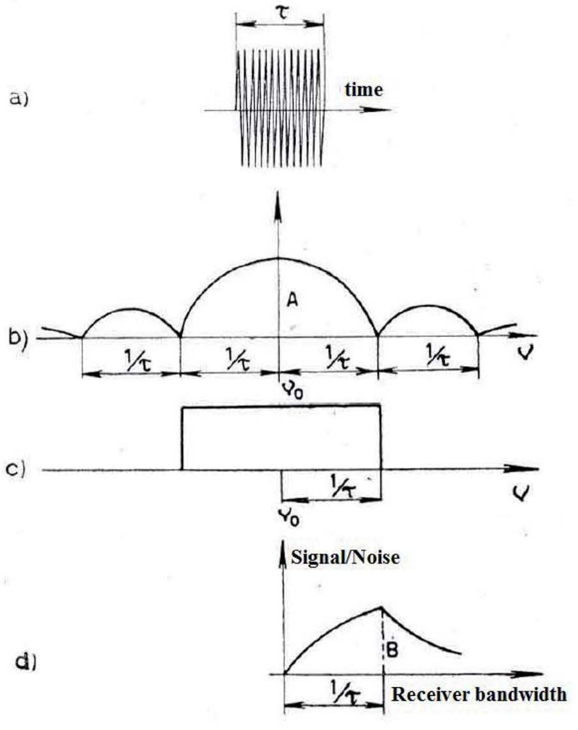

Figure 9. The pulse spectrum and matched filter as analyzed by Dr. Bay and his team [14].

5. Development of the Requirements for Hungarian Radar

The literature on theoretical basics and technical achievements was available for Hungarian researchers and engineers until 1939. The work of James Clerk Maxwell, Heinrich Rudolf Hertz, Nikola Tesla, Guglielmo Marconi, Alexander Stepanovich Popov, and the patent of Christian Hülsmeyer were known. The Hungarian researchers were well aware of the theoretical basis underlying the physics of electromagnetic waves. In addition, they assumed that radars were built in strict secrecy in Germany, in the United Kingdom, in the USA and maybe in Italy, as well.

The Hungarian radios were world famous in the middle of the 1930s, proven by the fact that about 60% of the world's high-quality radio manufacturing was in the hands of Hungarian companies such as Orion, Tungsram, and Standard. Other companies, such as Philips and Telefunken, had special cooperation and interest in Hungary [12]. At that time, the Hungarian companies had permanent legal or RF-technology transfer cases with the biggest radio manufacturers, worldwide. In 1932, Tungsram started R&D activities in the field of television. They started cooperation with the Radio Corporation of America in 1938 (Figure 8). The Standard Co. had close connections with the International Telephone & Telegraph Co. After the bankruptcy of Ericsson in 1937, all its Hungarian properties and purchase requests became Standard properties [12]. Since 1928, all Hungarian Military

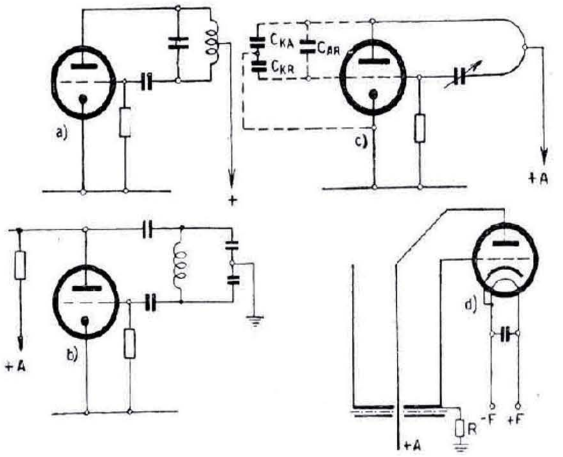

Figure 11. Different RF signal generators based on the EC 102 [13].

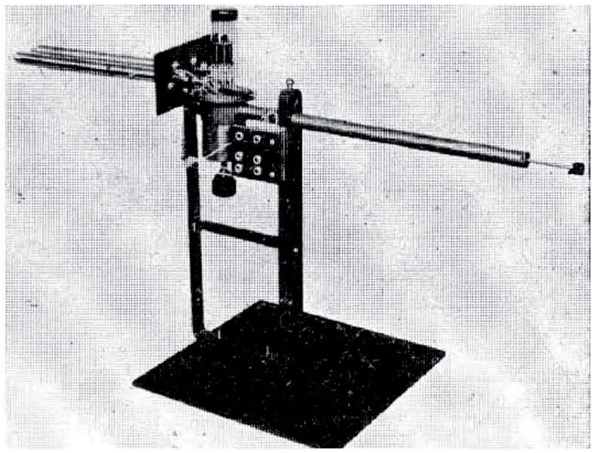

Figure 12. An experimental RF signal generator based on the EC 102 [13].

Radios were manufactured at Standard Co., supervised by Dr. Jáky's department at IMT. E. Winter, Dr. Szepesi, and A. Budincsevics developed a *mini RF tube* at the Tungsram Co. at the end of the 1930s for military radios, which was also used in radar applications. Dr. Bay and his team knew about the importance of the application for radar of the Barkhausen-Kurz reflex triode oscillator, the split-anode magnetron and Heil-oscillation, and the Klystron, which was limited to very low power at that time [13]. As Hungary gained top-level knowledge of electron-tube RF technology, and while the allocated time for R&D and manufacturing was short given the available engineering resources, the RF electron tubes were selected as key RF components for Hungarian radar.

Most likely, Dr. Bay got the preliminary research task from the IMT Department 4 to produce a survey for the development of a Hungarian radar prototype at the end of the 1930s. He and his colleagues knew the main challenges of radar equipment that had to be solved from the literature, and from their own ionospheric research. The first challenges mentioned by Dr. Bay were that the radar could be built only at RF frequencies higher than the commercial radio-broadcasting services used at that time [10]. His two main arguments were that the RF energy radiation and collection from a small spherical object could be more efficient at short wavelengths, and the modulation flexibilities–bandwidth allocation of the RF signal at shorter wavelengths – would increase.

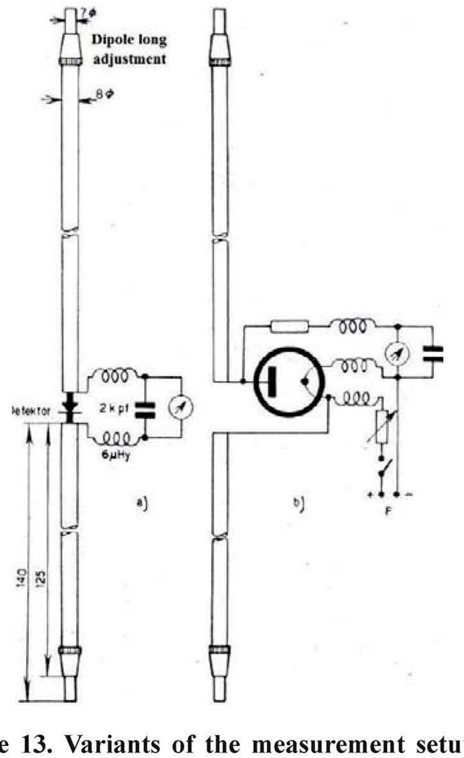

Figure 13. Variants of the measurement setup for measuring EME strength at a 50 cm wavelength [13]

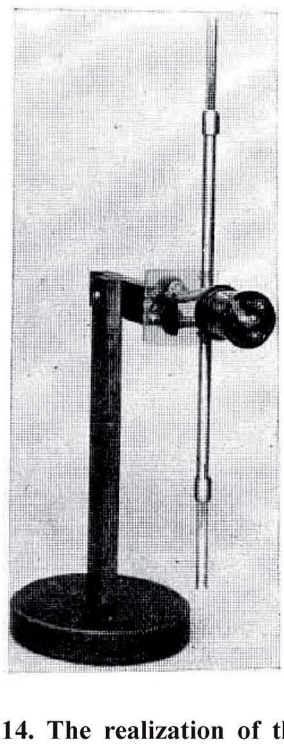

Figure 14. The realization of the EME measurement [13].

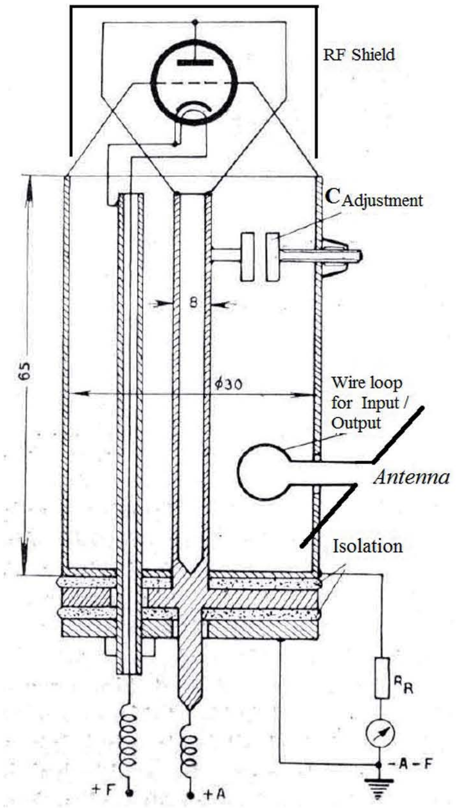

Figure 15. A cavity-resonator-based RF transmitter final amplifier with an antenna for a 50 cm wavelength [13].

From that moment, Dr. Bay's team's activities focused on uncertain factors of radar theory, such as RF signal excitation, RF signal propagation at higher frequencies, energy transmission, energy reflected from the collecting target surface, and improvement of the signal-to-noise ratio at the receiver's output.

We know that two modulation types for the radar application were analyzed by Bay's team. The first was the pulse modulation of radio waves used to measure the height of the ionosphere and to probe its interior layers, published by Gregory Breit and Merle Tuve in 1926. The second was the continuous-wave frequency-modulation method, used for the same aims as Breit and Tuve, published by E. V. Appleton and M. Barnett in 1925 [13].

The question was which modulation had advantages from the point of view of target detection, and which was the simplest in realization? Theoretical analyses were carried out by Dr. György Papp, Dr. Károly Simonyi [23], Dr. Antal Sólyi, and Dr. Zoltán Bay. Figure 9 shows a) the transmitted pulse, b) its Fourier spectrum, c) the simplified shape of the spectrum, and d) the signal-to-noise ratio at the output of the receiver as a function of the receiver's bandwidth.

After mathematical justification, they found that the (amplitude of the voltage) signal-to-noise ratio at the receiver output [14] was given by

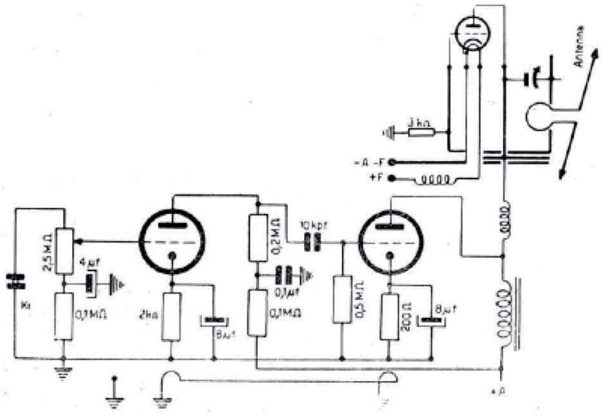

Figure 16. An RF transmitter final amplifier with an antenna for a 50 cm wavelength [13].

$$\frac{\text{signal}}{\text{noise}} = \frac{\chi}{\sqrt{4kTR}} V \sqrt{\tau}$$

where χ is a constant, including the radar cross section (RCS) of the target; R is the input resistance of the receiver (in practice, it was measured at the grid resistance of the electron tube); k is Boltzmann's constant; T is the receiver temperature (290 K); V is the transmitted pulse voltage; and τ is the transmitted pulse width.

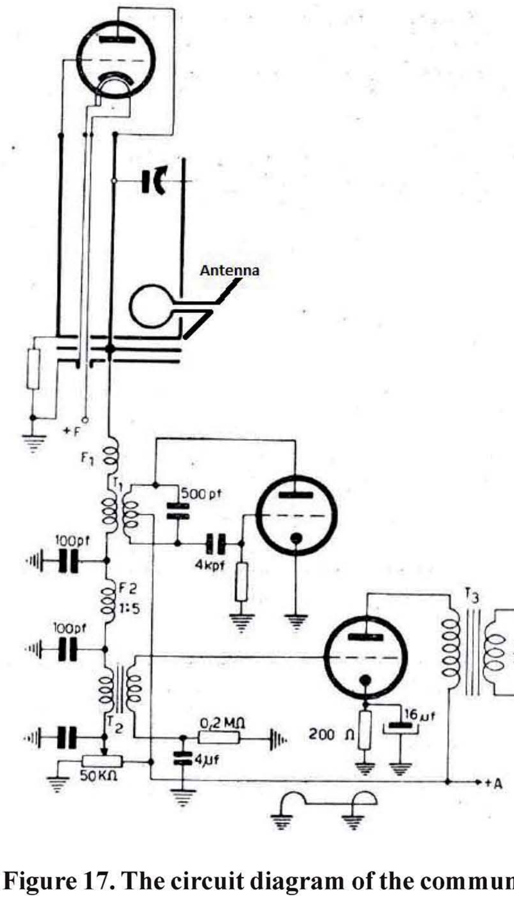

Figure 17. The circuit diagram of the communication test bed receiver for a 50 cm wavelength [13].

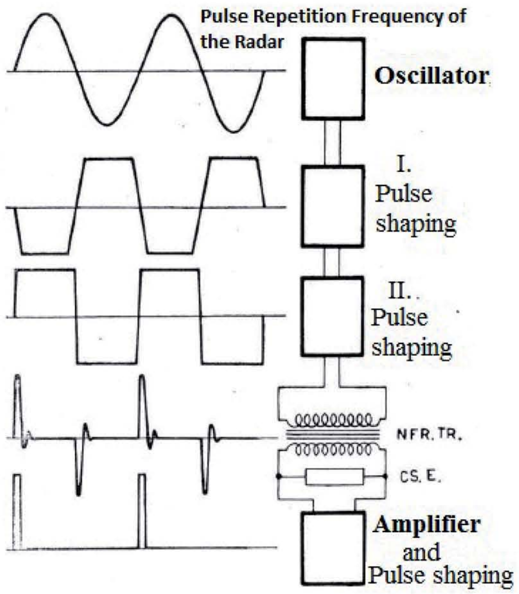

Figure 18. The RF pulse from pulse-repetition-frequency modulation [14].

This equation proved that target detection depended only on the *signal energy*. Subsequently, radar development based on continuous wave was dropped: the pulse technology was more familiar to them. A second conclusion of Dr. Bay was that the optimum bandwidth of the receiver was determined by the transmitter's pulse width.

The EC 102 tubes, manufactured by Tungsram Co., made it possible to do experiments and clarify some unknown questions related to the radar RF technology. The electron tube EC 102 with a 250 V anode voltage emitted 2 W power at a wavelength of 50 cm to 60 cm with 35% efficiency, while still working at 43 cm with 1 W. Figure 10 shows the EC 102 tube, while Figure 11 shows the connections for the signal generation. Figure 12 shows the full RF signal generator based on the EC 102 electron tube, which was used as a stable signal source generator for the experiments.

In building the equipment for transmission and reception of RF energy and its proper measurement peculiarities, the first steps to be solved concerned the development of test equipment. György Dallos carried out the required development. The antenna of the test system was the simplest part to be solved, since a half-wavelength dipole, 25 cm with 80 ohm radiation resistance, was very easy to balance. The electromagnetic energy (EME) was detected and measured with a crystal diode or a specially connected triode (see Figures 13 and 14).

Both the transmitter and the receiver used EC 102 tubes for simplicity (Figures 15-17). The first experiments were related to the determination of the signal-to-noise ratio, realized between Újpest and Vác, some 30 km apart, using less than 10 mW power. Having results on crystal-clear communication within the line of sight, it was possible to prove the theoretical calculations of the minimum detectable power required for target detection by experiment. The team assumed that the target was located at a 100 km distance from the radar, and that its surface reflected back 10% of the received energy. They assumed the receiver bandwidth was 10 kHz, and the receiver temperature was 290 K. Theoretical calculations showed that 50 mW power was enough for a 100 km communication range. This result was unusually small compared to the power of broadcast HF transmitters used at that time, but it was still 100 times larger than required for radar signal detection. The difference was explained by Dr. Bay as the higher signal-to-noise-ratio requirement for the crystal-clear radio communication than required for detection of the target echo with a signal-to-noise ratio equal to 10.

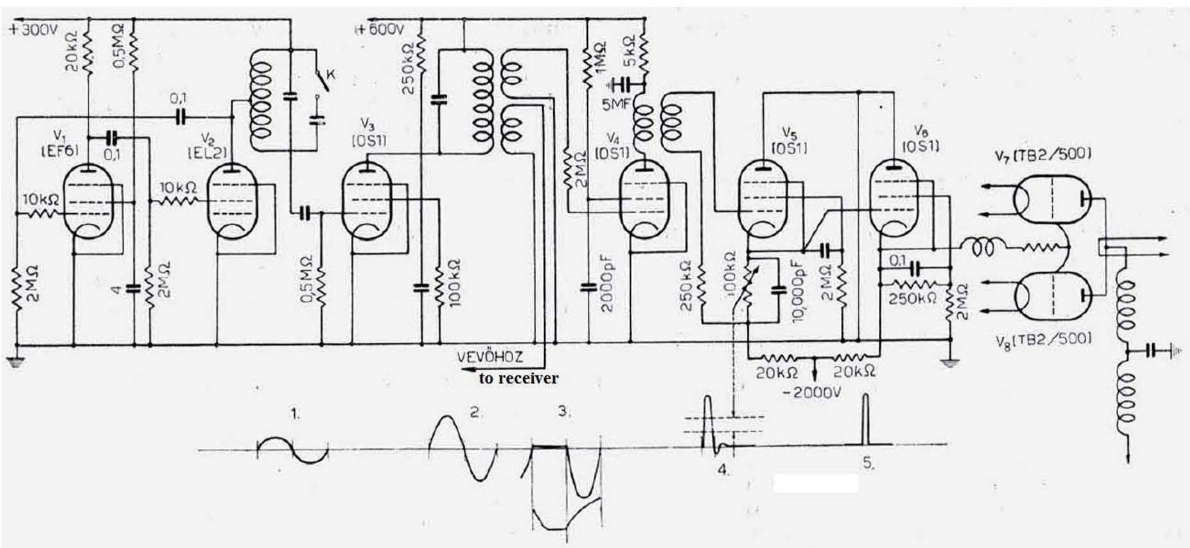

Figure 19. The transmitter exciter and modulator of the Sas (Eagle) air-surveillance radar [16].

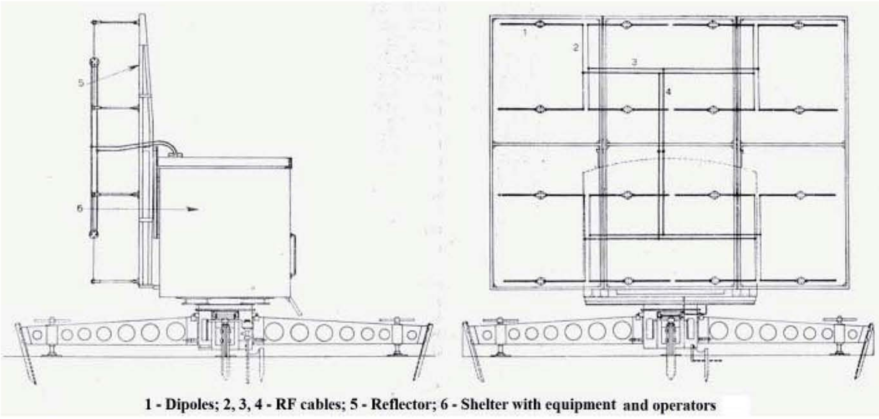

Figure 20. The Sas (Eagle) air-surveillance radar [15].

Using mobile receivers, atmospheric losses were determined under different weather conditions and environmental circumstances. Measurement results showed that the atmospheric losses were smaller at a 50 cm wavelength than in the HF band, and could be neglected. With further analyses and calculations of the 10 m^2 target, located at a 40 km distance, detection requirements for pulse radar were determined. Dr. Bay concluded that the radar parameters should be as follows: the transmitter wavelength was 50 cm; the parabolic antenna dish/reflector diameter was 3 m; the pulse repetition frequency was 4000 Hz; the pulse width was 1 μsec; and the transmitted peak power was 10 kW.

The next question to be solved was the RF signal pulse generation with the required pulse repetition frequency. Dr. György Papp, Dr. Zoltán Szepesi, and Antal Sólyi analyzed the advantages and shortcomings of the grid- and anode-controlled solutions. They found the grid-controlled case easier to realize, but that the reliability of the anode-controlled solution was higher. Figure 18 shows the pulse repetition frequency and the transmitter pulse generation method for Hungarian radars. This was a unique method compared to British or USA types of radar, which had separate modulators. Both the British and Hungarian solutions had advantages and disadvantages.

In parallel to this work, E. Winter and A. Budincsevics developed the EC-103 for 2.5 kW and the EC-108 for 12 kW peak powers for the 50 cm to 60 cm wavelength radars! The EC-108 electron tube was used for Borbála, Bagoly, and could also be used for the final amplifiers of the "Turul" radars.

The results were handed over to the Standard Co., Dr. Edvin Istvánffy's industrial team, in order to develop radar devices for practice in October 1942.

6. Technical Performance of Hungarian Radars

The work order was so secret amongst the teams that even if somebody's close colleagues knew each other's studied problems, it was prohibited to be informed about the details. The only exception to this rule related to the team leaders. Dr. Edvin Istvánffy had done some preliminary preparatory work on radar subsystems, such as the transmitter and phased-array antenna designs, for the "m-" wave band.

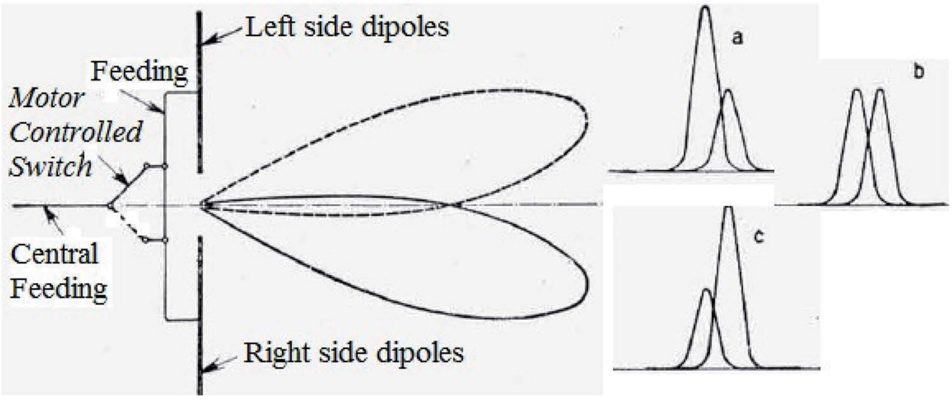

Figure 21. The "Monopulse" technique of the Sas (Eagle) air-surveillance radar [15].

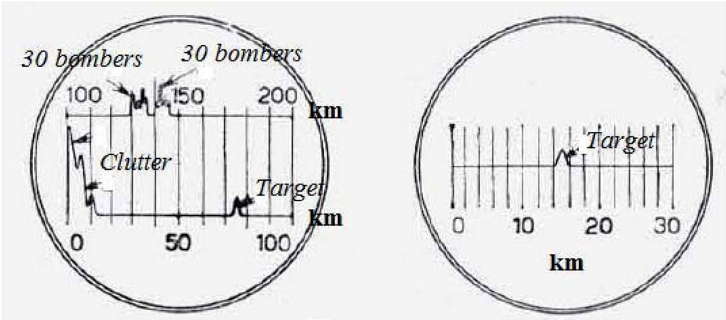

Figure 22. The "general and target-dedicated" indicators of the Sas (Eagle) air-surveillance radar [15].

6.1 Sas (Eagle) Air Surveillance Radar

The detailed theoretical requirements of the "Sas" radar were formulated by the team of Dr. Bay. The technical realization and manufacturing was solved by Dr. Istvánffy and his team. Here is a summary of the radar's technical performance:

- Operational frequency: around 121 MHz
- Maximum detection range above 200 km; required early warning range below 200 km
- Transmitter peak power: 20 kW
- Transmitter pulse width: 8 µsec (variable from 5 µsec to 50 µsec, *1 msec for moon radar*)
- Pulse repetition frequency: 750 Hz (about)
- Antenna: Horizontally polarized planar phased array with 16 parallel-feed dipoles, while the reflector size was 4 m × 5.3 m

Figure 19 shows the circuit diagram of the "Sas" radar transmitter-exciter. The 20 kW peak power produced by the TB2/500 transmitter electron tubes was connected in parallel with a 9000 V anode voltage and had a negative grid-control voltage. The high anode voltage caused sparking at the beginning, but this stopped when the burn-in process of the tubes and the power supply was modified for current limiting to avoid damage of the tubes in case of sparking. The pulse repetition frequency of 750 Hz was generated as in Figure 18. The transmitted pulse width was 8 µsec for normal air surveillance, and variable by potentiometer in position 4 of Figure 19 for sector searching or fighter control. A special output transformer produced the reference signal required for the heterodyne receiver.

The receiver's front end contained a spark gap for receiver protection, with a preamplifier. The EFF-50 mixer tube produced down conversion to 9.2 MHz, three tubes then amplified the signal, and subsequently a mixer for 3.2 MHz down conversion was followed by three tubes for signal

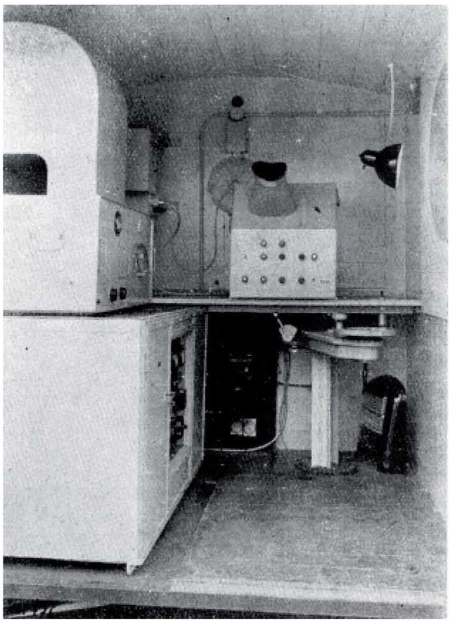

Figure 23. An inside-the-cabin view of the Sas No. 1 air-surveillance radar, equipped with one indicator [15].

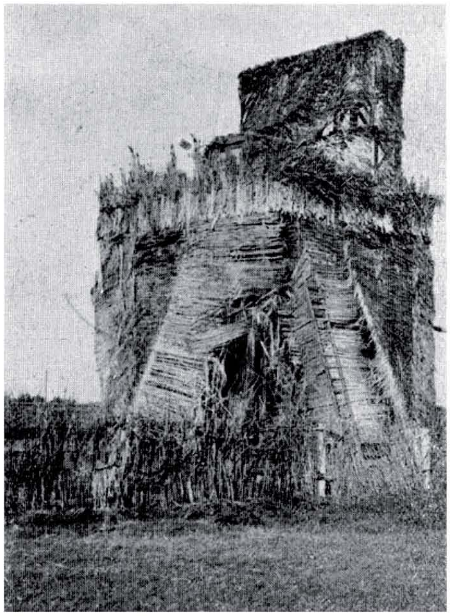

Figure 24. A covered Sas air-surveillance radar in operation [15].

amplification. The bandwidth of the receiver was optimal for an 8 μsec pulse, 200 kHz, as Dr. Bay's calculation for transmitter signal matching required.

The antenna system and the shelter with the equipment was modified a few times as operational requirements changed (Figure 20). The shelter with the antenna system, equipment, and operators rotated on its main axis. The horizontally polarized planar phased array contained $4 \times 4 = 16$ dipoles, with symmetrical feeding at the end of the neighbors' dipoles. The distances between neighboring dipoles were half a wavelength, while the distance between the dipoles and the aluminum reflector was a quarter wavelength. Horizontal polarization was chosen because observations showed that the horizontal size of the airplanes was six to eight times larger than the vertical size. The radar cross section (RCS) of the targets was therefore higher in horizontal polarization. The calculated half-power antenna radiation beamwidth was $\pm 9.5°$ in azimuth for common transmit-receive. In practice, the drop of the target power was very well detectable at $\pm 5°$ off-boresight azimuth [15]. Targets at a distance of 100 km could be measured with a standard deviation of 1.7 km in azimuth. An improved azimuth-accuracy measurement technique was developed and implemented for the "Sas" radar, as Figure 21 shows.

Istvánffy wrote in [15] that "it was required to change the beam position of the planar array a few hundred times per second," and later on, he wrote about the pulse repetition frequency of 750 Hz. No more details are known today, but we hope a precise document will be found in the future. We imagine it was a special rotary-joint-like device, which had a small gap between the two halves of the antenna-feeding elements and the rotating arm sliding on the surface of the feeding-network connection. The sync motor switch, controlled by pulse-repetition-frequency pulses, changed the length of the feeding network, resulting in a phase shift to the left and to the right side, with half a pulse-repetition-frequency period to one side. This simple solution allowed moving the beam and the target positions in the second indicator, as is shown in the subfigures of Figure 21 labeled "a," "b," and "c." This type of "monopulse technique" allowed precisely measuring the target's position.

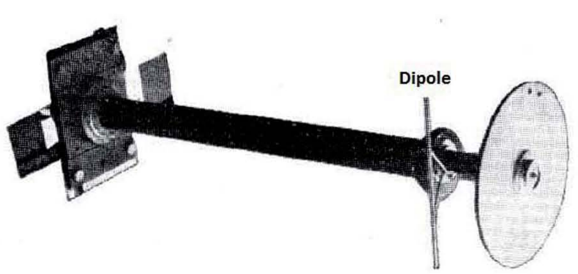

Figure 26. The "Borbála" rotating-dipole position and its armature [14].

However, the second "Sas" radar had already been produced with two target indicators supporting this idea, as Figure 22 shows. The first indicator was used for a general overview of the air picture, while the second indicator was used for fighter control. The first indicator showed different types of targets and clutter. It was mentioned in [15] that targets with a large RCS were frequently seen on the indicators at the beginning of the time line as second-time-around targets, and they could possibly be followed with the second indicator, which had a 30 km range and was positioned at the required distance.

Figure 23 shows an internal view of the "Sas" radar cabin. The largest part of the equipment was the power supply, located in the left bottom part, while the transmitter and receiver can be seen on top of the power supply. The indicator was in the middle, surrounded with communication and auxiliary equipment. Figure 24 shows the "Sas" #1 radar in operational position.

6.2 Borbála Fire-Guidance/ Control Radar

The category of the Borbála fire-guidance/control radar needs further clarification, because the radar was connected to the Juhász-Gamma target-position calculator for artillery usage. The Juhász-Gamma target-position calculator was separately developed. This analog computer continuously gave the target-position prediction for the air-

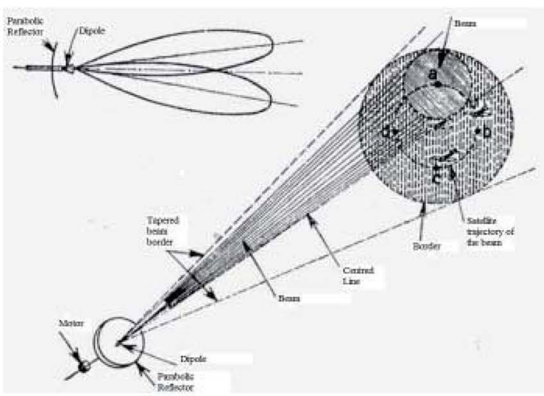

Figure 25. The "monopulse" technique of the "Borbála" fire-control radar [15].

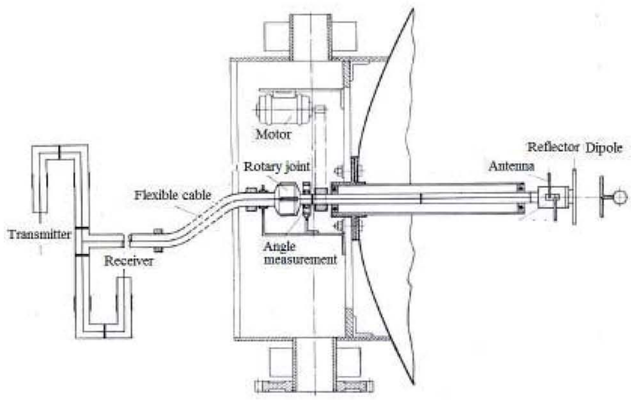

Figure 27. The Borbála antenna's armature, the rotating dipole, and auxiliary equipment [14].

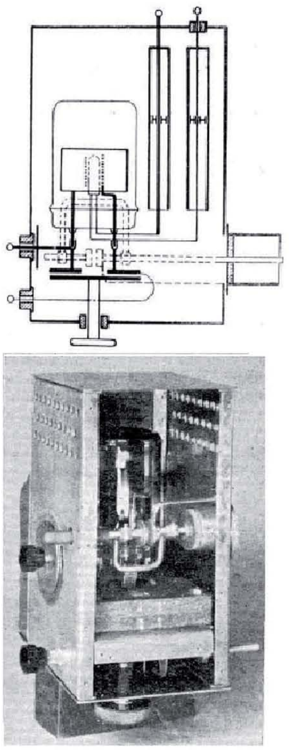

Figure 28. The connection and realization of the RF pulse oscillator of the Borbála radar [14].

defense guns. The Borbála radar and the Juhász-Gamma target-position calculator were connected for automatic control of air-defense guns in their usual operational mode. In the case where the input parameters of the Juhász-Gamma target-position calculator were of low quality, the Borbála radar could give fire guidance operating alone.

The detailed technical requirements of the Borbála radar were formulated by Dr. Bay's team. The technical realization and manufacturing were due to Dr. Istvánffy and

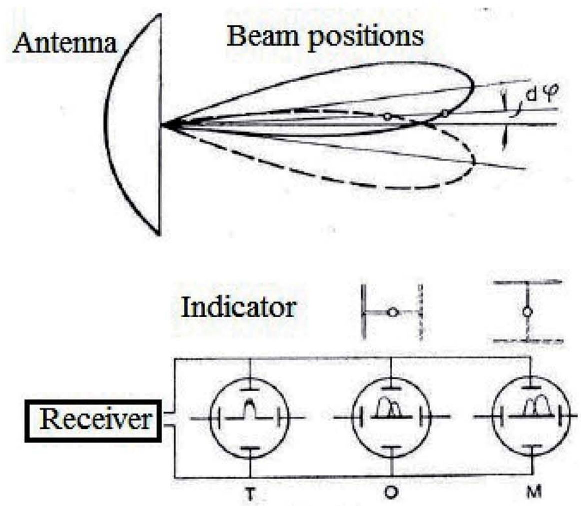

Figure 30. Target positioning in the indicators of the Borbála radar [14]

his team. Here is a short summary of the radar's technical performance:

- Operational frequency range: 500 MHz to 600 MHz (still operational at 700 MHz)
- Maximum detection range: 40 km; required fire-control range from 20 km
- Transmitter peak power: 10 kW
- Transmitter pulse width: 1 μsec
- Pulse repetition frequency: about 4000 Hz
- Diameter of the parabolic reflector: 3 m

The main challenge was the determination of the movement and position of the tapered (shaped) beam. During visits to Germany, Dr. Jáky had seen rotating dipoles on the Würzburg radar. The advantage of this solution for the target's angular-accuracy measurement became clear

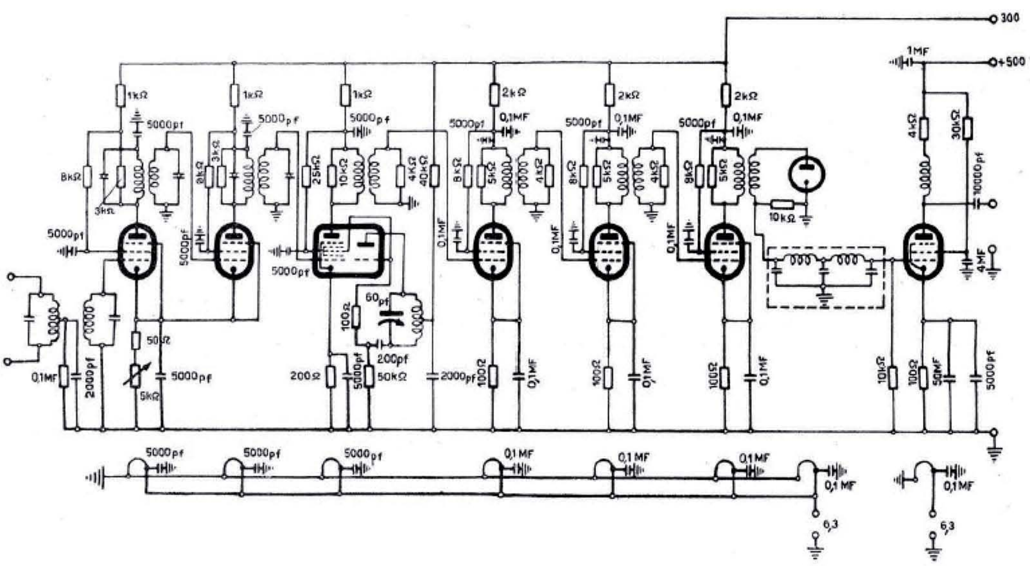

Figure 29. The receiver of the Borbála radar [14].

Figure 31. Antenna adjustment of the Borbála fire-control radar. Dr. Károly Simonyi is shown in front of the antenna [23].

to the Hungarian researchers. Figure 25 illustrates how the tapered beam of the Borbála fire-control radar moved in the case of two closely spaced targets. Figure 26 shows the Borbála rotating dipole's position and its armature. Dr. Istvánffy developed an electronic version of beam movements similar to those that were implemented for the "Sas" radar, but details of the implementation in the Borbála radar solution have not yet been found.

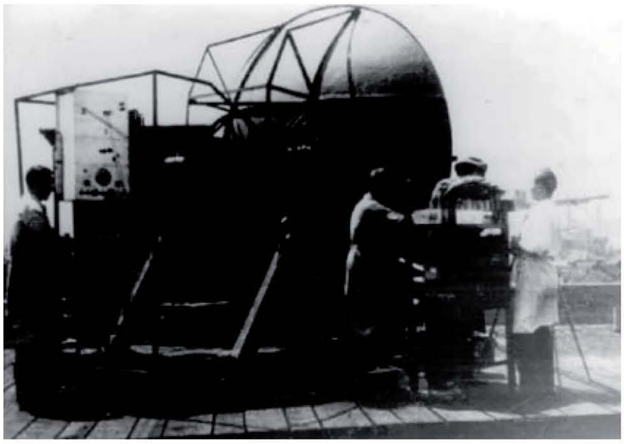

Figure 32. Testing and adjustment of the Borbála fire-control radar; Dr. Károly Simonyi is at right [23].

Figure 27 shows the detailed construction of the Borbála radar-antenna system. The dipole to the right of the reflector was required for beam-position calibration and adjustment. One of the most challenging tasks was for Dr. Bay's team to develop and implement a stable signal source. Figure 28 shows the connections, cavity resonator, and shielding of the Borbála radar RF pulse oscillator (left), developed by Dr. Zoltán Szepesi. It was constructed in the form shown at the bottom part of the picture.

Figure 29 shows the receiver details and the component connections of the Borbála radar. The main developer was György Dallos.

The "Borbála" radar receiver was based on Philips EFF 50 pentodes. The transmitter pulse width was 1 µsec, and as a consequence, the receiver required 1 MHz bandwidth, with very low noise and high-gain amplification.

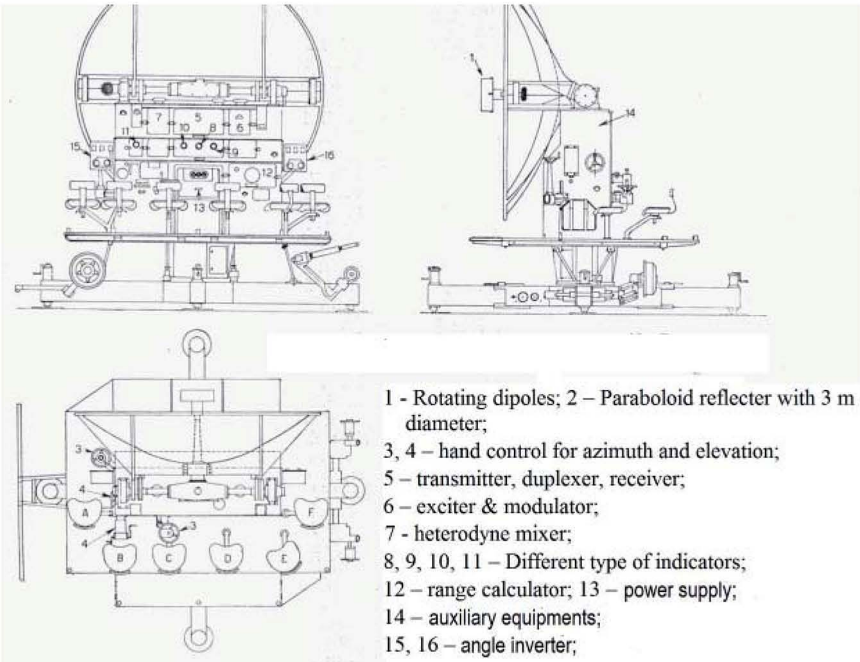

Figure 33. The Borbála fire-control radar on a mobile platform [14].

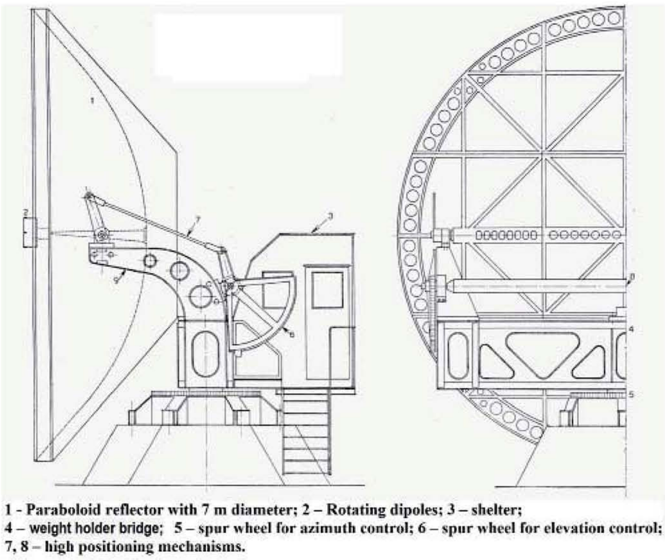

Figure 34. The 14-ton Bagoly (Owl) fighter-control radar [14].

The main issue was the double frequency conversion from 600 MHz down to 37.5 MHz, amplification, and then down conversion of the IF signal to 6 MHz, signal amplification, and detection. The local oscillator was stabilized with a cavity resonator at 250 MHz, but its working point was set on a higher harmonic to get the 37.5 MHz IF. The solution was developed by Lőrinc Vámbér.

Continuous operation of the "Borbála" radar with a pulse repetition frequency of 4000 Hz allowed measuring the target distance at 40 km with ±15 m theoretical precision, which could not be practically achieved, because the indicator resolution was 400 m. Special measures were required for expanding the indicator's resolution.

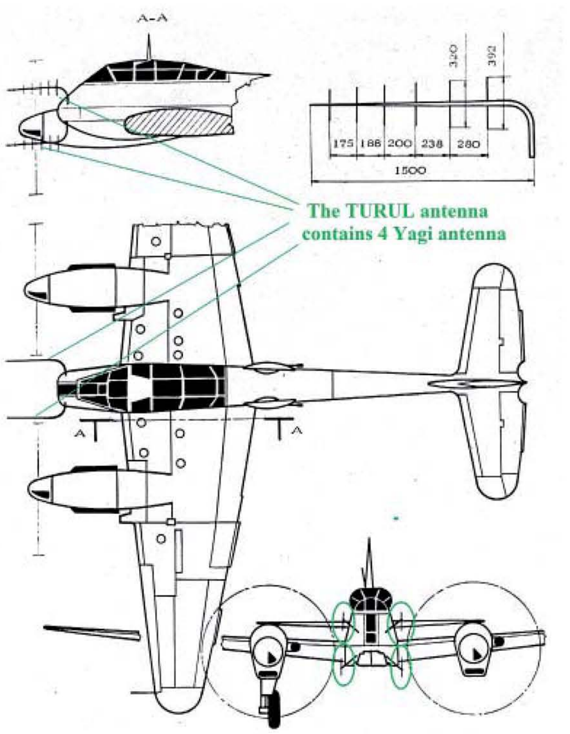

Figure 35. The Turul airborne radar [15].

The solution suggested by Dr. Bay allowed improving the determination of the angular position to close to the theoretical one, while all targets in the search volume were indicated relative to the center of the indicator. It was developed by Károly Simonyi, Kálmán Magó, and György Papp, and patented. Target positioning on the indicator is shown in Figure 30.

Figure 31 shows the dipole positioning process in the antenna reflector.

The first experimental test of the Borbála prototype for echo detection of environmental objects and vessels on the river Duna was successful within an 18 km range on April 2, 1943. The picture in Figure 32 was taken at that time. Figure 33 gives an overview of the Borbála radar's main equipment's location, and the operator's position within the radar.

6.3 Bagoly (Owl) Fighter-Control Radar

The detailed technical requirements of the Bagoly radar were formulated by Dr. Bay's team. The technical realization and manufacturing were solved under the leadership of Dr. Istvánffy and his team, belonging to the Hungarian Optical Machinery Co. (hereafter called HOM), and the Bamart Co. Here is a summary of the radar's technical performance:

- Operational frequency range: 500 MHz to 600 MHz (still operational at 700 MHz)
- Detection range around 70 km
- Transmitter peak power: 10 kW
- Transmitter pulse width: 1 µsec
- Pulse repetition frequency: about 2000 Hz
- Diameter of the parabolic reflector: 7 m

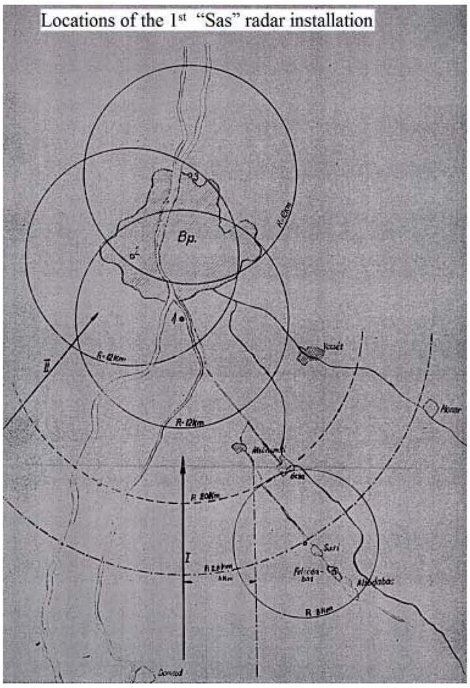

Figure 36. The locations of the first "Sas" radar installations (courtesy of *Haditechnika*).

The electrical parts of the technical challenges were solved during development and fabrication of the "Sas" and "Borbála" radars, but the mechanical construction required a professional in this field. Dr. Jáky tasked the RÁBA Automotive Group Co. and Machinery works Diósgyőr for development and installation of the 14 tons of construction armature. Figure 34 shows the construction of the radar.

6.4 Turul (Hungarian Mythological Bird) Airborne Radar

The detailed technical requirements of the "Turul" airborne radar were formulated by Dr. Bay's team. The technical realization and manufacturing were solved under Dr. Istvanffy's leadership, and his team belonged to Philips Hungary Co. Here is a short summary of the radar's technical performance:

- Operational frequency range: 500 MHz to 600 MHz (still operational at 700 MHz)
- Detection range around 6 km to 7 km
- Transmitter peak power: 1 kW to 2 kW?
- Transmitter pulse width: 1 µsec (variable)
- Pulse repetition frequency: 4000 Hz (about?)
- Antenna: four Yagi antennas on the nose of ME-210 Ca.

The electrical parts of the technical challenges were solved during development and fabrication of the "Sas" and "Borbála" radar. The main challenges were related to the installation peculiarities of the ME-210 fighter. Hungary procured licenses for the ME-210 for production, and the first airplane manufactured in the RÁBA Automotive Group Co. flew in March 1943. The prototype was tested, but disappeared with all related documents in 1944. Most likely, the management of Philips Hungary Co. put it in safe keeping. Figure 35 shows the construction of the Turul airborne radar. Most of the information related to this radar was based on [9].

7. The Situation at the End of WW II

7.1 Hungarian Radar Dislocation and Operational Uncertainties

The first installation of the "Sas" long-range air-surveillance radar on the top of the Jánoshegy mountain, within Budapest, produced catastrophic target-detection performance. The radar was installed close to the location

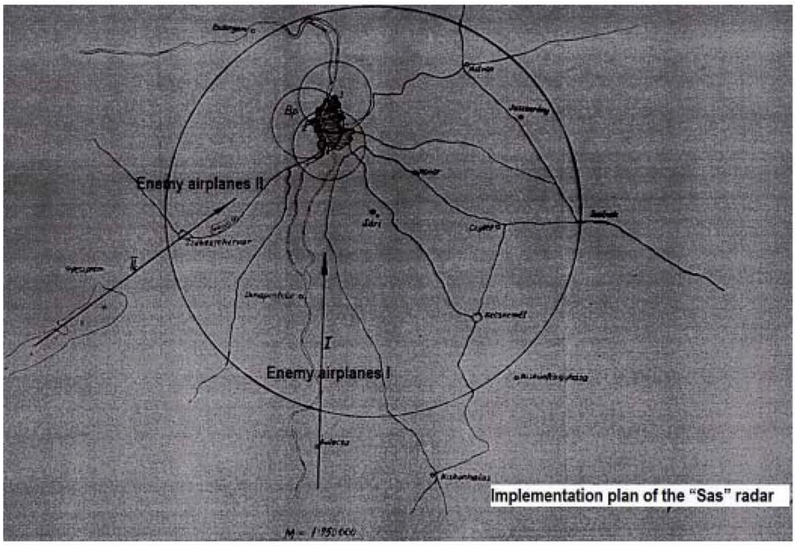

Figure 37. The implementation plan for the "Sas" radar (courtesy of *Haditechnika*).

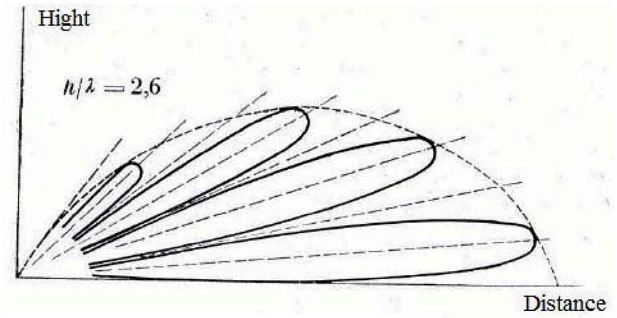

Figure 38. The vertical antenna pattern of the "m" (today called "VHF") band radar [16].

marked as "2" in Figure 36 in August 1943. Figure 36 shows three locations of the "Borbála" fire-control radar around Budapest. It has to be mentioned that the codename "Borbála" was used by the Hungarian Air Force for the Würzburg-D radar, procured and delivered in May 1943. At this time, the Hungarian-manufactured fire-control radar was not ready for military operation. A fully functioning signal network was built for the tests, for training the crew, and for the adjustment of local radar settings. Support of the Hungarian Air Force was requested and guaranteed. The "Sas" radar tests task list focused on the collection of data on the detection performance of the airplanes and the military operational usage, such as target allocation time and precision requirements determined by the operational possibilities of the air-defense guns. A high-priority task was to gather experience on how to select a radar site, on installation, and on operational and maintenance issues required for upgrade of the three other radars that were already being manufactured. A similar method was implemented for preparation of the manufacturing of the "Borbála" radar a few months later.

The Hungarian Air Force fighters flew flight paths determined by Dr. Jaky. The first flight path was planned for Budapest's airspace from a distance of 150 km at noon for two hours. The first measured observation indicated that the targets were detected and tracked at a range of 40 km to 100 km, while the detection differed over the time of day and the weather conditions. The experimental data collection continued until November 1943. It became clear that the Würzburg-D radars could not be supplied with precise and timely information on targets from this "Sas" radar position because the continuous efficient detection range was 12 km to 14 km in daytime, and 20 km to 25 km at night. The radar had an 8 km cone of silence in the middle of Budapest, dead zones, and unwanted reflections due to the Buda Mountains, while the Würzburg-D radars required at least a 20 km continuous track on approaching airplanes. These requirements could not be fulfilled from this position, as the flight paths of enemy airplanes approaching Budapest from the Duna valley and lake Balaton in Figures 36 and 37 show.

Deeper analyses of the measurement results and calculations of Dr. Isvánffy on the "m"-band multipath observations indicated that reallocation of the radar required a flat surface, of which Hungary had a lot. Figure 38 shows the antenna's vertical pattern for the "m-" band radar, installed on a flat surface, published by Dr. Istvánffy [16]. The vertical antenna pattern had maximums and notches caused by multipath. They were calculated for the case of a ratio between the antenna's phase center to the wavelength equal to 2.6. Dr. Jaky's team found a suitable location for "Sas" systems far from high buildings and trees, north of the Sári village, 200 m from the main road. There were power lines in service, and it was easily accessed by train and vehicle. The radar operators and support teams could be quartered in good conditions. Last but not least, the radars and other equipment could be camouflaged as agricultural equipment. Figure 39 shows the first two Hungarian-manufactured "Sas" radar installations.

On December 20, 1943, the first two "Sas" Hungarian-built radars went into military operation. One of the radars was in permanent 360° azimuth air-surveillance mode. The second radar had a sector-search task on targets requiring more precise position and/or determination of the number of targets for fighter control or early warning. The military operational requirements and applications of the

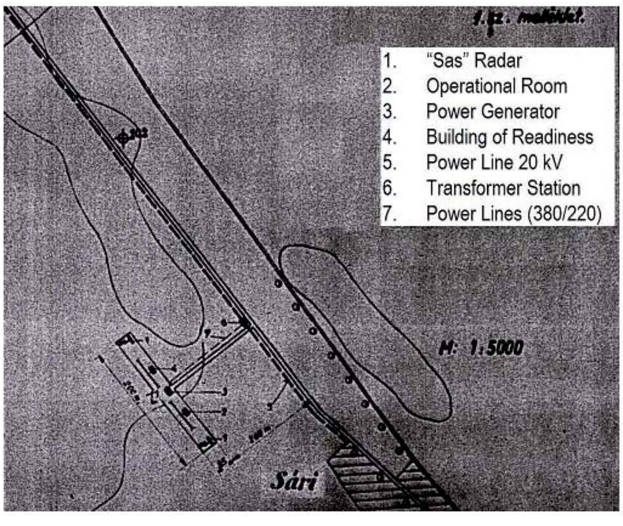

Figure 39. The installation of the "Sas" radars at Sári village (courtesy of *Haditechnika*).

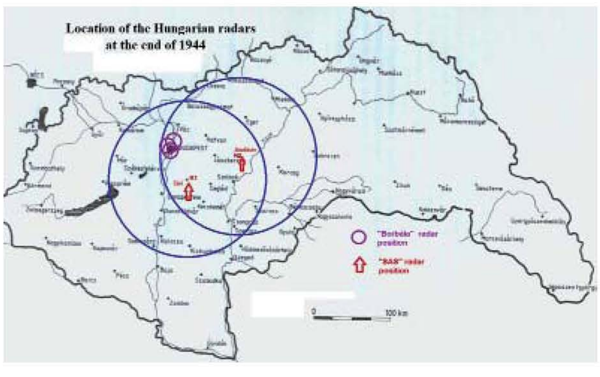

Figure 40. The locations of the Hungarian WW II radars (courtesy of *Haditechnika*).

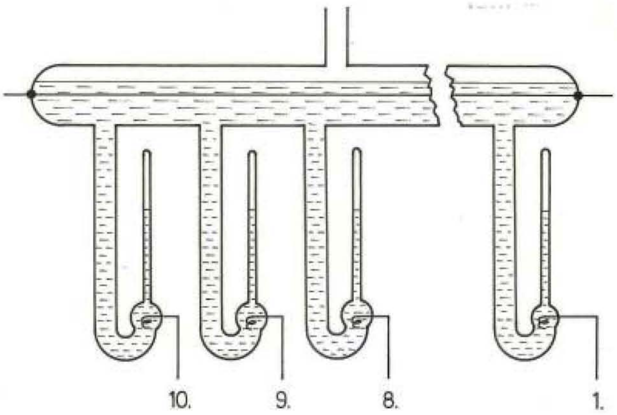

Figure 41. The first radar pulse integrator: the hydrogen coulometer (courtesy of Természet Világa).

Hungarian-made radars were very similar to the techniques applied by the German experts. It was planned for them to be operational, but no account has been found of the real operation of the Borbála and Bagoly radar installation for this radar site. A similar installation of "Sas" radars was in Jászkisér. From this moment, "Sas" air-surveillance radars sites played a significant role in Budapest's air-defense system.

Figure 40 shows the location of the Hungarian radars at the end of 1944. Four units of the "Sas" long-range air-surveillance radar and (with some uncertainty) four units of the Borbála fire-control radar were in military operational usage. They were elements of the air defense of Budapest. The Hungarian air-defense system, augmented by Hungarian surveillance and fire-control radars, efficiently destroyed the enemy aircraft, or the enemy was forced to use a high altitude. Bombing targets from high altitudes, such as South and North Railway Bridges located in Budapest, was not at all efficient. The fact was that more than 1000 bombs were dropped on each of both bridges, but only the North Bridge was hit by one bomb. Unfortunately, mass bombing caused many civilian casualties. After the occupation of Hungary by Germany, only the "Sas" radar locations were able to provide useful information to the Hungarian military leadership.

Four Borbála radars were manufactured to supply data for anti-aircraft artillery at the end of 1943. The first, the prototype of the Borbála radar, started an intensive series of tests in September 1943. Findings and new ideas for improvement were issued for the radars already in production. Production of the mobile-radar-platform turntables delayed the project until the first quarter of 1944. Statistics for the precise account of the Borbála military usage are not available today. After the occupation, there were no aircraft provided for adjustment of this radar for high altitude, and the manufacturer did not find the moral basis to finish the development.

The first two Bagoly radars were assembled at the premises of the Bamert factory in Újpest. At least one location was prepared in Sari, but presumably they also were not finished.

One Turul radar was built to be airborne equipment for fighter aircraft. Its prototype was built in an ME-210 Ca aircraft and was tested, but the work did not continue [9].

7.2 Political Uncertainties

On March 19, 1944, the Wehrmacht issued an occupation plan for Hungary, and deployed its own radar system within three weeks. Eight Freya air-surveillance radars, three Würzburg Riese radars, 50 mobile Würzburg-D radars with 88-mm air-defense guns, and 11 powerful radio stations were connected to the air-defense command center located in Budapest. The formation of a very curious and complex political situation could be observed in Hungary at that time. The government was changed to be in favor of the occupation forces. The resistance, markedly Endre Bajcsy-Zsilinszky (1886-1944), also started. Dr. Jáky, and most of the radar developers, became members of or were involved in the underground movement. Participation in Hungarian radar developments resulted in some temporal protection, but arrests started for different reasons. For example, Lipót Aschner (1872-1952), the General Director of the Tungsram company, was arrested and imprisoned. He received his freedom only after his company's subsidiary company, located in Switzerland, paid 100,000 Swiss Francs for his release.

Governor Horthy kept his position, and secretly started to collect forces that were required to stop war against the western alliance. The 1st Tank Regiment, which was eliminated during fighting on the eastern front in 1942-1943, was reformed, and equipped with the latest German Tiger and the newly developed heavy Hungarian "Toldi" tanks, and reallocated to villages around Budapest, in deep secrecy [17].

On July 5-6, 1944, Col. Ferenc Koszorús (1899-1974), commander of the 1st Tank Regiment, moved to the streets of Budapest on the order of Governor Horthy, and saved 363,000 Hungarian citizens from deportation [18]. As secretly formed forces became known, Hungary lost its strategic initiative. Since the rise of this movement, everybody in Hungary could be arrested at any time, such as Dr. Bay, who was arrested for a short time, and Dr. György Dallos, who died from torture at the end of 1944.

On October 15, 1944, Governor Horthy lost his symbolic position. Later on, General Gerhard Schmidhuber (Wehrmacht commanding officer in Budapest) saved some 60,000 to 70,000 inhabitants of Budapest from liquidation, including radar developers and manufacturers.

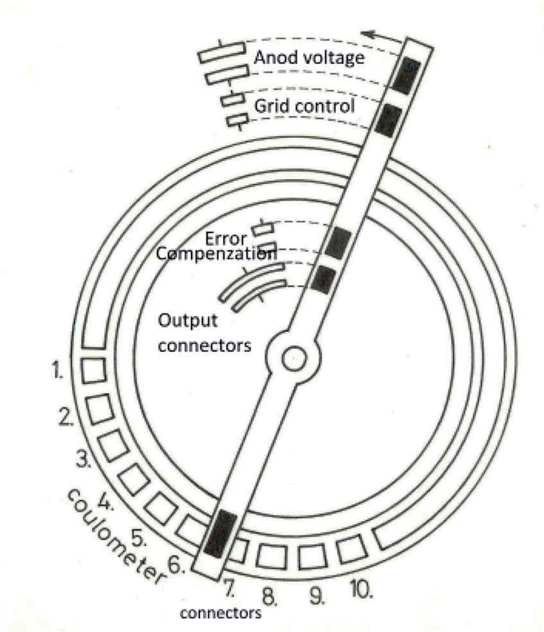

Figure 42. The control device for the hydrogen coulometer (courtesy of Természet Világa).

7.3 Other Radar-Related "Exotic" Projects at This Time

In addition to the radar projects, several "exotic" development topics were launched at the IMT. The organizer was Dr. Jáky, in cooperation with the Standard Co., Tungsram Co., and HOM firms. After the occupation of Hungary, these projects lost their importance for Hungarian developers, manufacturers, and these projects were even frequently sabotaged. Today, we know that Dr. Jáky's team was part of the resistance movement. As such, Dr. Jáky's department started to build high-power VHF radios using different radar components. These radios were aimed at connecting the resistance leadership with the western alliances.

Sometimes, the radar developers did not understand each other's initiatives and movements. One example was where Dr. Jáky came into conflict with another genial engineer developer, Kálmán Tihanyi (1897-1947). Kálmán Tihanyi was the greatest ground breaker of television engineering and the inventor of the iconoscope. He repatriated before the war, and launched an ambitious project to develop an ultrasound weapon with the code-name "Titan." The essence of the weapon was the projection of an amplified sound effect, which created a series of detonations. It was focused by parabolic mirrors in the required direction. According to the principles of military developmental activities at that time, Tihanyi and his development team would have worked under the supervision of the IMT. However, Tihanyi was worried about his invention, on the one hand, and was even more afraid having his invention taken by unauthorized (German) hands, on the other. Having taken advantage of good contacts with Governor Horthy, he was exempted from being supervised by the IMT, which Dr. Jáky had tried to press on him several times, with no success. After the occupation of Hungary by German forces, Tihanyi sabotaged the creation of the weapon. Development of the "Titan" came to a standstill at 80% completion. Tihanyi was arrested, and survived WW II [7].

Another "exotic" topic was "the remote control of flying bombs." In August of 1944, at a discussion held and recorded in Dr. Jáky's office, the fiasco of the traditional anti-aircraft artillery was mentioned. Reference [11] describes the tests of a prototype of a surface-to-air missile that was planned. Dr. Edvin Istvánffy, on Standard's part, Director General Grosh, and senior counselor Dr. Vágó, on HOM's part, did not report any technical difficulty, and no financial problems arose. The remote-control system was under development in the HOM and Standard firms, while the rocket was to be designed at the IMT. The expected operational range was 10 km to 20 km. About 40 missiles were manufactured and used in the defense of Budapest without proper remote-control electronics.

At the end of 1944, Budapest was under intensive air attacks that destroyed the capital, and caused lots of civilian casualties. Dr. Jáky's house was ruined while nobody was at home. His family moved to the IMT territory, known as the safest in Budapest. In January of 1945, during a Soviet air attack, a bomb burst through the roof of the IMT building, and it exploded in the basement. Among the dead were Dr. Jáky, his wife, and their two daughters, and staff engineer Colonel Béla Cserneczky (1898-1945). Only his youngest daughter survived. With his death, the community of Hungarian military radar and radio communications lost one of the greatest technical leaders of its heroic era [11].

8. Measurement of Earth-to-Moon Distance

It was well known at that time that Dr. Bay examined microwave propagation in the atmosphere and reflections from the ionosphere. His dream since his childhood was to measure the Earth-to-moon distance. After the German

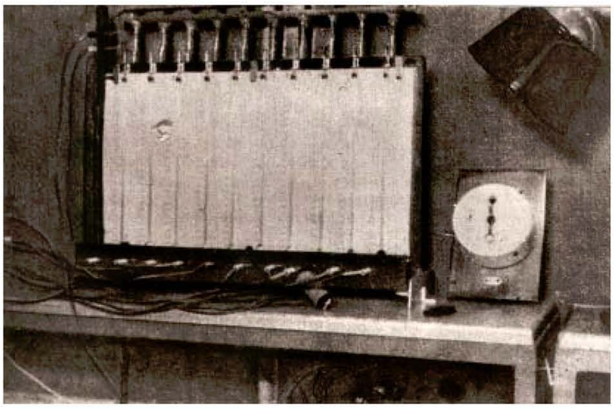

Figure 43. The realization of the hydrogen coulometer (courtesy of Természet Világa).

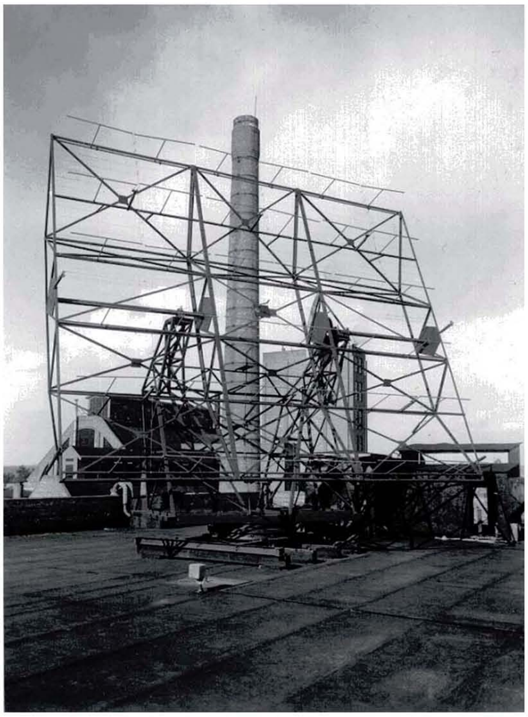

Figure 44. The planar phased-array antenna of the moon radar, size 6×8 m, with 36 dipoles (courtesy of Pál Szabó) [5].

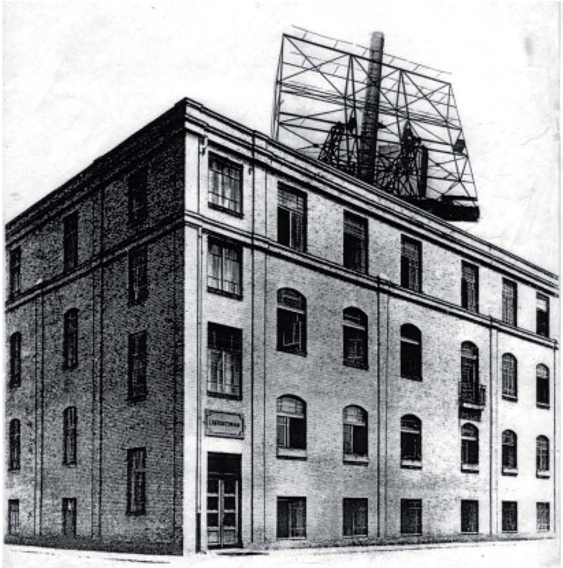

Figure 45. The moon radar antenna on the roof of the Standard Co. (courtesy of Pál Szabó) [5].

occupation, most of the Hungarian radar developers lost their enthusiasm to be successful in developing military technology. As the situation in the country deteriorated more and more, everyone tried to save themselves, their colleges, and the property of factories, labs, and institutes. In this atmosphere, Dr. Bay suggested measuring the Earth-to-moon distance using radar. This task was not only accepted but supported by Engineer-Colonel Dr. József Jáky, national coordinator of radar manufacturing. Dr. Bay and his team moved to Nógrádverőce (not so far from Budapest) to develop the theory required, and carried out experiments in April 1943. They had a "Borbála" radar installed there. Calculations to get echoes from the moon were carried out for this radar. At that time, the following uncertainties had to be clarified, and the theories for solving them developed:

- Could 0.5 m microwaves penetrate through the ionosphere?
- What was the radar cross section of the moon?
- Was the reflectivity factor of the surface of the moon similar to the Earth, that is, about 10%?
- How could the required minimum detectable signal level at the output of the radar receiver be achieved?

The moon is about 380,000 km away from the Earth, and the signal strength decreases with the fourth power of the distance. Dr. Istvánffy analyzed the moon's radar cross section with a method of calculation that was different from that introduced in the West, the Fresnel-zone-based method. Both methods proved that the moon was a point target from the measurement point of view. The moon's movement caused a Doppler shift of the RF signal. It was required to apply filters with a 30 Hz bandwidth, which were not possible to develop in Hungary from a financial point of view. The calculated minimum required signal-to-noise ratio at the output of the radar receiver was at least 100 times higher than Hungarian scientists were able to produce with the modified

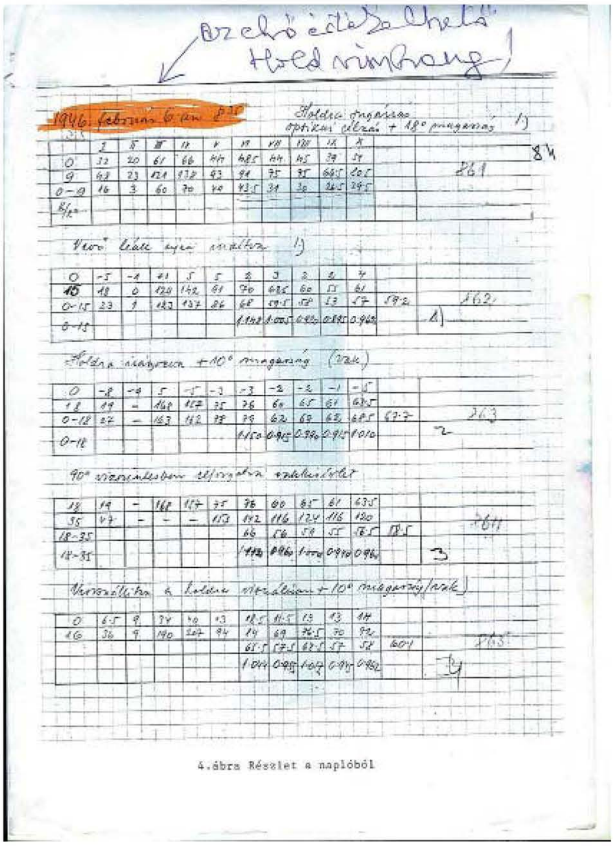

Figure 46. A photo on the successful measurement test minutes (courtesy of Pál Szabó) [5].

Figure 47. Dr. Bay presenting the moon measurement (courtesy of Pál Szabó) [5].

Borbála radar. To cover the energy gap, Dr. Bay suggested an idea of sending repeated signals, and integrating them on receiving before the detection. The radar pulses need 2.5 seconds to travel the Earth-moon-Earth distance. The scientists calculated a 50-minute period for transmitting 1000 pulses, integrating them every three seconds, and finally detecting the moon's reflected signal. Radar-pulse integration had not yet been invented. The solution was suggested by Andor Budincsevics (1905-1995) and Emil Várbíró (1908-1977?), János Patak, and János Pintér, who built the test equipment. They developed a device called a hydrogen coulometer, shown in Figure 41. This generated hydrogen gas in the channel-dedicated distance/range cell where the radar pulses were received. The dedicated range cell was selected with the coulometer control device shown in Figure 42. The calculation indicated that the signal-to-noise ratio would be improved about 30 times, because the hydrogen level produced from noise only was distributed over all lags of the hydrogen coulometer, while the radar pulses produced hydrogen only in the moon-range-related lag of the coulometer. Figure 43 shows a photo of the hydrogen coulometer.

Besides the actual moon radar experiment, blind tests were conducted in order to get reference measurements for free space, and to estimate the noise level of free space. The first trials with a modified Borbála radar and its 3 m (10 ft) parabolic-dish antenna had no success, most likely because the power supply of the radar was frequently interrupted. The scientists moved back to Tungsram Co. in autumn 1944.

Figure 48. Dr. Bay presenting the moon measurement in 1946 (courtesy of Pál Szabó) [5].

At the end of the war, the appearance of the living conditions for Hungarians and Europeans was not like a Hollywood show for New Yorkers. Budapest was in ruins, most of the Hungarian territory was controlled by local militias, and occupation forces started sacking the country. In this atmosphere, Dr. Bay reinitiated a project for a measuring the distance to the moon [19]. He requested and got support from his former colleagues in radar development, and from the Hungarian Academy of Science. The new trials started in July 1945, with the remainders of the "Sas" long-range air-surveillance radar. Dr. Istvánffy modified the "Sas" radar platform to make the antenna beam steerable, not only in azimuth, but in elevation, too. The antenna increased in size to 6 × 8 m, with 36 dipoles, and was installed on the roof of the Standard Co. as shown in Figures 44 and 45. The rest of the measurement setup was the same as was used during previous trials in Nógrádverőce, with improved special narrowband receiver filters designed by István Barta. Lajos Takács and Tibor Horváth calculated the moon's position, Dr. Papp and Dr. Simonyi were responsible for tests, while Jenő Pócza, Zalán Bodó, Jenő Csiki, and László Tary contributed to "Sas" radar modification developments, and carried out the measurements.

On February 6, 1946, the accumulating coulometer showed a signal of 4% above noise level. Figure 46 shows the picture with the minutes of the successful measurement. Dr. Bay and his colleagues considered this high enough to call it a success. Figures 47 and 48 show Dr. Bay during the presentation of the measurement success [5]. Figure 49 shows the moon radar receiver and coulometer in the laboratory, with Dr. Bay in the middle.

A few weeks earlier, the US Diana project had a "touch" of the moon's surface using radar. However, the method used by Dr. Bay's team was more advanced, as it was the first time in history that radar-pulse integration was invented and applied for radar measurement. At that moment, radio astronomy opened a new era of scientific thinking and experimenting of the cosmos.

8.1 Performance Comparison of Hungarian-Produced Radars with Other WW II Radars

After WW II, Edvin Istvánffy compared the technical performance of the "Sas" air-surveillance radar with other radars that played a significant role on the WW II battlefields [16]. The maximum detection range, D_m in Table 2, was calculated for a 10 m^2 target in free-space conditions. The "Würzburg Riese" radar's maximum detection range was 2.6 times larger than the small "Würzburg" radar's detection range [20]. Dr. Istvánffy applied the following equations for the calculations [16]:

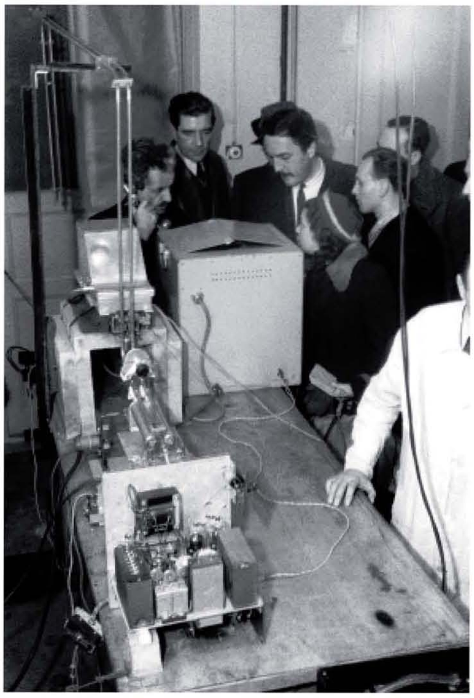

Figure 49. The moon radar receiver and coulometer in the laboratory, with Dr. Bay in the middle (courtesy of Pál Szabó) [5].

$$D_{sz} = \sqrt[4]{\frac{A_e}{4\pi}\frac{P_a}{P_{min}}}\sqrt{\frac{G\lambda}{4\pi}},$$

$$P_{min} = \frac{V_z^2}{4R} = kT\Delta f,$$

$$\frac{P_a}{P_{min}} = \frac{P_a}{kT\Delta f} = \frac{E_a}{kT\Delta f \tau},$$

$$E_a = P_a \tau \text{ Joule},$$

where A_e is the radar cross section, using a Liberator type with $10\ \mathrm{m}^2$ for calculations; P_{min} is the minimum detectable signal for the case when the signal-to-noise ratio is equal to one and the noise contains only Johnson noise; P_a is the transmitted peak power; and G is the antenna gain (transmitting equal to receiving). There are documents [4, 5] that mention that the "Sas" radar detected targets "at 500 km distances in special propagation conditions." These "rumors" were analyzed by authors to prove or disprove the claims. We carried out a simulation, applying the "Sas" radar technical parameters to the Blake chart. We determined that the free-space detection of the "Liberator" type target, with a radar cross section of $10\ \mathrm{m}^2$, and the "Sas" radar performance of Table 1, could be proven. For our calculation, we used $P_d = 0.5$ and $P_{fa} = 10^{-6}$, with the

Figure 50. The "LRB-T1" fire-control radar in operational position (courtesy of *Haditechnika*).

Swerling Case 1 fluctuation model, a single-pulse signal-to-noise ratio of 18.93 (12.77 dB), an antenna half-power beamwidth of 18°, and with the antenna rotating at three revolutions per minute. If the pattern propagation factor was chosen as 1.74 (which was still very common for a properly selected VHF-band radar installation), the target-detection range increased to 231 km (125 nmi). Details of the calculation are available from the authors.

Figure 39 shows two "Sas" radars installed in quasi-monostatic configuration, where the radars are 200 m from each other. The term bistatic radar was first coined by K. M. Siegel and R. E. Machol in 1952 (K. M. Siegel, "Bistatic Radars and Forward Scattering," Proceedings of the National Conference of Aeronautical Electronics, May 12-14, 1958, pp. 286-290 [21]). The requirements of quasi-monostatic radars are that the bistatic angle between radars be very small, i.e., less than 3°, and that the radars use the same carrier frequency, modulation, and pulse-repetition frequency, with proper triggering. Such radar systems were in operation in Hungary. Further information on the subject can be found in [22].

Among the many advantages of the quasi-monostatic configuration application shown in Figure 39, one is that the two "Sas" radar antennas searched the same azimuth sector three times per minute. In this case, the transmitted powers of "Sas1" and "Sas2" were added on the surface of the target, the received antenna gains were added, while twice the pulse-repetition-frequency-determined number of pulses could be observed on the indicators. Both radar pulses hit the target, or clutter, and selected, amplified by each other's antennas and receivers, while the received signal pulses were observable on each other's indicators. In this case, the target-detection performance increased by +3 dB transmitted power, +3 dB received antenna gain, and +3 dB signal integration, resulting in a sum of 9 dB. The normal target-detection range was therefore increased to 384 km (207 nmi) for targets with a radar cross section of $10\ \mathrm{m}^2$. The detection performance of the "Sas" radars did not depend on special propagation conditions. The only issues here for us were the most likely unsynchronized transmitter triggering, and the unknown system losses. Our

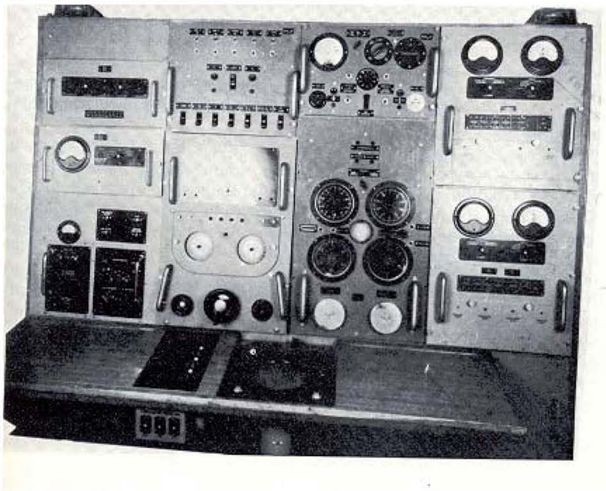

Figure 51. The "LRB-T1" fire-control radar indicator and control station (courtesy of *Haditechnika*).

experience shows that the slightly different pulse repetition frequencies, within 3 Hz, allowed exploitation of the quasi-monostatic operation with increased losses. These cases gave a good opportunity to detect targets, 30 bombers, at 500 km range, or to see the clutter returns from the Alps Mountains, as military reports indicated.

9. The End of Hungarian Radar Manufacturing

At the end of 1950, the Hungarian Army was already equipped with military weapons manufactured by the former Soviet Union, remaining from WW II. Radars were found missing on the lists of product names. The IMT got the task of creating a separate department, dedicated to radar developments, and of establishing a "Radar Committee" responsible for new Hungarian radar developments. The "Radar Committee" consisted of the best experts on RF technology at that time. Without attempting to be comprehensive, we mention some names: Dr. György Almásy (1919-1984), Dr. Edvin Istvánffy (1895-1967), Dr. István Barta (1910-1978), Dr. Géza Bognár (1909-1987), Ferenc Bajáki, Dr. András Dallos, Dr. Albert Korodi (1898-1995), Dr. György Mezei, István Nyári, Dr. Jenő Pócza (1915-1975), Dr. Tamás Sárkány (1925-2012), Dr. Nándor Szabó, Dr. Rezső Tarján (1908-1978), and Dr. Ernő Winter (1897-1971).

The expertise for construction of long-range air-surveillance and fire-control radars still remained. Requirements were settled to be better in performance than the USA SCR-584 fire-control radar. A prototype radar was developed and assembled with the name LRB-T1 at Gamma Technical Co. and HOM. Subsystems of the radar were developed and manufactured in facilities of Tungsram, Orion, Standard, Telefongyar and Ikarusz. Figure 50 shows the fire-control radar in its operational position, while Figure 51 shows the "LRB-T1" fire-control radar indicator and control station. The following is a summary of the LRB-T1 fire-control radar technical performance:

- Operational frequency: around 3 GHz (magnetron dependent)
- Detection range around 100 km, automatic target tracking up to 70 km
- Transmitter peak power: 250 kW
- Transmitter pulse width: 0.8 µsec
- Pulse repetition frequency: around 1000 Hz

The prototype was built with an original USA 2J32-type magnetron, because Hungary was not manufacturing magnetrons at that time. The power supply of the radar

Table 2. A comparison of "Sas" radar performance with other WW II radars 16].

Type	λ m	P_a kW	τ µsec	E_a joule	G	Δf MHz	$\tau\Delta f$	Z	PRF Hz	L	D_m km
"Sas" air surveillance	2.5	20	8	0.16	59	0.2	1.6	12	750	1.3	135
"SCR-588" air surveillance	1.44	125	2.5	0.31	210	0.74	1.85	16	400	1.76	160
"SCR-584" air surveillance & fire control	0.1	300	0.8	0.24	2300	1.7	1.36	31.5	1707	1	140
"AN/MPG-1" fire control	0.03	60	1/0.25	0.06	12000	10	10/2.5	50	1024	1.17	64
"Würzburg"	0.54	7	2	0.014	230	0.5	1	107	3750	0.76	42

Note: λ is wavelength; P_a is transmitter peak power; τ is transmitted pulse width; E_a is energy; G is the gain compared to an isotropic antenna; Δf is the receiver bandwidth; Z is the noise figure; PRF is the pulse repetition frequency; L is the indicator losses.

worked on 500 Hz, which allowed constructing a smaller and more compact transformer than is usual for systems built with the common 50 Hz. The prototype introduced to the Hungarian Government and Communist Party was representative of the IMT firing-test range, and was located at the village of Táborfalva in 1951. The "LRB-T1" fire-control radar was connected to an upgraded version of the Juhász-Gamma target-position calculator for artillery usage. The maneuvering fighter was locked onto and precisely followed with the "LRB-T1" fire-control radar within 70 km range. After successful demonstration of the technical and military operational performance, 10 new modernized versions of the "LRB-T1" fire-control radar, such as "LRB-T2" and "LRB-T21," were ordered and delivered to the Hungarian Air Defense Forces.

The "LRB-T1" radar technical performance was compared with the original USA-produced SCR-584 fire-control radar as a reference, and with the former-Soviet-Union-manufactured SZON-4 radar, during special test trials where the targets were flying and maneuvering at altitudes of 1000 m, 2000 m, and 4000 m. The test results focused on the static and dynamic errors of the target-position measurements and speed calculations. The "LRB-T1" radar technical performance fulfilled all requirements, while the SZON-4 failed. At that time, the "LRB-T1" radar was completely manufactured in Hungary. Both the SZON-4 and the SCR-584 had a weight of 16.5 tons, compared to 7.5 tons for the "LRB-T1." The part numbers of the resistors of the SZON-4 subsystems were exactly the same as for the SCR-584.

Political decisions included the harmonization of the weapon systems of Hungary and the former Soviet Union, and required stopping any Hungarian radar development. The "LRB-T1" radar manufacturing was changed into SZON-4 production; this also stopped in 1957. Finally, all Hungarian radar research, development, and manufacturing drawings, documentation, technical manuals, and test minutes were collected and destroyed in 1958.

10. Conclusion

This paper sought to highlight the importance – not only from a Hungarian radar-system-development point of view – of topics related to radar and microwave technology research, radar manufacturing, and its military applications, from the period of the 1940s to mid-1950s. This was a period when Hungarian radar developers, Dr. Zoltán Bay, Dr. Edvin Istvánffy, and their teams, were in a unique situation under the leadership of the Institute of Military Technology and Dr. József Jáky.

The conditions were very frustrating at that time. The Hungarian elite was not able to defend Prime Minister Pál Teleki, and could not keep our country independent. The Hungarian Home Defense Forces were small, and modernization was delayed. At that time, the modernization of military radar systems was one of the most urgent tasks, but our ally made it quite clear that Germany would not supply Hungary either with radar nor with technical assistance.

In accomplishing these tasks, the Hungarian experts were forced to find out how the newly required radar systems worked from theoretical and system philosophical points of view, and how to develop and manufacture radars. Within two years, 11 radars were researched, developed, prototyped, and manufactured: four surveillance, four fire control, two fighter control, and one airborne prototype.

Dr. Bay and his team invented or reinvented the matched filter for the pulse radar; the radar receiver characterized with minimal noise figure; the widely used cavity resonator as a high-quality filter; indicators with high resolution; and deeply investigated other segments of the radar equation. Dr. Istvánffy and his team invented or reinvented the optimal installation requirements for "VHF" radars, such as exploration of multipath and quasi-monostatic configurations, the advantages of a horizontally polarized planar phased array, and increased azimuth measurement accuracy applying the fast beam-steering technique, and introduced standards for efficient radar manufacturing for VHF and UHF bands.

The "Sas" long-range radars installed in the Hungarian Platoon considerably contributed to the early warning of the population of Budapest during air attacks, and saved Hungarian citizens beginning on December 20, 1943. This success was possible only because the relatively small Hungarian radar community had professional knowledge in RF technology, and in widely applied and accepted RF standardization processes. It is also important to highlight that the Institute of Military Technology played a crucial rule in radar R&D project management.

The trains of thought and souls of Dr. Jáky and Dr. Bay were so close to each other in the advanced radar-related research that, when Dr, Bay suggested: "we should try to detect and measure microwave, which are reflected from 380,000 km, from the moon," it not only was accepted by Dr. Jáky, but full military support was given to Dr. Bay in April 1944. On February 6, 1946, Dr. Bay's project for a measurement of the Earth-to-moon distance using radar-pulse integration succeeded. This opened a new era for radio astronomy, and gave a proud day for Hungarian science.

Other facts showed that radar manufactured in Hungary was 30% to 40% less expensive, compared to similar types from the German allies. The following comparison based, on the figures from the Hungarian Procurement contracts, shows that the cost of the "Freya" radar was 656 tHUP (thousand HUngarian Pengo), against the "Sas" radar at 150 tHUP; the "Würzburg Riese" at 574 tHUP, against the Bagoly at 250 tHUP; the "Würzburg" at 410 tHUP, against the "Borbála" at 150 tHUP.

At the beginning of the 1950s, Hungarian radar experts again introduced their talent when they developed and manufactured the "LRB-T1" fire-control radar, and proved its superior performance against the SZON-4 radar produced by the former Soviet Union. The political circumstances and the pertaining decision of the destruction of the Hungarian radar activities was not their fault.

The generation of Dr. Bay, Dr. Istvánffy, and Dr. Jáky was very powerful in radar-technology-related expertise. The picture shows that their generation spread all over the world, and had a significant impact on improving western radar systems. Today, everybody knows at least a few of them. Mr. Rudolf (Rudy) Emil Kalman (in Hungarian, Kálmán Rudolf Emil, born in 1930) is a Hungarian-American electrical engineer and mathematical system theorist, best known for his "Kalman Filter." Microwave holography was invented by Mr. Dennis Gabor (1900-1979), a Hungarian-British electrical engineer. His original Hungarian name was Gábor Dénes. Mr. John von Neumann (original name, Neumann János, 1903-1957) was a Hungarian-born American mathematician, who made major contributions to the development of high-speed computers, and was one of the founders of game theory.

11. Acknowledgement

This article consumed a huge amount of work, research, and dedication. Implementation would still not have been possible if we had not had the support of many individuals. We therefore would like to extend our sincere gratitude to all who helped us: especially to Prof. Ing. Gaspare Galati, Tor Vergata University, Roma, Italy, and Prof. Ir. Piet van Genderen, Delft University of Technology, The Netherlands, for support and constructive criticism; and to Gyula Sárhidai, co-Editor of the journal *Haditechnika*, IMT, Hungary, for more than 40 years of collections of material and relevant documents and material analyses support.

12. References

1. I. Balajti and F. Hajdú, "Radar Developments in Hungary During World War II," Microwave and Radar Week, Krakow, May 9-12, 2016, pp. 1-10, ISBN 978-1-5090-2517-6.

2. P. Renner, "The Role of the Hungarian Engineers in the Development of Radar Systems," *Periodica Polytechnica Social and Management Sciences*, **12**, 2, 2004, pp. 277-291.

3. G. Berkovics and Z. Krajnc, "The Beginning of Radars in Hungary," AFASES 2013, The 15th International Conference of Scientific Papers, Brasov, May 23-25, 2013, http://www.afahc.ro/ro/afases/2013/ air_force/ Berkovics_Krajnc.pdf.

4. N. Wassits, *A Magyar Radar 1943-1946*, Békéscsaba, Typografika Kft, 2011, ISBN 978-963-86574-9-9 (The Hungarian Radar) (in Hungarian).

5. P. J. Szabó, *Radarokkal a Lopakodók Ellen*. A magyar katonai légtérellenőrző és radarrendszer története 1917-2014, Budapest, Zrínyi Kiadó, 2014, ISBN: 978 963 327 621 1 (Radars Against Stealth Targets) (in Hungarian).

6. L. I. Farkas, *A Trianoni Diktátum:* eredeti szöveg francia és magyar nyelven, Budapest, 2009, ISBN 978-963-9428-83-6 (The Trianon Treaty) (in Hungarian and French).

7. Z. Barczy and G. Sárhidai, *A Magyar Légvédelmi Tüzérség 1914-1945:* A Boforstól a Doráig, Budapest, Petit Reál, Budapest 2008, ISBN 978 963 9267 39 8 (in Hungarian).

8. Időrosta, L. Kalmar, guest G. Nyári, Echotv, 02. 04. 2016, http://www.echotv.hu/video/111718/20160402_Idor-osta, downloaded May 15, 2016 (in Hungarian).

9. "Budincsevics Andor visszaemlékezése", Kézirat. 1972, Haditechnika archívum. (Remembering Dr. Andor Budincsevics, manuscript) (in Hungarian).

10. "A HTI részletes javaslatai rádiólokátor hazai gyártására," Haditechnikai Intézet, 1942, HIM 62969/ eln.-szám., (HTI Detailed Proposals from Domestic Radar Production) (in Hungarian).

11. F. Hajdú, and G. Sárhidai, *A Magyar Királyi Honvéd Haditechnikai Intézettől a HM Technológiai Hivatalig 1920-2005*, (The Royal Hungarian Military Institute of the Ministry of Defense Technology from 1920-2005), Budapest, HM Technológiai Hivatal, 2005. ISBN 963 219 666 X (in Hungarian).

12. E. Kollar, Virtuális Rádiómúzeum. A Hazai Rádió-gyártás, (Virtual Radio Museum, the National Radio Production) http://www.radiomuseum.hu/ hradgy_m.html, downloaded May 15, 2016 (in Hungarian).

13. Z. Bay, "Hazai Mikrohullám Kísérletek," *Elektrotechnika*, **38**, 1-5, May 1946, pp. 1-6 ("Microwave Investigations in Hungary During the Second World-War, Part I") ISSN 0367-0708 (in Hungarian).

14. Z. Bay, "Hazai Mikrohullám Kísérletek," *Elektrotechnika*, **38**, 6-8, August 1946, pp. 29-40 (Microwave Investigations in Hungary During the Second World-War, Part II) ISSN 0367-0708 (in Hungarian).

15. E. Istvánffy, "Hazai és Külföldi Radarkészülékek," *Elektrotechnika*, **40**, 1, January 1948, pp. 1-12 ("Home and Foreign Made Radars") ISSN 0367-0708 (in Hungarian).

16. E. Istvánffy, "Radarkészülékek Elméleti és Gyakorlati Problémái," *Elektrotechnika*, **40**, 8, August 1948, pp. 167-184 ("Theoretical and Practical Problems of Radar") ISSN 0367-0708 (in Hungarian).

17. "Kiút többszemközt. Gondok Koszorús Ferenc szobra körül," Echo Tv, 16. 04. 2016. ("The way out of opposite events. Problems around the statue of Ferenc

Koszorús") (http://www.echotv.hu/video/112036/20160416_Kiut_tobbszemkozt, downloaded May 15, 2016 (in Hungarian).

18. Z. Hantó and N. Szeker (eds.), "Páncélosokkal az Életért – Koszorús Ferenc, a Holokauszt Hőse," Bp. Kiskapu, 2015, ISBN: 9786158013529 (*Armored with for Life – Koszorús Francis, the Hero of the Holocaust*) (in Hungarian).

19. T. Látos, "Zoltán Bay and the Moon Radar Experiment," http://www.pulispace.com/en/education/ space-moon-and-the-hungarians/105-zoltan-bay-and-the-moon-radar-experiment, downloaded June 17, 2016.

20. K. A. Norton and A. C. Omberg, "The Maximum Range of Radar Set," *Proceedings of the IRE*, **35**, 1, January 1947, pp. 4-24.

21. H. D. Griffiths and H. Kuschel, "Passive Radar Systems," RADARCON 2013 Conference, Ottawa, April 29, 2013.

22. I. BalajtiI, I., G. Kende, and E. Sinner, "Increased Importance of VHF Radars in Ground-Based Air Defense," *IEEE Aerospace and Electronic Systems Magazine*, **27**, 1, 2012, pp. 4-18.

23. K. Simonyi, "Emlékezés és Töprengés," *Természet Világa*, **127**, 7, 1996, pp. 299-303, ISSN 0040-3717 ("Remembering and Pondering") (in Hungarian).

Introducing the Authors

István Balajti was born in Debrecen, Hungary, in 1955. He received his MSc in Electronics, specializing in air-defense radar technology and military tactics studies in Kiev, Ukraine, for six years in 1980. He received his CSc – Candidatus Scientarum for a thesis in radar signal processing from the Hungarian Academy of Sciences, Budapest in 1992. From 1986-2001, he was with Military Technology MoD, Hungary. He has worked for NSPA since 2001. He is a part-time lecturer and (scientific) supervisor of applied military radar technology and science. His main research interests are VHS radar, Gaussian monostatic-twin radar applications, and radar performance "in situ" measurements.

Ferenc Hajdú was born in Budapest in 1965. He graduated from the Military Technical College as a radar engineer. After graduation, he served in the Hungarian air-defense system as a radar company commander for 10 years. He did post-graduate work in Miklós Zrínyi National Defense University in 1999. He has worked in the Military Technical Institute since 2001 as deputy head of the research and development section of MoD. In 2009, he obtained his PhD. His primary field of research is the history of Hungarian military technical research and development. He is a part-time senior lecturer at the National University of Public Service Military Technical Department and the Doctoral School of Military Engineering.