Introduction to the Special Section on Some Less-Well-Known Contributions to the Development of Radar: From its Early Conception Until Just After the Second World War

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Abstract

The invention of radar is 112 years old. A continuing interest has been and is being addressed in the long history of radar, with many old as well as recent publications. However, historical data on radar research and development are spread over many archives in the many nations where the independent and secret development of military radars almost simultaneously started in the 1930s, leaving important material still to be analyzed in both national and private archives. Moreover, unreliable and biased documents exist on this sensitive topic, calling for a wise usage of the written material. As a result of recent and careful archive research (and a result of some personal interviews), done by leading radar experts from four different nations, this special section presents numerous interesting, less-known (in some cases, unknown) elements concerning the development of radar before and during the Second World War (WW II) in France, Ukraine (and former USSR), South Africa, and Hungary.

1. On the Origins of Radar

The main lines of the history of radar are well known, especially concerning the key period that started in the early 1930s. In fact, the rise of Hitler into power (followed by the rearmament of Germany) gave a tremendous push to the development of effective, operational military radars. The climax was reached immediately before and during WW II, with hectic research, development, and operational activities for many types of radar (including new air-defense, fire-control, and naval, as well as airborne, radars).

Most of the related literature originated from the United Kingdom and from the United States of America, the winners of WW II. Much less of the literature came from the nations on the other side (i.e., Germany, Japan, and their allies, including Italy until the Italian armistice of September 8, 1943). This literature was mainly produced in some well-defined periods after WW II: directly after the war (some books or papers were first-hand accounts by the key persons involved in radar development), in the 1980s, and in 2004, the *centennial* of radar (as well as some years later, until today). In fact, it was only many years after the WW II period that everybody understood that the very early beginning of radar was with the *Telemobiloskop*. This apparatus was invented, and built as a prototype, in 1904 by Christian Hülsmeyer, with the aim of installing it on vessels for collision-avoidance purposes. This significant achievement unfortunately was only documented in a few patent applications [1, 2]; a large and updated list of references on the whole history of radar can be found in [3-7].

Radar was then a "forgotten invention" until the real breakthrough in the 1930s, when electro-technology had advanced, in particular in the domains of high-power radiofrequency generators, and of very sensitive receivers. At the same time (around 1933-1935), the operational benefits of radiolocation (versus optical and acoustic location) were understood and assessed, leading to a kind of "rediscovery" of the concept embodied into the *Telemobiloskop*. Such a "simultaneous reinvention" had different names in the many nations independently involved: *radio direction finder* (RDF) in the United Kingdom; *Dezimeter-Telegraphie* (DeTe), and later *Funkmeß* (FuMG, FuMO), in Germany; *détection electro magnetique* (DEM) in France; *radio echo equipment* or *pulse radio equipment* in the USA; *radiotelemetro* (RaRo) in Italy, *radio locator* in the USSR; and so on. It was only since the end of 1940 that the term *RADAR* (*Ra*dio *D*etection *a*nd *R*anging), proposed in November 1940 by Lieutenant Commanders F. R. Furth and S. M. Tucker of the US Navy, came into use. The word "radar" quickly came into general use, although the British retained the terms "radiolocation" and "RDF" for their work in this field until 1943, when "radar" was adopted through international agreement. Each nation worked practically alone, with the noticeable exception of the technology transfer started in 1941 from the United Kingdom to the USA and Canada, and to the Dominion nations including, as described in this special section, South Africa. On the opposite side, i.e., among the Axis powers, the technology exchanges were very limited, certainly within Europe. Technical-information transfer from Germany, the technically most advanced Axis nation, to its allied nations was practically nil.

One of the major technological developments supporting a significant leap forward in the development of operational, compact, and high-power radars during WW II was of course the invention of the *high-power cavity magnetron*. Much has been said about who invented this device. In 1953, this led Wathen to state, "As many agencies had become involved in magnetron research by the end of 1942, it is difficult, indeed, to trace from the literature the true origin of various discoveries and inventions" [8]. Moreover, a dedicated conference was held in 2010 on the 70th anniversary of the high-power cavity magnetron [9]. The cavity magnetron may surely be called a *simultaneous invention with many fathers* [10]. The concept of multiple discovery (also known as simultaneous invention) is the hypothesis that very often, real scientific discoveries and inventions are made independently – and more or less simultaneously – by different scientists and inventors.

In the history of science and technology, it is often found that scientists and engineers from many countries were doing experiments with technology and performing measurements, quite a few with surprising and stimulating outcomes. Such outcomes were not always appreciated for their potential at the time. The same applies to radar, itself: at the time of the breakthrough of radar, i.e., the mid-1930s, the development of radar was a military activity, pursued under strict secrecy by at least ten different nations, with two main development lines: one on the side of the Allies, and the other in Nazi Germany. We could comment that although these two lines are well documented [3-7, 10, 11], the early developments in other countries became known in the public domain – sometimes partly and anyway later – with a rather delayed pace. One aim of this special section is to try to cover this gap, in conjunction with the most recent publications (see, for instance, [12-17]), showing a continuing interest in this particular section of the history of technology.

Knowledge of the reasons for the aforementioned late disclosure of radar-related inventions (some arriving at a complete operational radar set; some remaining at the technological but not-yet-operational level) is uncertain. Maybe countries other than those competing in either of the two main lines of development were "in the wings of the theater" of the development of radar: not directly visible to the spectators, but still participating, aware and ready to join the play. Anyway, there is no doubt that – similarly to the cavity magnetron – radar was a simultaneous development, as well.

2. On the Literature Related to the History of Radar

In reality, it turns out not to be true that everything (or, at least, the most significant contributions) on the early development of radar has already been said in open and reliable sources. For instance, it has to be pointed out that in the Preface of [3] it was clearly written: "The work in the United Kingdom is then chosen for more detailed attention." Concurrently with that, in [3], only 21 pages (out of 325 pages) were dedicated to the "Beginning of Radar" in all of the following nations: France, Italy, Japan, Russia (more precisely, the Soviet Union or USSR), Holland, and Hungary, while nothing was said in [3] about South Africa, Canada, Australia, and New Zealand.

Moreover, so many contributions have been presented in the literature from a biased point of view. For example, in [11], at page 127, one may read: "France, Germany, Japan and the US had each in their different ways investigated the detection of aircraft from reflected electromagnetic waves....It was only in Britain that the significance of the technique was realized at the highest level." The interested reader is referred to [18] for the instructional history of the *rise and fall* of radar activities in Canada during and just after the WW II period.

Scanning the rich literature about the history of radar, some early exploratory developments – precursors to the device later called "radar" – can be found. They concern developments with a clear objective but an uncertain outcome, as already mentioned above. This is what had to be expected at such an early stage, with many efforts exploring technology, experimenting whether or not any operational benefit could be achieved. Quoting again from Swords [3],

> ...actual radars did not...directly emerge from visionary writing...but from people who...went ahead and discovered experimentally that aircraft and ships had significant scattering cross-sections. Under the pressure

of the Second World War, all manner of radar systems emerged. The diversification was principally in function and frequency.

There could be a reason for the transfer – or, sometimes, the lack of transfer – of insight in technology and application potential from the technical community to the application domains. One reason has nothing to do with the competences of scientists and engineers, but with the structure of the communication between the communities contributing to the technical developments and the communities using these developments. Skolnik [19] observed this as follows:

> The communication problem is not that we don't know what is going on in other Services, but has been in getting the message of the technical radar community to a higher (decision) level in the military management chain where actions can be taken. In World War II this problem didn't exist in the US because civilians seemed to have more control of the direction of military R&D. If you look at the history of military technology in World War II, you will find that those countries which had civilians in control of the new directions in technology (the UK and the US) were far more successful in introducing new technology as compared to the totalitarian countries (Germany, Japan, and Italy) where the military were in direct charge of R&D.

A similar comment was expressed by Sir Robert Watson-Watt in a discussion of a series of papers on the development of the cavity magnetron in 1947 [20]:

> It was a very great triumph of individual thinking and of the merging of individual conceptions that produced the work which has been described in these papers, which deal primarily with the work carried out at Wembley and other establishments of the production industry. Even then, however, there was a missing element. The availability of skilled and sceptical [sic] critics in the Government research establishments was, I believe, the third essential contribution to the most fascinating story that is given in the papers.

However, when reading the words by Skolnik and Watson-Watt, one should not forget that their perspective, as said before, remained that of the winners of WW II, not putting in the right perspective some very advanced achievements by the hostile nations. In reality, the strongest of them, Germany, before WW II and during the first years of the war, in spite of its "walls" between technology developers and military leadership, developed some of the most advanced radar techniques in the world [7, 14, 17, 21]. These included large reflector antennas for precise angular tracking (Würzburg Riese), steerable phased-array antennas (Mammut), anti-chaff filtering, stealth, three-dimensional radar (Wassermann), radar on submarines, OTH radar (See Elefant, Knickebein J), imaging radar at K band, and more.

Anyway, under the conditions in which military systems were firstly developed, communication did follow the present line via publications in the open, but, rather, a more complicated way via committees, working parties, notes, meetings, demonstrations, etc. Generally, these types of communication were not in open archives, and were partly accessible (much) later. In particular, some radar developments were known at a late stage, i.e., since the archives of World War II have become accessible to historians. Several interesting details were disclosed after analysis of notes and reports in these now-open archives (e.g., [22]). However, other maybe-even-more-interesting aspects were lost forever due to the (voluntary or not) destruction of the then-secret documents in wartime. For example, [7] showed that the original documents by Ugo Tiberio and Algeri Marino, on the birth of Italian naval and airborne radar, were destroyed in Livorno and in Guidonia, respectively, not to mention the huge devastations, often by fire, in Germany in 1945.

3. Critical Aspects and Lessons Learned Concerning the History of Radar

When addressing the literature on the history of radar, one must bear in mind that it is not free from errors. Publications must be "used with care," double-checks generally being needed. Some errors were simply due to a pure lack of care, while others were inspired by a particular intention, and not by a search for historical truth (e.g., due to a political bias, such as sympathy with Fascism, or friendship or even kinship), with all the possible balances between those extremes. A very recent example of the effect of kinship – or better, "filial love" – was found in [23], a short paper with an interview of Marconi's daughter Elettra, married Giovanelli. This paper contained the *old story*[1] according to which Marconi invented radar and built "the first radar station in the world...in 1935 in Santa Marinella." As a consequence, the paper adds that "without the radar of Marconi, in 1941 the Battle of Britain against the Nazis would have almost certainly been lost." Unfortunately, all of that has been shown (*inter alia*, in [7, pp. 6-11]) to be fully false, together with the claim, also in [23], that the late invention by Marconi was "the extraction of gold from seawater" [sic!].

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1 This *story* is also present in some Italian papers and books of the after-war period. They are referenced in [7, p. 8, 385]. Some of them are readily attributed to nostalgic authors oriented to the past Fascist regime, a regime strongly supported by Guglielmo Marconi from its beginning until Marconi's death. A deeper discussion in Italian about Marconi, with a very rare photo of him bearing the *fez*, can be found at http://radarlab.uniroma2.it/stscradar/marconi.pdf.

A first lesson learned by studying the history of radar therefore tells us to please dig in historical archives (some of them may not yet be disclosed), to dust off old statements, and only then – and possibly with a significant delay – to arrive at fair conclusions, and to publish.

A second lesson might be that important inventions (such as radar and, much more recently, for instance, digital processing of signals, the Internet, cellular telephony, Web-based services, intelligent personal terminals,...) arrive without advertisement. One could argue that the inventors (the engineers) are too busy to find time to advertise, and, maybe, do not even like to do. For example, this is to say that when signal processing became digital (first in radar, later in communications equipment), nobody advertised this revolutionary change; it simply happened. In general, engineers do not care about advertising. On the other hand, scientists, mostly physicists, seem to be more focused on publicity. Sometimes this situation has produced "long-time advertised inventions" that after decades of advertisements didn't arrive at any practical use. Many more examples can be found. They include the quantum distribution of cryptographic keys using entangled photons, a proposed technique not leading, in 30 years, to any real system (one of the related protocols is the BB-84 protocol, published by C. H. Bennett and G. Brassard in 1984, followed by E91 by Ekert in 1991). Other related examples of "long-time-advertised inventions" are quantum computers, recently followed by some empty words on "quantum radar," not to mention that the well-known nuclear-fusion reactors never arrived, in a half century, at any production of power.

Organizing an invention is probably self-contradictory, as engineers' experience tells us that the best products were invented when the ideas in the inventor's minds were internally "ignited," i.e., not at organized events. It seems that the invention was in the mind of the inventor for a long while, maturing by every new piece of technology or user need that the (future) inventor observed, until its "sparking" in some unexpected moment. The related results may be hard to forecast: hence, the prevalence of "effective not-advertised inventions" over "advertised ineffective inventions."

4. Scanning this Special Section

Along the above-mentioned philosophical line related to the development of radar in the period mostly considered in this special section, one might consider four different types of overall activity:

1. Development of radar going on at a high pace, driven by success (examples: United Kingdom, USA, and, with some delay after 1940, Germany).

2. Development of technologies useful for radar either directly or indirectly, but frustrated, and so not encouraged, by the cause of the war (France and Netherlands after the German invasion, and Italy after September, 1943).

3. Development of radar at a pace that was lower, but still leading to fielded systems (examples: USSR including Ukraine, Italy).

4. Development of radar in countries that were dependent companions to the key players (South Africa dependent on the United Kingdom, Hungary dependent on Germany, but both having their own design effort as a backup).

Keeping in mind those thoughts, we have set up with our best effort this special section on the history of radar, reporting on "less-known aspects" of the development of radar all over the world. There could be many more papers as candidates for this special section: the history of radar is quite rich, although, as explained before, not always clear. In this issue, one will find publications on the autonomous developments by France [24] and by Ukraine/USSR [25]. Two more papers describe developments made with a dedicated link with either England or with Germany, i.e. in South Africa [26] and in Hungary [27], respectively. These four papers are rich in terms of original data and drawings, obtained by careful research in archives.

To be more precise, the paper by Yves Blanchard, "A French Pre-WWII Attempt at an Air-Warning Radar: Pierre David's Electromagnetic Barriers" [24], is dedicated to a kind of early "forward-scattering" radar, the so-called Pierre David Radio Barriers. They were designated as the "*maille en Z*" (mesh in a Z shape), and were able to retrieve multidimensional localization details of aircraft in a forward-scatter multi-static arrangement. In many respects, today this would rank under the umbrella of the class of radar designs called MIMO (multiple-input, multiple-output). If computational tools had been available in the field at the time of the David Barrier, the system would have readily been recognized as useful and operable in the field. However, such tools did not exist at the time. Just as Klein Heidelberg was a hitchhiking bistatic radar system "avant la lettre" [22], the Pierre David Electromagnetic Barrier was a MIMO system "avant la lettre."

The paper also shows that the pressure of the upcoming war had a very strong impact on the appreciation of research, and on the pressure to arrive (preferably overnight) at useful designs. Visionary and imaginative scientists/engineers and military are rare!

The paper by Felix J. Yanovsky, "Glimpses of Early Radar Developments in Ukraine and the Former Soviet Union" [25], describes the very intensive research and development efforts in the radar area made around the WW II period in the USSR, mostly in Ukraine. They were carried out in the closest secrecy, with a difficult coordination between the many involved governmental and military bodies, and with some "stop and go" phases. It is interesting to note that the first detection of an aircraft in the USSR by their "Rapid" radar happened in July 1934, before the celebrated Daventry trials [3, 7], carried out by the R. A. Watson-Watt team in February 1935. In addition, the early proposal for a radio-detection system for air defense, outlining the basic radar principles, was presented by P. Oshchevpok in the second half of 1933, i.e., more than a year before Watson-Watt's well-known report, written in early 1935, and submitted on February 27, 1935 [3]. The "oscillation" of the USSR authorities between the continuous wave (CW) and the pulse solution was also common to other nations. The competition between the CW and pulsed solutions was present in the radar community for many decades[2].

The history of radar in South Africa hasn't received major attention until today. The former dominion of the UK benefited from the lessons learned by Sir Robert Watson-Watt and his team in the mid-1930s, as is shown in Brian A. Austin's paper, "On the Development of Radar in South Africa and its Use in the Second World War" [26]. Since December 1939, this nation was at war with Nazi Germany. The efforts by the team led by Basil Schonland, a physicist and expert in lightning research, at the Bernard Price Institute of Geophysics (BPI), produced in only three months the prototype of a new radar, the JB0. This showed its first detection on December 16, 1939. The South African team developed its own designs. After the prototype JB0, more designs followed, and JB1 detected bomber aircraft at 80 km. A suite of mobile coastal radars, JB3, was designed and manufactured. In total, 31 JB radars were built and installed, later augmented by a variety British radars. Interesting "ducting" phenomena were observed, causing echoes to be detected from targets very far away.

Finally, the paper by István Balajti and Ferenc Hajdú, "Surprising Findings from the Hungarian Radar Developments in the Era of the Second World War" [27], describes the many intensive radar developments in Hungary. These originated in defense needs, and from the fact that Germany did not supply to allied Hungary either technical information nor adequate radar sets, a situation in some ways similar to Italy before the armistice. Thanks to the leadership of József Jáky, the Hungarian Institute of Military Technology developed the air-surveillance radar *Sas* (Eagle), the fire-control radar *Borbála* (Barbara), the airborne radar *Turul*, and the fighter-control radar *Bagoly* (Owl). These developments (also from the technology point of view) were similar to those of Italy, with its radar called Folaga, *Veltro*, and *Gufo*. By chance, the latter name translates into English as Owl, the same as Bagoly. The paper by Balajti and Hajdú exhibits a wealth of images, drawings, names, and historical facts that have not been previously seen in accessible publications on Hungarian radar development.

5. Comments and Conclusion

Adding interesting details, the papers in this special section confirm that the events prior and during WW II pushed many nations to develop effective radar systems. With the noticeable exception of the Anglo-American cooperation, this was done independently of each other. These systems were based on the ground, along the coast, at sea (including on submarines), and airborne, and were directed to surveillance, antiaircraft fire, guidance of fighters and bombers, and naval operations. Before the advent of the cavity magnetron, the main technological difficulties were in the high-power radio-frequency sources, initially based on existing radio and TV valves. The most practical solution at that time was perhaps the British solution, mostly based on the BBC radio transmitters at HF. Other nations (Germany, Hungary, Italy) preferred to try the VHF band, arriving soon at the "ultra-short waves" of 50 cm to 70 cm. From the overall system point of view, the requirements for air defense (as well as those for the guidance of anti-aircraft and anti-ship artillery) were very clear to all since the 1930s. However, to comply with these requirements, some nations (e.g., France, Italy, and URSS) had a more conservative approach, maintaining for some time the inadequate Earphones, or Sound Mirrors, while the United Kingdom was quicker in substituting for them, once the effectiveness of the radar technique was demonstrated. There were also difficult relationships between armed forces in some nations (Japan, Germany, France) that sometimes slowed down radar developments. In some cases (e.g., Italy), these difficulties were exacerbated by difficult relationships between the customer (e.g., the armed forces, or national military committees) and national industries, and a lack of continuity, thus slowing down development and production. Commenting on this situation after WW II, Watson-Watt was correct in stressing the tripartite cooperation (research, industry, and a competent administration): "Success has many fathers!"

6. References

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