TECHNICAL AND MILITARY IMPERATIVES

A RADAR HISTORY OF WORLD WAR II

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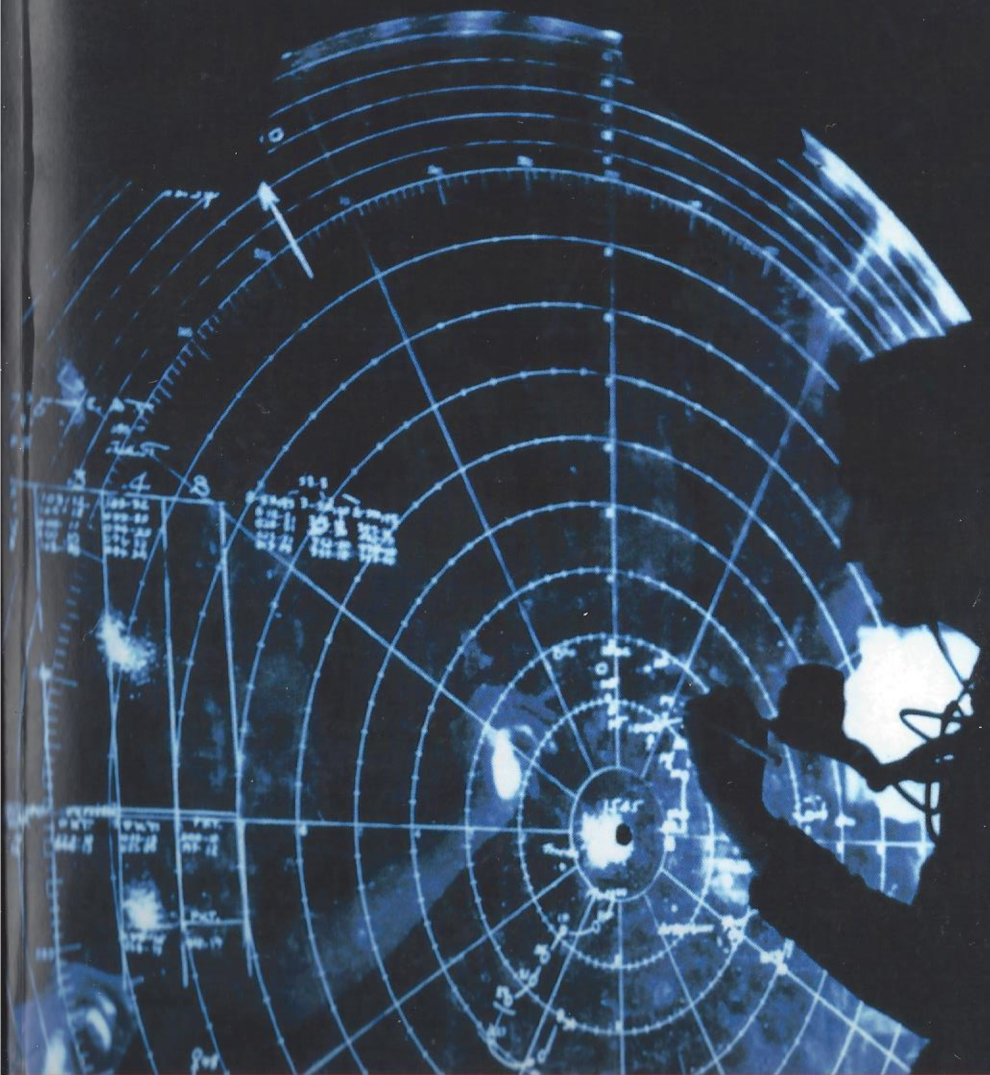

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ing submarine telegraph cables but which had troublesome losses even for the audio frequencies of telephony, so polyethylene's electrical properties were soon determined and found very satisfactory. It proved to have excellent high-voltage and high-frequency properties. Coaxial cables holding in excess of 50 000 volts became available to the radar men. On the day Germany invaded Poland a plant began producing hundreds of tons per year, and use of it in field installations is reported within months [26]. In 1941 DuPont and Union Carbide equipped themselves to produce huge quantities of the wonder insulator [27], and pre-polyethylene electronics went the way of spark wireless.

The German electronic use of polyethylene came about through radar equipment taken from a British bomber downed near Rotterdam in February 1943, an incident much more famous for the discovery of a cavity magnetron, the microwave generator that so greatly altered radar. It was quickly ascertained that the material used in the British high-frequency cables was a plastic manufactured since 1938 by I G Farben under the name Lupolen H [28]; they had missed its remarkable electric properties.

After the war the United States sent investigators to evaluate the German plastics industry and found a plant in construction hidden away at Gendorf, Austria to escape the air attacks that made production in Ludwigshafen impossible [29]. The Germans were manufacturing the substance by a more advanced process than the ICI–DuPont method. Further investigation showed that this was the same process developed by the Liquid Nitrogen Division of what is today Union Carbide and transmitted to their affiliate, I G Farben [30]. Given the secretiveness of the chemical industry, one must assume Union Carbide accepted the task of making polyethylene from ICI without comment.

2.2. BEGINNINGS, 1902–1934

For convenience the mind likes to associate inventions with inventors, even though most readers realize that things are often too complicated for such a simple correspondence. Most new devices have long pedigrees with persons other than the titular inventor furnishing important elements. Radar may provide the extreme example of multiple origins. Certainly one cannot attribute radar to any single person. Indeed one cannot even honestly say who first thought of building such a device, for it was an idea that was incipient in Hertz's experiments, which demonstrated reflections of short waves quite prominently, as well as the disturbing effects of nearby objects. A description of relevant technical work in the years preceding the first prototype radar sets should remove the idea of a single inventor without much further evidence.

Most remarkable of the early suggestions was in fact an experimental demonstration. Christian Hülsmeyer patented and built a device that he demonstrated to numerous witnesses. It used all of the elements of Hertz's

experiments: a spark-dipole transmitter with a cylindrical parabolic reflecting antenna mounted next to a similarly constituted receiver. The assembly was to be mounted aboard ships and give indication of objects with which the vessel might be in danger of colliding. Hülsmeyer tried to convince ship owners to buy it, but the primitive state of the technology of the day, especially the receivers of 1902–1904 and above all the absence of the range data, which required accurate timing, easily explains why such a thing would not have appealed to mariners [1].

The Hertz parabolic reflector used by Hülsmeyer was not a bad radar transmitter, although a modern engineer would find design elements to criticize. Each spark created a short wave train for which the peak power was very high, and the time between sparks was of the same order as the time between typical radar pulses. The receiver, of course, was woefully inadequate, having orders of magnitude less sensitivity than modern equipment and no time resolution.

Those familiar with early wireless history will find it no surprise that Nikola Tesla made an early suggestion for using reflected radio waves to detect distant objects, but given the complete lack of guiding detail it is hardly surprising that the idea did not inspire the engineers of the time. That Tesla was already noticeably on the path from brilliance to self-delusion did little to advance interest, and the idea was lost among the myriad proposals coming from his fertile imagination.

The World War of 1914–1918 brought wireless techniques to many projects, but the closest things to radar were attempts to locate aircraft from the radiation generated by the ignition systems of their engines. Edwin H Armstrong, serving as a major in the American Signal Corps, worked unsuccessfully on the project. The interest generated in him for sensitive receivers led him to the fundamentally important superheterodyne principle [2].

The World War brought various experiments for locating aircraft by observing the infrared radiation produced by the motors, and this approach was continued during the postwar years but with insufficient improvement for use in aircraft detection. In a world in which the doors of public buildings are opened, television sets are switched, the deaf are allowed to hear the actors at the theater, intruders are detected and missiles are guided by infrared, one may well question the lack of application in the 1939–45 conflict. Infrared detection depended then on its heating of a substance, thereby changing its electrical properties. Postwar semiconductors extended the sensitivities of these effects and added the photoelectric effect, which provided startling improvements in sensitivity. Infrared is unsuitable in any case for many of radar's functions because of its inability to penetrate fog and rain.

Probably the most often cited suggestion of radar is from a review paper on radio telegraphy delivered by Guglielmo Marconi at the meeting of the Institute of Radio Engineers in New York in 1922 [3]. The idea proposed was Hülsmeyer's without spark and with vacuum tube. The earlier work was not mentioned, most probably being unknown to Marconi. For completeness one must note that King George V made a similar suggestion to the Admiralty Director of Scientific Research in 1925, probably without knowledge of any previous proposals. He asked whether a radio method for locating aircraft analogous to the acoustical methods used against submarines could not be devised and was told 'no' [4]. The Royal suggestion evidently caused afterthoughts because the Navy's Signal School entered a comprehensive patent a few years later for radio location [5]. While these experiments of the mind were going on, electrical engineers were beginning to bump into radar as they mastered the techniques of tens of megahertz. All through the 1920s and 1930s many papers were written and patents issued describing methods of determining distance by radio [6].

Engineers examining the propagation of high-frequency waves during the late 1920s, especially those planning television, found much to tickle their imaginations. Their experiences were much the same as those of the reader who has noted the effect of human movement in a room in which a television or fm radio is receiving a weak station. Strong reflection and interference are easily observed, and with care one can note the passage of an airplane. Such disturbances are reduced in modern equipment by automatic gain control and were far more prominent with the early detectors. In 1931 Marconi experimented with a 50 cm transmission link between the Vatican City and Castel Gandolfo and noted a disturbance in the signal that he traced to the motion of a steam roller, initiating an interest that led to Italian prewar development [7]. It was the kind of knowledge that must have spread informally and widely among high-frequency experimenters.

2.2.1. *The United States*

In September 1922 Hoyt Taylor and Leo Young, engineers from what soon became the US Naval Research Laboratory (NRL), were studying various characteristics of 5 m equipment with which they hoped to design sets that might be less easily overheard than the long-wave sets that dominated maritime communication at the time [8]. They noticed interference and standing waves resulting from reflections from buildings, followed by an observation guaranteed to arouse the interest of naval men: a steamer passing on the river produced strong variation in the signal recorded by the receiver from the transmitter on the opposite shore. Memoranda were written, ideas for harbor defense discussed.

Three years later NRL was to furnish a transmitter for an experiment with pulsed radiation. Fifteen kilometers north by west of NRL is the Department of Terrestrial Magnetism, Carnegie Institution. At that time one of its staff, Gregory Breit, and a Johns Hopkins student and future staff member, Merle Tuve, devised a successful demonstration of the existence of the ionosphere by measuring its height. They had an NRL transmitter

modulated with a sine function and measured the phase lag between the modulation of the wave received directly at their laboratory and of the wave reflected off the ionosphere. The transmitter was soon changed to pulsed modulation, which greatly improved accuracy. The aircraft traffic of a nearby field often disturbed their measurements [9].

In June 1930 Young and Lawrence Hyland carried out experiments at NRL observing reflections from airplanes with 9.1 m equipment, and succeeded in attaining Navy authorization for two low-priority radio detection programs. One was to develop superfrequencies, as most thought that very short wavelengths were highly desirable, possibly necessary, because the radio searchlight that was envisioned meant the antenna would have to be large compared with the wavelength. If anything, all the work around 10 m emphasized how difficult direction determination was going to be with long wavelengths. The other program was to concentrate on aircraft detection with designs that relied on circuits known to work. There were more reflections, big ones from the airship *Akron*.

Young and Hyland devised with Taylor a system of widely spaced transmitters and receivers based on these observations that would signal the passage of aircraft into the area. It was at best a qualitative effect with little or no localization of the plane possible, something of a 'radio screen'. It was also obviously of little value at sea, so Taylor tried to interest the Army Signal Corps in the idea as a means of protecting cities. The Director of the Signal Corps Laboratories at Fort Monmouth was Major William Blair, who was quite interested in a radio or any other technique for the detection of aircraft and was invited to a demonstration of the method at NRL. Blair's comment that there was really nothing new being demonstrated—which tells us something about the general perception of the principles involved at the time—followed by his inability to see any use for it in air defense so long as position was not determined led to Taylor breaking off the meeting abruptly. Blair was never invited to NRL again and remained bitter over the incident [10]. In late 1935 the Bureau of Standards suggested the same idea to the Signal Corps [11].

Blair's and Taylor's discordant points of view about there not having been anything new in the NRL work are not revealed in the source of this dispute, but can be reconstructed with some assurance. Blair worked at Fort Monmouth in metropolitan New York where Bell Telephone and RCA had their laboratories. In the 1920s engineers from Bell had observed strong reflection and interference from New York's tall buildings and noted that the patterns altered greatly with slight changes of frequency [12]. In July 1931 engineers measuring signal strength in the second floor of the RCA Building produced by all-electronic television transmissions from the top of the Empire State Building found they could monitor the motion of the elevator in their building and the automobile traffic in the street below, stop and go conditions being clearly discernable [13].

No engineer working with meter-wave amplitude-modulated televi-