by Massimo Guarnieri

The Early History of Radar

Scientific disputes date back to ancient times when Greek pre-Socratic natural philosophers such as Thales, Anaximenes, and Democritus argued about what we now call the "structure of matter." Later, natural philosophers forgot Democritus' atomic model, and his ideas went unnoticed for more than two millennium. Centuries later, the heliocentric model of Aristarchus was overwhelmed by the geocentric theories of Hipparchus and Ptolemaeus that lasted up until the scientific revolution.

In the modern era, scientific debates have often concerned priority issues, which have also involved prominent scientists as in the case of Newton against Hooke and Leibniz. With the emerging importance of technology, such disputes expanded to inventions, which brought with them patent issues and economical interests.

Communication systems have typically developed from research efforts carried out in different countries. Credits for the electrical telegraph are claimed for the Swiss Georges-Louis Lesage, the Spanish Francisco Salvà y Campillo, the German Samuel Thomas von Sömmering, the Russian Pavel Lvovitch Schilling, the German Karl Friedrich Gauss, Wilhelm Eduard Weber, and later Carl August Ritter von Steinheil, the British Charles Wheatstone and William Fothergill Cooke, and the American Samuel Finley Breese Morse, whose system eventually prevailed because of its simpler and cheaper hardware.

The telephone emerged from a similar international competition. Antonio Meucci of Italy achieved the very first results in 1849 and improved his devices for over 22 years. He was followed by Johann Philipp Reis (Germany), Innocenzo Manzetti (Italy), Elisha Gray (United States), and the Anglo-American Alexander Graham Bell who led his apparatus to full economical success, starting the company that eventually developed into ATT and Bell Labs.

Similarly, major contributions for wireless telegraphy are credited to the French Edouard Eugène Désiré Branly, the British Oliver J. Lodge, the Russian Alexander Popov, the Serbo-American Nikola Tesla, the German Karl F. Braun, and the Irish-Italian Guglielmo Marconi, who was the first to radio transmit across the Atlantic Ocean, despite a strong resistance from cable telegraph companies. Both Braun and Marconi gave major contributions to the early wireless communication industry and shared the 1909 Nobel Prize in physics.

The history of radar has often been told by the nations who used it to win World War II (WWII). History books often stated that radar won the war for the Allies. This is probably an overstatement, as both sides used radar.

Research on radar started in eight nations well before WWII: France, Germany, Italy, Japan, The Netherlands, the Soviet Union, the United Kingdom, and the United States. The first evidence of the radar principle sprung from wireless technology as early as 1897, when Alexander Popov observed interference caused by a passing ship while he was transmitting wireless signals.

The first operating device, the telemobiloscope, was built in 1904 by the German Christian Hülsmeyer. This was a rudimentary continuous wave device operating at 650 MHz, capable of detecting the presence of ships (but not their distance or movement) at sea within 2 mi in dense fog. As in the following developments, its performance was restrained by the lack of effective electronics and antennas.

The idea of radar was introduced in the United States by Nikola Tesla in 1914. Eight years later, Guglielmo Marconi delivered a lecture on the principle of radar at the 1922 Institute of Radio Engineers Conference, and, in 1933, he presented his idea to the Italian Warfare Ministry to obtain financial support. This allowed Ugo Tiberio to start a systematic research in 1935, achieving the main theoretical results such as the radar equation, while the first experimental tests begun the following year with a 200-MHz continuous wave frequency-modulated device, the Radio Detector Telemetro.

In 1934, the French Émile Girardeau started building a radar system and installed first devices on board of the cargo ship *Oregon* and of the ocean liner *Normandie* the year after.

Meanwhile, in the USSR, P.K. Oschepkov built an experimental apparatus capable of detecting an aircraft 3 km away. During the same years, Hungarian technology on radar was moving in the same direction with Zoltán Bay, which succeeded in producing an operational radar device, working in cooperation with Tungsram Ltd. research laboratory in 1936.

In December 1934, Robert M. Page tested in the United States an experimental 60-MHz pulse-modulated radar

Digital Object Identifier 10.1109/MIE.2010.937936

tracking a plane 1.6 km away. A year later, Page received a federal grant of US$100,000 to support radar research. By 1936, Page's group had developed a 28.6-MHz device that could detect planes as far as 40 km away. Over the years, Page maintained a key role in the development of American radar, serving as the director of the U.S. Naval Research Laboratory. In 1940, the U.S. Navy created the acronym *Radar* which comes from "radio detection and ranging." By 1937, independent research was underway at the U.S. Signal Corp, which eventually lead to the development of the SCR-270 ground-based radar that was operative in July 1941 (Figure 1). A few months later, one of them detected the incoming Japanese raid at Pearl Harbor.

In the same year, Great Britain, afraid that German scientists could develop death rays, an idea first claimed by Nikola Tesla many years before, appointed British scientists to investigate electromagnetic wave energy. They stated that the death ray was science fiction, but they also asserted that it was possible to use em-wave for aircraft detection and ranging. Thus, Robert Watson-Watt developed a radar-working prototype that was patented in 1935. It was from this prototype that the famous early warning defense radar system known as Chain Home was set up from 1937. At the start of WWII, the Chain, consisting of 19 stations, played a key role in the Battle of Britain (Figure 2). At this time, the device was known as RDF in Great Britain (for range and direction finding and later for radio direction finding).

Germany, a leader in the field of electromagnetic technology, was equally investing time and effort in radar development. Early research was started by Rudolf Kühnhold and Hans Erich Hollmann. The former obtained first successful results in 1934 using a continuous wave system fed with a Philips 600-MHz split-anode magnetron. In 1934, microwave expert Hollmann built the first operating radar for naval use. Innovative development appeared in 1937, leading to pulsed-type radars as the Freya ground-based model (120–130 MHz), the shipborne Seetakt (600, 500, and 390 MHz), and the Telefunken Würzburg (553–566 MHz, Figure 3), which were operative by 1940.

Japan started experimental radar research in the 1930s, but practical developments were delayed. By 1942, they developed centimetric wavelength

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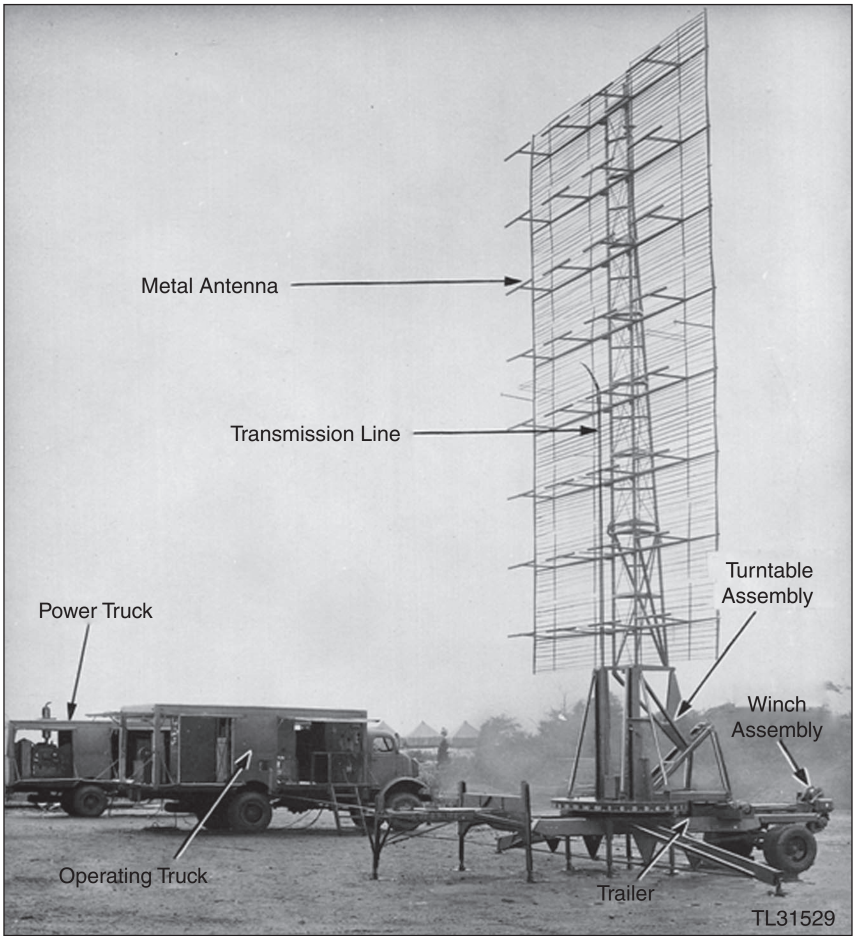

IMAGE IN PUBLIC DOMAIN

FIGURE 1 – SCR-270.

IMAGE IN PUBLIC DOMAIN

FIGURE 2 – Home Chain.

IMAGE IN PUBLIC DOMAIN

FIGURE 3 – Würzburg mobile radar.

in China," by Prof. Mark Dehong Xu, "Robotics, Jump to the Next Generation," by Erich Lohrmann, and "Power Electronics for Renewable Energy Systems," by Prof. Frede Blaabjerg. Finally, on 17 March, the talks dealt with "Predictive Control Applied to Torque Control in Synchronous Reluctance Machines," by Prof. Graham Goodwin, and "Energy Storage for Electric Vehicles," by Prof. Juan W. Dixon.

FIGURE 2 – Attendees enjoy the ICIT 2010 gala dinner.

A cocktail party was held on 14 March at the entrance court of the university. Attendees enjoyed Chilean food and wine with a great view of Valparaíso's bay. The welcome reception on 15 March was also held at the Universidad Técnica Federico Santa María. The 250 participants and invited guests enjoyed the ICIT 2010 gala dinner, held on 16 March at the Enjoy Viña del Mar Convention Center (Figure 2). There was a musical and dance group, showing the Chilean folk songs of different country regions.

Participants had an opportunity to explore Valparaíso, a city that was the key point of the sea routes from the Atlantic Ocean, especially through Cape Horn, to the coasts and islands of the Pacific. The streets are a mixture of ancient buildings and modern construction. The downtown is surrounded by stepped hills with picturesque streets, passages, and walkways.

In conclusion, conference organizers extend their deepest gratitude to the volunteers who served as reviewers, track and special session chairs, session chairs, publication and information managers, and students, who helped to make IEEE-ICIT 2010 a great conference.

Historical

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radars, and operative devices (ground based, shipborne, or airborne) were operative by 1944. These radars were also developed on the basis of British sets captured in the beginning of the war.

All historical events previously mentioned show that the first radars were built around 1934–1935 in a kind of parallel but independent international effort. Lack of cooperation was due to strategic issues, political climate, and later, warfare conditions.

The performance of the first radars was restricted mainly by a couple of technological limitations. The first was from the rectifiers needed for visualization on the receiver screen and promoted an in-depth understanding of crystal growing that years later would pay off in unexpected areas (e.g., mass solid-state electronics). The second limitation stemmed from the limited power and frequency of the transmitter generators, which restricted the detection range and called for large antennas. Generators in use were magnetrons derived from the 1921 American Hull's split-anode archetype, the German Haben's device, and the klystron tubes. The latter stemmed from the germinal idea of the German Oskar Heil and the Russian Agnesa Arsenjewa in 1935. Heil himself worked on klystrons first in Great Britain and then in Germany, after the war began. The Varian brothers built the American klystron in 1937.

The cavity magnetron, devised in 1940 by John T. Randall and Henry A.H. Boot at the University of Birmingham, was a breakthrough, having the capacity to operate at much higher power and frequencies (3.3 GHz), thus allowing much shorter wavelengths (9.1 cm), suitable for small antennas of airborne radars. The first model, British H2S, was operative in the beginning of 1943 and played a key role in the bomber raids on German cities.

By the end of the conflict, radar systems had advanced to a level inconceivable before the war and continued to be refined in the post-war era, when microwave technology triggered the development of unexpected electronics markets, such as the microwave oven and mobile phone.

Biography

Massimo Guarnieri graduated with honors in electrical engineering at Padua in 1979, received the master's degree in plasma engineering in 1982, and the Ph.D. degree in electrical science in 1987. In 1982, he joined the CNR and in 1983 the University of Padua, where he has been a full professor of electrical engineering since 2000. Initially, he centered his work on the analysis and design of large electromagnetic devices for fusion energy research experiments. He later moved his interests to innovative computational electromagnetism, coupled problems, and fuel cells systems. He is also interested in history of technology and science.